results from the 48th Rencontres de Moriond

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Séminaires du SPP: **Résumé des conférences d'hiver**
25.04.2013

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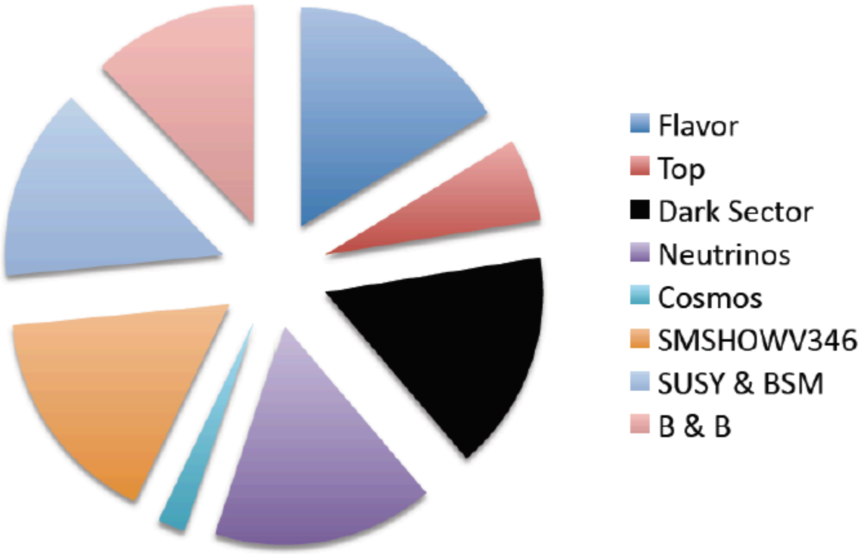
OVERVIEW

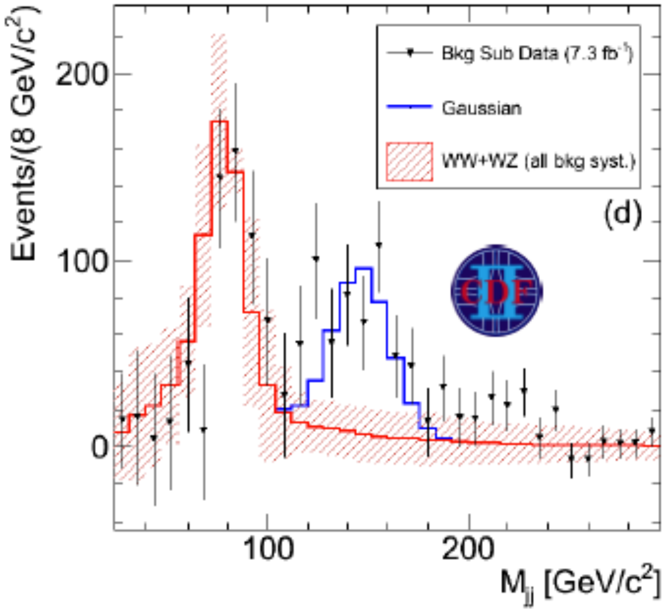
- Trying to do a summary of Moriond 2013
- Many physics results were presented from many collaborations (LHC and Tevatron experiments, Fermi-LAT, Ice-cube, ...)
  - ★ I will only discuss a (biased) selection of particle physics results

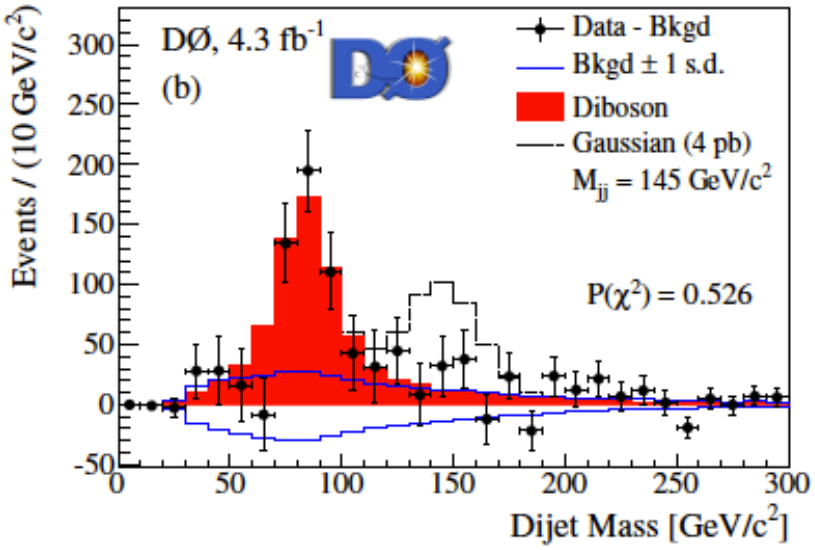
for astro-particle results see Denis' presentation

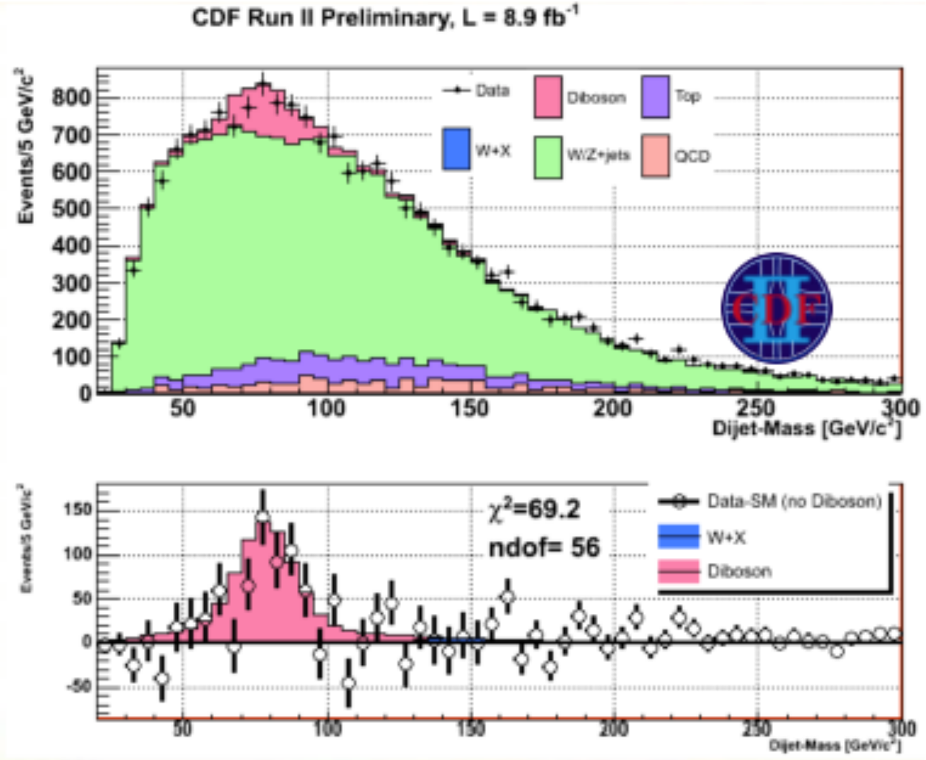
- Event the highlights amount to a lot of physics in a short time...
  - ★ Standard Model (SM) precision measurements
  - ★ Higgs boson
  - ★ Searches for new physics (both direct and indirect)
- Will try to draw some conclusions
  - ★ mainly from discussion at the conference, and the two very good summary talks at Morion EW



TEVATRON DI-JET EXCESS DISAPPEARING

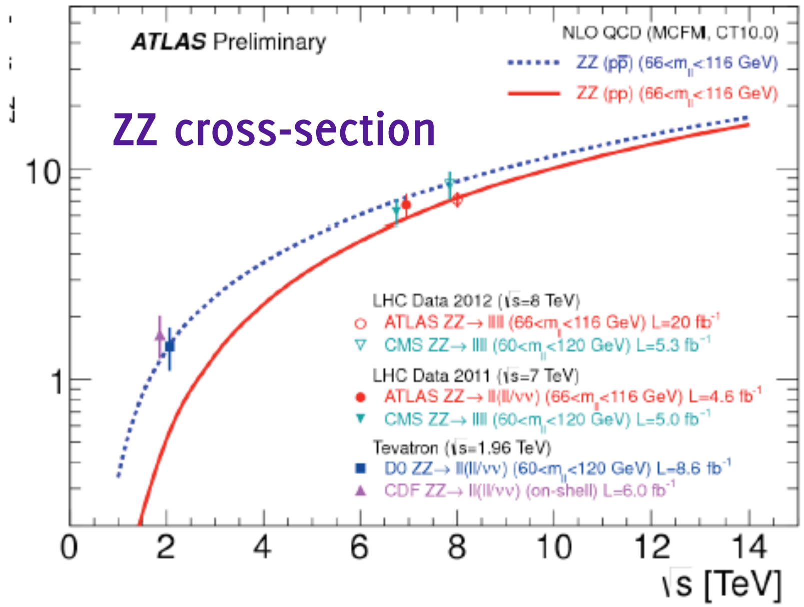


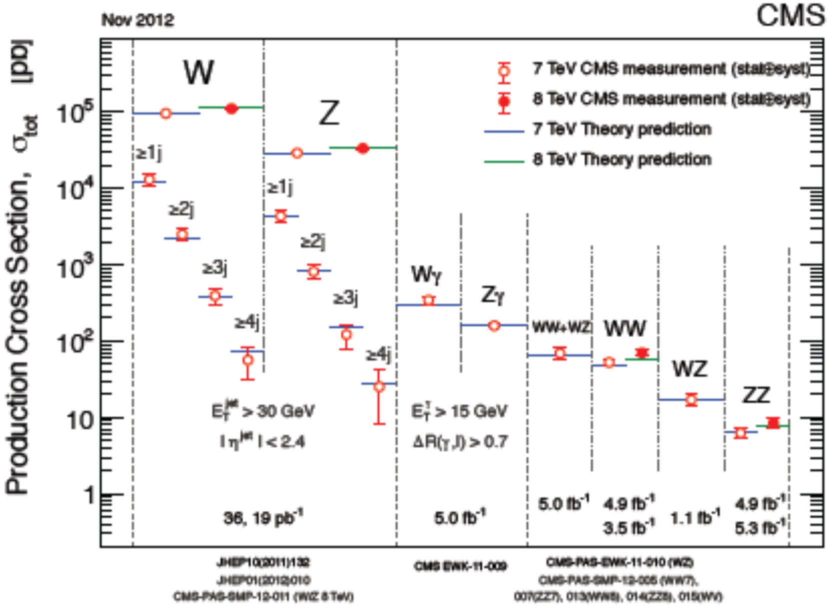


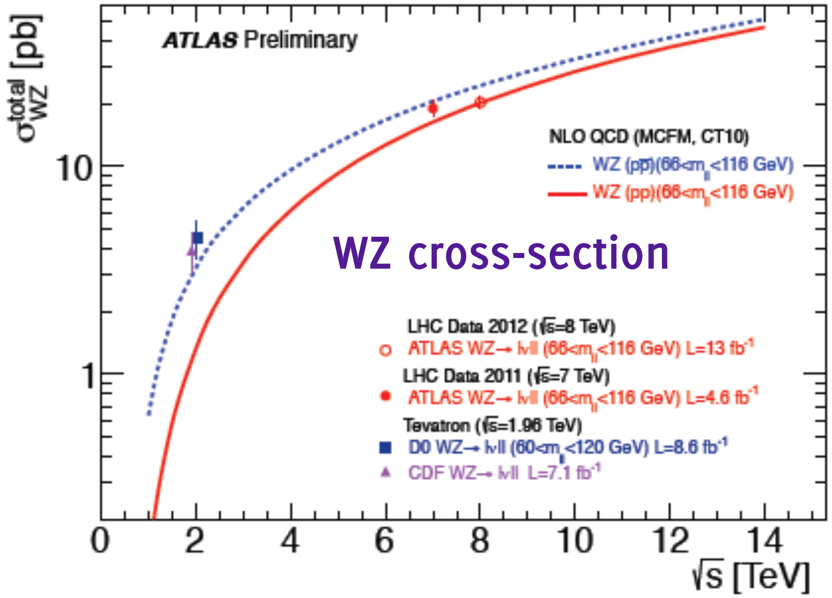


- **CDF saw an excess** in the di-jet mass spectrum in the $WW/WZ \to l\nu jj$, **not confirmed by Do**
- new **improved jet calibration** to account for differences in gluon and quark jets reconstruction using γ+jets and Z +jets events → **disappearance of the excess**

DIBOSON CROSS-SECTION MEASUREMENTS

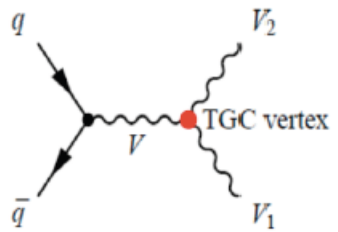


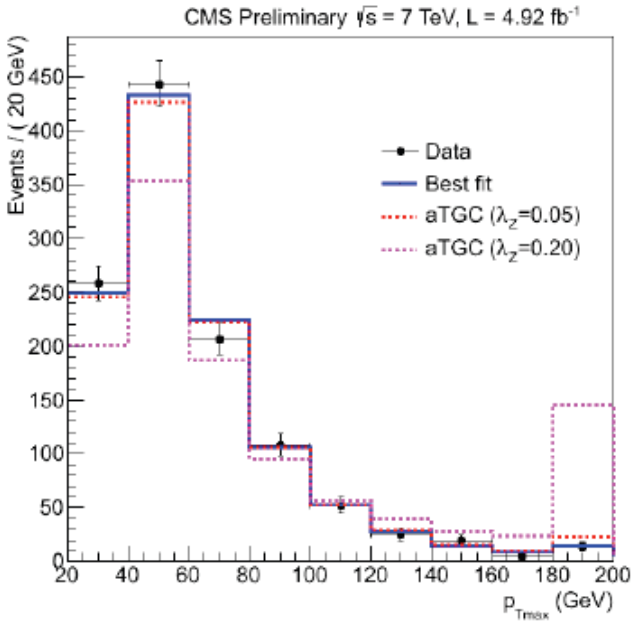




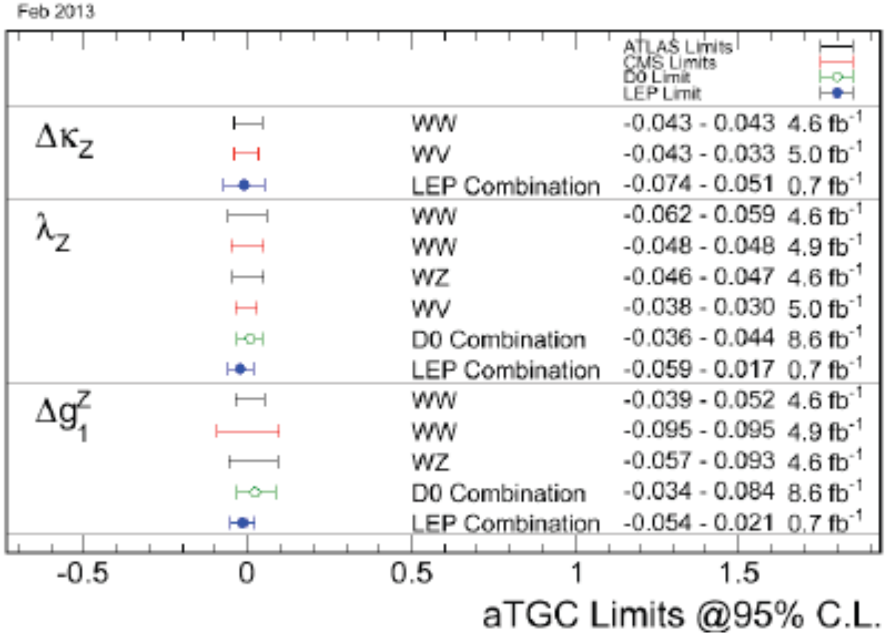
- why study diboson production at LHC?
  - ★ provide fundamental tests of the SM (**cross-section measurements**, anomalous TGC, ...)
  - ★ main backgrounds for Higgs studies
- very good data-MC agreement
- at LHC and Tevatron **no deviations** from the SM predictions are observed

DIBOSON aTGC MEASUREMENTS





Limits on WWZ aTGC couplings



- why study diboson production at LHC?
  - ★ provide fundamental tests of the SM (cross-section measurements, **anomalous TGC**, ...)
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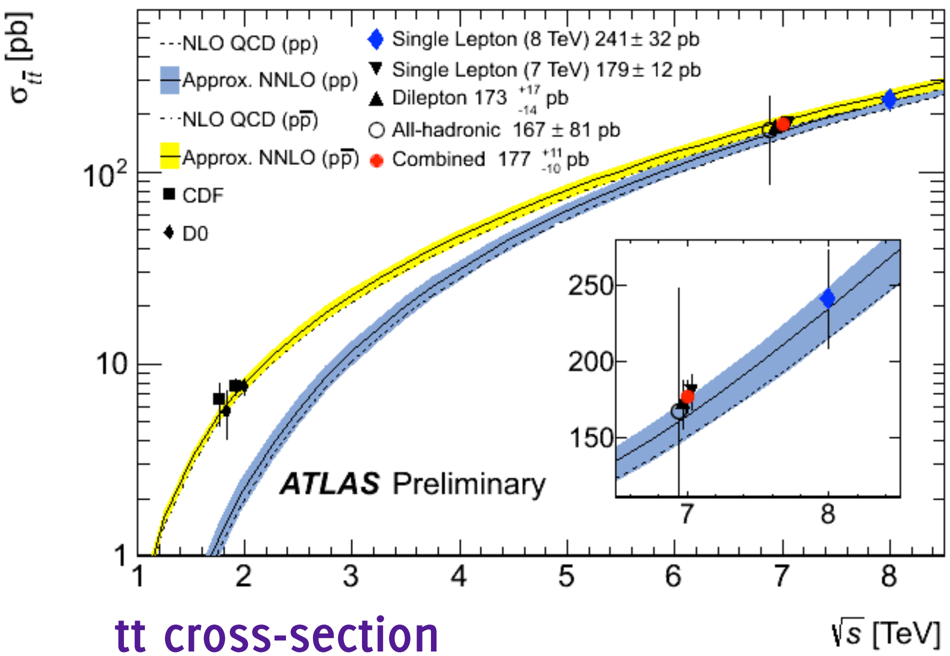
Top Studies

- may probe theoretical SM predictions
  - ⋆ or reveal non SM contributions...
- top is an important background for many SM (Higgs) and Beyond the SM (BSM) searches

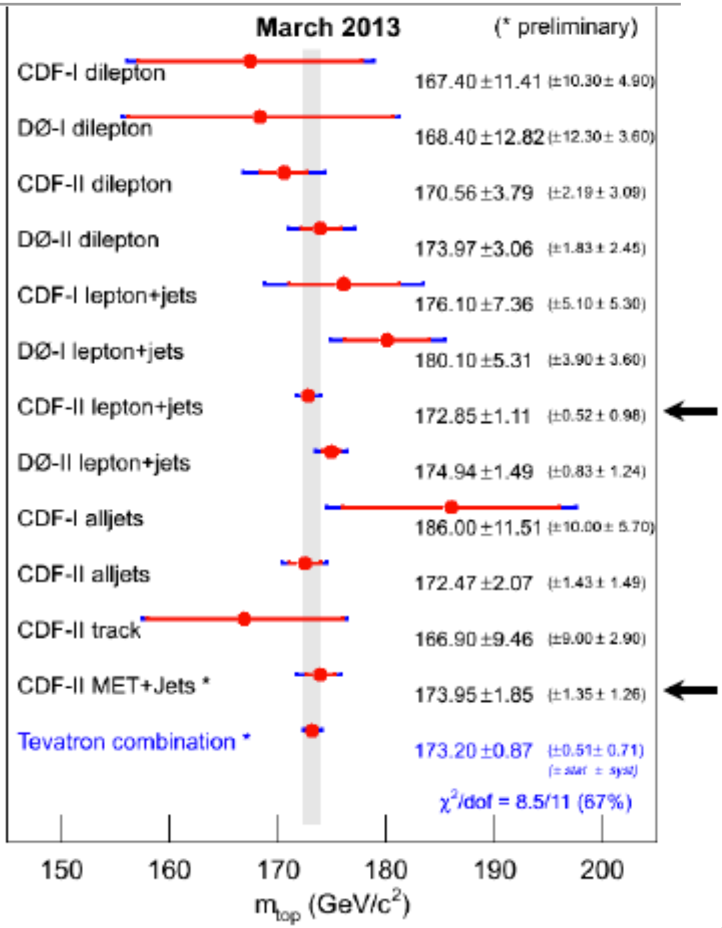


tt cross-section

→ remarkable agreement with theoretical expectations reached

→ LHC top results start to be competitive with the Tevatron ones

top mass measurement



Tevatron (march 2013):

m_t = 173.20 ± 0.51 (stat.) ± 0.71 (syst.) GeV

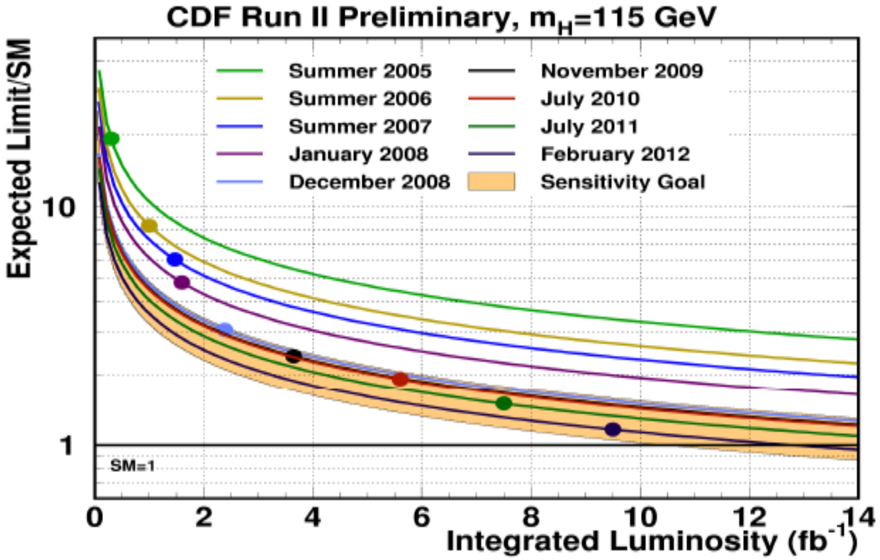
= 173.20 ± 0.87 GeV

CMS (7 TeV data):

m_t = 173.36 ± 0.38 (stat.) ± 0.91 (syst.) GeV

= 173.36 ± 1.10 GeV

HIGGS TEVATRON LEGACY

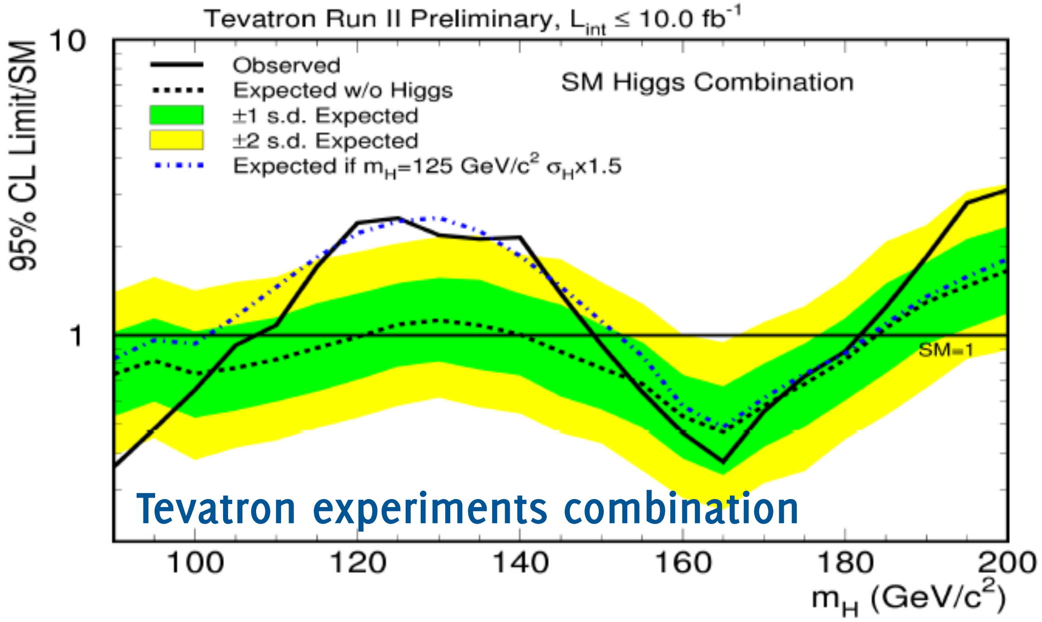


- the yellow band corresponds to the projection made in 2007
- reached today thanks to the **introduction of new and improvement of existing analysis techniques**
    - → Tevatron techniques extensively used at the LHC experiments

- excluded regions @ 95% C.L.
    - ★ high mass: $149 < m_H < 182$ GeV
    - ★ low mass: $90 < m_H < 107$ GeV
- broad excess observed
    - ★ significance > 2σ for $115 < m_H < 140$ GeV

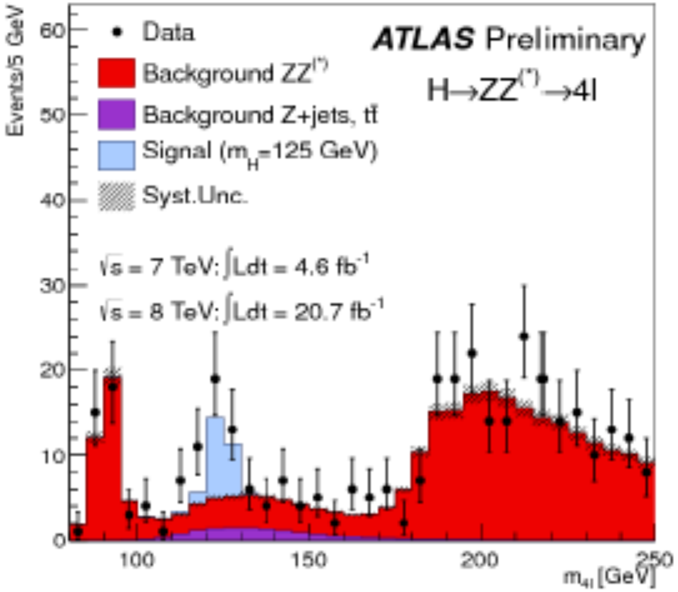
→ overall agreement with LHC discovery

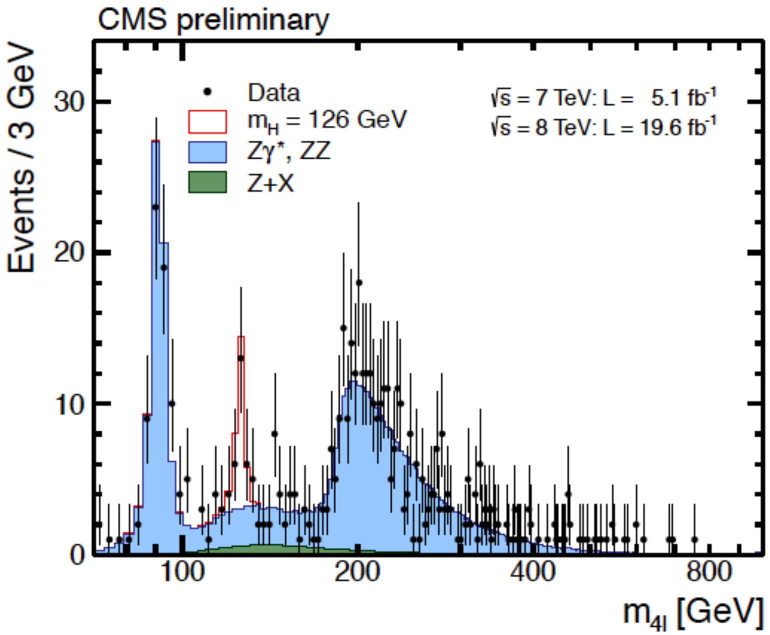
→ compatibility with SM Higgs boson

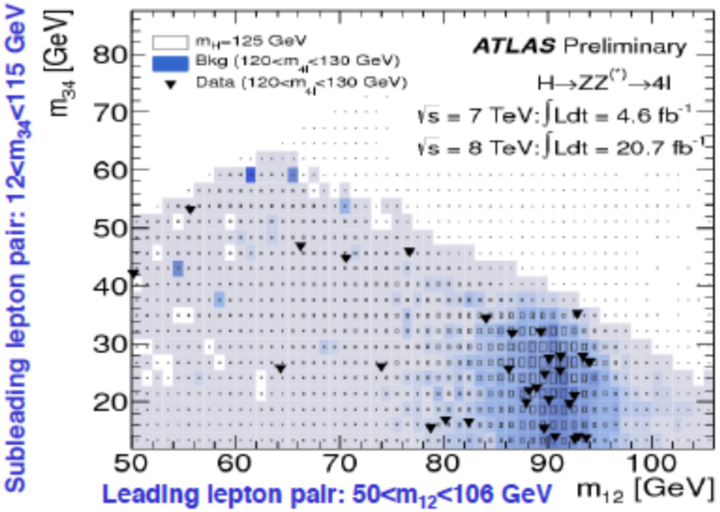


Tevatron experiments combination

HIGGS BOSONIC DECAYS: $H\rightarrow ZZ^{(*)}\rightarrow 4L$

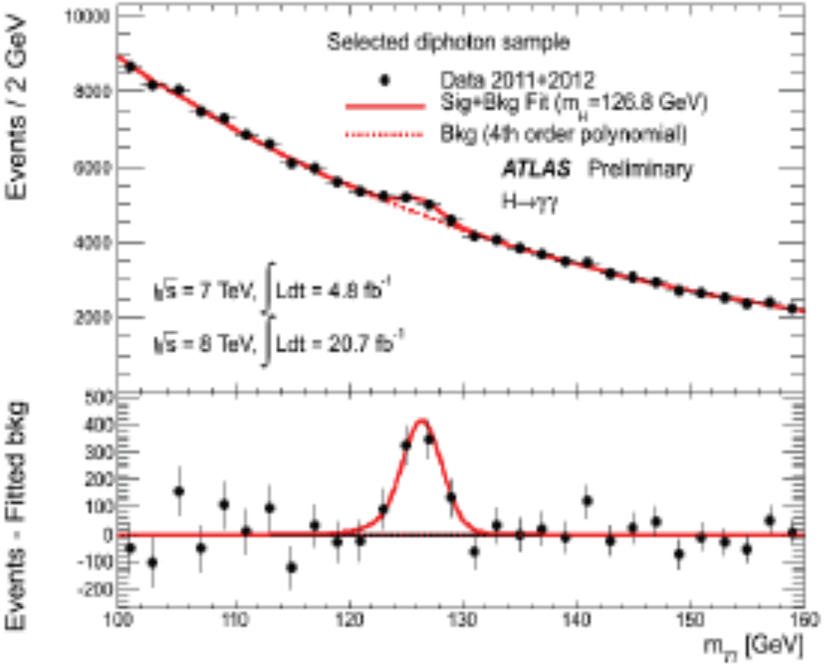




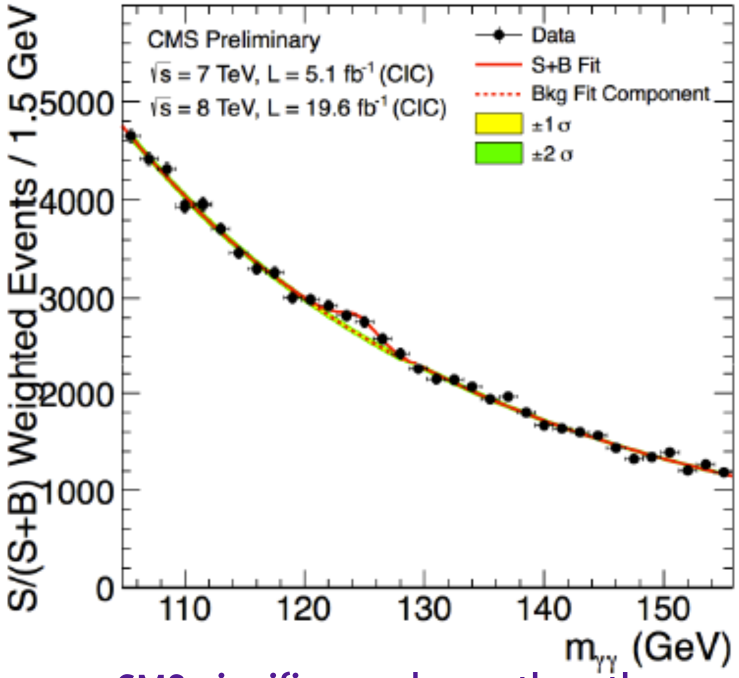


- update/confirmation of summer discovery
- local significance
  - CMS: **7.2σ** (vs **6.7σ exp.** for a SM Higgs) **@ 125.8 GeV**
  - ATLAS: **6.6σ** (vs **4.4σ exp.** for a SM Higgs) **@ 124.3 GeV**
- signal strenght **[$\mu = \sigma/\sigma_{SM}$]**
  - CMS: **$\mu = 0.91^{+0.30}_{-0.24}$**
  - ATLAS: **$\mu = 1.7^{+0.5}_{-0.4}$**

HIGGS BOSONIC DECAYS: H→γγ



CMS cut based analysis



- update/confirmation of summer discovery
- observed excess, local significance
  - CMS: **3.9σ** (vs **3.5σ exp.** for a SM Higgs) **@ 125.0 GeV**
  - ATLAS: **6.6σ** (vs **4.4σ exp.** for a SM Higgs) **@ 126.8 GeV**
- signal strenght **[$\mu = \sigma/\sigma_{SM}$]**
  - CMS: **μ = 0.78$^{+0.28}_{-0.26}$**
  - ATLAS: **μ = 1.65$^{+0.34}_{-0.30}$**

CMS significance lower than the one previously published: observed changes are statistically compatible at less than 2σ

→ cross-section compatible with a SM Higgs!

→ to say more we need to measure its parameters and couplings...

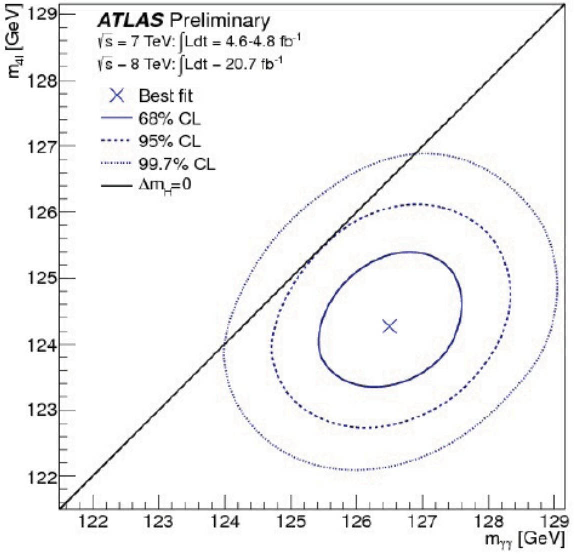
MASS MEASUREMENT

- best mass fit [combining γγ and 4l] **ATLAS**

$125.5 \pm 0.2\ (\text{stat.})^{+0.5}_{-0.6}\ (\text{syst.})$

- ★ full 2011+2012 data sample used
- ★ uncertainties dominated by e/γ energy scale

- mass difference: $2.3^{+0.6}_{-0.7}(\text{stat.})\pm 0.6(\text{syst.})$
  - ★ **2.4σ from $\Delta m_H = 0$** → statistical effect?



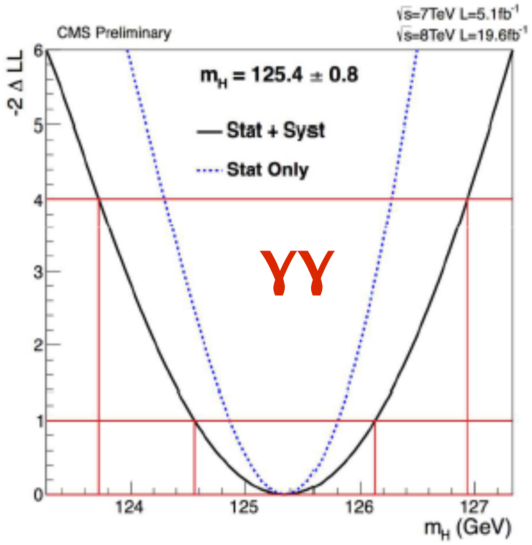
$\Delta m_H = m_{\gamma\gamma} - m_{4l}$

- good agreement between mass measurements **CMS**

$\gamma\gamma$: $125.4 \pm 0.5\ (\text{stat.}) \pm 0.6\ (\text{syst.})$

$4l$: $125.8 \pm 0.5\ (\text{stat.}) \pm 0.2\ (\text{syst.})$

- ★ full 2011+2012 data sample used
- ★ uncertainties dominated by lepton/γ scales



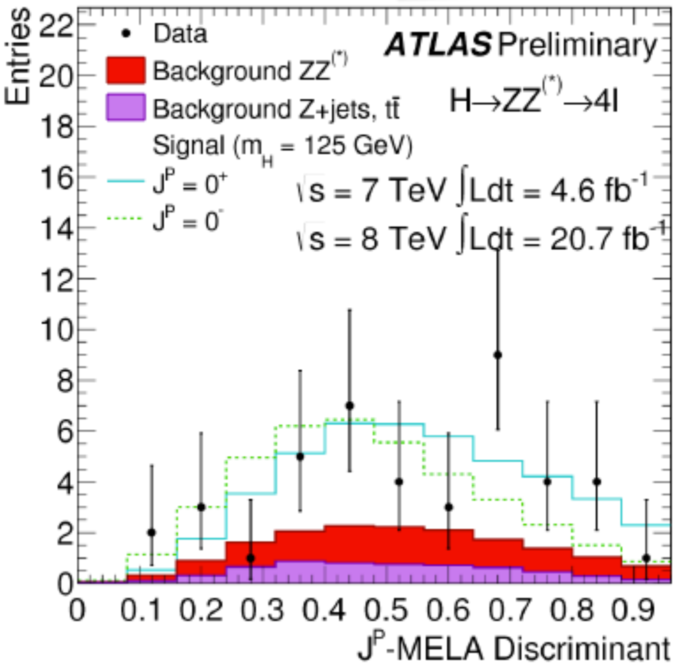
overall good agreement between mass measurements

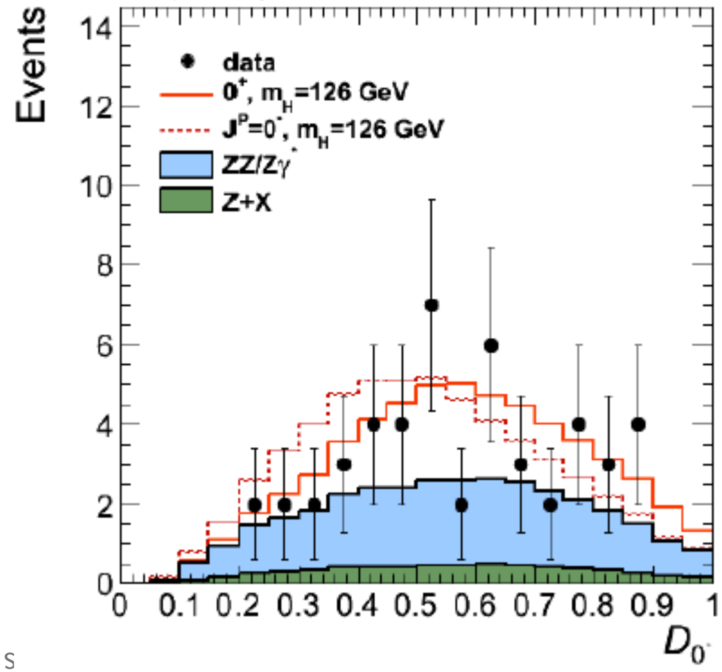
next goal: moving to precision measurements

Higgs Properties: Spin/CP Measurement

- spin-parity measured in different decay channels [ZZ$^{(*)}$, γγ, WW]
- $H \rightarrow ZZ^{(*)} \rightarrow 4l$
  - assuming 0^+: pseudo-scalar, spin-1 and spin-2 (minimal coupling model) excluded at ≥95% CLs
- $H \rightarrow \gamma\gamma$ **ATLAS** [only sensitive to spin-0 vs spin-2]
  - assuming 0^+: spin-2 (minimal coupling model) excluded at ≥ 93% CLs

0^+ is generally favoured against the other models tested
measurements still dominated by limited statistics



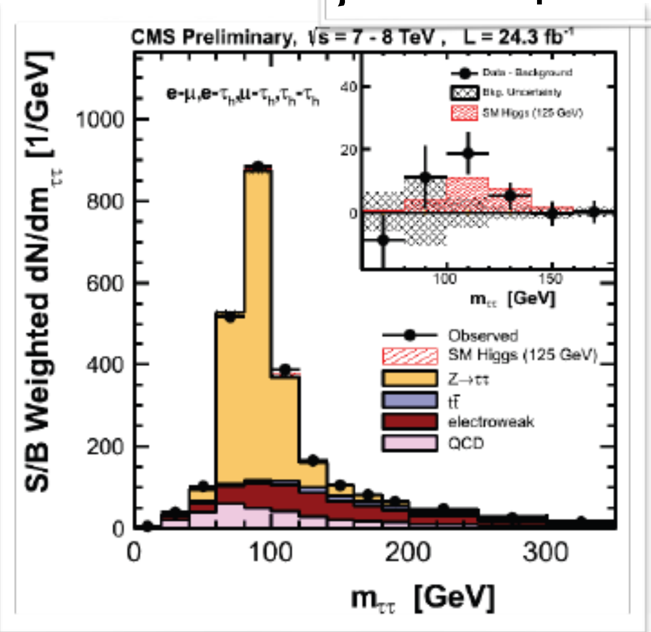


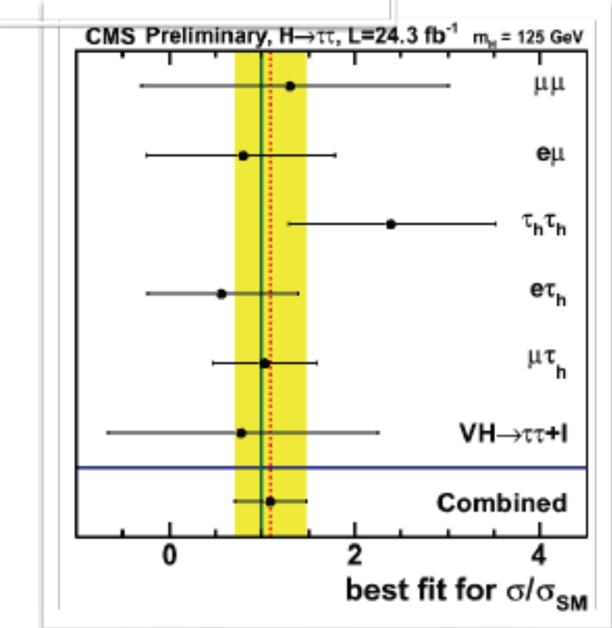
OTHER HIGGS DECAY CHANNELS: H→ττ

- details on two leading channels, but many other nice studies have been shown:
  - low mass, **bosonic** decays: H→WW, H→Zγ, VH decays, ...
  - low mass, **fermionic** decays: H→ττ, H→μμ, $ttH \to ttb\bar{b}$, $VH \to Vb\bar{b}$, ...
  - **high** mass searches: H→ZZ→2l2q, H→ZZ→2l2ν, H→ZZ→2l2τ, ...
- a lot of excitement for Higgs fermionic decays:
  - first hint that **the new boson decays to fermions**: H→ττ [CMS]
  - reinforces the hypothesis of a SM Higgs giving mass to bosons **AND fermions**

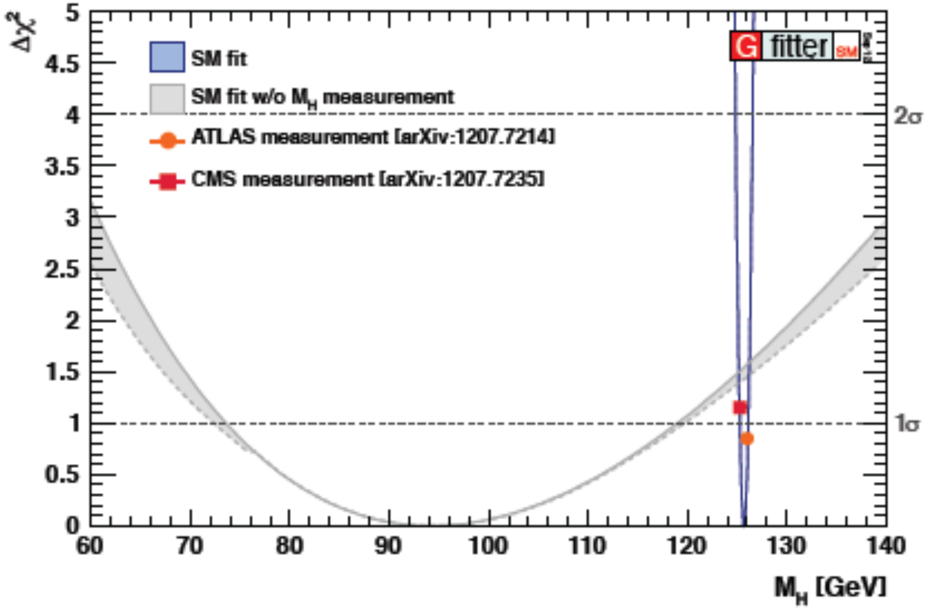
2.85σ observed @ 125 GeV (2.62σ expected)

μ = 1.1±0.4

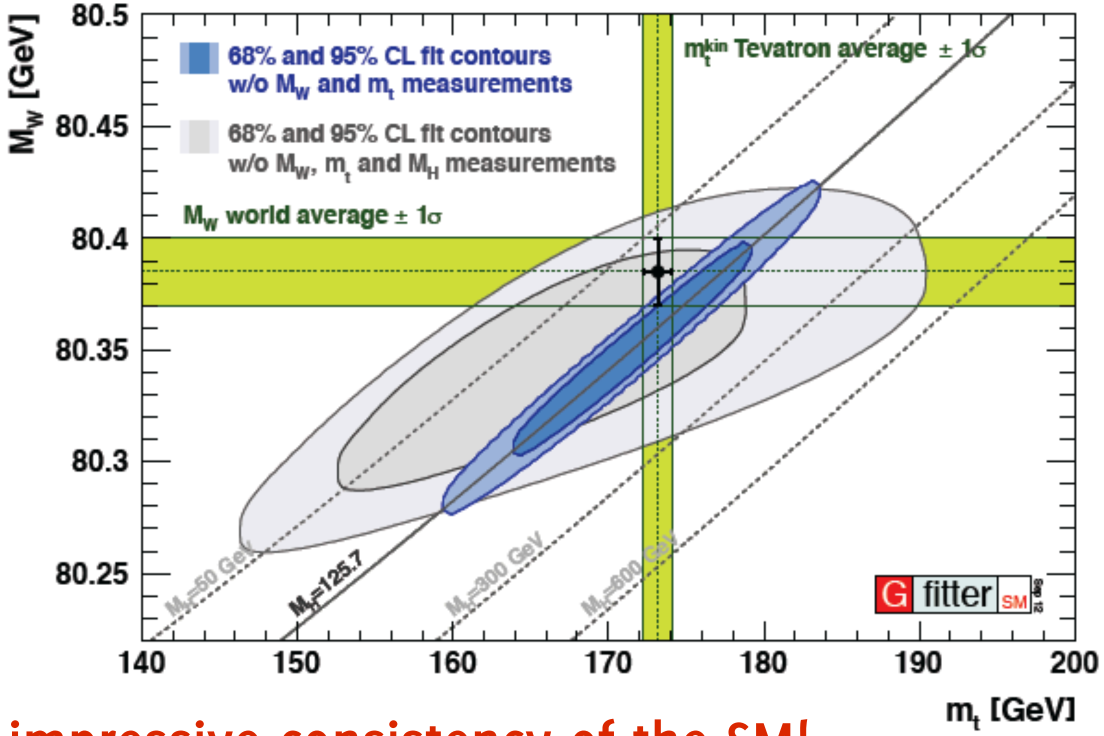




ELECTROWEAK FIT WITH GFITTER



here assuming that the new particle is the SM Higgs boson



- **blue line:** full SM fit
- **grey band:** fit without M_H measurement included → gives $M_H = 94^{+25}_{-22}$ GeV, 1.3σ from the measured value
- M_H measurement allows for precise constraints of M_W, M_t

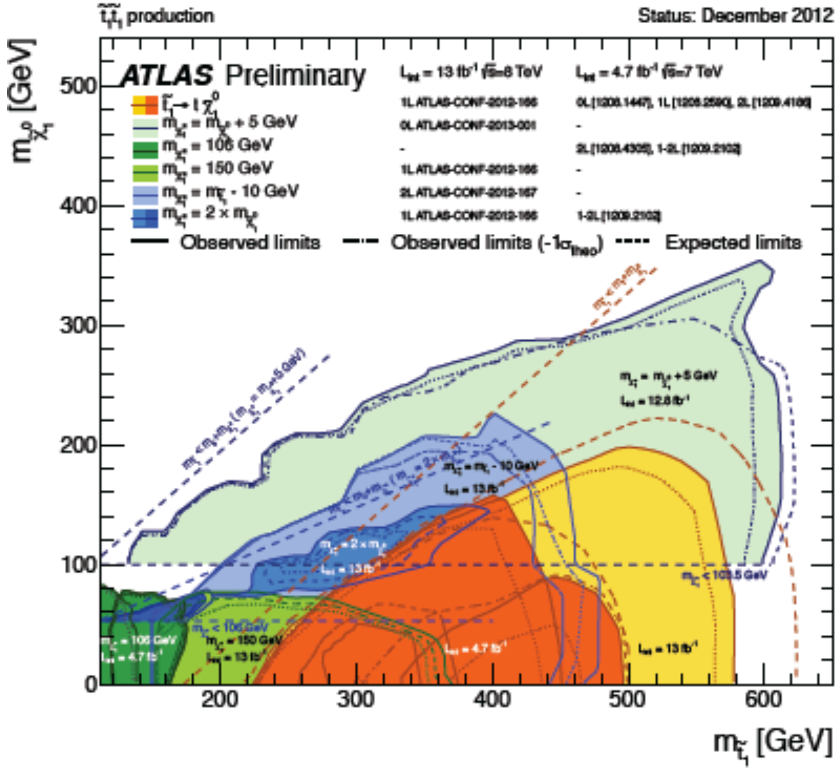
impressive consistency of the SM!

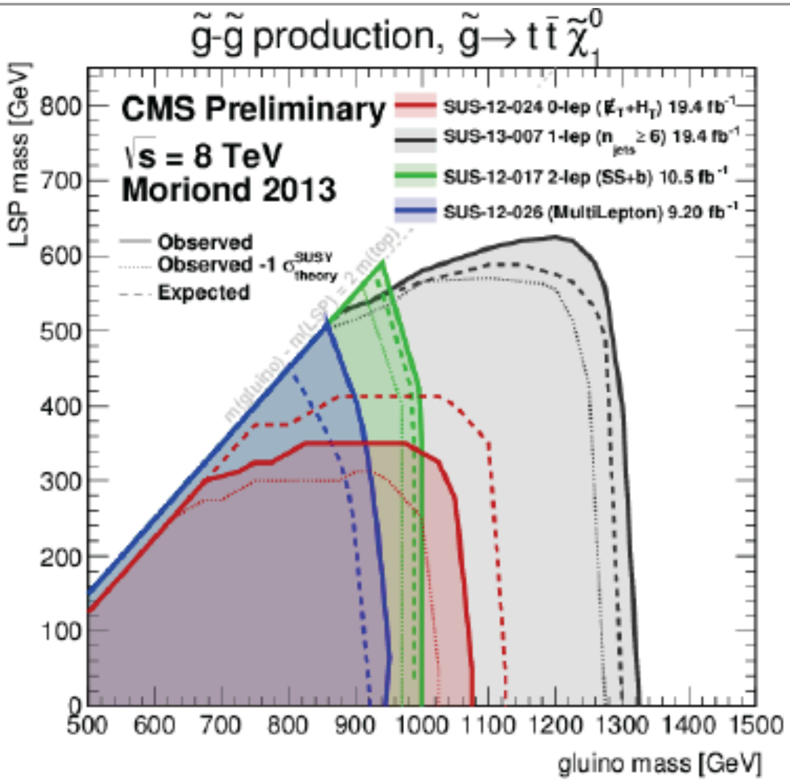
what do other direct and indirect searches for new physics say?

→ susy, exotics

→ heavy flavours

NATURAL SUSY SEARCHES

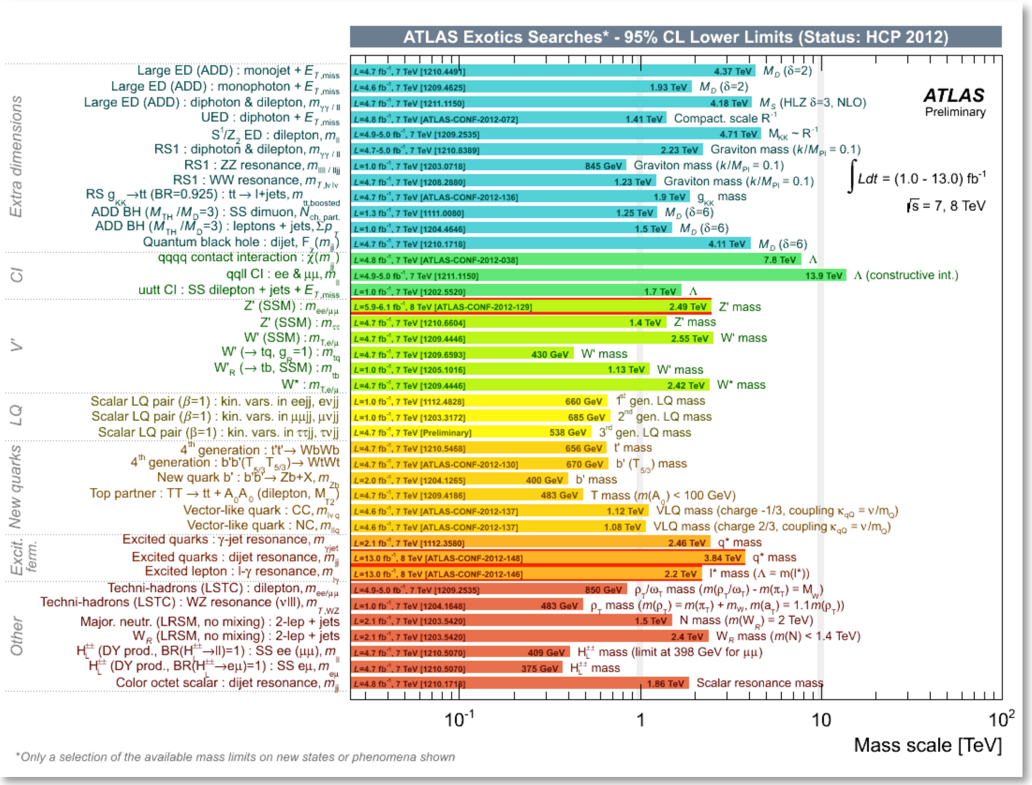




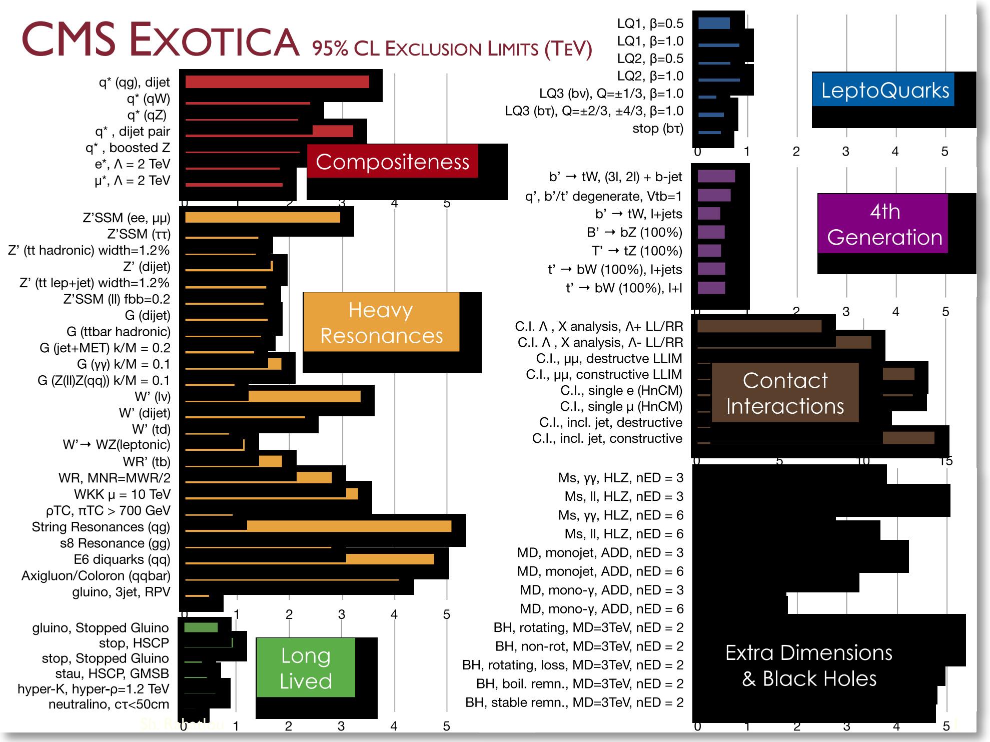
- contours shown belong to different stop decay channels, different sparticle mass hierarchies and simplified decay scenarios

R-Parity Conserving	Direct stop (neutralino)	Direct sbottom (neutralino)	Gluino-induced stop	Gluino induced sbottom
Best limit:	560 GeV	600 GeV	1280 GeV	1240 GeV
No limit beyond LSP:	175 GeV	300 GeV	570 GeV	650 GeV

DIRECT SEARCHES FOR NEW PHYSICS



*Only a selection of the available mass limits on new states or phenomena shown

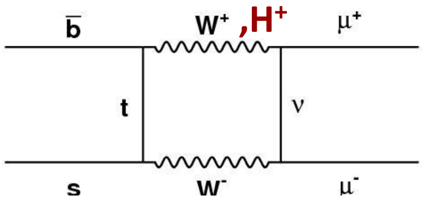


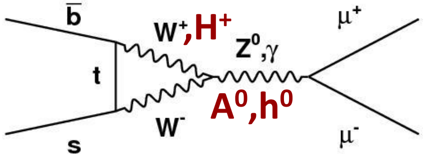
very comprehensive list of new physics searches going on!

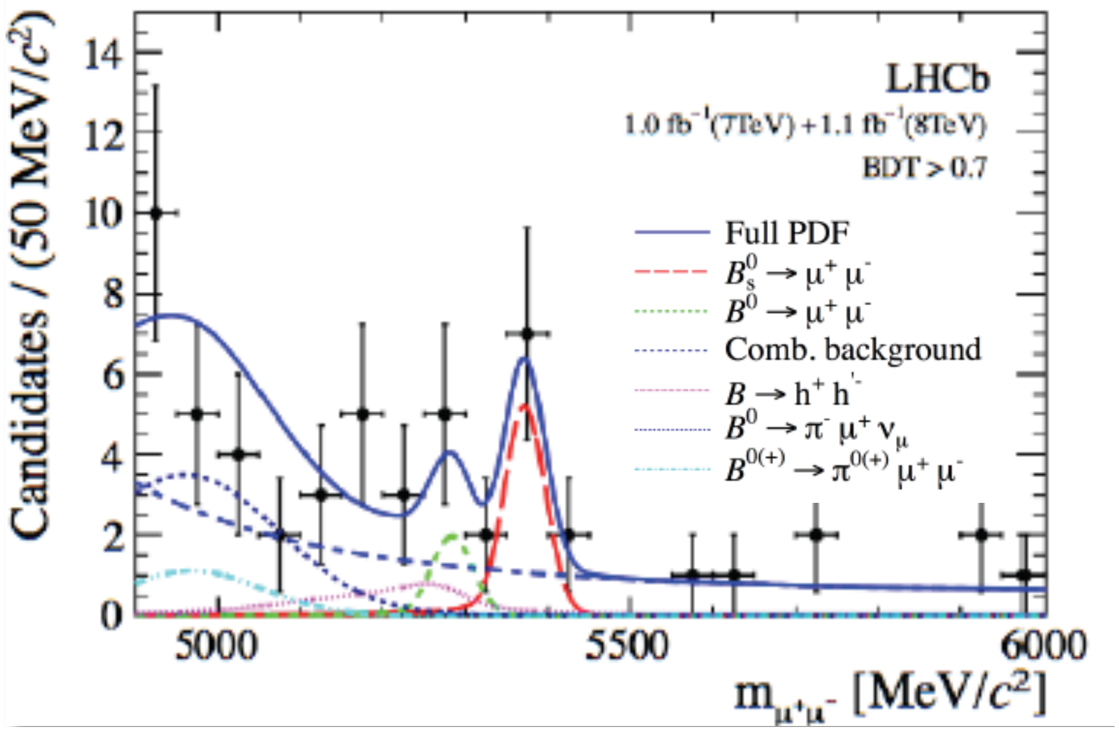
unfortunately the bottom line is...we don't see anything new [for the moment]!

$B_{S,D} \rightarrow \mu\mu$ Results from LHCb

- Highly suppressed decays in SM
  - ★ flavour changing neutral current restricted
  - ★ enhancement or suppression of BR can provide indirect evidence of physics Beyond the SM (BSM)







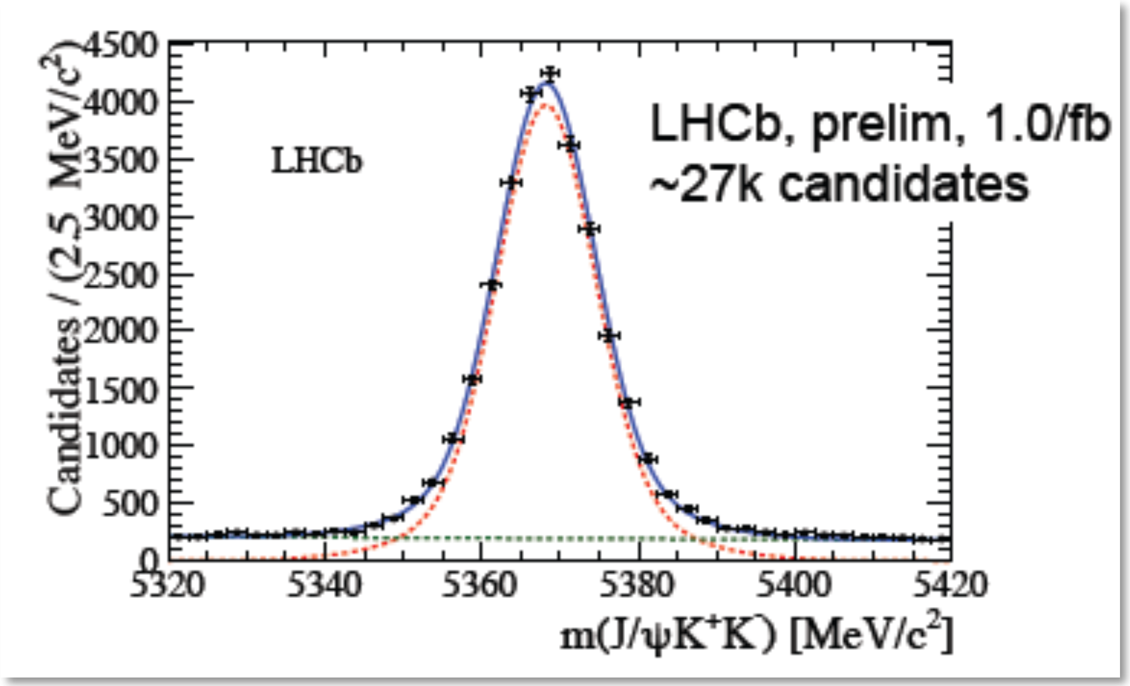
$BR(B_S \rightarrow \mu\mu) = (3.5^{+1.5}_{-1.2}\ (\text{stat.}) \pm 0.2\ (\text{syst.})) \times 10^{-9}$

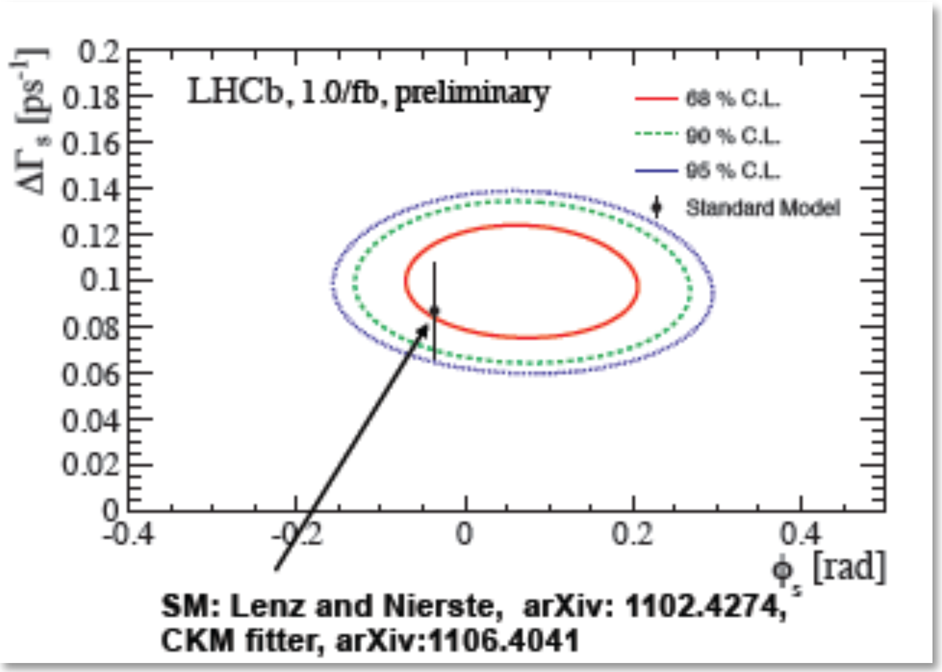
SM expectation: $(3.54 \pm 0.30) \times 10^{-9}$

first evidence, in agreement with the SM prediction

[probability of background only fluctuation $5\text{x}10^{-4}$ corresponding to 3.5σ]

$B_s \rightarrow J/\psi\Phi$ MEASUREMENT FROM LHCb





SM: Lenz and Nierste, arXiv: 1102.4274, CKM fitter, arXiv:1106.4041

- $B_s \rightarrow J/\psi\Phi$ and $B_s \rightarrow J/\psi\pi^+\pi^-$ provide a direct measurement of CP violating phase Φ_s
  - mass, lifetime and angular information simultaneous fit performed

confirmed very good agreement with the SM prediction

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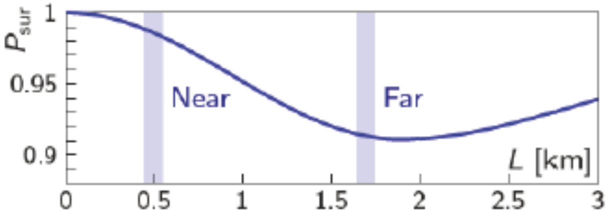
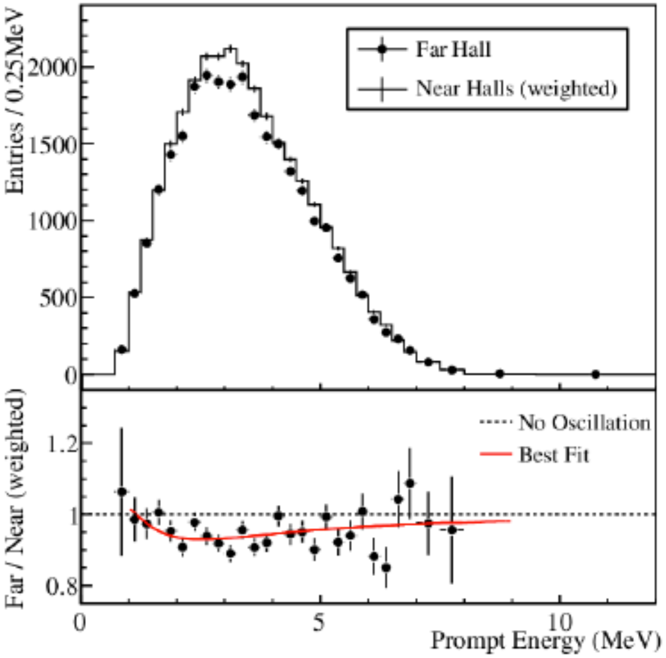
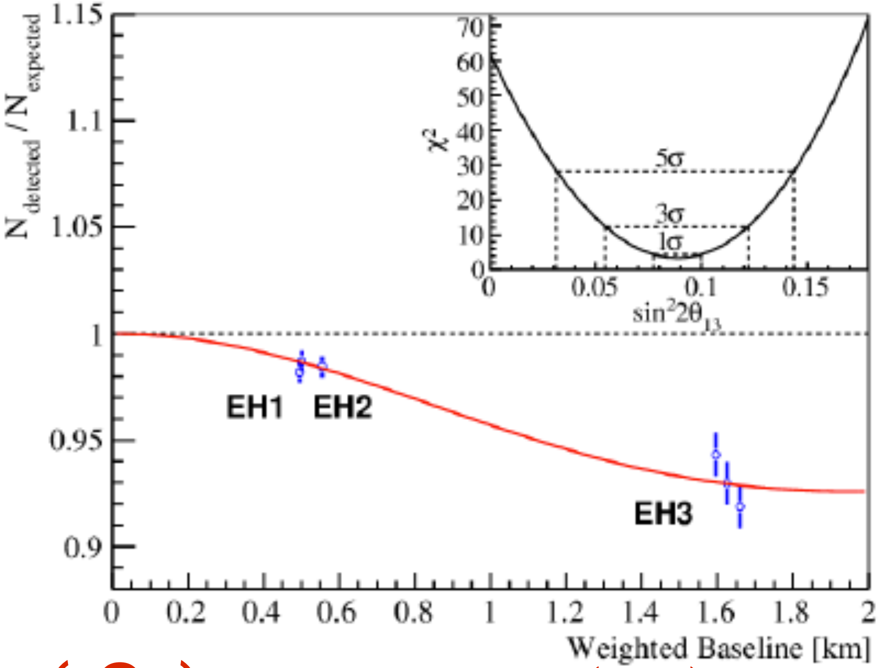
Θ_{13} MEASUREMENT FROM DAYA BAY



Daya Bay is a short baseline reactor neutrino experiment measuring the flux of anti-neutrinos from the reactors via inverse beta-decay reaction





$R = 0.944 \pm 0.007$ (stat.) ± 0.003 (syst.)

$\sin^2(2\Theta_{13}) = 0.944 \pm 0.007$ (stat.) ± 0.003 (syst.)

important for the CP violation in the neutrino sector:

$CPv \sim \sin\Theta_{12} \sin\Theta_{23} \sin\Theta_{13} \,\delta_{CP}$

→ CP phase?

→ mass hierarchy?

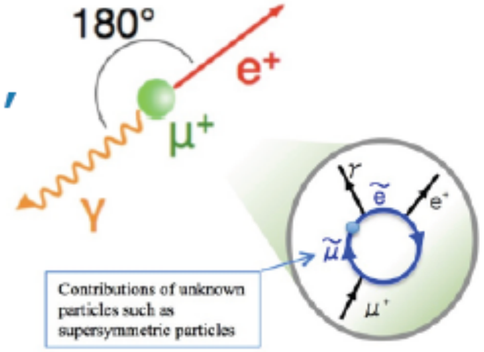
Current Status:

solar and reactor: $\Theta_{12} = 33.6^{0} \pm 1.0^{0}$

atmospheric, accelerator: $\Theta_{23} = 45^{0} \pm 6^{0}$ (90% C.L.)

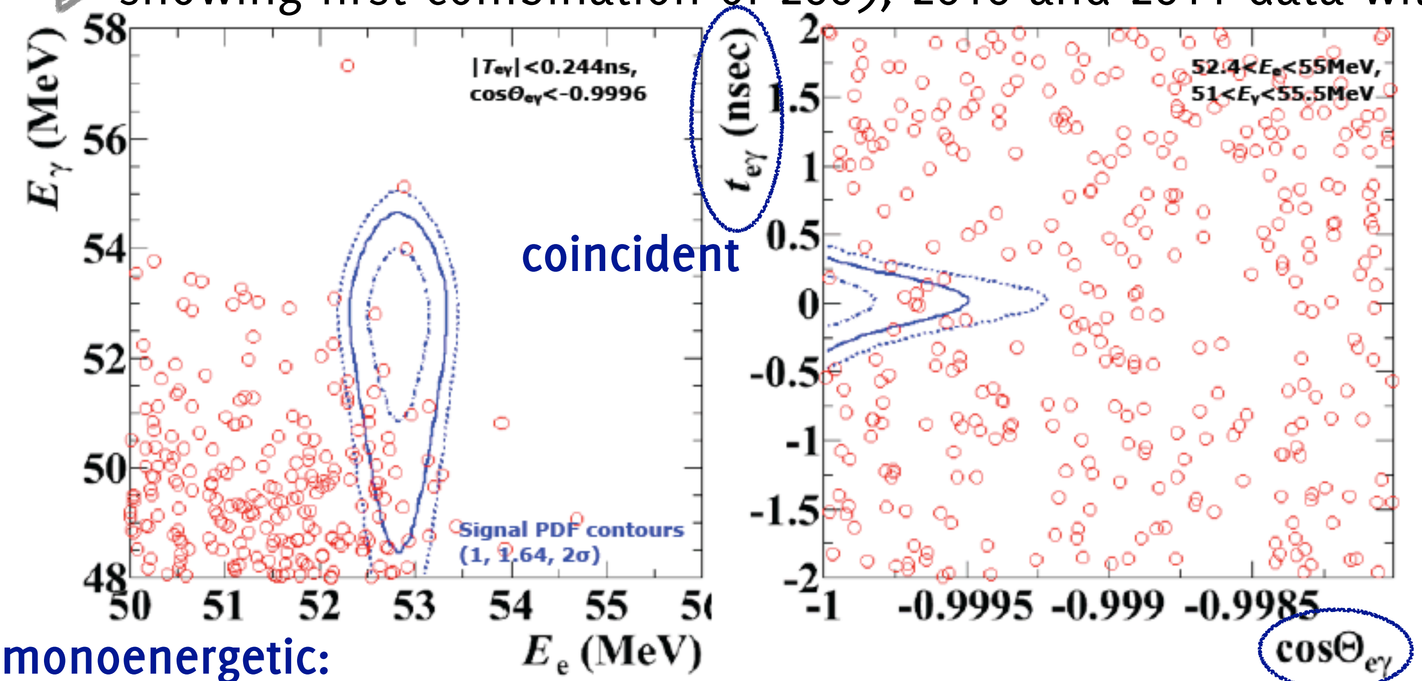
accelerator, reactor: $\mathbf{\Theta_{13} = 9.1^{0} \pm 0.6^{0}}$**!**

LATEST RESULTS FROM MEG



Contributions of unknown particles such as supersymmetric particles

- world's most intense μ^+ beam at PSI
- detectors: 900L Xenon γ-rays detector + positron spectrometer
- $\mu \to e\gamma$ can occur in SM at a very low rate: **if measured → evidence of BSM**
- showing first combination of 2009, 2010 and 2011 data with improved analysis



coincident

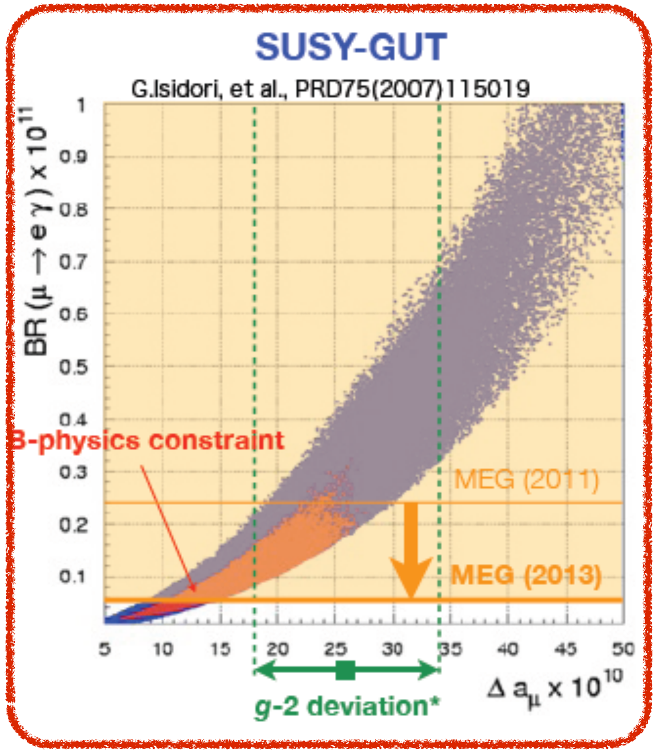
monoenergetic:

$E_e = E_\gamma = 52.8$ MeV $= m_\mu/2$

back-to-back

BR < 5.7×10^{-13} (2009-2011 data)

4x more stringent than previous result



* a_μ(EXP):PRD73(2006)072,
a_μ(SM):Hagiwara et al., JPG38(2011)085003

(MY) CONCLUSIONS

- showed only a small **biased** selection of results
- **up to now, the Standard Model stands his ground**
  - ★ no signs of deviation from its predictions are found in a very broad range of measurements
  - ★ the new-found particle looks like a SM Higgs
  - ★ no new physics has been found in direct or indirect searches
- perspectives: **there are open issues still!**
  - ★ dark matter: new matter? new force?
  - ★ naturalness and fine tuning problems indicate existence of new physics at the TeV scale **we just reached the TeV scale, but haven't quite explored it yet**
  - ★ neutrinos: CP violation phase? mass hierarchy? Majorana neutrinos?
- very intense (experimental) physics programme for the next years
  - ★ precision measurements of new boson parameters and couplings
  - ★ increase precision in the heavy flavour sector measurements
  - ★ continue searches for new physics (SUSY, more Higgs-bosons, more gauge bosons, ...)
  - ★ more on neutrino physics perspectives from Denis'...

BACKUP SLIDES

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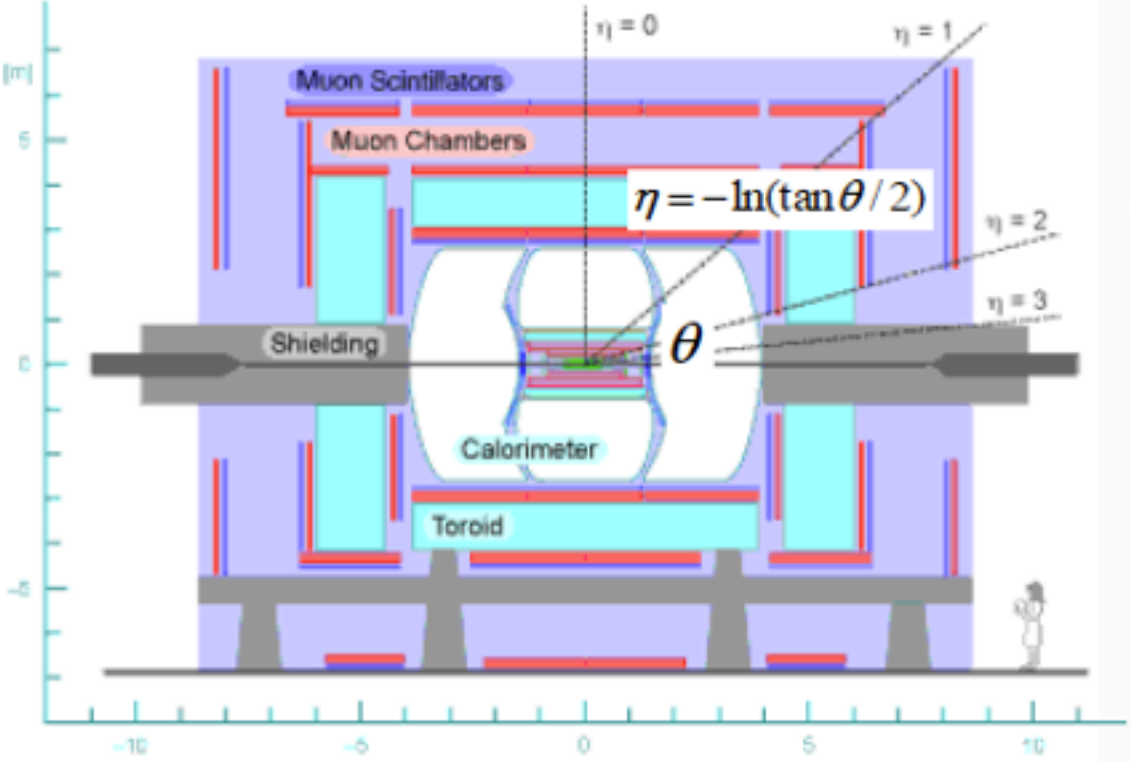
http://atlas.ch

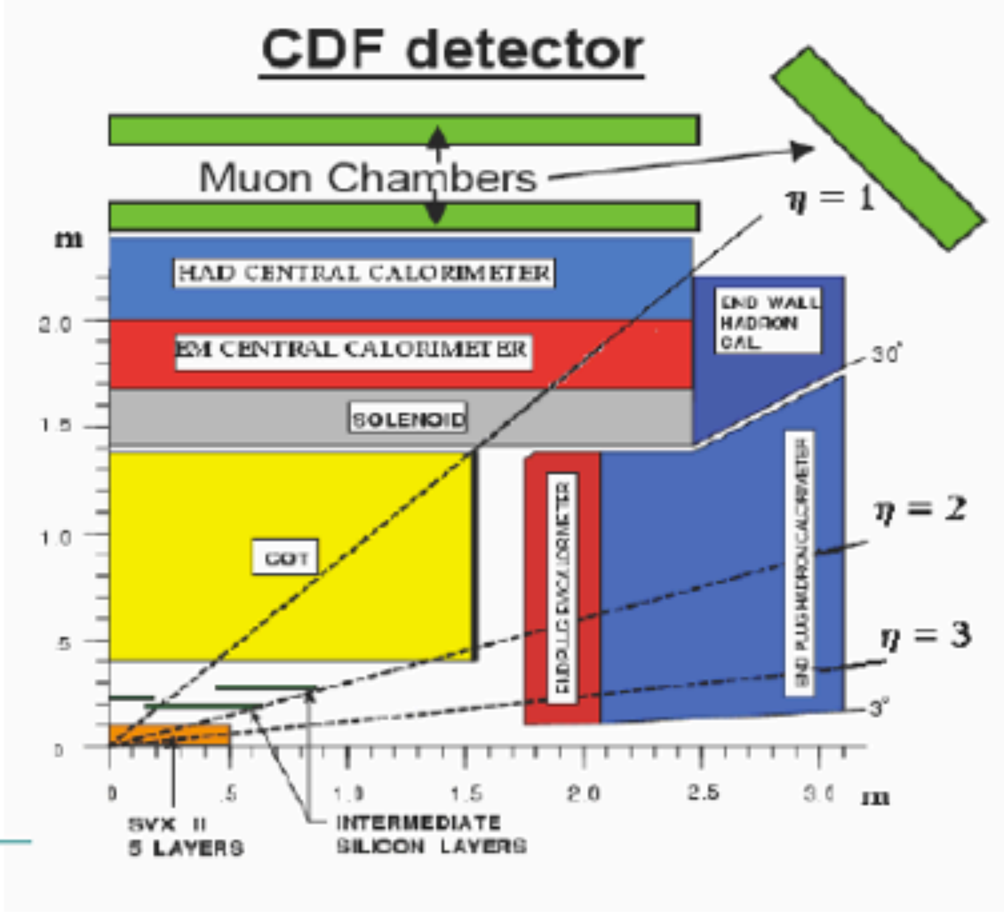
Both detectors have similar structure
with different particular advantages

D0 detector



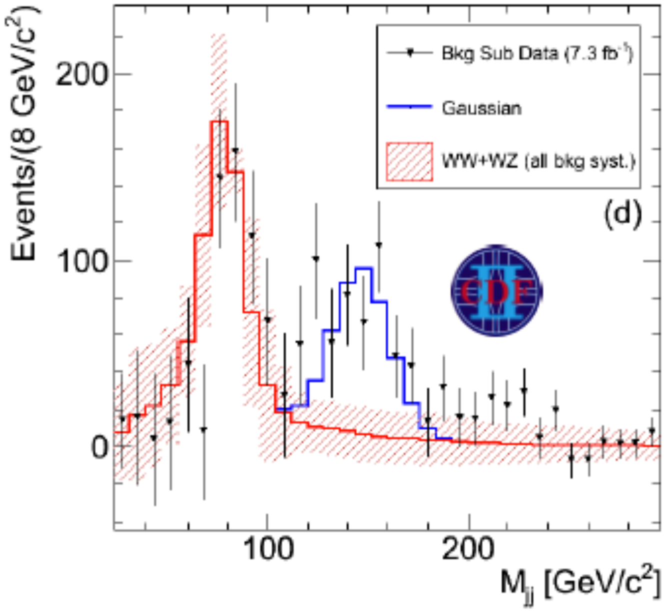
Hermetic LAr calorimeter
Muon detector with large coverage
in iron toroid

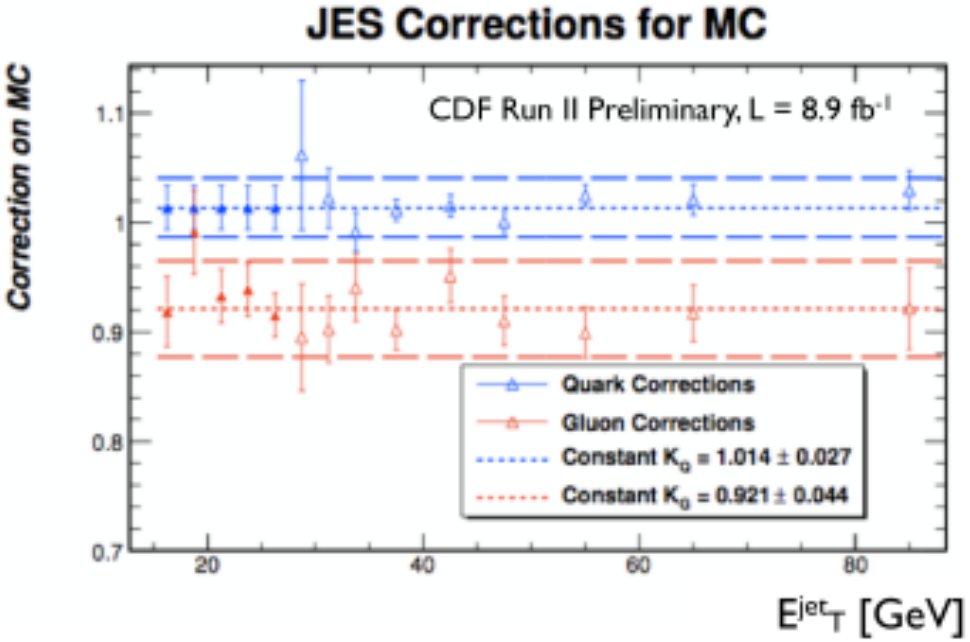
CDF detector

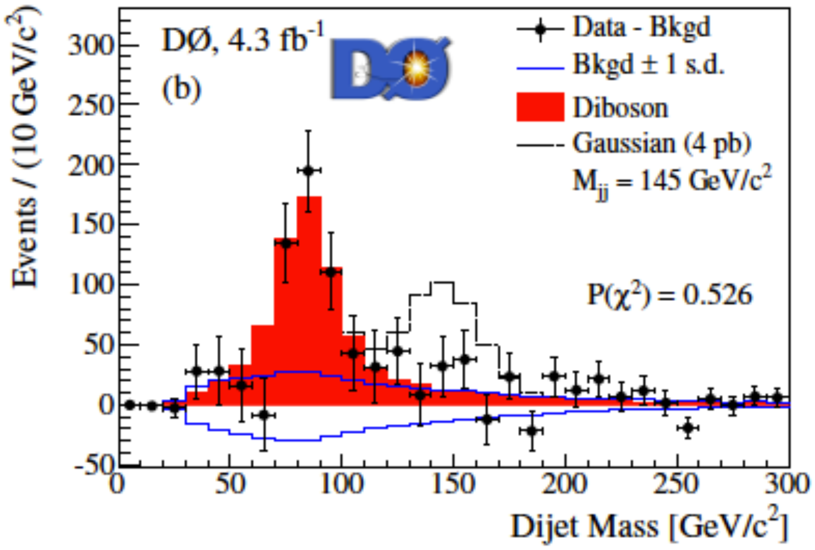


Central tracking system
with large lever arm

Tevatron di-jet Resonance Disappearing







- **CDF saw an excess** in the di-jet mass spectrum in the WW/WZ→lνjj, **not confirmed by Do**
- new **improved jet calibration** to account for differences in gluon and quark jets reconstruction using γ+jets and Z +jets events → **disappearance of the resonance**

TEVATRON DI-JET RESONANCE DISAPPEARING

- gluons are more coupled to the strong force field than quarks → a gluon produces more particles in hadronization than a quark with the same energy
- calorimeter response is in general non-linear: a quark jet is better reconstructed than a gluon jet (where you have more particles with lower energies)
- why the problem was seen at CDF but not at Do or the LHC experiments?
  - ★ CDF was calibrating jets only using γ+jets events, dominated in $p\bar{p}$ collisions by γ+quark jet events → **mis-calibration for gluon jets**
  - ★ now using Z+jets **and** γ+jets events the calibration is correct, Do was already using this
  - ★ at the LHC: very good calorimeters compensating a lot (small difference in reconstruction), also Z/γ+jets dominated by quark jets used for calibration together with QCD events (50-50 gluon/quark jets) → **few percents difference at low p_T**

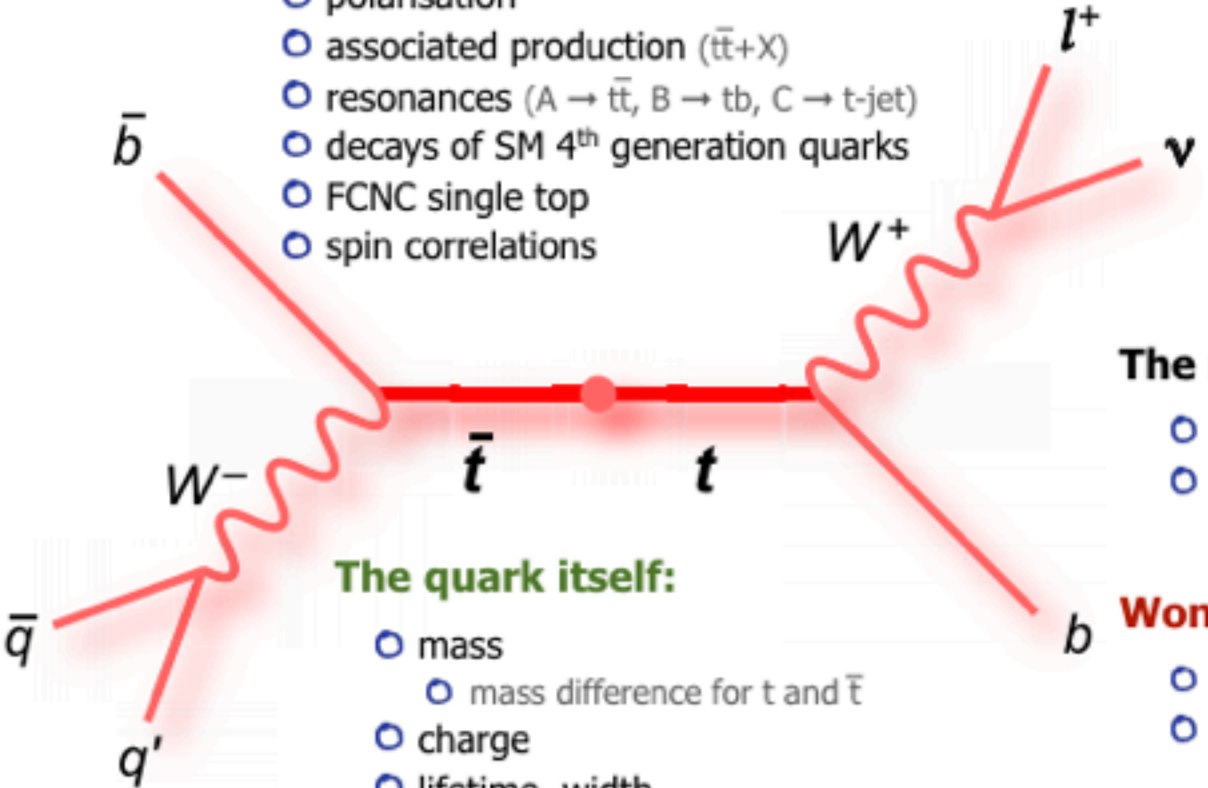
Top studies in a nutshell

Production:

- cross sections
  - for $t\bar{t}$ pairs, single top
- asymmetries
- polarisation
- associated production ($t\bar{t}$+X)
- resonances ($A \to t\bar{t}$, $B \to tb$, $C \to$ t-jet)
- decays of SM 4th generation quarks
- FCNC single top
- spin correlations

The decay:

- BR(tWb)/BR(tWq)
  - CKM $|V_{tb}|$
- W-helicity
  - anomalous couplings
- $t \to H^+b$



The quark itself:

- mass
  - mass difference for t and $\bar{t}$
- charge
- lifetime, width

The number of aspects to study is huge

- different analyses per decay/production channel
- two datasets with different $\sqrt{s}$ energies

Won't cover all aspects in detail

- try to present wide overview of results
- priority given to most recent ones

More results are available here:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

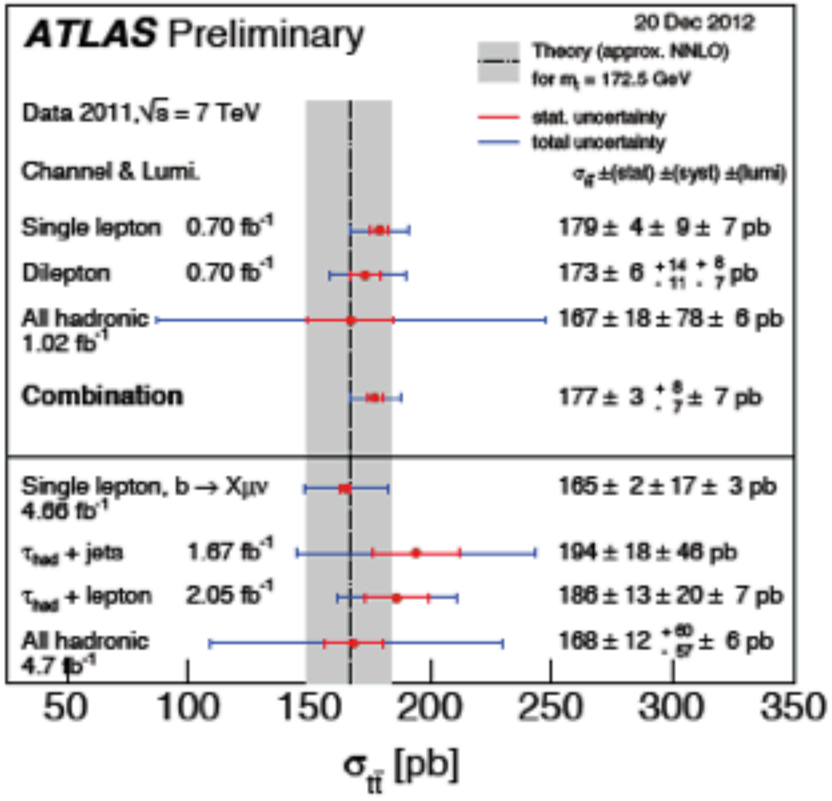
Cross section results at 7 TeV

Measurements from likelihood (profile) **fits** (counting)

- systematics can be included as nuisance parameters in the fit

Data driven estimation for main backgrounds

- QCD, W+jets, DY+jets ...

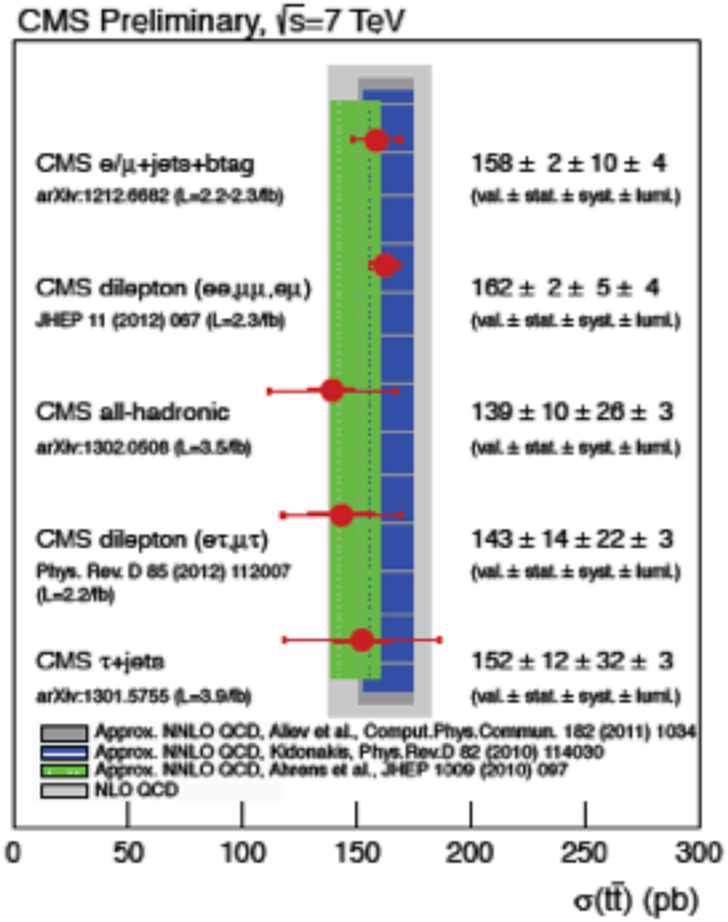


Combination [ATLAS-CONF-2012-024 up to 1.02 fb^{-1}]

- $\sigma = 177 \pm 3_{(stat)} \pm^{8}_{7(syst)} \pm 7_{(lumi)}\, pb$

~4% uncertainty most precise single measurement @ 7TeV

Compatible with theory at approx. NNLO



Combination [CMS PAS TOP-11-024 up to 1.1 fb^{-1}]

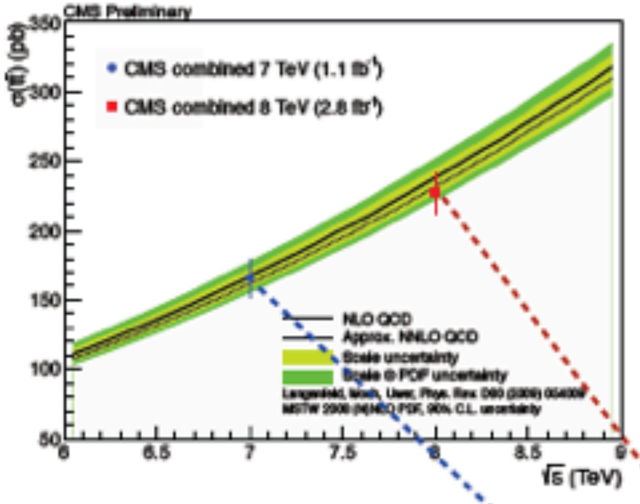
- $\sigma = 165.8 \pm 2.2_{(stat)} \pm 10.6_{(syst)} \pm 7.8_{(lumi)}\, pb$

Full NNLO calculation now available:

A. Mitov at Rencontres de Physique de la Valle d'Aoste

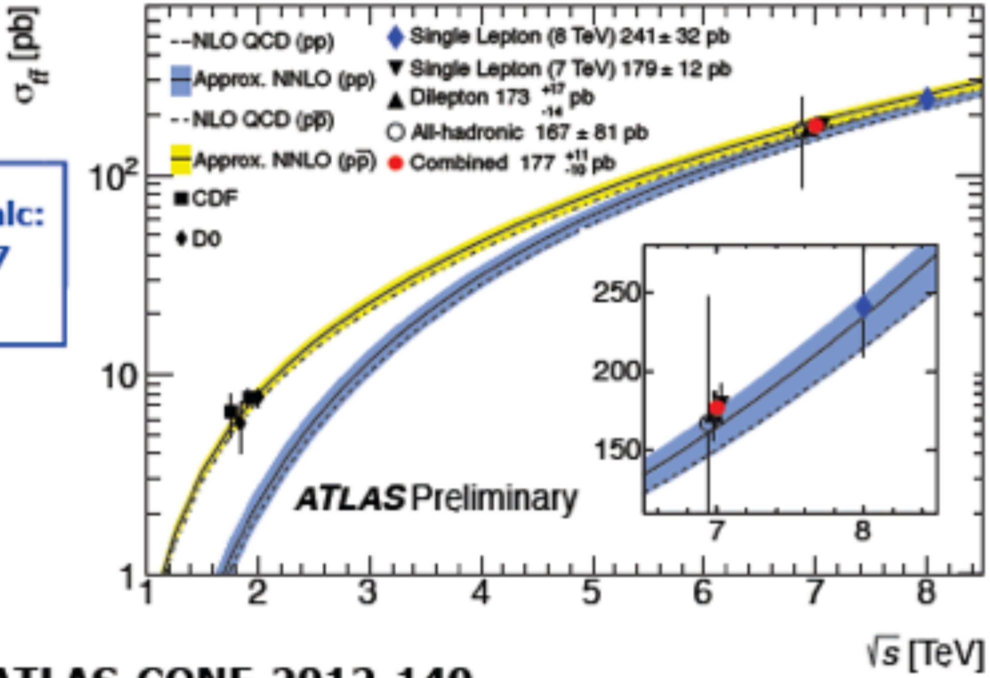
https://agenda.infn.it/getFile.py/access?contribId=37&sessionId=11&resId=0&materialId=slides&confId=5540

Cross section results at 8 TeV



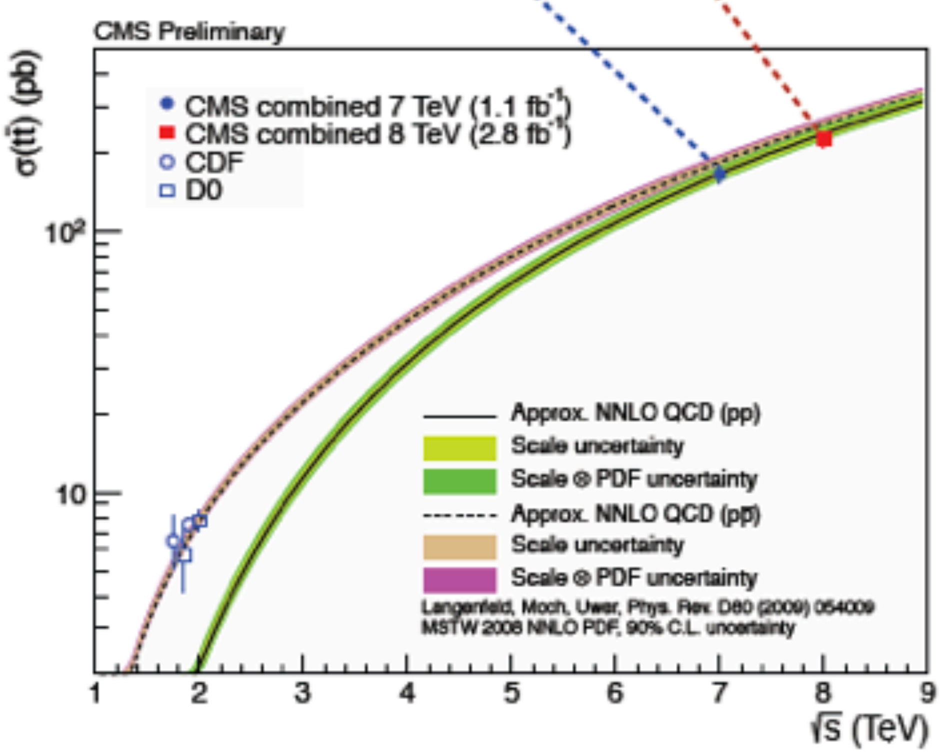
Ratios:

Back on the envelope calc:
ATLAS: $\sigma_{8TeV}/\sigma_{7TeV} = 1.37$
CMS: $\sigma_{8TeV}/\sigma_{7TeV} = 1.36$



ATLAS-CONF-2012-149

- use fit on multivariate likelihood discriminant from relevant parameters
- **l+jet: $\sigma = 241 \pm 2$ (stat) ± 31 (syst) ± 9 (lumi) pb**



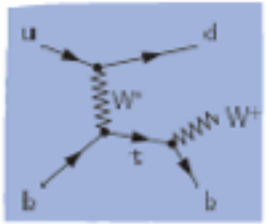
CMS PAS TOP-12-006/007

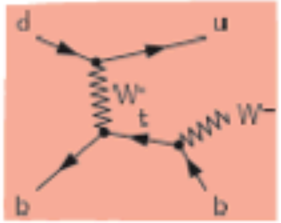
- performed using binned maximum likelihood fit (l+jets) & counting (dilepton)
- **COMB: $\sigma = 227 \pm 3$ (stat) ± 11 (syst) ± 10 (lumi) pb**

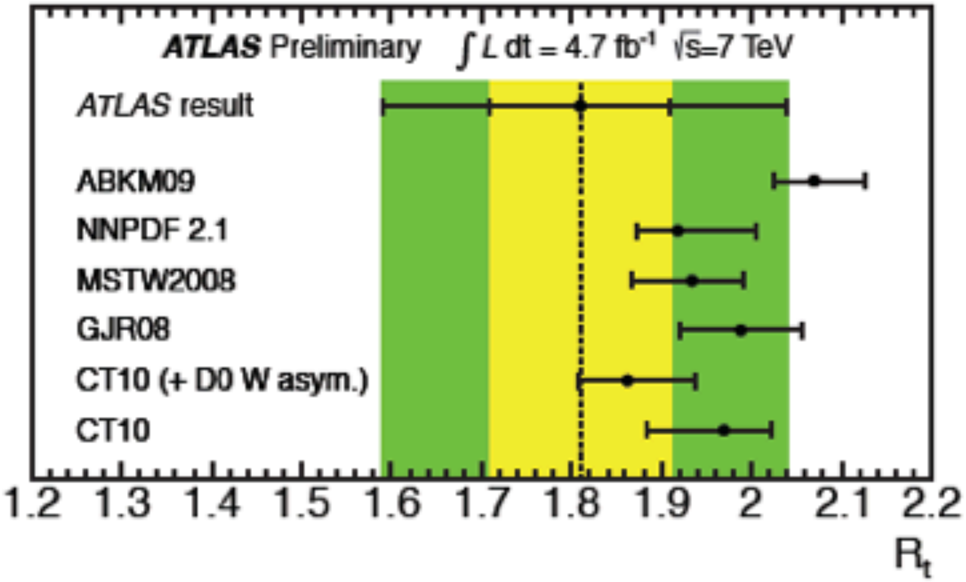
t-channel t/$\bar{t}$ cross section ratio

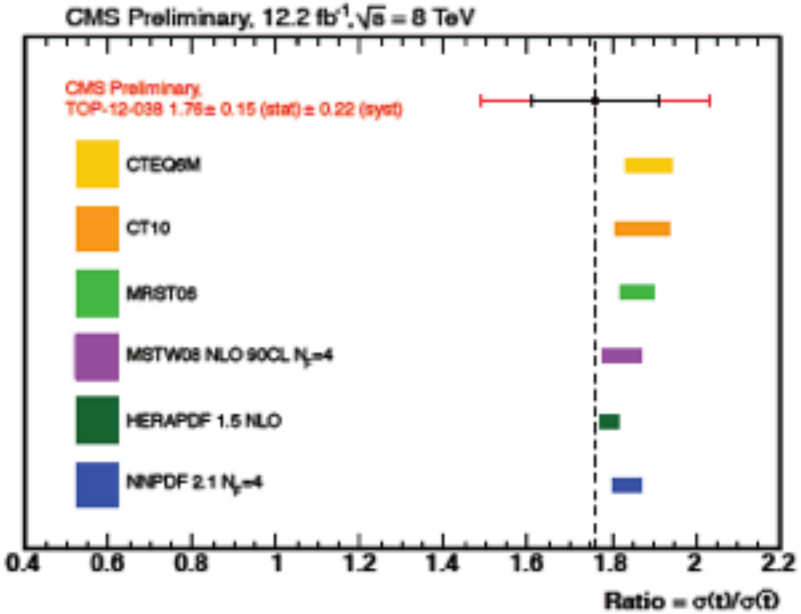
At LHC single top t($\bar{t}$) t-channel prod. happens mainly via u(d)-b W exchange

- and since: in pp collisions the u density is almost twice the d density
- therefore: at LHC the cross section ratio between tops and antitops in t-channel is expected to be larger than 1









ATLAS [ATLAS-CONF-2012-056]

- performed on l+ 2/3 jet samples
- result from fits on NN outputs for l^+/l^-
- $R_t = 1.81 \pm 0.10_{(stat)} \pm^{0.21}_{0.20(syst)}$

CMS [CMS PAS TOP-2012-038] New

- performed fitting the η distribution of the non b-tagged jet and separating l^+ and l^-
- $R_t = 1.76 \pm 0.14_{(stat)} \pm 0.21_{(syst)}$

Mass measurement methods

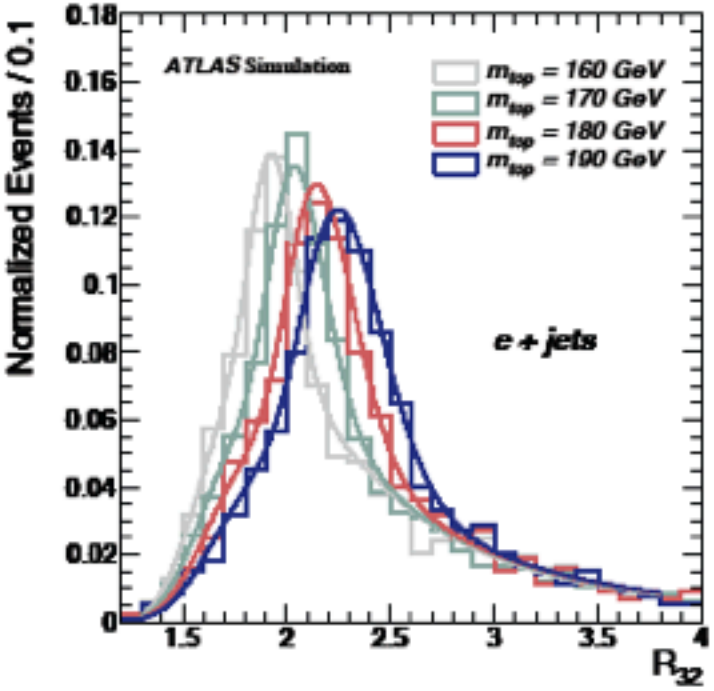
Methods used to measure m_t in the following slides (more exist not covered here)

- **Template Fit Method**
  - select reconstructed variable(s) sensitive to the top mass (e.g $M_3/M_2=R_{32}$)
  - build template fits for that variable(s) for signal (many from MCs with different m_t) and for bkg, to be used in a likelihood fit comparing data/templates

- **Analytical Matrix Weighting Technique** (AMWT)
  - used for dilepton analyses with two neutrinos (under-constrained system)
  - reconstruct analytically possible neutrino solutions for a given m_t in range of possible m_t values (many possible solutions/combinations - smear for resolutions)
  - assign a weight based on PDF and $p(p_{T\text{-lep}}|m_t)$ for each solution and take as m_t the one with largest sum of weights
  - get m_t from likelihood comparing data and MC (for different m_t values)

- **Ideogram Method**
  - reconstruct $m_{t\text{-fitted}}$ via a kinematic fit (l+jets fully-hadronic)
  - ev. by ev. likelihood for fit results to be consistent with a given m_t
  - based on the $p(m_t|m_{t\text{-fitted}})$ given signal (different m_t) and background, accounts all different combinations weighted by the likelihood of the fit

- **In-situ Jet Energy Scale (JES/JSF) calibration**
  - impact m_t measurements
  - use m_W constraint to compute a global scale factor for JES within the measurement itself

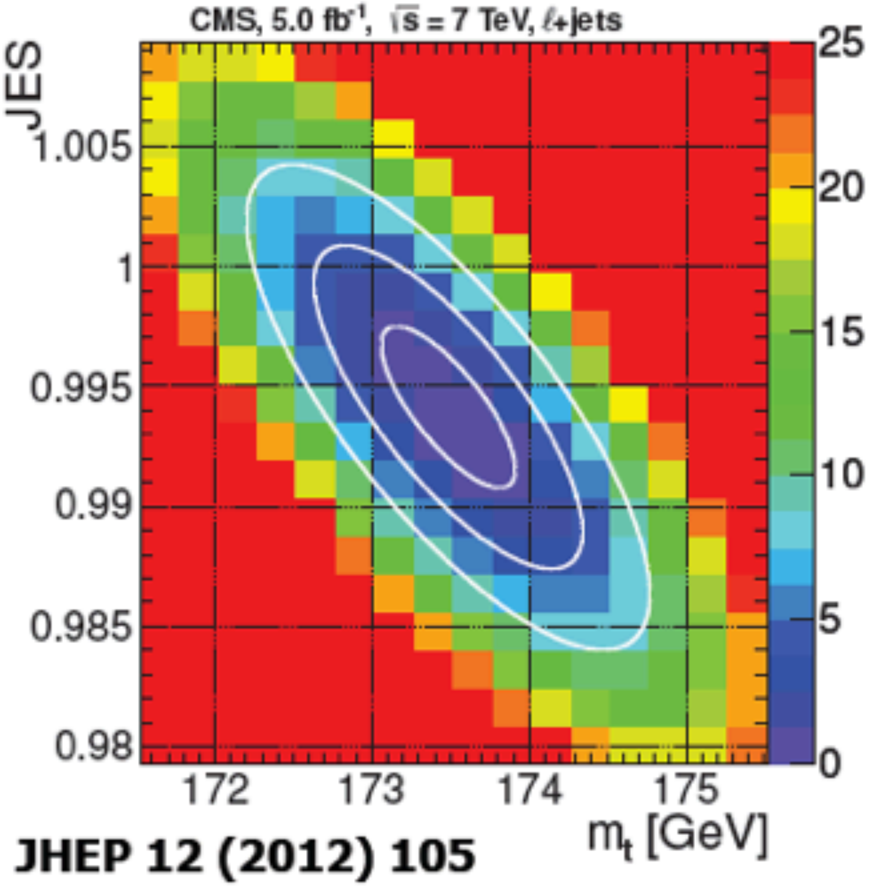


Top mass results

CMS result from Ideogram Method on l+jets

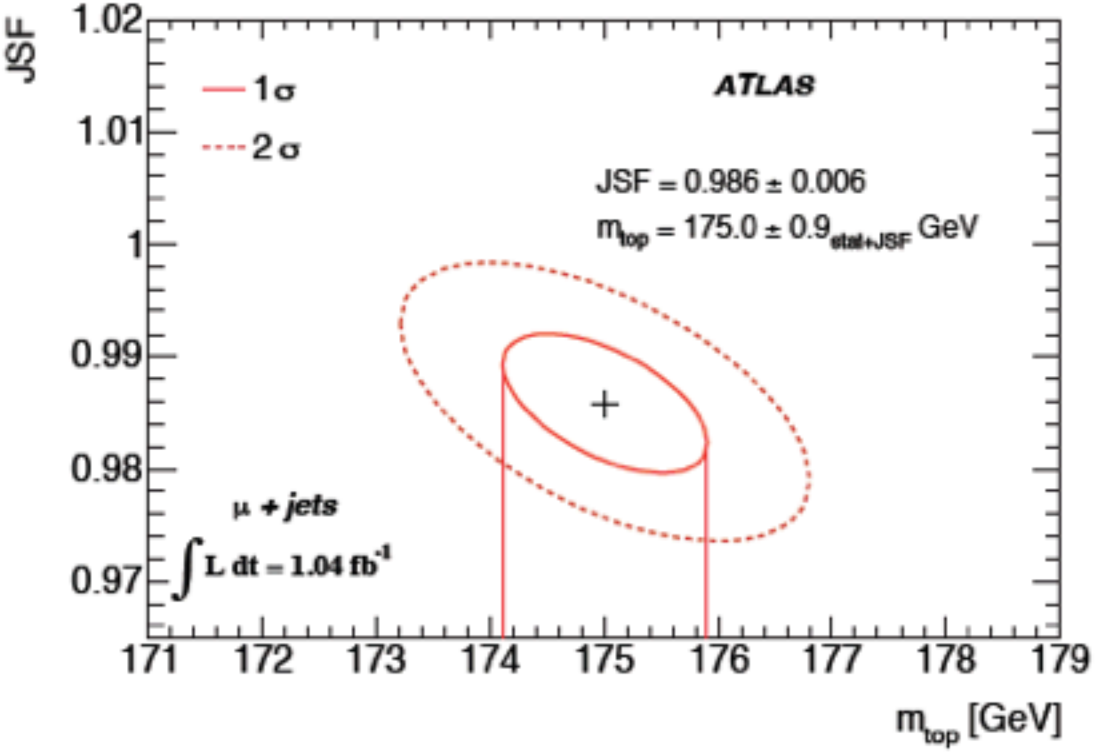
- uses kin fit to get m_t and reco for m_W
- JES correction evaluated from method
- method validated/calibrated using MC
- $m_t = 173.49 \pm 0.43$ (stat+JES) ± 0.98 (syst) GeV

most precise single meas.



JHEP 12 (2012) 105

Eur. Phys. J C72 (2012) 2046



ATLAS measurement based on Template Fit Method on l+jets

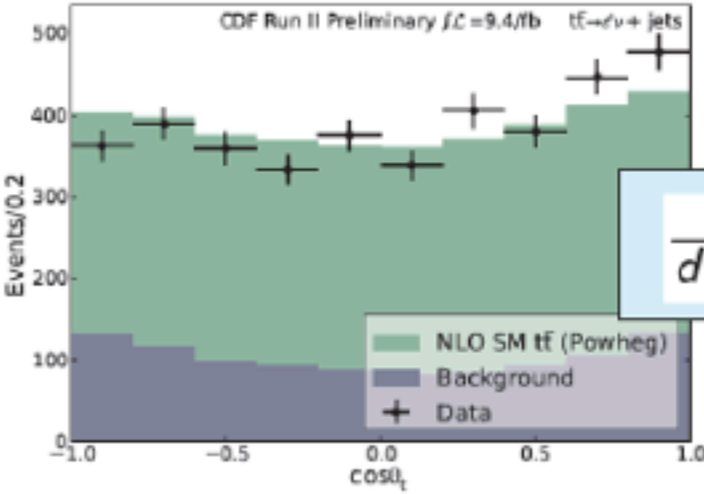
- uses reco m_t and m_W as input to the fit
- JSF impact evaluated in situ from m_W
- method validated using MC
- $m_t = 174.5 \pm 0.6$ (stat) ± 2.3 (syst) GeV

Forward-backward asymmetry

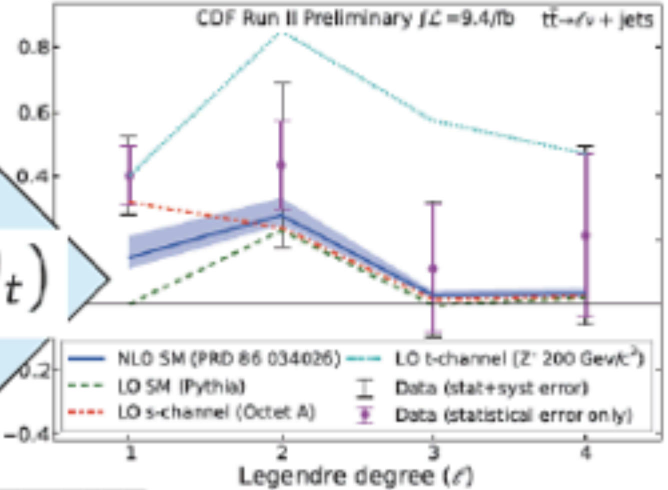
Jonathan Wilson

- **Full cosθ$_t$ distribution (A_{FB}: 2 bins)**
  - **Expand in Legendre polynomials:**

a_1 accounts for A_{FB}

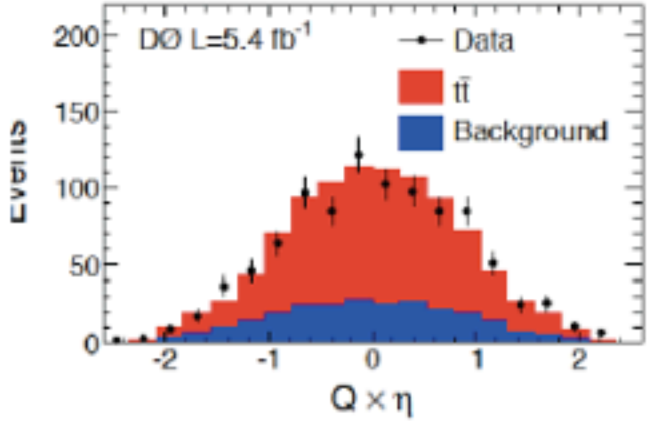


$$\frac{d\sigma}{d\cos\theta_t} = \sum_\ell a_\ell P_\ell(\cos\theta_t)$$



- **Added dileptons:**

$$A_{FB}^{\ell} = \frac{N(q_\ell\eta_\ell > 0) - N(q_\ell\eta_\ell > 0)}{N(q_\ell\eta_\ell > 0) + N(q_\ell\eta_\ell > 0)}$$



=0.058±0.053

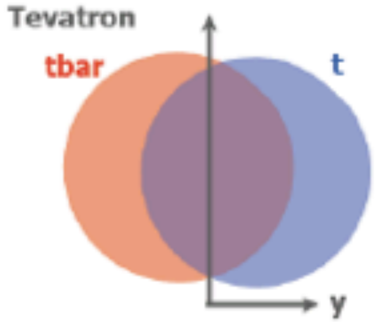
- **Then lepton+jets**

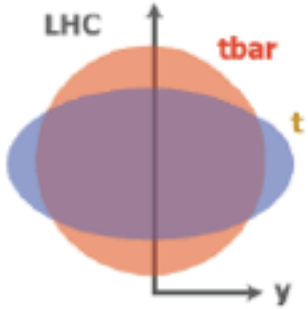
$$A_{FB}^{\ell} = 0.094^{+0.032}_{-0.029}$$

Expected from A_{FB}: ~0.76

Forward-backward asymmetry at LHC

Carlo Battilana





Reconstructing tt̄: $\Delta|y| = |y_t| - |y_{\bar{t}}|$

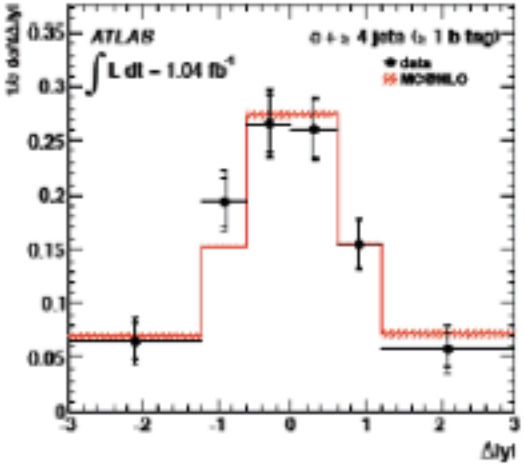
$$A_C = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$$

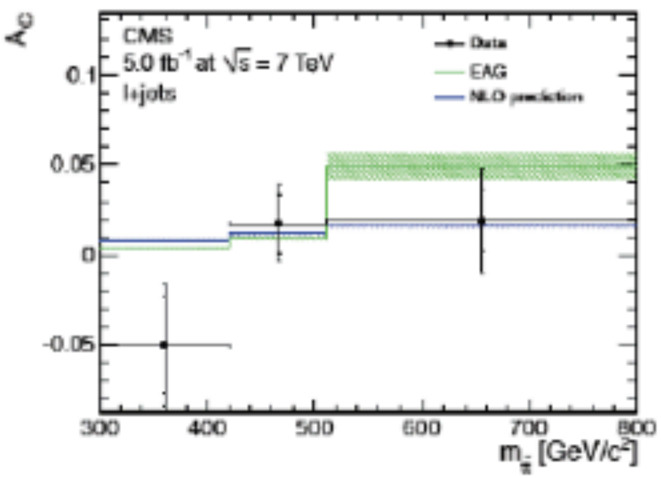
In dilepton decays can also use: $\Delta|\eta| = |\eta_{l+}| - |\eta_{l-}|$

$$A^{ll}{}_C = \frac{N(\Delta|\eta|>0) - N(\Delta|\eta|<0)}{N(\Delta|\eta|>0) + N(\Delta|\eta|<0)}$$

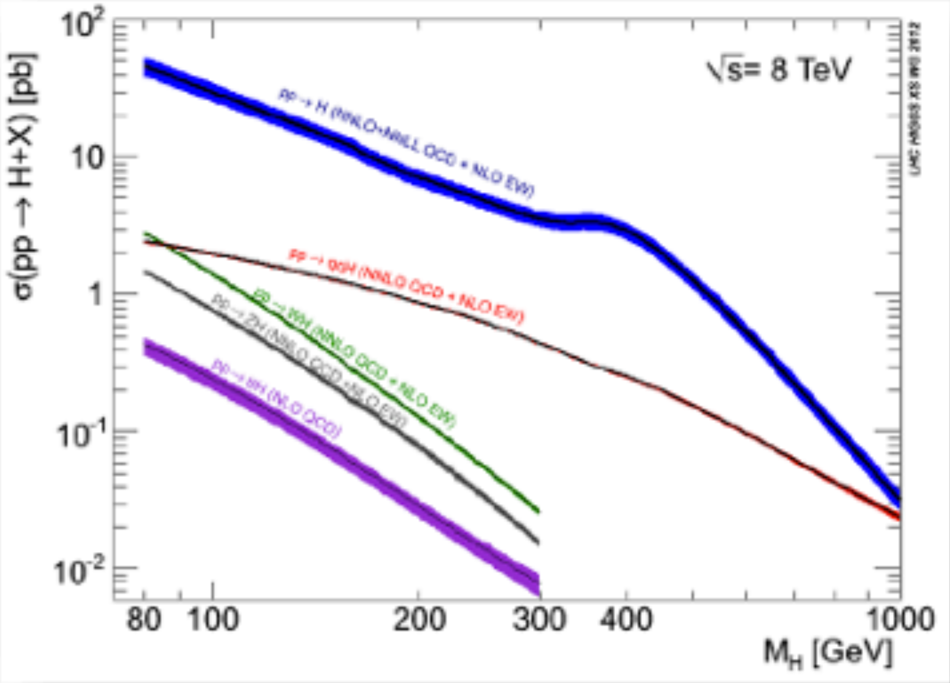
ATLAS Combined [ATLAS-CONF-2012-057]:

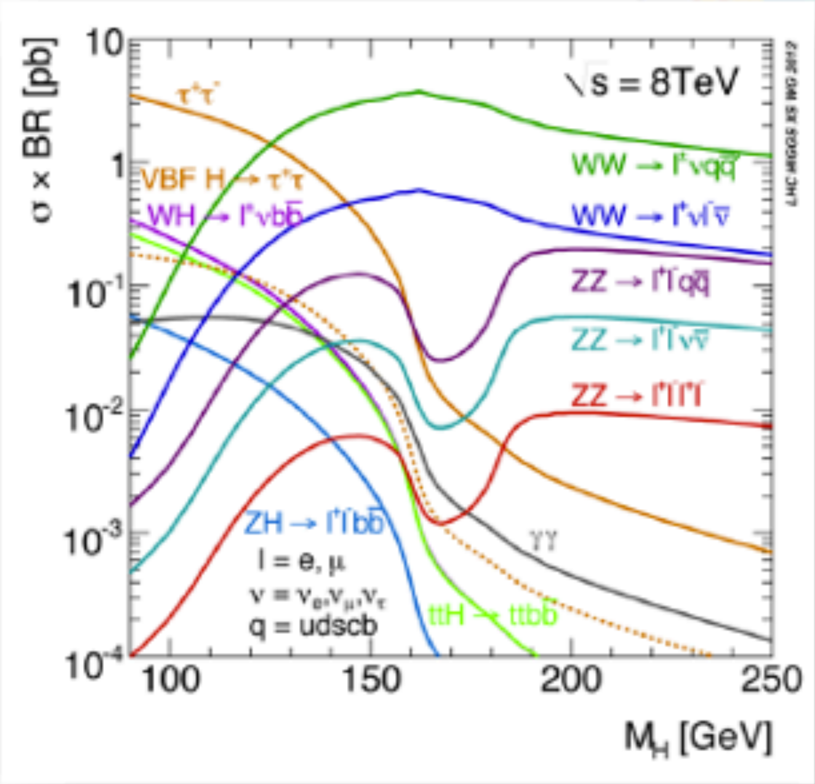
$A_C = 0.029 \pm 0.018_{(stat)} \pm 0.014_{(syst)}$



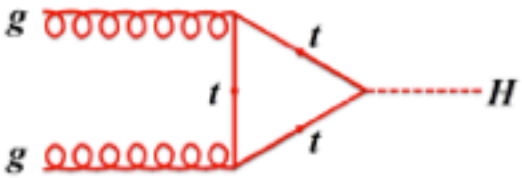


Higgs production and decays

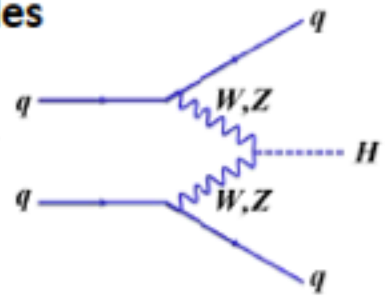




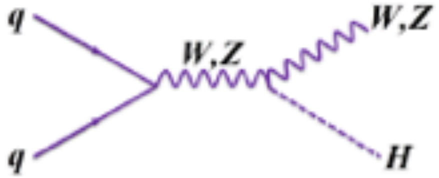
SM scalar production modes



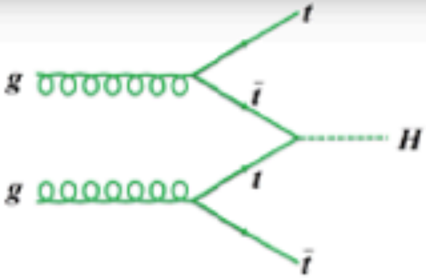
gluon fusion



vector boson fusion



W/Z-associated production



tt-associated production

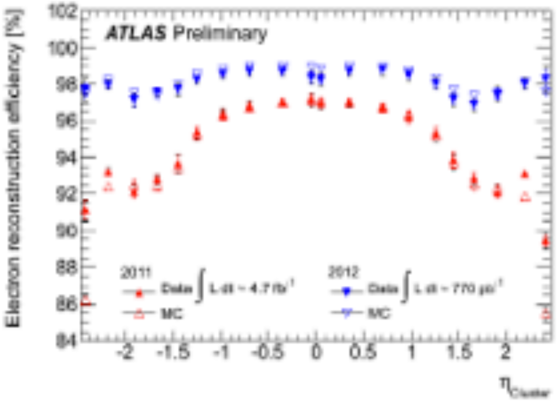
$H \rightarrow ZZ^{(*)} \rightarrow 4l$ ($l=e,\mu$) : Overview

ATLAS-CONF-2013-013

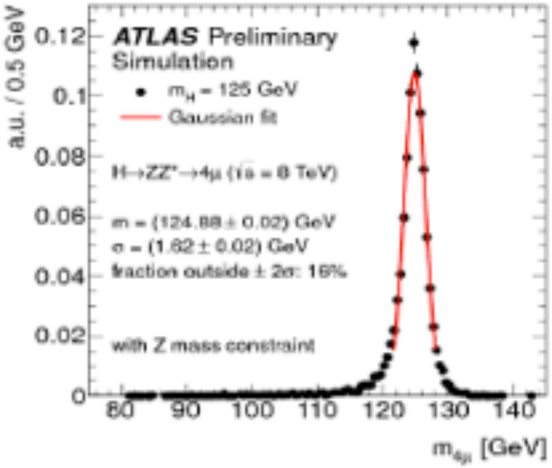
The golden channel, with small cross-section but very good S/B ratio and fully-reconstructed mass

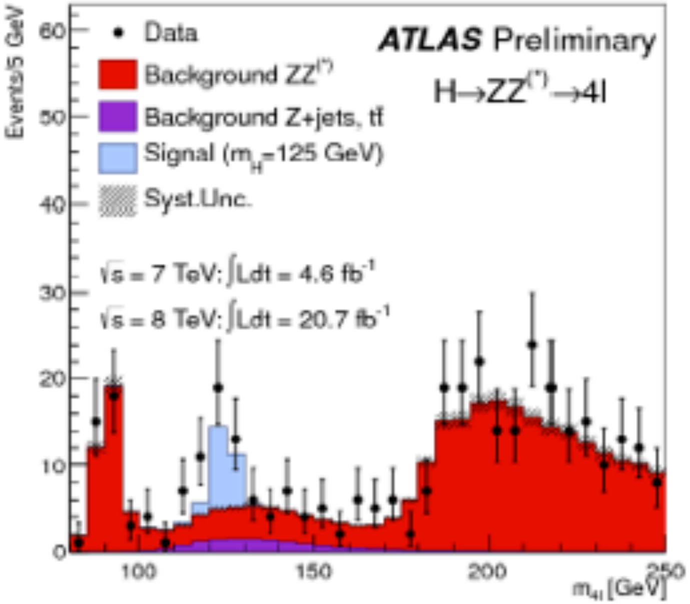
Signal reconstruction

Electron reco ε measured with Z→ee



Mass resolution in 4-μ channel

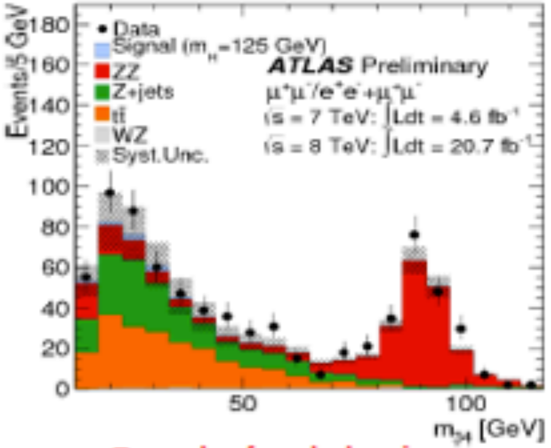




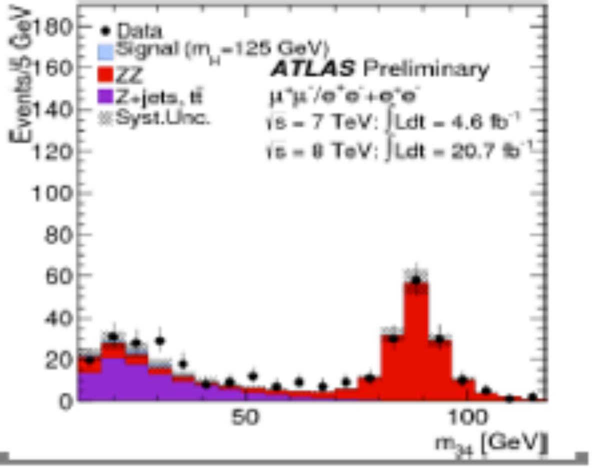
Two pairs of opposite-sign same-flavor isolated leptons

➔ In region 125±5 GeV: 32 events observed [11.1±1.3 expected from bknd & 15.9±2.1 from SM Higgs]

Background control



Example of control regions: no isolation nor IP cuts on softest leptons



Spin-2 model

Spin 2 model for X→VV:

$$
\begin{aligned}
A(X \to VV) = \Lambda^{-1} \Big[& 2g_1 t_{\mu\nu} f^{*1,\mu\alpha} f^{*2,\nu\alpha} + 2g_2 t_{\mu\nu} \frac{q_\alpha q_\beta}{\Lambda^2} f^{*1,\mu\alpha} f^{*2,\nu\alpha} \\
& + g_3 \frac{\tilde{q}^\beta \tilde{q}^\alpha}{\Lambda^2} t_{\beta\nu} (f^{*1,\mu\nu} f^{*2}_{\mu\alpha} + f^{*2,\mu\nu} f^{*1}_{\mu\alpha}) + g_4 \frac{\tilde{q}^\nu \tilde{q}^\mu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta} f^{*(2)}_{\alpha\beta} \\
& + m_V^2 \left(2g_5 t_{\mu\nu} \epsilon_1^{*\mu} \epsilon_2^{*\nu} + 2g_6 \frac{\tilde{q}^\mu q_\alpha}{\Lambda^2} t_{\mu\nu} (\epsilon_1^{*\nu} \epsilon_2^{*\alpha} - \epsilon_1^{*\alpha} \epsilon_2^{*\nu}) + g_7 \frac{\tilde{q}^\mu \tilde{q}^\nu}{\Lambda^2} t_{\mu\nu} \epsilon_1^* \epsilon_2^* \right) \\
& + g_8 \frac{\tilde{q}_\mu \tilde{q}_\nu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta} \tilde{f}^{*(2)}_{\alpha\beta} + g_9 t_{\mu\alpha} \tilde{q}^\alpha \epsilon_{\mu\nu\rho\sigma} \epsilon_1^{*\nu} \epsilon_2^{*\rho} q^\sigma \\
& + \frac{g_{10} t_{\mu\alpha} \tilde{q}^\alpha}{\Lambda^2} \epsilon_{\mu\nu\rho\sigma} q^\rho \tilde{q}^\sigma (\epsilon_1^{*\nu} (q\epsilon_2^*) + \epsilon_2^{*\nu} (q\epsilon_1^*)) \Big],
\end{aligned}
$$

General interaction of spin-2 particle with gauge bosons pair has 10 independent tensor couplings

- Excluding generic spin-2 model is impossible at this stage
- Start with model with minimal couplings (g1=g5=1)
- Two production modes allowed: gg and qqbar
- Study 5 different gg fractions from 0% to 100%

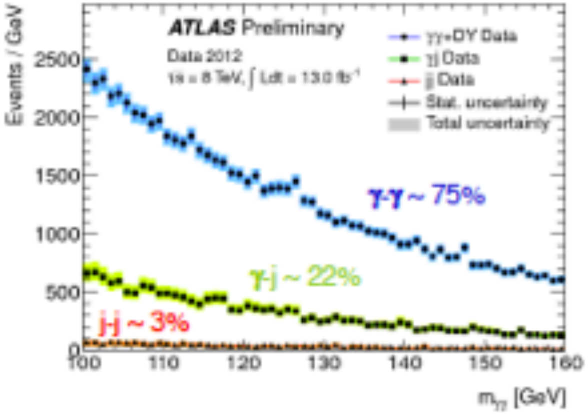
$H \rightarrow \gamma\gamma$: Overview

ATLAS-CONF-2013-012

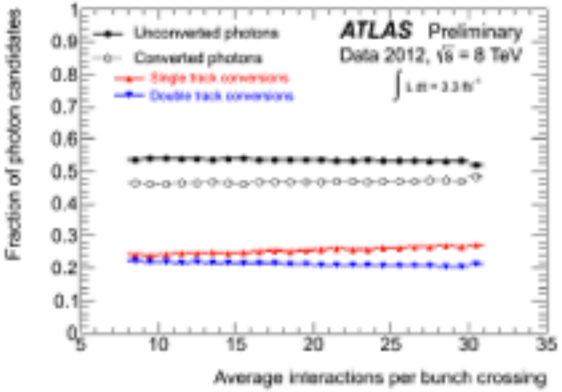
Main production mode and decay through loops → sensitive to t / W couplings and to New Physics

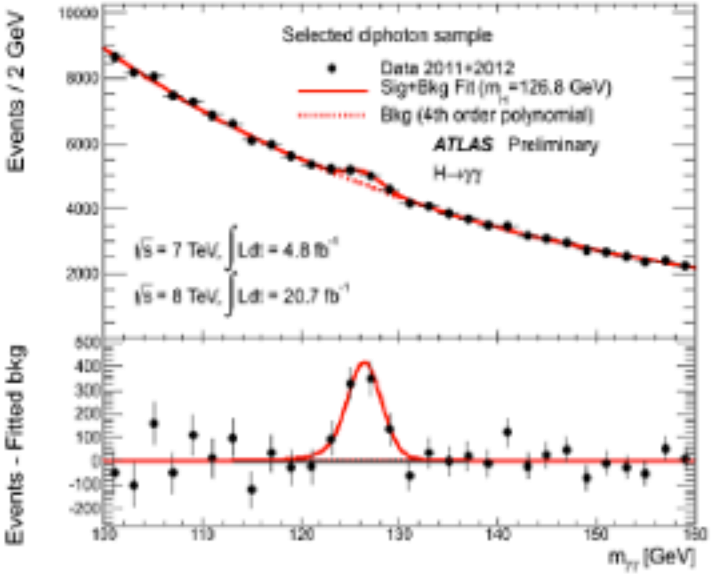
Background reduction

Data-driven background decomposition



Fraction of photon candidates per conversion status





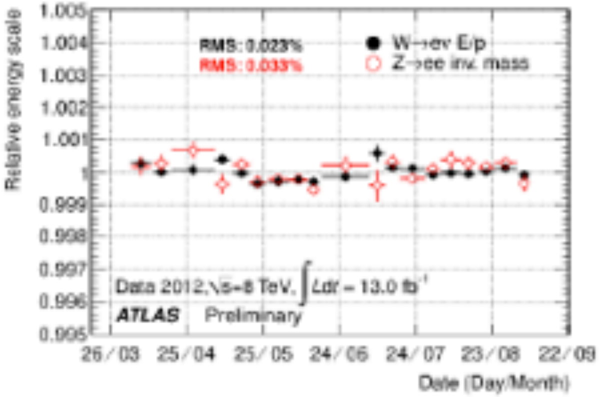
Simple topology: two high-E_T (>40,30 GeV) isolated photons

142681 events in $100 < m_{\gamma\gamma}$ [GeV]<160

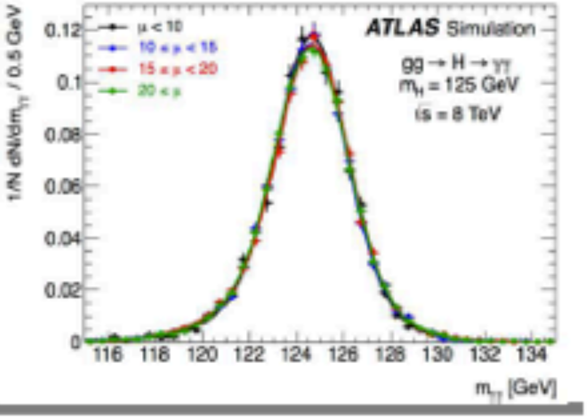
➔ S/B~3% in mass window ~125 GeV with 90% signal

Invariant mass resolution

Stability of EM calorimeter response vs time (and pile-up) <0.1%



Mass resolution is pile-up robust

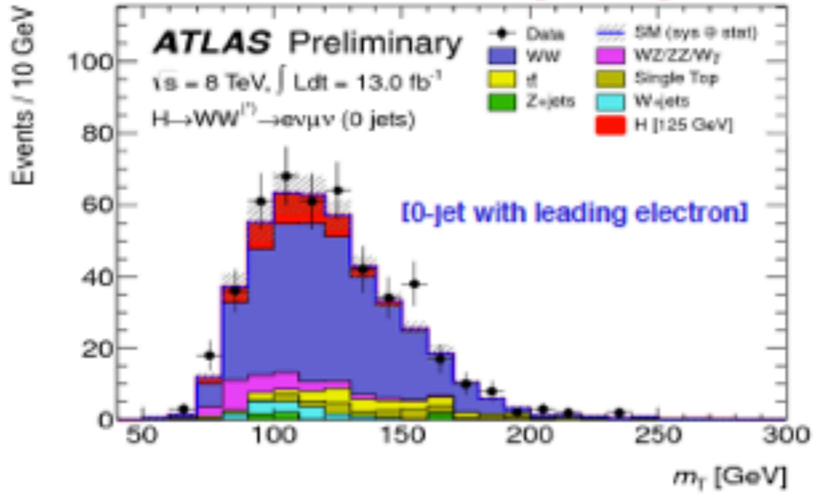


$H\rightarrow WW^{(*)}\rightarrow l\nu l'\nu$ ($l=e,\mu$)

ATLAS-CONF-2012-158

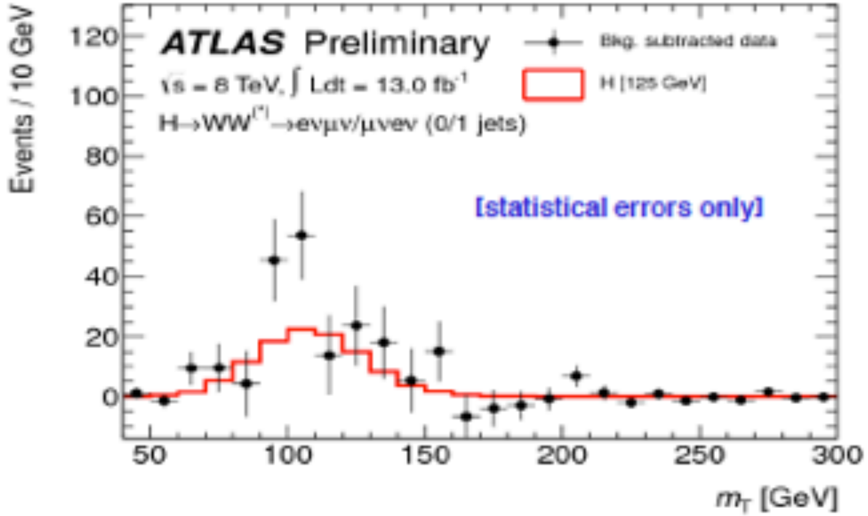
Results using different lepton-flavor final states with 0/1-jet and 13 fb^{-1} of 8 TeV data

Transverse mass in Signal region

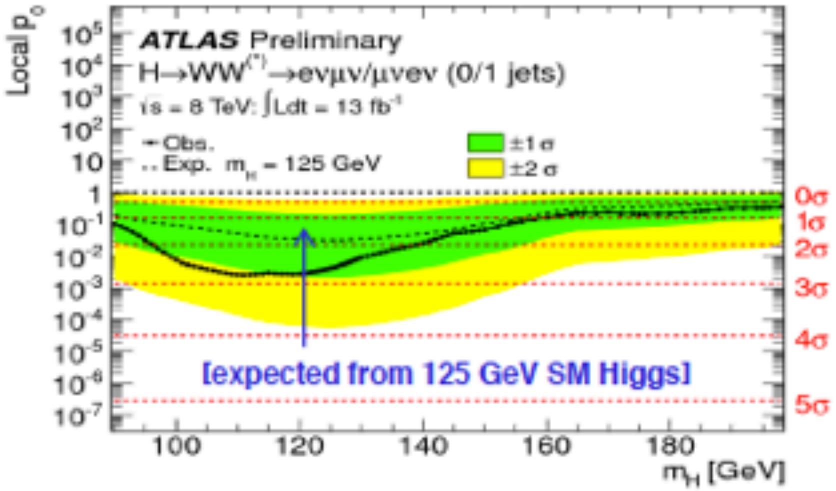


[0-jet with leading electron]

Background-subtracted data and signal MC



[statistical errors only]



[expected from 125 GeV SM Higgs]

- Main backgrounds estimated from signal-free control regions in data
- Observed local significance of the broad excess @ 125 GeV: **2.6σ** (1.9σ expected for SM Higgs)
- Signal strength @ 125GeV **μ=1.5±0.6**

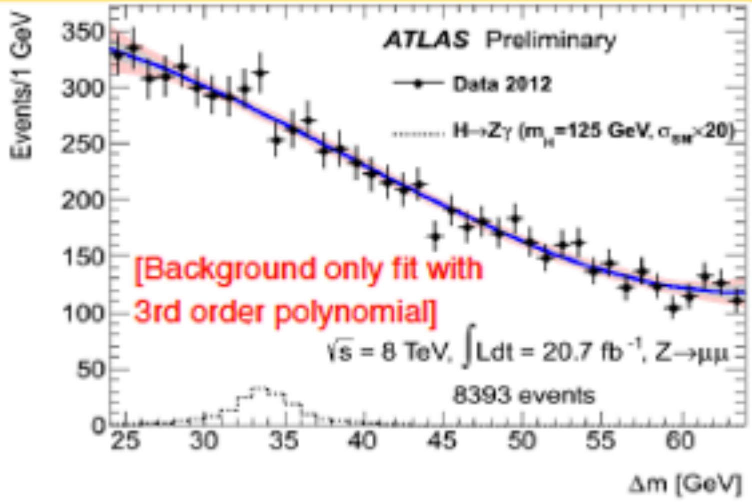
[dominated by systematic uncertainties]

H→Zγ : First results

ATLAS-CONF-2013-009

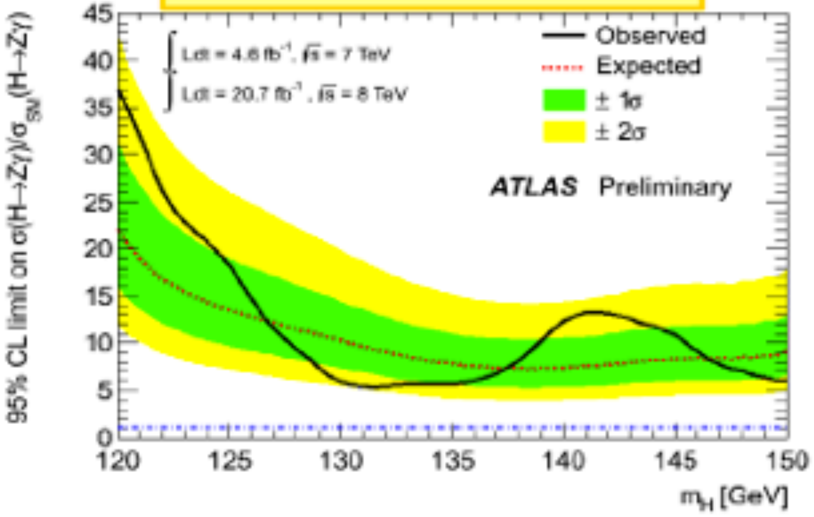
- Decay through loops → BSM particles can affect Br(H→γγ) and Br(H→Zγ) in different ways
- In SM, σ(H→Z(ll)γ)~2 fb @125 GeV → expect ~15 events in whole LHC dataset [ε_{event}~30%]
- Analysis using full 2011+2012 dataset, with event selection: 2 SF-OS isolated leptons p_T>10 GeV and m_{ll}>m_Z-10 GeV - 1 isolated photon E_T>15 GeV and $\Delta R_{l\gamma}$>0.3. Categories: e^+e^- / $\mu^+\mu^-$
- Main backgrounds: SM Z+γ (~82%) and Z+jets (~17%) – obtained from fit in sidebands (similar to H→γγ) of discriminating variable $\Delta m = m_{ll\gamma} - m_{ll}$ (+ data-driven checks of background composition)
- No excess observed → limit at m_H=125 GeV: 18.2×SM cross section (expected 13.5×SM)

Example of Δm distribution: muon channel - 8 TeV data



[Background only fit with 3rd order polynomial]

Production cross section limits



High-mass BSM Higgs searches

- Analyses published with full 2011 dataset (4.7 fb^{-1} @ $\sqrt{s}$=7 TeV) → no excess above SM

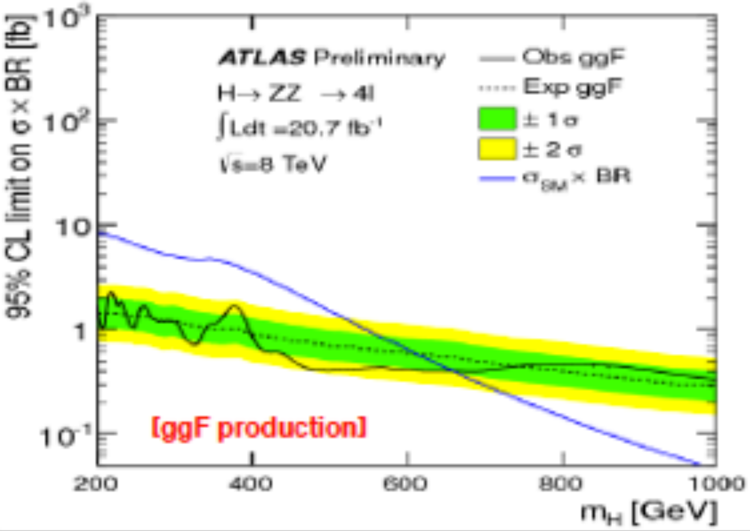
H→ZZ→llνν (l=e,μ)	**H→ZZ→llqq (l=e,μ)**	**H→WW→lνlν (l=e,μ)**	**H→WW→lνqq (l=e,μ)**
PLB 717 (2012) 29	PLB 717 (2012) 70	PLB 716 (2012) 62	PLB 718 (2012) 391

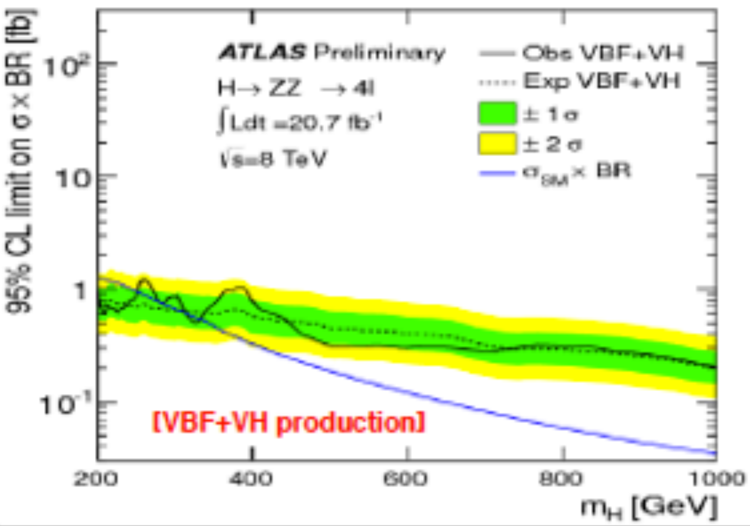
→ Need to be re-interpreted in light of the new boson discovery

- Complement the analyses made with ZZ→4l final state at high-mass

► updated H→ZZ→4l analysis in mass range [200-1000] GeV with full LHC dataset, assuming signal with SM-like width [Complex-Pole-Scheme] ATLAS-CONF-2013-013

→ Upper limits on production cross section × branching ratio





H→ZZ →4l: Beyond m4l

CMS-HIG-13-002

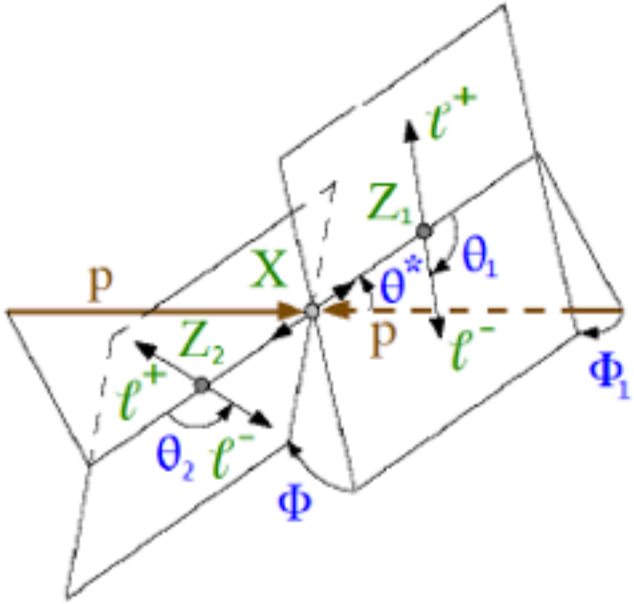
In addition to m4l, use more information in the final fit to:

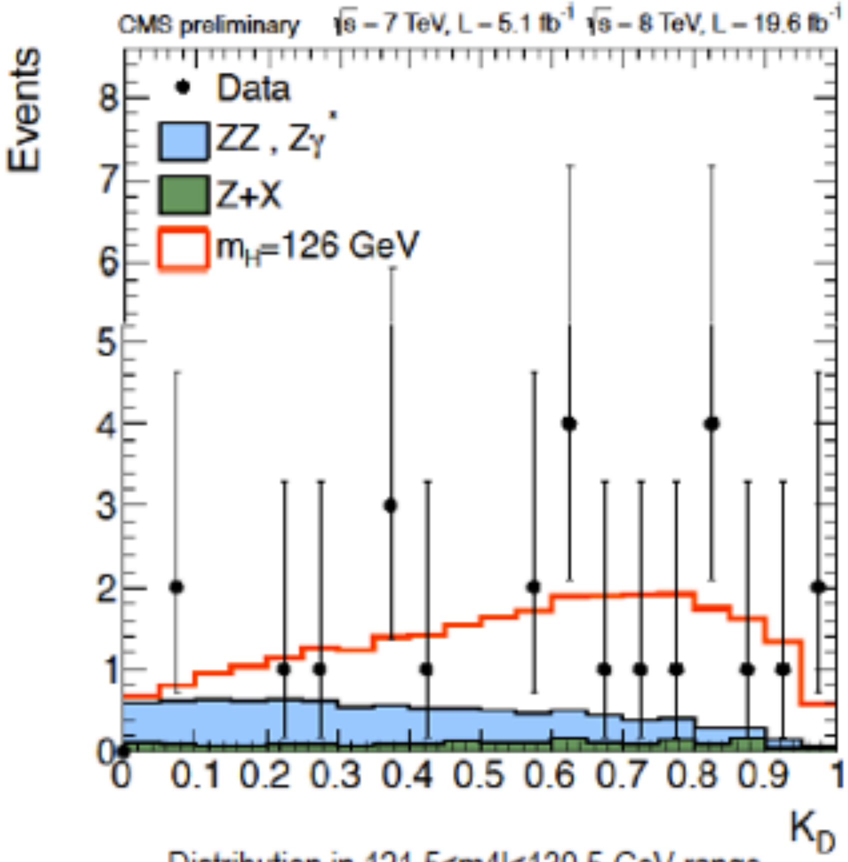
further separate signal from background…

➢ **Build Kinematic Discriminant from Matrix Element techniques**

Other approaches give similar performances

$$K_D(\theta^*, \Phi_1, \theta_1, \theta_2, \Phi, m_{Z_1}, m_{Z_2}) = \mathcal{P}_{sig}/(\mathcal{P}_{sig} + \mathcal{P}_{bkg})$$





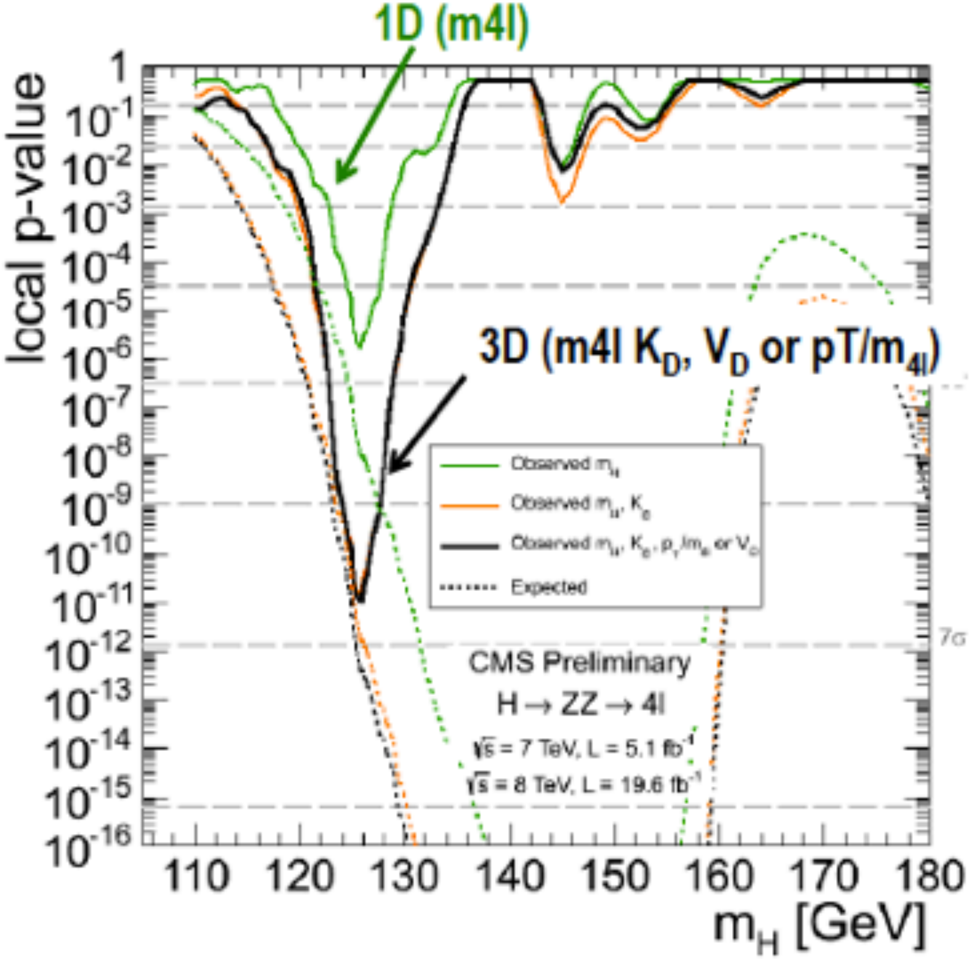
Distribution in 121.5<m4l<130.5 GeV range

H→ZZ →4l: Results

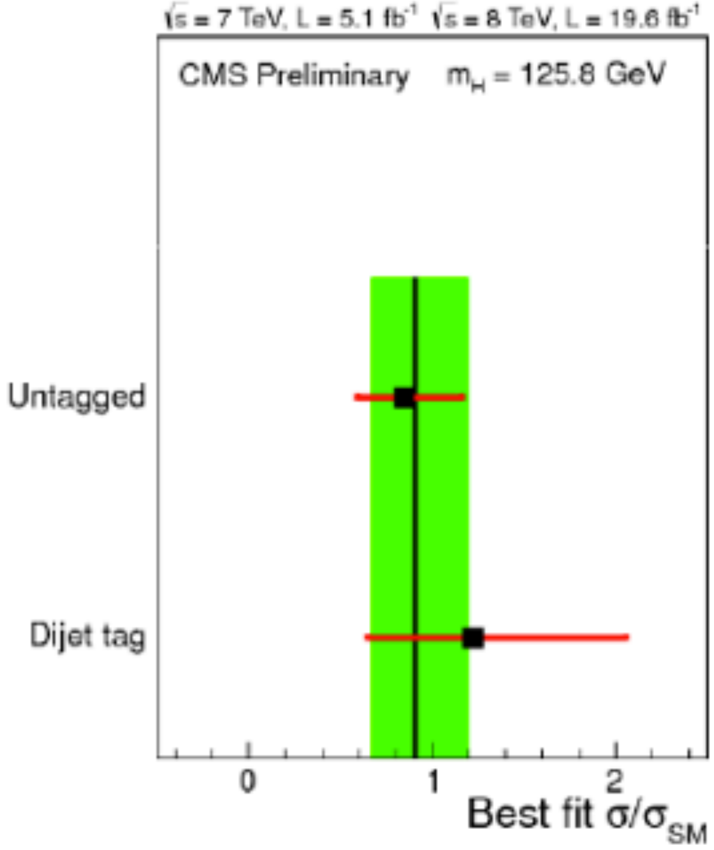
CMS-HIG-13-002

Significance @ 125.8 GeV: 6.7 σ (7.2 expected)
with 3D (m_{4l}, K_D, V_D or pT/m_{4l}) model

Consistent (but better) wrt 2D (m4l, KD) or 1D (m4l) models.



σ/σ_{SM} @ 125.8 GeV = 0.91 $^{+0.30}_{-0.24}$

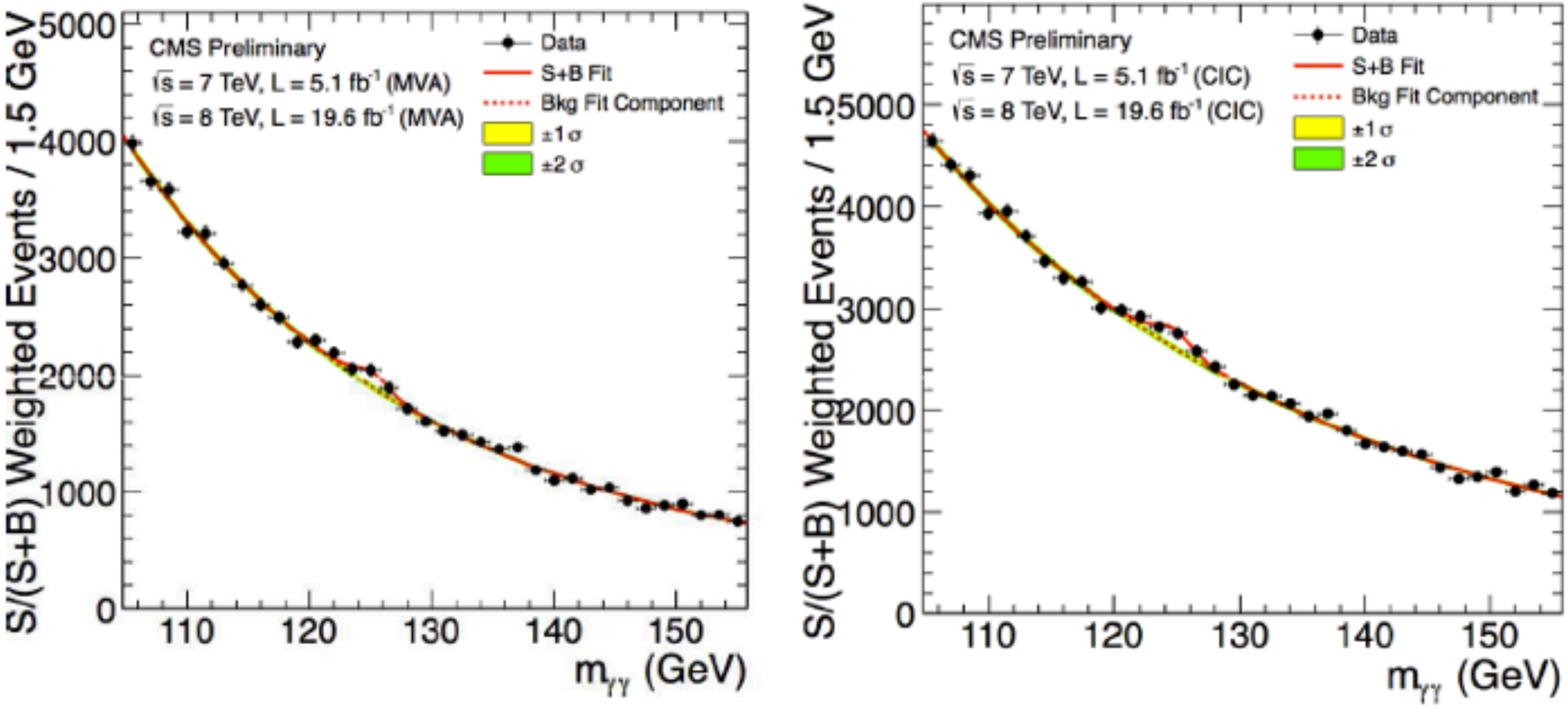


$H\rightarrow\gamma\gamma$: Combined mass plot: 7+8 TeV

CMS-HIG-13-001

MVA mass-factorized

Cut-based



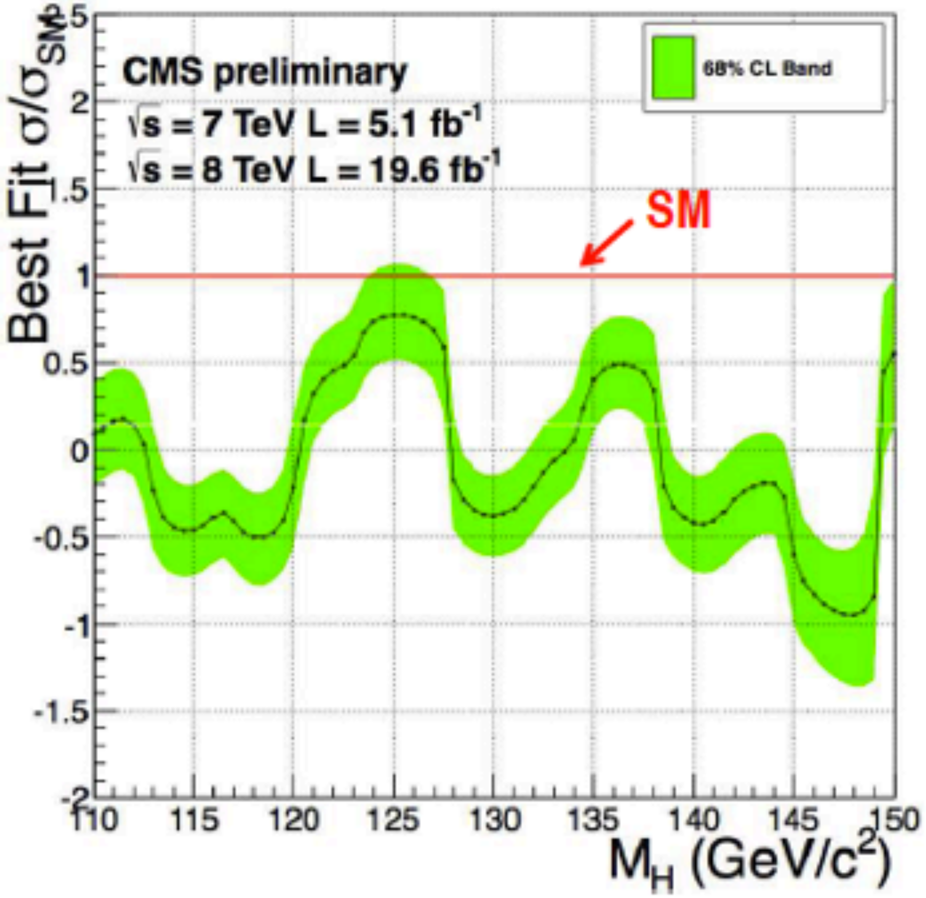
Bump at ~125 GeV consistent with expectations

Each event category is **weighted by its S/(S+B)** only for visualization purpose

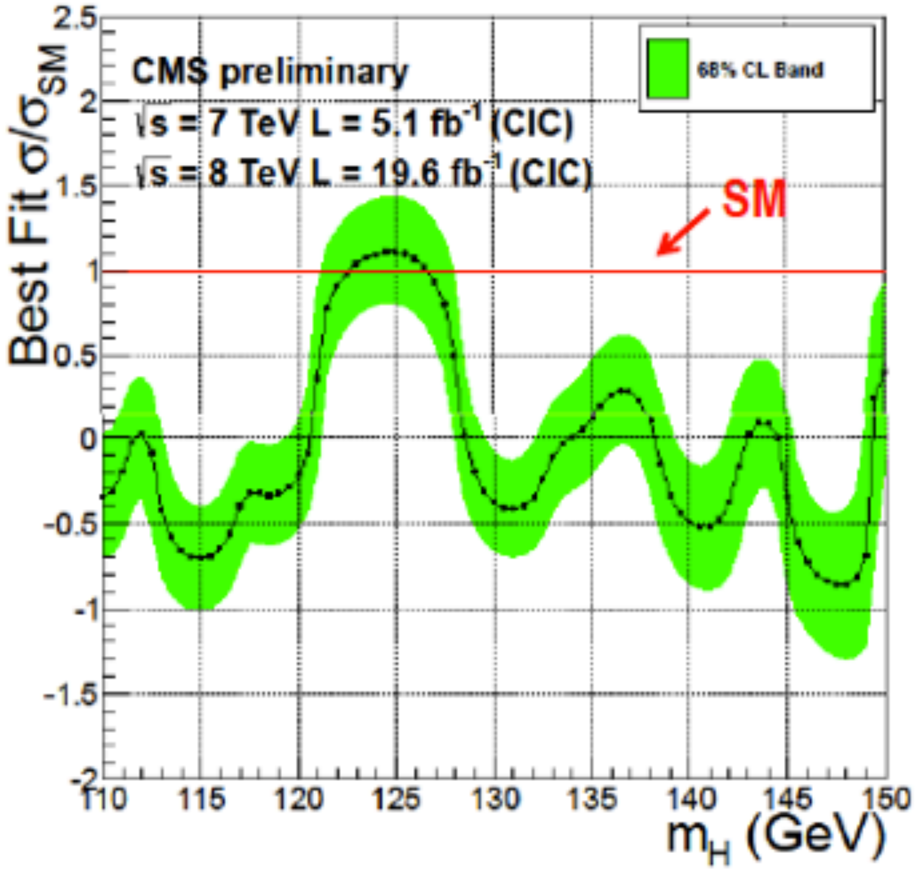
H→γγ: Results (signal strength)

CMS-HIG-13-001

MVA mass-factorized



Cut-based



- Compared to the published results, the measured **σ/σ_{SM}** decreased.

$H \rightarrow \gamma\gamma$: Compatibility among the two analysis CMS-HIG-13-001

- **Low signal to background ratio a fundamental feature of this channel**
  - Uncertainty on signal strength driven by statistical fluctuations of the background
  - Analysis changes can lead to statistical changes due to fluctuations in selected events and their mass

- The correlation coefficient between the MVA and cut-based signal strength measurements is found to be **r=0.76** (estimated using jackknife techniques)

	Signal strength compatibility (including correlation)
MVA vs CiC 7+8 TeV	1.5 σ
MVA vs CiC 8 TeV only	1.8 σ
Updated MVA vs published (5.3/fb 8TeV)	1.6 σ
Updated CiC vs published (5.3/fb 8TeV)	0.5 σ

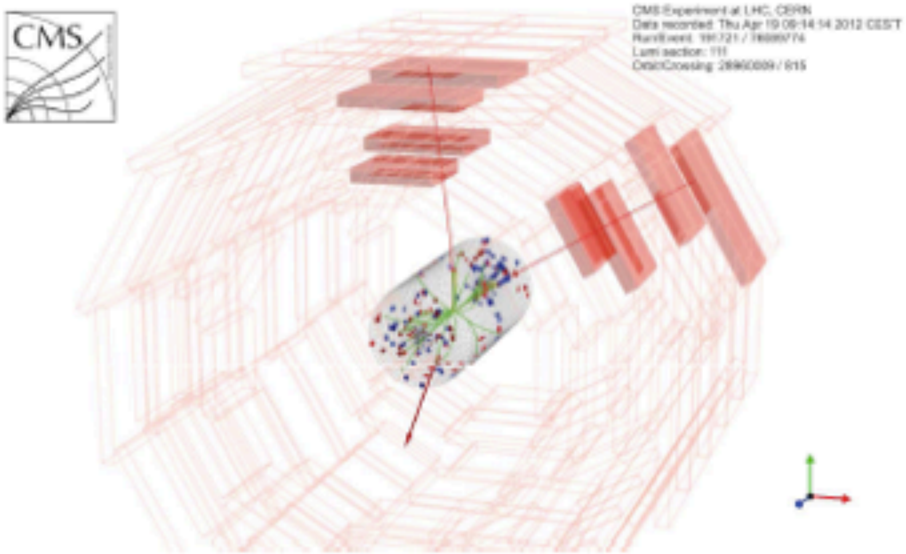
- Observed changes in results and differences between analyses are all **statistically compatible at less than 2σ**

H →WW→2l2ν: Overview

CMS-HIG-13-003

Search for excess of events with two high pT isolated leptons (e, μ) + moderate MET

Full 2011+2012 dataset



- ➢No mass peak but large σXBR.
- ➢ Split events in categories:
  - ▪ 0 and 1 jet (VBF not updated)
  - ▪ Different Flavor (DF), Same-Flavor (SF)
- ➢ Expect small Δφ (l,l) and m(l,l) if SM Higgs boson
  - ▪ Can distinguish between different spin hypothesis (**see Andrew's talk**)

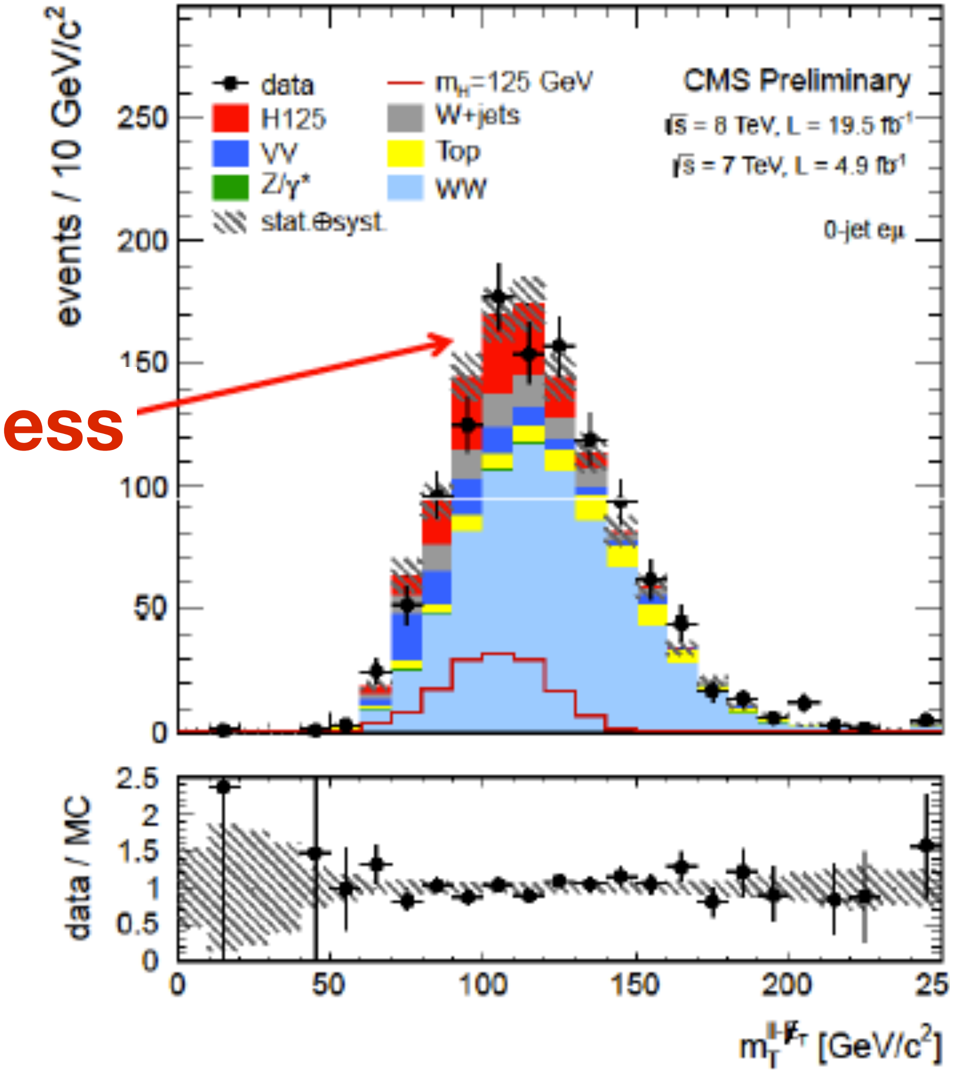
➢ Backgrounds control is the key !
- ▪ Irreducible: qq/gg→WW
- ▪ Reducible: Top, W+jets, di-bosons, DY

Main improvements wrt November (CMS-HIG-12-042):
- ▪ 7 TeV re-analyzed.
- ▪ better understanding of main backgrounds

CMS

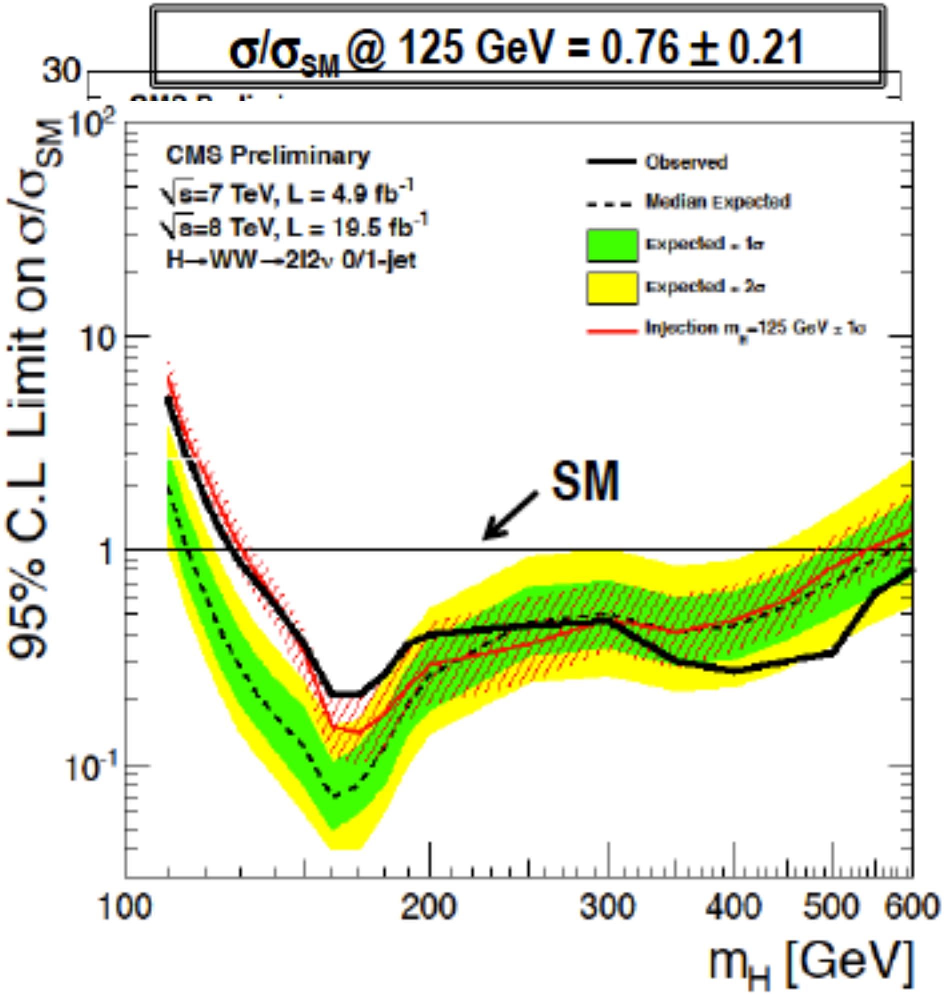
HIGGS BOSONIC DECAYS: H→WW→lνl'ν' (l=e, μ)

M_T (0 jet, DF)



excess

Significance @ 125 GeV: 4.0 σ (5.1 expected)



σ/σ_{SM} @ 125 GeV = 0.76 ± 0.21

Signal expectations

For a Higgs at 125 GeV , in parenthesis (2011/2012) for ATLAS (CMS not provided):

- ☐ **ATLAS**
  - ☐ 4e : 3.3 (0.4/2.9)
  - ☐ 2e2μ/2μ2e : 8.1 (1.1/7.0)
  - ☐ 4μ : 6.8 (1.0/5.8)
- ☐ **CMS**
  - ☐ 4e : 3.5
  - ☐ 2e2μ/2μ2e : 8.9
  - ☐ 4μ : 6.8

A tentative conclusion would be that we have the same efficiency for muon and that in 2012 we have a similar efficiency also for electrons .

Results

- ATLAS observed significance 6.6 σ (expected 4.4 σ) at 124.3 GeV . Expectation at 125.8 ~5.1 σ.
- CMS (1D just using m4l) observed 4.7 σ (expected 5.6 σ) at 125.8 GeV.

ATLAS :

- Fit only m4l.
- Inclusive results are without categorization.
- Rectangular cuts for categories (mjj>350 GeV, $\Delta\eta<3$).
- Additional lepton-tag category (VH-like).

CMS

- Uses a 3D fit in both the less than 2 jets (category I) and more than 2 jets (category II) categories.
- For the category I : The fit is on m4l, K_D (“MELA vs $ZZ^{(*)}$”) and the pT4l/m4l.

The PT4l/m4l : Can provide a control on the VBF and ZZ contamination.

- For the catagory II : The fit is on m4l, K_D (MELA vs $ZZ^{(*)}$) and the V_D which is a linear discriminant using $\Delta\eta$ and mjj.

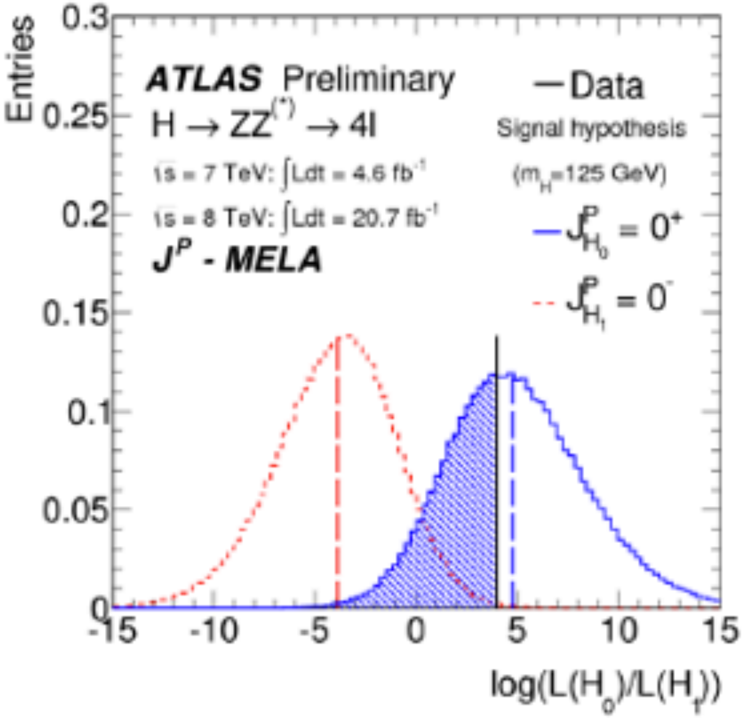
- For the mass : 3D fit (m4l, KD , per-event error). Categories are not used.

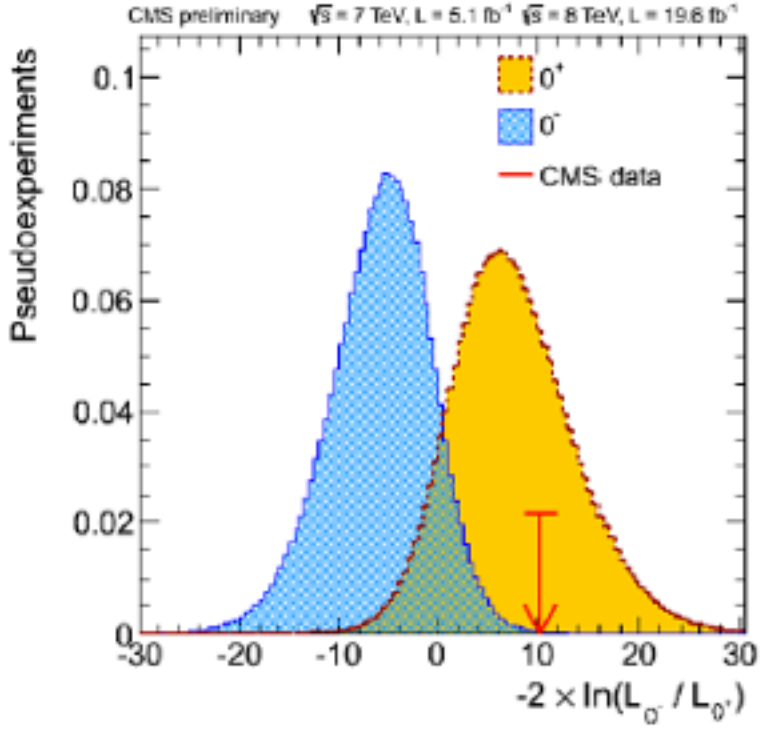
$$P(m4l,KD,\delta m4l) = P(m4l \mid mH,\delta m4l) * P(KD|m4l) * P(\delta m4l|mH)$$

0^+ vs 0^-

- ATLAS (j^P-MELA)
  - Expected p_0 for 0^- = 3.1 σ .
  - Observed p_0 for 0^- = 2.8 σ .
  - Observed p_0 for 0^+= 0.25 σ .
  - CLs = 0.004 (1-CLs = 99.6 %) .

- CMS (D_{JP})
  - Expected p_0 for 0^- = 2.6 σ .
  - Observed p_0 for 0^- = 3.3 σ .
  - Observed p_0 for 0^+= 0.5 σ .
  - CLs = 0.0016 (1-CLs = 99.84 %) .

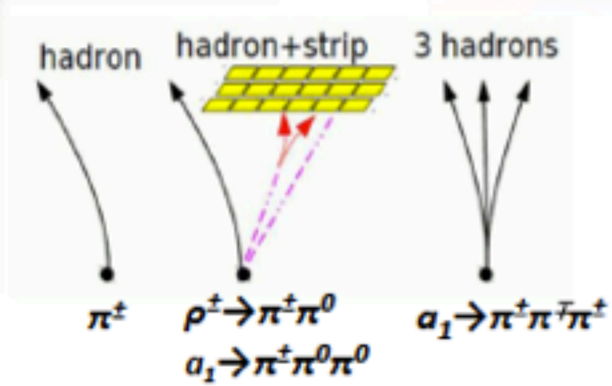




τ_h identification

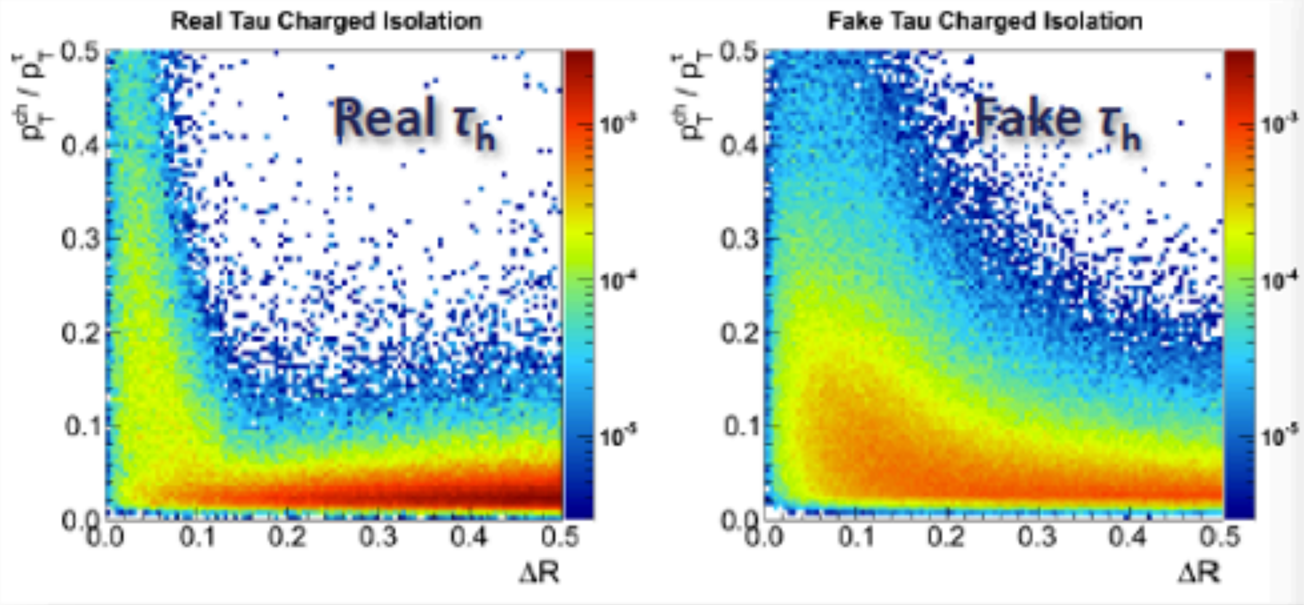
Identification:

- Reconstructed based on decay modes: charged hadrons + ECAL deposits

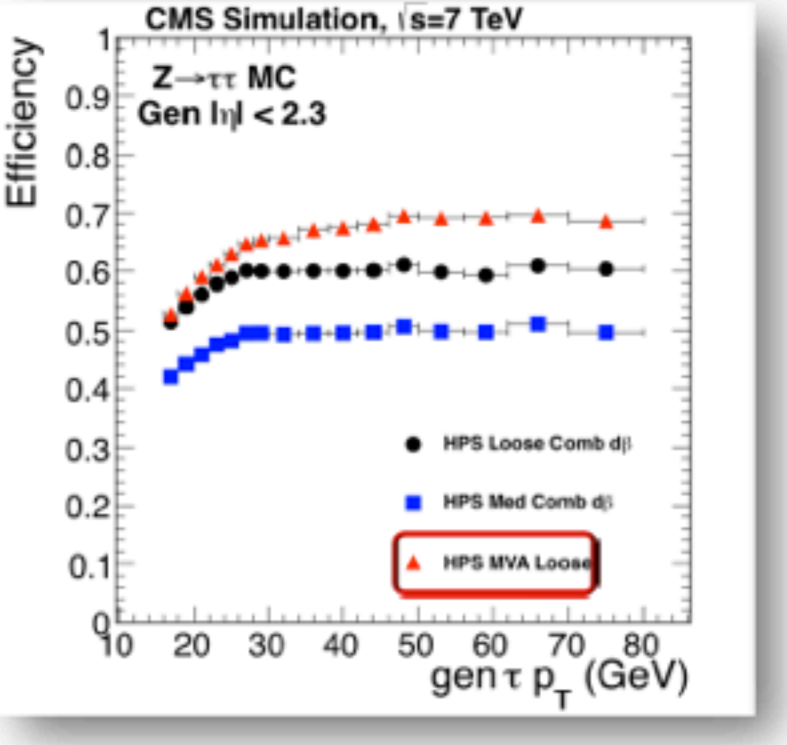


Isolation: **New in 2012**

- Multivariate isolation using relative Σp_T of particle-flow candidates in concentric rings around τ



Σp_T(charged hadrons)/$p_T(\tau)$ vs. ΔR

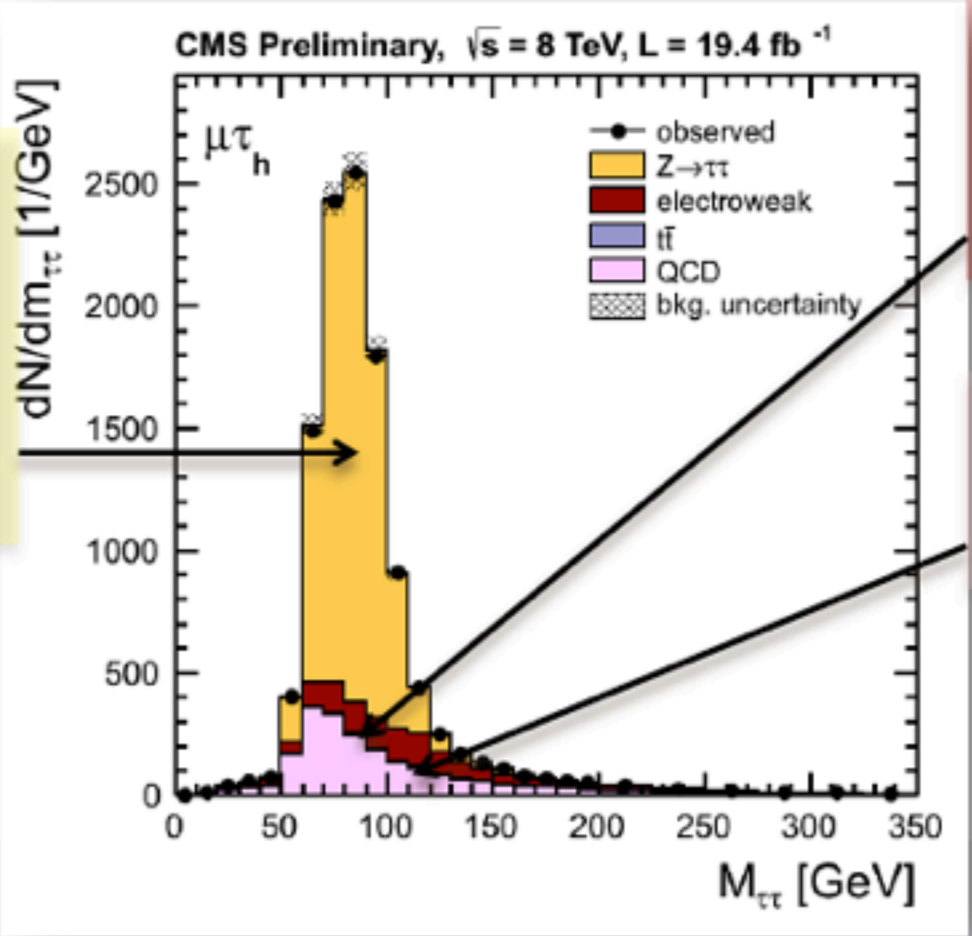


Anatomy of the analysis

$Z \rightarrow \tau\tau$

Embedding: $Z \rightarrow \mu\mu$ data, replace μ with simulated τ decay

Normalization from $Z \rightarrow \mu\mu$ data



W+jets

Shape from simulation

Normalization from control region

QCD

SS data, corrected for SS/OS ratio

Strategy:

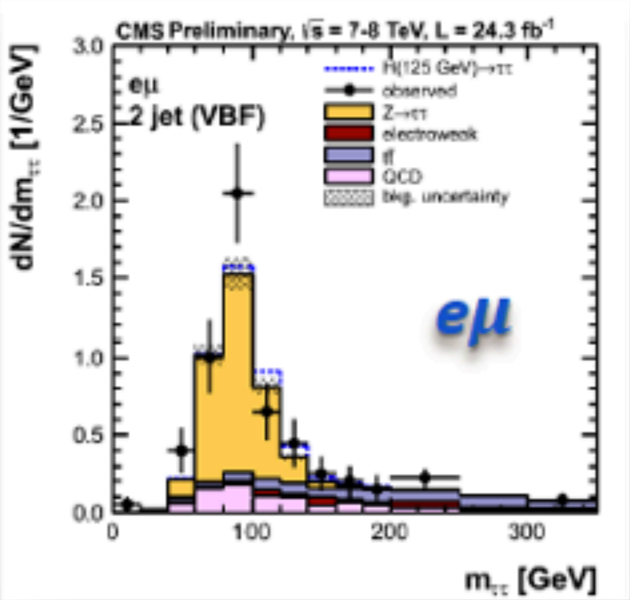
- Select isolated, well-identified **leptons, τ_h**
- Topological cuts (e.g. m_T in $l\tau_h$, $p_T(H)$ in $\tau_h\tau_h$) to suppress backgrounds
- Categorize events based on number of jets, τ p_T
- Template fit to $m_{\tau\tau}$ shape

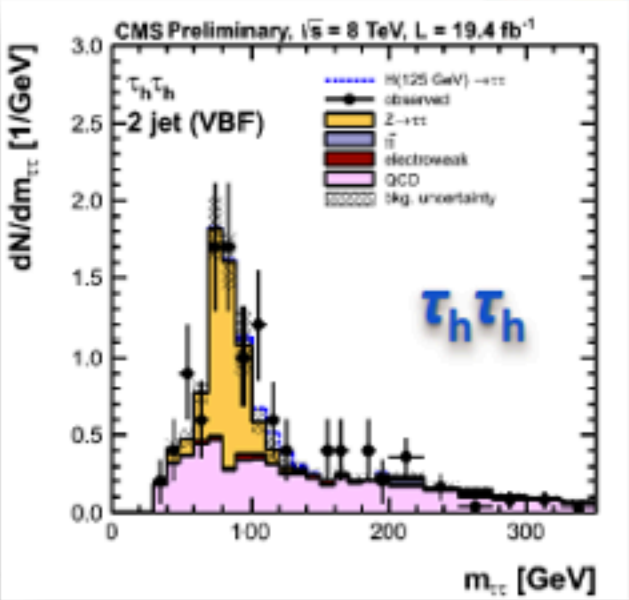
$m_{\tau\tau}$ distributions

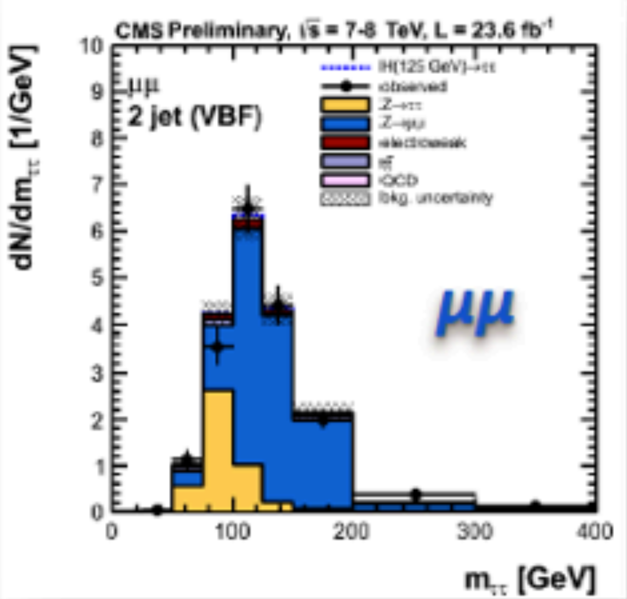
7TeV (2011)	8TeV (2012)
5 fb^{-1}	19 fb^{-1}

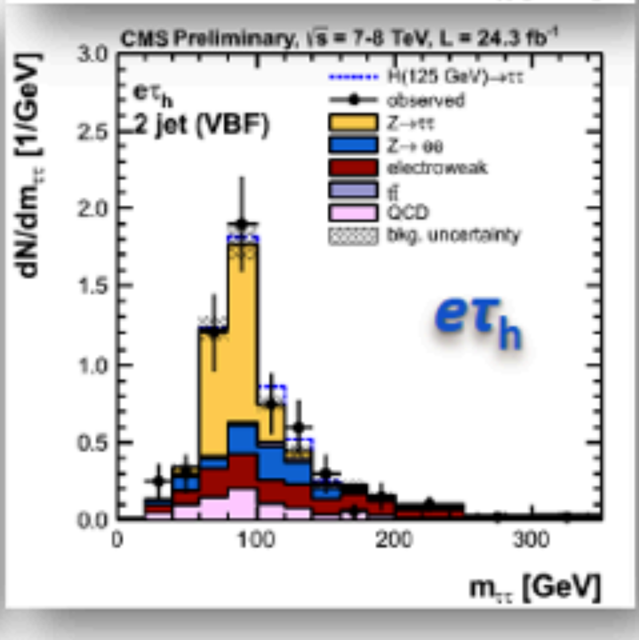
2-jet (VBF)

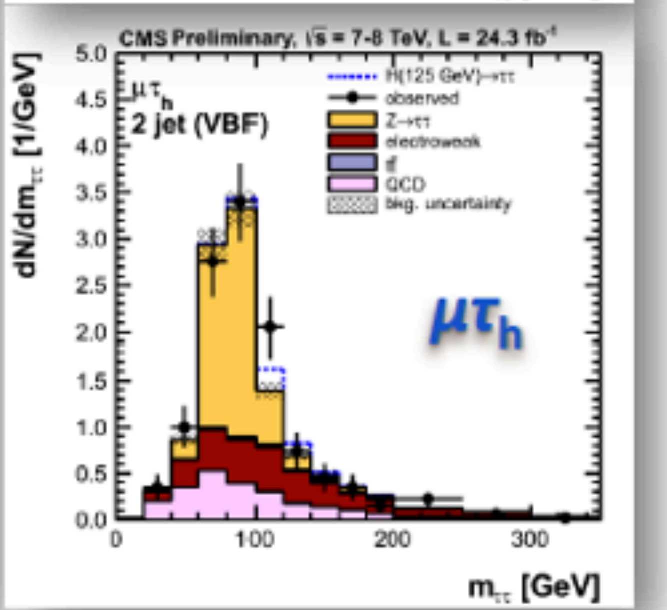
- Enhancement for VBF signal
- Category with best S/B





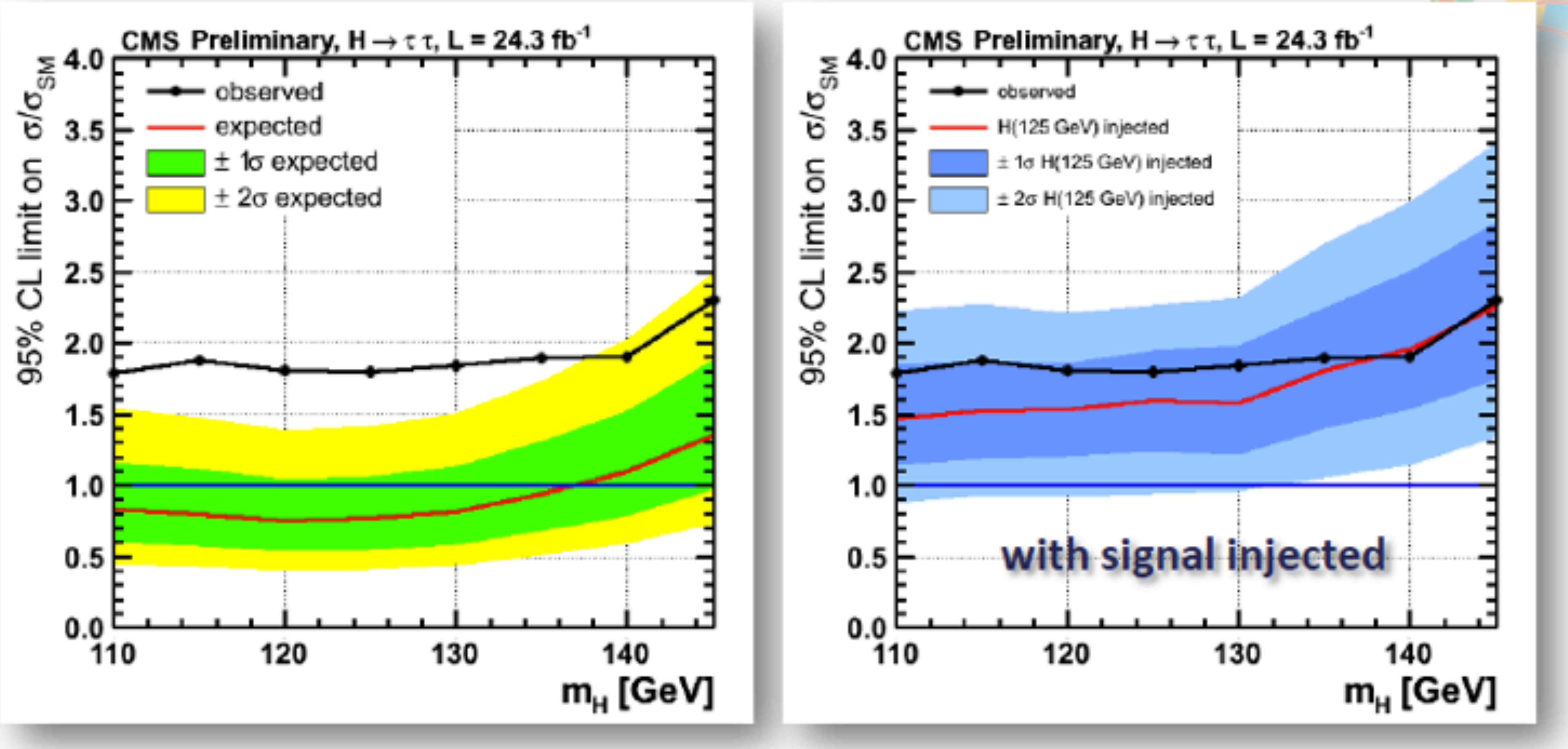






H→ττ

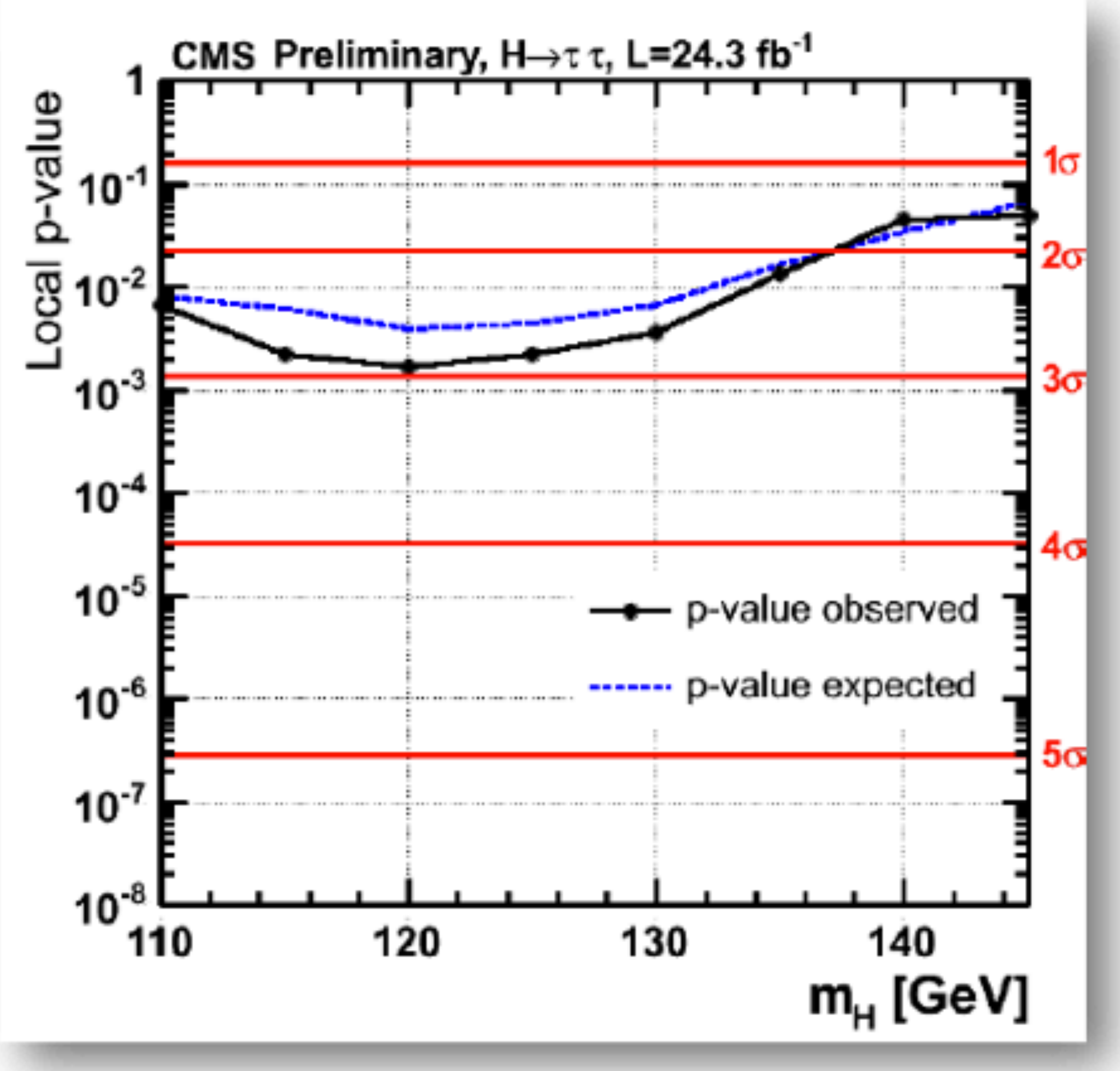
Limits



Results consistent with expectation for background + SM scalar at 125 GeV

$H\rightarrow\tau\tau$

Significance



- Broad excess observed over range of m_H
- Maximum local significance of **2.93σ** at 120 GeV, compatible with presence of 125 GeV SM scalar boson
- Observed (expected) significance of **2.85*σ*** (**2.62*σ***) for m_H = 125 GeV

"Natural" SUSY?

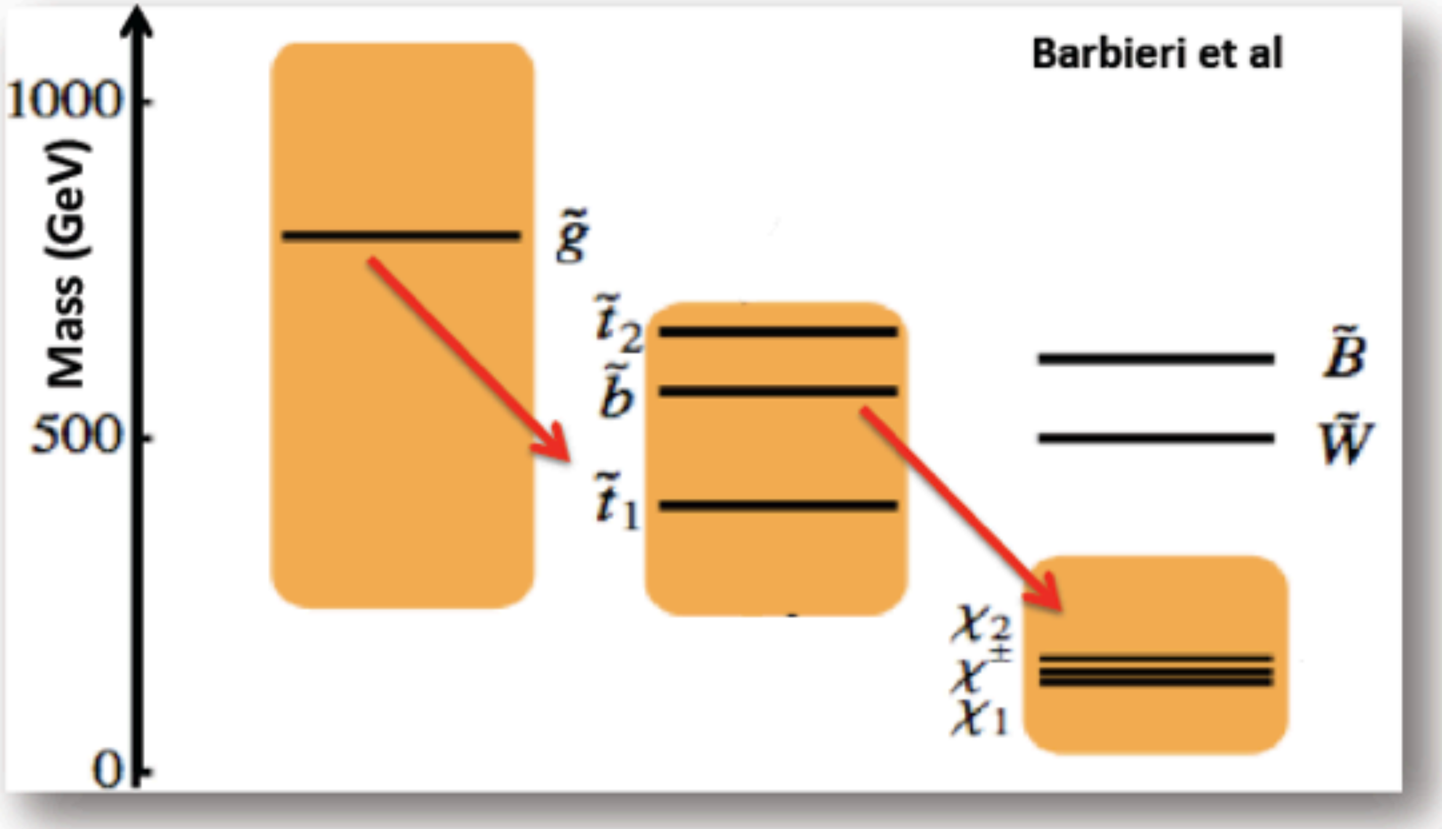
Discovery of new boson has further shifted attention towards pieces relevant for SUSY to solve the hierarchy problem.

Require relatively light:

- Gluino
- Third-generation (3G) squarks: stop, sbottom

→ Should be within mass reach of LHC:

Known as "Natural" SUSY:

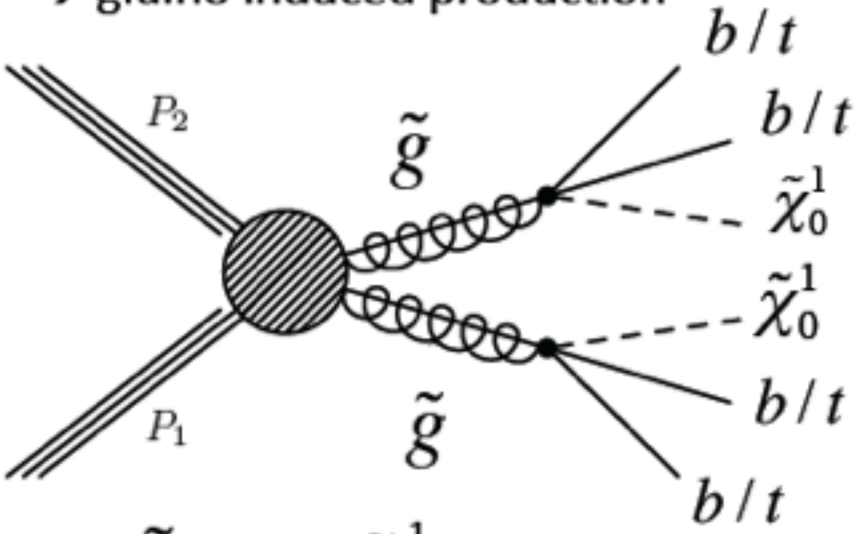


$\tilde{\chi}_0^1$ = Lightest Supersymmetric Particle (LSP) if R-Parity conserved

“Natural” SUSY?

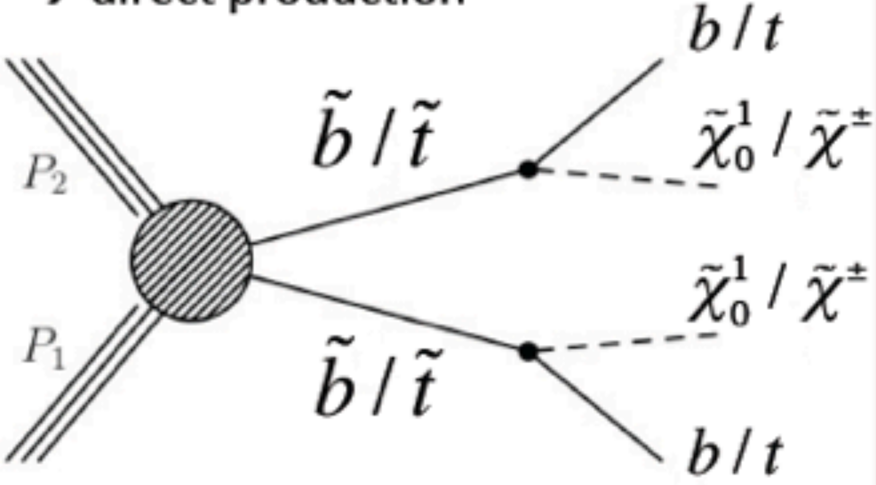
Initial SUSY search strategies → inclusive, model independent
Now complemented by dedicated searches → especially for “Natural” SUSY signatures:

If gluino light enough:
→ gluino induced production



$$\tilde{g} \rightarrow t\tilde{t} \rightarrow tt\tilde{\chi}_0^1$$
$$\tilde{g} \rightarrow b\tilde{b} \rightarrow bb\tilde{\chi}_0^1$$

If third-generation squarks light enough:
→ direct production

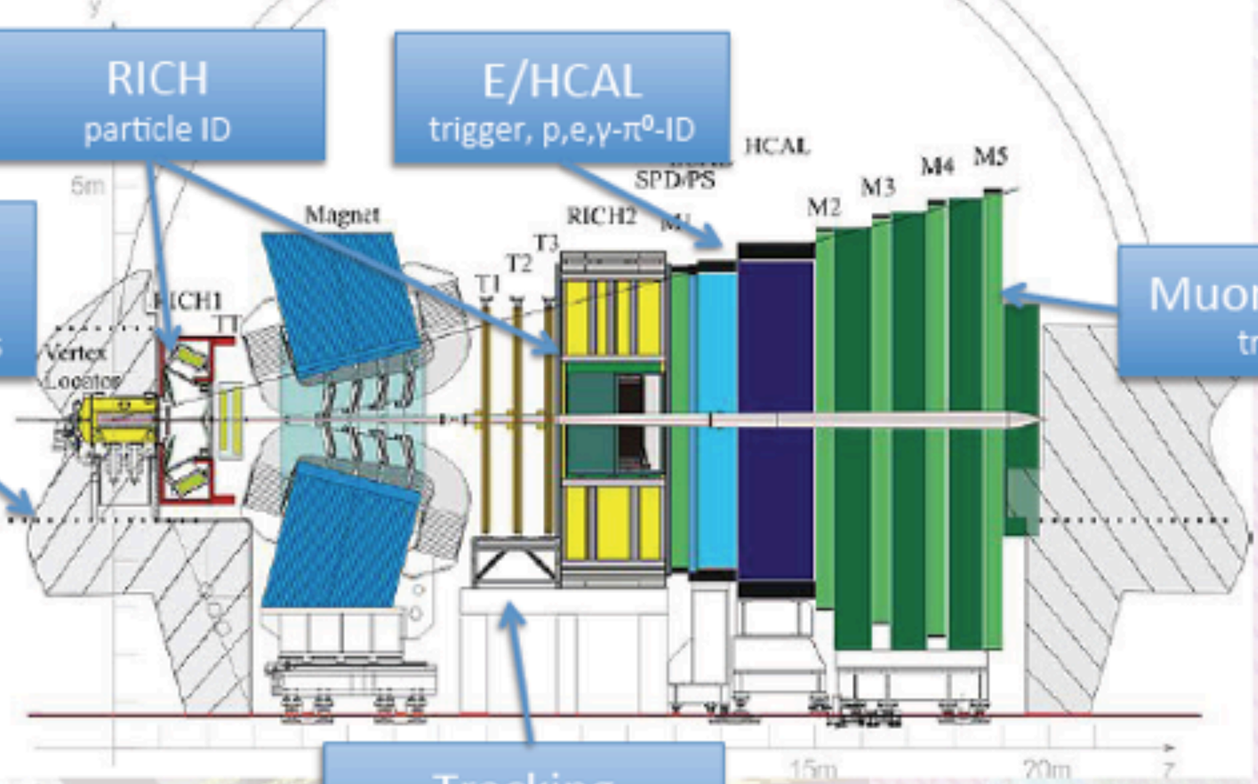


$$\tilde{t} \rightarrow t\tilde{\chi}_0^1 \quad \tilde{t} \rightarrow b\tilde{\chi}^{\pm} \rightarrow bW\tilde{\chi}_0^1$$
$$\tilde{b} \rightarrow b\tilde{\chi}_0^1 \quad \tilde{b} \rightarrow t\tilde{\chi}^{\pm} \rightarrow tW\tilde{\chi}_0^1$$

These simplified model spectra (SMS) assume a single production and decay channel and are used to interpret results of the searches. Predominant final state:

- Jets, especially b-jets, and missing transverse energy (LSP)
- Leptonic channels important via decay of the top quarks (and also via chargino)

Detector cont.



RICH
particle ID

E/HCAL
trigger, p,e,γ-π^0-ID

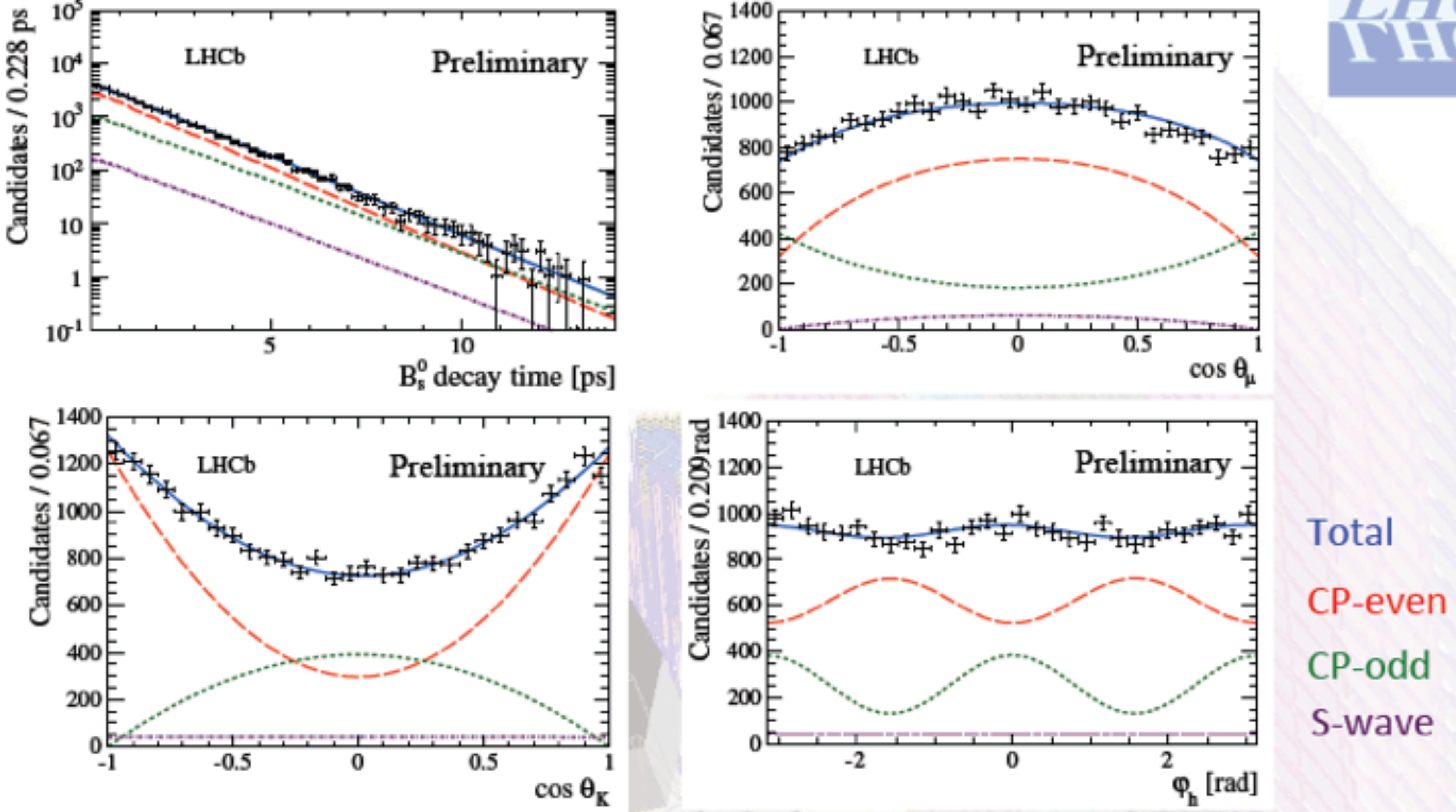
VELO
primary and secondary vertices

Muon chambers
trigger, μ-ID

Tracking stations
momentum resolution

- LHCb is a forward arm spectrometer (pseudo-rapidity range: $2 < \eta < 5$),
- Accurate decay time resolution through vertex locator (VELO),
- Accurate particle ID provided by RICH detectors,
- High muon reconstruction efficiency from muon stations.

$B_s \to J/\psi\phi$: Time and angular distributions



Angular acceptance corrections are applied due to detector geometry
➔Correction from simulated events.

The selection criteria and vertex reconstruction methods give rise to a decay time acceptance ➔ Data driven methods used utilising events without such biases.

Motoyasu Ikeda

Neutrinos and mixing

Flavor (e,μ,τ) Eigenstate

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = U_{PMNS} \times \begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Mass (m_1,m_2,m_3) Eigenstate

$$U_{PMNS} = \begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}$$

$$c_{ij} \equiv \cos\theta_{ij}$$

$$s_{ij} \equiv \sin\theta_{ij}$$

atmospheric neutrinos unknown solar neutrinos (KamLAND)

Current status

Solar and reactor (KamLAND)

$$\theta_{12} = 33.6° \pm 1.0°$$

Atmospheric, accelerator

$$\theta_{23} = 45° \pm 6° \quad (90\%CL)$$

Accelerator, reactor (DayaBay,DoubleChooz,RENO)

$$\theta_{13} = 9.1° \pm 0.6°!$$

Remaining questions:

- Is $\theta_{23} = \pi/4$?
- CP phase (δ) ?
- Mass hierarchy

  $m_1<m_2<m_3$? $m_3<m_1<m_2$?

Daya Bay Experiment Layout

- 6 reactor cores, 17.6GW$_{th}$ total power
- Relative measurement
    - ➢ 2 near sites, 1 far site
- Multiple detector modules
- Good cosmic ray shielding

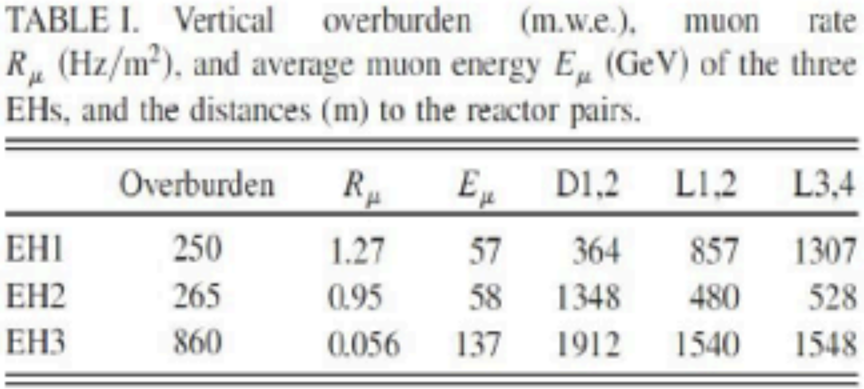
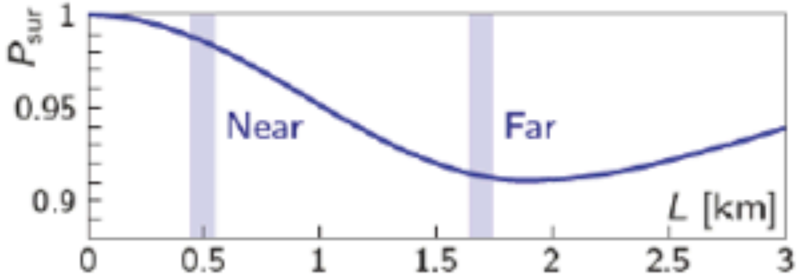
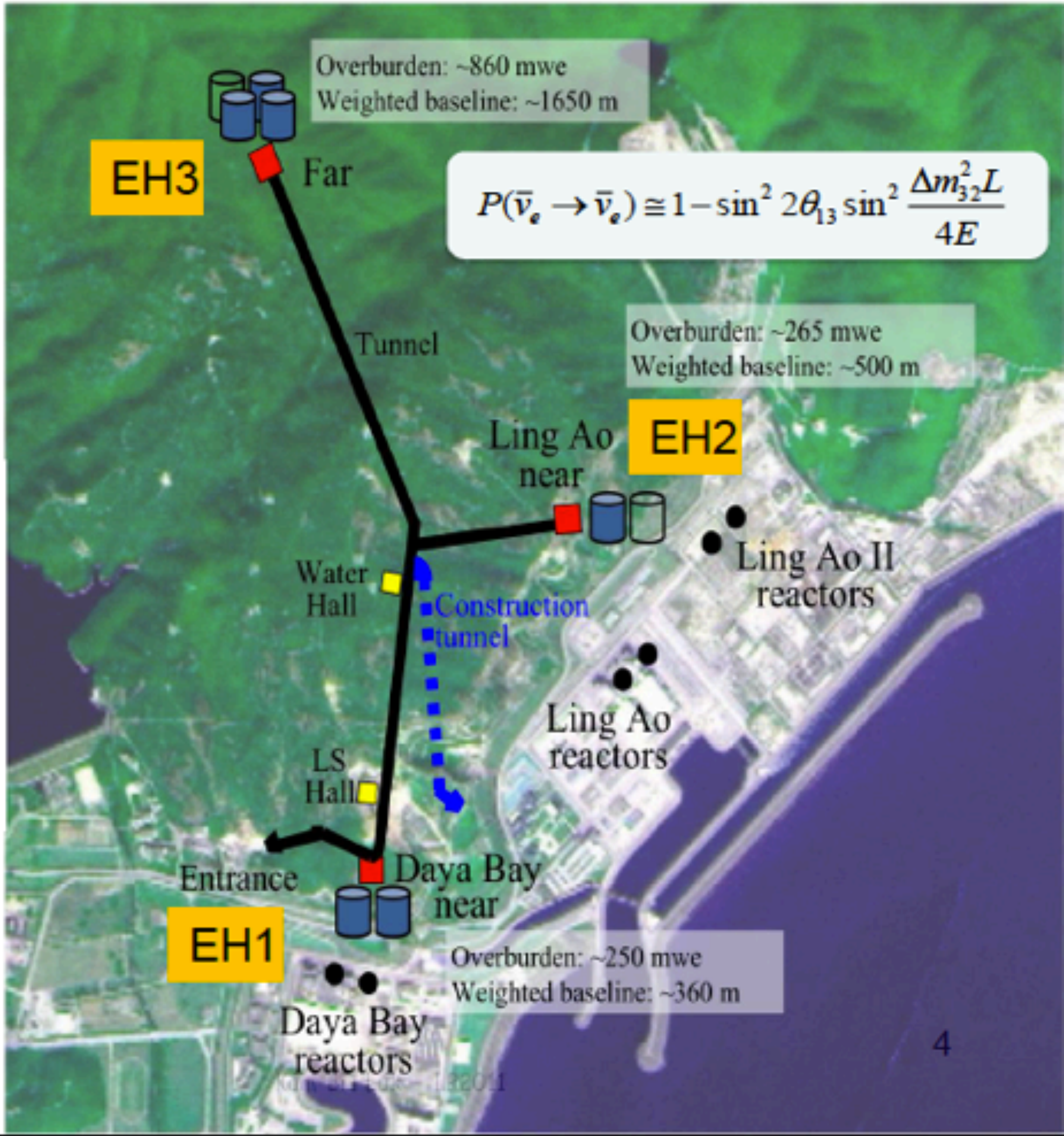


TABLE I. Vertical overburden (m.w.e.), muon rate R_μ (Hz/m^2), and average muon energy E_μ (GeV) of the three EHs, and the distances (m) to the reactor pairs.

	Overburden	R_μ	E_μ	D1,2	L1,2	L3,4
EH1	250	1.27	57	364	857	1307
EH2	265	0.95	58	1348	480	528
EH3	860	0.056	137	1912	1540	1548





Overburden: ~860 mwe
Weighted baseline: ~1650 m

$$P(\bar{\nu}_e \to \bar{\nu}_e) \cong 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m_{32}^2 L}{4E}$$

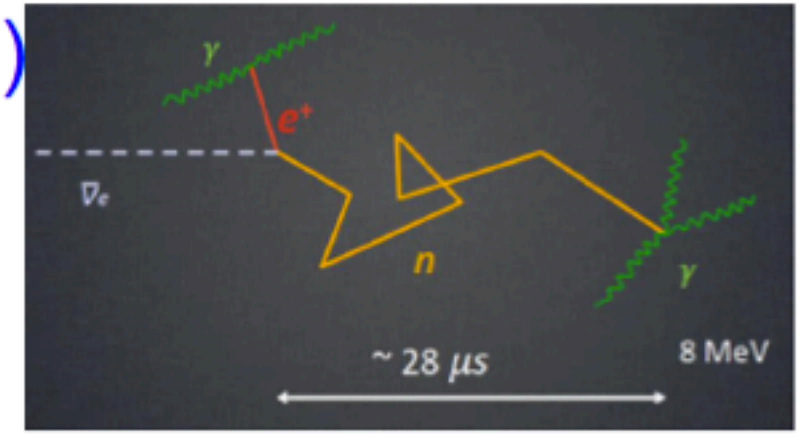
Overburden: ~265 mwe
Weighted baseline: ~500 m

Overburden: ~250 mwe
Weighted baseline: ~360 m

Neutrino Event Signature in Gd-LS

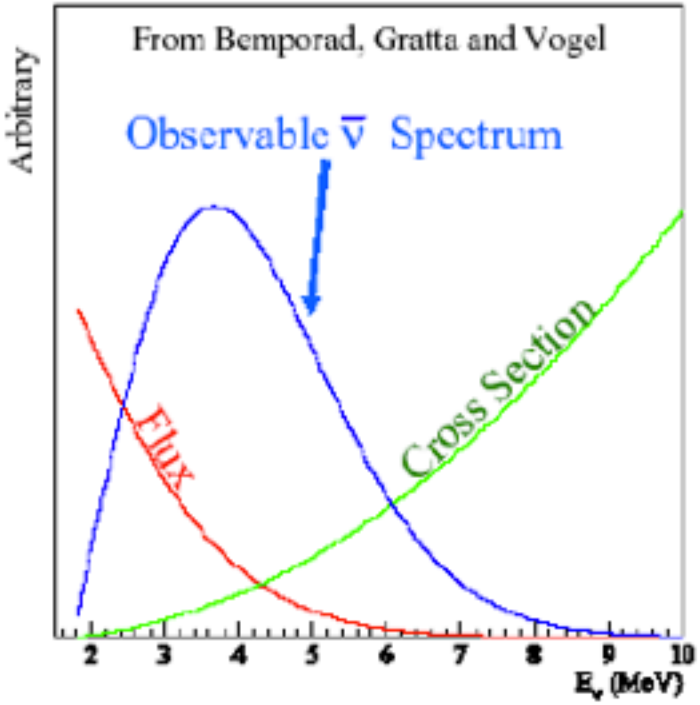
Liquid Scintillator drugged with Gadolinium

Signature: $\bar{\nu}_e + p \rightarrow e^+ + n$ (IBD)



- **Prompt:** **e^+,** **E: 1-10 MeV**
- **Delayed:** **n,** **E: 2.2 MeV@H, 8 MeV @ Gd**
- **Capture time:** **28 μs in 0.1% Gd-LS**

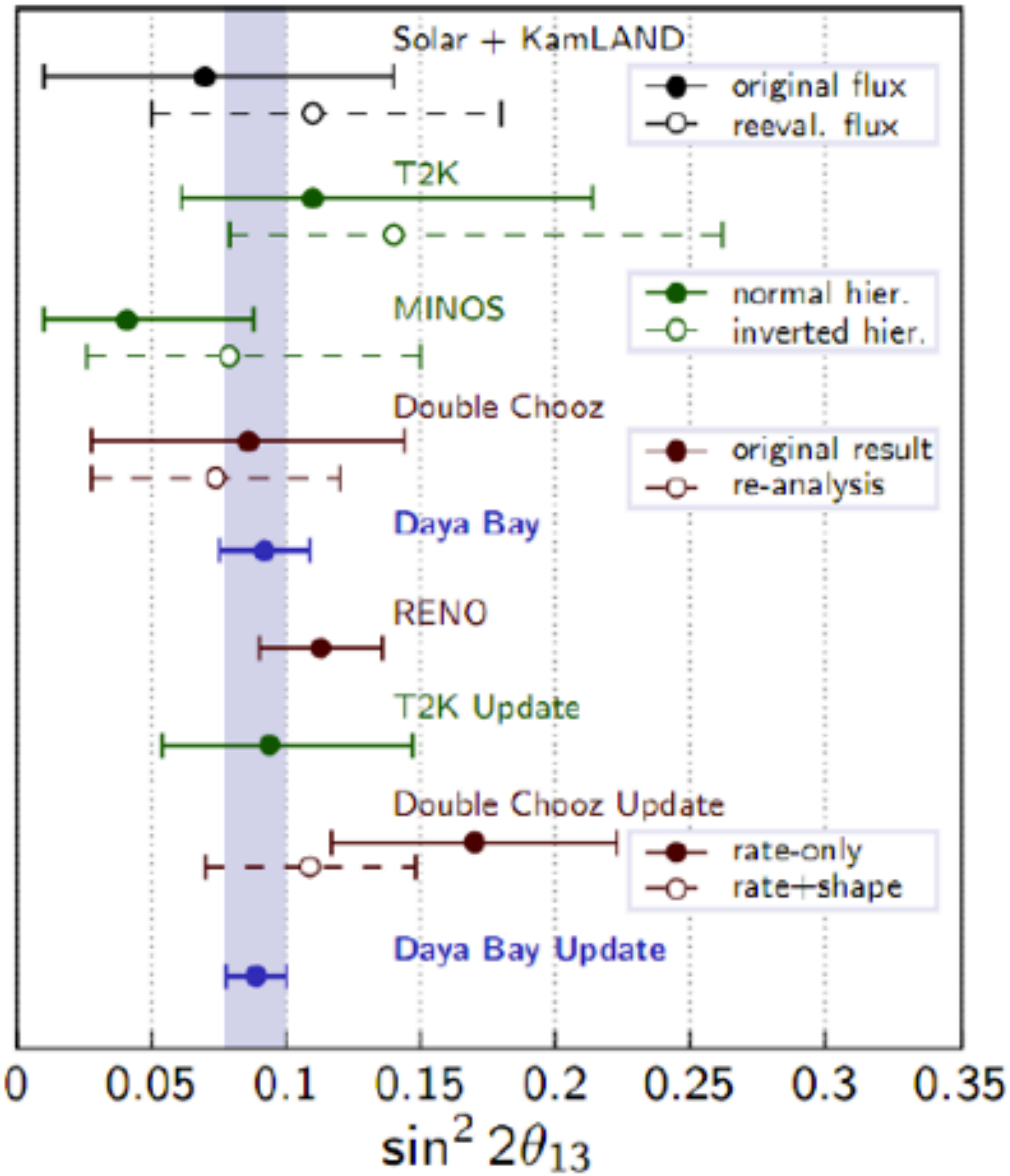
Neutrino Event: coincidence in time, space and energy



Neutrino energy:

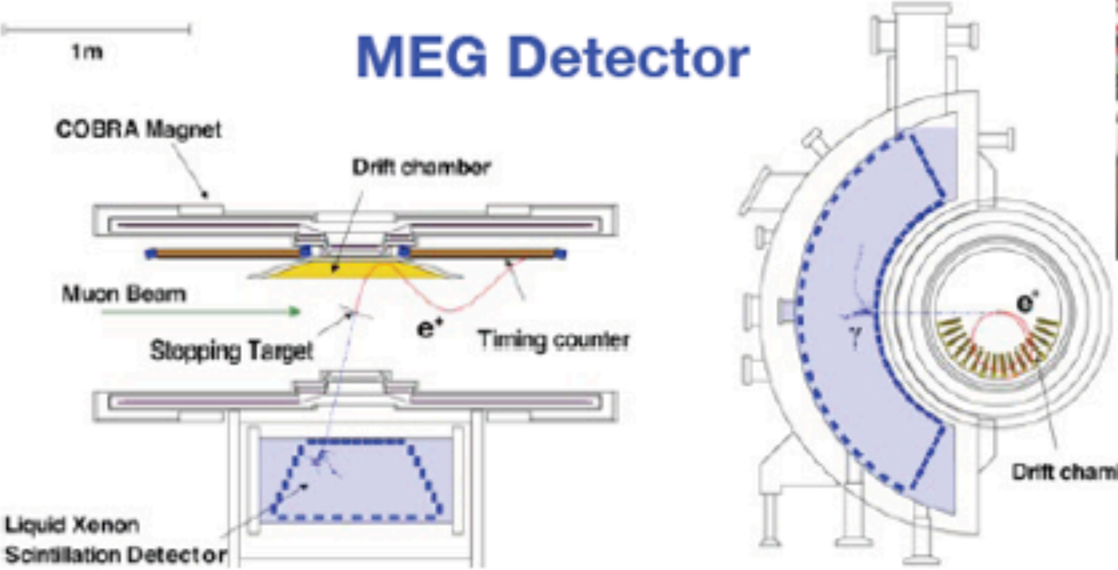
$$E_{\bar{\nu}} \cong \boxed{T_{e^+}} + \underbrace{T_n}_{10\text{-}40\ keV} + \underbrace{(M_n - M_p)}_{1.8\ MeV:\ Threshold} + m_{e^+}$$

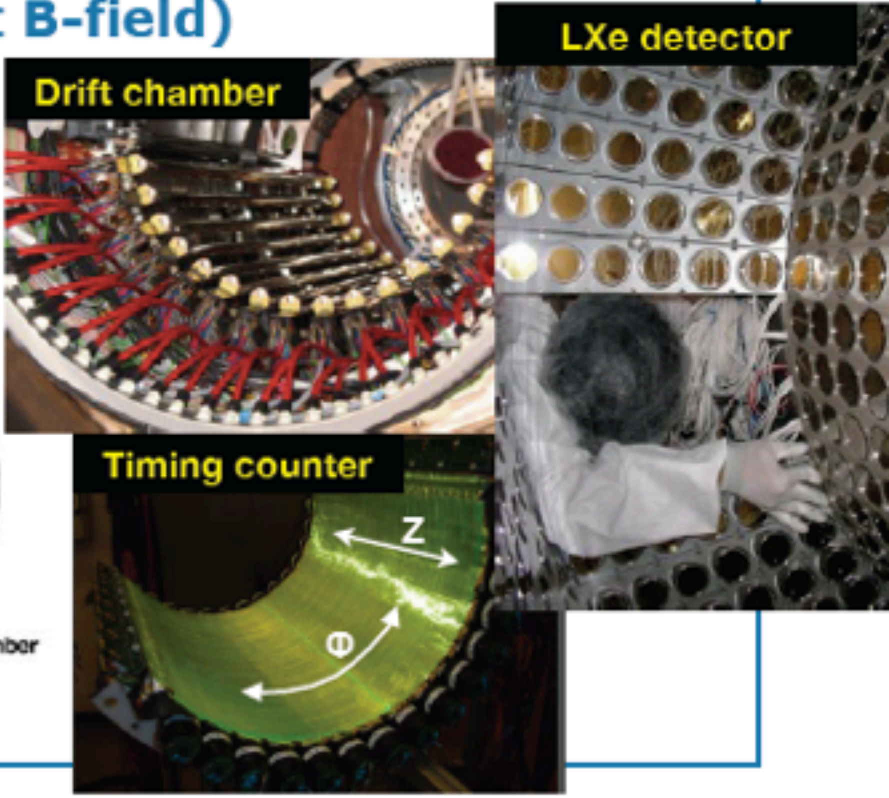
Global landscape of $\sin^2 2\theta_{13}$



MEG Experiment

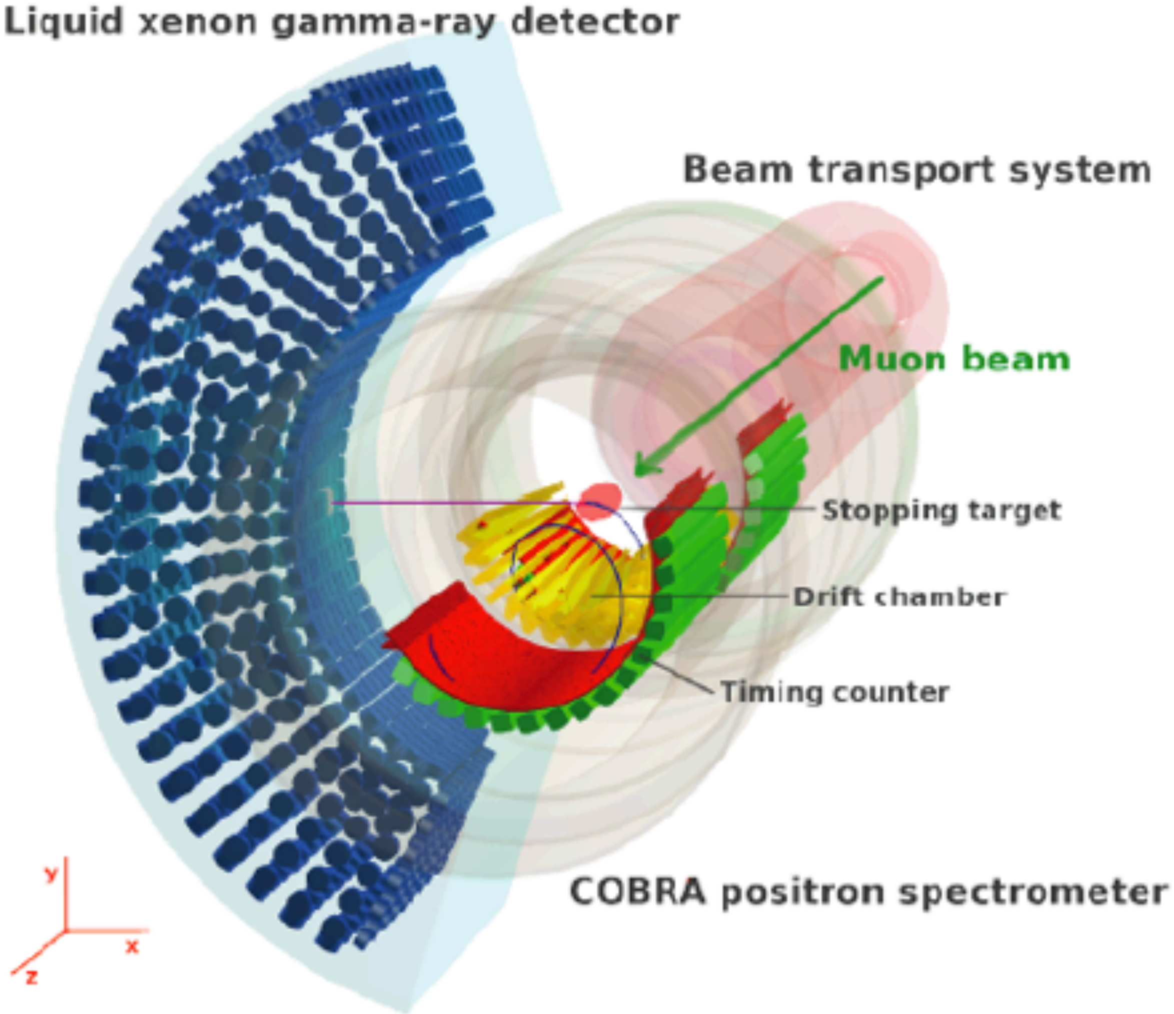
- ☑ World's most intense μ^+ beam at Paul Scherrer Institute (PSI) (3×10^7 μ^+/sec at MEG)
- ☑ Detectors
  - ☑ 900L LXe γ-ray detector with PMT readout
  - ☑ Positron spectrometer (low-mass drift chamber system +fast timing counter in gradient B-field)





THE MEG DETECTOR

Ingredient 2: high resolutions

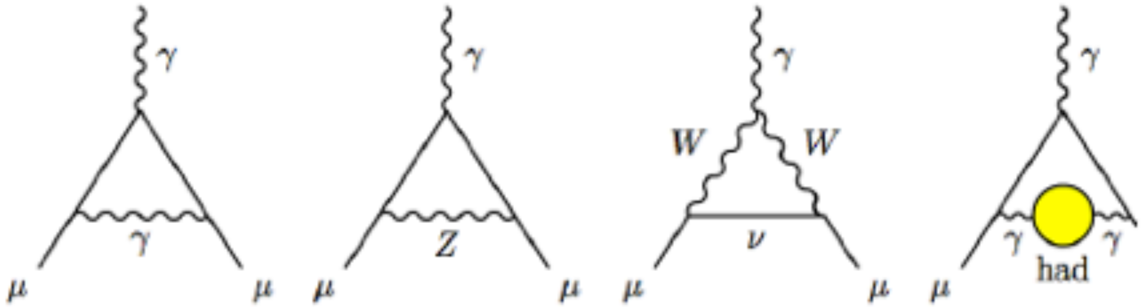


in sigma	
Gamma Energy (%)	2.1 (w>2cm)
Gamma Position (mm)	5(u,v) / 6(w)
e+ Momentum (%)	0.74 (core)
e+ Angle (mrad)	7.1(ϕ core),11.2(θ)
Vertex position (mm)	3.4 (Z), 3.3 (Y)
Gamma - e+ Timing (psec)	142
Gamma Efficiency (%)	58
Trigger Efficiency (%)	83.5

What’s New in This Work

- **Hardware improvements in run 2011**
  - Higher resolution BGO array detector introduced in LXe energy calibration with CEX reaction ($\pi^+p\rightarrow n\pi^0$, $\pi^0\rightarrow 2\gamma$)
  - New optical survey technique with laser tracker
- **New data and new analysis with improved algorithms**
  - Reduced drift chamber noise with FFT filtering
    - Angular resolution improved by <10%
  - Totally revised track fit algorithm based on Kalman filter technique
    - Reduced tail in response function, 7% better efficiency, per-event error matrix introduced to likelihood analysis
  - Improved pileup elimination algorithm in LXe γ-detector
    - Less pileup, 7% better efficiency

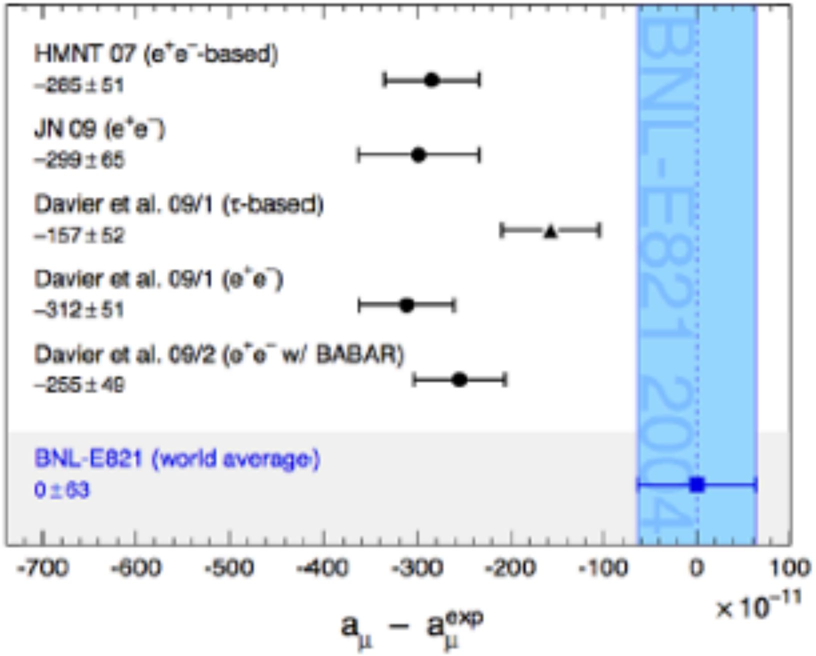
MUON ANOMALOUS MAGNETIC MOMENT



$$\vec{M} = g_\mu \frac{e}{2m_\mu} \vec{S}$$

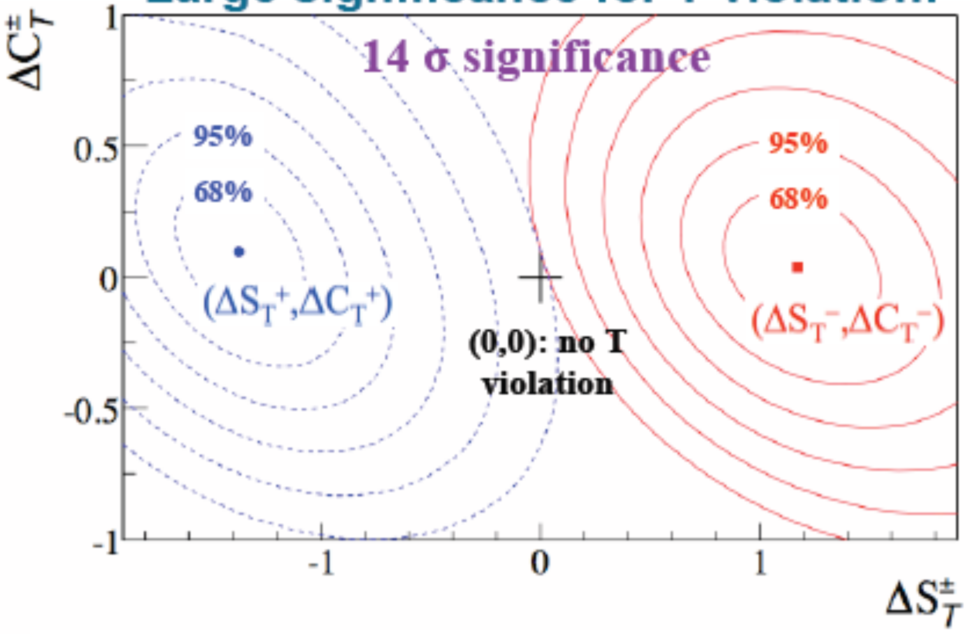
Figure 1: Representative diagrams contributing to $a_\mu^{\rm SM}$. From left to right: first order Q (Schwinger term), lowest-order weak, lowe order hadronic.

$$a_\mu \equiv \frac{g_\mu - 2}{2}$$



T Violation Measurement From BaBar

Large significance for T violation:



$$g^{\pm}_{\alpha,\beta}(\Delta\tau) \propto e^{-\Gamma\Delta\tau}\{1+S^{\pm}_{\alpha,\beta}\sin(\Delta m_d\Delta\tau)+C^{\pm}_{\alpha,\beta}\cos(\Delta m_d\Delta\tau)\}$$

$$\alpha \in \{B^0,\ \overline{B}^0\}; \quad \beta \in \{K^0_S,\ K^0_L\}$$

$\Delta S_T^+ = S^-_{\ell^-,K^0_L} - S^+_{\ell^+,K^0_S}$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S_T^- = S^+_{\ell^-,K^0_L} - S^-_{\ell^+,K^0_S}$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C_T^+ = C^-_{\ell^-,K^0_L} - C^+_{\ell^+,K^0_S}$	$0.10 \pm 0.14 \pm 0.08$
$\Delta C_T^- = C^+_{\ell^-,K^0_L} - C^-_{\ell^+,K^0_S}$	$0.04 \pm 0.14 \pm 0.08$

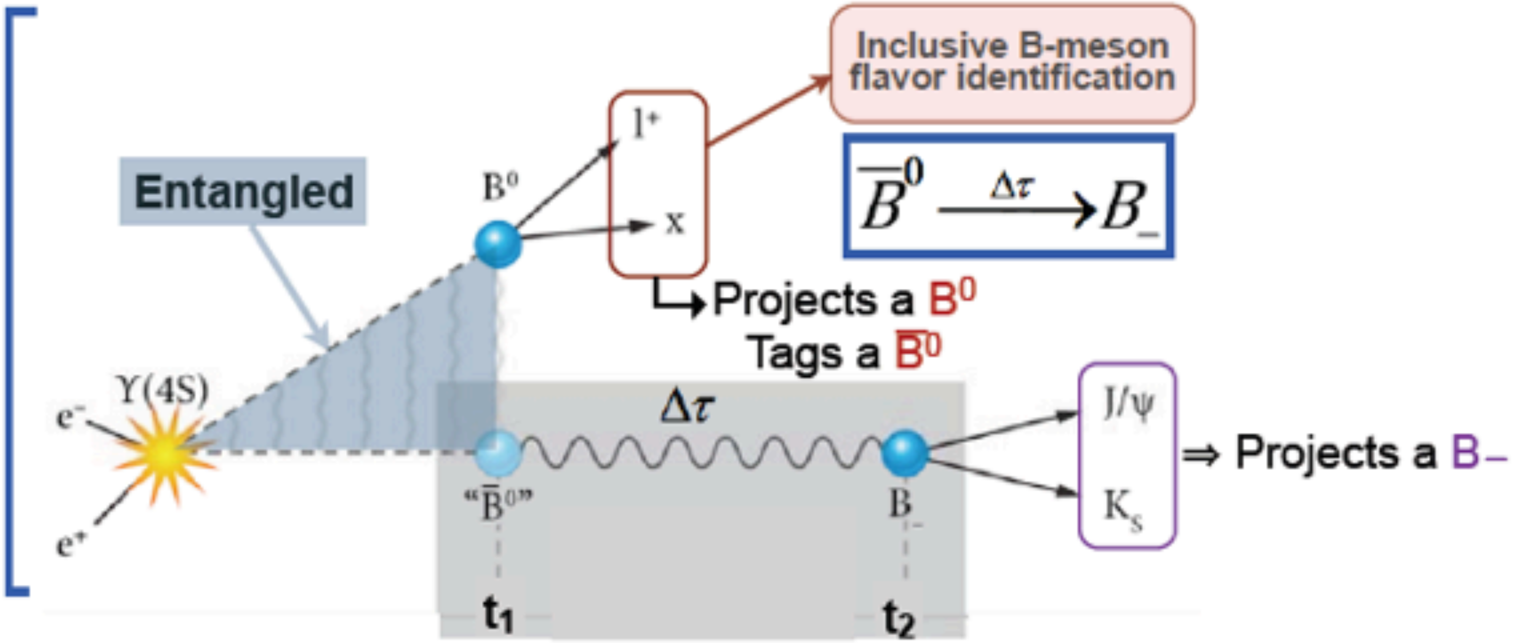
- very nice measurement of **time reversal violation** in the B^0 meson system
  - ★ not the first observation, but quite direct, unambiguous one
- Υ(4S) decays into an entangled pair of B^0 mesons

$$\begin{aligned} |i\rangle &= 1/\sqrt{2}\,[B^0(t_1)\overline{B}^0(t_2) - \overline{B}^0(t_1)B^0(t_2)] \\ &= 1/\sqrt{2}\,[B_+(t_1)B_-(t_2) - B_-(t_1)B_+(t_2)] \end{aligned}$$

  - ★ the state of the first B at time t_1 dictates the state of the second B at time $t_2 > t_1$
  - ★ **Flavour tag:** a B decay to l^+X (l^-X) projects it to B^0($\overline{B}^0$) state, tag → $\overline{B}^0$(B^0)
  - ★ **CP tag:** a B decay to $J/\psi K_L$ ($J/\psi K_S$) projects it to B_+(B_-) state, tag → B_-(B_+)

TIME REVERSAL VIOLATION

ANALYSIS (1)



Inclusive B-meson flavor identification

$$\overline{B}^0 \xrightarrow{\Delta\tau} B_-$$

↳ Projects a B^0
Tags a $\overline{B}^0$

⇒ Projects a B_-

$\beta\gamma \sim 0.56$ (BABAR)
$\Delta z = \beta\gamma c\Delta\tau$
$< \Delta z > \sim 250\mu m$

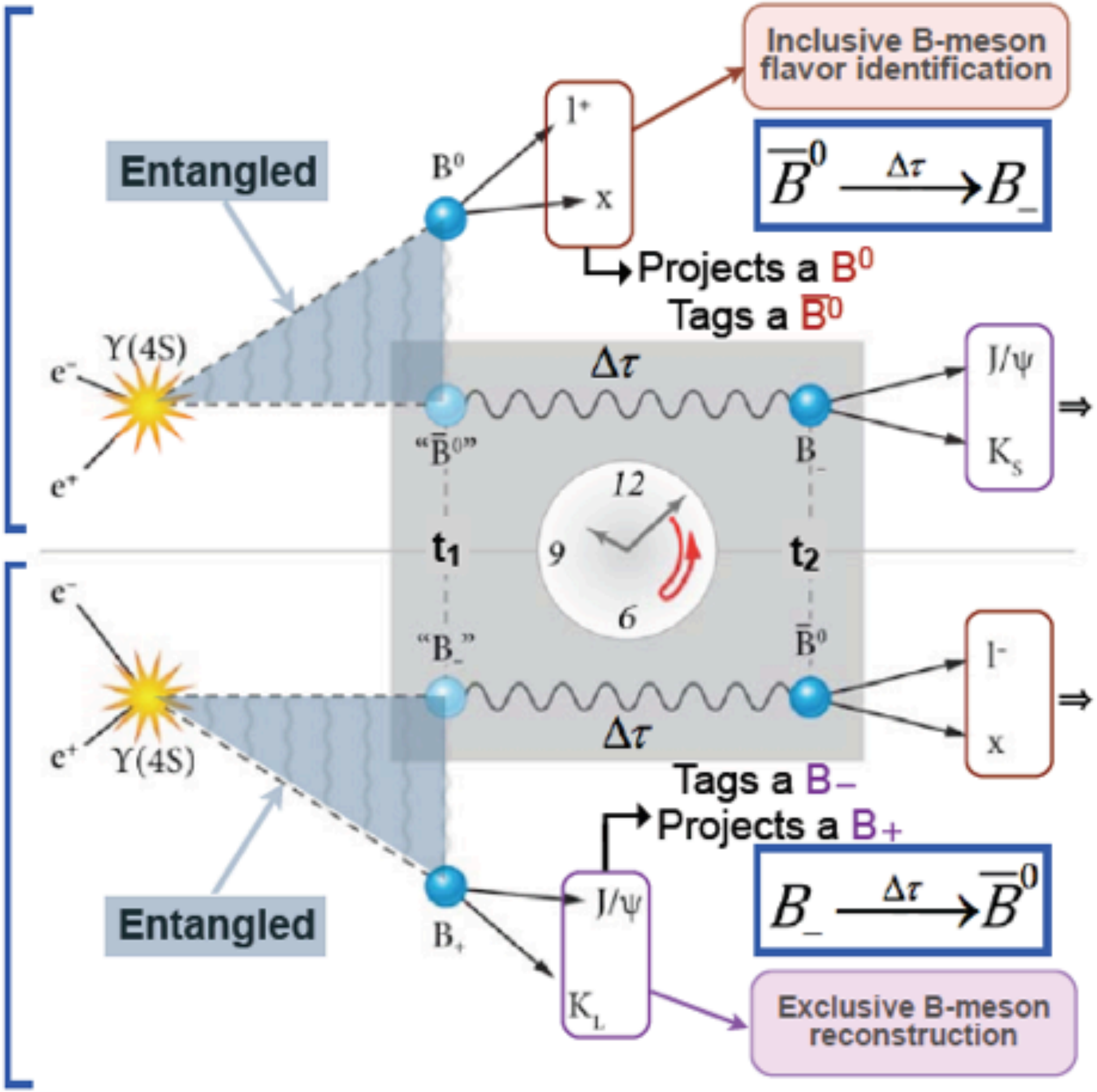
- **Quantum (EPR) entanglement:**
  - **Υ(4S) decay yields an entangled state of B mesons**
  - **The state of the 1st B to decay at t_1 dictates the state of the other B, which decays afterwards at $t_2 > t_1$**
  - **Flavor tag: B semileptonic decay to $l^+ X$ ($l^- X$) projects B^0 ($\overline{B}^0$) → $\overline{B}^0$ (B^0) tag**
  - **CP tag: B decay to $J/\psi K_L$ projects $B_+ \approx 1/\sqrt{2}\,[B^0 + \overline{B}^0]$ → B_- tag ("CP-odd")**
    B decay to $J/\psi K_S$ projects $B_- \approx 1/\sqrt{2}\,[B^0 - \overline{B}^0]$ → B_+ tag ("CP-even")

$$\begin{aligned} |i\rangle &= 1/\sqrt{2}\,[B^0(t_1)\overline{B}^0(t_2) - \overline{B}^0(t_1)B^0(t_2)] \\ &= 1/\sqrt{2}\,[B_+(t_1)B_-(t_2) - B_-(t_1)B_+(t_2)] \end{aligned}$$

Bernabeu & Bañuls,
PLB464, 117 (1999)

TIME REVERSAL VIOLATION

ANALYSIS (2)



$\beta\gamma \sim 0.56$ (BABAR)
$\Delta z = \beta\gamma c\Delta\tau$
$< \Delta z > \sim 250\mu m$

T mirror

It is not an exchange $t_1 \rightleftarrows t_2$

T-Transformed Processes

Physical Process / Reco. Final State	Physical Process / Reco. Final State
$B^0 \rightarrow B_+$ $(l^-, J/\psi K_L)$	$B_+ \rightarrow B^0$ $(J/\psi K_S, l^+)$
$B^0 \rightarrow B_-$ $(l^-, J/\psi K_S)$	$B_- \rightarrow B^0$ $(J/\psi K_L, l^+)$
$\bar{B}^0 \rightarrow B_+$ $(l^+, J/\psi K_L)$	$B_+ \rightarrow \bar{B}^0$ $(J/\psi K_S, l^-)$
$\bar{B}^0 \rightarrow B_-$ $(l^+, J/\psi K_S)$	$B_- \rightarrow \bar{B}^0$ $(J/\psi K_L, l^-)$

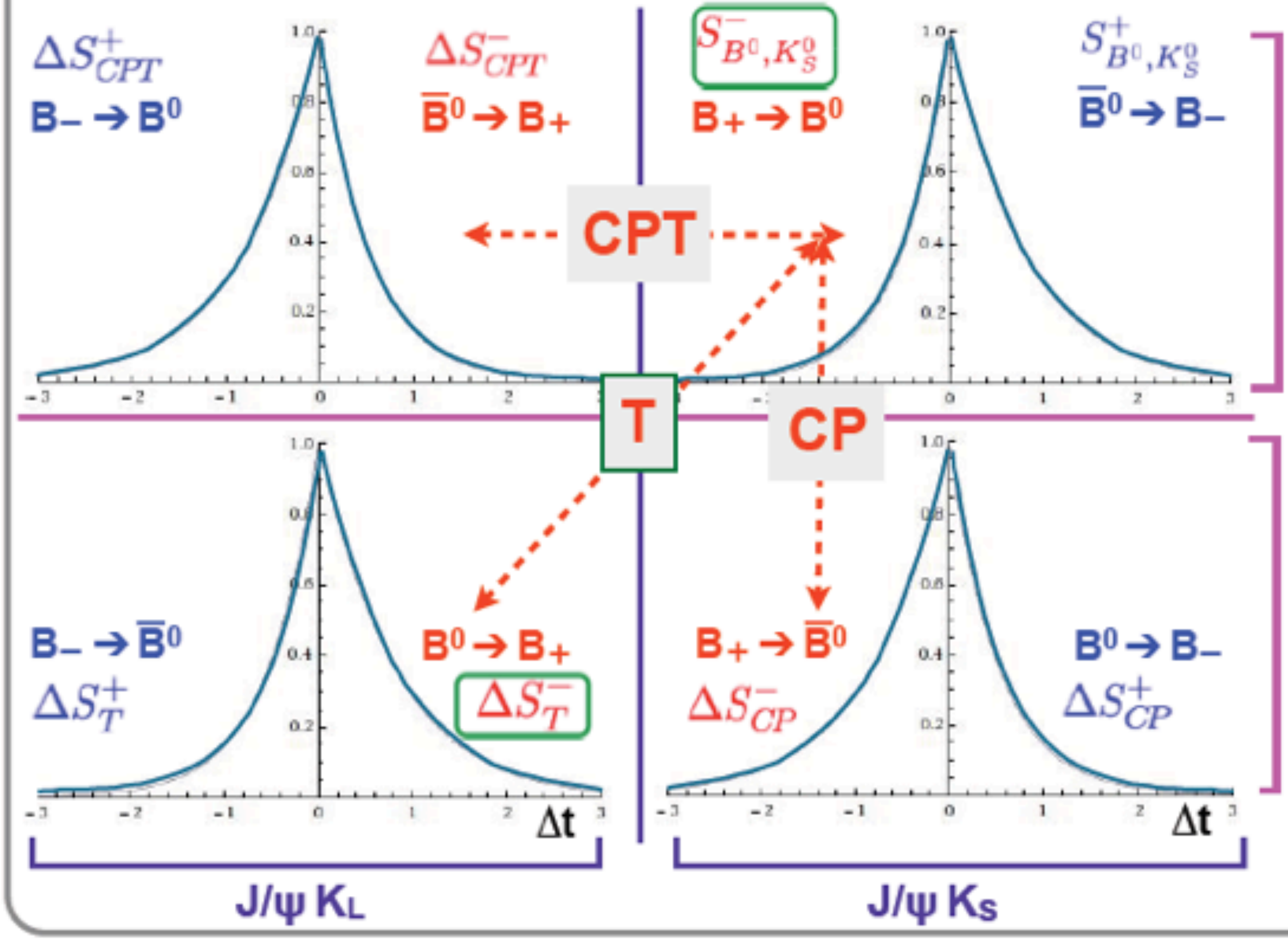
TIME REVERSAL VIOLATION

ANALYSIS (3)

8 sets of S and C parameters:

$$g^{\pm}_{\alpha,\beta}(\Delta\tau) \propto e^{-\Gamma\Delta\tau}\{1+S^{\pm}_{\alpha,\beta}\sin(\Delta m_d\Delta\tau)+C^{\pm}_{\alpha,\beta}\cos(\Delta m_d\Delta\tau)\}$$

$$\alpha \in \{B^0,\ \overline{B}^0\};\quad \beta \in \{K^0_S,\ K^0_L\}$$



ΔS^+_{CPT} B− → B^0

ΔS^-_{CPT} $\overline{B}^0$ → B+

$S^-_{B^0,K^0_S}$ B+ → B^0

$S^+_{B^0,K^0_S}$ $\overline{B}^0$ → B−

CPT

T

CP

B− → $\overline{B}^0$ ΔS^+_T

B^0 → B+ ΔS^-_T

B+ → $\overline{B}^0$ ΔS^-_{CP}

B^0 → B− ΔS^+_{CP}

I^+

I^-

J/ψ K_L

J/ψ K_S

$\Delta t = t_{CP} - t_{flav}$

$= \begin{cases} +\Delta\tau \text{ for “flavor tag”} \\ -\Delta\tau \text{ for “CP tag”} \end{cases}$

4 independent T comparisons
(as **4 CP** and **4 CPT** comparisons)

T implies comparison of:

1) Opposite Δt sign
2) Different reconstructed states (J/ψK_L vs. J/ψK_S)
3) Opposite flavor states