Summer conferences' summary : news from collider experiments

Séminaire du SPP

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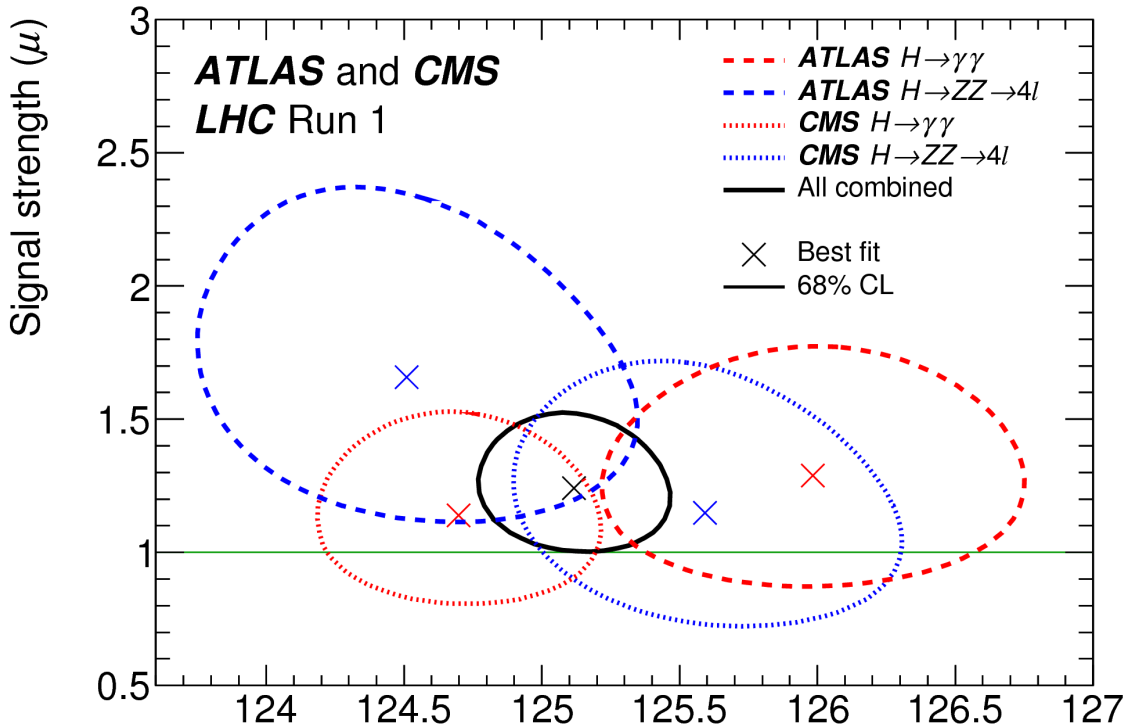
19th Oct. 2015

Special thanks to Dieter Zeppenfeld and Fabiola Gianotti for their summary talks given at EPS HEP 2015.

Outline

... and many other interesting topics that will not be discussed here

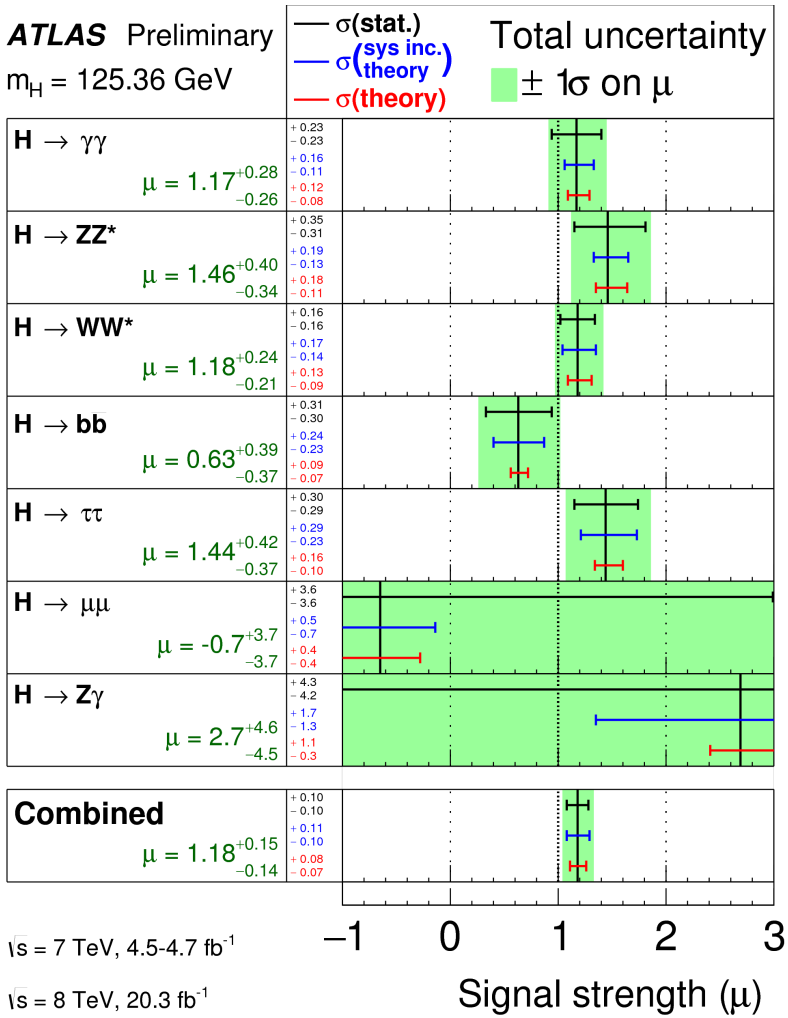
Higgs mass measurement at the LHC run 1



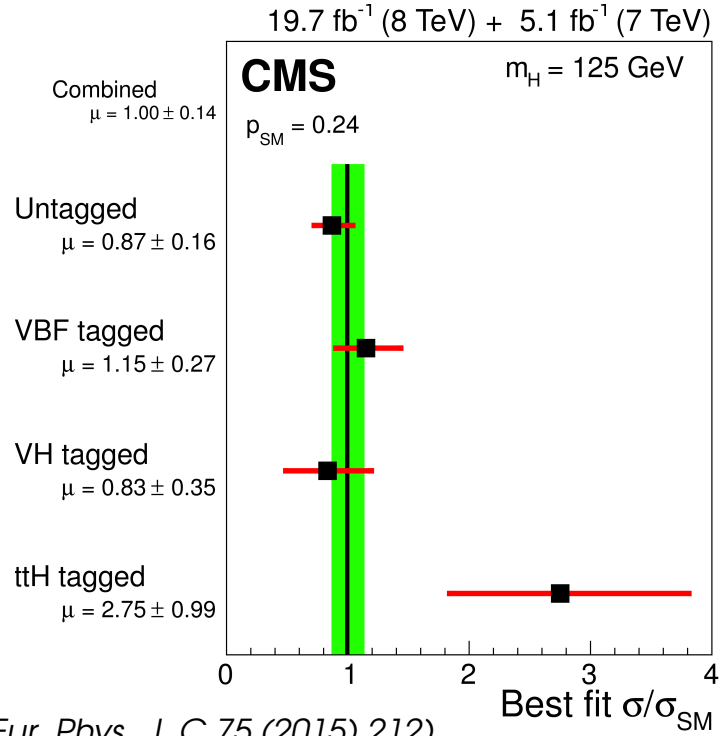
(Phys. Rev. Lett. 114, 191803)

- The Higgs mass is a free parameter of the Standard Model which needs to be measured.
  - CMS: 125.02 $\pm$ 0.27 (stat.) $\pm$ 0.15 (syst.) GeV
  - ATLAS: 125.36 $\pm$ 0.37 (stat.) $\pm$ 0.18 (syst.) GeV
  - **LHC run 1 combinaison: 125.09 $\pm$ 0.21 (stat.) $\pm$ 0.11 (syst.) GeV**
- Precision $<$ 0.2% + strong effort from theory $\rightarrow$ very accurate predictions of Higgs production cross section and decay rates

Decay modes and production cross sections at the LHC run 1



(ATLAS-CONF-2015-007)



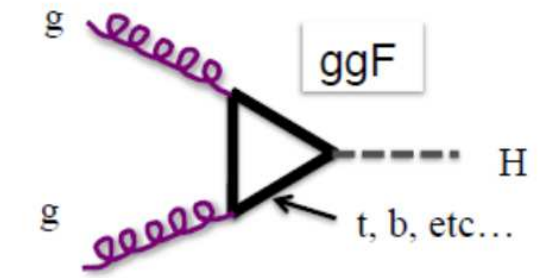
(Eur. Phys. J. C 75 (2015) 212)

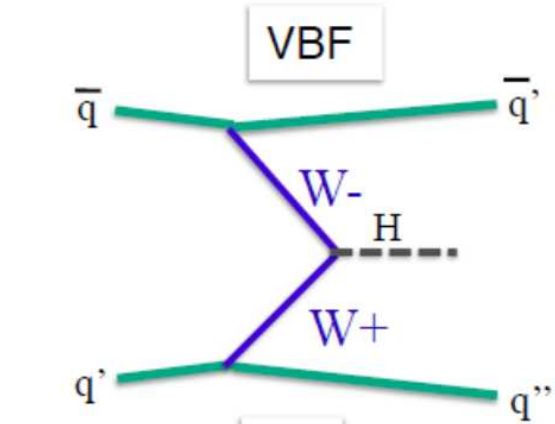
$\mu = 1$ if SM Higgs

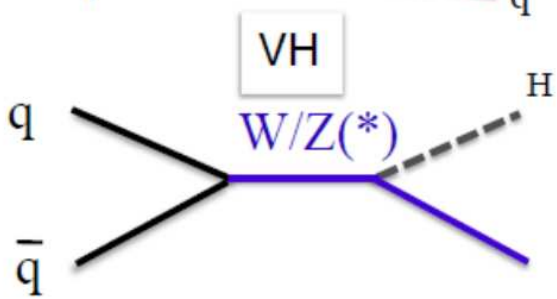
Good agreement with the SM in terms of decay rates and production rates.

ttH production mode, small excess also in ATLAS but with very large statistical uncertainty.

Higgs cross section increase at 13 TeV

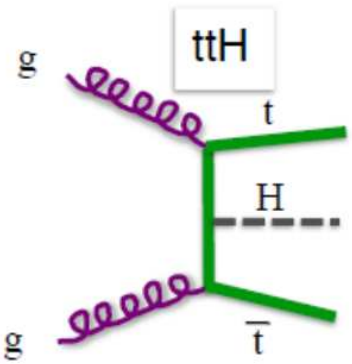


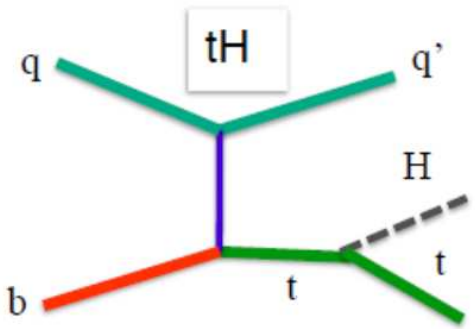




	process	8 TeV	13 TeV
ggF	gluon-gluon fusion	19 pb	44 pb
VBF	vector-boson fusion	1.6 pb	3.7 pb
VH	associated production	1.1 pb	2.2 pb
ttH	associated production	0.13 pb	0.51 pb
tH	Associated production	~20 fb	~90 fb

SM Production Modes
(M_H = 125 GeV)





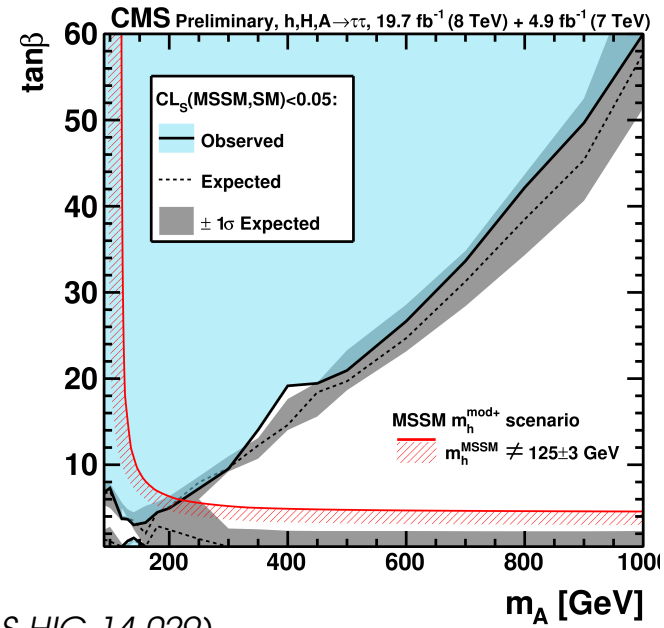
(Pierre Savard at EPS-HEP 2015)

The LHC run 2 will allow to measure more precisely many Higgs production modes

Search for Higgs rare decays or Higgs-like resonances as a probe for New Physics

Process	limit (times SM)
$\mu\mu$ (ATLAS)	7.0
$\mu\mu$ (CMS)	7.4
$Z\gamma$ (ATLAS)	11
$Z\gamma$ (CMS)	9
$\gamma\gamma$* (CMS)	7.7
$J/\psi\gamma$ (ATLAS)	540
$J/\psi\gamma$ (CMS)	540
ee(CMS)	10^5

(Pierre Savard at EPS-HEP 2015)



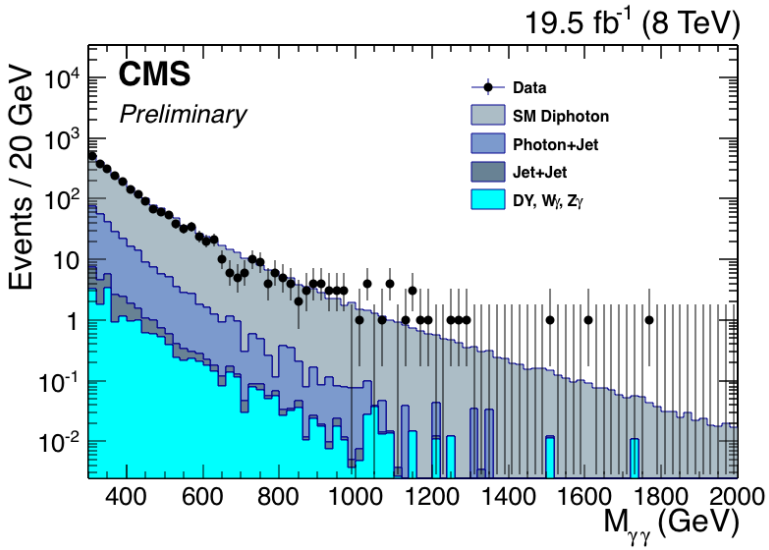
(CMS-PAS-HIG-14-029)

$\tau\tau$ final-state, sensitivity at high tan β (SUSY)

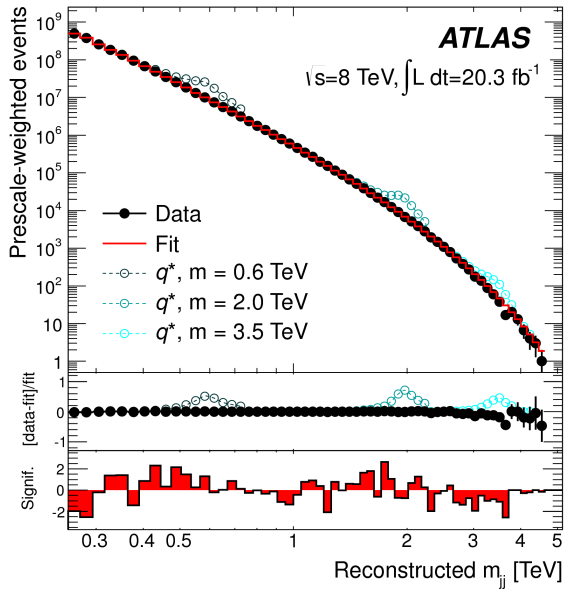
- Higher rates among the Higgs "rare" decays as predicted in the SM could be a hint for new physics (SUSY Higgs, composite Higgs, ...)
- It includes typically, $\mu\mu$, ee, $Z\gamma$, J/ψ, ...
- Also : search for Higgs-like resonance at higher mass, with different event topologies, etc ... no excess found.

Heavy, narrow resonance searches : di-jet and di-photon final states

di-photon *(CMS-PAS-EXO-12-045)*

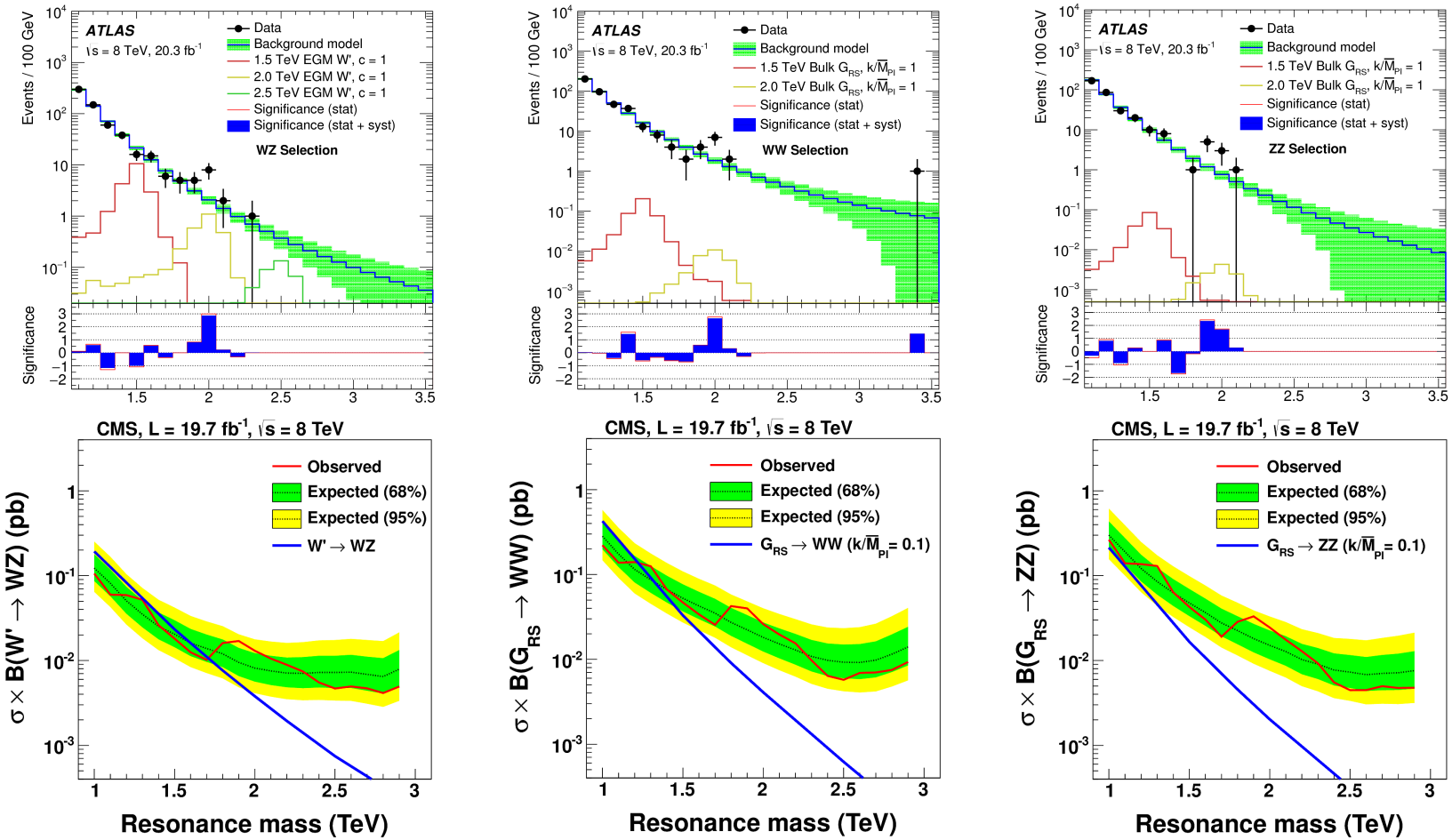


di-jet *(PRD 91, 052007 (2015))*



- Many channels are explored: di-jet, di-photon, di-lepton, $t\bar{t}$, $W/Z\gamma$, W/Z + lepton, Higgs + W/Z, di-boson, ...
  $\rightarrow$ no significant excess is observed.
- Di-photon resonances, reach up to 2 TeV. Exclusion of masses from 1.4 to 2.7 TeV. Sensitivity to extra-dimension models. Resonant and non-resonant signals considered.
- Di-jet resonances, reach up to 5 TeV. Exclusion of masses from 2 to 5 TeV. Classic bump search analysis with limits relevant for many models.

The di-boson to hadrons final-state



CMS : *JHEP 1408 (2014) 173, 174 and PAS-EXO-14-010* ATLAS : *arxiv:1506.00962*

- Di-boson resonances at high mass ($>$ 1 TeV) $\rightarrow$ boosted heavy bosons.
- Reconstruction very challenging $\rightarrow$ fat jet and study of jet substructure. Small positive deviation in both ATLAS and CMS, not in all channels.
- Positive small deviation for semi-leptonic as well (CMS only, I think).

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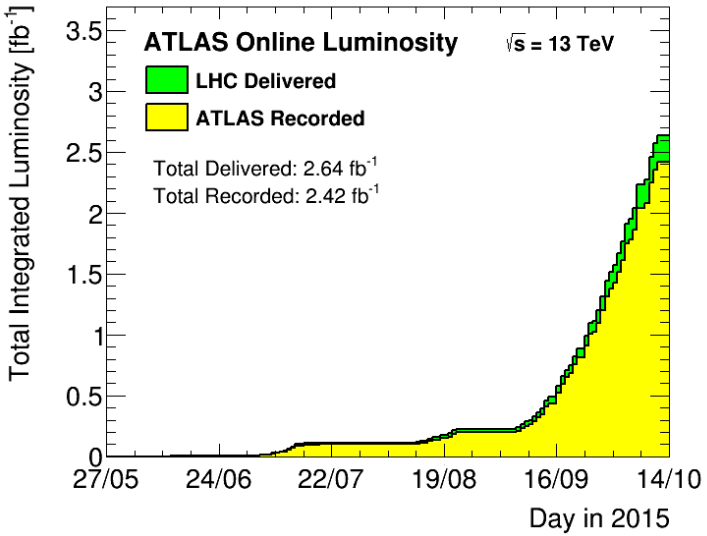
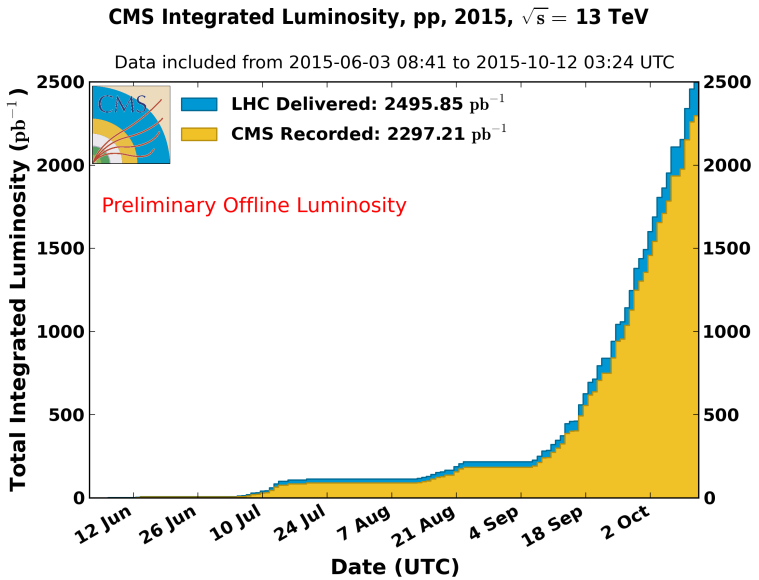
Status of the LHC run 2

(ATLASPublic/LuminosityPublicResultsRun2)

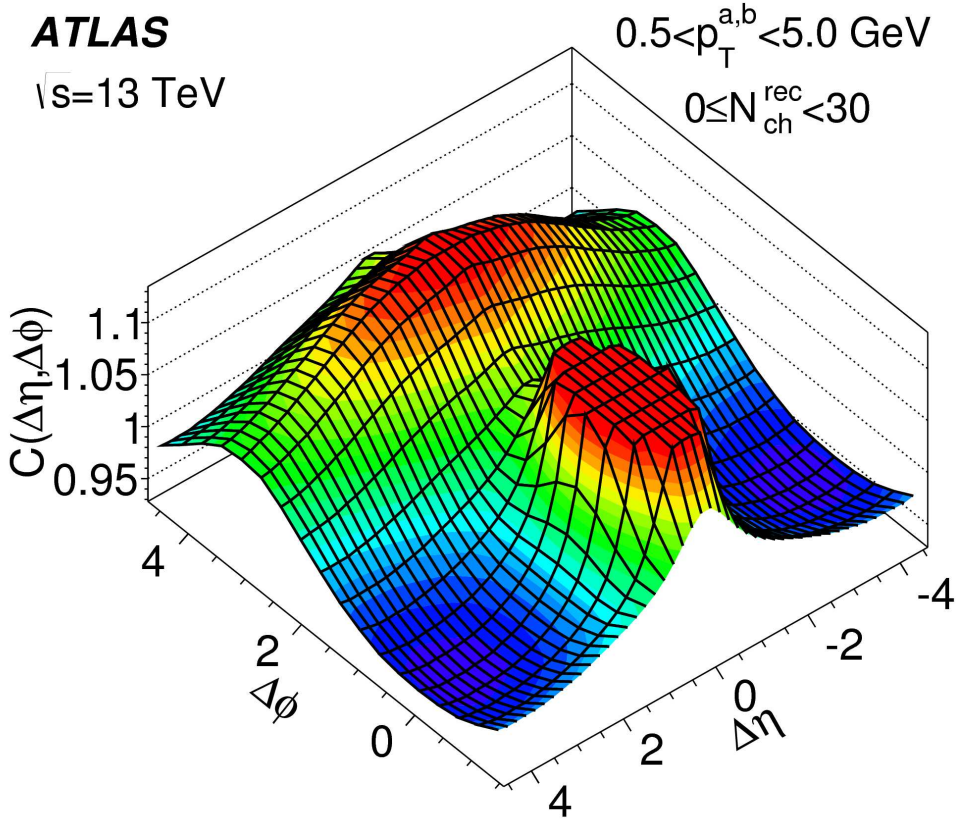


(CMSPublic/LumiPublicResults)



- Runs at 13 TeV with 50 (June to September, a few 100 pb^{-1}) and 25 ns (as of September) bunch spacing.
- Since the middle of September, the LHC is delivering a lot of data and both ATLAS and CMS are working well, with more than 2 fb^{-1} already recorded in each, *ie.* $\simeq$ half the statistics acquired during the whole year 2011.
- About 13 mean interaction per bunch crossing are observed in 25 ns data so far (a bit less than 2012 data).
- Already quite of few paper/conf notes are out, some constraints from previous data almost superseeded by 13 TeV data already.

Two-charged-particle correlations



(ATLAS, *arXiv:1509.04776*, CMS *arXiv:1510.03068*, *LHCb-CONF-2015-004*)

- Observations of long-range elliptic anisotropies in *pp* collisions using charged particles.
- Seen by CMS already at 7 TeV, now measured at 2.76 TeV (ATLAS) and 13 TeV (both). $\simeq$ same correlation but reach extended in multiplicity.
- Seen in $p-Pb$ and $Pb-Pb$ collisions as well in both ATLAS and CMS.
- Seen in forward and backward $p-Pb$ collisions by LHCb

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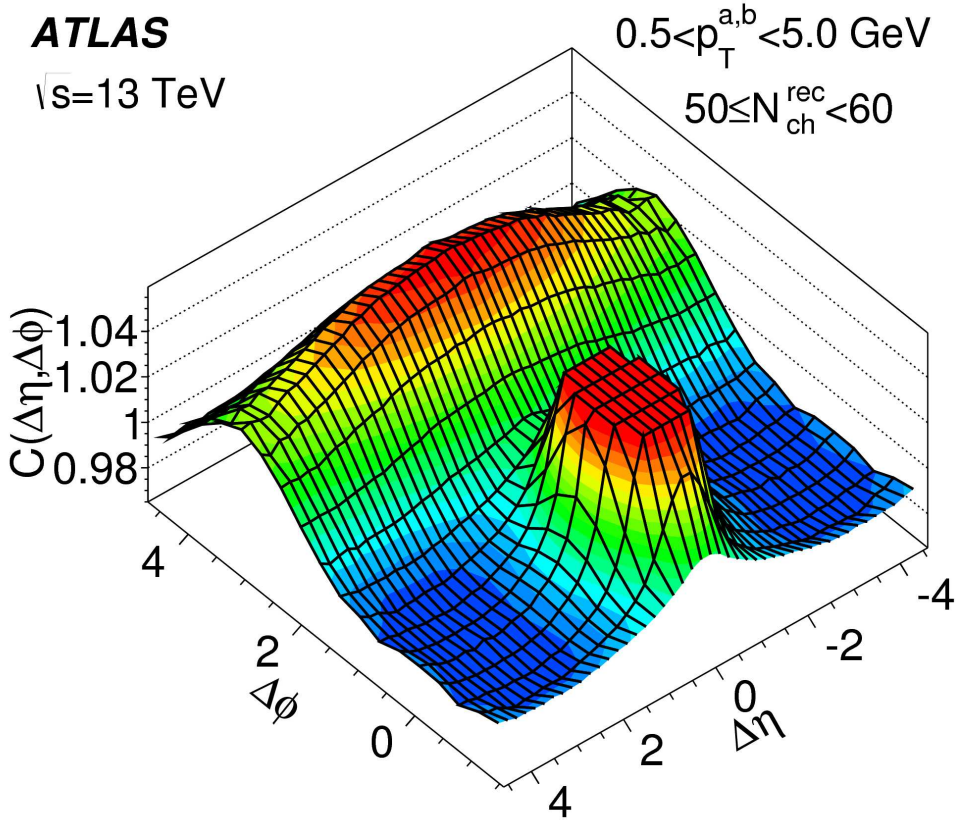

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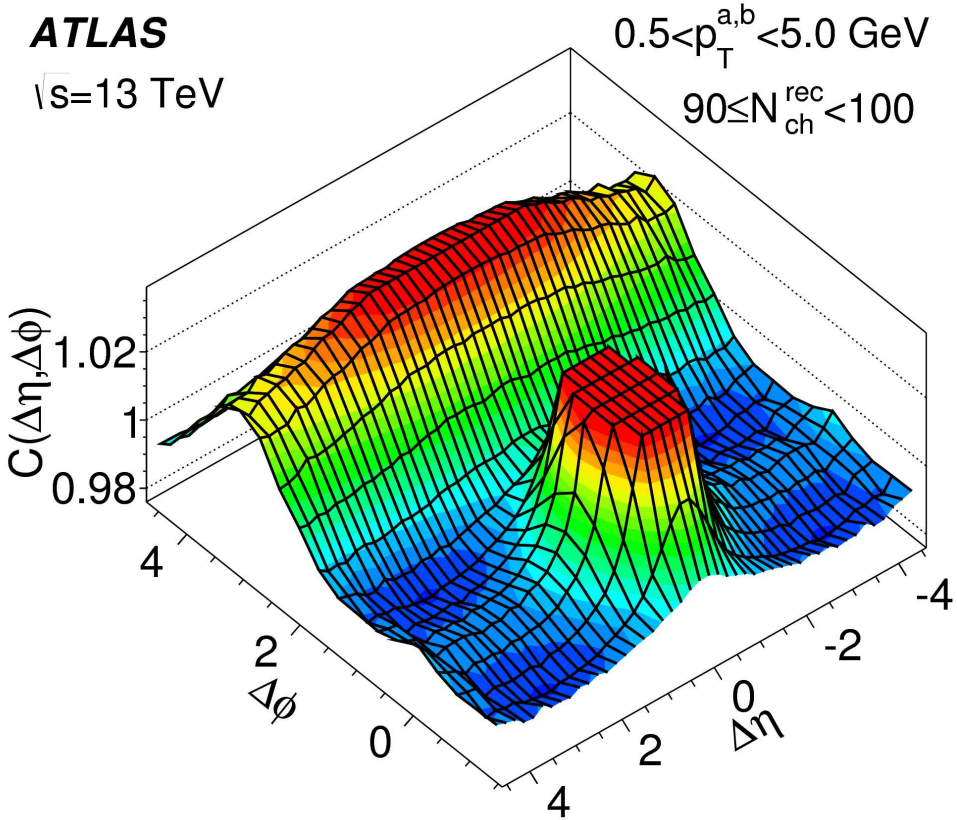

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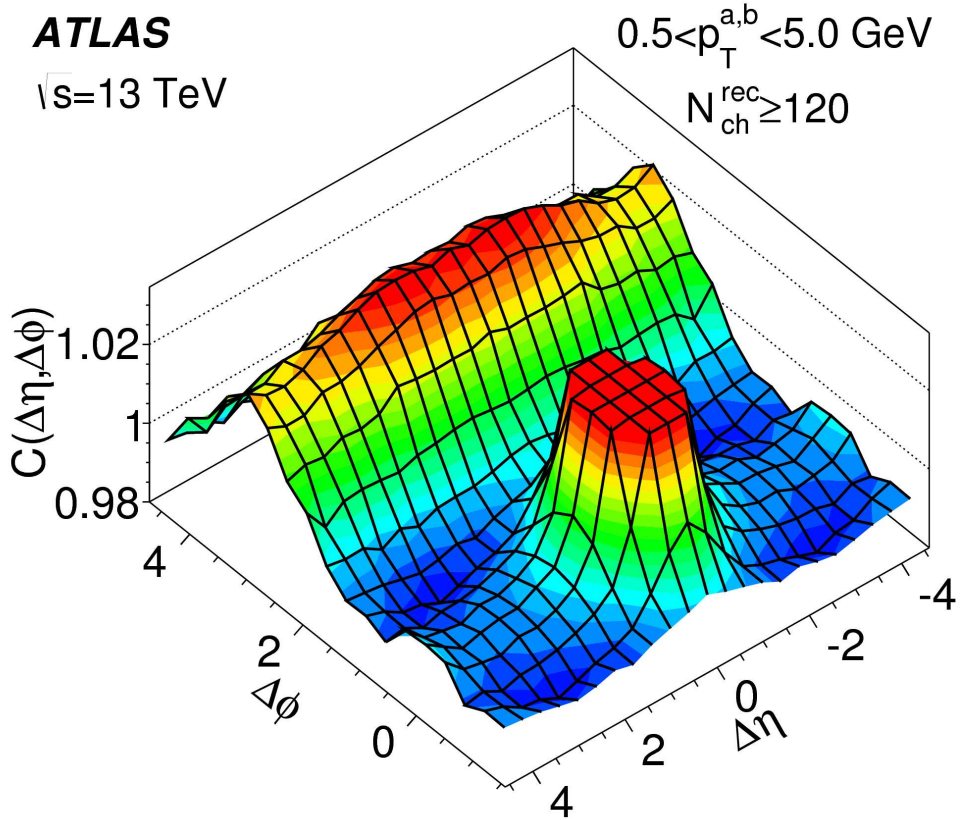

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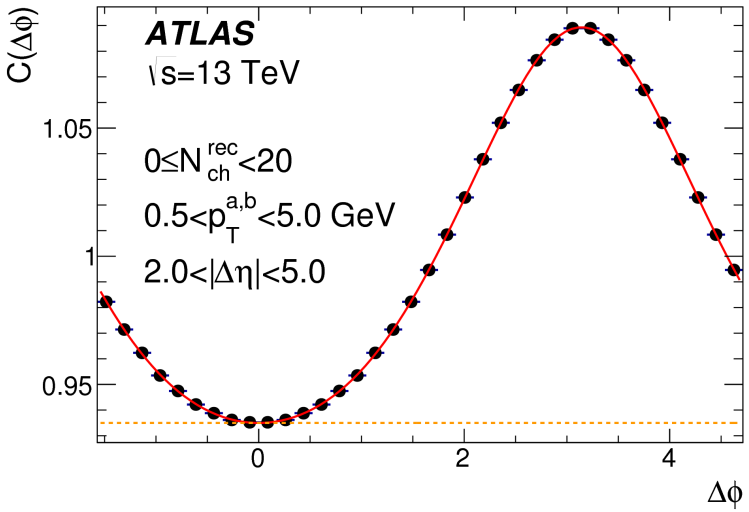
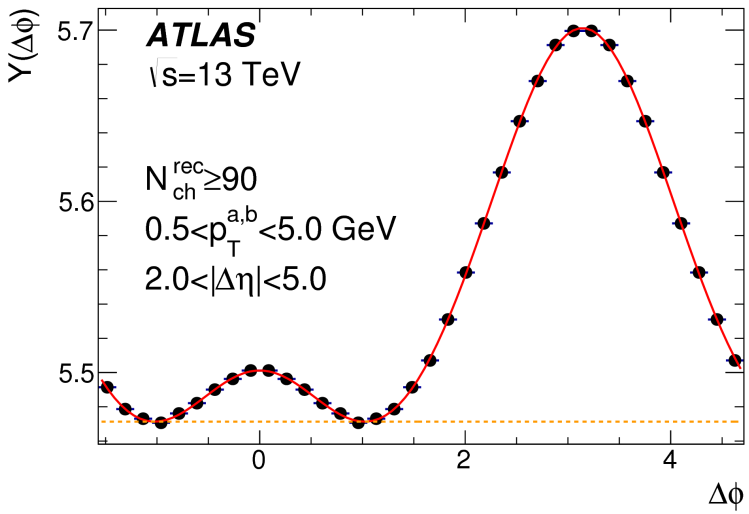
Projection on $\Delta\phi$ and other results

ATLAS : *arxiv:1506.00962*





No theory provides a satisfactory explanation on this phenomenon at the moment (as far as I understood).

- Many other preliminary results available already !

  Measurements : two-charged particle correlations, pseudorapidity distributions of charged particles, inelastic *pp* cross-section, inclusive jet, top/anti-top, Z+jets, W/Z, ...

  Searches : di-jet resonances, lepton + jet, multi-jet, ... nothing seen (yet?), some very high mass events observed in *ee*, di-jet (2.9 and $>$ 5 TeV) but nothing significant (yet?).

- First papers submitted

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NLO automation

The NLO automation

- Unitarity and on-shell methods

MadGraph5_aMC@NLO BlackHat+Sherpa NJet

GoSam+Sherpa Helac-NLO

- Numerical off-shell methods

Combine efficiency of the numerically stable tensor-integral reduction with the automation made possible by a completely recursive approach

OpenLoops+Sherpa Recola

see also Van Hameren (2009)

The final goal is really automatic NLO calculations

Specify process (input card), define cuts/distributions → run and get the results

The problem is "in principle" solved

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NNLO revolution

The NNLO revolution

Grazzini

NNLO calculations important for:

1) Benchmark processes measured with high accuracy

- ✅ $e^+e^- \to 3$ jets
- ✅ $pp \to W, Z$
- ✅ $pp \to t\bar{t}$ and single top
- (✅) $pp \to 2$ jets
  - ↘ towards completion

2) Processes with large NLO corrections

- ✅ $pp \to H$
  - ↘ even N^{3}LO known now
- ✅ $pp \to H$+jet
- ✅ $pp \to HH$

3) Important backgrounds for Higgs and NP searches

- ✅ $pp \to \gamma\gamma$
- ✅ $pp \to W\gamma, Z\gamma$
- ✅ $pp \to WW$
- ✅ $pp \to ZZ$
- ❌ $pp \to WZ$
- ✅ $pp \to W(Z)$+jet

It is essential to provide fiducial cross sections and distributions with which the data can be directly compared

(for more processes see also Les Houches 2013 NNLO wish list)

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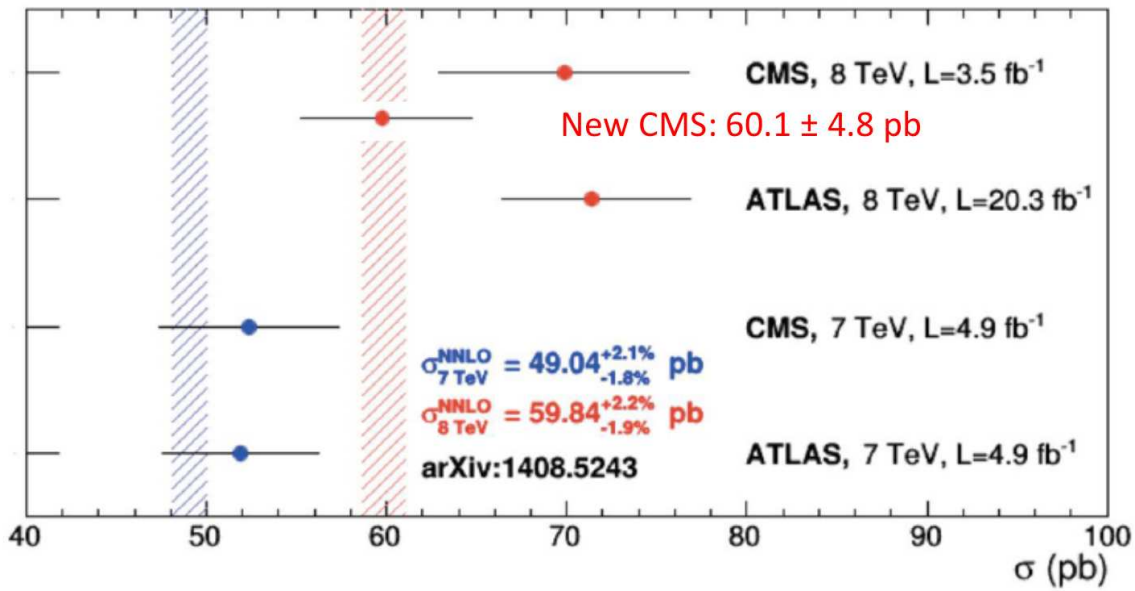
WW cross-section measurement at the LHC with improved predictions

Theory papers: Meade et al. Phys. Rev. D 90 (2014) 114006, Jaiswal et al. Phys. Rev. D 90 (2014) 073009
ATLAS at 8 TeV : *ATLAS-CONF-2014-033* CMS at 8 TeV : *arXiv:1507.03268*



- Discrepancy for the *WW* cross-section measurement at the LHC with NNLO predictions in both CMS and ATLAS, for all channels, solved in the final CMS analysis at 8 TeV.
- Theory : issue related to *WW* p_T distribution from $q\bar{q}$ component. The higher-order corrections becomes very large if one applies restriction on the number of jets. They are now resummed.
- Measurement : Signal efficiency was biased by the wrong *WW* p_T of the calculations → biased cross section

Lattice QCD impressive improvements for ϵ/ϵ' determination

New anomaly in ε'/ε: direct CPV in $K_L \to \pi\pi$

- Highly BSM-sensitive observable, precisely measured

  $(\varepsilon'/\varepsilon)_{\rm exp} = (16.6 \pm 2.3) \times 10^{-4}$ world average (KTeV & NA48)

- Major driver of flavour theory in 1990's

  Buras-Buchalla-Lautenbacher; Buras-Jamin-Lautenbacher-Weisz; Bosch-Buras-Gorbahn-Jaeger-Jamin-Lautenbacher-Silvestrini; Bertolini et al; Ciuchini et al; Pallante-Pich; Cirigliano et al; ...

  situation murky due to uncertain hadronic matrix elements (nonperturbative)

- @ EPS 2015: first complete lattice calculation (tour de force; evaluation of 20 hadronic matrix elements in isospin limit)

  $(\varepsilon'/\varepsilon)_{\rm SM} = (1.4 \pm 7.0) \times 10^{-4}$

  RBC-UKQCD collaboration [Z Bai et al]; talk A Soni at this conference

- @ EPS 2015: impose Delta I=1/2 to reduce number of independent hadronic matrix elements; isospin and NNLO corrections; corroborate lattice with new large-N relations (and vice versa)

  $\varepsilon'/\varepsilon = (2.2 \pm 3.7) \times 10^{-4}$ $3.3\,\sigma$ from expt

  Buras, Gorbahn, Jaeger, Jamin; Buras and Gerard; talk A Buras at this conference

Excellent prospects as BSM probe if theory errors are confirmed/further reduced

Big improvements on hadronic matrix elements for B-physics , talk R. van de Water

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→ *Lattice QCD reaches a new precision era with a set of new predictions available now or very soon on CP violation and hadronic physics in general.*

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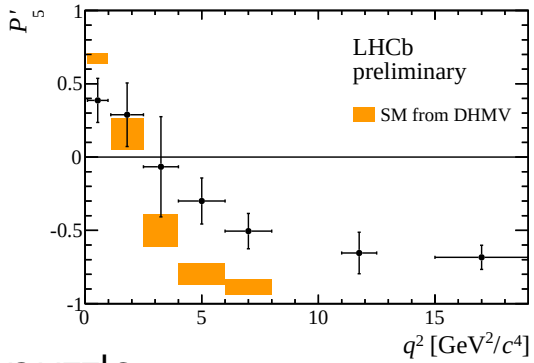
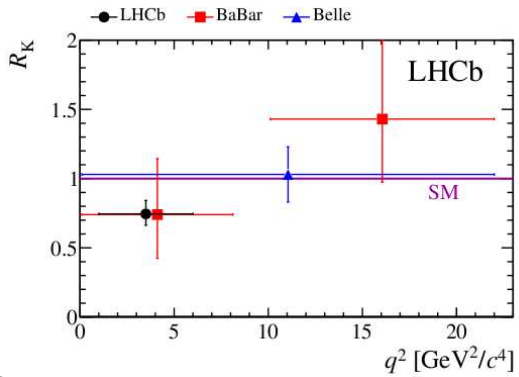
A few anomalies in the B sector

LHCb-CONF-2015-002, Phys. Rev.Lett. 113 (2014) 151601, arXiv:1504.06339, Nature Physics 3415 (2015)

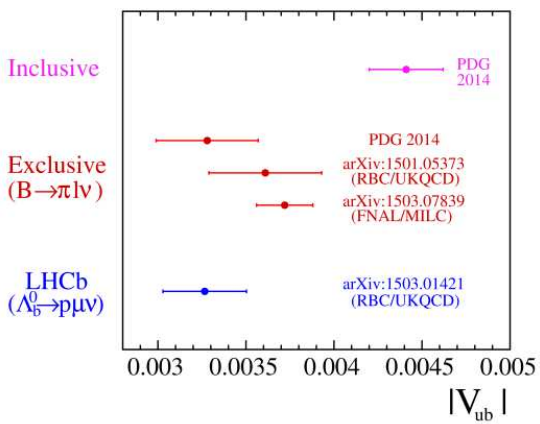
P'_5 in $B \to K^* \mu^+ \mu^-$



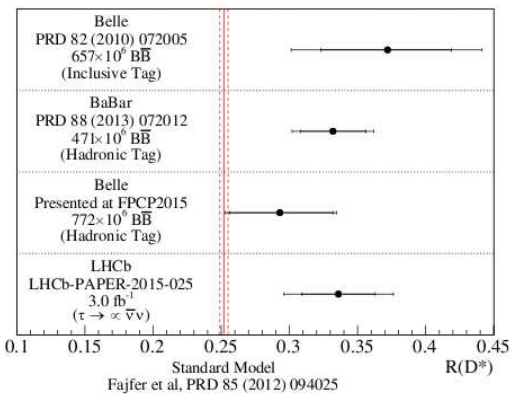
Lepton universality



$|V_{ub}|$ puzzle



$B \to D^* \tau \nu$



- In general, *CP* asymmetry measurements consistent with the Standard Model, precision and pinguin control increased. The uncertainties are often limited by data in LHCb so good improvements are expected for run 2.
- However, a few intruiging 3-4 σ anomalies are present.

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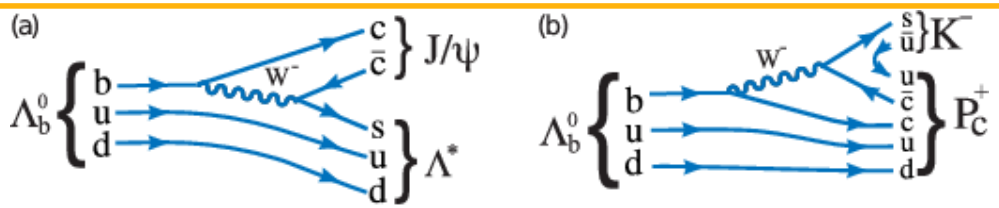
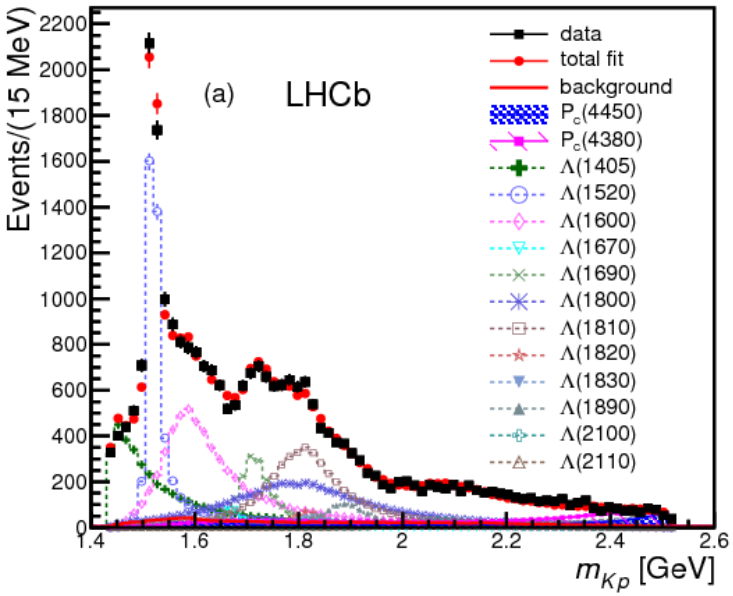
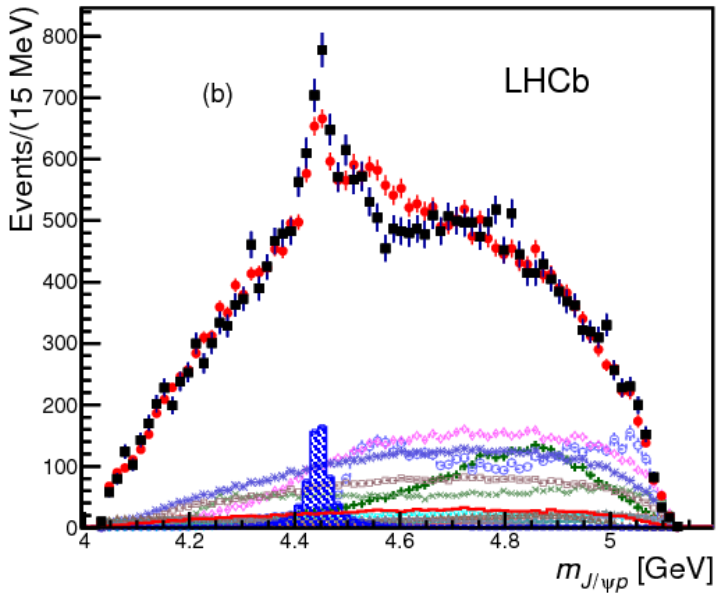
Pentaquark state at LHCb

Phys. Rev. Lett. 115, 072001 (2015)







- Observation of $J/\psi p$ resonances consistent with pentaquark states in $\Lambda_b^0 \to J/\psi K^- p$ decays in LHCb
- No reasons that those states should not exist. Some of them were even predicted by Gell-Mann and others (60's) and in the 70's (Jaffe 76, ...)
- Two resonances decaying into $J/\psi p$ consistent with ($uud\bar{c}c$) content at masses 4380 MeV and width 205 MeV (9σ) and 4449.8 MeV and width 39 MeV (12σ) observed.
- Best fit with $J^P = (3/2^-, 5/2^+)$ (also $3/2^+$,$5/2^-$ and $5/2^+$,$3/2^-$)

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Physics prospects at high-energy colliders : what is next?

- The discovery of the Higgs boson is a triumph for particle physics, however the SM is still unable to answer many crucial questions
- A few options to pursue collision studies after the LHC-era : Linear and circular *ee* collider, very high energy *pp* collider (, muon, *ep*, $\gamma\gamma$ and ion colliders).
- Strong volonty from CERN to continue the exploitation of the LHC if new physics or not (HL-LHC in 2026-2037, 3000 fb^{-1} at 13 TeV)

  "Accelerators have been our most powerful tool for particle physics exploration" F. Gianotti
- *ee* colliders: Low background, precision measurements, weakly coupled physics : $\Delta m_W < 1$ MeV, EW observable precision x 20-100. ttH and HH requires $\sqrt{s} > 500$ GeV though.

  Ex: ILC, CepC, FCC-ee. Technology mature today for 500 GeV ILC.
- 100 TeV *pp* colliders: Capability to address "structural issues" (electroweak symmetry breaking mechanism, naturalness) and provide direct exploration of the "energy frontier" (WIMP, ??). *HZ* and *H* self-coupling precise measurement.

  Ex: SppC, FCC-hh. Many big technological challenges.

  $\rightarrow$ can in principle also be configurable for AA and pA mode (versatility)

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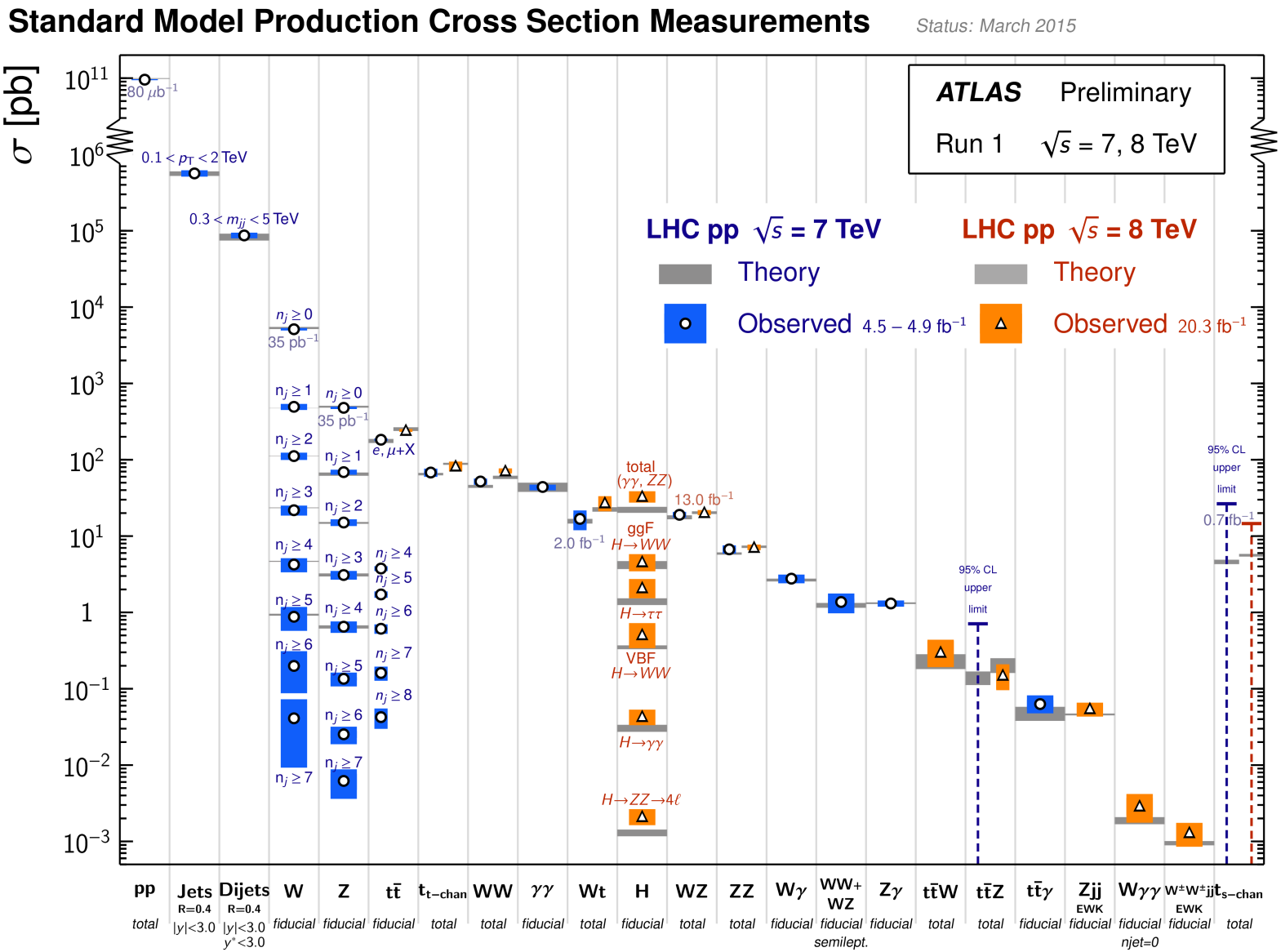
Conclusion

- Many other interesting topics not covered in the talk (including my talk in the top/EW parralel session at EPS on $\gamma\gamma\gamma\gamma$ anomalous couplings)
- The LHC provided us with no clear signs of new physics during run 1, maybe some hints (di-boson resonances, *B* physics, ?)
- The LHC restarted well at 13 TeV, with benefits from run 1 experience $\rightarrow$ a new energy frontier has been reached! Bunch of new results expected for the end of the year (= very soon).
- Many theoretical developments for the LHC run 2 : NLO, NNLO calculations, but also resummation techniques (*WW*), jet substructure studies (boosted topologies).
- Strong improvements in Lattice QCD : CP violation predictions with uncertainties under control for the first time. Others expected in the coming years (B-physics and CP observables, hadronic cross sections at low mass, ...).
- Some unexpected phenomenon in the non-perturbative domain : correlations on charged-particles at high multiplicity, unexpected pentaquark states, ...

  pp inelastic cross section at small $|t|$ also
  (not mentioned during the talk)

Overview of the (unbroken) Standard Model



Summer conferences' summary : news from collider experiments

Back-up

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