Résumé des Rencontres de Moriond 2018

http://moriond.in2p3.fr

S. Loucatos
DPhP-Irfu et APC

The 53rd **Rencontres de Moriond** session devoted to **ELECTROWEAK INTERACTIONS AND UNIFIED THEORIES** were held in La Thuile from **Saturday March 10th to Saturday March 17th, 2018**.
La Thuile is a pleasant winter sport resort located in the Italian Alps, at 1450 m alt., about 120 km from Geneva. Conference founded in 1966 by Jean Tran Thanh Van.

Meribel 1974

Organisateurs CEA:
E. Armengaud,
S. Loucatos
D. Denegri
L. Schoeffel
JM Le Goff
F. Vernizzi

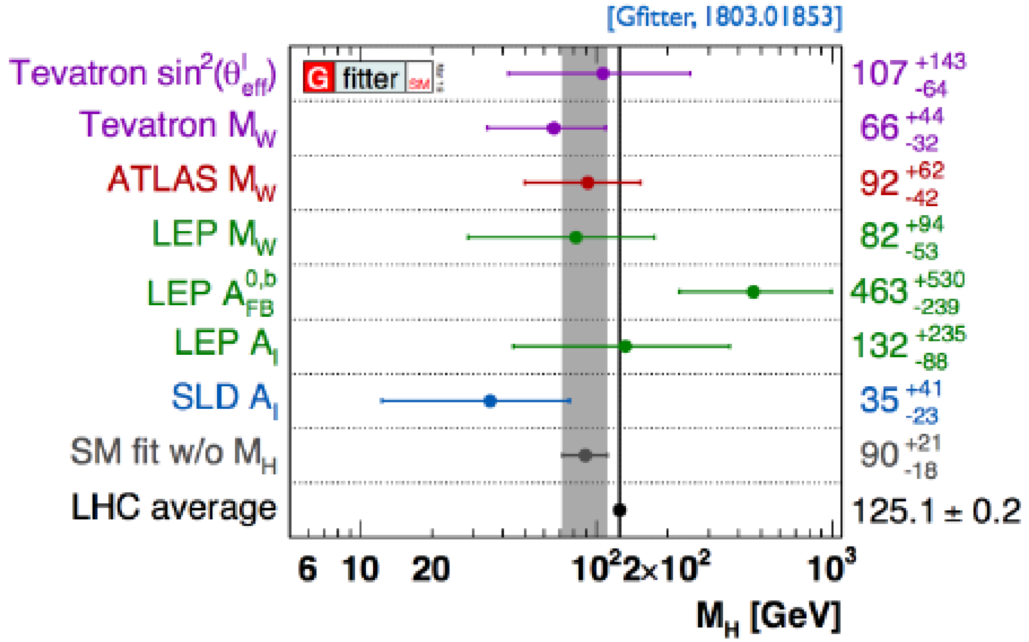
EW experimental summary
Augusto Ceccucci CERN

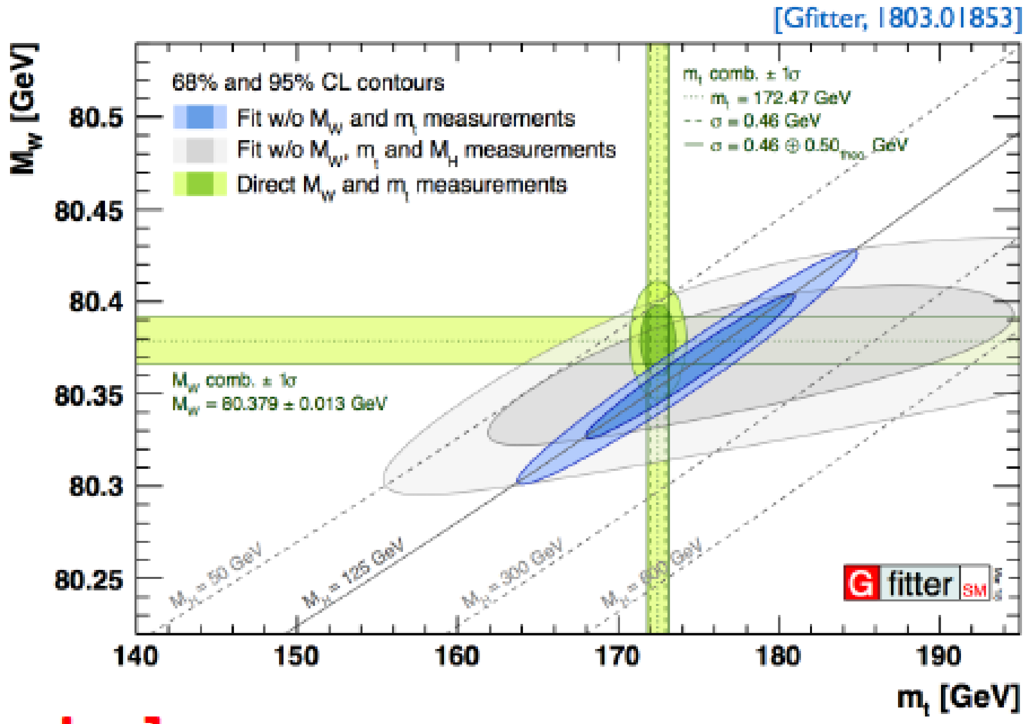
- There is a lot more than “just” EW
- Spanning from B physics to gravitational waves…
- From precision EW tests to exploratory searches of dark photons
- Searching new particles from the 10^{-22} eV scale to the LHC and highest energy cosmic rays
- Tools and techniques

  - EW theory summary JoAnne Hewett SLAC
  - QCD summaries Tulika Bose (Exp - Boston),
    Gudrun Heinrich (Th - Munich)

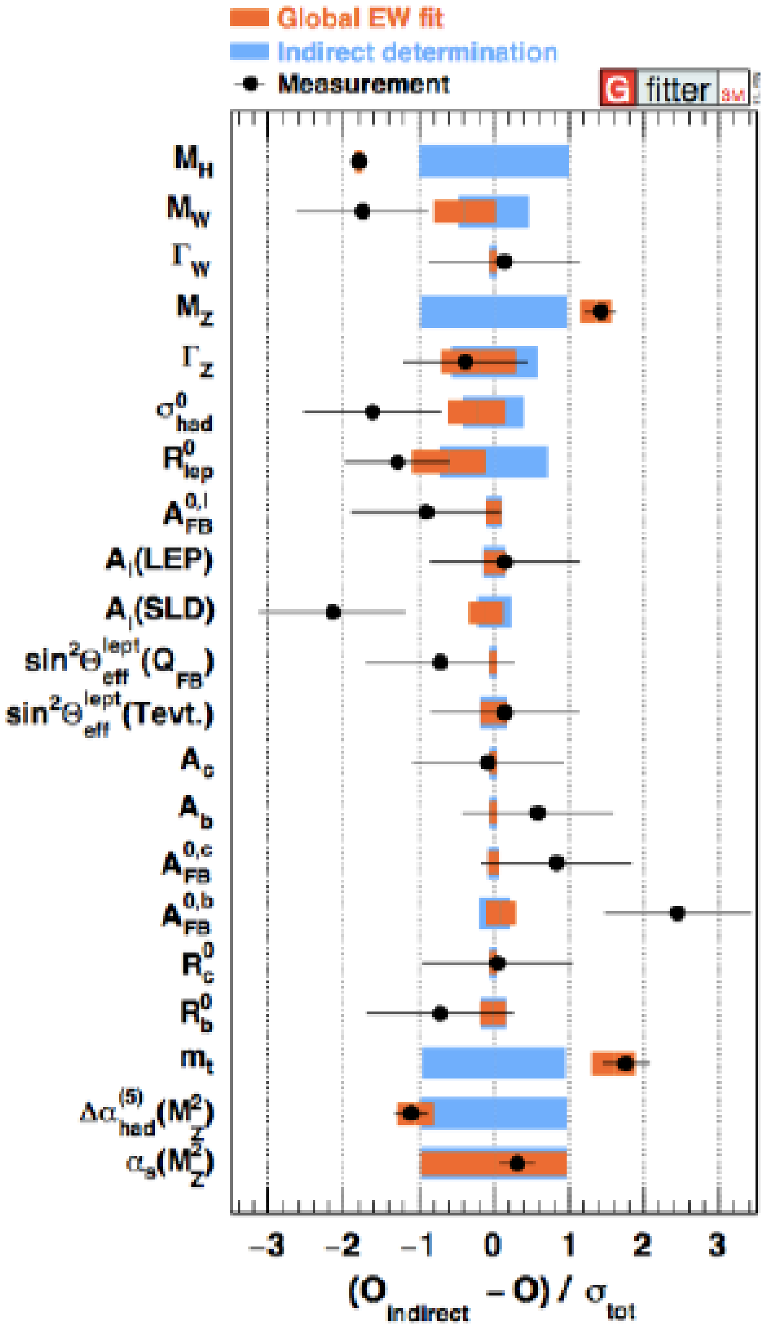
Standard Model measurements

SM FIT: "Incredibly Healthy"





[Kogler]



- Latest global EW fit
- Agreement with SM continues as measurements improve
- Tension between A^l_{FB}, A_l(LEP & SLD), A_b(SLD) & A^b_{FB} remains…

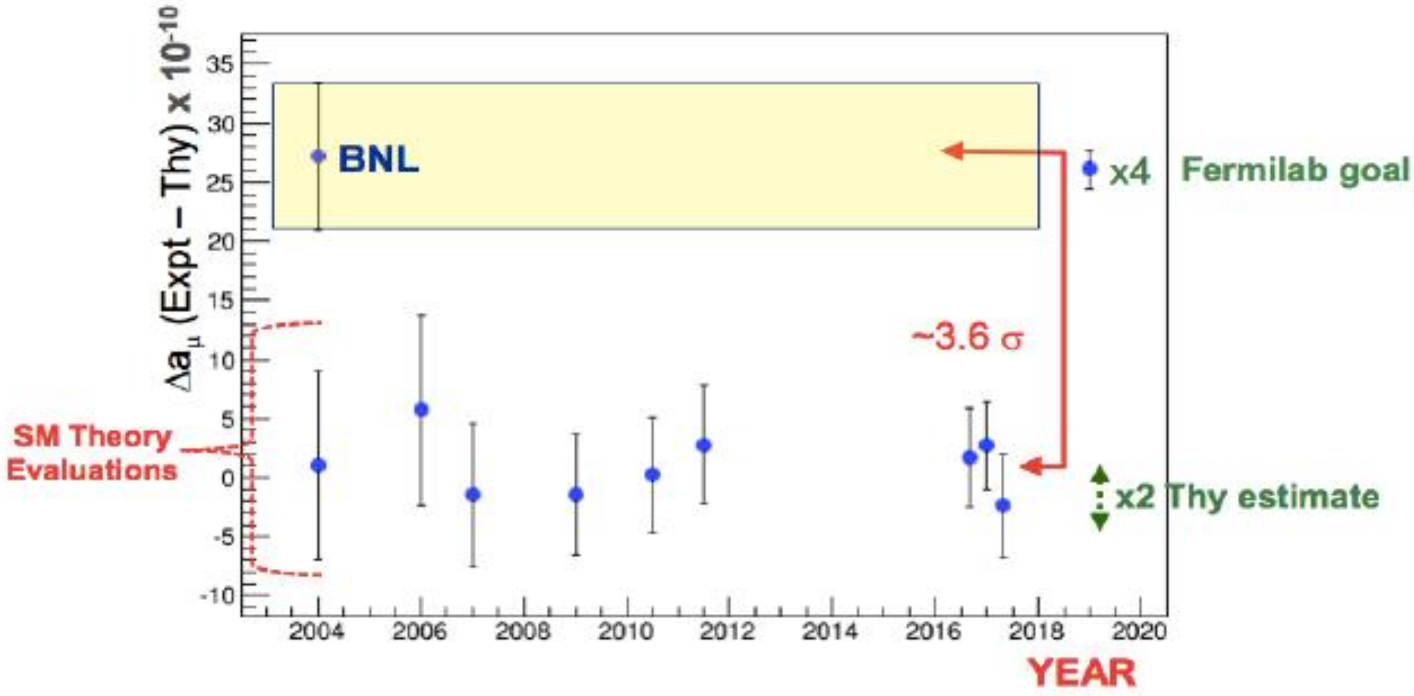
Gfitter 1803.01853

Hewett

Anomalous magnetic moment of the muon

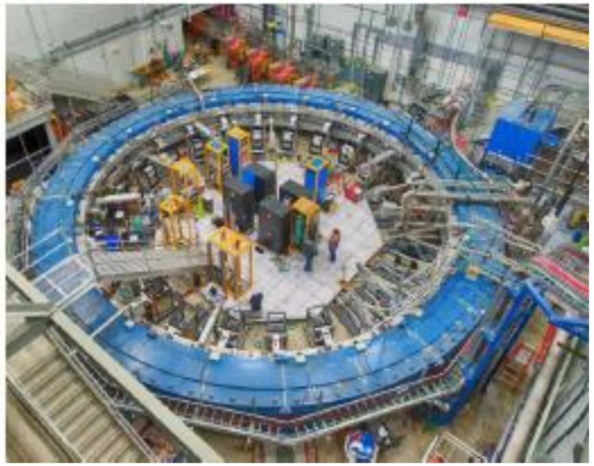
Long-standing discrepancy with the SM

a = (g-2)/2



a_μ is now measured to 540 ppb; Goal is 140 ppb

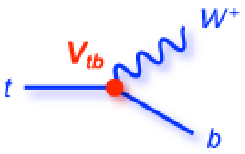
FNAL exp't in commissioning phase



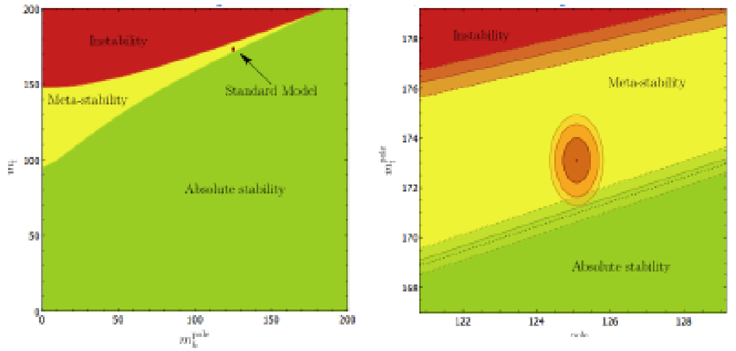
Top physics

Why do we care about precision in top quark physics ?

- the top quark is special
  - this is the only quark with natural mass:
    - $y_t \approx 1$, strongly interacts with the Higgs sector
  - this is the only quark that decays before hadronizing and before spin-flipping
  - this is the only quark that drastically affects the stability of the Higgs mass
    - naturalness argument: BSM top partners should be light



Andreassen, Frost, Schwartz, arXiv:1707.08124



- Need for precision in the top quark sector
  - background to BSM search: $t\bar{t}$ spectrum, top pt, $t\bar{t}$ + MET (dark matter search), single top ...
  - deviation from predictions: indirect detection of new particles, anomalous couplings, ...

$$\tau_{SM} = \left(\frac{\Gamma}{V}\right)^{-1/4} = 10^{139^{+102}_{-51}} \text{ years}$$

$\Delta m_t < 250$ MeV to rule out absolute stability

arXiv:1802.07237

Interpreting top-quark LHC measurements in the standard-model effective field theory

J. A. Aguilar Saavedra,[1] C. Degrande,[2] G. Durieux,[3] F. Maltoni,[4] E. Vryonidou,[2] C. Zhang[5] (editors), D. Barducci,[6] I. Brivio,[7] V. Cirigliano,[8] W. Dekens,[8,9] J. de Vries,[10] C. Englert,[11] M. Fabbrichesi,[12] C. Grojean,[3,13] U. Haisch,[2,14] Y. Jiang,[7] J. Kamenik,[15,16] M. Mangano,[2] D. Marzocca,[12] E. Mereghetti,[8] K. Mimasu,[4] L. Moore,[4] G. Perez,[17] T. Plehn,[18] F. Riva,[2] M. Russell,[18] J. Santiago,[19] M. Schulze,[13] Y. Soreq,[20] A. Tonero,[21] M. Trott,[7] S. Westhoff,[18] C. White,[22] A. Wulzer,[2,23,24] J. Zupan.[25]

- $t\bar{t}$ differential cross section
  - latest theoretical predictions
  - the top pt saga
  - improving the modelling
- top quark mass
  - latest discussions on the mass definition and on the theoretical uncertainties
- top quark couplings
  - the Effective Field Theory (EFT) approach

Deliot

Top mass@LHC / Tevatron

Direct: templates/ideograms Indirect: cross section, m^{top}_{pole}

Method	Channel	ATLAS (GeV) (stat/syst/th)	CMS (GeV) (stat/syst/th)
Direct	Lepton+Jets	172.08 +/- 0.39 +/- 0.82	172.25 +/- 0.08 +/- 0.62
Direct	Di-lepton	172.99 +/- 0.41 +/- 0.94	172.22 +/- 0.18 $^{+0.89}_{-0.93}$
Direct	Full Hadronic	173.72 +/- 0.55 +/- 1.01	172.32 +/- 0.25 +/- 0.59
Indirect	tt + 1 jet	173.7 +/- 1.5 +/- 1.4 $^{+1.0}_{-0.5}$	169.1 +/- 1.1 $^{+2.5}_{-3.1}$ $^{+3.6}_{-1.6}$
Indirect	Lepton+Jets		170.6 +/- 2.7
Indirect	Di-lepton	173.2 +/- 0.9 +/- 0.8 +/- 1.2	
Average		172.51 +/- 0.50	172.44 +/- 0.13 +/- 0.47*

Table compiled from the talk of **Menke** (LHC) *CMS Legacy

Method	Tevatron Combinations
Template / matrix element	174.98 +/-0.58 +/- 0.49
Cross Section	169.1 +/- 2.5

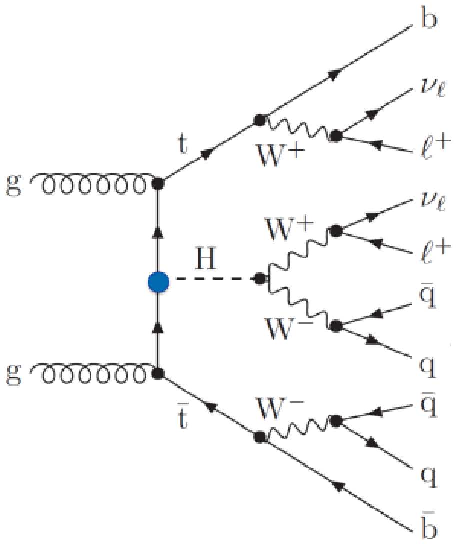
Combinations from the talk of **Brandt**

The BEH(iggs) News

- Measurement of the ttH coupling at ATLAS **[Zanzi]** and CMS **[Peruzzi]** → Run2 36 fb^{-1}
- Associate production of H → bb and H → cc with W and Z in ATLAS **[Nielsen]**
- Higgs Rare decays **[Marini]**
- Higgs masses and couplings **[Sperka]**
- Diboson final states **[Nomidis]**
- Search for HH production **[Kagan]**

Measurement of ttH couplings

- Top Yukawa coupling (**$y_t \simeq \sqrt{2}m_{top}/v \simeq 1$**), the coupling between the two heaviest known particles, is a key parameter of the SM
- Irreducible backgrounds from ttV and di-boson final states
- Reducible background from tt

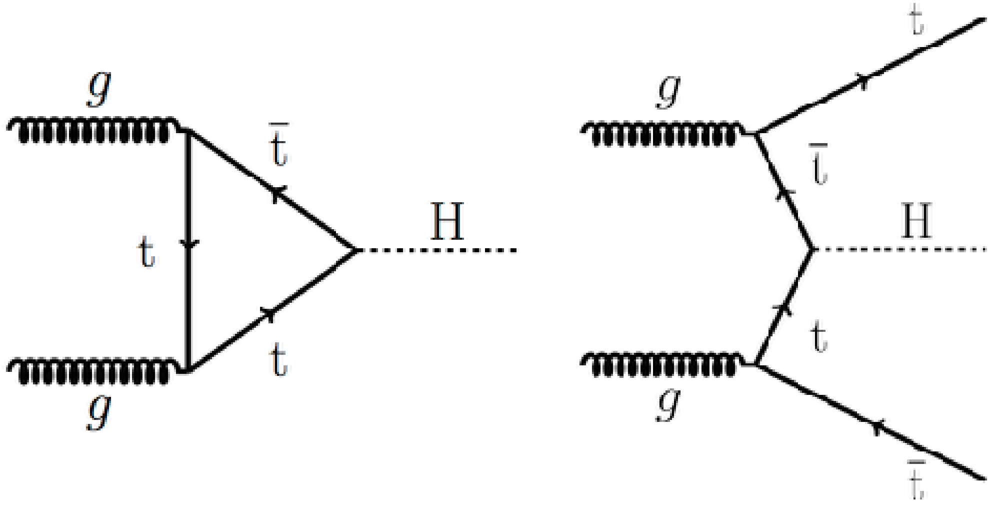


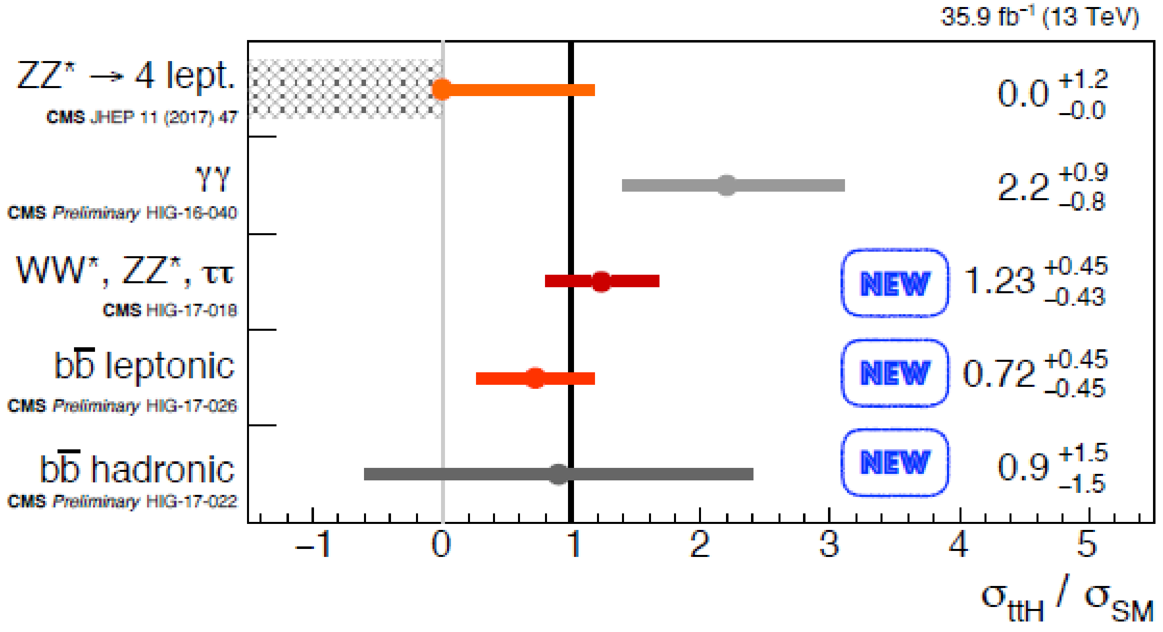
[Zanzi] ## *ttH* Combination

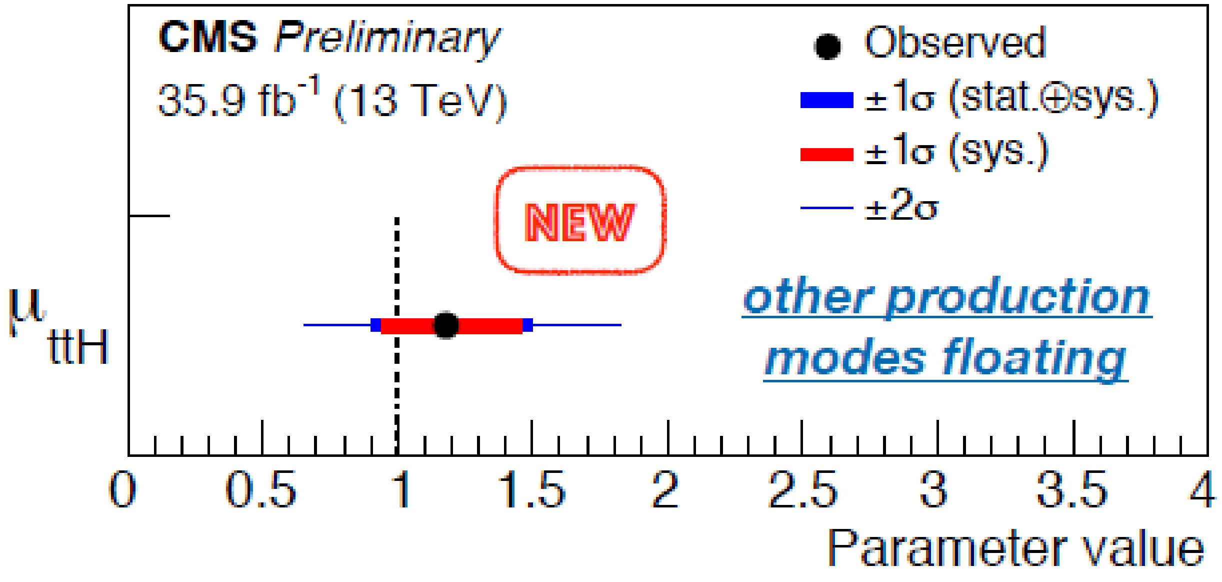
- Combination of *ttH(→bb)*, *ttH*→multilepton and *ttH*-enhanced categories in *H*→$\gamma\gamma$ [1802.04146] and *H*→*ZZ**→*4l* [1712.02304]
- Assumptions:
  - *tHqb*, *WtH* and other non-*ttH* processes treated as backgrounds and fixed to SM predictions
  - Higgs decay BR as in SM
- **Evidence for *ttH* production at 4.2σ (exp 3.8σ)**
- **Best-fit μ_{ttH}=1.17±0.19(stat)$^{+0.27}_{-0.23}$(syst)**

ttH in CMS Peruzzi

Analyse ttH avec H->bb présentée pour la première fois à Moriond et nouvelle combinaison CMS



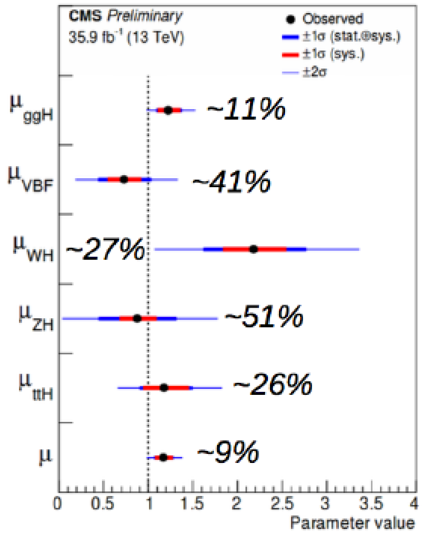




BEH mass and couplings in CMS and ATLAS

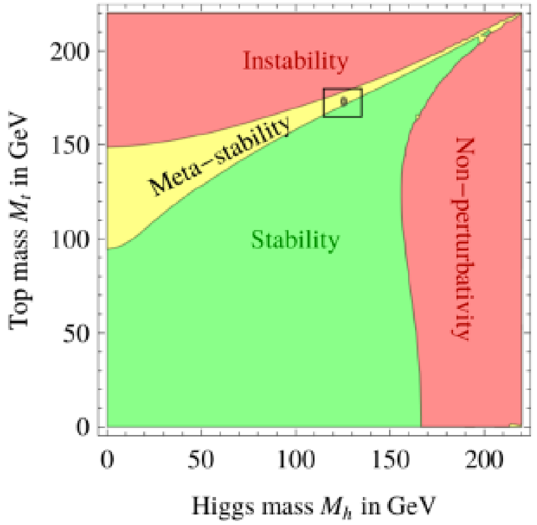
[Sperka]

- **Precision Higgs measurements are truly starting to put the SM (and BSM) to the test**
- **First combined 13 TeV results shown, surpassing Run 1 precision in key measurements, e.g. ggH**
- **With more data, should be able to see the deviations predicted by many BSM models**



$$m_{\mathrm{H}} = 125.26 \pm 0.21\ (\pm 0.20\ \mathrm{stat.} \pm 0.08\ \mathrm{sys.})\ \mathrm{GeV}$$ **CMS**

$$m_{\mathrm{H}} = 124.98 \pm 0.28\ (\pm 0.19\ \mathrm{stat.} \pm 0.21\ \mathrm{sys.})\ \mathrm{GeV}$$ **ATLAS**



Multiverse statistics:
Giudice https://www.youtube.com/watch?v=b8z6HfSq7l8

Wrap-up of “The BEH news”

- Remarkable progress on ttH, evidence of the signal with SM strength is building up. Nice to see so many results based on Run2 (full 2016 statistics)
- Advancing in a steady way to see H(bb) and H(cc) in W/ ZH associated production
- Tantalizing close to H→$\mu\mu$; H→ invisible being pinned down
- The combinations of the H couplings are improving rapidly; the H mass is in good shape
- The sensitivity to HH production is “only” a factor 20xSM away and fast improving

BSM searches (SUSY & Exotics)

- One CMS result based on full 2016+2017 data set: Z’
- Largest deviation from background only 3.6 sigma local (2.2 global)
- ATLAS BSM scalar
- Most analyses will remain statistically limited for a long time
- Jet substructure becomes important
- Interest to fit broad resonances fits in addition to narrow ones
- Moving towards lower energy SUSY searches (has something escaped?)
- Introduce some amount of RPV to extend and reinterpret SUSY searches

Théorie

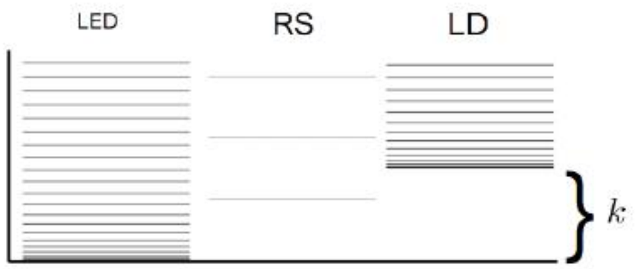
Example: new models - clockwork theories

Linear Dilaton: extra dimension lies between ADD and RS

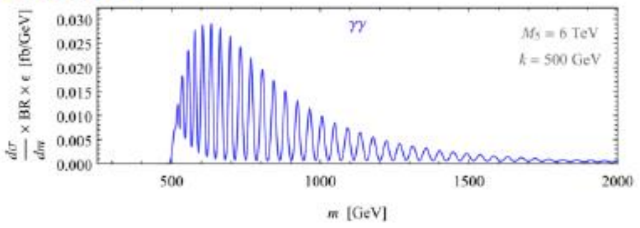
novel LHC phenomenology that provides an interesting benchmark!

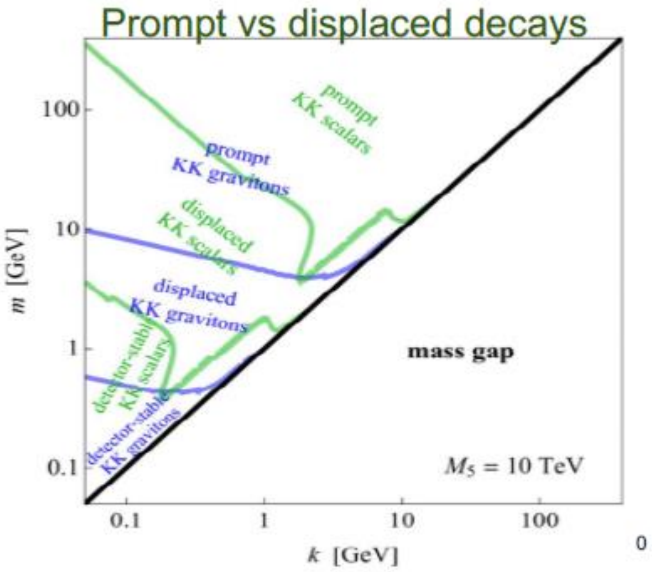
Giudice etal, 1711.08437

KK gravitons have cascade and displaced decays



a forest of resonances





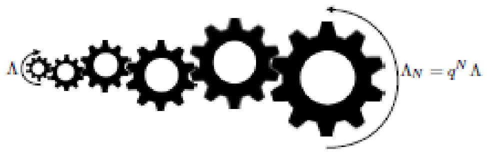


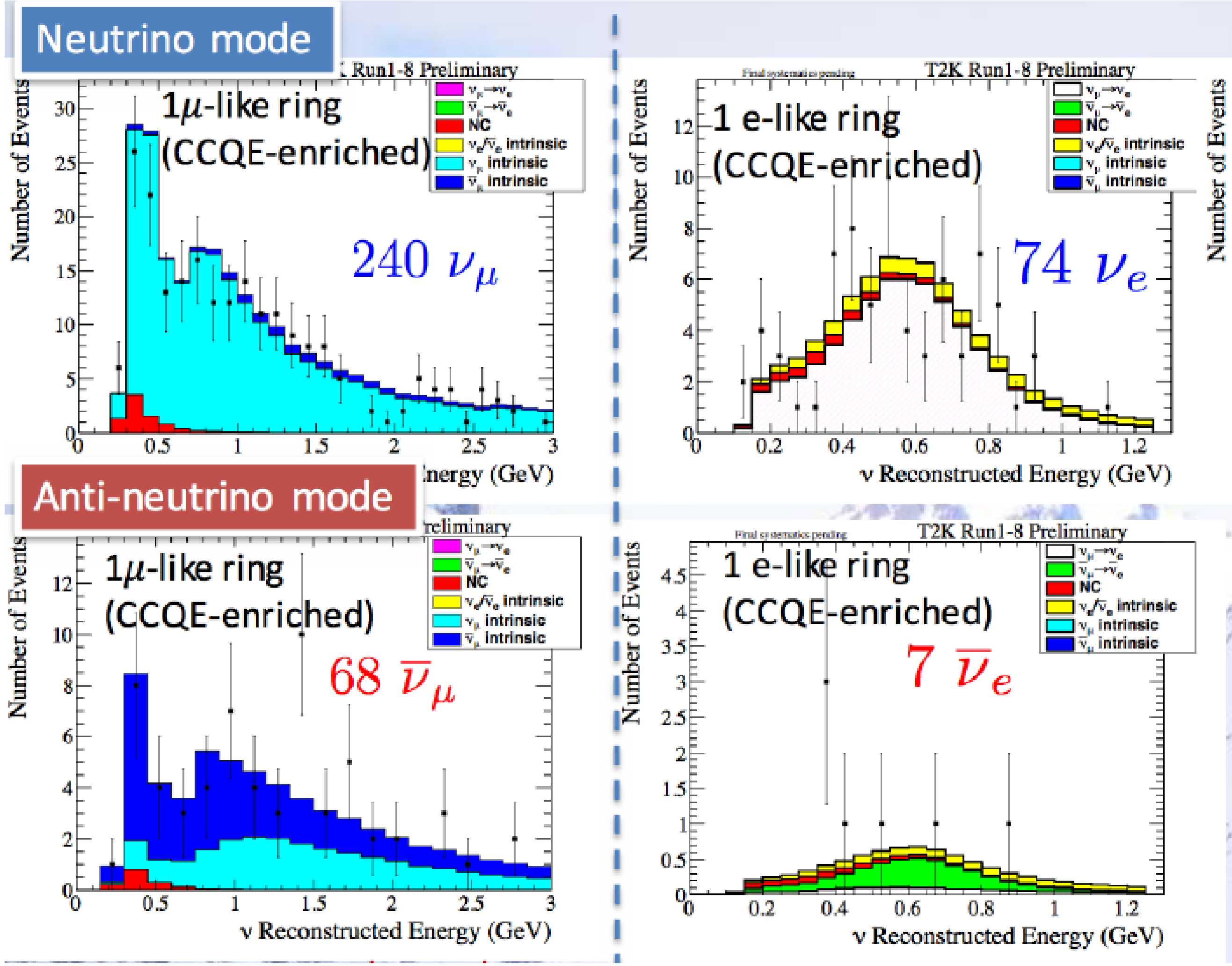
Figure 1. A schematic representation of the clockwork mechanism increasing the interaction scale of a non-renormalisable operator.

Giudice McCullough JHEP02(2017)036

Neutrinos

- T2K **[Cao]**
- NovA **[Backhouse]**
- CC from Monoenergetic Muon neutrinos **[Spitz]**
- Measurement of CEvNS by COHERENT **[Rich]**
- HNL from Kaon decays **[Parkinson]**
- Daya Bay **[Ling]**
- STEREO **[Lhuillier]**
- IceCube **[Larson]**
- Antares **[Bruijn]**
- HNL in CMS and future efforts **[Negro]**

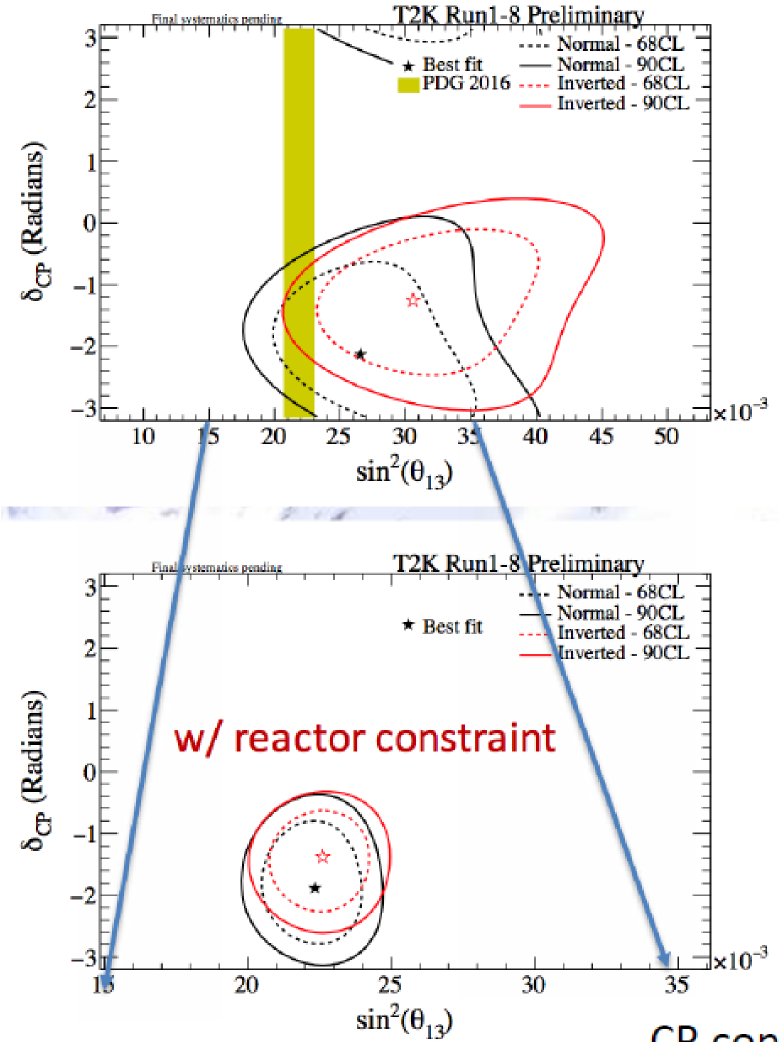
T2K: ν_e appearance latest Data

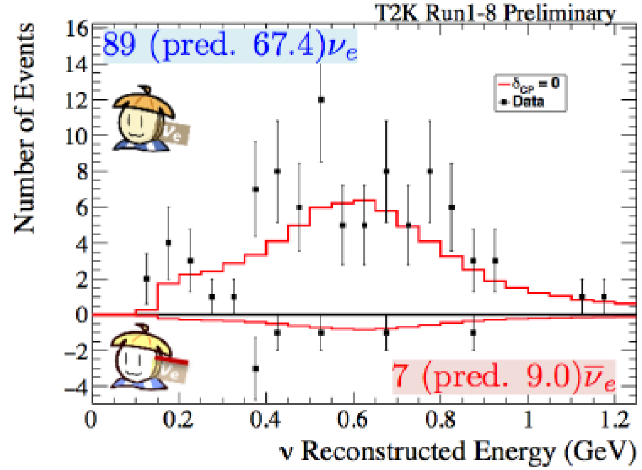


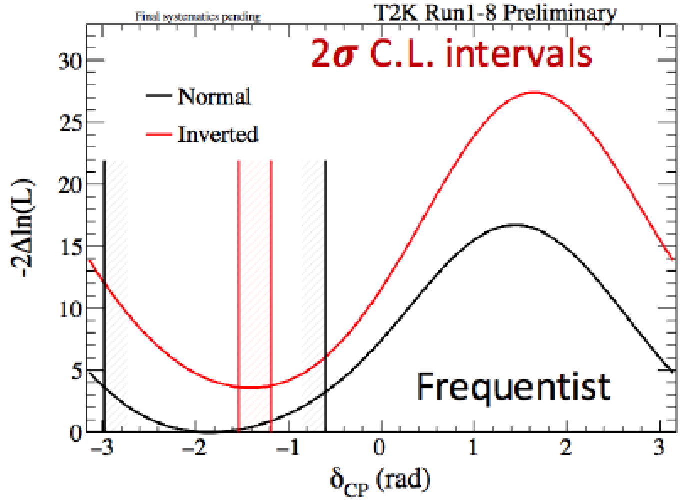
No CC1π in anti-neutrino mode due to π^- absorption

[Cao] Run 1-8

T2K δ_{CP}





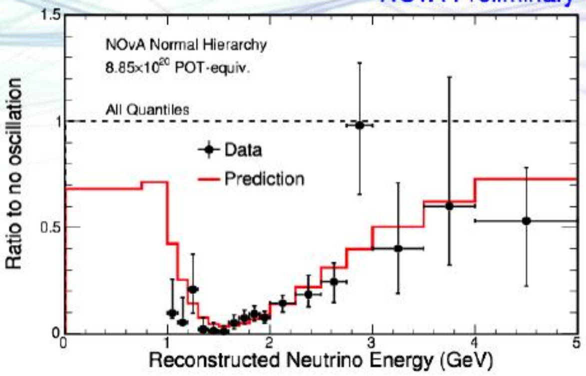


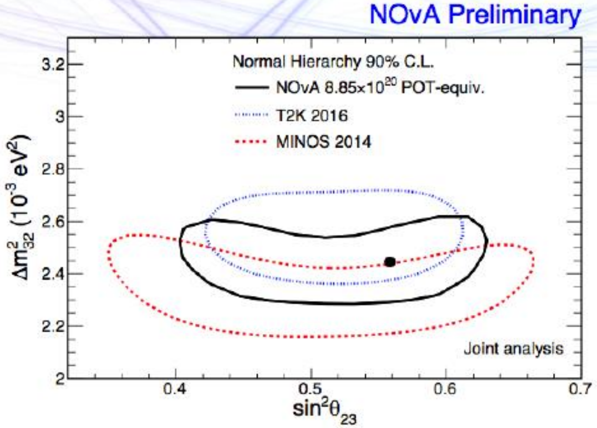
[Cao]

CP conserving values $(0, \pi)$ fall outside of the 2σ C.L. confidence/credible interval

NOvA

ν_μ disappearance results



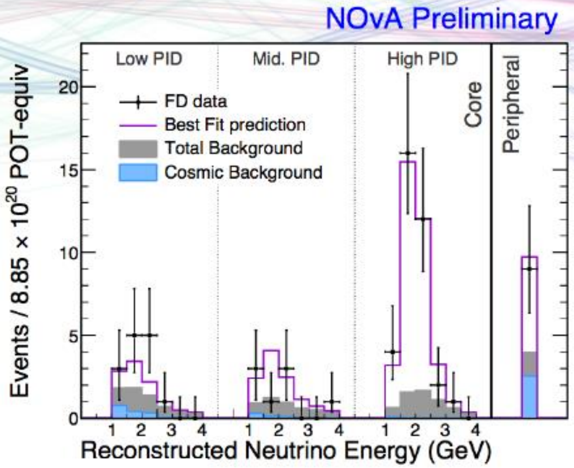


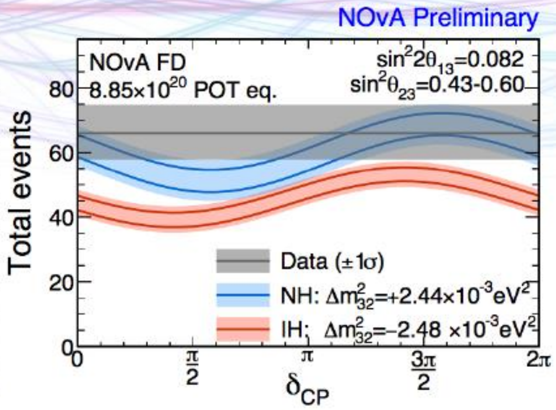
- Expect 763 FD ν_μ CC events with no oscillation
- Observe 126 (inc. 3.4 beam bkg. and 5.8 cosmic)

[Backhouse]

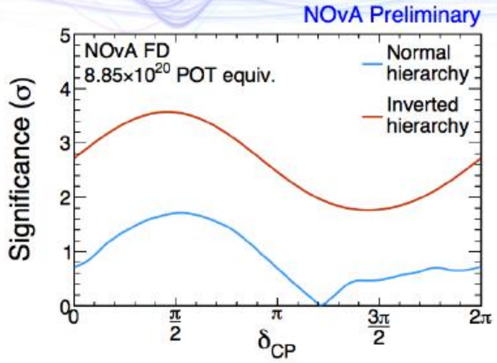
$$\Delta m^2_{32} = (2.44 \pm 0.08) \times 10^{-3}\text{eV}^2 \text{ (NH)}$$
$$\sin^2\theta_{23} = 0.56^{+0.04}_{-0.03} \quad \text{or} \quad 0.48^{+0.04}_{-0.04}$$

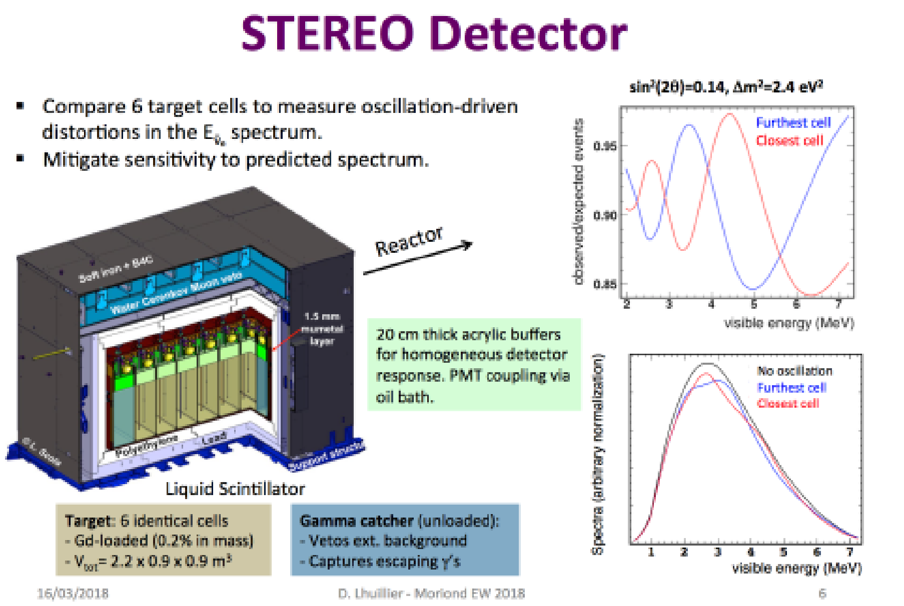
ν_e appearance results

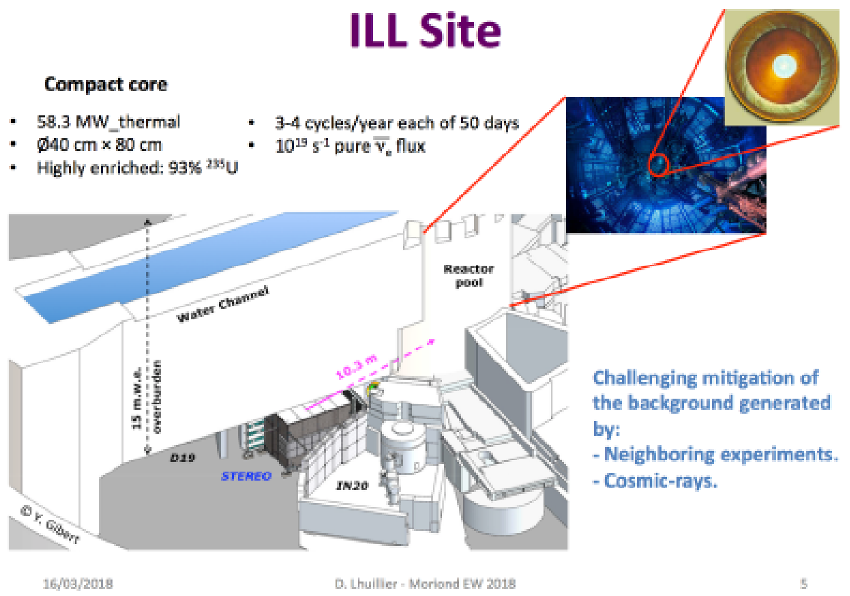


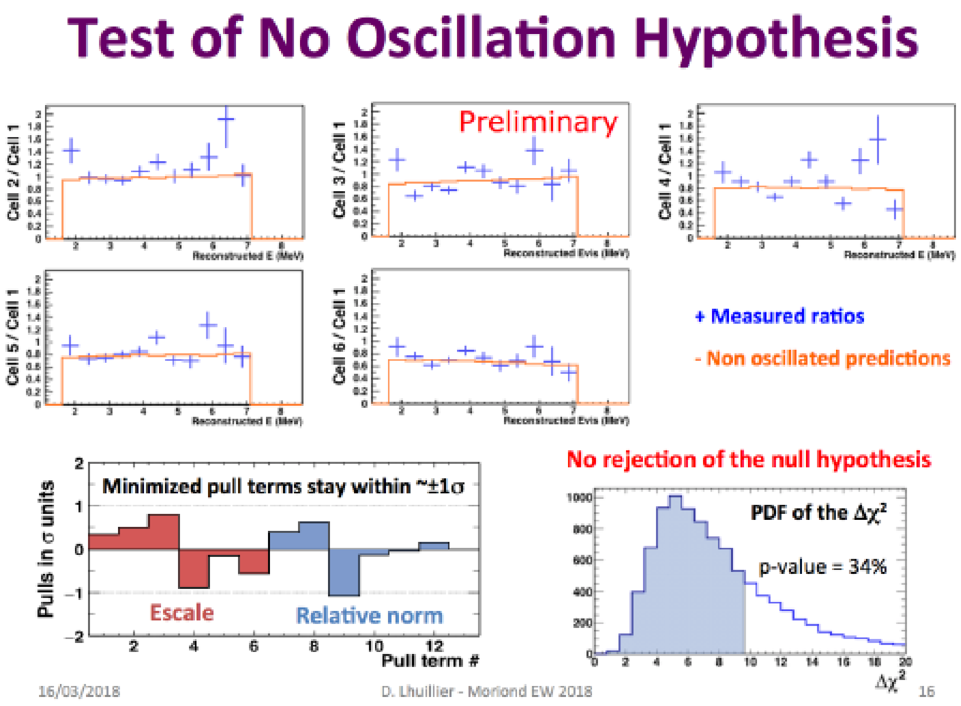


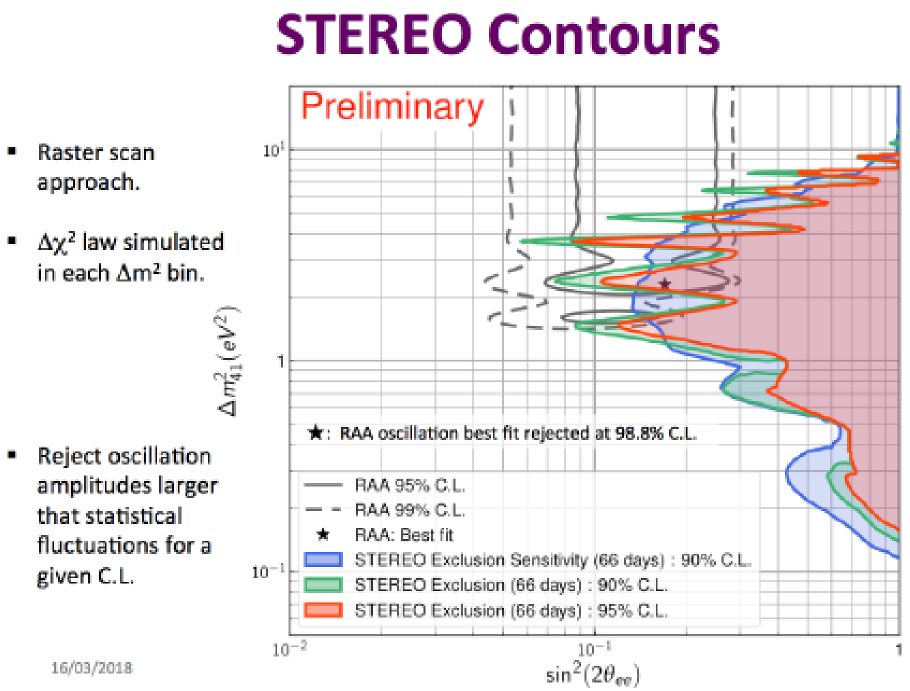
- Joint fit from ν_μ and ν_e spectra
- Constrain θ_{13} to reactor avg. $\sin^2 2\theta_{13} = 0.082 \pm 0.005$
- Prefer NH and (weakly) $\delta_{CP} \sim 3\pi/2$
- IH disfavoured at 2σ level











Lhuillier

Irfu-DPhN

MINOS/MINOS+

Limite ν stériles, par disparition de ν_μ, controversée:

Search for sterile neutrinos in MINOS and MINOS+ using a two-detector fit arXiv:1710.06488

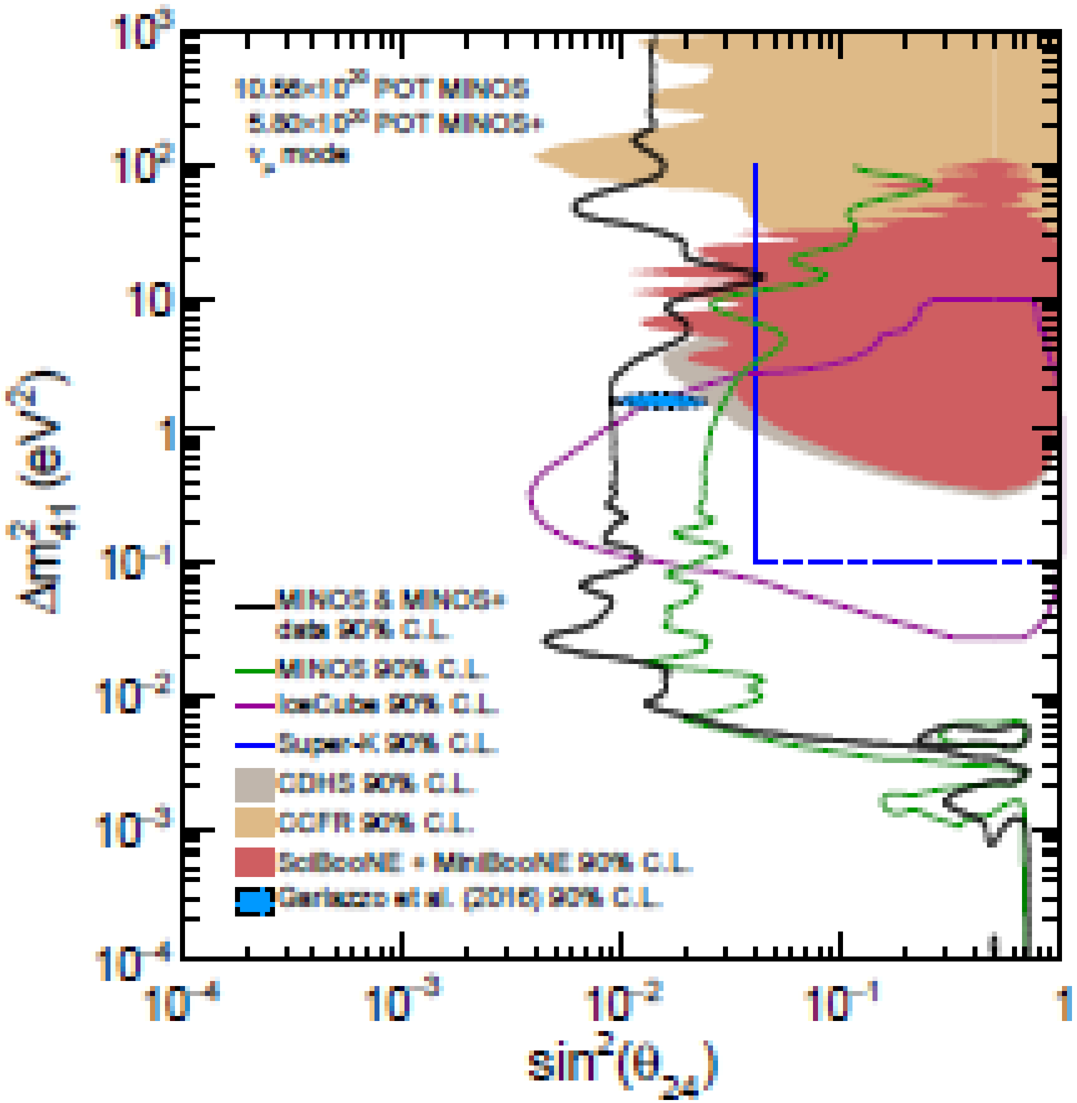
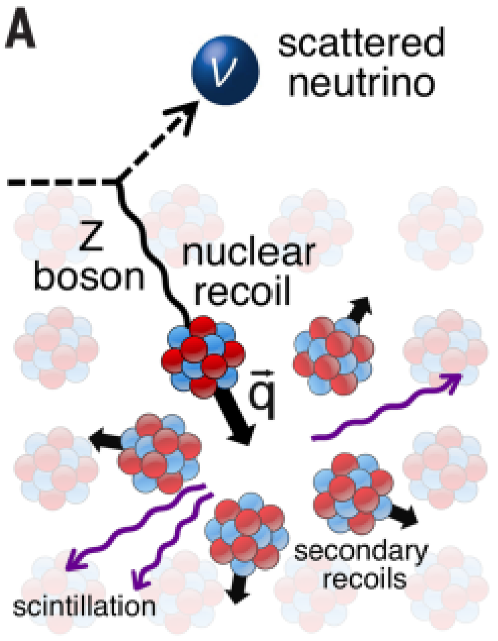


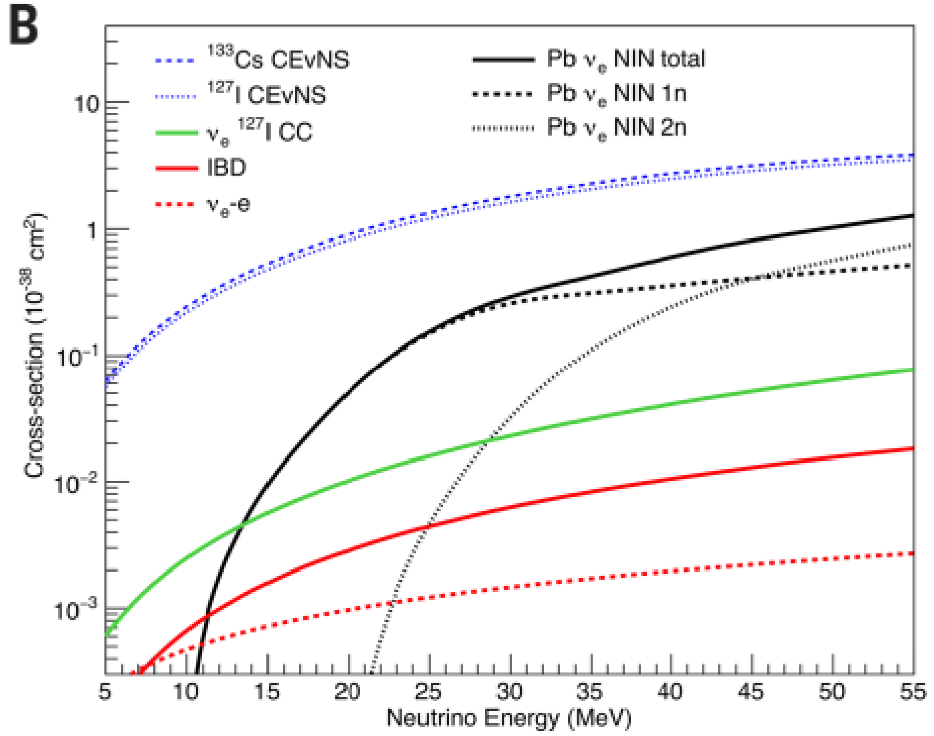
Figure 4. The MINOS and MINOS+ 90% exclusion limit compared to the previous MINOS result [17] and results from other experiments [20, 35–38]. The Gariazzo et al. region is the result of a global fit to neutrino oscillation data [39].

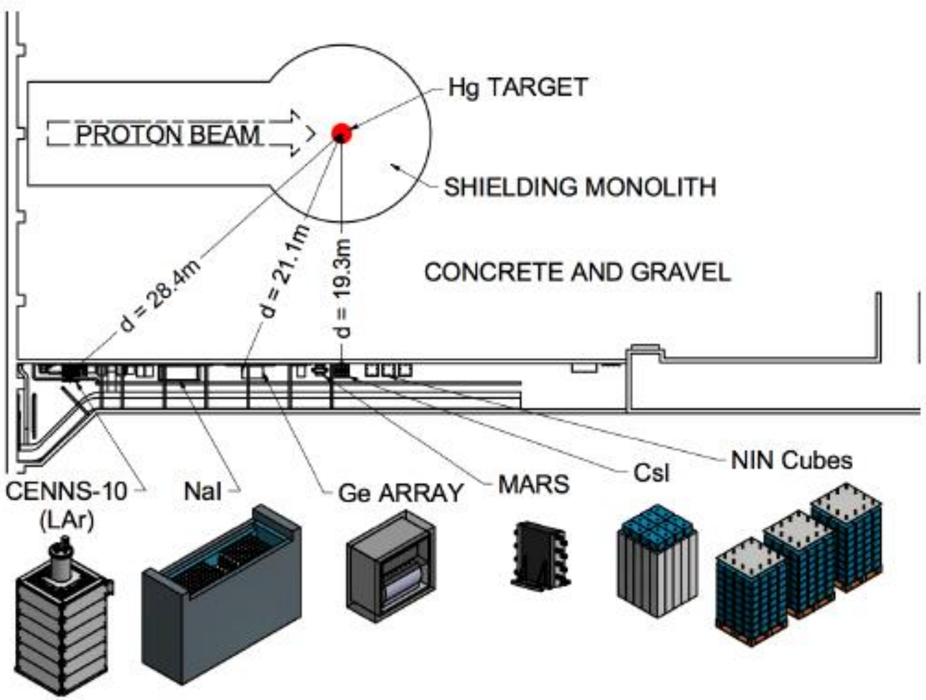
- MiniBooNE has continued running as MicroBooNE took data and now has a signal which is just, just shy of 5sigma, agrees much better with LSND (the extra statistics filled in a region that was giving disagreement) and is above 6sigma when combined with LSND.

Observation of coherent elastic neutrino-nucleus scattering D. Akimov *et al.*, *Science* 10.1126/science.aao0990 (2017).

[Rich]

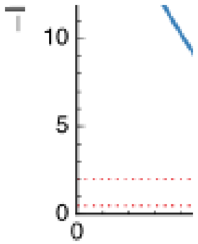


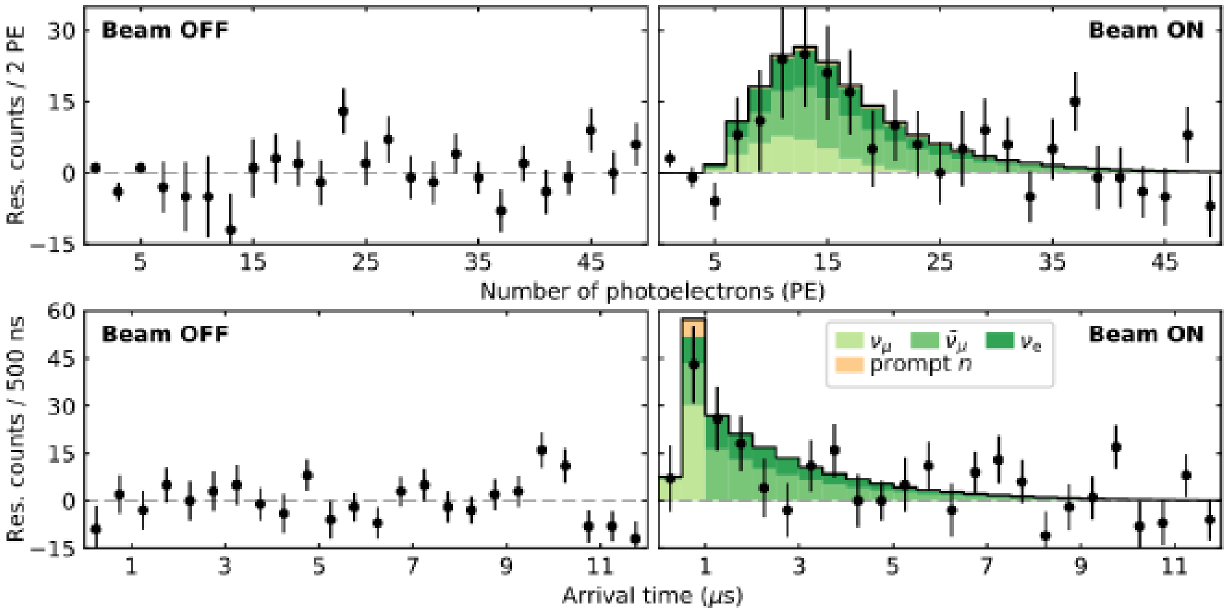




$$\sigma \sim N_n^2$$

- 134 ± 22 counts
- 77% ± 16% of the SM prediction of 173 ± 48
- Null hypothesis disfavored at 6.7σ level relative to best-fit number of counts





Coherent CEvNS interest:

searches for sterile neutrinos, a neutrino magnetic moment, non-standard interactions mediated by new particles, probes of nuclear structure, and improved constraints on the value of the weak nuclear charge.

The reduction in neutrino detector mass may lead to a number of technological applications, such as non-intrusive nuclear reactor monitoring.

CEvNS is also expected to dominate neutrino transport in neutron stars, and during stellar collapse. Direct searches for WIMPs will soon be limited by an irreducible CEvNS background from solar and atmospheric neutrinos.

0ν2β Experiments

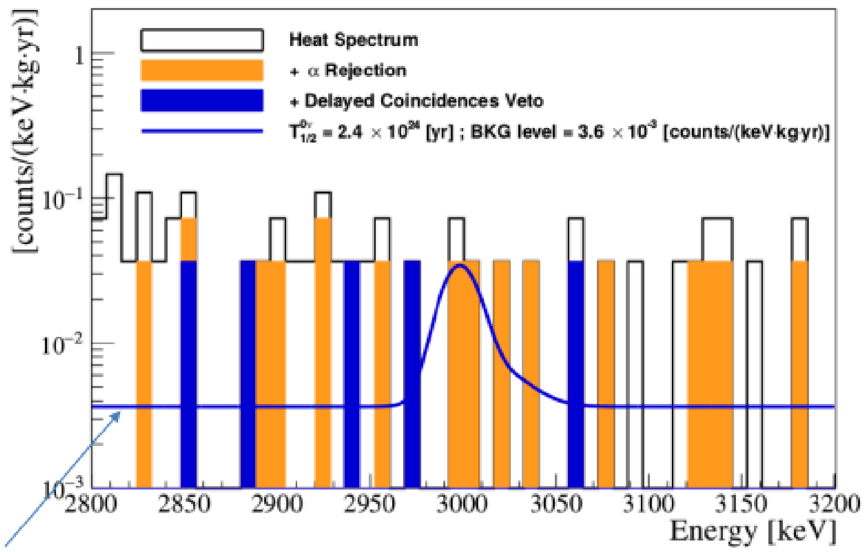
CUPID-0: Cuore Upgrade with Particle IDentification

Testing the nature of the neutrino mass:
Dirac or Majorana?

- EXO-200 LXe TPC **[Der Mesrobian-Kabakian]**
- CUORE Bolometers **[Tomei/Vignati]**
- CUPID Scintillating Bolometers **[Gironi]**

Scintillating bolometers $T^{0\nu}_{1/2} > 2.4 \cdot 10^{24}$ yr (90% C.I.)

$m_{\beta\beta} < 376 - 770\ meV$ ← range due to the nuclear matrix element calculations



fitted spectrum together with a hypothetical signal corresponding to the 90% C.I. limit

BKG level: 3.6 conts/(keV Kg y)

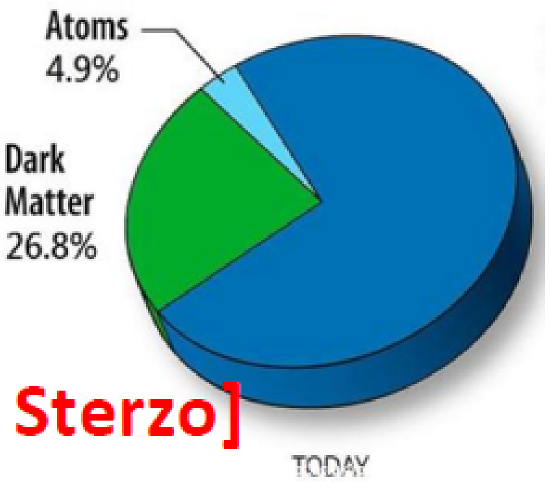
[Gironi]

Previous NEMO limit $T^{0\nu}_{1/2}(^{82}Se) > 3.6 \cdot 10^{23}$ yr (exposure ~3.5 kg · y)

Wrap Up Neutrinos

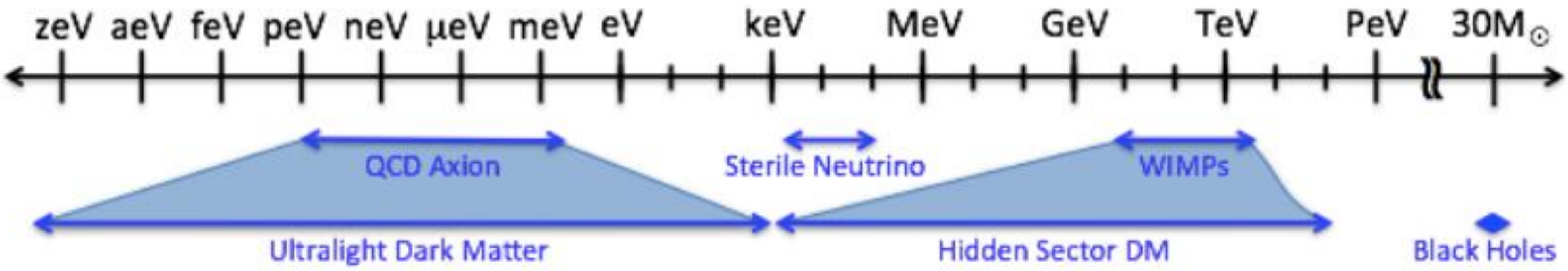
- 2σ exclusions of CP conservation
- IH Disfavoured at 2σ
- 5% deficit in reactor flux, RAA
- Clarification of Sterile Neutrinos required…
- Interesting DAR techniques revival
- CEνNS observed
- HNL (RH neutrinos) searches at accelerators
- 0ν2β Experiments reaching the IH sensitivities

Dark Matter Session



- ATLAS Heavy Mediator Collider **[Lo Sterzo]**
- CMS Heavy Mediator Collider **[Sung]**
- XENON1T LXe TPC **[Coderre]**
- DARKSIDE LAr TPC **[Franco]**
- NEWS-G spherical proportional counter **[Katsioulas]**
- ADMX2 Gen2 RF Cavity **[Wollett]**
- nEDM   **[Ayres]**

Large mass range for DM candidates



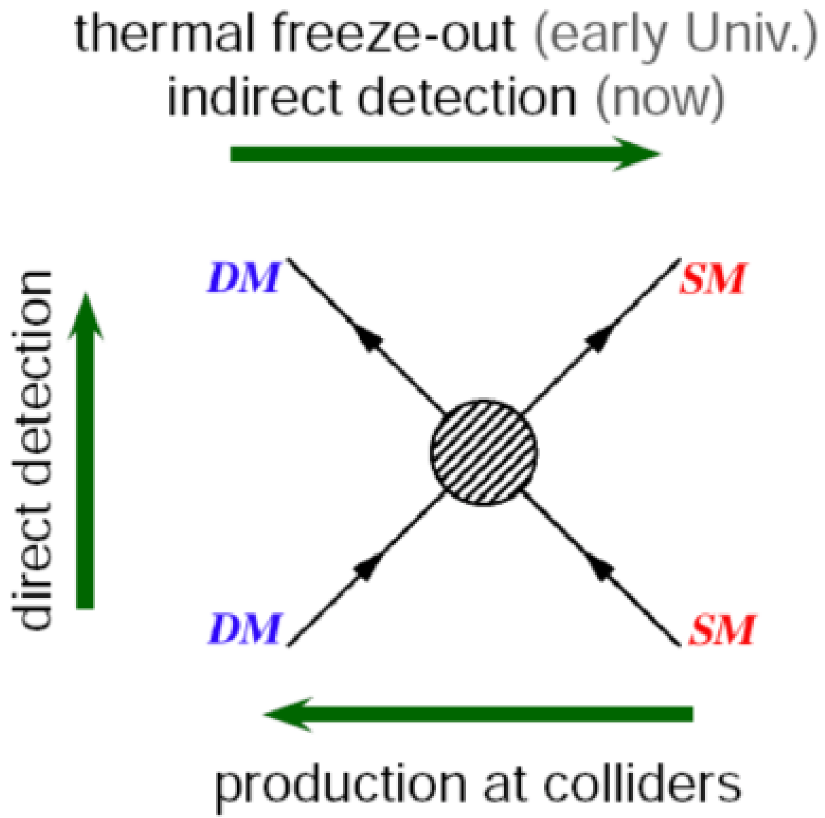
- bosonic DM produced during inflation or high temp phase transition
- DM acts as oscillating classical field

- WIMPs: act through SM forces
- Hidden Sector: act through new force, very weakly coupled to SM
- Thermal contact in early universe

Beyond WIMPS: novel, low-cost, search techniques

Dark Matter Searches (examples)

DAMPE



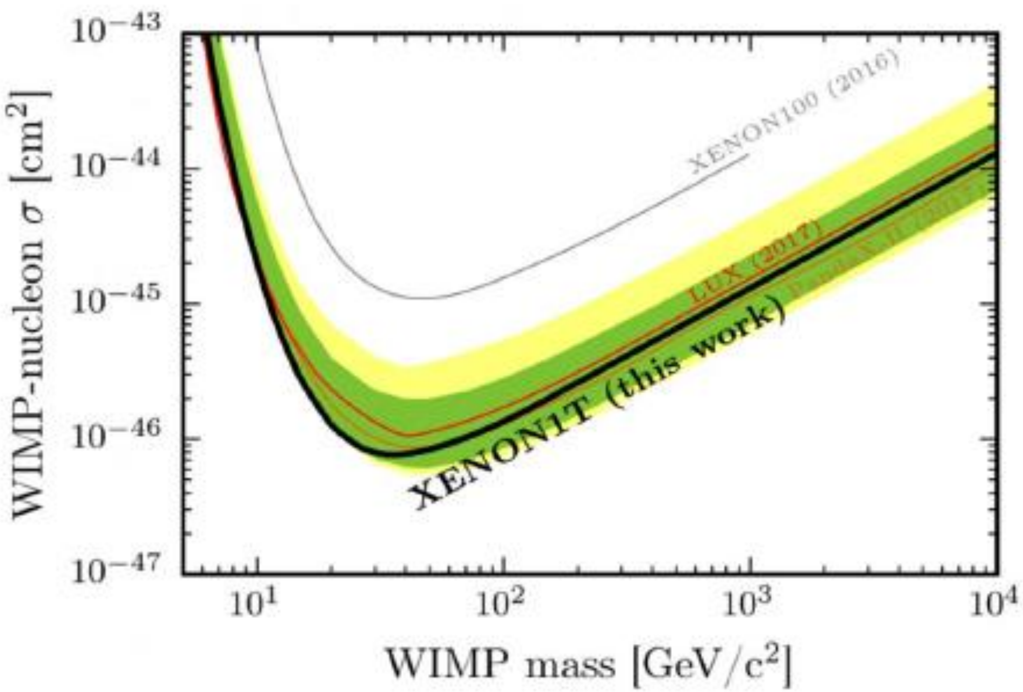
XENON

ATLAS/CMS

XENON 1Ton

[Coderre]

- 34 live days dark matter exposure Oct 2016-Jan2017
- No evidence of a signal → upper limit
- Additional 247 live days of data collected to date
    - the rest of this talk



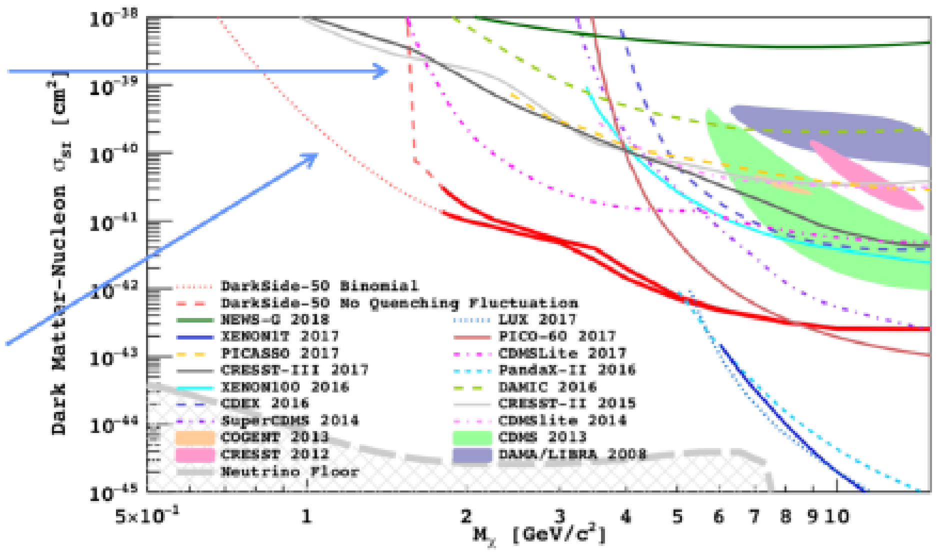
DarkSide

new result
@ low mass

[D. Franco - APC]

Assuming quenching a non-stochastic process

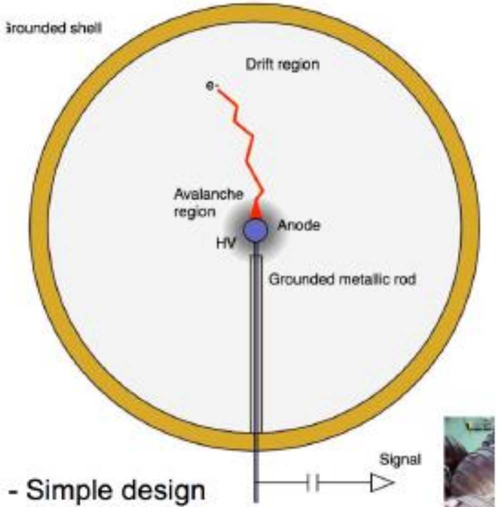
Assuming binomial quenching fluctuations



NEWS-G

[Katsioulas]

Irfu- DEDI



- Simple design
- Single readout

I.Giomataris et al ,JINST,2008, P09007

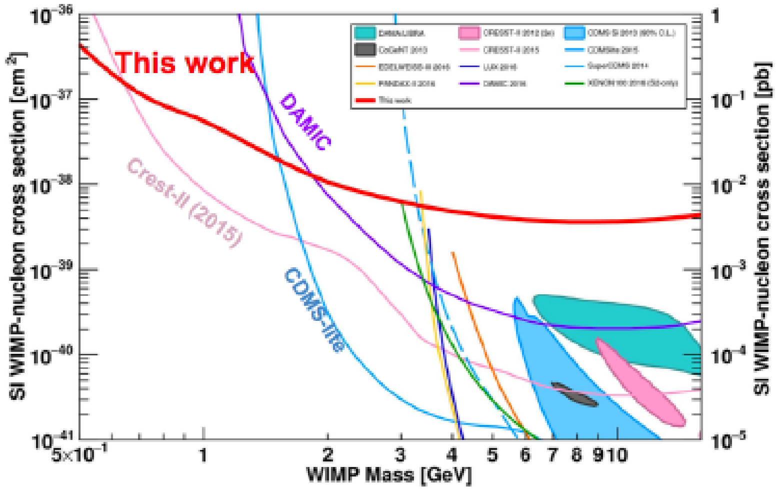
- Lowest surface to volume ratio
- Sustains higher pressure
- Low capacitance → Low noise
- High gain
- Anode Ø 1 mm-6.3 mm)
- Event discrimination
- Fiducialization
- SEDINE detector at **LSM**

Vessel
Ø 60cm copper

Sensor
Ø 6.4mm Si

First results of NEWS-G with SEDINE

NEWS-G collaboration, Astropart. Phys. 97, 54 (2018), doi: 10.1016/j.astropartphys.2017.10.009



Limit set on spin independent WIMP coupling with standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM

Exclusion at 90% confidence level (C.L.) of cross-sections above $4.4\cdot10^{-37}$ cm^2 for a 0.5 GeV/c^2 WIMP

Next detector at SNOLAB

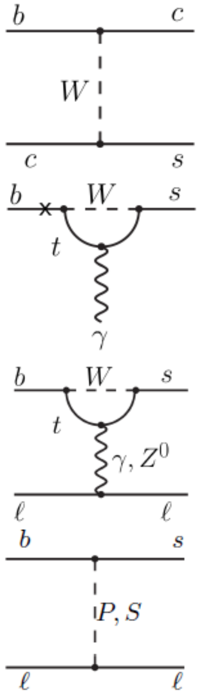
Heavy flavours– b physics

- Rare decays as new physics hunting tools
- $b \to s\ell^+\ell^-$ observables in LHCb, ATLAS and CMS
- Some recent results
- For lepton flavour universality tests: see Christoph Langenbruch talk

How are rare decays sensitive?

EFT and Wilson coefficients

Complex interactions substituted with Fermi-like operators: couplings hide the high energy information



Charged current	$G_F V_{cb} V_{cs}^* C_2 \bar{c}_L \gamma^\mu b_L \bar{s}_L \gamma_\mu c_L$
photon penguin	$\frac{e}{4\pi^2} G_F V_{tb} V_{ts}^* m_b C_7 \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$
EW penguin	$G_F V_{tb} V_{ts}^* C_{9(10)} \bar{s}_L \gamma^\mu b_L \bar{\ell} \gamma_\mu (\gamma_5) \ell$
NP (pseudo)-scalar	$\propto C_{S(P)} \bar{s}_L b_L \bar{\ell} (\gamma_5) \ell$

Plus chirally flipped operators...

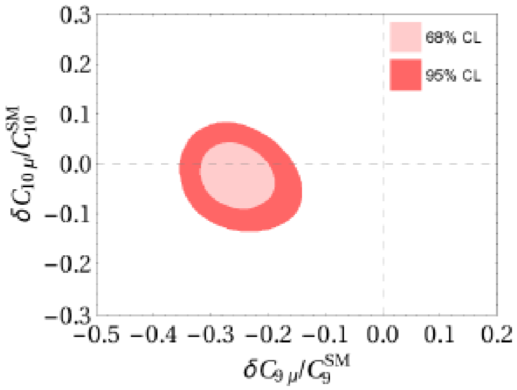
Dettori

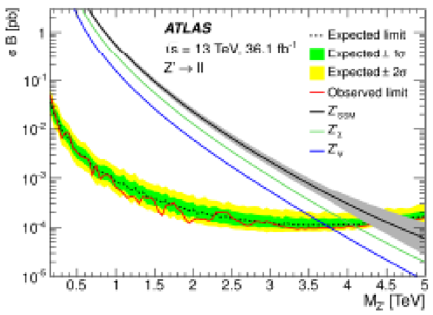
How are rare decays sensitive?

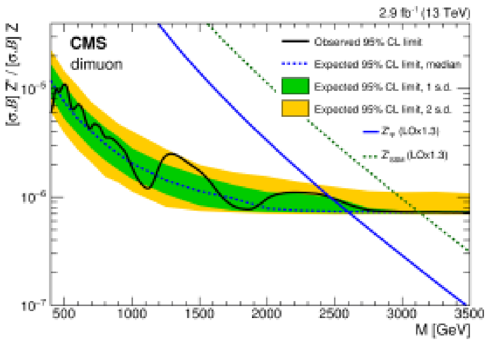
EFT and Wilson coefficients (2)

- New physics interactions can enter through new operators $(S, P, \ldots)$ or modifying the coefficients of SM operators
- If Wilson coefficients are thought of effective couplings with a NP scale: $\sim G_F V_{tb} V_{ts}^* \frac{\alpha}{4\pi} C_9 = \frac{g^2}{\Lambda}$
- Probing scales (masses!) up to hundreds of TeV (depending how large the coupling you allow to be)
- Not necessarily having the CKM flavour structure (MFV)

Hence doing this: is similar to:







[Hurth et al. PRD 96, 095034 (2017)] [ATLAS - JHEP 10 (2017) 182] [CMS - Phys. Lett. B 768 (2017) 57]

Dettori

Summary of B anomalies

Are we there yet?

1. Low $b \to s\mu\mu$ branching fractions
2. Discrepancies in angular observables of $B_d^0 \to K^*\mu^+\mu^-$
3. Signs of lepton non-universality in: $B^+ \to K^+\mu^+\mu^-$ and $B_d^0 \to K^*\mu^+\mu^-$

- All seems to be related to a change in the C_9 coefficient (or maybe C_9 and C_{10}, but V-A)
- Global fits start to exhibit several standard deviations of discrepancy
- $c\bar{c}$ interference explanation seems not justified
- Additional discrepancies in tree-level $B \to D^{(*)}\ell\nu$ decays
- Many NP explanations: Z', leptoquarks, low mass resonances etc

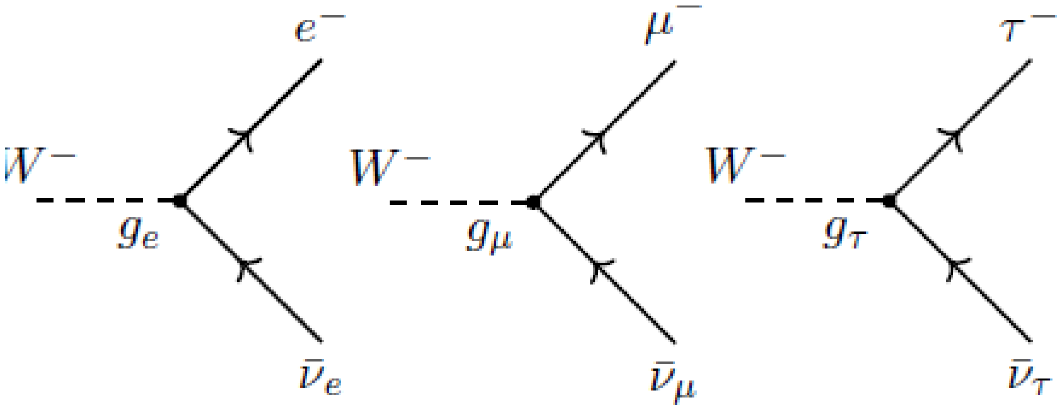
Dettori

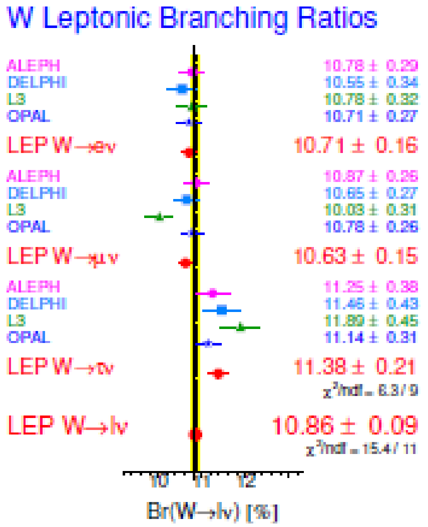
- Rare heavy flavour decays are a great laboratory to test the SM: precise predictions and clean experimental observables
- Model independent sensitivity to NP:
  - ⋆ New (pseudo)-scalar interactions tightly constrained by $B_s^0 \to \mu^+\mu^-$ decays
  - ⋆ Possible new vector (or V-A) interactions seem to explain several B anomalies
- Variety of complementary observables
- For some decays: healthy competition between 4 experiments!
- Vibrant field: many new results will come soon to confirm or disprove this tantalising results!

Dettori

Lepton Flavour Universality in the SM

- Lepton Flavour Universality: In the Standard Model (SM), the couplings of the charged leptons to the gauge bosons are equal ($g_e = g_\mu = g_\tau$)
- Differences in branching fractions only due to lepton mass differences
- Well established in $Z \to \ell\ell$, $\tau \to \ell\nu\nu$, $J/\psi \to \ell\ell$, $\pi \to \ell\nu$, $K \to \pi\ell\nu$





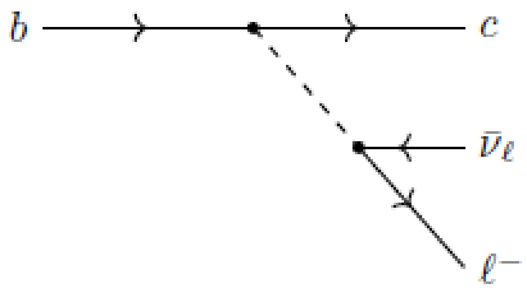
[PR 532 (2013) 119]

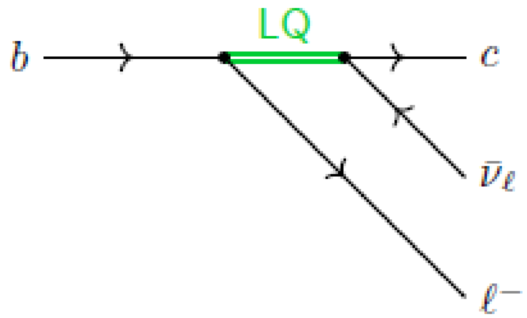
- Tension in $W \to \ell\nu$: $\frac{2\mathcal{B}(W\to\tau\bar{\nu}_\tau)}{\mathcal{B}(W\to e\bar{\nu}_e)+\mathcal{B}(W\to\mu\bar{\nu}_\mu)} = 1.066 \pm 0.025\ (2.6\sigma)$
  (Nb. strong constraints from $\Gamma(\tau \to \mu\nu\nu)/\Gamma(\mu \to e\nu\nu)$)
- Large number of BSM models with non-universal couplings to third generation quarks and leptons (Charged Higgs, Leptoquarks, ...).

Langenbruch

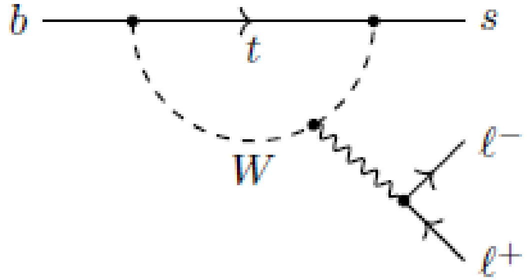
Lepton Flavour Universality in heavy flavour decays

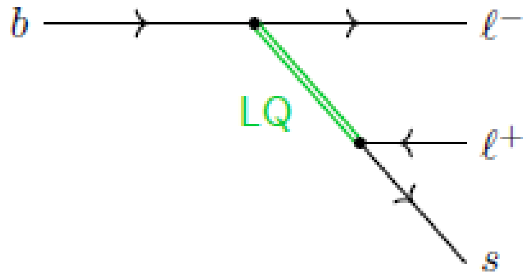
- Lepton universality tests in tree-level decays, *e.g.* $R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\mu\nu)}$
  - Abundant $b \to c\ell\nu$ semilept. decay
  - Well known in the SM
  - Possible NP coupling mainly to 3rd family





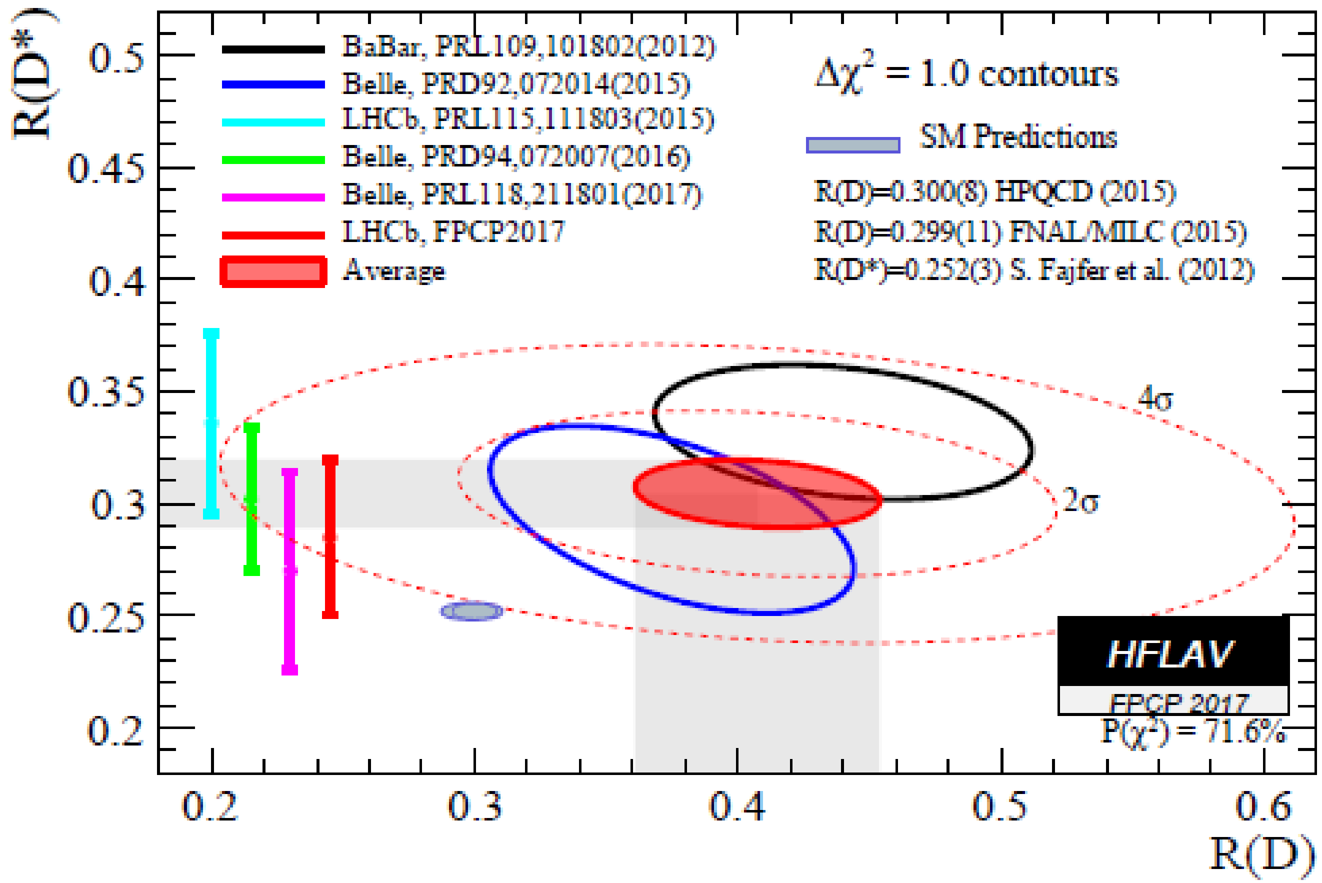
- Lepton universality tests in rare (loop-level) decays, $R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(B \to K^{(*)}ee)}$
  - $b \to s\ell\ell$ FCNC
  - Forbidden at tree-level in SM
  - Sensitive to NP contributions in loops





Langenbruch

- Usually: Determine ratios of branching fractions
  - Experimentally clean: cancellation of many systematic uncertainties
  - Theoretically clean: cancellation of QCD effects



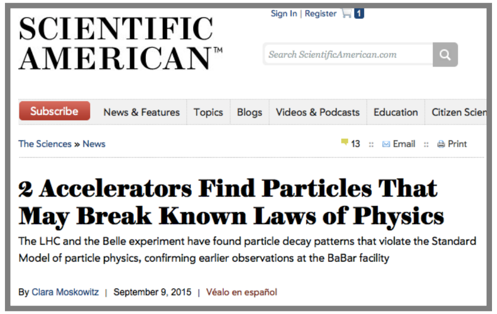
- Combine LHCb R_{D^*} measurements with B-factory results
- All measurements are above SM predictions
- Deviation of R_D/R_{D^*} combination corresponding to $\sim 4.1\,\sigma$
- Recent theory input reduces tension [JHEP 11 (2017) 061]

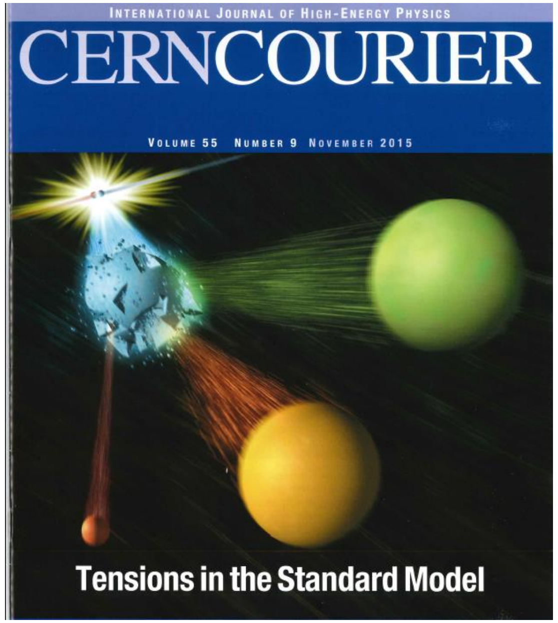
Langenbruch

- Flavour anomalies
  - $b \rightarrow s\mu^+\mu^-$
  - $b \rightarrow c\tau\nu$
  - a_μ

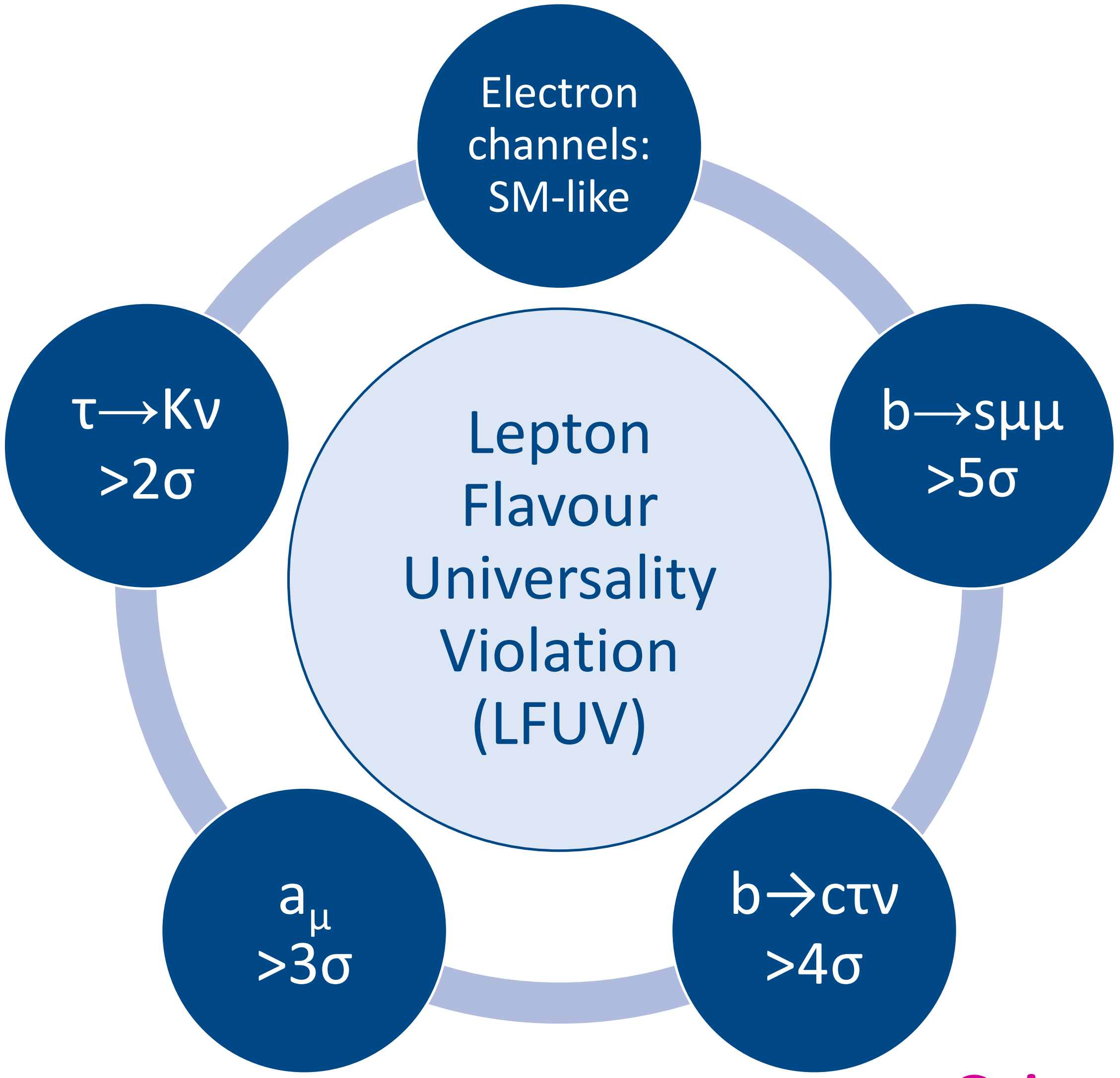
Talks of Gudrun, Andrew and Johannes

- Simultaneous explanations with leptoquarks
  - 2 scalar leptoquarks
  - Vector leptoquark
- Conclusions and outlook





Crivellin QCD



Leptoquarks provide a very promising solution to the flavour anomalies

Crivellin QCD

Heavy Flavour outlook

- There is some progress to improve the determination of the CKM angles with run2 data at LHCb
- The huge D sample of LHCb provides good opportunities to search for CP-violation in this sector
- LHCb is becoming a general purpose experiment able to get best limits of rare decays with pairs of muons in the final state (among other things it has become a KS factory…)
- New results are eagerly awaited to clarify the “B-anomalies”
- In the mean time at high energy one keeps looking for solutions of the puzzles seeking, for instance, LQ at high mass
- Belle is close to observe $B \rightarrow \mu \nu$
- BESIII continues to do a very good job with leptonic and semi-leptonic D decays
- NA62 has shown the first $K^+ \rightarrow \pi^+ \nu \nu$ result from decays in flight
- KOTO is closer to open the signal box for $K^0_L \rightarrow \pi^0 \nu \nu$

Ceccucci

Merci de votre attention