Experimental Summary*

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March 17, 2018

Rencontres de Moriond, EW Session

*The usual disclaimers apply

(Don't register early to a conference, it enhances the likelihood to end up "summarizing"it…)

Moriond EW Session

- There is a lot more than “just” EW
- Spanning from B physics to 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
- The number of tools and techniques has never been so rich….overwhelming to summarize
- Studying the elusive neutrinos in and out
- OK, so let’s start with ….

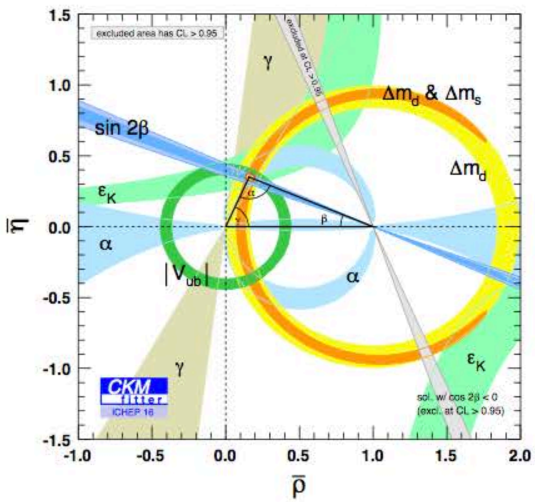
Heavy Flavours

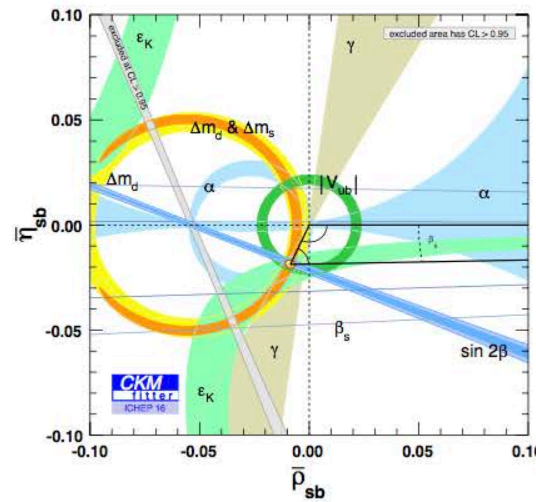
- CP-Violation in B at the LHC **[Garcia Pardinas]**
- Very rare decays at the LHC **[van Veghel]**
- Measurement of CPV in charm at the LHC **[Marino]**
- Status and prospects on b to sll decays **[Dettori]**
- LFU in B decays as a probe for new physics **[Langenbruch]**
- Search for Leptoquarks in CMS in the context of hints of LFUV **[Takahashi]**
- Isospin asymmetries in B to K* γ and hint of B^+ to $\mu^+ \nu$ **[Mohanti]**
- Leptonic and semi leptonic D decays **[Li]**
- $K^+ \rightarrow \pi^+ \nu\nu$: first NA62 results **[Marchevski]**
- Status of $K^0_L \rightarrow \pi^0 \nu\nu$ (KOTO) **[Nakagiri]**

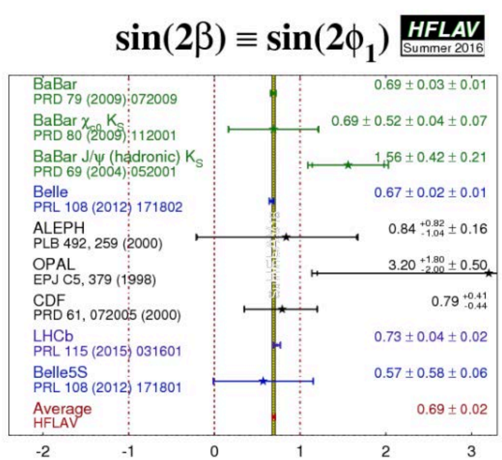
CP-Violation in B **[Garcia Pardinas]**

- The only source of CP violation in the SM comes from the **CKM matrix**, governing the quark mixing.
- Unitarity matrix. $\rightarrow$ **Unitarity triangles**.

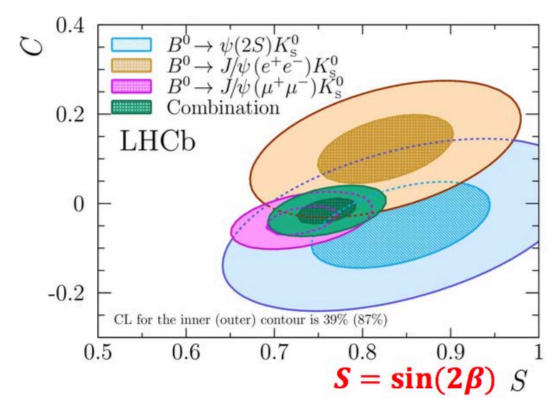
$$
\begin{array}{c} \\ u \\ c \\ t \end{array}
\begin{array}{c}
\begin{array}{ccc} d & s & b \end{array} \\
\begin{pmatrix}
1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\
-\lambda & 1-\lambda^2/2 & A\lambda^2 \\
A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1
\end{pmatrix}
\end{array}
$$







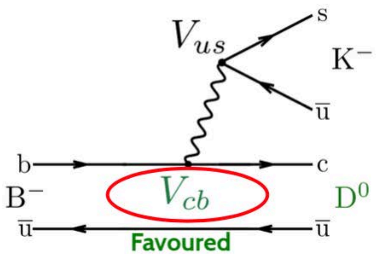
Ave still dominated by B-factories but LHCb moves on

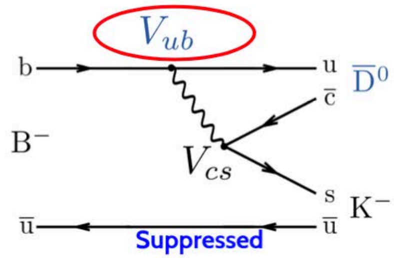


New LHCb combination for γ/ϕ_3 angle **[Garcia Pardinas]**

Determined from tree level decays, the interpetation is theoretically clean

New LHCb Combination: $\gamma = (76.8^{+5.1}_{-5.7})^\circ$

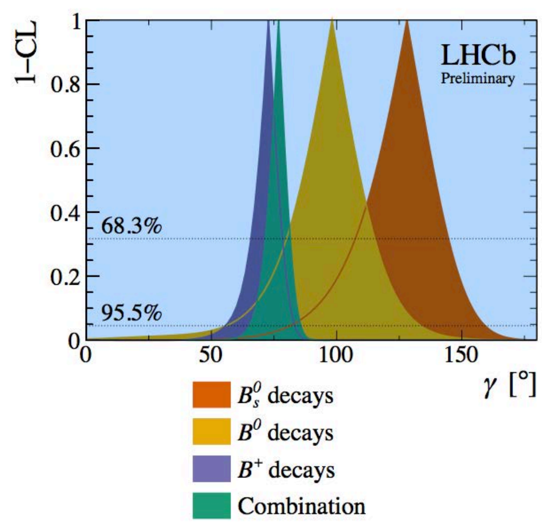




Slight "tension" with unitarity fit"

$\gamma = (65.3^{+1.0}_{-2.5})^\circ$ [CKMfitter]

B decay	D decay	Method	Ref.	Status since last combination [1]
$B^+ \to DK^+$	$D \to h^+h^-$	GLW	[16]	Updated to Run 1 + 2 fb^{-1} Run 2
$B^+ \to DK^+$	$D \to h^+h^-$	ADS	[17]	As before
$B^+ \to DK^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[17]	As before
$B^+ \to DK^+$	$D \to h^+h^-\pi^0$	GLW/ADS	[18]	As before
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ	[19]	As before
$B^+ \to DK^+$	$D \to K^0_S K^+\pi^-$	GLS	[20]	As before
$B^+ \to D^*K^+$	$D \to h^+h^-$	GLW	[16]	New
$B^+ \to DK^{*+}$	$D \to h^+h^-$	GLW/ADS	[21]	New
$B^+ \to DK^+\pi^+\pi^-$	$D \to h^+h^-$	GLW/ADS	[22]	As before
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS	[23]	As before
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz	[24]	As before
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	GGSZ	[25]	As before
$B^0_s \to D^\mp_s K^\pm$	$D^+_s \to h^+h^-\pi^+$	TD	[26]	Updated to 3 fb^{-1} Run 1



Most precise determination from a single Experiment

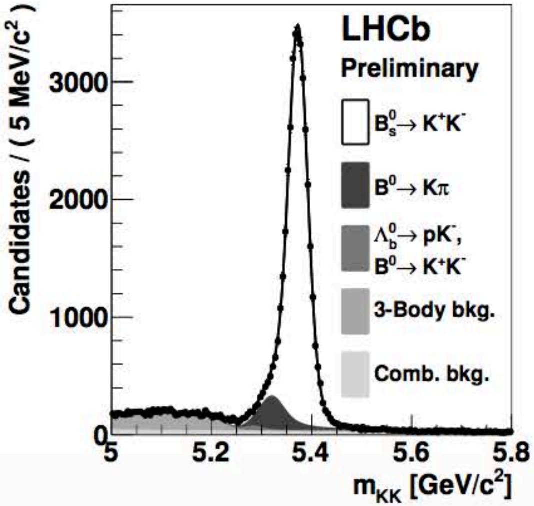
Expect 4° by end of Run 2

CP violation in $B^0_{(s)} \to hh'$

[New result! Preliminary!]

LHCb-PAPER-2018-006 (in preparation)

[Garcia Pardinas] LHCb



$$\begin{aligned}
C_{\pi^+\pi^-} &= -0.34 \pm 0.06, \\
S_{\pi^+\pi^-} &= -0.63 \pm 0.05, \\
C_{K^+K^-} &= 0.20 \pm 0.06, \\
S_{K^+K^-} &= 0.18 \pm 0.06, \\
A^{\Delta\Gamma}_{K^+K^-} &= -0.79 \pm 0.07, \\
A_{CP}\left(B^0 \to K^+\pi^-\right) &= -0.084 \pm 0.004, \\
A_{CP}\left(B^0_s \to \pi^+K^-\right) &= 0.213 \pm 0.015,
\end{aligned}$$

Most precise measurements from a single experiment.

$(C_{K^+K^-}, S_{K^+K^-}, A^{\Delta\Gamma}_{K^+K^-})$ deviates **4.0 σ** from $(0, 0, -1)$

$\Longrightarrow$ Strongest evidence for time-dependent CP violation in the B^0_s sector!

CPV in $B^+ \to D^+_{(s)}\overline{D}^0$ LHCb

[New result! Preliminary!]

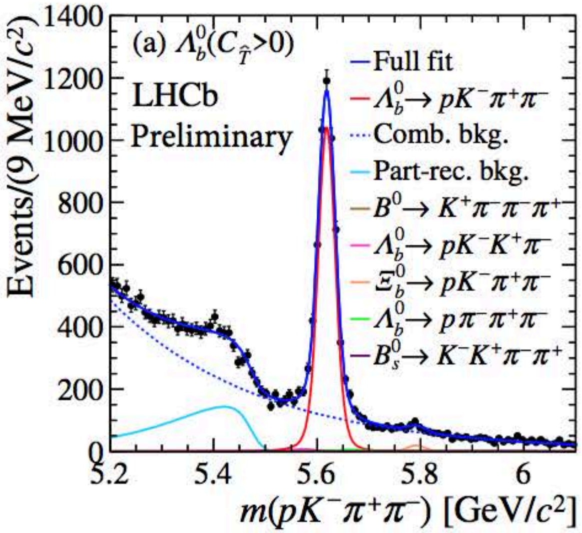
LHCb-PAPER-2018-007 (in preparation)

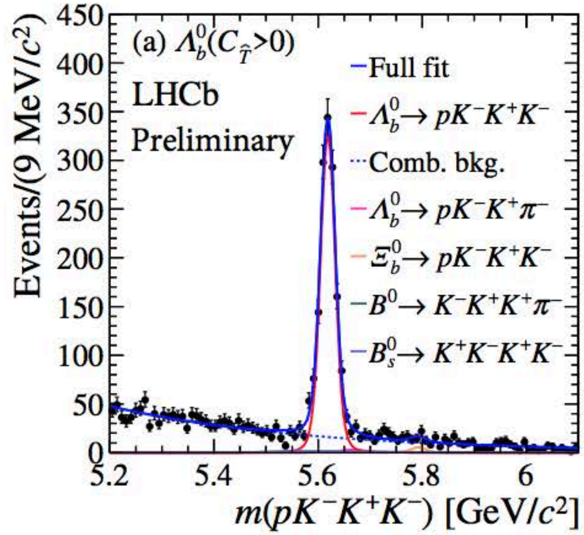
$$\mathcal{A}^{CP}(B^+ \to D^+_s \overline{D}^0) = (-0.4 \pm 0.5 \pm 0.5)\%, \qquad \mathcal{A}^{CP}(B^+ \to D^+ \overline{D}^0) = (\ 2.3 \pm 2.7 \pm 0.4)\%$$

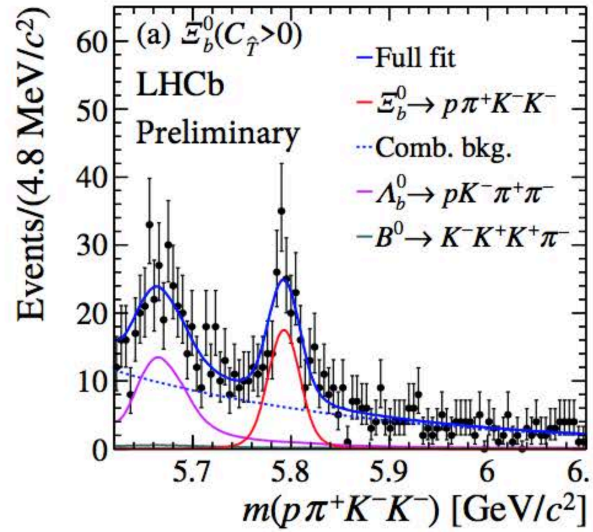
- **No evidence of CP violation** is found.
- **First measurement** in $B^+ \to D^+_s \overline{D}^0$ and **most precise one** in $B^+ \to D^+ \overline{D}^0$.

LHCb [New result! Preliminary!]

LHCb-PAPER-2018-001 (in preparation)







	$\Lambda_b^0 \to pK^-\pi^+\pi^-$	$\Lambda_b^0 \to pK^-K^+K^-$	$\Xi_b^0 \to pK^-K^-\pi^+$
$a_P^{\widehat{T}\text{-odd}}$ (%)	$-0.60 \pm 0.84 \pm 0.31$	$-1.56 \pm 1.51 \pm 0.32$	$-3.04 \pm 5.19 \pm 0.36$
$a_{CP}^{\widehat{T}\text{-odd}}$ (%)	$-0.81 \pm 0.84 \pm 0.31$	$1.12 \pm 1.51 \pm 0.32$	$-3.58 \pm 5.19 \pm 0.36$

- Results compatible with neither CP nor P asymmetry.
- **Same conclusion** is reached when looking at **per-bin asymmetries**.

[Garcia Pardinas]

Measurements of CPV in beauty at LHC

Recent results previously presented

Kindly summarized in one slide!

- Combined measurement of γ (LHCb, Run1 + Run2, LHCb-CONF-2017-004): most precise from a single experiment.
- Measurement of β using $B^0 \to J/\psi(ee)K_s$ and $B^0 \to \psi(2S)(\mu\mu)K_s$ (LHCb, Run1, JHEP 11 (2017) 170): combines with previous measurements of β.
- Measurement of β_s using $B_s^0 \to J/\psi K^+K^-$, with $M(K^+K^-)$ above the $\phi(1020)$ (LHCb, Run1, JHEP 08 (2017) 037): first measurement of the phase in final states dominated by a tensor.
- First measurement of $\phi_s^{s\bar{d}d}$ using $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ (LHCb, Run1, arXiv:1712.08683): many amplitudes, fit using GPUs

New results, presented for the first time

- CPV in $B^0_{(s)} \to hh'$ (LHCb, Run1, LHCb-PAPER-2018-006): TD asymmetries in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ + TI asymmetries in $B^0 \to K^+\pi^-$ and $B_s^0 \to pi^+K^-$, most precise measurements, strongest evidence for TD CPV in the B_s^0 sector.
- Direct CP violation in $B^+ \to D^+_{(s)}\overline{D}^0$ (LHCb, Run1, LHCb-PAPER-2018-007): no evidence of CPV, first measurement in $B^+ \to D_s^+\overline{D}^0$ and most precise one in $B^+ \to D^+\overline{D}^0$.
- CPV through triple-product asymmetries in $\Lambda_b^0 \to pK^+\pi^-\pi^-$, $\Lambda_b^0 \to pK^-K^+K^-$ and $\Xi_b^0 \to pK^-K^-\pi^+$: no evidence for CPV, neither overall nor in bins of the phase-space.

Global comment: results so far compatible with SM, waiting for new analyses with more data.

Mixing and CP violation in $D^0 \to K^+\pi^-$ decays

[Marino] **LHCb**

$$R(t)^{\pm} = \frac{\mathrm{WS}(t)^{\pm}}{\mathrm{RS}(t)^{\pm}} \approx R_D^{\pm} + \sqrt{R_D^{\pm}}\, y'^{\pm} \frac{t}{\tau} + \frac{(x'^{\pm})^2 + (y'^{\pm})^2}{4} \left(\frac{t}{\tau}\right)^2$$

[PRD 97 031101 (2018)]

$$x'^{\pm} = x\cos(\delta \pm \varphi) + y\sin(\delta \pm \varphi)$$
$$y'^{\pm} = y\cos(\delta \pm \varphi) - x\sin(\delta \pm \varphi)$$

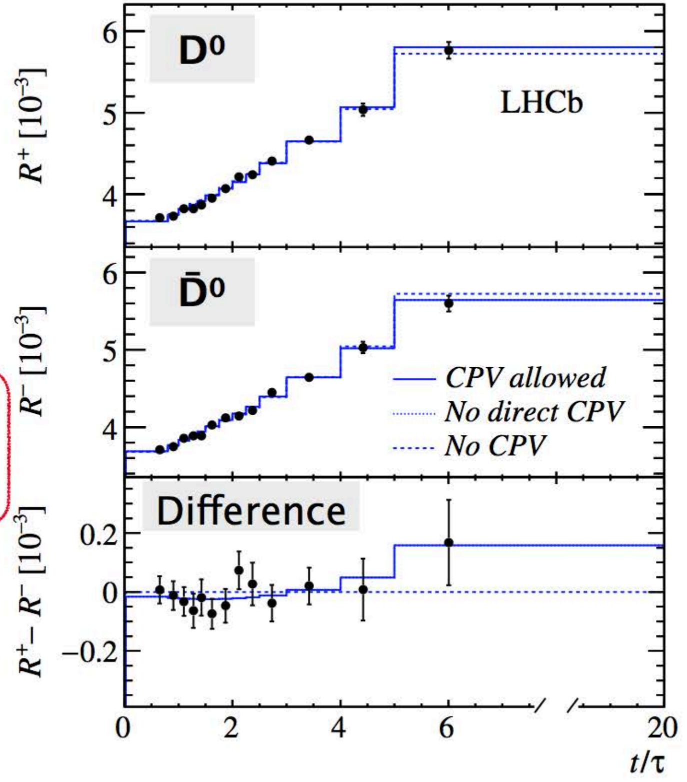
$$\varphi = \arg[qA(\bar{D}^0 \to K^+\pi^-)/(pA(D^0 \to K^+\pi^-))]$$

- No measurable CP violation observed.
  - $1.00 < |q/p| < 1.35$ @ 68.3% CL
- Mixing parameters in the assumption of no CP violation:

$x'^2 = (0.39 \pm 0.023 \pm 0.014)\times 10^{-3}$

$y' = (5.28 \pm 0.45 \pm 0.27)\times 10^{-3}$

- Twice as precise as previous prompt measurement; now superseded [PRL 111 251801 (2013)].



Indirect CP violation in $D^0 \to h^+h^-$ decays

[PRL 118 261803 (2017)]

$$A_\Gamma \equiv \frac{\hat{\Gamma}(D^0 \to f) - \hat{\Gamma}(\bar{D}^0 \to f)}{\hat{\Gamma}(D^0 \to f) + \hat{\Gamma}(\bar{D}^0 \to f)} \approx \frac{1}{2}\left[\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) y \cos\phi_f - \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) x \sin\phi_f\right]$$

LHCb

[Marino]

- Everything compatible with no CP violation at **0.3 per mille**

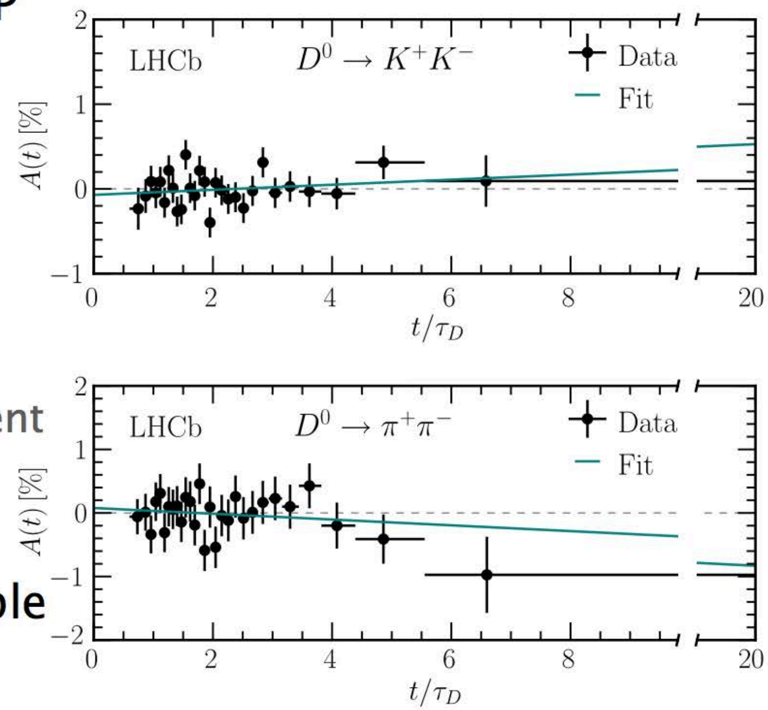
  $A_\Gamma(KK) = (-0.30 \pm 0.32 \pm 0.10) \times 10^{-3}$

  $A_\Gamma(\pi\pi) = (0.46 \pm 0.58 \pm 0.12) \times 10^{-3}$

- Complementary measurement yields compatible results.
  - Data-driven calculation of per-event acceptance.

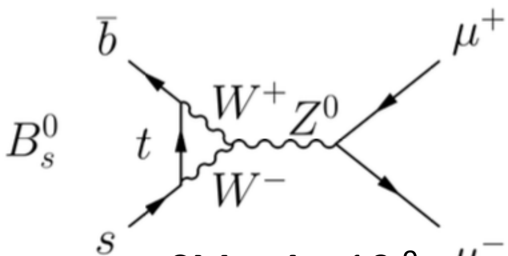
- Combined with the statistical independent muon-tagged sample ($B \to D^0 \mu^- X$) [JHEP 04 (2015) 043]:

  $A_\Gamma = (-0.29 \pm 0.28) \times 10^{-3}$



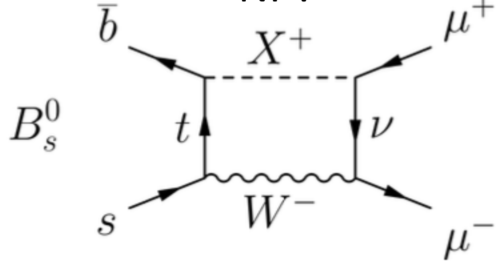
[Van Veghel]

$B^0_{(s)} \to \mu^+\mu^-$

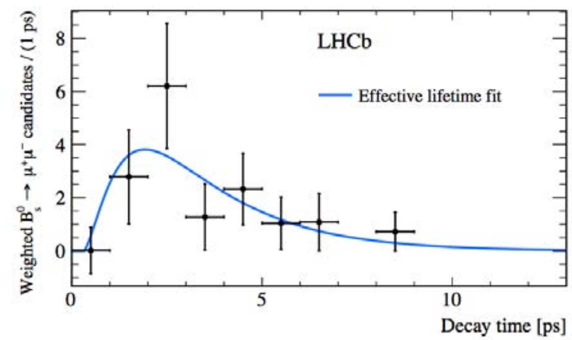


SM ~ 4 x 10^{-9}

NP?

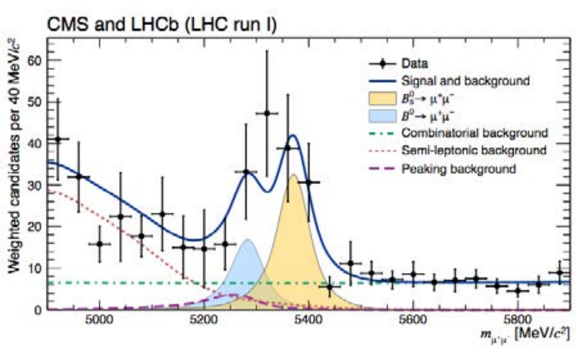


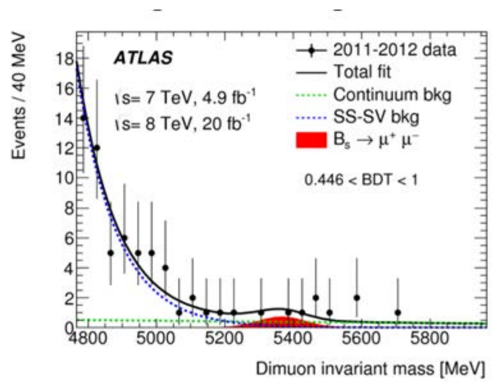
LHCb Update **2017**
Run1 + 1.4 fb^{-1} Run2

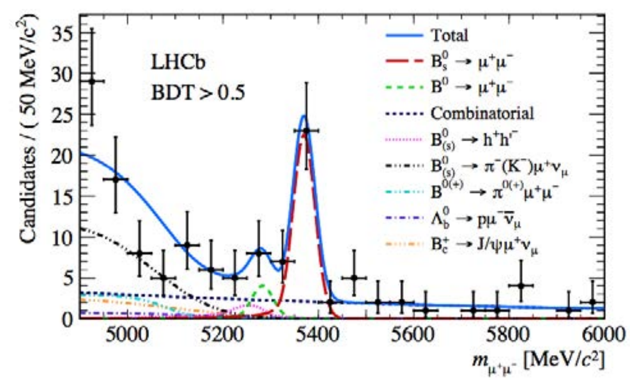


Brief history:
First observation in **2015**
By CMS+LHCb

ATLAS **2016**







$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$$

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = 0.9^{+1.1}_{-0.8} \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10} \text{ [95\% CL]}$$

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10} \text{ [95\% CL]}$$

Rare Decays with l+ l- in final states

LHCb

$\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 2.1\times10^{-3}$ [95% CL]

$\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 6.8\times10^{-3}$ [95% CL]

$\mathcal{B}(B^0 \to e^\pm\mu^\mp) < 1.3\times10^{-9}$ [95% CL]

$\mathcal{B}(B_s^0 \to e^\pm\mu^\mp) < 6.3\times10^{-9}$ [95% CL]

$\mathcal{B}(K_s^0 \to \mu^+\mu^-) < 1.0\times10^{-9}$ [95% CL]

$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = 2.1^{+1.6}_{-1.2}\times10^{-8}$

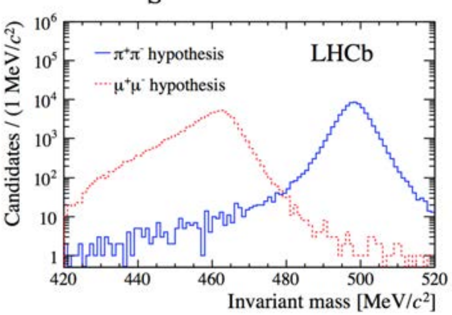
$\mathcal{B}(\Sigma^+ \to pX^0(\to\mu^+\mu^-)) < 1.2\times10^{-8}$ [95% CL]

$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 9.8\times10^{-8}$ [95% CL]

$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = 9.64\pm0.48\pm0.51\pm0.97\times10^{-7}$

$\mathcal{B}(D^0 \to K^+K^-\mu^+\mu^-) = 1.54\pm0.27\pm0.09\pm0.16\times10^{-7}$

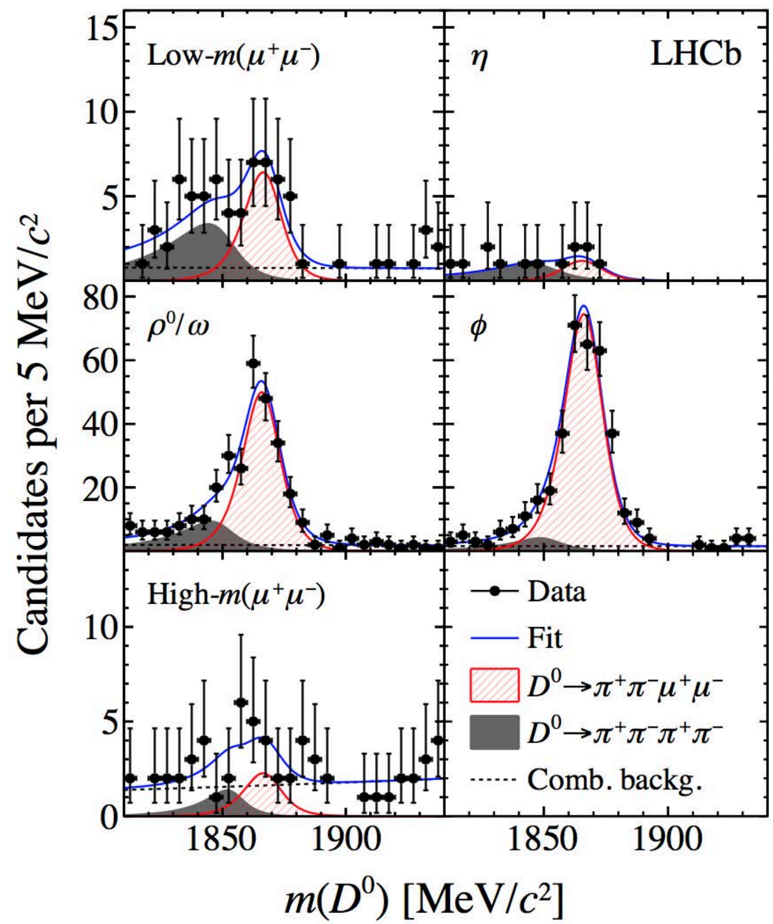
$K_S^0 \to \pi^+\pi^-$



LHCb as a $K^0{}_s$ factory

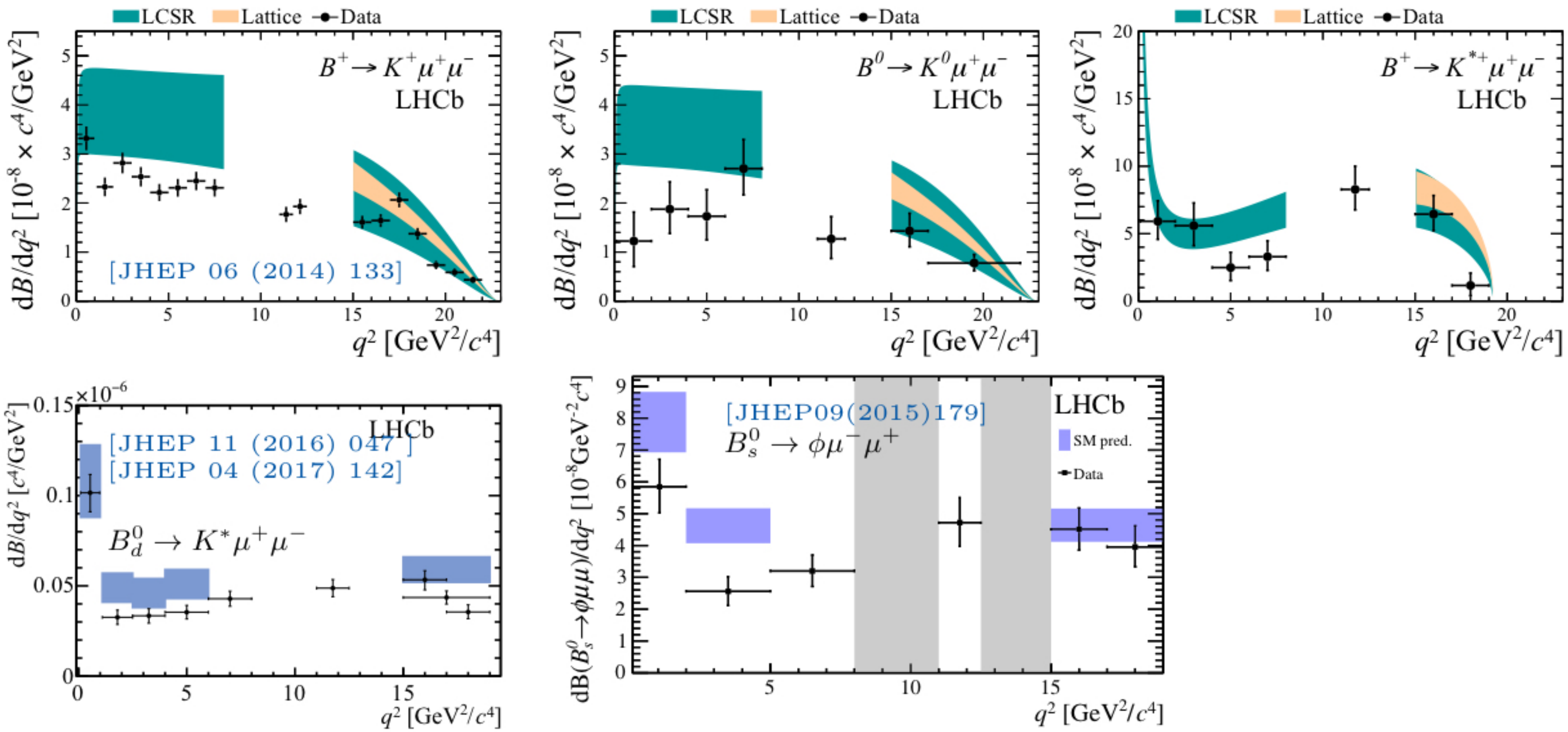
[van Veghel]

$D^0 \to \pi^+\pi^-\mu^+\mu^-$



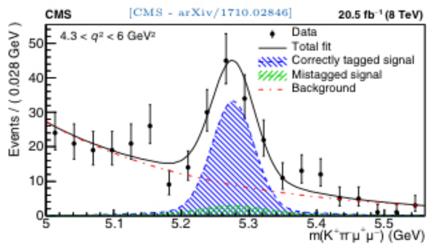
B “Anomalies” [Dettori]

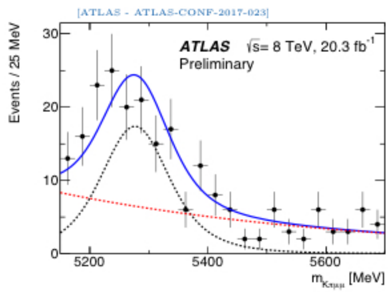
- Measurements of various $b \to s$ transitions systematically below the SM:
- Might be all due to modification of C_9

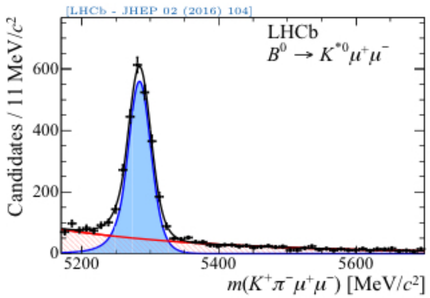


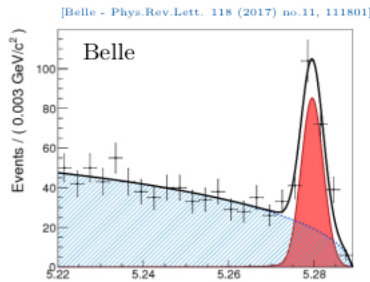
Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

Many recent measurements









Evidence for the rare decay $B_s^0 \to K^* \mu^+ \mu^-$

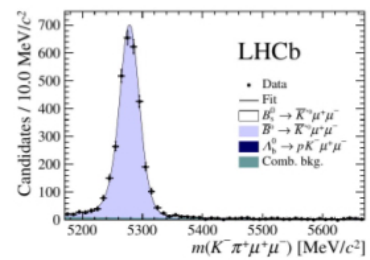
NEW!

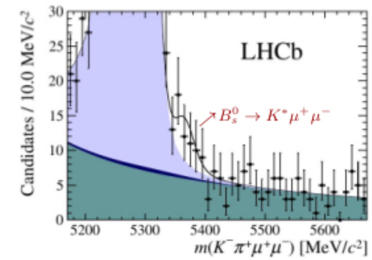
[LHCb-PAPER-2018-010]

- Search for $b \to d\ell\ell$ transition
- Rarer of older brother $B_d^0 \to K^* \mu^+ \mu^-$ due to CKM
- Sensitive to new physics and probe of V_{td}/V_{ts}
- No full SM prediction but BR expected of $\mathcal{O}(10^{-8})$
- Analysis with 3 fb^{-1} Run1 and 1.6 fb^{-1} Run 2
- First evidence for this decay with 3.4σ
- Normalise to $B_s^0 \to K^* J/\psi$

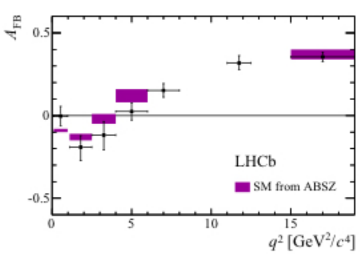
[Dettori]

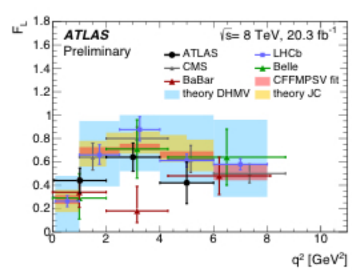
$$\mathcal{B}(B_s^0 \to K^* \mu^+ \mu^-) = (3.0 \pm 1.0(\text{stat}) \pm 0.2(\text{syst}) \pm 0.3(\text{ext}) \times 10^{-8}$$



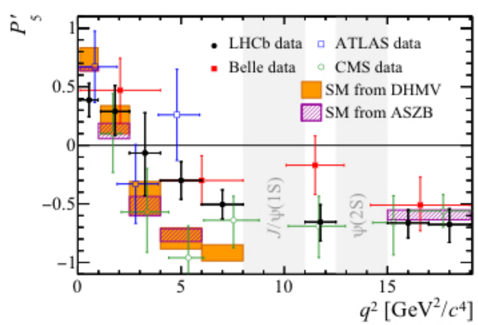


$B_d^0 \to K^* \mu^+ \mu^-$ results





- Several observables appear different than SM
- In particular P_5' has significant discrepancy
- Global fits show large disagreement



Angular analysis of $B^+ \to K^+ \mu^+ \mu^-$ at CMS

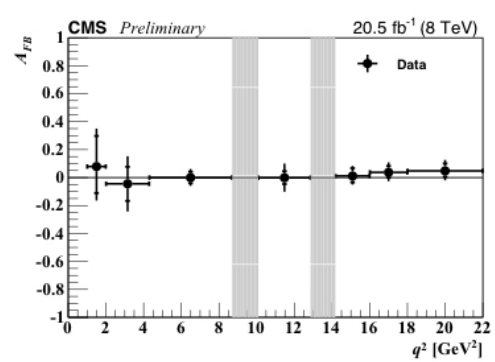
NEW

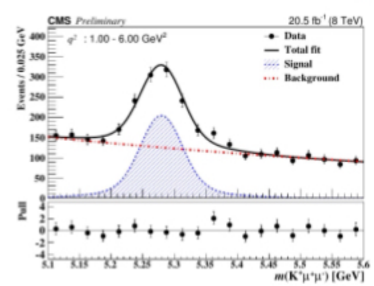
[CMS - CMS-PAS BPH-15-001]

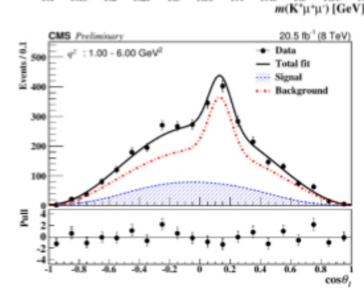
- Result with 20.5 fb^{-1}
- Angular analysis in terms of F_H, A_{FB}
- Sensitive to scalar and tensors

$$\frac{1}{\Gamma_\ell}\frac{d\Gamma_\ell}{d\cos\theta_\ell} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_\ell)+\frac{1}{2}F_H+A_{FB}\cos\theta_\ell$$

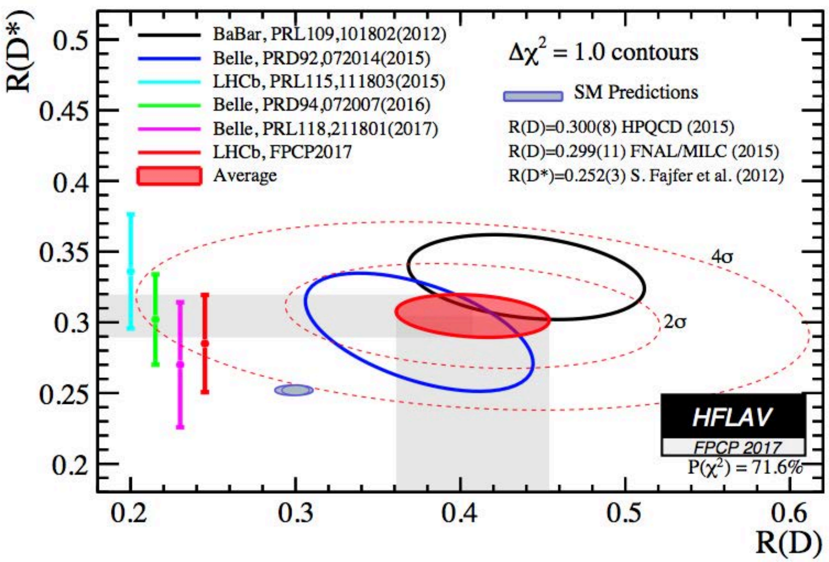
- In good agreement with SM

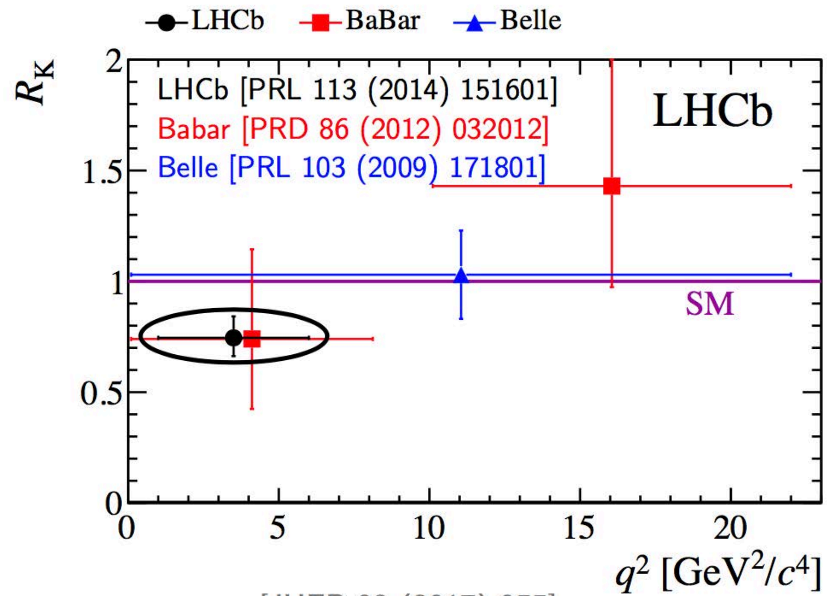


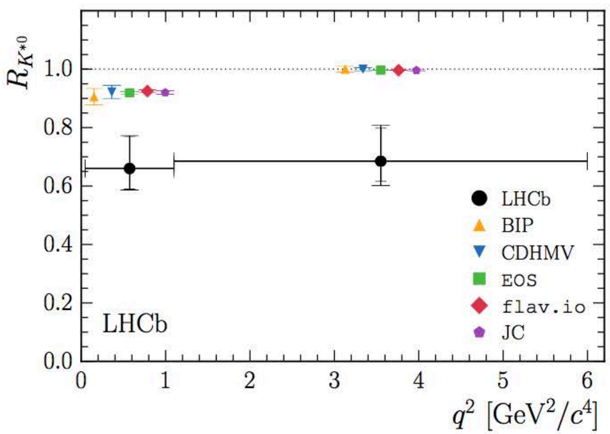


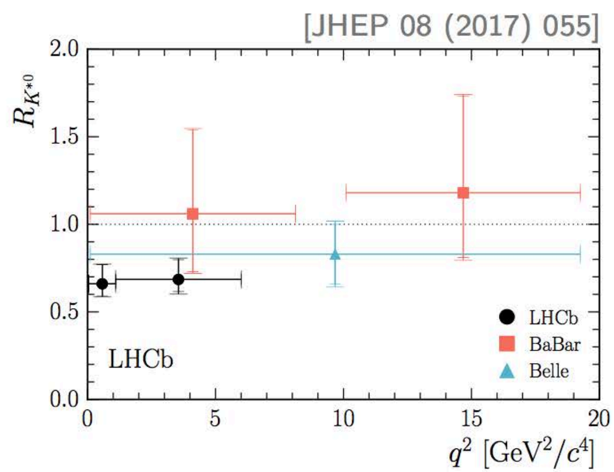


Lepton Flavour Universality in B decays









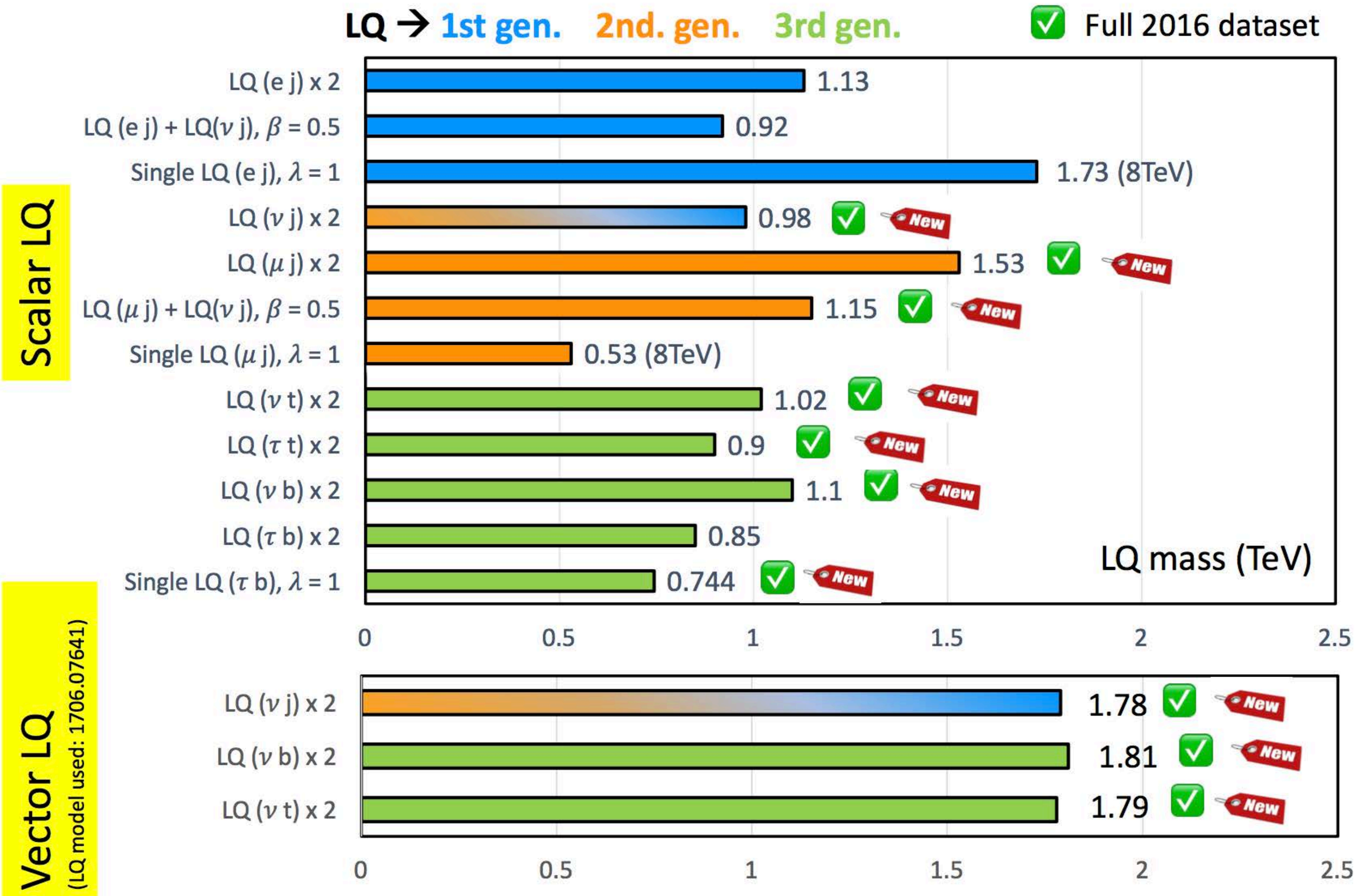
New results eagerly awaited

- BIP [EPJC 76 (2016) 440]
- CDHMV [JHEP 04 (2017) 016]
- EOS [PRD 95 (2017) 035029]
- flav.io [EPJC 77 (2017) 377]
- JC [PRD 93 (2016) 014028]

- Babar [PRD 86 (2012) 032012]
- Belle [PRL 103 (2009) 171801]

[Langenbruch]

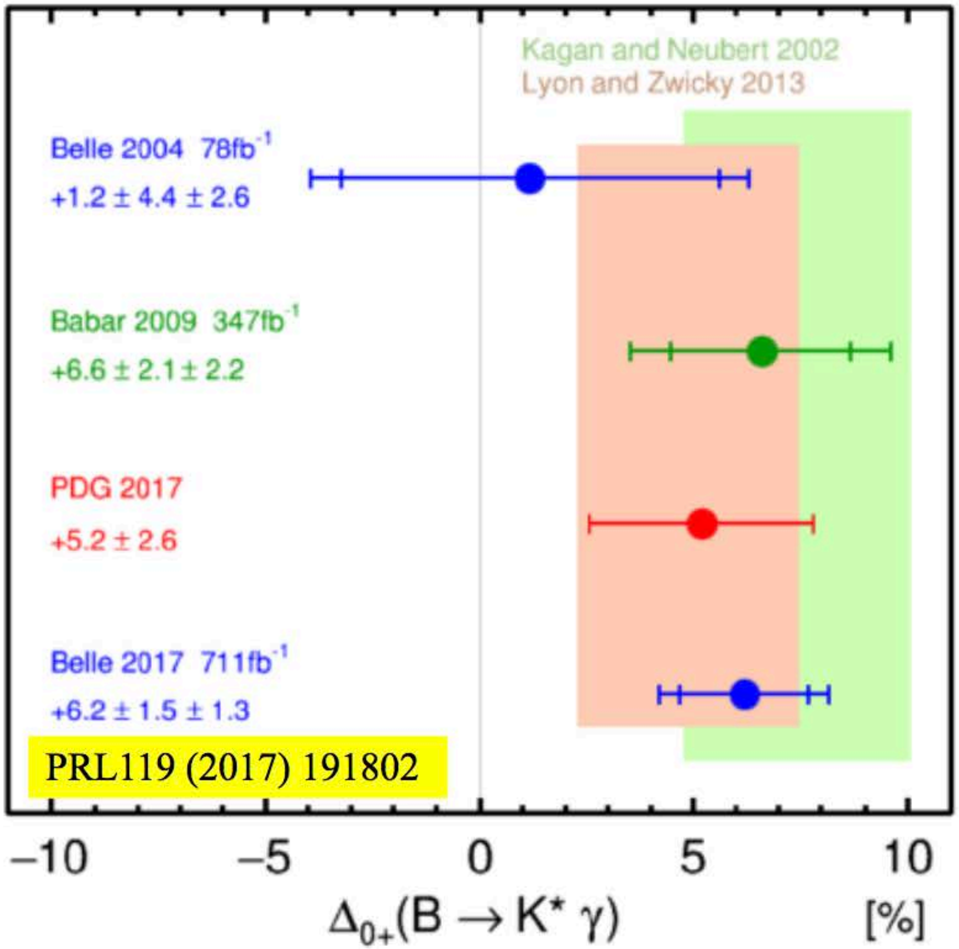
CMS LQ search summary [Takahashi]



Belle

Isospin Asymmetry

[Mohanti]



PRL119 (2017) 191802

- First evidence for isospin violation in $b \to s$ transition exceeding 3σ significance
- Agree with theory predictions of

  Lyon and Zwicky PRD88 (2013) 094004

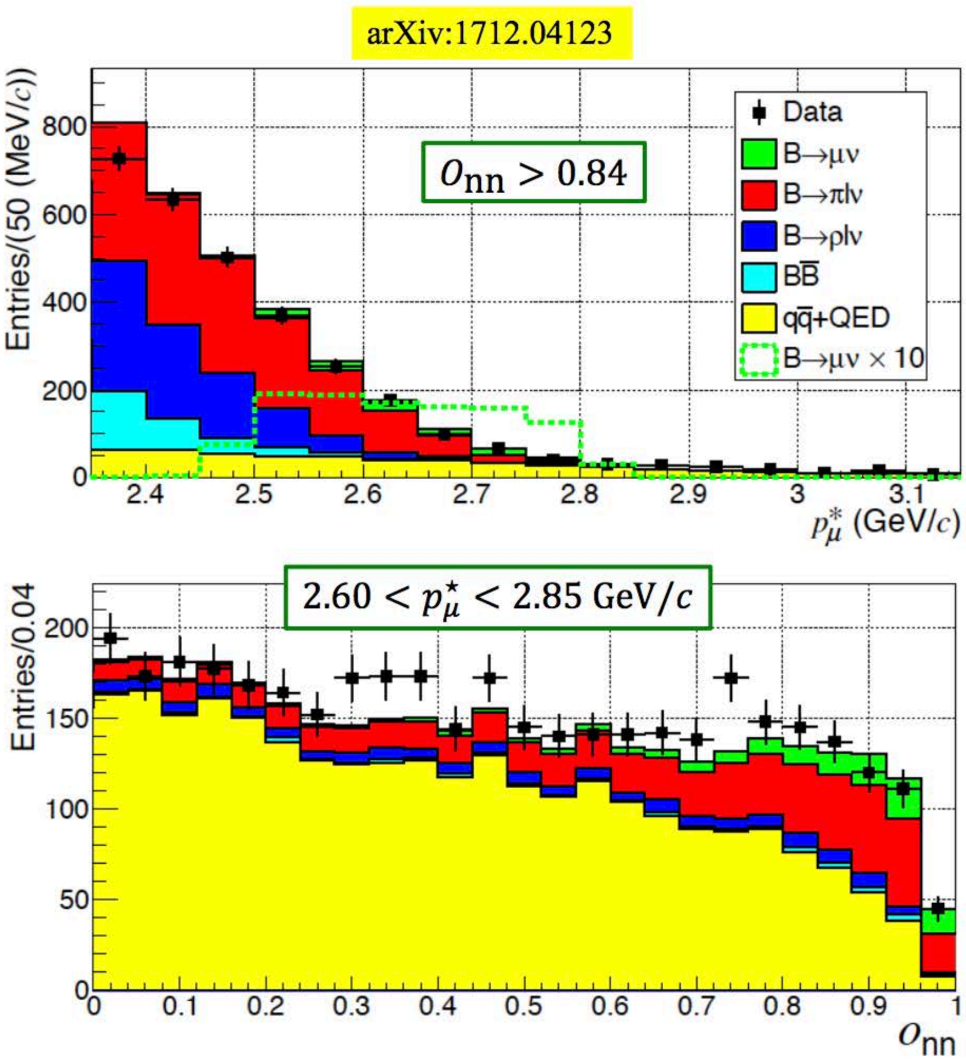
  Kagan and Neubert PLB 539 (2002) 227

- Consistent with and more precise than BaBar result

➢ To observe isospin violation with 5σ significance at Belle II, reduction of dominant systematic uncertainty due to f_{+-}/f_{00} is also essential

$B^+ \to \mu^+ \nu$

Belle **[Mohanti]**



- Fit the ratio

$$R = N_{B\to\mu\bar{\nu}_\mu}/N_{B\to\pi\mu\bar{\nu}_\mu}$$

- We get $R = (1.66 \pm 0.57)\times 10^{-2}$, which is equivalent to:

$$N_{B\to\mu\bar{\nu}_\mu} = 195 \pm 67$$

Branching fraction

$$\mathcal{B}(B \to \mu\bar{\nu}_\mu) = (6.46 \pm 2.22) \times 10^{-7}$$
$$= (6.46 \pm 2.22_{\rm stat} \pm 1.6_{\rm syst}) \times 10^{-7}$$

➢ 3.4σ statistical significance $\Rightarrow 2.4\sigma$ including systematic uncertainties

- 90% confidence interval for BF ∈ $(2.9,10.7)\times10^{-7}$

➢ Belle II will make definitive measurement

D leptonic and semi-leptonic decays

[Huijing Li]

$$B(D_s^+ \to \mu^+ \nu) = 5.28 \pm 0.15 \pm 0.14 \times 10^{-3}$$

$$B(D^0 \to \pi^- \mu^+ \nu_\mu) = 0.267 \pm 0.007 \pm 0.007$$

$$B(D^+ \to \pi^0 \mu^+ \nu_\mu) = 0.342 \pm 0.011 \pm 0.010$$

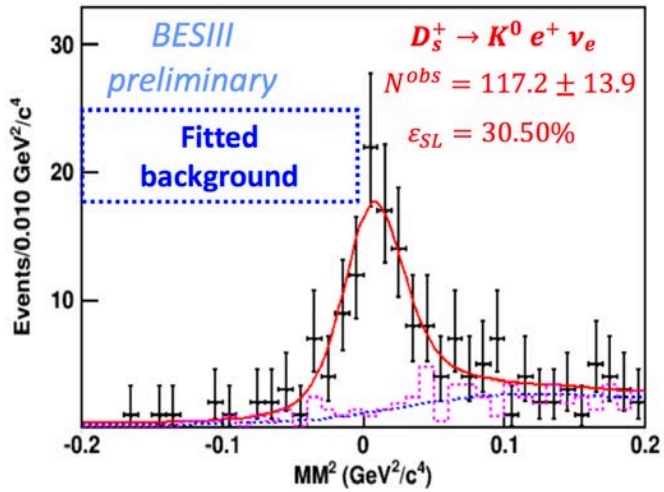
$$B(D^+ \to \bar{K}^0 \mu^+ \nu_\mu) = 8.72 \pm 0.07 \pm 0.18 \times 10^{-2}$$

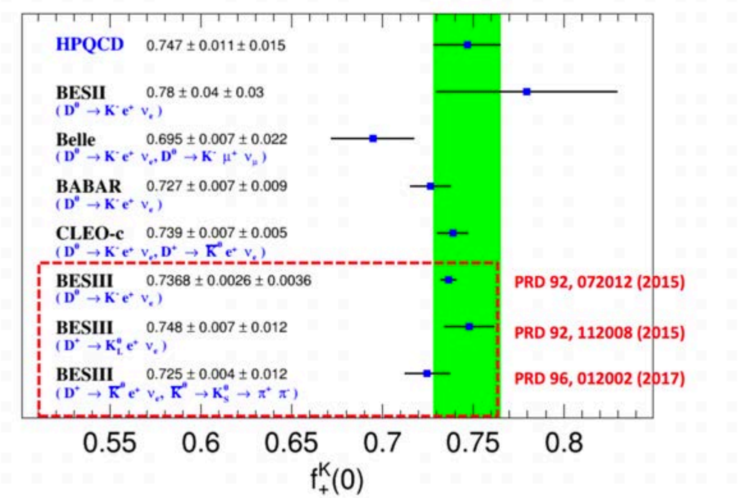
$$B(D^+ \to \bar{K}^0 e^+ \nu_e) = 8.60 \pm 0.06 \pm 0.15 \times 10^{-2}$$

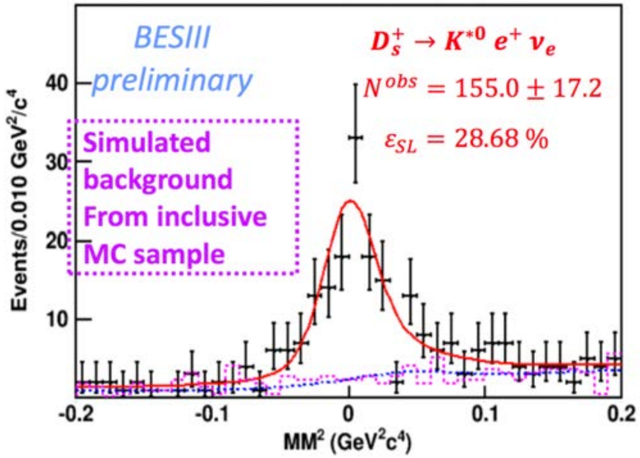
$$B(D^+ \to \pi^0 e^+ \nu_e) = 0.363 \pm 0.008 \pm 0.005 \times 10^{-2}$$

$$B(D_s^+ \to K^{(*)0} e^+ \nu_e) = 3.25 \pm 0.38 \pm 0.14 \times 10^{-3}$$ New Result

$$B(D_s^+ \to K^0 e^+ \nu_e) = 2.38 \pm 0.26 \pm 0.12 \times 10^{-3}$$ New Result







NA62: $K^+ \rightarrow \pi^+ \nu\nu$ in-flight [Marchevski]

CERN SPS

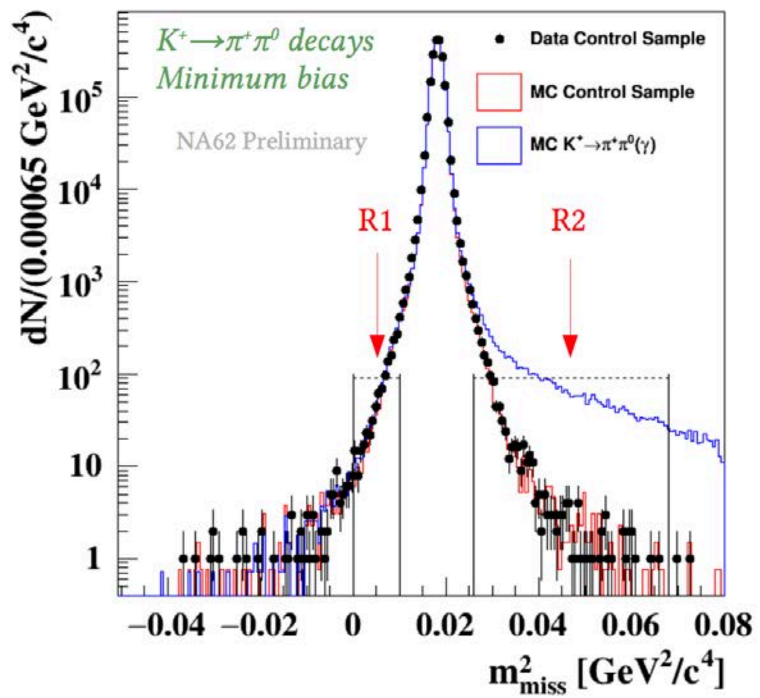
NA62: $K^+ \rightarrow \pi^+ \nu\nu$ in-flight

[Marchevski]

Data from 2016 run

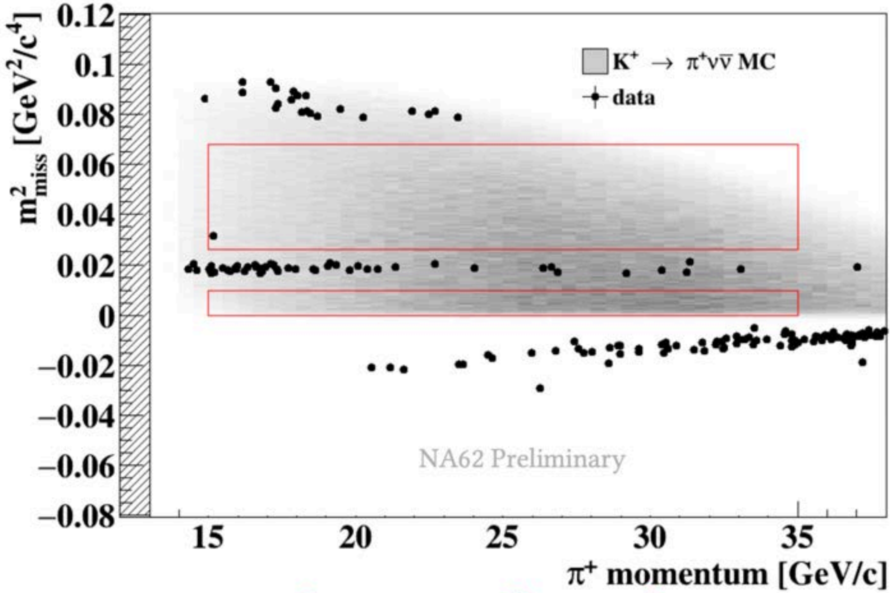
Background summary

Process	Expected events in R1 + R2
$K^+ \to \pi^+ \nu \bar{\nu}$ (SM)	$0.267 \pm 0.001_{stat} \pm 0.029_{syst} \pm 0.032_{ext}$
$K^+ \to \pi^+ \pi^0 (\gamma)$ IB	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+ \nu_\mu (\gamma)$ IB	$0.020 \pm 0.003_{stat} \pm 0.003_{syst}$
$K^+ \to \pi^+ \pi^- e^+ \nu_e$	$0.018^{+0.024}_{-0.017}\|_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^+ \pi^- \pi^+$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
Upstream background	$0.050^{+0.090}_{-0.030}$
Total background	$0.15 \pm 0.09_{stat} \pm 0.01_{syst}$



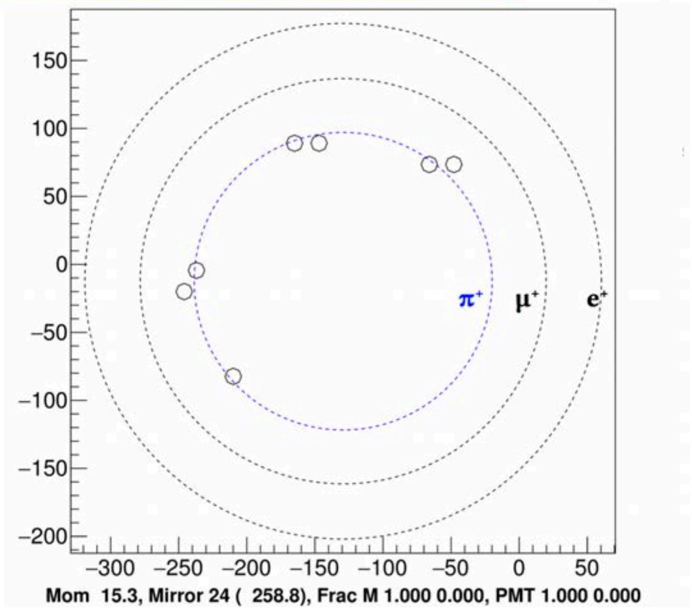
$$SES = (3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \cdot 10^{-10}$$

Results



One event observed

Results: RICH ring for the event



Results

$$BR(K^+ \to \pi^+\nu\bar{\nu}) < 11 \times 10^{-10} \text{ @ } 90\%\ CL$$

$$BR(K^+ \to \pi^+\nu\bar{\nu}) < 14 \times 10^{-10} \text{ @ } 95\%\ CL$$

- One event observed in Region 2
- Full exploitation of the CLs method in progress
- The results are compatible with the Standard Model
- For comparison: $BR(K^+ \to \pi^+\nu\bar{\nu}) = 28^{+44}_{-23} \times 10^{-11}$ @ $68\%\ CL$

$$BR(K^+ \to \pi^+\nu\bar{\nu})_{SM} = (8.4 \pm 1.0) \times 10^{-11}$$

$$BR(K^+ \to \pi^+\nu\bar{\nu})_{exp} = (17.3^{+11.5}_{-10.5}) \times 10^{-11} \text{ (BNL, "kaon decays at rest")}$$

NA62

Prospects

- Processing of 2017 data is ongoing
  - ~ 20 times more data than the presented statistics
  - expected reduction of upstream background
  - improvements of the reconstruction efficiency
- Preparing 2018 data taking
  - 218 days including stops
  - ongoing studies to improve the signal acceptance
- ~ 20 SM events expected before LS2
- Running after 2018 to be approved
  - Conditions for ultimate sensitivity under evaluation

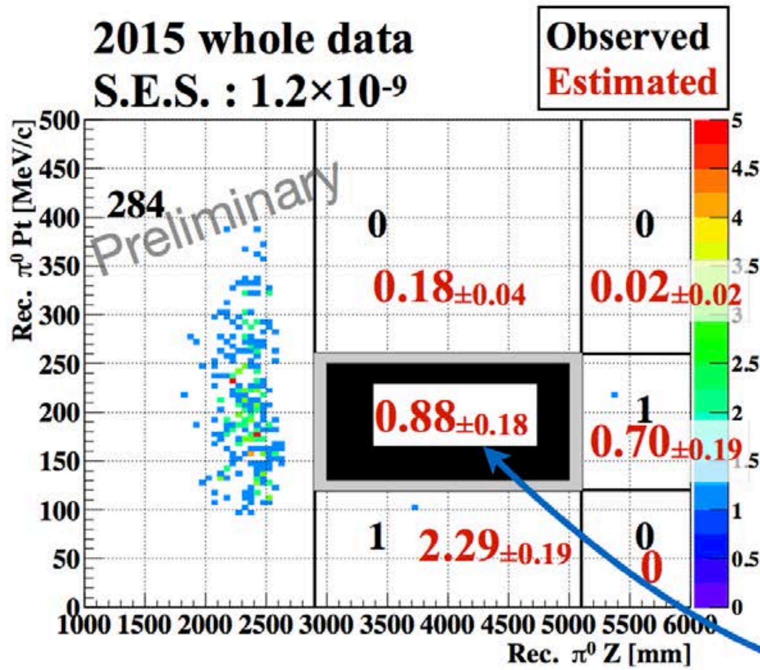
[Marchevski]

Status of $K_L \to \pi^0 \nu\bar{\nu}$ analysis at J-PARC KOTO

Kota Nakagiri (Kyoto Univ.)
for the KOTO collaboration

[Nakagiri]

2015 run status



mode	# of BG
$K_L \to 2\pi^0$	0.07 ± 0.07
$K_L \to \pi^+\pi^-\pi^0$	0.18 ± 0.05
$K_L \to 3\pi^0$	0.17 ± 0.12
$K_L \to 2\gamma$	0.02 ± 0.02
Hadron Cluster	0.26 ± 0.08
NCC-π^0	0.13 ± 0.07
CV-η	0.05 ± 0.02
Total	0.88 ± 0.18

Summary & Prospects

- KOTO 2015 run analysis is ongoing
  - $K_L \to \pi^0 \nu\nu$ search with S.E.S. = 1.2 ×10^{-9}
  - expected to improve the current upper limit by a factor of 10
- Remaining work
  - finalize sensitivity / BG estimation
    - final MC production is now ongoing
  - evaluate systematic uncertainty
- We will release the result this summer !

Wrap up of Heavy Flavour

- 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 $K^0_L \rightarrow \pi^0 \nu\nu$

Top/EW Session

- The phenomenological intricacies to measure the top mass were detailed by **Deliot**. As we enter precision top physics, and given the importance of the top mass for the SM fit and Higgs potential, there are important questions: how is he top mass defined? (Over)tuning of generators?PT puzzle?Non-perturbative effects?...
- The top mass measurements at LHC where reviewed by **Menke**
- **Brandt** and **Hays** reviewed top mass and EW measurements at the Tevatron
- Associated top production (ttV and tV) where presented by **Sanchez**…interesting to compare different experiments
- The recent EW measurements in CMS and ATLAS were presented by **Apyan/Bendavid** and **Helary/Schott** respectively
- Finally, a medical check-up of the SM was presented by **Kogler** in the form of the latest fit (Gfitter)

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)

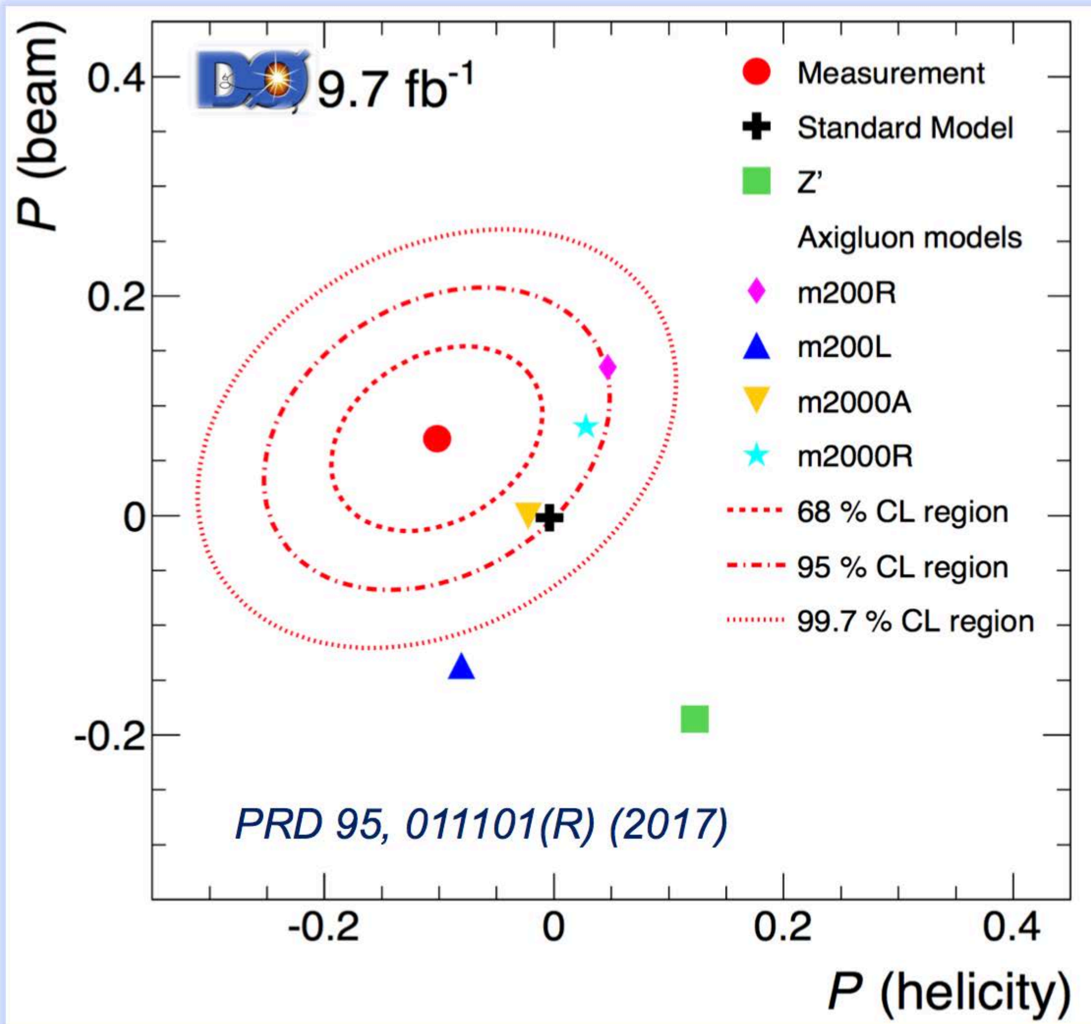
*CMS Legacy

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

Combinations from the talk of **Brandt**

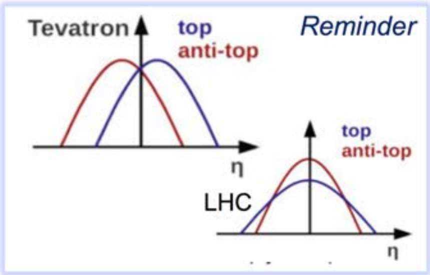
Top Polarization (lepton+jets)

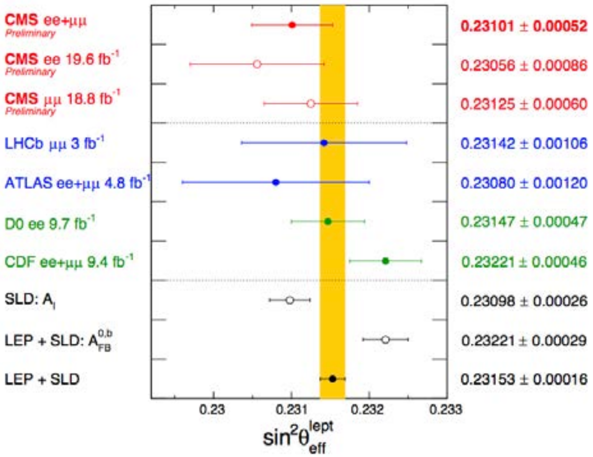
Also recent
Results from CDF

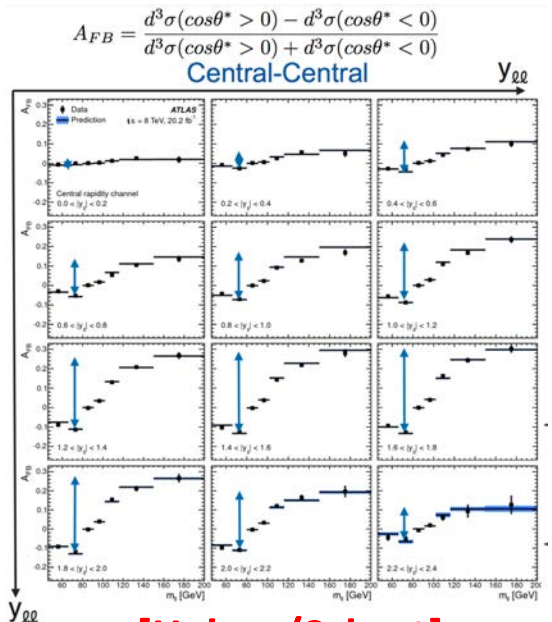


[Brand]

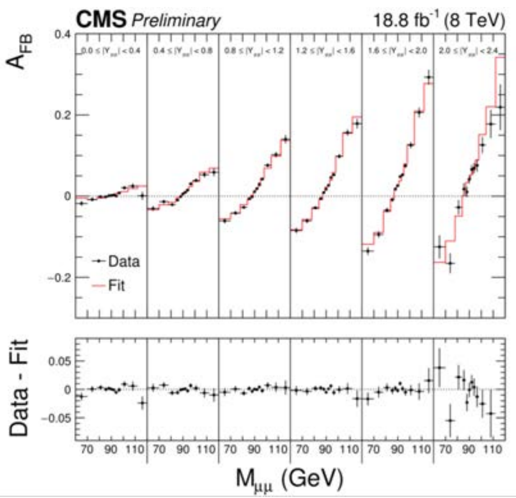
A_{FB} /$\sin^2\theta_{eff}$



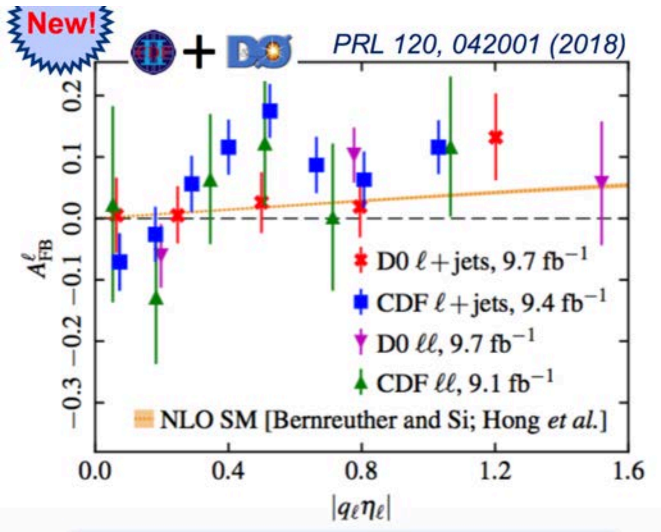




[Helary/Schott]

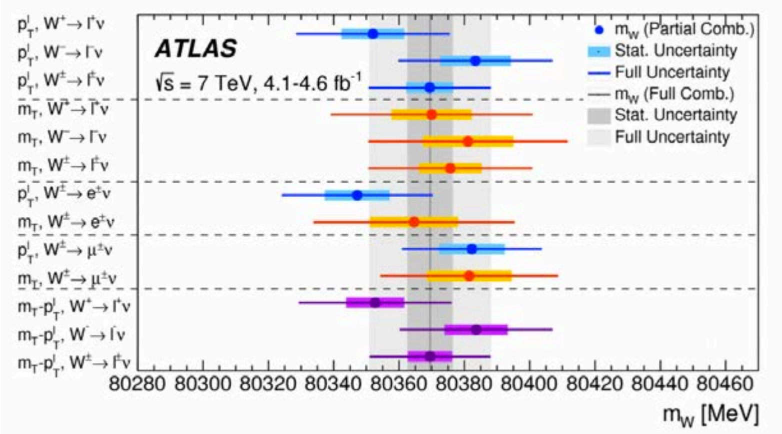


[Apyan/Bendavid]



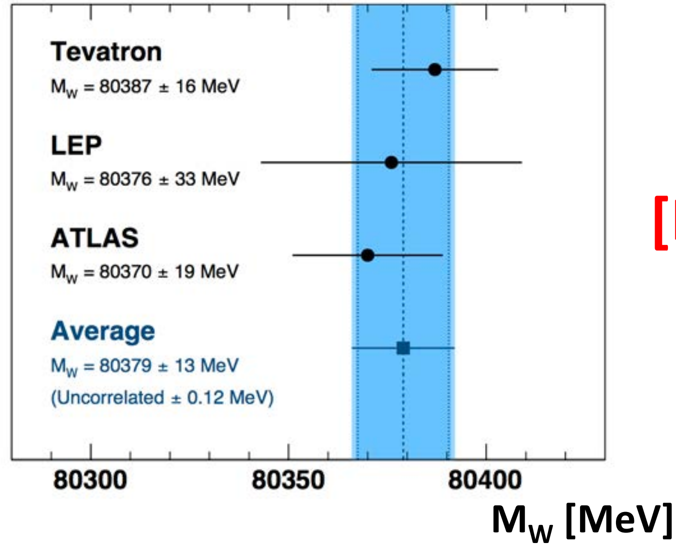
[Brandt]

M_W



[Helary/Schott]

EPJC 78 (2018) 110



[Kogler]

$$M_W = 80370 \pm 7\,(\text{stat}) \pm 11\,(\text{exp. syst.}) \pm 14\,(\text{model. syst.})\ \text{MeV} = 80370 \pm 18.5\ \text{MeV}$$

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T-p_T^ℓ, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

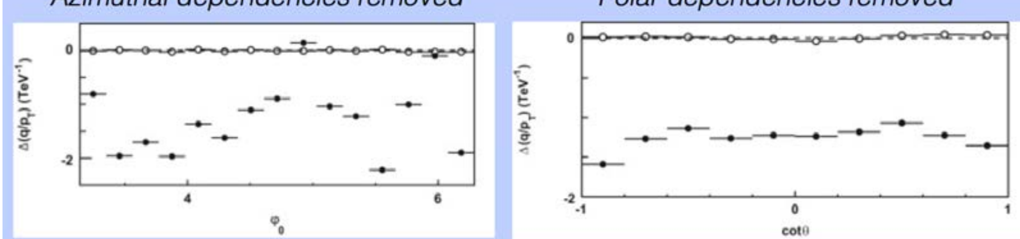
4.2 million W→lν candidates in complete CDF data set

Potential to reduce Tevatron uncertainty to ~10 MeV (~0.01%)

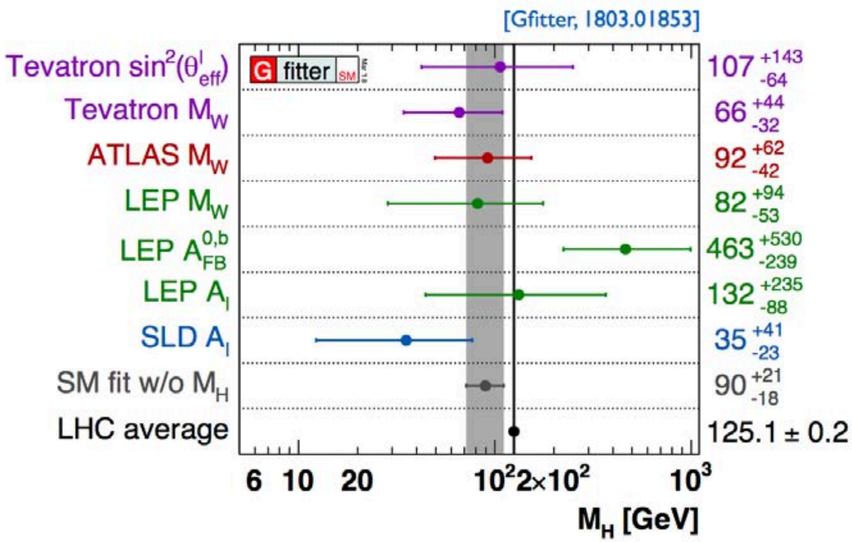
Will require reduction of PDF uncertainty to ~5 MeV

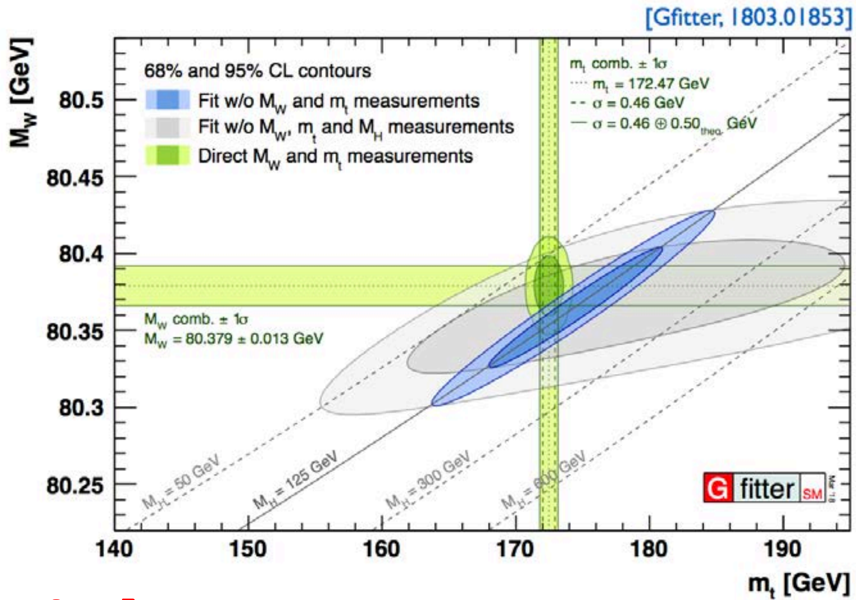
[Hays]

Azimuthal dependencies removed *Polar dependencies removed*

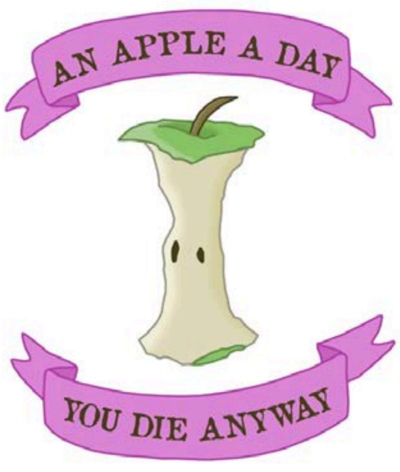


SM FIT: "Incredibly Healthy"





[Kogler]



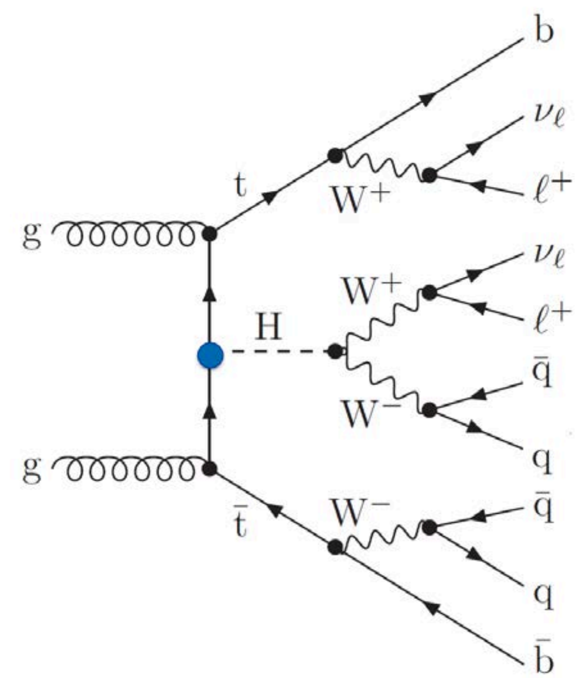
"The BEH News"

- Measurement of the ttH coupling at ATLAS **[Zanzi]** e 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

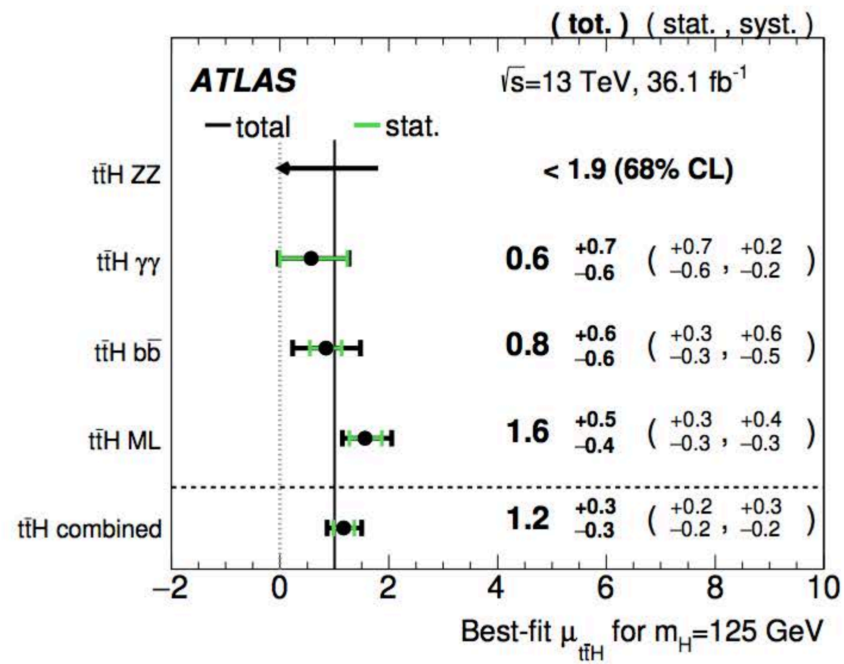
- Irreducible backgrounds from ttV and di-boson final states
- Reducible background from tt



[Zanzi] # ttH Combination

- Combination of $ttH(\rightarrow bb)$, $ttH\rightarrow$multilepton and ttH-enhanced categories in $H\rightarrow\gamma\gamma$ [1802.04146] and $H\rightarrow ZZ^*\rightarrow 4l$ [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)**
  - 38% compatibility between individual channels and combination

Channel	Best-fit μ Observed	Best-fit μ Expected	Significance Observed	Significance Expected
Multilepton	$1.6\ ^{+0.5}_{-0.4}$	$1.0\ ^{+0.4}_{-0.4}$	4.1σ	2.8σ
$H\rightarrow b\bar{b}$	$0.8\ ^{+0.6}_{-0.6}$	$1.0\ ^{+0.6}_{-0.6}$	1.4σ	1.6σ
$H\rightarrow\gamma\gamma$	$0.6\ ^{+0.7}_{-0.6}$	$1.0\ ^{+0.8}_{-0.6}$	0.9σ	1.7σ
$H\rightarrow 4\ell$	< 1.9	$1.0\ ^{+3.2}_{-1.0}$	—	0.6σ
Combined	$1.2\ ^{+0.3}_{-0.3}$	$1.0\ ^{+0.3}_{-0.3}$	4.2σ	3.8σ



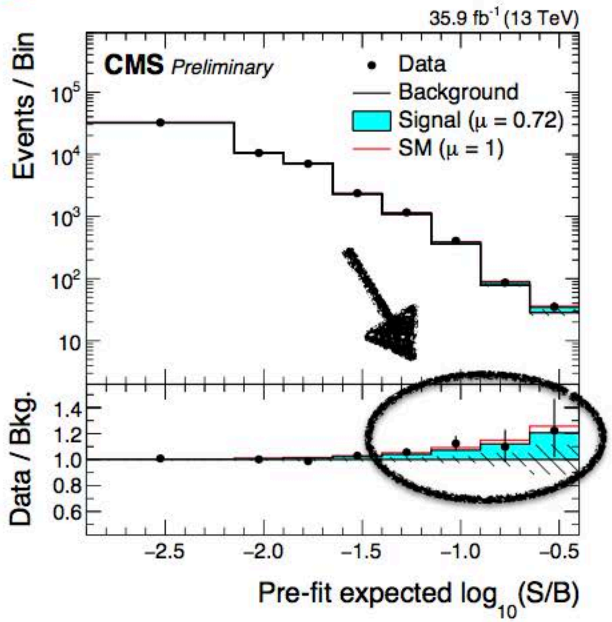
Uncertainty Source	$\Delta\mu$	
$t\bar{t}$ modeling in $H\rightarrow b\bar{b}$ analysis	+0.15	−0.14
$t\bar{t}H$ modeling (cross section)	+0.13	−0.06
Non-prompt light-lepton and fake τ_{had} estimates	+0.09	−0.09
Simulation statistics	+0.08	−0.08
Jet energy scale and resolution	+0.08	−0.07
$t\bar{t}V$ modeling	+0.07	−0.07
$t\bar{t}H$ modeling (acceptance)	+0.07	−0.04
Other non-Higgs boson backgrounds	+0.06	−0.05
Other experimental uncertainties	+0.05	−0.05
Luminosity	+0.05	−0.04
Jet flavor tagging	+0.03	−0.02
Modeling of other Higgs boson production modes	+0.01	−0.01
Total systematic uncertainty	+0.27	−0.23
Statistical uncertainty	+0.19	−0.19
Total uncertainty	+0.34	−0.30

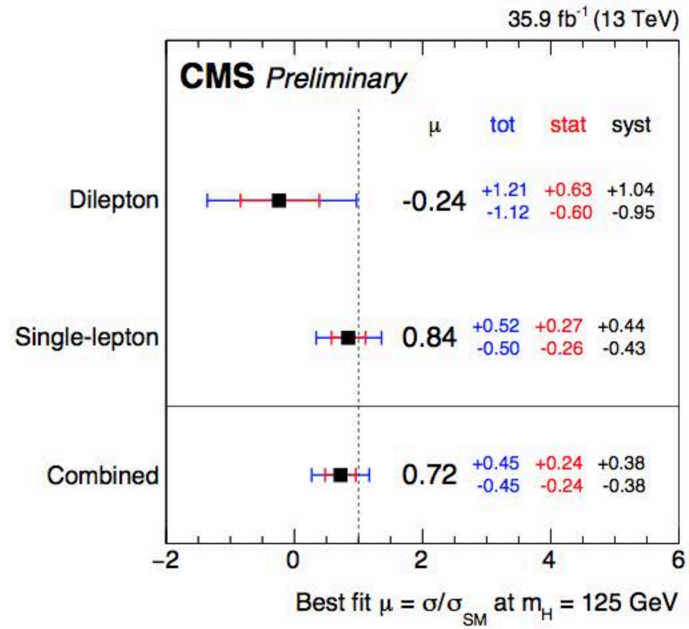
Most sensitive channels limited by systematic uncertainties, mostly theoretical uncertainties. Other channels still statistically limited

NEW RESULT

bb, 1ℓ + 2ℓ results

CMS PAS HIG-17-026





Uncertainty source	$\pm\sigma_\mu$ (observed)
total experimental	+0.15/-0.16
b tagging	+0.11/-0.14
jet energy scale and resolution	+0.06/-0.07
total theory	+0.28/-0.29
$t\bar{t}$+hf cross-section and parton shower	+0.24/-0.28
size of MC samples	+0.14/-0.15
total systematic	+0.38/-0.38
statistical	+0.24/-0.24
total	+0.45/-0.45

- **Very significant improvement over the previous version of the analysis**
- Main systematic uncertainties:
  - tt + heavy flavor theory prediction
  - b-tagging and jet energy calibration

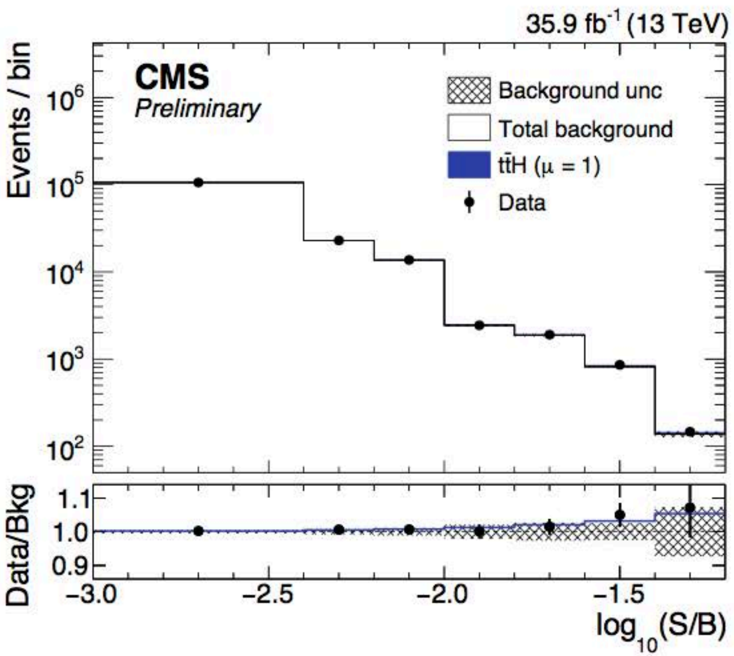
[Peruzzi]

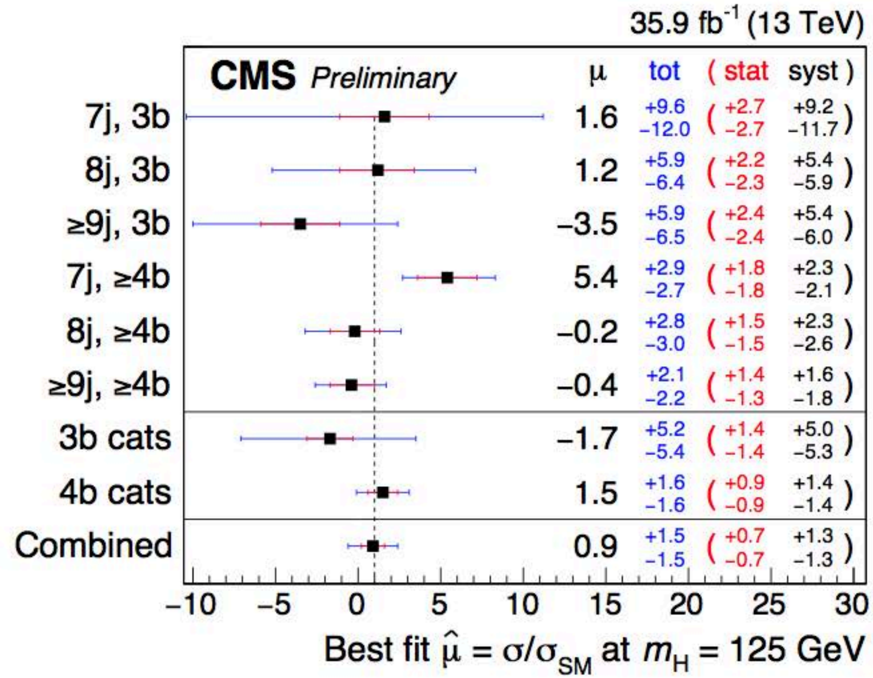
bb, 0ℓ results

NEW RESULT

CMS Preliminary HIG-17-022

New channel in CMS

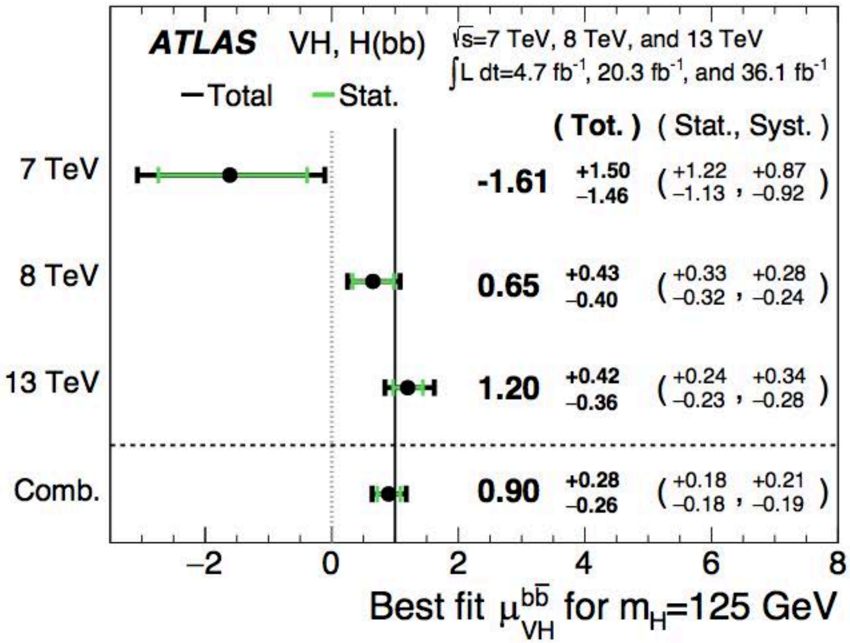


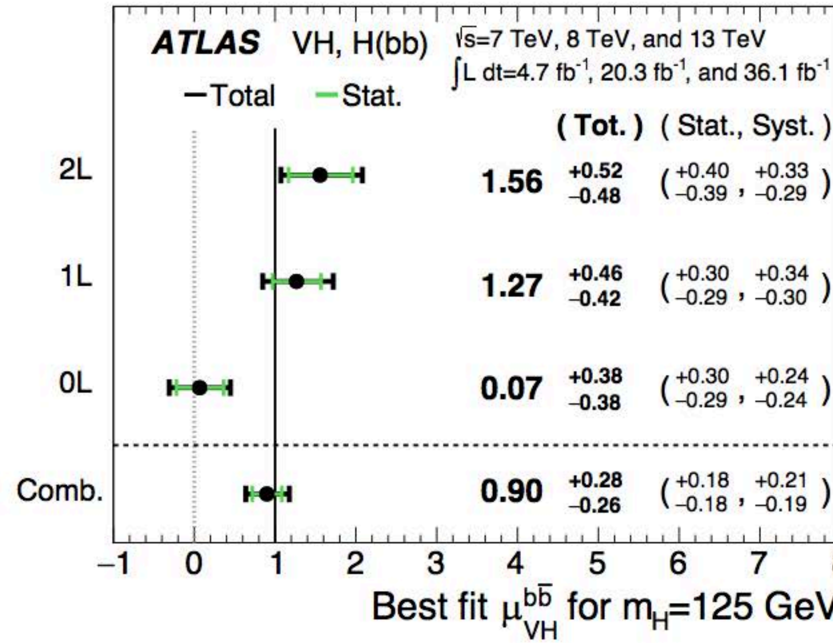


- In agreement with SM expectation, **driven by ≥4b categories**
- Main experimental uncertainties: b-tagging, QCD shape modeling
- Nicely complements the sensitivity provided by semi- and di-leptonic top decays

Combined ATLAS VH($b\bar{b}$) Results

- Comparison with 7 & 8 TeV results from LHC Run 1
  - Use the signal strength μ_{VH} for different values of $\sqrt{s}$
  - Combined observed significance 3.6σ (4.0σ expected)





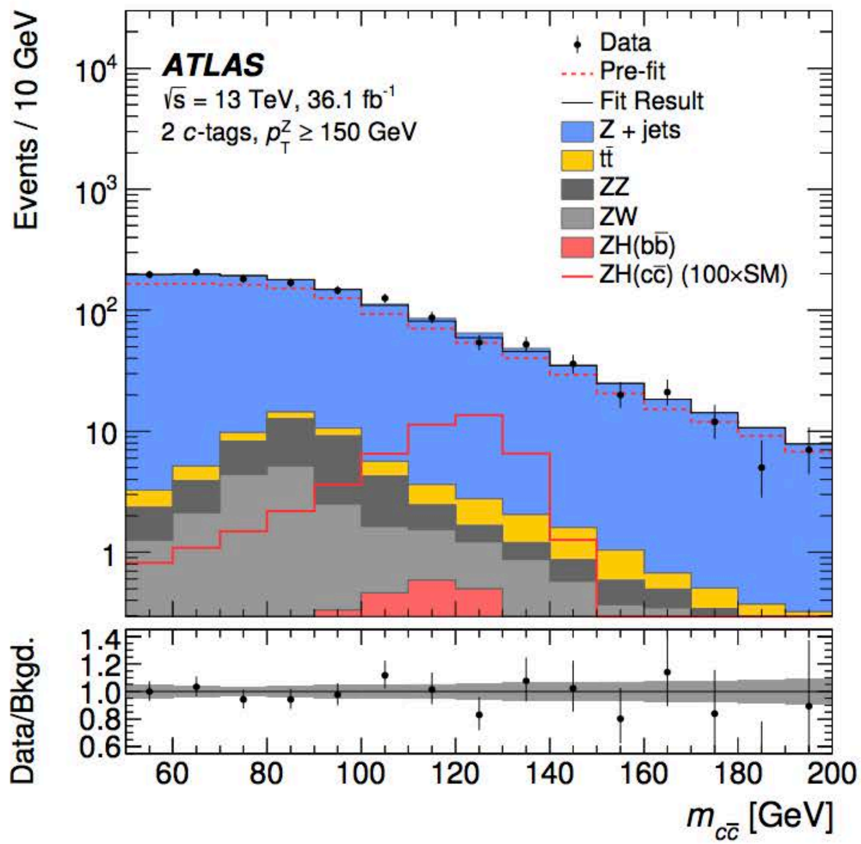
- Consistent with Standard Model, so far… **[Nielsen]**

Results for ZH($c\bar{c}$) and ZZ/ZW

Cut-based event selection with fit to m_{cc}

[Nielsen]

- Target $c\bar{c}$ resonances
  - Requirement on ΔR_{cc} varies from 2.2 at low p_T^Z to 1.3 at high p_T^Z (>200 GeV)
  - p_T^Z ranges 75-150, >150 GeV
- Simultaneous fit of signal and Z+jets background
  - Flavor tagging uncertainty is dominant limitation on uncert.

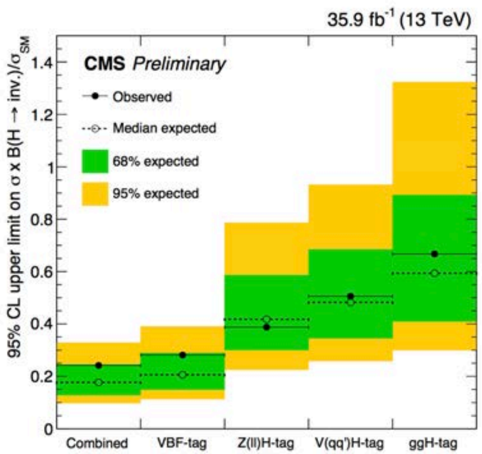


Validation: $\mu_{ZV} = 0.6^{+0.5}_{-0.4}$
(1.4σ observed, 2.2σ expected)

Observed upper limit of 2.7 pb on $\sigma(ZH) \times B(H \to c\bar{c})$
(SM predicts 26 fb at 13 TeV)

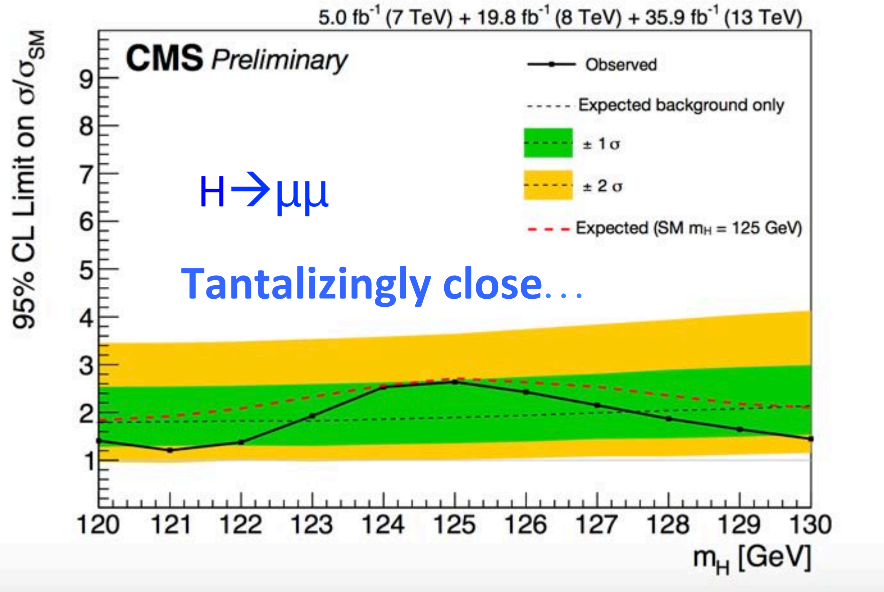
Higgs Rare Decays in CMS [Marini]

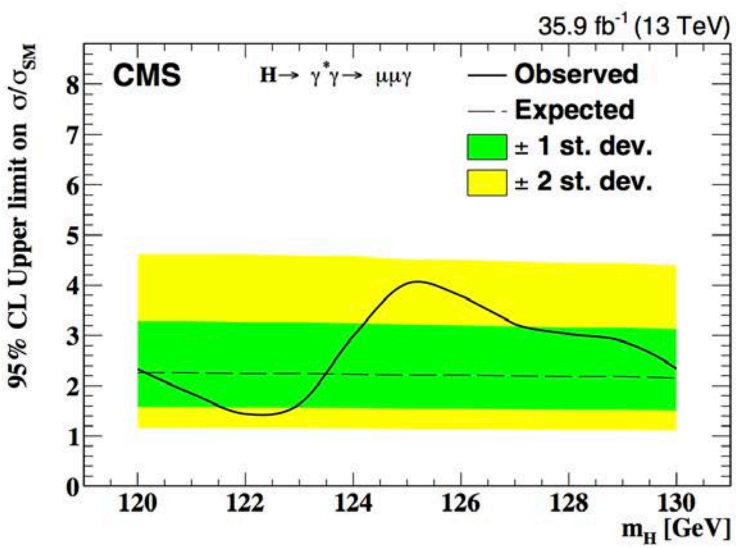
B(H→inv)<0.24 95% CL

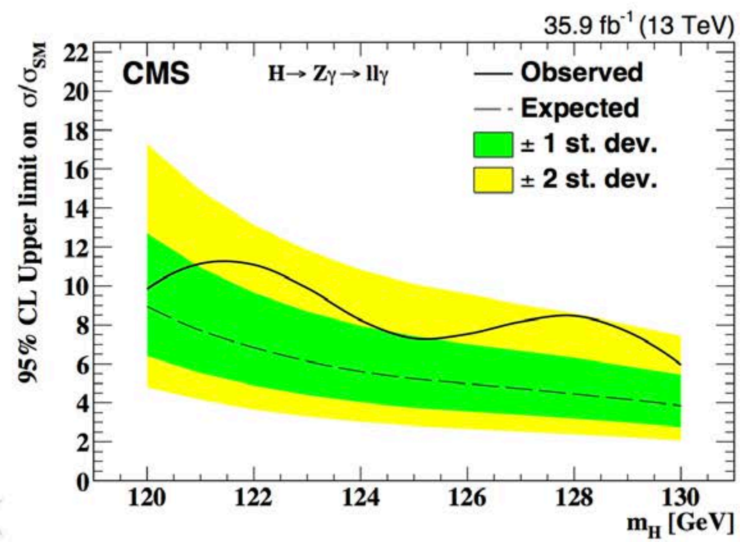


HIG-17-023 arXiv:1712.02345

arXiv:1711.00431



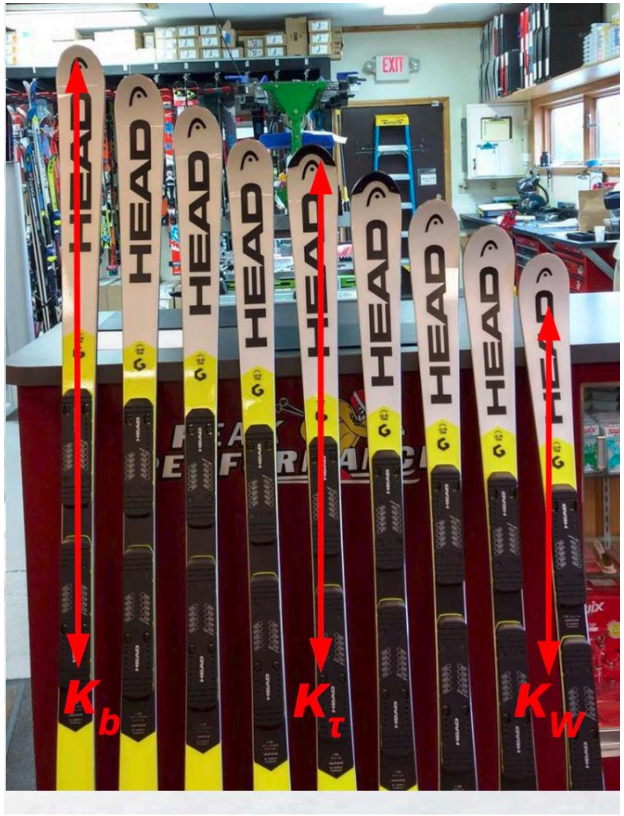




Higgs Couplings

[Sperka]

- Most important to see how standard is the Higgs particle
- Large combination of production and decay channels
- Progress at on this subject LHC crucial for the future of particle physics
- Spectacular consistency so far

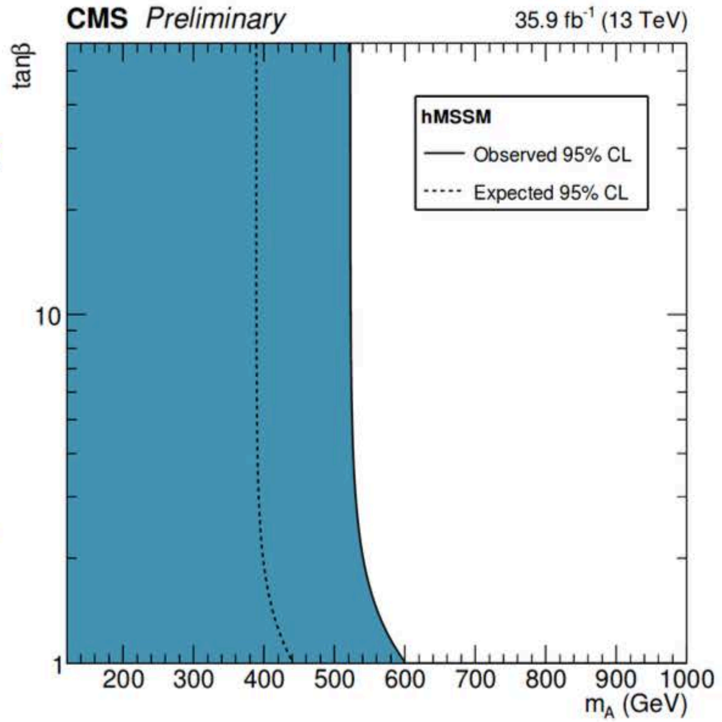


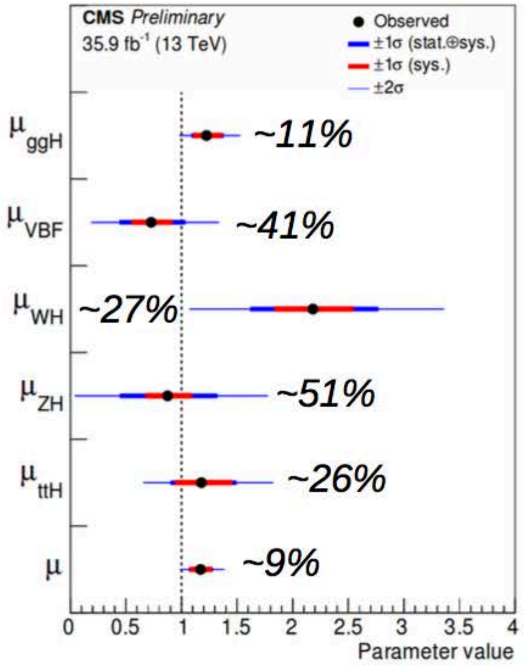
Massive amount of results summarized in Sperka's talk

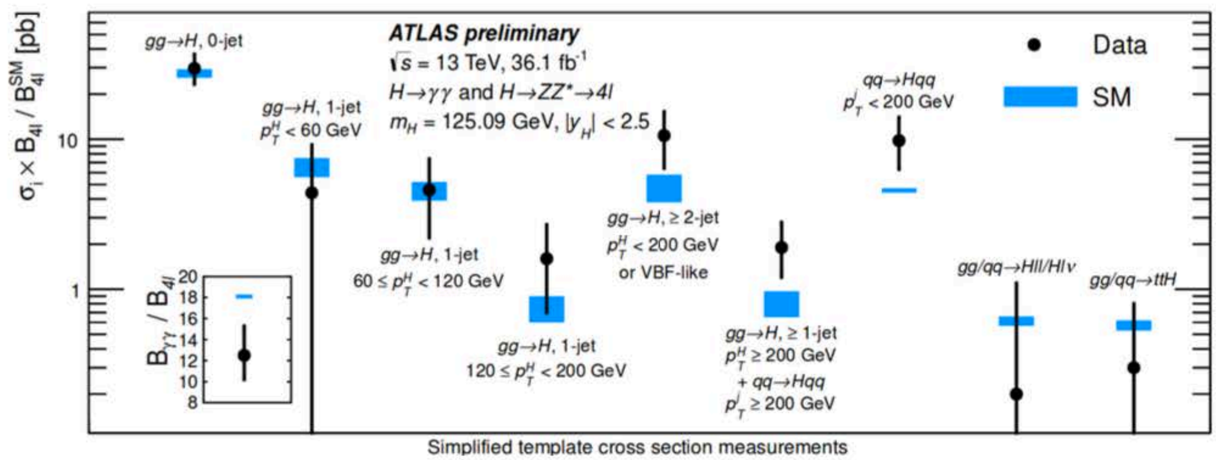
Summary

[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

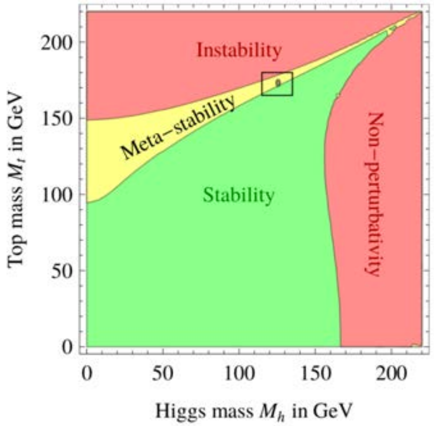






[Sperka]

M_H



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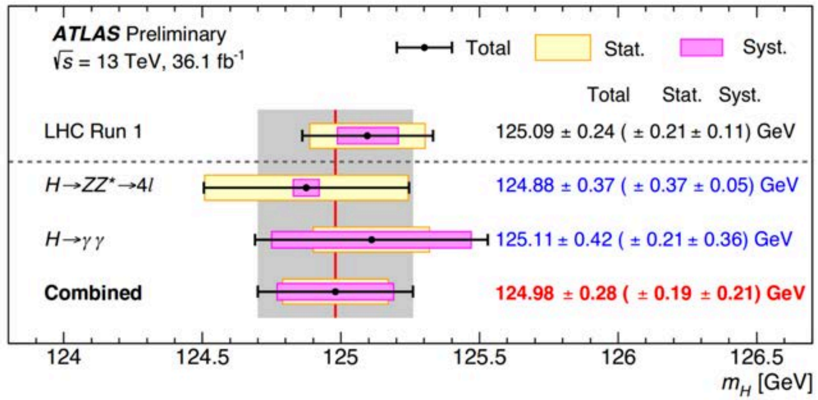
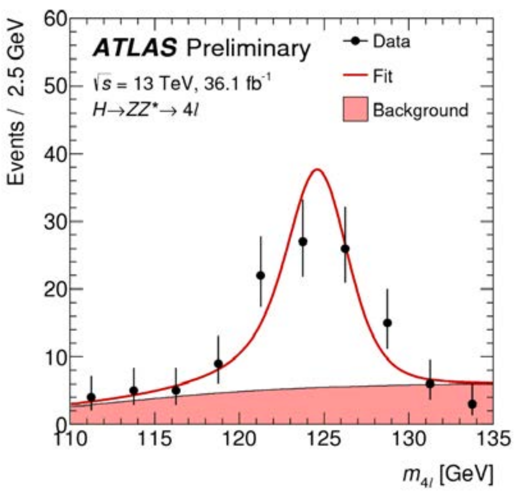
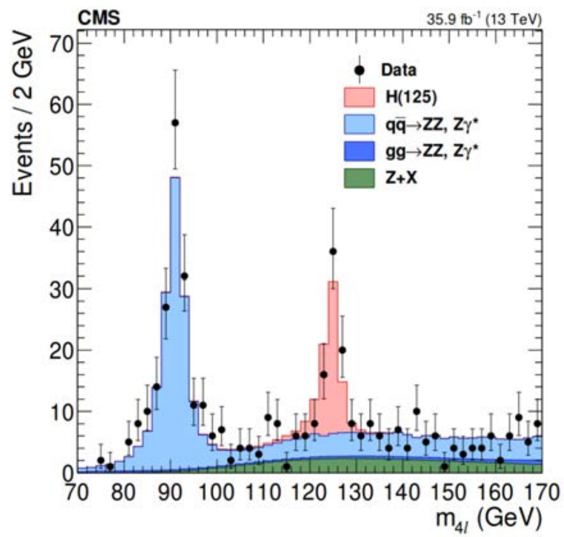
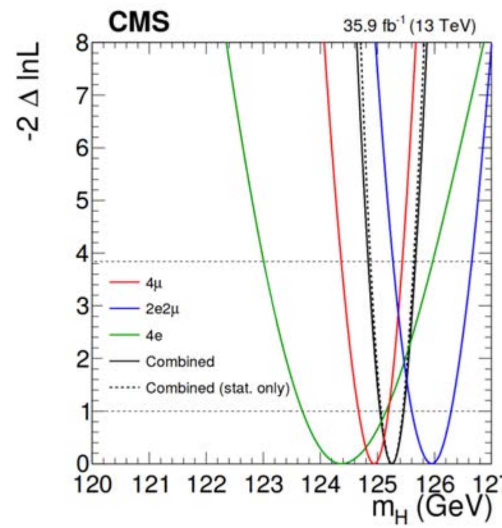




JHEP11(2017)047





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

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

H→WW*: results **New!** [Nomidis]

- Signal strength:

$$\mu_{ggF} = 1.21^{+0.12}_{-0.11}(\text{stat.})^{+0.18}_{-0.17}(\text{sys.}) = 1.21^{+0.22}_{-0.21}$$

$$\mu_{VBF} = 0.62^{+0.30}_{-0.28}(\text{stat.}) \pm 0.22(\text{sys.}) = 0.62^{+0.37}_{-0.36}$$

➪ *Uncertainties in good agreement with expectations*

$$\mu^{exp}_{ggF} = 1.00 \pm 0.10(stat.) \pm 0.18(sys) = 1.00^{+0.21}_{-0.21}$$

$$\mu^{exp}_{VBF} = 1.00^{+0.33}_{-0.31}(stat.) \pm 0.25(sys) = 1.00^{+0.42}_{-0.40}$$

➪ *Precision as good or better than the Run-1 combination*

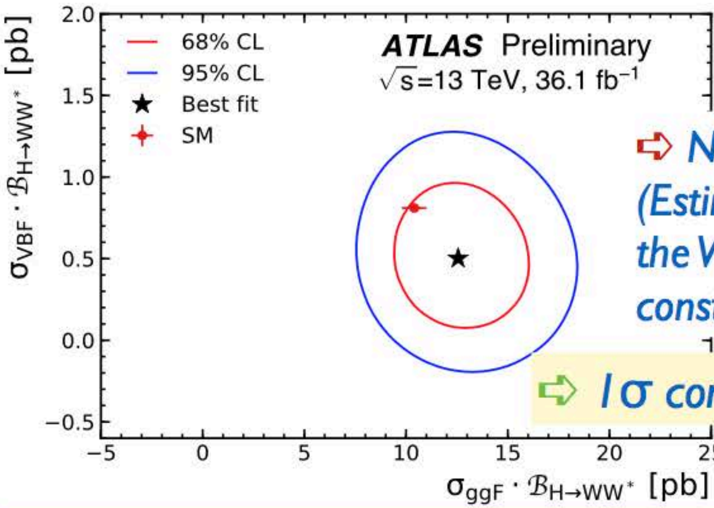
Best H→WW measurements*

	Run-1 ATLAS+CMS	Run-2 15 fb^{-1} CMS
	$0.84^{+0.17}_{-0.17}$	
	$1.2^{+0.4}_{-0.4}$	$1.4^{+0.8}_{-0.8}$

- Cross-section times branching ratio:

$$\sigma_{ggF} \cdot \mathcal{B}_{H\to WW^*} = 12.6^{+1.3}_{-1.2}(\text{stat.})^{+1.9}_{-1.8}(\text{sys.})\ \text{pb} = 12.6^{+2.3}_{-2.1}\ \text{pb}$$

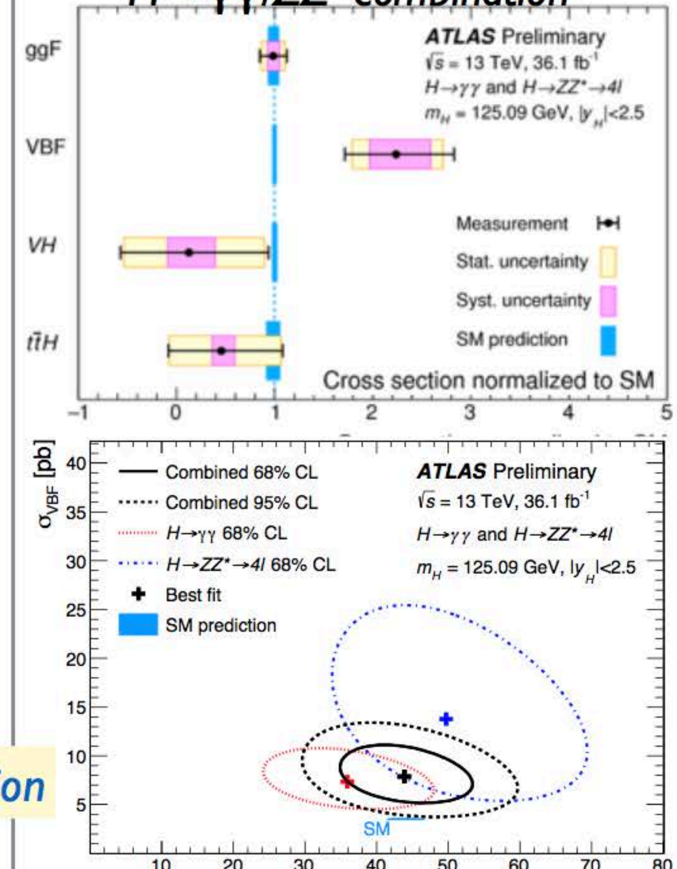
$$\sigma_{VBF} \cdot \mathcal{B}_{H\to WW^*} = 0.50^{+0.24}_{-0.23}(\text{stat.}) \pm 0.18(\text{sys.})\ \text{pb} = 0.50^{+0.30}_{-0.29}\ \text{pb}$$



➪ *No strong correlation (Estimate of ggF leakage into the VBF signal region is well-constrained by the 0,1j data)*

➪ *1σ compatibility with SM prediction*

H→γγ/ZZ combination*



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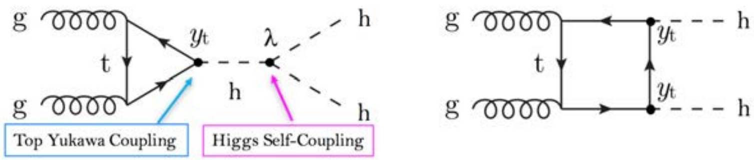
Search for HH Production



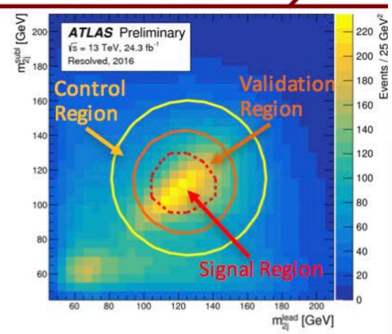
[Kagan]

NEW!

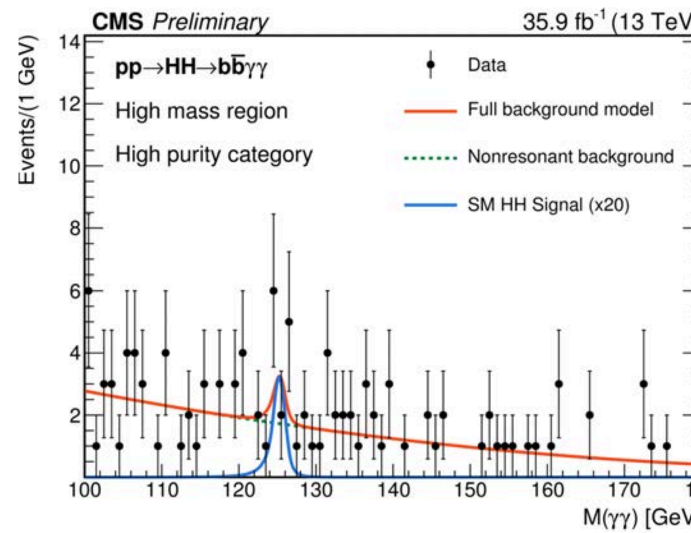
ATLAS-EXOT-2016-31 9

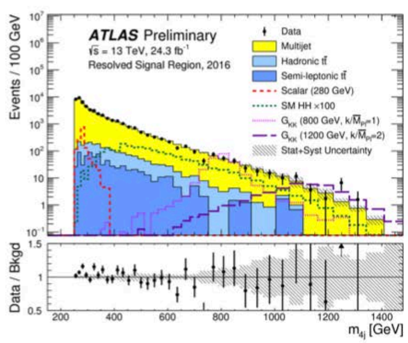
hh→bbbb

Background QCD

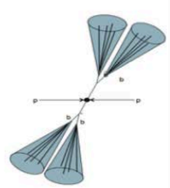


$$\lambda_{SM} = \frac{m_h^2}{2v^2}$$

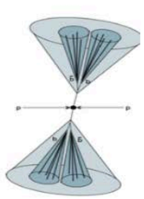


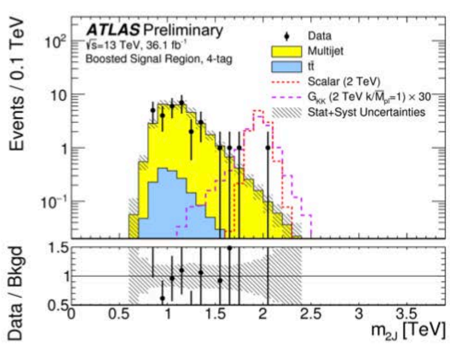


Resolved



Boosted





- SM production limits reach ~20xσ_{SM}
- Best channel limits on anomalous trilinear coupling: $\frac{\lambda}{\lambda_{SM}} \in [-8, 15]$
- Assuming $\sqrt{N}$ improvements L=120 fb^{-1} in Run II will bring single channel limits at or below 10xσ_{SM}!

Wrap-up of "The BEH news"

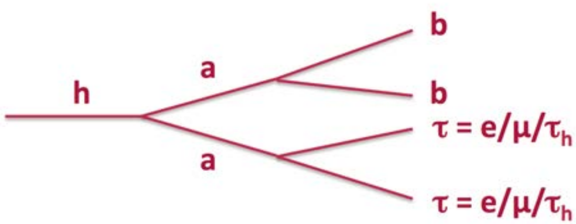
- Remarkable progress on ttH, evidence of the signal with SM strength is building up. Nice to see so many results based on Run2 (full 2016 statistics)
- Advancing in a steady way to see H(bb) and H(cc) in W/ZH associated production
- Tantalizing close to H→μμ; H→ invisible being pinned down
- The combinations 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 (SUSY and Exotics)

- Search for H→aa CMS **[Caillol]**
- Searches for BSM scalars in ATLAS **[Stark]**
- Dilepton (ee, mumu, emu) in CMS **[Berry]**
- Heavy resonances with jet sub-structure techniques **[Janski]**
- Search for heavy vector quarks in ATLAS **[Nikiforou]**
- Search for Higgsinos and related challenges **[Mete]**
- Progress on SUSY final states with soft leptons **[Botta]**
- Squorks and gluino searches with RPV **[Barberis]**
- Long-lived particles in LHCb **[Borsato]**

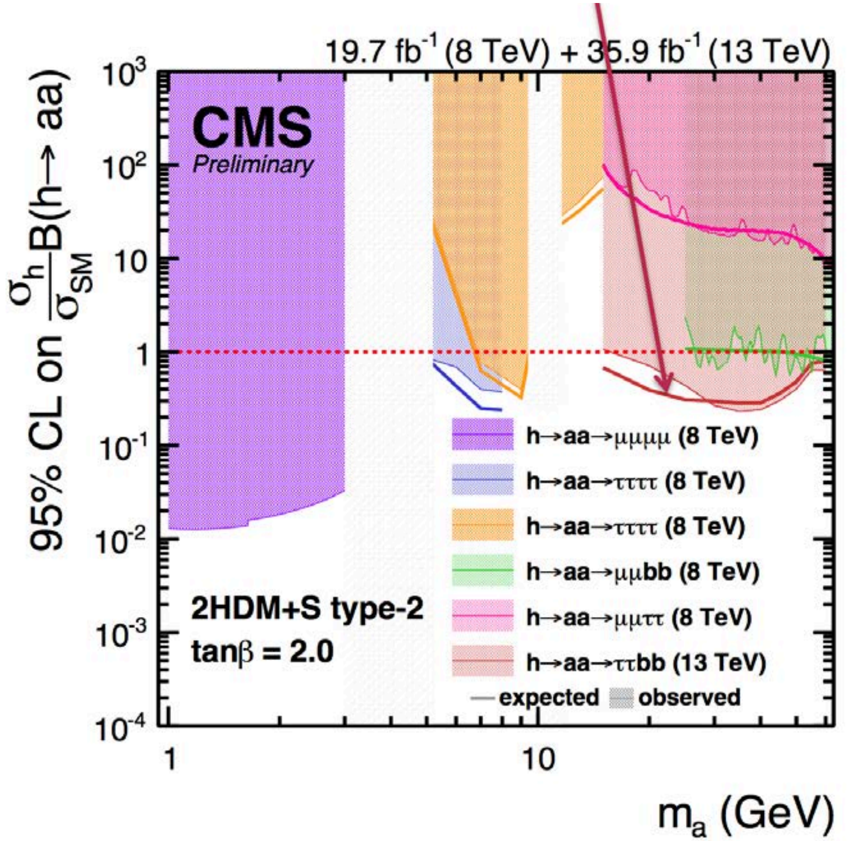
H→aa→bbττ

New Run 2 result



CMS-PAS-HIG-17-024

[Caillol]



Systematics

Uncertainty	Description
τ_h identification	5%
e/μ identification	2%
τ_h energy scale	1.2% per decay mode, with effect on $m_{b\tau\tau}$ and $m_{\tau\tau}$ distributions
b jet identification	5—10% depending on p_T, with effect on $m_{b\tau\tau}$ distribution
Norm Z→ll bkg	7%
Norm. j→τ_h fakes bkg	20%, constrained to 7% after fit
Norm ttbar bkg	6%
Shape Z→ττ	Uncertainties on Z p_T and $m_{b\tau\tau}$ corrections, with effect on $m_{\tau\tau}$ distribution
Bin-by-bin	Each bin or each distribution can be varied within its statistical uncertainty (coming from limited MC statistics, or limited observed events in control regions)

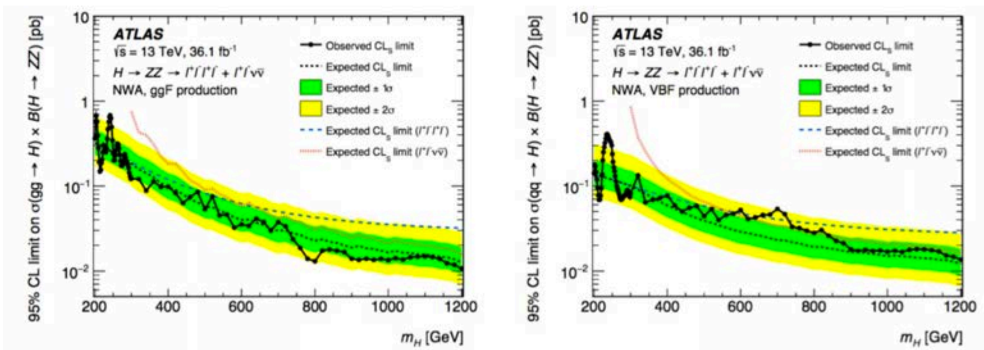
[Stark]

Searches for BSM scalars

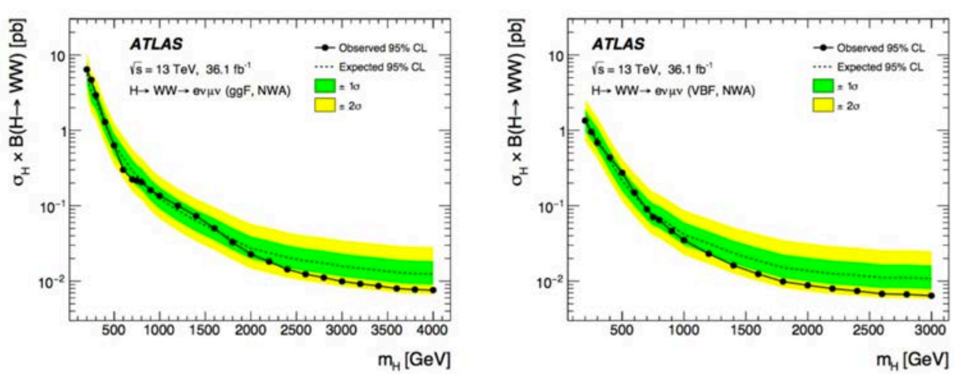
Various strategies for searches for an extended Higgs sector:

Indirect	**Direct**	**Decays of 125 GeV Higgs**
Look for non-standard properties of 125 GeV Higgs (couplings, CP, etc)	Directly search for new particles (BSM Higgs[es]) decaying to SM particles	Directly search for decays of the 125 GeV Higgs to BSM states (light scalars, ...)

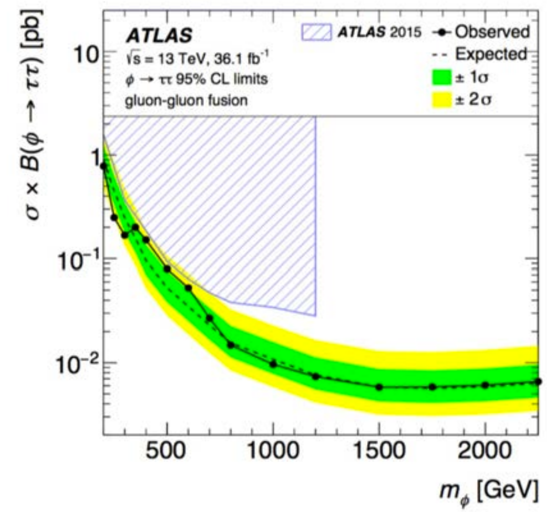
H→ZZ

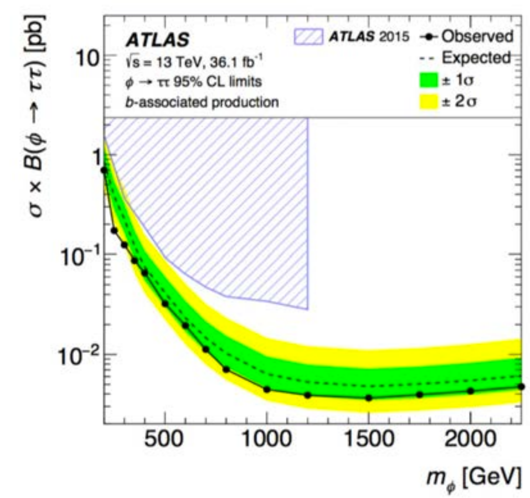


H→WW



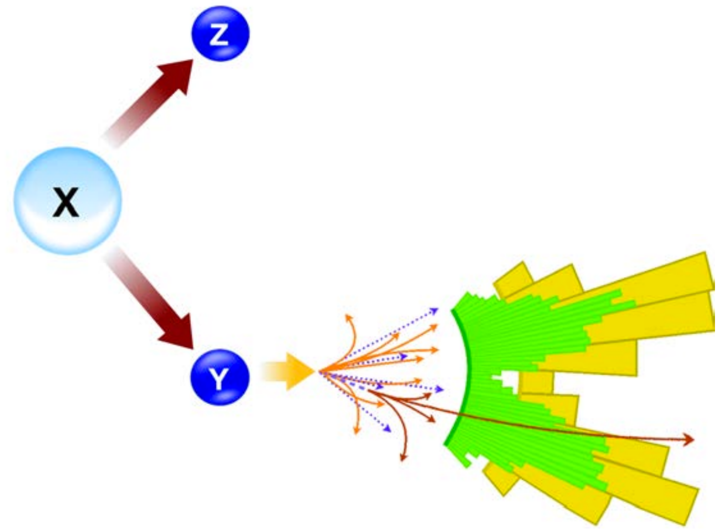
H/A→ττ





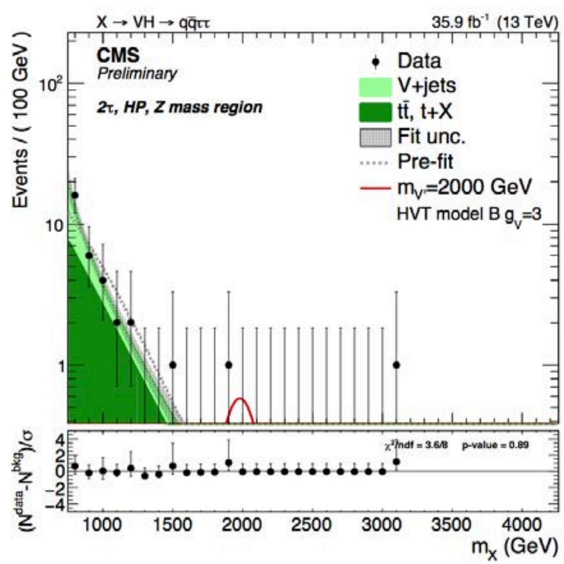
Searches for Heavy Resonances

Process	Final State(s)	Boosted Object Tagging	Luminosity (fb⁻¹)	CMS PAS	Publication
X→ZV	ℓℓqq	Yes	35.9	B2G-17-013	Preparing for JHEP
X→HV X→HH	ττqq ττbb	Yes	35.9	B2G-17-006	Preparing for JHEP
X→tt̄	ℓvqq bqqbqq	Yes	2.6	B2G-16-015	JHEP 07 (2017) 001
X→tb	ℓvbb	No	35.9	B2G-17-010	PLB Phys. Lett. B 777 (2017) 39
X→ℓℓ	ee/μμ	No	35.9	EXO-16-047 & EXO-18-006	Preparing for JHEP
X→ℓv	ev	No	35.9	EXO-16-033	Preparing of JHEP
X→eμ	eμ	No	35.9	EXO-16-058	arXiv:1802.01122 Submitted to JHEP

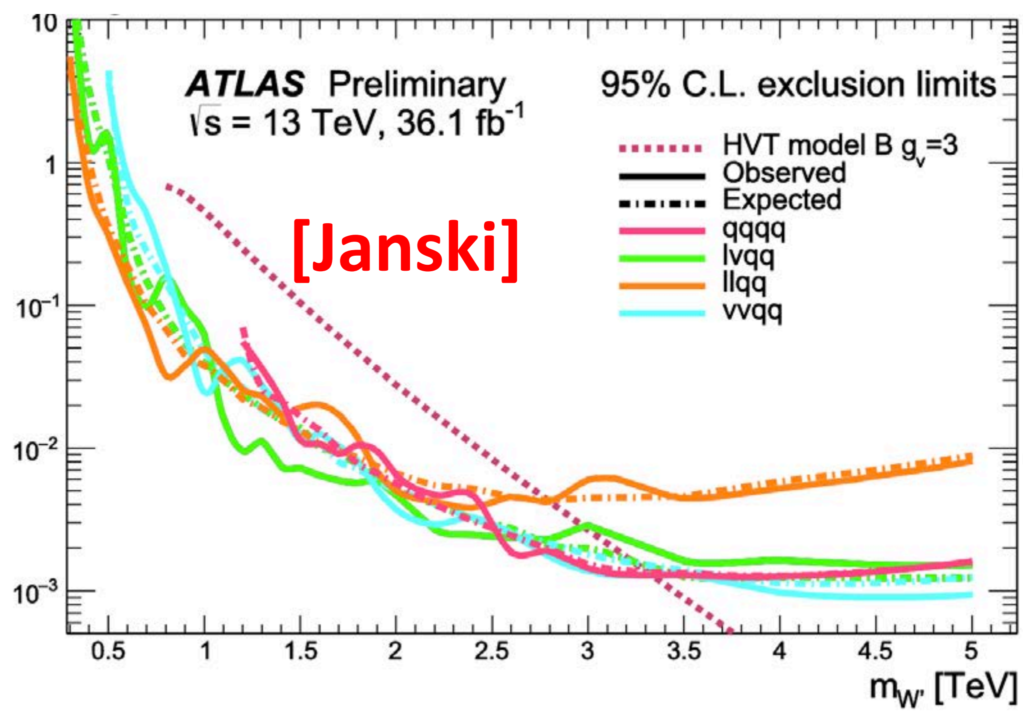


[Berry]

2 Taus and a high purity Z-jet

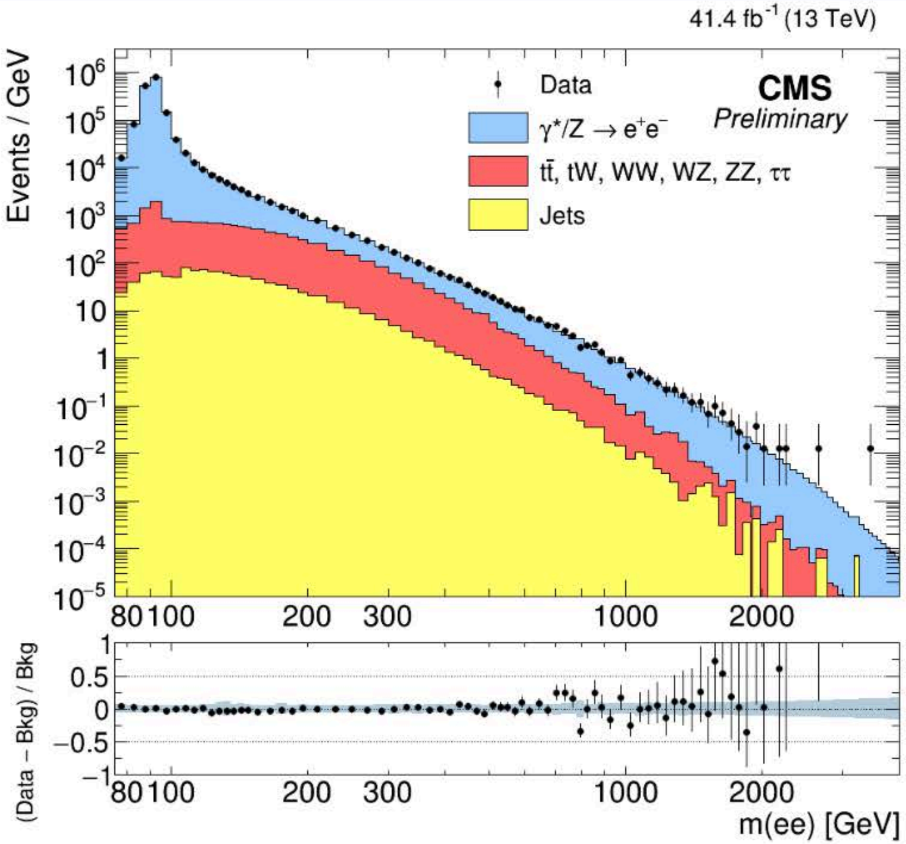


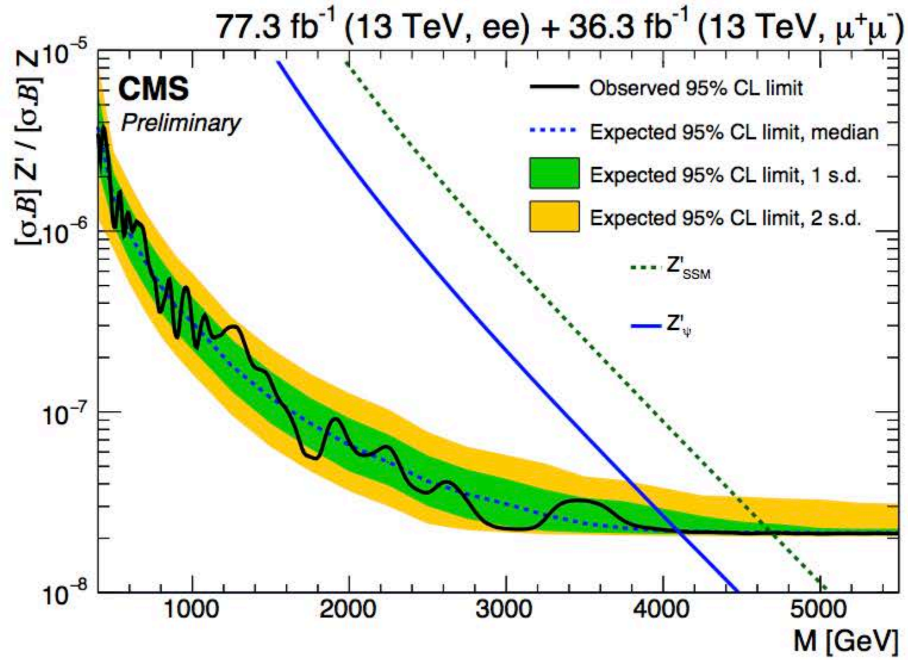
[Janski]



2017 Results!

UIC UNIVERSITY OF ILLINOIS AT CHICAGO



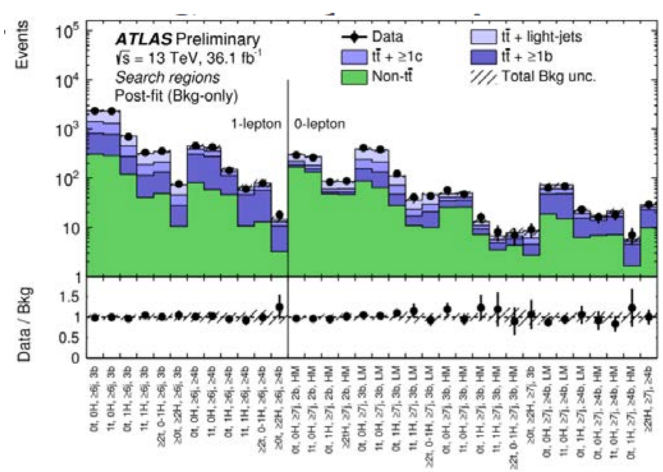


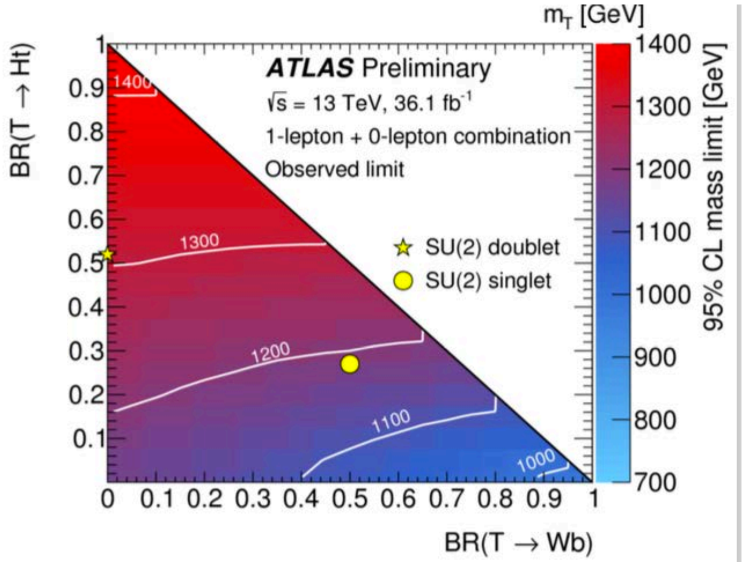
- No excess seen in 2017 electron channel
- Other interpretations in backup slides
- Can extend the Z' exclusion to 4.7 and 4.1 TeV for the Z'_{SSM} and Z'_{ψ}, respectively

[Berry]

Search for Heavy Quarks [Nikiforou]

$$T\bar{T} \to Ht + X$$



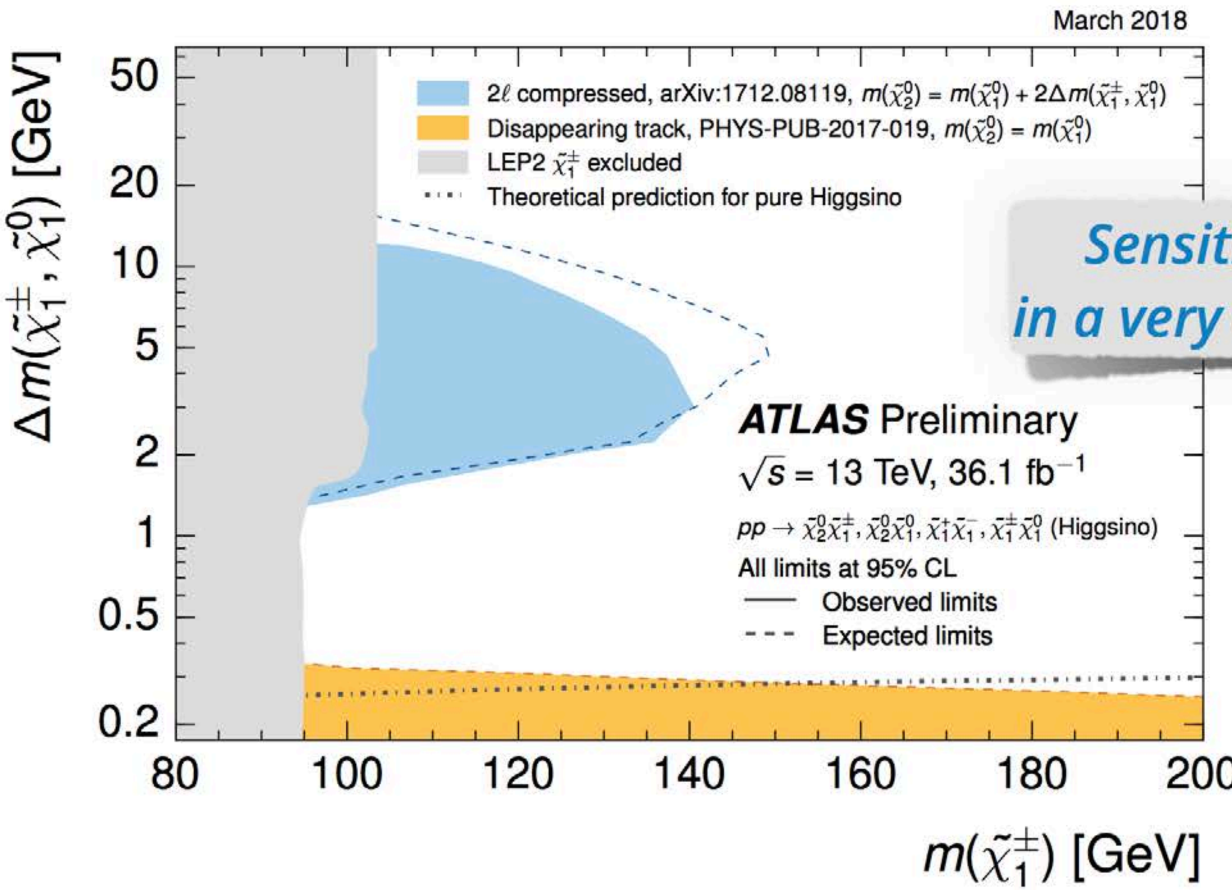


- Vector like $\boldsymbol{T}$ masses up to ~**1.2** to **1.4 TeV** are excluded assuming 100% BR to $\boldsymbol{Zt}$, $\boldsymbol{Wb}$, or $\boldsymbol{Ht}$
- Vector like $\boldsymbol{B}$ masses up to **1.25 TeV** are excluded assuming 100% BR to $\boldsymbol{Wt}$
- ~$\mathbf{500\ GeV}$ impro- vement compared to previous 8 TeV ATLAS result

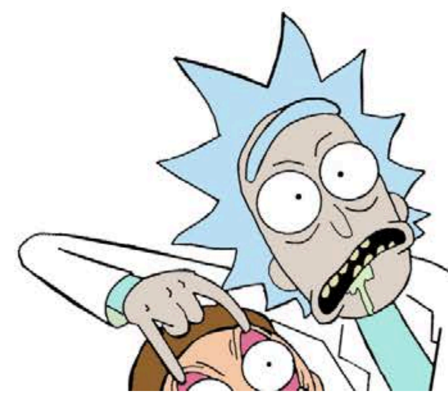
Higgsinos searches in ATLAS

Testing several scenarios with compressed spectra

[Mete]



Sensitivity beyond LEP limits in a very challenging phase-space!

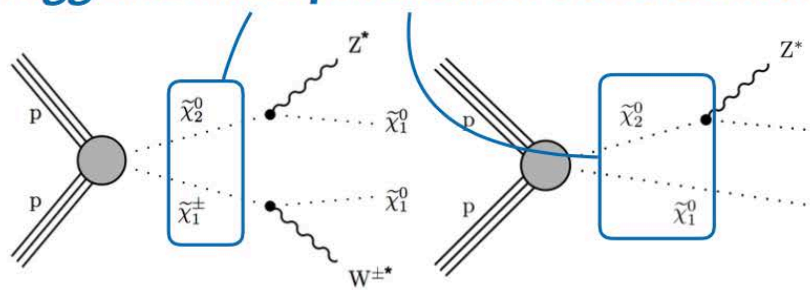


Higgsinos search in CMS (soft leptons)

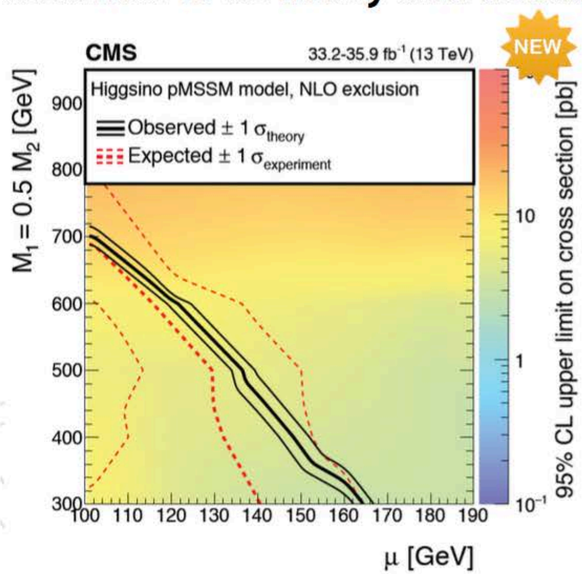
[Botta]

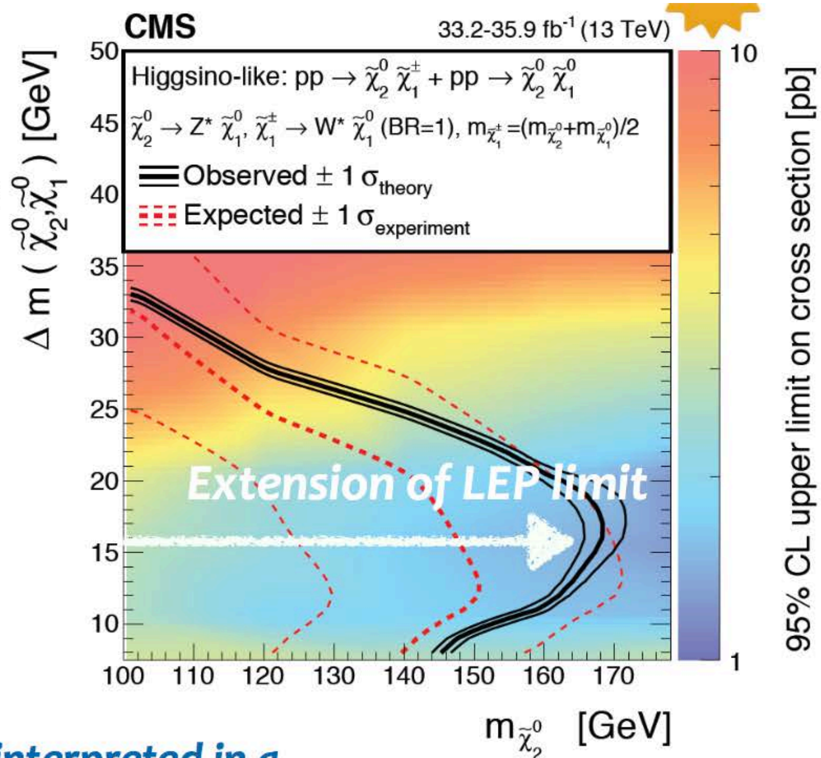
Also Compressed Stops

Higgsino-like[1] production cross section



100% BR into Z*/W*, other SUSY particles assumed to be heavy and decoupled



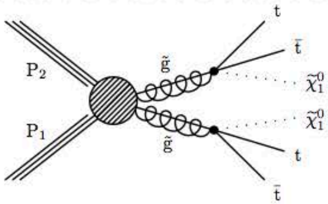


Results also interpreted in a phenomenological MSSM model:

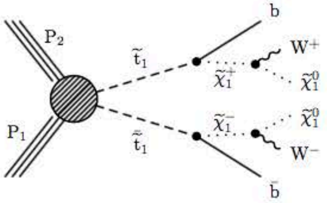
μ(higgsino), M1 (bino) are varied, M2 (wino) = 2M1

[1] B. Fuks et al. "Realistic simplified gaugino-higgsino models in the MSSM", arXiv:1710.09941

Is SUSY hiding somewhere? [Seitz]



- Extensive search programs for SUSY signatures
  - Mostly R-parity = $(-1)^{2s+3B+L}$ conserving (RPC) scenarios → Stable LSP → MET in the final state
  - **Gluino/Squark** limits are pushing **1.5 - 2 TeV**
  - **Stop** limits are pushing **1 TeV**

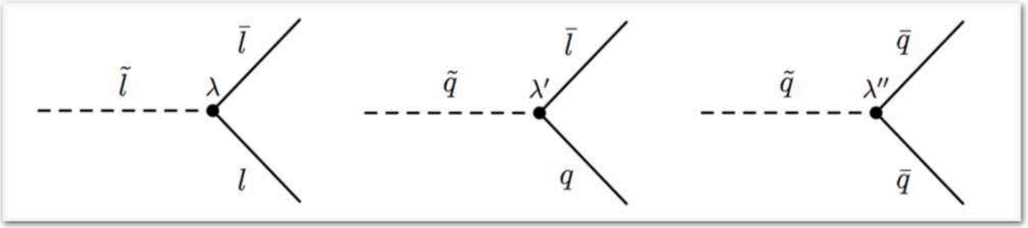


The RPV landscape

$$W_R = \lambda_{ijk} L_i L_j e_k + \lambda'_{ijk} L_i Q_j d_k + \lambda''_{ijk} u_i d_j d_k$$

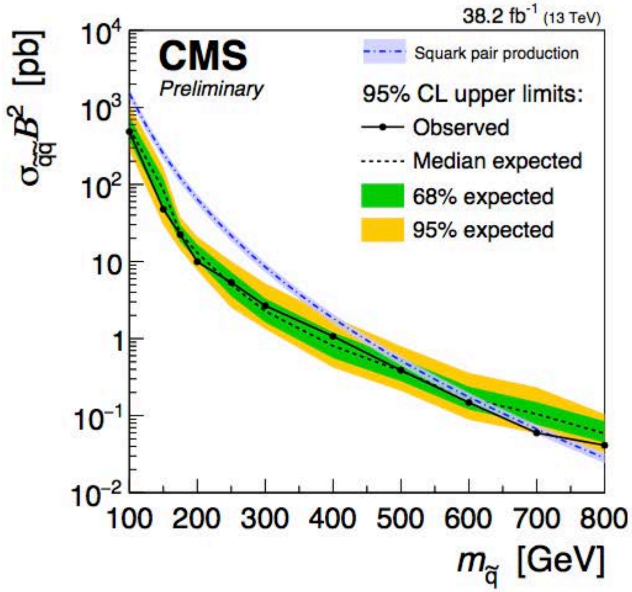
$L = l_l/\nu_L \quad E = l_R$
$Q = q_L \quad u,d = q_R$
i,j,k = generations

Lepton number violation *Baryon number violation*

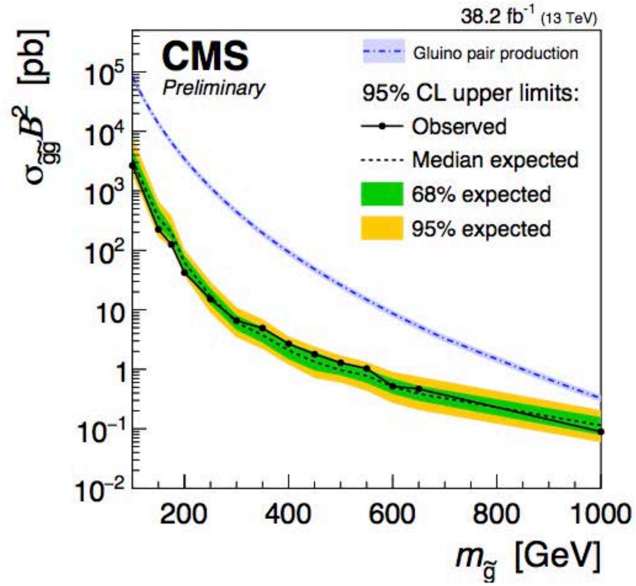


Typically only one **λ** is assumed to be non-zero

[Seitz]



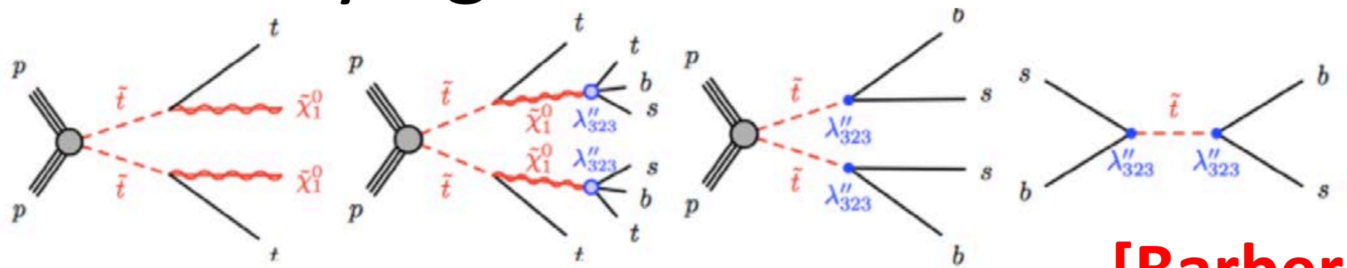
RPV Squarks excluded between 100 - 700 GeV



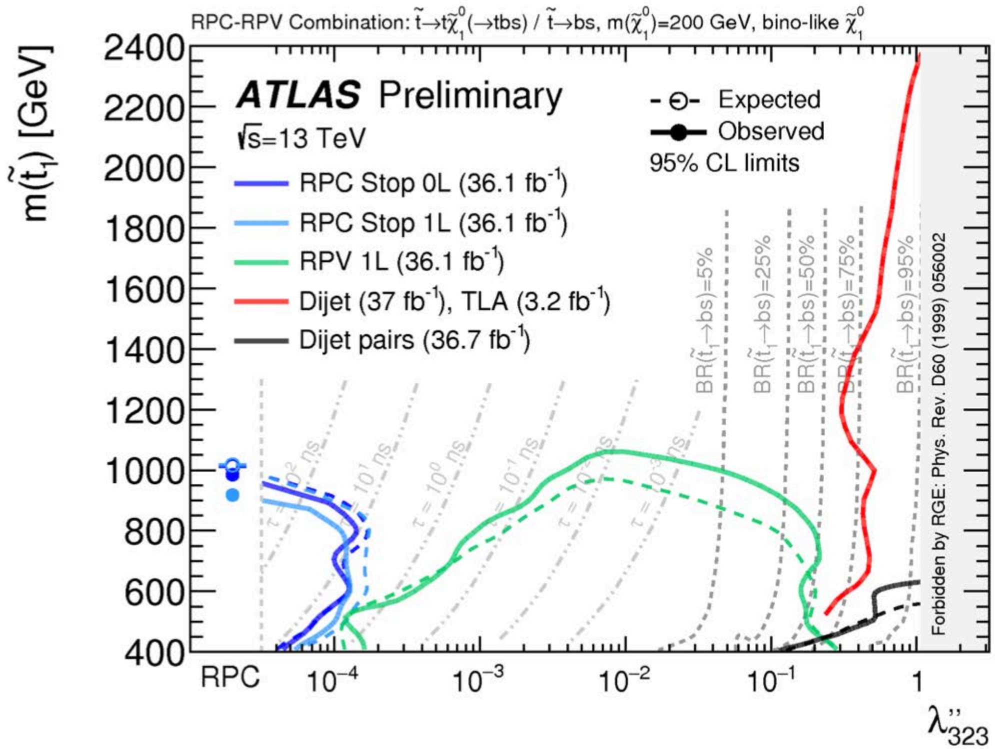
RPV Gluinos excluded between 100 - 1000 GeV

- Focus here was on hadronic RPV
  - Some low mass ranges were previously unexplored
    - New **100 - 700 GeV for squarks and 100 - 1000 GeV gluinos with intermediate RPV Higgsinos → first result of its kind**
    - **80 - 240 GeV for RPV stops → qq**
  - High mass limits are pushing upward
    - **1600 GeV for RPV gluinos → tbs**

Reinterpretation of SUSY Searches varying amount of RVP



[Barberis]



Example: Stop model varying the strength of the baryon number violating parameter λ''_{323}

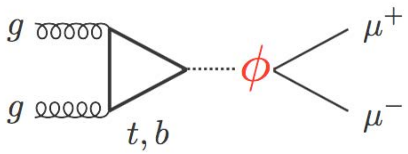
Weakest points in the Transitions between the analyses

LHCb: light bosons and dark photons searches

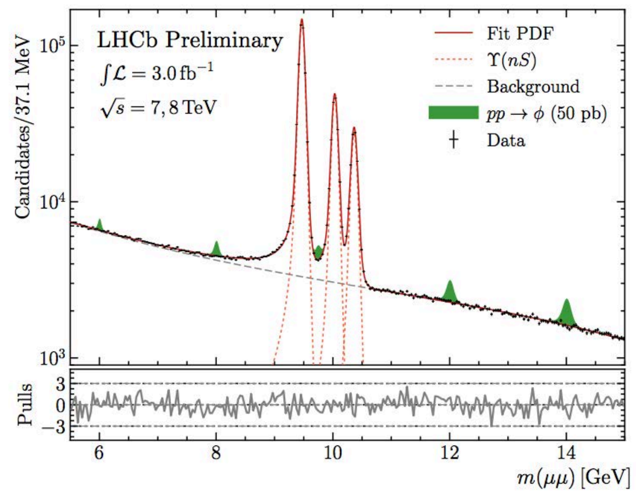
[Borsato]

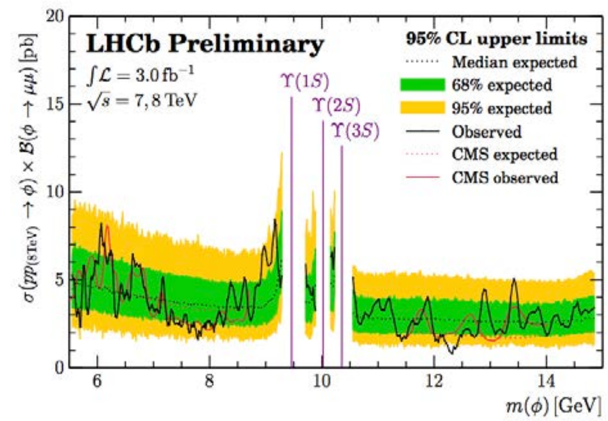
LHCb-PAPER-2018-008 in preparation

Light Boson

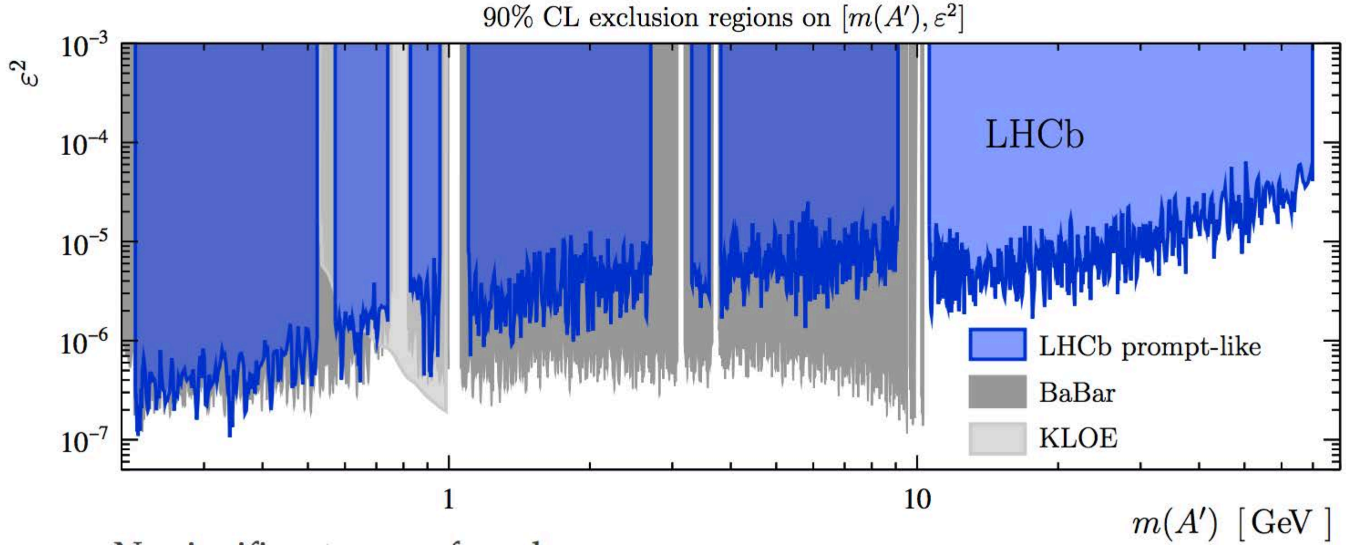


First limits 8.7-11.5 GeV





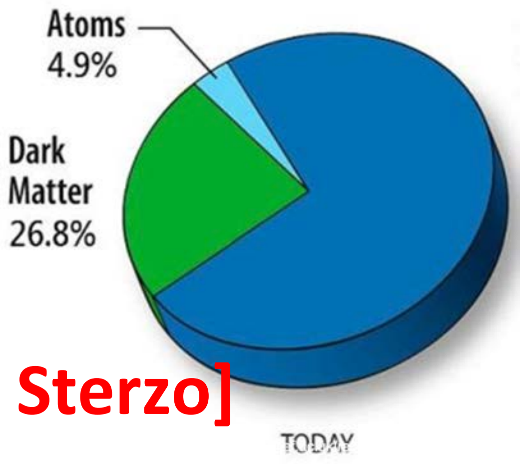
Dark Photon



Wrap-up of BSM (SUSY & Exotics)

- One CMS result based on full 2016+2017 data set
- Largest deviation from background only 3.6 sigma local (2.2 global) ATLAS BSM scalar [relegated to backup slide…]
- Most analyses will remain statistically limited for a long time
- Jet substructure becomes important
- There are searches with "Little background, no signal but data" (P. Janot)
- 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 to reinterpret SUSY searches

Dark Matter Session

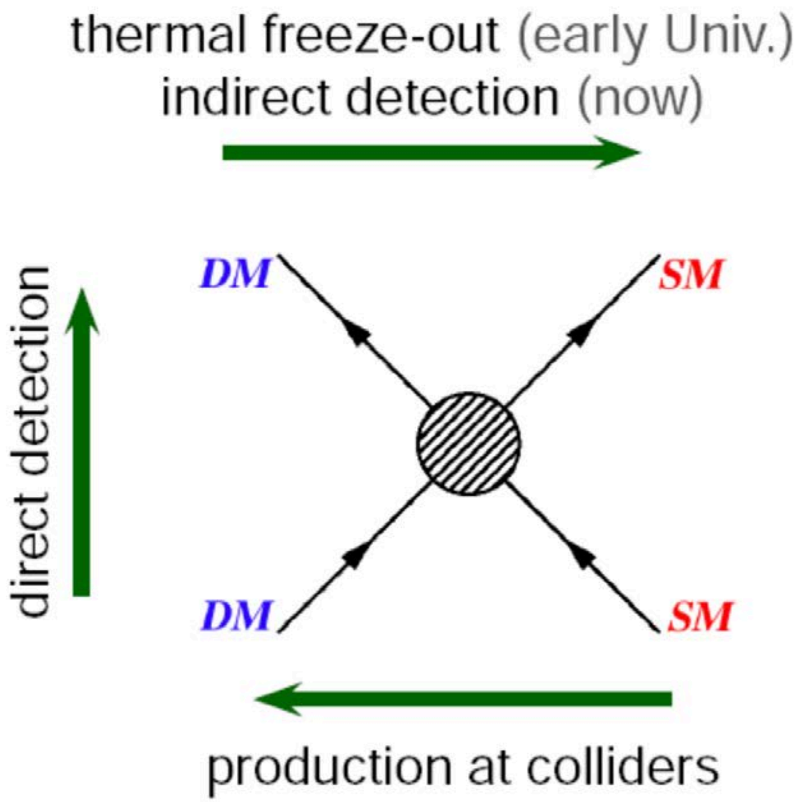


- ATLAS Heavy Mediator Collider **[Lo Sterzo]**
- CMS Heavy Mediator Collider **[Sung]**
- XENON1T LXe TPC **[Coderre]**
- DARKSIDE LAr TPC **[Franco]**
- NEWS-G spherical proportional counter **[Katsioulas]**
- ADMX2 Gen2 RF Cavity **[Wollett]**
- nEDM   **[Ayres]**

Dark Matter Searches (examples)

DAMPE

XENON

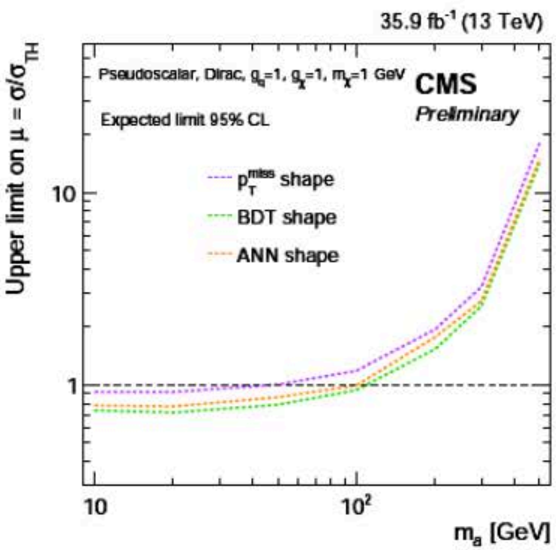


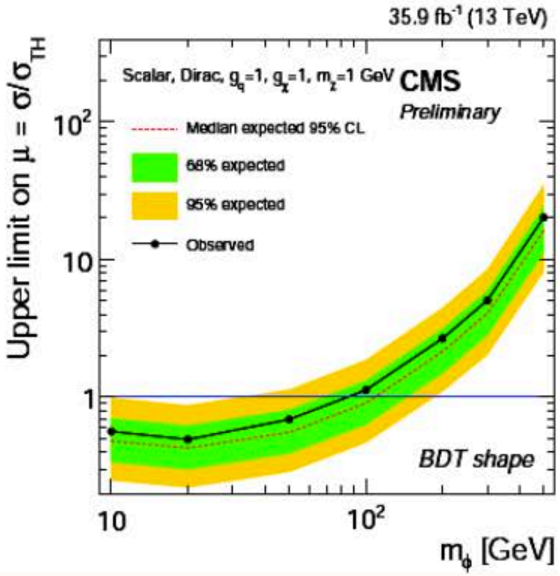
ATLAS/CMS

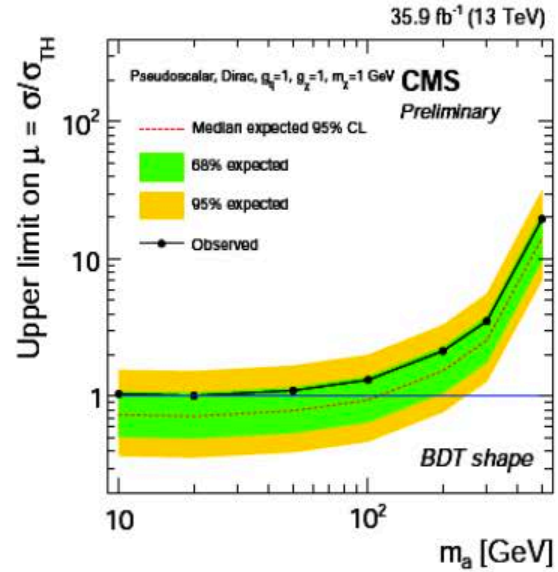
[Sung] $t\bar{t}$+DM: Dileptonic

NEW CMS-EXO-17-014

- Signal normalization updated to NLO cross sections
- Result of BDT analysis on 36 fb^{-1} collected in 2016
  - Scalar model: m_φ excluded up to 86 GeV
  - Pseudoscalar model: no observed exclusion
  - ~20% better than MET-shape strategy, ~10% better than ANN strategy







Summary of ATLAS results in mono-X

[Lo Sterzo]

mono-jet
36.1/fb $\sqrt{s}$ = 13 TeV
JHEP 01 (2018) 126
arxiv:1711.03301

mono-γ
36.1/fb $\sqrt{s}$ = 13 TeV
Eur. Phys. J. C 77 (2017) 393
arxiv:1704.03848

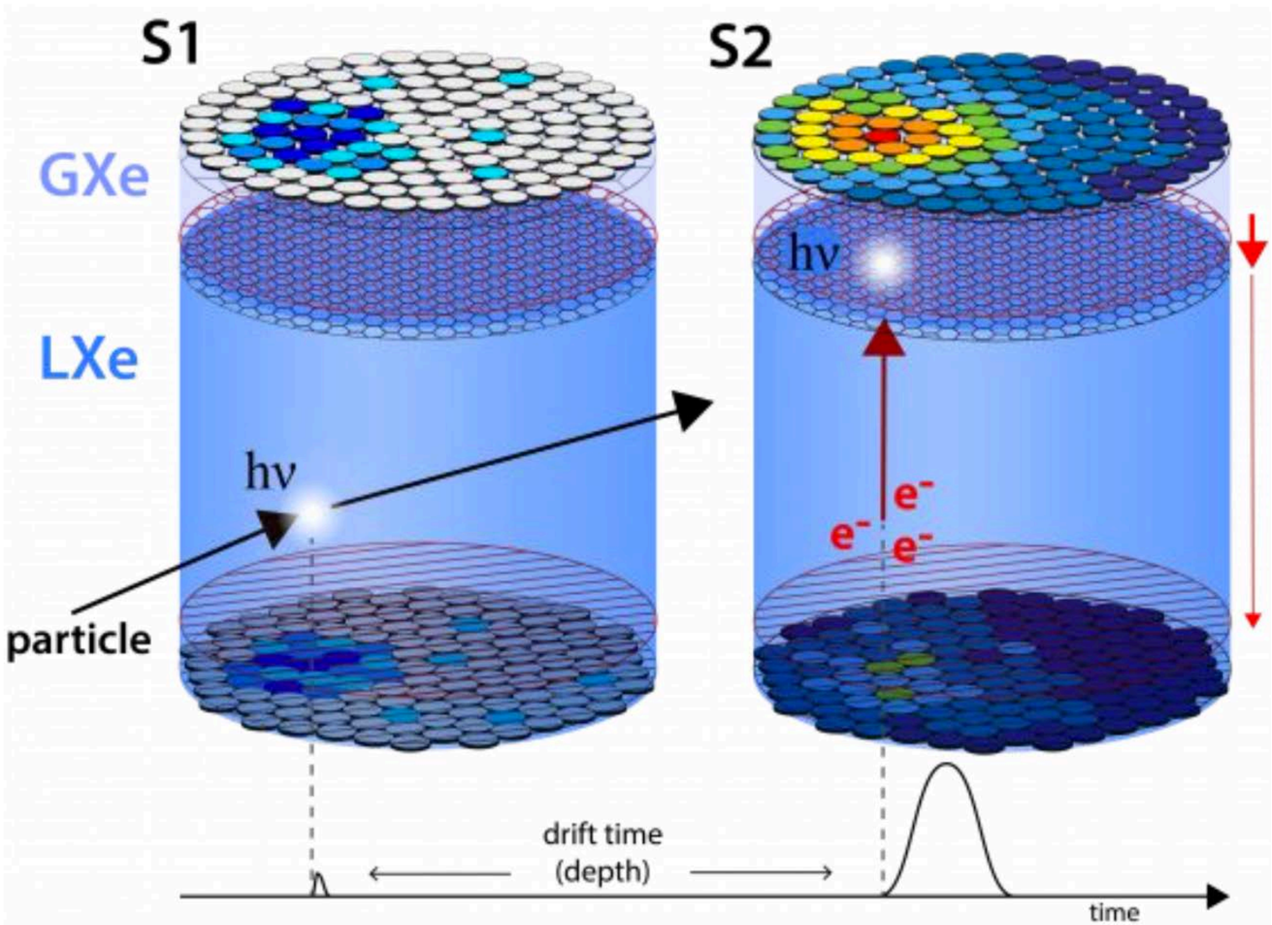
mono-V(had)
3.2/fb $\sqrt{s}$ = 13 TeV
Phys. Lett. B 763 (2016) 251
arxiv:1608.02372

mono-Z(lep)
36.1/fb $\sqrt{s}$ = 13 TeV
Phys. Lett. B 776 (2017) 318
arxiv:1708.09624

mono-H(bb)
36.1/fb $\sqrt{s}$ = 13 TeV
PRL 119, 181804 (2017)

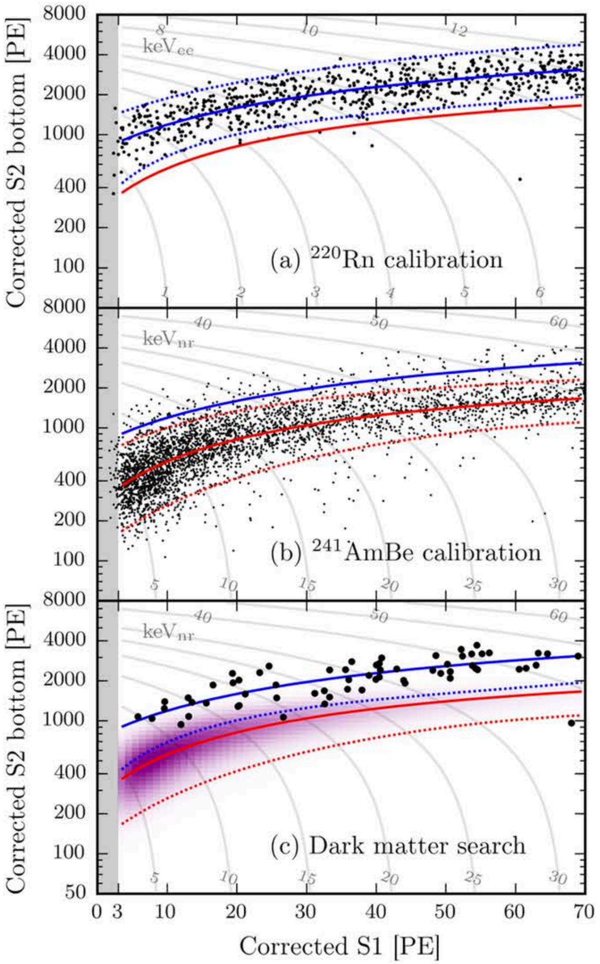
mono-H(γγ)
36.1/fb $\sqrt{s}$ = 13 TeV
Phys. Rev. D 96, 112004 (2017)

XENON1T LXe TPC



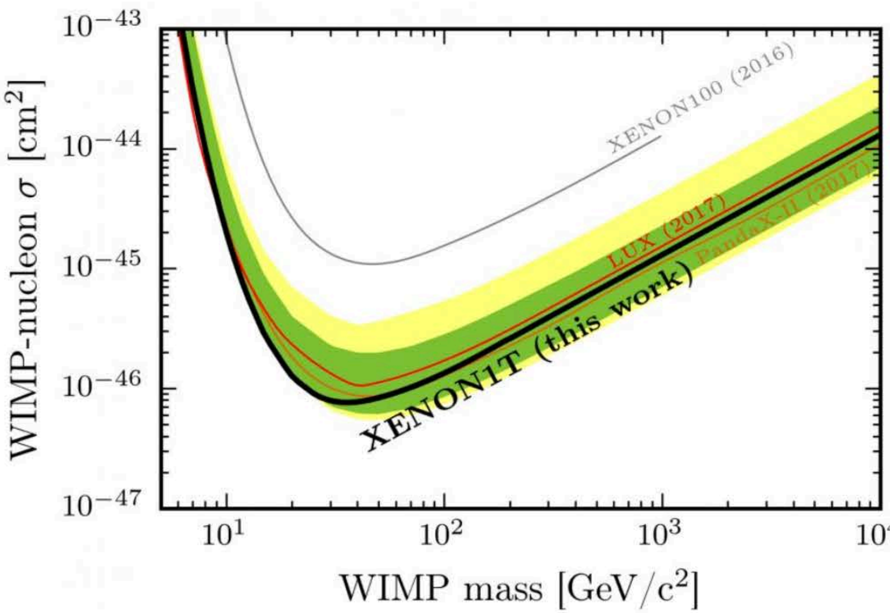
Recap: First XENON1T Results

Phys. Rev. Lett. 119, 181301 (2017)



[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

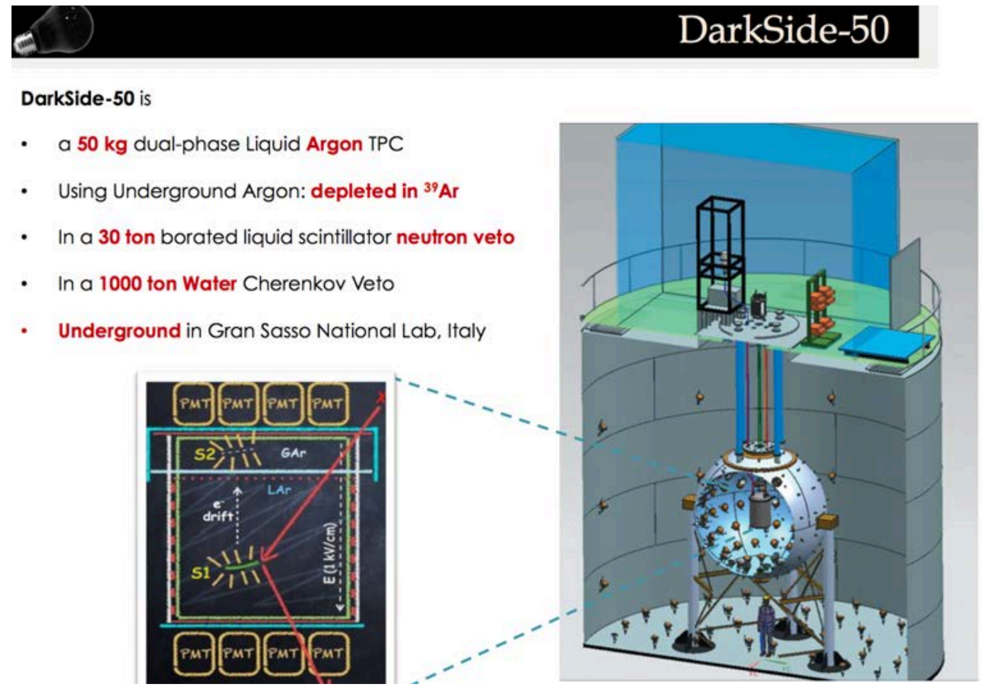


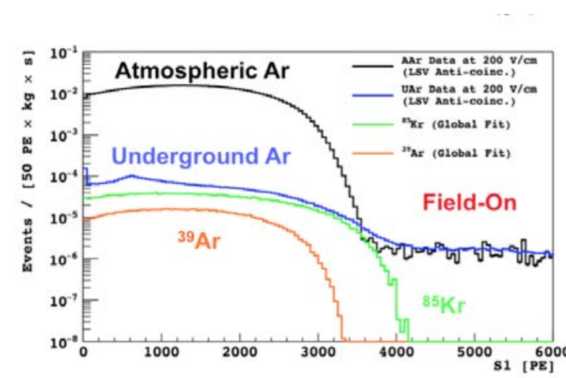
State of the art DM Detector: stay tuned

DARKSIDE

[Franco]

- Unique feature: pulse shape discrimination
- New results: Low Mass (Best limit background free). High mass (of course not competitive yet)
- DARKSIDE 20 tons → LNGS 2021
- DARKSIDE 300 tons → SLOLAB?



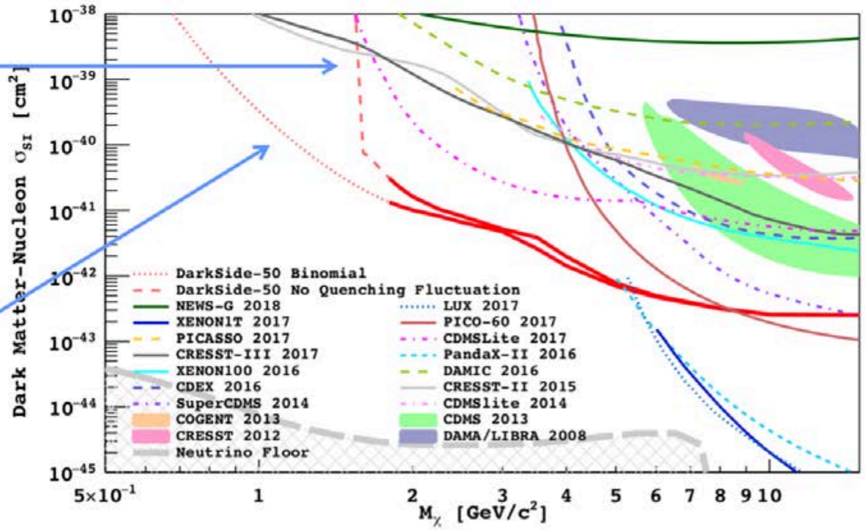


DARKSIDE: New Results

Low-Mass

Assuming quenching a non-stochastic process

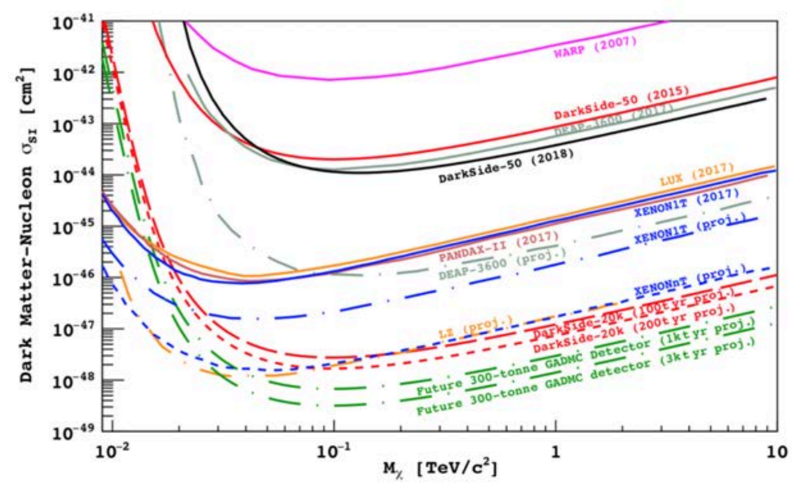
Assuming binomial quenching fluctuations



[Franco]

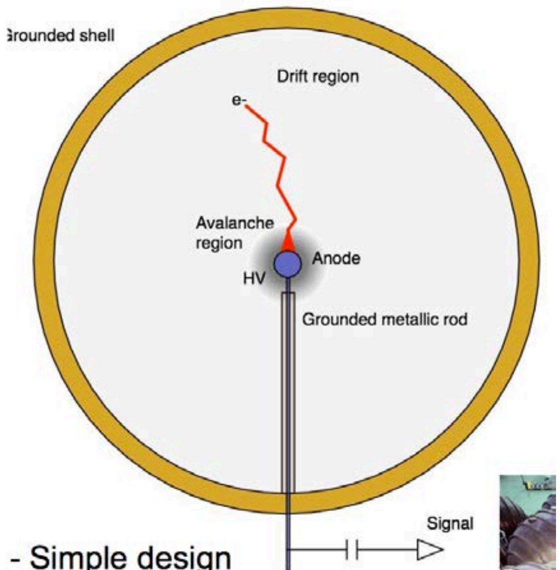
BEST LIMIT!!

High-Mass



NEWS-G

[Katsioulas]



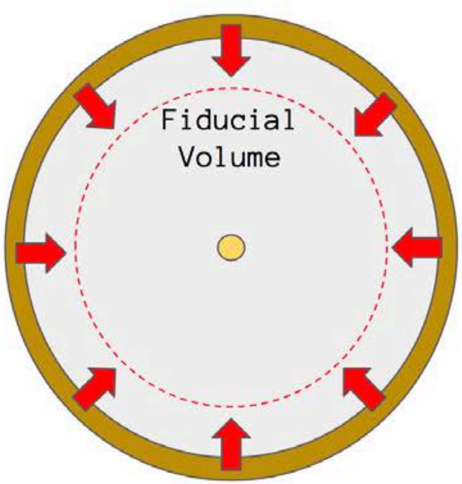
- Simple design
- Single readout

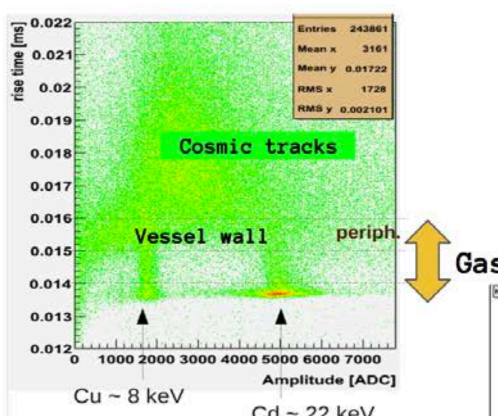
I.Giomataris et al ,JINST,2008, P09007

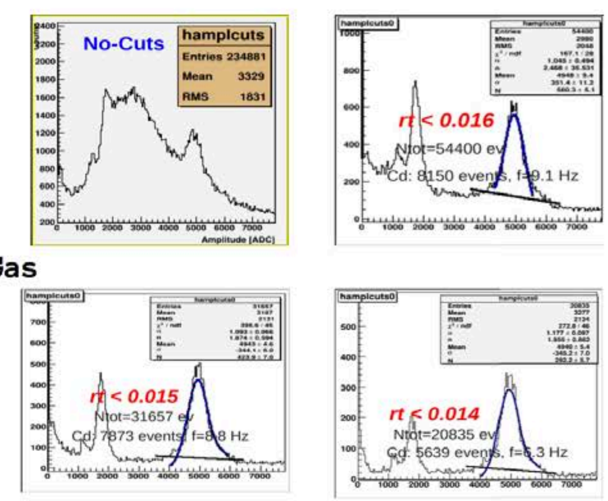
- Lowest surface to volume ratio
- Sustains higher pressure
- Low capacitance → Low noise
- High gain
- Anode Ø 1 mm-6.3 mm)
- Event discrimination
- Fiducialization
- SEDINE detector at **LSM**

Vessel
Ø 60cm copper

Sensor
Ø 6.4mm Si

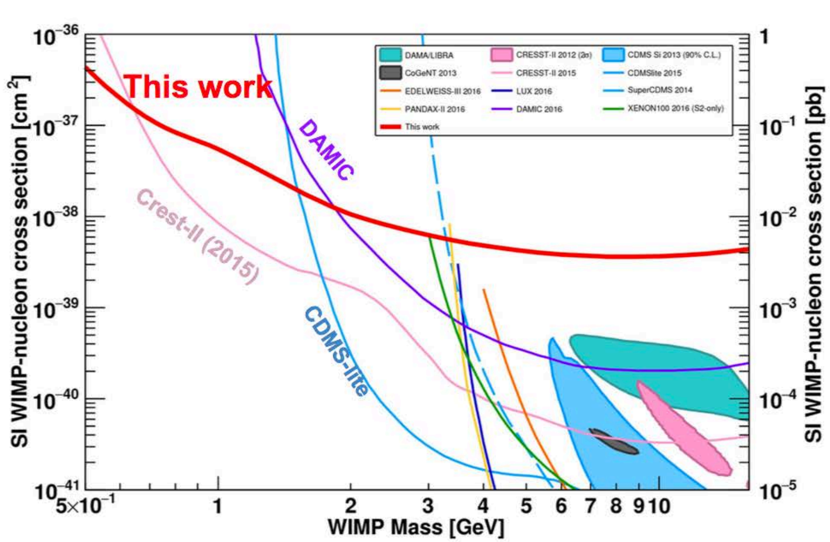






First results of NEWS-G with SEDINE

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

[Katsioulas]

Exclusion at 90% confidence level (C.L.) of cross-sections above $4.4 \cdot 10^{-37}$ cm^2 for a 0.5 GeV/c^2 WIMP

Next detector at SNOLAB

Target: Ne+0.7%CH_4 at 3.1 bar
→ 280 gr target mass

Duration: 42 days in sealed mode

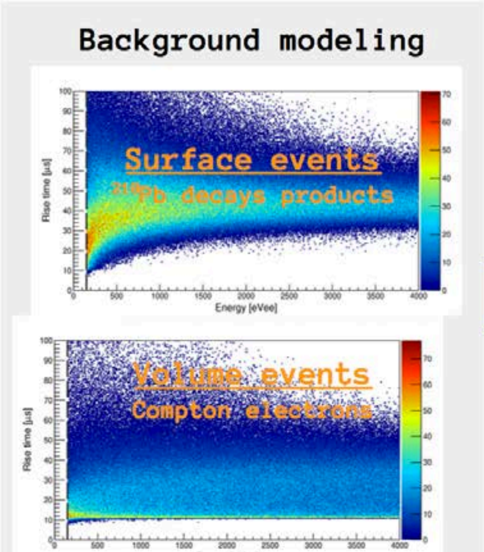
Dead time: 20.1%

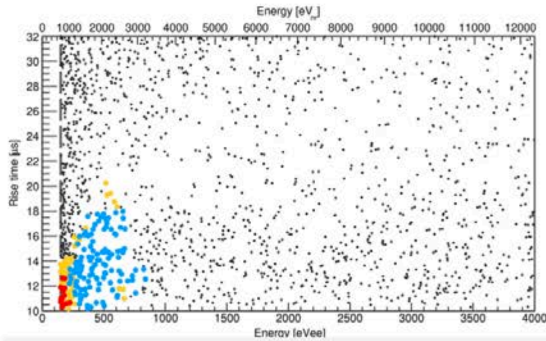
Exposure: 9.6 kg*days (34.1 live-days x 0.28 kg)

Trigger threshold: 35 eVee (~100% efficient at 150 eVee)

Analysis threshold: 150 eVee(~720 eVnr)

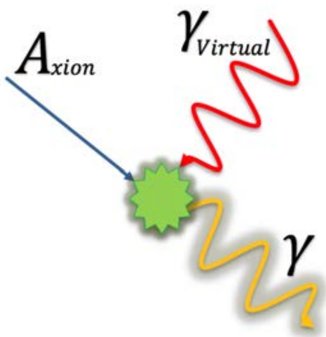
Calibration: ^{37}Ar gaseous source, 8 keV Cu fluorescence, AmBe neutron source





1620 events recorded in the preliminary ROI
- **Failed any of the BDT cuts**
- **pass the BDT cut for 0.5 GeV/c^2 : 15 events**
- **pass the BDT cut for 16 GeV/c^2 : 123 events**
- **pass the BDT cut for other masses**

ADMX Gen2

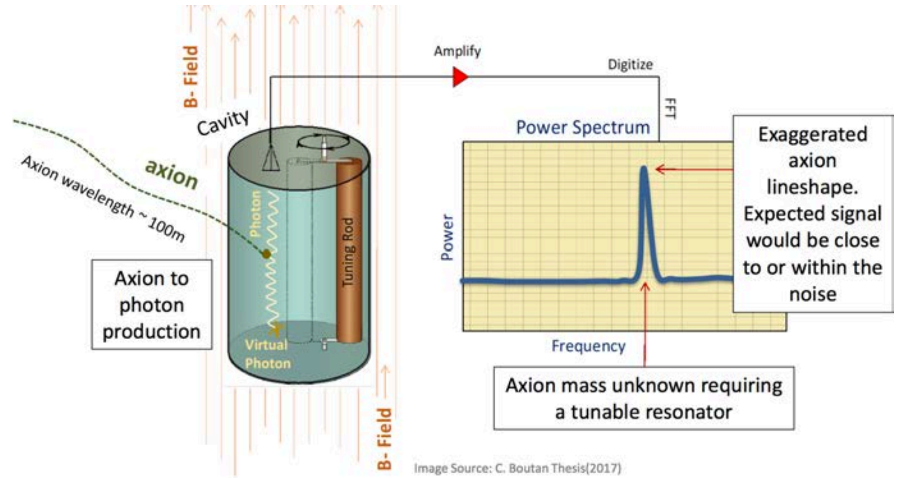


[Woollett]

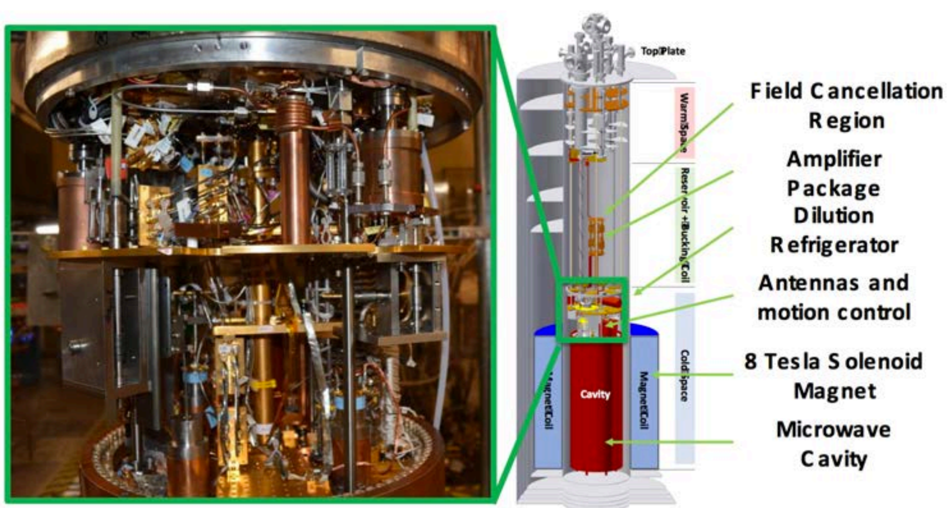
Simplicity of the principle

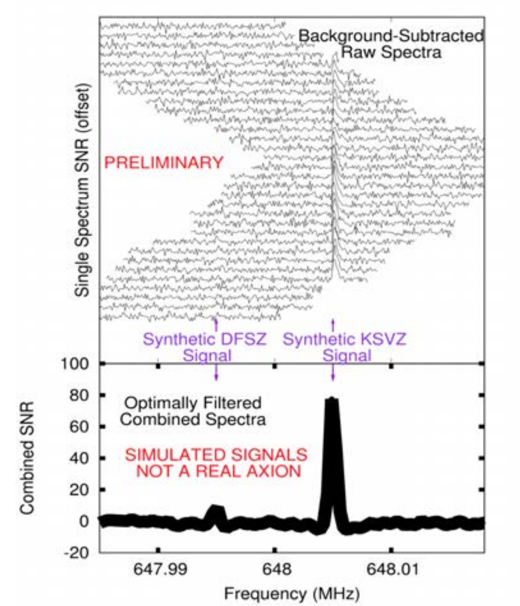
Search for Axions
To solve the
Strong CP problem

$$\mathcal{L}_{A\gamma\gamma} = -g_{A\gamma\gamma}\boldsymbol{E} \cdot \boldsymbol{B}\phi_A$$

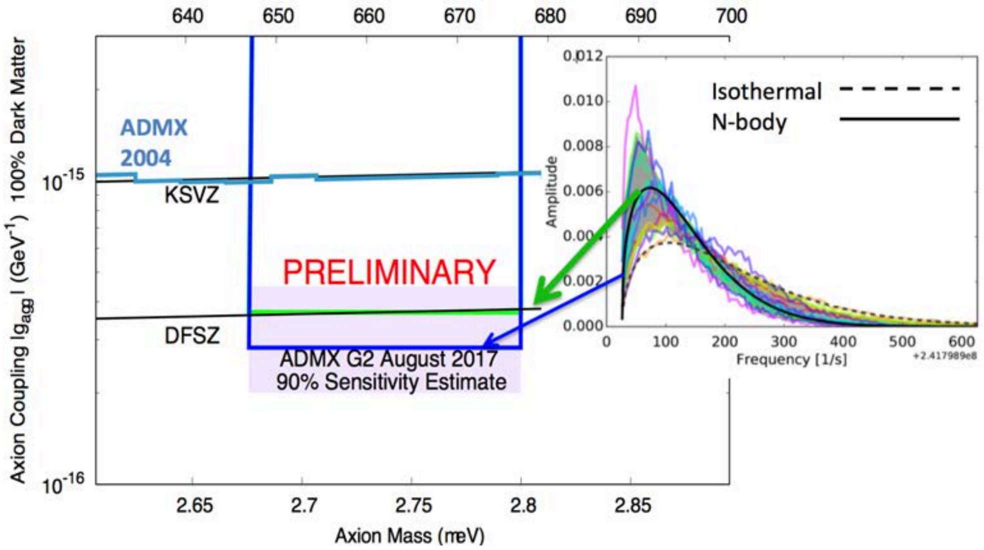


Experimental complexity

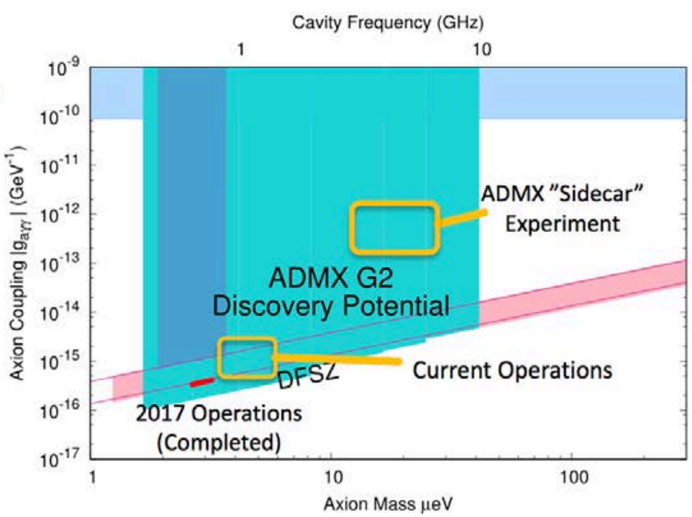




ADMX Gen2 [Woollett]



- Currently ADMX is scanning 700-890 MHz
- We anticipate faster frequency coverage in the future due to:
  - Higher magnetic field
  - More stable quantum electronics
  - Lower temperatures
  - Reduced engineering overheads.
- Speed up of ~6x

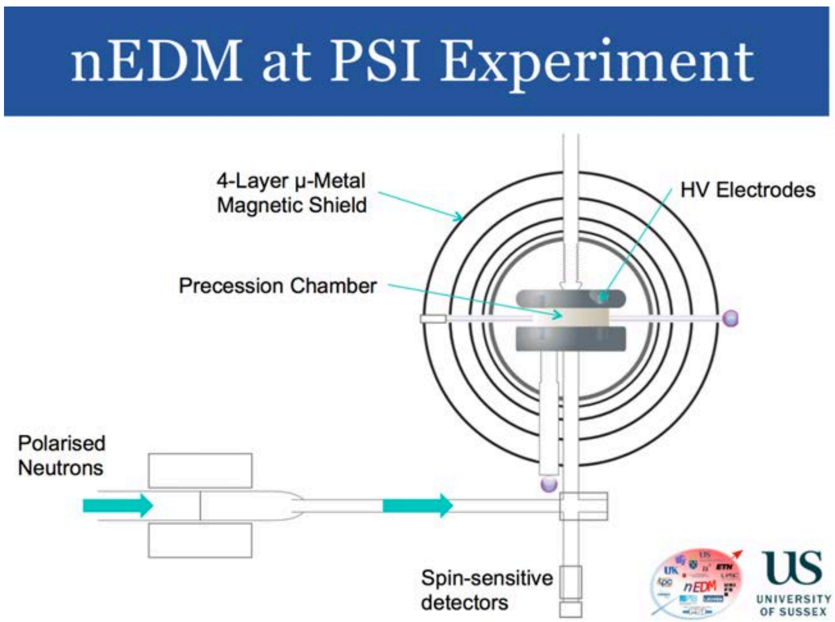


nEDM data to look for ALPs

Byproduct of the search for electric dipole moments

Oscillation in the neutron precession frequency

Data from ILL and PSI sister experiments



$$\mathcal{L} = \frac{C_G}{f_a}\frac{g^2}{32\pi^2} a G^b_{\mu\nu}\tilde{G}^{b\mu\nu} - \frac{C_N}{2f_a}\partial_\mu a \bar{N}\gamma^\mu\gamma^5 N$$

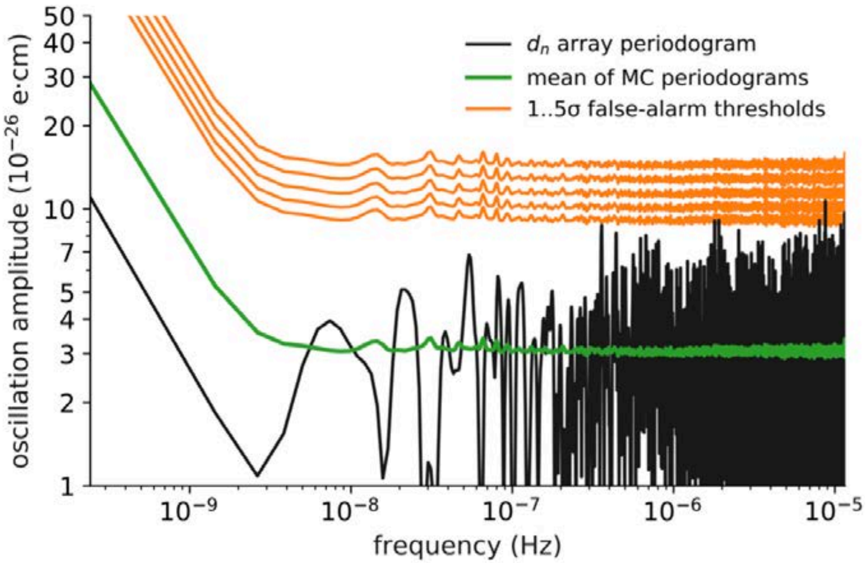
Axion-gluon coupling
Induces neutron EDM oscillation through same mechanism as QCD theta

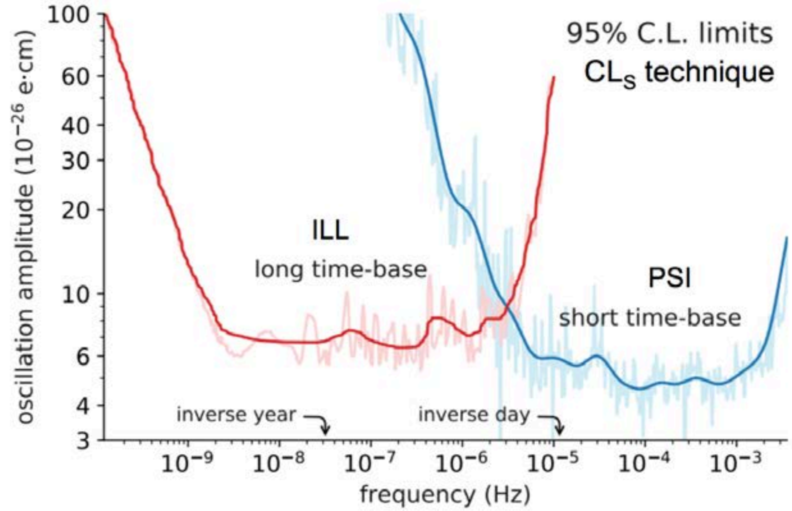
Axion-nucleon coupling
Non E dependant frequency modulation

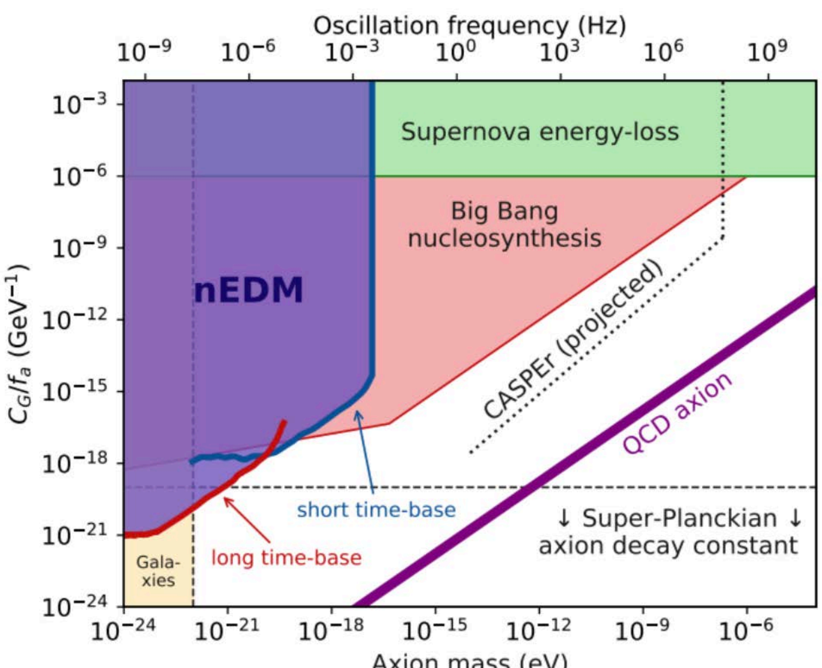
$$\mathcal{L} = \frac{g^2}{32\pi^2}\theta G^b_{\mu\nu}\tilde{G}^{b\mu\nu}$$

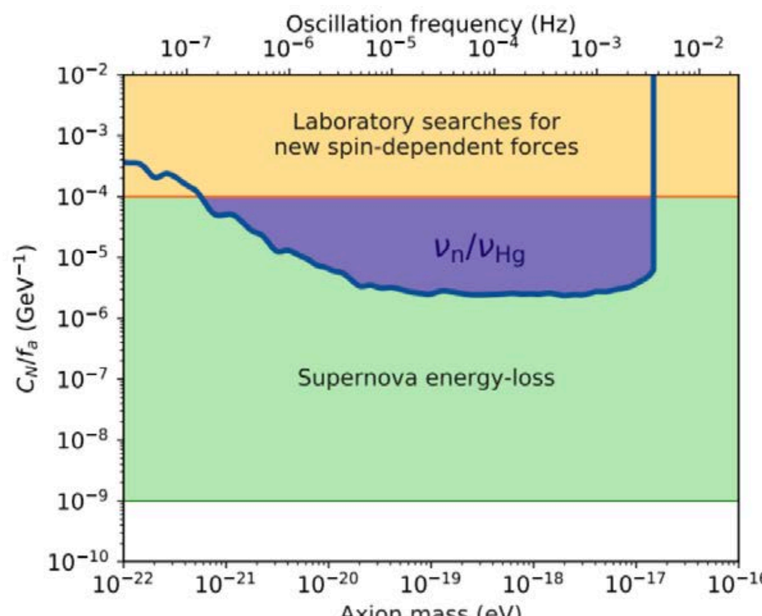
[Ayres]

First Laboratory limits









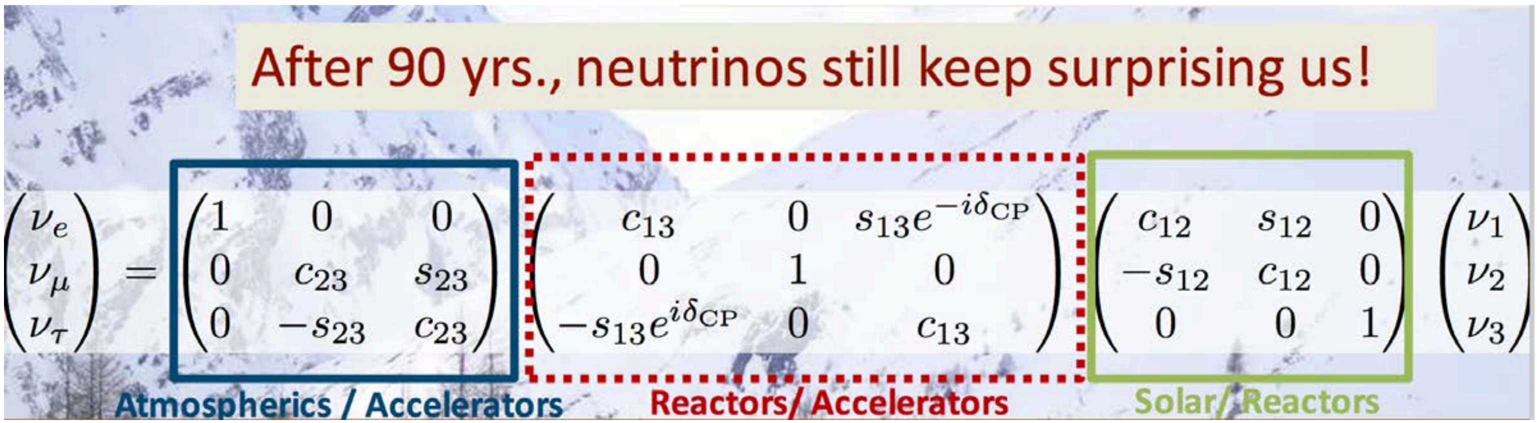
Wrap Up Dark Matter

- Interplay of direct searches and Accelerator searches (high energy and beam dump)
- Stay tuned for new XENON1T result; "salting" the data to protect the efficiency
- DARKSIDE: already best limit at low mass with just 20 Kg of LAr (New results!)
- Direct Collider searches complementary to Direct detection experiments; caveats about what is plotted, these are not DM colliders
- NEWS-G with H/He/Ne, very low threshold for nuclear recoil thanks to gas gain and low capacitance
- ADMX 2nd Generation first results
- Limits on ALPS from analysis of ILL/PSI nEDM data

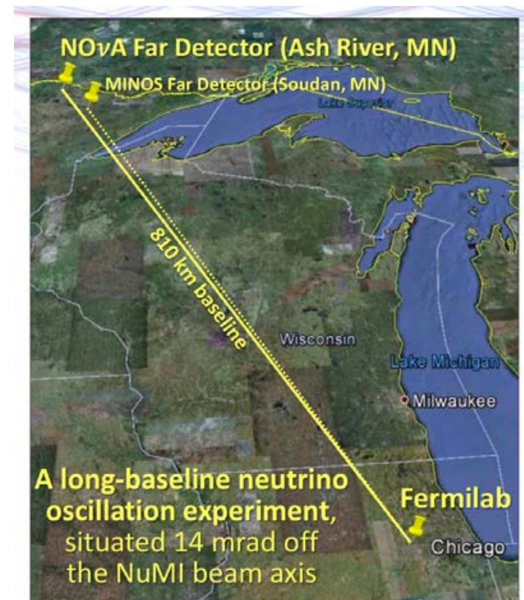
Neutrinos

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

Long Baseline Neutrino Oscillations: ν_μ disappearance and ν_e appearance

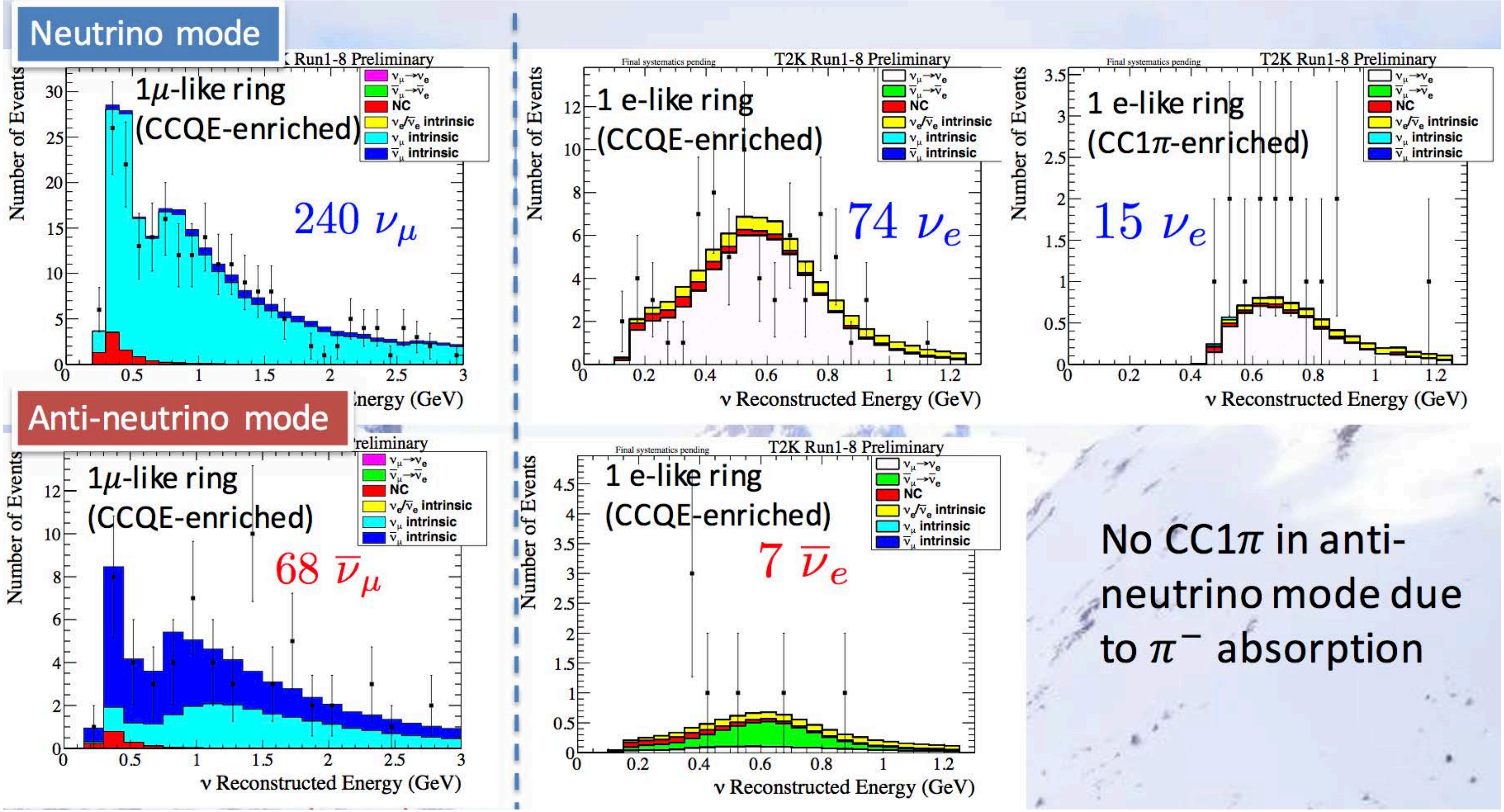


T2K [Cao]



NOvA [Backhouse]

T2K: ν_e appearance latest Data

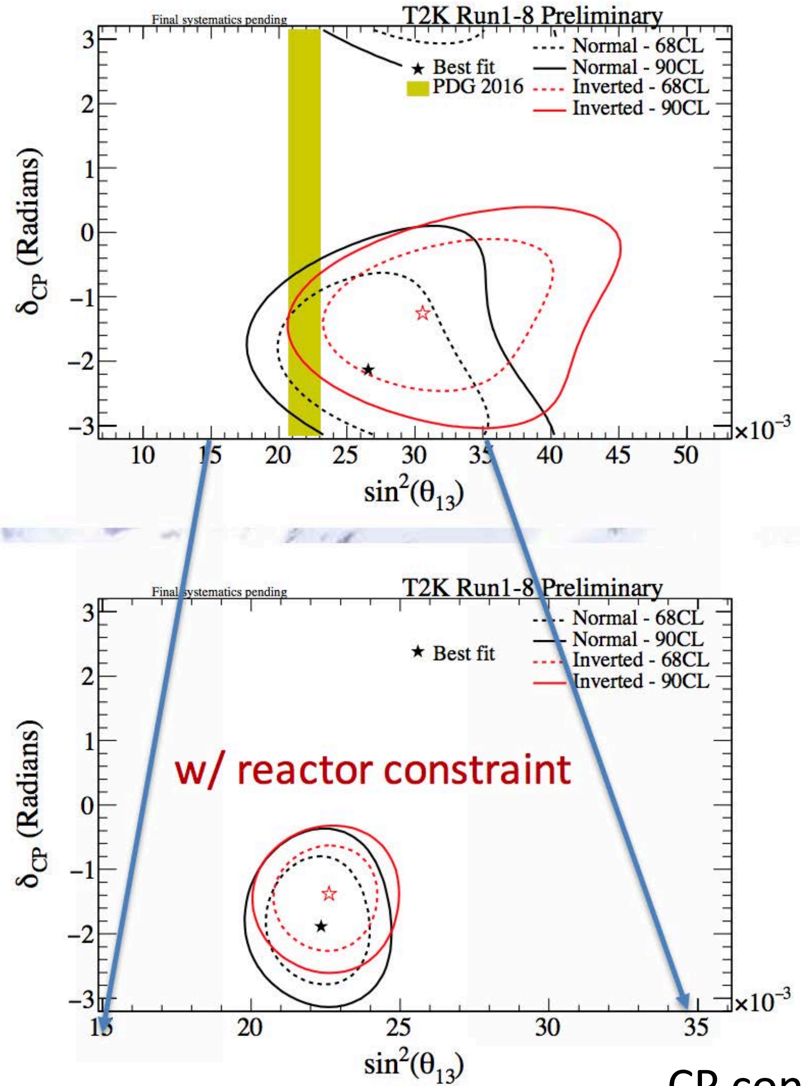


No CC1π in anti-neutrino mode due to π^- absorption

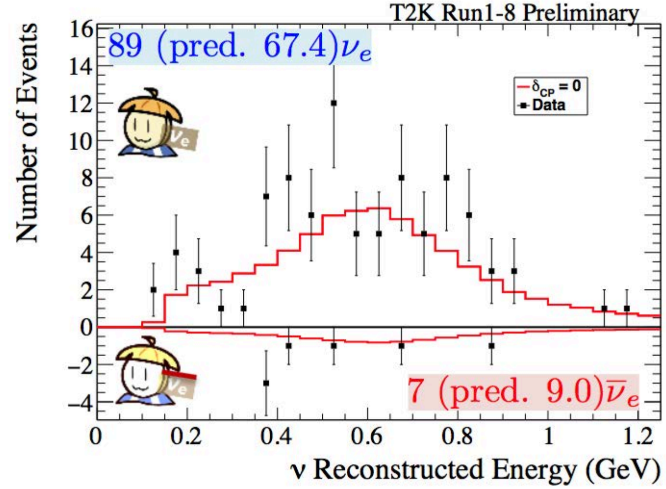
[Cao]

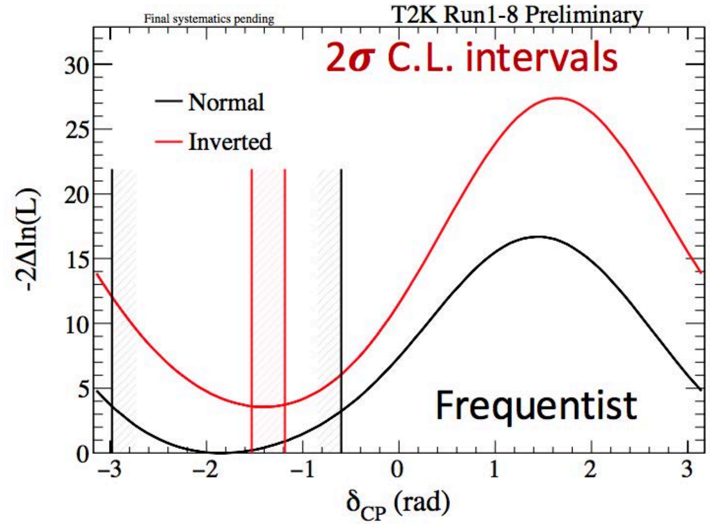
Run 1-8

T2K δ_{CP}



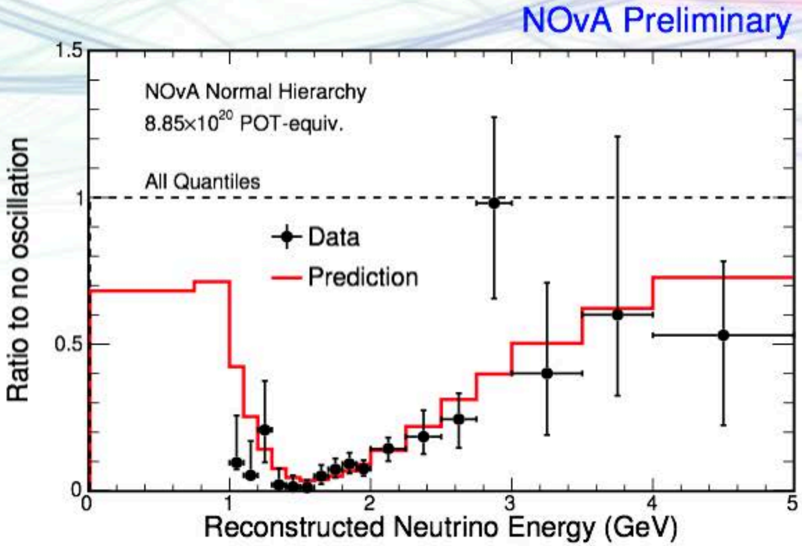
[Cao]

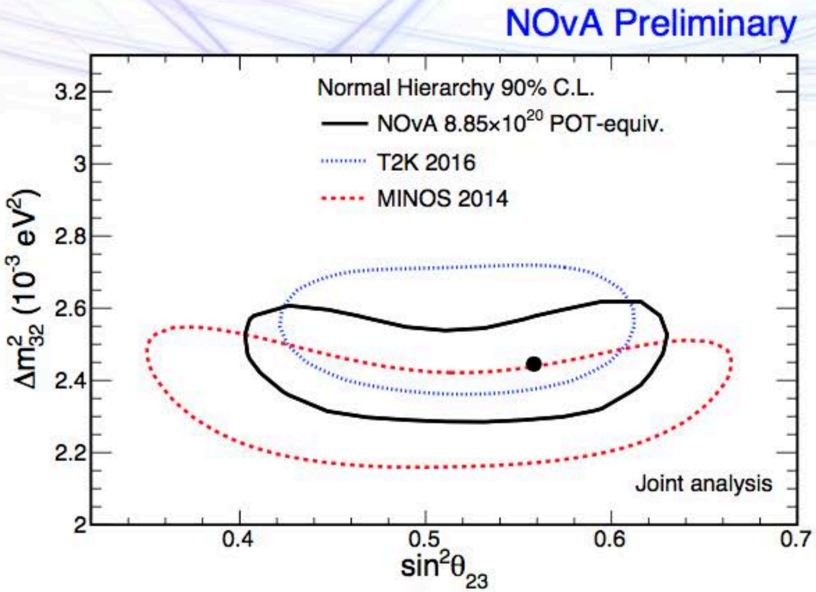




CP conserving values (0, π) fall outside of the $2\boldsymbol{\sigma}$ C.L. confidence/credible interval

ν_μ disappearance results



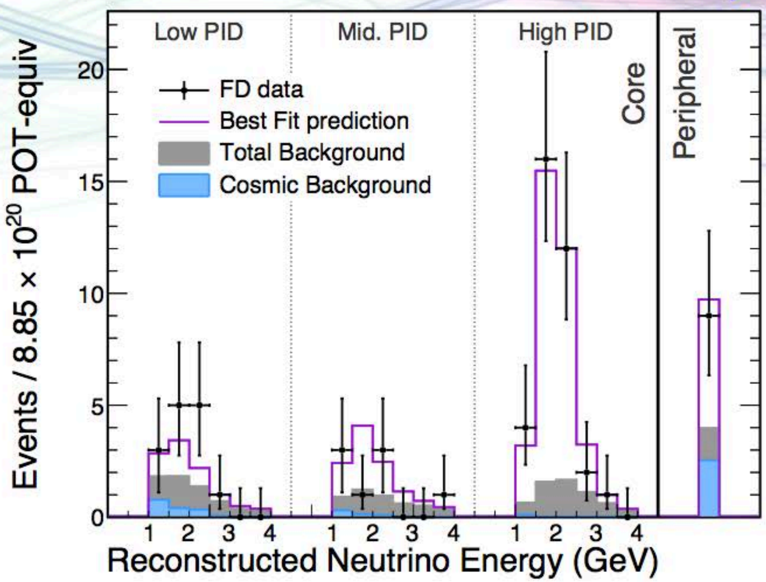


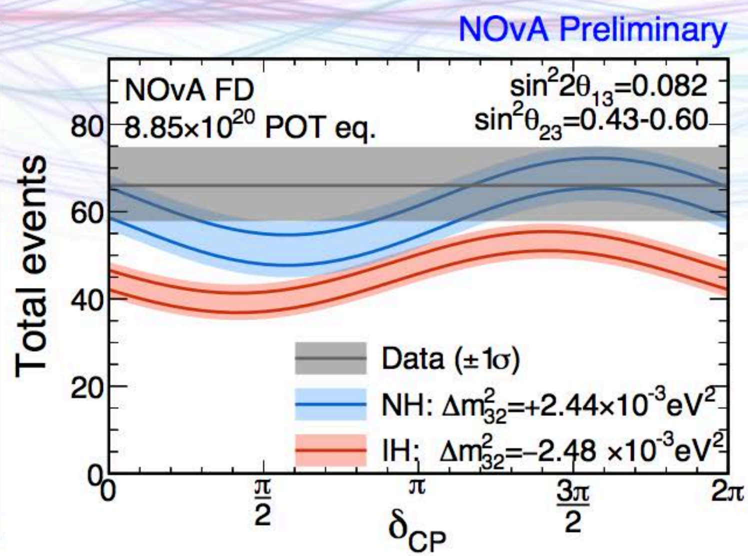
- Expect 763 FD ν_μ CC events with no oscillation
- Observe 126 (inc. 3.4 beam bkg. and 5.8 cosmic)

[Backhouse]

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

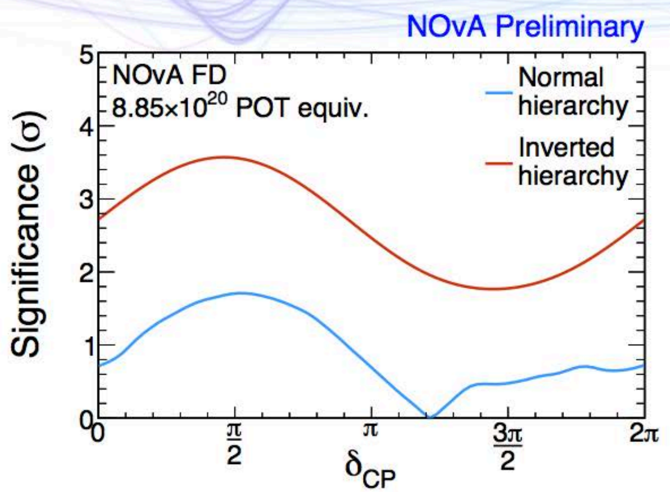
ν_e appearance results

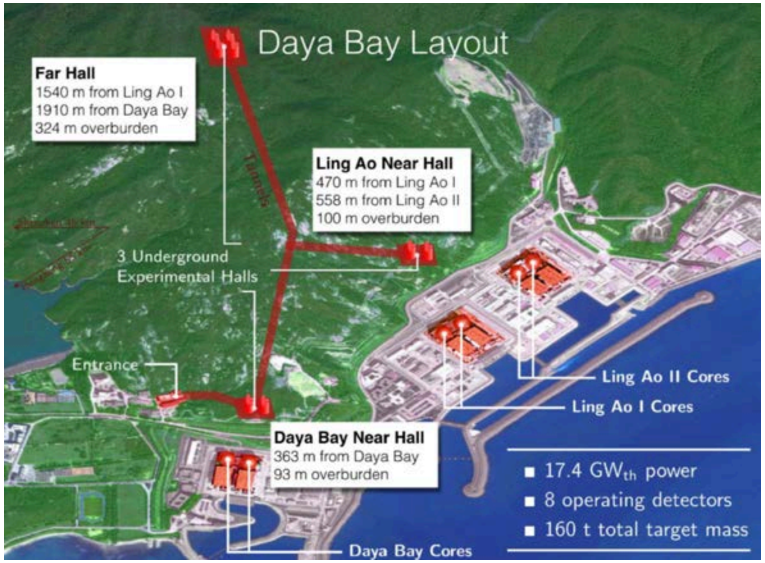




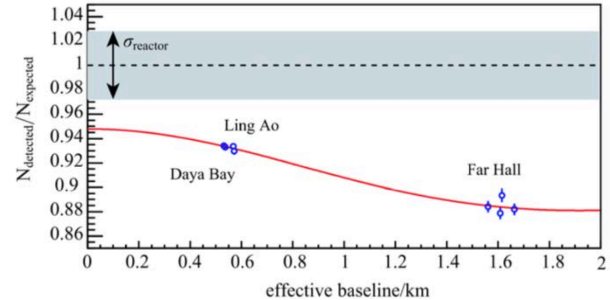
[Backhouse]

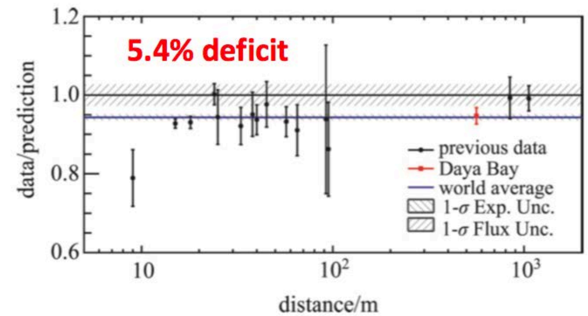
- Joint fit from ν_μ and ν_e spectra
- Constrain θ_{13} to reactor avg. $\sin^2 2\theta_{13} = 0.082 \pm 0.005$
- Prefer NH and (weakly) $\delta_{CP} \sim 3\pi/2$
- IH disfavoured at 2σ level

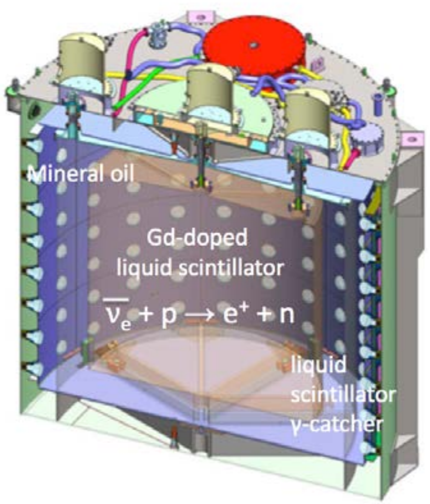




$$R = \frac{data}{Model\ (Huber + Mueller)}$$







target mass: 20 t Gd-LS
other mass: 20 t LS + 40 t MO
photo sensors: 192 8" PMTs

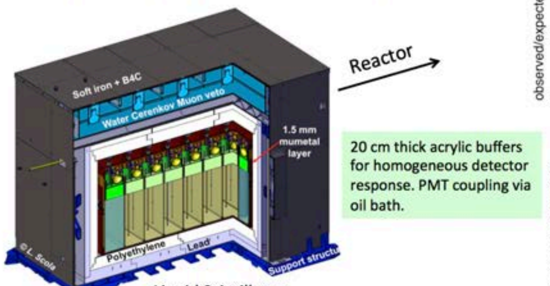
[Ling]

- Daya Bay have made the most precise measurements on
  - $\sin^2 2\theta_{13} = [8.41 \pm 0.33] \times 10^{-2}$
  - $\Delta m^2_{32} = [2.45 \pm 0.08] \times 10^{-3}\ eV^2$ *(Normal Hierarchy)*
  - $\Delta m^2_{32} = [-2.55 \pm 0.08] \times 10^{-3}\ eV^2$ *(Inverted Hierarchy)*
  - Expected to reach 3% by 2020
- Reactor neutrino measurement
  - Flux: 5.4% deficit than the model prediction
  - Spectrum: clear deviation at 4-6 MeV energy region
  - Fuel evolution: neutrino yield of ^{235}U different from the model

[Lhuillier]

STEREO Detector

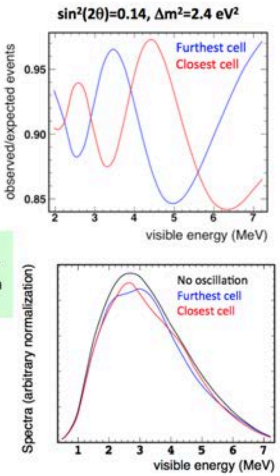
- Compare 6 target cells to measure oscillation-driven distortions in the $E_{\bar{\nu}_e}$ spectrum.
- Mitigate sensitivity to predicted spectrum.



20 cm thick acrylic buffers for homogeneous detector response. PMT coupling via oil bath.

Target: 6 identical cells
- Gd-loaded (0.2% in mass)
- V_{tot} = 2.2 x 0.9 x 0.9 m^3

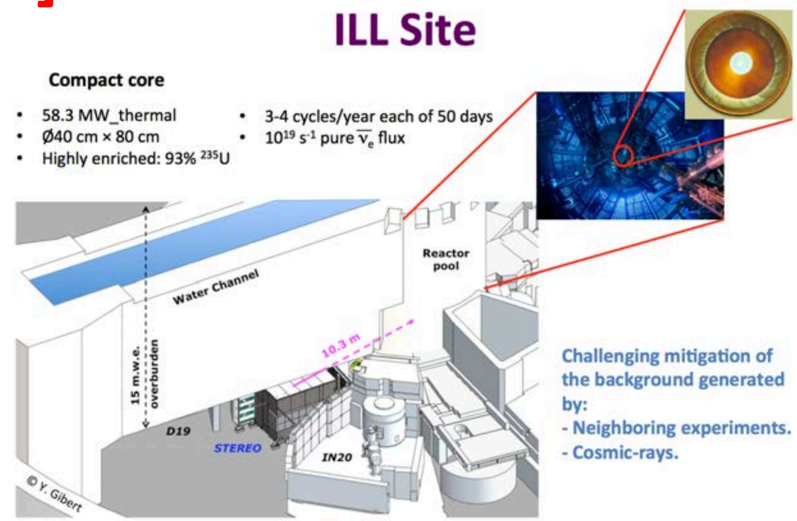
Gamma catcher (unloaded):
- Vetos ext. background
- Captures escaping γ's



ILL Site

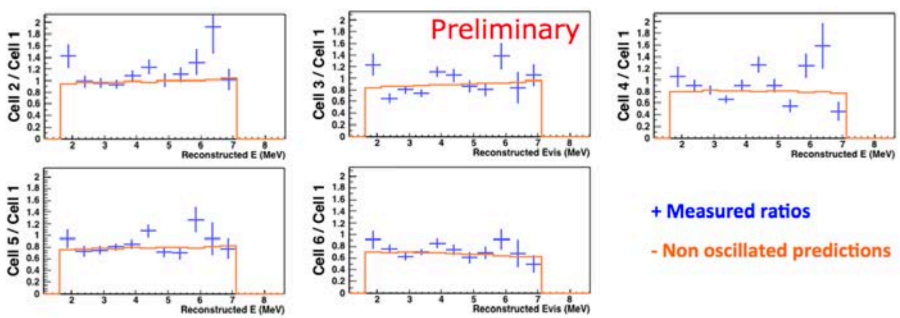
Compact core

- 58.3 MW_thermal
- Ø40 cm × 80 cm
- Highly enriched: 93% ^{235}U
- 3-4 cycles/year each of 50 days
- 10^{19} s^{-1} pure $\bar{\nu}_e$ flux



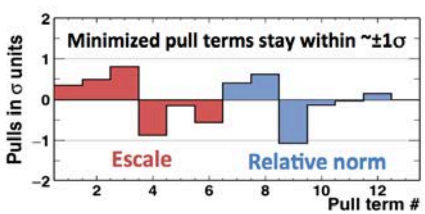
Challenging mitigation of the background generated by:
- Neighboring experiments.
- Cosmic-rays.

Test of No Oscillation Hypothesis

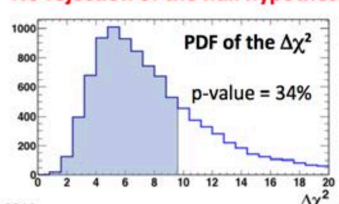


+ Measured ratios

- Non oscillated predictions

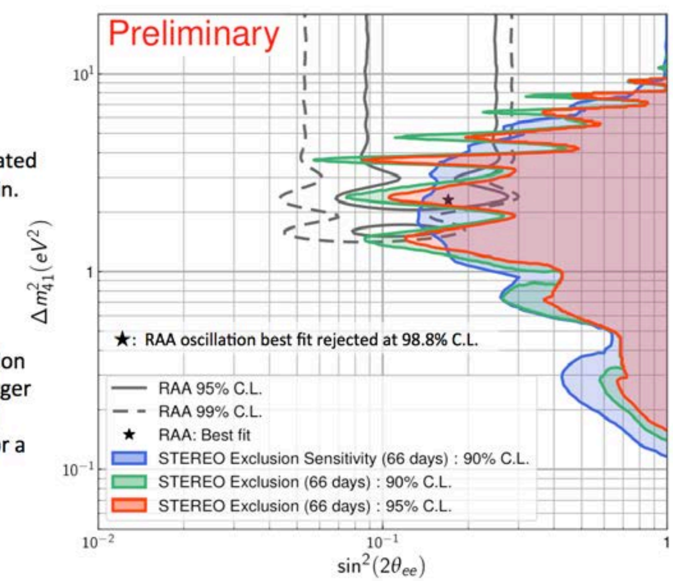


No rejection of the null hypothesis



STEREO Contours

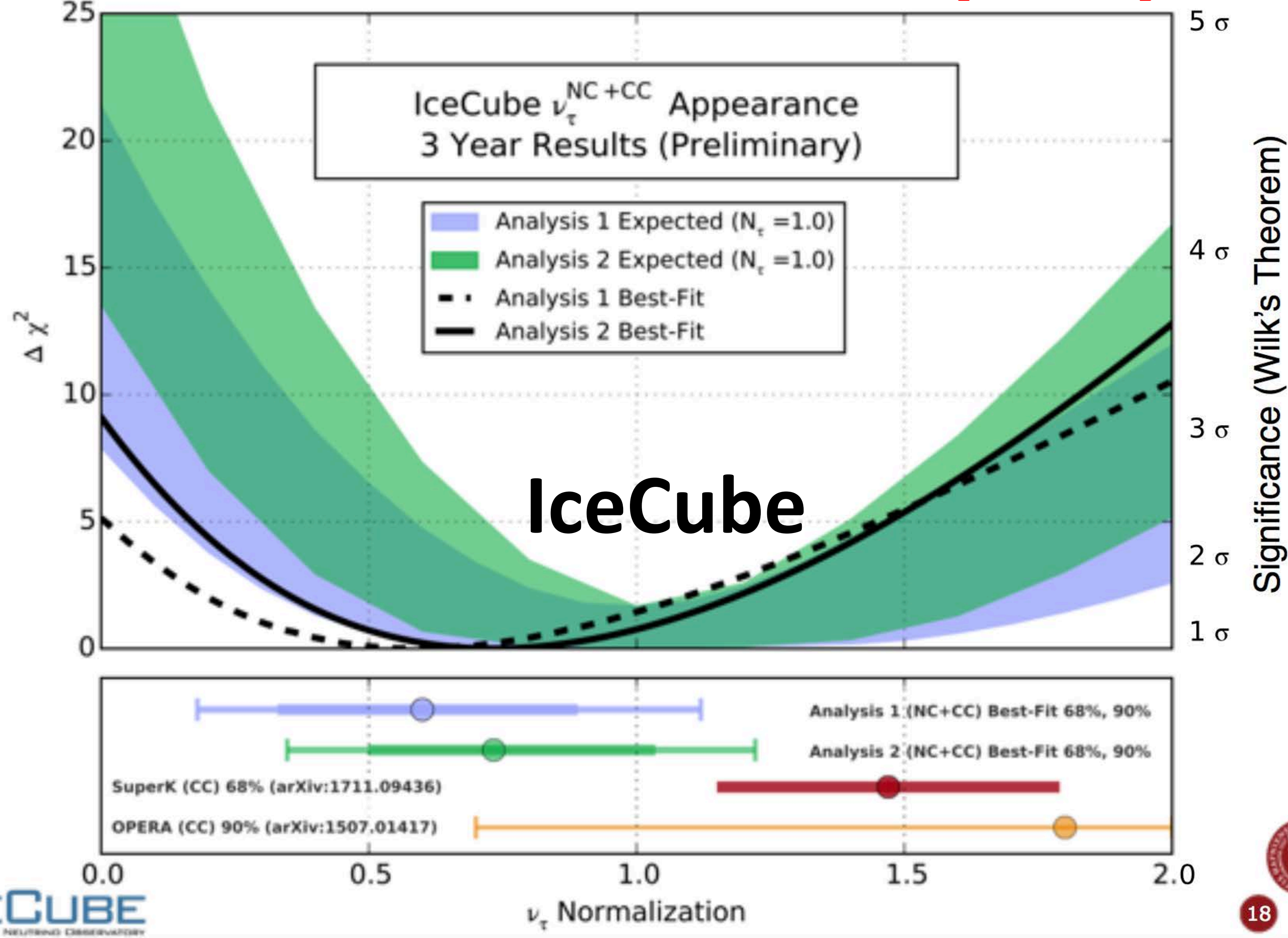
- Raster scan approach.
- $\Delta\chi^2$ law simulated in each Δm^2 bin.
- Reject oscillation amplitudes larger that statistical fluctuations for a given C.L.



Appearance Best-Fit Values from DeepCore

[Larson]

NEW

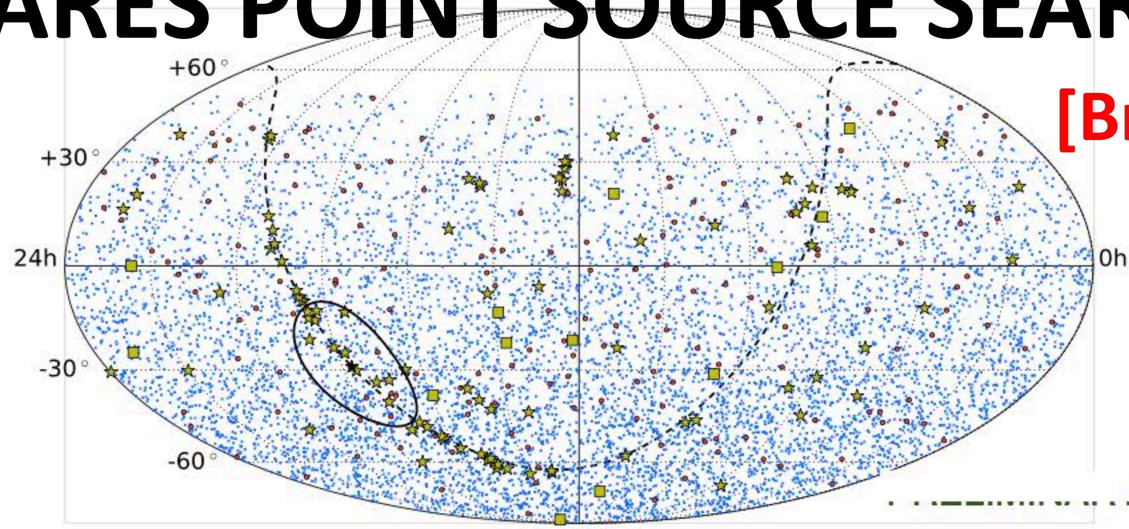


ANTARES POINT SOURCE SEARCH

[Bruijn]

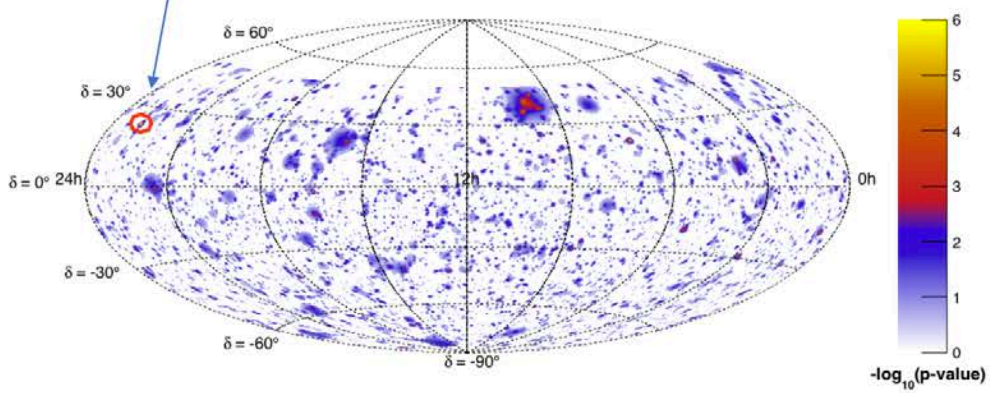
Ingredients :

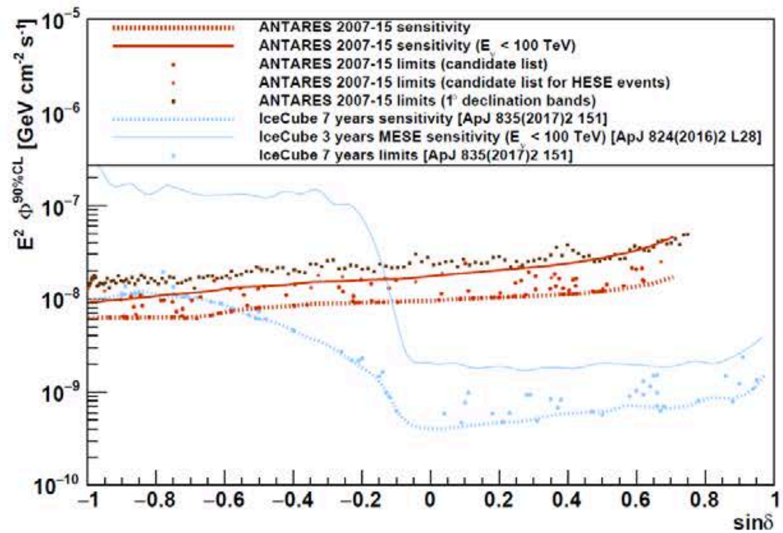
Dataset:
- o 2007 - 2015
- o 2424 days lifetime
- o All-flavour analysis:
  - 7622 tracks
  - 180 showers



X : track ● : shower

Most significant cluster : 1.9 σ





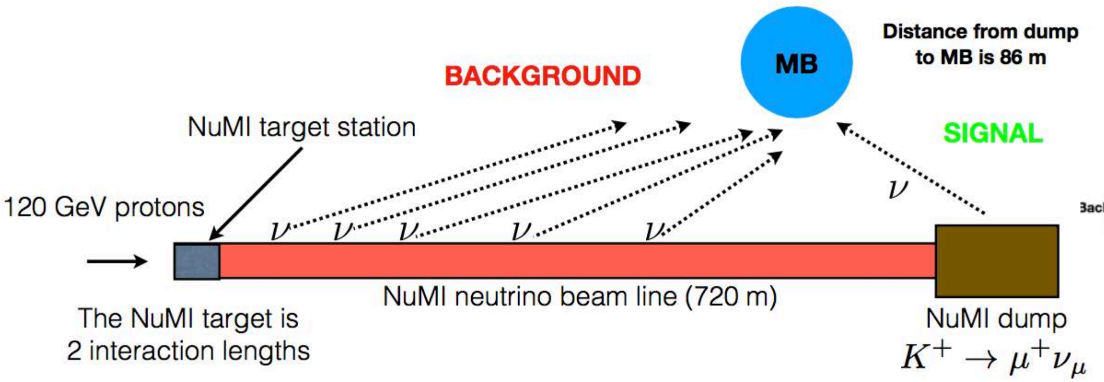
Most sensitive upper limit in fraction of the sky in particular at low energies (< 100 TeV)

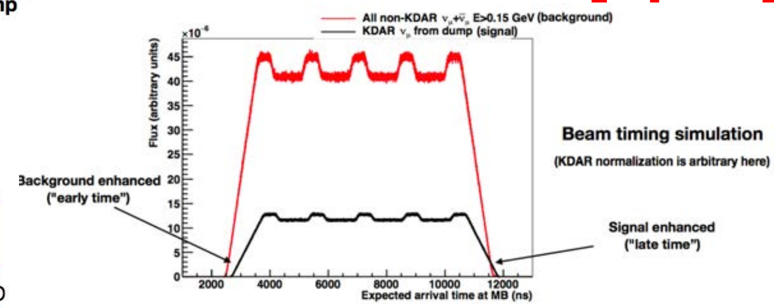
Charged currents from monoenergetic ν_μ

arXiv:1801.03848v1, accepted by PRL

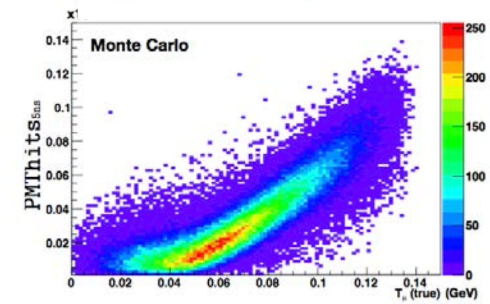
Miniboone Detector + NUMI beam

[Spitz]

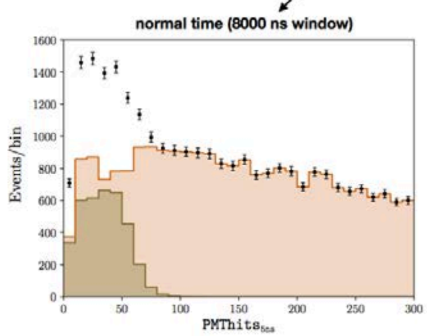




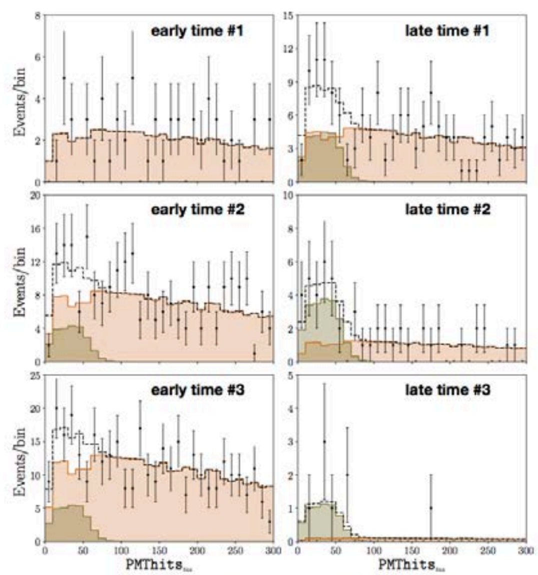
$$\nu_\mu\,{}^{12}\mathrm{C} \to \mu^- X$$



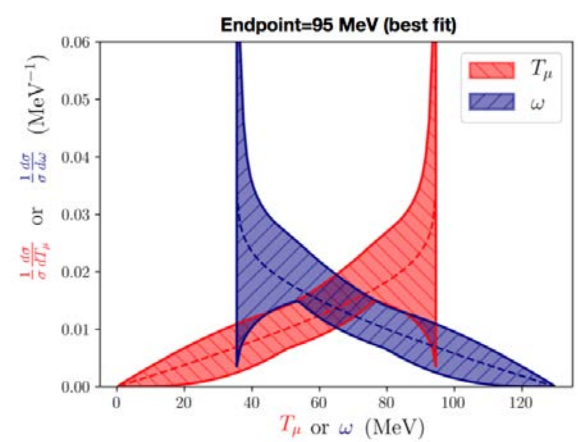
S:B is expected to
1) **increase in early and late time**
2) **remain constant in normal time**



black is data
green is a signal hypothesis
orange is background

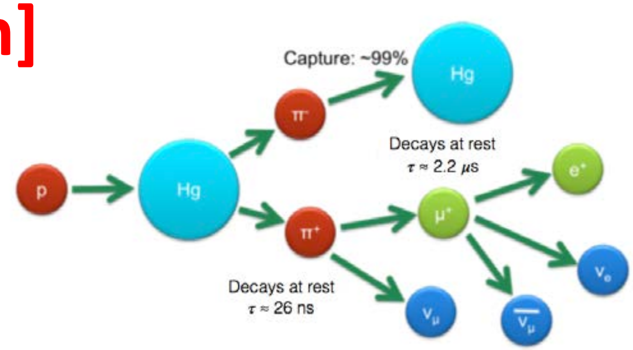


each time window above is 200 ns

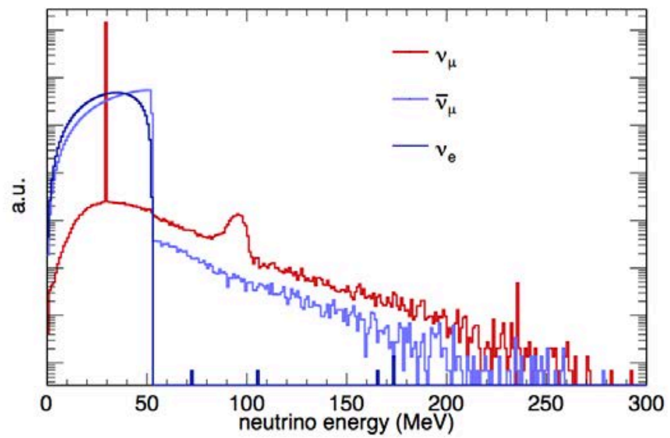


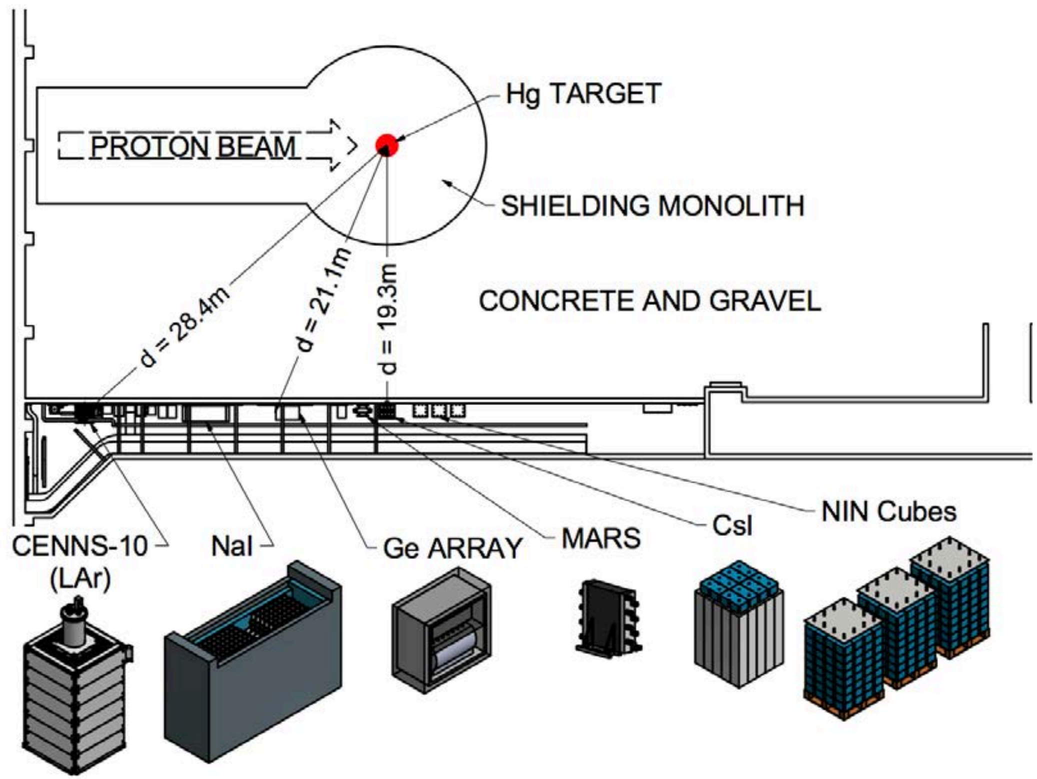
Measurement of CEνNS

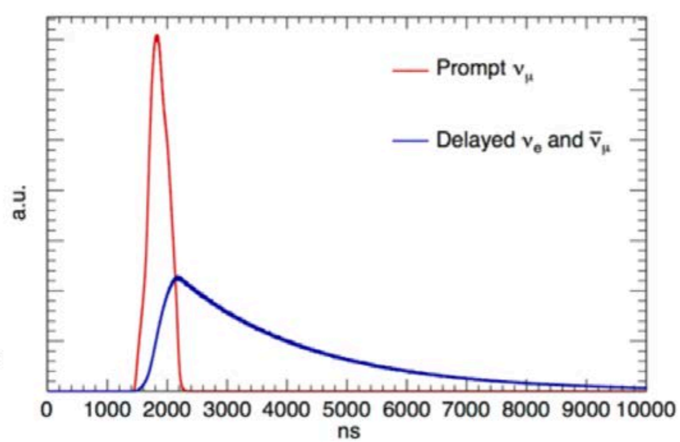
[Rich]



Spallation Neutron Source

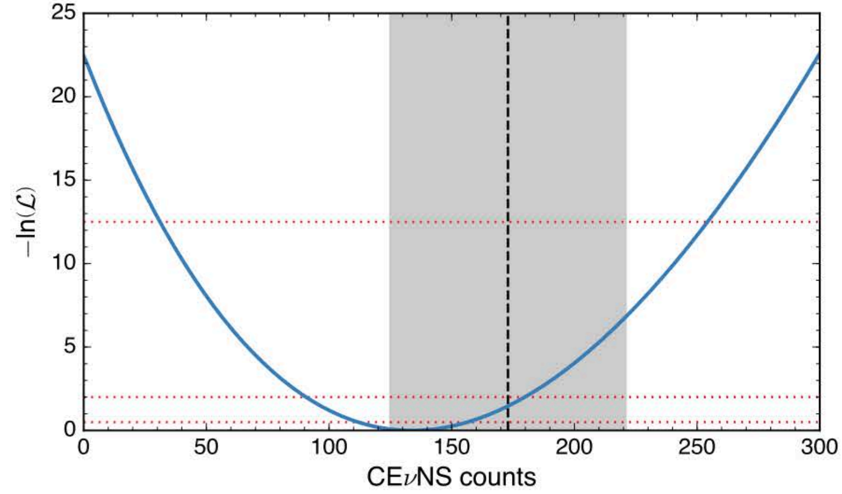


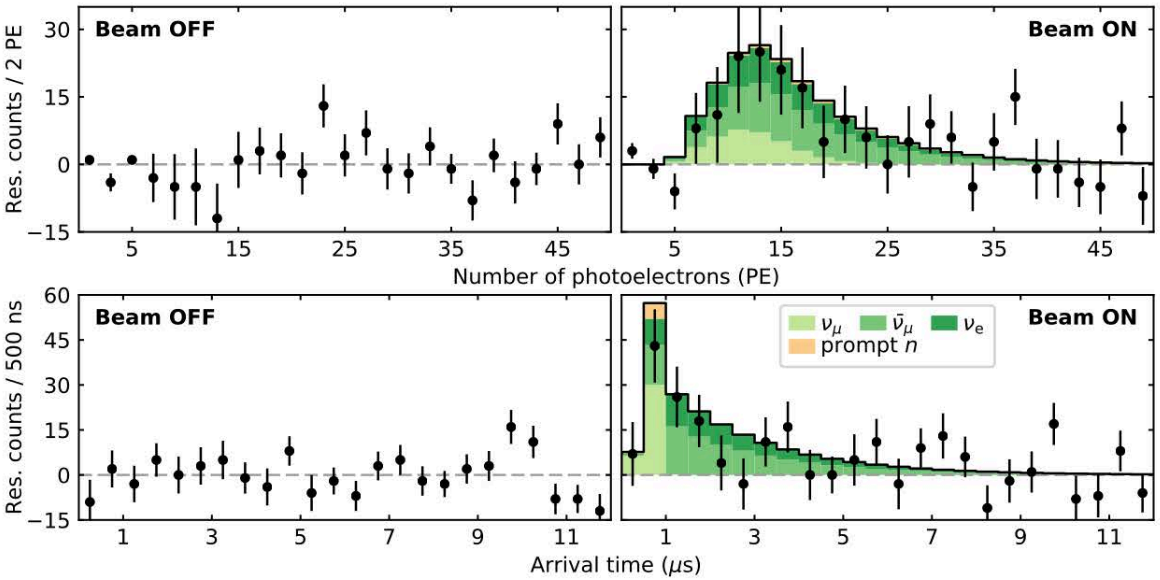


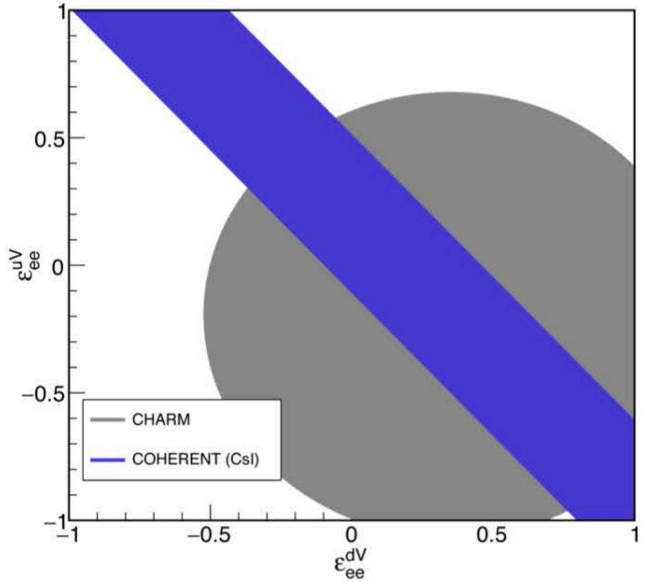


Measurement of CEνNS [Rich]

- Analyzed as a simple counting experiment
  - 136 ± 31 counts
- 2-D profile likelihood analysis
  - 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



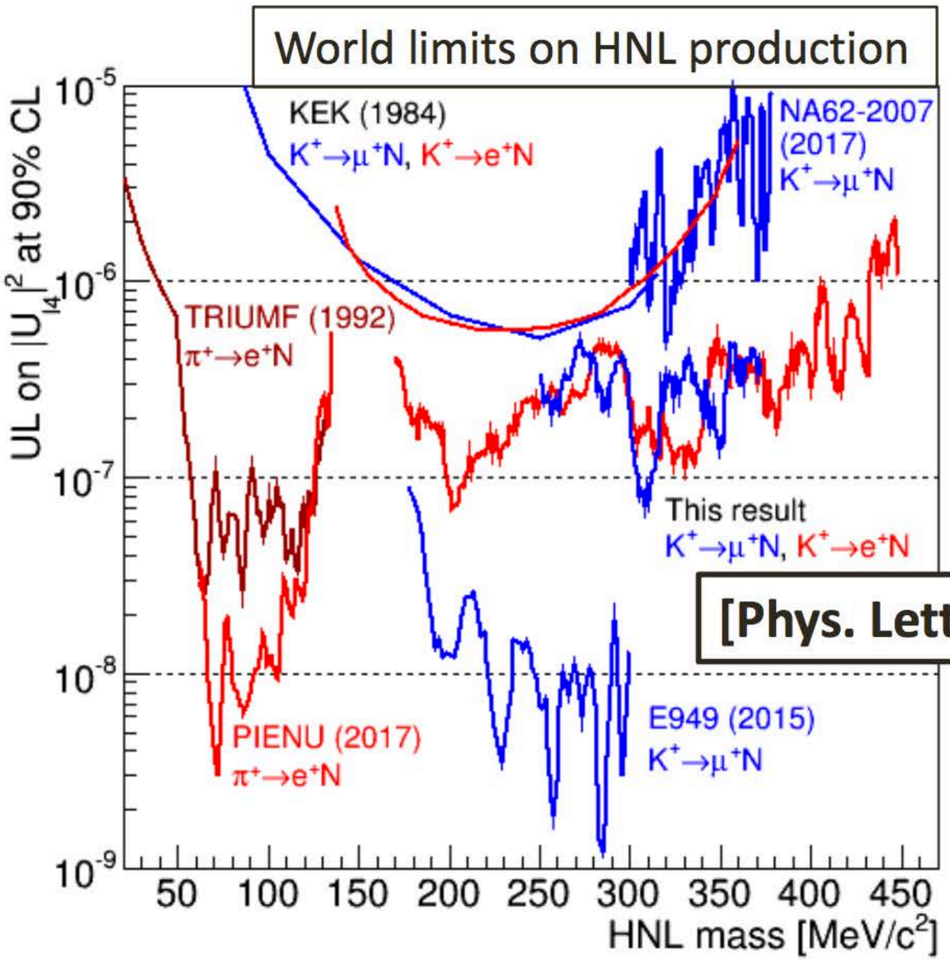




HNL from *K* Decays (NA62)

- The limits on $\mathbf{n_{UL}}$ are converted into a limit on the mixing elements $|U_{e4}|^2$ **(red)** and $|U_{\mu 4}|^2$ **(blue)** via $|U_{\ell 4}|^2 = \frac{B(K^+ \to \ell^+ N)}{B(K^+ \to \ell^+ \nu)} \times \frac{1}{\rho(m_N)}$

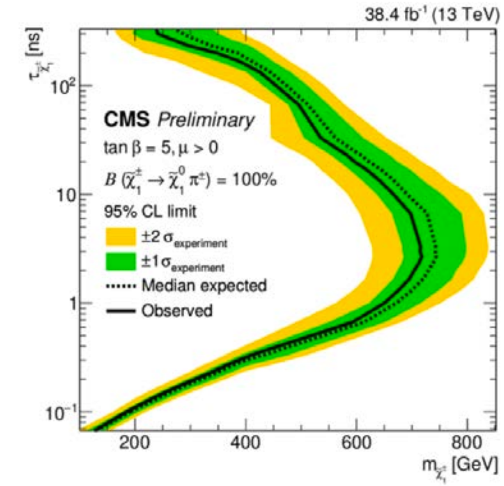
[Parkinson]



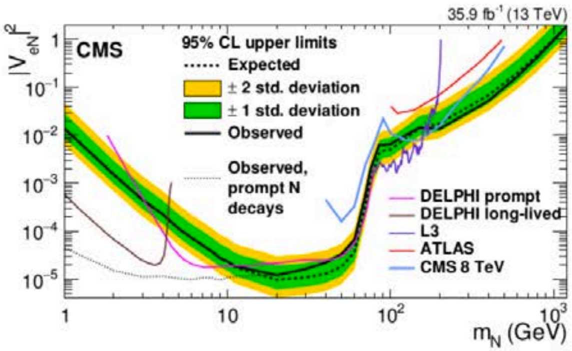
[Phys. Lett. B 778 (2018) 137]

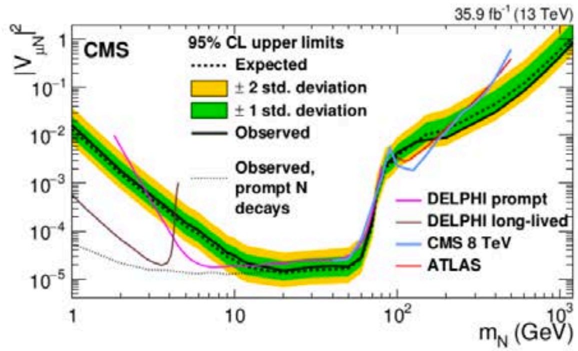
[Negro]

Disappearing tracks



HNL: trileptons final state

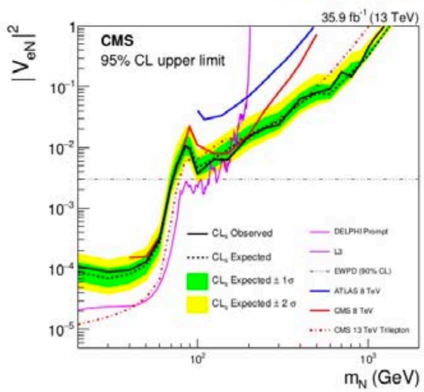


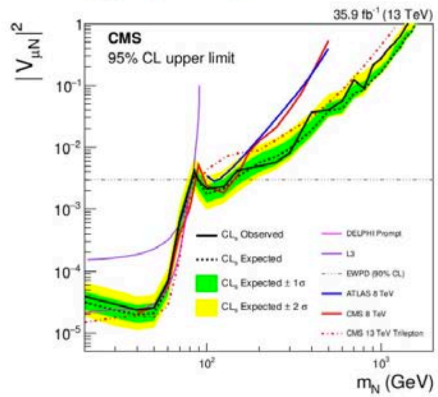


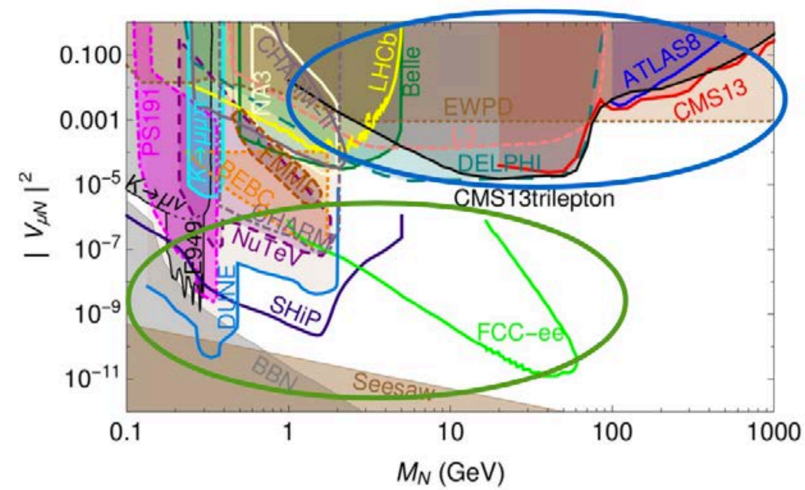
HNL: SS dileptons final state

- Limits set on mixing parameters $|V_{eN}|^2$ and $|V_{\mu N}|^2$

→ 2.3 x 10^{-5} – 1 for 20<m_N<1600 GeV







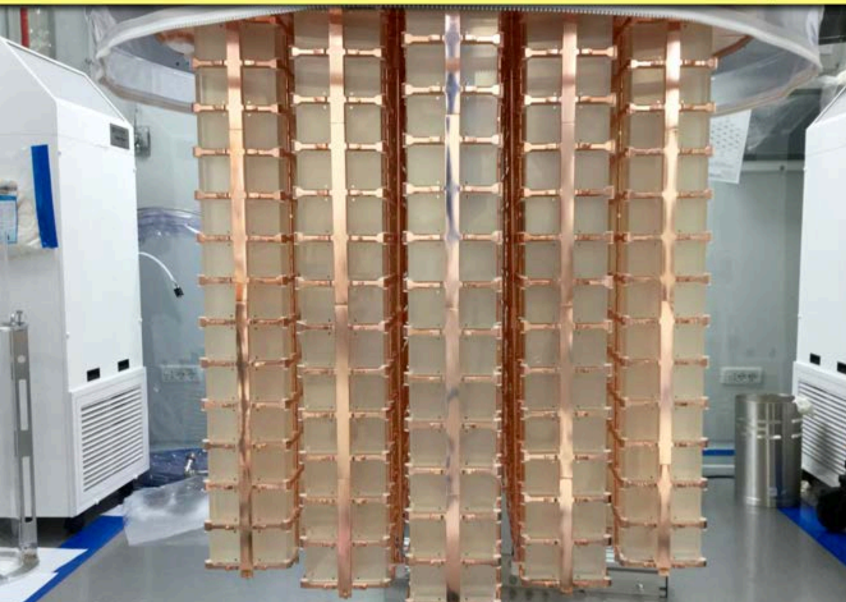
$0\nu2\beta$ Experiments at this session

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]**

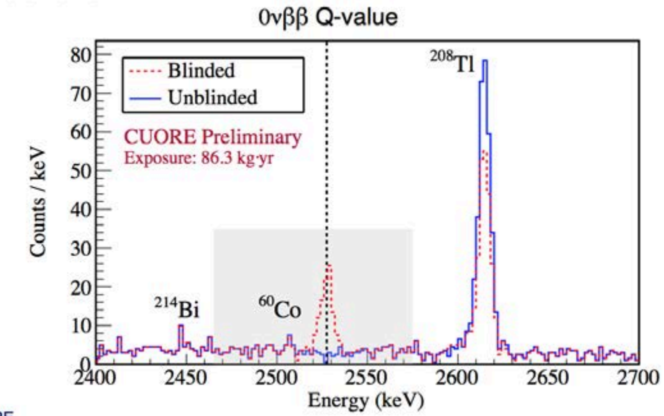
26/8/16: CUORE detector complet



M. Vignati - CUORE

Blinding of the result

- Data at the Q-value are salted by randomly exchanging events with the nearby ^{208}Tl background line. This creates an artificial peak that hinders the true rate at the Q-value;
- Once the analysis procedures are fixed data are unblinded by exchanging back the events.



M. Vignati - CUORE 13

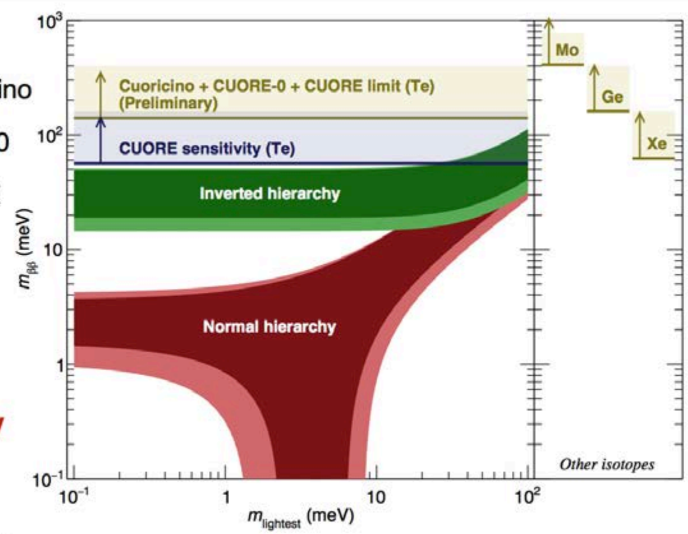
Combined with previous Te experiments

Exposure ^{130}Te:

- 19.75 kg yr Cuoricino
- 9.8 kg yr CUORE-0
- 24.0 kg yr CUORE

Combined 90% limit:

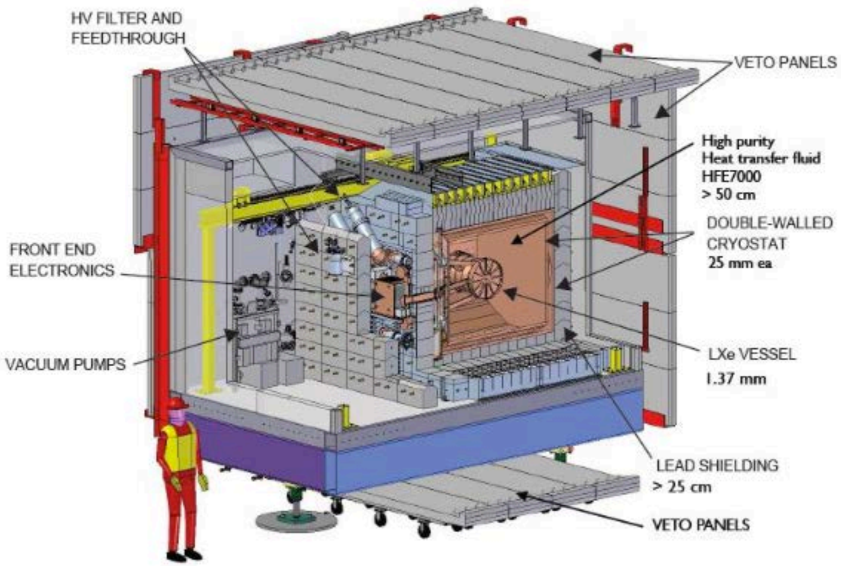
- $T^{0\nu} > 1.5 \times 10^{25}$ yr
- $m_{\beta\beta} < 140\text{-}400$ meV



Experimental half lives:
^{130}Te: 1.5×10^{25} yr from this analysis
^{76}Ge: 5.3×10^{25} yr from Nature 544, 47–52 (2017)
^{136}Xe: 1.1×10^{26} yr from Phys. Rev. Lett. 117, 082503 (2016)
^{100}Mo: 1.1×10^{24} yr from Phys. Rev. D 89, 111101 (2014)
CUORE sensitivity: 9.0×10^{25} yr

M. Vignati - CUORE 15

[Tomei/Vignati]



EXO-200

[Der Mesrobian-Kabakian]

Sensitivity and limits

- Combined analysis:
  - Total exposure = 177.6 kg.yr

Sensitivity of $3.7\text{x}10^{25}$ yr
$T_{1/2}^{0\nu\beta\beta} > 1.8\text{x}10^{25}$ yr
$\langle m_{\beta\beta} \rangle < 147 - 398$ meV

(90% CL)

arXiv: 1707.08707

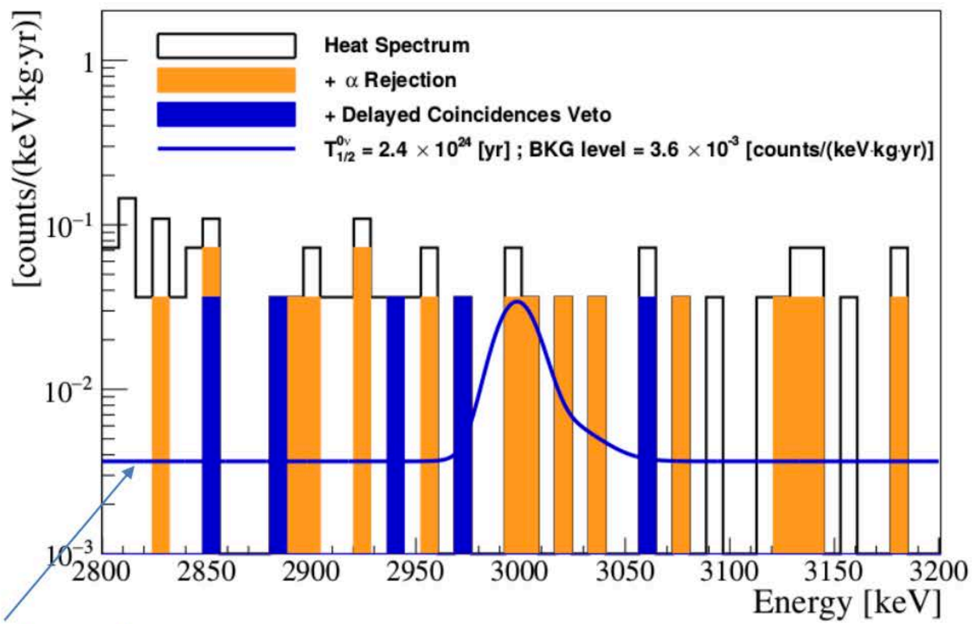
- Individual phase limits:

	Livetime	Exposure	Limit (90% CL)
Phase 1	596.7 d	122.0 kg.yr	$T_{1/2}^{0\nu\beta\beta} > 1.0\text{x}10^{25}$ yr
Phase 2	271.8 d	55.6 kg.yr	$T_{1/2}^{0\nu\beta\beta} > 4.4\text{x}10^{25}$ yr

CUPID-0: Cuore Upgrade with Particle IDentification

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

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



BKG level:
3.6 conts/(keV Kg y)

[Gironi]

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

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

Wrap Up Neutrinos

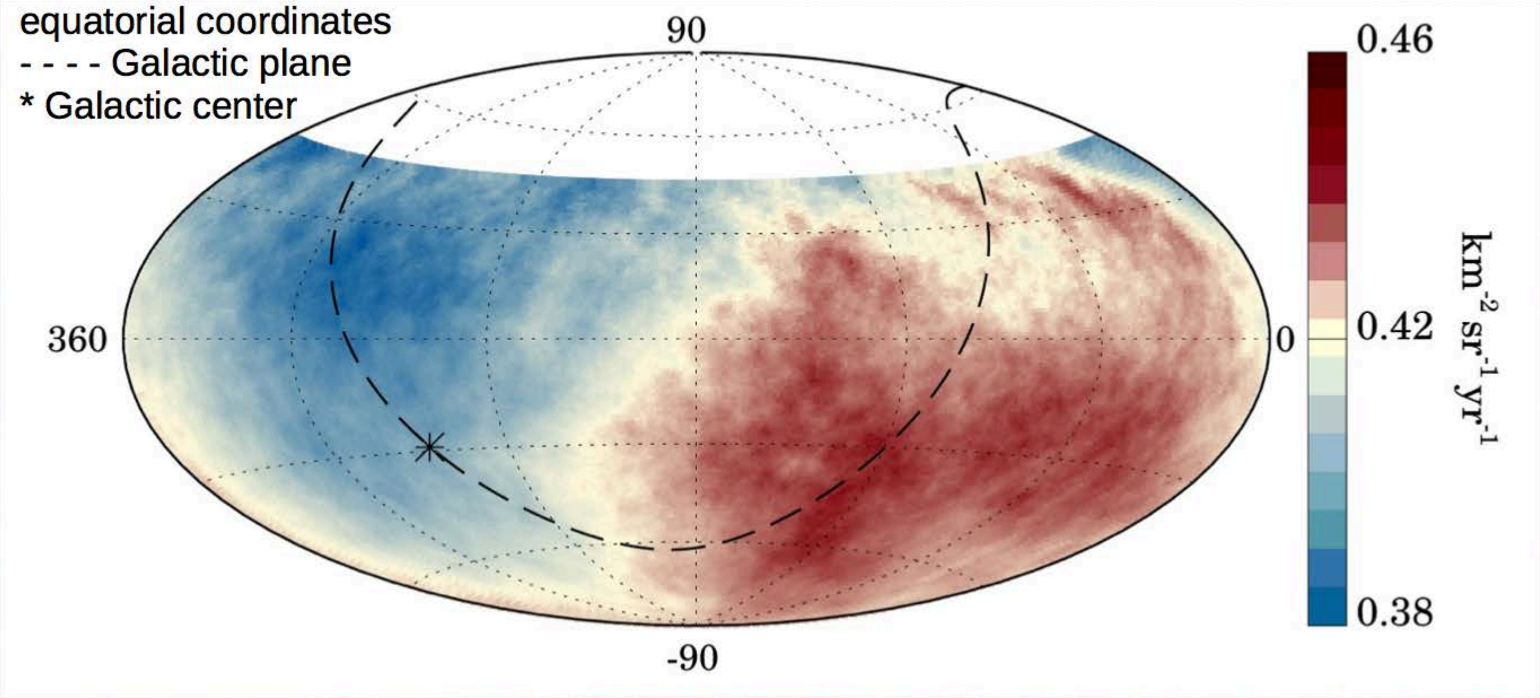
- 2σ exclusions of CP conservation
- IH Disfavoured at 2σ
- 5% deficit in reactor flux, RAA
- Clarification of Sterile Neutrinos required…
- Interesting DAR techniques revival
- CEvNS observed
- HNL (RH neutrinos) searches at accelerators
- $0\nu2\beta$ Eexperiments reaching the IH sensitivities

Cosmic rays & Gravitation

- Auger **[Bohacova]**
- DAMPE **[Xiang Li]**
- Ligo-Virgo **[Cella]**

[Bohacova]

Arrival directions
Large scale distribution



E > 8 EeV : ~ 30 000 events

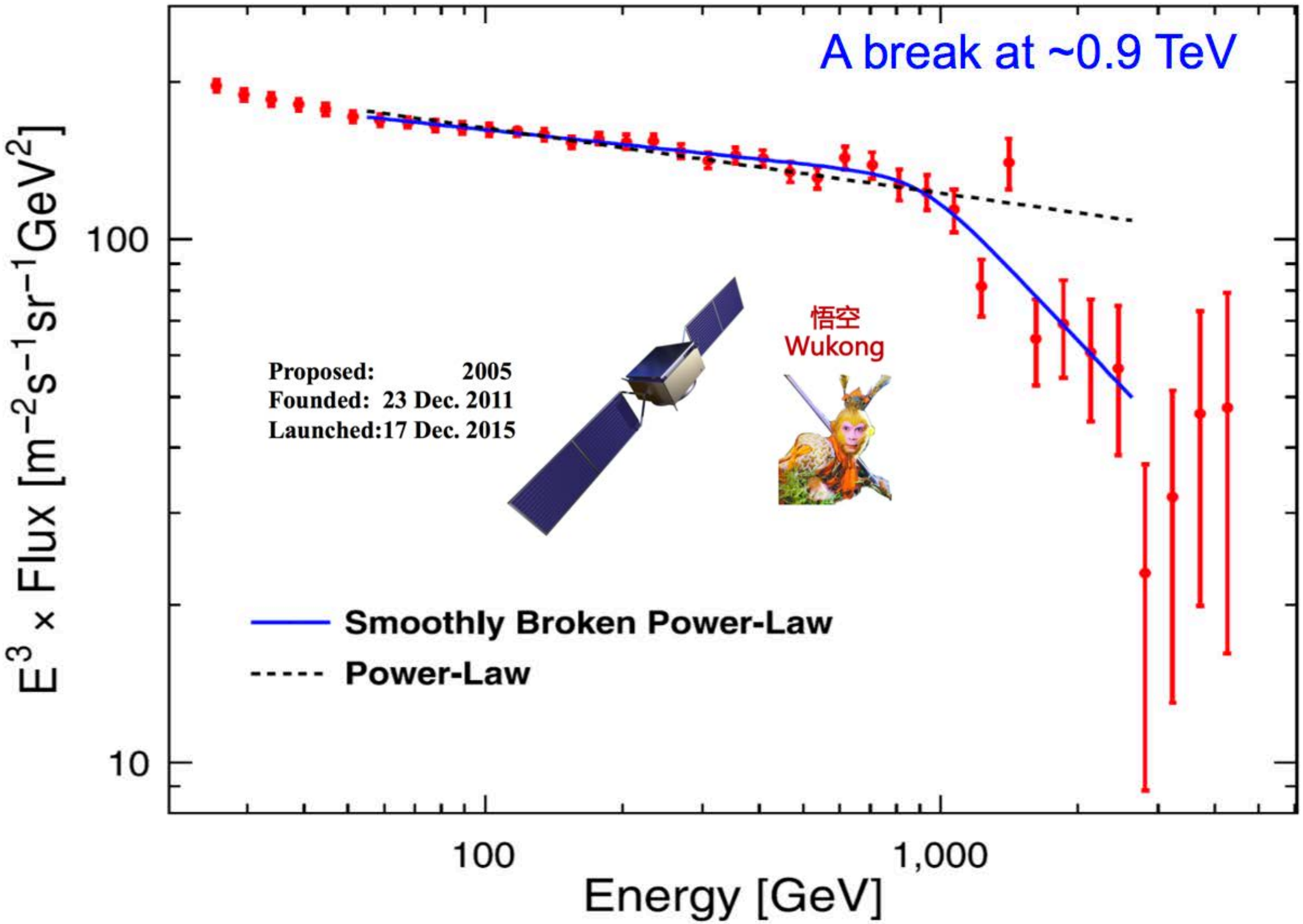
- indication of extragalactic origin
- distribution of nearby galaxies is also dipolar
  - 2MRS catalogue dipole points 55° away

physicsworld BREAKTHROUGH OF THE YEAR 2017

Science 357 (22 September 2017) 1266

First result: CRE spectrum

[Xiang Li]

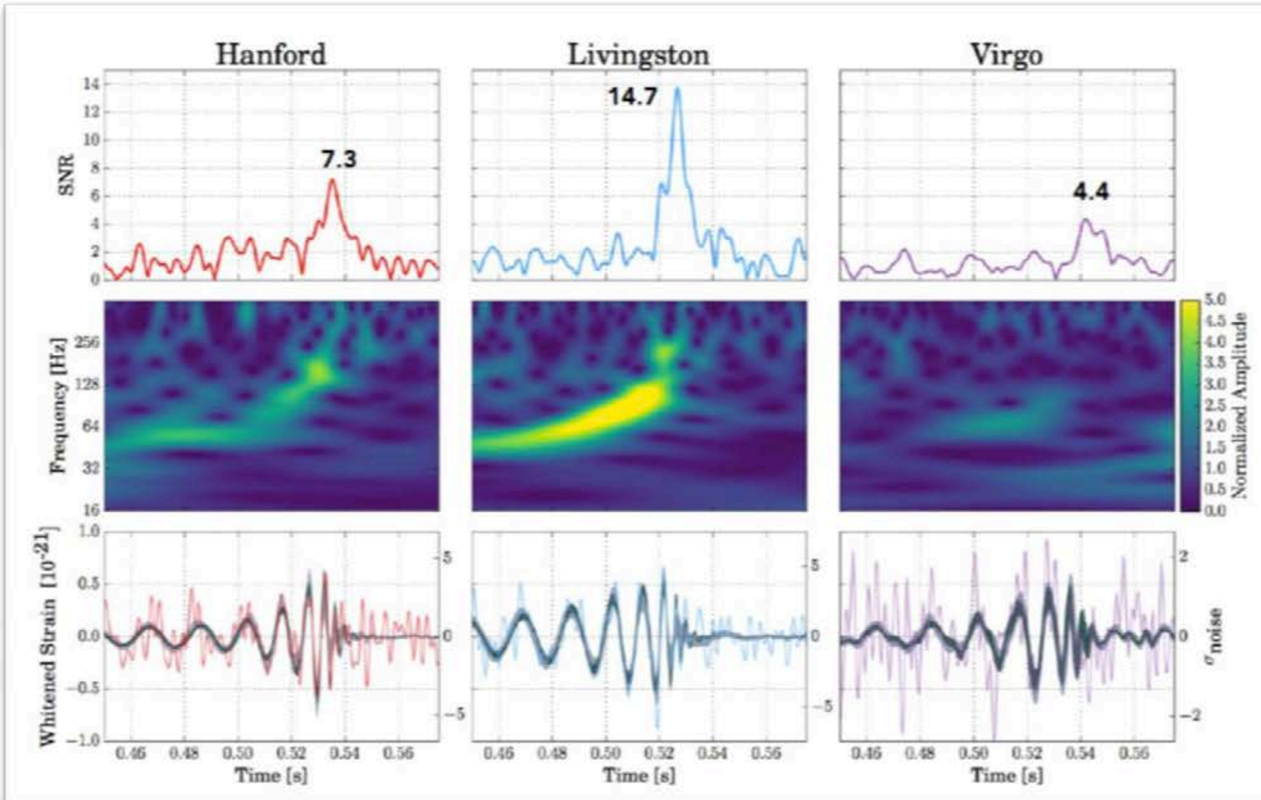


(DAMPE collaboration, 2017, Nature, 552, 63)

LIGO-VIRGO

GW170814

[Cella]



- «Still» a BBH coalescence.
- Three detectors detection:
  - Localization
  - Polarization

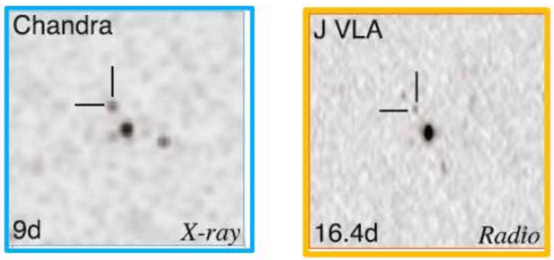
Phys. Rev. Lett. 119, 141101 (2017)

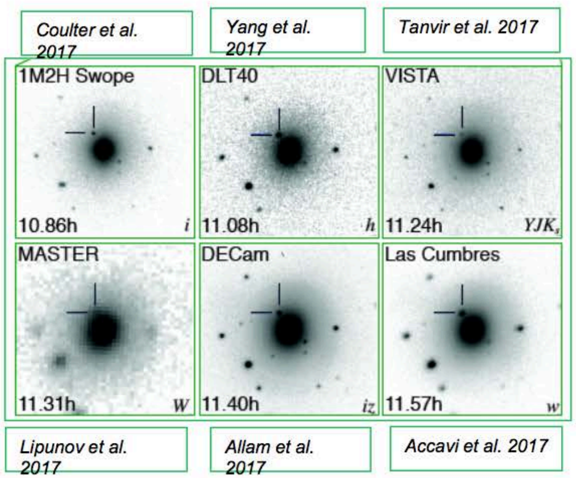
GW170817

[Cella]

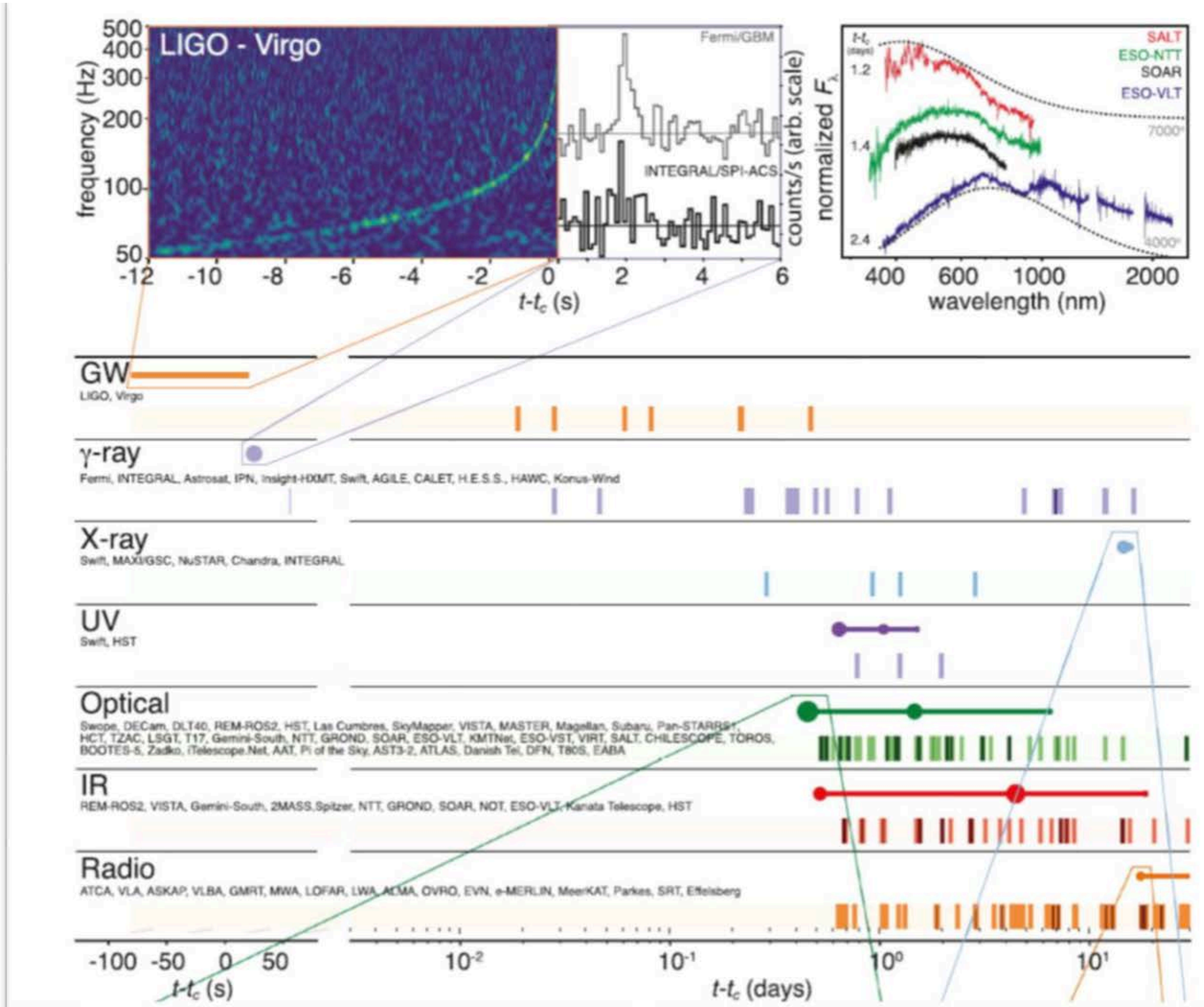
Multi-messenger astronomy is born

Counterparts





[Astrophys. J. Lett. 848, L12 (2017)]



Thank You

- I am honored to have been invited to summarize the conference
- The quality of the talks was outstanding
- It made it easier to prepare a summary…
- …leaving a couple of hours of free time to go and see the Monte Bianco!

Mont Blanc

Monte Bianco