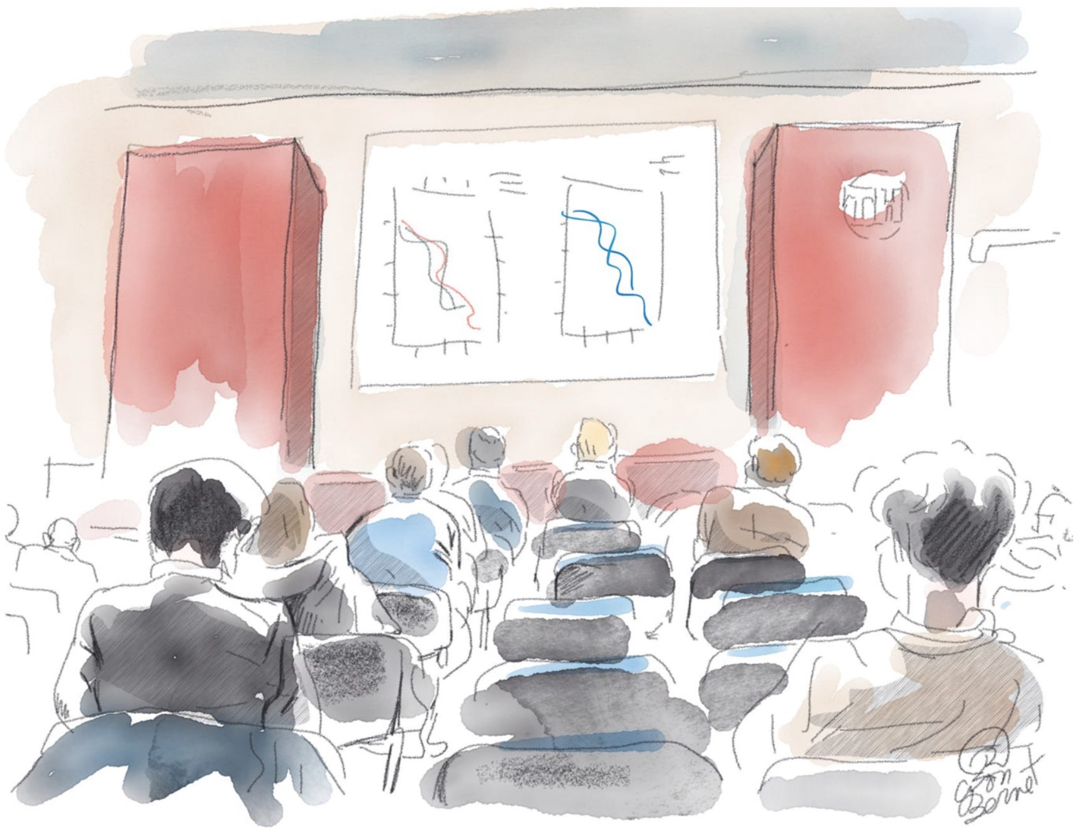
24 - 31 March 2024



Packed sessions with exciting recent results
52 experimental talks and lively discussions

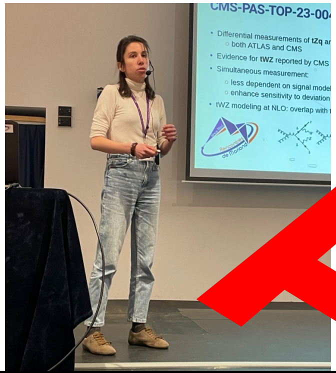
Challenge to summarise !

Apologize for not covering many topics !
Focus on recent results

Barbara Clerbaux
Université libre de Bruxelles
Sunday 31/03/2024
58th rencontres de Moriond

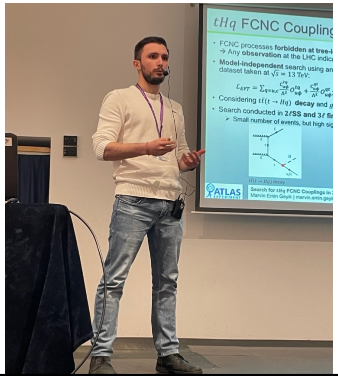
Amasing!

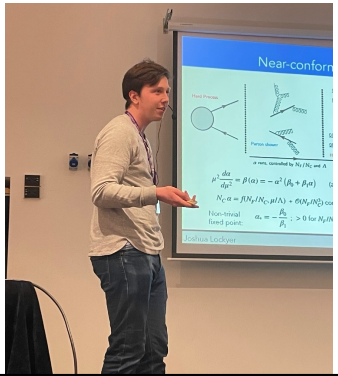

Mihaela Marinescu

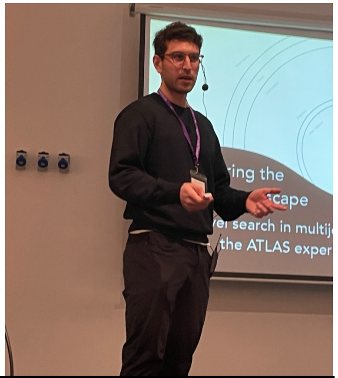

Federica Colombina


A andr tto


Riccardo Bartocci


Marvin Geyik

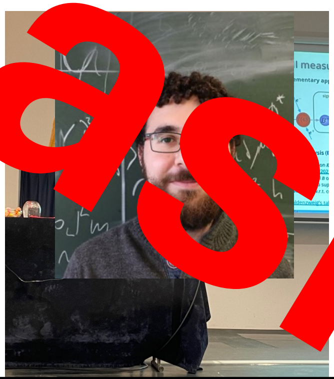

Joshua Lockyer


Anthony Badea

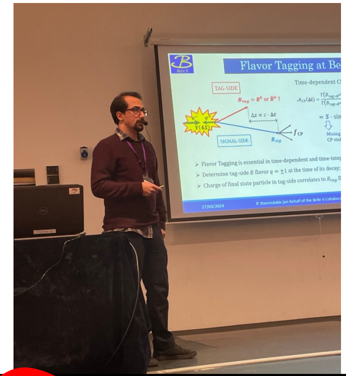

Niall Mchugh


Nico Kleijne


Leon Carus


Mustafa Tabet


Ste o M eta

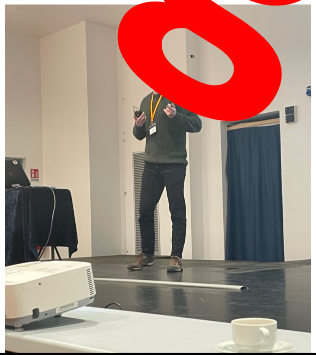

Petros S avroulakis


Shu-Ping Lin


Praveen Tiwari


David Cabo


Pietro Grutta


Victor Enguita Vileta


Daniel Naredo

MORIONND FAN ... my Moriond history :

MORIOND 1995 (QCD) – Les Arcs
- Session on the top discovery
- LHC was approved, presentation of the detectors
- Structure functions, diffraction ...

MORIOND 1999 (QCD) – Les Arcs
SM fits m_H = 71 +75-42 GeV

MORIOND 2007 (EW)
(young scientist forum appeared,
summary in French disappeared)

MORIOND 2010 (COSMO) - proceeding in colours
(start of the LHC)

MORIOND 2012 (EW) :
- H local significance of 2.5σ and 2.8σ by ATLAS and CMS 2010 data (5 fb^{-1}) at 7 TeV
- θ_{13} is measured to be non-zero (5.2σ)

MORIOND 2013 (EW) :
Nobel prize in October
LHCb : observation of $B_s \to \mu\mu$ (3.5σ)

MORIOND 2015 (EW) :
Anniversary : 50th Rencontres de Moriond

PLAN

- H boson results
- Electroweak precision measurements
- Beyond the SM
- Flavour physics
- Neutrino and dark matter

H BOSON

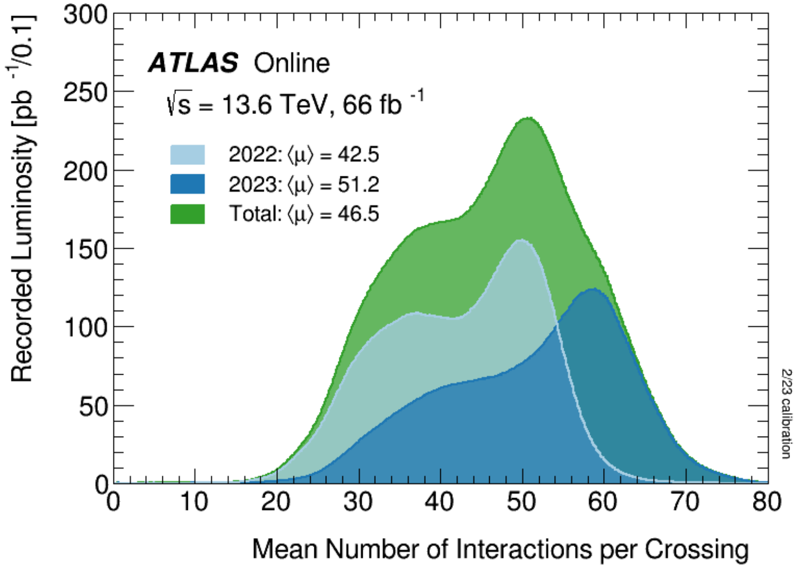
ATLAS and CMS results

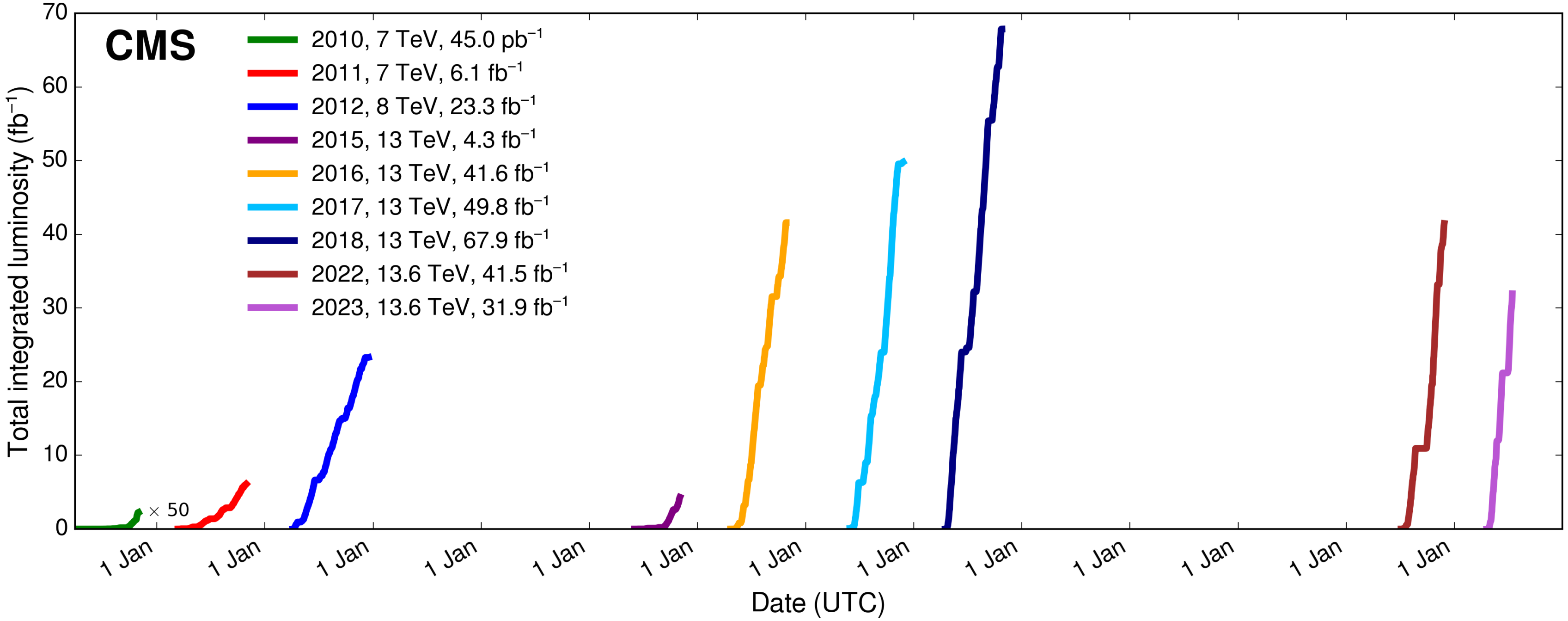
Andrew Chrisholm
Louis D'Eramo
Jean-Bapiste de Vivie
Abdollah Mohammadi
Nicolo Trevisani
George Uttley

Machine and luminosity ：

CMS and ATLAS

Run 1	2010-12	7-8 TeV	30/fb
Run 2	2015-18	13 TeV	160/fb
Run 3	2022-25	13.6 TeV	(40+30 +…)/fb
Long shutdown			
Run 4	2029-32	High-Lumi phase	
Run 5	2035-28	Major upgrade of the	
Run 6	2040-41	CMS/ATLAS detectors	

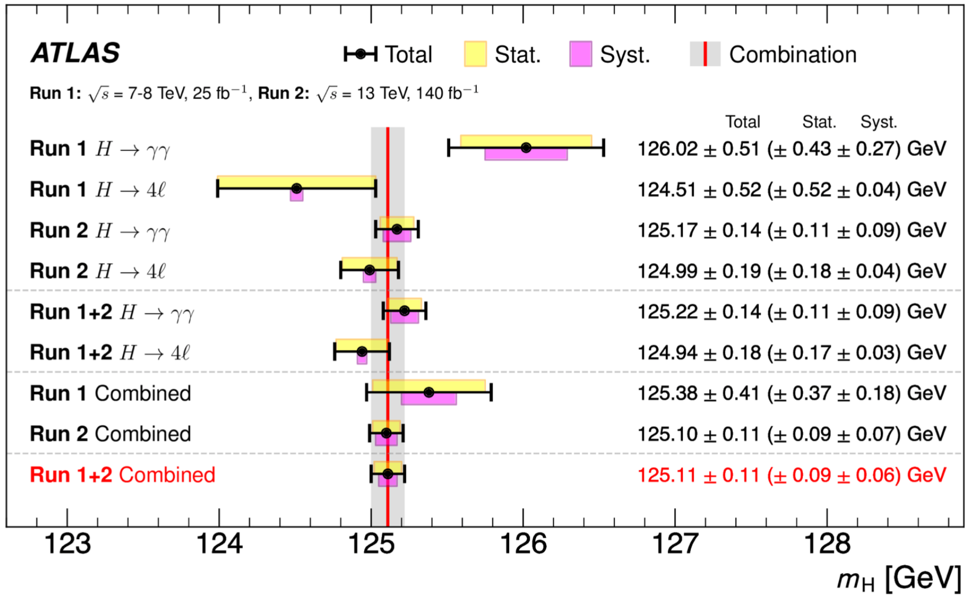




H mass and Width measurements (Jean-Baptiste de Vivie)
Fundamental parameters of the SM
from H→$\gamma\gamma$ and H→ZZ→4l

H mass : with the Run 1: m_H = 125.09 ± 0.21(stat) ± 0.11(syst) GeV
Key uncertainties : lepton and photon energy scales

- Run 2 : CMS H→4l : m_H = 125.04 ± 0.11(stat) ± 0.05(syst) GeV
Beam spot constraint, per-event m4ℓ uncertainty, use categorisation, improve the line shape description
Most precise single measurement
- Run 2: ATLAS H→$\gamma\gamma$: m_H = 125.17 ± 0.11(stat) ± 0.09(syst) GeV
Refined calibration model, linearity fit - Keep syst below stat error



ATLAS RUN 1 and run 2 combined :
Precision $\mathcal{O}$(0.09%)

Target for HL-LHC : mass uncertainty of about 20 MeV

H Width : tiny width predicted in SM : Γ_{SM} = 4.1 MeV << mass resolution (1-2 GeV)
BSM contributions could bring enhancement (e.g. Higgs portal to DM)
On–shell line shape from CMS : Γ < 330 MeV @ 95% CL (~ 80×Γ_{SM})

Indirect limit from off-shell regime :

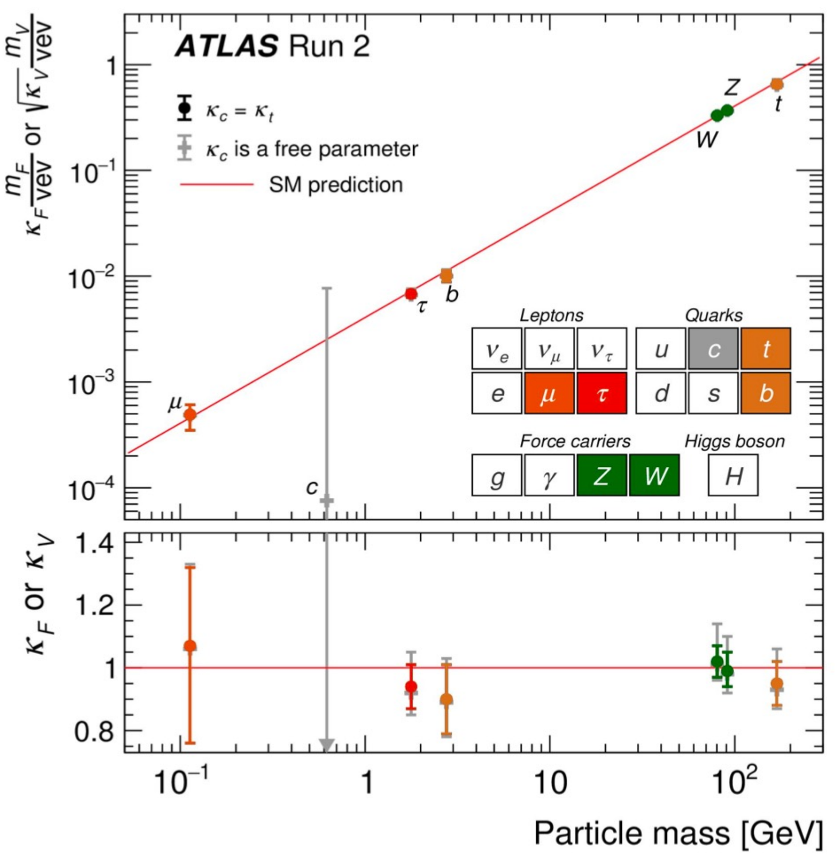
$$\sigma(i \to H^{(*)} \to f) \sim \frac{g_i^2 g_f^2}{(\hat{s} - m_H^2)^2 + m_H^2 \Gamma^2}$$

$\Gamma = 2.9^{+1.9}_{-1.4}$ MeV, $\in$ [0.6,7.0] MeV @ 95 % CL ATLAS

(Expected : $\Gamma = 4.1 \pm 3.5$ MeV, $\in$ [0.1,10.5] MeV @ 95 % CL)

assuming $[g_i g_f]_{\text{off-shell}} = [g_i g_f]_{\text{on-shell}}$

Nature 607, 52–59 (2022)



H coupling measurements (Nicola Trevisani)

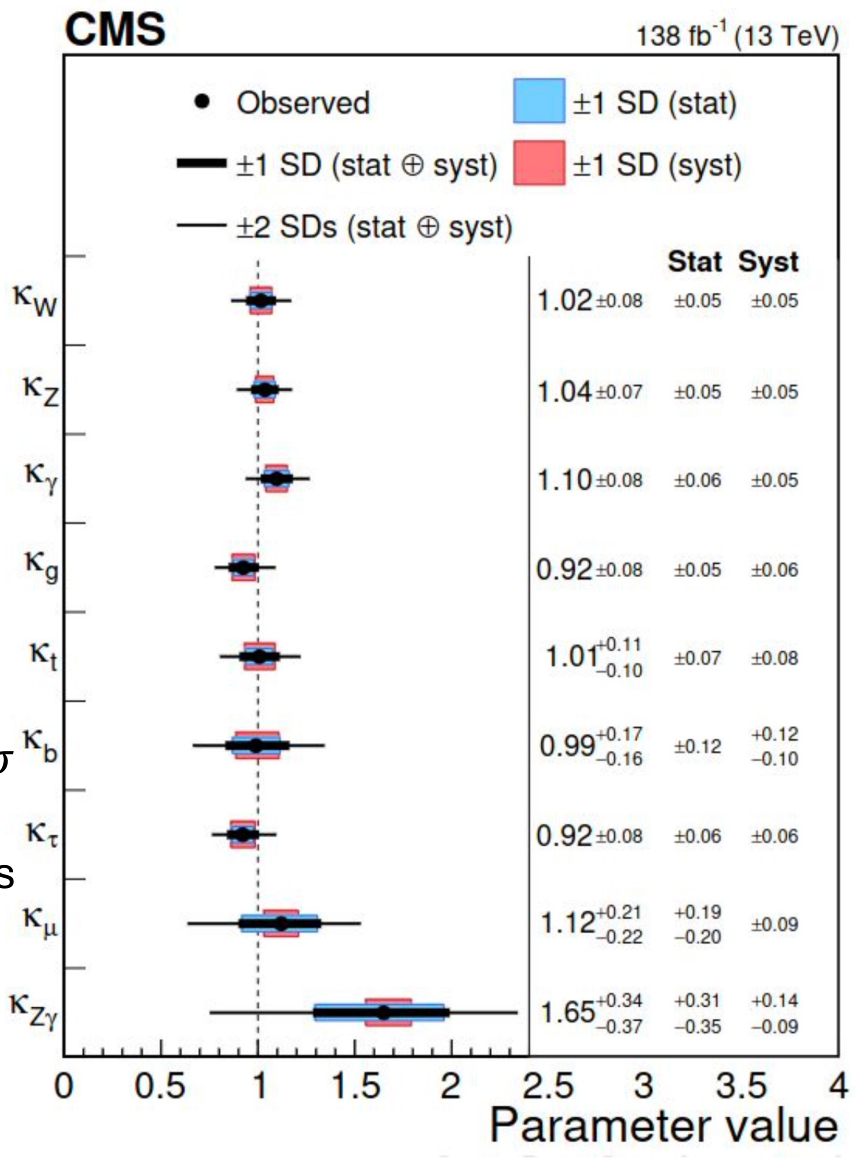
Fundamental parameters of the SM

Nature 607 (2022) 60

Couplings to the most massive particles are well established

H→$\mu\mu$: Evidence in 2020
Next challenge : H→cc

Kappa value : coupling constant ratio $\kappa = \lambda/\lambda_{SM}$



- **H→cc :** CMS : First observation of VZ, Z → cc at a hadron collider at 5.7σ
  σ(VH) x BR(H→cc) < 14 SM at 95% CL
- **ttH, H→bb :** process allows to measure both the κ_t and κ_b coupling values
  ATLAS : $\mu = 0.35^{+0.36}_{-0.34}$ CMS : $\mu = 0.33 \pm 0.26$
  Definition : signal strength $\mu = \sigma/\sigma_{SM}$
- **New : bbH** process, challenging channel
  CMS : H→WW, H→ $\tau\tau$, Obs. (exp) UL of 3.7 (6.1) times the SM at 95% CL

Fiducial Differential cross section measurements

(Abdollah Mohammadi)

Enough statistics to go differential !

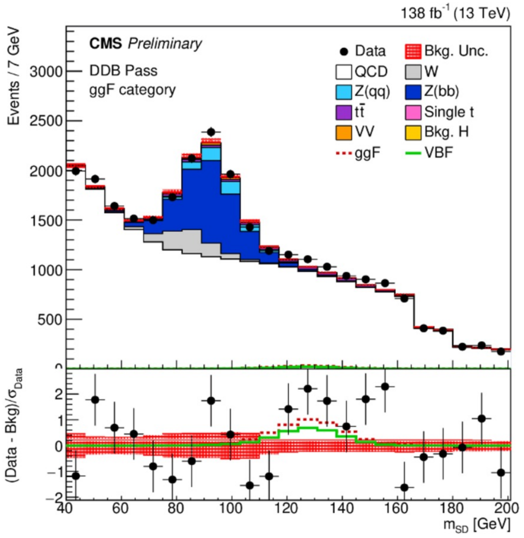
Differential cross section as function of :

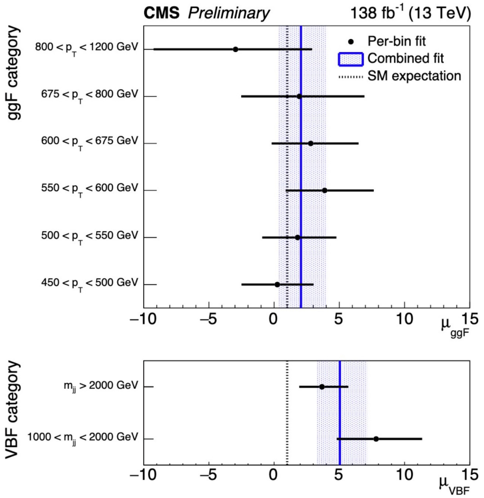
$p_T(H)$ (QCD perturbative modelling, sensitivity to BSM scenarios) and N_{jet} (sensitive to the production mode composition)

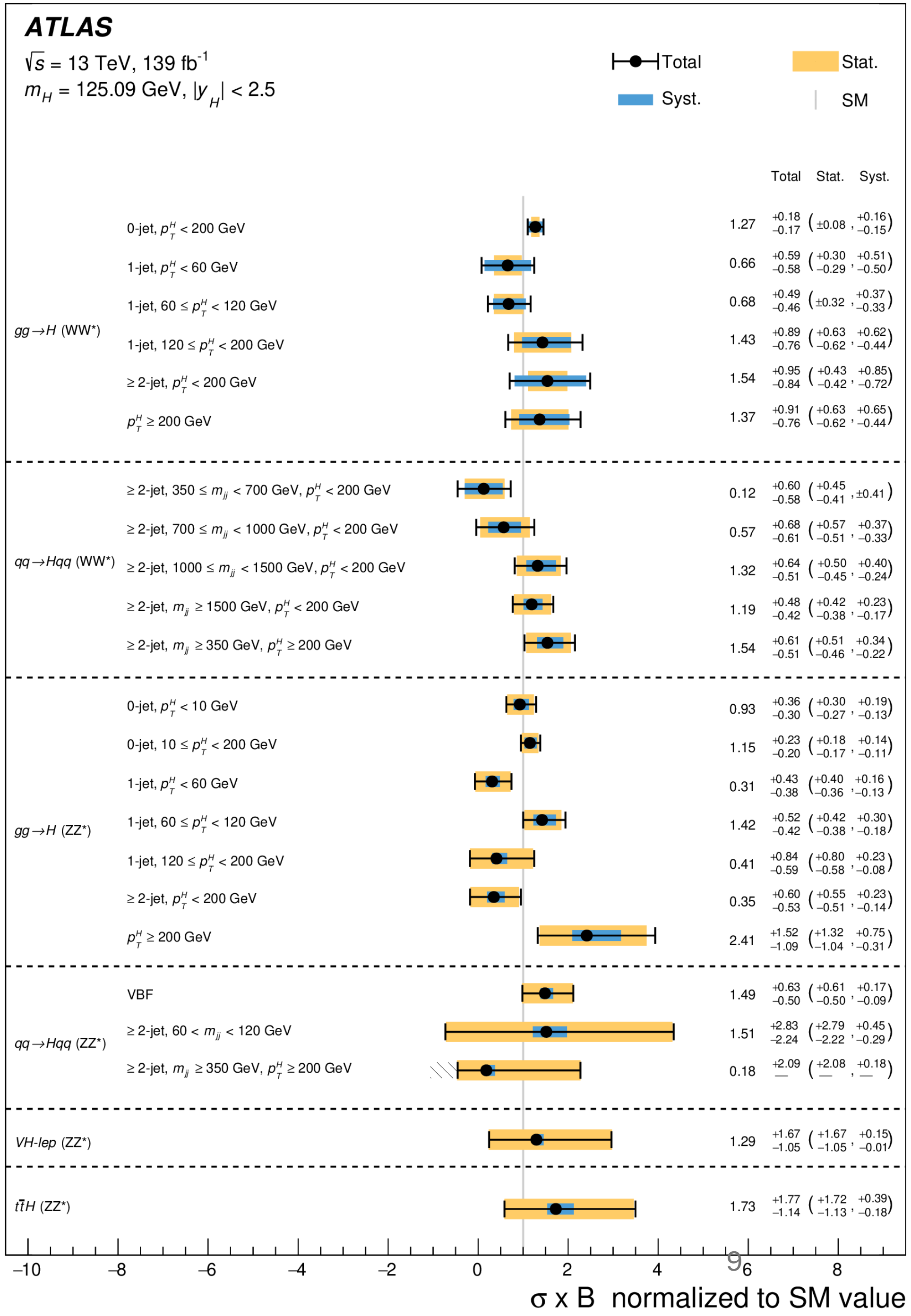
- **$H \rightarrow \gamma\gamma$ and $H \rightarrow$ ZZ, WW, VBF $H \rightarrow$ WW**
- **$H \rightarrow bb$, $H \rightarrow \tau\tau$, boosted $H \rightarrow \tau\tau$**

Example : New $H \rightarrow bb$: large BF but small S/B, high $p_T(H)$ event >450 GeV (boosted bb system, large radius)

CMS Events are split into a signal and BG control regions based on the value of ***DeepDoubleB*** tagger.



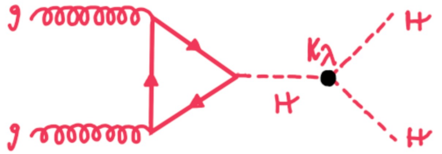




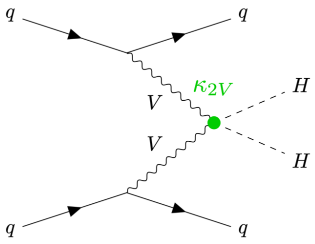
Di-H searches: HH and HX (Louis D'Eramo)

Searching for HH production is directly connected to probing the H potential, in particular the trilinear coupling λ_{HHH}
The HH invariant mass shape very dependent on the κ_λ

$$\kappa_\lambda = \lambda_{HHH}/\lambda_{SM}$$



gluon-gluon Fusion (ggF): σ = 31.02 fb
(1000x smaller than single H)



Vector Boson Fusion (VBF): σ = 1.72 fb
tests also VVHH coupling: κ_{2V}

The leading 3 (ggF) channels (bbγγ, bbττ, bbbb) are close with expected limits around ~ 5 x SM prediction
The combination leads to a limit **~ 2.5-3 x SM**.
→ κ_λ **in range : -6 to +6**

New results presented :
ATLAS VBF HH→bbbb and CMS HH→$\gamma\gamma\tau\tau$

BSM : sensitive to new particle (spin 0 or spin 2)

Impressive list of final states covered ! (Also for BSM searches)

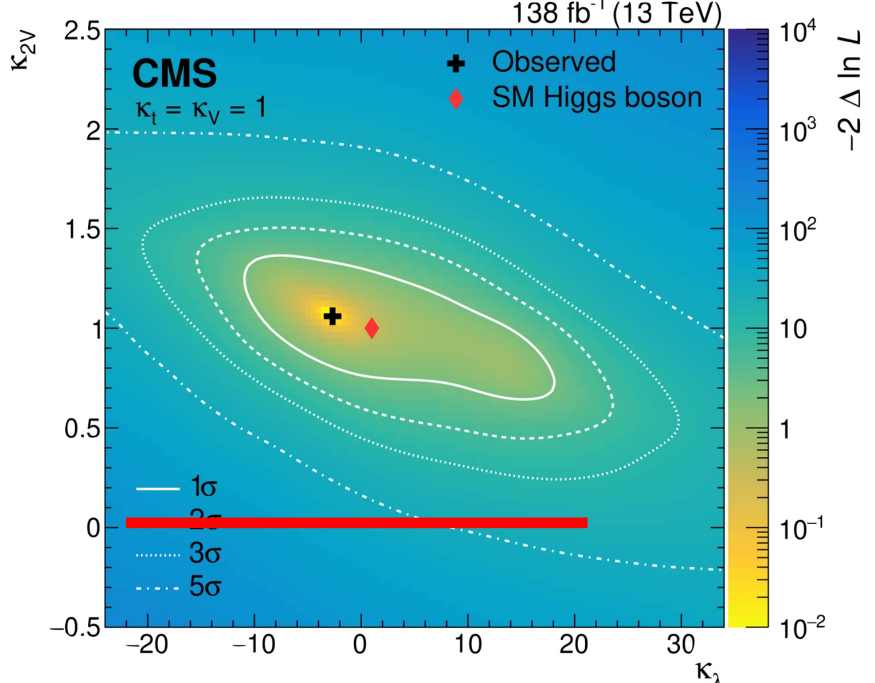
$BR(HH \to XXYY)$ (gluons, c, muon not shown)

	bb	WW	ττ	ZZ	γγ
bb	34 %				
WW	25 %	4.6 %			
ττ	7.3 %	2.7 %	0.39 %		
ZZ	3.1 %	1.1 % A	0.33 % A	0.069 %	
γγ	0.26 %	0.10 %	0.028 %	0.012 % A	0.0005 %

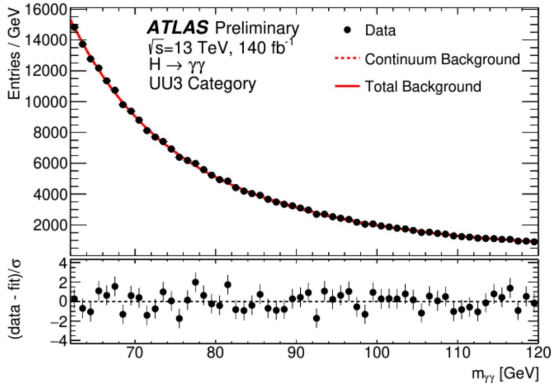
Full Run-2 analyses: A for ATLAS only

The H→bbbb boosted analysis excludes the value κ_{2V}=0 with a significance of 6.3σ

Phys. Rev. Lett. 131 (2023)



Search for BSM H boson (George Uttley)

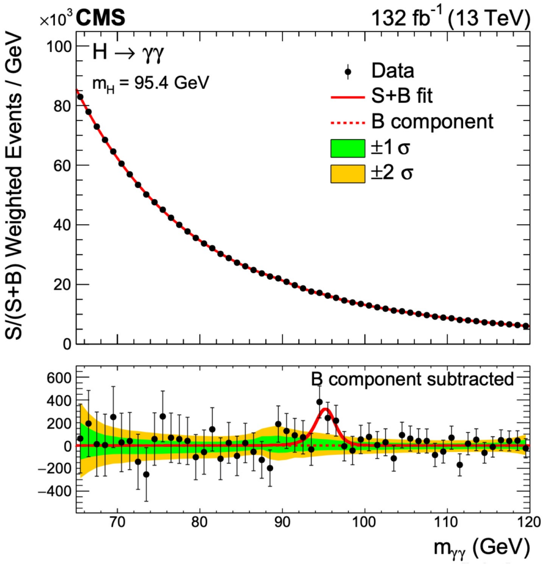


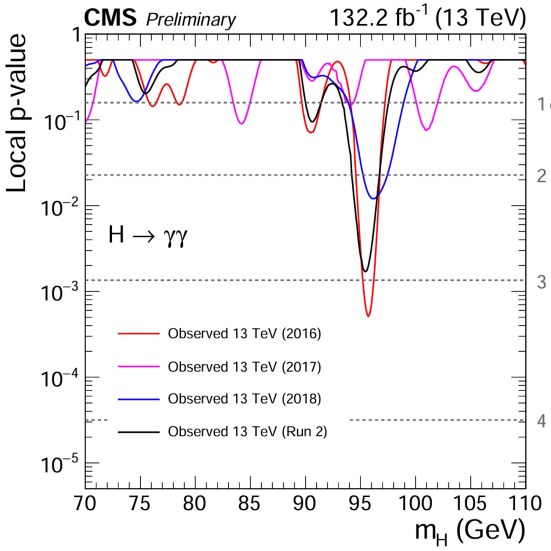
Low mass $H \to \gamma\gamma$

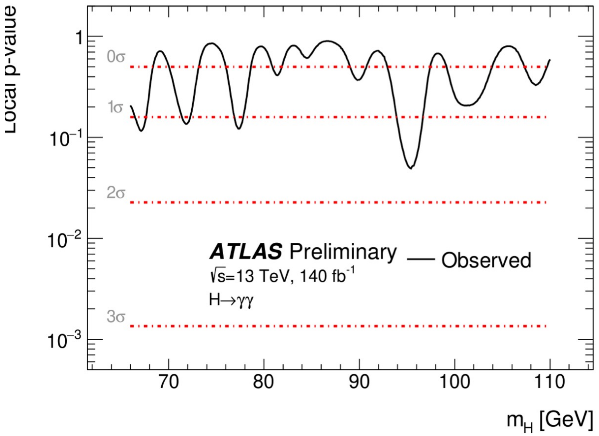
There are many 2HDM extensions which can give rise to additional low mass Higgs bosons

CMS observes an excess of local (global) significance of 2.9σ (1.3σ) at 95.4 GeV.

ATLAS observes a local significance of 1.7σ at 95.4 GeV



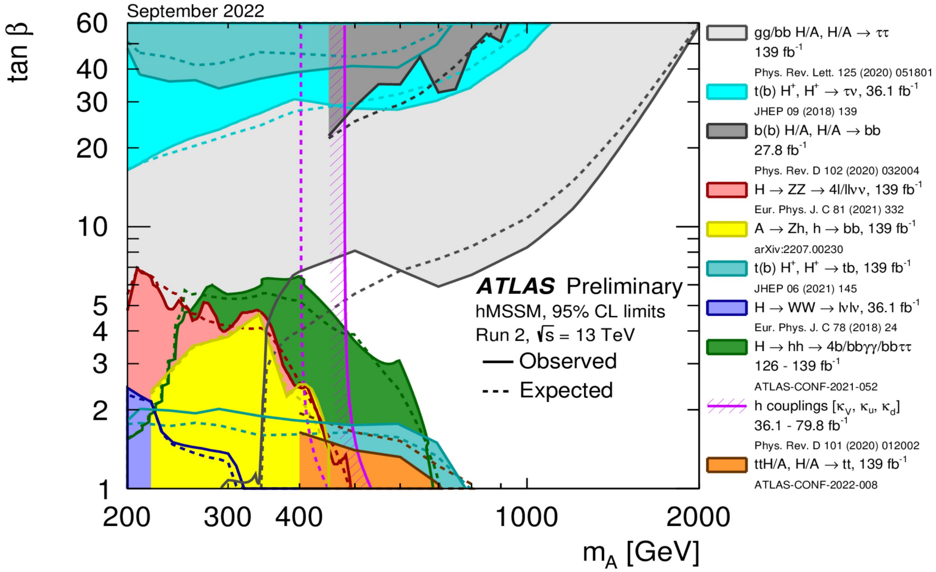




Wide scope of new BSM H boson searches released by ATLAS and CMS

- BSM H/A → tt, BSM qg → tH/A → ttq
- A→ZH→lltt, A→ZH→vvbb, A→ZH→4l+jj/MET
- Z*→h/HA→4 taus

Still a large amount of phase space available for extended H sectors



Current status of the hMSSM (type II 2HDM)

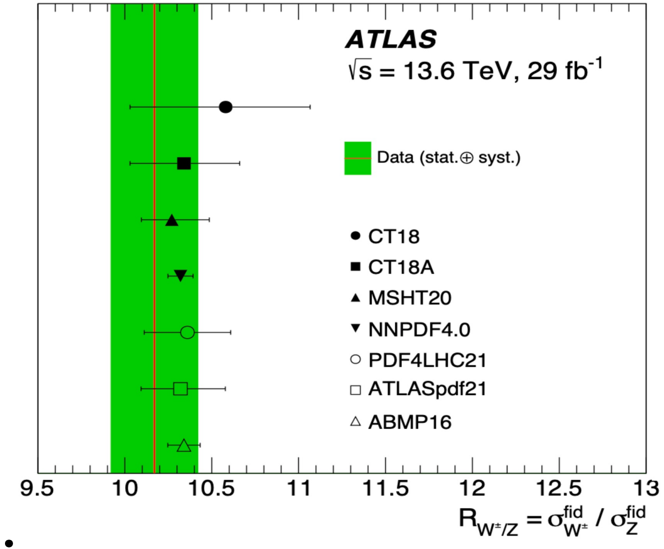
Electroweak precision measurements

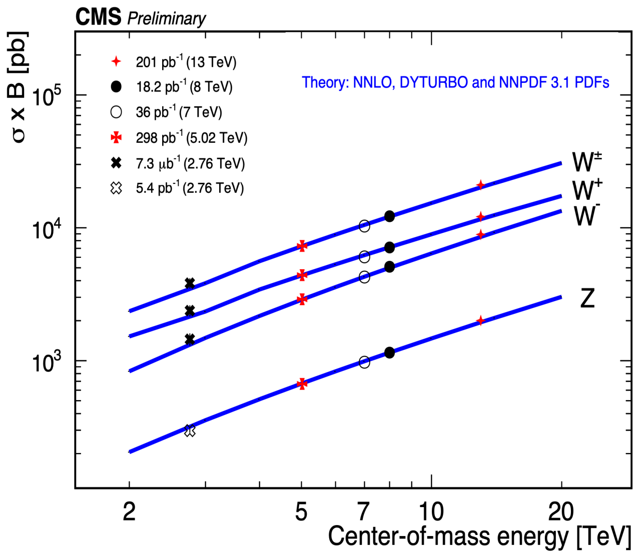
ATLAS and CMS results

Saptaparna Bhattacharya
Cécile Caillol
Aleko Khukhunaishvili
Andrea Knue
Kenneth Long

EW results : single W/Z measurement
(Kenneth Long)

- **New ATLAS W and Z cross sections** (+ ratio)
  at 13.6 TeV (Run3)
  "Special LHC runs" at 5 and 13 TeV with low PU

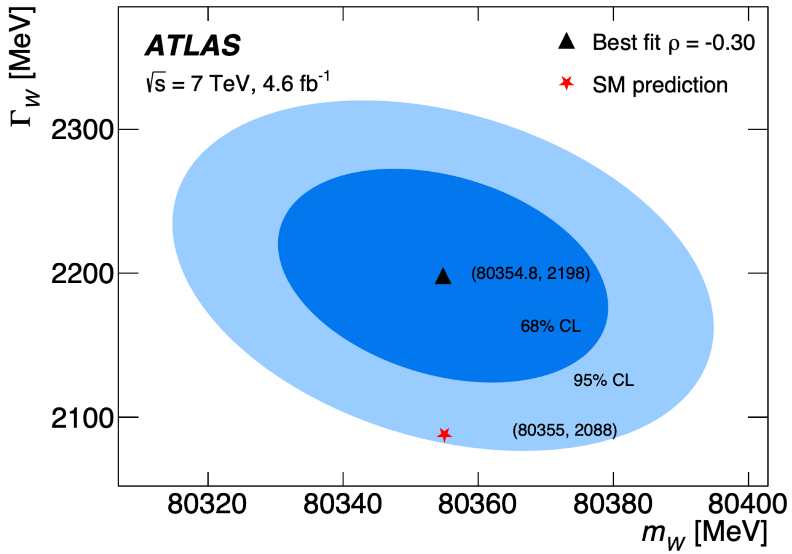


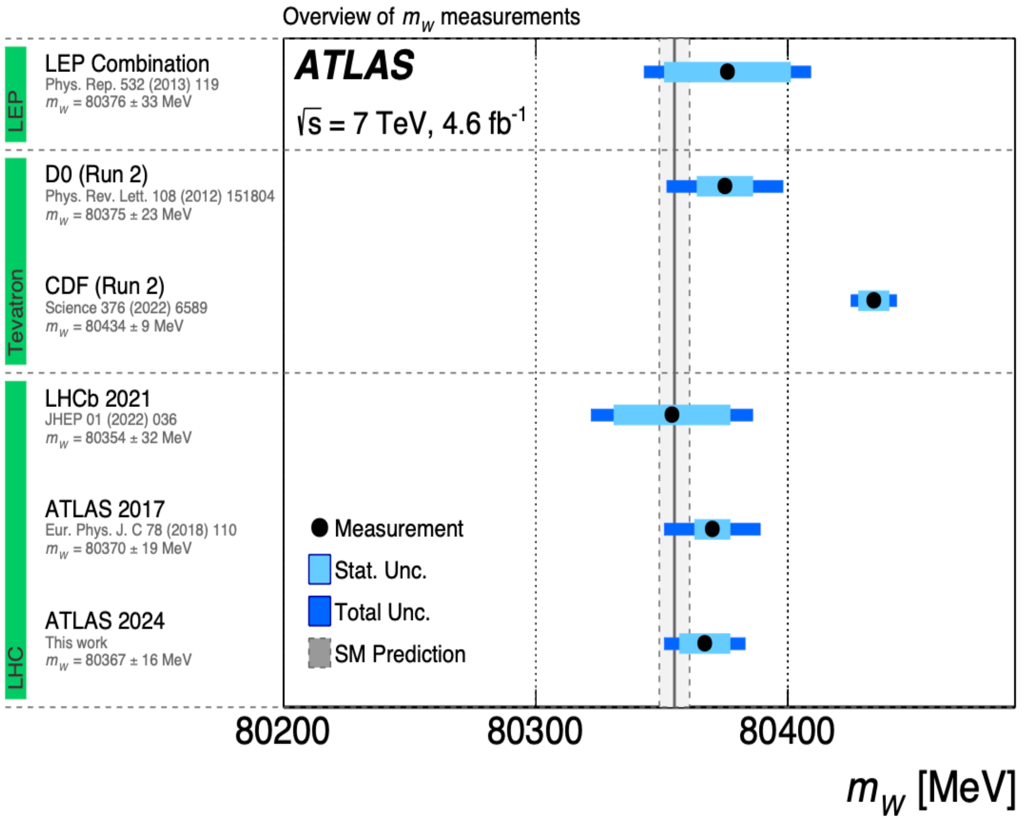


- **NEW ATLAS W mass and width measurements :**
  Updated results with extended studies of PDF
  W mass is measured from the W boson m_T and p_T distributions
  The analysis is also sensitive to Γ_W

Γ_W = 2202 ± 47 MeV

M_W = 80366.5 ± 15.9 MeV



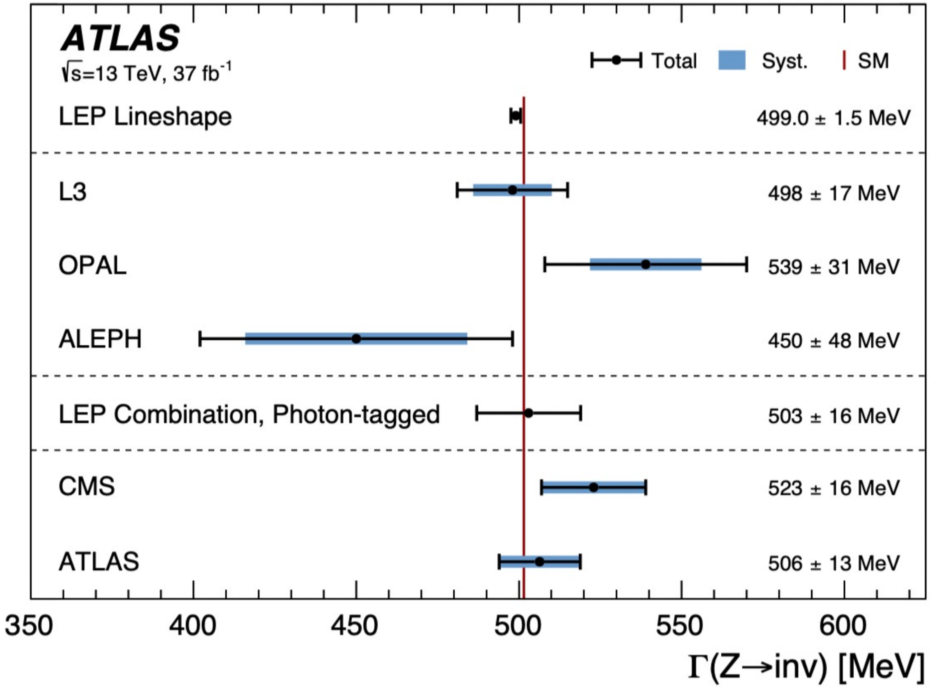


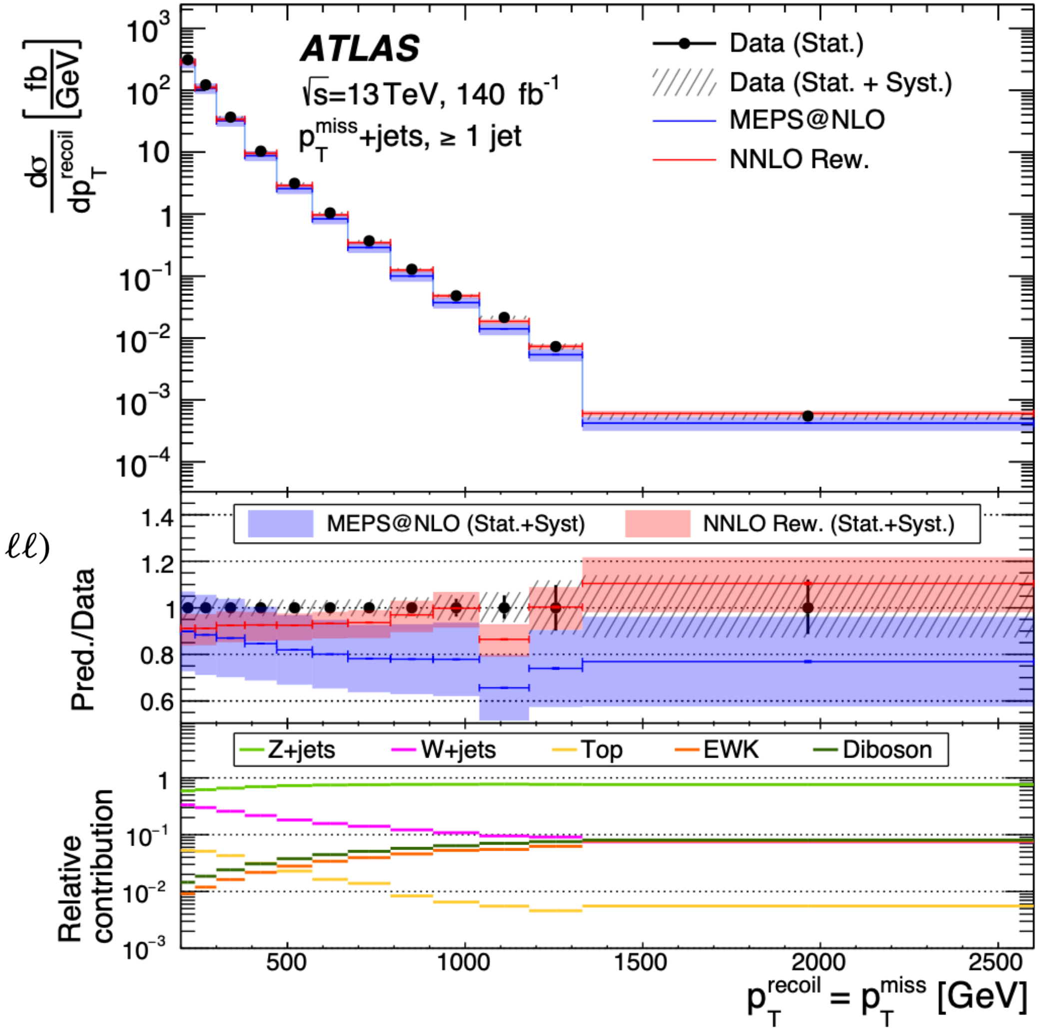
- **New ATLAS Differential study of MET+jets**

Very comprehensive result, with Z,W, γ dominated
Unfolded results for combined EW processes and single-process only
Measure of differential Z(νν) cross section versus $p_T(Z)$

Study of Z(νν) can be recast as partial width measurement:
Indirect $\Gamma_{Z\to\nu\nu}$ measurement :

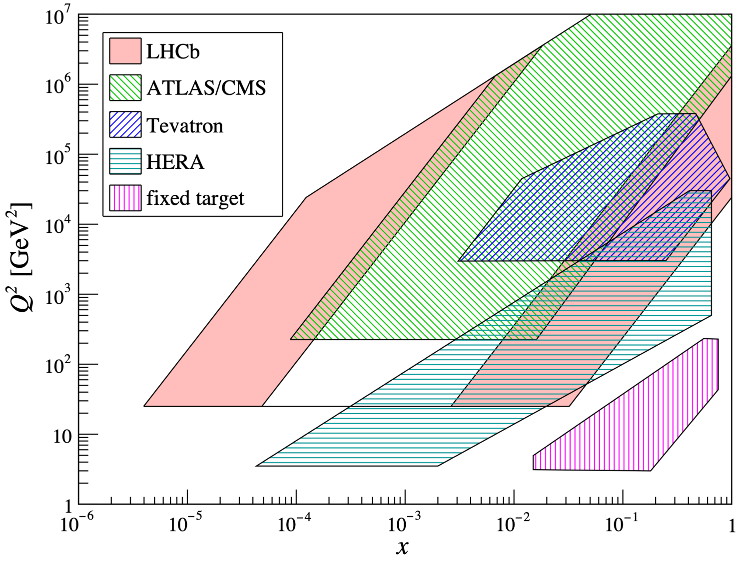
$$\Gamma(Z\to\nu\bar{\nu}) = \frac{\sigma(Z\text{+jets})\mathcal{B}(Z\to\nu\bar{\nu})}{\sigma(Z\text{+jets})\mathcal{B}(Z\to\ell\ell)}\Gamma(Z\to\ell\ell)$$

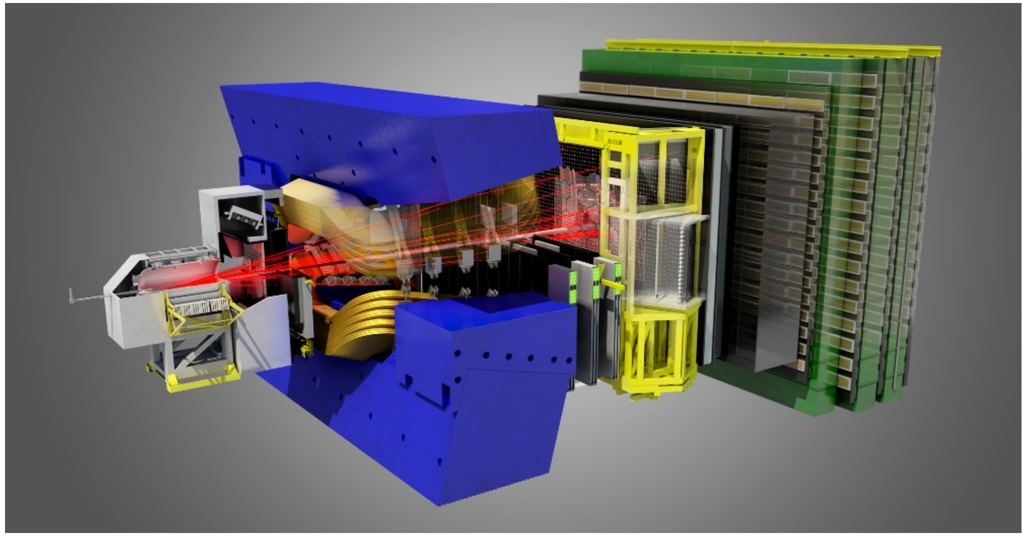




$$\Gamma_{Z\to\nu\nu} = 506 \pm 2\ (\text{stat.}) \pm 12\ (\text{syst.})\ \text{MeV}$$

EW results at LHCb
(Andrea Merli)



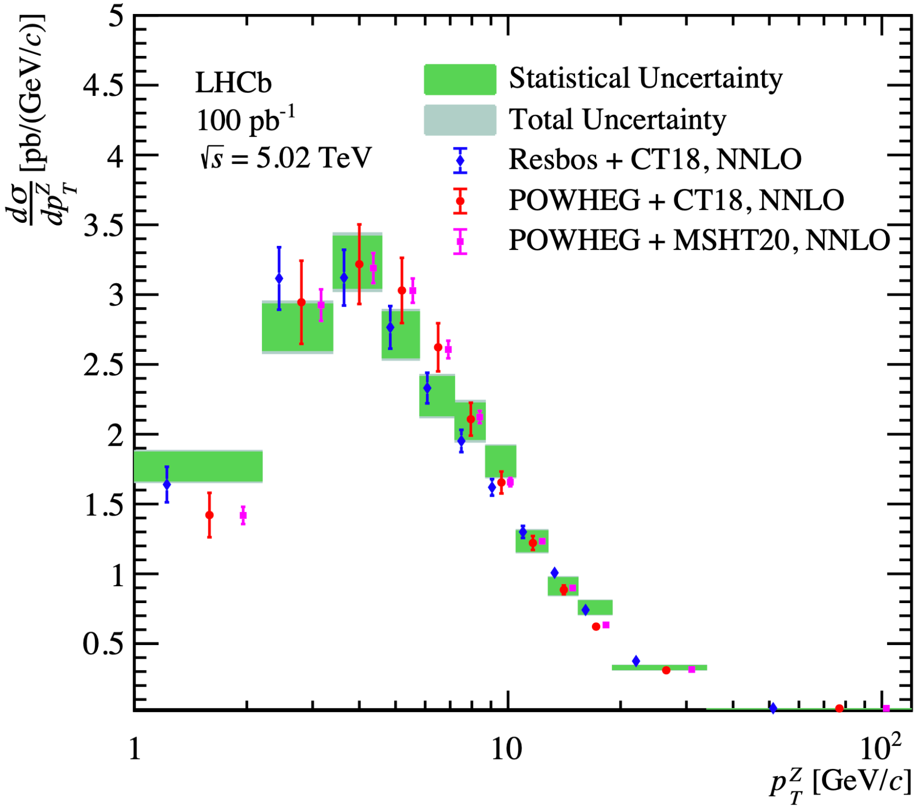


- W mass measurement :
Uncertainty from PDFs at LHCb is anticorrelated to that of ATLAS/CMS

M_W = 80354 ± 23(stat) ± 10(exp) ± 17(th) ± 9(PDF) MeV
M_W = 80354 ± 32 MeV

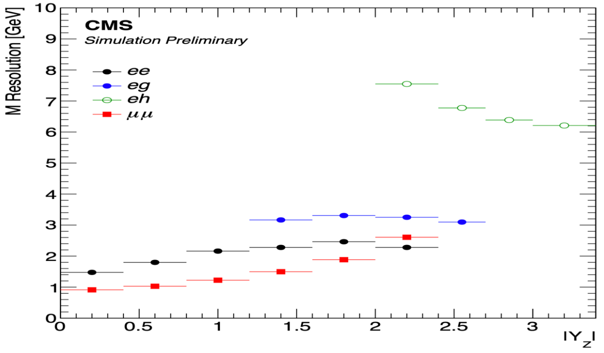
LHCb used roughly 1/3 of the Run-II dataset
Expected statistical precision with full run 2 : ~14 MeV

- New measurement of Z boson cross section
at 5.02 TeV: pp→Z→μ+μ−
Performed with 2017 pp dataset of ~100 pb^{-1}
2.0 < η < 4.5 with p_T > 20 GeV
Constraining the uncertainties of PDF

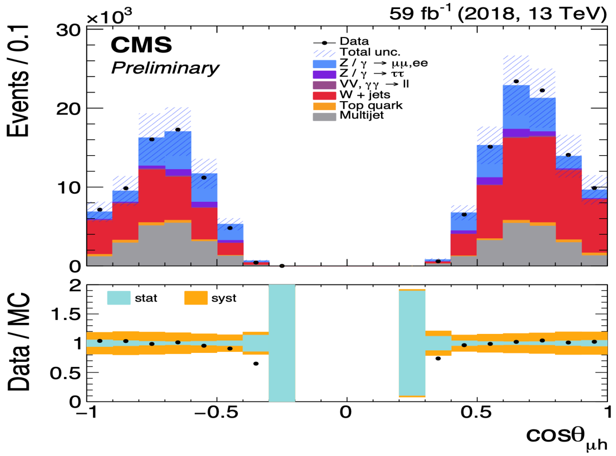


CMS Wildcard

NEW: Measurement of $\sin^2\theta^l_{eff}$ and $A_{FB}(y,m)$ (Aleko Khukhunaishvili)

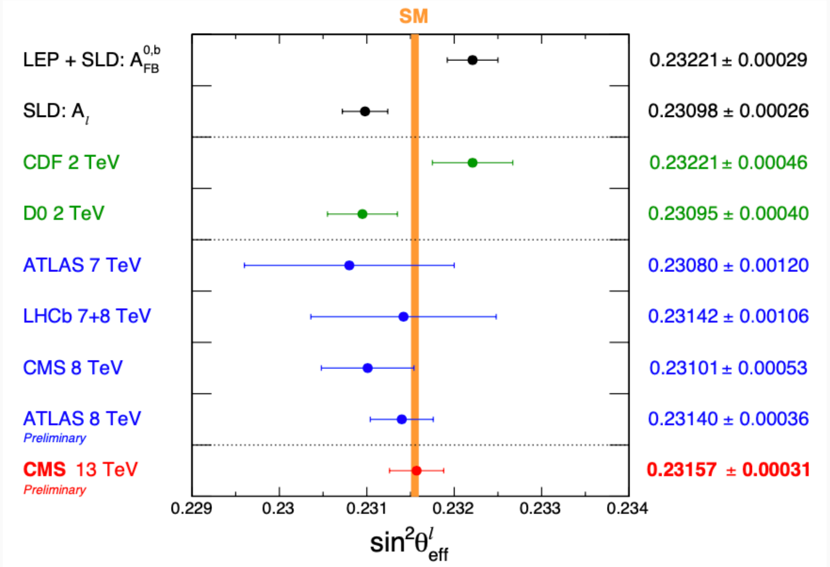


Key electroweak parameters: M_W and $\sin^2\theta^l_{eff}$
can be calculated in SM using other precise experimental inputs:
$\sin^2\theta^l_{eff}$ = 0.23155 ±0.00004 (SM)
Two most precise $\sin^2\theta^l_{eff}$ results from LEP and SLD differ by ~ 3σ



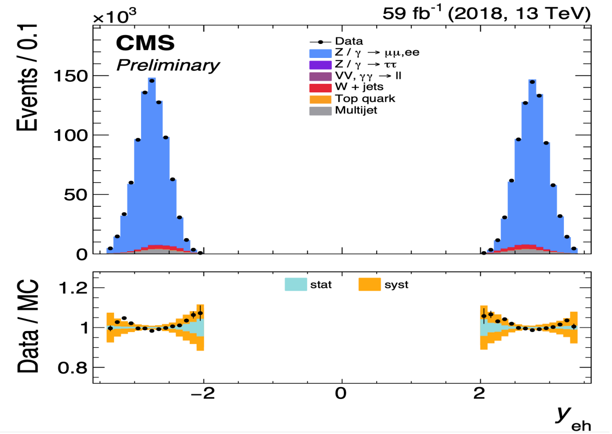
Measurements at hadron colliders are now also competitive :
- Use $Z/\gamma \rightarrow ll$ events (Drell-Yan)
- Asymmetry in lepton decay angle :

$$1+\cos^2\theta+0.5A_0(1-3\cos^2\theta)+A_4\cos\theta$$
$$\rightarrow A_{\rm FB}=3/8A_4$$



- Four ll channels : $\mu\mu$, ee, eg,eh

μ	– muon: $\lvert\eta\rvert < 2.40$
e	– central electron: $\lvert\eta\rvert < 2.50$
g	– EF electron: $2.50 < \lvert\eta\rvert < 2.87$
h	– HF electron: $3.14 < \lvert\eta\rvert < 4.36$



$$\sin^2\theta^\ell_{\rm eff}=0.23157\pm0.00010({\rm stat})\pm0.00015({\rm syst})\pm0.00009({\rm theo})\pm0.00027({\rm pdf})$$

$$\sin^2\theta^\ell_{\rm eff}=0.23157\pm0.00031$$

→ precision comparable to LEP and SLD results

ATLAS Wildcard

NEW: Test of Lepton Flavour Universalty (LFU) in W boson decays (μ, e)

(Andrea Knue)

- Use tt→bWbW events
- 3 analysis regions : opposite flavour tt, same flavour tt, same flavour Z
- Reduce as much as possible the systematics – derive dedicated scale factors and weights

$$R_W^{\mu/e} = \frac{\mathcal{B}(W \to \mu\nu_\mu)}{\mathcal{B}(W \to e\nu_e)}$$

$$R_{WZ}^{\mu/e} = \frac{R_W^{\mu/e}}{\sqrt{R_Z^{\mu\mu/ee}}}$$

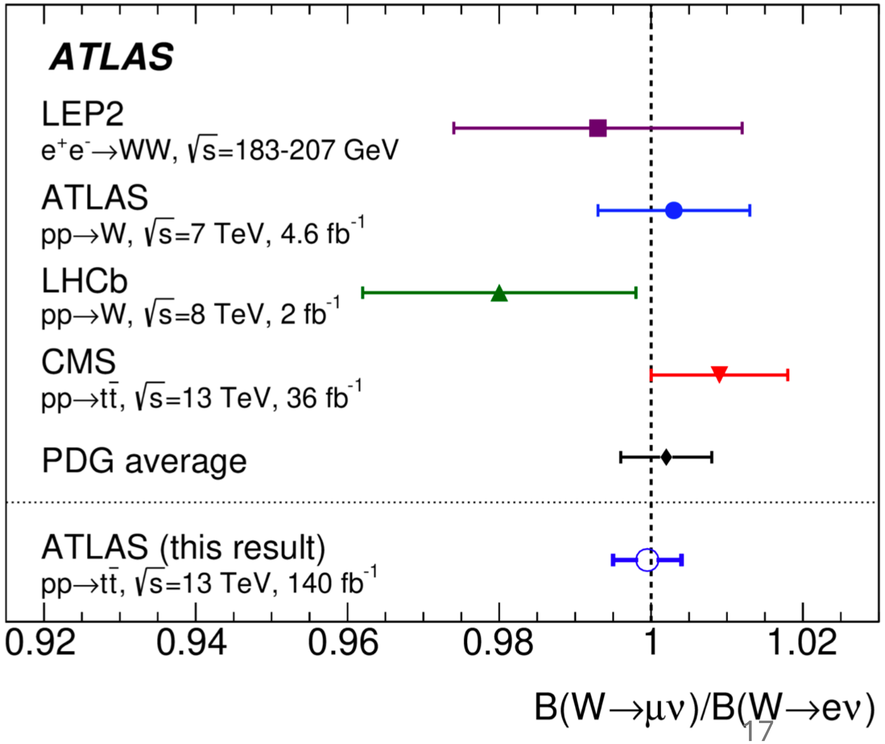
$$R_W^{\mu/e}(\text{ATLAS}) = R_{WZ}^{\mu/e}(\text{ATLAS}) \cdot \sqrt{R_Z^{\mu\mu/ee}}(\text{LEP+SLD})$$

Largest systematics for R_{WZ} : PDF, fake leptons, lepton uncertainties and Z modelling

$$R_W^{\mu/e}(\text{ATLAS}) = 0.9995 \pm 0.0022\,(\text{stat.}) \pm 0.0036\,(\text{syst.}) \pm 0.0014\,(\text{LEP+SLD})$$

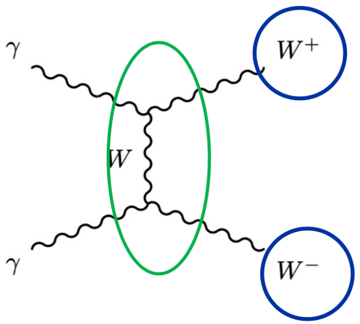
$\hookrightarrow$ agrees with assumption of lepton-flavour universality!

Relative uncertainty of 0.45%
Most precise single measurement to date!
also more precise than previous PDG average

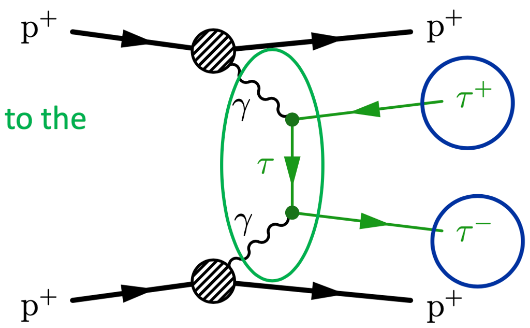


New : EW results in two photon collisions
(Cécile Caillol)

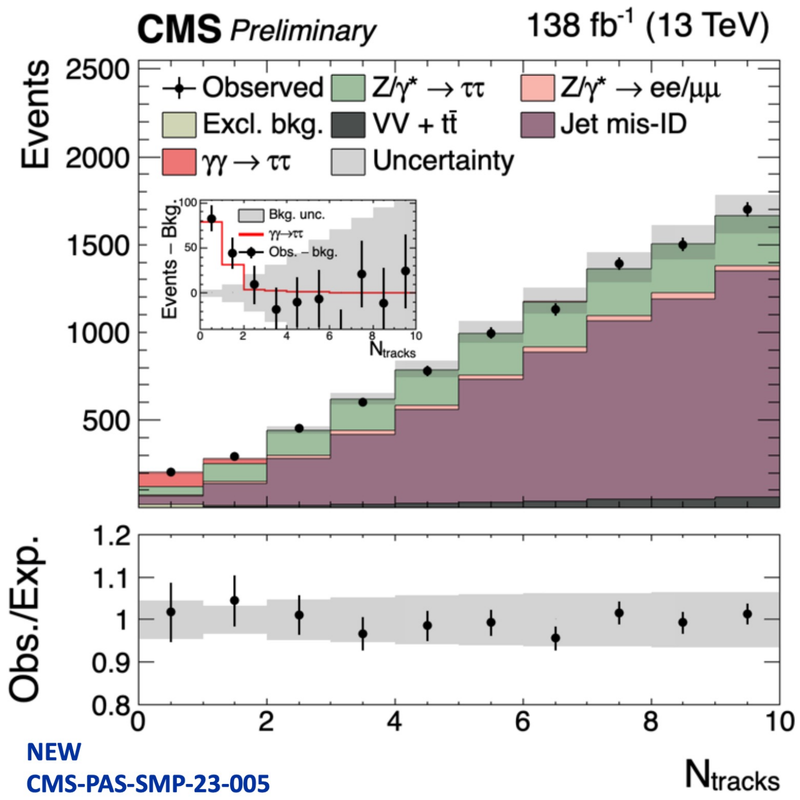
- LHC is also a photon collider !
- Measurement of $\gamma\gamma\rightarrow WW$ (ATLAS) and $\gamma\gamma\rightarrow\tau\tau$ (CMS)



- 2 back-to-back objects
- No hadronic activity close to the di-W/τ vertex
  - N_{tracks} = 0



- Ntrack=0 challenge: from Pile-up, correct for proton dissociation

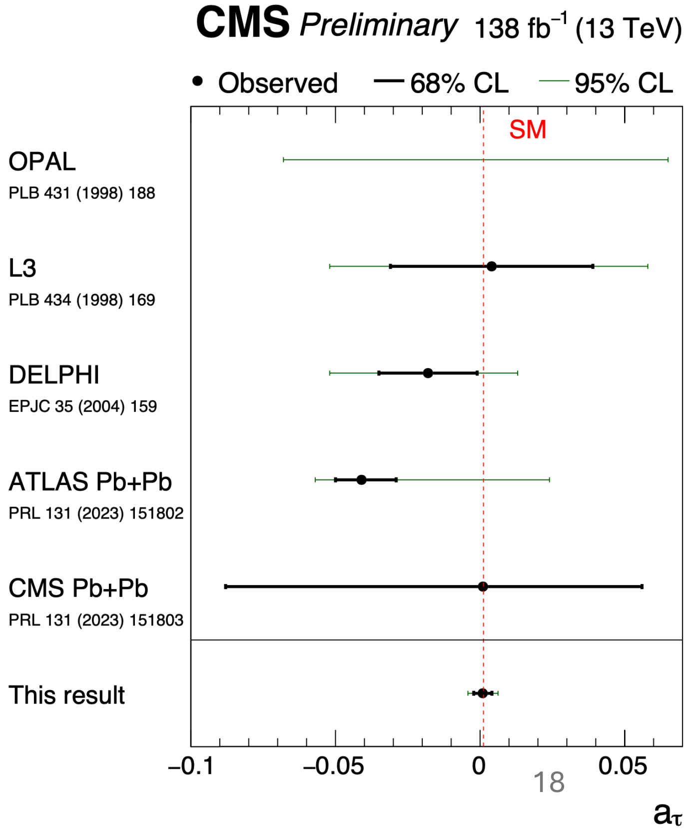


NEW
CMS-PAS-SMP-23-005

- First observation of $\gamma\gamma\rightarrow\tau\tau$ in ultraperipherical pp collisions
5.3σ observed, 6.5σ expected

- Modifying the τ g-2 modifies the $\gamma\gamma\rightarrow\tau\tau$ cross section and modifies the p_T and mass distributions of the signal

Dirac $a_\tau = 0$ | Schwinger $a_\tau = 0.00116$ | SM $a_\tau = 0.00118$



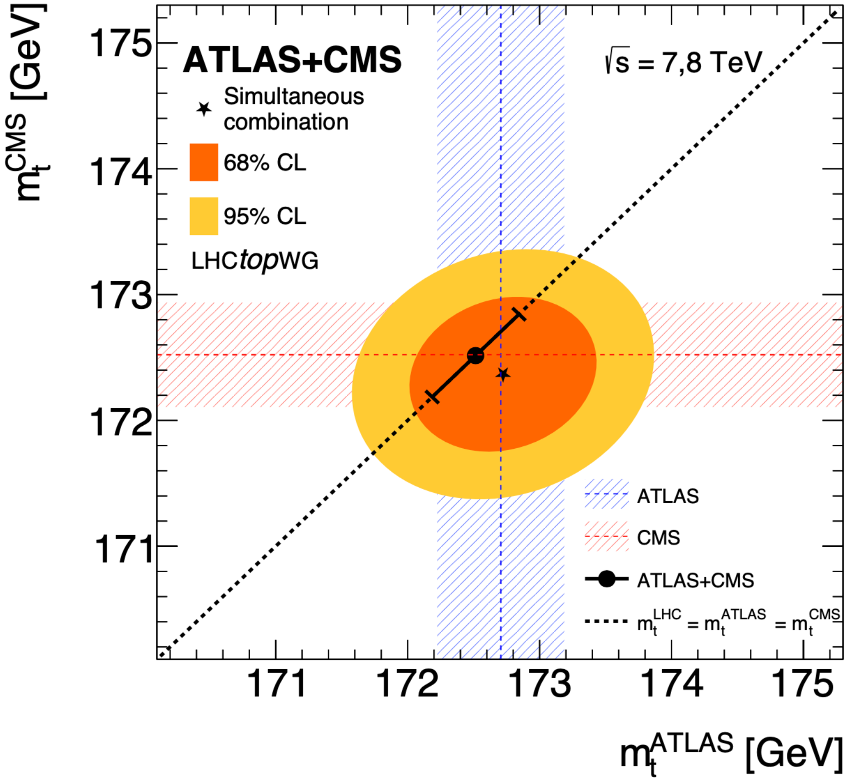
Top quark measurements

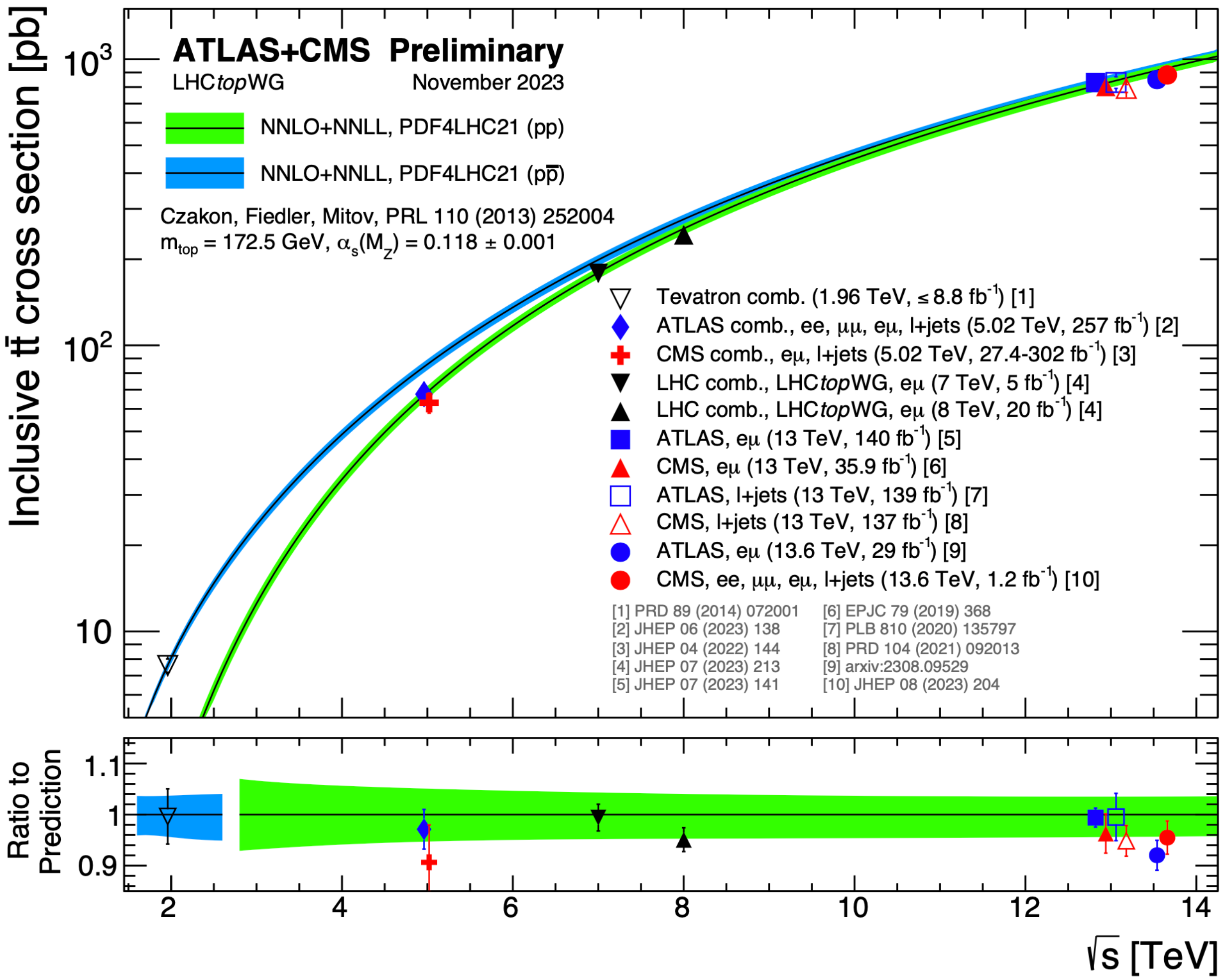
Djamel Boumediene
Andrea Merli
Sebastien Wuchterl

Measurement of the top quark properties
(Sebastian Wuchterl)

- tt cross section at 13.6 TeV

- Top quark mass : new ATLAS/CMS combination :
  172.52 ± 0.33 (± 0.14 ± 0.30)
  dominant syst : b-jet energy scale





- **Comprehensive review** of CMS on the M(top) measurements

Measurement of the top quark properties
(Sebastian Wuchterl)

- ATLAS observation of quantum entanglement in tt events
Cross section dependent on decay-lepton properties :
C: Spin correlations matrix
Criterium for entanglement: $\mathrm{tr}[\mathbf{C}] + 1 < 0$

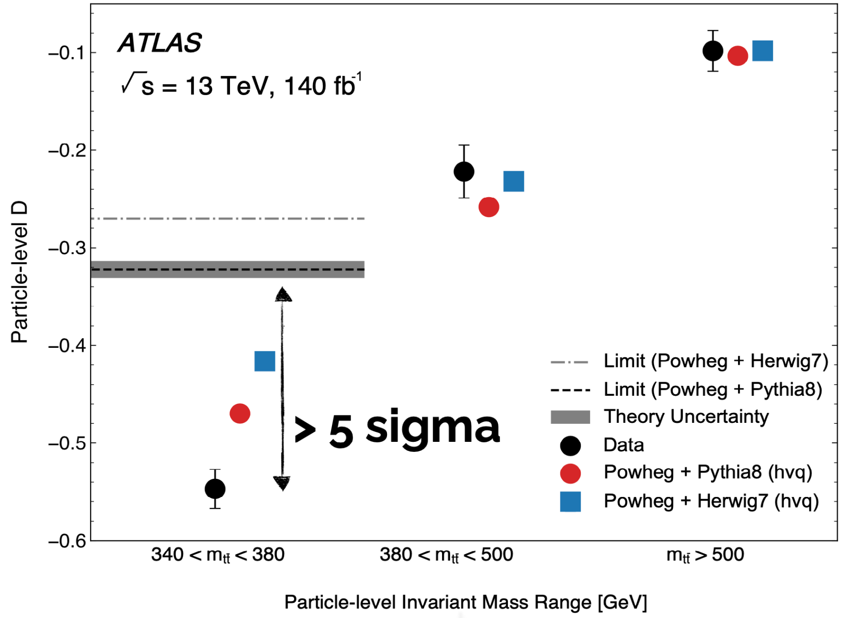
$$D = \frac{\mathrm{tr}[\mathbf{C}]}{3} \qquad D = -3 \cdot \langle \cos\varphi \rangle$$

Phi : Angle between leptons in tt restframe

Can be measured from $\frac{1}{\sigma}\frac{d\sigma}{d\cos\varphi}$

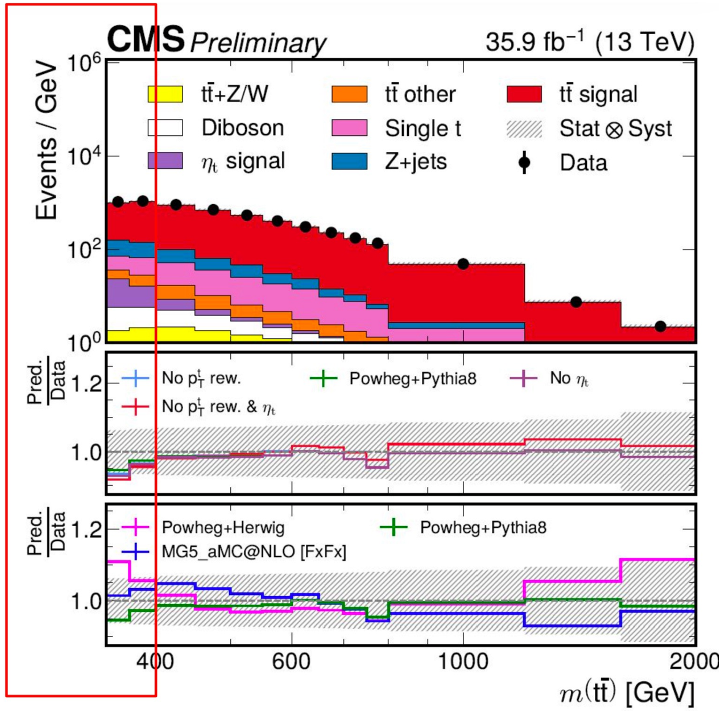
$$D < -1/3$$

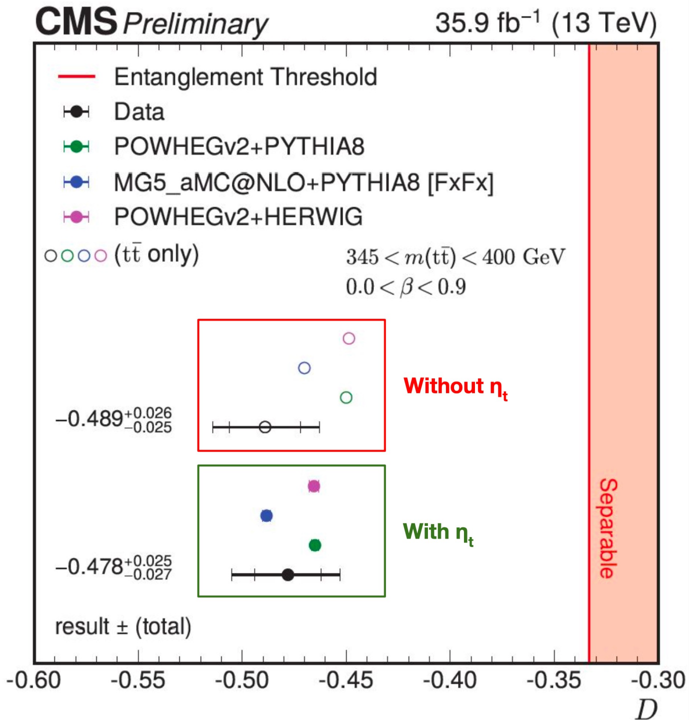
Entanglement marker



- **CMS Wildcart** **(Alberto Bragagnolo)**

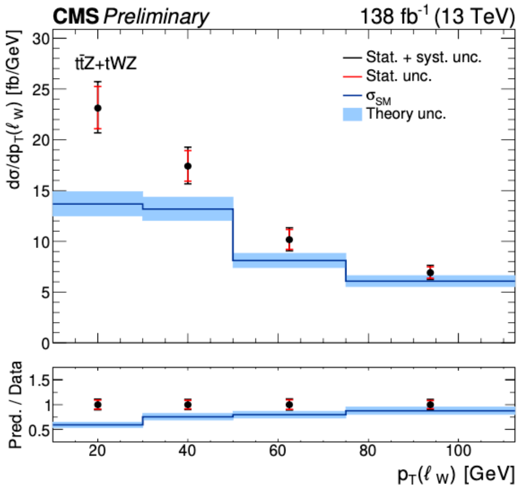
New:
Combined signal model: $t\bar{t}$ + toponium (η_t)
Only spin-0 η_t accounted (colour singlet pseudo-scalar state)
η_t improves data modelling in the threshold region

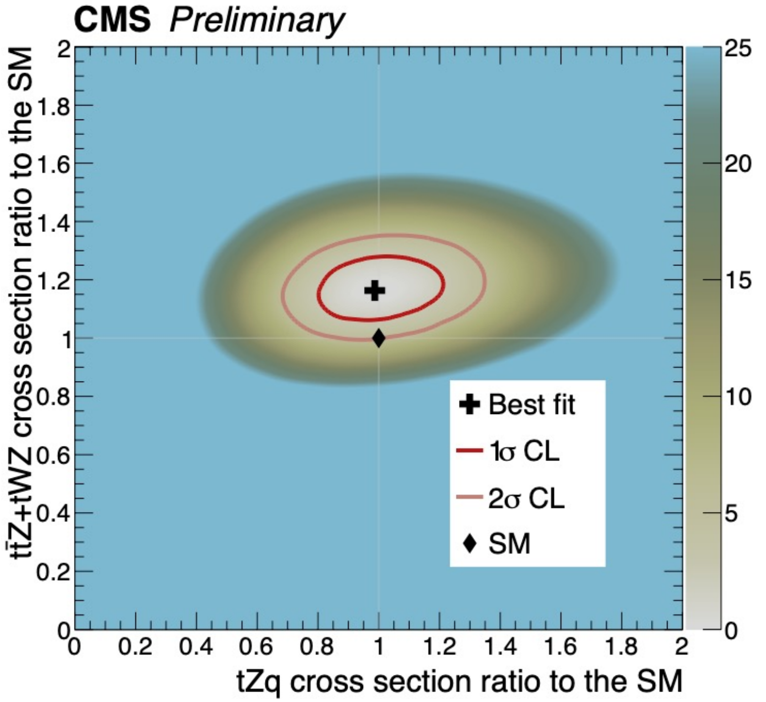




Top associated production in ATLAS/CMS
(Djamel Boumediene)

- Probing top quark coupling for understanding EWSB and searching for new physics
- Sensitive to a wide range of EFT operators
- Increasing precision





- New CMS ttZ, tWZ, tZq production

Leptonic signature 3l with a Z mass resonance

DNN 3 categories : ttZ+tWZ, tZq, and background

Simultaneous measurement of ttZ and tWZ production cross section

Small tension with SM

- New ATLAS ttγ production

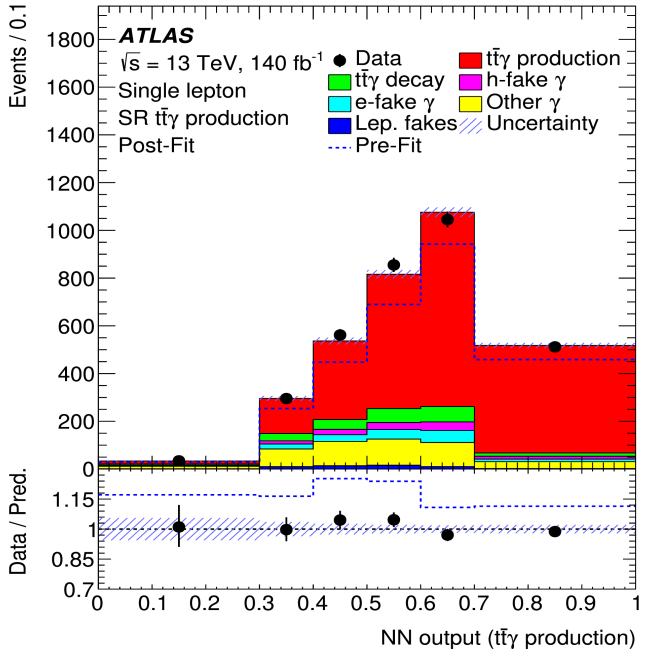
In agreement with SM

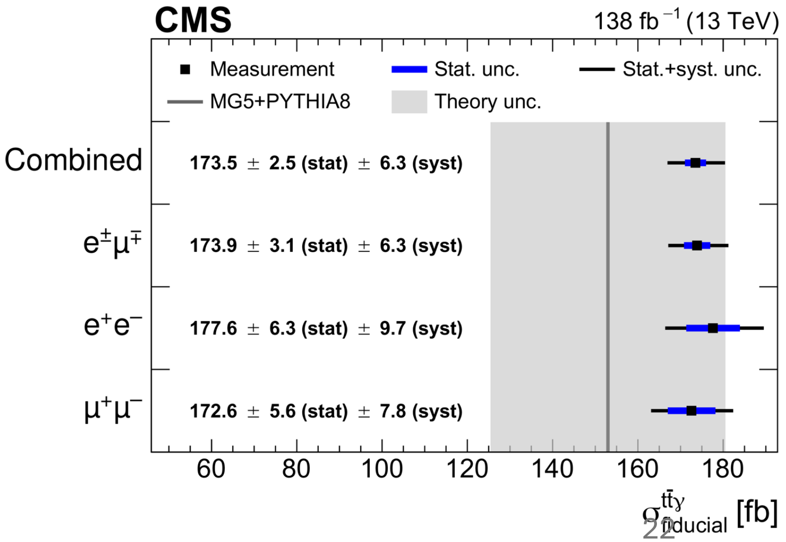
Differential cross-sections

measured for several variables

$$\sigma_{t\bar{t}\gamma\ \text{production}} = 322^{+16}_{-15}\ \text{fb} = 322 \pm 5\ (\text{stat}) \pm 15(\text{syst})\ \text{fb}.$$

$$\text{NLO MG5:}\quad 299^{+29}_{-30}(\text{scale})^{+7}_{-4}(\text{PDF})\ \text{fb}$$



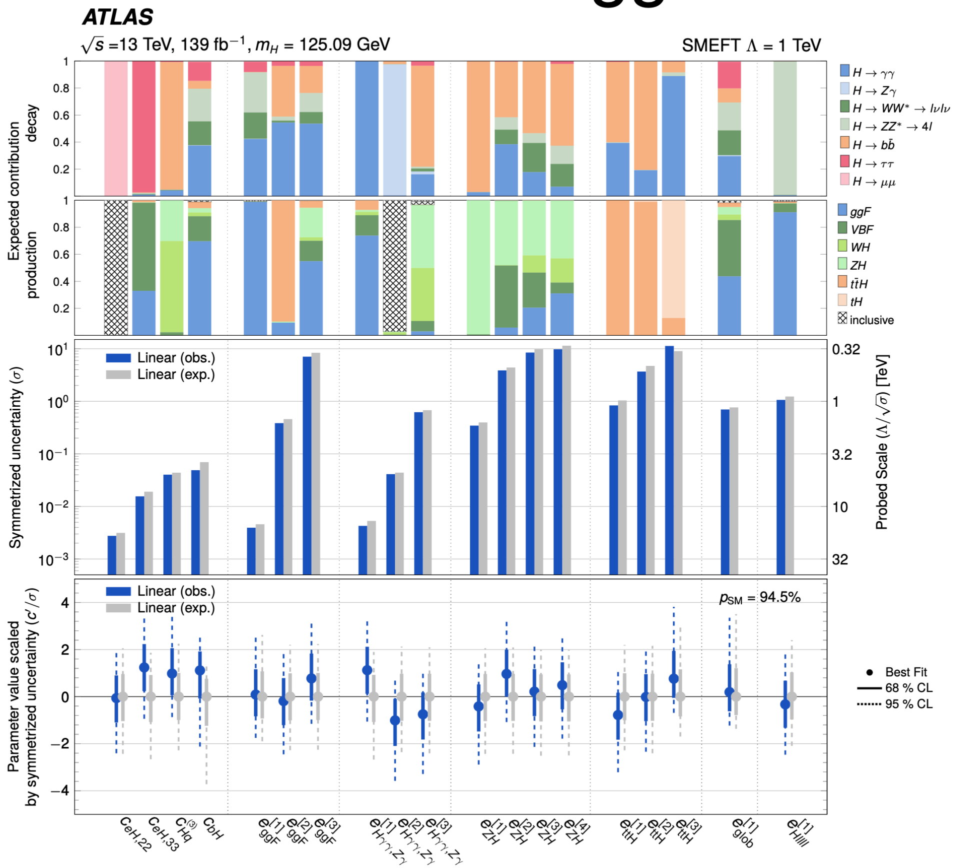


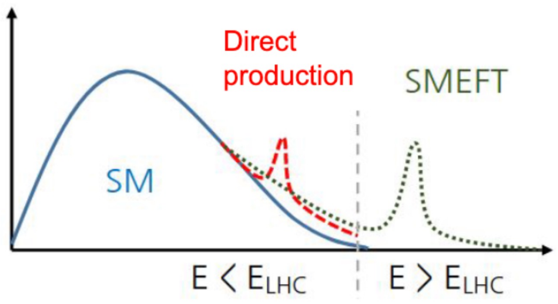
BSM

Christophe Clément
Sergio Grancagnolo
Ellis Kay
Andrea Merli
Jennifer Ngadiuba
Mark Owen
Francesco Santanastasio

Experimental overview of EFT in ATLAS/CMS
(Mark Owen)

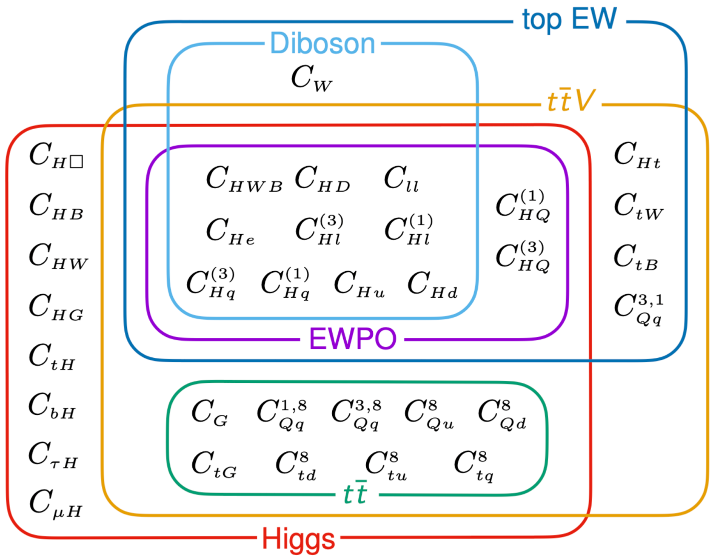
Combined Higgs fit





$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \frac{1}{\Lambda^2}\sum_i c_i \mathscr{O}_i$$

Effect on observables



→ Combine fit needed

- EFT limits produced from a diverse range of analyses : CMS γγ → ττ , ATLAS W±W±jj , ATLAS hh → bbγγ , ATLAS ttZ + ttγ, CMS tt + leptons

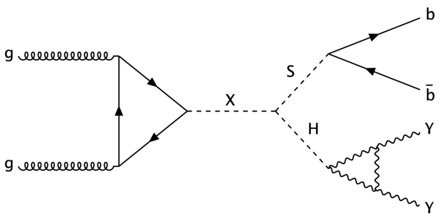
- Number / choice of operators still a challenge
- Both strategies of fitting directly reconstructed level data vs fitting measured cross-section have been deployed

ATLAS Wildcard (Christophe Clément)

New: Search for new spin-0 resonances in X → SH → bb$\gamma\gamma$

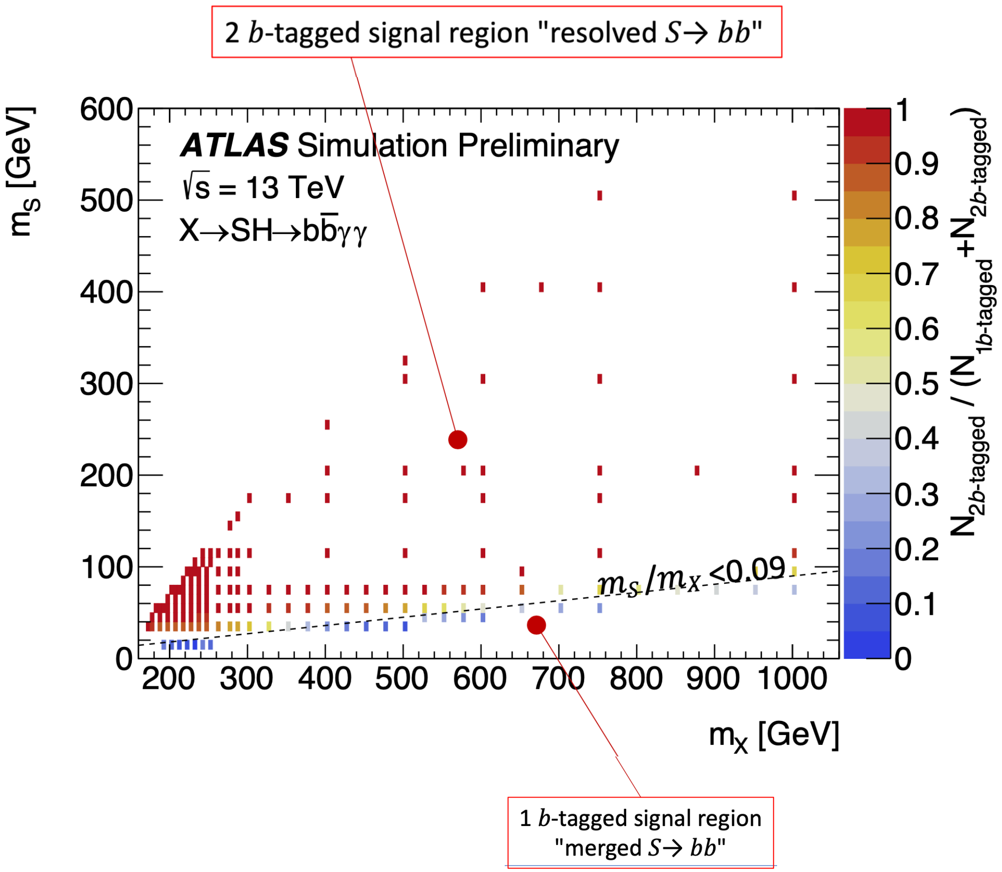
- Phenomenology arises in many **BSM models**
- 2 tight photons and 1 or 2 b-tagged jet(s)
  Main bg : $\gamma\gamma$+jets and ttH, ZH, (ggF) H

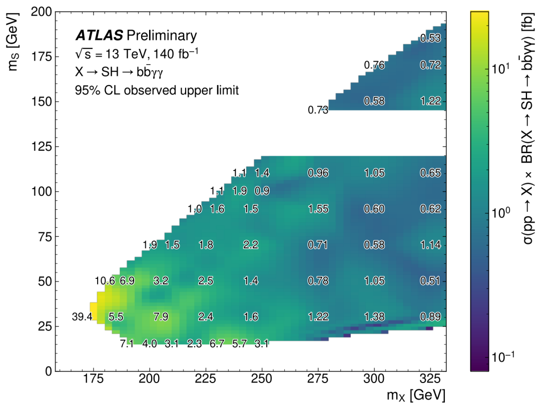
Use a parameterised Neural Network (PNN),
Side-bands are used as control regions:
$m(\gamma\gamma) \in [105,120] \cup [130,160]$ GeV

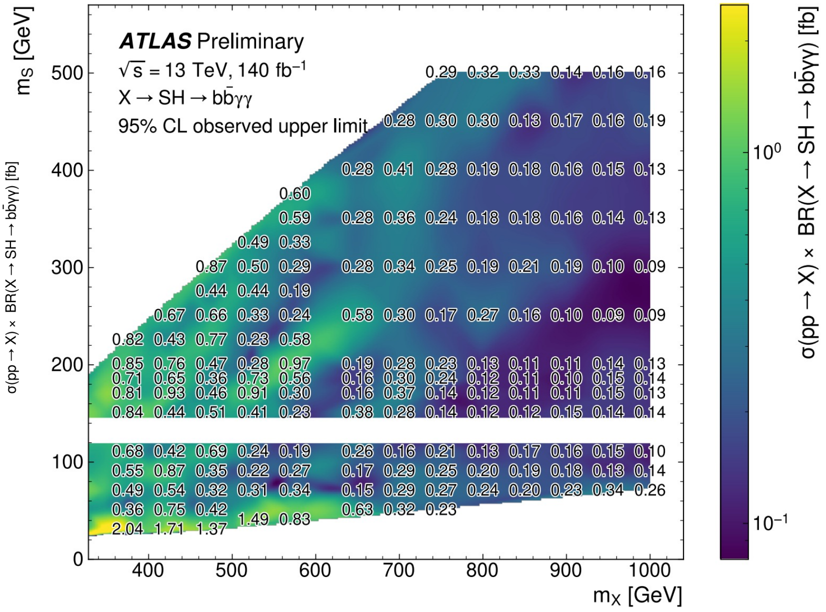


Largest excess at (m_X,m_S)=(575,200) GeV
Local (global) significance of 3.5 (2.0) standard deviations
Limits are set on σ(X→SH→$b\gamma\gamma$) :

(X, S) mass plane : define a boosted region and a resolved region



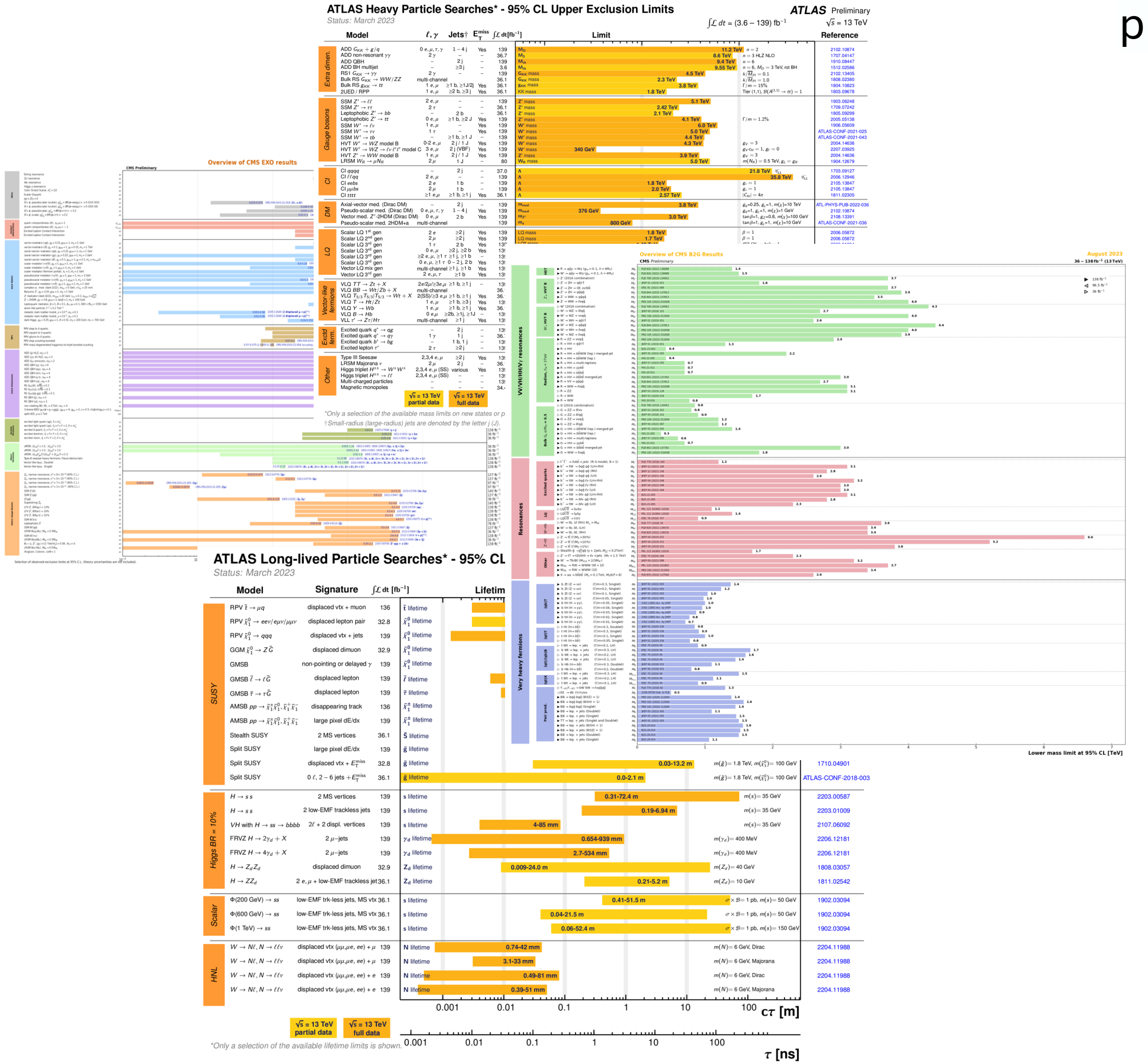




ATLAS/CMS (quick) cross check :

- At (m_X,m_S)=(650,90) GeV where CMS reported an excess, ATLAS observes good agreement with the background-only hypothesis ($p_0 > 0.5$)
- At (m_X,m_S)=(575,200) GeV : no CMS excess at these masses

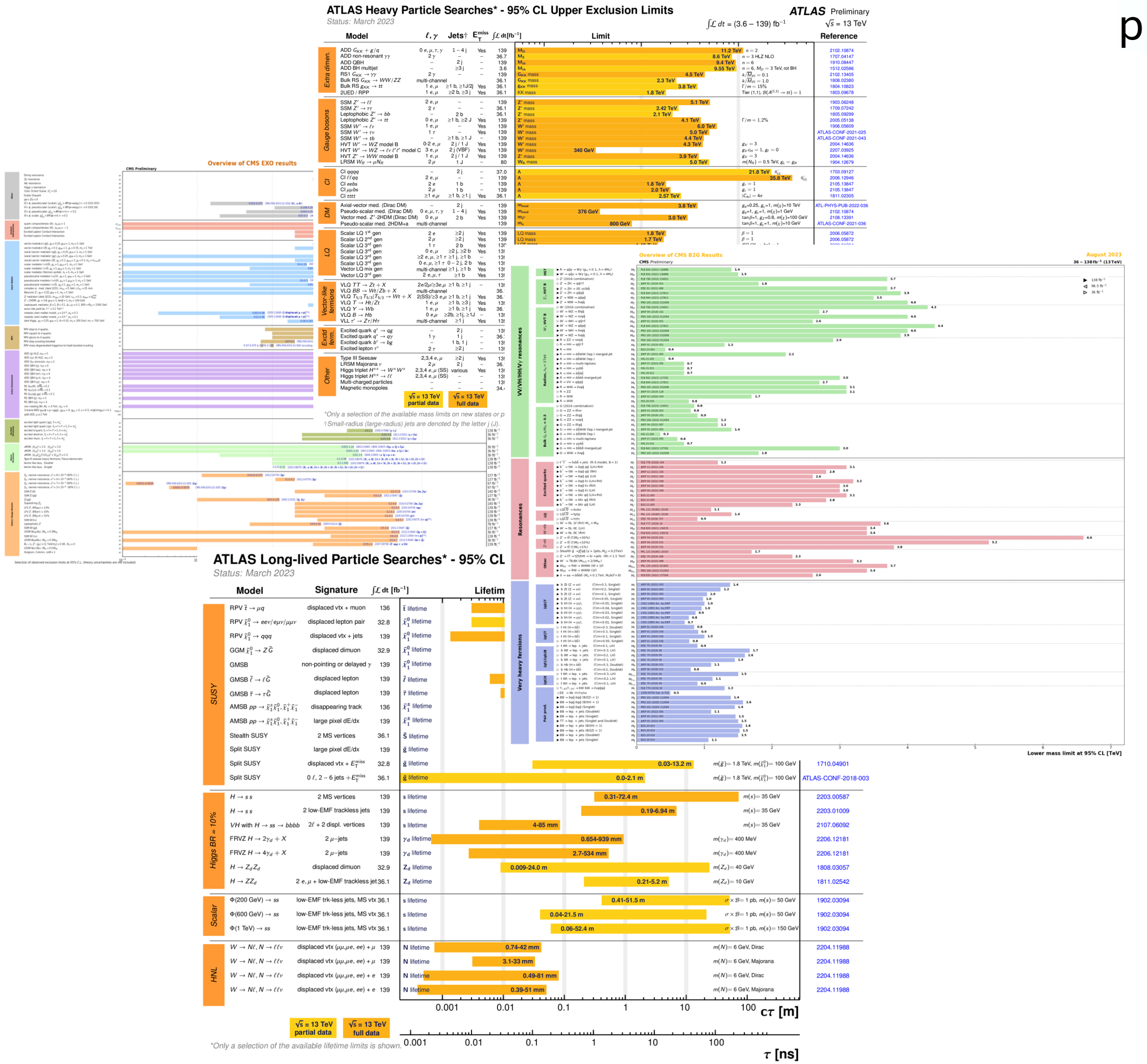
Search for VLQ, HNL, LLP in ATLAS/CMS (Sergio Grancagnolo)
Other exotic searches by CMS (Francesco Santanastasio)
Other exotic searches by ATLAS (Ellis Kay)



In all these analyses : we have not found evidence for new physics

Ellis :
“We unfortunately did not detect BSM physics…
but not for lack of trying”

Search for VLQ, HNL, LLP in ATLAS/CMS (Sergio Grancagnolo)
Other exotic searches by CMS (Francesco Santanastasio)
Other exotic searches by ATLAS (Ellis Kay)

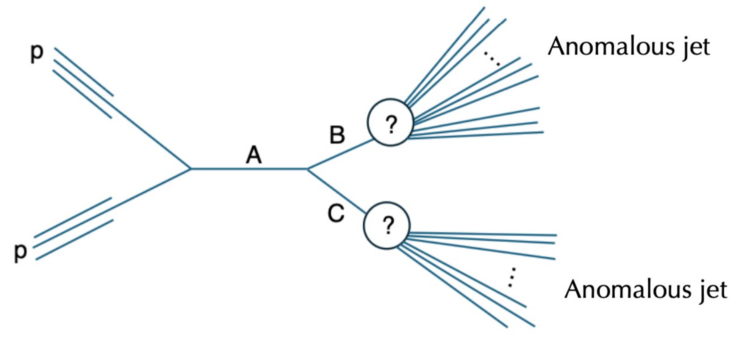


In all these analyses : we have not found evidence for new physics

Looking at the wrong place ?
Need new ideas

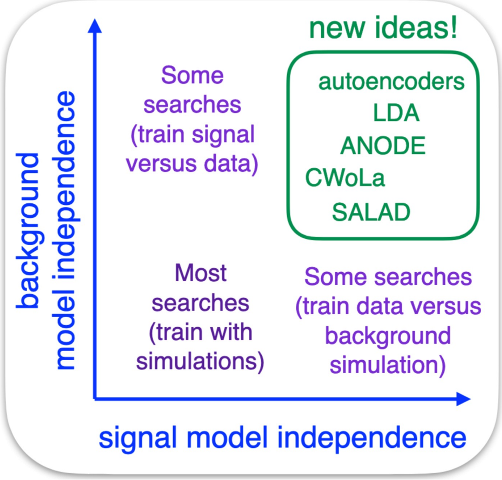
An example → "Anomaly detection"
Novel analysis strategy :
Use deep learning to learn (train) directly from data
Do not rely on signal models, nor on SM simulations

Model independent searches at the LHC (Jennifer Ngadiuba)

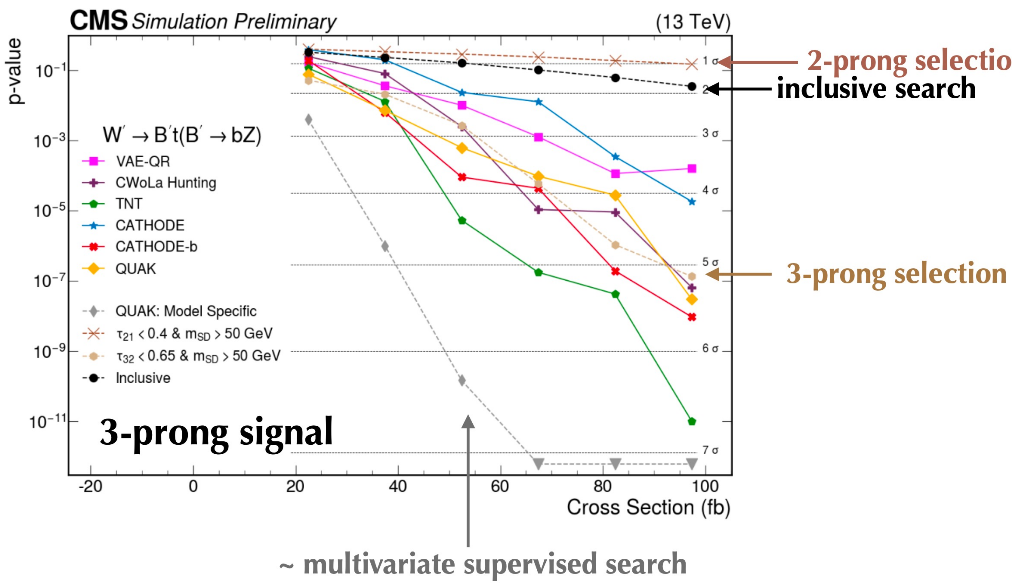


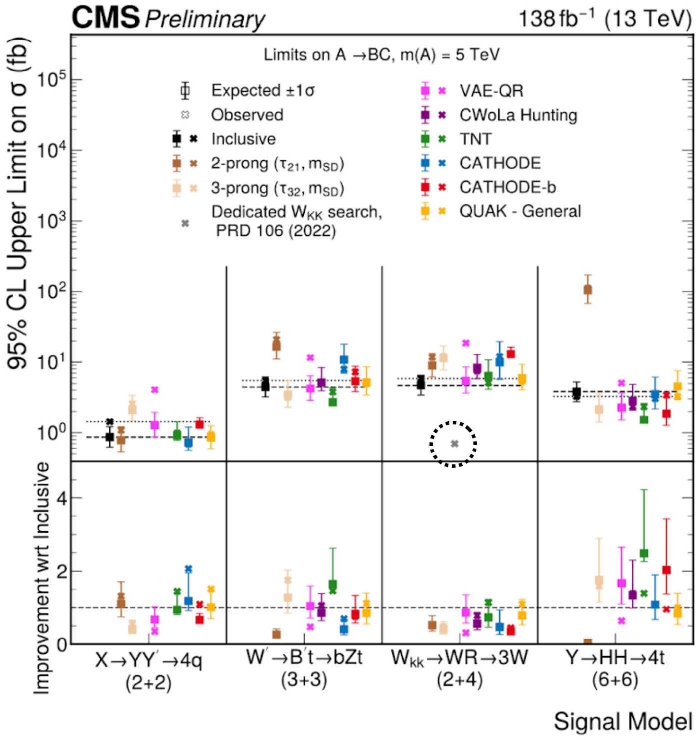
Focus on large-radius boosted jets

Many new ideas that make use of deep learning to **learn directly from data how the standard model looks like → eliminate signal priors**
and search for anything anomalous wrt standard model
This approach is called :
Anomaly detection

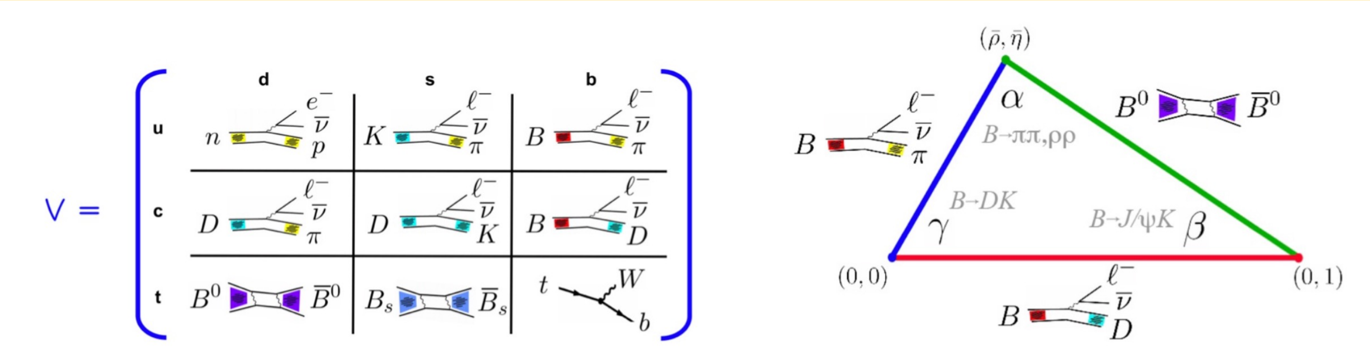


MC only studies





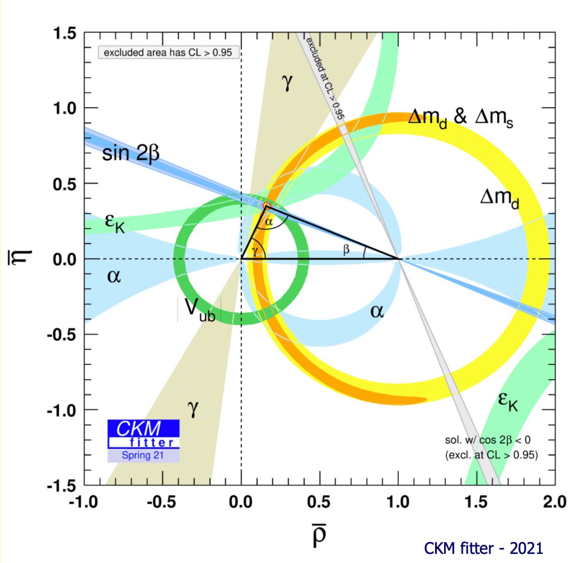
- Also : CMS : Bring anomaly detection to the trigger:
  two anomaly detection autoencoders for the L1 Trigger on one FPGA



Flavour session

Alberto Braganolo
Francesco Brizioli
Angel Campoverde
Giulia Casarosa
Lu Cao
Luigo Corona
Julian Garcia Pardinas

Pablo Gondenzweig
Ondrej Kovanda
Peilian Liu
Niharika Rout
Ryota Shiraishi
Mark Smith
Mark Williams



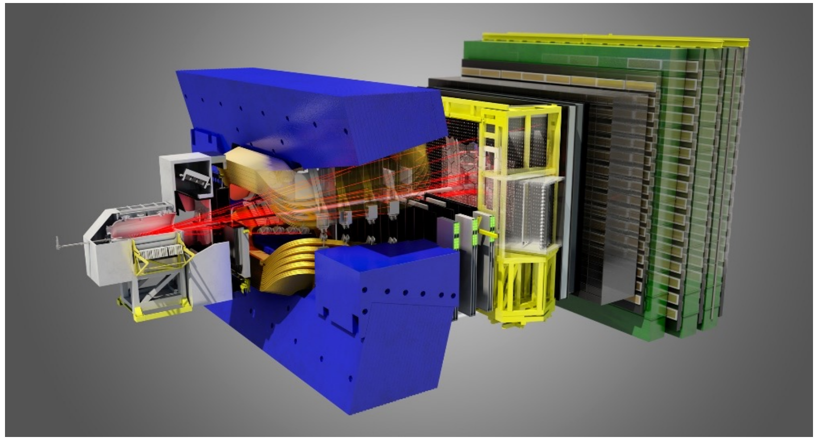
Machine and luminosity :

CMS and ATLAS

Run 1	2010-12	7-8 TeV	30/fb
Run 2	2015-18	13 TeV	160/fb
Run 3	2022-25	13.6 TeV	(40+30 +...)/fb
Long shutdown			
Run 4	2029-32	Major upgrade of the CMS/ATLAS detectors	
Run 5	2035-28		
Run 6	2040-41		

LHCb

Run 1	3/fb
Run 2	6/fb
Run 3	Upgrade I of LHCb
Long shutdown	
Run 4	
Run 5	Upgrade II of LHCb
Run 6	

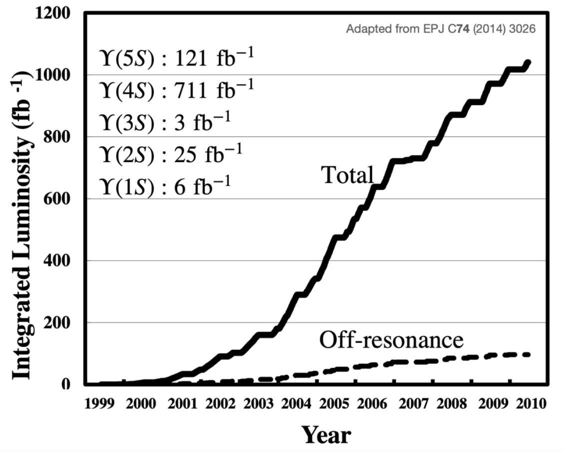


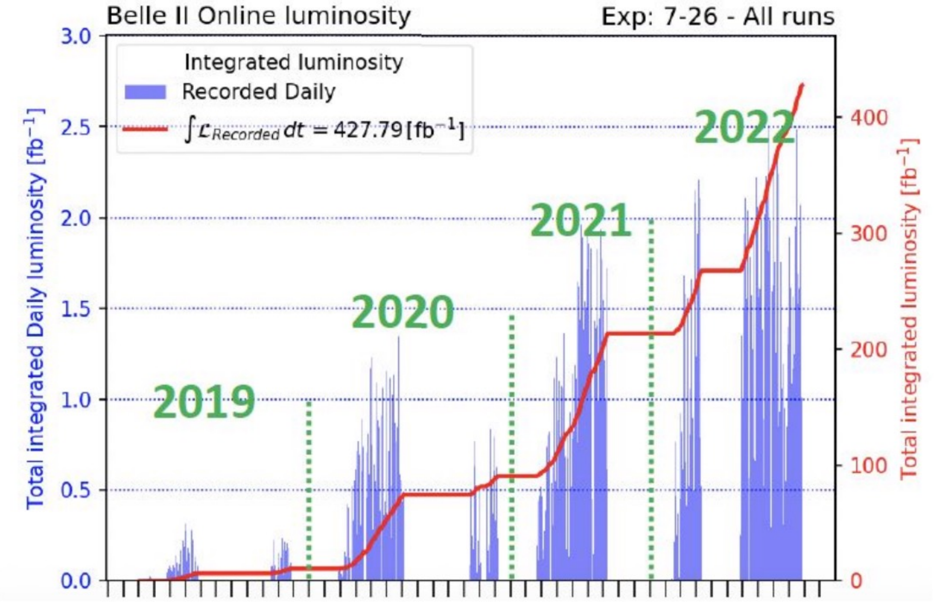
Belle@KEKB : 1999-2010 1/ab

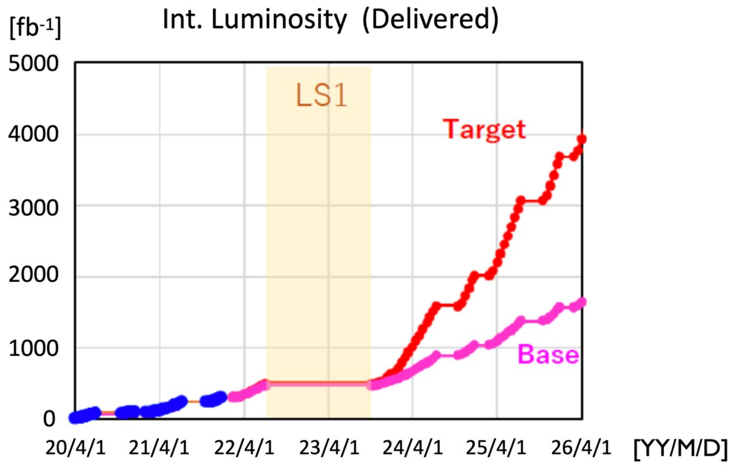
Belle2@SuperKEK : run 1 (2019-22) 0.42/ab

run 2 ongoing

BELLE & *Belle II*
are now **synergic** experiments





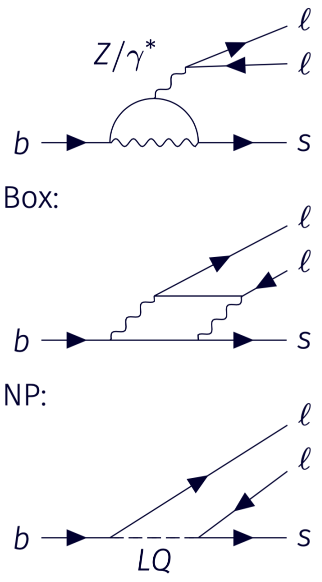


Results from LHCb b → s ll
(Mark Smith)

Penguin:

Box:

NP:



Small SM amplitude ⟶ excellent place to search for NP!

Lepton Flavour Universality
$\frac{\mathcal{B}(H_b \to F\mu^+\mu^-)}{\mathcal{B}(H_b \to Fe^+e^-)}$

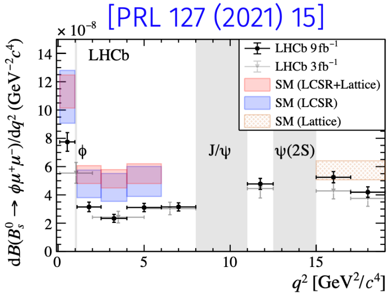
(Differential) BFs
$\frac{d\Gamma(H_b \to F\ell\ell)}{d\,q^2}$

Angular analyses
P_5', A_{FB} etc

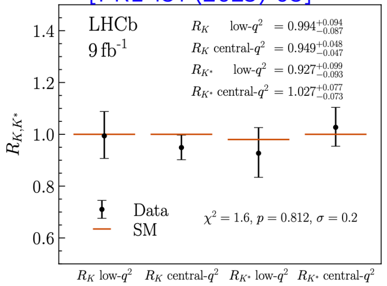
multifarious possibilities

$B^+, B^0, B_s^0, \Lambda_b$ ⟶ $K^+, K^0, K^{*+}, K^{*0}, \phi, f_2'(1525), pK^-$, none + $e^+e^-, \mu^+\mu^-, (\tau^+\tau^-)$

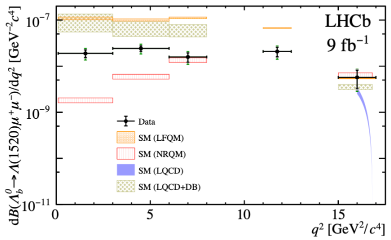
[PRL 127 (2021) 15]



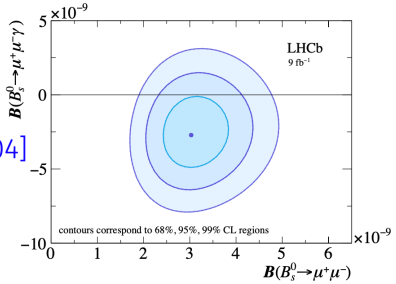
[PRL 131 (2023) 05]

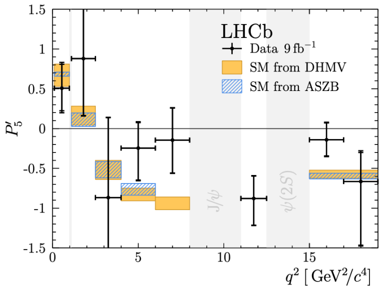


[PRL 131 (2023) 15]



[PRL 128 (2022) 04]



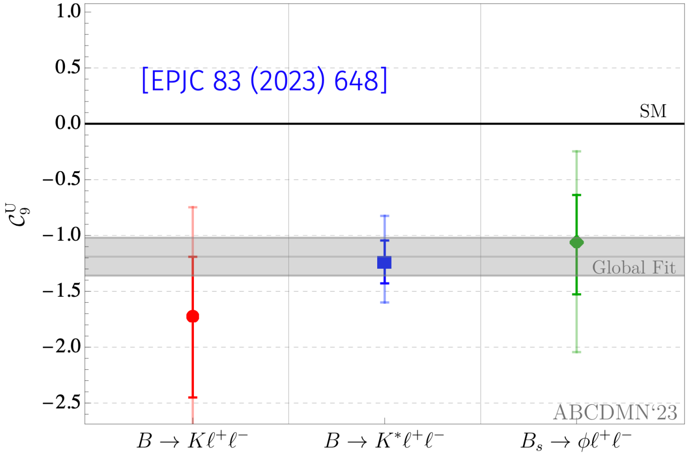


[PRL 126 (2021) 16]
$B^+ \to K^{*+}\mu^+\mu^-$

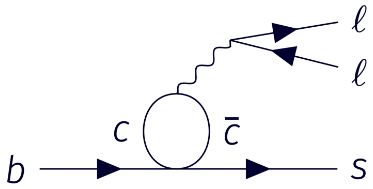
Results from LHCb   b → s ll
(Mark Smith)

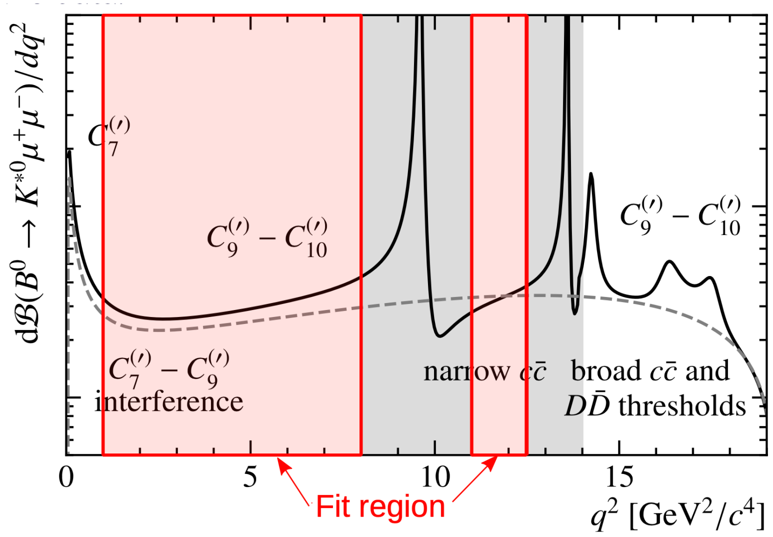
$$\mathcal{A}_\lambda^{L,R} = \mathcal{N}_\lambda \left\{ \underbrace{\left[(C_9 \pm C_9') \mp (C_{10} \pm C_{10}')\right]}_{\text{WCs}} \overbrace{\mathcal{F}_\lambda(q^2)}^{\text{FFs}} + \frac{2 m_b M_B}{q^2} \underbrace{\left[(C_7 \pm C_7')\right.}_{\text{WCs}} \overbrace{\mathcal{F}_\lambda^T(q^2)}^{\text{FFs}} - 16\pi^2 \frac{M_B}{m_b} \underbrace{\mathcal{H}_\lambda(q^2)}_{\text{non-local}} \left.\right] \right\}$$

E.g. fit for C_9^U, assuming SM for other WCs:



Is it NP ? Could be due to long-distance charm loop :



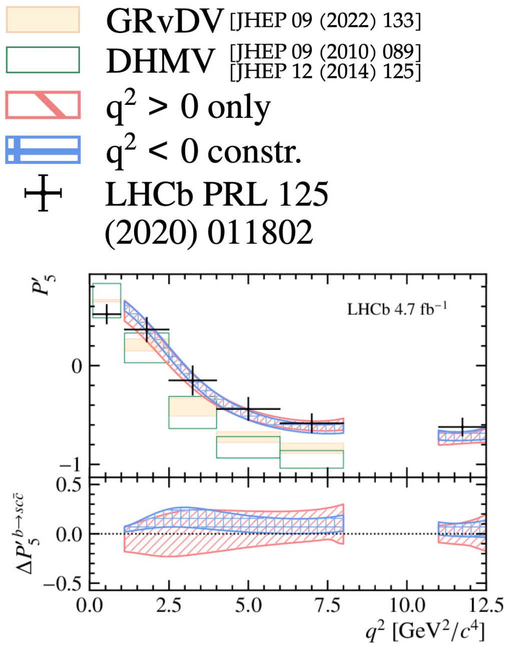


4.7 fb^{-1} of data: Run 1 + 2016

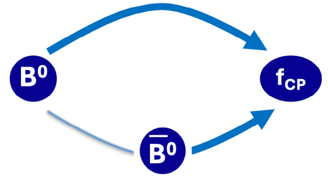
First unbinned amplitude analysis of $B_0 \to K^{*0}\mu+\mu-$
(Complementary information to the previous binned analysis)
Determination from data of the non-local contribution with and without theory constraint
Model dependent analysis
Maximum sensitivity to non-local effects

In general, good agreement with binned results
Example for P'_5 : minimal difference between fit with or without constraint

Even with freedom of non-local component, the data prefers a shift in C_9 from the SM



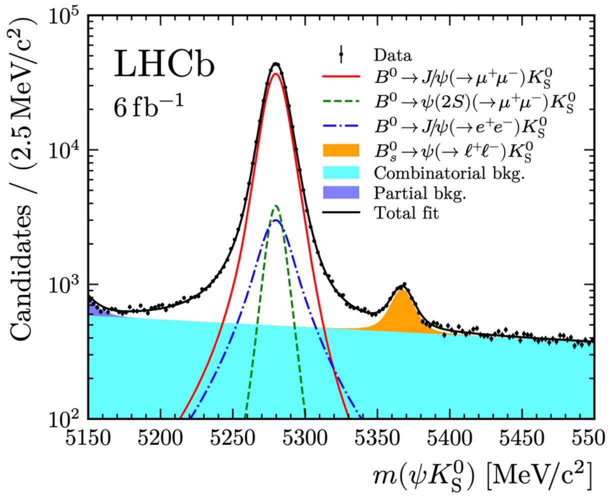
Results from LHCb : CPV in beauty and charm
(Mark Williams)

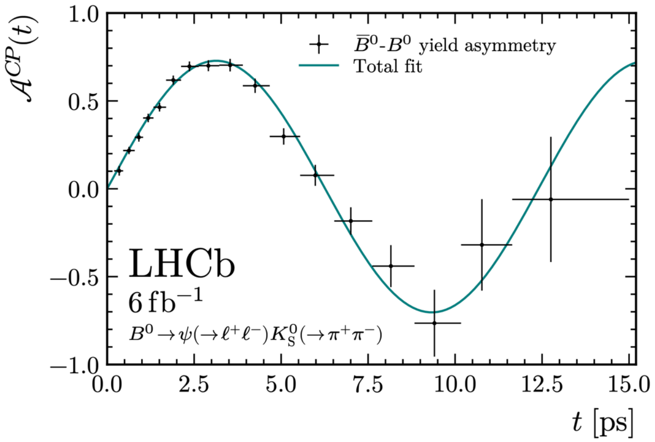


- Time dependent CPV in B^0 decays : β angle
  Full run 2 analysis

$J/\psi(\to\mu\mu,ee)K^0_S$ ~306k ~43k

$\psi(2S)(\to\mu\mu)K^0_S$ ~24k





$$\mathcal{A}^{CP}(t)=\frac{\Gamma(\bar{B}^0(t)\to f)-\Gamma(B^0(t)\to f)}{\Gamma(\bar{B}^0(t)\to f)+\Gamma(B^0(t)\to f)}=\frac{S\sin(\Delta m_d t)-C\cos(\Delta m_d t)}{\cosh(\frac{1}{2}\Delta\Gamma_d t)+\mathcal{A}_{\Delta\Gamma}\sinh(\frac{1}{2}\Delta\Gamma_d t)}$$

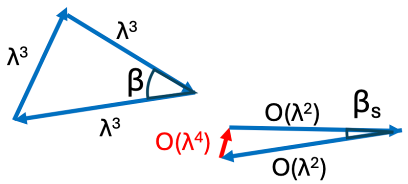
Time-dependent asymmetry

CPV parameters: C, S, $A_{\Delta\Gamma}$

$$S=\sin(2\beta+\Delta\phi_d+\Delta\phi_d^{NP})$$

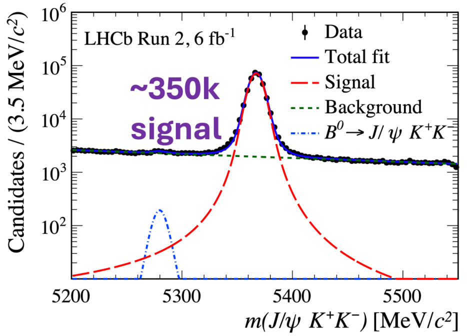
$$S_{\psi K^0_S}=0.717\pm0.013\,(\text{stat})\pm0.008\,(\text{syst})$$
$$C_{\psi K^0_S}=0.008\pm0.012\,(\text{stat})\pm0.003\,(\text{syst})$$

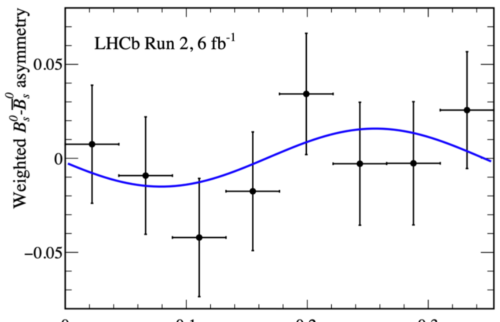
(WA : sin(2β) = 0.699 ± 0.017)



- Time dependent CPV in B^0_s decays : ϕ_s angle

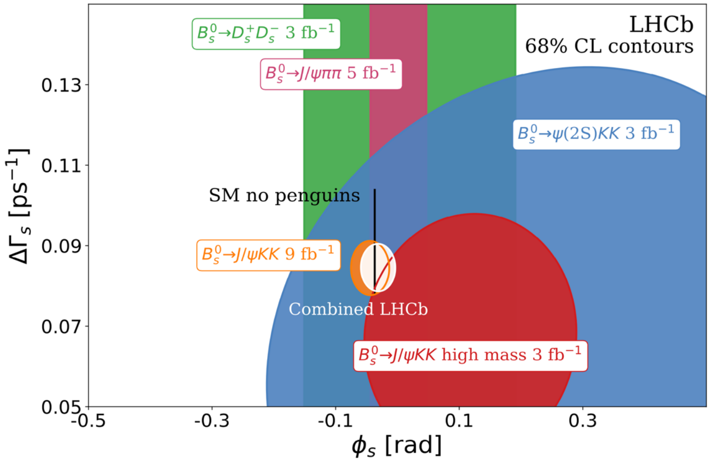
For b→ccs measure phase $\phi_s \approx -2\beta_s$ = −0.0368(9) rad (SM)





No evidence for CP asymmetry
Most precise ϕ_s measurement, still stat. limited

LHCb combination: $\phi_s = -0.031\pm0.018$ rad



CMS Wildcard (Alberto Bragagnolo)

Precision measurement of CP violation in B_s mesons

final-state CP eigenvalue | CP violation | flavor oscillations

$$a_{CP}(t) = \frac{-\eta_{fs}\sin(\phi_s)\sin(\Delta m_s t)}{\cosh(\frac{1}{2}\Delta\Gamma_s t)+\eta_{fs}\cos(\phi_s)\sinh(\frac{1}{2}\Delta\Gamma_s t)}$$

Dataset: L = 96 fb^{-1} collected in 2017-2018

Measurement of the weak phase ϕ_s

Predicted by the SM to be $\phi_s \approx -2\beta_s$

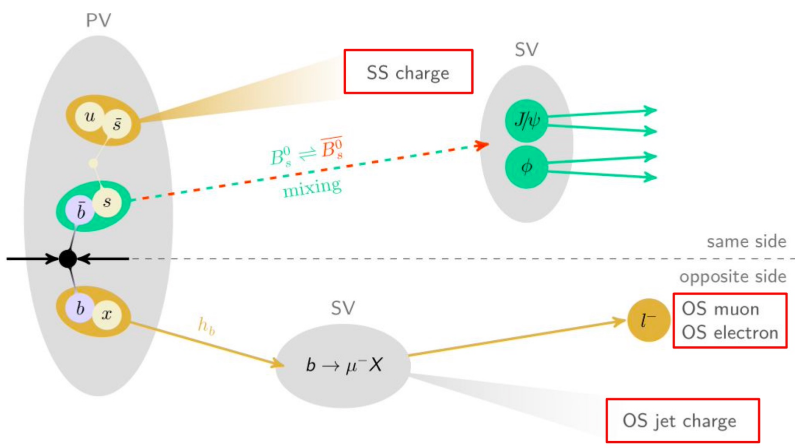
β_s determined by CKM global fits to be **$-2\beta_s = -37 \pm 1$ mrad**

New physics can change the value of ϕ_s up to ~100% via new particles

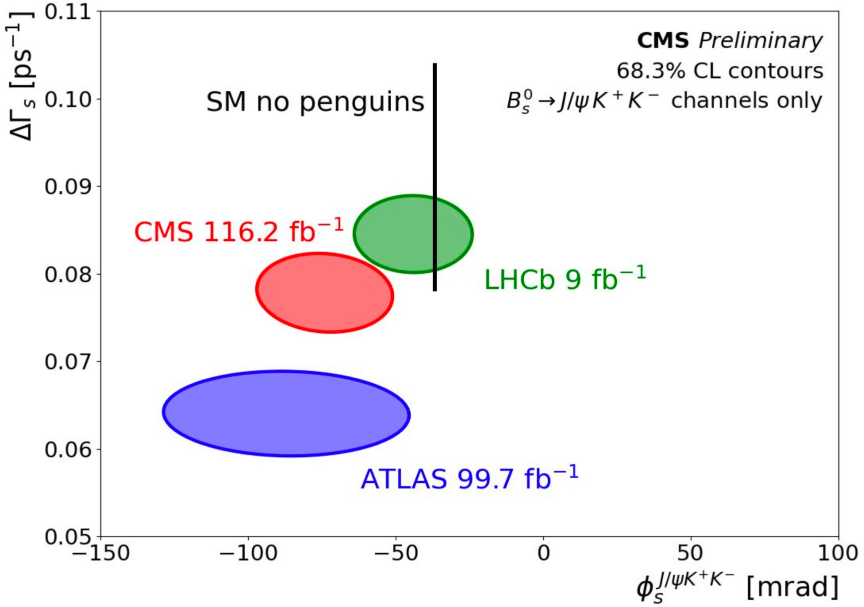
The golden channel B → J/ψ ϕ(1020) → μ+μ- K+K-

Time-, flavour and angular dependent measurement

Schematic representation of a generic HLT JpsiTrkTrk event



Comparison with other LHC experiments



New flavour tagging framework (4 DNN-based algorithms)

Using the charge-based Same Side techniques

$$\phi_s = -74 \pm 23 \text{ [mrad]}$$

$$\Delta\Gamma_s = 0.0780 \pm 0.0045 \text{ [ps}^{-1}\text{]}$$

competitive results comparable to the most precise single measurements by LHCb

Results from LHCb : b → c lv
(Julian Garcia Pardinas)

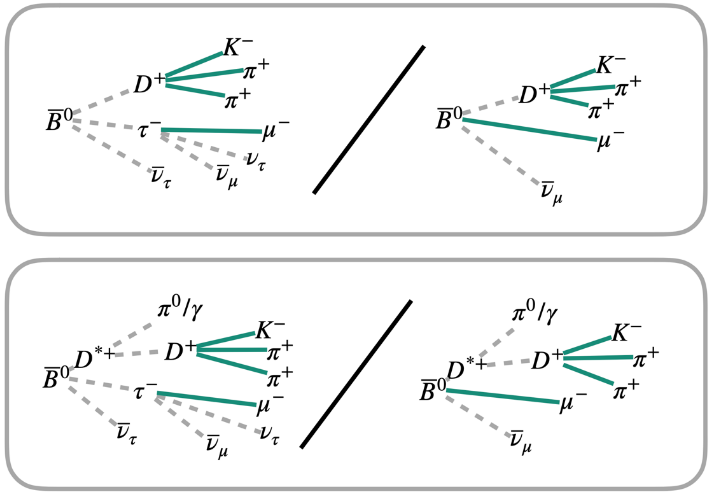
$$R(H_{\tau/\ell}) = \frac{\mathcal{B}(B \to H\tau\nu)}{\mathcal{B}(B \to H\ell\nu)}$$

$$H = D, D^*, X, \pi, \text{etc}. \quad \ell = e, \mu$$

- **Ratio measurements** provide stringent LFU tests:
  branching fractions, angular asymmetry, etc.
  Normalization (|Vxb|) cancels
  Part of theoretical, experimental uncertainties cancels

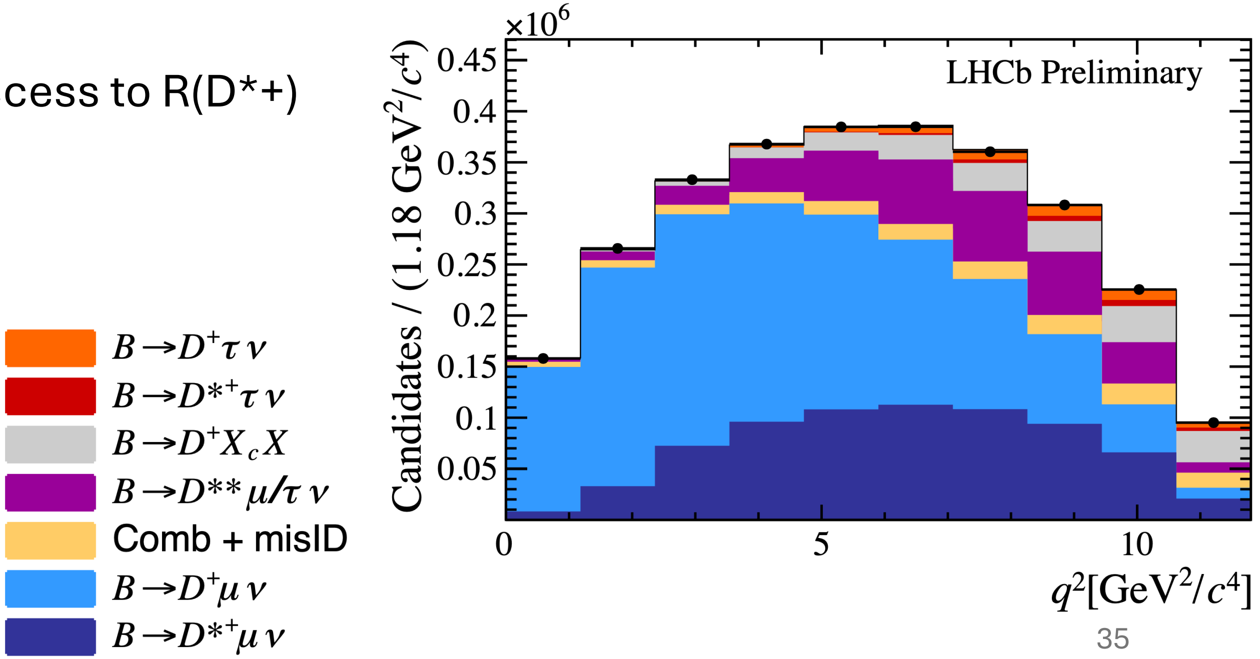
R(D+) =

R(D*+) =



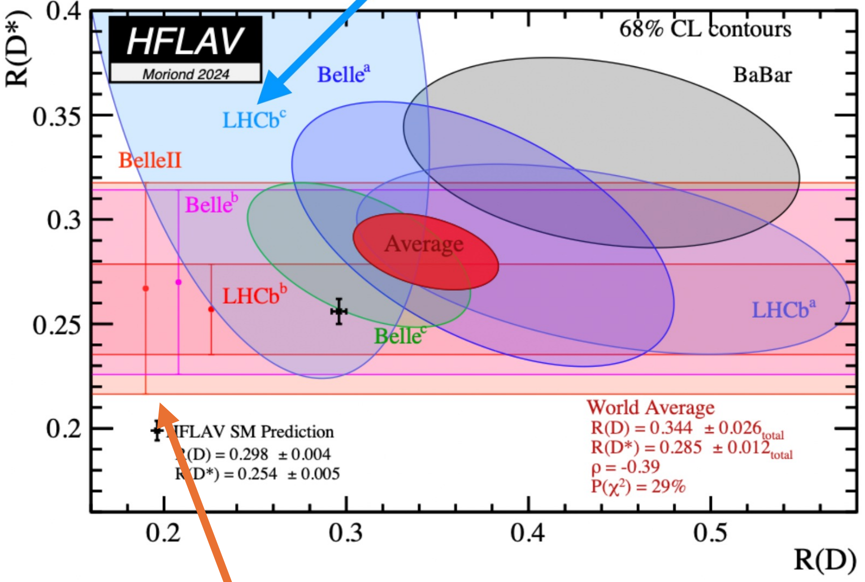
- **Measurement of R(D(*)+) :**
  First LHCb measurement using the D+ ground state,
  with D+→K-π+π+, muonic-tau decay
- D*+→D+π^0/γ with not reconstructed $\pi0/\gamma$ gives also access to R(D*+) in the same visible final state K-π+π+μ-

- 2015-16 data sample: 2fb^{-1}
- Simultaneous fit to four data samples :
  one signal region (D+ μ-)
  +1pion sample, +2 pion sample, +1K sample



This result
[LHCb preliminary]

[NEW!]
[HFLAV]



New World Average.
Tension with SM at the level of **3.17 σ**.

Belle II :

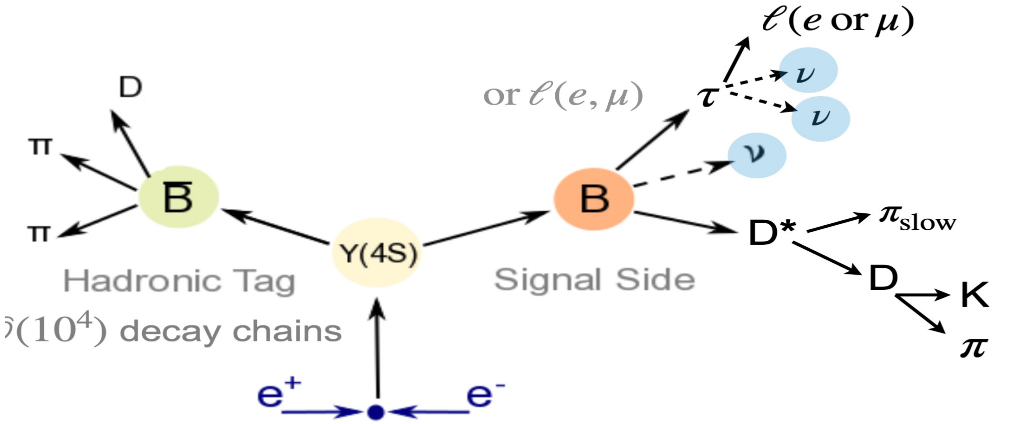
$$R(D^*) = 0.262\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.035}_{-0.032}(\text{syst})$$

Extract R(D*) using 2D fit on M^2miss
and residual energy in the calorimeter E(ECL)

Results from Belle II on LFU in b → c lv

(Lu Cao)

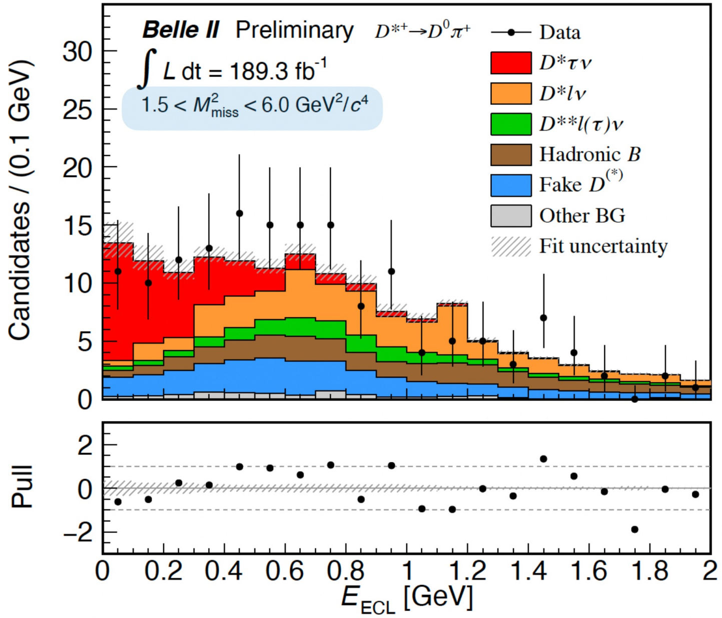
BELLEII dataset (189 fb^{-1}) with Hadronic Tagging Analysis
HTA : full event interpretation: higher purity, lower efficiency than the inclusive tagging analysis (ITA)



$D^{*+} \to D^0\pi^+$

$D^{*+} \to D^0\pi^+/D^+\pi^0$: $\mathcal{B}$~98%
$D^{*0} \to D^0\pi^0$: $\mathcal{B}$~65%

Eight D^0 modes: $\mathcal{B}$~36%,
Three D^+ modes: $\mathcal{B}$~12%



E(ECL) = residual energy in ECAL

Hadronic B decay at Belle and Belle II
(Niharika Rout)

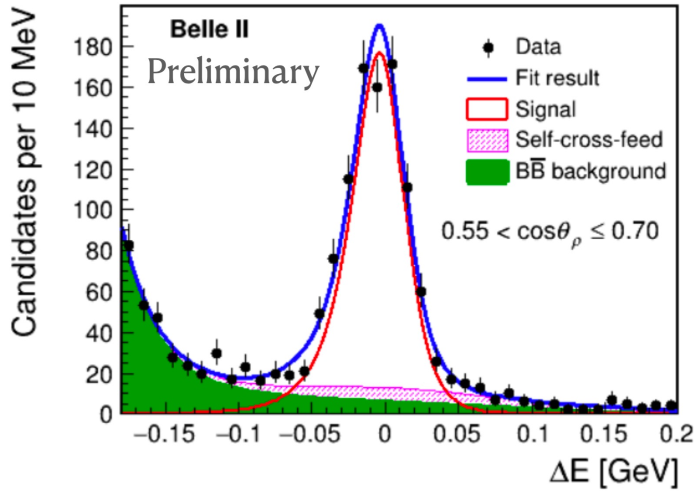
- Branching fraction of $B+ \to D0\ \rho+(770)$

WA BF: (1.35 ± 0.18)%; driven by an old CLEO measurement, with large (14 %) uncertainty

Challenge: separate $B \to D^0\rho(\to \pi+\pi0)$ and non-resonant $B \to D^0\pi+\pi0$ component

Run1 Belle2 dataset
World best result

$$\mathscr{B}(B^+ \to D^0\rho^+) = (0.939 \pm 0.021 \pm 0.050)\,\%$$



Difference between the expected and the observed B energy

- New hadronic decay measurements

First observation for 3 channels, and improved precision for others:

Channel	Yield (K_S^0 / K^{*0})	Average ε (K_S^0 / K^{*0})	$\mathcal{B}$ [10^{-4}]	
$B^- \to D^0 K^- K_S^0$	209 ± 17	0.098	$1.82 \pm 0.16 \pm 0.08$	3 × higher precision
$\overline{B}^0 \to D^+ K^- K_S^0$	105 ± 14	0.048	$0.82 \pm 0.12 \pm 0.05$	First observation
$B^- \to D^{*0} K^- K_S^0$	51 ± 9	0.044	$1.47 \pm 0.27 \pm 0.10$	
$\overline{B}^0 \to D^{*+} K^- K_S^0$	36 ± 7	0.046	$0.91 \pm 0.19 \pm 0.05$	
$B^- \to D^0 K^- K^{*0}$	325 ± 19	0.043	$7.19 \pm 0.45 \pm 0.33$	3 × higher precision
$\bar{B}^0 \to D^+ K^- K^{*0}$	385 ± 22	0.021	$7.56 \pm 0.45 \pm 0.38$	
$B^- \to D^{*0} K^- K^{*0}$	160 ± 15	0.019	$11.93 \pm 1.14 \pm 0.93$	
$\bar{B}^0 \to D^{*+} K^- K^{*0}$	193 ± 14	0.020	$13.12 \pm 1.21 \pm 0.71$	
$B^- \to D^0 D_s^-$	144 ± 12 / 153 ± 13	0.04 / 0.09	$95 \pm 6 \pm 5$	World's best
$\overline{B}^0 \to D^+ D_s^-$	145 ± 12 / 159 ± 13	0.02 / 0.05	$89 \pm 5 \pm 5$	
$B^- \to D^{*0} D_s^-$	30 ± 6 / 29 ± 7	0.02 / 0.04	$65 \pm 10 \pm 6$	
$\overline{B}^0 \to D^{*+} D_s^-$	43 ± 7 / 37 ± 7	0.02 / 0.04	$83 \pm 10 \pm 6$	

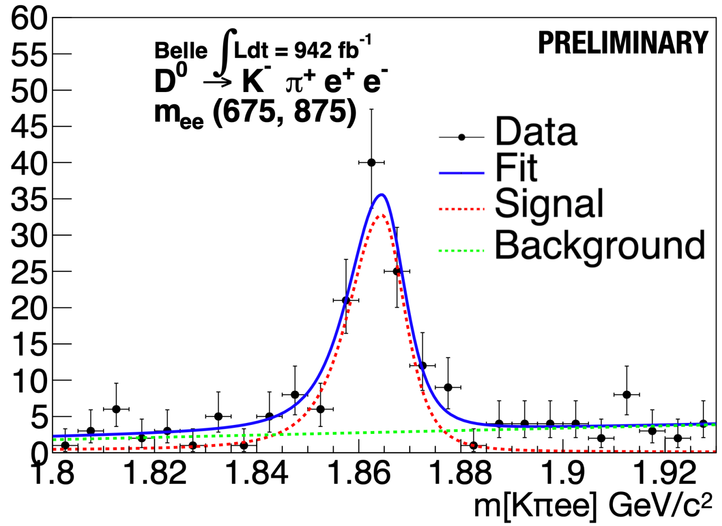
Charm physics at Belle and Belle II
(Giulia Casarosa) - new results

- Study of rare FCNC decay $D0 \rightarrow hh'e+e-$

signal observed in $D0 \rightarrow K\pi e+e-$, in the ρ/ω region

measured BR = $(39.6 \pm 4.5 \pm 2.9)\times10^{-7}$ [11.8σ]

No signal observed in the other regions & channels



- Study of $\Xi c \rightarrow \Xi 0 h0$, $h0 = \pi^0, \eta, \eta'$ decays

Selection of signal candidates with ε≃o(1%),

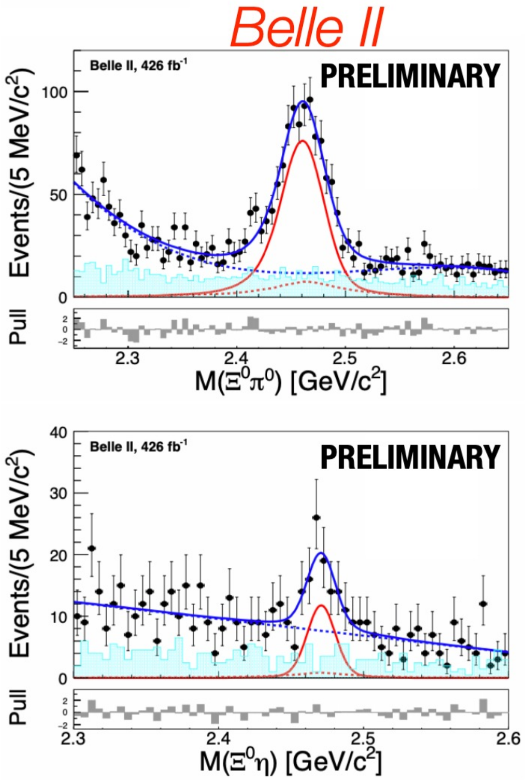
Reference mode : $\Xi c \rightarrow \Xi{-}\pi{+}$

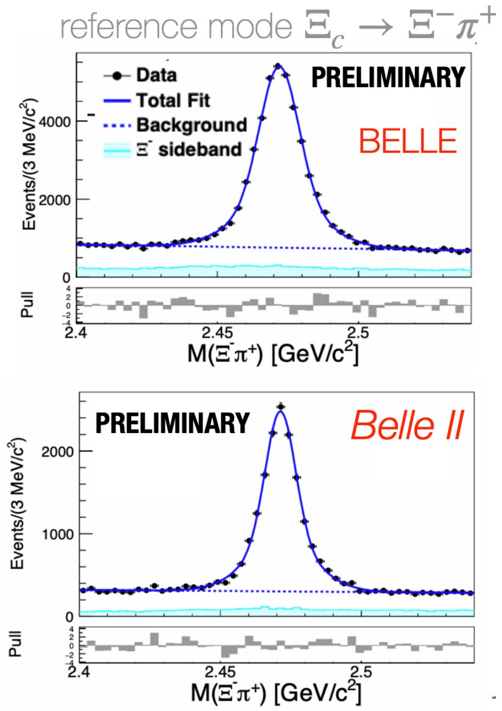
Simultaneous fit to Belle and Belle II

$$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0) = (6.9 \pm 0.3(\text{stat.}) \pm 0.5(\text{syst.}) \pm 1.5(\text{norm.})) \times 10^{-3}$$

$$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta) = (1.6 \pm 0.2(\text{stat.}) \pm 0.2(\text{syst.}) \pm 0.4(\text{norm.})) \times 10^{-3}$$

$$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta') = (1.2 \pm 0.3(\text{stat.}) \pm 0.1(\text{syst.}) \pm 0.3(\text{norm.})) \times 10^{-3}$$





Results rule out several theoretical approaches proposed to deal with non-factorizable amplitudes

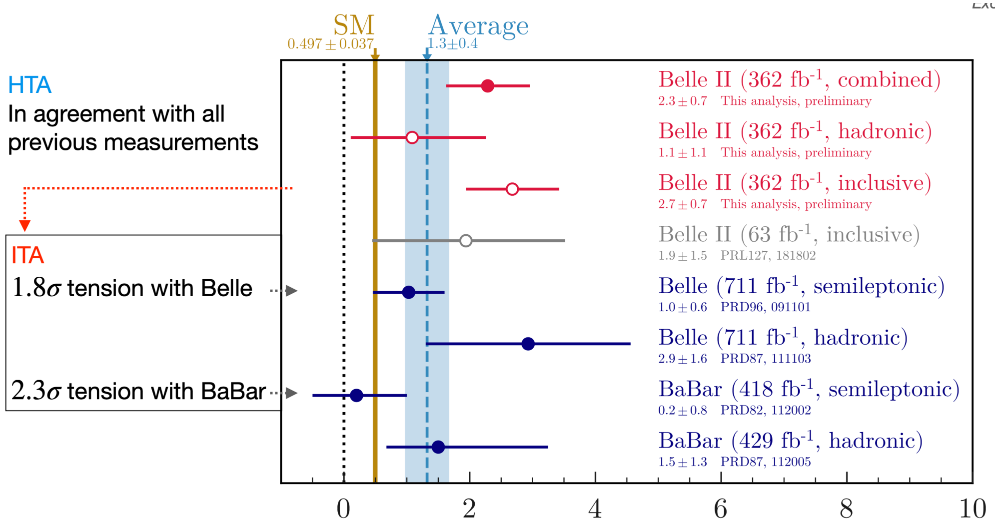
Radiative and electroweak penguin results from Belle and Belle II
(Pablo Goldenzweig)

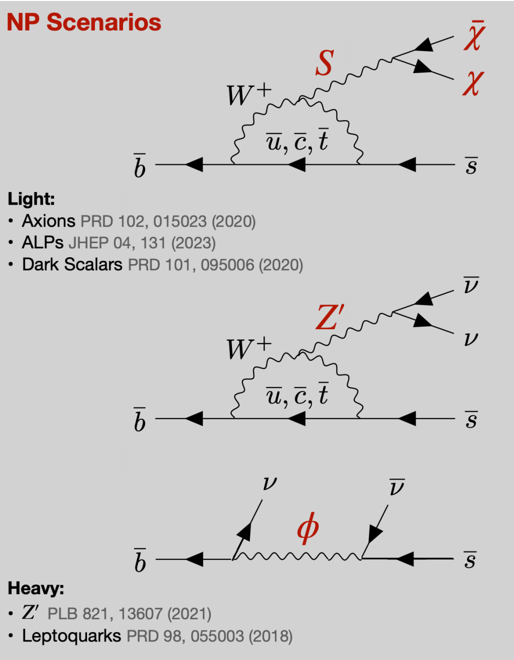
- Evidence for $B^+ \to K^+\nu\nu$

FCNC transition with precise SM prediction:

$BR(B^+ \to K^+\nu\nu) = (5.58 \pm 0.37) \times 10^{-6}$

Analysis : ITA (Inclusive) and HTA (hadronic) tagging analysis





2.7σ deviation from the SM prediction

- Study of $B^0 \to \gamma\gamma$

Very rare decay with $B_{SM}=(1.4 +1.4-0.8)\ 10^{-8}$

Highly CKM suppressed relative to $B^0_s \to \gamma\gamma$

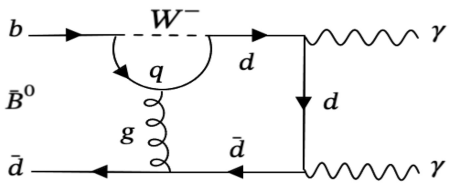
Challenging γγ final state : large background

Dominant bg from ee → qq

Event shape variable used in a BDT for discrimination

Signal with 2.5σ significance

- *No direct interaction between the b and d quarks;*
- *An effective FCNC is induced by a 1-loop or penguin diagram.*

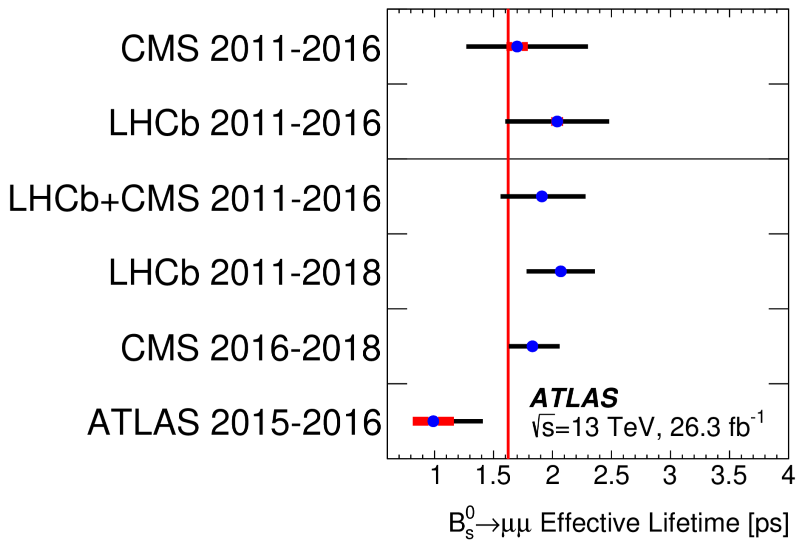


	$\mathcal{B}(B^0 \to \gamma\gamma)$	$\mathcal{B}(B^0 \to \gamma\gamma)$ (at 90% CL)
Belle	$(5.4^{+3.3}_{-2.6} \pm 0.5) \times 10^{-8}$	$< 9.9 \times 10^{-8}$
Belle II	$(1.7^{+3.7}_{-2.4} \pm 0.3) \times 10^{-8}$	$< 7.4 \times 10^{-8}$
Combined	$(3.7^{+2.2}_{-1.8} \pm 0.7) \times 10^{-8}$	$< 6.4 \times 10^{-8}$

B physics in ATLAS and CMS
(Onda Kovanda)

- **First ATLAS measurement : $B^0_S \rightarrow \mu^+\mu^-$ effective lifetime**

Data from 2015-16, L=26.3 fb^{-1}
Complementary to the $B^0{}_S \rightarrow \mu^+\mu^-$ branching ratio
Use the dimuon invariant mass distr., proper decay time distribution
Measurement statically limited



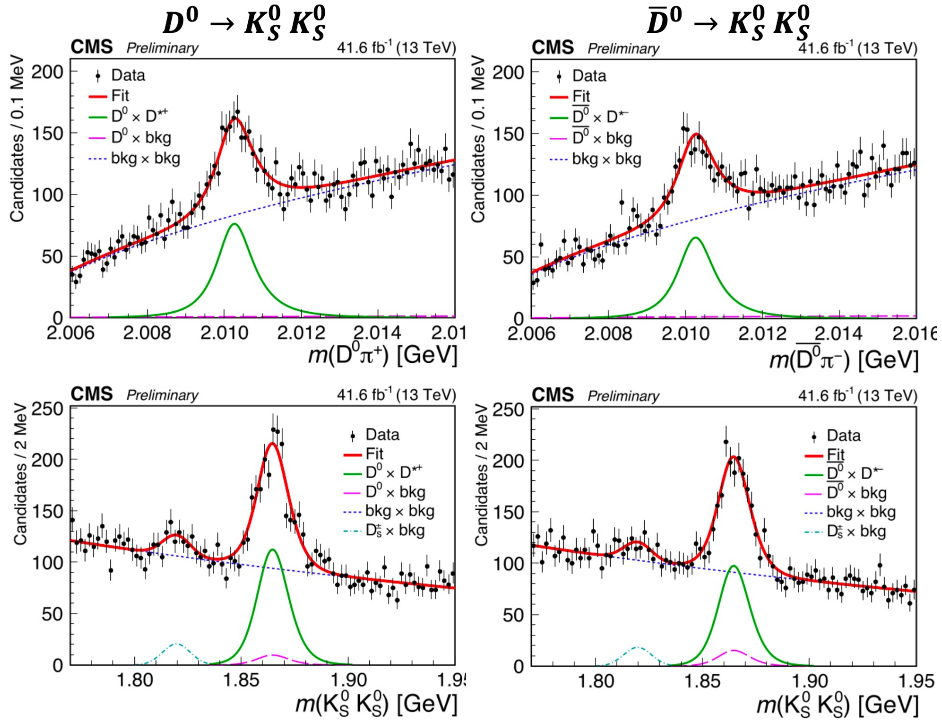
- **New CMS : Search for CP violation in $D^0 \rightarrow K^0_S K^0_S$**

2018 data (41/fb)

$$A_{CP} = \frac{\Gamma(D^0 \rightarrow K^0_S K^0_S) - \Gamma(\bar{D}^0 \rightarrow K^0_S K^0_S)}{\Gamma(D^0 \rightarrow K^0_S K^0_S) + \Gamma(\bar{D}^0 \rightarrow K^0_S K^0_S)}$$

A_{CP} in signal measured relative to $\mathbf{D^0 \rightarrow K^0 \pi^+\pi^-}$ reference channel

→ Yields obtained in a 2D fit to the $D*\pm$ and D^0 inv. mass
No significant CP violation observed in the pilot CMS CP measurement in the charm sector



Latest result from BESIII : charm hadron BF decay measurement (Peilian Liu)

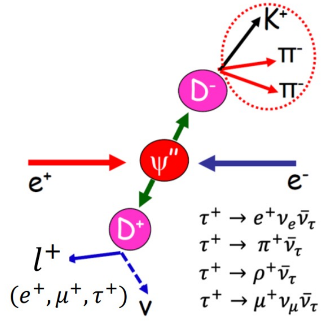
At the BEPCII (beam energy from 1 to 2.5 GeV), BESIII detector is operating since 2008

The largest charmed hadron data samples collected near the mass threshold of charmed hadron pairs

$D_s^+ \to \mu^+ \nu_\mu$

Ref	$\mathcal{L}$ [fb^{-1}]	$\mathcal{B}$ [$\times 10^{-3}$]	$f_{D_s^+}\|V_{cs}\|$ [MeV]	Precision [%]
PRL122(2019)071802	3.2@4.18 GeV	$5.49 \pm 0.16 \pm 0.15$	$246.2 \pm 3.6 \pm 3.5$	2.1
PRD104(2021)05200	6.3@4.18–4.23GeV	$5.35 \pm 0.13 \pm 0.16$	$243.1 \pm 3.0 \pm 3.7$	2.0
PRD108(2023)112001	7.3@4.13–4.23GeV	$\mathbf{5.29 \pm 0.11 \pm 0.09}$	$241.8 \pm 2.5 \pm 2.2$	**1.4**

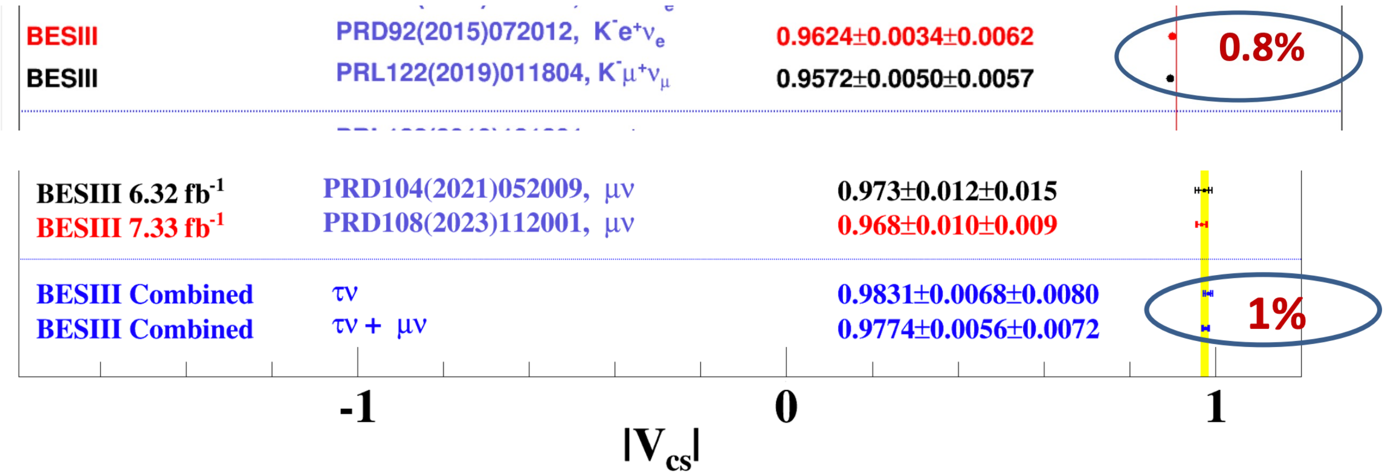
Hadronic tagging of charmed hadrons



$$N_{tag} = 2N_{D\bar{D}}\mathcal{B}_{tag}\epsilon_{tag}$$

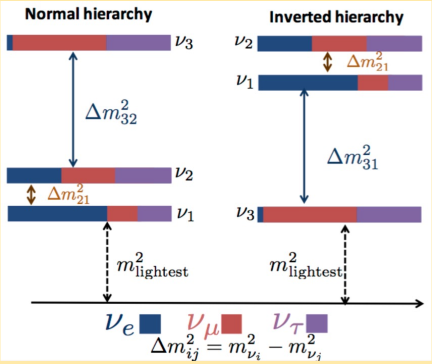
Charmed hadrons	$N_{tag} (\times 10^6)$
$D^0/\bar{D}^0$	7.3
$D^\pm$	4.6
$D_s^\pm$	0.8
$\Lambda_c^+/\bar{\Lambda}_c^-$	0.12

With the input of hadronic form factor from LQCD → extract precise measurement of the CKM matrix element |Vcs| at 1% precision level :



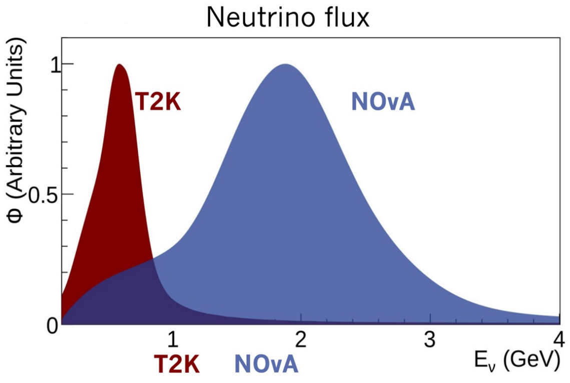
Neutrino and DM

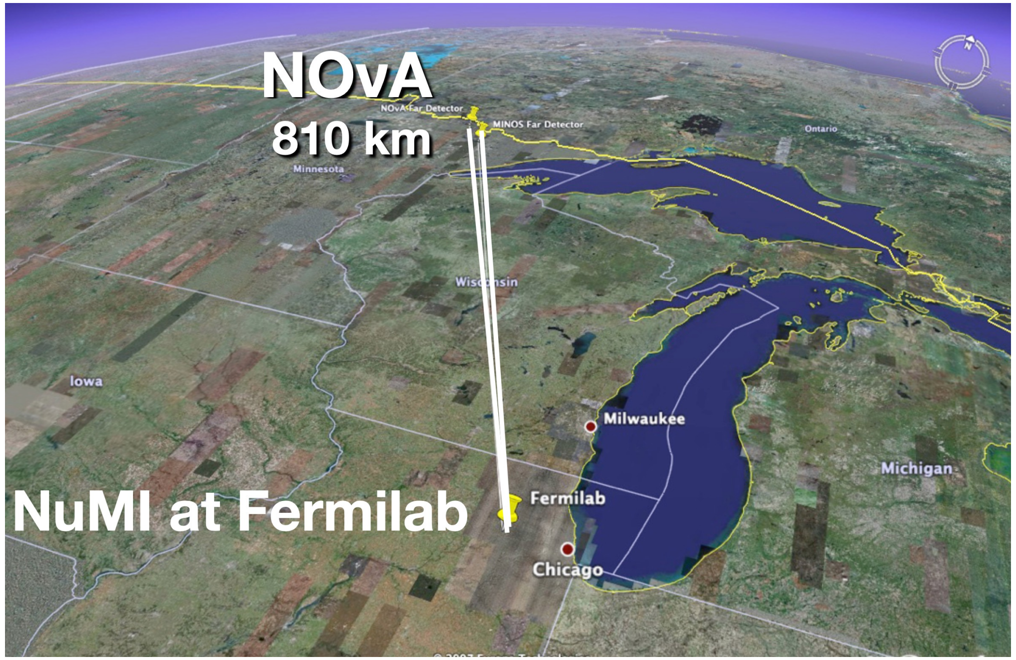
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\rm CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\rm CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



	T2K	NOvA
L (baseline)	295 km	810 km
Energy (beam peak)	0.6 GeV	2 GeV
Matter effect*	~ ±9%	~ ±19%
CP effect*	~ ±30%	~ ±25%

*calculated at beam peak energy

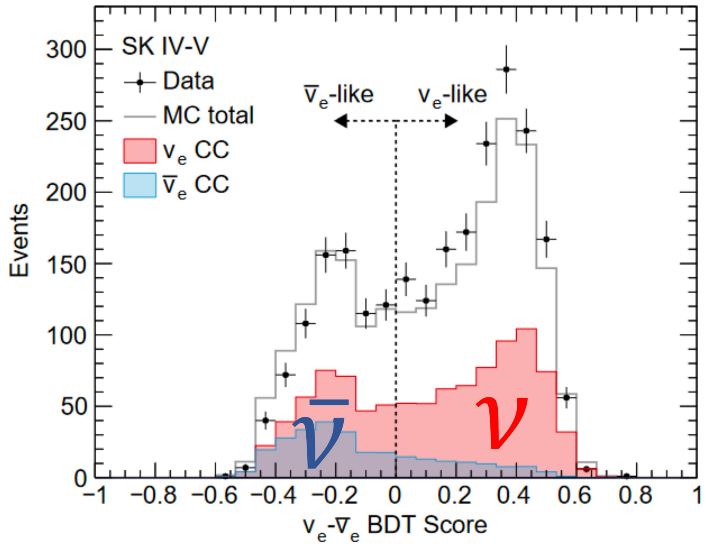


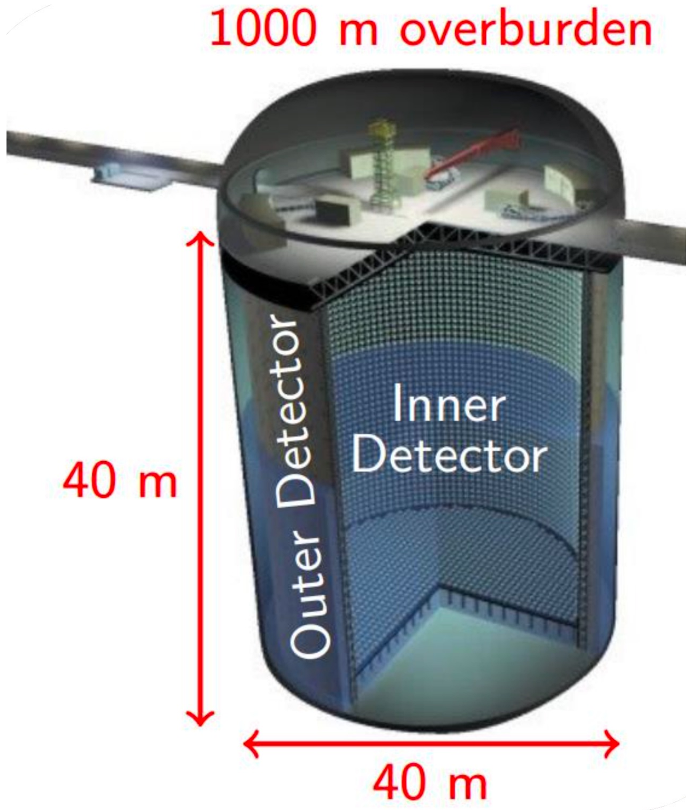


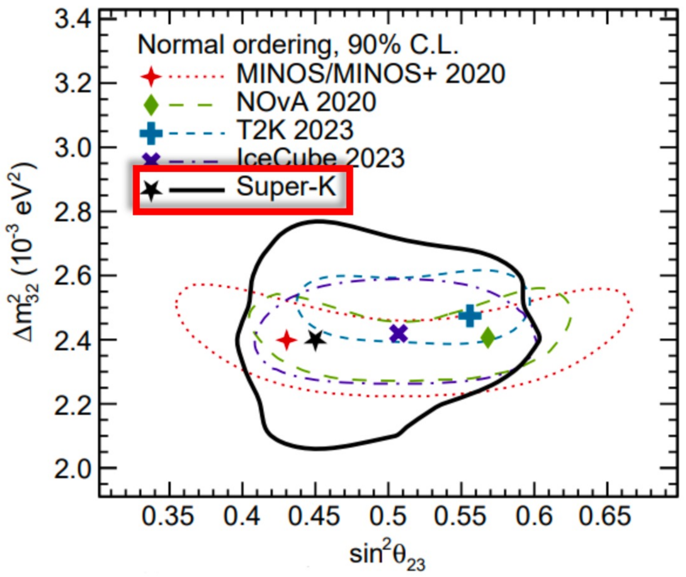
Latest results from Super Kamiokande (Andrew Santos)

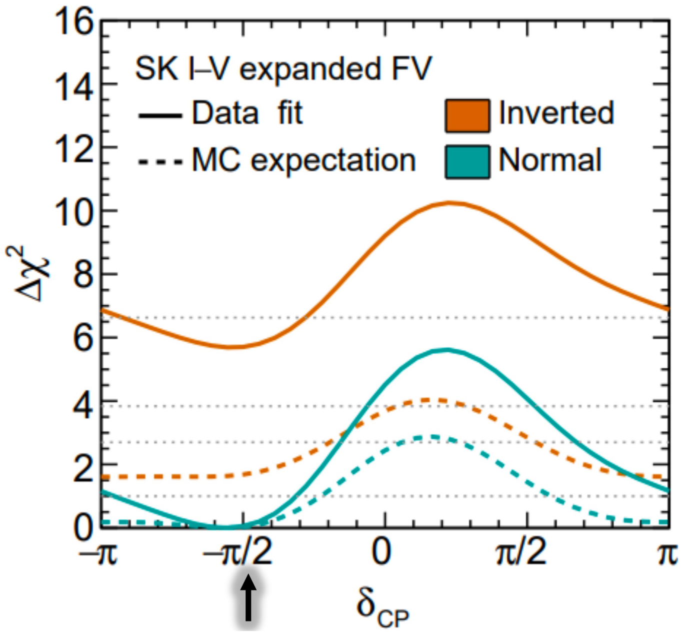
Around 11 000 PMTs in inner detector with an outer detector muon veto
Gadolinium-doped water since 2020 for easier neutron capture identification
Running since 1996 (phases I-VII)

Study of atm ν :
Fully-contained (expanded fiducial volume)
e-like vs μ-like (event topology)
New neutron tagging (ν vs anti-ν interactions)
New BDT for enhanced ν sample from anti-ν









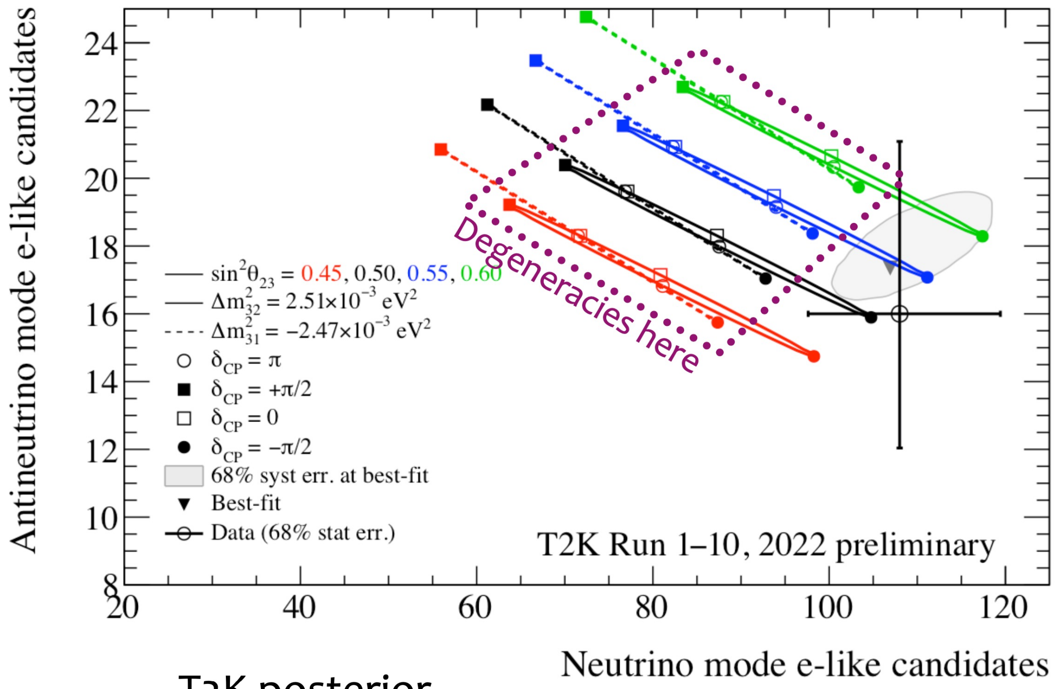
Competitive measurements (especially θ_{23}) with other experiments

Best-fit $\boldsymbol{\delta_{CP}}$: preferring $\delta_{CP} = -\pi/2$ is maximal CP violation
Favour normal hierarchy at around 2σ
+ Combination with T2K

Latest results from T2K experiment
(Phill Lichfield)

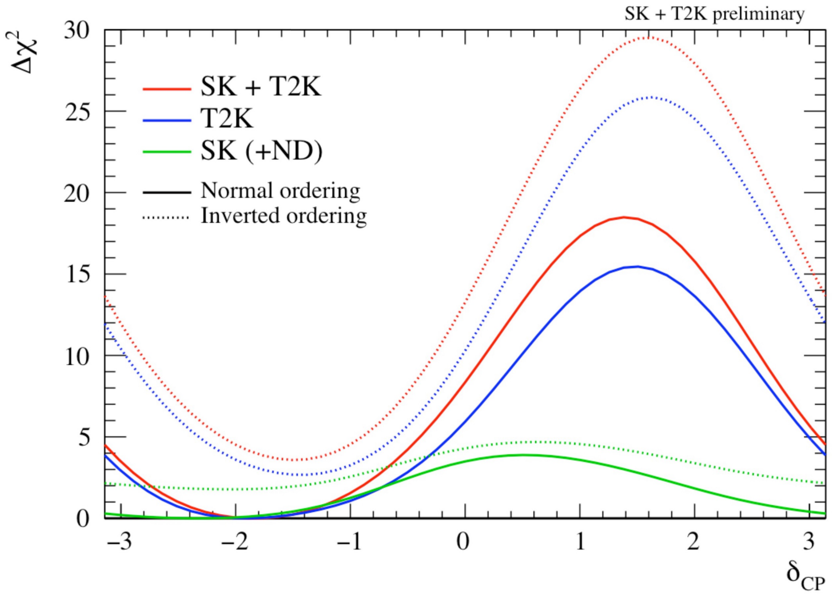
In 2020 : end of run10
From 2021-2023 : upgrades (beam power, ND80)
Feb 2024 : data taking

T2K (ν beam) and SK (ν atm) combination :
(December 2023)
MSW resonance changes mixing for high energy neutrinos:
~13 GeV (crust); ~2.5 GeV (core)
SK helps in breaking T2K's MO – δ_{CP} degeneracies
Construct full correlation for joint analysis



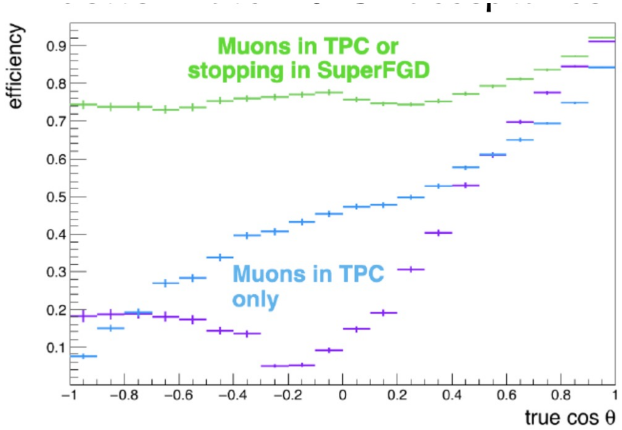
T2K posterior probability	
$\Delta m^2_{32} > 0$	0.80
$\Delta m^2 < 0$	0.20

Find $\delta_{CP} = -0.63^{+0.31}_{-0.22}\,\pi$



CP conser-vation disfavoured by 'about' 2σ

Upgrade ND80 :
replacement
of the high-angle
tracker

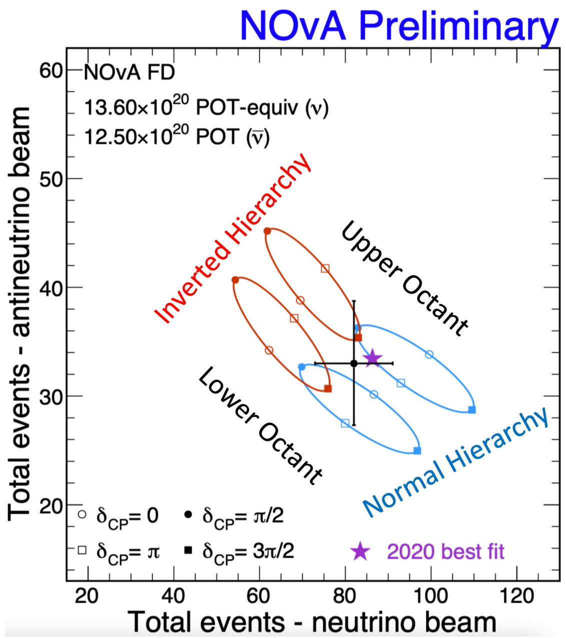


Run up to 2028 (when HK starts)

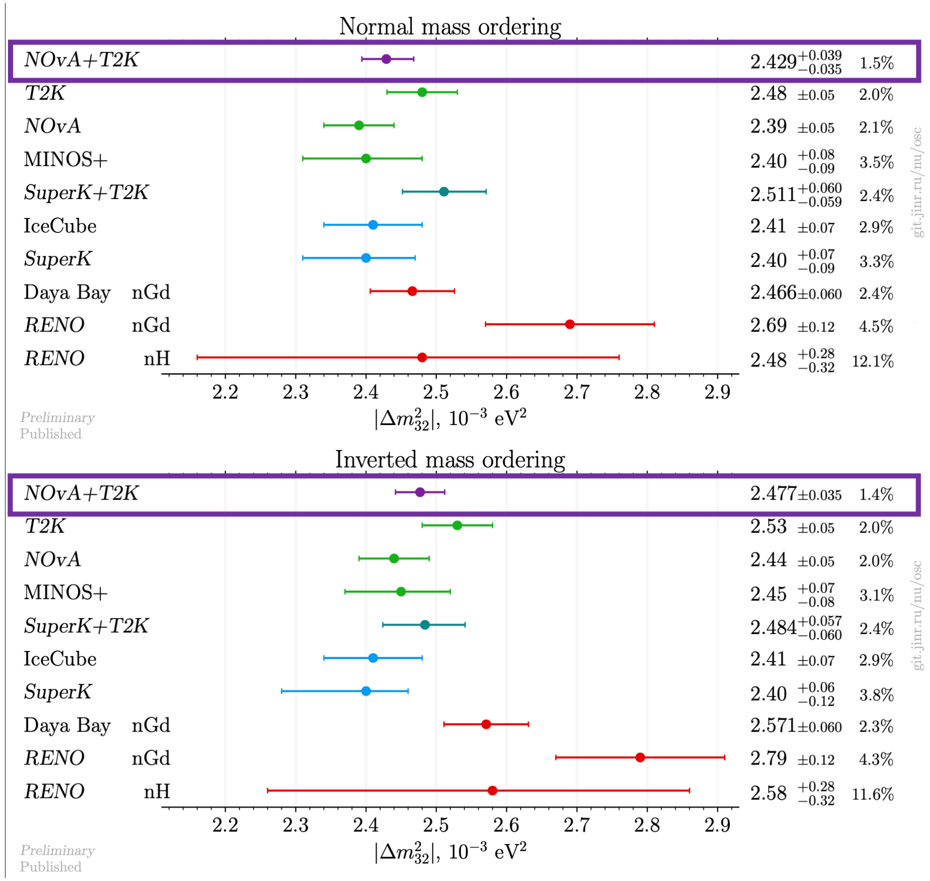
N0vA and T2K joint results
(Mayly Sanchez)

- Lot of work (cross-checks) to combine NOvA and T2K results

The experiments have different ν energy, ν interactions, matter effect …
Different analyses approaches
In particular : matter effects modify the energy spectrum depending on the NMO and ν versus anti-ν
Effect is larger for longer baseline



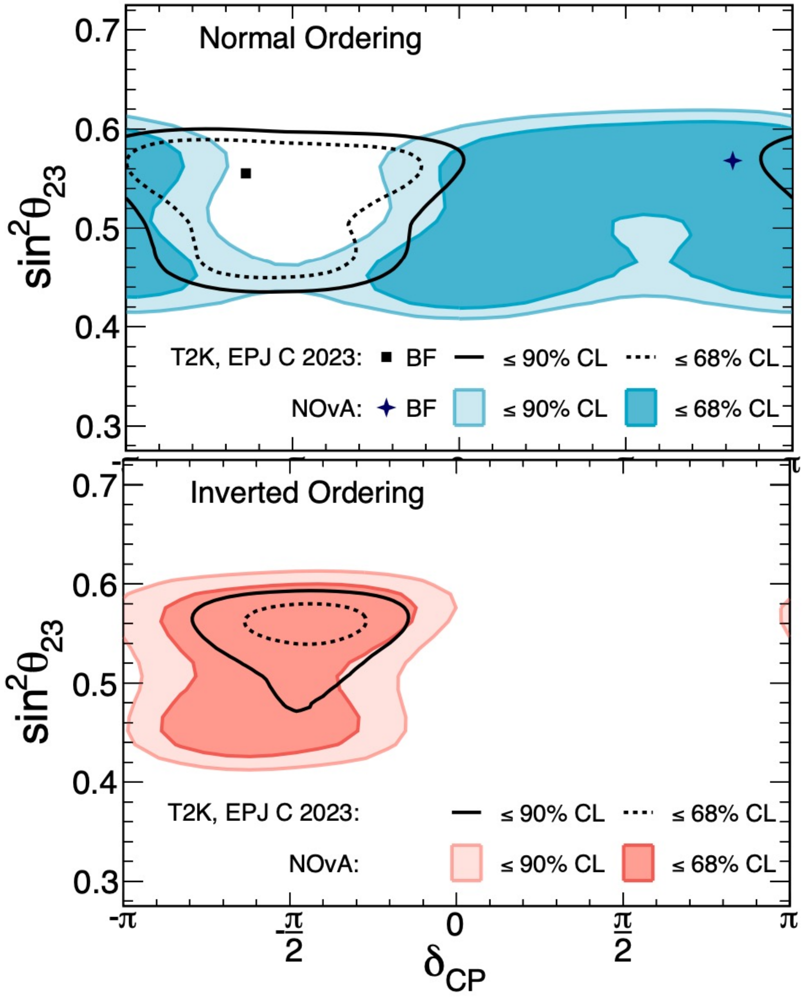
Channel	NOvA	T2K
ν_e	82	94 (ν_e) 14 ($\nu_e 1\pi$)
$\bar{\nu}_e$	33	16
ν_μ	211	318
$\bar{\nu}_\mu$	105	137

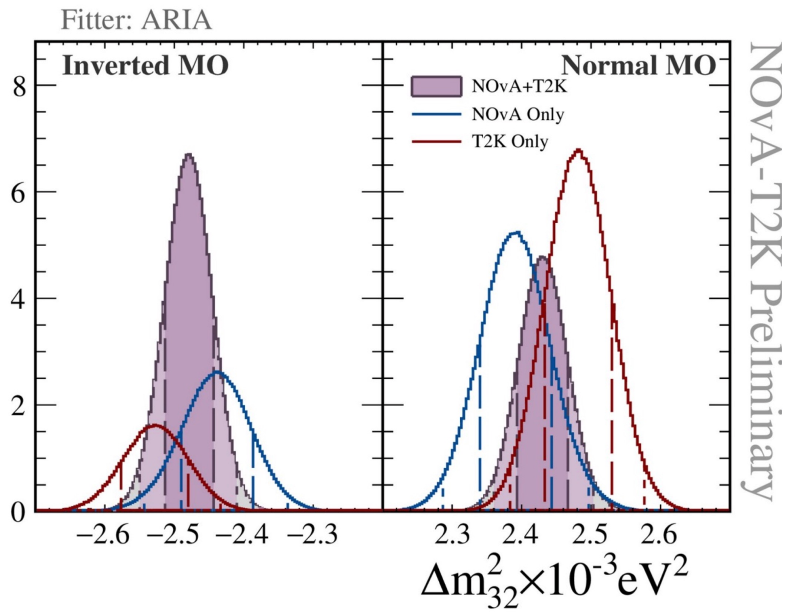


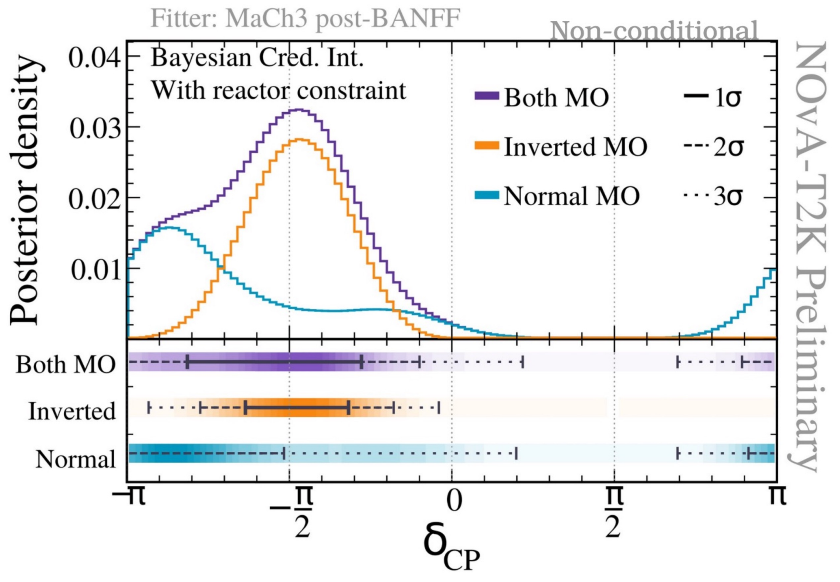
The joint analysis shows a strong constraint on $|\Delta m^2_{32}|$

N0vA and T2K joint results
(Mayly Sanchez)

T2K measurements isolate the impact of CP violation whereas NOvA has more mass ordering sensitivity







Including the Δm^2_{32} constraint from the Daya Bay experiment reverses the preference back to NO

The ν mass ordering remains inconclusive

$\delta_{CP} = \pi/2$ lies outside 3σ interval for both mass orderings

CP conserving values for the IO fall outside the 3σ range

→ Need more data

Searching for 0νββ in the Cuore experiment

(Irene Nutini) - New results

CUORE : Cryogenic Underground Observatory for Rare Events

Cryogenic experiment at tonne-scale,
utilising oxide of tellurium TeO_2 thermal detectors operated at ~10 mK
Located at Laboratori Nazionali del Gran Sasso

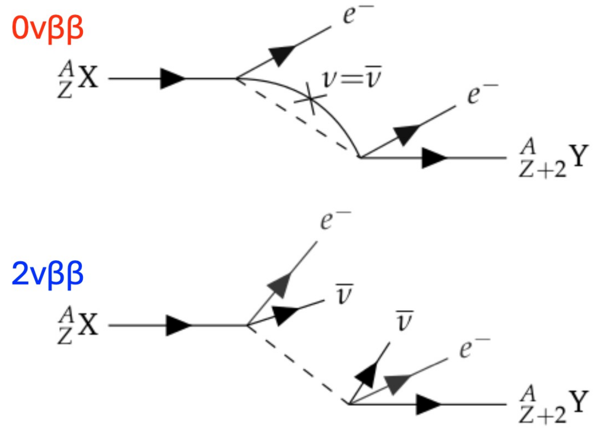
Challenges :
- low temperature and low vibrations over time for about 1000 detectors
- low background

Results today based on data taken from 2017-2023, for 2039 kg.yr TeO_2

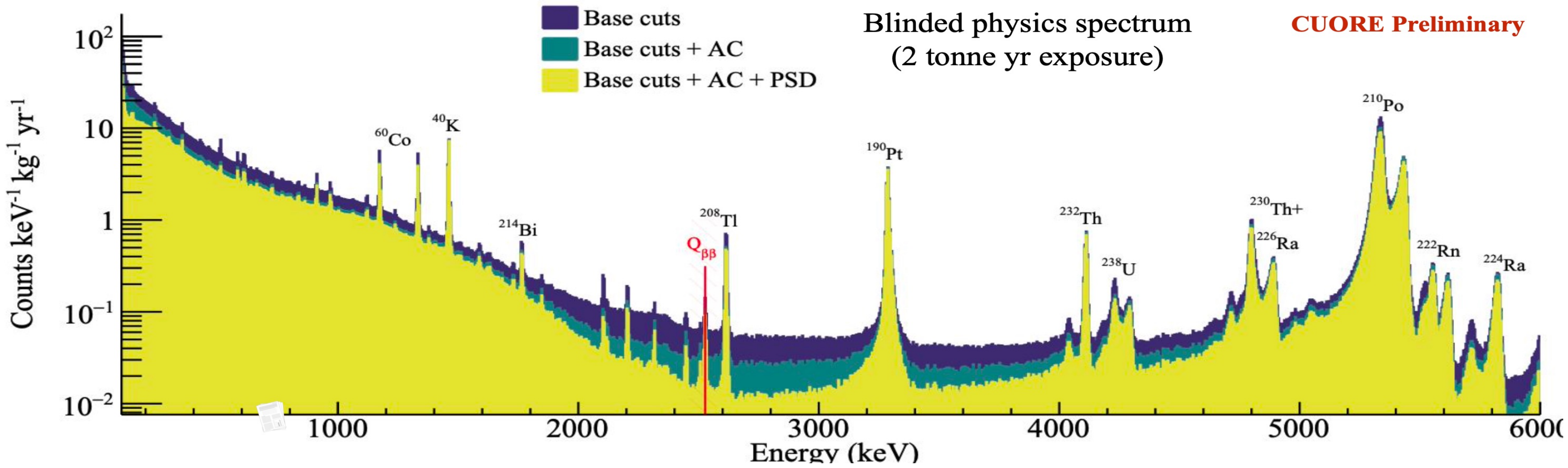
Beyond Standard Model process (ΔL = 2)

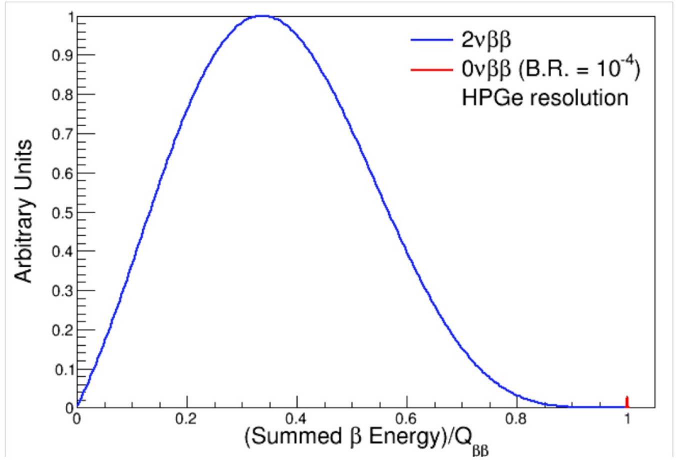
$$(A, Z) \longrightarrow (A, Z+2) + 2e^-$$

Not yet observed: $T^{1/2}_{0\nu\beta\beta} > 10^{22\text{-}26}$ yr



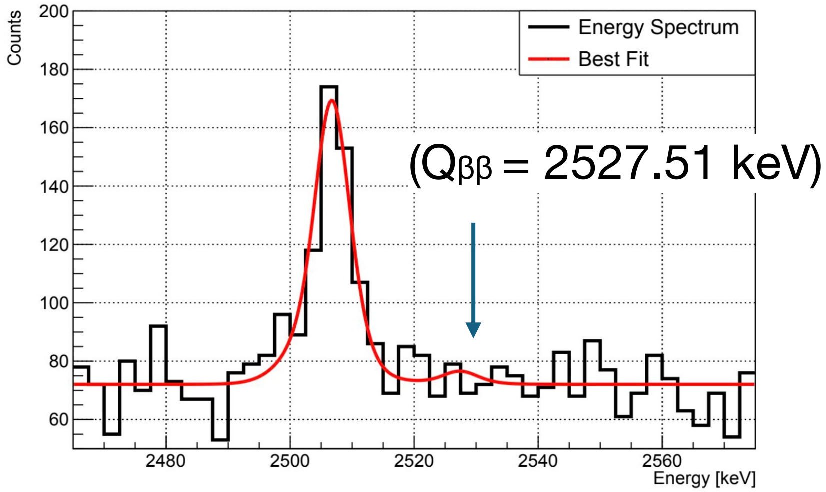
Reference 208Tl gamma peak at 2615 keV from calibration data





($Q_{\beta\beta}$ = 2527.51 keV)

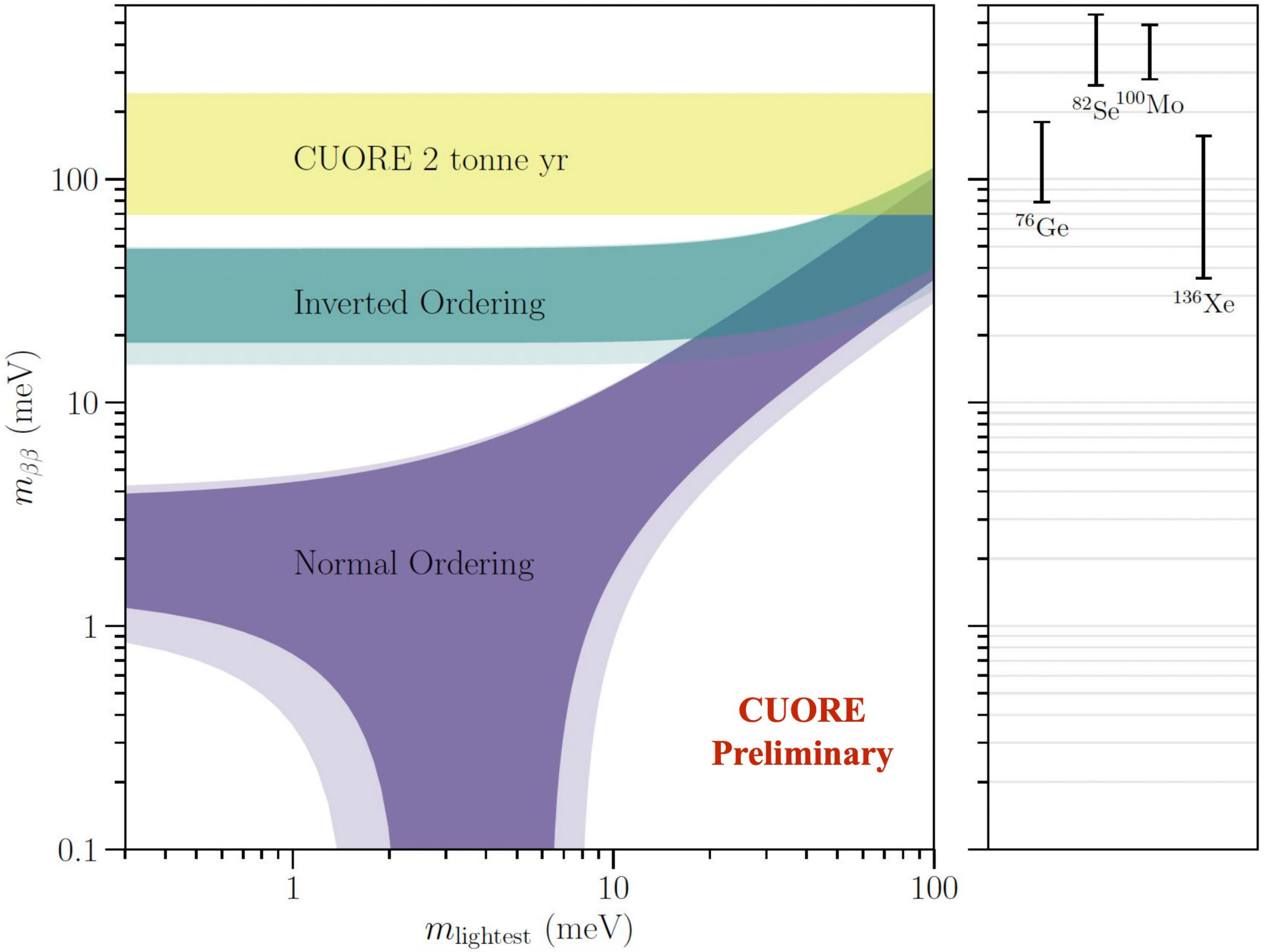
Searching for 0νββ in the Cuore experiment
(Irene Nutini)



$T_{0\nu}^{1/2}$ (^{130}Te) > 3.8 x 10^{25} yr

(90%C.I. including syst.)

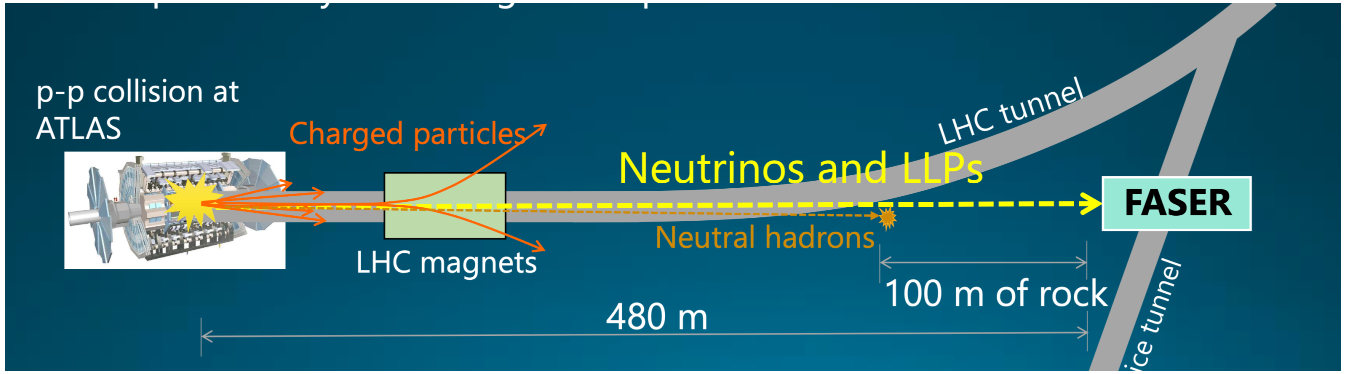
(new most stringent limit for ^{130}Te)



Limit on the effective Majorana mass, assuming light Majorana neutrino-exchange:
$m_{\beta\beta}$ < 70-240 meV

Faser experiment

(Akitaka Ariga) – New results



Forward search experiment at the LHC

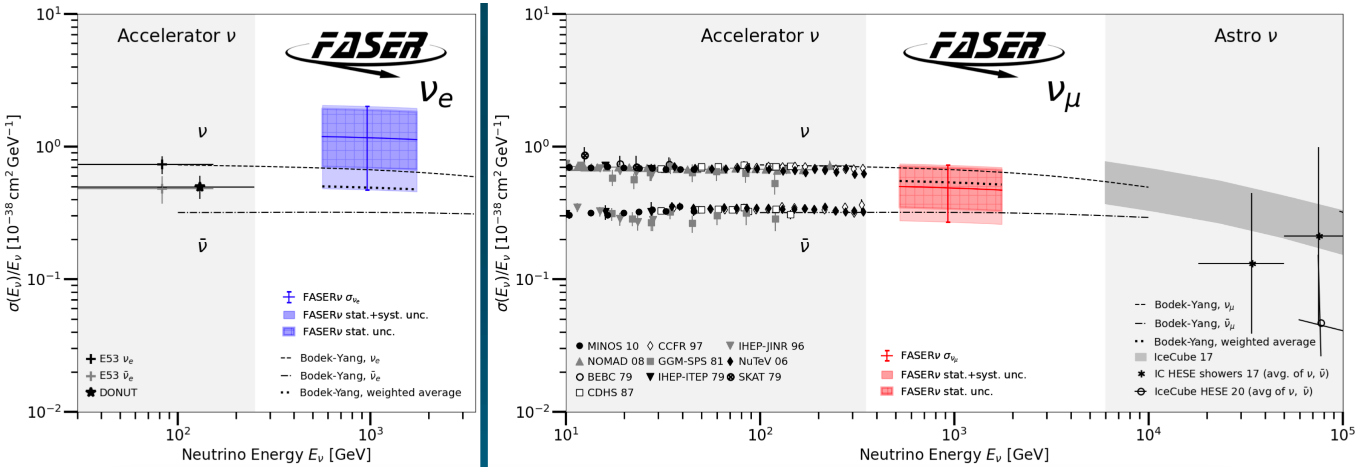
Targets long-lived BSM particles (e.g. A', ALPs) and SM ν

Located 480 m downstream of ATLAS interaction point

LHC-FASER is taking data in LHC Run 3, ~70 fb^{-1} collected, Run4 is approved

- Neutrino studies : Emulsion/tungsten neutrino detector

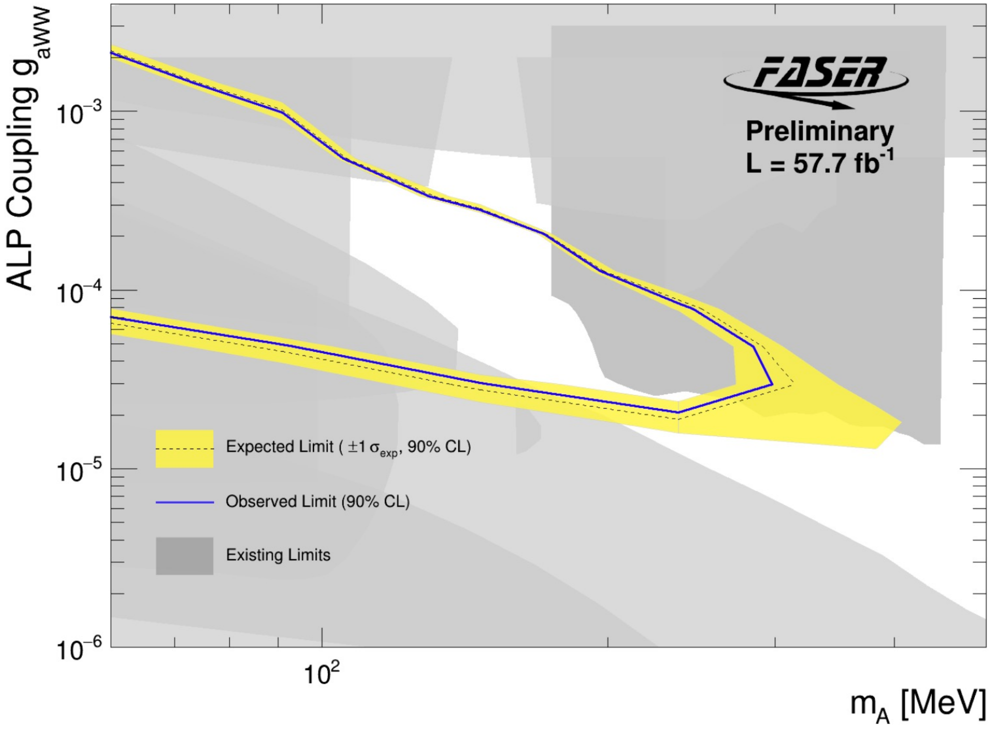
  Measure neutrino cross sections at unexplored TeV energies, constrain hadron production at pp collisions



- Axion-like Particles (ALPs) search results

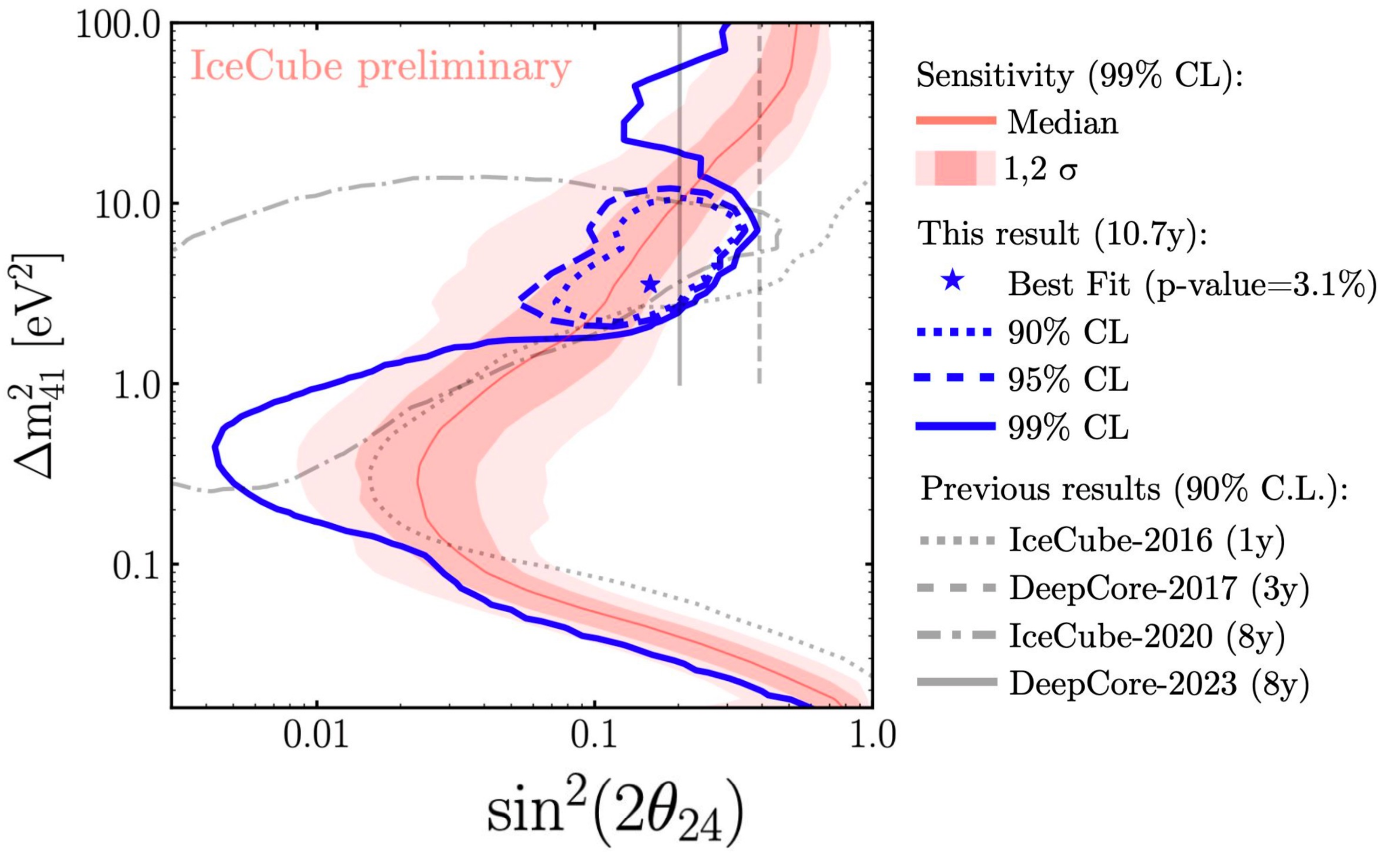
  Signal: $a \rightarrow \gamma\gamma$ appearing from 'nothing' with ~TeV of energy

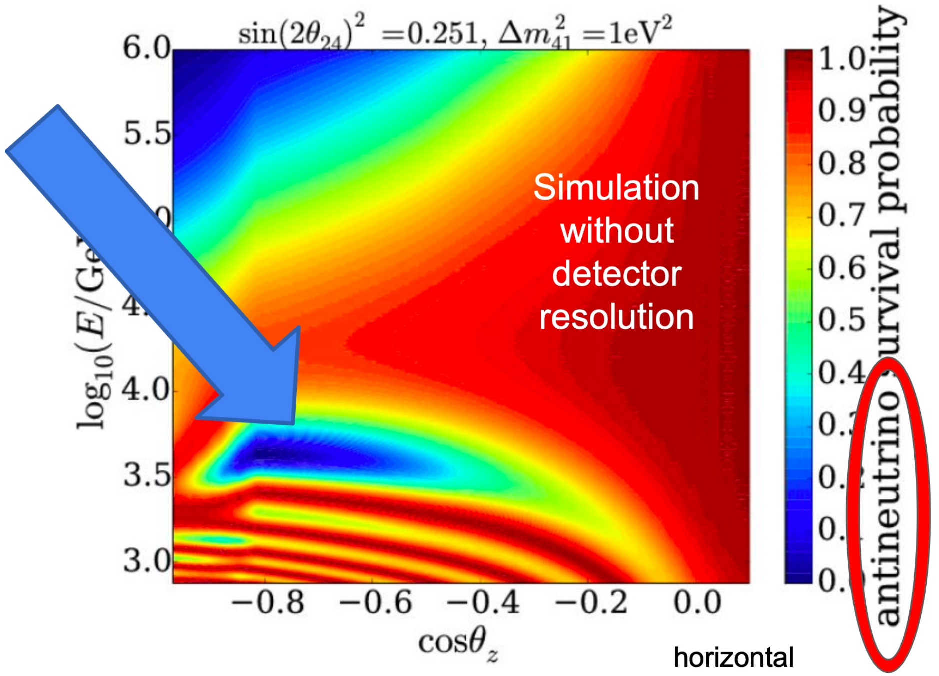
- Have also performed a dark photon search



Search for New Physics in IceCube
(John Hardin)

Search for sterile neutrino :
The sterile portion does not interact in the earth.
Different matter potential for sterile and non-sterile neutrinos
Produces a resonant term.
➔ Matter effect : large disappearance of upgoing anti-ν



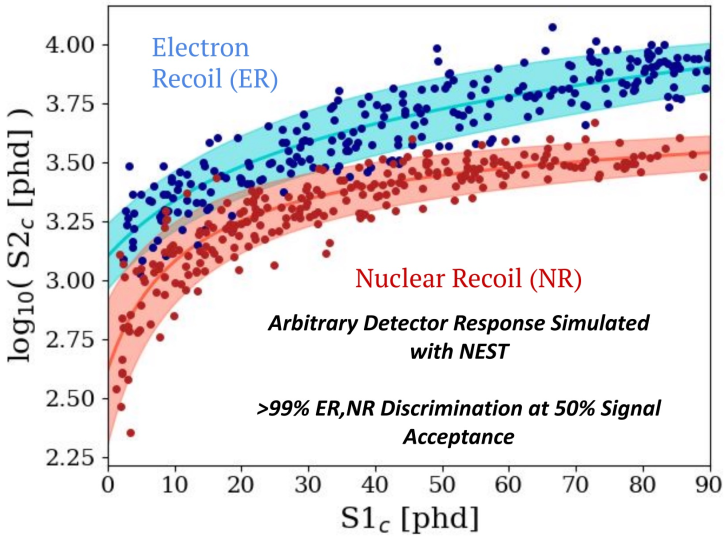


- $\Delta m^2 = 3.5 eV^2$
- $\sin^2(2\theta_{24}) = 0.16$

The p-value for the null hypothesis of sterile neutrinos in the muon disappearance channel is 3.1%
Does not rise to evidence

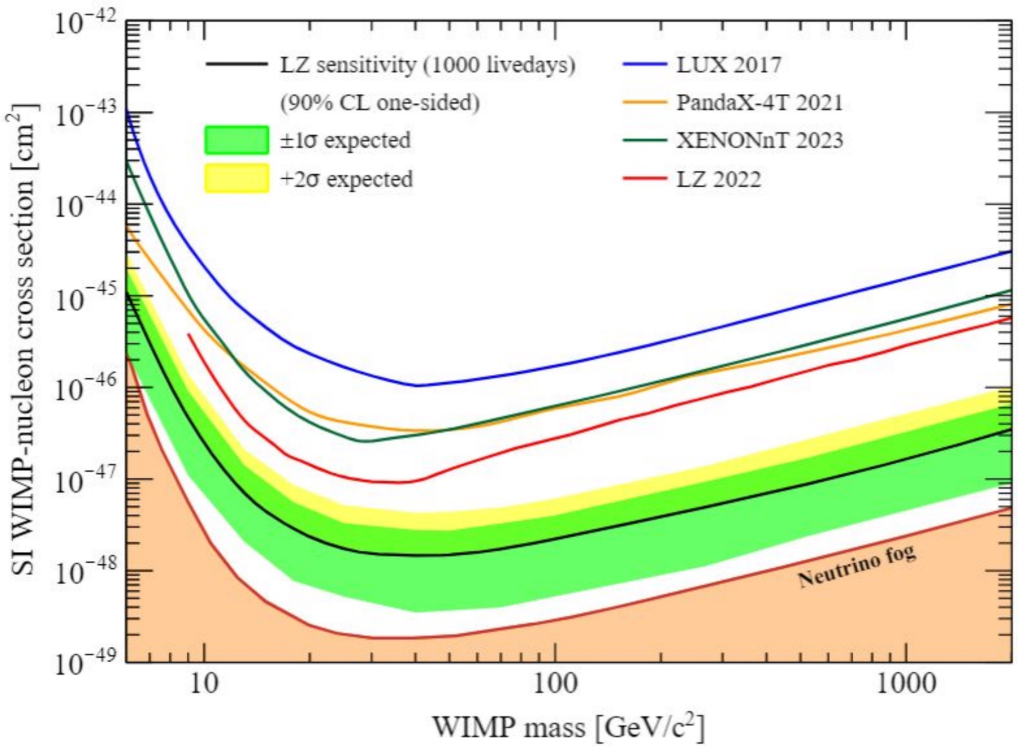
Results from LUX-ZEPLIN (Greg Rischbieter) and Results from PANDAX (Ning Zhou)

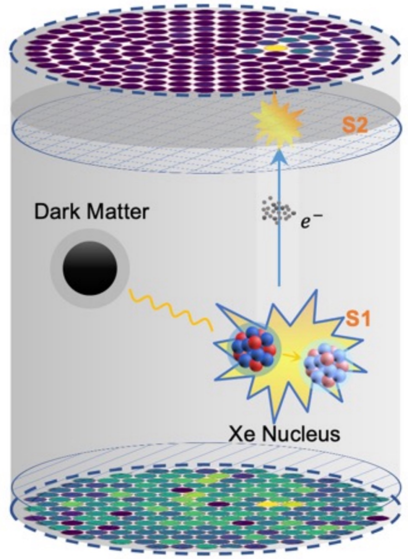
WIMP direct detection with a Dual Phase TPC - Measures the Scintillation (S1) and Ionization (S2) response
Precise E measurement – 3D position reconstruction – Discrimination btw nuclear recoil and electron recoil signals
Xenon target



-Data collected between Dec. 2021-May 2022
-5.5 ± 0.2 tonnes fiducial volume
Reach : 9.2×10^{-48} cm^2

Recap :
limits on DM-nucleon scattering (SI) :





-Commissioning started from Nov/2020 (95 days) –
-Sensitive volume: 3.7 tonnes Xenon
Reach : 3.8×10^{-47}cm^2

New results: searches beyong Spin-independent WIMPS:

Residual weak EM properties: coupling with photons (millicharged, charge radius, … UV complete models

Non-Relativistic Effective Field Theory

Intense sessions with an impressive number of new results and interesting discussions !

Very high quality of talks

Intense sessions with an impressive number of new results and interesting discussions !
Very high quality of talks

Big thank to the Moriond committee and support staff for organising such an interesting program and beautiful conference