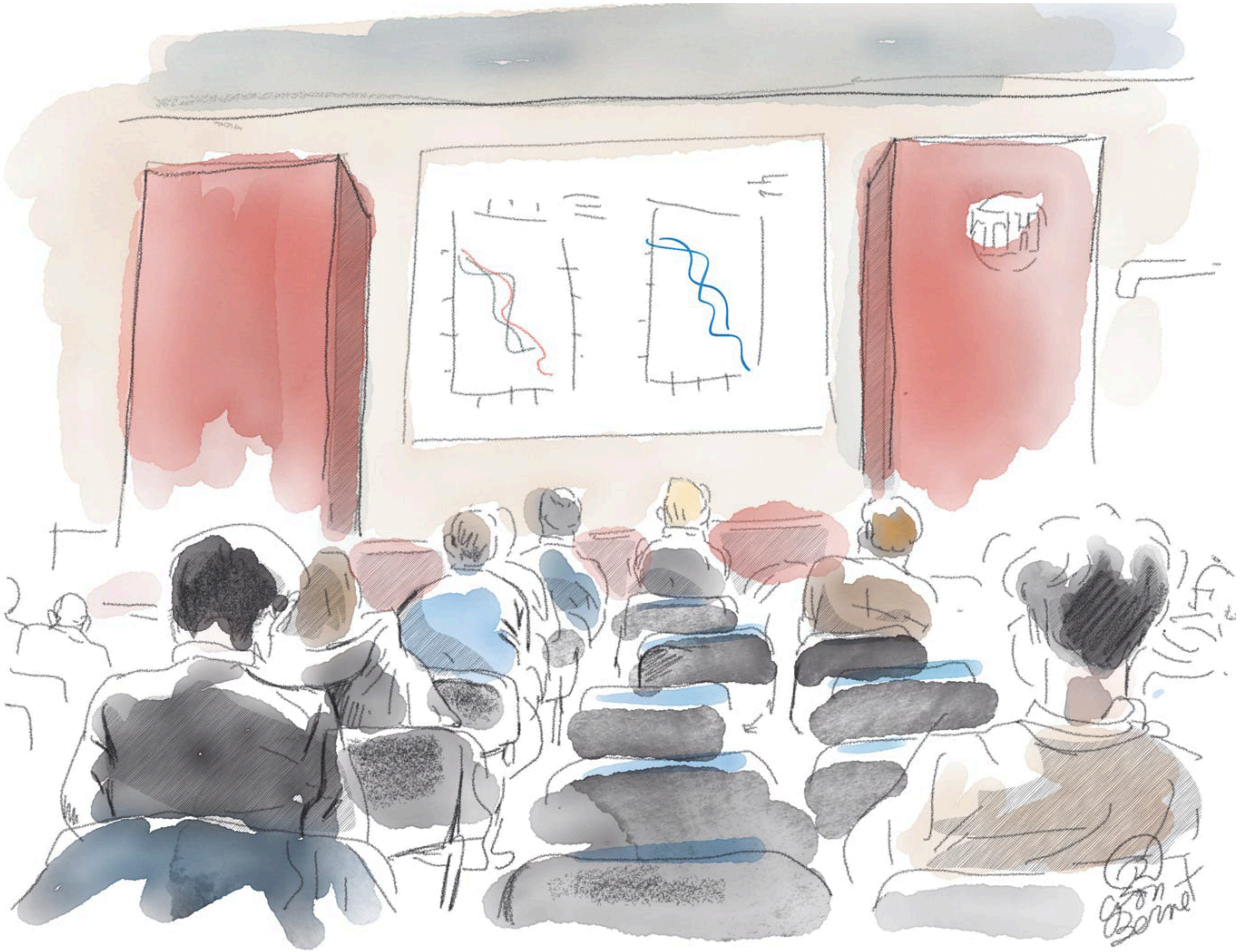
Electroweak Experimental Summary and Highlights



56 splendid EXP talks, several hundreds of experimental results presented, very dense Moriond - **Many apologies to those whose result(s) are not presented.**

57th Rencontres de Moriond

2023

Disclaimer

Splendid Talks by all young Scientists, many apologies for not summarising them here!

Experimental ‘EW’ Landscape

- LHC has a clean and well calibrated dataset of ~140 fb^{-1}, still numerous results from Run-2… Run 3 with ~40 fb^{-1} in 2022 is ramping up, results shown here for the first time!

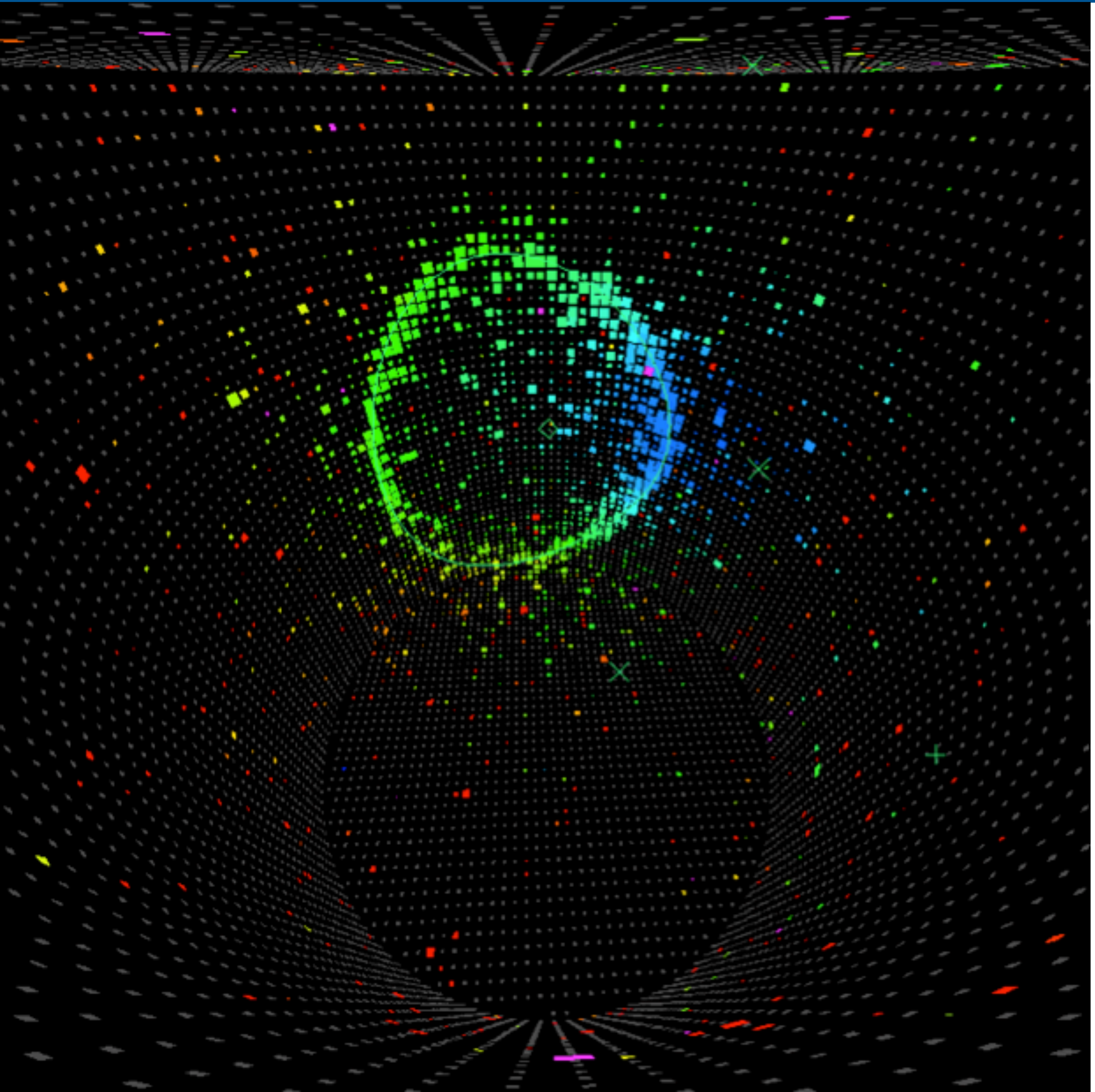
- Super KEK-B and Belle II world’s highest instantaneous luminosity (4.7x10^{34} $cm^{-2}s^{-1}$) 360 fb^{-1} at the Y(4s) in 2019-22, corresponding to 387M $B\bar{B}$ pairs - BES also taking data

- Neutrino experiments are not waiting for the next generation (Hyper K, Dune, JUNO, Legend, CUPID, nEXO, etc…) with a thriving flurry of experiments covering a broad Neutrino program!

- New generation Xenon DM searches delivering new results (Xenon nT, Lux Zeppelin, PandaX). Next generation in preparation Darkside 20k,

- Precision from low energy observables: nEDM, pEDM, eEDM, g-2 of muon, etc…

The Neutrino Physics (and Astrophysics)



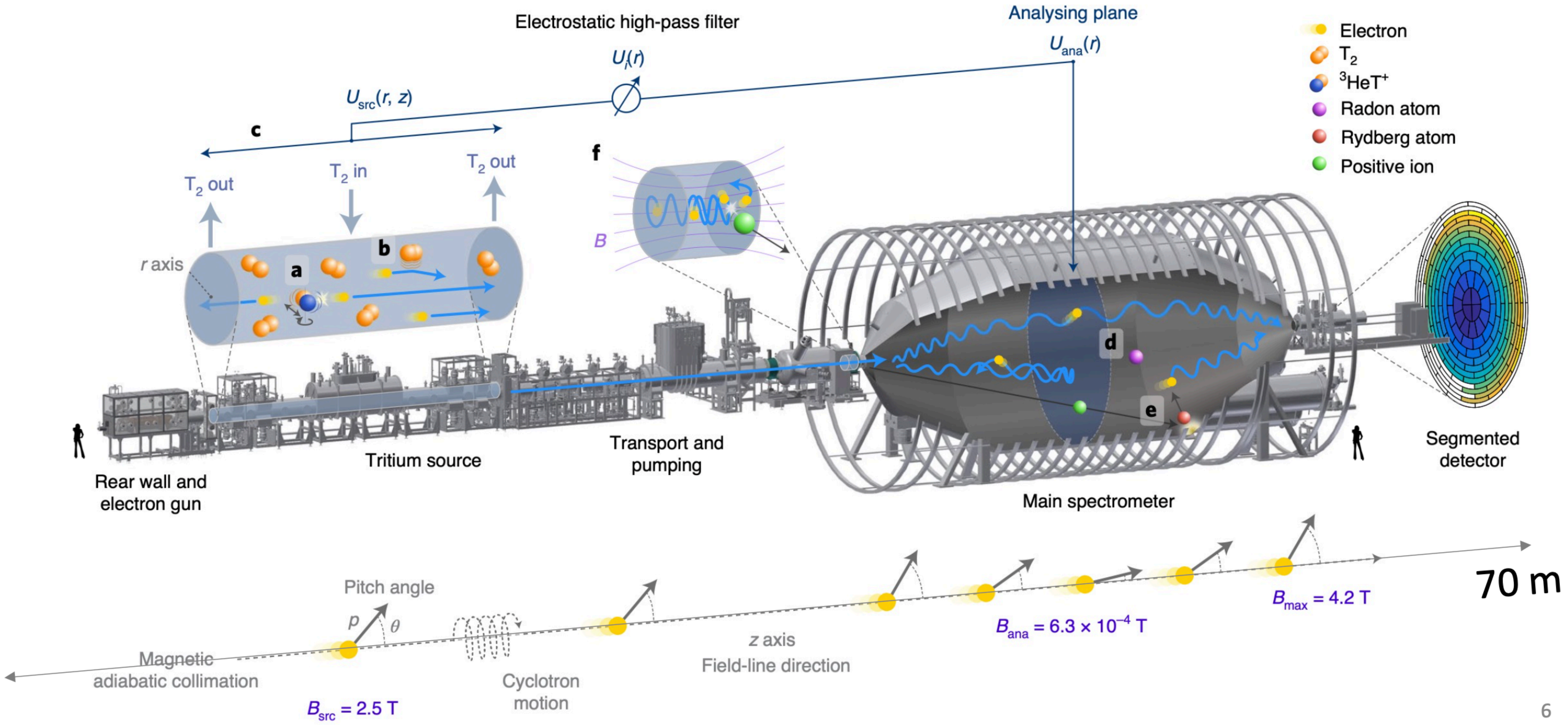
- Mass ordering
- Absolute neutrino mass
- Is the 3 flavour paradigm failing? Are there sterile neutrinos?
- Is there CP violation in the neutrino sector
- Is the neutrino a Majorana particle?
- Do we understand neutrino mass effects?
- Ultra high energy neutrino physics!

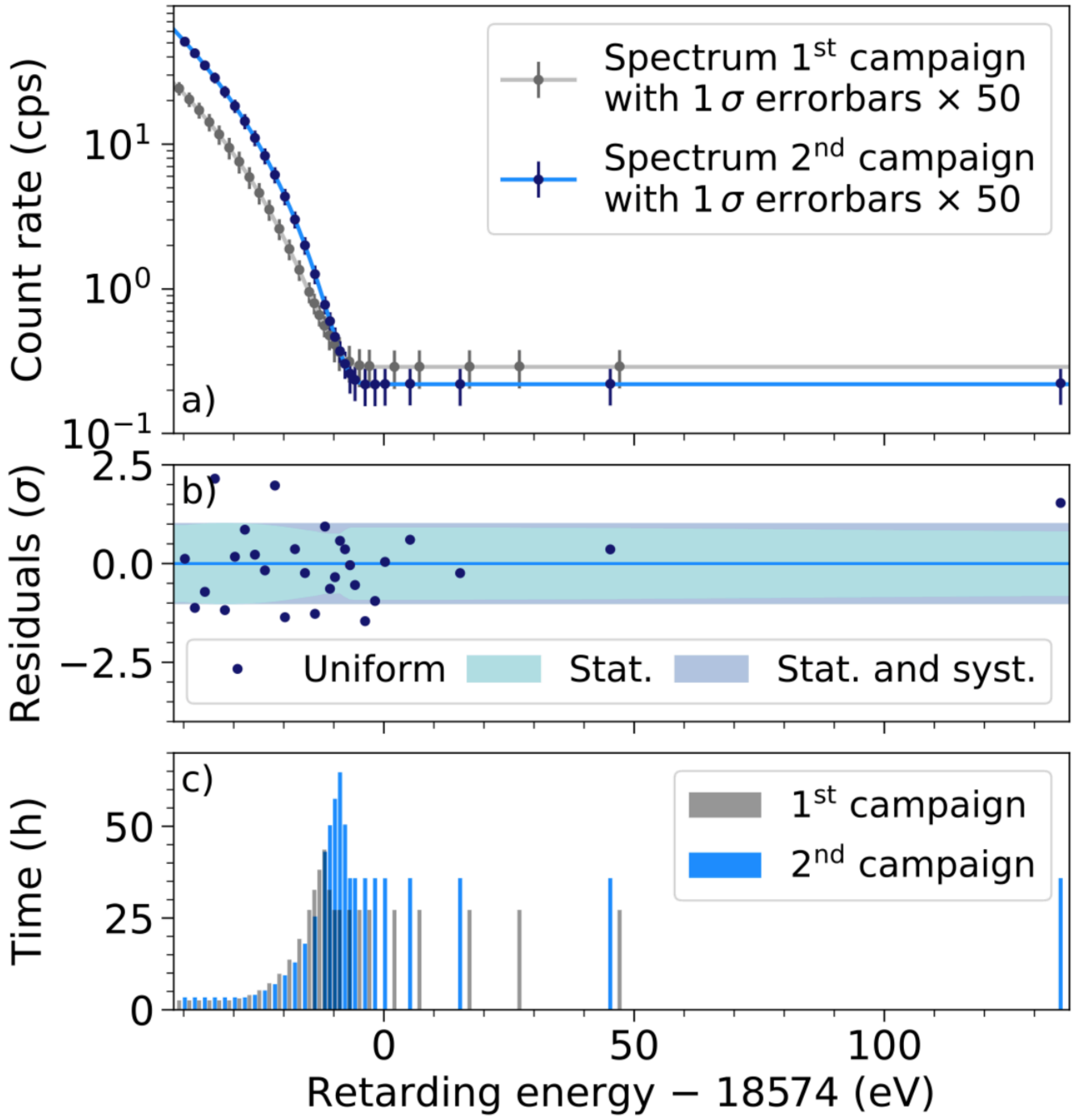
… and Anomalies (reactor - including 6 MeV bump, Short baseline, Gallium)!

Thierry Lasserre

Absolute Neutrino Mass

KATRIN Experiment





Data analysed with first two data taking campaigns in 2019
(one order of magnitude more data already taken)!

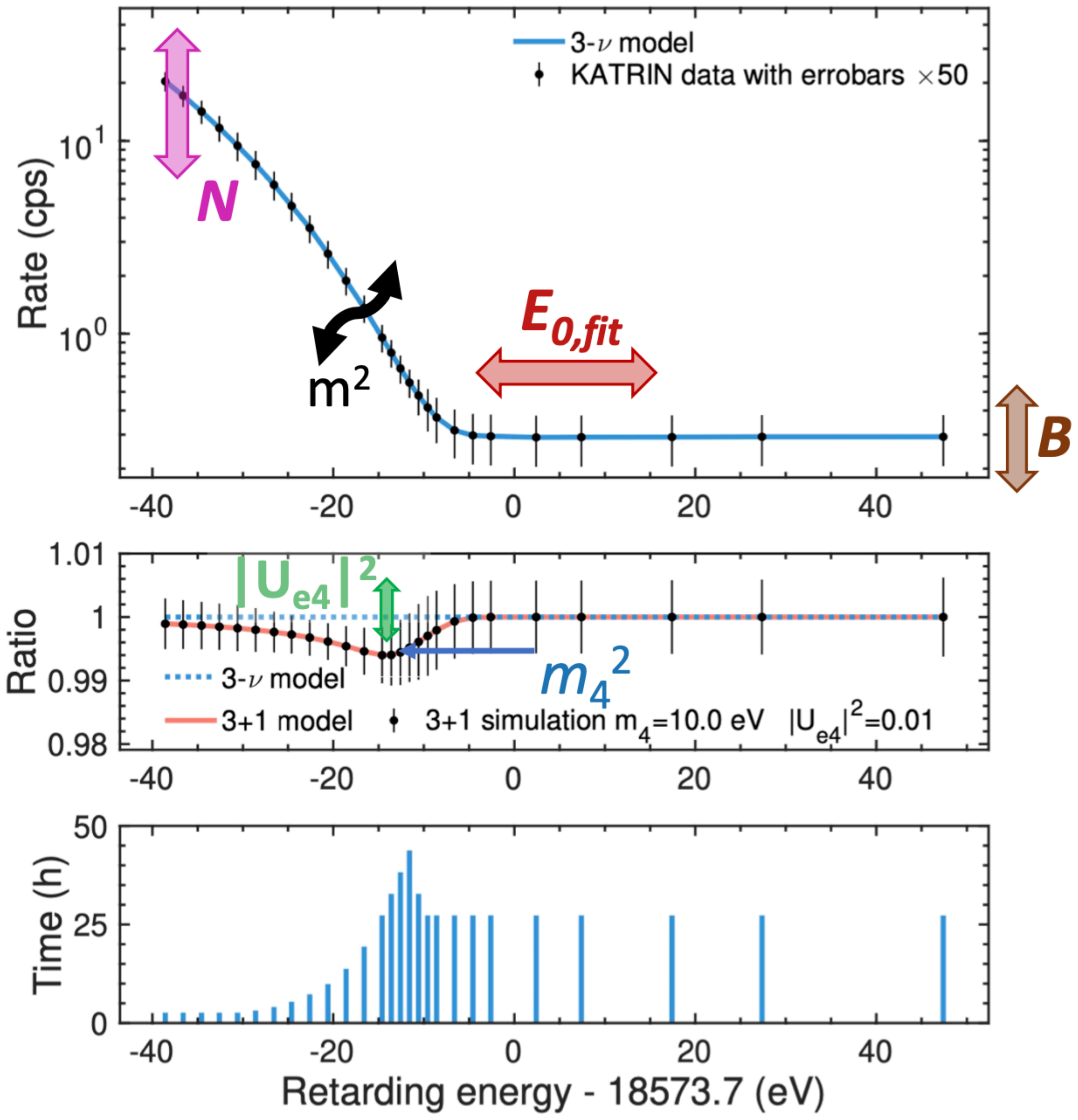
Absolute upper bound on neutrino mass!

Combined result: $m_\nu < 0.8$ eV (90% CL)

Limit dominated by statistics

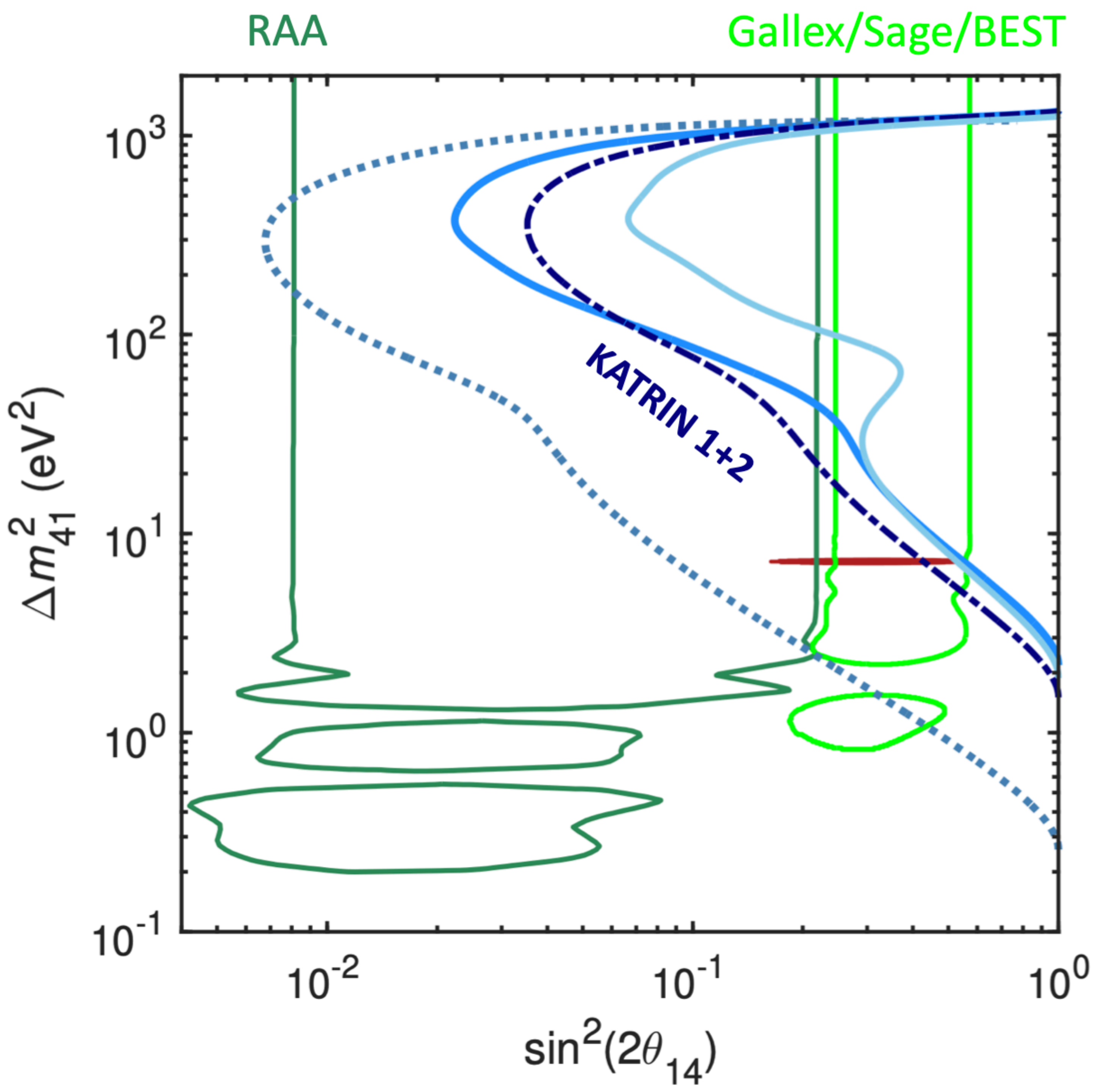
Absolute Neutrino Mass

KATRIN Experiment



Use KATRIN as short baseline and search for sterile oscillations through spectrum deformations!

Excludes in part Gallium anomaly



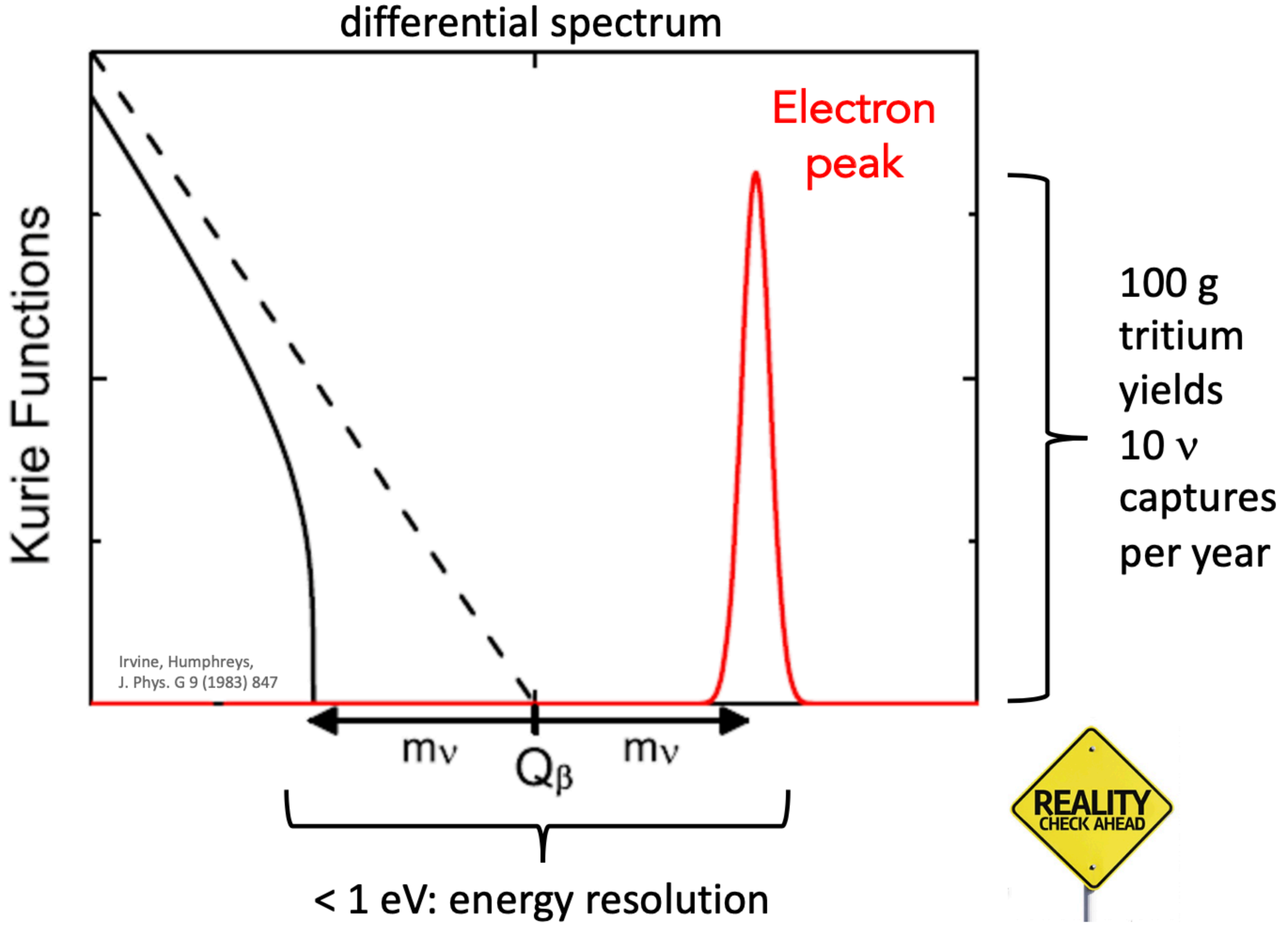
Can only look at huge over densities of relic neutrinos!

Also dream big… !!!

Cosmologic Relic Neutrinos

Through Inverse Beta Decay

$$^3\mathrm{H} + \nu_e \longrightarrow\ ^3\mathrm{He}^+ + e$$



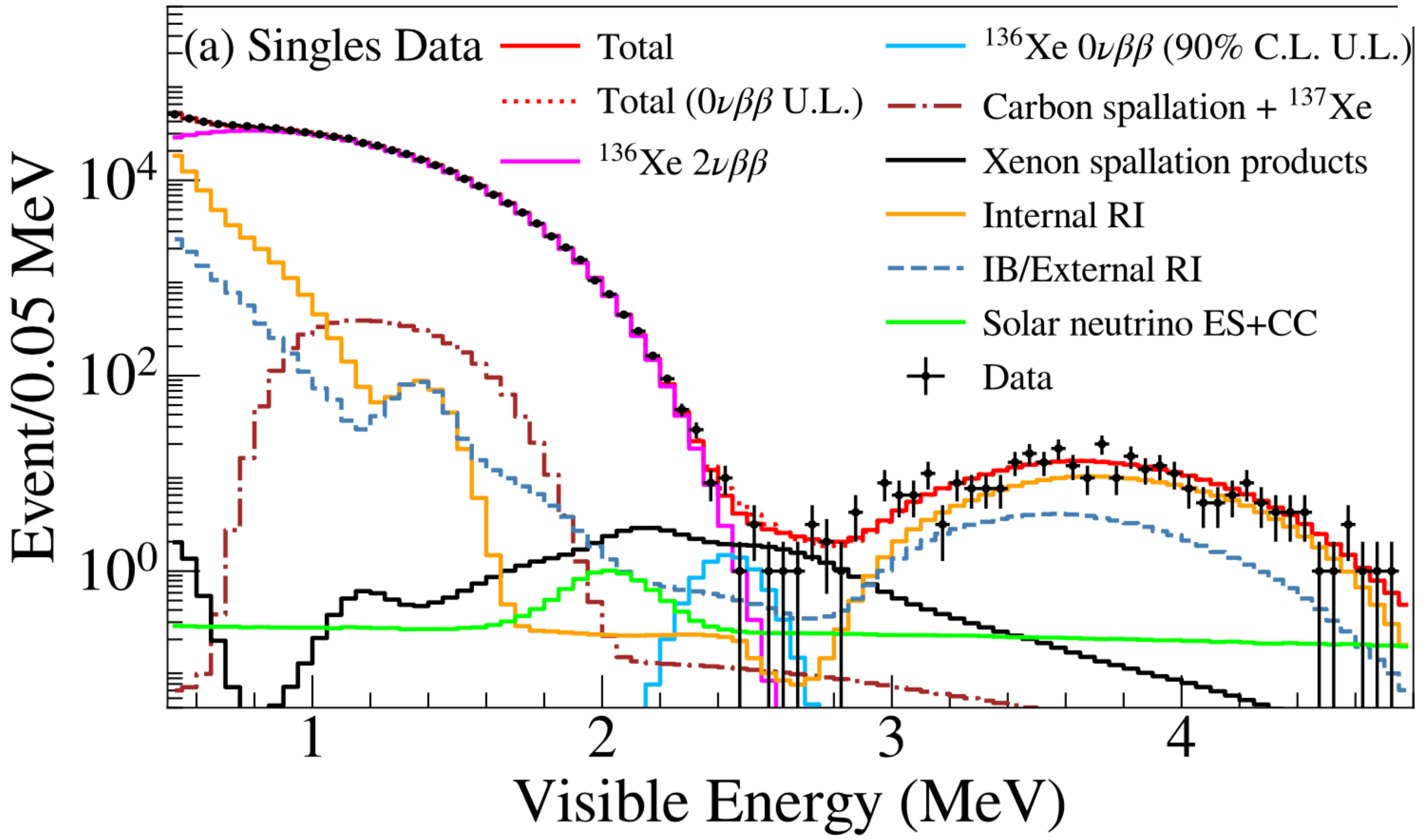
30 µg of tritium at any time

10^{-6} ν capture/year (depends on Dirac/Majorana nature)

KamLandZen

The largest amount of ββ nuclei.
Low BG by distillation and filtration of both Liquid Scintillator and Xenon.

$0\nu\beta\beta$ candidate data set

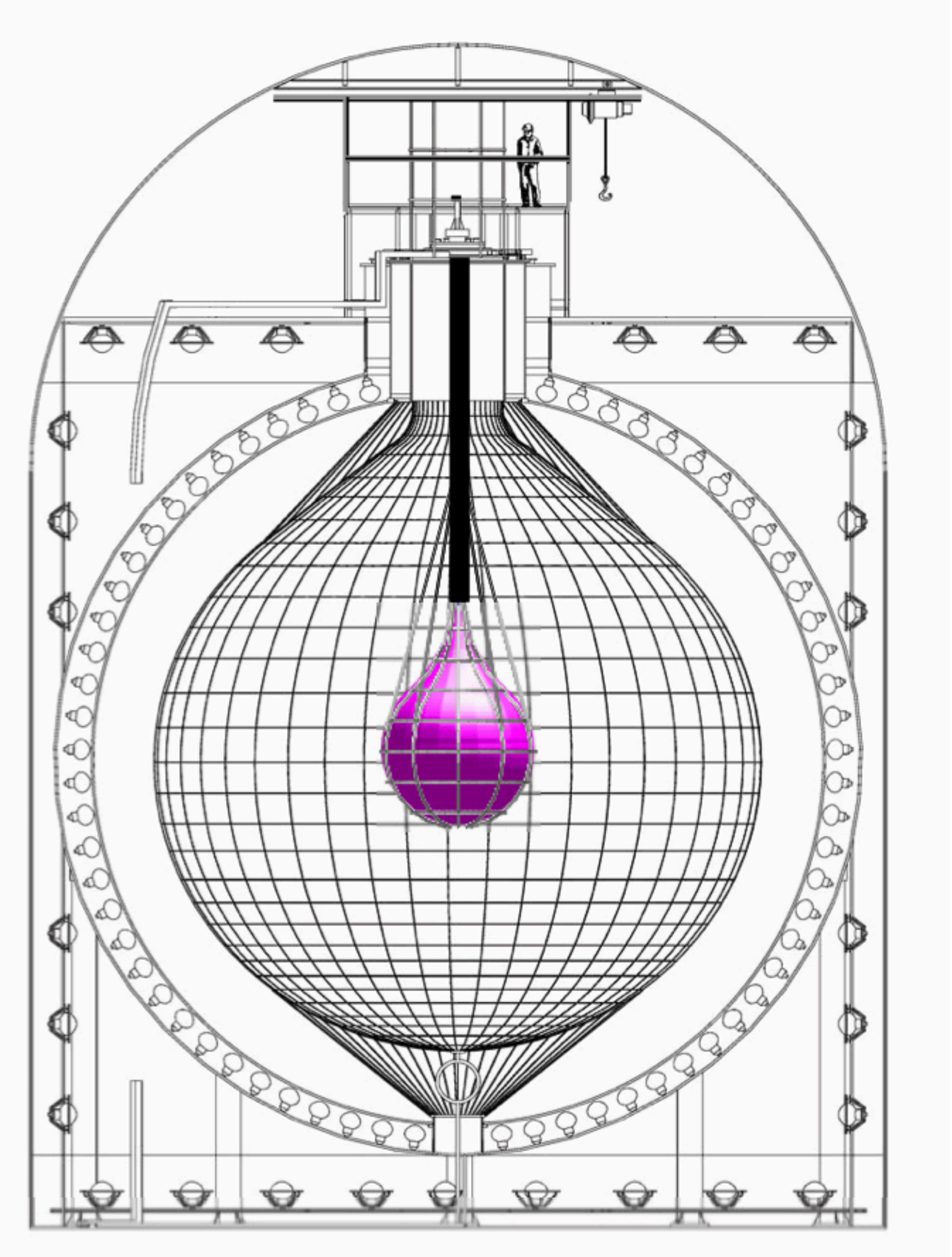


Limiting factor is the muon spallation of Xenon background.

$\langle m_{\beta\beta}\rangle < 36 - 156$ meV

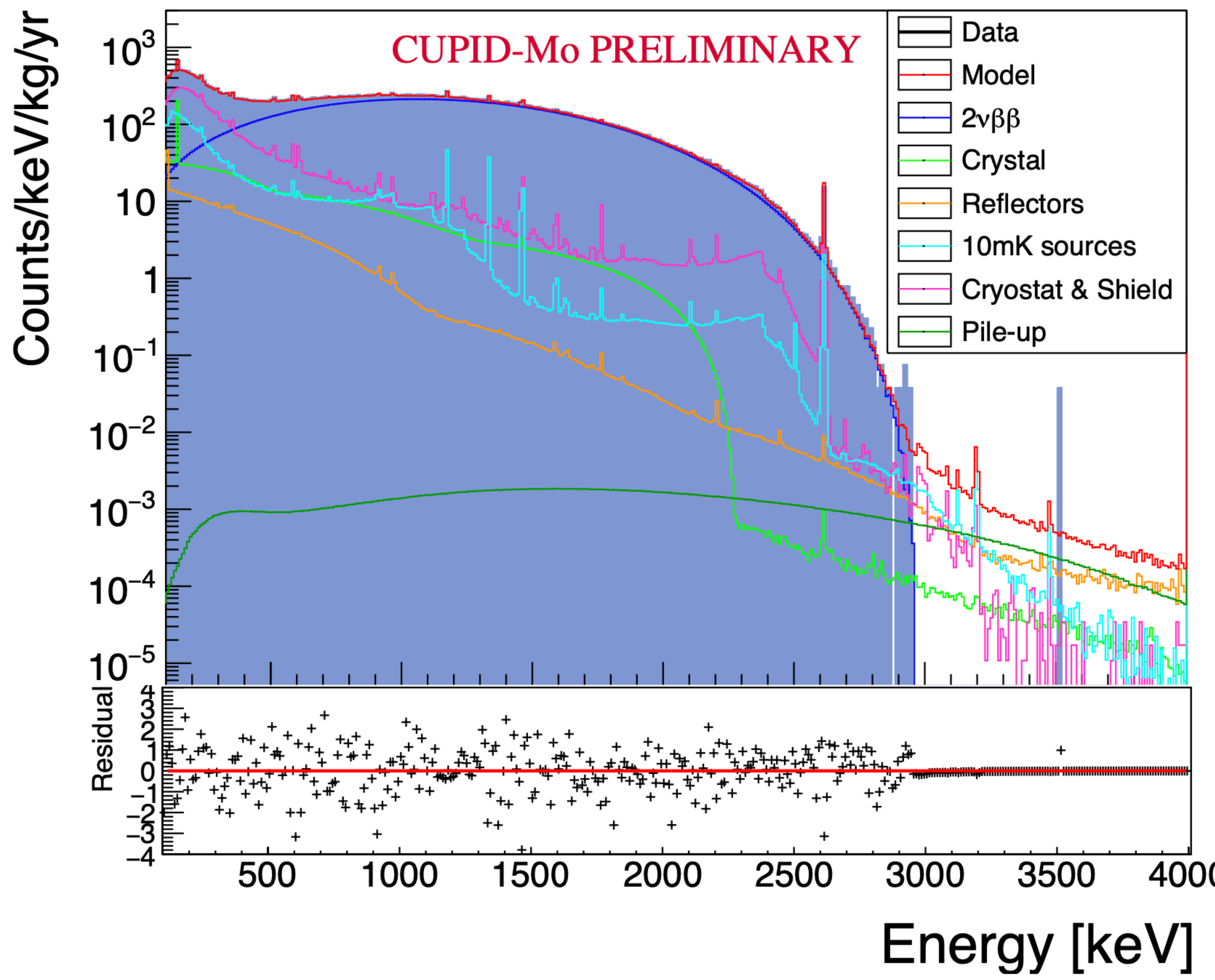
KamLAND-ZEN-1T: $\langle m_{\beta\beta}\rangle <$ ~20 meV

Mini-balloon Radius = 1.90 m
Xenon mass = 750 kg
Data taking started in 2019



Cupid-Mo

Cupid 100Mo Scintillating and cryogenic bolometric technology (evolution from CUORE 130Te with PID and light to reduce backgrounds)



Rached CUPID specs! Lowest background 0vββ decay experiment!!

$\langle m_{\beta\beta}\rangle < 280 - 490$ meV

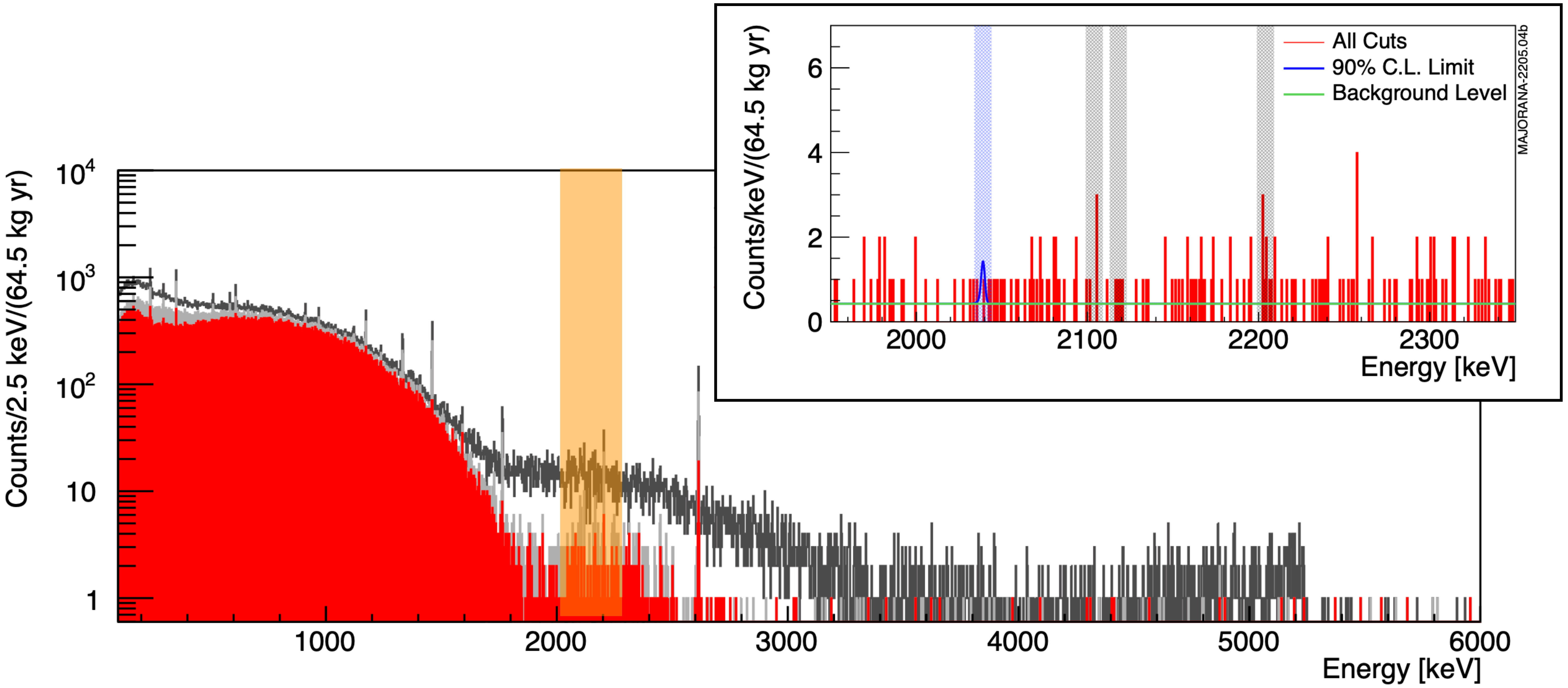
CUPID sensitivity: $\langle m_{\beta\beta}\rangle < 12 - 20$ meV

Absolute Mass and Majorana Nature

Majorana Demonstrator

76Ge in High Purity Ge detectors (important for the desing of LEGEND) at the Sanford Underground Research Facility

Reached an exposure of ~65 kg-yr



MAJORANA result ⟨mββ⟩ < 113 – 219 meV   LEGEND expected ⟨mββ⟩ < 9 – 21 meV

Also probe of Wave Function Collapse models

Spontaneuous wave function collapse models through a non-linear term in the Schrodinger equation (through a 'noise field' e.g. gravity through Diosi and Penrose models)

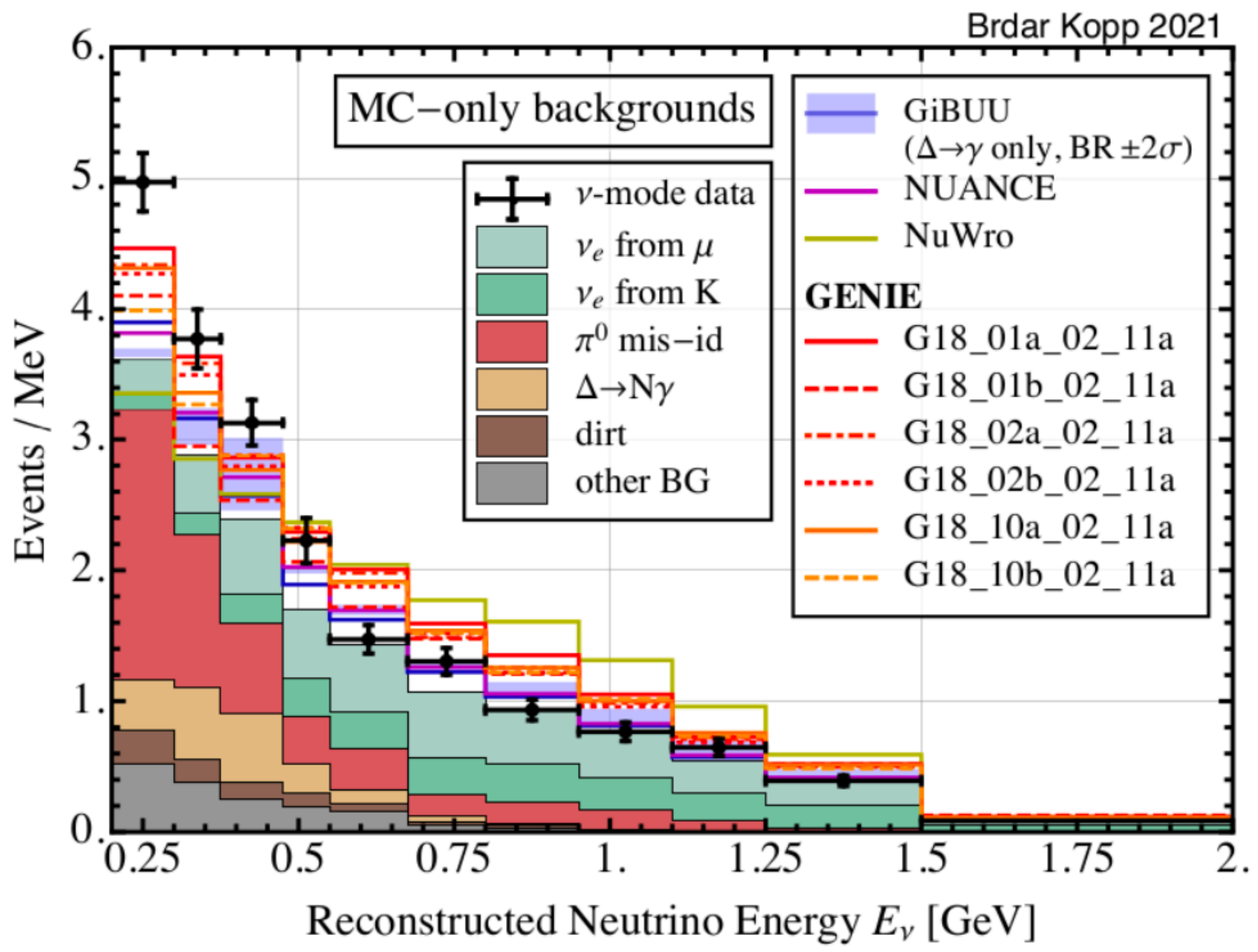
Wave function Collapse would induce an observable EM radiation from charged particles (of X-rays in this case).

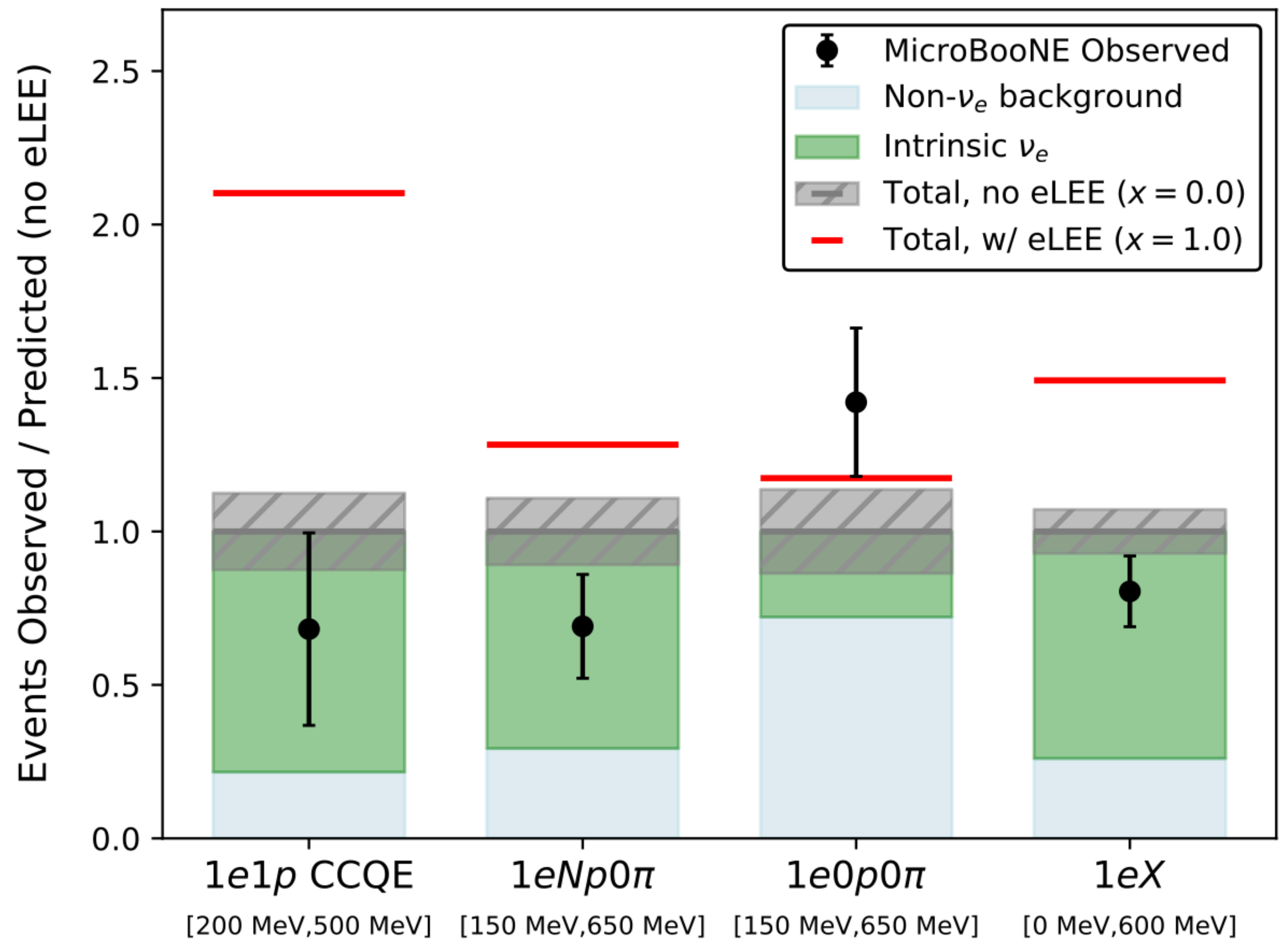
Germanium already sued in GS experiment, MAJORANA further constrains possible models of WFC (S. Donadi et al., Nature Physics)) !

Short Baseline, Reactor and Gallium Anomalies

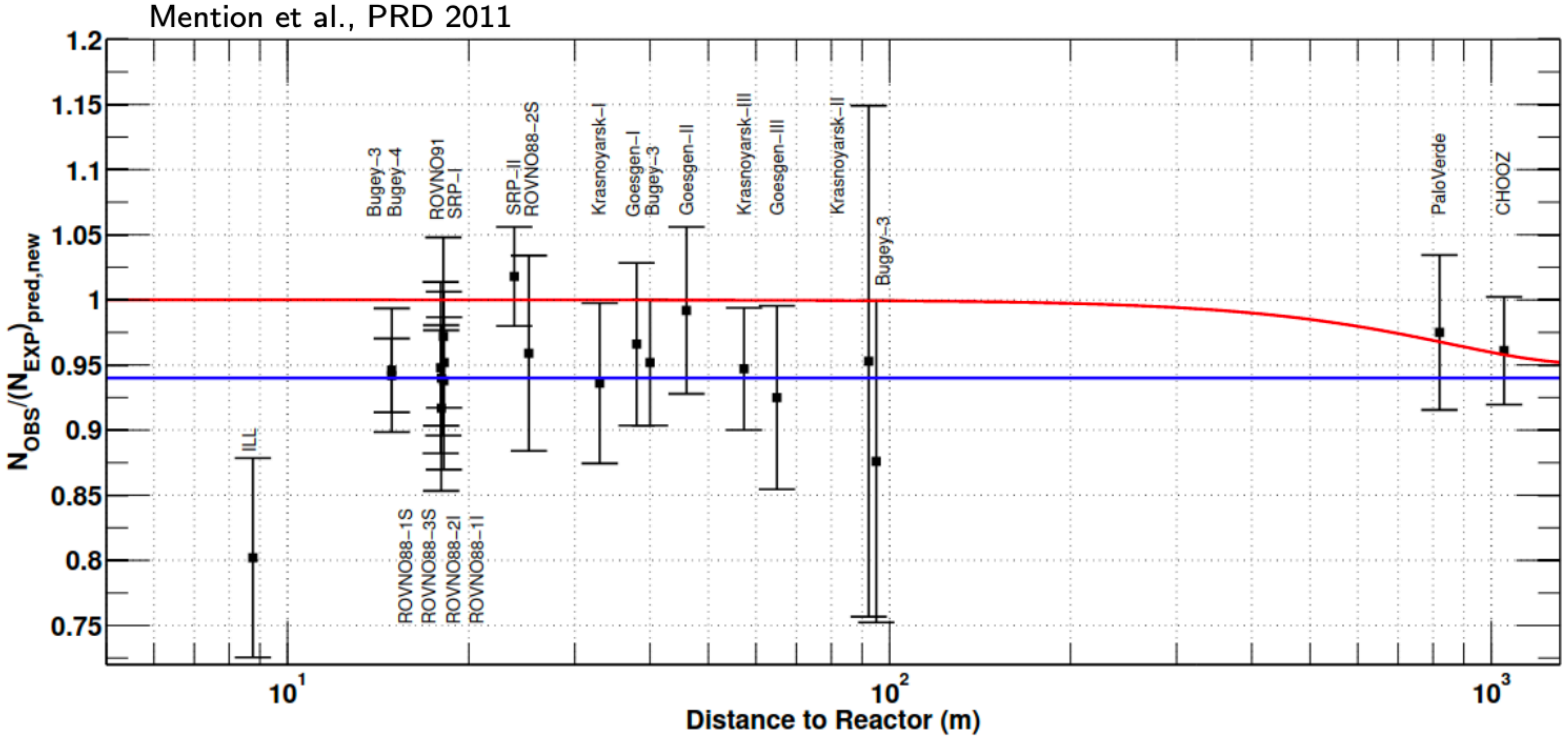
Short baseline anomaly

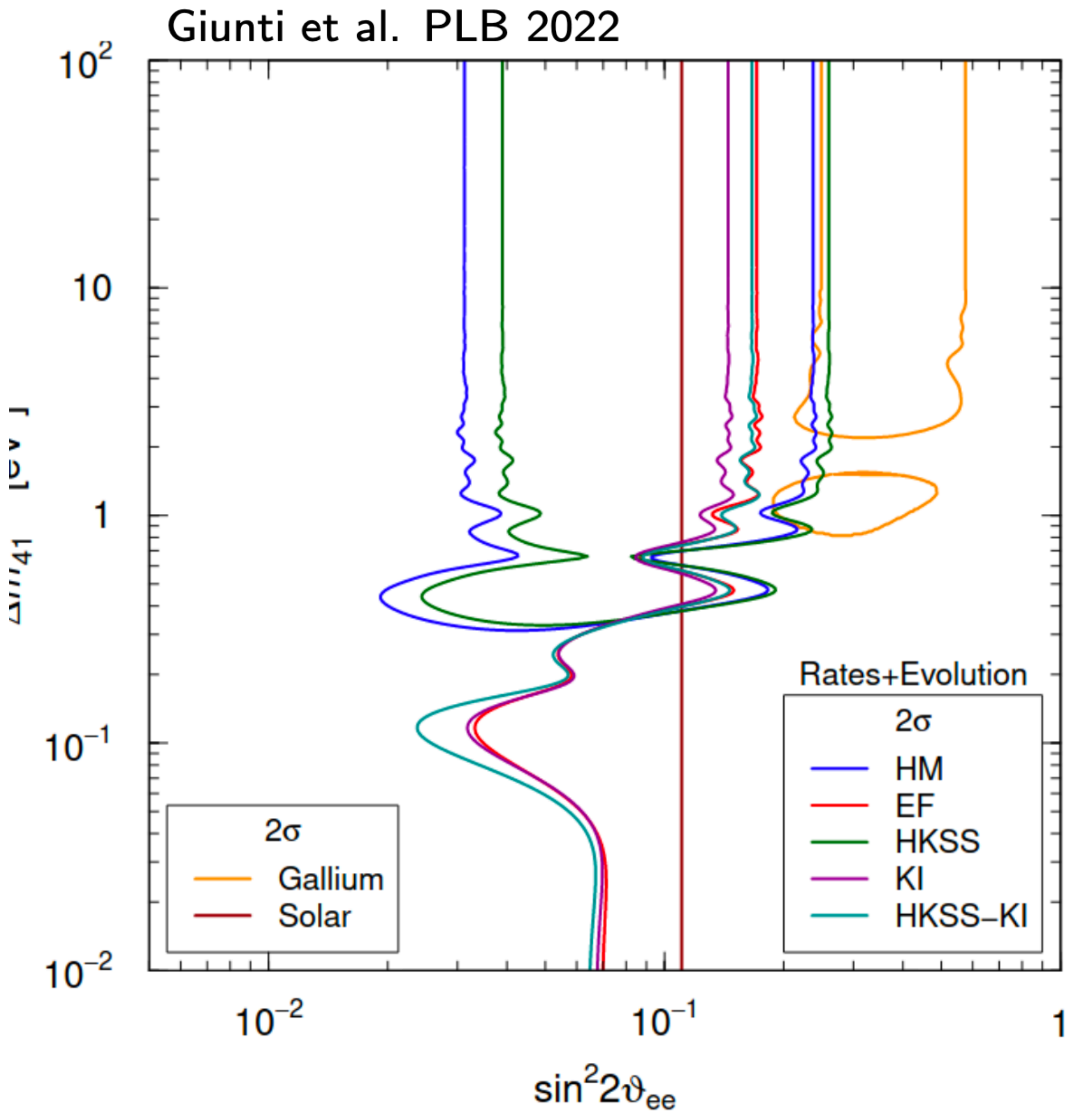
- Backgrounds re-evaluation (e.g. $\Delta \to N\gamma$)
- No excess seen so far in Microboone (other short baseline experiments ongoing)
- Sterile neutrino interpretation excluded by muon-v disappearance (MINOS, SK, IceCube, etc…)





Reactor anomaly





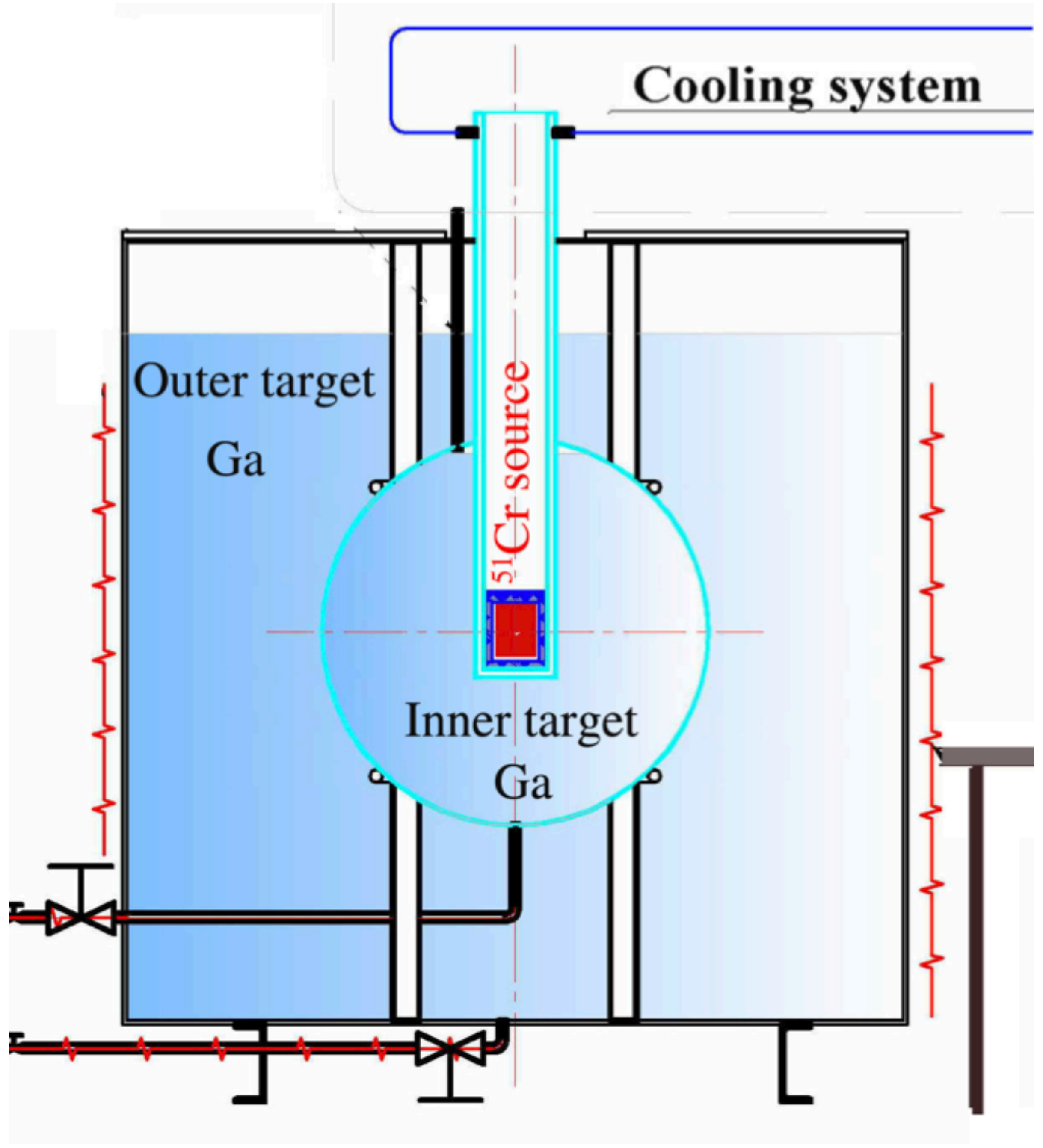
Recent analysis of the reactor deficit anomaly in the light of several flux models shows that:

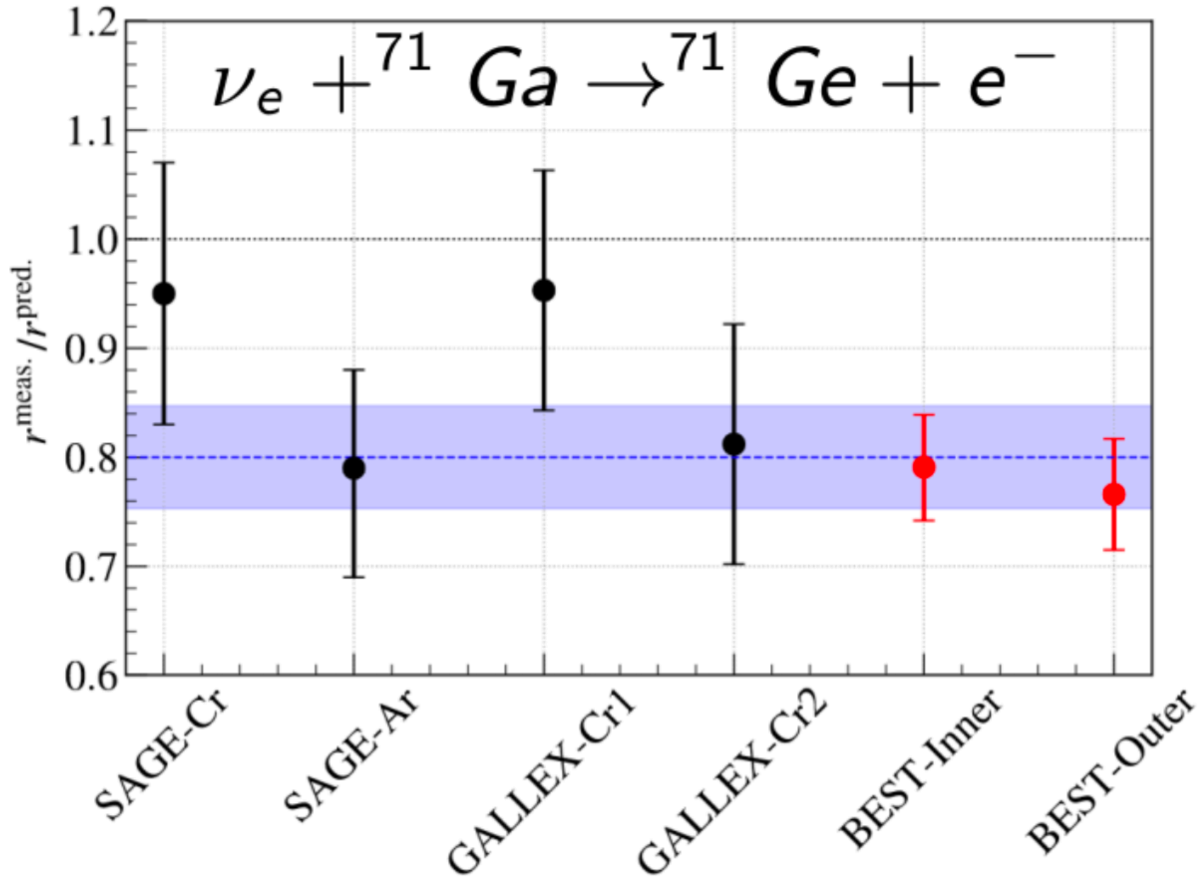
- Anomaly not very significant
- In tension with the Gallium anomaly

Short Baseline Neutrinos and the Gallium Anomaly

Baksan Experiment on Sterile Transitions (BEST)

The Gallium Anomaly was originally from the GALLEX and SAGE experiments (aimed at solar neutrinos)





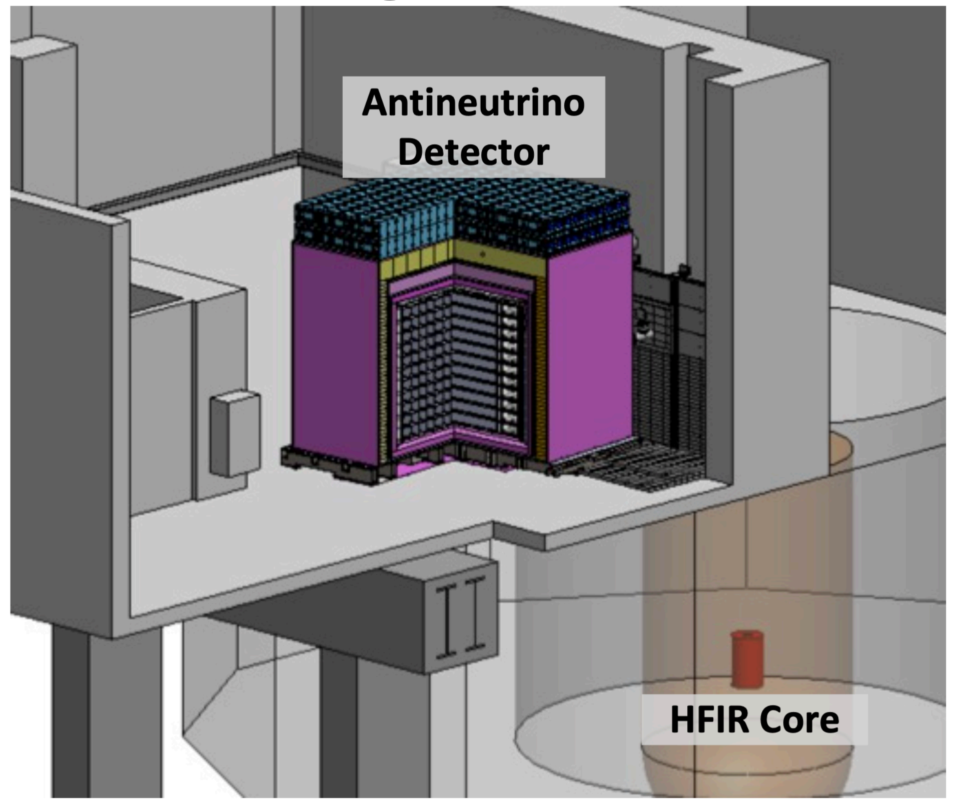
$$R = \frac{\text{measured}}{\text{predicted}} = 0.803 \pm 0.035 \Longrightarrow \gtrsim 5\sigma \text{ effect}$$

But absence of a clear oscillatory with distance - no smoking-gun evidence of oscillations in the Gallium data.

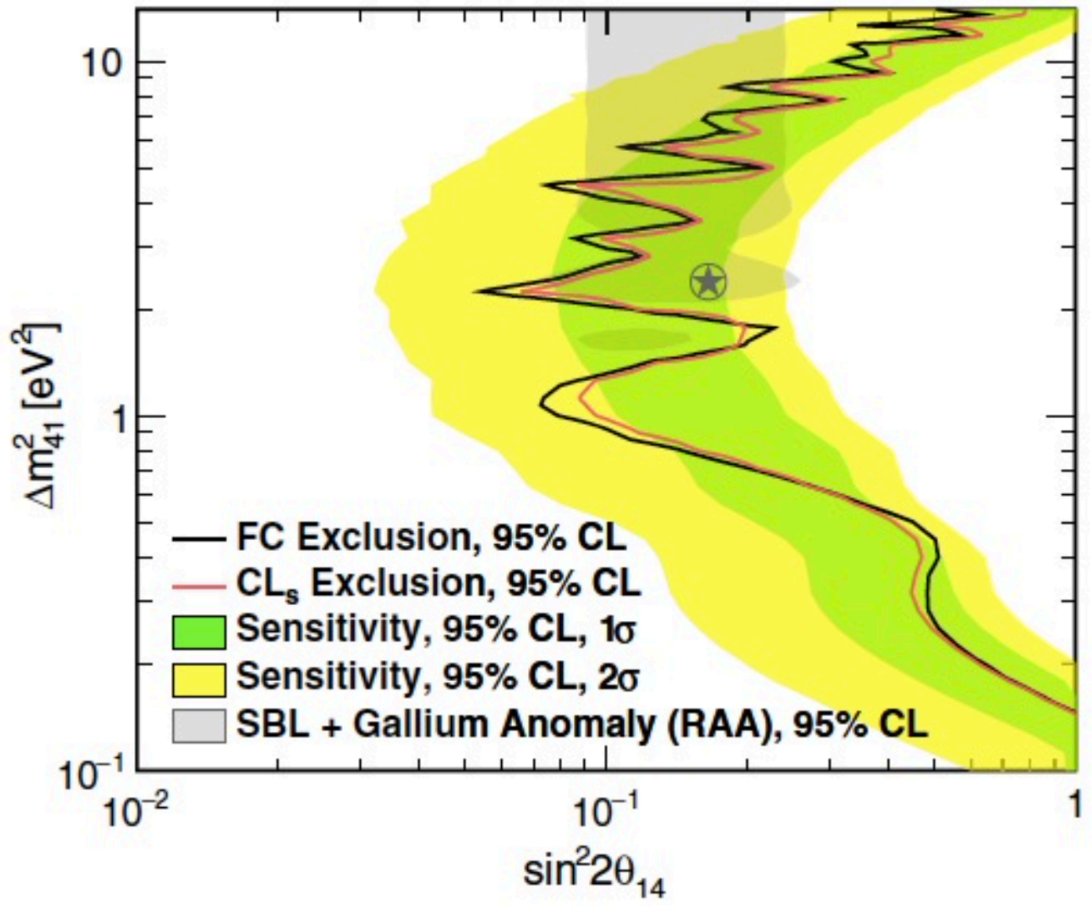
Precision Spectrum and Oscillation (PROSPECT)

On the High flux Isotope reactor (HFIR), Oakridge,

Optically Segmented Detector

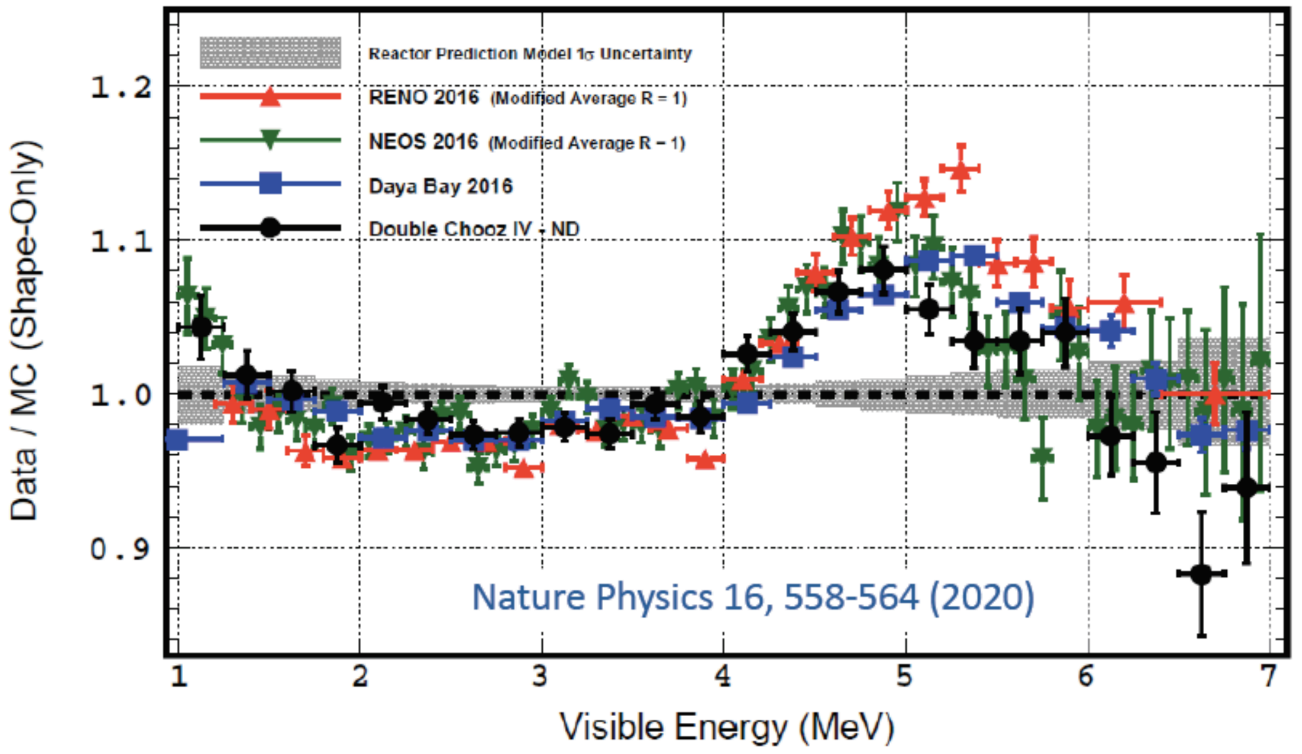


PRD 103, 032001 (2021)



Sterile interpretation of Gallium anomaly excluded at 98% CL

Precise measurements of spectrum to further check the ‘honourable mention’ anomaly - bump at 4-6 MeV

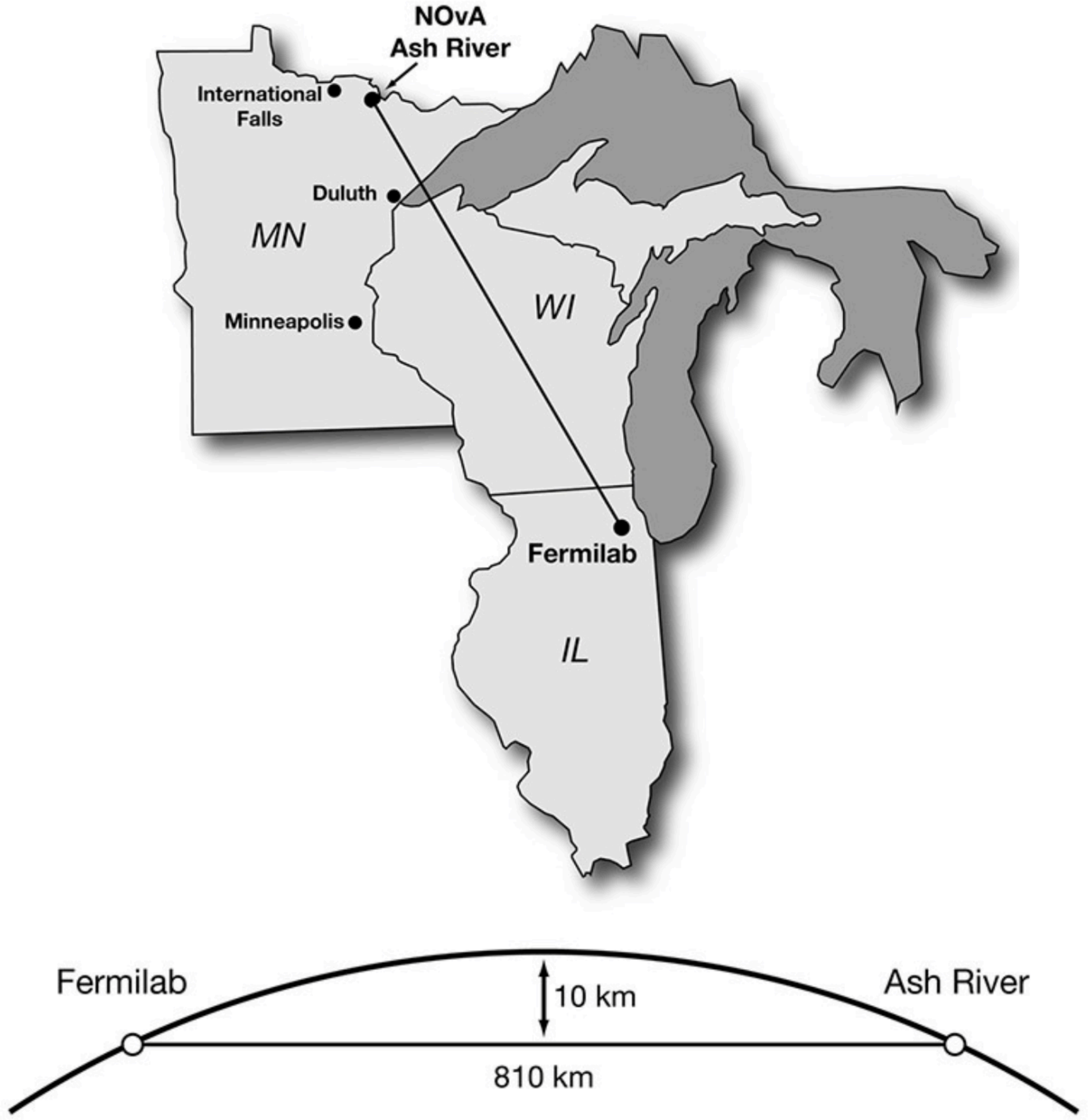


Accelerator Neutrinos

The current two main players ν_μ-beam experiments!

NOvA

Off Axis

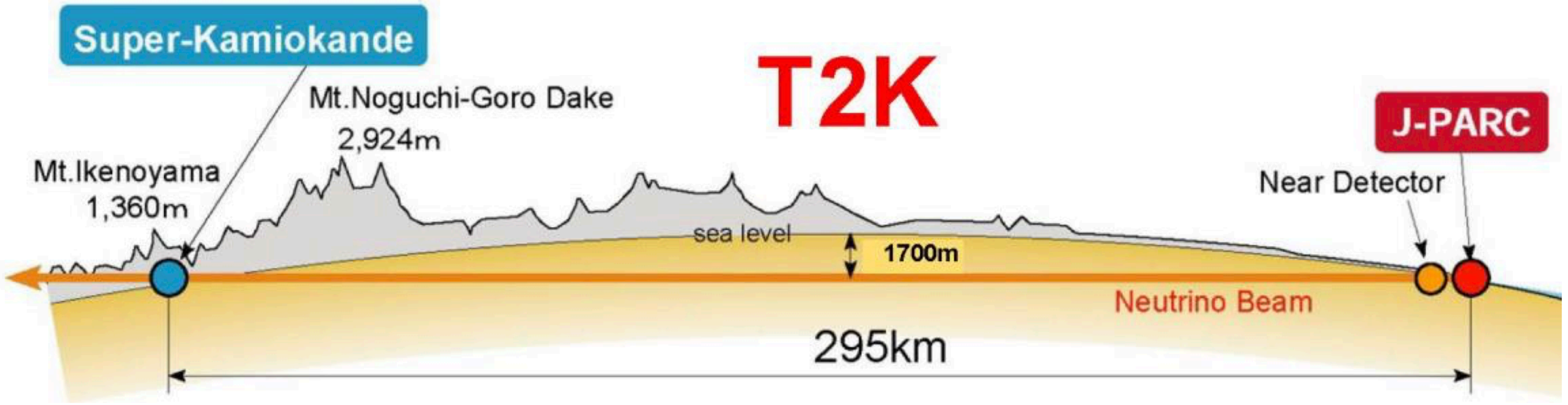


810 km/GeV - E 2 GeV - 0.8° off-axis

Improved sensitivity to mass ordering!

T2K

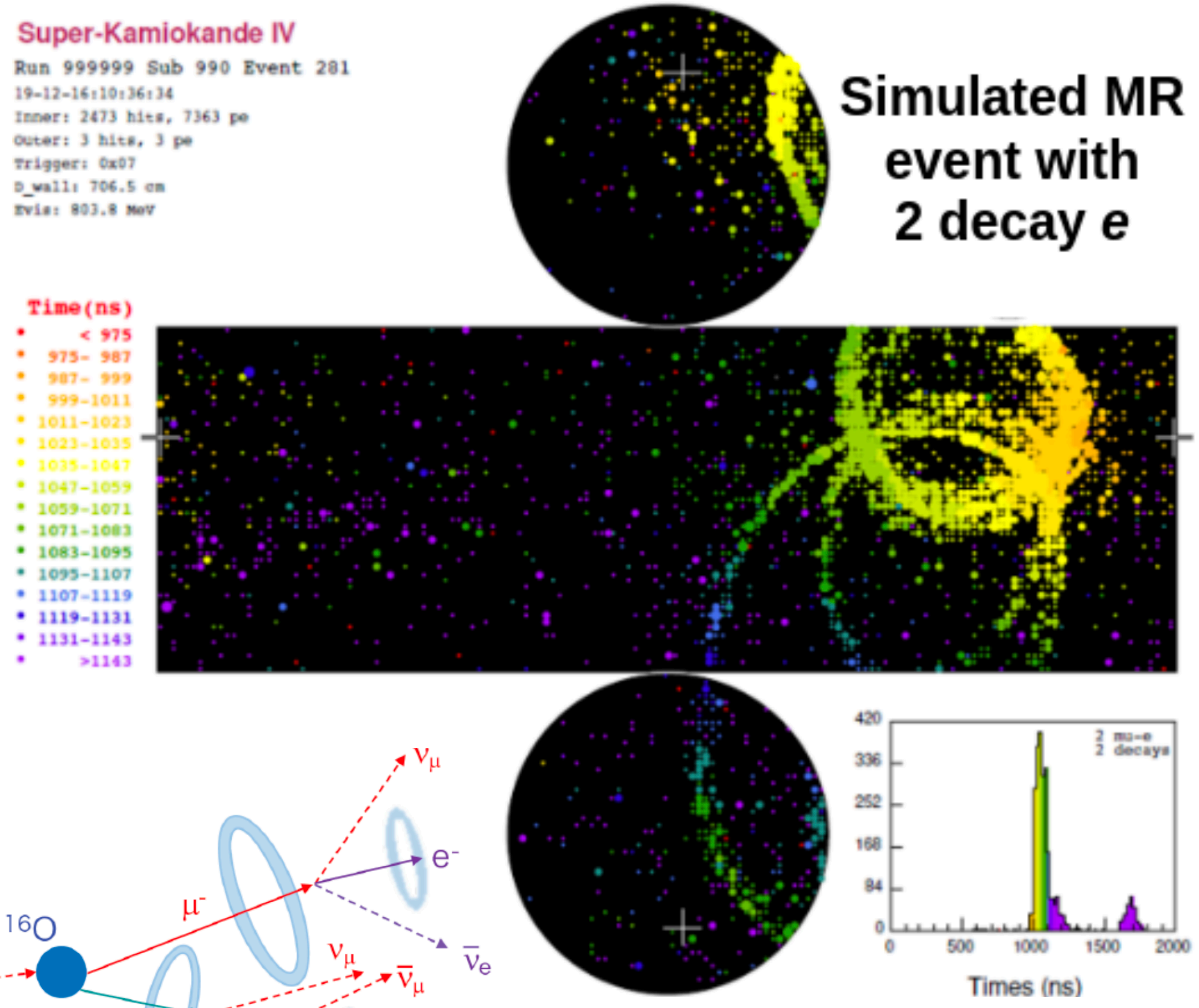
Slightly off axis

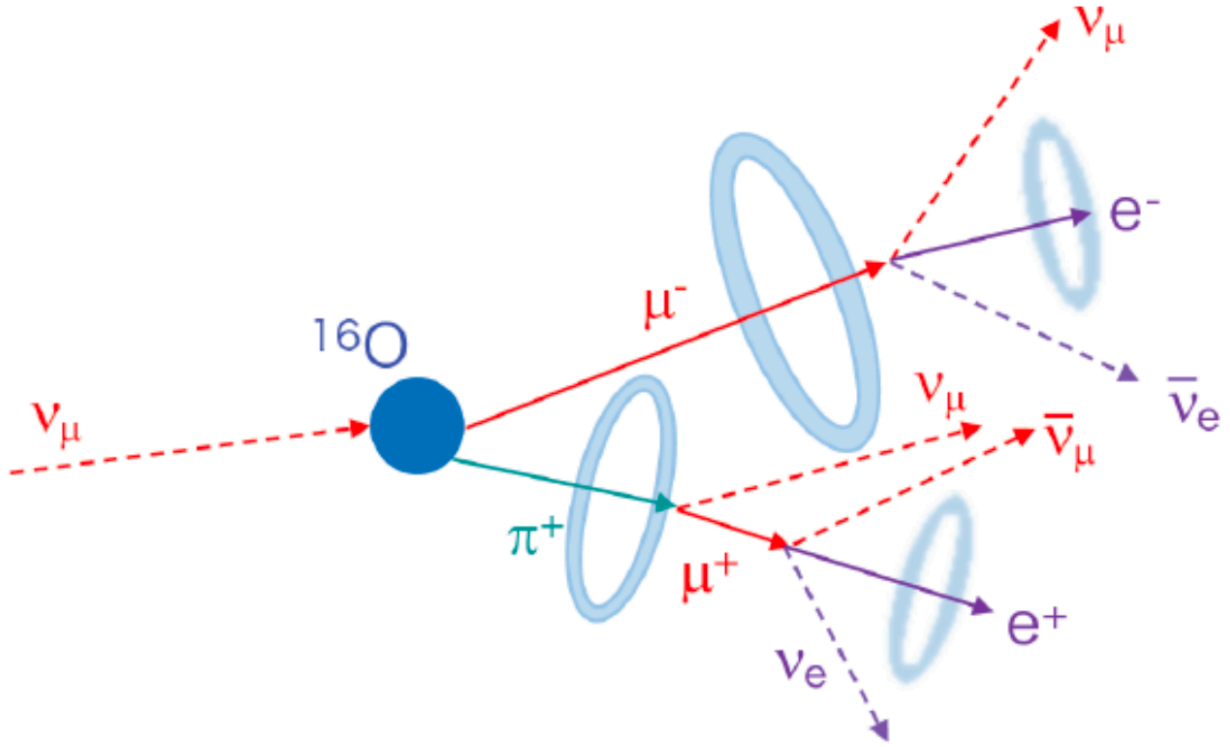


490 km/GeV - E 0.6 GeV - 2.5° off-axis

Accelerator Neutrinos

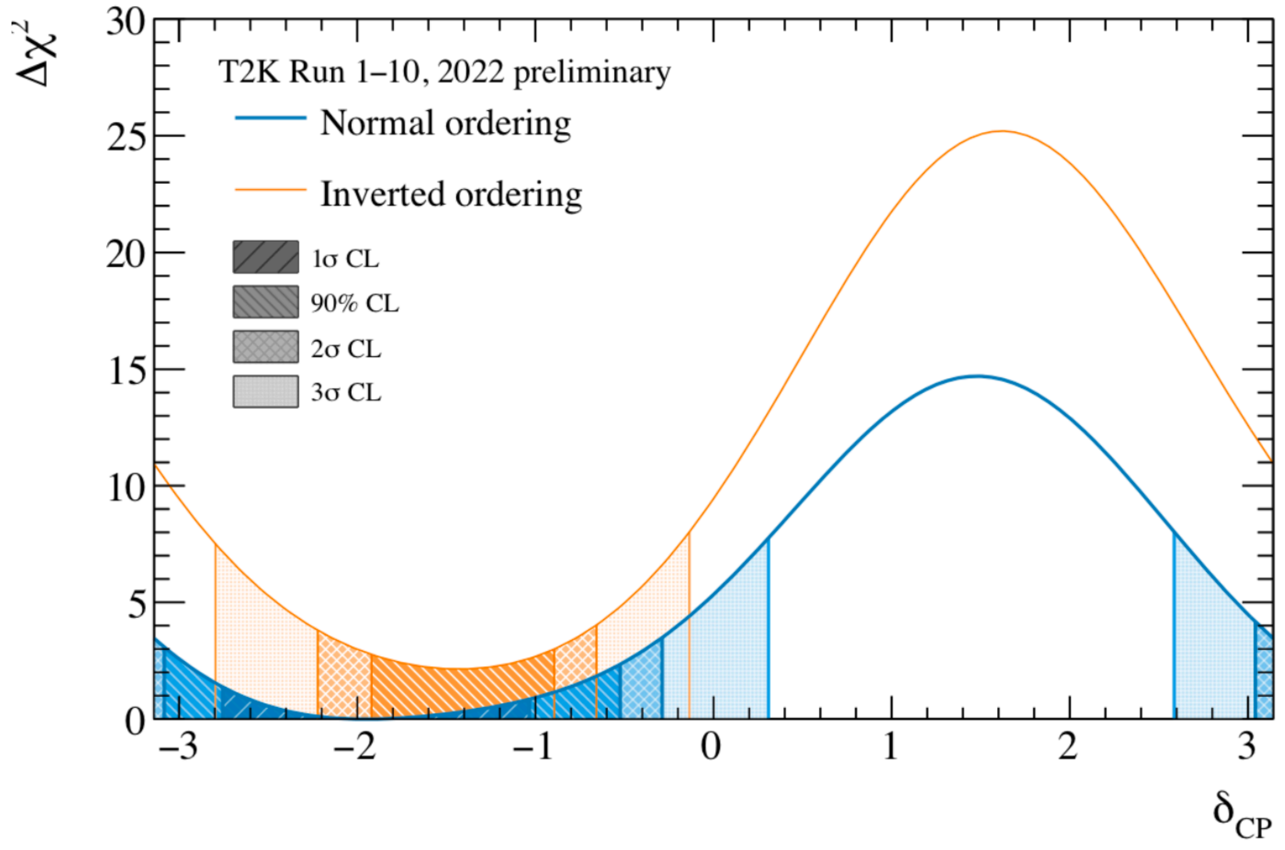
T2K





- New analysis on the ~ 36×10^{20} POT collected up to 2020
- New analysis (with the addition of multi-ring events from additional pions/decay products)
- Overall fit uses θ_{13} from reactor data (bayesian and frequentist analyses yielding consistent results), **slight preference for upper octant and normal ordering!**

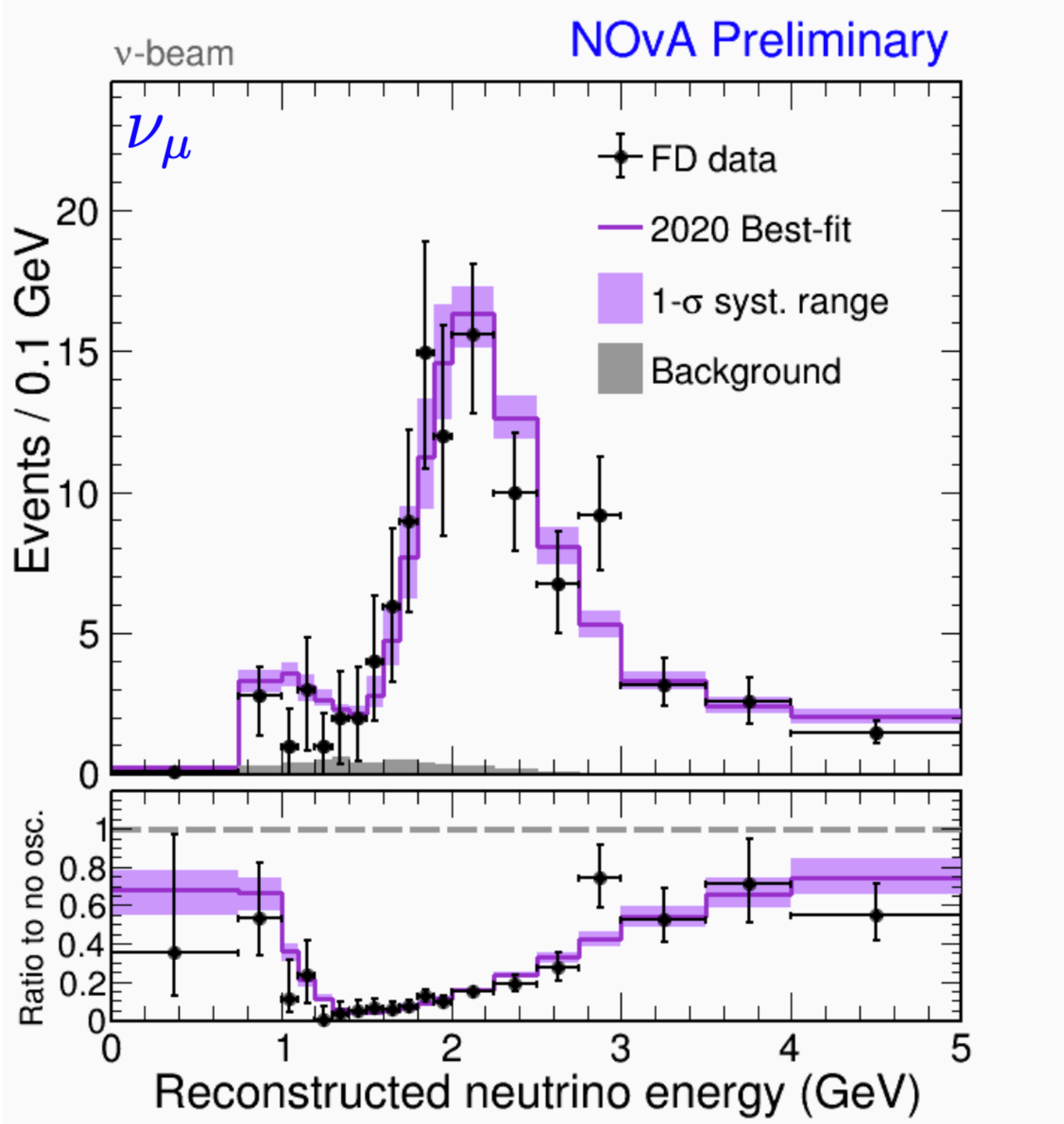
	$\sin^2\theta_{23} < 0.5$	$\sin^2\theta_{23} > 0.5$	Line total
Normal ordering	0.236	0.540	0.776
Inverted ordering	0.049	0.174	0.224
Column total	0.285	0.715	1.000

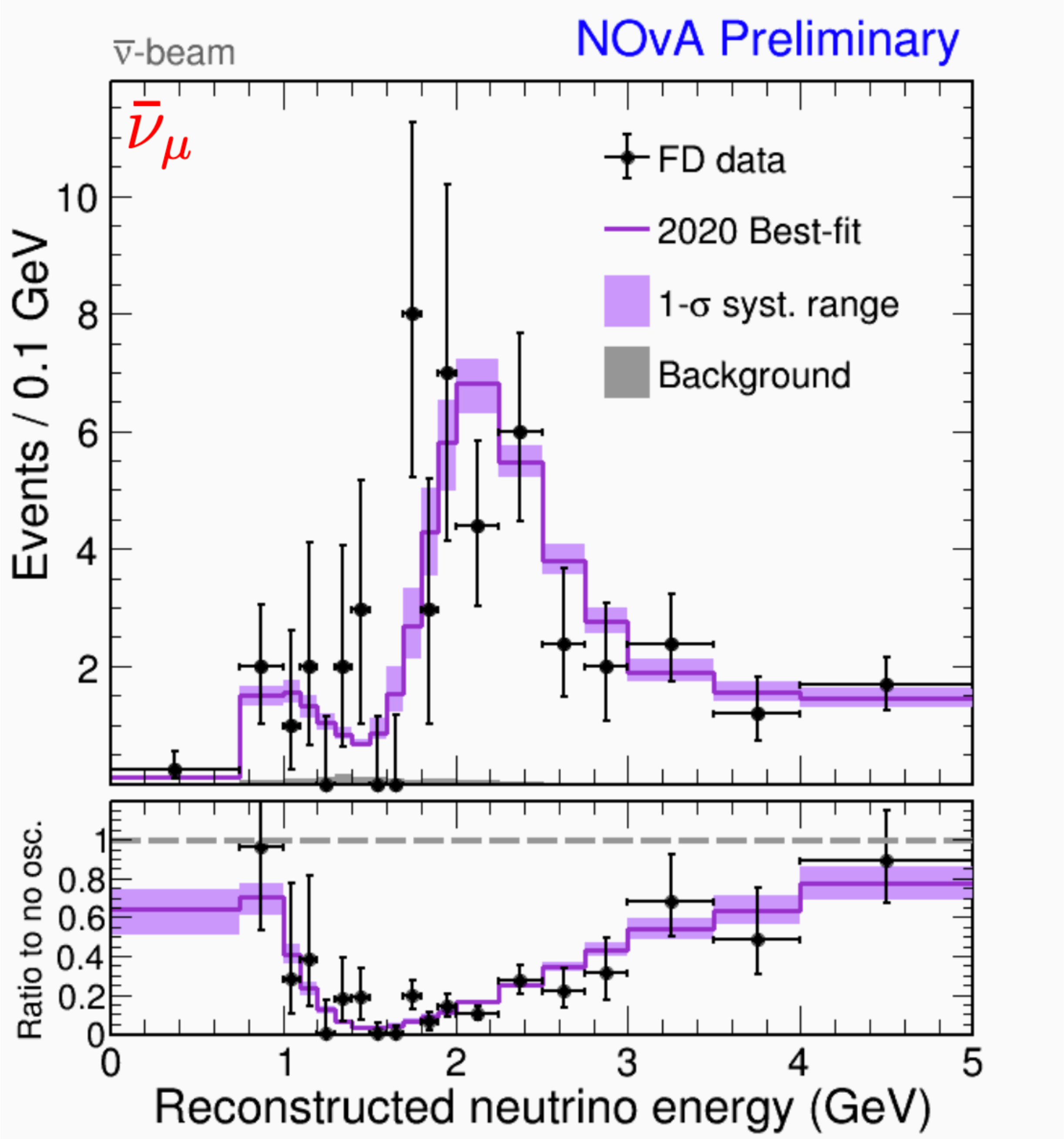


δ_{CP} best fit at -2.18 (-0.694π), CP conserving values 0 and π are outside of 90% CL intervals

Accelerator Neutrinos

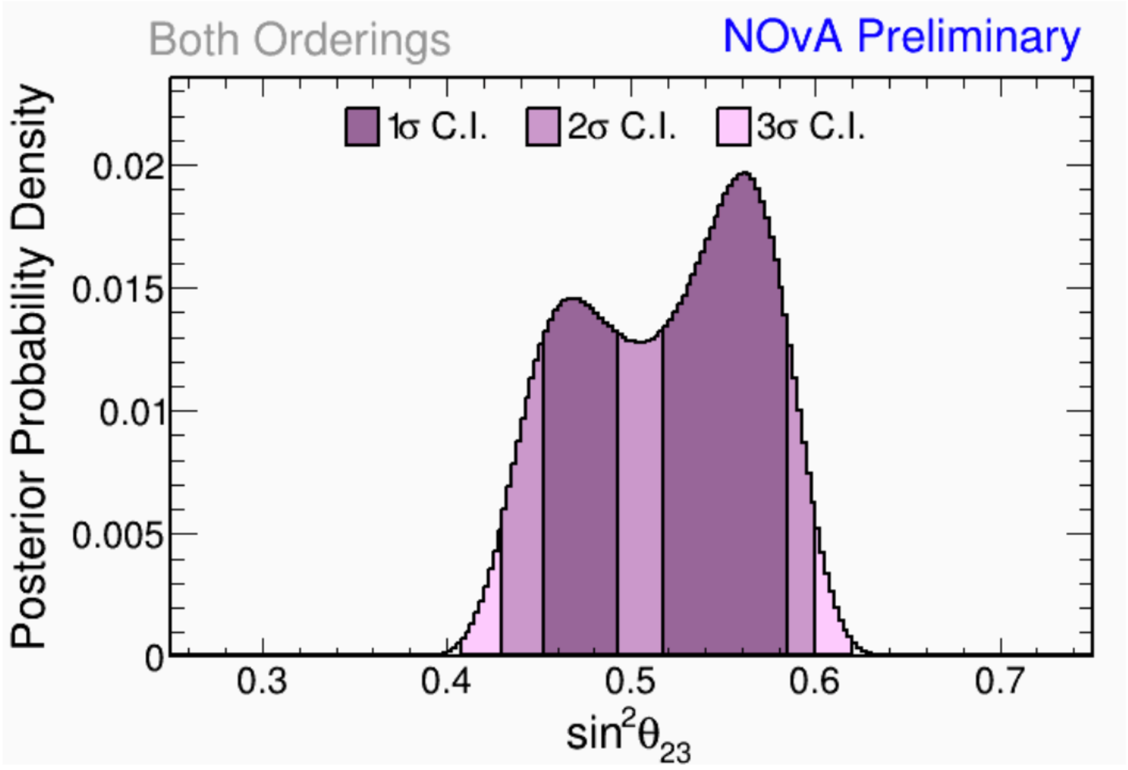
NOvA

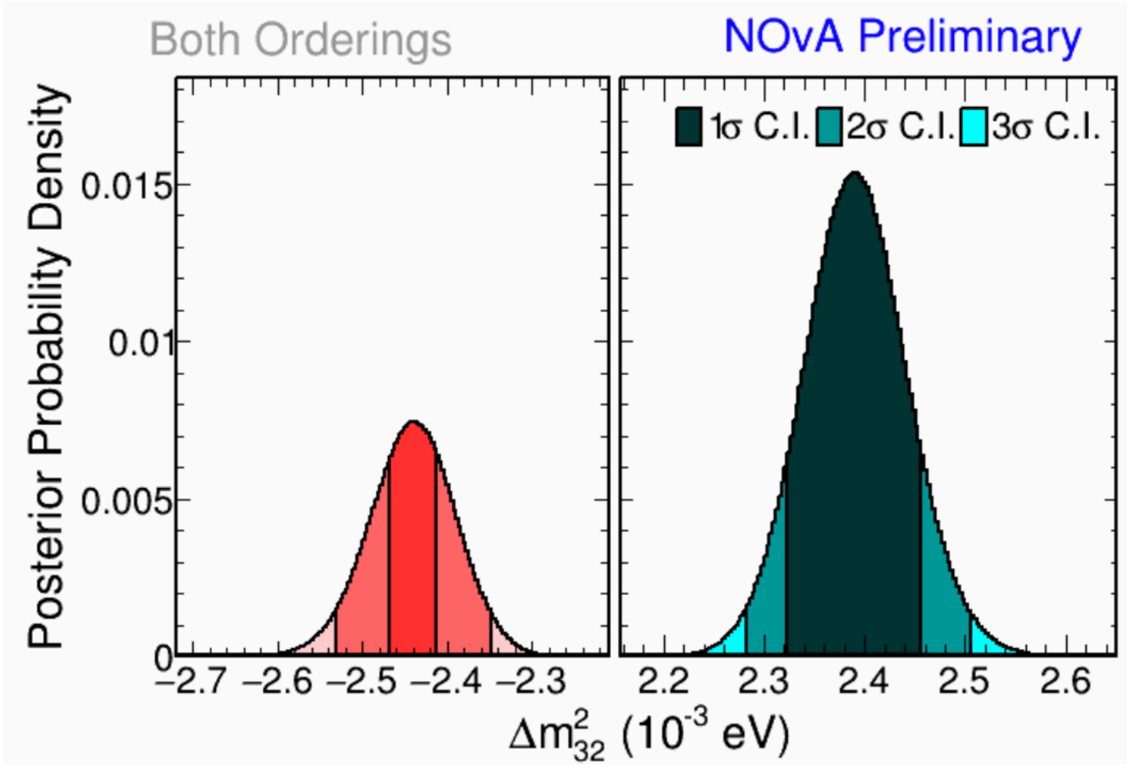


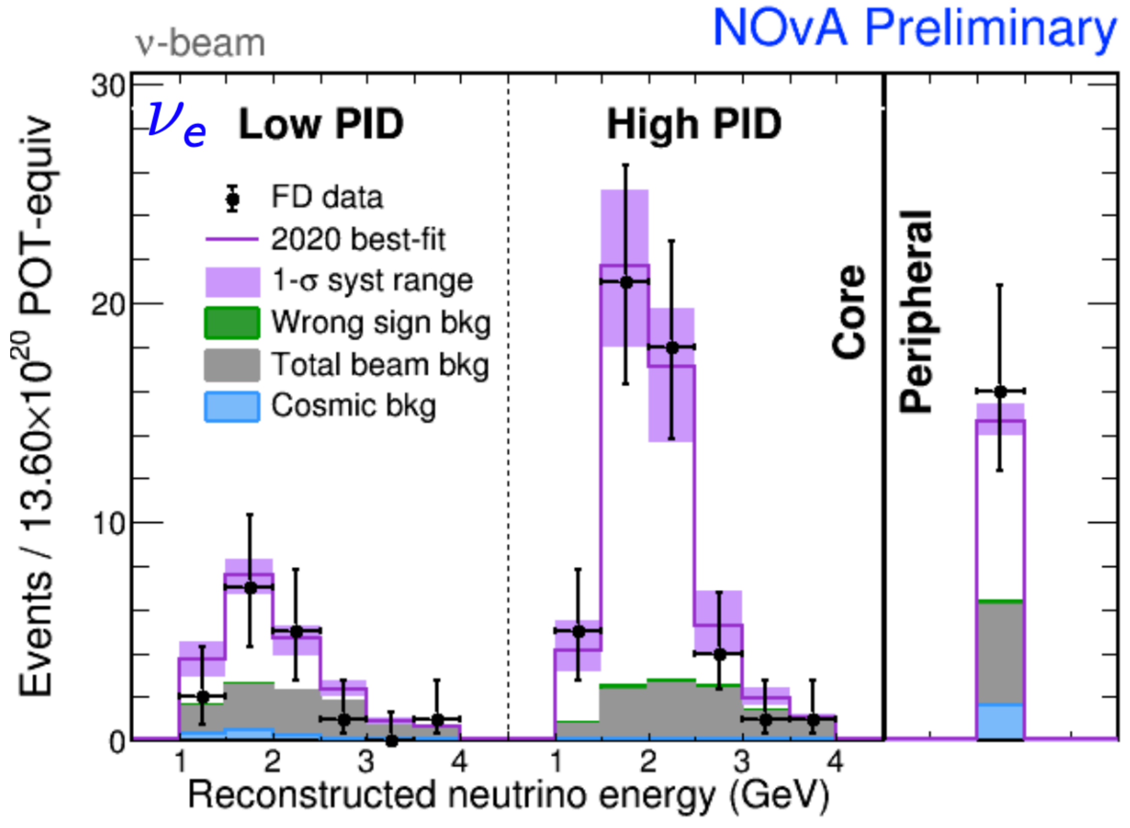


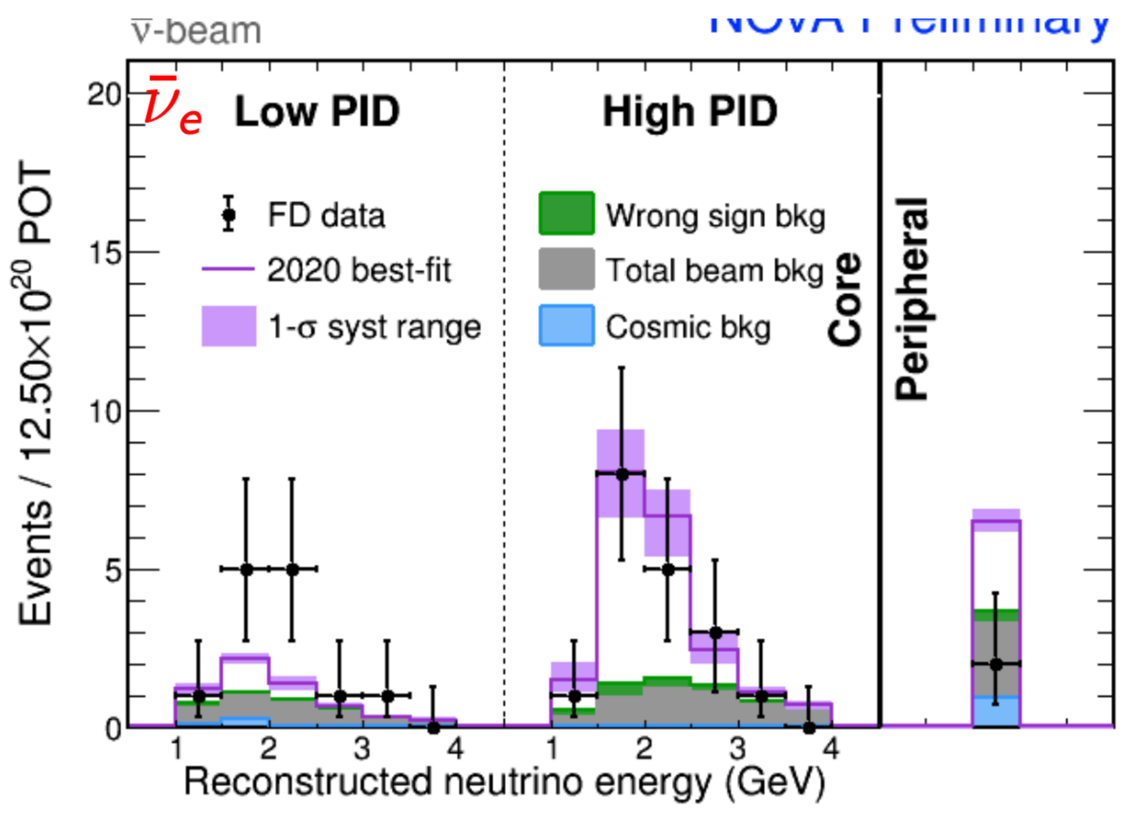
- New analysis on the ~ 26×10^{20} POT collected up to 2020 (Bayesian analysis)
- 37×10^{20} POT neutrino data available now
- Slight preference for upper octant and normal ordering

New for Moriond EW 2023



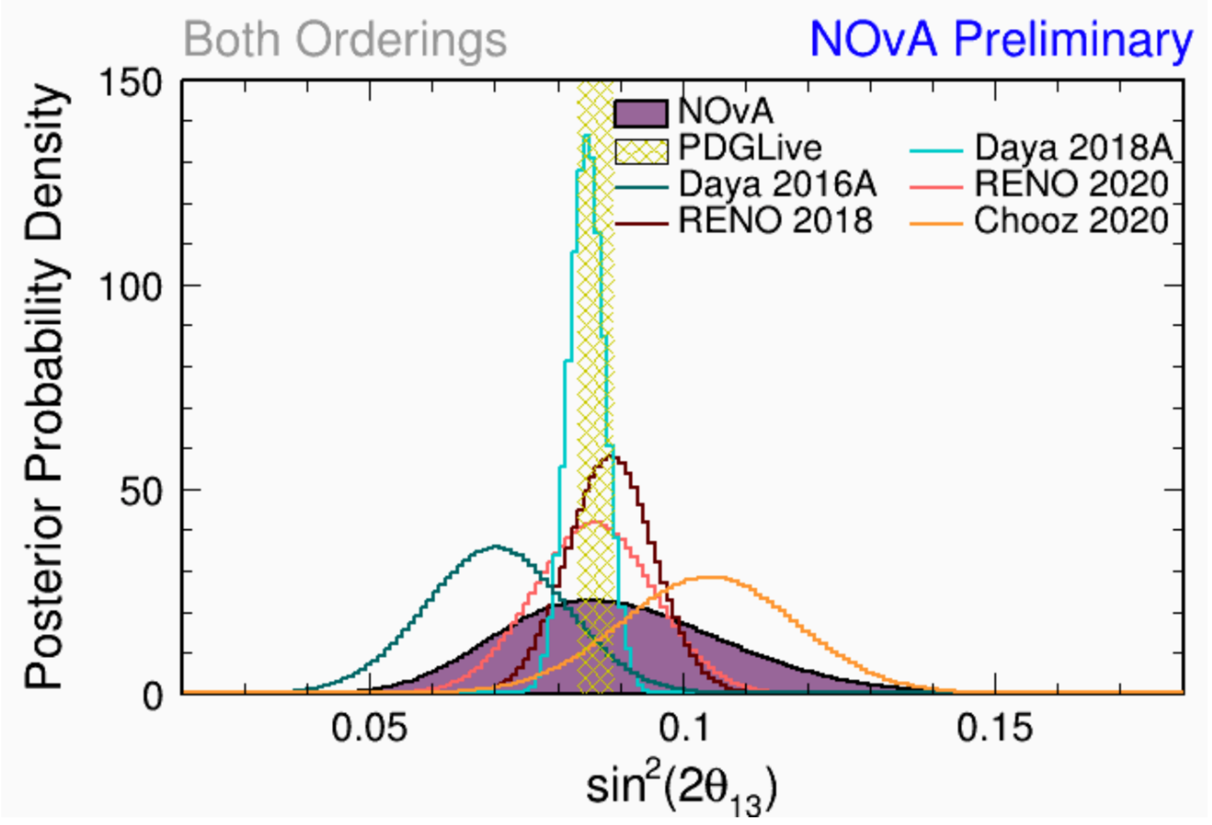






First NOvA measurement of $\sin^2\theta_{13}$

$$\sin^2(2\theta_{13}) = 0.085^{+0.020}_{-0.016}$$

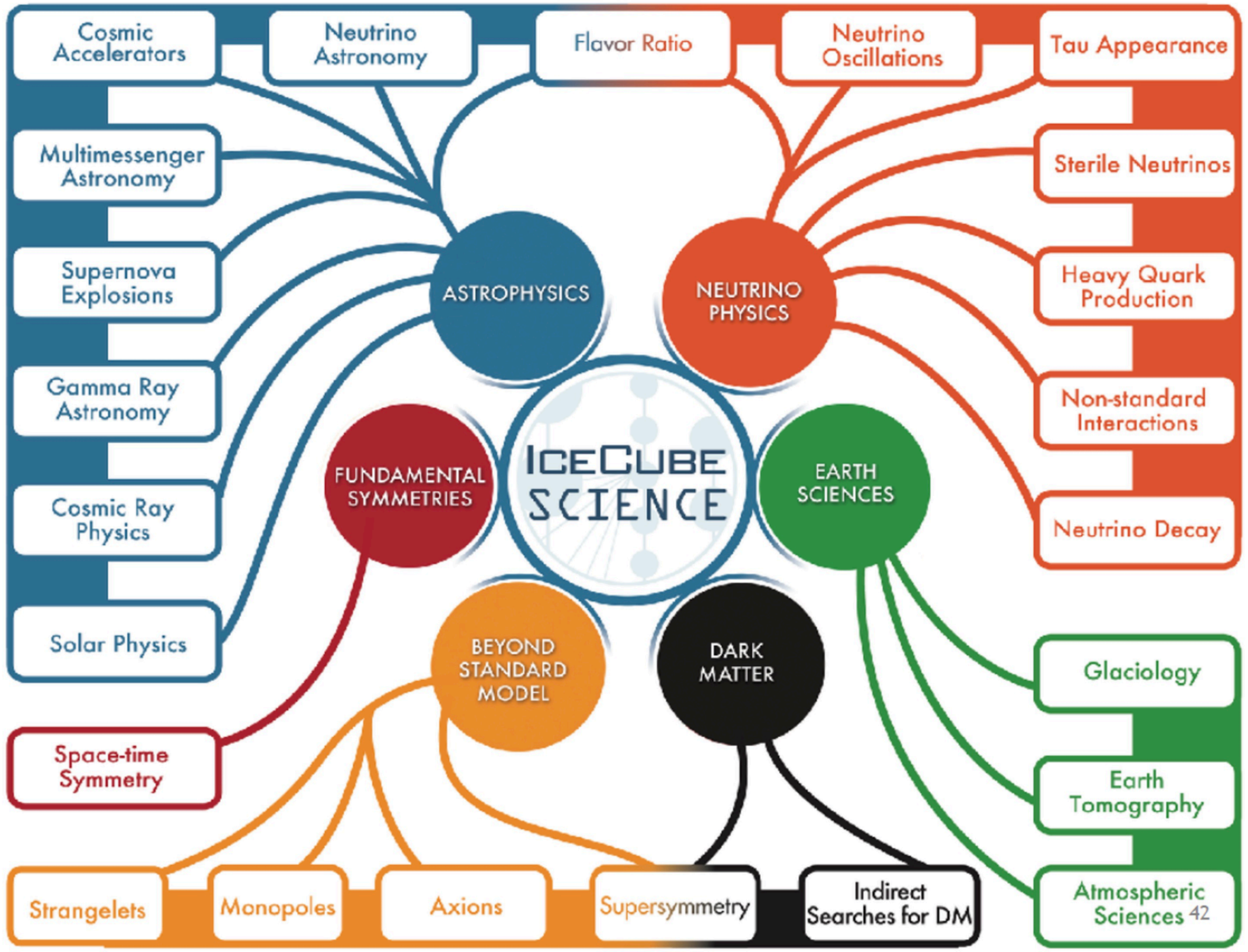


$> 4\sigma$ evidence of electron antineutrino appearance

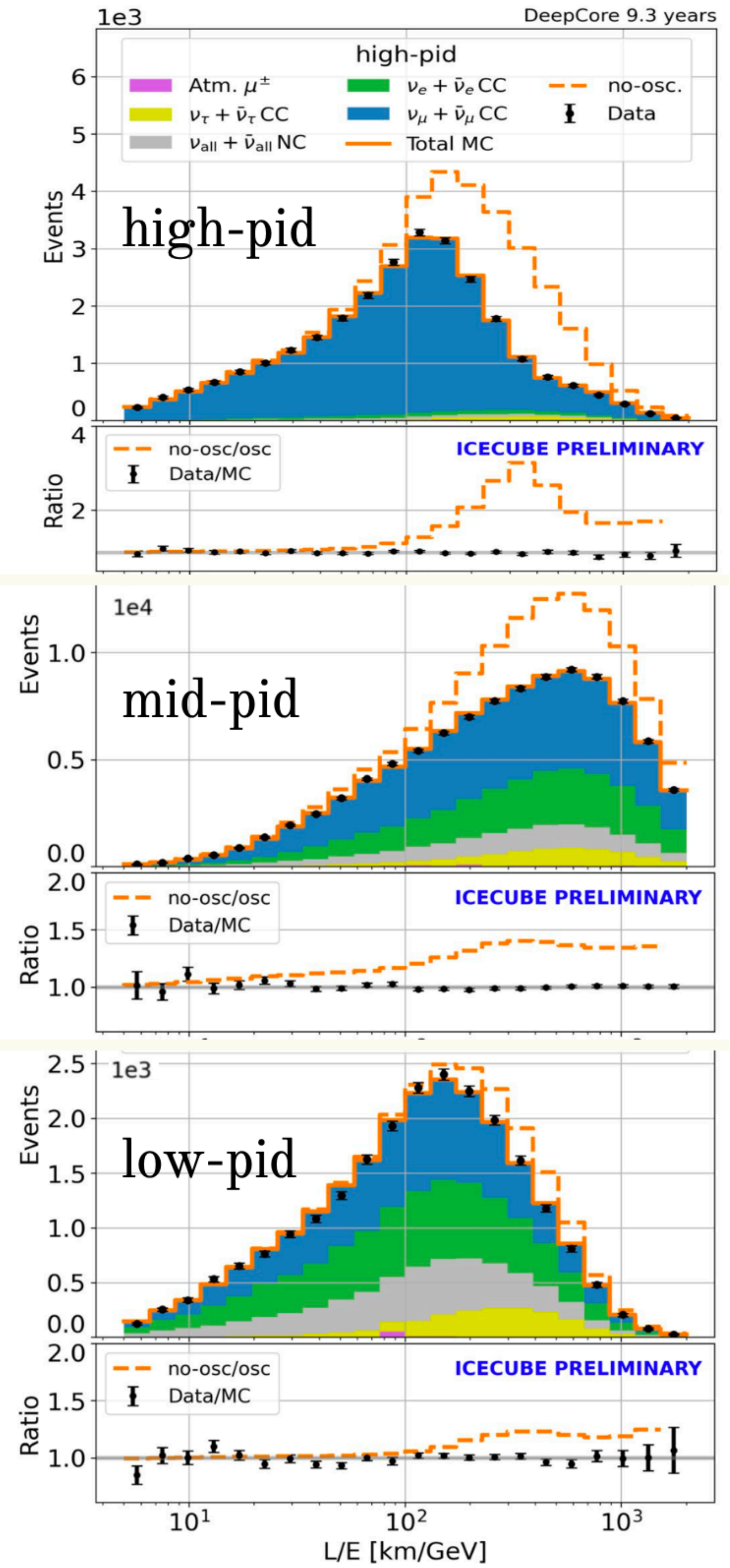
Impressive precision on θ_{13} nice to have frequentist cross check!

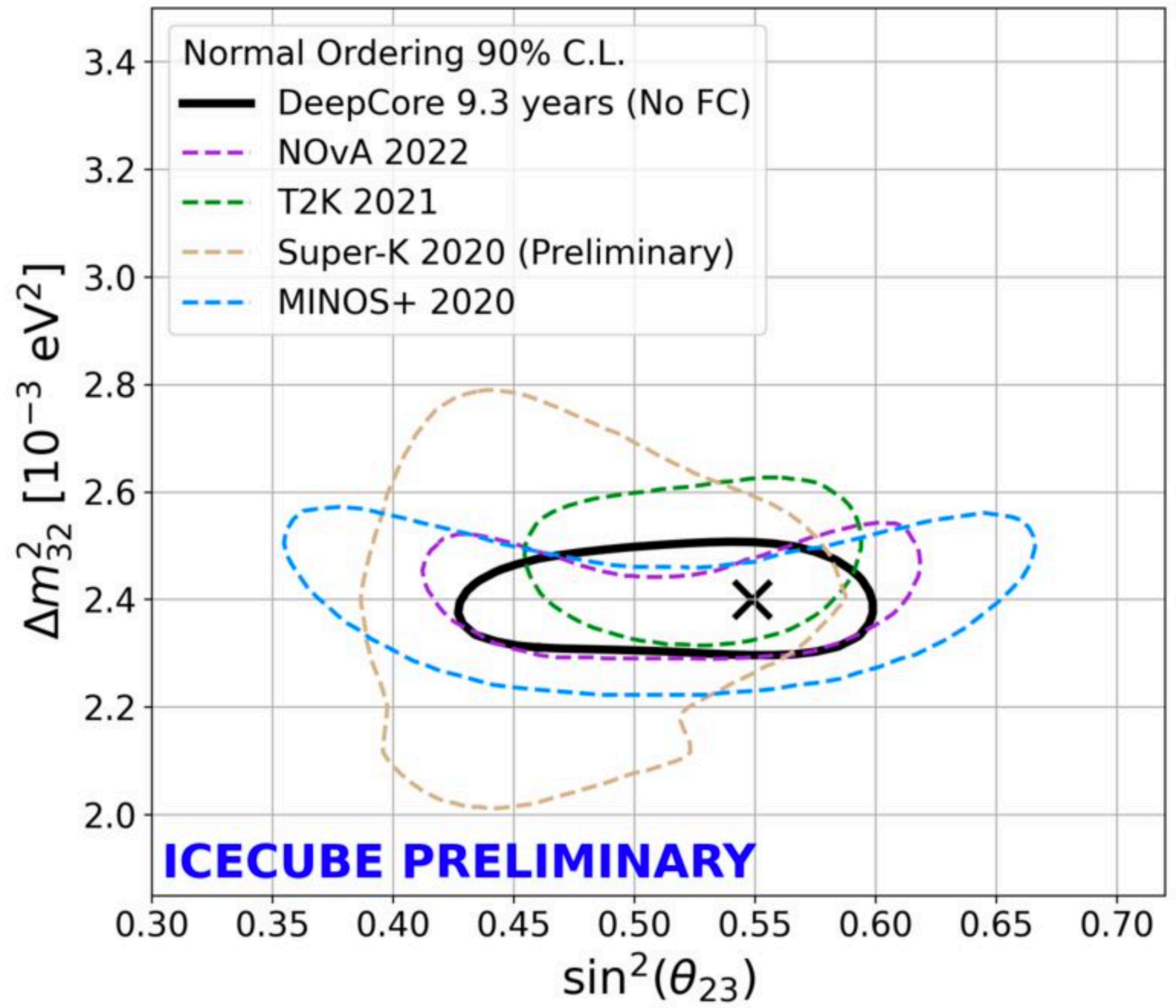
Ice Cube w/ Deep Core

Ice Cube… an amazingly broad program!

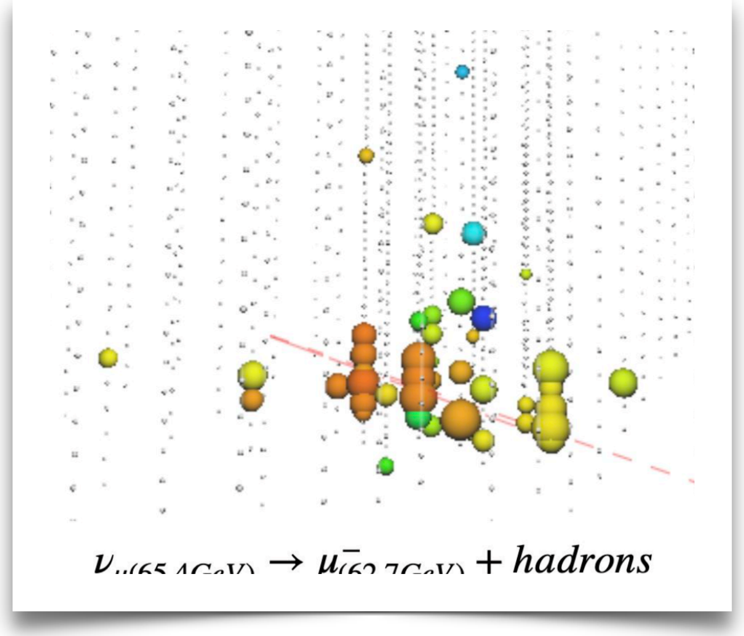


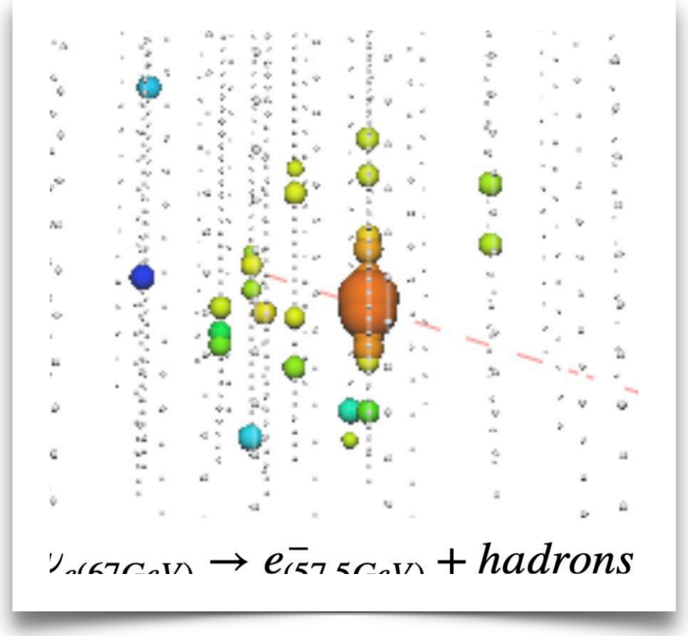
Deep Core with Deep CNNs!



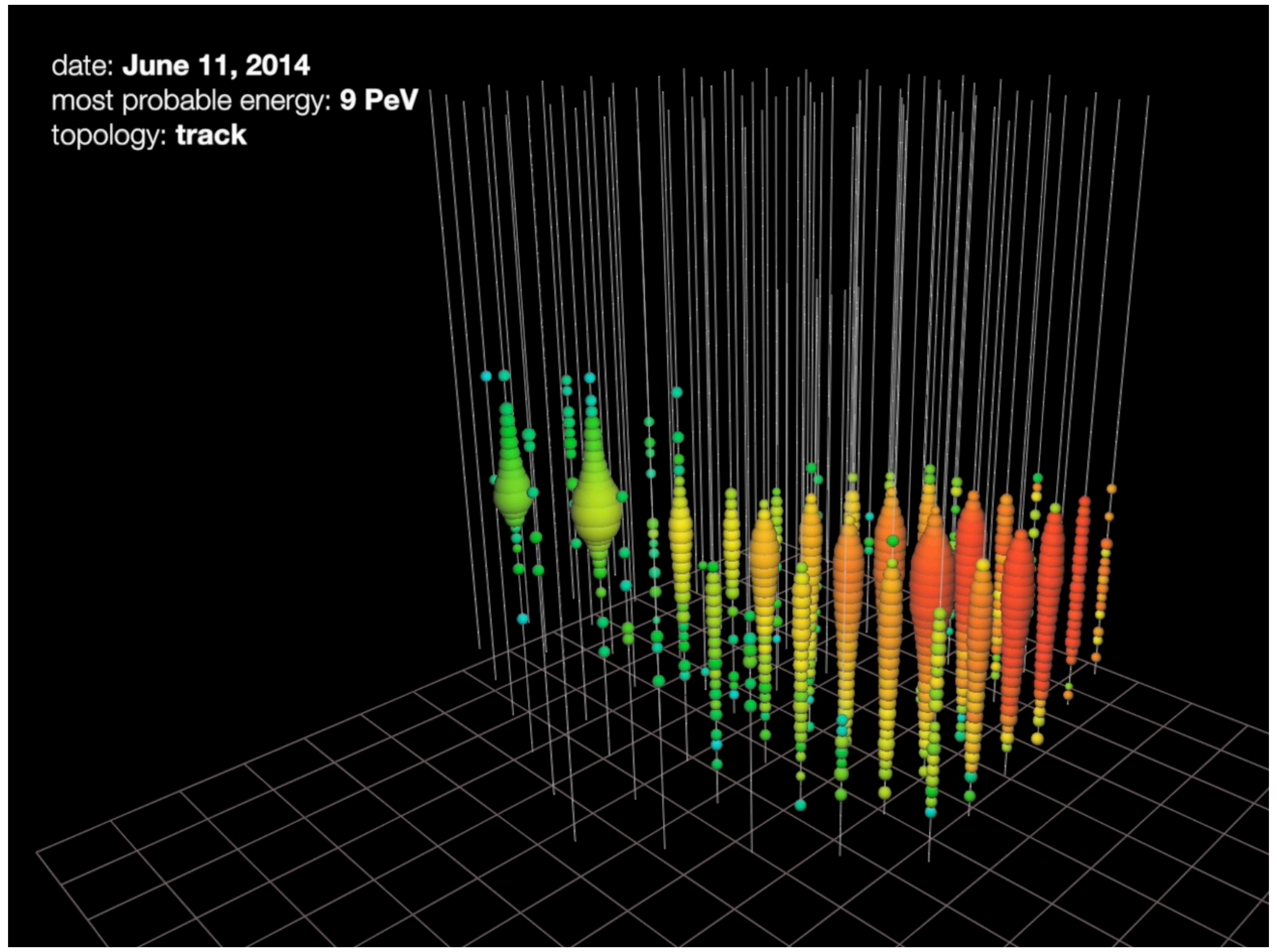


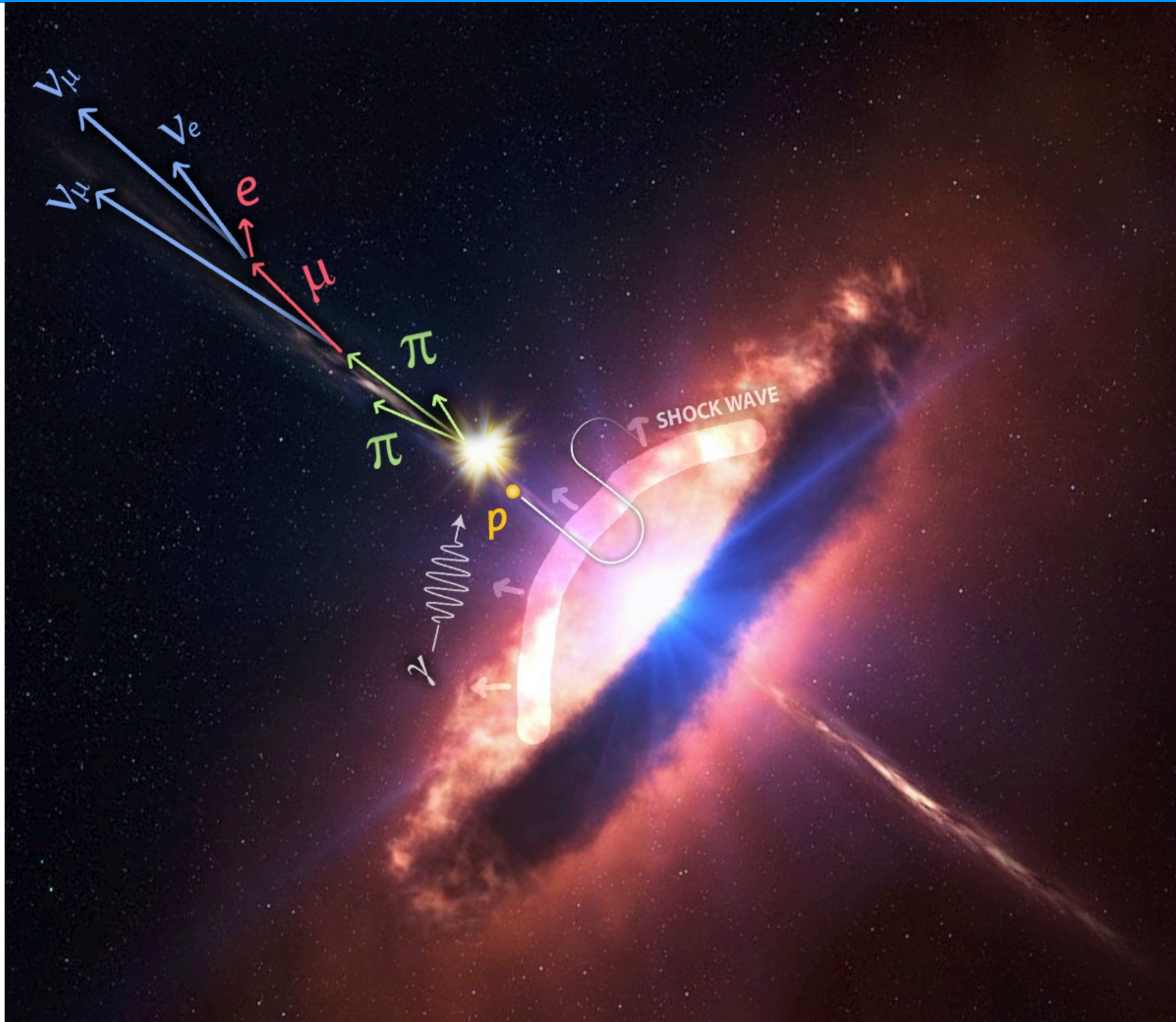
- Results competitive with SK and Long Baseline results!
- Much more to come!!





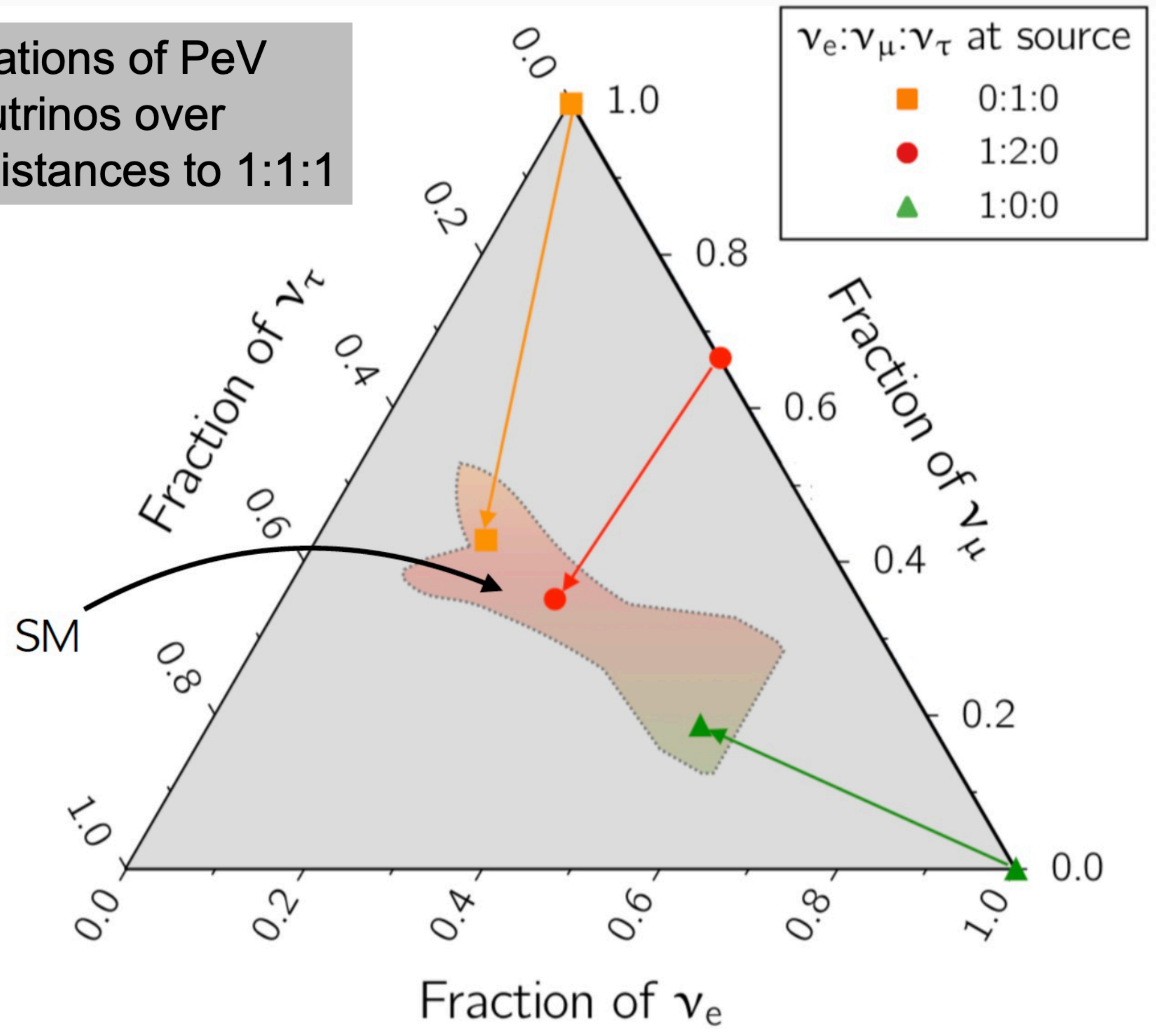
Superb review of the birth of multi-messenger and high energy neutrino astronomy!



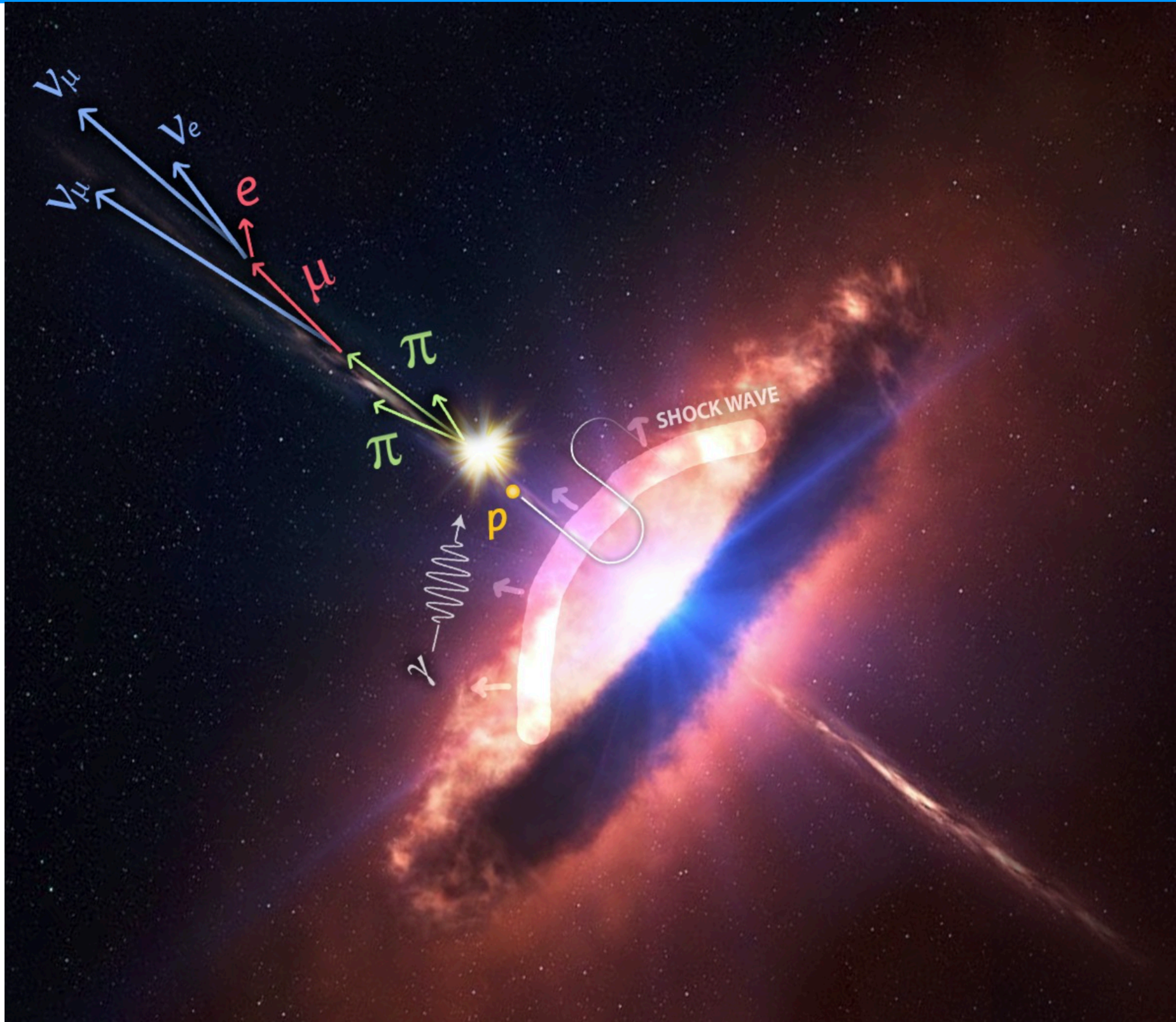


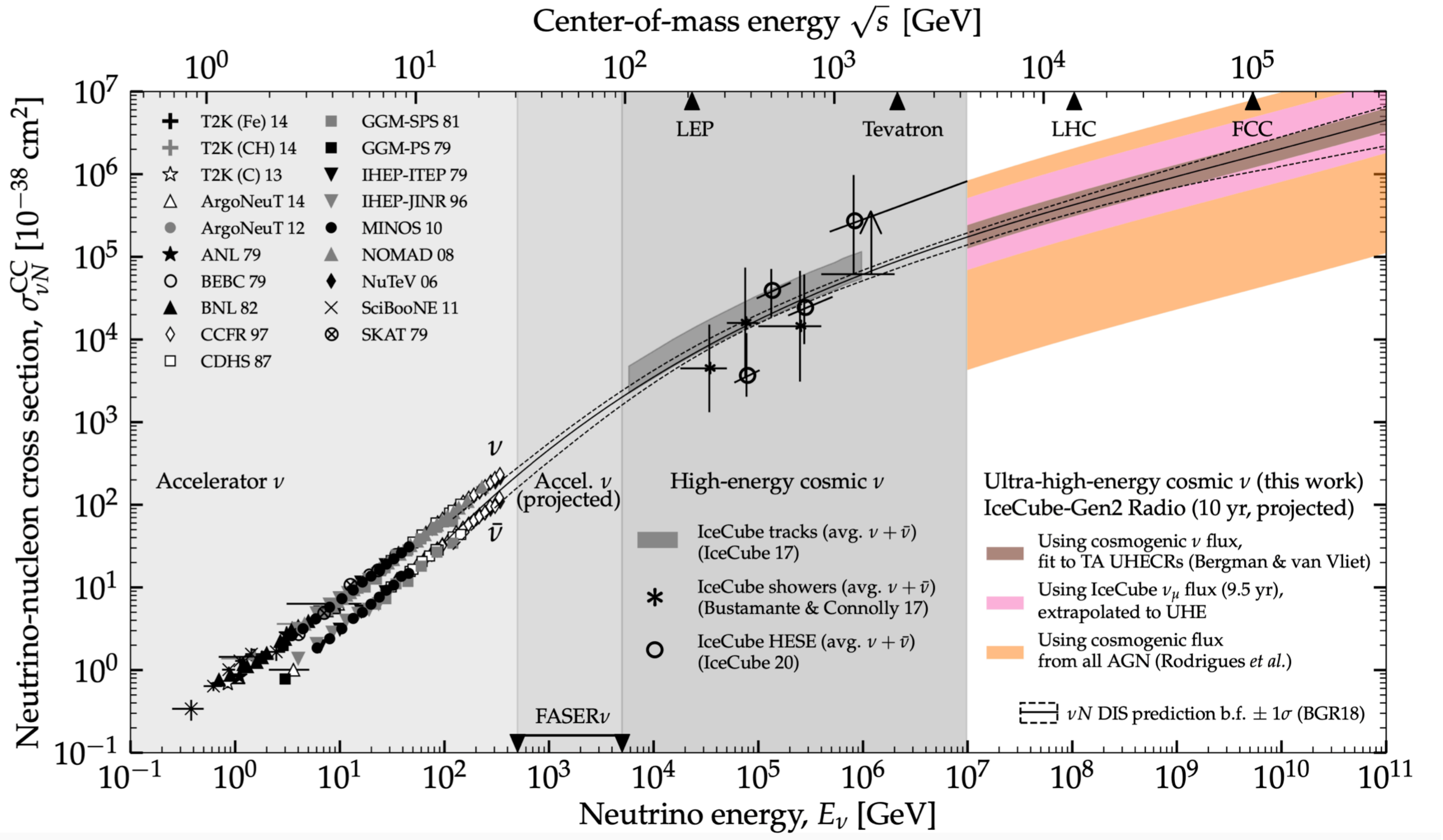
Superb review of the birth of multi-messenger and high energy neutrino astronomy!

oscillations of PeV neutrinos over cosmic distances to 1:1:1



… but not only! PeV neutrinos traveling over cosmic distances can probe the Standard Model!

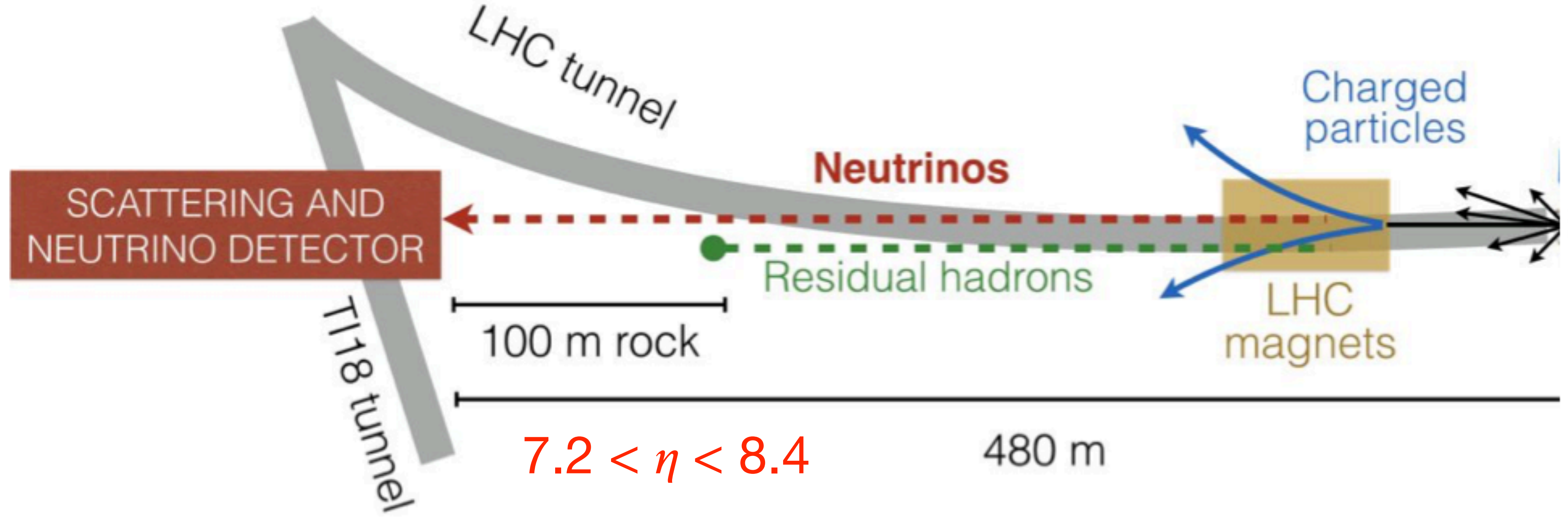


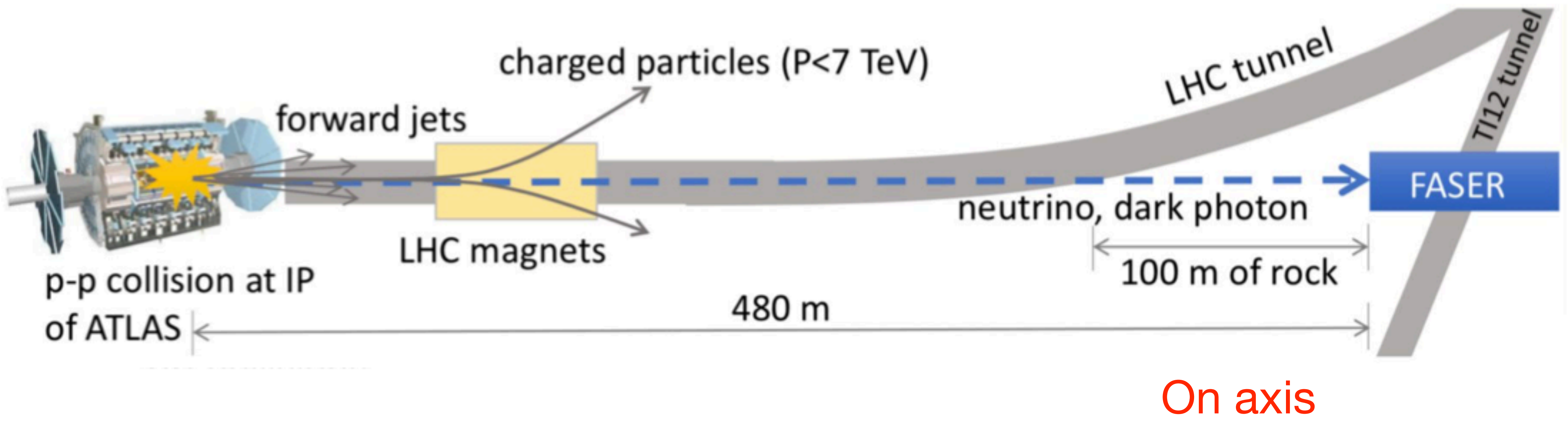


Accelerator neutrinos, up to O(100 GeV)

Cosmic neutrinos

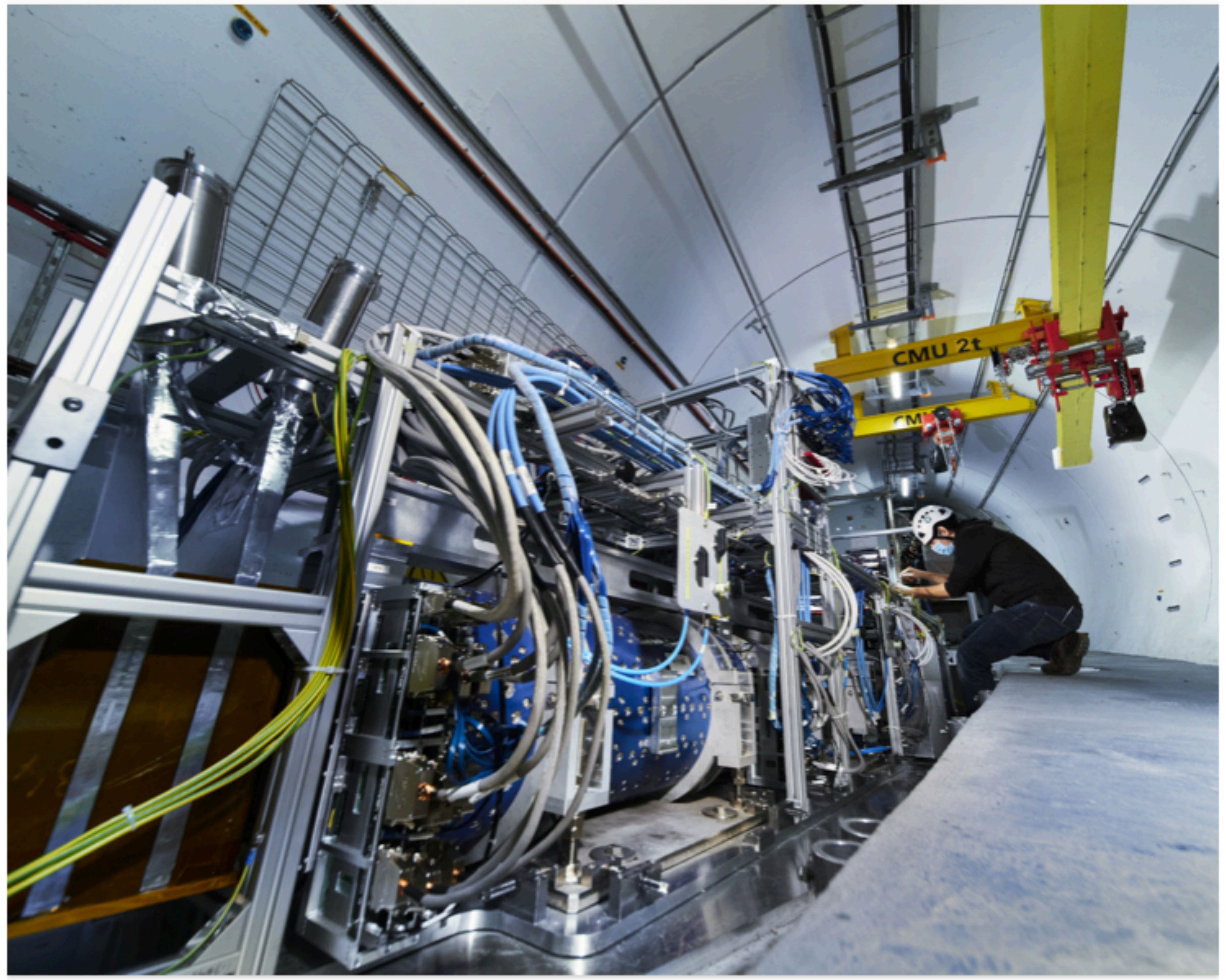
The birth of Collider Neutrinos (at the LHC)



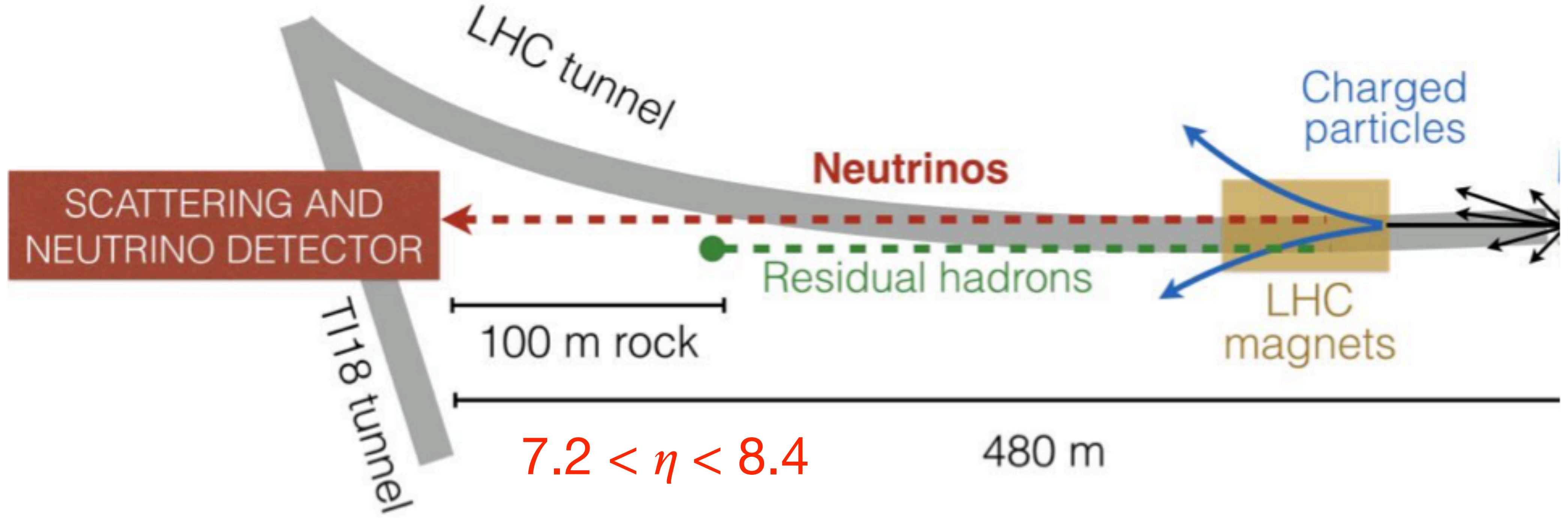


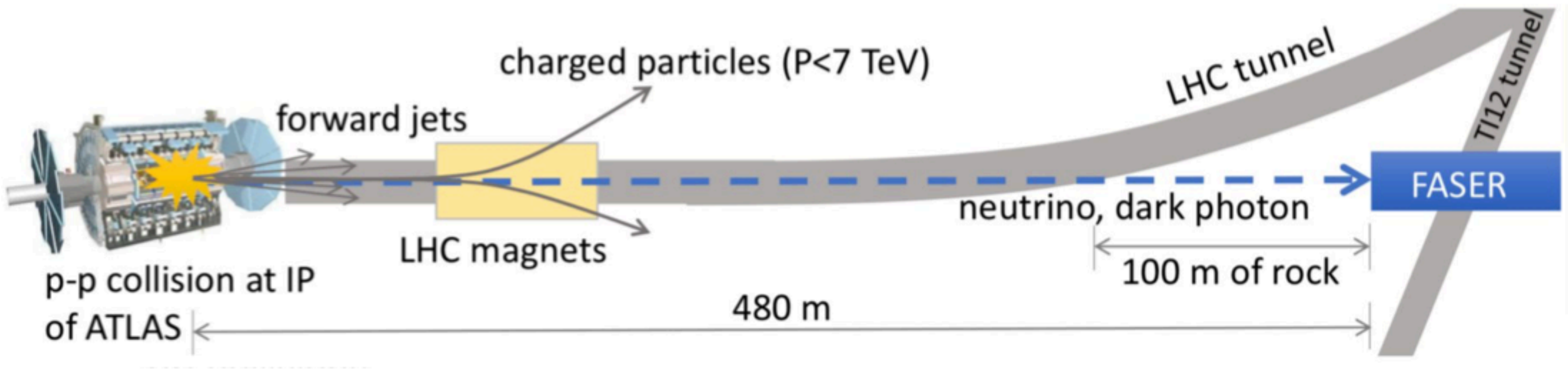
SND

Faser-ν

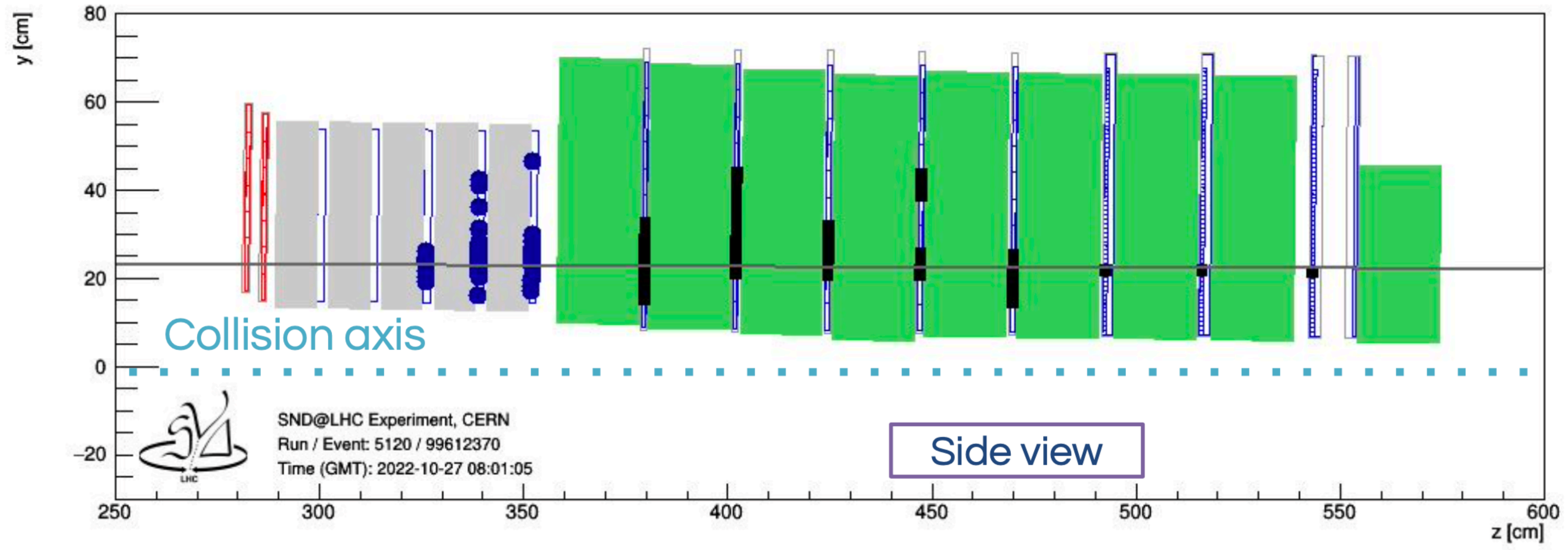


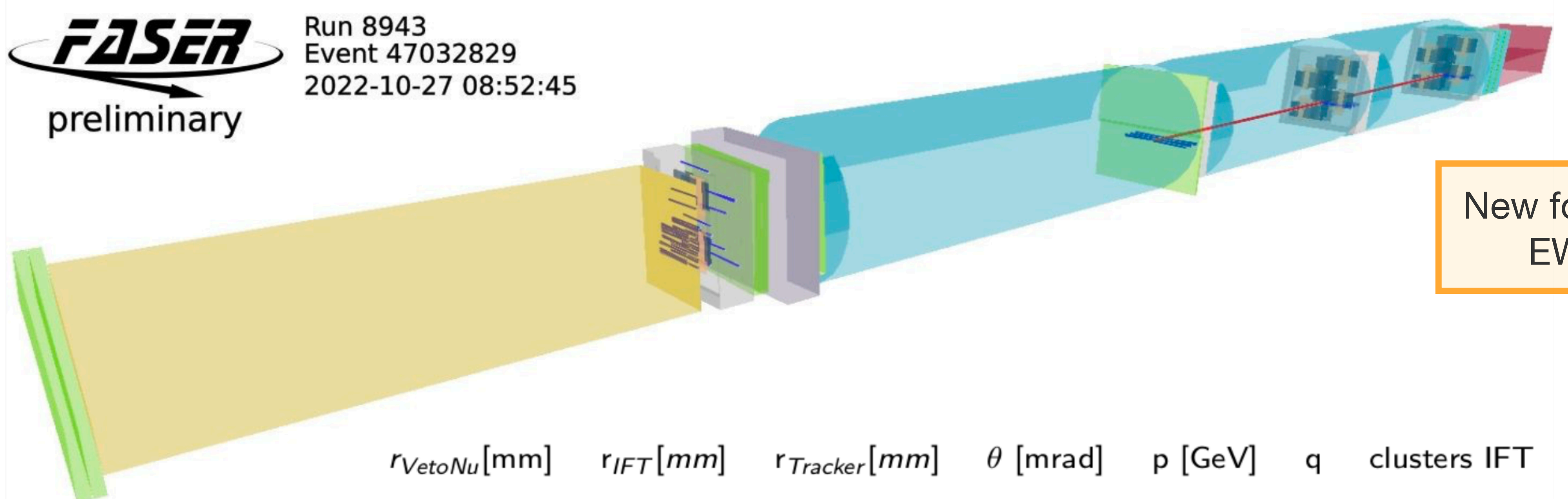
The birth of Collider Neutrinos (at the LHC)





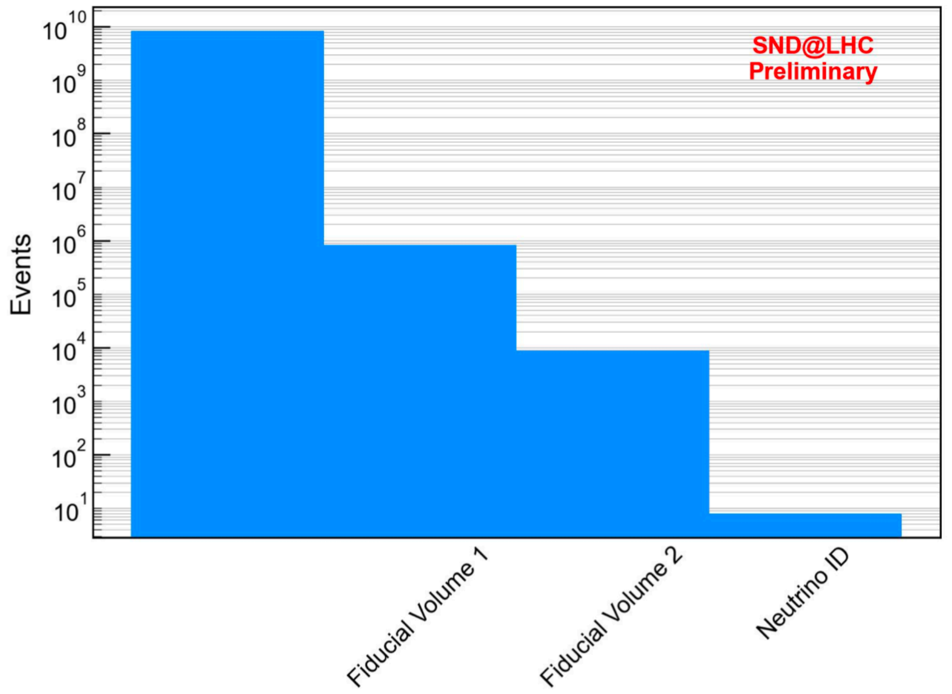
SND New for Moriond EW 2023 **First results from SciFi/Silicon tracking devices** **Faser-ν**





r_{VetoNu}[mm]	r_{IFT}[mm]	$r_{Tracker}$[mm]	θ [mrad]	p [GeV]	q	clusters IFT
57.2	55.8	54.6	2.5	843.8	−1	57

New for Moriond EW 2023

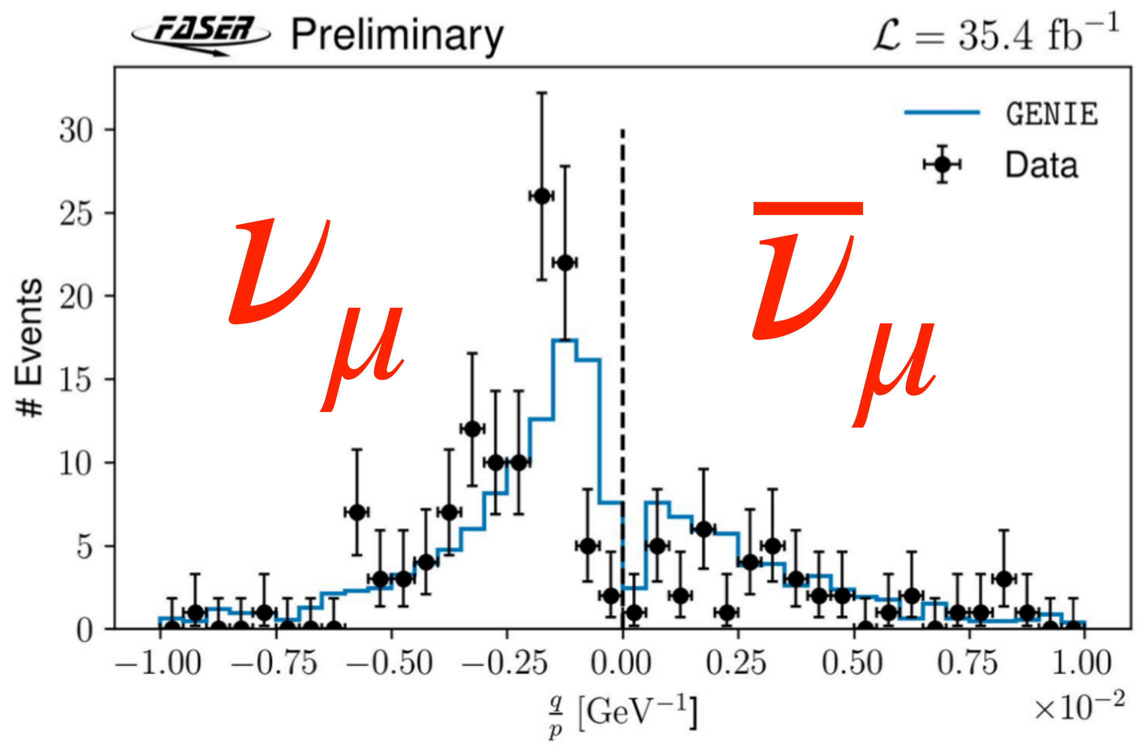


5 events expected and 8 observed (0.2 background)

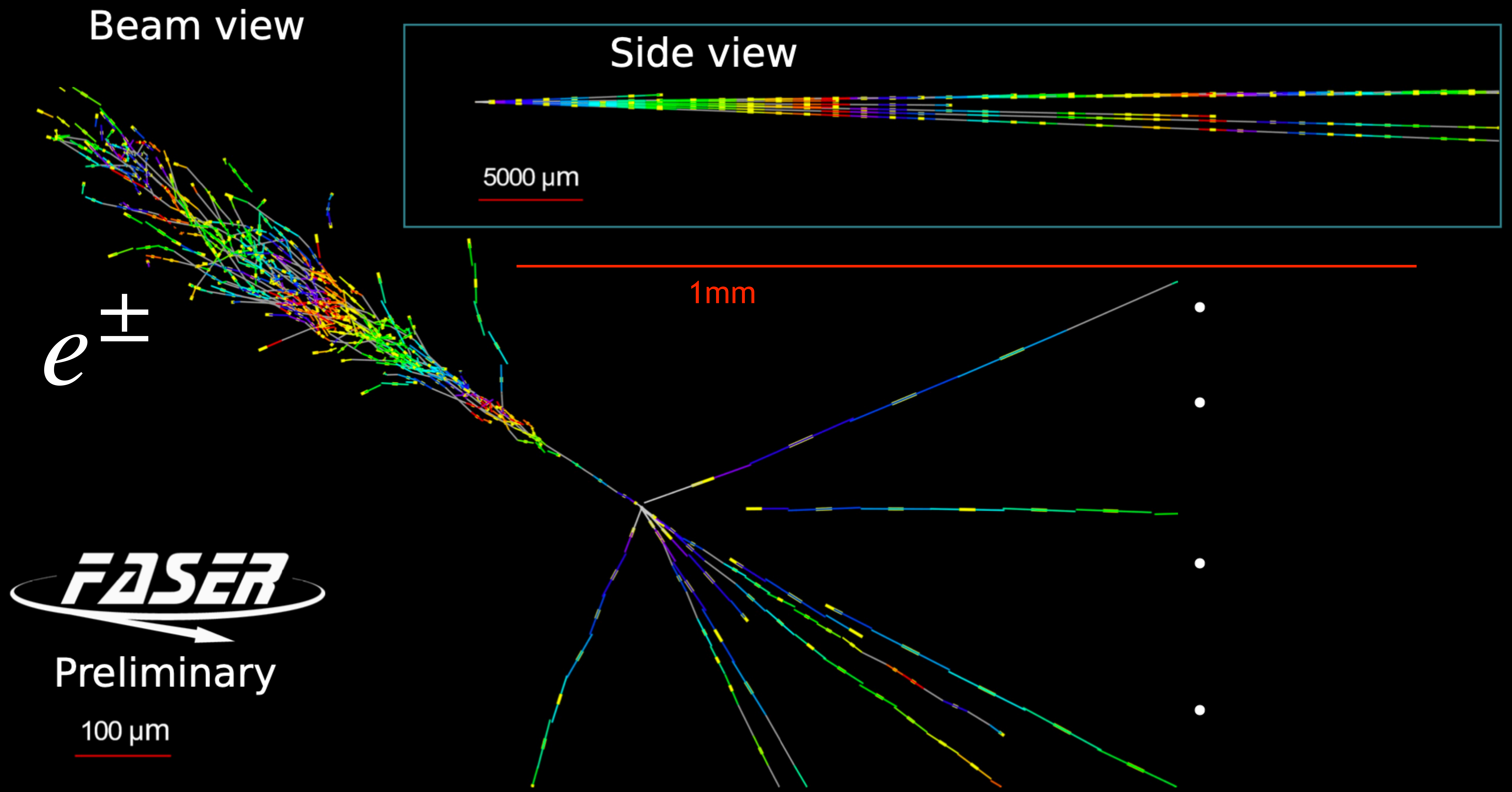
Approximately 5σ observation!

150 events expected and 153 observed (0.2 background!!)

16σ observation!



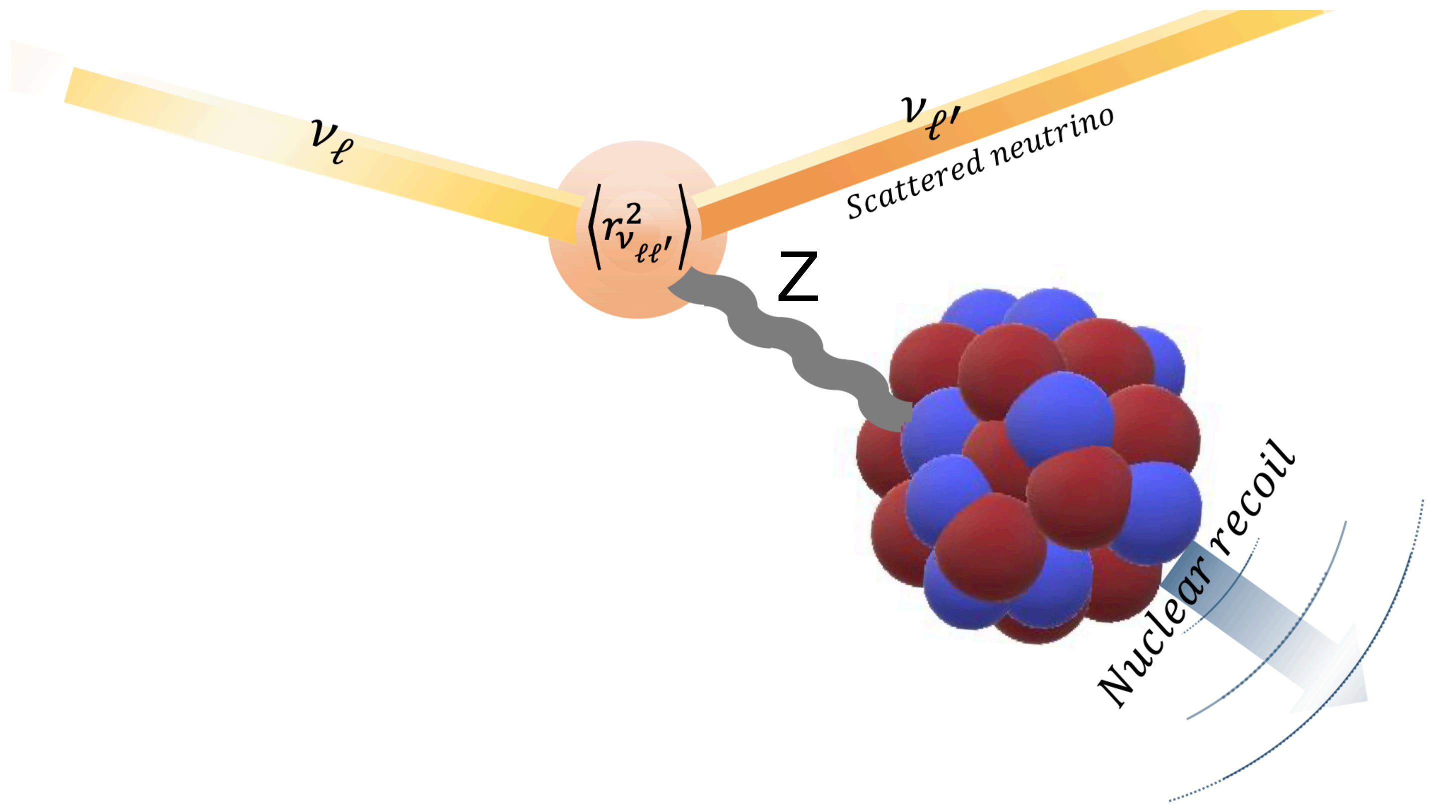
Looking forward to the emulsion results!



Coherent Neutrino Scattering

CONUS Experiment

Coherent Elastic neutrino Scattering can occur for any neutrino species below 50 MeV (at low energy neutrino interacts with the nucleus - effective sum of amplitudes) the rate $\propto N^2$



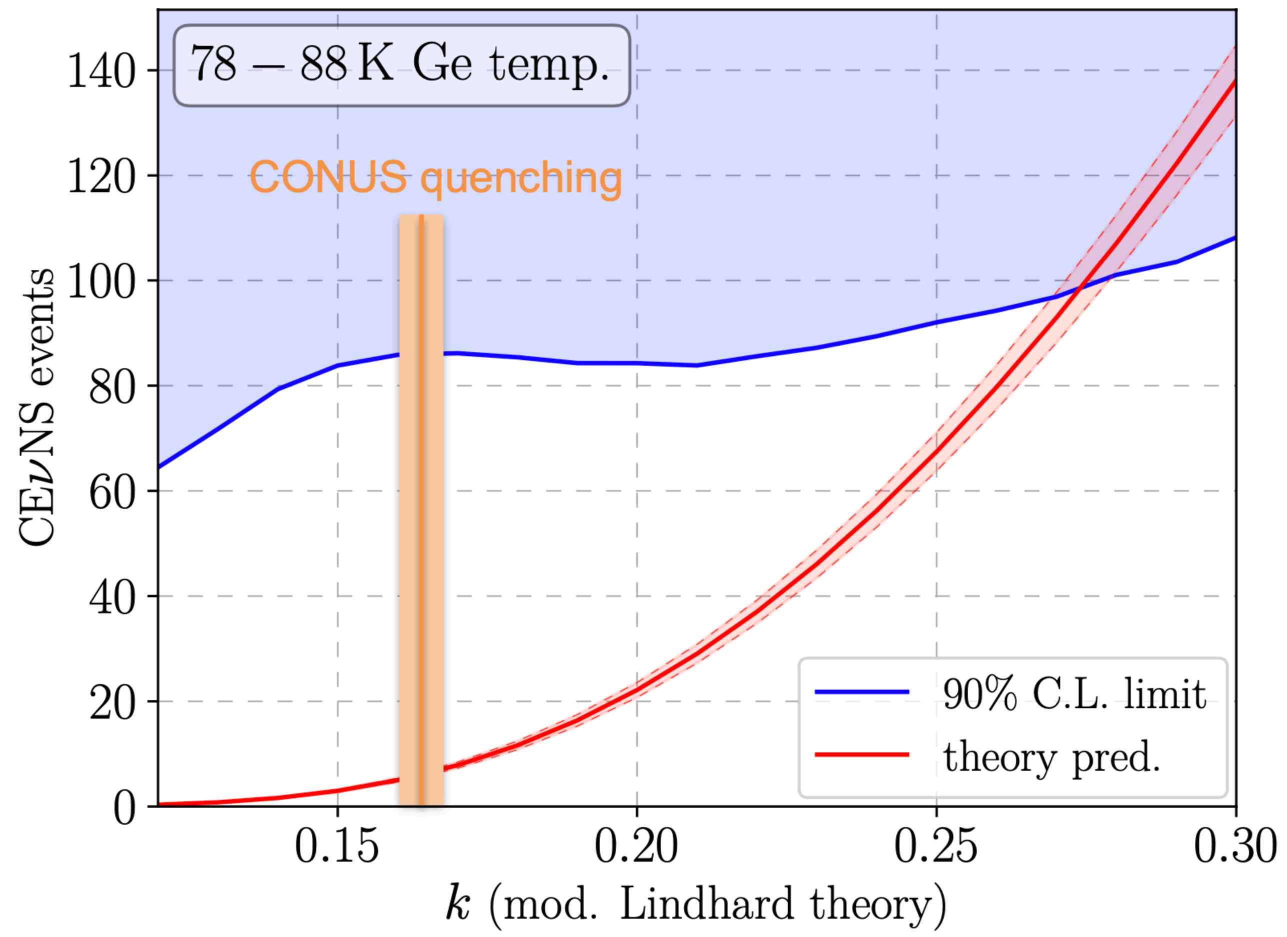
- MeV-neutrino relevant for modelling of supernovae
- Background for Direct Dark Matter detection
- New technique for neutrino experiments
- Searches for BSM phenomena

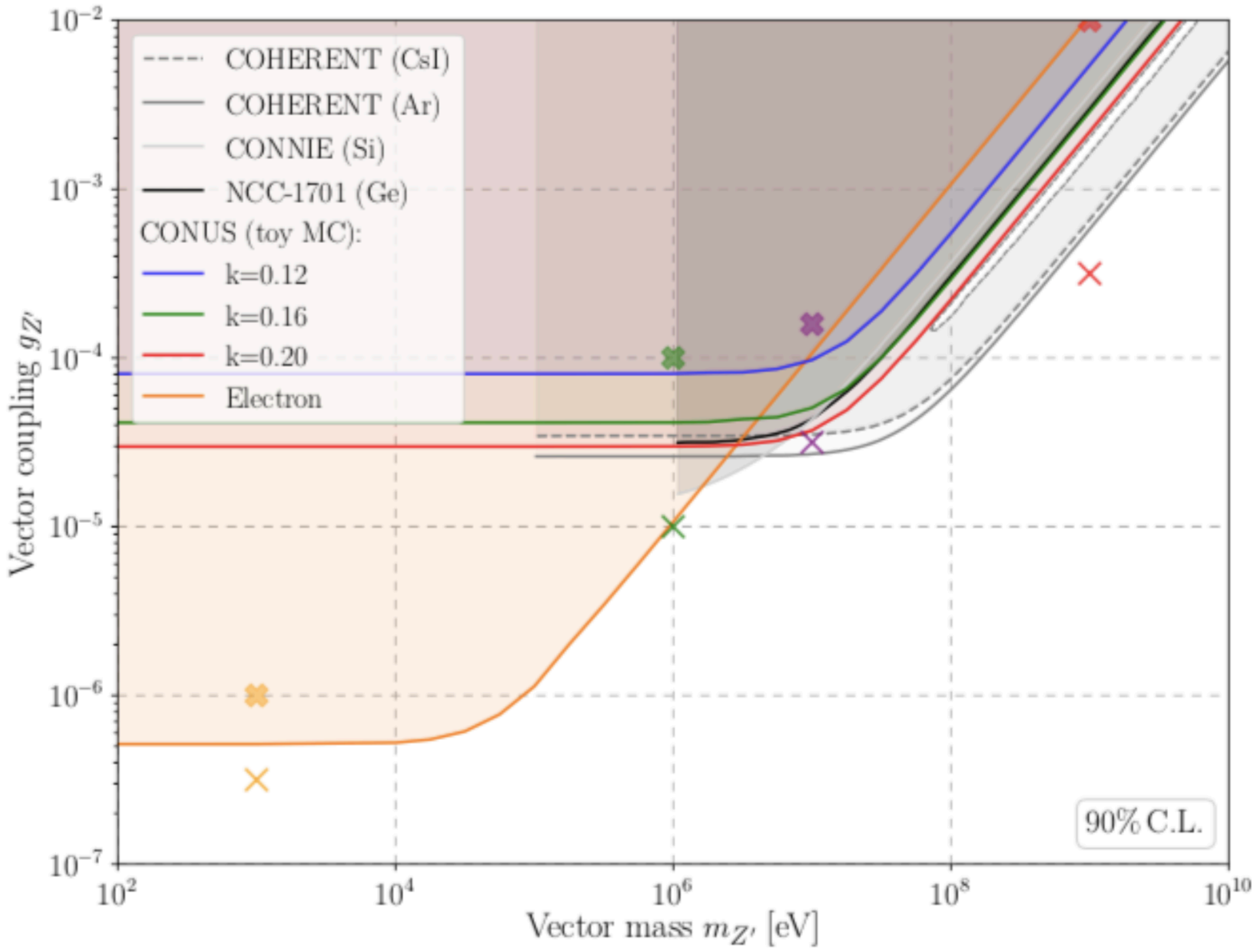
Coherent elastic scattering of neutrinos off nuclei observed at 6.7σ with neutrinos from the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (COHERENT experiment).

Investigating the lower energy regime (<10 MeV) with a Ge detector at Brodkorf Nuclear Power Plant

Quench factor measurement made with neutron source

Difficult for Ge based detector observation to be made at reactor!



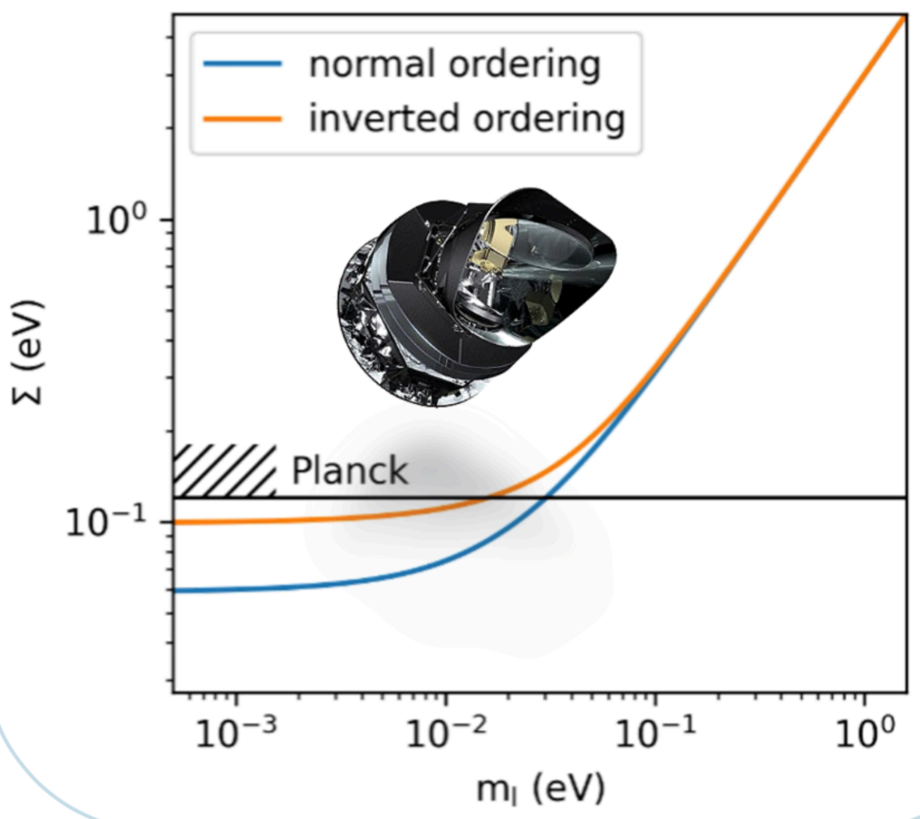


Interesting first limits (at low mass) on **light vector mediators** or **neutrino magnetic moment**!

Neutrino Overview

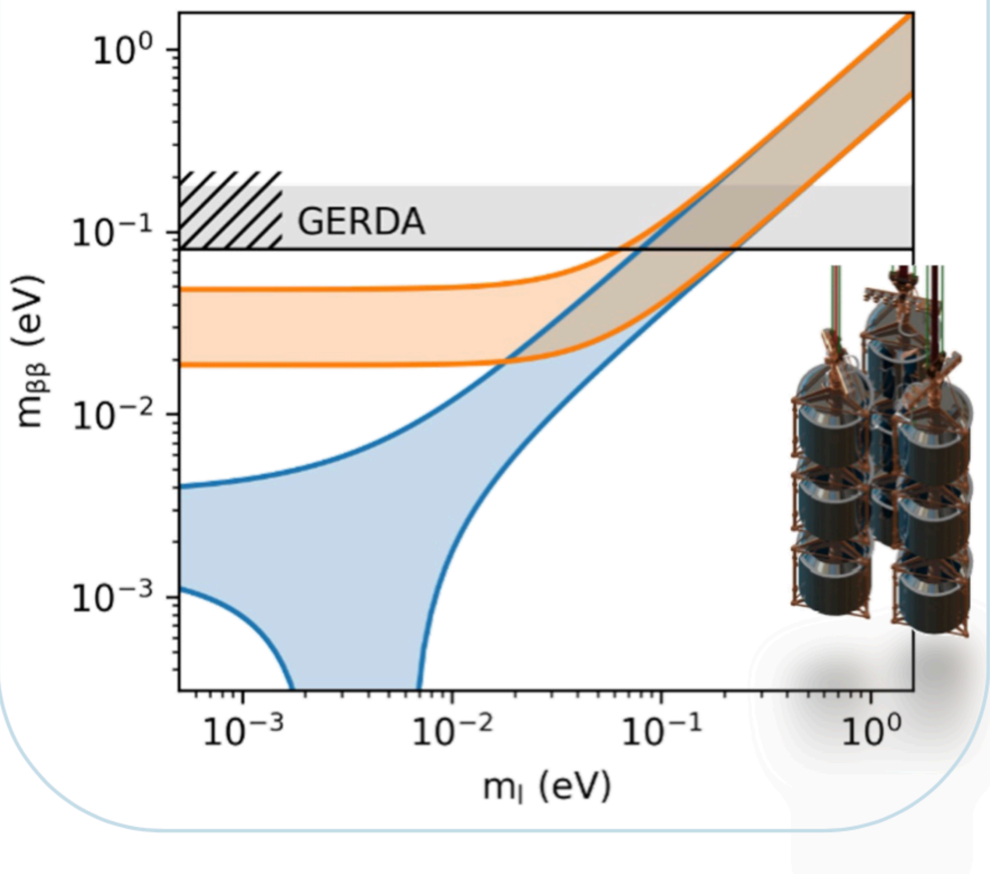
Cosmology

$$\Sigma = \sum_i m_i$$



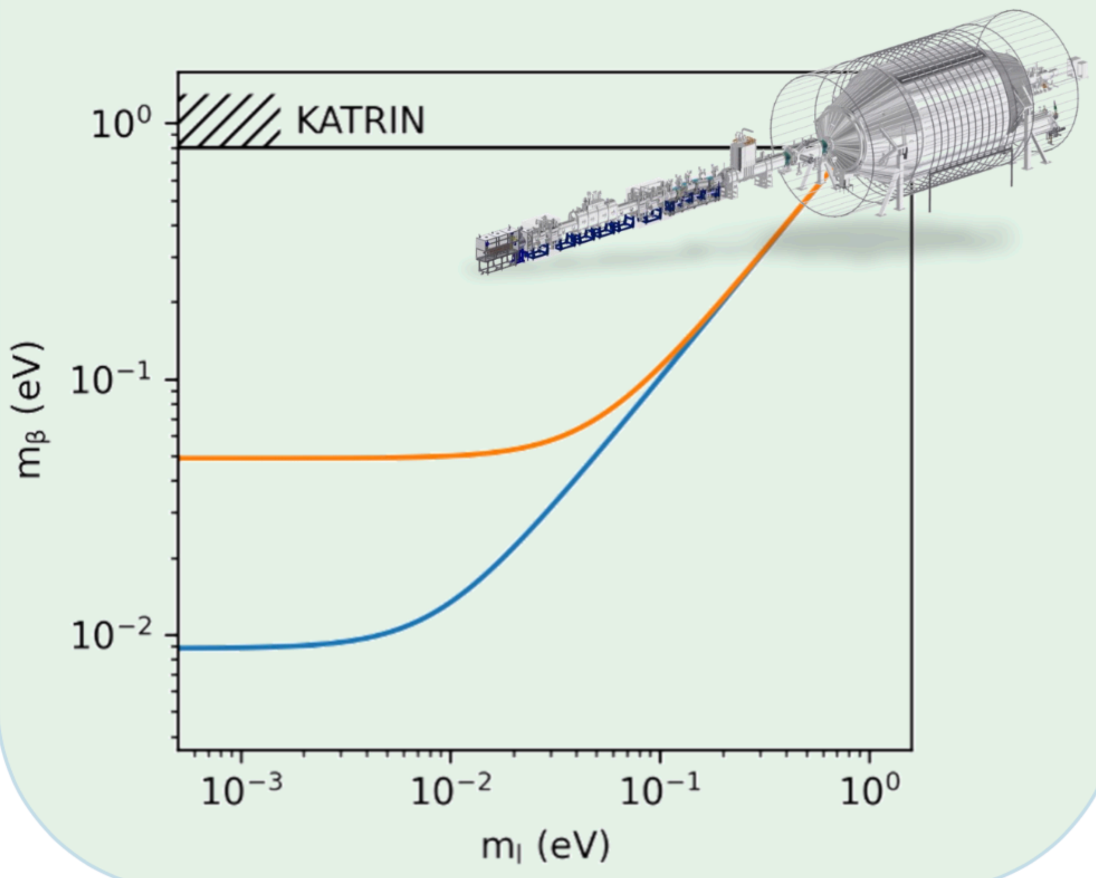
Neutrinoless ßß decay

$$m_{\beta\beta} = \sum_i {U_{ei}}^2 \cdot m_i$$



ß-decay kinematics

$$m^2_{\nu\,/\,\beta} = \sum_i |U_{ei}|^2 \cdot m_i^2$$

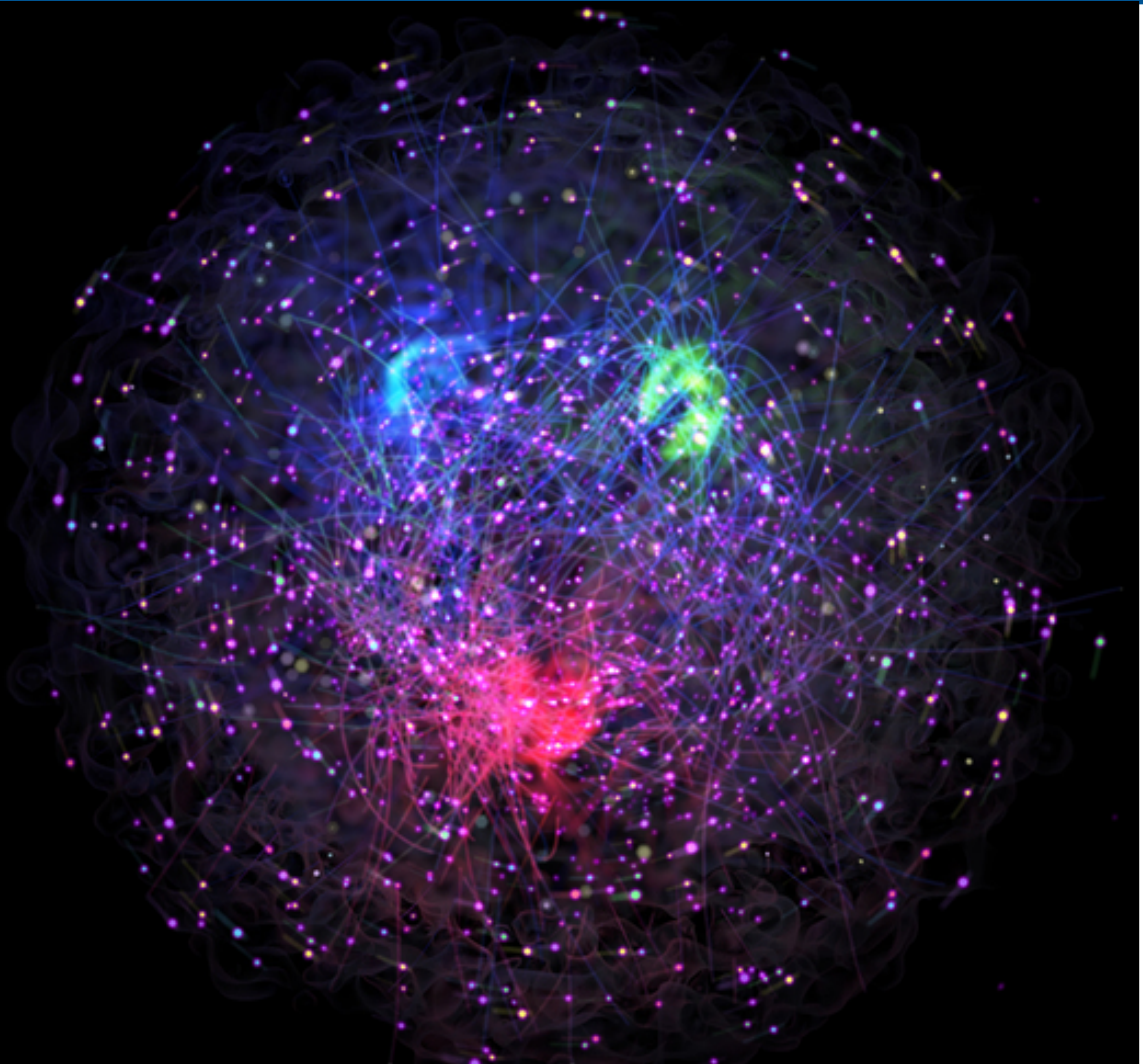


- Excellent agreement between long baseline (NOVA and T2K) with reactor PMNS data
- Anomalies don't seem to be interpretable as sterile neutrinos (backgrounds and nuclear models)
- Strong limits from double beta and KATRIN experiments

Three flavour picture seems to be standing tall!

- Indirect evidence of Cosmic Neutrino Background
- In fact strong limit on $\Sigma m_\nu < 0.11$ eV (while inverted ordering $\Sigma m_\nu > 0.11$ eV)

Quark Sector Flavour Physics

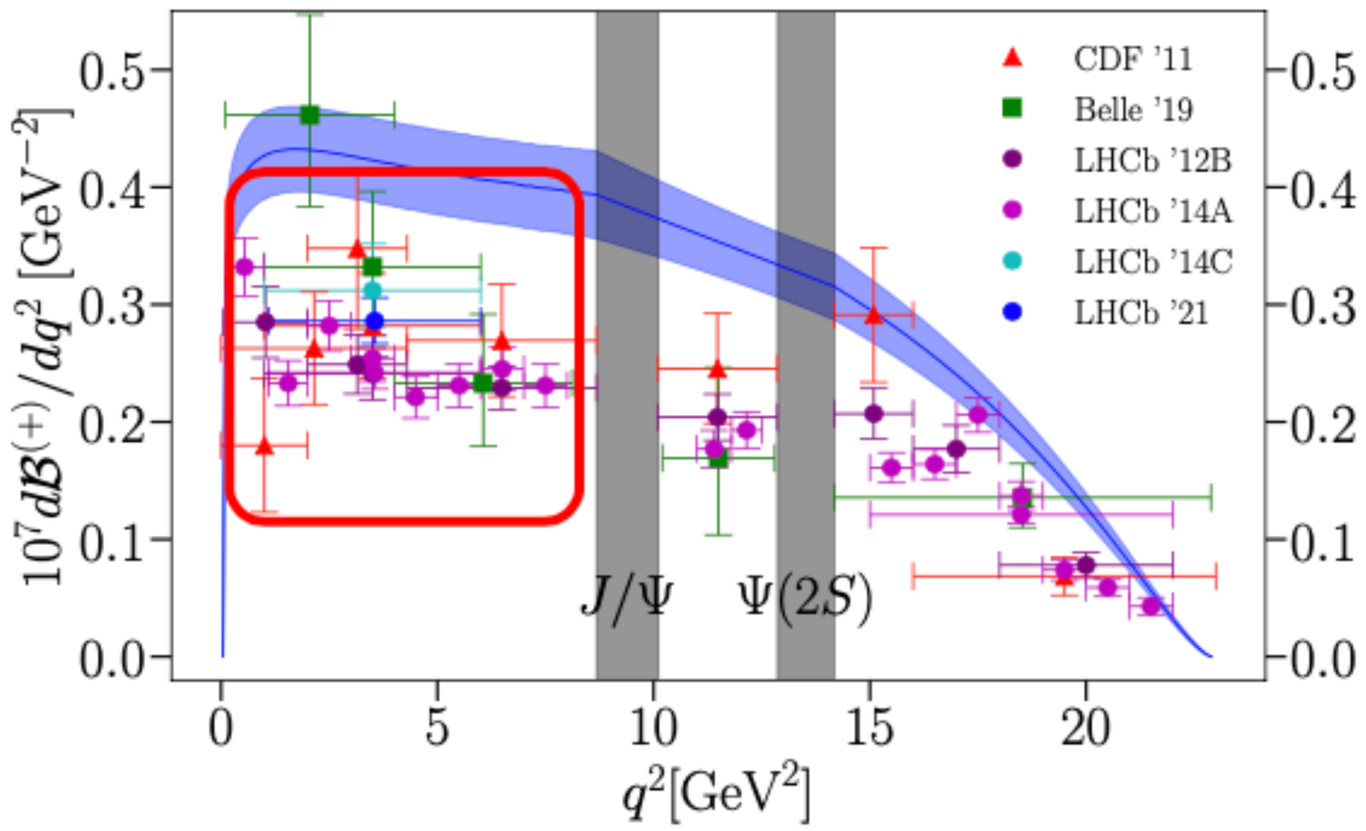

Visualizing the proton MIT news

- Lepton Flavour Universality
- Stringent probes of the CKM matrix
- Direct CP violation in K
- Searches for new physics in FCNCs
- Neutron and proton EDMs

… and anomalies (LFU, Vub-Vcb Puzzle, Cabibbo anomaly)!

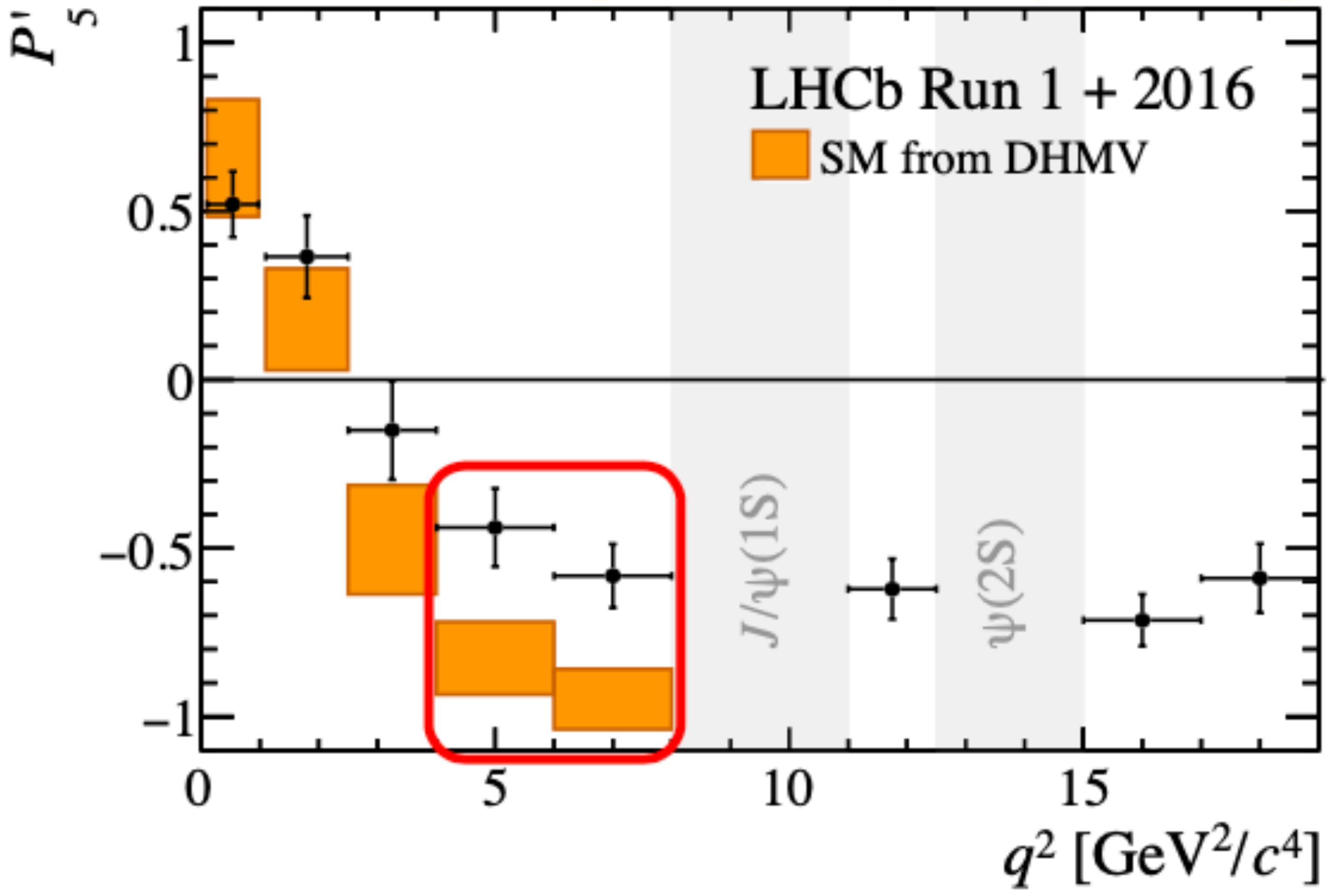
LHCb a step back

[JHEP 06 (2014) 133] [PRD 107 (2023) 014511]



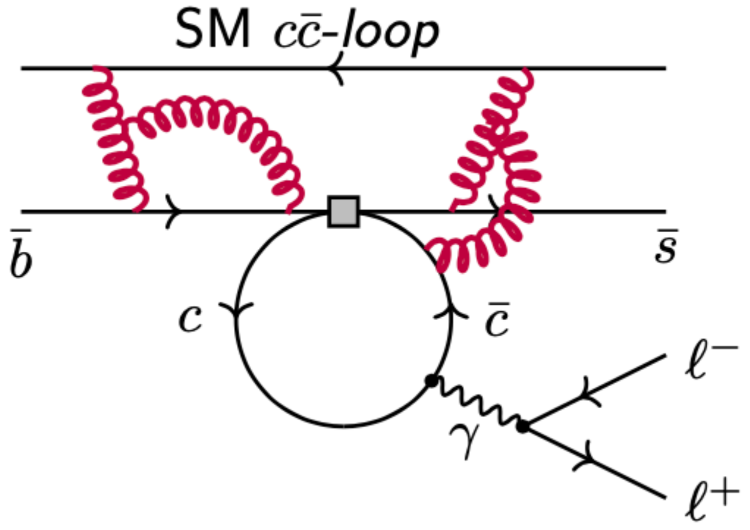
Branching fractions
affected by form-factors and $c\bar{c}$-loop

[PRL 125 (2020) 011802]



Angular observables
affected by $c\bar{c}$-loop

Lepton Universality measurements inspired in trying to find TH clean observables!

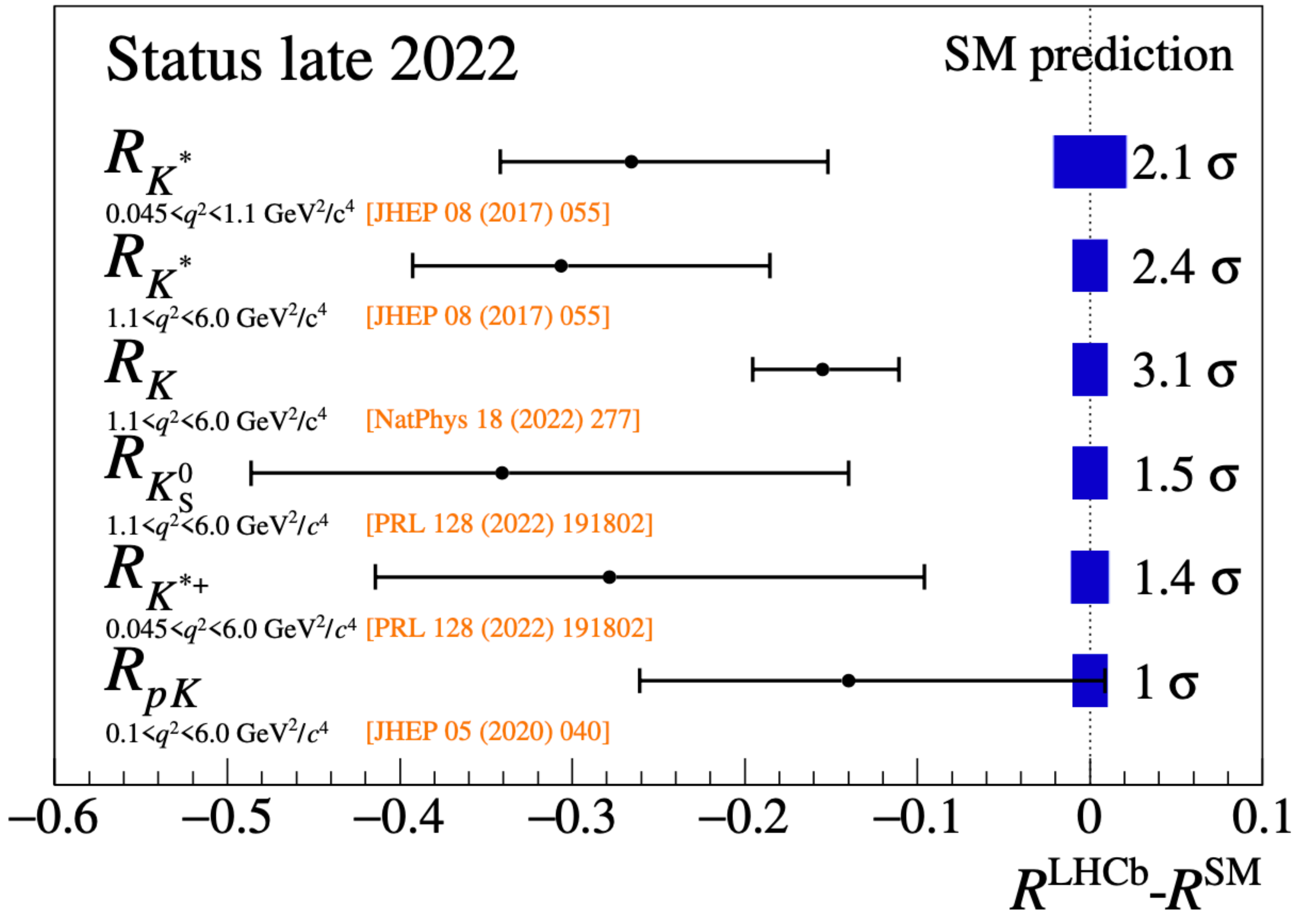


As EXP clean as possible…

$r^{-1}_{J/\psi}=1$ [PRD 88 (2013) 3]

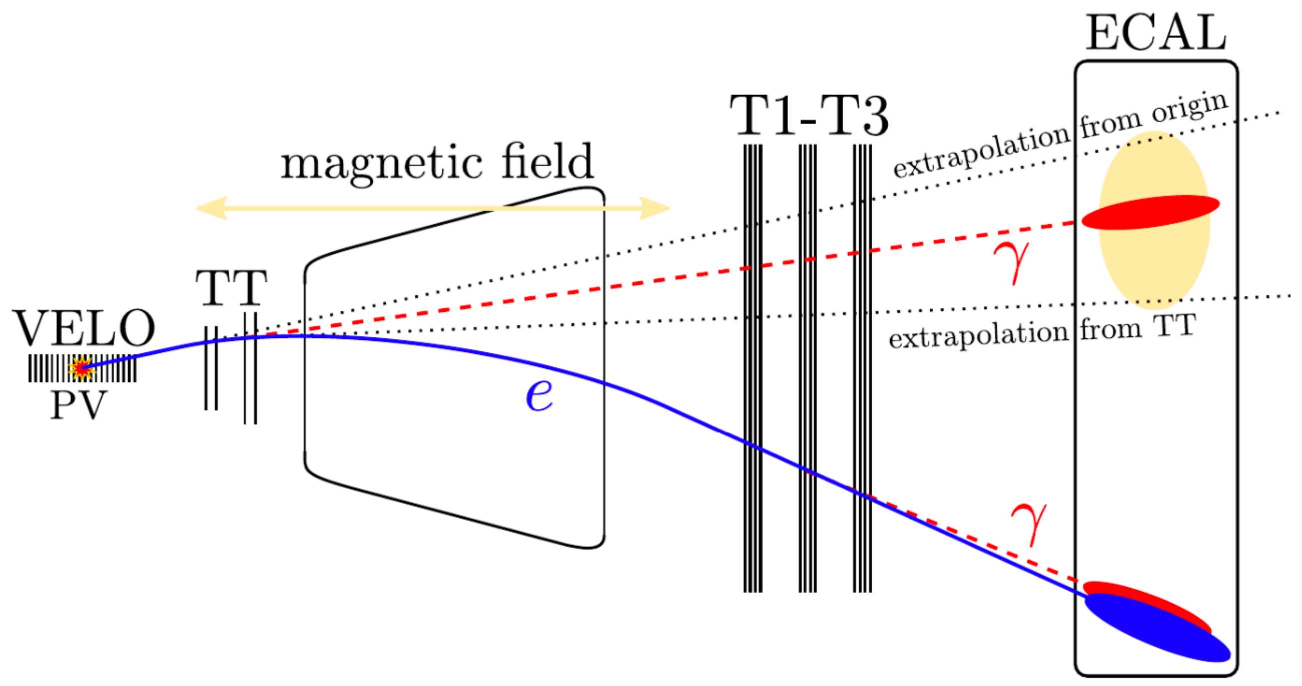
$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+ e^+e^-)} \times \frac{\mathcal{B}(B^+ \to K^+ J/\psi\,(\to e^+e^-))}{\mathcal{B}(B^+ \to K^+ J/\psi\,(\to \mu^+\mu^-))}$$

Lepton Universality Tests
clean



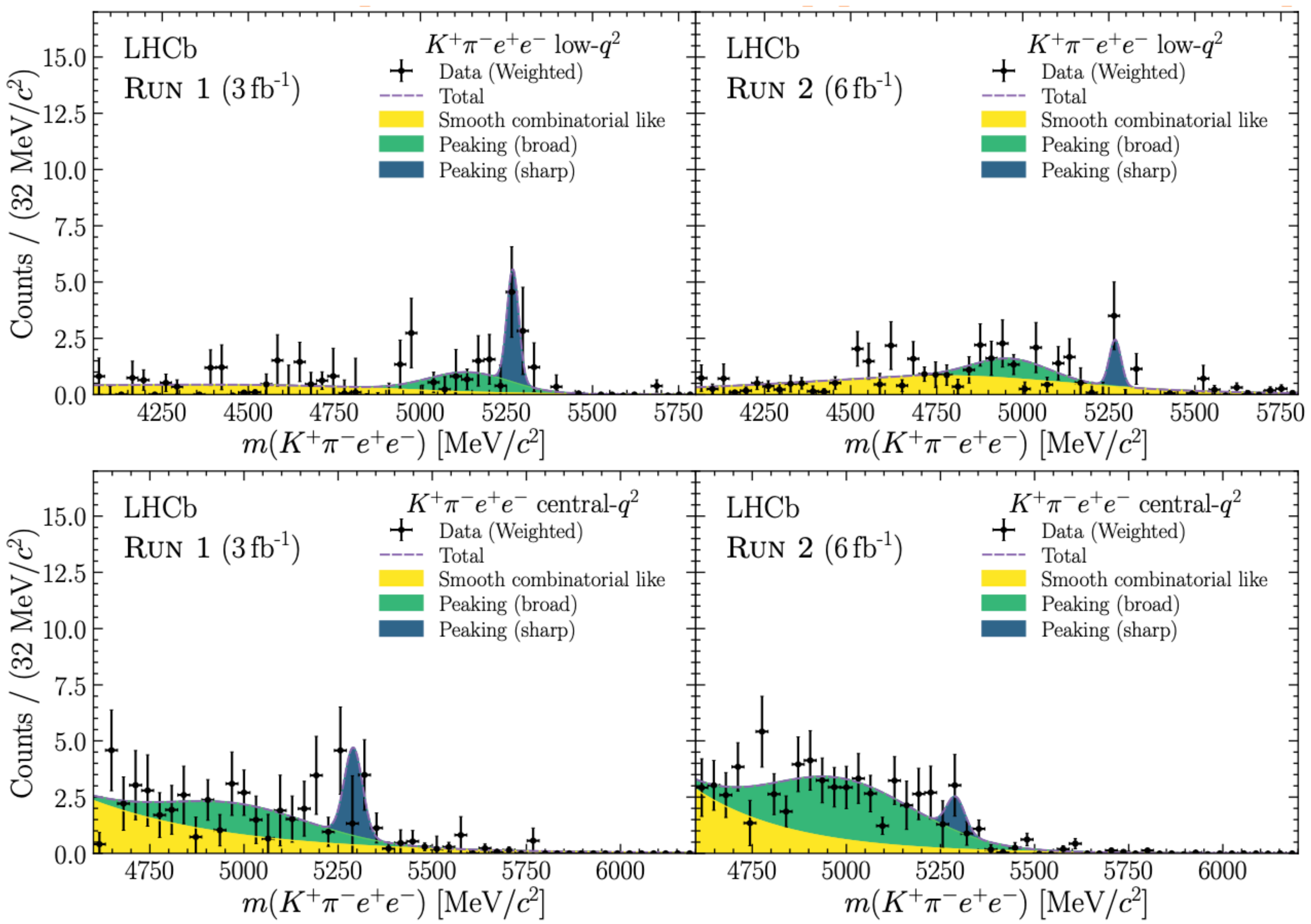
*Penguin diagrams

Lepton Flavour Universality



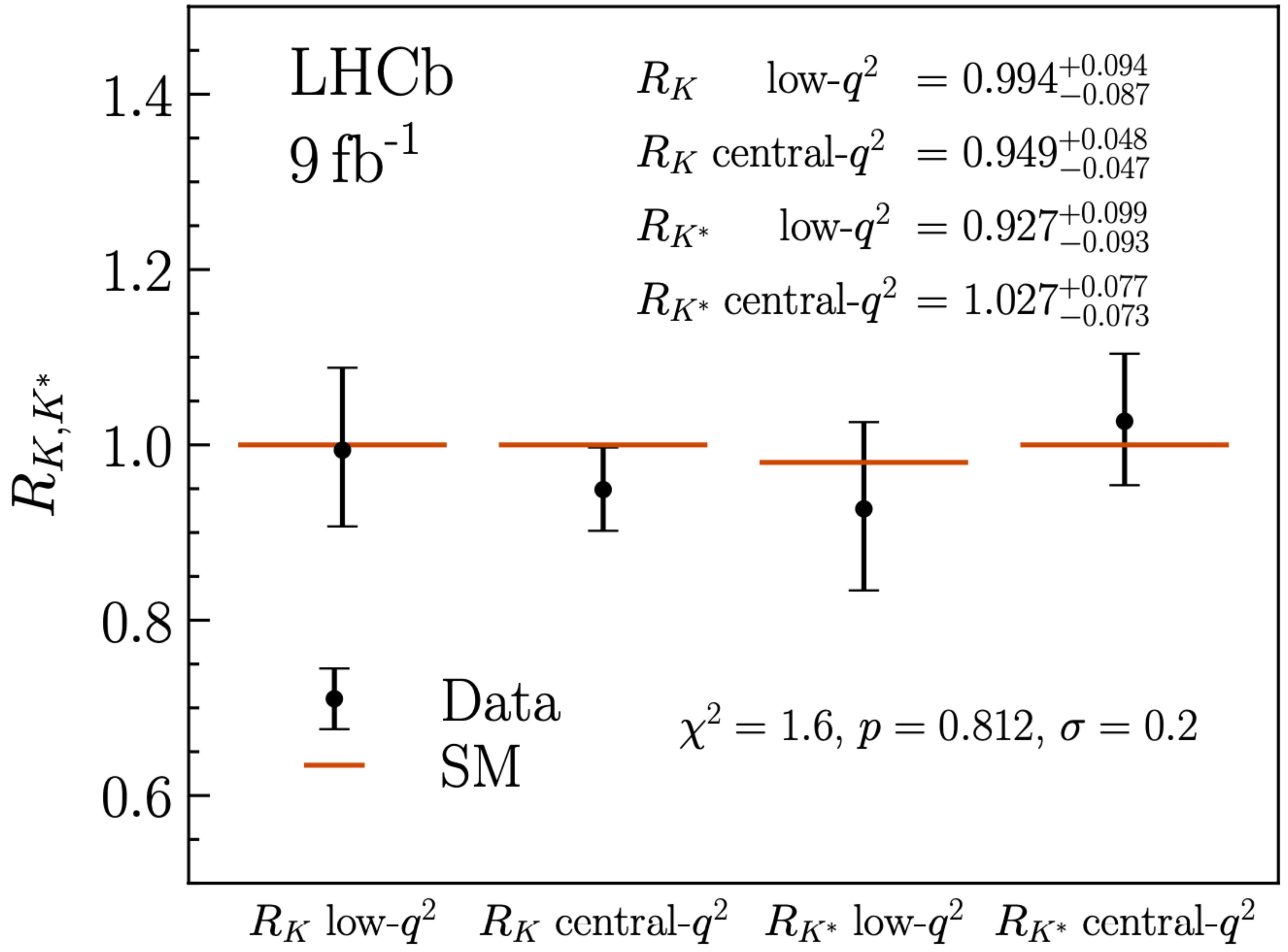
Experimentally electrons are very different than muons and intricate to reconstruct!

Sneaky backgrounds peaking in B mass but at low q^2 were not identified yet (e.g. KKK, $K\pi\pi$)



With a new tighter electron identification and taking into account all backgrounds, measurements are in perfect agreement with the SM!

[arXiv:2212.09152] [arXiv:2212.09153]

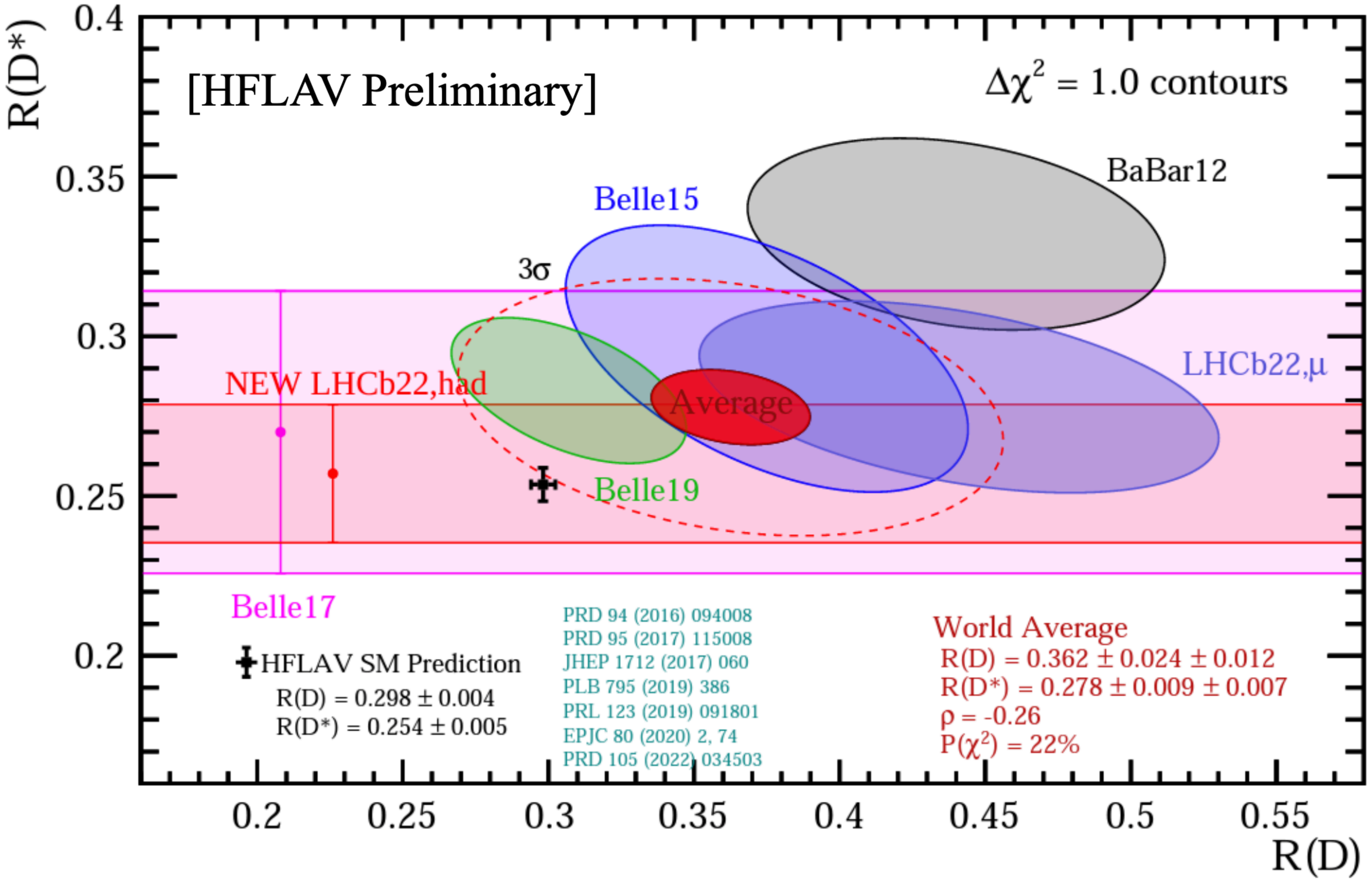


Lepton Flavour Universality in $b \to c\ell\nu$*

LHCb measurement of RD*

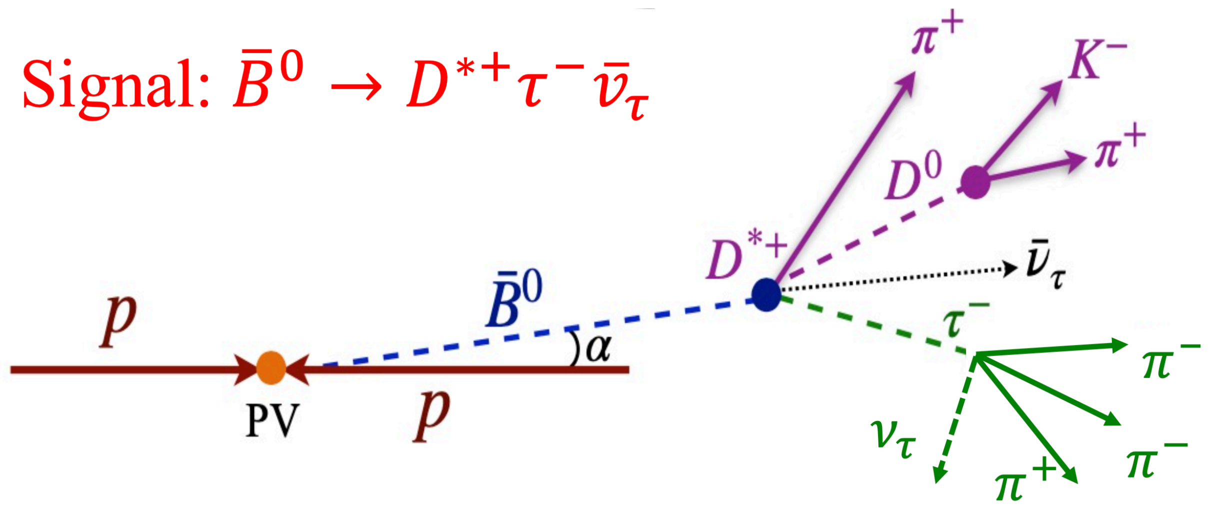
$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}\left(B^0 \to D^{(*)-}\tau^+\nu_\tau\right)}{\mathcal{B}\left(B^0 \to D^{(*)-}\mu^+\nu_\mu\right)}$$

Both TH and EXP clean!



Two updates from LHCb:

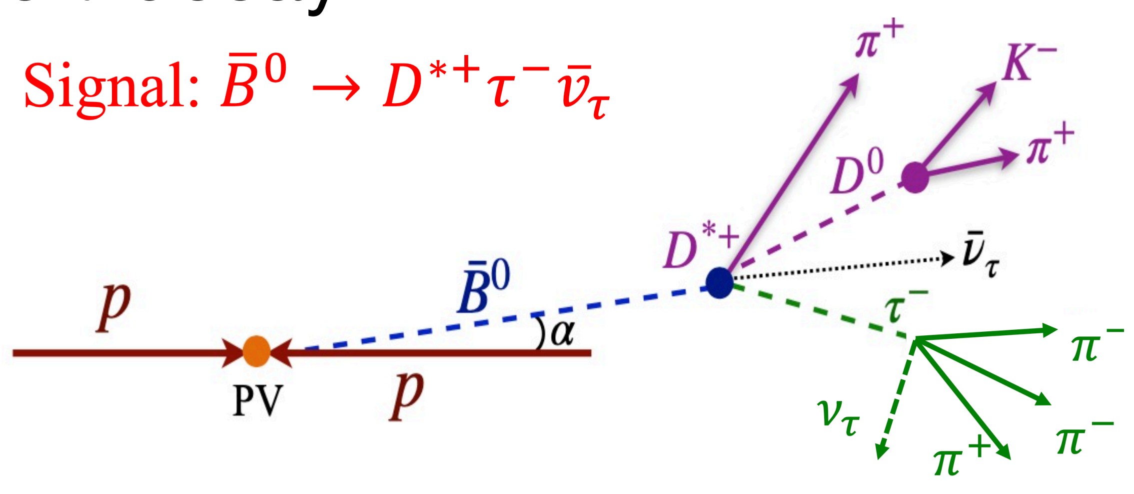
- Combined measurement of $\boldsymbol{R(D)}$ and $\boldsymbol{R(D*)}$ with a muonic $\boldsymbol{\tau}$ decay



1. 9σ tension with SM WA:3.3σ →**3.2σ wrt SM**

- $\boldsymbol{R(D*)}$ with a hadronic $\boldsymbol{\tau}$ decay!

New for Moriond EW 2023



No tension with SM WA:3.2σ →**3.0σ wrt SM**

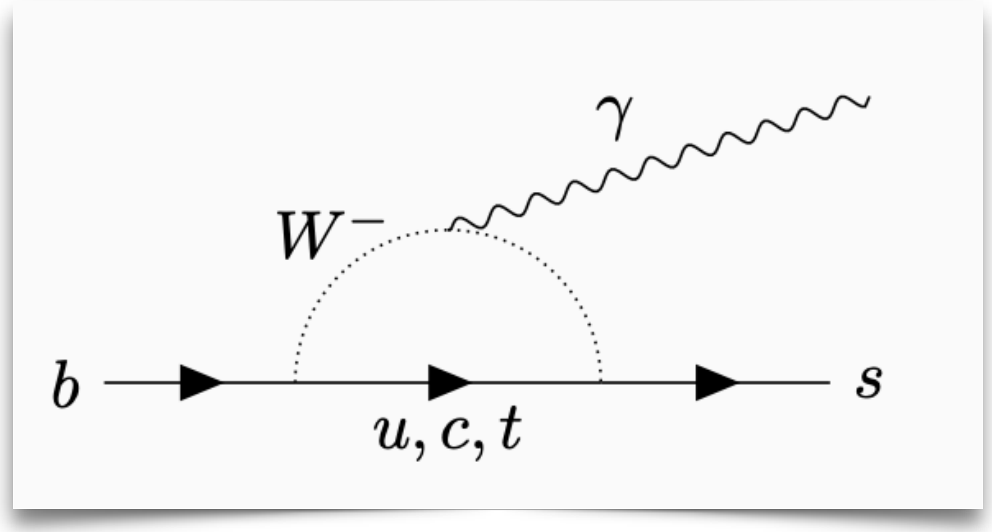
The new precise LHCb measurement of $\boldsymbol{R(D*)}$ does not show any tension, still present in the more challenging $\boldsymbol{R(D)}$ channel

*Tree level decay

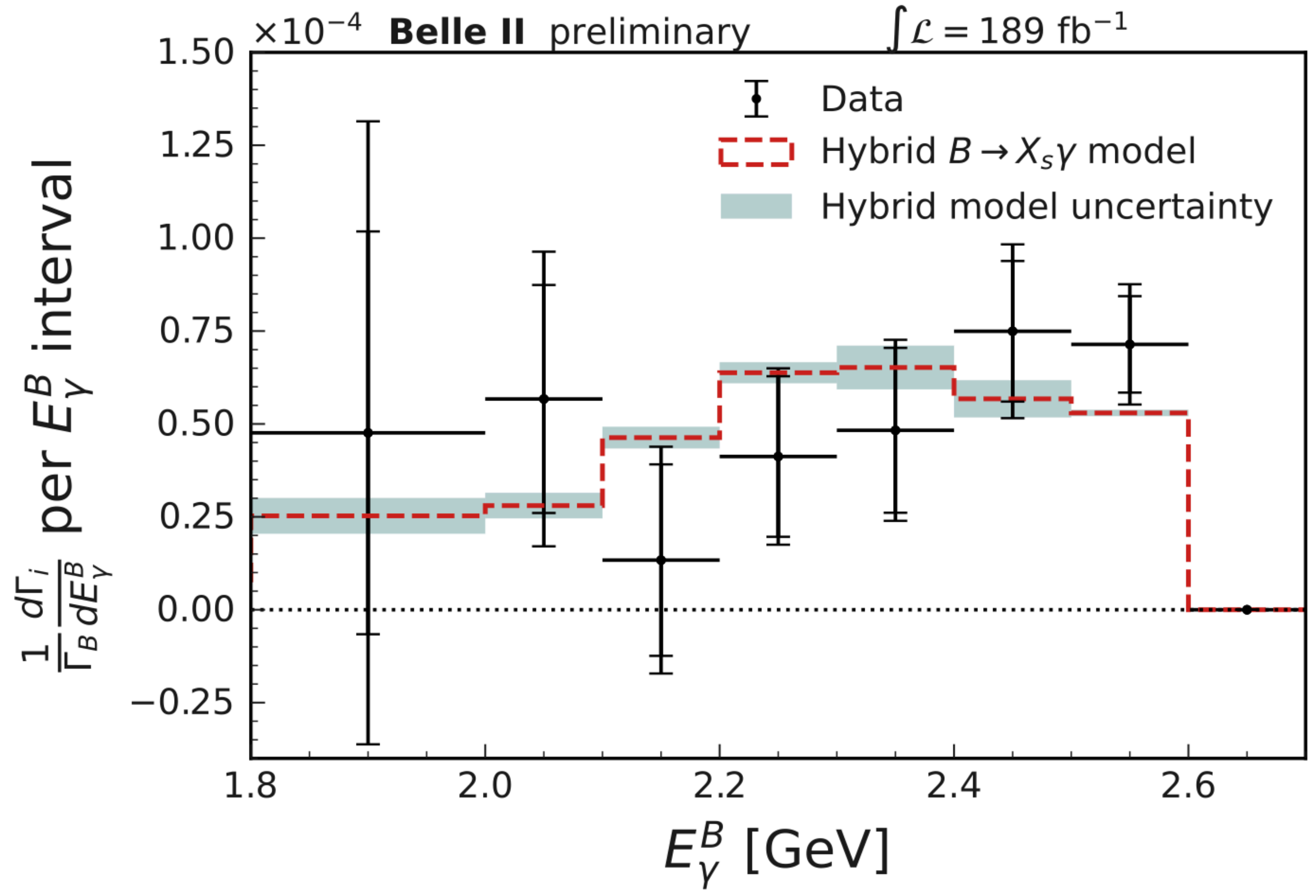
More Studies of $b \to s$ Transitions in Belle II

Cyrille Praz

Fully inclusive $B \to X_s\gamma$ with hadronic tagging

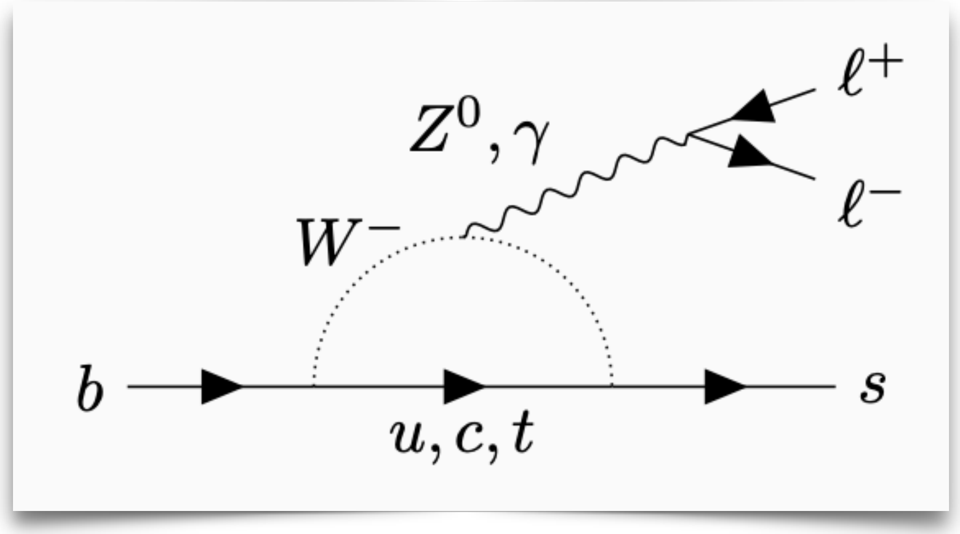


New for Moriond EW 2023

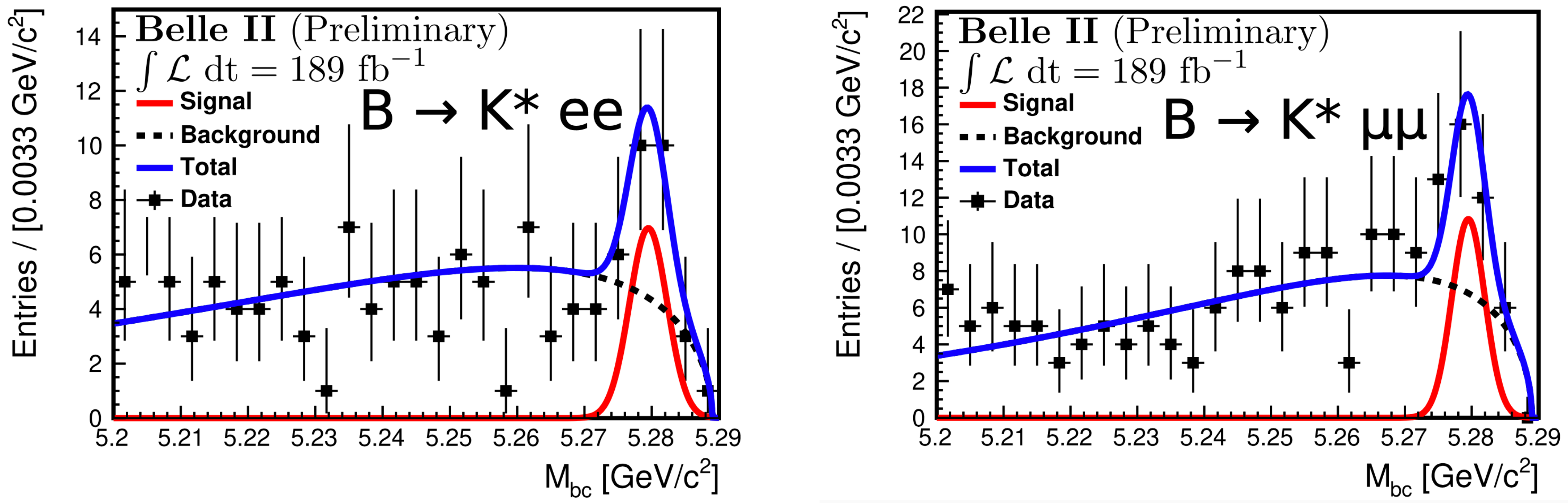


Sensitive to non-SM effects and photon-energy spectrum offers access the mass of the b quark and the function describing its motion inside the B meson!

branching fraction for the decay $B \to K^*\ell^+\ell^-$



New for Moriond EW 2023



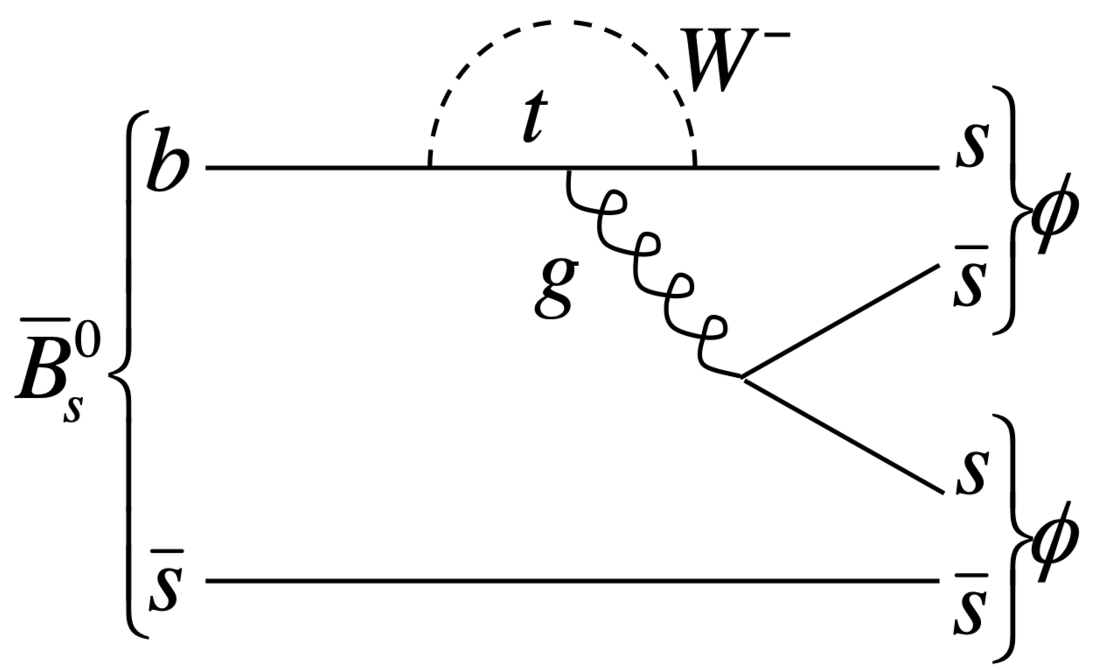
Observable	Signal Yield	Measured value $[10^{-6}]$	PDG $[10^{-6}]$
$\mathcal{B}(B \to K^*\mu^+\mu^-)$	22 ± 6	$1.19 \pm 0.31^{+0.08}_{-0.07}$	1.06 ± 0.09
$\mathcal{B}(B \to K^*e^+e^-)$	18 ± 6	$1.42 \pm 0.48 \pm 0.09$	1.19 ± 0.20

Many more radiative FCNC B decay results to come!

CPV Measurements - Latest News (LHCb)

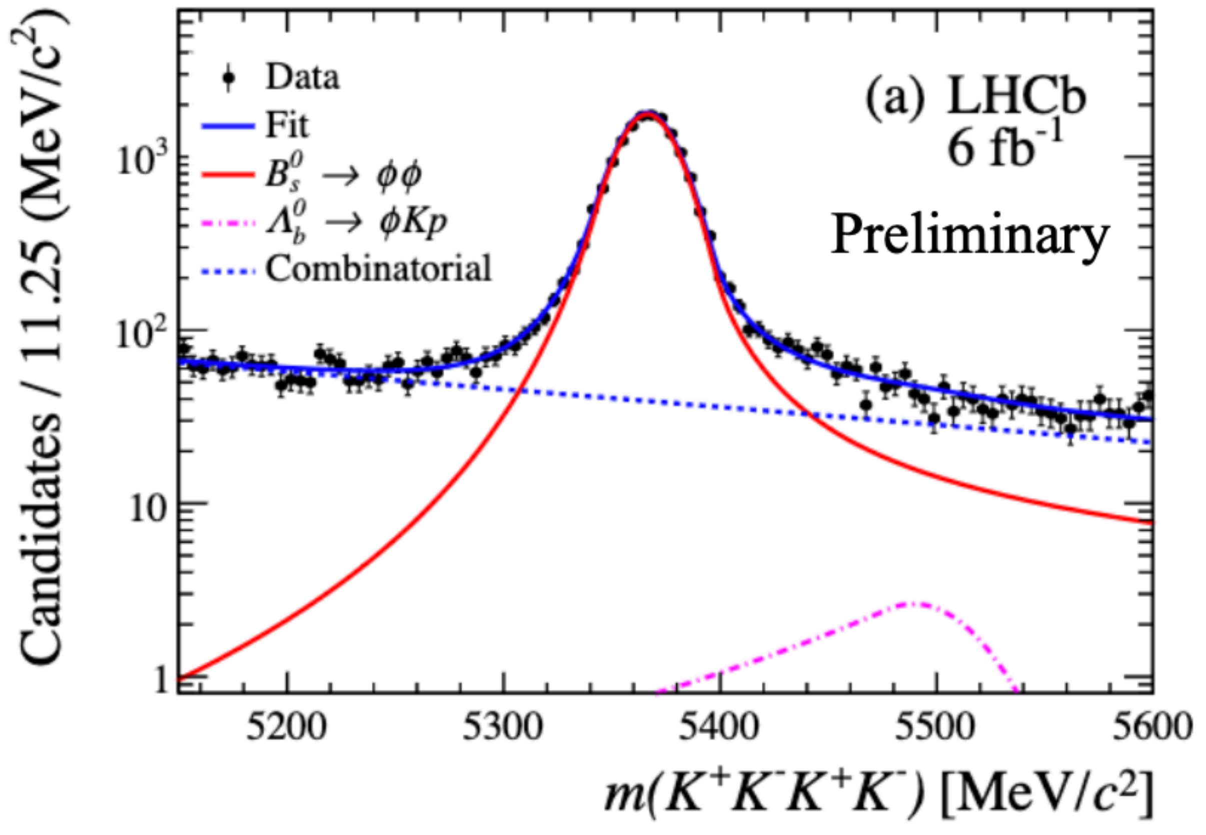
Time dependent CP Violation in interference between mixing and decay (in $b \to s$ transition)

$b \to s s \bar{s}$



B_s^0-$\bar{B}_s^0$

New for Moriond EW 2023



From fit of the differential cross section as a function of decay time and angular distribution

$\phi_s^{s\bar{s}s} = (-0.074 \pm 0.069)$ rad — CP violating phase (small in SM)

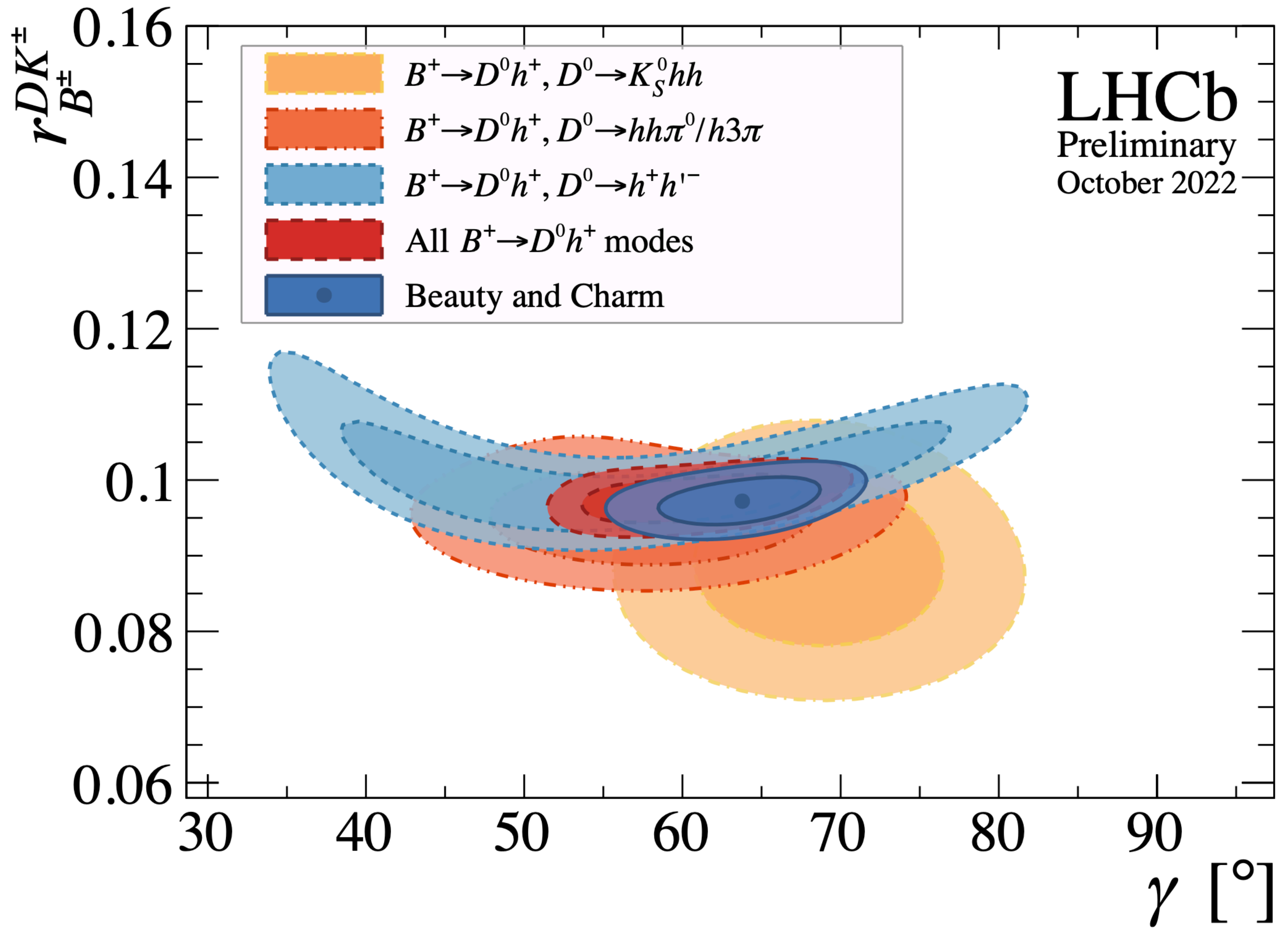
$|\lambda| = 1.009 \pm 0.030$ — Direct CP violating parameter (1 in the SM)

Also polarisation dependent results for the first time!

Also new measurement of γ in the channel:

$$B^{\pm} \to D[K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\mp}]h^{\pm}$$

As well as a overall combination with charm measurements leading to a precision in excess of 4 degrees on γ



$$\gamma = \left(63.8^{+3.5}_{-3.7}\right)^{\circ}$$

$\gamma = \left(65.7^{+0.9}_{-2.7}\right)^{\circ}$ CKMfitter

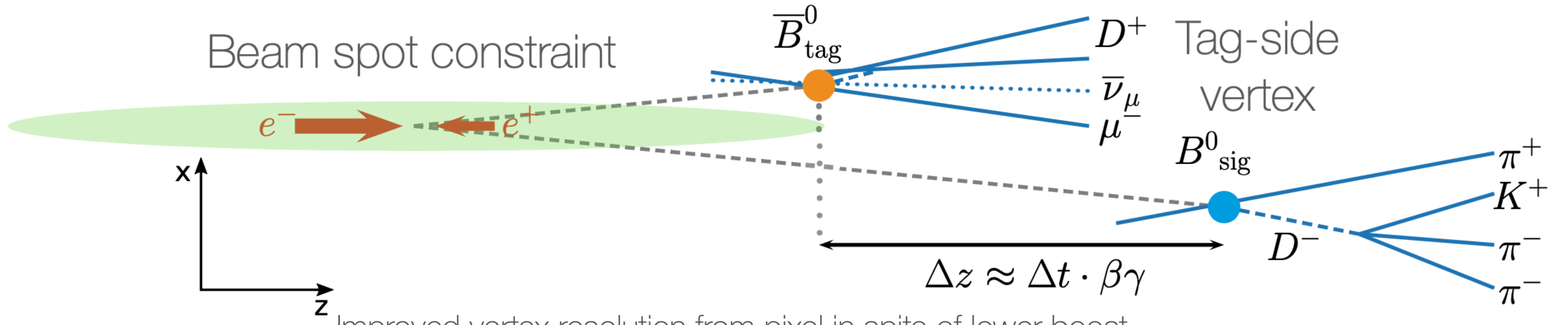
$\gamma = \left(65.8 \pm 2.2\right)^{\circ}$ UTFit

CPV Measurements - Latest News (Belle II)

Michele Veronesi and Sagar Hazra

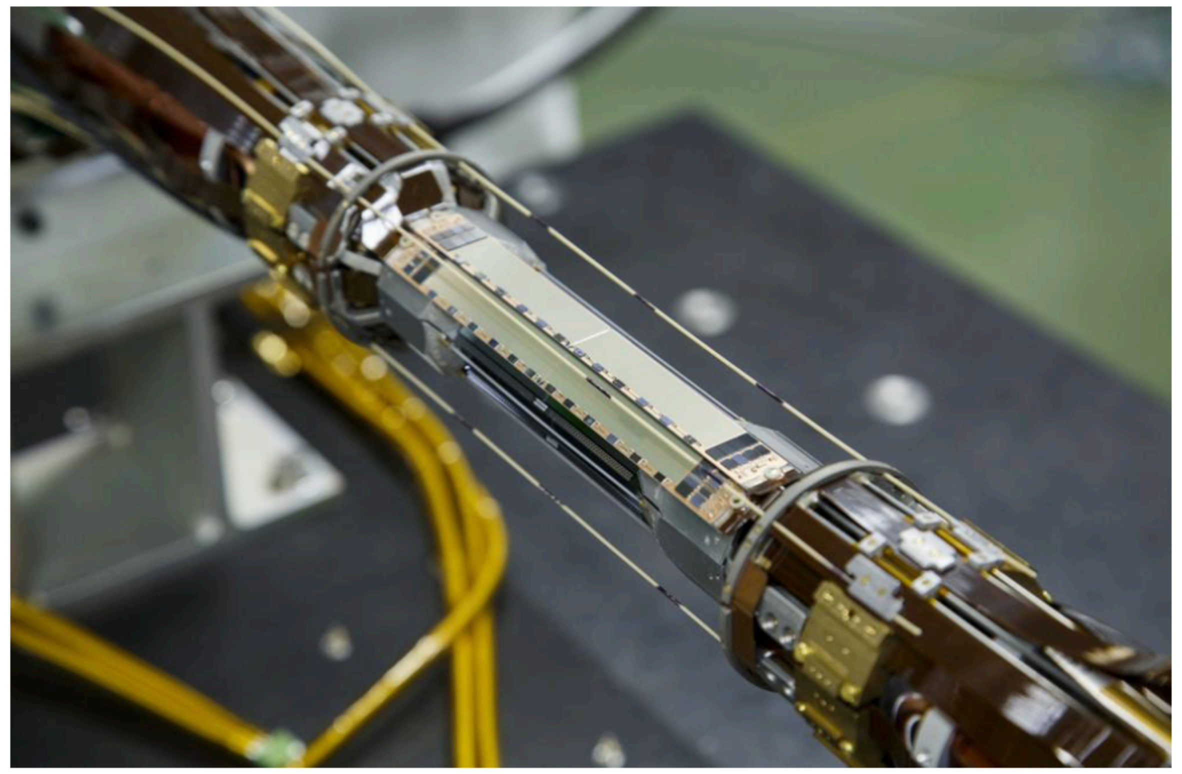
3 new results on time-dependent CP observables with penguins for Moriond

Precision on par with world's best determinations in spite of much less luminosity



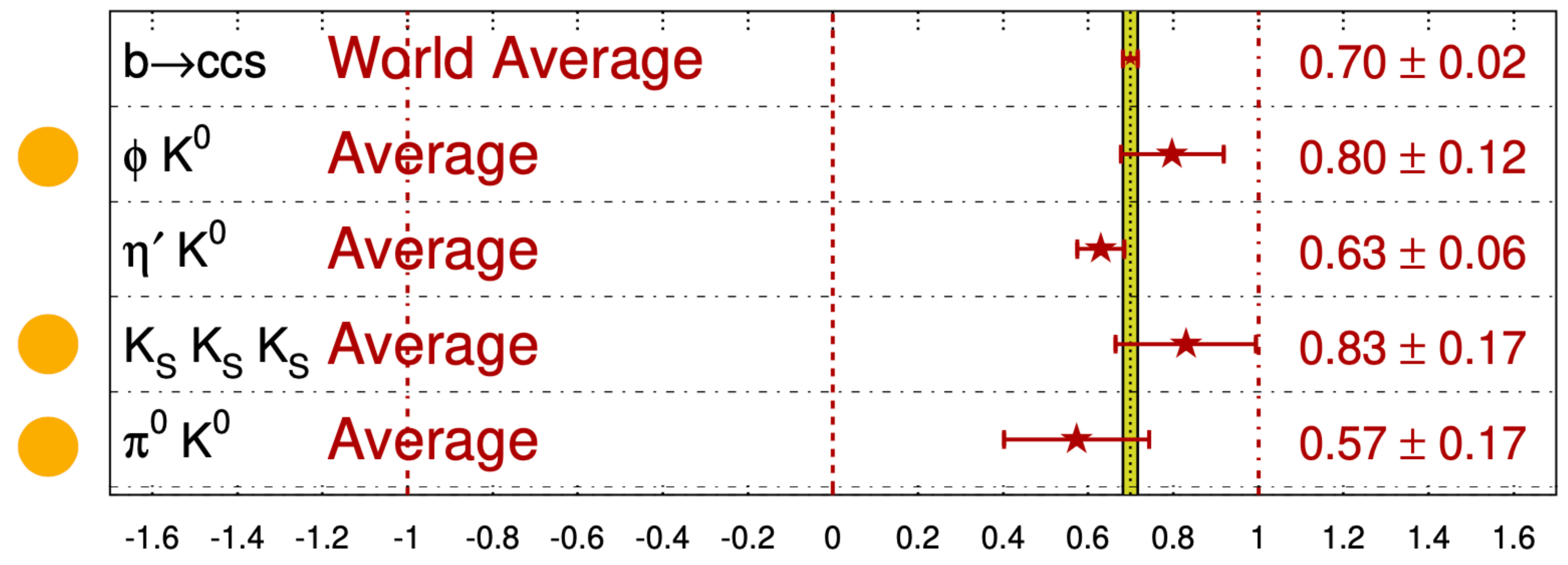
Improved vertex resolution from pixel in spite of lower boost

- Belle: βγ=0.43, Δz≈200μm —> Belle II: βγ=0.29, Δz≈130μm



Pixel detector radius ≈ 1.4 cm

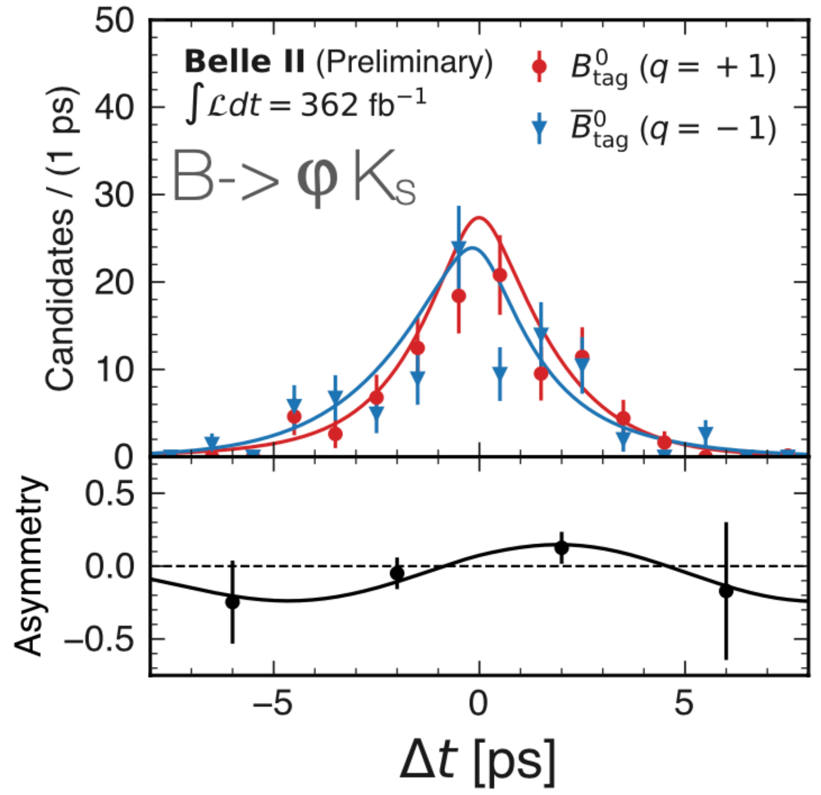
$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$



NEW FOR MORIOND

Results are already on-par or comparable with world's best and illustrate how with much less luminosity, the improved performance of Belle-II.

New for Moriond EW 2023

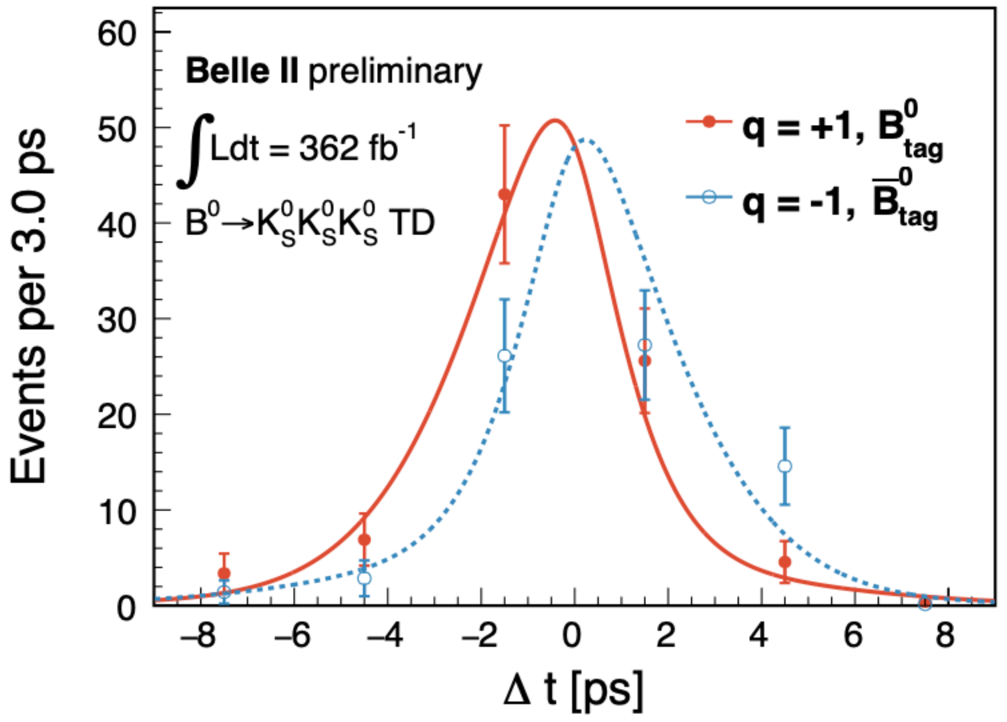


B-> φ KS

$$A_{CP} = 0.31 \pm 0.20^{+0.05}_{-0.06}$$
$$S_{CP} = 0.54 \pm 0.26^{+0.06}_{-0.08}$$

HFLAV: S = $0.74^{+0.11}_{-0.13}$, A = -0.01±0.14

New for Moriond EW 2023

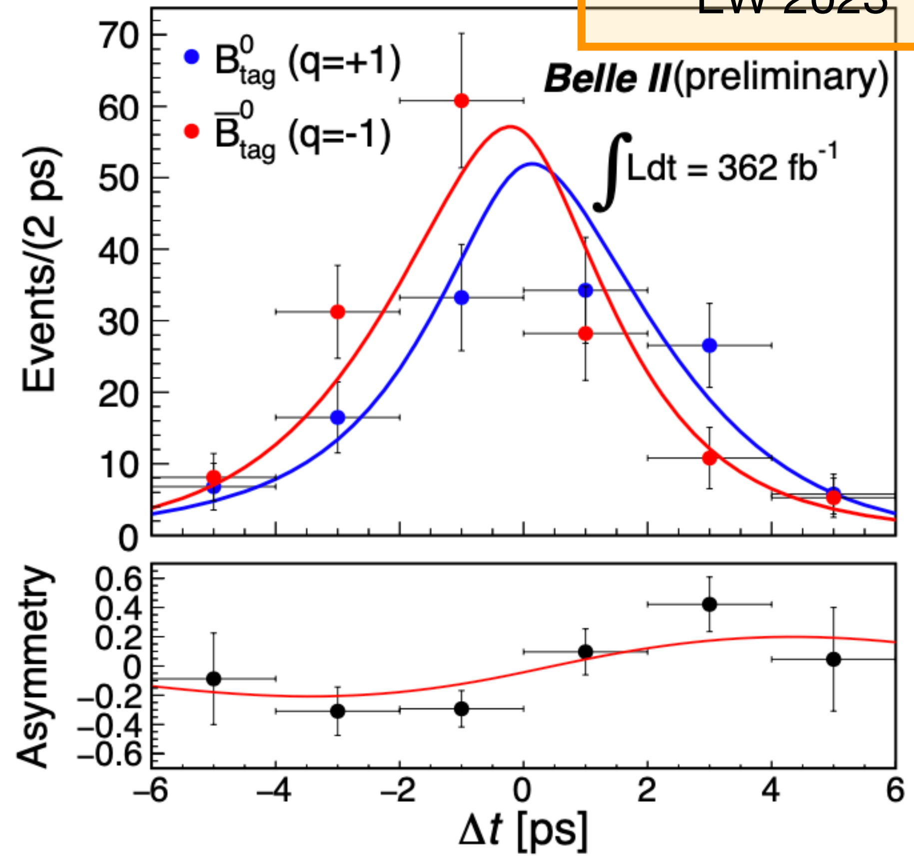


B->KSKSKS

$$A_{CP} = 0.07^{+0.15}_{-0.20} \pm 0.02$$
$$S_{CP} = -1.37^{+0.35}_{-0.45} \pm 0.03$$

HFLAV: S = -0.83±0.17, A = 0.15±0.12

New for Moriond EW 2023

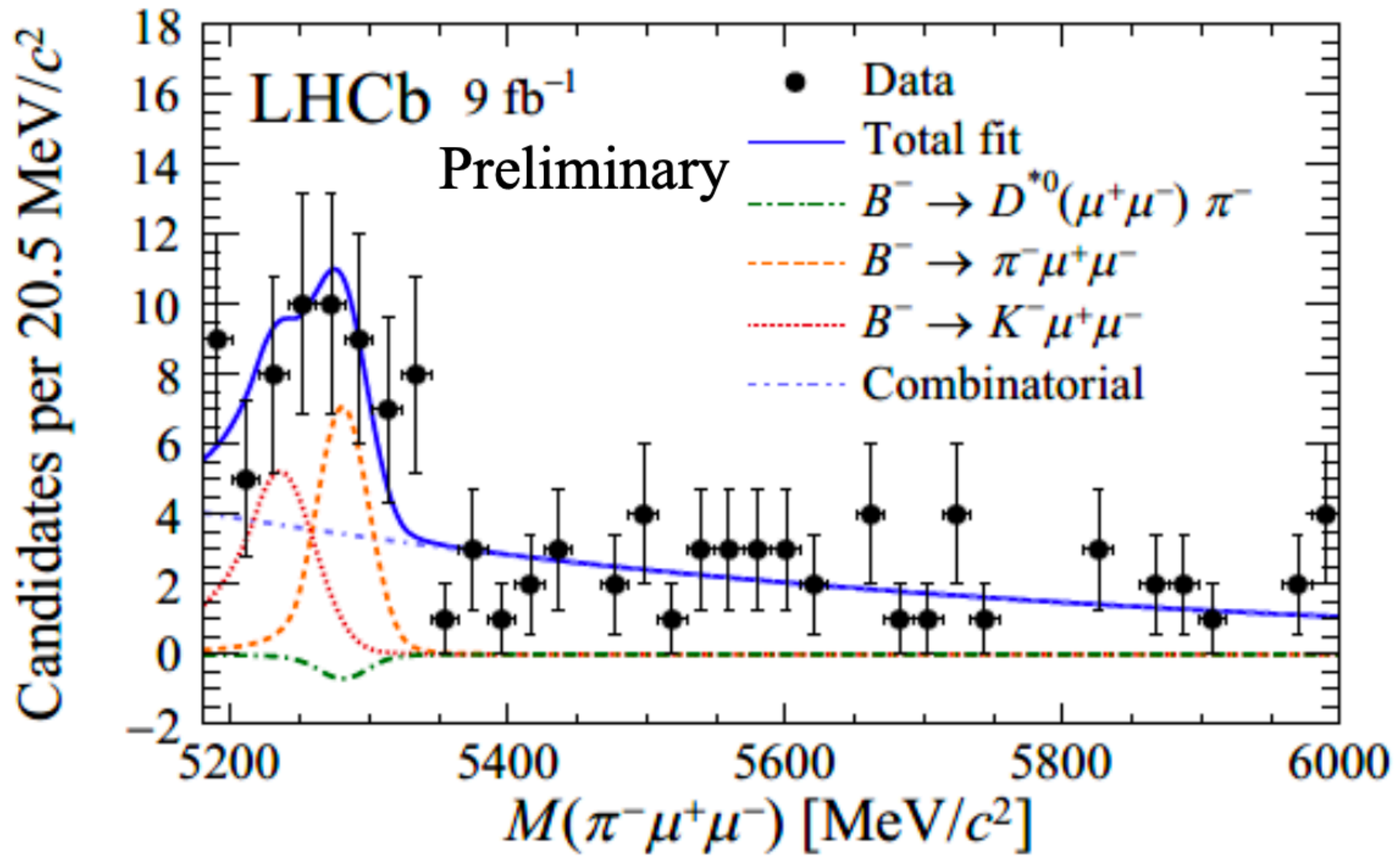


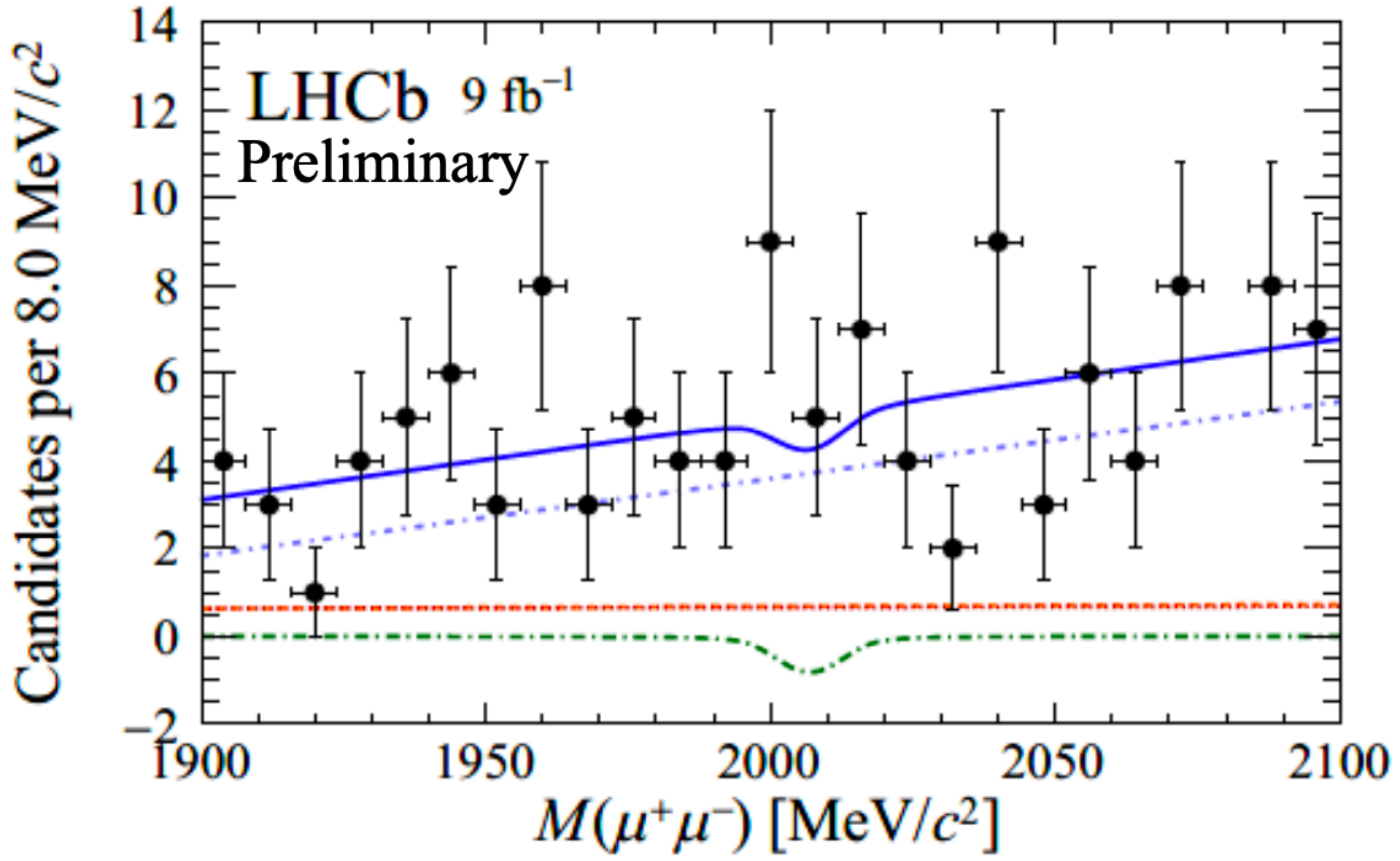
B->KSπ0

$$A_{CP} = 0.04 \pm 0.15 \pm 0.05$$
$$S_{CP} = 0.75^{+0.20}_{-0.23} \pm 0.04$$

HFLAV: S = 0.57±0.17, A = -0.01±0.10

(Very) rare charm decays in LHCb





Expected level of suppression

- $D^0 \to \mu^+\mu^-$
- $D^{*0} \to \mu^+\mu^-$ (new!)
- $B^0_{(s)} \to p\,\mu^-$
- $B^0 \to K^{*0}\tau^\pm\mu^\mp$

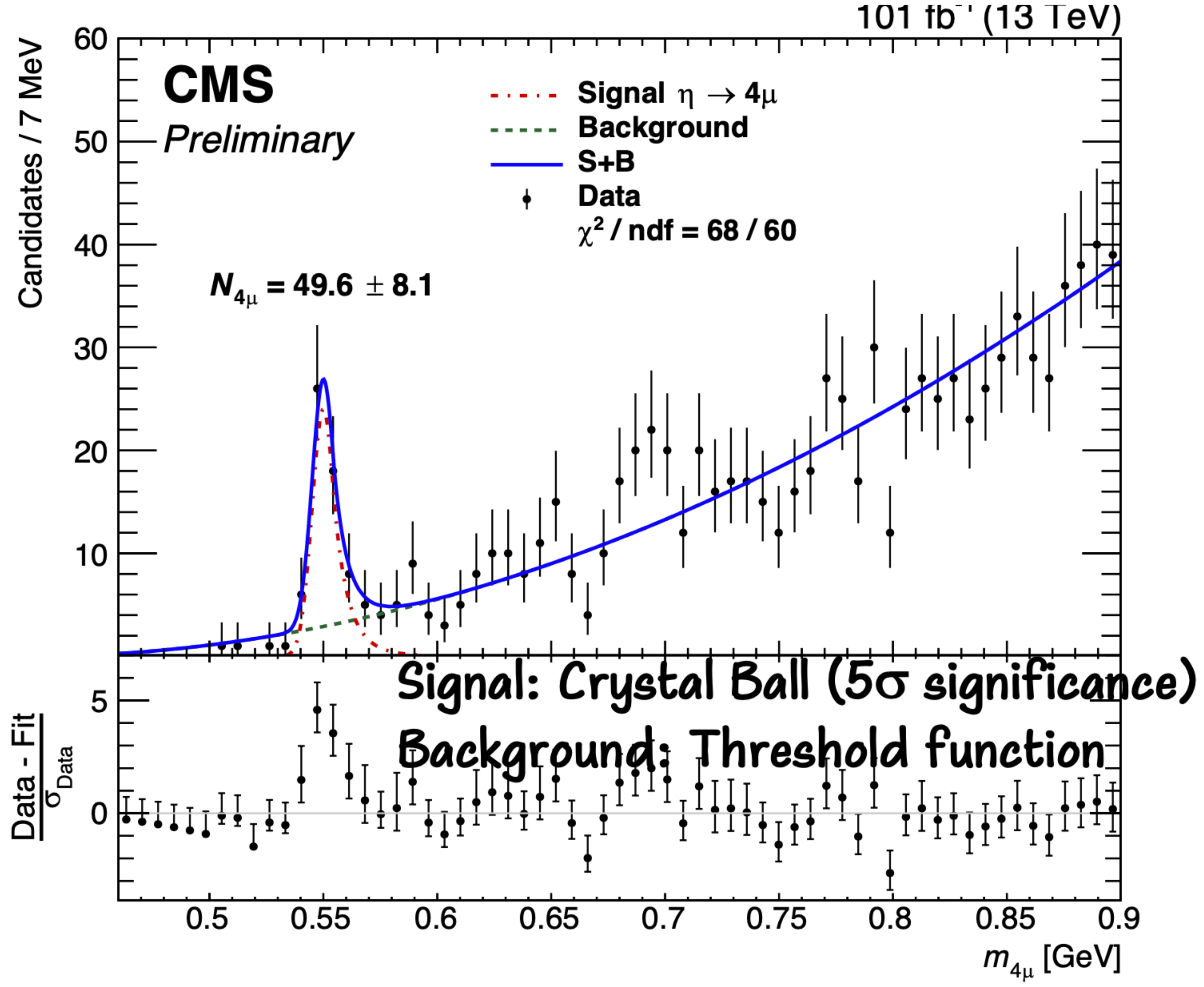
$$\mathcal{B}(D^{*0} \to \mu^+\mu^-) < 2.6\,(3.4) \times 10^{-8} \text{ at } 90\ (95)\% \text{ CL}$$

B-Physics at ATLAS and CMS

Observation of $\eta \to 4\mu$ narrow resonance Mass of 548 MeV (using high rate **low threshold triggers**)

$$\eta = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$$

10^{-9}

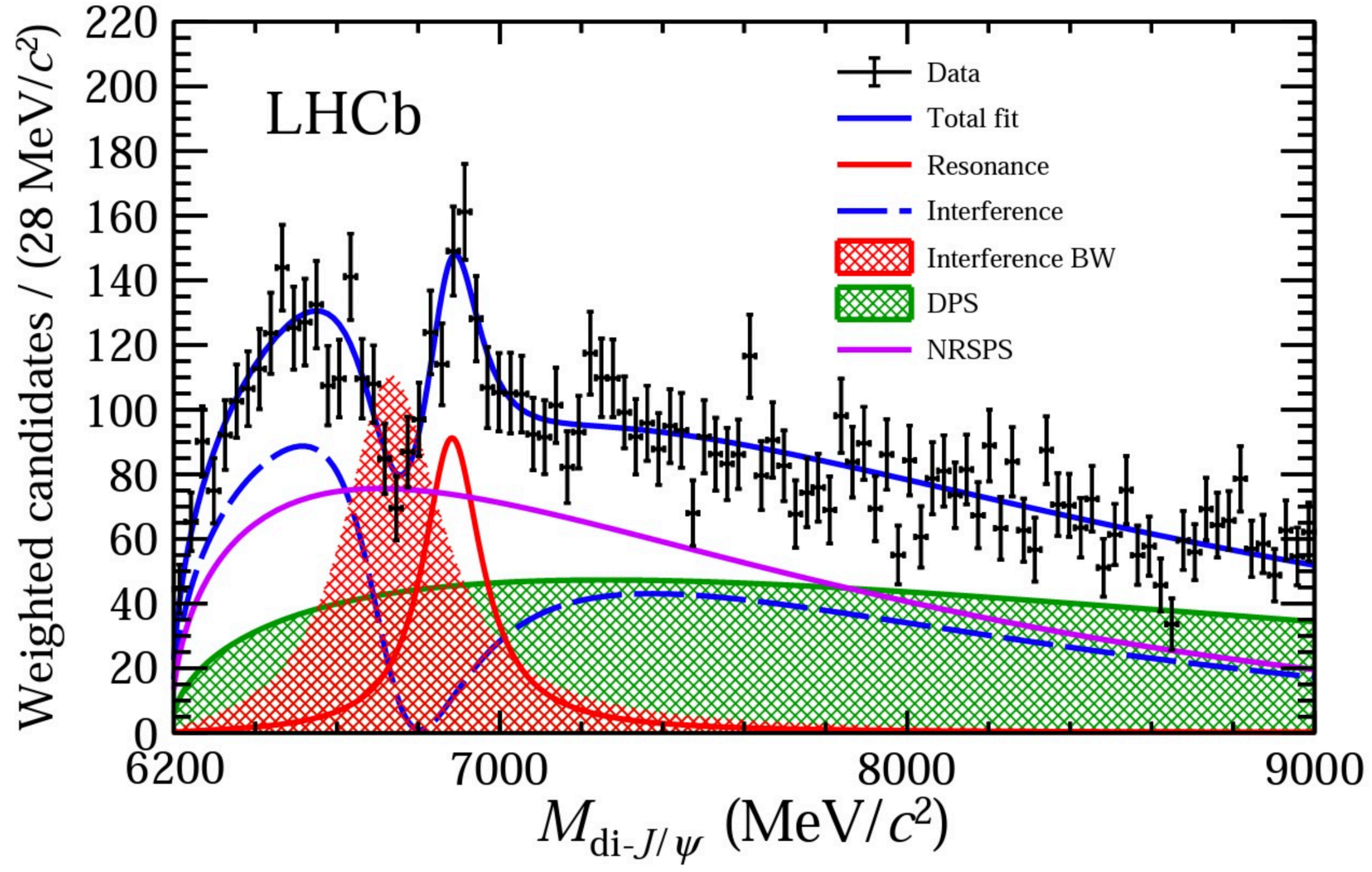


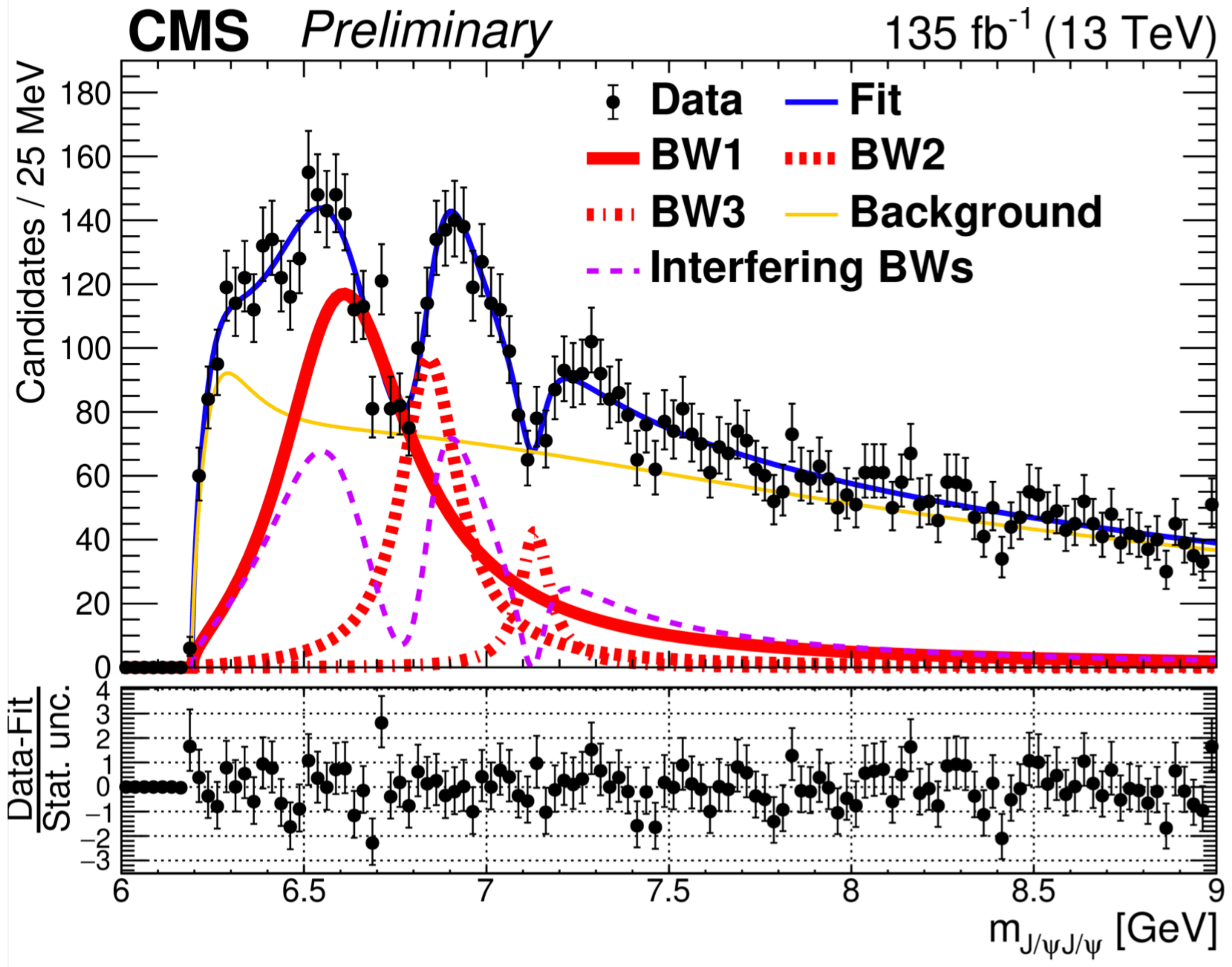
$$\mathcal{B}(\eta \to 4\mu) = (5.0 \pm 0.8\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.7\,(\mathcal{B})) \times 10^{-9}$$

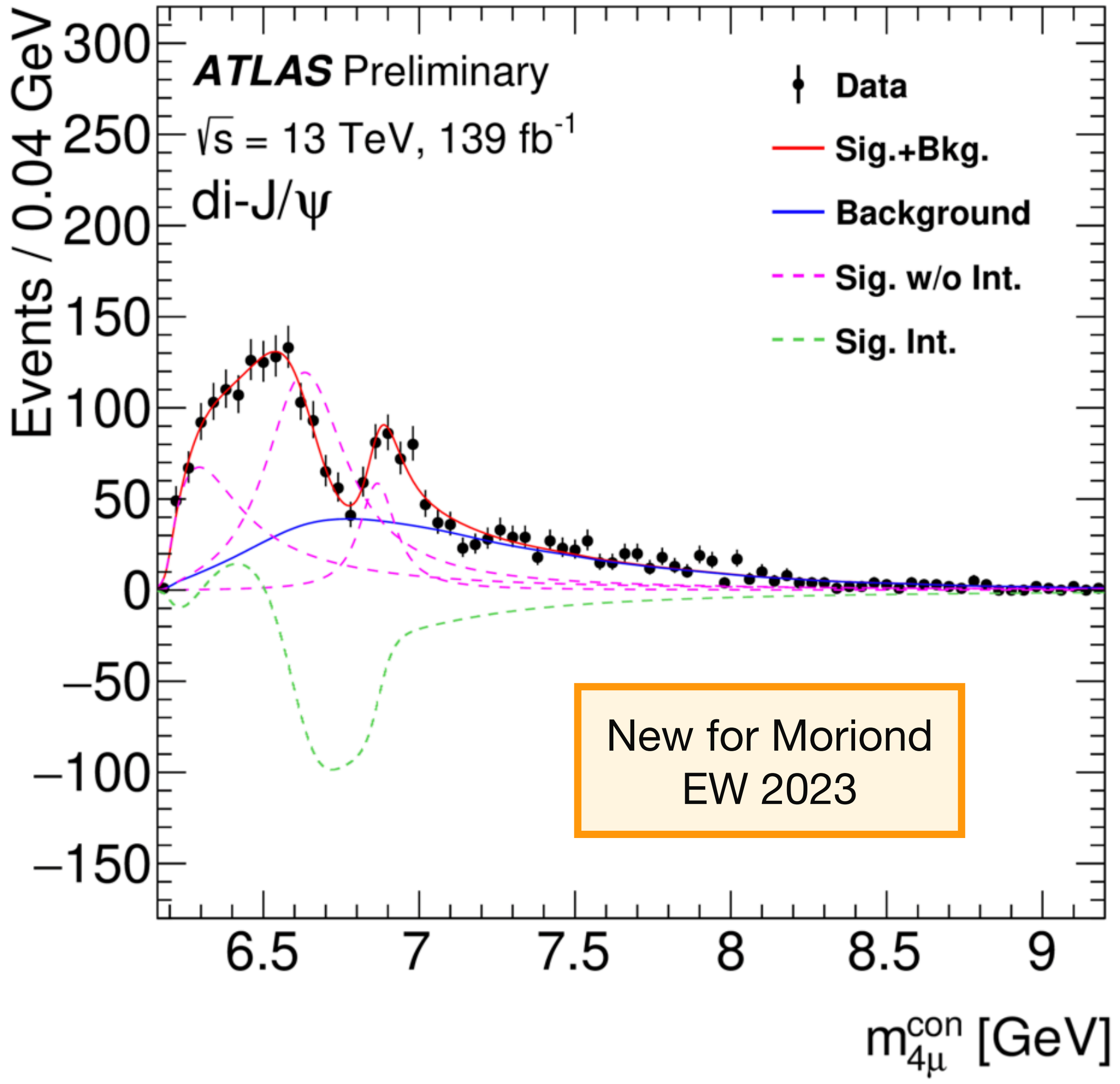
In agreement with SM: $(3.98 \pm 0.15) \times 10^{-9}$

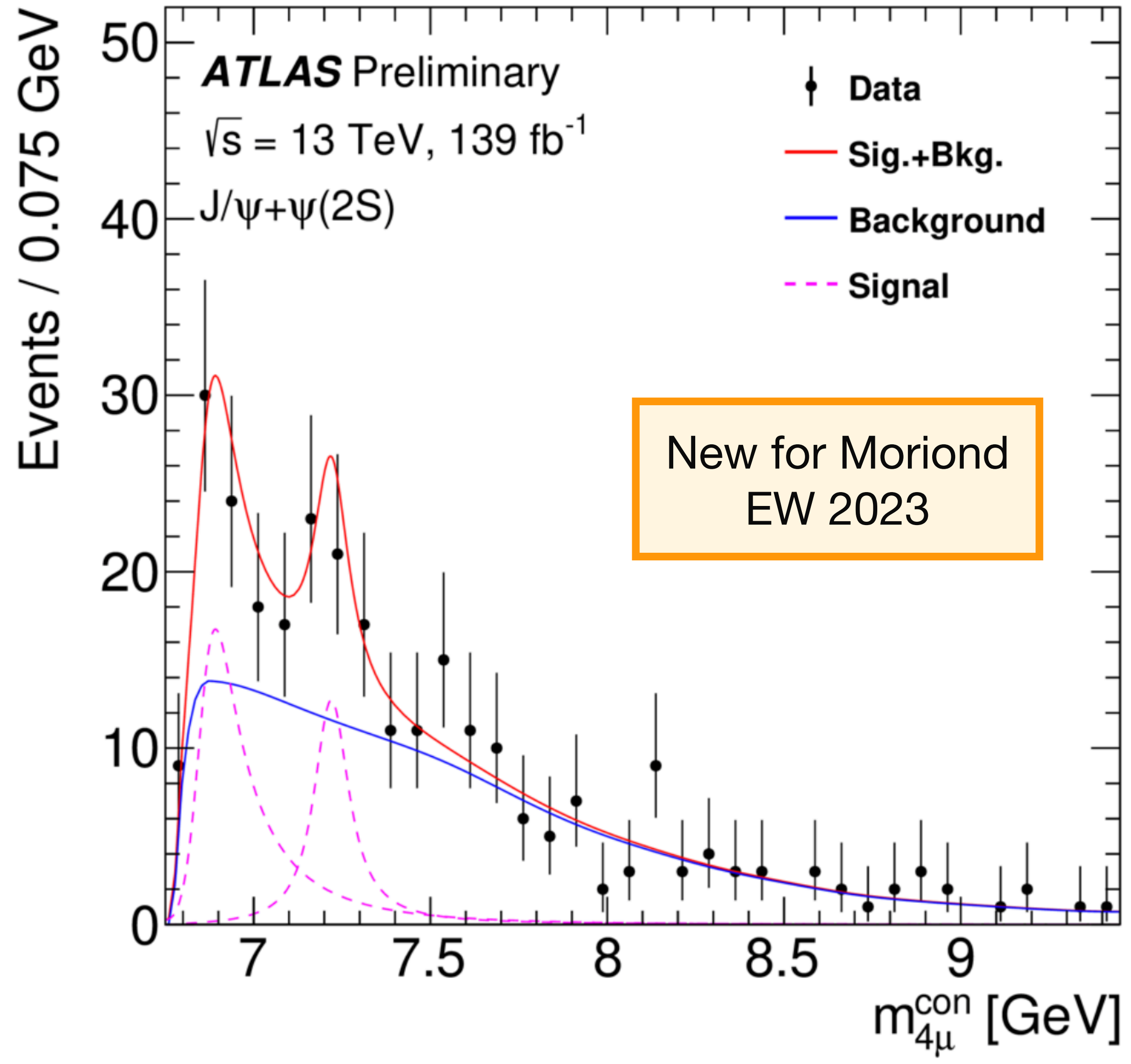
Di-Charmonium State Observation

Di-charmonium ($J/\psi J/\psi$, $J/\psi\psi_{2s}$) mass spectrum studied by CMS and ATLAS (following observation by LHCb).







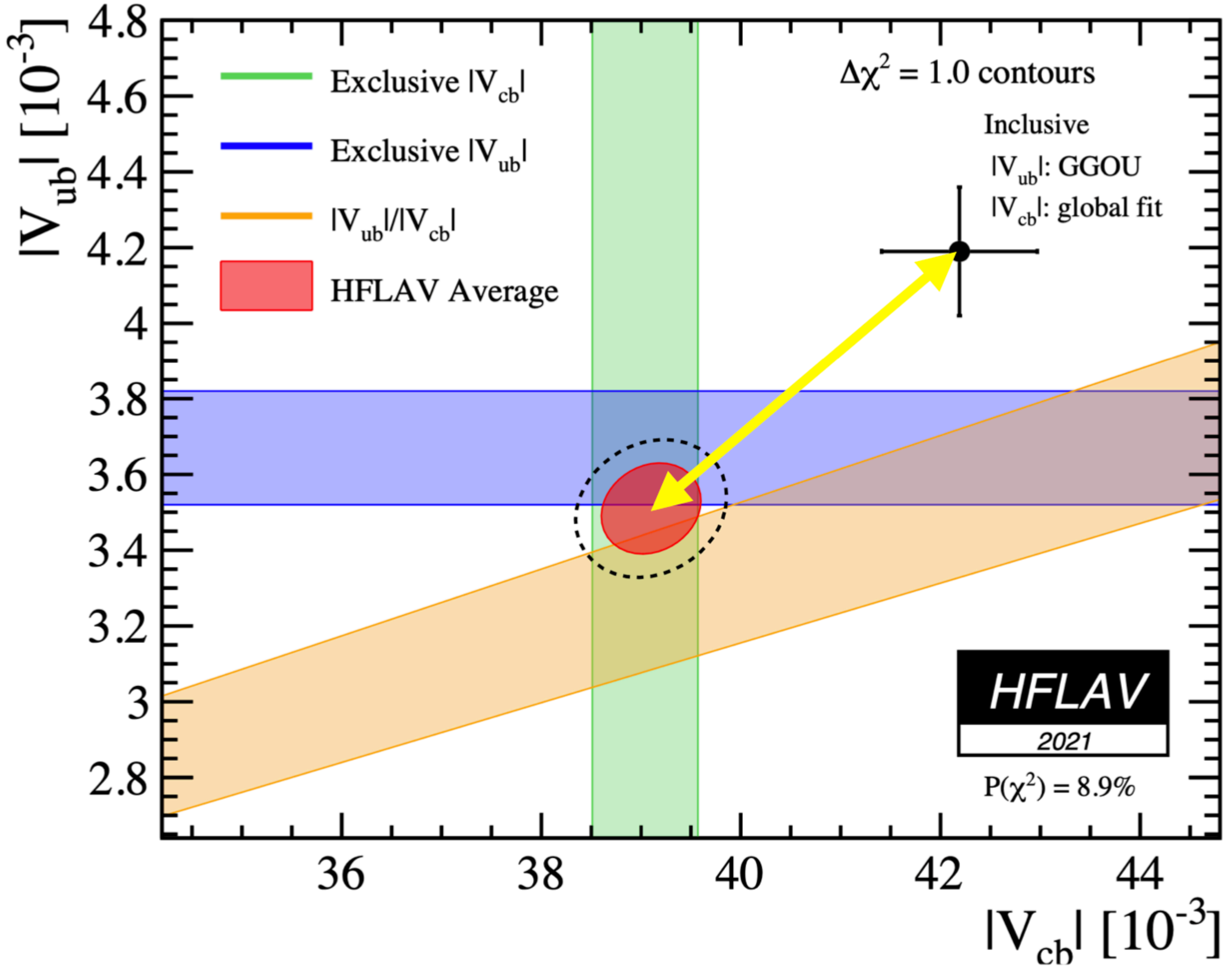


The detailed interpretation of the structures still have to be confirmed (four charm tetra quark?)

The Vub and Vcb Puzzle (Belle II)

New exclusive and untagged measurements at Belle II !

$|V_{cb}|$ and $|V_{ub}|$ discrepancy~3σ between exclusive and inclusive (have different TH uncertainties)!



Limiting factor in precision flavour physics!

New results from Belle II (only two examples here)…

New for Moriond EW 2023

$B \to \pi \ell \nu$

The golden mode for $|V_{ub}|$ exclusive

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.426 \pm 0.056(\mathrm{stat}) \pm 0.125(\mathrm{syst})) \times 10^{-4}$$

$$|V_{ub}|_{B^0 \to \pi^- \ell^+ \nu_\ell} = (3.55 \pm 0.12(\mathrm{stat}) \pm 0.13(\mathrm{syst}) \pm 0.17(\mathrm{theo})) \times 10^{-3}$$

New for Moriond EW 2023

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

Very new **untagged measurement** for this conference!

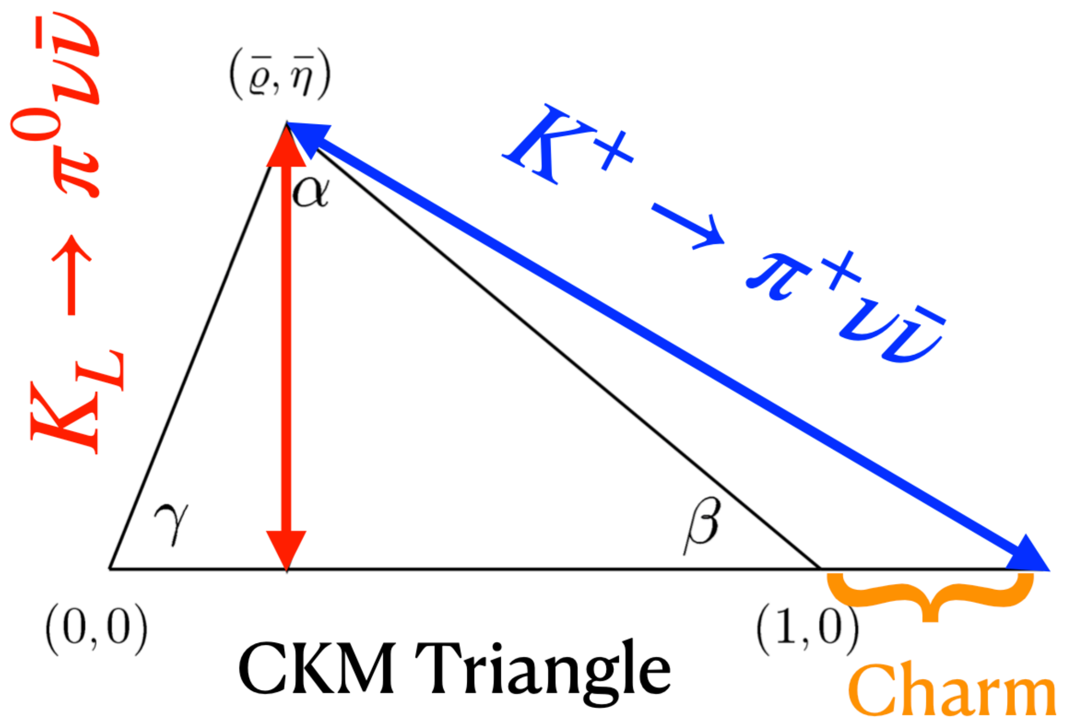
Reconstructing: $D^{*+} \to D^0(\to K^- \pi^+)\pi^+$

$$|V_{cb}| = (40.9 \pm 3.0_{\mathrm{stat}} \pm 1.0_{\mathrm{syst}} \pm 0.6_{\mathrm{th}})$$

Lubos Bician
Yu-Chen Tung

Direct CP Violation in K decays

Two very rare golden channels to probe CKM and New Physics!



$K^{\pm} \to \pi^{\pm}\nu\bar{\nu}$ by the NA62 experiment at CERN

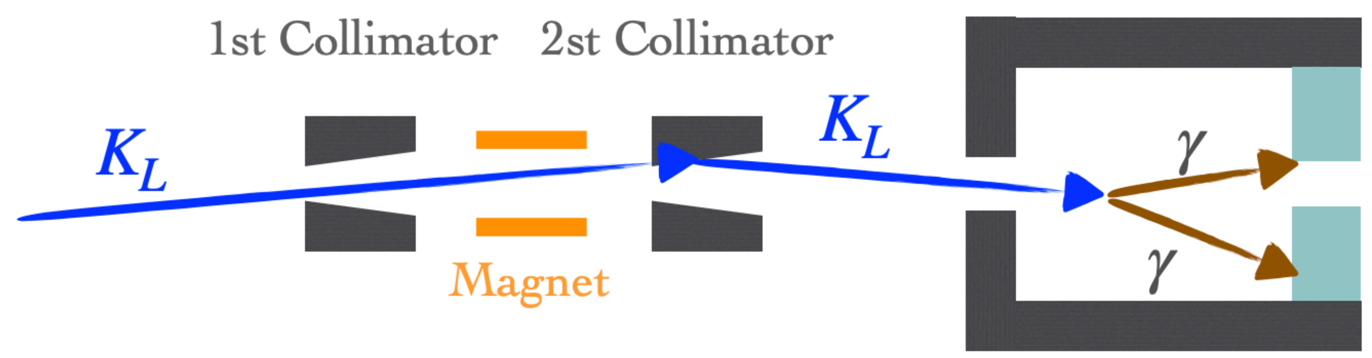
$K_L \to \pi^o \nu\bar{\nu}$ by the KOTO experiment at J-PARC

$BR(K_L \to \pi^0 \nu\bar{\nu})_{SM} = 3 \times 10^{-11}$ [Buras et al, JHEP 1511]

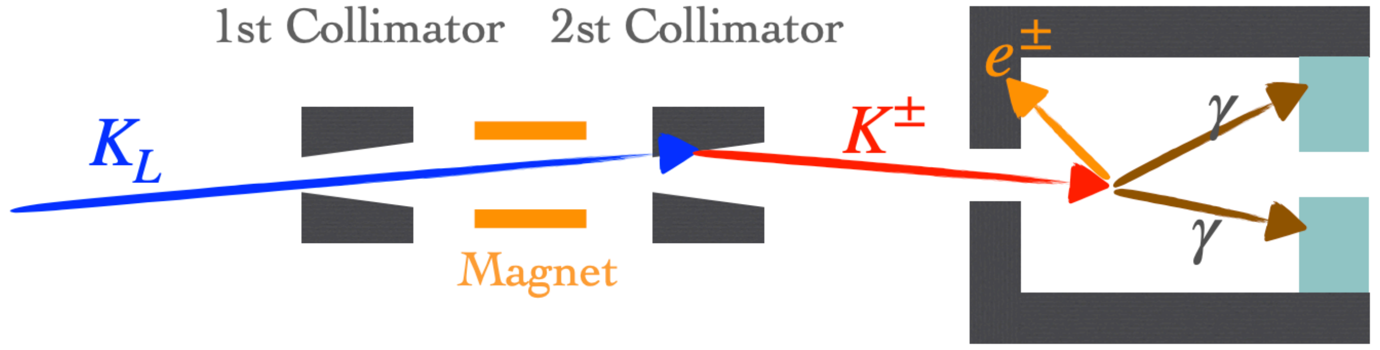
2% uncertainties

Two new backgrounds have been identified and studied:

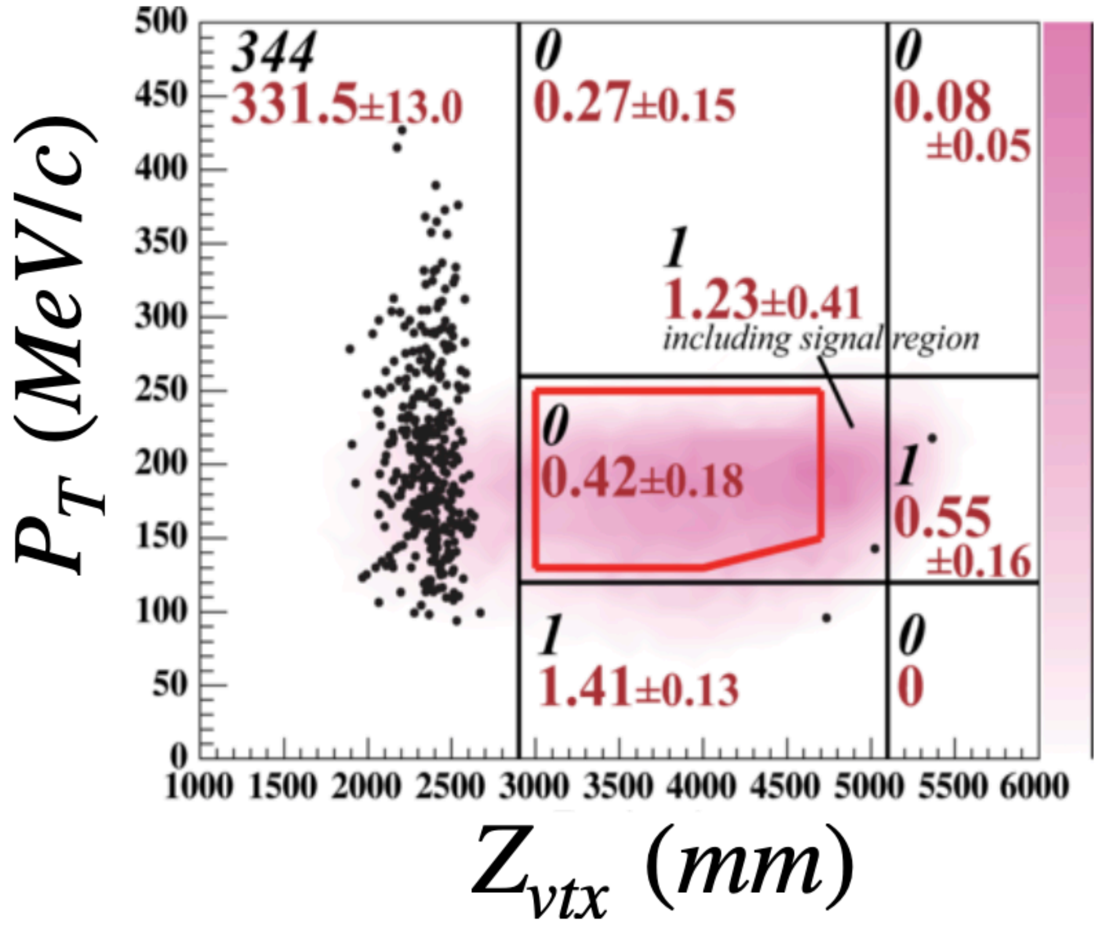
Beam halo K_L BG ($K_L \to \gamma\gamma$)



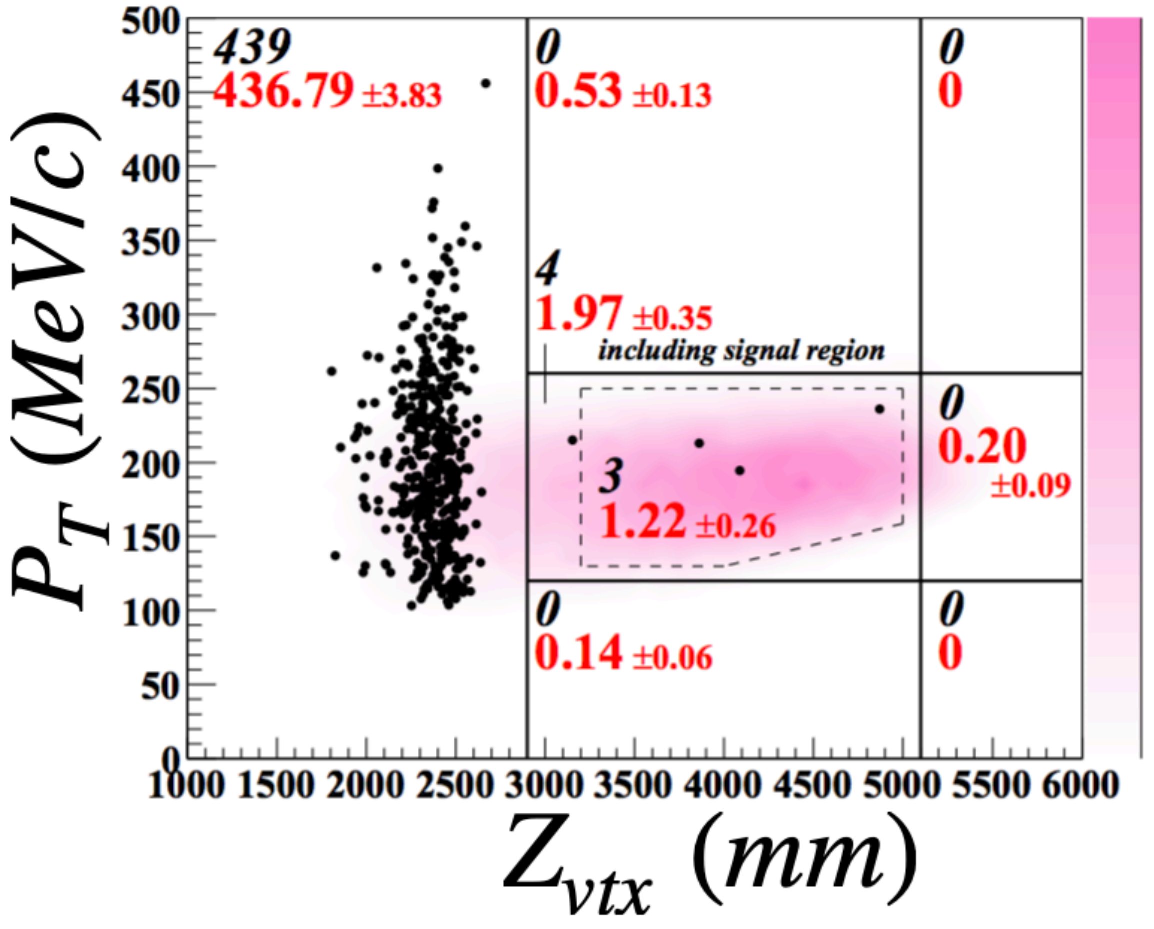
K± BG ($K^{\pm} \to \pi^0 e^{\pm} \nu$)



2015 Data



2016-2018 Data



2015 data [PRL.122.021802]

- $BR(K_L \to \pi^0 \nu\bar{\nu}) < 3.0 \times 10^{-9}$ at 90 % C.L.
- The current best limit on $BR(K_L \to \pi^0 \nu\bar{\nu})$

2016-2018 data [PRL.126.121801]

- $BR(K_L \to \pi^0 \nu\bar{\nu}) < 4.9 \times 10^{-9}$ at 90 % C.L.
- New background sources were found.

2019-2021 data a new detector and analysis tools are available!

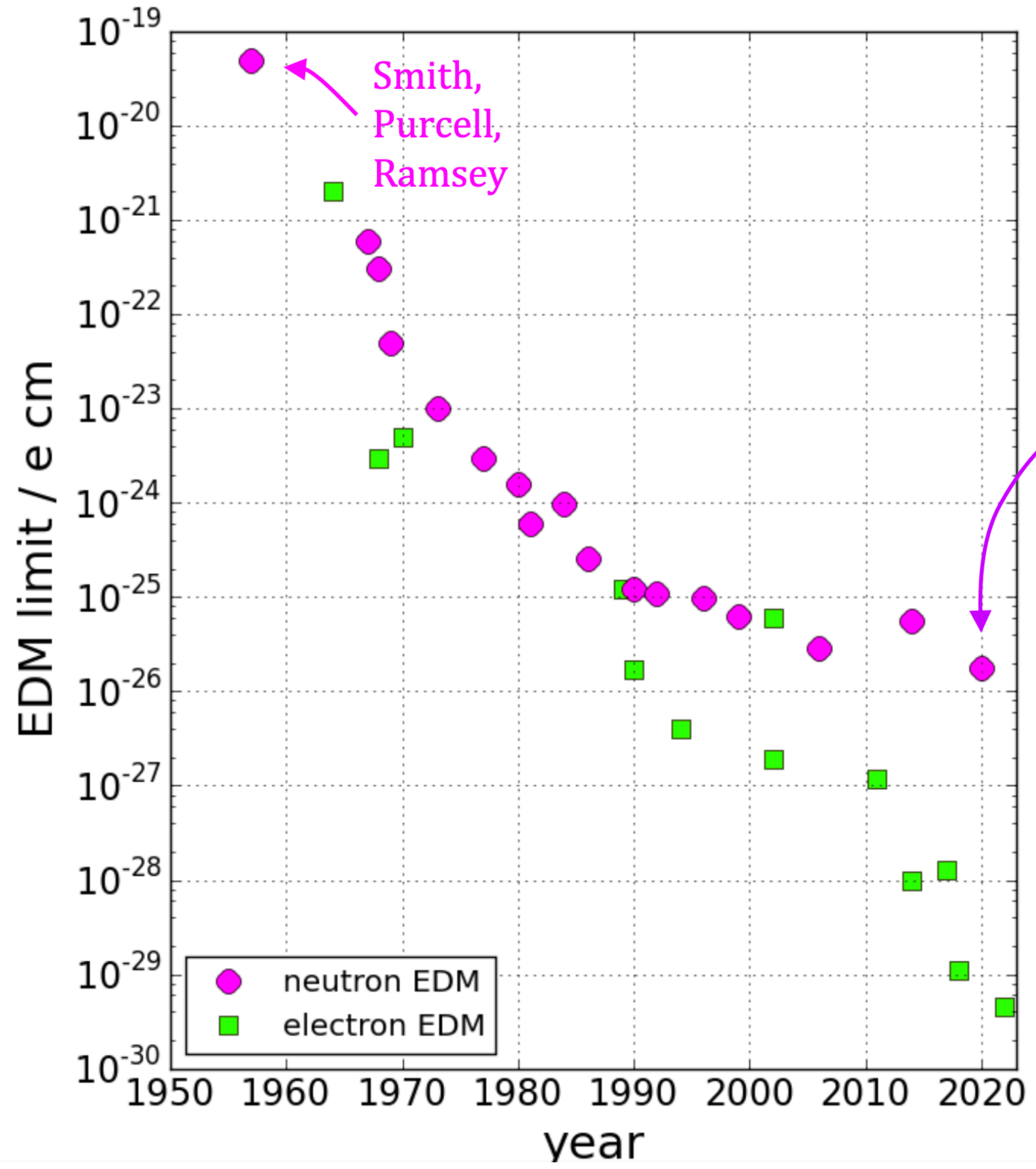
Looking forward to see the new data

KOTO expects to improve the S.E.S. below $O(10^{-10})$ by 2027.

Extreme Precision in nEDM

Superb experiment! Powerful probe for New Physics!

BEst recent limit from nEDM at PSI (2020)



Best limit from the nEDM experiment @PSI

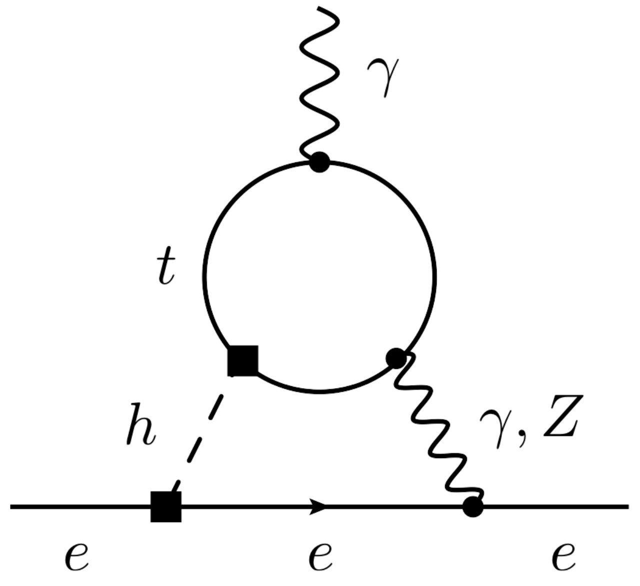
$|d_n| < 1.8 \times 10^{-26}\ e\ \mathrm{cm}$ Abel et al, PRL (2020)

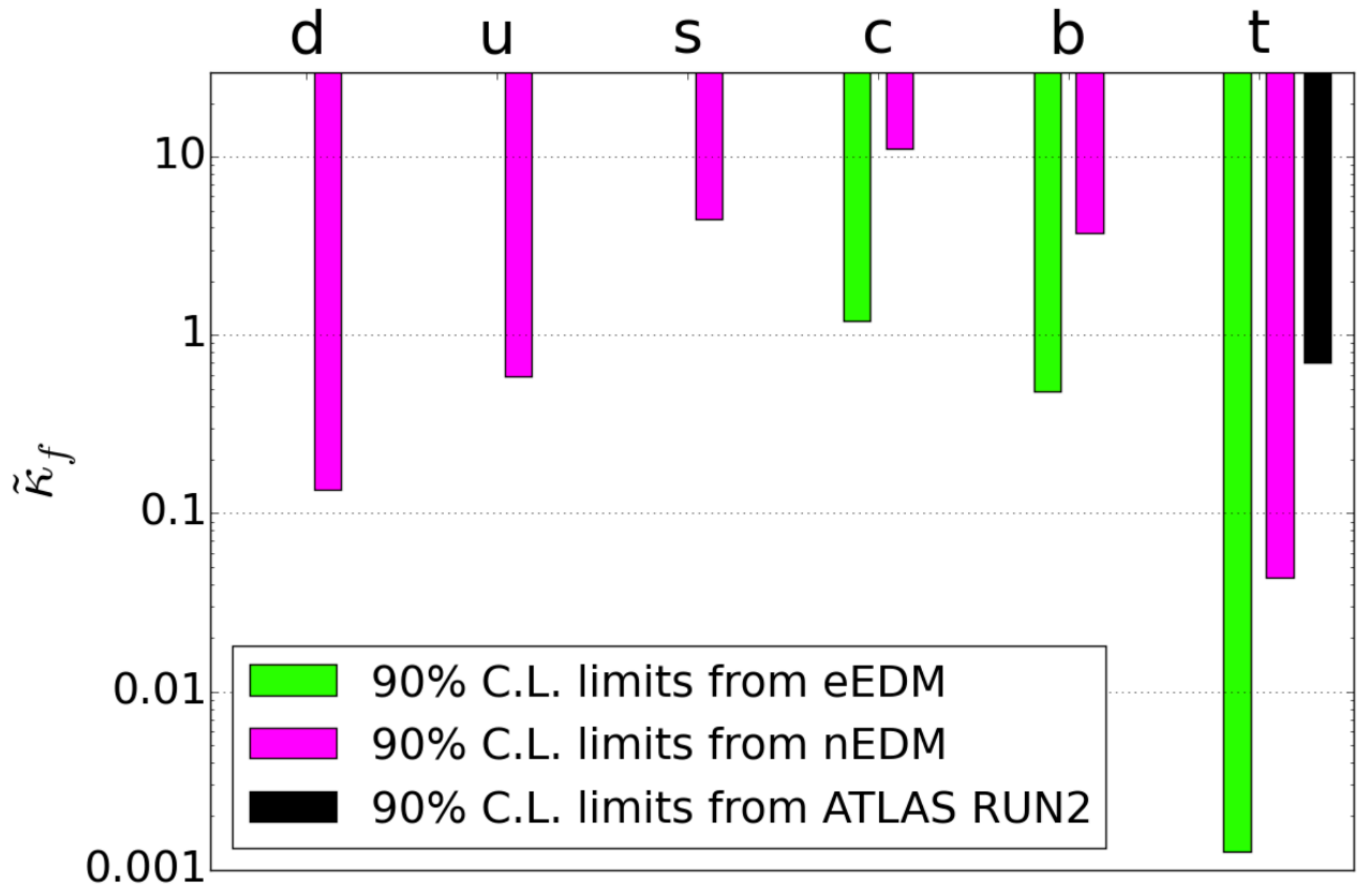
CKM background uncertain, possibly 10^{-31} e cm

Modified Higgs-fermion Yukawa coupling

$$\mathcal{L} = -\frac{y_f}{\sqrt{2}}\left(\kappa_f \bar{f} f h + i\tilde{\kappa}_f\, \bar{f}\gamma_5 f h\right)$$

CPV

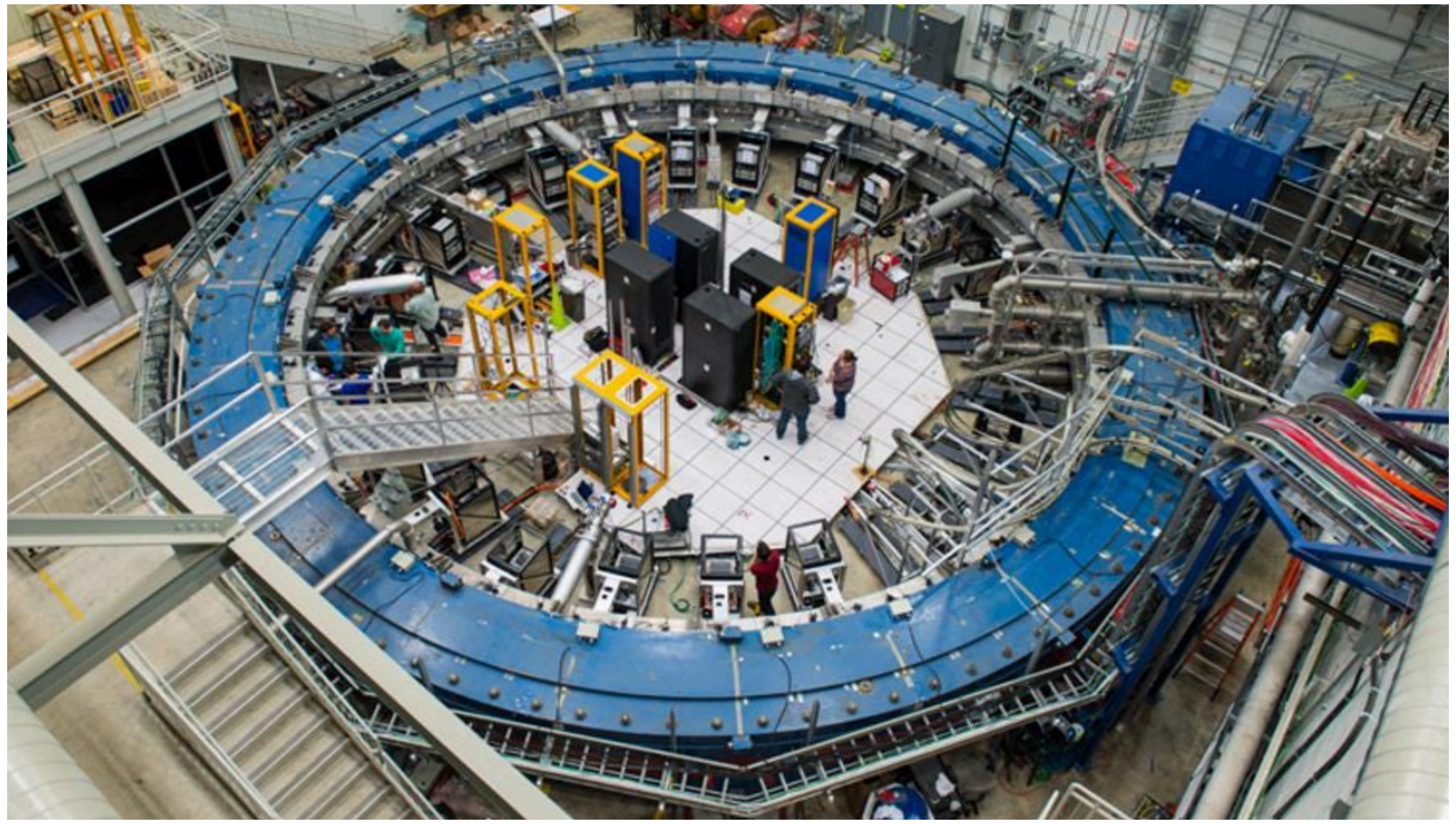




The electron EDM constraint is weaker for taus $\tilde{\kappa}_\tau < 0.3$

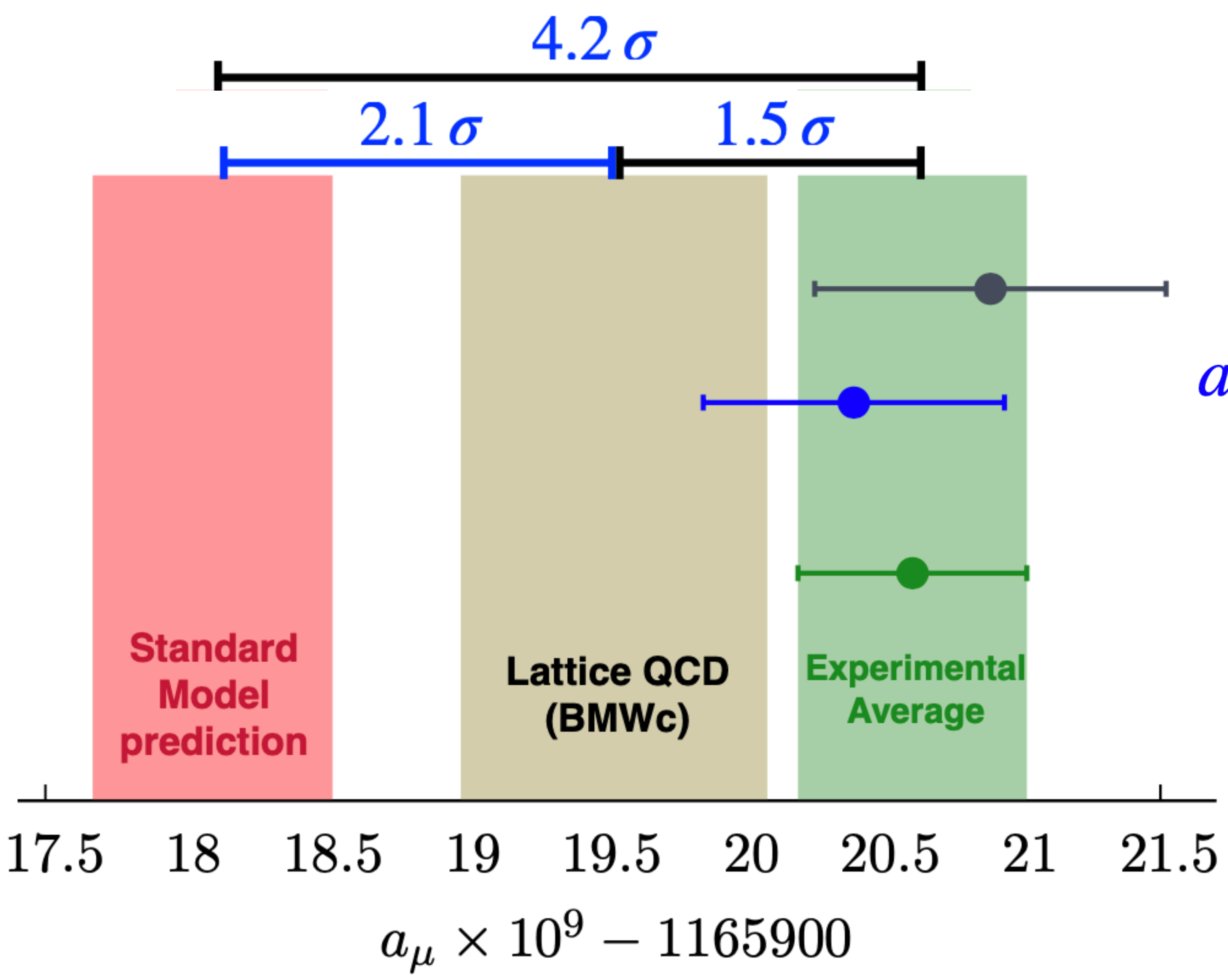
Charged Lepton Sector

Cedric Delaunay



- Magnetic moments (anomalous muon magnetic moment)
- eEDM
- Muon EDM
- Charged Lepton Flavour Violations (MEG II running, and many planned experiments)

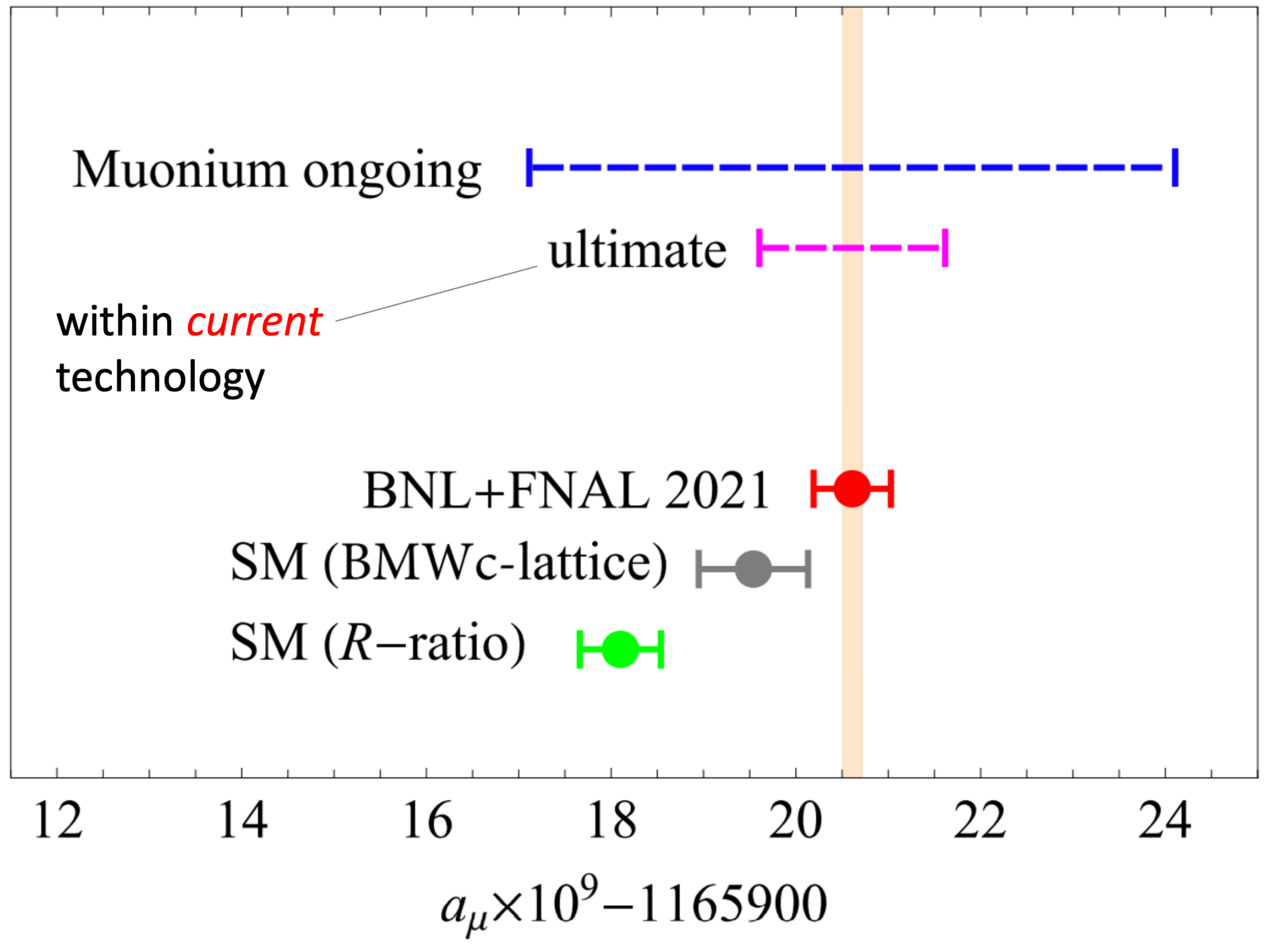
… and anomalies $(g-2)_\mu$

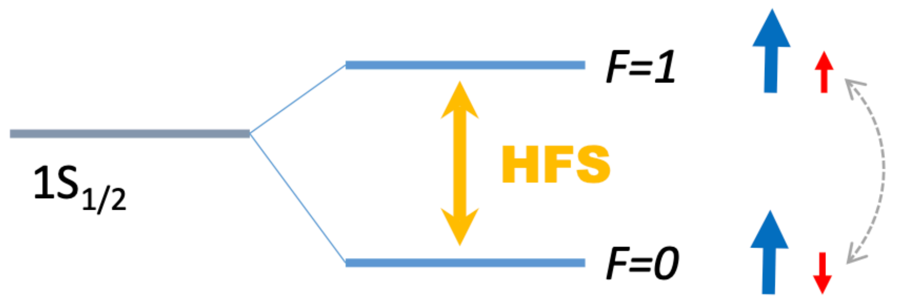


$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (25.1 \pm 5.9) \cdot 10^{-10}$$

Difference as large as EW corrections!

Possible measurement with Hyperfine Splitting in Muonium atoms ($e^- - \mu^+$)

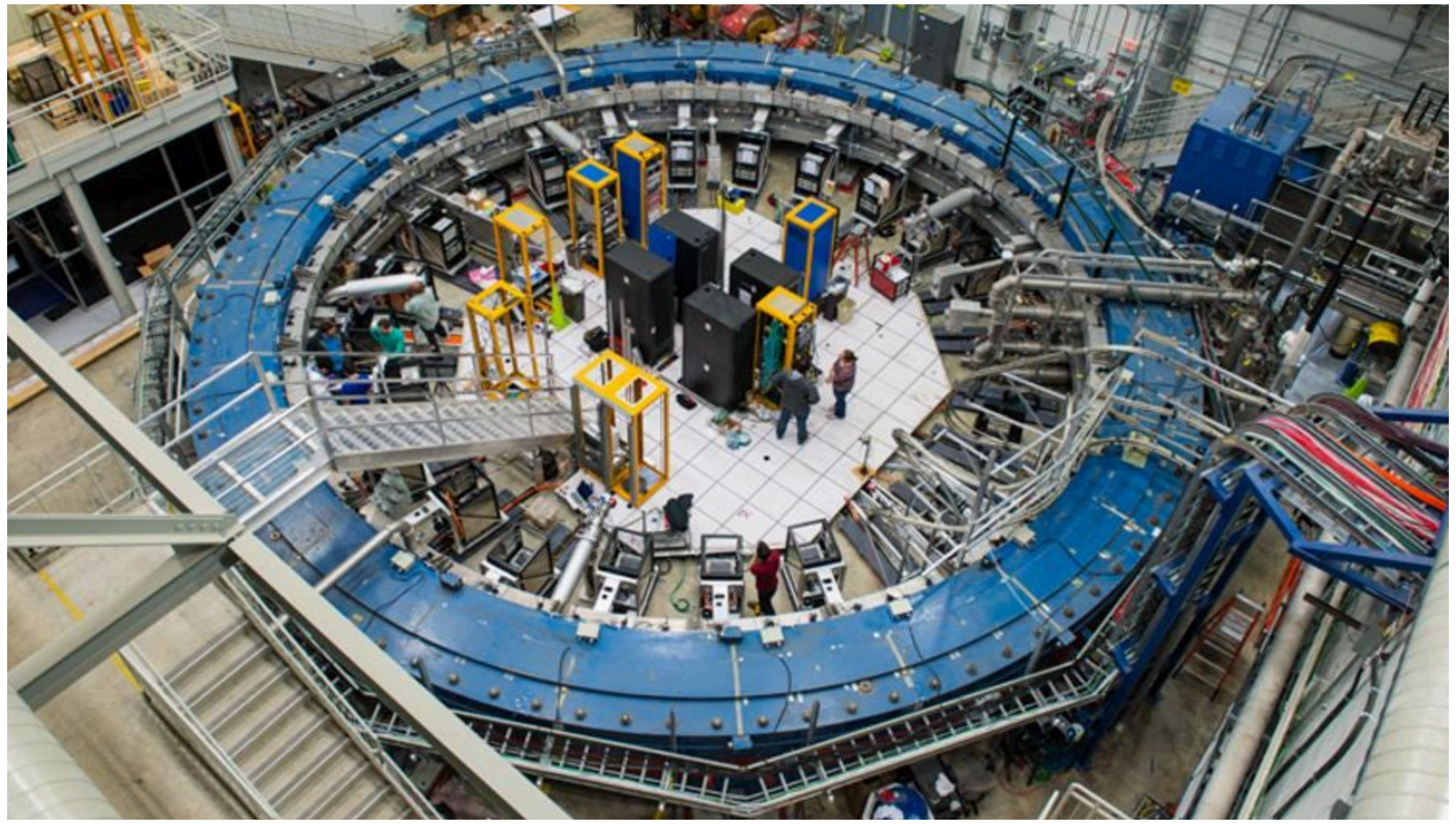




$$H_{\text{HFS}} = -\frac{2\mu_0}{3}\vec{\mu}_e \cdot \vec{\mu}_\mu \, \delta^3(r)$$

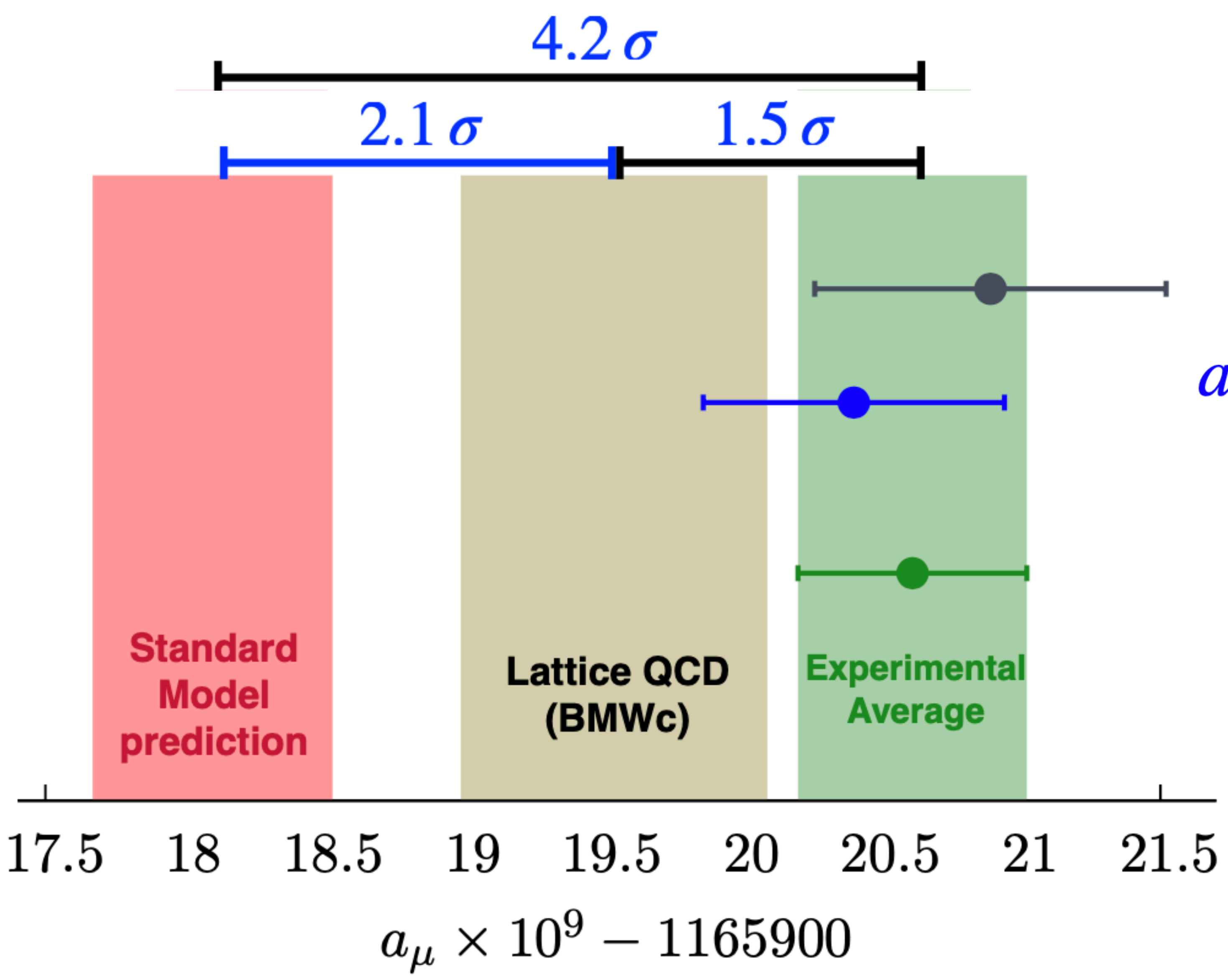
1ppm sensitivity
(2ppm anomaly)

Charged Lepton Sector



- Magnetic moments (anomalous muon magnetic moment)
- eEDM
- Muon EDM
- Charged Lepton Flavour Violations (MEG II running, and many planned experiments)

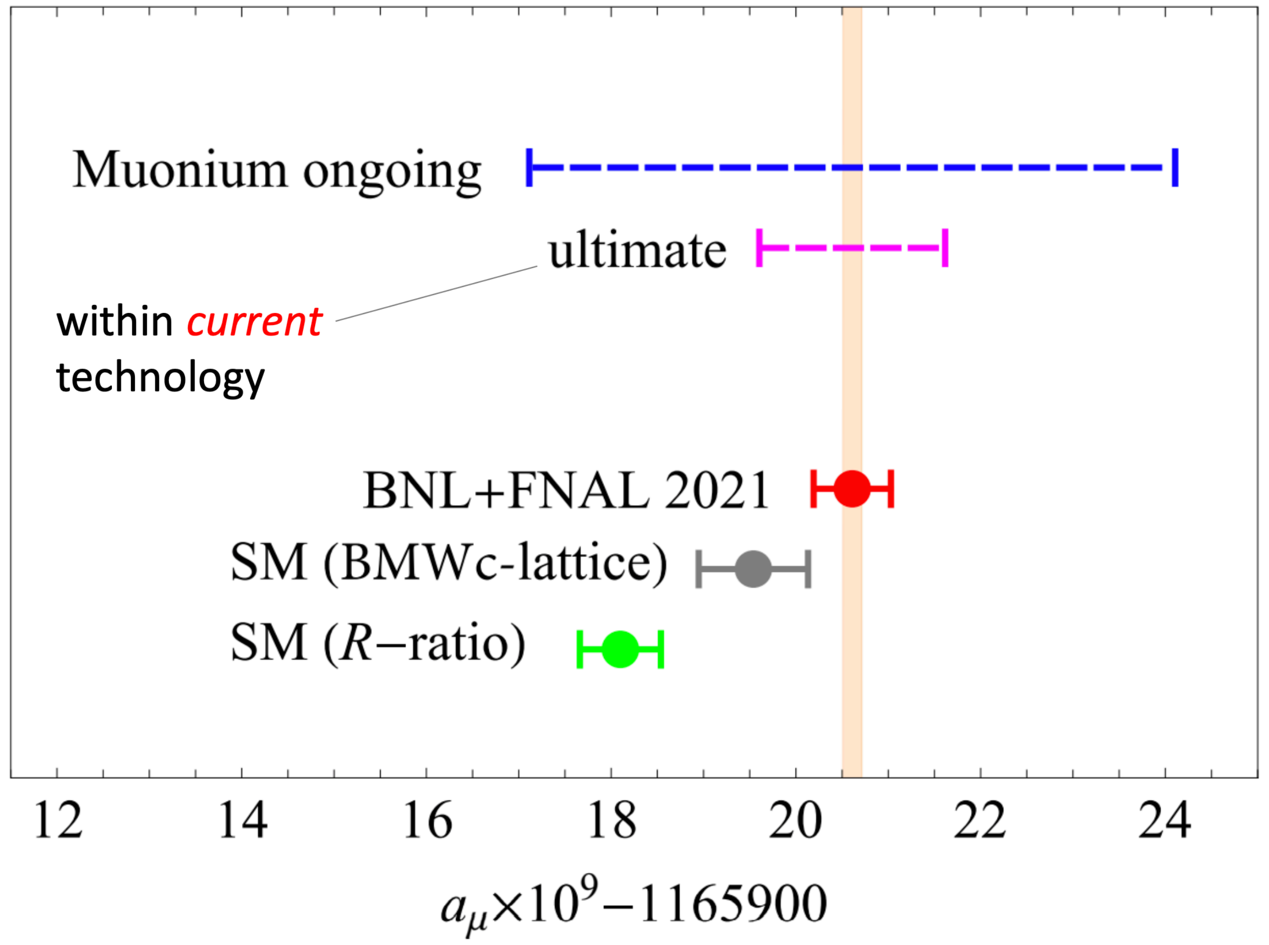
… and anomalies $(g-2)_\mu$

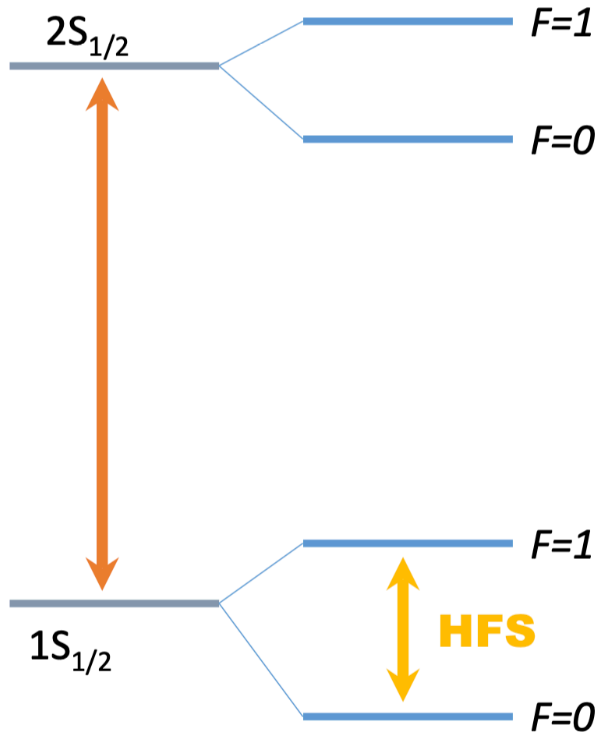


$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (25.1 \pm 5.9) \cdot 10^{-10}$$

Difference as large as EW corrections!

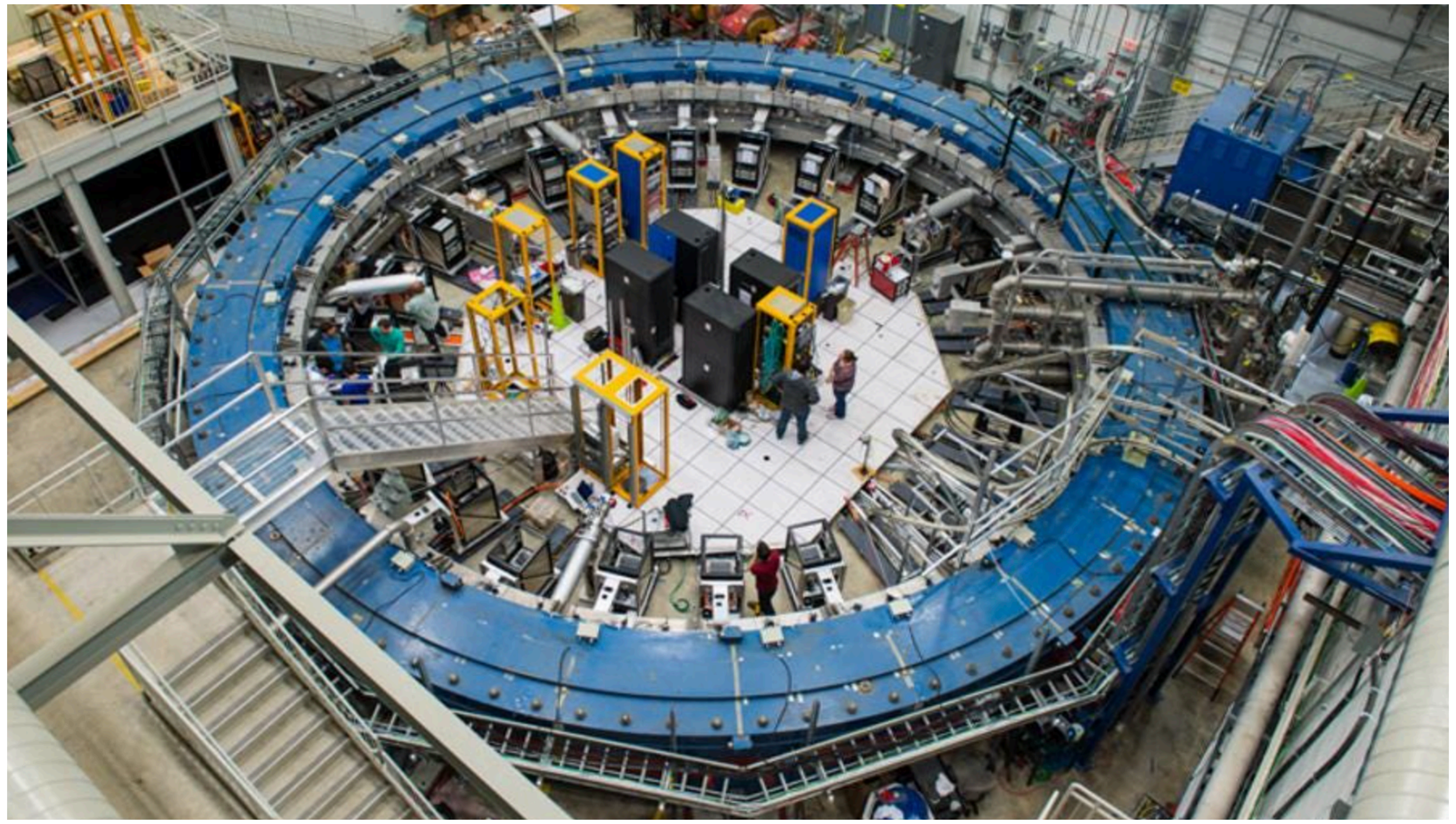
Possible measurement with Hyperfine Splitting in Muonium atoms ($e^- - \mu^+$)





Another observable needed

Charged Lepton Sector



- Magnetic moments (anomalous muon magnetic moment)
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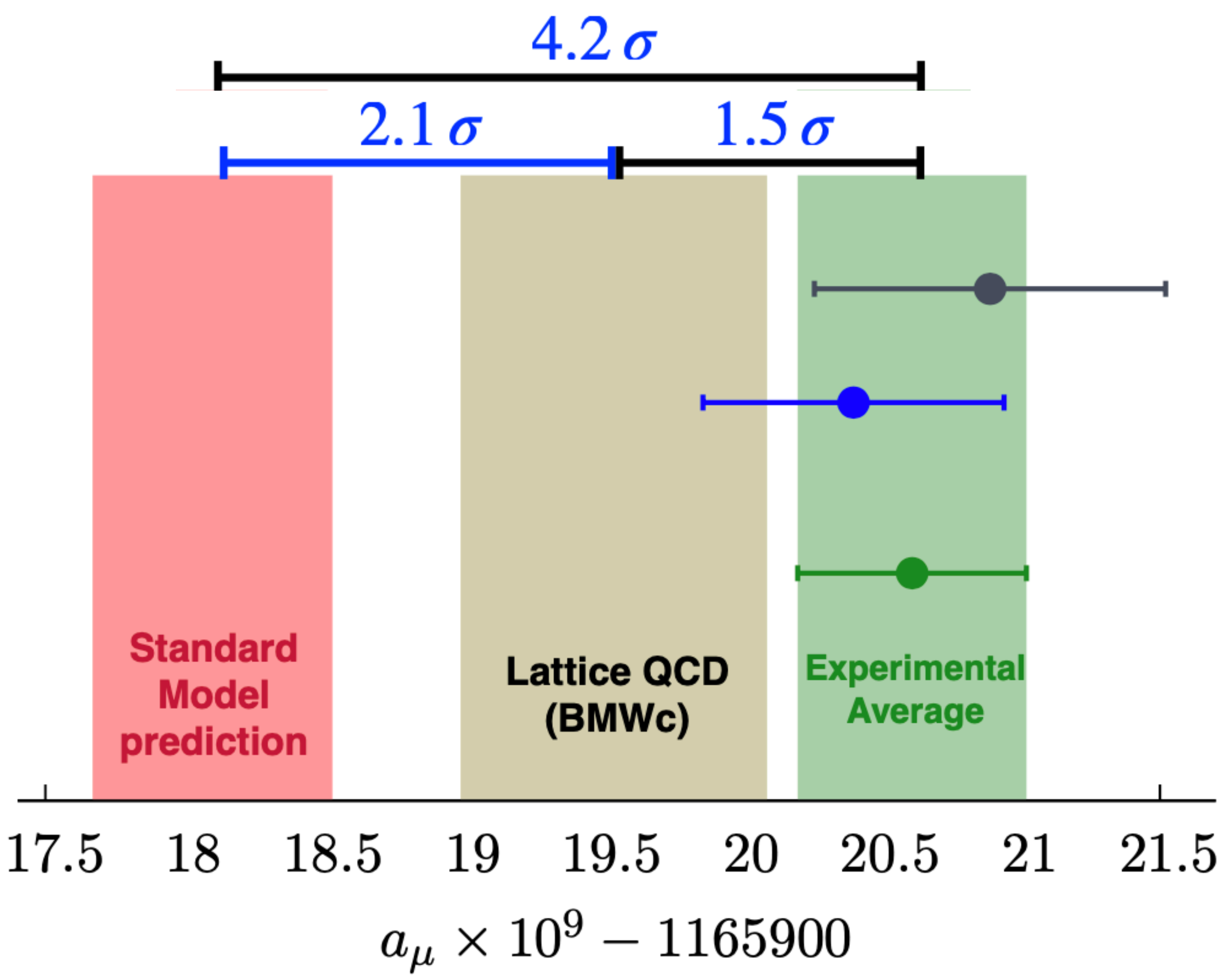
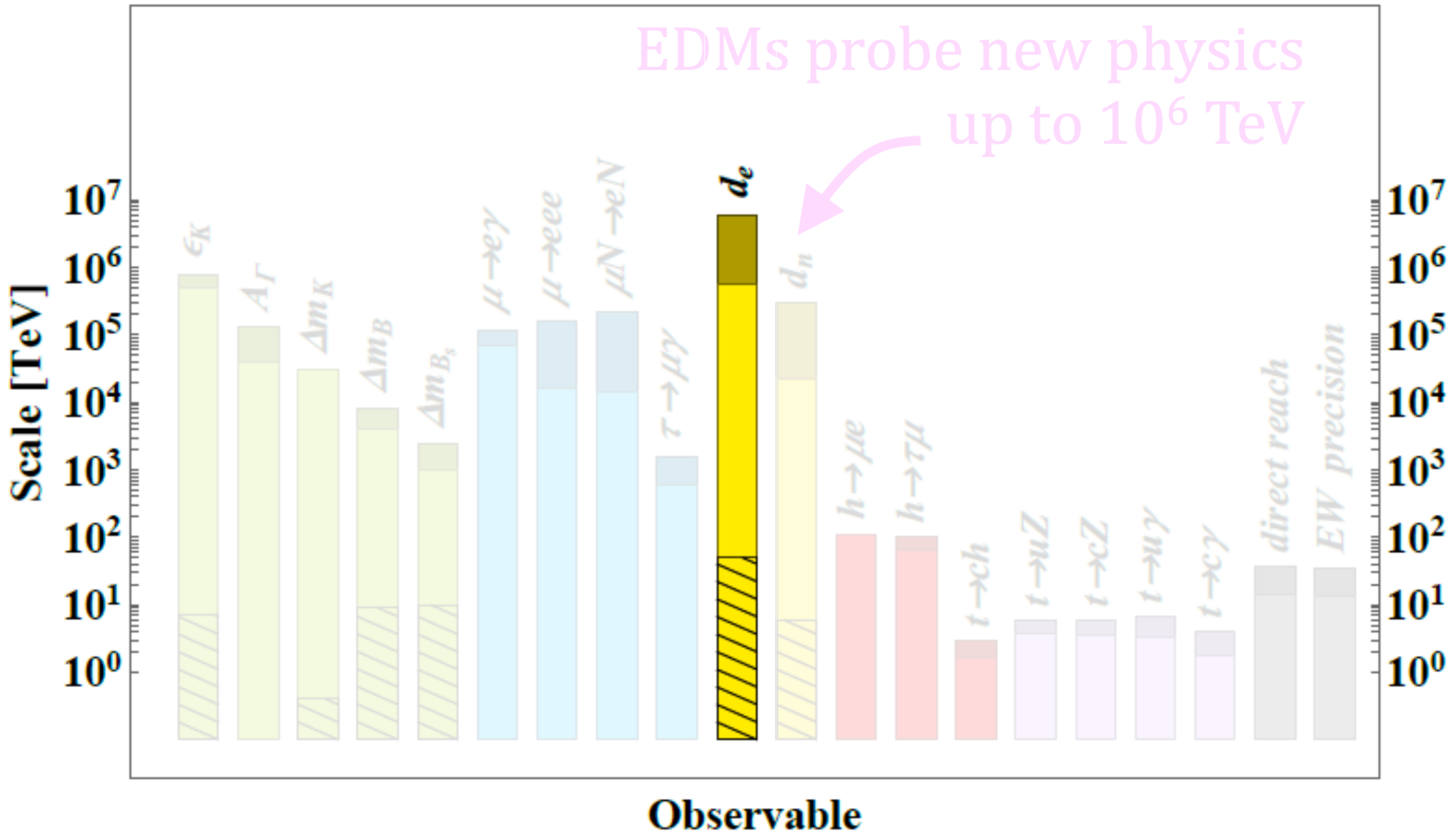


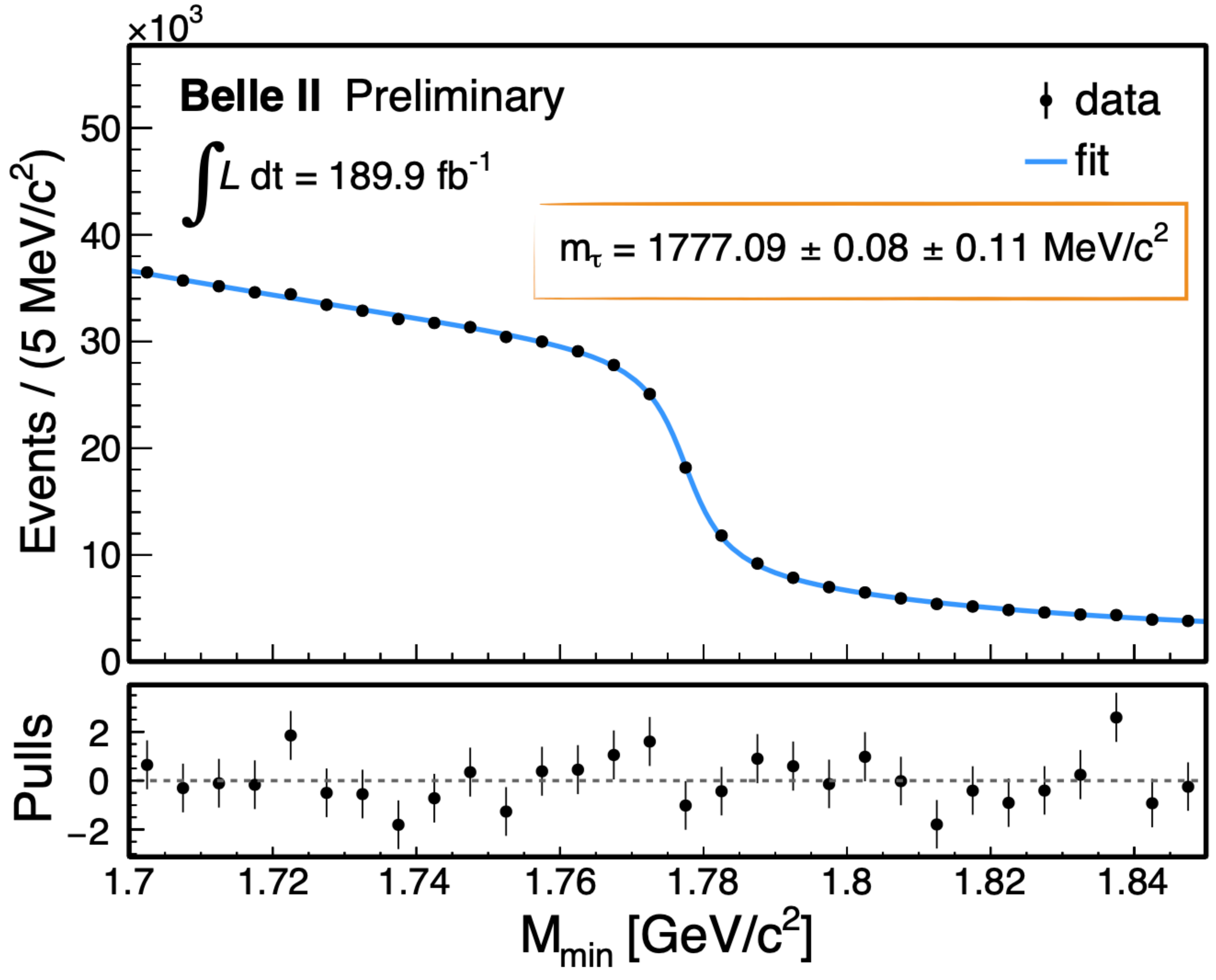
$$a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (25.1 \pm 5.9) \cdot 10^{-10}$$

Difference as large as EW corrections!



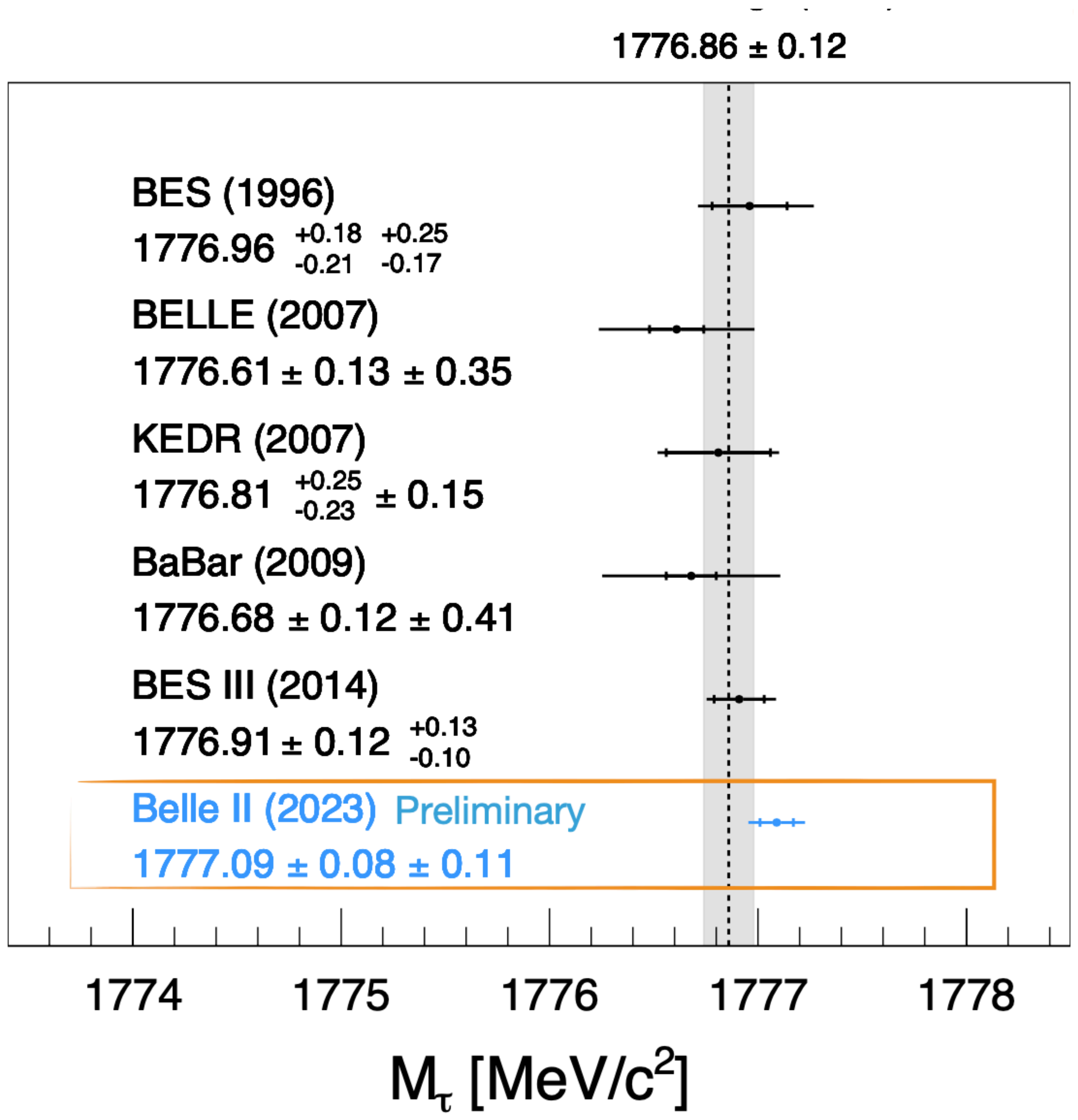
Belle II - Tau Lepton Mass

- Large $e^+e^- \to \tau\tau$ cross-section and clean environment allow high precision τ measurements



- Benchmark for precision capabilities of Belle II
- Control of **systematic uncertainties** is key:
- $M_{\text{min}} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} \leq m_\tau$

- Reconstruct $\tau_{\text{tag}}^{\pm} \to \pi^{\pm}(\pi^0)\nu, \ell\nu\nu$ and $\tau_{\text{sig}} \to 3\pi\nu$ (ν missing)



New for Moriond EW 2023

World's most precise measurement of the tau mass ($6\,.\,10^{-5}$)!

Dark Matter and a Possible Dark Sector

Neutron Stars can teach us a lot on particle physics and Dark Matter!

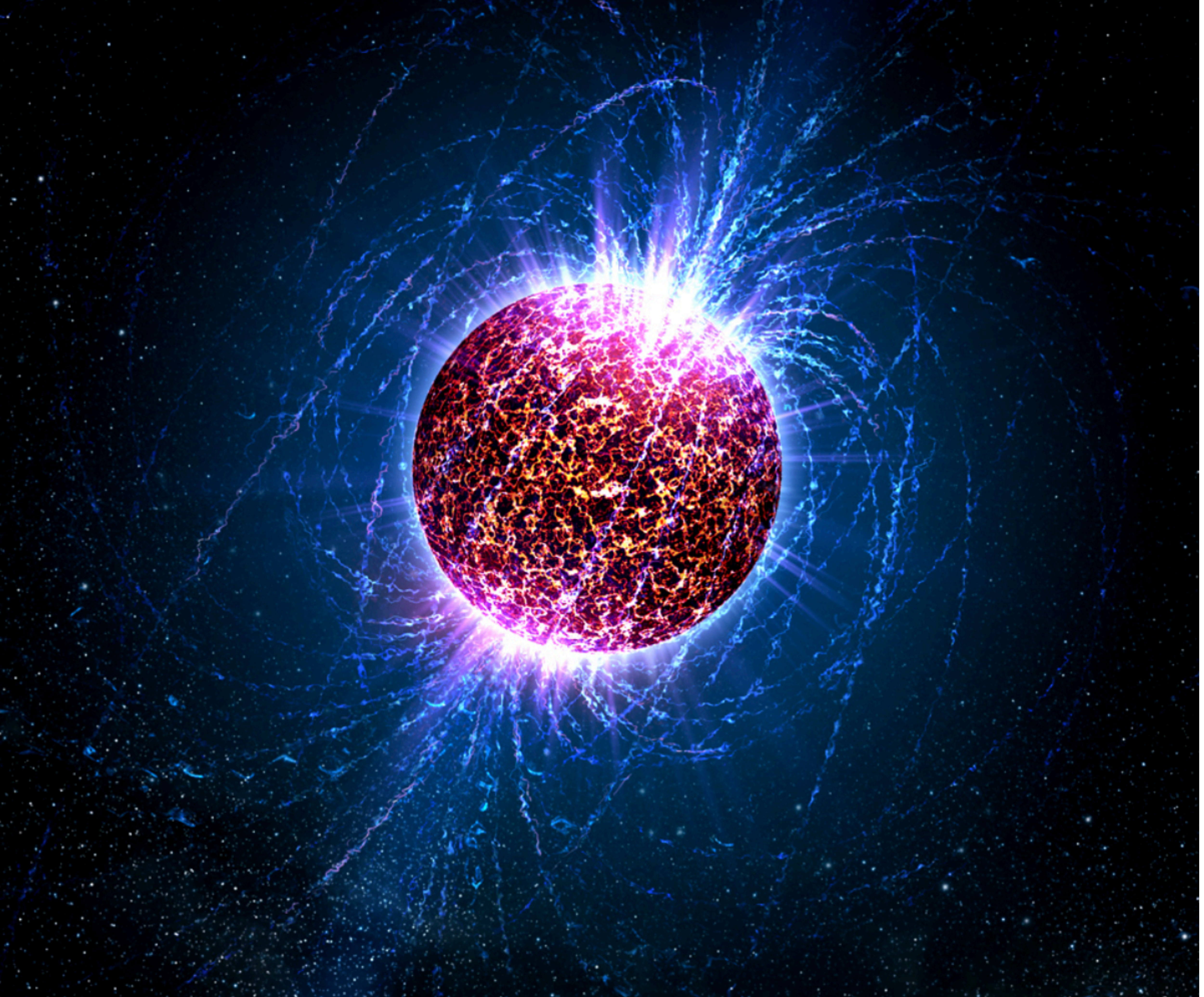


Illustration of a neutron star (wikipedia)

- What astrophysical observations do or can teach us (of neutron stars and primordial black holes)
- Direct Dark Matter searches news!
- Dark photon searches
- Axions (and gravitational waves!)
- ALPs: motivated by Cosmology (Axion Inflation), EW Hierarchy (Relaxion), Flavour Symmetry (Flaxion or Axiflavon)

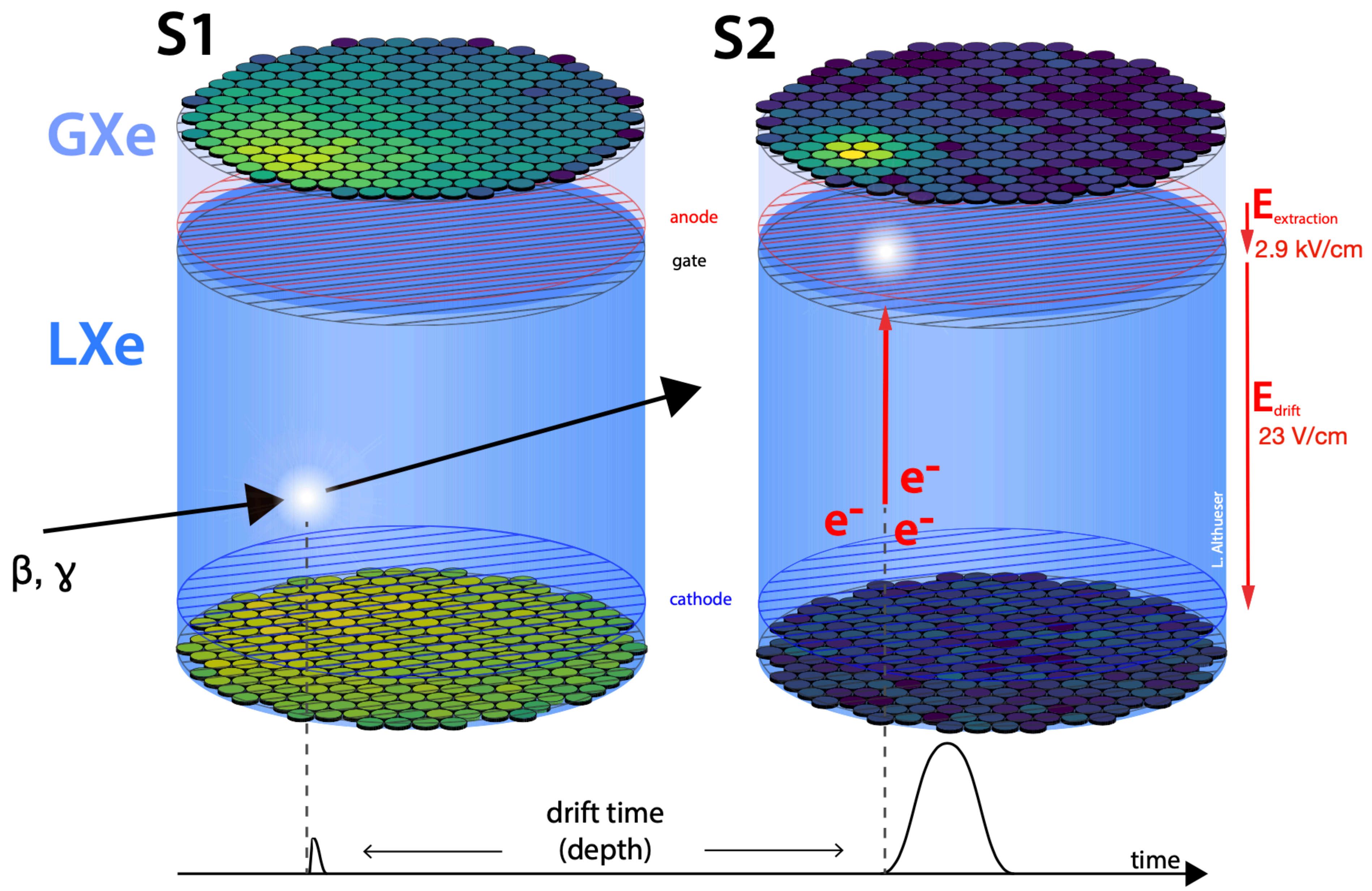
… and anomalies (^8Be excess)!

Direct Dark Matter Searches

Xenon nT Hot Off the Press for Moriond!

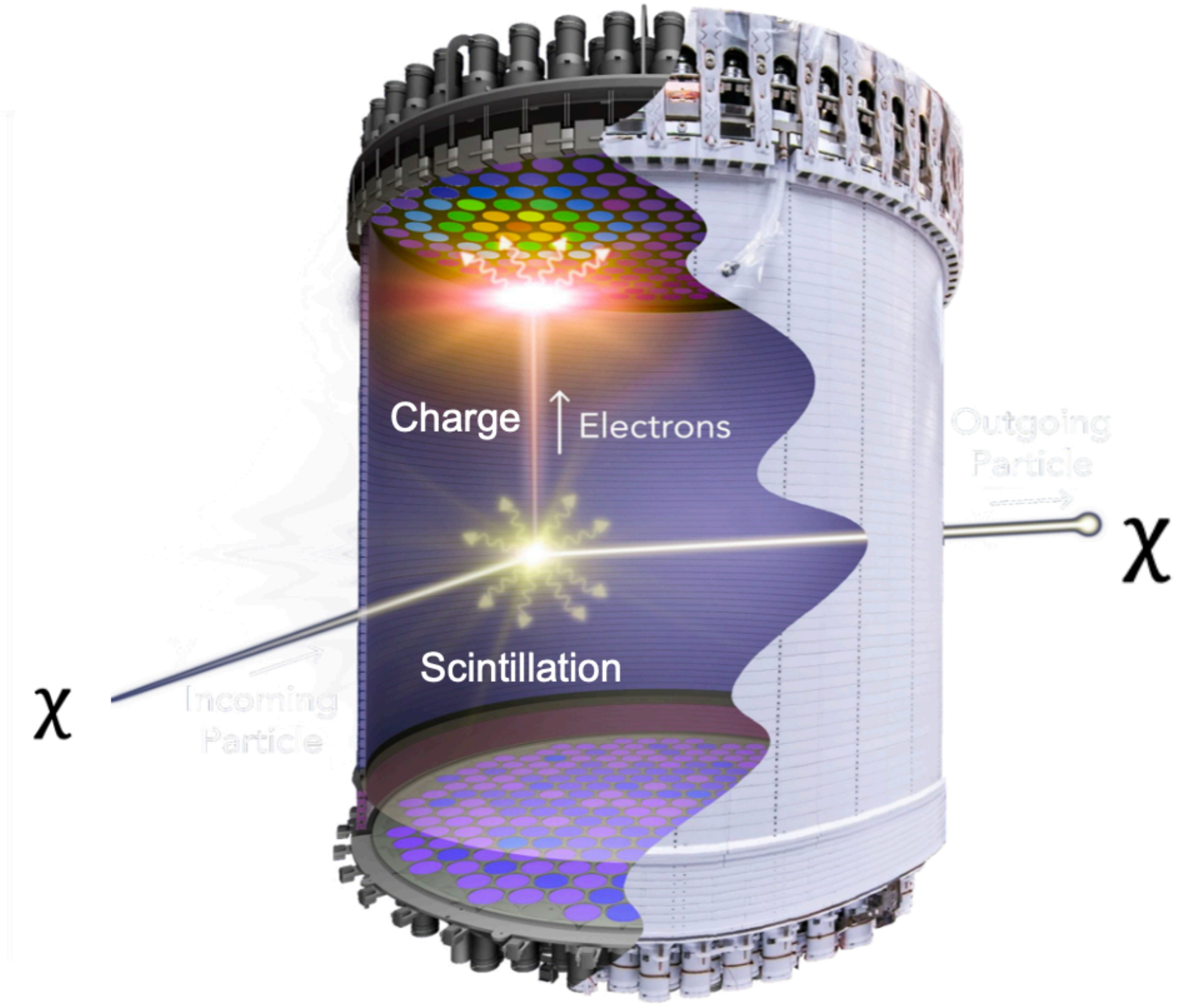
Science Run-0 Nuclear Recoil Search Data
95.1 days exposure
(4.18 ± 0.13) ton Fiducial Volume
Exposure: 1.1 tonne-year

New for Moriond EW 2023



LZ Results

Science Run-0 Nuclear Recoil Search Data
60 days exposure
(5.3 ± 0.2) ton Fiducial Volume
Exposure: 0.9 tonne-year



Both are dual phase Xenon TPCs

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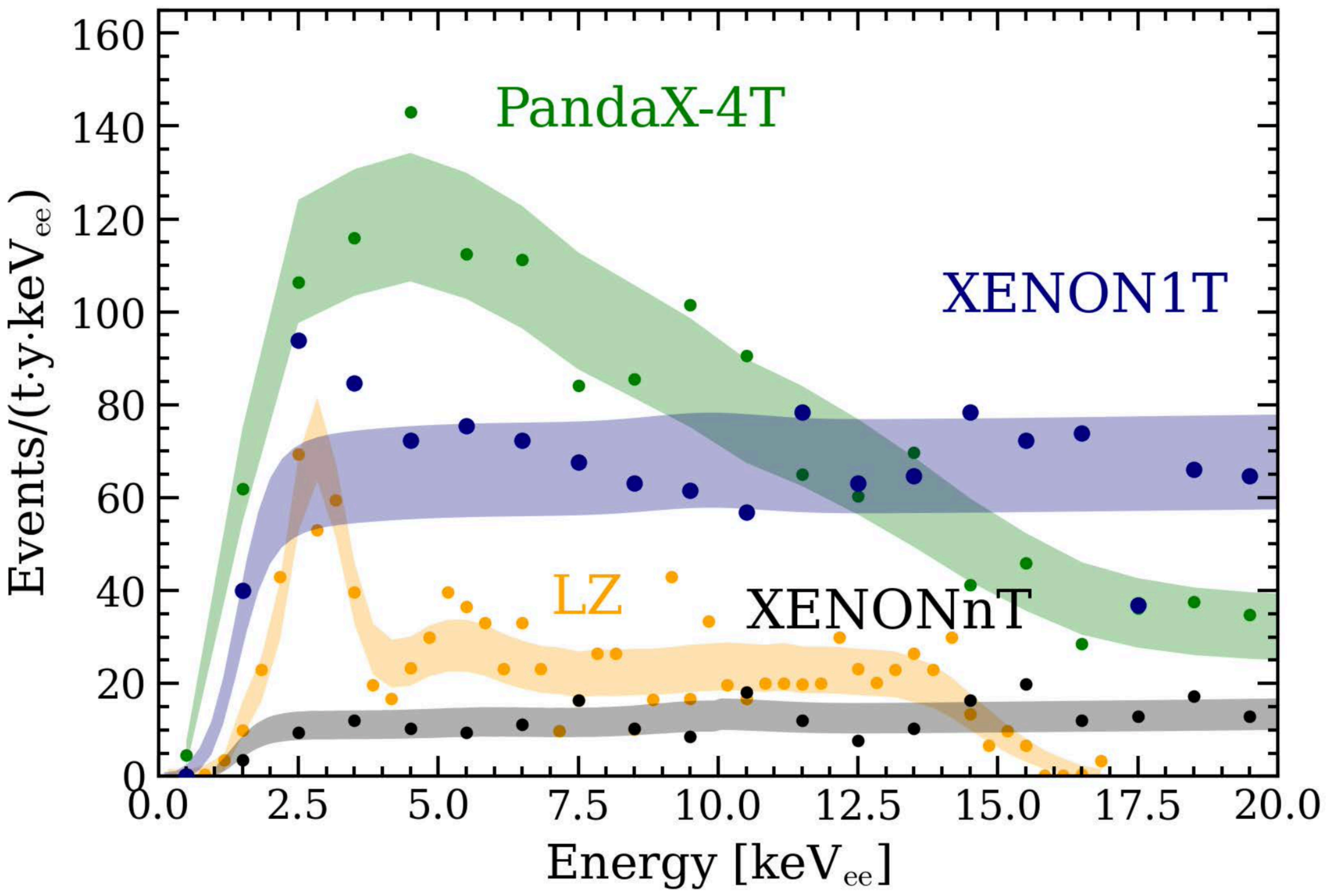

Xenon nT Background reduction: Careful screening, material selection and Continuous Radon Removal through distillation

LZ Continuous purification of Xe

Direct Dark Matter Searches

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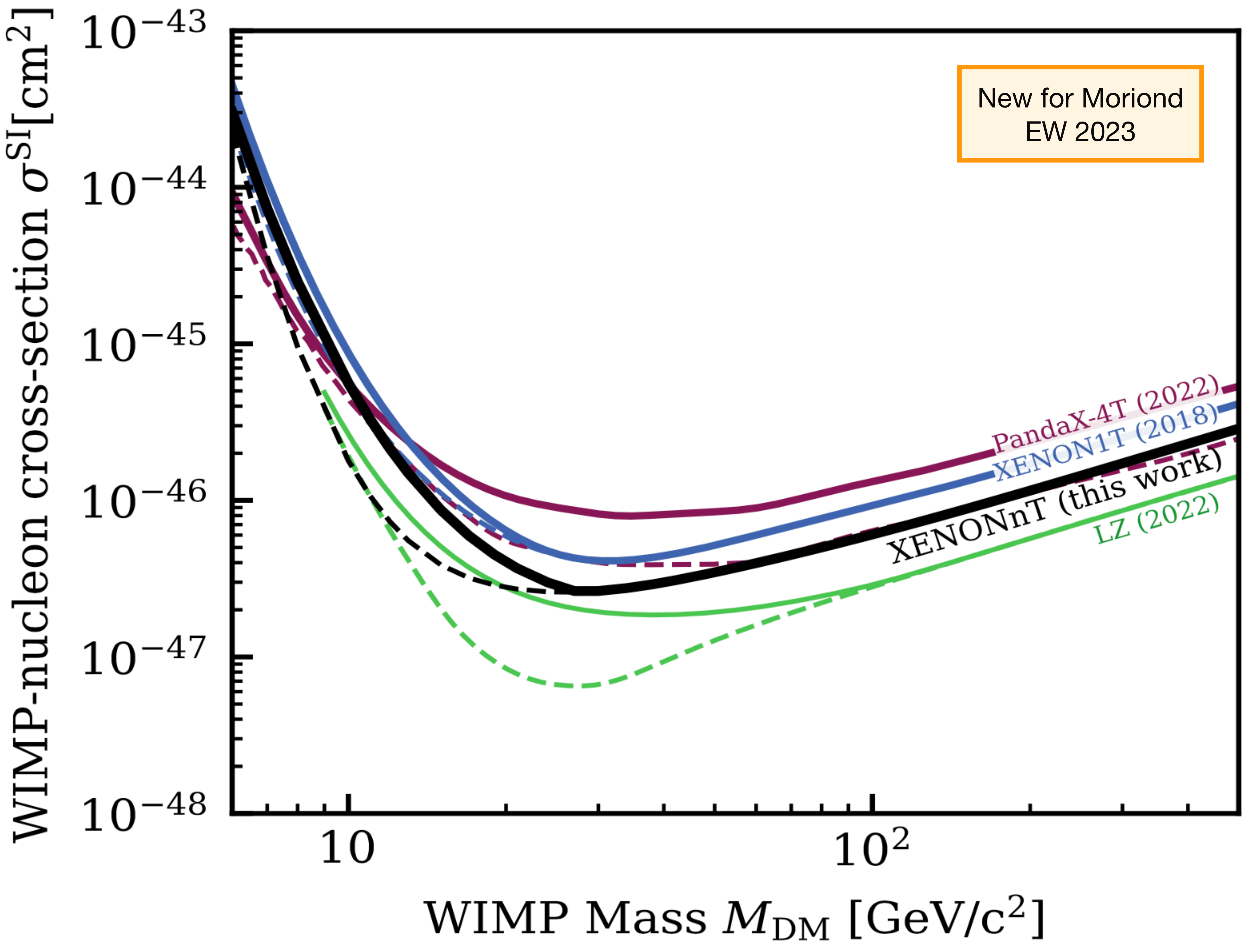

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Xenon nT First results!

LZ Achieved leading sensitivity

Xenon/DARWIN and Lux Zeppelin join forces for future project, however meanwhile…

Direct Dark Matter Searches

Xenon nT Hot Off the Press for Moriond!

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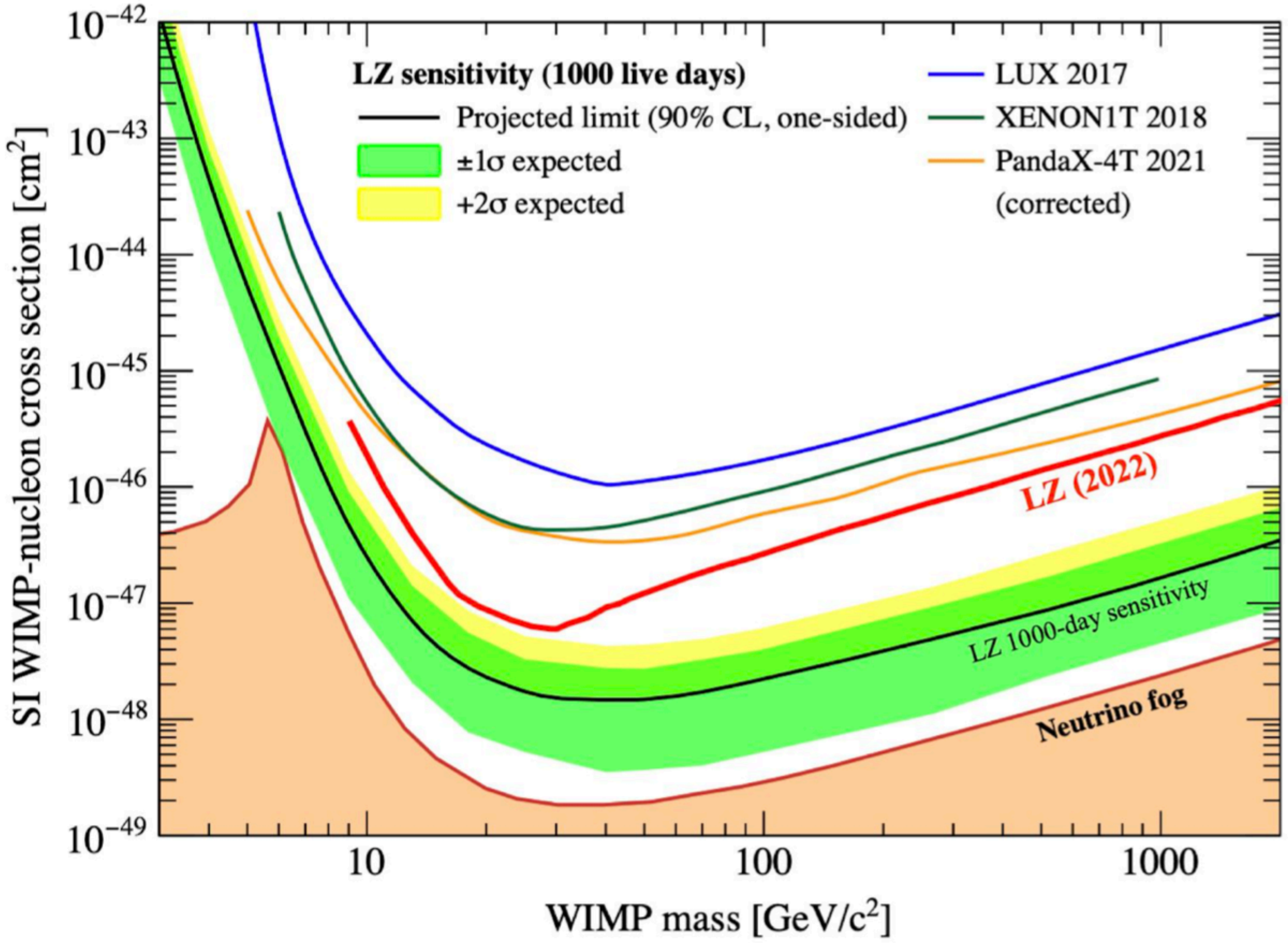


Xenon nT First results!

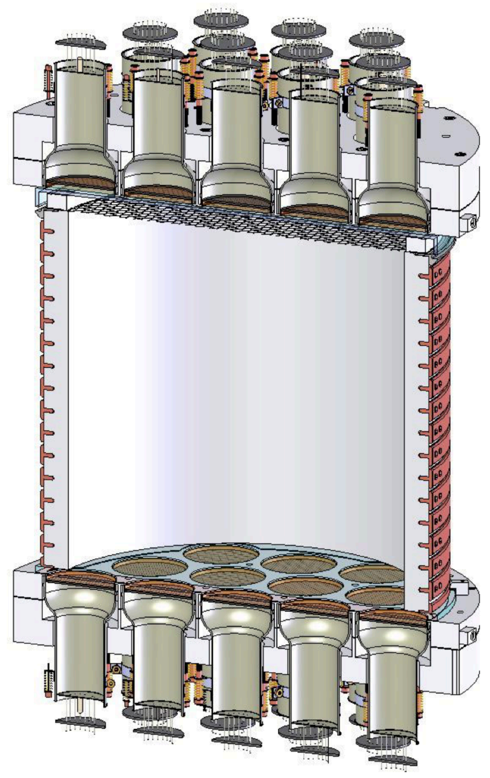
LZ Achieved leading sensitivity

Xenon/DARWIN and Lux Zeppelin join forces for future project, however meanwhile…

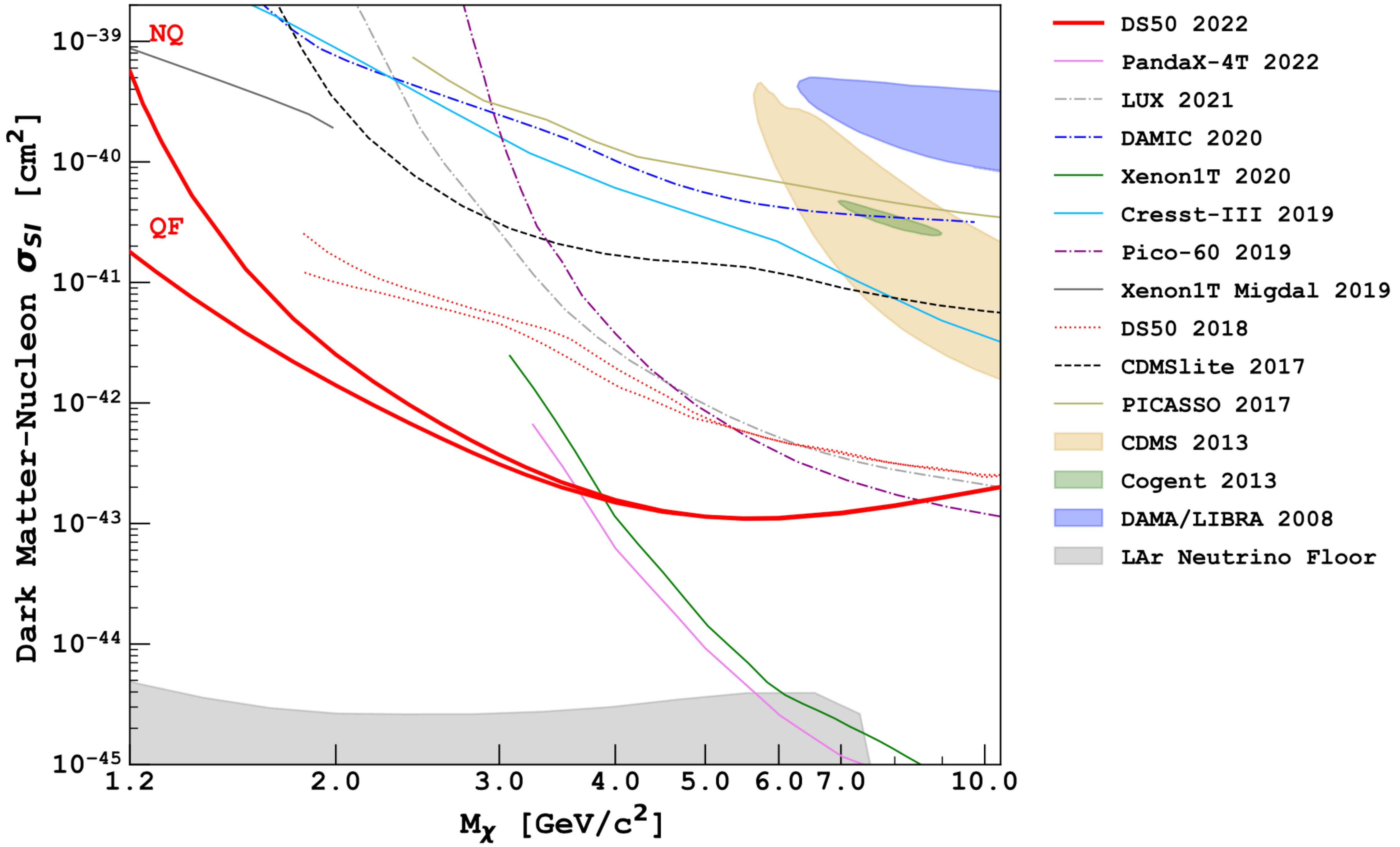
Still a lots of data to come!

DarkSide 50

Dual phase Argon TPC @ LNGS
50 kg of active mass
Exposure: 12 tonne-**day**



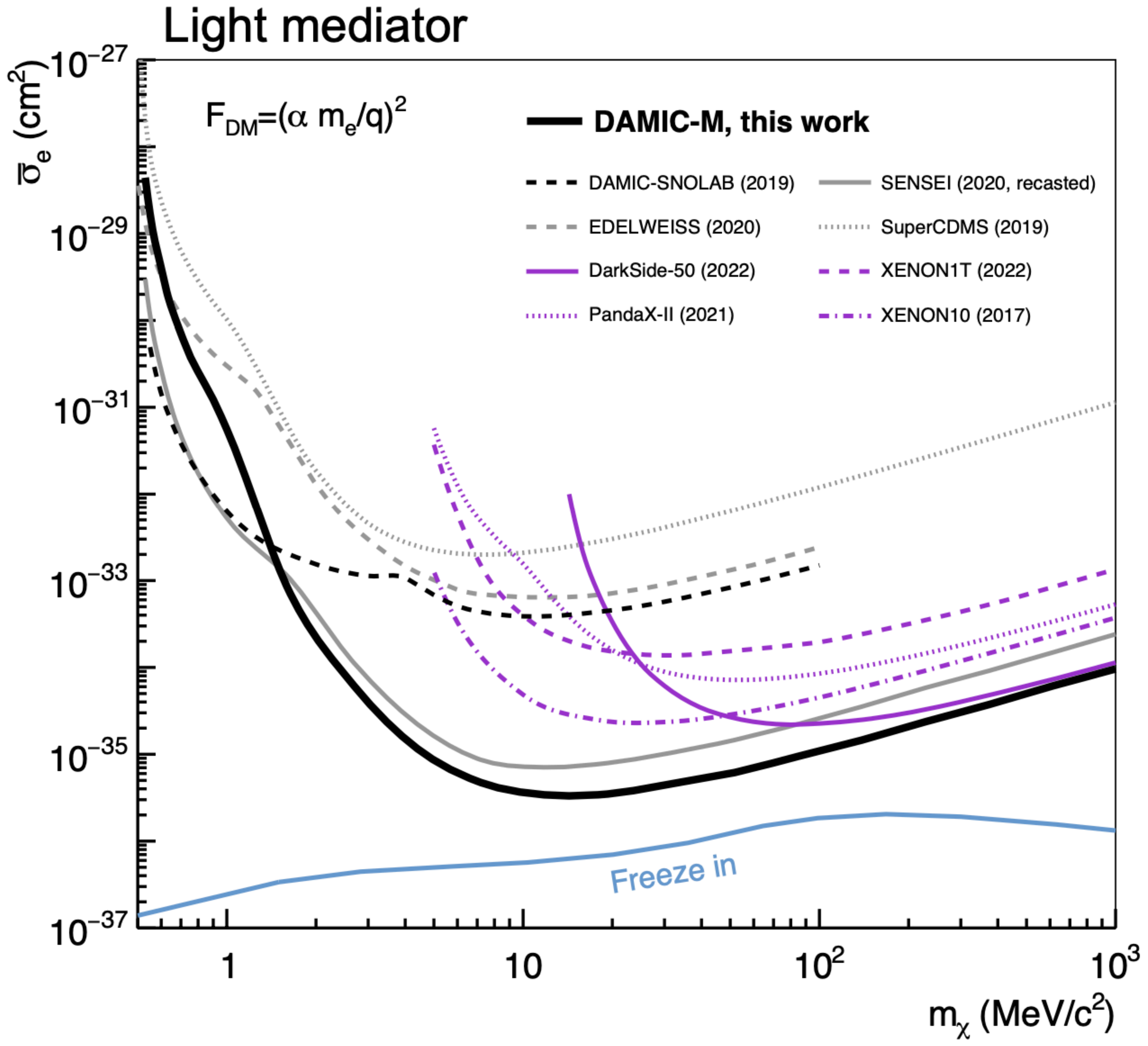
WIMP Nuclear recoil search at low mass!

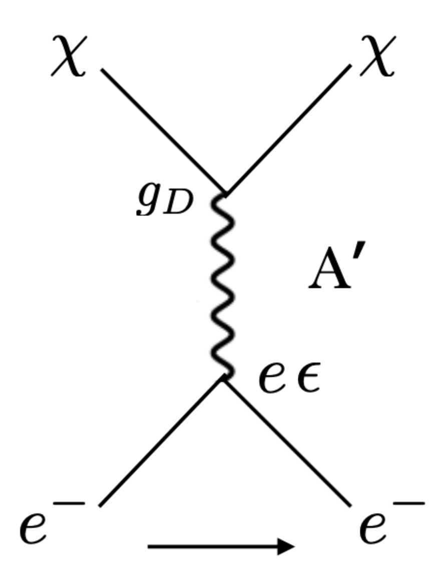


DAMIC-M

Low Background chamber at Modanne
Two 24 Pixel DAMIC prototype CCDs
Exposure: 85 g-day

DM-e$^-$ scattering

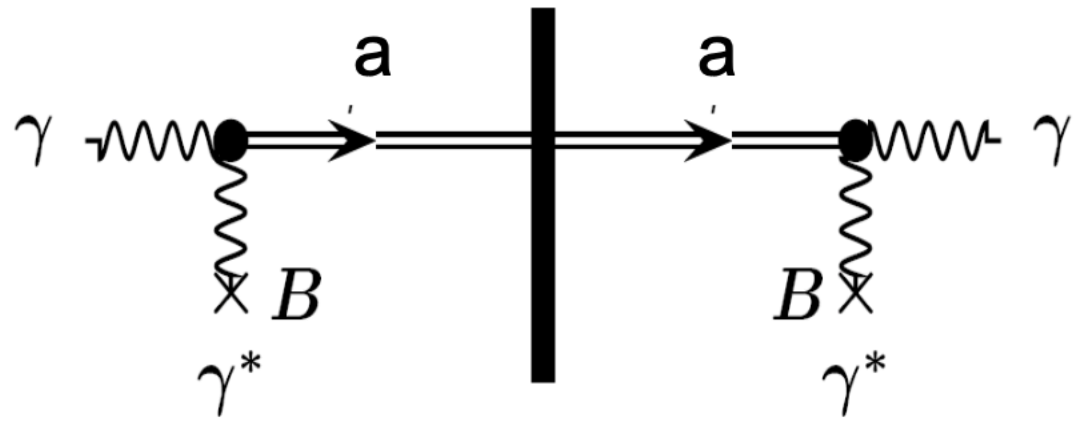




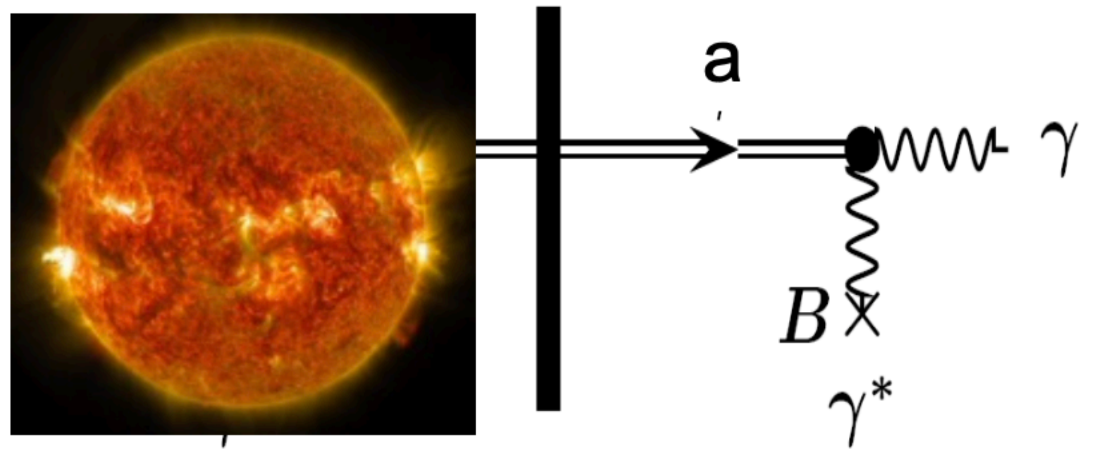
Electron recoil searches for very low mass hidden sector DM!

Axions : an Ambitious Program…   In Hamburg

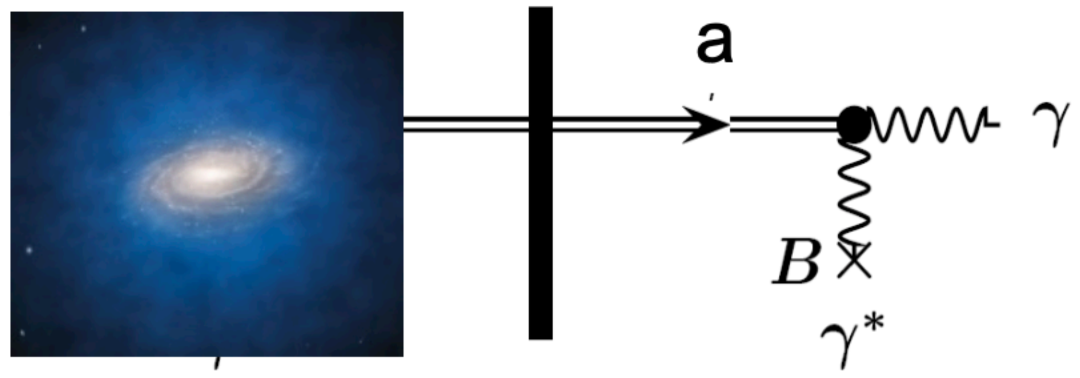
Light shining through a wall (LSW)
[Anselm 85; van Bibber 87]



Helioscope: Sun shining through a wall
[Sikivie 83]

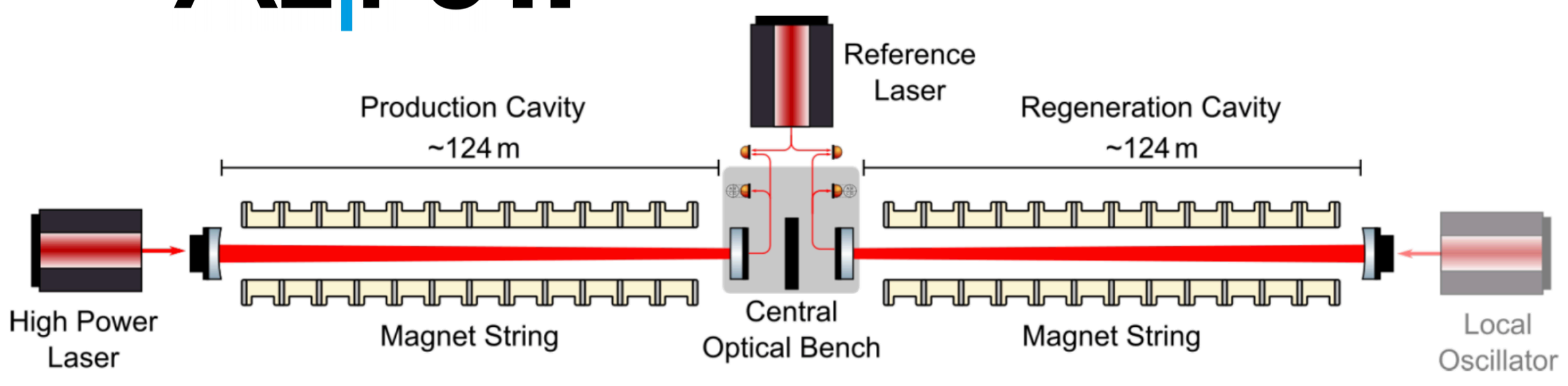


Haloscope: DM shining through a wall
[Sikivie 83]

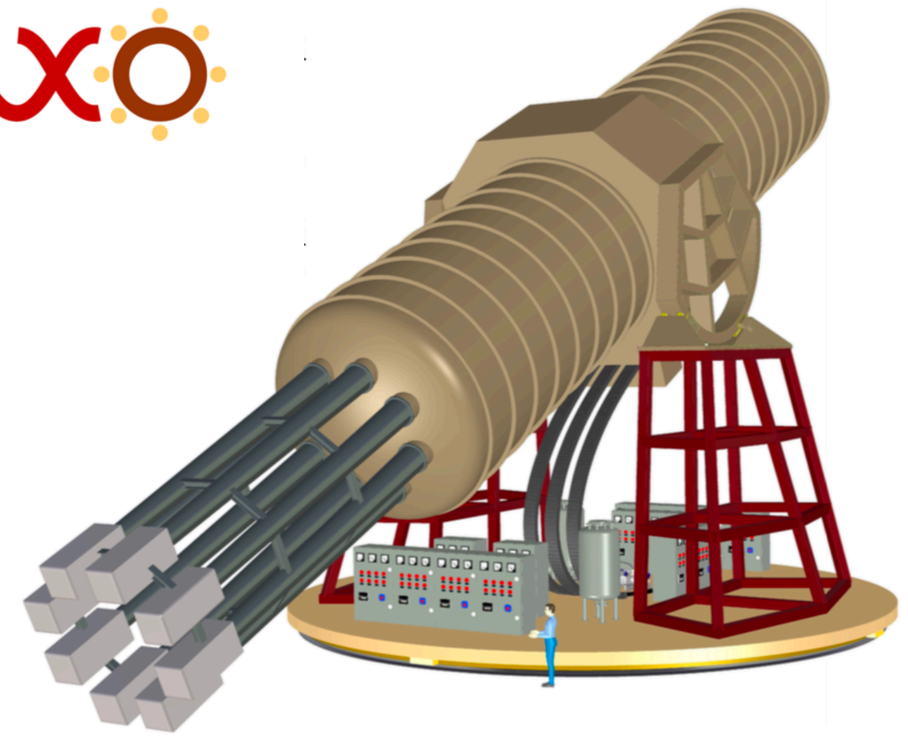


[Lindner]

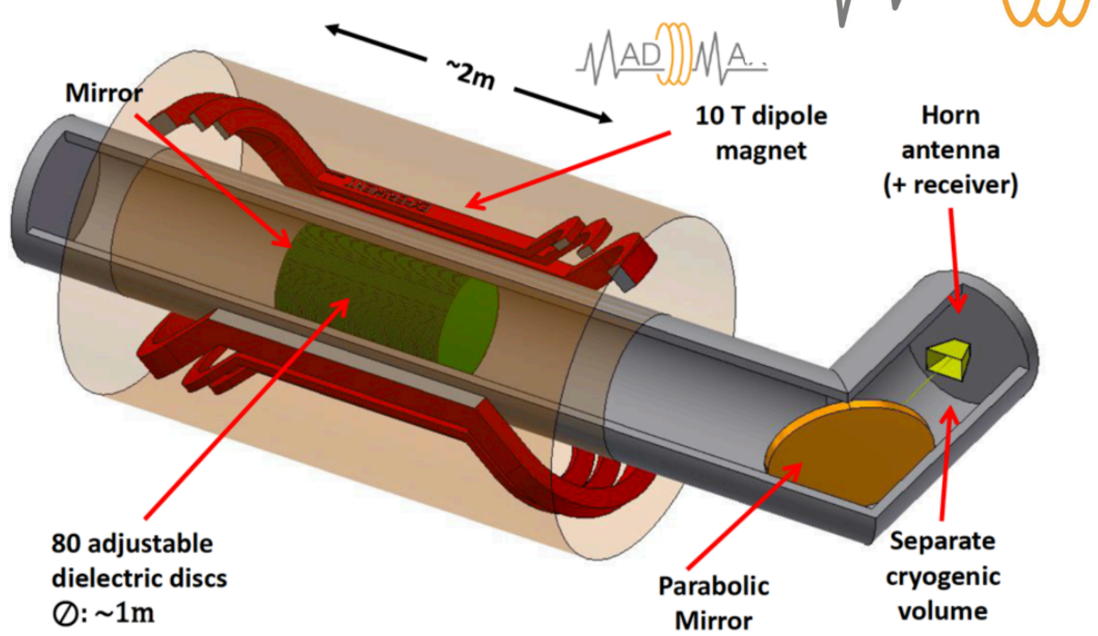
ALPS II

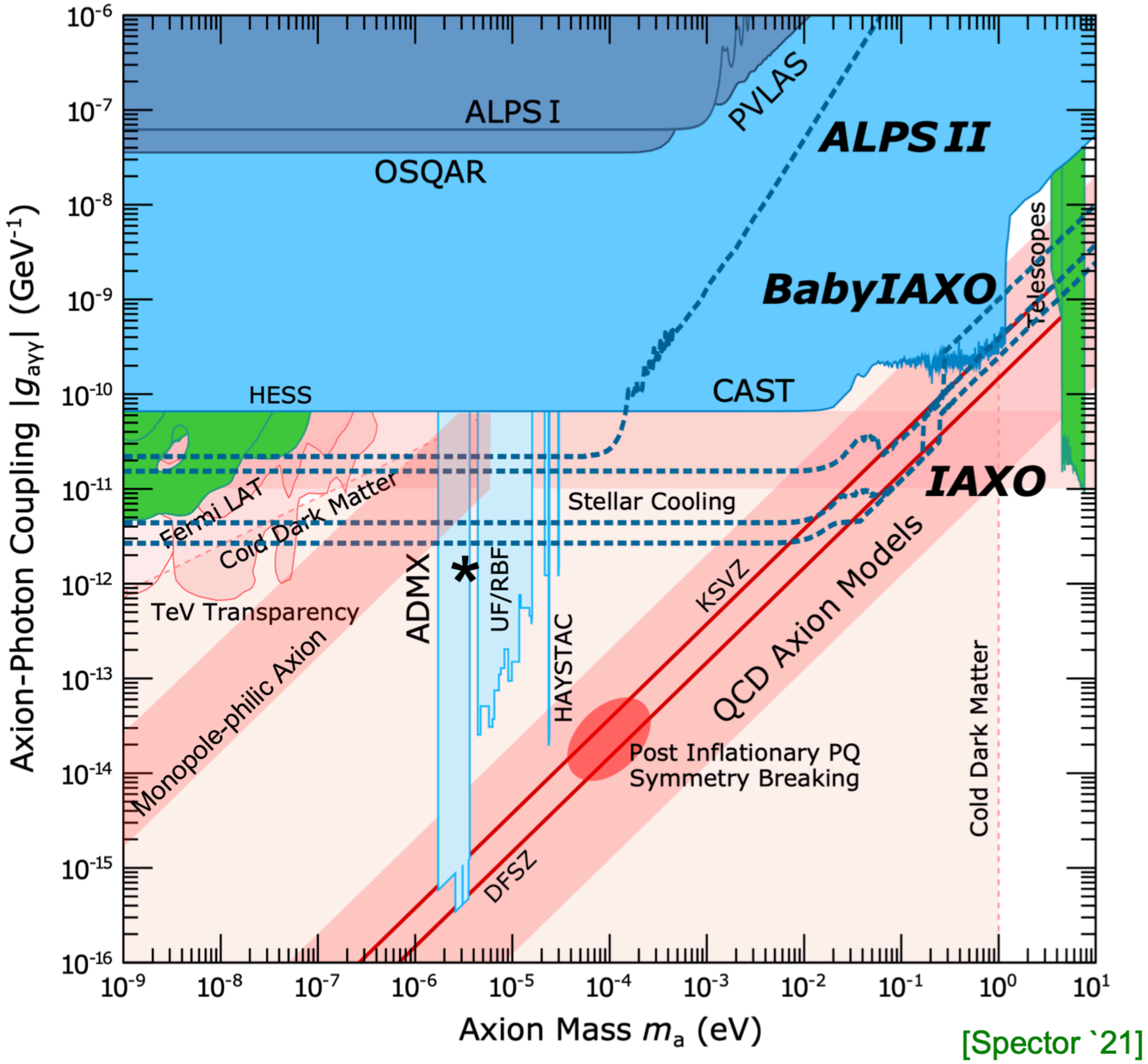


IAXO



MADMAX

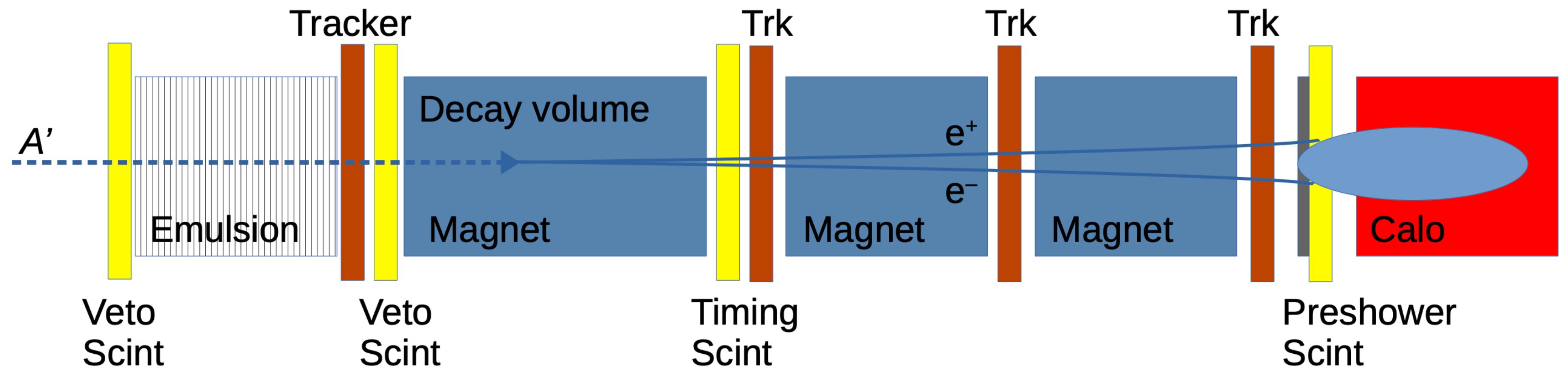




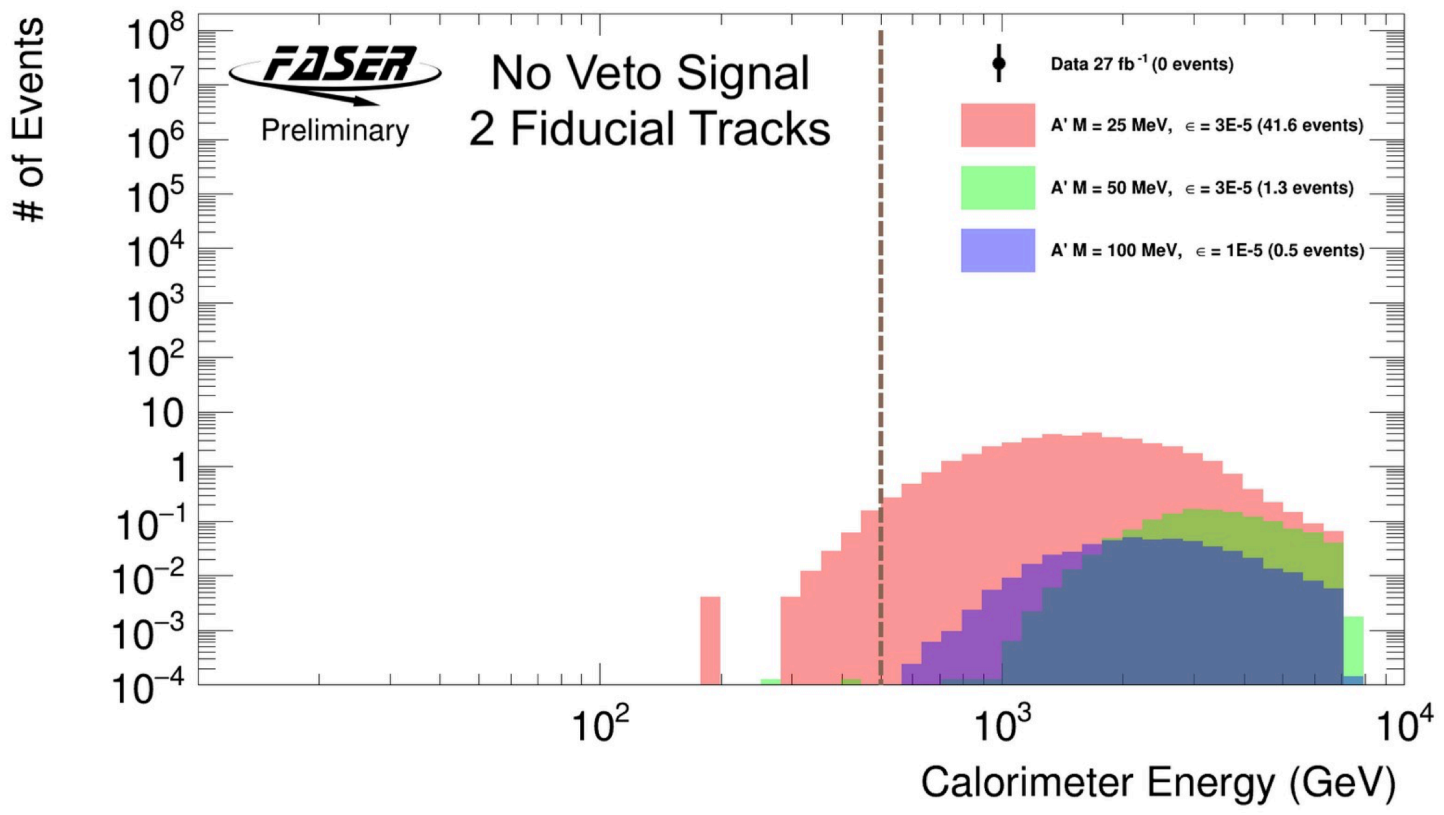
[Spector `21]

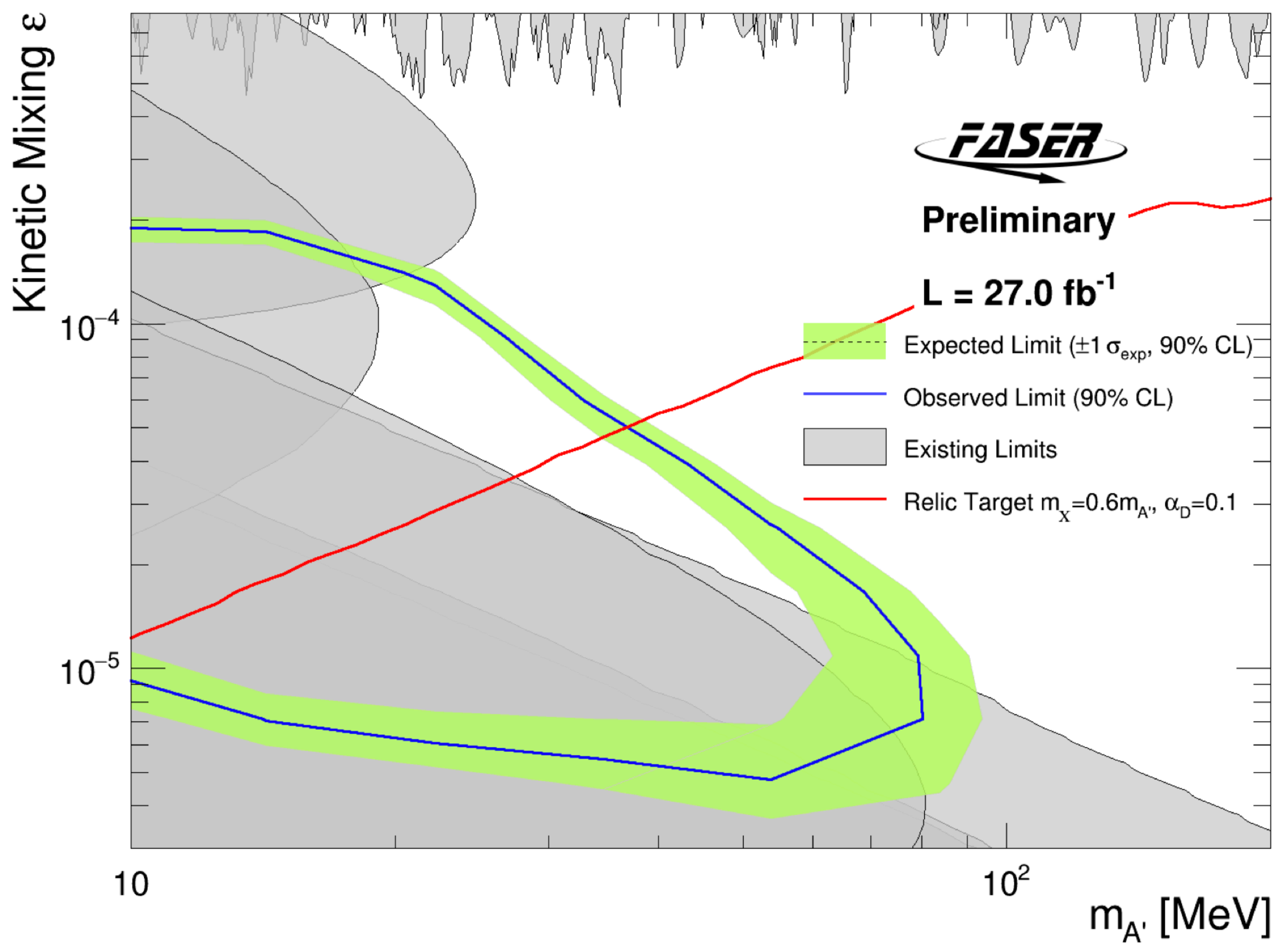
Outstanding ‘Examples’ Dark Photon and ALPs Searches

Faser



First search for Dark Photons using FASER



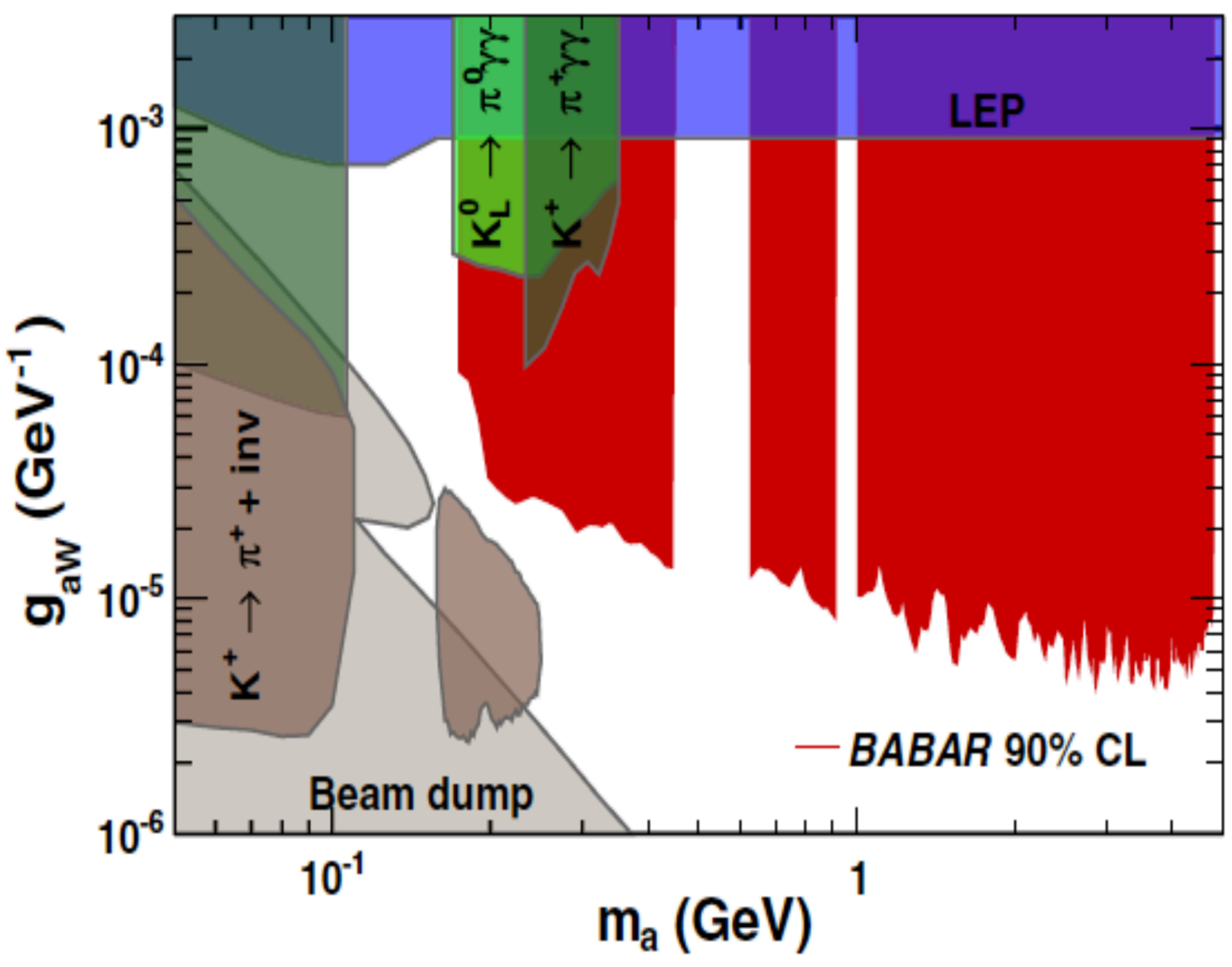


BaBar

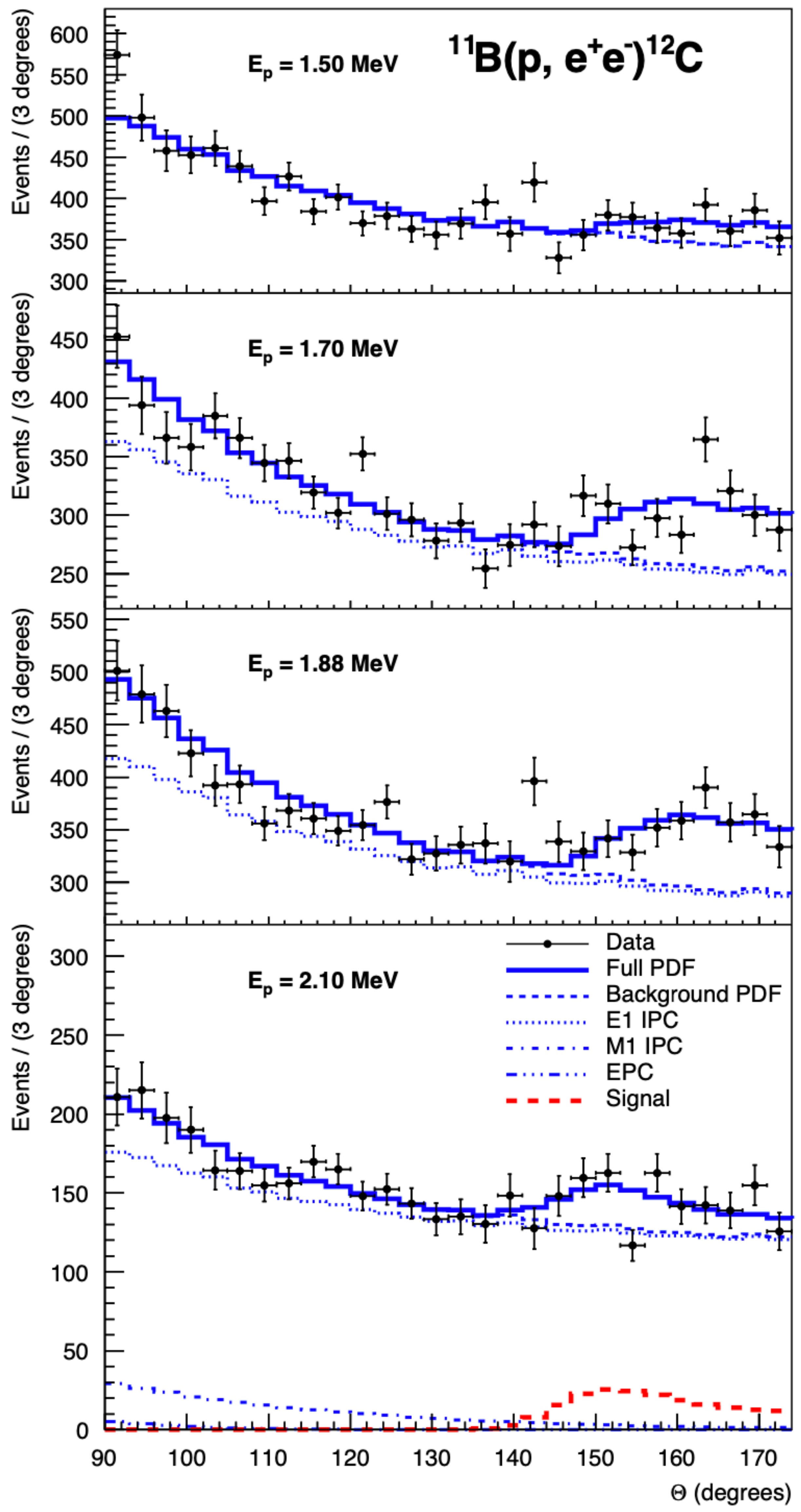
Searches for ALPs with BaBar (new result!)

New for Moriond EW 2023

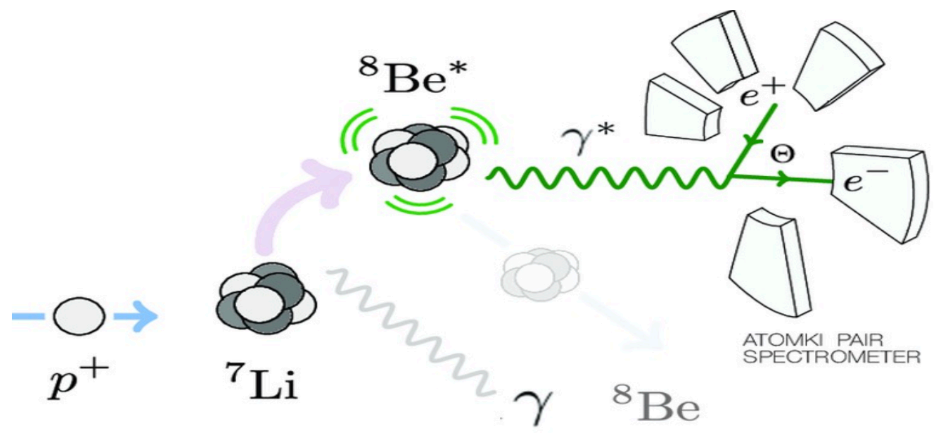
$$B^{\pm} \to K^{\pm} a\ (+a \to \gamma\gamma\ )$$



^{8}Be Anomaly and PADME

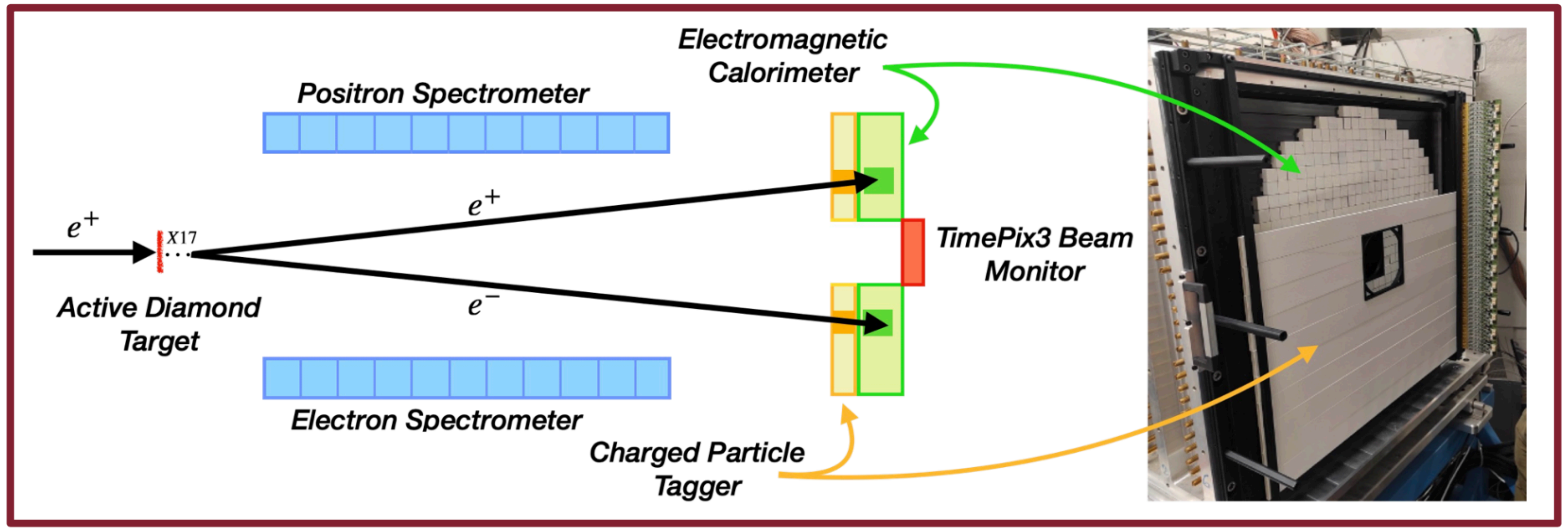


The ATOMKI institute observes the long standing ^{8}Be anomaly, observed also in ^{4}He and ^{12}C, i.e. a significant excess compatible with new particle of 17 MeV mass.



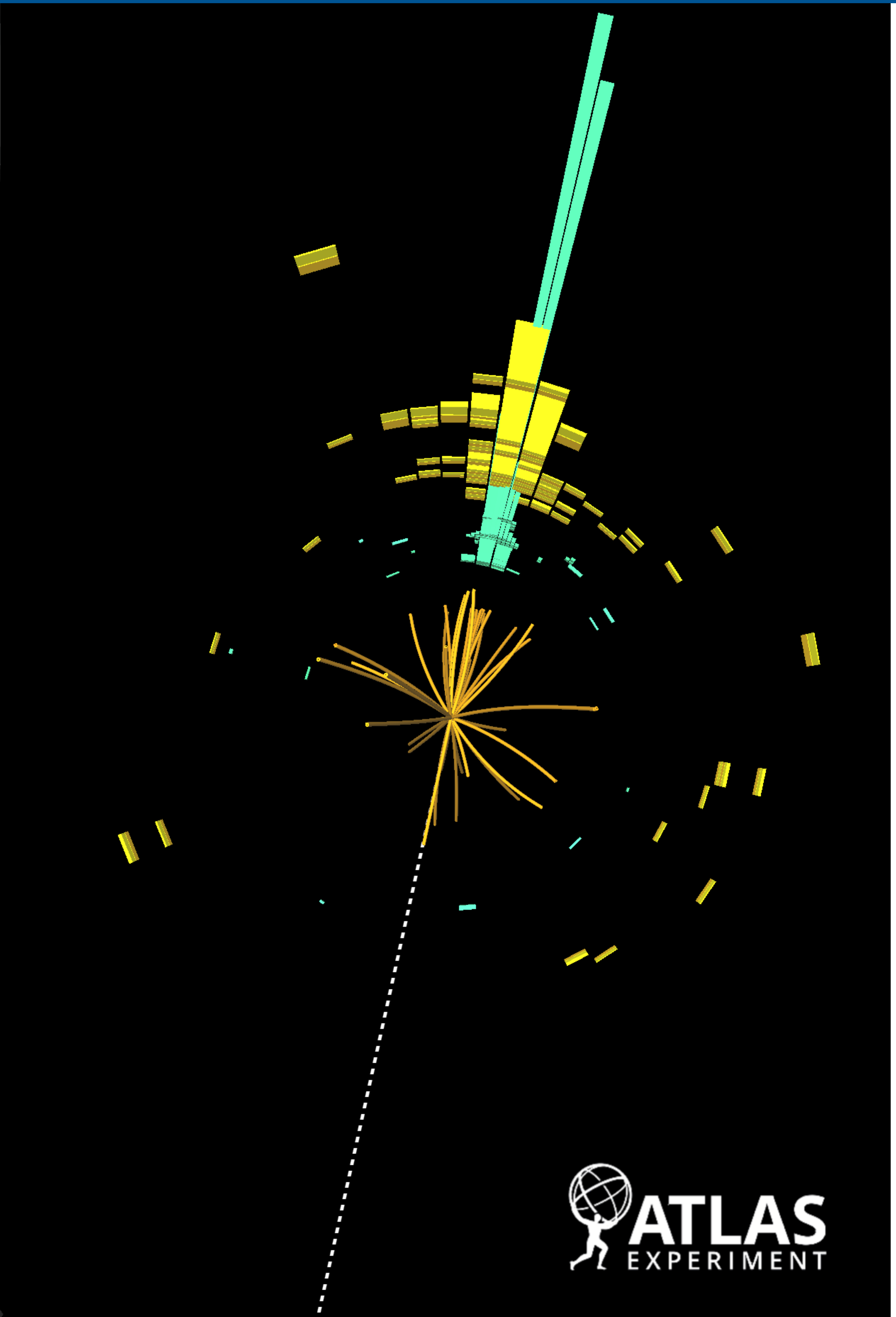
DAΦNE Beam Test Facility is the only facility in the world with a positron beam at 282 MeV (yielding 17 MeV centre-of-mass collisions with fixed target electron!)

PADME experiment (**P**ositron **A**nnihilation into **D**ark **M**atter **E**xperiment)



Run has finished and data analysis is ongoing, hoping to shine light on ^{8}Be

Direct Searches for new Physics at the LHC



- Searches for high energy phenomena responsible for Flavour Anomalies (Leptoquarks) — **Aurelio Juste**
- Searches for high energy phenomena responsible for Neutrino masses (searches for HNL, VL-leptons) — **Haifa Rejeb Sfar**
- Searches for low mass BSM Higgs bosons — **Susanne Gascon-Shotkin**
- Searches for BSM Higgs bosons — **Katharine Leney**
- Searches for SUSY (Strong, EW, compressed, stealth, etc…) — **Aaron Paul O'Neill**, **Jaana Heikkilä**
- Searches for Exotics scenarios of new physics — **Jeremy Niedziela**
- Searches for Long Lived particles — **Steven Lowette**

What to Take Home?

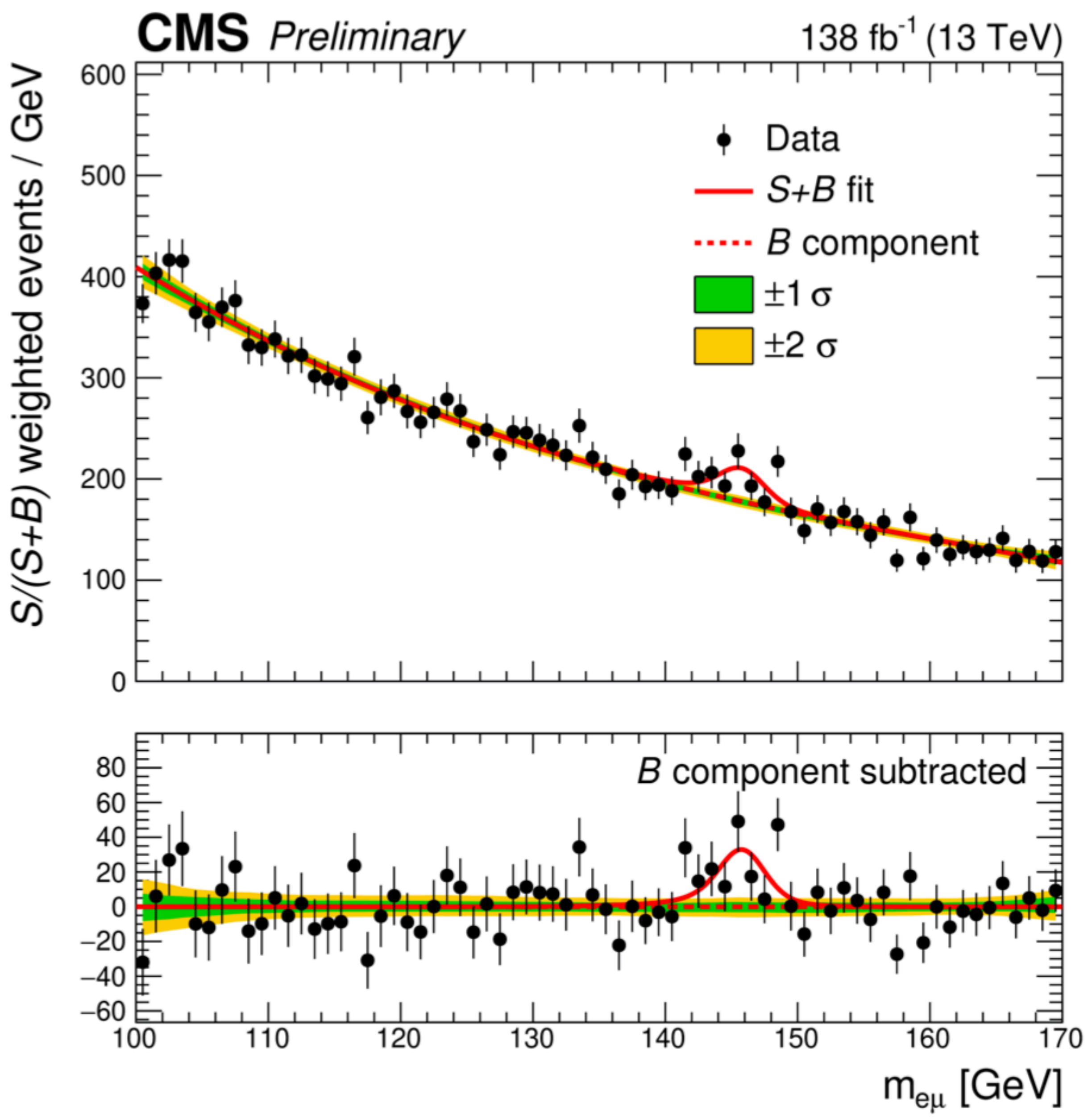
1.- Low energy anomalies can be immediately checked at the energy frontier at the LHC

2.- The search program of the LHC aims at leaving no stone unturned

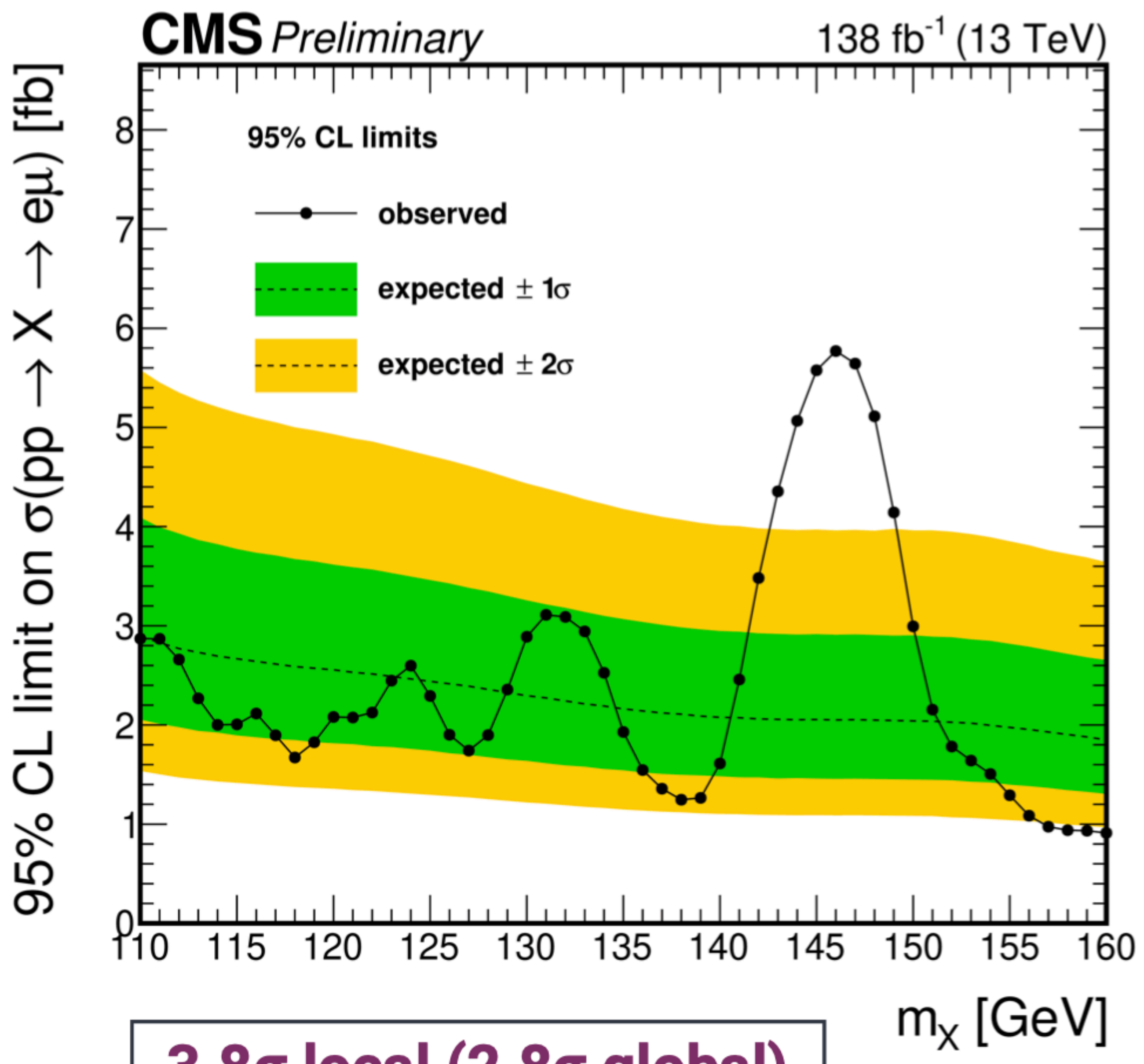
3.- The strength of having several experiments!

Susanne Gascon-Shotkin
Katharine Leney

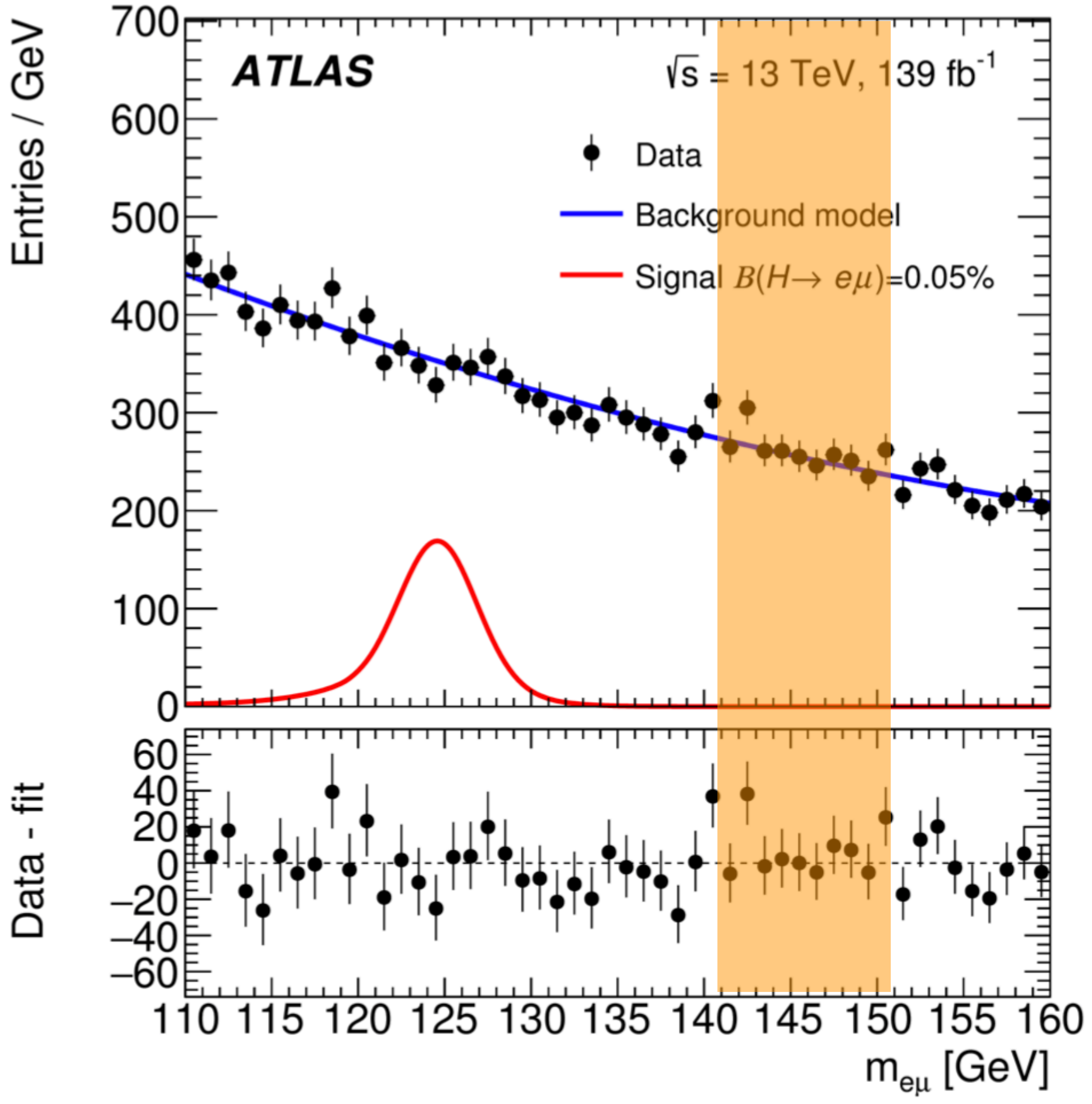
New for Moriond EW 2023



Katharine Leney



3.8σ local (2.8σ global) excess at $m_X \approx 146$ GeV



Seems disfavoured but needs to be properly checked!

What to Take Home?

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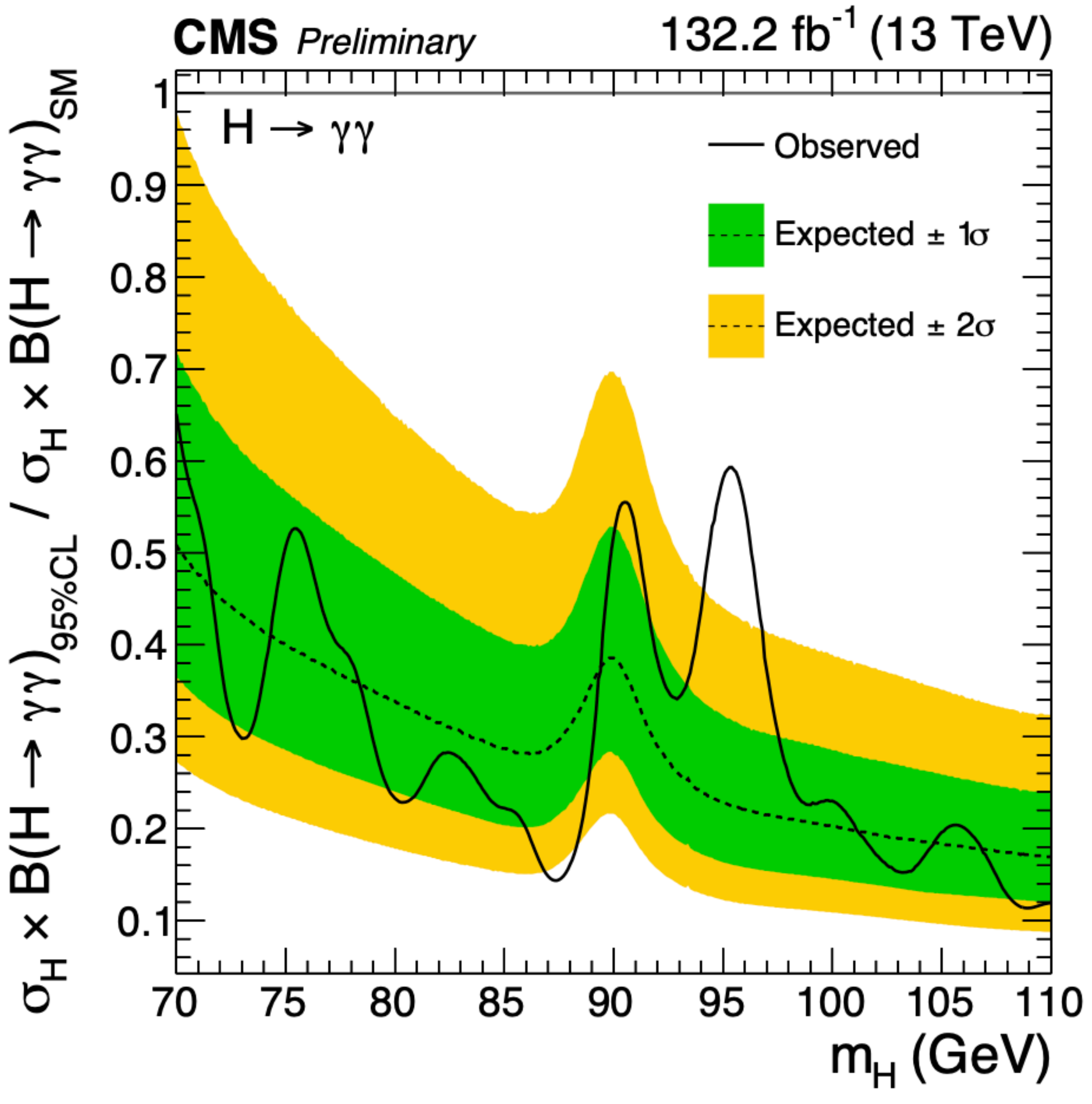
2.- The search program of the LHC aims at leaving no stone unturned

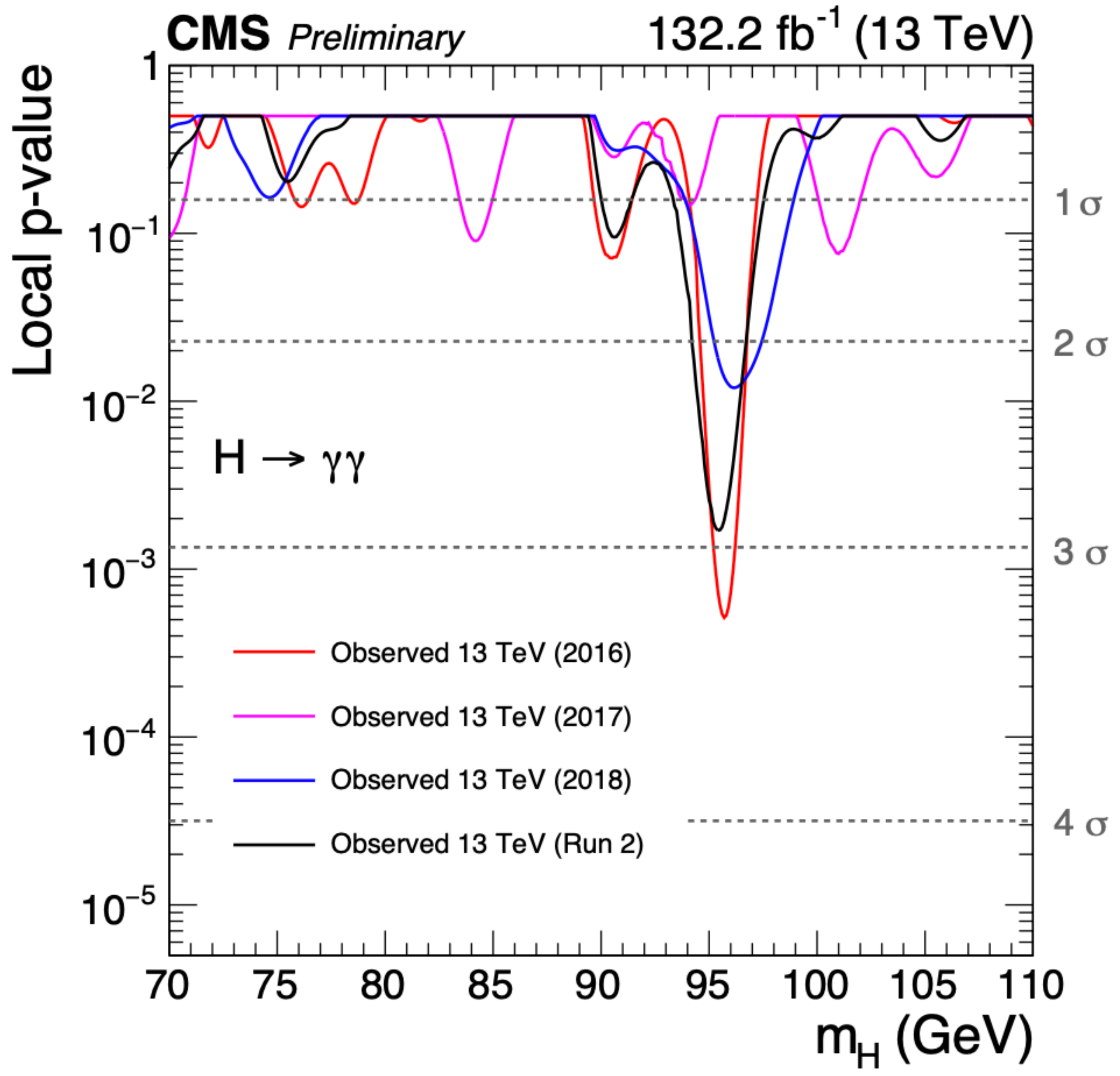
3.- The strength of having several experiments!

Susanne Gascon-Shotkin
Katharine Leney

New for Moriond EW 2023

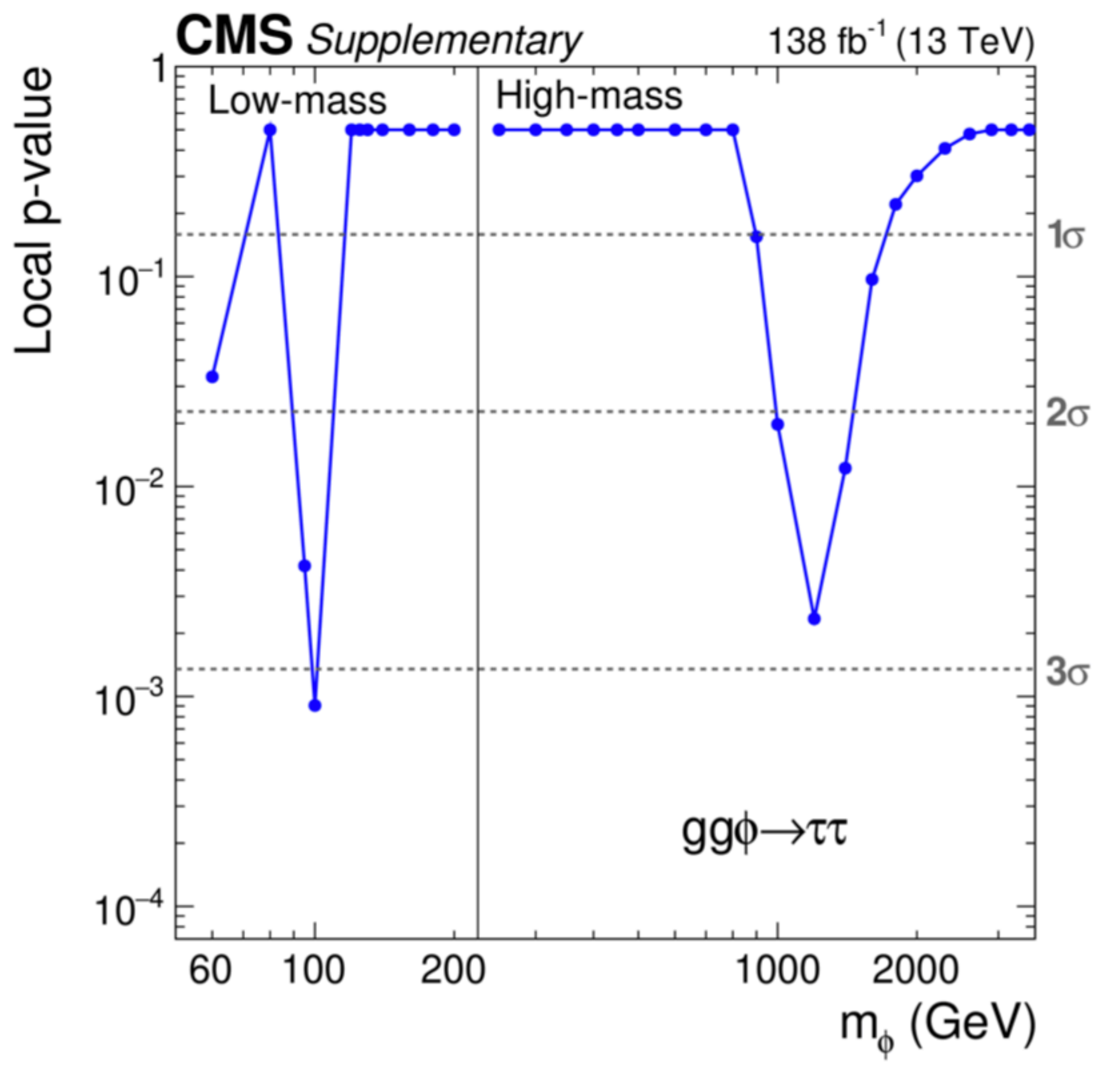
2.9σ local (1.35σ global) excess at m_X = 95.4 GeV





Best-fit mass consistent with 3.1σ local (2.7σ global) excess at m_X = 100 GeV in ggF X→ττ channel.

arXiv:2208.02717 (accepted by JHEP)



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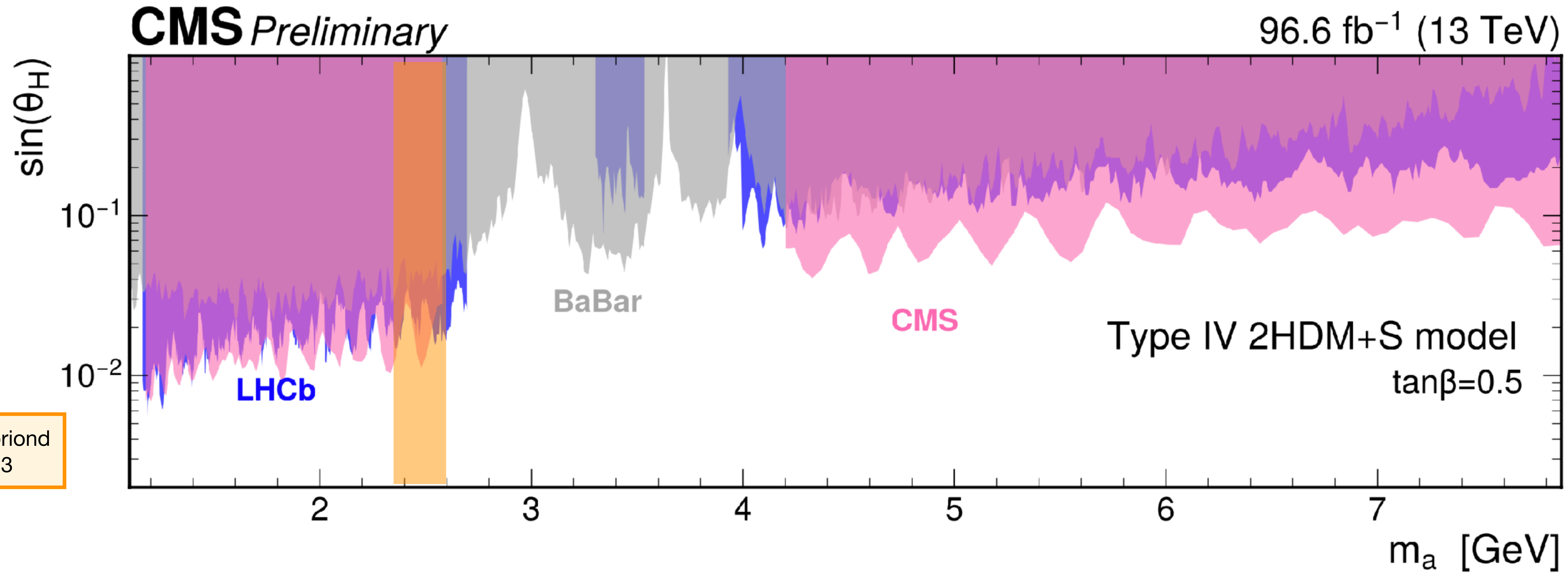
Jeremy Niedziela



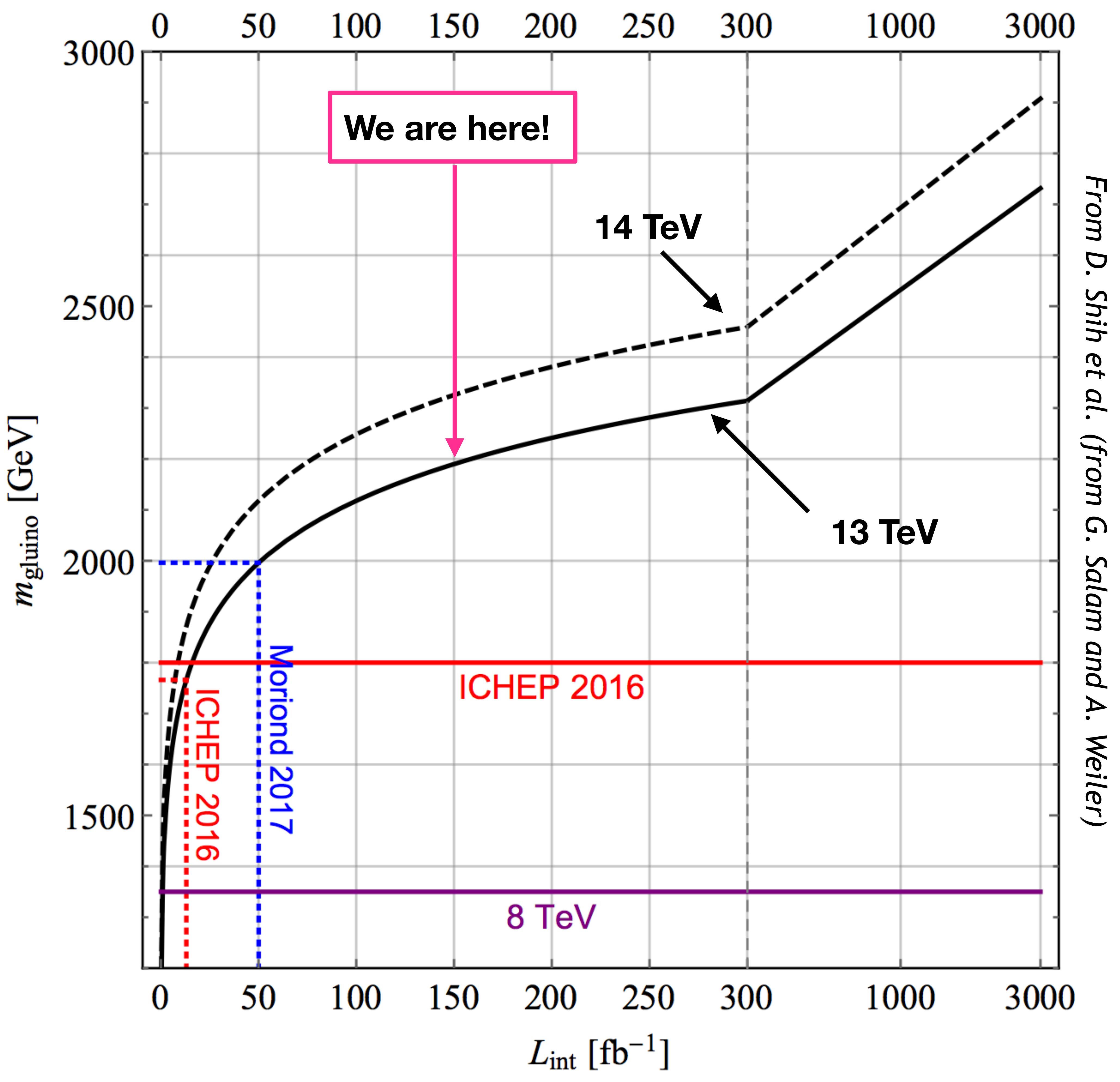
New for Moriond EW 2023

the **largest excess at 2.41 GeV** (local: 3.24σ, global: 1.27σ),

→ side note: 3.1σ LHCb excess at 2.42 GeV,

Still Room for Discoveries?

Evolution of **exclusion** search sensitivity for generic strongly interacting particle (e.g. **gluino**)

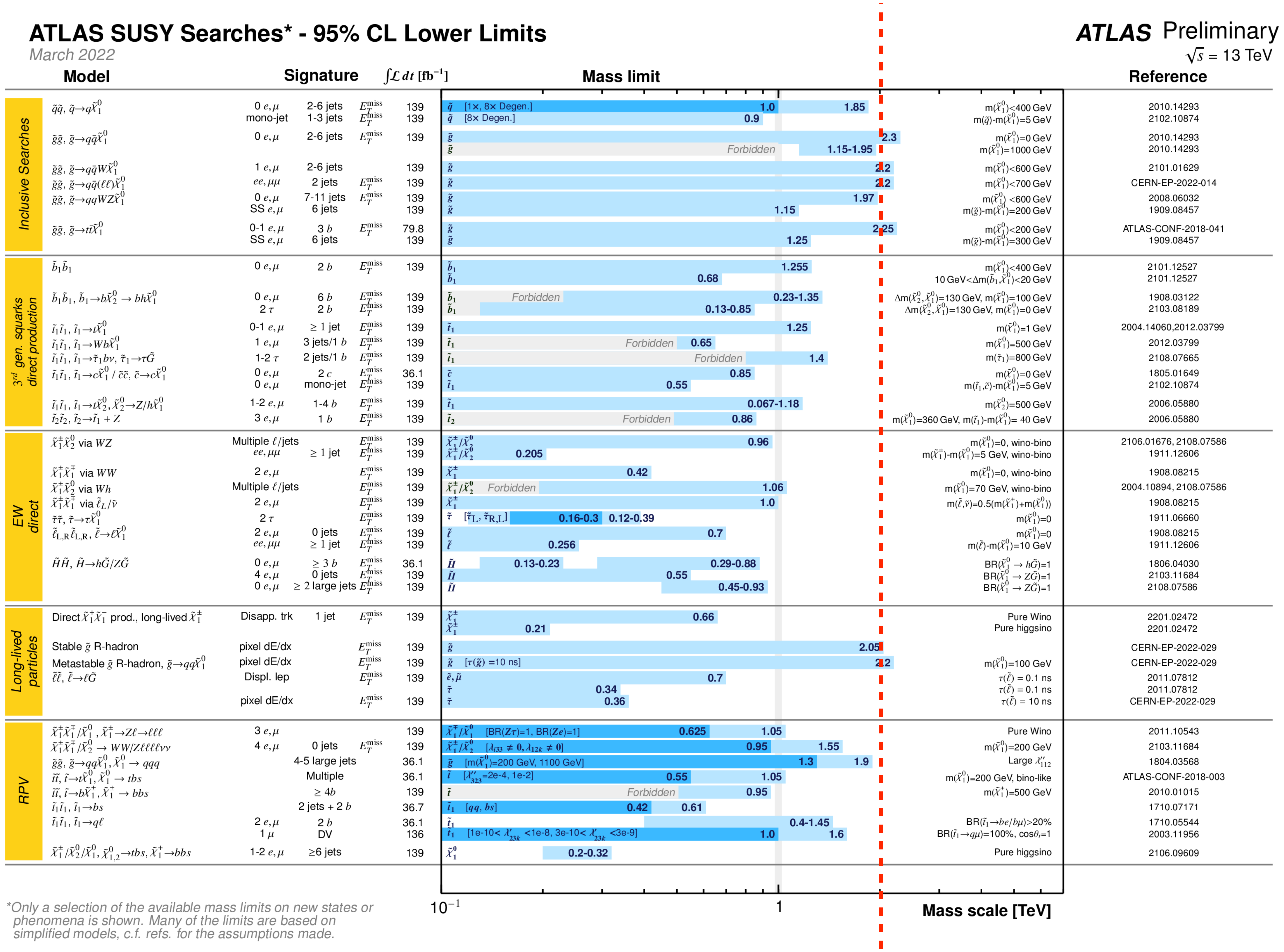


At HL-LHC still a **factor of 20** in luminosity:

- Still **room for discoveries!** (~1σ can become 5σ)
- Performance can be improved!
  - With new ideas and developments at all levels.
  - **Improving precision will be key!**
- Discoveries will however take longer: **doubling time of the luminosity of several years**

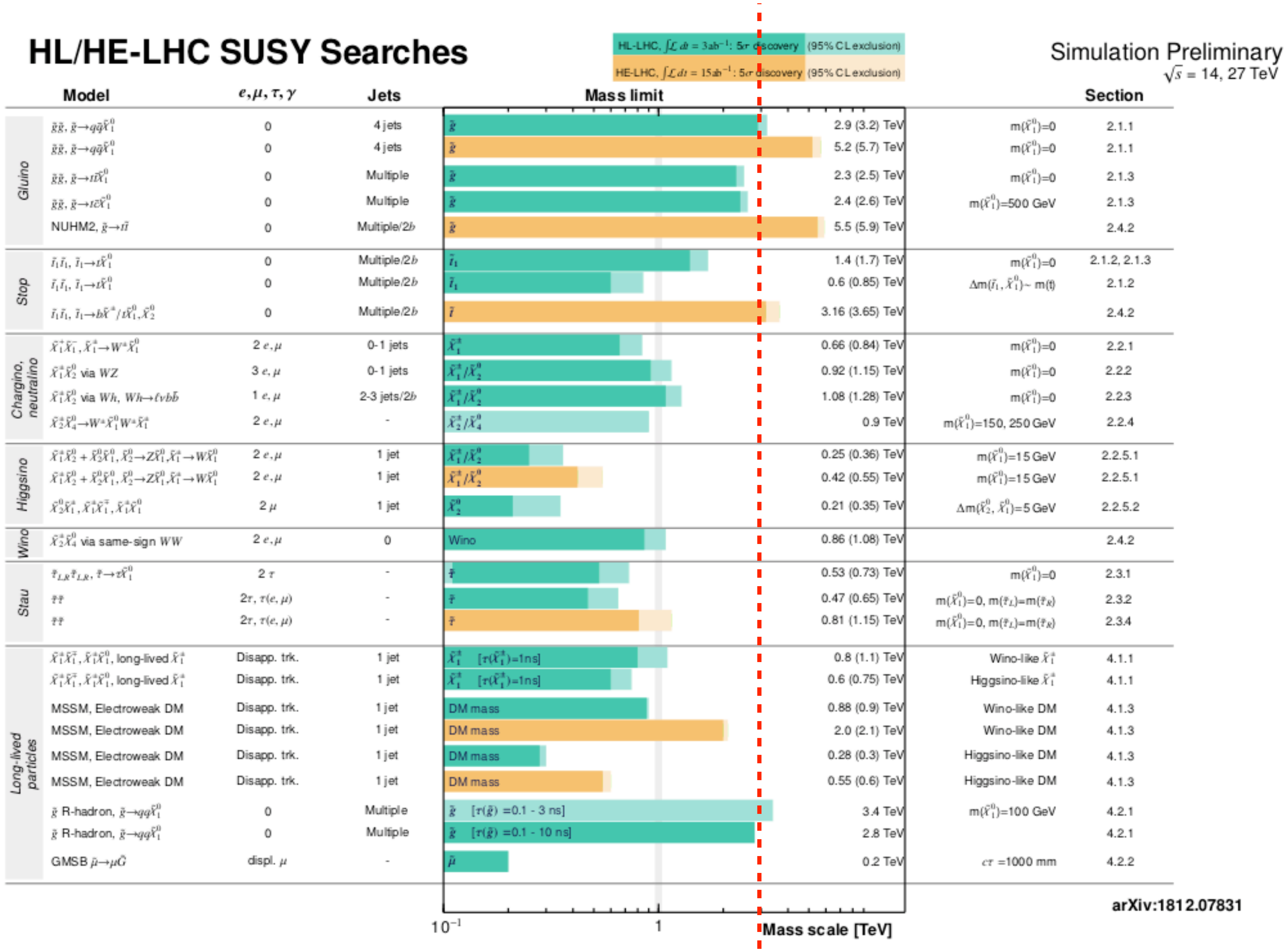
Very Large Number of SUSY Searches

(in large variety of topologies and models)



2 TeV

Example from ATLAS (similar for CMS)

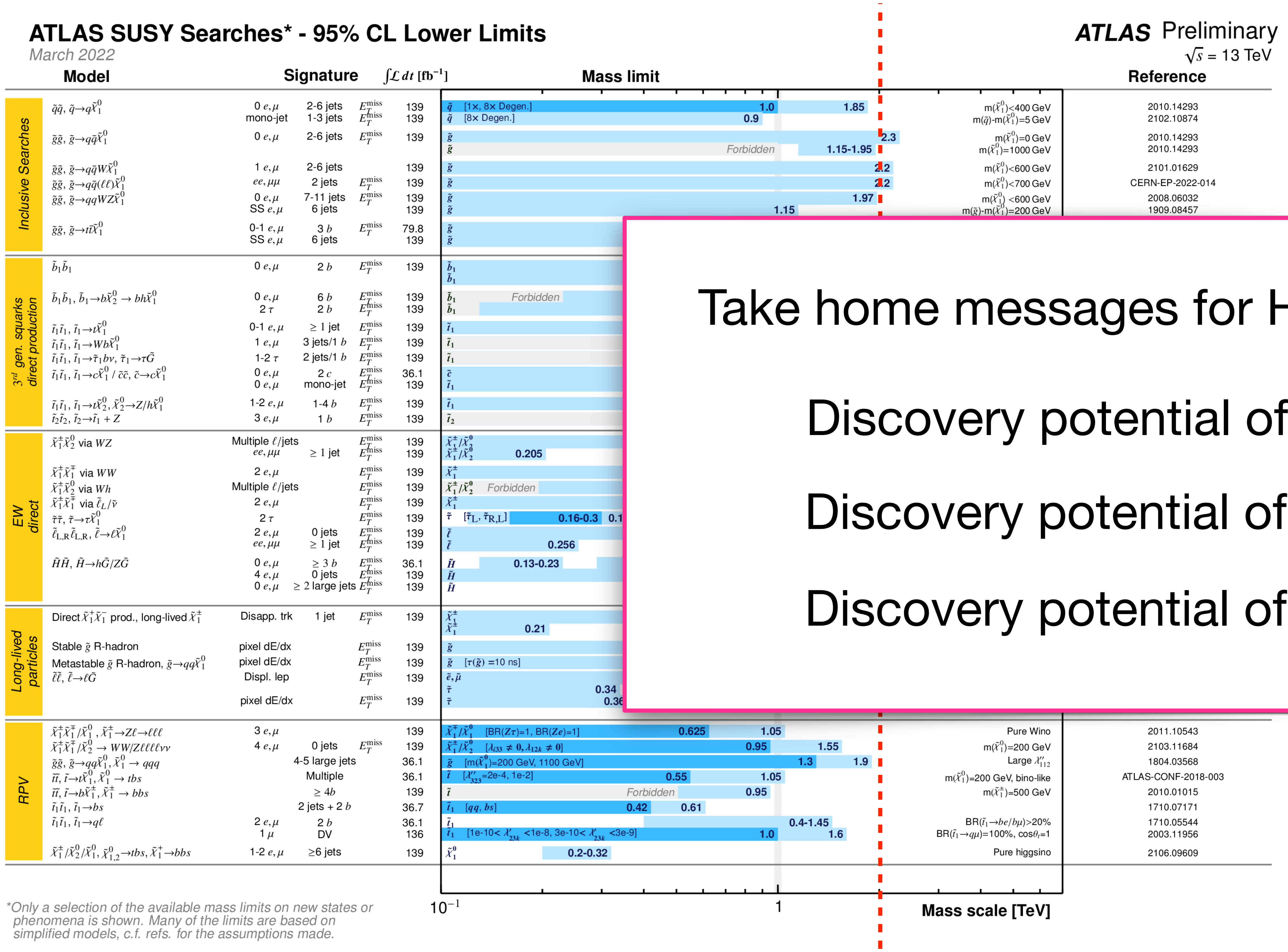


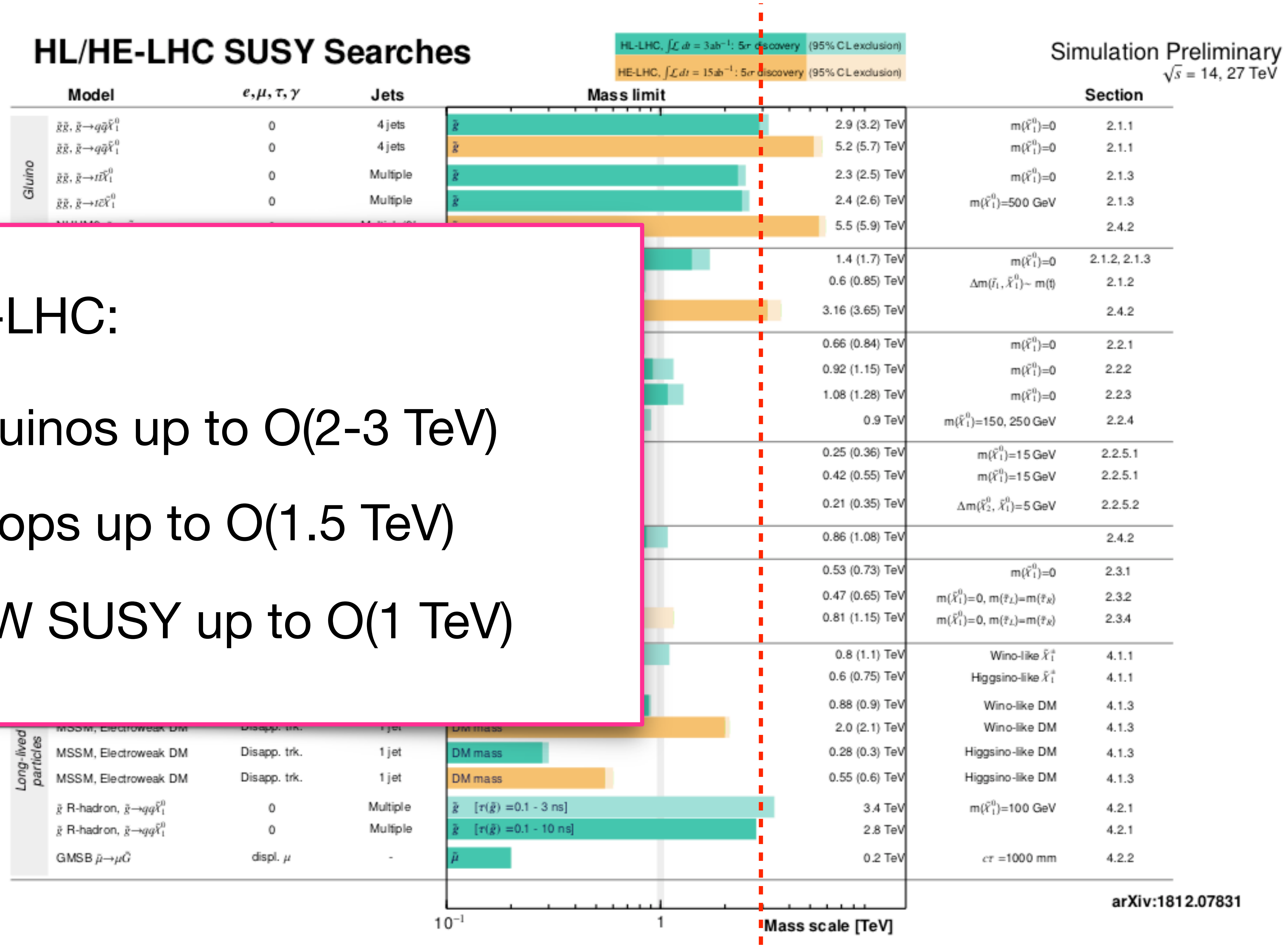
3 TeV

HL-LHC YR 1812.07831

Very Large Number of SUSY Searches

(in large variety of topologies and models)





Take home messages for HL-LHC:

- Discovery potential of gluinos up to O(2-3 TeV)
- Discovery potential of stops up to O(1.5 TeV)
- Discovery potential of EW SUSY up to O(1 TeV)

2 TeV

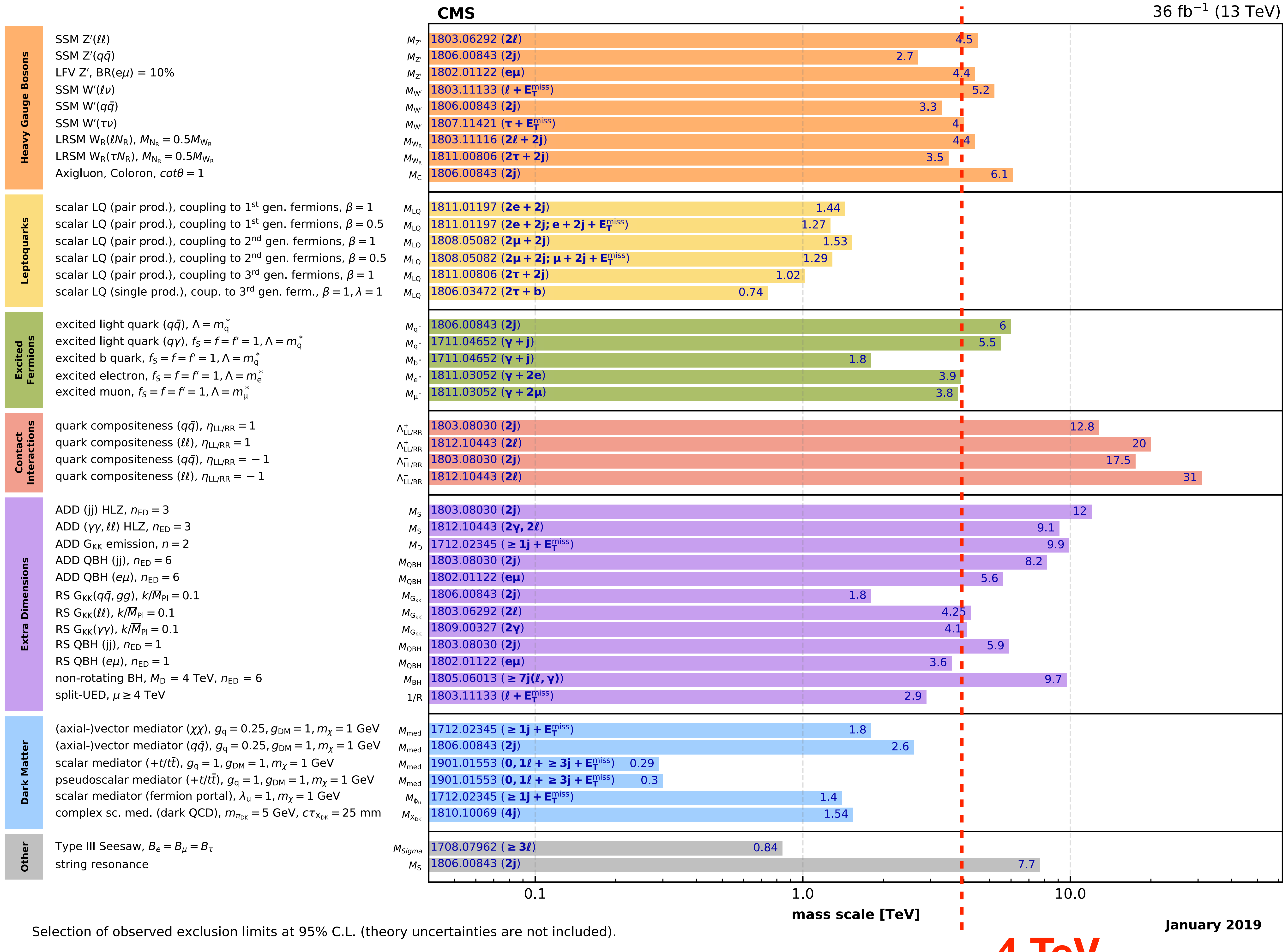
3 TeV

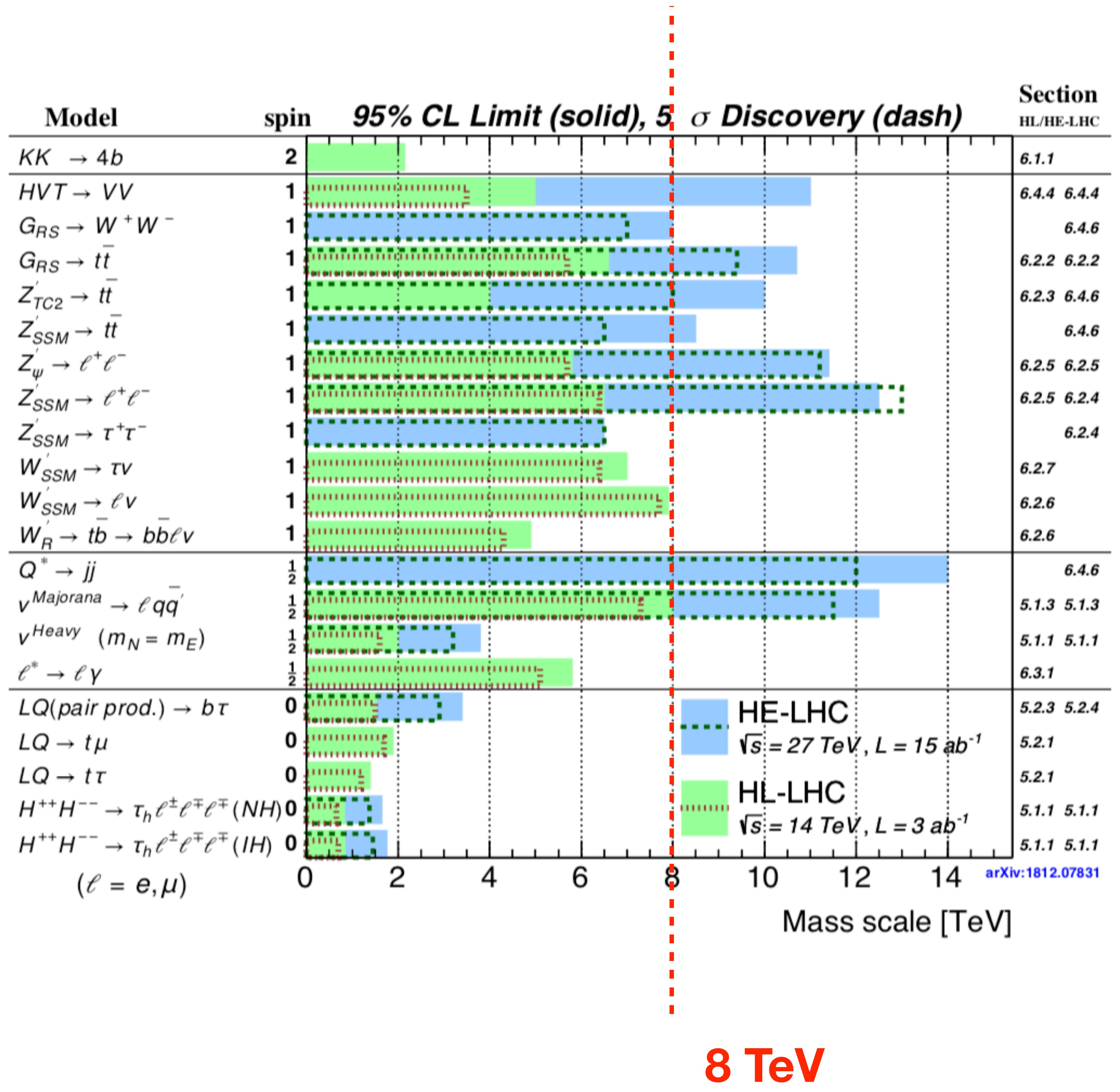
Example from ATLAS (similar for CMS)

HL-LHC YR 1812.07831

Very Large Number of Searches

(in large variety of topologies and models)





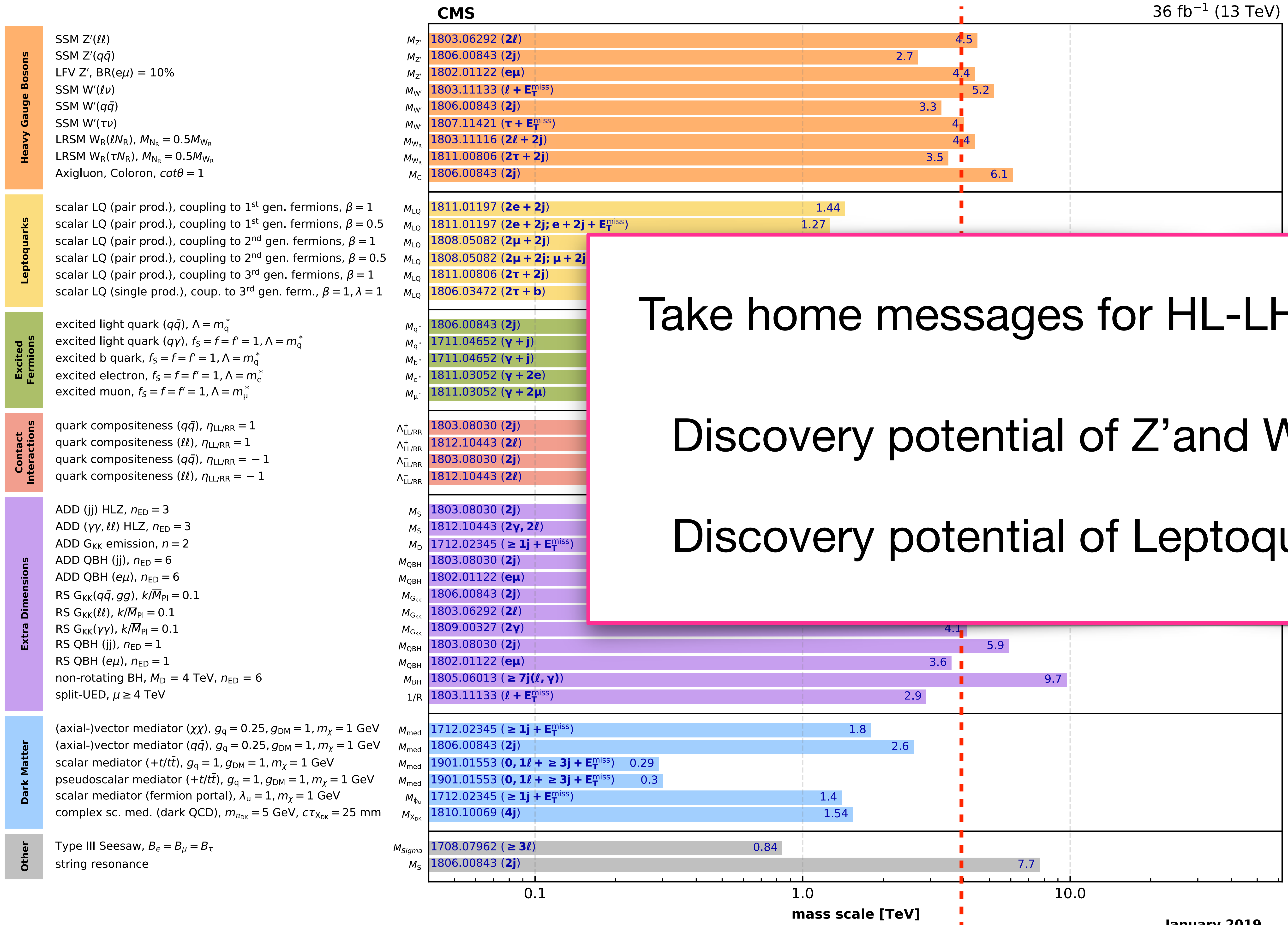
HL-LHC YR
1812.07831

Example from CMS (similar for ATLAS) - latest plot in the backup!

Very Large Number of Searches

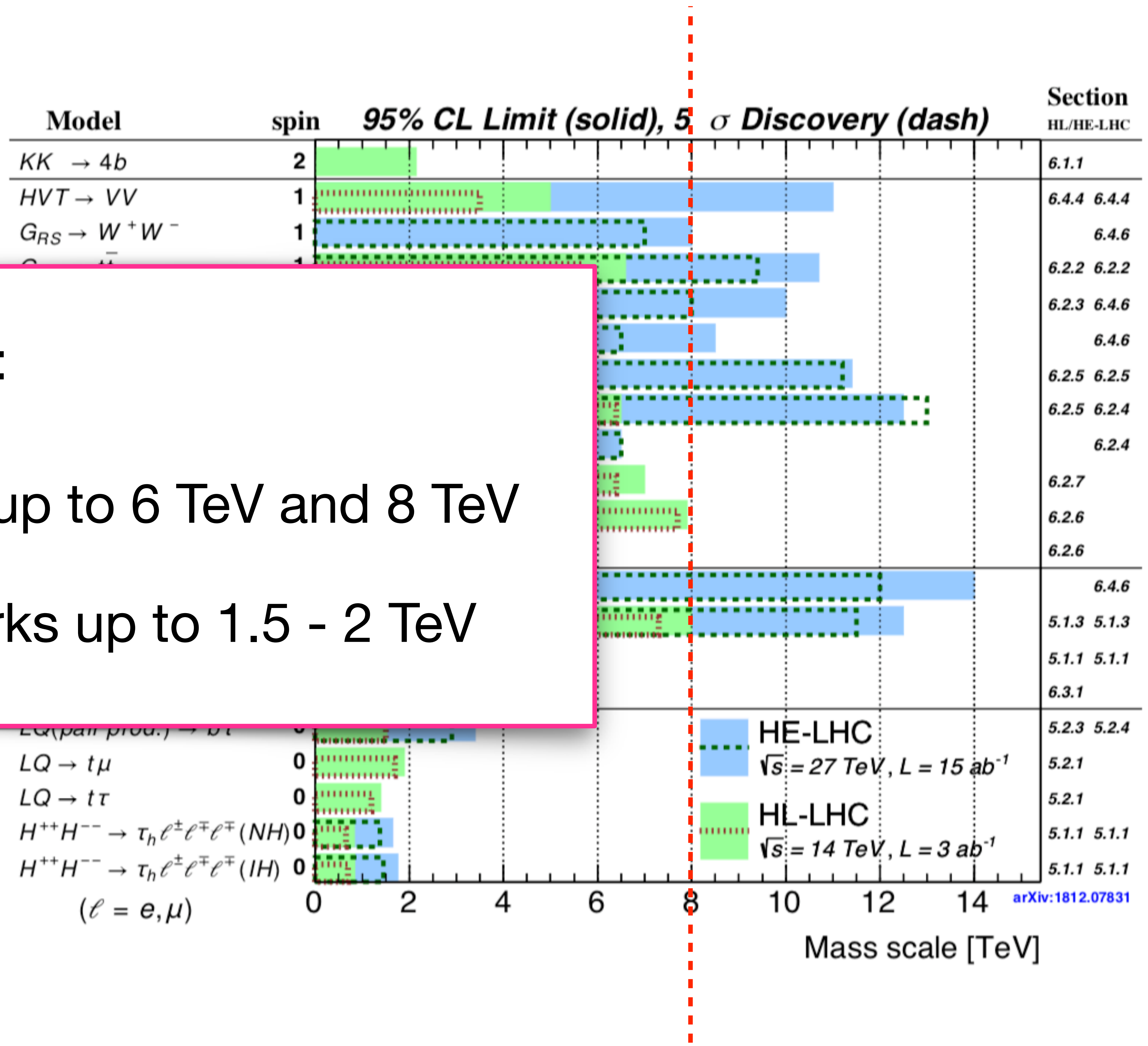
(in large variety of topologies and models)

Overview of CMS EXO results



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

4 TeV



Take home messages for HL-LHC:

Discovery potential of Z'and W' up to 6 TeV and 8 TeV

Discovery potential of Leptoquarks up to 1.5 - 2 TeV

8 TeV

HL-LHC YR
1812.07831

Example from CMS (similar for ATLAS)

Leaving No Stone Unturned !

Steven Lowette

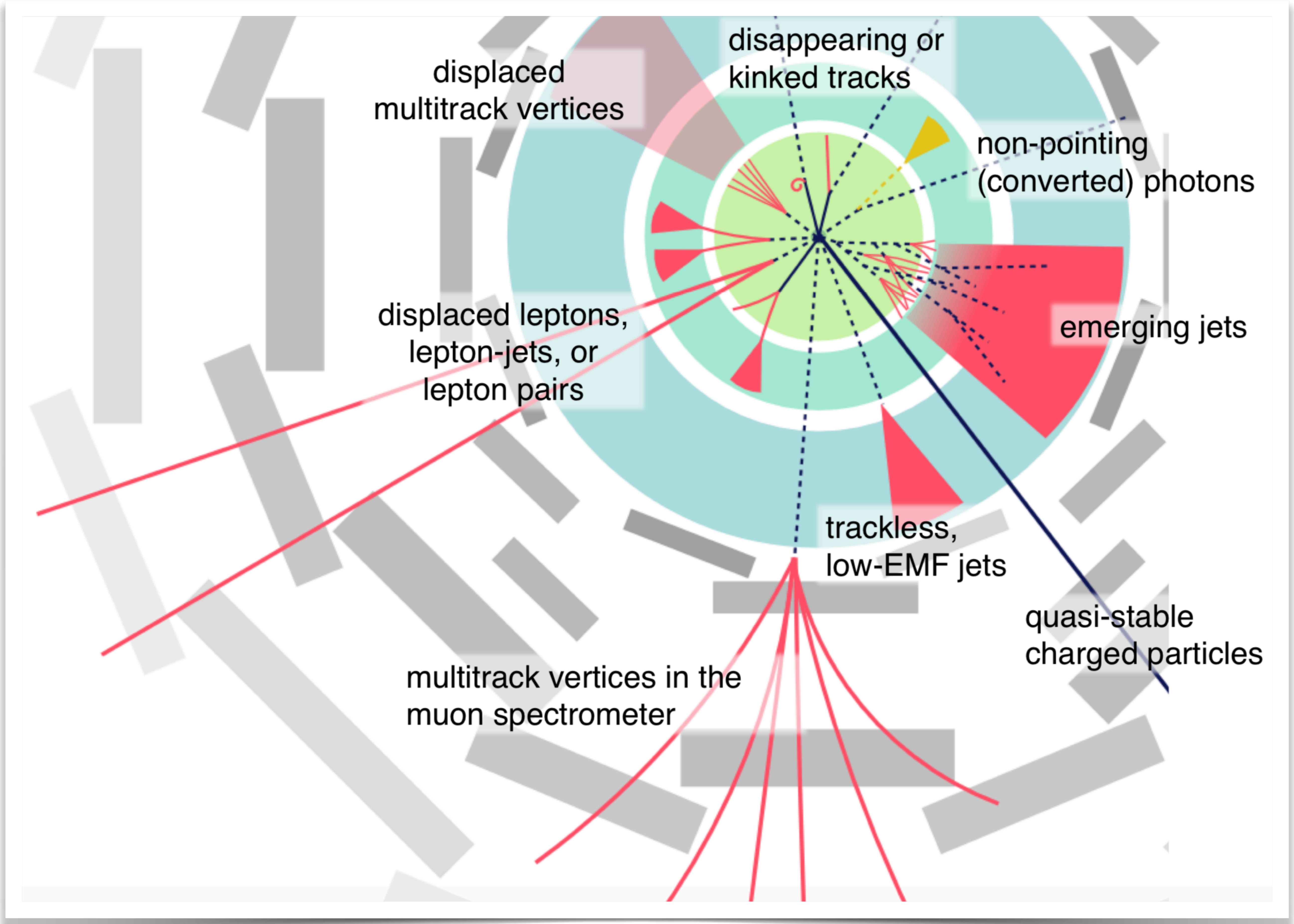
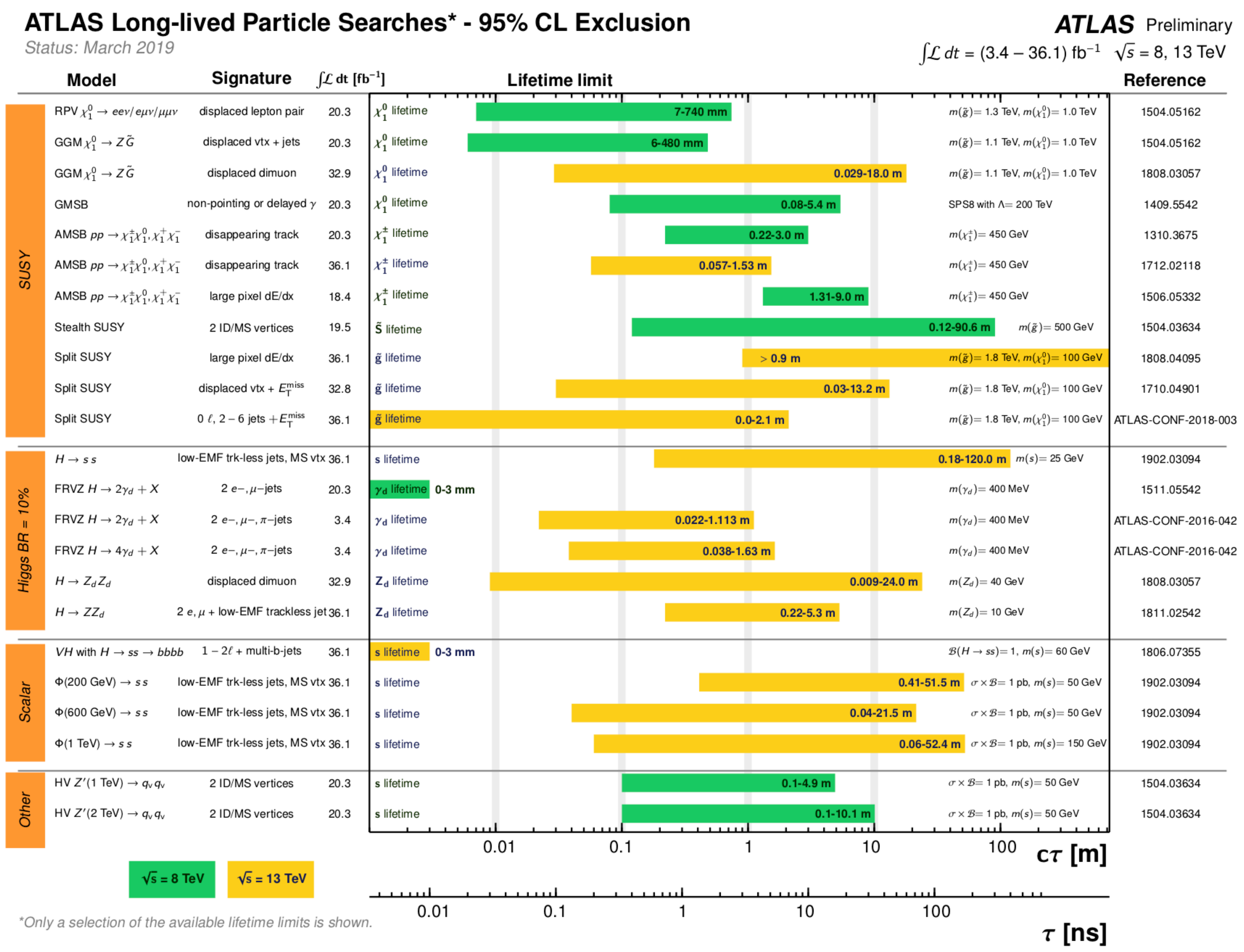


Image from H. Russel



Sample for ATLAS (same for CMS)

Difficult signatures requiring specific complex reconstruction and trigger!

Faithful Uncertainties in Machine Learning

$f_\theta(x) \simeq g(x)$	$p_\theta(x) \in [0,1]$	$p_\theta(x) \simeq p_{data}(x)$
Regression	**Classification**	**Generation**

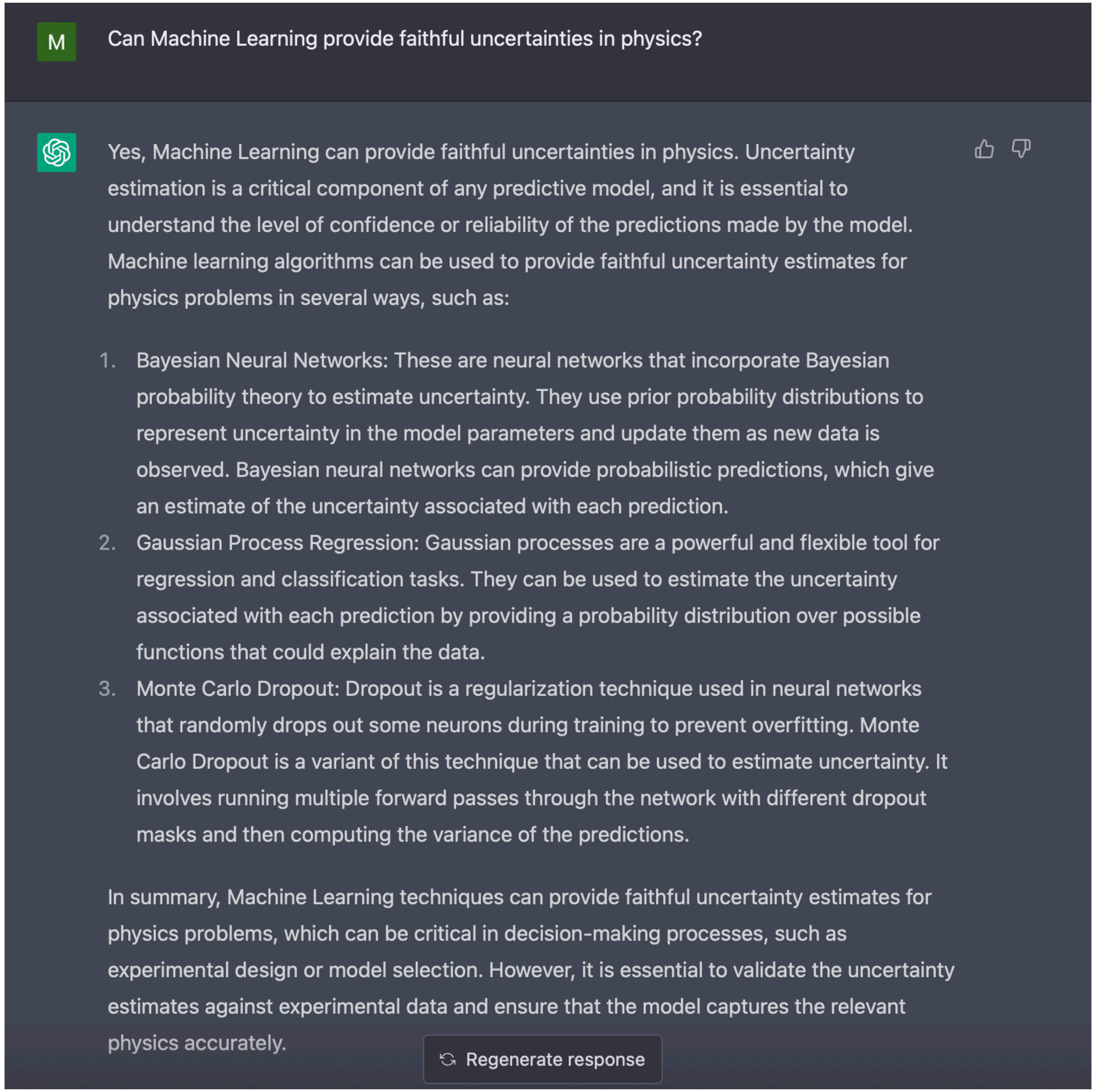
Highly expressive, non-linear parameterizations

Machine learning has the potential to significantly enhance our understanding of fundamental physics!

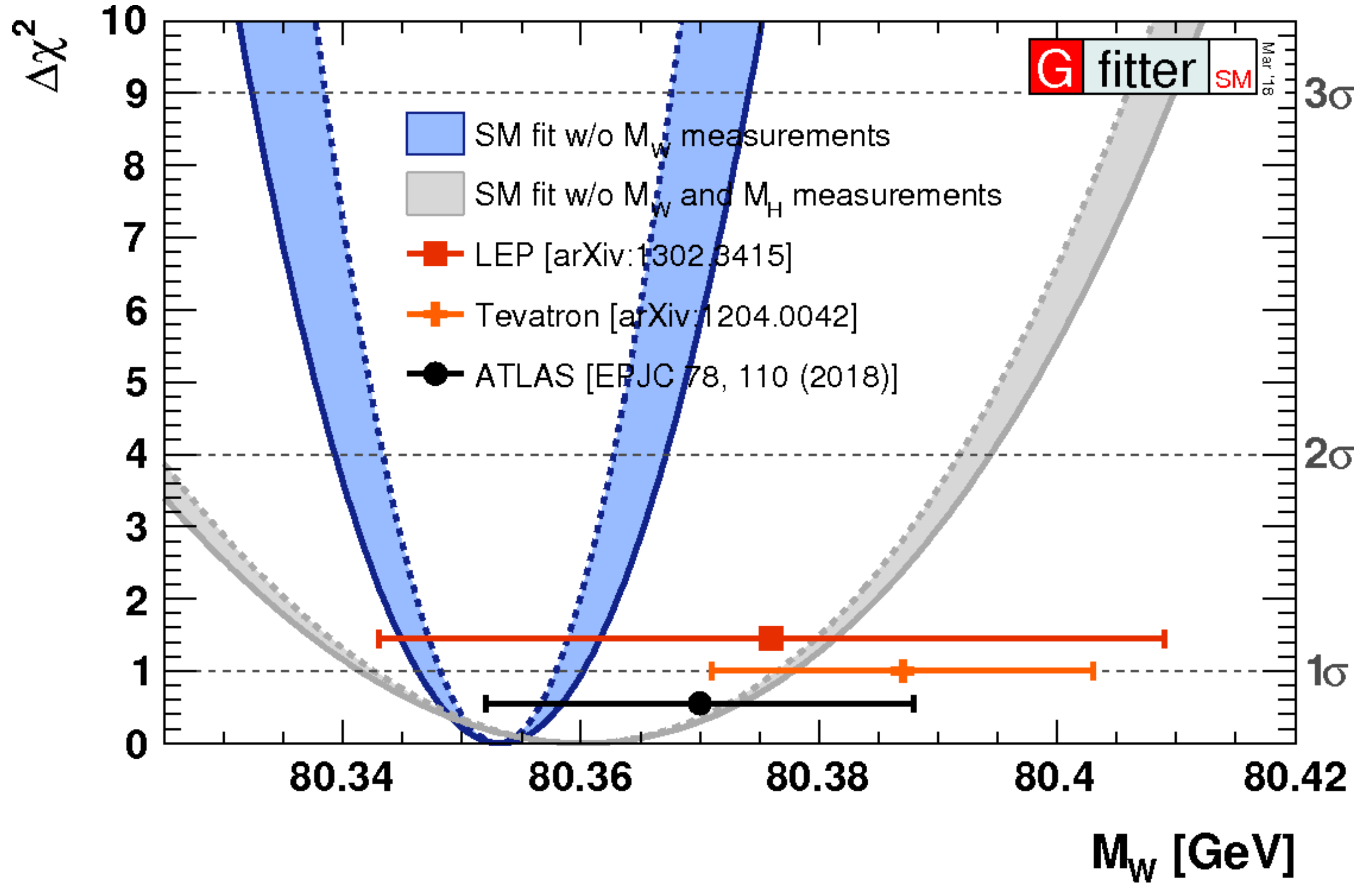
Yes, faithful uncertainties in physics can be provided in several ways:

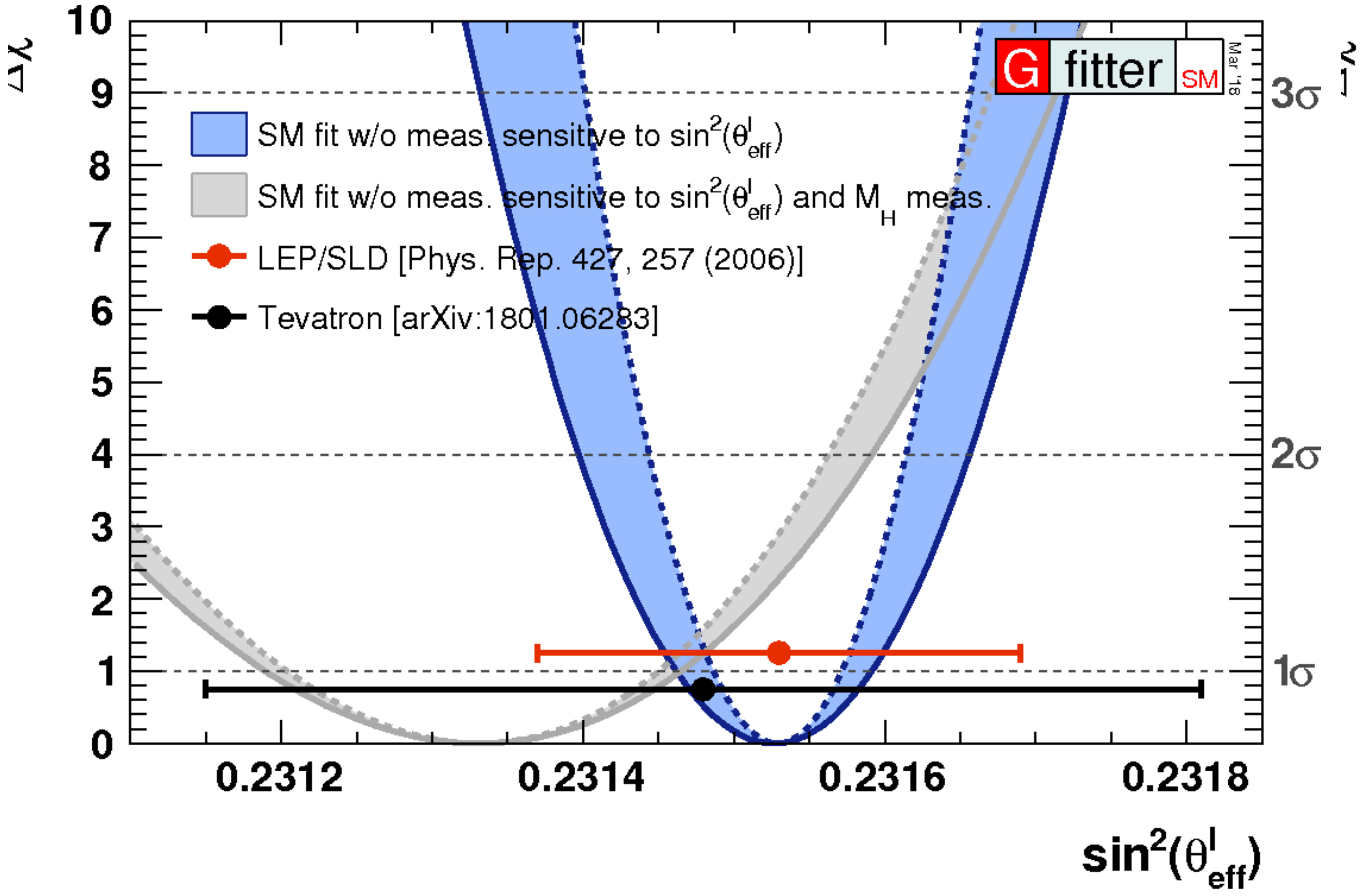
- Bayesian Neural Networks
- Gaussian Process regression
- Monte Carlo drop out

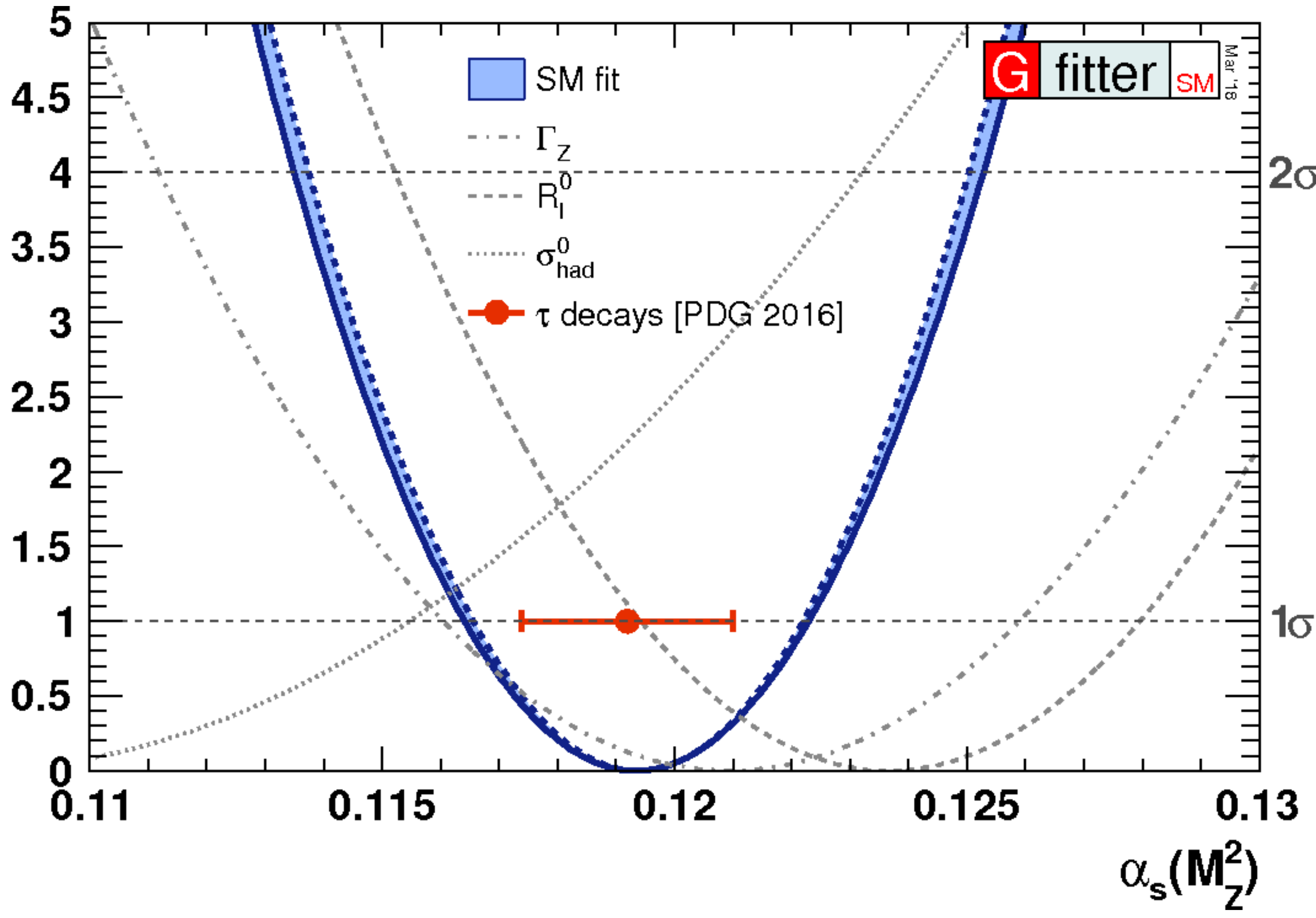
Essential to validate the uncertainty estimates against experimental data and ensure that the model captures the relevant physics accurately.



The Precision Frontier at the LHC





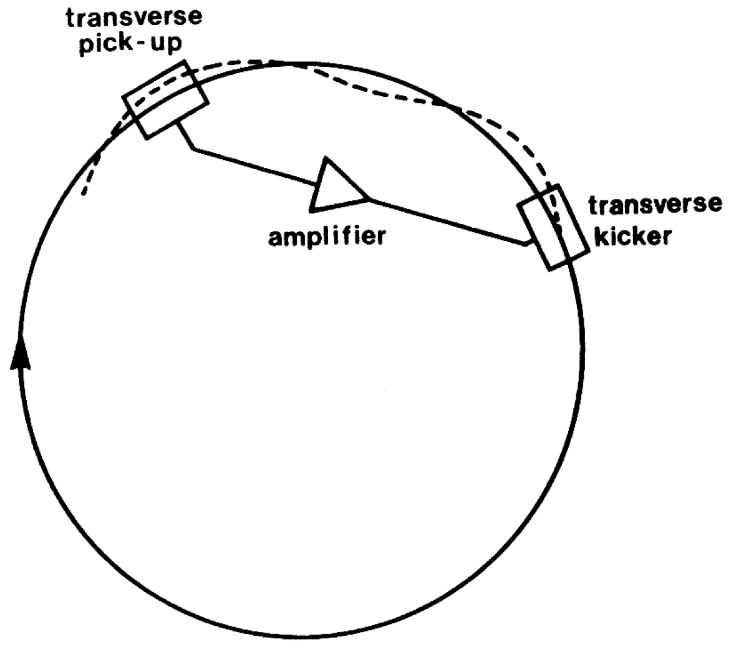


- Probe the SM through the measurements of its fundamental parameters
- Make ancillary measurements to increase precision in other measurements or searches

… and anomaly (W mass)!

Intermezzo: The W and Z bosons turn 40!

Following the success of putting anti-protons ‘on’ Initial Cooling Experiment (ICE)



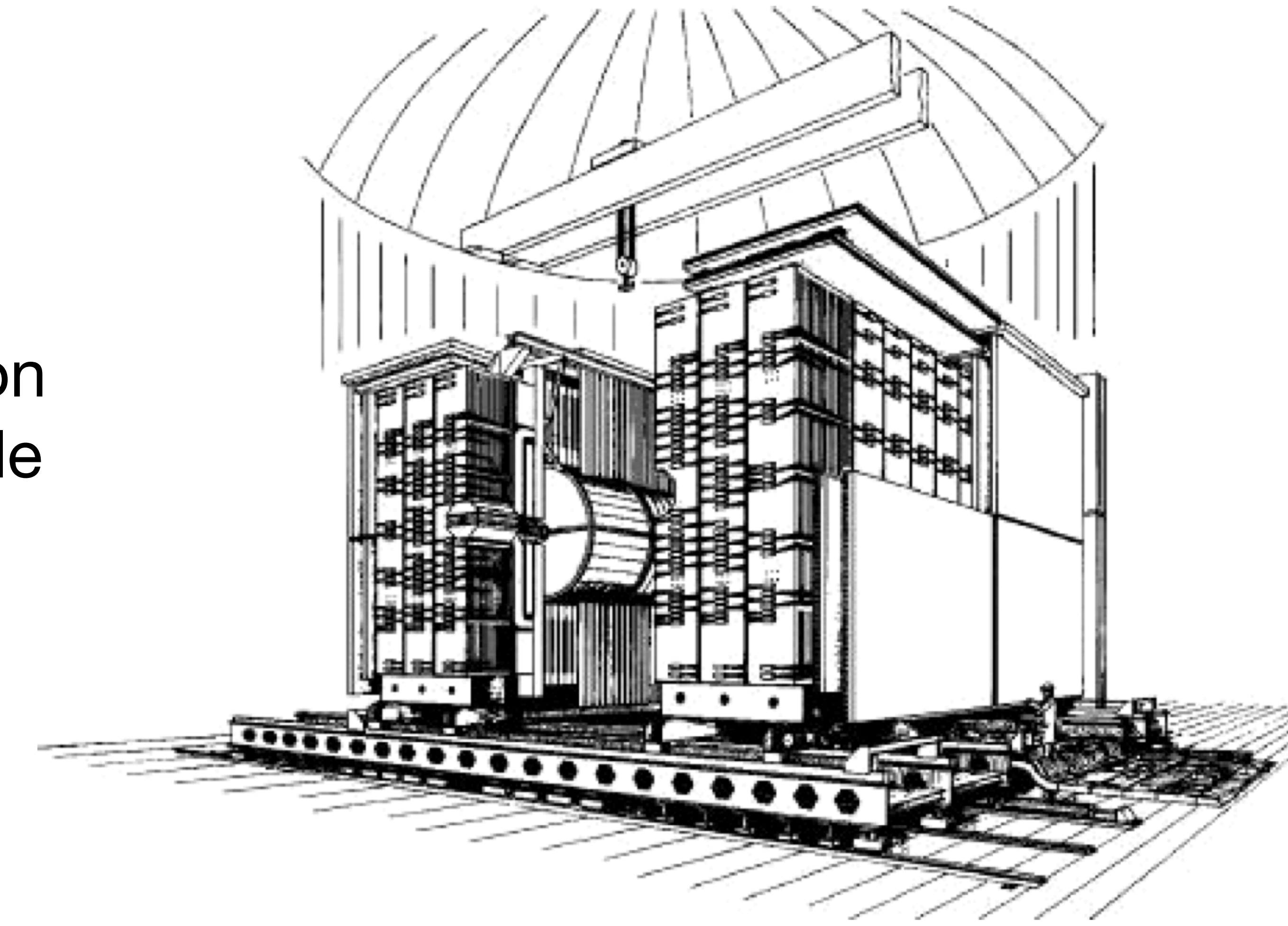
(Stochastic cooling)

In 1978 the SppS approved!

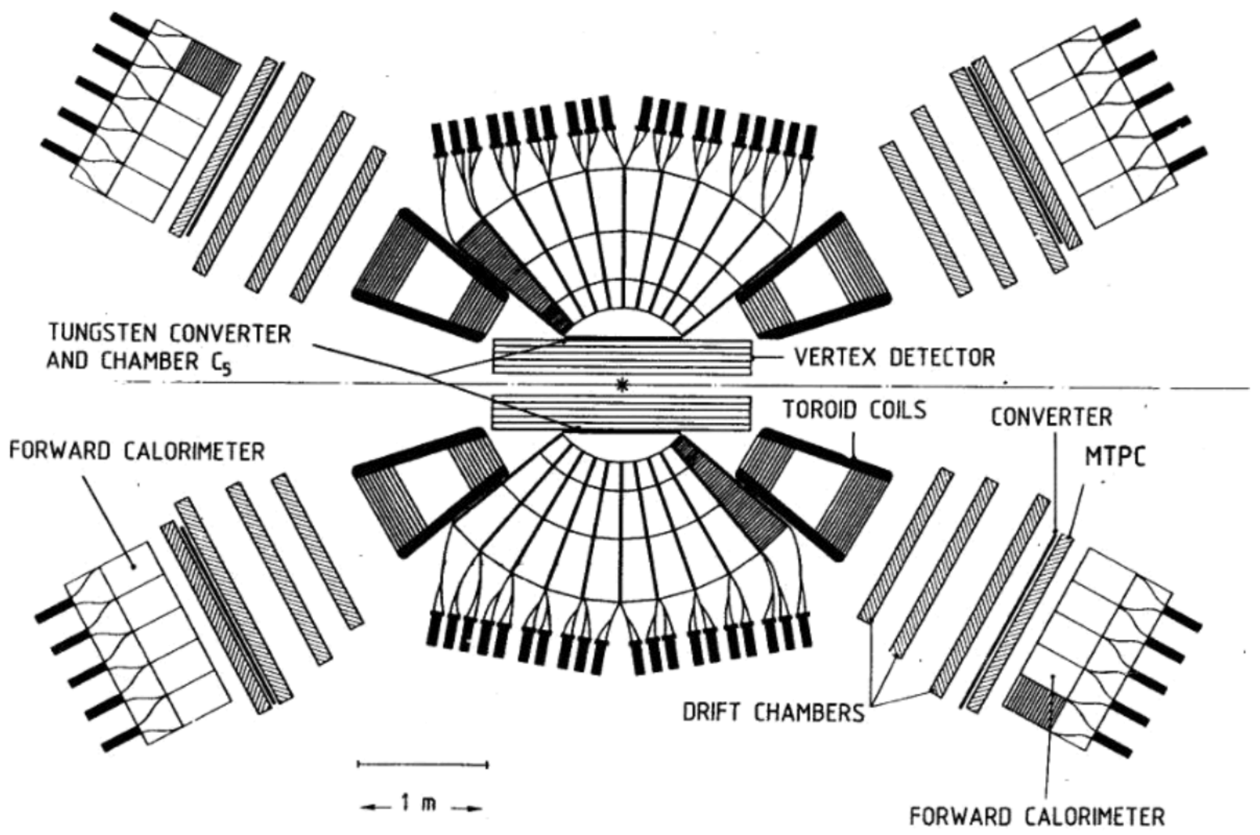
The Antiproton Accumulator

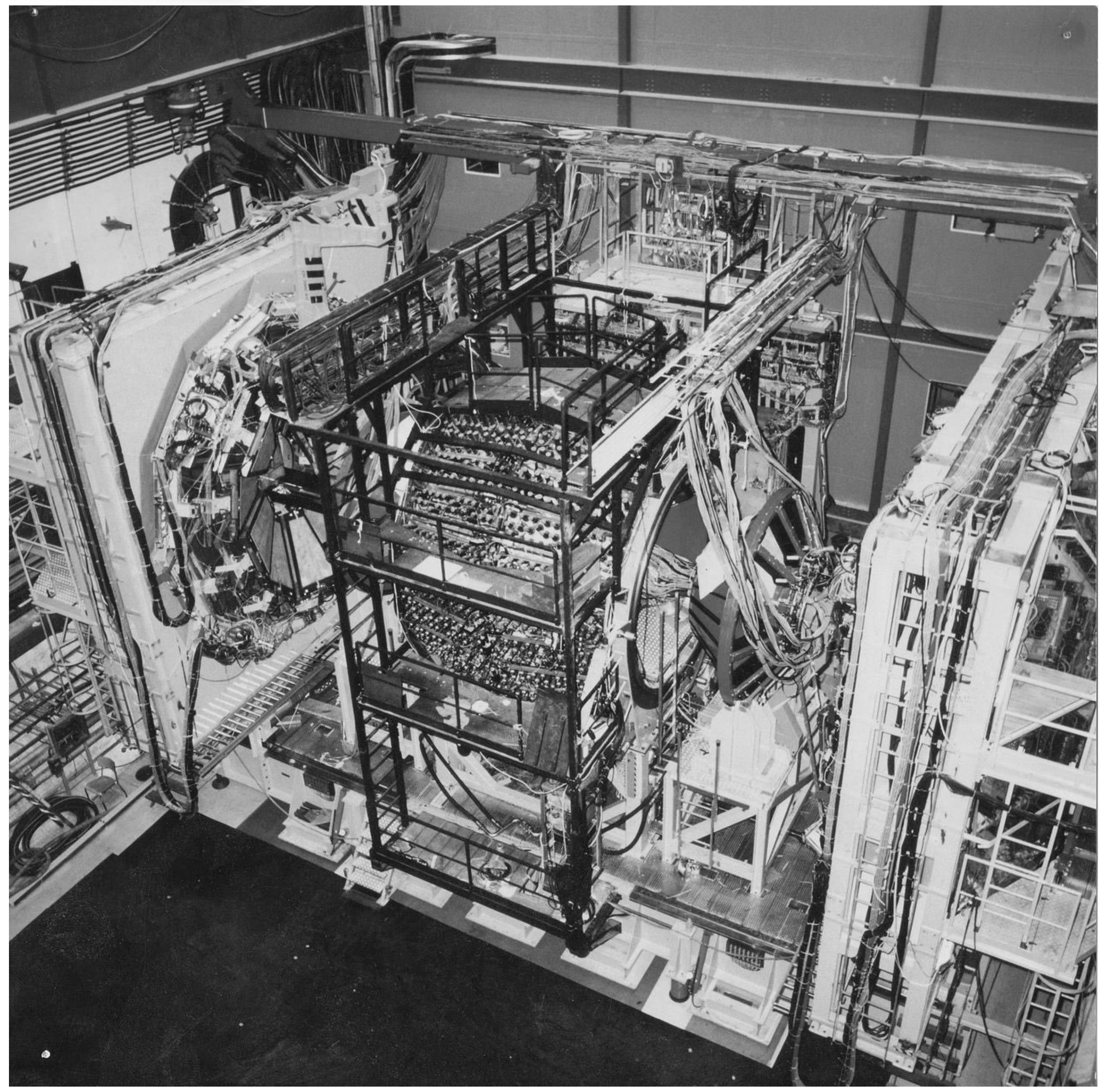
… to first collisions in 1981 !?

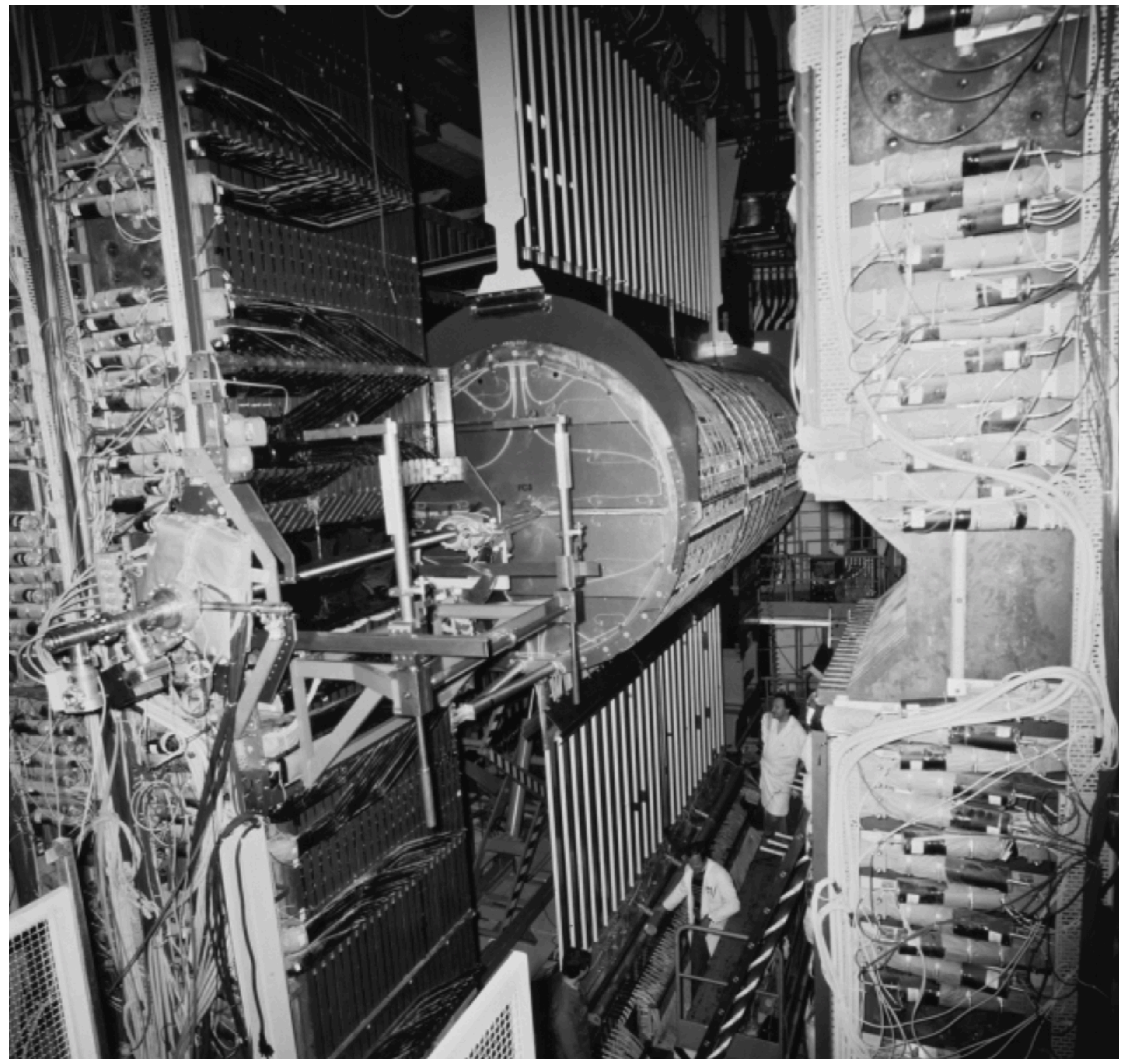
UA1
Tracking drift chamber, calorimeters, large muon system, and 0.7 T dipole magnet



UA2
Aiming at electron channel, no magnetic field, no muon system, high-granular projective calorimeter (later installed first silicon vertex detector).



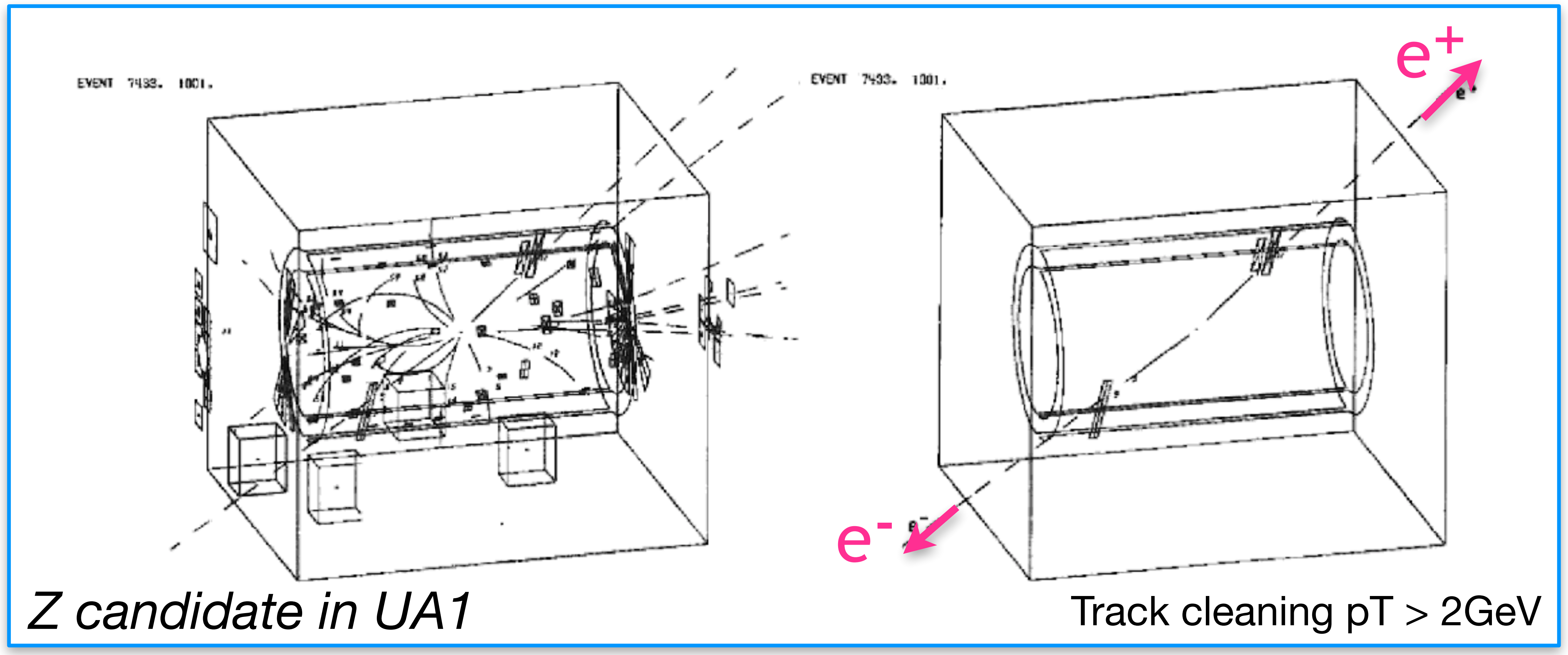




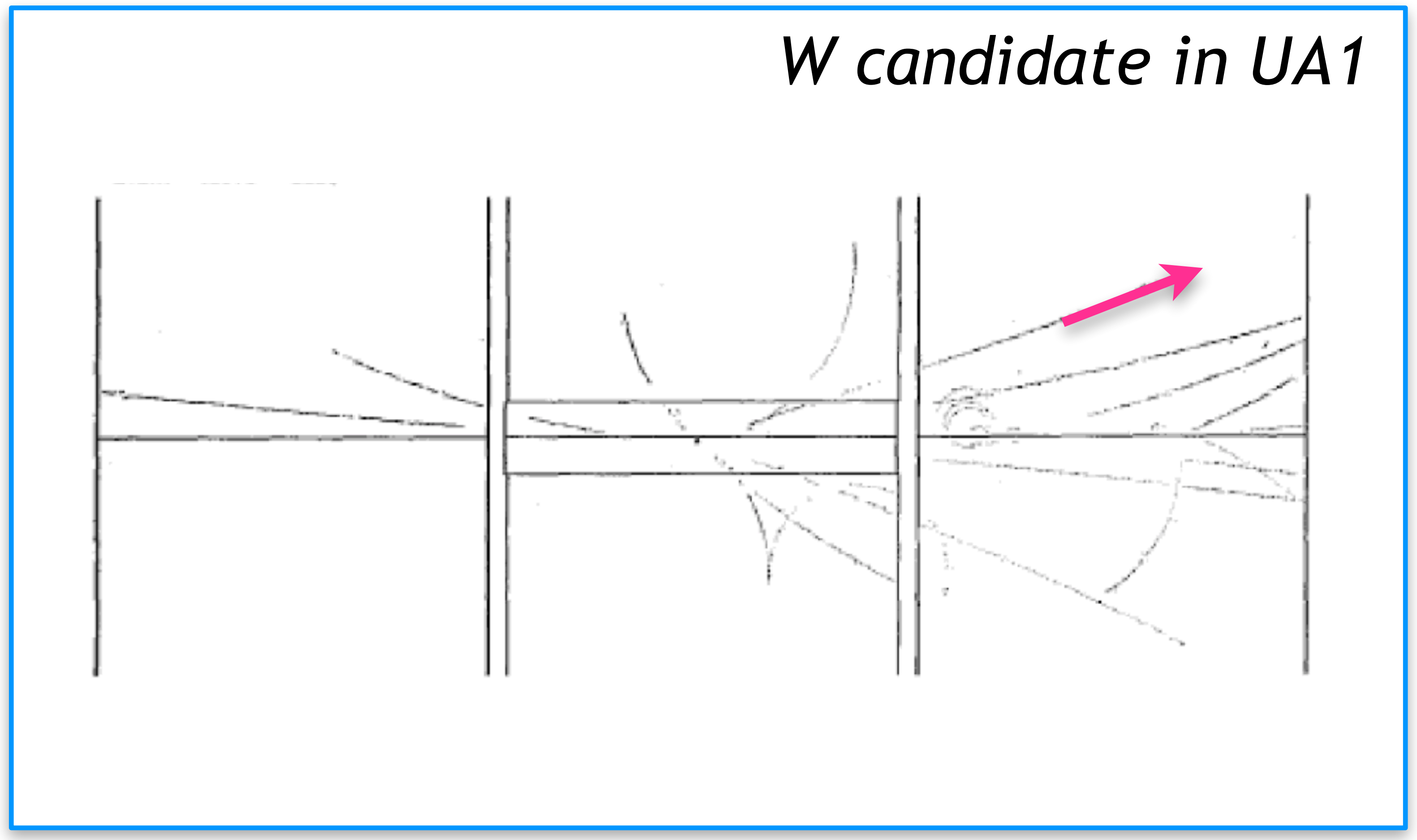
CERN Seminar of 1983

Intermezzo: The W and Z bosons turn 40!

Discovery of the W and Z bosons announced in January 1983 with 6 W events in UA1 and four in UA2!



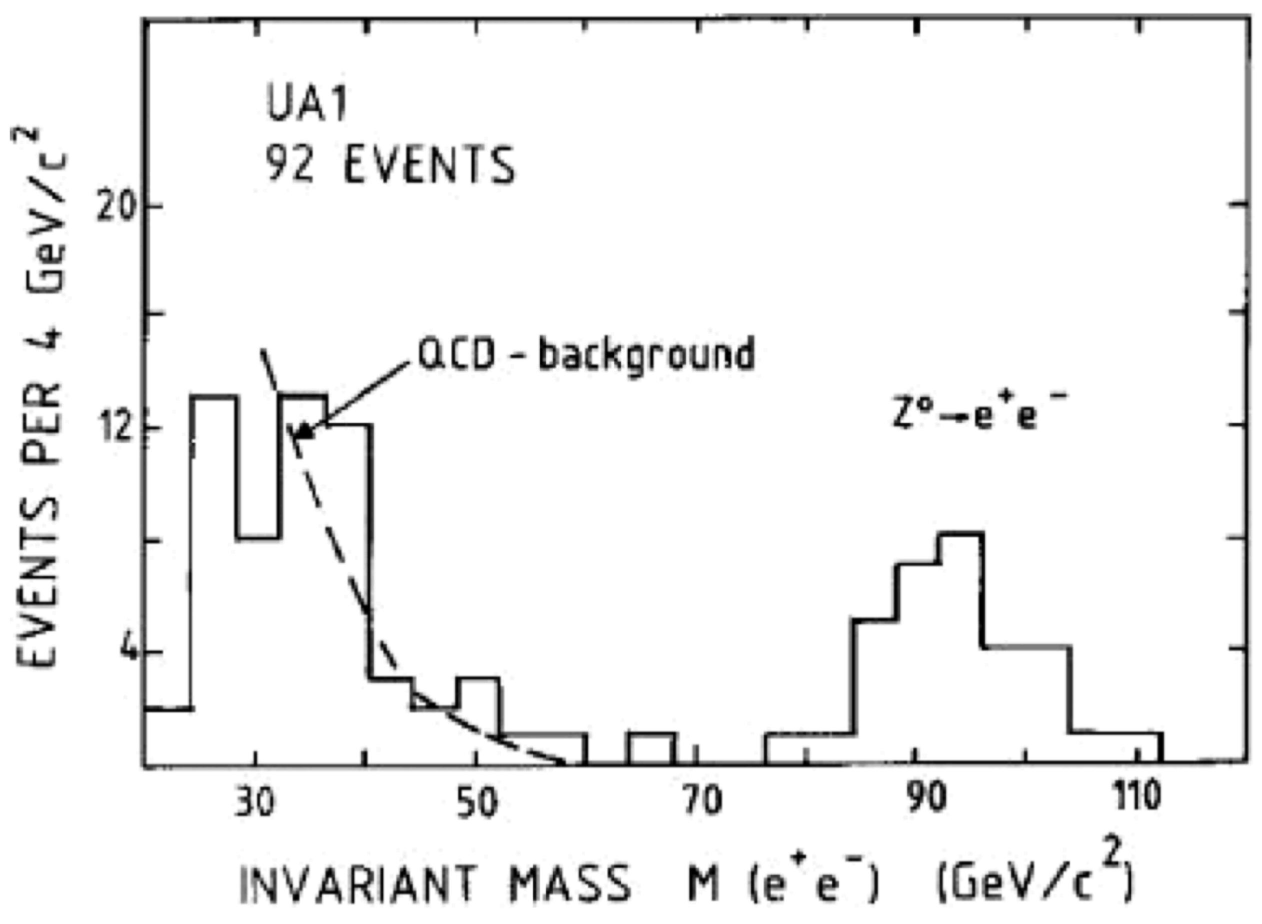
Z candidate in UA1

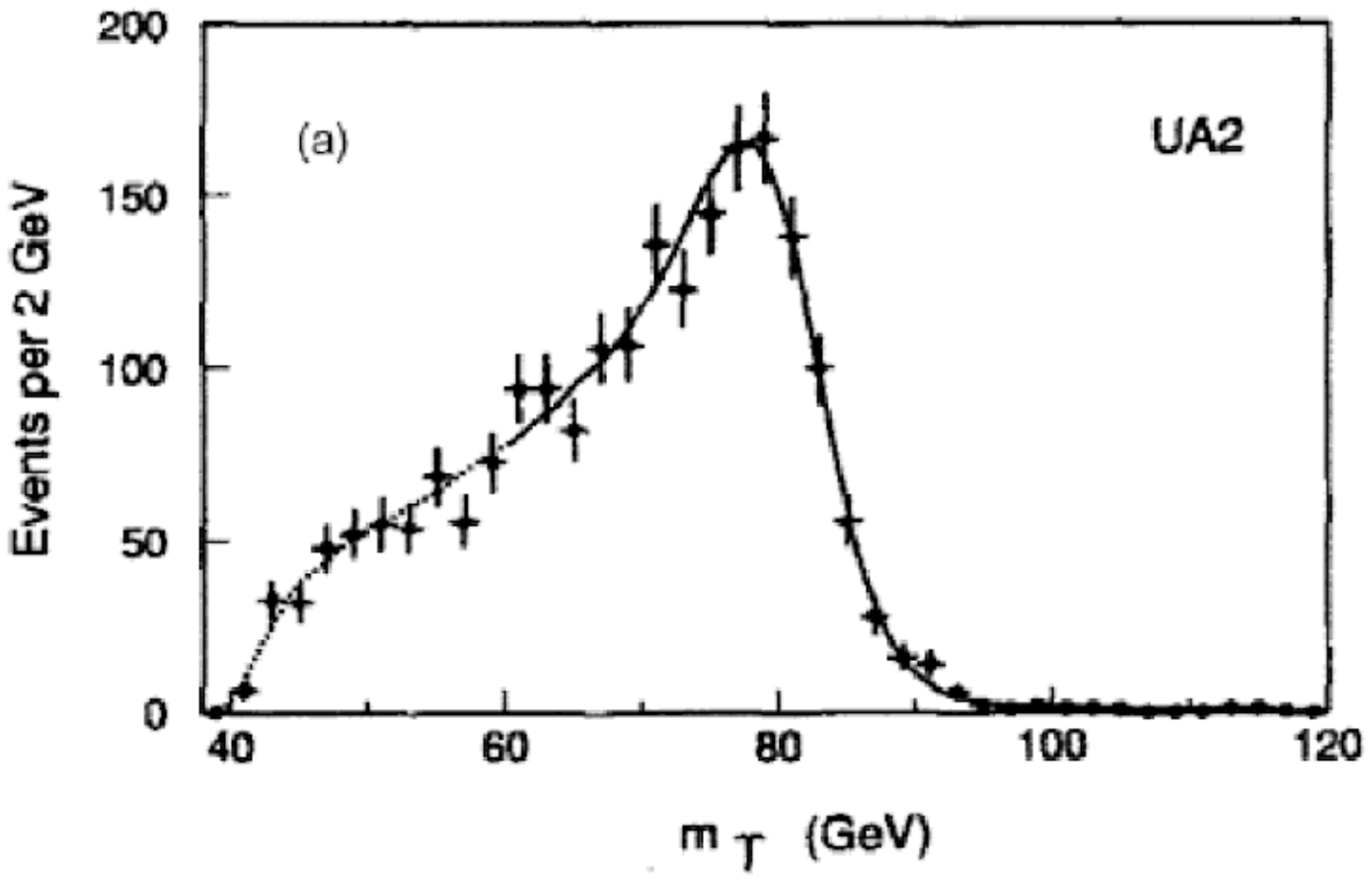


W candidate in UA1

Altogether O(100) Z events

Altogether O(1000) W events





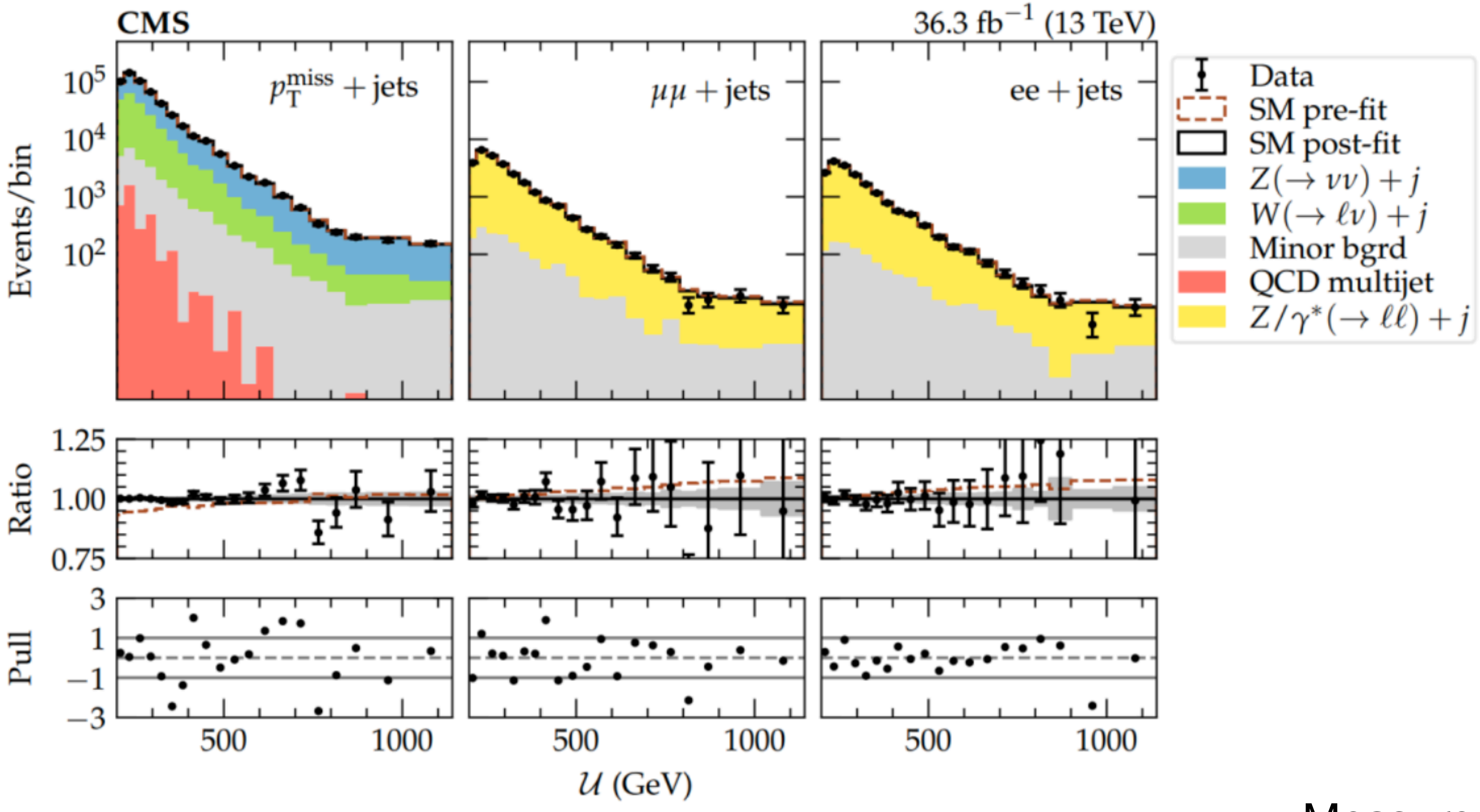
1984

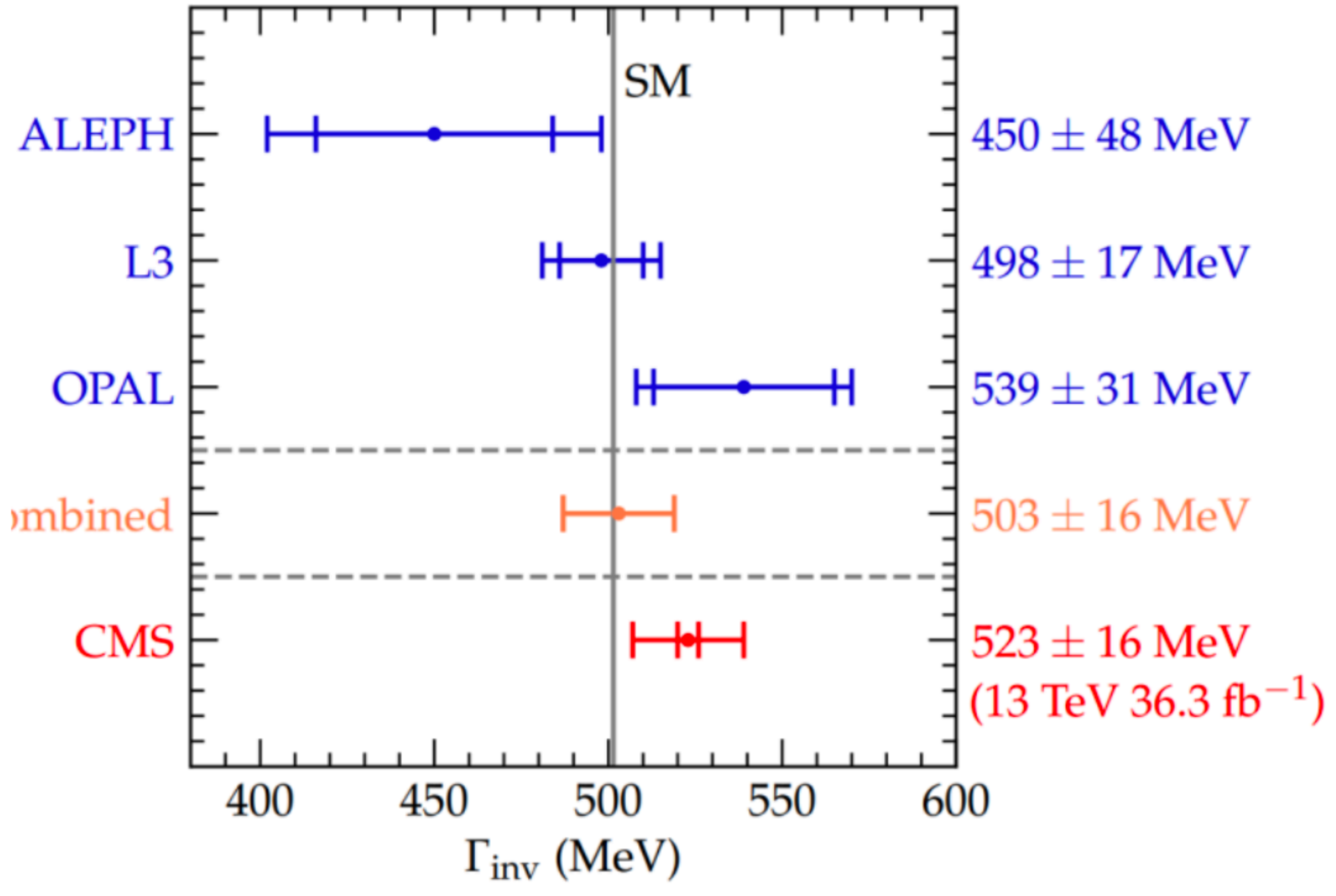
Discovery of the W and Z bosons

Carlo Rubbia, Simon Van der Meer

Precise direct invisible Z Width by CMS!

Measurement based on missing transverse momentum

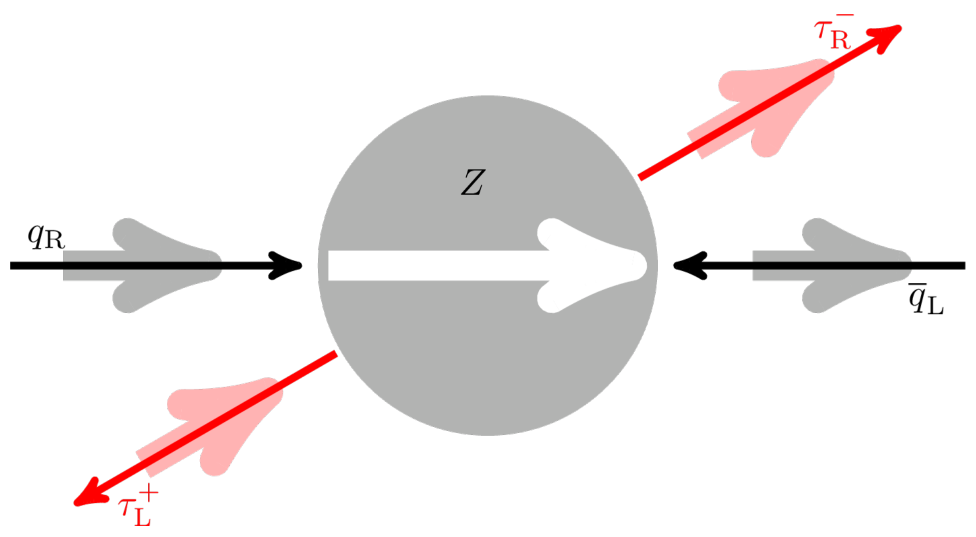




$$\Gamma_{inv} = 523 \pm 3\,(\text{stat}) \pm 16\,(\text{syst})\,\text{MeV}$$

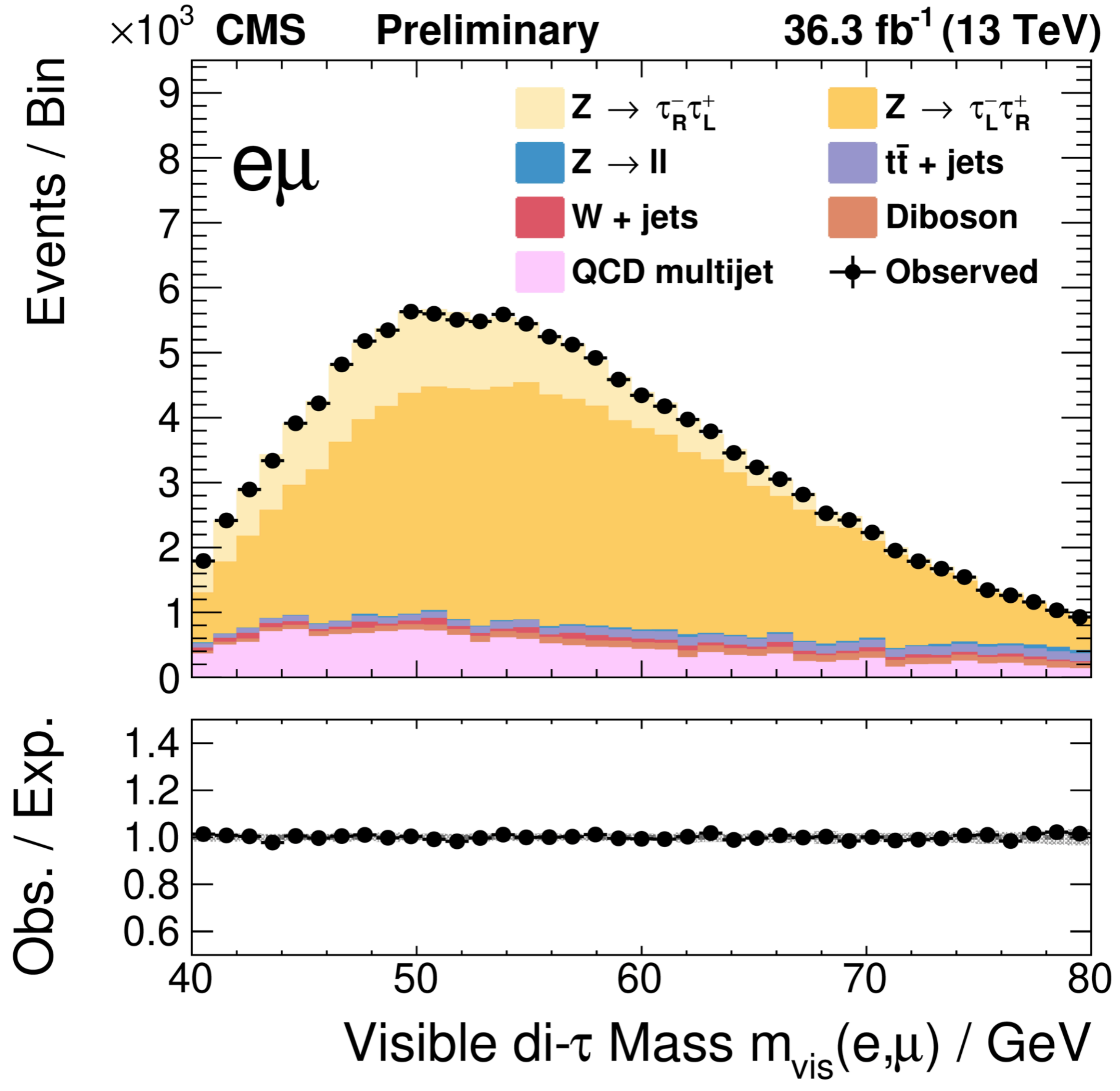
Measurement already dominated by systematic uncertainties!

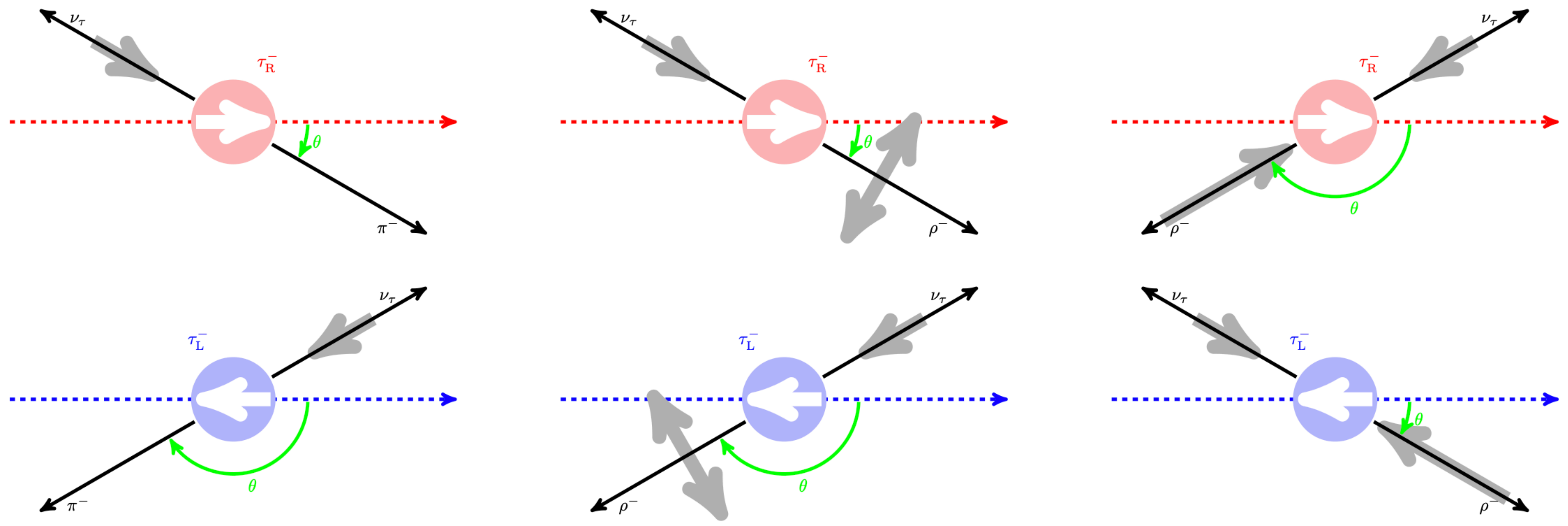
Tau Polarisation in Z Decays - CMS



In contrast to e+e– collisions the polar emission angle of the τ lepton and its sign is not, or only very poorly, known and can not be used in the analysis.

Measurement relies in measuring the fraction of tau helicity states, using polarisation sensitive variables!





$$P_\tau = -A_\tau = -\frac{2v_\tau a_\tau}{v_\tau^2 + a_\tau^2} \approx -2 \cdot \frac{v_\tau}{a_\tau} = -2(1 - 4\sin^2\theta_W^{\text{eff}}).$$

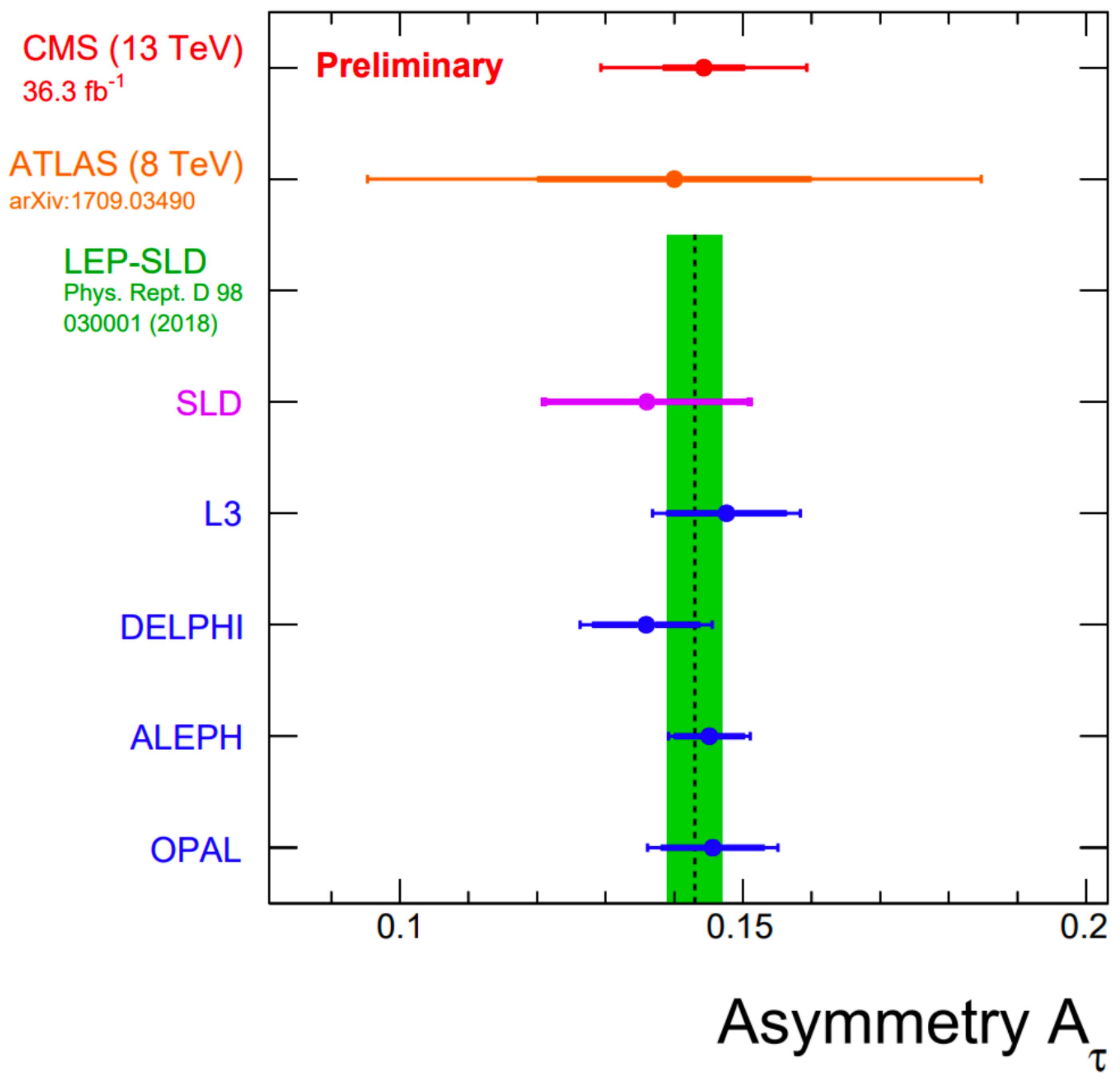
$$\mathcal{P}_\tau(Z^0) = -0.144 \pm 0.015 = -0.144 \pm 0.006\,(\text{stat}) \pm 0.014\,(\text{syst}).$$

$$\sin^2\theta_W^{\text{eff}} = 0.2319 \pm 0.0019 = 0.2319 \pm 0.0008\,(\text{stat}) \pm 0.0018\,(\text{syst}).$$

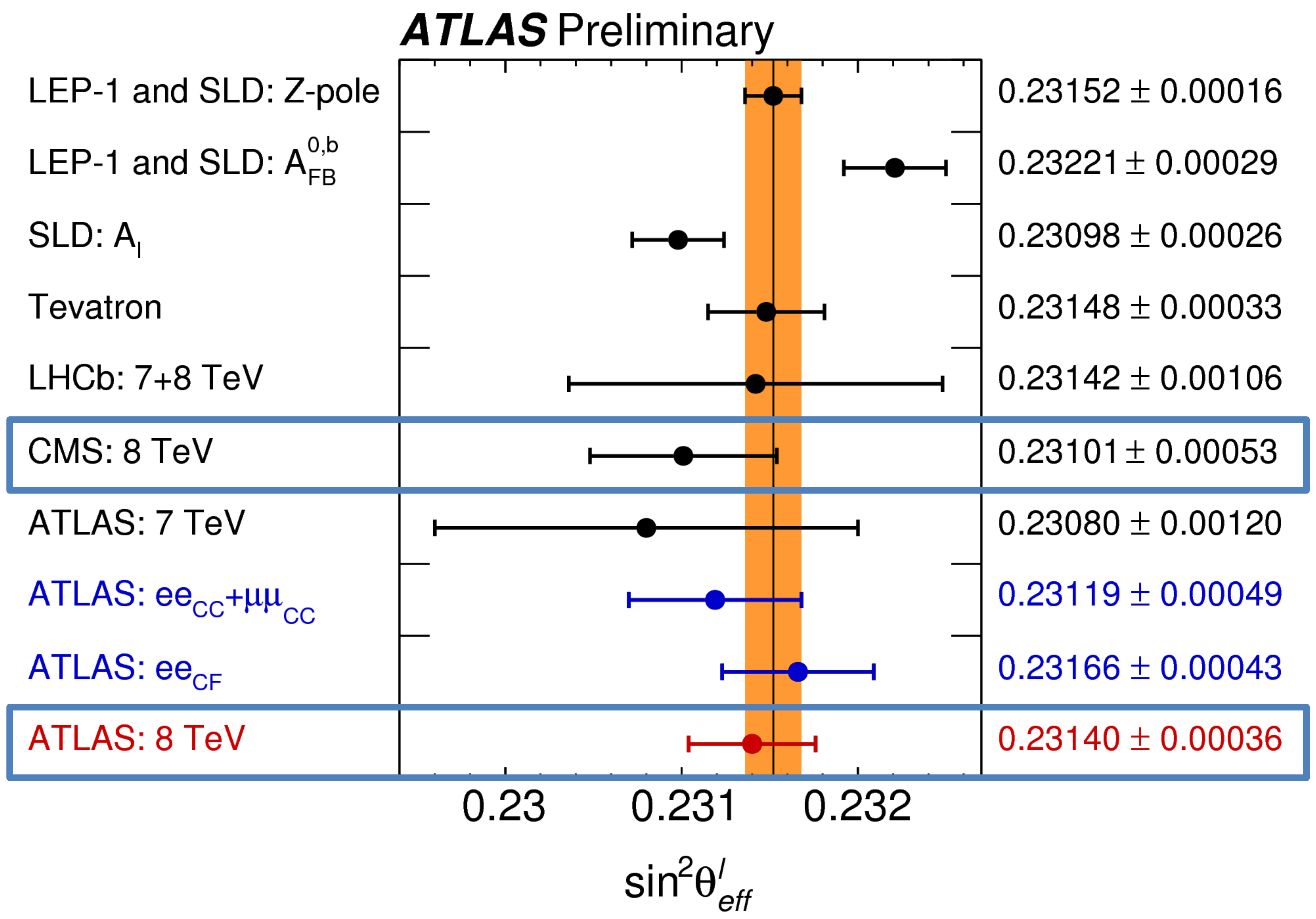
Tau Polarisation in Z Decays - CMS

$$\sin^2\theta_W^{\text{eff}} = 0.2319 \pm 0.0019 = 0.2319 \pm 0.0008\,(\text{stat}) \pm 0.0018\,(\text{syst}).$$

New CMS measurement with partial Run 2 dataset comparable precision as measurements at e^+e^- colliders, but…



Measurement already dominated by systematic uncertainties already!



ATLAS and CMS measurements in e^+e^- and $\mu^+\mu^-$ final states dominate the precision.

PDF uncertainties are dominant in this measurement!

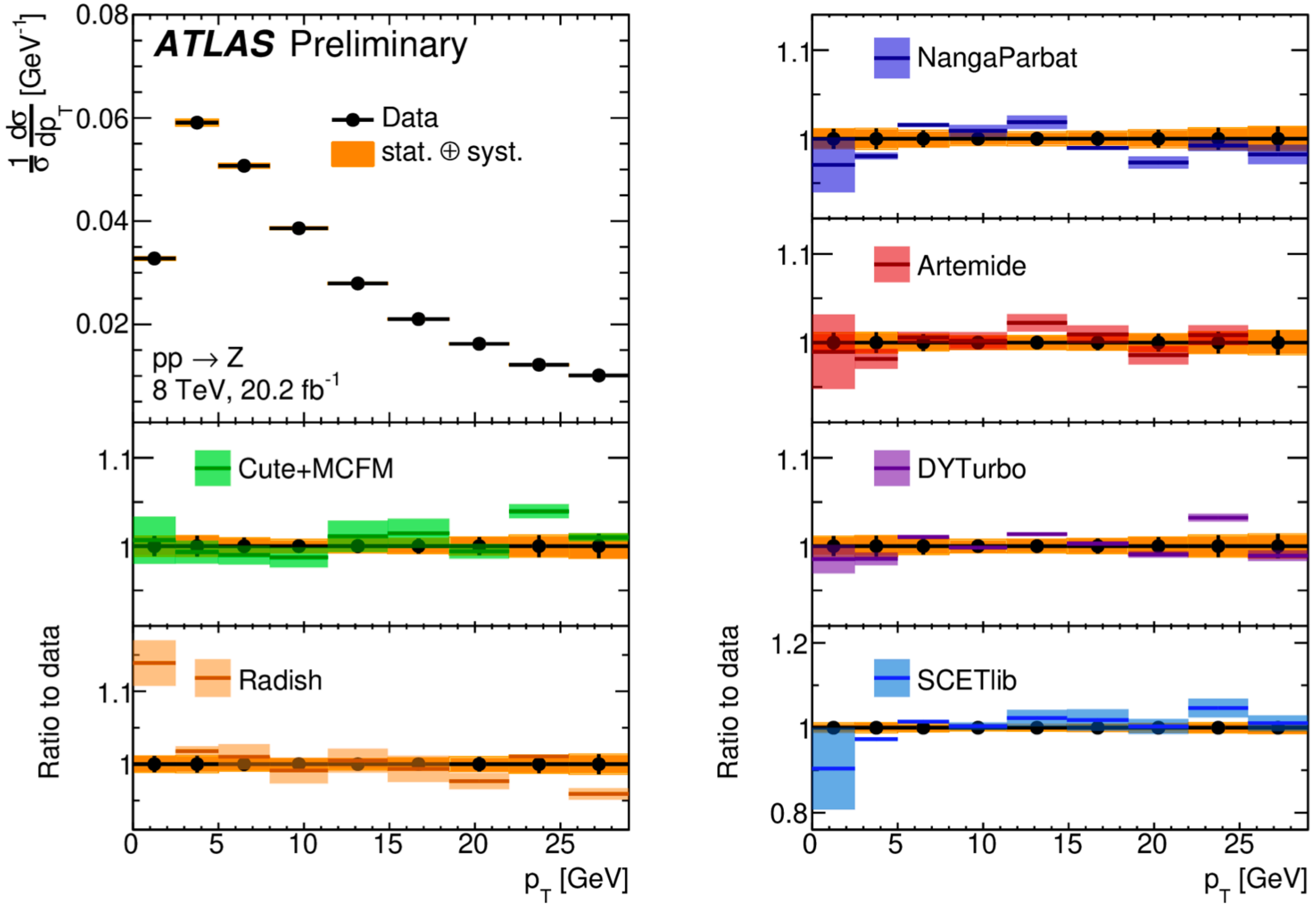
Precise Determination of α_S - ATLAS

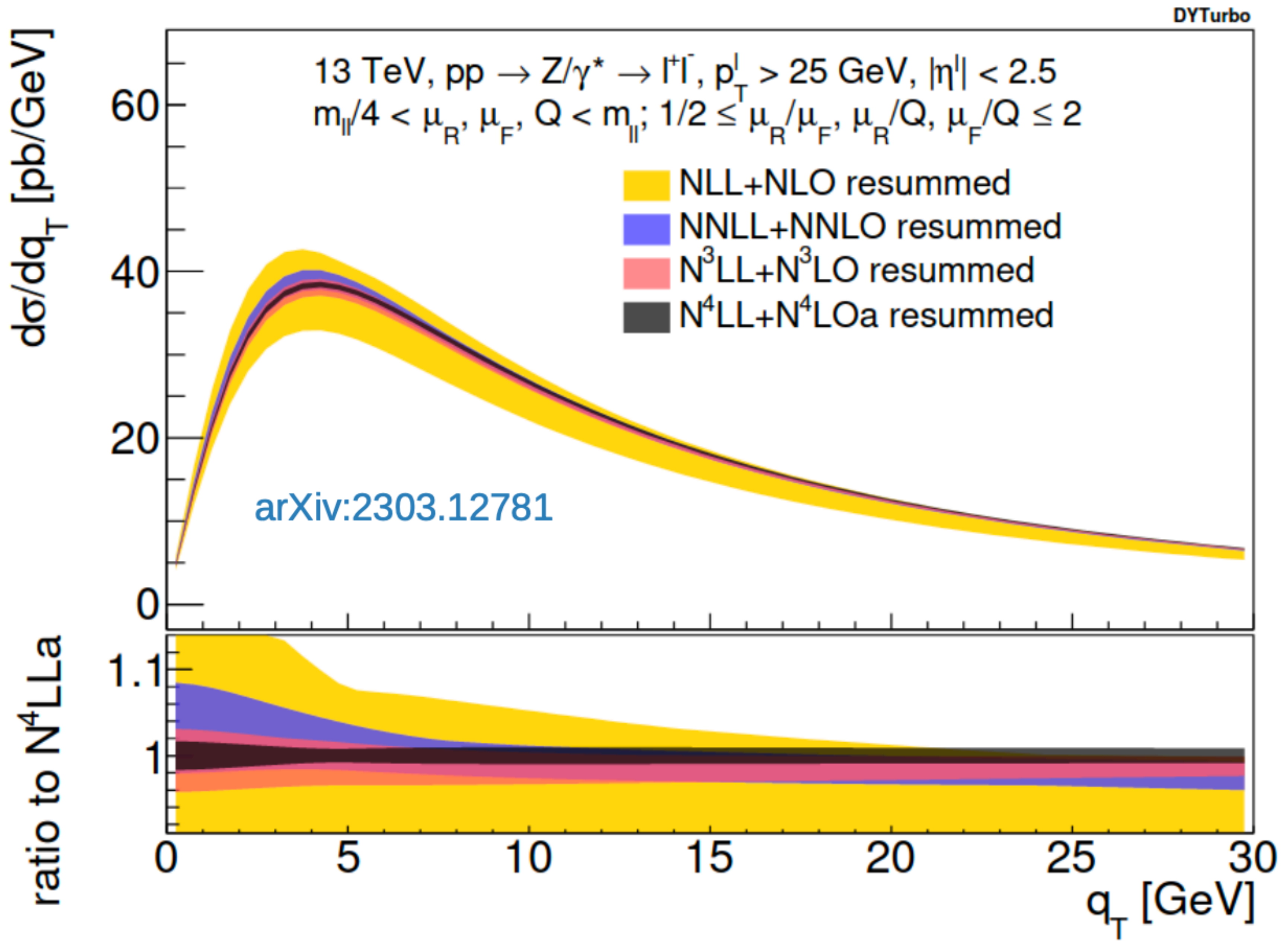
New for Moriond EW 2023

$$\frac{d\sigma}{dpdq} = \frac{d^3\sigma^{U+L}}{dp_T\,dydm}\left(1+\cos^2\theta+\sum_{i=0}^{7}A_i(y,p_T,m)P_i(\cos\theta,\phi)\right)$$

Measurement of the differential **full-lepton phase space** Z cross section!

Also talk by Menglin Xu for LHCb

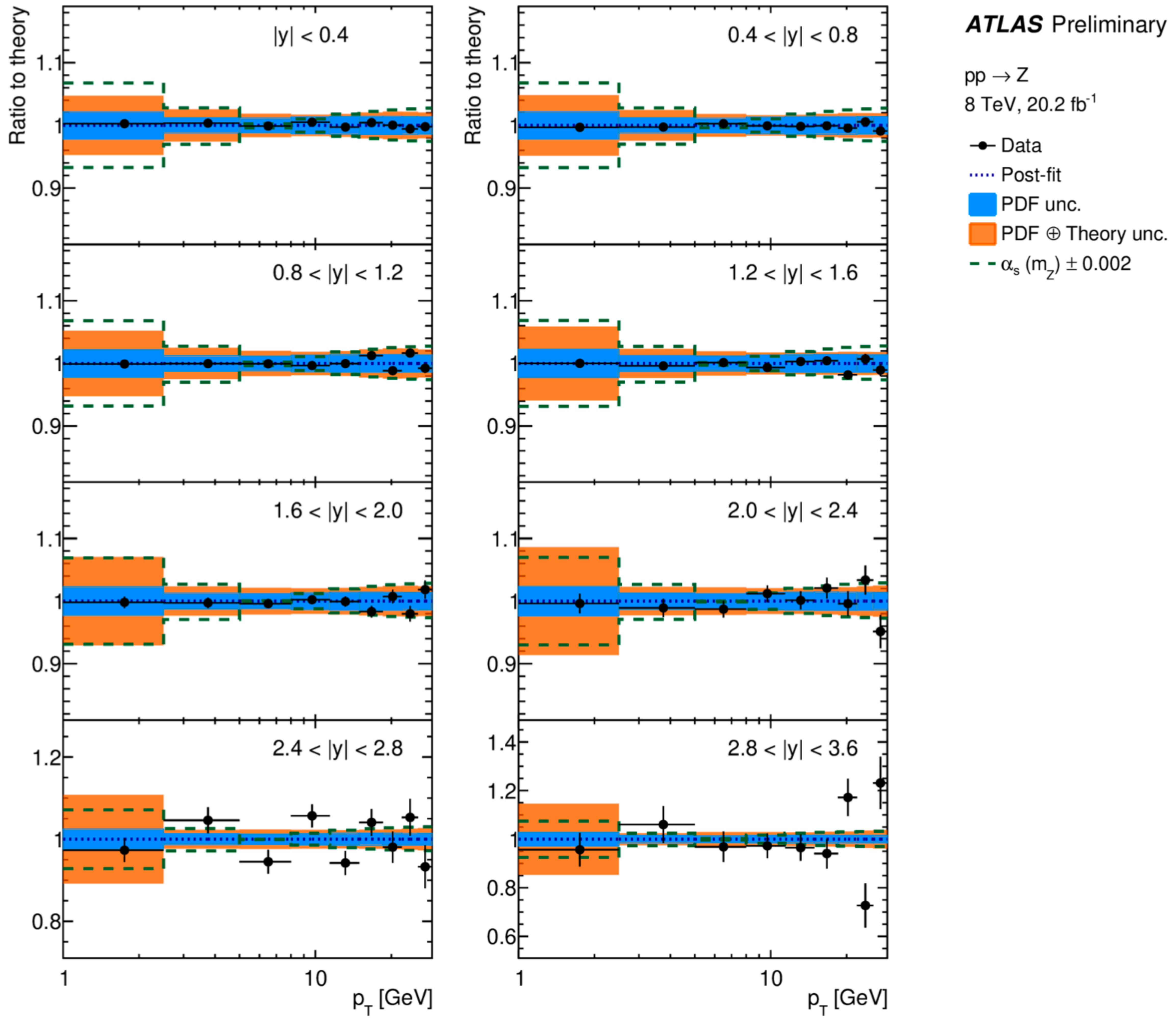


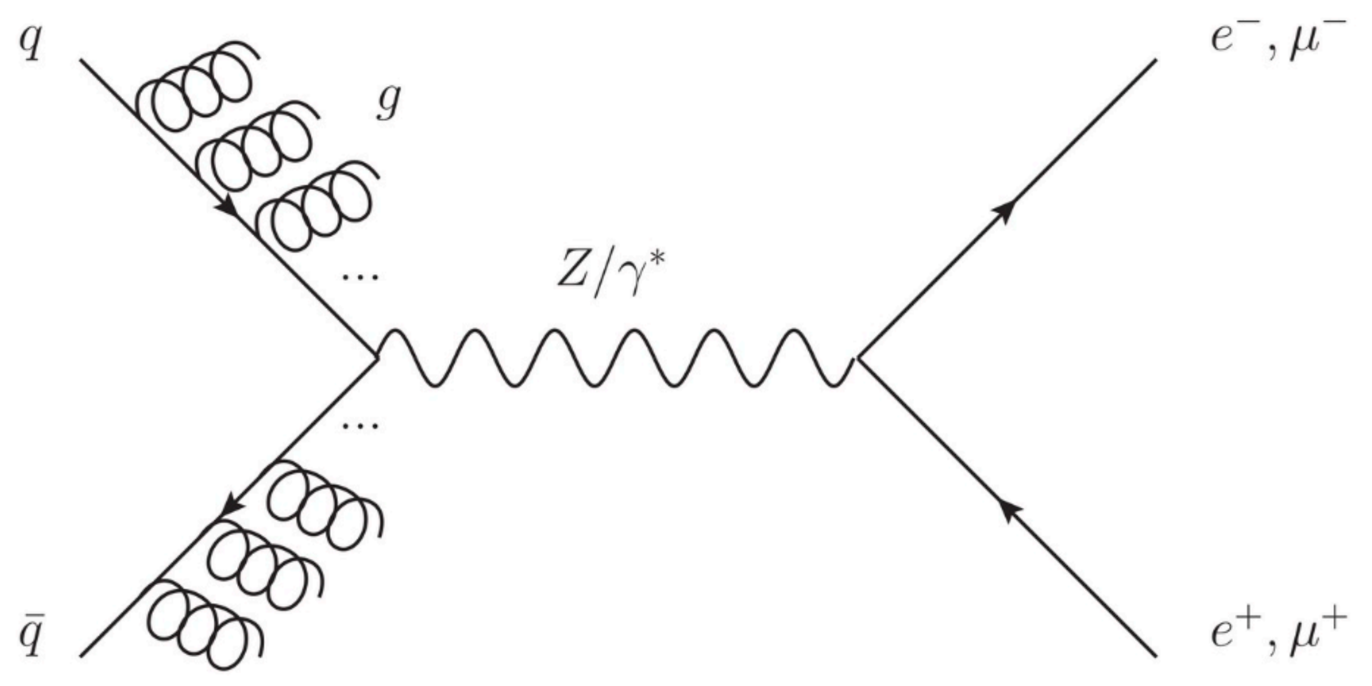


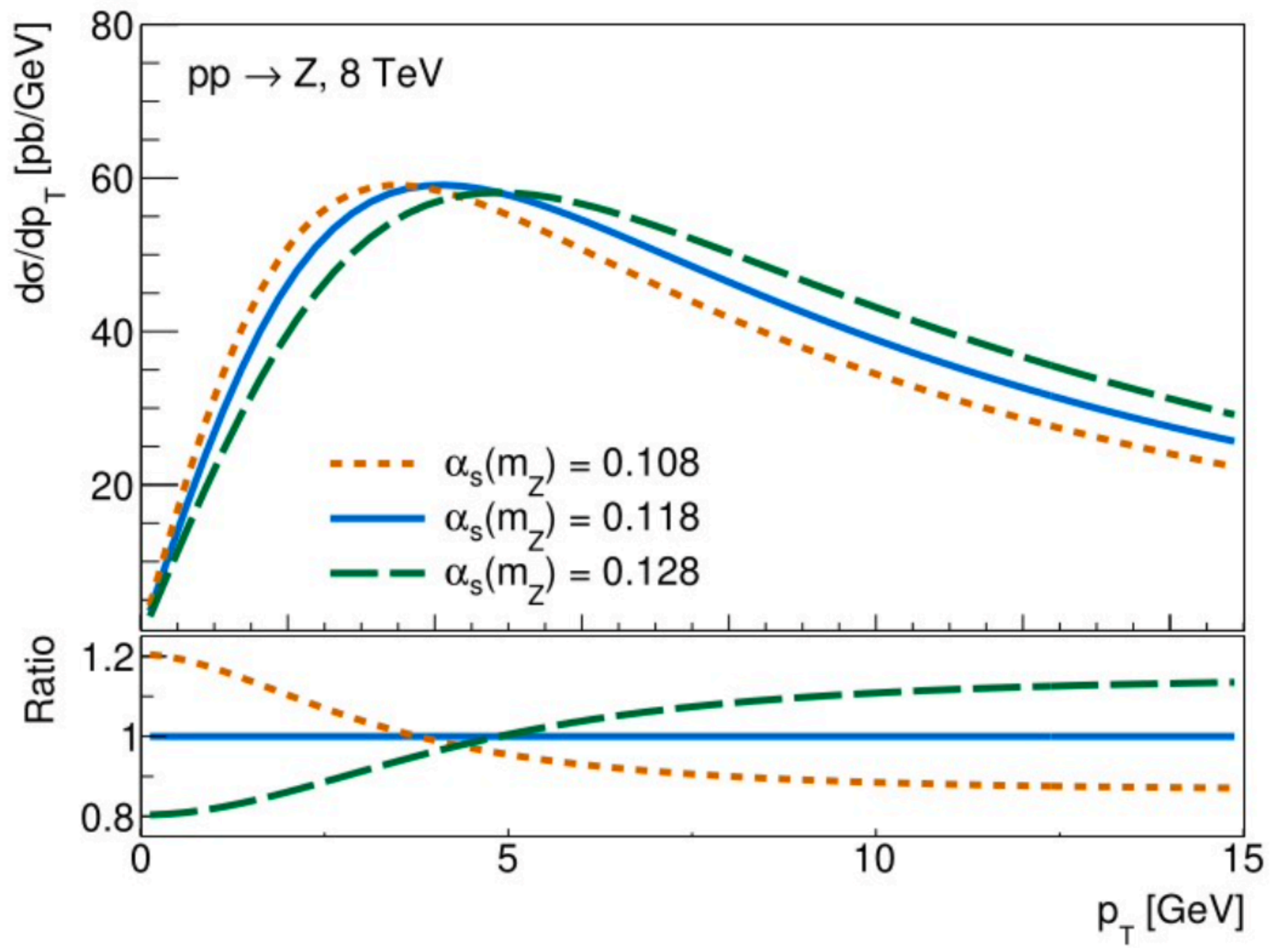
Comparisons done at N3LO-N4LL with N3LO PDFs

Precise Determination of α_S - ATLAS

Most precise determination of α_S based on the Sudakof peak, first measurement based on resummation







Precise Determination of α_S - ATLAS

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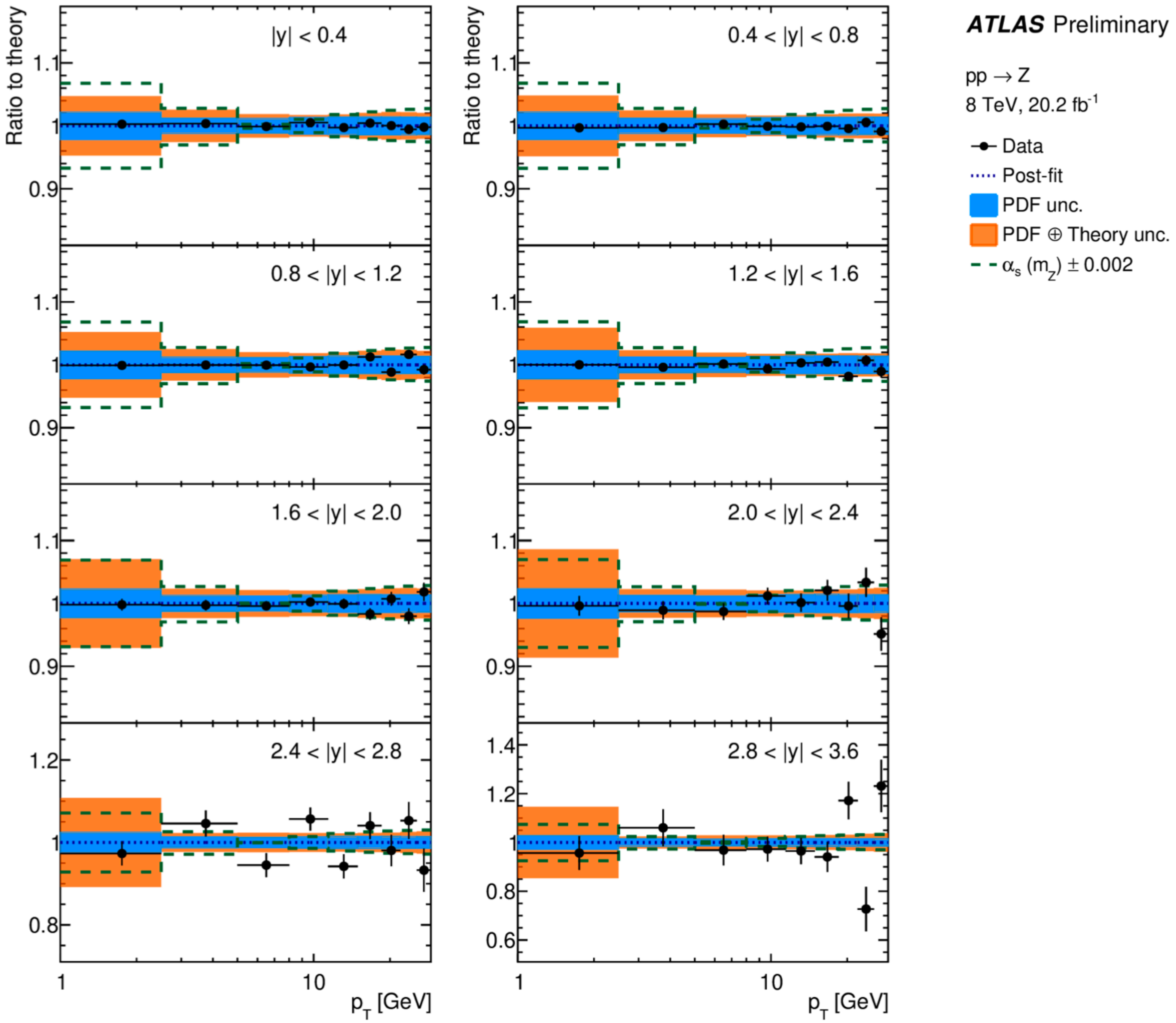
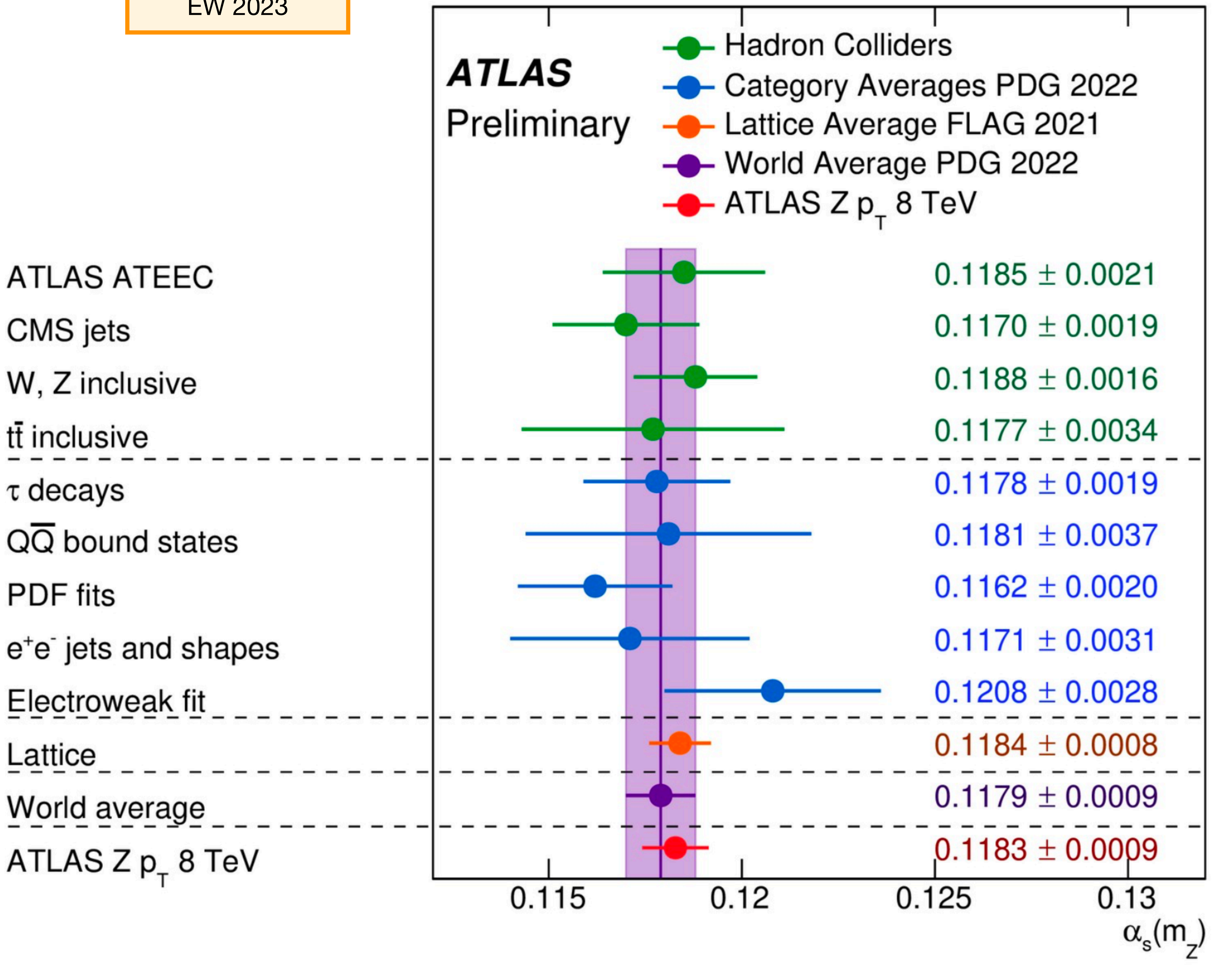
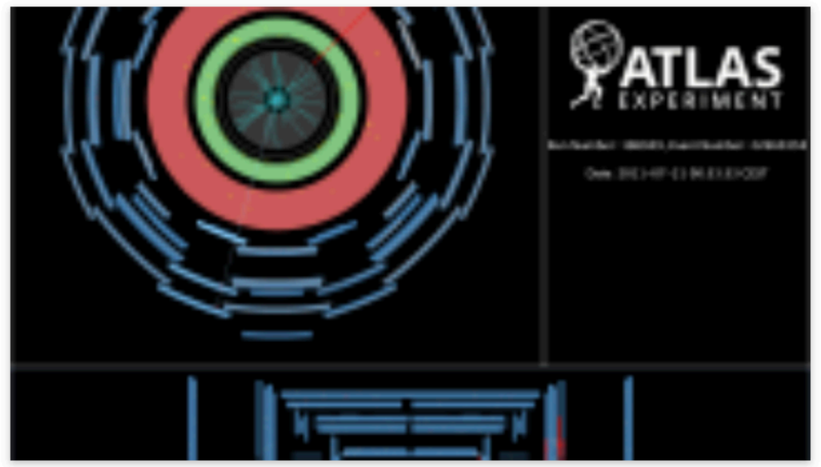


New for Moriond EW 2023



W Mass Update - ATLAS



Improved ATLAS result weighs in on W boson

An improved ATLAS measurement of the W boson mass is in line with the Standard Model of particle physics

Press release | Physics | 23 March, 2023

CERN press release on Thursday!

Several small improvements, but mostly relying on the huge analysis effort of the first 7 TeV result but relying on profiling paradigm (?!)

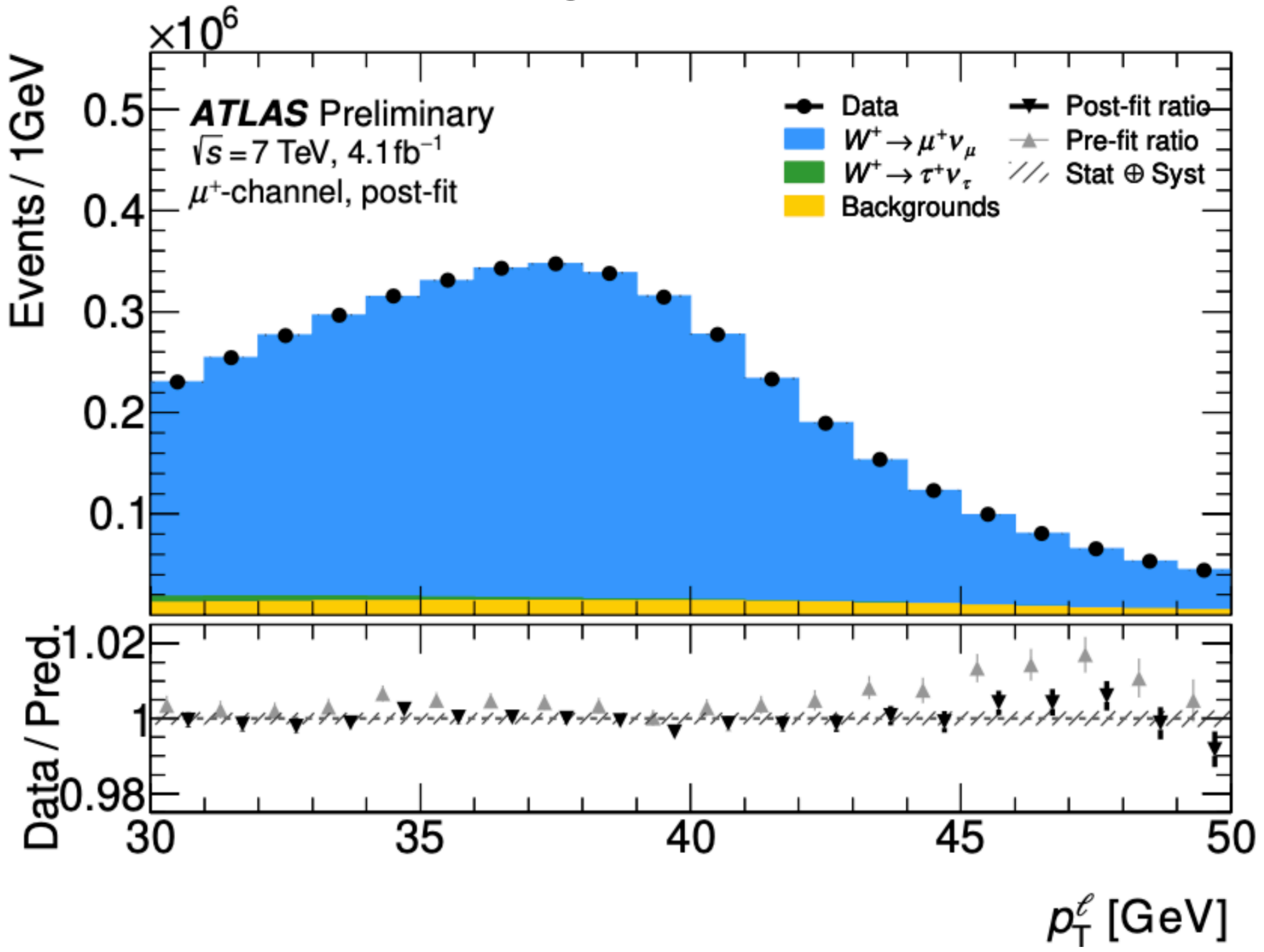
Systematic uncertainties are considered as nuisance parameters which enter the fit. What does this mean?

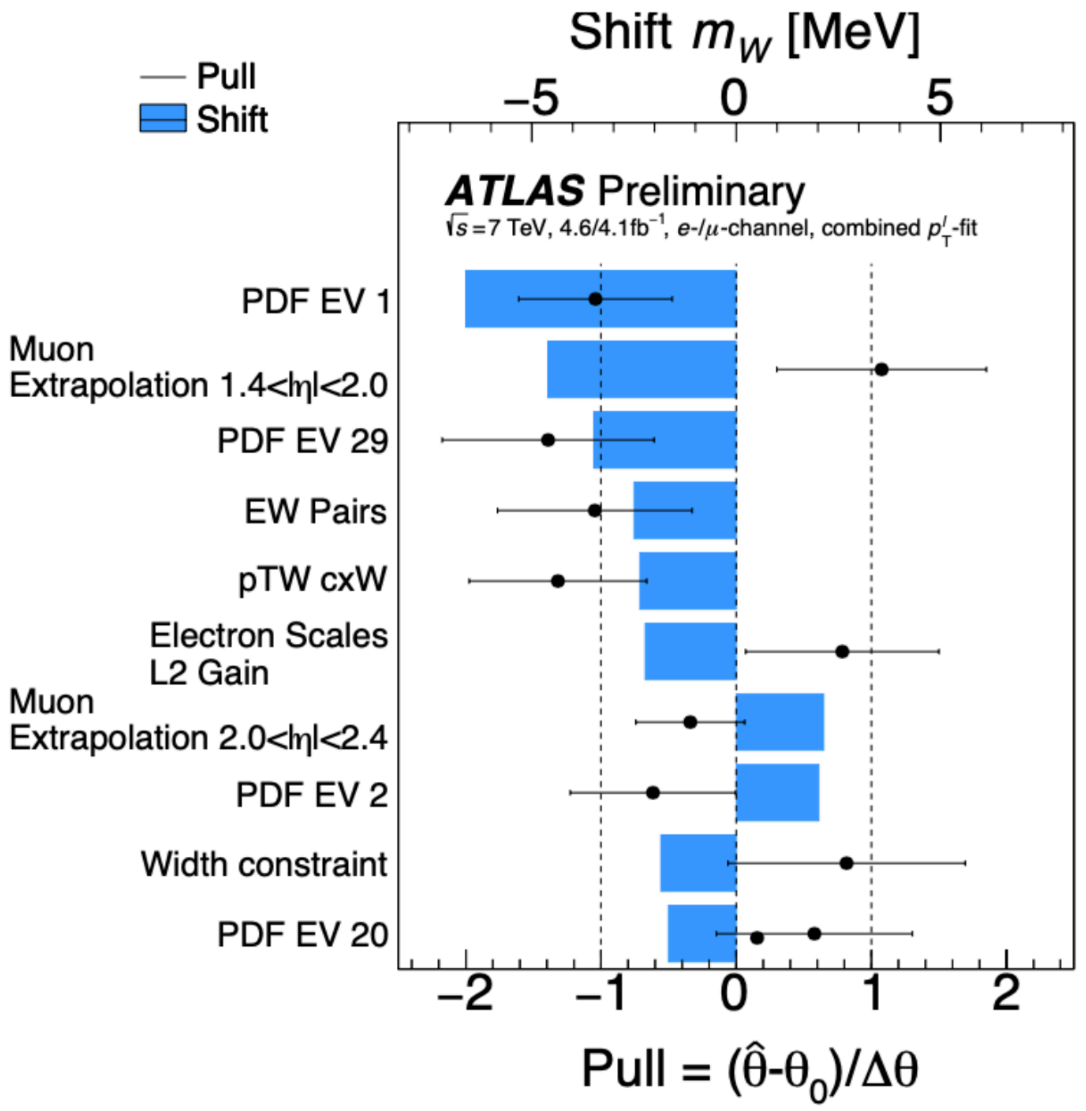
1.- All systematic effects are parametrised!

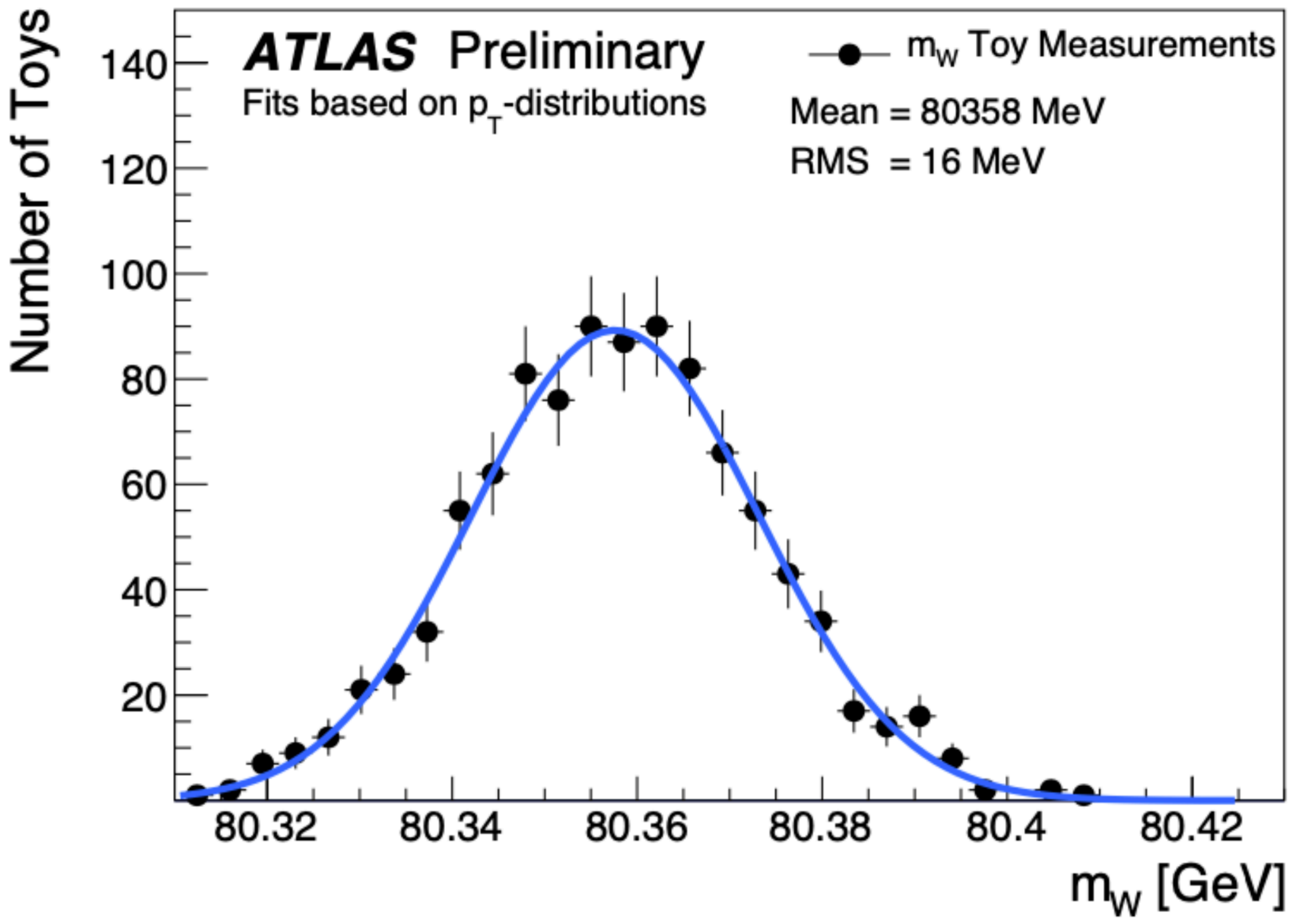
2.- Parameters are fitted along with the Parameters of Interest (e.g. W mass), affect the measurement through their correlation with the POI(s).

3.- The parameters can be constrained (or measured) in the fit! e.g. PDF parameters can be changed through the data, and thus is equivalent to PDFs simultaneously fitted on the data!

New for Moriond EW 2023



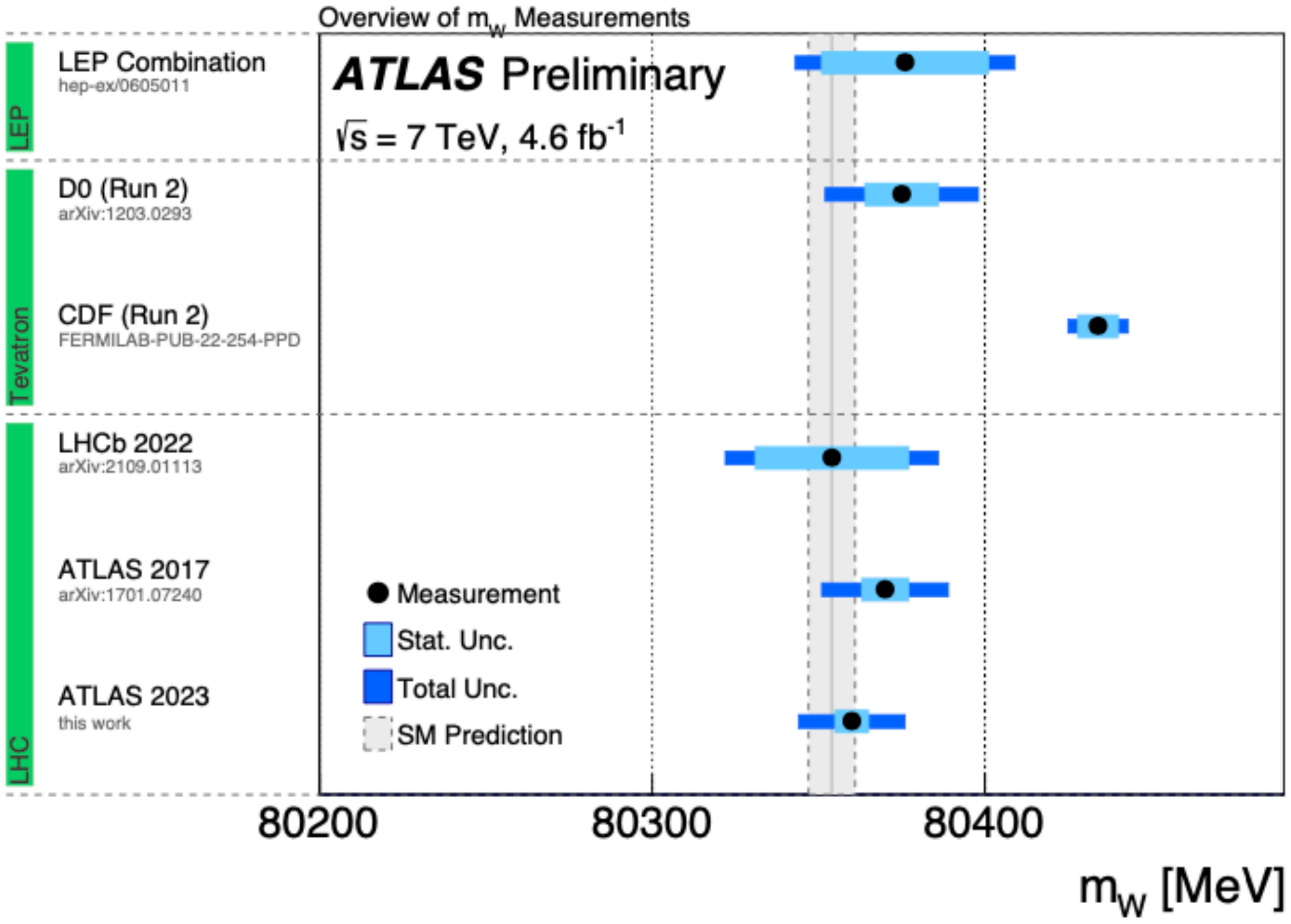




W Mass Update - ATLAS

New for Moriond EW 2023

Observed shift 10 MeV and precision improved by 16 MeV!



$m_W = 80360 \pm 5_{(stat.)} \pm 15_{(syst.)} = 80360 \pm 16$ MeV

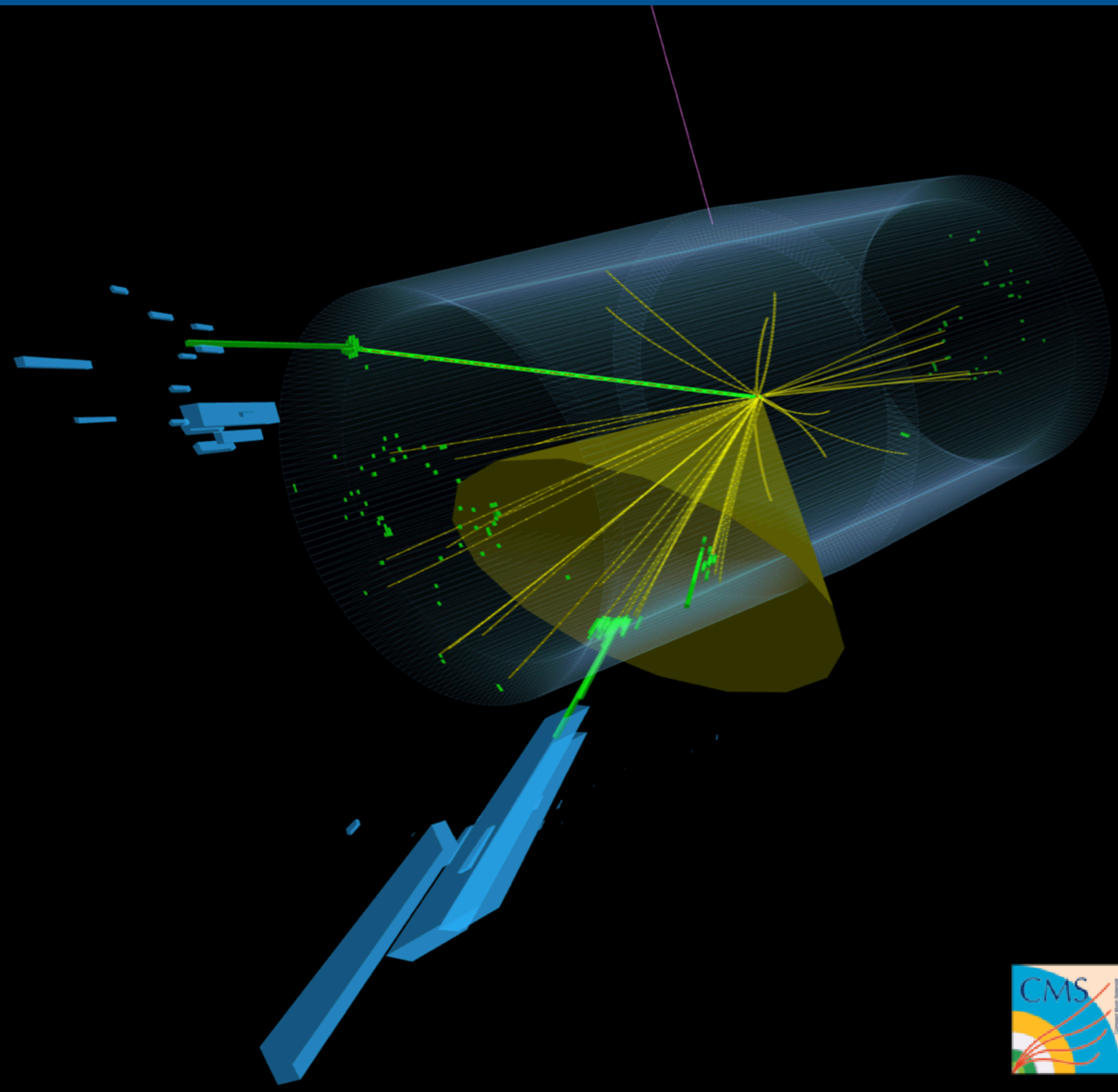
$m_W = 80370 \pm 19$ MeV

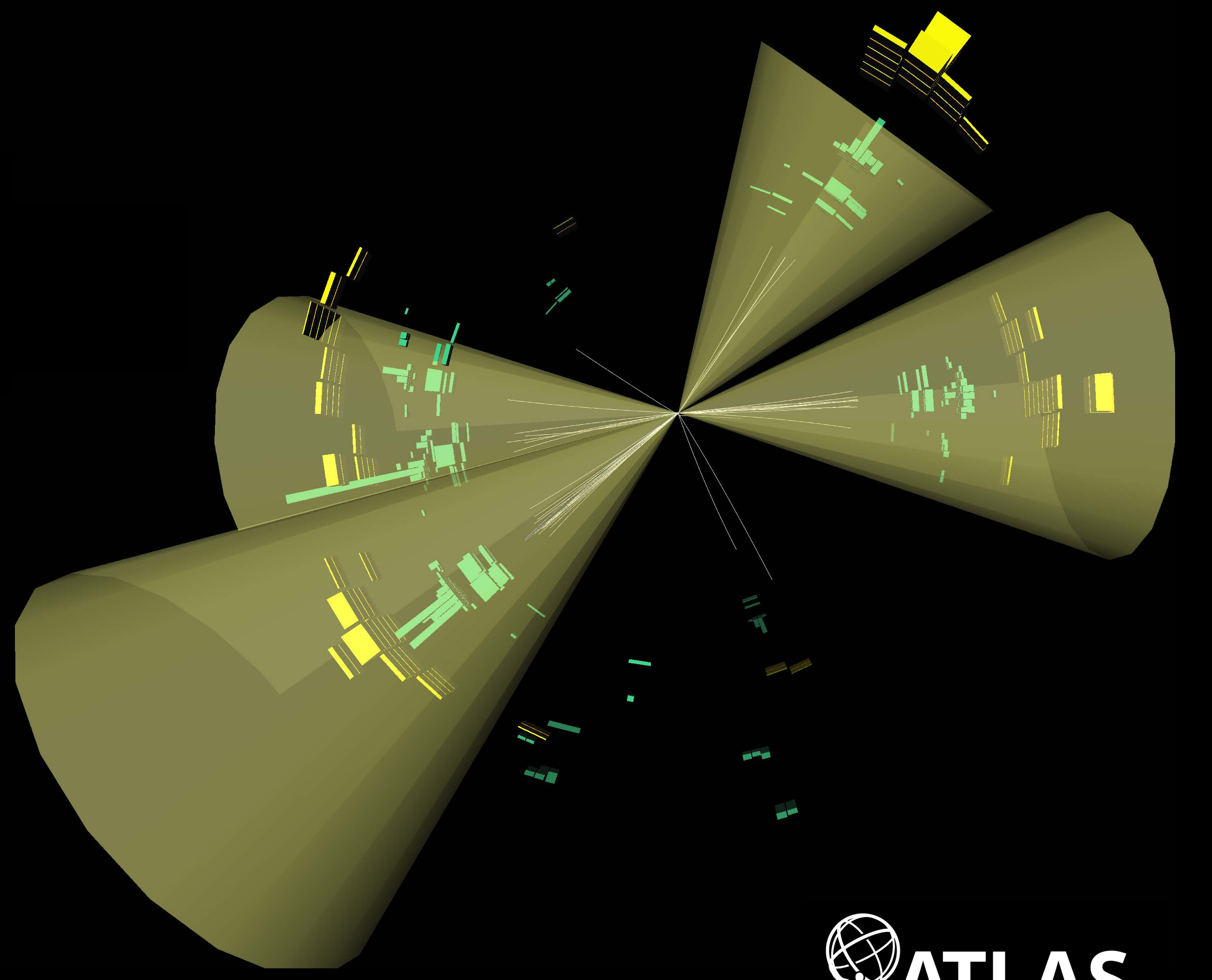
- New W mass measurement from ATLAS is agreeing even ore with the SM prediction
- The tension with the CDF W mass is larger between ATLAS (only) and CDF 3.4σ now 4σ
- (Tension of CDF measurement with the SM 7σ)

Where do we go from here?

Significant evidence of measurement systematic bias: need a collective effort to understand this puzzle!

Higgs, Multi-boson and Top Physics at the LHC





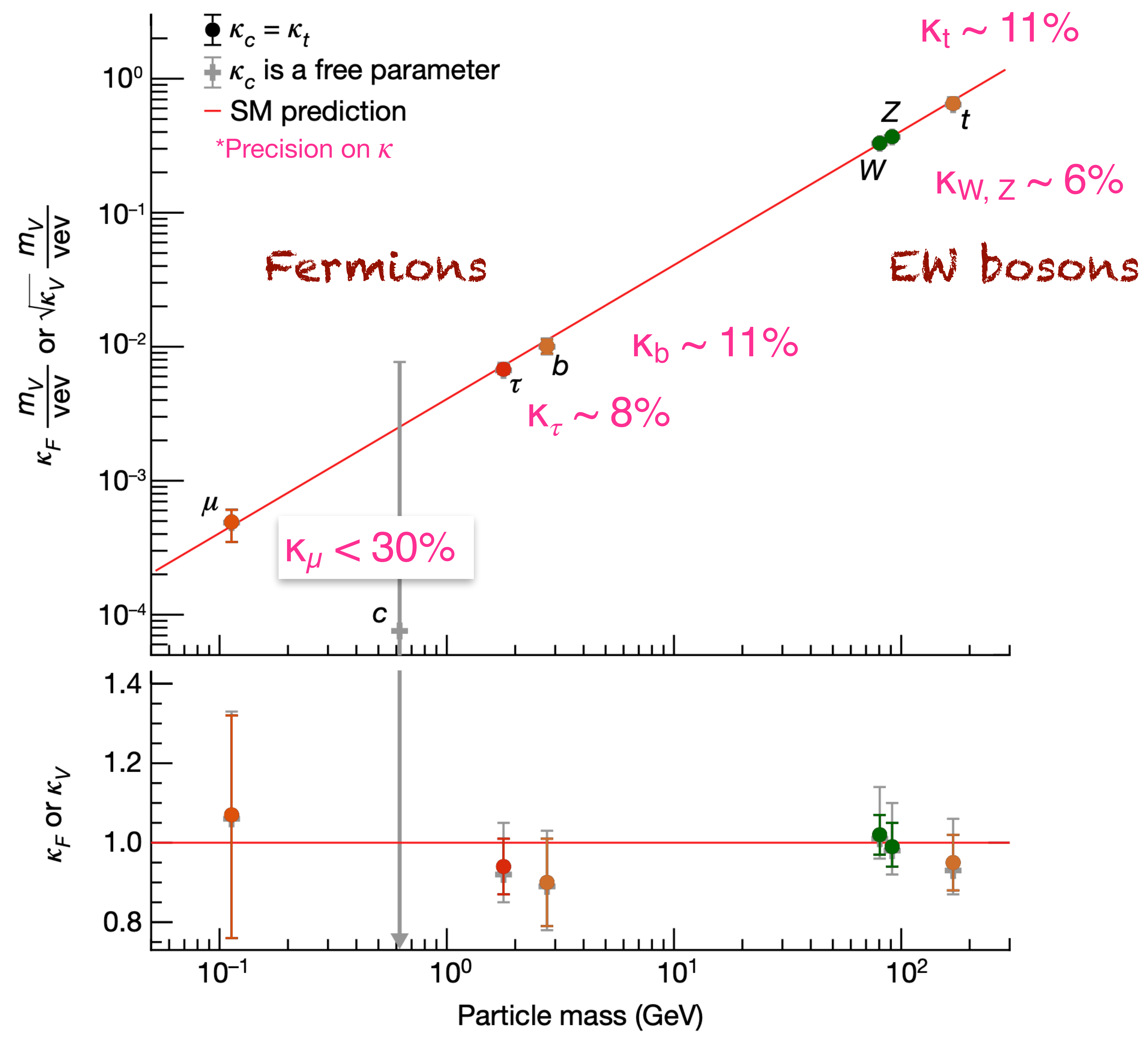
CMS

ATLAS
EXPERIMENT

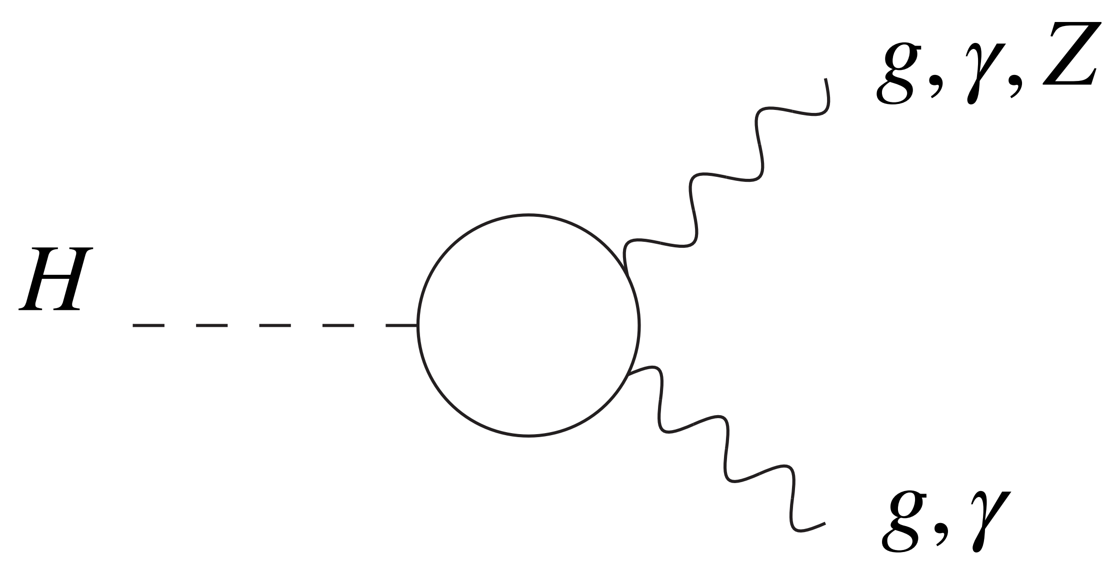
Christos Anastopoulos
Haider Abidi
Katharine Leney

The 'Big Picture'

Effective tree level couplings of the Higgs boson



Effective loop couplings



$\kappa_\gamma \sim 6\%$

$\kappa_g \sim 7\%$

$\kappa_{Z\gamma} \sim 30\%$

Gluon and photon

Invisible branching fraction $Br_{inv} < 11\%$ DM?

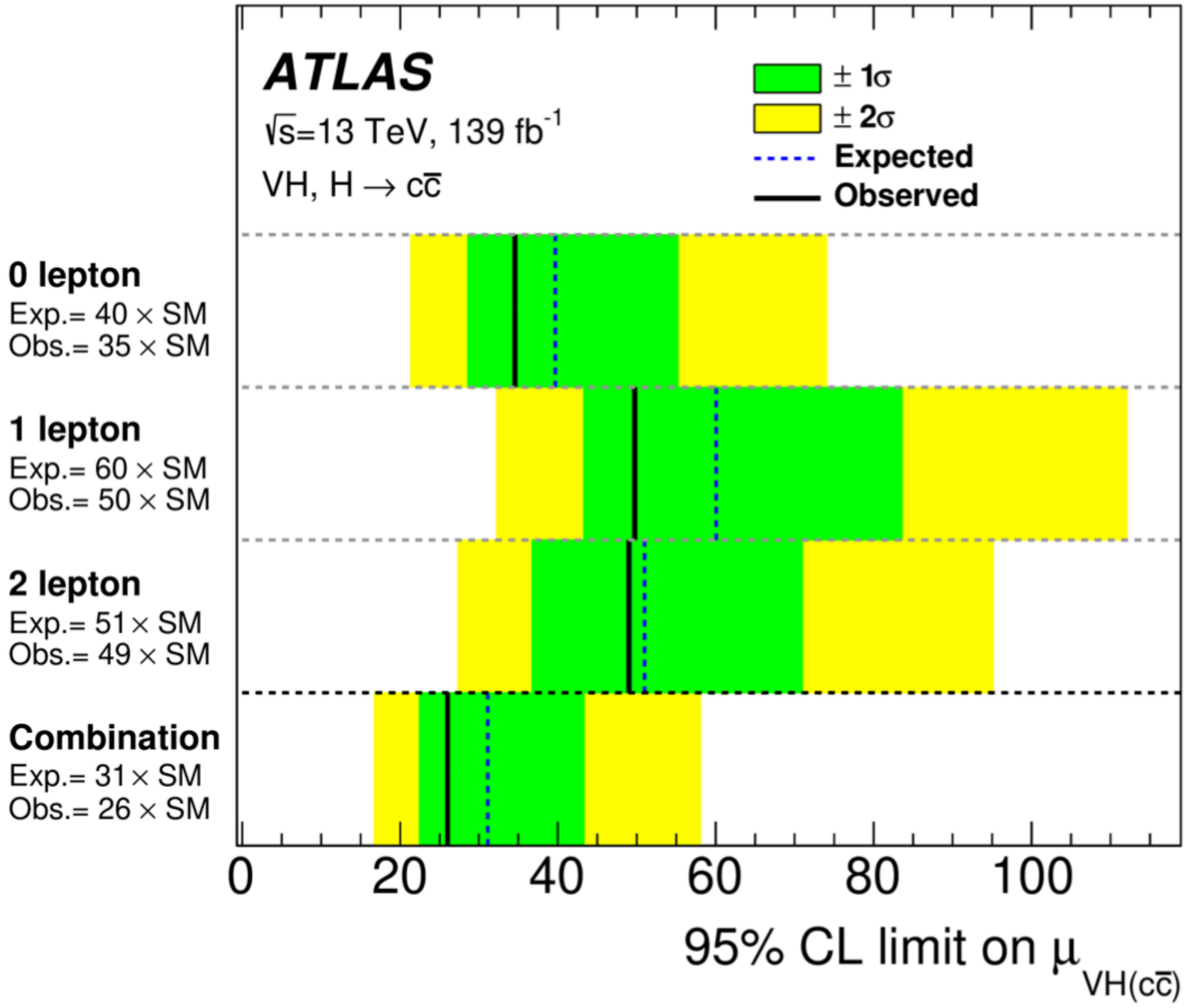
Higgs total width $\Gamma_H \sim 100\%$

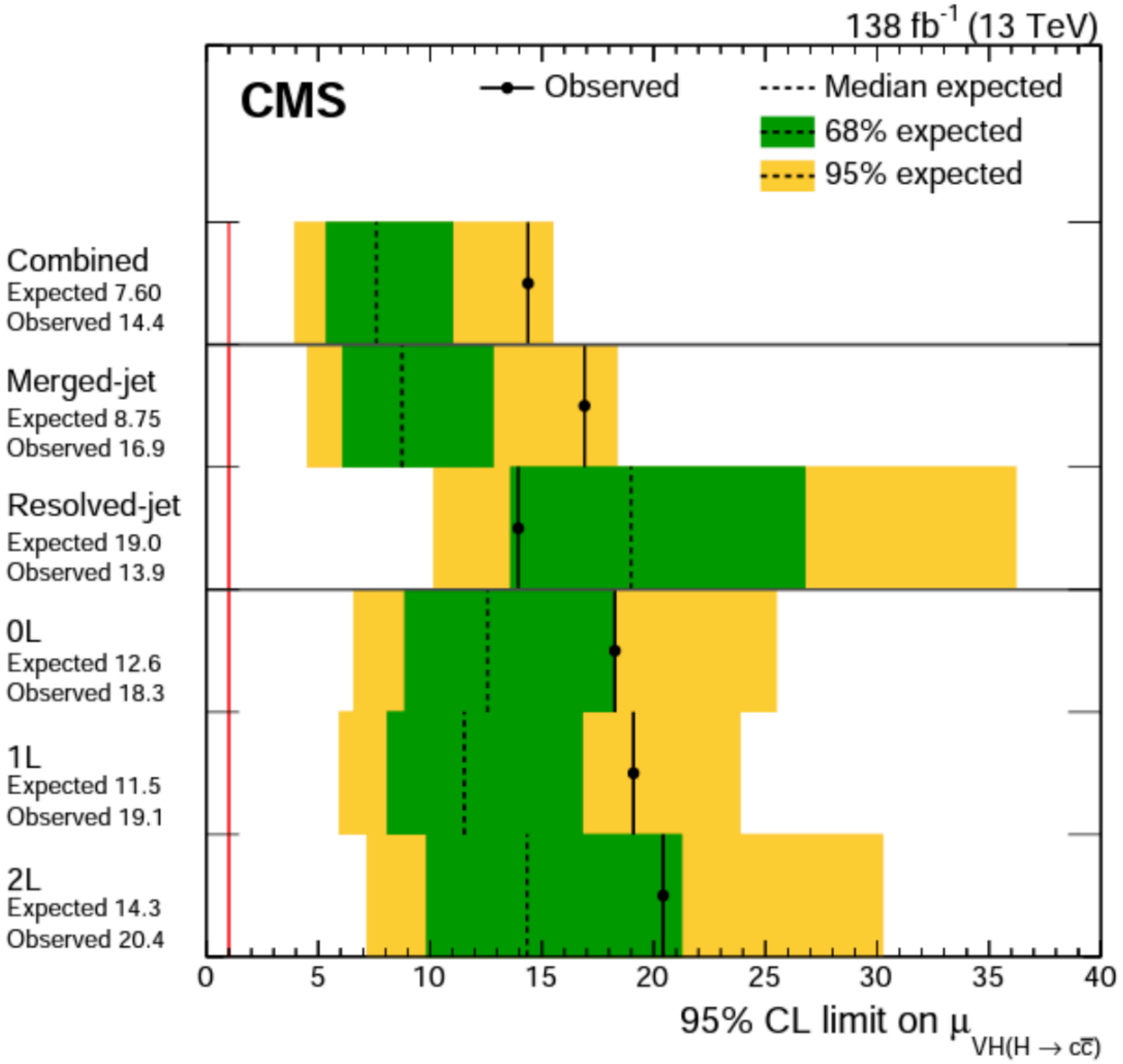
And much more…

CP mixing in production and decays of the Higgs boson, LFV Higgs decays, FCNC top decays to Higgs, rare Higgs decays to quarkonia and photon, and searches for new scalar and pseudo scalar states!

Charm Yukawa Coupling at the LHC?

Taking a closer look at the search for Higgs boson decays to charm in the VH associated production…

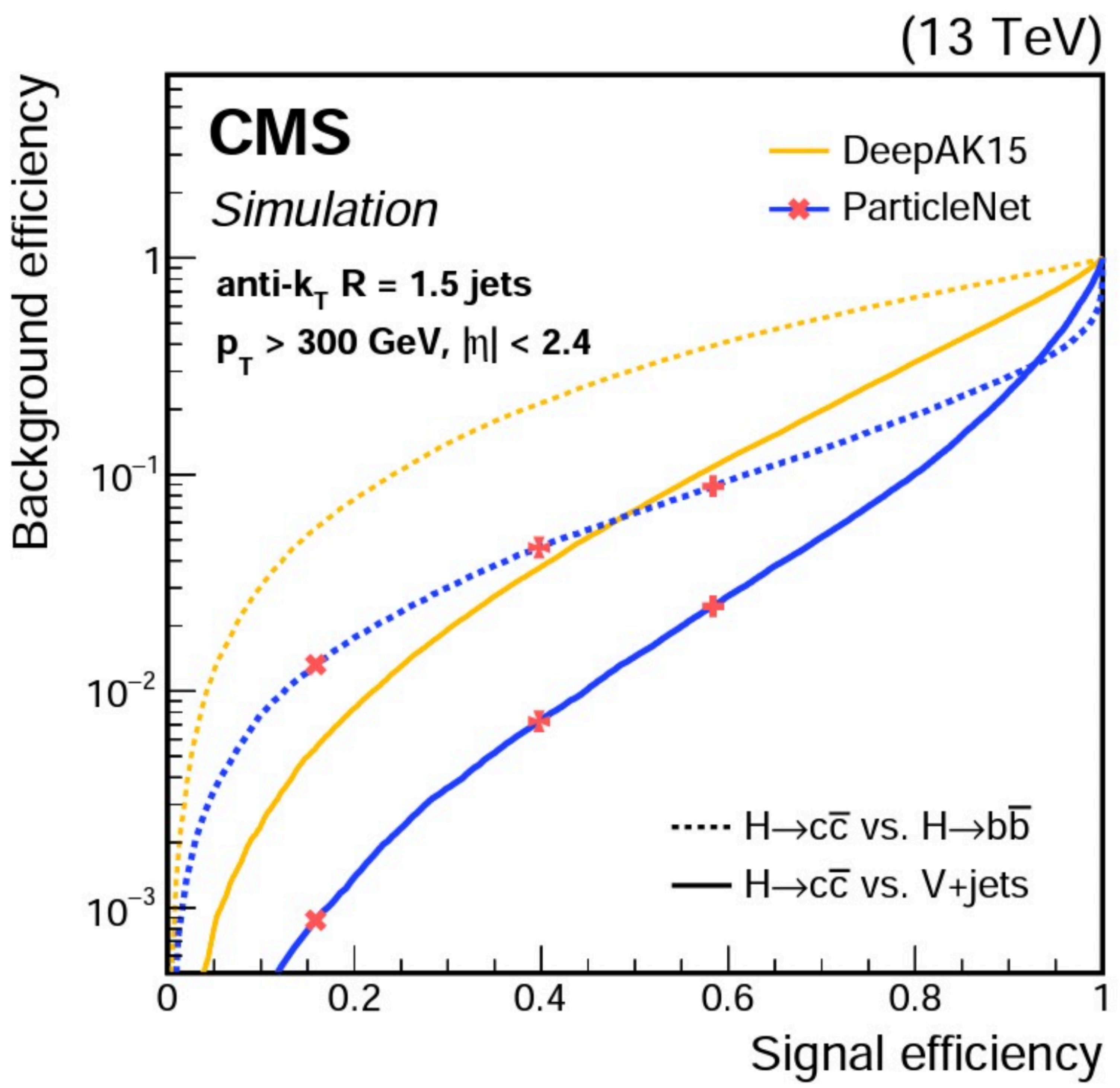




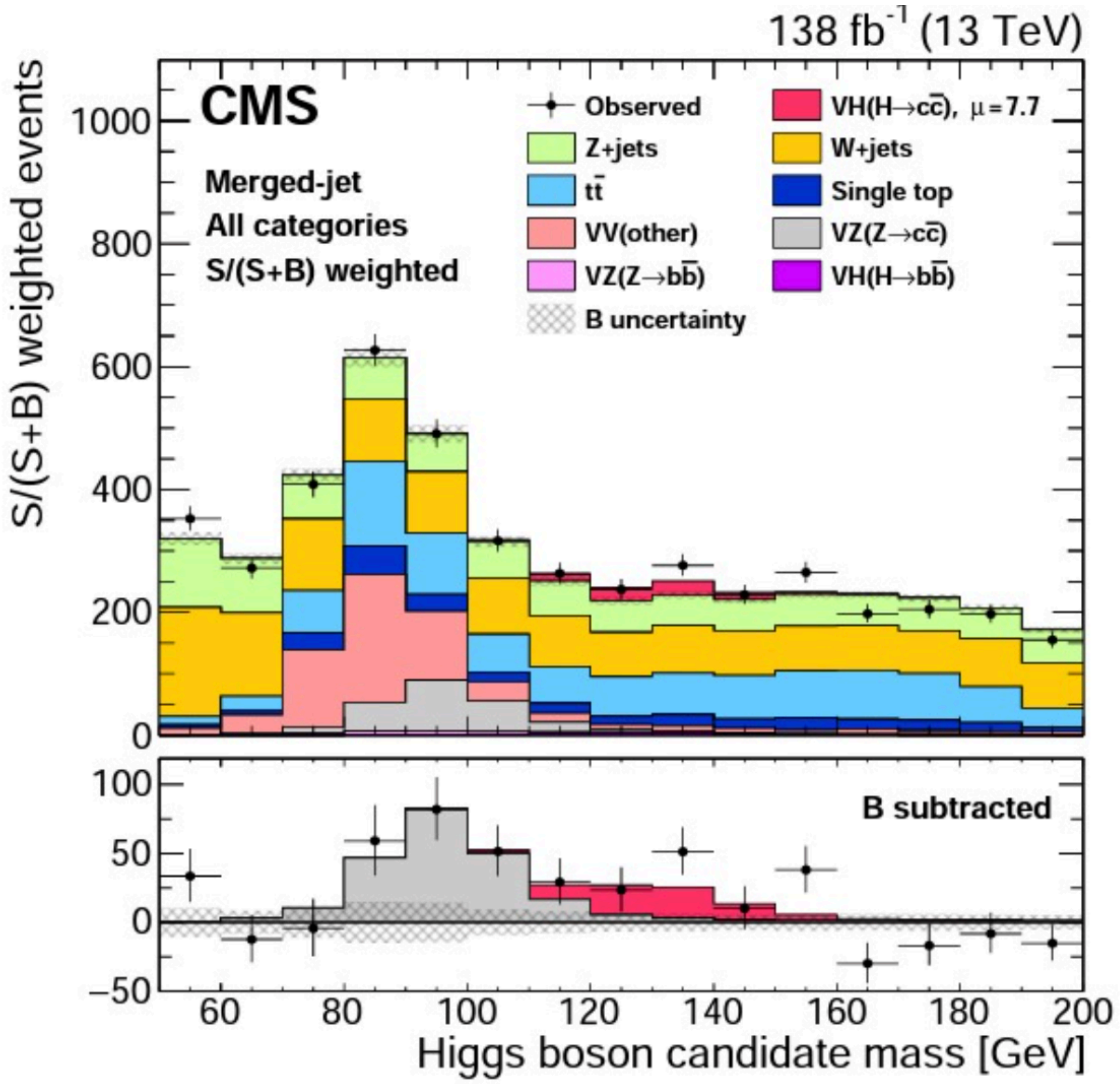
Yuri Maravin
Christos Anastopoulos

Charm Yukawa Coupling at the LHC?

In contrast to e+e– collisions the polar emission angle of the τ lepton and its sign is not, or only very poorly, known and can not be used in the analysis.



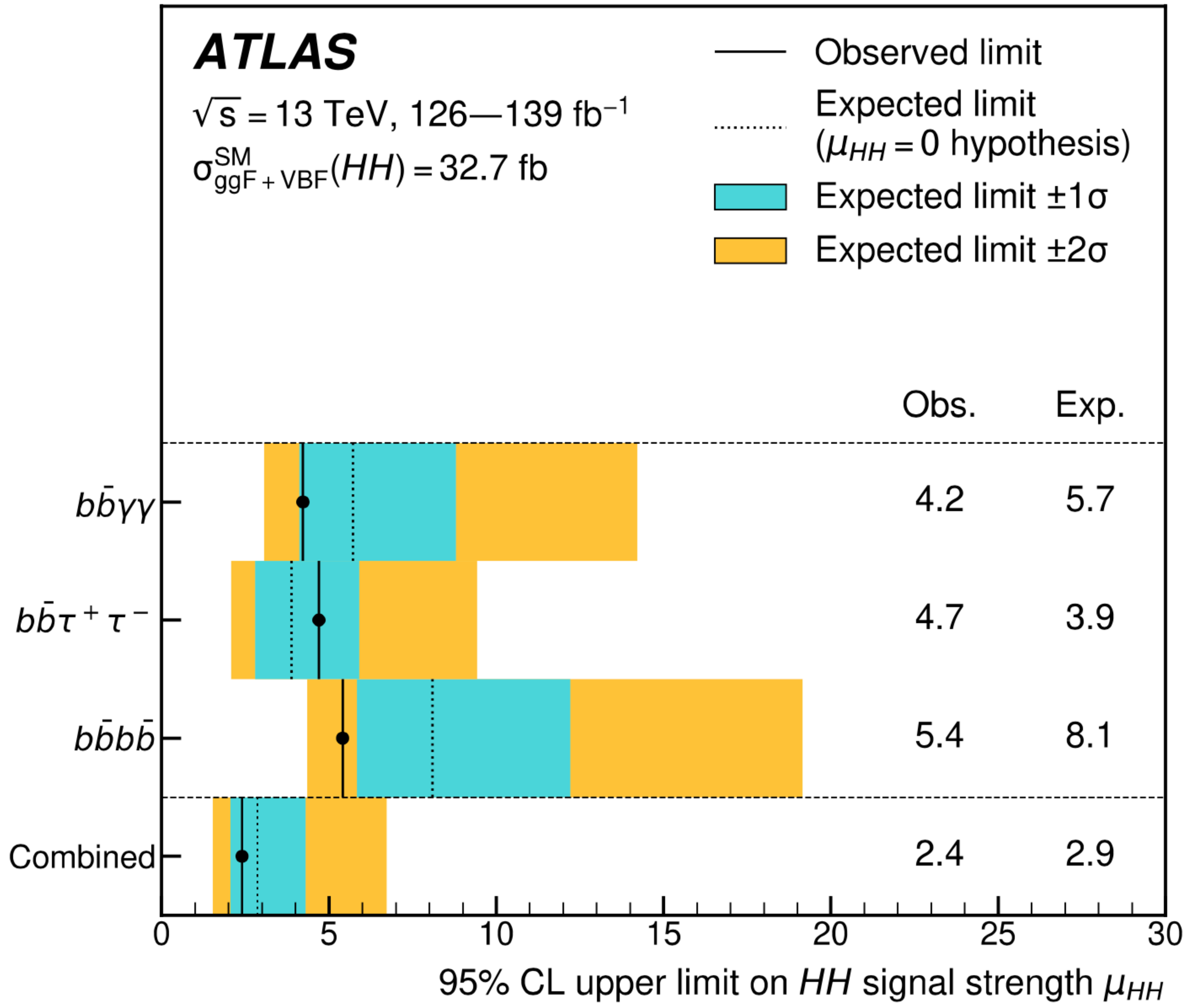
A leap in sensitivity comes from improved tagging of Higgs and charm!

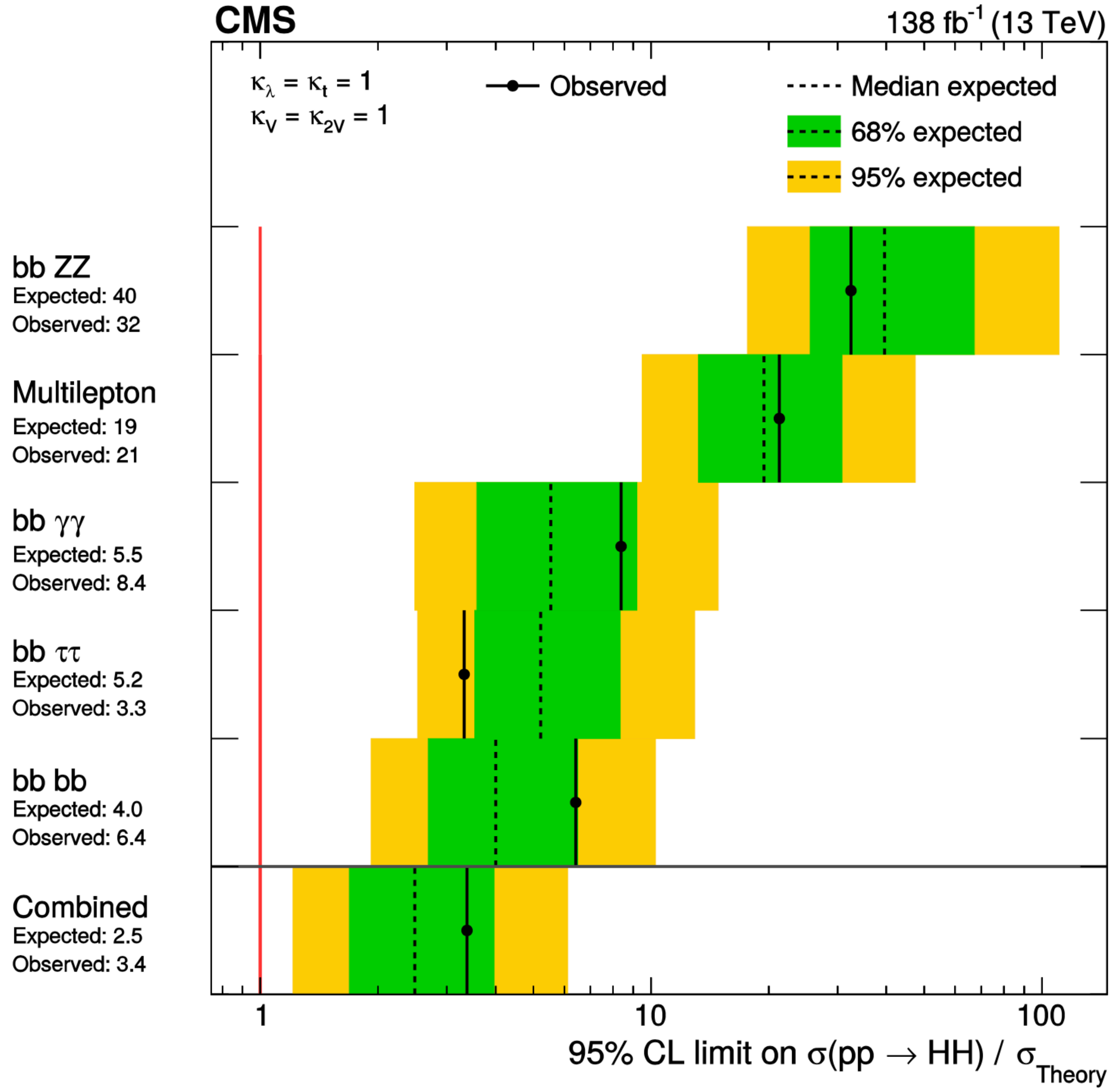


First observation of VZ(Z → cc̄) @ 5.7σ

Di-Higgs and Higgs Self Coupling

Tagging the Higgs boson and b quarks also has an important impact on the di-Higgs production !





Direct evidence of di-Higgs production by both ATLAS and CMS should be achievable at the HL-LHC!

Two new ATLAS Tri-Boson Observations!

New for Moriond EW 2023

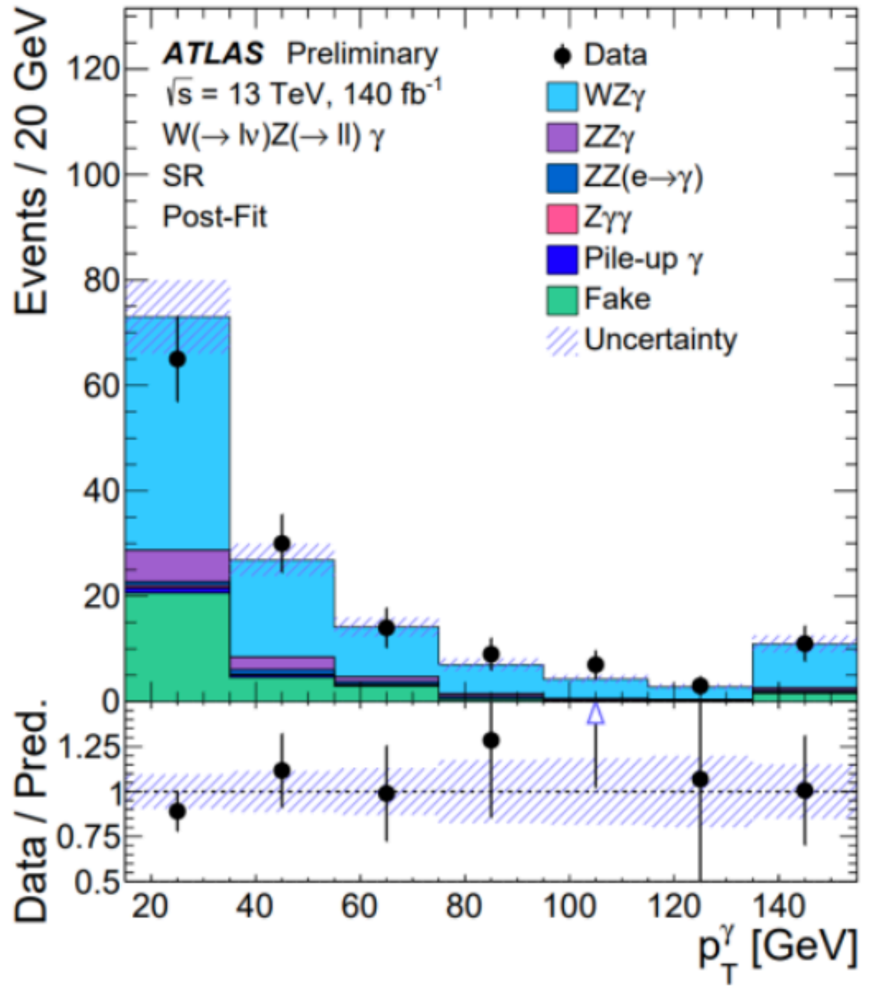
$WZ\gamma$ observation

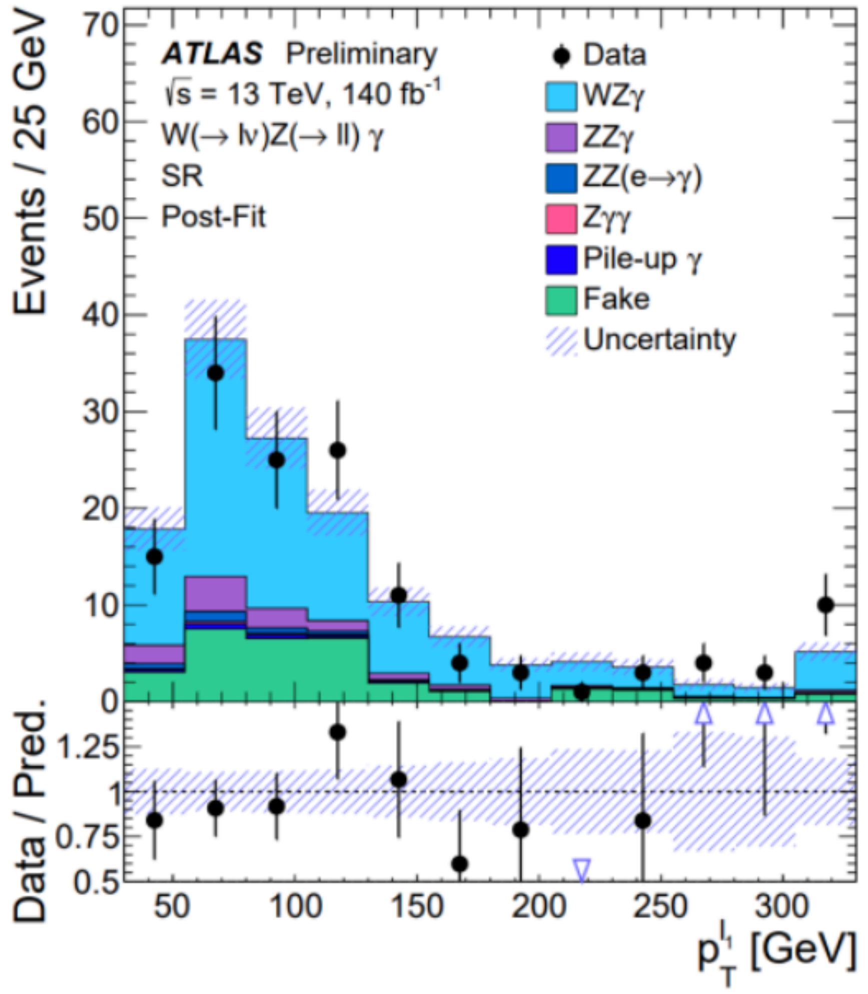
Simultaneous fit with $\mu_{ZZ\gamma}, \mu_{ZZ}$;

$WZ\gamma$ observed with 6.3 σ

$$\sigma_{WZ\gamma} = 2.01 \pm 0.30\ (\text{stat.}) \pm 0.16\ (\text{syst.})\ \text{fb}$$

Process	SR	$ZZ\gamma$ CR	$ZZ(e\to\gamma)$ CR
$WZ\gamma$	92 ± 15	0.21 ± 0.07	0.56 ± 0.14
$ZZ\gamma$	10.7 ± 2.3	23 ± 5	1.8 ± 0.4
$ZZ(e\to\gamma)$	3.0 ± 0.6	0.028 ± 0.020	30 ± 6
$Z\gamma\gamma$	1.05 ± 0.32	0.15 ± 0.06	0.29 ± 0.10
Fake background	30 ± 6	-	-
Pile-up γ	1.9 ± 0.7	-	-
Total predicted	139 ± 12	23 ± 5	33 ± 6
Data	139	23	33





New for Moriond EW 2023

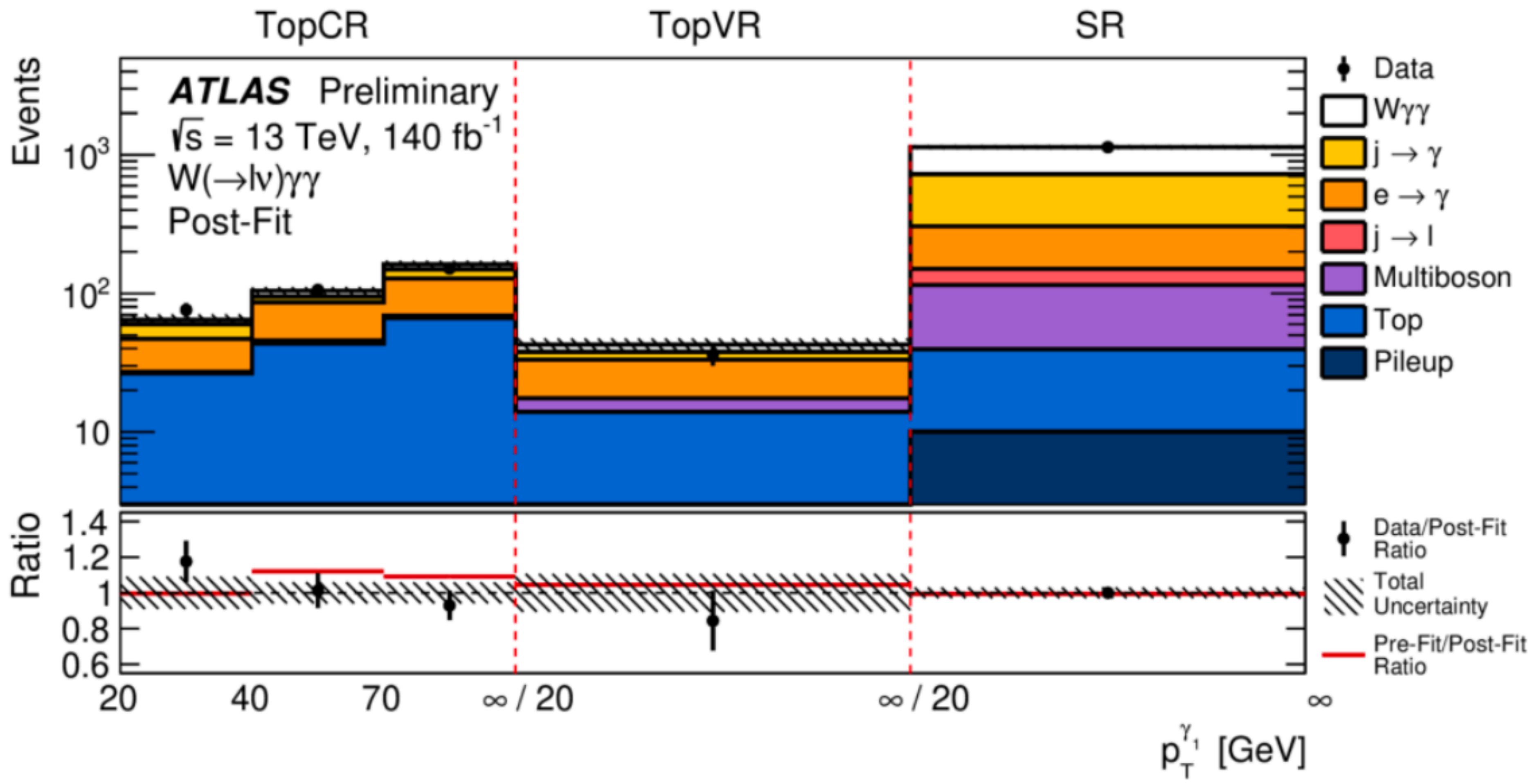
$W\gamma\gamma$ observation

data-driven Fake estimated in control regions

$WZ\gamma$ observed with 5.6 σ

$$\sigma_{fid} = 12.1^{+2.5}_{-2.2}\ \text{fb}^{-1}$$

	SR	TopCR
$W\gamma\gamma$	410 ± 60	28 ± 5
Non-prompt $j \to \gamma$	420 ± 50	42 ± 20
Misidentified $e \to \gamma$	155 ± 11	120 ± 9
Multiboson ($WH(\gamma\gamma)$, $WW\gamma$, $Z\gamma\gamma$)	76 ± 13	5.2 ± 1.7
Non-prompt $j \to \ell$	35 ± 10	–
Top ($tt\gamma$, $tW\gamma$, $tq\gamma$)	30 ± 7	136 ± 32
Pileup	10 ± 5	–
Total	$1\,136 \pm 34$	332 ± 18
Data	1 136	333



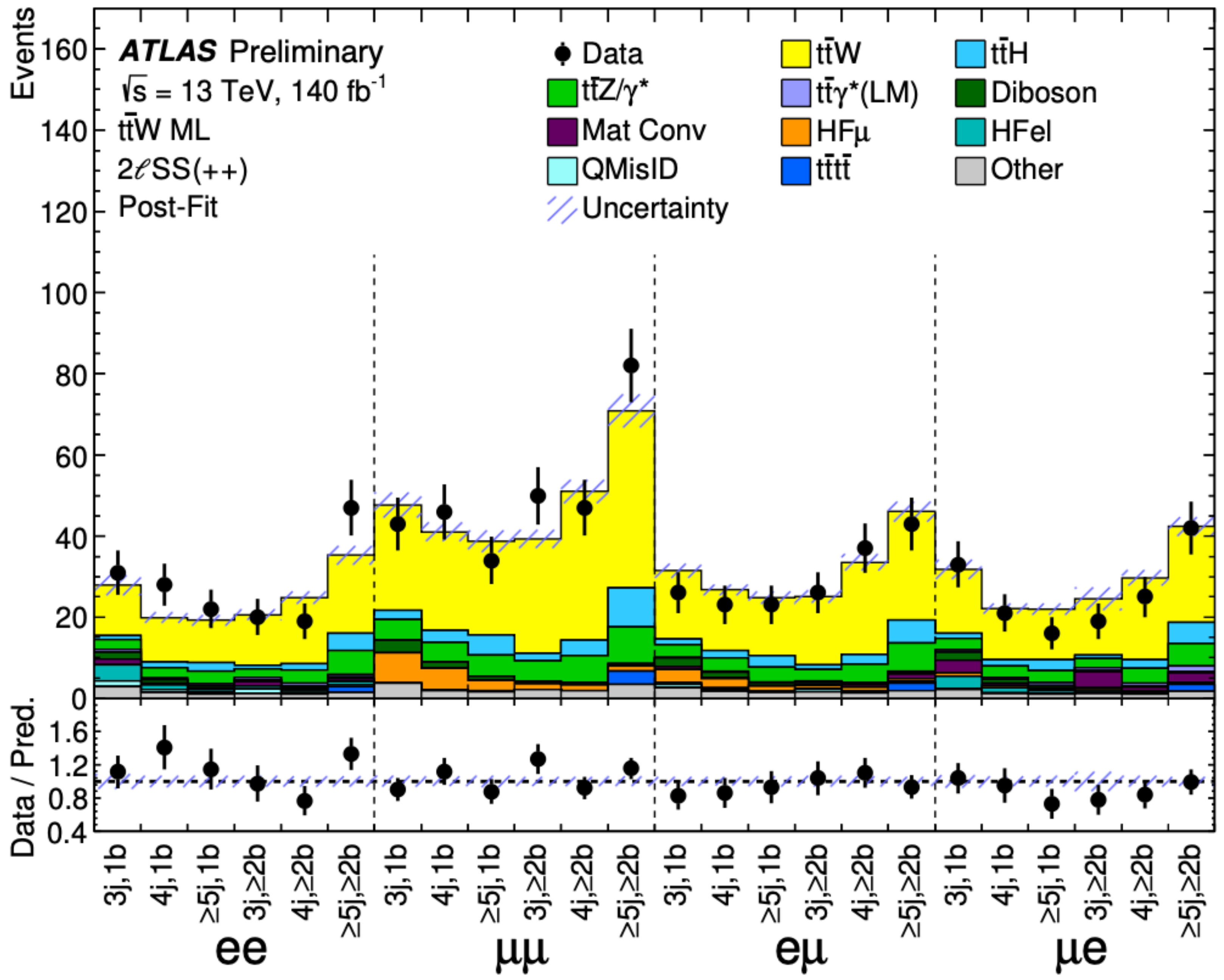
Elizavetta Shabalina
Michele Fauci Giannelli

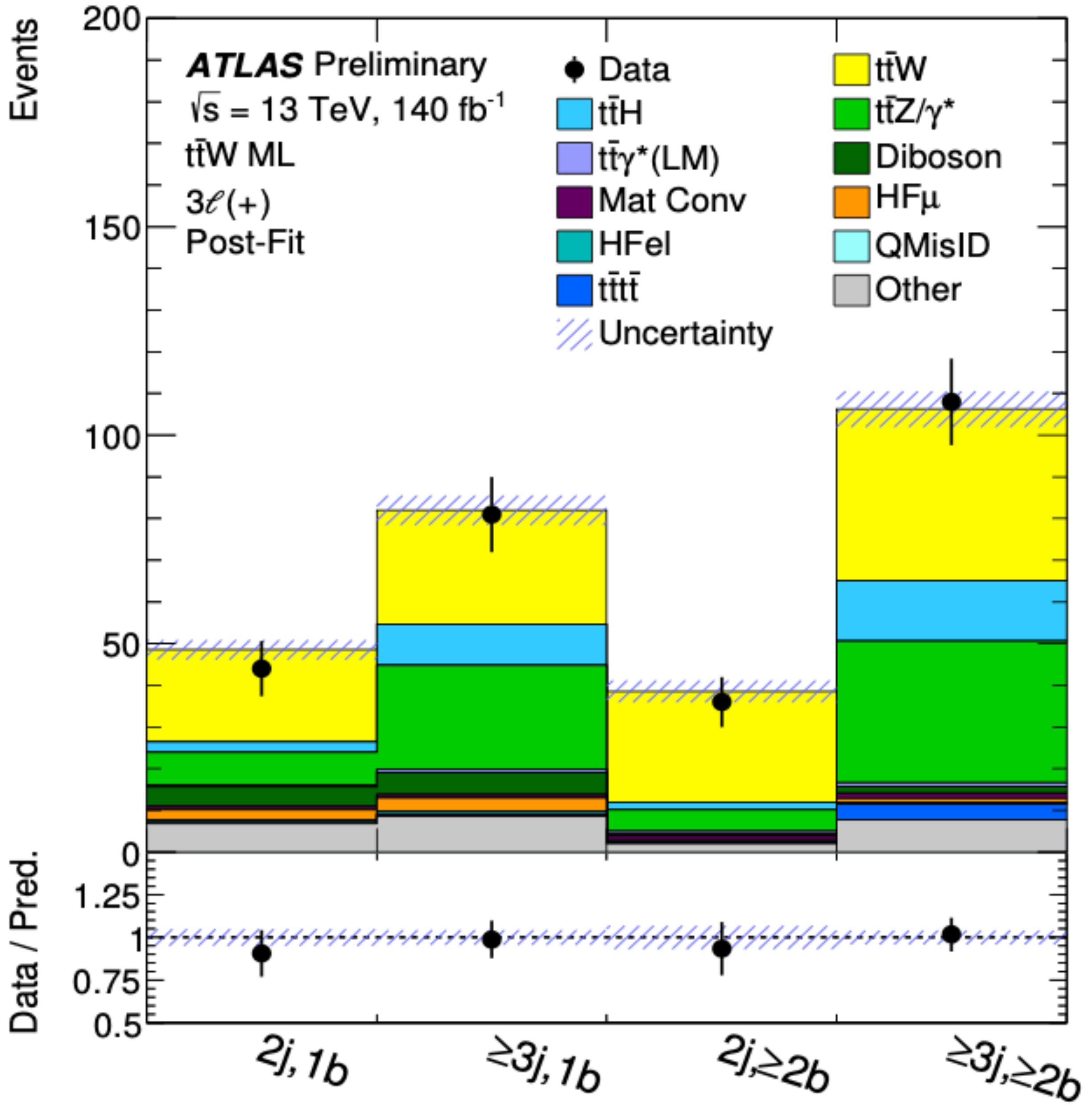
Top Physics Highlight I

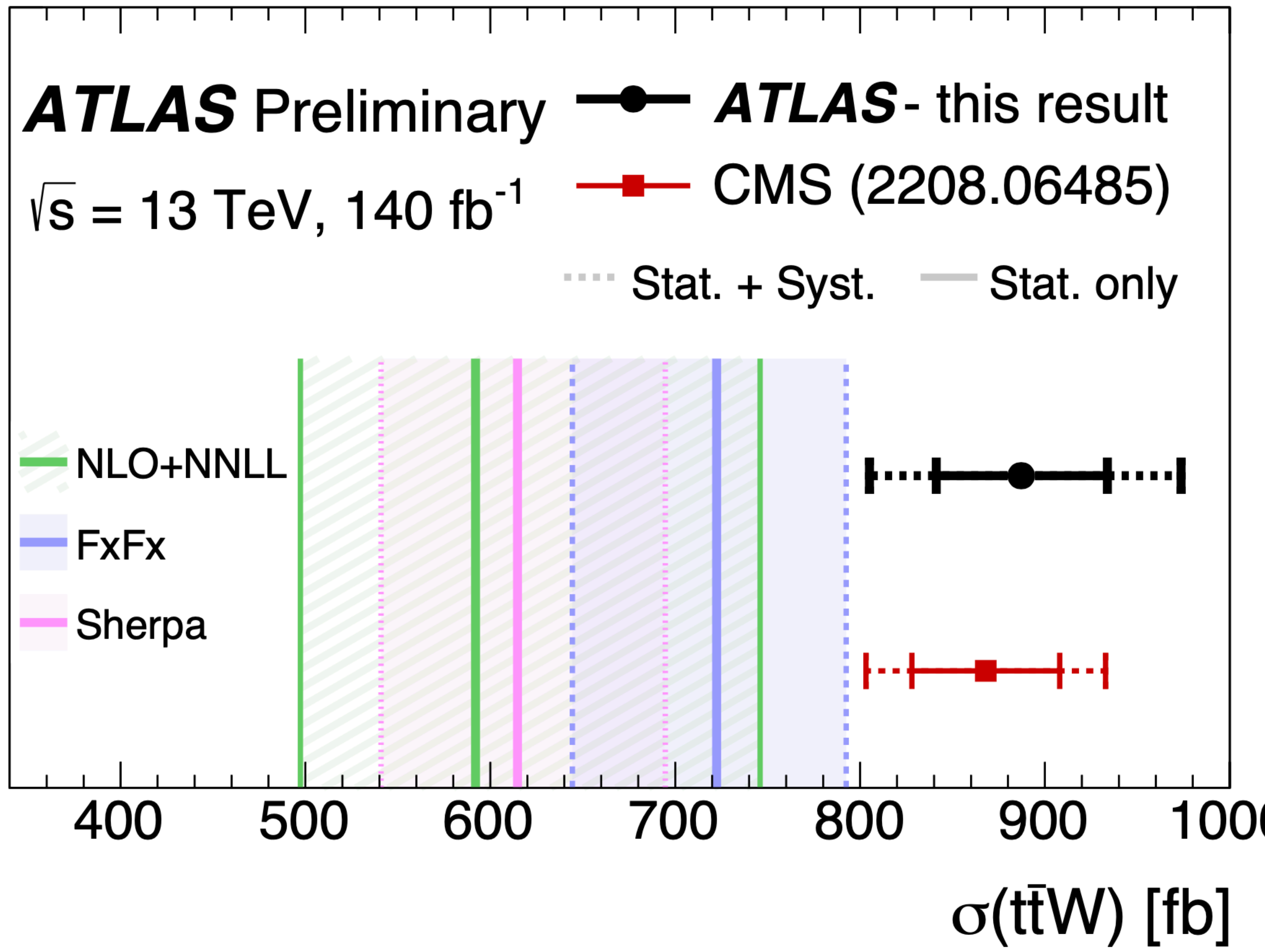
New for Moriond EW 2023

ATLAS Measurement of the ttW inclusive and differential cross sections (in 2 same sign leptons channel and 3 leptons)

- Long standing discrepancies
- Critical ancillary measurement for very large number of measurements (e.g. ttH)







consistent at 1.5σ with theory calculation

$\sigma_{t\bar{t}W} = 722^{+70}_{-78}$ (scale) $\pm$ 7 (PDF) fb

JHEP 11 (2021) 029

$\sigma_{t\bar{t}W} = 890 \pm 50$ (stat) $\pm$ 70 (syst) fb

9% relative uncertainty

Soureek Mitra
Elizavetta Shabalina

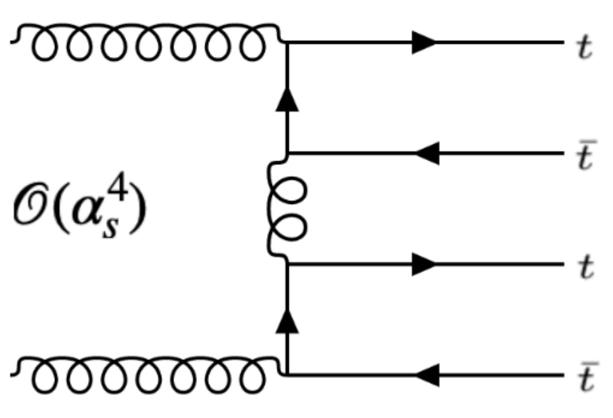
Top Physics Highlight II

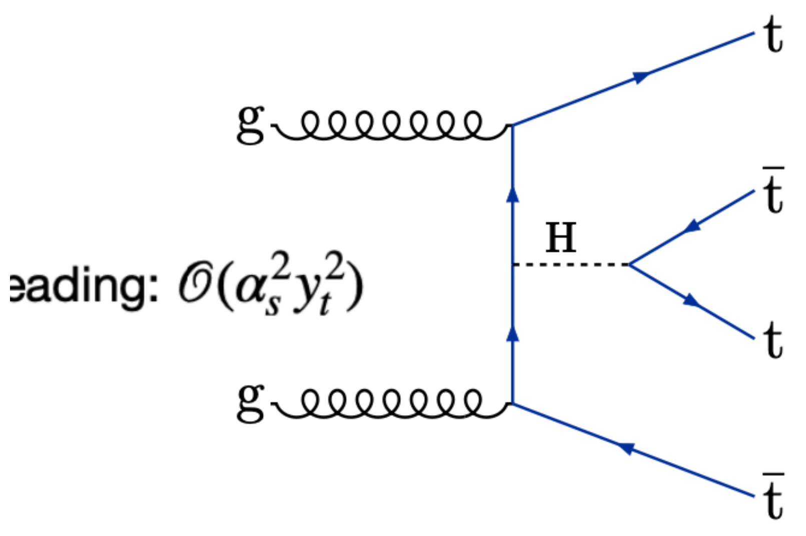
New for Moriond EW 2023

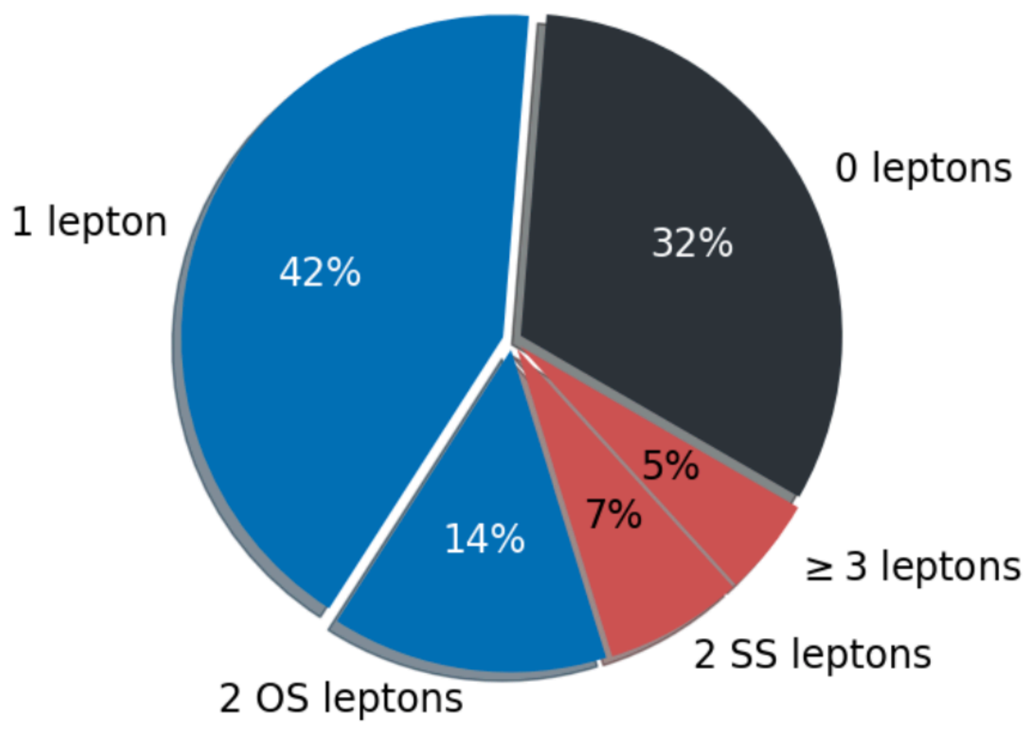
For Moriond EW 2023 !!

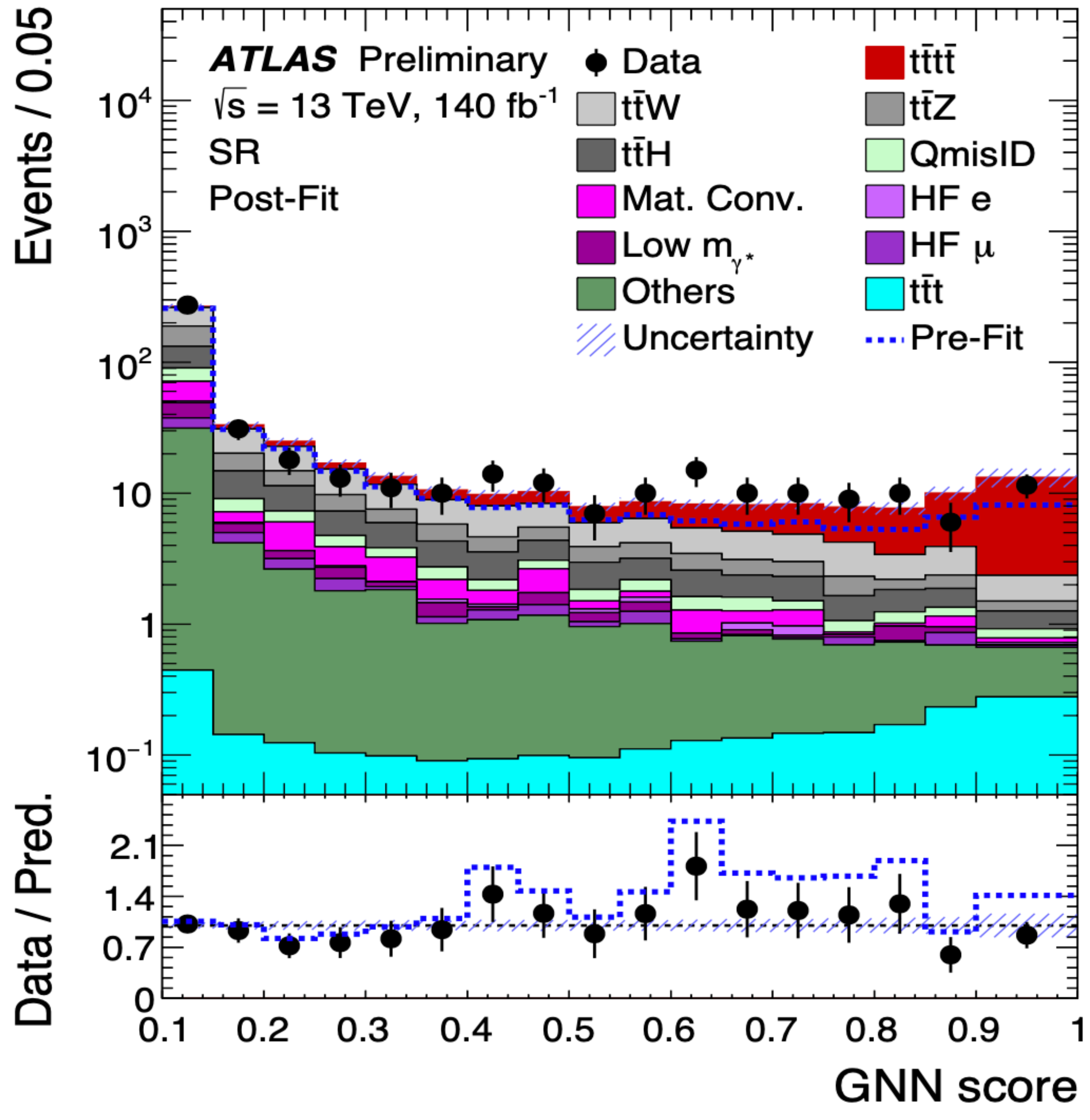
(Independent) Observation by ATLAS and CMS of 4 top production!

Leading: $\mathcal{O}(\alpha_s^4)$

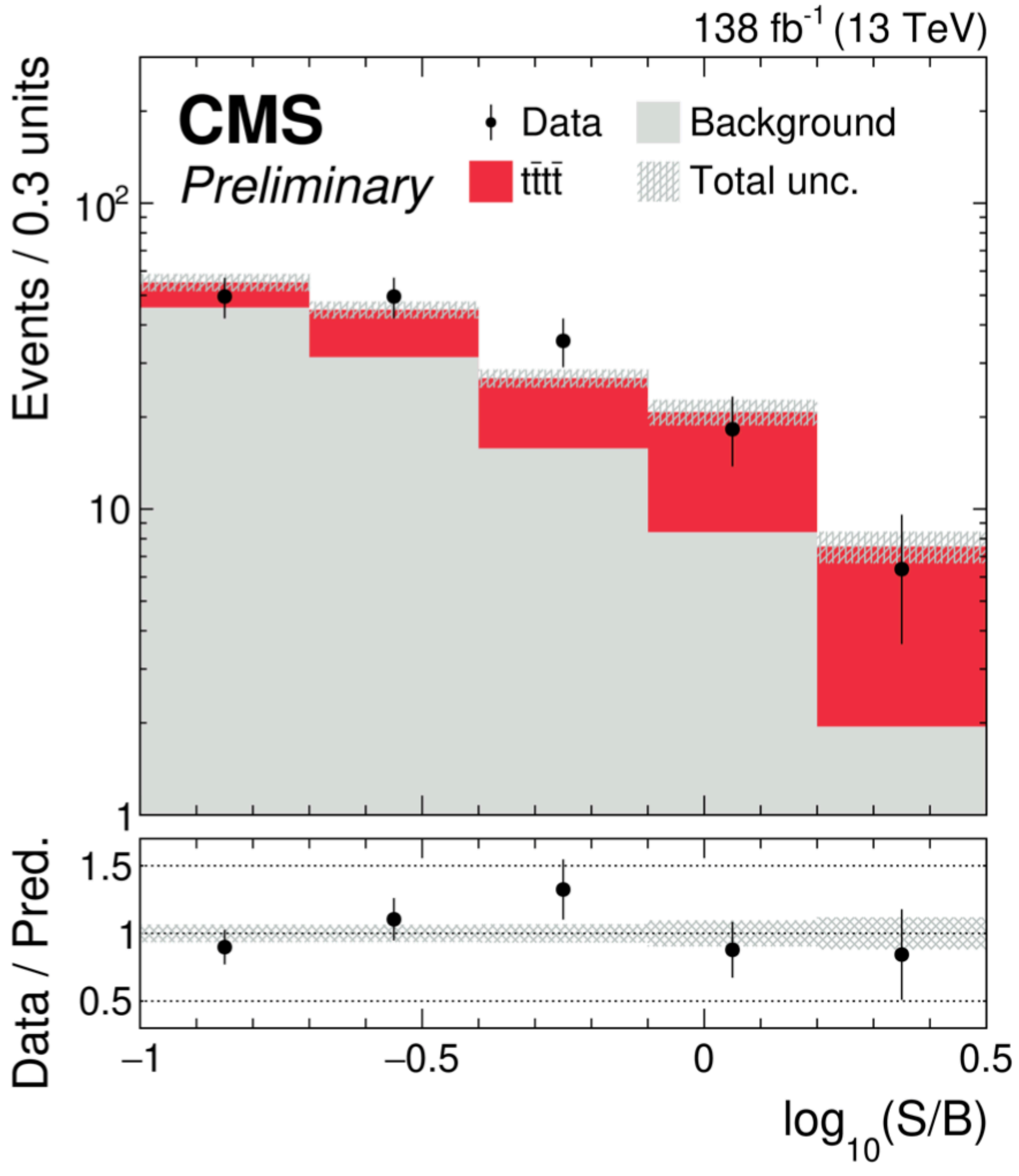






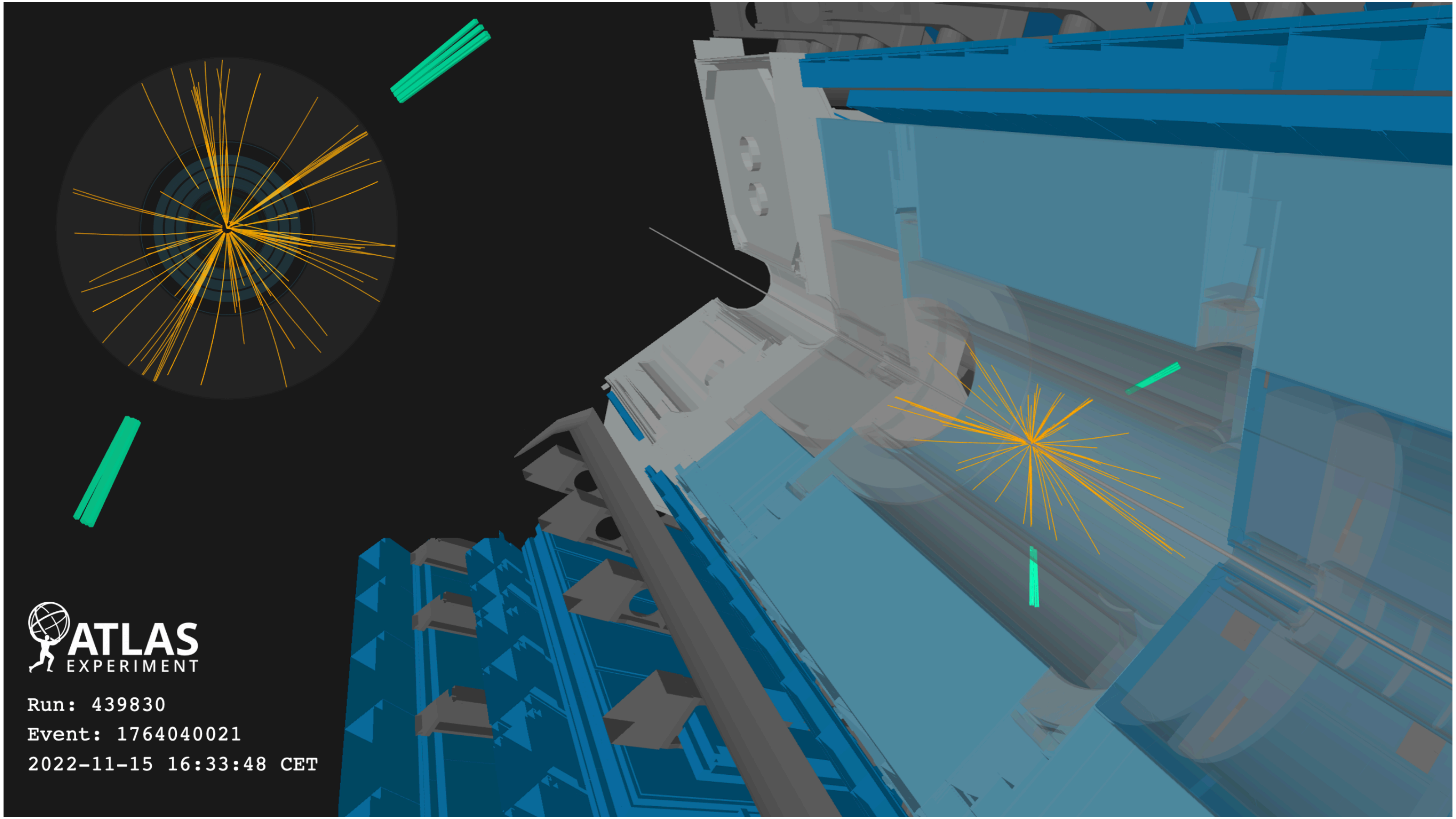


6.1 (4.3) σ observed (expected)



5.5 (4.9) σ observed (expected)

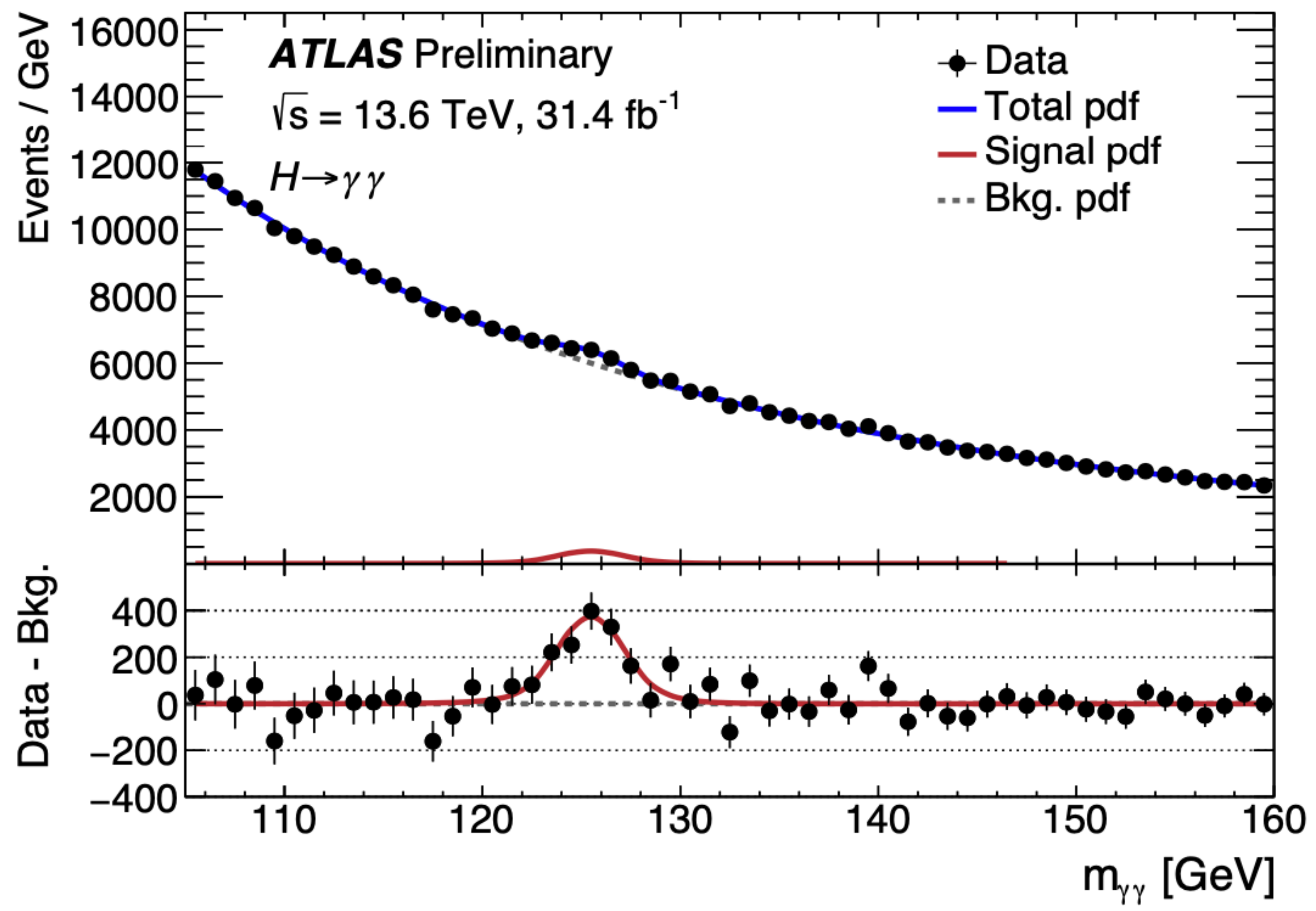
Outlook: New Results from LHC Run-3

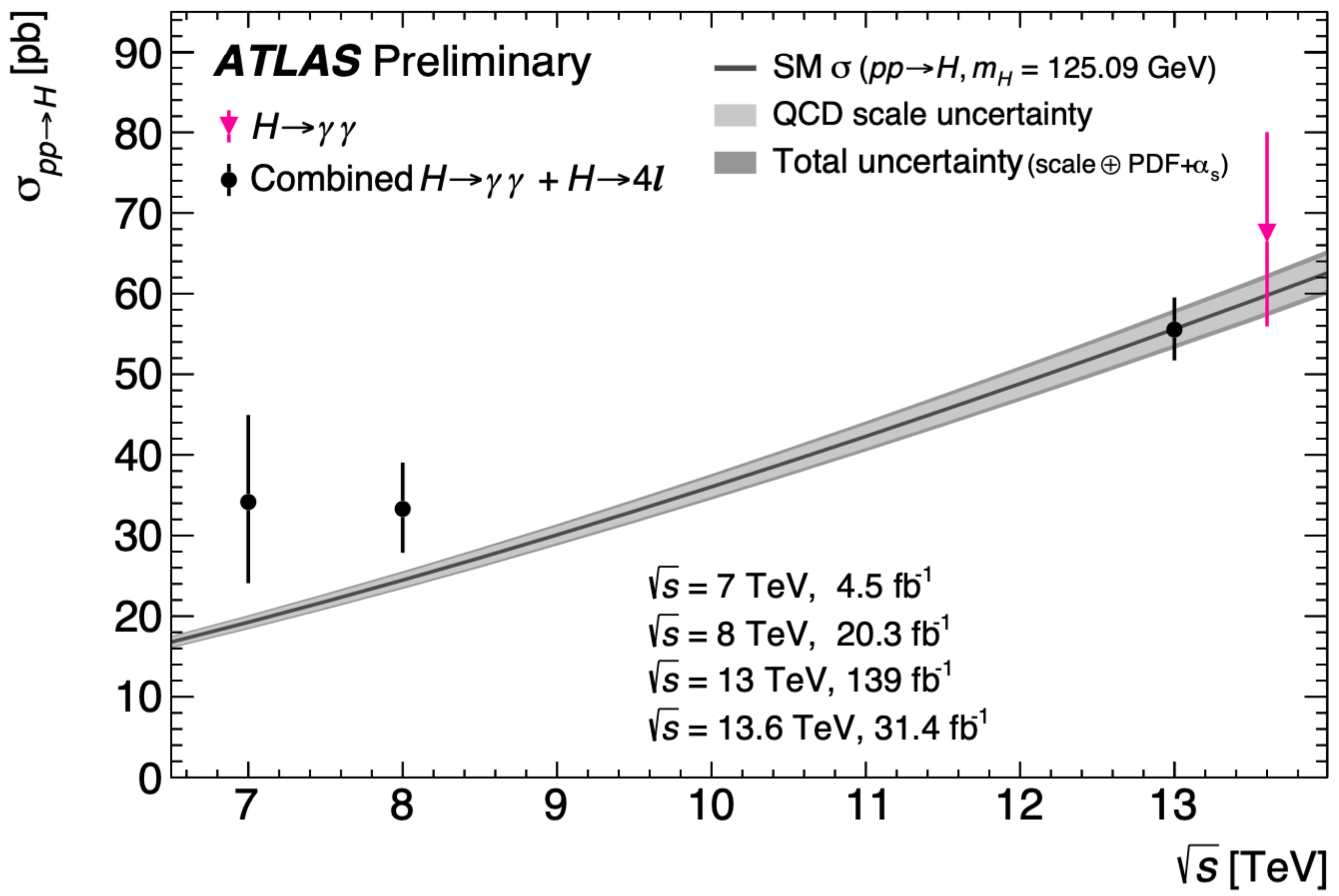


Outlook: New Results from LHC Run-3

New for Moriond EW 2023

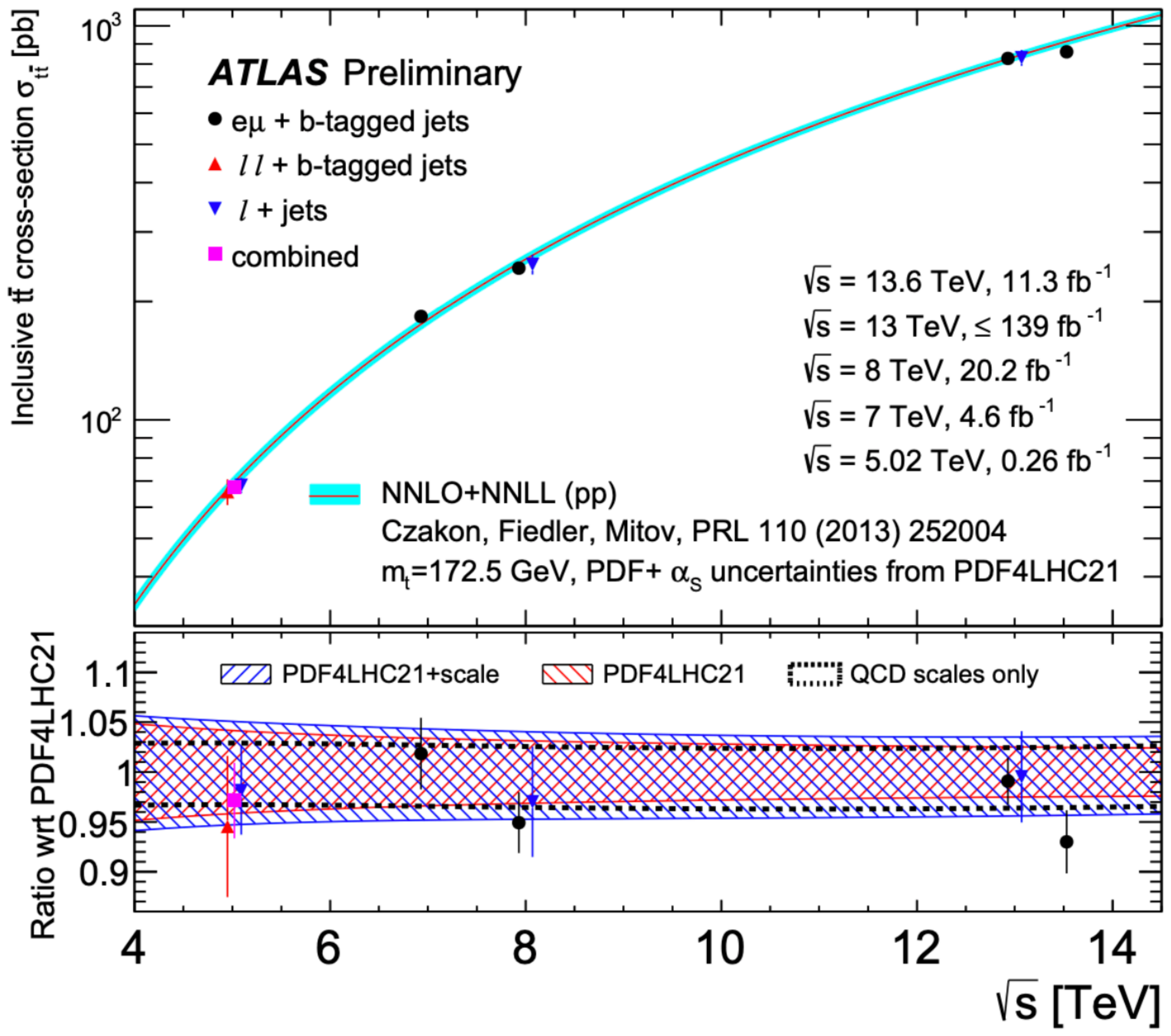
ATLAS Higgs cross section at 13.6 TeV





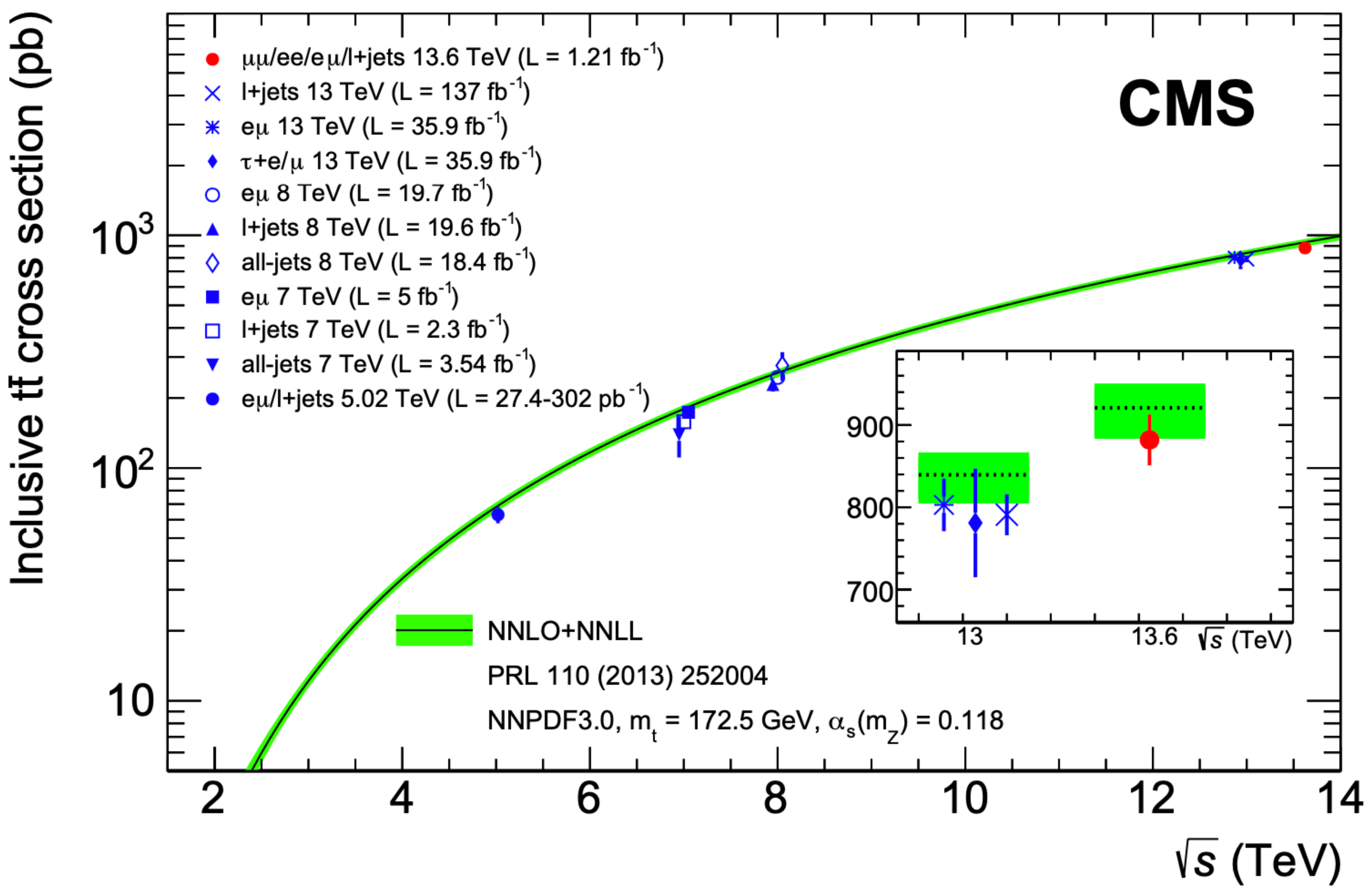
New for Moriond EW 2023

ATLAS top and Z cross sections at 13.6 TeV



New for Moriond EW 2023

CMS top cross sections at 13.6 TeV



Conclusion

Very intense Moriond 2023 with a landslide of new results!

The number of new results for this conference was overwhelming

Moriond has proved again to be a landmark for the community

Many thanks to all our colleagues for their heroic effort in preparing for this conference!

Many thanks to the organisers for the outstanding 57th Rencontres de Moriond!!