Selected highlights from Ongoing Winter conferences

March 2023, nuno@cern.ch

57th Rencontres de Moriond 2023

18-25/03 : Electroweak Interactions & Unified Theories

18-25/03 : Gravitation

25/03-01/04 : Mesoscopic Physics

25/03-01/04 : QCD and High Energy Interactions

New! Bulletin #3

https://indico.in2p3.fr/event/29681/timetable/#all.detailed

Winter conferences season!

Moriond EWK last week
Moriond QCD this week
Hard Probes this week

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,

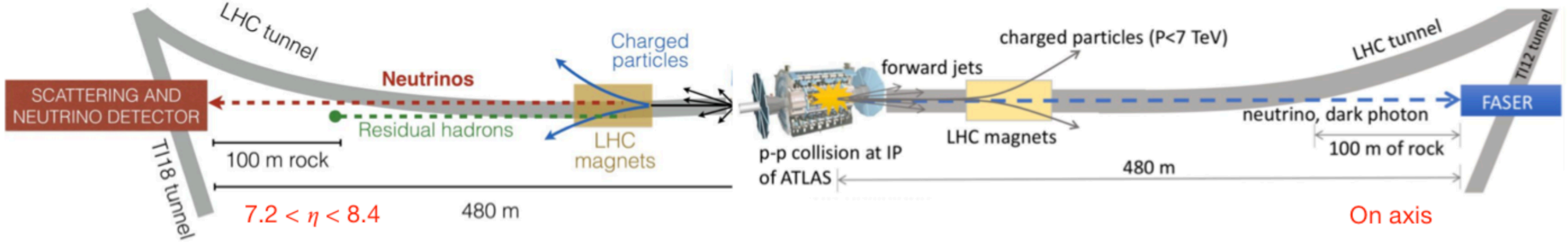
- Precision from low energy observables: nEDM, pEDM, eEDM, g-2 of muon, etc…

neutrinos

The birth of Collider Neutrinos (at the LHC)

Ettore Zaffaroni

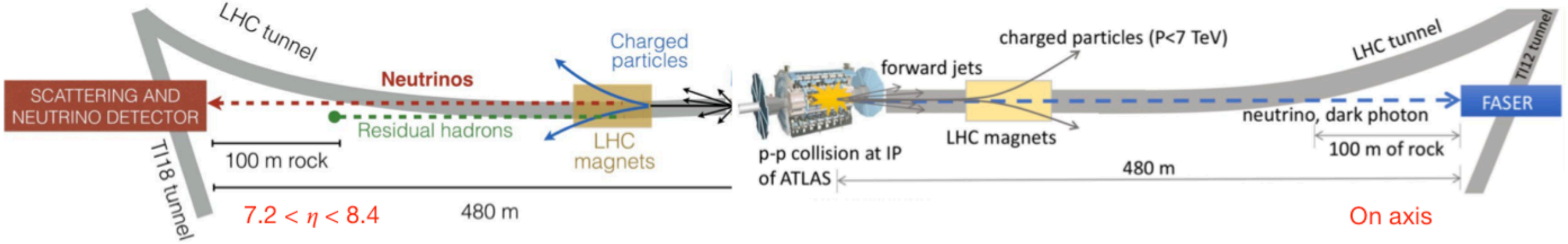
Brian Petersen



SND

Faser-ν

The birth of Collider Neutrinos (at the LHC)

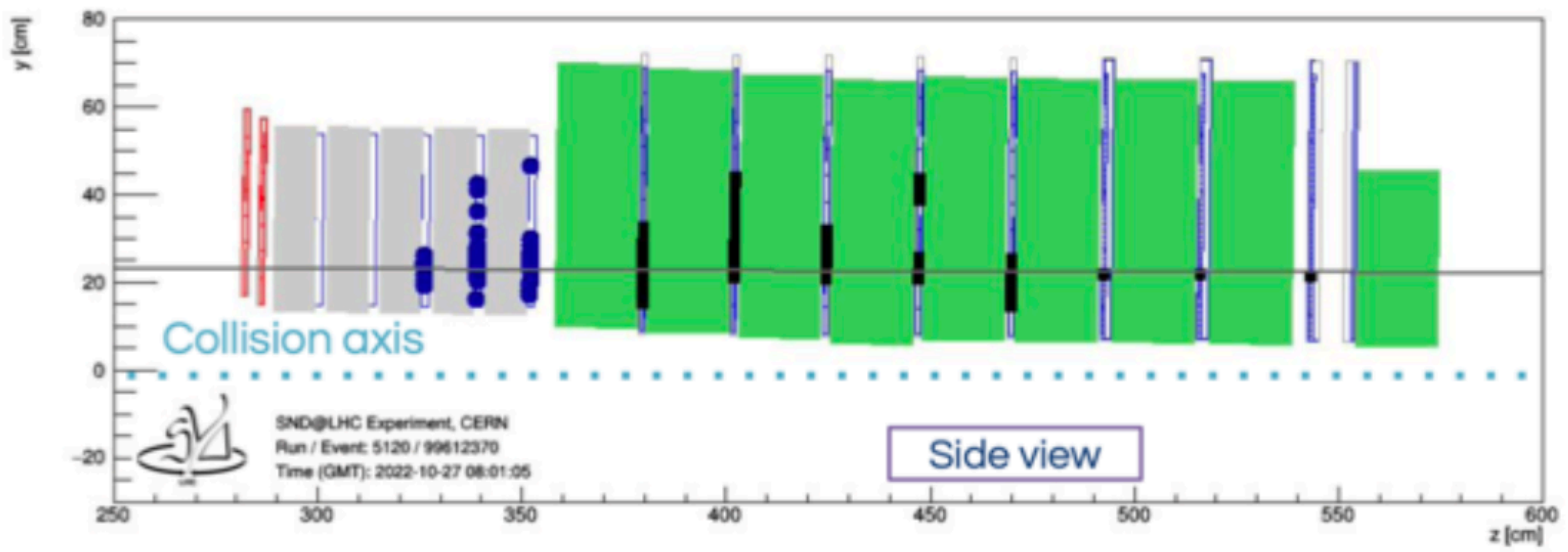


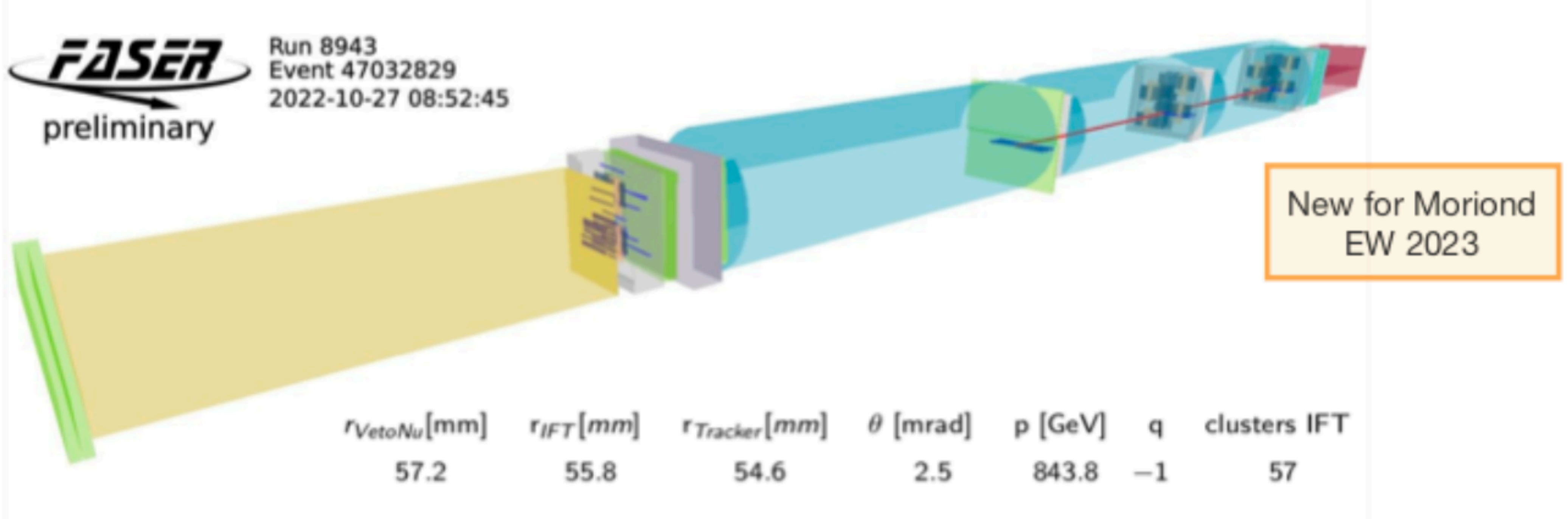
SND

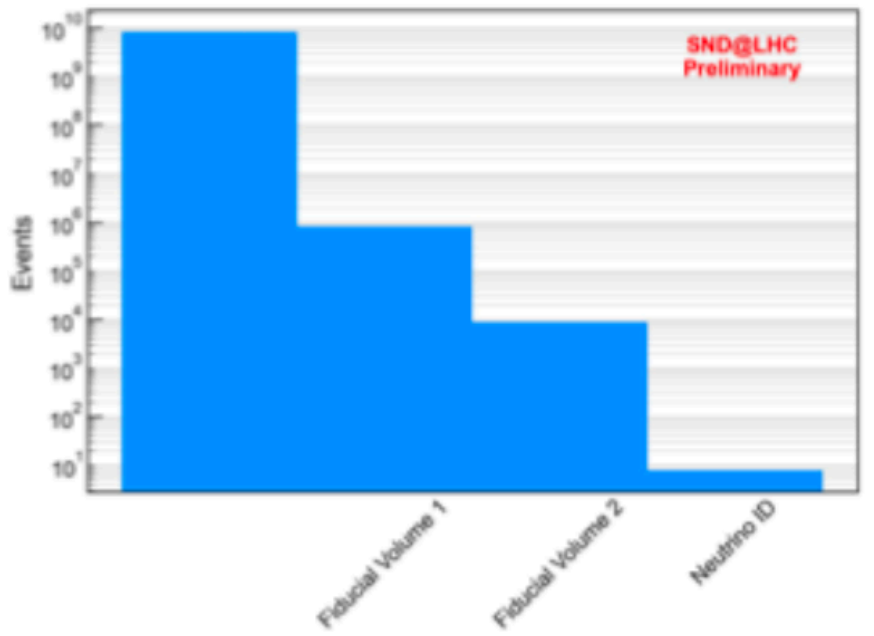
New for Moriond EW 2023

First results from SciFi/Silicon tracking devices

Faser-ν





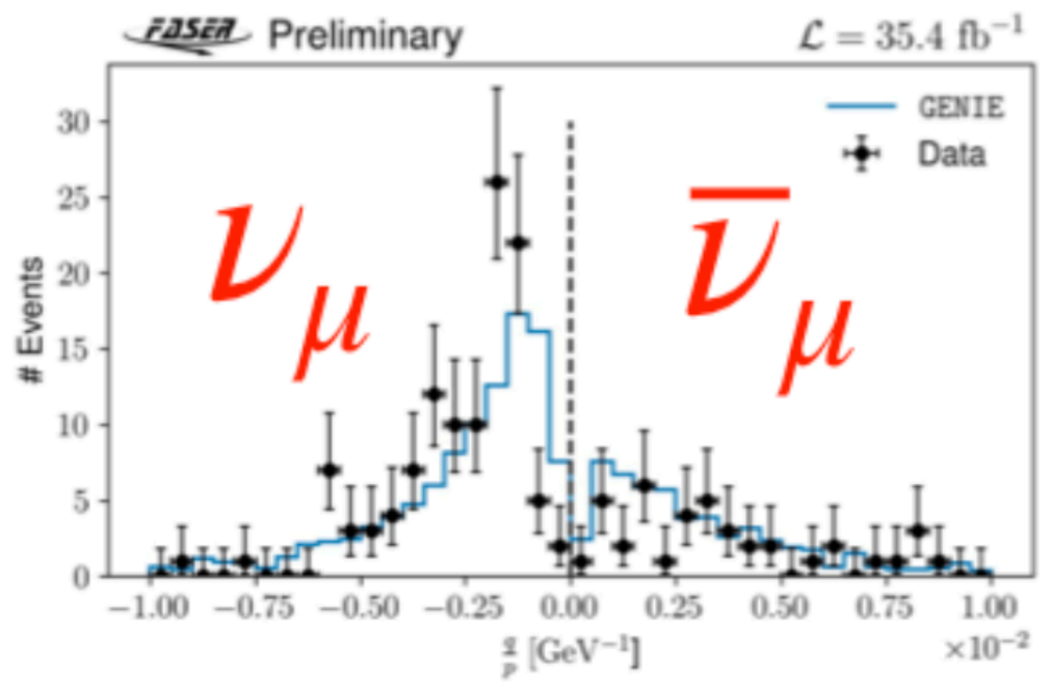


5 events expected and 8 observed (0.2 background)

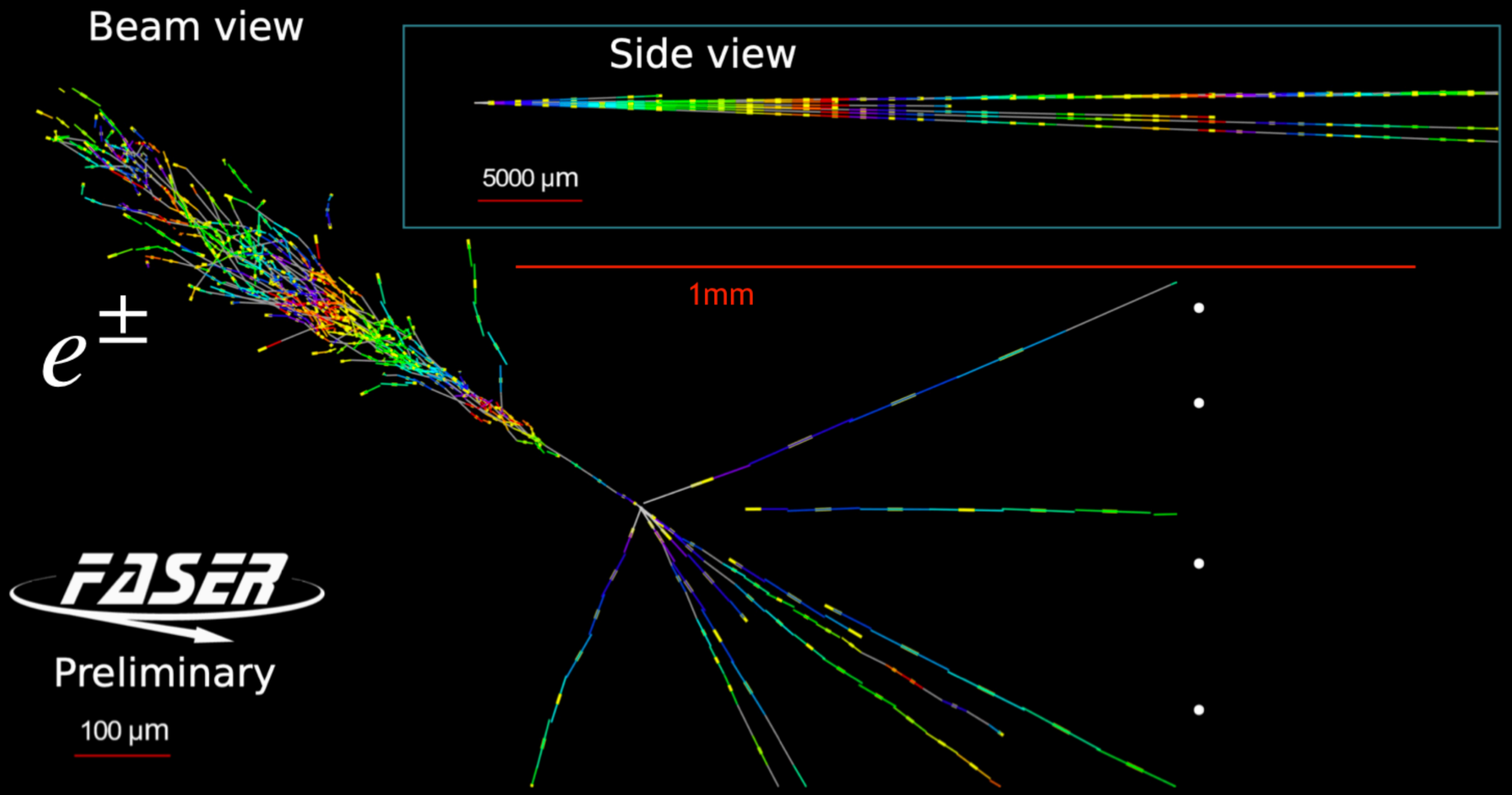
Approximately 5σ observation!

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

16σ observation!

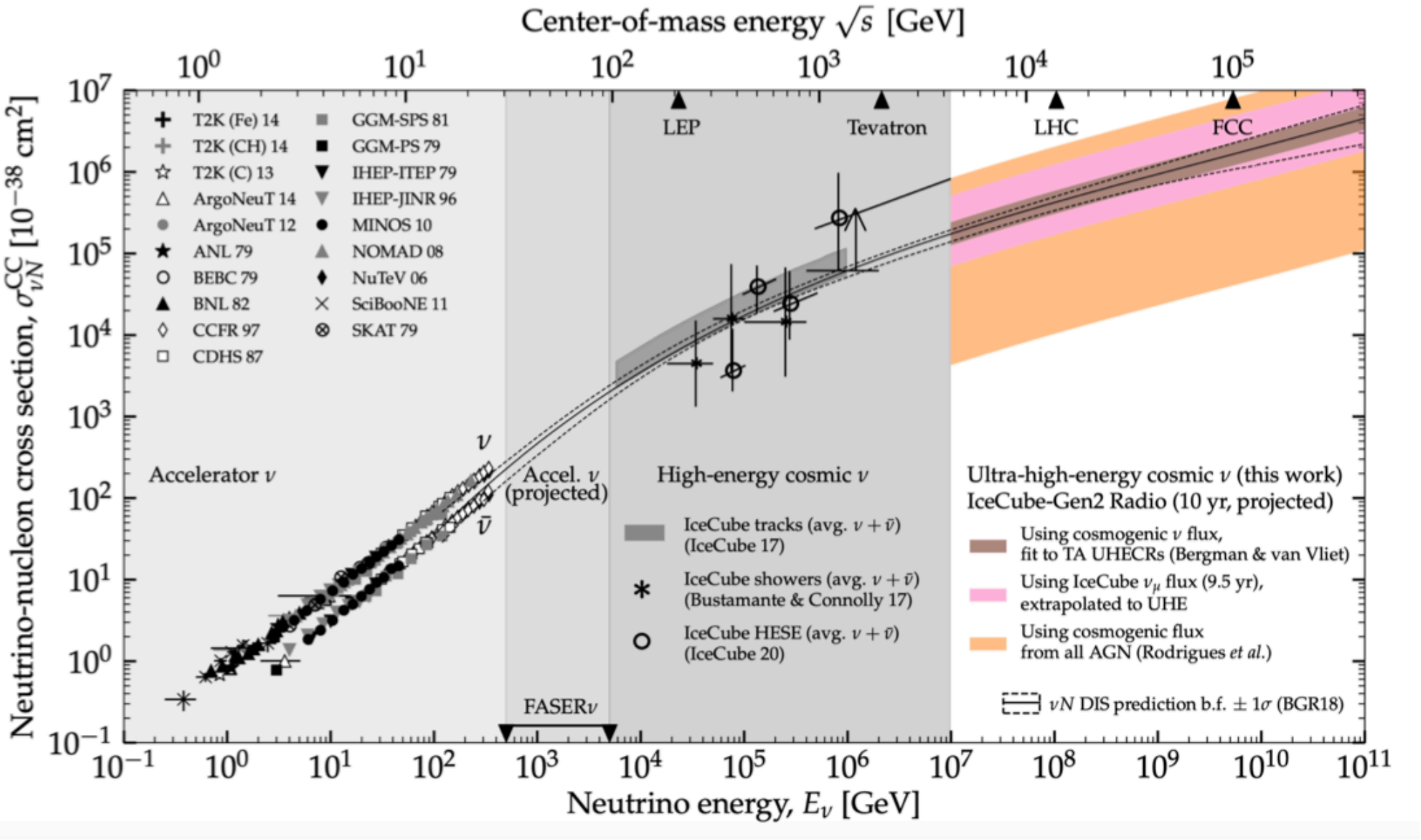


Looking forward to the emulsion results!



The First Decade of High Energy Neutrino Astronomy

Francis Halzen

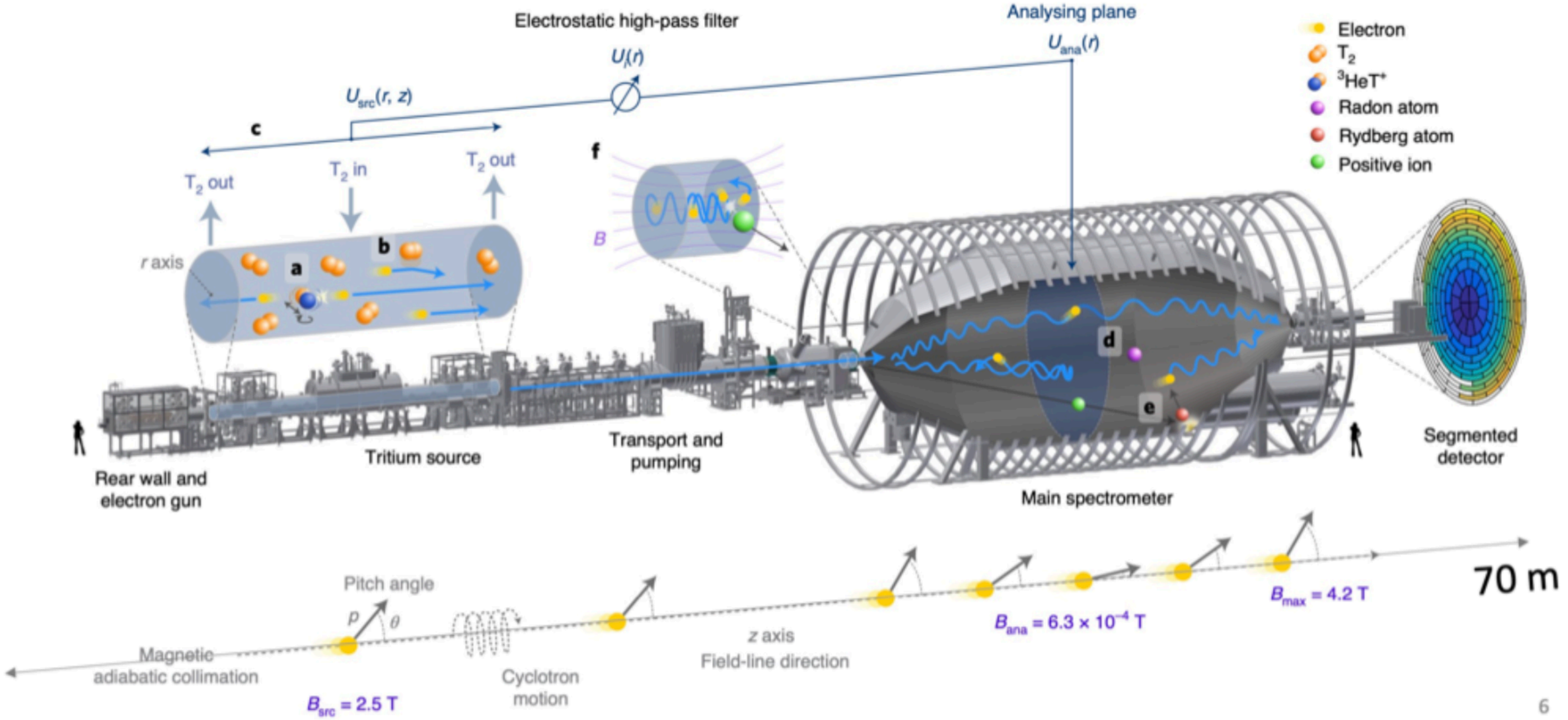


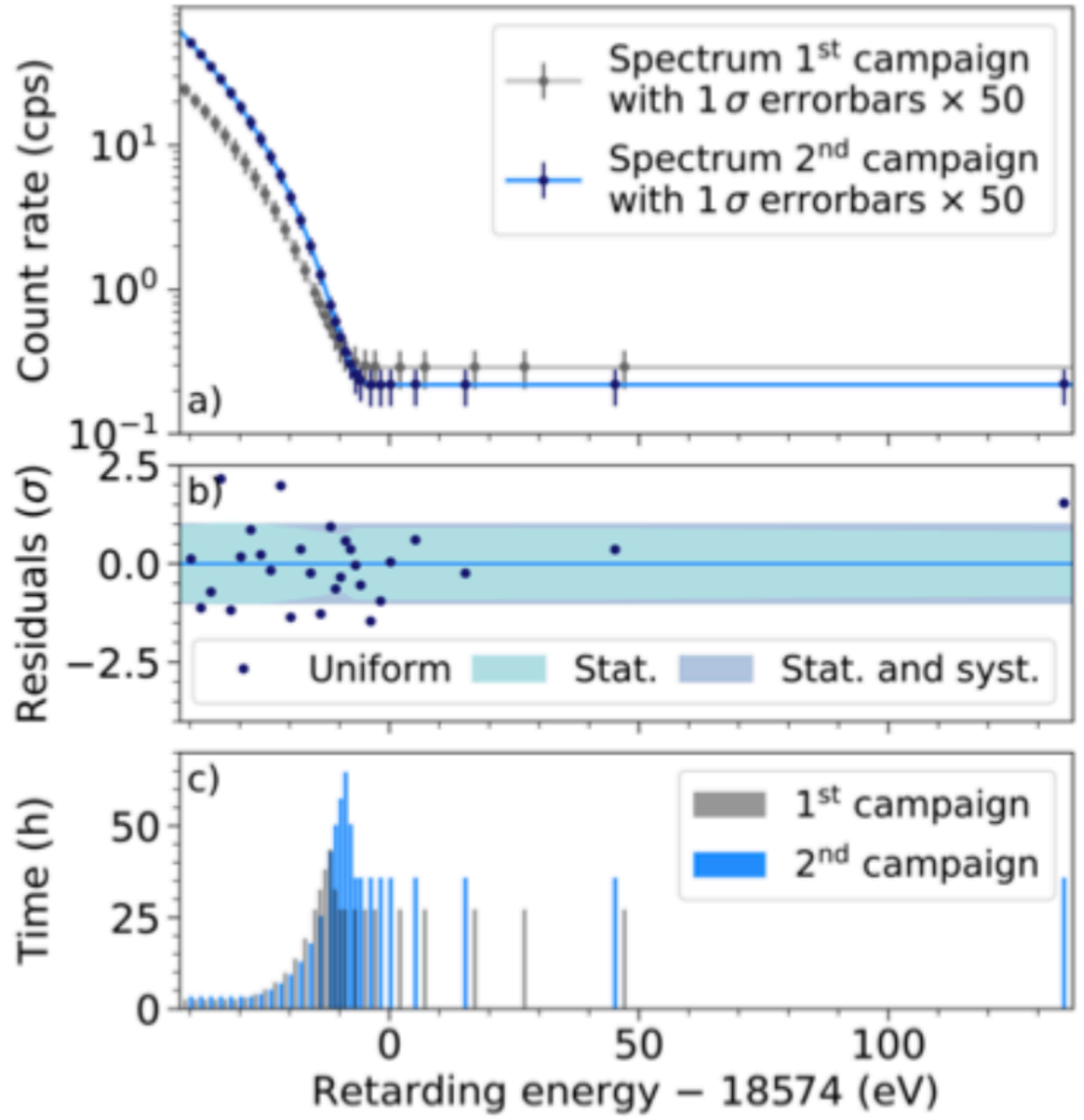
Accelerator neutrinos, up to O(100 GeV)

Cosmic neutrinos

Absolute Neutrino Mass

KATRIN Experiment





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

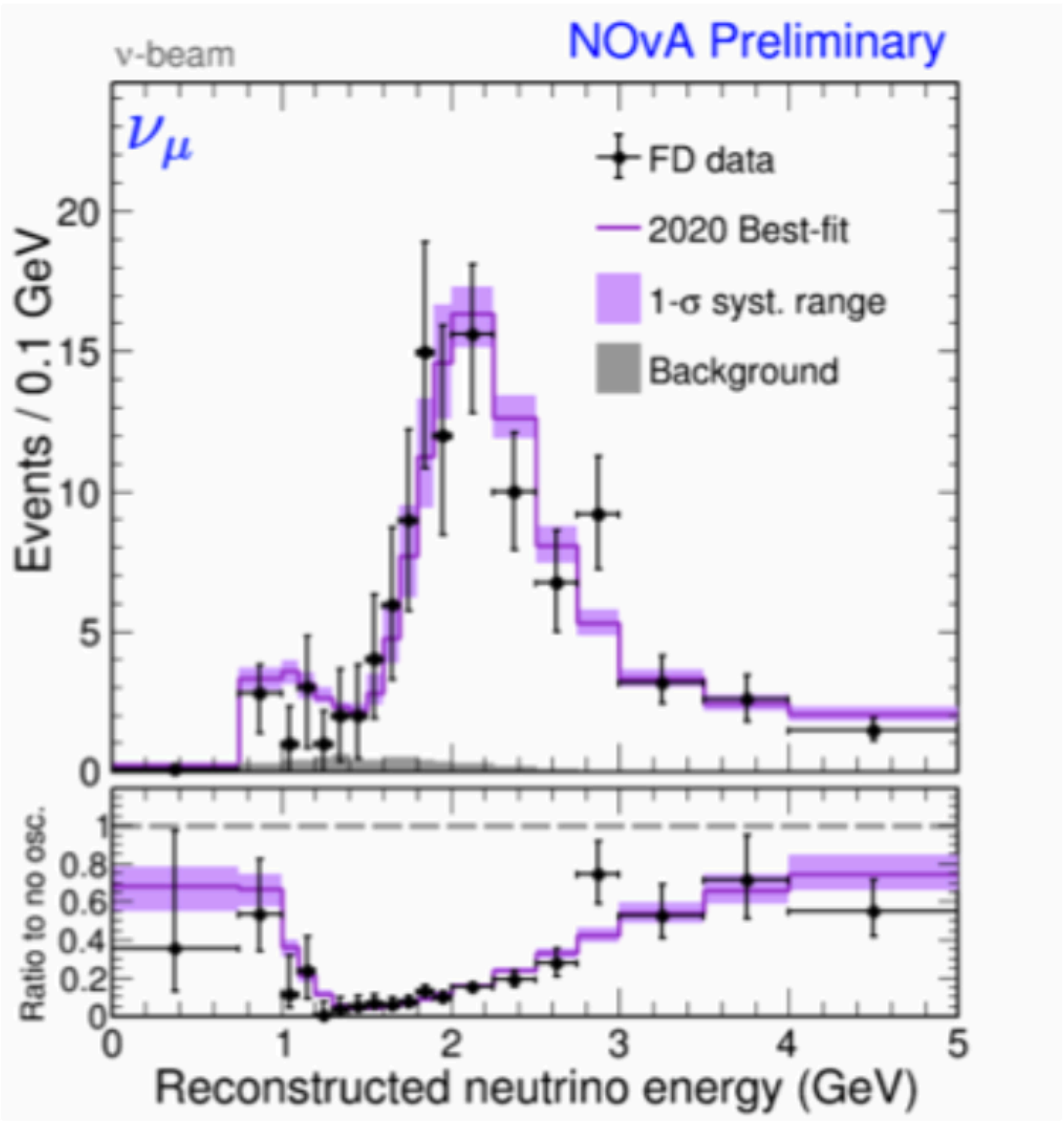
Absolute upper bound on neutrino mass!

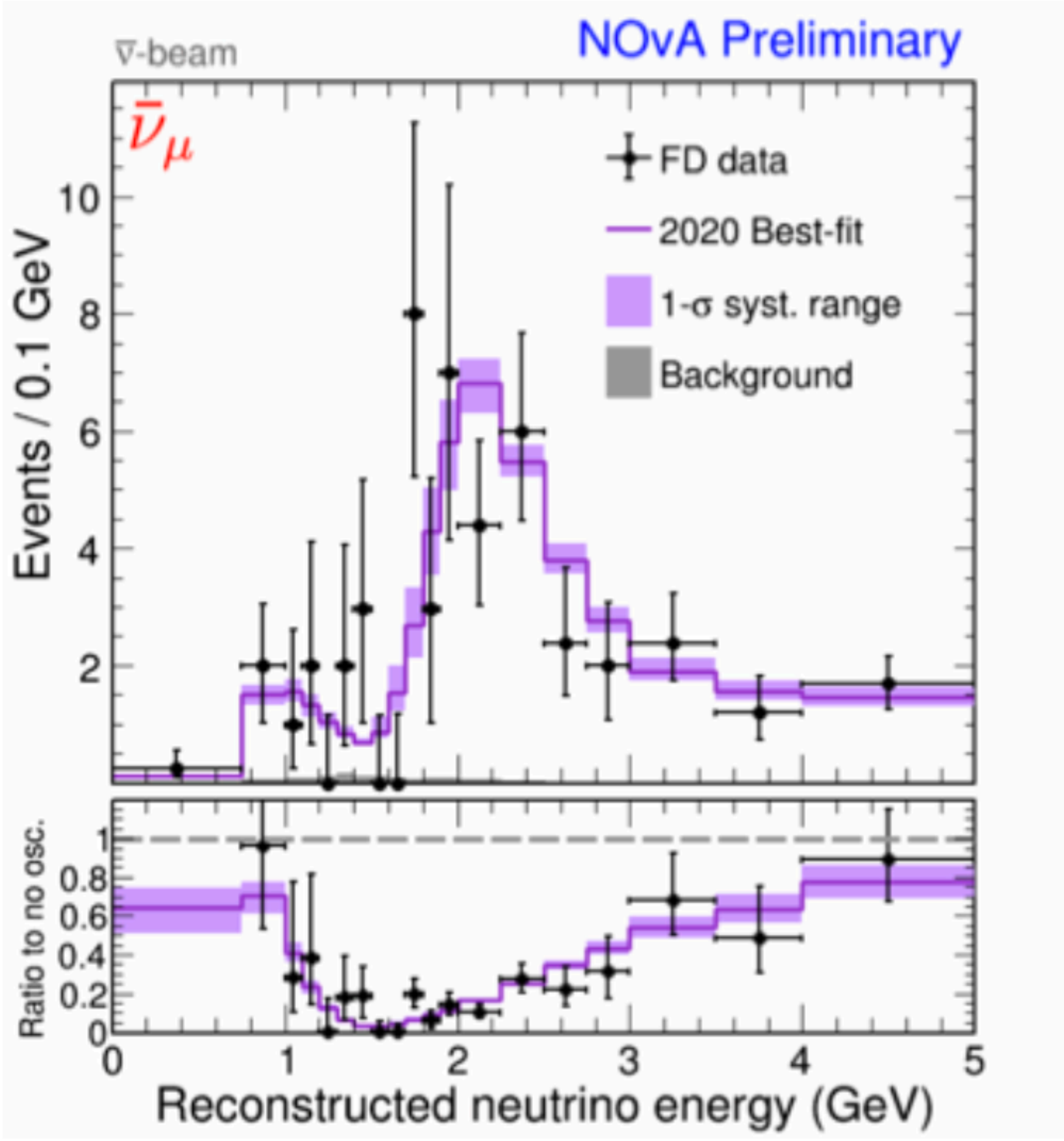
Combined result: $m_\nu < 0.8$ eV (90% CL)

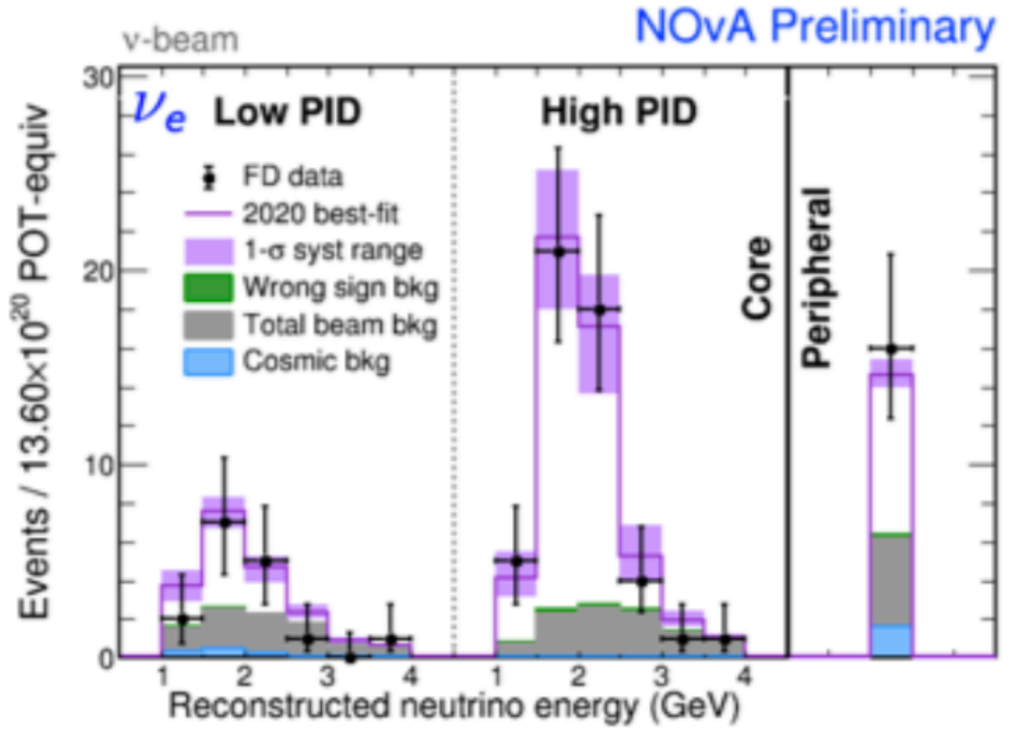
Limit dominated by statistics

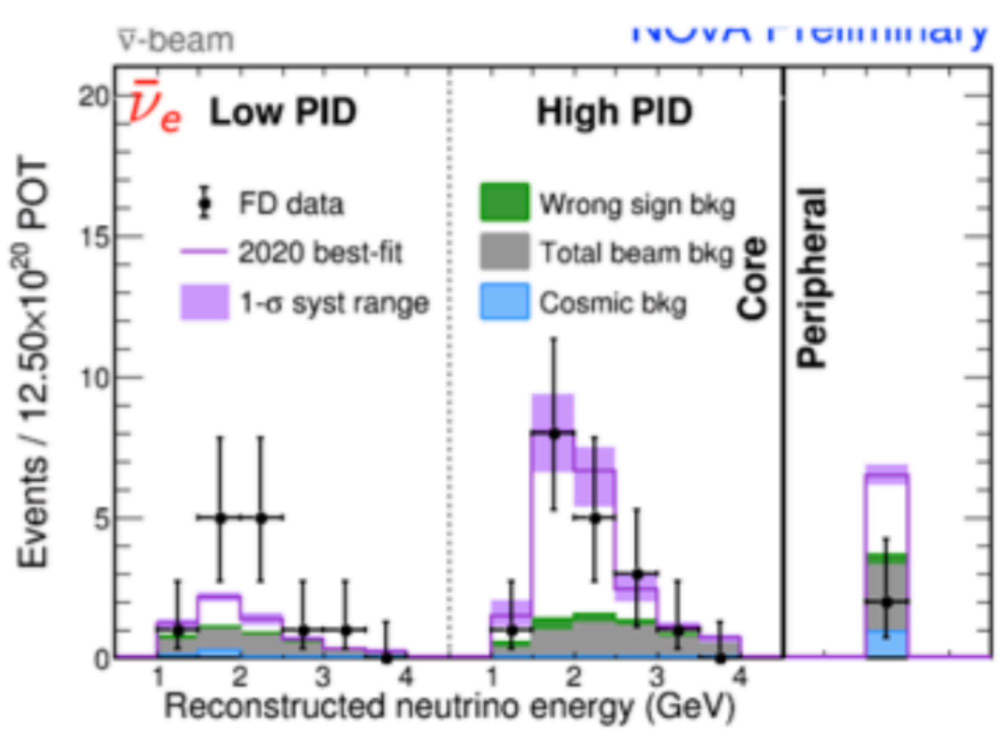
Accelerator Neutrinos

NOvA







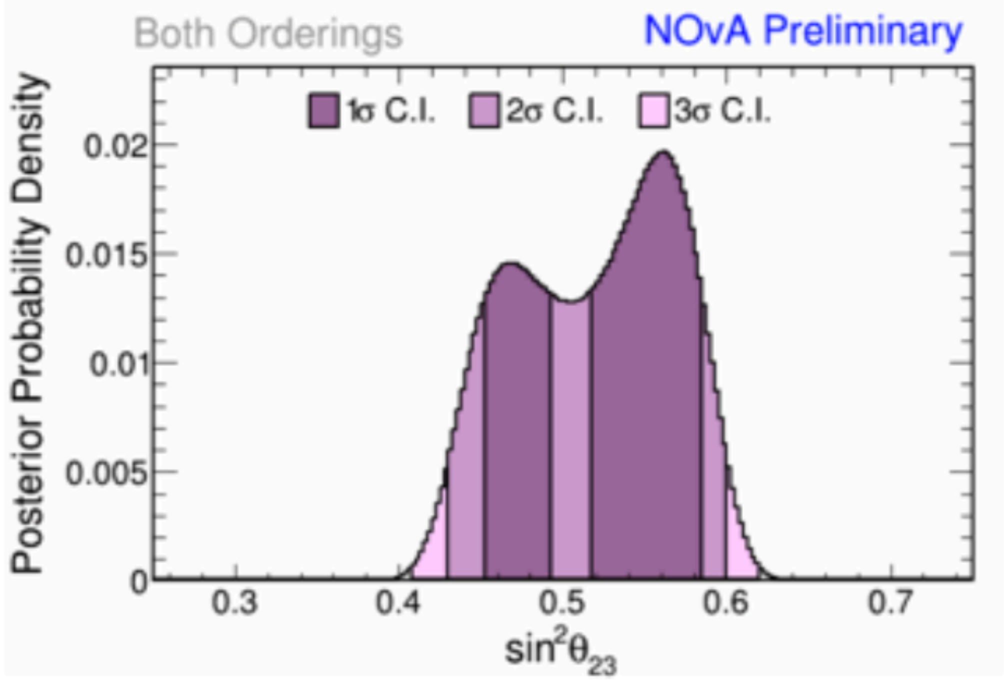


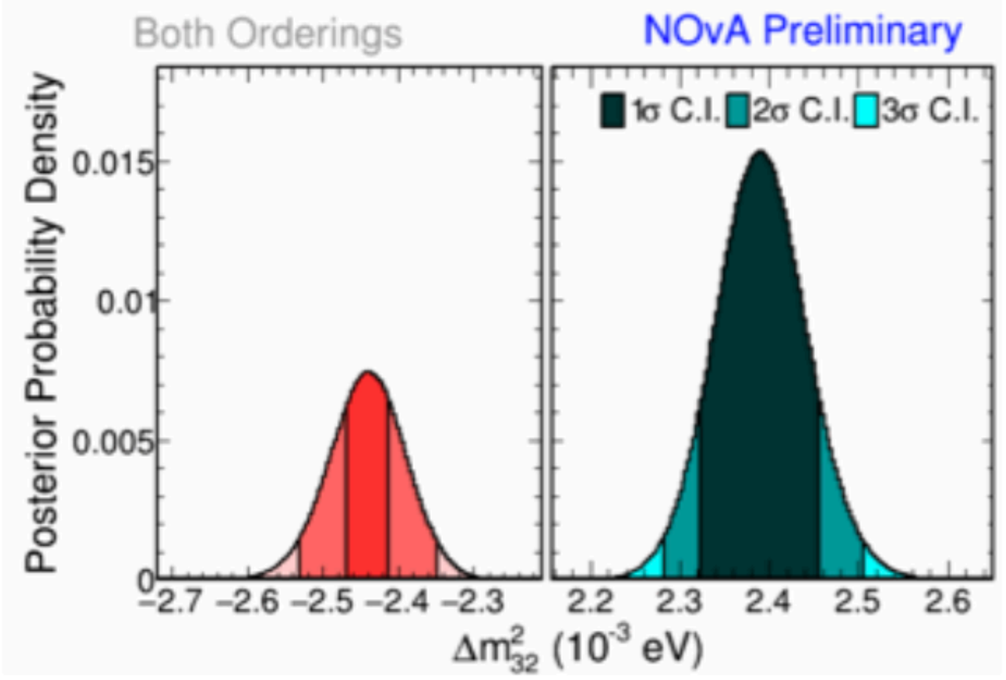
$> 4\,\sigma$ evidence of electron antineutrino appearance

- New analysis on the ~ 26×10^{20} POT collected up to 2020 (Bayesian analysis)
- 37×10^{20} POT neutrino data available now

New for Moriond EW 2023

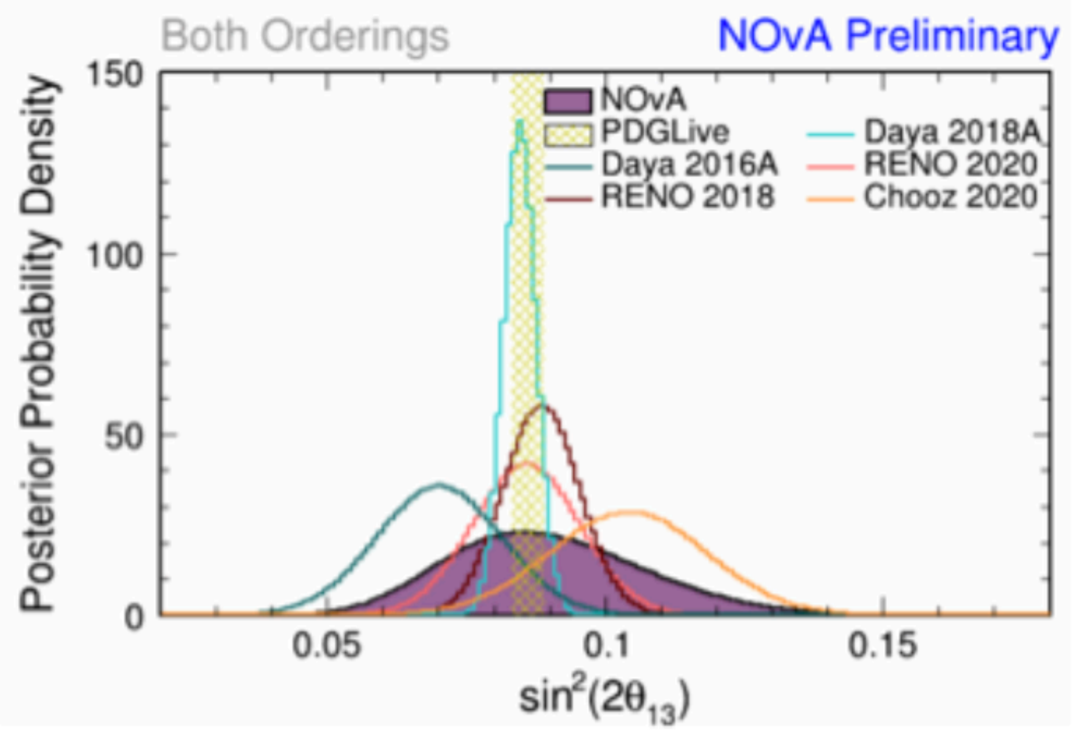
- Slight preference for upper octant and normal ordering





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

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



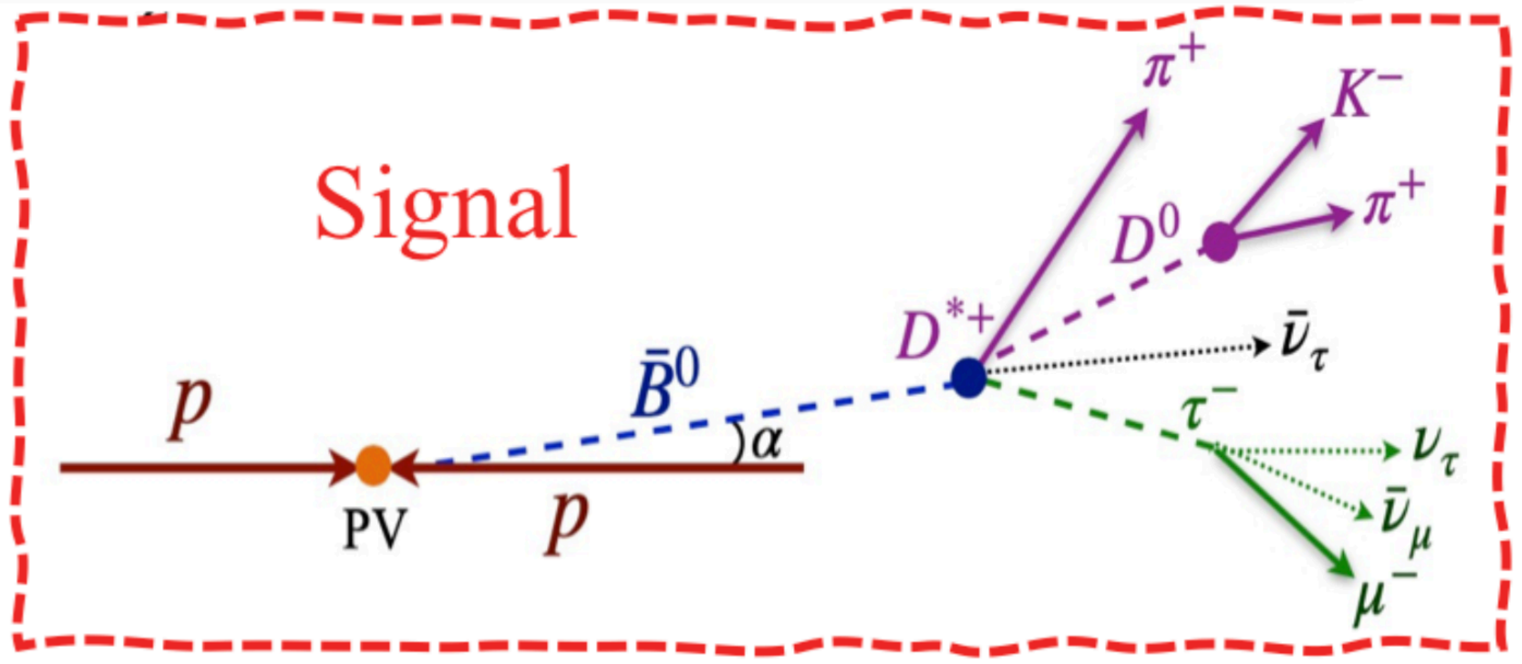
Impressive precision on θ_{13} nice to have frequentist cross check!

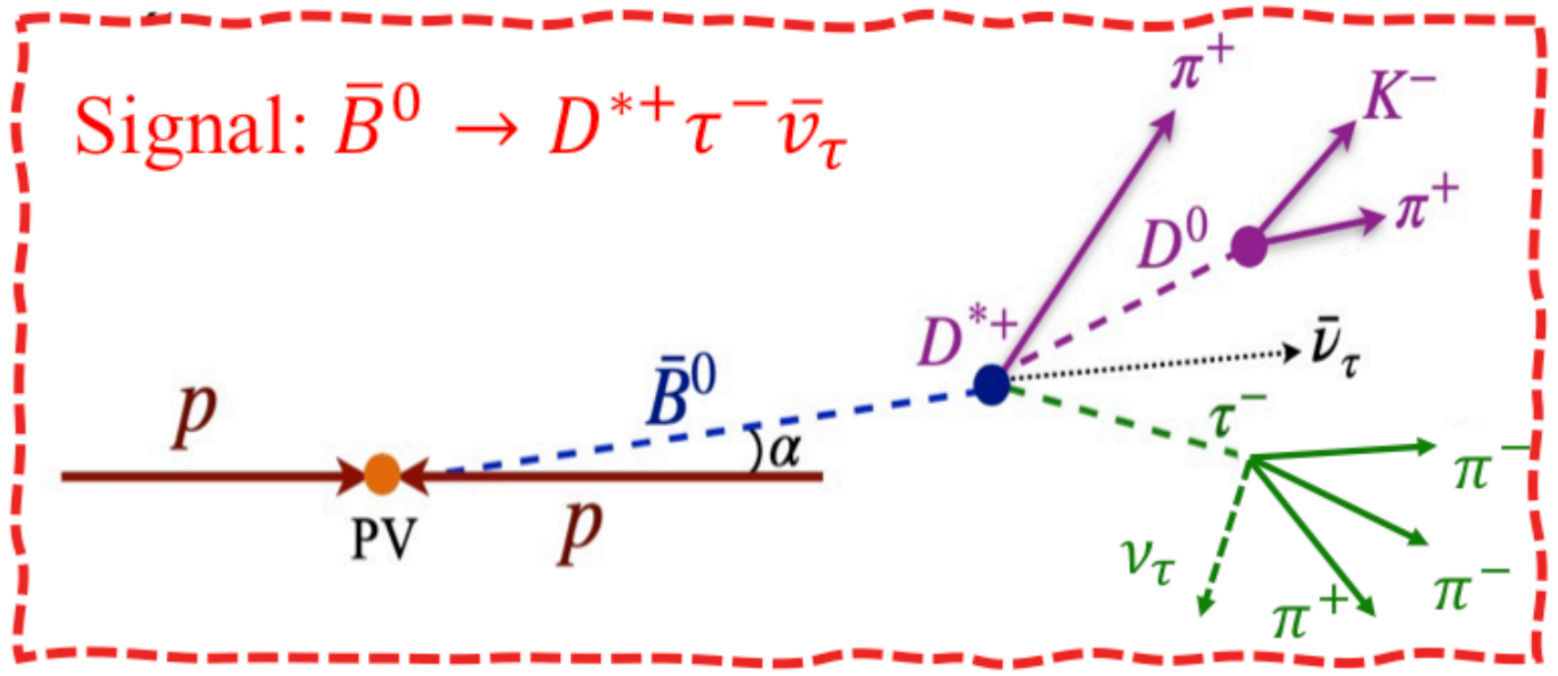
anomalias

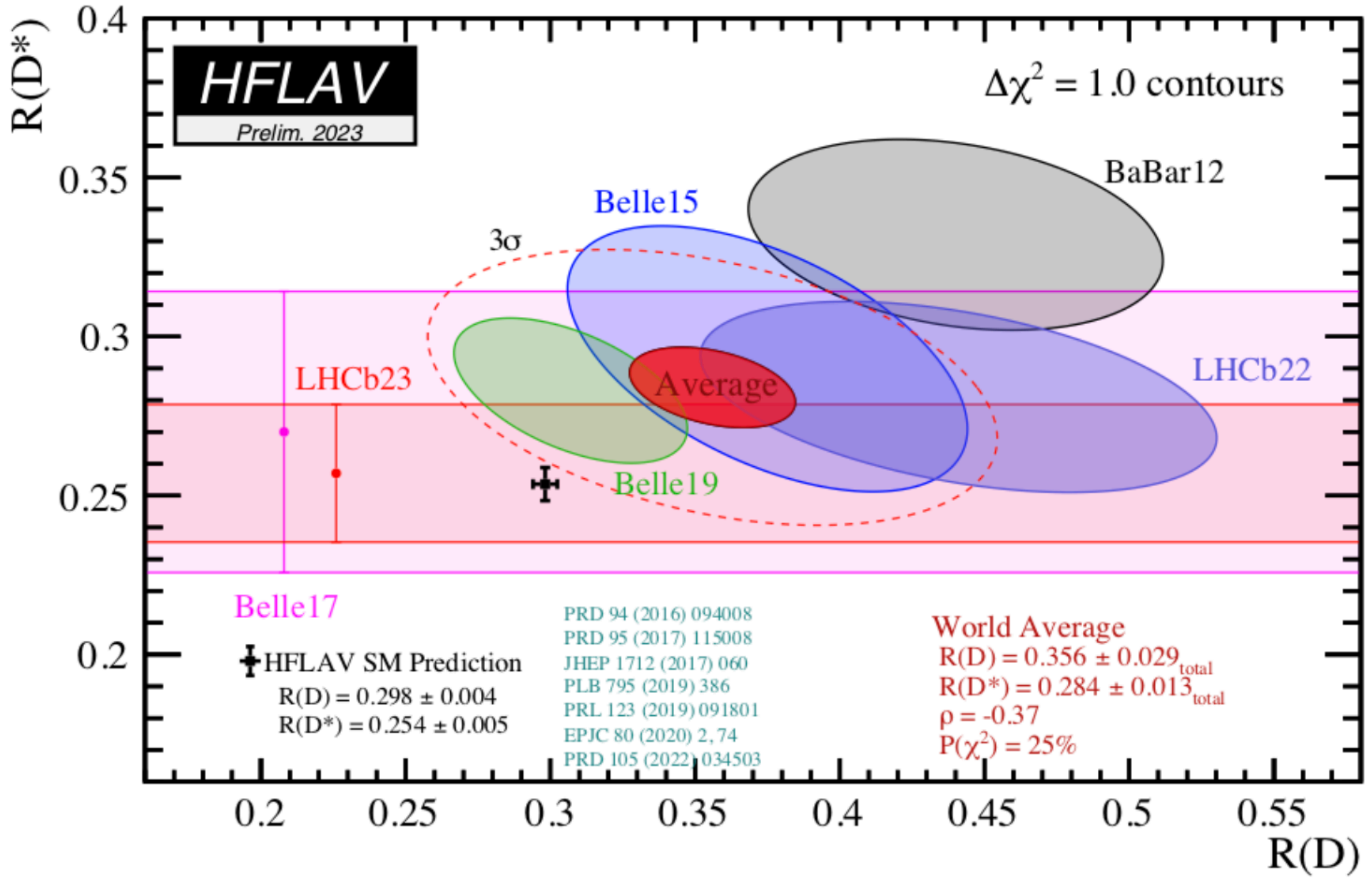
see last week's CERN seminar

$R(D^*)$ with hadronic τ decays

$$R(X_c) = \frac{BF(X_b \to X_c l \nu)}{BF(X_b \to X_c l' \nu)}$$

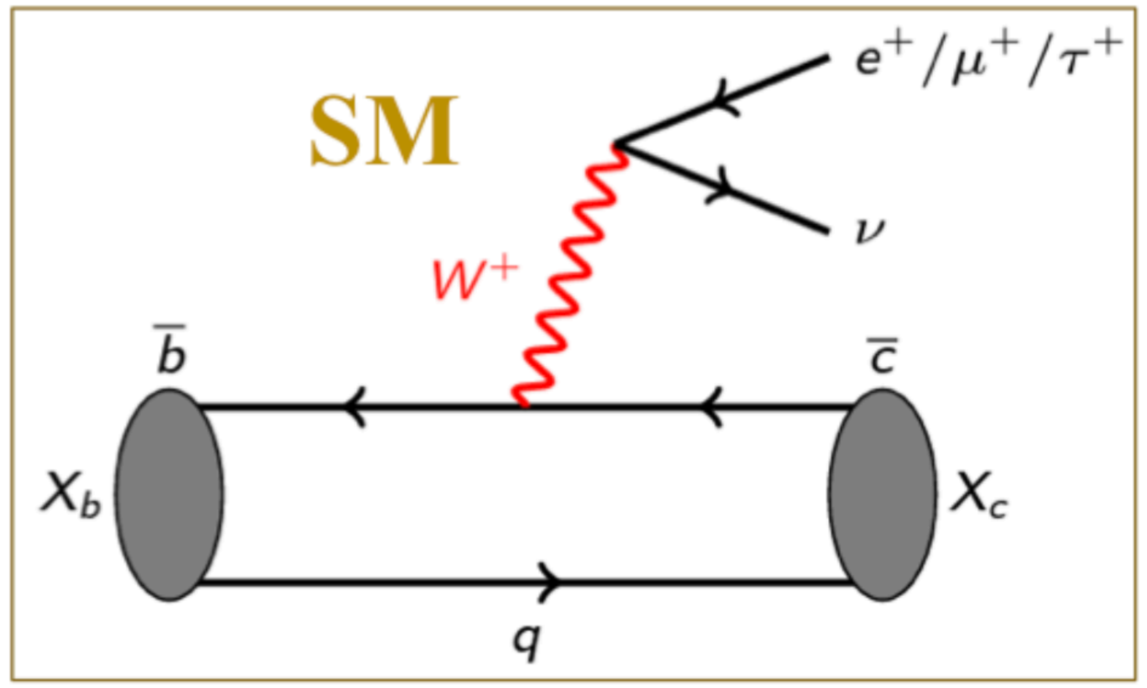


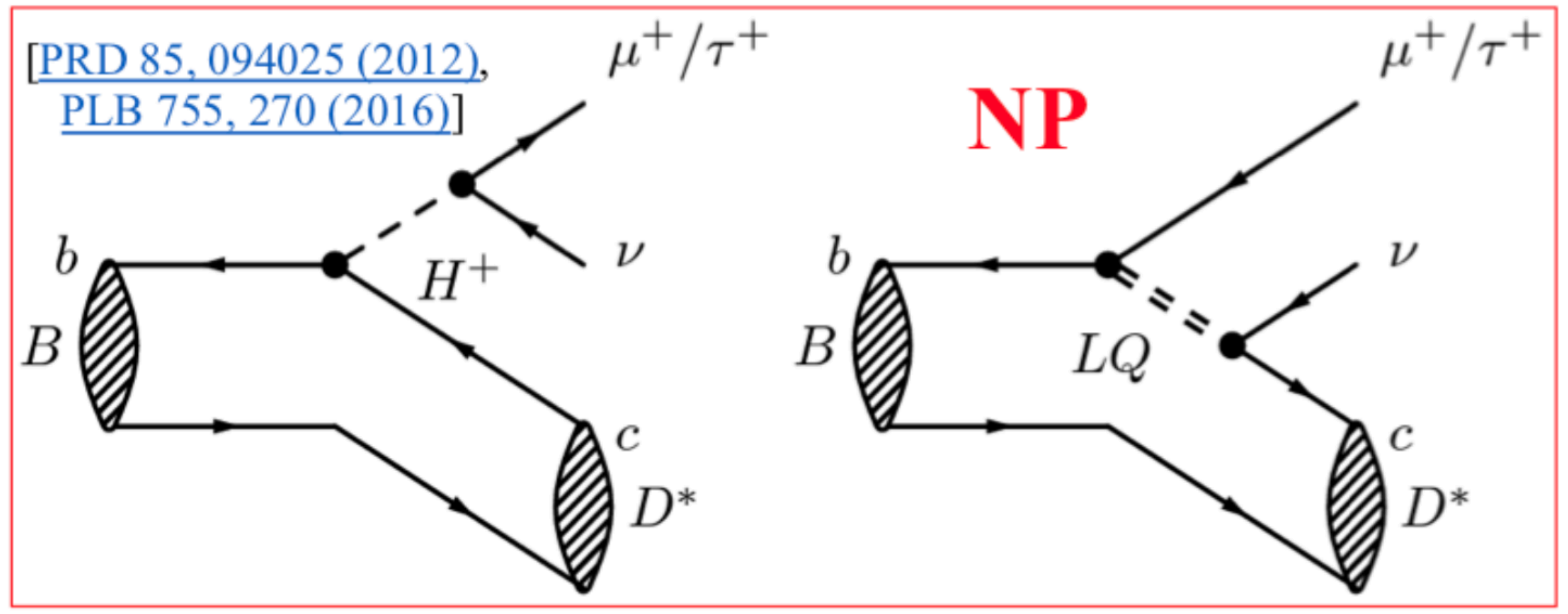




- Including this result, the world average becomes
  $R(D^*) = 0.284 \pm 0.013$; $R(D) = 0.356 \pm 0.029$ [HFLAV]
- The deviation w.r.t. the SM is at **3.2σ** for the combination of $R(D)$-$R(D^*)$

b→clv





R_K and R_{K^*} results

- Most precise test of Lepton Flavour Universality in $b \to s\ell^+\ell^-$ transitions
- Supersedes previous results
- Compatible with the SM at $0.2\,\sigma$ using a simple χ^2 test
- Statistical uncertainty dominates
- Scaling R_{K,K^*} with measured muon $\mathcal{B}$:
  [JHEP 06 (2014) 133] [JHEP 11 (2016) 047]

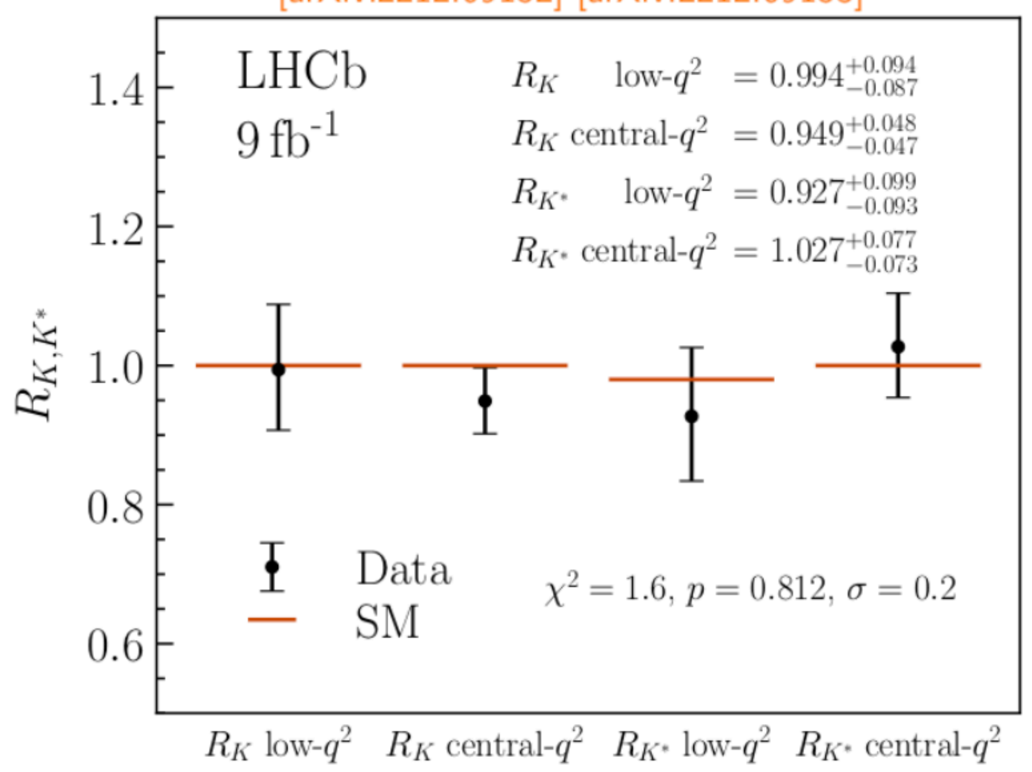
$$\frac{d\mathcal{B}(B^+ \to K^+e^+e^-)}{dq^2} = (25.5^{+1.3}_{-1.2} \pm 1.1) \times 10^{-9}\ \text{GeV}^{-2}$$

$$\frac{d\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{dq^2} = (33.3^{+2.7}_{-2.6} \pm 2.2) \times 10^{-9}\ \text{GeV}^{-2}$$

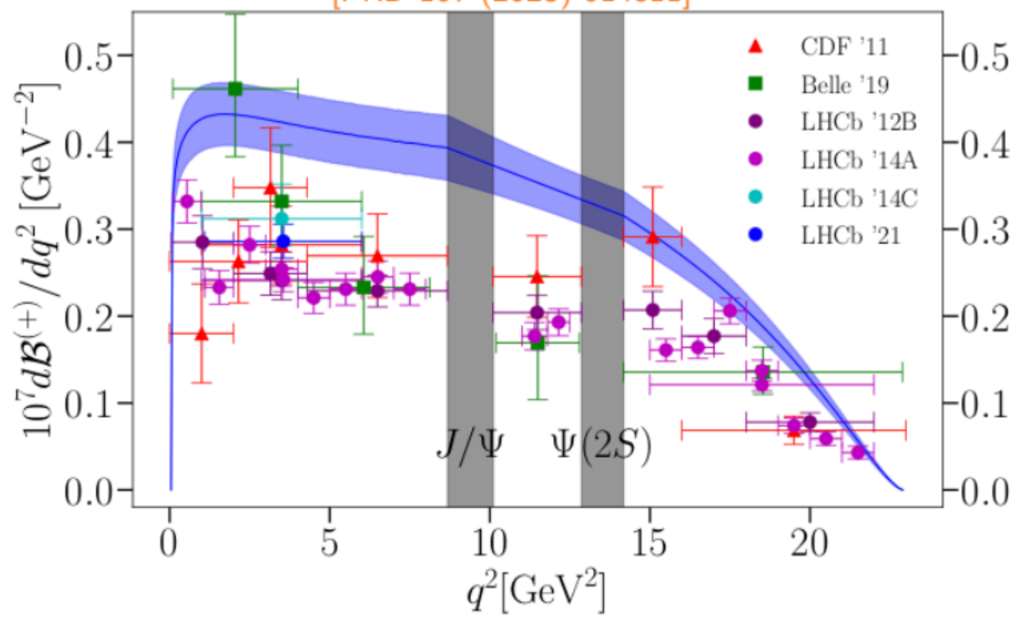
- Dedicated $\mathcal{B}$ measurements of ee modes and angular analyses ongoing

see also [talk by A. Snoch]

[arXiv:2212.09152] [arXiv:2212.09153]



[PRD 107 (2023) 014511]



b→sll

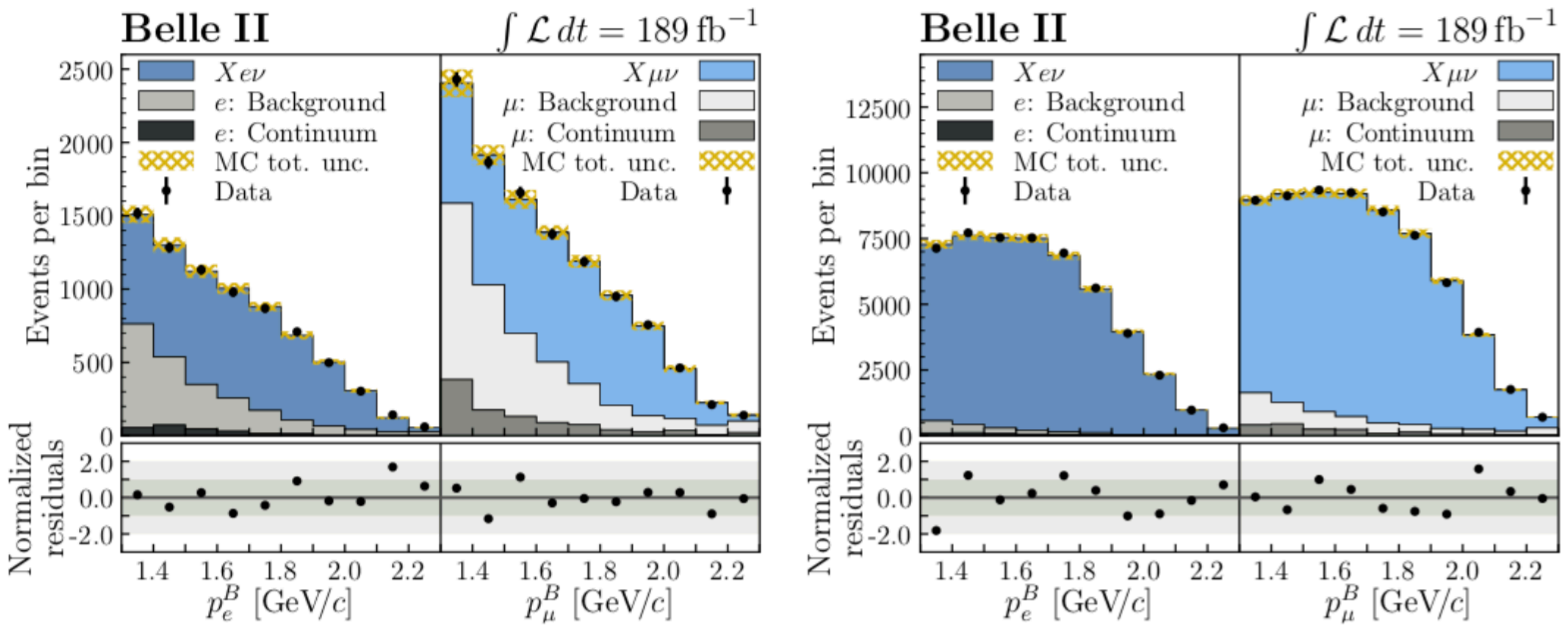
- $b \to s\ell\ell$ decays powerful probes of the SM
- Lepton Flavour Universality tests exhibit the most precise SM prediction in this area
- Data in excellent agreement with lepton flavour universality
- Tensions in muon branching fractions and angular analyses remain
- Measurement statistically limited
  $\to$ More precision needed
- Run 3 just started with brand new LHCb detector
- Will increase $\int \mathcal{L}dt$ by more than factor 5 during Runs 3–4, allowing for unprecedented reach with precision flavour observables

Light-Lepton Universality Test: $R(X_{e/\mu})$ Measurement

We tested light-lepton universality by $R(X_{e/\mu}) = \frac{\mathcal{B}(\bar{B} \to X e^- \bar{\nu}_e)}{\mathcal{B}(\bar{B} \to X \mu^- \bar{\nu}_\mu)}$ of the inclusive signal B modes through a fit on the lepton momentum in the B_{sig} rest frame, p_ℓ^B.

arXiv:2301.08266

Control channel ($B^0 B^0 / B^+ B^+$) Signal channel ($B^0 \bar{B}^0 / B^+ B^-$)



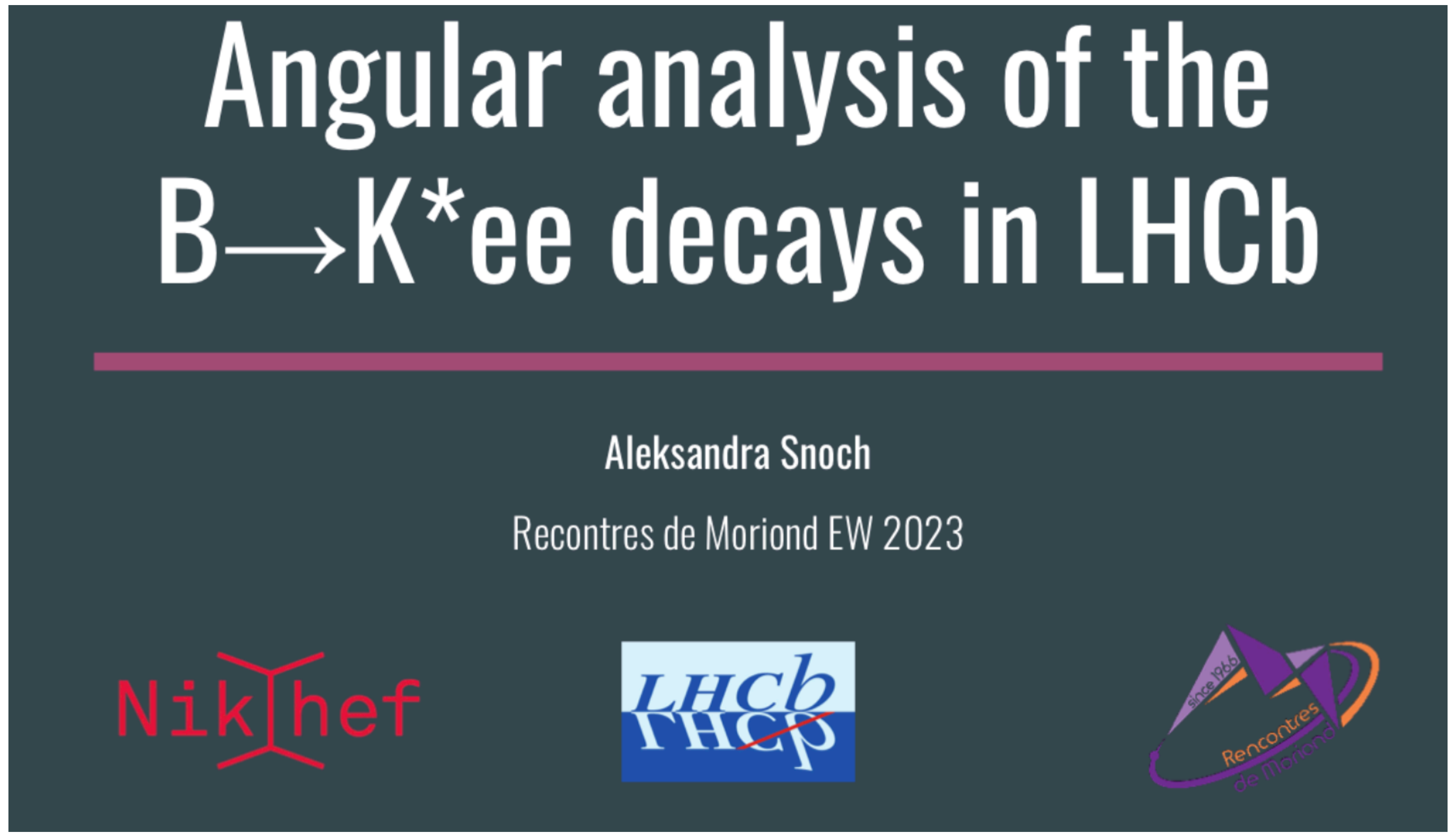
$$R(X_{e/\mu}) = 1.033 \pm 0.010\ (\mathrm{stat}) \pm 0.019\ (\mathrm{syst})$$

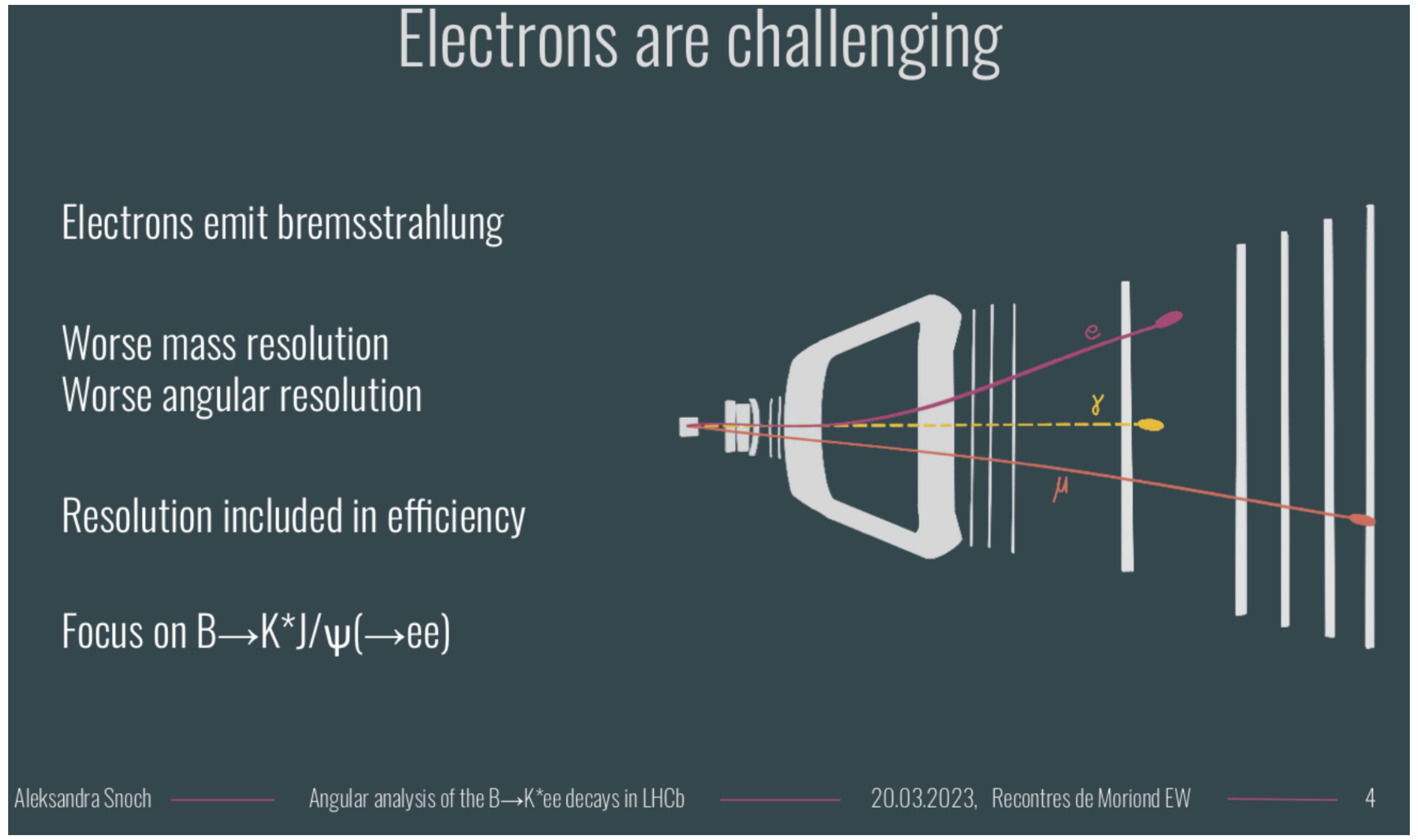
First branching-fraction based e-μ universality test using inclusive semi-leptonic B decays

The most precise test of e-μ universality of semi-leptonic B decays

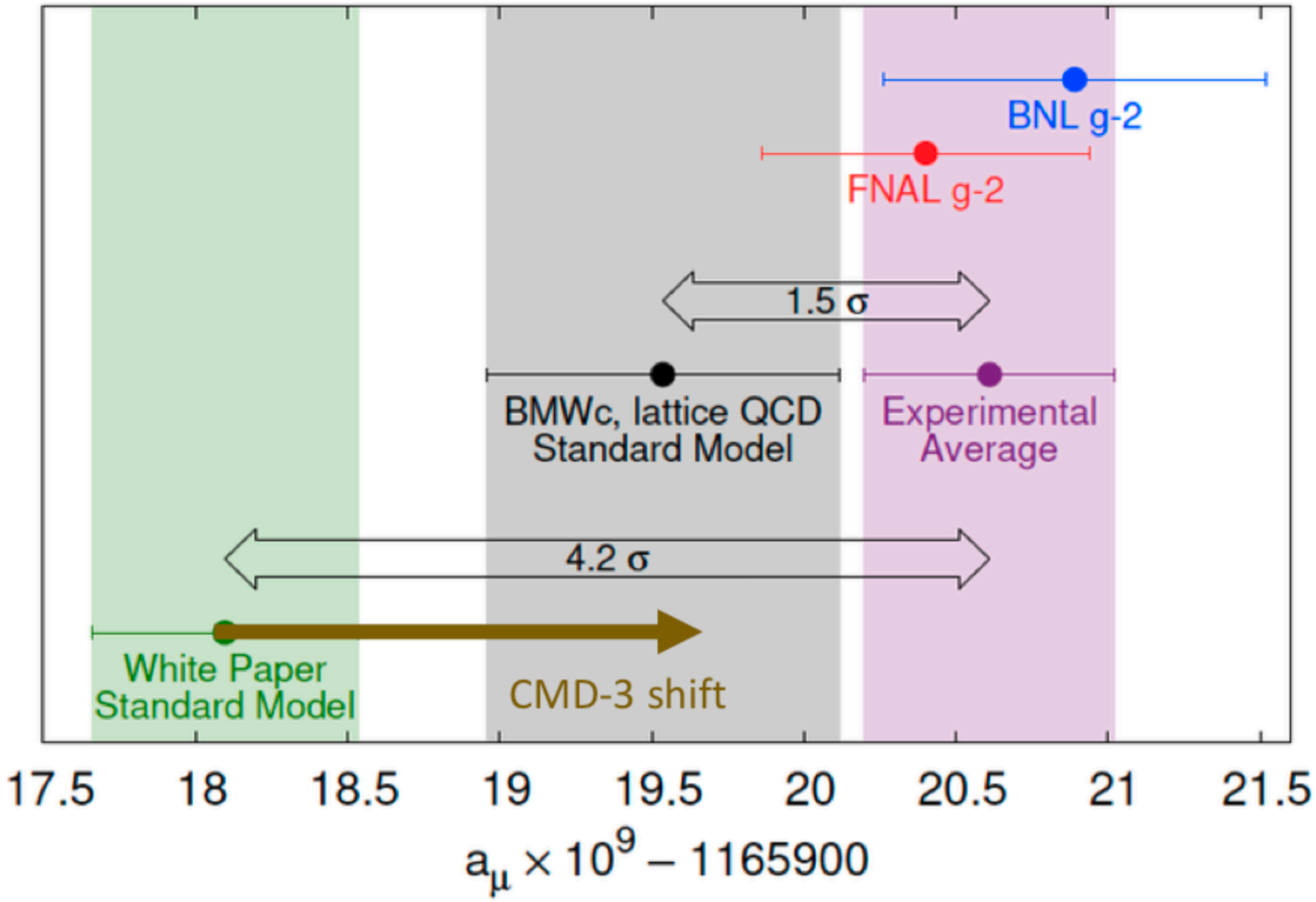
Consistent with SM $R(X_{e/\mu})_{\mathrm{SM}}$ [1] by 1.2σ and the exclusive Belle $R(D^*{}_{e/\mu})$ [2],[3].

[1] J. High Energy Phys. **11**, 007 (2022), [2] Phys. Rev. D **100**, 052007 (2019), [3] arXiv:2301.07529





The Muon g-2 puzzle



Towards solving the puzzle

New experimental determinations of a_μ are more than welcome!

JPARC is coming up, but like BNL/FNAL it could be affected by « environmental » NP effects, *e.g.* [Davoudiasl-Szafron hep-ph/2210.14959] [Agrawal et al. hep-ph/2210.17547]

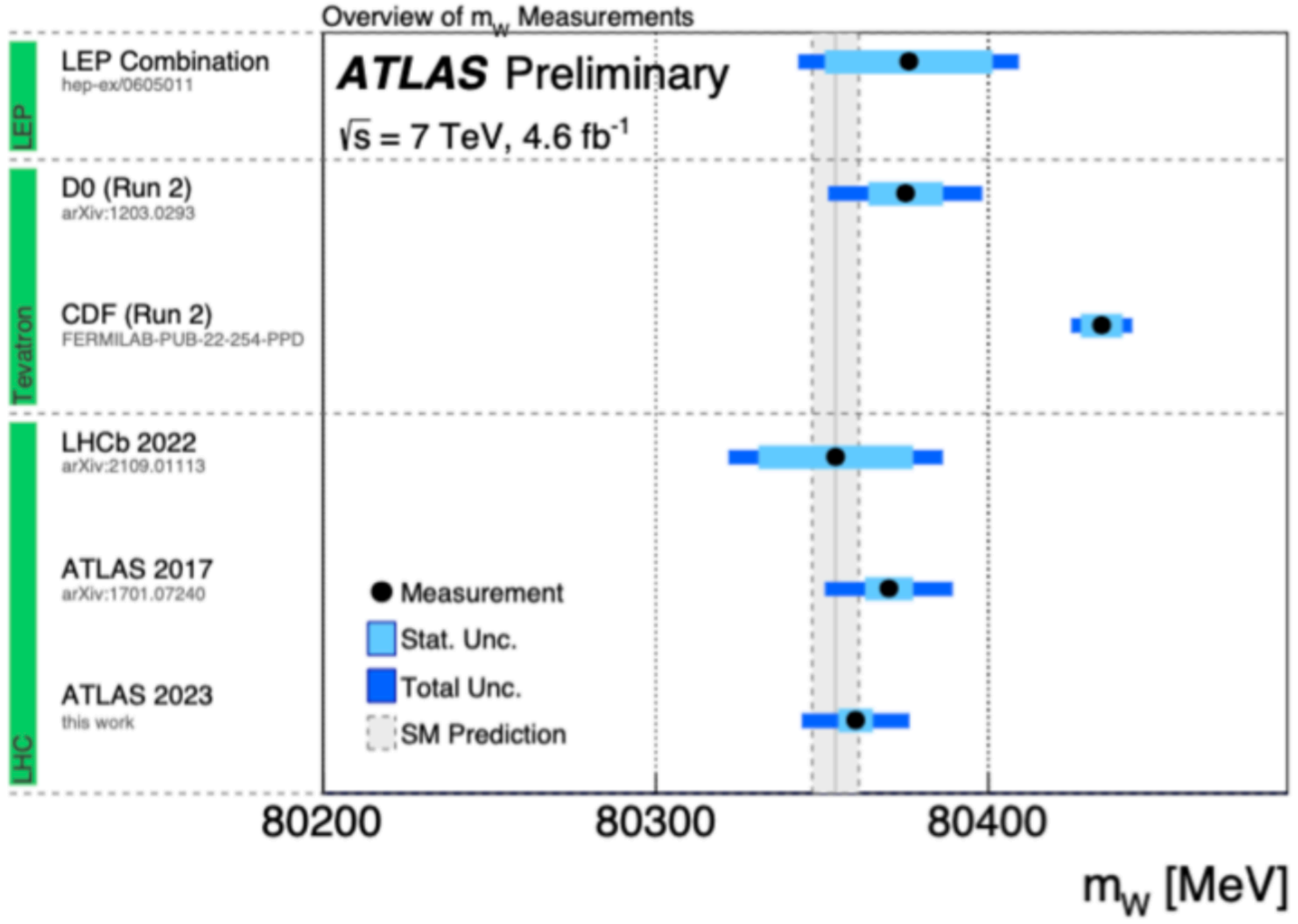
MUonE will measure HVP directly, should be clean from NP, see *e.g.* [Masiero-Paradisi-Passera PRD 2020]

Muonium spectroscopy in <10yrs will offer another test at 1ppm!

W Mass Update - ATLAS

New for Moriond EW 2023

Observed shift 10 MeV and precision improved by 16 MeV!



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

m_W = 80370 ±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!

And a fresh excess (released last Friday)

last^2

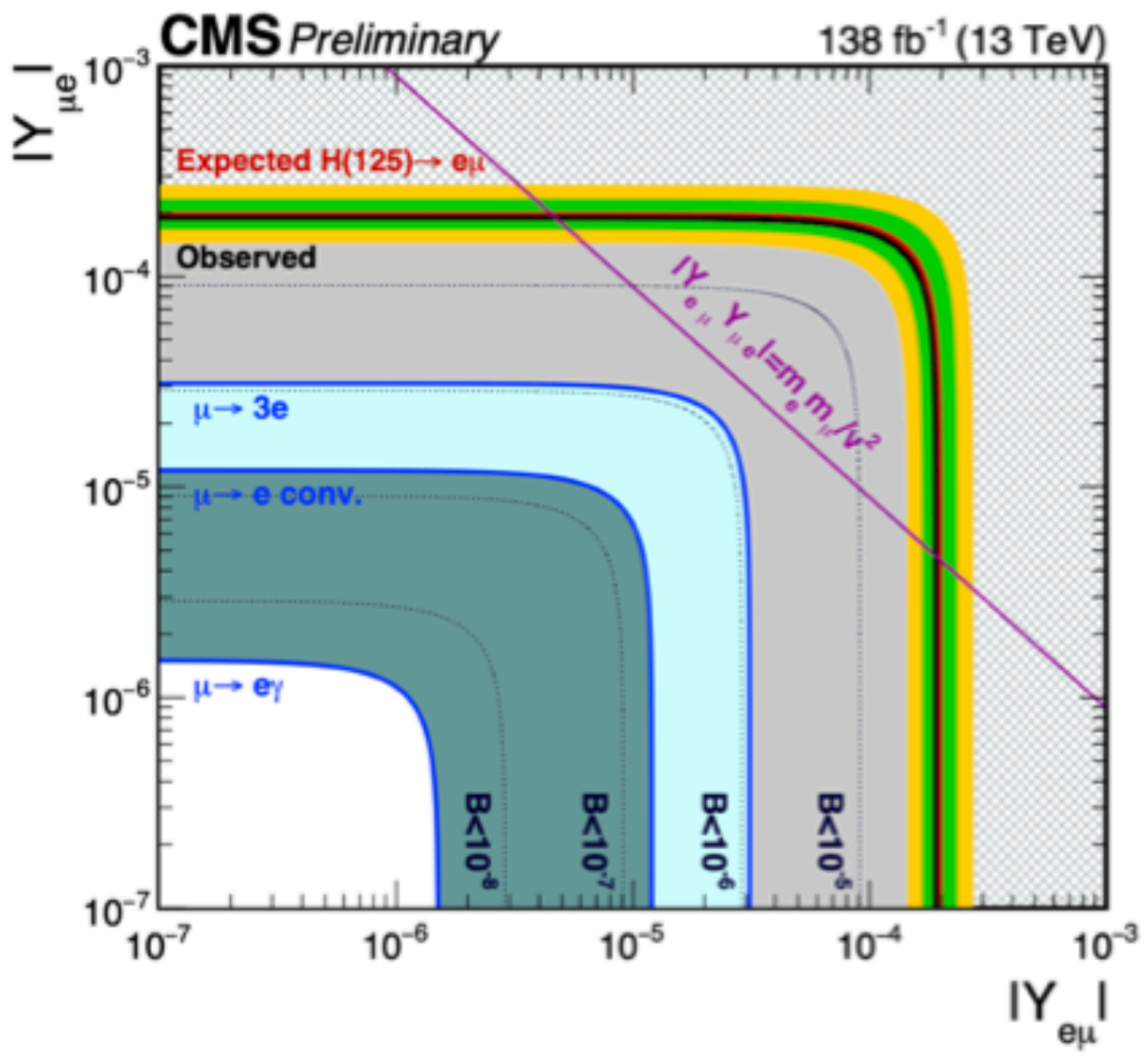
Search for lepton-flavour violating decay of a Higgs boson to an eμ pair

HIG-22-002

➡ most stringent indirect limit on B(H(125) → eμ) from null result of μ → eγ: < 10−8

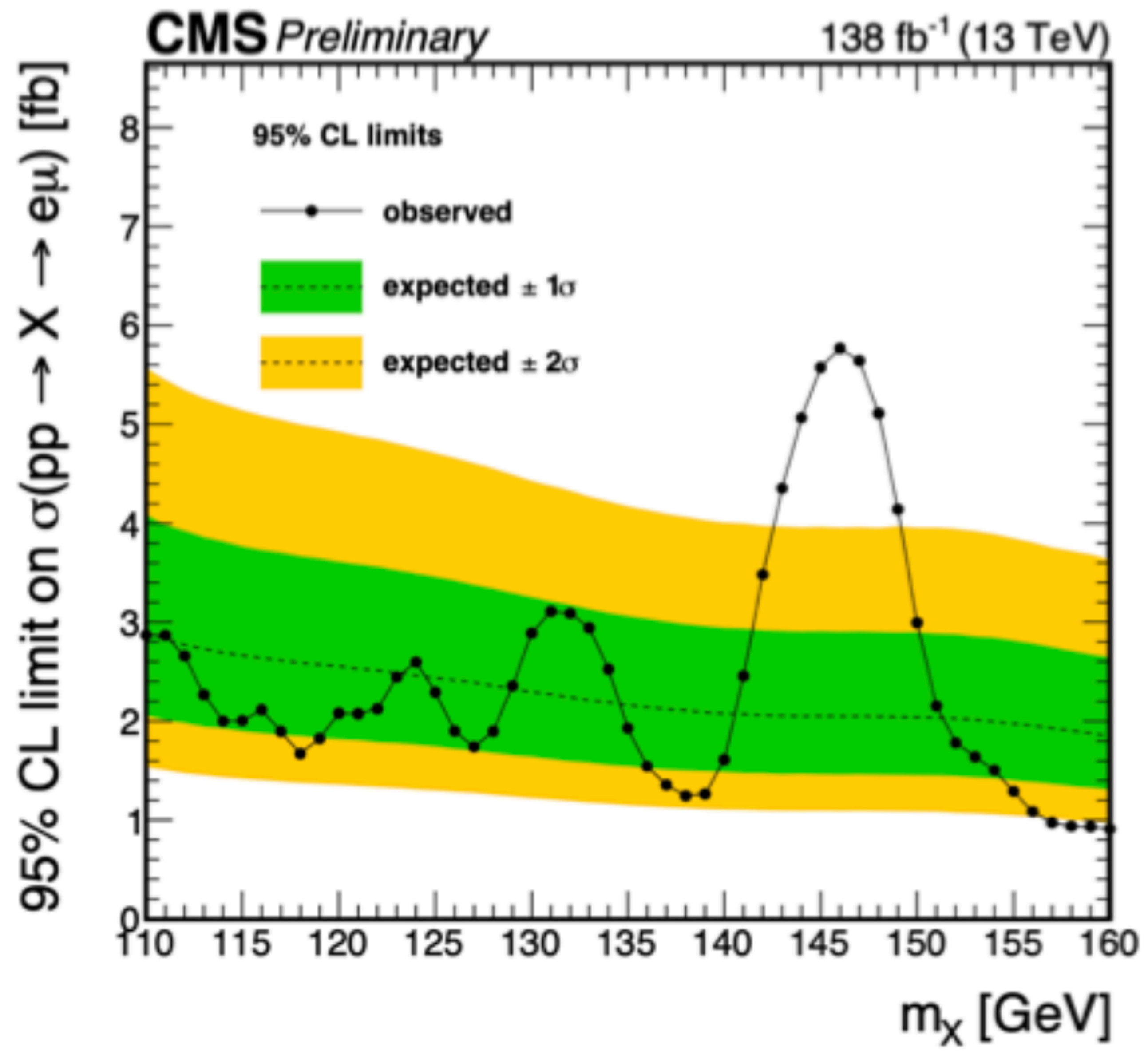
Observed (expected) upper limit on the branching fraction for 125 GeV Higgs boson:

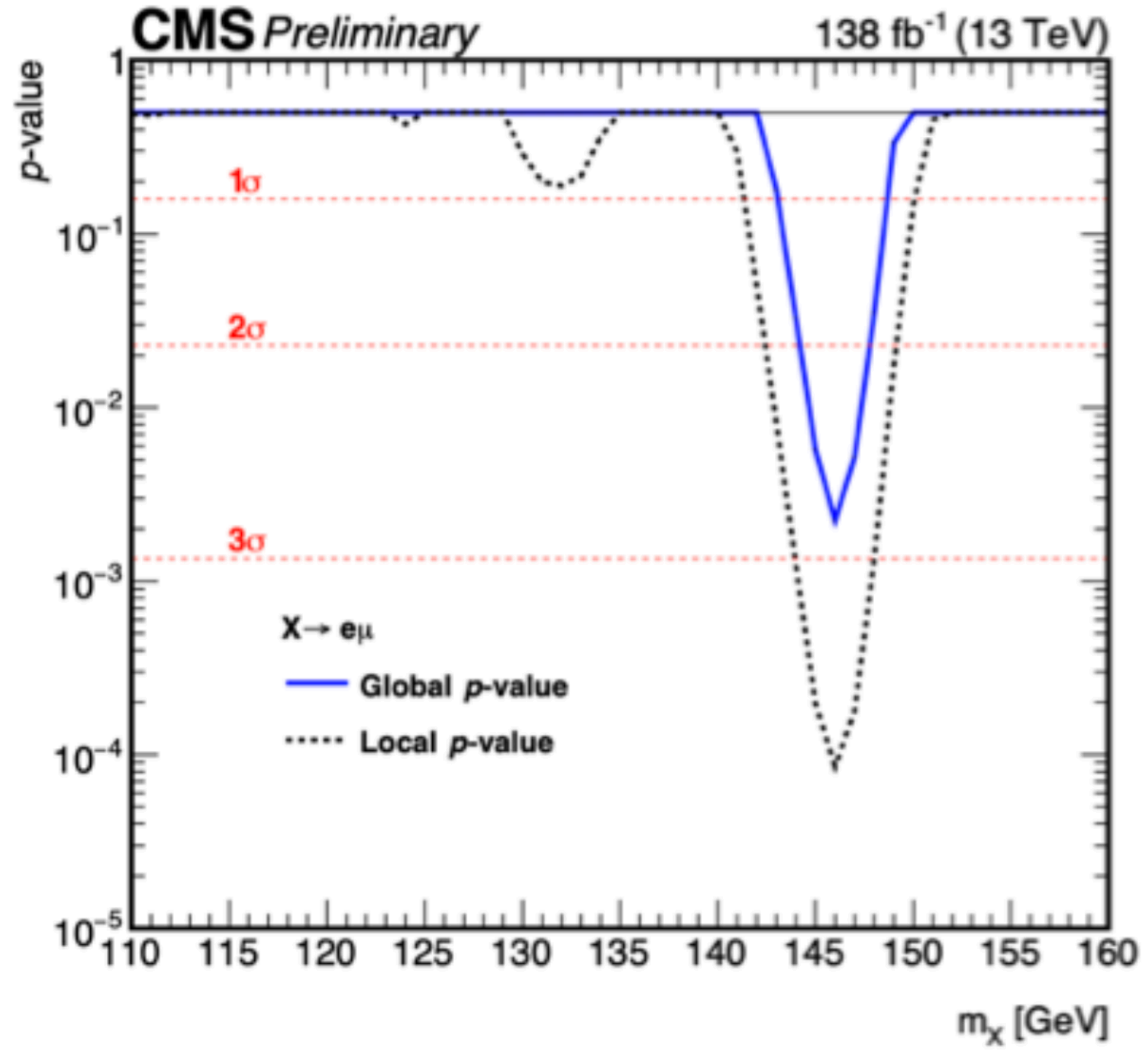
4.4 × 10−5 (4.7 × 10−5) at 95% CL



Observed excess of events around 146 GeV

global (local) significance of 2.8 (3.8) standard deviations

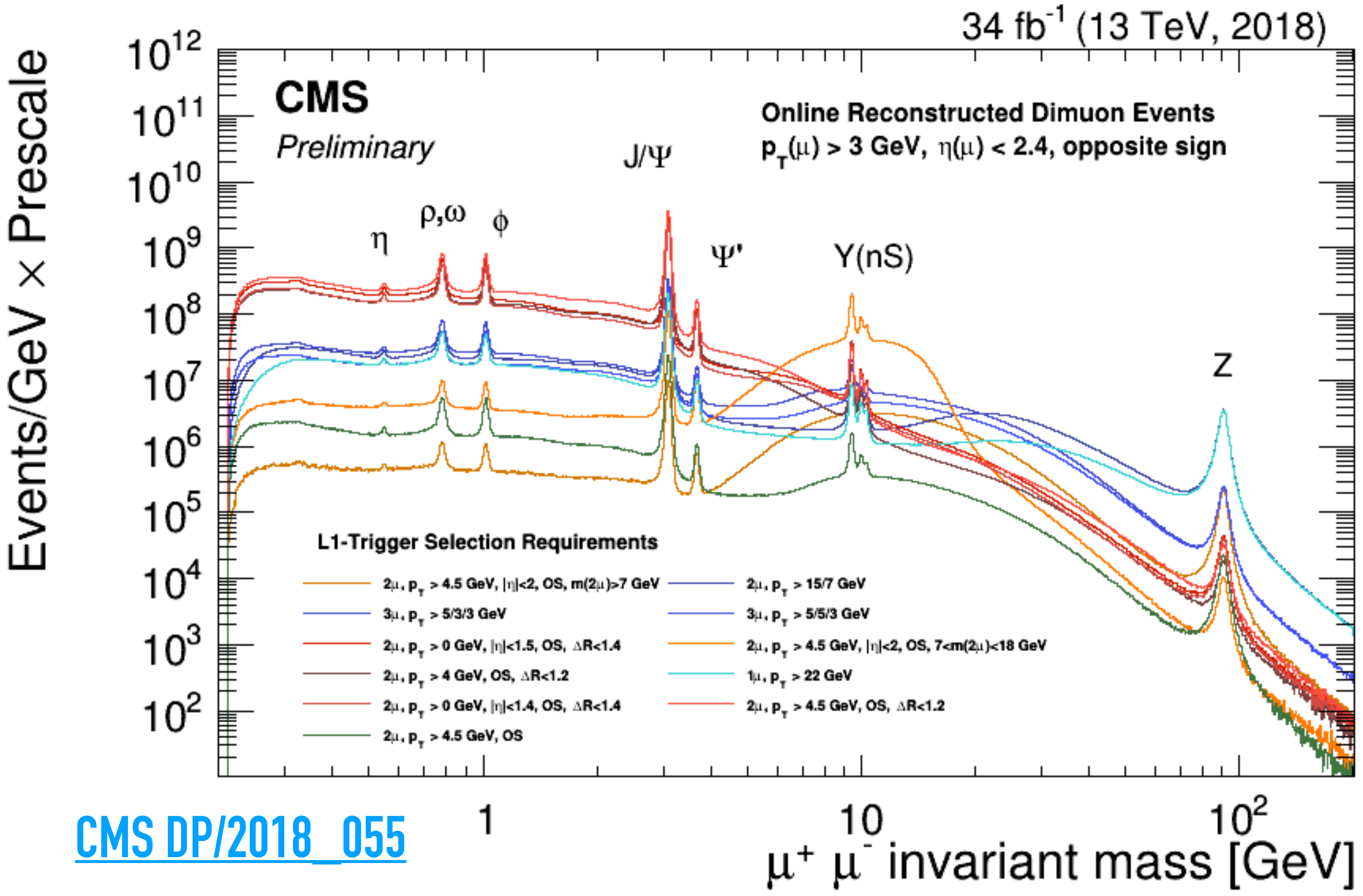




excess not corroborated by ATLAS …

CMS

novel data-taking paradigms



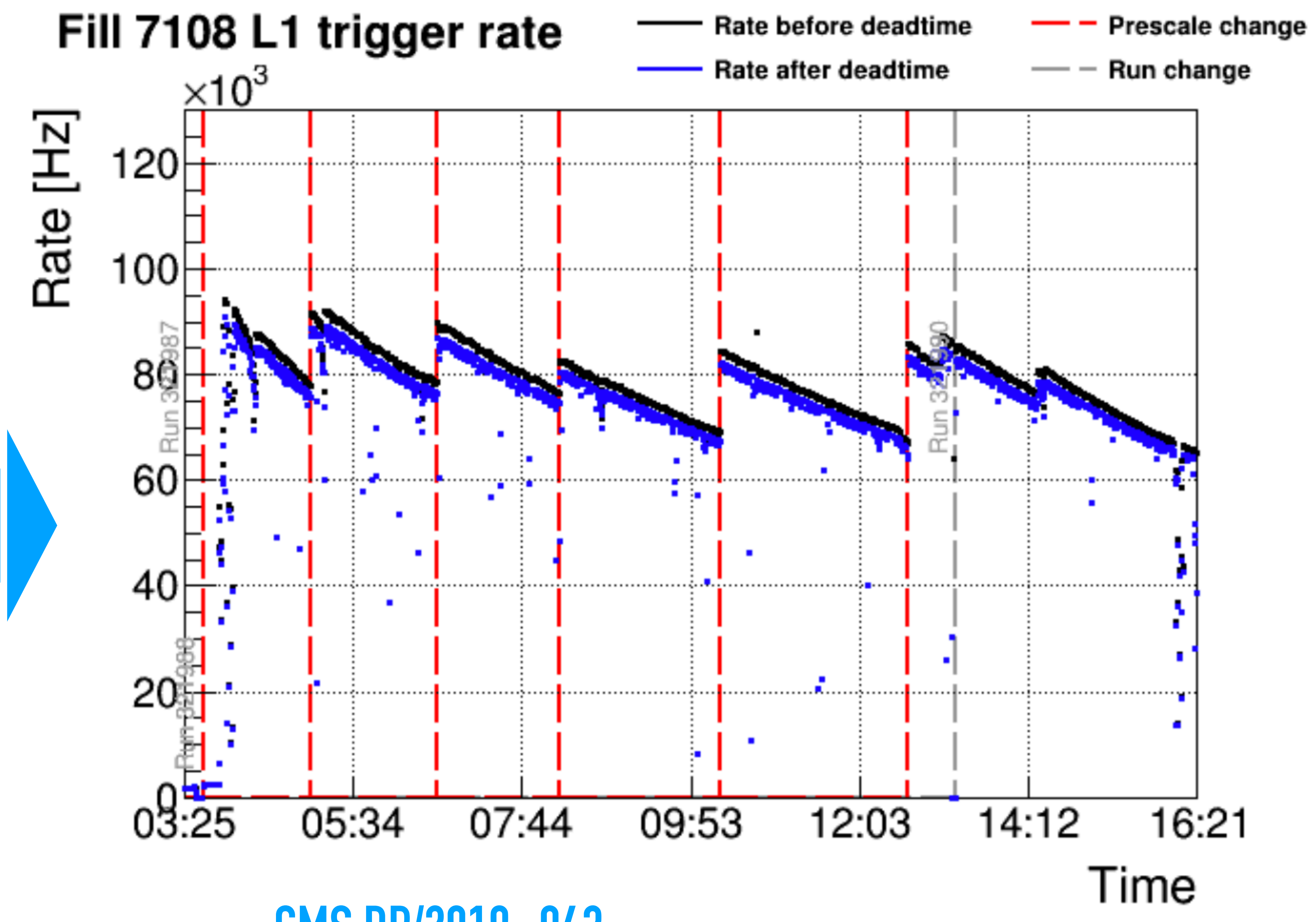
CMS DP/2018_055

Data Scouting

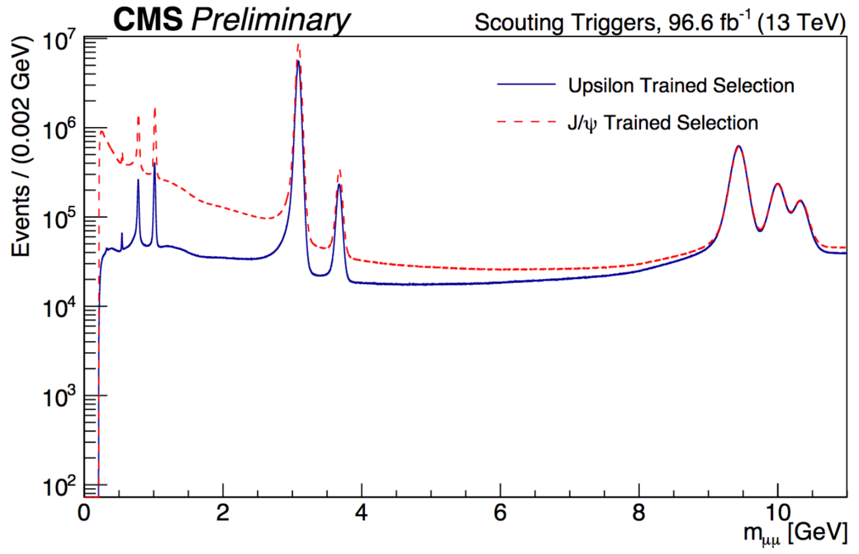
Save reduced event content e.g. HLT only

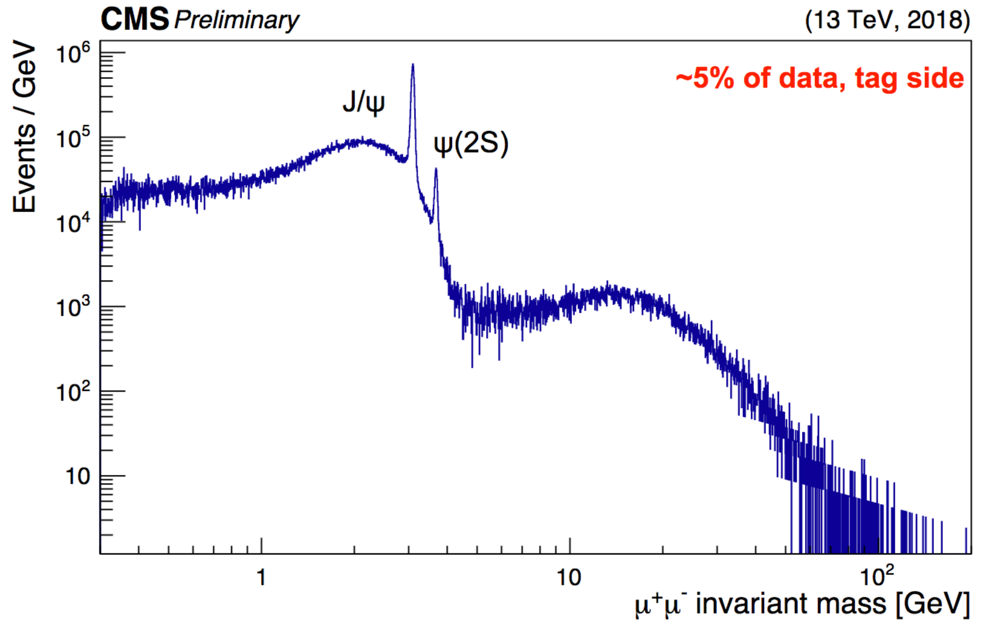
Data Parking

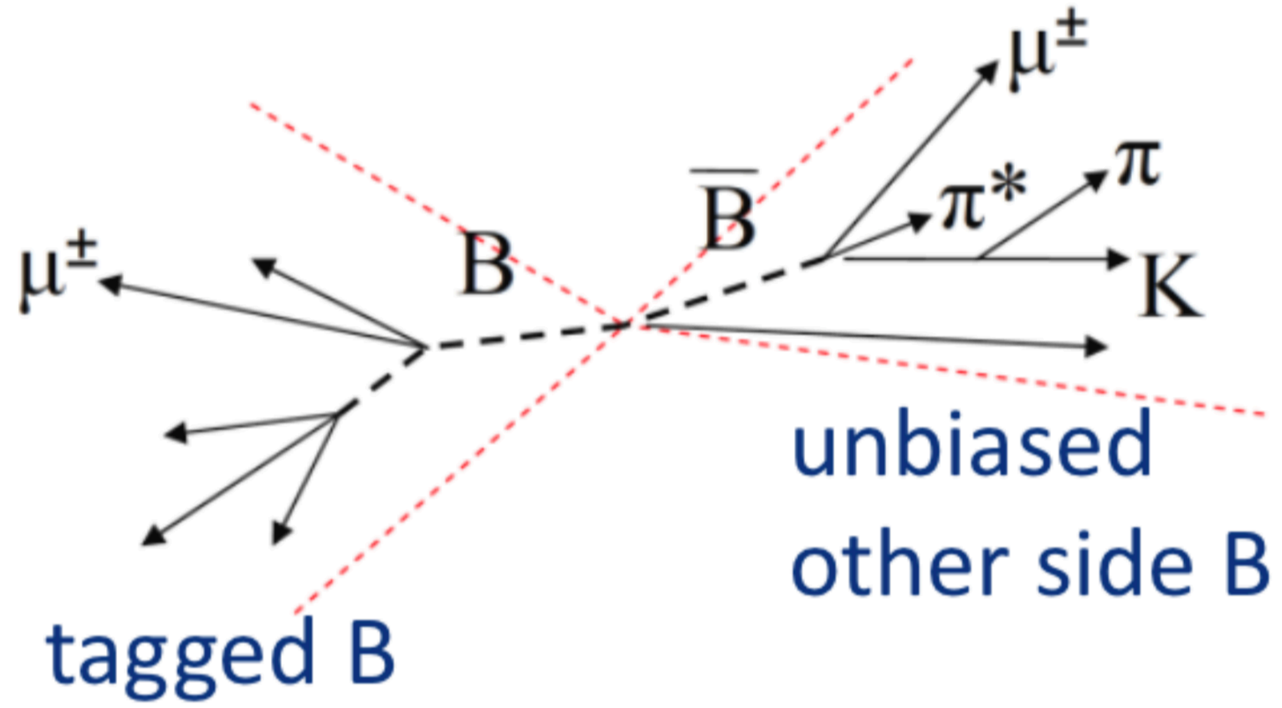
Park RAW data, postpone RECO



CMS DP/2019_043



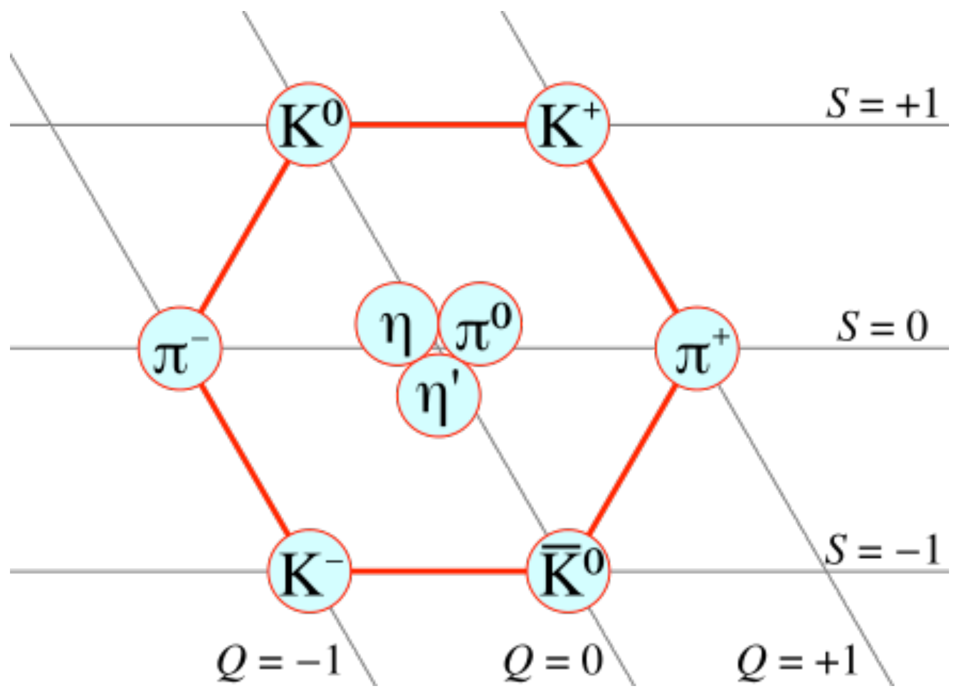




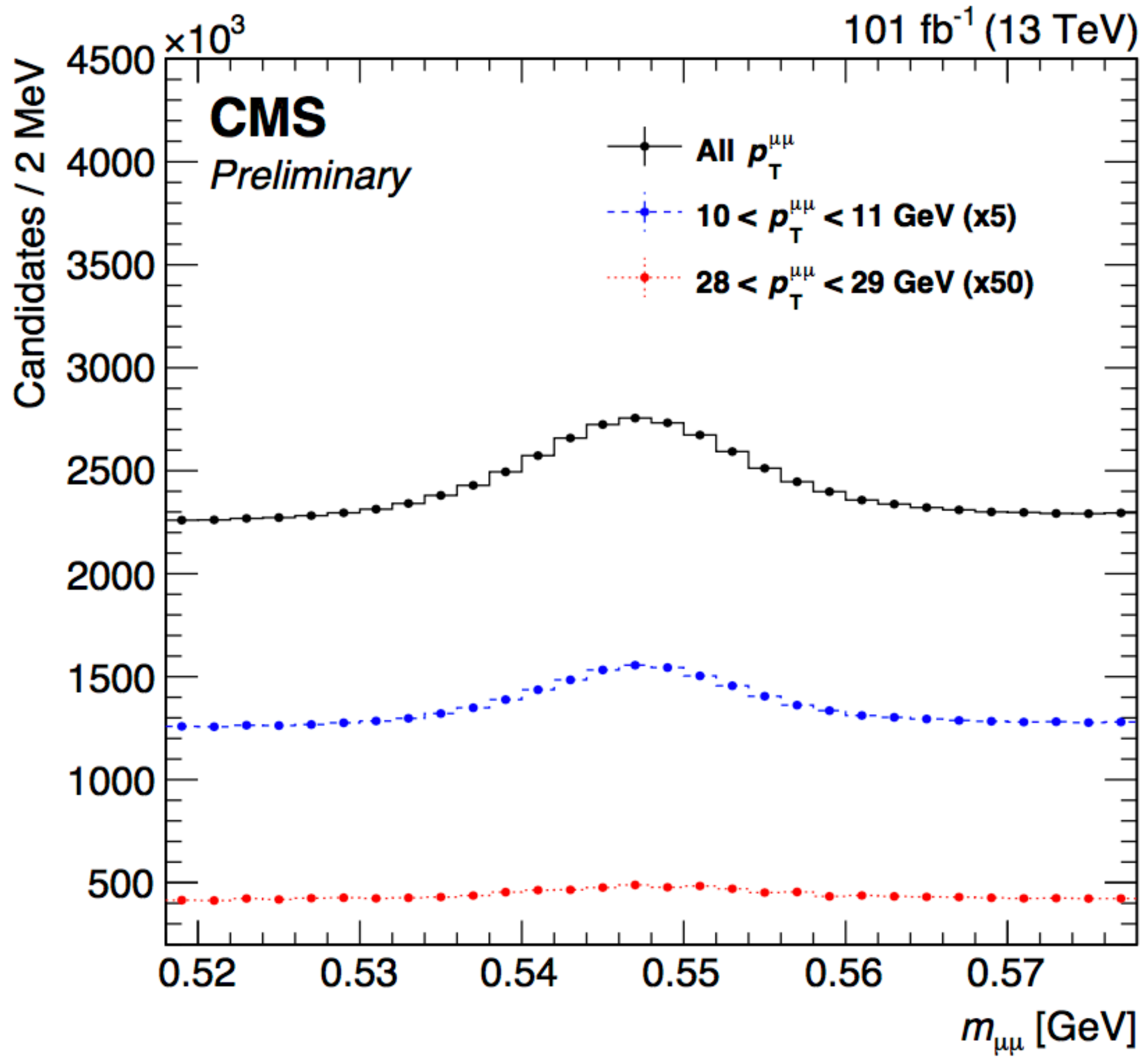
Trigger bandwidth

Event rate	x	Event size	
~ 1 kHz	x	~ 1 MB	= ~ 1 GB/s
increase rate	↩	decrease event size	
5 kHz	x	1.5 kB	= 7.5 MB/s

Observation of rare η decay



- observation of the double-Dalitz **η→μμμμ** decay
  - first **positive observation** employing **scouting** data
- studies allow precision tests of SM and sensitive to BSM
  - test low-energy QCD, hadronic contribution to $(g-2)_\mu$, search new light particles

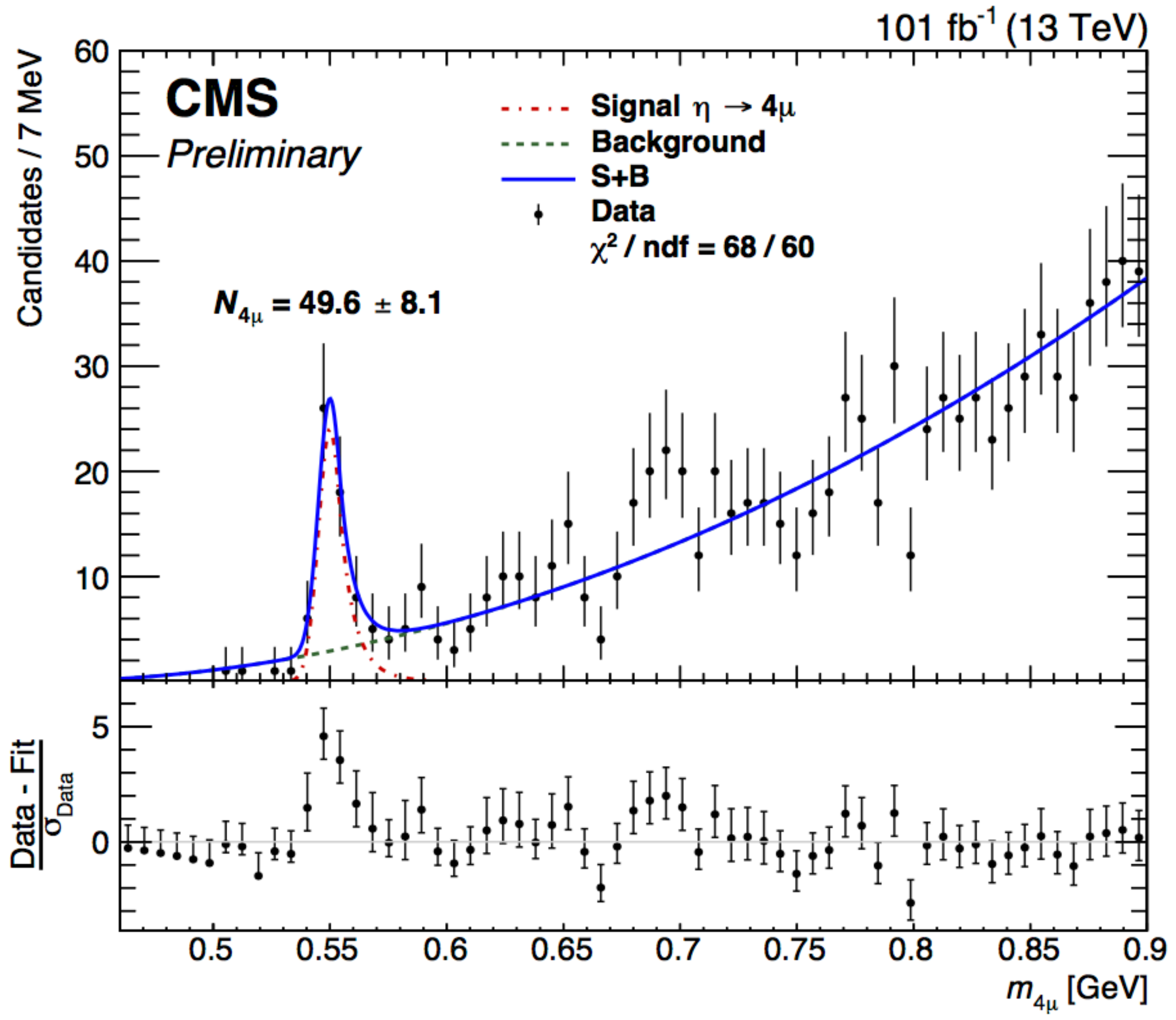


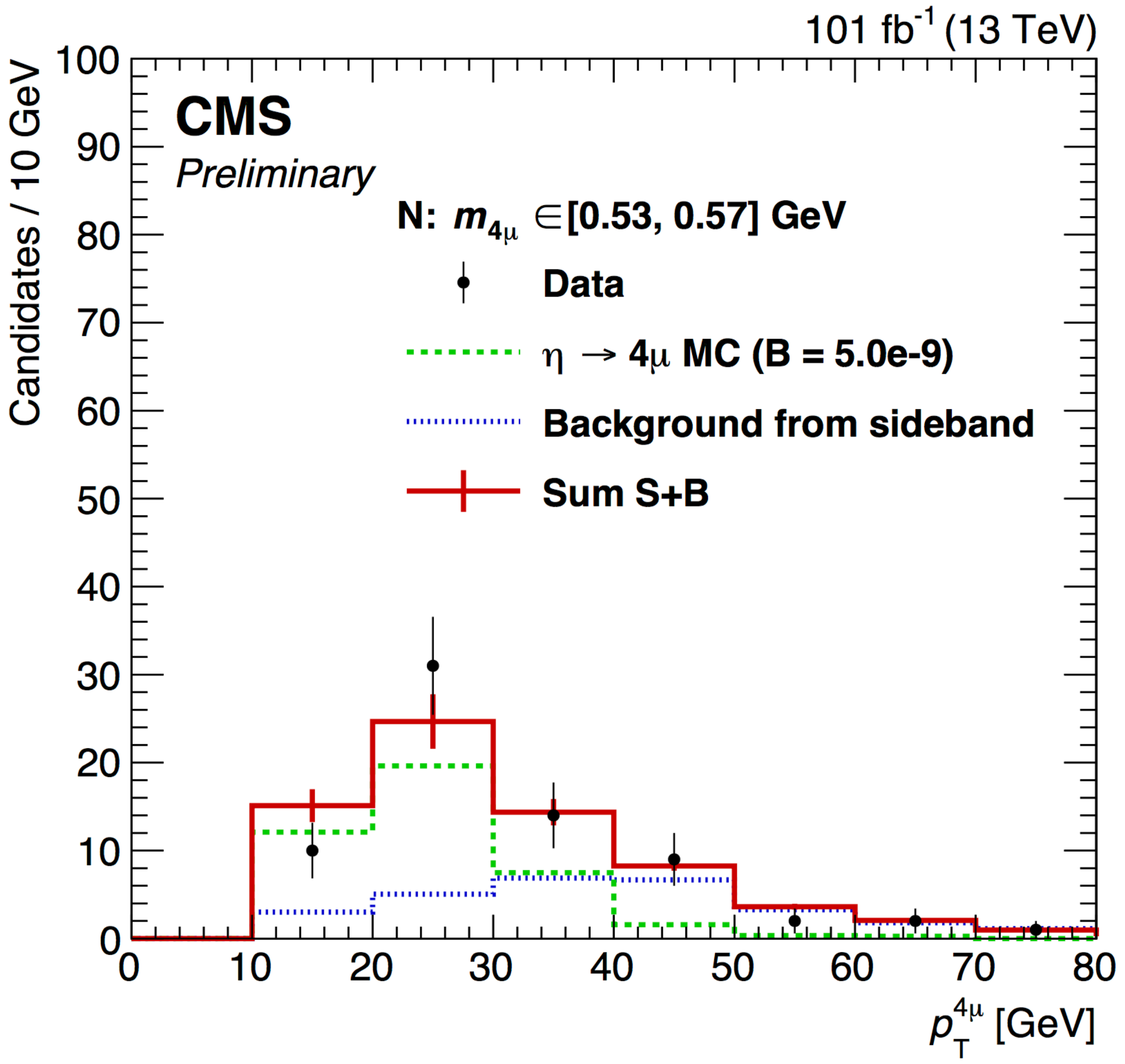
$B(\eta \to \mu\mu)$ =

5.8(0.8)×10^{-6}

$N_{\mu\mu} \approx 4.5 \cdot 10^6$

$N_\eta \approx 10^{12}$





$$\frac{B_{4\mu}}{B_{2\mu}} = \frac{N_{4\mu}}{\sum_{i,j} N_{2\mu}^{i,j} \frac{A_{4\mu}^{i,j}}{A_{2\mu}^{i,j}}} = (0.9 \pm 0.1\,(\text{stat}) \pm 0.1\,(\text{syst})) \times 10^{-3}$$

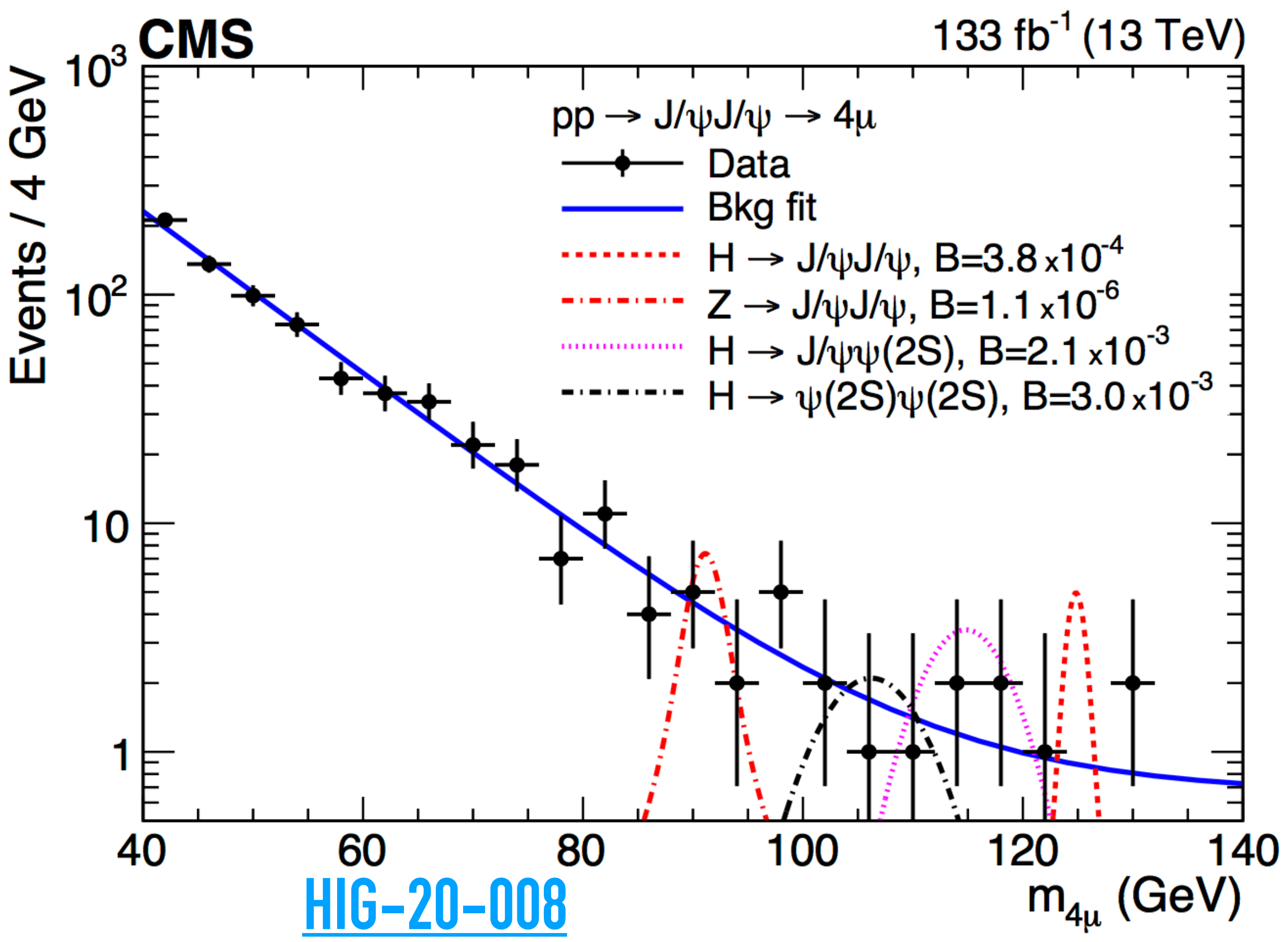
$$\mathcal{B}(\eta \to 2\mu) = (5.8 \pm 0.8) \times 10^{-6}$$

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

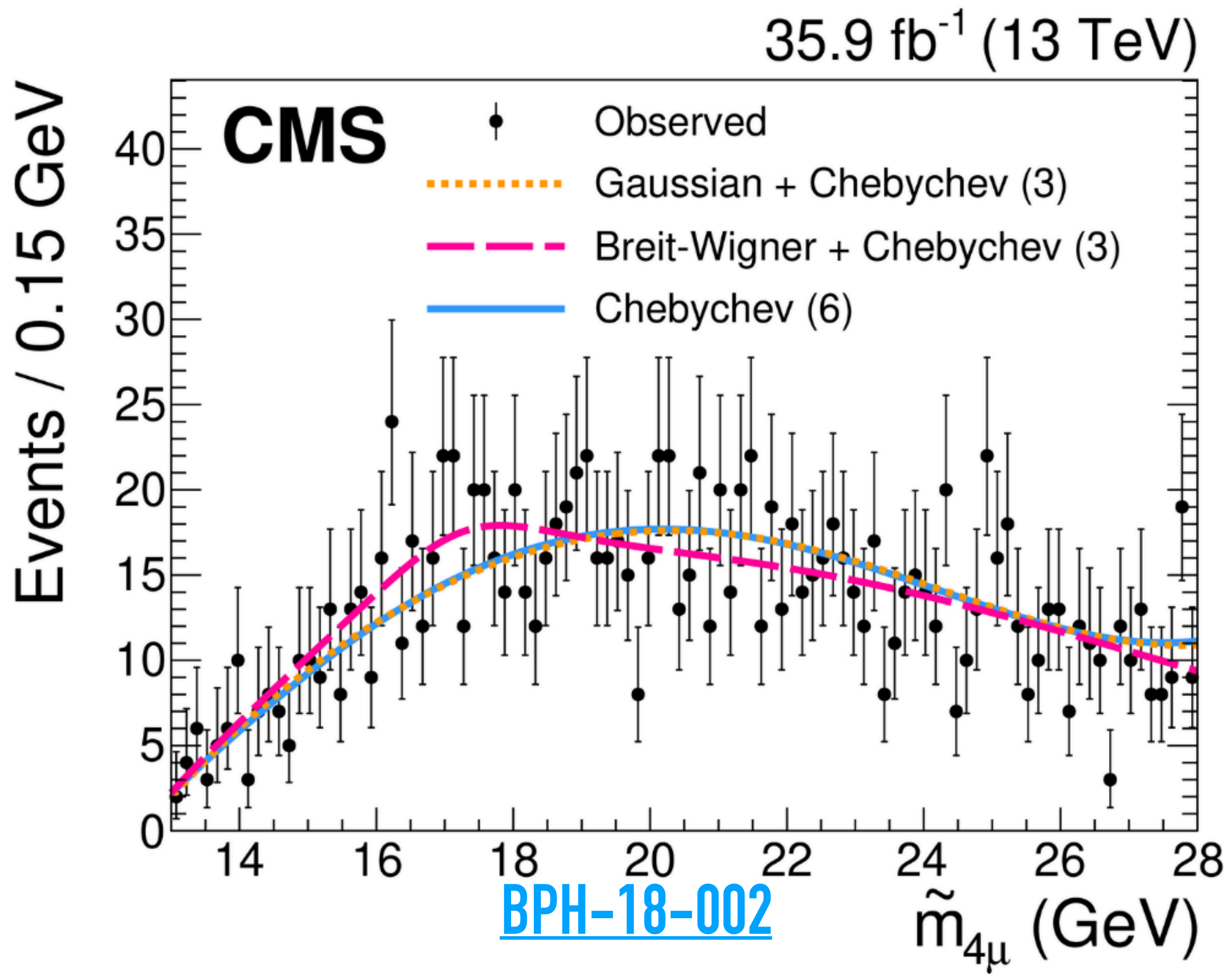
CMS-BPH-22-003

Di-quarkonium mass spectrum

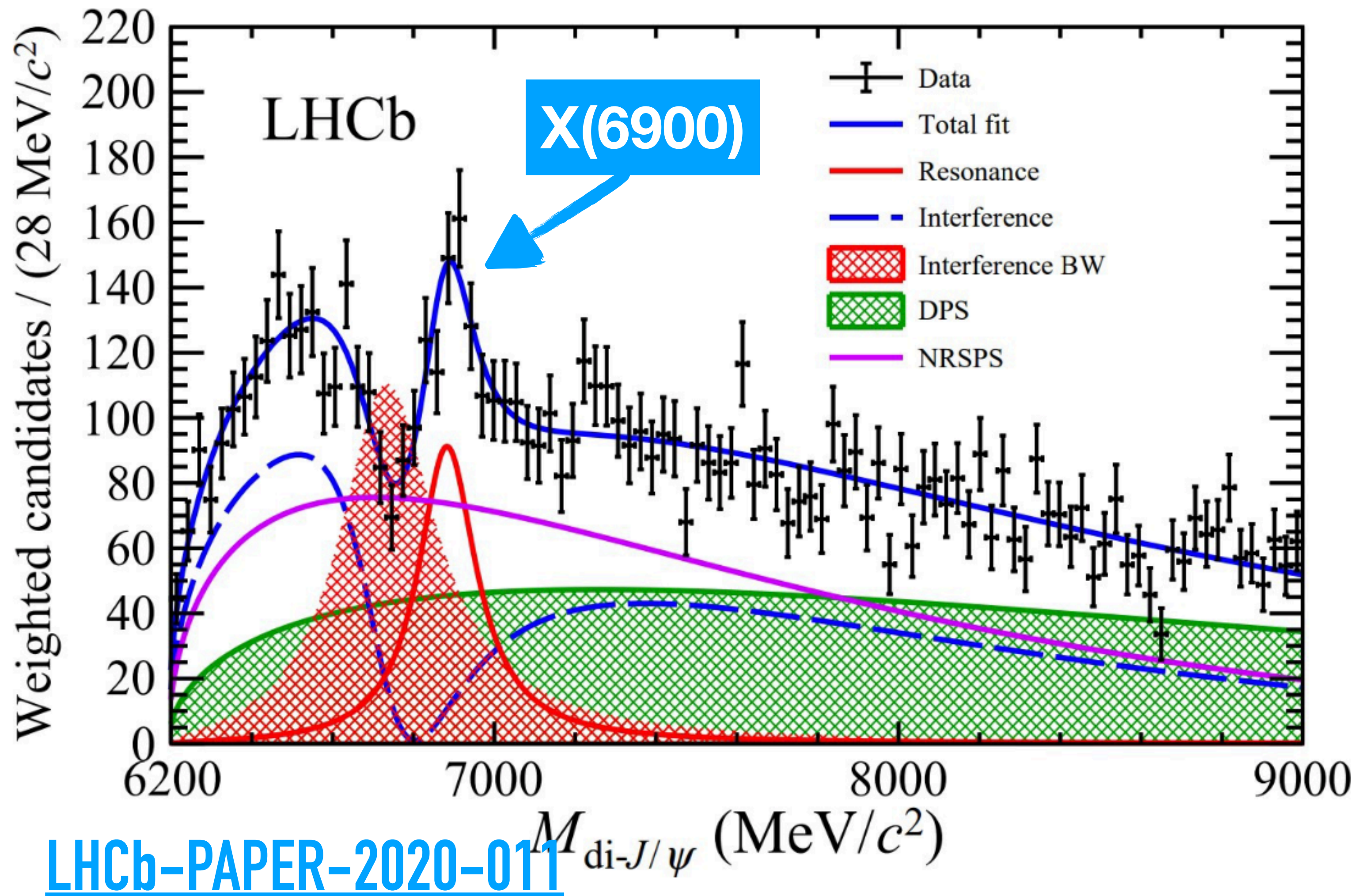
- final states with multiple quarkonia provide clean and robust canvas for searches
  - at both low- and high p_T
- first new structure reported by LHCb in 2020 in J/ψ J/ψ mass spectrum
  - narrow structure near the kinematic threshold, denoted **X(6900)**
- all-heavy tetra-quark candidate
  - after several doubly-heavy exotic candidates, this all-heavy possibility raises particular interest
  - the X(6900) peak is compelling, but proper understanding of J/ψJ/ψ mass spectrum remains uncertain



HIG-20-008

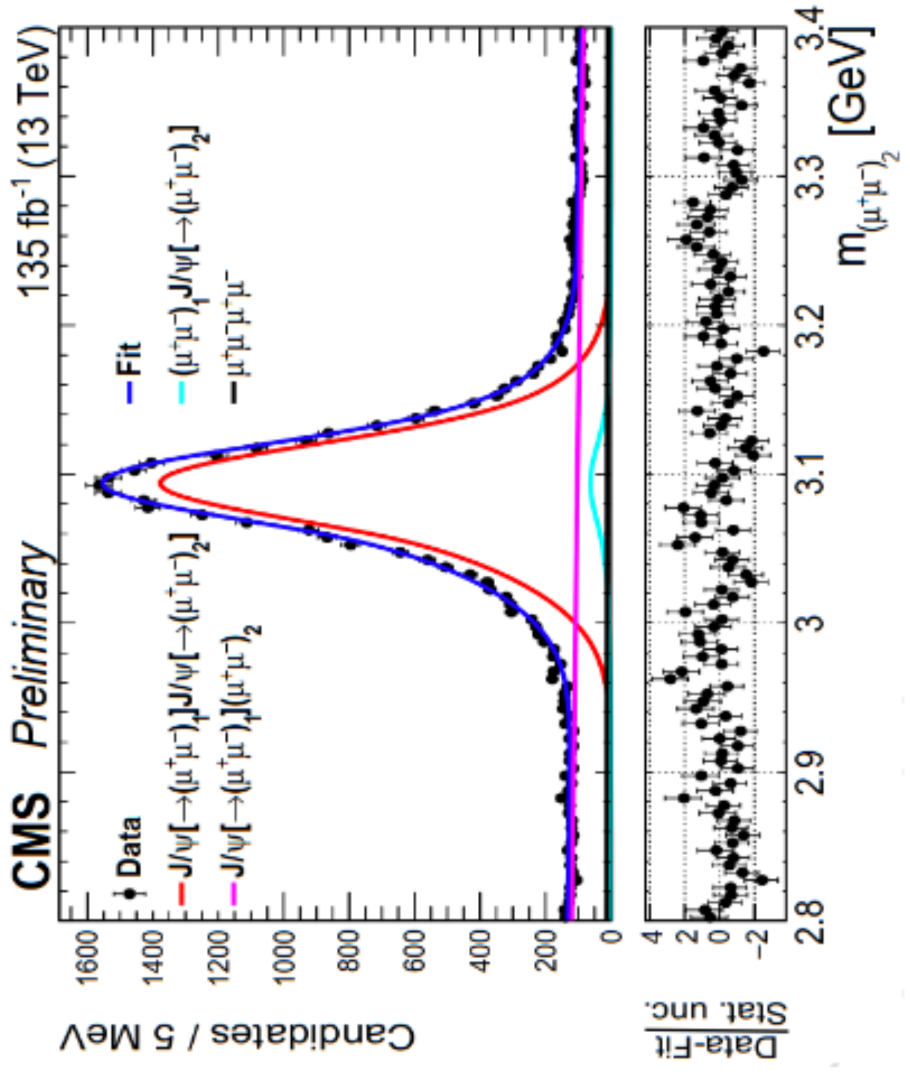


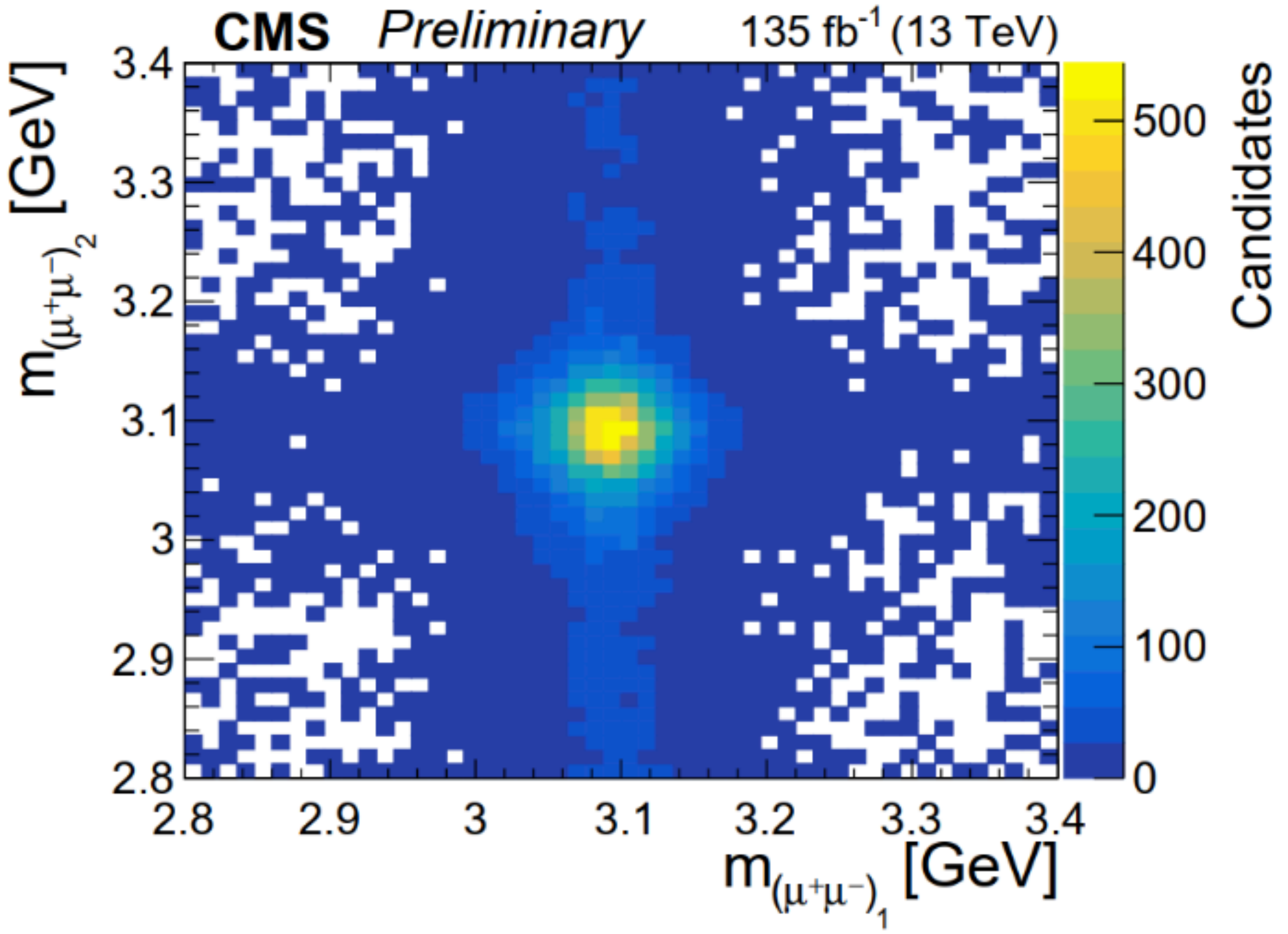
BPH-18-002

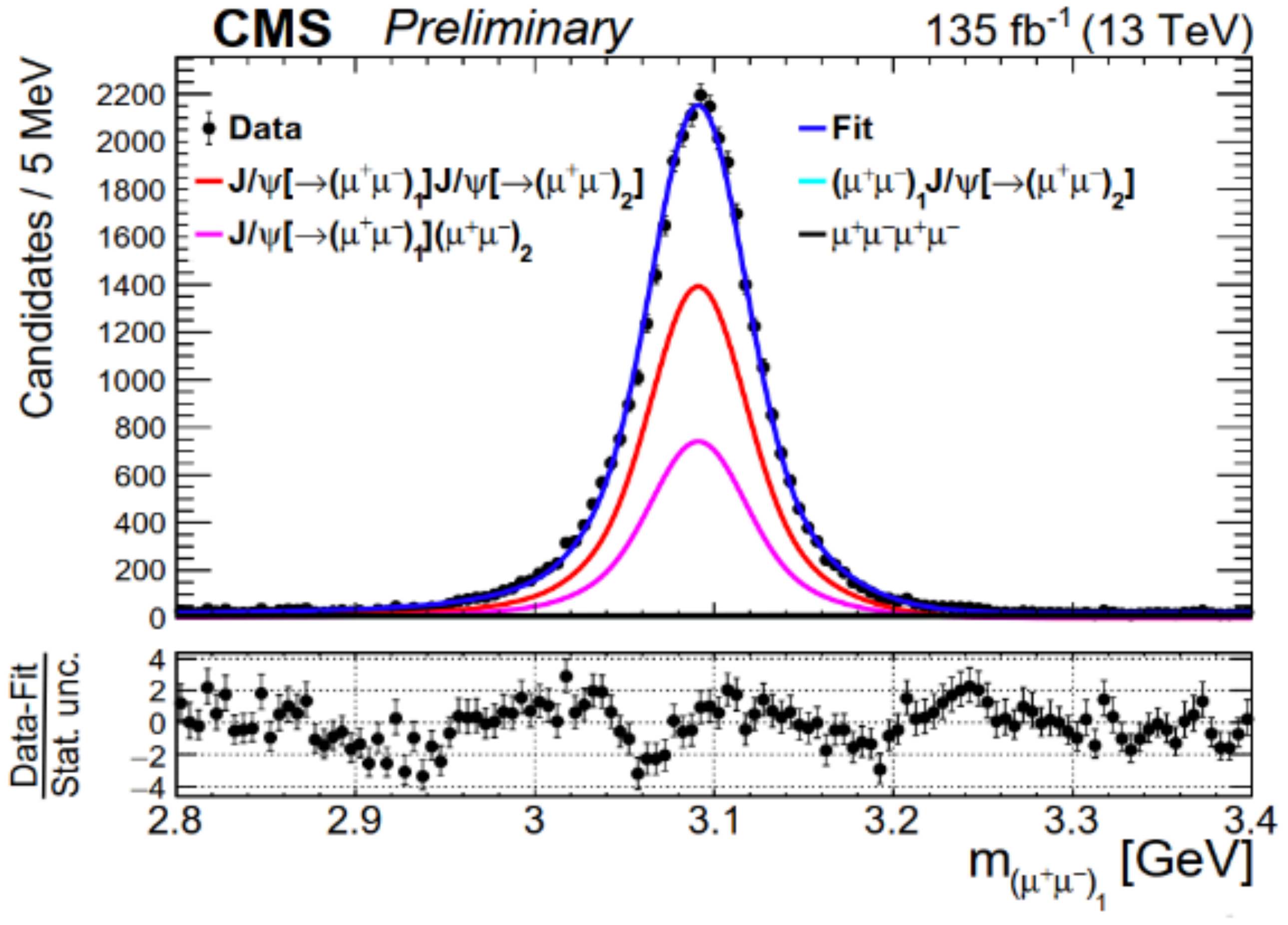


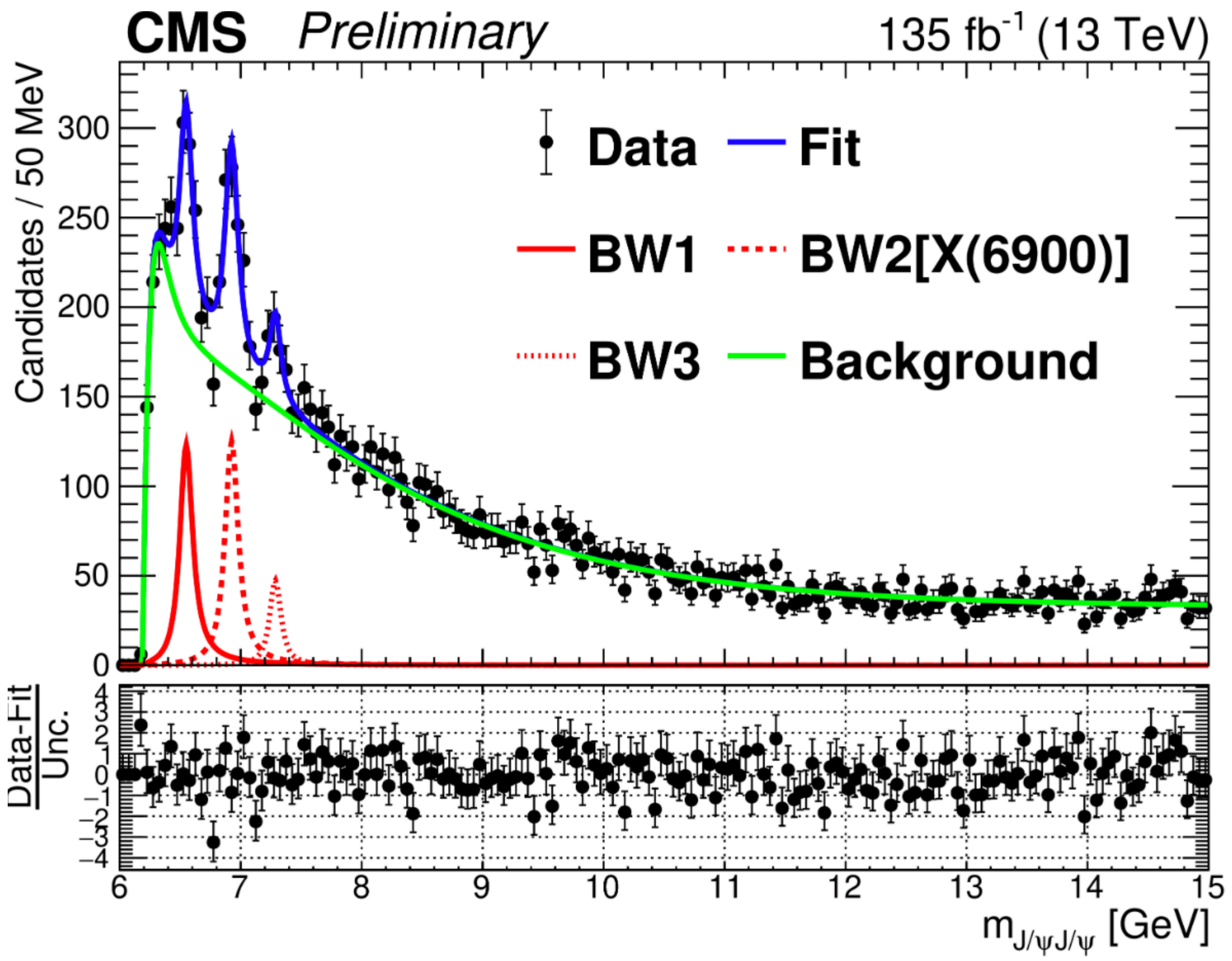
LHCb-PAPER-2020-011

Probing the J/ψJ/ψ (→μμμμ) mass spectrum







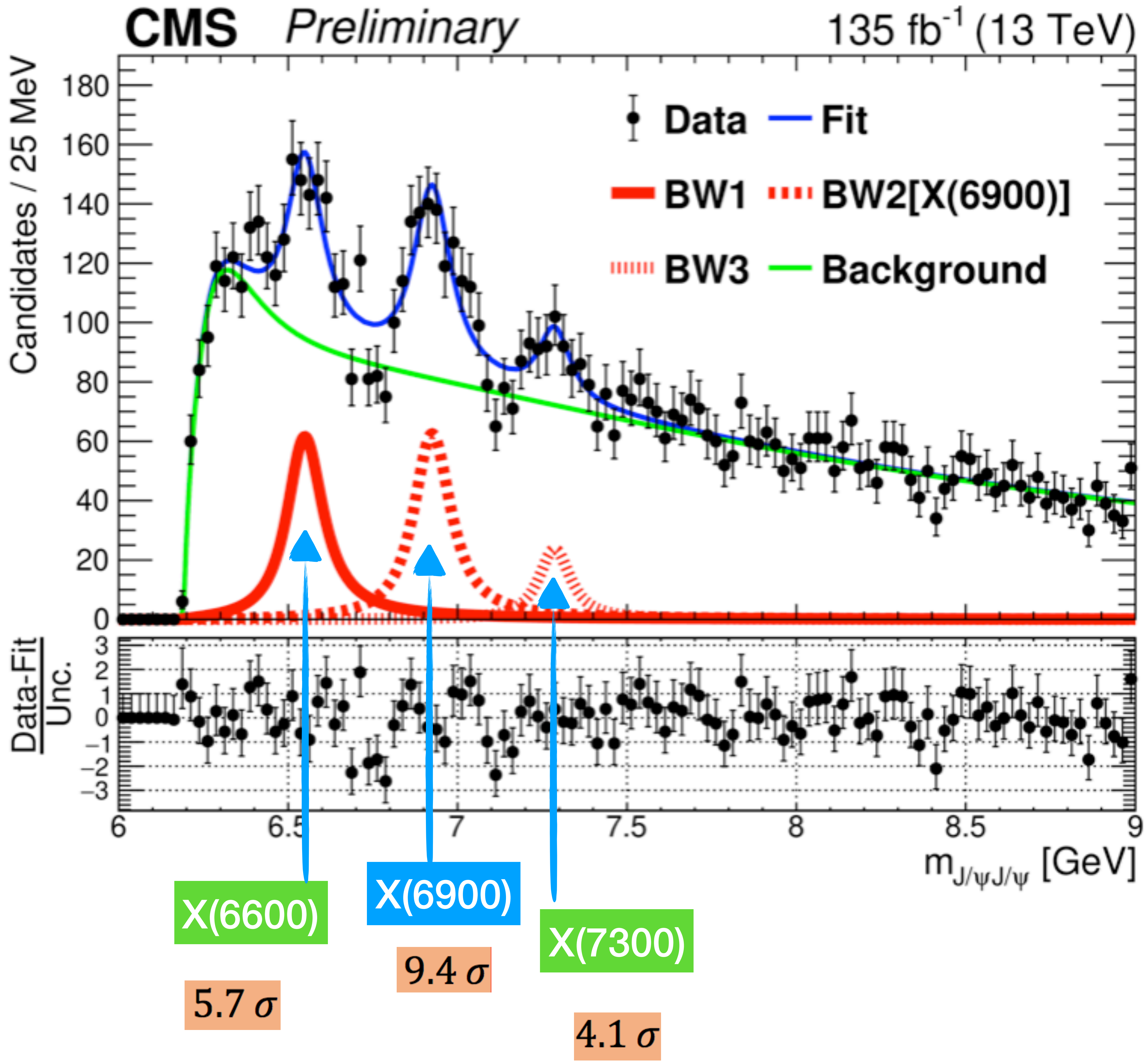


$J/\psi J/\psi \rightarrow (\mu\mu)_1(\mu\mu)_2$

- 2016+2017+2018 data (135 fb^{-1})
- trigger: 3μ, one pair around m(J/ψ)
- blind region: 6.2-7.8 GeV
- require 4μ vertex prob. > 0.5%
- obtain ~1500 J/ψ pairs after selection

Observation of new structures in *m(J/ψJ/ψ)*

CMS-PAS-BPH-21-003



- background model
  - NRSPS & NRDPS: threshold x pol2 x exponential
  - relativistic BW near J/ψJ/ψ threshold
  - background = BW_0 + NRSPS + DPS
- structures visible above background-only hypothesis (baseline model)
  - add BWs sequentially to baseline if >3 s.d.
- structures described by 3 additional BWs

	BW1 (MeV)	BW2 (MeV)	BW3 (MeV)
m	6552 ± 10	6927 ± 9	7287 ± 19
Γ	124 ± 29	122 ± 22	95 ± 46
N	474 ± 113	492 ± 75	156 ± 56

- X(6900) **confirmed**, compatible with LHCb
  - plus 2 new structures denoted X(6600), X(7300)

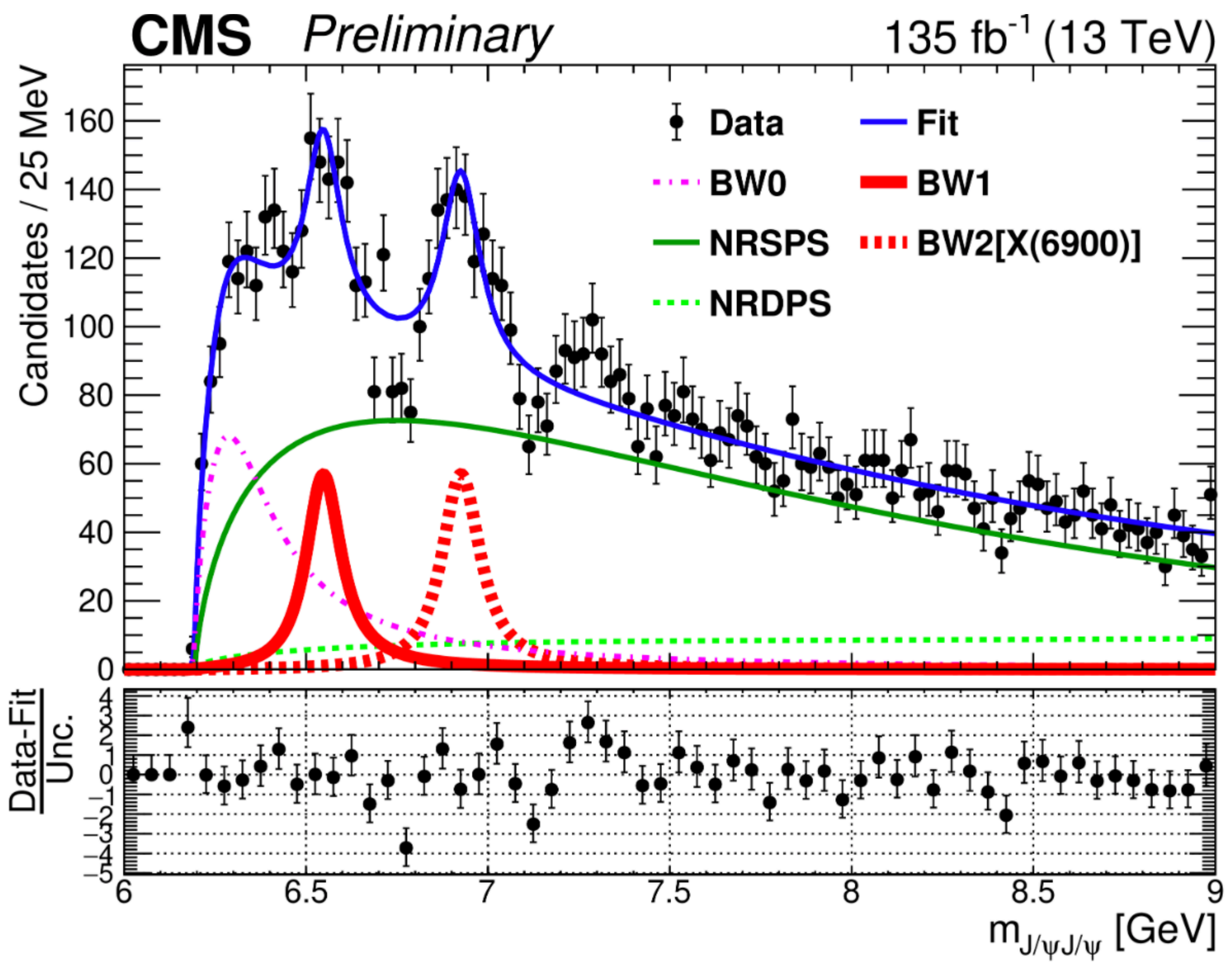
Background studies

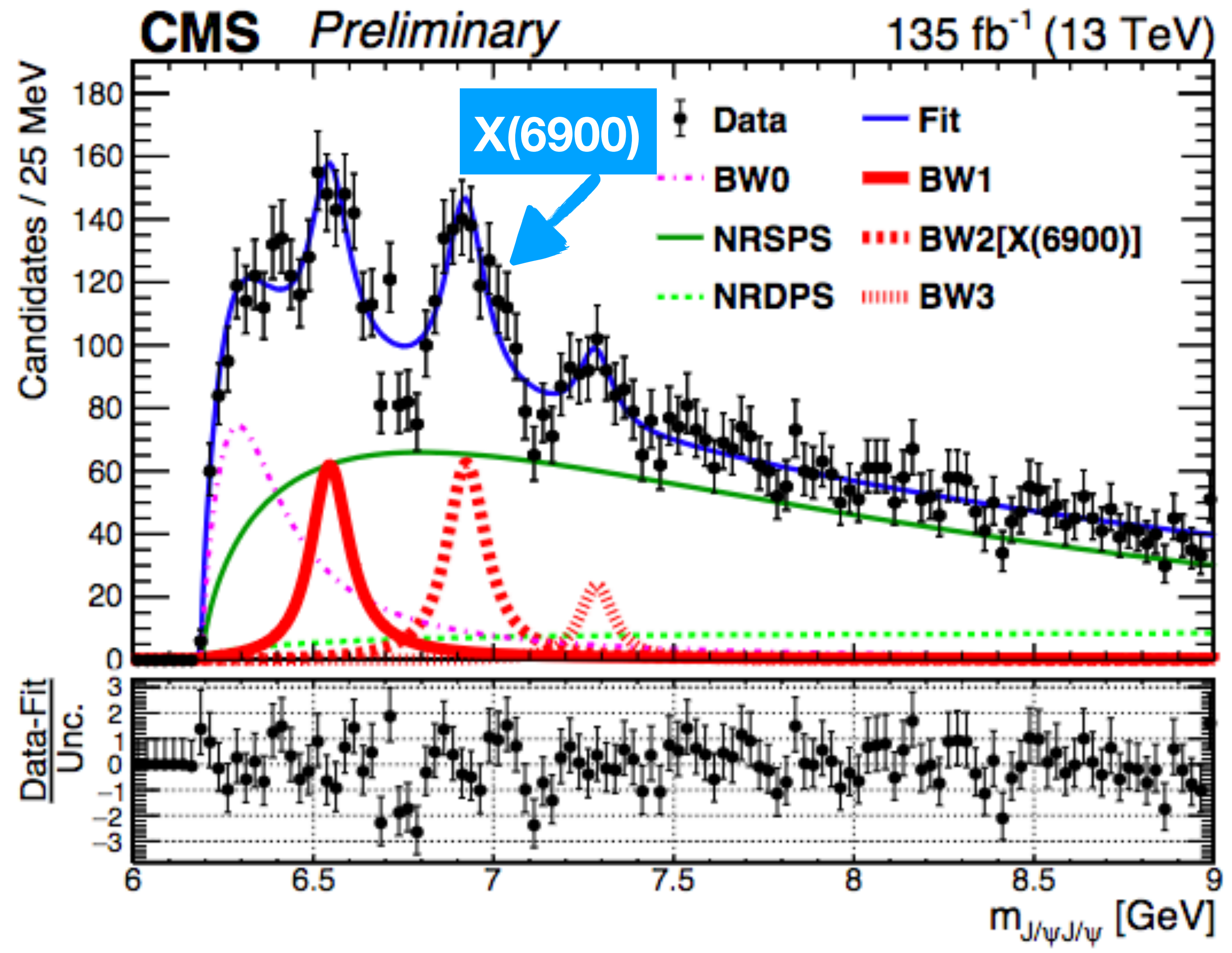
- dips at 6750 & 7160 MeV not fully described → probe alternative models
- non-interference

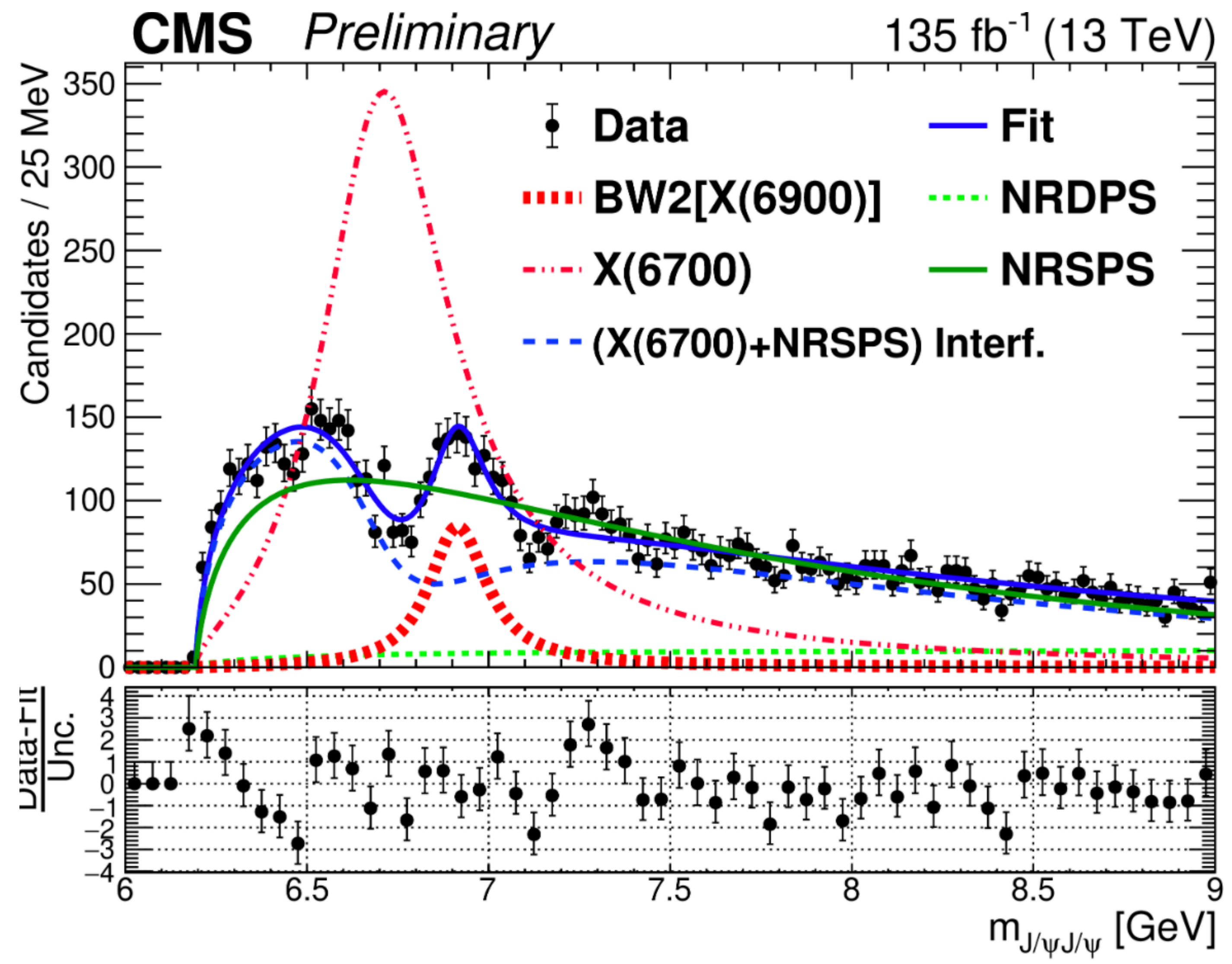
LHCb M1
  - BW_0 + NRSPS+DPS + 2xBW
  - BW_0 + NRSPS+DPS + 3xBW
- interference

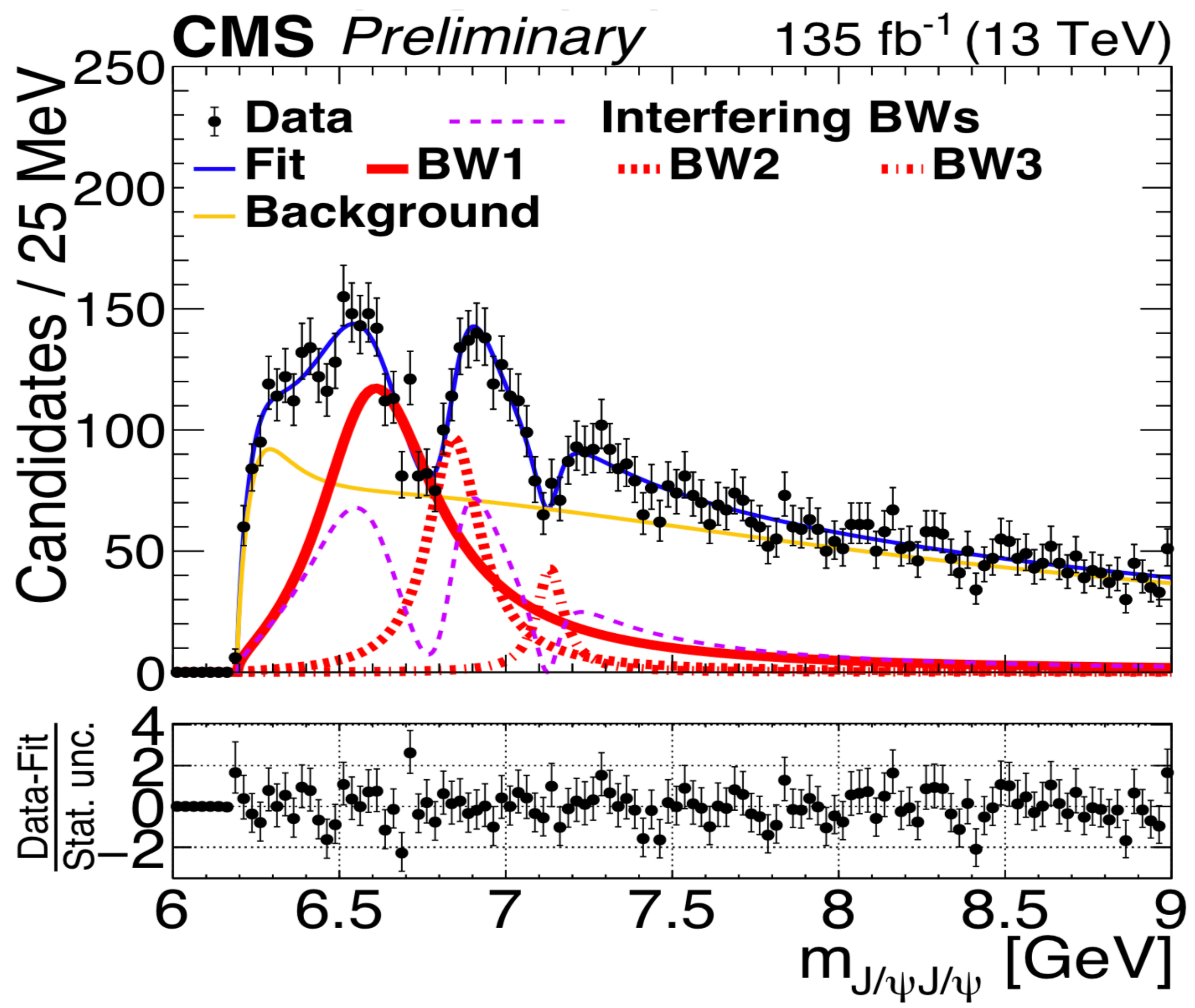
LHCb M2
  - DPS + X(6900) + BW/NRSPS
  - background + $BW_1/BW_2/BW_3$
- none but model w/3 interfering BW signals describes data well

		BW1	BW2	BW3
Interference	m [MeV]	6638^{+43+16}_{-38-31}	6847^{+44+48}_{-28-20}	7134^{+48+41}_{-25-15}
	Γ [MeV]	$444^{+226+109}_{-199-235}$	191^{+66+25}_{-49-17}	97^{+40+29}_{-29-26}



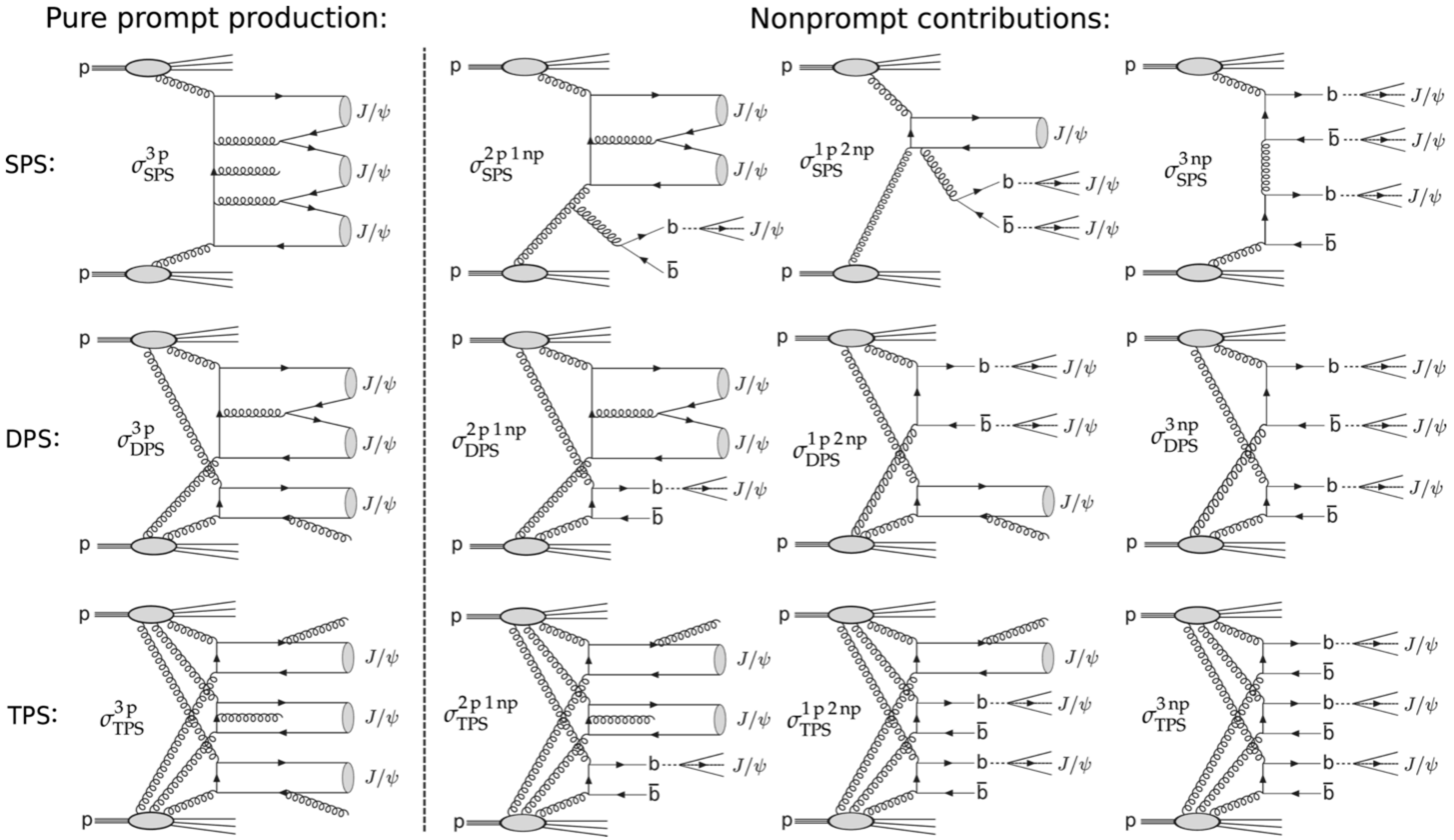






Triple *J/ψ* production and Multi-parton interactions

- observe pp → J/ψ J/ψ J/ψ X ⇐ combines direct (pp→J/ψ) and non-pompt (pp→b→J/ψ)



f_{SPS} ~ 6%

f_{SPS} ~ 74%

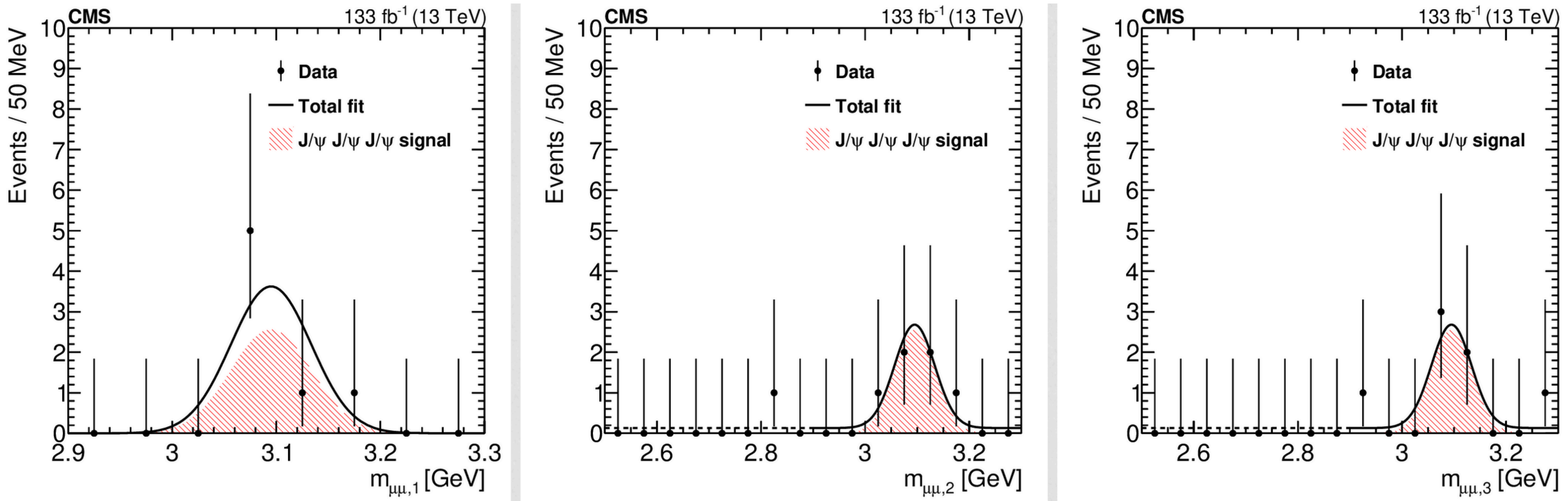
f_{TPS} ~ 20%

Observation of triple J/ψ production

BPH-21-004

- signal observed with 5.5σ
- measure fiducial cross section

For all muons	$p_T > 3.5\,\text{GeV}$ for $\lvert\eta\rvert < 1.2$ $p_T > 2.5\,\text{GeV}$ for $1.2 < \lvert\eta\rvert < 2.4$
For all J/ψ mesons	$p_T > 6\,\text{GeV}$ and $\lvert y\rvert < 2.4$ $2.9 < m_{\mu^+\mu^-} < 3.3\,\text{GeV}$

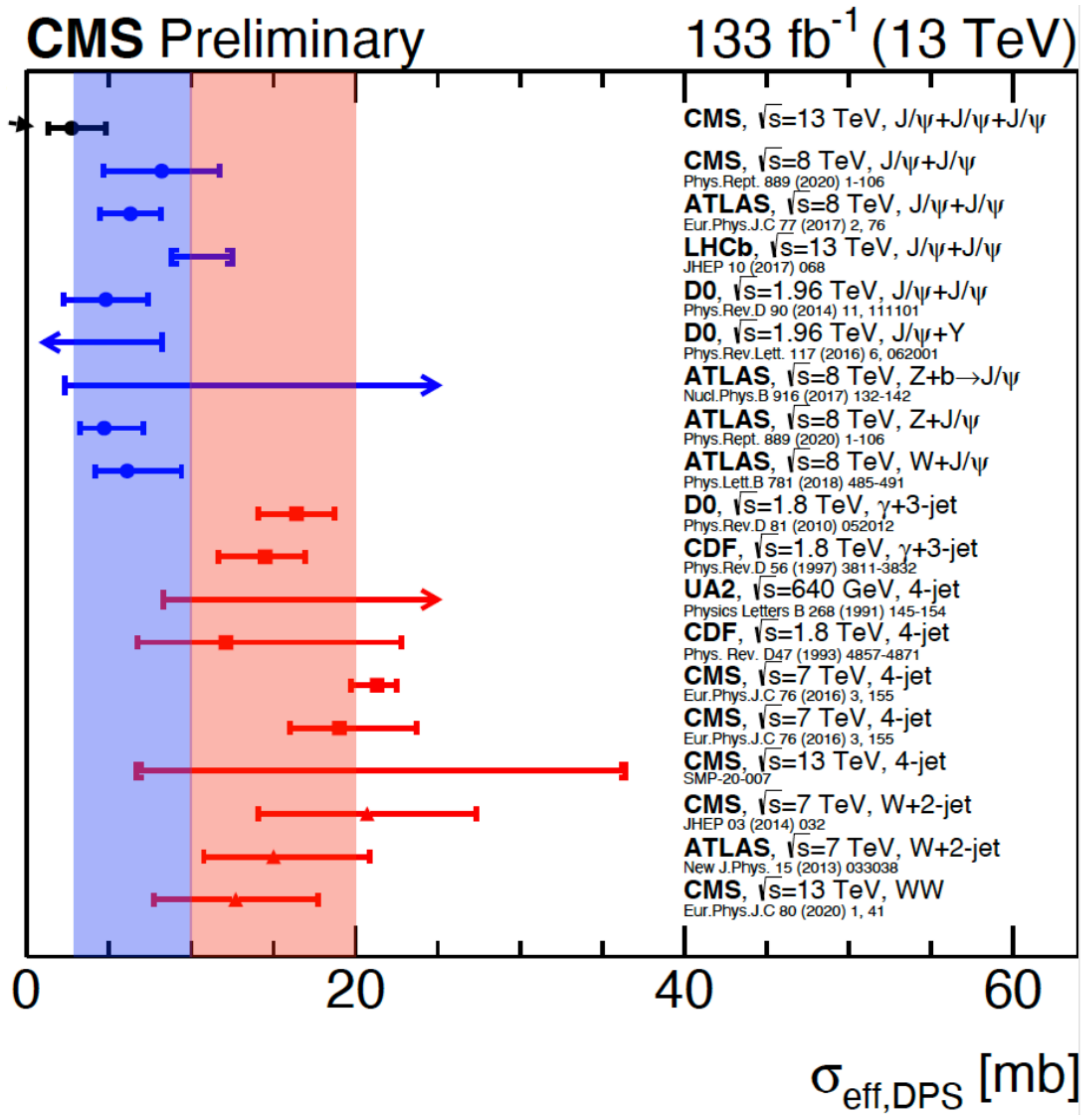


$$\sigma(pp \to J/\psi\, J/\psi\, J/\psi\, X) = N_{sig}^{3J/\psi} / (\epsilon\, \mathcal{L}_{int}\, \mathcal{B}^3_{J/\psi\to\mu^+\mu^-}) \Rightarrow 272^{+141}_{-104}\,(\text{stat}) \pm 17\,(\text{syst})\,\text{fb}$$

- assuming MPS factorization in terms of SPS cross sections

$$\sigma_{eff,DPS} = 2.7^{+1.4}_{-1.0}(exp)^{+1.5}_{-1.0}(theo)\, mb$$

- result aligned with measurements of di-onia and EWK+onia production, and smaller than those involving jets/photon/W

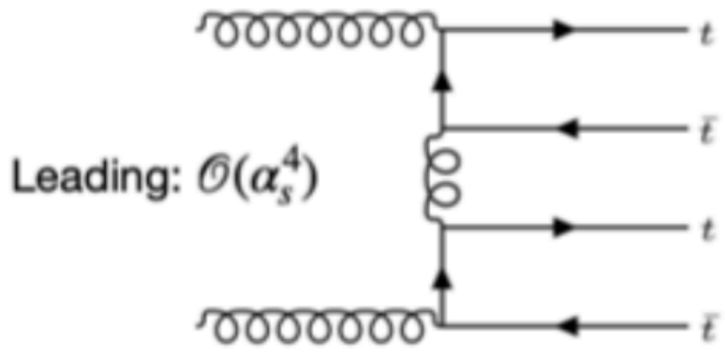


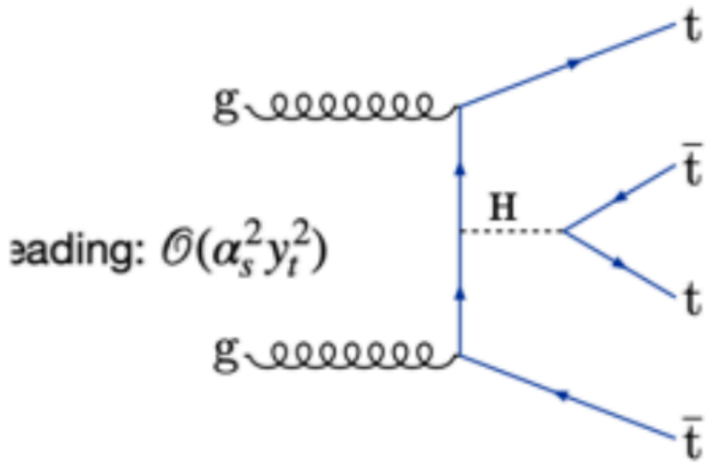
Two top Physics Highlight II

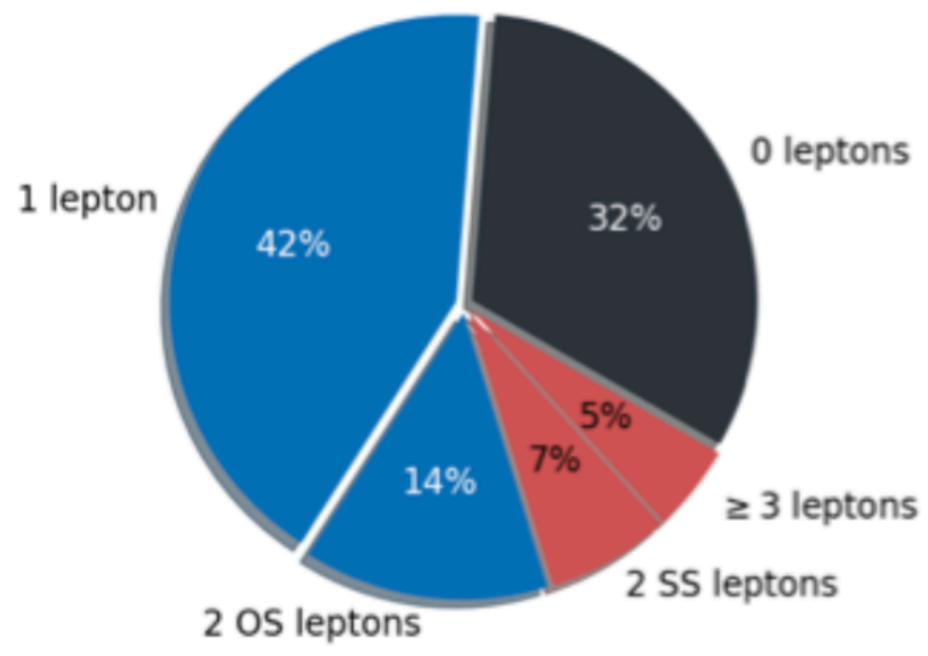
New for Moriond EW 2023

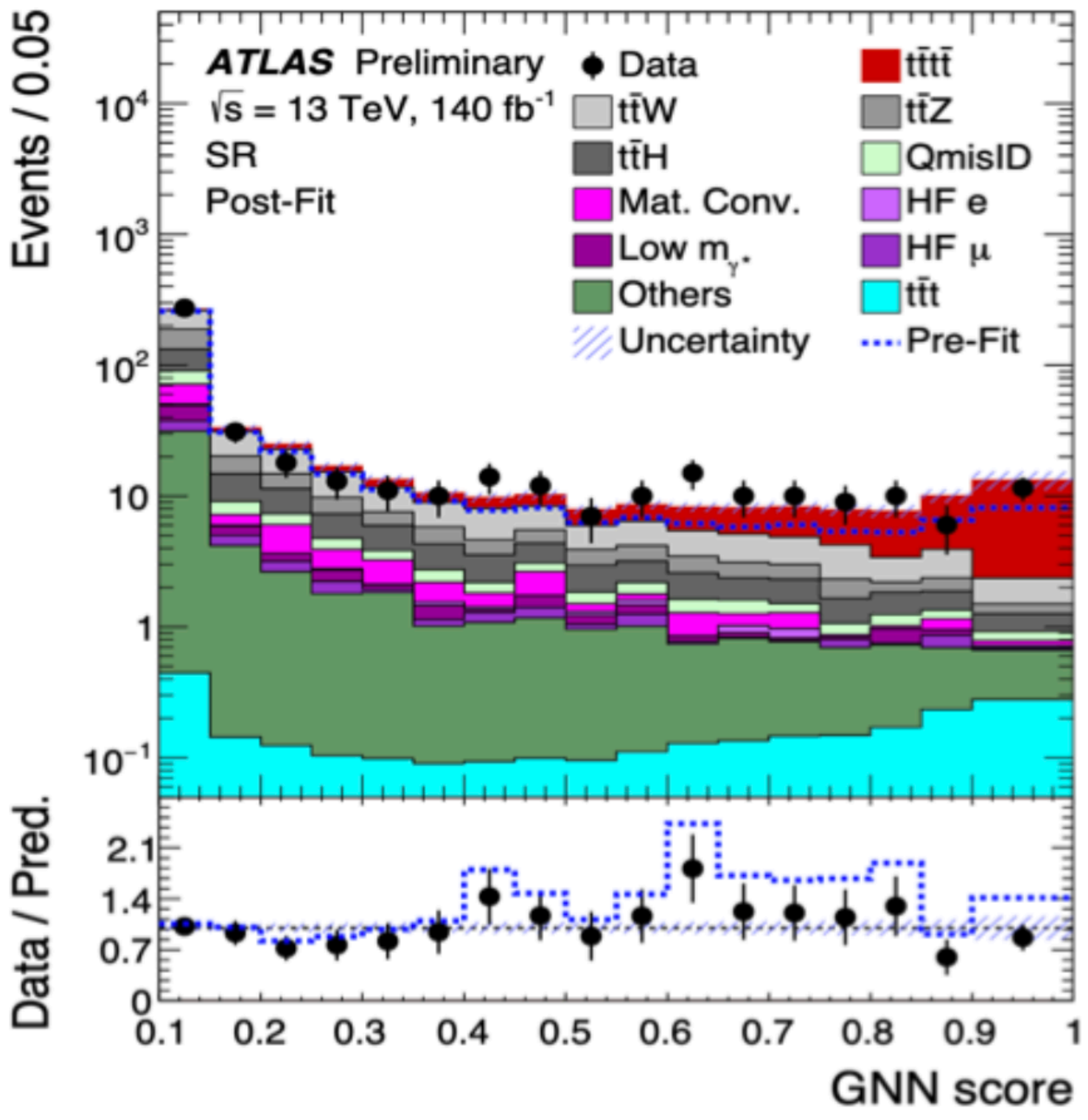
For Moriond EW 2023 !!

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

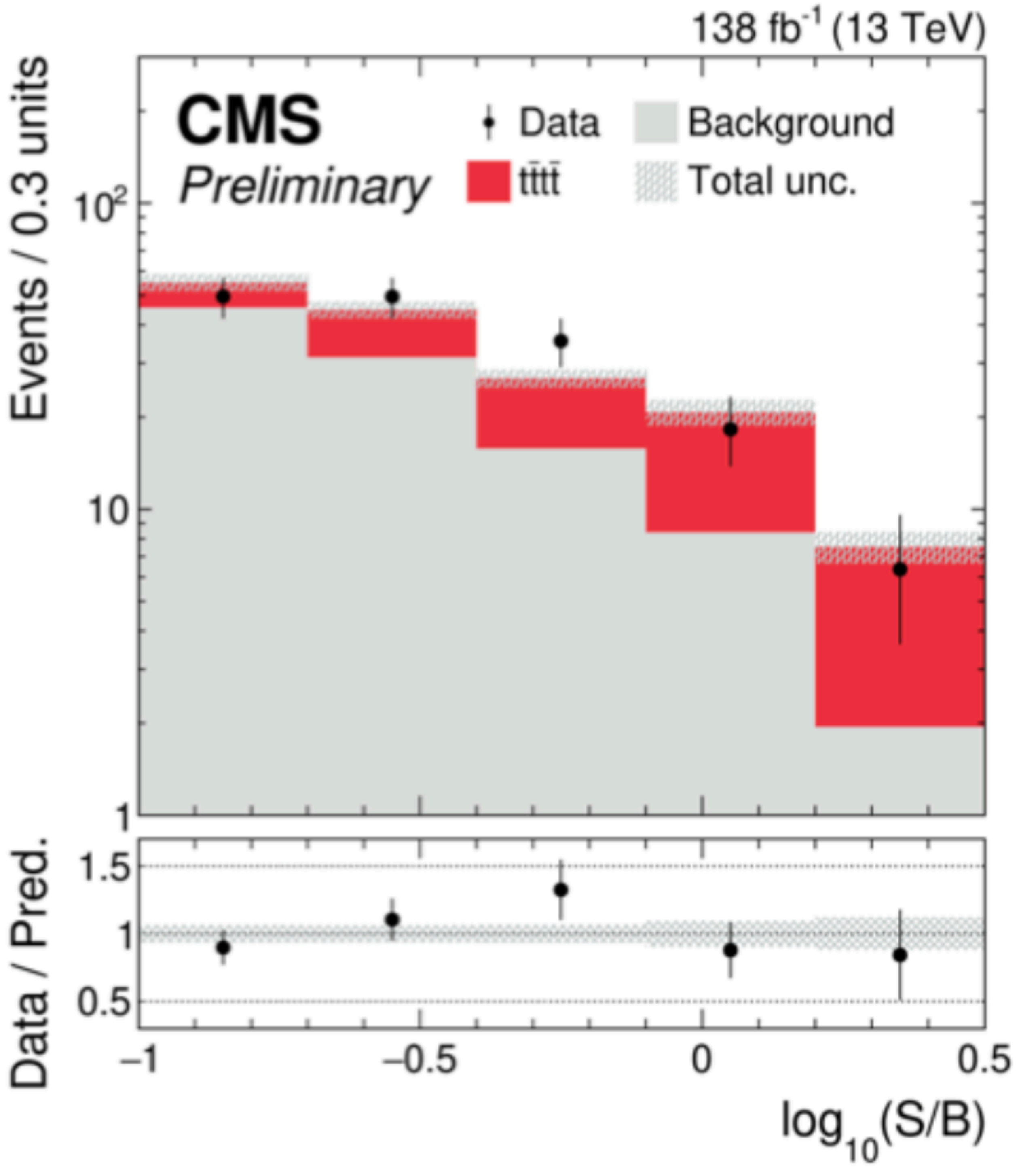








6.1 (4.3) σ observed (expected)

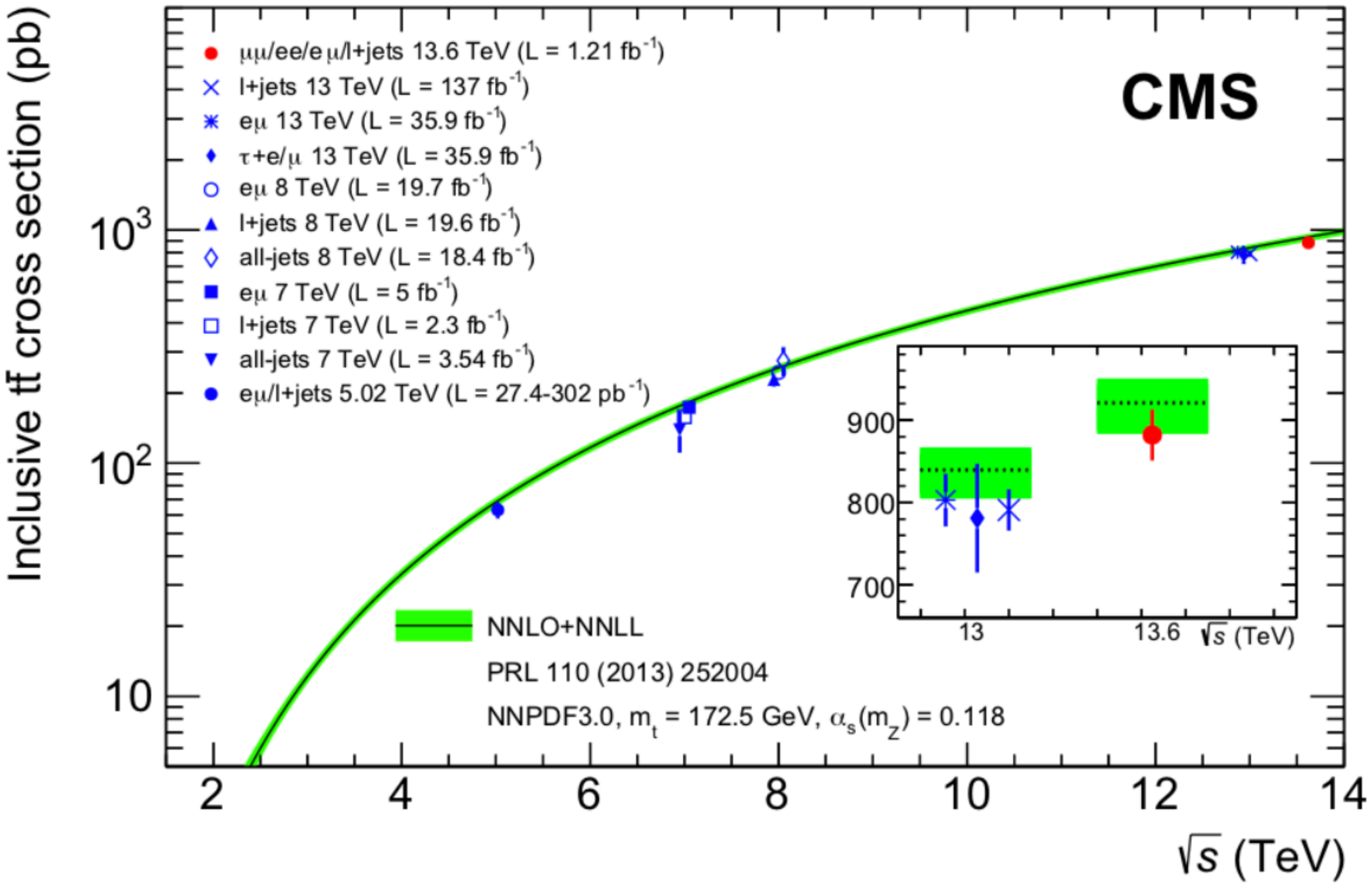


5.5 (4.9) σ observed (expected)

Run3 dataset, starting to be explored

Summary

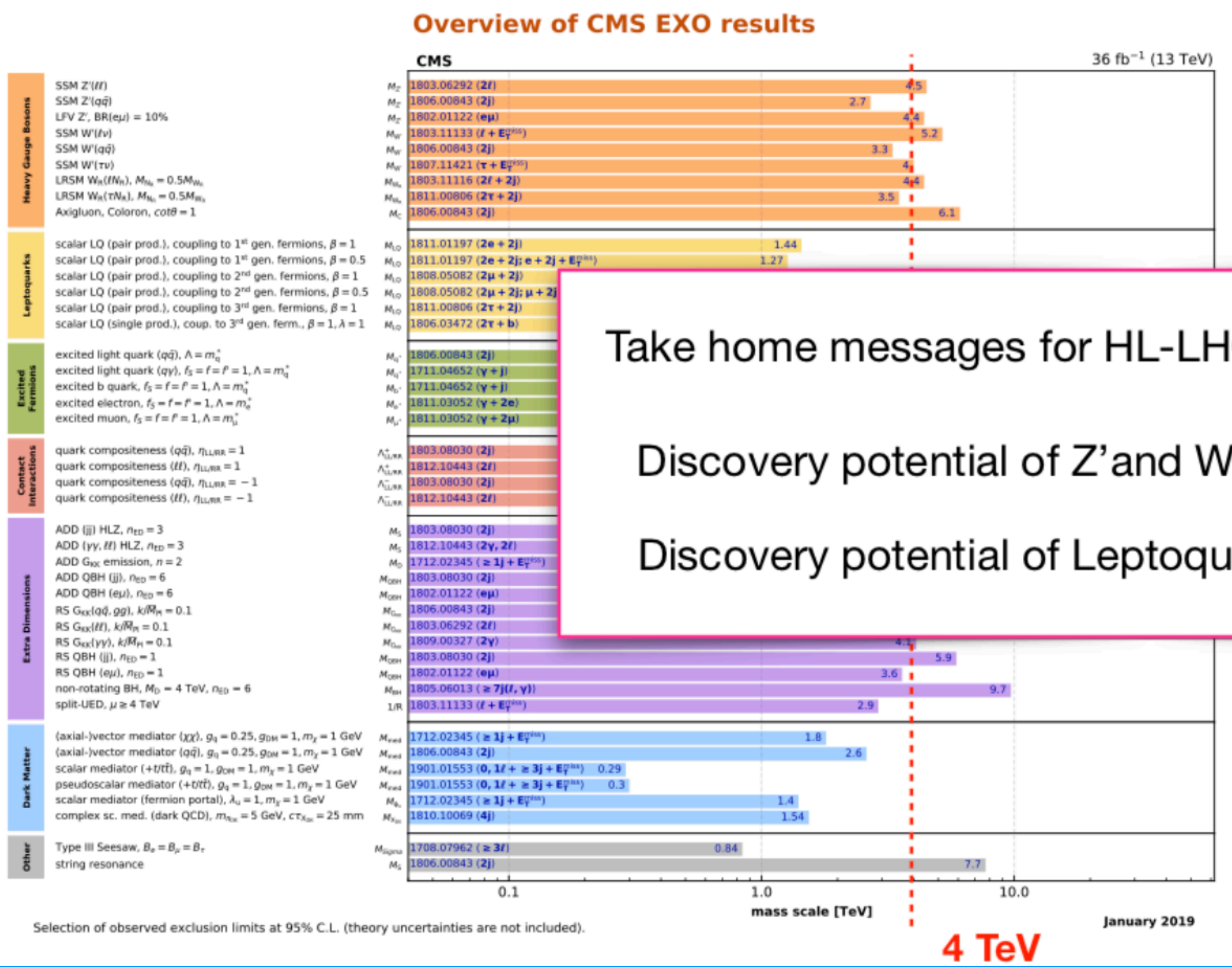
- successful start of Run-3 data taking
- jet energy calibration with PUPPI jets
- excellent tracking performance
- luminosity measurement: Z counting and interim VdM results
- first $t\bar{t}$ cross section measurement at 13.6 TeV
  - now available at arXiv:2303.10680 (submitted to JHEP)



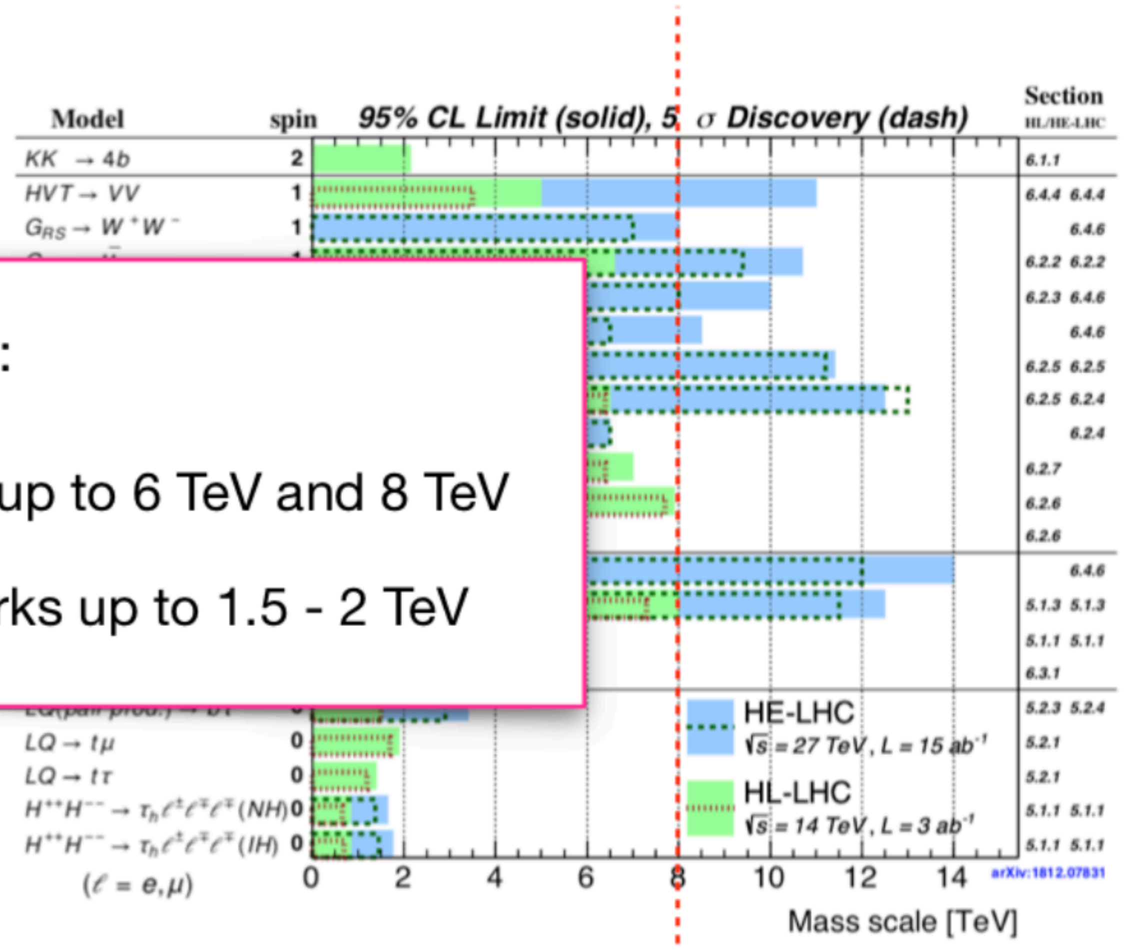
Very Large Number of Searches

(in large variety of topologies and models)

Overview of CMS EXO results



4 TeV



8 TeV

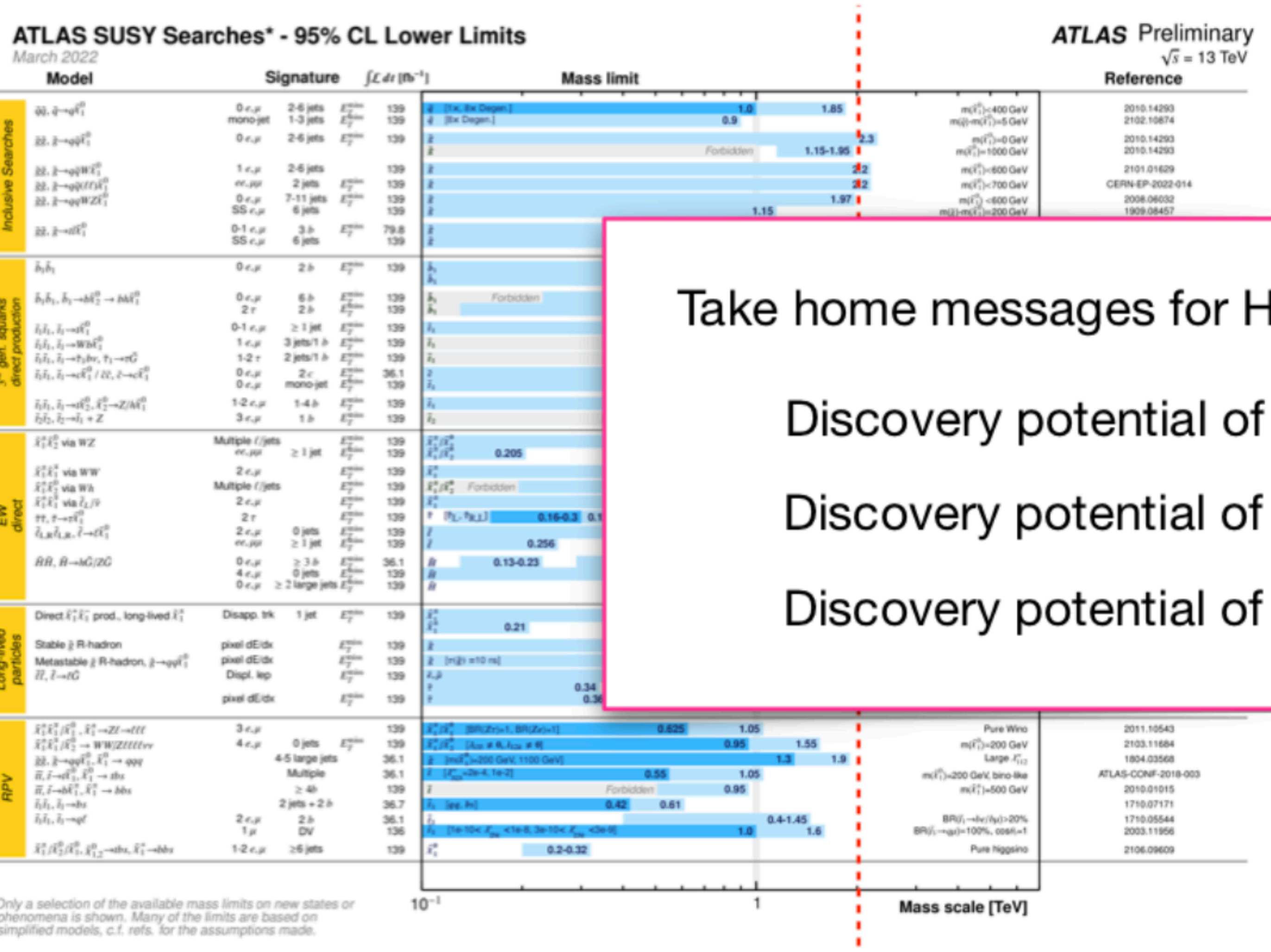
Take home messages for HL-LHC:

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

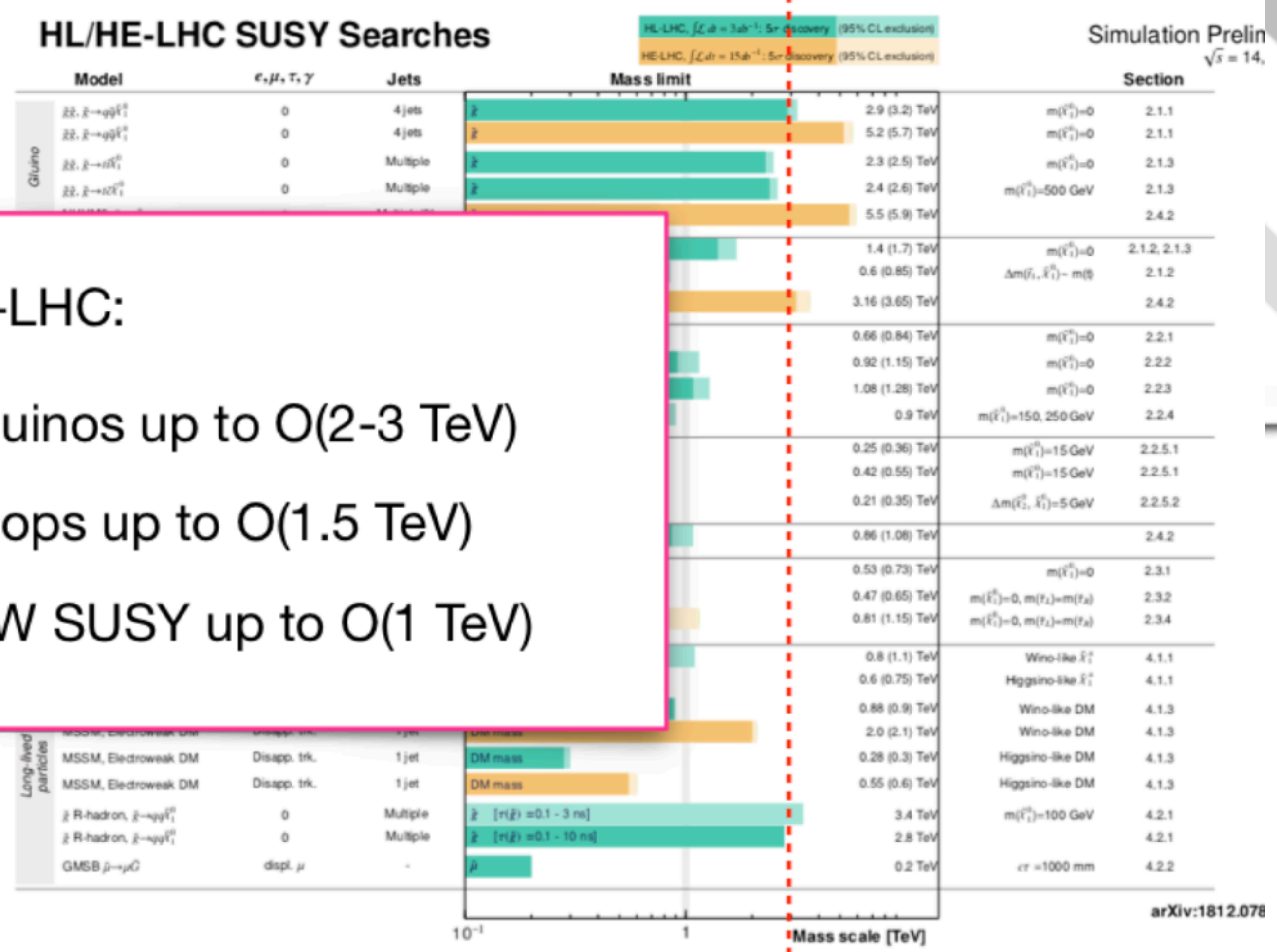
Discovery potential of Leptoquarks up to 1.5 - 2 TeV

Very Large Number of SUSY Searches

(in large variety of topologies and models)



2 TeV



3 TeV

HL-LHC YR 1812.07831

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)

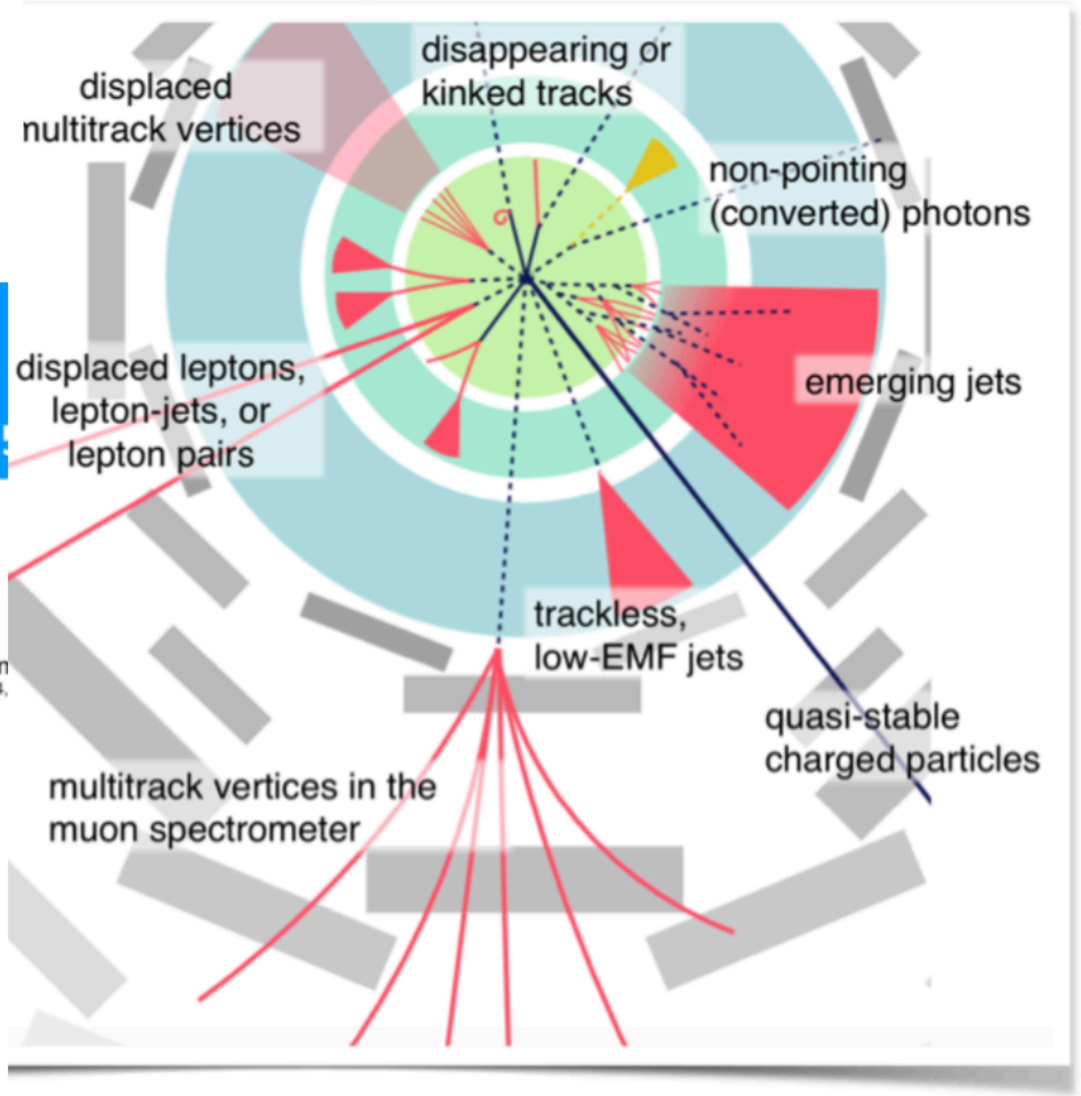
Discovery potential of EW SUSY up to O(1 TeV)

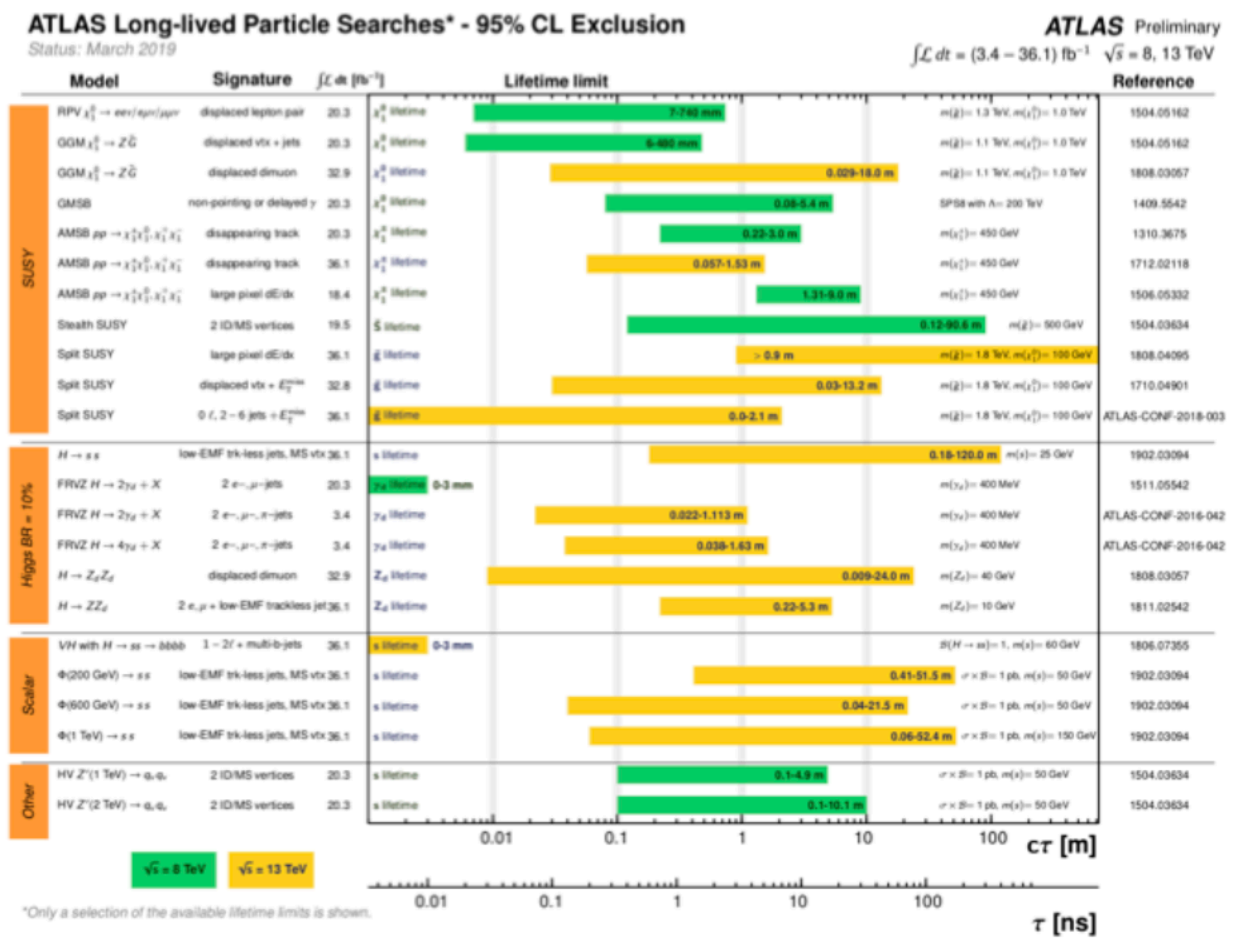
Example from ATLAS (similar for CMS)

direct searches for new particles

Leaving No Stone Unturned !

Steven Lowette



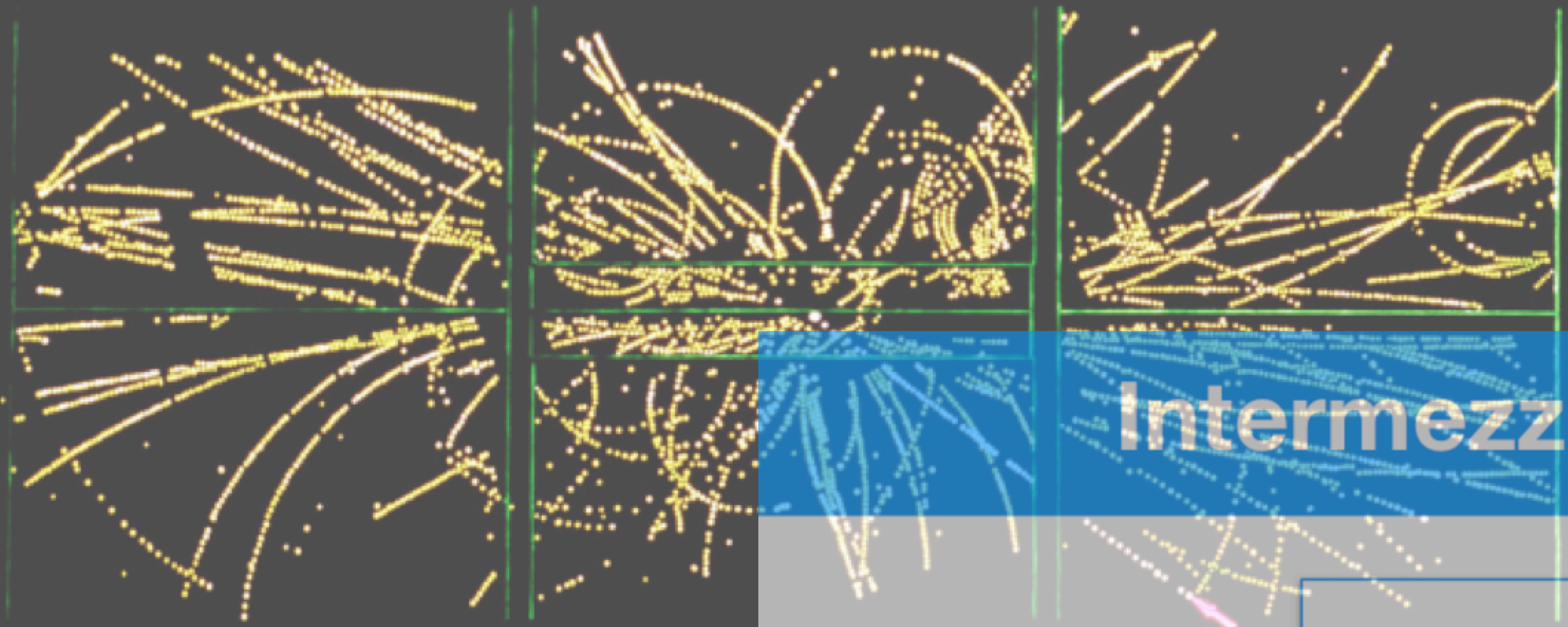


Sample for ATLAS (same for CMS)

Difficult signatures requiring specific complex reconstruction and trigger!

the new frontier: LLPs

Memories from the W Boson Discovery

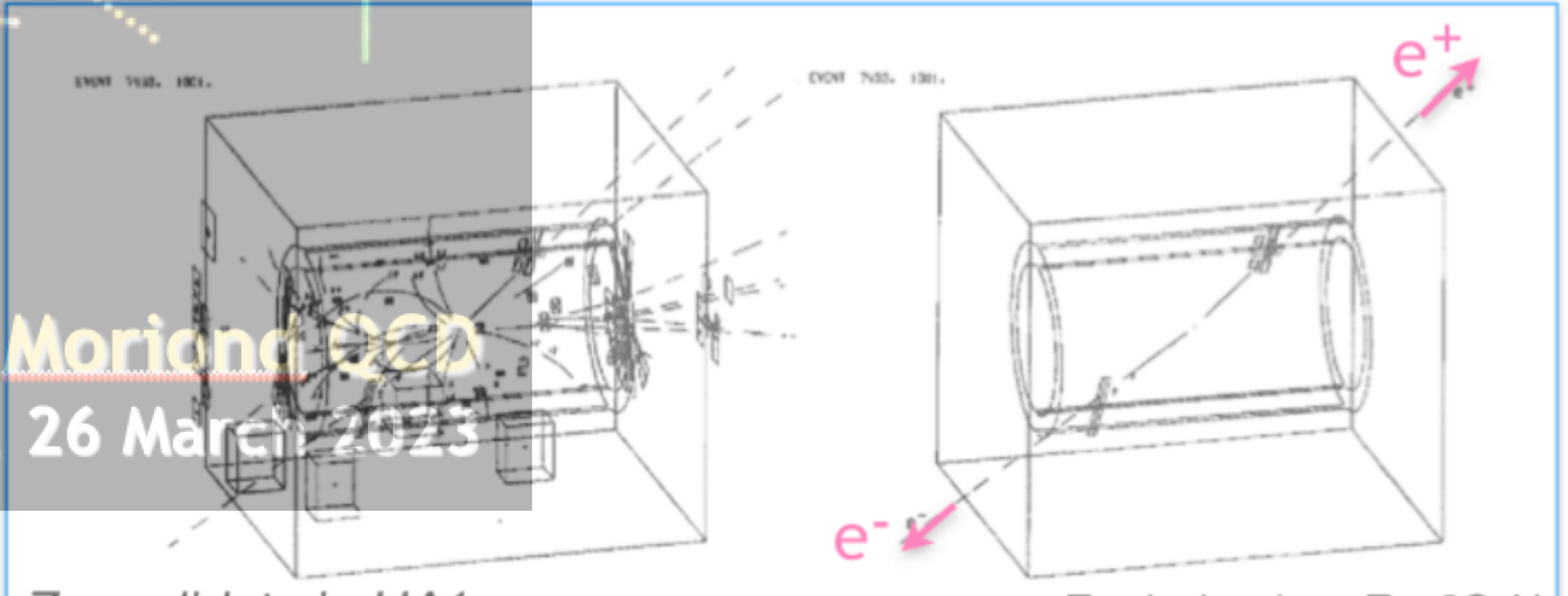


Claudia-Elisabeth Wulz
Institute of High Energy Physics
Austrian Academy of Sciences, Vienna

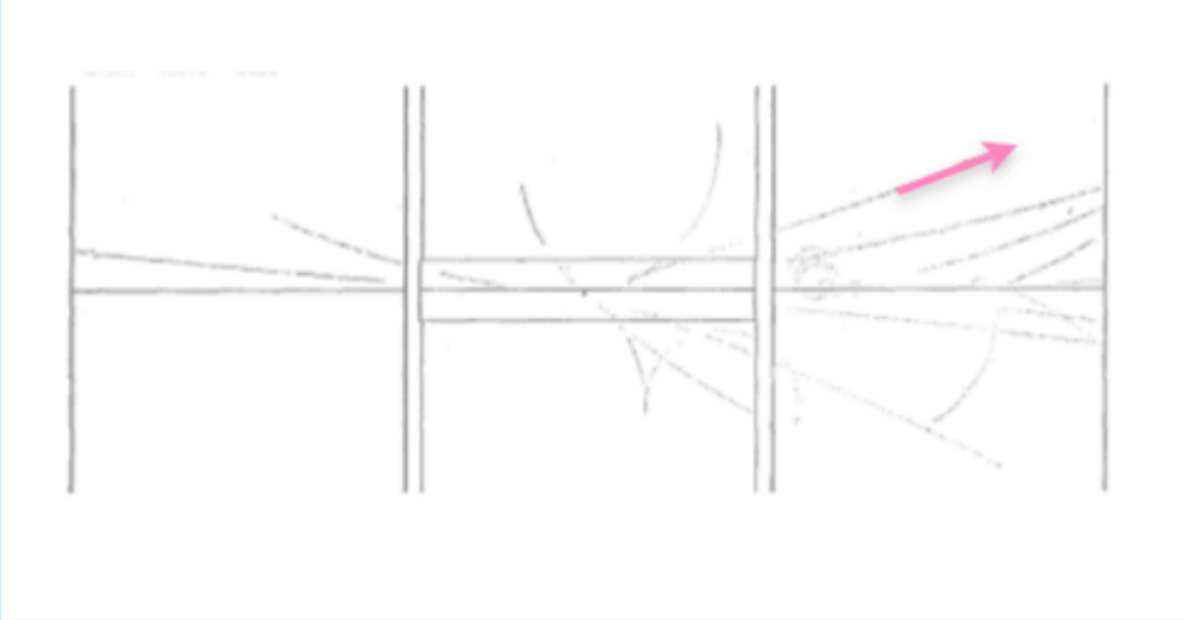
Moriond QCD
La Thuile, 26 March 2023

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!



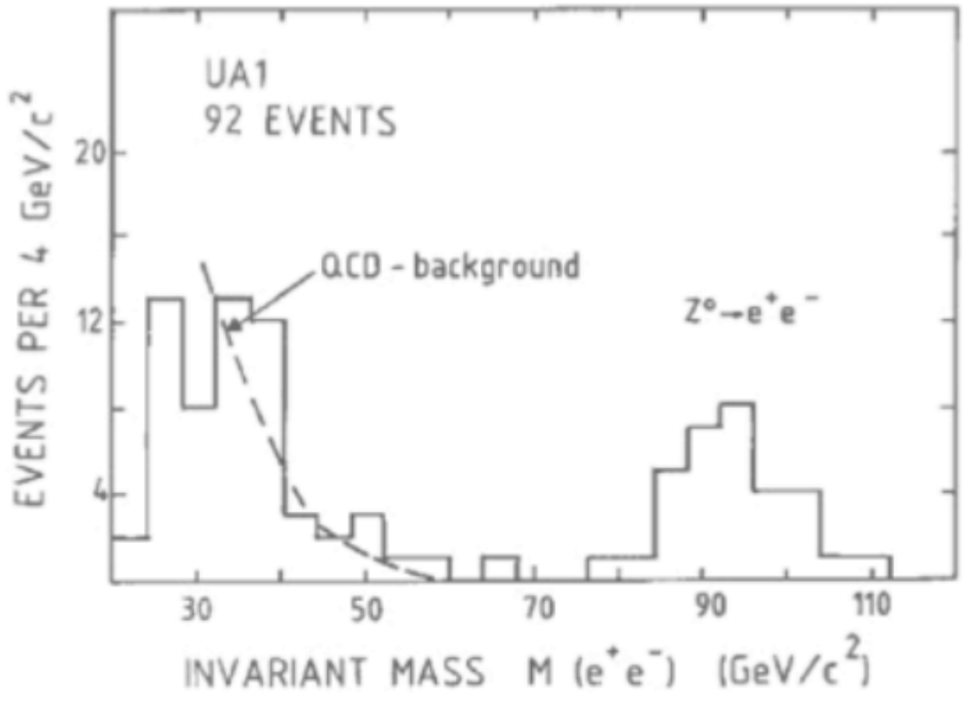
Z candidate in UA1   Track cleaning pT > 2GeV

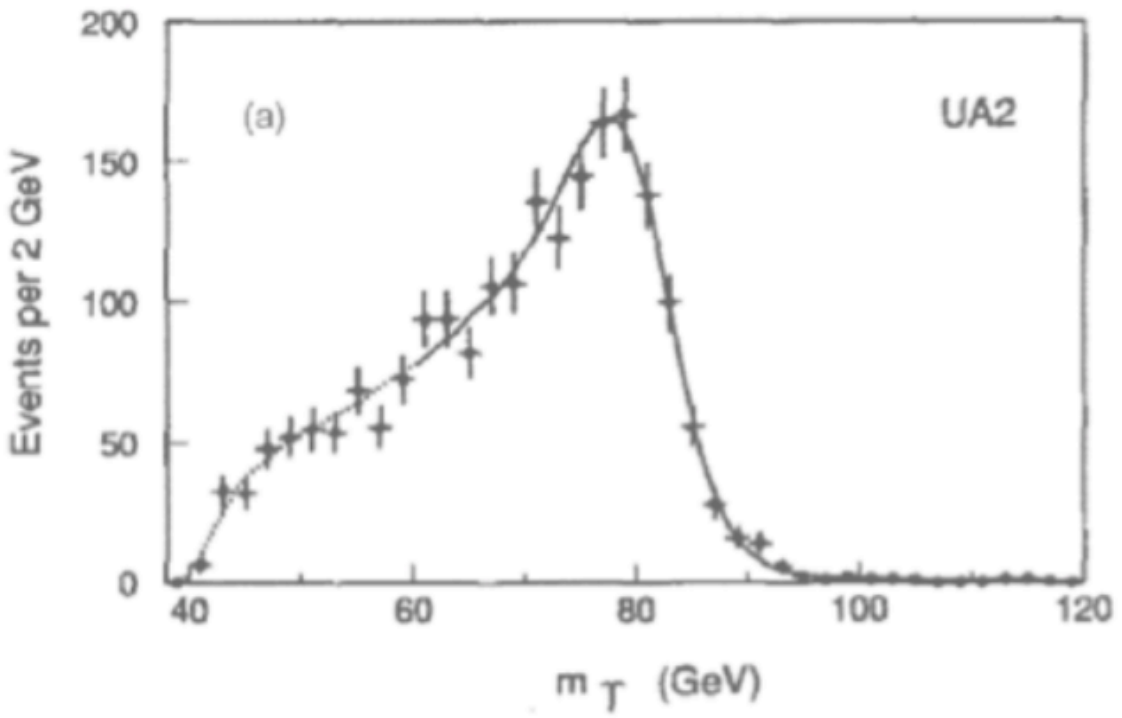


W candidate in UA1

Altogether O(100) Z events

Altogether O(1000) W events





1984

Discovery of the W and Z bosons

Carlo Rubbia, Simon Van der Meer

lots of nice results from LHC and beyond
https://indico.in2p3.fr/event/29681/timetable/#all.detailed

see summary talks esp. experimental
https://indico.in2p3.fr/event/29681/contributions/122580

more results in ongoing Moriond QCD session + Hard Probes

https://moriond.in2p3.fr/2023/QCD/Program.html

https://wwuindico.uni-muenster.de/event/1409/