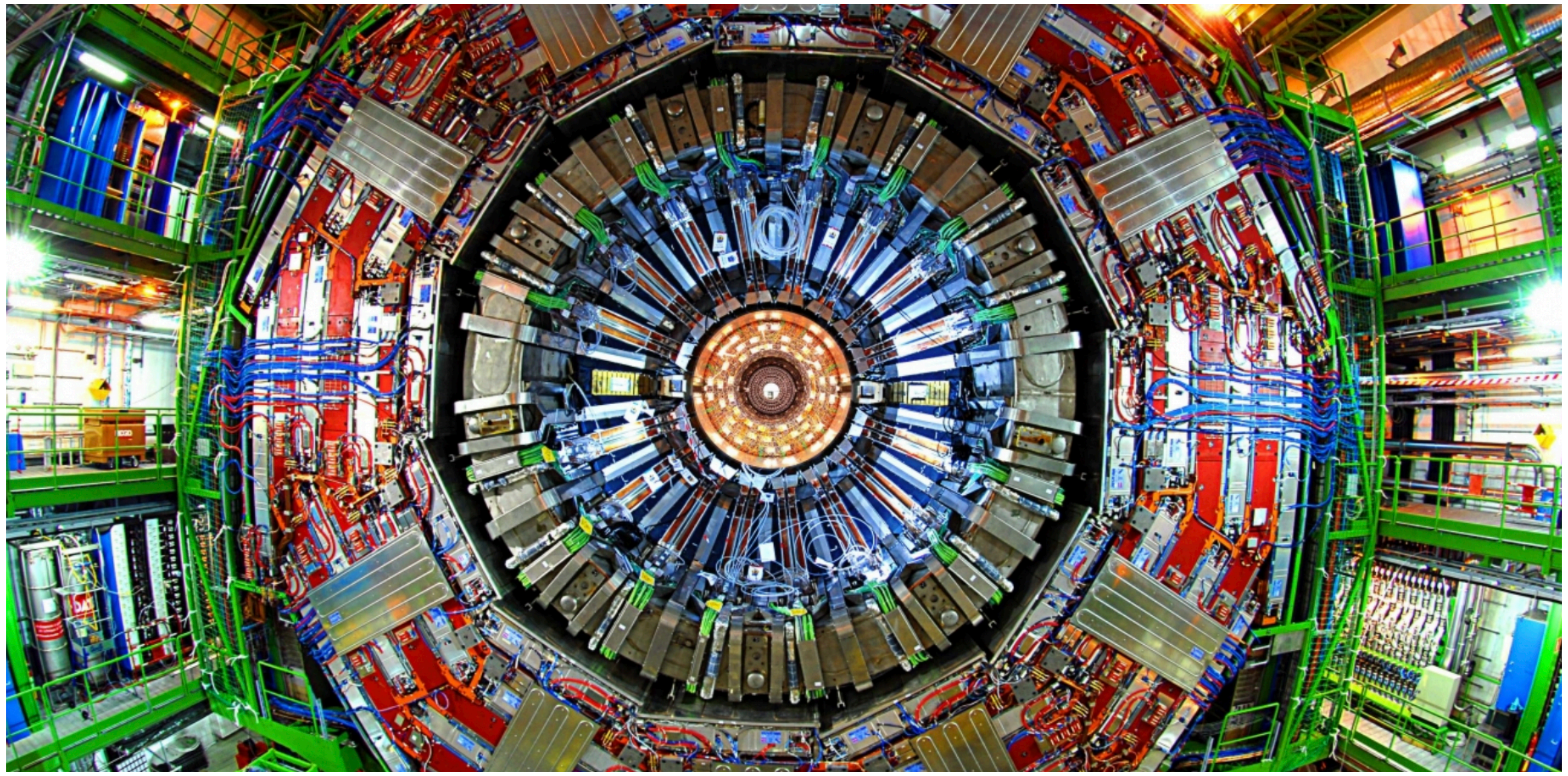
Early Run III Measurements

… let’s have some fun!

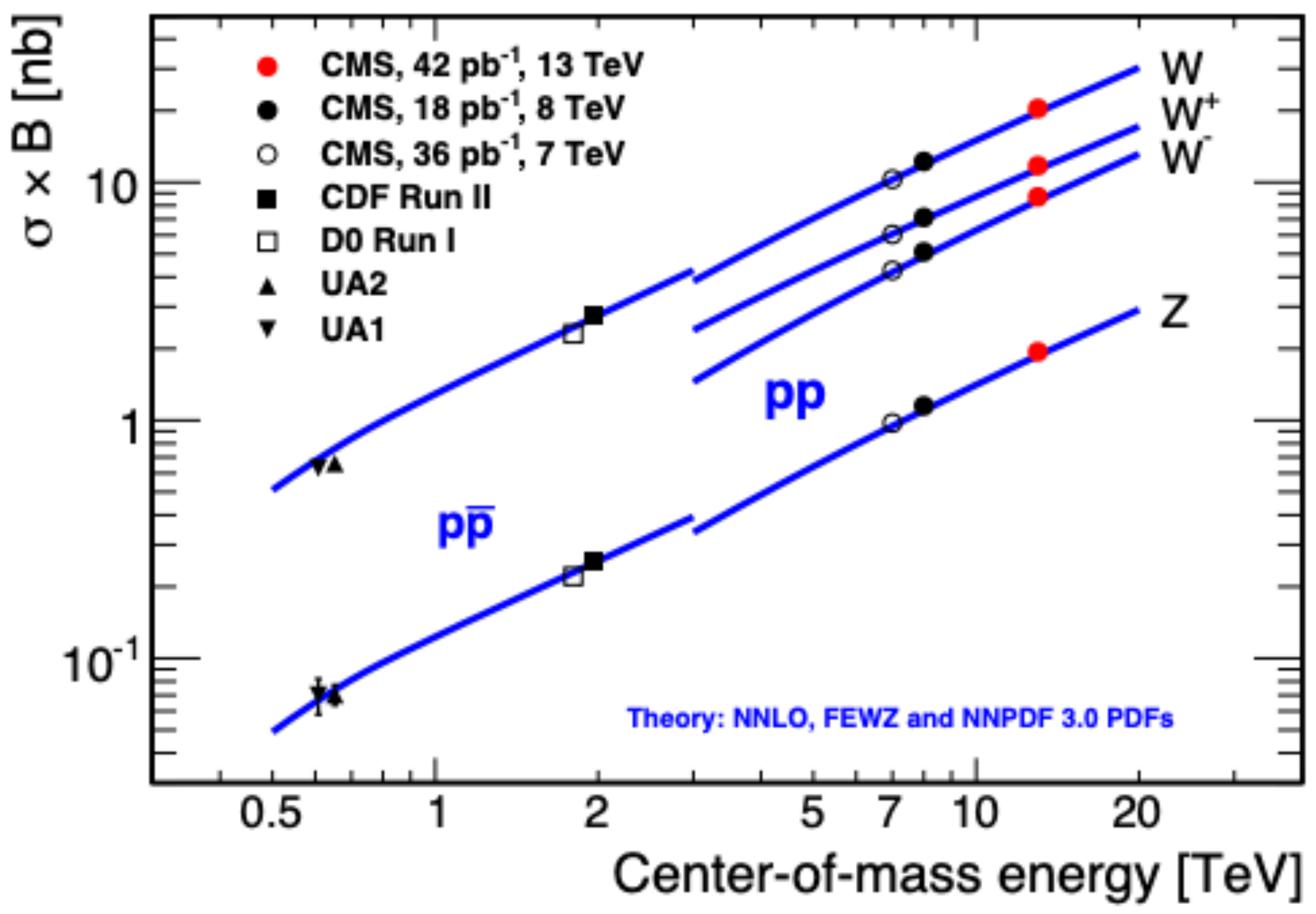


Markus Klute - April 12th 2022, ETP Meeting

Cross Section Measurements

… What are the Goals?

- New center of mass energy :)
- SM precision test
- Constrain PDFs
- **Trigger & Physics object validation**



$$\sigma = \frac{N}{A\epsilon \int \mathcal{L} dt}$$

Acceptance

Compute with MC

Systematics from missing theory calculations

Luminosity

Efficiency

Tag and probe

MC corrected to data

Systematics from signal, background shape modeling, binning

Signal Extraction

Z from di-lepton mass

W from fit to MET

Systematics from MET modeling, energy scale, resolution

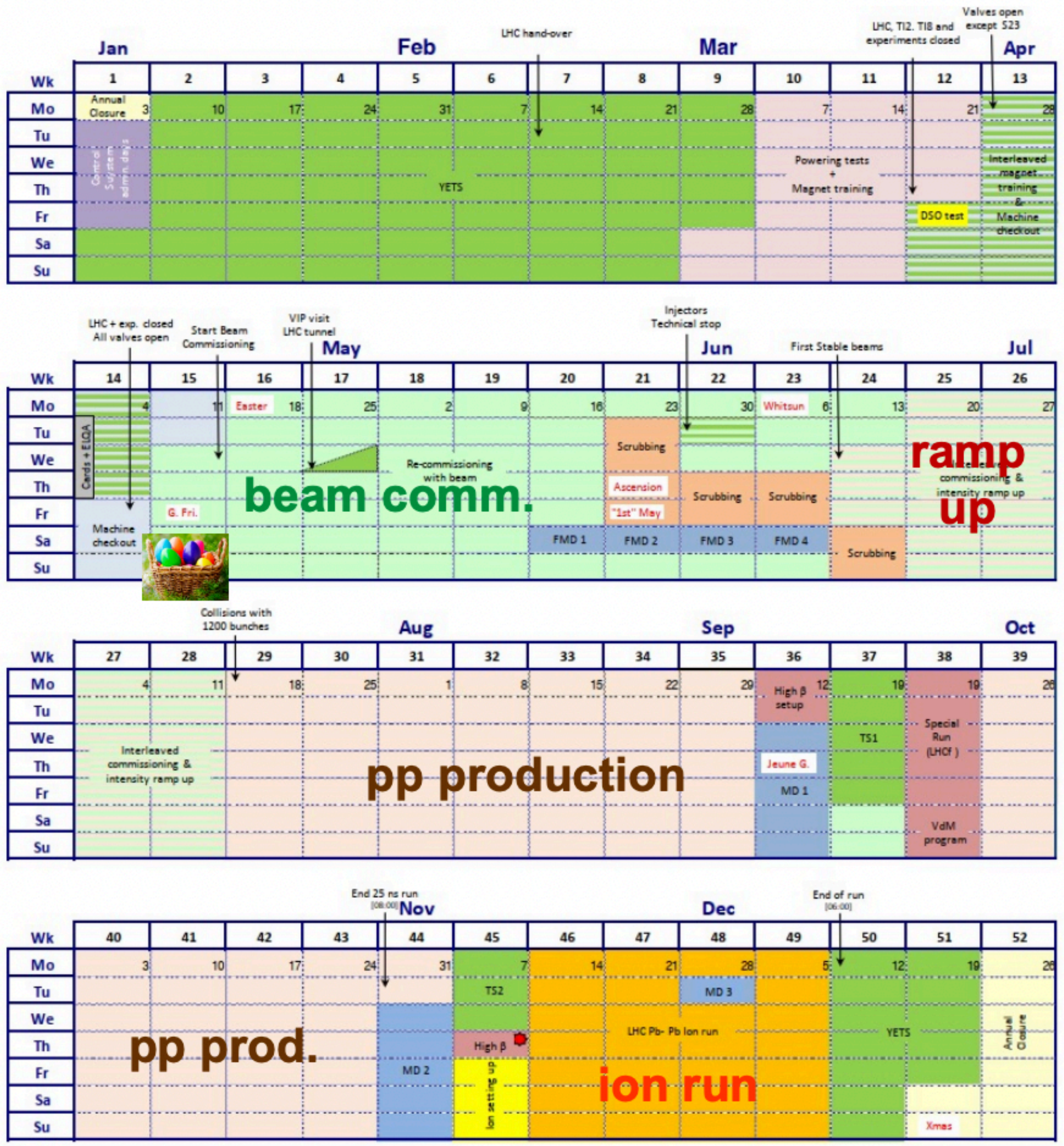
The LHC Schedule in 2022

… we are in week 15

LHC 2022 schedule

Baseline schedule:

- Expt. caverns were closed on March 24th
- 8 weeks of **beam commissioning**
- 2 weeks of **interleaved scrubbing**
- 4.5 weeks of **intensity ramp up** to 2700 bunches
- 12 weeks of **proton production**
- 3 days **ion setup** + 4 weeks of **ion run**
  (last week is pp ref run)
- 2 **MD blocks** + few **MD days**
- 2 **technical stops**
- **special physics** runs (VdM, LHCf, 90m b*)



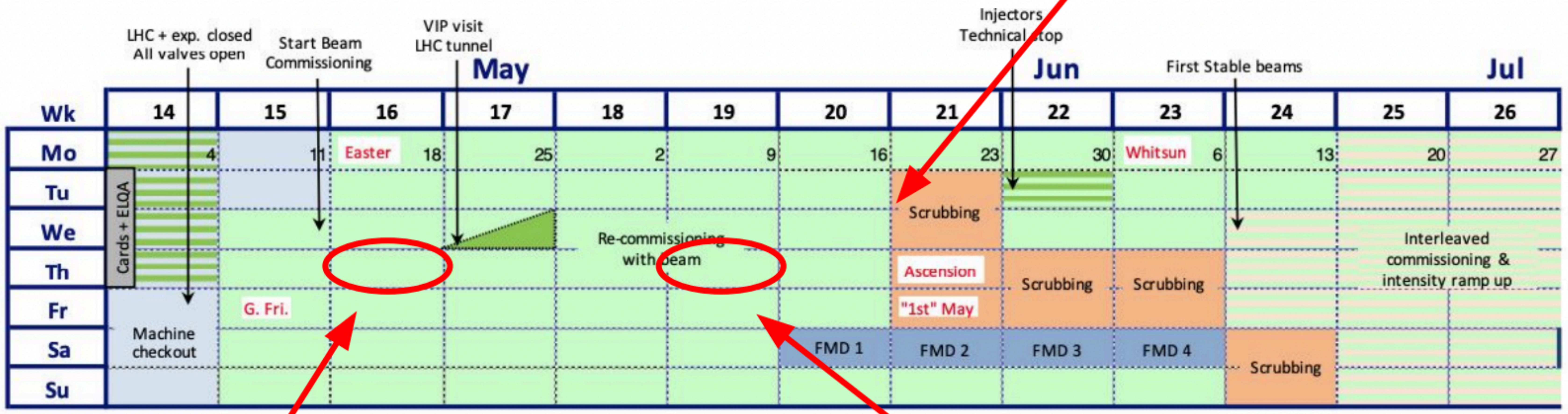
Slide by Filip Moortgat

The LHC Schedule in 2022

… we are in week 15

LHC plans for next weeks

First 900 GeV stable beam: second half of May



First beam (and first splashes events for experiments) delayed of at least 1 week due to cryo incident in P4

All RF systems ready for beam. Full time beam commissioning will start only at this point. Uncertainty: LHCb will require 1 week in May (still not sure when they are ready) to instal velo. We hope that this intervention is in the shadow of the RF setup.

Slide by Giani Masetti

The LHC Schedule in 2022

… intensity ramp up parameter

With 1.2×10^{11} ppb and 2748 bunches:

Most likely at beginning

Emittance	ε = 2.5 μm	ε = 1.8 μm
Beta* = 60 cm	PU = 33 Lumi = 1.3×10^{34} $cm^{-2}s^{-1}$	PU = 43 Lumi = 1.6×10^{34} $cm^{-2}s^{-1}$
Beta* = 30 cm	PU = 55 Lumi = 2.1×10^{34} $cm^{-2}s^{-1}$	PU = 69 Lumi = 2.7×10^{34} $cm^{-2}s^{-1}$

If $\varepsilon > 2.3$ μm, PU never exceeds 60. In case of smaller emittance, LHC will level on PU if needed.

With less bunches in machine: same PU but less inst. luminosity (at ε = 2.5 μm, β^*= 30, PU = 55):

# bunches	3/12	75	300	600	900	1200	1800	2400	2700
Lumi ($cm^{-2}s^{-1}$)	2×10^{31}	6×10^{32}	2.4×10^{33}	4.7×10^{33}	7×10^{33}	9.4×10^{33}	1.4×10^{34}	1.8×10^{34}	2.1×10^{34}

For 1.4×10^{11} ppb, multiply the lumi and PU by 1.36

Slide by Giani Masetti

- Intensity ramp will take about 5 weeks
- Difficult to estimate the integrated luminosity as the fill length is not known
- Historical: 3 fills with 20h each
- That means:
  - **3/12 bunches: O(1 pb^{-1})**
  - **75 bunches: O(30 pb^{-1})**
  - **300 bunches: O(160 pb^{-1})**

The LHC Schedule in 2022

… luminosity and pileup

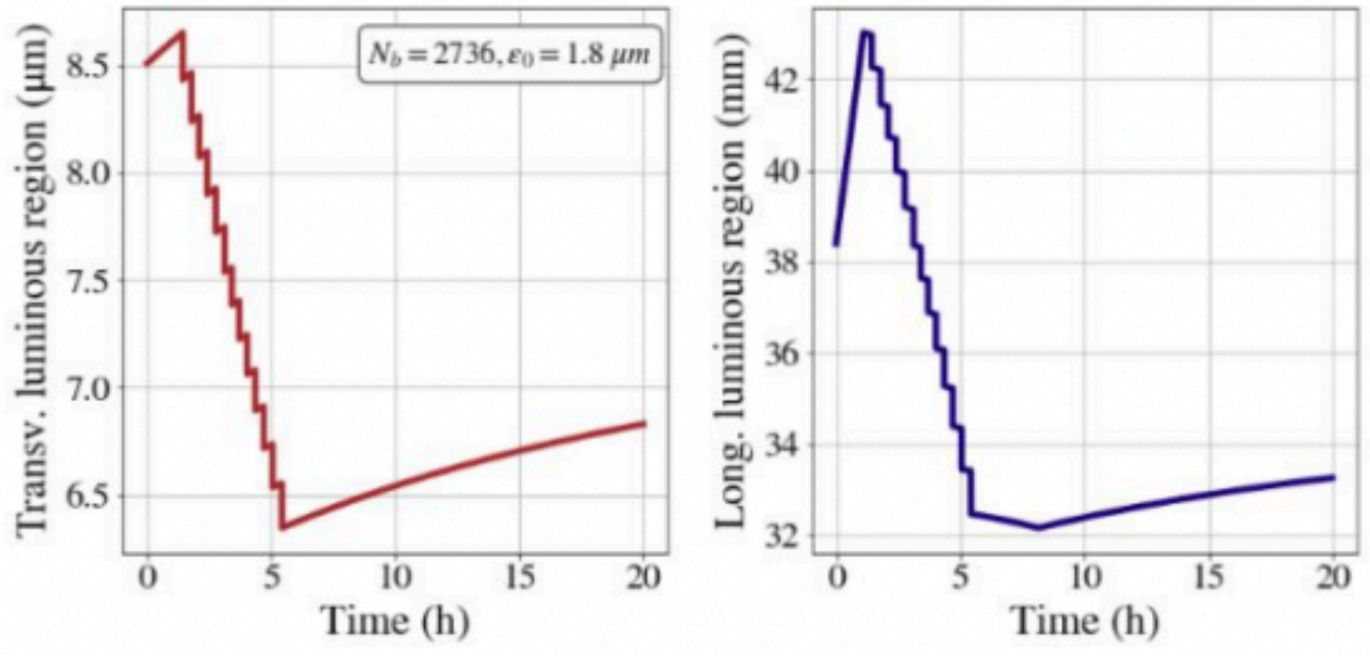
Luminosity and pile-up limitations for ATLAS and CMS:

- Foreseen to level at $2 \times 10^{34}\ cm^{-2}s^{-1}$
- Both experiments limited to PU below ~ 60
- Luminosity jumps during levelling should be below ~ 5%
    - Optimal use of trigger bandwidth
    - data recorded during beta* change can be used without issue

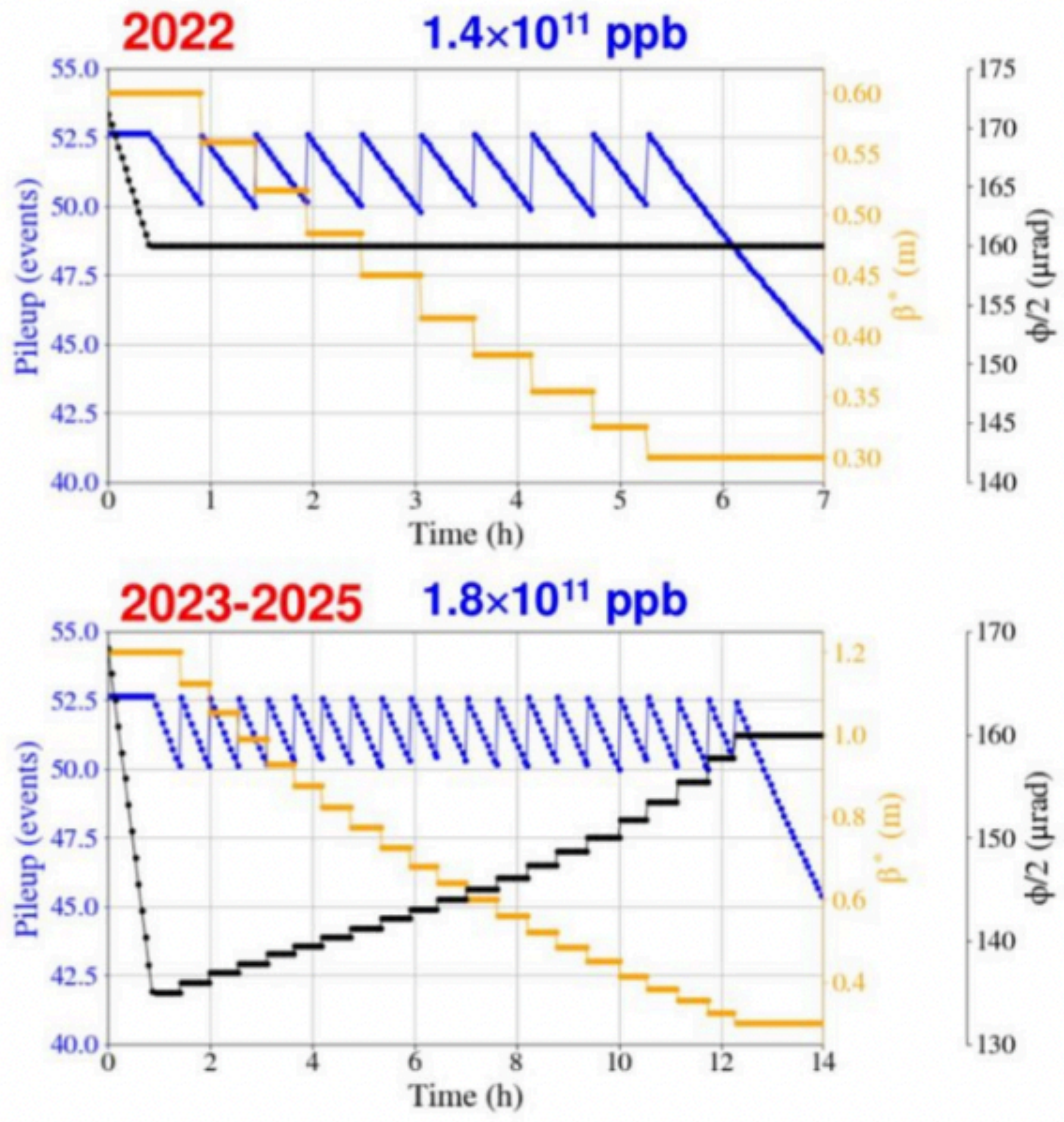
Luminous region limitations

- Beta* leveling implies change of luminous region during a fill
- Small effect:

Lumi-region size vs time



Pile-up leveling vs time



Crossing angle leveling only from 2023 onwards

Slide by Giani Masetti

Cross Section Measurements

… What are the Goals?

- Reference: SMP-20-004 or other W/Z inclusive cross section measurements

$$\sigma \times Br = \frac{N}{A\epsilon\mathcal{L}}$$

- Number of observed signal events
- Acceptance
- Efficiency
- Luminosity

$$\frac{\sigma_W}{\sigma_Z} = \frac{N_W}{N_Z}\frac{A_Z\epsilon_Z}{A_W\epsilon_W}$$

1. Normalise dataset (luminosity calibration) with precision < 2% using Z(μμ) yield
2. Inclusive W and Z cross sections and cross section ratios with electrons and muons
3. Inclusive Z cross section with tau

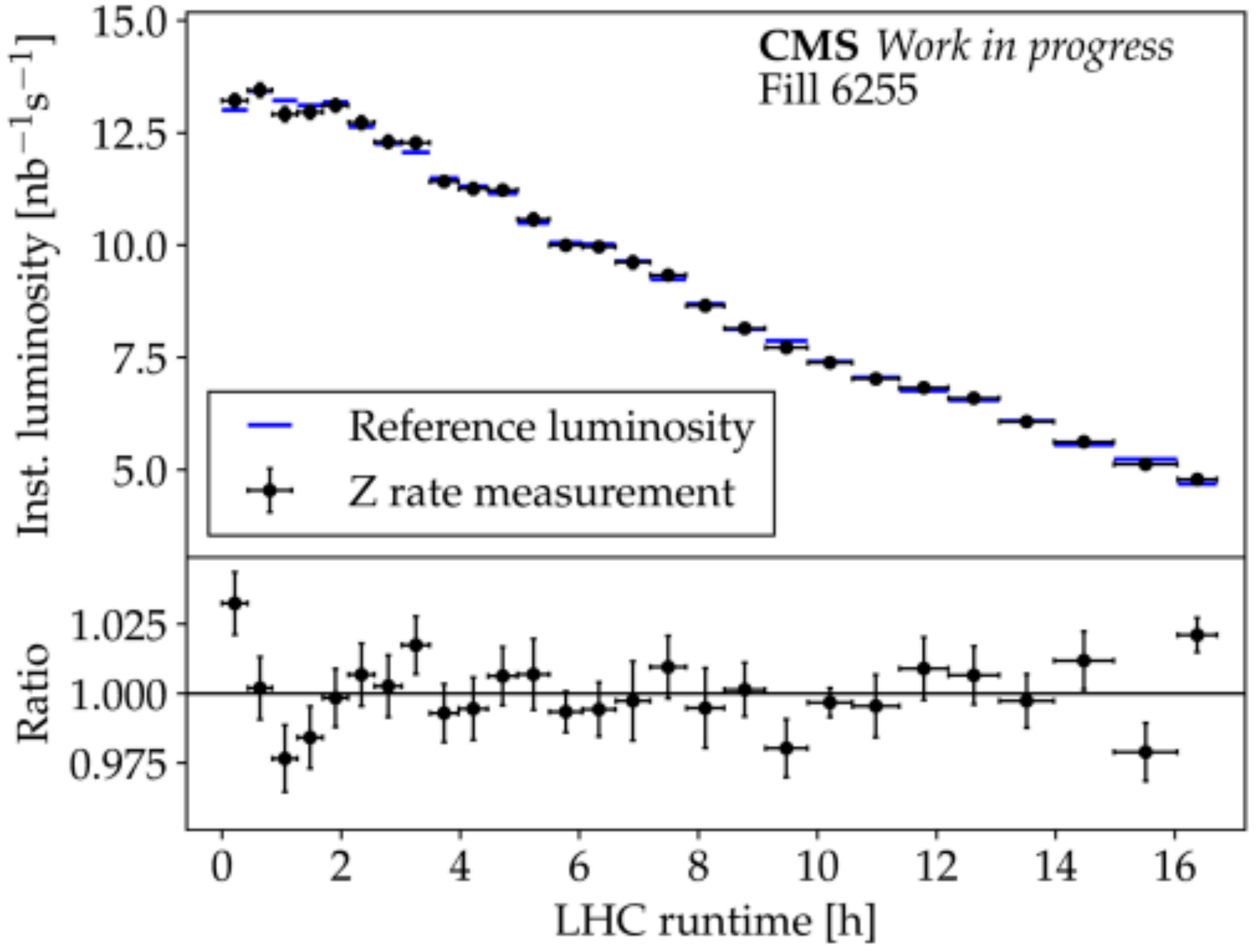
Cross Section Measurements

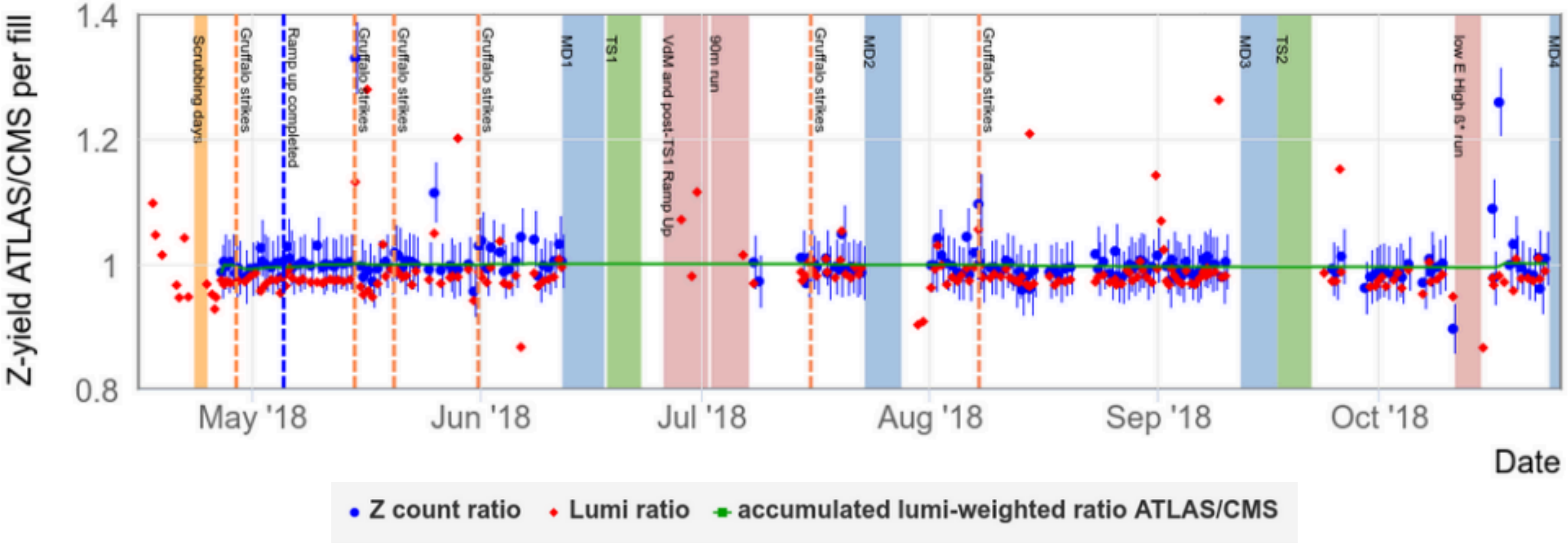
… What are the Goals?

1. Normalise dataset (luminosity calibration) with precision < 2% using Z(μμ) yield

$$\mathcal{L} = \frac{N^{Z}_{\text{Reco}}}{\sigma^{Z}_{\text{fid}} \cdot \epsilon^{Z}_{\text{Reco}}}$$

from LUM-21-001 paper draft





Event Selection

… From SMP-20-004

General

- Single Muon or Single Electron trigger match
- Electrons pass Medium cut-based ID
- Muons pass Tight cut-based ID
- Veto lepton uses Loose cut-based ID

Triggers:

- Single Muon
  - pT > 17 GeV [both]
- Single Electron
  - pT > 20 GeV [13 TeV]
  - pT > 17 GeV [5 TeV]

Z selection

- 2 well-identified leptons
  - Same flavor
  - Opposite charge
- Lep1: $p_T > 25$ GeV, $|\eta| < 2.4$
- Lep2: $p_T > 25$ GeV, $|\eta| < 2.4$
- 60 GeV < m_{ll} < 120 GeV

W selection

- 1 well-identified lepton
- Veto selection on presence of same-flavor lepton passing Loose ID
- Lep1: $p_T > 25$ GeV, $|\eta| < 2.4$

Fiducial Region Definition

… From SMP-20-004

Z selection

- Two leptons
  - Same flavor
  - Opposite charge
- Lep1: $p_T > 25$ GeV, $|\eta| < 2.4$
- Lep2: $p_T > 25$ GeV, $|\eta| < 2.4$
- 60 GeV < m_{ll} < 120 GeV

W selection

- Lep1: $p_T > 25$ GeV, $|\eta| < 2.4$
- m_T >40 GeV

Signal Extraction

… From SMP-20-004

- Simultaneous fit using all three signals per channel
  - W^+, W^-, and Z
- Cross sections for W^+, W^-, W, Z, and ratios W^+/W^-, W^+/Z, W^-/Z, W/Z
  - Directly define ratios as parameters to be fit for

Fit observables:

Z:	m_{ll}
W:	$m_T = \sqrt{2 p_T^l p_T^{miss} \left(1 - \cos\Delta\phi\left(\vec{l}, \overrightarrow{p_T}^{miss}\right)\right)}$

Karlsruhe Institute of Technology

Lepton Efficiency Studies

… From SMP-20-004

Lepton Reconstruction & Identification Efficiency

- Efficiency for leptons can be factorized and each category derived separately:

$$\epsilon_e = \epsilon_{HLT} \times \epsilon_{GSF}$$
$$\epsilon_\mu = \epsilon_{HLT} \times \epsilon_{Sta} \times \epsilon_{sel+ID+trk}$$

- ϵ_{GSF} - create ECAL-driven GSF electron passing ID & iso criteria
- ϵ_{Sta} - matching of track from muon to global muon
- $\epsilon_{sel+ID+trk}$ - matching of standalone muon to global muon and pass ID & iso criteria
- ϵ_{HLT} - electron or muon passing ID & iso requirements being selected by HLT

Tag & Probe with $Z \rightarrow ll$

- Tag lepton:
  - Pass standard analysis selection
  - Matched to trigger
- Probe lepton:
  - Very loose requirements
  - Classified as passing/failing categorizations on prior slide
- Efficiency calculation:

$$\epsilon = \frac{N_{pass}}{N_{pass} + N_{fail}}$$

Lepton Efficiency Studies

… From SMP-20-004

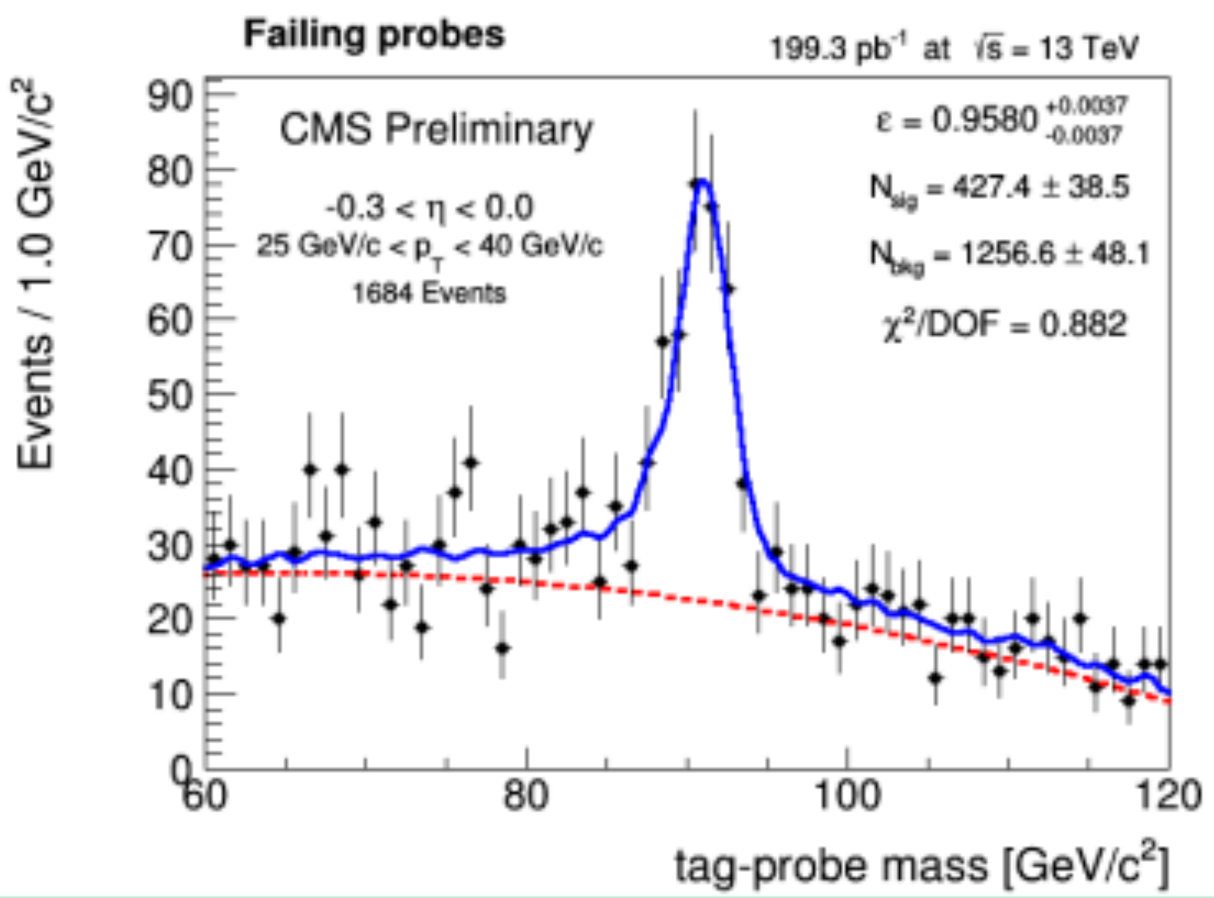
Deriving Efficiencies

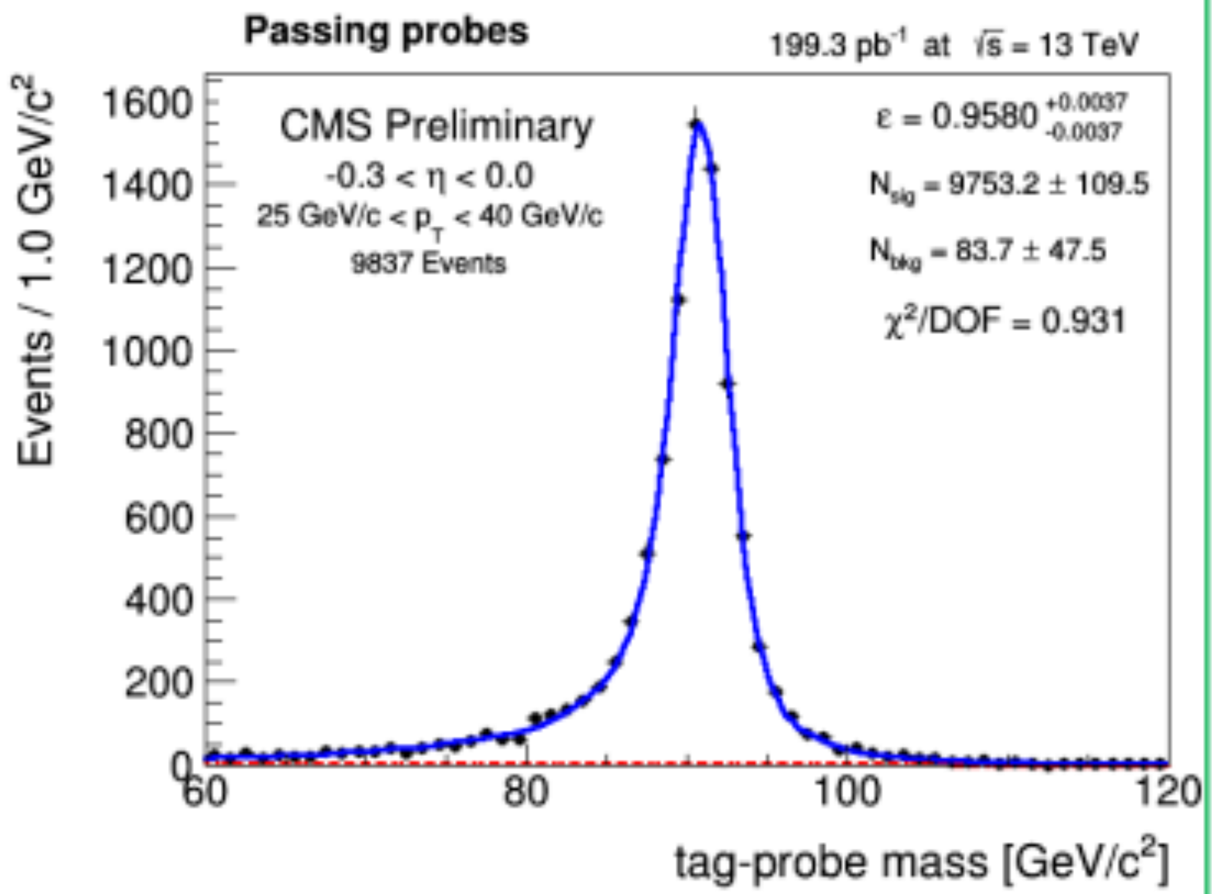
- Calculate in bins of probe (p_T, η)
- Simultaneous fit of pass and fail events for given bin to extract N_{pass} and N_{fail}
  - Signal shape – MC (X) Gaussian
  - Background shape – particular to category

    Exponential, Quadratic, Exp(X)Erf,…

$$\epsilon = \frac{N_{pass}}{N_{pass} + N_{fail}}$$

Fit examples: Muon standalone reconstruction efficiency fits showing failing & passing probes for a (p_T, η) bin



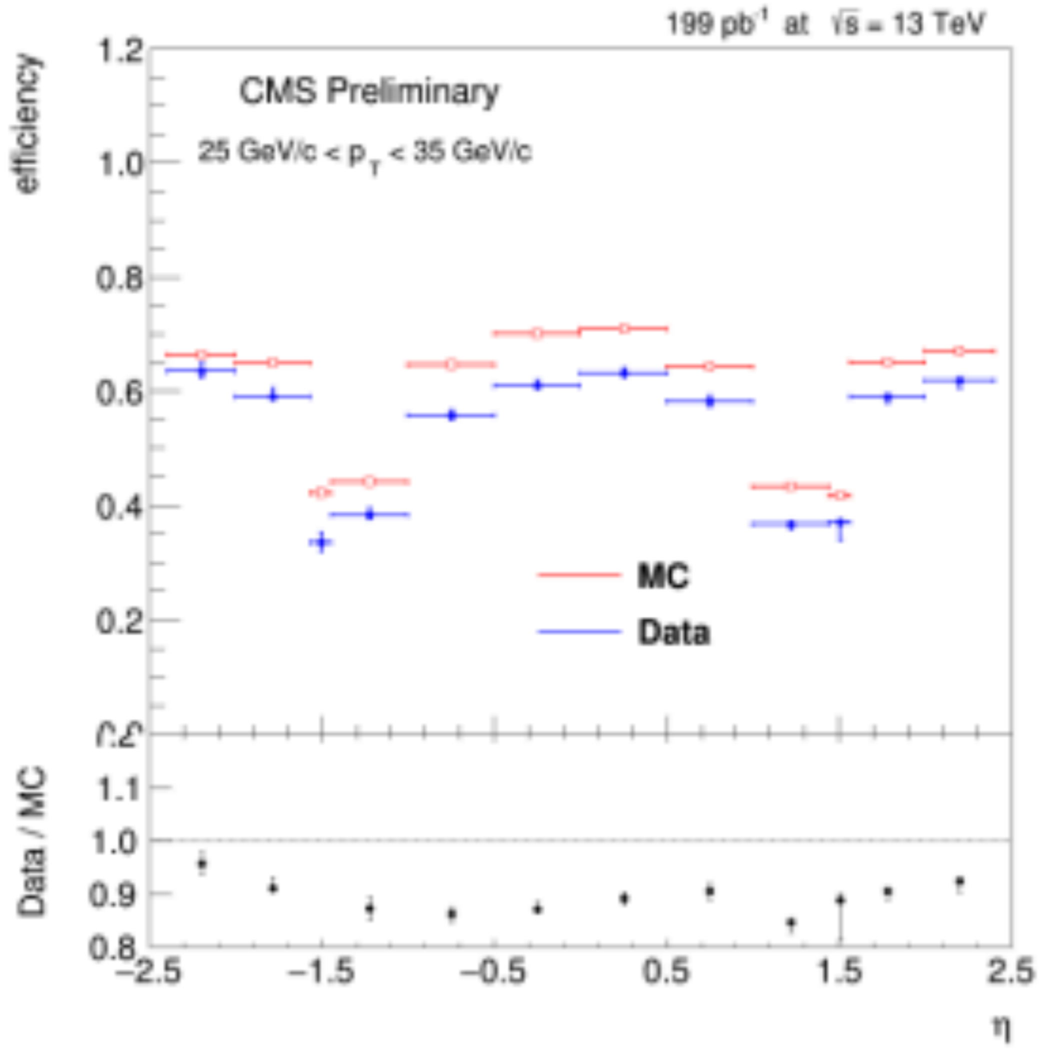


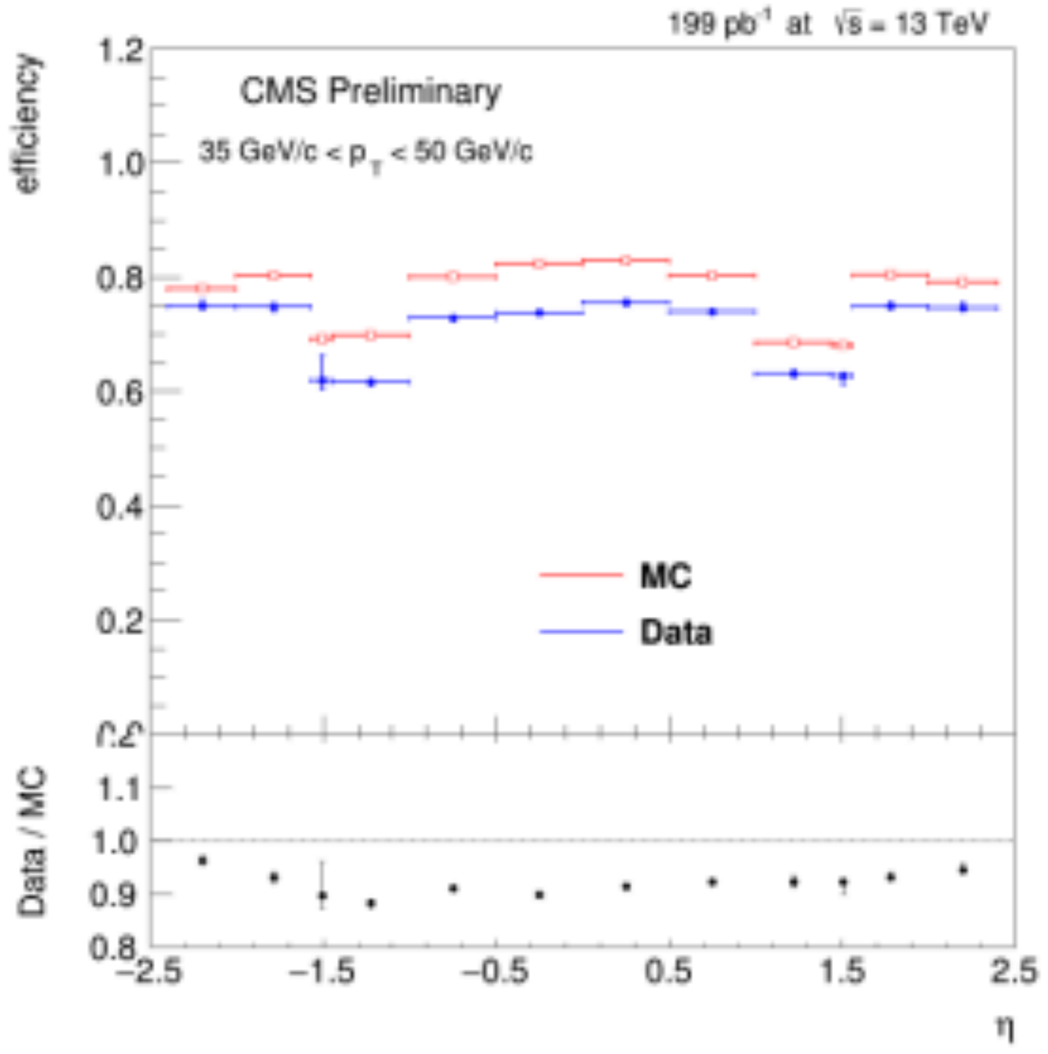
Lepton Efficiency Studies

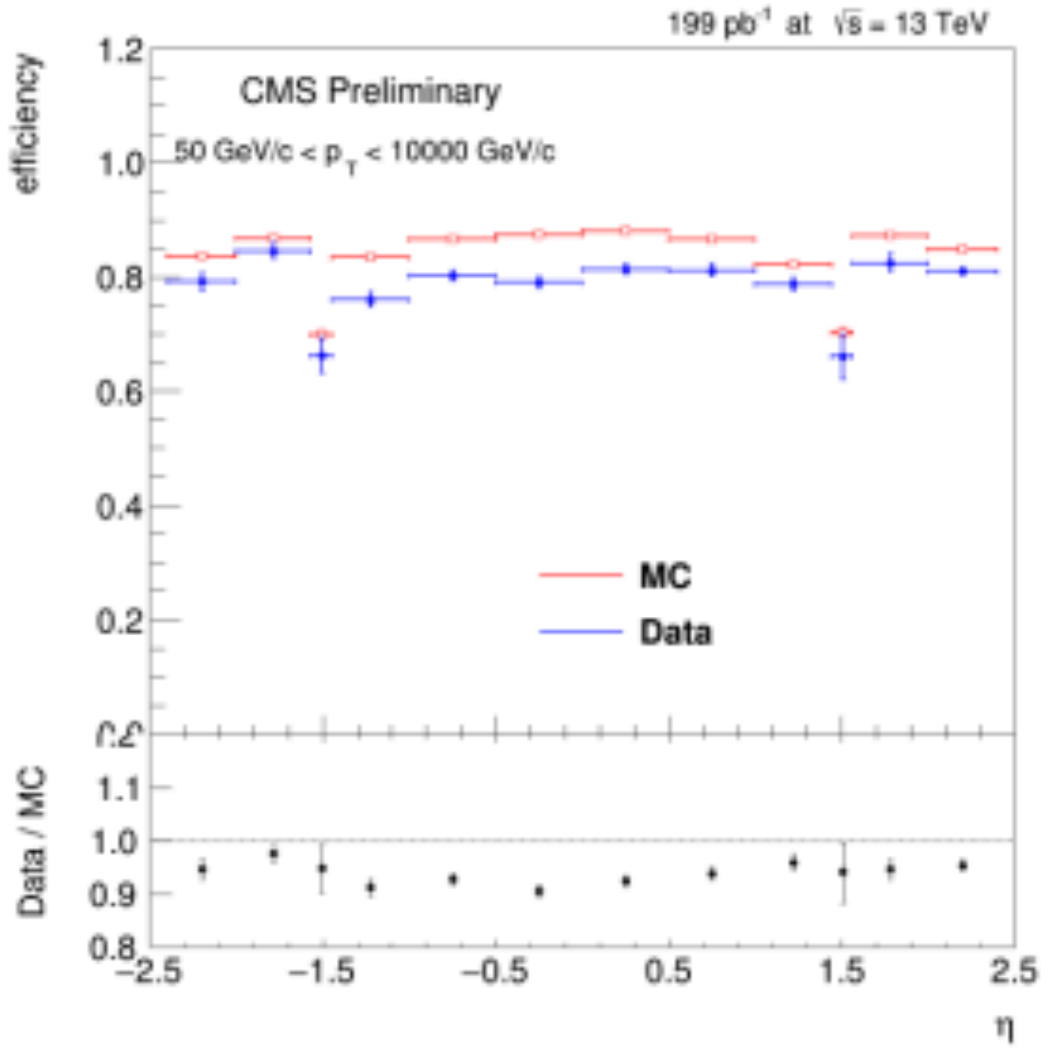
… From SMP-20-004

Efficiency Scale Factors

Examples of Electron GSF reconstruction + ID + Isolation efficiency, binned by pT







Lepton Efficiency Studies

… From SMP-20-004

Efficiency Uncertainties

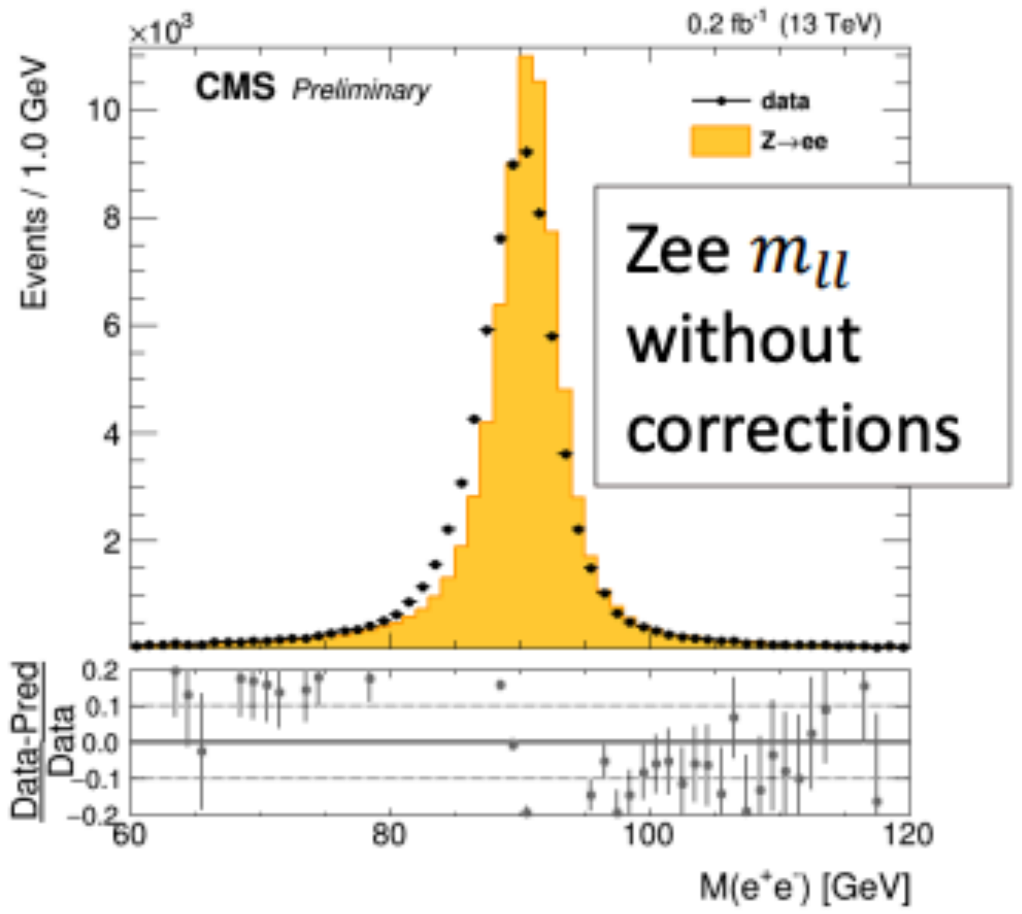
- Systematic – alternatives to fitting model choice
  - Different MC
    - FSR modeling (Photos vs. Pythia)-> Reweight reconstructed Z->ll mass distributions based on gen-level post-FSR lepton info
    - Generator choice (aMC@nlo vs. minlo)
  - Background
    - Use different function
  - Tag selection
    - Different tag pT cut (25 GeV vs. 30 GeV)
- Recompute efficiency using alternate models, propagate via shape uncertainties in final fit
- Statistical uncertainties

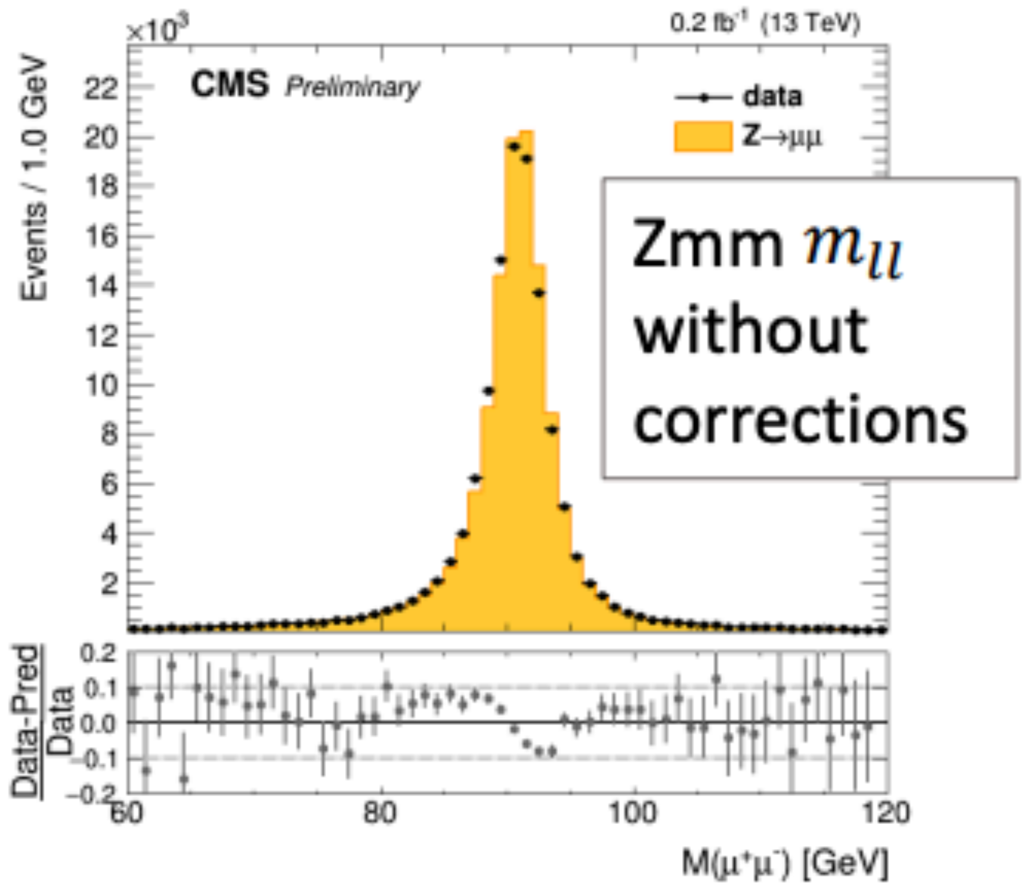
Lepton Scale and Resolution Studies

… From SMP-20-004

Lepton Energy Scale & Resolution

- Additional correction to ensure data/MC agreement in lepton momentum measurements
- Scale – generally too low in data, dilepton mass peak is shifted → rescale lepton pT in data
- Resolution – MC finer resolution than data → Gaussian smearing on lepton pT in MC
- Electrons & Muons both need corrections
- Corrections are data-driven and electron energy scale is run-dependent

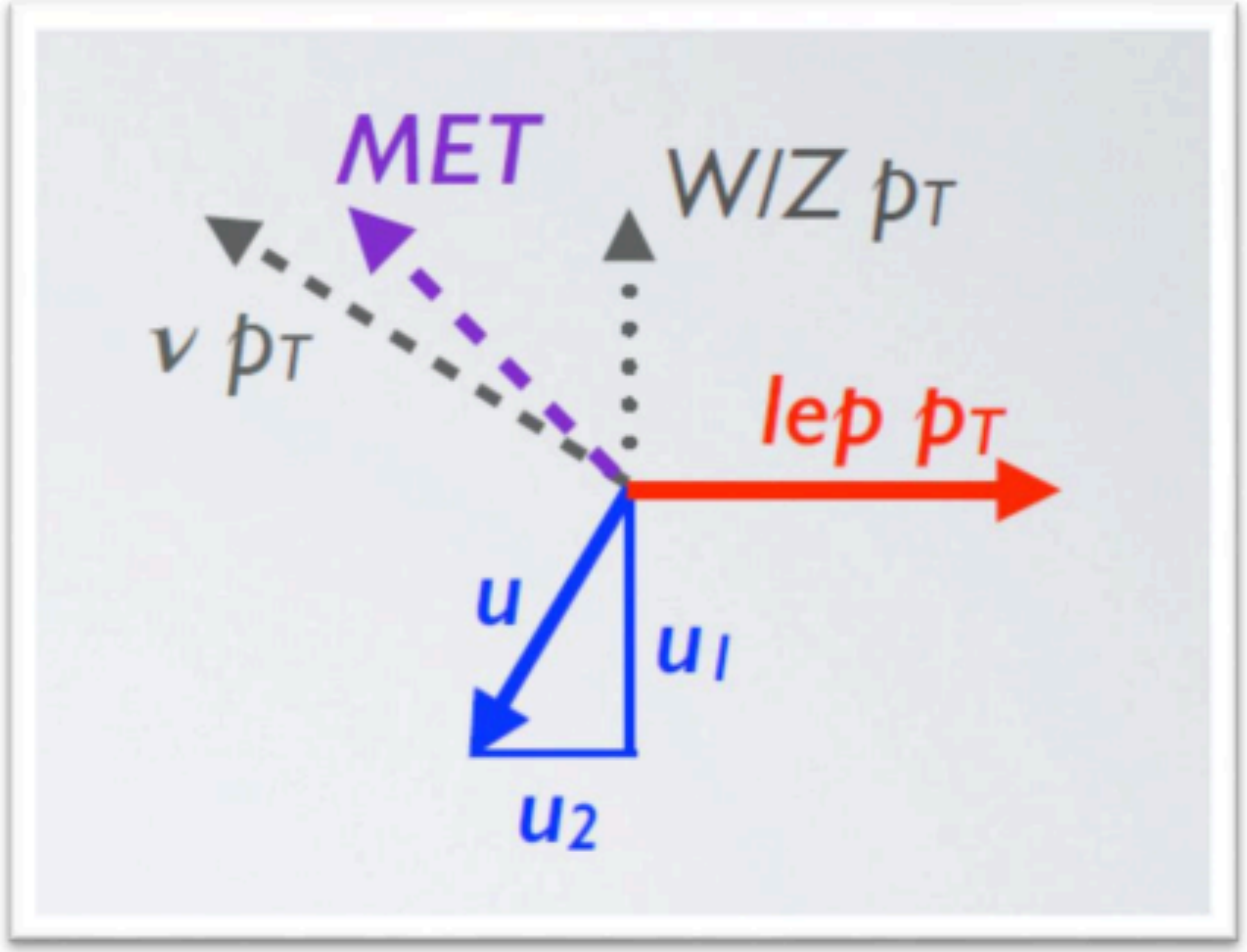




Hadronic Recoil Studies

… From SMP-20-004

- Hadronic recoil is the
- –(MET+lepton) , i.e. everything in the event that isn't from the W
  - Project recoil along parallel (u1) or perpendicular (u2) axis w.r.t. the boson
- Generate sets of recoil distributions:
  - W+ and W- MC
  - Z MC
  - Z Data
- Model & correct recoil distributions

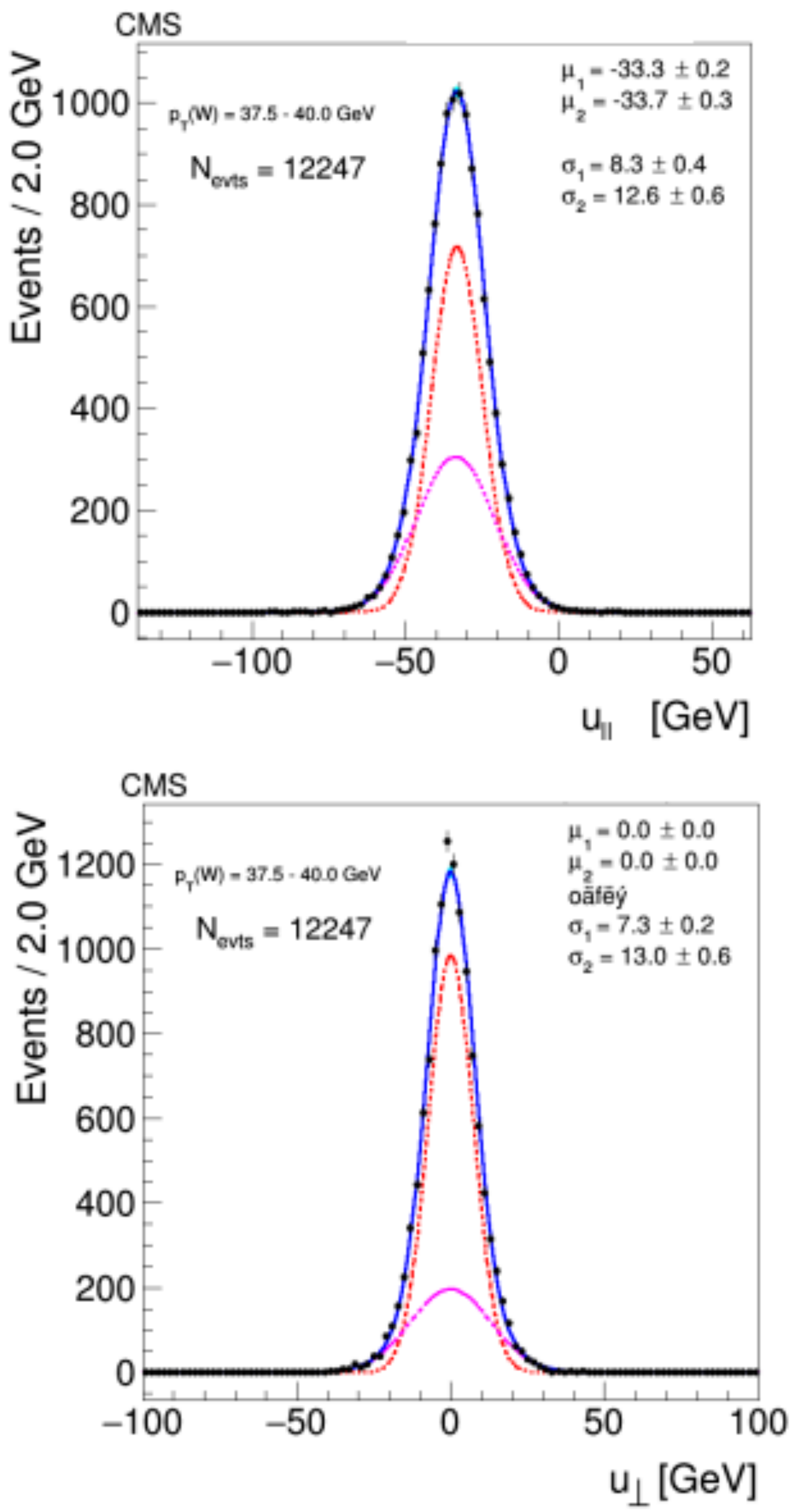


Hadronic Recoil Studies

… From SMP-20-004

- $u_{\parallel}$ and $u_{\perp}$ binned by boson p_T
  - Gen-level for W MC
  - Dilepton pT for Z data and Z MC
- Fit with double-Gaussians
  - $u_{\parallel}$ - 6 free parameters: 2 means, 2 sigmas, 2 normalizations
  - $u_{\perp}$ - 4 free parameters: both Gaussian means fixed to 0

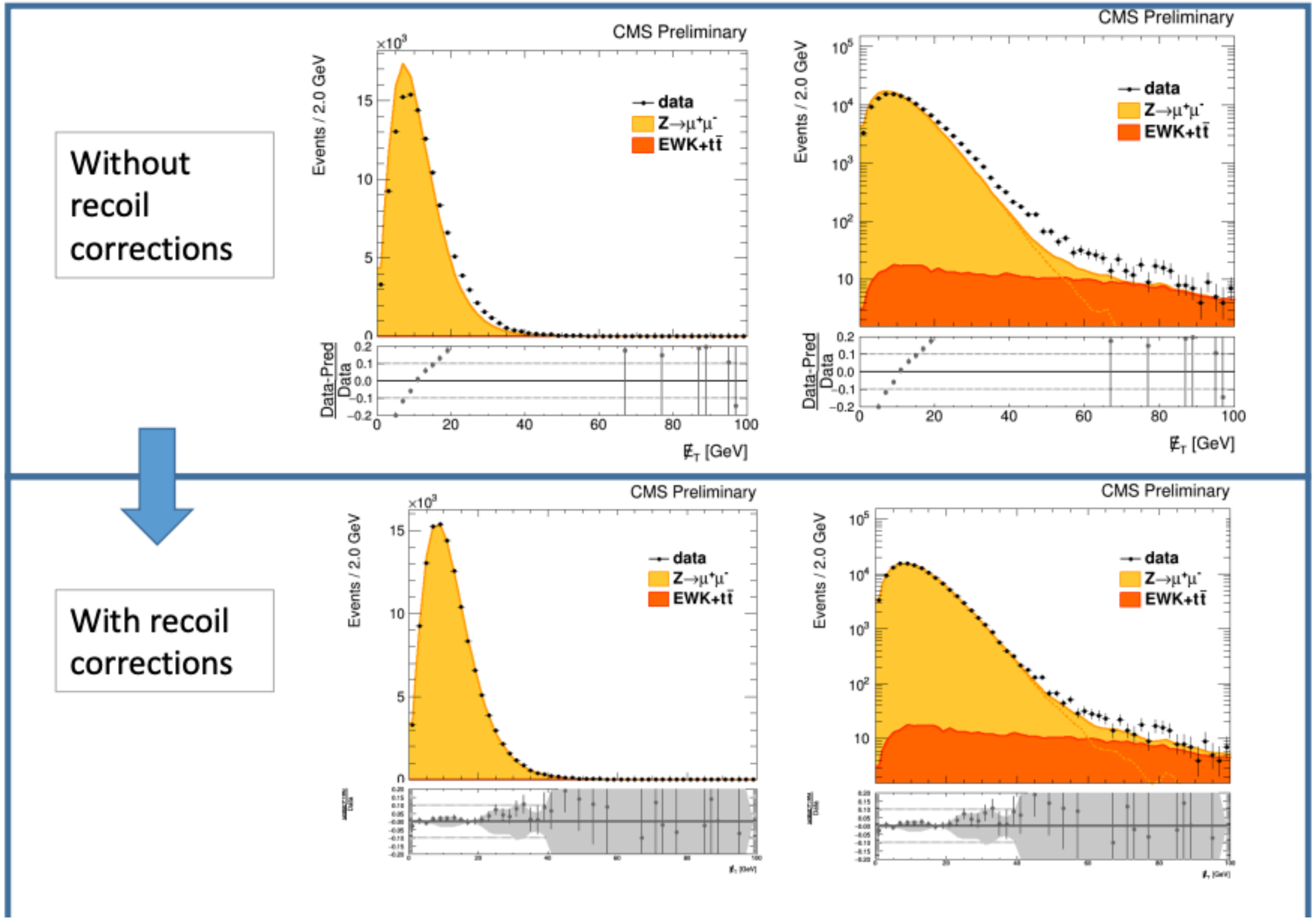
Examples of double-Gaussian fits for W MC



Hadronic Recoil Studies

… From SMP-20-004

MET

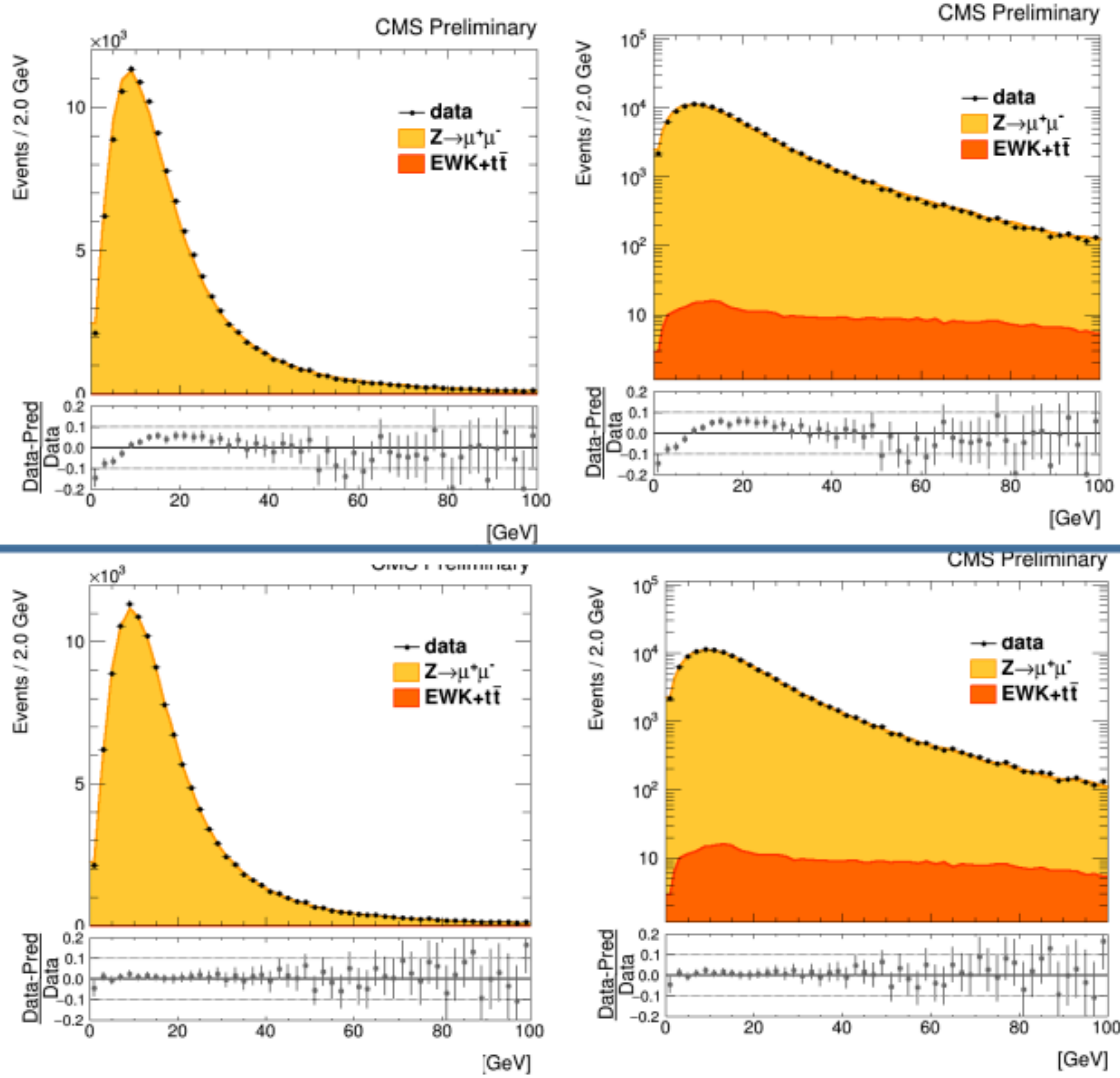


Hadronic Recoil Studies

… From SMP-20-004

RECOIL

Without recoil corrections



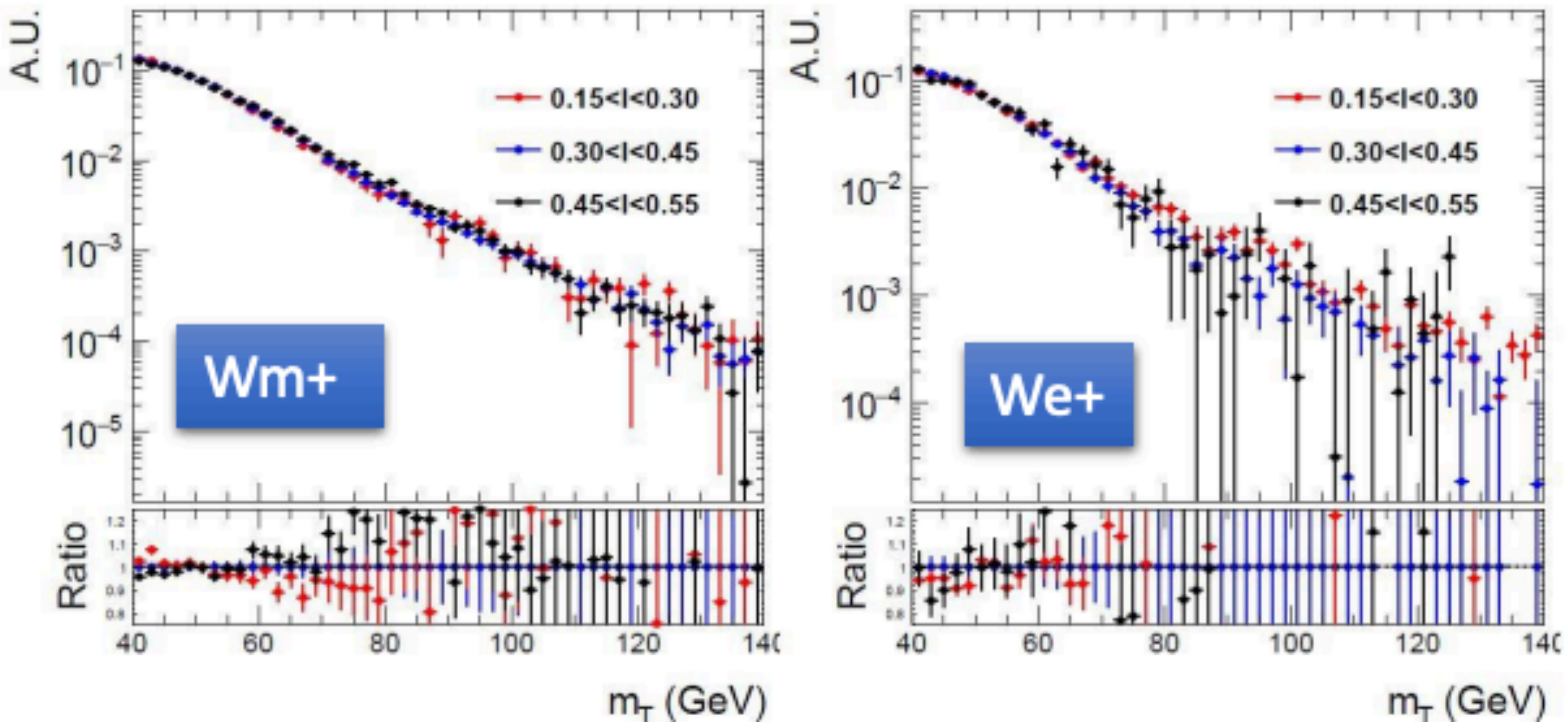
With recoil corrections

QCD Background for W

… From SMP-20-004

- No simulated sample available
- Selection from data of QCD-enriched sample by reversing isolation cut in lepton IDs
- Variations in the QCD distribution due to the control region choice are included in the fit as a shape uncertainty

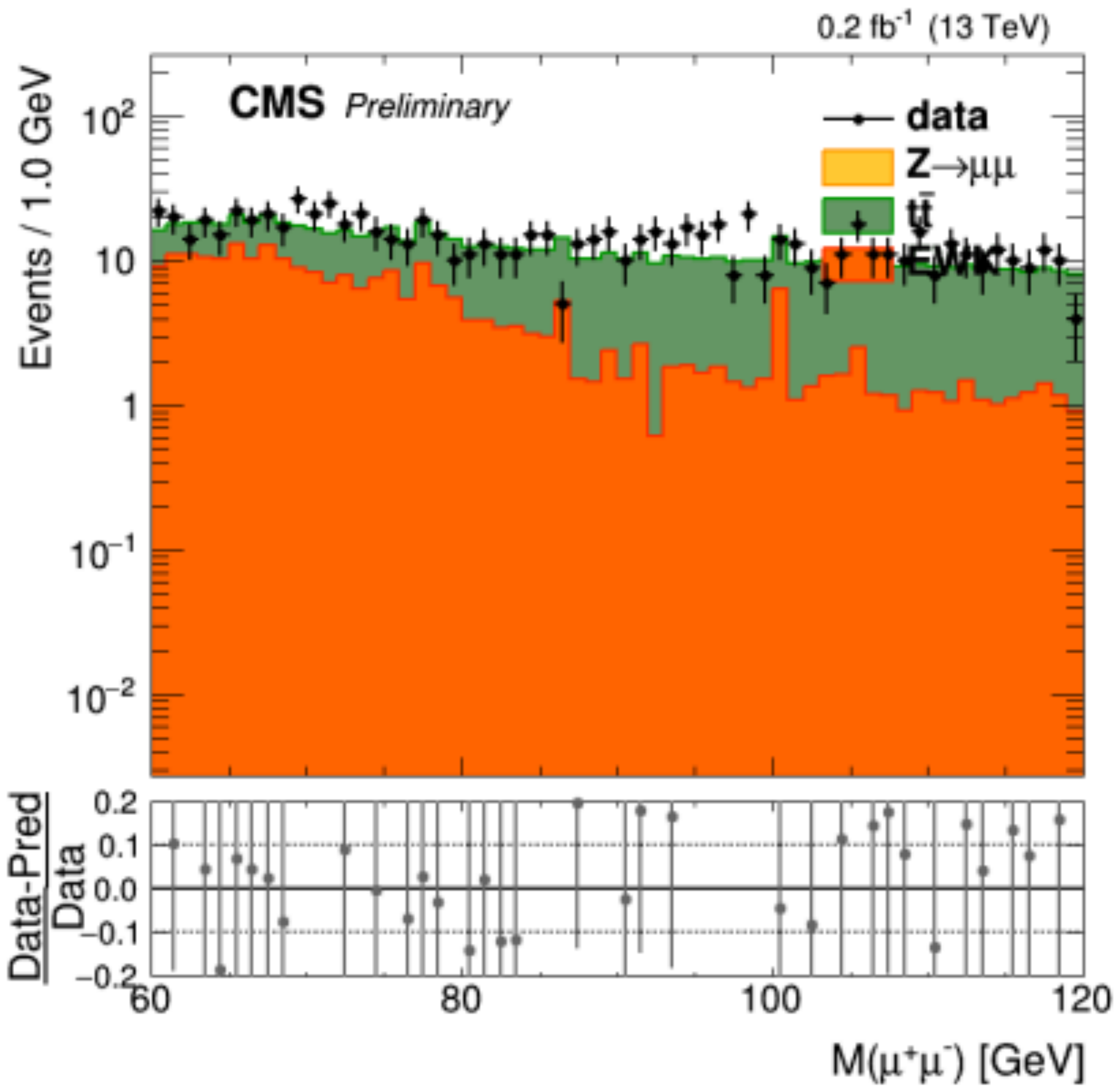
mT distrubutions for W+ channels. Distributions for 3 different isolation bins are shown.



QCD Background for Z

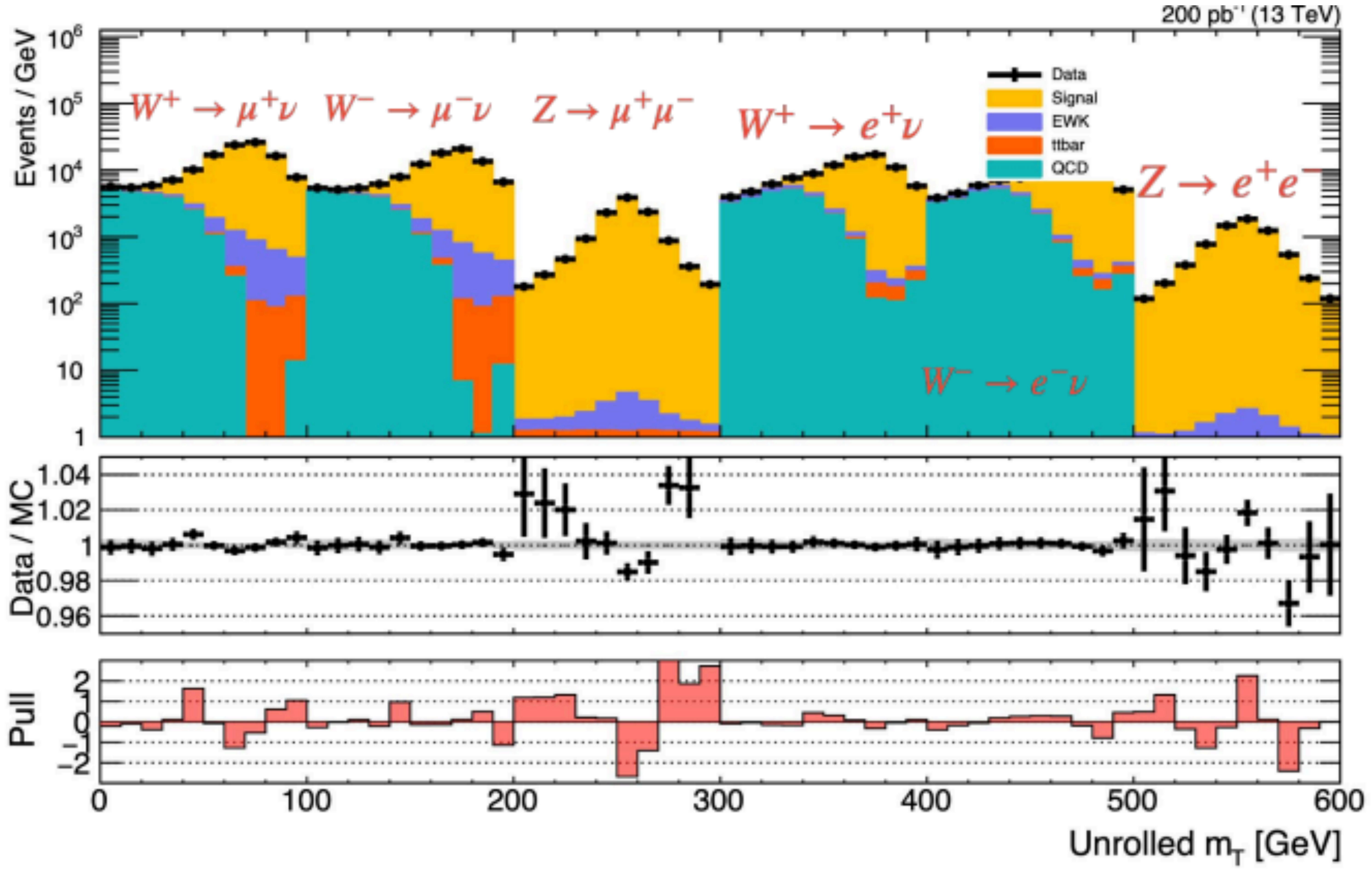
… From SMP-20-004

- Check non-resonant W+Jets and the QCD multijet background
- Select Electron-Muon pairs with opposite charge



PostFit distributions

… From SMP-20-004



Unrolled post-fit distributions of m_T and m(ll)

Fit of 6 channels with 3 POIs according to charge (i.e., with the lepton universality constraint)

PostFit distributions

… From SMP-20-004

$W^+ \to l^+ nu$	%
Lumi	1.70
Theory	0.64
Efficiency Stat	0.27
QCD Stat.	0.25
Prefire	0.23
Bin-by-bin Stat	0.16
QCD Sys.	0.16
Efficiency Syst.	0.15
Recoil Stat.	0.15

$W^- \to l^- nu$	%
Lumi	1.70
Theory	0.59
Efficiency Stat	0.25
QCD Stat.	0.22
Prefire	0.21
QCD Syst.	0.17
Recoil Stat.	0.16
Bin-by-bin Stat.	0.16
Efficiency Sys.	0.13

W->lnu	%
Lumi	1.70
Theory	0.62
Recoil Stat.	0.23
QCD Stat.	0.23
Prefire	0.21
Efficiency Stat.	0.20
Bin-by-bin Stat.	0.16
Efficiency Sys.	0.13
QCD Sys.	0.11

$Z \to l^+ l^-$	%
Lumi	1.68
Theory	0.49
Prefire	0.35
Efficiency Stat.	0.33
Efficiency Sys.	0.29
Stat.	0.22
QCD Stat.	0.22
Bin-by-bin Stat.	0.16
QCD Sys.	0.13

PostFit distributions

… From SMP-20-004

W+/W-	%
QCD Stat.	0.49
Efficiency Stat.	0.39
QCD Sys	0.19
Recoil Sys.	0.14
Bin-by-bin Stat.	0.14

W/Z	%
Theory	0.31
Recoil Stat.	0.29
Stat.	0.23
Efficiency Syst.	0.18
Efficiency Stat.	0.15

Theory

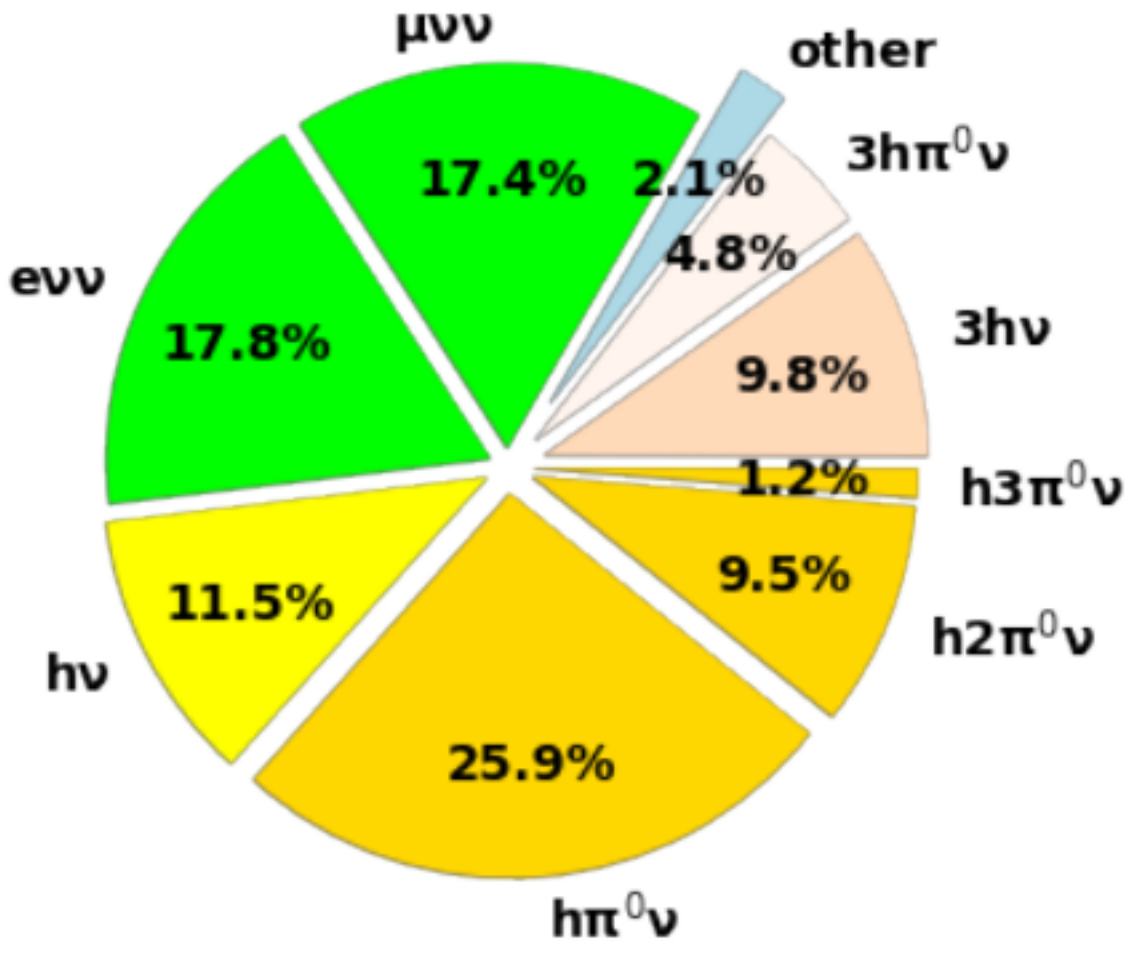
… cross sections and acceptance

- Total and differential cross sections
  - https://dyturbo.hepforge.org qT resummation at N3LL accuracy and fiducial cross sections at N3LO
  - https://powhegbox.mib.infn.it NLO QCD and NLO EW
- Use MC at NLO to set baseline and quote differences as systematic uncertainty, i.e. scale, resummation, FRS, and also PDF.
- PDFs: CT18, MSHT20, NNPDF3.1

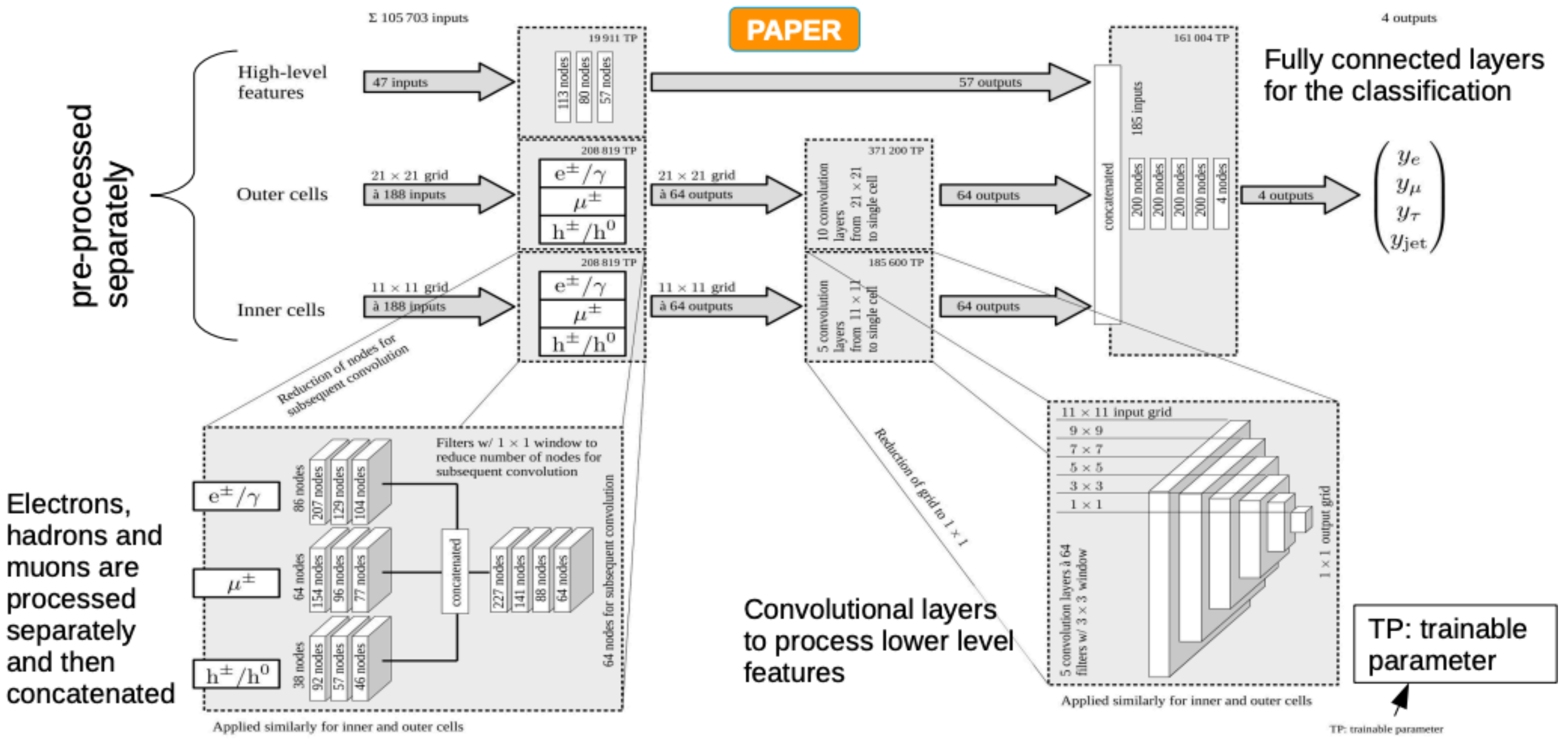
Tau Leptons (really up for discussion!)

… Object Performance and Validation and / or $Z \to \tau\tau$ cross section

- Tau ID efficiency measurement
  - Tag and probe
  - $Z \to \tau\tau$ events with $Z \to \tau\tau / Z \to \mu\mu$ ratio method
  - $W \to \tau\nu$ events (for high-pT τ)
- Observables
  - m_{vis}, $n_{charged}$, MET
- Jet → Tau fake rate
- e → tau fake rate
- Tau charge misID
- Tau scale corrections

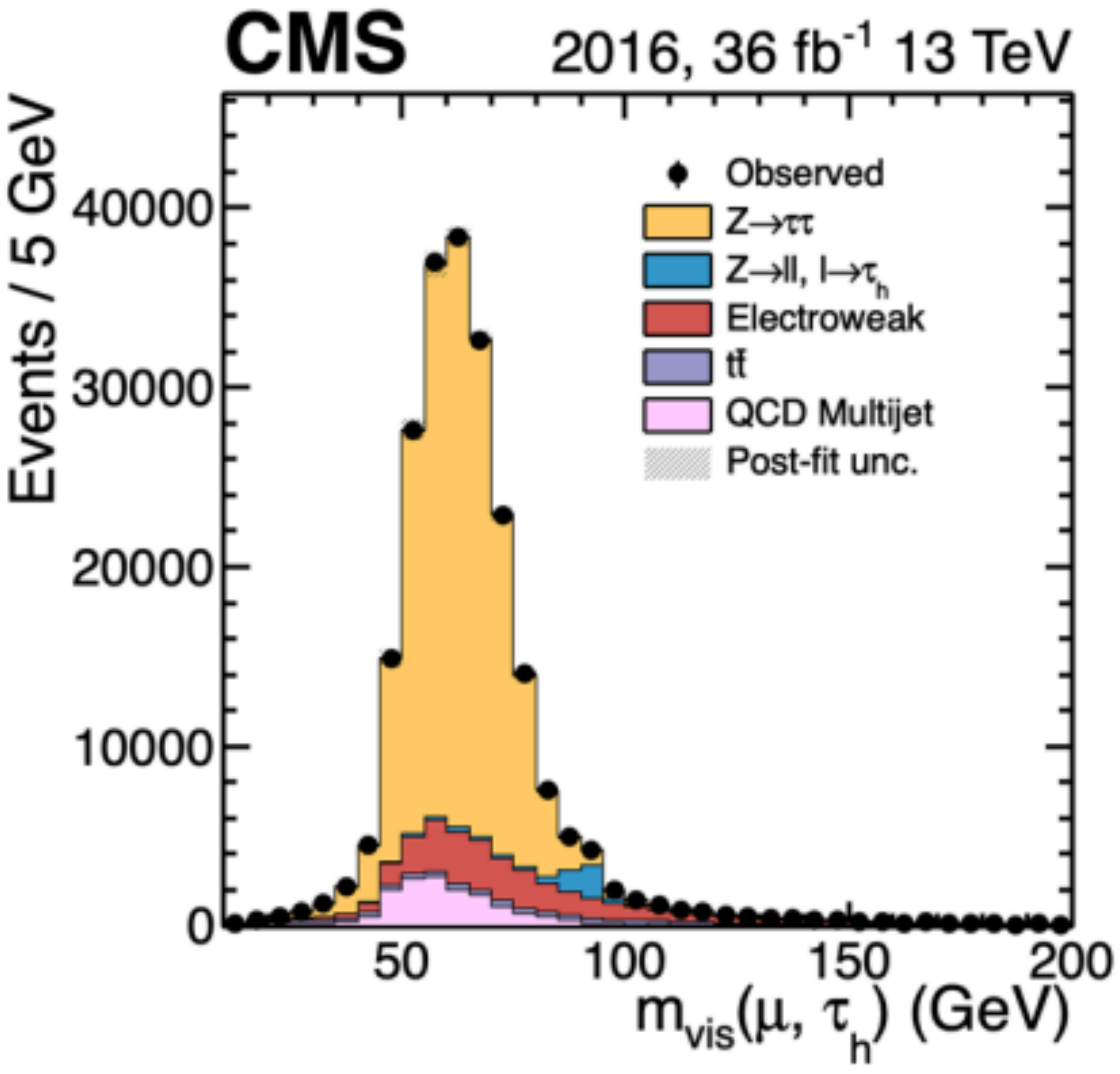


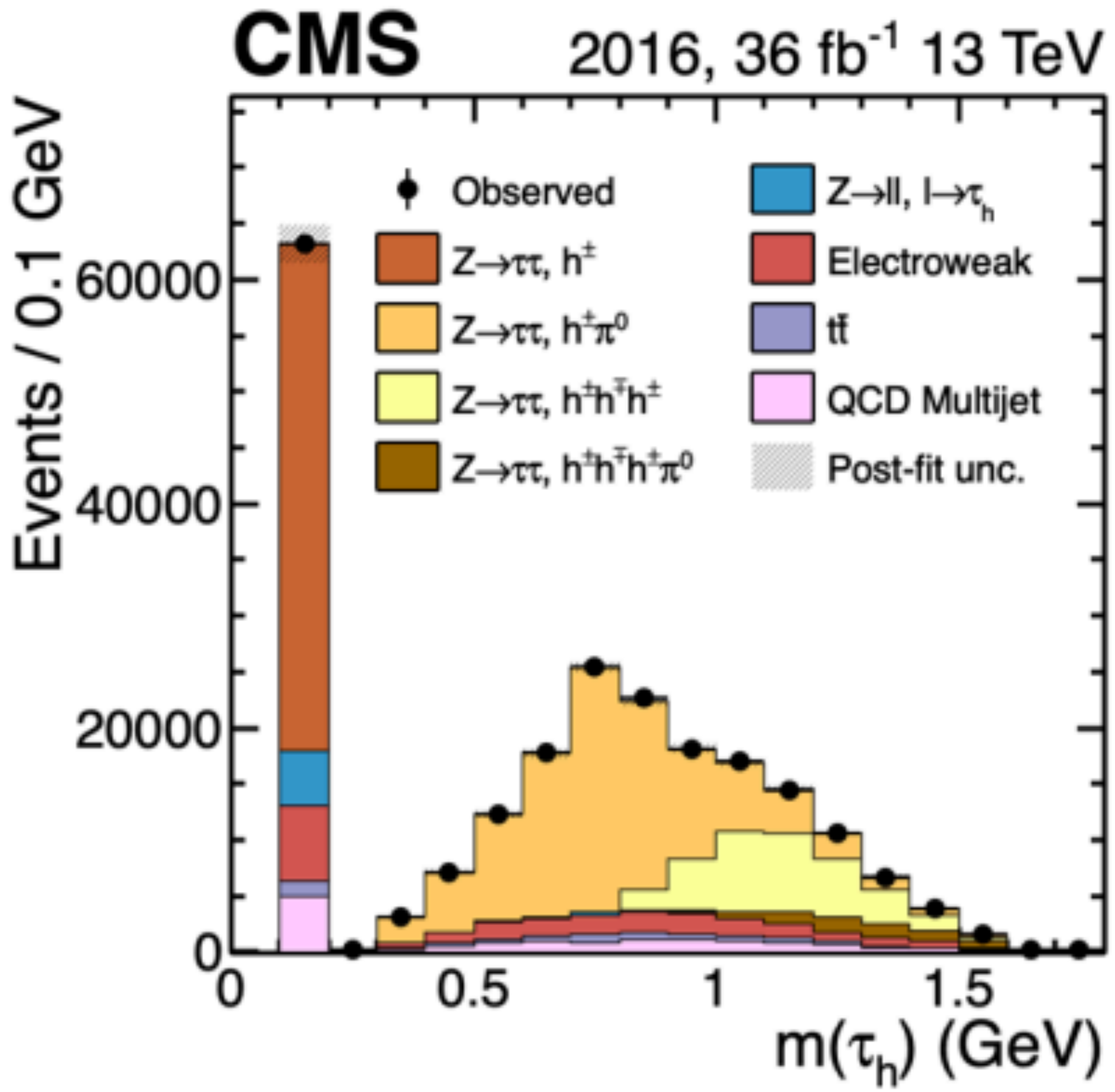
DEEP TAU



Tau Leptons (really up for discussion!)

… Object Performance and Validation and / or $Z \rightarrow \tau\tau$ cross section





Ingredients

… What do we need (to do) before data taking starts?

- Trigger / Datasets
  - Identify, check, and potentially implement triggers as well as primary datasets
- Simulated Samples
  - Check current requests and add missing samples
  - Signal: MADGRAPH and POWHEG at QCD NLO. Try to produce EW@NLO in POWHEG
  - Backgrounds: standard samples for di-boson and top
- Lepton selection
  - Check updated lepton definitions with POG
  - Establish methods corrections
- Missing ET
  - Establish methods corrections

Ingredients

… What do we need (to do) before data taking starts?

- Theory and acceptance
  - Recalculated cross sections, acceptances, and systematic uncertainties for 13.6 TeV
- Analysis framework
  - Prepare and/or adopt tools
- Fitting framework
  - Review code and/or migrate to combine
- Z-Counting
  - Engage with Z-counting team
- Documentation
  - Start from SMP-20-004 and AN-19-088

Discussion

…