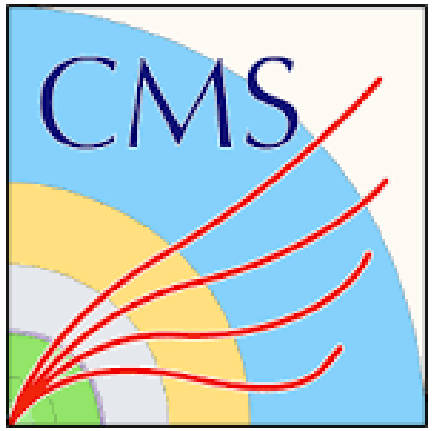
Measurements of WZ properties in Run 3 with the CMS detector

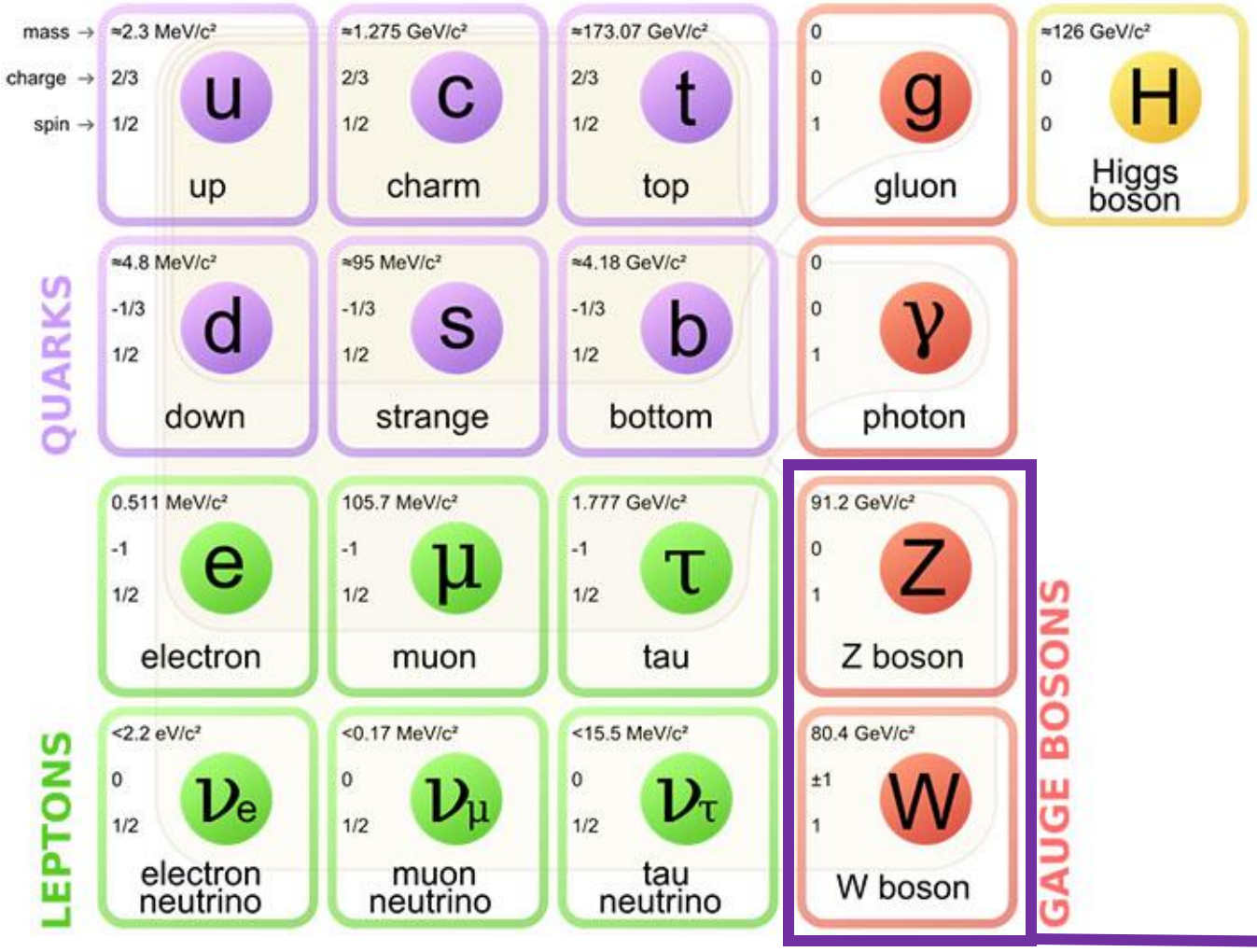
Miguel Obeso Menéndez for the WZ Run 3 analysis team

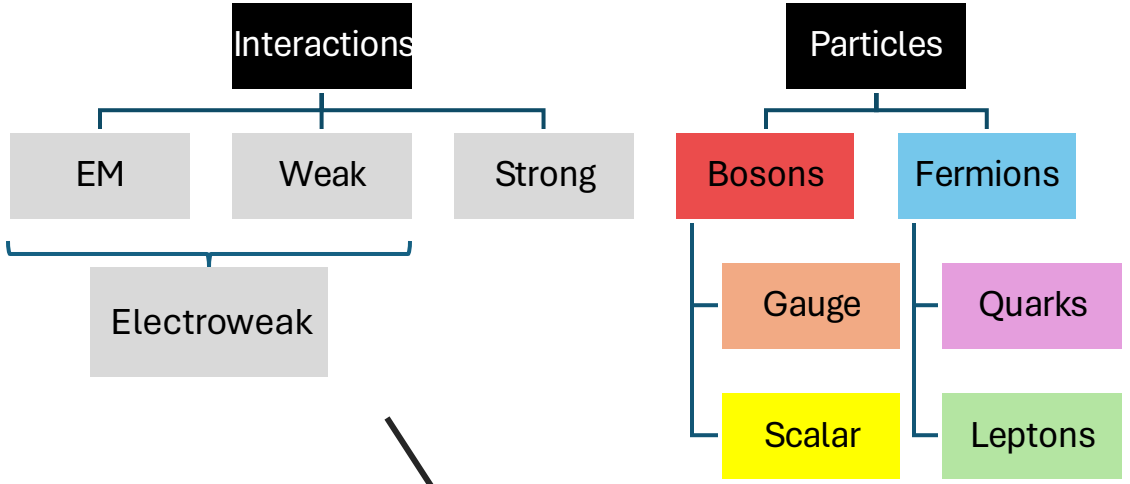


Universidad de Oviedo

Contents

Standard Model (SM)





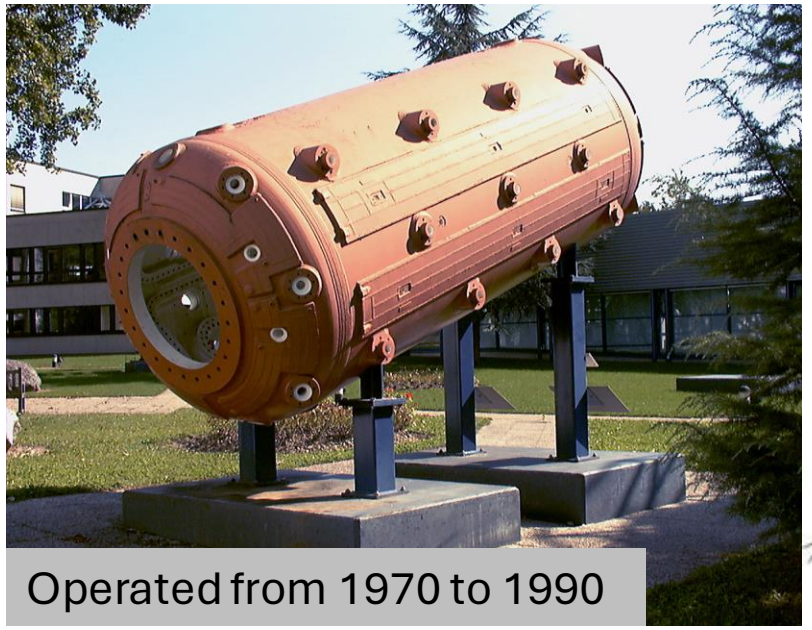
Gauge Symmetry group:
SU(3) x SU(2) x U(1)

-Weak intermediate bosons.
-Massive Gauge bosons.

Discovery of W and Z bosons

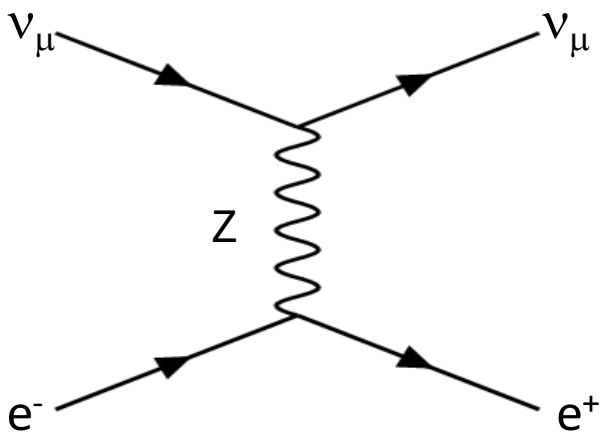
Standard Model (before Higgs) → Bosons/fermions expected to be massless → Higgs mechanism →

$$m_W = \frac{gv}{2}$$
$$m_Z = \frac{v}{2}\sqrt{g^2 g'^2}$$



Operated from 1970 to 1990

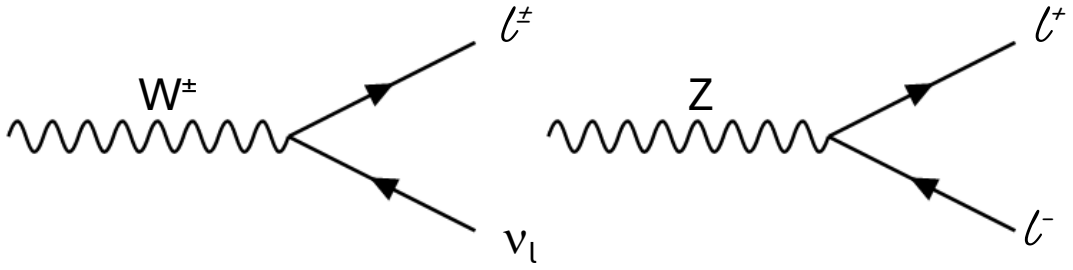
-**Gargamelle bubble chamber:** Experiment in search of neutrino. Evidence of the existence of a massive, electrically neutral, virtual particle.

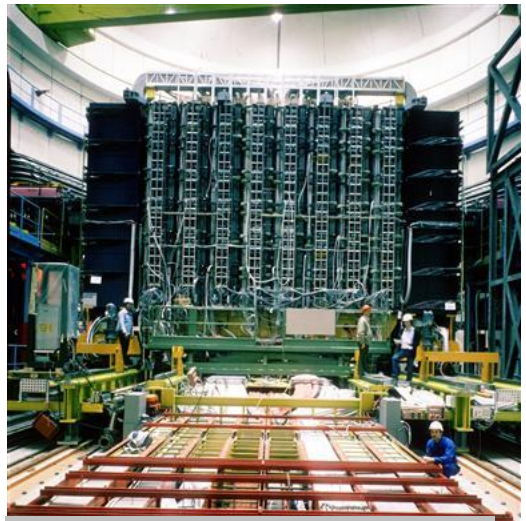


Discovery of W and Z bosons

UA1 and UA2 in (SPS): High energy proton-antiproton collisions to produce and measure the W (1982) and Z (1983) bosons in leptonic final states.

W/Z decays in leptonic final states where ℓ could be an electron (e) or a muon (μ)...





UA1: Operated from 1981 to 1990

UA1 measurement of W and Z masses using the dataset collected from 1982 to 1985:

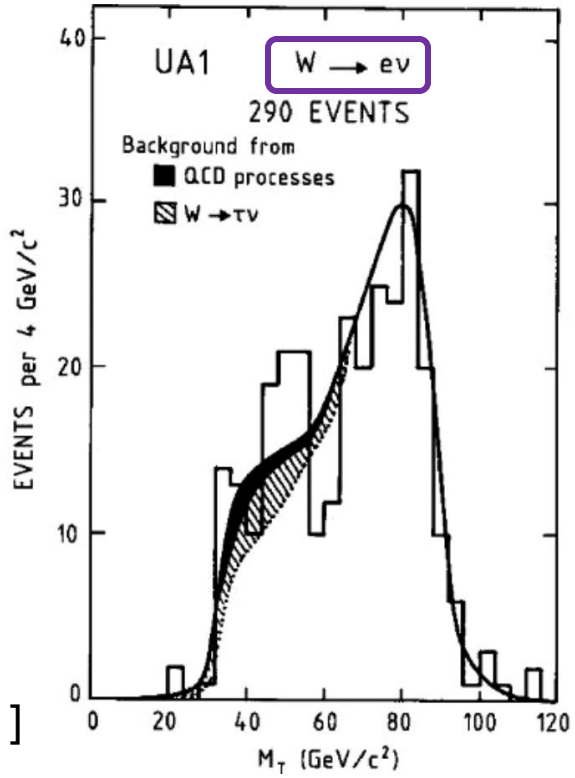
$$m_{\mathrm{W}} = 82.7 \pm 1.0 \pm 2.7 \text{ GeV}$$

$$m_{\mathrm{Z}} = 93.1 \pm 1.0 \pm 3.1 \text{ GeV}$$

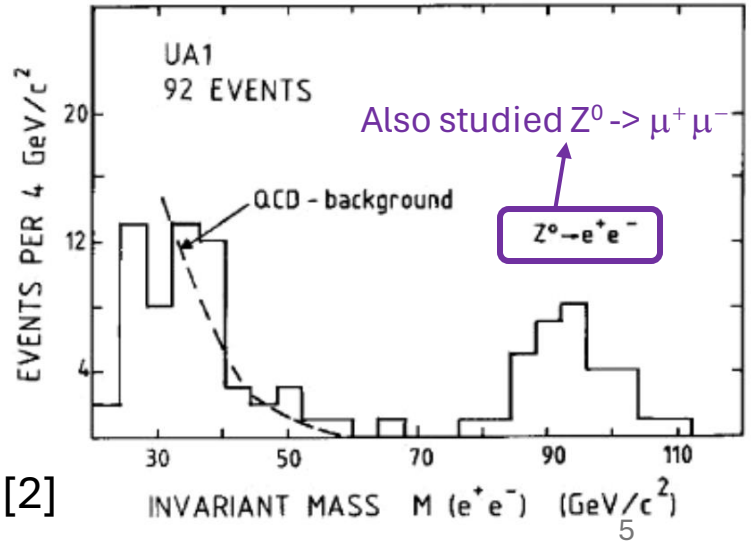
UA1 measurement of W and Z cross section in electron final states using the dataset collected from 1982 to 1985:

$$\sigma_{\mathrm{W}} \mathrm{BR}(\mathrm{W} \to \mathrm{e}\nu) = 630 \pm 50 \pm 100 \,\mathrm{pb}$$

$$\sigma_{\mathrm{Z}} \mathrm{BR}(\mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-) = 74 \pm 14 \pm 11 \text{ pb}.$$



[1]

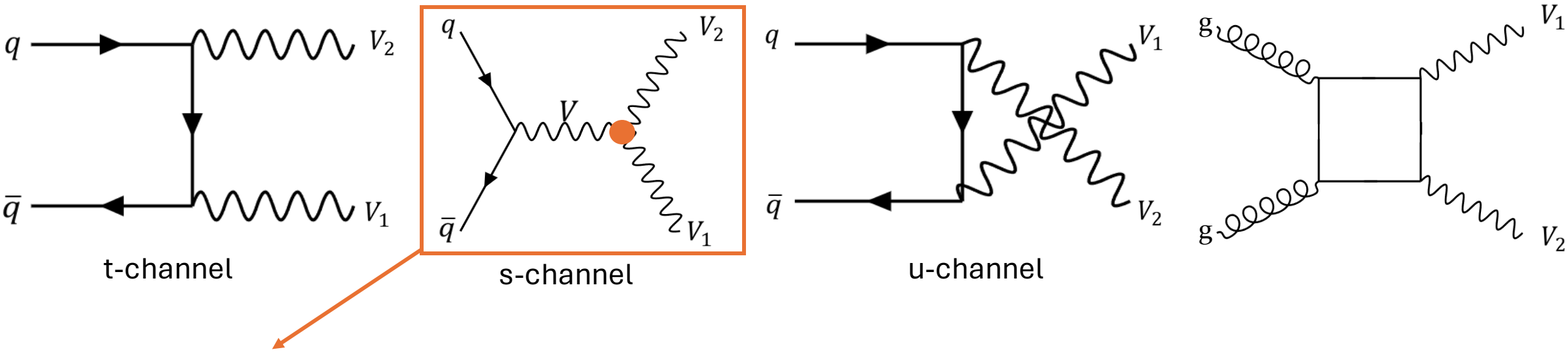


[2]

Dibosonic production (VV')

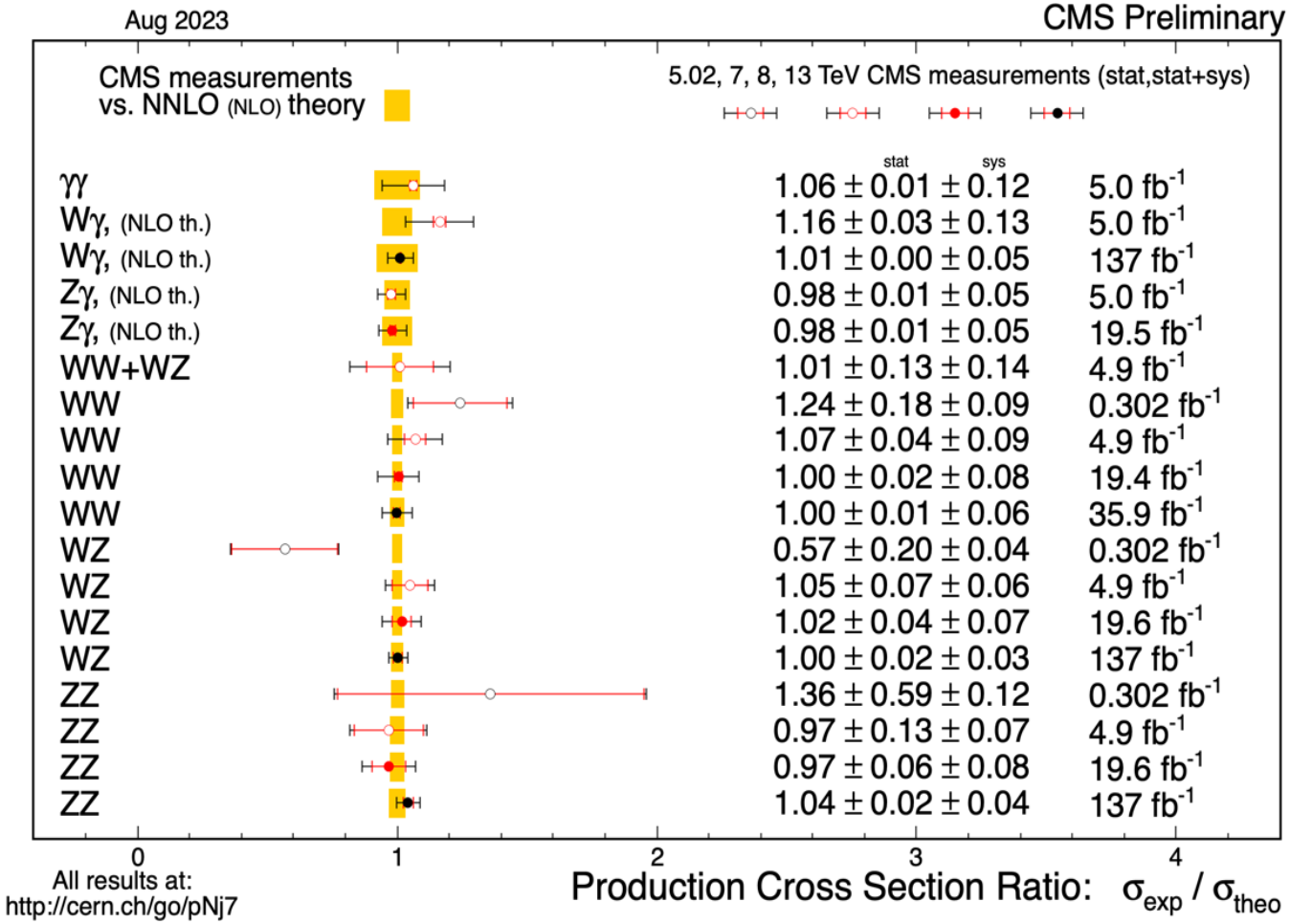
All possible dibosonic process:
$\gamma\gamma$, Wγ, Zγ, WW, WZ, ZZ

- Accurate testing of Standard Model physics of the $SU(2)_L xU(1)$ gauge group.
- The precision on the measurements help to constrain SM contribution (background) in searches (Higgs or other physics models).
- Search of new physics.

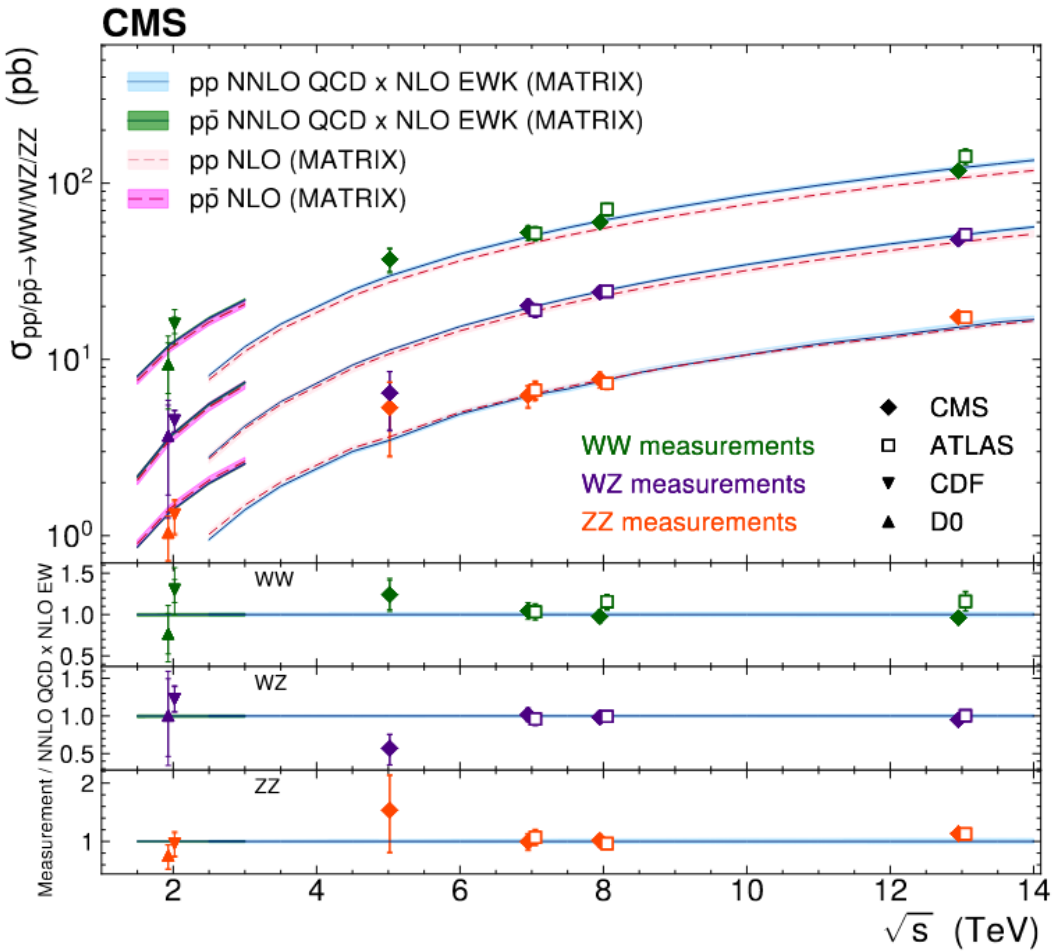


The s-channel leads to trilinear gauge bosons interactions in the electroweak sector (only allowed in the SM charged couplings such as WWZ, WWγ).

Dibosonic production

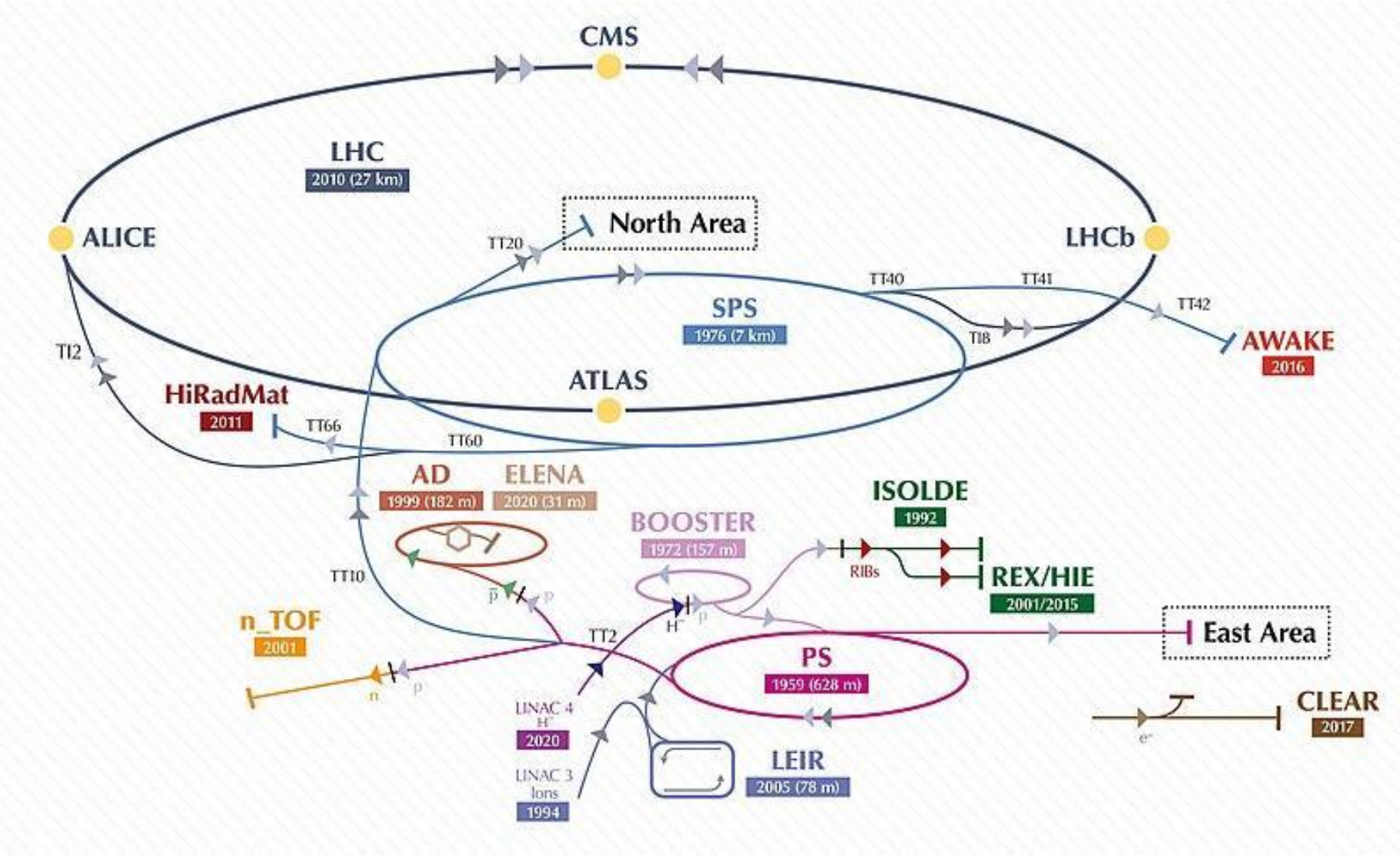


https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined



https://doi.org/10.1103/PhysRevLett.127.191801

Large Hadron Collider (LHC)



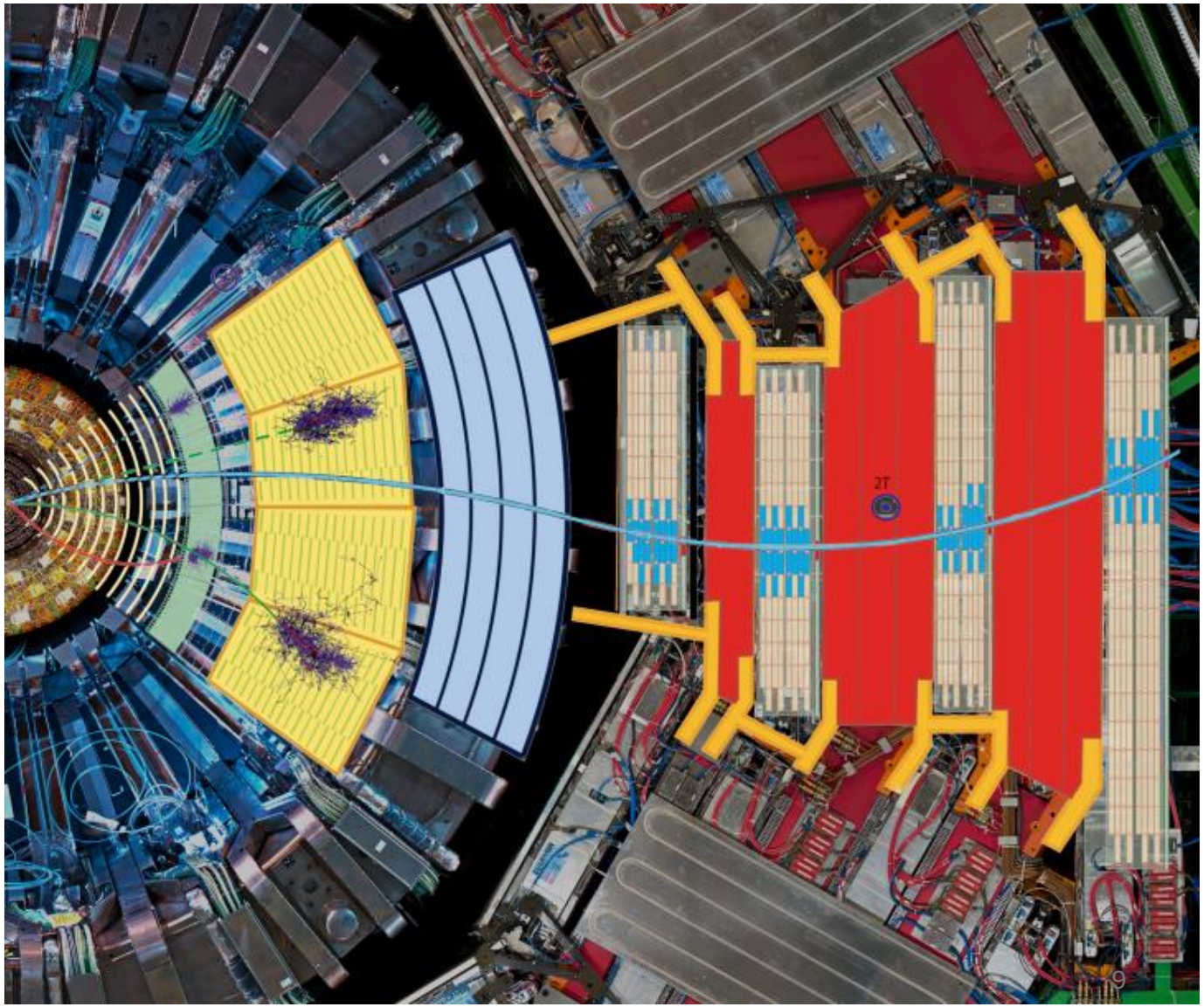
Four experiments:
CMS
ATLAS
LHCb
ALICE

Proton-proton collisions

Center-of-mass energy (Run 3): 13.6 TeV

Compact Muon Solenoid (CMS)

Tracker
Electromagnetic Calorimeter (ECAL)
Hadronic Calorimeter (HCAL)
Solenoid
Steel Yoke
Muon chambers



Trigger system…

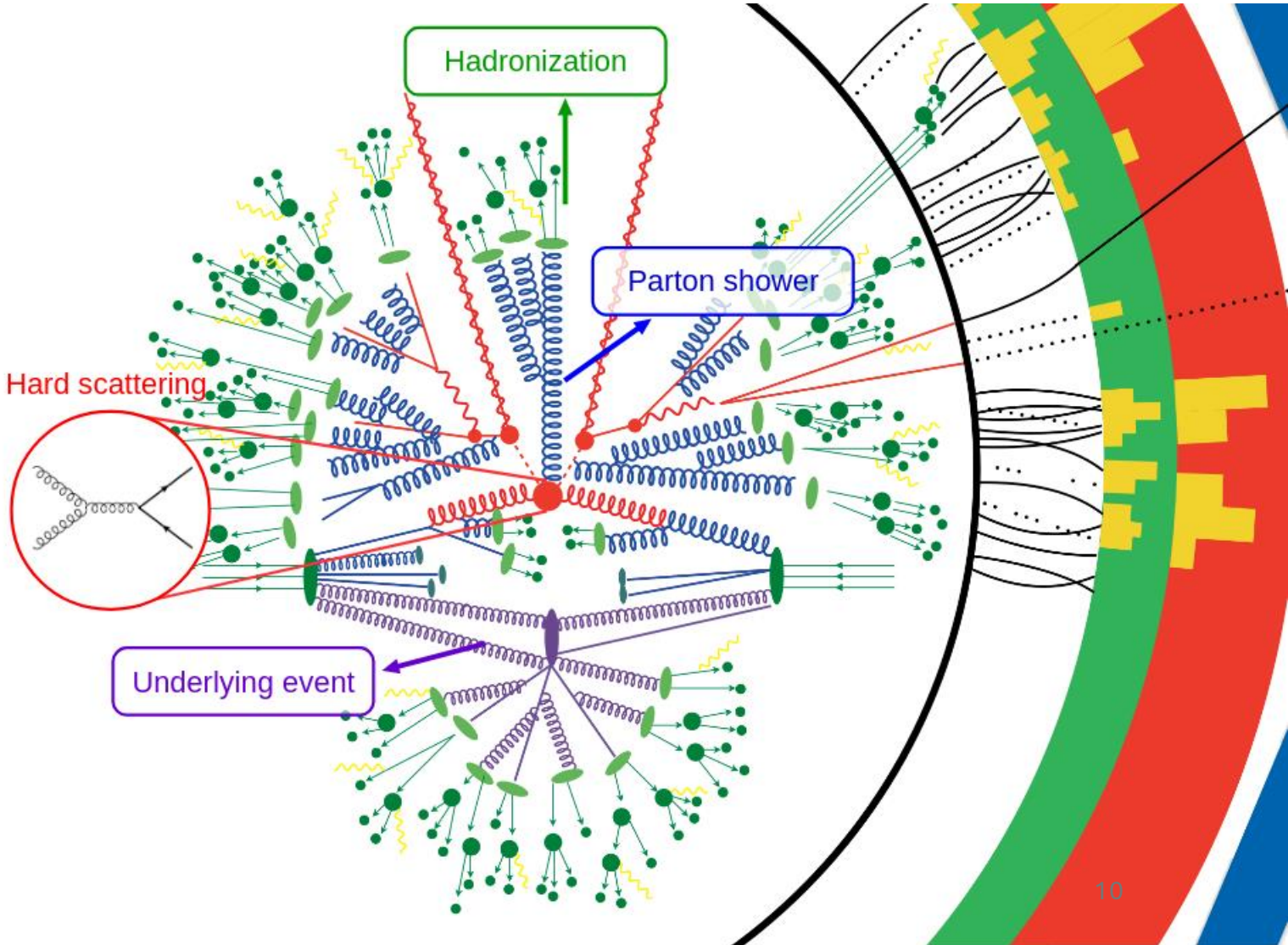
Initial data (40MHz) → Level 1 Trigger (10 kHz) → High Level Trigger (1 kHz)

Event simulation

Generation: Matrix element of QFT and hard scattering.

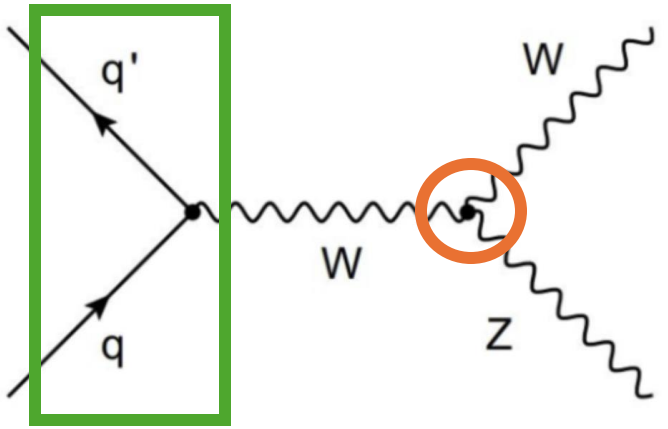
Simulation: Hadronization and detector simulation.

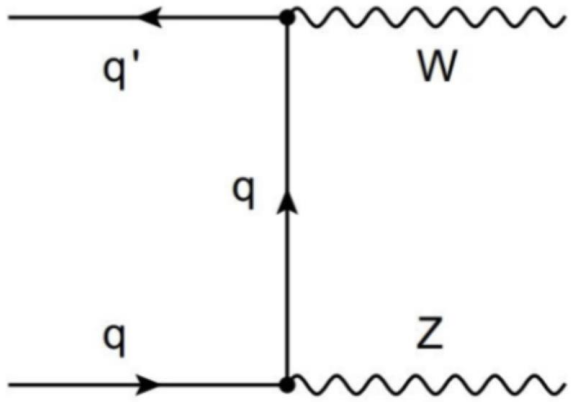
Reconstruction: Same way as data.

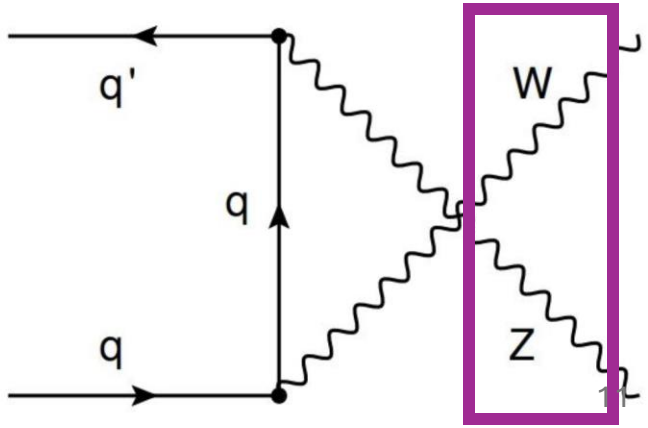


WZ process

- WZ as a process of interest for SMP and BSMP:
  - Sensitive to charge asymmetries.
  - Boson polarization effects (final state leptons).
  - Direct access to Trilinear Gauge Couplings and anomalies.
- Main goal...
  - Continue the previous studies done in Run 2 (13 TeV) in leptonic final states.
  - Perform the first WZ measurements at the new energy regime of 13.6 TeV.





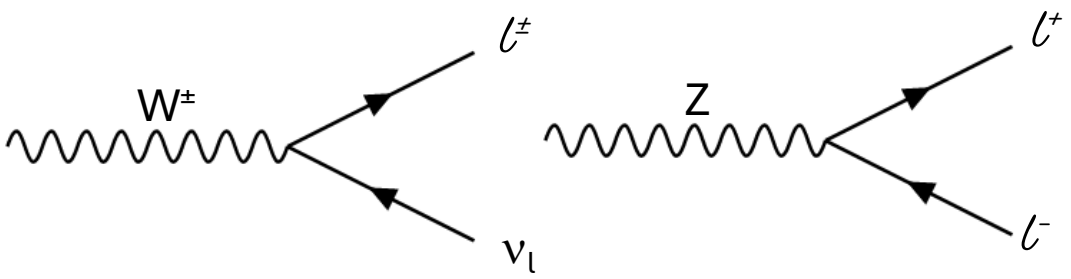


First WZ cross section at 13.6 TeV using the 2022 dataset-> Ongoing!!

$$\sigma_{tot}(pp \longrightarrow WZ) = \frac{N_{WZ}}{BR(W \longrightarrow l\nu)BR(Z \longrightarrow l'l')\mathcal{A}\varepsilon\mathcal{L}}\left(1 - \frac{N_{non-fid}}{N_{tot}}\right)$$

Analysis strategy → Object selection → Events selection

- Light leptons (electrons and muons): The core of the analysis. Following techniques and criteria based on kinematic variables.
- Jets/ b-jets: Using algorithms PUPPI/DeepJET.
- Missing transverse energy (MET): The negative sum of all transverse momentum of the objects identified in the event.



3 charged leptons →

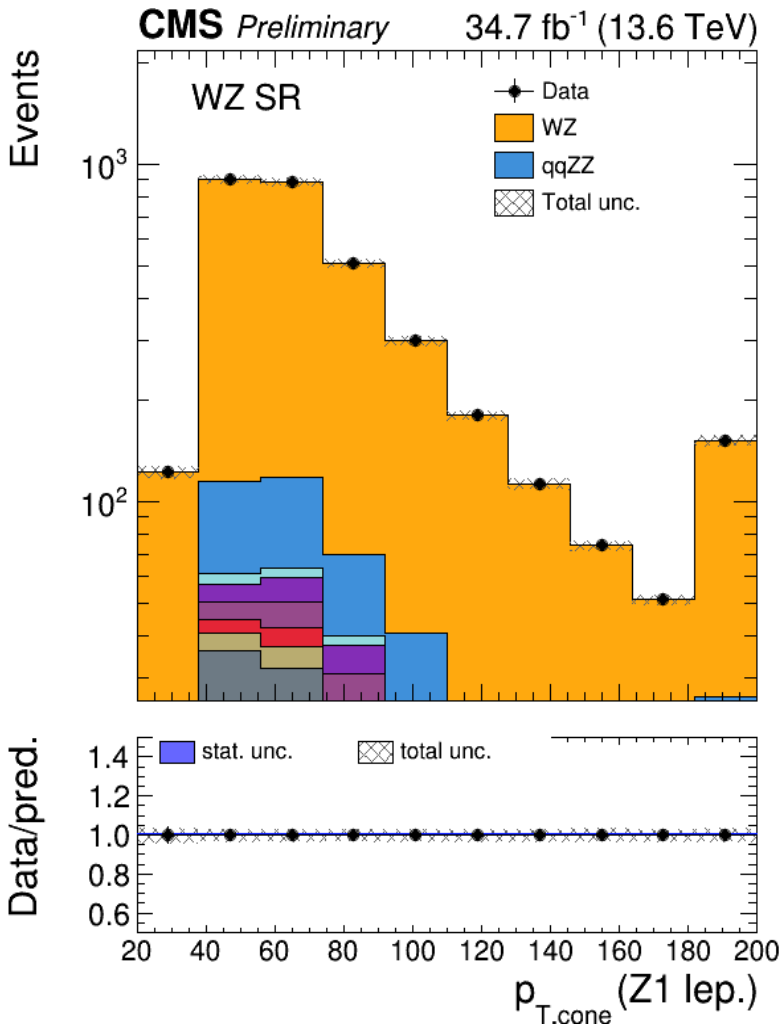
Baseline Selection (pure WZ signal)
Z-leptons: Two opposite sign and same flavor with invariant mass close to m_z.
W-leptons: The third lepton and a missing transverse energy (MET).

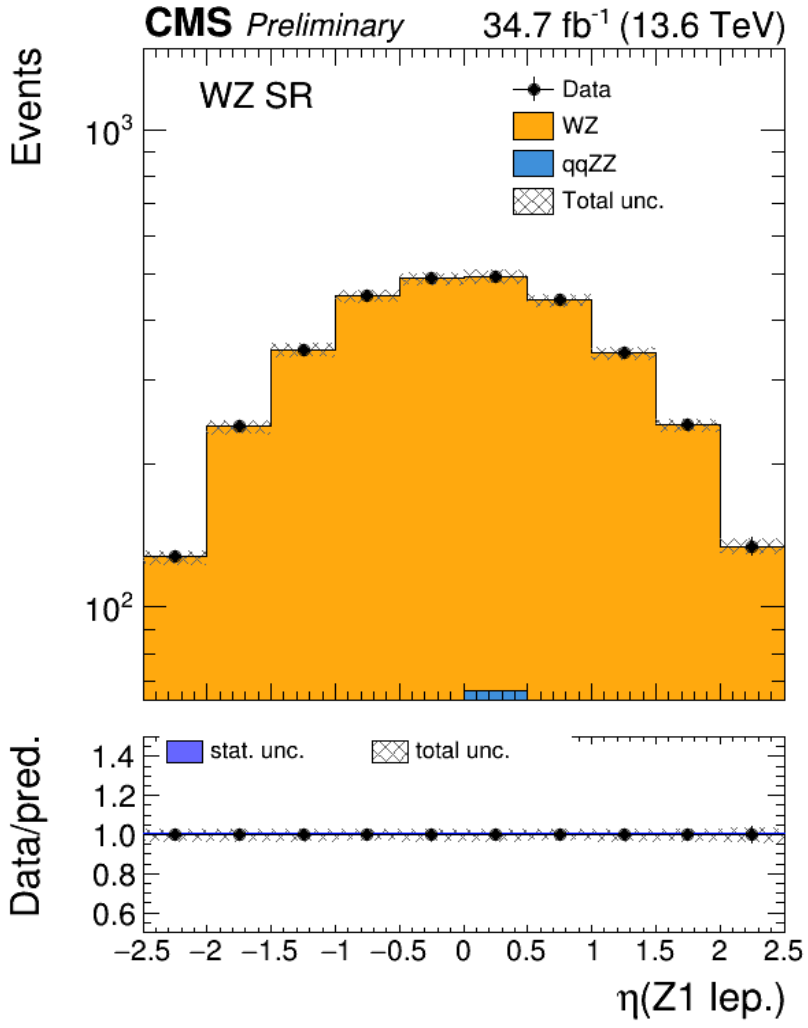
Also this criteria allows to separate the leptons that comes from a W and a Z.

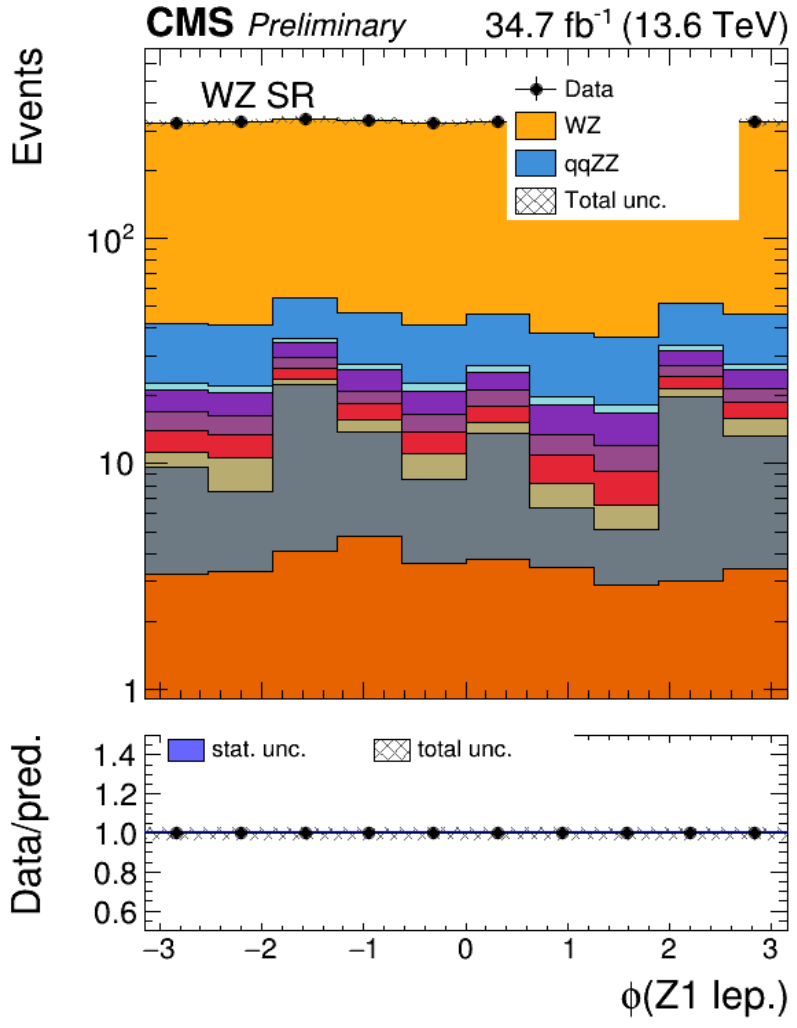
->Some processes emulate a final state similar to our signal selection criteria (background process).
->Enriched in backgrounds regions (control regions) are studied for the estimation and understanding of the main backgrounds of the process

Some WZ distributions:

- Data not used to avoid bias in the measurement.
- Existence of different backgrounds (ZZ, ttX and conversion).



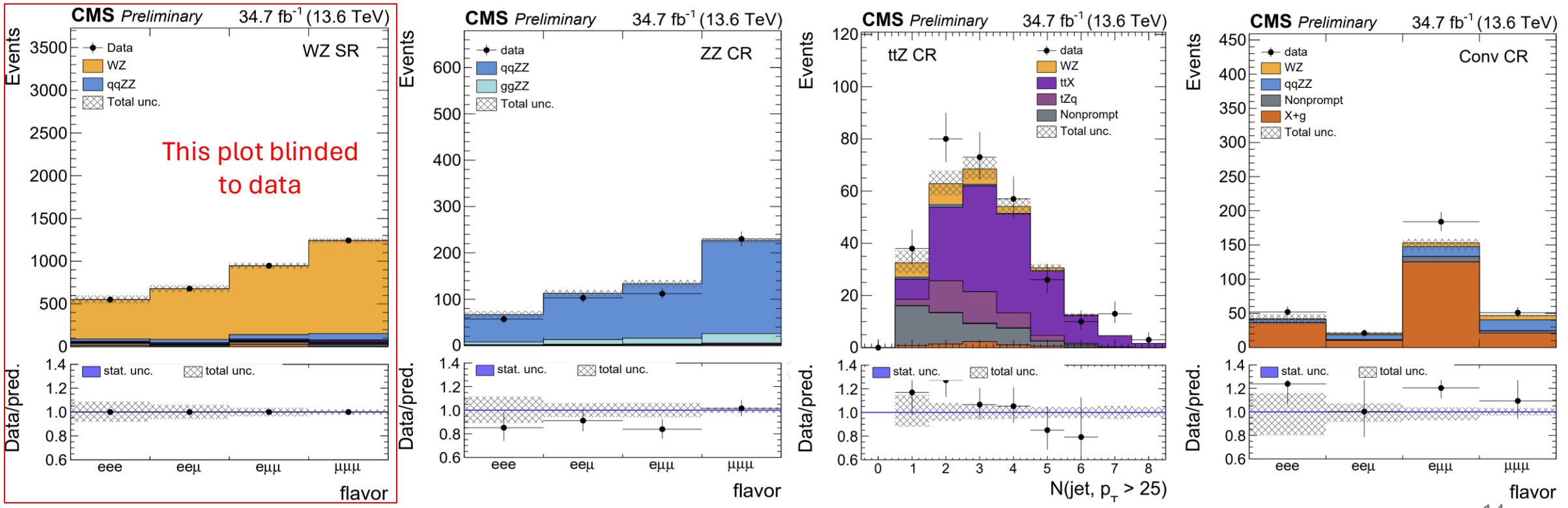




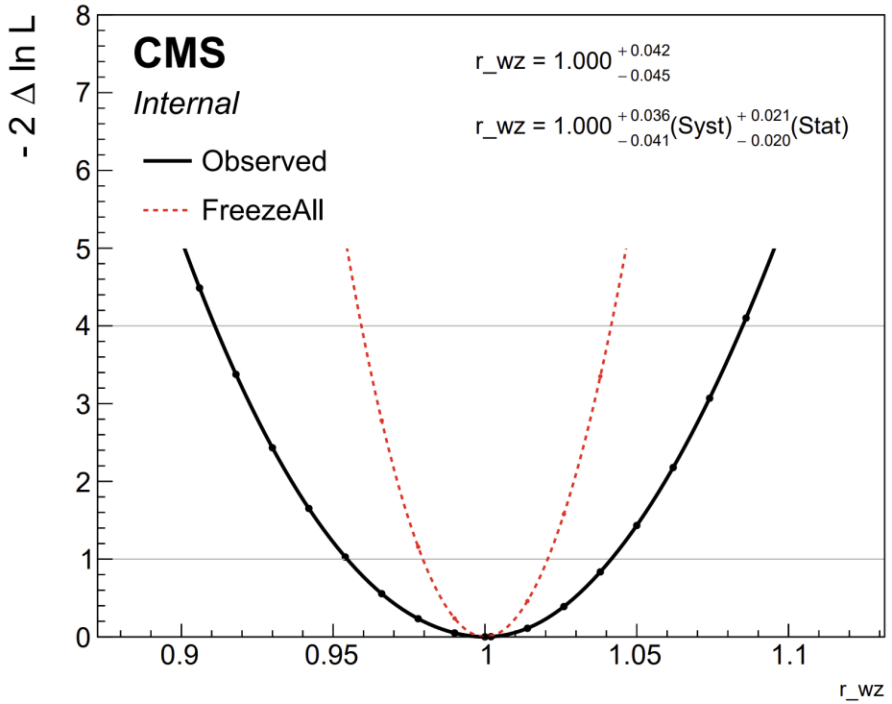
Inclusive cross section measurement:

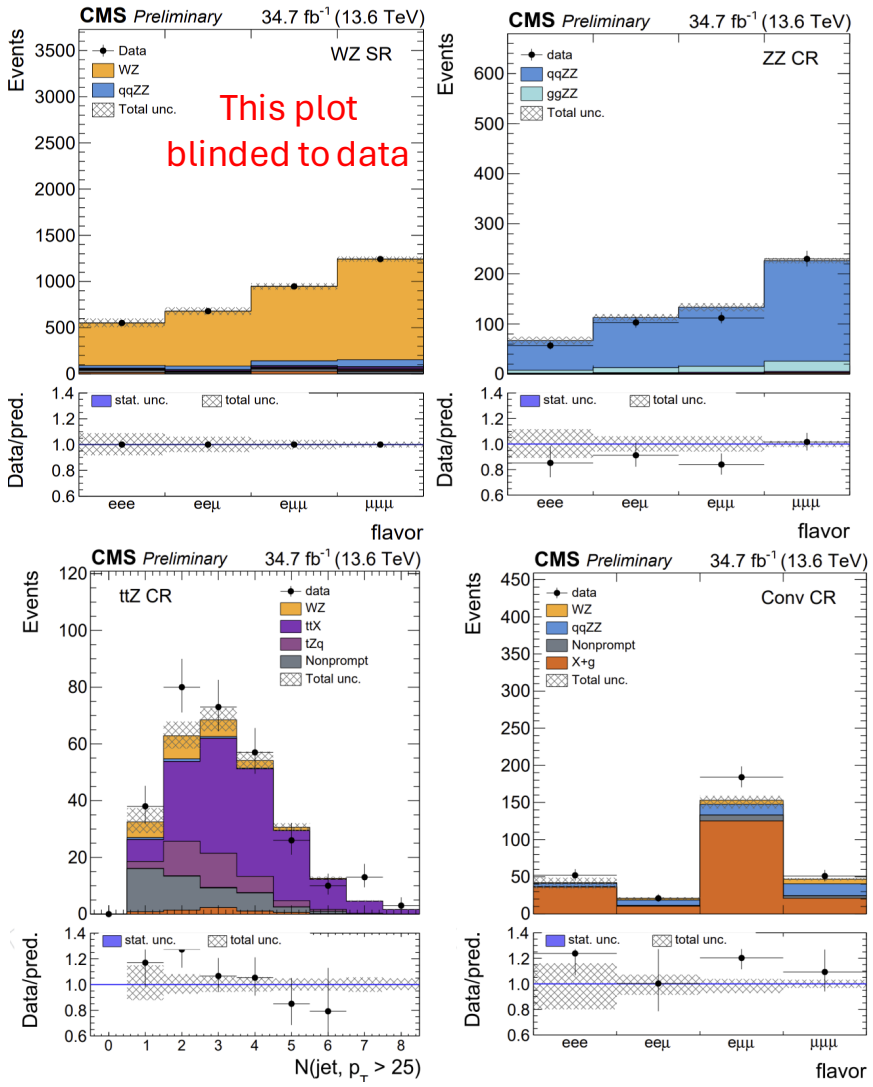
$$r_{WZ} = \frac{\sigma_{exp}}{\sigma_{SM}}$$

- Perform a ***maximum likelihood fit*** to the flavor distribution.
- Measure the signal strenght (r_{WZ}).
- Use the background regions in the fit to estimation/control/minimize its normalization in the fit.



Inclusive cross section measurement:





Other WZ interesting measurements:

- **Charge assymetries:** The differences between W^+Z and W^-Z production are studied based on the charge ratio asymmetry quantity. The study of properties of the initial state qq' (PDFs) can be extracted from the study of the final state

$$A_{WZ}^{+-} = \frac{\sigma_{\text{fid}}(\text{pp} \to \text{W}^+\text{Z})}{\sigma_{\text{fid}}(\text{pp} \to \text{W}^-\text{Z})}$$

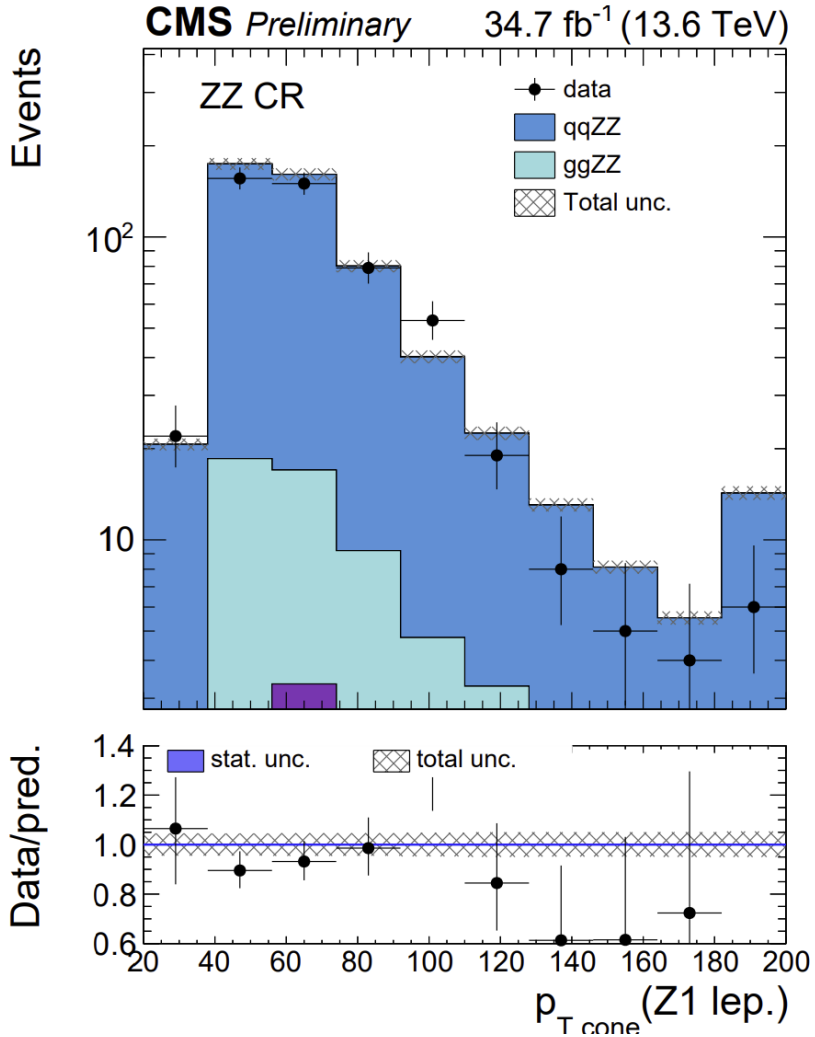
- **Boson polarization:** W and Z bosons can show longitudinally–polarized states as a consequence of their massive nature, itself derived from the spontaneous symmetry breaking mechanism. A probe of the Higgs mechanism of the SM.

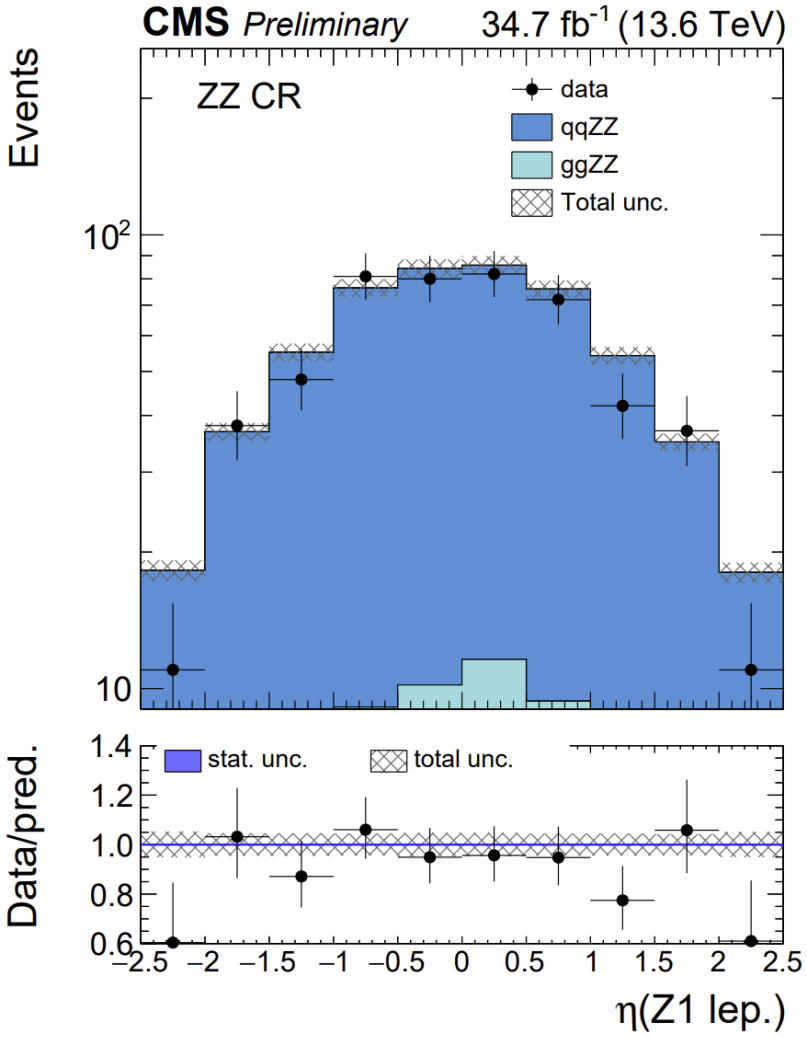
- **New physics:** EFT interpretations, anomalies…

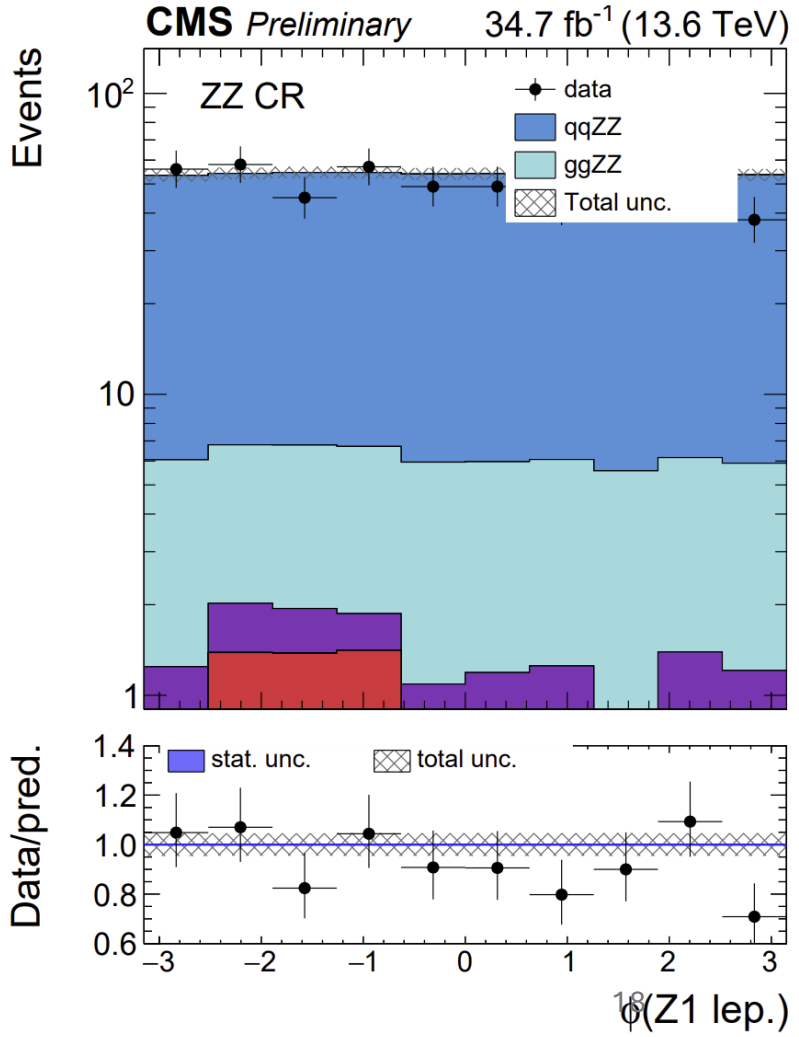
BACKUP

Some ZZ distributions:

Four leptons. Two leptons per Z boson.
Two pairs of opposite sign and same flavor with invariant mass close to m_z.

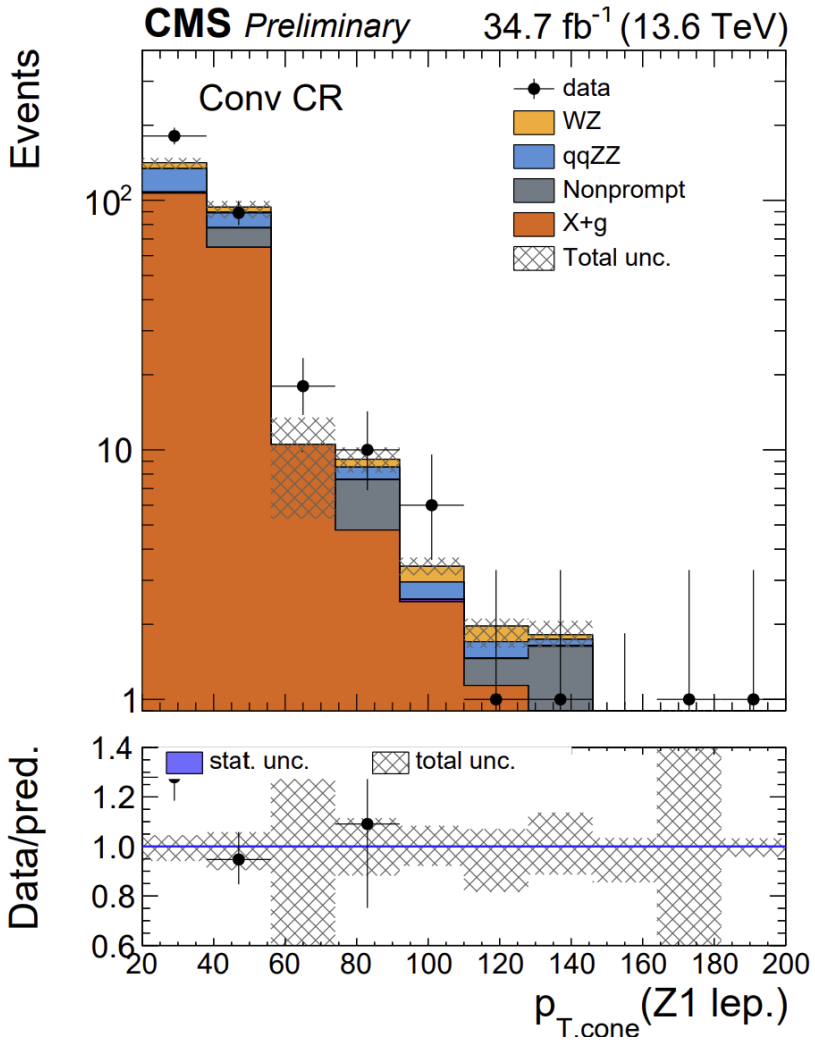


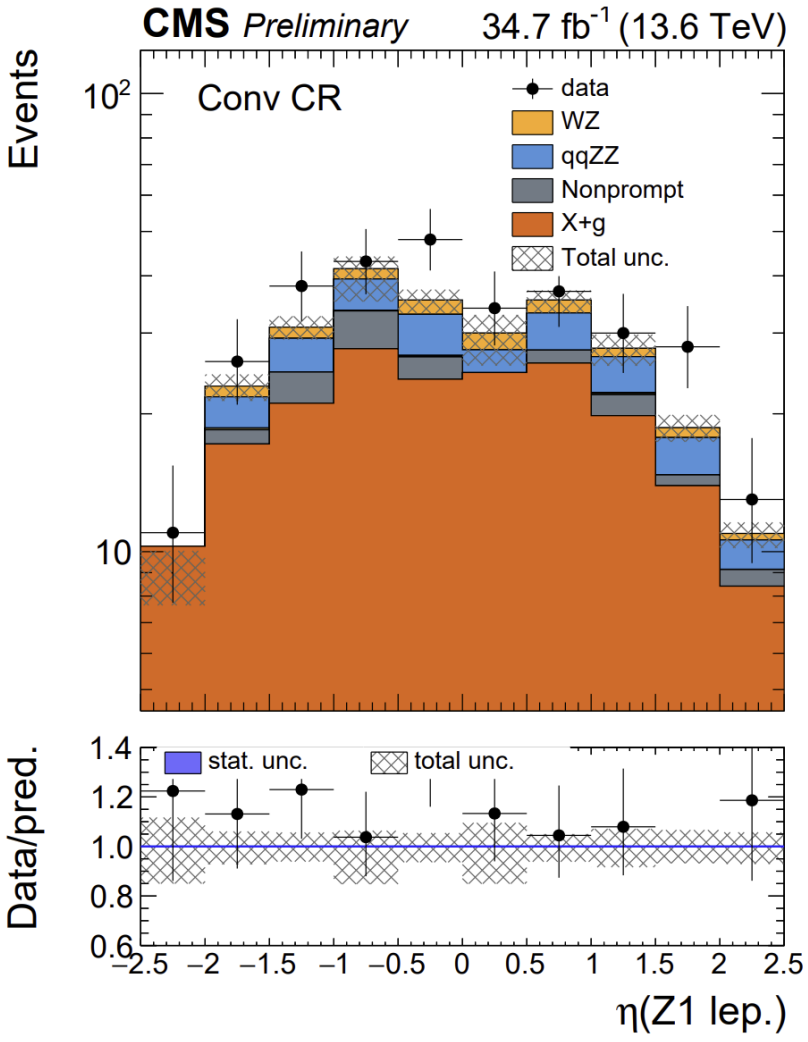


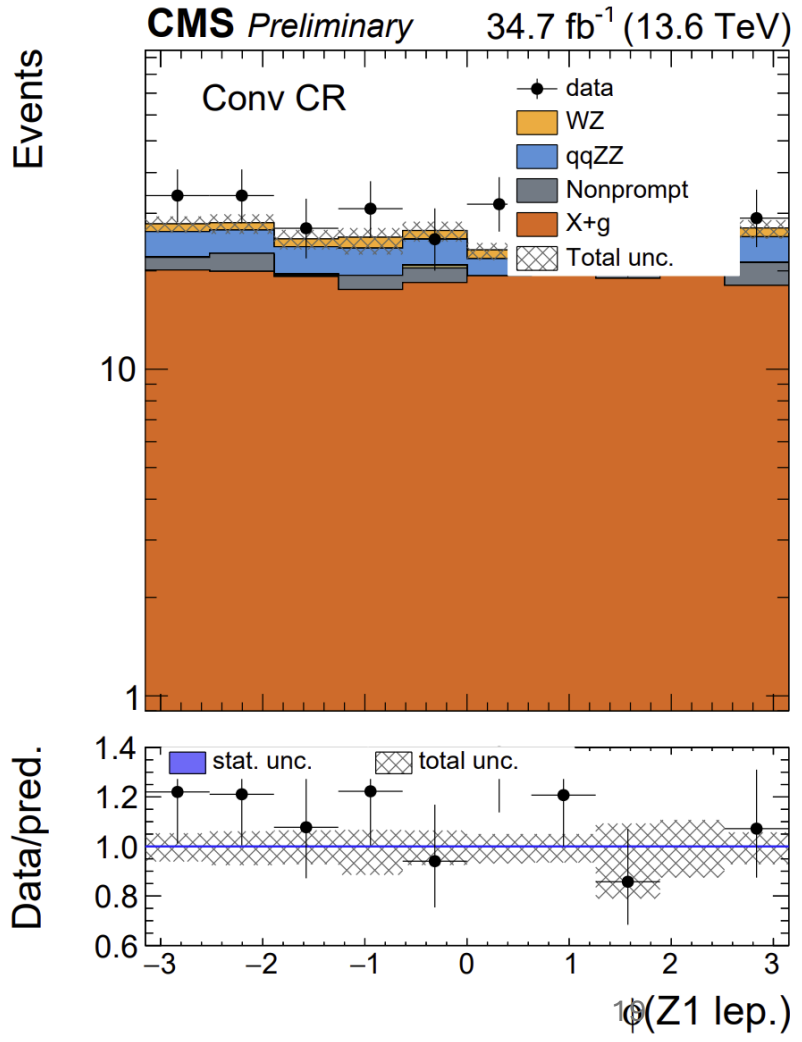


Some conv. distributions(Xγ):

Defined by inverting the MET and mass reconstruction criteria of the WZ selection.







Some ttX distributions:

Two or more light leptons.
Enriched b jets in the event selection criteria.