PHYSICS AT COLLIDERS

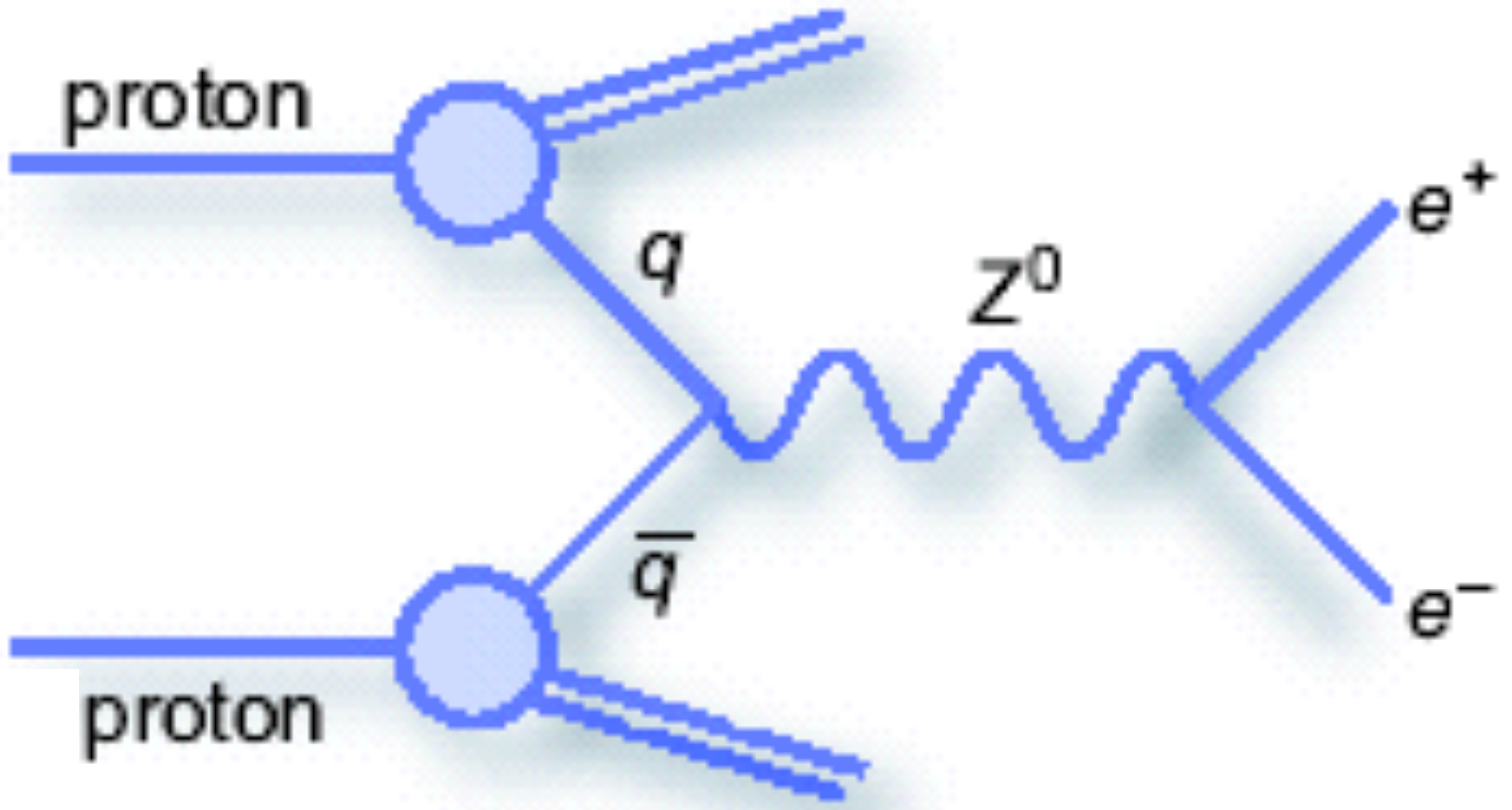
Tutorial I and II

TRISEP Summer School, July 2022

DATA ANALYSIS

- You will be analyzing 1 fb^{-1} of LHC data at $\sqrt{s} = 8$ TeV from the ATLAS experiment

- Goals
  - Measure Z boson production cross-section
  - Learn some collider / detector physics along the way



- First, break into groups

DATA ANALYSIS: GETTING SETUP

- We will be using data and MC provided by the ATLAS experiment
- Datasets are provided in ntuple format
- Analysis will be done in pyROOT
- Navigate to:
  - https://jupyter.trisep.triumf.ca/
  - Choose: Notebook Python 3.6 (with ROOT)
  - in /trisep/collider/, find:
    - Data and MC files
    - Notebooks to get you started
    - Information on ntuple format

DATA ANALYSIS: PART 1

- We will start with data
  - Lepton-triggered data set
- First choice
  - team electron, lep_type == 11
    - data file: /trisep/collider/DataEgamma.root
    - Permanently stored at: http://opendata.atlas.cern/release/samples/Data/DataEgamma.root
  - team muon, lep_type == 13
    - data file: /trisep/collider/DataMuons.root
    - Permanently stored at: http://opendata.atlas.cern/release/samples/Data/DataMuons.root
- First question
  - What do you expect the inclusive lepton pT spectrum to look like? Discuss with your group. Be as specific as you can
- First task
  - Plot inclusive lepton pT spectrum. Compare to your prediction.
  - Use "ATLAS_data_example_lepton_pT.ipynb" for example (copy to your local area)

DATA ANALYSIS: PART 2

- Now, your turn to do a mini analysis
- Discuss how to select Z candidates with your group
- Implement event selection (start simple)
- What do you expect the invariant mass of the Z candidates to look like? Discuss first. Make a prediction for peak position, width of the peak, what happens outside the peak?
- Plot invariant mass of your Z candidates. Compare to your prediction.

$$m = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

(or use TLorentzVector! shown in example NB)

- If you were going to fit the Z peak, what function would you use to fit it?

DATA ANALYSIS: PART 3

- Make the following plots. Before each one, make a prediction about what you expect the distribution to look like and discuss with your group. After plotting, compare to your prediction:
  - Leptons from Z boson decay:
    - pT
    - phi
    - eta
  - Z boson candidate:
    - pT
    - rapidity y
    - pseudo-rapidity η

DATA ANALYSIS: PART 4

- You will be analyzing 1 fb^{-1} of LHC data at $\sqrt{s} = 8$ TeV from the ATLAS experiment
- Measure the Z—>ll boson cross section
  - Assume no background
    - How could/would convince yourself that the background contribution is small?
  - Do you need to run over all events in the data sample? What do you gain?
  - Do you need any Monte Carlo?
  - Make any reasonable assumptions that simply your life
  - Which Z cross-section? Feel free to make a choice…

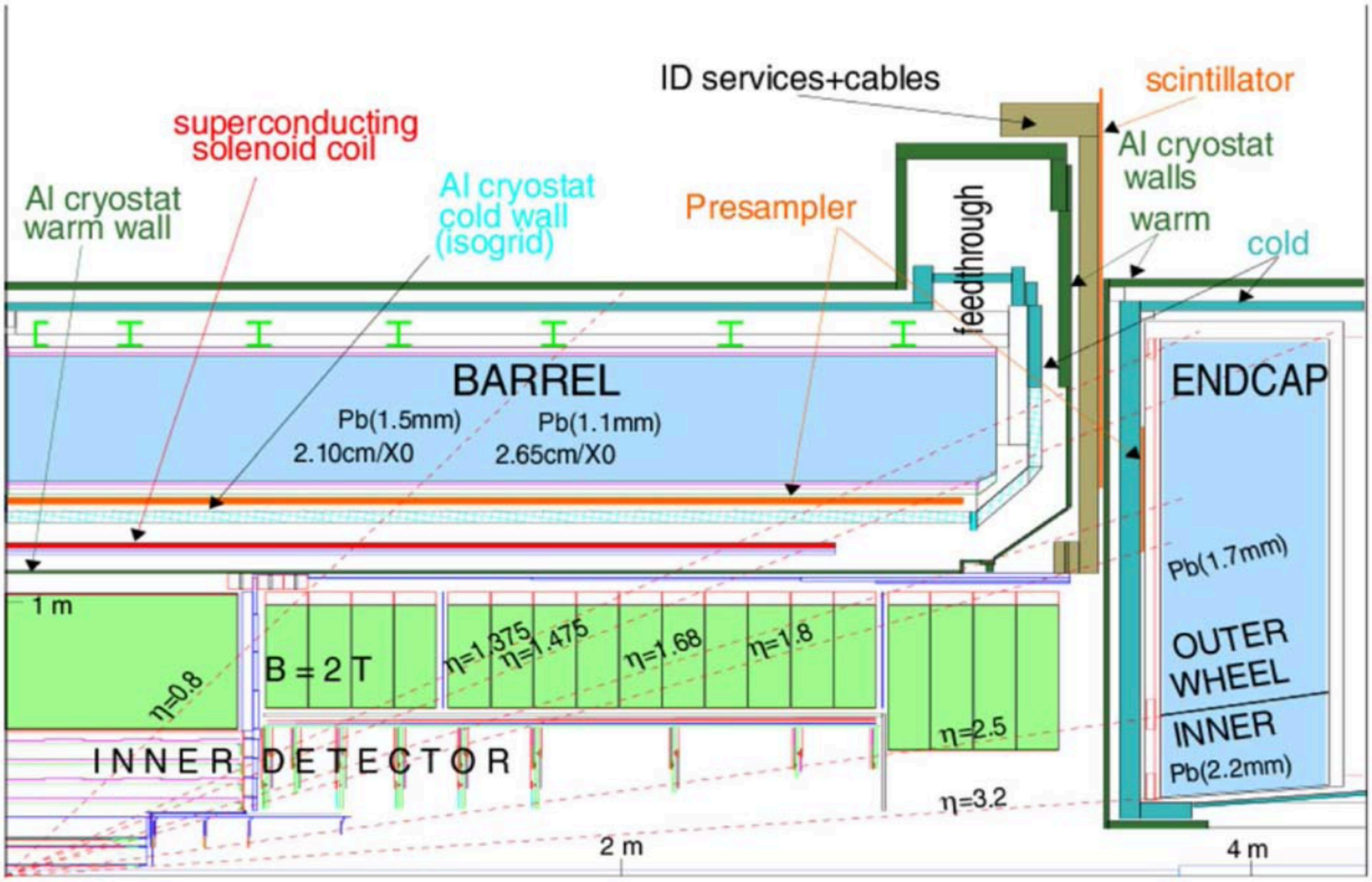
$$N_{signal} = \int L\, dt \times \sigma \times \epsilon$$

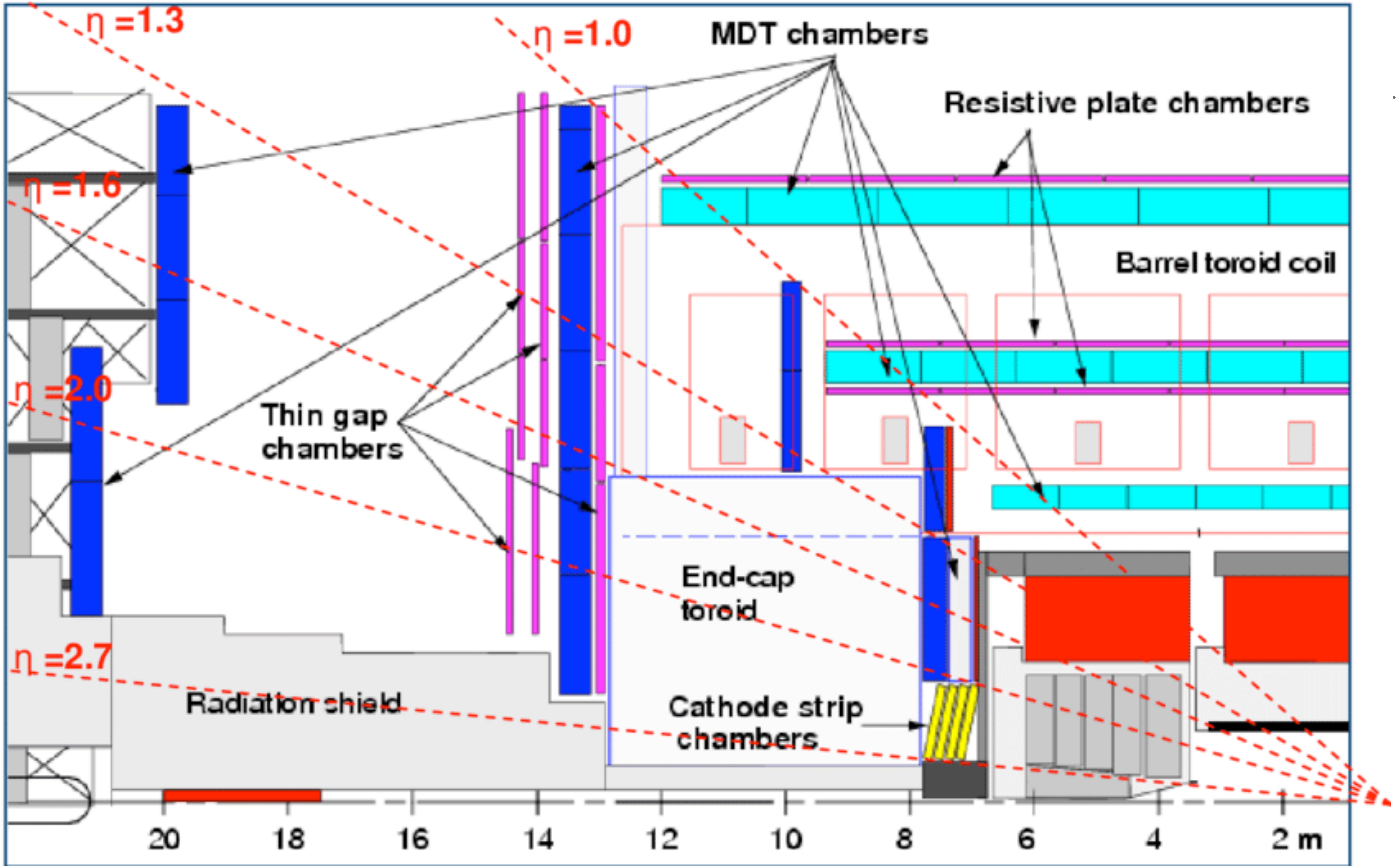
- fiducial cross-section (no A)
- total cross-section (extrapolate to full phase space)

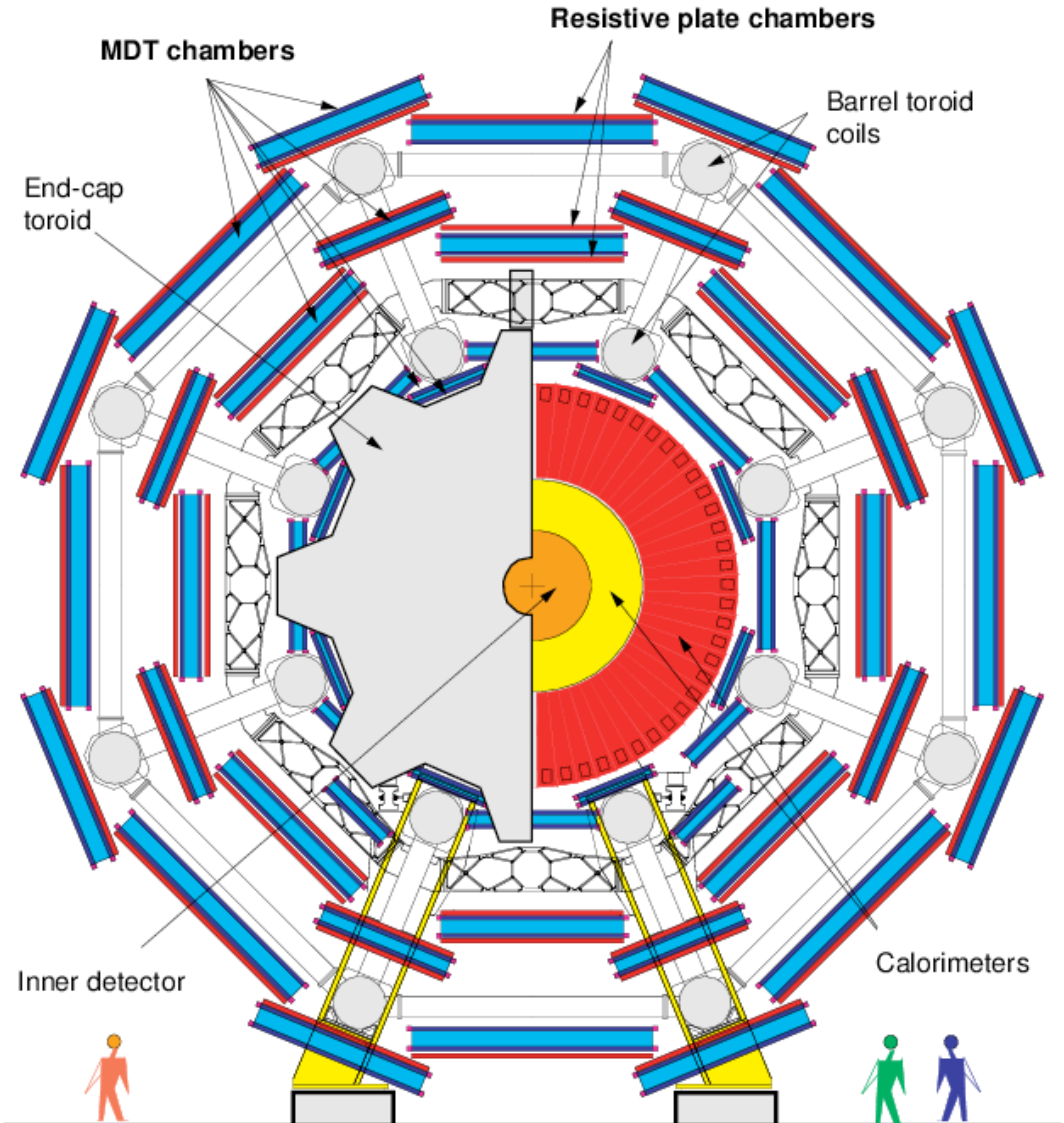
- *(note, no BR since we are measuring Z—>ll cross-section, not total Z cross-section)*

DATA ANALYSIS: PART 5 (IF TIME PERMITS)

- Other fun things to look at:
  - What happens if you select same-charge leptons (but all other selections) and plot invariant mass distribution? Is this different for electrons and muons?
  - How well does the simulation reproduce the data?
  - What happens if you select 4 lepton events and plot invariant mass of all same-flavor, opposite-charge pairs?
  - What does the jet pT distribution look like? What does it tell you?


ID services+cables
scintillator
superconducting solenoid coil
Al cryostat walls
warm
cold
Al cryostat warm wall
Al cryostat cold wall (isogrid)
Presampler
feedthrough
BARREL
Pb(1.5mm)
Pb(1.1mm)
2.10cm/X0
2.65cm/X0
ENDCAP
Pb(1.7mm)
OUTER WHEEL
INNER
Pb(2.2mm)
1 m
B = 2 T
η=0.8
η=1.375
η=1.475
η=1.68
η=1.8
η=2.5
η=3.2
INNER DETECTOR
2 m
4 m


η =1.3
η =1.0
MDT chambers
Resistive plate chambers
η =1.6
Barrel toroid coil
η =2.0
Thin gap chambers
End-cap toroid
η =2.7
Radiation shield
Cathode strip chambers
20
18
16
14
12
10
8
6
4
2 m


Resistive plate chambers
MDT chambers
Barrel toroid coils
End-cap toroid
Inner detector
Calorimeters

COMPARE TO: HTTPS://ARXIV.ORG/PDF/1612.03016.PDF

	$\sigma^{\text{tot}}_{W\to\ell\nu}$ [pb]
$W^+ \to \ell^+\nu$	$6350 \pm 2\,(\text{stat}) \pm 30\,(\text{syst}) \pm 110\,(\text{lumi}) \pm 100\,(\text{acc})$
$W^- \to \ell^-\bar{\nu}$	$4376 \pm 2\,(\text{stat}) \pm 25\,(\text{syst}) \pm 79\,(\text{lumi}) \pm 90\,(\text{acc})$
$W \to \ell\nu$	$10720 \pm 3\,(\text{stat}) \pm 60\,(\text{syst}) \pm 190\,(\text{lumi}) \pm 130\,(\text{acc})$
	$\sigma^{\text{tot}}_{Z/\gamma^*\to\ell\ell}$ [pb]
$Z/\gamma^* \to \ell\ell$	$990 \pm 1\,(\text{stat}) \pm 3\,(\text{syst}) \pm 18\,(\text{lumi}) \pm 15\,(\text{acc})$

Table 9: Total cross sections times leptonic branching ratios obtained from the combination of electron and muon channels with statistical and systematic uncertainties, for W^+, W^-, their sum and the Z/γ^* process measured at $\sqrt{s} = 7$ TeV. The Z/γ^* cross section is defined for the dilepton mass window $66 < m_{\ell\ell} < 116$ GeV. The uncertainties denote the statistical (stat), the experimental systematic (syst), the luminosity (lumi), and acceptance extrapolation (acc) contributions.

	$\sigma^{\text{fid}}_{Z/\gamma^* \to \ell\ell}$ [pb]
$Z/\gamma^* \to e^+e^-$	$502.7 \pm 0.5\,(\text{stat}) \pm 2.0\,(\text{syst}) \pm 9.0\,(\text{lumi})$
$Z/\gamma^* \to \mu^+\mu^-$	$501.4 \pm 0.4\,(\text{stat}) \pm 2.3\,(\text{syst}) \pm 9.0\,(\text{lumi})$
$Z/\gamma^* \to \ell\ell$	$502.2 \pm 0.3\,(\text{stat}) \pm 1.7\,(\text{syst}) \pm 9.0\,(\text{lumi})$

Central $Z/\gamma^* \to \ell\ell$: $p_{\text{T},\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, $46 < m_{\ell\ell} < 150$ GeV