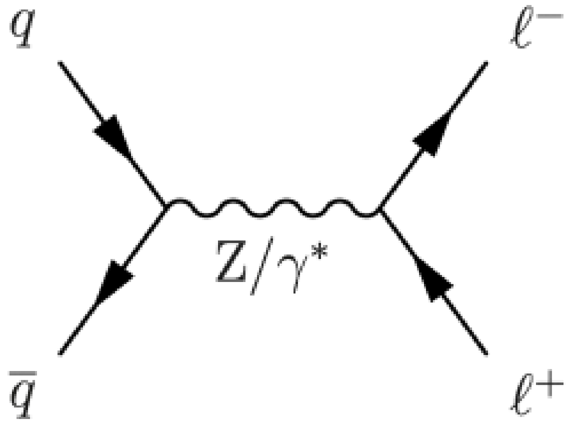
Study of isolation Working Points for the High Mass Drell-Yan cross-section measurement with the ATLAS experiment

Makridou Magdalini(U. Strasbourg)
Supervisor: Tetiana Berger-Hryn’ova (LAPP)

Introduction

- The Standard Model (SM) represents our current understanding of elementary particles and their interactions.
- Indications that SM is not the complete theory of particle physics.
- SM processes well predicted which can be measured precisely, have to be studied.
- One of the most prominent processes of this kind is the Drell-Yan (DY) process.

- It was first suggested by Sidney D. Drell and Tung-Mow Yan in 1970 in order to describe the production of dilepton pairs in high energy hadron collisions.
- It takes place when a quark of one hadron and an antiquark of another hadron annihilate, creating a virtual photon or Z boson which then decays into a pair of oppositely-charged leptons.



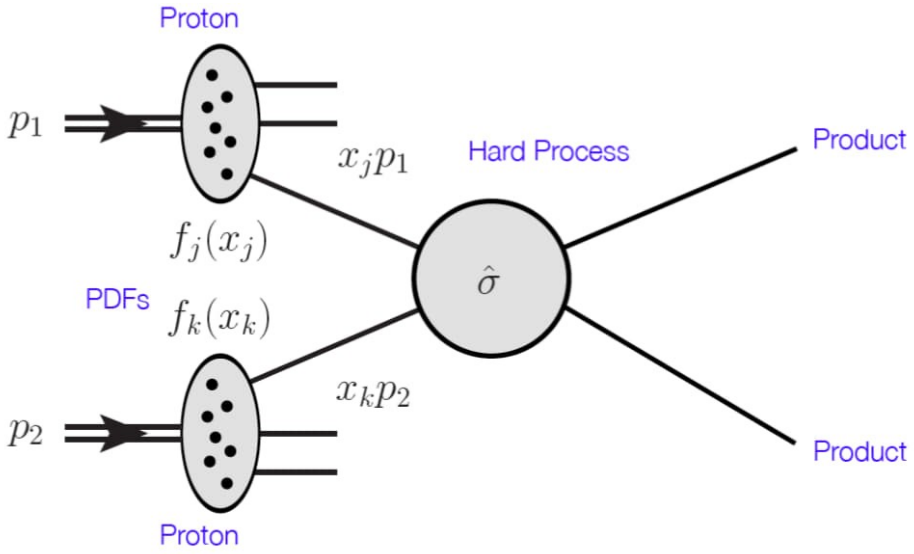
- Provides a way to test and verify the SM predictions at a high level of precision.
- Additionally the dilepton mass spectrum may be modified by new physics phenomena.

- The Large Hadron Collider (LHC), a proton-proton (pp) accelerator at CERN : a powerful machine which allows to search for new physics phenomena and to test the predictions of the Standard Model at the highest yet reached energy scales.
- To obtain a high level of accuracy of a hard-scattering process at the LHC a very good understanding of the structure of the proton is important.

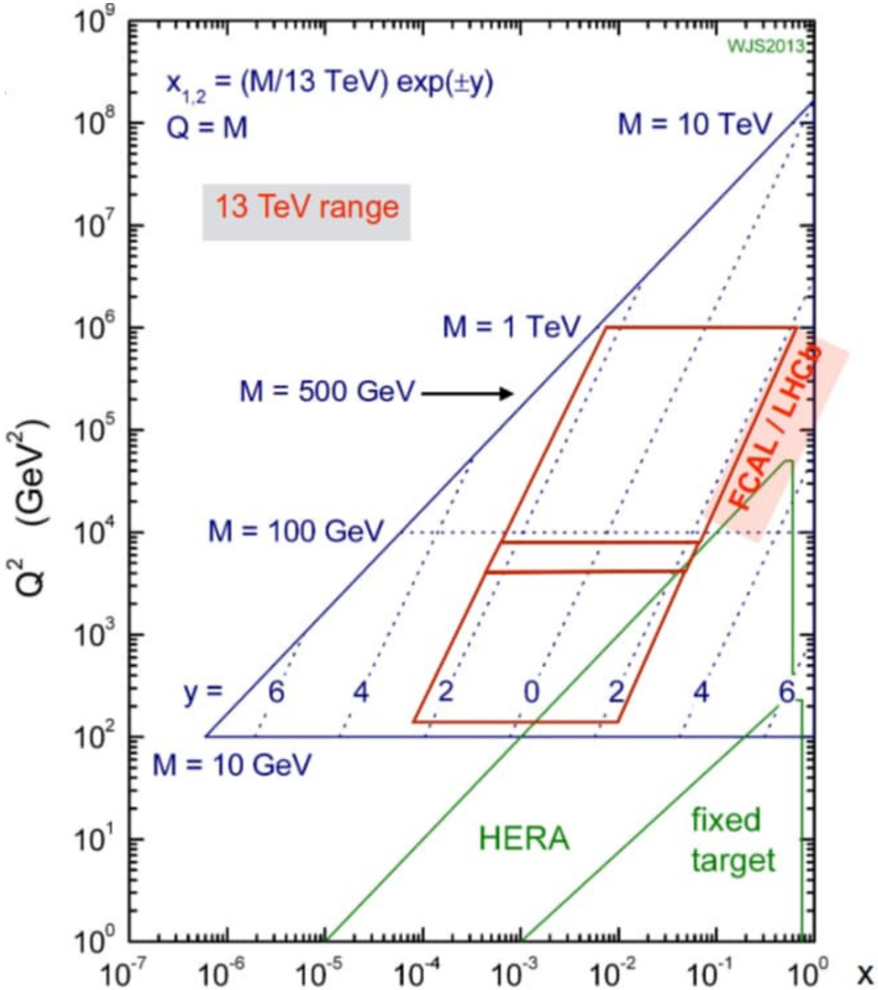
Proton:

- Hadron (composite particle)
- Consists of so-called partons (valence and sea quarks, gluons)

Scattering process:

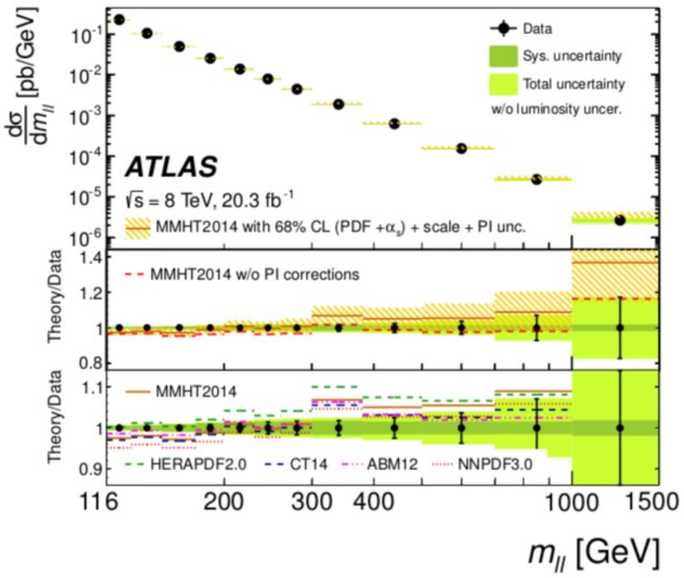


- The partons carry a momentum fraction of the proton (Bjorken x).
- The probability to find a parton with a given x inside the proton is parametrized by the parton distribution functions (PDF).
- The PDFs have, besides the dependency on x, a dependency on the Q^2 (Q: the scale of the momentum transfer in a given process).



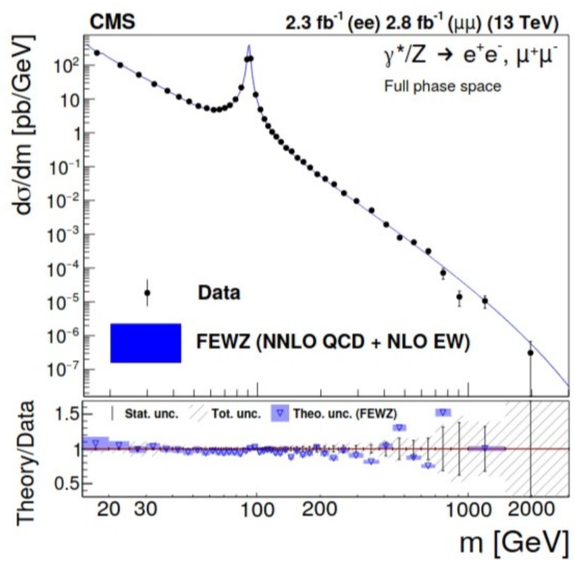
$$x = \frac{m_{ll}}{\sqrt{s}} e^{y_{ll}}$$

- Different dilepton invariant masses m_{ll} and different rapidities y_{ll} probe different values of the parton x.
- The measurement of Drell-Yan production of dilepton pairs provides an important test of QCD, which can also provide constraints on the parton distribution functions (PDFs) of the proton.
- In particular measurements differential in dilepton rapidity, y_{ll}, provide access to the momentum fraction, Bjorken x, of the participating partons in the interaction, which kinematically extends to higher x as the invariant mass, m_{ll} , increases.



- Latest ATLAS analysis with 20.3 fb^{-1} at $\sqrt{s}$ = 8 TeV resulting uncertainties of 2% at 200 GeV & 11% at 1 TeV (2012 data)

- Latest CMS analysis with 2.8 (2.3) fb^{-1} in the dimuon (dielectron) channel and $\sqrt{s}$ =13 TeV with uncertainties of 7.5% at 200 GeV & 48% at 1 TeV (2015 data).



- Current analysis:
- → The integrated luminosity has increased to 139 fb^{-1} → smaller statistical uncertainties
- → Increase in $\sqrt{s}$ to 13 TeV, the analysis probes even higher parton momentum fraction

Signal and Background Samples

Process	Generator
Drell-Yan	Powheg
Photon-Induced	Pythia
$t\bar{t}$	Powheg
Diboson	Sherpa
W+jets	Powheg

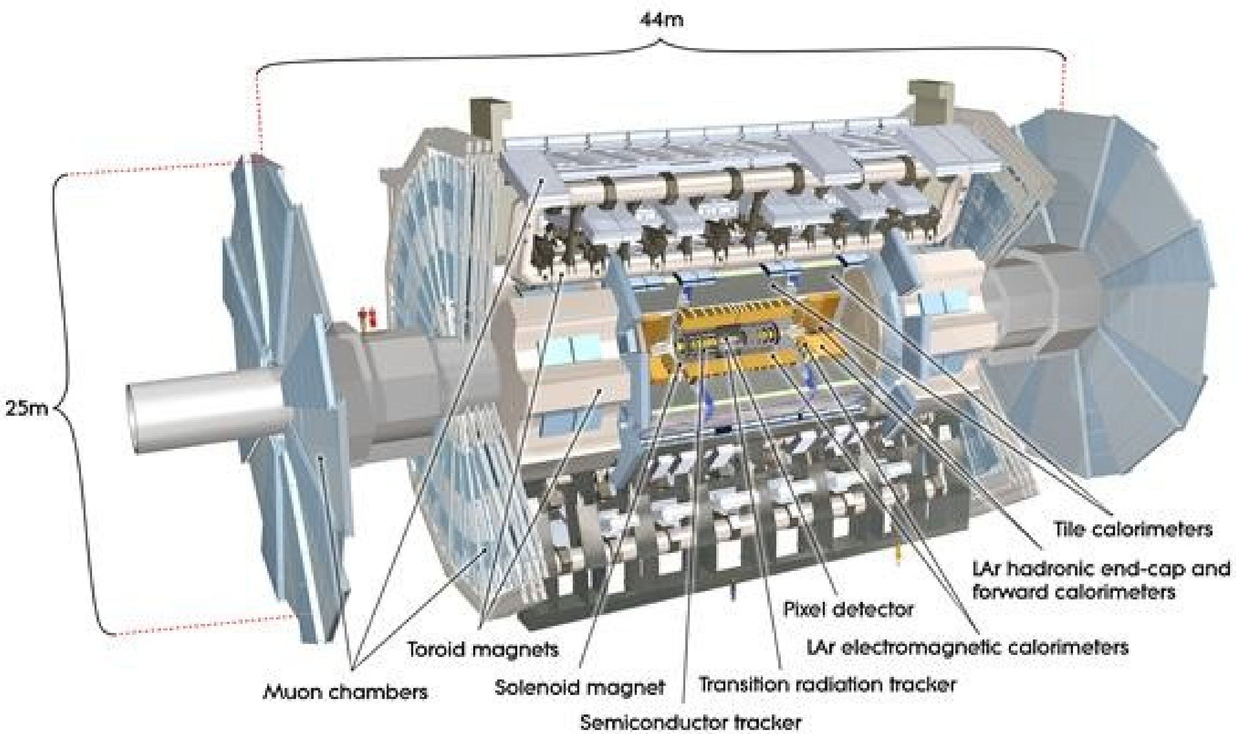
- DY samples are generated in 13 bins of true dilepton invariant mass between 116 GeV and 3000 GeV → ensure adequate statistics at high invariant mass.

- Background contribution comes from the $t\bar{t}$, Diboson and W+jets & multijets processes.

- The production of the simulated events is performed on the LHC Computing Grid in several steps:
  - ESD (Event Summary Data): the whole information on detector level is transformed into information on object level
  - AOD (Analysis Object Data): only contain information about specific physics objects which are needed for the analysis.
  - DAOD: extraction of the AODs to a compressed version, so-called derivation → targeting a specific analysis signature, which in our case is at least one lepton in the event.
  - Further sample size reduction is performed by applying additional identification and isolation requirements -> the event selection is performed using the AnalysisTop package within the Athena framework and the information is stored into ROOT Ntuples.

The ATLAS Detector

- Inner Detector (ID) surrounded by superconducting solenoid magnet
  - Pixel detector, semiconductor tracker, transition radiation tracker



- Electromagnetic (EM) Calorimeter (lead-liquid argon (LAr) sampling calorimeter) :
  - barrel section
  - two end-cap sections
- Hadronic Calorimeter :
  - scintillator-tile barrel calorimeter
  - liquid argon end-cap and forward calorimeters
- Air-Core Toroid Magnets :
  - instrumented with muon chambers
- Muon Spectrometer :
  - precision tracking chambers
  - fast detectors for triggering

Object and event selection

Electron Selection

- $E_T > 30$ & $|\eta| < 2.47$ excluding track region $1.37 < |\eta| < 1.52$ from the barrel-endcap transition
- “Medium” identification requirements

Muon selection

- $P_T > 30$ & $|\eta| < 2.5$
- “Medium” identification working point

Event Selection & Reconstruction

- Event cleaning: The event needs to be measured in a time period where the detector is fully operational. Additional event-level vetoes are applied to reject bad or corrupted events, e.g. due to noise bursts, based on data-quality flags of certain detector subsystem.
- Primary vertex: Events are required to have a primary vertex with at least two associated tracks.
- Trigger selection : Events are required to satisfy single lepton or dilepton trigger requirements (electron/muon).

- Exactly two same-flavour leptons (third lepton veto)
- From the available same-flavour leptons, the leading and subleading leptons must fulfill $p_T > 40$ *and* $p_T > 30$ respectively.
- Opposite sign requirement
- $m_{ll} > 116$ GeV

Lepton Isolation

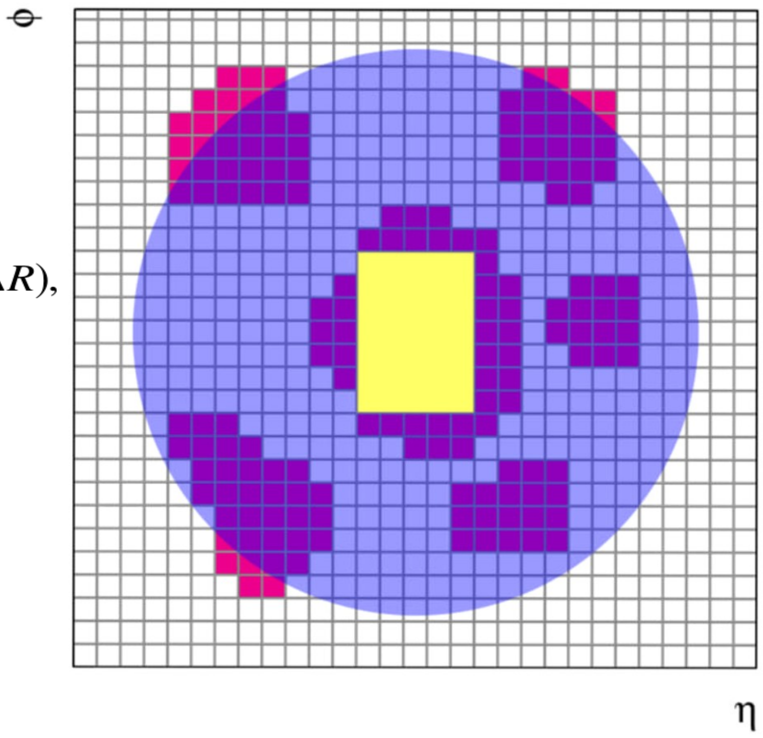
- One of the most powerful tools to discriminate signal against background.
- Define a proper ”isolation energy” around leptons to reduce the contamination from non-prompt and fake objects.
- Isolation consists in assessing the activity surrounding the trajectory of the lepton in the Inner Detector (ID) and the Calorimeter.
- To calculate the isolation variables, a cone in the η and φ plane is defined around the particle and the energy of close-by objects falling in this cone is added, having subtracted the contribution of the particle itself.

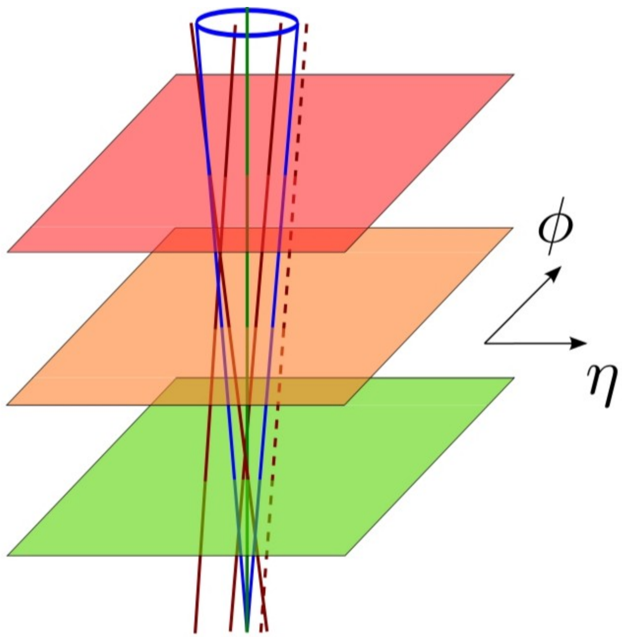
➔ **Calorimeter Isolation**

The fully corrected ***topoetcone*** calorimeter isolation variable is computed as:

$$E_{\mathrm{T}}^{\mathrm{coneXX}} = E_{\mathrm{T,raw}}^{\mathrm{isolXX}} - E_{\mathrm{T,core}} - E_{\mathrm{T,leakage}}(E_{\mathrm{T}}, \eta, \Delta R) - E_{\mathrm{T,pile\text{-}up}}(\eta, \Delta R),$$

*XX : refers to the size of the cone , ΔR = XX/100.





Track Isolation

The track isolation variable, called ***ptcone*** (p_T^{coneXX}) is computed by summing the transverse momentum of selected tracks within a cone centered around the lepton track direction. For leptons is defined with a variable cone size, called ***ptvarcone*** ($p_T^{varconeXX}$)- the cone size shrinks for larger momentum of the lepton:

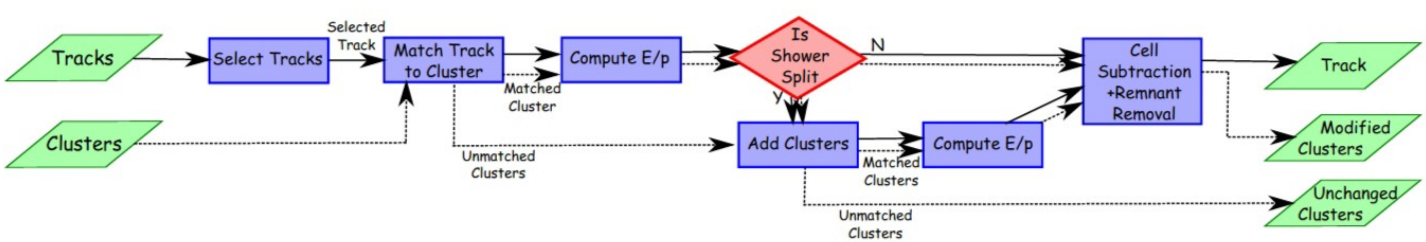
$$\Delta R = \min\left(\frac{10}{p_{\mathrm{T}}[\mathrm{GeV}]}, \Delta R_{\mathrm{max}}\right)$$

ΔR_{max}:maximum cone size, (typically 0.2 to 0.4)

Two variants of the ptvarcone variable, ptvarconeXX($p_T^{varconeXX}$) and ptvarconeXX_TightTTVA_pt1000 ($p_{T,TTVA}^{varconeXX}$), requiring different selections for the tracks used to build them.

Particle Flow Isolation

It combines the ID and calorimeter information to take the best of each detector.



The particle flow isolation consists in a charged part, that is equivalent to the track isolation and a neutral part called ***neflowisol***, built in a similar way with the previously described calorimeter isolation but using the neutral energy flow leptons.

Standard Isolation Working Points

- The different electron isolation WPs used in our study are represented in the table

WPs	Calorimeter isolation	Track isolation
TightTrackOnly	-	ptvarcone30_TightTTVALooseCone_pt1000/p_T < 0.06
TightTrackOnly_FixedRad	-	ptvarcone30_TightTTVALooseCone_pt1000/p_T < 0.06 below 50 GeV, ptcone20_TightTTVALooseCone_pt1000/p_T < 0.06
Tight	topoetcone20/p_T < 0.06	ptvarcone20_TightTTVA_pt1000/p_T < 0.06
Loose	topoetcone20/p_T < 0.2	ptvarcone20_TightTTVA_pt1000/p_T < 0.06
PflowTight	(ptvarcone30_TightTTVALooseCone_pt500+0.4neflowisol20)/p_T < 0.045	

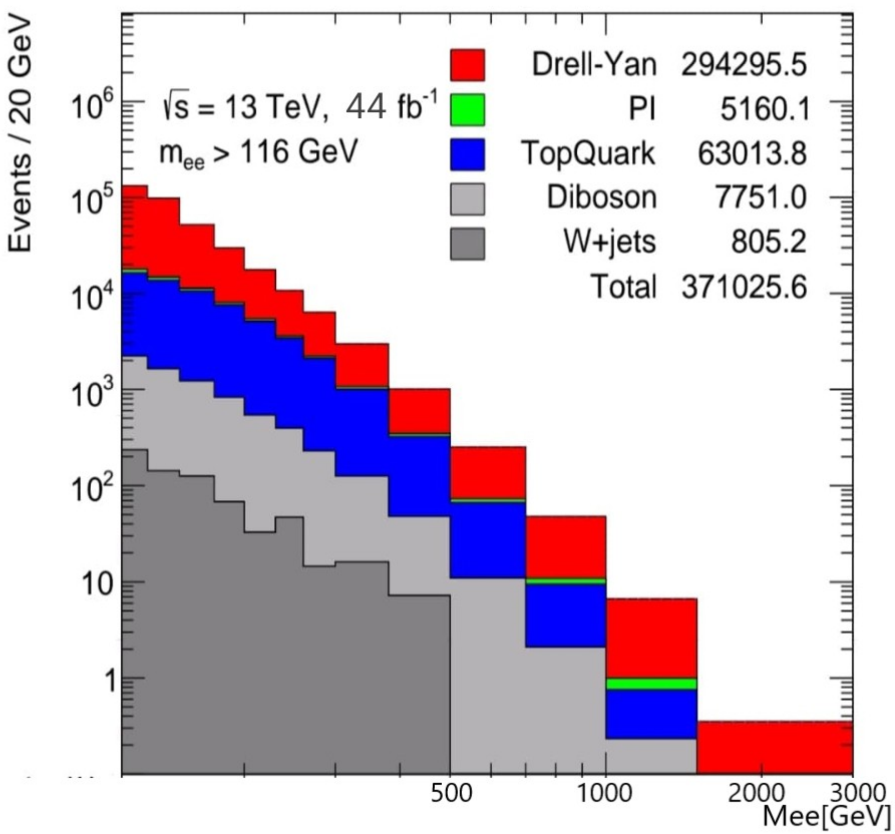
- The different muon isolation WPs used in our study are represented in the table

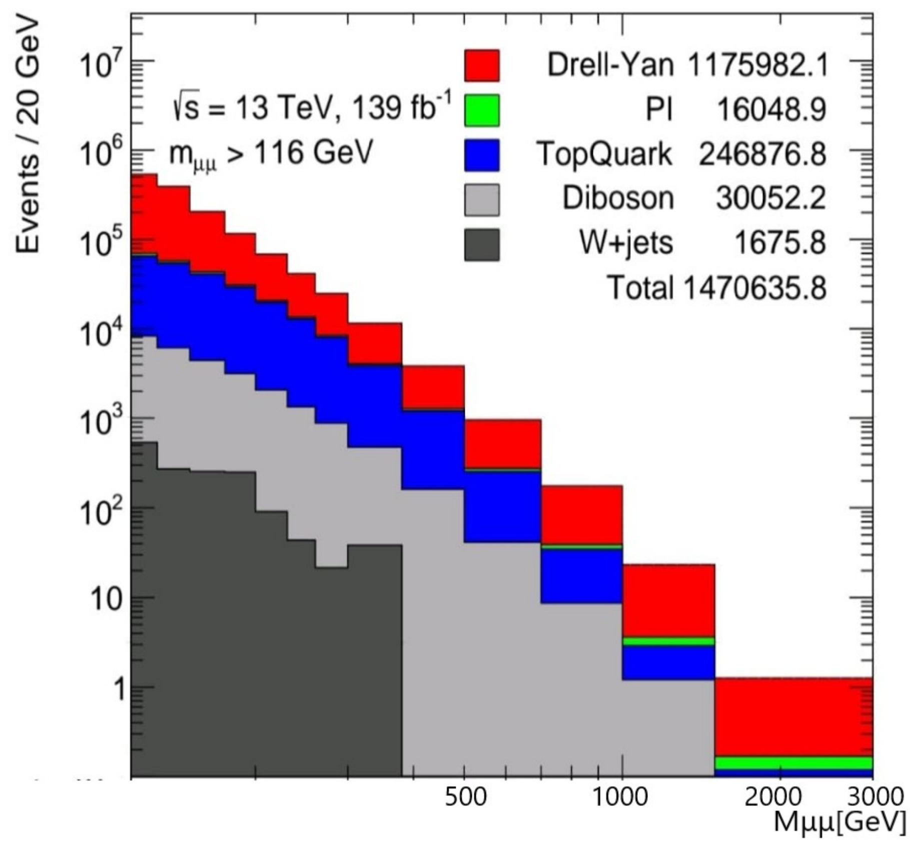
WPs	Calorimeter isolation	Track isolation
Loose	topoetcone20/p_T < 0.03	ptvarcone30/p_T < 0.15
Tight	topoetcone20/p_T < 0.06	ptvarcone30/p_T < 0.06
TightTrackOnly_FixedRad	-	ptvarcone30_TightTTVALooseCone_pt1000/p_T < 0.06 below 50 GeV, ptcone20_TightTTVALooseCone_pt1000/p_T < 0.06
PflowTight	(ptvarcone30_TightTTVALooseCone_pt500+0.4neflowisol20)/p_T < 0.045	
PflowLoose	(ptvarcone30_TightTTVALooseCone_pt500+0.4neflowisol20)/p_T < 0.16	

My Contribution

- My task was to study and decide which isolation WP is best suited for the DY measurement.
- Production of the ROOT Ntuples → Full analysis selection is applied.

- Dielectron and dimuon mass distributions for the range 116-3000 GeV for “Loose” Isolation WP





Typical background is:
- 88 % for $t\bar{t}$
- 10 % for Diboson
- 2 % for W+jets

Typical background is:
- 88.5 % for $t\bar{t}$
- 11 % for Diboson
- 0.5 % for W+jets

Evaluation Method

In order to compare the different isolation working points we use a criteria called significance, defined as:

$$\text{significance} = S/\sqrt{(S+B)}$$

It is a non-dimensional number, which we use to measure something more precisely.

Signal = DY events
Background = TopQuark + Diboson + W+jets events

Table with mass range and corresponding significance for each electron isolation WP

m_{ee} (GeV)	Loose	Tight	TightTrackOnly	TightTrackOnly_FixedRad	PflowTight
116-130	**265**	252	263	262	254
130-150	**268**	257	266	265	260
150-175	**202**	195	201	200	197
175-200	**142.4**	138.7	142.1	141.8	140.5
200-230	**114.3**	111.8	114.2	113.9	113.2
230-260	85.2	83.6	**85.2**	85.00	84.7
260-300	74.2	73.1	**74.2**	74.0	73.9
300-380	71.1	70.4	**71.2**	71.1	71.0
380-500	51.7	51.4	**51.9**	51.8	51.7
500-700	36.2	36.0	**36.2**	36.1	36.1
700-1000	21.0	21.0	**21.0**	21.0	21.0
1000-1500	11.2	11.2	**11.2**	11.2	11.2
1500-3000	4.8	4.8	**4.8**	4.8	4.8

Table with mass range and corresponding significance for each muon isolation WP

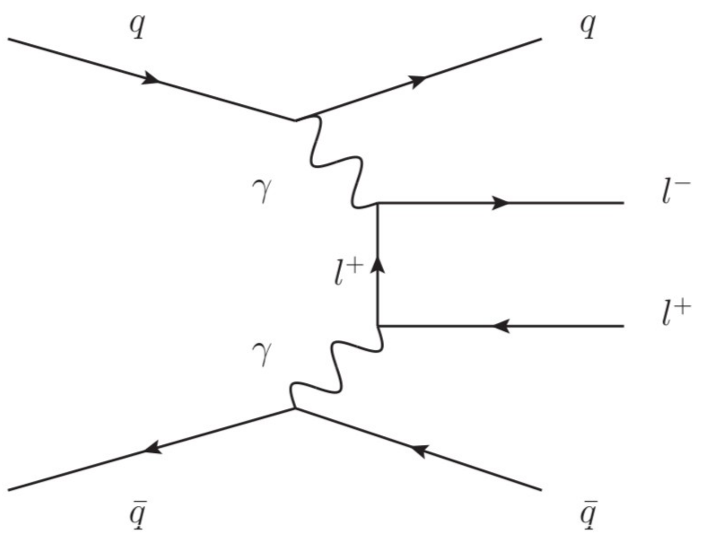
$m_{\mu\mu}$ (GeV)	Loose	Tight	PflowTight	PflowLoose	TightTrackOnly_FixedRad
116-130	537	540	531	**555**	550
130-150	538	539	531	**550**	546
150-175	402.4	401.5	396.6	**407.2**	405.0
175-200	282.6	281.5	278.8	**284.4**	283.2
200-230	225.9	224.7	222.8	**226.4**	225.6
230-260	169.3	168.3	167.2	**169.4**	168.9
260-300	**148.6**	147.7	146.9	148.5	148.1
300-380	**141.3**	140.6	140.0	141.3	140.9
380-500	**102.5**	102.0	101.6	102.4	102.2
500-700	**70.6**	70.3	70.0	70.6	70.4
700-1000	**40.6**	40.4	40.3	40.6	40.5
1000-1500	**20.7**	20.6	20.5	20.7	20.7
1500-3000	**8.6**	8.6	8.5	8.6	8.6

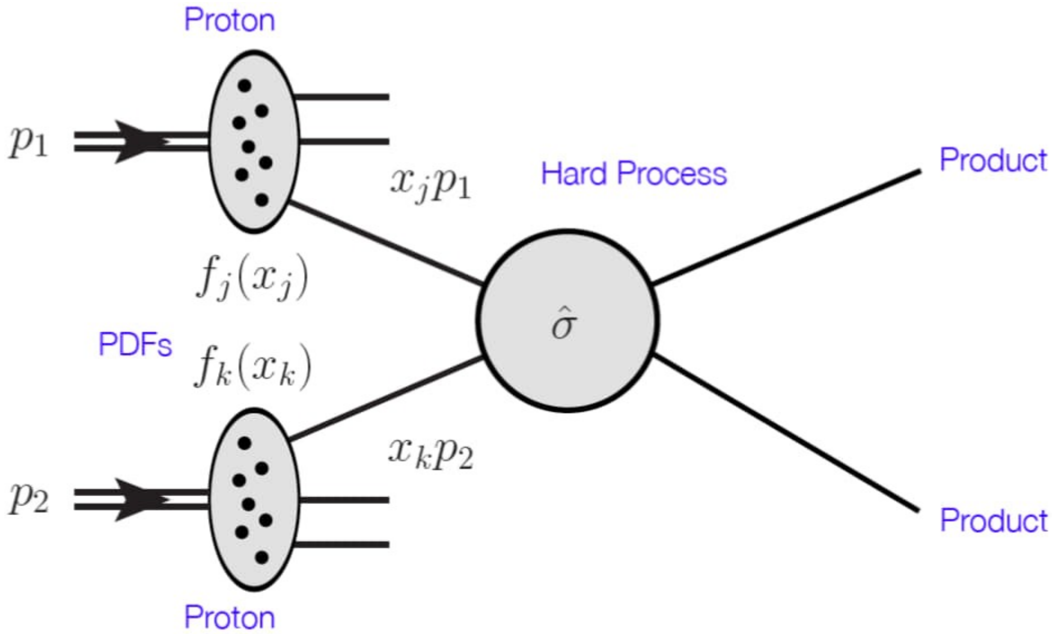
Conclusions

- The analysis is not sensitive to the isolation configuration used.
  - main background sources are dominated by the real leptons in the dilepton mass range considered.
- Statistical uncertainties are expected to be ~2% per channel in the 700-1000 GeV range, which is about a factor of five improvement on the previous results.
  - These uncertainties would become compatible to the expected systematic uncertainties in this dilepton mass range

Back up Slides

- The quarks carry electric charges themselves → can radiate photons.
- Photon-Induced (PI) process arises from a γγ, γq or γq̄ initial state.
- The latter two involve photon absorption and Z/γ* emission with a subsequent dilepton decay.
- It is consider as part of the signal.





- The four vectors of the incoming partons can be written as (assuming $m_{parton} = 0$):

$$p_j^\mu = \frac{\sqrt{s}}{2}(x_j, 0, 0, x_j), p_k^\mu = \frac{\sqrt{s}}{2}(x_k, 0, 0, -x_k)$$

- Using the four vectors, the rapidity of the leptons pair can be expressed as:

$$y_{ll} = \frac{1}{2}\log(\frac{x_j}{x_k})$$

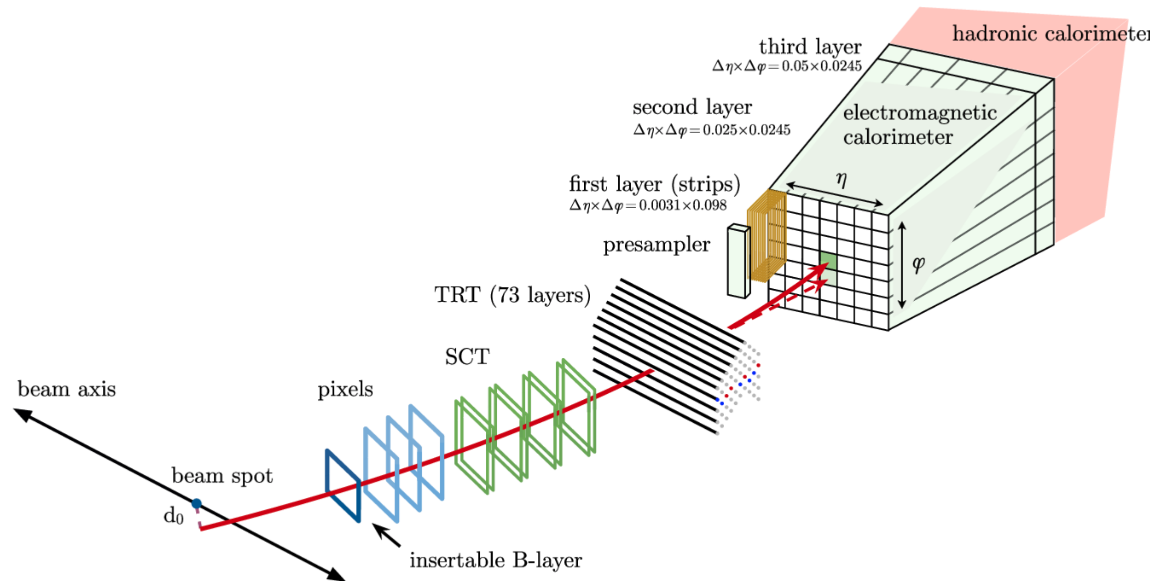
- Since the invariant mass of the dilepton system is equal to the center-of-mass energy of the colliding partons $m^2_{ll} = x_j x_k s$:

$$x_j = \frac{m_{ll}}{\sqrt{s}} e^{y_{ll}}, x_k = \frac{m_{ll}}{\sqrt{s}} e^{-y_{ll}}$$

Reconstruction and Identification

Electrons

- An electron candidate is reconstructed from a cluster built from energy deposits in the EM calorimeter and a matched track (or tracks).
- The identification of prompt electrons relies on a likelihood discriminant constructed from quantities measured in the ID, the calorimeter and the combined information.



Muons

- Muon reconstruction is first performed independently in the ID and MS. The information from individual subdetectors is then combined to form the muon tracks that are used in physics analyses.
- Muon identification is performed by applying quality requirements that suppress background, mainly from pion and kaon decays, while selecting prompt muons with high efficiency and/or guaranteeing a robust momentum measurement.