CMS Winter Camp

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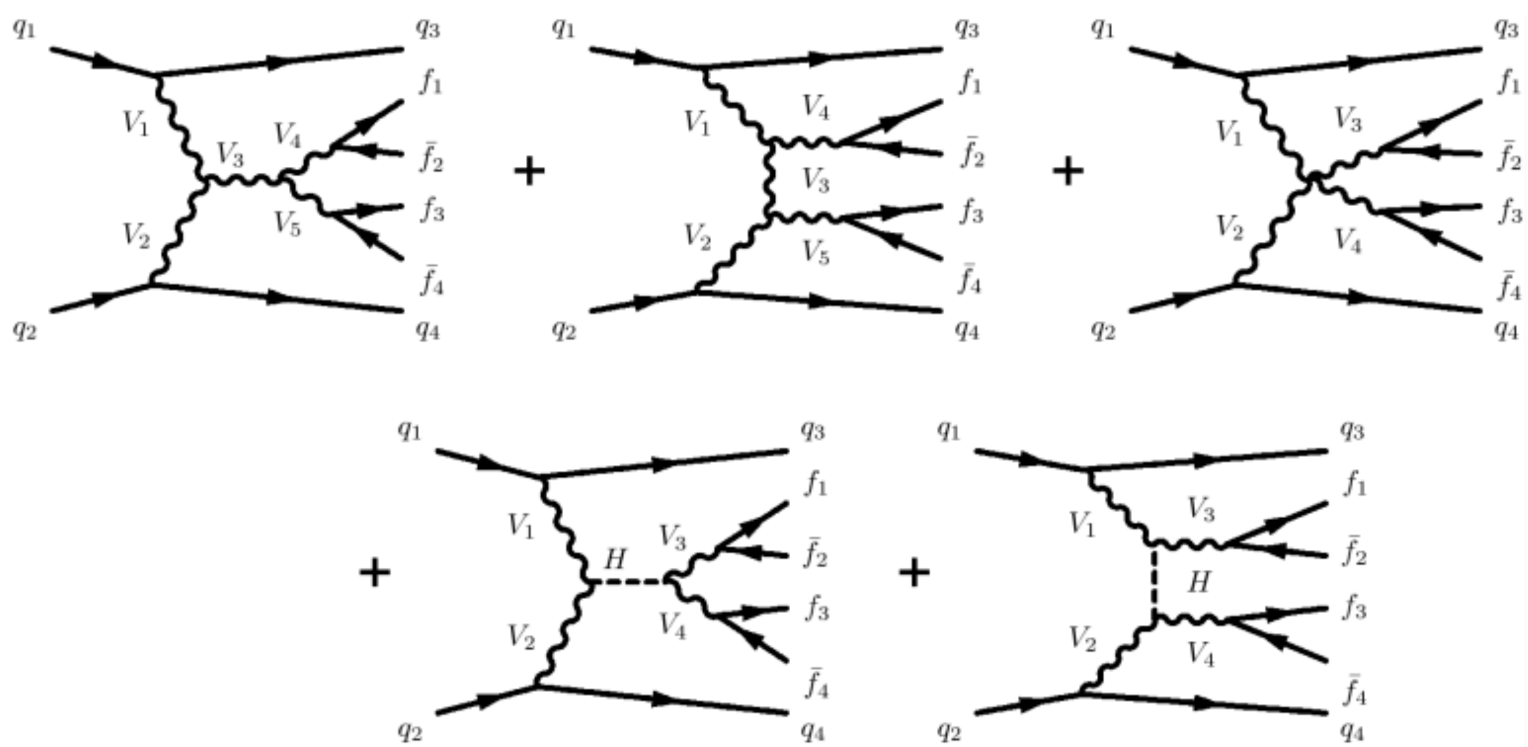
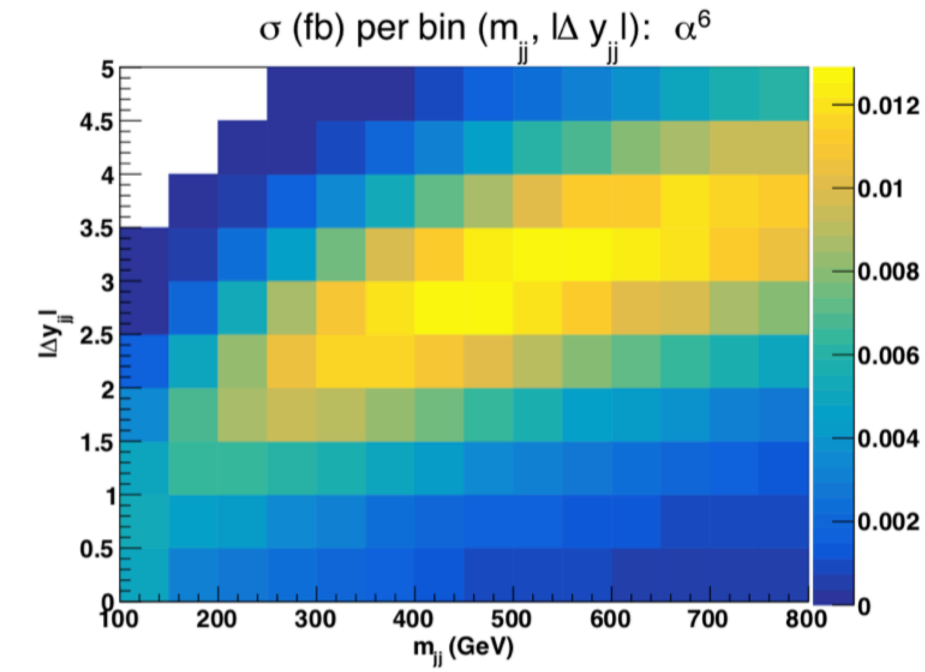
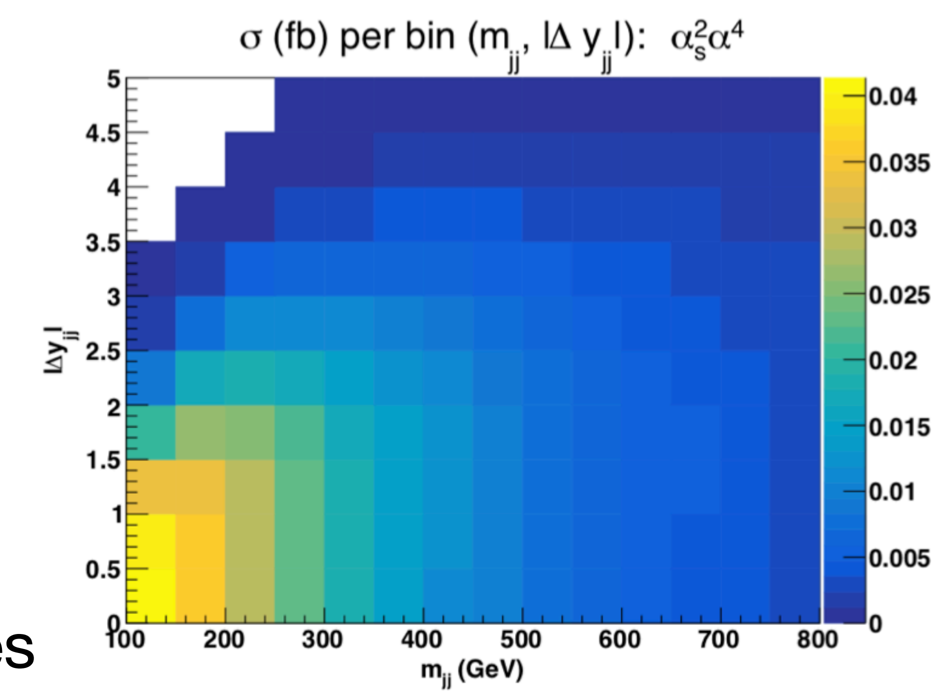
CMS

Introduction & Motivation







- **Signal:** six fermions final state at leading order $\mathcal{O}(\alpha^6)$
- **Irreducible background:** QCD-induced $\mathcal{O}(\alpha^4\alpha_s^2)$
- Interference: between EW and QCD $\mathcal{O}(\alpha^5\alpha_s)$
- **Reducible** background due to mis-ID of final state particles
- Significant systematic uncertainties from jet energy reconstruction and background modeling

Introduction & Motivation

Important process to investigate electroweak symmetry breaking(EWSB)

- ☑ Probe the nature of EW symmetry breaking
- ☑ Unitarity preservation visible only in VV scattering

Complimentary to direct Higgs Boson measurement

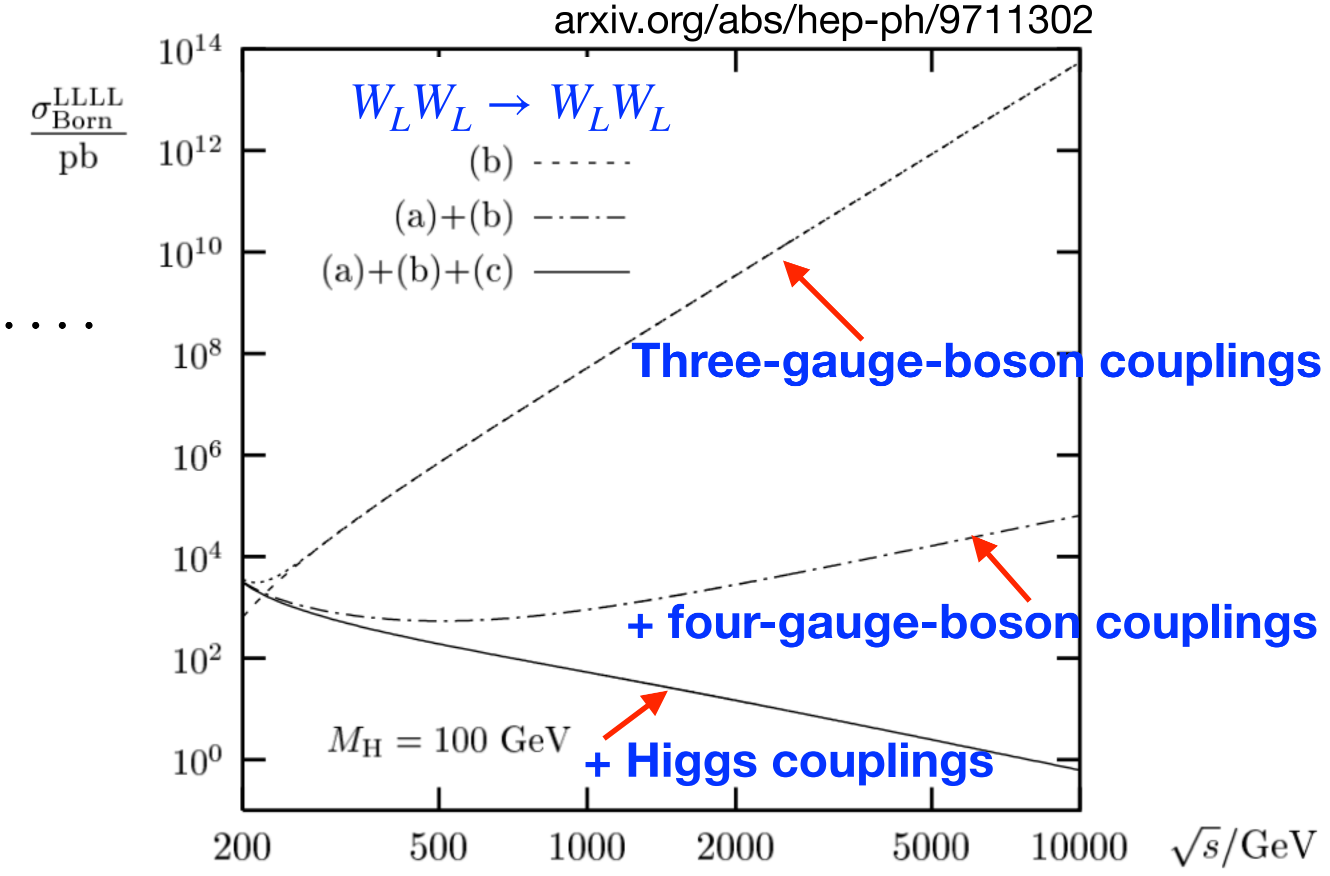
- ☑ The perturbative cross section of longitudinal VBS ($V_L V_L \rightarrow V_L V_L$) diverges, if there was no Higgs boson or a similar mechanics

Sensitive to anomalous coupling

- ☑ Triple and quartic gauge coupling

$$\mathscr{L}_{EFT} = \mathscr{L}_{SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}^{(6)} + \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}^{(8)} + \dots$$

arxiv.org/abs/hep-ph/9711302



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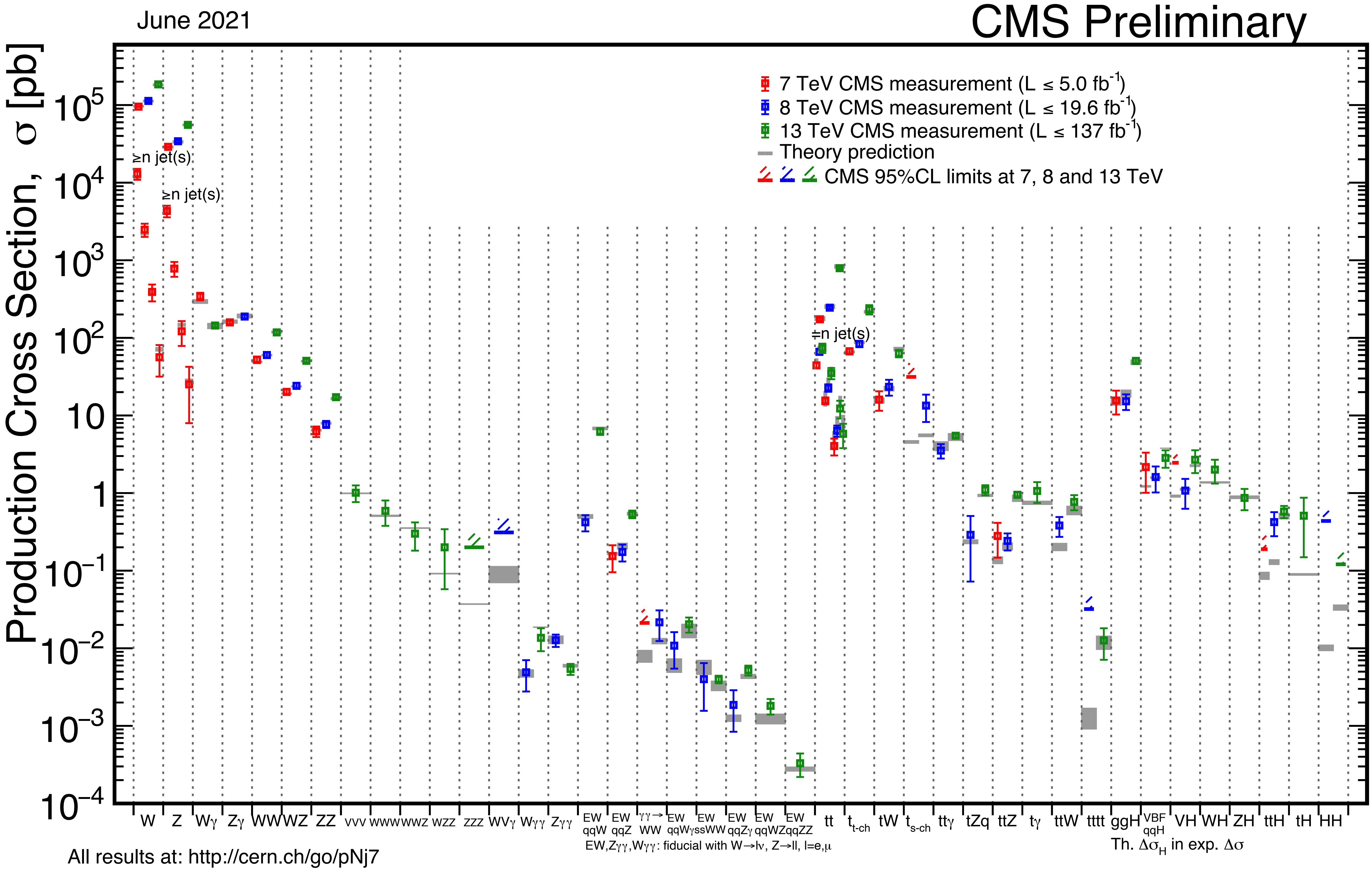

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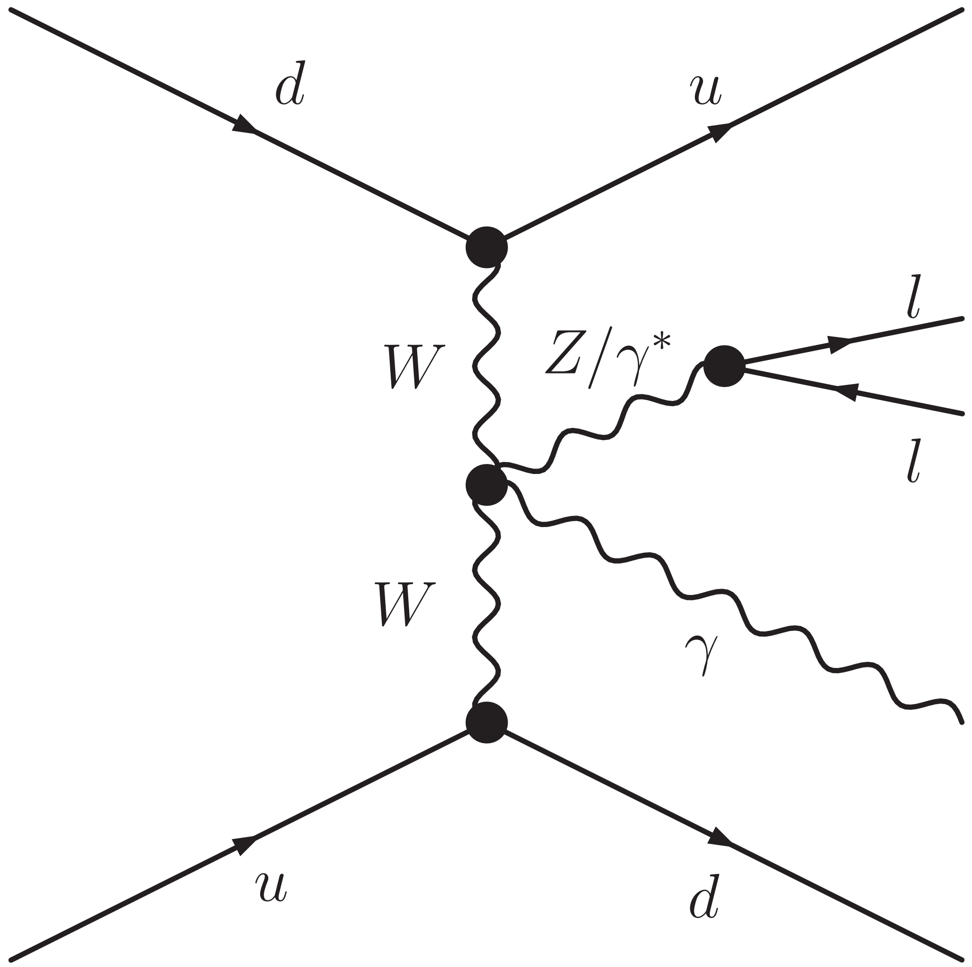
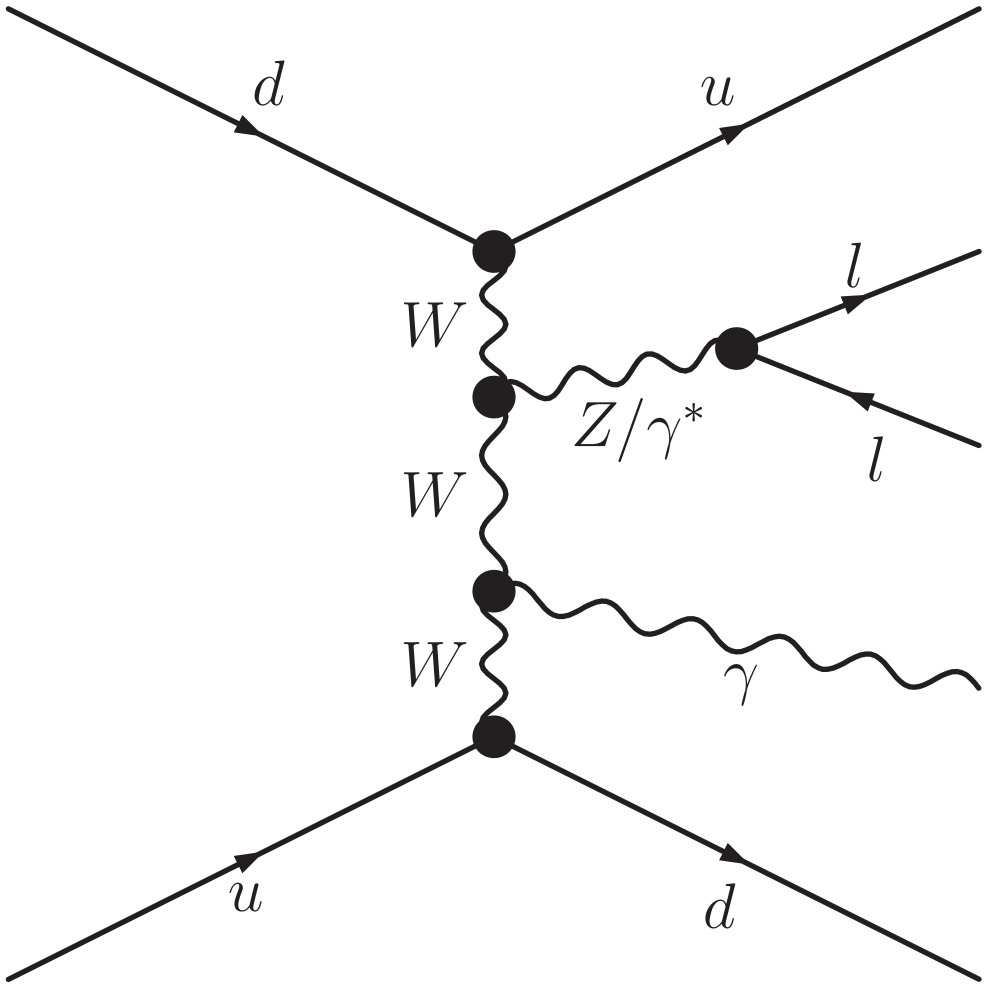




Sample & Selection

Good Muon
- Tight muon WP
- Relative PF-isolation (0.4 cone) <0.15
- p_T > 20 GeV, $|\eta| < 2.4$

Veto Muon
- Loose muon WP
- Relative PF-isolation (0.4 cone) <0.25
- p_T > 20 GeV, $|\eta| < 2.4$

Veto Electron
- Loose electron WP
- p_T > 20 GeV, $|\eta| < 2.5$, $|\eta| < 1.4442$ or $1.566 < |\eta| < 2.5$

For third lepton veto

Good Electron
- Medium electron WP
- p_T > 25 GeV, $|\eta| < 2.5$

Good Photon
- Medium photon WP
- Electron veto
- p_T > 20 GeV and $|\eta| < 1.4442$ or $1.566 < |\eta| < 2.5$

Jets
- Particle-flow jets and AK4CHS (0.4 cone; charged particles from pileup are removed)
- Tight jet WP and pileup jet WP ($p_T < 50$ GeV)
- p_T>30 GeV
- $|\eta| < 4.7$

Question:

Why a looser ID is used to reject the extra leptons?

Exercise1

Code example in Jupyter notebook

```
fdir='/data/pubfs/pku_visitor/public_write/zajj_ori/'
f=ROOT.TFile(fdir+'cutla-outZA17.root')
tree=f.Get('ZPKUCandidates')
c1=ROOT.TCanvas('c1','',600,500)
c1.Draw()
tree.Draw('massVlep>>h1(20,70,110)','(Mjj>150)*scalef','HIST')
```

Task:

Please use the signal sample saved in /data/pubfs/pku_visitor/public_write/zajj_ori/ named cutla-outZA-EWK17.root and draw plots for variable named “massVlep”, “photonet”, “Mva”, “Mjj” and some variables you are interested in. (tree.Print() can be used to see the branch list)

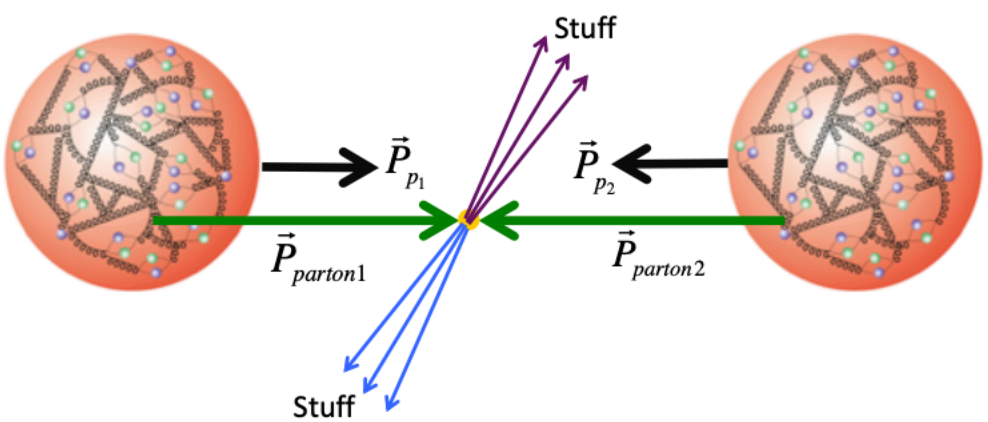
Question:

Why there are two peaks in the Mva distribution?
Why the Z mass distribution in QCD ZA sample have more events in the low mass region?

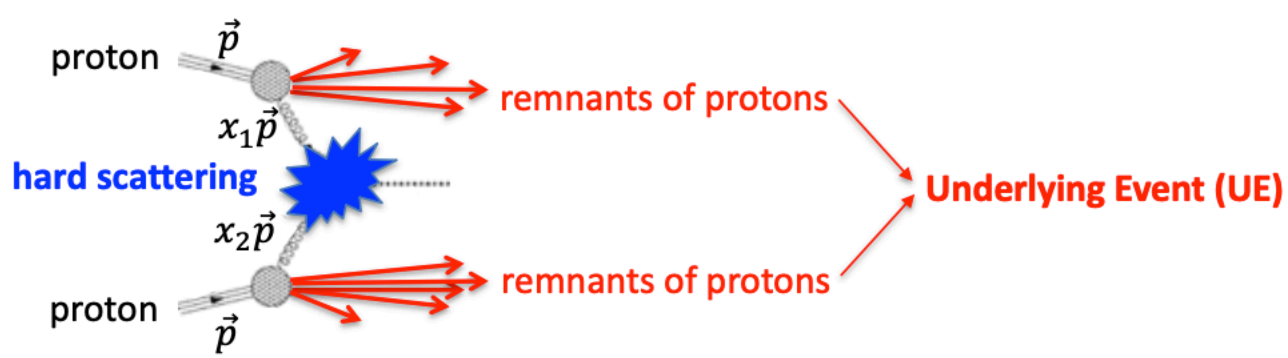
Introduction — Collision

protons are not elementary objects

pp collision = collision of two "garbage cans" full of <u>quarks</u> and <u>gluons</u> (a.k.a. partons)



- **Hard collision:**
  - **hard scattering of two partons**
  - **quark/gluon showering + hadronization**
  - **underlying event (UE) = remnants of protons**
  - this factorization is approximate (!)



$$\sigma(pp \to H) \;=\; \int \hat{\sigma}(gg \to H | x_1, x_2) \cdot f_g(x_1) \cdot f_g(x_2) \cdot dx_1 dx_2 \;+\; \ldots$$

where

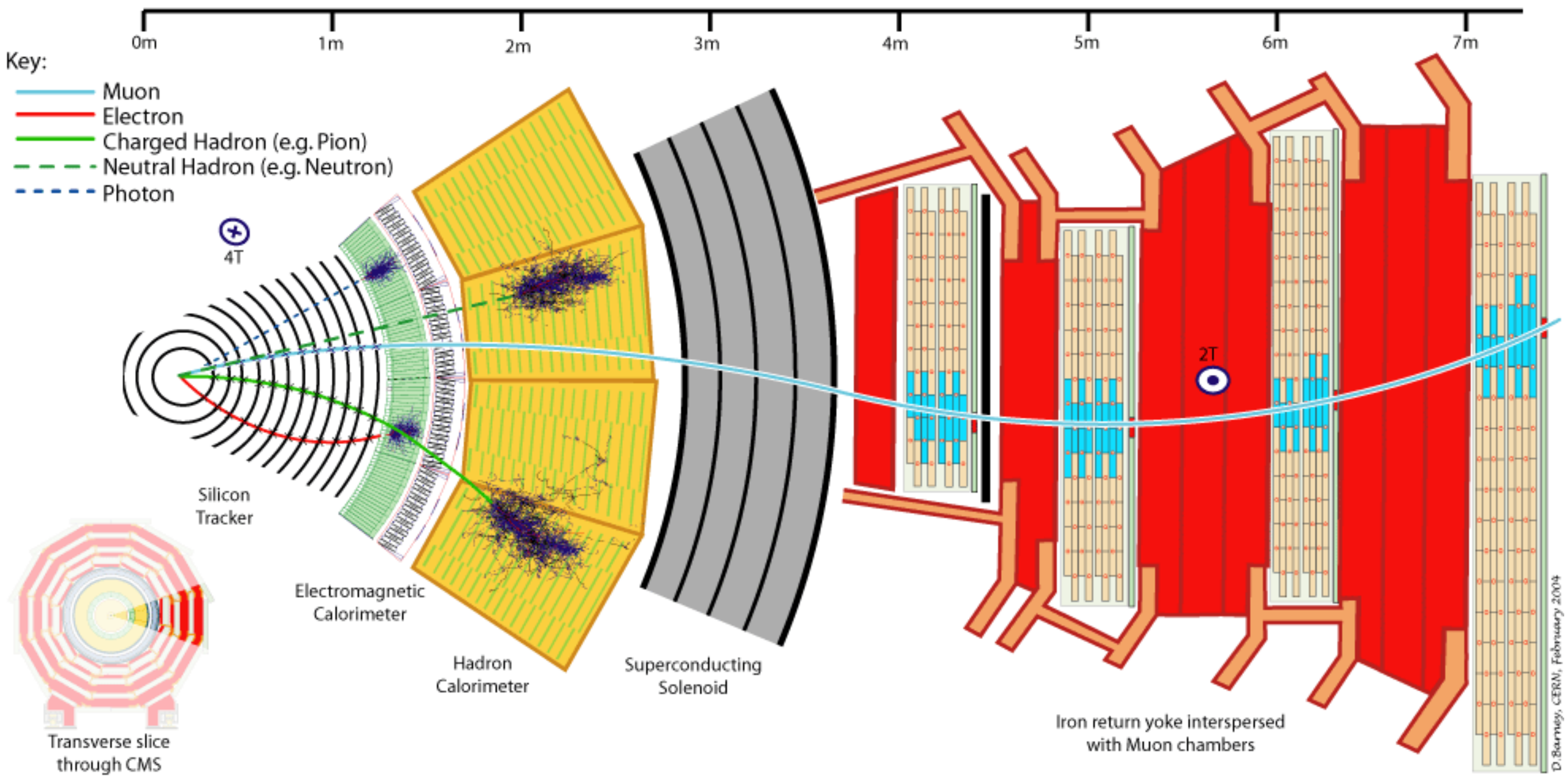
x_1 - fraction of proton momentum carried by one gluon

x_2 - fraction of proton momentum carried by another gluon

$\hat{\sigma}(gg \to H | x_1, x_2)$ - partonic cross section $gg \to H$, given they have momenta x_1 and x_2

$f_g(x)$ - probability density function to find a gluon with fractional momentum x

Introduction — CMS



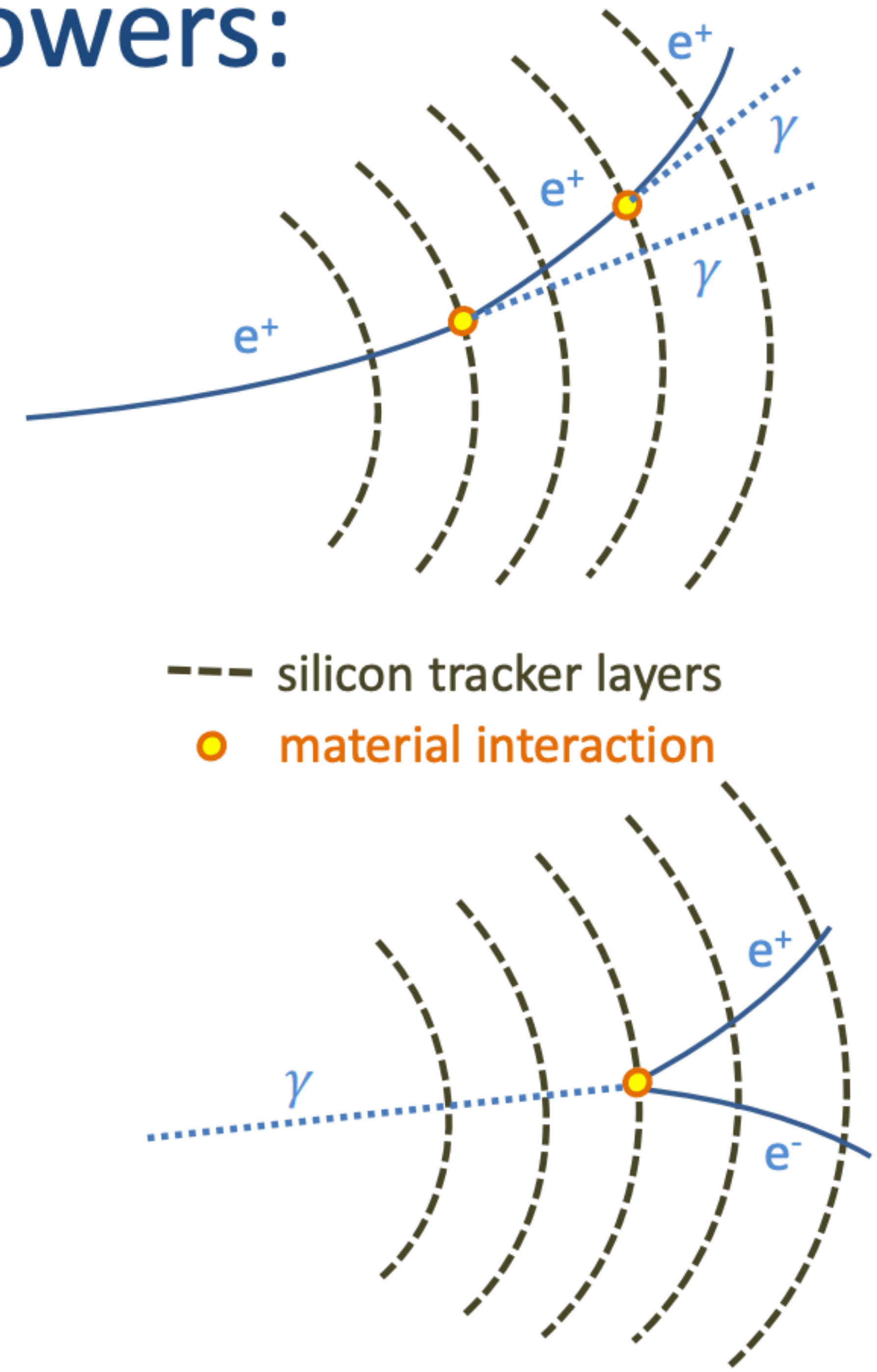
Object reconstruction

- **primary vertex:** *point from where a large number of charged tracks come out*
- **muon:** *track in Tracker matching a track in Muon System*
- **electron:** *track in Tracker matching EM cluster in ECAL and no energy deposits in HCAL*
- **photon:** *EM cluster in ECAL, no tracks pointing to it, and no energy deposits in HCAL*
- **jet:** *fairly collimated spray of hadrons originating from knocked off quarks and gluons*
- **hadronic τ:** *τ decaying hadronicly (1 or 3 collimated tracks + close-by photons from π^0)*
- **b-tagged jet:** *jet with a heavy-flavor quark inside (b or c)*
- **MET:** *missing transverse momentum*
- **π/K/p:** *some analyses care about distinguishing between individual charged hadrons*
  (this is possible for relatively small momenta of O(1) GeV, using time-of-flight $\sim 1/v$ and $dE/dx \sim 1/v^2$)

Object — EGamma

E/γ Tracker Material Showers:

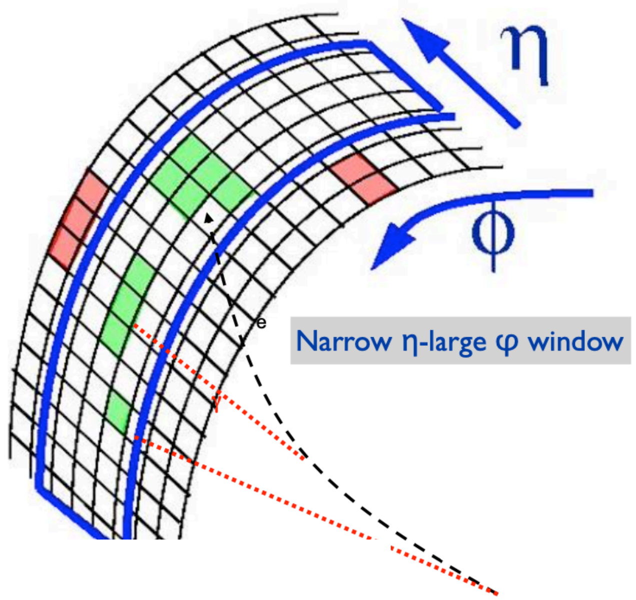
example of a showering electron and a converting photon in the tracker material

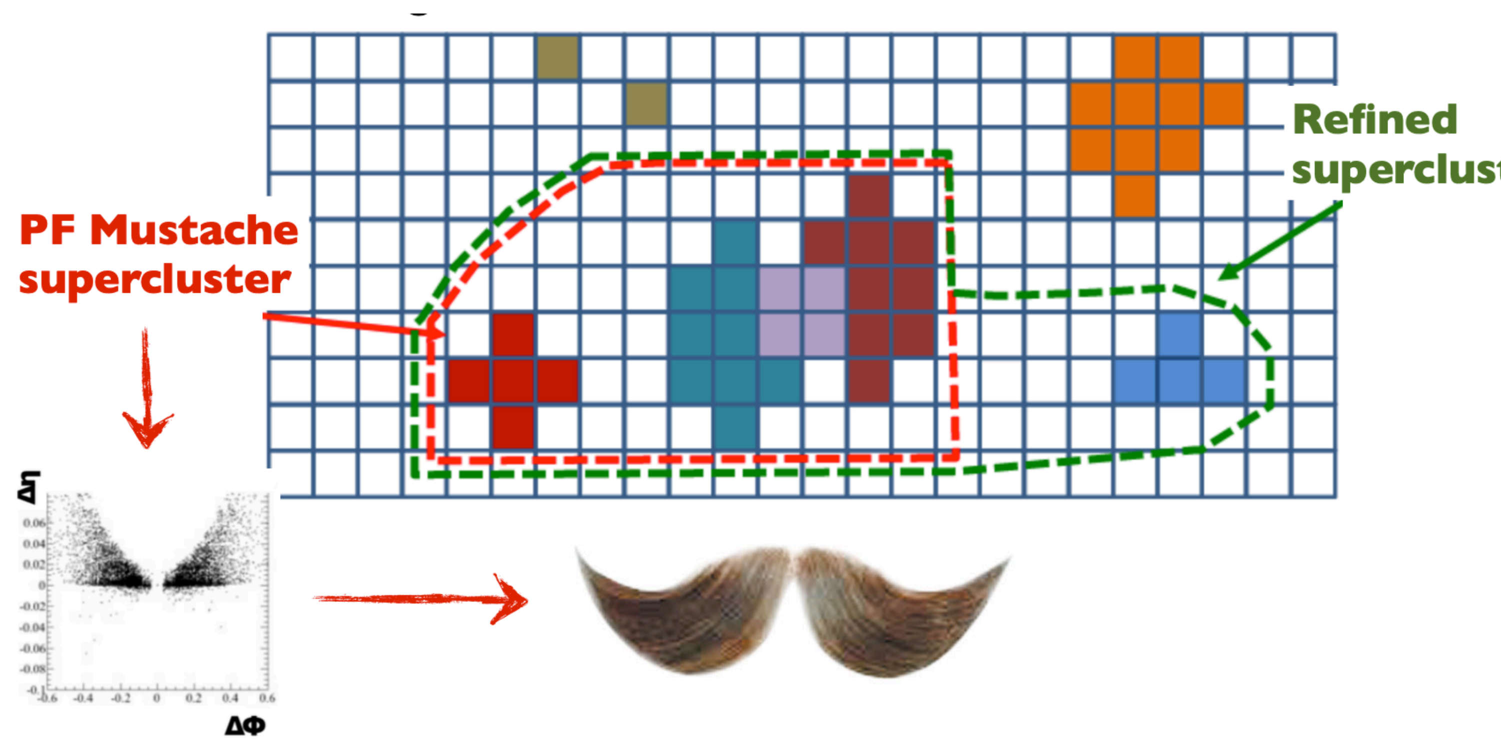


two key features

- electron loses energy and starts to bend more in B-field as it radiates photons
- photon now leaves two tracks, starting from a common vertex at a tracker layer
  - 20 to 60% of photons convert depending on η

Object — EGamma





BARREL	Loose (90.08%)	Medium (80.29%)	Tight (70.24%)
Background Rejection	Loose (86.25%)	Medium (89.36%)	Tight (90.97%)
HoverE	0.04596	0.02197	0.02148
$sigma_{ietaieta}$	0.0106	0.01015	0.00996
Rho corrected PF charged hadron isolation	1.694	1.141	0.65
Rho corrected PF neutral hadron isolation	24.032 + 0.01512*pho_pt + 2.259e-05*pho_pt^2	1.189 + 0.01512*pho_pt + 2.25 9e-05*pho_pt^2	0.317 + 0.01512*pho_pt + 2.259e-05*pho_pt^2
Rho corrected PF photon isolation	2.876 + 0.004017*pho_pt	2.08 + 0.004017*pho_pt	2.044 + 0.004017*pho_pt

Exercise2

```
fdir='/data/pubfs/pku_visitor/public_write/zajj_ori/'
fdy=ROOT.TFile(fdir+'dyJets_94X_massTreeV2.root')
tree3=fdy.Get('EventMassTree')
```

Task:

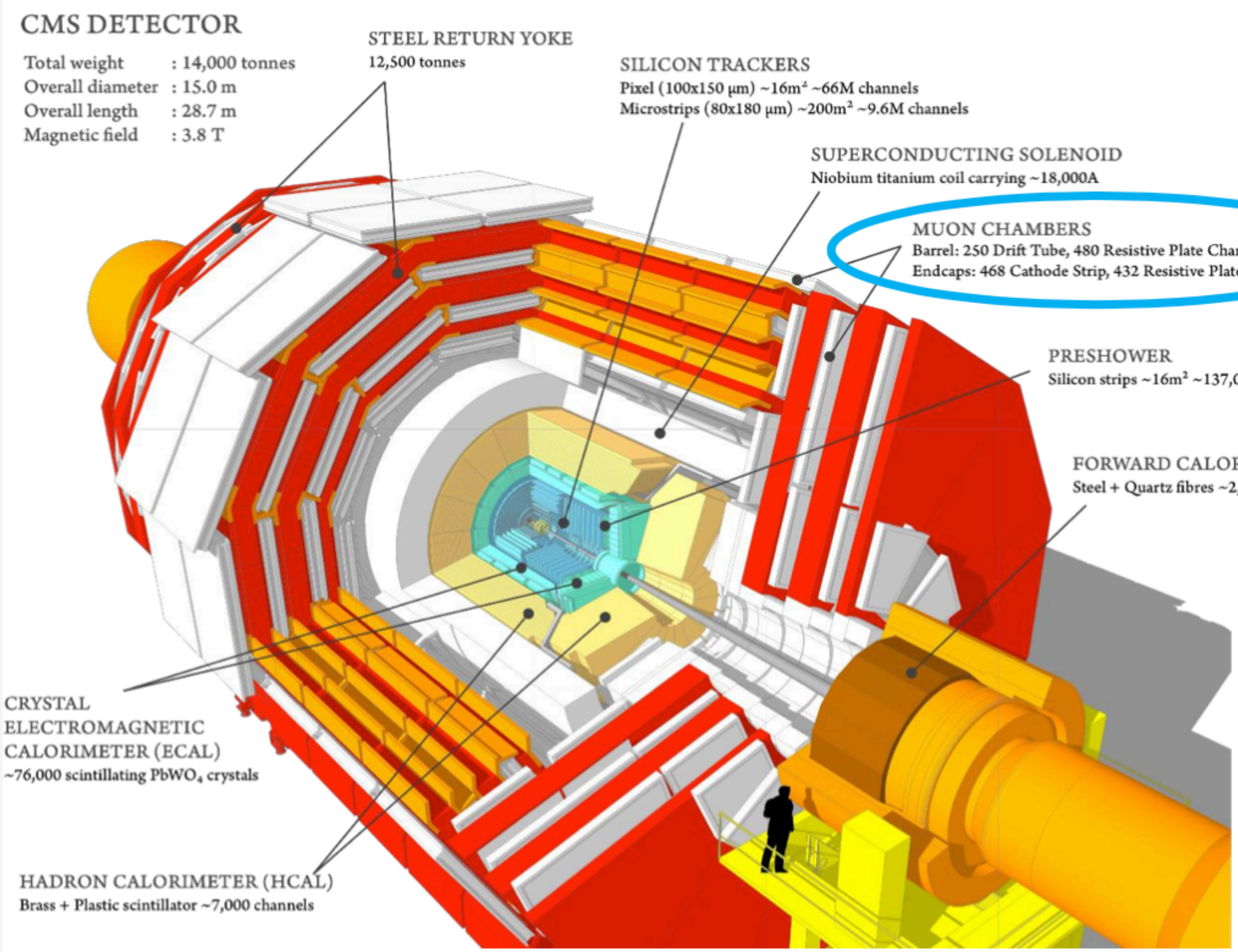
Draw plots for some variables related with the electron identification

- ele1SigmaIEtaIEta
- ele1HoverE

Question:

Why the HoverE is not 0?

Object — Muon



CSC
Cathode strip chamber

DT
Drift tube

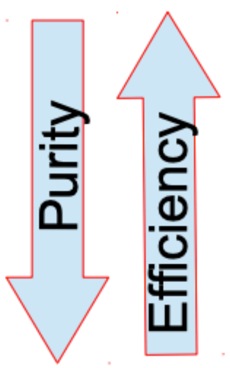
RPC
Resistive plate chamber

Object — Muon

Muon identification:

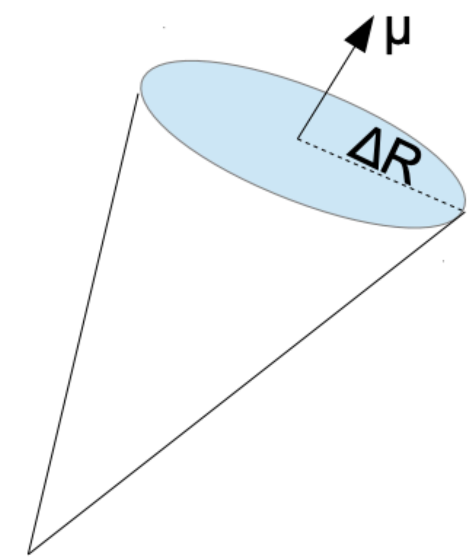
- Set of criteria to balance between efficiency and purity
- Criteria include:
  - Muon reconstruction goodness (eg χ^2)
  - Hits per track
  - Degree of matching between tracker / standalone tracks
- Best choice depends on the analysis

	ID	Suited for
Standard ID	Loose	Prompt and μ from light/heavy flavour
Standard ID	Medium	Prompt and μ from heavy flavour
Standard ID	Tight	Prompt μ
	Soft	Low p_T μ (B analysis)
	High p_T	For μ with p_T>200GeV



Muon isolation:

- Distinguish prompt μ from μ within jets
- Relative to $p_T(\mu)$
- Sum energy within a ΔR cone around μ
- Two strategies:
  - Track-based; uses tracks
  - PF-based; uses PF candidates
- PF isolation takes into account neutral hadron contribution
- WP are defined for 95% and 98% efficiency



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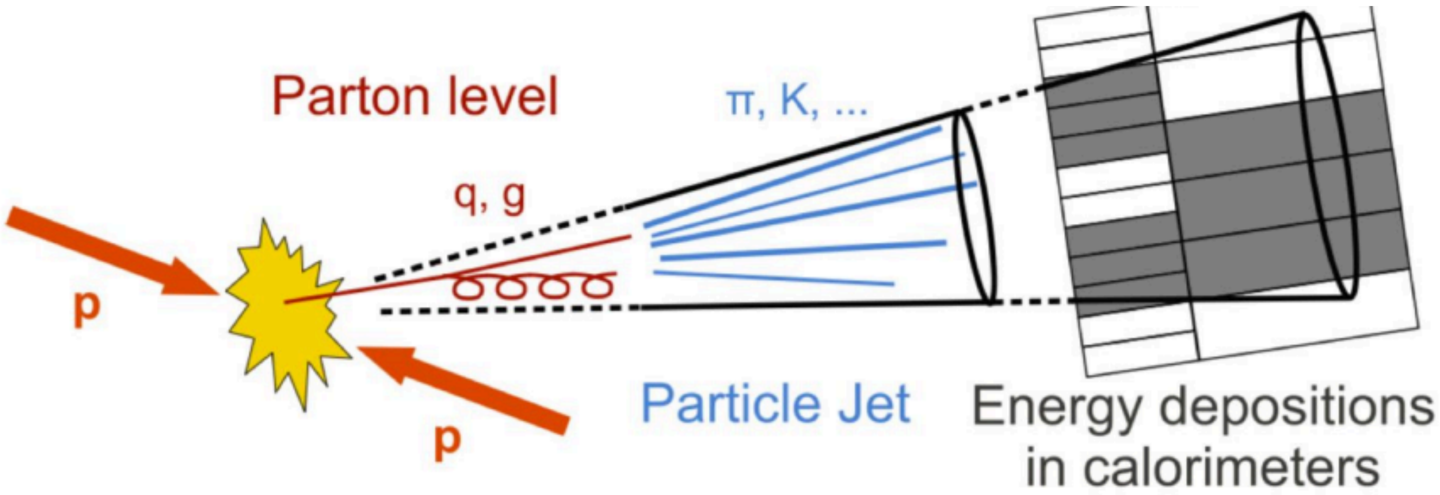
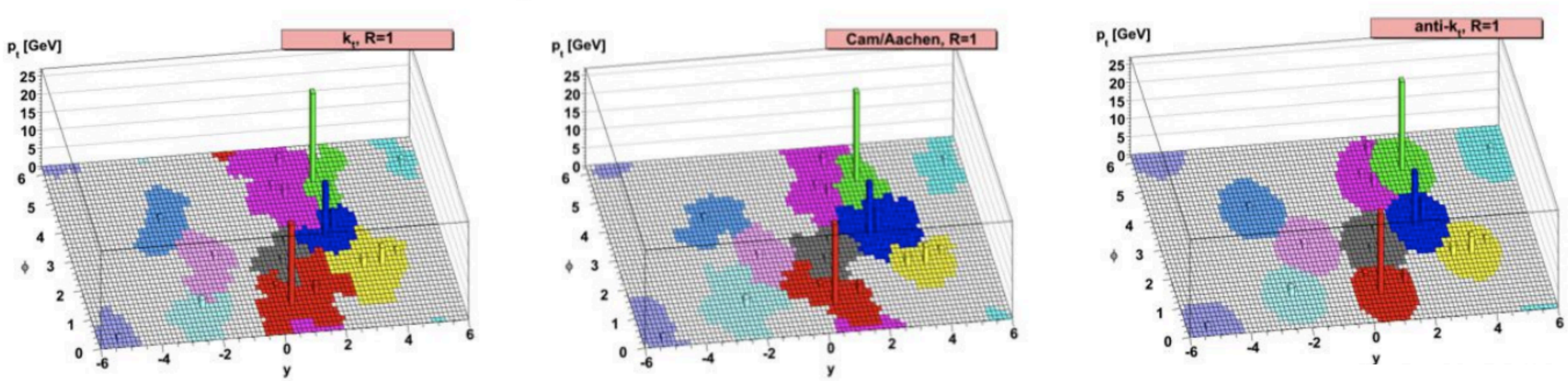
Object — Jet





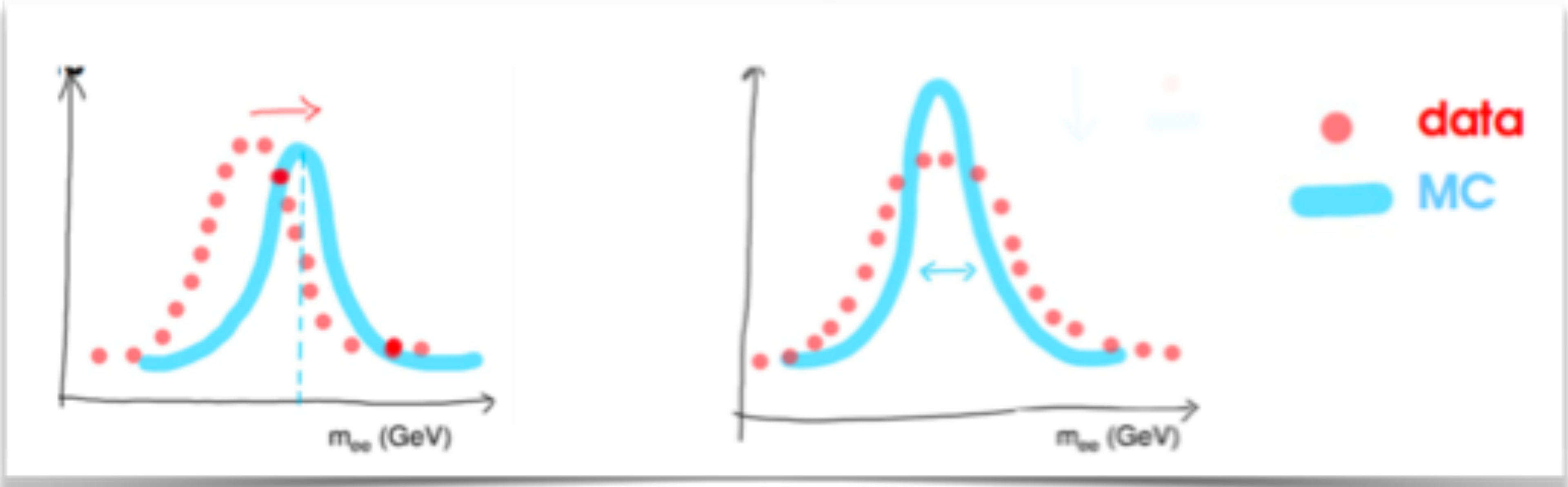
k_T **Cambridge-Aachen** **anti-k_T**

Standard Method

Cone-size: ΔR = 0.4 (regular) or 0.8 (FatJet) [Atlas ΔR = 1]

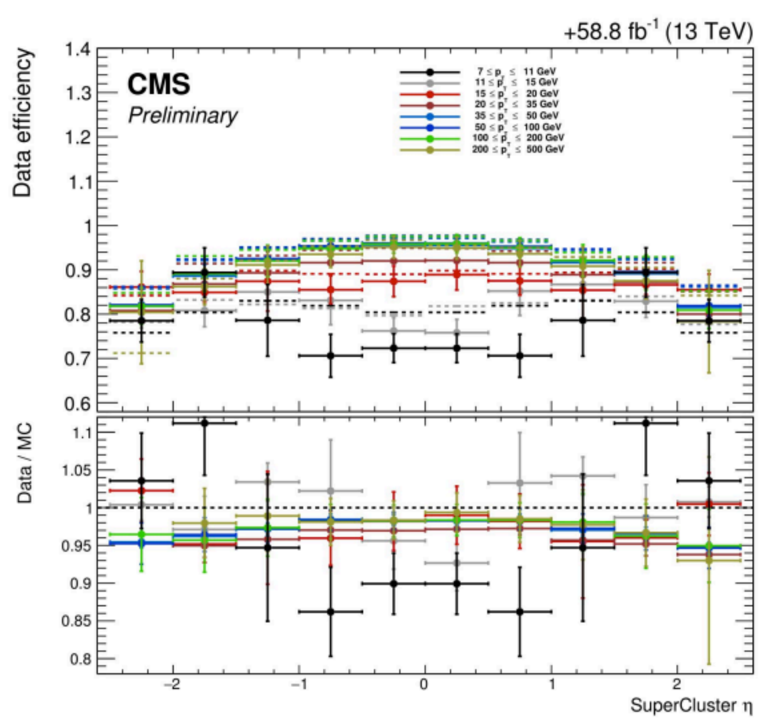
Clustering: anti-k_T

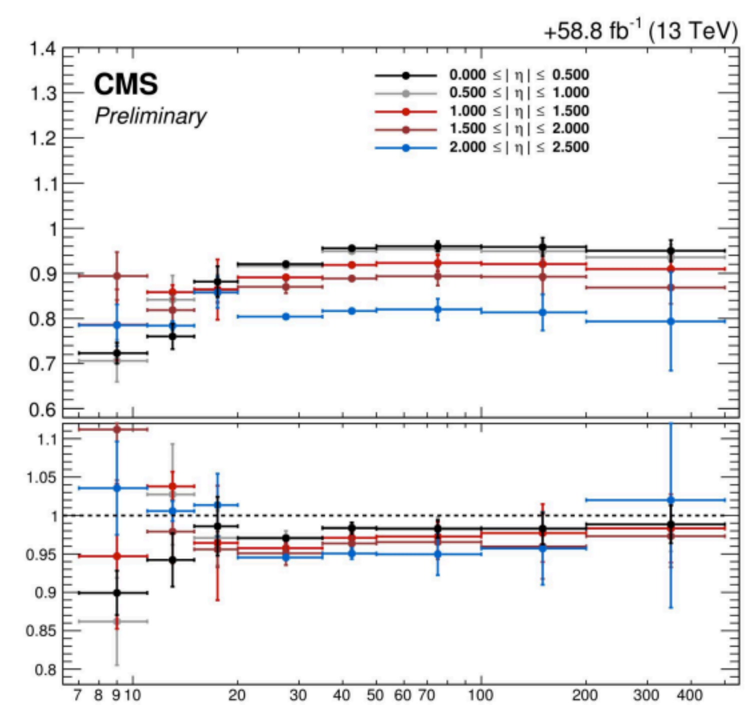
Object — Correction



Scale Factors

- Needed to scale Monte Carlo to Data



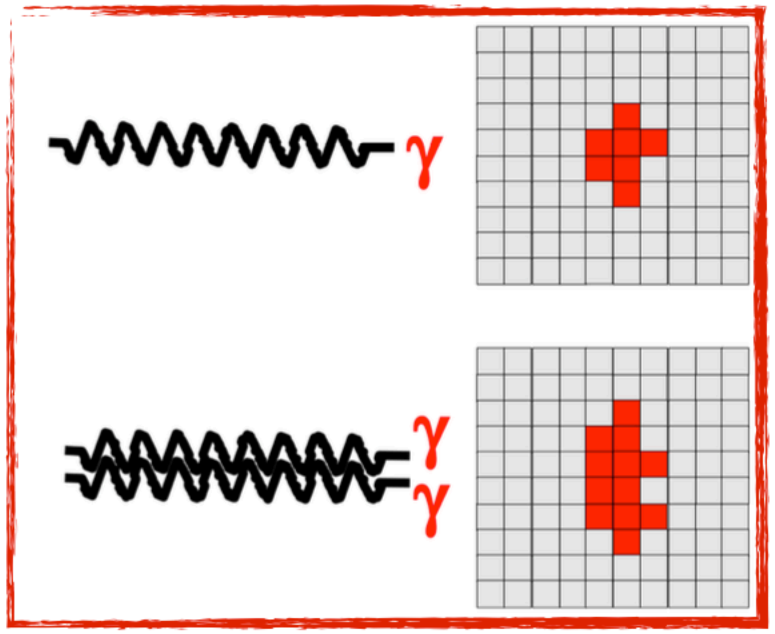


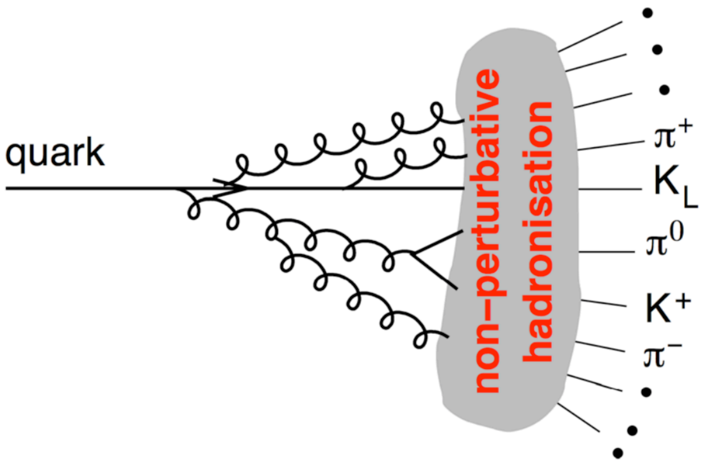
Analysis —Background

Background sources for :

Photons

- Neutral mesons
- Pions with collimated π→γγ
- Electrons without well reconstructed track





- Can radiate a photon easily
- Will be mis-identifies as photon

Exercise3

```
fdir='/data/pubfs/pku_visitor/public_write/zajj_ori/'
f=ROOT.TFile(fdir+'cutla-outZA-EWK17.root')
tree=f.Get('ZPKUCandidates')
```

Task:

The photon_isprompt can be used to discriminate the prompt and nonprompt photon, please draw the distribution of the $\sigma_{i\eta i\eta}$ with branch name photon_sieie for the prompt and nonprompt photon.

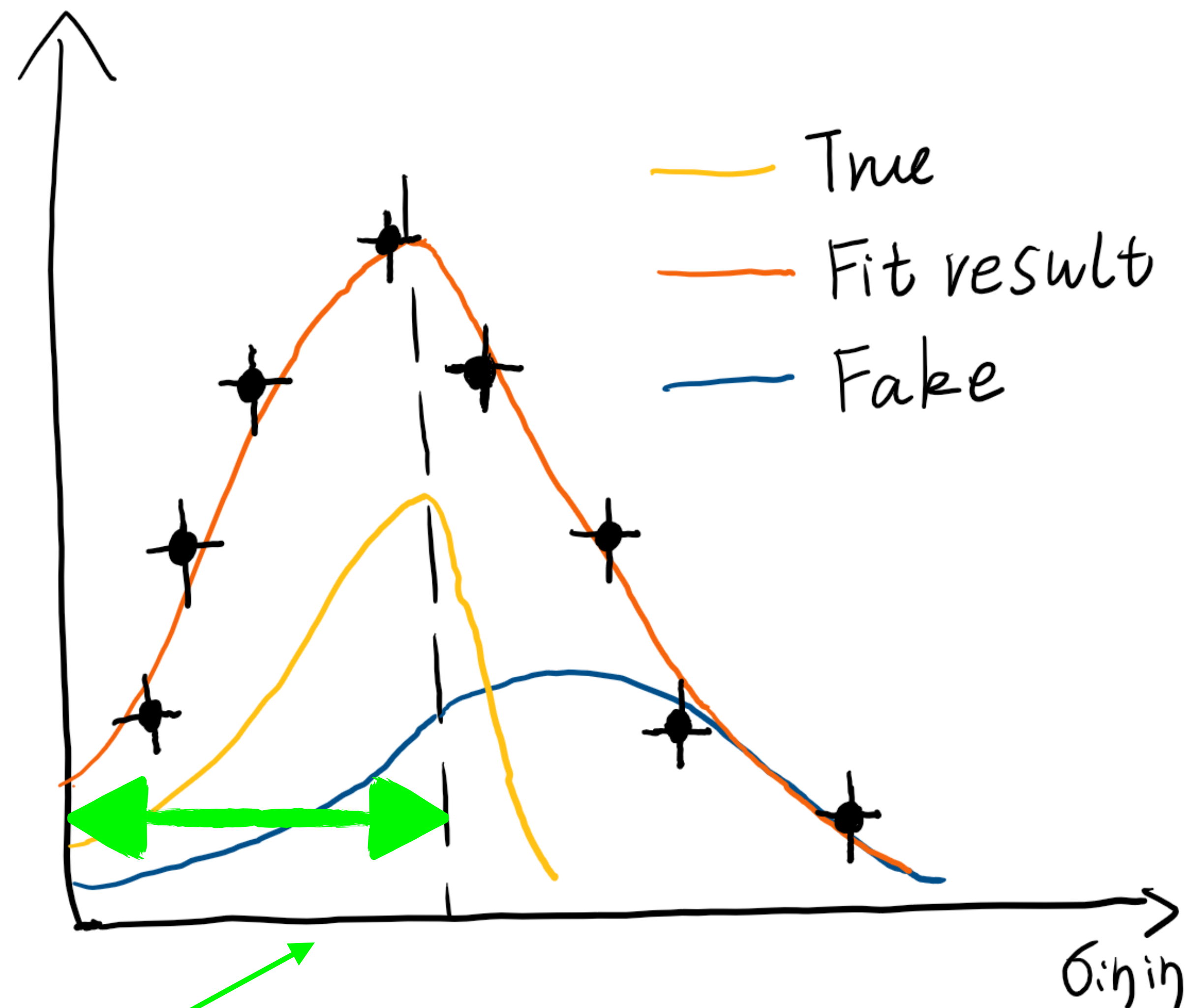
Question:

Why there are two peaks? What's the difference between the prompt and nonprompt?

VVγ — Nonprompt photon

Based on the Z+jets events, two good leptons from Z. $70 < m_{ll} < 110$ GeV

Data	Remove $\sigma_{i\eta i\eta}$ cut
True Template	Remove $\sigma_{i\eta i\eta}$ cut $\Delta R(\gamma^{reco},\gamma^{gen}) < 0.3$ Get shape from simulation.
Fake template	Remove $\sigma_{i\eta i\eta}$ cut Invert the charged isolation variable Get shape from data.



$$weight(p_T^\gamma) = \frac{n_{data}(p_T^\gamma)}{N_{fake}^{unweighted}(p_T^\gamma)} \times \epsilon_{\text{fake-fraction}}(p_T^\gamma)$$

Nonprompt photon fraction in the medium photon WP region.

Applied to

Signal region events where the tight photon ID is replaced by the fake photon ID

WWγ inherits the method from VBS Zγ (SMP-20-016)

Systematic uncertainty

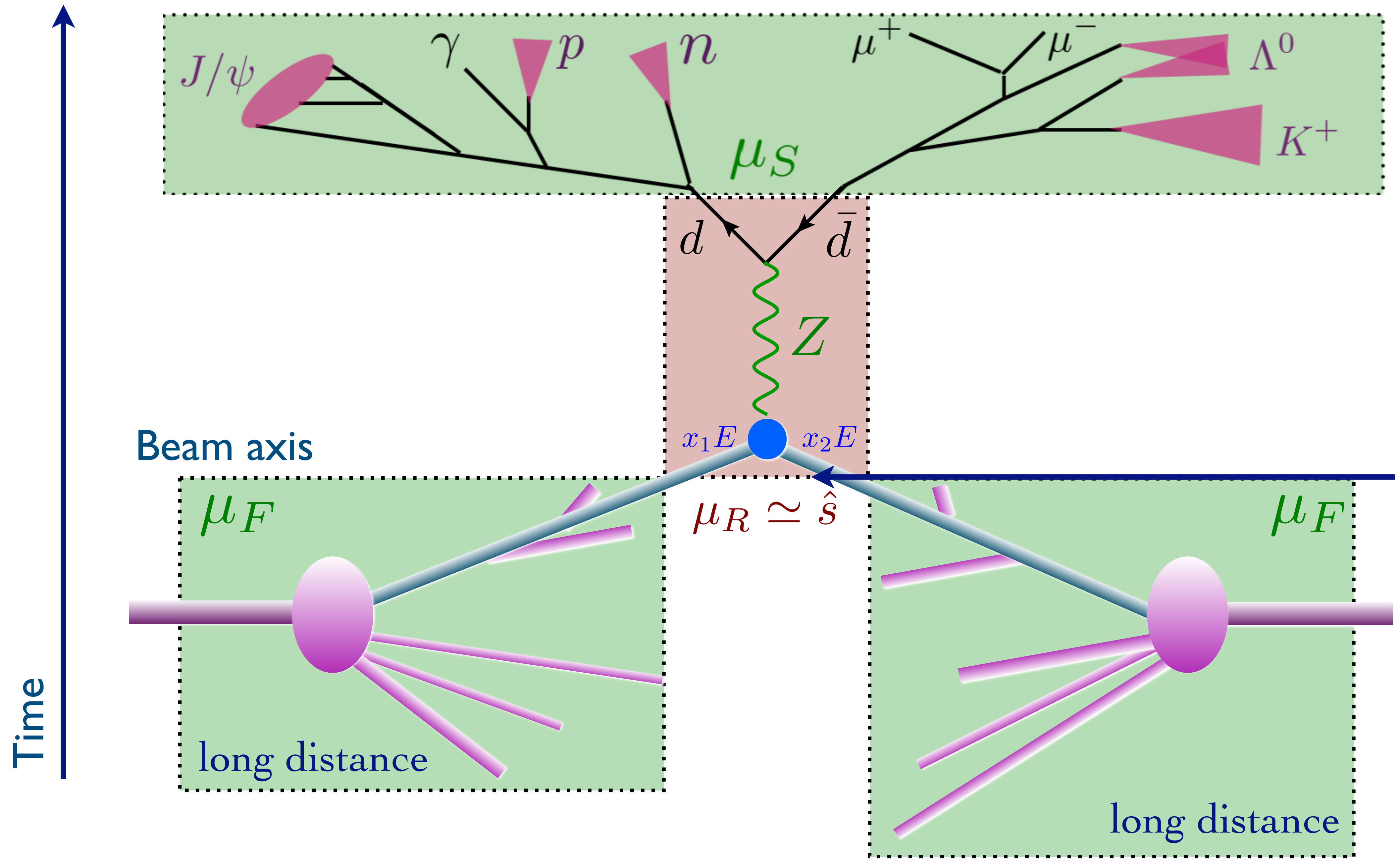
$$\sum_{a,b} \int dx_1 dx_2 d\Phi_{\rm FS}\, f_a(x_1,\mu_F) f_b(x_2,\mu_F)\, \hat{\sigma}_{pp\to\{P\}}(\mu_F,\mu_R,\mu_S)\, \mathcal{S}_{\{P\}\to\{H\}}(\mu_S)$$

Phase-space integral

Parton density functions

Parton-level differential cross section

Parton evolution operator



Exercise4

```
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f=ROOT.TFile(fdir+'cutla-outZA17.root')
tree=f.Get('ZPKUCandidates')
```

Task:

Draw the mjj distributions with different weights.