Experimental Techniques

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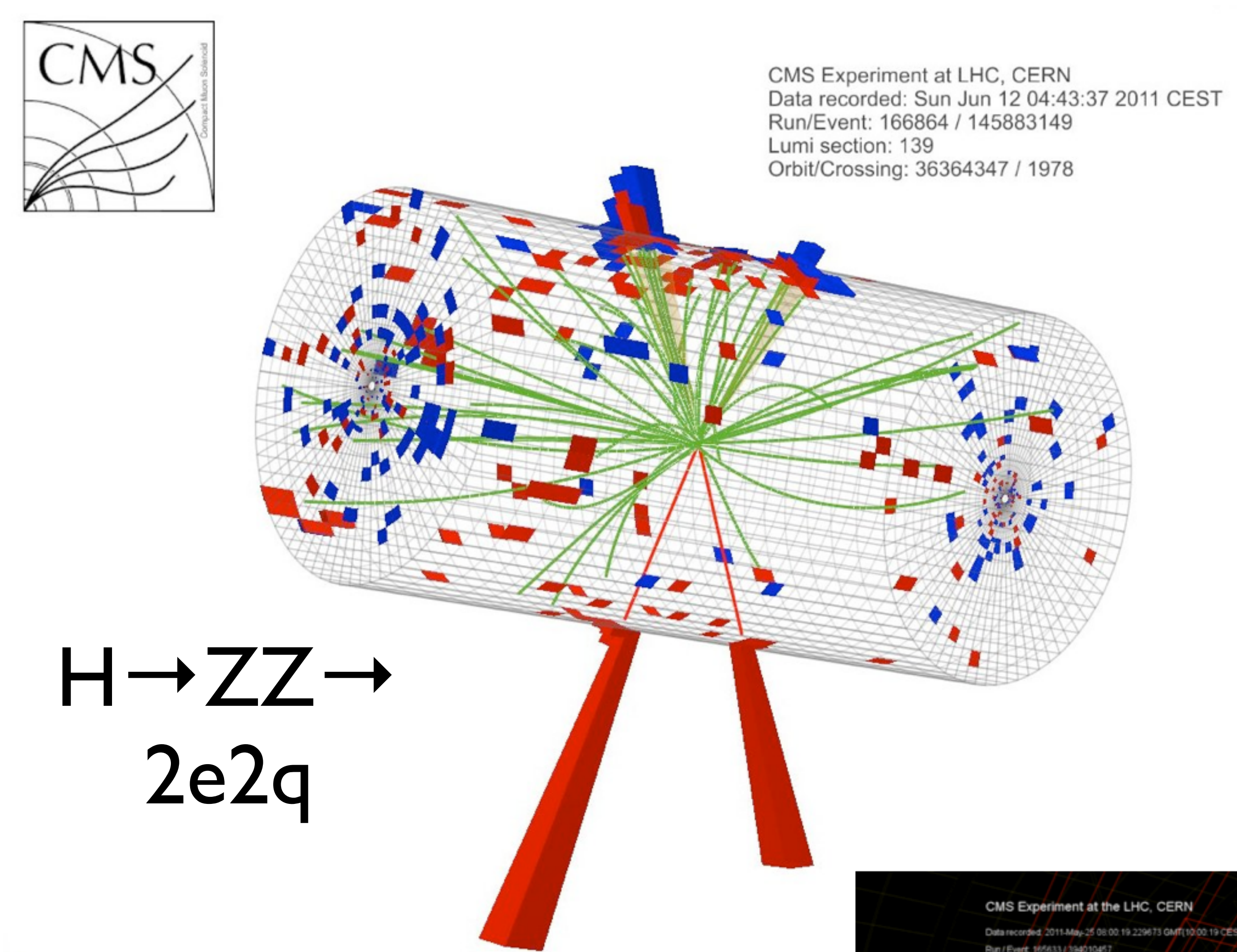
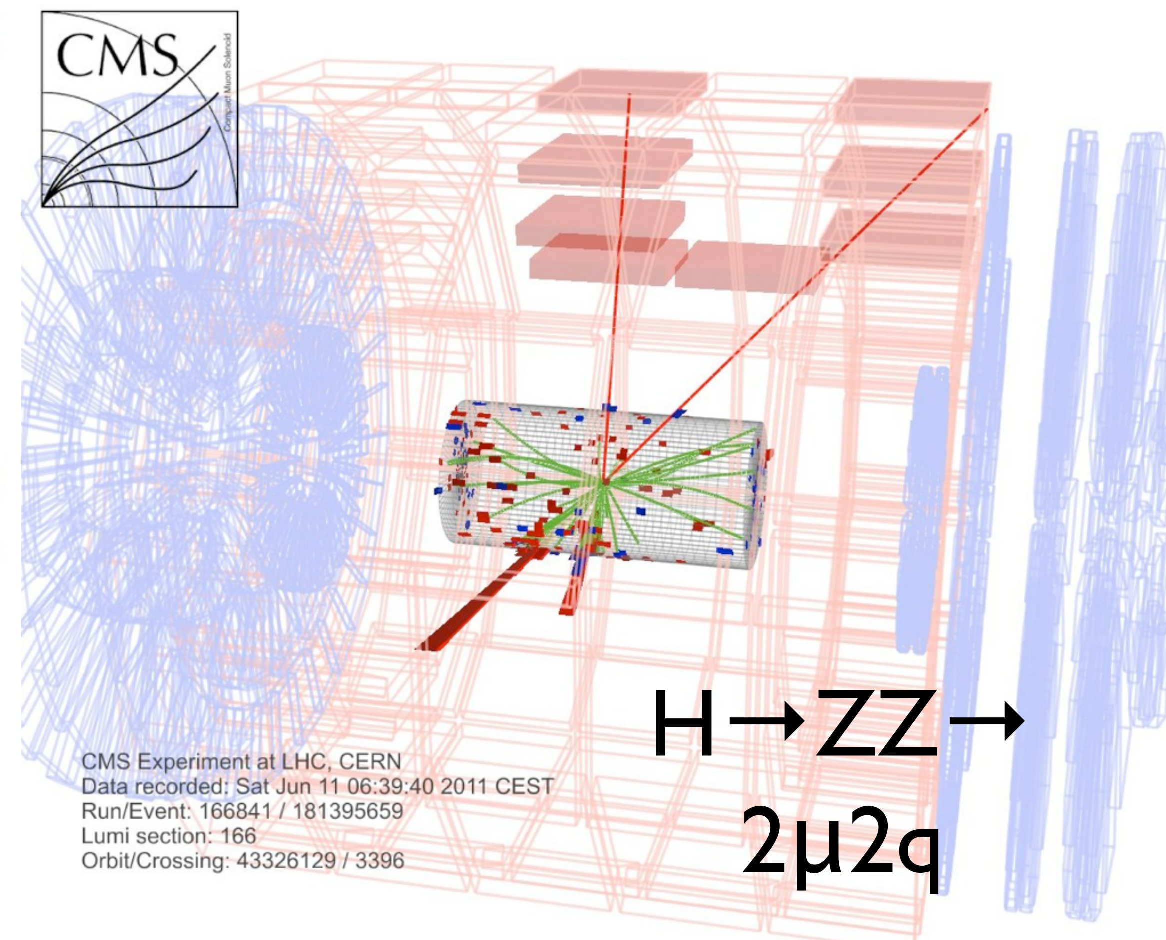
Department of Physics,
National Central University

2nd Taipei School on FeynRules-Madgraph for LHC Physics,
2013/09/07

Namely, How You Transform



H→ZZ→
2e2q



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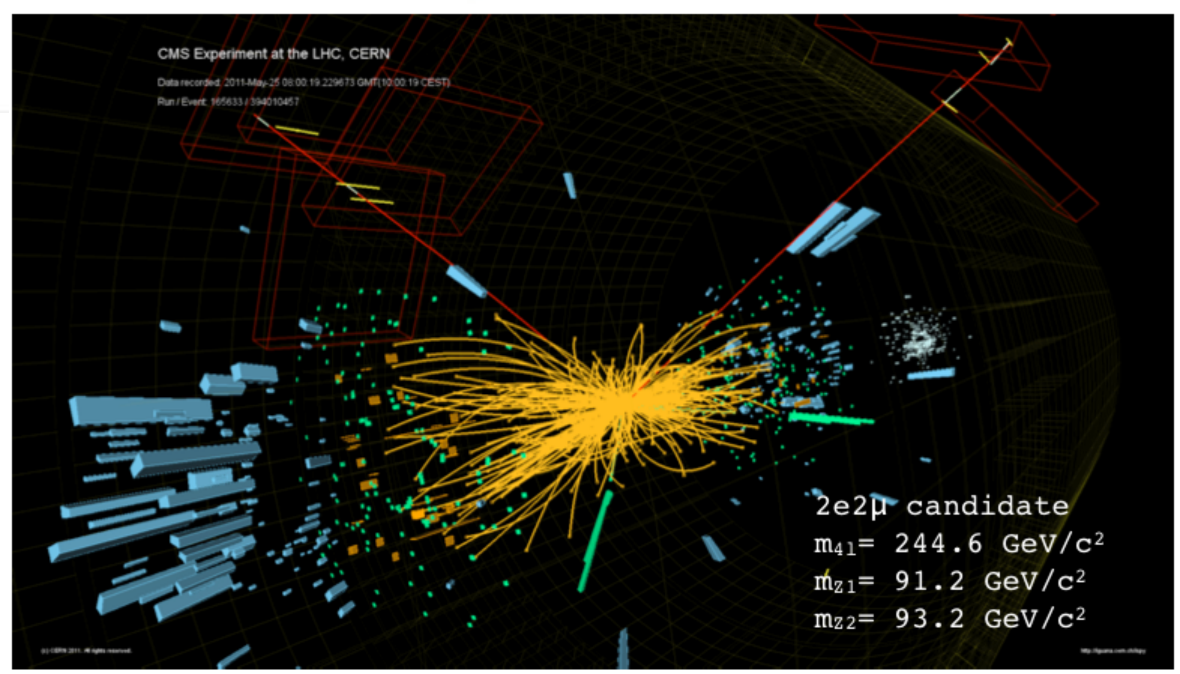
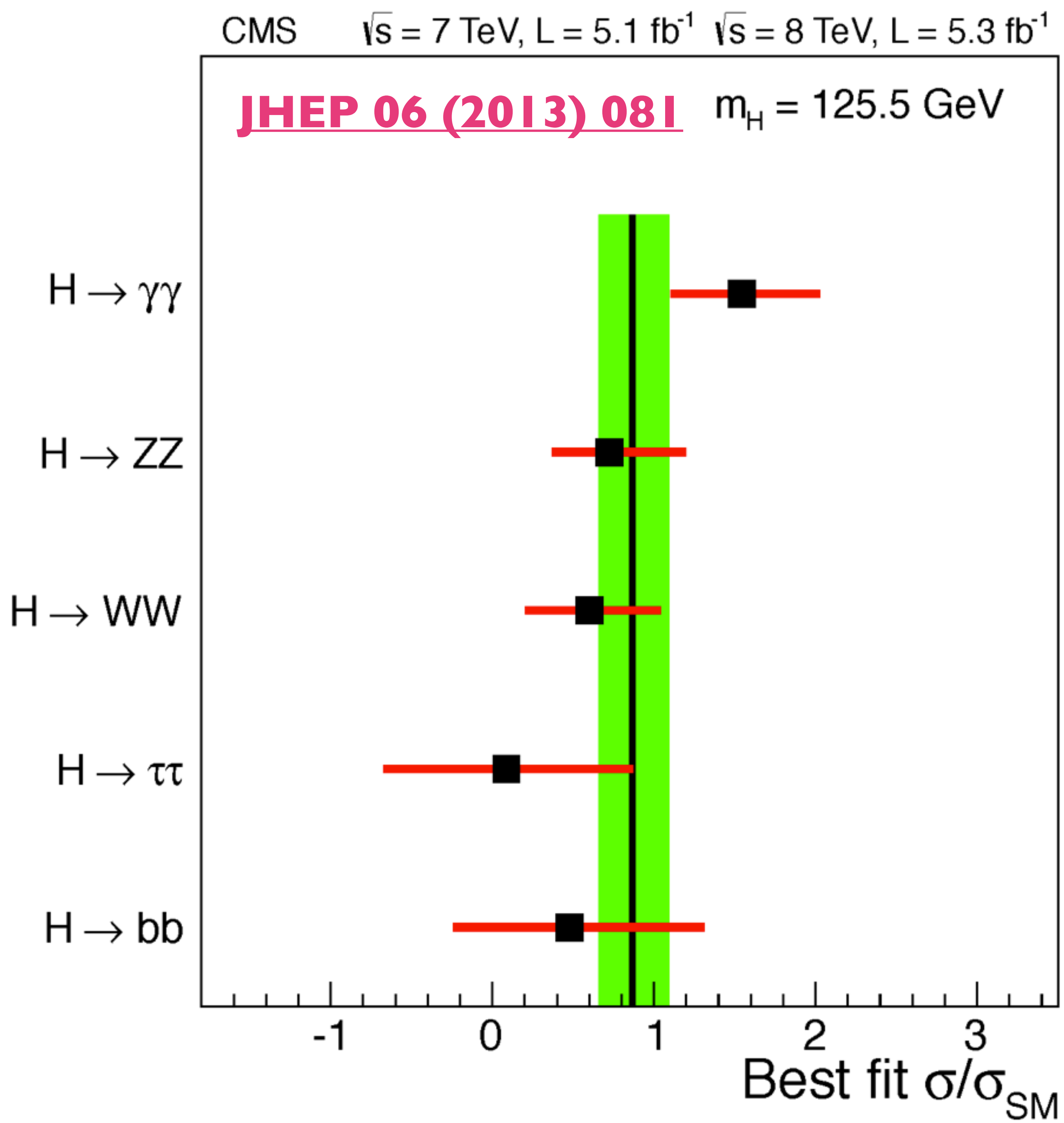


Into The Following Figure



Disclaimers

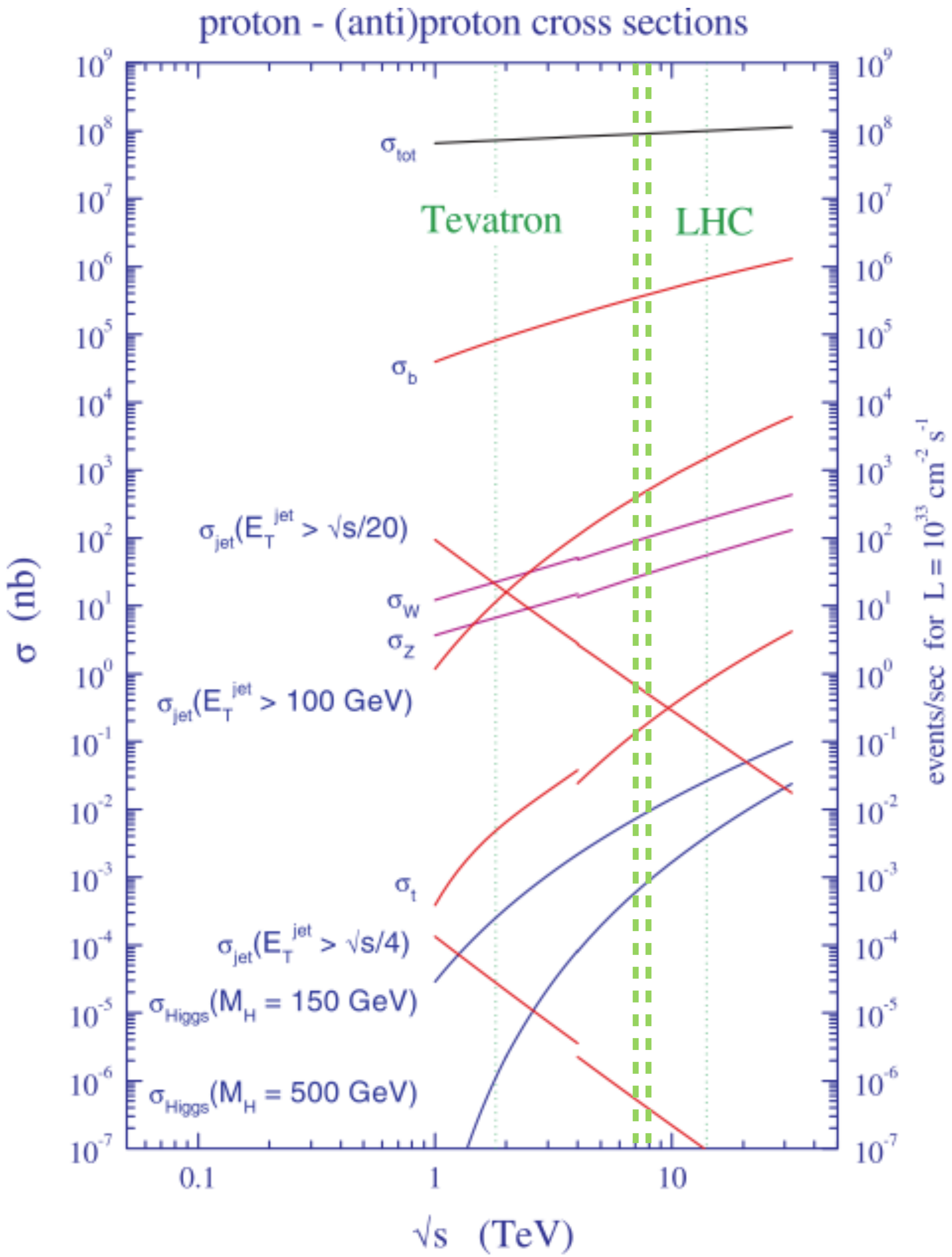
- Experimental techniques is a huge topic and I will not cover everything
    - I will not talk about tau object, detector simulation, detector technology, or analysis techniques
- 50% pictures are taken from other talks
    - Biased towards CMS
    - Please forgive repetition of things you may have seen before
- More details of experimental techniques can be found in CERN-Fermilab Hadron Collider Physics Summer Schools

In This Talk

- Collider basics
- Reconstruction of objects, their resolutions, and possible backgrounds
    - Tracks, muons, photons, electrons
    - Jets, missing momentum

Collider Basics

Number Of Produced Events Per Second



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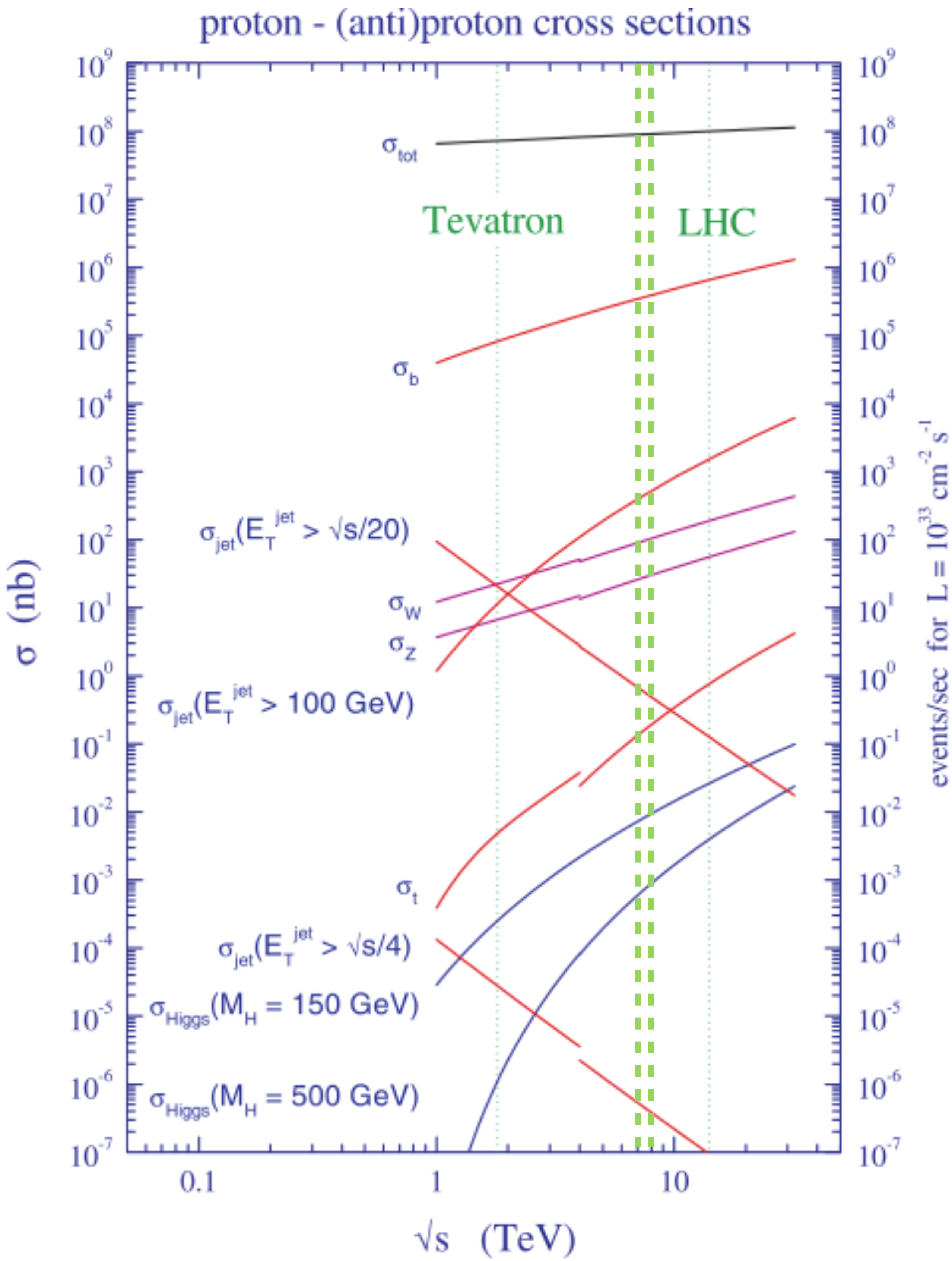
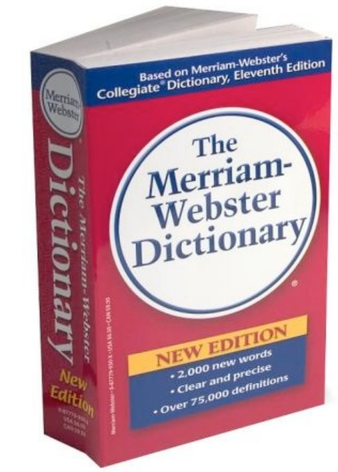


- 10^8/sec Total number of pp interactions, ~60% inelastic
- 100/sec W boson
- 30/sec Z boson
- 0.2/sec top quark
- 0.001/sec Higgs

- **Event rates [N/s]**

$$\frac{dR}{dt} = \sigma \times \mathcal{L}$$

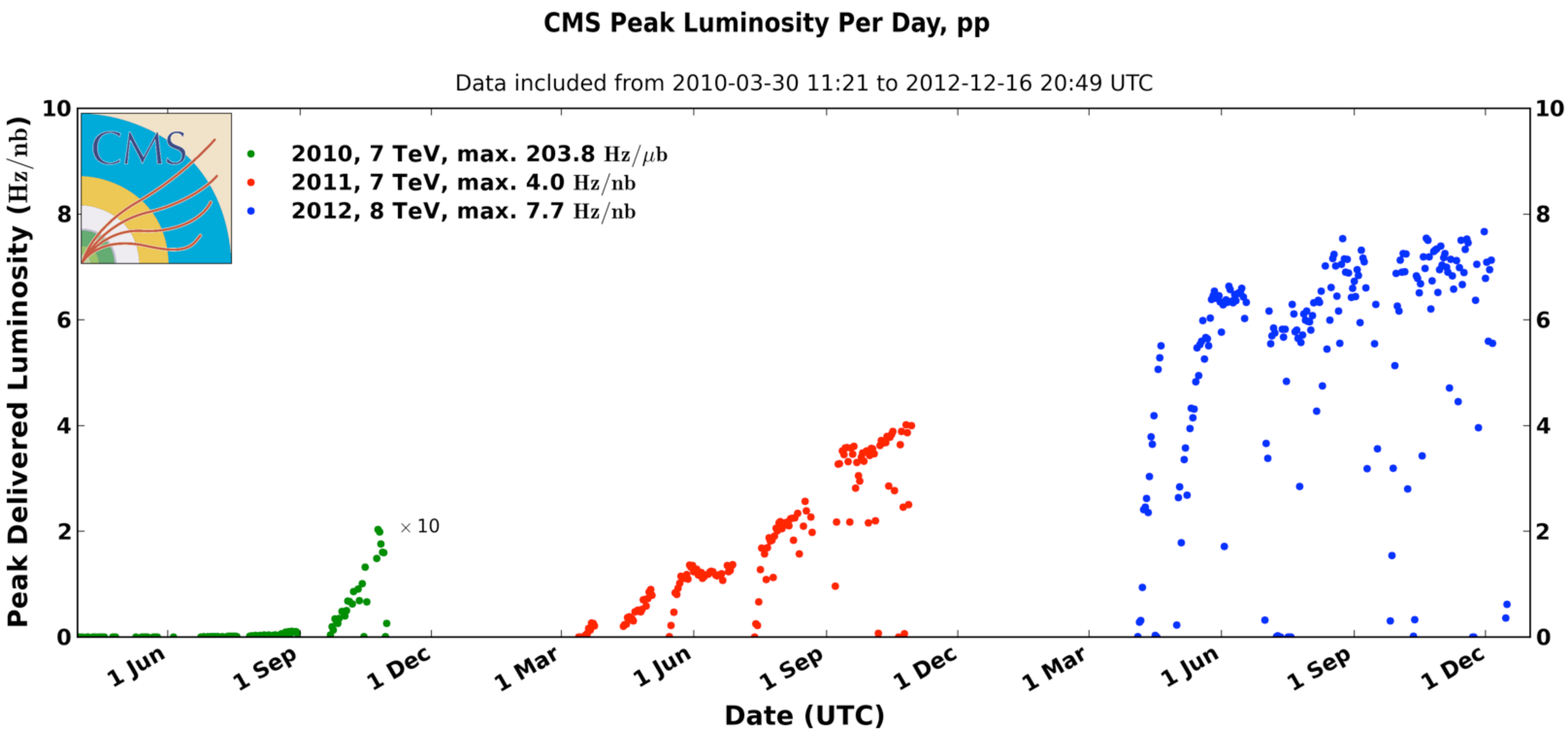


- **Cross section [barn]**
  - The likelihood to have interaction between a pair of protons
  - Determined by physics processes and beam energy (coupling strength, mass, parton luminosity)

1 barn= 10^{-28} m^2

- **Instantaneous Luminosity [cm^{-2}s^{-1}]**
  - Driven by the accelerator performance: number of particles in each proton bunch, collision frequency, beam profile

$$\mathcal{L} = f \frac{n_1 n_2}{4\pi\sigma_x\sigma_y}$$



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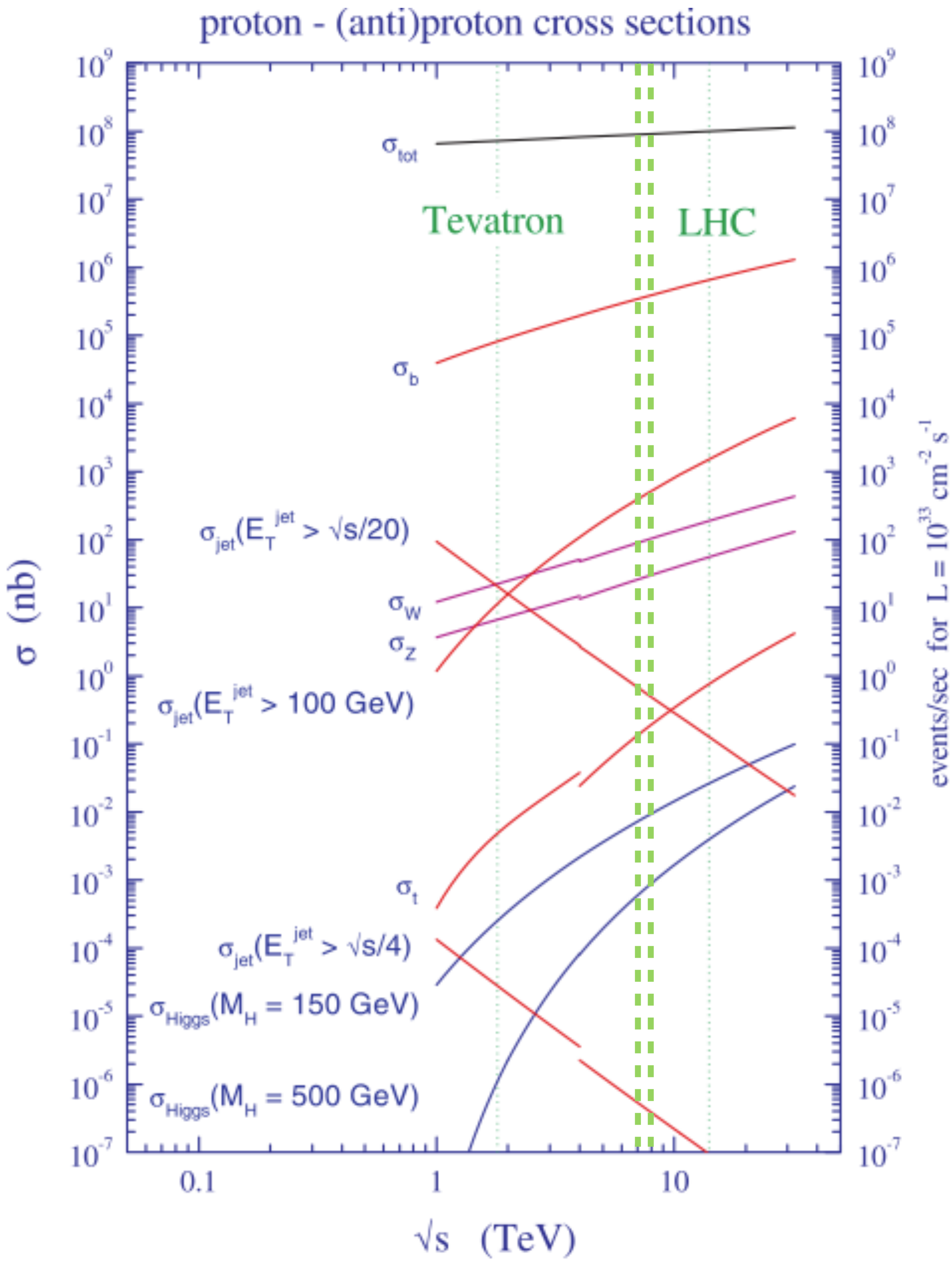

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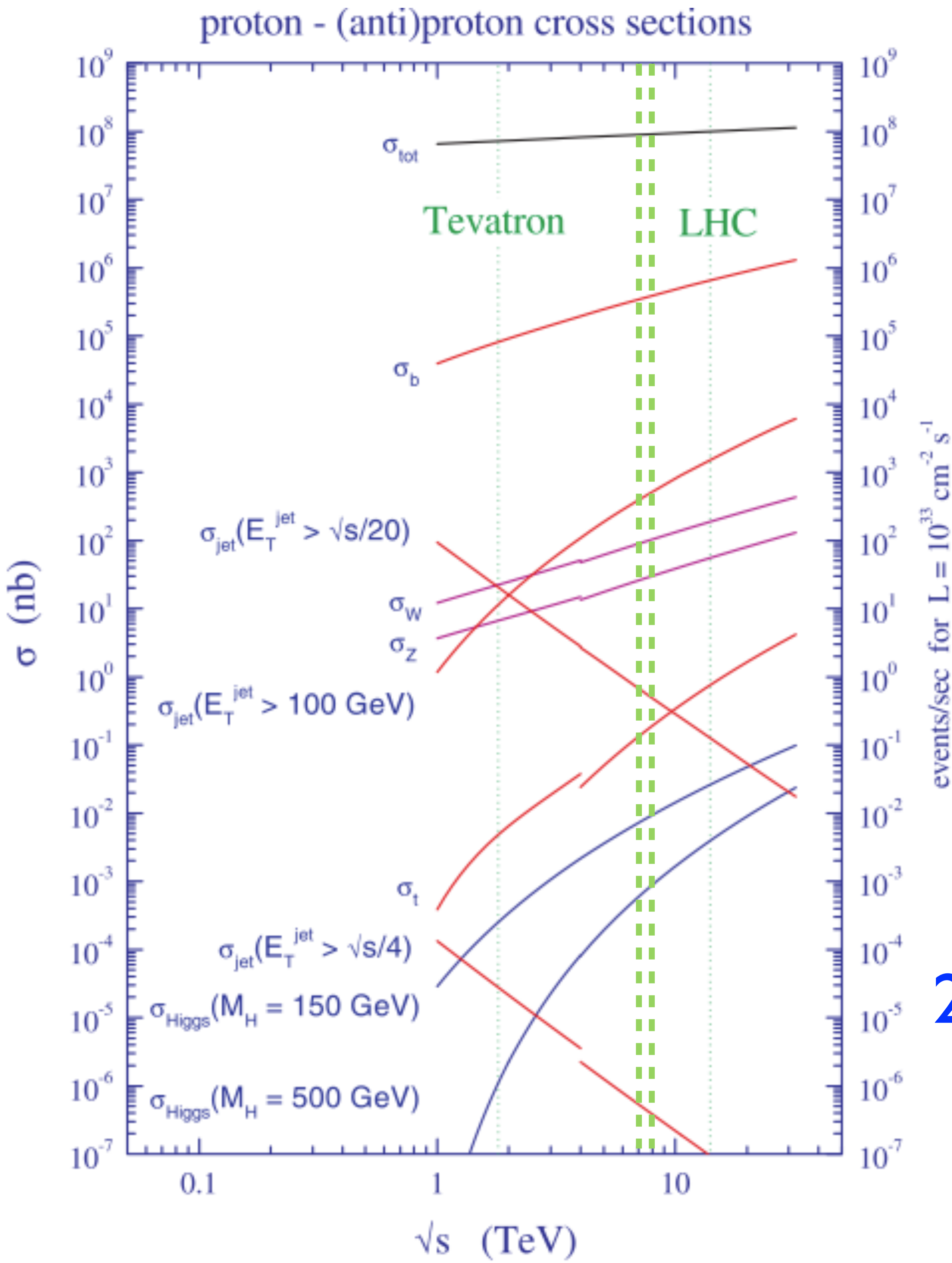

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2012 average $\mathscr{L} = 7\times10^{33}$ cm^{-2} s^{-1}

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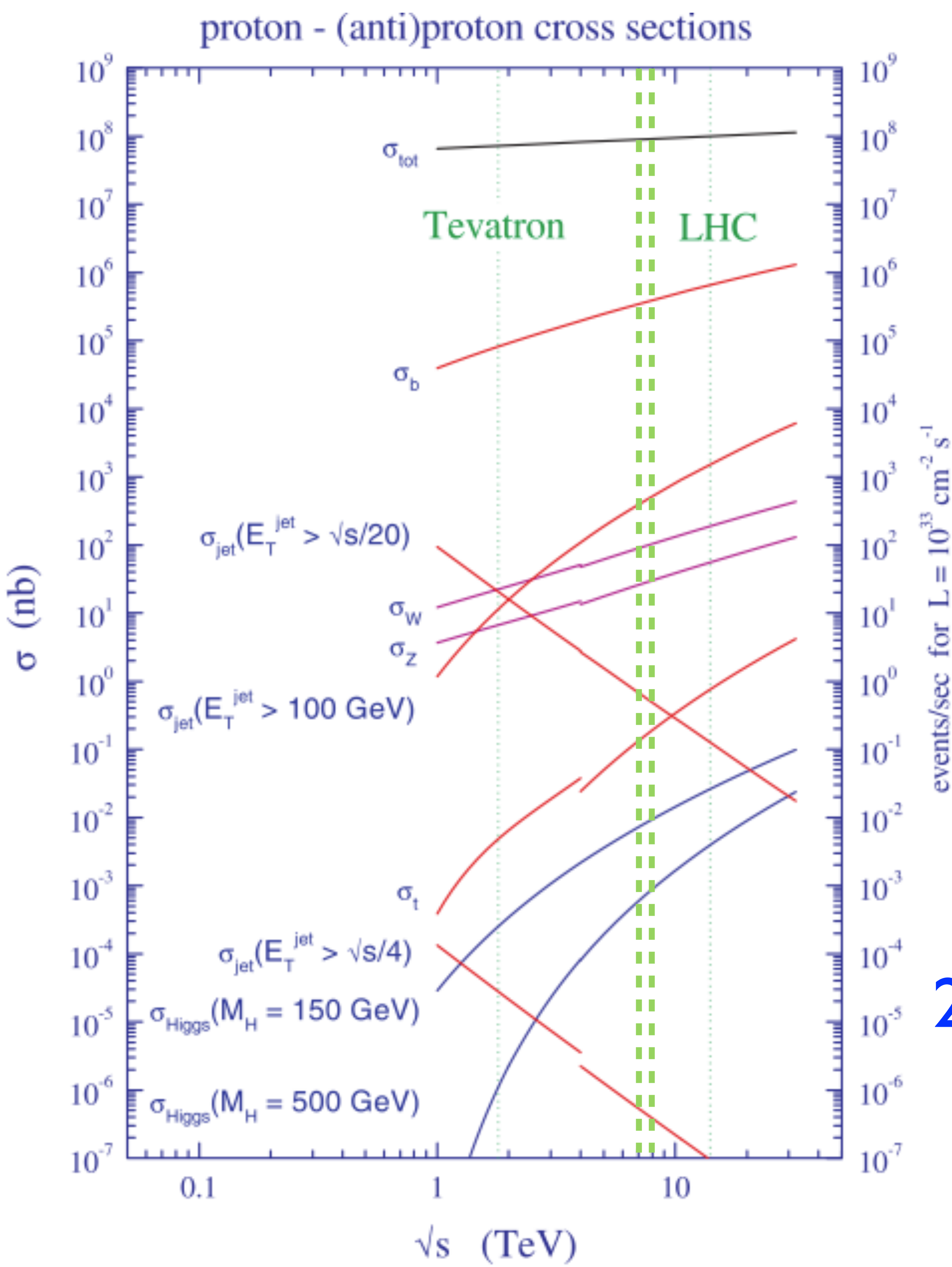

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Will reach 1-5×10^{34} cm^{-2} s^{-1}

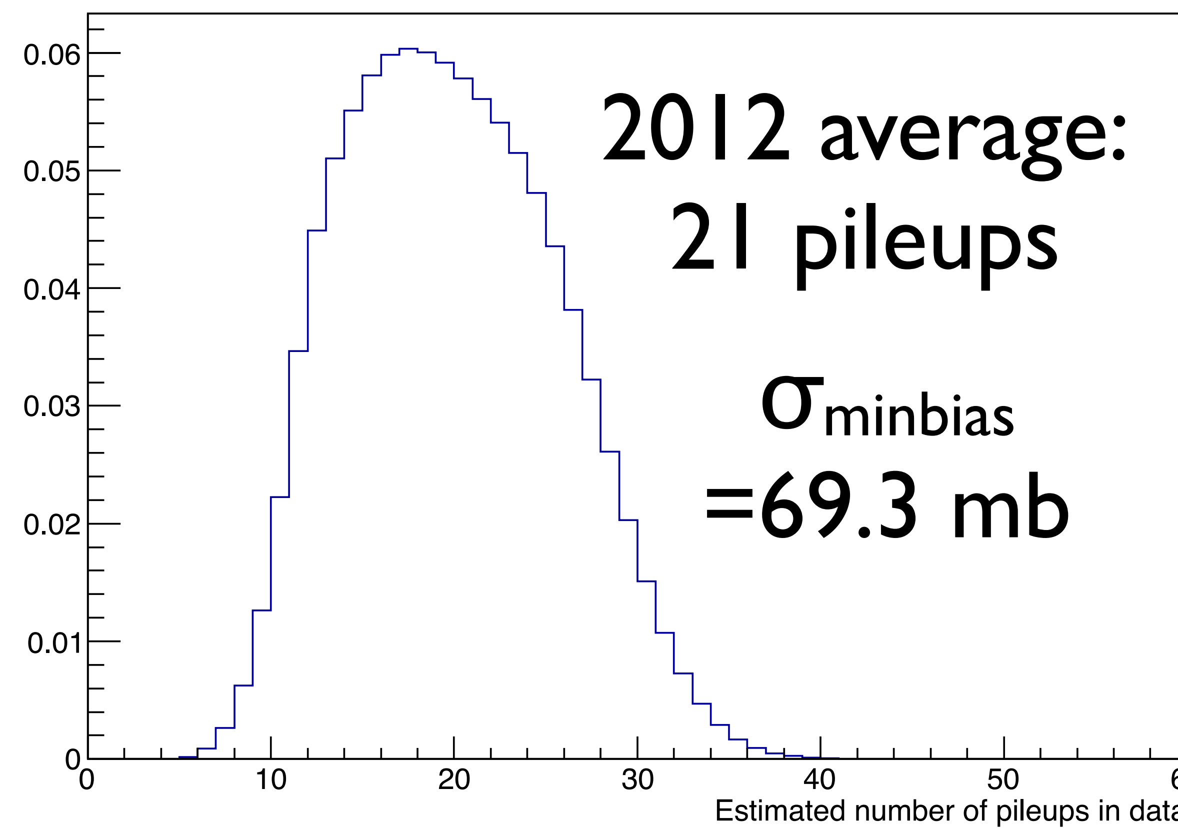
LHC Facts

Parameter	Design Value
Center of Mass Energy	14 TeV
# of bunches	2808
Bunch Spacing (ns)	25
# of protons per bunch	1.15E+11
Peak Luminosity (/cm*cm/sec)	1E+34
# of collisions per bunch crossing	25
Interaction Rate (Hz)	1E+09
Average # of tracks	1000

What Does This Mean For Lhc?

- Something happens for every bunch crossing
  - In 2012, we have 50-ns bunch crossing and ~21 pileups
  - Need to subtract contribution of pileups
- Need to select events of interest carefully
  - trigger threshold, trigger algorithm

Number of pileups in data



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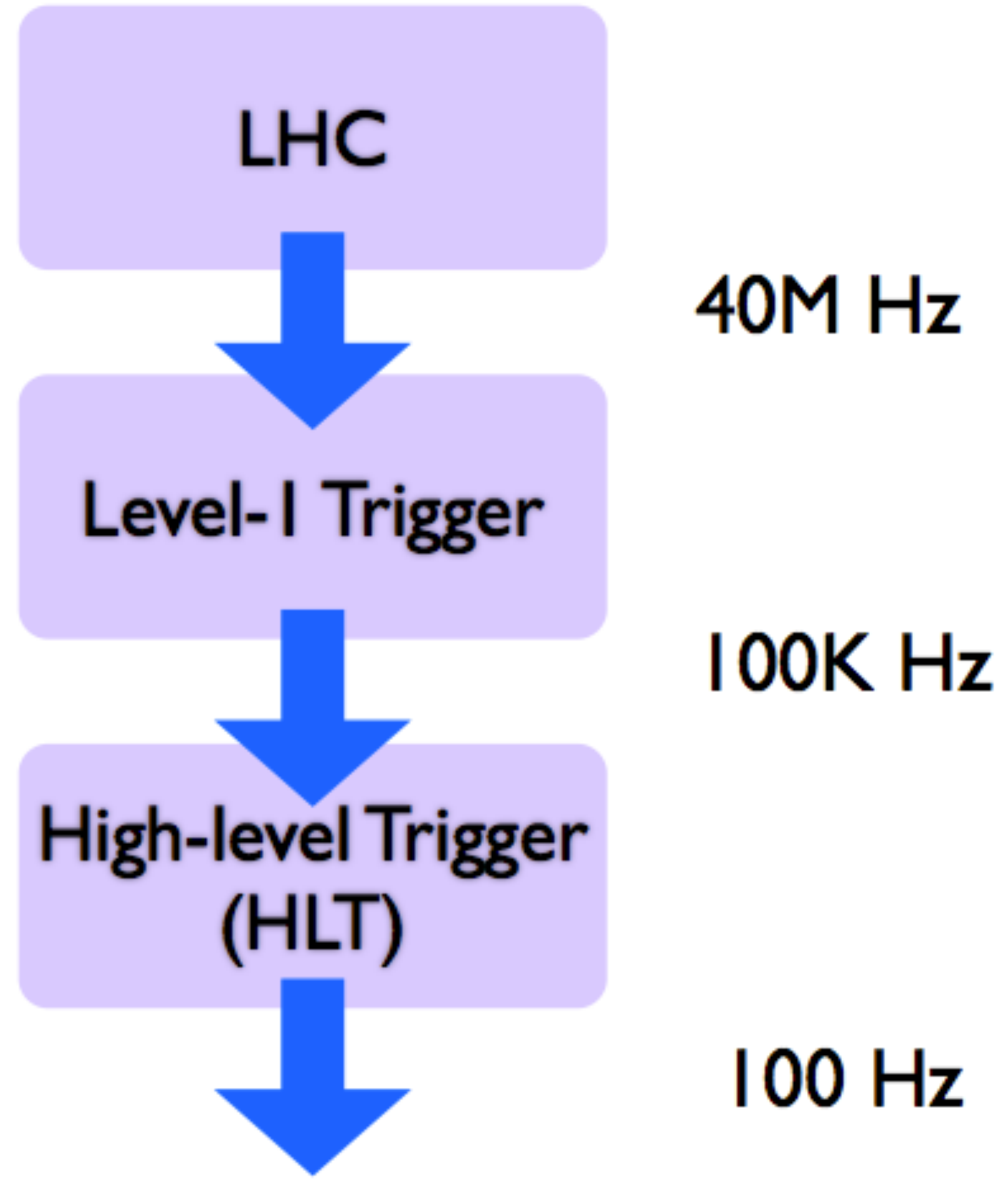

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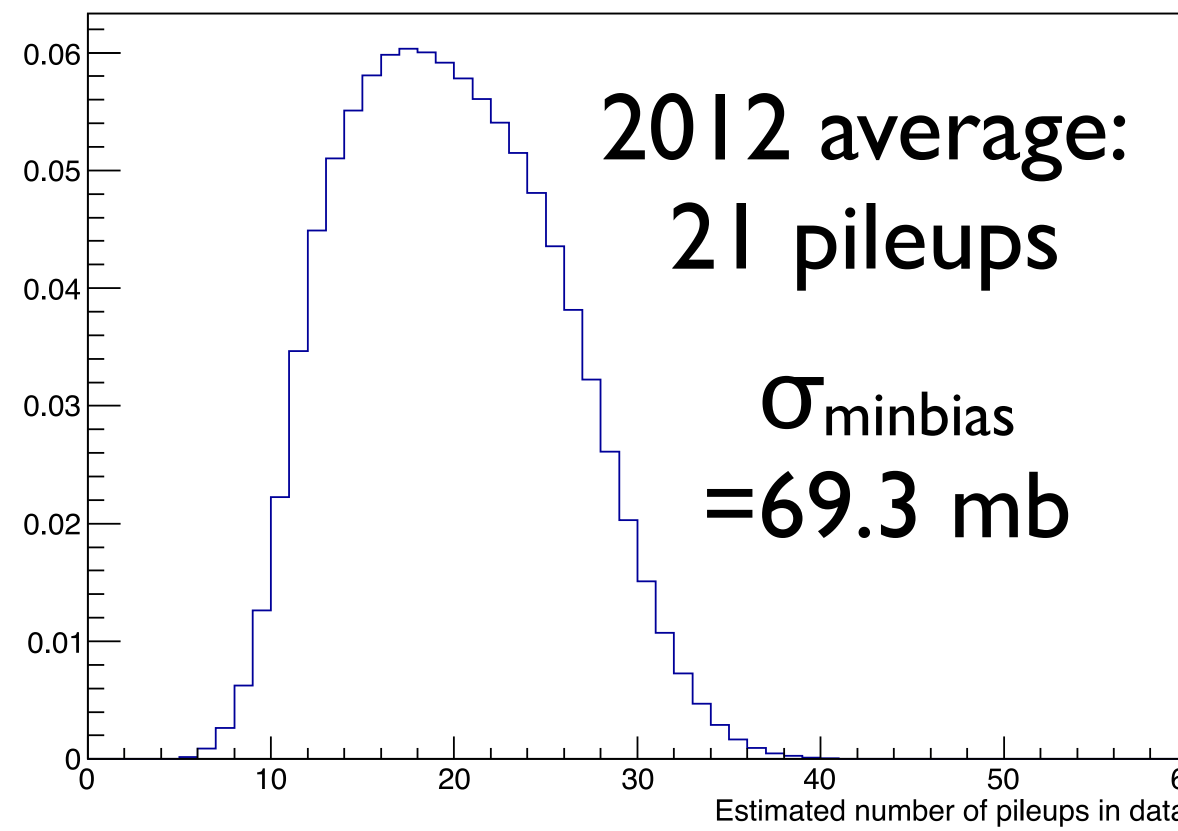
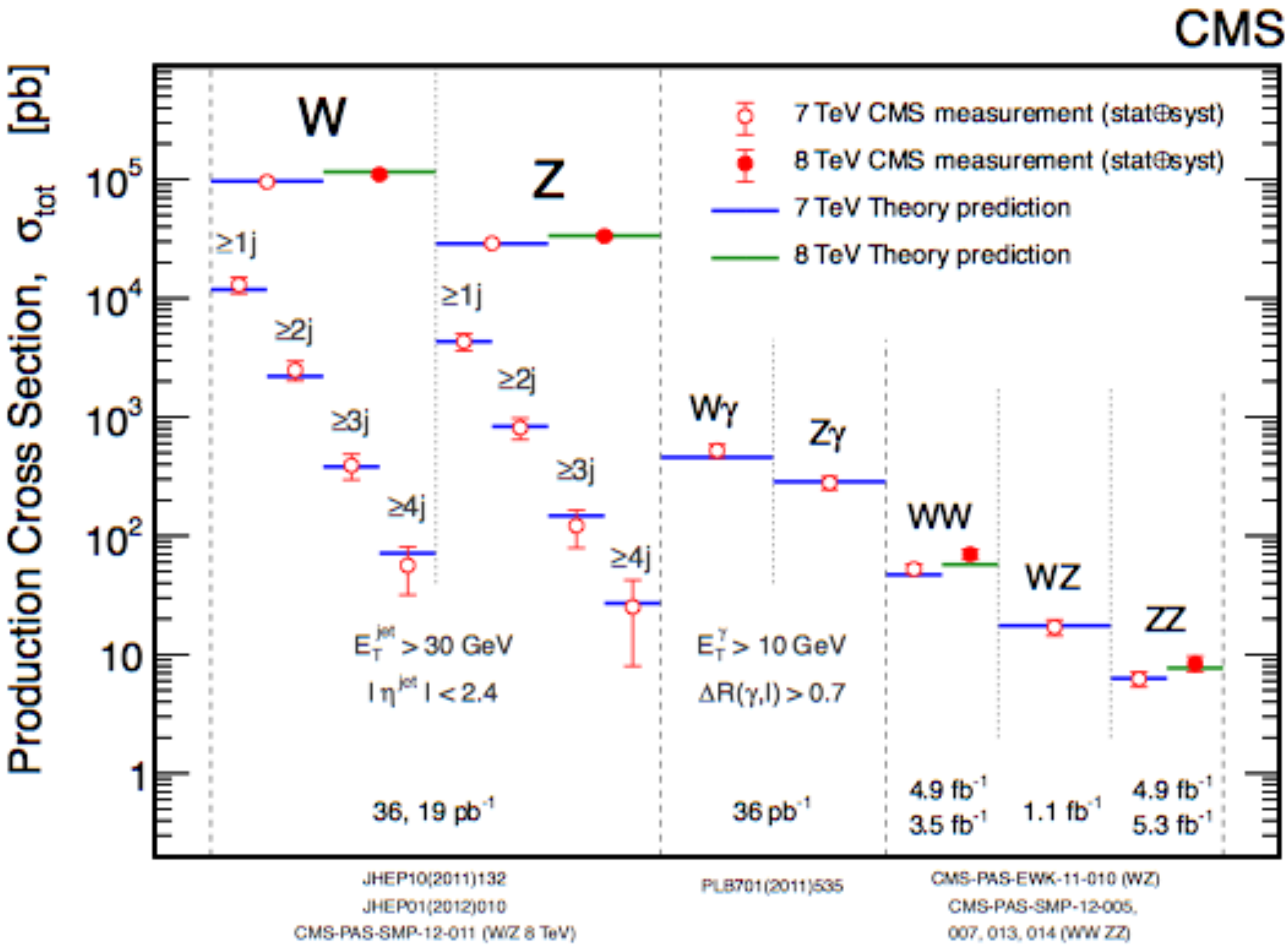


Our signal today may be our background tomorrow ..

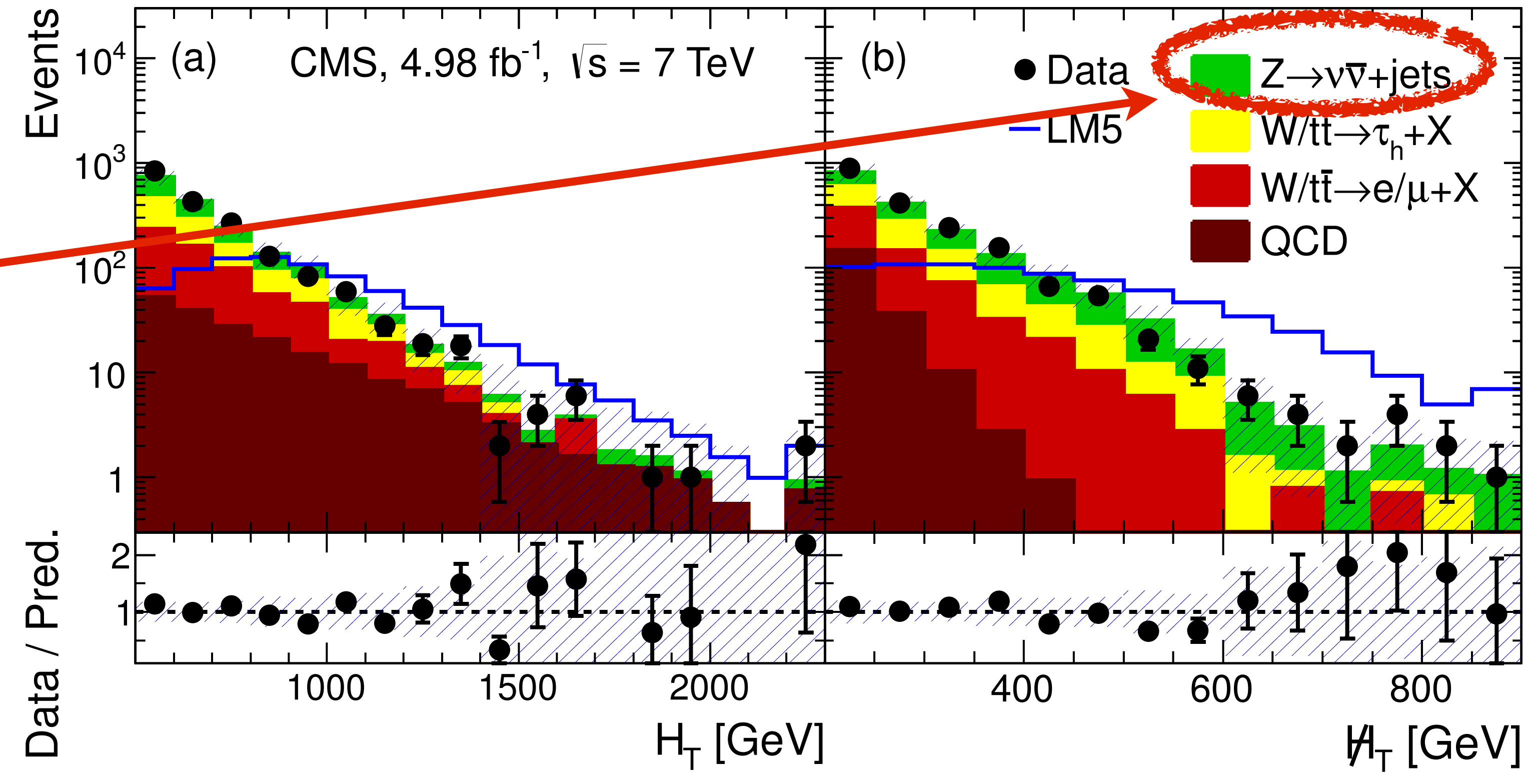
Lhc Production Cross Section



Backgrounds To Searches

- Search for squarks and gluinos in jets + MET
  - Estimated with γ+jets and Z(→μμ)+jets

  [Phys. Rev. Lett. 109 (2012) 171803]



$$N^{\text{observed}}_{Z(\to\nu\nu)+\text{jets}} = \boxed{N^{\text{observed}}_{\gamma+\text{jets}}} \times \boxed{\frac{\sigma_{Z(\to\nu\nu)+\text{jets}}}{\sigma_{\gamma+\text{jets}}} \times \frac{\varepsilon_{Z(\to\nu\nu)+\text{jets}}}{\varepsilon_{\gamma+\text{jets}}}}$$

Inclusive photon result

Predictions from BLACKHAT and Madgraph

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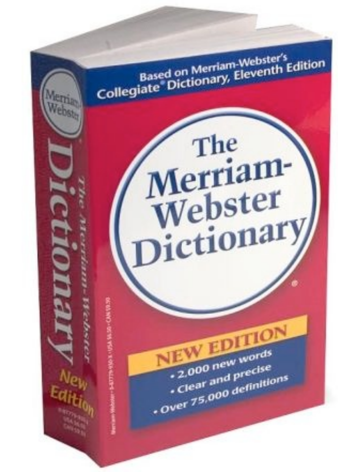

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  - How we quote the amount of data collected

$$L_{\text{int}} = \int \mathcal{L}\, dt$$

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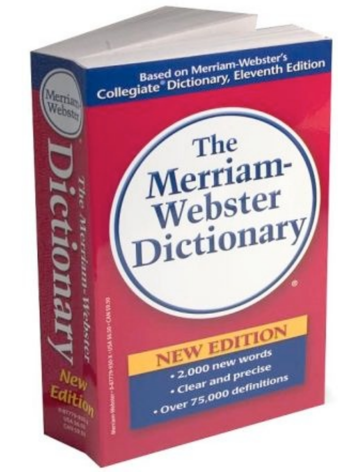

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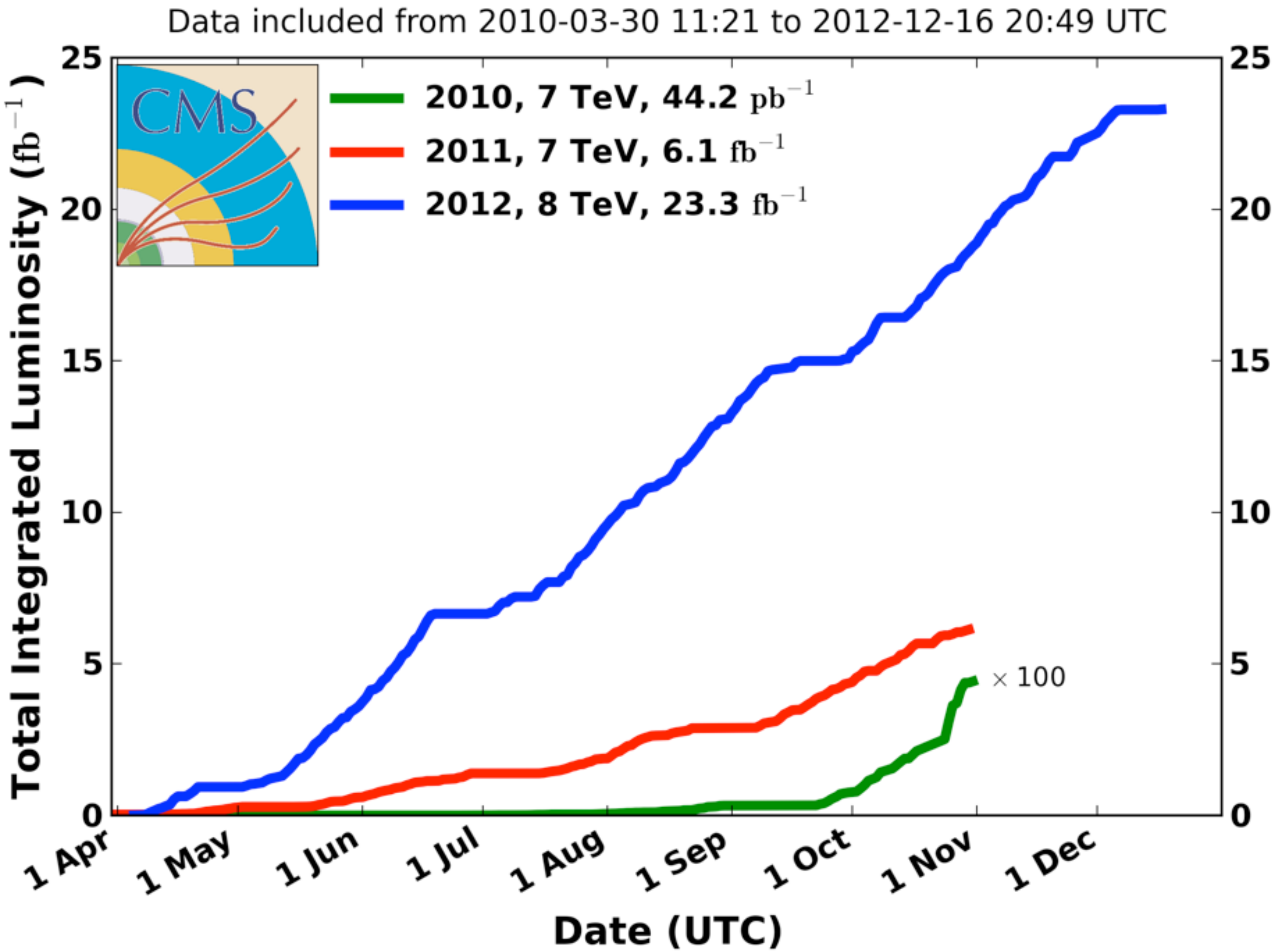

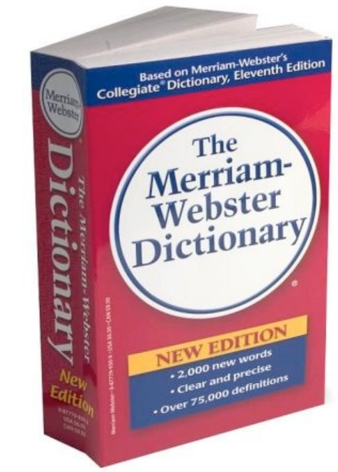

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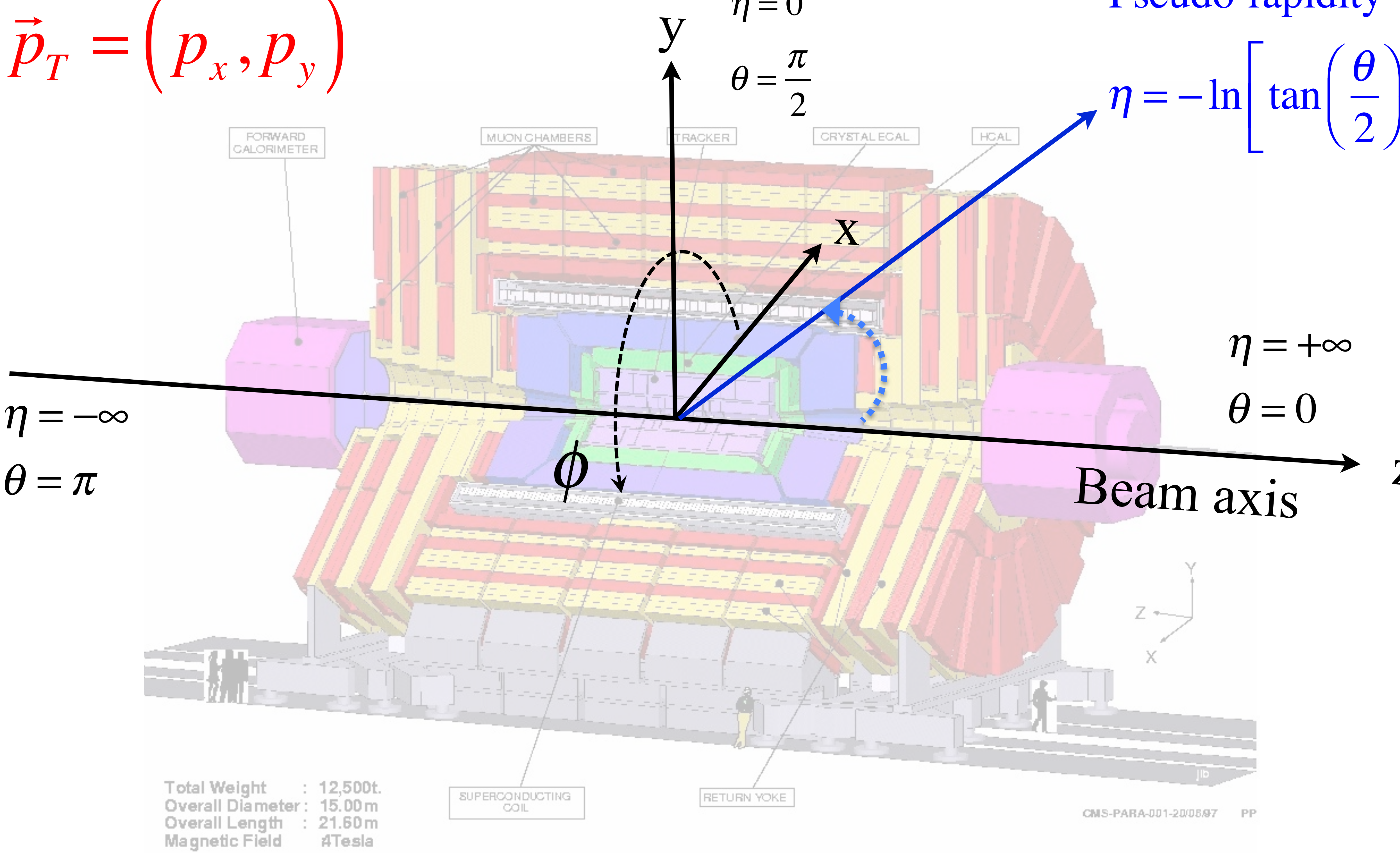
Standard Collider Kinematic Variables

$\vec{p}_T = \left(p_x, p_y\right)$

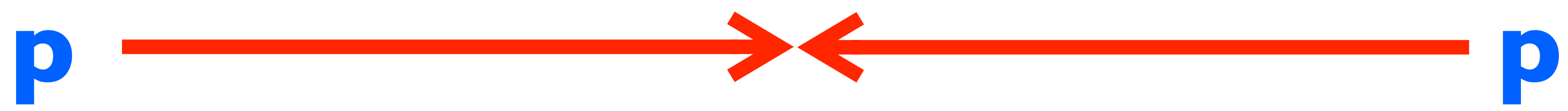
Pseudo-rapidity

$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$

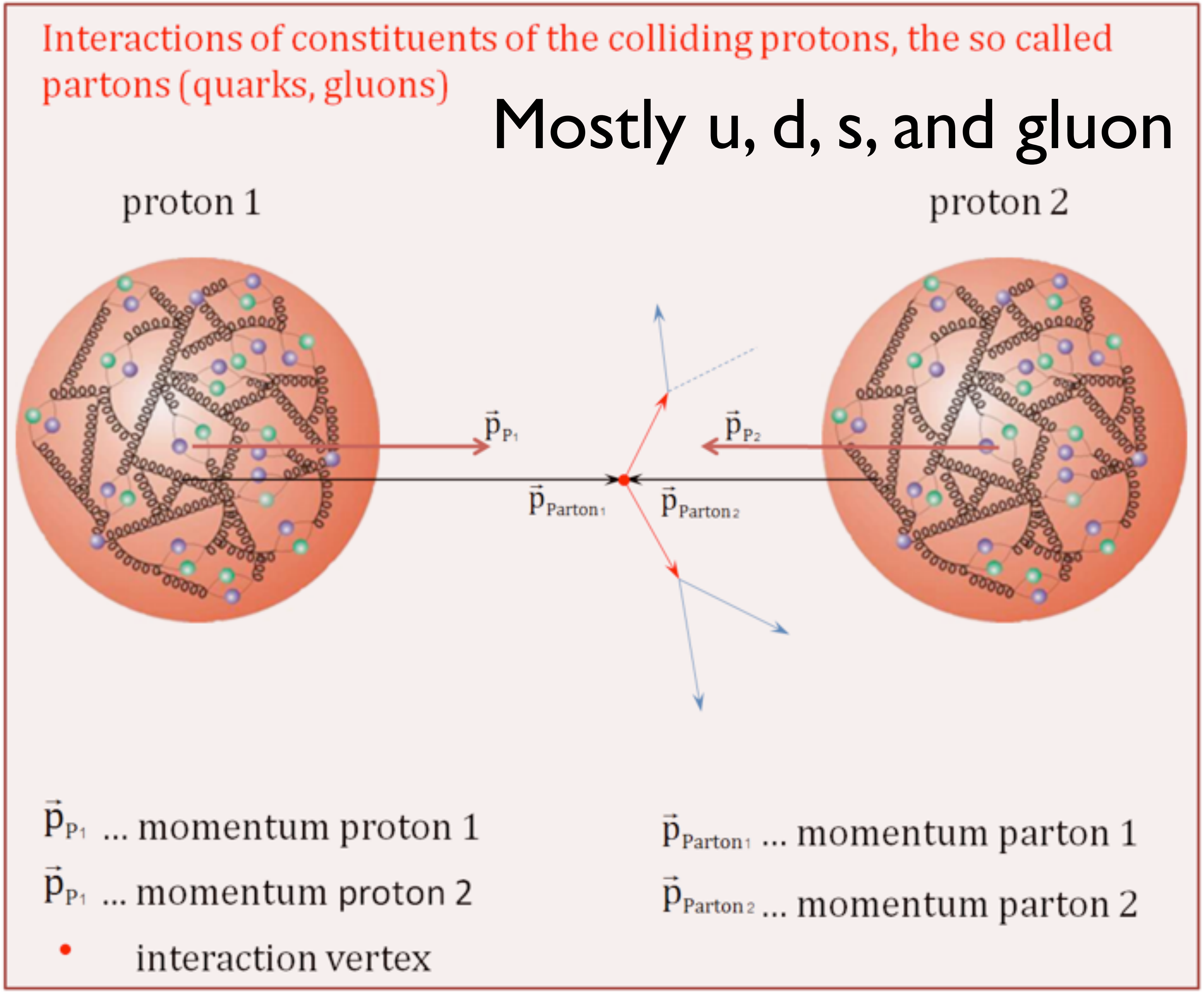


Center Of Momentum Frame

If proton were a point-like particle, lab frame is also the center of momentum frame of the hard scattering.



Proton Is Not An Elementary Particle



Mostly u, d, s, and gluon

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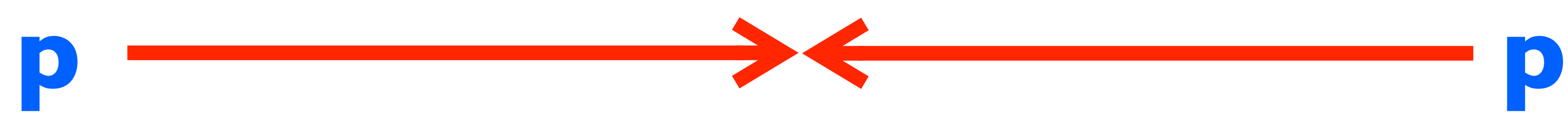
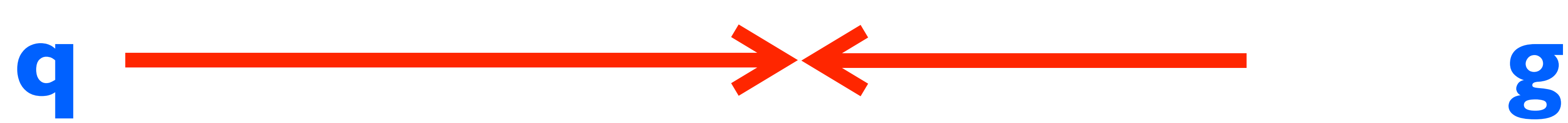


But ... proton has substructure, and the scattering constituents are partons inside proton (quarks and gluons). Therefore, the center of momentum frame varies event by event and does not coincide with the lab frame.



Therefore, we want to use kinematic variables that are invariant under the boost along the z direction.

Kinematic Variables

Lorentz-invariant phase space volume

$$d\tau = \frac{d^3 p}{E} = \frac{dp_x dp_y dp_z}{E} \quad , \int f(p)\, d\tau \text{ is also invariant}$$

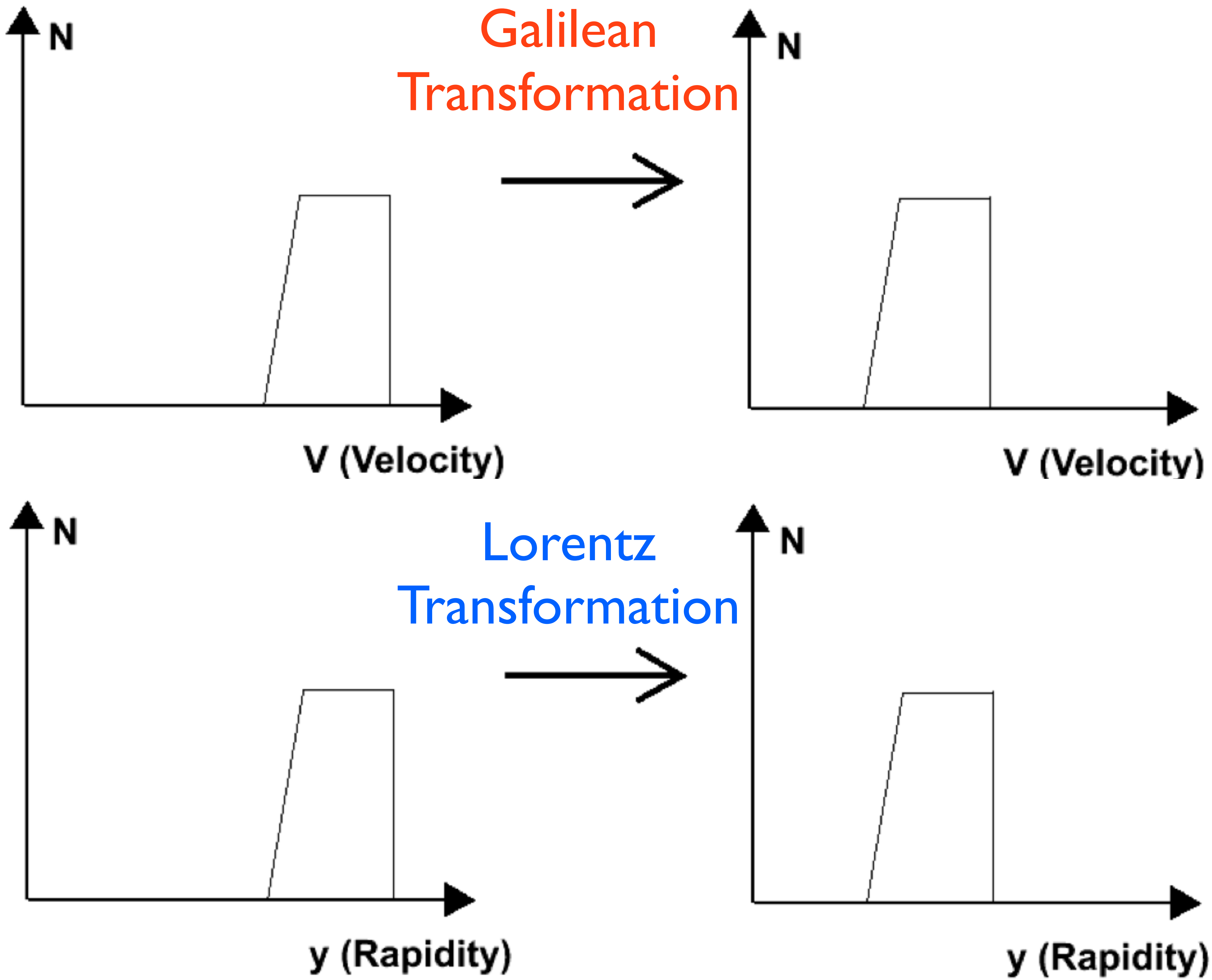
$$= \frac{1}{2} dp_T^2 \, d\phi \, dy$$

where rapidity $y = \frac{1}{2} \ln\left(\frac{E + p_z}{E - p_z}\right)$ and $dy = \frac{dp_z}{E}$

Homework

Under boost along the z direction

$$y \rightarrow y + \Delta y_b$$

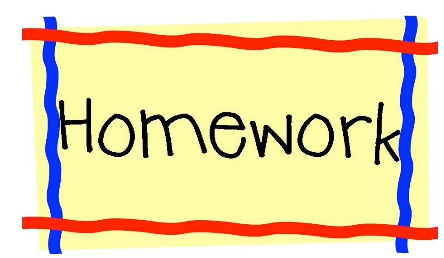

N
Galilean
Transformation
N
V (Velocity)
V (Velocity)
N
Lorentz
Transformation
N
y (Rapidity)
y (Rapidity)

Kinematic Variables

$$\text{rapidity } y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

For relativistic particle, $p \gg m$

$$y \to \eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



Object Reconstruction

Kinematic Variables We Use

$$\Rightarrow \; \phi, \; p_T \, , \; \eta$$

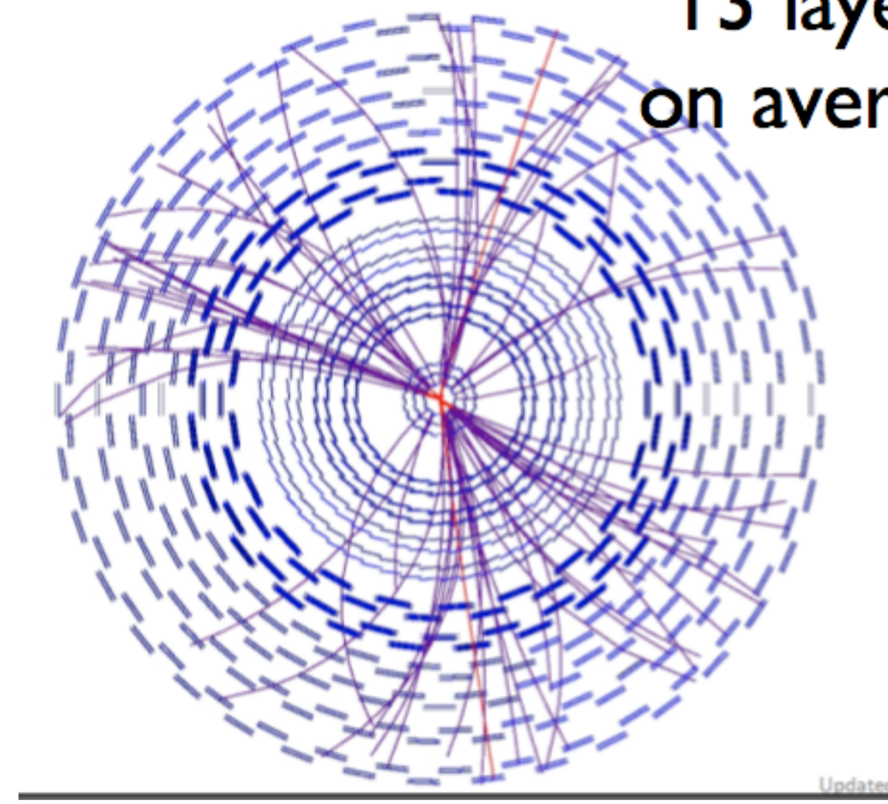
How do we measure these quantities?

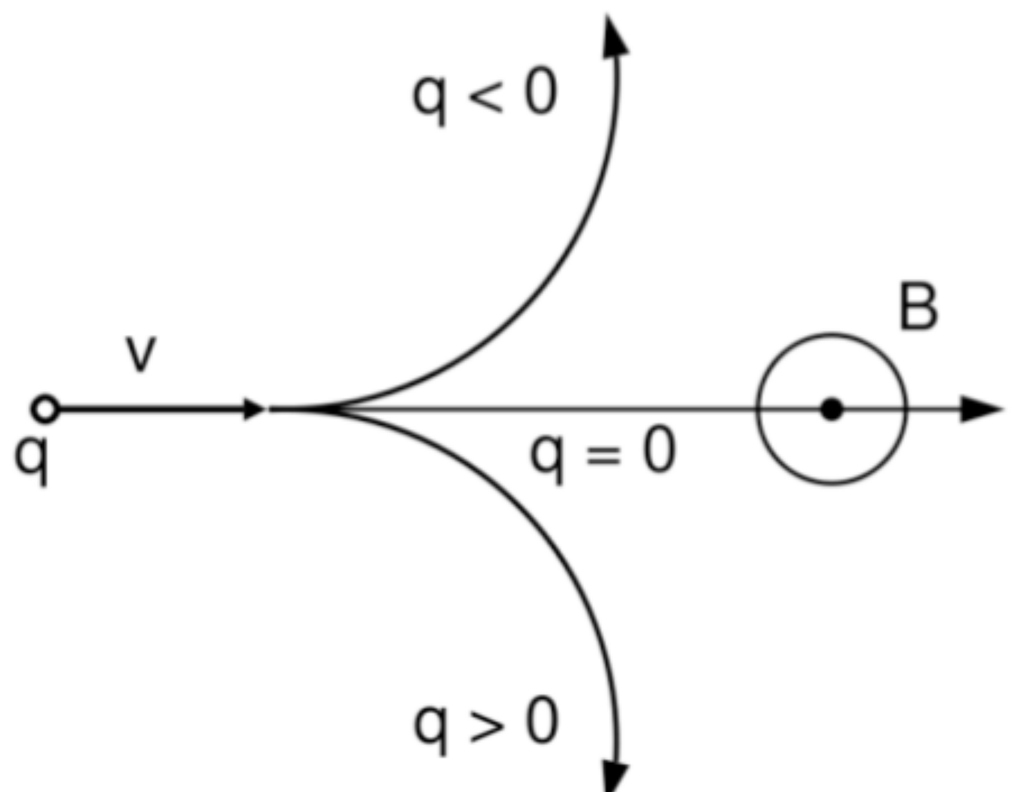
Basically, we need to measure the direction of momentum and the magnitude of transverse momentum.

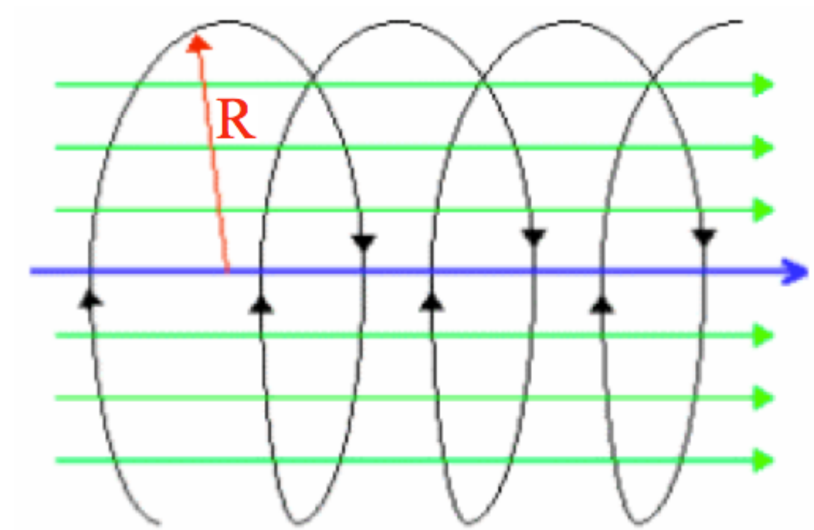
How To Measure Momentum?

- Charged particle
  - ➡ Measure trajectory with tracker (silicon detector, gas chamber) + a magnetic field

13 layers on average

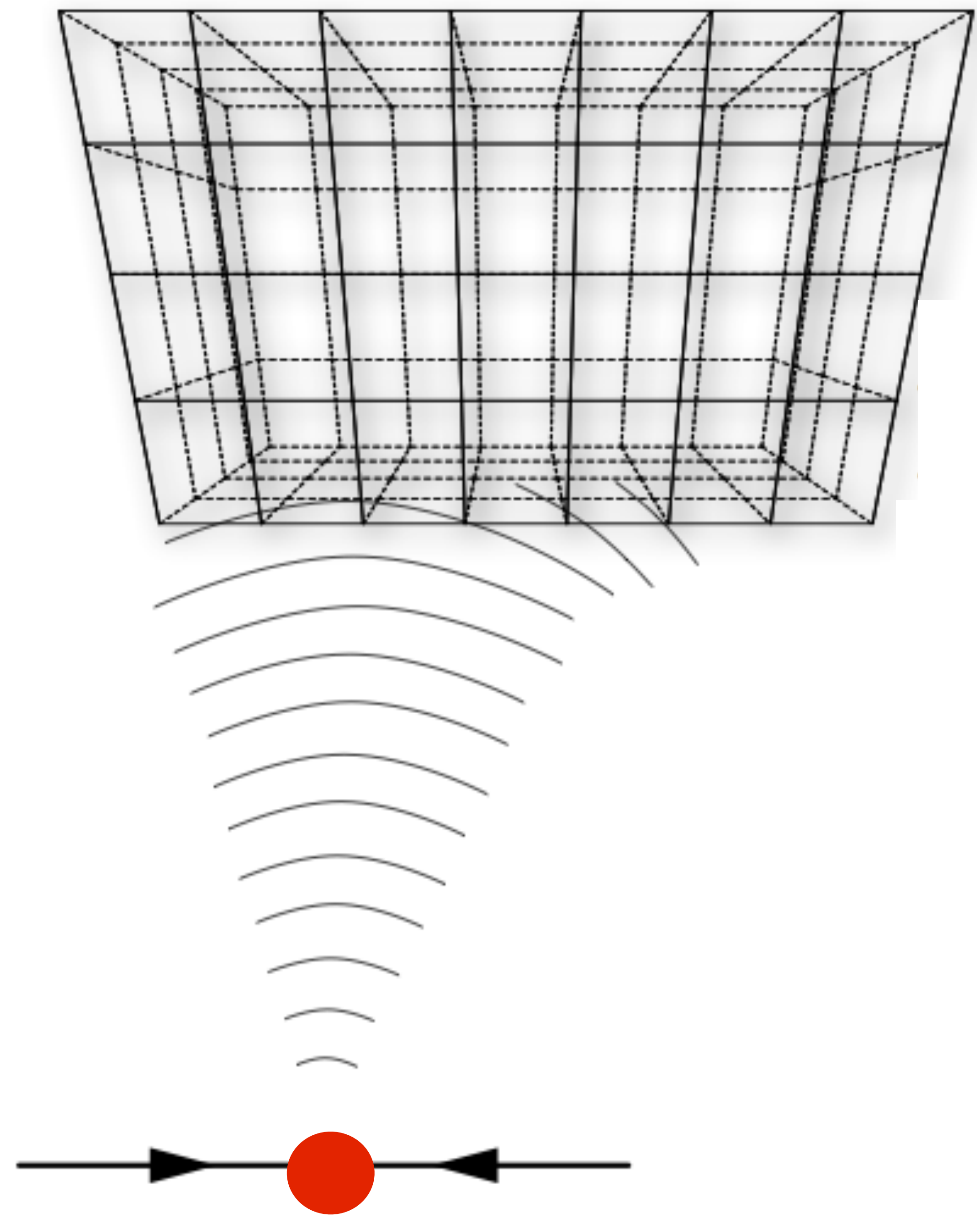






How To Measure Momentum?

- Neutral and interacting particle(s)
  - ➡ Connect the spot of energy deposit in calorimeter with primary interaction point
  - ➡ Due to the poor segmentation of hadron calorimeters, most of the time we are studying momentum of merged hadrons



R. Cavanaugh

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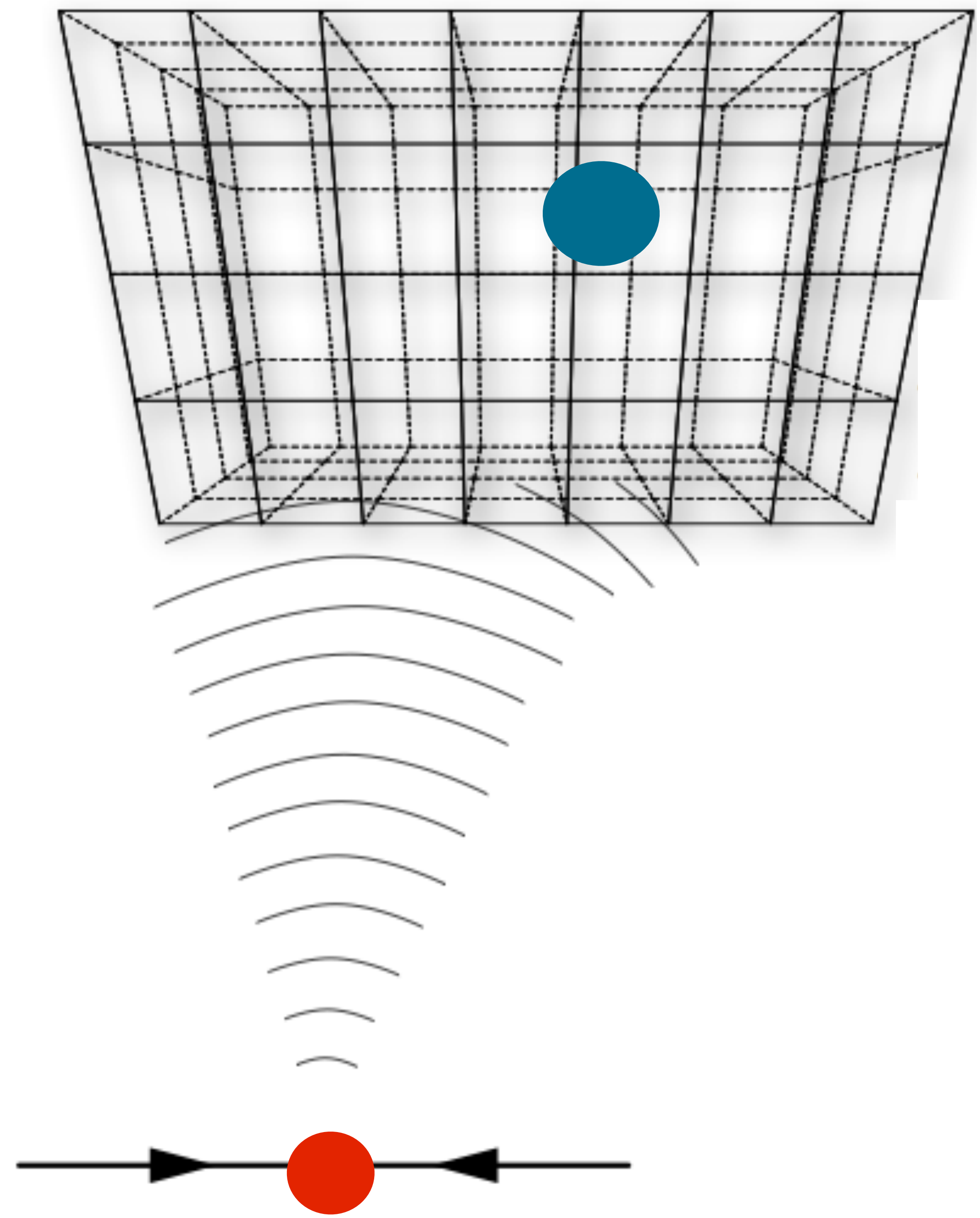

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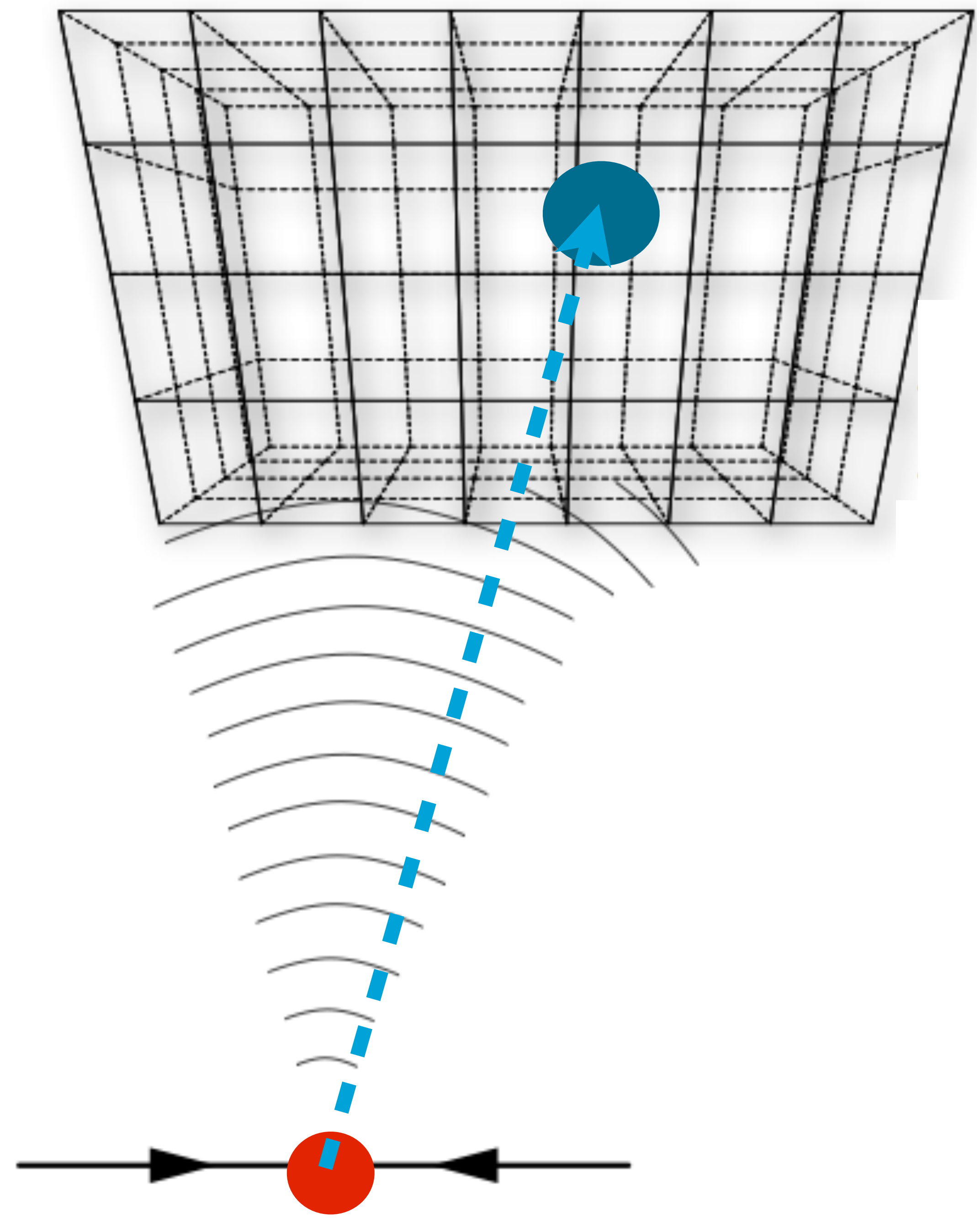

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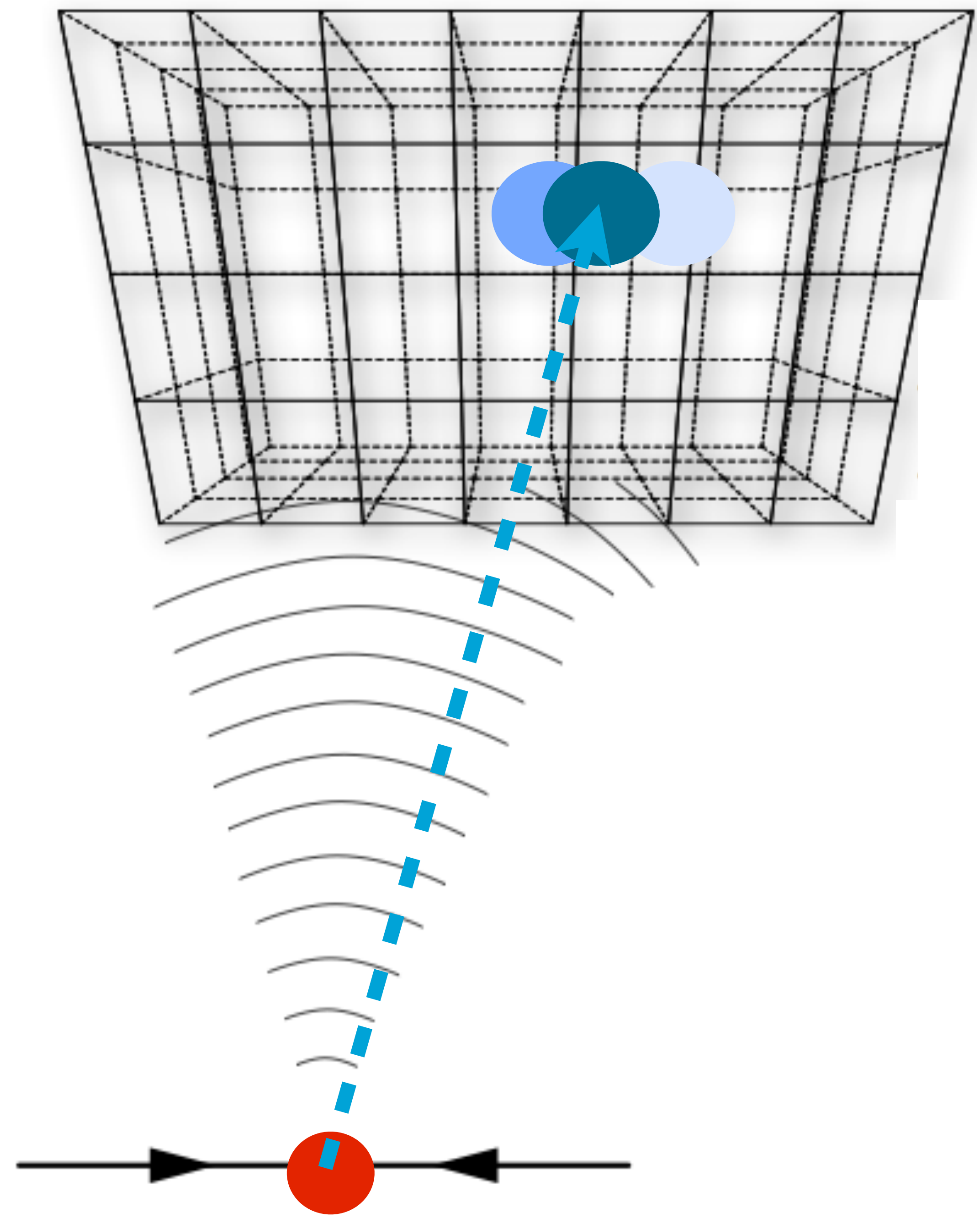
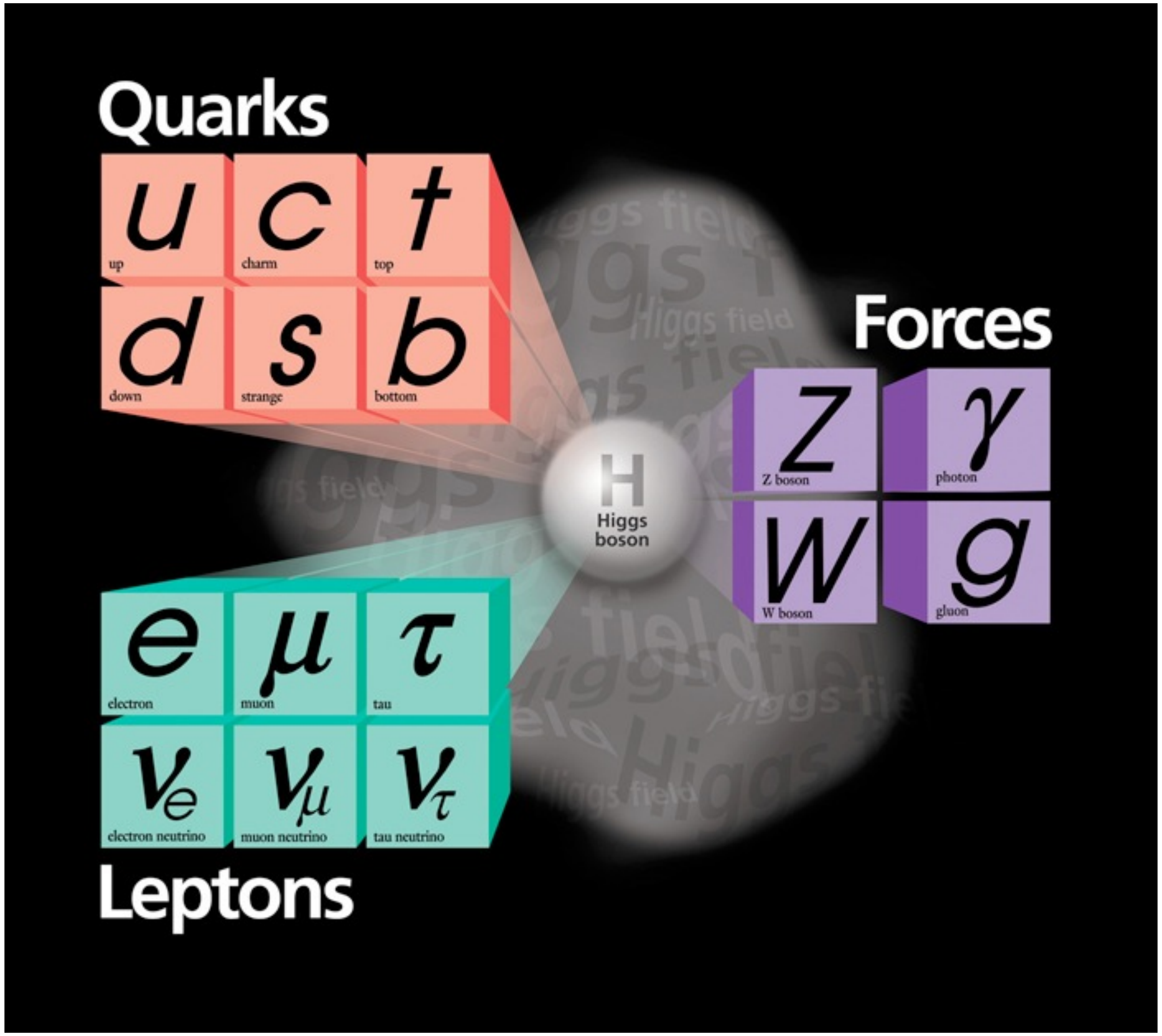


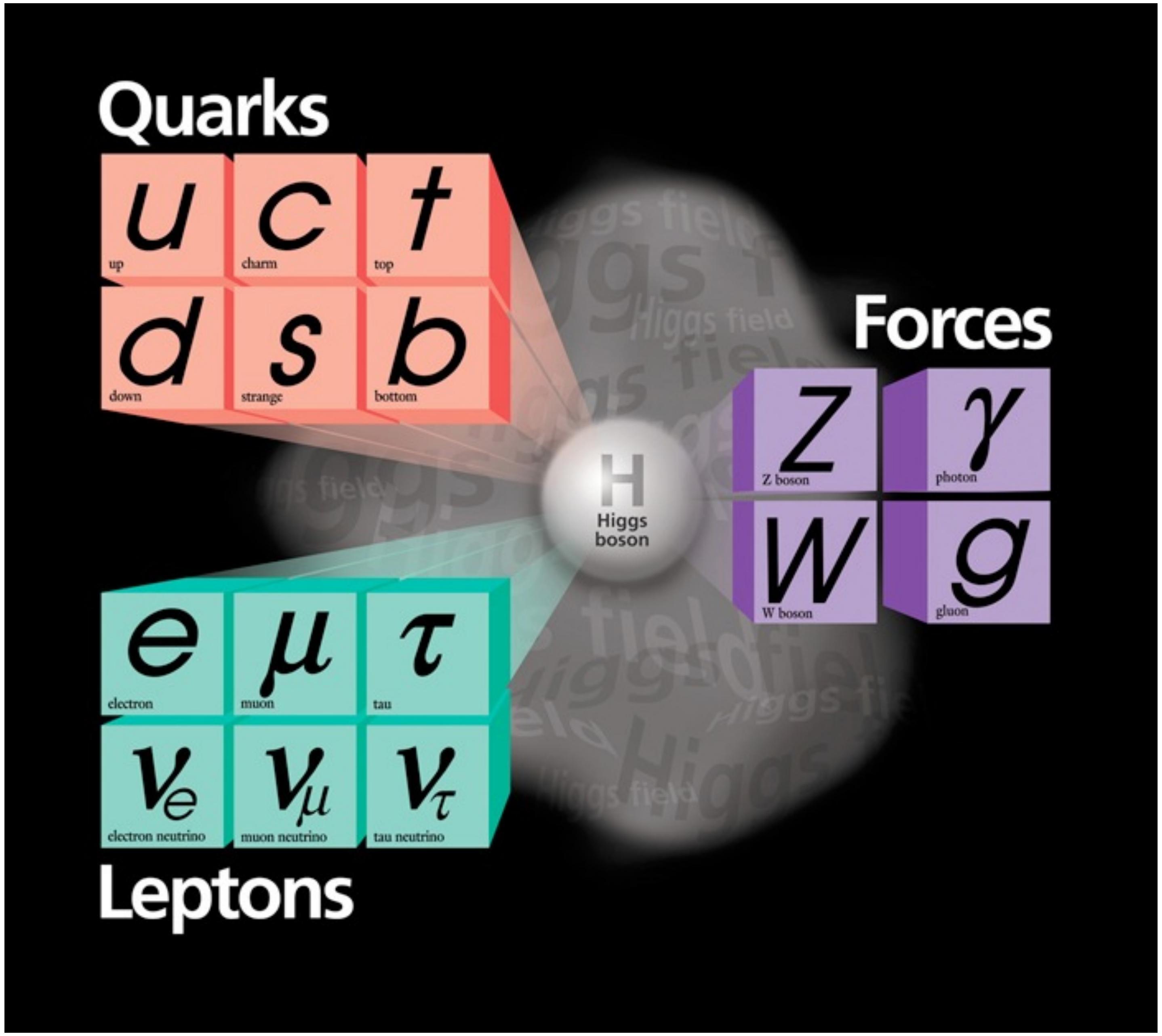
R. Cavanaugh

The Standard Model Of Particle Physics



Which particle can we see in the detector?

The Standard Model Of Particle Physics



Which particle is stable in the collider detector?

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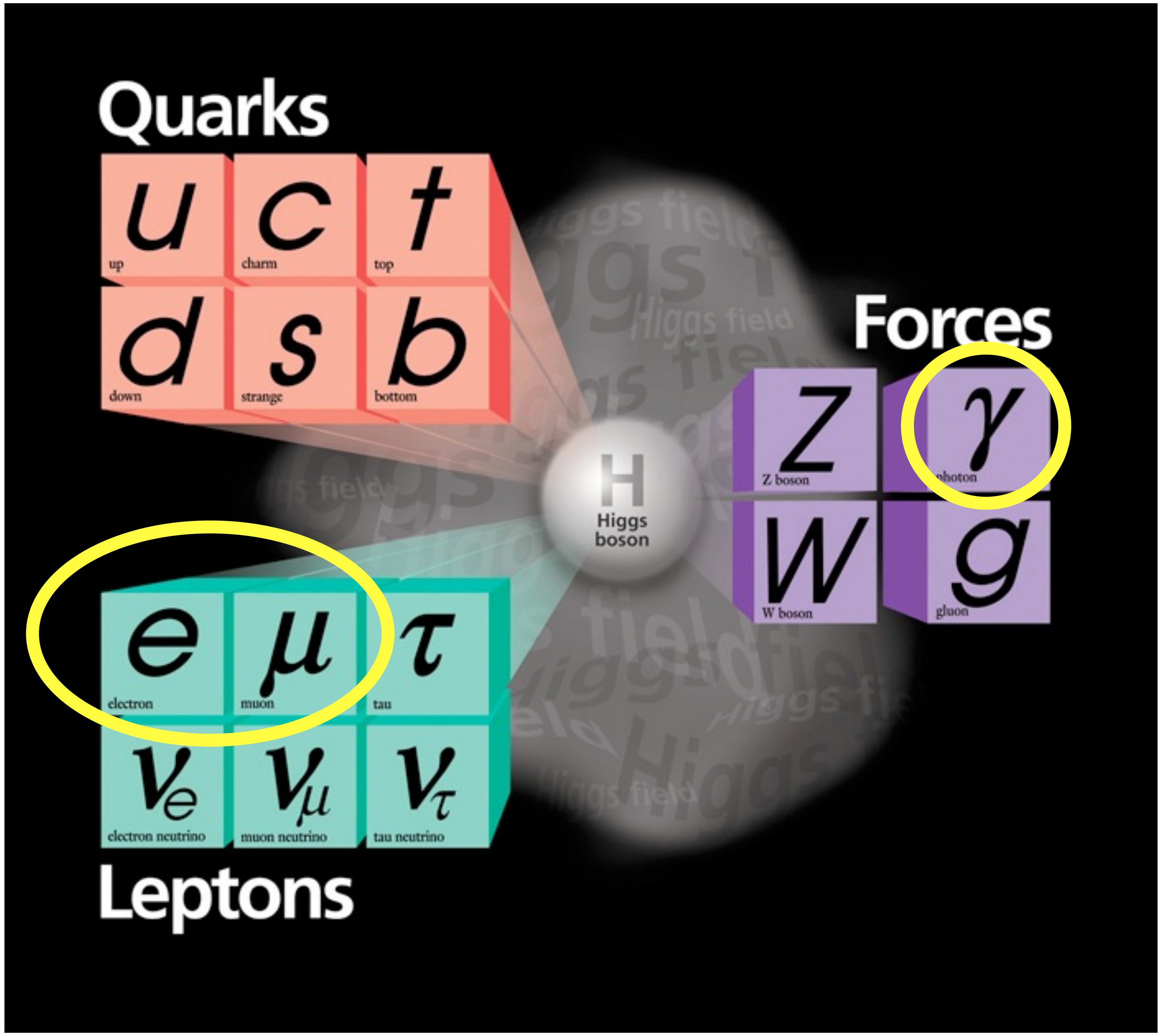

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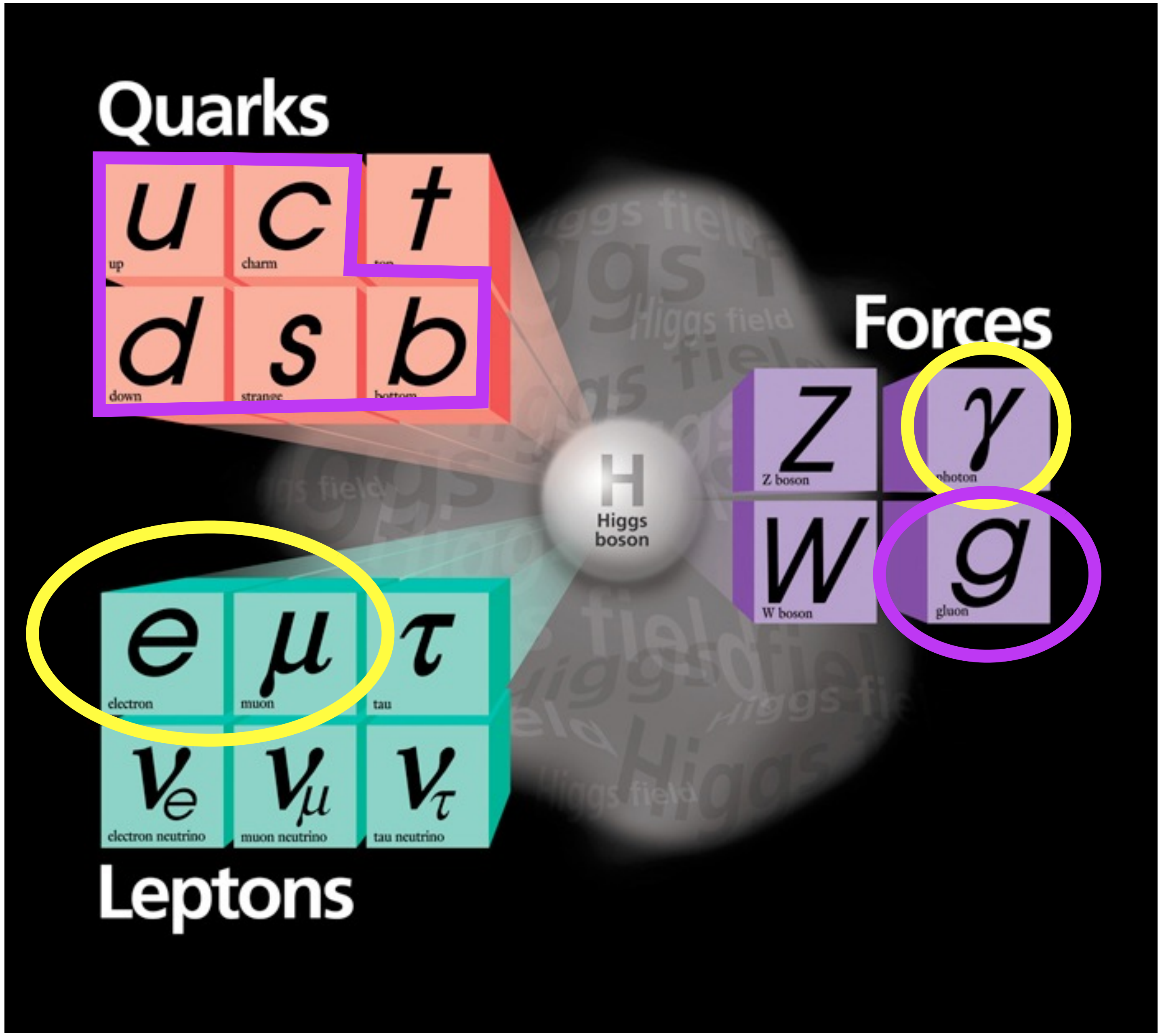
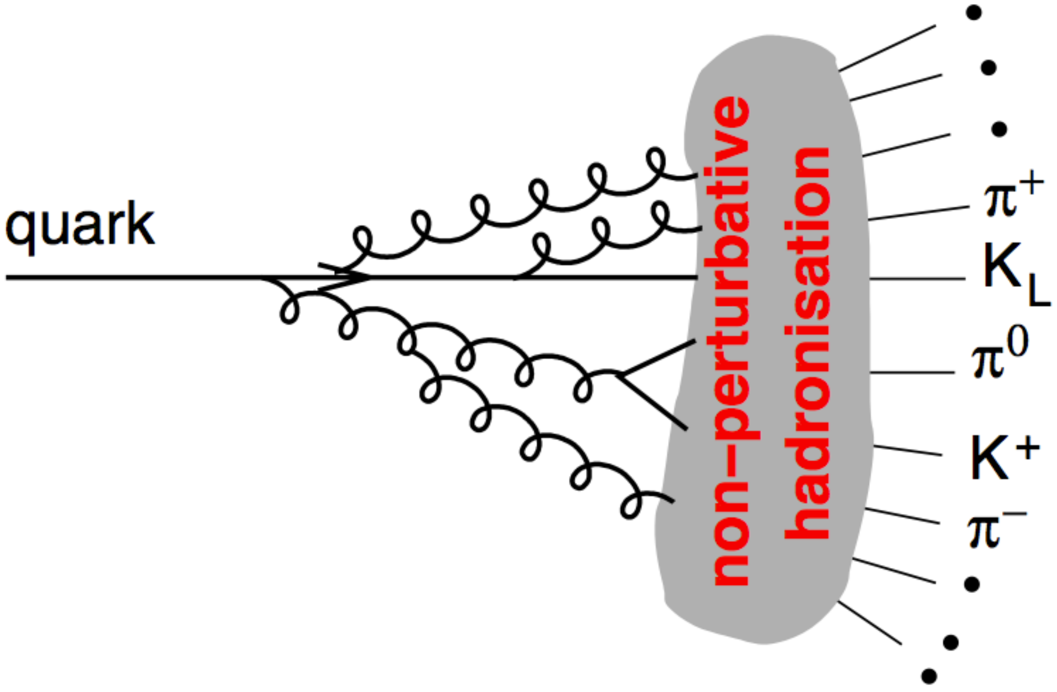


Appear as jets



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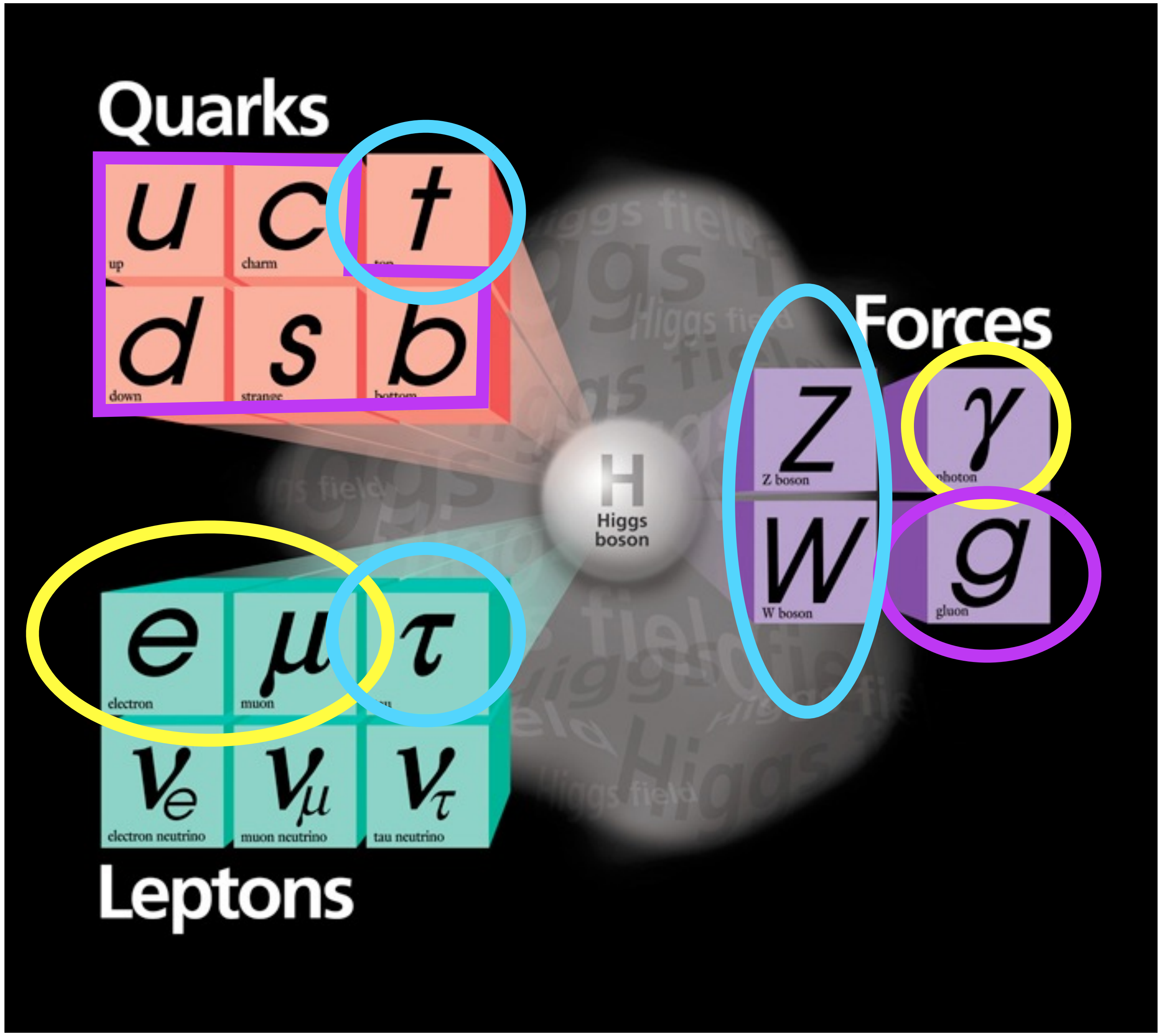
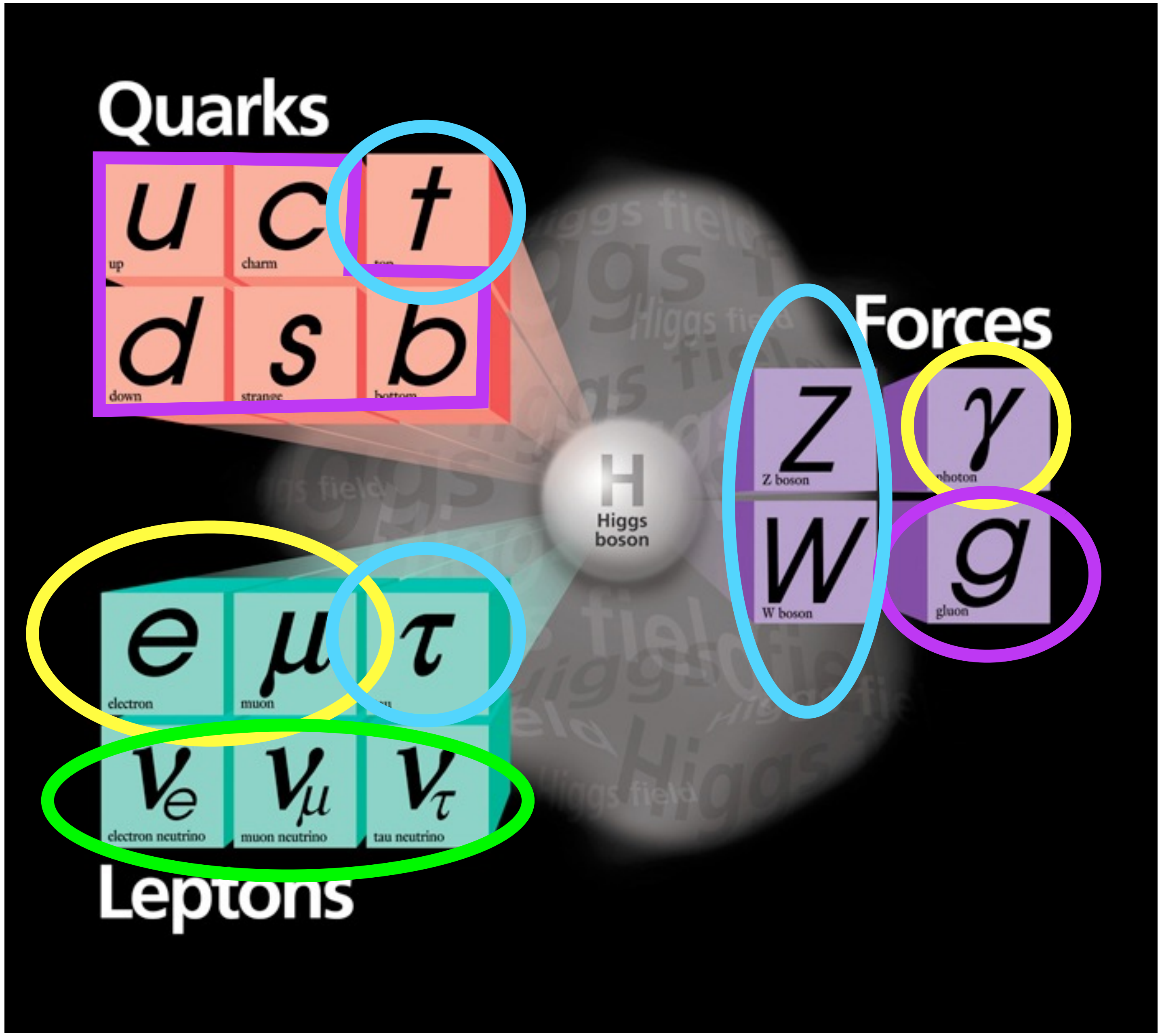


Appear as jets

We detect their decay products

Which particle is stable in the collider detector?

The Standard Model Of Particle Physics



Appear as jets

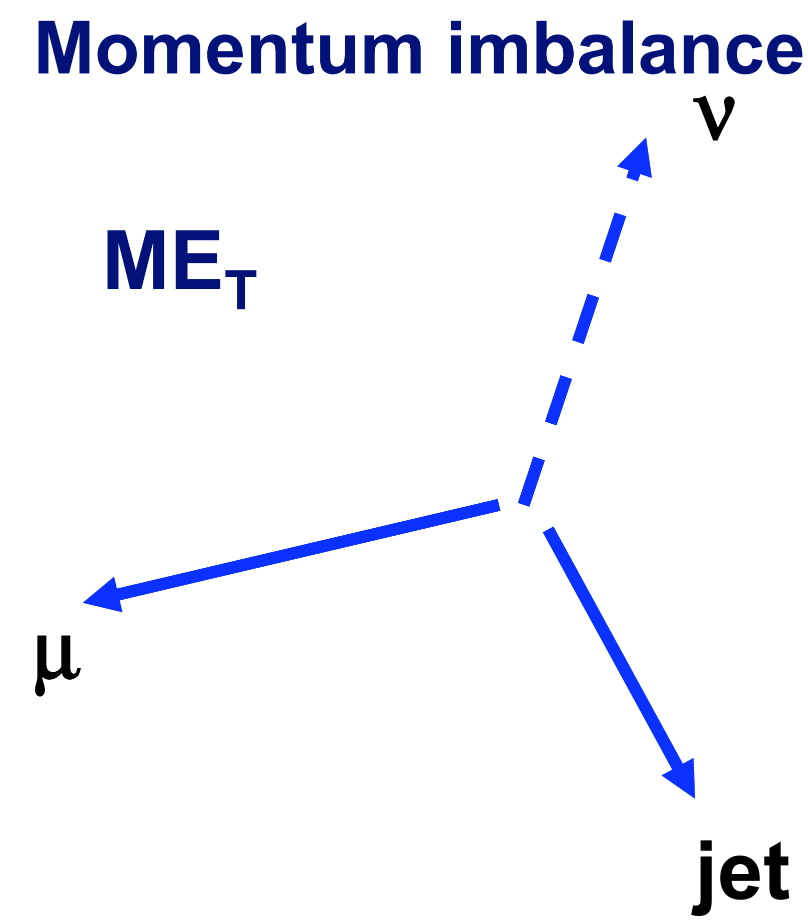
We detect their decay products

Appear as missing momentum

Which particle is stable in the collider detector?

Missing Momentum

- Vector-sum the energy/momentum measured in calorimeter or tracker cells
  - Take information from identified objects
  - For unclustered energy:
    - consider particle massless
    - direction of particle momentum is defined by the cell position and primary vertex
- The opposite of this vector sum is momentum imbalance.
- Project the momentum imbalance on to the transverse plane, we get ME_T.



$$p_{x,y}(\mu) + p_{x,y}(j) \neq 0$$

Particles In The Detector

Name	Mass (MeV)	Lifetime	Travel for 1 GeV [m]
e	0.51	$>4.6\times10^{26}$ year	$>8.5\times10^{45}$
μ	105.66	2.2×10^{-6} sec	6250
τ	1776.82	2.9×10^{-13} sec	4.9×10^{-5}
π^0	134.98	8.4×10^{-17} sec	1.9×10^{-7}
$\pi^\pm$	139.57	2.6×10^{-8} sec	56
$K^\pm$	493.68	1.2×10^{-8} sec	7.5
B^0	5279.5	1.5×10^{-12} sec	8.7×10^{-5}
p	938.27	$>2.1\times10^{29}$ year	$>2.1\times10^{45}$
n	939.57	885.7 sec	2.8×10^{11}
W	80399	10^{-25} sec	3.7×10^{-19}
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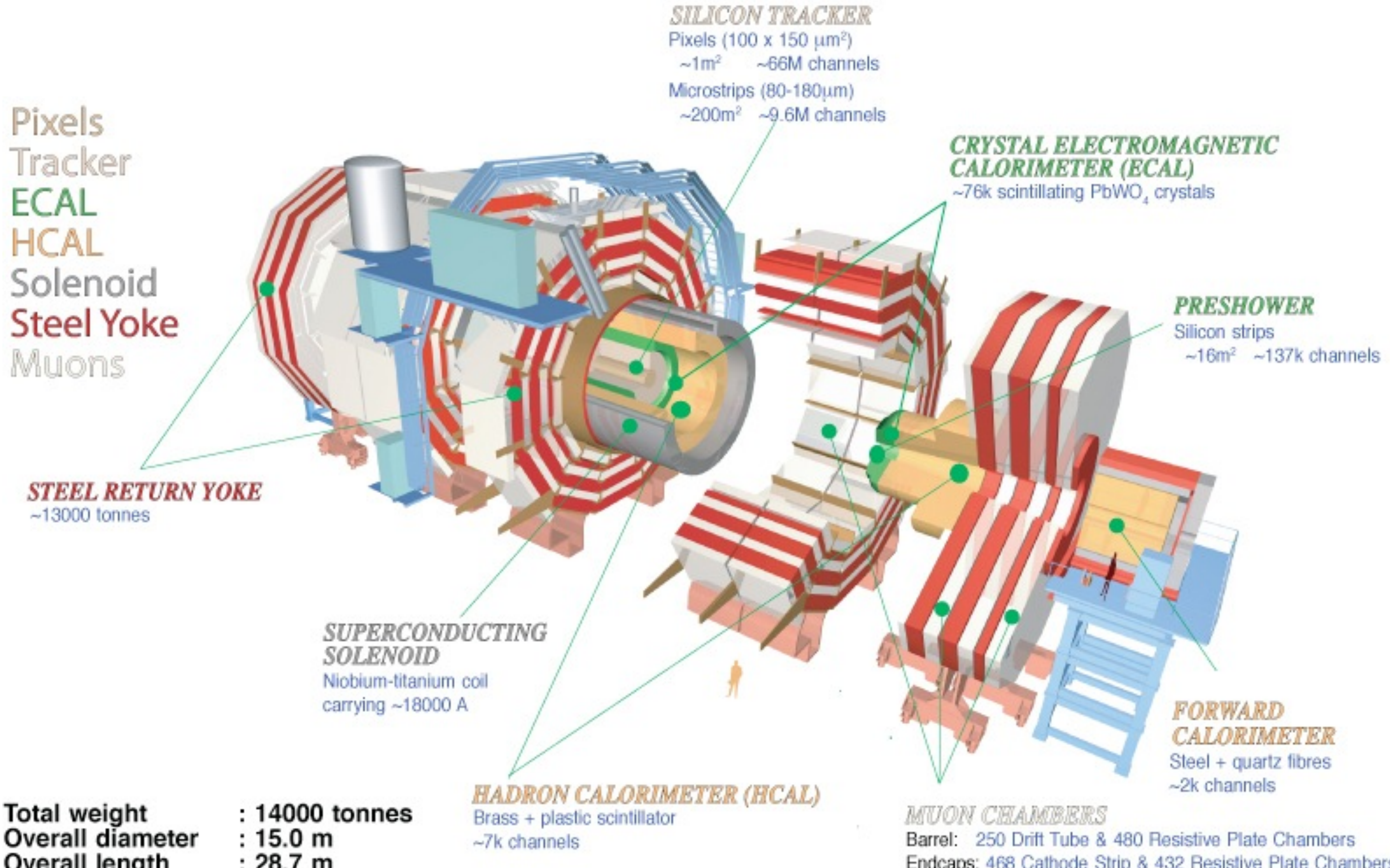
Jets

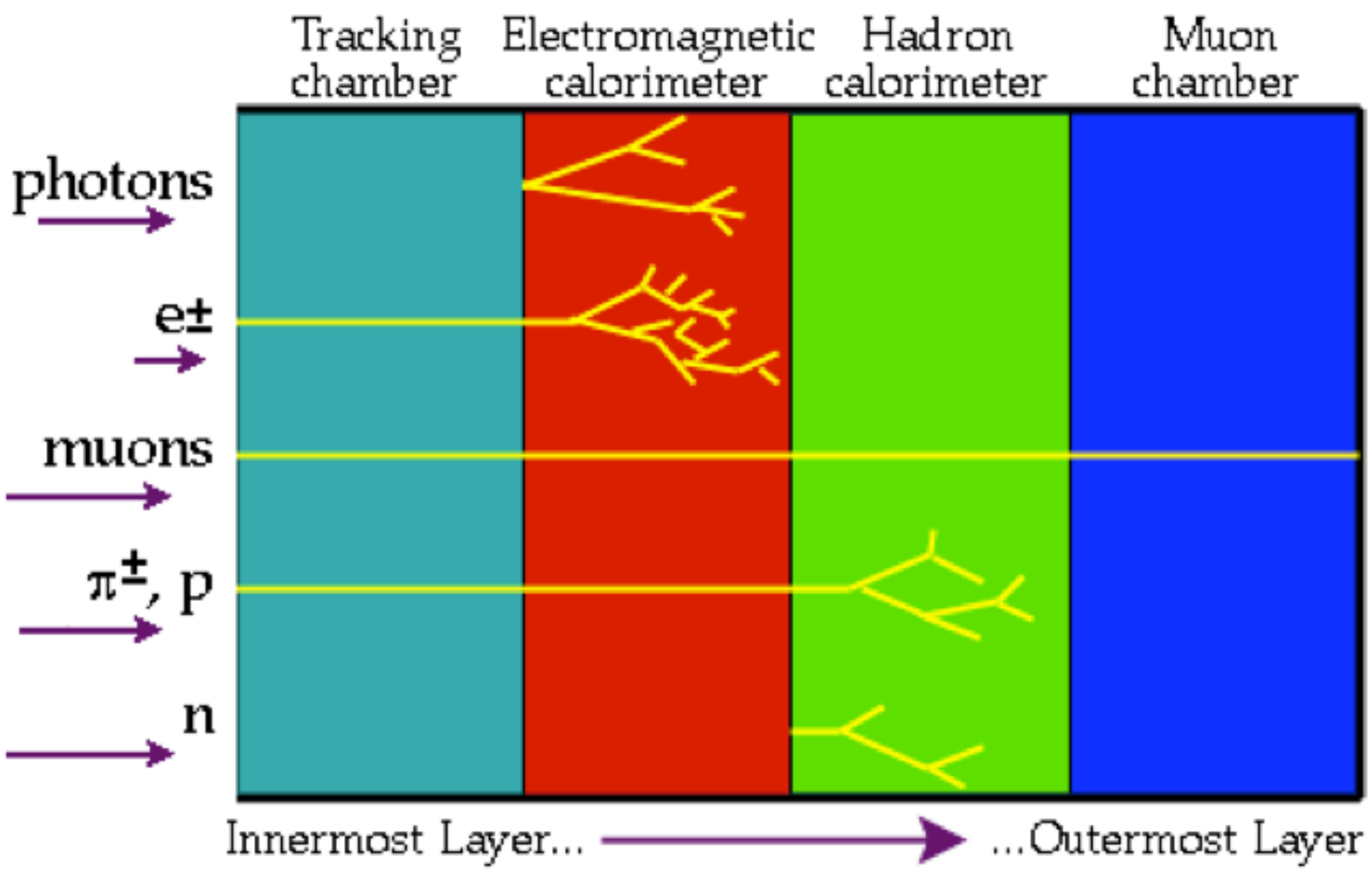
The Compact Muon Solenoid (Cms)

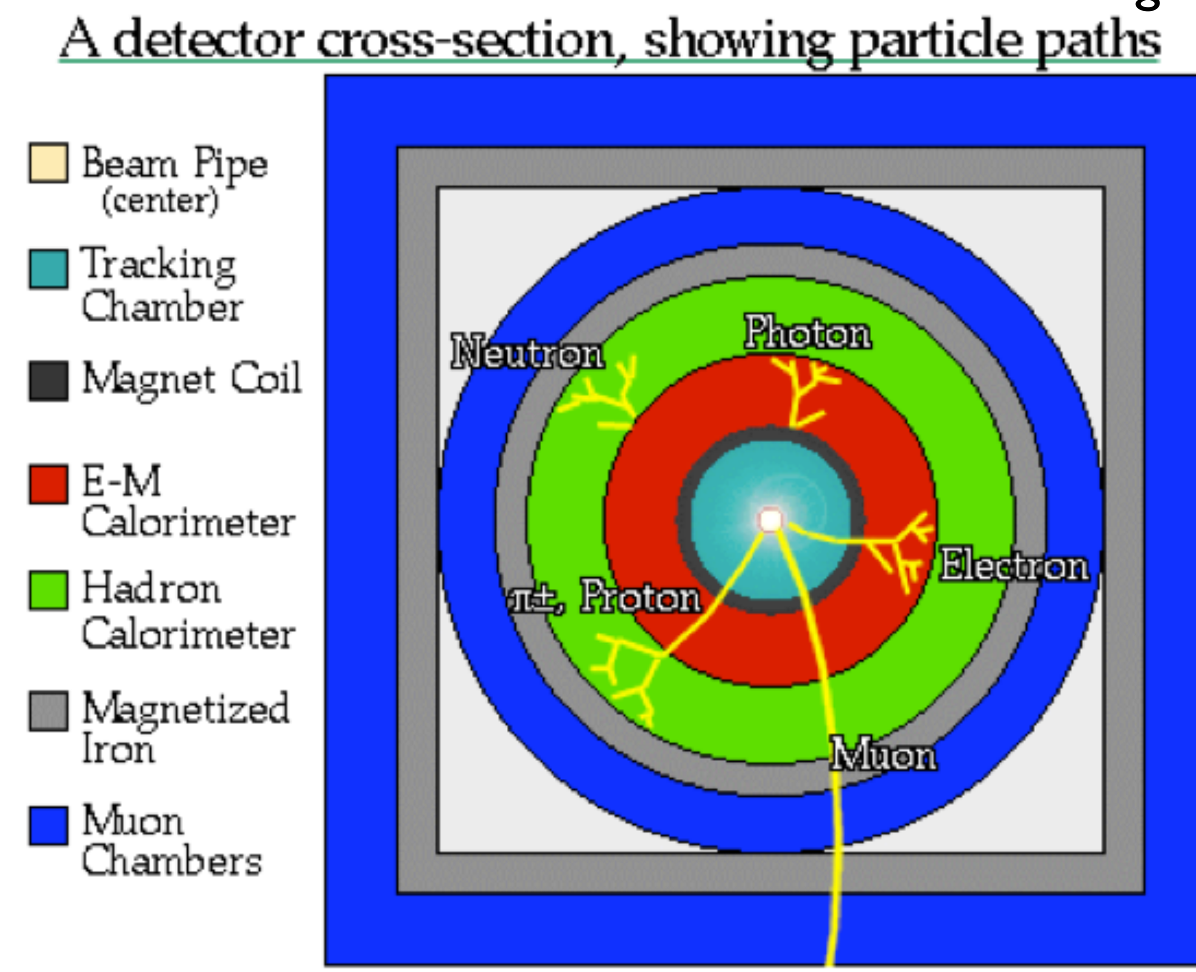


Total weight	: 14000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

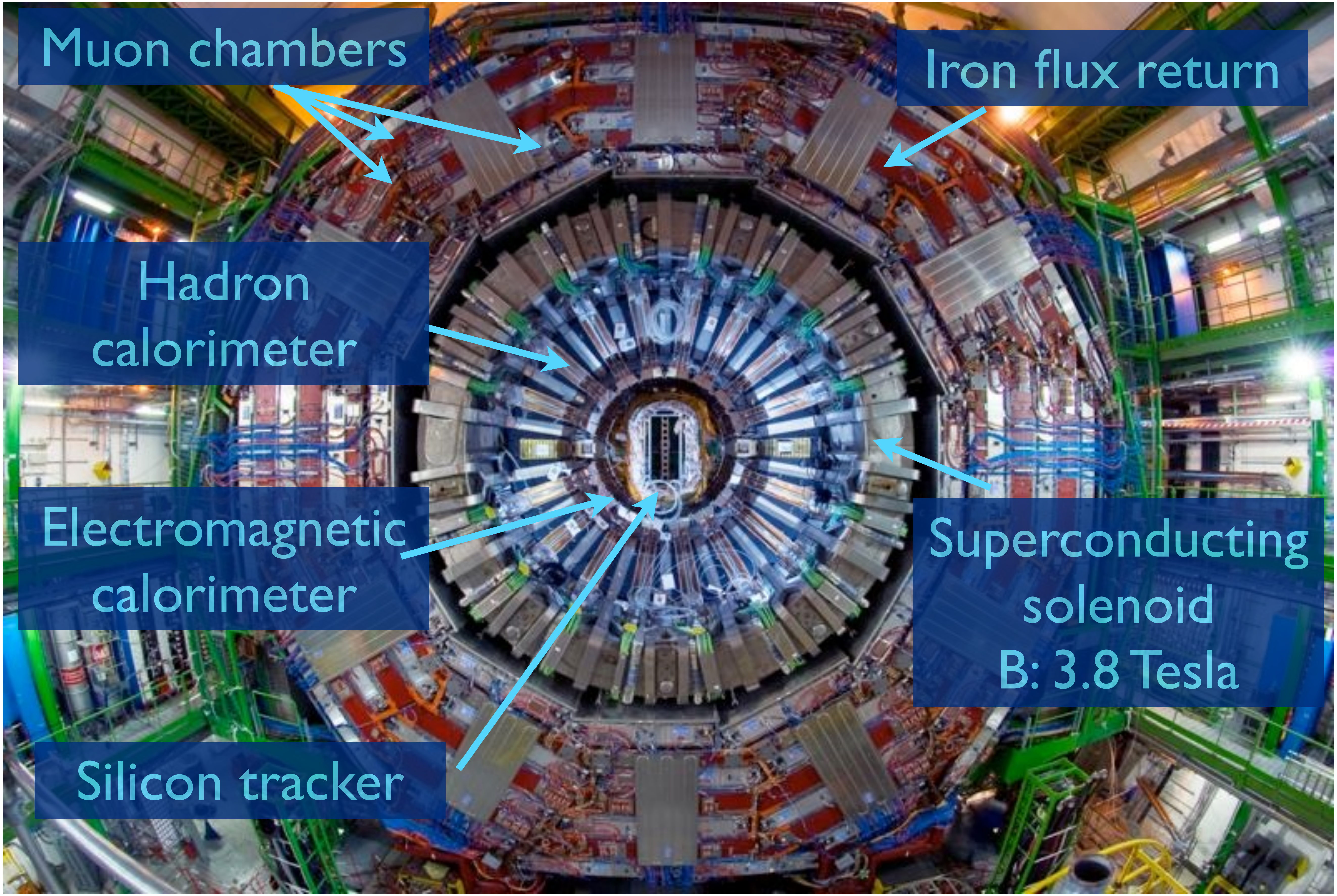
Particle Signatures

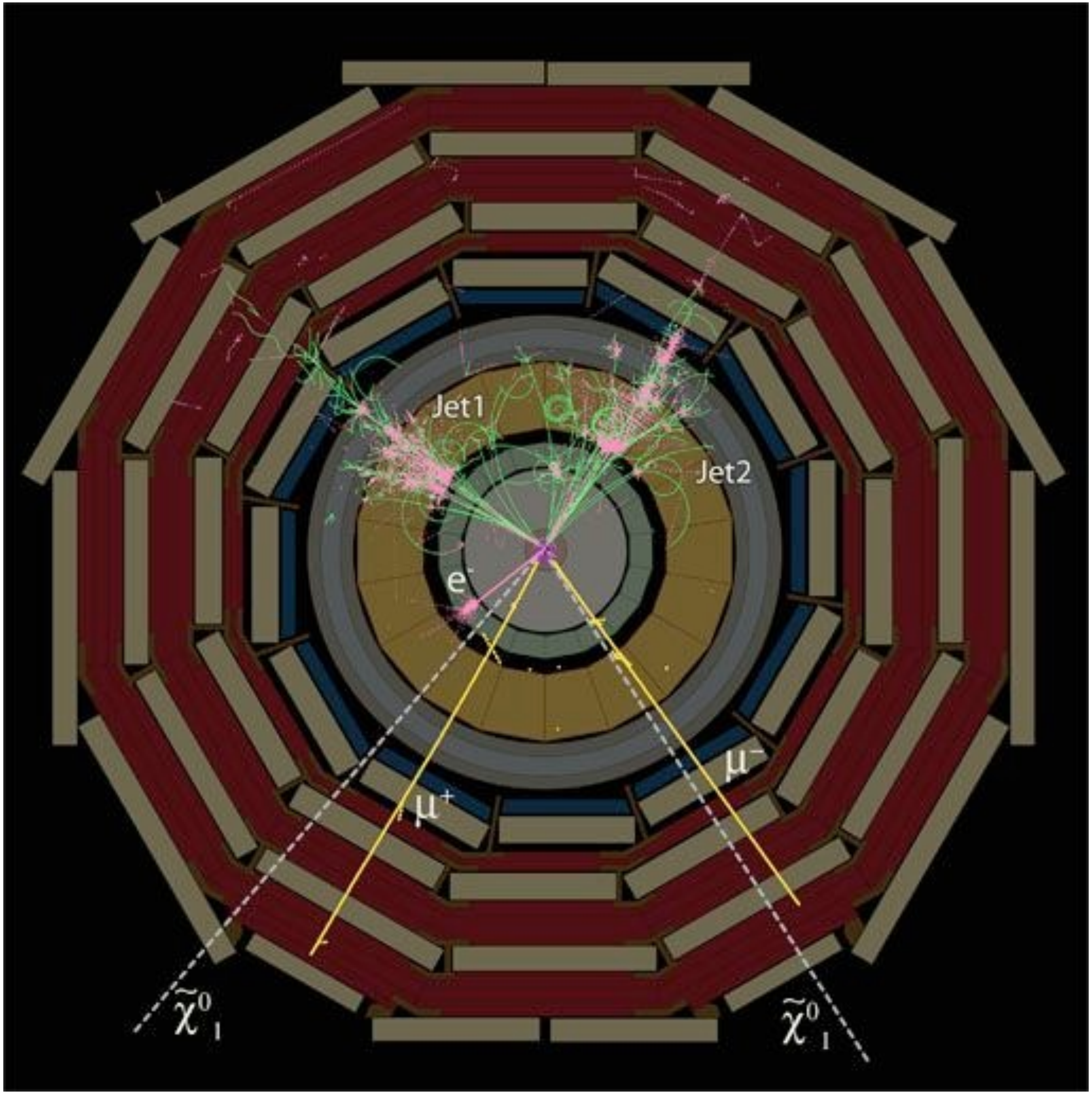
R. Cavanaugh



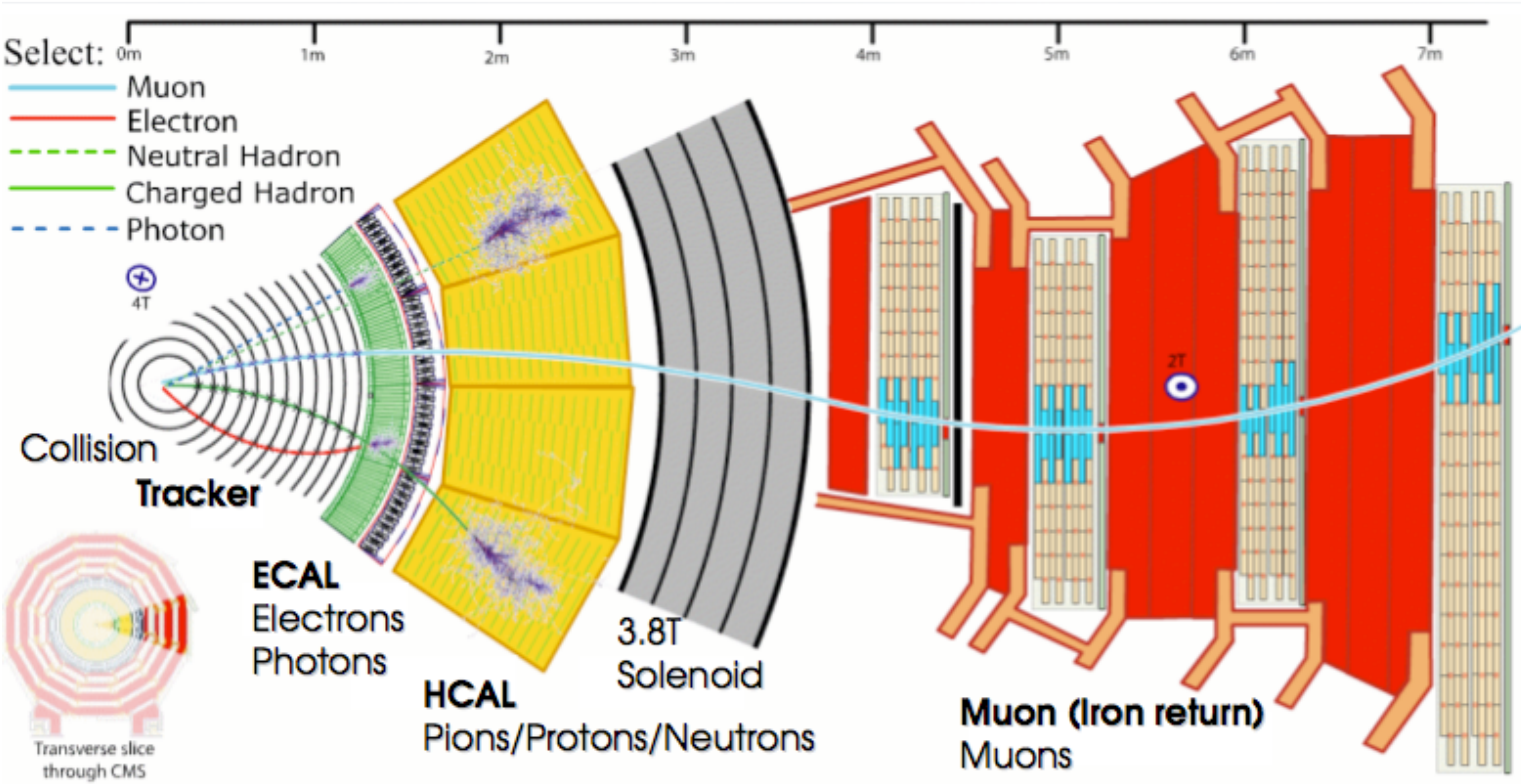


- Muon: most penetrating, hits in the muon chamber matched to a track
- Electron: deposit all energy in ECAL, matched to a track
- Photon: like an electron but without track (if no conversion)
- Hadronic tau: like a narrow jet
- Charged hadron: deposit all energy in ECAL+HCAL, matched to a track
- Neutral hadron: like a charged hadron but without a track


Muon chambers
Iron flux return
Hadron calorimeter
Electromagnetic calorimeter
Superconducting solenoid
B: 3.8 Tesla
Silicon tracker

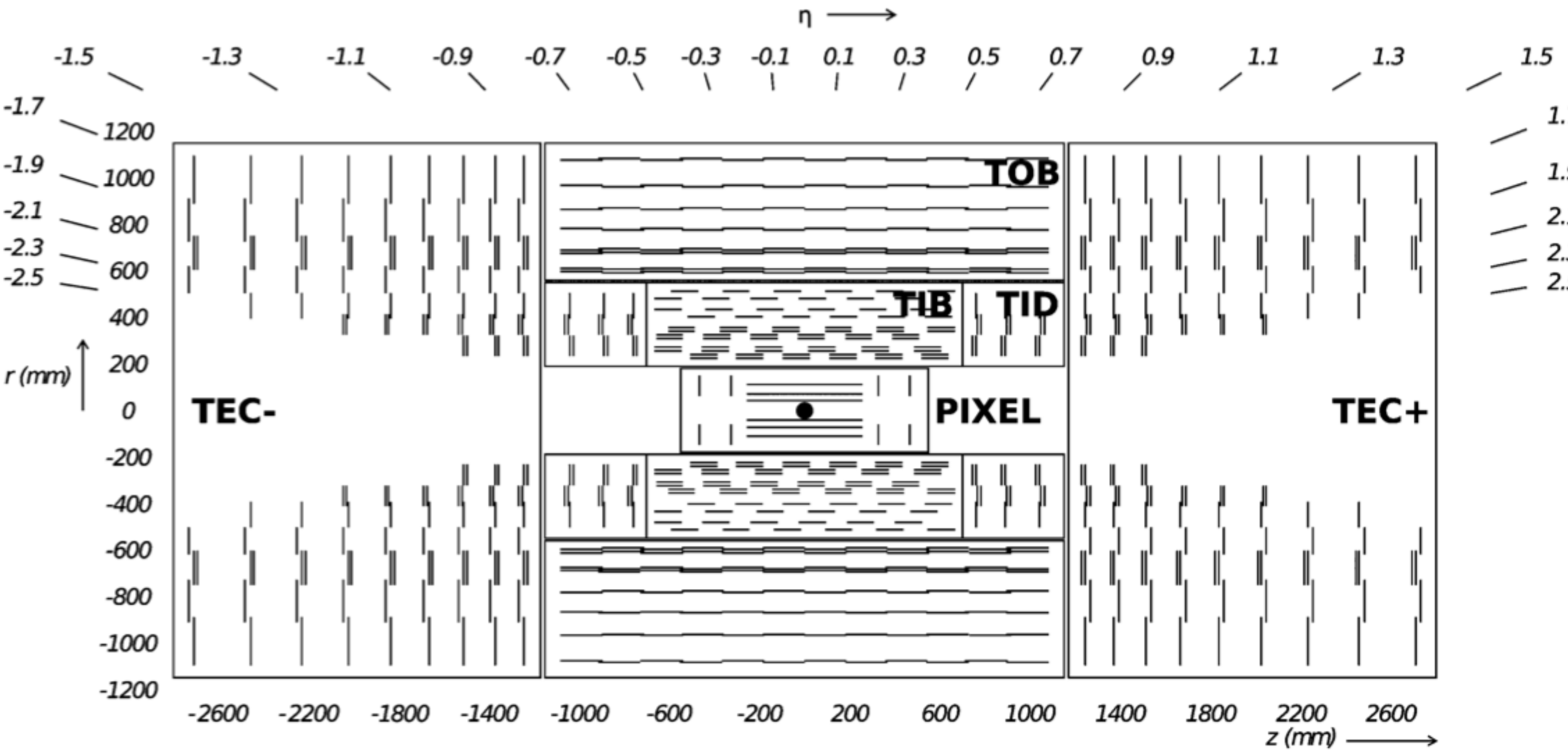

Jet1
Jet2
e
μ+
μ−
$\tilde{\chi}^0_1$
$\tilde{\chi}^0_1$

Trajectories Of Particles

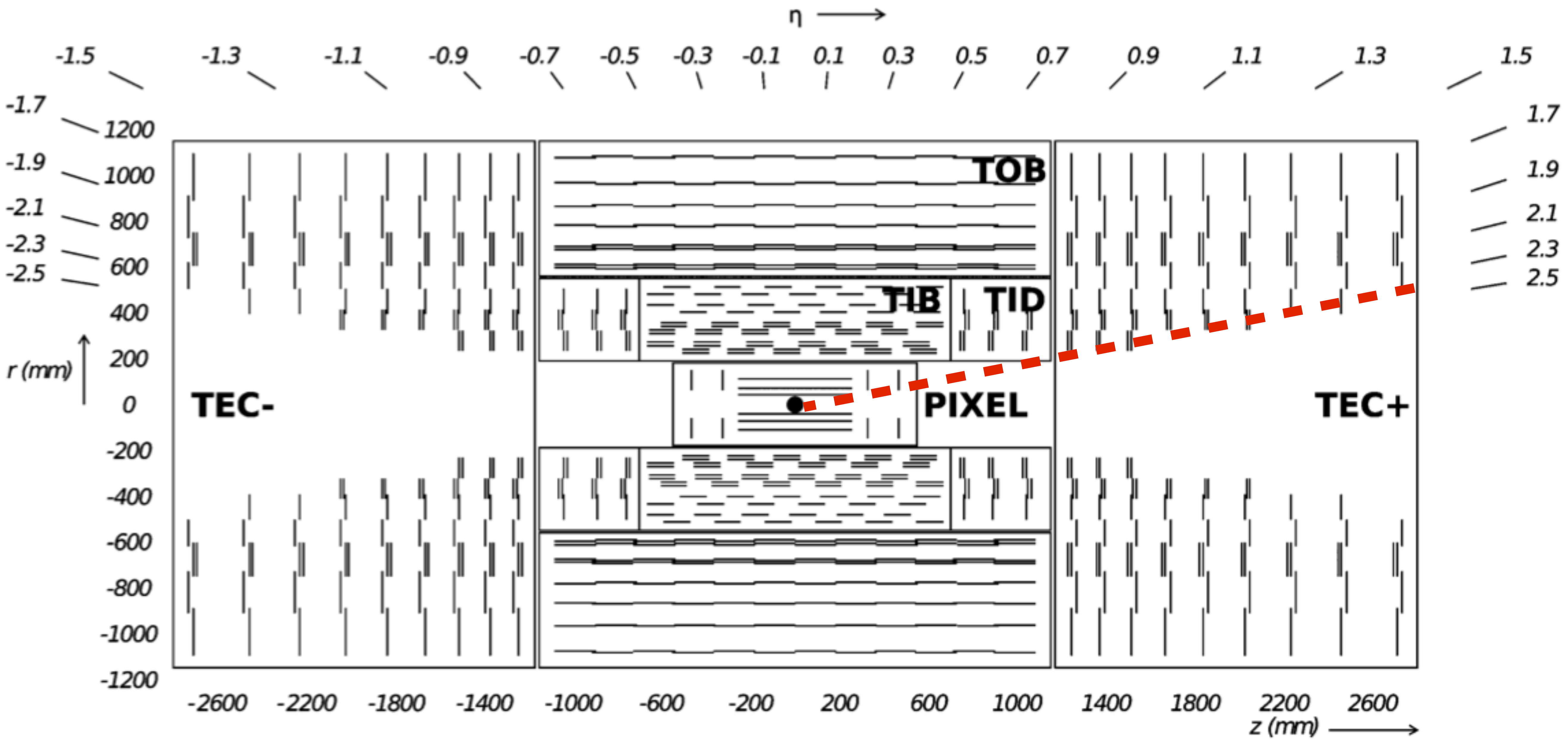


More in ppt file

Cms Tracker


η
-1.5
-1.3
-1.1
-0.9
-0.7
-0.5
-0.3
-0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
-1.7
-1.9
-2.1
-2.3
-2.5
1.7
1.9
2.1
2.3
2.5
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
r (mm)
TOB
TIB
TID
PIXEL
TEC-
TEC+
-2600
-2200
-1800
-1400
-1000
-600
-200
200
600
1000
1400
1800
2200
2600
z (mm)

Cms Tracker


η
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-2600
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-1800
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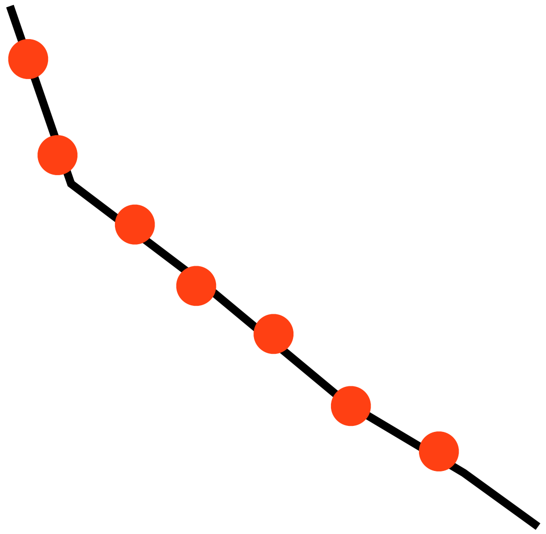
-200
200
600
1000
1400
1800
2200
2600
z (mm)

Tracks

- Trajectory of charged particles
- Only possible for charged particle due to their ionization loss



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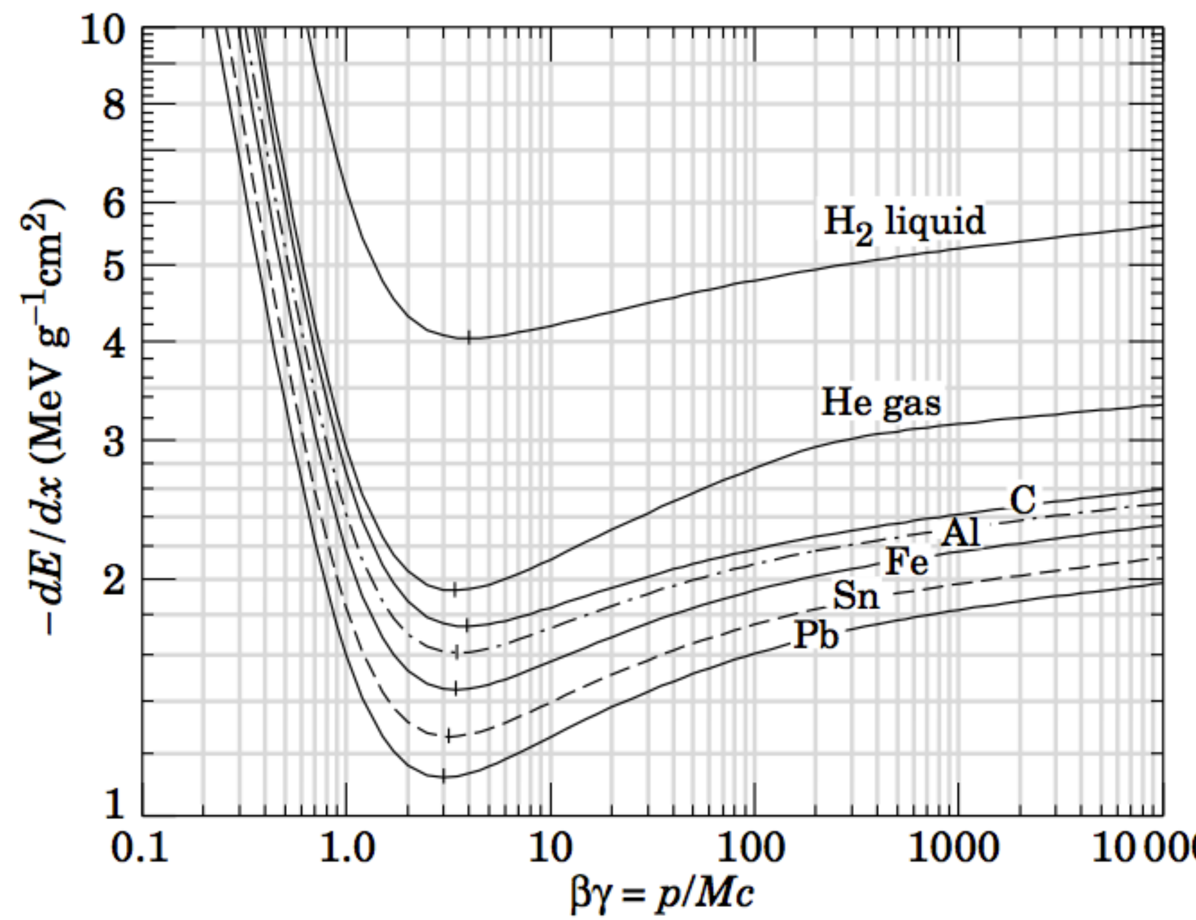
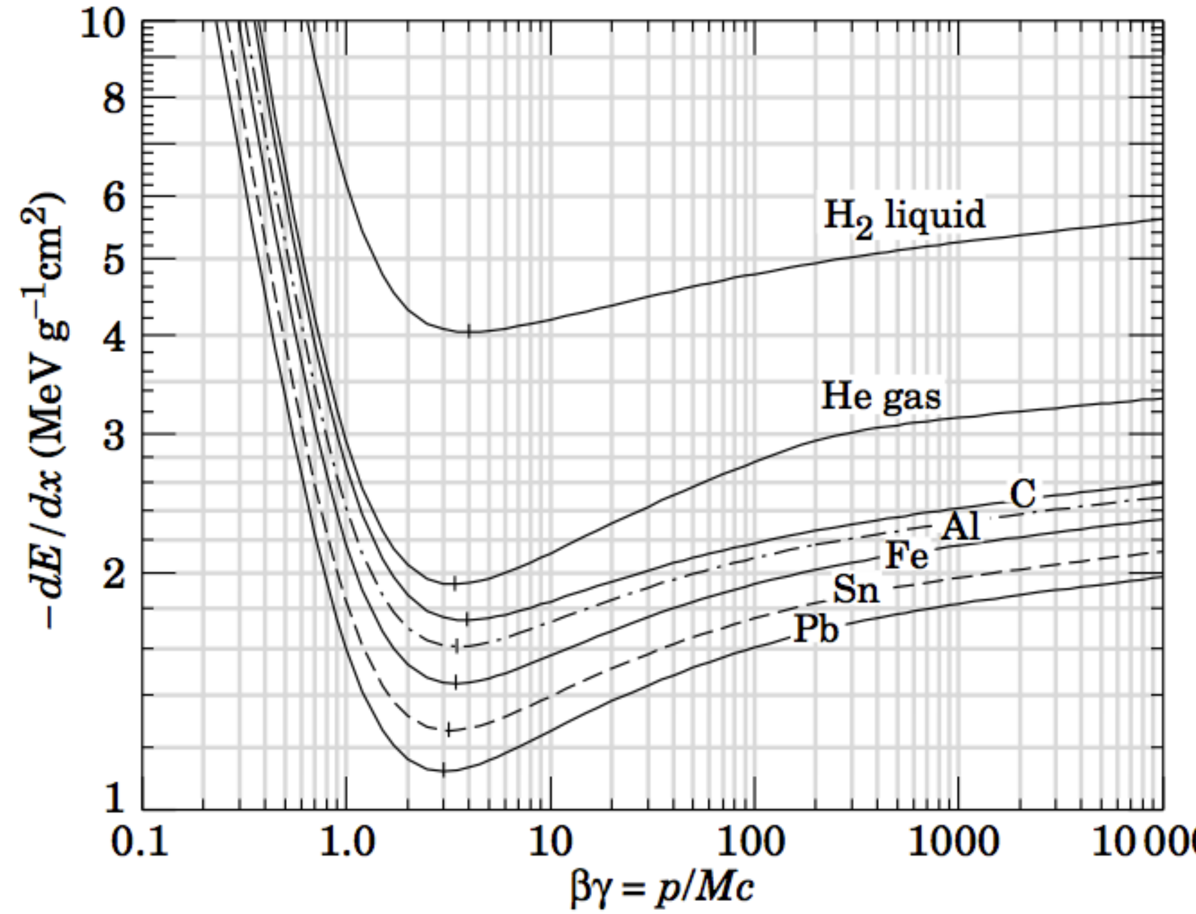


Gas: ~0.5 keV/cm
Liquid: ~300 keV/cm
Solid: ~4 MeV/cm

$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Tracks

- Trajectory of charged particles
- Only possible for charged particle due to their ionization loss



Gas:	~0.5 keV/cm
Liquid:	~300 keV/cm
Solid:	~4 MeV/cm

Relative energy loss for 10 GeV particle:
< 0.001% for a gas detector,
~ 5% for a solid detector

$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Typical Track Parameters

Five helix parameters:

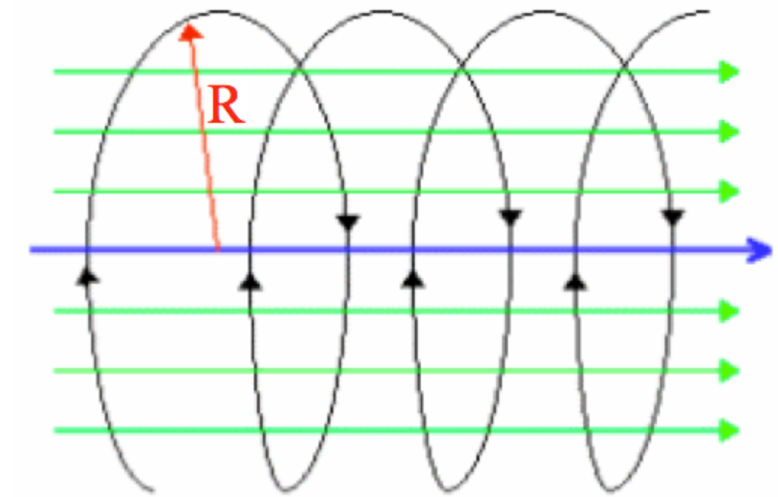
C: [half] curvature, signed

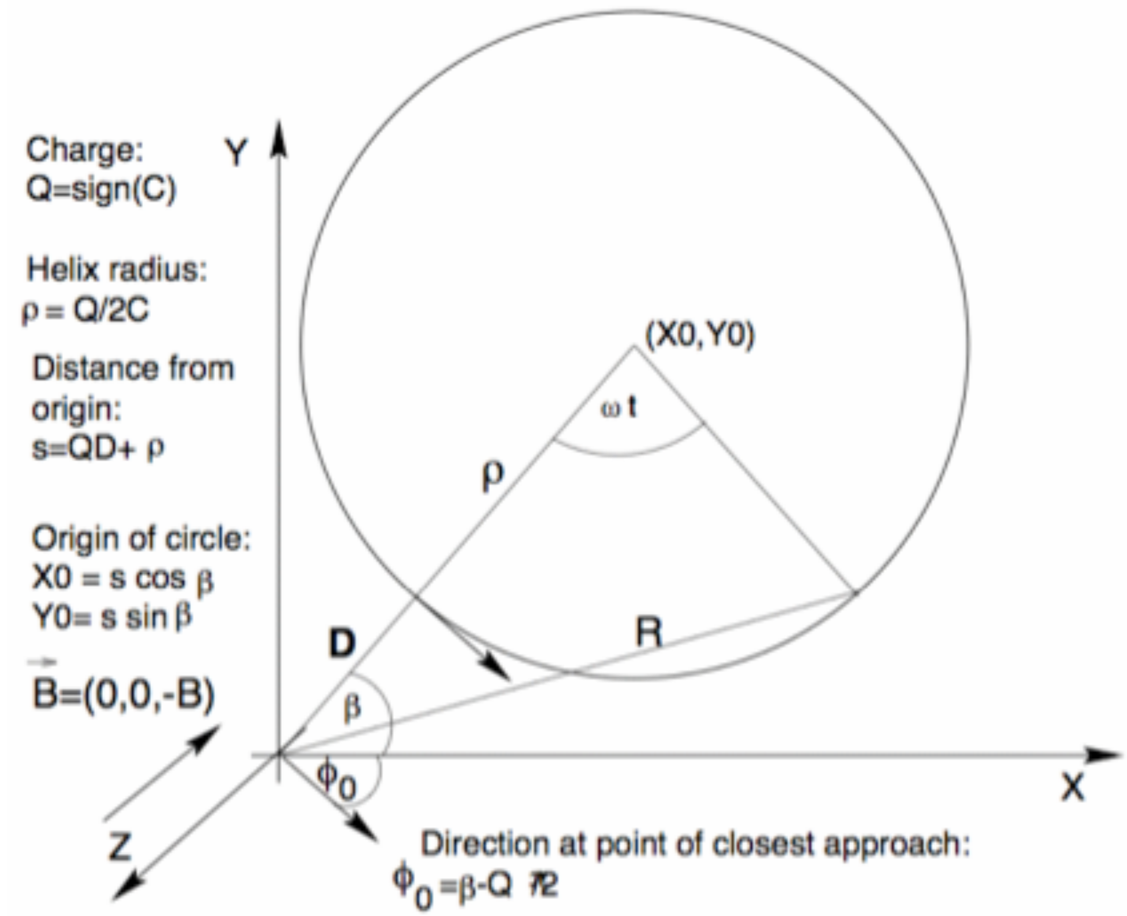
$\cot(\theta)$: polar angle

D: Distance of closest
approach to orign.
(Also called
impact parameter, d_0).

ϕ_0: Phi at closest approach

z_0: z at closest approach

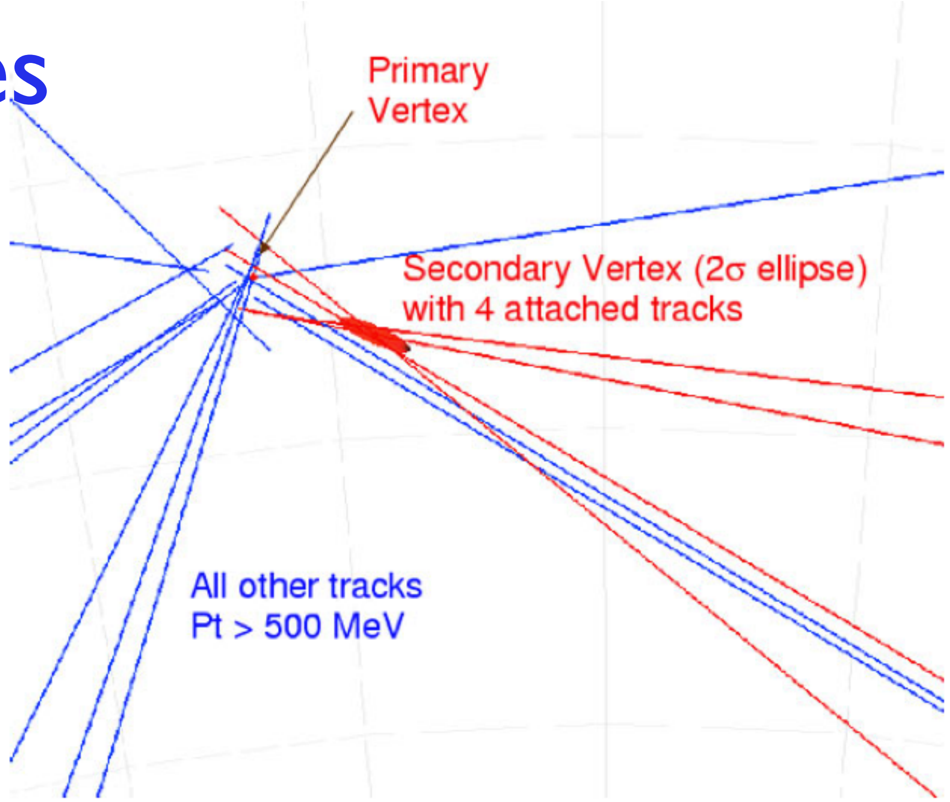




Hanz Wenzel, CDF Note 1790

What Could We Do With Tracks?

- Charge of a particle
    - Knowing they originate from the collision point, not from the sky
- Momentum of a particle (direction and magnitude)
- Reconstruct primary vertex
    - Momentum for neutral particles
    - pileup removal
- Reconstruct secondary vertex
    - b-tagging



How To Obtain p_T

Homework

$$p_T = qBR \xrightarrow{\substack{\text{Singly charged,}\\ \text{in units of GeV,}\\ \text{meter, and Tesla}}} p_T = 0.3\ BR$$

Example: The CMS magnetic field is 3.8 Tesla. The trajectory of a 10 GeV charged particle at CMS is a helix with a radius of 8.8 m.

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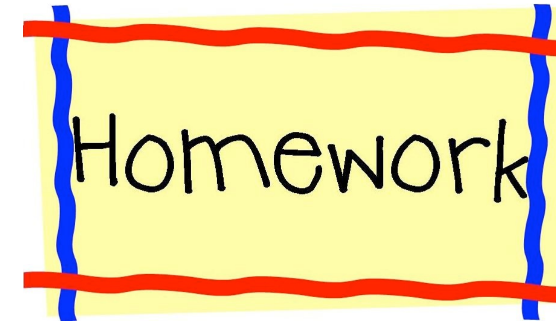
Example: The CMS magnetic field is 3.8 Tesla. The trajectory of a 10 GeV charged particle at CMS is a helix with a radius of 8.8 m.

A typical tracker has an outer radius of 1~1.5 m. ➡ Its trajectory is an arc (rather than a full circle)!

How To Obtain p_T



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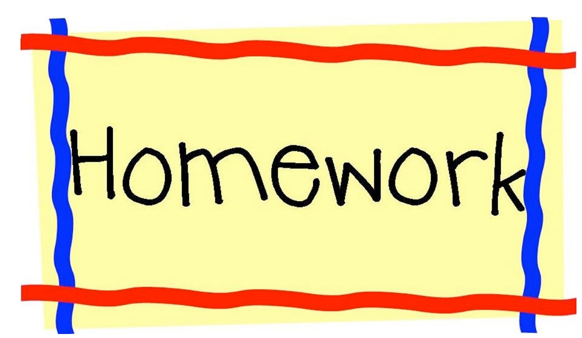
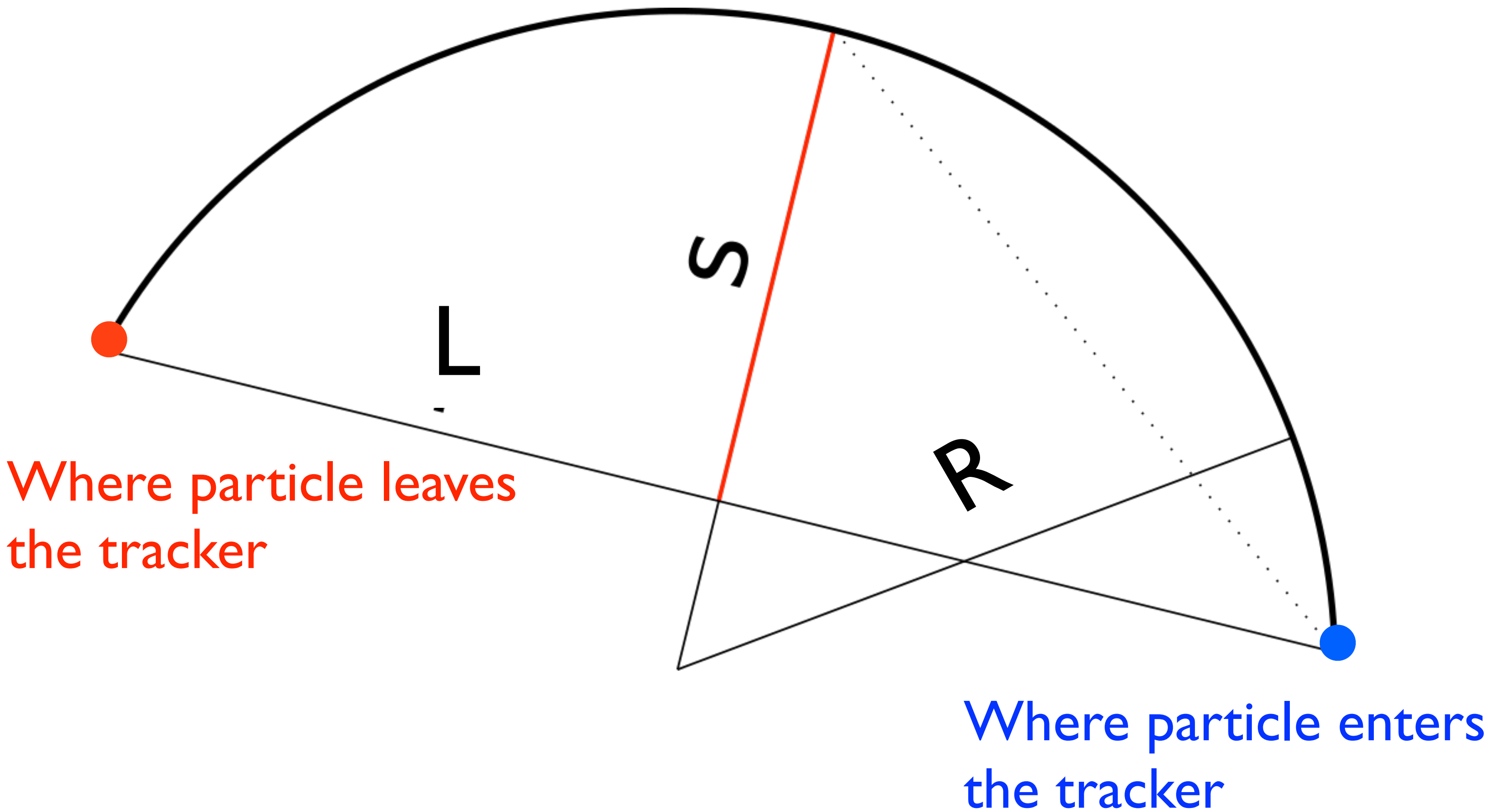
Example: The CMS magnetic field is 3.8 Tesla. The trajectory of a 10 GeV charged particle at CMS is a helix with a radius of 8.8 m.

(1) What happens to a 0.1 GeV or 1 GeV charged particle?
(2) How do we obtain p_z?



Sagitta And Momentum Resolution



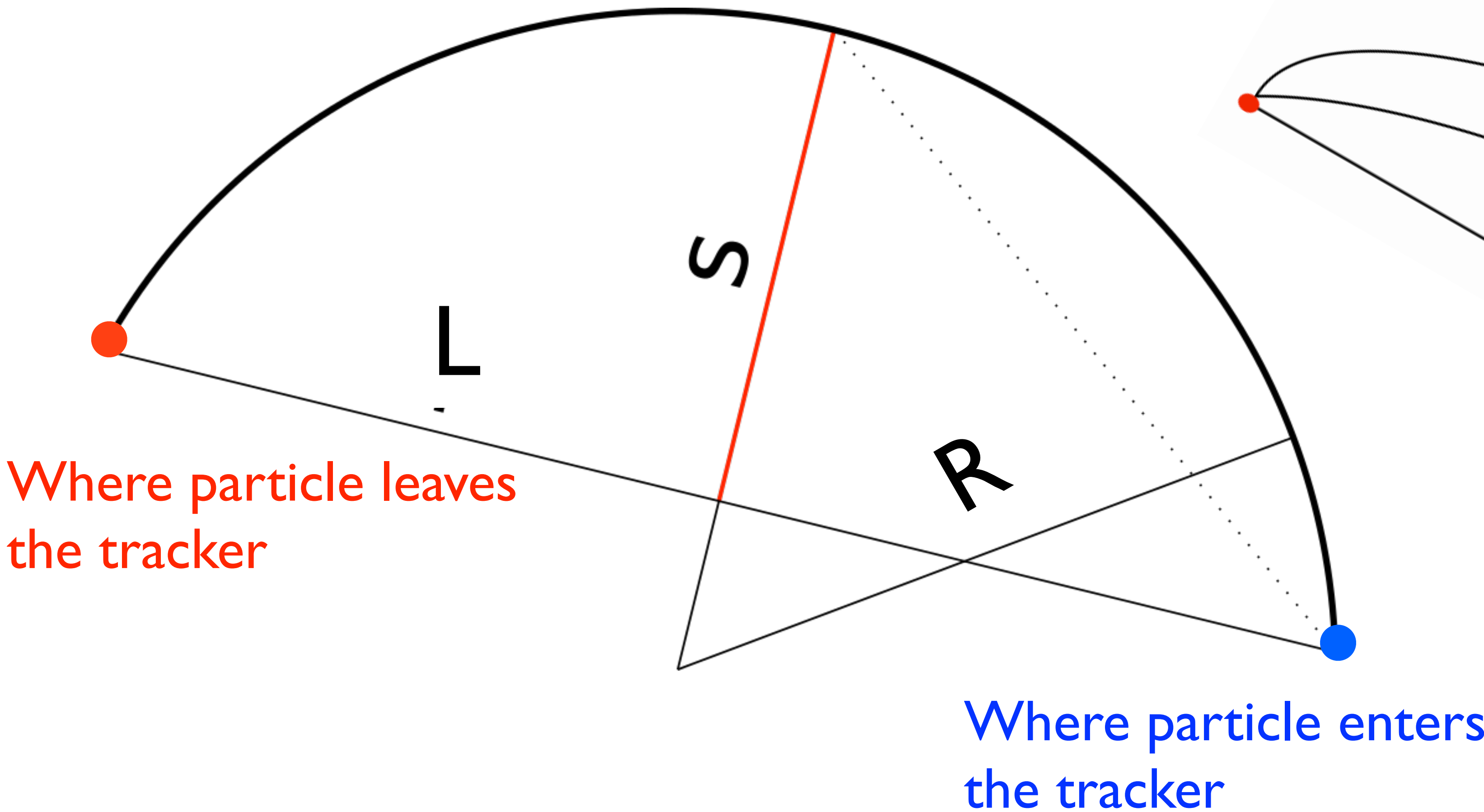
L (level arm): tracker outer-inner radius

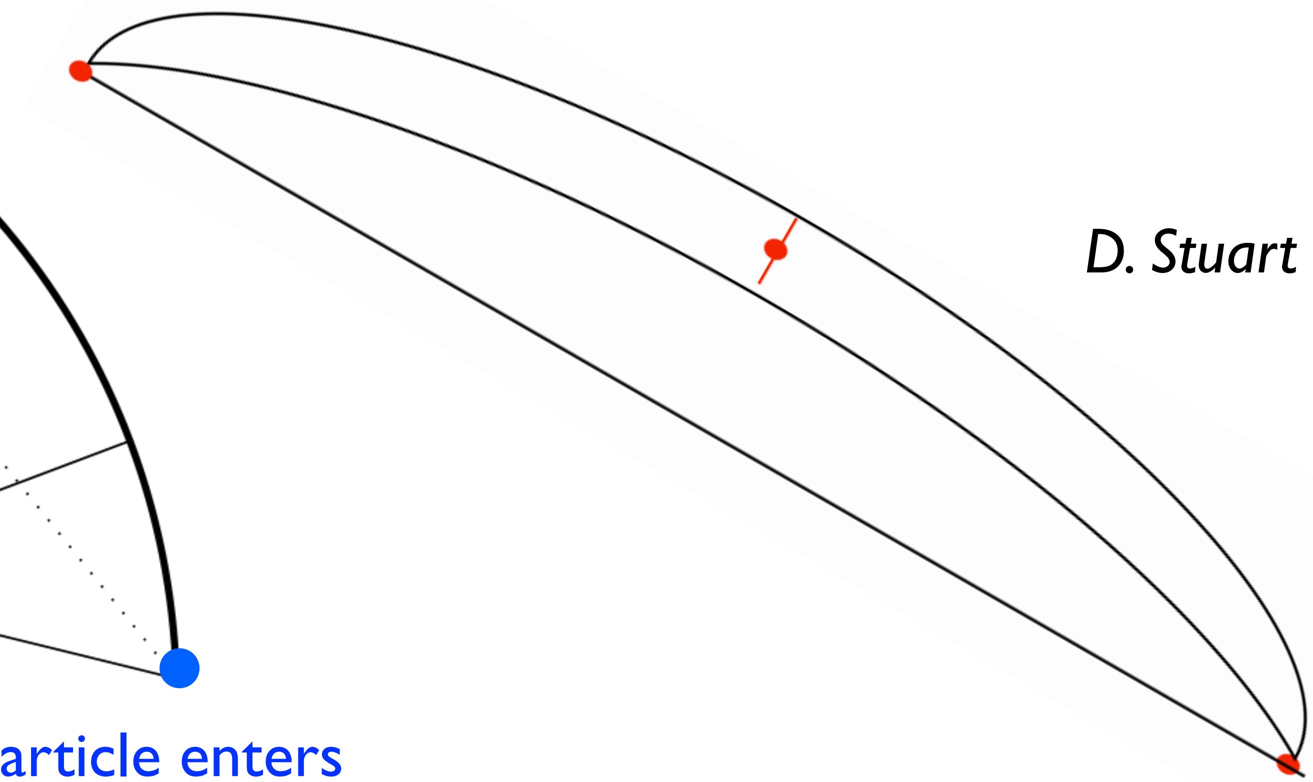
Usually s (sagitta) $\ll R$

$$\Rightarrow R \cong \frac{L^2}{8s},\quad p_T \cong \frac{qBL^2}{8s} = \frac{0.3\,BL^2}{8s}$$

Homework

Sagitta And Momentum Resolution





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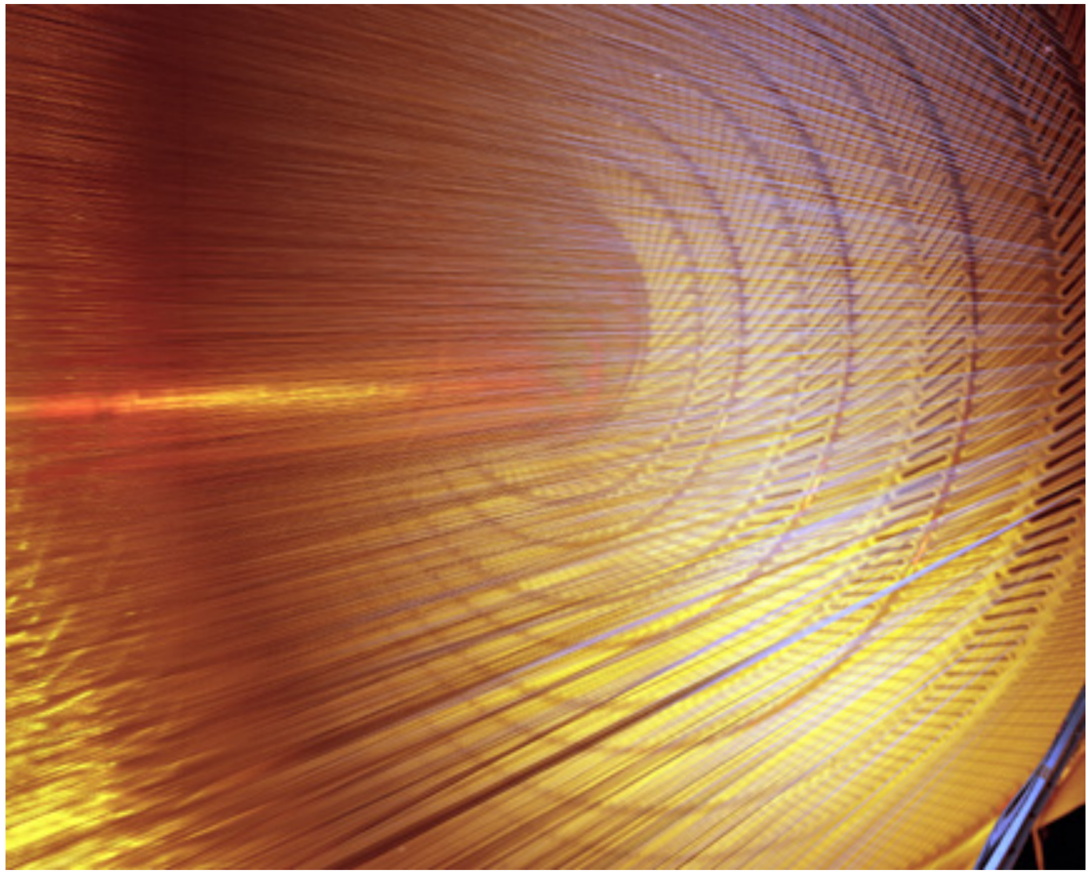
$$\boxed{\frac{\delta p_T}{p_T} \propto \frac{\delta x}{BL^2} \frac{1}{\sqrt{(N+4)}} \times p_T}$$

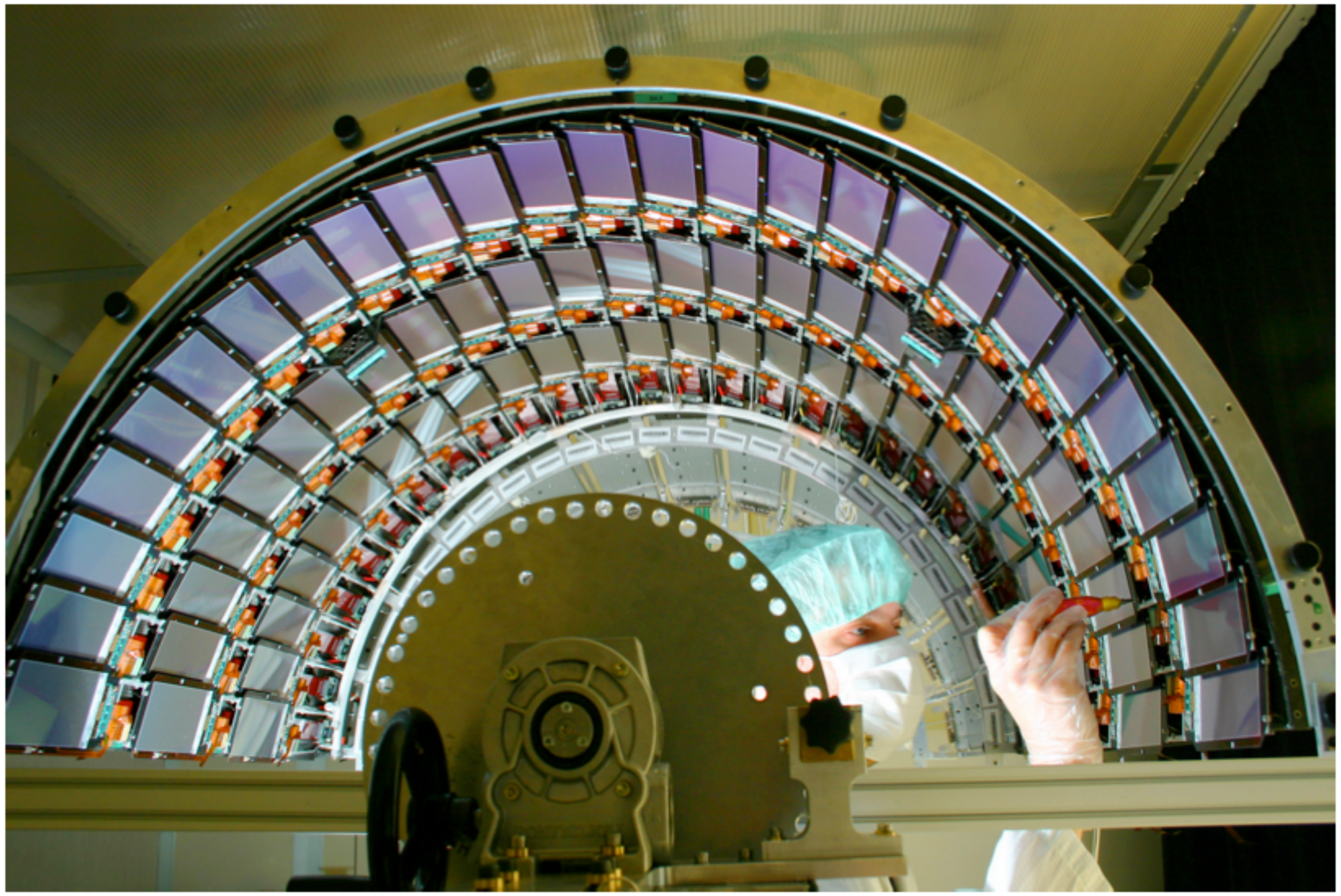
Atlas And Cms Trackers

	ATLAS	CMS
Tracker Radius	110 cm	115 cm
Tracker Length	7 m	5.4 m
Solenoid Field	2T	4T
Pixels		
# Barrel Layers	3	3
Barrel Radii	5.05, 9.85, 12.25	4.4, 7.5, 10.2
#Fwd Disks	3	2(3)
Disk Positions	49.5, 56.0, 65.0 cm	35.5, 48.5, 61.5 cm
Microstrips		
#Barrel Layers	4	10
# Disk Layers	9	9
Radial Span	25-50 cm	20-110 cm
Measurement points in central region	7 precision + 36 TRT	13 precision

Tracking Resolution

$$\frac{\delta p_T}{p_T} \propto \frac{\delta x}{BL^2}\frac{1}{\sqrt{(N+4)}} \times p_T$$





Hit position resolution

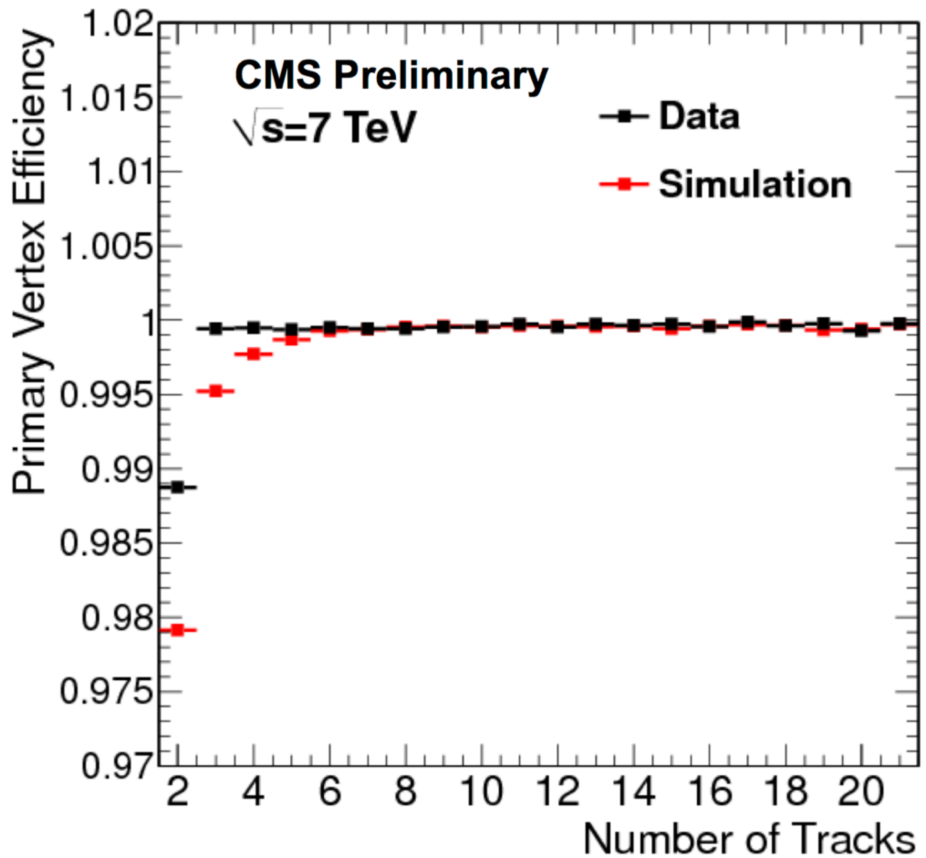
Gas: $\delta x \sim 150\ \mu$m

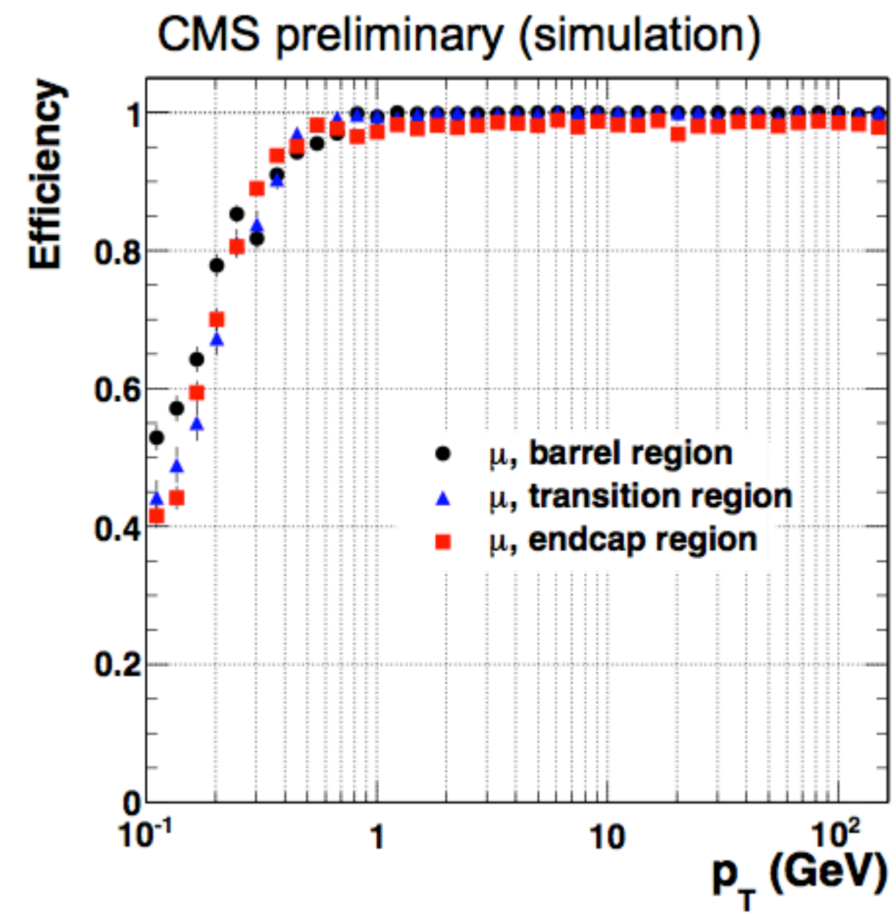
Silicon: $\delta x \sim 10-20\ \mu$m

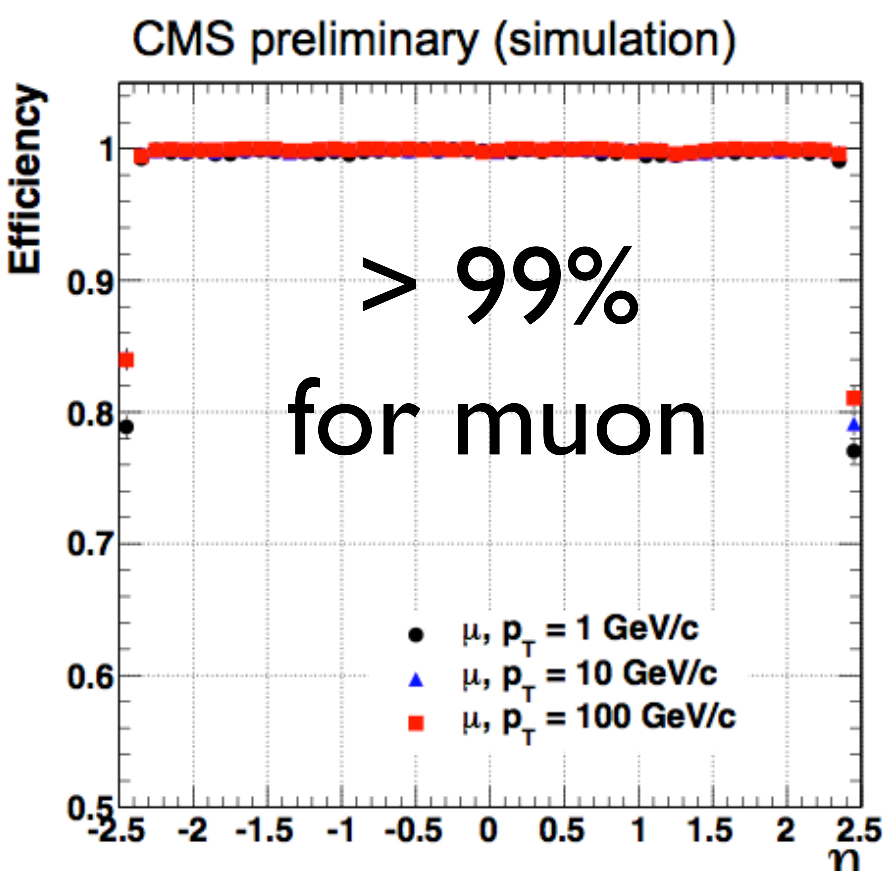
Typical Tracking Resolution

- ATLAS has similar performance
- p_T resolution for 1 GeV (TeV) particle is 0.7% (5%)
- Impact parameter resolution is 10 (15) µm in xy (z) direction for high momentum tracks

Typical Tracking Efficiency

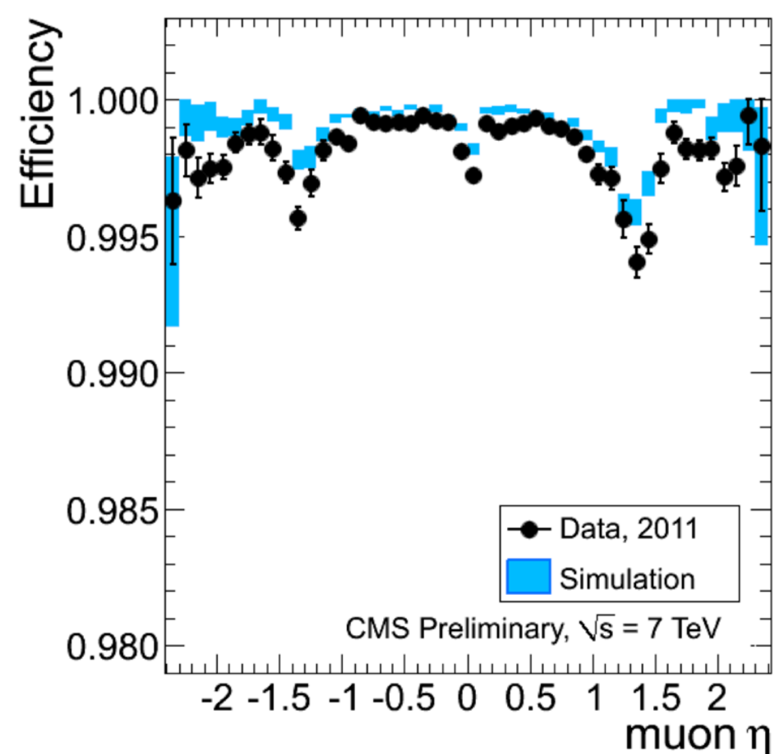


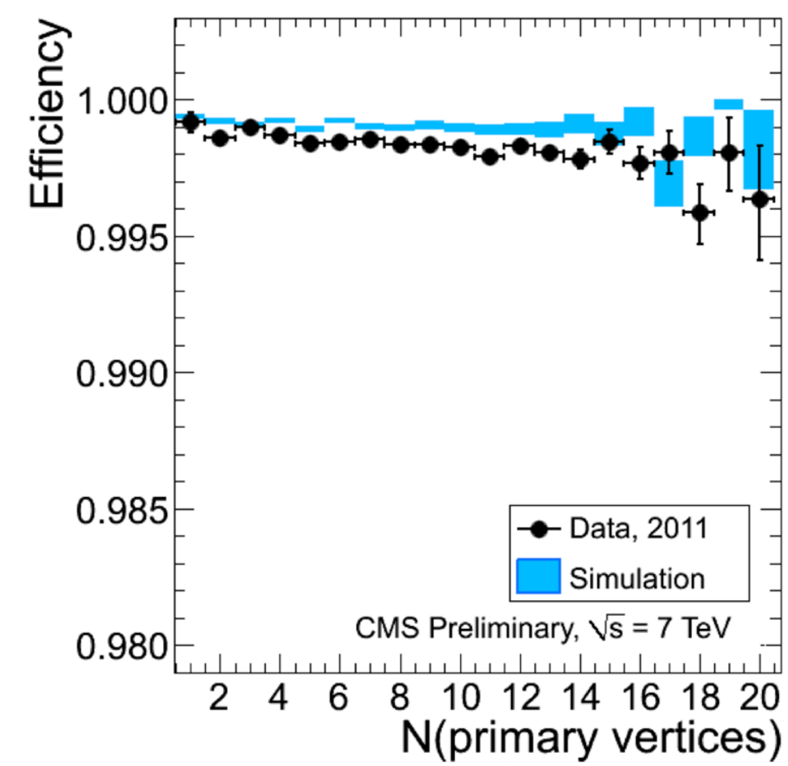




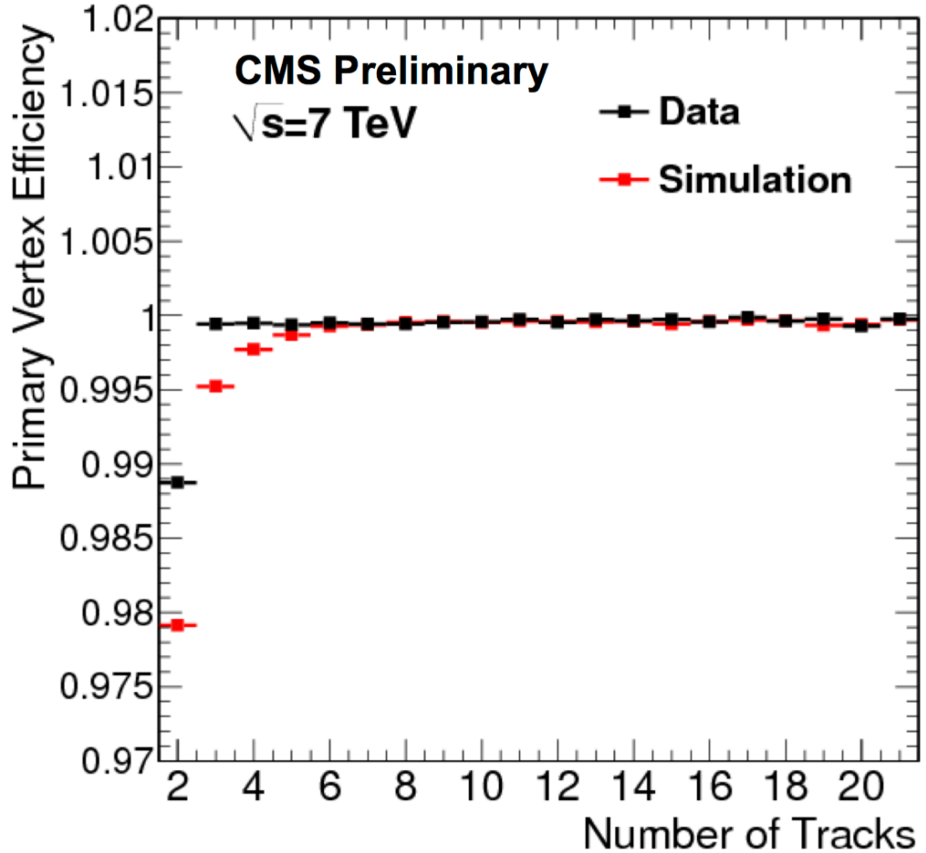
> 99%

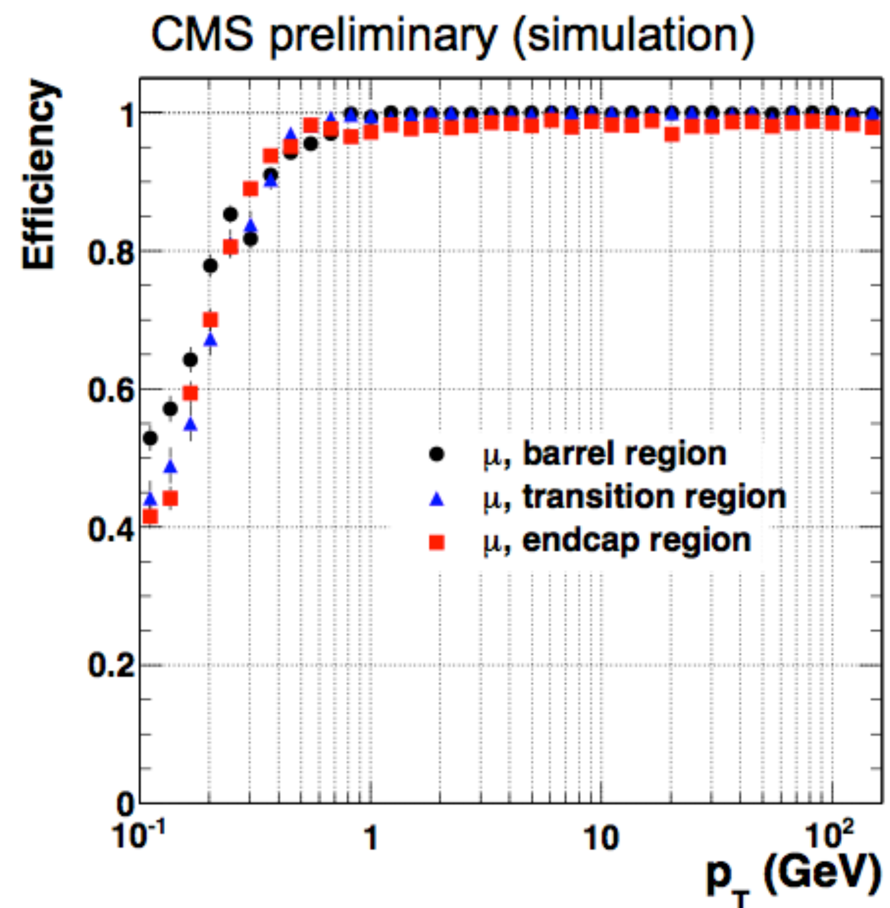
for muon

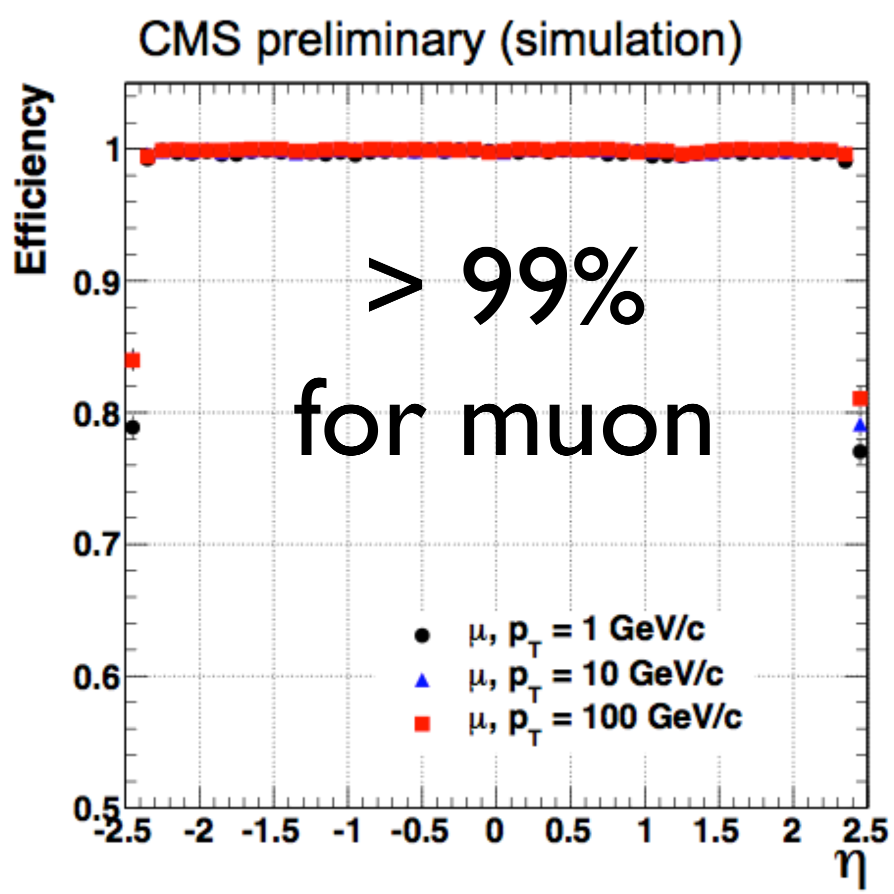


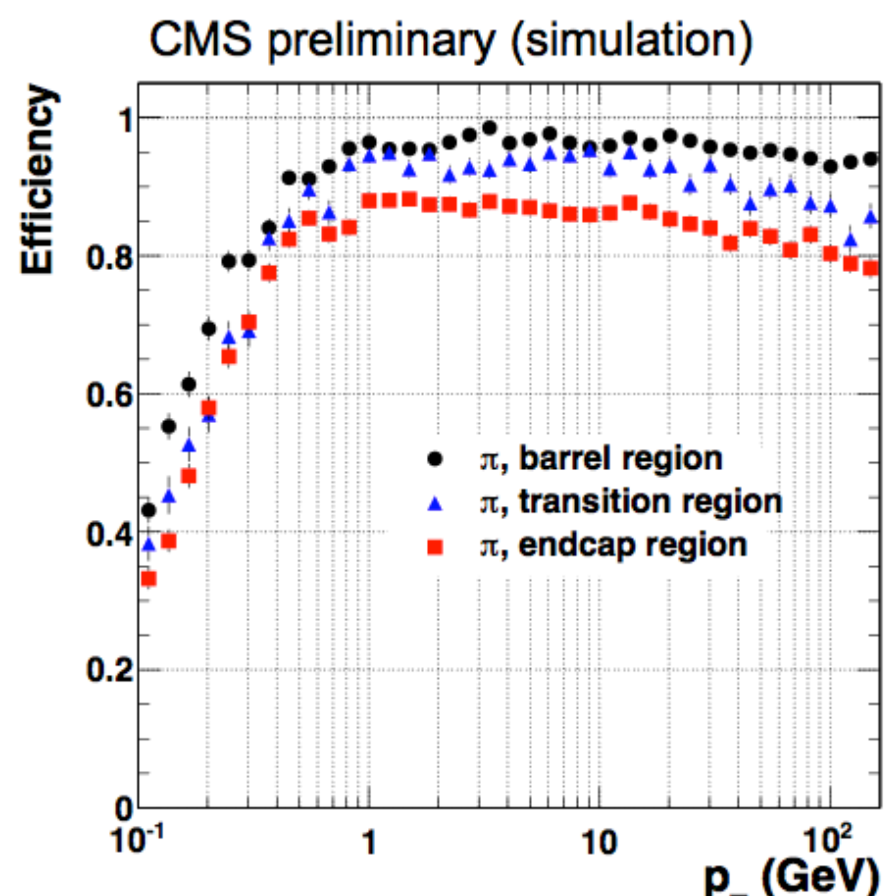


Typical Tracking Efficiency



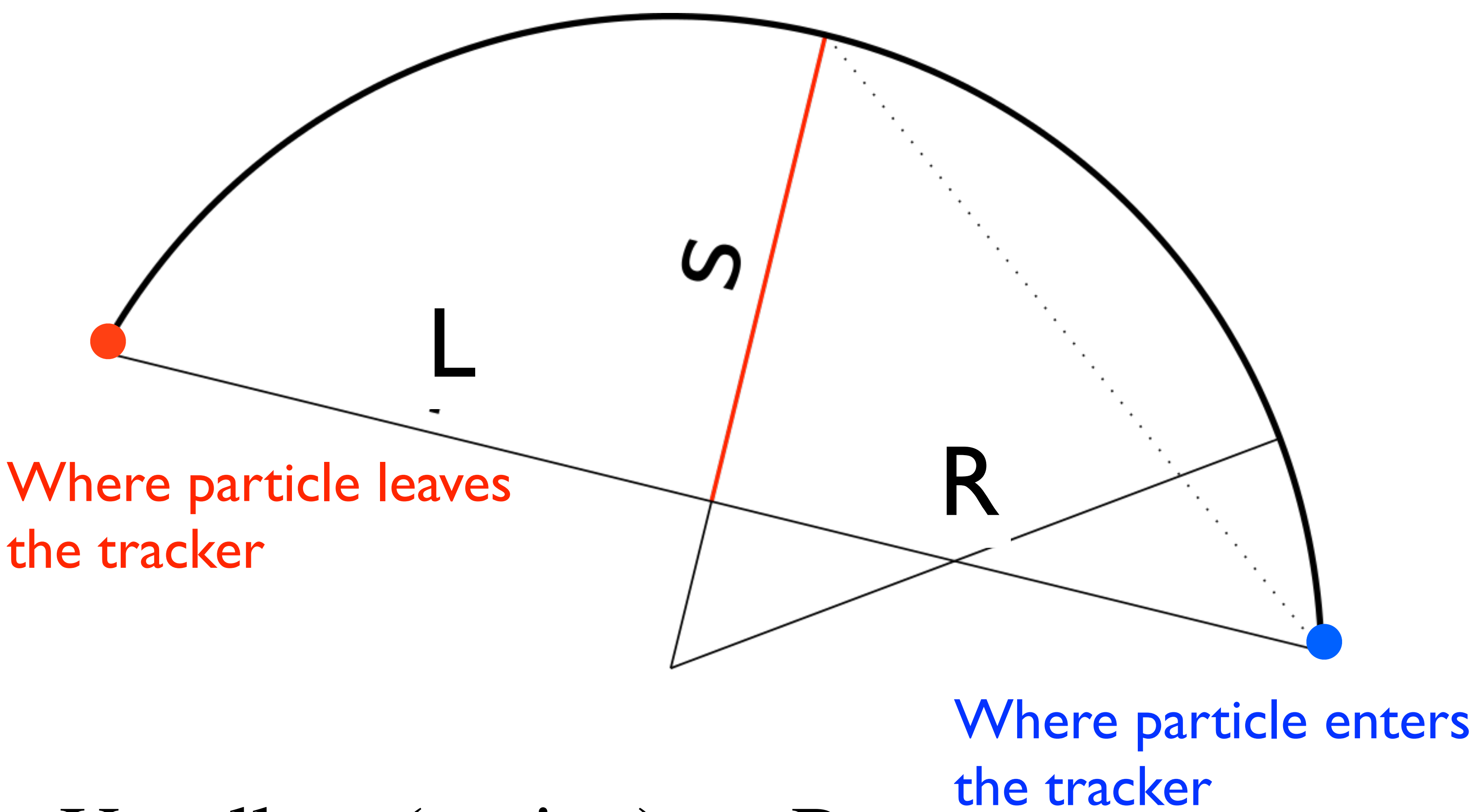






Sagitta And Bending Distance

D. Stuart



Usually s (sagitta) $\ll$ R

$$\Rightarrow R \cong \frac{L^2}{8s} \text{ or } s \cong \frac{L^2}{8R} = \frac{0.3\,BL^2}{8\,p_T}$$

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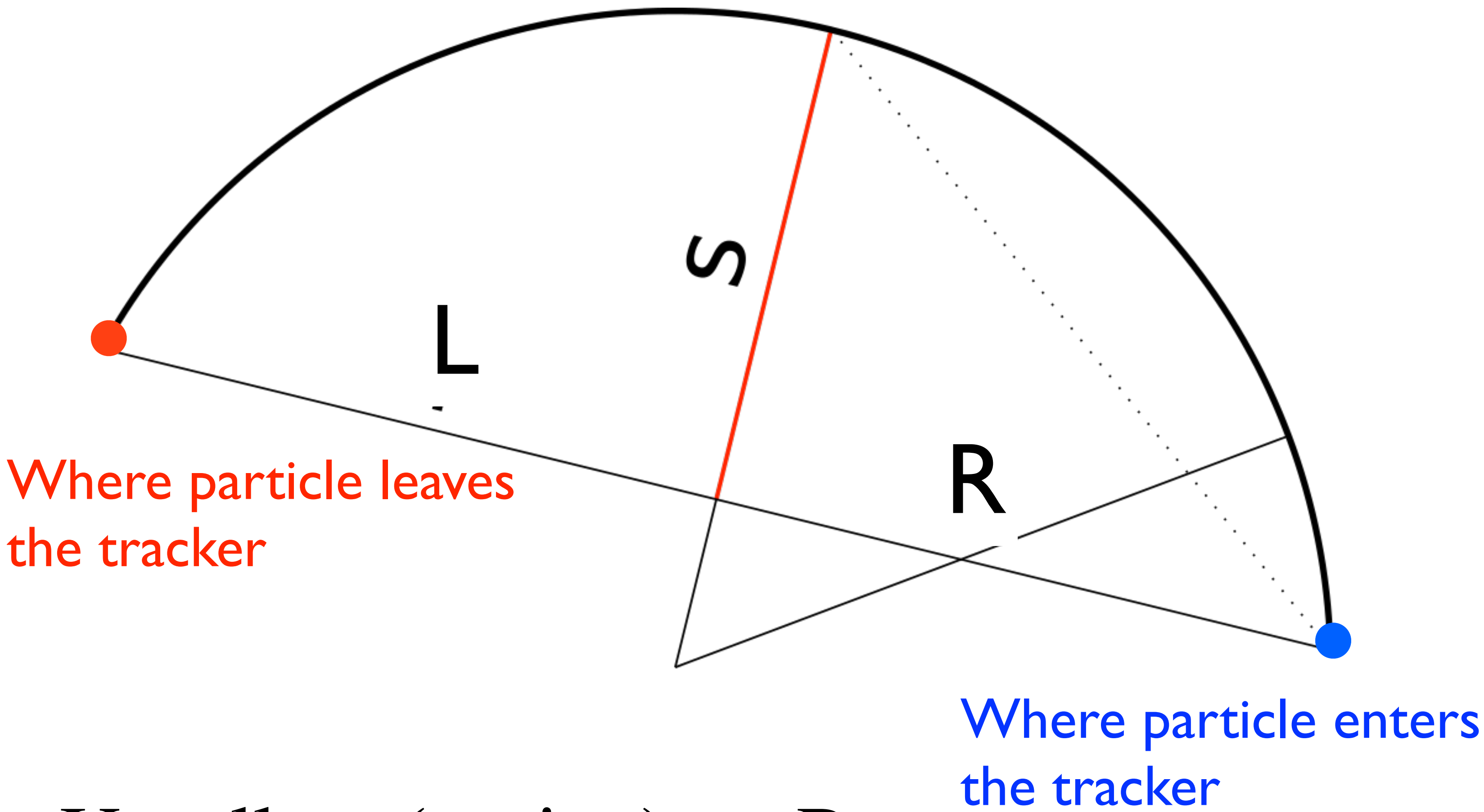

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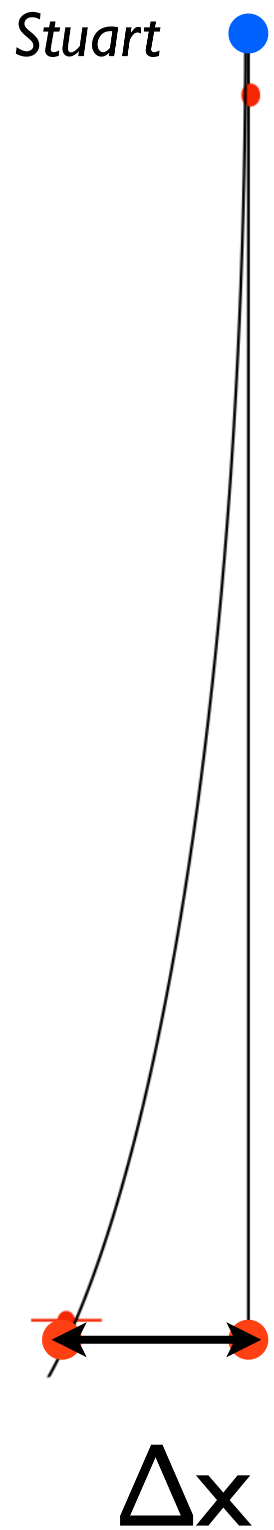

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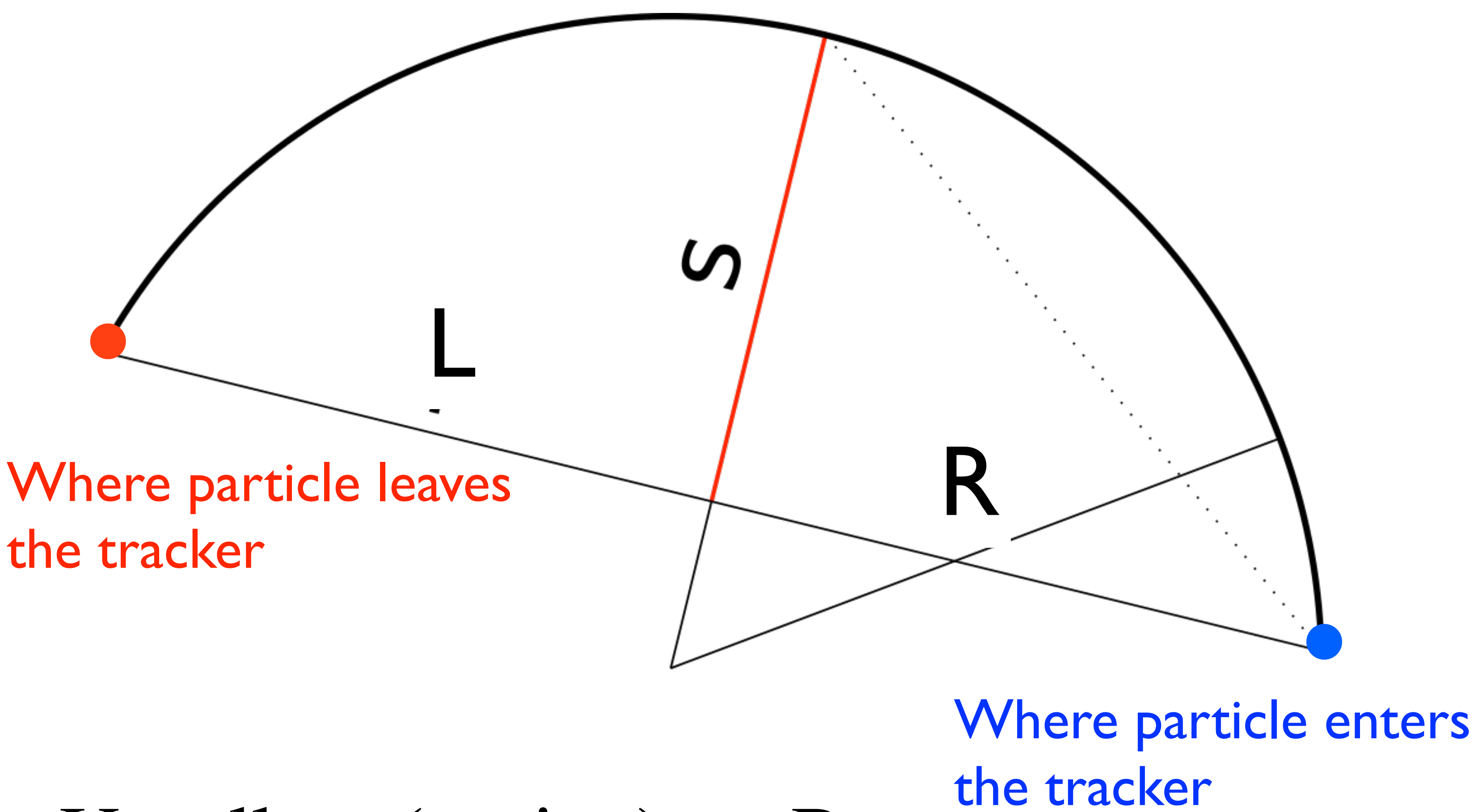

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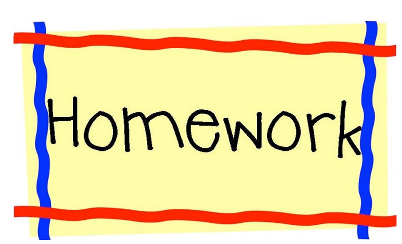
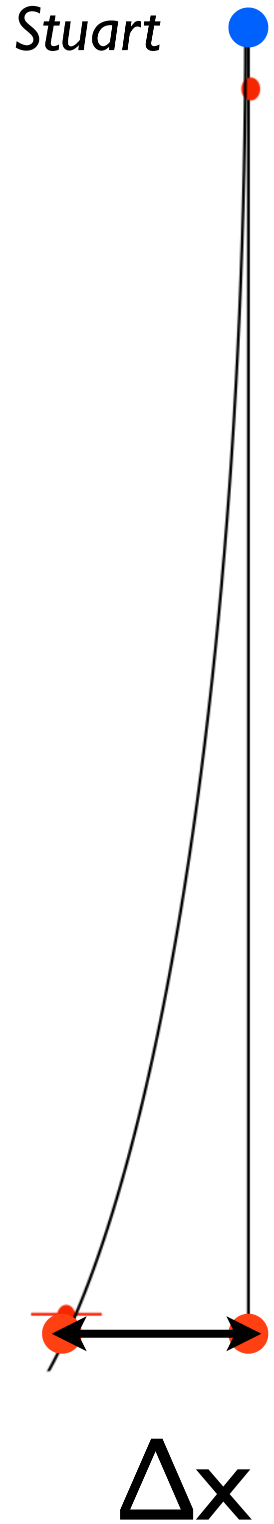


$$\boxed{\Delta x = 4s \cong \frac{0.3\, BL^2}{2\, p_T}}$$

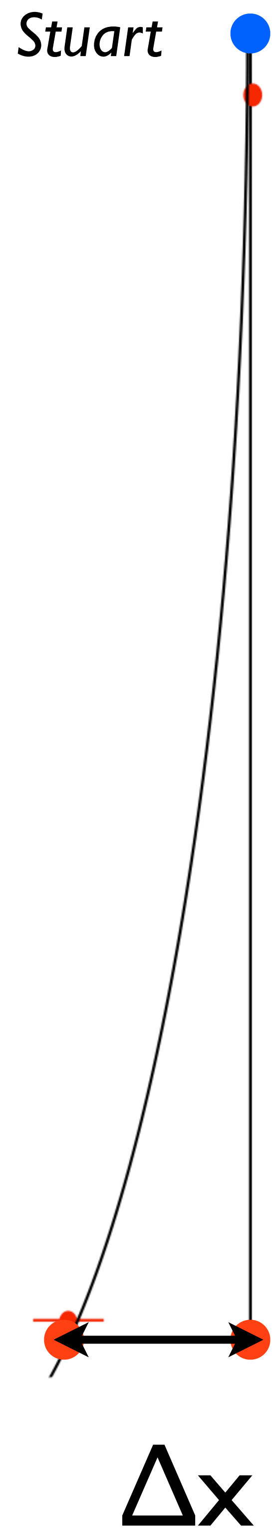


Sagitta And Bending Distance

D. Stuart

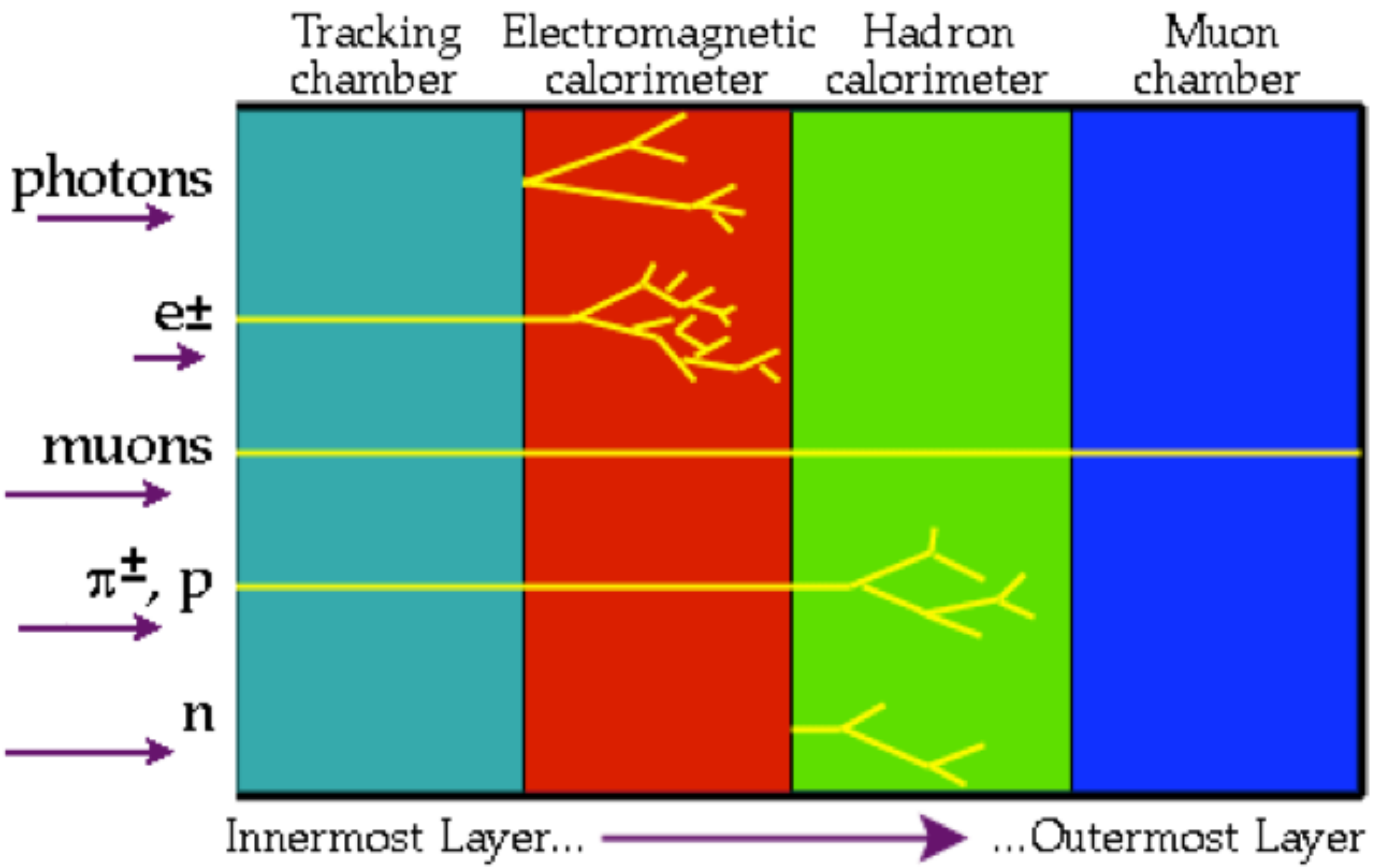
Important for estimating separation between electrons and photons due to bremsstrahlung and conversion, also separation between neutral and charged particles in the particle flow algorithm.

$$\boxed{\Delta x = 4\,s \cong \frac{0.3\,BL^2}{2\,p_T}}$$



The Cleanest Object: Muon

- High reconstruction (~99%) and identification efficiency (~95%)



- Better than 10% pT resolution for muon pT

The Cleanest Object: Muon

- High reconstruction (~99%) and identification efficiency (~95%)
- Backgrounds:
  - Decay in flight
  - Punch through
- Identification variable
  - Track-muonHit matching
  - Isolation
  - Track quality, impact parameter
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π^+ DECAY MODES

π^- modes are charge conjugates of the modes below.

For decay limits to particles which are not established, see the section on Searches for Axions and Other Very Light Bosons.

	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\mu^+\nu_\mu$	[a]	(99.98770 ± 0.00004) %	

B^0 DECAY MODES

$\overline{B}^0$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing. Modes which do not identify the charge state of the B are listed in the $B^\pm/B^0$ ADMIXTURE section.

The branching fractions listed below assume 50% $B^0\overline{B}^0$ and 50% B^+B^- production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_s, D^*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

For inclusive branching fractions, *e.g.*, $B\rightarrow D^\pm$anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\ell^+\nu_\ell$anything	[a]	(10.33 ± 0.28) %	

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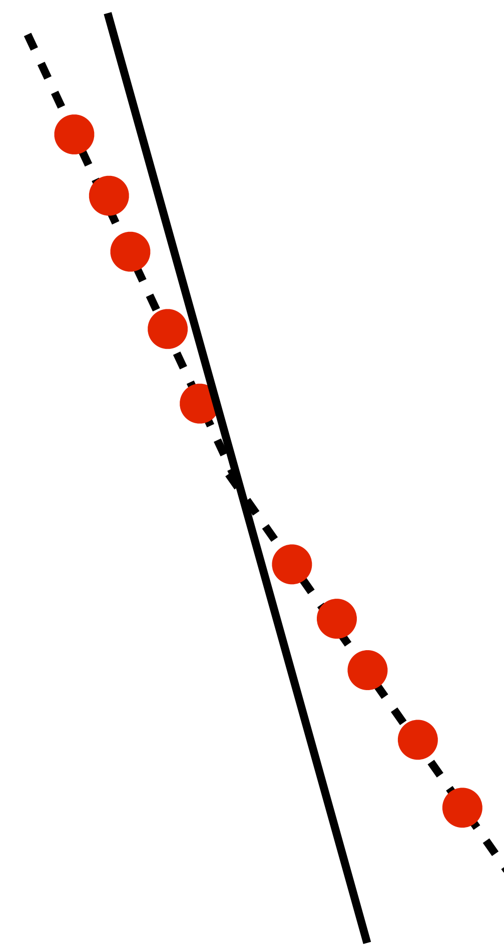

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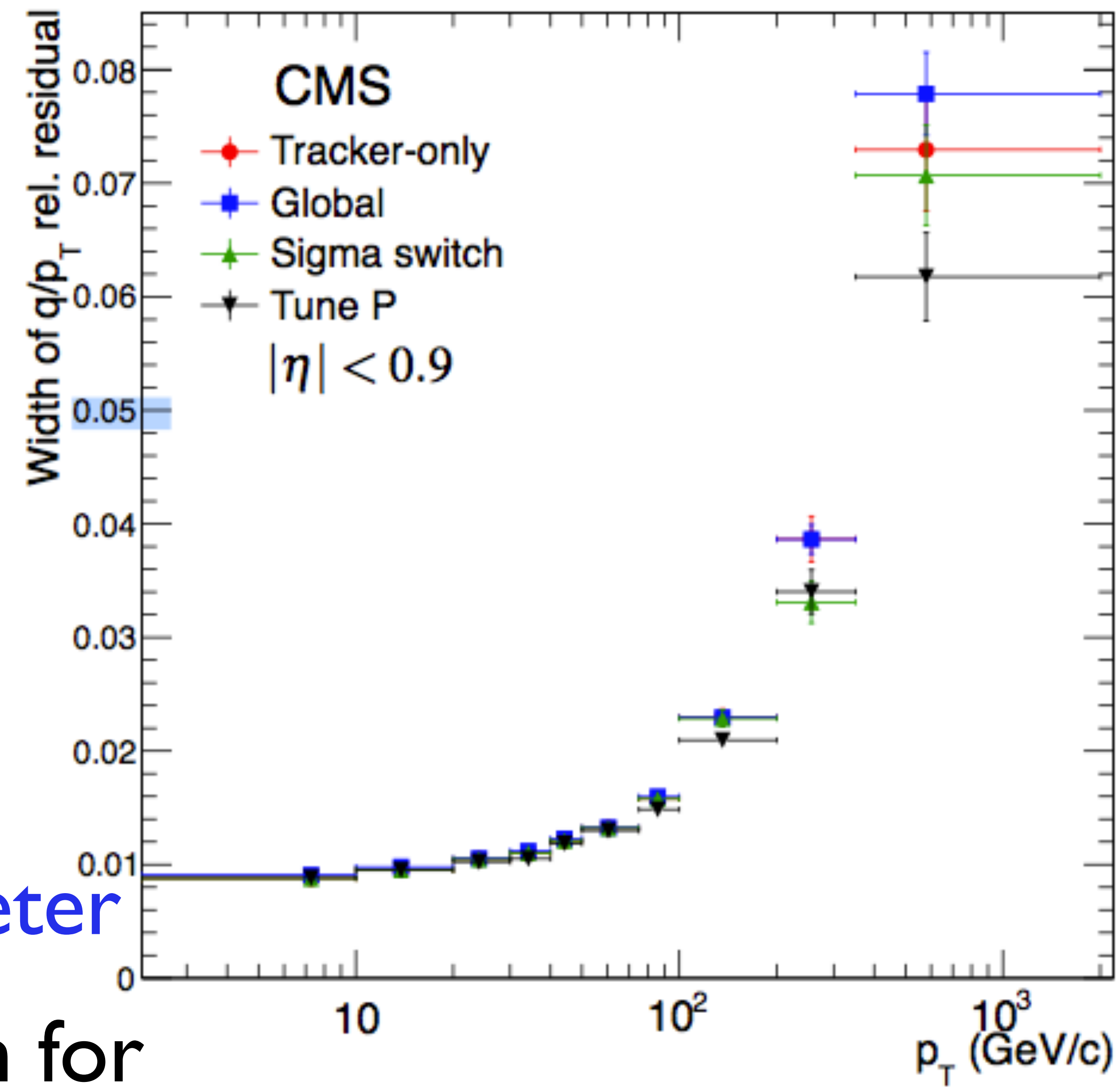

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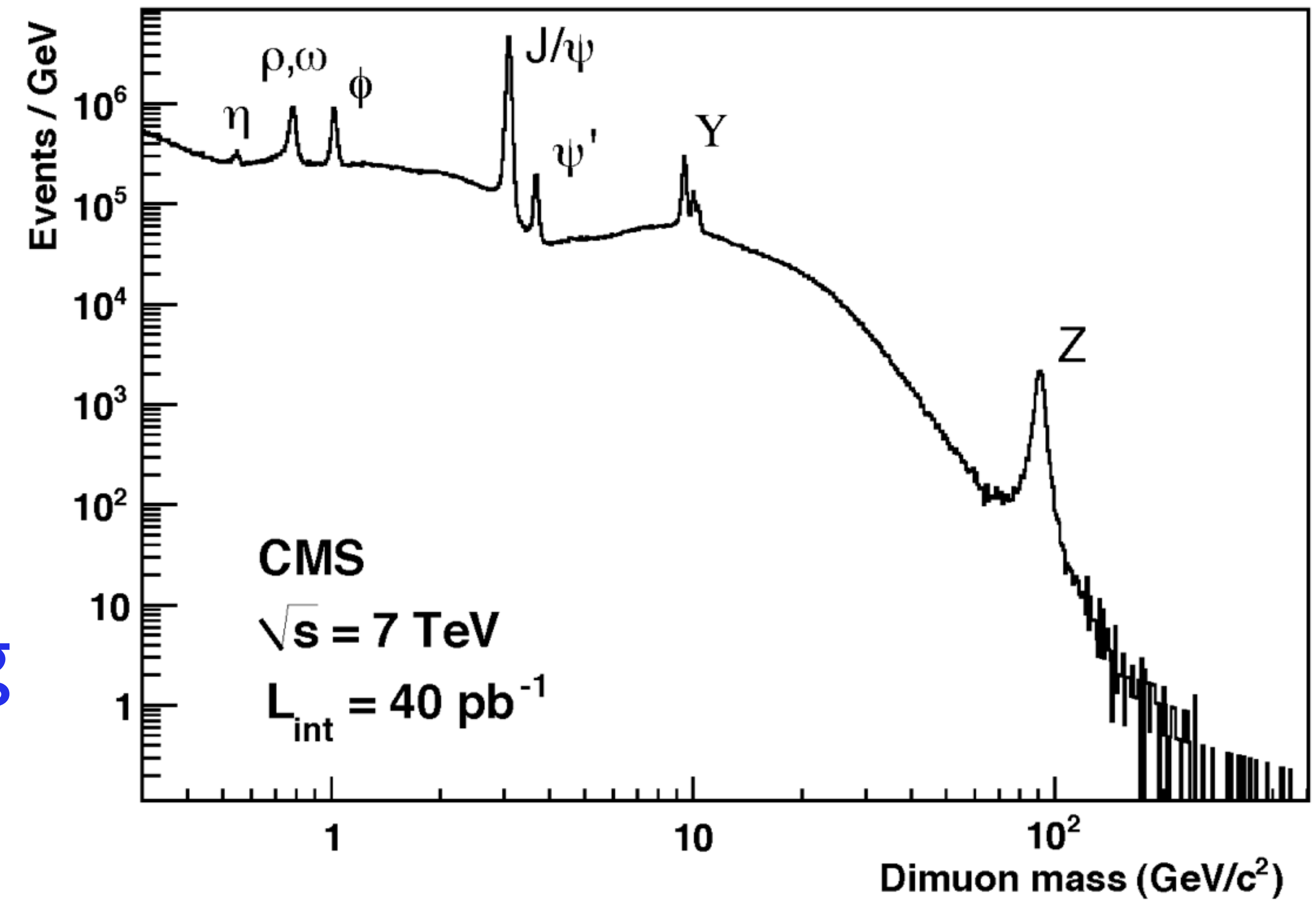

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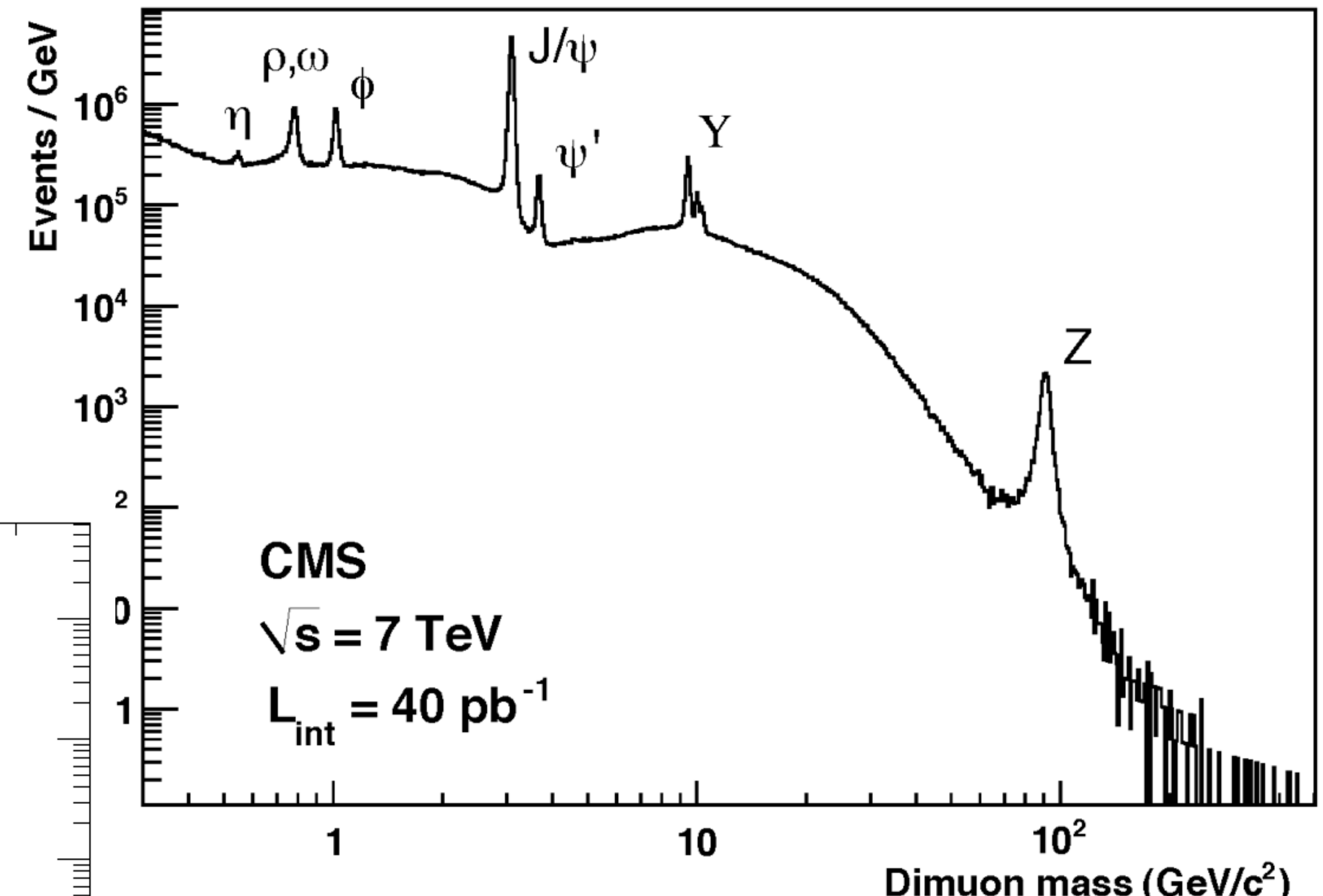

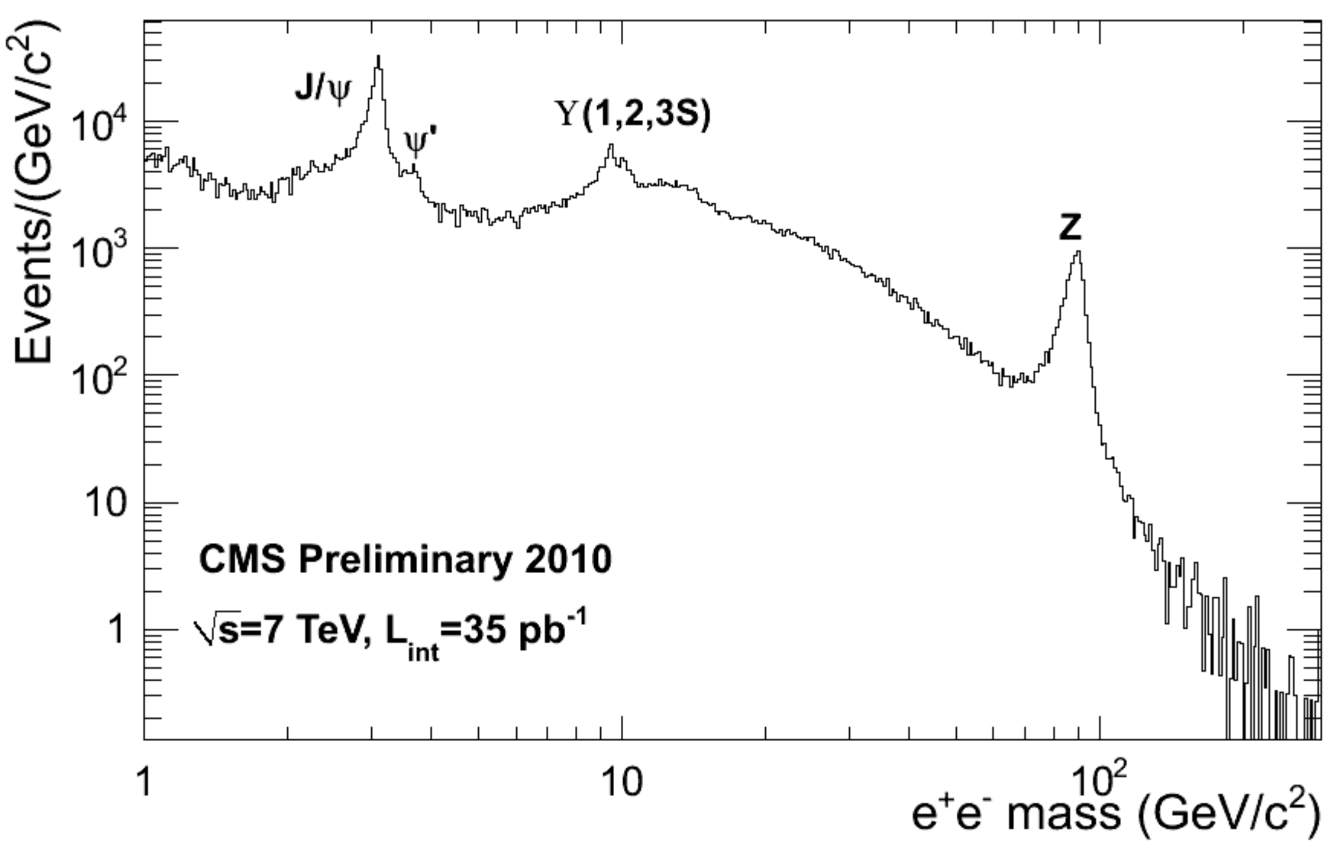

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n for

The Cleanest Object: Muon

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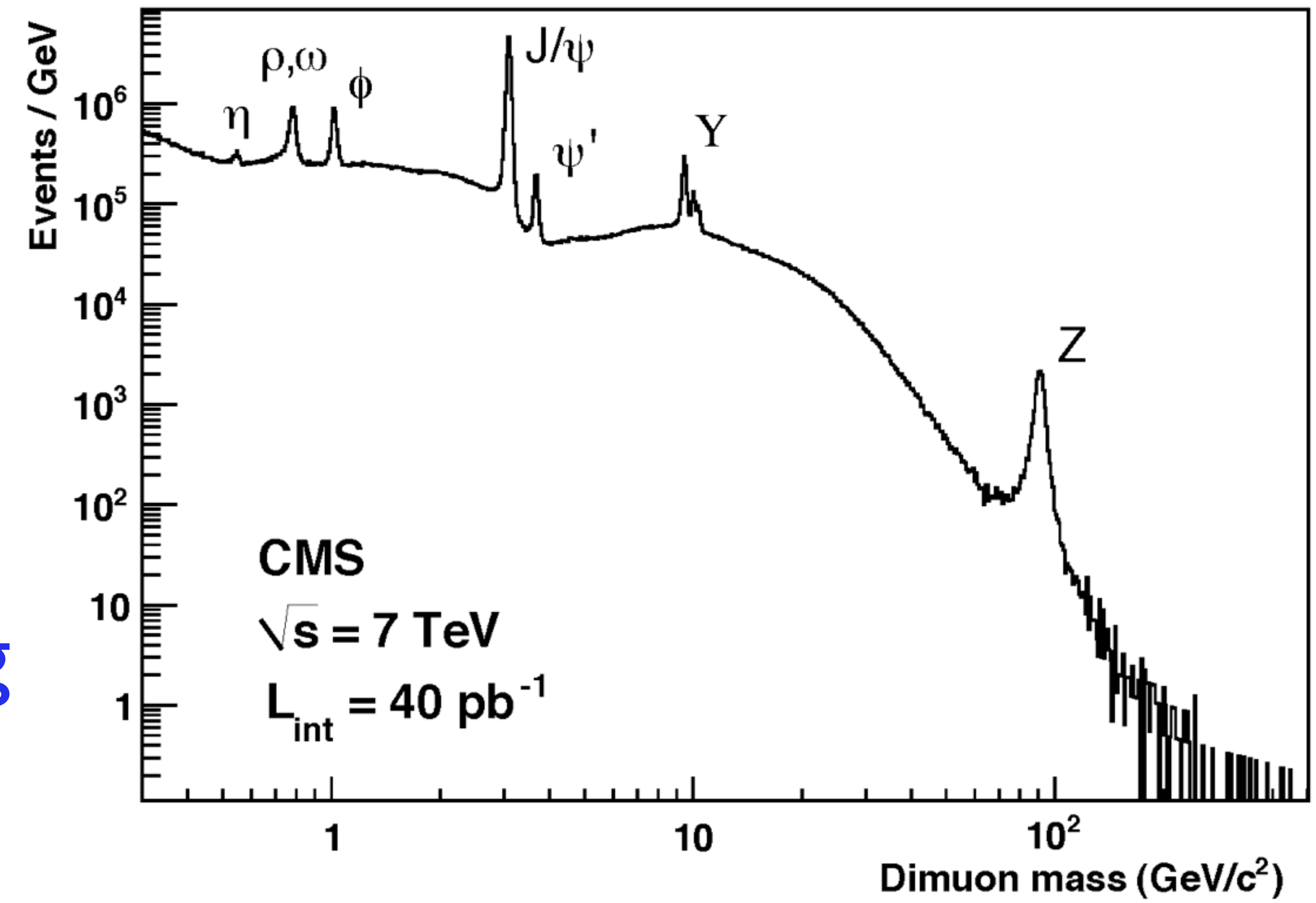
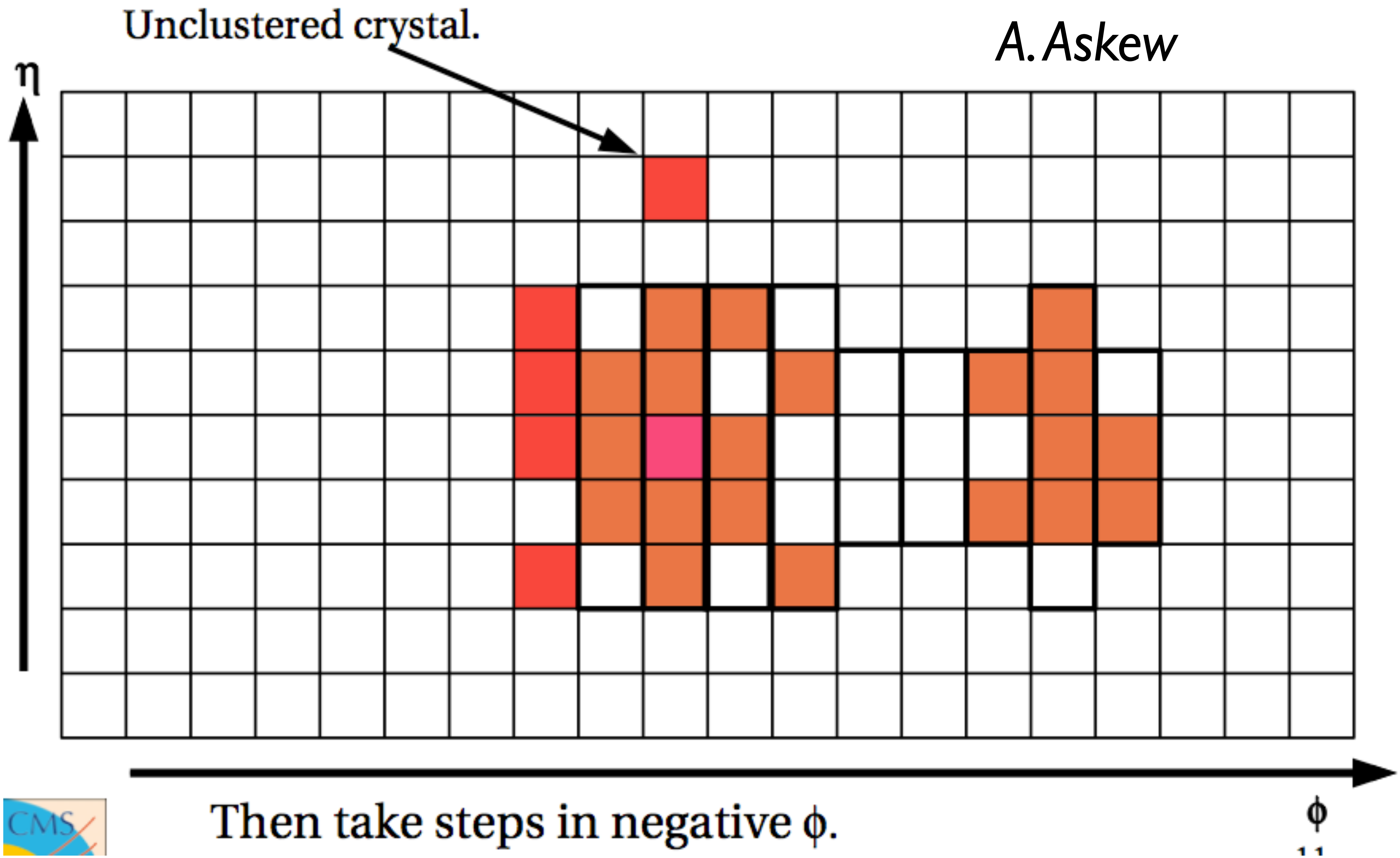
  - Track quality, impact parameter
- Better than 10% pT resolution for muon pT



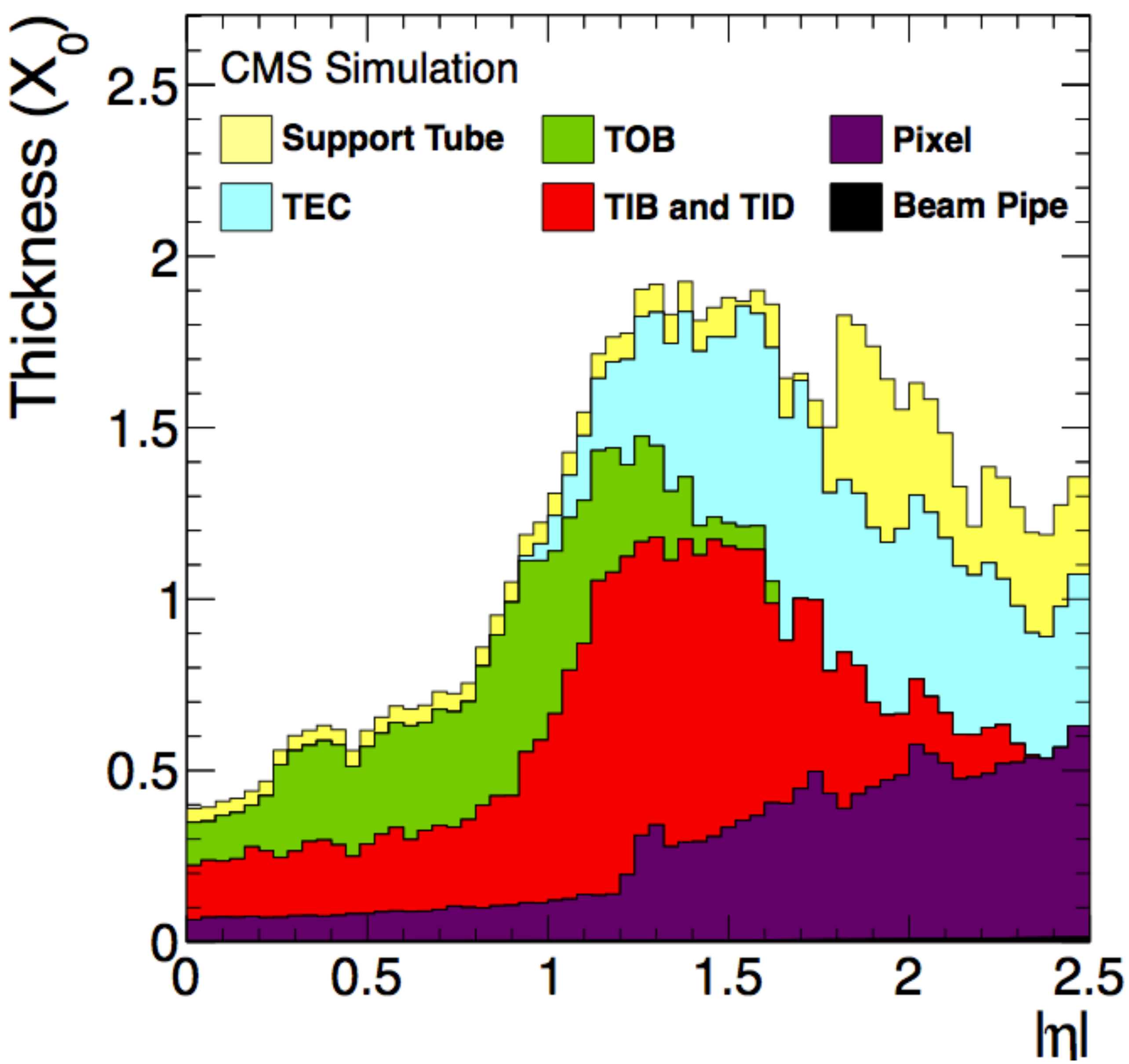
Superclustering Algorithm

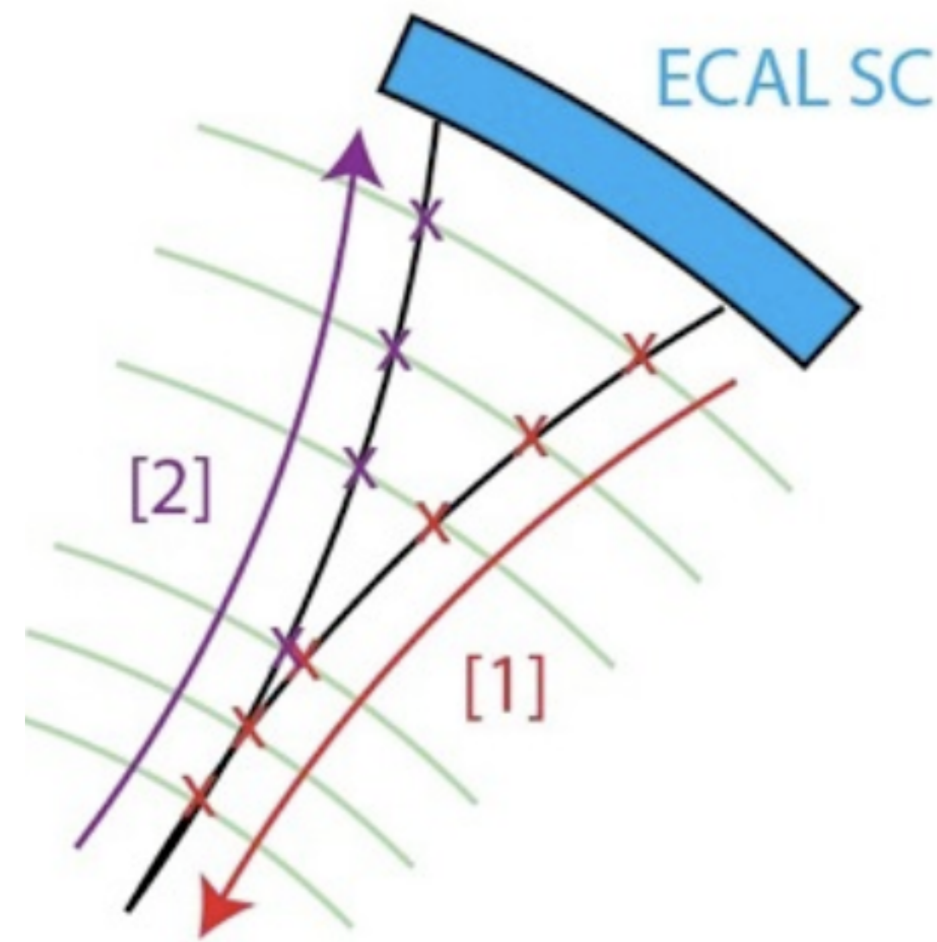


The magnetic field is along the z axis.

Photon Conversion

- Our tracker is a pre-shower
- Dedicated algorithm applied to reconstruct photon conversions (pair production)

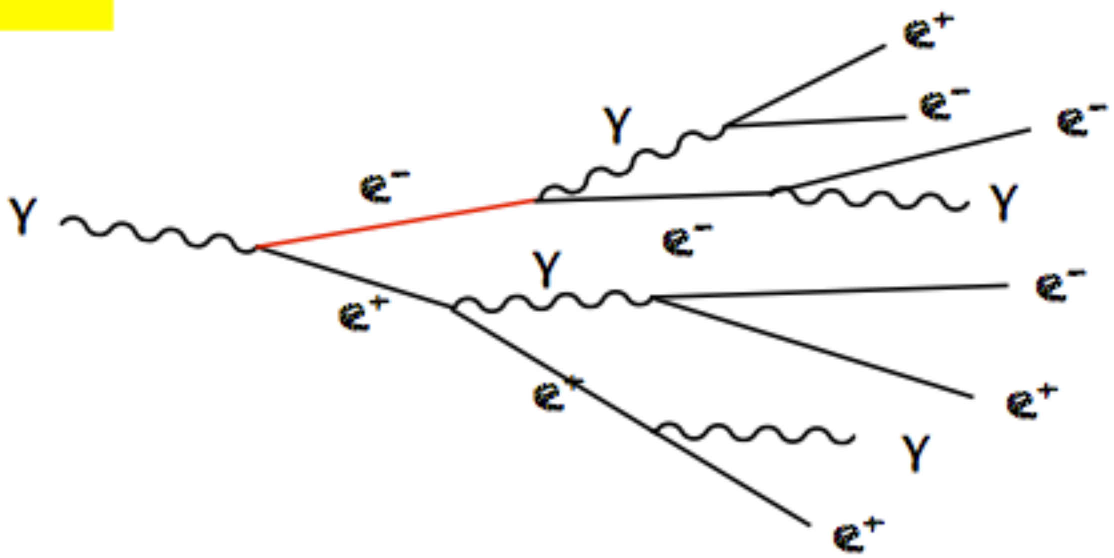


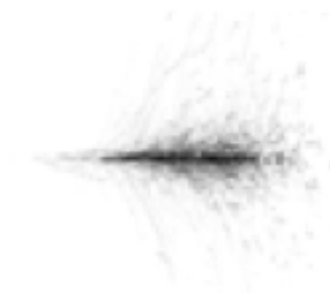


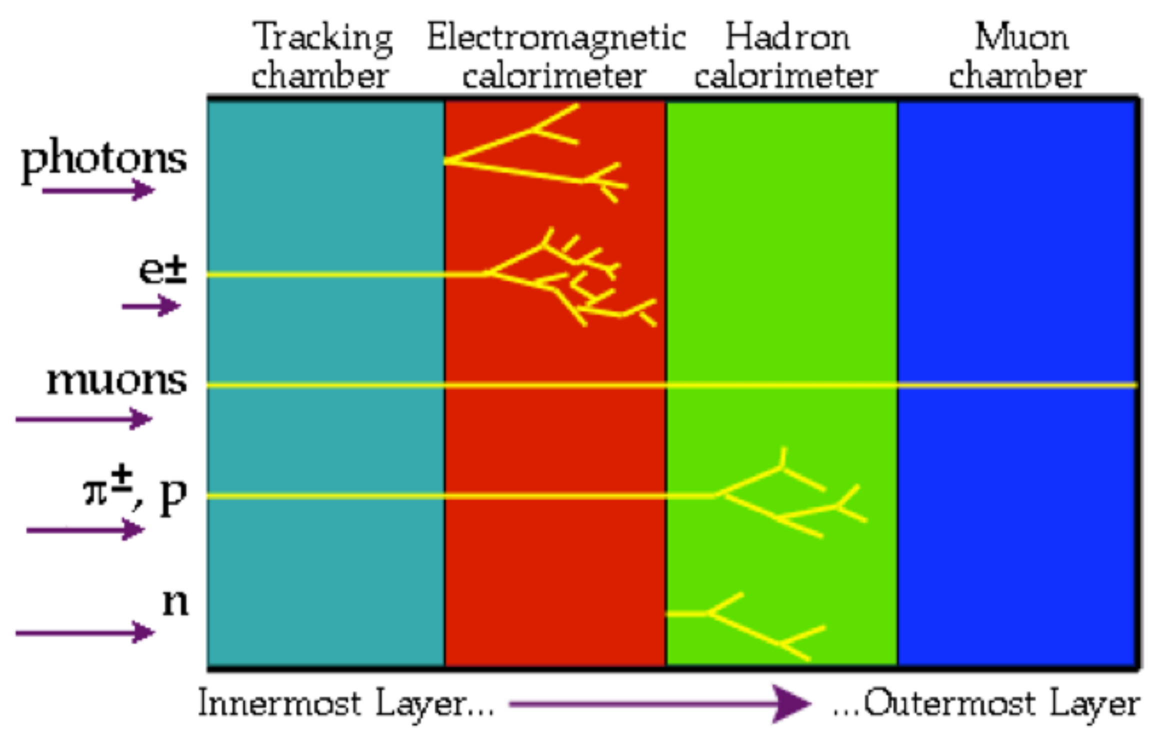
Photons

- Background photons come from decays of hadrons (π^0, η) or electron that brems hard

Photons

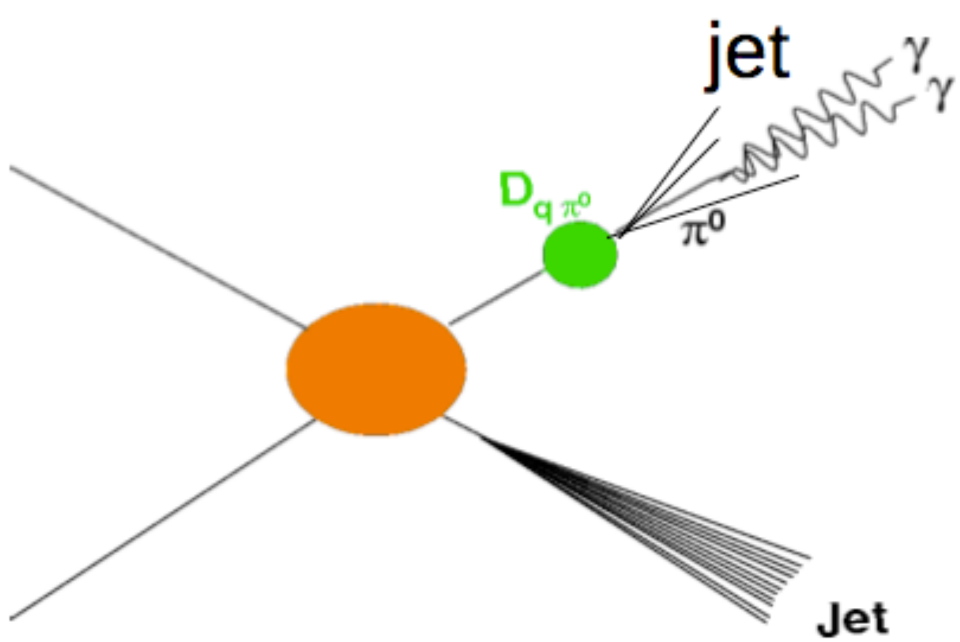


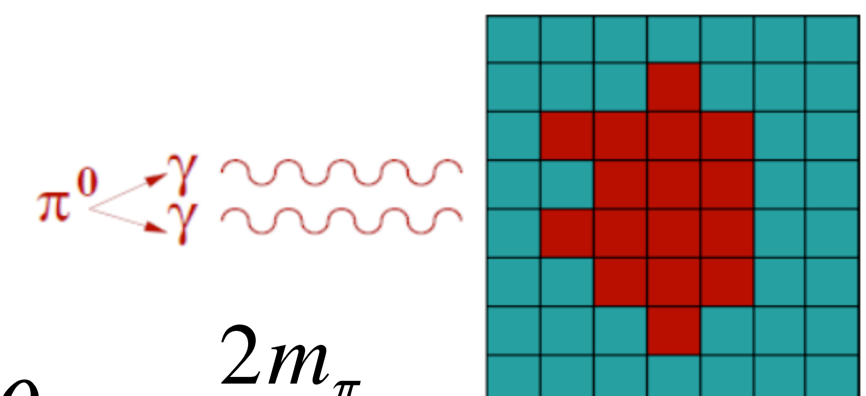




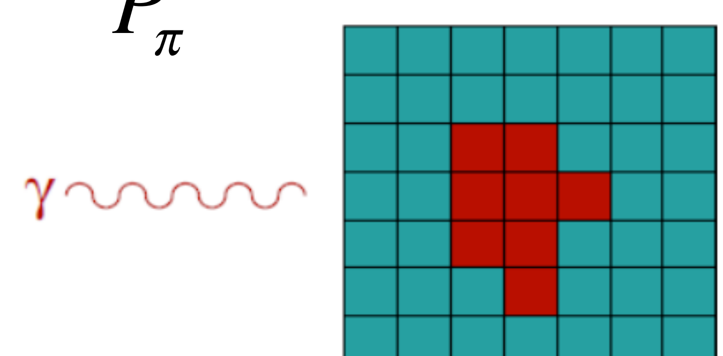
Photons

- Background photons come from decays of hadrons (π^0, η) or electron that brems hard
- When the two photons are close by, a jet could be mis-identified as a single photon

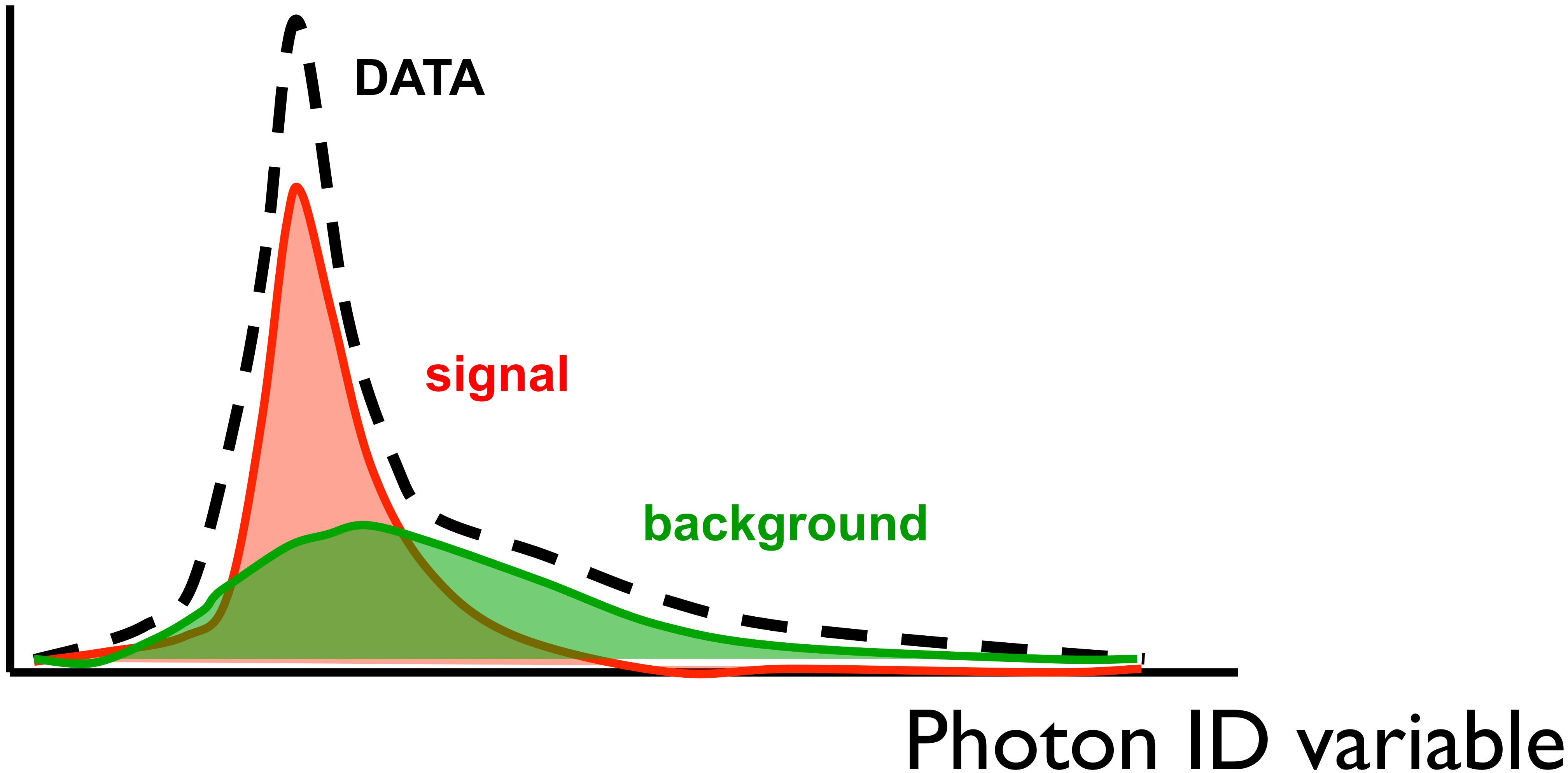




$$\Delta\theta_{\min} \sim \frac{2m_\pi}{P_\pi}$$

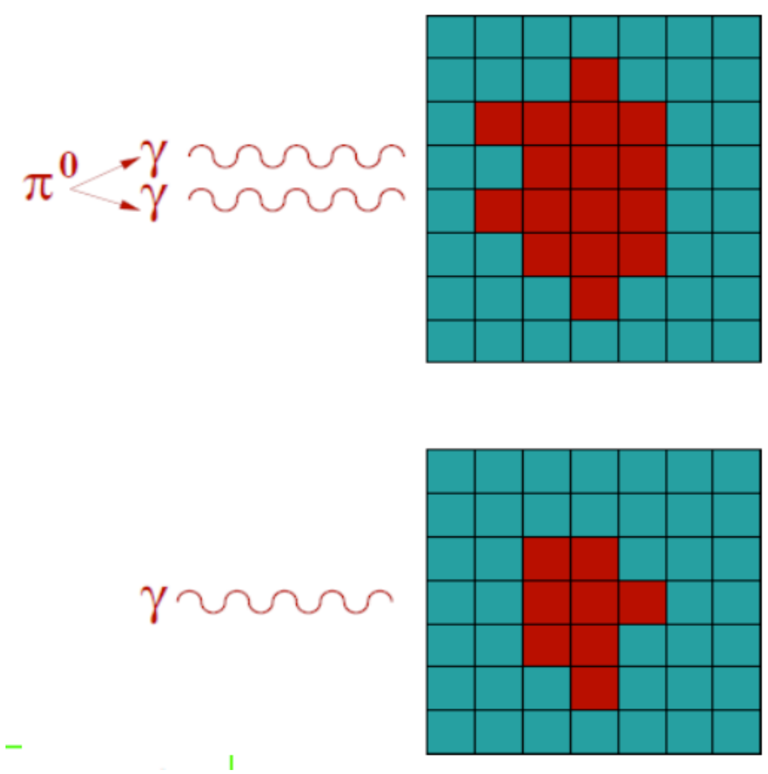


Strategy

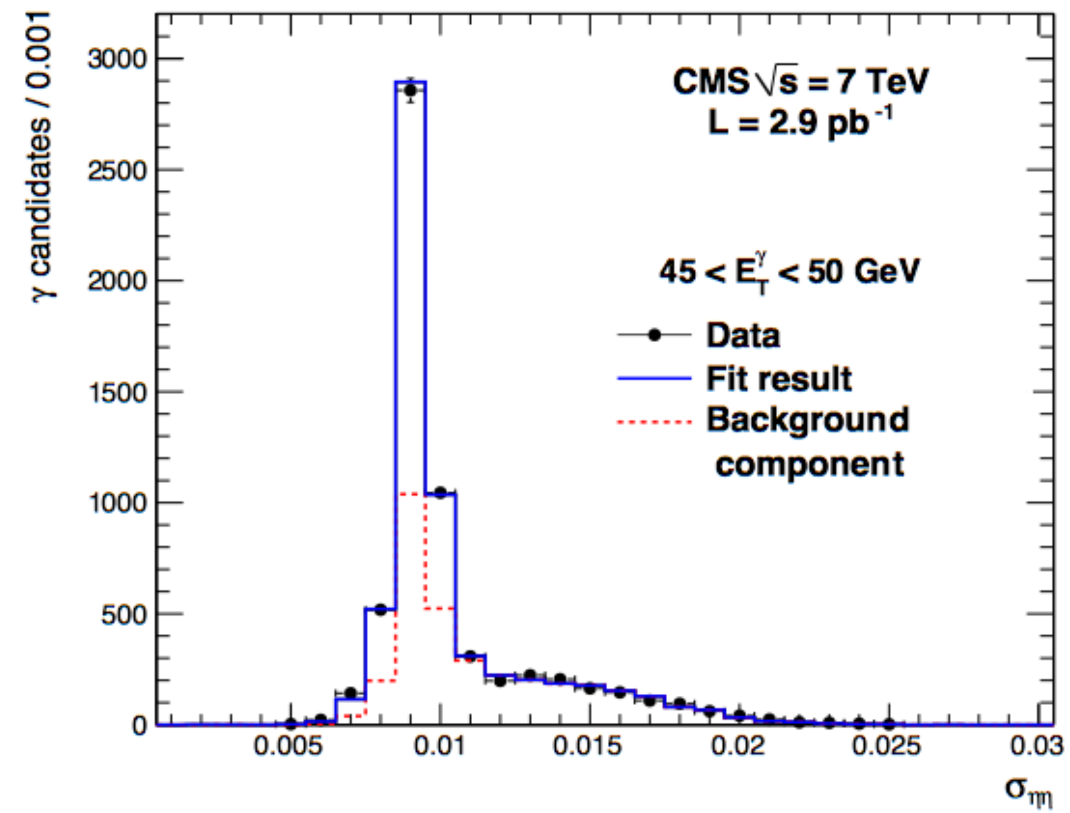


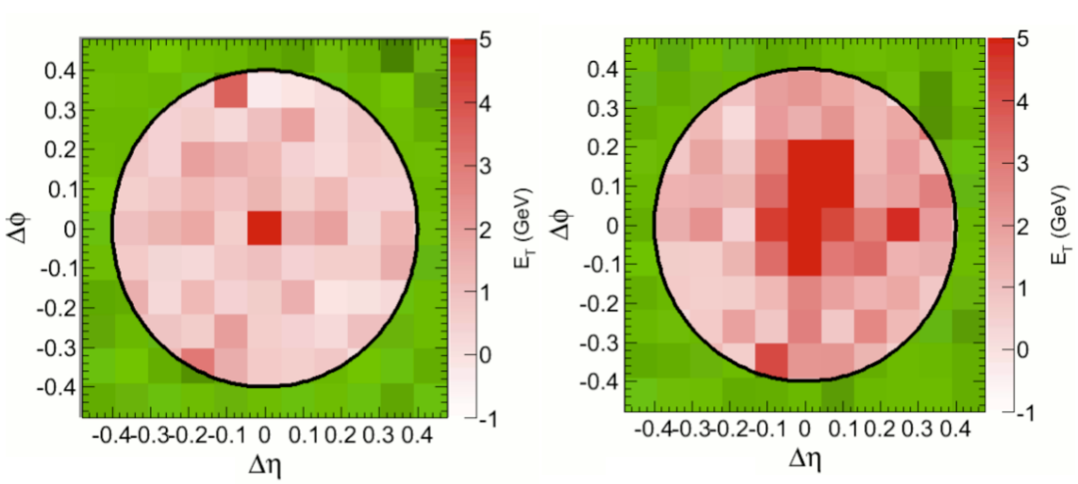
- Obtain signal and background templates from the control samples
- Fit data to $N_{\rm data} = N_{\rm sig}\mathcal{P}_{\rm sig} + N_{\rm bkg}\mathcal{P}_{\rm bkg}$

Photon Id Variables



EM shower shape

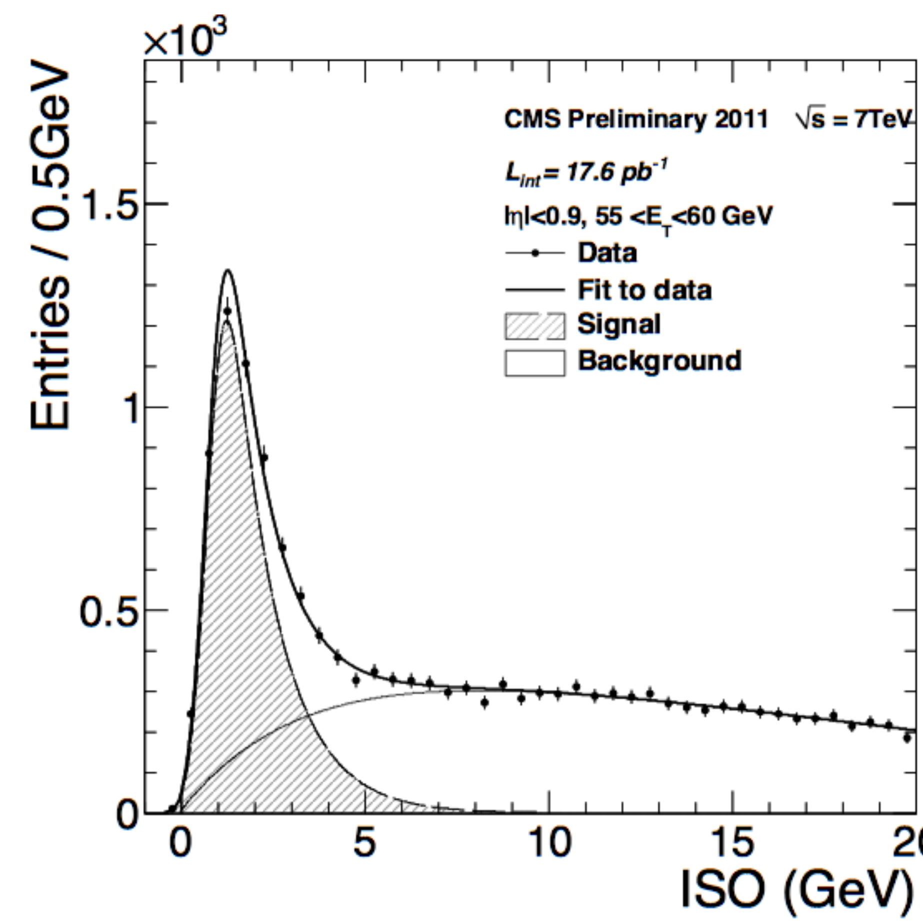




Signal

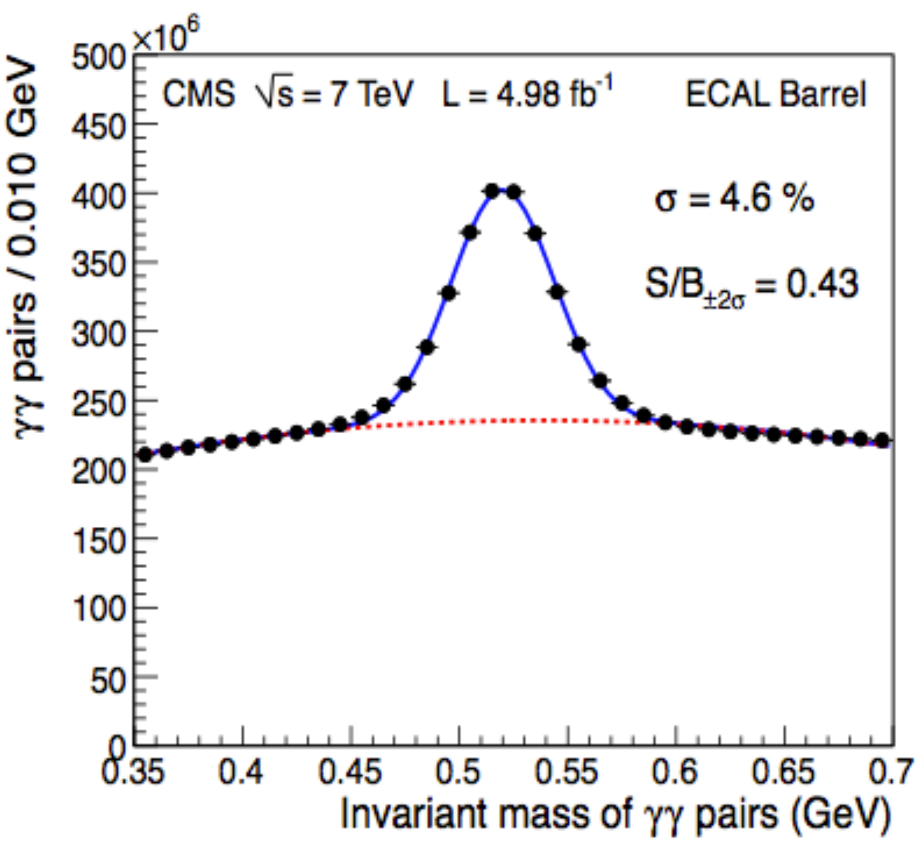
Jet

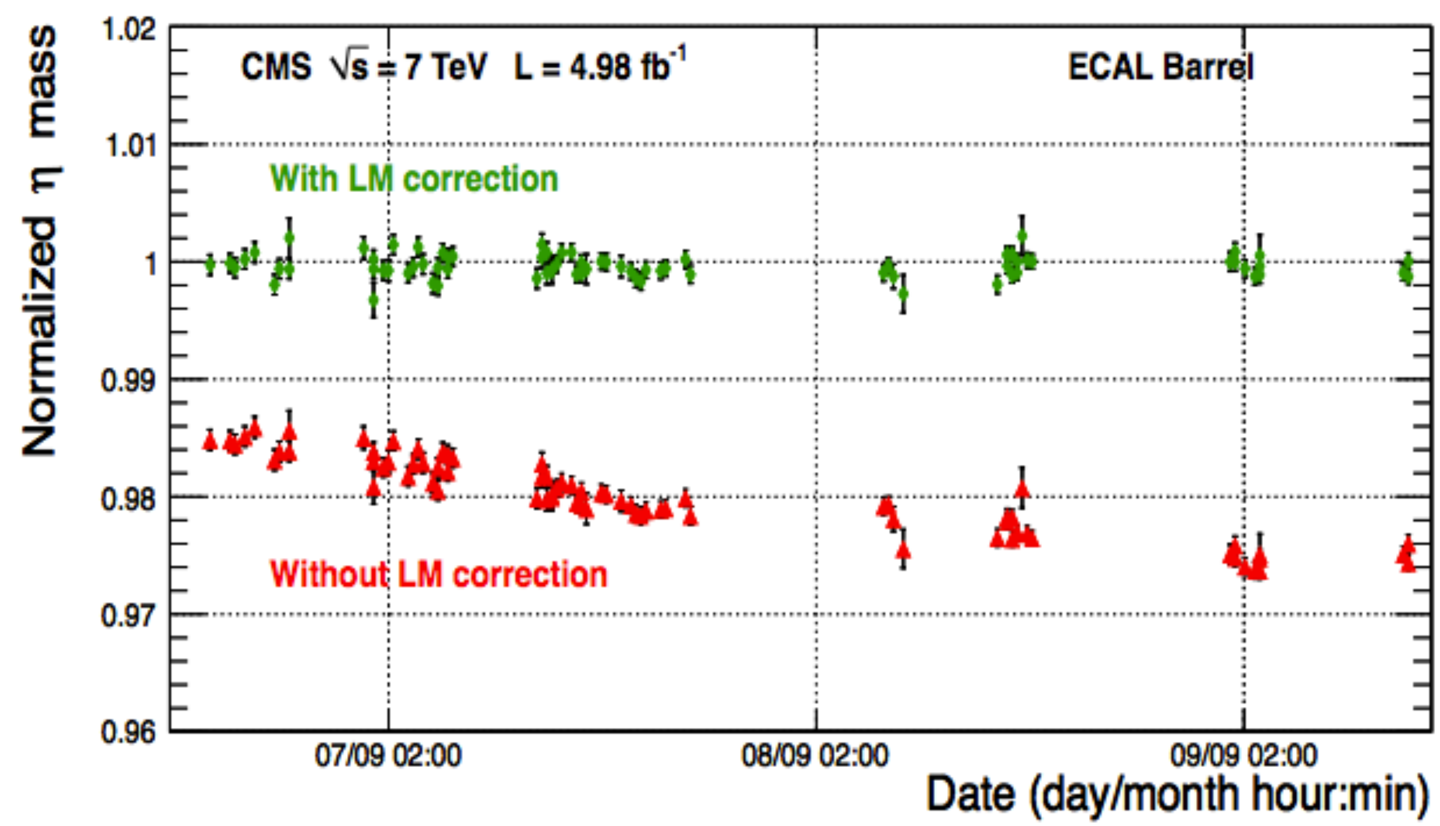
Isolation



Photon Energy Resolution

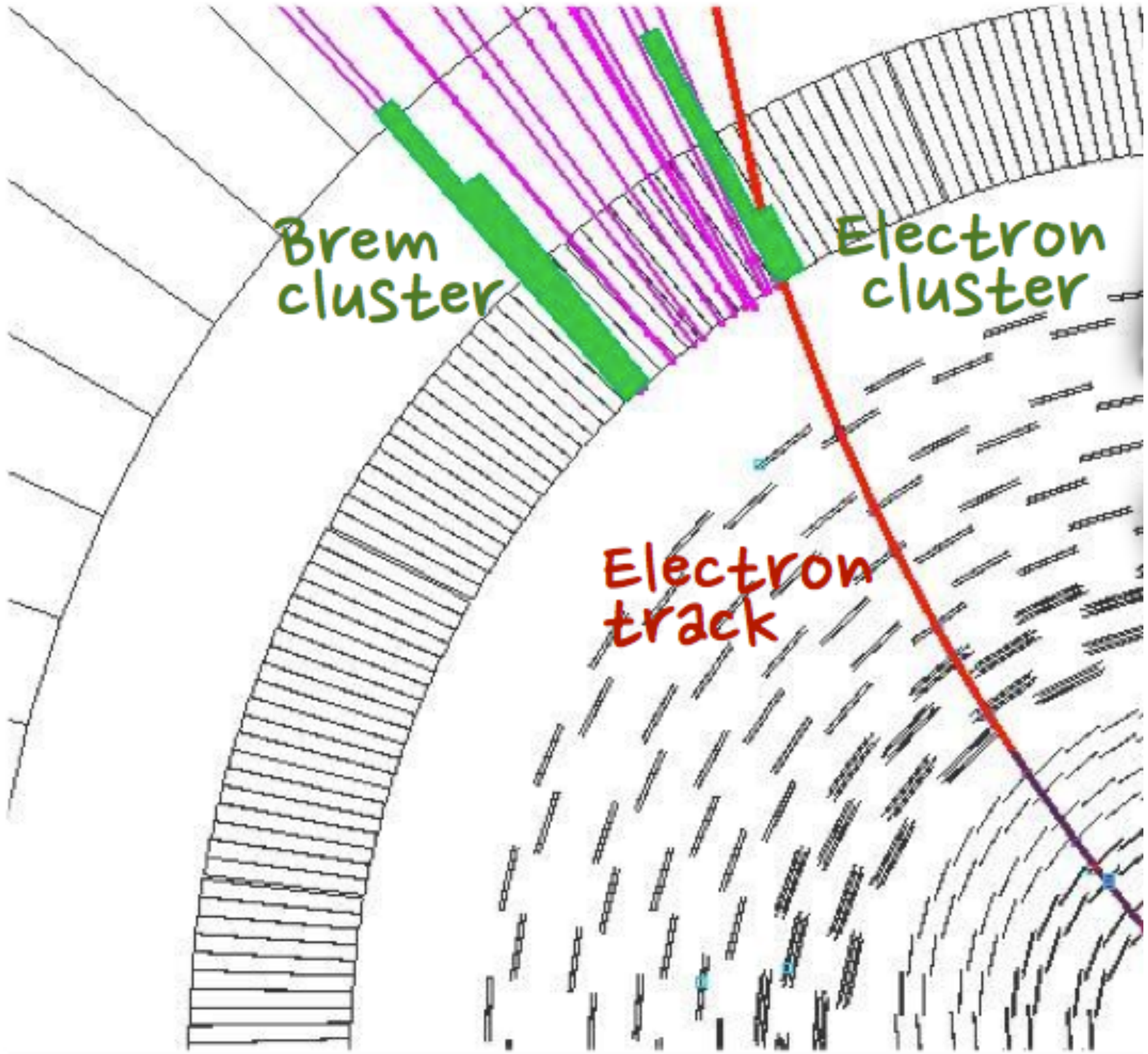
- ECAL energy resolution calibrated with π^0, η^0, Z and cross-checked with $Z \rightarrow \mu\mu\gamma$
- For photon at pT=60 GeV, resolution is 1.1-2.6% in barrel and 2.2-5.0% in endcaps





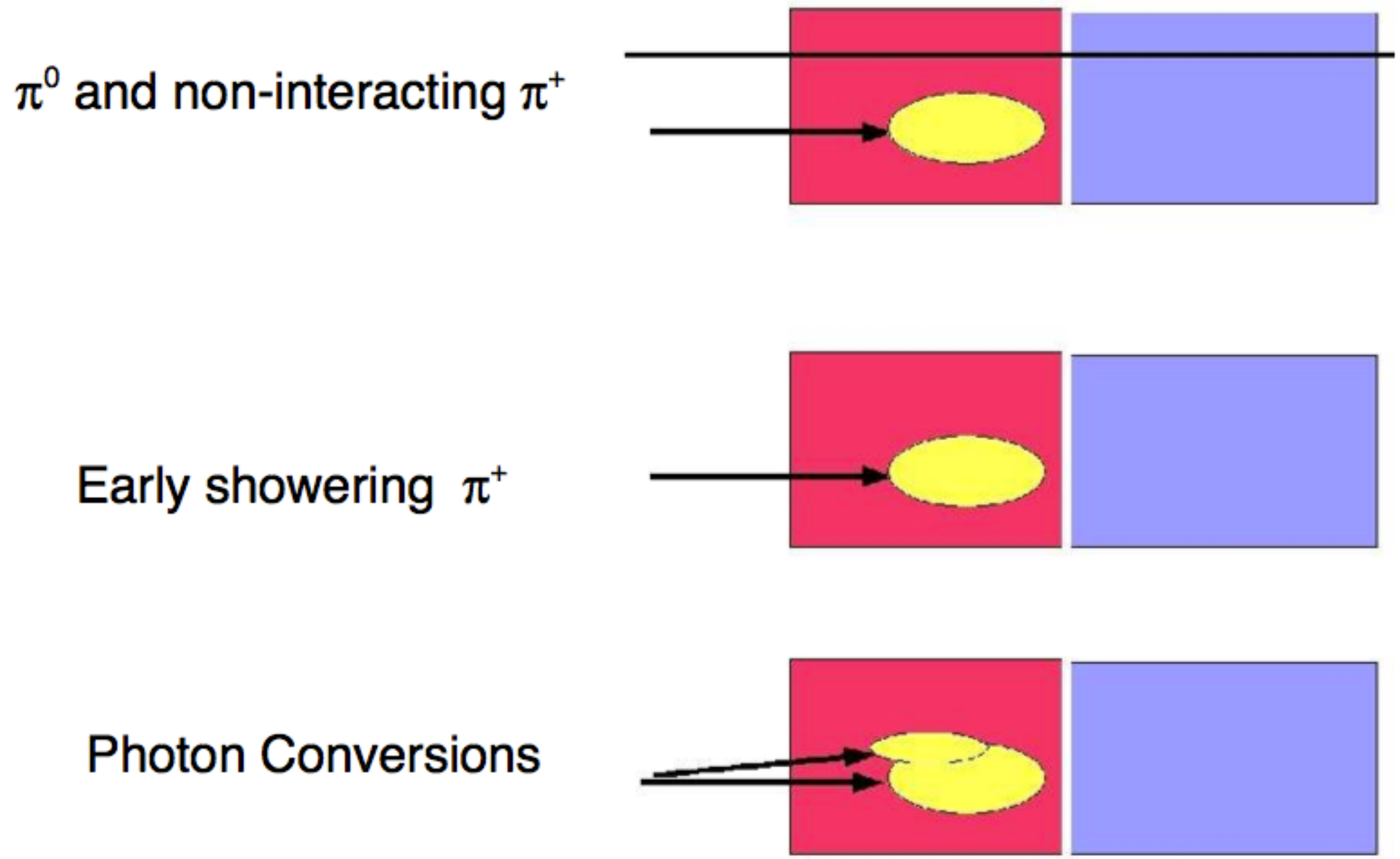
Electron

- Ideally, like a photon with a track
  - Tracker material complicates things, energy spreads in Φ
  - Need to add 4-momentum of photons back



R. Cavanaugh

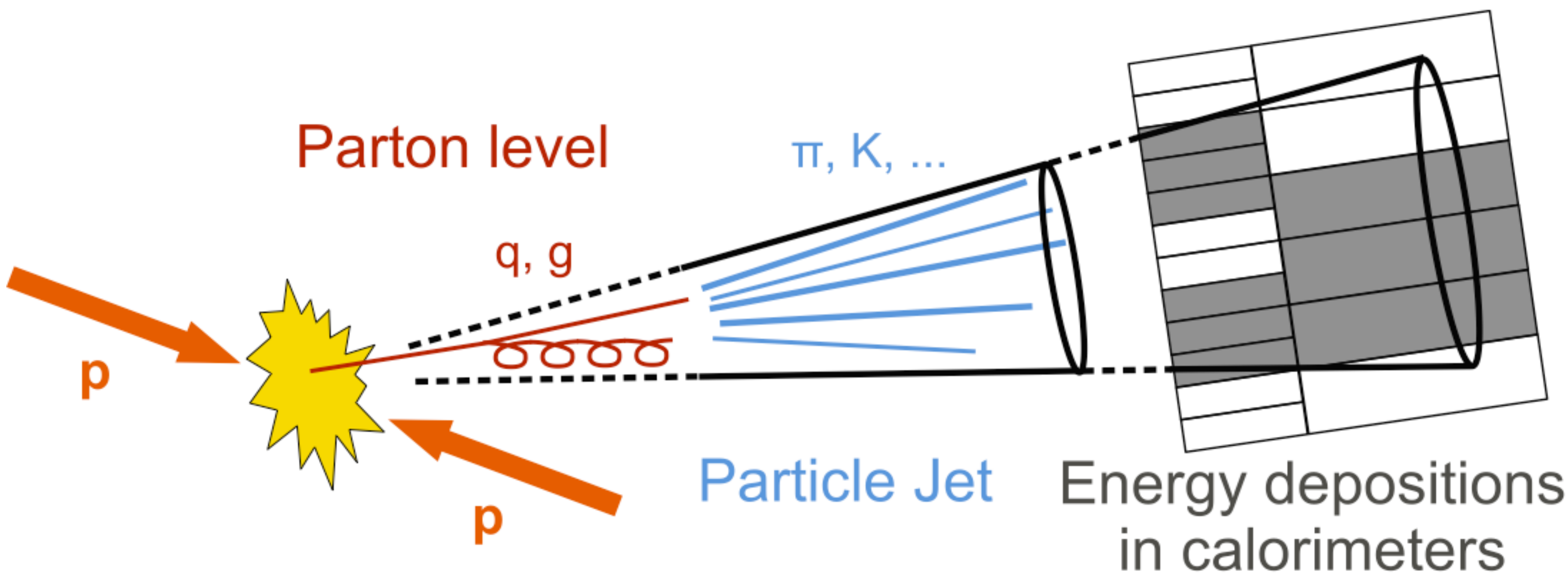
Electron Identification



- Isolation, transverse shower shape, track-ECAL matching quality, energy in HCAL to ECAL, photon-conversion-rejection

Jets

At Tevatron, we used to have calorimeter-only (mostly) and track-only jets (recently developed)

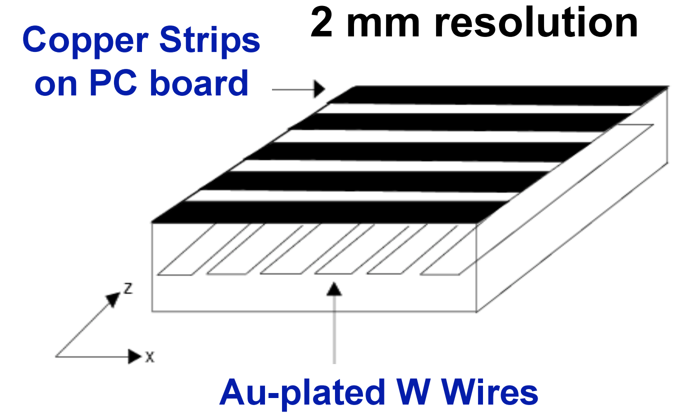


Everything is merged: calibration of response for neutral and charged hadrons

→ Did not make the best use of detector

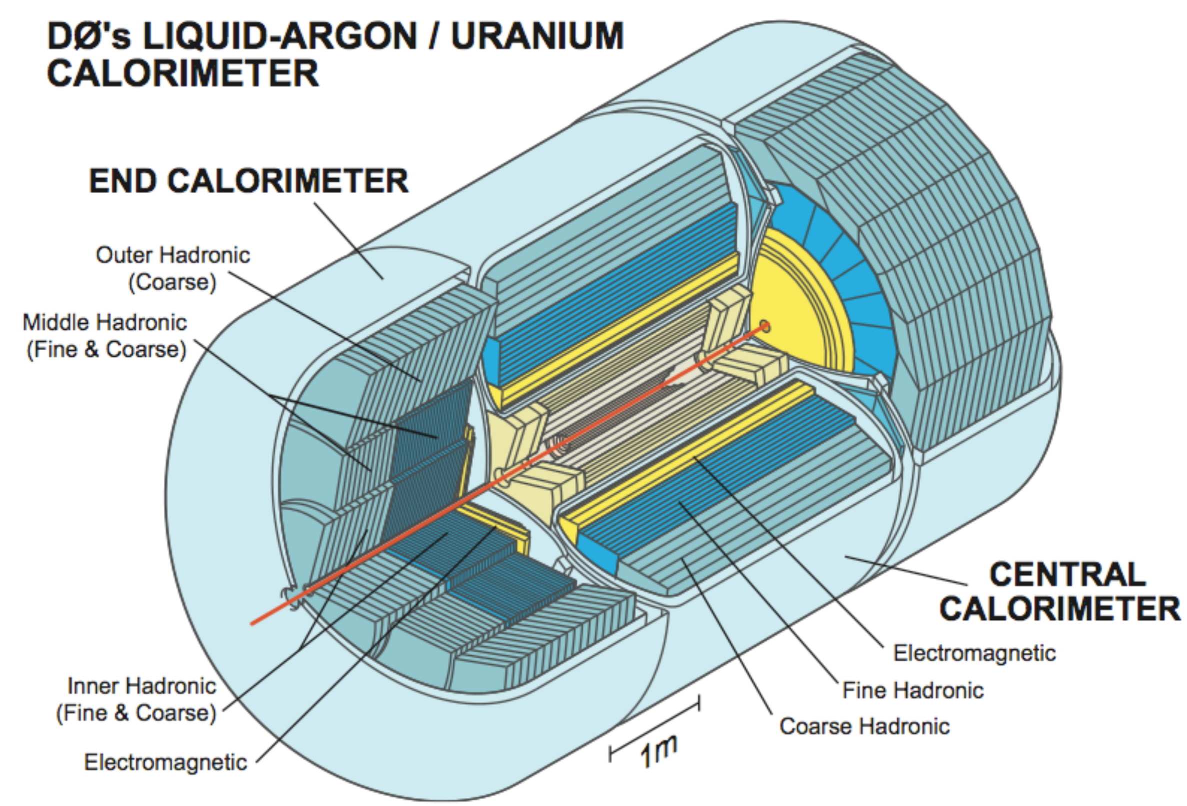
Tevatron Detectors

- CDF central ECAL (lead+scintillator), $|\eta| < 1.1$
  - shower profile detector at 6 X_0
  - 18 X_0, $\Delta\eta\times\Delta\varphi=0.1\times0.26$
  - tracker 0.2 X_0, B=1.4 Tesla
  - ~3% energy resolution at 50 GeV



$\Delta\eta\times\Delta\varphi$
$=0.01\times0.01$

- D0 central ECAL (uranium + liquid argon), $|\eta| < 1.1$
  - four longitudinal readouts (2, 2, 7, 10 X_0)
  - $\Delta\eta\times\Delta\varphi=0.1\times0.1$ (0.05 × 0.05 for EM3)
  - tracker 0.3 X_0, B= 2.0 Tesla
  - ~3.6% energy resolution at 50 GeV



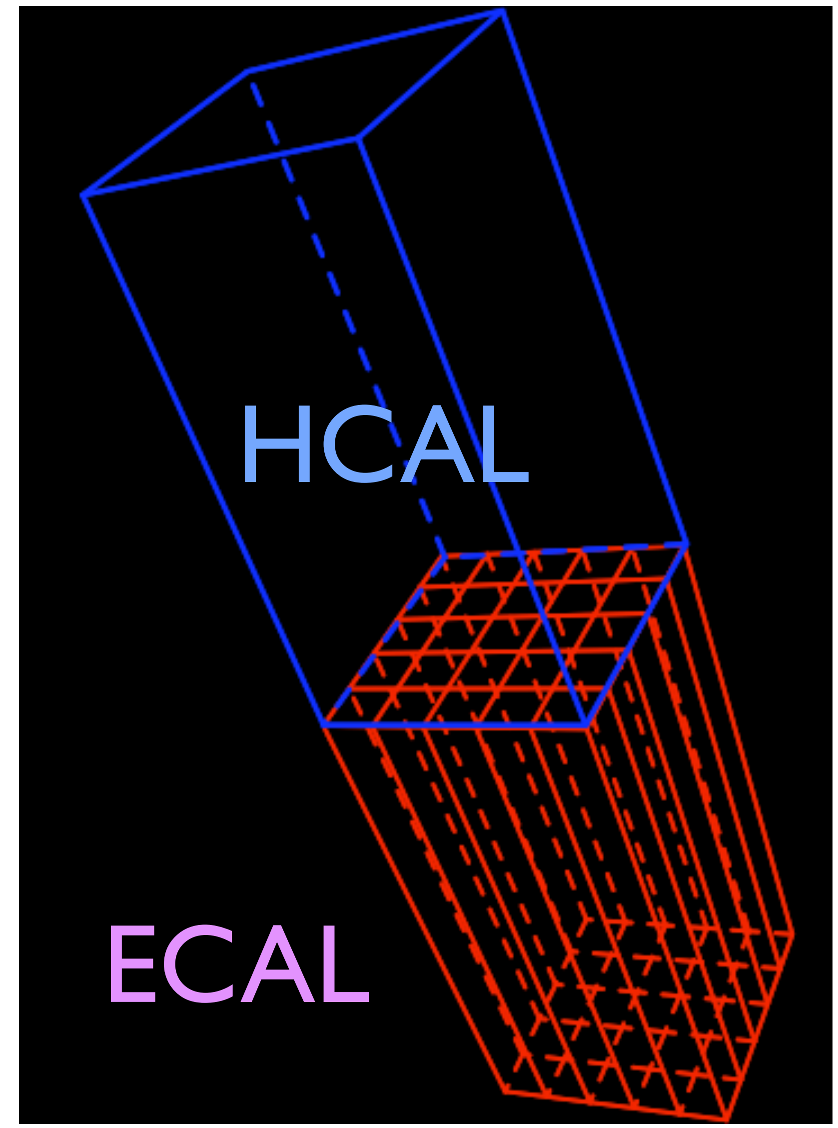
Jets

- At CMS, we use particle-flow algorithm, mostly for jets, MET, tau (recently also for electrons, photons, and muons)
  - Led by Patrick Janot and Colin Bernet
  - See Janot's talk for an interesting discussion
- Follow the trajectory of each particle in the detector and identify each of them, as if they were coming from a MC generator
  - Neutral hadrons (K_L, n) are merged
- Make the best use of each detector component

What Are Required For Pf

- Good tracking detector (large and finely segmented)
  - strong magnetic field
  - not so much material
- Finely segmented calorimeters
  - not so much material in front of calorimeters
- 3-D granularity for each sub-detector (better)
- Redundancy of measurements

R. Cavanaugh



$$\mathrm{ECAL}: \Delta\eta \times \Delta\phi = 0.0175 \times 0.0175$$

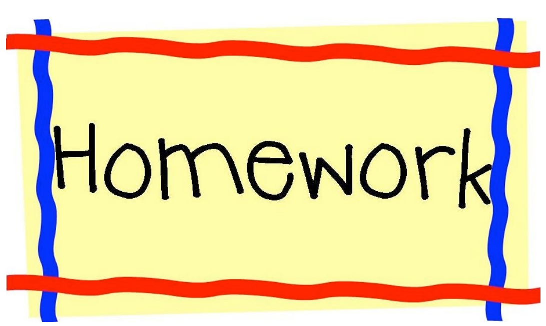
Make Best Use Of Detector

$$\delta E_T \text{ for ECAL} \sim 1 \sim 10\% \sqrt{E_T}$$

$$\delta E_T \text{ for HCAL} \sim 100\% \sqrt{E_T}$$

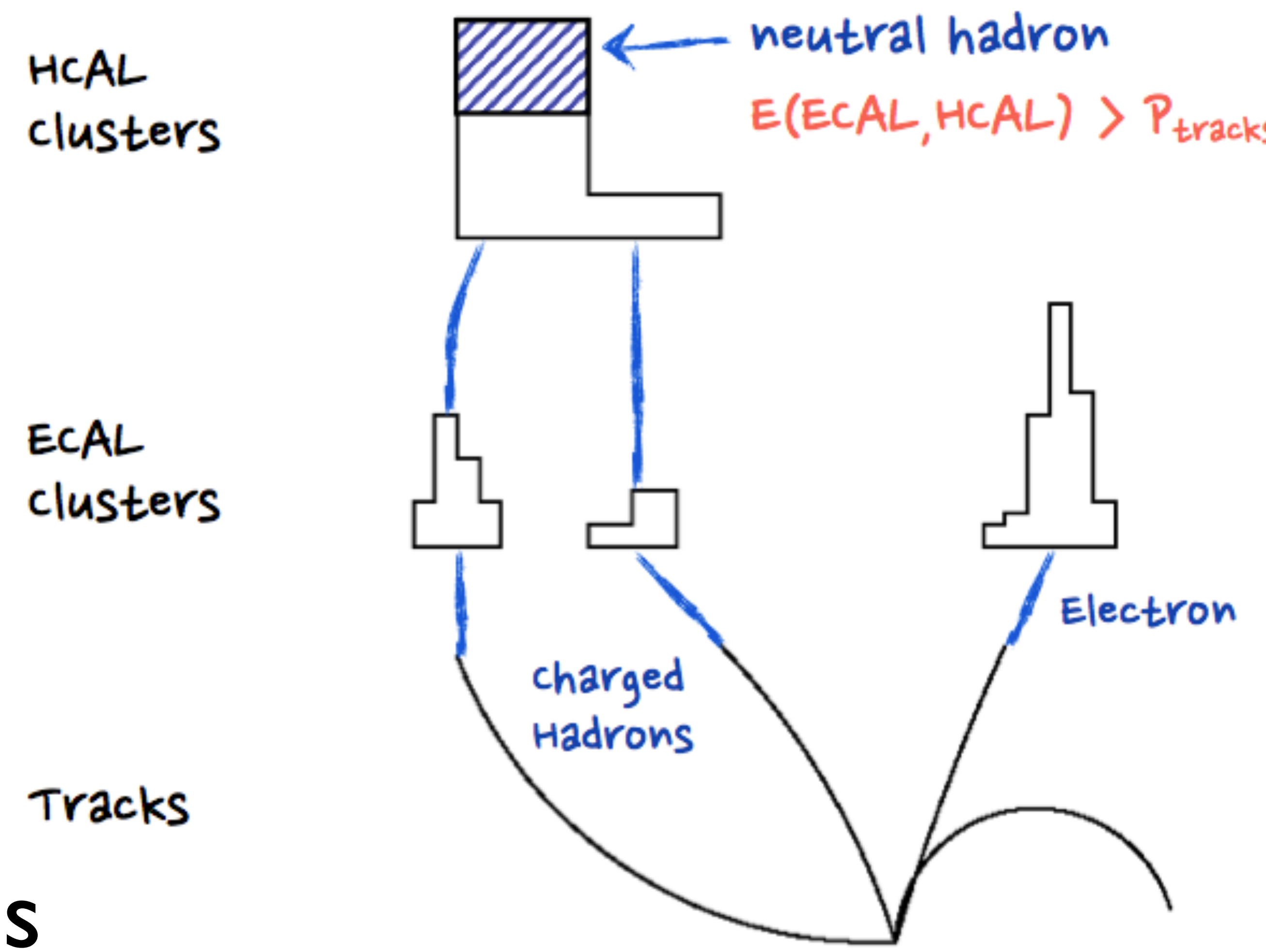
$$\delta p_T \text{ for tracker} \sim 0.01\%\, {p_T}^2$$

When will calorimeter resolution overcome tracker resolution?



Particle Flow 101

1. Find and remove muons
2. Find and remove electrons
3. Find and remove charged hadrons
4. Find and remove converted photons, Λ, Ks
5. Assign remaining energy in ECAL and HCAL to photons and neutral hadrons



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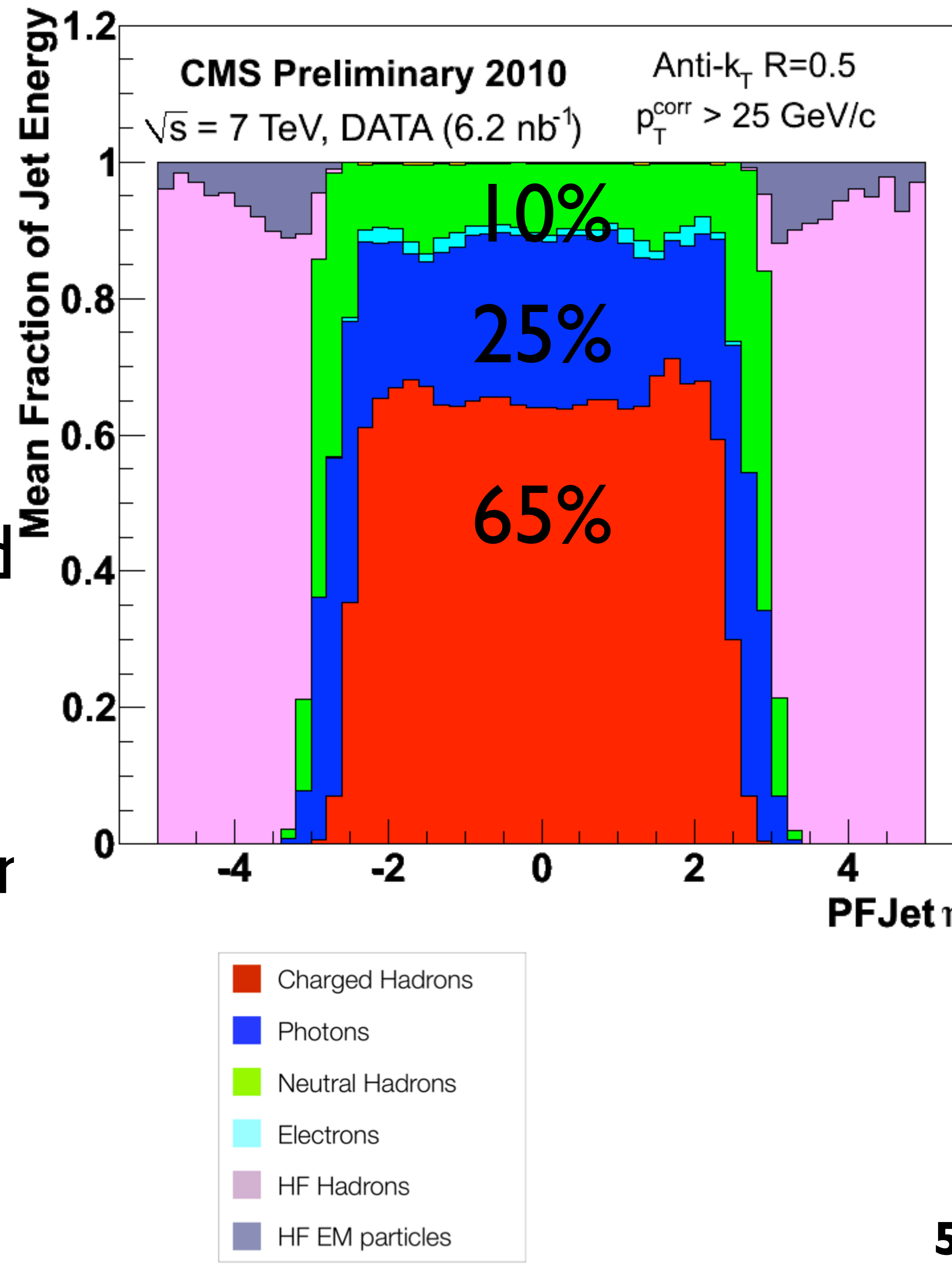
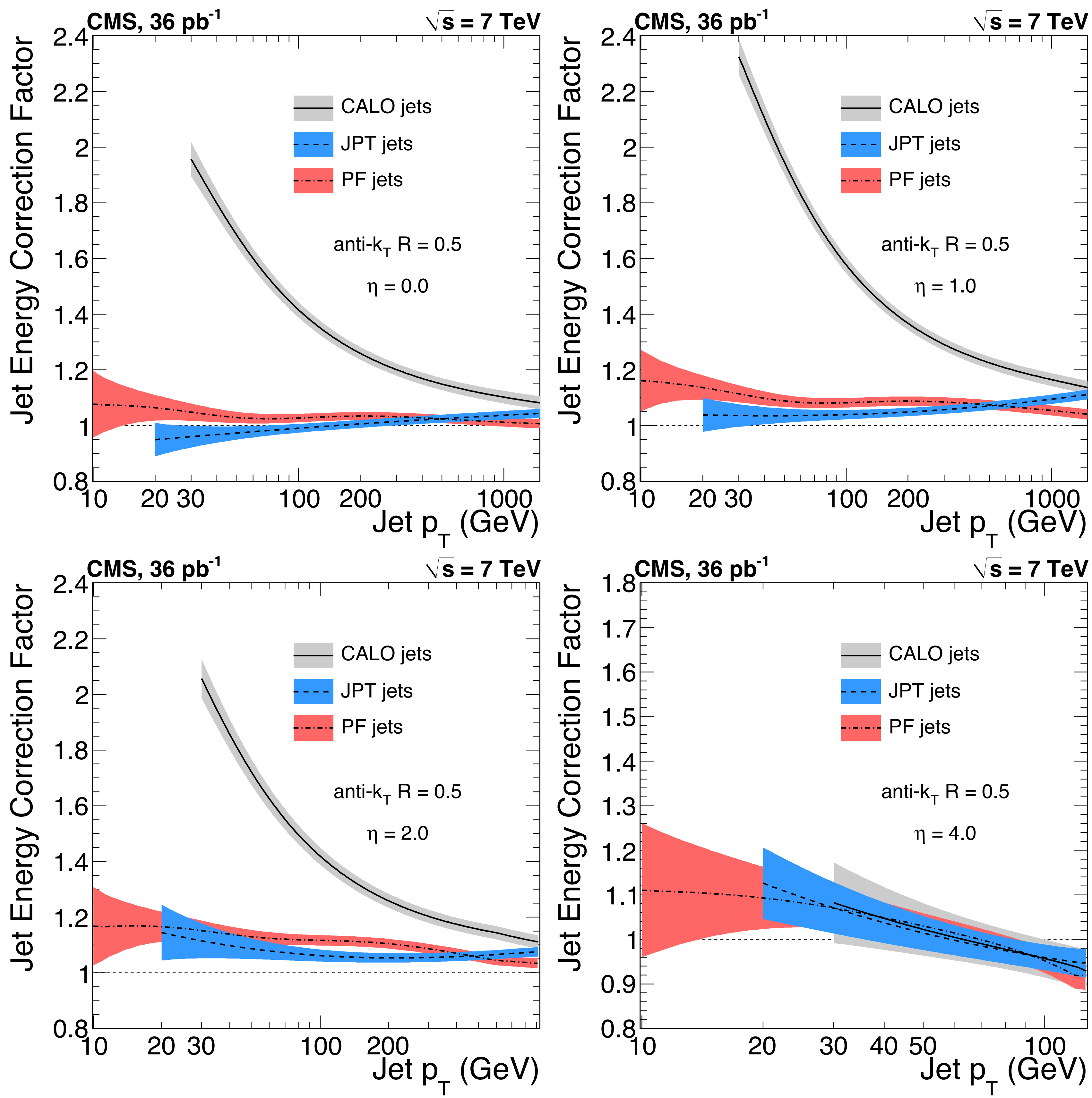
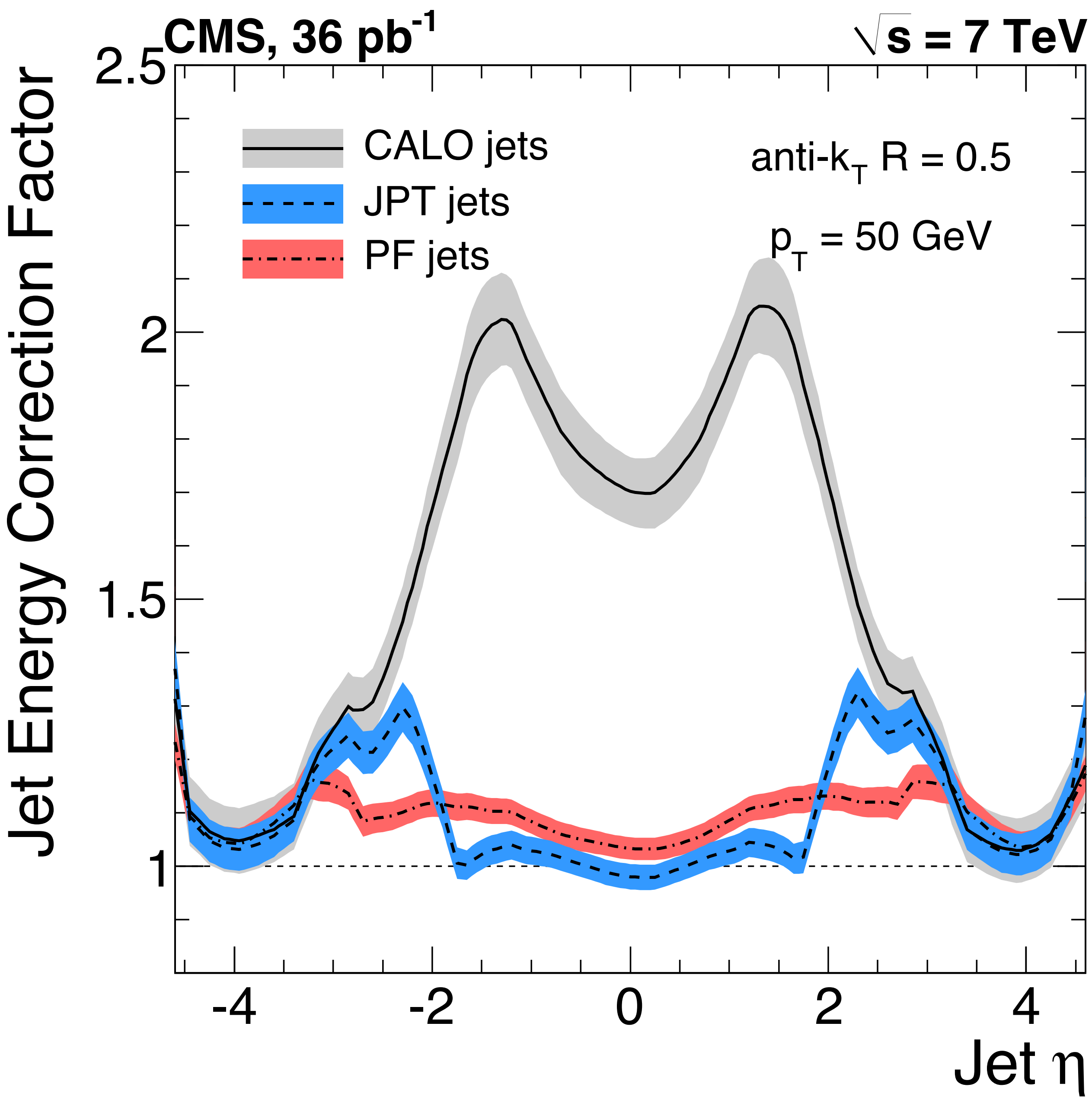
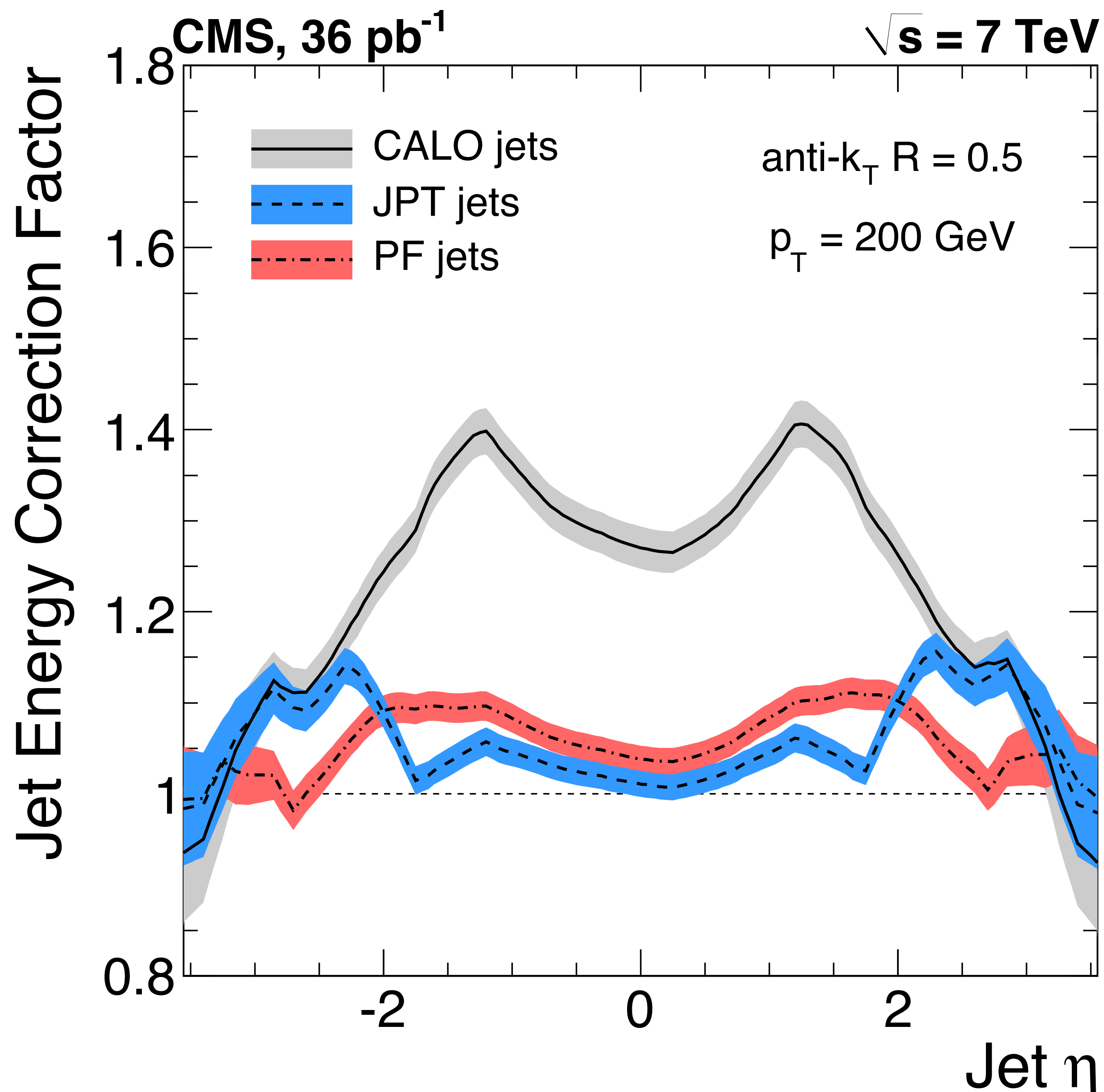


Cms Jes Correction Vs Pt

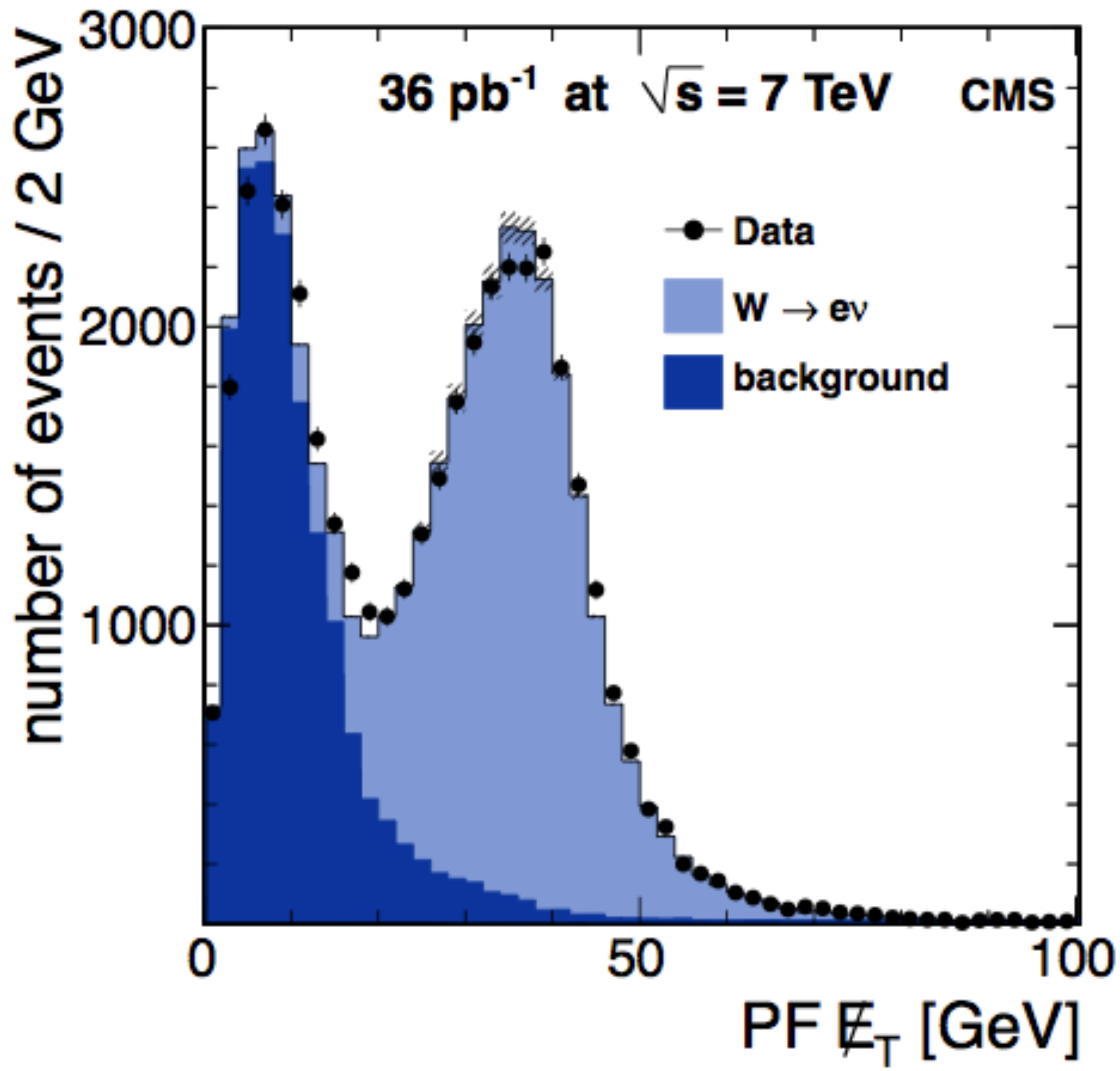


Cms Jes Correction Vs η



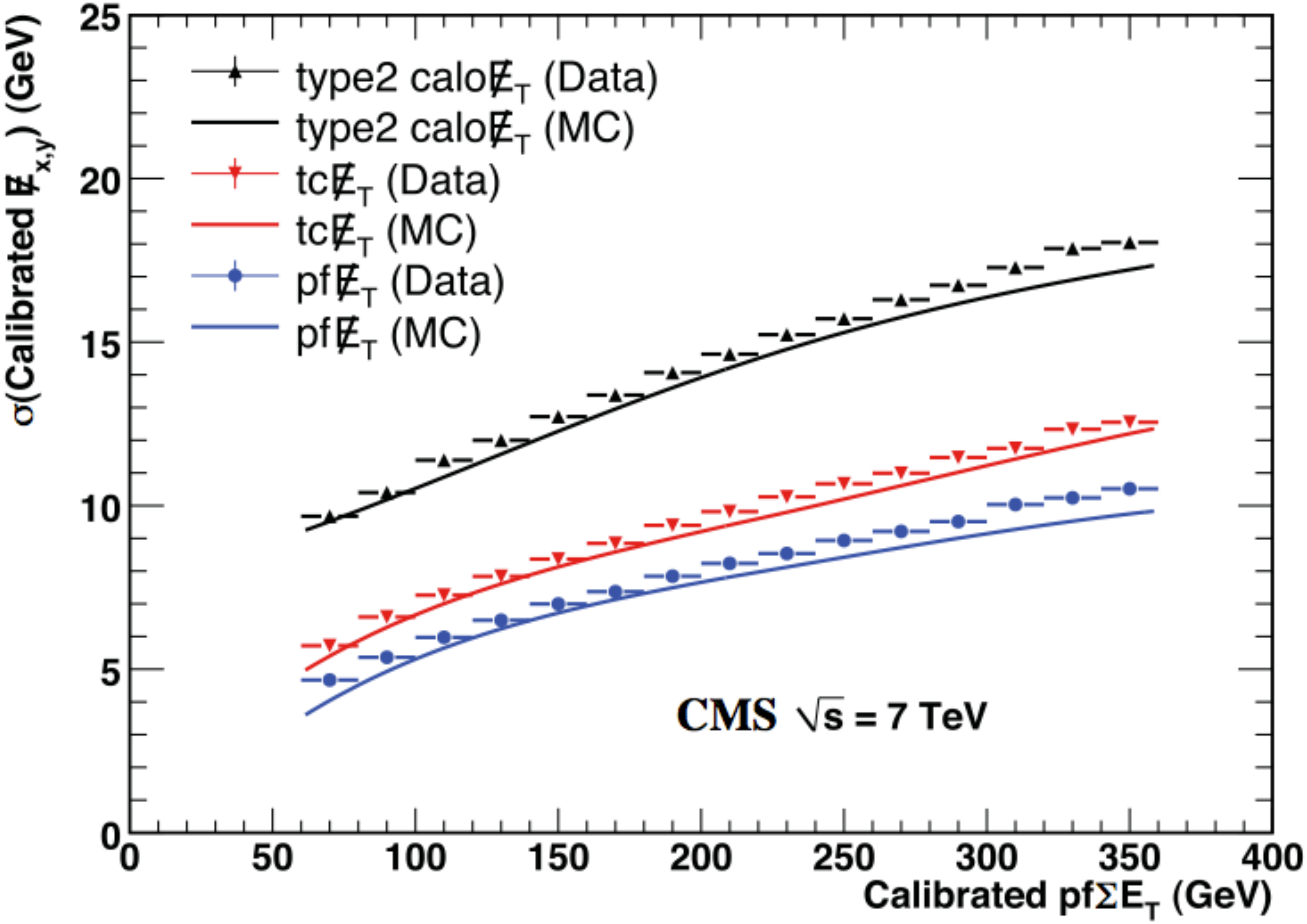


Missing Momentum Distributions



A good match between data and MC

Missing Momentum Resolution



Particle flow has the best performance

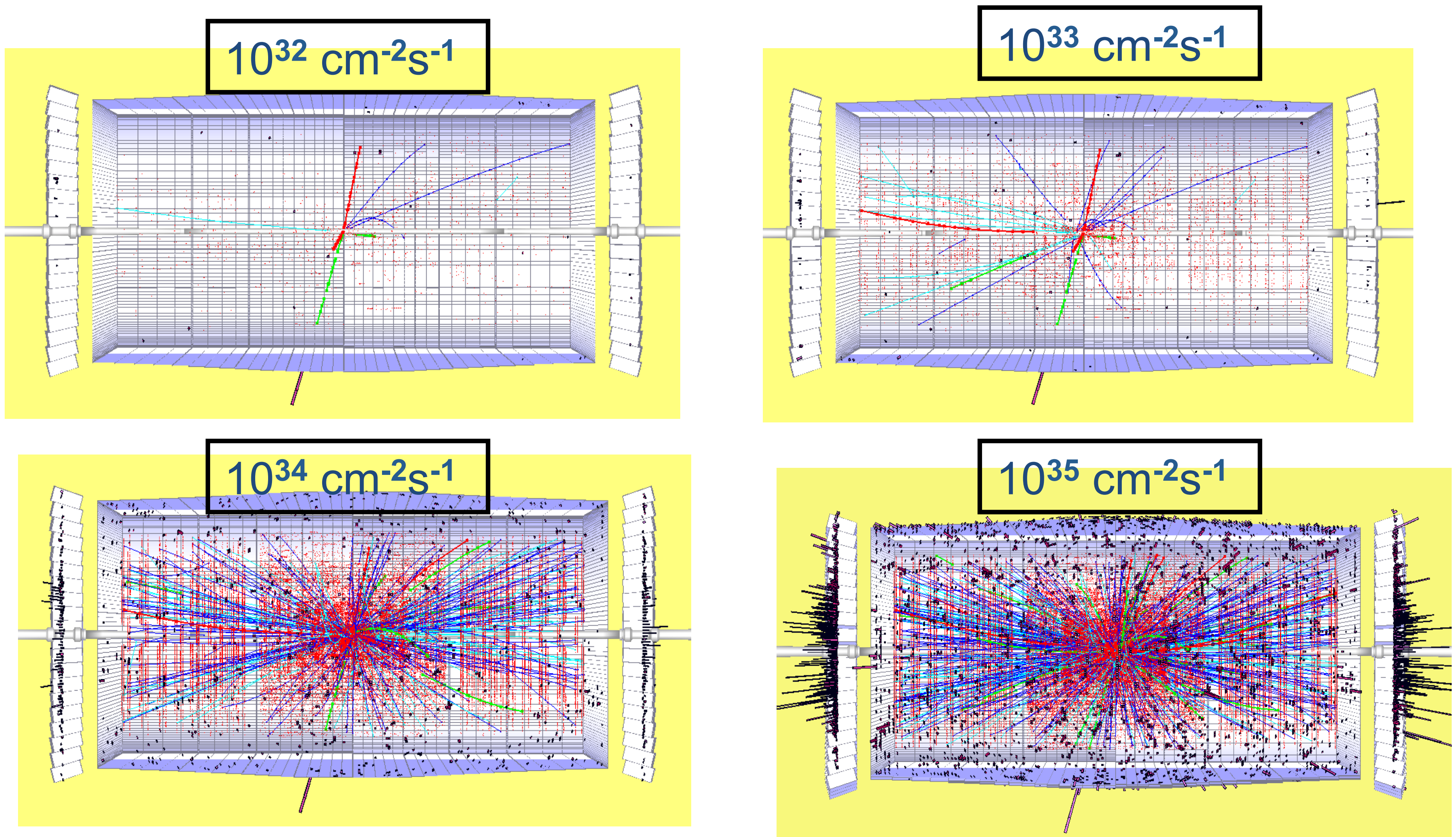
Conclusion

- Described the basics of tracks, muons, photons, electrons, jets, and particle flow
- Challenge ahead of us in 1.5 years
- Try the homework!

T. Liu

Conclusion

- Described the basics of tracks, muons, photons, electrons, jets, and particle flow
- Challenge ahead of us in 1.5 years
- Try the homework!



T. Liu

Backup Slides

How Are Production Rates Calculated

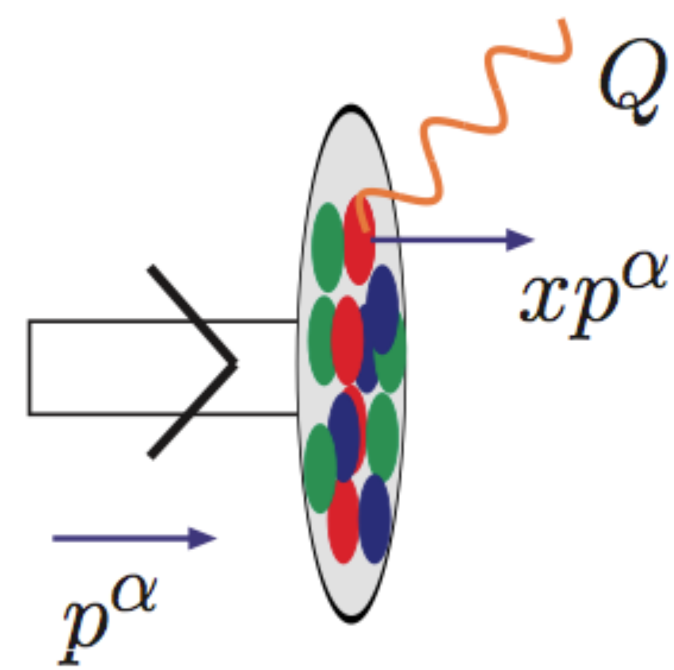
PDFs, non-perturbative

$$\sigma_{pp\to X} = \sum_{\text{partons}} \int dx_a\, dx_b\, \boxed{f_{a/p_1}\left(x_a, Q^2\right) f_{b/p_2}\left(x_b, Q^2\right)}\, \boxed{\hat{\sigma}_{ab\to X}}$$

partonic cross section, perturbative

In the simplest (leading-order) interpretation, the PDF $f_{a/p}(x, Q)$ is a probability for finding a parton a with 4-momentum xp^α in a proton with 4-momentum p^α

$f_{a/p}(x, Q)$ depends on **nonperturbative** QCD interactions



Ingredients To Get Cross Section

$$N_{\text{sig}}^{\text{produced}} = L_{\text{int}} \times \sigma \quad \Rightarrow \quad N_{\text{sig}}^{\text{obs}} = L_{\text{int}} \times \sigma \times \varepsilon_{\text{sig}}$$

$$\Rightarrow \left(N_{\text{total}}^{\text{obs}} - N_{\text{bkg}}\right) = L_{\text{int}} \times \sigma \times \varepsilon_{\text{sig}}$$

$$\Rightarrow \sigma = \frac{\left(N_{\text{total}}^{\text{obs}} - N_{\text{bkg}}\right)}{L_{\text{int}}\varepsilon_{\text{sig}}}$$

ε_{sig} : efficiency to reconstruct/ID signal

To Minimize Uncertainty On σ

$$\sigma = \frac{\left(N_{\text{total}}^{\text{obs}} - N_{\text{bkg}}\right)}{L_{\text{int}}\varepsilon_{\text{sig}}}$$

$$\frac{\delta\sigma}{\sigma} = \sqrt{\frac{\left(\delta N_{\text{total}}^{\text{obs}}\right)^2 + \left(\delta N_{\text{bkg}}\right)^2}{\left(N_{\text{total}}^{\text{obs}} - N_{\text{bkg}}\right)^2} + \left(\frac{\delta L_{\text{int}}}{L_{\text{int}}}\right)^2 + \left(\frac{\delta\varepsilon_{\text{sig}}}{\varepsilon_{\text{sig}}}\right)^2}$$

$$= \sqrt{\frac{\left(\delta N_{\text{total}}^{\text{obs}}\right)^2 + \left(\delta N_{\text{bkg}}\right)^2}{\left(N_{\text{sig}}^{\text{obs}}\right)^2} + \left(\frac{\delta L_{\text{int}}}{L_{\text{int}}}\right)^2 + \left(\frac{\delta\varepsilon_{\text{sig}}}{\varepsilon_{\text{sig}}}\right)^2}$$

☞ Optimize selection to enhance signal

☞ Reduce uncertainty on the signal efficiency and background estimation

Ingredients To Get Cross Section

$$\sigma = \frac{\left(N_{\text{total}}^{\text{obs}} - N_{\text{bkg}}\right)}{L_{\text{int}}\varepsilon_{\text{sig}}} \Rightarrow \frac{d^2\sigma}{dp_T d\eta} = \frac{\left(N_{\text{total}}^{\text{obs}} - N_{\text{bkg}}\right)}{L_{\text{int}}\varepsilon_{\text{sig}}\Delta p_T \Delta\eta}$$

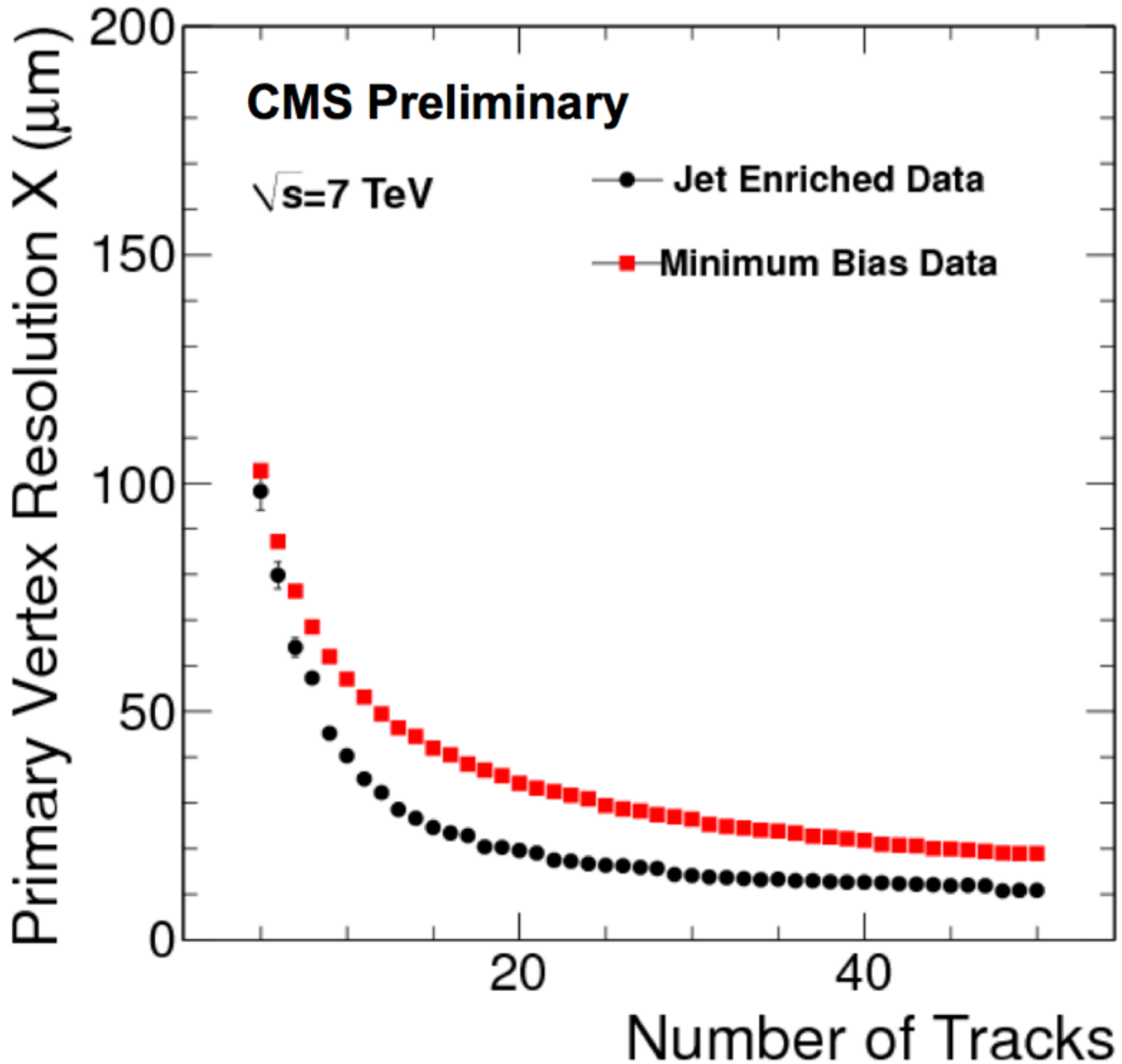
p_T, η: kinematic variables

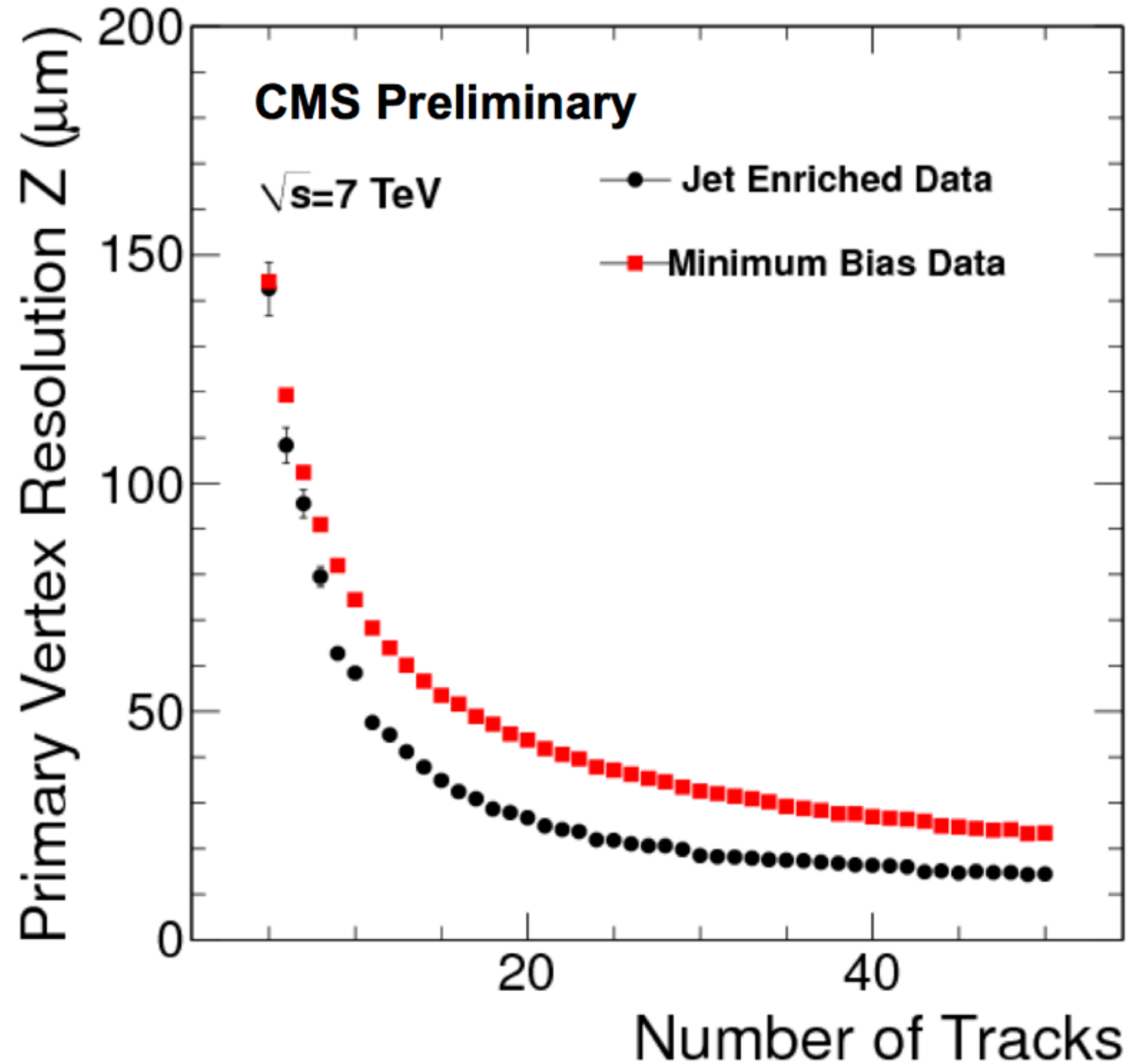
ε_{sig} : efficiency to reconstruct/ID signal

Predictions On The Market

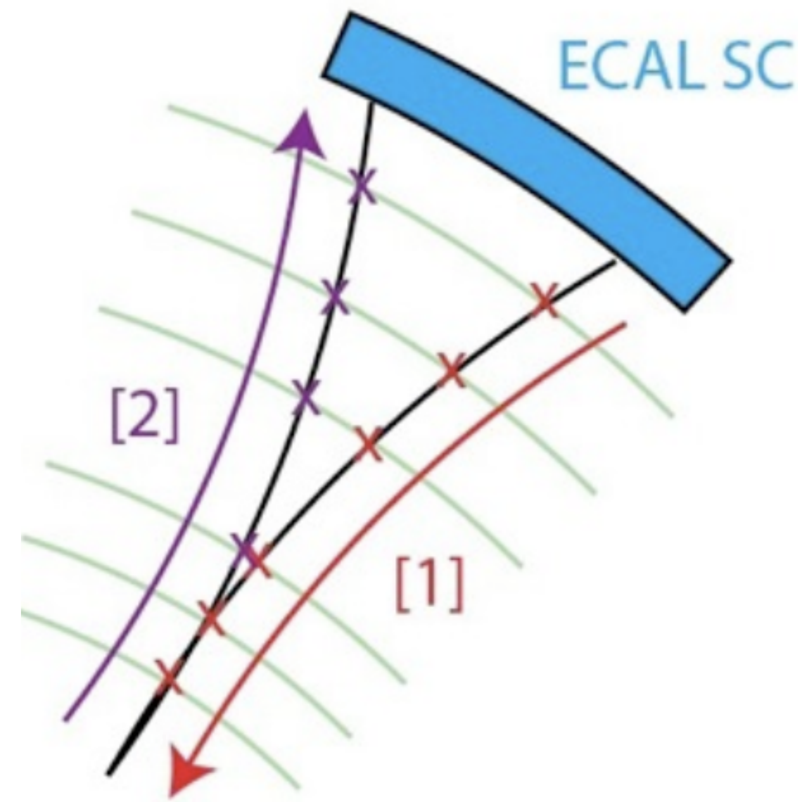
- LO matrix element + matching to parton shower (PYTHIA, HERWIG)
  - **ALPGEN**, **MADGRAPH**, **SHERPA** (CKKW or MLM matching)
- Fixed-order NLO calculation
  - **Blackhat-Sherpa**: NLO up to Z + ≥4 jets, W + ≥5 jets
  - **Rocket + MCFM**: NLO up to W + ≥3 Jets
  - **MCFM**: NLO up to W/Z + ≥2 Jets
- Fixed-order NLO + parton shower
  - **POWHEG** + **PYTHIA**, **aMC@NLO**, **SHERPANLO**
- Resummation
  - **HEJ**: all-order resummation of perturbative contribution of wide angle emission (for ≥2 Jets)
- Approximate NNLO
  - **LOOPSIM+MCFM** (JHEP 1009 (2010) 084)
- NLO QCD ⊗ NLO EW (JHEP 1106 (2011) 069)

Cms Primary Vertex Resolution





Explicitly Reconstruct Converted Photons

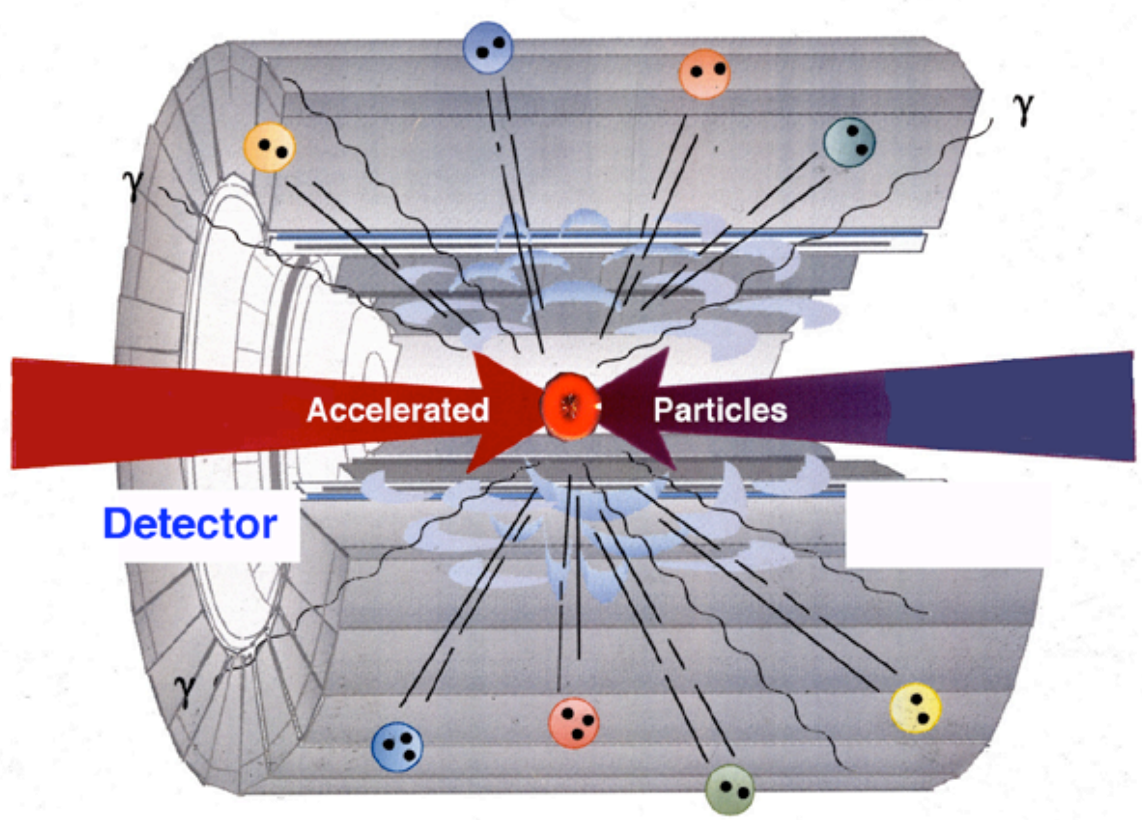


- Start from ECAL cluster, going inwards to find hits in the tracker
  - the search road depends on energy measured in ECAL
- From the inner most layer where the track ends, going outwards to find the second track
- Alternative method by starting from tracker

Fixed Target And Collider Experiments

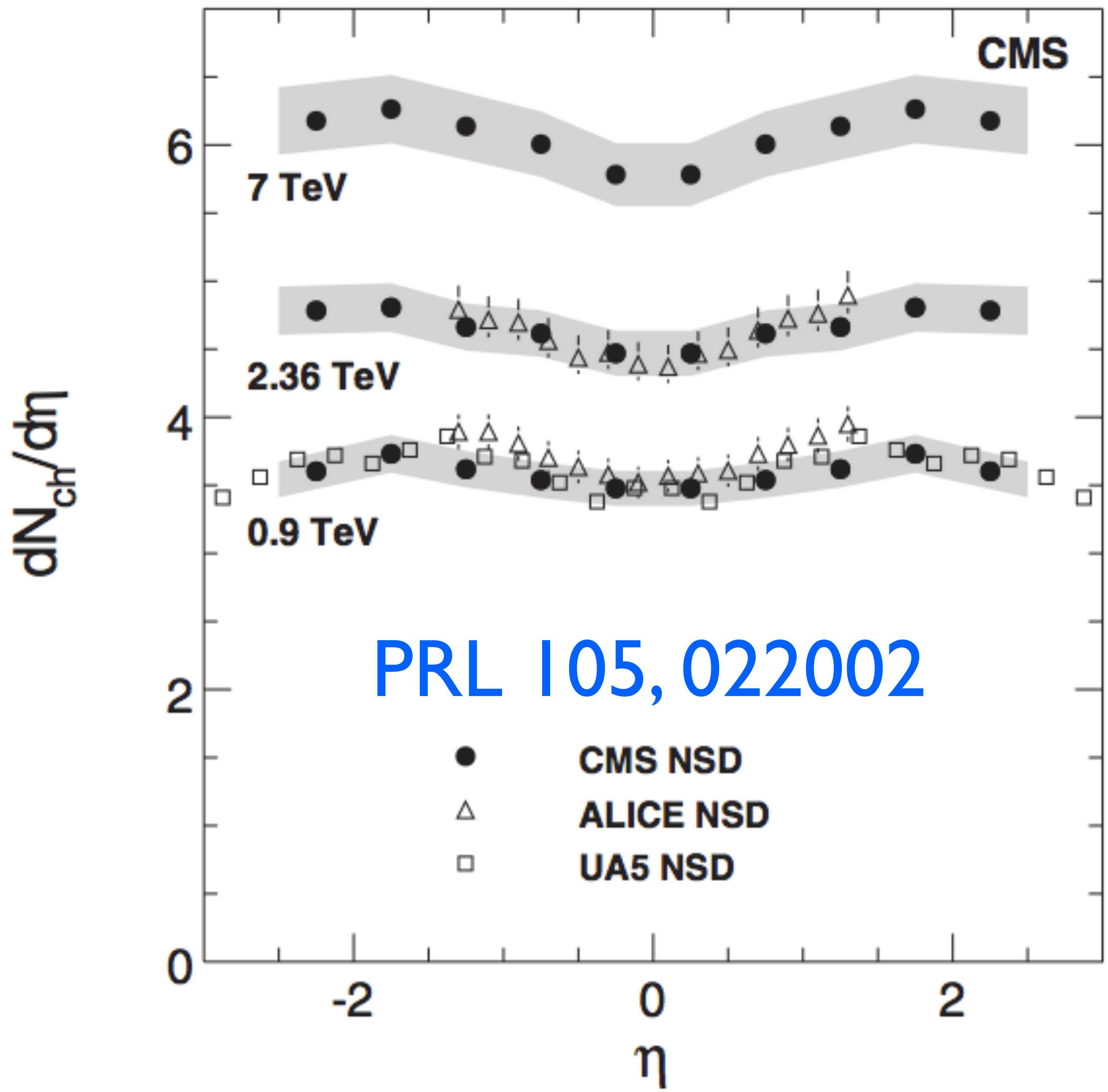
$$E_{CM} \sim \sqrt{2m_t E_b}$$

Assuming $\mathrm{E} \gg m_t, m_b$



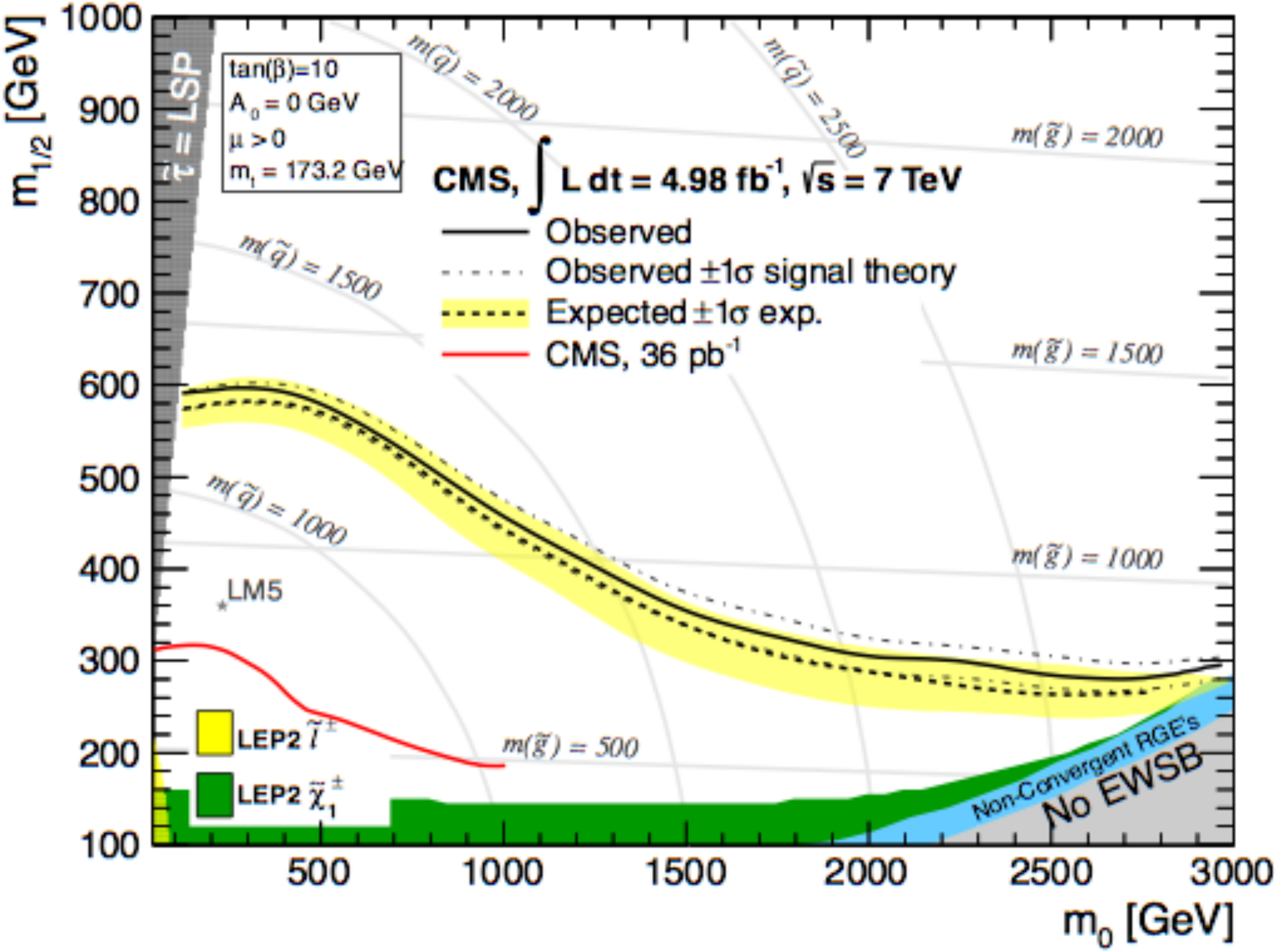
$$E_{CM} \sim \sqrt{4E_1E_2}$$

Dn/Deta



CMS
7 TeV
2.36 TeV
0.9 TeV
PRL 105, 022002
CMS NSD
ALICE NSD
UA5 NSD
$dN_{ch}/d\eta$
η
0
2
4
6
-2
0
2

Susy Result



tan(β)=10
A0 = 0 GeV
μ > 0
mt = 173.2 GeV
CMS, ∫ L dt = 4.98 fb-1, √s = 7 TeV
Observed
Observed ±1σ signal theory
Expected ±1σ exp.
CMS, 36 pb-1
τ̃ = LSP
m(q̃) = 2000
m(q̃) = 2500
m(q̃) = 1500
m(q̃) = 1000
m(g̃) = 2000
m(g̃) = 1500
m(g̃) = 1000
m(g̃) = 500
LM5
LEP2 l̃±
LEP2 χ̃±1
Non-Convergent RGE's
No EWSB
m1/2 [GeV]
m0 [GeV]
1000
900
800
700
600
500
400
300
200
100
500
1000
1500
2000
2500
3000

Lhc Facts

Parameter	Design Value	2010	2012
Center of Mass Energy	14 TeV	7 TeV	8 TeV
# of bunches	2808	312	1374
Bunch Spacing (ns)	25	150	50
# of protons per bunch	5,000,000,00	1E+11	1.6-1.7E+11
Peak Luminosity (/cm*cm/sec)	1E+34	1.48E+32	7.73E+33
# of collisions per bunch	25	2	21
Interaction Rate (Hz)	1E+09	1E+07	4E+08

Un-Interesting Vs Interesting Events