A Tale of Two Uncertainties:

Analyzing P_T Bias and its Effects on the Dimuon Mass Spectrum

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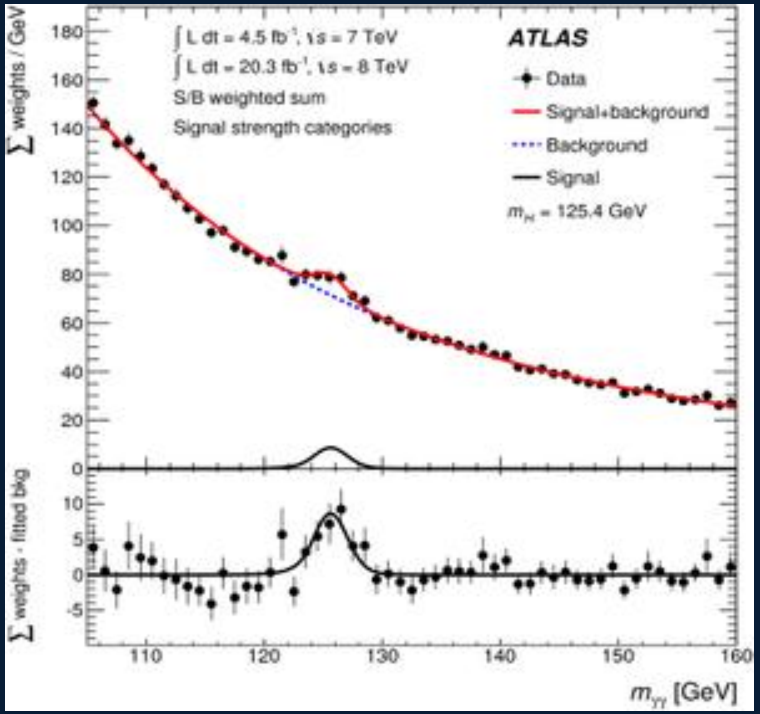
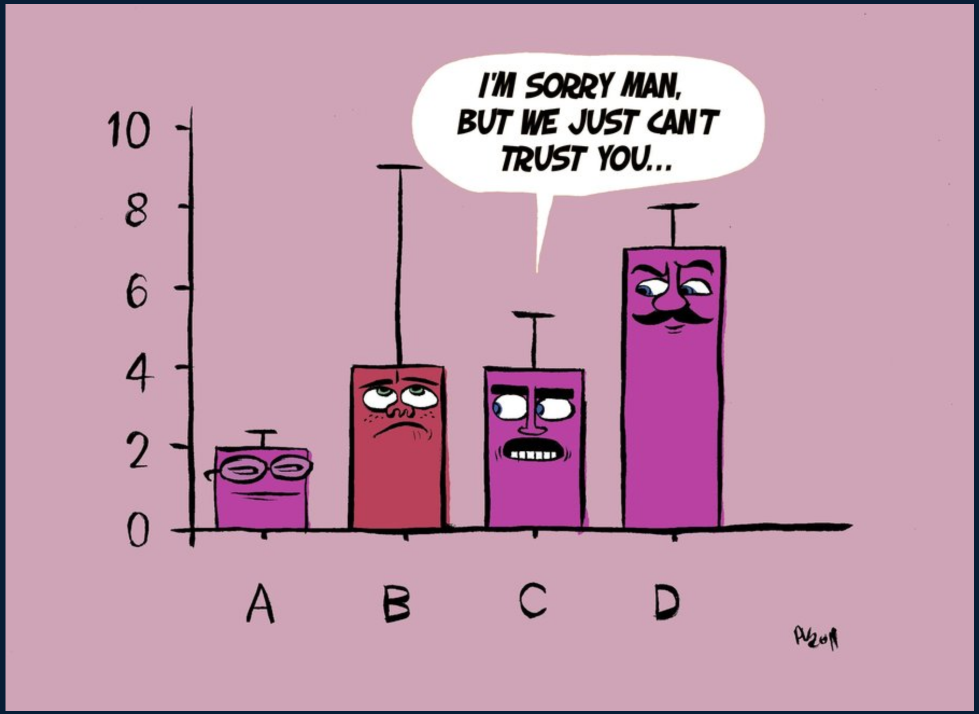
Fermilab, *CMS*

Why Uncertainty Matters

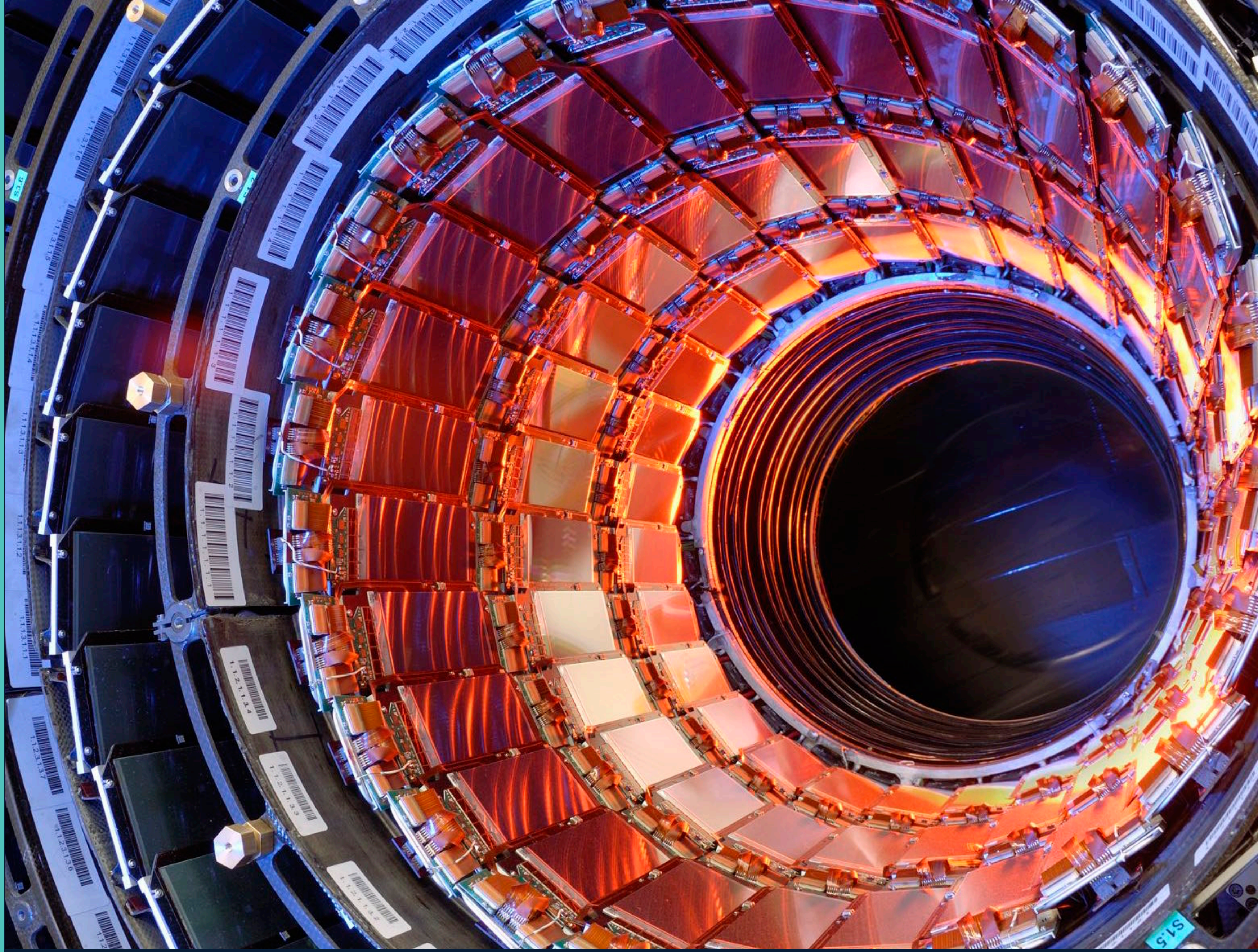
- It changes conclusions!
  - Ex: particle identification based on peaks



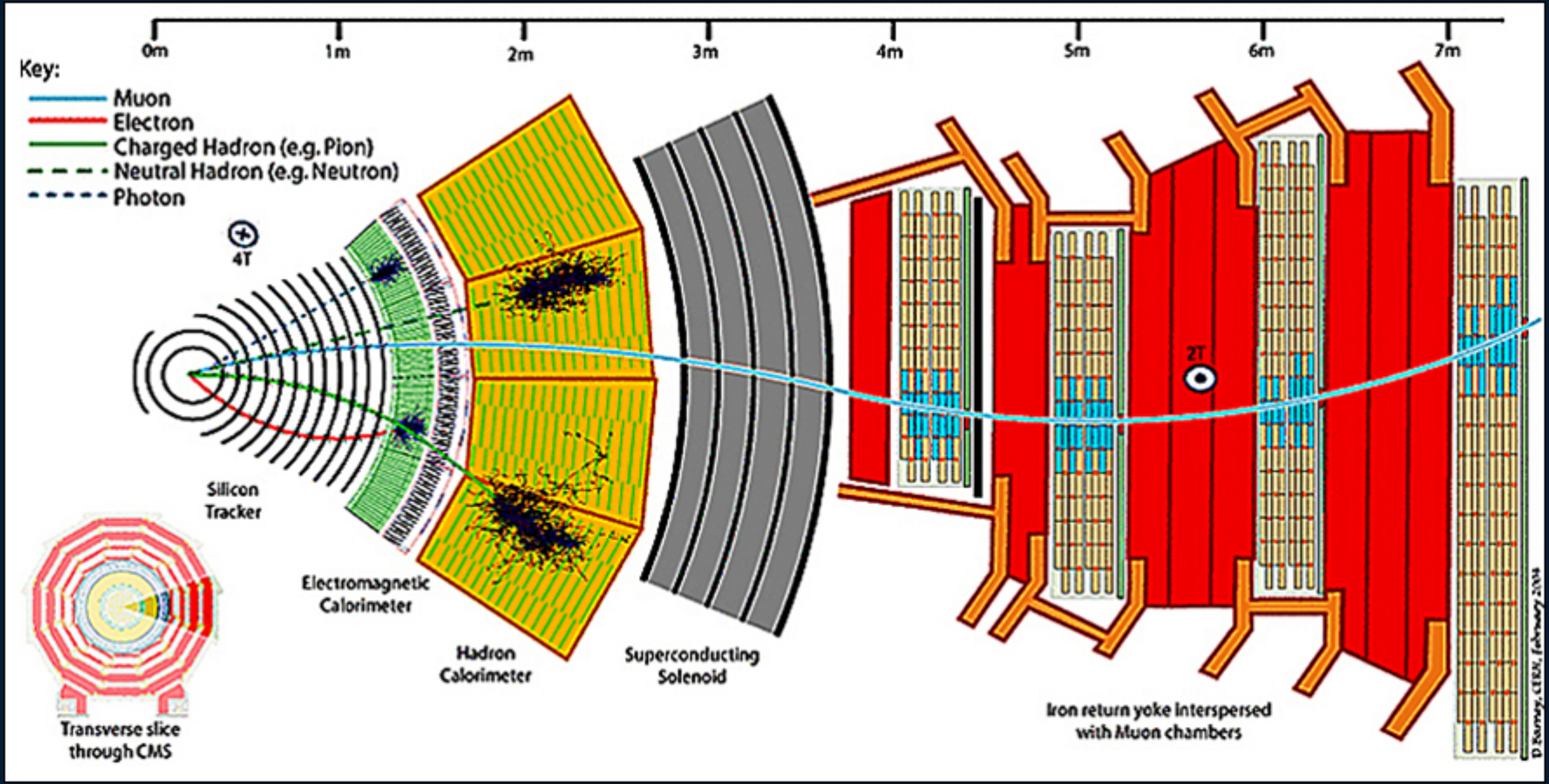


Compact Muon Solenoid (CMS) Detector

A general purpose LHC detector

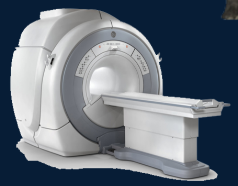


The Layers of CMS



CMS Specs

- Heaviest LHC detector
- 2nd largest general purpose detector in volume
- 100 meters underground
- 14 million kgs = 14,000  = 5,000 
- 4 T magnet = 100,000 

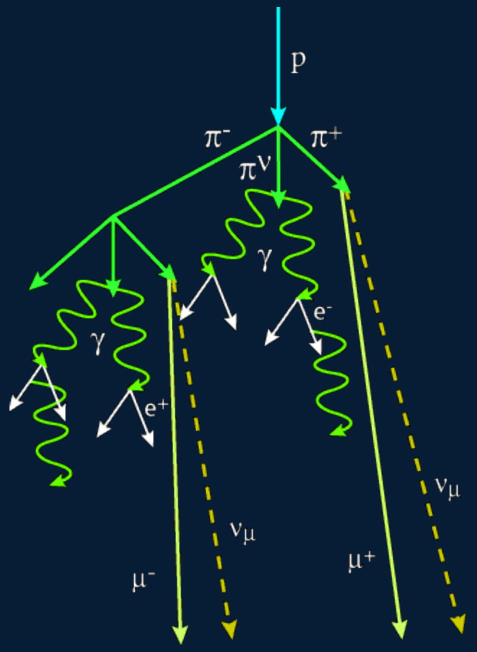
= 2.7 
- 5 layers – silicon tracker, EM calorimeter, hadron calorimeter, solenoidal magnet, muon detection layer

My Data

Cosmic muon data collected from CMS in 2015

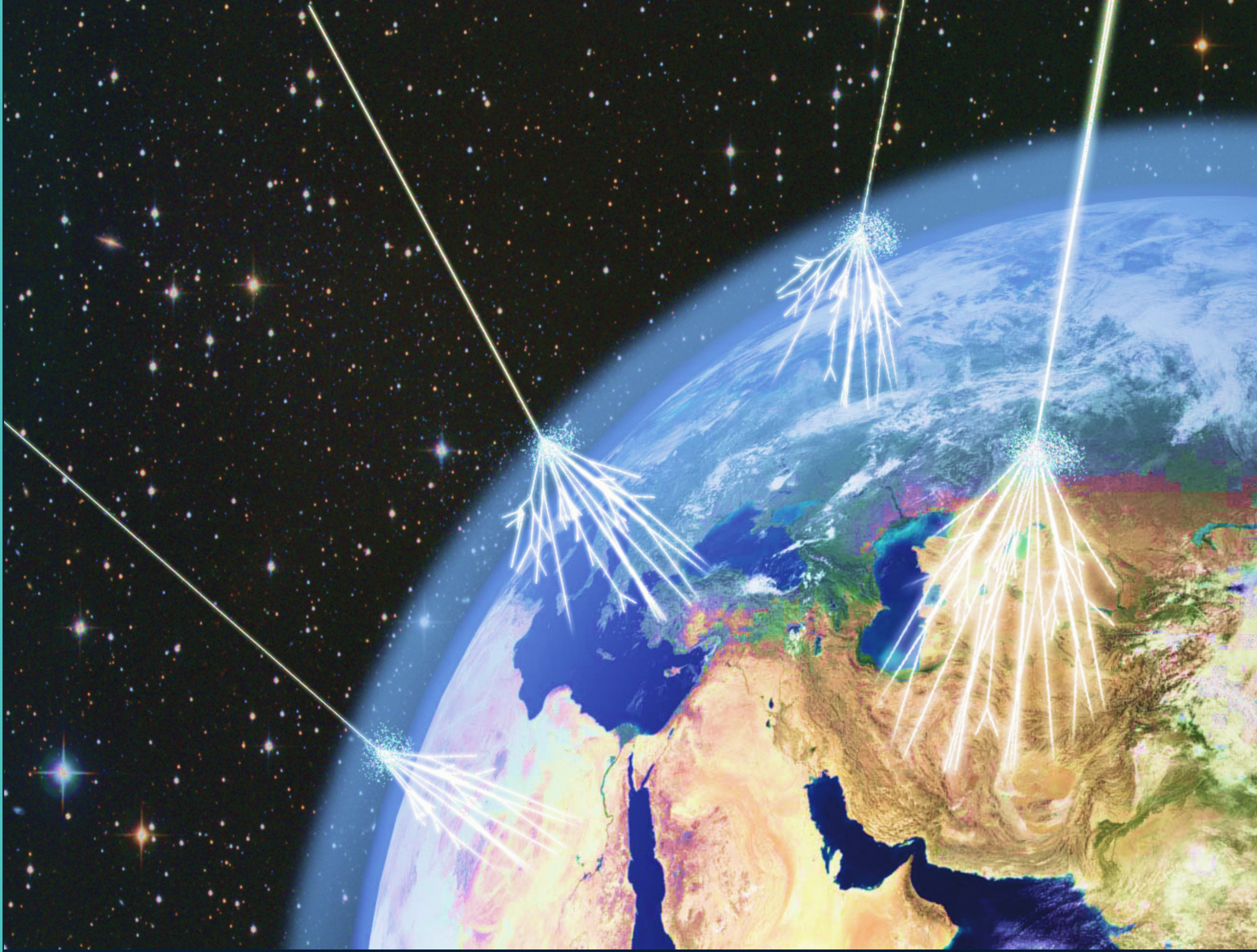
Monte carlo simulations of cosmic muons

Simulations of collision events generated in Pythia8

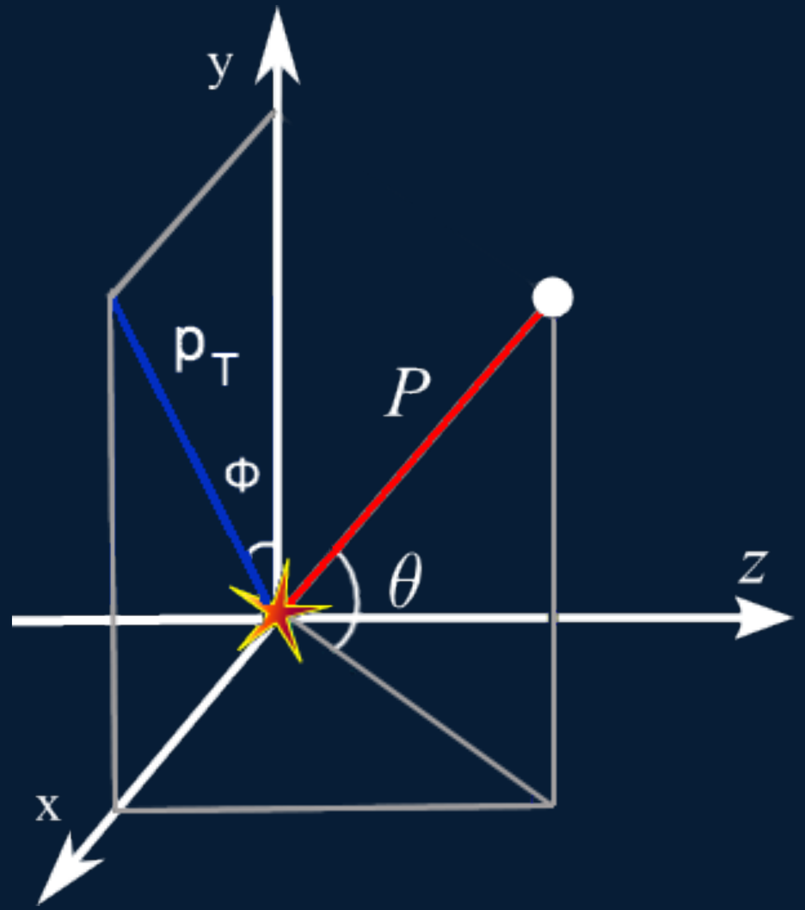


Cosmic Endpoint Method

Measuring uncertainty in p_T



What Kind of Measurements?



- These variables can be used to calculate virtually every property of the particle we're interested in!
- Physicists also like to use η

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

- In my study, I studied distributions of p_T

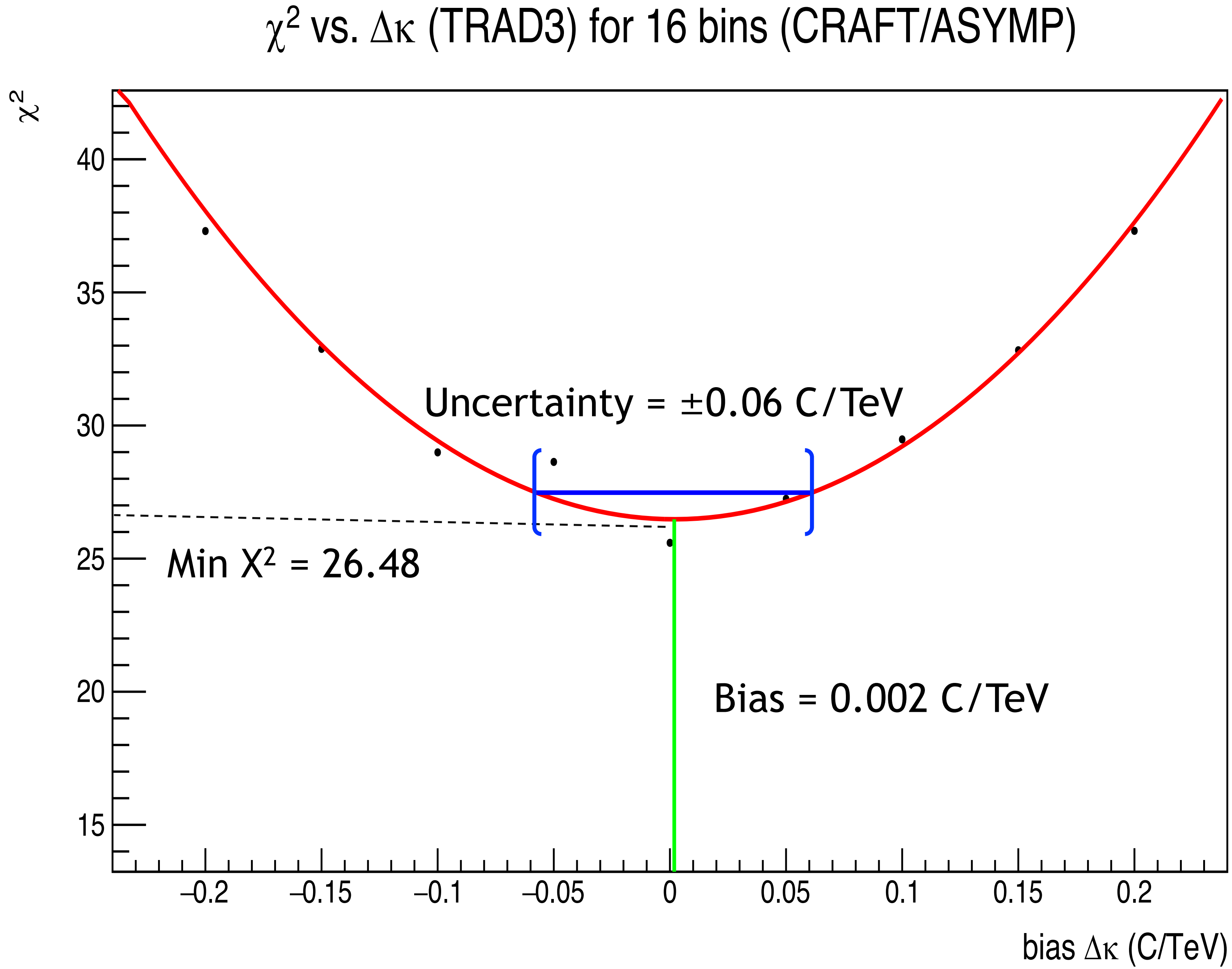
The Study

- Assume: detector has systematic error or bias that causes p_T to be scaled up by factor that depends on p_T
  - $p_T' = \alpha\, p_T$ where α depends linearly on p_T
- This is equivalent to a constant shift in curvature $\kappa = \frac{q}{p_T} = \frac{\pm 1}{p_T}$
- Procedure
  1. Make p_T histograms
  2. Calculate and make κ histograms
  3. Apply shift to κ of simulation
  4. Compare data and simulation
  5. Rinse and repeat

RESULTS

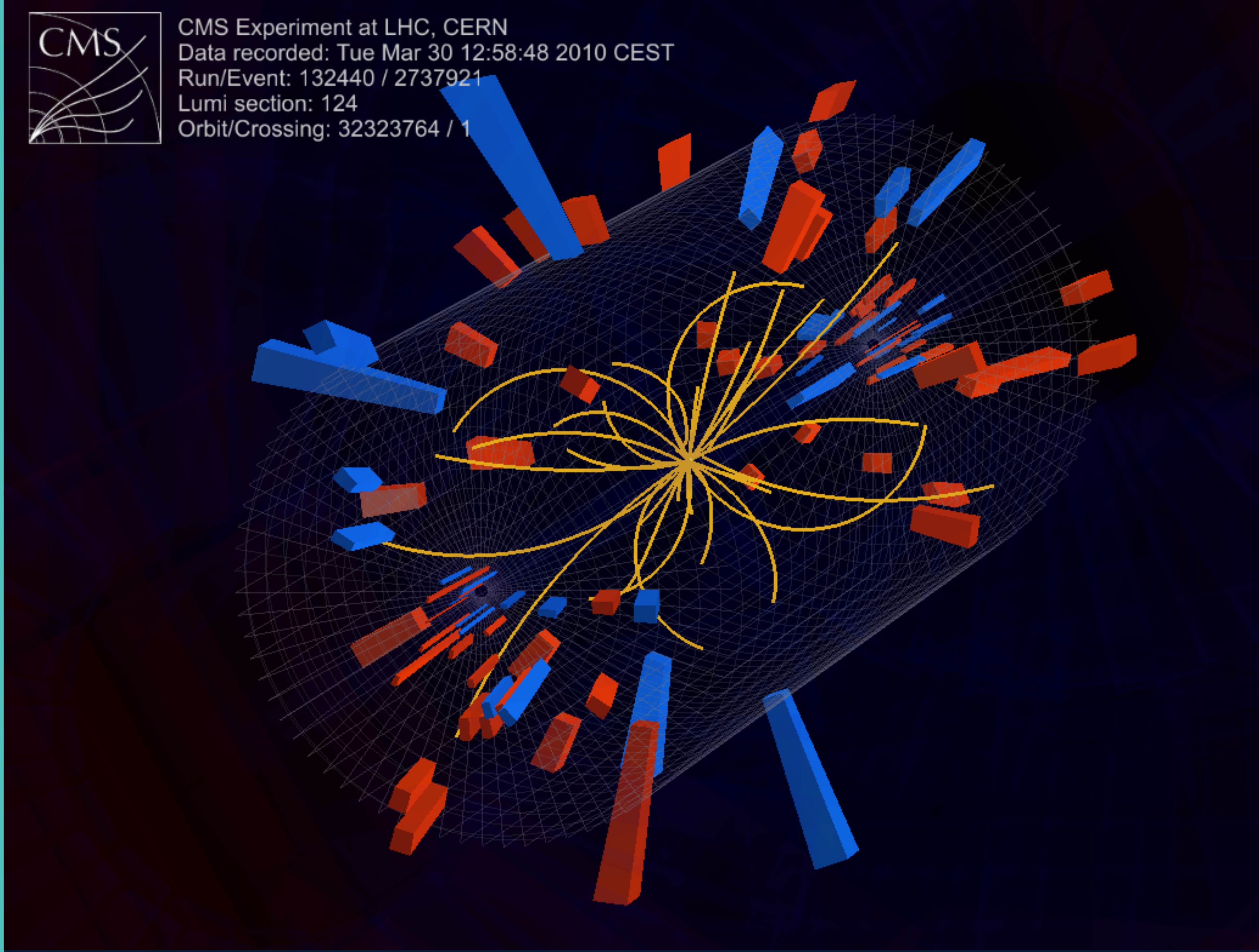
The bias in the detector is very small!

...but now we have uncertainty...



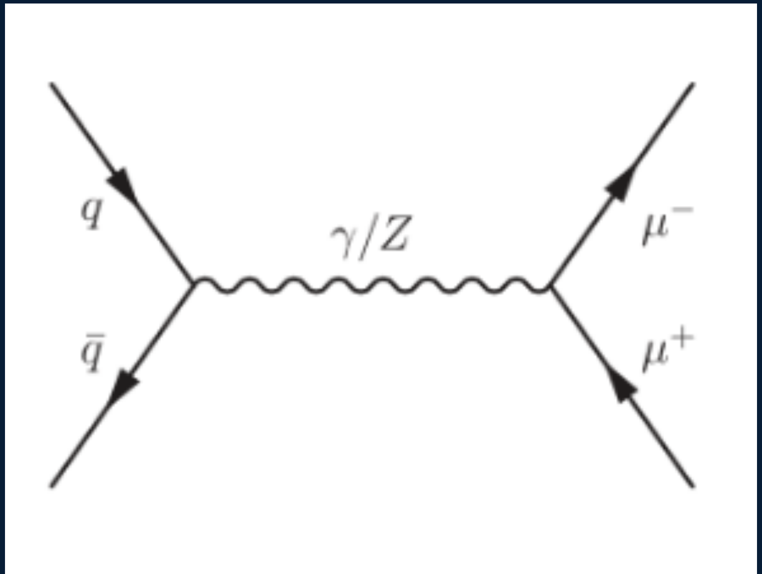
Relative Difference Study

Propagating uncertainty in p_T to the mass spectrum



Quark Compositeness

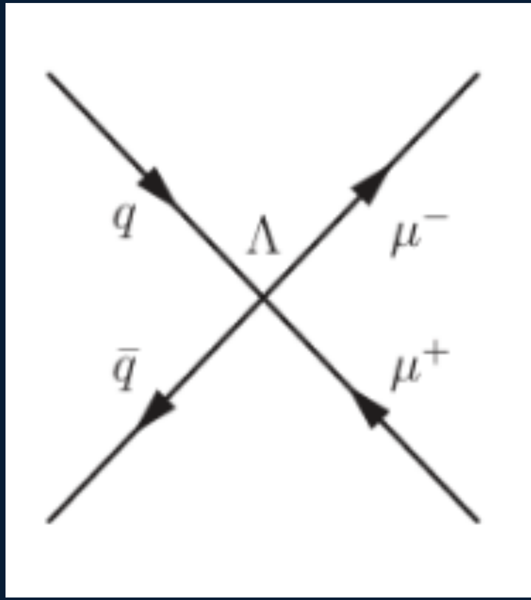
Drell-Yan (DY)



$q\bar{q} \rightarrow Z\ /\ \gamma^* \rightarrow\ \ l^+l^-$

Z boson intermediate

Contact Interaction (CI)



$q\bar{q} \rightarrow l^+l^-$

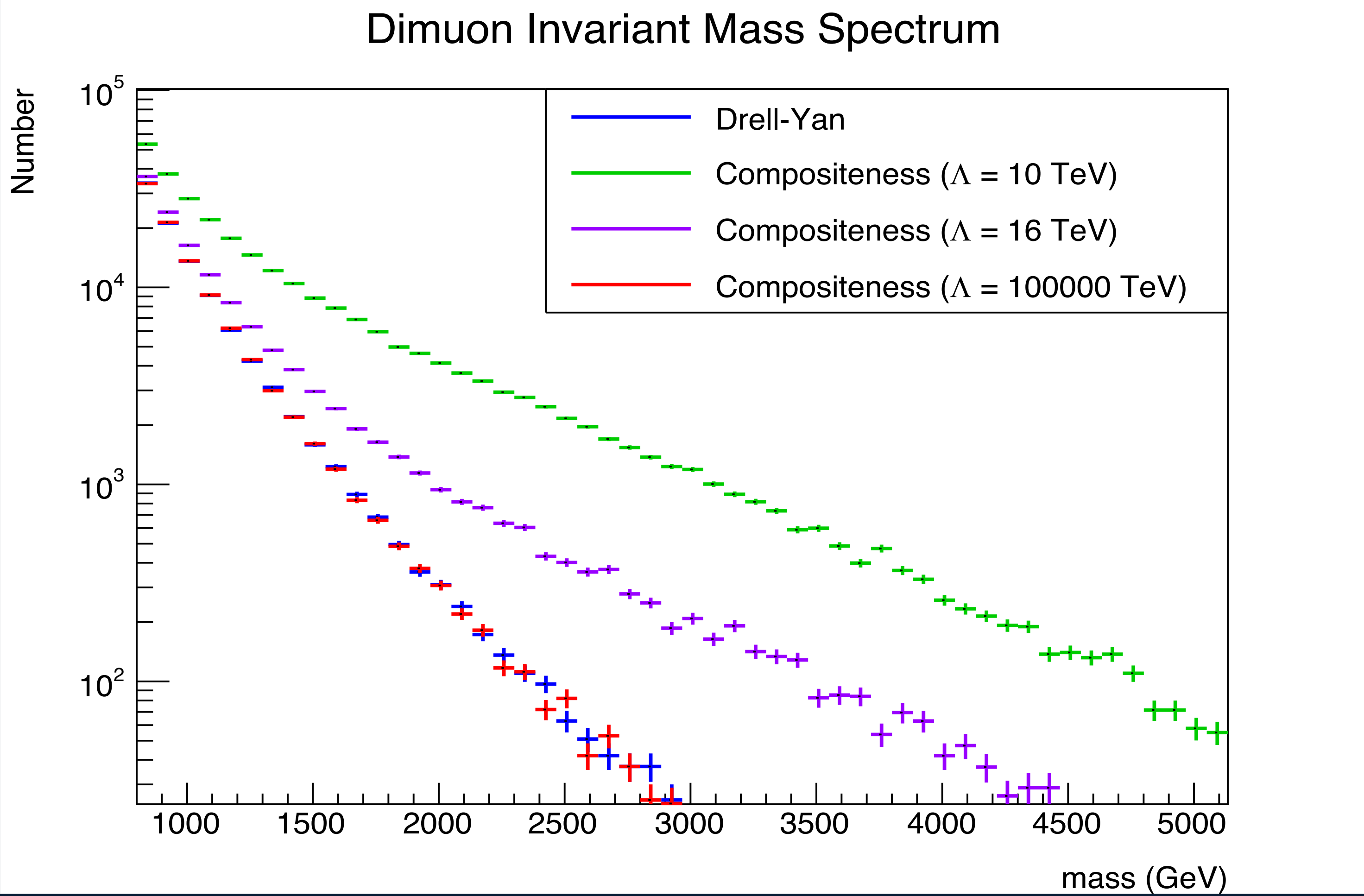
No Z boson intermediate

Invariant Mass

- Is the rest mass of the two-muon system
  - NOT the sum of the rest masses!!
- By conservation of mass-energy, should be more or less equivalent to the mass of the parent Z boson
- Derived from $E^2 = (m_0c^2)^2 + (pc^2)^2$
- In the highly relativistic (E >> m) case, approximates to

$$M = \sqrt{2p_{\mathrm{T}_1}p_{\mathrm{T}_2}\left(\cosh\left(\eta_1 - \eta_2\right) - \cos\left(\phi_1 - \phi_2\right)\right)}$$

Drell-Yan vs. Contact Interaction

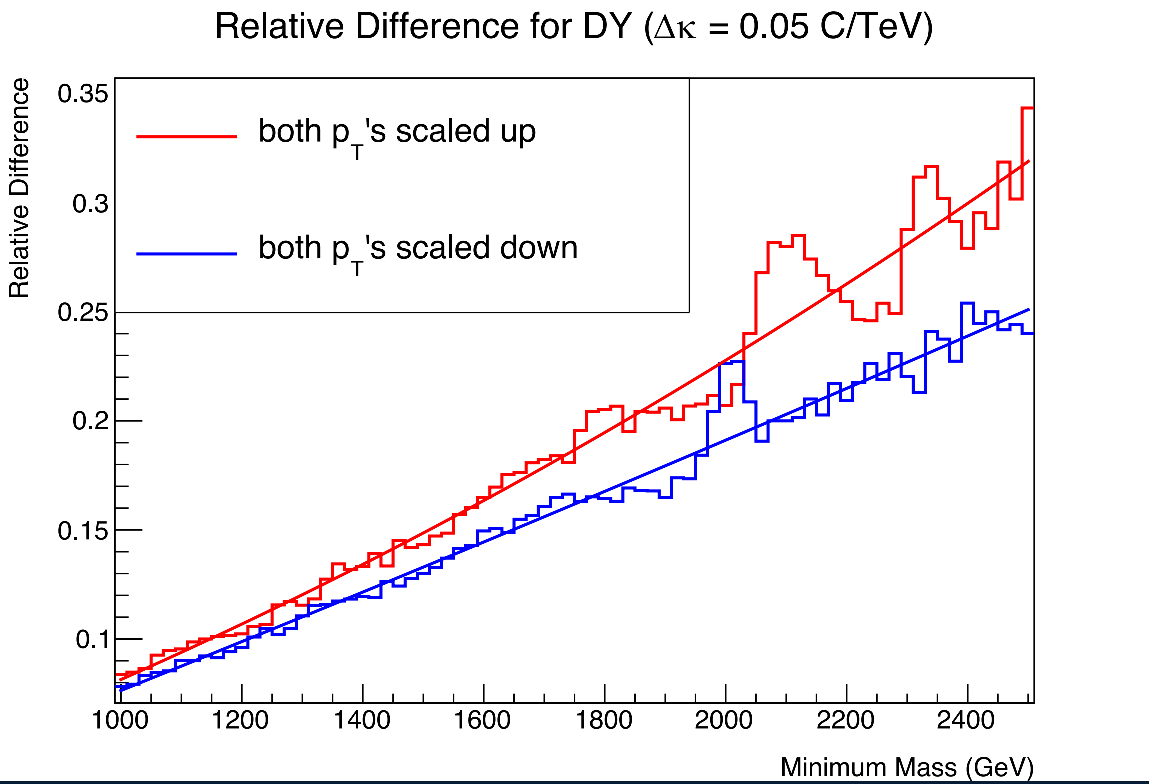


The Study

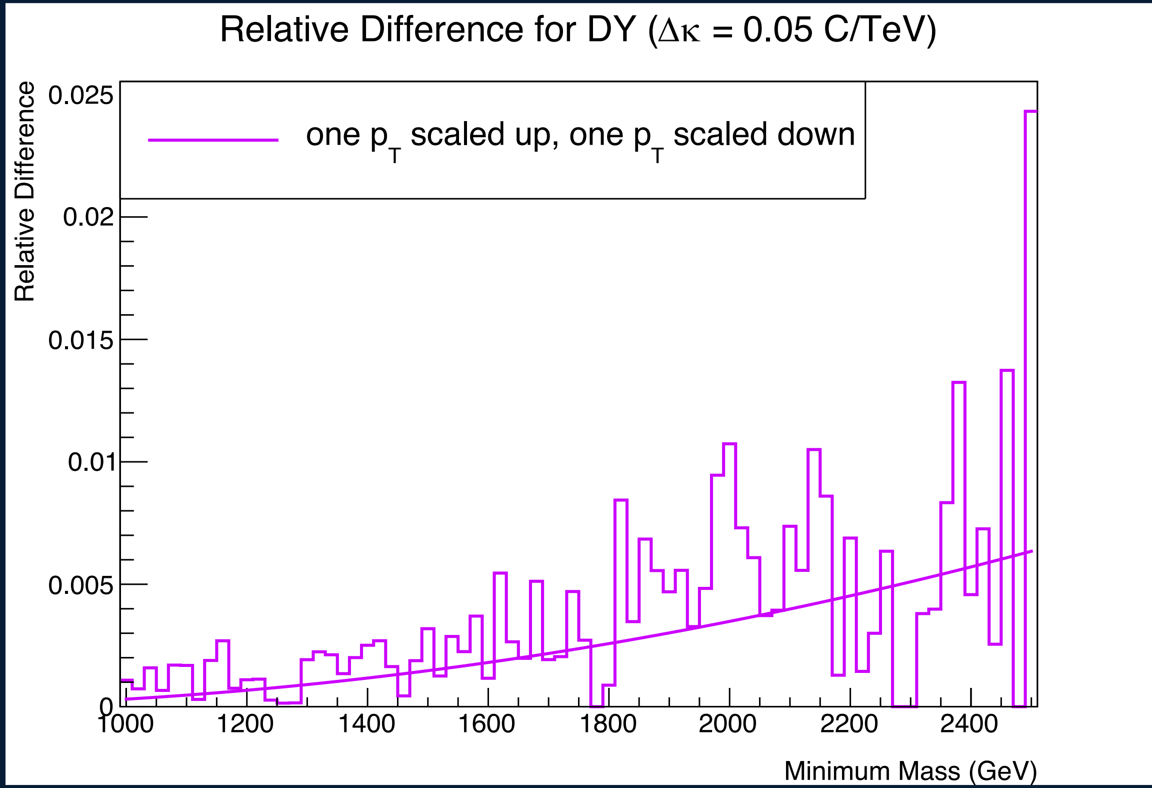
- Recalculate the masses using a shifted value of p_T
  - shifting $\kappa \rightarrow$ shifted $p_T \rightarrow$ shifted mass
- Perform a counting experiment!
  1. Pick a minimum mass
  2. Count up the number of entries above that mass value in the unshifted spectrum
  3. Count again for the shifted spectrum
  4. Calculate the relative difference between the shifted and unshifted mass spectra

$$\text{Relative Difference} = \frac{|\text{Shifted Integral} - \text{Unshifted Integral}|}{\text{Unshifted Integral}}$$

RESULTS



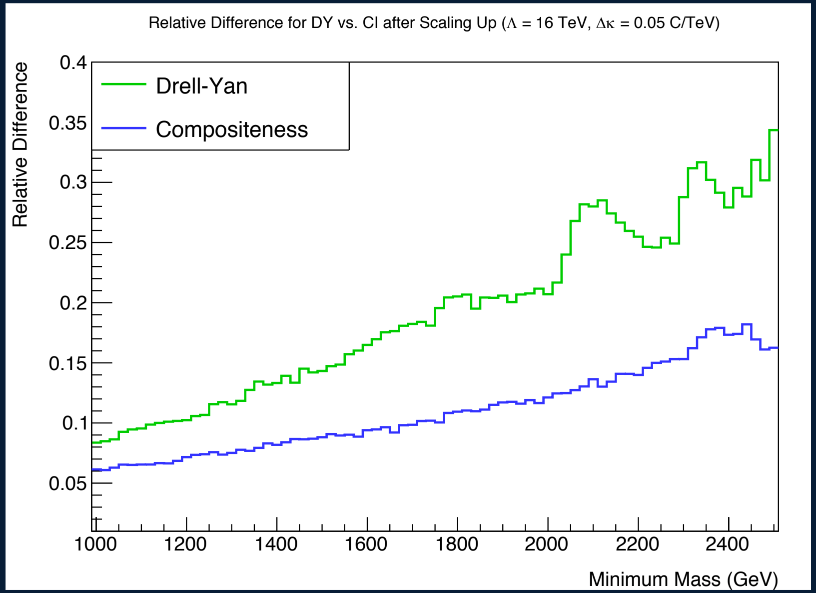
Relative Difference for DY (Δκ = 0.05 C/TeV)
both p_T's scaled up
both p_T's scaled down
Relative Difference
0.35
0.3
0.25
0.2
0.15
0.1
1000
1200
1400
1600
1800
2000
2200
2400
Minimum Mass (GeV)

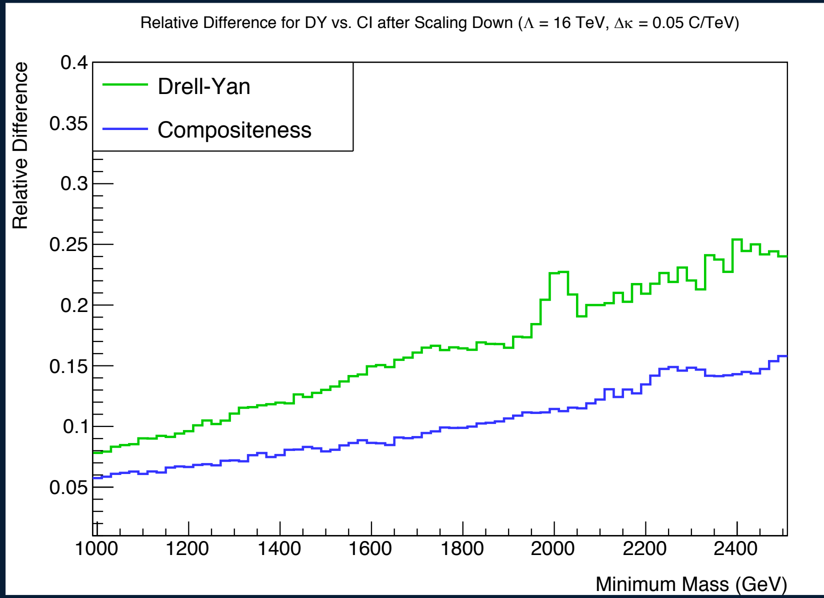


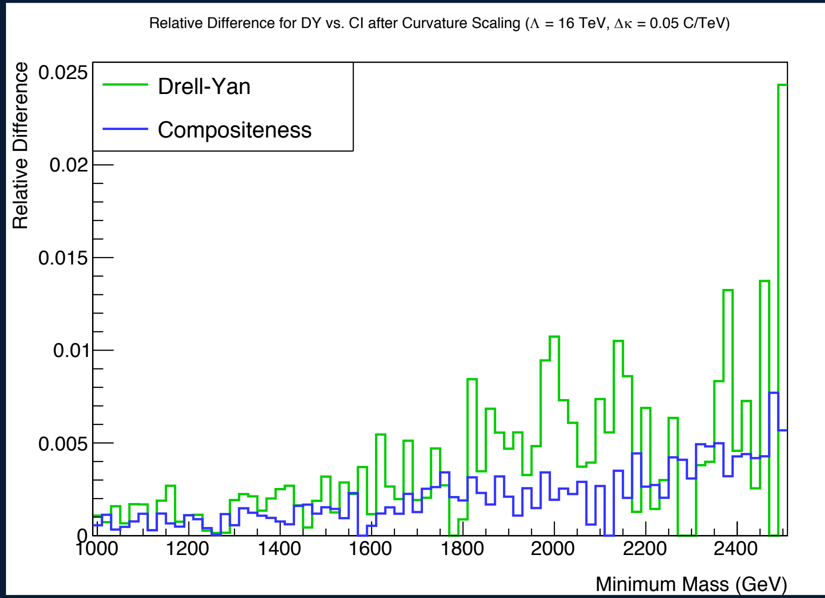
Relative Difference for DY (Δκ = 0.05 C/TeV)
one p_T scaled up, one p_T scaled down
Relative Difference
0.025
0.02
0.015
0.01
0.005
0
1000
1200
1400
1600
1800
2000
2200
2400
Minimum Mass (GeV)

Drell-Yan vs. Contact Interaction

Scaling up	Scaling down	One up, one down

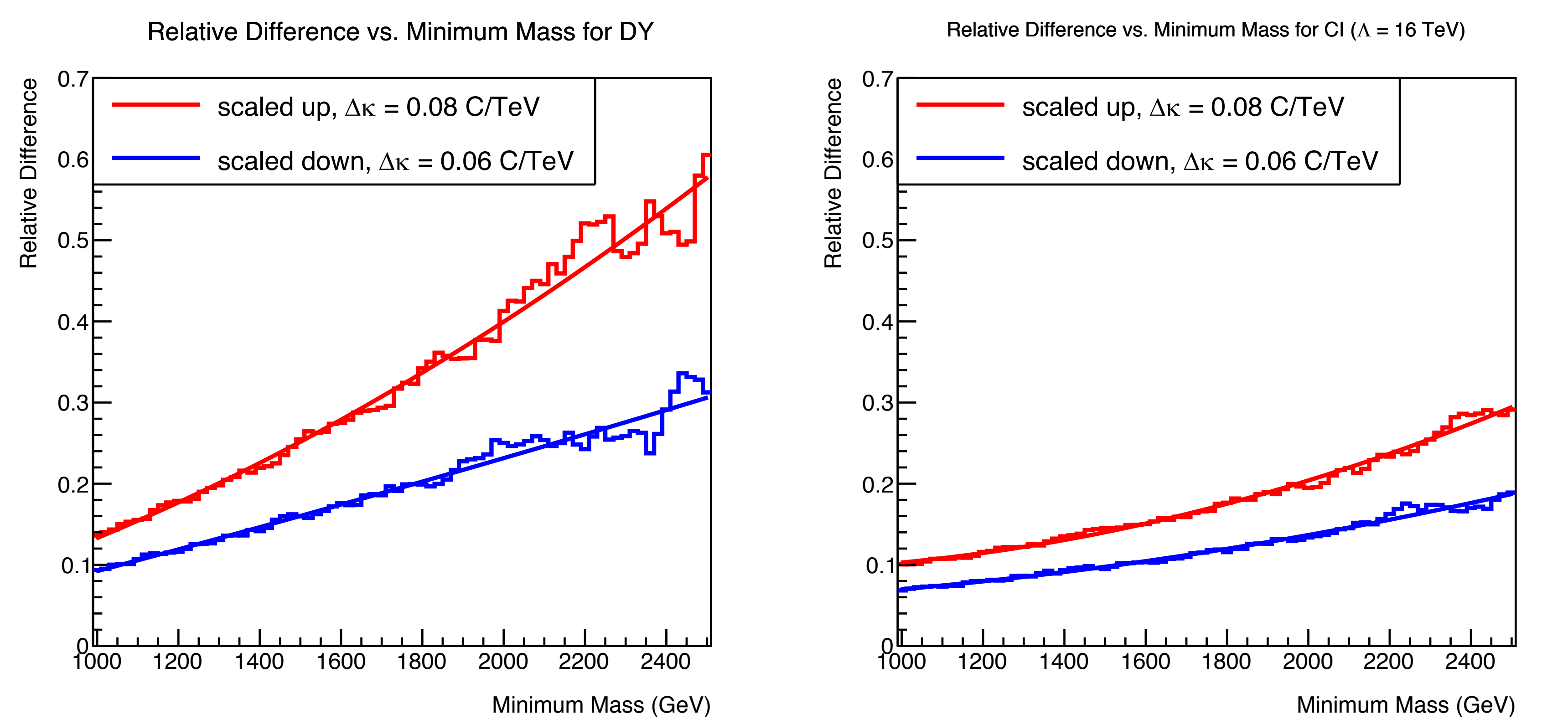






Connecting the dots

Use the uncertainty in p_T obtained by the Cosmic Endpoint Method to get an uncertainty band in the dimuon mass spectrum



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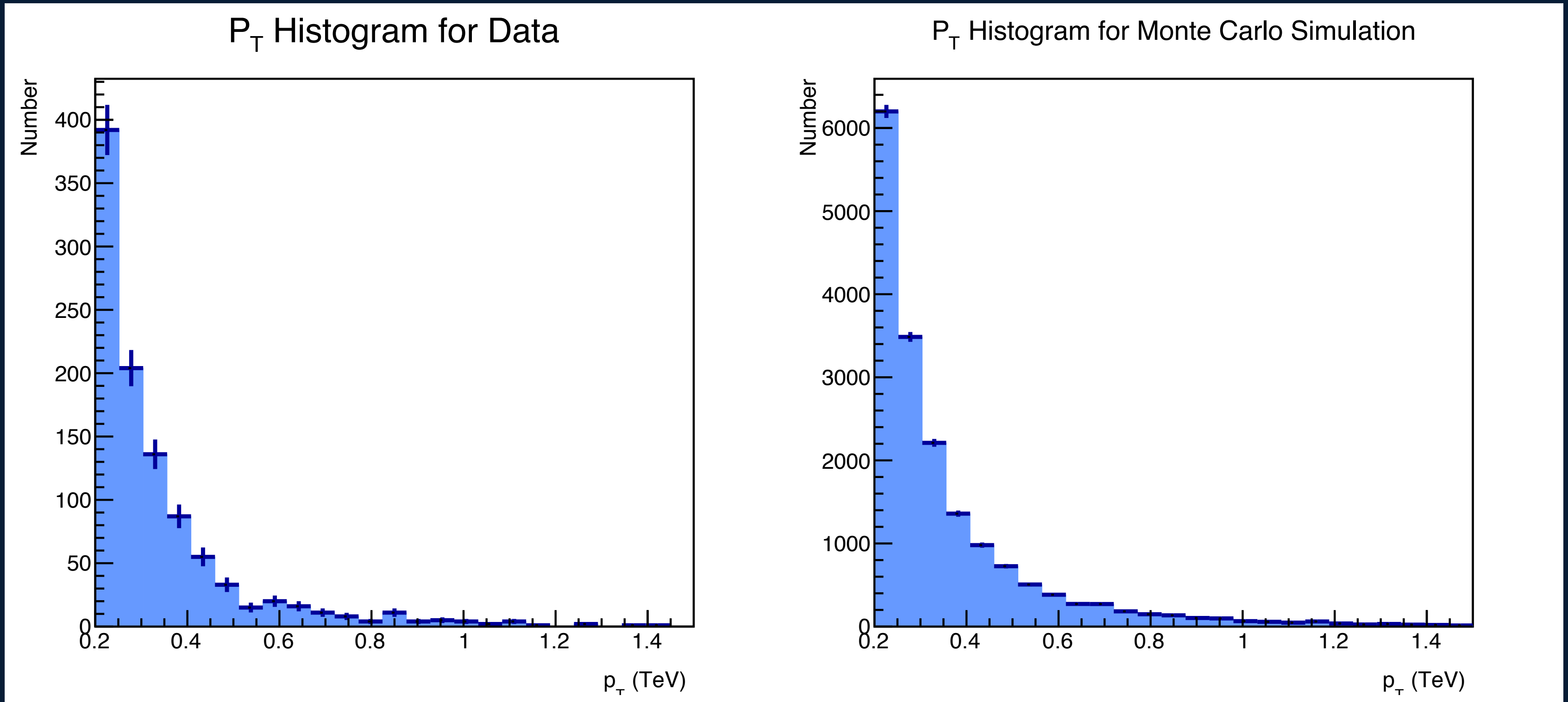
- Dr. Elliott McCrory, Sandra Charles, and the entire SIST committee and staff
- My SIST mentors William Freeman and Jodi Coghill
- You guys!


I THOUGHT I WAS INTERESTED IN UNCERTAINTY BUT NOW I'M NOT SO SURE
TOSHIO

Backup Slides

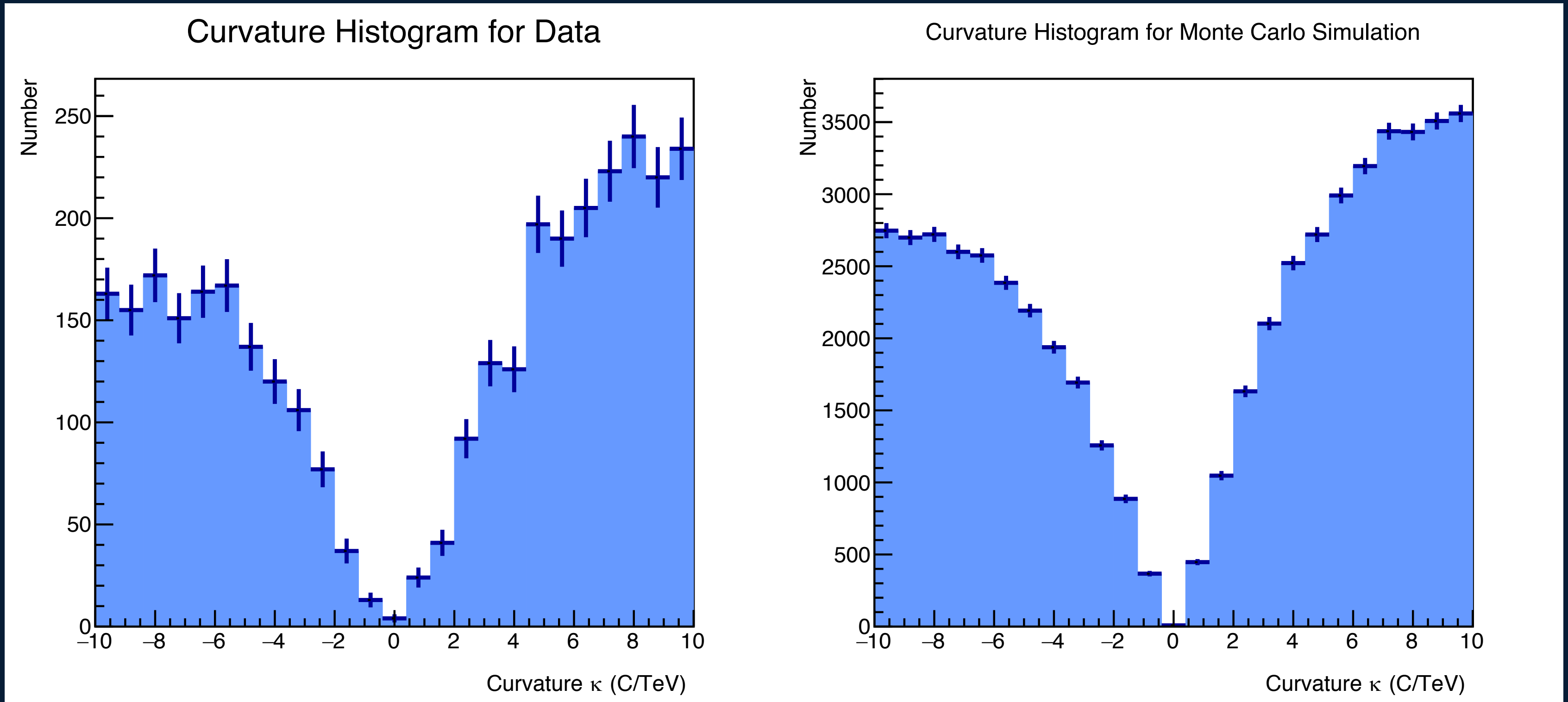
Procedure

1. Calculate and make histograms of p_T



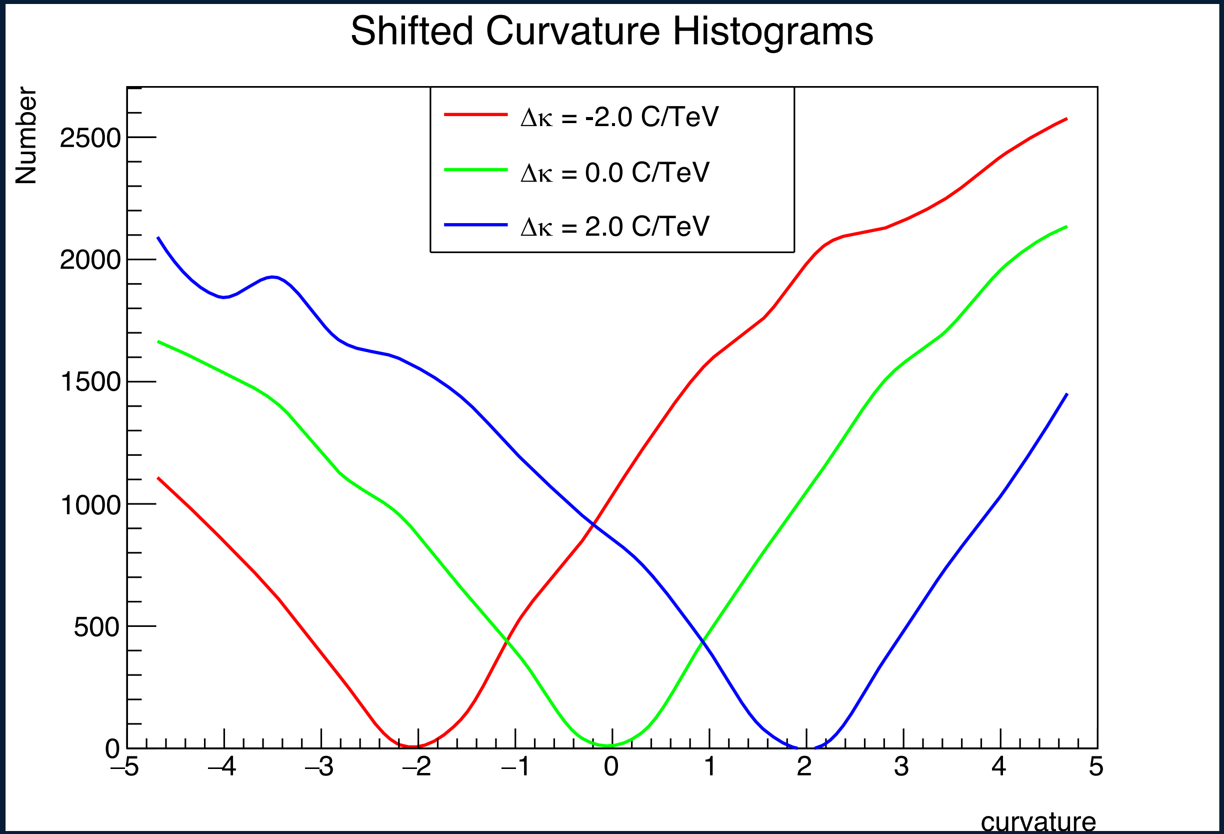
Procedure

2. Calculate and make histograms of κ

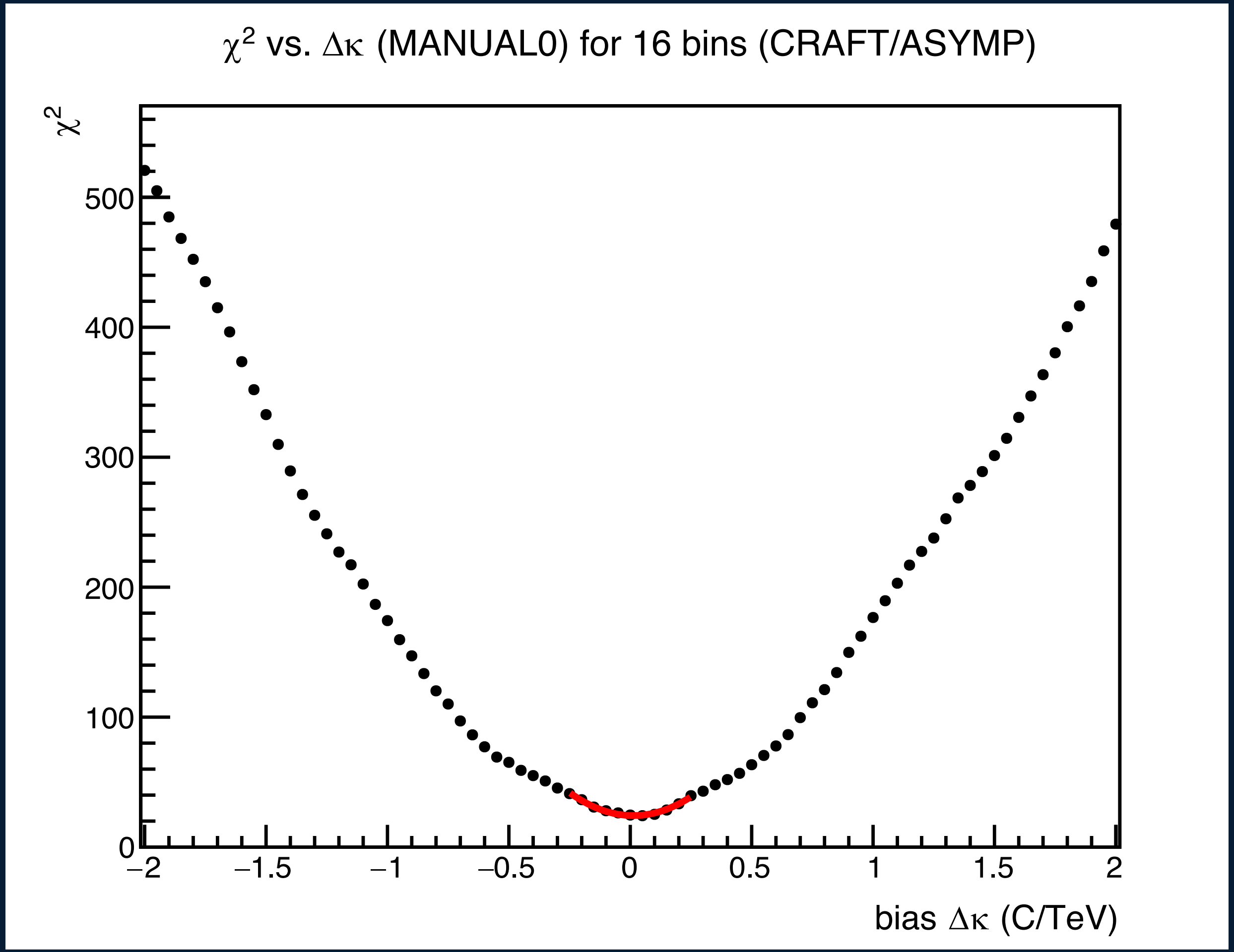


Procedure

3. Apply shift to κ



Comparing Data and Simulation



Compositeness

- Theory that all elementary particles are actually made up the same fundamental building blocks, which are called preons
- If true, would observe compositeness effects at some energy scale Λ
  - So far, not observed up to 9.5 TeV in one model of compositeness, and 13.1 TeV in another model

"The finder of a new elementary particle used to be rewarded by a Nobel Prize, but such a discovery now ought to be punished by a 10,000 dollar fine."

--Willis Lamb

Quark Compositeness

- At some energy scale Λ , can essentially "break apart" quarks without a Z intermediate and get some fraction of DY events and some fraction of CI events
- However, if Λ is infinite (i.e. it takes infinite energy to break the preons apart) that means the quarks are effectively the smallest indivisible particle
  - In this case, all of the events would be DY

$$\frac{d\sigma^{\mathrm{CI/DY}}}{dM_{\mu\mu}} = \frac{d\sigma^{\mathrm{DY}}}{dM_{\mu\mu}} - \eta_{ij}\frac{\mathcal{I}}{\Lambda^2} + \eta_{ij}^2\frac{\mathcal{C}}{\Lambda^4},$$

Additional terms for CI events