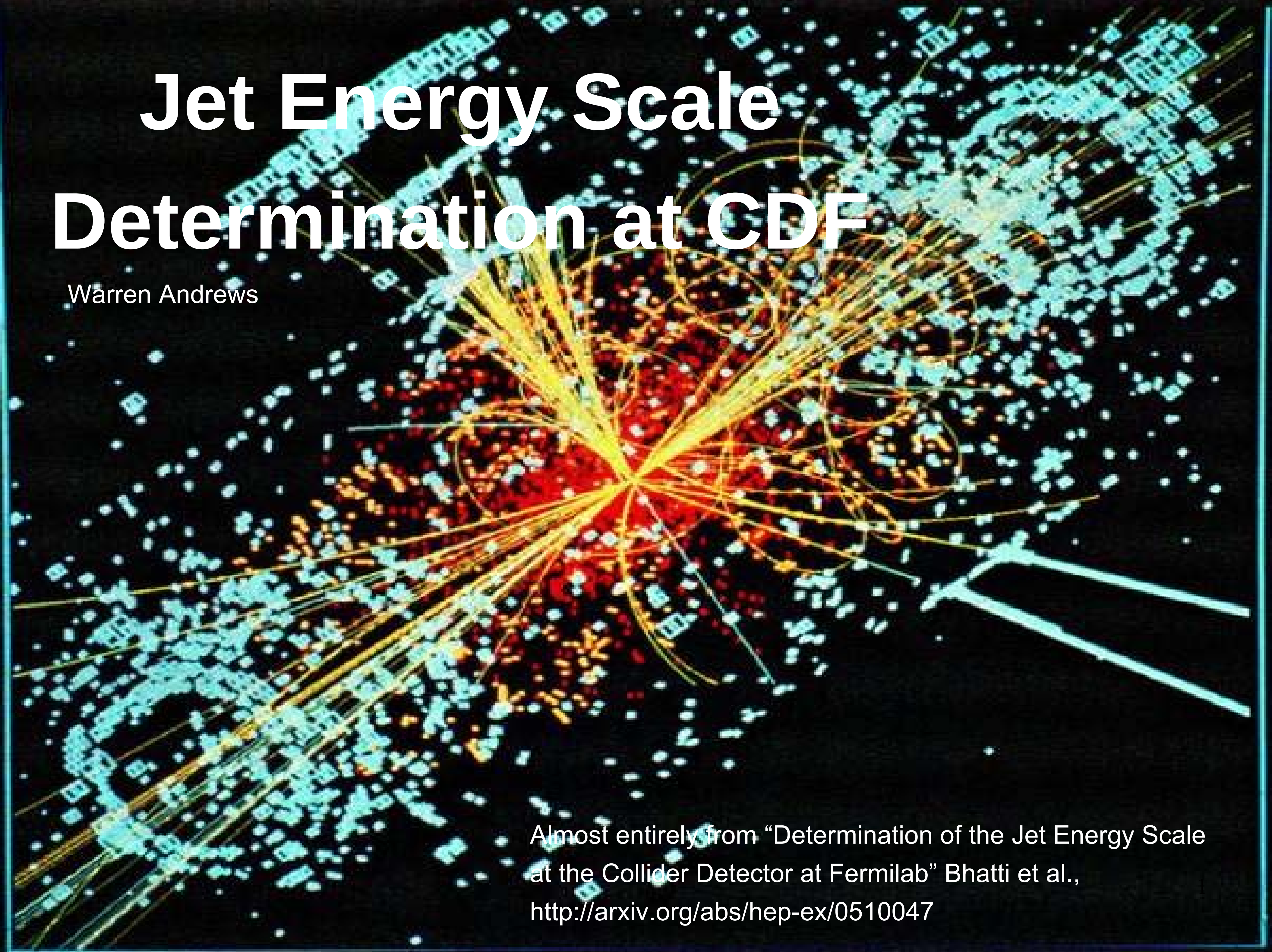
Jet Energy Scale Determination at CDF

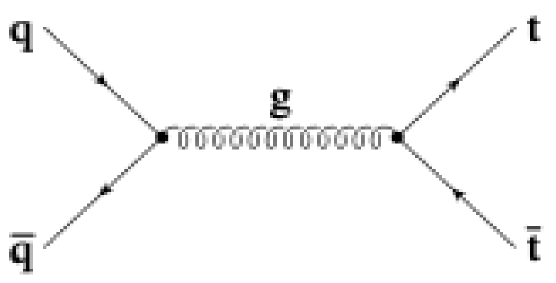
Warren Andrews

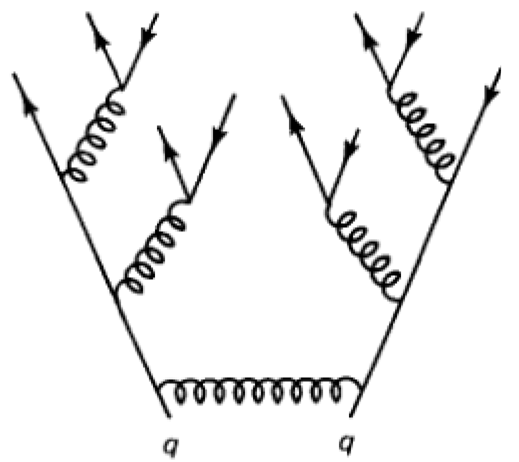


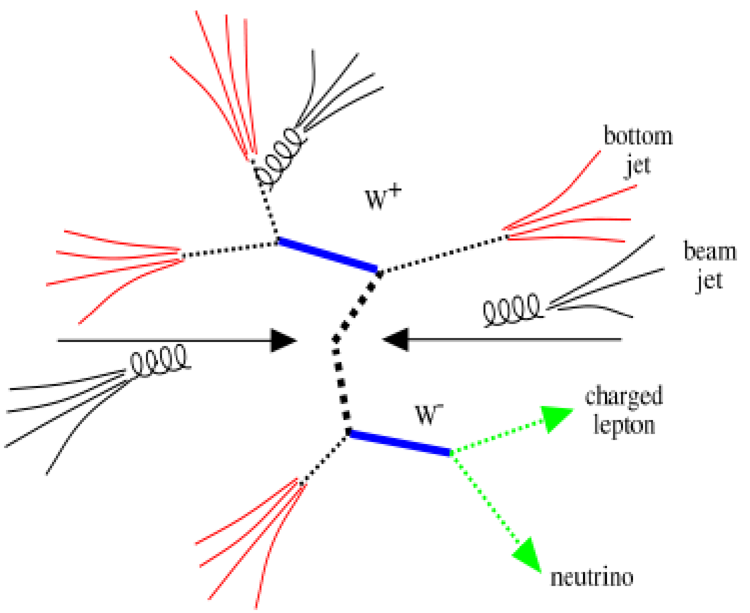
Almost entirely from “Determination of the Jet Energy Scale at the Collider Detector at Fermilab” Bhatti et al., http://arxiv.org/abs/hep-ex/0510047

What is a Jet?

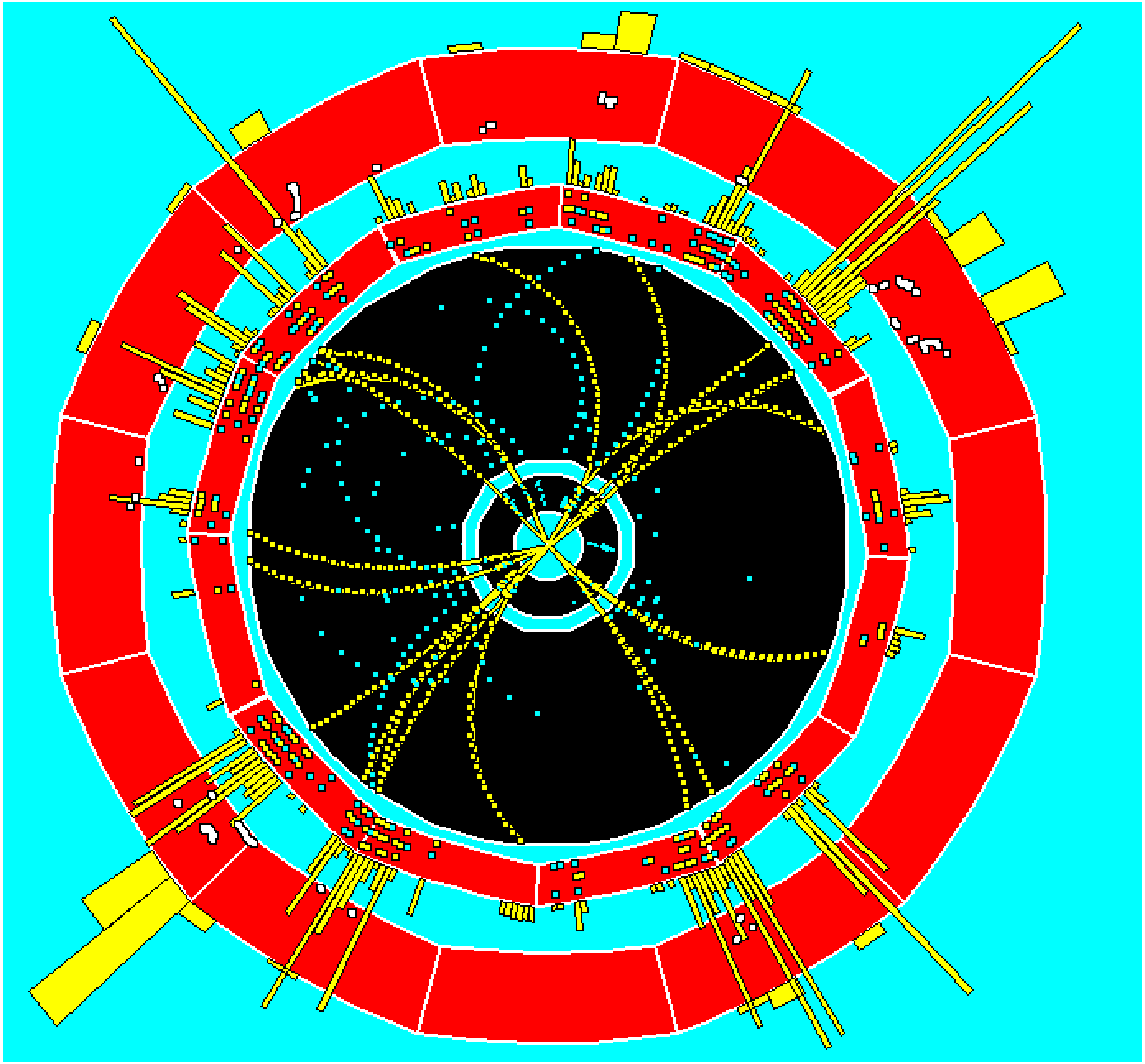
- $p\bar{p}$ collisions (at CDF) (pp collisions at CMS)
- Hard Scatter: inelastic parton - parton (quark or gluon) scatter
- Partons in final state fragment into collimated jets
- Fragmentation from strong interactions--like color confinement
- Jets because confinement says hard radiation is rare, but soft is common





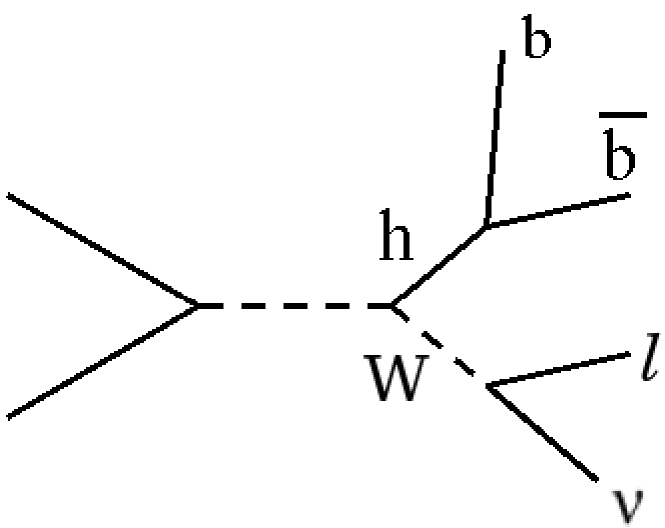


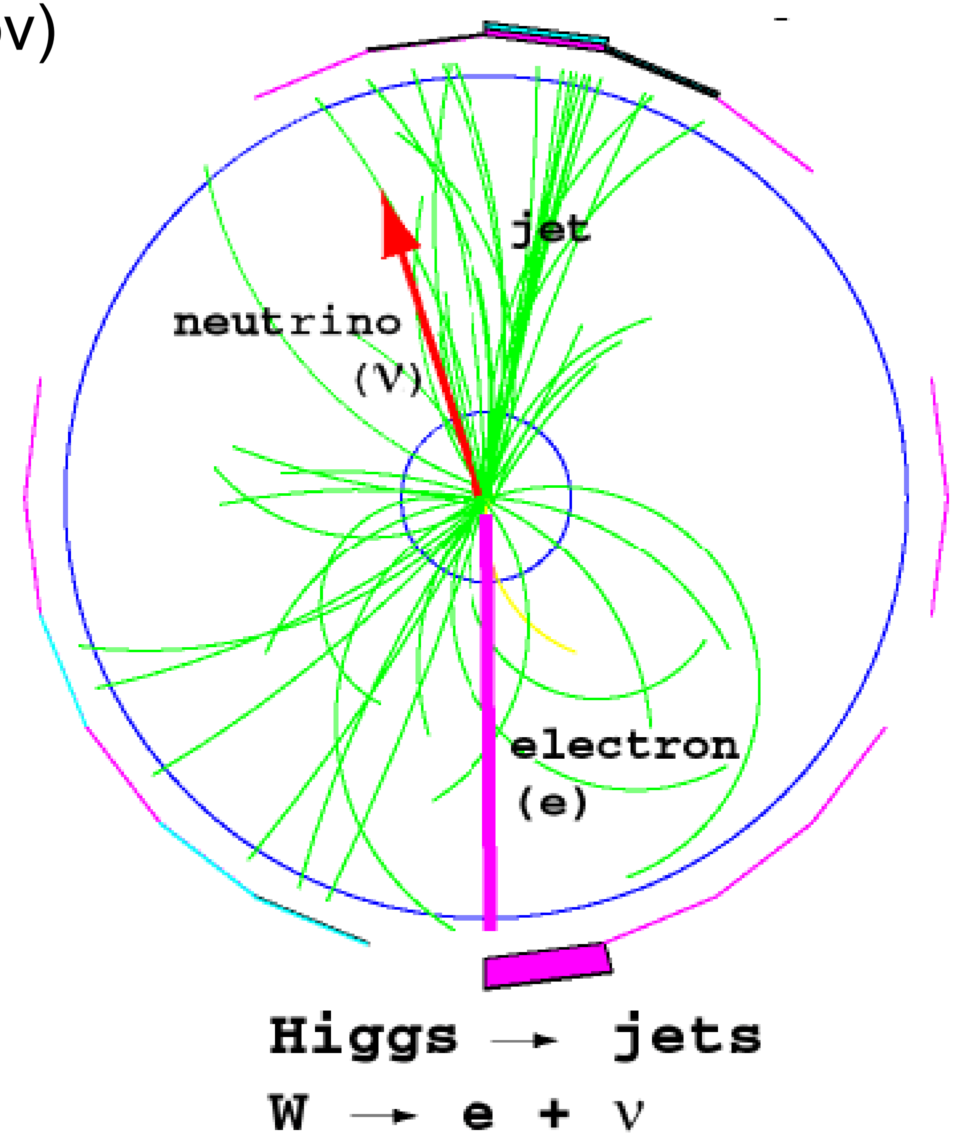
Example of 4 jet event at Aleph detector at LEP



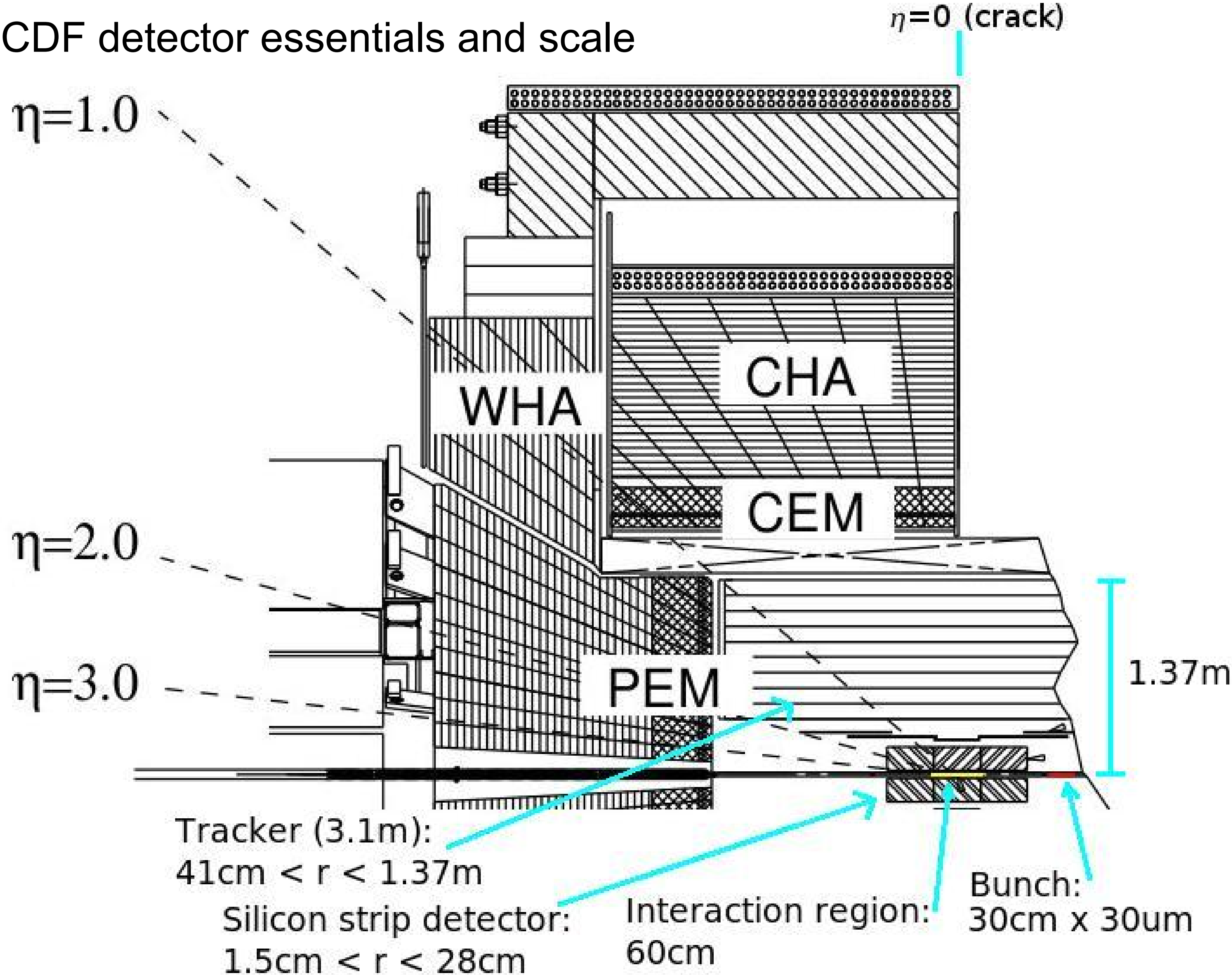
simulated HW → Jets + eν event

(somewhere on fnal.gov)





CDF detector essentials and scale



Why are jets important?

- Must know p^{μ} of hard scatter parton
- Many parameters depend on energy of jets:
  - σ for jet production, M_{top}, M_{higgs}

- Examples:
  - $t\bar{t} \rightarrow$ 2Wb $\rightarrow$ 4jets+$l\,\nu$
  - H $\rightarrow$ jets
  - Dijet resonances of new particles

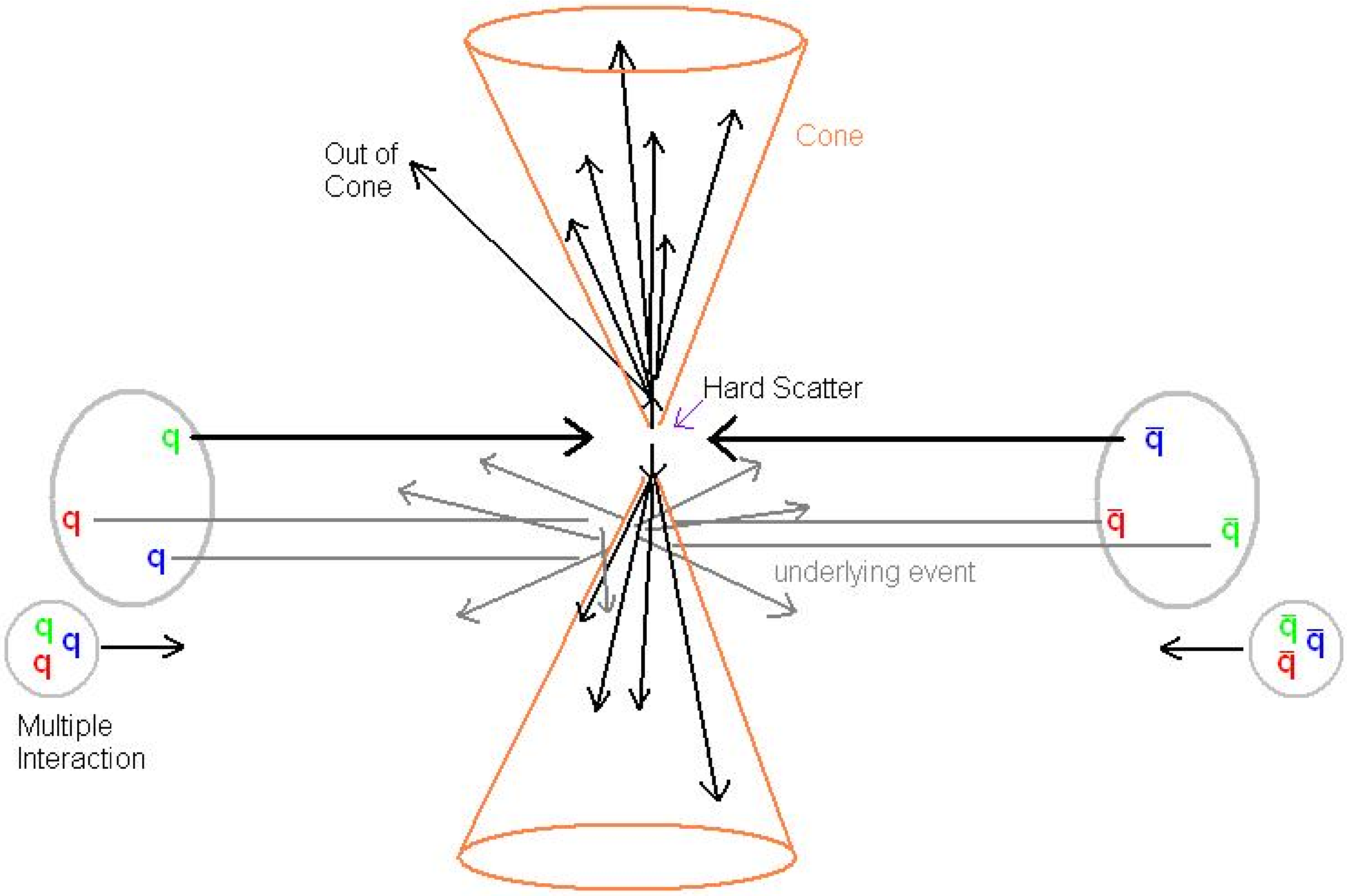
Jet Reconstruction

- Goal is to determine the p_T of hard scatter parton (p_T^{parton}) from detector signal: p_T^{jet}
- Jets are observed as clustered energy depositions in calorimeters. Must correct:

$$
\begin{aligned}
p_T^{parton} &= (p_T^{jet} \times C_\eta - C_{MI}) \times C_{Abs} - C_{UE} + C_{OOC} \\
&= p_T^{particle} - C_{UE} + C_{OOC}
\end{aligned}
$$

- Purpose of talk is to explain these corrections

$$p_T^{parton} = (p_T^{jet} \times C_\eta - C_{MI}) \times C_{Abs} - C_{UE} + C_{OOC}$$



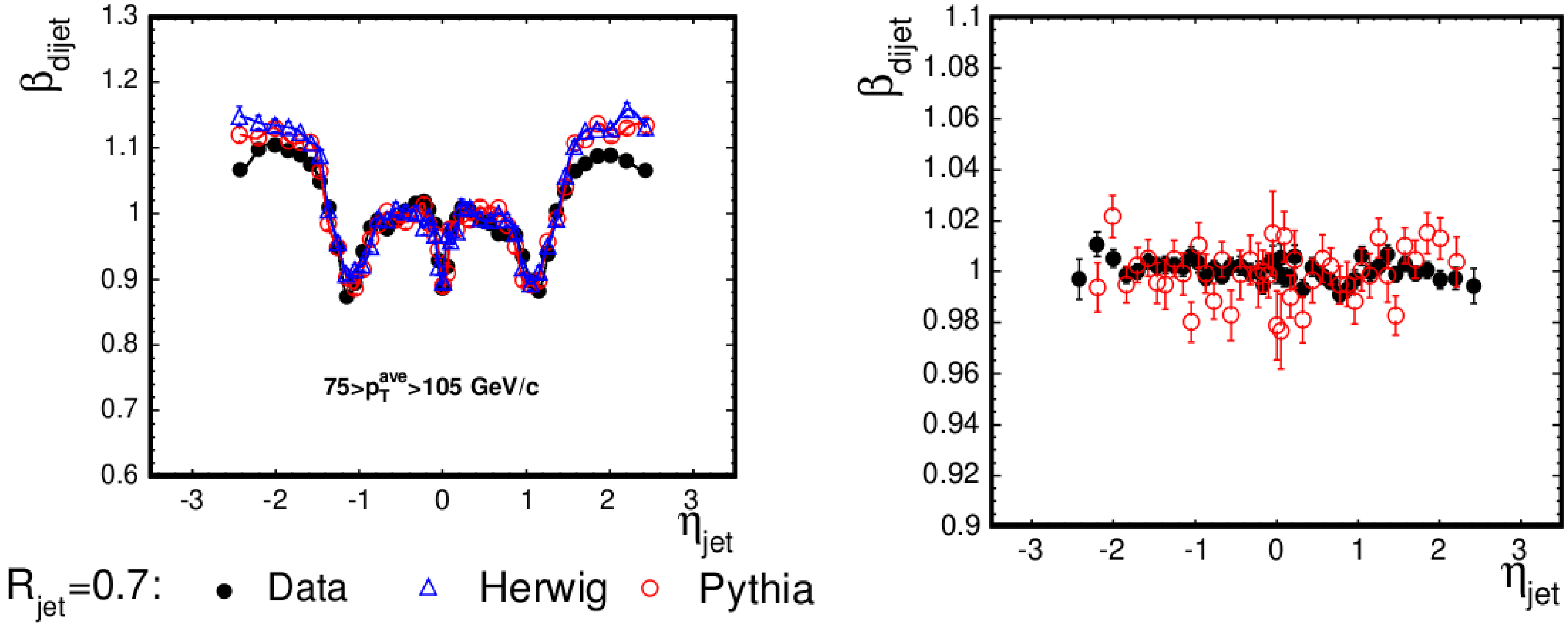
- All corrections are p_T, R dependant
- Last 3 corrected from simulation, first 2 mostly from data

Jet Clustering Algorithm

- Jets are clustered (made) from calorimeter towers (EM+HA) with E_T > 1GeV
- Cone size--radius: R = $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$
- Algorithm also run on stable final state particles from simulation

C_η

- Correct non-uniform η response of detector due to cracks, plug (end-caps), etc.
- How: Dijet balancing: dijets required to be back to back in r-φ plane ($0.2 < |\eta_{trigger}| < 0.6$)
- Result: systematic uncertainty of ~1-2%

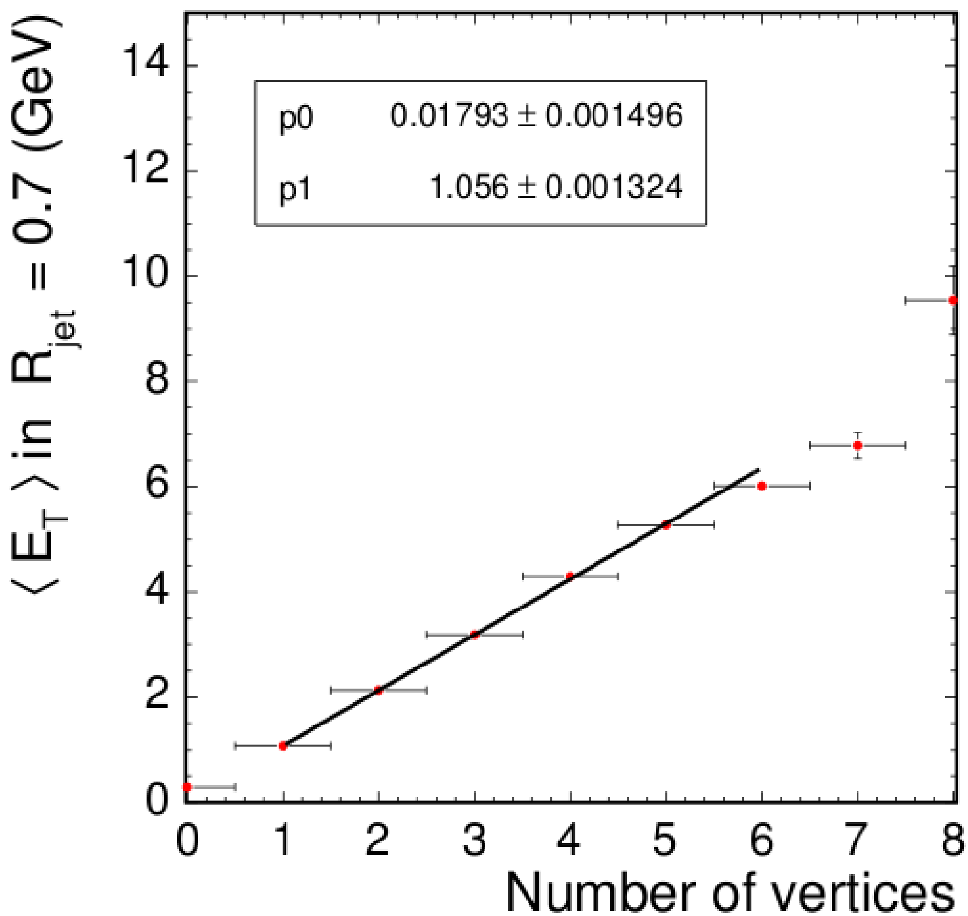


$$\beta_{dijet} = \frac{p_T^{probe}}{p_T^{trigger}}$$

C_{MI} : Multiple Interactions

- Number of pp interactions per bunch crossing depends linearly on instantaneous luminosity:
  - ~1 to 3 for 2001-2004, $L \approx 0.5*10^{32}$ $cm^{-2}s^{-1}$
  - Run II until to 2010, currently $L \approx 1.5*10^{32}$ $cm^{-2}s^{-1}$
- Number of reconstructed primary z-vertices (intersection of particle tracks with beam line) is best estimate of number interactions
- Efficiency of vertex finding algorithm depends on track multiplicity, determines uncertainty

C_{MI} : Results



Correction per interaction per jet:

R jet	C_{MI}(MeV)
0.4	50
0.7	150
1.0	300

C_{Abs} : Jet Energy Scale

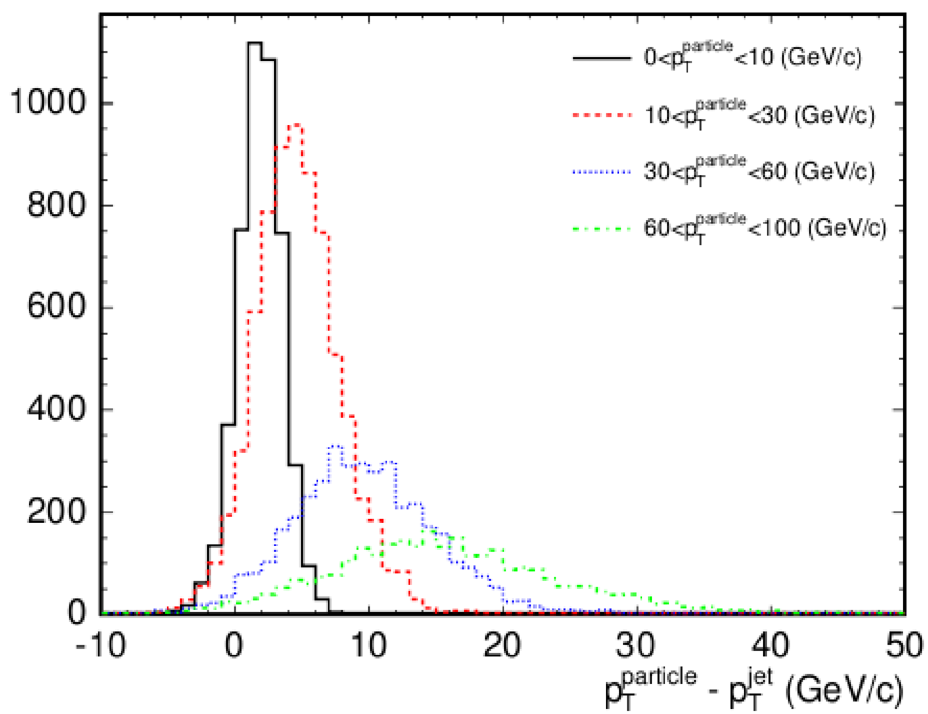
- Correct for all detector effects (with C_{MI} and C_{η})

$$p_T^{parton} = (p_T^{jet} \times C_\eta - C_{MI}) \times C_{Abs} - C_{UE} + C_{OOC}$$

$$= p_T^{particle} - C_{UE} + C_{OOC}$$

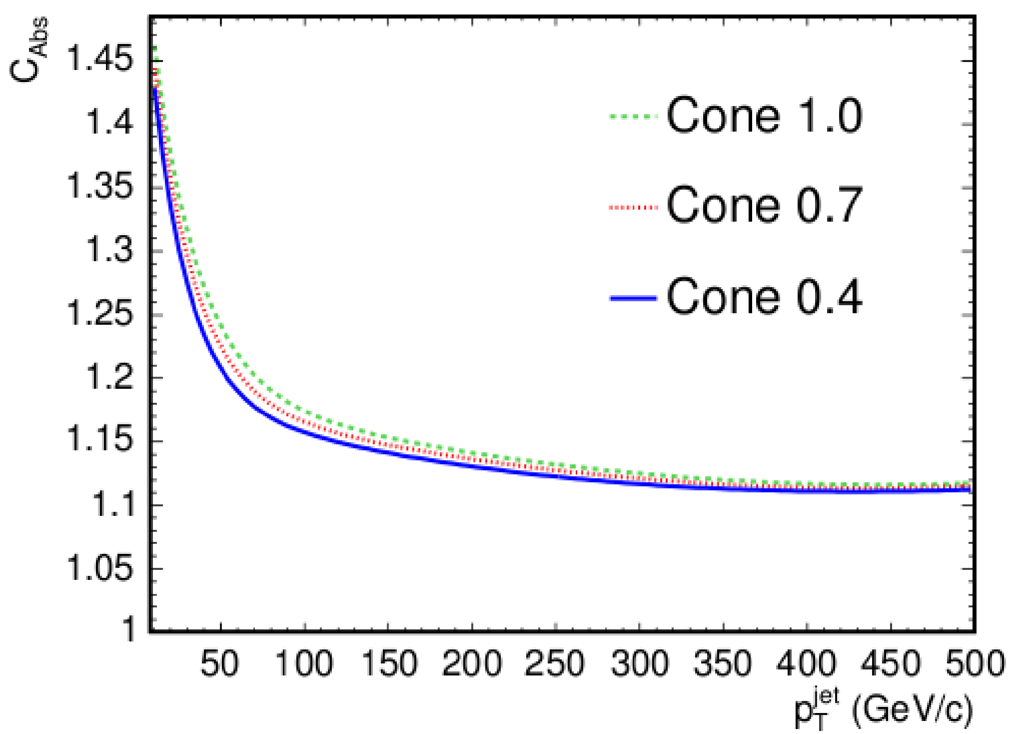
- Compare physics simulation results ($p_T^{particle}$) to detector simulation (p_T^{jet}) event by event
  - Calorimeter simulation optimized for single particle response
  - physics simulation creates spread in p_T

- $p_T^{particle} - p_T^{jet}$ biased positive due to energy loss in detector
- modeled as double Gaussian



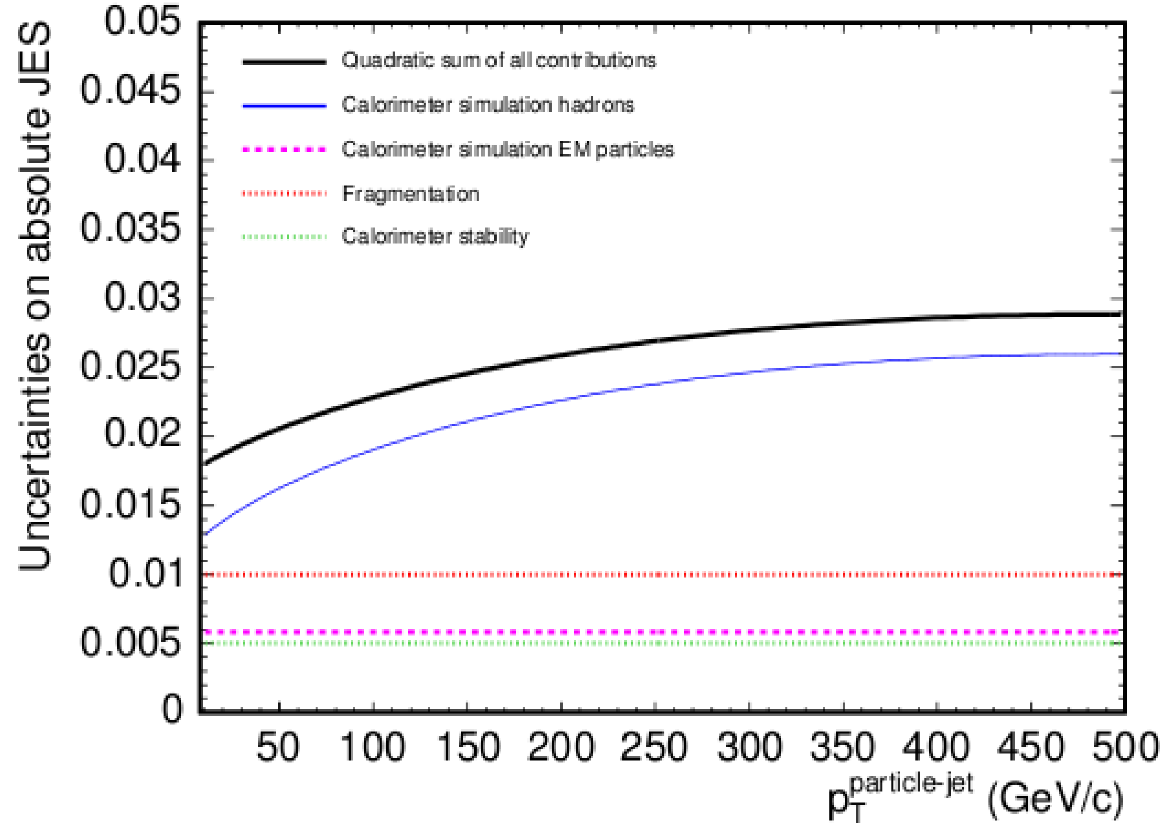
R jet = 0.4

- C_{Abs} determined from likelihood fit of product of all particle jets (not just $p_T^{particle}/p_T^{jet}$)



Uncertainty of C_{Abs}

- Uncertainties on single particle response propagate
- Differences between data and simulations:
  - Calorimeter
  - Fragmentation



C_{UE} : Underlying Event

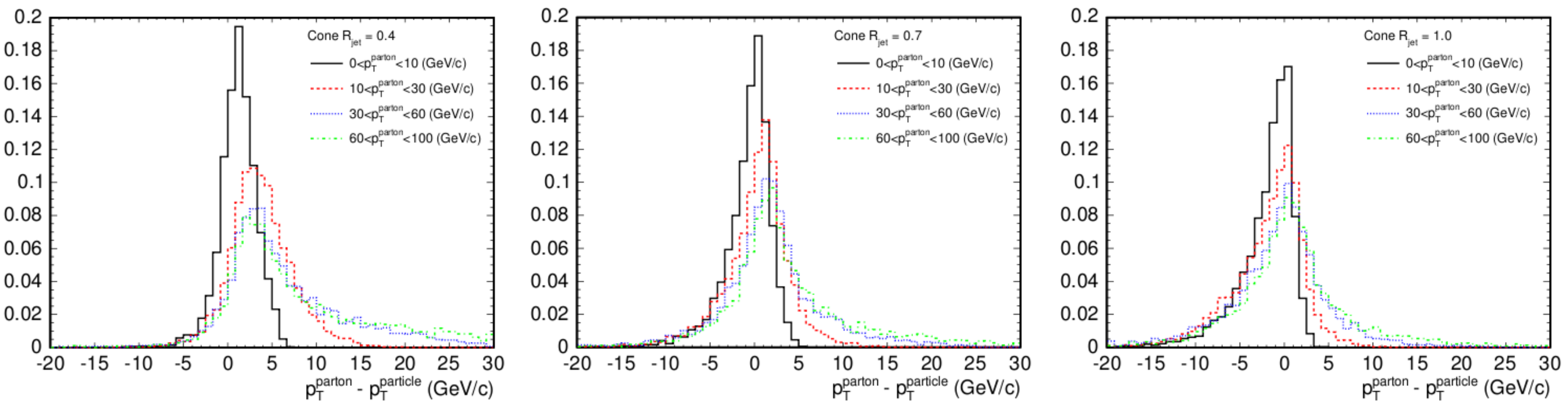
- Originates from partons other than the partons in the hard scatter of interest:
  - Initial state gluon radiation, spectator partons
- UE effects are uncorrelated with scatter partons
  - Independent of jet position, energy (almost)

C_{ooc} : Out of Cone

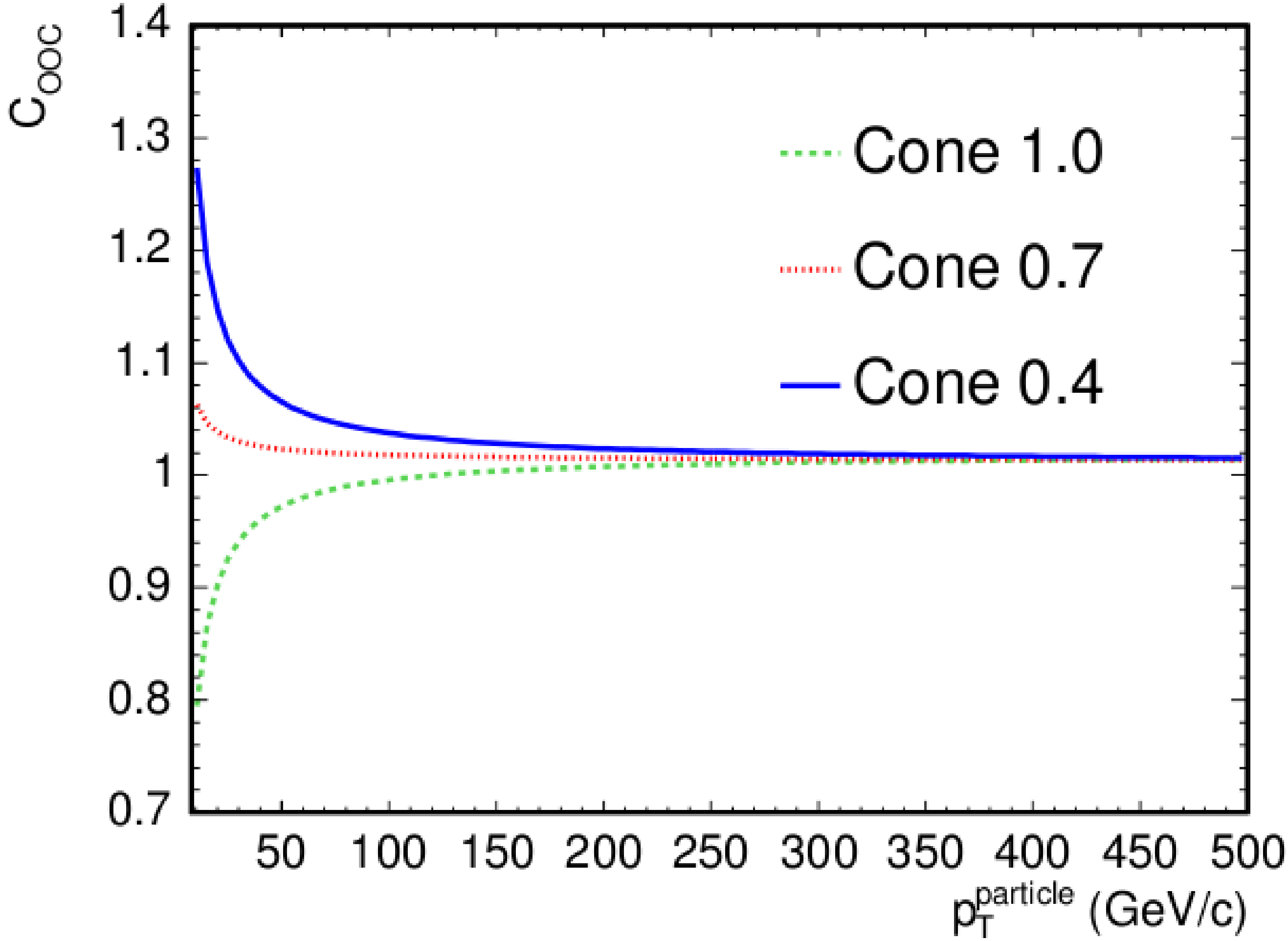
- Energy from the hard scatter parton escapes jet cone
  - Final state gluon radiation, fragmentation, low p_T particles bending in B field
- Both C_{UE} and C_{ooc} are corrected simultaneously from simulation at particle generator level independent of CDF detector (no C_{Abs} effects)

C_{UE} and C_{ooc} corrections

- Same method as C_{Abs}, but use $p_T^{parton} - p_T^{particle}$ now instead of $p_T^{particle} - p_T^{jet}$
- At small cone sizes the OOC losses dominate over the energy increase due to UE, but at large cone sizes the extra energy from the UE is larger than the OOC losses.



C_{UE} and C_{ooc} results

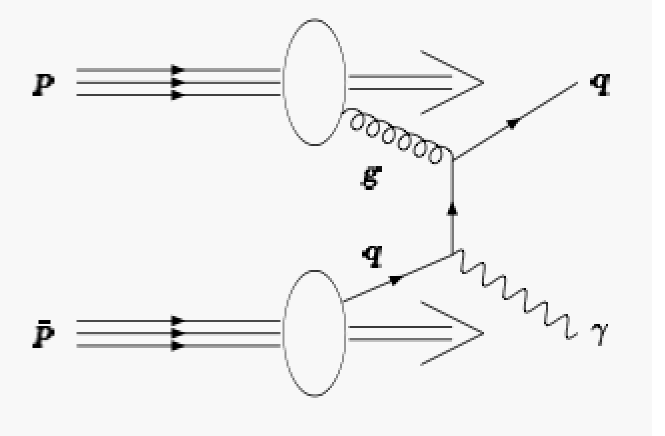


C_{UE} (GeV)	Cone Size
0.4	0.4
1.1	0.7
2.2	1.0

- Systematic uncertainty determined from comparison with data

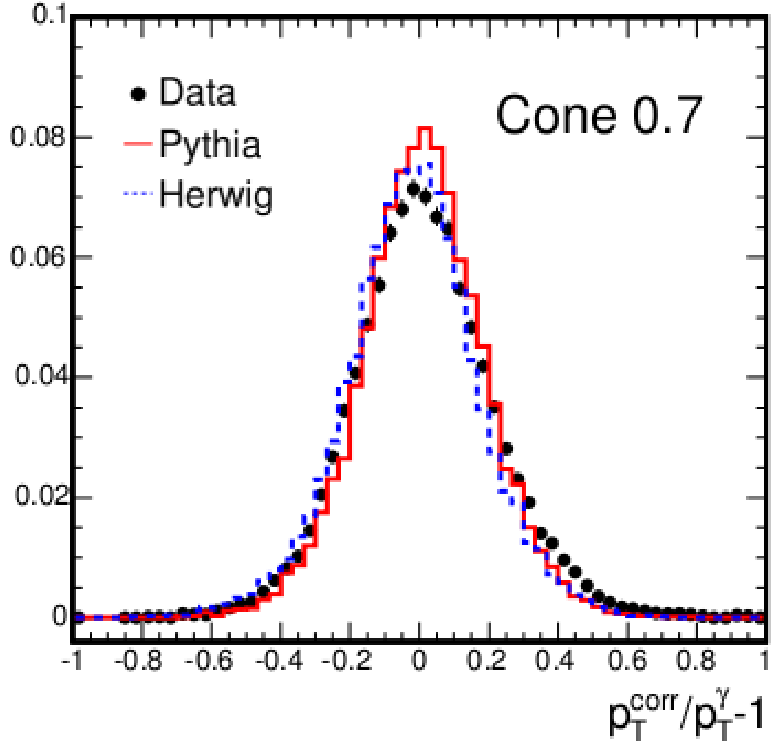
Validation of the JES Determination

- Compare to data samples:
  - γ-jet: photon energy accurately measured, background from π^0, $\eta \rightarrow \gamma\gamma$
  - Z-jet: nearly free from background, smaller statistics
    - agrees with MC to 3%



Prompt photon

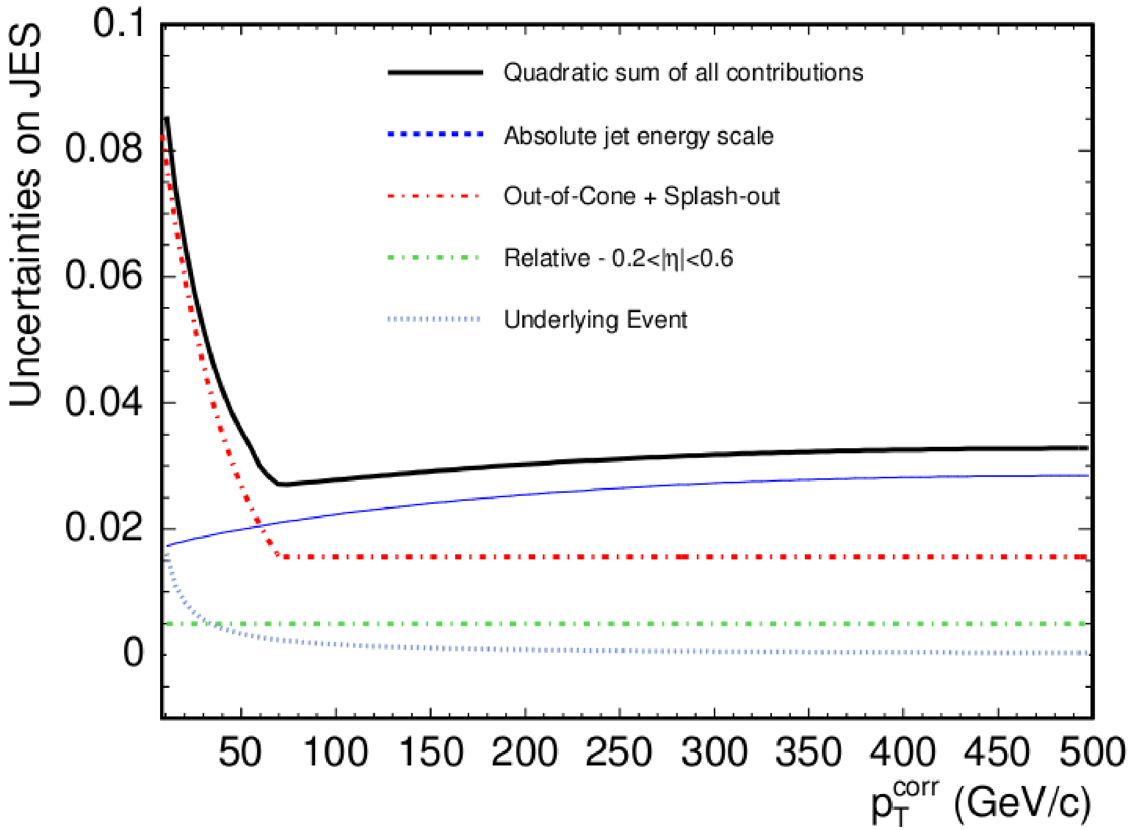
γ-jet Validation results



- After all corrections, data and MC agree to within 2%

Systematic Uncertainties on JES

- Mostly arise from modeling of jets by MC and from knowledge of single particle response (reconstruction)
- For p_T > 60GeV largest contribution is from C_{Abs} which is limited by response to charged hadrons
- Improvements via better simulations, more data



Conclusions: Jets, Jets, and Jets

FR Class II source: quasar 3C175

- Jet energy scale important to many parameters (SM and new physics)
- Correct from detector signal to parton p_T via:

$$p_T^{parton} = (p_T^{jet} \times C_\eta - C_{MI}) \times C_{Abs} - C_{UE} + C_{OOC}$$

- Corrections rely heavily on MC, cross-checked to data