8.882 LHC Physics

Experimental Methods and Measurements

Jet Energy Scale

[Lecture 23, May 04, 2009]

Organization

Project 3

- there are missing hand-ins please send them in :-)

Final Conference

- program is final
- it is very important you get started very soon
- there will be technical details next lecture

Final Conference Project

LHC Physics: “Experimental Methods and Measurements”

Plenary Session (12:00–13:30, May 19, 5th floor 26-528 Room)

- Welcome and LHC Overview (C.Paus)
- Search for Standard Model Higgs Boson: Overview (?)
- Search for Higgs in $H \to ZZ^*$ (M.Chan)
- Search for Higgs in $H \to WW^*$ (H.Gray)

Lecture Outline

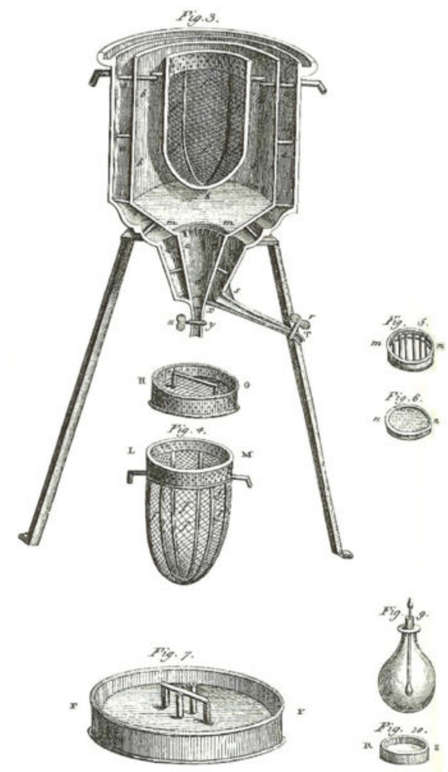
Jet Energy Scale calibration

- CMS calorimeters
- outline of the problem
- γ+Jet sample calibration

Calorimetry

Definition (from Wikipedia)

- "‥ the science of measuring the heat of chemical reactions or physical changes. Calorimetry involves the use of a calorimeter. The word calorimetry is derived from the Latin word calor, meaning heat."
- calorimetry in particle physics does not:
  - measure heat directly, but nevertheless determines the energy
  - does not measure heat of chemical reactions of physical changes, but it measures the energy of particles
- calorimeters in particle physics are split into electromagnetic and hadronic

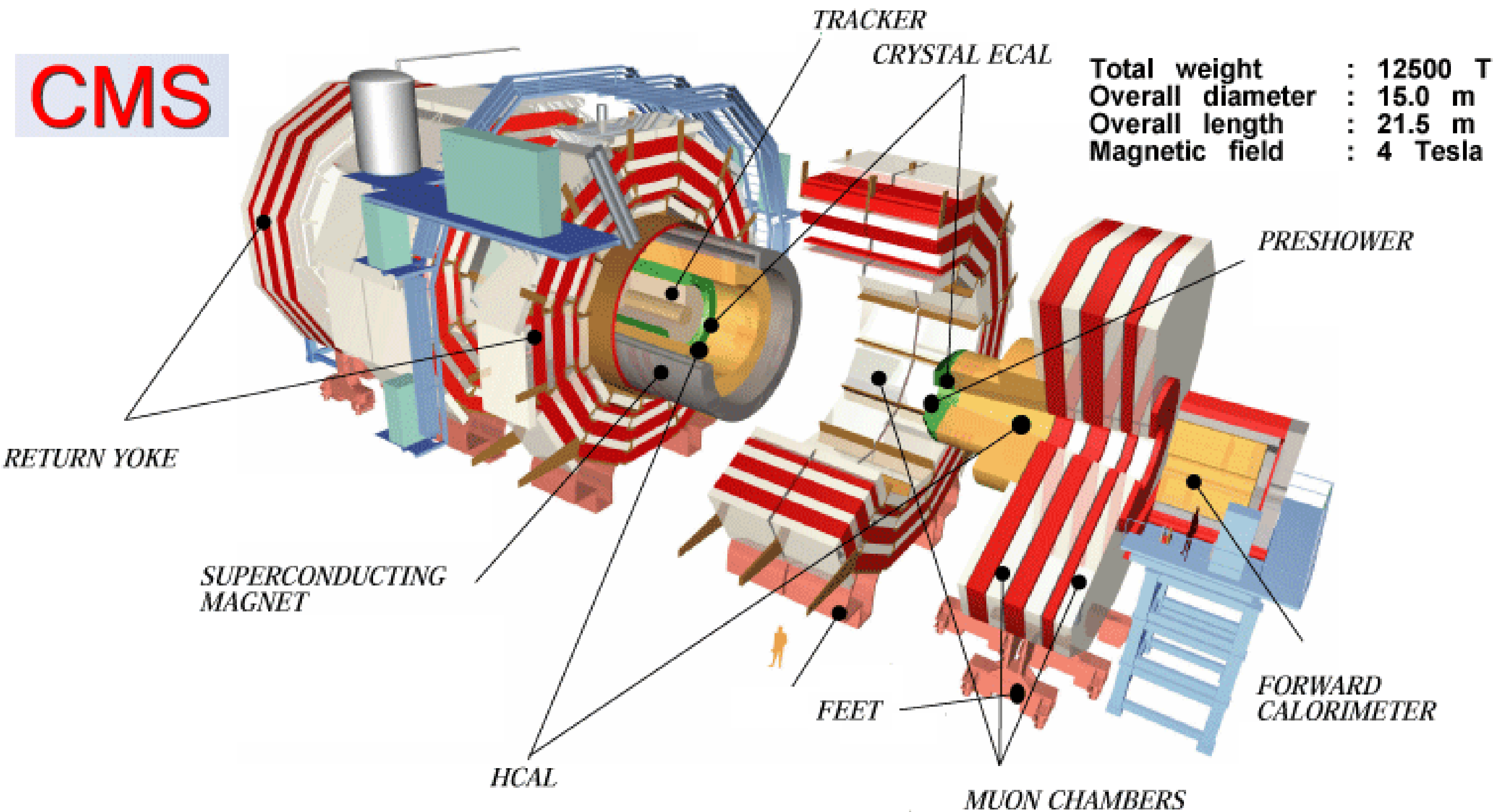


Ice-calorimeter from Antoine Lavoisier's 1787 Elements of Chemistry.

Calorimetry in CMS

Overview

- ECAL: Lead Tungstate ($PbWO_4$), silicon pre-shower
- HCAL: brass and steel with scintillators



Calorimetry Usage

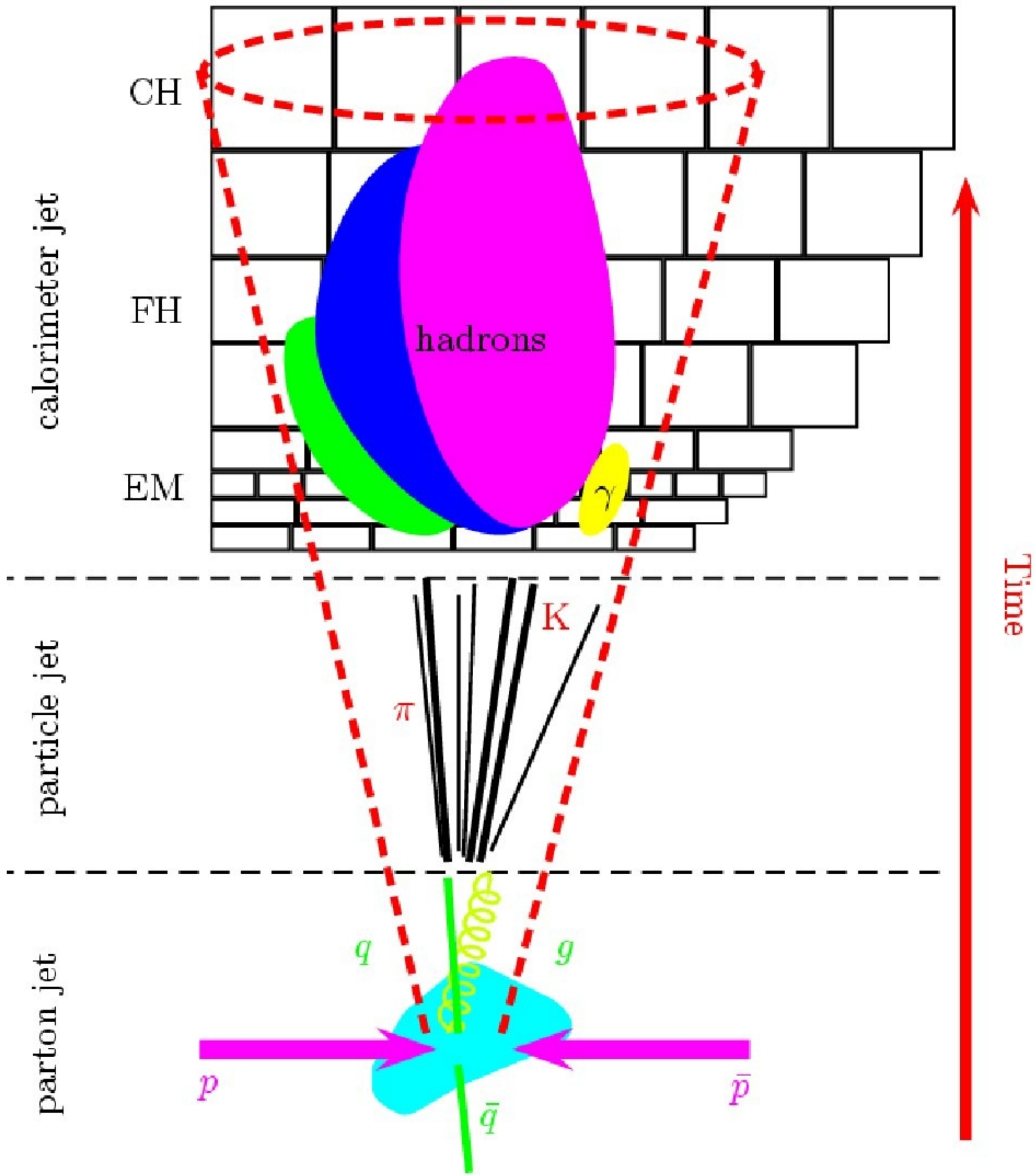
Largest amount of particles

- hadrons and photons
- neutral hadrons and photons are only measured in the calorimeter
- ECAL – electromagnetic calorimeter are usually very precise (shower is simpler, detector easier to instrument)
- HCAL – hadronic calorimeter make a huge differences for jets and the missing energy (they drive the resolution)
- quarks and gluons (partons) manifest themselves as jets
- jets are mostly measured in the calorimeters
- essential in many searches and “bread and butter” measurements
- calibration of calorimetry is far from trivial

Determination of Jet Energies

Energy measurement

- electromagnetic: straight forward and precise
- hadronic more complex
- single pion is easy
- but particles come in jets
- overlapping energy depositions
- tracks are measured ....
- have to find optimal way to combine all information
- various variables influence energy determ.
- depends on spec. sample



Jet Energy Scale determination

The Jet Energy Scale (JES)

Three main parts of Jet Energy Scale

- Offset: not from hard process (noise, pile-up, underlying event)
- Response: calorimeter response function ($R_j(E)$, $R_j(\eta,\varphi)$)
- Showering: energy leakage (into/out of) jet cone

$$E_{\text{particle/parton}} = \frac{E_{\text{cal}} - \text{Offset}}{\text{Response} \times \text{Showering}}$$

Remarks

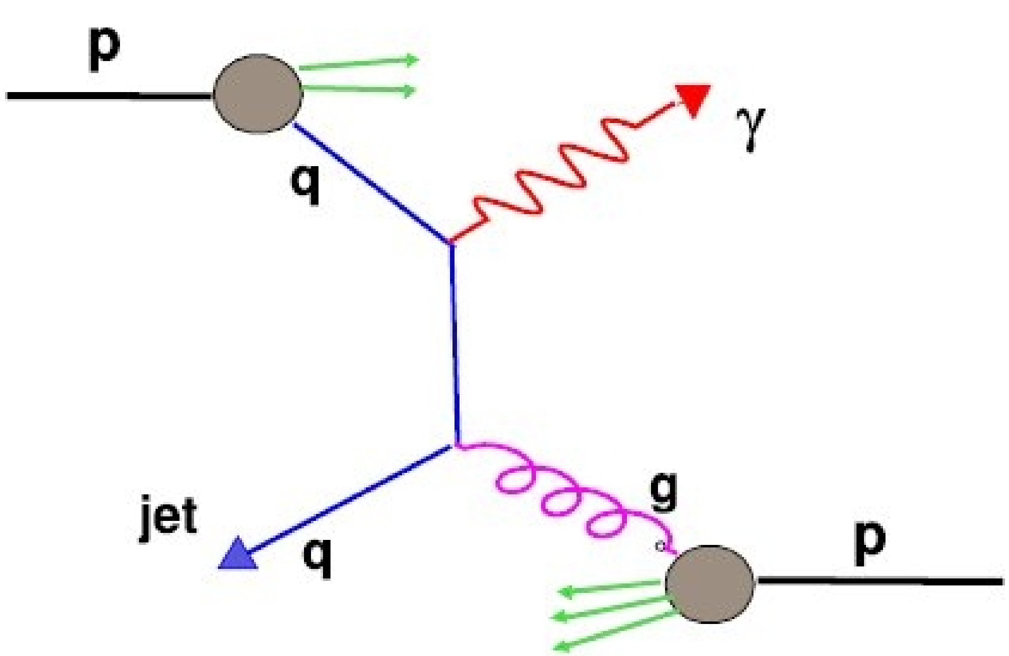
- largest effect is usually the response function
- once η,φ dependence is corrected, overall (absolute) response can be calibrated
- test beam calibrations crucial for overall understanding
- absolute calibration in data with γ+Jet

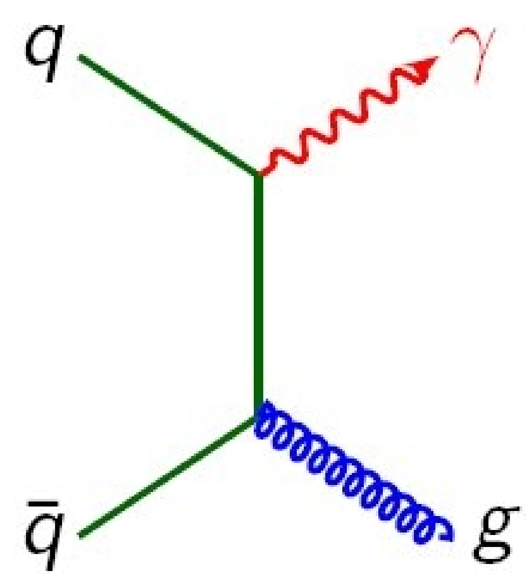
stealing from: http://www-clued0.fnal.gov/~cammin/CMS-042607.pdf

γ+*Jet Events*

Event properties

- single photon and single jet in event (gluon/quark jets)
- photon energy very well known (ECAL)
- transverse energy has to be conserved
- careful though, there details like are higher orders *etc.*
- do not know much about energy in *z* direction

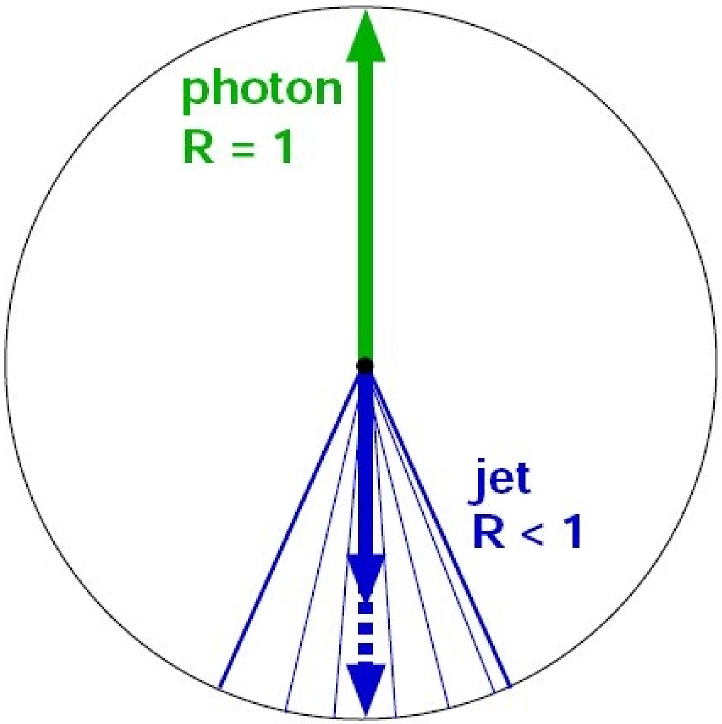




γ+*Jet Events*

Transverse energy balance

$$k_{\text{jet}} = \frac{p_T^{\text{jet}}}{p_T^{\gamma}}$$ corrects to parton level



Technically more inclusive

- response + shower in one step
- corrects to parton level
- better for jet cross section *etc.*
- depends on the jet algorithm

Alternatively

- remove jet forming and add all measured energy
- corrects to particle level (better for top or Higgs mass)

γ+Jet Events

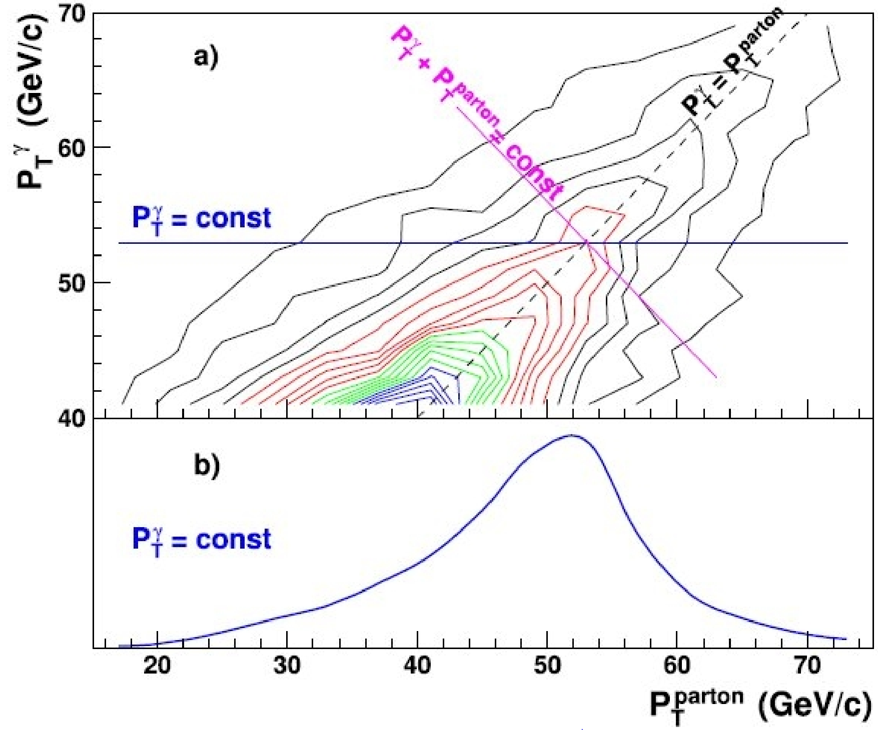
Transverse energy balance

- already conceptually

$$k_{\text{jet}} = \frac{p_T^{\text{jet}}}{p_T^{\gamma}} \neq 0$$

because

$$p_T^{\gamma} \geq p_T^{\text{parton}}$$



Higher order diagrams are present

- initial state radiation reduces parton momentum
- long tail in p_T(parton)
- measure peak position in bins of p_T^{γ}

sources: CMS NOTE-2006/042, CMS IN-2003/036

γ+*Jet Events*

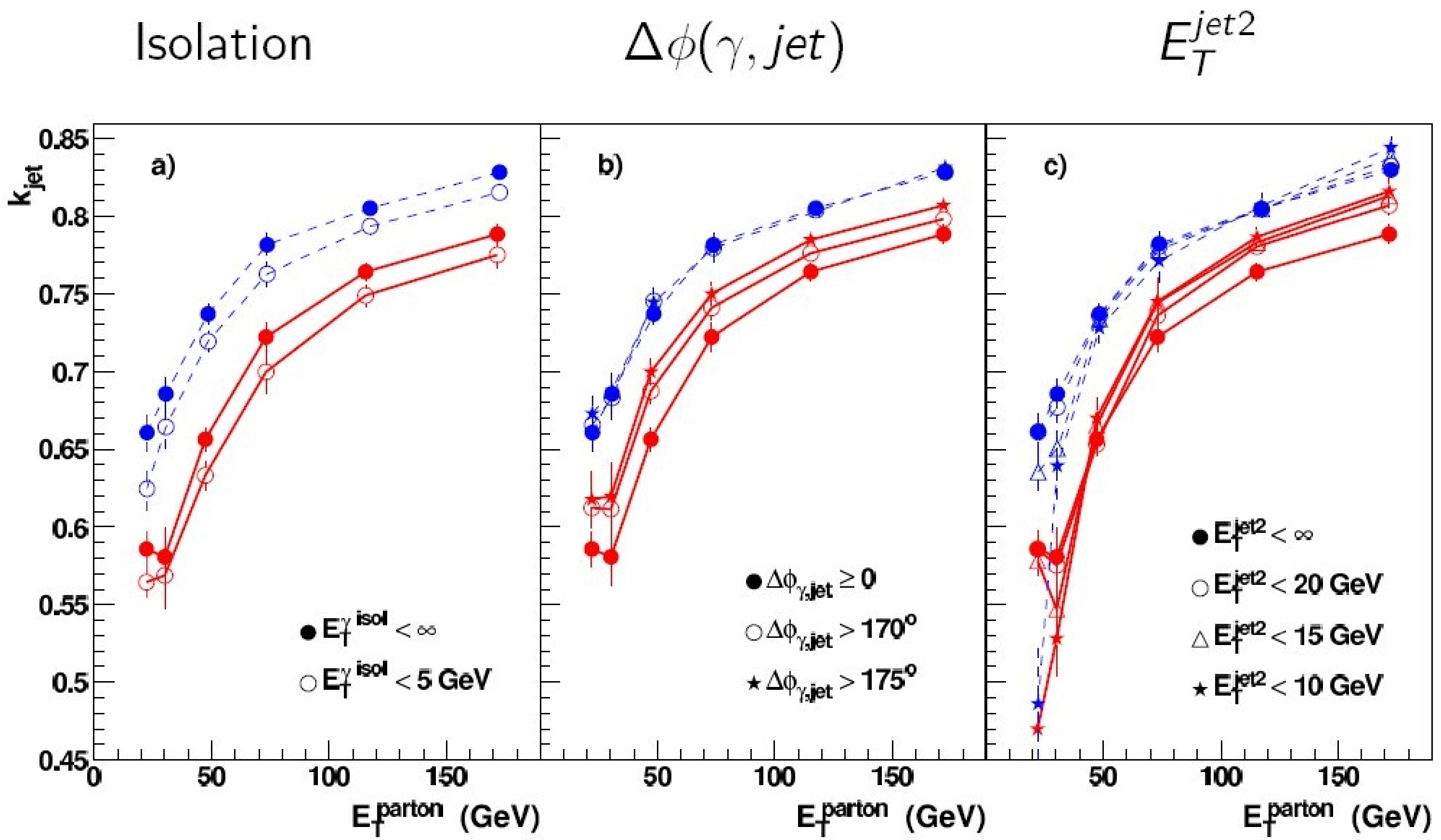
Methods brings intrinsic biases

- selection of events
- initial state radiation
- background: di-jet events with γ like jet (p_T dependent)
- different quark-gluon composition of signal and background
- imbalance caused by zero suppression (algorithm in calorimeter readout)

γ+Jet Events

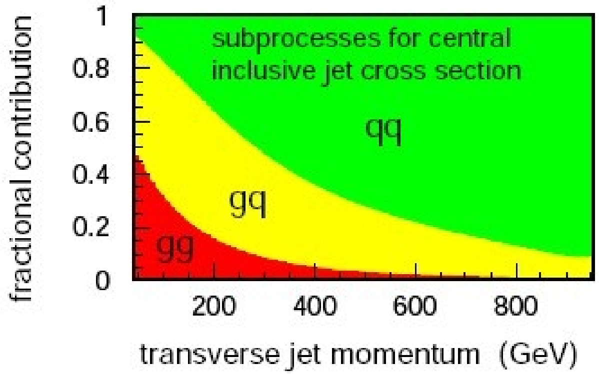
Sensitivity to selection cuts (blue-true, red-measured)

- isolation of photons
- opening angle jet-photon: Δφ
- veto a 2nd jet

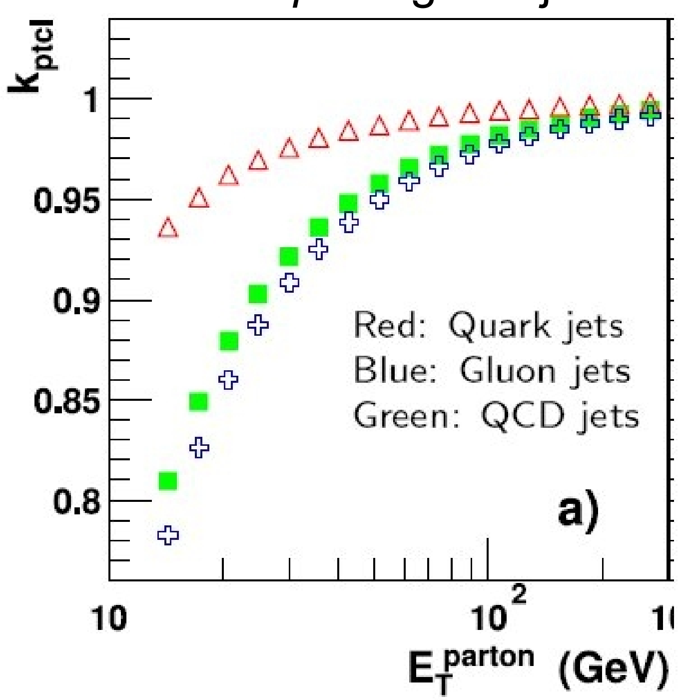


γ+*Jet Events*

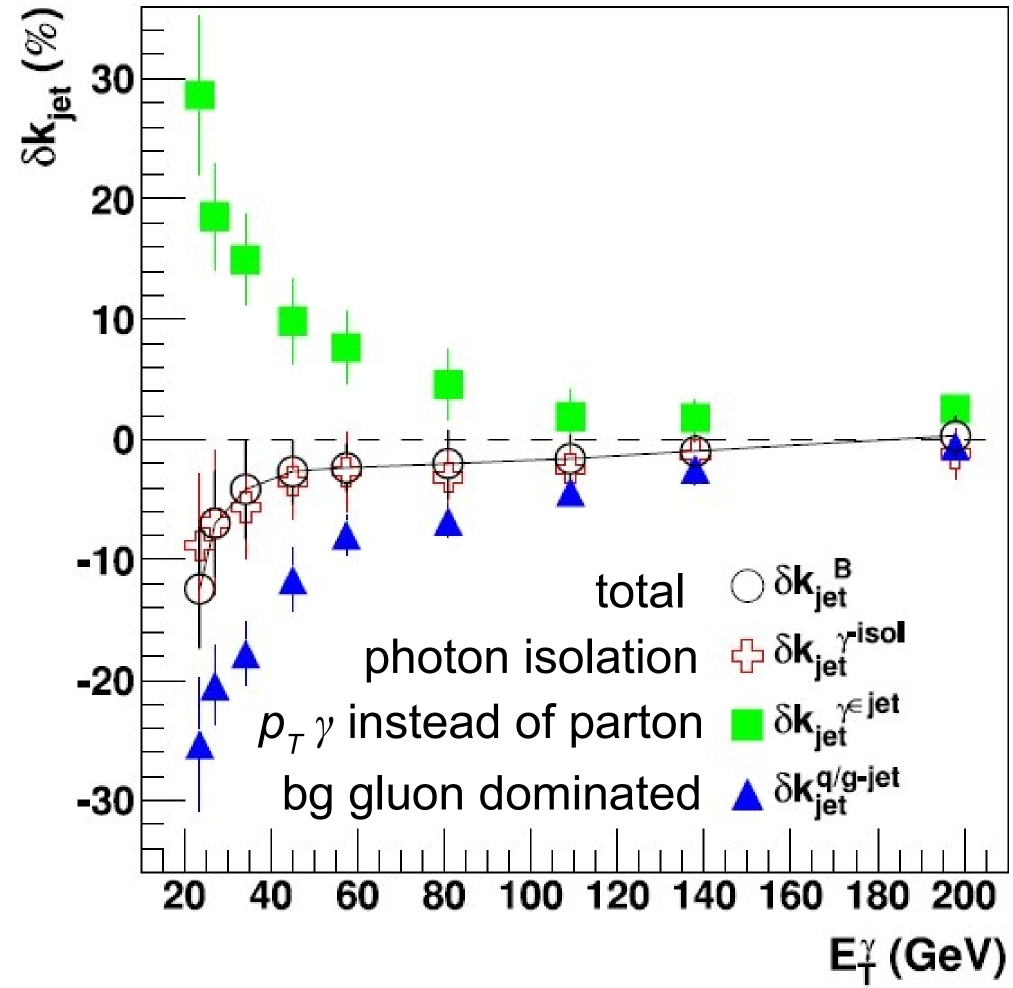
Incl. jets @ Tevatron



(0.5 cone jets) Differences between *q* and gluon jets

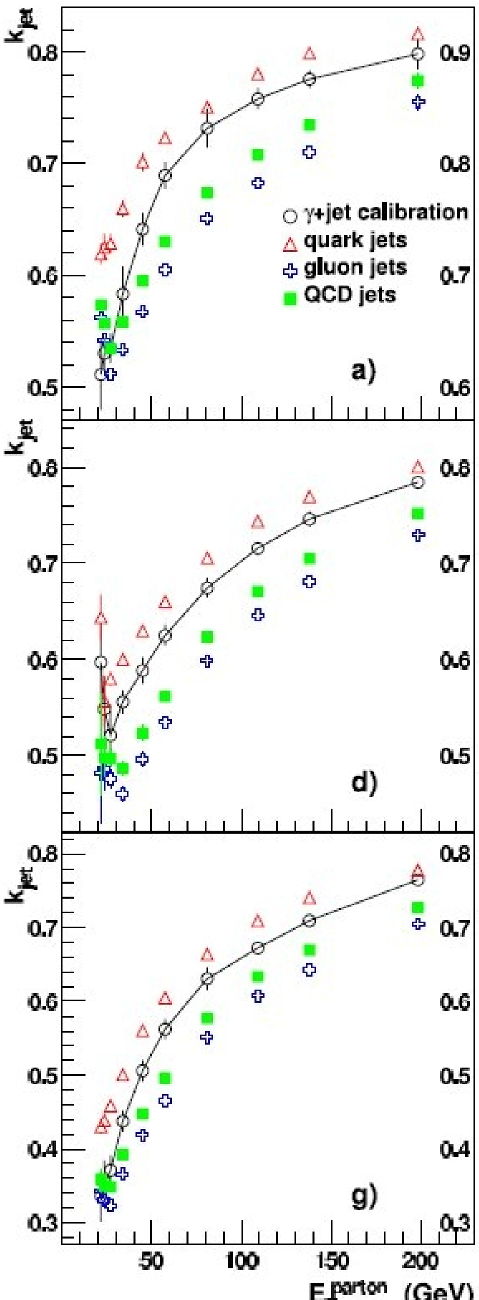


Combined biases from background



Biases cancel partially.

γ+Jet Events



←

Predicted calibration coefficients and true values for quark, gluon, and QCD jets for different threshold of tower energy: a) $E_T^{tower} > 0.5$ GeV, d) $E_T^{tower} > 1$ GeV, g) $E_T^{tower} > 1.5$ GeV.

Relative JES systematics for same three tower energy thresholds as above.

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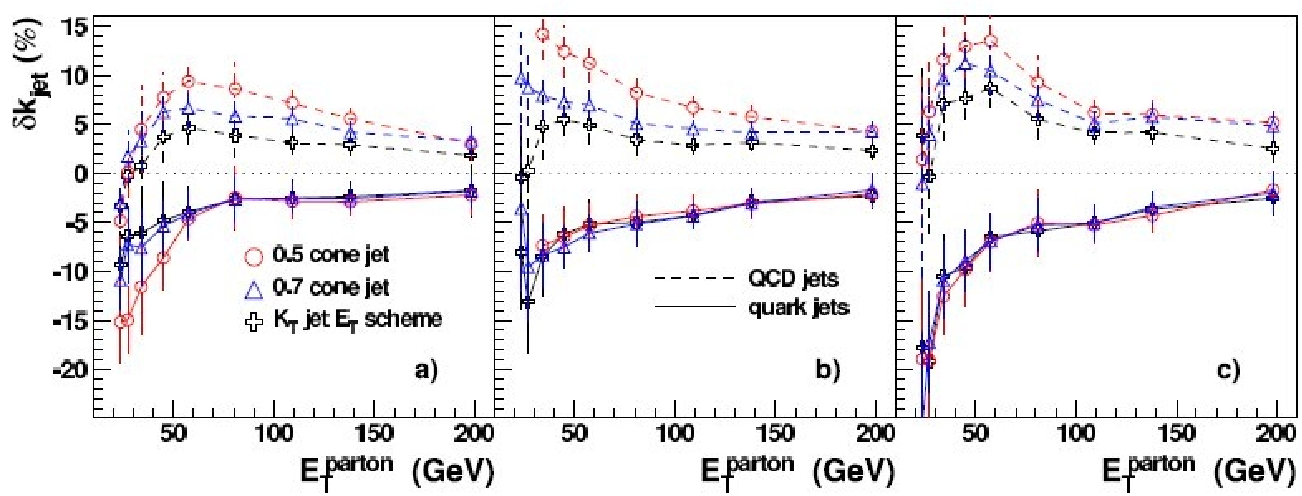

Conclusion

Jet Energy Scale calibration

- use γ+Jet sample
  - balance in transverse momentum
  - correct only to first order (ISR causes bias)
- corrections are sample dependent
  - correction in sample similar to signal desirable
  - top sample will become very important (W inside top decay)

Next Lecture

Details of Higgs Analyses

- Search for Higgs in $H \rightarrow (qq)ZZ^*$
- Search for Higgs in $H \rightarrow (qq)WW^*$
- Search for Higgs in $H \rightarrow \gamma\gamma$