Search for a Standard Model Higgs Boson in the Decay Channel $H \rightarrow ZZ \rightarrow \ell^+\ell^- q\bar{q}$ at the CMS Experiment

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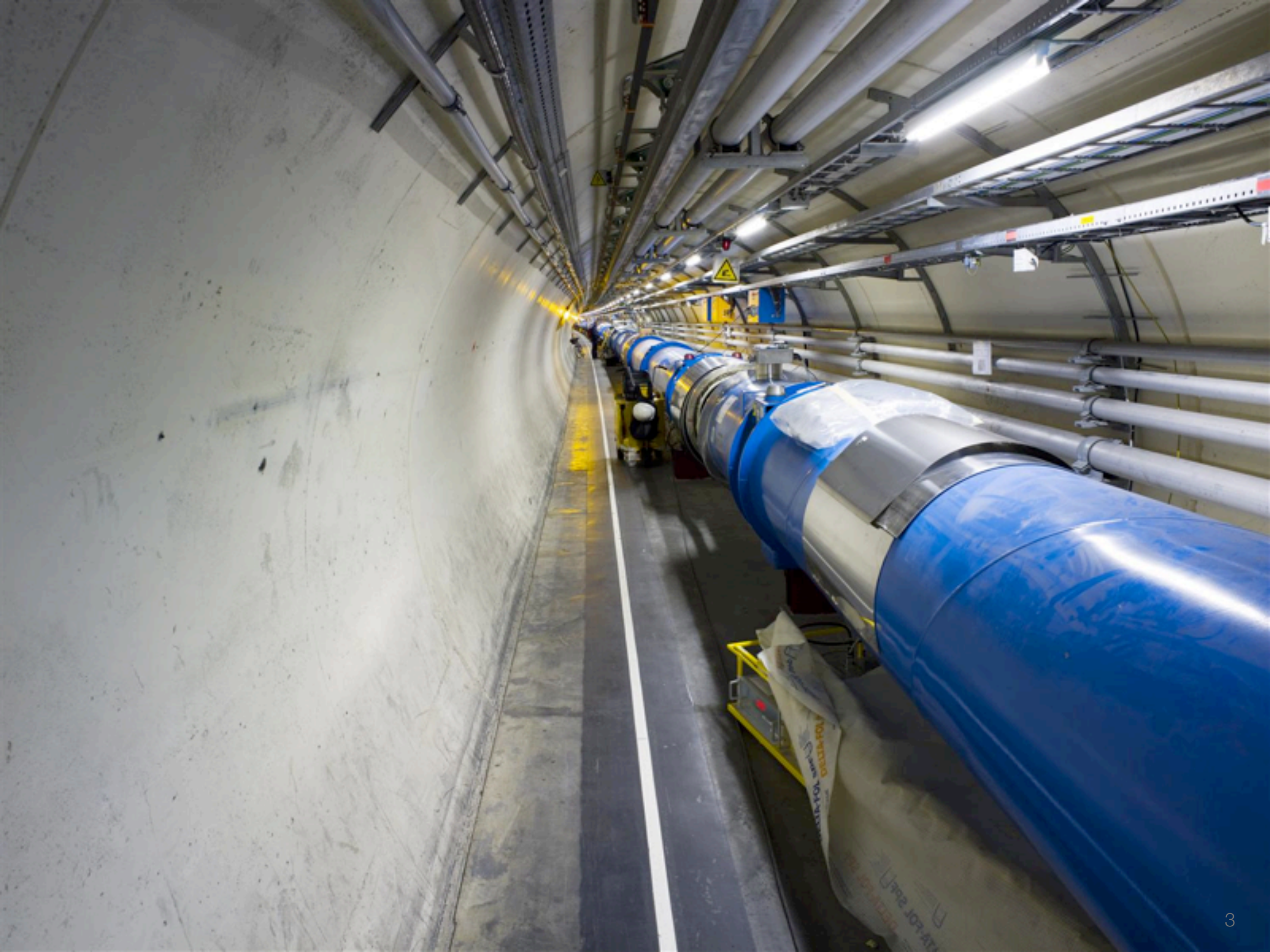
Seminario sul Progetto di Tesi
11.06.10

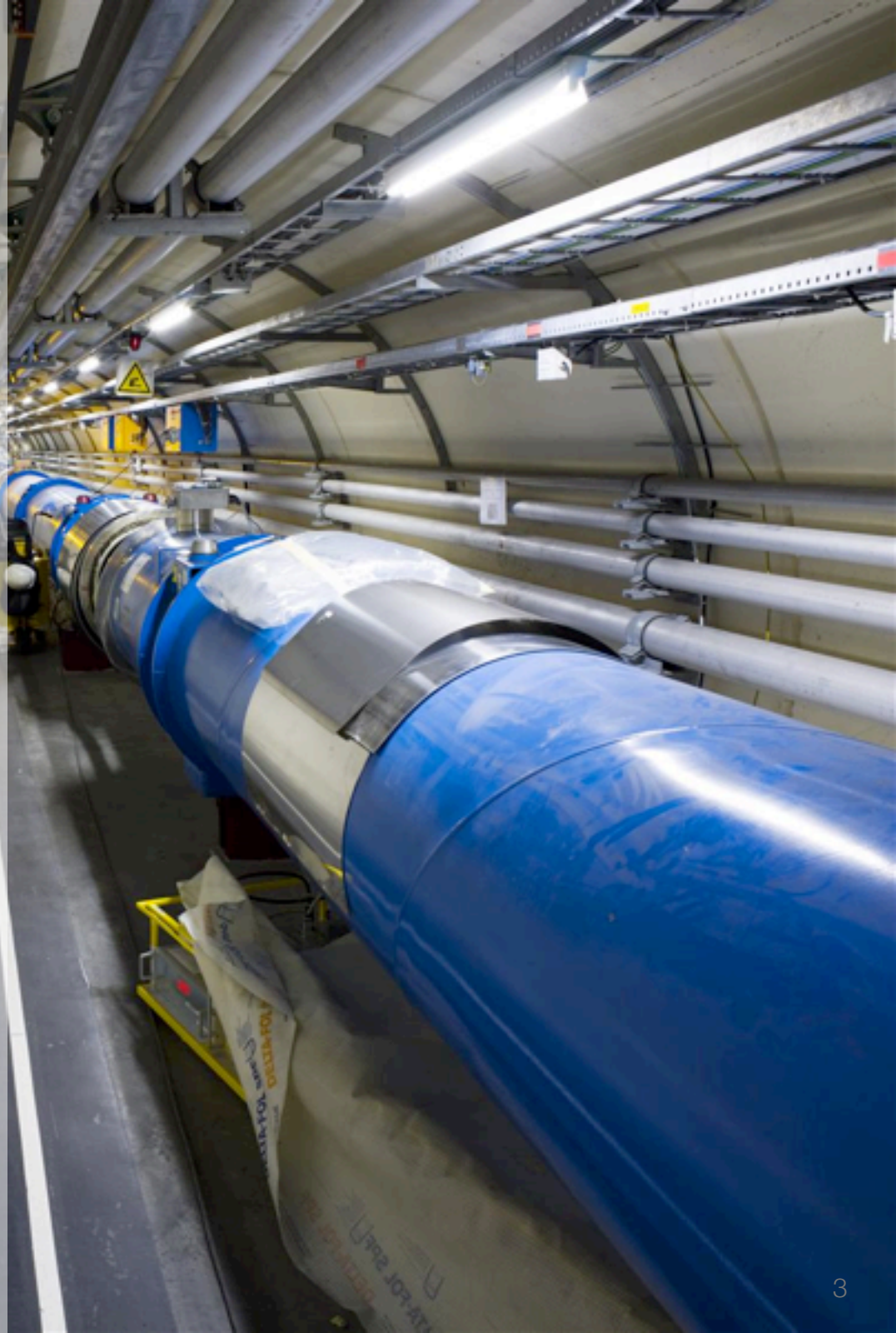
Outline

- The Large Hadron Collider
- Compact Muon Solenoid
- Higgs Hunting
  - A new possibility in the H → ZZ decay channel
- The Particle Flow event reconstruction
  - Improvements in CMS jet reconstruction performance
- Jet commissioning and calibration on 7 TeV data
  - Response and resolution measurement with photon+jet events
- Conclusions and prospects



The Large Hadron Collider

- Proton-proton collider
- Circumpherence: 27 km
- 2010-2011 Physics Run:
  - $\sqrt{s} = 7 \ \ \mathrm{TeV}$
  - $\mathcal{L} = 10^{32} \div 10^{33} \ \ \mathrm{cm}^{-2} \ \mathrm{s}^{-1}$



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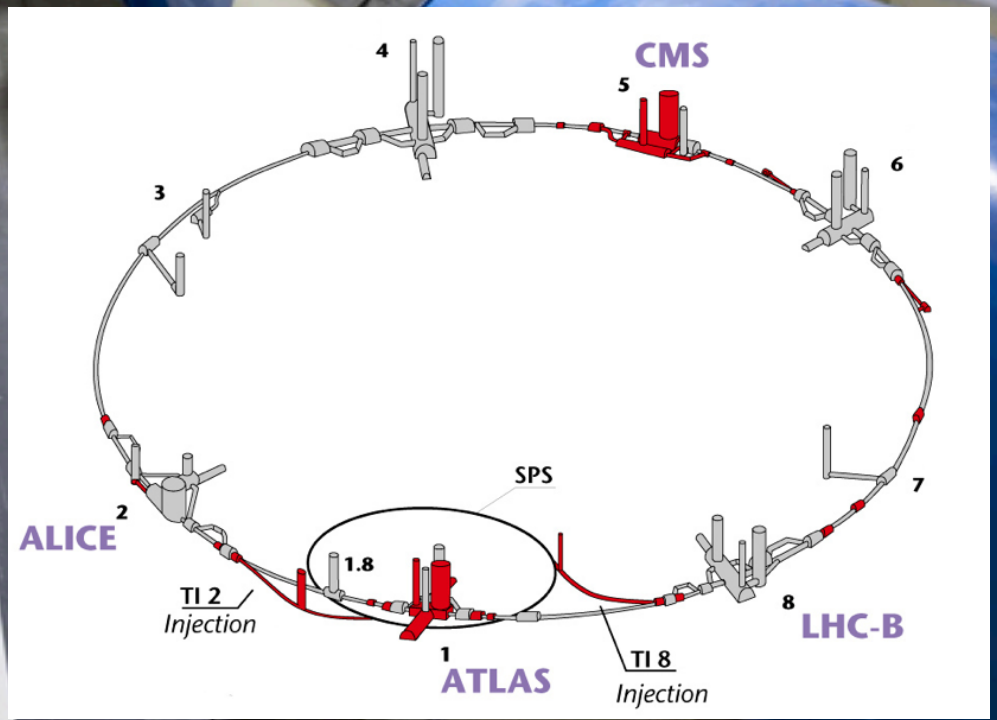
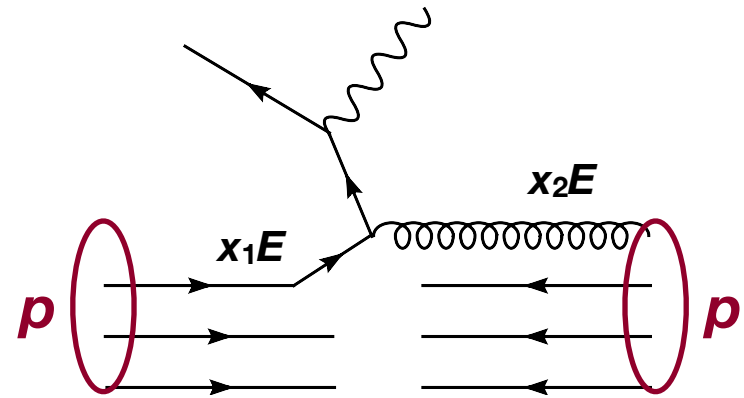
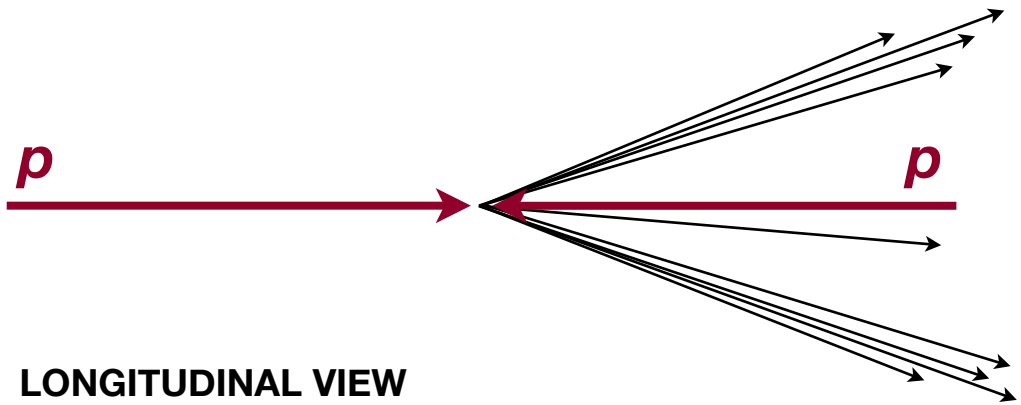


Collisions in a Hadron Collider

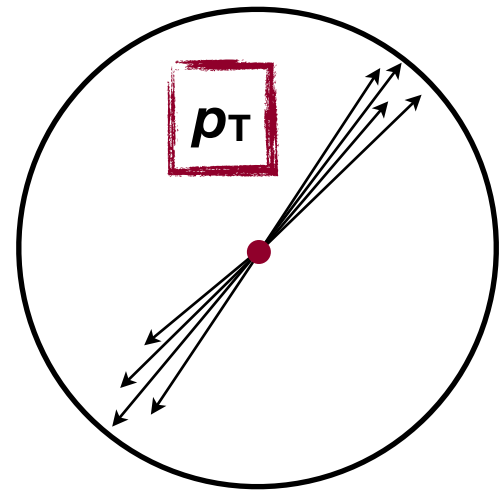
- Protons are composite particles: reactions happen at parton level
  - Hadron colliders are **discovery** colliders: can span broad energy ranges
  - Event is not closed kinematically: center of mass frame ≠ lab frame
  - **But** event is closed on trasverse plane



$x_1 \neq x_2$

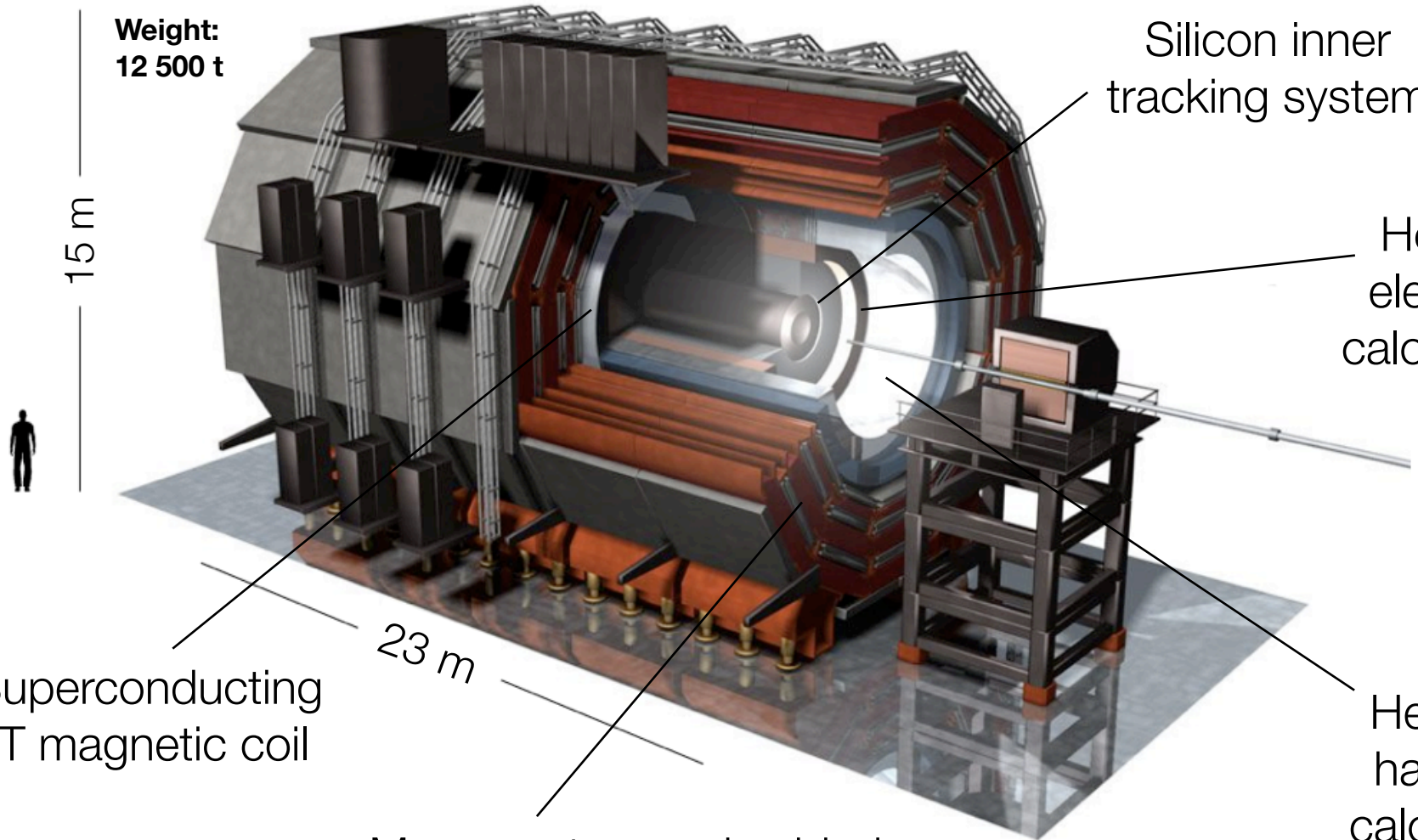


LONGITUDINAL VIEW



TRANSVERSE VIEW

The Compact Muon Solenoid



Silicon inner tracking system

Homogeneous electromagnetic calorimeter (ECAL)

Superconducting 4T magnetic coil

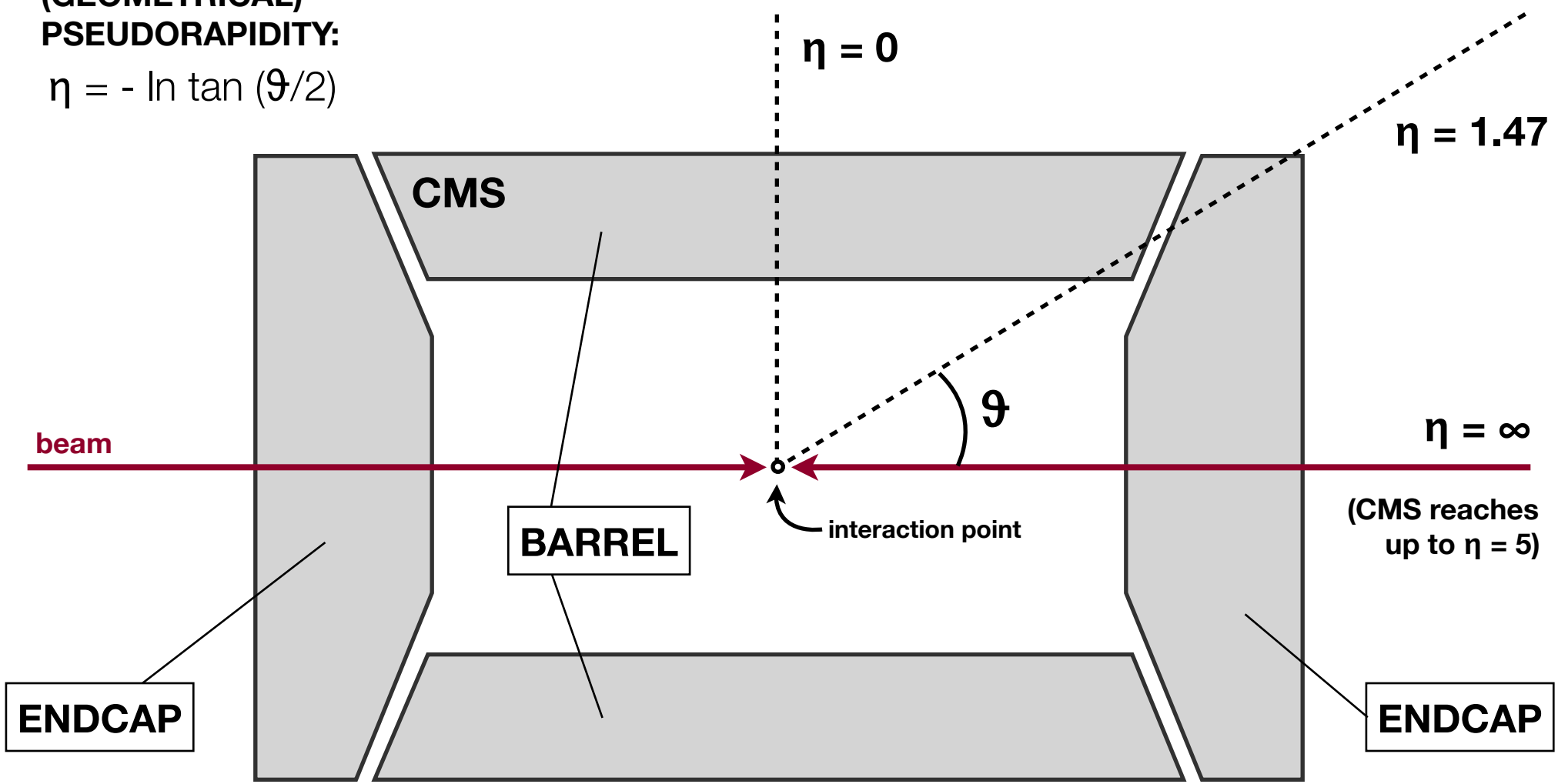
Muon system embedded in magnet return yoke

Hermetic hadronic calorimeter (HCAL)

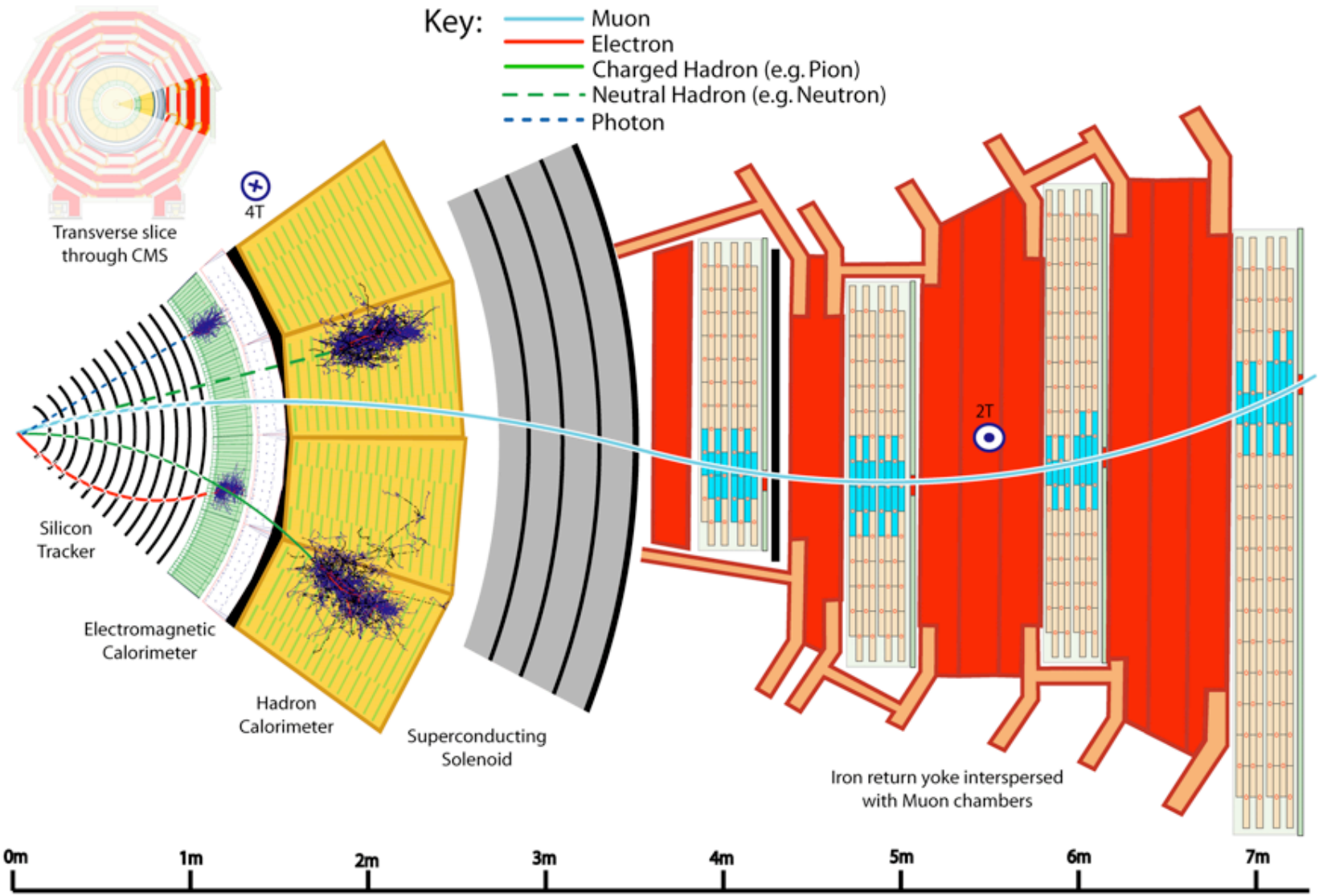
A 4π-Detector Glossary

(GEOMETRICAL) PSEUDORAPIDITY:

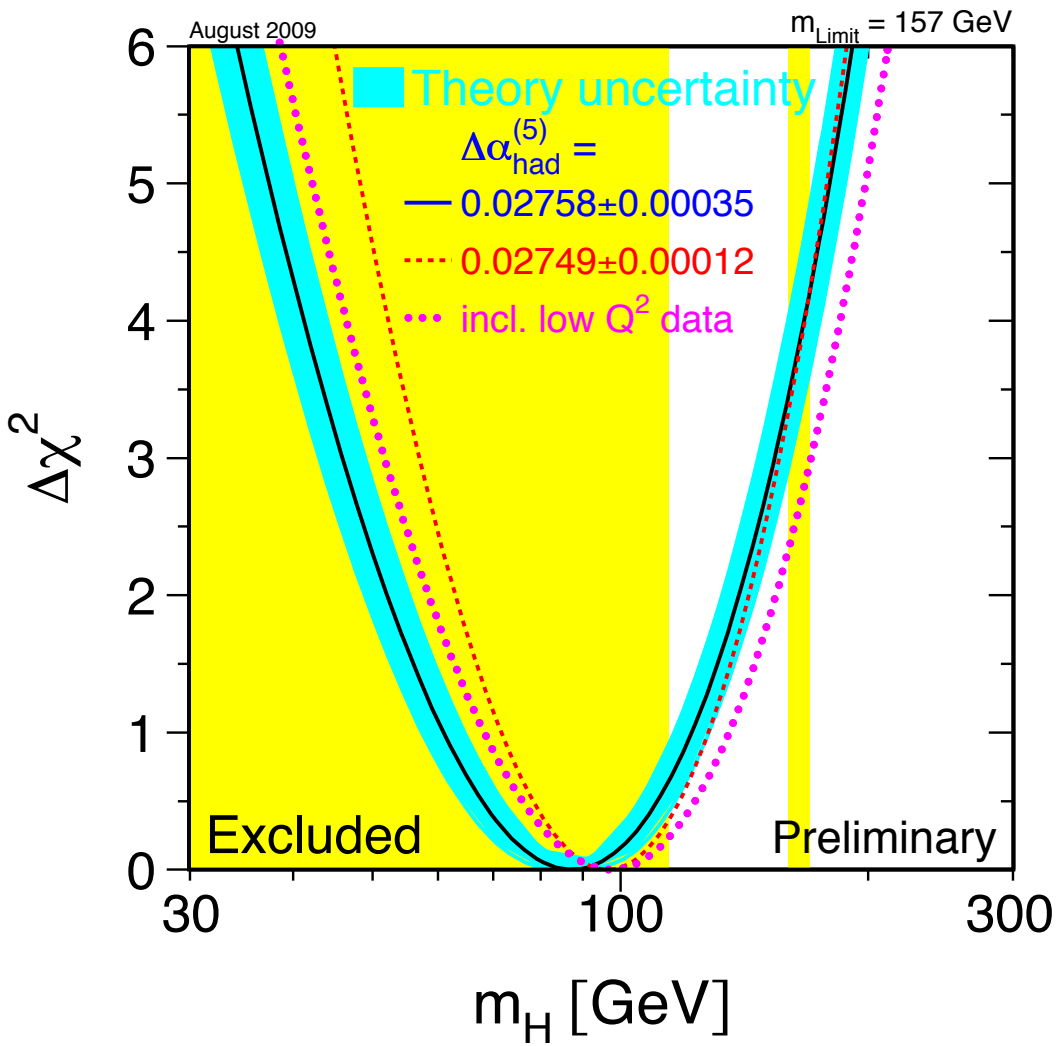
$\eta = - \ln \tan (\vartheta/2)$



Particle Detection in CMS



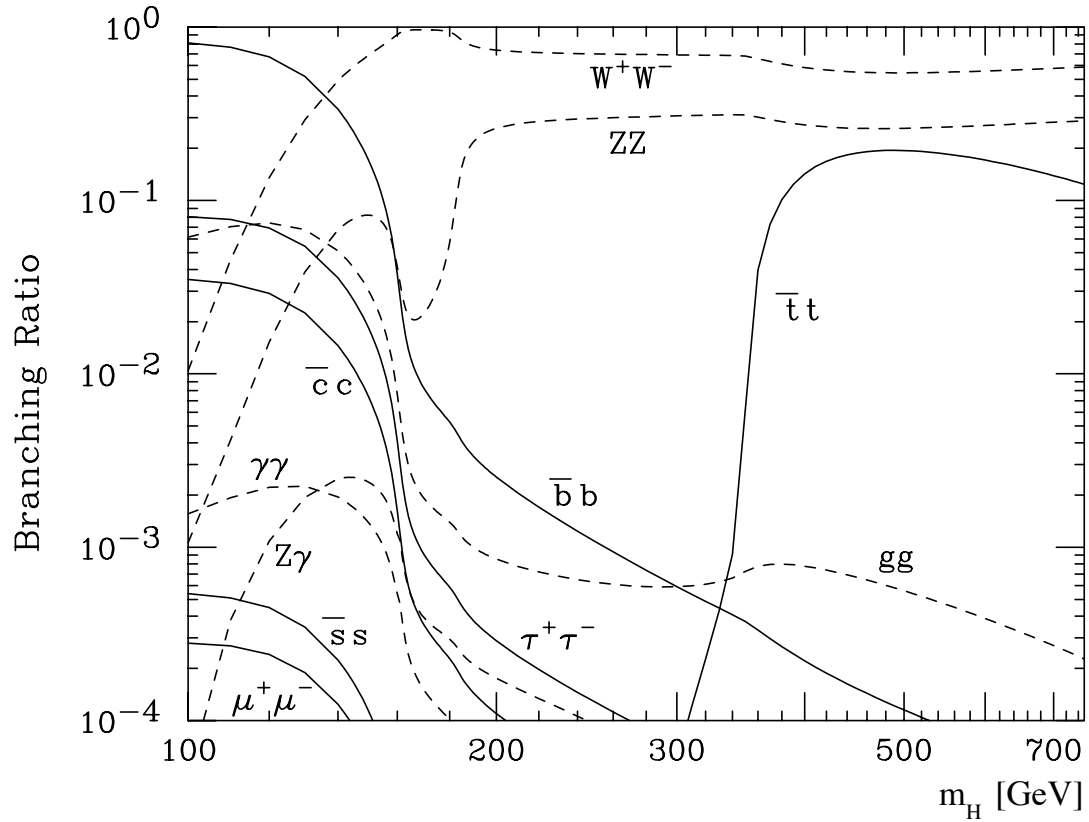
The Missing Piece



- Nature of electroweak symmetry breaking is still a mystery
- Simple solution: Higgs boson
- Higgs mass free parameter
- Experimental constraints:
  - From **direct** searches at LEP and Tevatron
  - **Indirect** ones from LEP precision EWK measurements

Discovering the Higgs

- Discovery strategy depends on the available decay channels
- Decays with leptons provide most clean signatures



MAIN DISCOVERY CHANNELS:

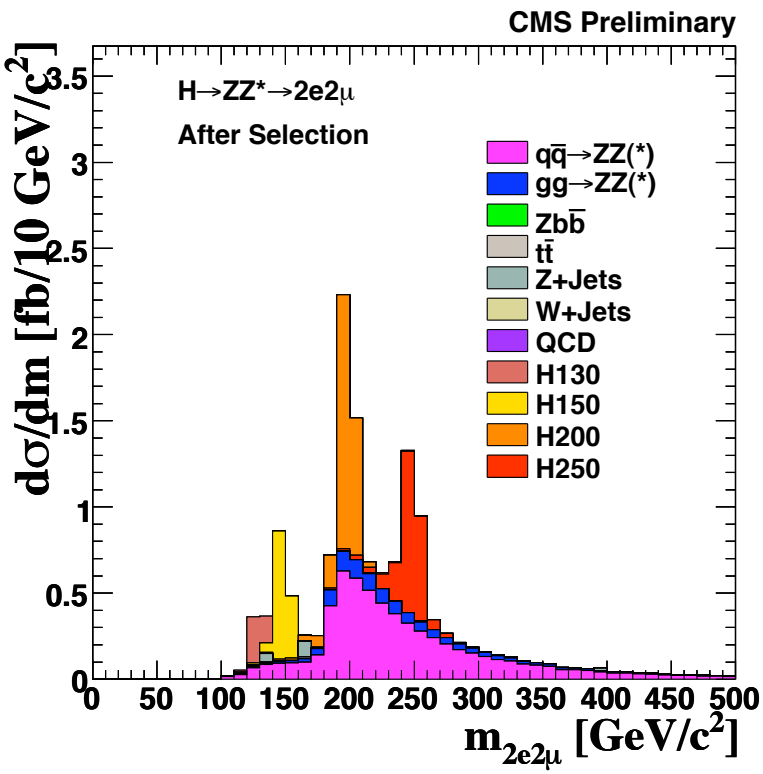
$H \to \gamma\gamma$

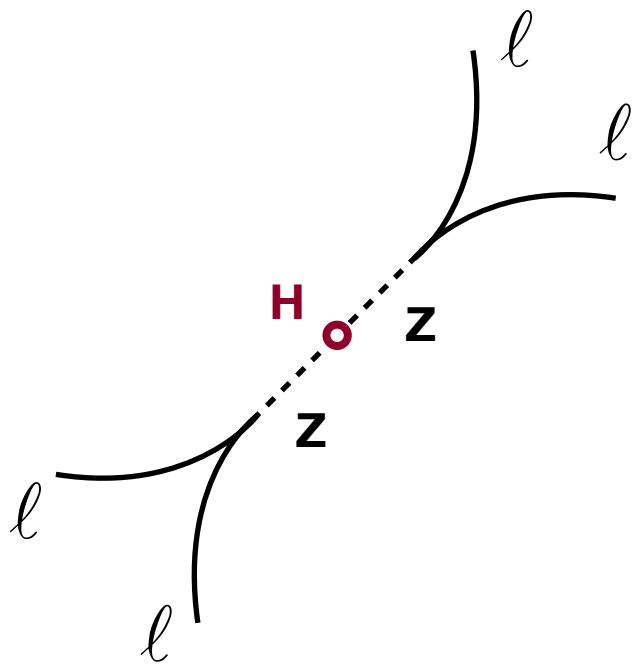
$H \to W^+W^-$

$H \to ZZ$

The $H \rightarrow ZZ$ Decay

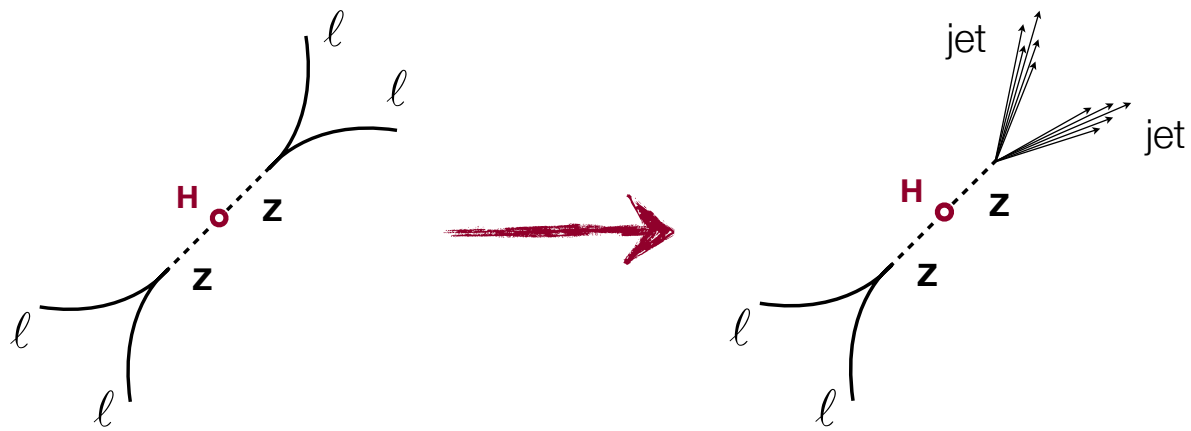
- Decay to two Z bosons most promising discovery channel for $m_H \geq 180$ GeV/c
- If both Z's decay to electrons or muons, very clean signature





...but what if one of the Z bosons decays to **quarks**?

The $H \to ZZ \to \ell^+\ell^- q\bar{q}$ Channel



- Quarks will hadronize and form particle “jets”
  - Jets are complex objects, challenging to reconstruct
- Exchanging precisely measured objects with less precise
- **But** Z can choose 5 different flavours × 3 colours
  - Overall cross-section more than 10 times larger

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d	**s**	**b**

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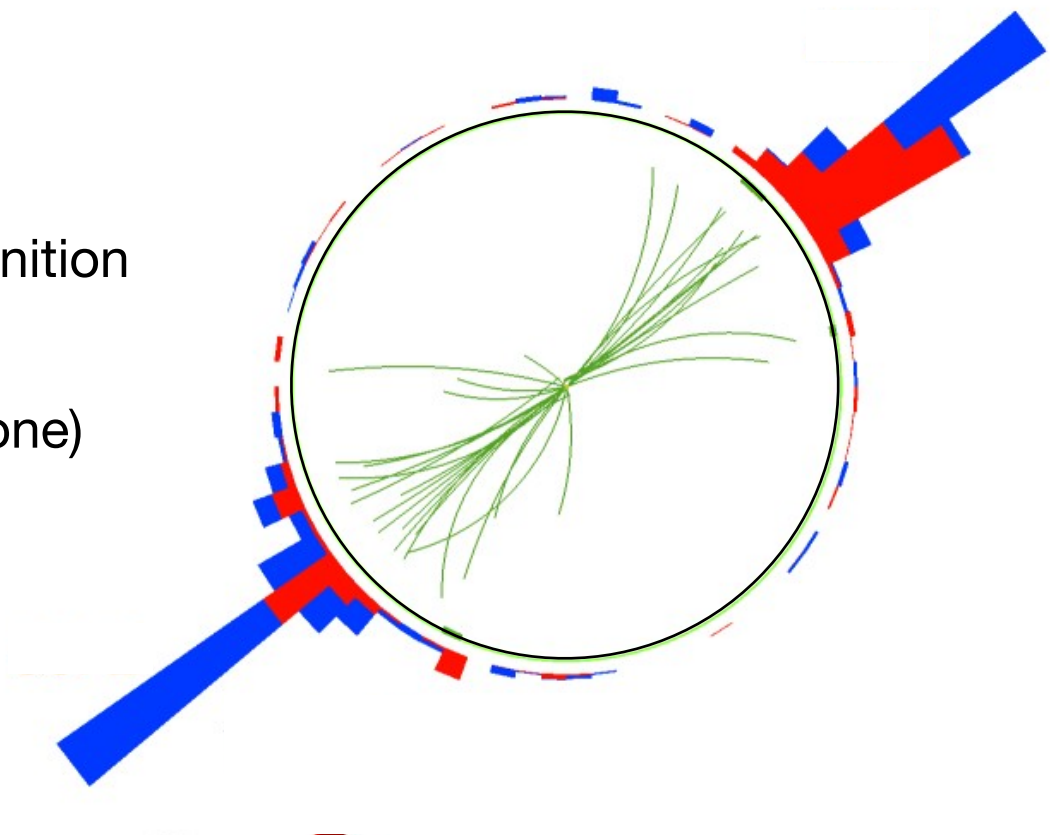
The Problem with Jets

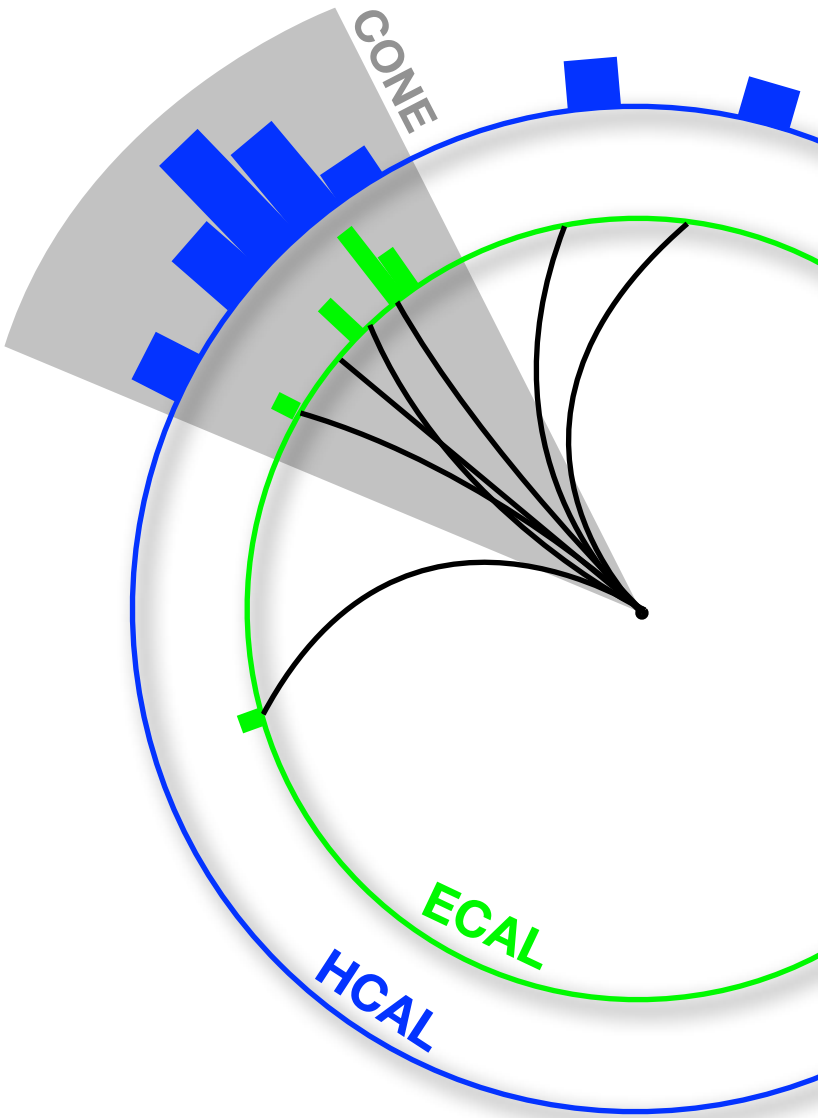
- Reconstructing bunched particles of different nature is challenging
  - Different detector response to different particles
  - Non-linearity: 1+1≠2
- "What is a jet?"
  - Composite objects need definition also at theoretical level
  - Clustering algorithms (e.g. cone)
- But what should be clustered?
  - Theory: particles
  - Experiment?



Traditional Approach: Calorimeter Jets

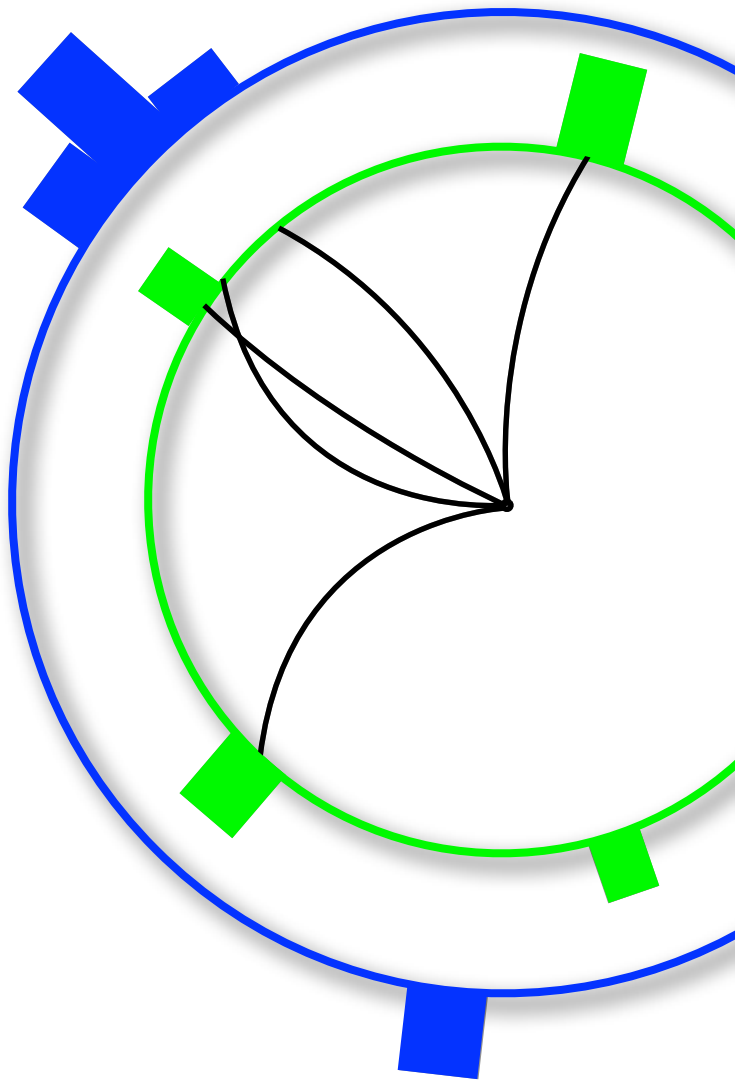
- **Assumption:** most particles will reach calorimeters close to each other
- So just cluster calorimeter energy deposits

PROS	CONS
straightforward	HCAL resolution
fast & unaffected by event complexity	p_T-dependent response
	low-p_T charged particles will be bent away and lost



The Particle Flow Event Reconstruction

Goal: reconstruct all stable final state particles, making use of all CMS sub-detectors.



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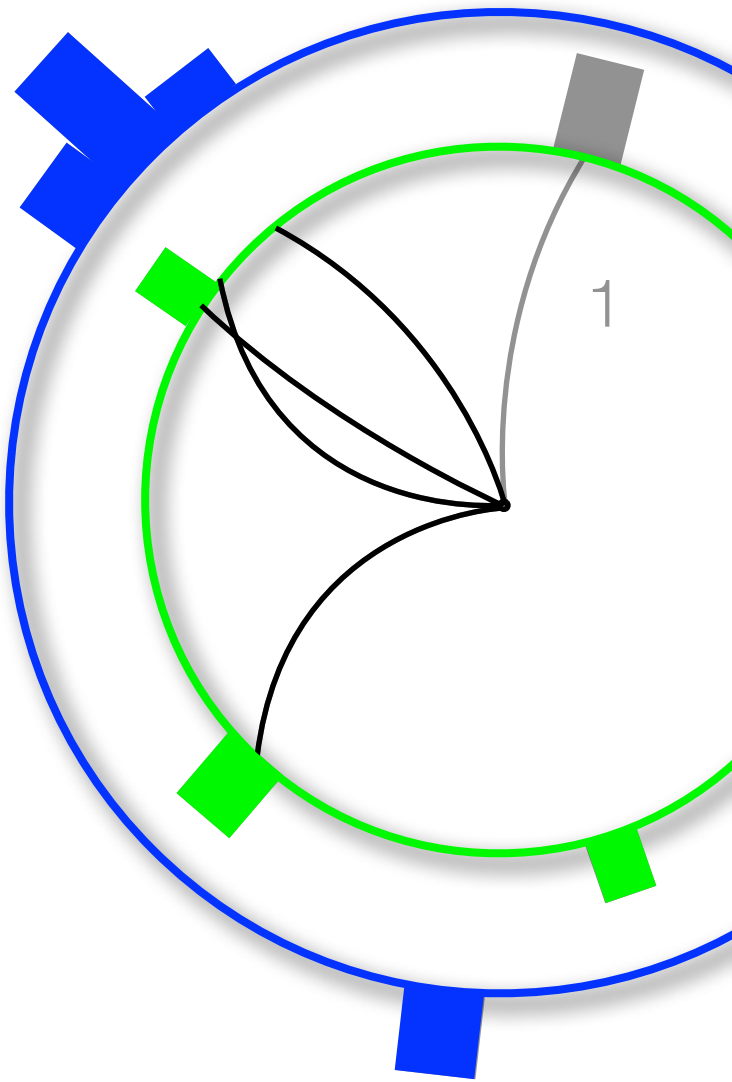

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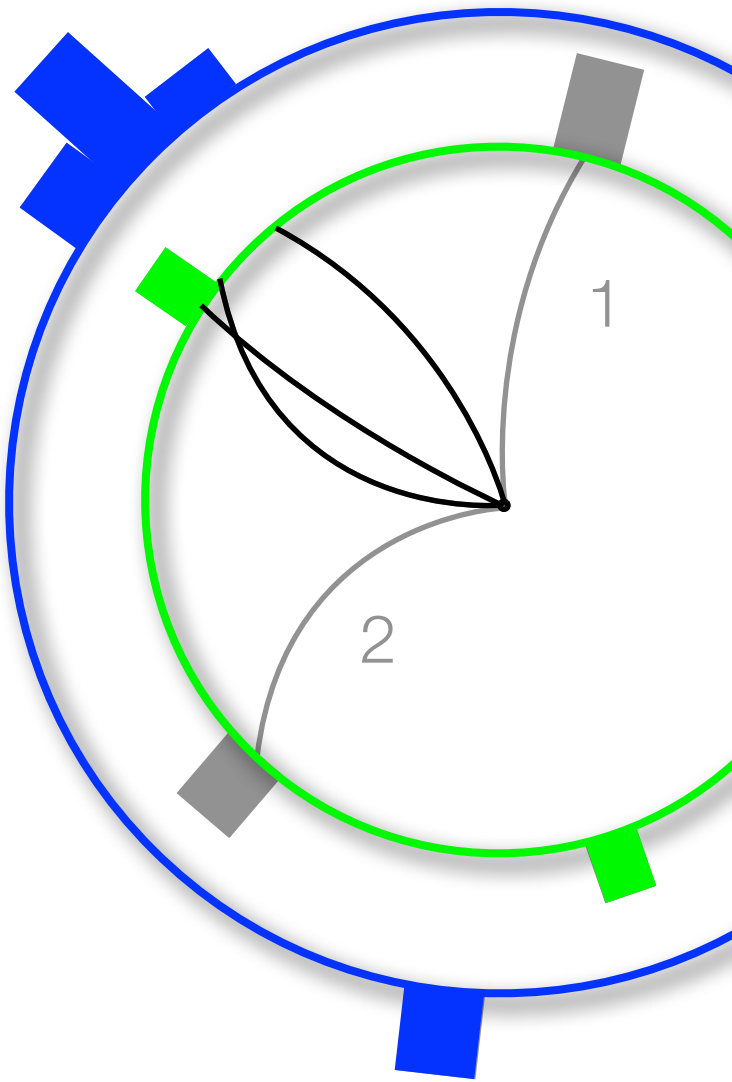

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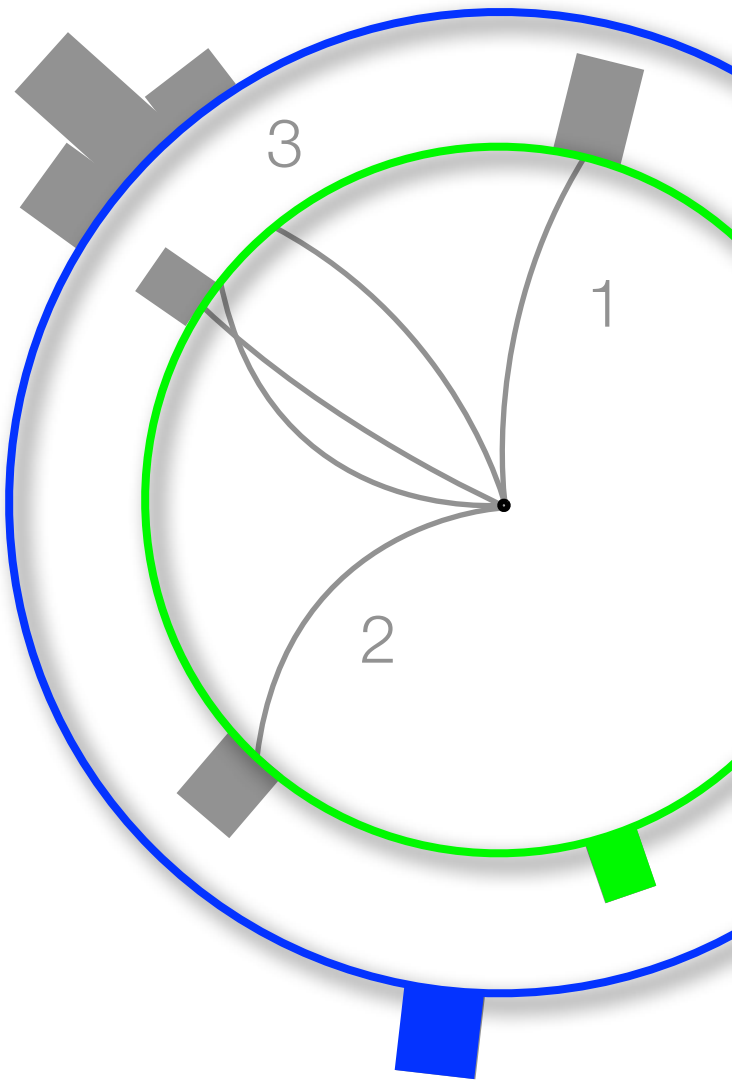
3. For each HCAL cluster get all linked tracks and all ECAL clusters linked to tracks. Compute $E_{calo} = E_{HCAL} + E_{ECAL}$

   - **if** (E_{calo} compatible with $\sum p_{tracks}$) create a charged hadron for each track
   - **if** ($E_{calo} > \sum p_{tracks}$) create photons and/or neutral hadrons to account for missing E_{calo}



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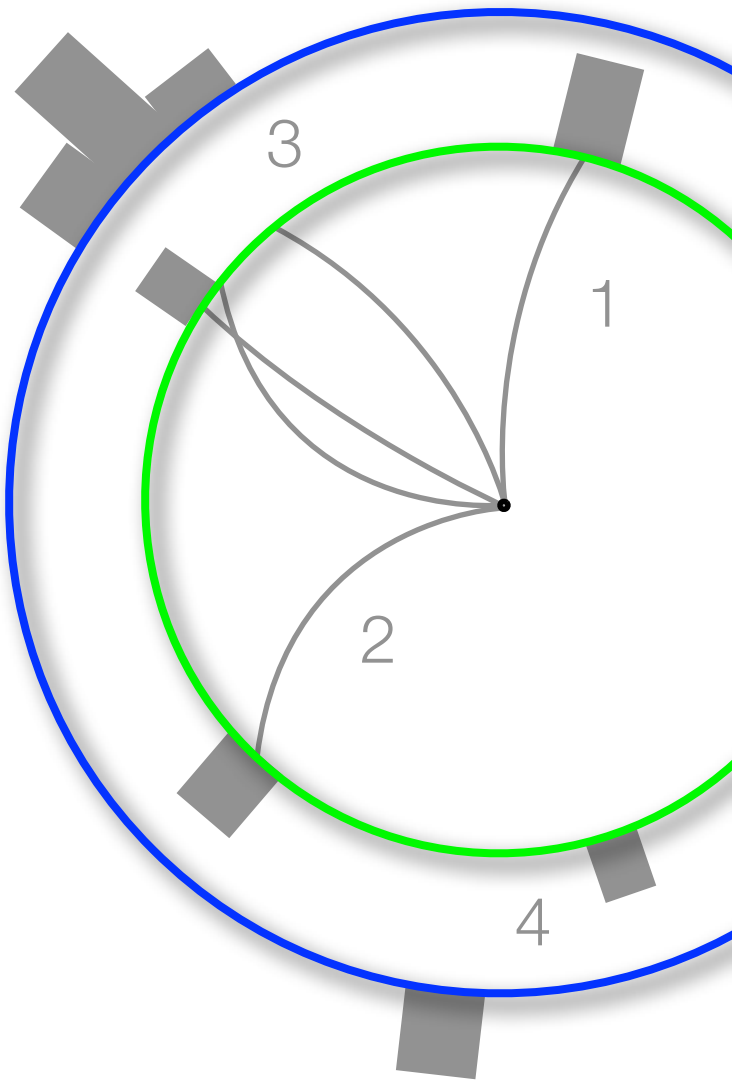
4. For all remaining ECAL (HCAL) clusters not linked to tracks, create a photon (neutral hadron)



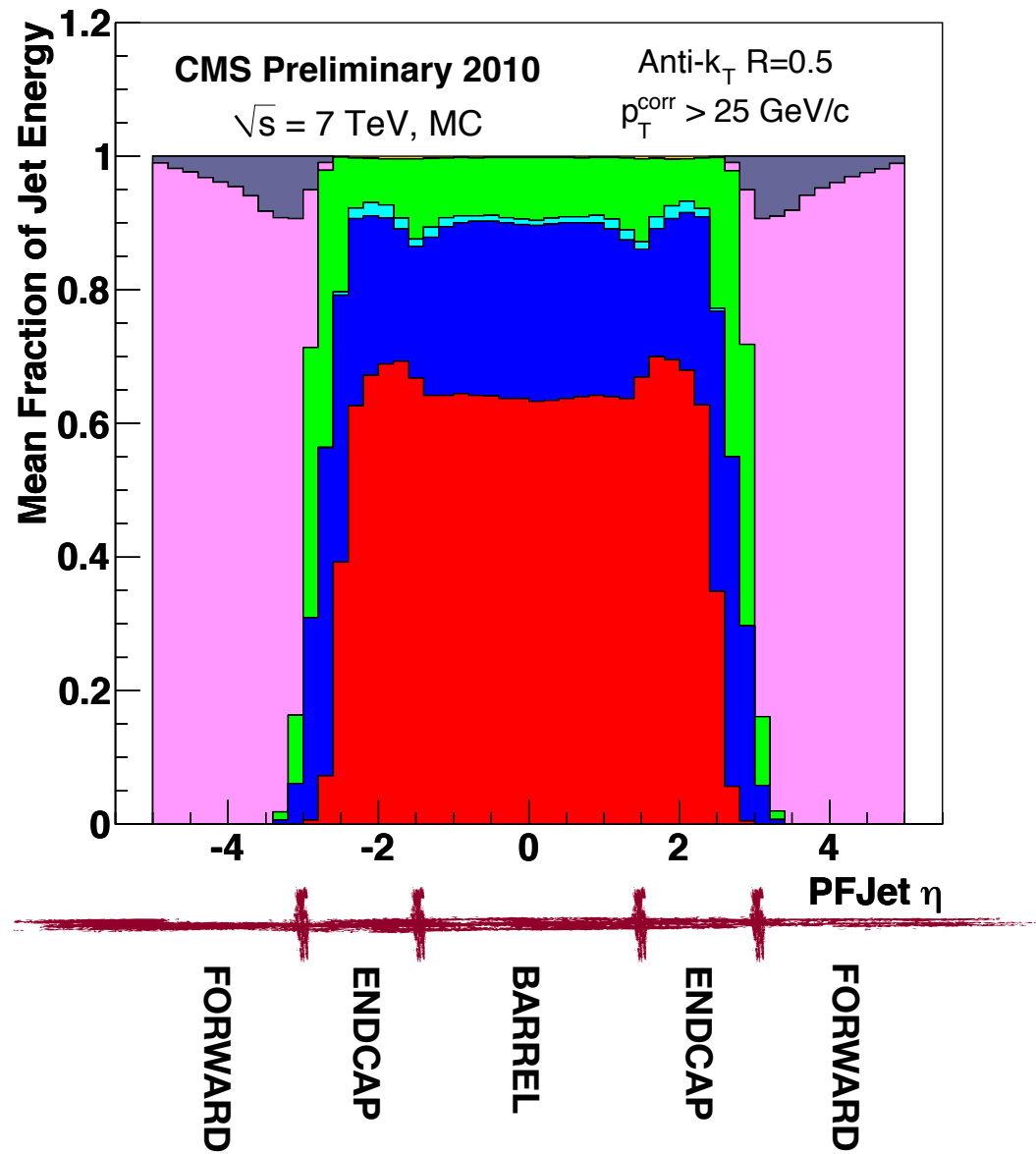
Particle Flow Jets

- Cluster particle candidates into PFJets

  - Charged Hadrons
  - Photons
  - Neutral Hadrons
  - Electrons
  - Forward Hadrons
  - Forward EM Particles

- Jet energy fractions:

A Typical Jet



Response and Resolution

- Two variables describe jet reconstruction performance:

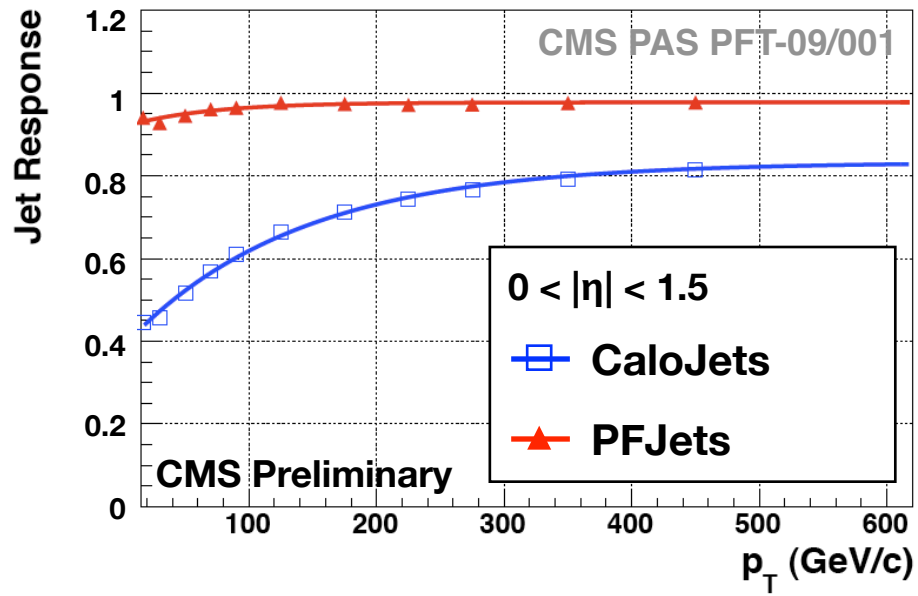
  Response: $\frac{p_{\mathrm{T}}^{\mathrm{reco}}}{p_{\mathrm{T}}^{\mathrm{gen}}}$

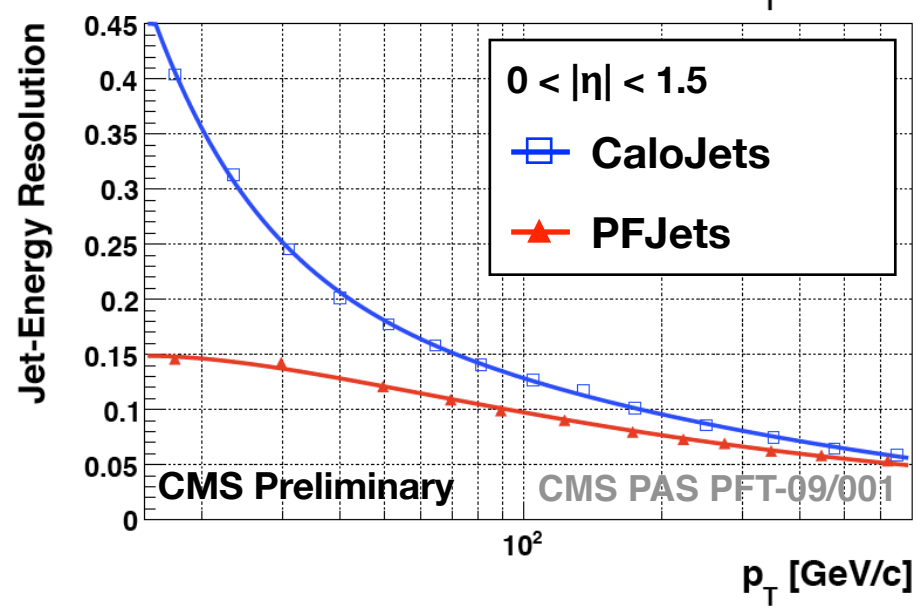
  Resolution: width of response, divided by the mean

- Particle Flow offers high-precision jets
  - Higher response
  - Better resolution

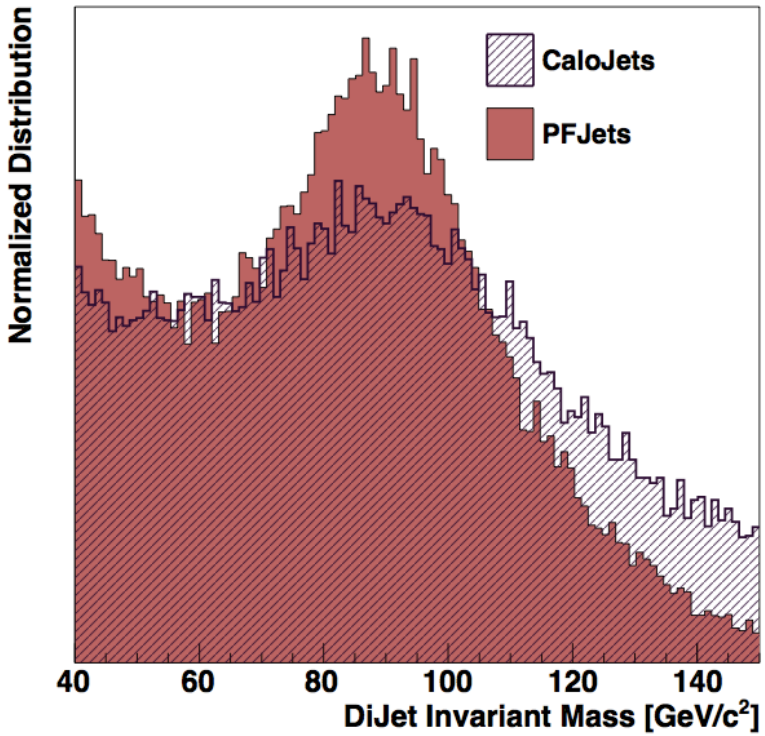
  wrt calojets

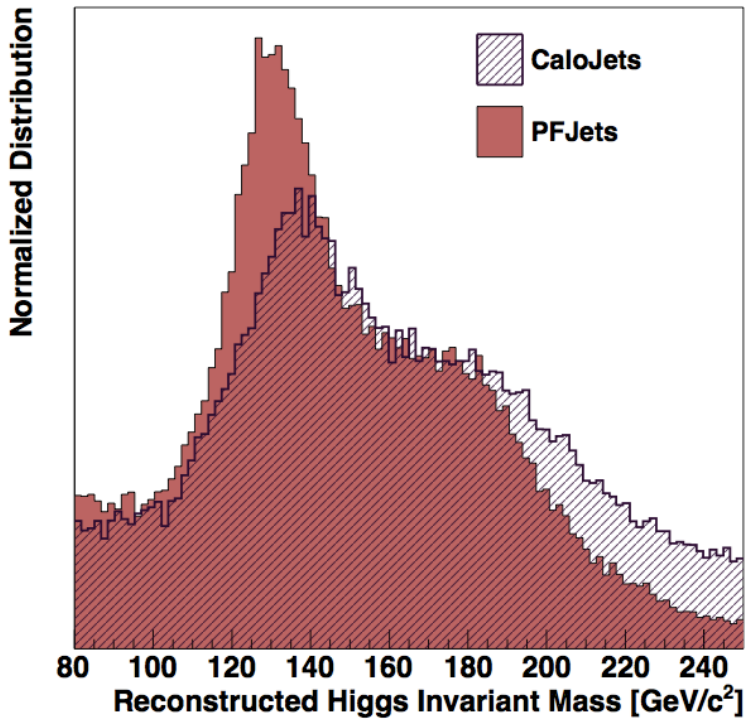
- Response and resolution must be measured on data before any jet analysis





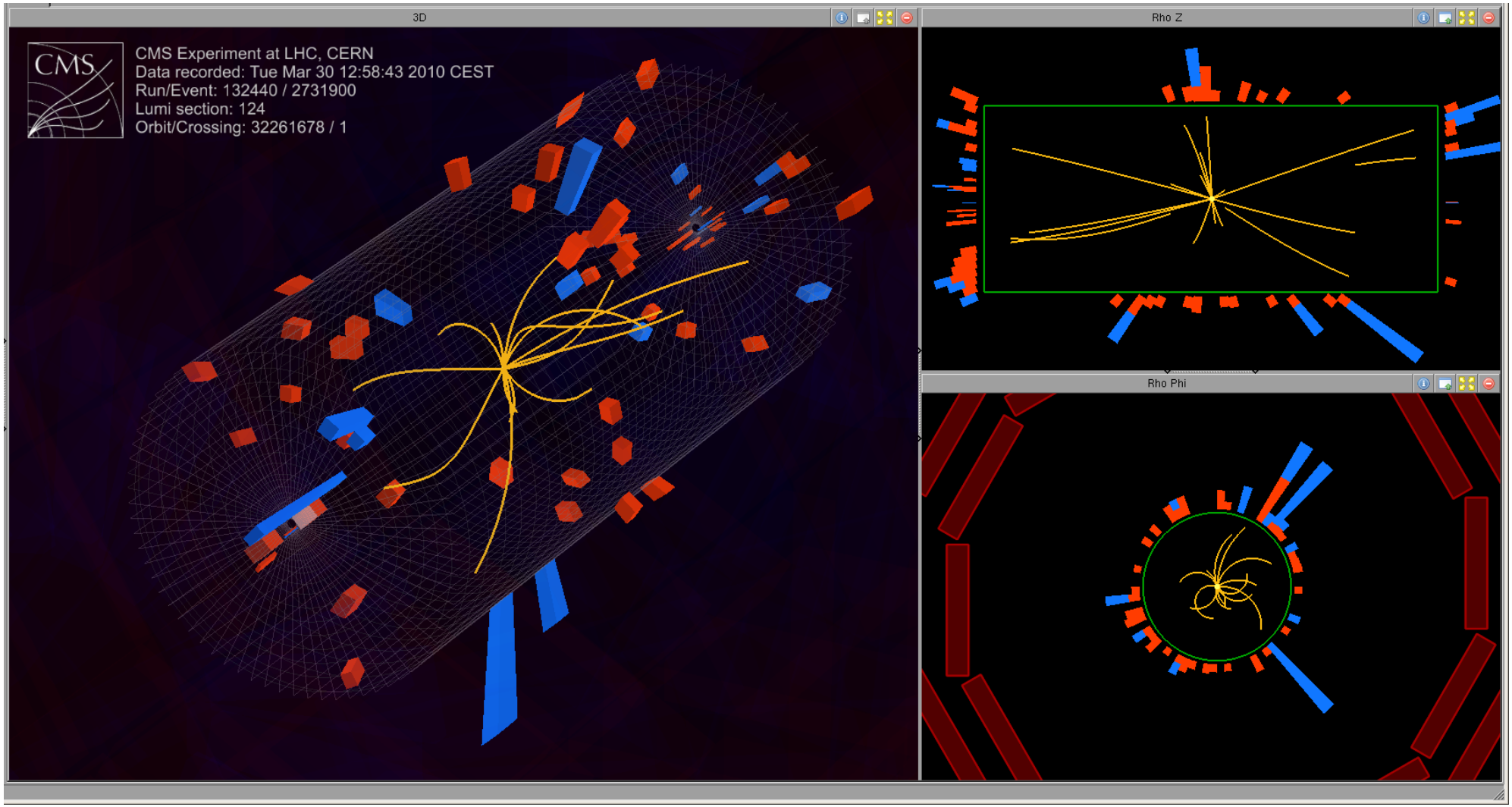
Improvements in Hadronic Z Mass





- Particle Flow Jets improve hadronic Z invariant mass reconstruction

- Translates in a better resolution on the reconstructed Higgs invariant mass

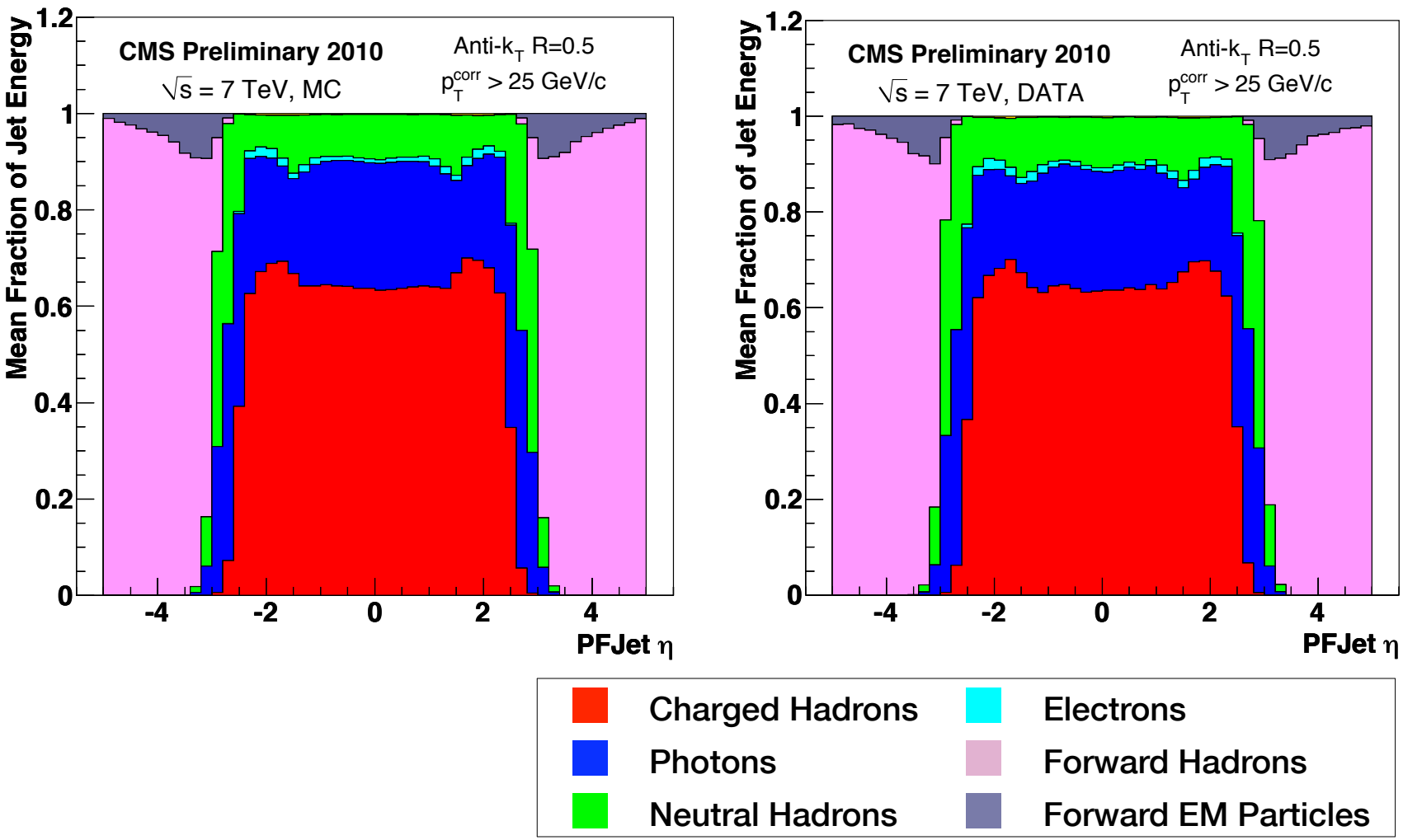


March 30th 2010, 12:58PM: Dawn of a New Era

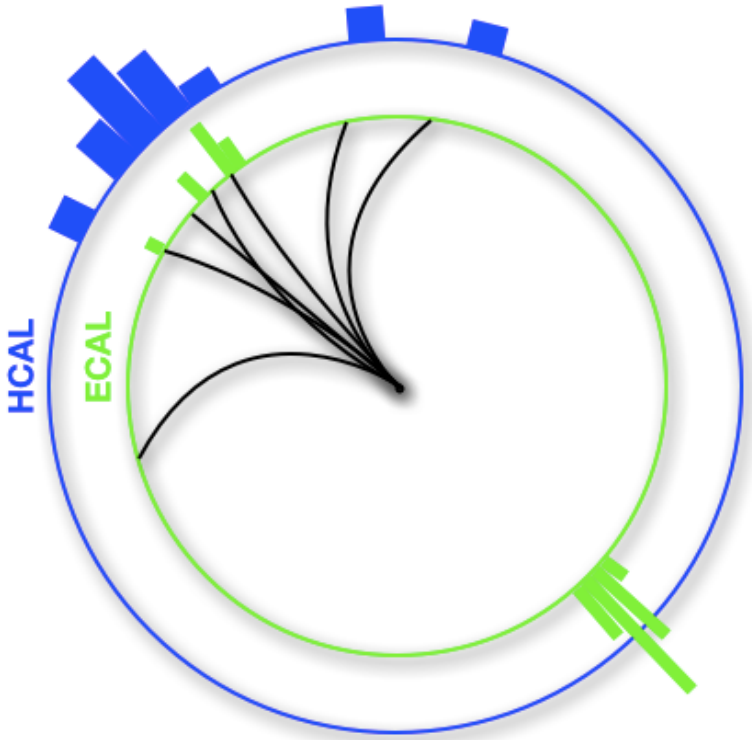
First 7 TeV collisions recorded by the CMS detector

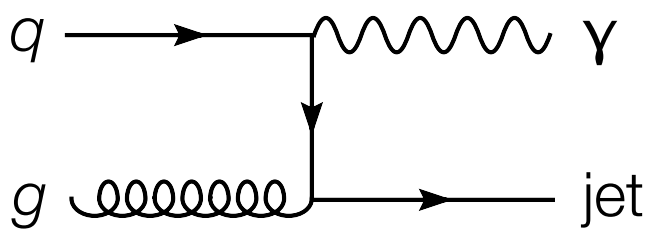
PFJet Commissioning on Data

- Simulation accurately describes PFJet composition



Jet Calibration with Photon+Jet Events



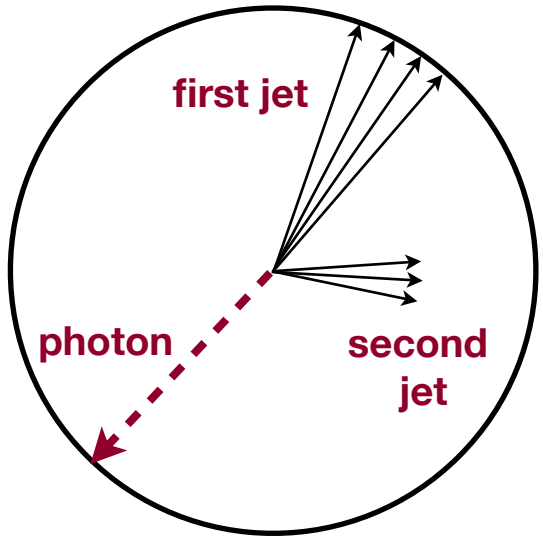


- Photons are measured with great precision in the CMS ECAL
- Event is balanced
  - Photon p_T ~ true jet p_T
- So distribution of

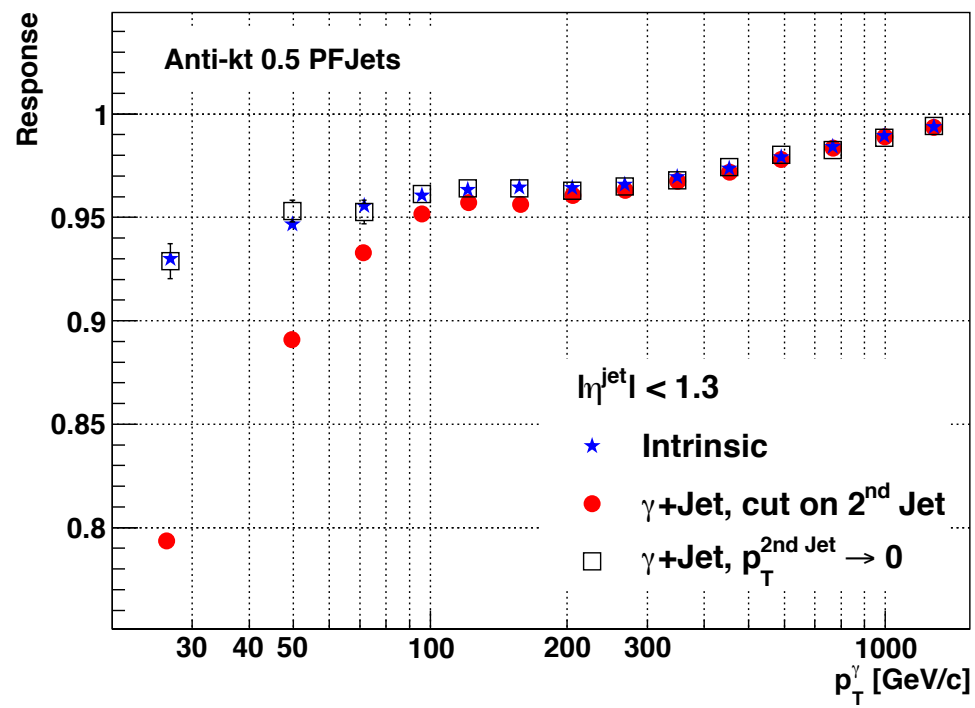
$$p_{\mathrm{T}}^{\mathrm{jet}} / p_{\mathrm{T}}^{\gamma}$$

is good estimate of jet response

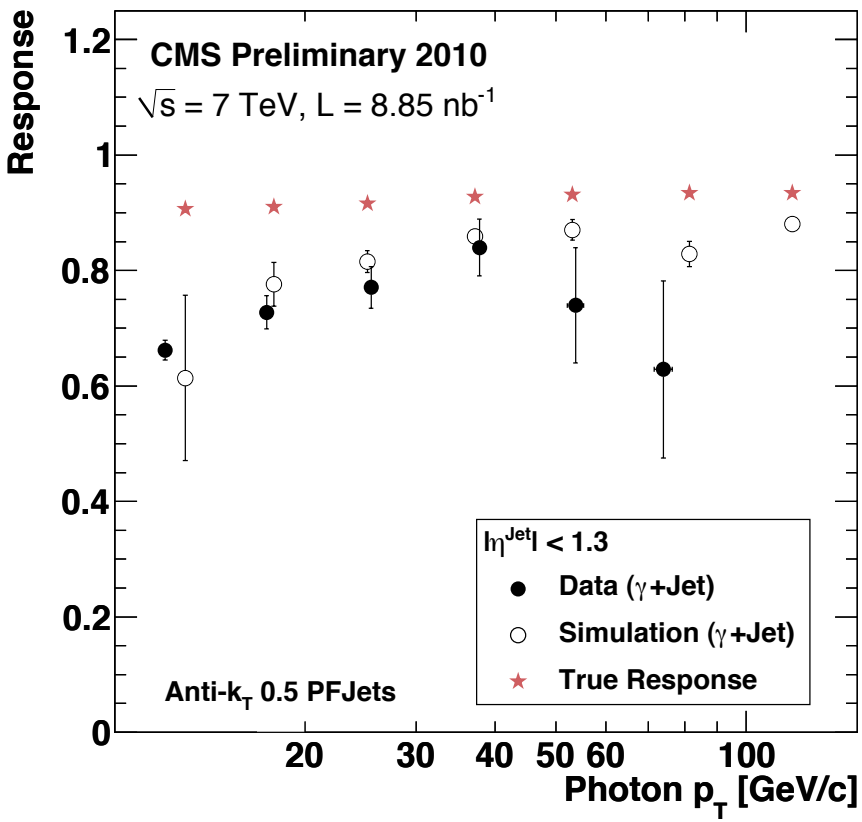
The Problem with the Second Jet



- Secondary jets spoil photon-jet balancing
- A bias introduced in response measurement
- Has to be accounted for
- Extrapolating to second jet $p_T \rightarrow 0$ gives precise estimates of response (and resolution)



So How's It Going?



- We already have some preliminary estimates of jet response
- Still large **bias** wrt true response
  - Very loose cuts on second jet
- As soon as enough stat, will start extrapolating 2nd jet $p_T \rightarrow 0$

A Road Map

Summer 2010

- Measurement of jet response and resolution with photon+jet events

Fall 2010 - Winter 2011

- Selection optimization of H→ZZ→llqq
- Study of backgrounds and uncertainties

Spring 2011 -

- Analysis finalization
- First measurement

Conclusions and Prospects

- Jets challenging objects to reconstruct
- The Particle Flow improves jet reconstruction performance at CMS
- This could open new frontiers in Higgs hunting
  - H → ZZ with a hadronic Z decay
- Any jet analysis needs response and resolution to be well under control
  - Commissioning of jet reconstruction ongoing successfully on data
  - Will have a first measurement this summer
- Next year will be exciting