Forward Physics Capabilities of CMS with the CASTOR calorimeter

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Outline

- CASTOR calorimeter
- Physics program
  - Parton Shower evolution
  - Multiple Partonic Interactions
  - Diffraction
- Measurements
  - Multi-Jet events with a forward jet
  - Central-Forward activity correlation
  - Presence of a rapidity gap
- Conclusions

CASTOR calorimeter

CASTOR calorimeter

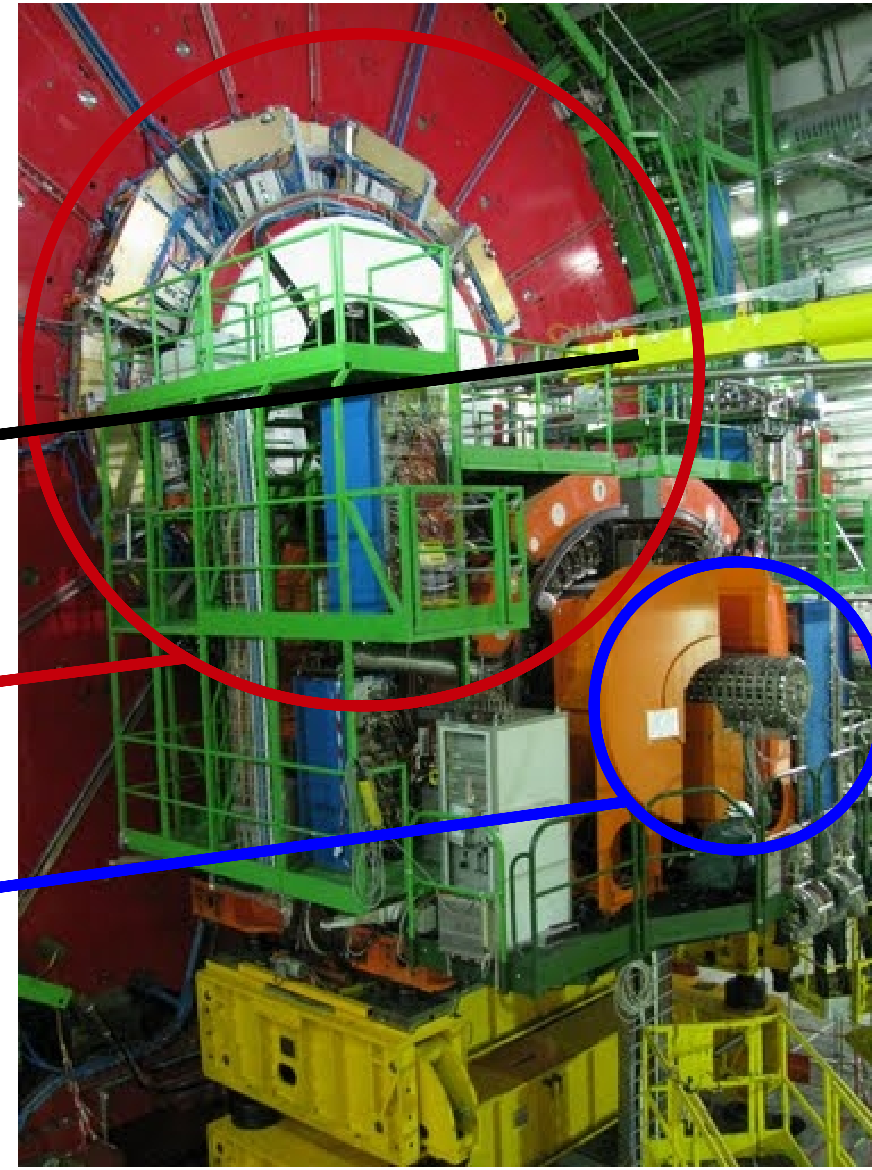
- located 14.37 m downstream of the CMS interaction point (negative *z* side)

- forward region coverage $-6.6 < \eta < -5.2$

Beam pipe

CMS

CASTOR
in parking position



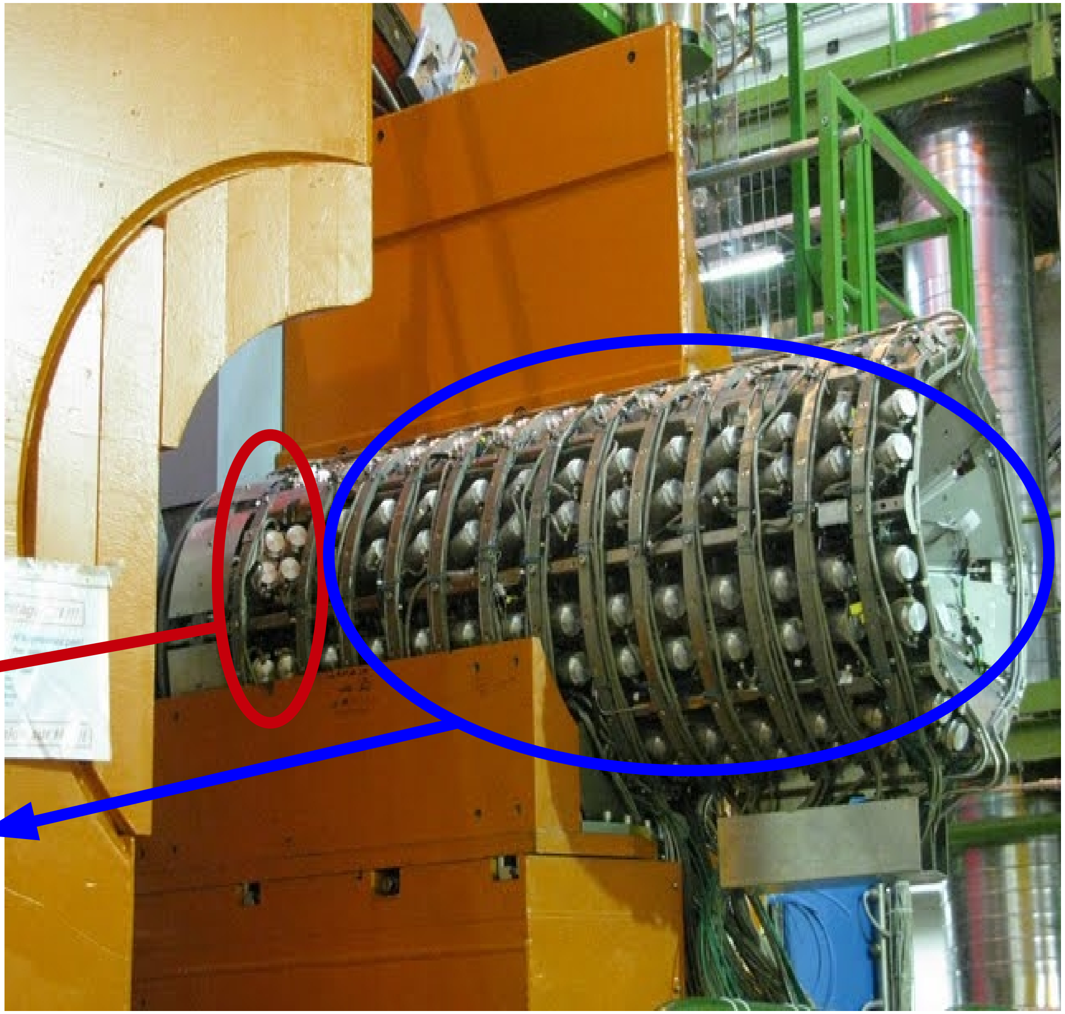
CASTOR calorimeter

- octagonal cylinder
  - inner radius = 3.7 cm
  - outer radius = 14 cm
- Cerenkov calorimeter
  - photons transmitted to PMT's through aircore lightguides
  - light collection efficiency = 25%
- W absorber plates and quartz plates as active material
- 2 elm sections = 20.1 X_0

  12 had sections, total depth = 10.3 λ_I
- 14-fold segmentation in z (modules)

  16-fold segmentation in ϕ (towers)

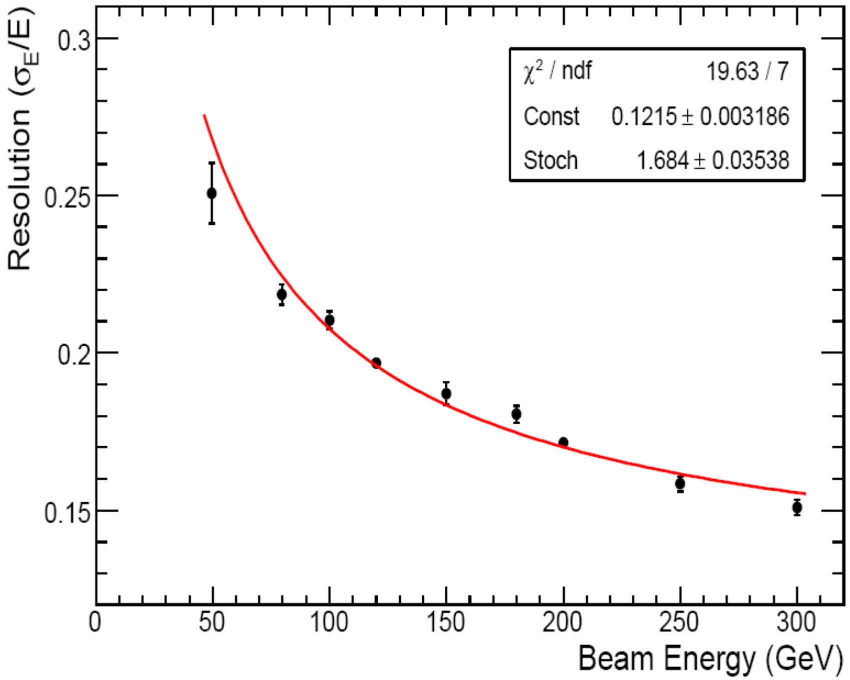
  no segmentation in η



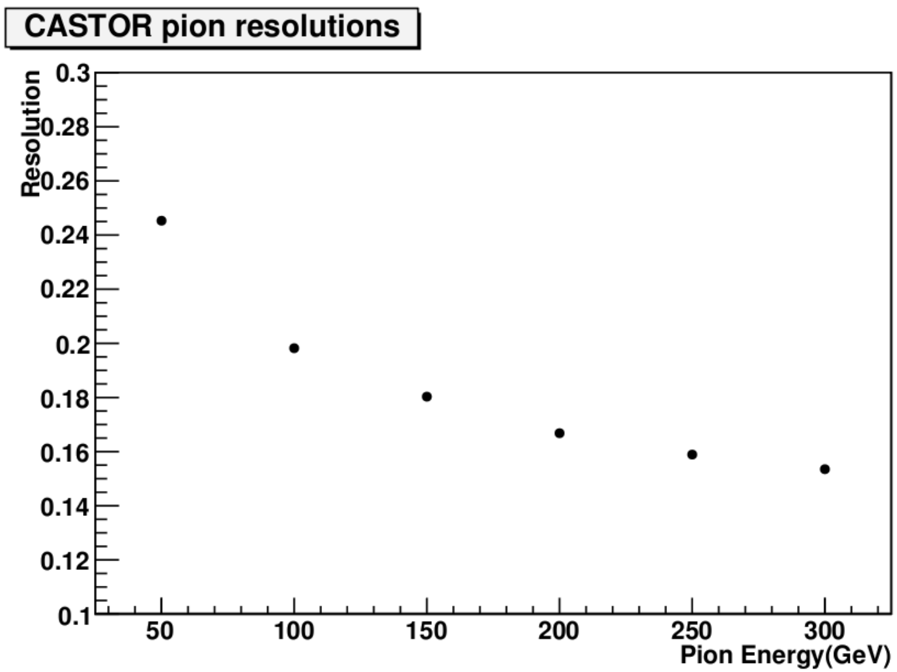
CASTOR energy resolution

Energy resolution for pions

TB 2007



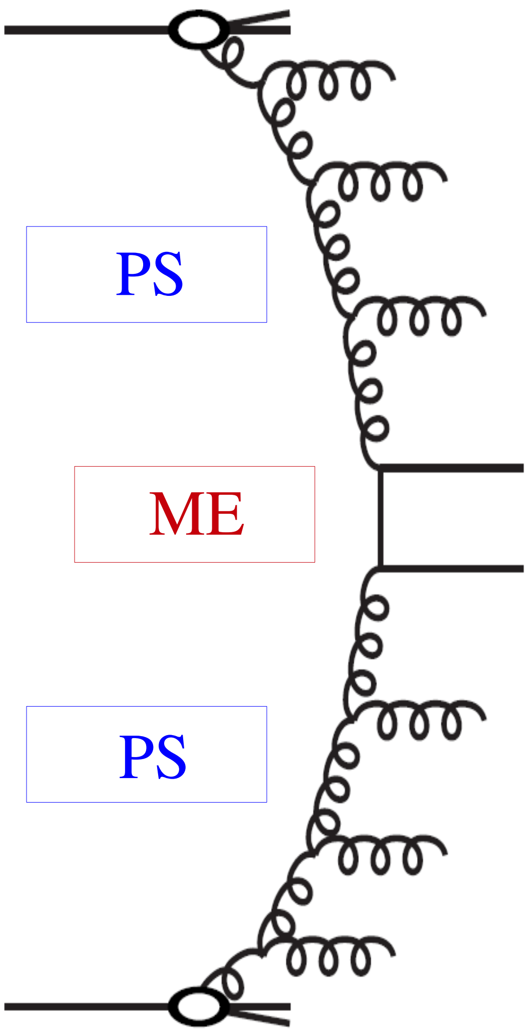
Full Simulation



from 25 % at 50 GeV to 15 % at 300 GeV
agreement between TB and simulation

Physics program

Description of *pp* collision



- Matrix Element associated to the hard scattering
  - exact QCD calculation at a given fixed order
  - hard scale $Q = p_t$, M of produced subsystem
  - at given value of Bjorken variable x_b
- Parton Shower links the hard scattering to the proton
  - takes into account higher order contributions
  - by resumming a subset of leading diagrams at each order of the perturbative expansion
- PS covers our lack of knowledge about the ME
  - correct matching of the PS to the ME considered

pp collision at low *x*

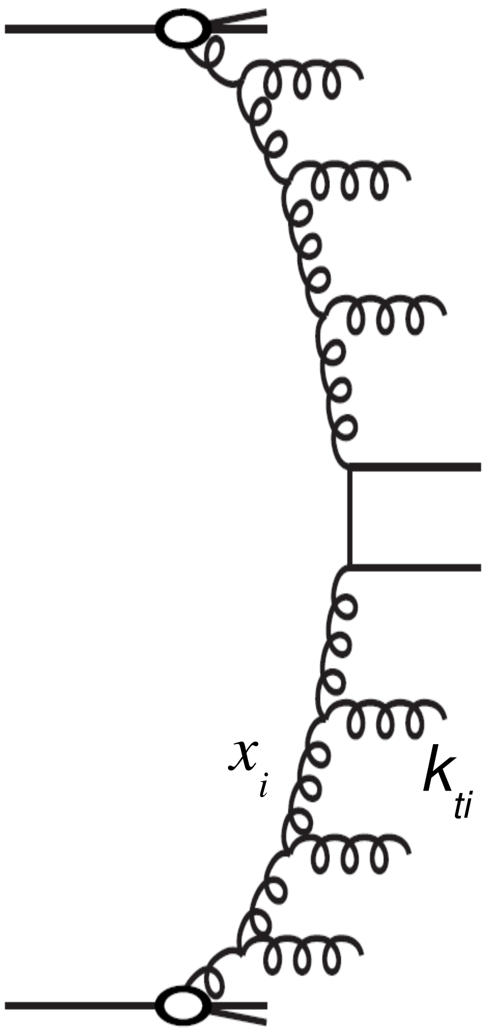
- at low x: partons undergo long Parton Shower before they meet
  forward particles production can arise in two ways
- collision between a low x and a high x parton
  - hard scattering subsystem goes forward: forward production from ME
  - low x parton and η of forward system are related by: $x = (Q/\sqrt{s})\, e^{-\eta}$
  - at LHC, for $Q > 10$ GeV and $\eta \sim 6$: $x \sim 10^{-6}$

  ⟶ saturation of pdf
- collision between two low x partons
  - hard scattering subsystem produce central dijets
  - forward jet comes from QCD evolution of the Parton Shower

  ⟶ sensitive to Parton Shower dynamics

Parton Shower dynamics

- **DGLAP evolution:** from low to high Q^2,
  emissions ordered in k_t,
  behaviour ~ $ln\ Q^2$, PYTHIA
- **BFKL evolution:** from high to low x,
  emissions ordered in x,
  behaviour ~ $ln\ (1/x)$
- **CCFM evolution:** in x and Q^2,
  angular ordering of the emissions,
  behaviour ~ $ln\ (1/x)\ ln\ Q^2$, CASCADE
- **Color Dipole Model:** independent dipole radiations,
  unordered in k_t,
  BFKL-like behaviour, ARIADNE



Multi-Jets analysis with a forward jet

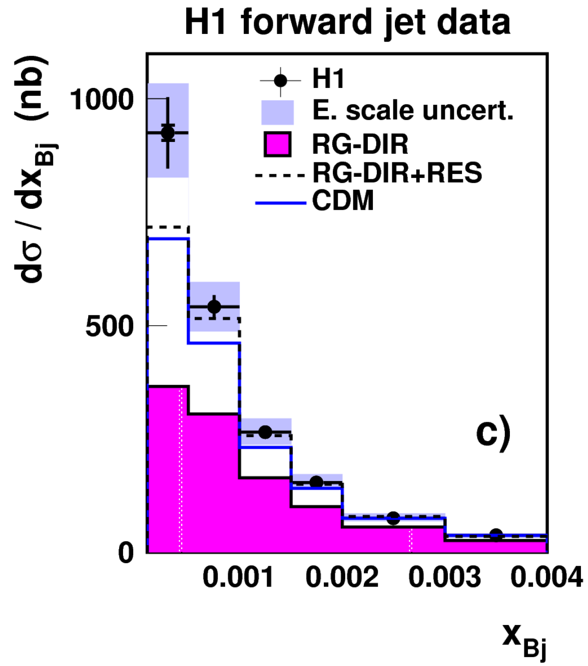
- Differences between the various models for the Parton Shower evolution are more prominent in the forward region

  DGLAP: k_t ordering: softest emissions in the forward direction

  BFKL/CDM: no k_t ordering: forward emissions can be arbitrarily large as long as they are allowed by the kinematics

  → possible to distinguish between models

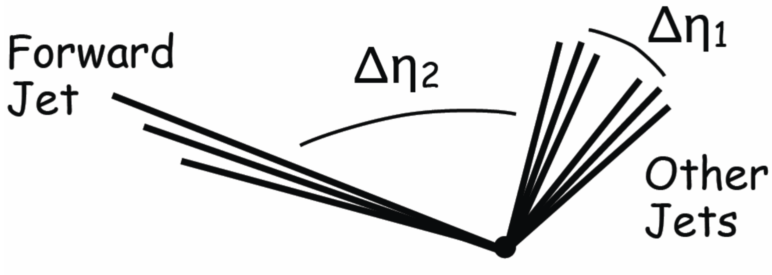
- Forward jet study at HERA: [Eur.Phys.J.C46:27-42,2006]



- RAPGAP: PS generated according to DGLAP
  - DIR: 1 DGLAP evol. chain: fails to describe
  - RES: 2 DGLAP evol. chains: better description
- CDM: independent gluon radiations: better

$\Delta\eta$ distribution in Multi-Jets events

- Consider events with at least 3 jets, one of them is a fwd jet in CASTOR
  - order jets by decreasing rapidity: $\eta_{fwdjet} > \eta_{jet2} > \eta_{jet1}$
  - define rapidity separation between jets: $\Delta\eta_1 = \eta_{jet2} - \eta_{jet1}$



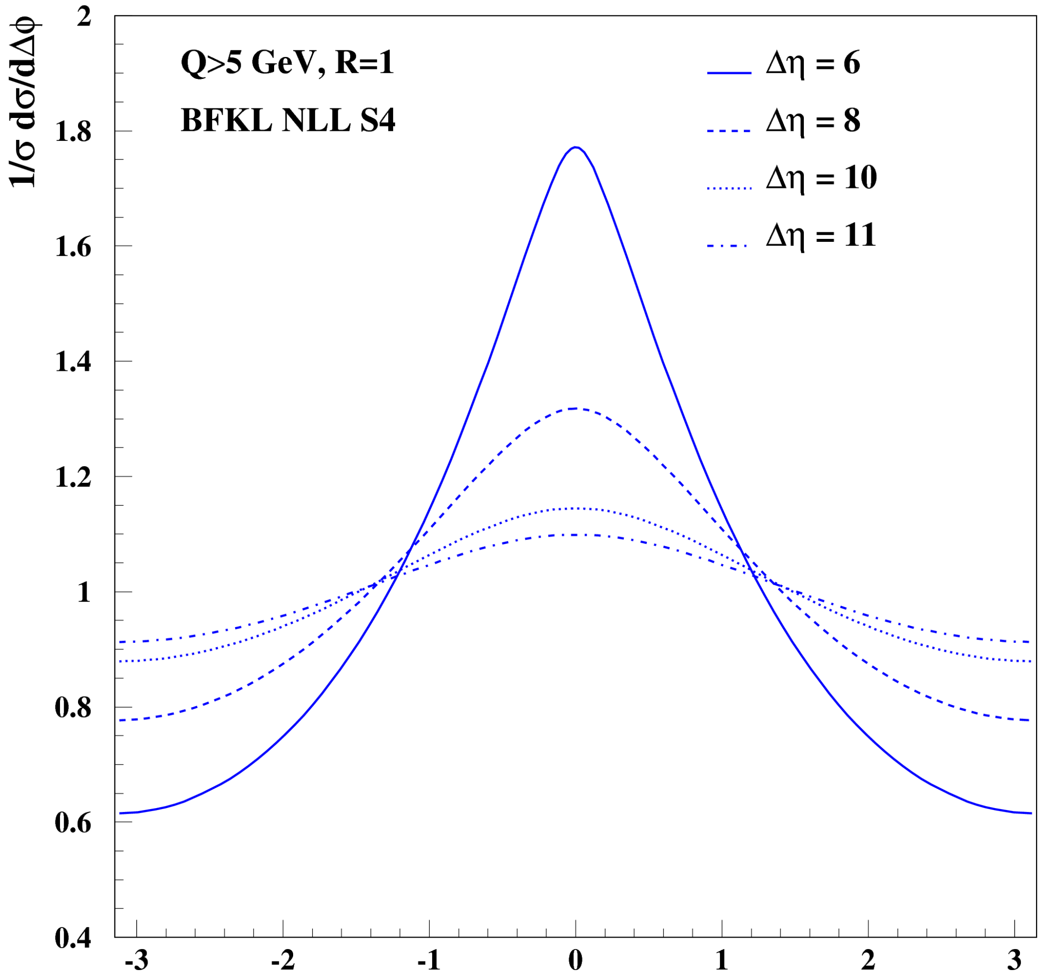
$$\Delta\eta_2 = \eta_{fwdjet} - \eta_{jet2}$$

- Look at $\Delta\eta$ distribution to distinguish between the various PS models
  - $\Delta\eta_1$ small, $\Delta\eta_2$ large $(6 < \Delta\eta_2 < 10)$: enhances the available phase-space in x for BFKL-type radiations between fwd jet and dijet system
  - $\Delta\eta_1$, $\Delta\eta_2$ small: all 3 jets in the forward region
  - $\Delta\eta_1$ large: possible BFKL evolution between the 2 jets of dijet system

Mueller-Navelet (MN) dijet events

- event in which a jet is detected in each of the forward directions
- process characterized by two hard scales: p_{t1}, p_{t2} of the 2 forward jets:
  - suppress DGLAP-like emissions ordered in k_t
- MN dijet separated by a large rapidity interval $\Delta\eta \sim ln\,(s\,/\,p_{t1}p_{t2})$
  - open the phase-space in x and enhance BFKL-type radiations
- study azimuthal decorrelation $\Delta\phi$ between MN dijet enables to access parton dynamics beyond DGLAP ($\Delta\phi = \phi_1 - \phi_2 - \pi$)
  - DGLAP evolution: 2 jets more balanced in p_t (at LO $\Delta\phi = 0$)
  - BFKL evolution: higher order emissions lead to flatter $\Delta\phi$

Mueller-Navelet (MN) dijet events



- MN dijet $\Delta\phi$ distribution in NLL BFKL for CDF kinematics, with $p_{t1} = p_{t2} > 5$ GeV

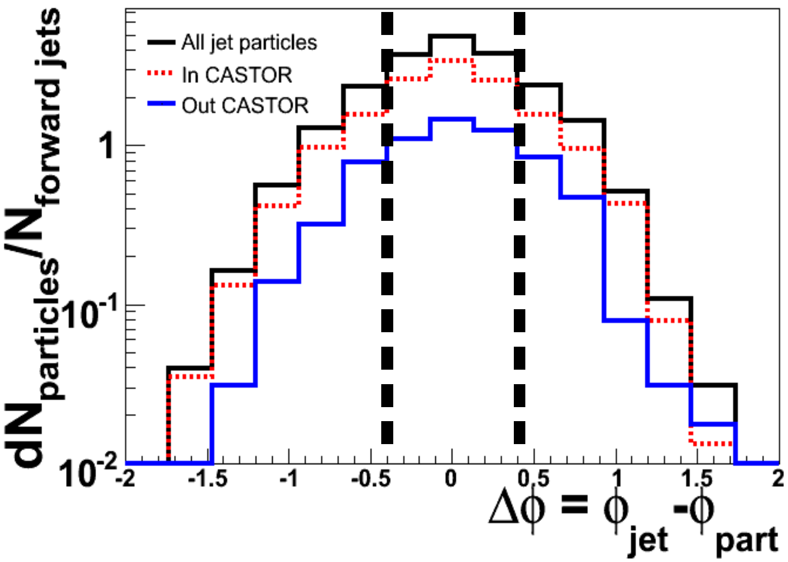
  [C.Marquet and C.Royon, Phys.Rev.D 79 (2009) 034028]

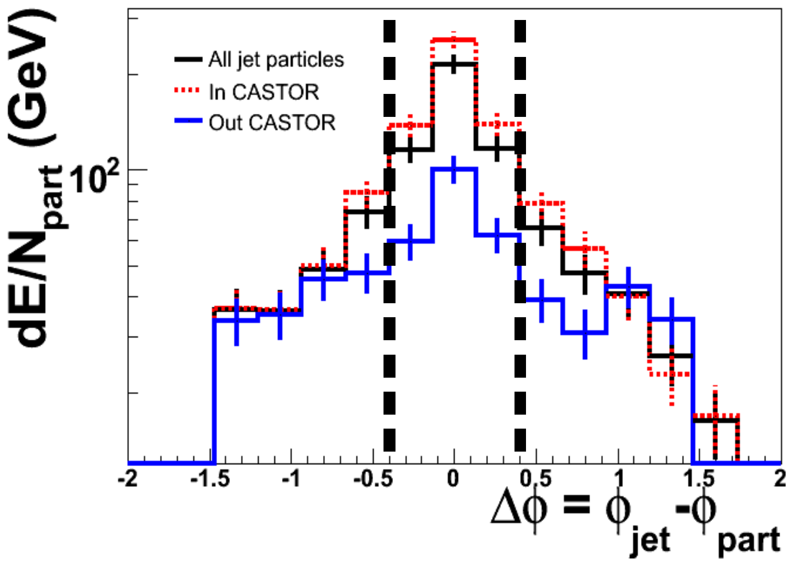
- For increasing $\Delta\eta$, more and more BFKL-type radiations, flatter $\Delta\phi$ distribution

- 1 jet in CASTOR and 1 backward jet for various $\Delta\eta$ between the 2 jets and various energies for the CASTOR jet

Forward jet in CASTOR

- Which profile do we expect for a forward jet in CASTOR ?
- Generator study with PYTHIA, CTEQ6L pdf, QCD jets mode
- Study at hadron level, no detector simulation applied
- Look at particle multiplicity and particle energy distribution in fwd jet as a function of the distance in ϕ between jet axis and particles in the jet (CASTOR has no segmentation in η)

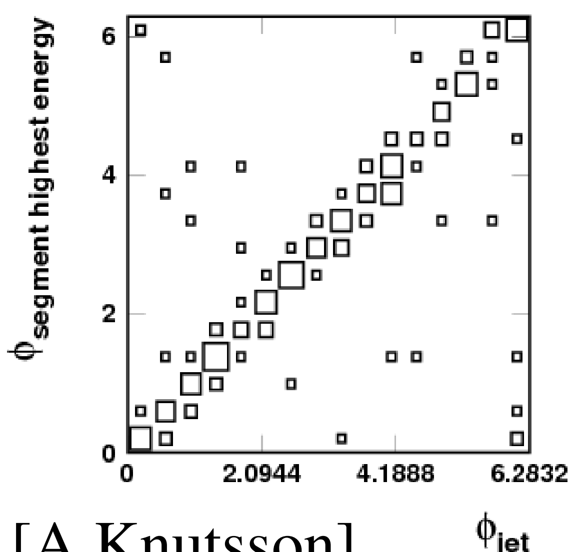




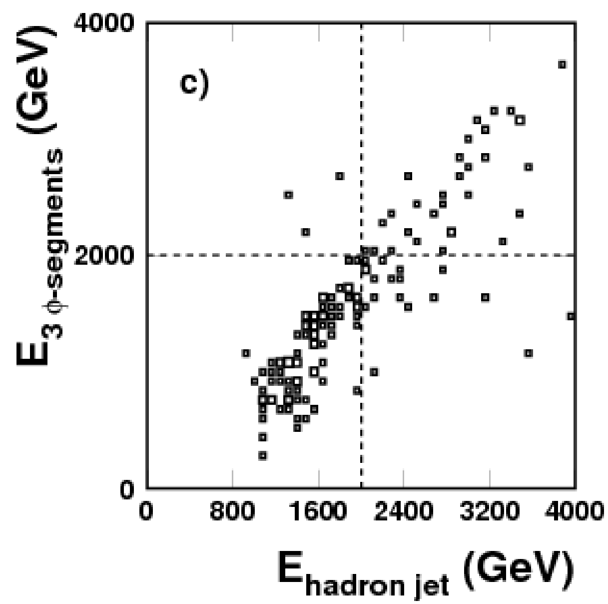
- On average ~10 particles in the octant around jet axis [A.Knutsson]
  ~100 GeV/ particle in the octant around jet axis

CASTOR Jet – Hadron Jet

- Generator level analysis of QCD jets with PYTHIA, CTEQ6L pdf
- Study at hadron level, no detector simulation applied
- CASTOR has no segmentation in η, 16-fold segmentation in ϕ (tower)
  - a CASTOR jet is defined by the most energetic tower to which the two neighboring ones are added
  - particle energy smeared according to Test Beam results
  - particle energy > 1 GeV to take noise into account
- Look at energy and ϕ correlation between CASTOR jet and hadron jet



[A.Knutsson]

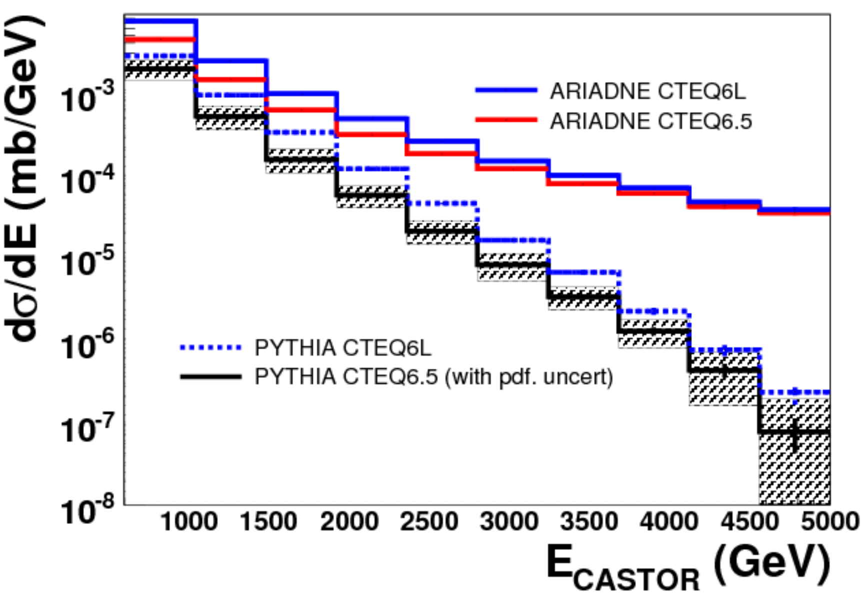


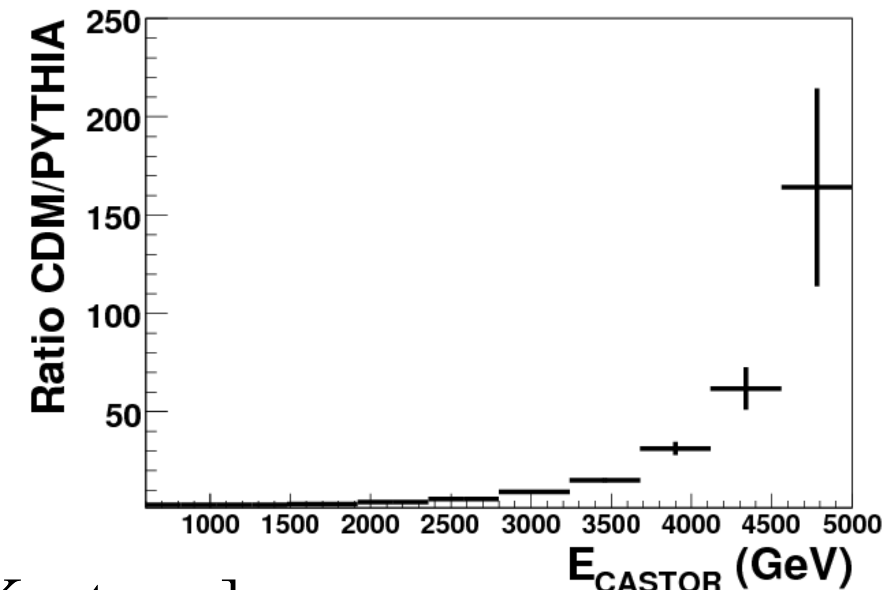
- Good correlation in ϕ
- Reasonable correlation in energy

CASTOR Jet and Parton Shower

- Predictions from PYTHIA (DGLAP) compared to ARIADNE (CDM)
- event selection: 1 forward jet in CASTOR

  1 central dijet system ($|\eta| < 2, p_t > 25$ GeV)
- study at CASTOR Jet level (no simulation applied) for 2 different pdfs sets



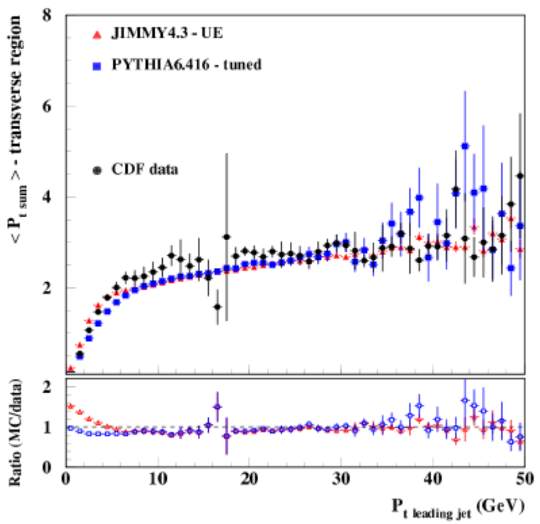


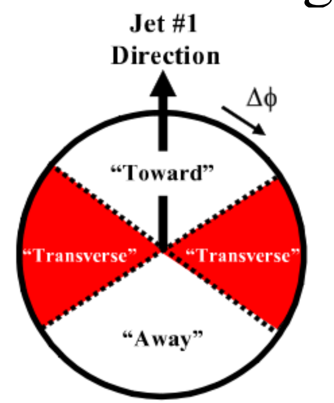
[A.Knutsson]

- sensitivity to PS dynamics at high energy where difference between DGLAP and BFKL-like behaviours is bigger than pdf uncertainty (L < 1 pb^{-1})

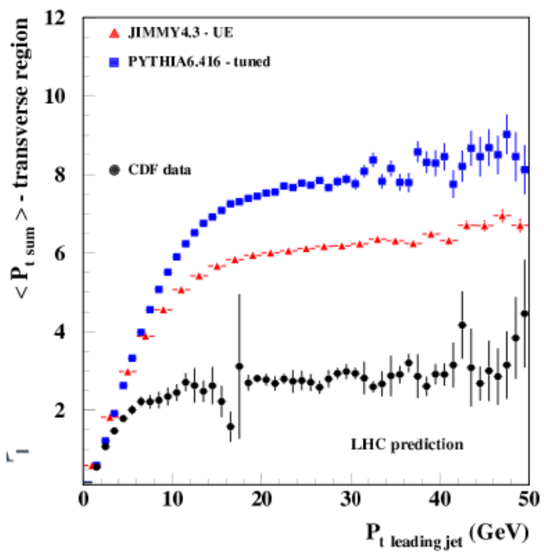
Underlying Event (UE)

- UE is defined as everything except the hard scattered components
  - Initial and Final state radiations: gluon emissions
  - Multiple Parton Interactions: additional softer parton scattering
  - Beam-Beam Remnants: particles coming from the proton breakup
- UE unavoidable background (jet reconstruction, isolation cut)
- UE studied in transverse region wrt leading jet





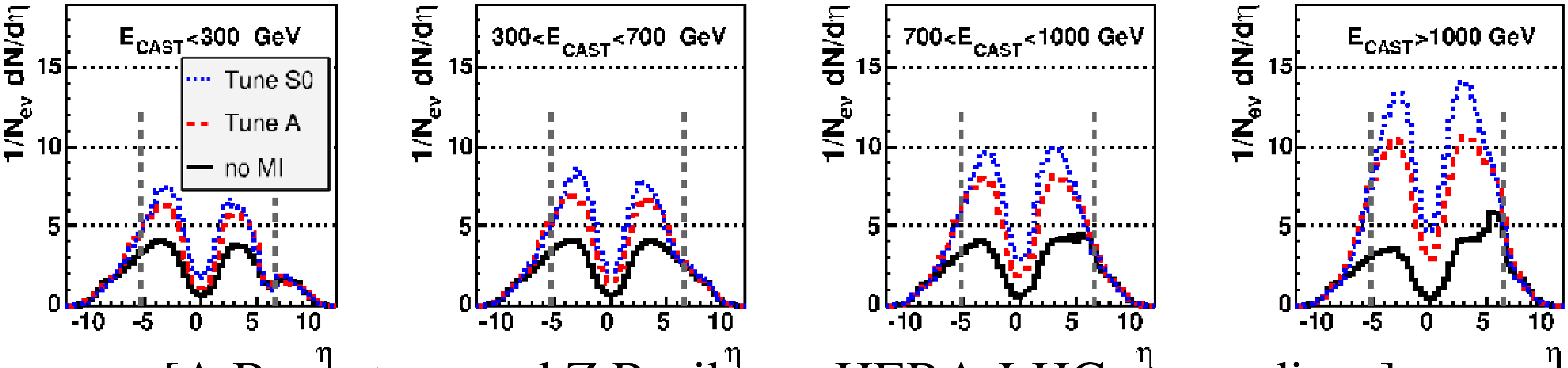
[A.Moraes,HERA-LHC proceedings]



- MPI tuned to describe Tevatron data give large difference at LHC
- MPI will need to be tuned as soon as data available

UE and CASTOR

- MPI occur between spectator partons of the colliding protons
- energy flow in forward region strongly affected by MPI
- energy deposit in CASTOR sensitive to the various MPI models
- MPI induced correlations between activity in central and forward regions studied at generator level with QCD inclusive processes with PYTHIA, for several MPI tunes: Rick Field tune A, Sandhoff-Skands tune S0

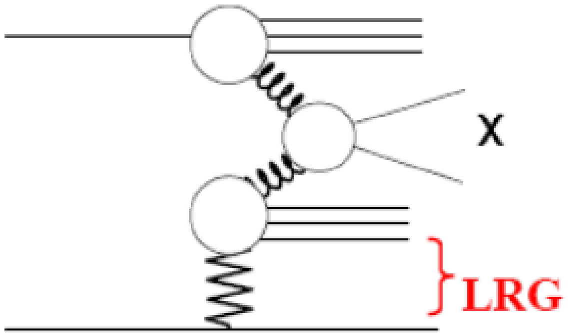


[A.Bunyatyan and Z.Rurikova, HERA-LHC proceedings]

- without MPI: no long range correlation observed
- with MPI: large energy in CASTOR → higher central particle multiplicity
- CASTOR may contribute to distinguish between various MPI tunes

CASTOR as veto detector

- Diffractive event (Single Diffraction) is characterized by a color singlet exchange in the *t* channel
- Signature in the detector:
  - presence of a subsystem *X* resulting from the hard scattering
  - proton leaving the detector through the beam-pipe after having lost a small amount of its longitudinal momentum
  - presence of a large rapidity interval in the forward direction without any hadronic activity due to the absence of color flow between *p* and *X*: Large Rapidity Gap



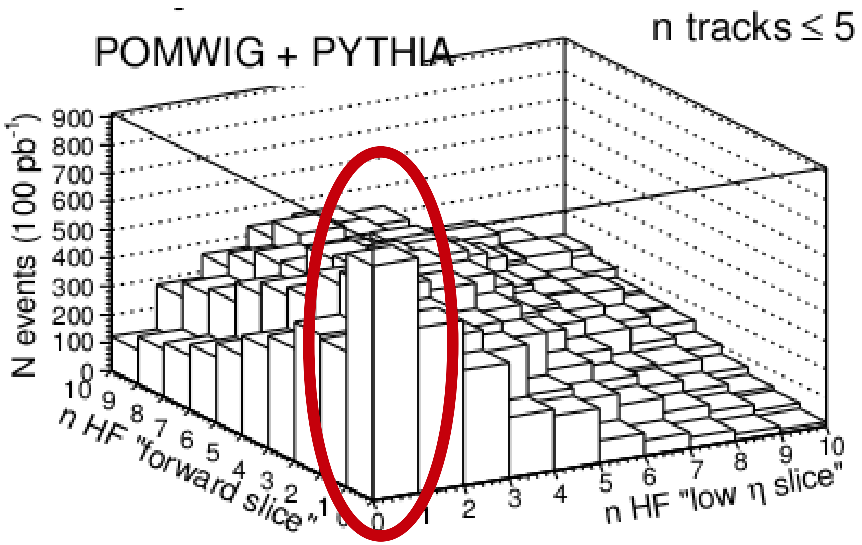
CASTOR as veto detector

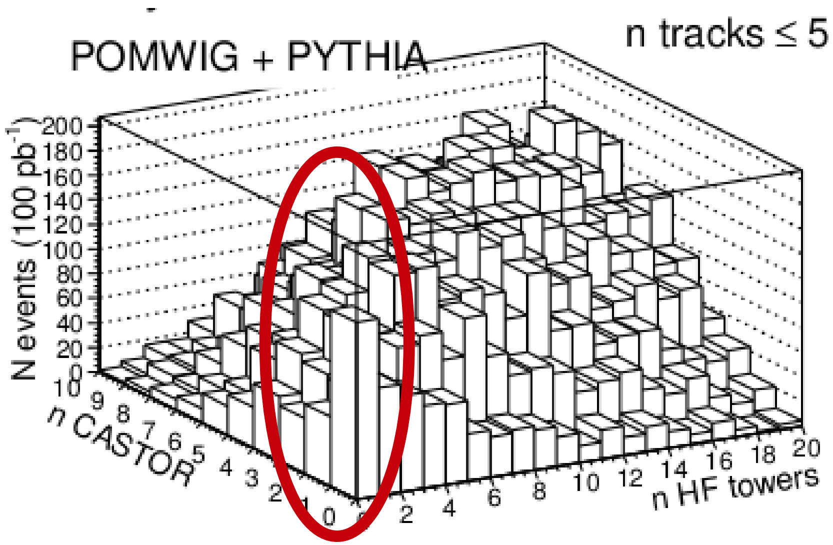
- Previous picture would be valid if there were no interaction between the spectator partons
- These latters fill the would-be rapidity gap
  break factorization theorem valid for *e p* diffractive scattering
- Decrease of the diffractive cross-section expressed by the rapidity gap survival probability $<|S^2|>$ which quantifies the rescattering effects

- CMS plans to measure Single Diffractive W production $pp \rightarrow pWX$
  - to constrain the quark component of the diffractive pdfs
  - to access to the rapidity gap survival probability

CASTOR as veto detector

- Selection of the diffractive W events by the presence of a LRG
- Look at the particle multiplicity in the forward calorimeters
  - HF (Hadron Forward Calorimeter): $3 < |\eta| < 5$
  - CASTOR: $-6.6 < \eta < -5.2$



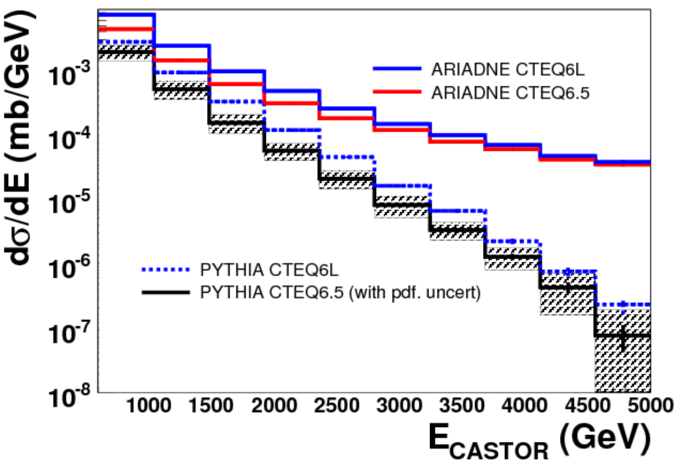


- HF tower multiplicity in low η region v. HF tower multiplicity in high η region
- HF tower multiplicity v. CASTOR tower multiplicity
- Much better rejection of non-diffractive backgrd with CASTOR (S/B→20)

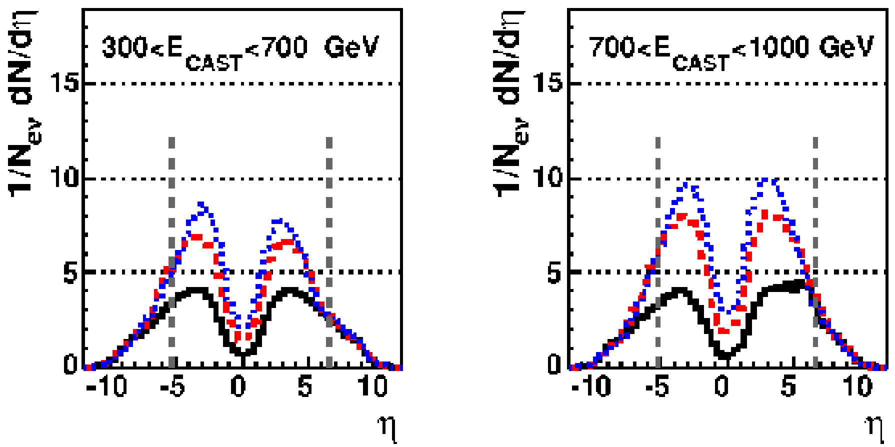
Conclusions

- CASTOR calorimeter and its physics program

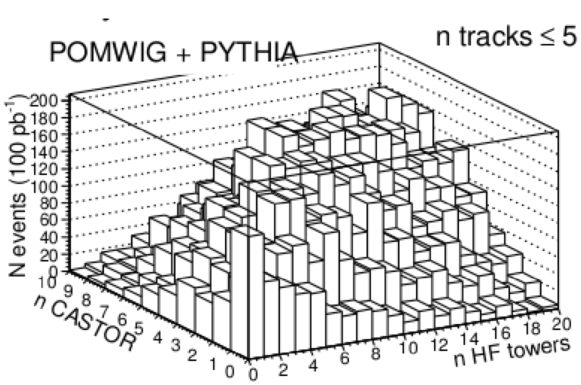
- Parton Shower dynamics



- Multiple Partonic Interactions



- Selection of Diffractive events

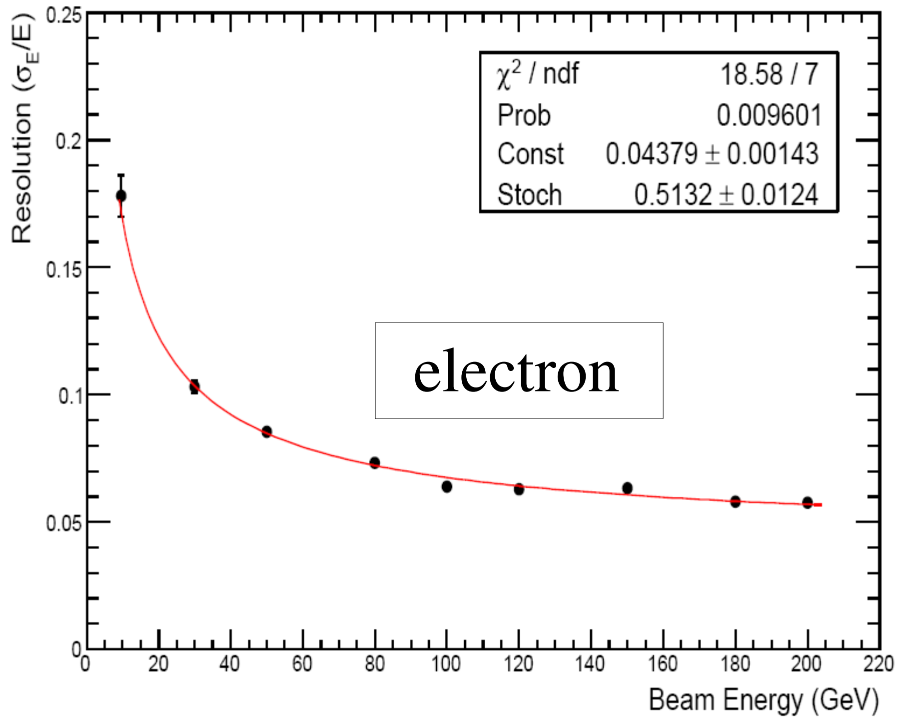


Back-up Slides

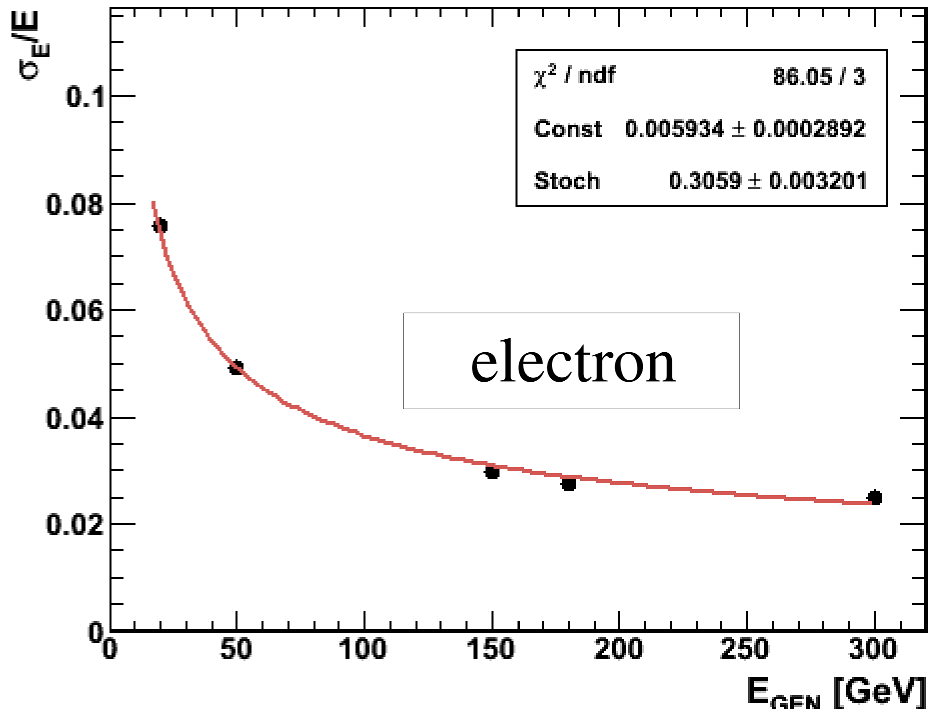
CASTOR energy resolution

Energy resolution for electrons

TB 2007



Full Simulation



from 18 % at 10 GeV to 6 % at 200 GeV

difference between TB and simulation due to the non-uniformity of the calorimeter response which is not implemented in the simulation