CMS results on forward physics and other of relevance for cosmic rays

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On behalf of the CMS collaboration

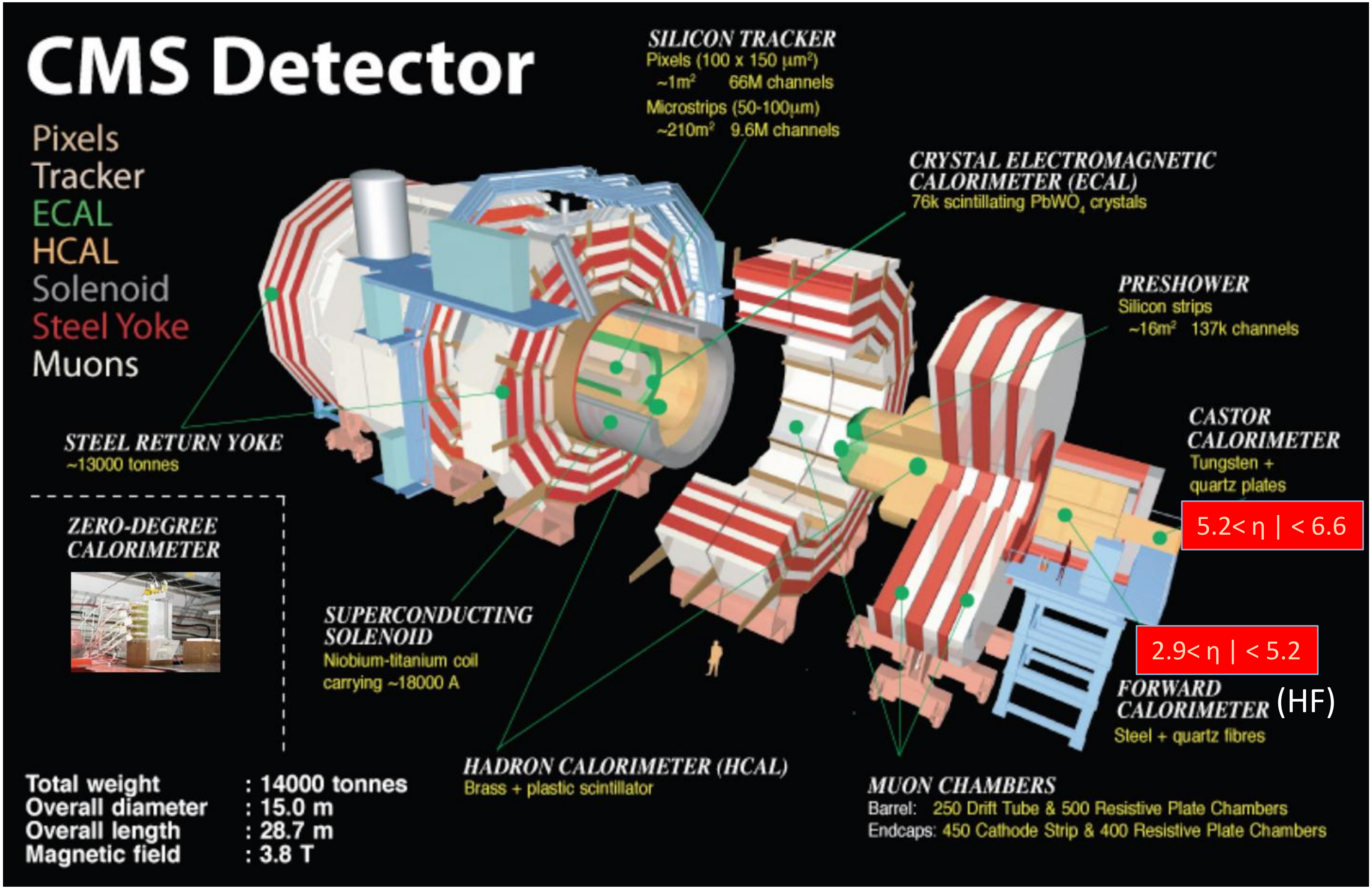
Workshop on Hadron-Hadron & Cosmic-Ray Interactions at multi-TeV Energies

ECT Trento, Nov 29th - Dec 3rd, 2010

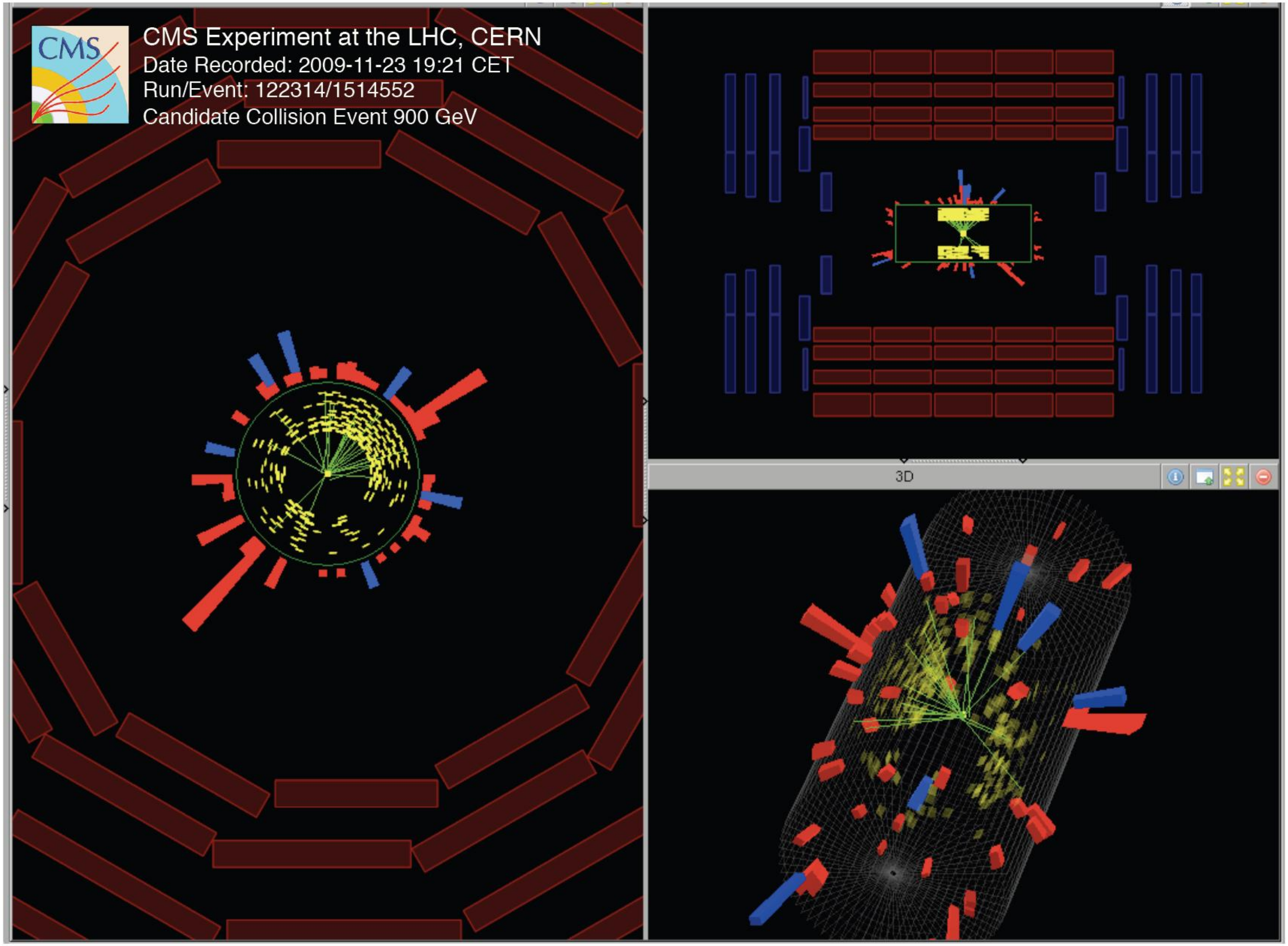
Outline

- Diffraction
- Forward energy flow
- Forward jets
- Charge assymetry of atmospheric muons
- Pseudorapidity distribution of charged particles
- Prospects
- Summary

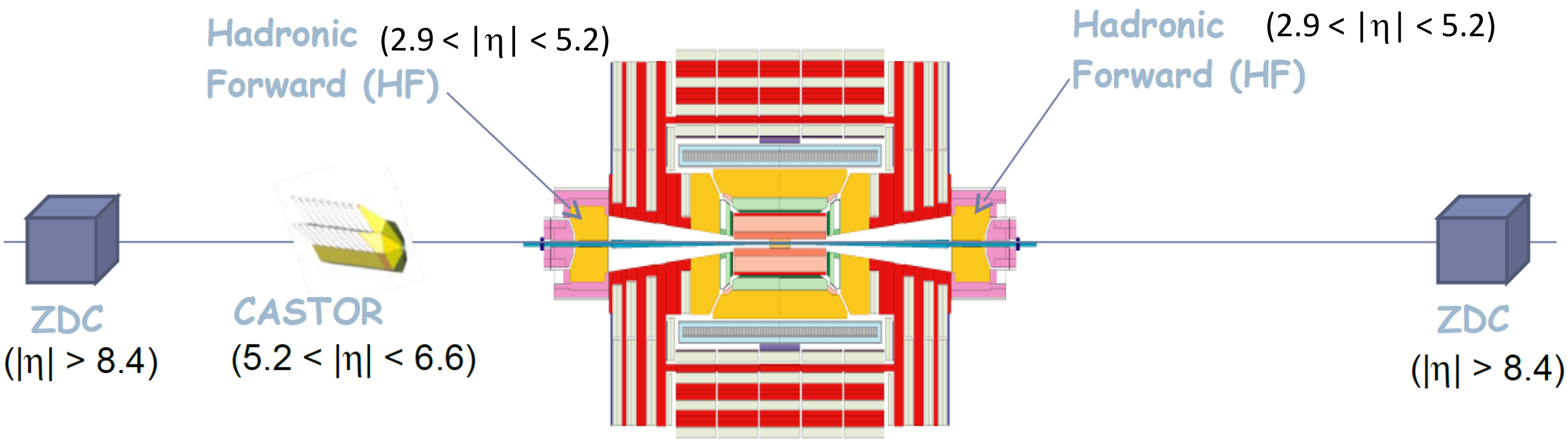
Reflected mainly a beginning of study.There are many more results at preliminary status which will be presented in near future


CMS Detector
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² 66M channels
Microstrips (50-100μm)
~210m² 9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
76k scintillating PbWO4 crystals
PRESHOWER
Silicon strips
~16m² 137k channels
CASTOR CALORIMETER
Tungsten + quartz plates
5.2< η | < 6.6
2.9< η | < 5.2
FORWARD CALORIMETER (HF)
Steel + quartz fibres
STEEL RETURN YOKE
~13000 tonnes
ZERO-DEGREE CALORIMETER
SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
MUON CHAMBERS
Barrel: 250 Drift Tube & 500 Resistive Plate Chambers
Endcaps: 450 Cathode Strip & 400 Resistive Plate Chambers
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

CMS event


CMS
CMS Experiment at the LHC, CERN
Date Recorded: 2009-11-23 19:21 CET
Run/Event: 122314/1514552
Candidate Collision Event 900 GeV
3D

CMS forward detectors



Hadronic Forward calorimeters (HF)

- located at 11.2 m from IP on both sides of CMS

- rapidity coverage $2.9 < |\eta| < 5.2$
- Cerenkov calorimeter made of steel absorbers and embedded radiation-hard quartz fibers, light from the fibers detected by PMT
- 2 types of fibers: long (run over the full depth) and short (start at 22 cm from the front of HF)
  → possible to distinguish showers generated by e/γ from showers generated by hadrons
- 13 rings in η with a segmentation $\Delta\eta = 0.175$ (except for the 2 most inner rings and the most outer one)

Only HF results are presented. Results from other forward calorimeters are in preparation.

Diffraction

Why diffraction?

- ✓ Diffraction is a difficult for treatment background when non-diffractive physics is to be studied due to trigger and offline selection limitations.
- ✓ Diffraction proceeds via pomeron exchange i.e. pomeron is object of diffractive study & pomerons govern ultra-high energy interactions, both diffractive and non-diffractive.
- ✓At HERA, main arguments for appearance of saturation were extracted from diffractive data.

  LHC p-p diffraction, although more complicated than HERA γ-p diffraction, due to much higher energies, could also provide valuable signatures of saturation. Treatment of non-linear effects is crucial ingredient of CR generators providing largest diversity of results of EAS simulation.

Diffraction: selection

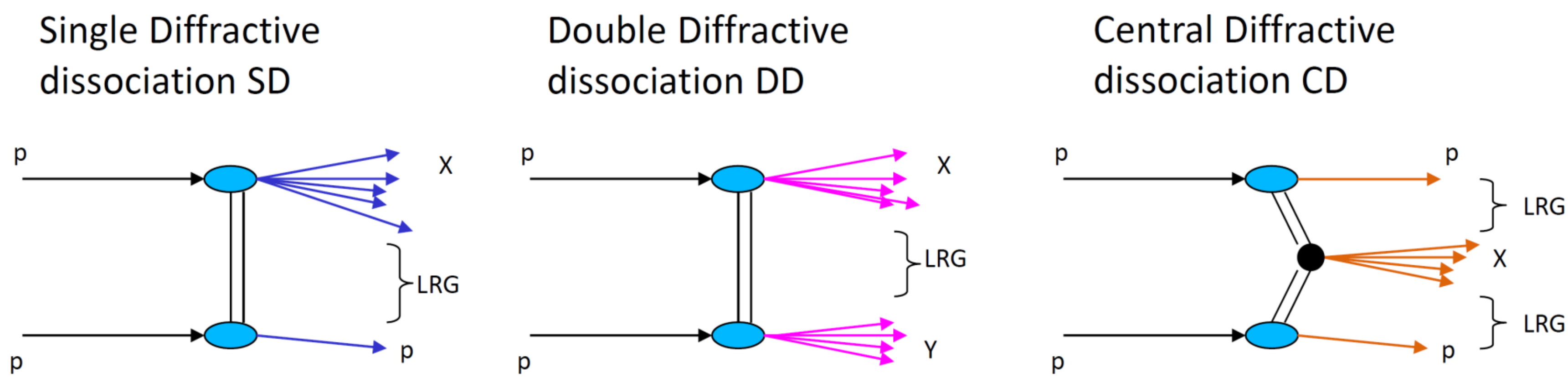
Trigger

- Beam bunches crossing the IP (beam pickups - BPTX)
- One hit in Beam Scintillator Counters (BSC)

Event selection

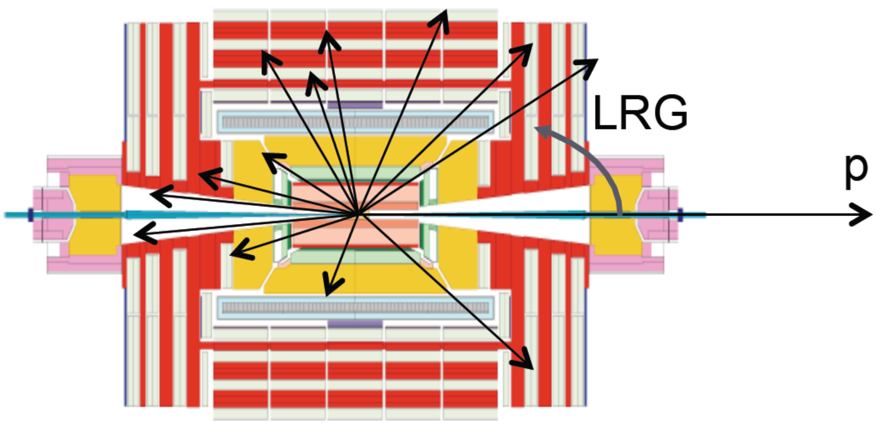
- Collision vertex: primary vertex with good quality and well centered **(important: this requirement kills low mass diffraction)**
- Beam Halo rejection (from BSC)
- Beam background rejection
- Filtering of events with characteristic noise in calorimeters
- High trigger efficiency (cross checked with Zero-bias stream)

Diffraction in CMS

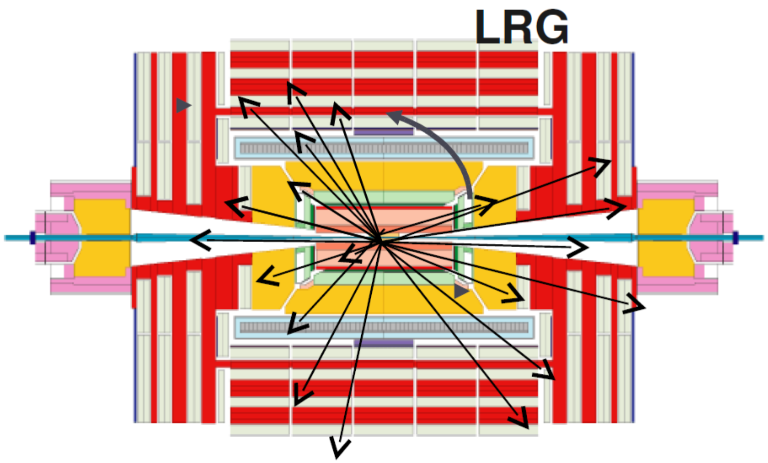


LRG = Large Rapidity Gap

Single diffraction in CMS



Double diffraction in CMS

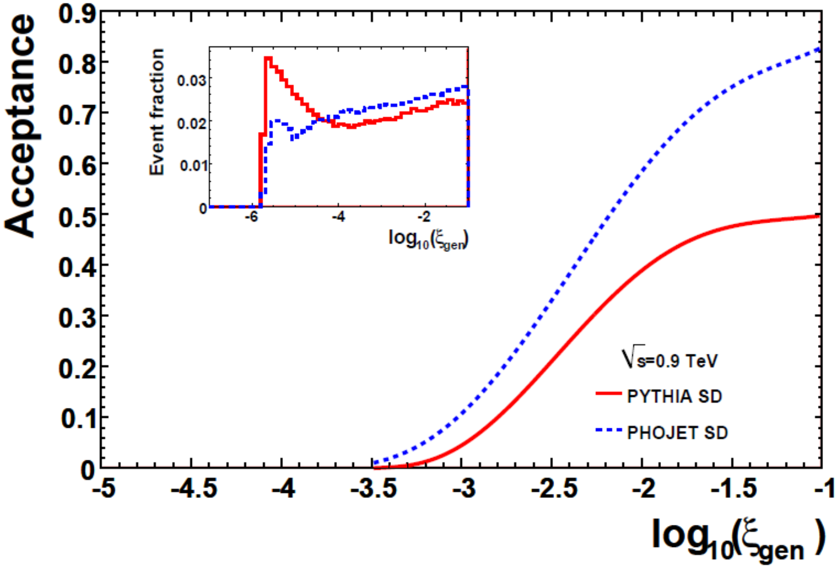


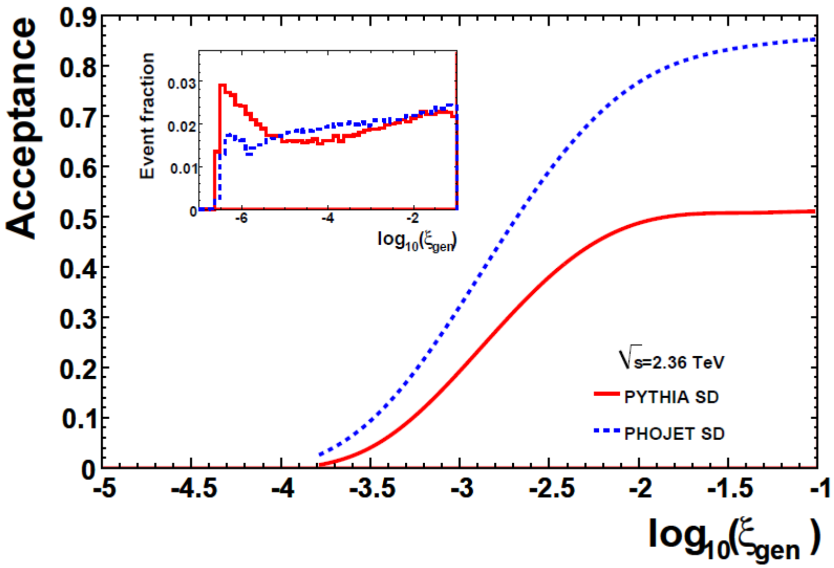
Diffraction efficiency

ξ -> fractional momentum loss of the scattered proton : $\xi = (M_X)^2/s$

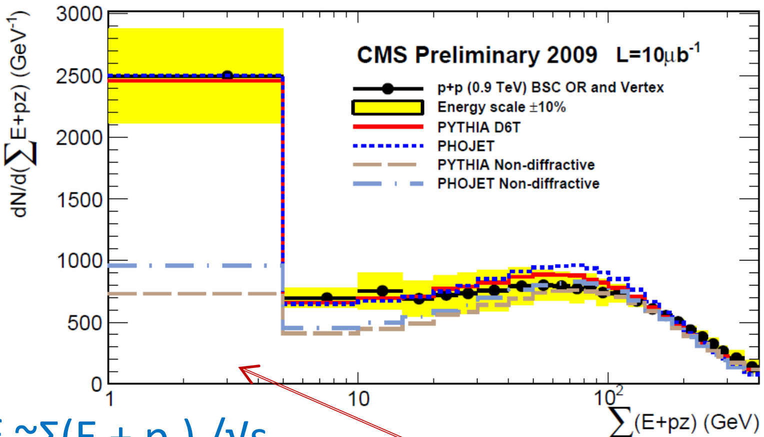
Low efficiency for selecting events which:
i) escape undetected with very low ξ values
ii) have almost no charged activity.

PYTHIA6 and PHOJET substantially differently model diffraction and provide different selection efficiencies.
Single-diffractive efficiency:
900 GeV: 18% (PYTHIA), 32% (PHOJET)
2360 GeV: 20% (PYTHIA), 37% (PHOJET)
Double-diffractive efficiency:
900 GeV: 15% (PYTHIA), 41% (PHOJET)
2360 GeV: 18% (PYTHIA), 45% (PHOJET)

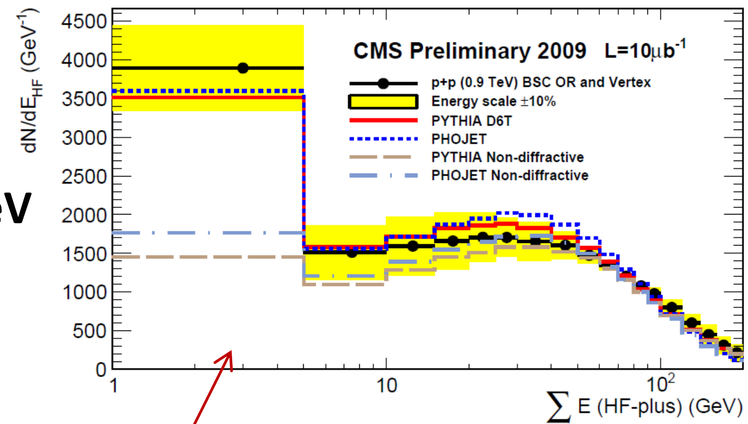




Diffraction: min-bias results



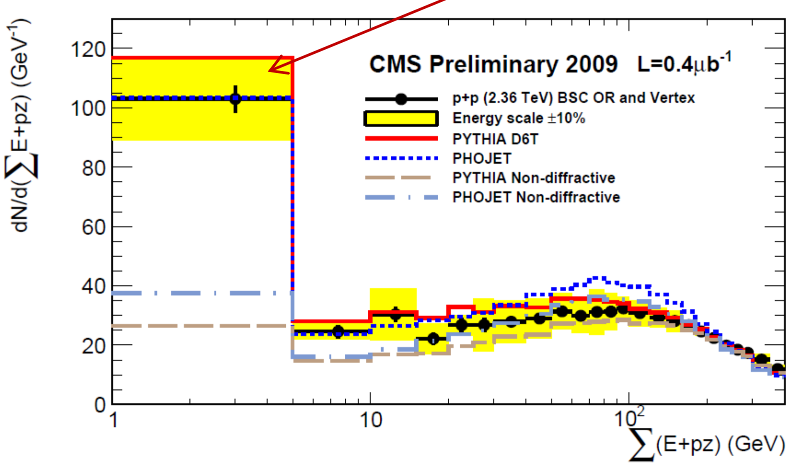
0.9 TeV



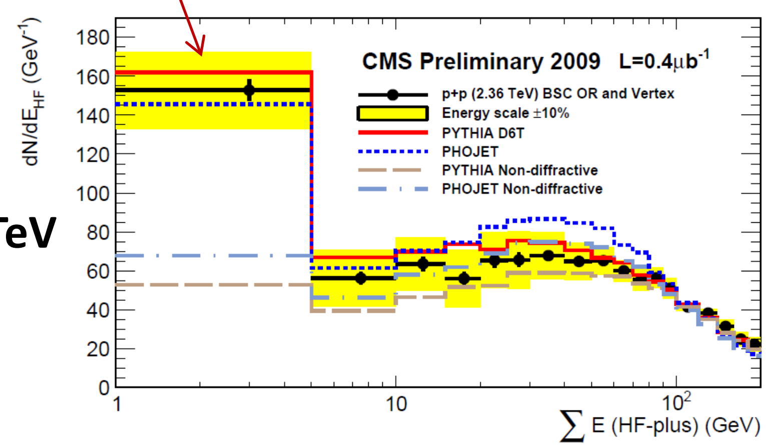
$\xi \approx \Sigma(E + p_z)/\sqrt{s}$

SD cross-section peaks at small values of ξ, $\sigma \sim 1/\xi$

Excess over non-diffractive MC predictions at low ξ and at rapidity gap over HF (3.0 < |η| < 5.0)



2.36 TeV

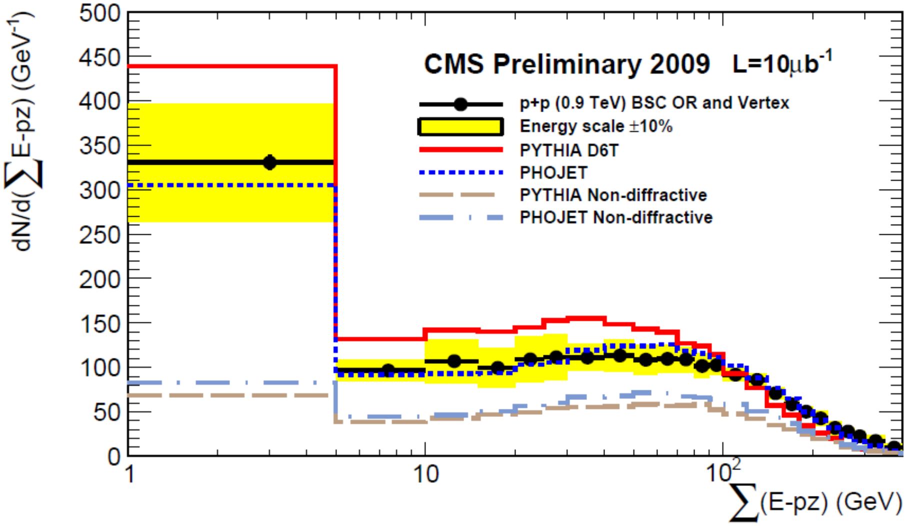


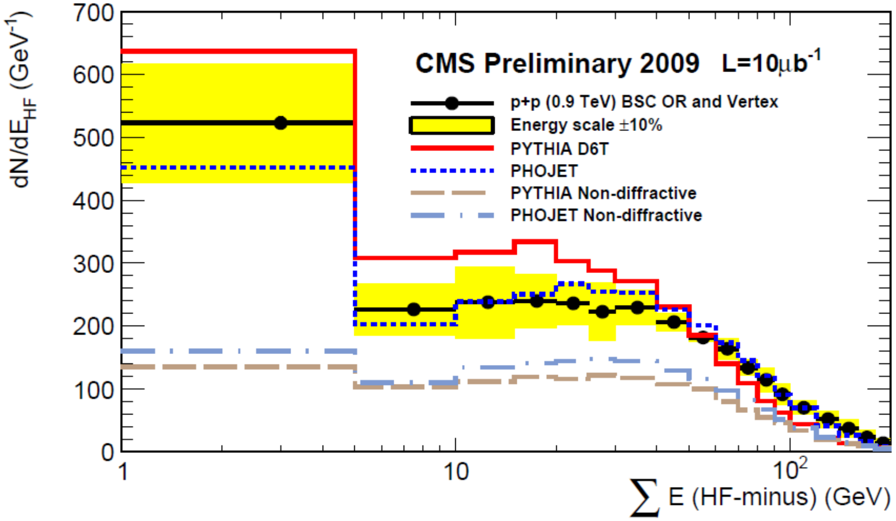
The bands illustrate effect of a 10% energy scale uncertainty in the calorimeters

Enhancing diffractive component

Requiring low activity on one side (HF+ or HF-) →
→ enriched by diffractive events sample .

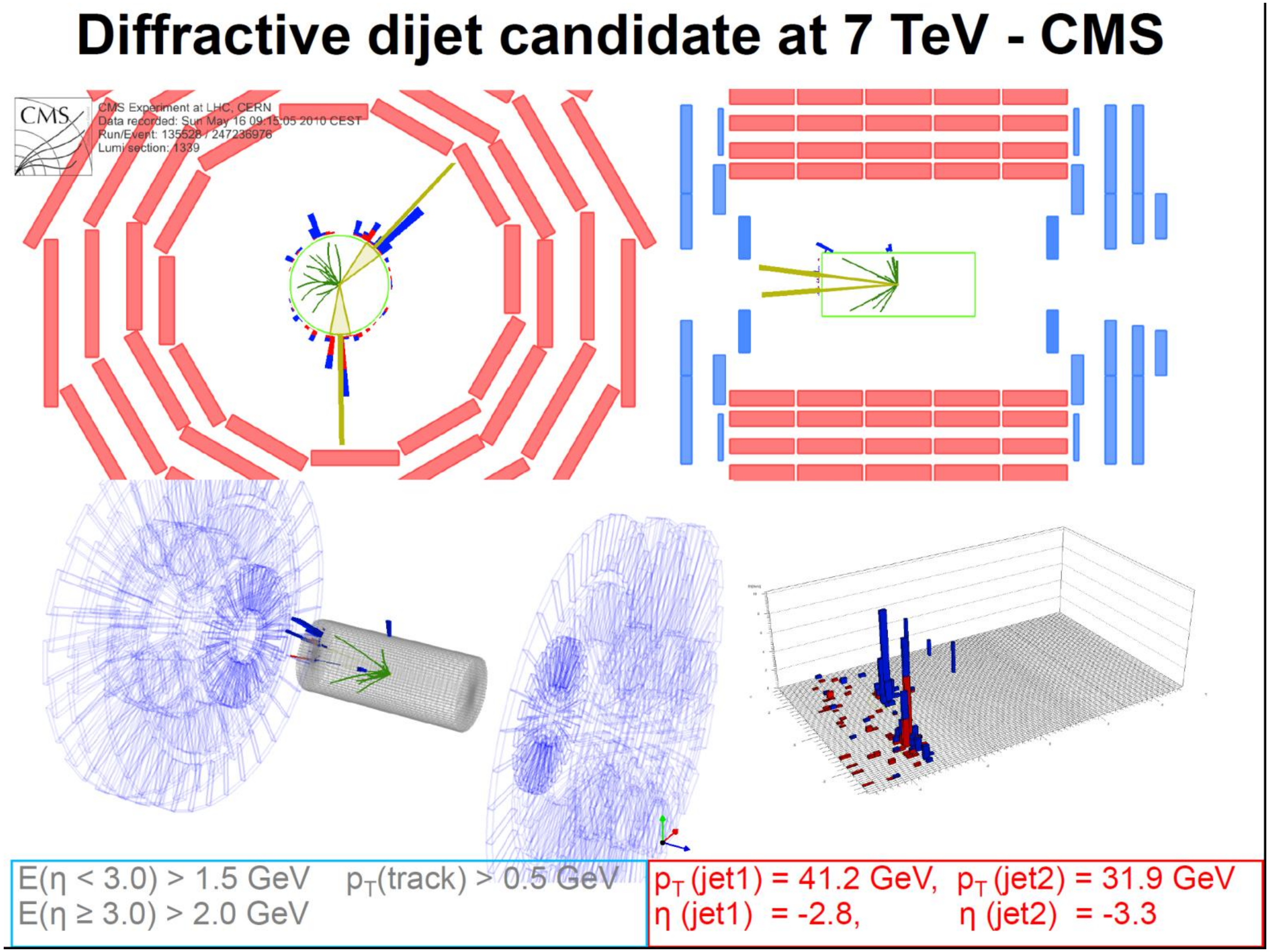
E(HF+) < 8 GeV **900 GeV**





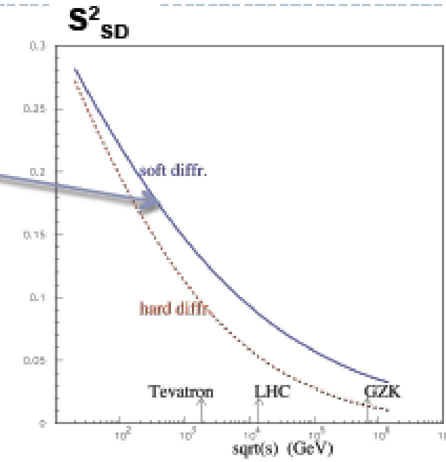
- **PYTHIA6 overpredicts low masses and underpredicts high masses.**
- **PHOJET consistent with data.**

Diffractive dijet

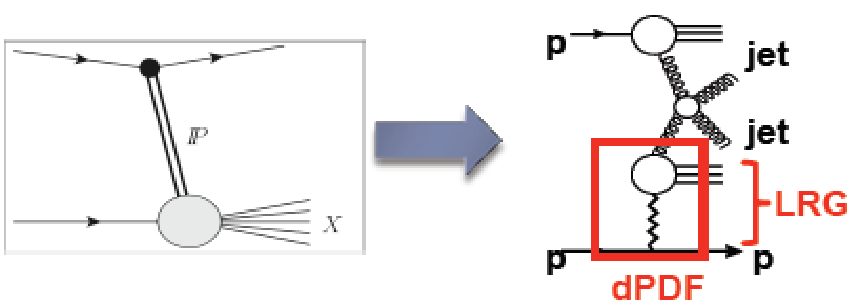


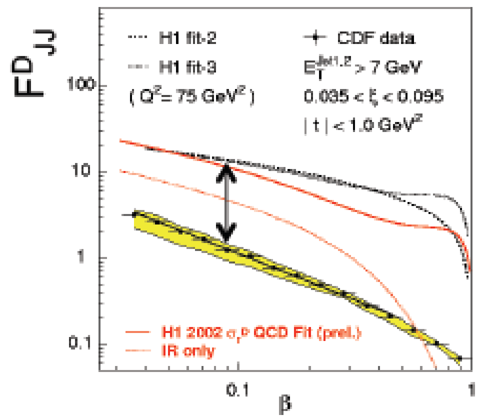
Moving forward

- Acceptance-corrected fraction of diffractive events in different √s values will probe the rapidity gap survival probability (<S²>)
- Looking at diffractive events where a large scale is present: high-p_T jets, W/Z's
- Natural extension of HERA/Tevatron studies on hard diffraction: dPDF's, <S²>, CEP,..
- Important benchmark for future searches in CEP channels



V.A.Khoze et al, Phys. Lett. B 643 (2006)



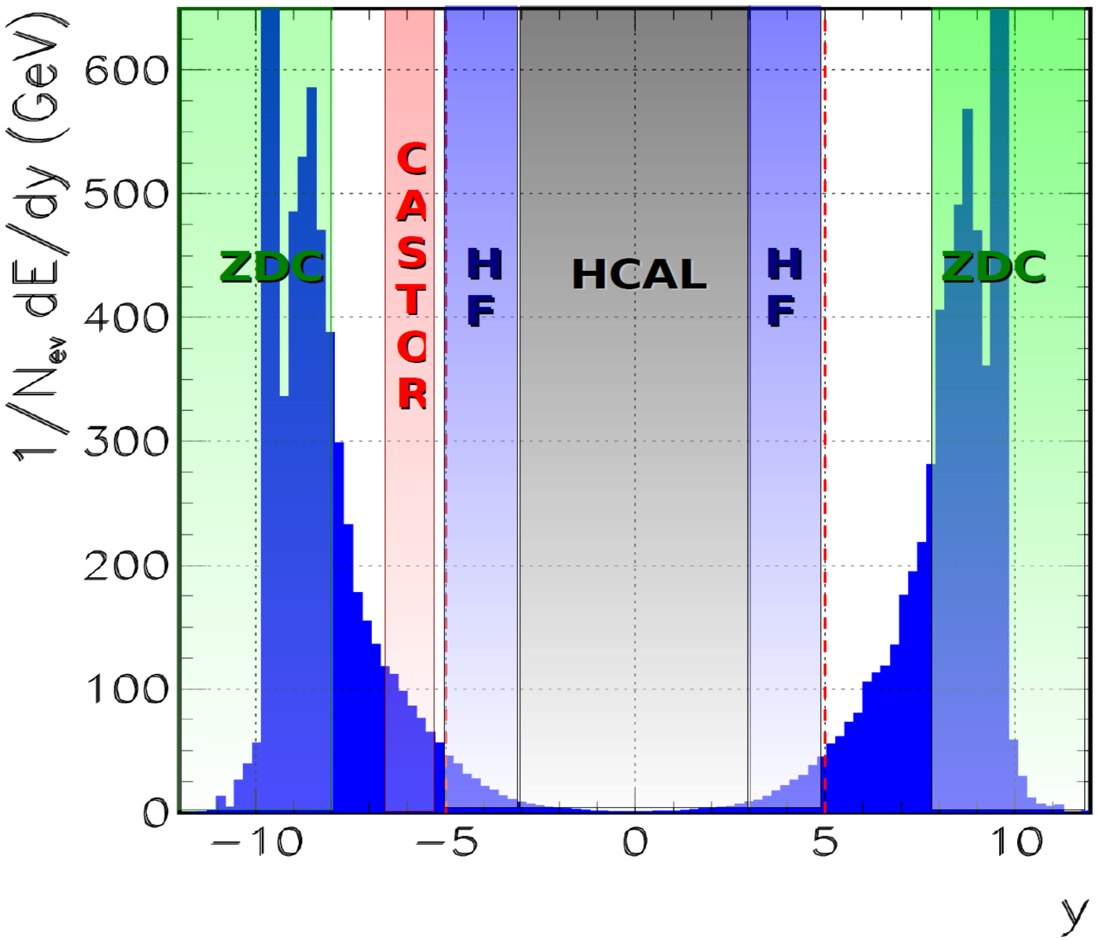


CDF Collaboration, Phys. Rev. Lett. 84, 5043 (2000)

A. Vilela Pereira

Forward energy flow

Rapidity distribution of energy flow



There is large diversity of treatment of target fragmentation both in HEP and CR generators which could result in large differencies of produced particles spectra in forward region. Measurements of energy flow at forward rapidities in CMS (HF & CASTOR) will be highly useful in fixing forward region and together with ZDC constraining treatment of proton remnant. Forward region is of crucial importance for CR since it contains main release of energy from primary to secondaries, that release determining shower development.

Forward energy flow in CMS: why and how

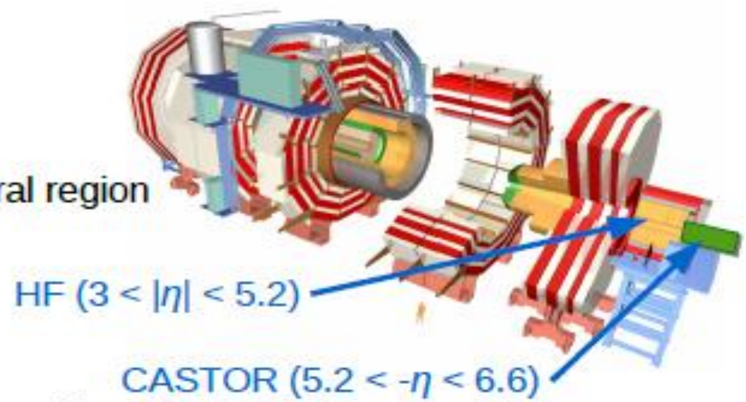
Measurement of forward energy flow by CMS

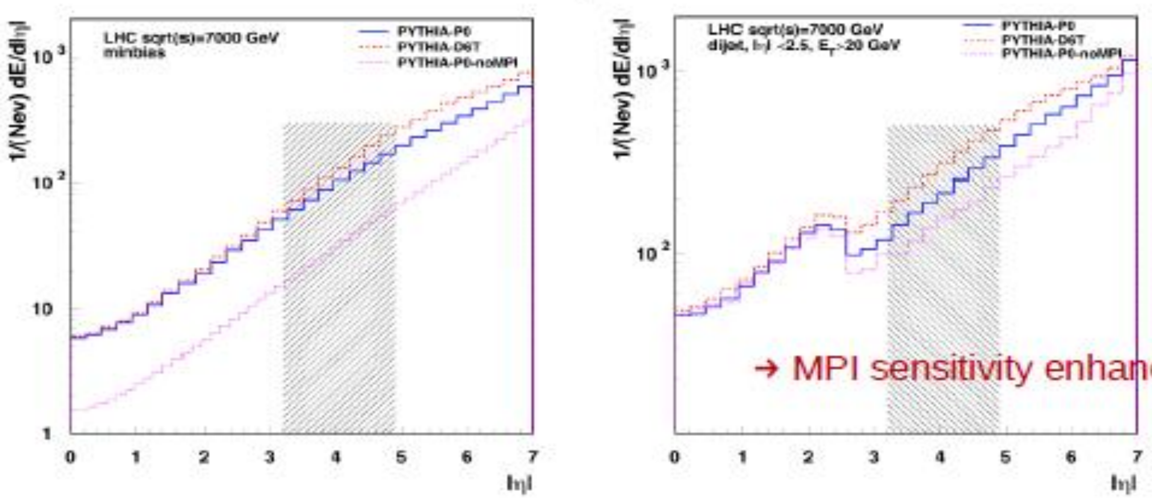
Motivation

- sensitive to parton radiation and to multi-parton interactions
- complementary to measurements in central region

Strategy:

- measurement of forward energy flow in
  - "minimum bias" events and
  - events with a hard central dijet system with $|\eta| < 2.5$, $|\Delta\varphi(j1,j2) - \pi| < 1.0$, $p_T > 8$ (20) GeV at $\sqrt{s} = 0.9$, 2.36 (7) TeV





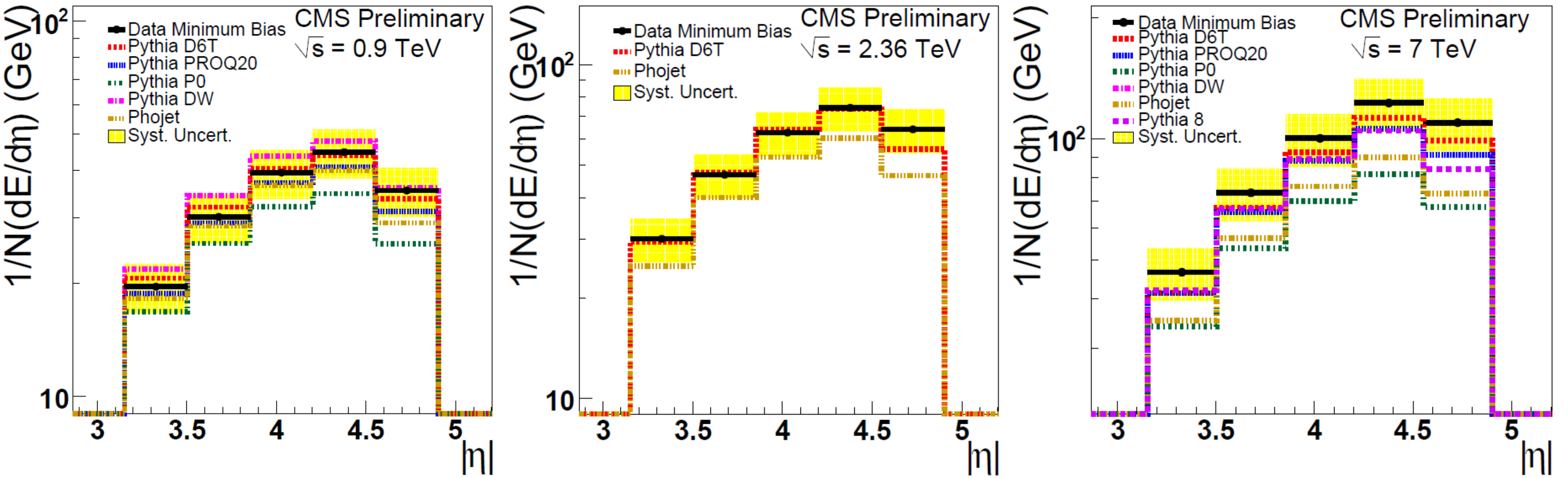
→ MPI sensitivity enhanced in dijet events!

Comparison with Pythia6 and PHOJET

Forward energy flow: selection

- Minimum Bias events selection
  - Trigger signal in each of the BSC in coincidence with a signal from both BPTX (rejects large fraction of diffractive events)
  - Good primary vertex
  - Rejection of beam halo candidates & beam background events
  - Rejection of events with large and isolated signal in HF
  - Threshold 4 GeV on energy of HF towers to avoid noise
- Dijet events selection
  - Jets reconstructed by anti-*kT jet algorithm (R = 0.5)*
  - At least two leading jets with $|\eta| < 2.5$ & $|\Delta\varphi(j1,j2)-\pi| < 1$
  - *$p_T > 8$ GeV ($\sqrt{s}$ = 900 GeV or 2.36 TeV), $p_T > 20$ GeV (7 TeV)*

Transverse energy flow in minimum bias events

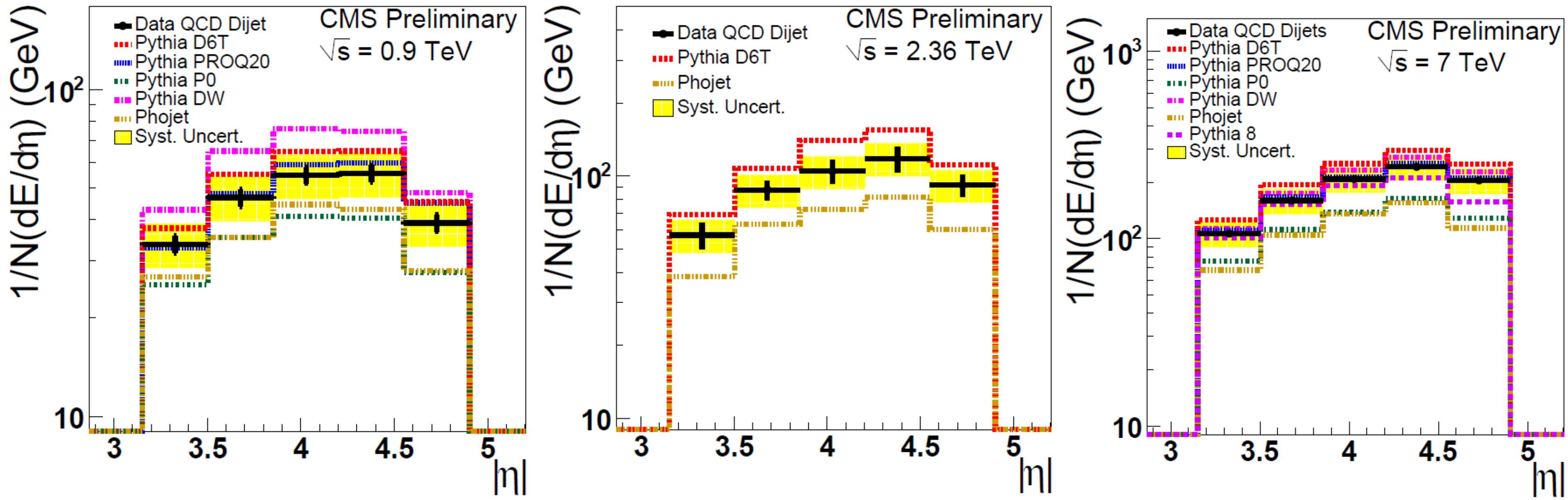


Measured energy flow increases more strongly with centre-of-mass energy than predicted by any of Monte Carlo.

At 900 GeV, energy flow is satisfactorily described by D6T tune, whereas other PYTHIA6 tunes and PHOJET are below measurement.

At 7 TeV, predicted energy flow in minimum bias events is below measurement for all tunes.

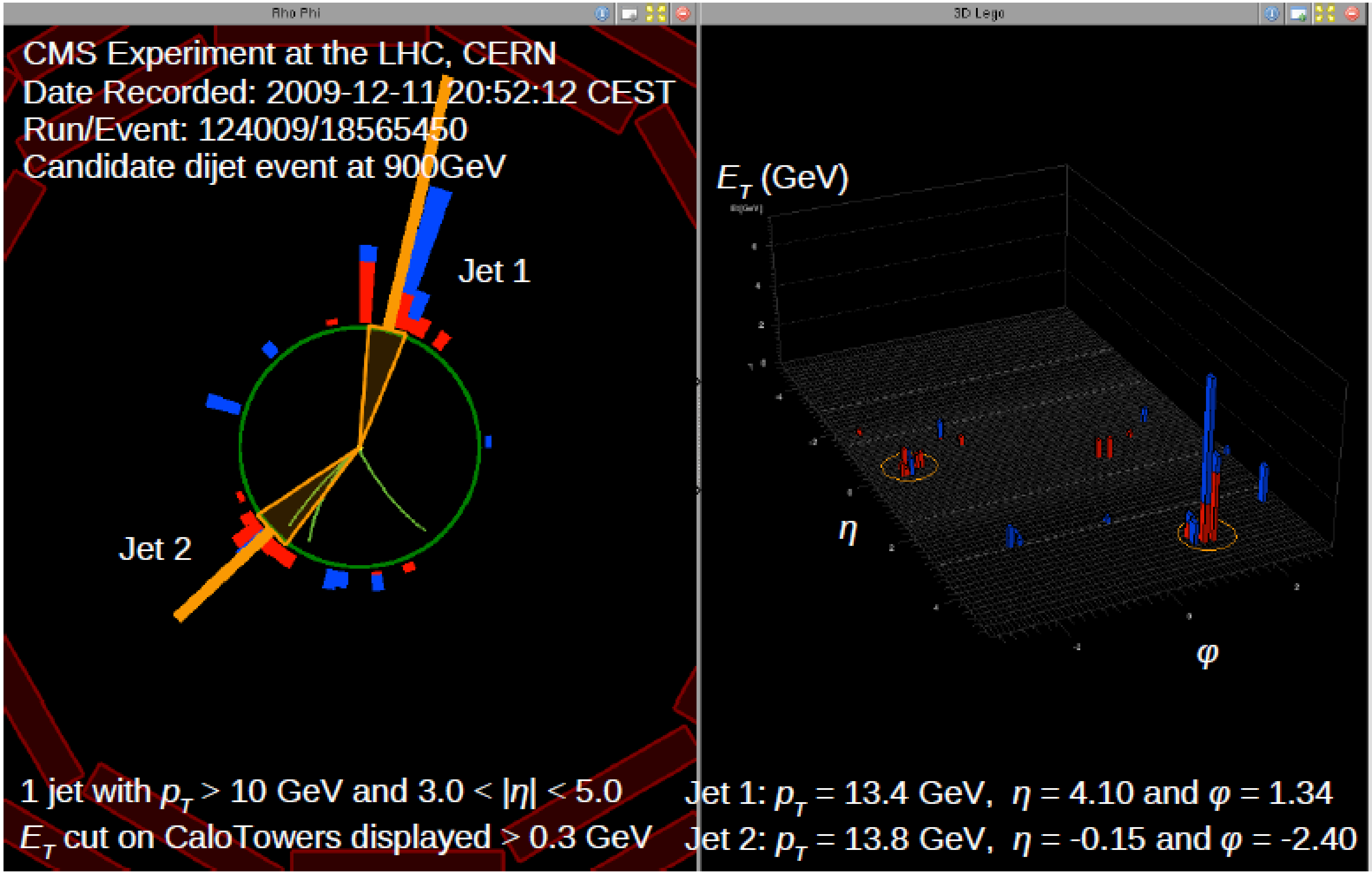
Transverse energy flow in events with dijet



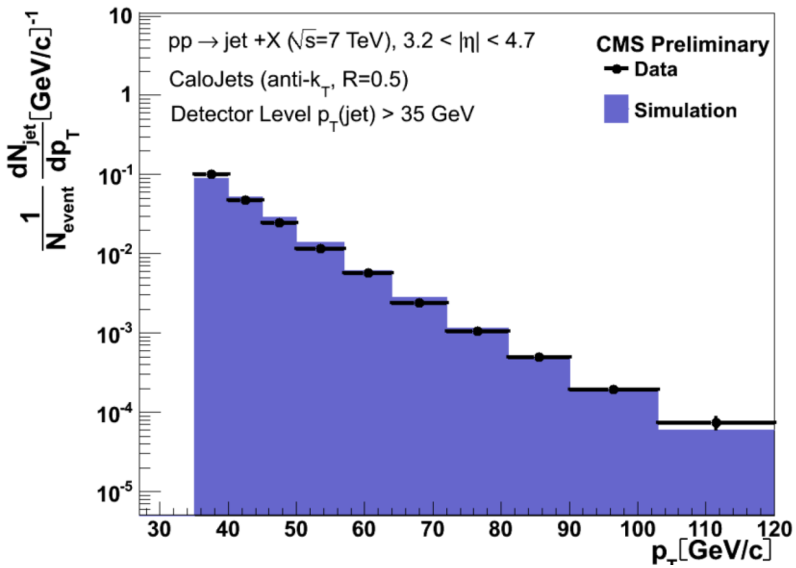
In dijet sample, increase of energy flow with centre-of-mass energy is much better reproduced by Monte Carlo than in min-bias sample. Unlike min-bias events, best description of measurements provides PROQ20 tune of Pythia, whereas D6T is above data and P0 tune of Pythia and Phojet are below data.

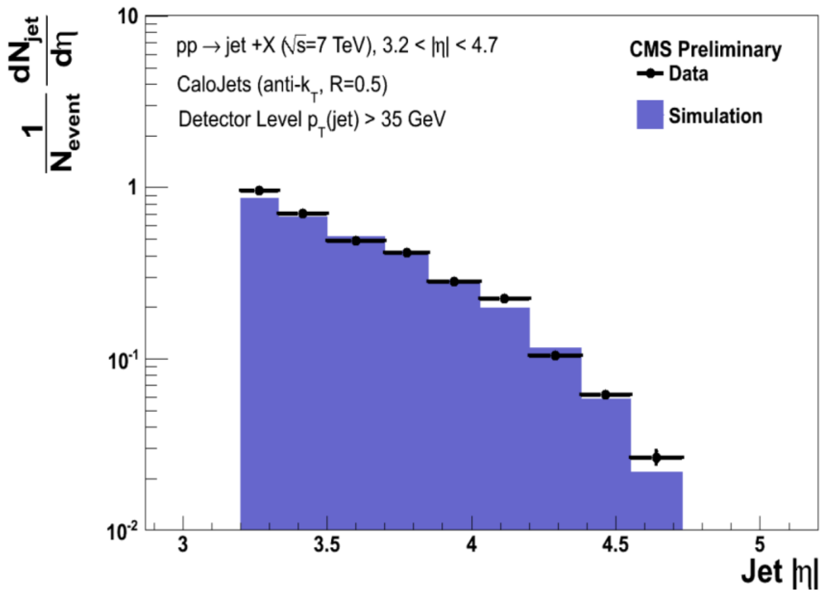
Forward jets

Event with forward jet



Inclusive forward jets





First measurement of forward jets in the range $3.2 < |\eta| < 4.7$ in p-p interactions. Probes small-x content of proton. Could reveal invalidity of DGLAP evolution expected to happen at small x and signatures of BFKL evolution.

Jet selection

– $3.2 < |\eta| < 4.7$
  $p_T > 20$ GeV
– Anti-kT algorithm (R>0.5)
– Detector-level distributions, no systematics

Reasonable agreement with MC (Pythia6 D6T)

Cosmic muons

Charge assymetry of atmospheric muons

Atmospheric Muons

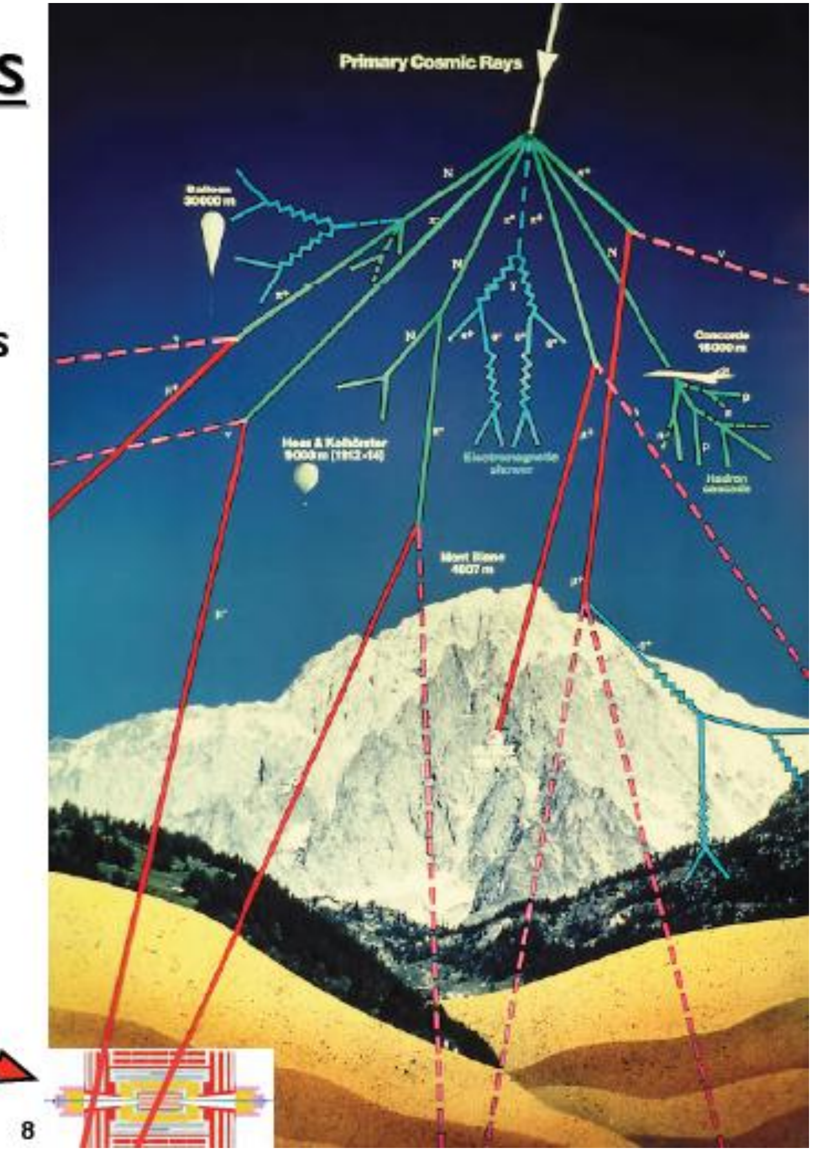
Stem from cosmic ray showers, produced via interactions of high-energy cosmic-ray particles (nuclei), entering the upper layers of the atmosphere, with air nuclei:

$(p, He, ..., Fe) \rightarrow$ hadrons, $e^{\pm}\gamma$

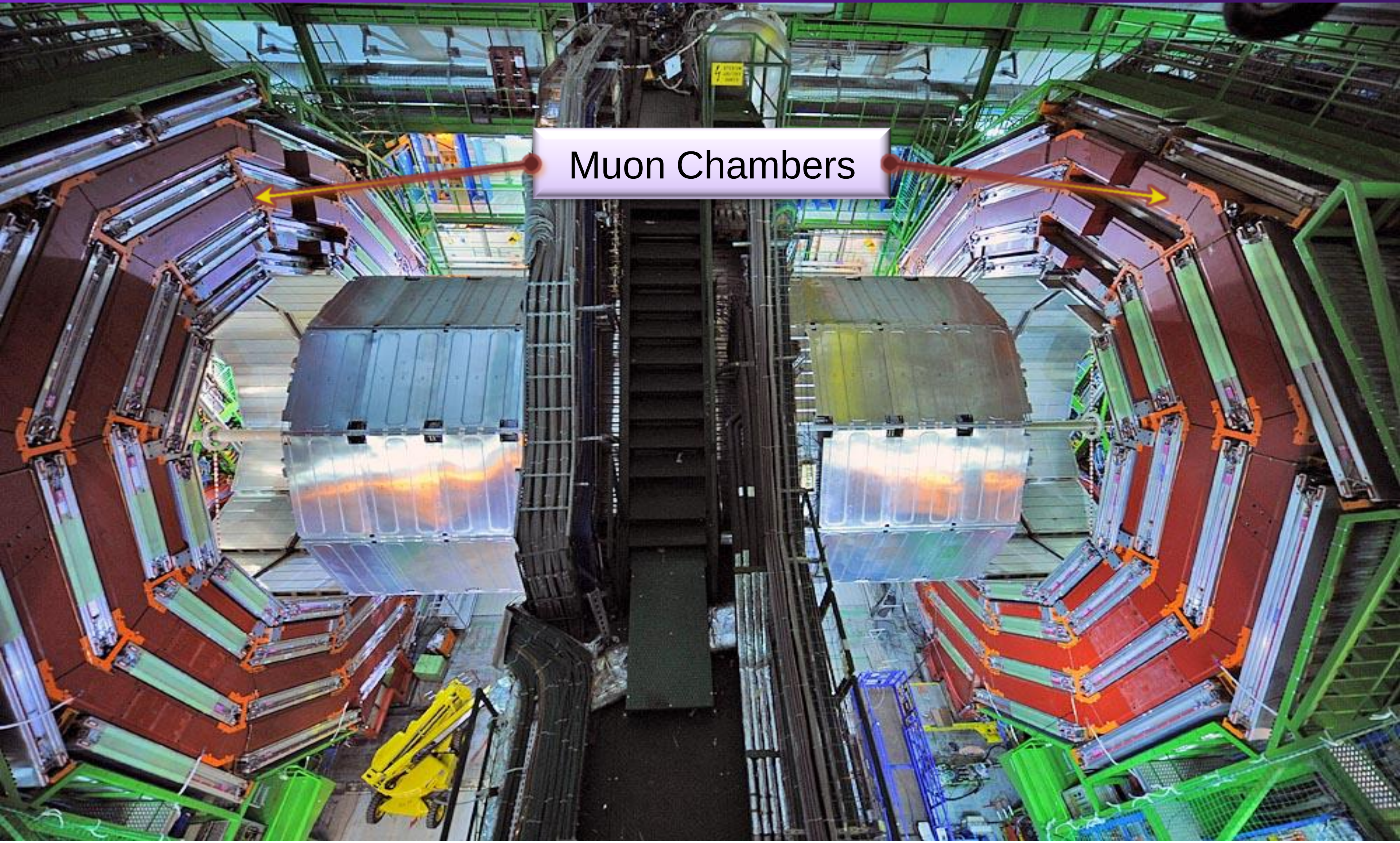
$(\pi^{\pm}, K^{\pm}) \rightarrow \mu^{\pm}\, \nu_{\mu}\, (\bar{\nu}_{\mu})$ and

$\mu^{\pm} \rightarrow e^{\pm}\, \nu_e\, \bar{\nu}_{\mu}\, (\bar{\nu}_e\, \nu_{\mu})$

Long-lived muons cross the overburden and reach CMS.

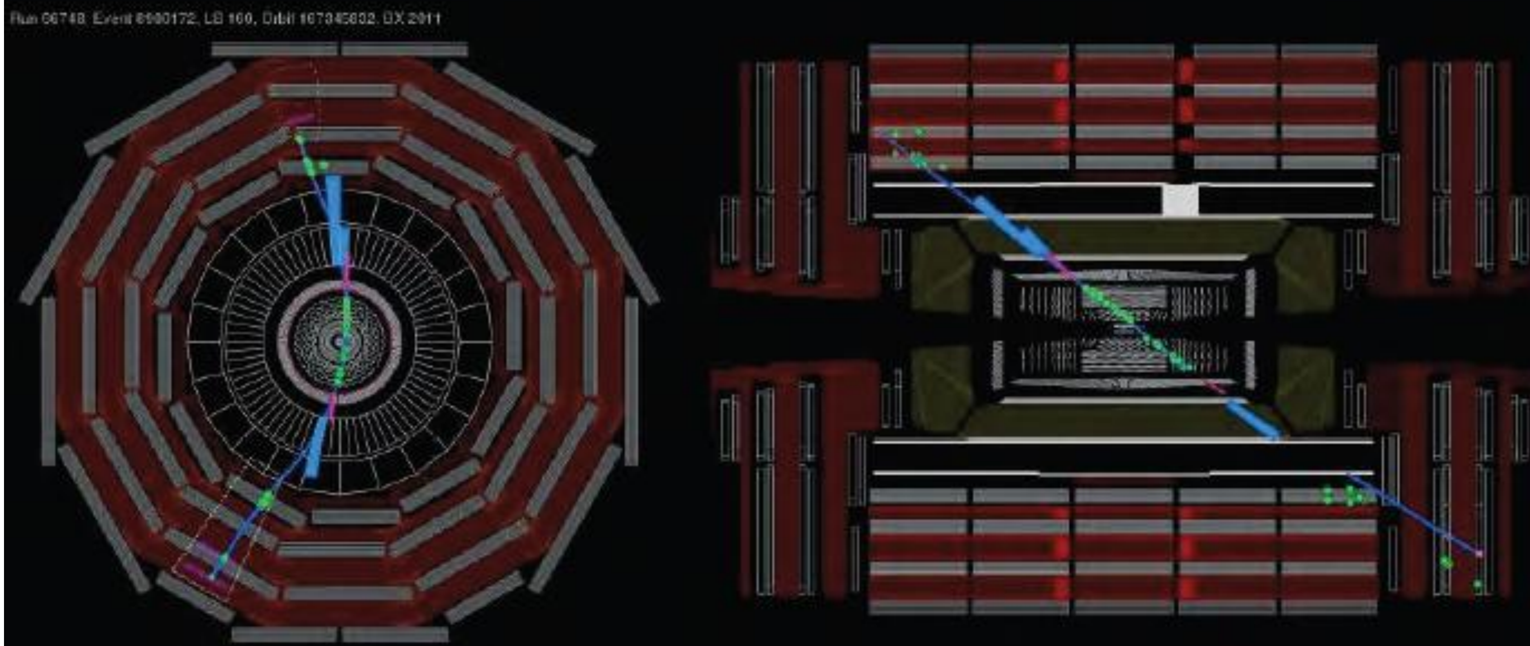


CMS



Cosmic muon

Typical cosmic muon event



High quality muon tracks in all subdetectors, similar to those expected from pp interactions.

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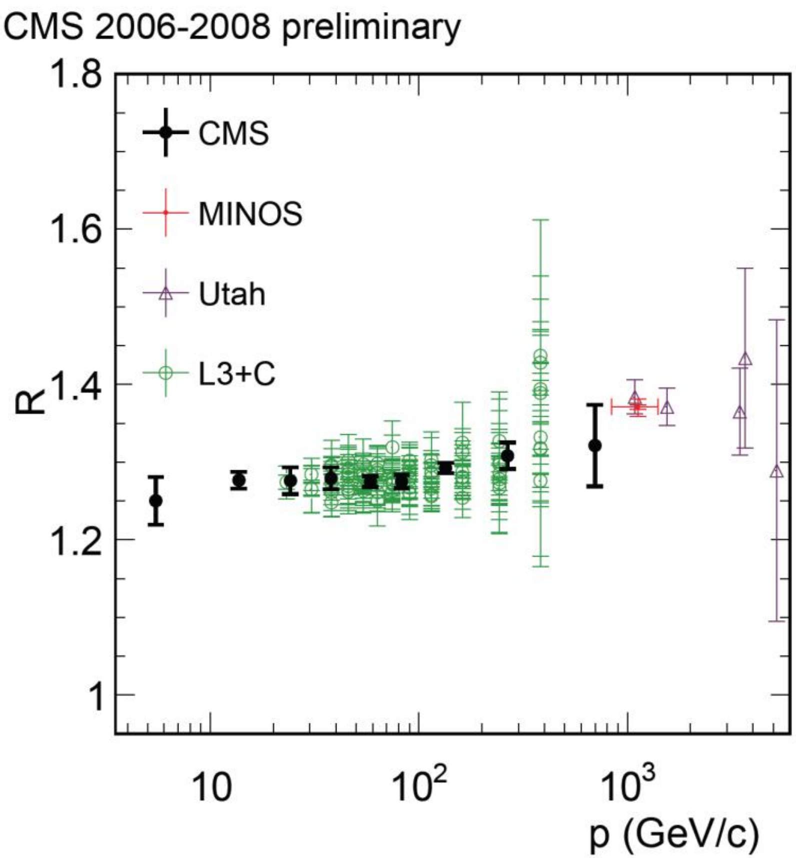
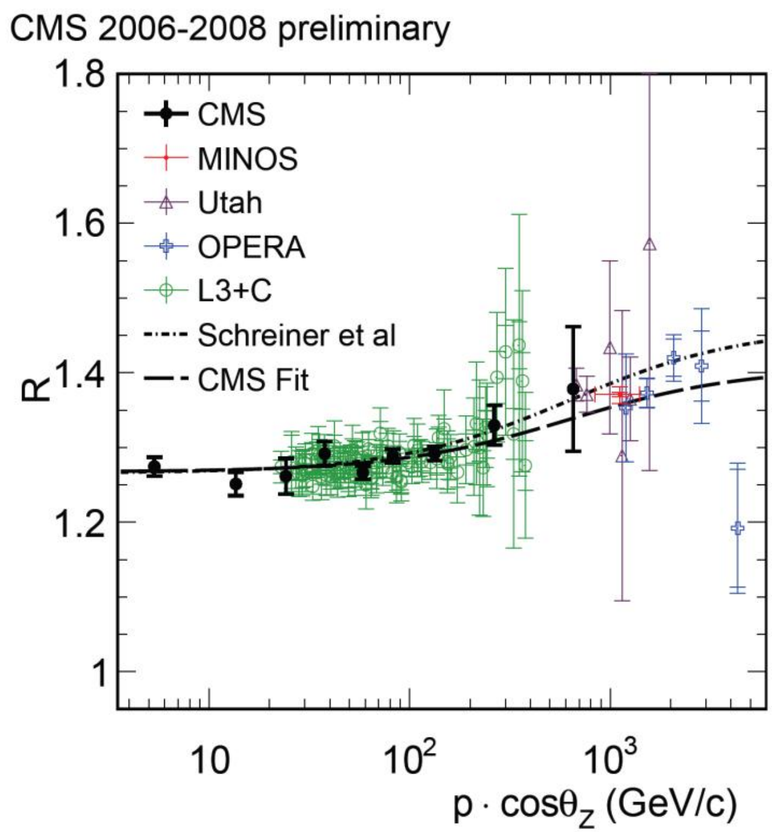
Charge assymetry of atmospheric muons



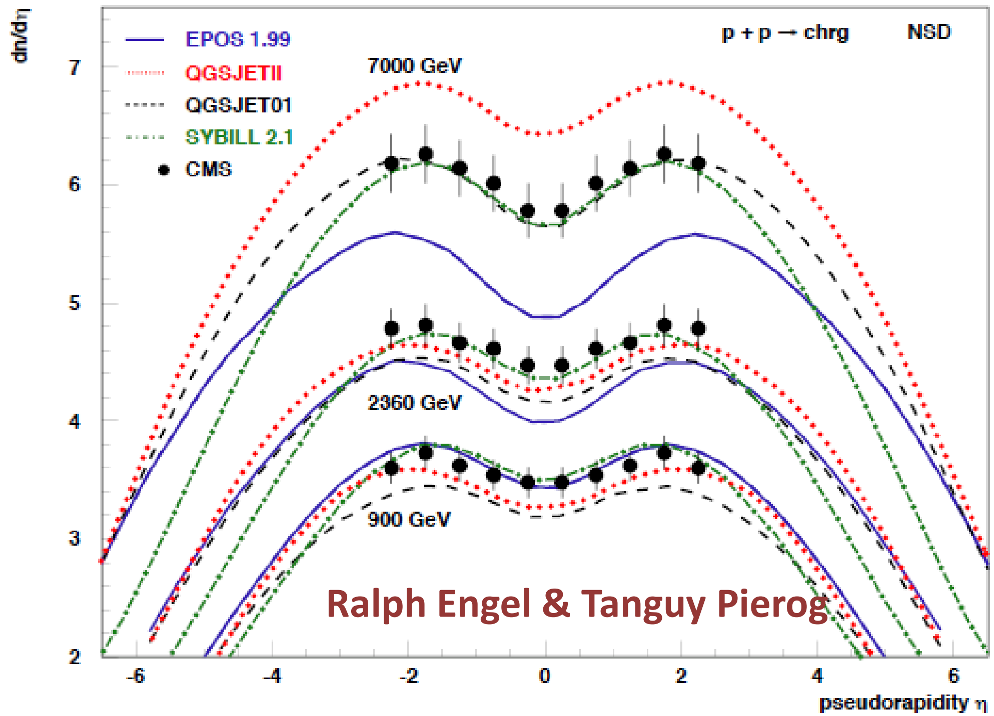


- **Most precise measurement of the muon charge ratio below 100 GeV**
- **Spanning within single experiment broad range 10 GeV – 1 TeV of transition from about constant to rising ratio**
- **Confirming other experiments climing rise of ratio.**

Charged particles

CR generators vs CMS

Pseudorapidity distribution of charged particles



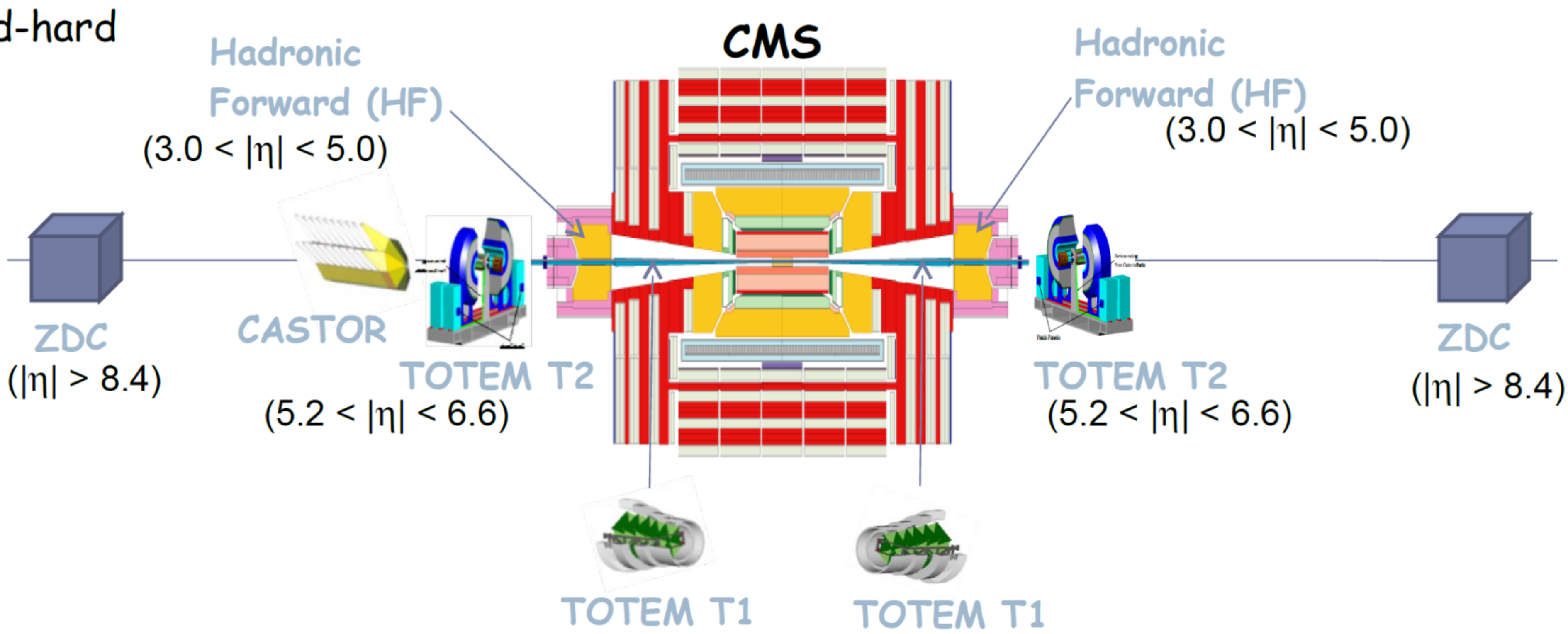
Highly increasing spread between generators with increase of energy from 900 GeV to 7 TeV.

Measurement: hadron trigger + correction based on PYTHIA

Models: theoretical non-single diffractive events

Forward prospects

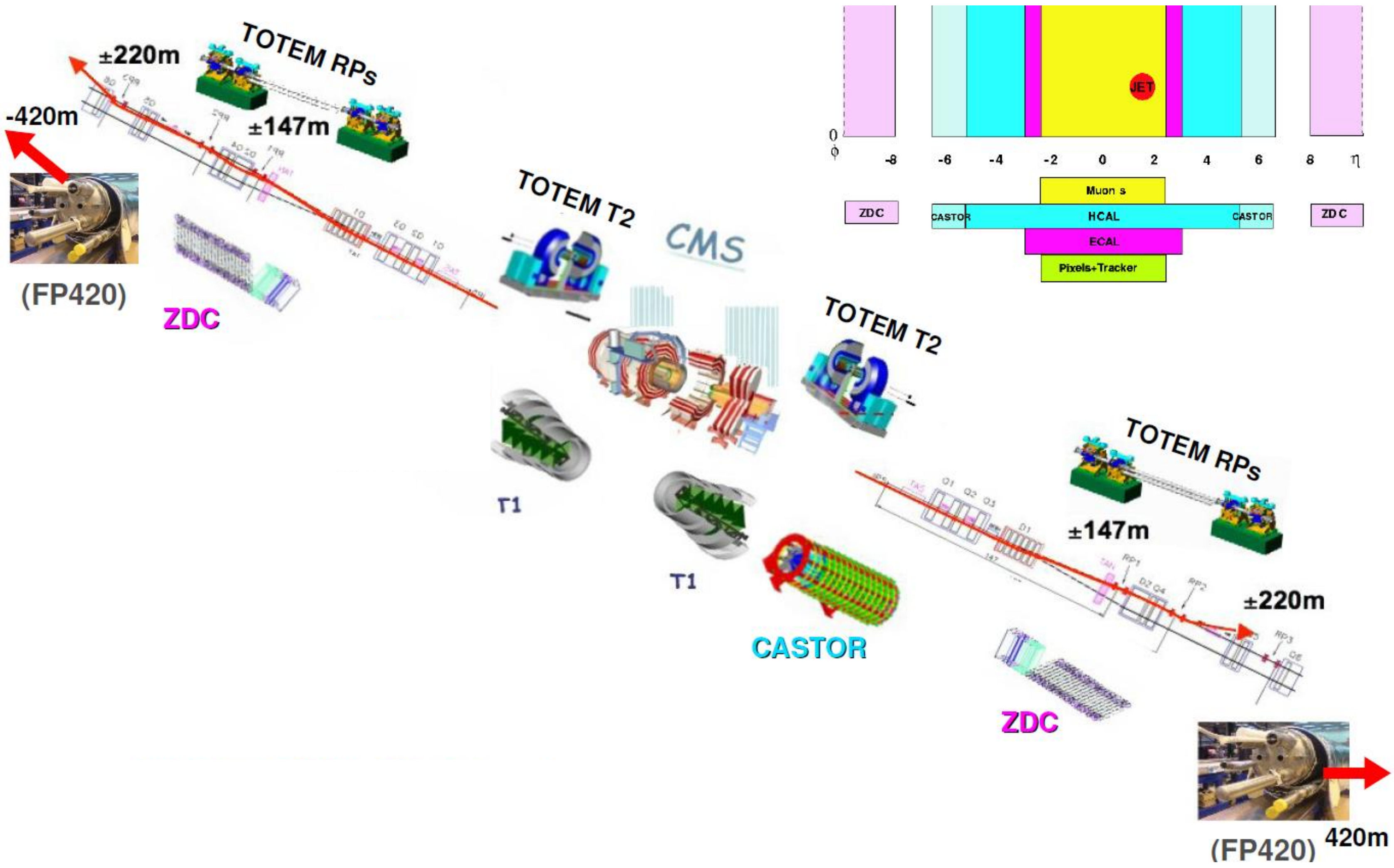
CMS + TOTEM



T2 perfectly fits CASTOR in η range.

Complementing T2 coordinates & CASTOR energy

CMS + TOTEM + FP420



Summary

- Diffractive signal clearly identified with different methods, comparison with MC generators performed on detector level. Pythia6 and POJET fairy well describe diffractive signal in minimum bias events.
- Large increase of forward energy flow with energy of interaction is not reproduced by MC in minimum bias events and fairy well reproduced in events with dijet.
- First results on forward jets at highest achieved for p-p η shown.
- Most precise measurement of muon charge ratio below 100 GeV, ratio is measured over broad range 10 GeV – 1 TeV of transition from approximately constant to rising value.
- Data on charged particle rapidity distribution are of high discriminative power for CR generators.

Backup

Diffraction for Cosmic Rays

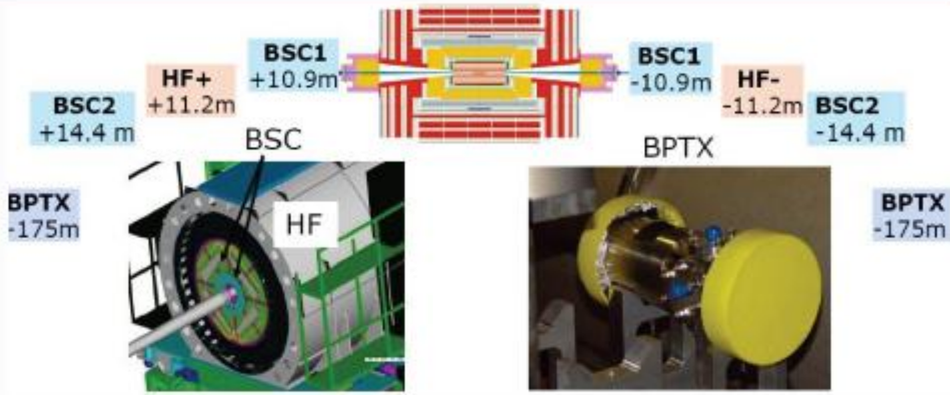
My note:

Contrary to common delusion, low-mass diffraction, which constitutes main part of diffractive cross-section, is much less relevant to shower development than non-diffractive interactions. Dissipation of energy and energy transfer from charged to neutral component determine rate of shower development. Both are much smaller in diffractive interactions than in non-diffractive. Evidently, elastic interactions, where either of above factors are absent, do not influence shower development. Diffraction is somewhat in between elastic and non-diffractive interactions. But: important is consistency between diffractive cross-section and particle production in diffractive process as they implemented in simulations. It is inconsistency that enhances sensitivity of shower development to accounting for diffraction.

Trigger

Minimum Bias Trigger

ETH Institute for Particle Physics



- **Trigger** :
  - any hit in the beam scintillator counters (BSC) AND
  - filled bunch passing the beam pickups (BPTX)
- **Offline event selection :**
  - 3 GeV in both sides of the HF
  - rejection of the beam halo using BSC timing
  - beam induced background rejection (pixel cluster shapes)
  - at least a reconstructed vertex near the collision point

Trento
Sep 10

G. Dissertori : QCD Results from CMS

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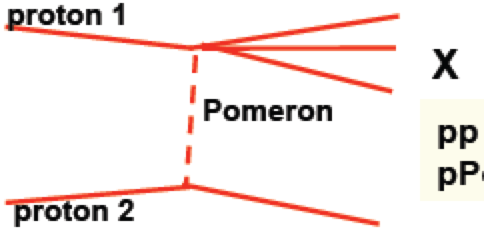
Diffraction

Meaning of $E \pm p_z$



pp --> pX
pPomeron --> X

- $\Sigma(E \pm p_z)$ runs over all calo towers
- Measure for the momentum of the Pomeron = momentum loss of the proton

Momentum and energy conservation:
E(Pomeron) + E(proton 1) = E(X)
p_z(Pomeron) + p_z(proton 1) = p_z(X)

Recall: in SD events proton loses almost none of its initial momentum.

If proton 1 moves in positive z direction: E(proton 1) - p_z(proton 1) ≈ 0 (and proton 2, and Pomeron, move in the negative z direction)

Hence:
E(Pomeron) - p_z(Pomeron) ≈ 2E(Pomeron) ≈ E(X) + p_z(X)

i.e. $\xi = 2E(\text{Pomeron})/\sqrt{s} \approx (E(X) + p_z(X))/\sqrt{s}$

A.Vilela Pereira

Cosmic muon charge ratio

- Muon energy spectrum underground (vertical muons, cosθ=1):

$$\frac{[dN]}{[dE_\mu]} = A\left\{\frac{1}{1+\frac{1.1E_\mu\cos\theta}{\epsilon_\pi}} + \frac{0.054}{1+\frac{1.1E_\mu\cos\theta}{\epsilon_K}}\right\} \qquad A \equiv \frac{0.14E_\mu^{-2.7}}{\mathrm{cm^2\ s\ sr\ GeV}}$$

- Both π and K contribute, ϵ is the energy where the probability of meson interaction and decay are equal: ϵ_π = 115 GeV and ϵ_K = 850 GeV.

- Generalizing for μ^+ and μ^-, the measured charge ratio on surface is:

$$\frac{N^{\mu^+}}{N^{\mu^-}} = \left\{\frac{f_\pi}{1+\frac{1.1E_{\mu^+}\cos\theta}{115\ \mathrm{GeV}}} + \frac{0.054\times f_K}{1+\frac{1.1E_{\mu^+}\cos\theta}{850\ \mathrm{GeV}}}\right\} / \left\{\frac{1-f_\pi}{1+\frac{1.1E_{\mu^-}\cos\theta}{115\ \mathrm{GeV}}} + \frac{0.054\times(1-f_K)}{1+\frac{1.1E_{\mu^-}\cos\theta}{850\ \mathrm{GeV}}}\right\}$$

- From L3+C, f_π = 0.555(2) and f_K = 0.667(7). These values imply the muon charge asymmetry induced by π and K is

$$r_\pi = f_\pi / (1-f_\pi) = 1.25 \quad \text{and} \quad r_K = f_K / (1-f_K) = 2$$