Observation of Diffraction, Measurement of the Forward Energy Flow and Observation of Forward Jets with the CMS Detector

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Outline

- **Observation of Diffraction**
  - Physics Motivation
  - CMS Detector
  - Event Selection
  - Diffractive Signal Observation and MC Comparison
- **Forward Energy Flow and Forward Jets**
  - Physics Motivation
  - Event Selection
  - Forward Energy Flow Measurement and MC Comparison
  - Observation of Forward Jets
- **Conclusion**

Observation of Diffraction in *p p* collisions at 900 GeV and 2.36 TeV CM energies at the LHC

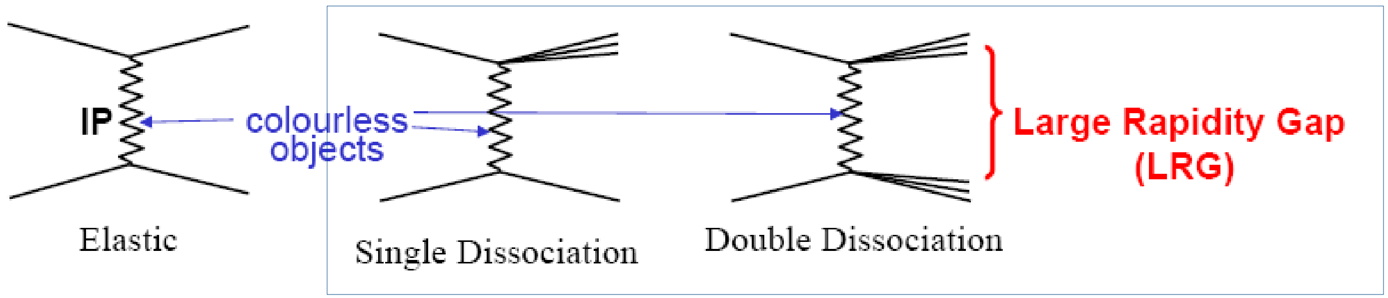
CMS PAS FWD-10-001

Physics Motivation

- Diffractive reactions in $p\ p$ collisions: reactions $p\ p \rightarrow X\ Y$ in which the systems X and Y are separated by a Large Rapidity Gap

→ diffraction is described by a colourless exchange carrying the quantum numbers of the vacuum

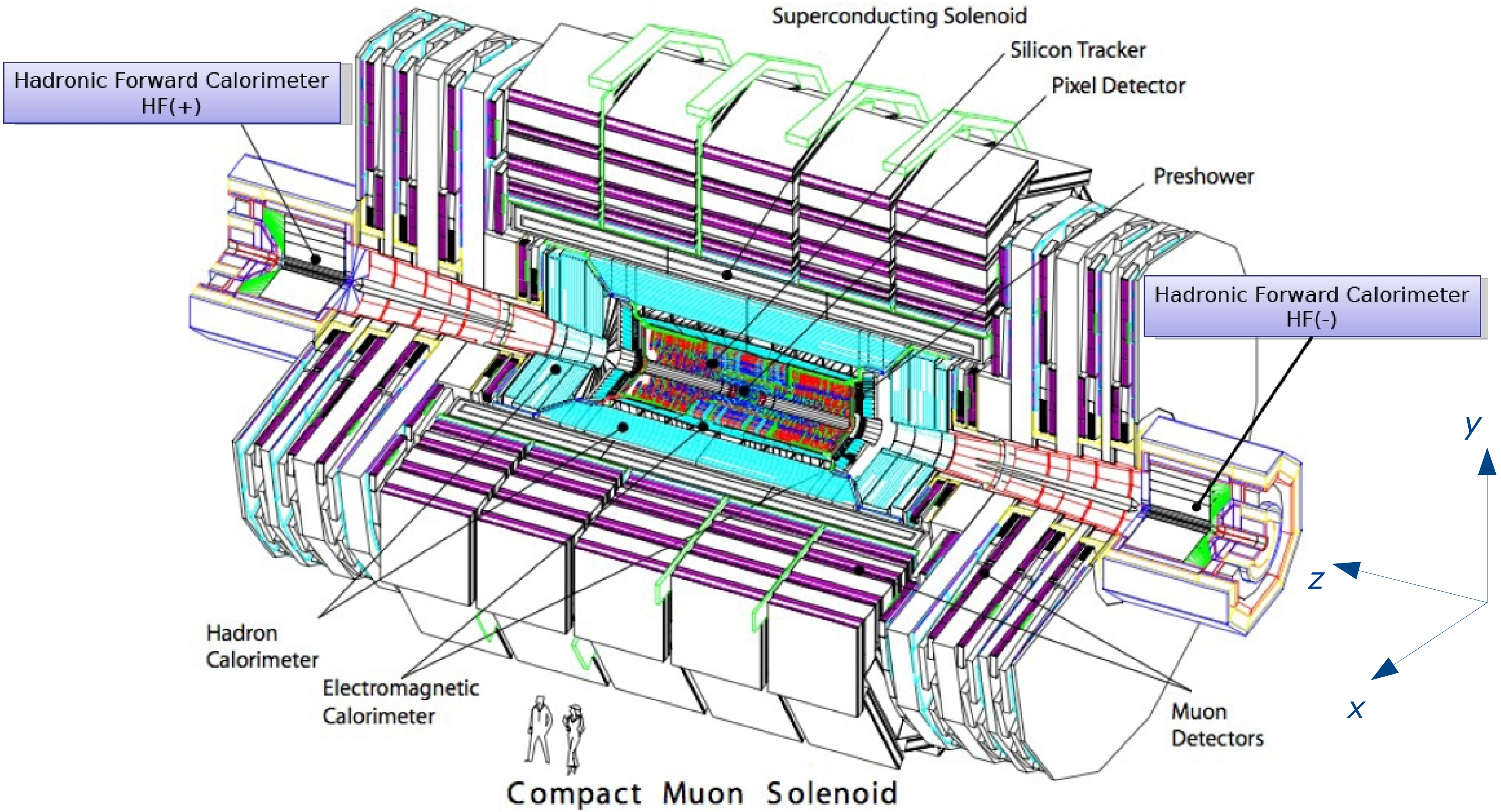
- Hard diffraction: QCD (q or g) ↔ Soft diffraction: Regge (Pomeron)



- Diffractive events contribute significantly to Minimum Bias data set (~ 30 % of the total $p\ p$ cross section)
- Modelling of soft diffraction is generator dependent

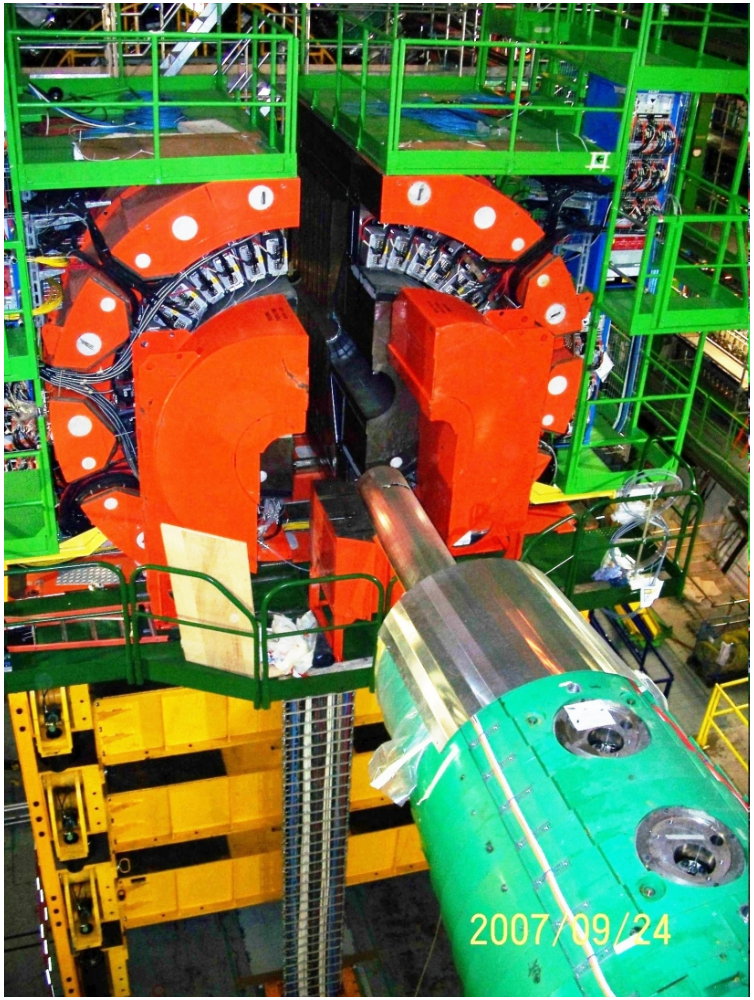
→ Constraint on diffractive contribution is essential to
  - understand the MB data set and improve the MB MC tunes
  - improve knowledge about PU

CMS Detector



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
- 13 rings with 0.175×0.175 segmentation in η and φ (except for the 2 most inner rings and the most outer one)
- 2 types of fibers: long (run over the full depth) and short (start at 22 cm from the front of HF)

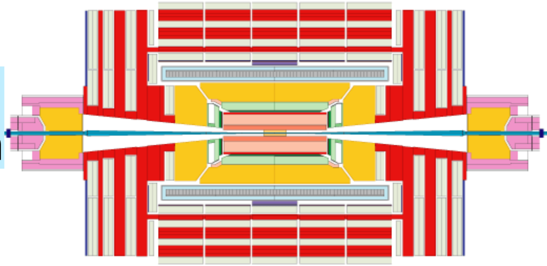
→ to distinguish between shower generated by e/γ and shower generated by hadrons

Trigger System

BSC2 +14.4 m

HF+ +11.2m

BSC1 +10.9m



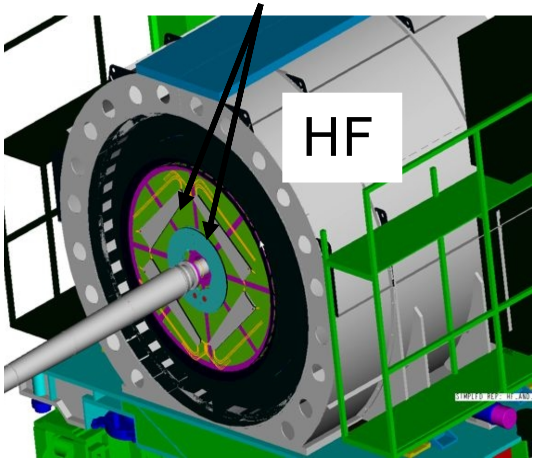
BSC1 -10.9m

HF- -11.2m

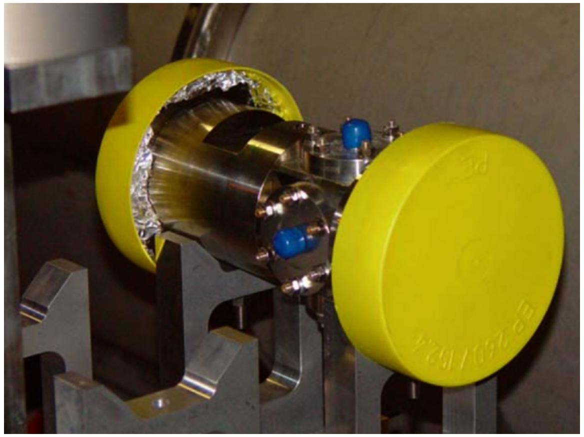
BSC2 -14.4 m

BPTX +175m

BSC



BPTX



BPTX -175m

- Beam Scintillator Counters
- located at ± 10.86 m from IP (± 14.4 m for BSC2)
- designed to provide hit and coincidence rates

- Beam Pick-up Timing for the eXperiments
- designed to provide precise info on the bunch structure and timing of the incoming beam

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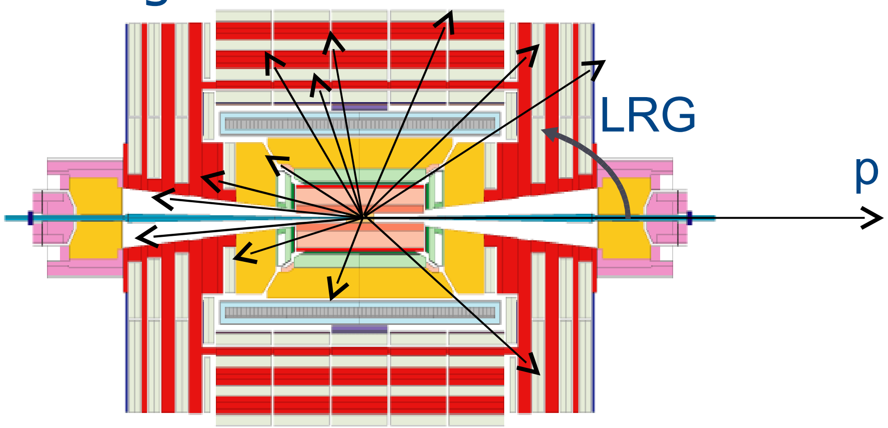
Diffractive Event Selection

- Trigger signal in either of the BSC scintillators in coincidence with a signal from both BPTX detectors (BSCs coincidence would have suppressed SD signals)
- Primary vertex with $|z| < 15$ cm
  transverse distance from z axis < 2 cm
  at least 3 tracks used in the vertex fitting
- Rejection of beam halo candidates
- Rejection of beam background events
- Threshold of 4 GeV in HF, of 3 GeV in the other calorimeters
- Rejection of events with large signal in HCAL consistent with noise

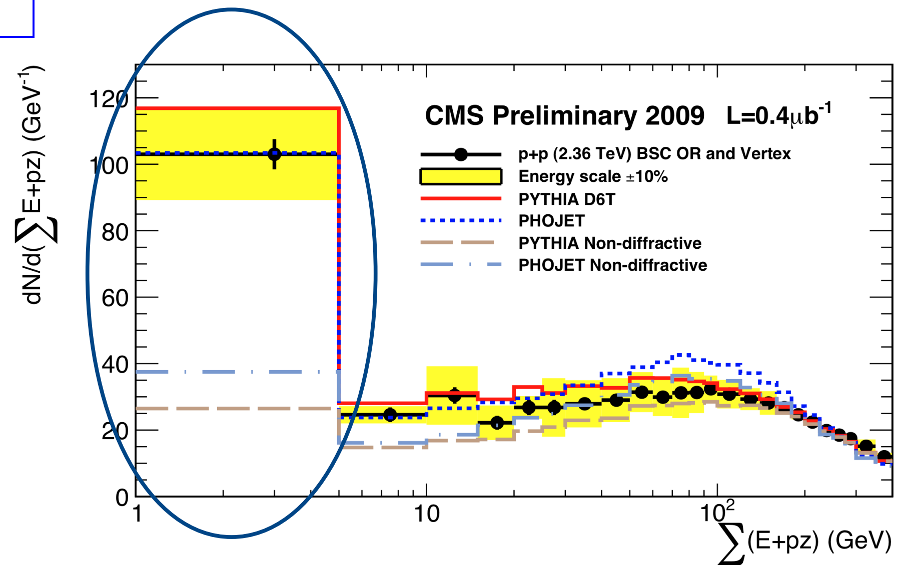
Diffractive Signal Observation: peak in ξ distribution

2360 GeV

single-diffractive event



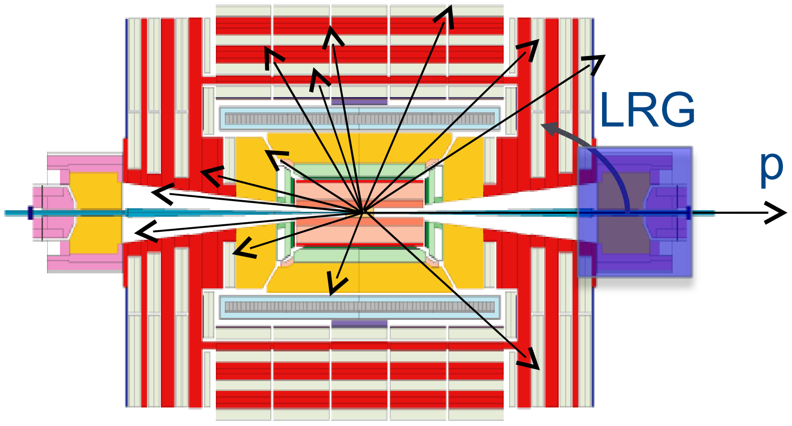
events below 5 GeV are mainly diffractive



- Σ (E ± Pz) related to the momentum loss of the scattered proton (runs over all energy depositions in the calorimeters)
- proton fractional momentum loss: $\xi \approx \Sigma$ (E ± Pz) / $\sqrt{s}$
- diffractive peak expected at low values of this variable ($\sigma \sim 1 / \xi$)

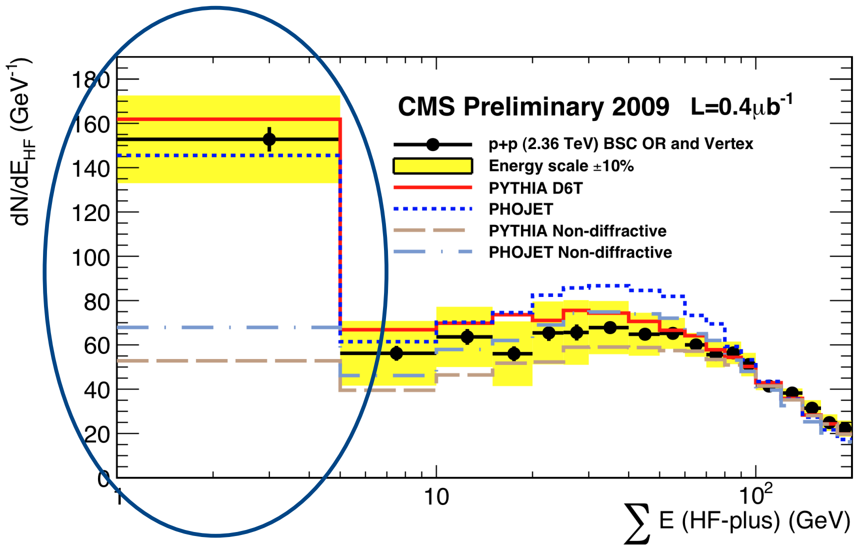
- uncorrected data shown and compared to PYTHIA D6T & PHOJET
- main systematic uncertainty due to ±10% energy scale variation
- PYTHIA describes better the non-diffractive part of the spectrum

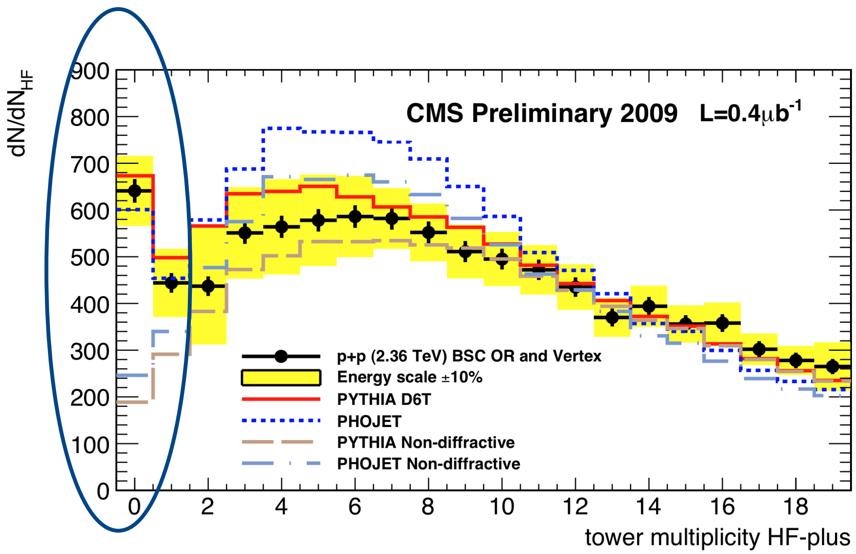
Diffractive Signal Observation: LRG



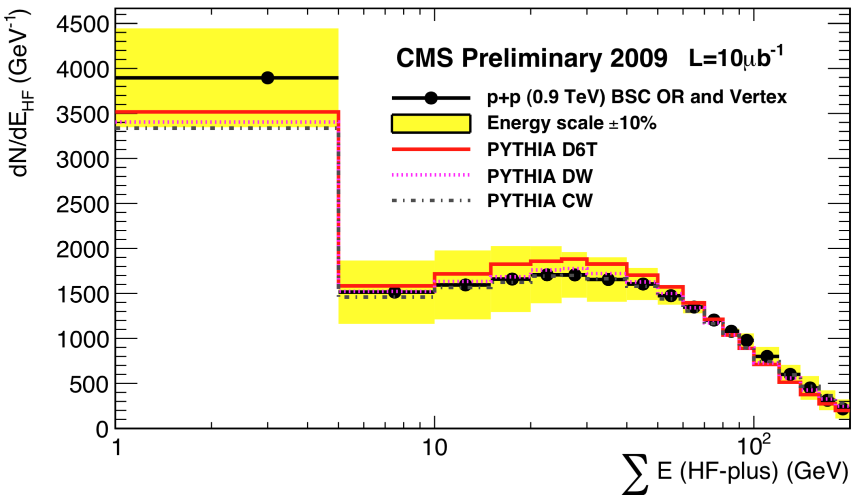
- Diffractive events characterized by the absence of forward hadronic activity in HF due to the presence of a Large Rapidity Gap
- Diffractive peak expected at low energy deposition and low tower multiplicity in HF

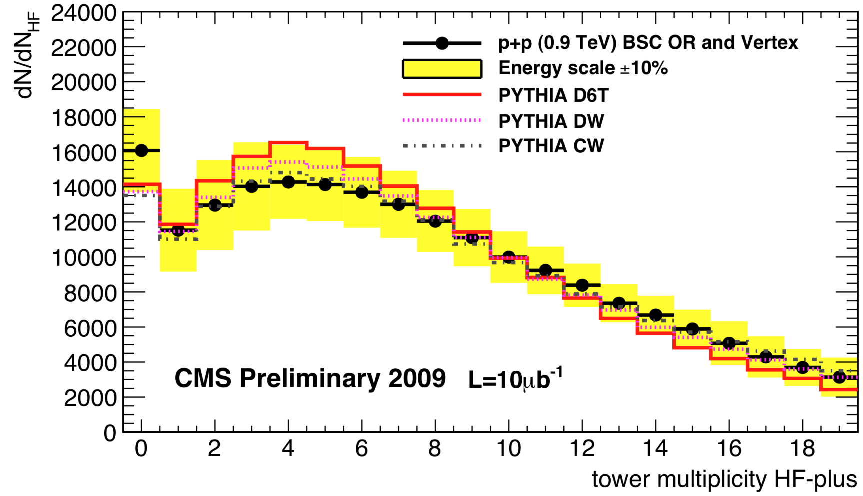
2360 GeV

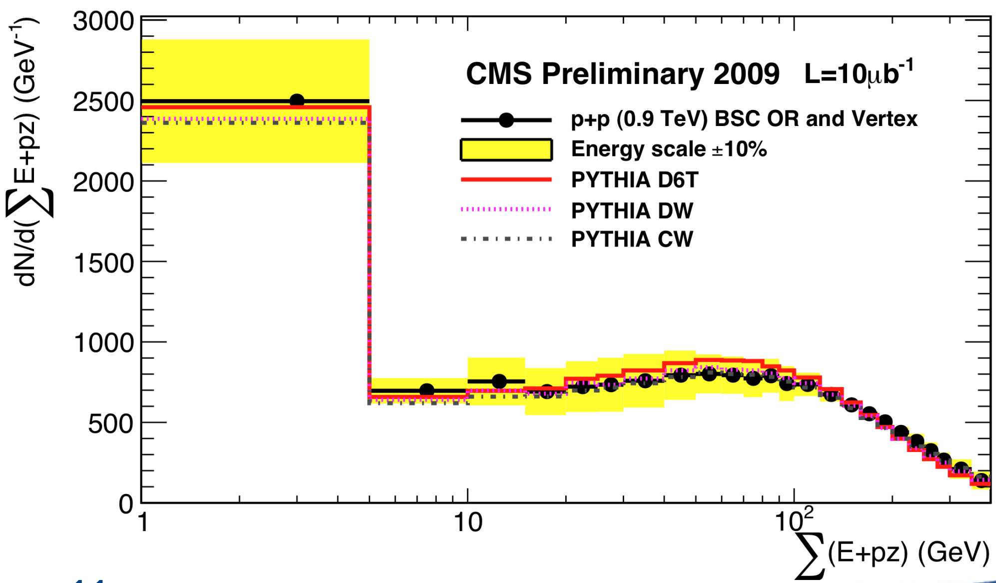




Diffractive Signal Observation: Comparison with different tunes



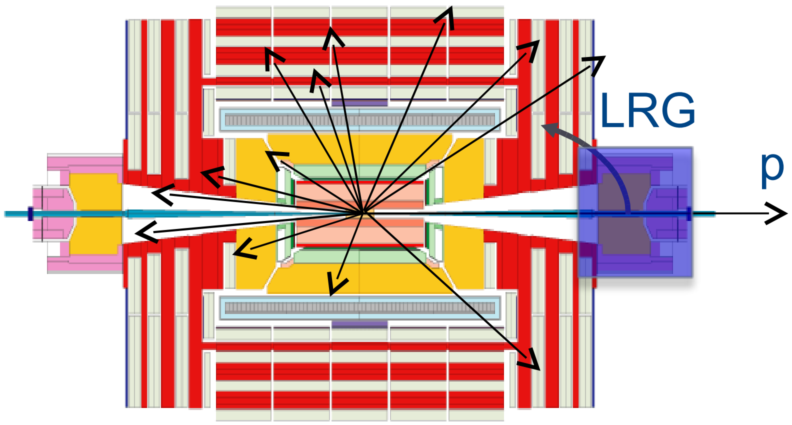




900 GeV

PYTHIA tunes D6T, DW and CW900A give similar overall description

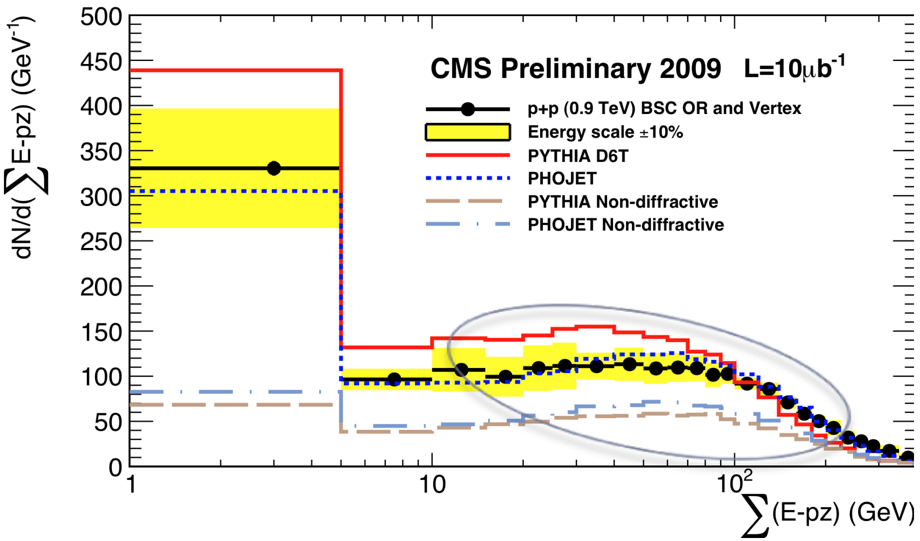
Enriched Diffractive Sample

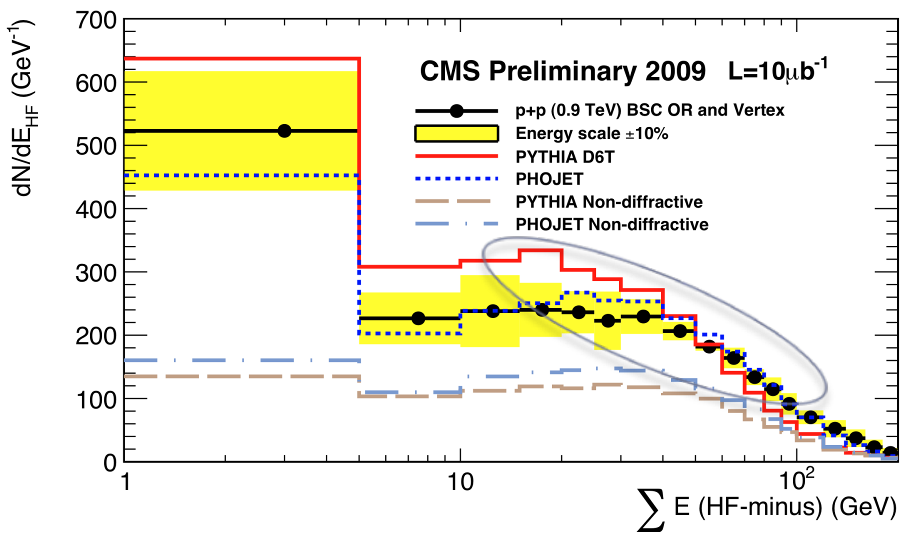


- Require low activity (Rapidity Gap) on one side (HF+ or HF-) of CMS
→ enhance the diffractive component
- Look at properties of diffractive system X to test MC description ($\xi = M_X^2 / s$)
- PHOJET gives a better description of the diffractive system

900 GeV

E(HF+) < 8 GeV





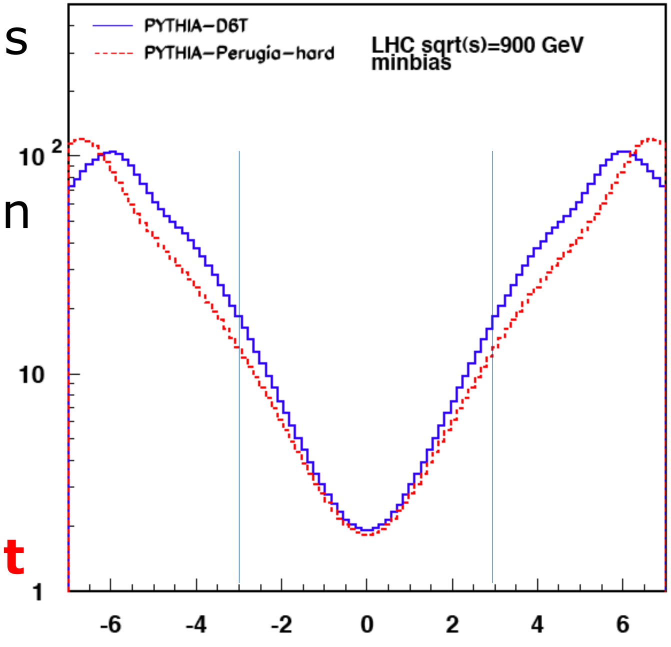
Forward Energy Flow

Physics Motivation

- In forward region: one probes the small x content of the proton
  - parton densities might become very large
  - probability for more than one partonic interaction per event should increase

→ **Measurement of the forward energy flow to distinguish between various models for the multiparton interaction**

- Energy flow as a function of η for minimum bias events at $\sqrt{s}$ = 900 GeV
- Predictions from PYTHIA using 2 parameters sets (D6T – Perugia) tuned to describe Tevatron data in the central region
- Significant difference in the fwd region $|\eta| > 3$
- Extrapolation from Tevatron to LHC energies very uncertain



→ **Input from fwd energy flow measurement complementary to central studies to constrain MPI**

Minimum Bias Event Selection

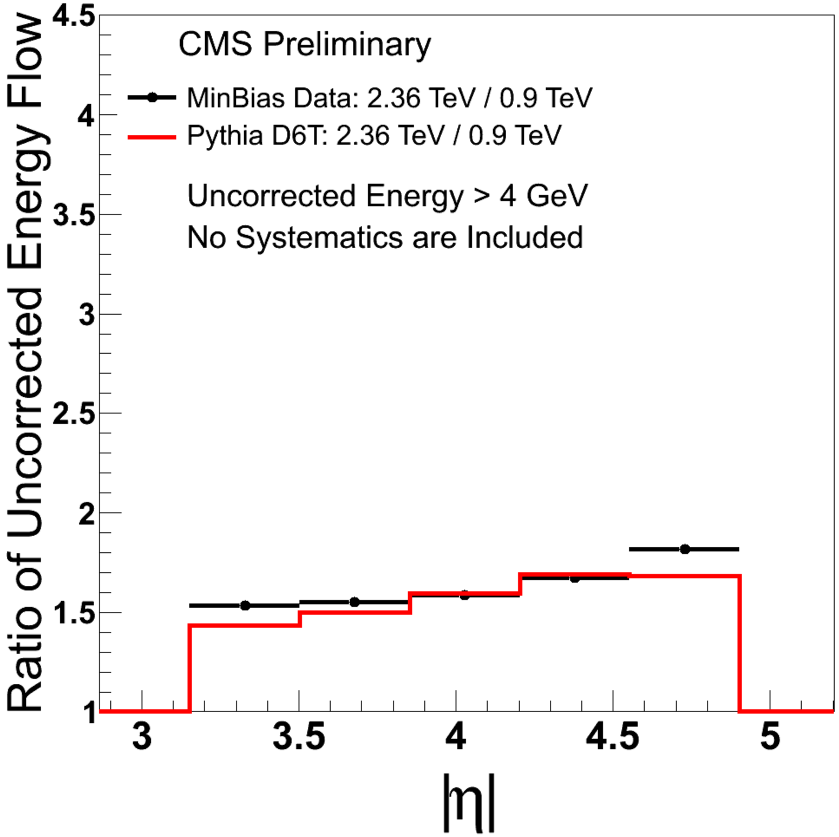
- Trigger signal in each of the BSC scintillators in coincidence with a signal from both BPTX detectors → reject a large fraction of diffractive events
- Primary vertex with $|z| < 15$ cm
  transverse distance from z axis < 2 cm
  at least 3 tracks used in the vertex fitting
- Rejection of beam halo candidates
- Rejection of beam background events
- Threshold of 4 GeV for the uncorrected energy in HF
- Rejection of events with large and isolated signal in HF consistent with noise

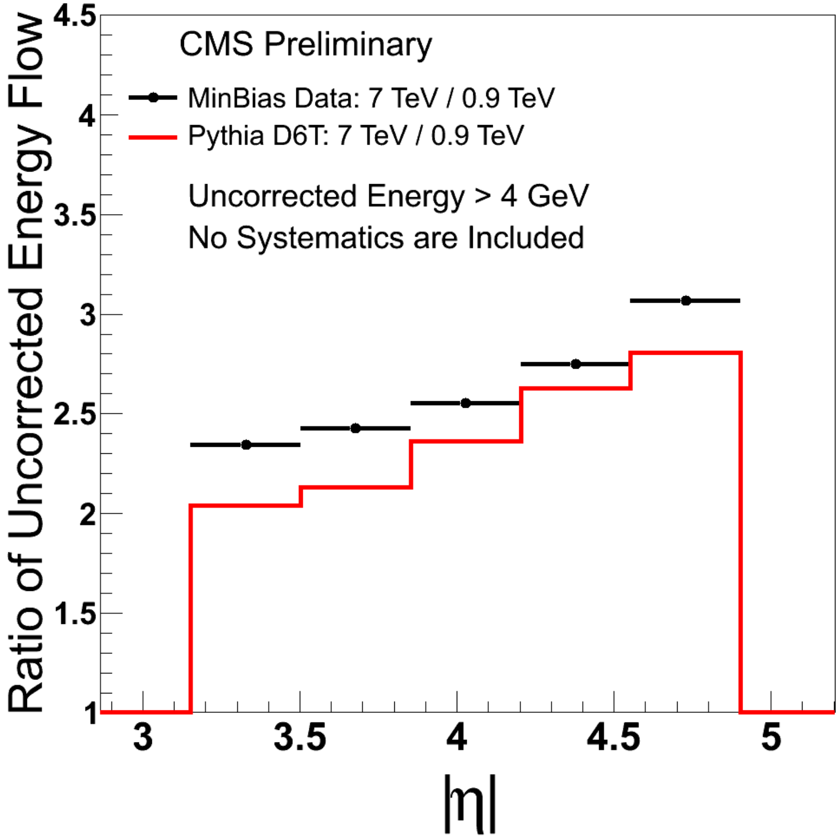
Forward Energy Flow Measurement

$$R_{Eflow}^{\sqrt{s_1},\sqrt{s_2}} = \frac{\frac{1}{N_{\sqrt{s_1}}}\frac{\Delta E_{\sqrt{s_1}}}{\Delta\eta}}{\frac{1}{N_{\sqrt{s_2}}}\frac{\Delta E_{\sqrt{s_2}}}{\Delta\eta}}$$

- $\sqrt{s_1}$ = 2.36 TeV or 7 TeV
- $\sqrt{s_2}$ = 0.9 TeV
- $N_{\sqrt{s}}$ = number of Minimum Bias events selected at the CM energy $\sqrt{s}$
- $\Delta E_{\sqrt{s}}$ = Energy deposition in the rapidity range $\Delta\eta$ at the CM energy $\sqrt{s}$

Forward Energy Flow Measurement





- detector level data, no systematic uncertainties
- energy flow is increasing with increasing CM energy & increasing η
- MC predictions in agreement with data, but no conclusion on the quality of the description can be made (missing systematics)

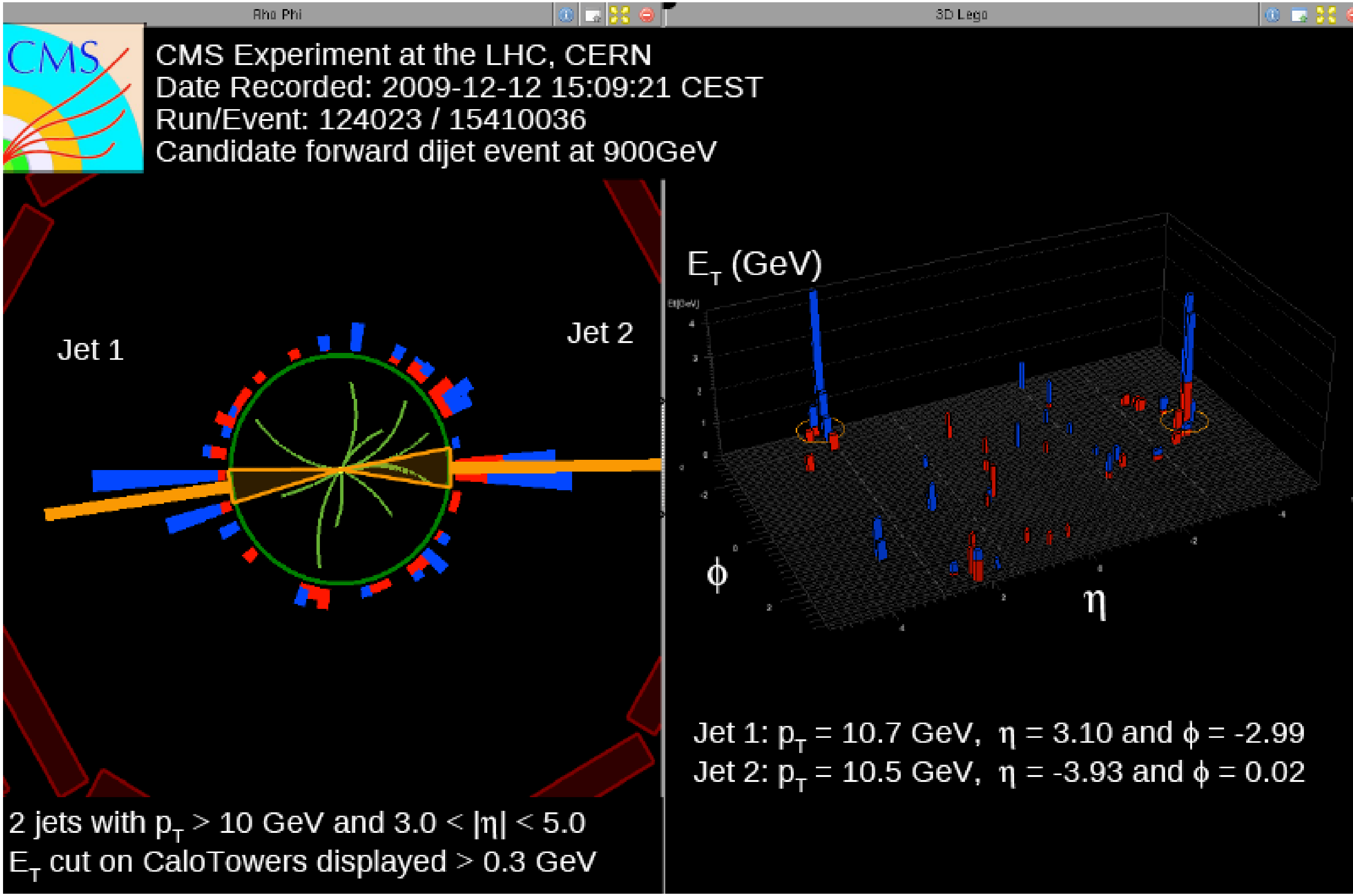
→ snapshot of what we have now, not yet a final measurement

→ more results available soon, stay tuned!

Observation of Forward Jets

- Cuts as for the Minimum Bias event selection
- Look for jets in the HF region $3.0 < |\eta| < 5.0$
- P_t corrected > 10 GeV

Forward Dijet at 900 GeV

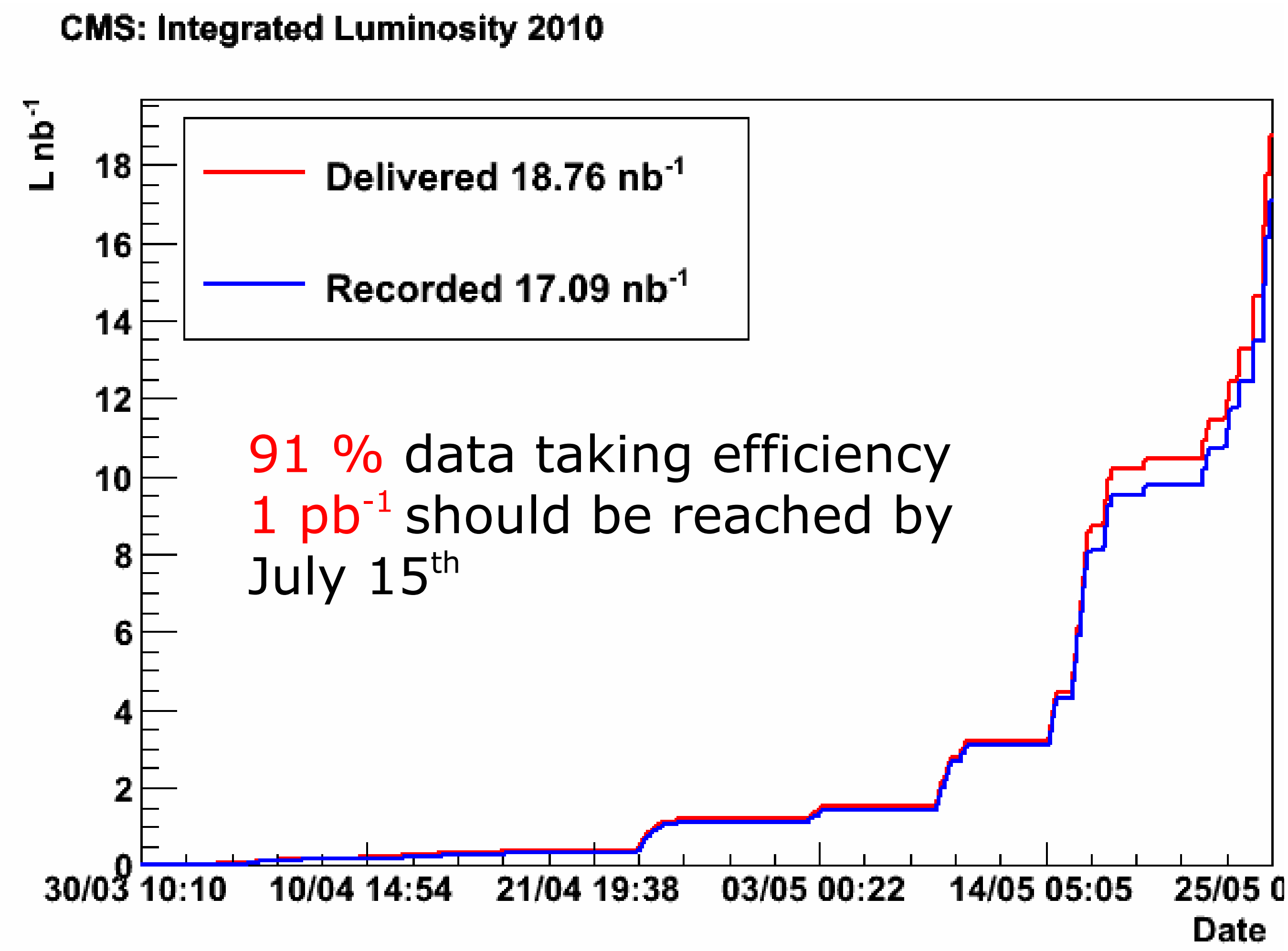


Conclusions

- Rediscovery of diffraction in *p p* collisions at 900 GeV & 2.36 TeV
- Diffraction observed in two ways: peak at low ξ values and presence of a Large Rapidity Gap
- Comparison to the MC event generators PYTHIA and PHOJET
  - PYTHIA describes better non-diffractive part of the spectrum
  - PHOJET describes better the diffractive system
- Constraint from diffraction important to improve MB MC tunes
  - PYTHIA tunes D6T, DW and CW give similar overall description
- First measurements of forward jets and forward energy flow in the HF acceptance ($2.9 < |\eta| < 5.2$)

Back Up

Integrated Luminosity 2010



91 % data taking efficiency

1 pb^{-1} should be reached by July 15th

Physics Motivation

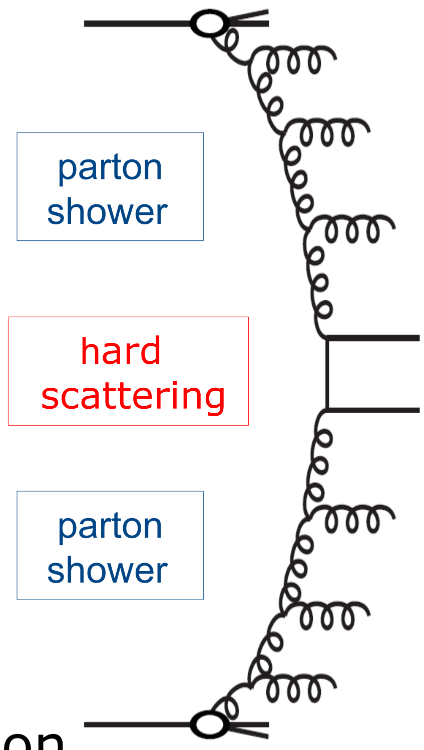
- *p p* collisions at high energies are described by the convolution of
  - matrix elements associated to the hard scattering with
  - parton densities evolved up to μ^2 by QCD evolution equations

- Hadronic final state receives contributions from
  - the hard scattering process
  - the partons radiated during QCD evolution

- In MC: radiation described by parton shower
  - takes into account higher order contributions by resumming a subset of leading diagrams
  - which diagrams are leading depends on hard scale Q^2 and momentum fraction x_1 and x_2

→ various models for the parton shower evolution:
  - DGLAP (PYTHIA) – BFKL – CCFM (CASCADE)
  - Differences more prominent in the forward region

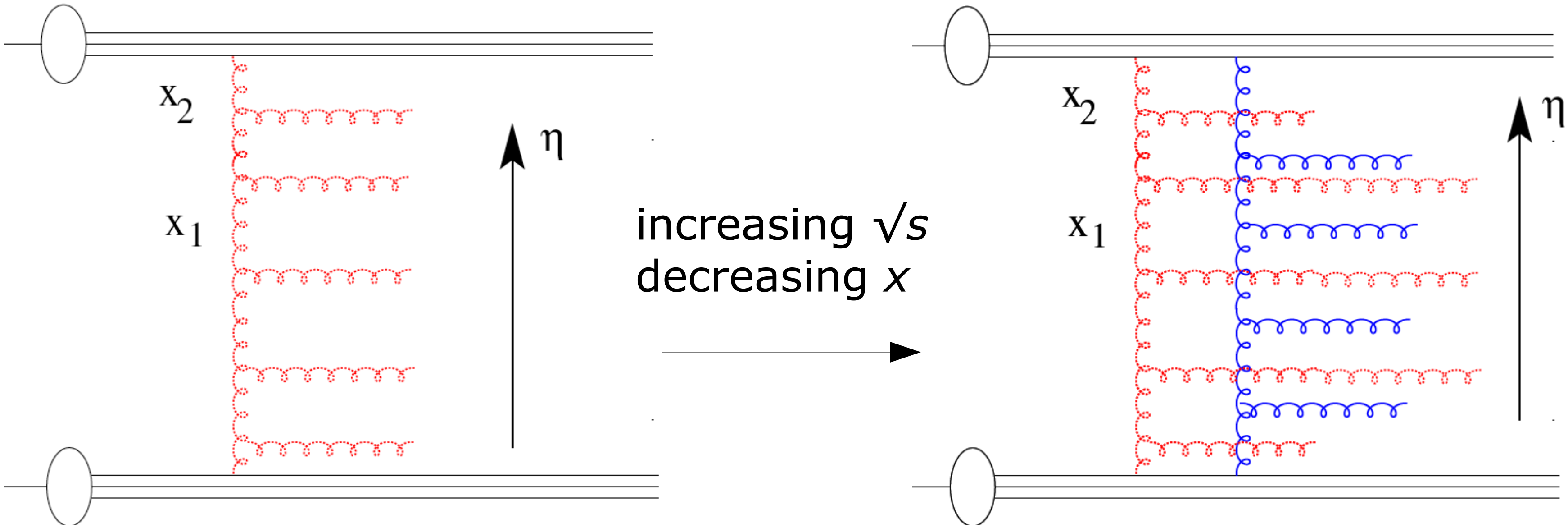
→ Measurement of the forward energy flow to distinguish between various models for the parton shower evolution



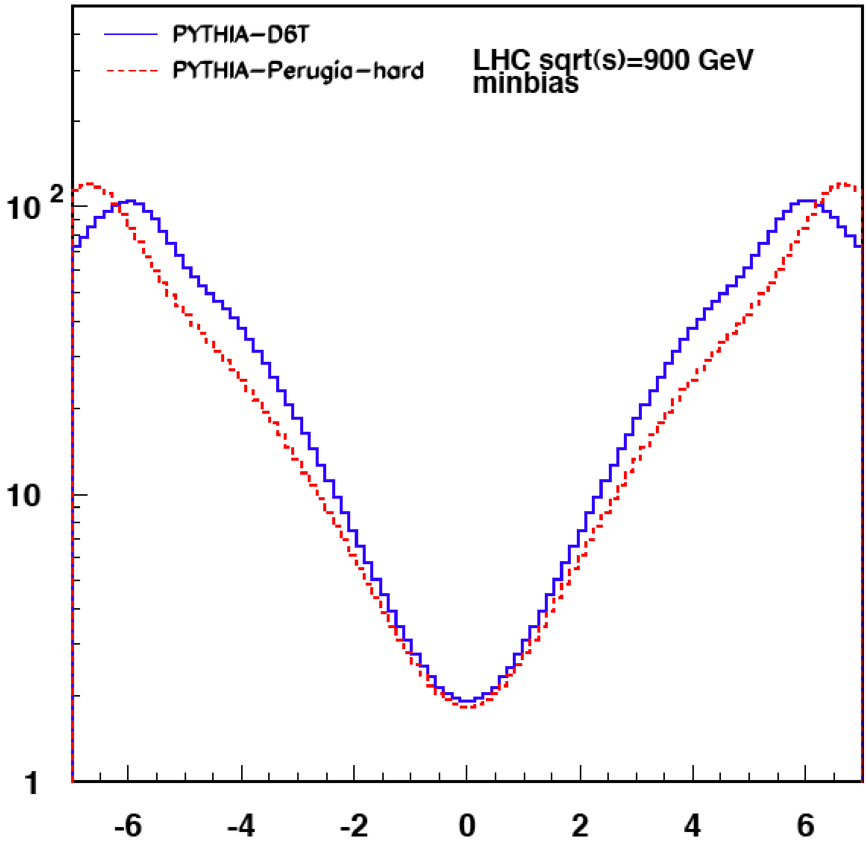
Physics Motivation

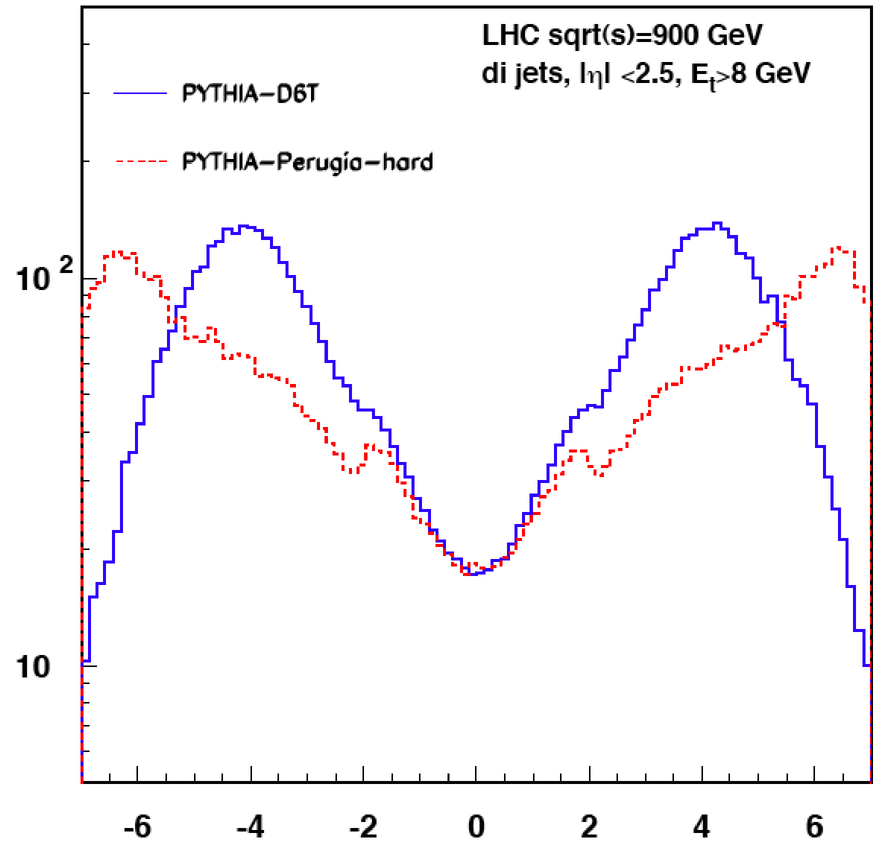
- DGLAP evolution
  - emissions ordered in k_t
  - evolution from low to high Q^2
  - implemented in PYTHIA
- BFKL evolution
  - emissions ordered in x
  - evolution from high to low x
- CCFM evolution
  - angular ordering of the emissions
  - unintegrated gluon distributions
  - implemented in CASCADE
- Differences more prominent in the forward region
  - DGLAP: k_t ordering: softest emissions near proton remnant
  - BFKL/CCFM: forward emissions can be arbitrarily large

Multiparton Interaction (MPI)



Forward Energy Flow





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Physics Motivation

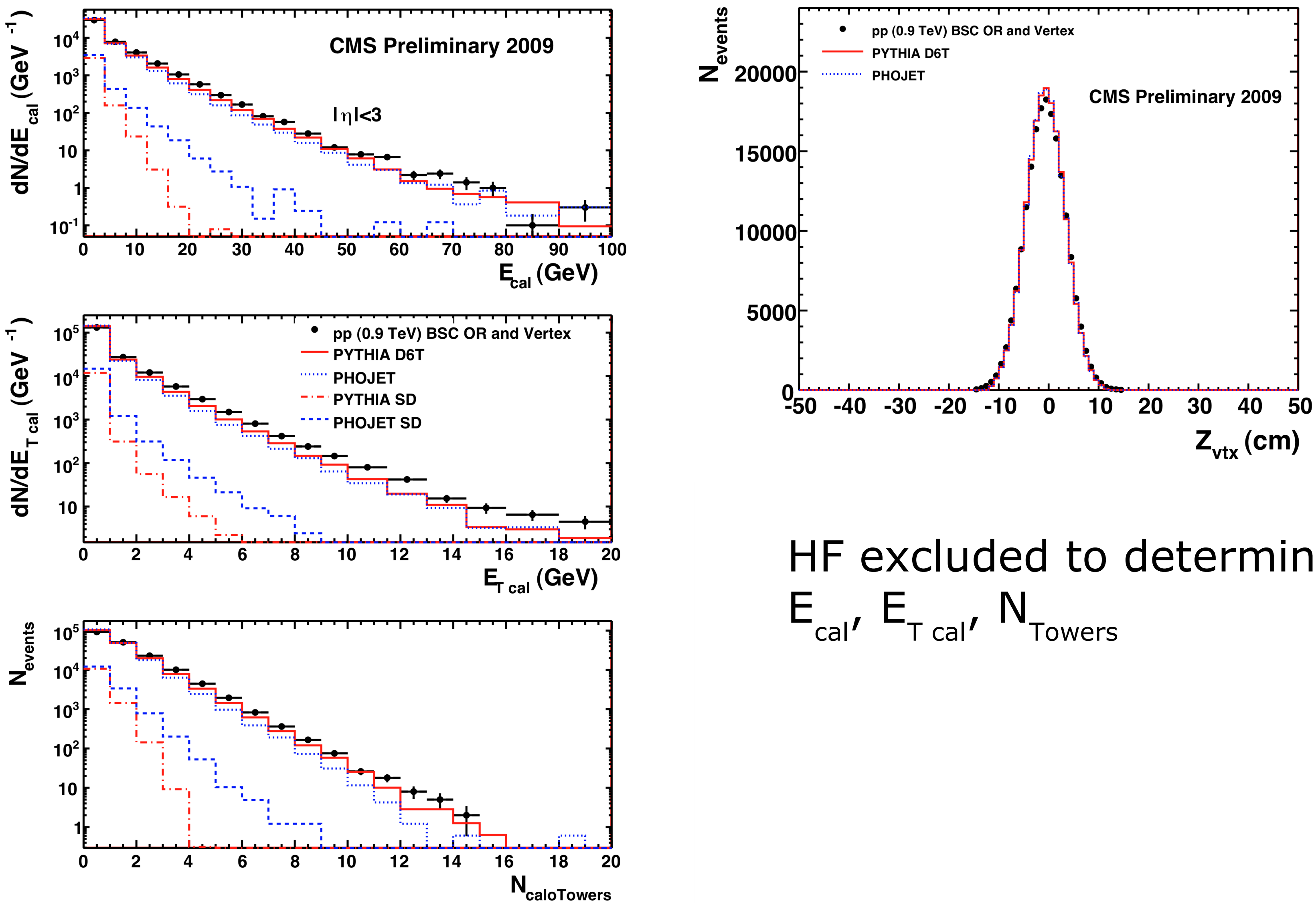
- Factorization of the diffractive cross section in *e p* interaction is broken at *p p* collider by the presence of soft interaction and rescattering among the spectator partons

- rescatterings fill the rapidity gap and suppress the visible diffractive cross section

- effect quantified by the rapidity gap survival probability $\langle S^2 \rangle$

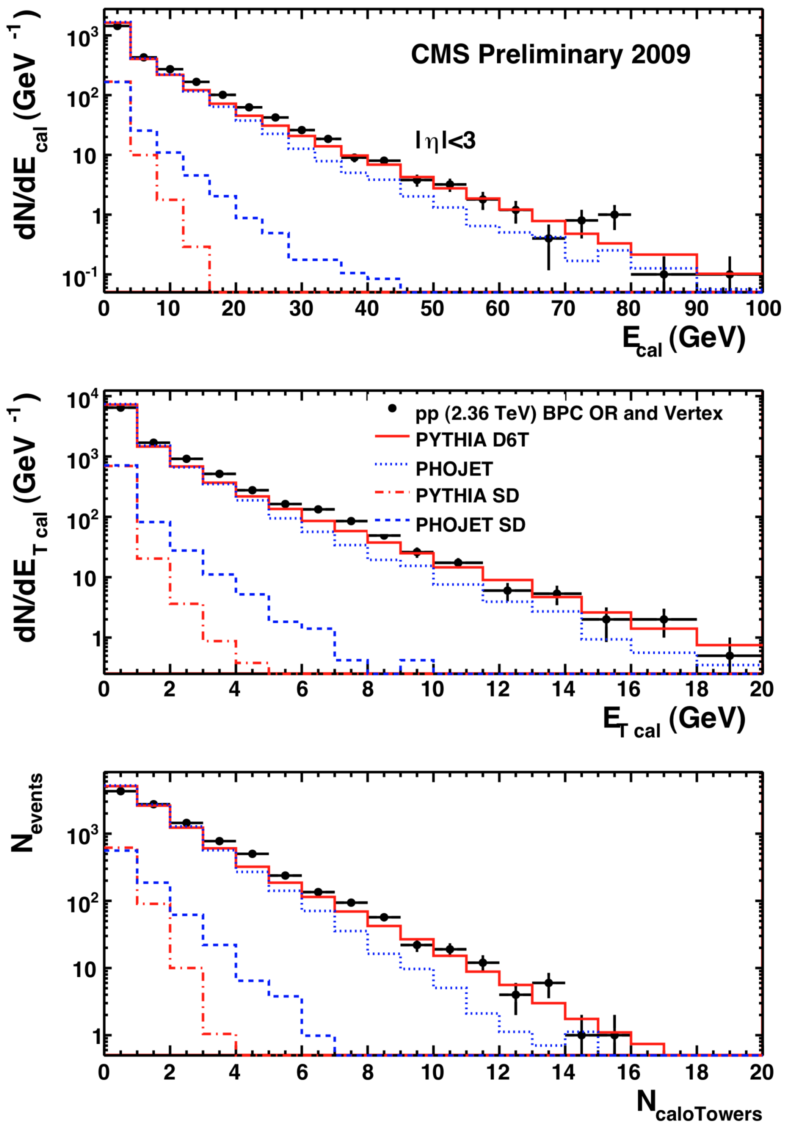
→ determination of $\langle S^2 \rangle$ is an important measurement to be done at low luminosity with early LHC data

Control Plots at 900 GeV



HF excluded to determine E_{cal}, $E_{T\ cal}$, N_{Towers}

Control Plots at 2.36 TeV



HF excluded to determine E_{cal}, $E_{T\ cal}$, N_{Towers}

PYTHIA MPI tunes

- Perturbative 2-to-2 partonic cross-section is regularized in PYTHIA by the introduction of a cutoff p_{t0}:

$$\sigma \propto 1/(p_t^2 + p_{t0}^2)^2$$

- p_{t0} governs the description of the amount of MPI: larger MPI activity for smaller values of p_{t0}

- $p_{t0}(\sqrt{s}) = p_{t0}(\sqrt{s_0}) \; (\sqrt{s} / \sqrt{s_0})^{\epsilon}$

- D6T: p_{t0}= 1.84, $\sqrt{s_0}$ = 1.96 TeV, ϵ = 0.16
- DW: p_{t0}= 1.9, $\sqrt{s_0}$ = 1.8 TeV, ϵ = 0.25
- CW900A: p_{t0}= 1.8, $\sqrt{s_0}$ = 1.8 TeV, ϵ = 0.30