Underlying Event Studies and Forward Physics at CMS

ICHEP 2010 – July 22-28, 2010 – Paris

(3 – Perturbative QCD Jets and Diffractive Physics)

Paolo Bartalini (National Taiwan University)
on behalf of the CMS collaboration

PAS QCD-10-001 & CERN-PH-EP/2010-014, submitted to EPJC: **"First Measurement of the Underlying Event Activity at the LHC with √s = 0.9 TeV".**

PAS QCD-10-010: **"Measurement of the Underlying Event Activity at the LHC with √s = 7 TeV and Comparison with √s = 0.9 TeV".**

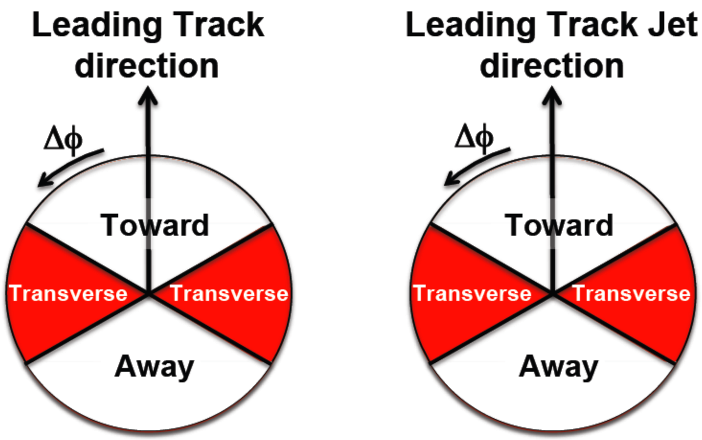
PAS QCD-10-005: **"Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 0.9 TeV".**

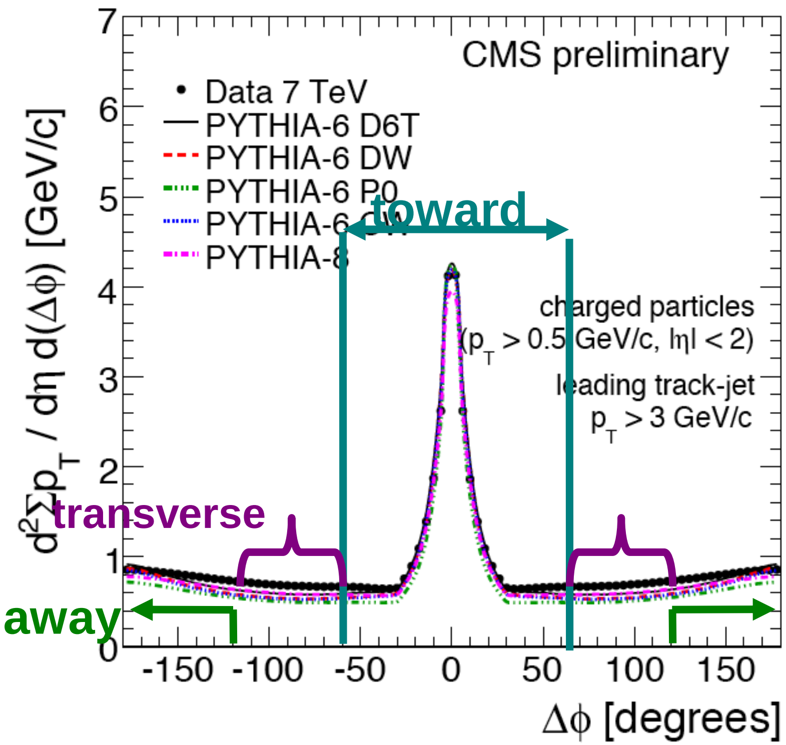
PAS FWD-10-002: **"Measurement of the energy flow at large pseudorapidity at the LHC at √s = 900, 2360 and 7000 GeV".**

PAS FWD-10-001: **"Observation of diffraction in proton-proton collisions at 900 and 2360 GeV centre-of-mass energies at the LHC".**

See also the poster contribution by A.Lucaroni
"Study of the underlying event with the CMS detector at the LHC"

Measuring the UE in pp at √s = 900 GeV and 7 TeV





UE Measurements among the foundation of the LHC Physics program: Isolation, vertices, etc. Also very interesting per se → MPIs, BBR.

[PAS QCD-10-001 and QCD-10-010]

The leading track or leading track-jet provide a scale and define a direction in the ϕ plane.

Observables built from **charged tracks**:

+ $d^2N_{ch}/d\eta d\phi$ multiplicity density

+ $d^2\Sigma pT/d\eta d\phi$, pT density.

The transverse region is expected to be particularly sensitive to the UE.

Unavoidable road to CMS MC Tuning.

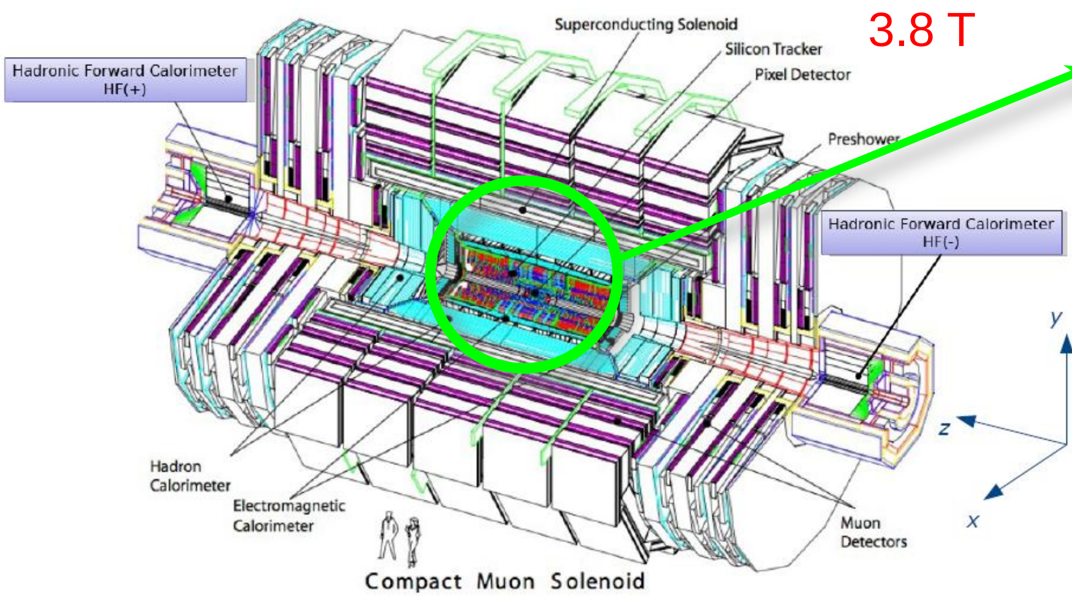
Part of a much more ambitious program to study Multiple Parton Interactions at the LHC.

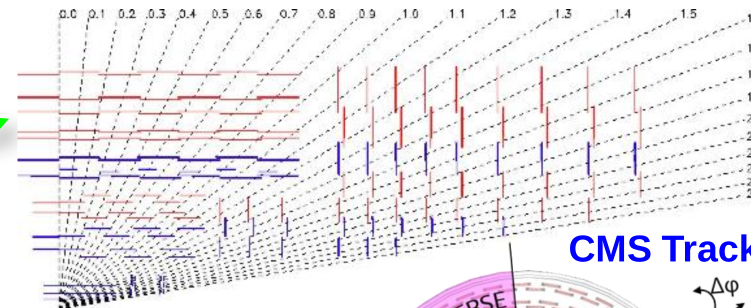
TRADITIONAL UE DISTRIBUTIONS & BRAND NEW ONES!

However UNCORRECTED for detector effects

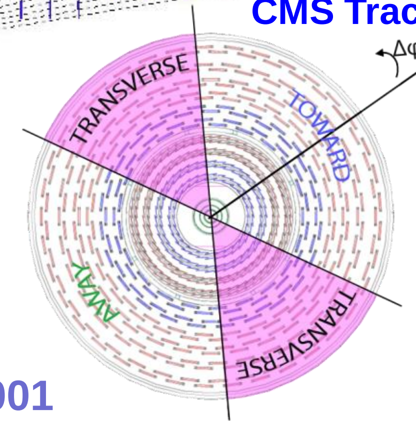
SUMMARY PAPER WITH CORRECTIONS VERY SOON!

CMS Detector





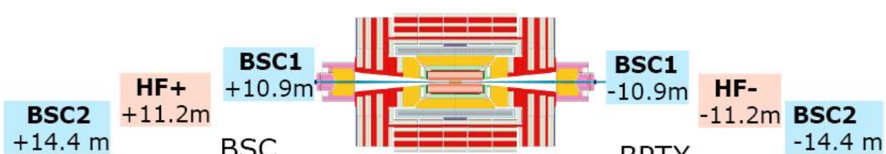
CMS Tracker



p_T resolution @ 1 GeV/c is: 0.7% at $\eta = 0$ *and* *2% at $|\eta| = 2.5$*

PAS TRK-10-001

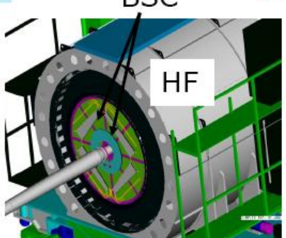
Trigger System

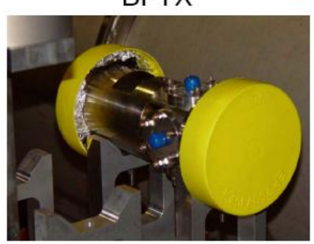


- Beam Scintillator Counters
- located at ± 10.86 m from IP (± 14.4 m for BSC2)
- designed to provide hit and coincidence rates

96.3% efficiency for MIPs and time resolution of 3 ns

BPTX
+175m





BPTX
-175m

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

time resolution better than 0.2 ns

Event and Track Selections (900 GeV)

- Trigger: coincidence of both ***Beam Pick-up Timing for eXperiments*** **(BPTX) and** ***Beam Scintillator Counters*** **(BSC)**
- **Good primary vertex**
- **Presence of leading object**

Event selection	Data [nb. events]	Data [%]	MC [%]
triggered	255 122	100	100
+ 1 primary vertex	239 038	93.7	92.9
+ 15 cm vertex z window	238 977	93.7	92.8
+ at least 3 tracks associated	230 611	90.4	88.7
leading track, $p_T > 0.5\,\mathrm{GeV}/c$	216 215	93.8	93.2
$p_T > 1.0\,\mathrm{GeV}/c$	131 421	60.8	55.0
$p_T > 2.0\,\mathrm{GeV}/c$	28 210	21.5	19.5
leading track-jet, $p_T > 1.0\,\mathrm{GeV}/c$	155 005	67.2	62.9
$p_T > 3.0\,\mathrm{GeV}/c$	24 928	16.1	15.9

ZeroBias events used for cross-checking efficiencies in data and MC

Good agreement in DATA VS MC comparison

- **Kinematic region for tracker acceptance and good tracking performances**
- **Association of tracks to primary vertex**
- **Additional quality cut**

Track selection	Data [nb. tracks]	Data [%]	MC [%]
reconstruction algorithm	4 004 923	100	100
+ $p_T > 0.5\,\mathrm{GeV}/c$	1 707 998	42.6	44.0
+ $\lvert\eta\rvert < 2.5$	1 689 910	98.9	98.7
+ $\lvert\eta\rvert < 2$	1 399 344	82.8	81.5
+ $d_{xy}/\sigma(d_{xy}) < 5$	1 235 193	88.3	88.8
+ $d_z/\sigma(d_z) < 5$	1 204 979	97.6	97.9
+ $\sigma(p_T)/p_T < 5\%$	1 168 530	97.0	96.9
Total	1 168 530	29.2	29.8

Final efficiency ~ 90%, fake rates ~ 2% at central rapidity (from Simulation)

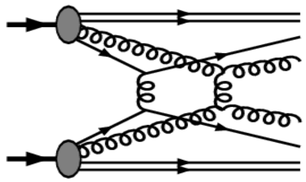
pQCD Models

ISR, FSR, SPECTATORS…
Not enough to account for the observed multiplicities & P_T spectra

→

The Pythia solution:
[T. Sjöstrand et al. PRD 36 (1987) 2019]
Multiple Parton Interactions (MPI)
(now available in other general purpose MCs: Herwig/Jimmy, Sherpa, etc.)

Inspired by observations of double high P_T scatterings



Main Parameter: P_T cut-off P_{T0}

$$\sigma(\widehat{P}_T) \rightarrow \sigma(\widehat{P}_T) \cdot \frac{(\widehat{P}_T)^4}{((\widehat{P}_{T0})^2 + (\widehat{P}_T)^2)^2}$$

(dampening)

- ✓ **Cross Section Regularization for $P_T \rightarrow 0$.**
- ✓ **P_{T0} can be interpreted as inverse of effective colour screening length.**
- ✓ **Controls the number of interactions hence the Multiplicity:** $\langle N_{int} \rangle = \sigma_{parton\text{-}parton} / \sigma_{proton\text{-}proton}$

Tuning for the LHC: Emphasis on the Energy-dependence of the parameters.

- **"post Hera" PDFs have increased color screening at low x ?**

  $x\,g(x,Q^2) \rightarrow x^{-\varepsilon/2}$ *for* $x \rightarrow 0$

$$P_{T0}^{s'} = P_{T0}^{s} \left(\sqrt{s'} / \sqrt{s}\right)^{\varepsilon}$$

Pythia tunes/versions in CMS

- Virtuality ordered showers, old MPIs
  - Pythia 6 Tunes **DW(T)**, **D6(T)**, **CW** (R.Field, CDF, CMS UE team). **[arXiv:1003.4220].**
  - **Pro-Q20** (Professor, automated, LEP fragmentation). **[arXiv:0907.2973].**
  - Describe UE@Tevatron, Describe other very important observables at Tevatron like pT(heavy bosons) and Jet azimuthal decorrelation.
- New MPIs with interleaved pT-ordered showers.
  - **Perugia-0** (consider Professor tunes), referred to as **P0.** **[arXiv:0905.3418].**
  - **Pythia 8** (different model! only one tune along the lines of **P0**).

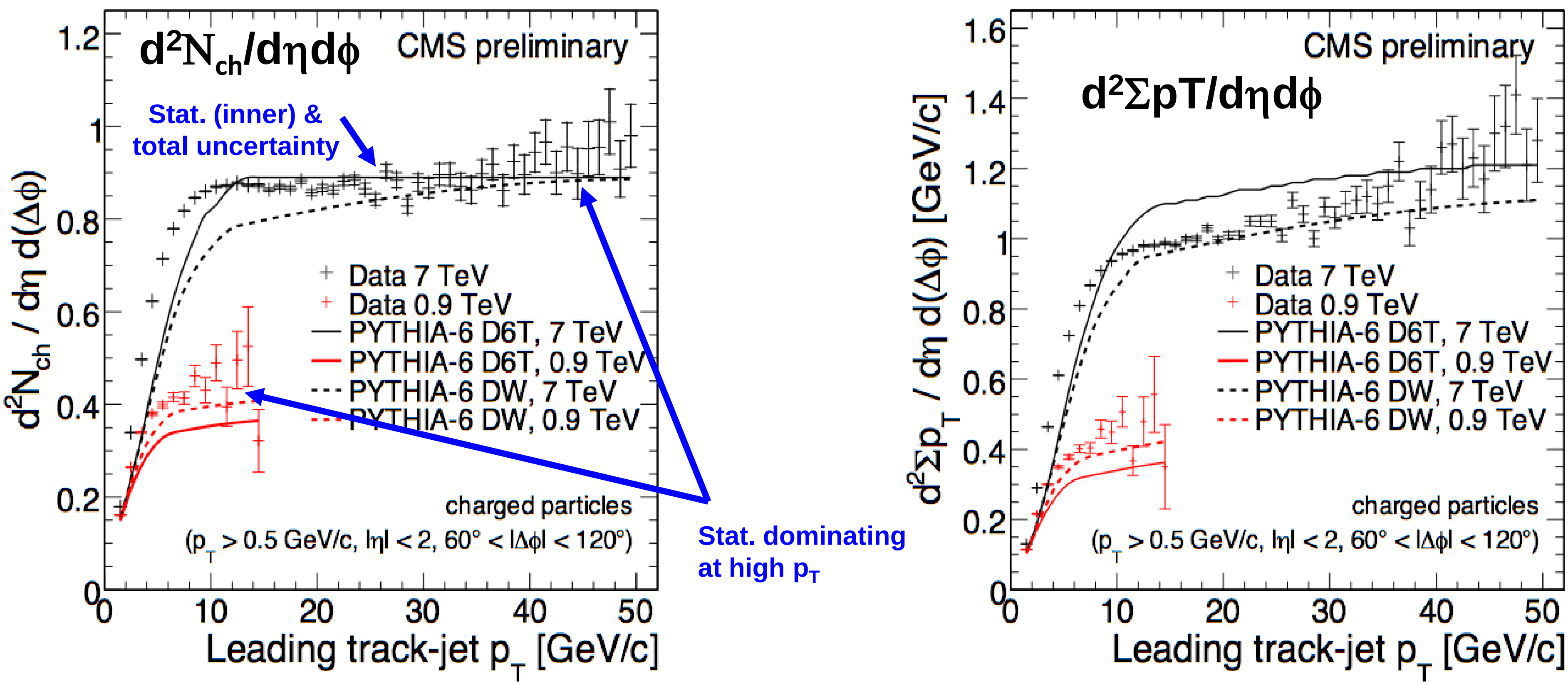
$$P_{T0}^{LHC} = P_{T0}^{Tevatron} (\sqrt{s}^{LHC} / \sqrt{s}^{Tevatron})^{\varepsilon}$$

where ε = PARP(90)

DWT, D6T	→ $\varepsilon = 0.16$	**Evolution of MB multiplicity@SPS [CERN 2000-004 pg. 293].**
DW, D6, Pro-Q20, P0, Pythia 8	→ $\varepsilon \approx 0.25$	**Consider 630 GeV and 1.8 TeV CDF UE data, compatible with UE@RHIC, UE@CMS (900 GeV).**
CW	→ $\varepsilon = 0.3$	**Ad hoc for CMS studies, maximize the UE activity at 900 GeV still compatible with CDF & RHIC.**

Densities in the Transverse Region

7 TeV and 900 GeV results for the reference charged multiplicity density and ΣpT density profiles including both D6T and DW predictions.

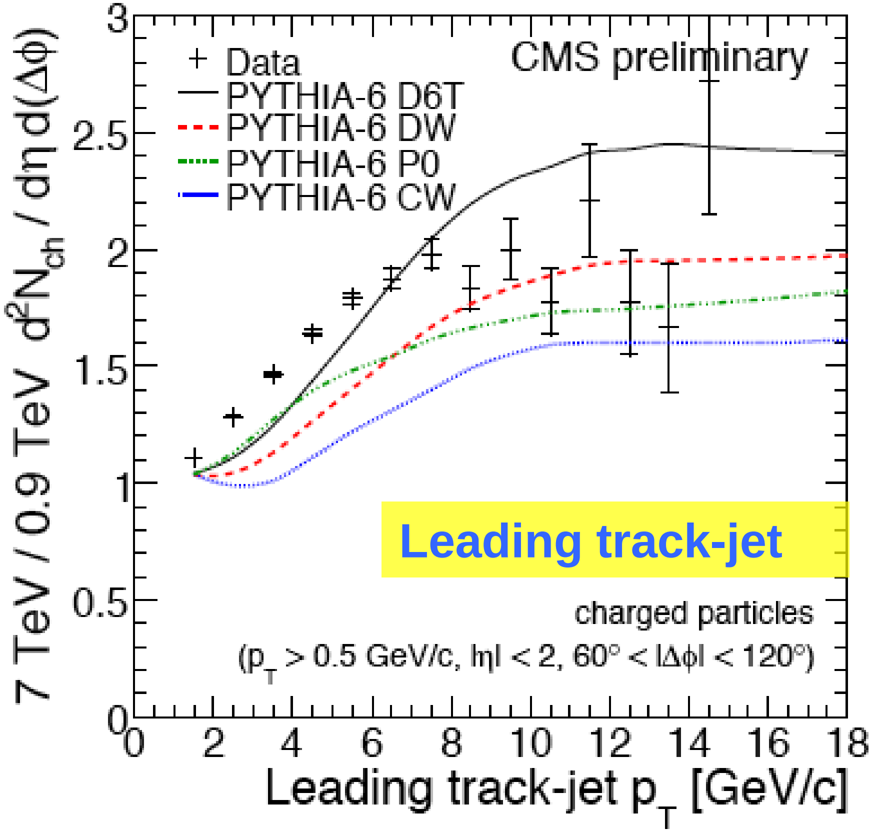


Fast rise for pT < 8 GeV/c (4 GeV/c), attributed mainly to the **increase of MPI activity**, followed by a **Plateau-like region** with ≈ constant average number of selected particles and a slow increase of ΣpT, in a **saturation regime**.

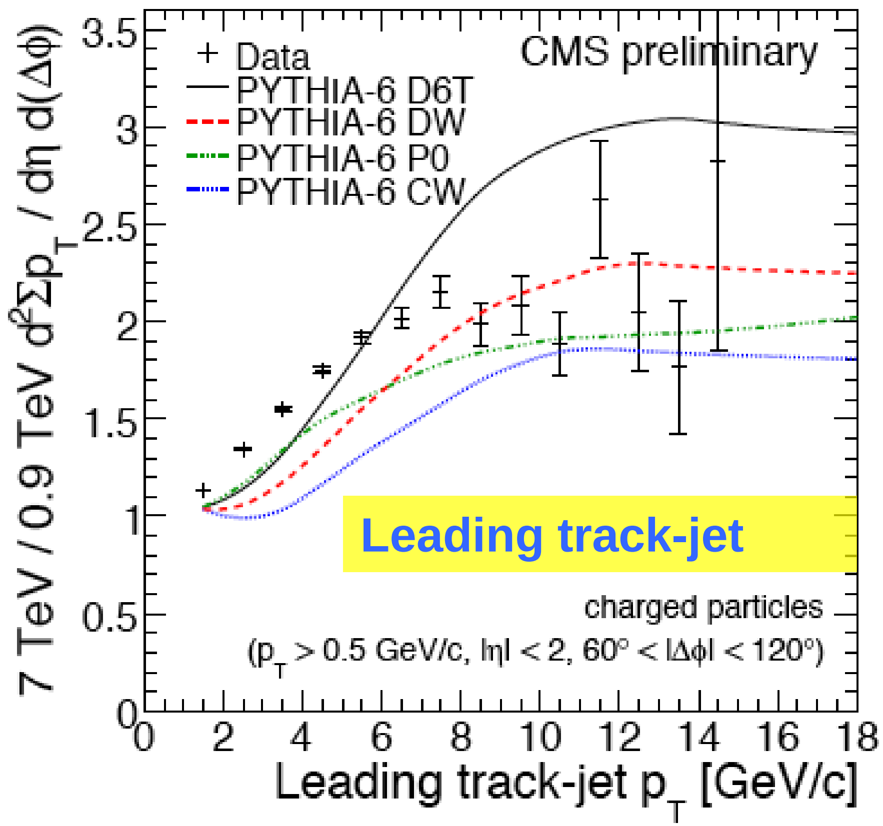
Increase of the activity with √s also corroborates MPIs (growth with PDFs).

Comparison between 7 TeV and 900 GeV

$d^2N/d\eta d\phi$ vs pT (7 TeV) / $d^2N_{ch}/d\eta d\phi$ vs pT (900 GeV)



$d^2\Sigma pT/d\eta d\phi$ vs pT (7 TeV) / $d^2\Sigma pT/d\eta d\phi$ vs pT (900 GeV)

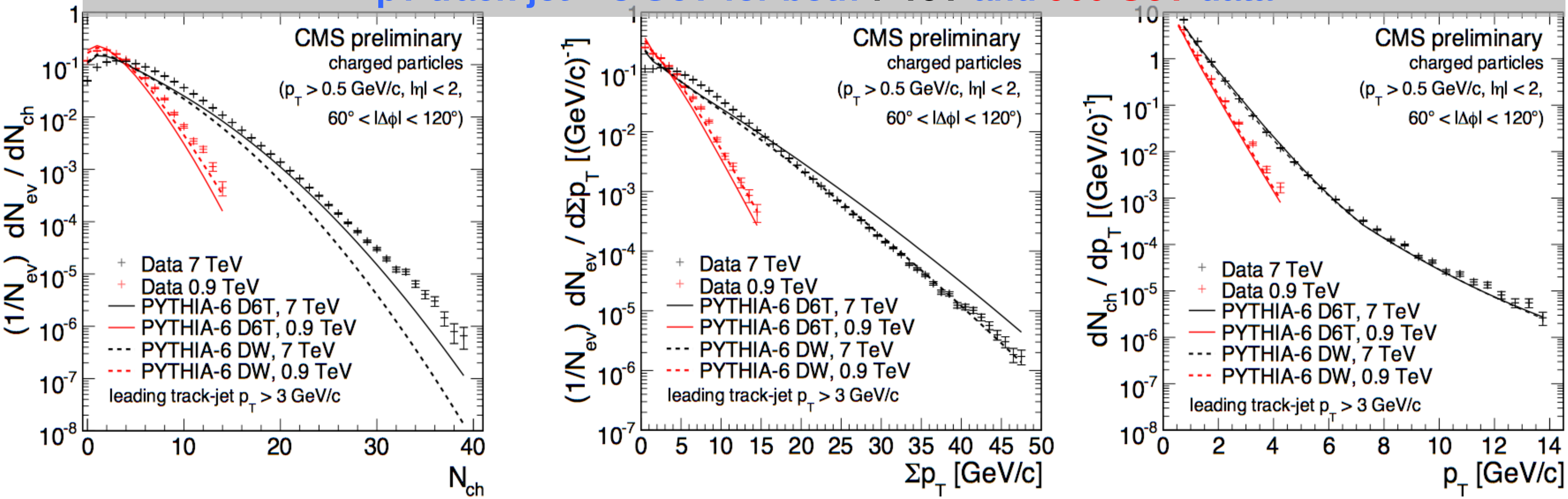


Poor description of the rise. **P0** has the worst shape. **CW** underestimates the plateau regions. **D6T**, with slower energy dependency of the p_T cut-off, overestimates the plateau regions.

N_{ch}, Σ(pT) and pT in the Transverse Region

7 TeV and **900 GeV** results for the reference distributions in the Transverse region including both D6T and DW predictions.

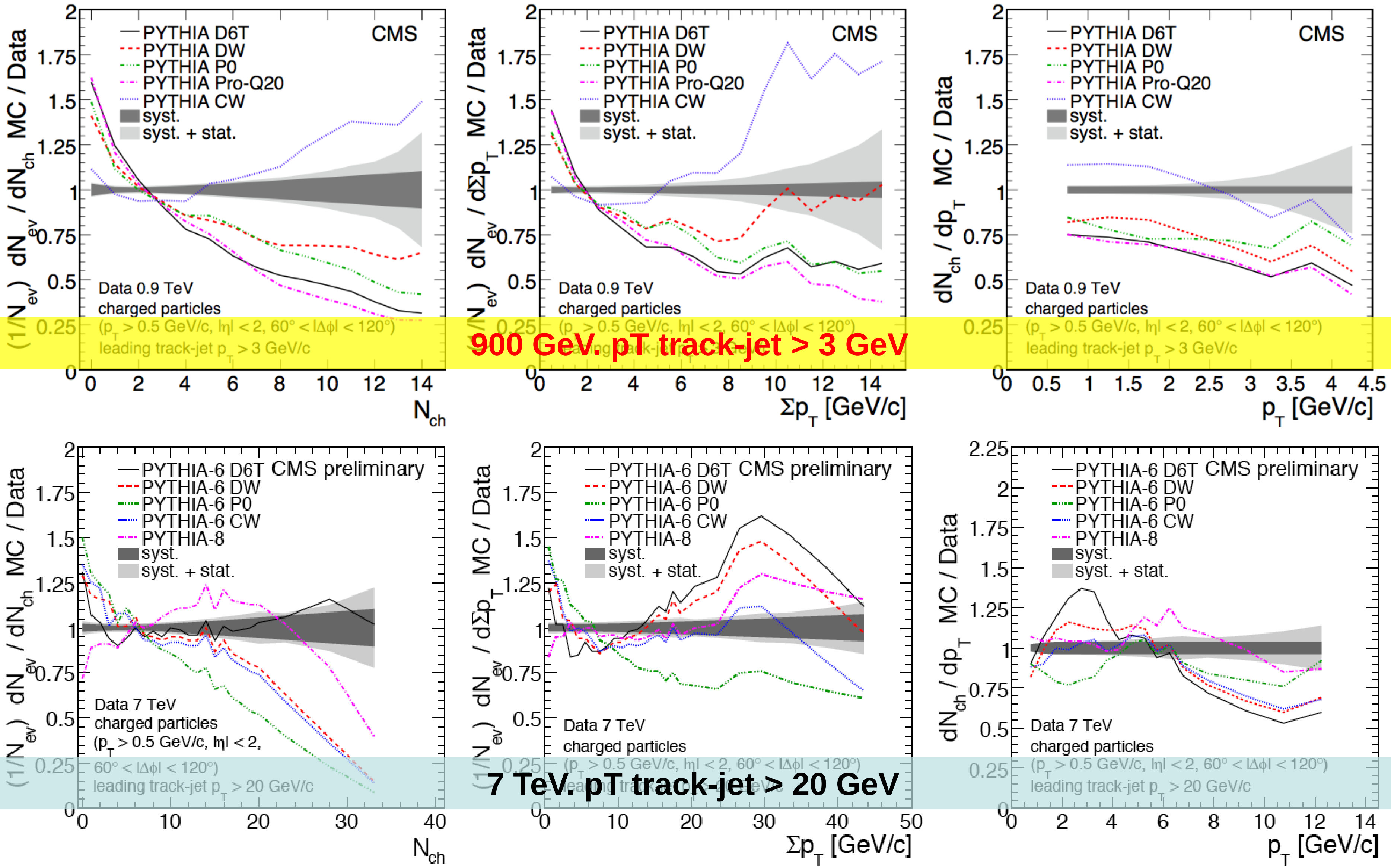
pT track-jet > 3 GeV for both 7 TeV and 900 GeV data



The three distributions, which extend up to quite large values of the selected observables in the transverse region, **are quite well described overall by the various MC models, over several orders of magnitude!**

At **7 TeV** the charged particle spectrum extends up to pT >10 GeV/c
→ Hard component in particle production in the transverse region.

N_{ch}, Σ(pT) and pT in the Transverse Region



A new approach to UE: Jet Area/Median

- Based on the paper: "On the characterisation of the underlying event"; JHEP04(2010)065; M. Cacciari, G. Salam, S. Sapeta.
- CMS: Track jets using kT jet algorithm with R=0.6 (infrared safe).
  - Preliminary results from 900 GeV data. Similar event, track selection and systematic uncertainty estimation as traditional UE method (see next slide).
- The underlying event activity is given by ρ=median{pT/A}.
  - The median is less sensitive to outliers, i.e. hard jets.
  - To estimate the jet area η–ϕ cells are filled by **ghost deposits** of O(10^{-100} GeV).
    - FastJet [arXiv:hep-ph/0512210] essential to speed up the calculation.
    - 900 GeV: **ghost jets** dominate the median!!!

→ Adjusted observable for low occupancy events:

$$\rho' = \underset{j \in physical\ jets}{median} \left[\left\{ \frac{p_{T,j}}{A_j} \right\} \right] * C$$

$$C = \frac{\Sigma_j A_j}{A_{tot}}$$

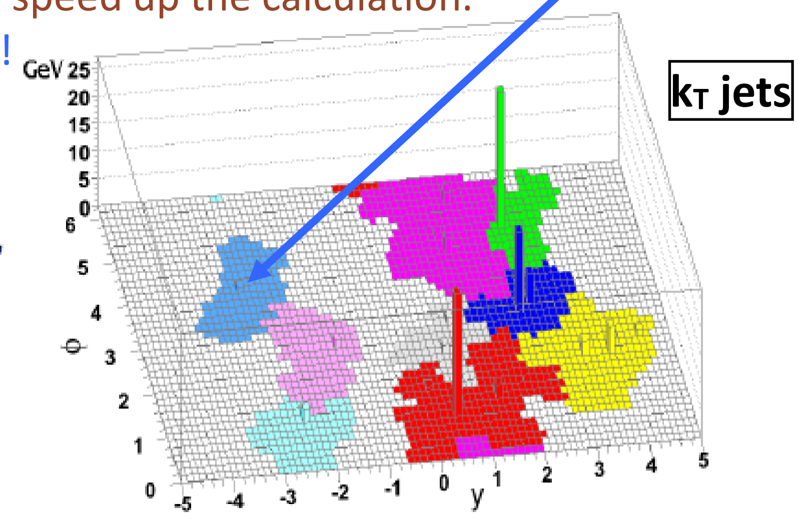
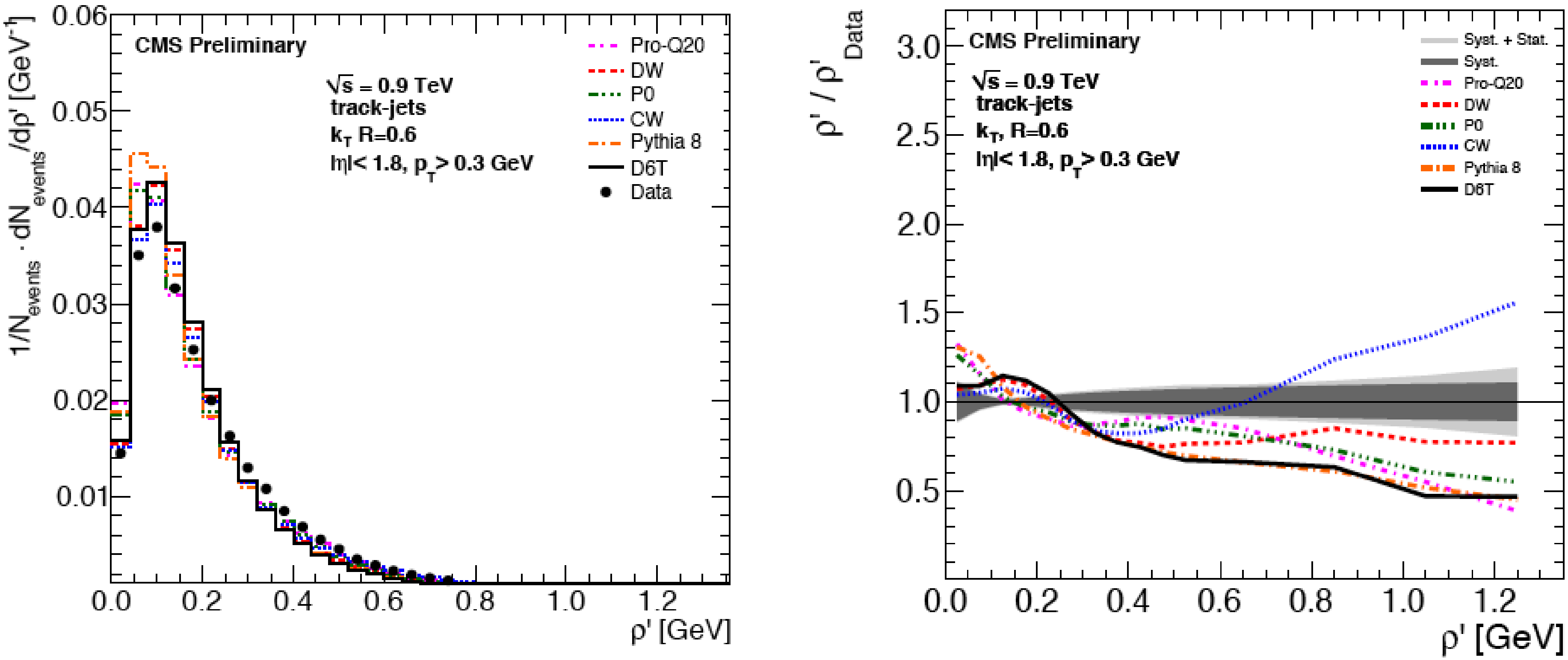


Figure 4: Active area for the same event as in figure 3, once again clustered with the k_t algorithm and $R = 1$. Only the areas of the hard jets have been shaded — the pure 'ghost' jets are not shown.

UE: Jet Area/Median (ρ□)



Event & Track Selection identical to the traditional UE measurement at 900 GeV, only differences →

pT track > 0.3 GeV instead of 0.5 GeV
|η| track < 2.3 instead of 2.5
|η| track-jet < 1.8 instead of 2.0

Clear sensitivity to the differences between the Models / Tunes

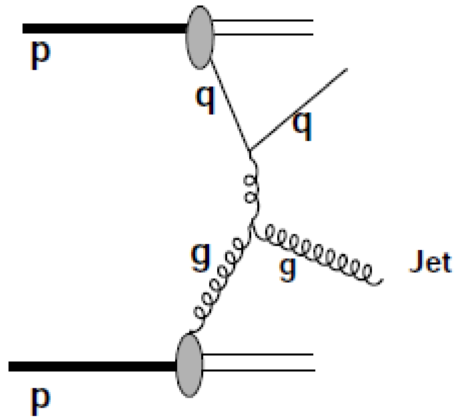
UE Bottom line

- **First Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 0.9 TeV and Extension to 7 TeV.**
  - **Exploits the performances of the CMS Tracker.**
  - **Increase of the activities with the scale of the interactions and with $\sqrt{s}$ corroborates MPIs.**
  - **Detailed study of distributions in the transverse region.**
  - **Challenging test of MC models in particular for what concerns the energy dependent parameters.**
    - **Higher values of ε ($\approx$ 0.25) favored by the data.**

- **First measurement of the UE with Jet Area/Median approach**
  - **Small adjustments (ρ to ρ') had to be made in order to account for the low particle multiplicity in 0.9 TeV MinBias events.**
  - **Complementary approach to evaluate the UE activity, very robust and flexible against different topologies, additional observables for MC tuning.**

Forward Jets: Motivation

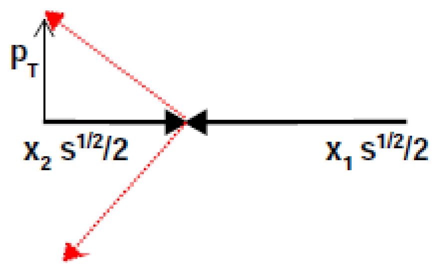
- CMS, with its large calorimetric coverage ($|\eta|<5.2$) can provide first measurements on forward jet production which was never investigated before.



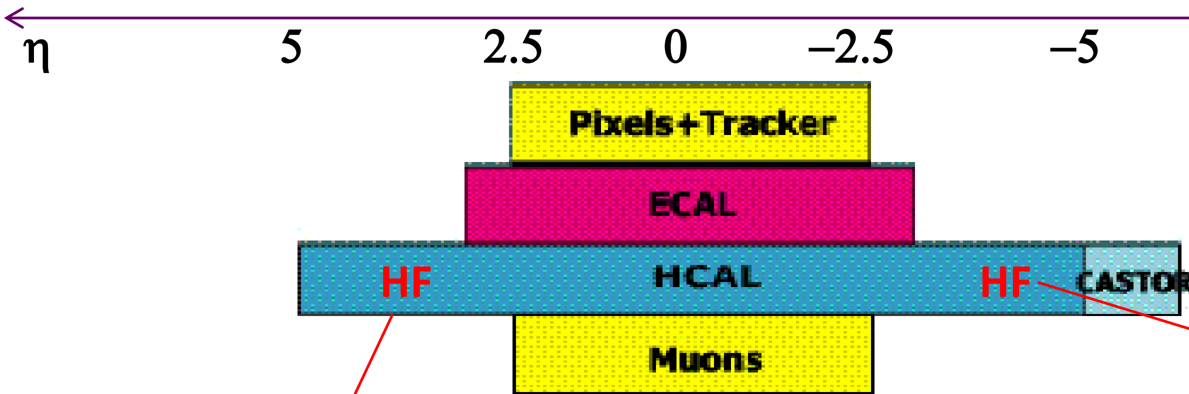
- Longer term prospects:
  - Forward jets probe the low-x domain; in 2→2 process

$$x_2^{min} \approx \frac{p_T}{\sqrt{s}} \cdot e^{-y} = x_T \cdot e^{-y}$$

  - Every 2 units of y: x_2^{min} decreases by ≈ 10.



- First step:
  - validate jet reconstruction in the forward region.

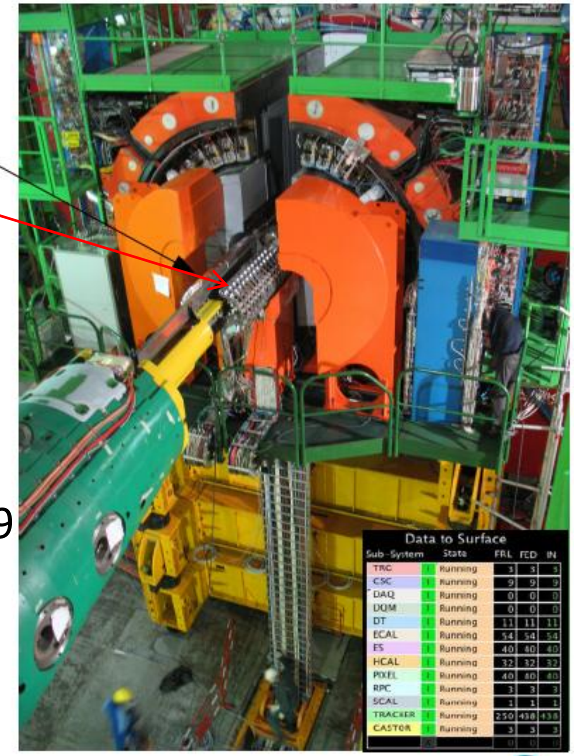


Hadron Forward:

- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers/ quartz fibers (Long +short fibers)
- 0.175x0.175 η/φ segmentation

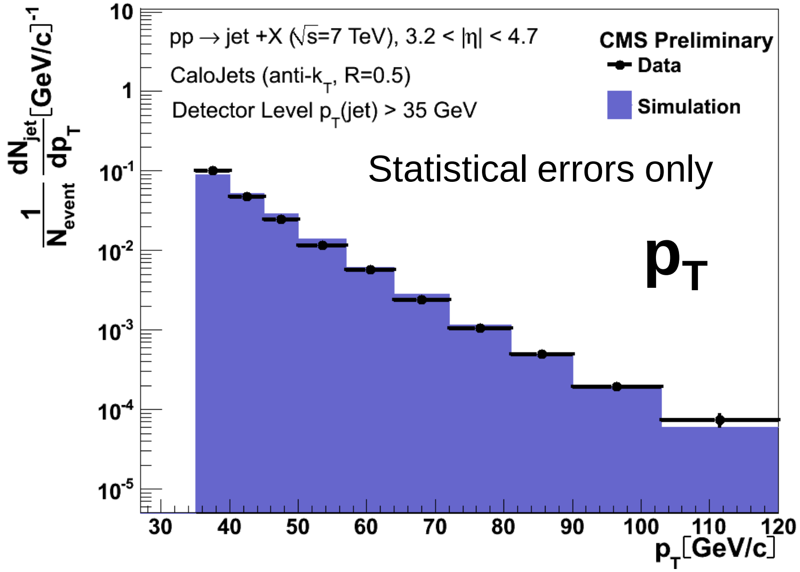
First CASTOR unit installed on collar table of HF platform (-z side) in June 2009

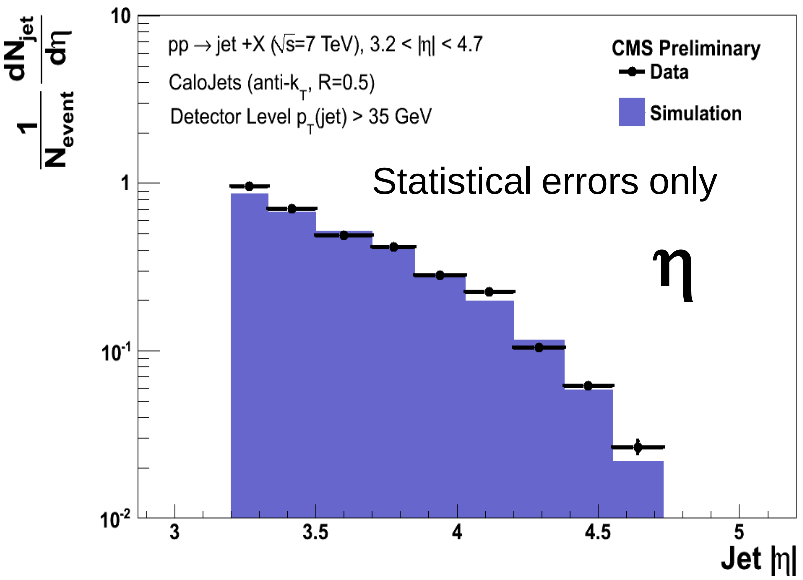
Fully functional and integrated into CMS operations



Rapidity coverage: $5.2 < |\eta| < 6.6$

Forward Jet p_T and η spectrum





Here 7 TeV data considered. $L \approx 10\ nb^{-1}$.

Jets reconstructed in HF only: $3.2 < \eta < 4.7$.

$p_T > 35$ GeV.

Distributions not corrected.

Reasonable data vs MC agreement.

Expected resolutions:

$\sigma(p_T)/p_T \approx 12\%$ @ 100 GeV.

$\sigma(R)/R \approx 0.035$ @ 100 GeV, $R = \sqrt{(\Delta\phi^2+\Delta\eta^2)}$.

Energy flow in the forward region

- Measurement relies on the energy flow in the Hadron Forward Calorimeter ($3 < \eta < 5$) in the presence of events "triggered" by a more central activity (Minimum Bias, di-Jets)

→Test of central-forward correlations

- Detector level no corrections to the hadron level applied
  - Distributions studied:

$$E_{FLOW}(dijet) = \frac{1}{N_{dijet}} \frac{\Delta E}{\Delta \eta}(dijet)$$

$$E_{FLOW}(minbias) = \frac{1}{N_{minbias}} \frac{\Delta E}{\Delta \eta}(minbias)$$

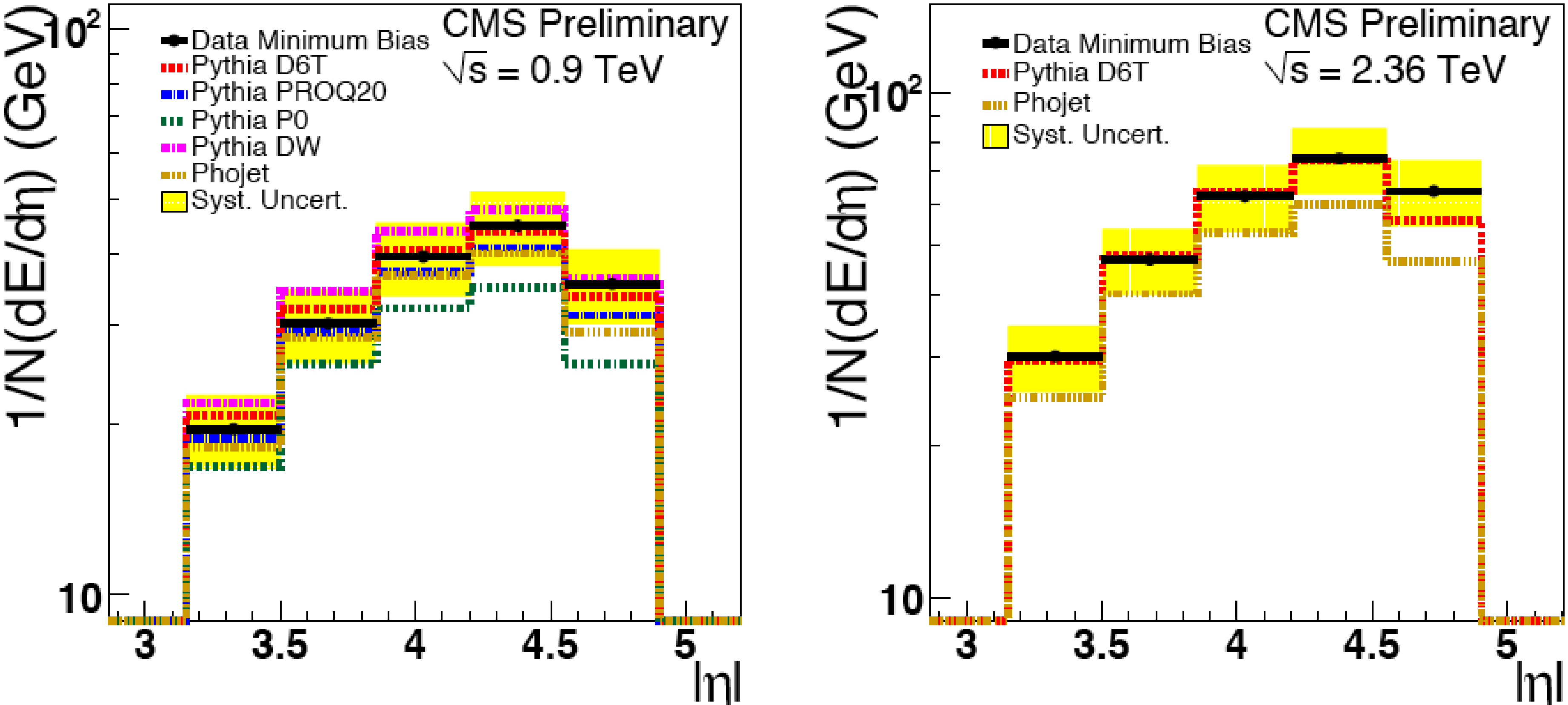
- Three different cms energies included: 900 GeV, 2360 GeV, 7000 GeV
- Definition of di-Jet samples:
  - p_T Calo Jet > 8 GeV at 900 and 2360 GeV
  - p_T Calo Jet >20 GeV at 7 TeV

(Definition of Minimum Bias samples along the lines of the other analyses)

Energy flow in the forward region

Energy flow in the **Minimum Bias** sample at 0.9 and 2.36 TeV:

Systematic uncertainty dominated by the energy scale (applies to all the distributions)

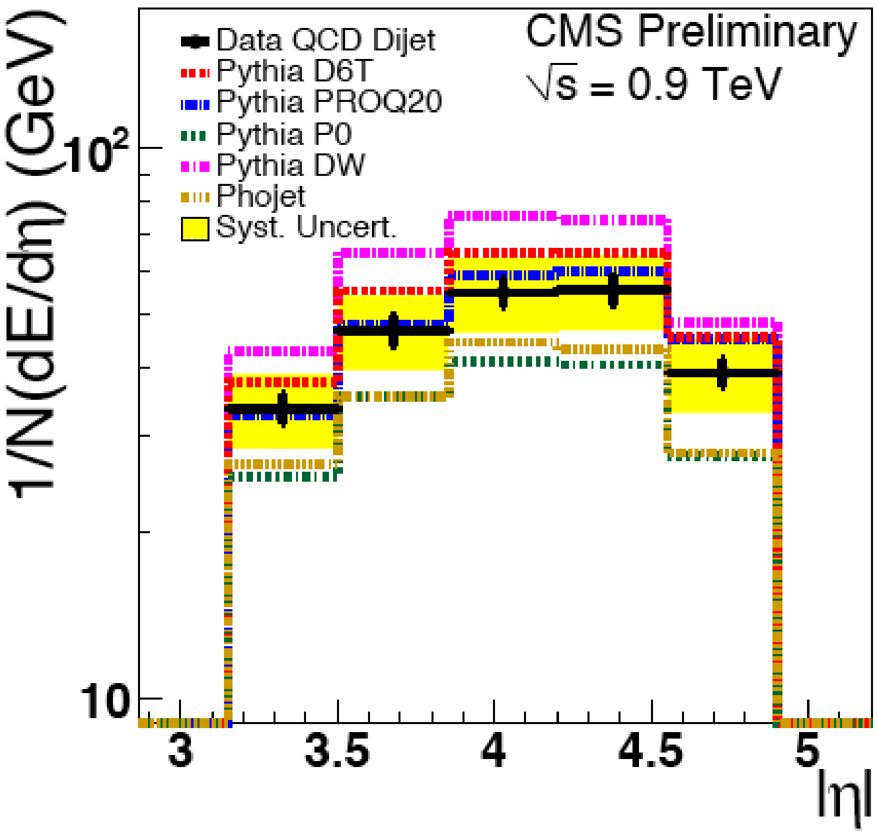


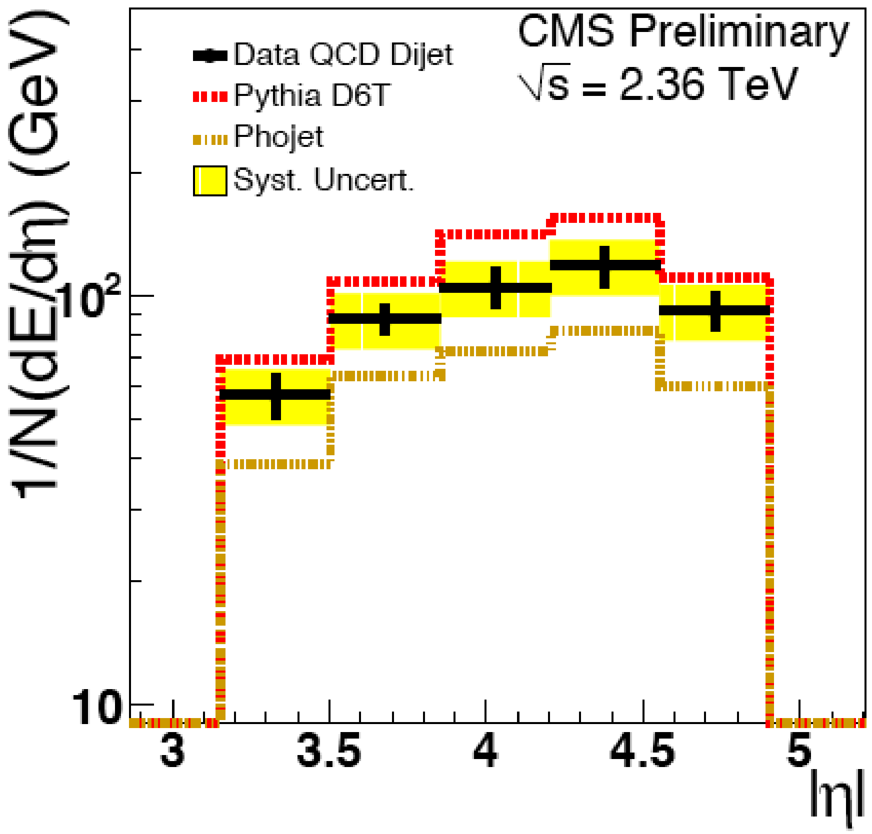
The increase of the fwd e-flow with the c.m.s. energy is well reproduced by the simulations.

At 900 GeV and 2.36 TeV the energy flow in minimum bias events is described by the D6T tune while PHOJET is lower than the data. PROQ20 and P0, tested at 900 GeV, are also too low.

Energy flow in the forward region

Energy flow in the **di-jet** sample at 900 GeV and 2.36 TeV:

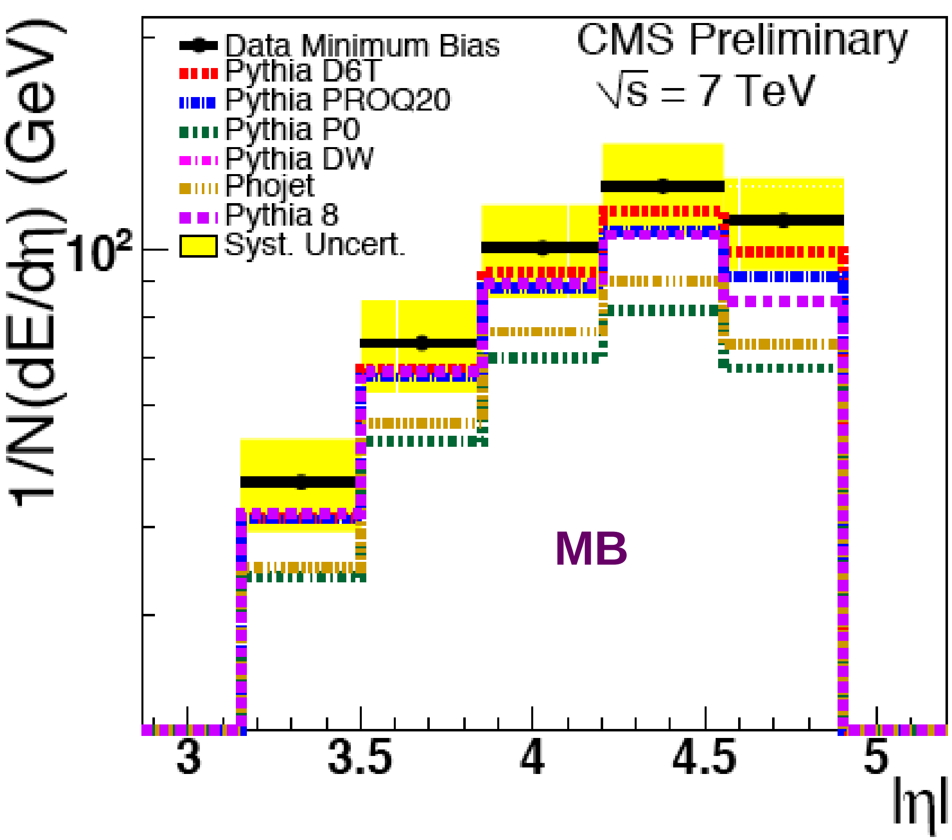


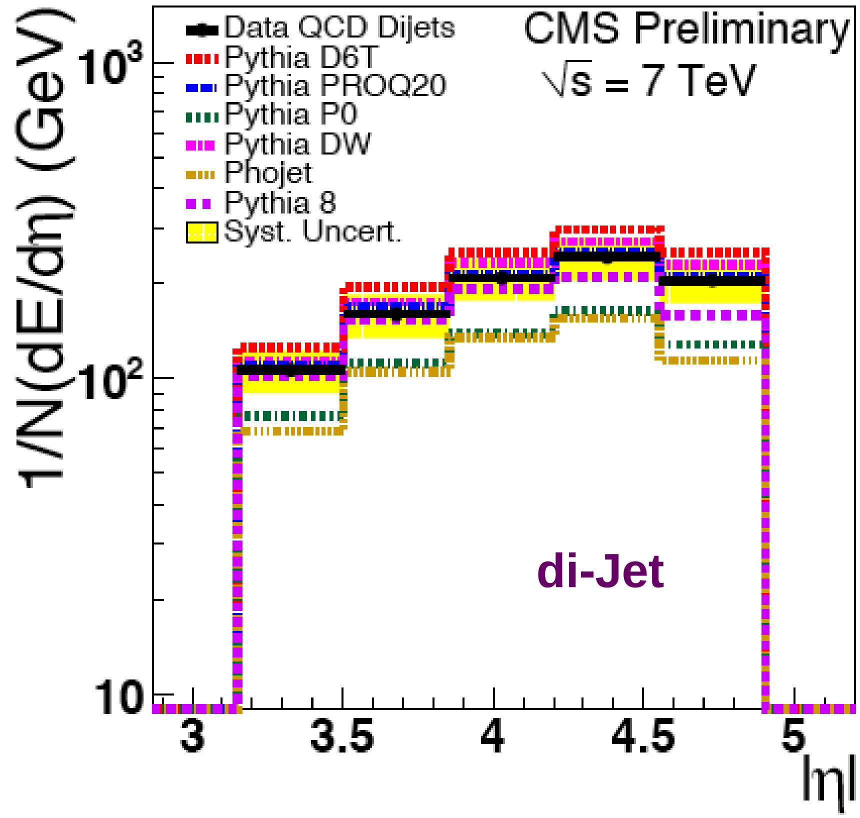


The increase of the fwd energy flow with increasing energy scale is qualitatively reproduced by the simulations. … but now the D6T tune predicts too high energy flow while PHOJET is below the data. 900 GeV: PROQ20 provides the best description while P0 is still too low.

Energy flow in the forward region

Energy flow in the **MB** and **di-jet** samples at 7 TeV:





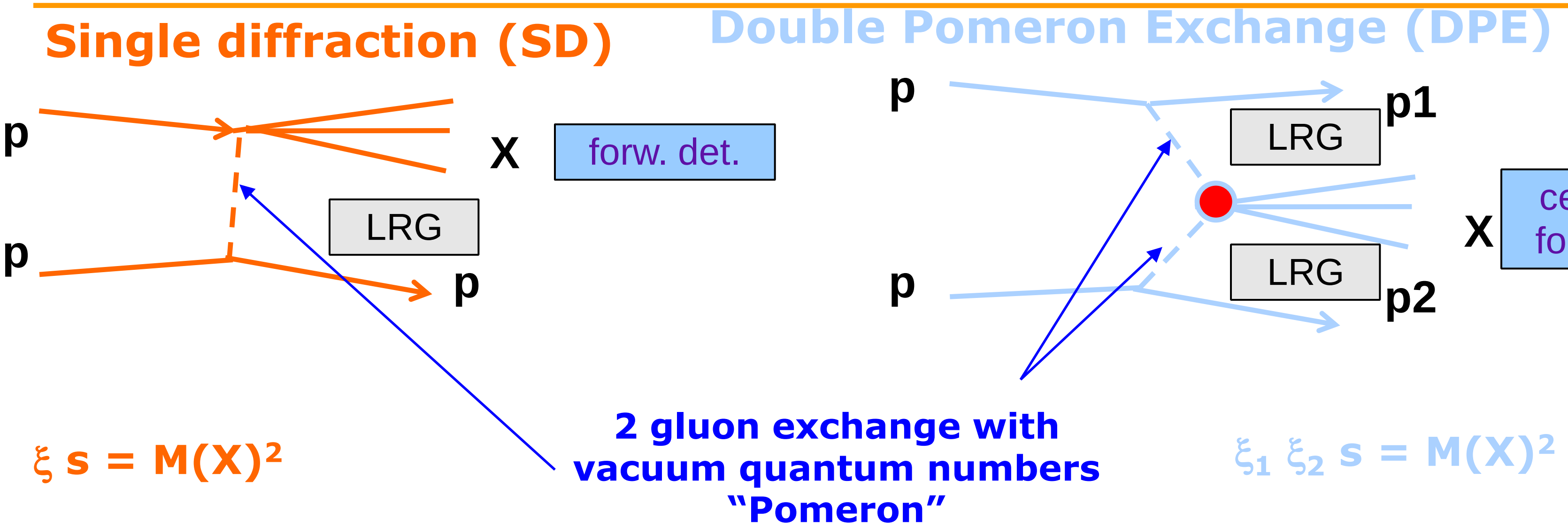
- **MB: the predicted fwd energy flow is below the data for all the tunes.**
- **Di-jet: PROQ20 confirmed as the best tested tune, the PYTHIA8 model is also fine. The D6T tune lays above the data. P0 and PHOJET turn out to be too low.**

Forward jets and energy flow: Bottom Line

- **Reconstruction of Forward Jets in HF well assessed.**
  - **Calo Jets up to $|\eta| \approx 5$.**

- **Measurement of the Forward energy flow provides complementary information with respect to the traditional measurements relying just on the central activity.**
  - **Forward central correlations well described by MPI models.**
  - **Conclusions on the preferred MC tunes differ with respect to the conclusions drawn in the CMS UE studies.**

Diffraction at the LHC



✓ Diffractives ~ 1/3 of the inelastic cross section at the LHC

(Processes can be hard or soft, scale given by X)

✓ Measure fundamental quantities of QCD: SD and DPE inclusive cross sections, their s, t, M_X dependences, with X including jets, W's, Z's, Higgs, …

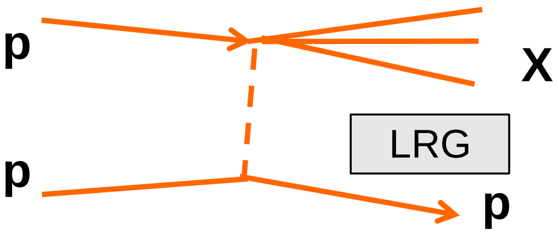
✓ Info on proton structure (dPDFs and GPDs), discovery physics, MPI, …

✓ **No measurement of the proton for the time being, rely on Large Rapidity Gaps**

✓ **Going step by step, first of all let's observe diffraction! Starting with SD**

SD Observation at the LHC: Strategy

Single diffraction (SD)



$\xi = M_X^2 / s$

$\sigma \approx 1/\xi$

$\Delta y \approx -\ln \xi$

$\xi \approx \Sigma_i (E_i \pm p_{z,i})$

Along the lines of a 35y old ISR paper

[Phys.Rep.55, No. 1(1979)1-132]

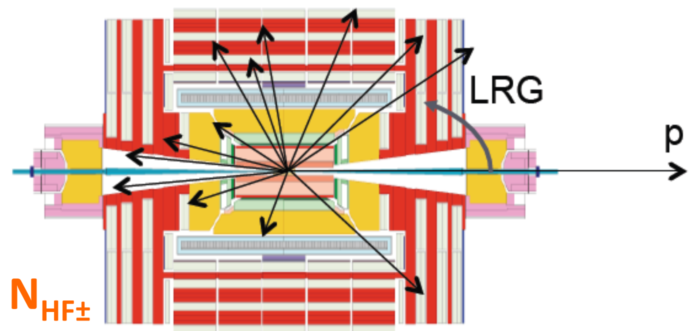
LOOK FOR A SD PEAK @ low $\xi = \Sigma_i (E_i \pm p_{z,i})$

Hadron Forward:

- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers/ quartz fibers (Long +short fibers)
- 0.175x0.175 η/φ segmentation

Sum runs over all the Calo Towers:

$p_{z,I} = E_i \cos \vartheta_i$



CONFIRM SD PEAK @ low $E_{HF\pm}$, $N_{HF\pm}$

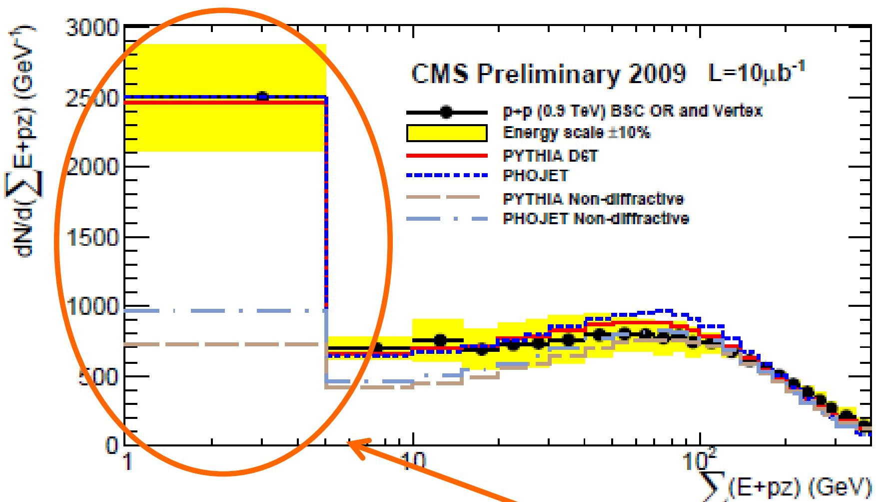
$E_{HF\pm}$ = energy deposition in HF±

$N_{HF\pm}$ = multiplicity of towers above threshold in HF±

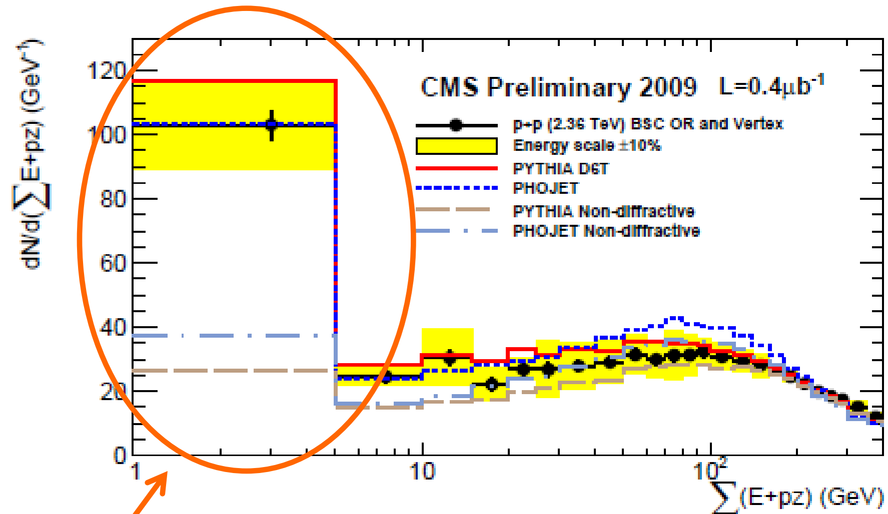
SD Observation at the LHC: Results

Uncorrected Distributions.

900 GeV



2360 GeV

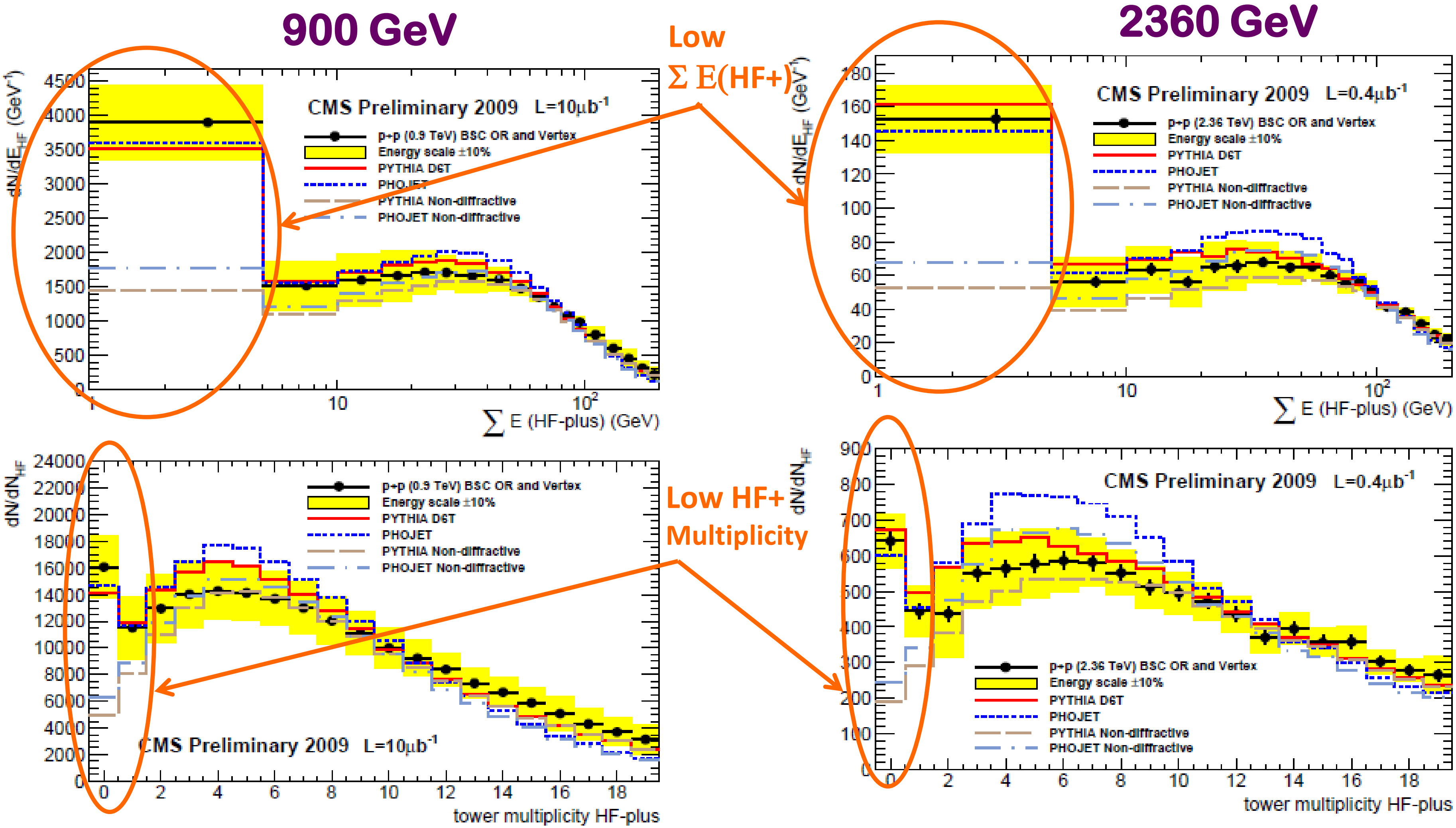


SD seen in Σ E+pz distribution due to cross section peaking at small values of ξ

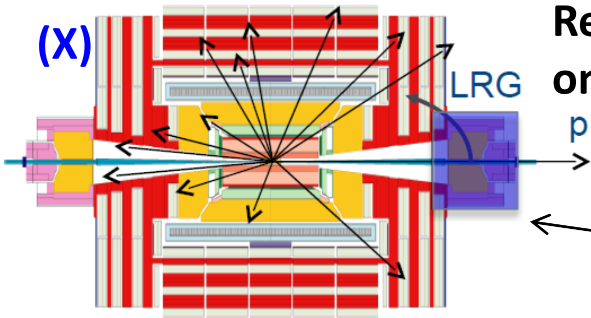
Systematic uncertainty dominated by energy scale

SD Observation at the LHC: Results

SD signature confirmed by the absence of forward hadronic activity (presence of a LRG)



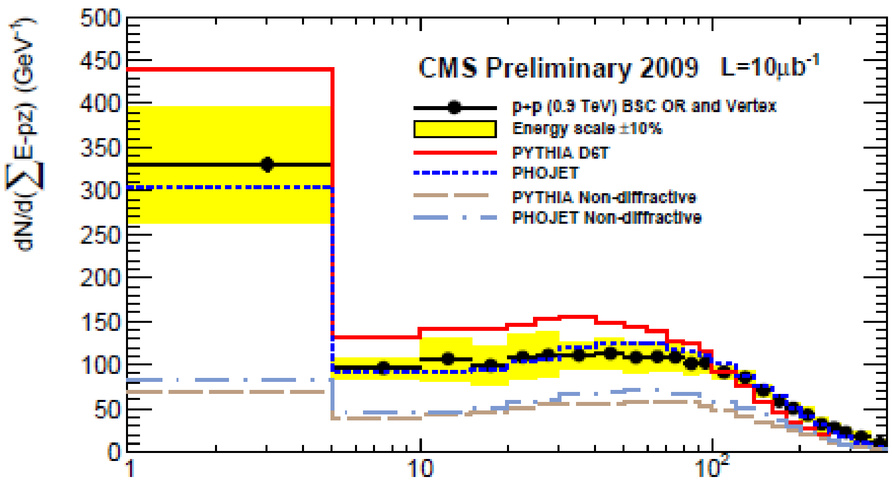
Enriched diffractive samples



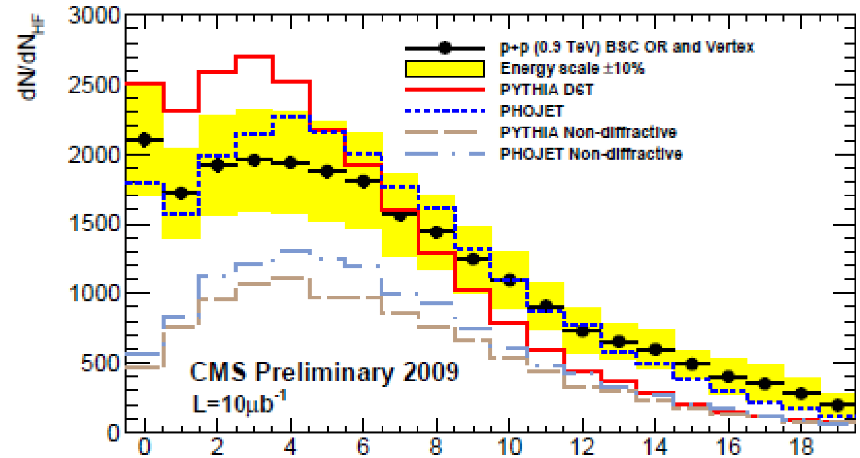
Requirement of low activity in one side of CMS

E(HF+) < 8 GeV

SD component of the data
LRG in z+ direction
Concentrating on the fragmenting object
(X) boosted in z- direction



$\xi = \Sigma_i (E_i \pm p_{z,i})$



HF- Multiplicity

- Uncorrected data shown and compared to PYTHIA D6T & PHOJET
- PHOJET gives a better description of the system with enhanced diffractive component

SD Observation. Bottom Line

- **First observation of SD events at LHC in pp collisions at 0.9 & 2.36 TeV**
  - **Peak at low ξ values and**
  - **Presence of a Large Rapidity Gap**

- **Comparison to the MC event generators**
  - **PYTHIA gives a better non-diffractive description**
  - **PHOJET describes the diffractive contribution better**
  - **No sensitivity to Pythia 6 Tunes**

Underlying Event Studies and Forward Physics at CMS

ICHEP 2010 – July 22-28, 2010 – Paris

PAS QCD-10-001 & CERN-PH-EP/2010-014, submitted to EPJC: **"First Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 0.9 TeV"**

PAS QCD-10-010: **"Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 7 TeV and Comparison with $\sqrt{s}$ = 0.9 TeV"**

PAS QCD-10-005: **"Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 0.9 TeV".**

PAS FWD-10-002: **"Measurement of the energy flow at large pseudorapidity at the LHC at $\sqrt{s}$ = 900, 2360 and 7000 GeV"**

PAS FWD-10-001: **"Observation of diffraction in proton-proton collisions at 900 and 2360 GeV centre-of-mass energies at the LHC"**

CREDITS: QCD and FWD colleagues, in particular:

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- BACKUP QCD-10-001

PYTHIA tunes

- Several PYTHIA tunes considered, differing in the description of parton fragmentation and multiple parton interaction.
- PYTHIA regularizes the $1/p_T^4$ divergence for final state parton $p_T \rightarrow 0$ using a cut-off parameter p_{T0}, used both for hard-scattering and MPI.
- The energy dependence of the cut-off is given by $p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0}) \cdot (\sqrt{s}/\sqrt{s_0})^{\varepsilon}$
- All considered tunes are compatible with Tevatron data.

Tune	p_{T0}(1.8TeV)	ε	notes/other features
D6T	1.8 GeV/c	0.16	Energy dependence from UA5 Minimum Bias data at SppS. Uses CTEQ6L.
DW	1.9 GeV/c	0.25	"Best fit" of Tevatron data: $p_T(Z)$ and di-jet $\Delta\phi$
Pro-Q20	1.9 GeV/c	0.22	Professor fit program using LEP data for fragmentation
P0	2 GeV/c	0.26	As above + new PYTHIA MPI model + pT-ordered shower
CW	1.8 GeV/c	0.3	Maximizes MPI at 900 GeV, still compatible with Tevatron

- BACKUP QCD-10-010

Event selection. UE 7 TeV

Table 1.

Table 1: Statistics and efficiencies of the vertex based event selection compared between data and Monte Carlo simulation. The different cuts are applied in sequence, the efficiencies are

Event selection	Data [nb. events]	Data [%]	MC [%]
triggered	28 475 724	100.00	100.00
+ 1 primary vertex	27 104 779	95.18	96.12
+ (±10 cm) vertex z window	27 045 773	99.78	99.95
+ vertex n.d.o.f. > 4	24 772 528	91.59	87.39
leading track jet, $\|\eta\| < 2$ and $p_T > 3.0\,\mathrm{GeV}/c$	9 103 746	36.75	28.35
leading track jet, $\|\eta\| < 2$ and $p_T > 20.0\,\mathrm{GeV}/c$	37 296	0.41	0.44

Only 1 real good vertex

Events used for "cumulative" distributions.
Lower threshold moved to 3.0 GeV to enable comparison w.r.t. 900 GeV UE Analysis (QCD-10-001)

Track selection. UE 7 TeV

PLENTY OF RESULTS SCRUTINIZED IN PAG/POG Meetings. See BACK-UP SLIDES

Table 2: Numbers of tracks in the selected event sample with a leading track-jet with $p_T > 3\,\mathrm{GeV}/c$, for successive track selection criteria, and corresponding fractions in the data and for the simulation based on PYTHIA with tune D6T. Each fraction is given with respect to the result of the previous selection cuts.

☆ Table 2.

Track selection	Data [nb. tracks]	Data [%]	MC [%]
reconstruction algorithm	491 228 197	100	100
$+\ p_T > 0.5\ \mathrm{GeV}/c$	256 716 859	52.26	60.01
$+\ \lvert\eta\rvert < 2.5$	254 290 734	99.05	98.94
$+\ \lvert\eta\rvert < 2$	212 357 949	83.51	82.83
$+\ d_{xy}/\sigma(d_{xy}) < 3$	181 128 780	85.29	85.72
$+\ d_z/\sigma(d_z) < 3$	175 700 636	97.00	97.67
$+\ \sigma(p_T)/p_T < 5\%$	170 834 393	97.23	96.96

{each efficiency computed w.r.t. previous surviving class}

highPurity algo → reconstruction algorithm

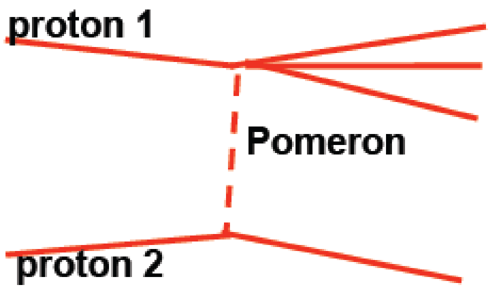
Analysis oriented → p_T and η cuts

primary tracks → d_{xy} and d_z cuts
- impact param. at real vtx
- vertex error propagated

Quality requirement → $\sigma(p_T)/p_T$ cut

- BACKUP FWD-10-001

Meaning of (E ± pz)



X

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)

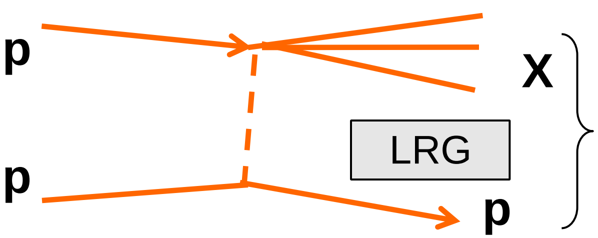
Recall: in SD events proton loses almost none of its initial momentum.

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

Single diffraction (SD)

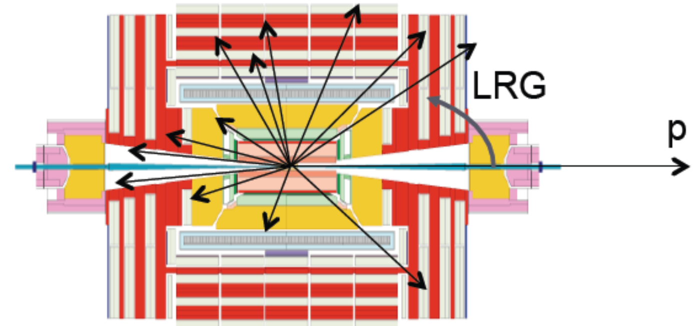


$\xi = M_X^2 / s$

$s \approx 1/\xi$

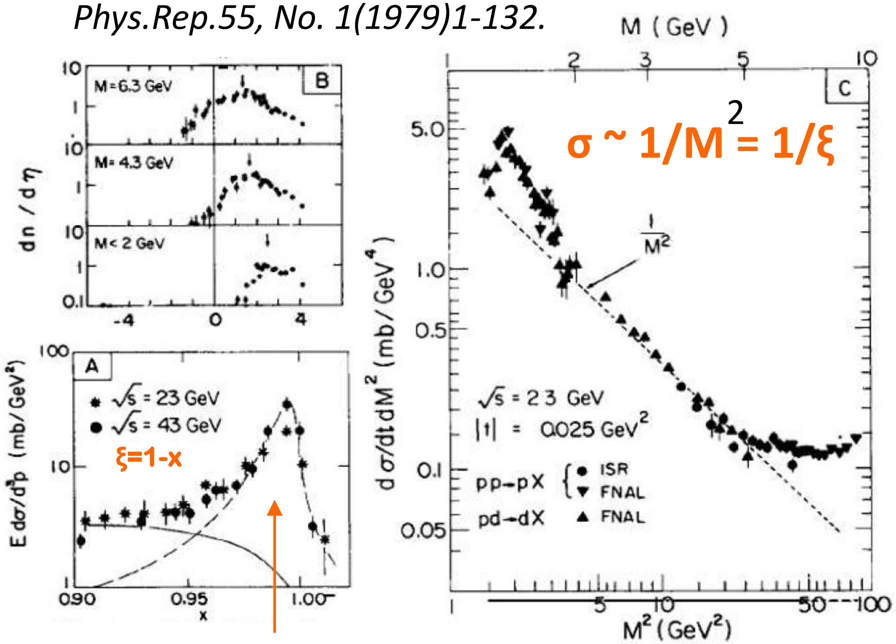
$\Delta y \approx -\ln \xi$

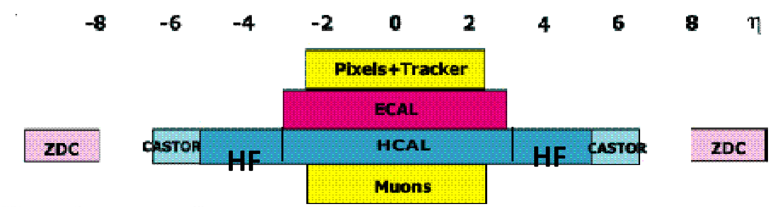
$\xi \approx \Sigma_i (E_i \pm p_{z,i})$



Along the lines of 35y old ISR paper

Phys.Rep.55, No. 1(1979)1-132.





Hadron Forward:

- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers/ quartz fibers (Long +short fibers)
- 0.175x0.175 η/φ segmentation

SD peak @ low $E_{HF\pm}$, $N_{HF\pm}$

$E_{HF\pm}$ = energy deposition in HF±

$N_{HF\pm}$ = multiplicity of towers above threshold in HF±

SD peak @ low $\xi = \Sigma_i (E_i \pm p_{z,i})$ → **Sum runs over all the Calo Towers: $p_{z,i} = E_i \cos \vartheta_i$**

Result: definition of variables

The selected events are plotted as a function of:

- $E \pm p_z = \sum(E_i \pm p_{z,i})$ - the sum runs over all CaloTowers, where
  E_i is the tower energy,
  $p_{z,i} = E_i \cos\theta_i$,
  θ_i is the angle between the z axis and the direction defined by the center of the tower and the nominal interaction point.

Diffractive peak expected at low values of this variable, reflecting the peaking of the cross section at small ξ.

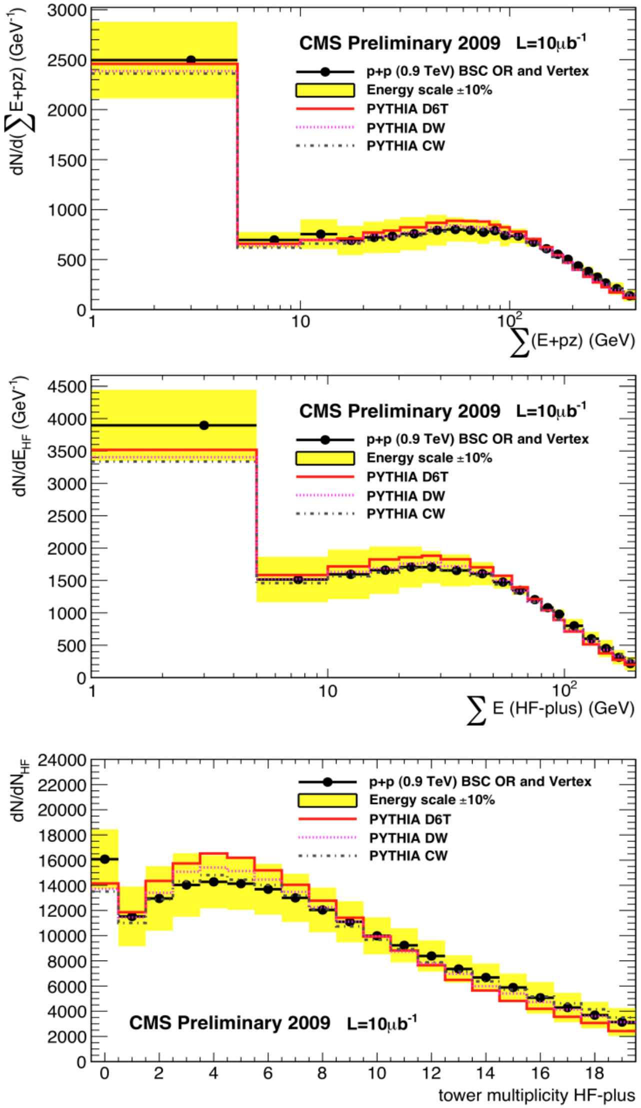
- E_{HF} - the energy deposition in the HF.

- N_{HF} - the multiplicity of the towers above threshold in the HF.

Diffractive peak expected at low tower multiplicity and at low energy deposition, reflecting the presence of a large rapidity gap over HF.

Comparison with different PYTHIA tunes: D6T, DW, CW

900 GeV

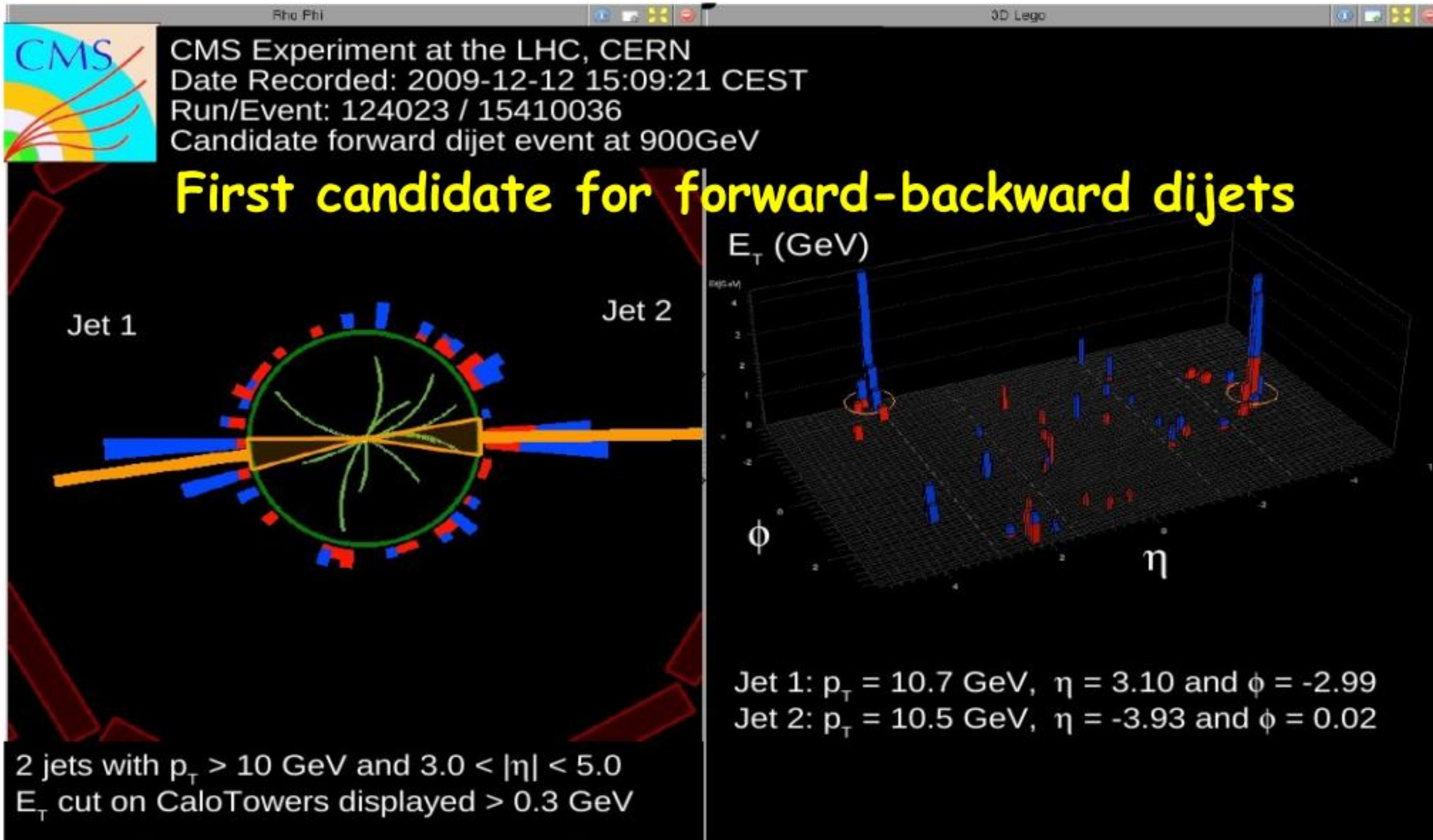


PYTHIA tunes D6T, DW and CW900A give similar overall description

- BACKUP FWD-10-002

FWD Jets

Forward Jets in CMS



First Forward Jets from CMS

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