OVERVIEW OF DIFFRACTION AT THE LHC

Sparsh Navin

University of Birmingham

United Kingdom

ISMD 2010, Antwerp

Many thanks to my supervisors and colleagues on ALICE, ATLAS and CMS

Outline

- Diffractive events – topology
- Detector set-up – ALICE, ATLAS & CMS

See TOTEM results - G. Catanesi (tomorrow)

- Results
  1) Diffraction
     1) Fractions
     2) Kinematics
  2) Dijets and central exclusive production
- Outlook

Diffraction

$$\sigma_{\text{tot}} = \sigma_{\text{elastic}} + \sigma_{\text{single-diffractive}} + \sigma_{\text{double-diffractive}} + \overbrace{\cdot\Lambda\cdot}^{\sigma_{\text{central-diffractive}}} + \sigma_{\text{non-diffractive}}$$

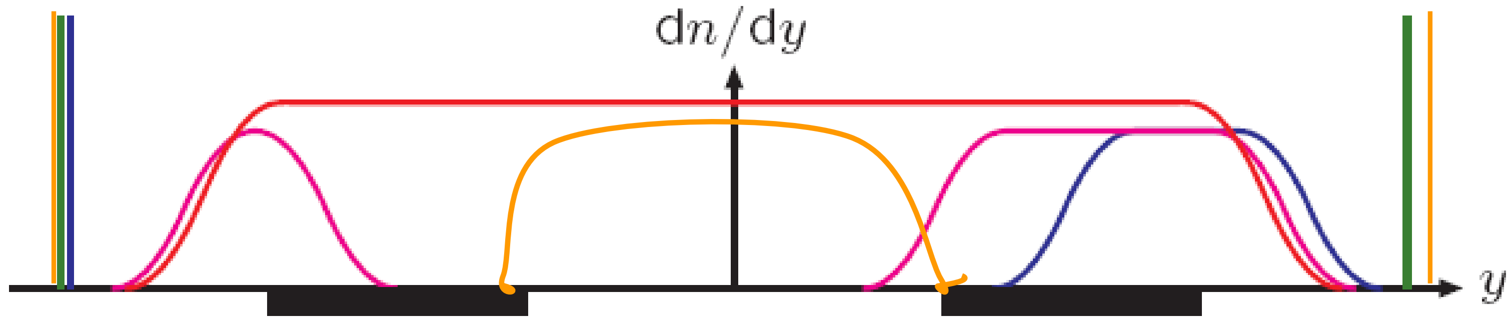
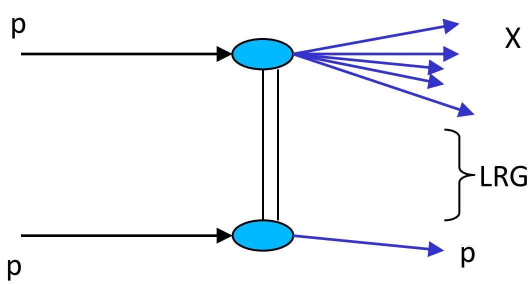
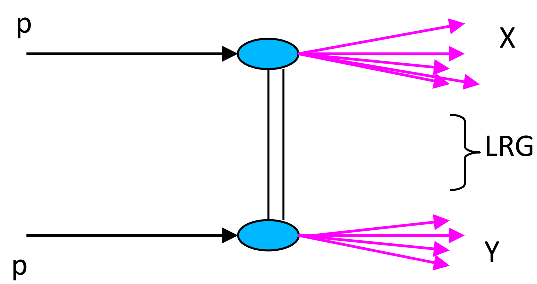


Figure adapted from Torbjörn Sjöstrand, MCnet school, 2008.

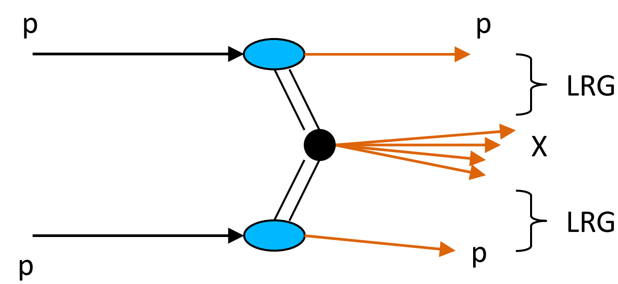
Single Diffractive dissociation SD



Double Diffractive dissociation DD



Central Diffractive dissociation CD



$$\xi s = {M_X}^2$$

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

Experimentally challenging to classify diffractive events – see R.Orava (tomorrow)

Detector set-up - ALICE

ITS (Inner Tracking System)

$|\eta| < 2$

$|\eta| < 1.4$

SPD – Inner layers
- 3.9 cm 7.6 cm radii
- better than 100μm resolution
- provide the SPD trigger signal

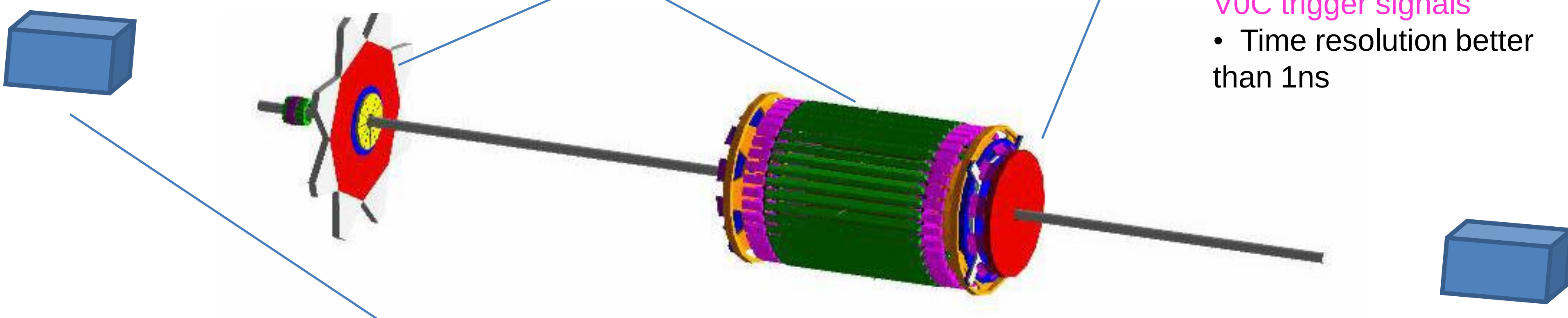
V0A $z = 3.3m$

$2.8 < \eta < 5.1$

V0C $z = -0.9m$

$-3.7 < \eta < -1.7$

- Provide the V0A and V0C trigger signals
- Time resolution better than 1ns



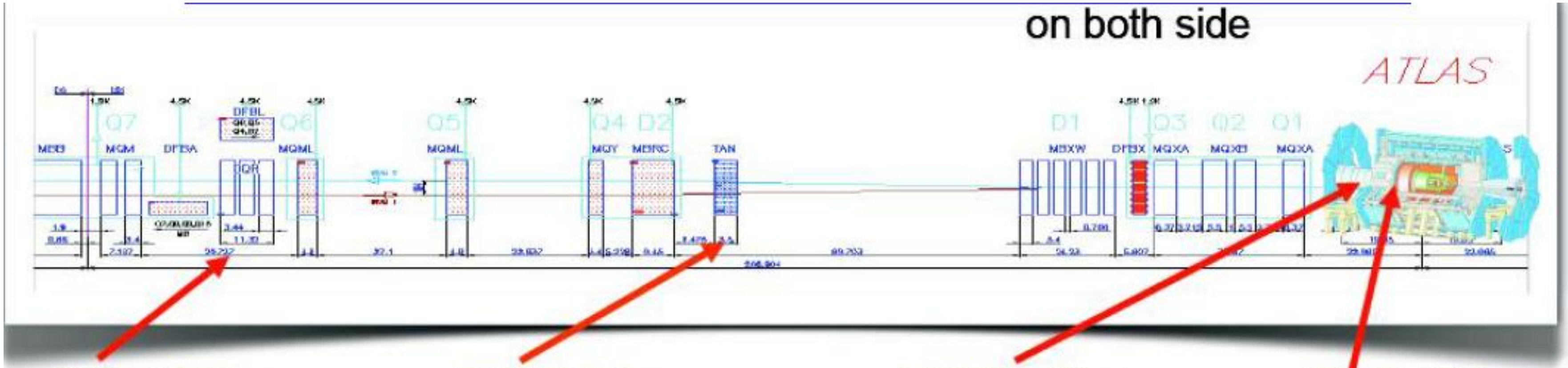
ZDC at $\pm 116m$

ZN $|\eta| > 8.7$

ZP $|\eta| > 8.4$

Provide the ZDCA and VZDCC trigger signals

ATLAS Forward detectors



ALFA at 240 m | ZDC at 140 m | LUCID at 17 m | MBTS at 3.6 m

$10.6 < |\eta| < 13.5$ | $|\eta| > 8.3$ | $5.6 < |\eta| < 5.9$ | $2.1 < |\eta| < 3.8$

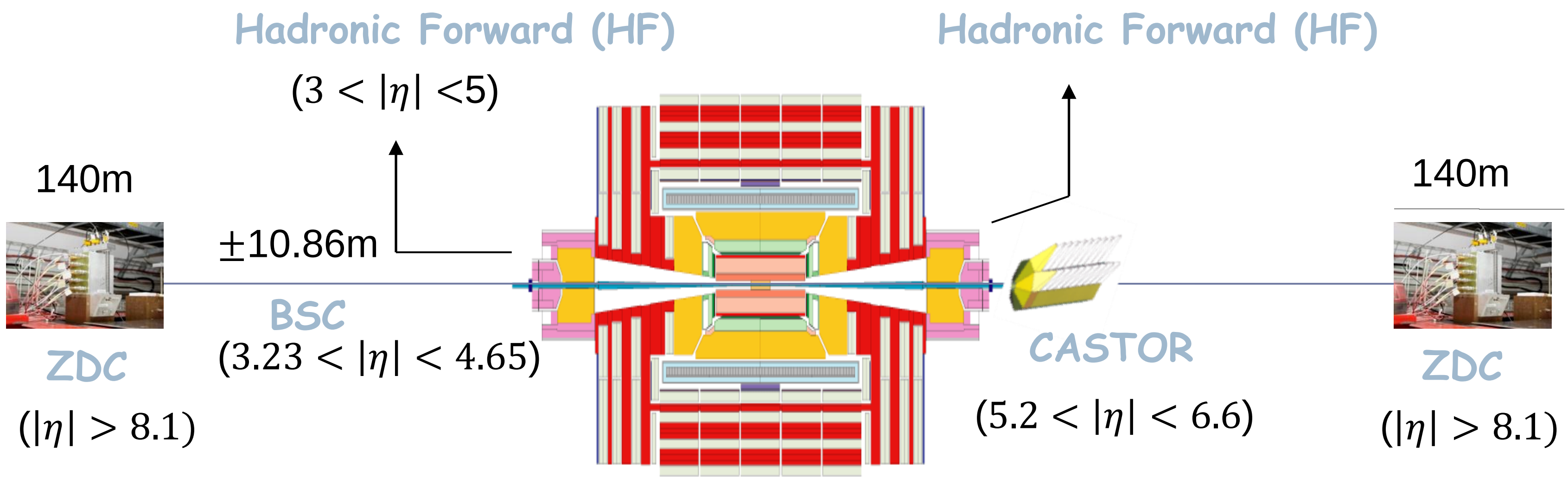
Not yet fully installed

Central Detector covers

Inner Tracker $|\eta| < 2.5$ | **EM calorimeter $|\eta| < 3.2$**

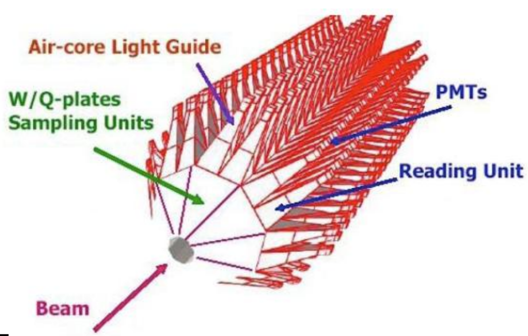
Hadronic Calorimeter $|\eta| < 4.9$ | **Muon Spectrometer $|\eta| < 2.7$**

Forward detectors - CMS



CASTOR:

- W absorber/quartz plates
- @14m from IP
- $5.2 < \eta < 6.6$
- 16 segments in φ (EM/HAD) segments in z (no η segmentation)

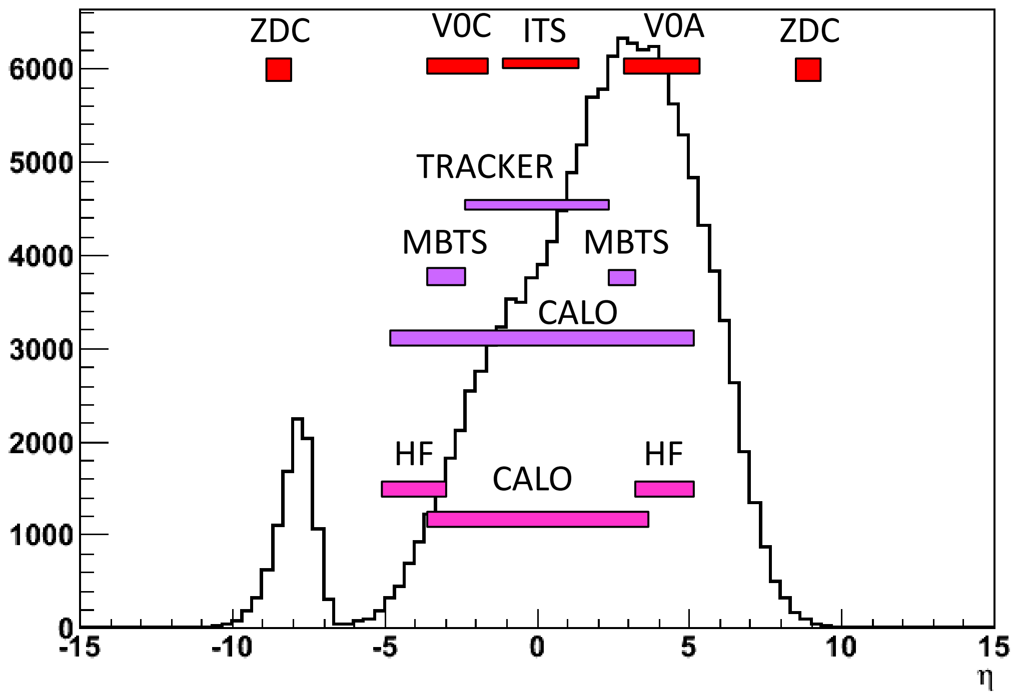


Hadron Forward:

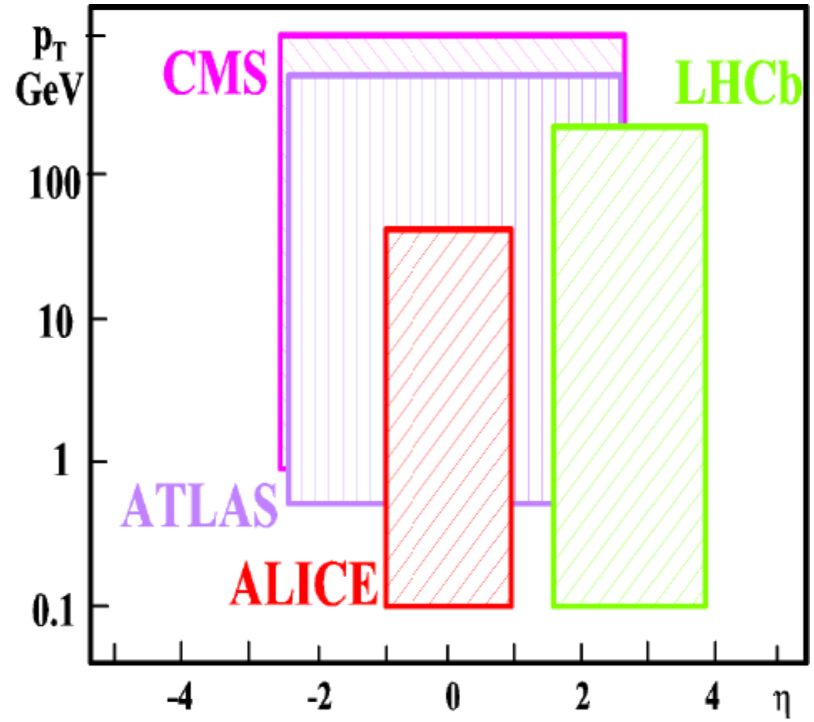
- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers/quartz fibers (Long+short fibers)
- 0.175x0.175 η/φ segmentation

p_T and η coverage

Detectors used in this study

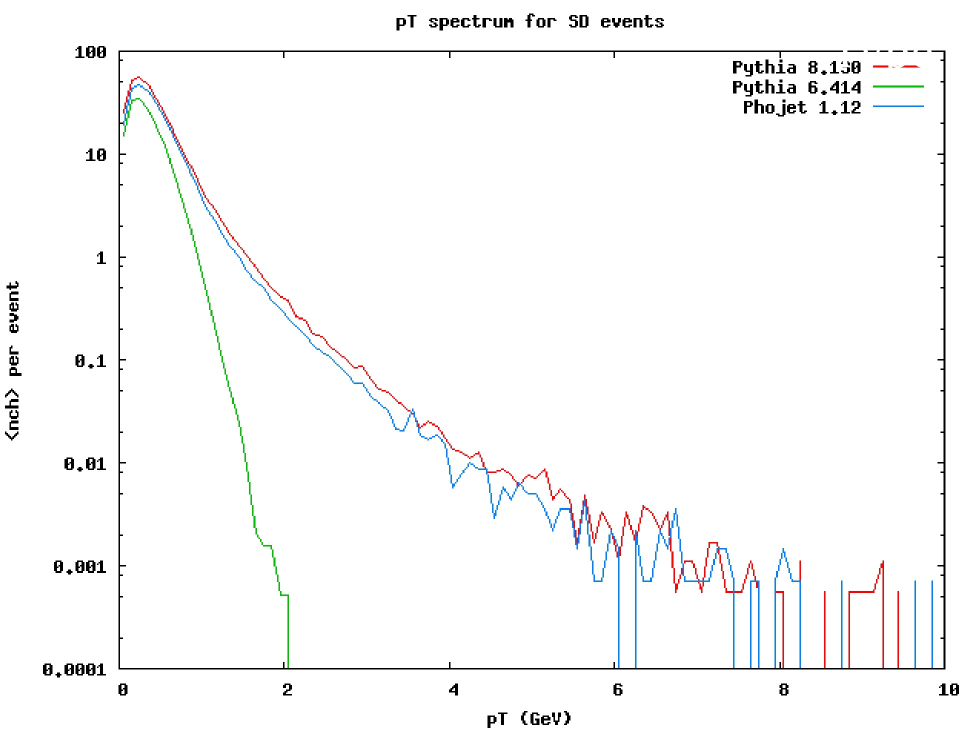


Central barrels



Differing Models

$\sqrt{s}$	SD		DD	
	PYTHIA	PHOJET	PYTHIA	PHOJET
900 GeV	22.2%	19.2%	12.2%	6.4%
2.36 TeV	21.0%	16.2%	12.8%	5.7%
7 TeV	19.3%	14.1%	12.8%	5.1%



- A large fraction of min-bias events are diffractive
- True cross sections at LHC energies are not known
- Scaling of cross sections with energy is model dependent

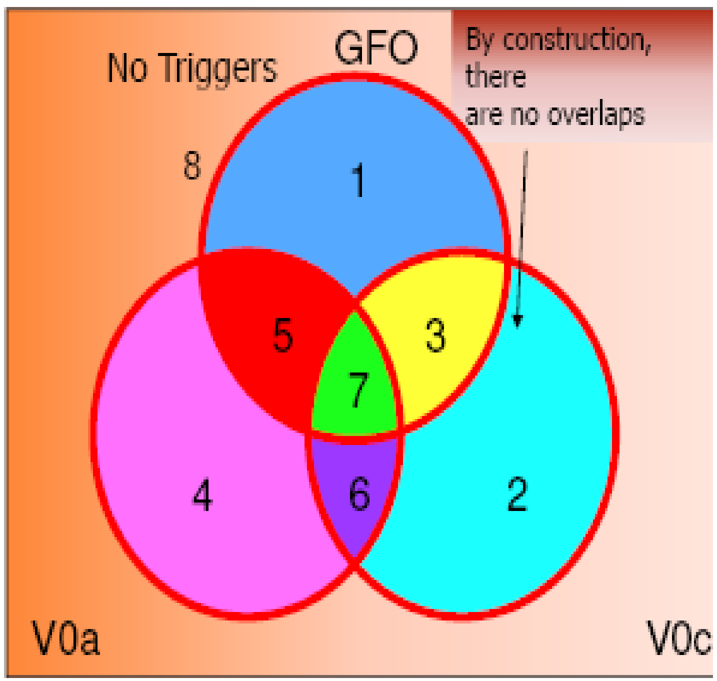
- Kinematics of diffractive events differ between models

Fractions - ALICE

- independent offline trigger combinations (GFO, V0A, V0C, ZDCA, ZDCC) : $2^5 = 32$ combinations

$$N_{trig} = N_{bc}(f^{ND}\varepsilon^{ND}{}_{trig} + f^{SD}\varepsilon^{SD}{}_{trig} + f^{DD}\varepsilon^{DD}{}_{trig} + f^{NI}\varepsilon^{NI}{}_{trig})$$

- efficiencies (ε) from model – sensitive to kinematic differences



- use N_{trig} of each type to minimise χ^2

$$\chi^2 = \sum_{\mathrm{trig}} \left(\frac{N_{\mathrm{trig}(i)} - N_{\mathrm{fit}(i)}}{\sigma\left(N_{\mathrm{trig}(i)}\right)} \right)^2$$

32 trigger combinations

4 unknown fractions (f)

1 constraint : $\sum f = 1$

$\Rightarrow$ 29 degrees of freedom (dof)

Z. Matthews et al. ALICE-INT-2009-027

Fractions - ALICE

Work in progress

PHOJET		
	50:50	FIT
ND	0.690	0.657±0.015
SD	0.206	0.012±0.017
DD	0.104	0.115±0.020
NI	0	0.0±0.030
χ^2/dof	-	18.9/29

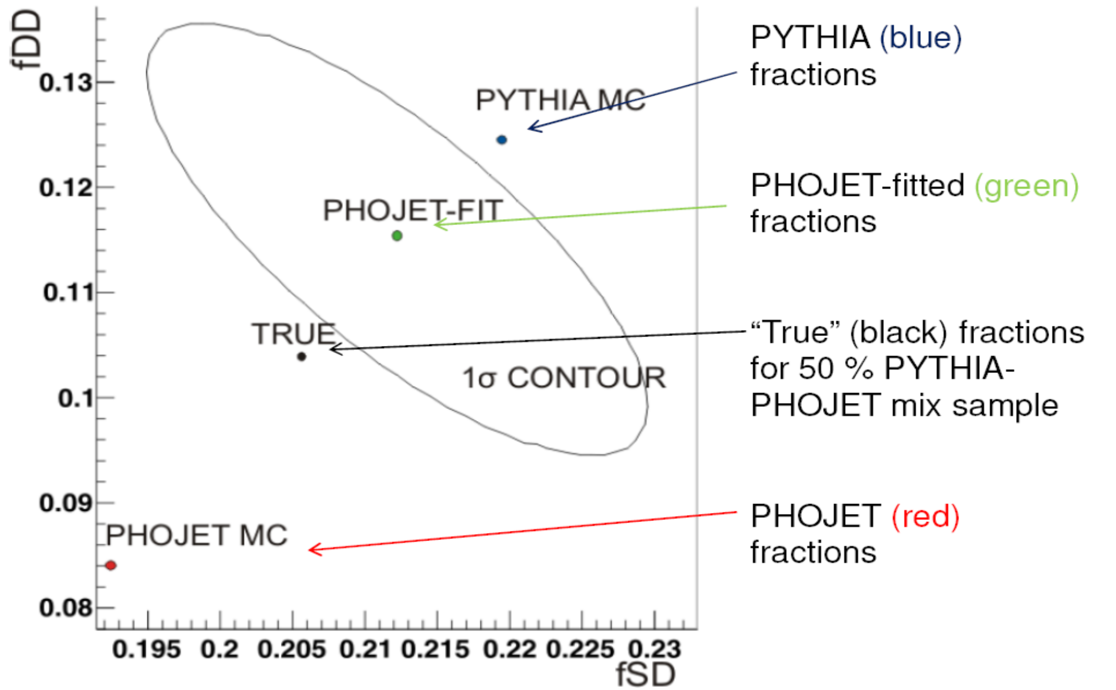
PYTHIA		
	50:50	FIT
ND	0.690	0.717±0.009
SD	0.206	0.212±0.010
DD	0.104	0.071±0.013
NI	0	0.0±0.0220
χ^2/dof	-	20.8/29

"data" created with "true" fractions the average of PYTHIA and PHOJET

100,000 events – 900 GeV

Errors propagated through fit.

FIT RESULTS COMPARED WITH USING MC FRACTIONS, AND 1σ CONTOUR



Fractions – ATLAS

ATLAS-CONF-2010-048

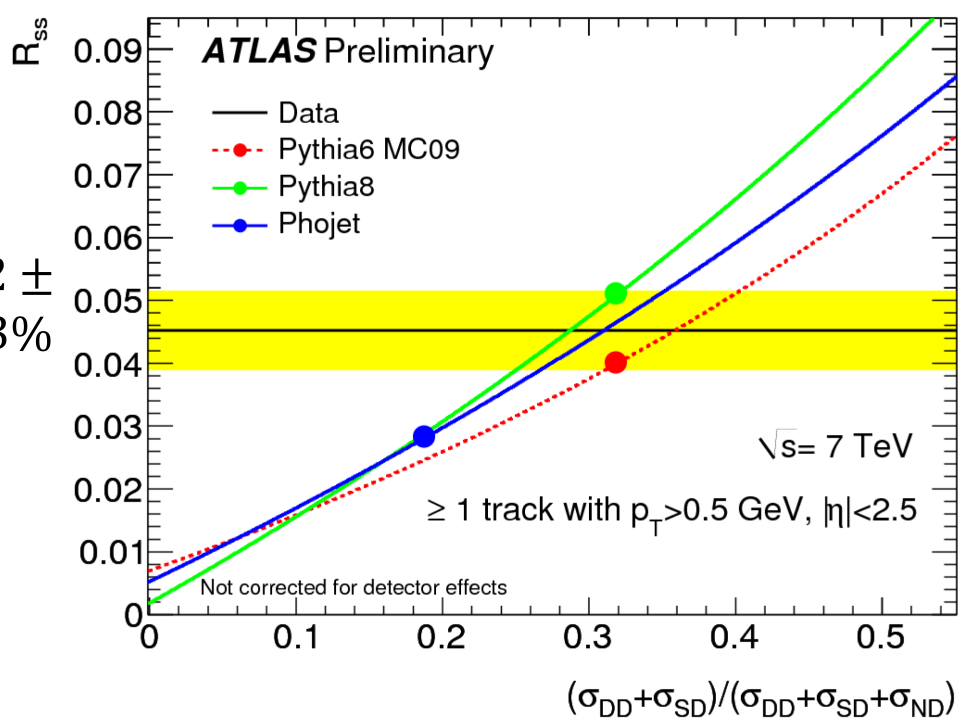
Inelastic events:
- events with activity in the MBTS (N_{any})
- atleast one track with $p_T > 500\ MeV$ and $|\eta| < 2.5$

1,169,508 - data
12-20% diffractive - MC

Gap events:
- events with activity only in one side of MBTS (N_{ss})
- atleast one track with $p_T > 500\ MeV$ and $|\eta| < 2.5$

52,801 - data
85-98% diffractive - MC

4.52 ± 0.63%



$$R_{ss} = \frac{N_{ss}}{N_{any}} = \frac{A_{ss}^{D}\sigma_{D} + A_{ss}^{ND}\sigma_{ND}}{A_{any}^{D}\sigma_{D} + A_{any}^{ND}\sigma_{ND}}$$

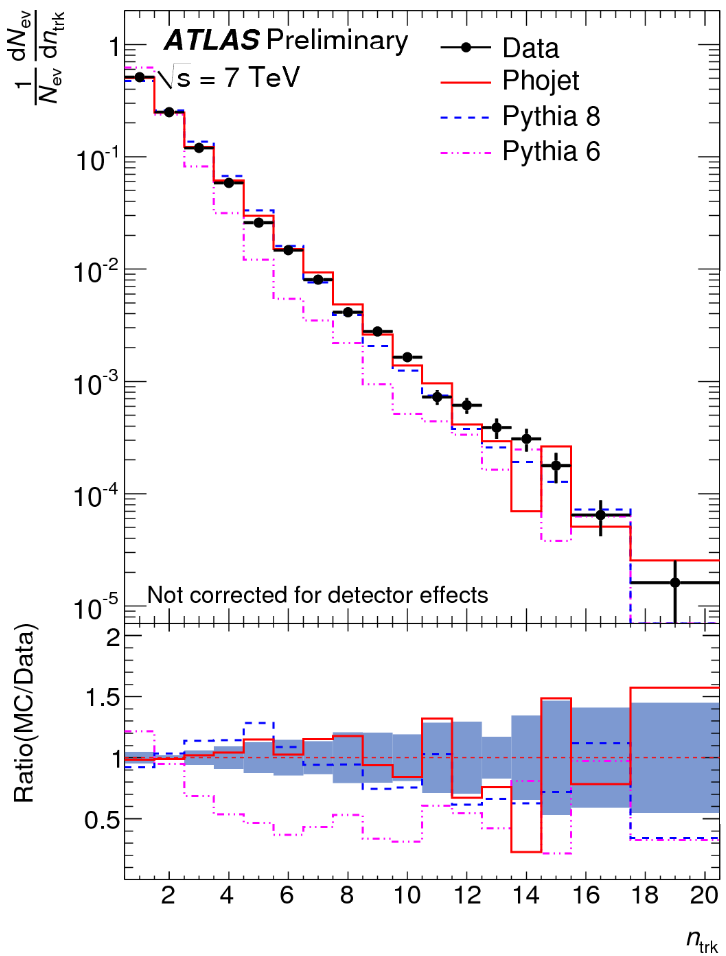
A = acceptance (model dependent)

- PYTHIA agrees better than PHOJET with data.
- Both models ~ 30% diffractive

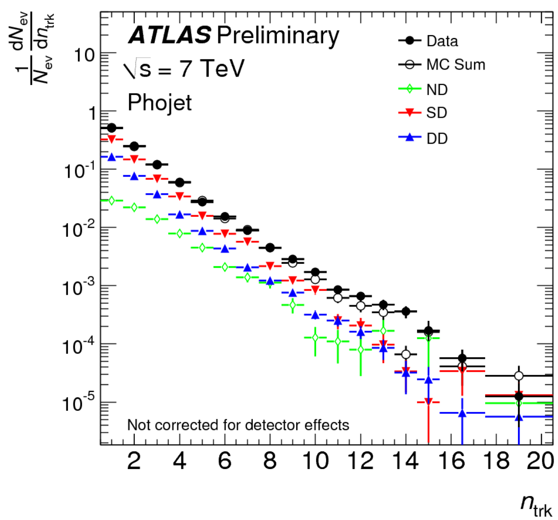
Diffraction kinematics - ATLAS

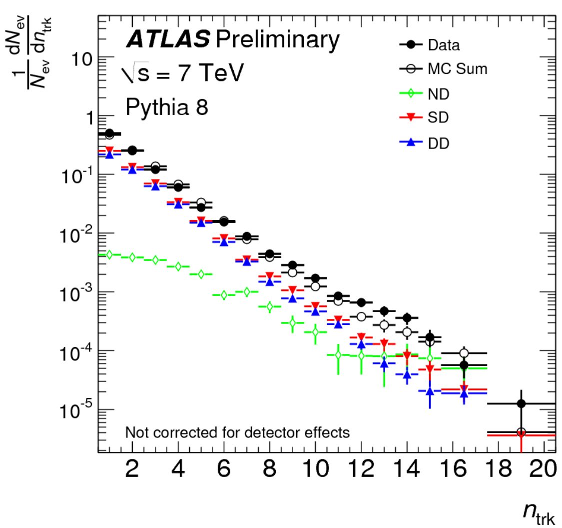
Gap event sample dominated by diffractive events

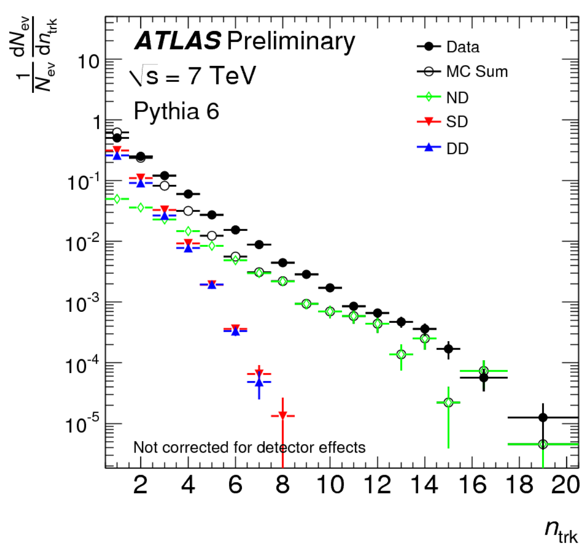
Distribution steeper than inclusive sample



ND more important at tail





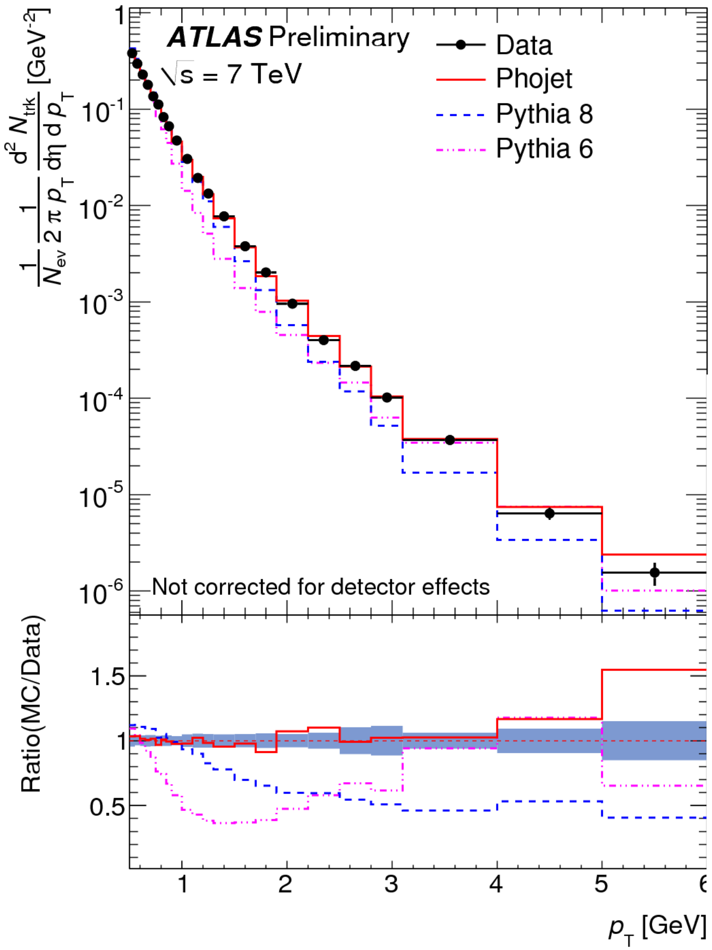


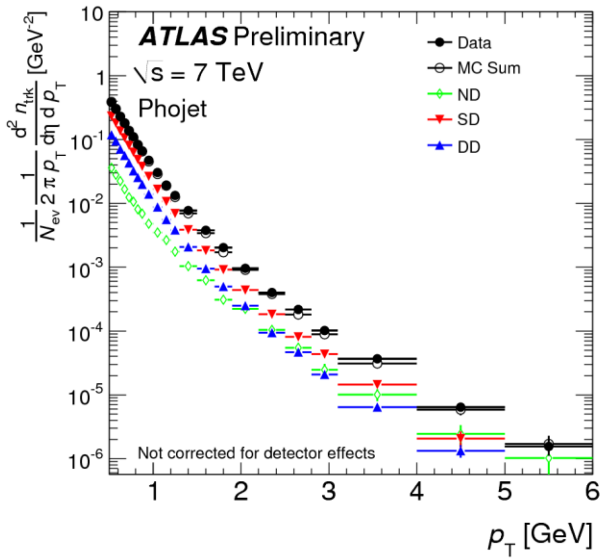
Uncorrected for detector and experimental effects

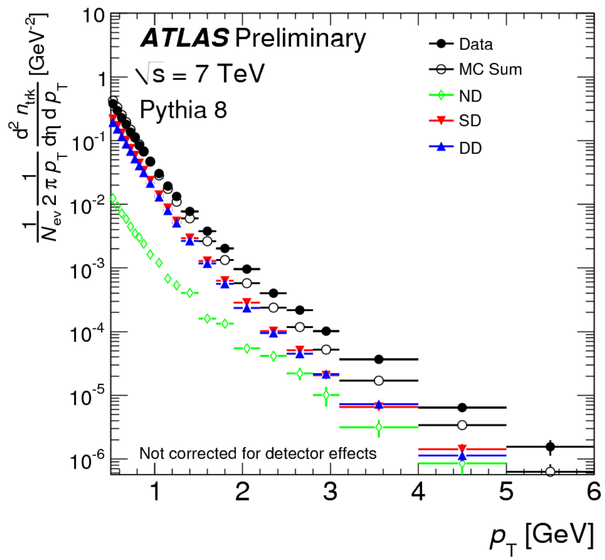
Diffraction kinematics - ATLAS

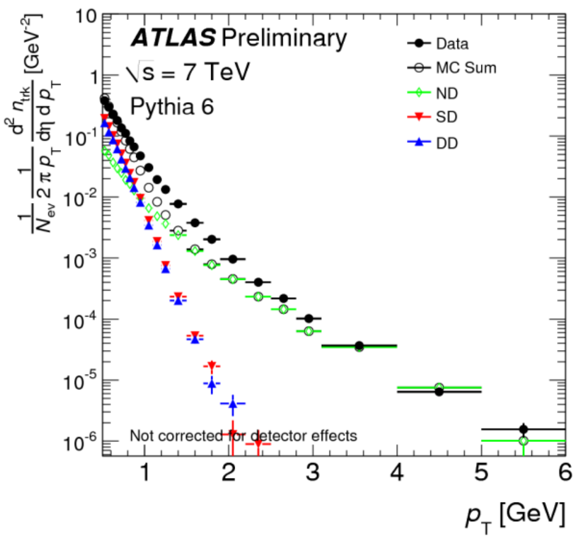
PHOJET agrees very well with data

PYTHIA 8 slightly softer







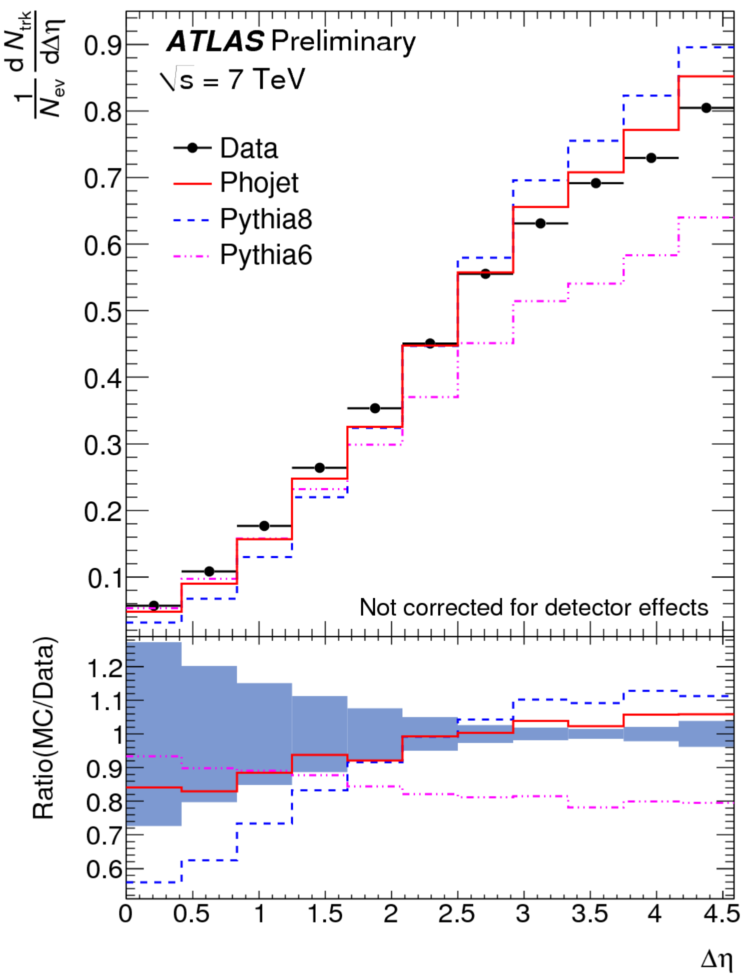


Uncorrected for detector and experimental effects

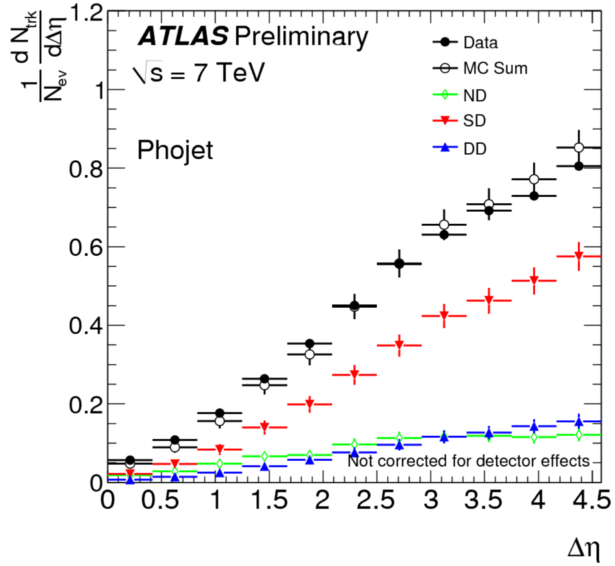
Diffraction kinematics - ATLAS

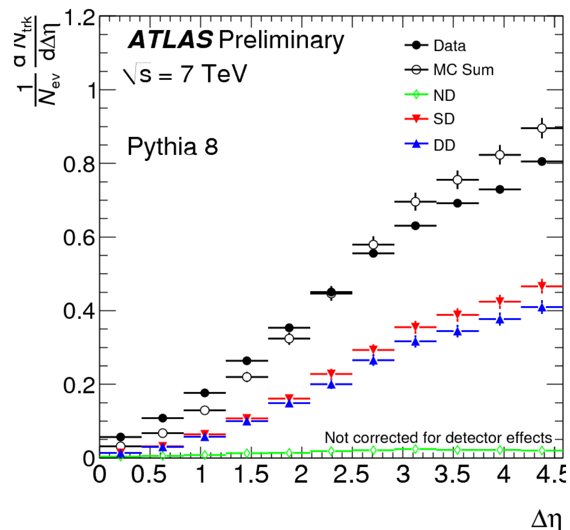
At low delta eta all 3 describe data well

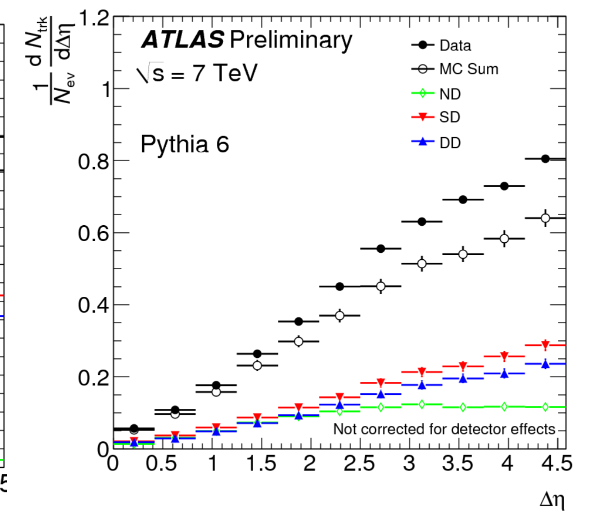
At high delta eta PYTHIA 6 underestimates rate of tracks



High uncertainty at low delta due to ND component and sensitivity to MBTS efficiency.





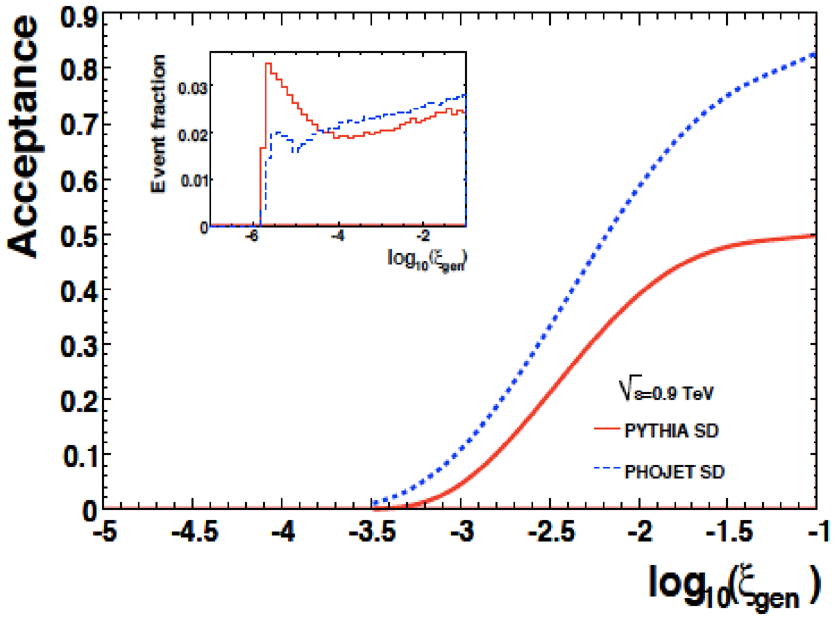


Uncorrected for detector and experimental effects

Observation of diffraction - CMS

CMS PAS FWD-10-001

- Trigger – BPTX and beam scintillator counter
- Number of events after cuts: 207345 for 900 GeV and 11848 for 2.36 TeV



ξ: fractional momentum loss of the scattered proton.

$$\xi s = {M_X}^2$$

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

Diffractive events identified in three ways:

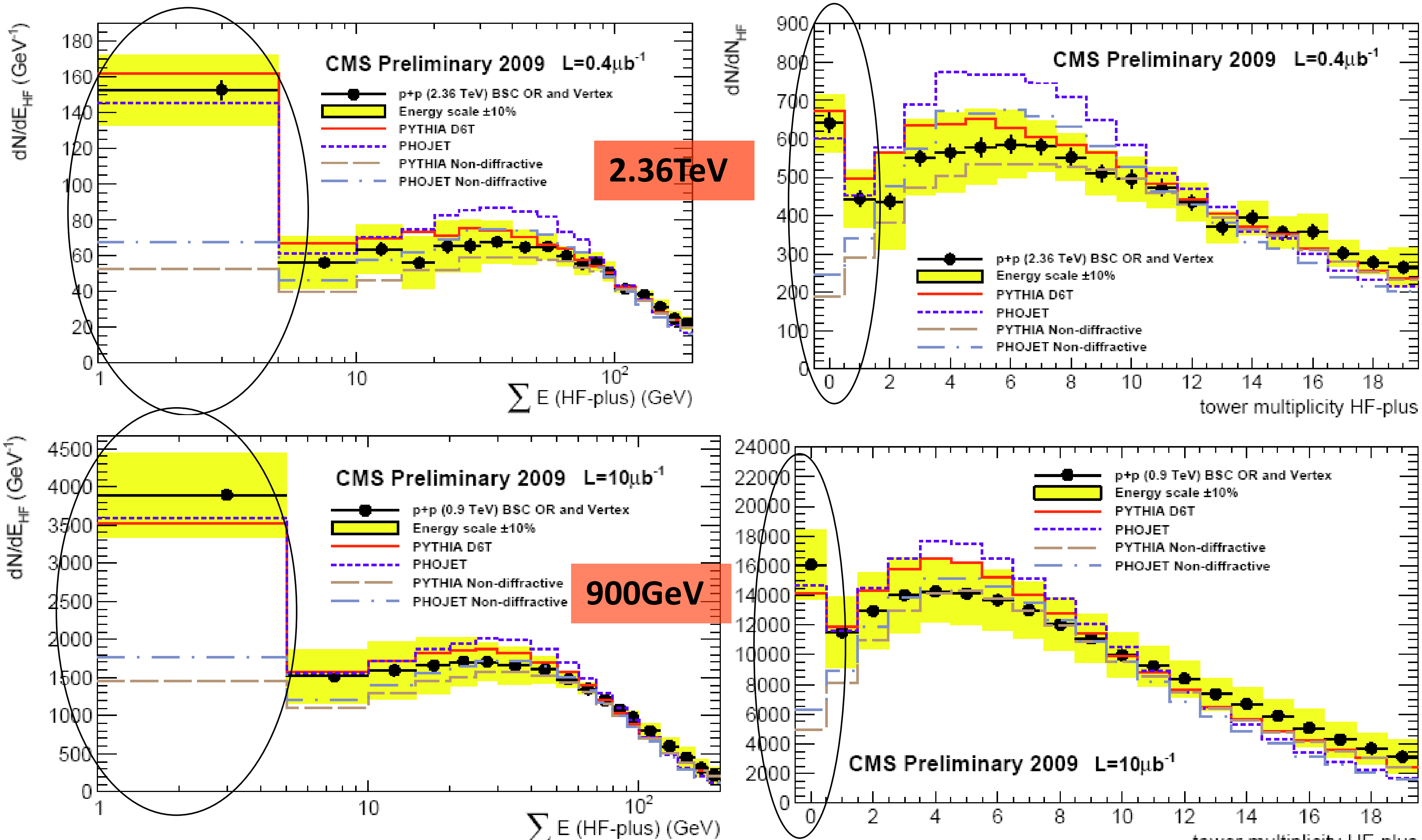
1. The multiplicity in the forward hadron calorimeter (HF).
2. The sum of HF tower energy.

Traditional forward gap definition

3. Sum over all calo towers: $\xi \approx \sum_i (E_i \pm p_{z_i})$; related to momentum loss of scattered proton – expect diffractive peak at low values

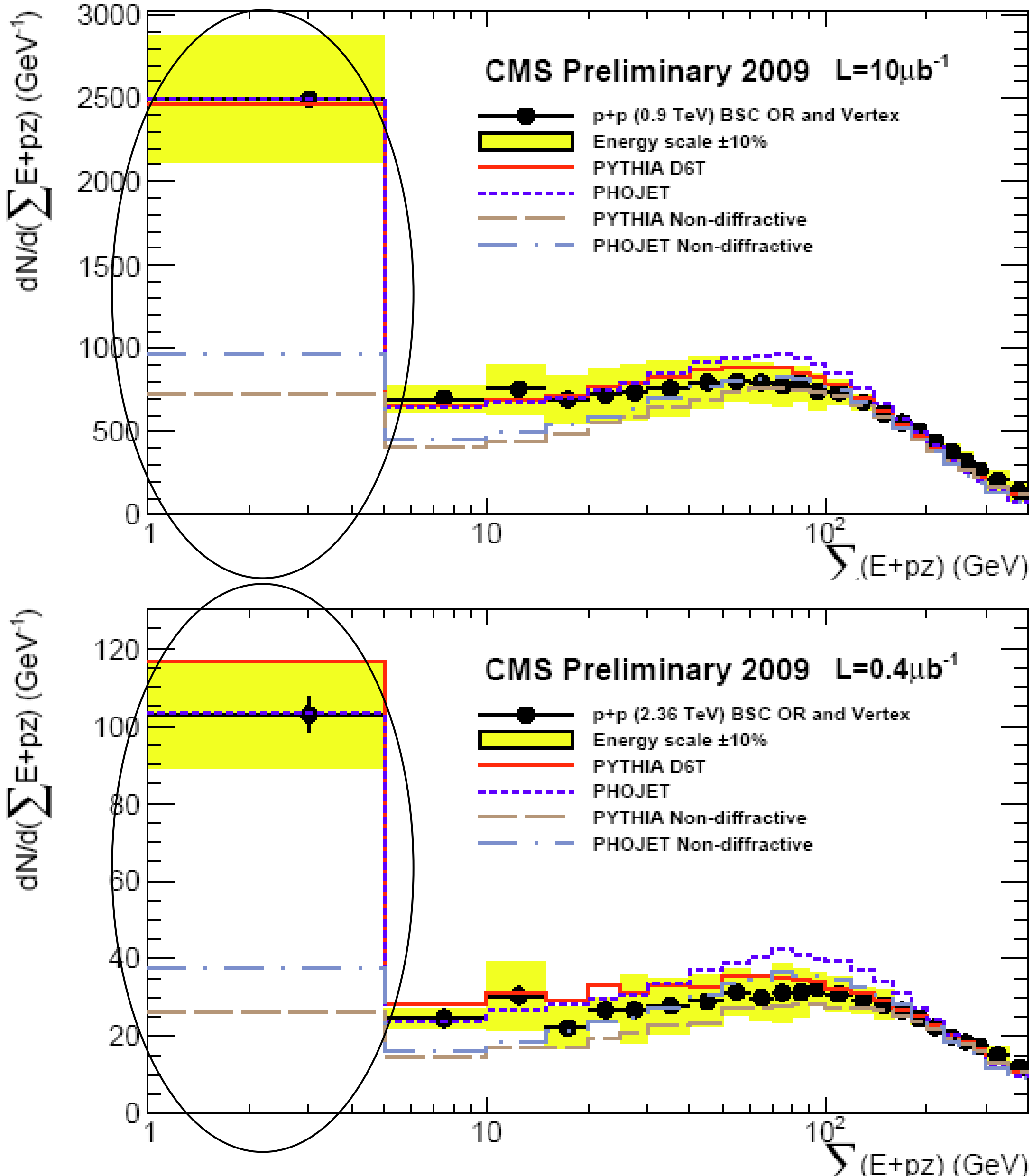
Observation of diffraction - CMS

SD signature = Large Rapidity Gap



Uncorrected for detector and experimental effects

Observation of diffraction - CMS



900GeV

SD cross section peaking at small values of $\xi s = {M_X}^2$

$$\xi \approx \sum_i (E \pm p_{z_i})$$

- Pythia 6 reasonably describes the ND component of data
- Phojet describes diffraction better

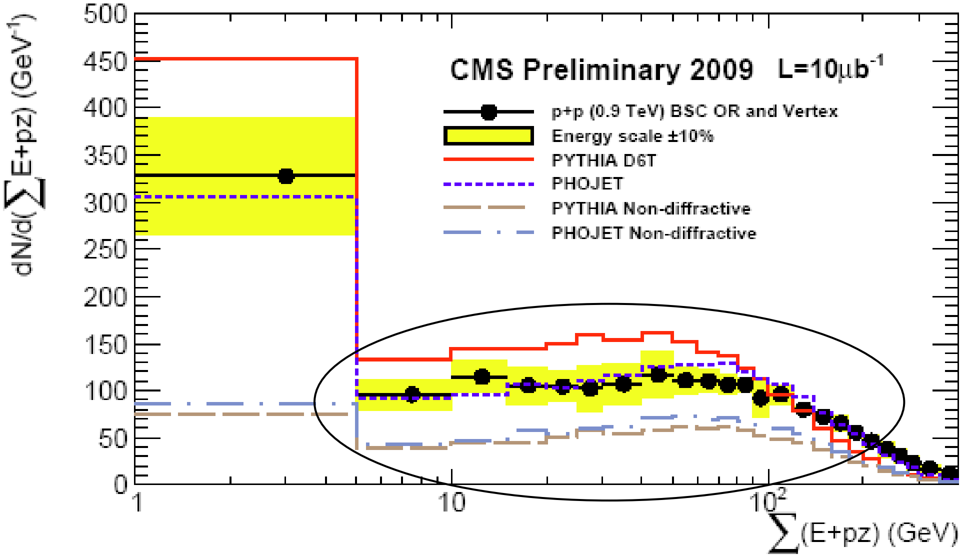
2.36TeV

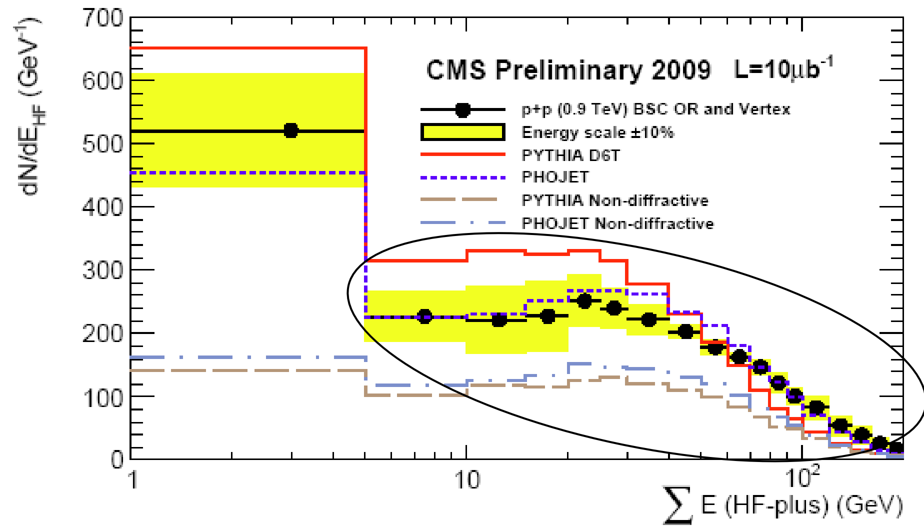
Uncorrected for detector and experimental effects

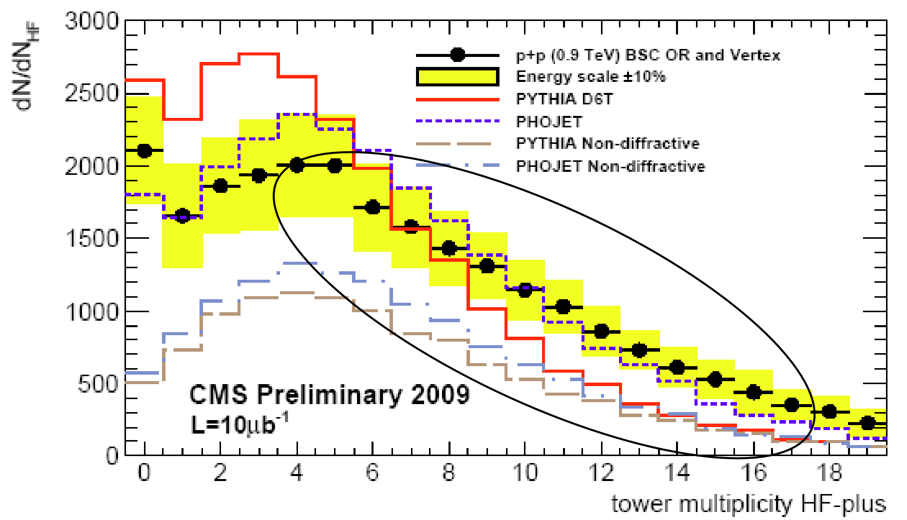
Enriched SD sample - CMS

Require low activity on one side
=> E(HF-) < 8 GeV

900GeV



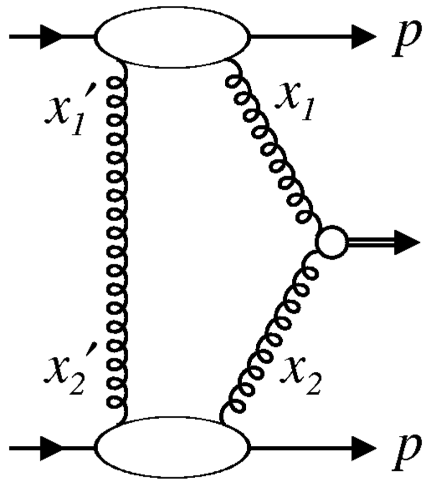




Uncorrected for detector and experimental effects

Central Exclusive production

- Intact protons can be detected in forward detectors
- Detection of rapidity gap
- Central system: $J_z = 0$, C-even, P-even state
- J/Psi, H_0
- Strong suppression of background => clean signal => only few events enough to determine Higgs quantum numbers



In CMS: High Precision Spectrometers, HPS
In ATLAS: ATLAS Forward Protons, **AFP**
In ALICE: ALICE Diffractive, **ADA, ADC**

However:

Low cross section

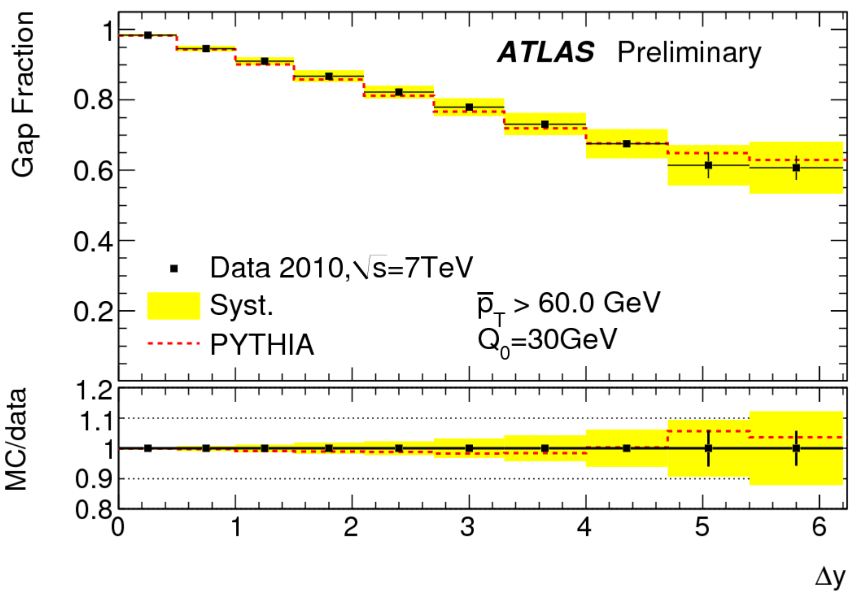
Pile-up

See Forward physics with CMS - D. Cerci (today)

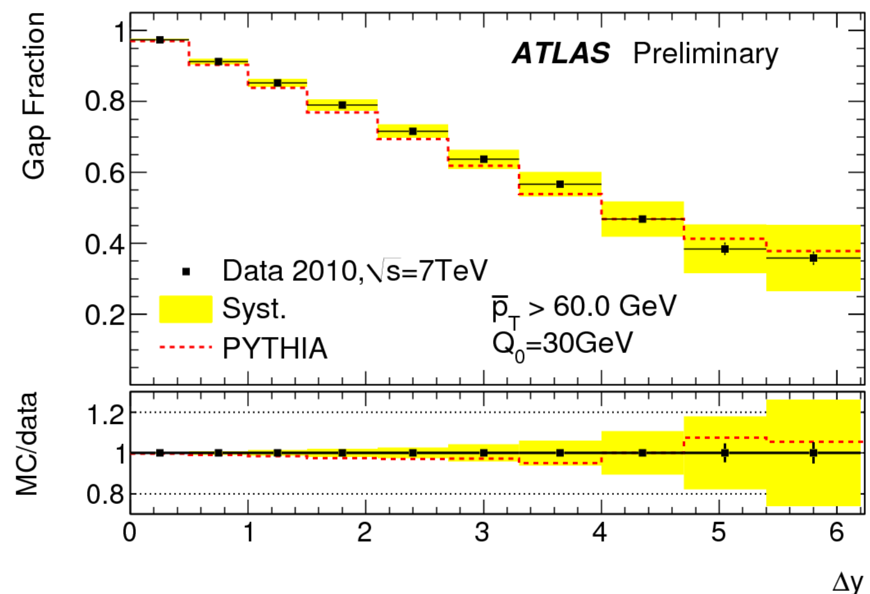
Dijet production with a jet veto- ATLAS

- Atleast 2 good anti $-k_T$ jets (R=0.6) with $p_T > 30\ GeV$ and $|y| < 4.5$
- Gap events are a subset of events that do not contain an additional jet with $p_T >$ veto scale ($Q_0 = 30\ GeV$) in the rapidity interval between the dijets
- Gap events fraction studied as a function of mean p_T and rapidity separation of the jets.
- Boundary dijet selection:

Selection A: hardest jets in the event

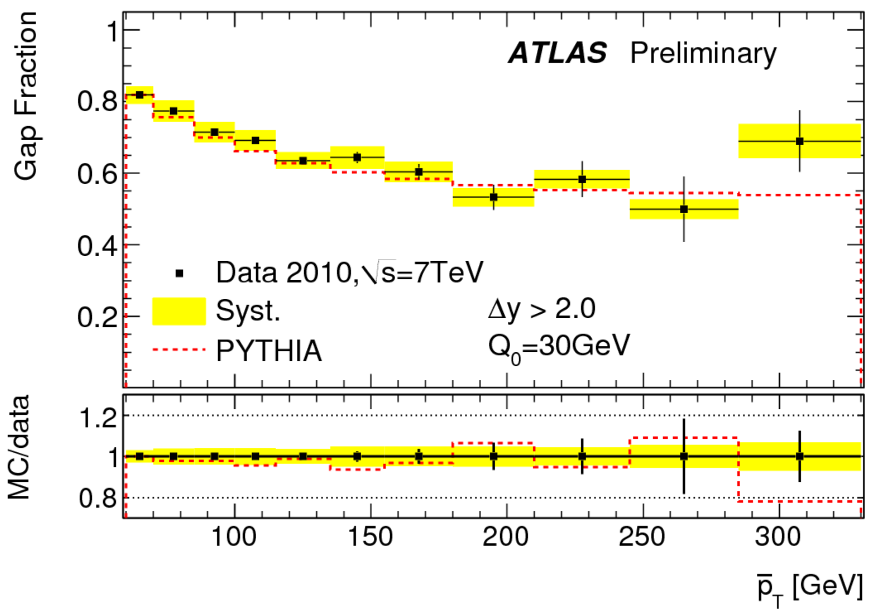


Selection B: most forward and most backward jets in the event

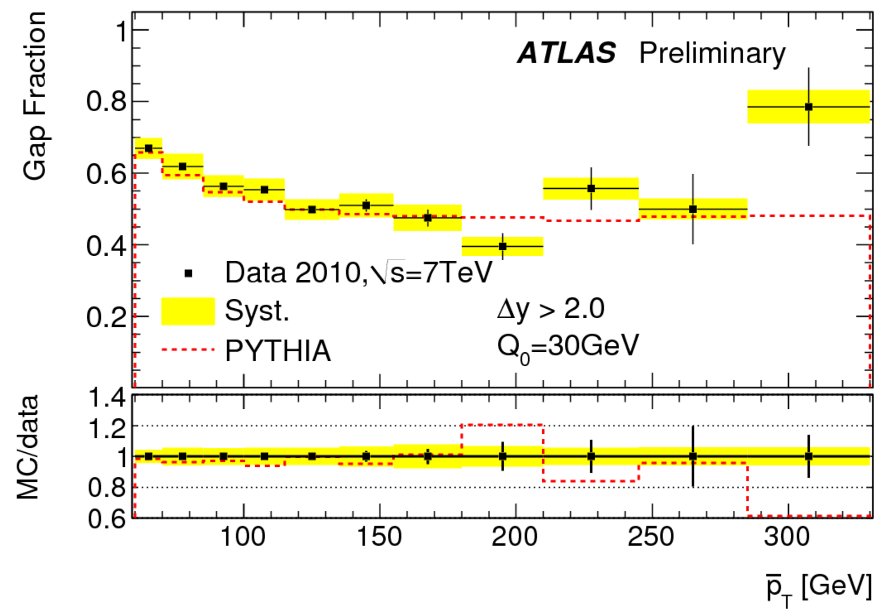


Dijet production with a jet veto- ATLAS

Selection A



Selection B



Reasonable agreement between PYTHIA and data

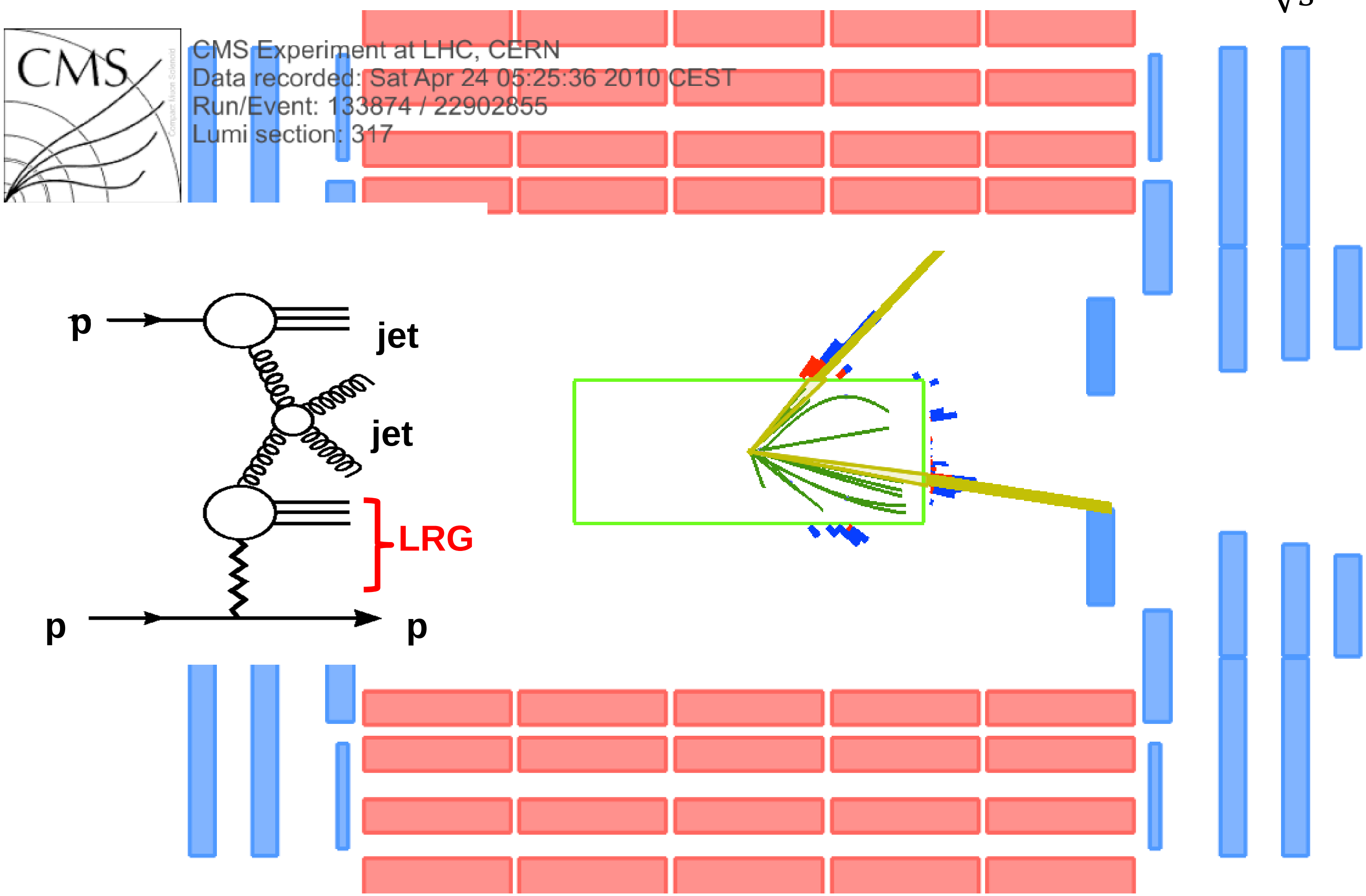
Fluctuations in high $\bar{p}_T$ bins due to low statistics

Diffractive dijets – CMS

$p_T(\text{jet1}) > 30\ GeV;\ p_T(\text{jet2}) > 20\ GeV$

Diffractive selection: No energy deposition in HF with E > 4 GeV

$\sqrt{s} = 7\ TeV$



Summary

- ALICE, ATLAS and CMS study diffraction.
- SD observed by the presence of a large rapidity gap in one direction.
- Model differences in fractions and kinematics – data constrains models:
  - PYTHIA gives a better ND description
  - PHOJET and PYTHIA 8 describe diffraction better
- ALICE results on fractions to be published soon.
- Central Diffraction:
  - Dijet studies in ATLAS show good agreement with PYTHIA
  - CMS results soon
- CEP is useful to look at – upgrades for ALICE, ATLAS and CMS

Dank u! **Merci!** **Danke schön**

See Hard Diffraction - R. Enberg (today)

Back up

- ALICE fractions uncertainties
- ATLAS acceptance + kinematics
- ALICE triggered events table
- $\xi \approx \sum(E \pm p_z)$
- CMS control plot HF- plots
- CMS dijet event displays
- Alice diffractive detector
- ATLAS - AFP

Calculating the Uncertainty

$$\chi^2 = \sum \frac{(N^{trig}_{fit} - N^{trig}_{measured})^2}{(Uncertainty)^2}.$$

$$\boxed{\sqrt{N^{trig}_{measured}}.}$$

N(measured)=N(trig)

$$\chi^2 = \sum \frac{(N^{bc}(f^{fit}_{ND}\varepsilon^{trig}_{ND} + f^{fit}_{SD}\varepsilon^{trig}_{SD} + f^{fit}_{DD}\varepsilon^{trig}_{DD} + f^{fit}_{NI}\varepsilon^{trig}_{NI}) - N^{trig}_{measured})^2}{(Uncertainty_{stat})^2 + (Uncertainty_{model})^2}$$

"Model error" covers uncertainty in kinematics

Error propogation (effs are independent)

$$\sqrt{\left(\frac{\delta N^{trig}_{fit}}{\delta\varepsilon_{ND}}\right)^2 (\sigma_{\varepsilon_{ND}})^2 + \left(\frac{\delta N^{trig}_{fit}}{\delta\varepsilon_{SD}}\right)^2 (\sigma_{\varepsilon_{SD}})^2 + \left(\frac{\delta N^{trig}_{fit}}{\delta\varepsilon_{DD}}\right)^2 (\sigma_{\varepsilon_{DD}})^2 + \left(\frac{\delta N^{trig}_{fit}}{\delta\varepsilon_{NI}}\right)^2 (\sigma_{\varepsilon_{NI}})^2}$$

$$\boxed{\sqrt{(N^{bc})^2 \sum \left(f^2_{proc}\sigma^2_{\varepsilon_{proc}}\right)}} \rightarrow \boxed{\sqrt{(N^{bc})^2 \sum \left(f^2_{proc}(\tfrac{1}{2}\Delta\varepsilon_{proc})^2\right)}}$$

Needs to be recalculated with fit parameter results once minimum is found

Zoe Louise Matthews, Diffractive Meeting, ALICE Week, 25th March 2010

7

Z. Matthews et al. ALICE-INT-2009-027

ATLAS - Acceptance

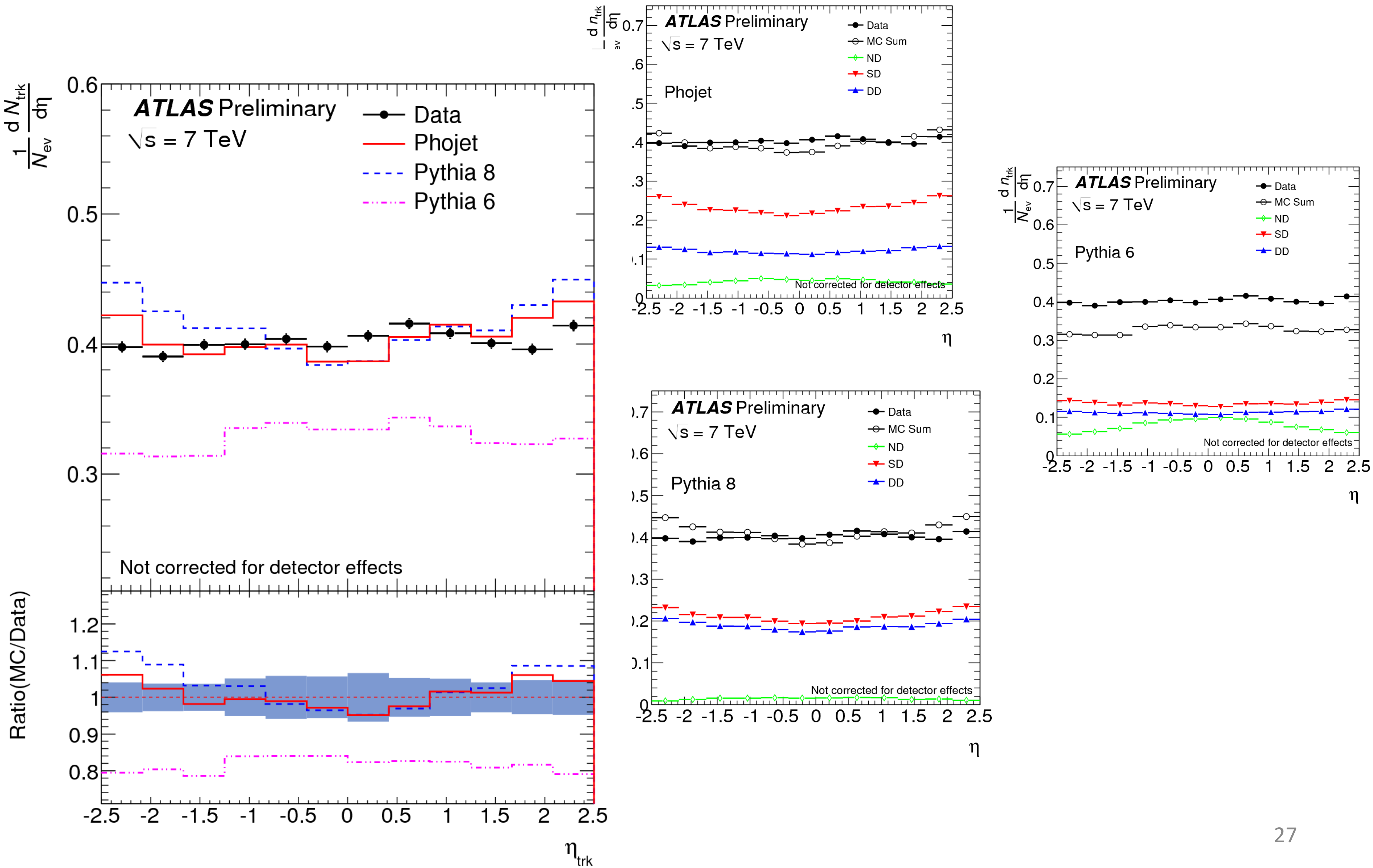
Track acceptance

Generator	ADD 1-trk	ASD 1-trk	AND 1-trk
PYTHIA6	39.2%	37.0%	97.5%
PYTHIA8	50.1%	55.6%	97.3%
PHOJET	52.2%	63.7%	95.9%

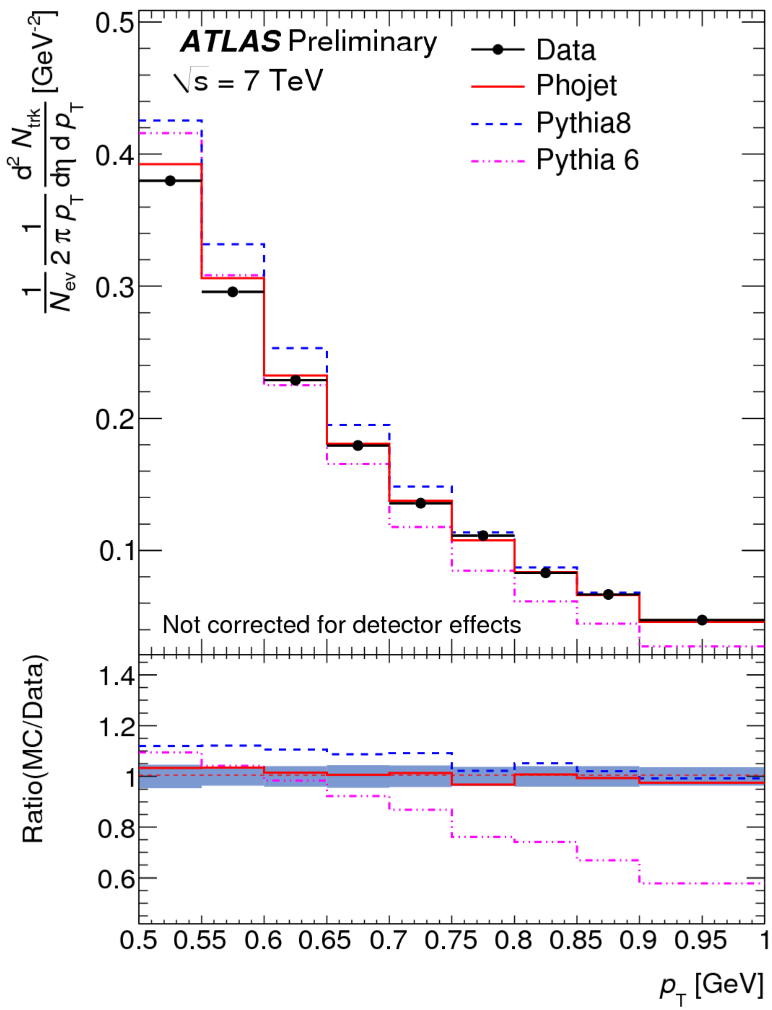
MBTS acceptance with atleast one track

Generator	DD		SD		ND	
	ADD any	ADD ss	ASD any	ASD ss	AND any	AND ss
PYTHIA6	97.2%	23.9%	97.7%	20.7%	99.9%	0.7%
PYTHIA8	100%	27.0%	100%	22.9%	100%	0.1%
PHOJET	97.9%	14.2%	97.8%	22.0%	100%	0.5%

ATLAS kinematics - eta



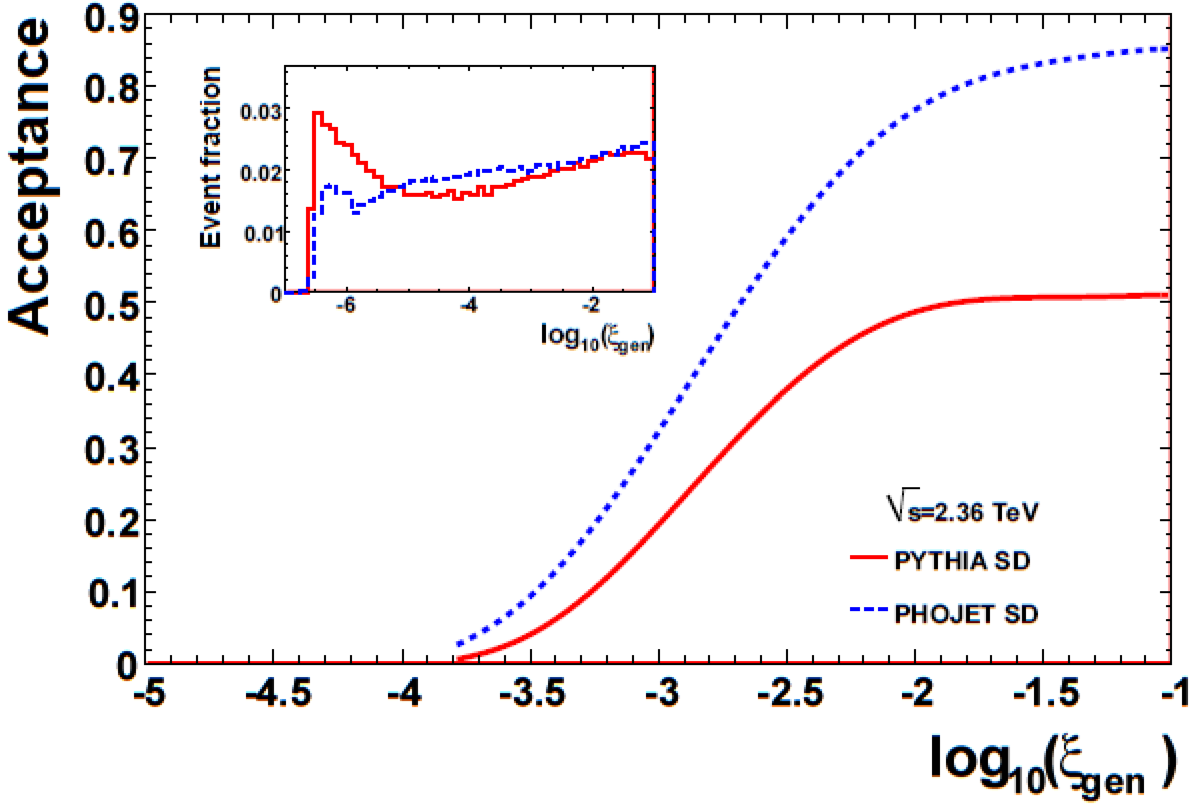
ATLAS kinematics – pt zoomed



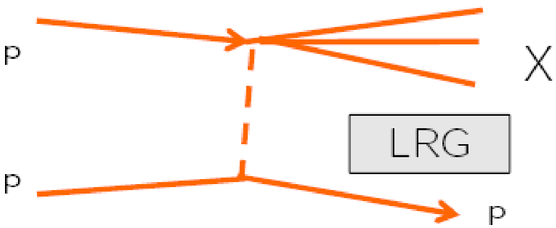
ALICE – triggered events table

Sample (# events)	% triggered	% triggered - process types
Phojet (269574)	3.9%	SD=28.8%; DD=6.5%; ND=0.6%; CD=50%
Pythia (240708)	4.9%	SD=30%; DD=9.8%; ND=0.7%

CMS – SD acceptance at 2.36 TeV



Single diffraction (SD)



$$\xi = M_X^2 / s$$
$$\sigma \approx 1/\xi$$
$$\Delta y \approx -\ln \xi$$
$$\xi \approx \Sigma_i (E_i \pm p_{z,i})$$

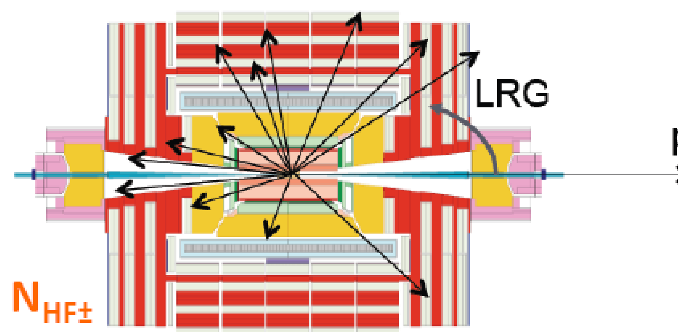
Along the lines of a 35y old ISR paper
[Phys.Rep.55, No. 1(1979)1-132]

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

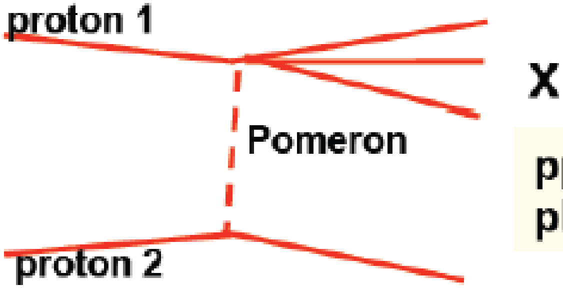


CONFIRM SD PEAK @ low $E_{HF\pm}$, $N_{HF\pm}$

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

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

Meaning of (E ± pz)



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

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.

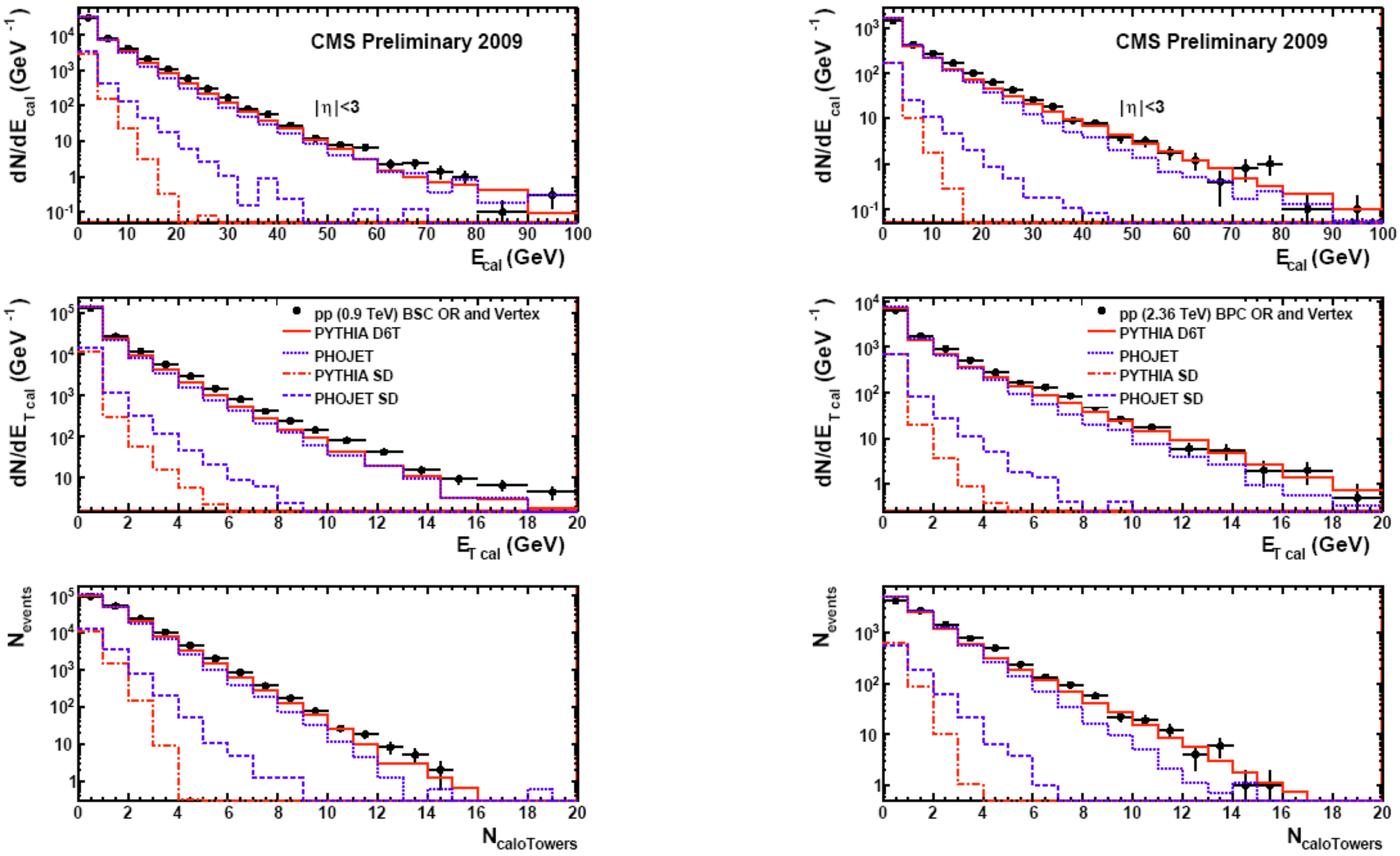
Diffractive peak expected at low values of this variable, reflecting the peaking of the cross section at small ξ.

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

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

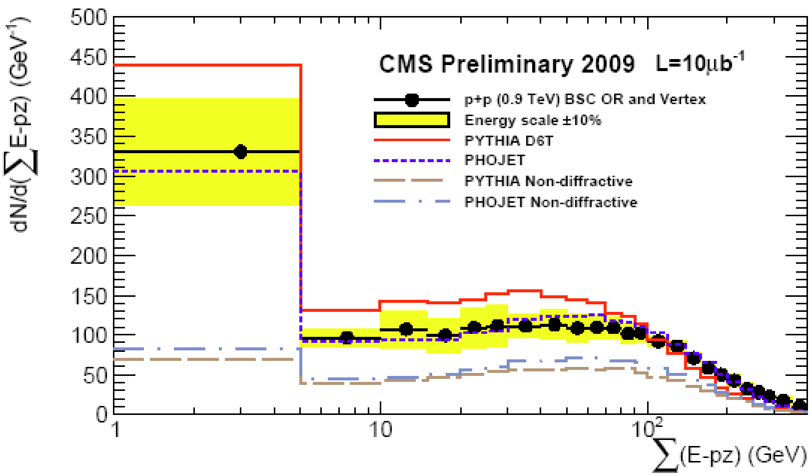
Diffractive peak expected at low tower multiplicity and at low energy deposition, reflecting the presence of a large rapidity gap over HF.

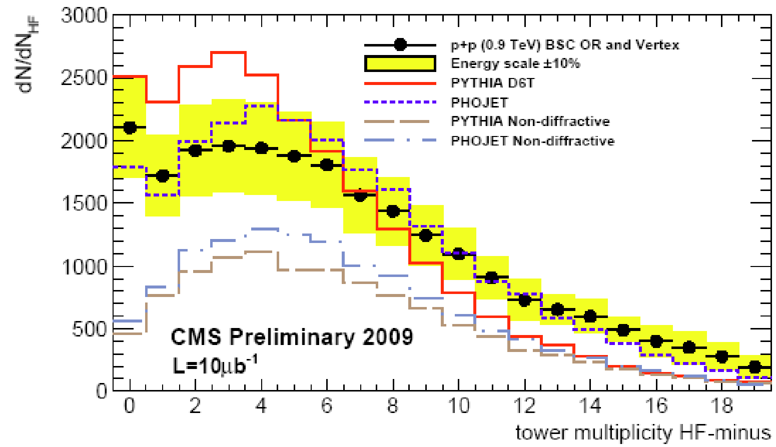
CMS – control plot

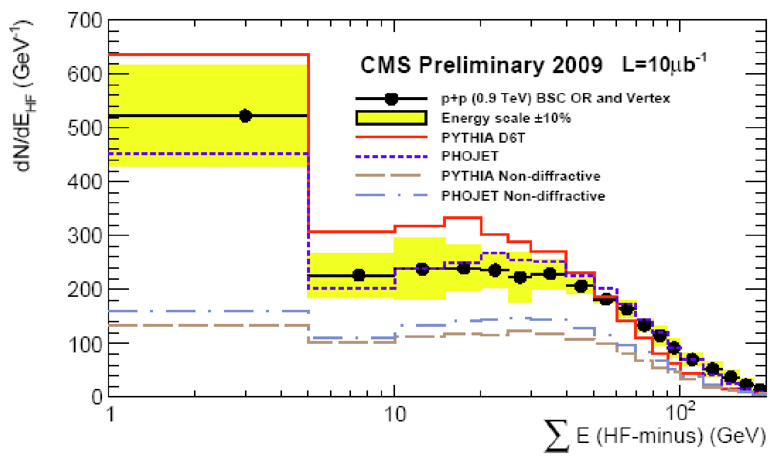


CMS – other side 900 GeV

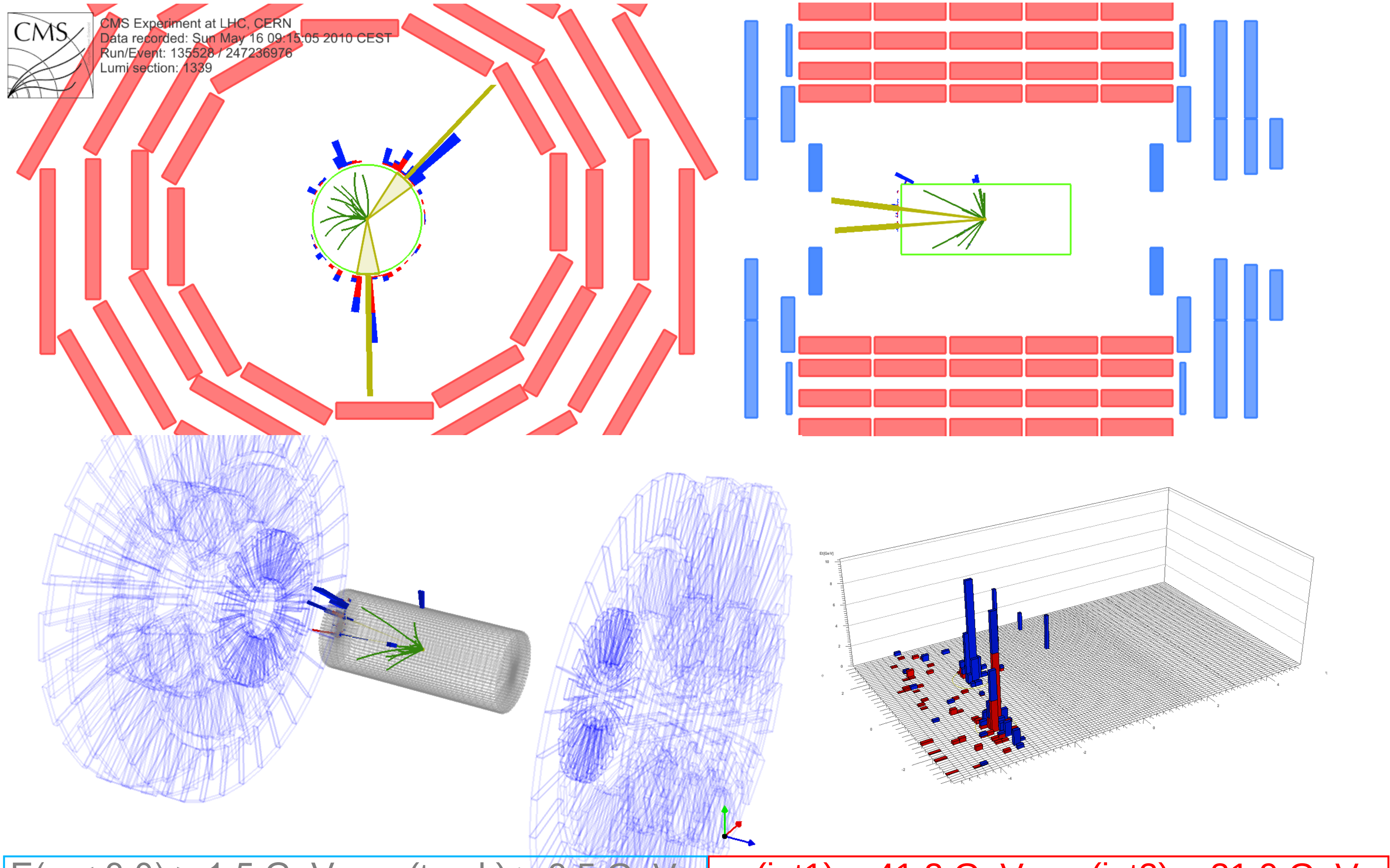
SD enhanced ⇒ $E_{HF+} < 8GeV$







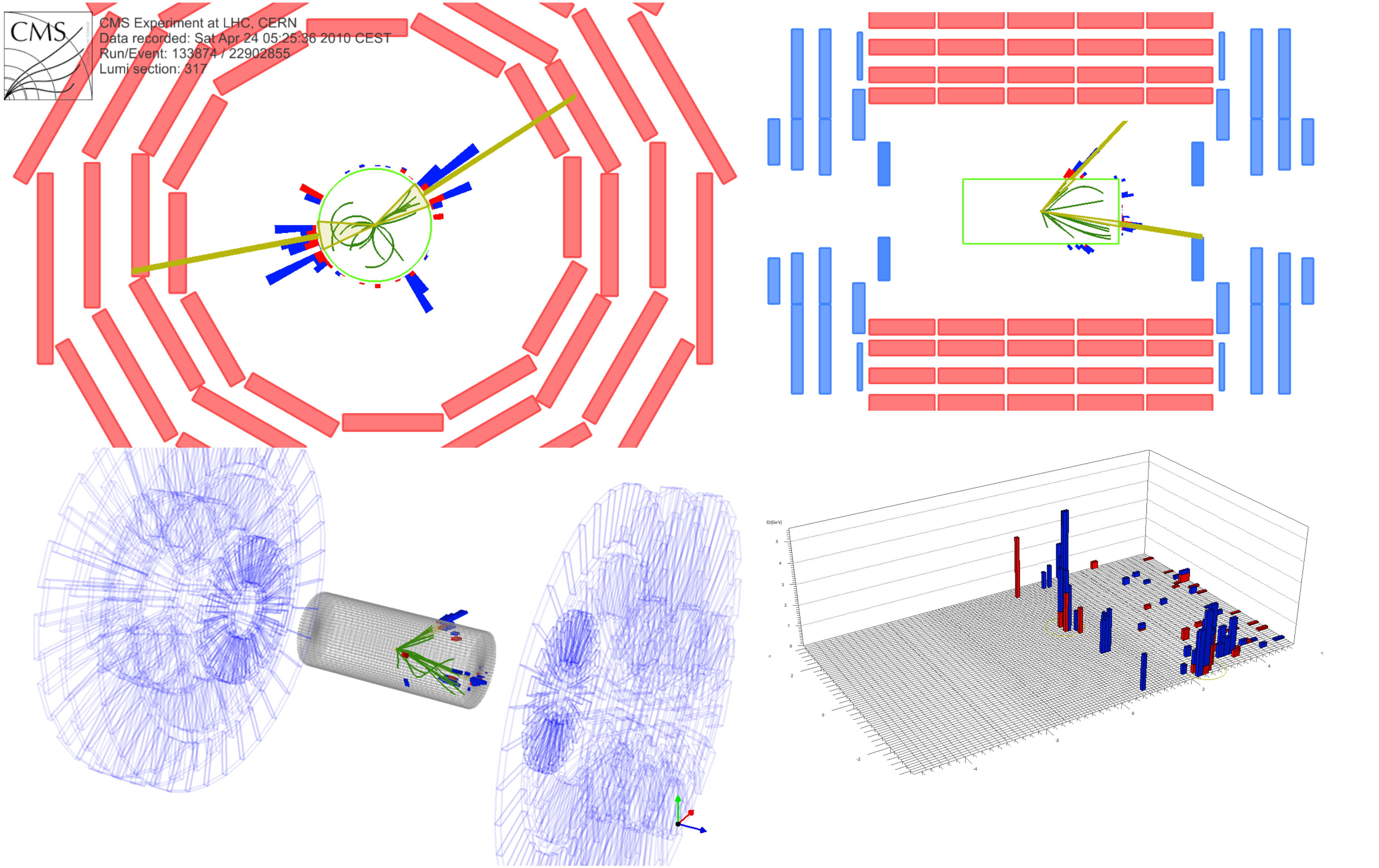
Diffractive dijet candidate at 7 TeV - CMS



E(η < 3.0) > 1.5 GeV p_T(track) > 0.5 GeV
E(η ≥ 3.0) > 2.0 GeV

p_T (jet1) = 41.2 GeV, p_T (jet2) = 31.9 GeV
η (jet1) = -2.8, η (jet2) = -3.3

Diffractive dijet candidate at 7 TeV - CMS



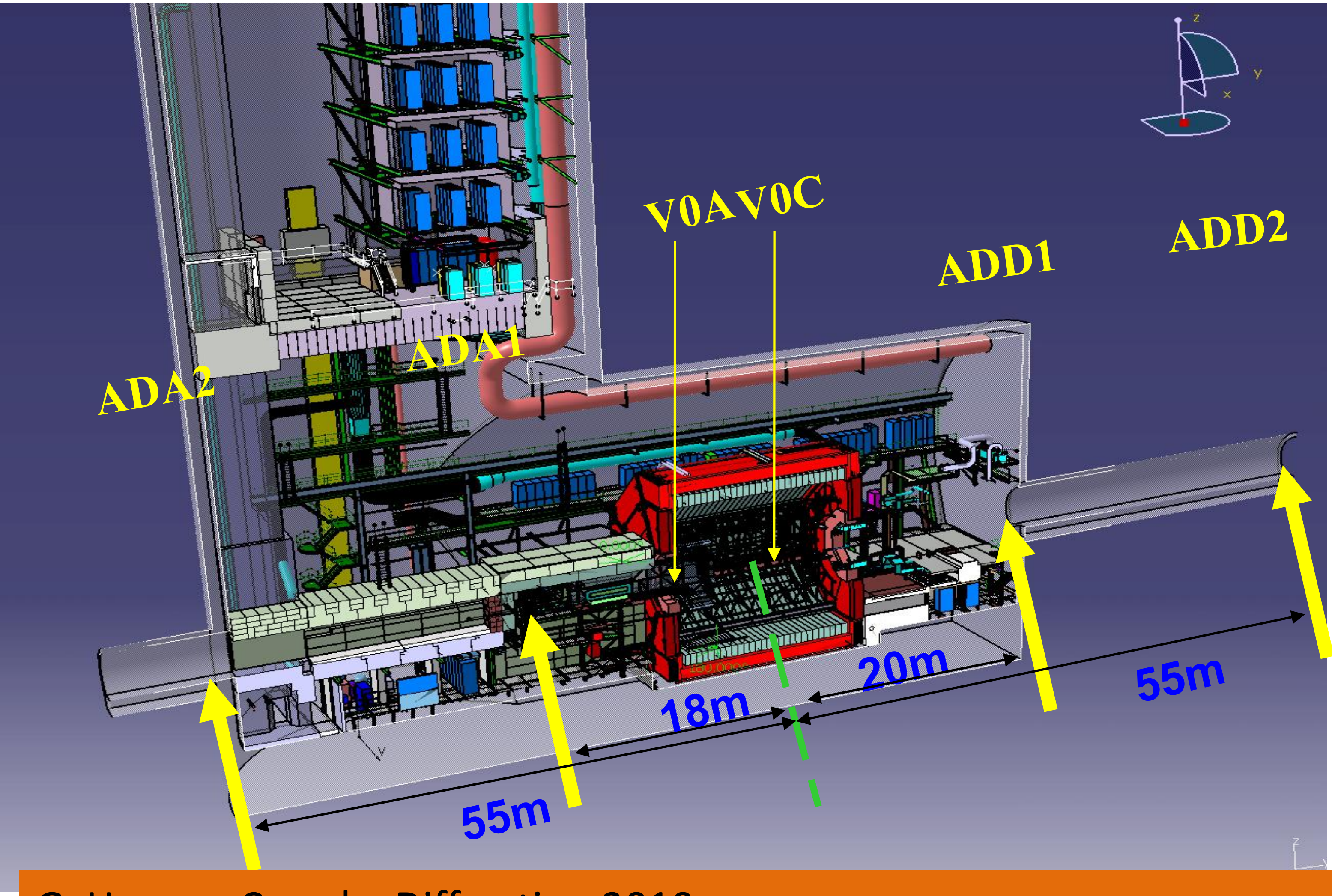
$E(\eta < 3.0) > 1.5$ GeV $p_T(\text{track}) > 0.5$ GeV
$E(\eta \geq 3.0) > 2.0$ GeV

p_T (jet1) = 43.5 GeV, p_T (jet2) = 36.9 GeV
η (jet1) = 0.83, η (jet2) = 2.55

Outlook – ALICE Diffractive

4 stations of scintillator detectors

ADA $5.5 < \eta < 7.5$
ADC -5.5 $> \eta > -7.5$
Sits in between V0 and ZDC



ATLAS Froward Proton - AFP

ATL-LUM-PROC-2010-003

Detector location

- what is needed? Good position and good timing measurements
- 220 m: movable beam pipes (in addition vertical roman pots for alignment purposes under study)
- 420 m: movable beam pipe (roman pots impossible because of lack of space available and cold region of LHC)