# Update on diffraction

- **Inclusive diffraction**
- **Diffractive di-jet production: event displays**
- **Diffractive W and Z production: event displays**

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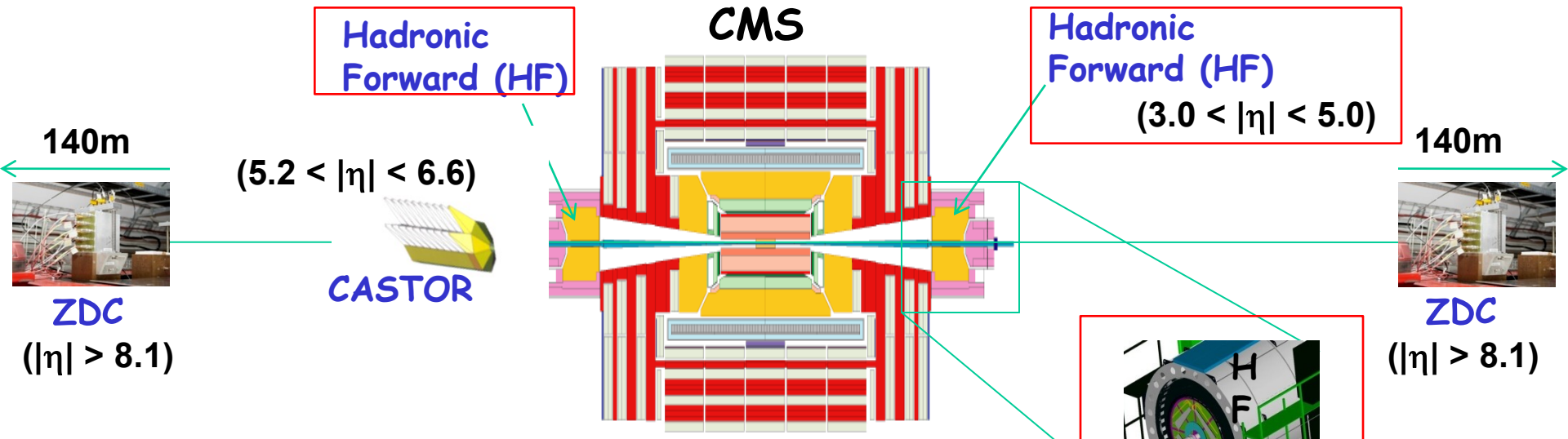
**(Univ. Piemonte Orientale, Novara, and INFN Torino)**
**on behalf of the CMS collaboration**
**MB/UE Workshop, 8 Feb 2011**

# Forward instrumentation at CMS

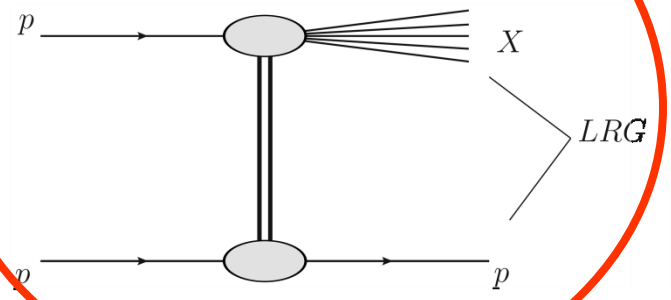



## Hadron Forward:

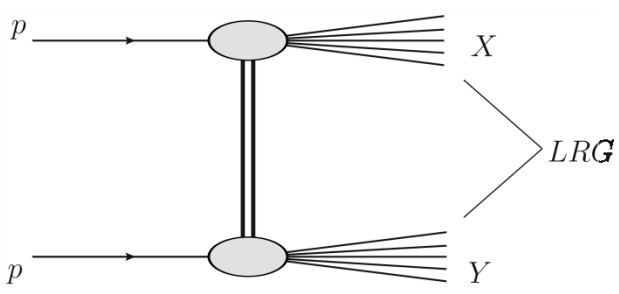
- @11.2m from interaction point (3 < |η| < 5)
- Steel absorbers/quartz fibers (Long+short fibers)

# Inclusive diffraction

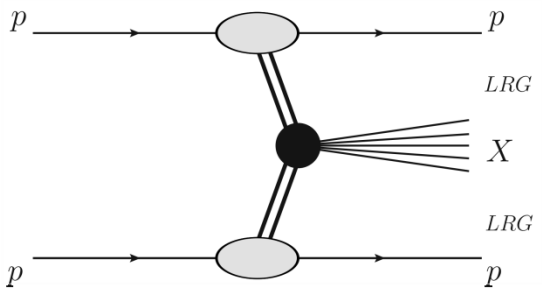
**Single-diffractive dissociation (SD):**



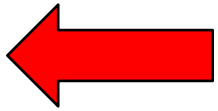

**Double-diffractive dissociation (DD):**




**Central-diffractive dissociation (CD):**




- **PAS FWD-10-001: Observation of diffraction at 900 and 2360 GeV (published in June 2010)**
- **PAS FWD-10-007: Observation of diffraction at 7 TeV**



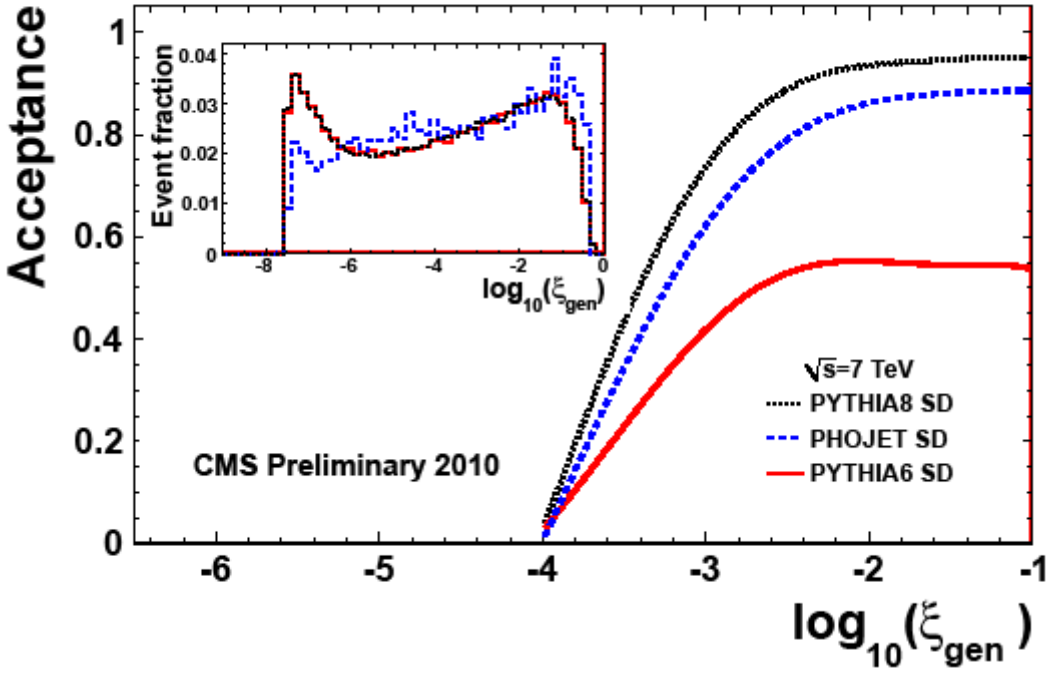
**NB All distributions uncorrected !**

# Event Selection/Acceptance

- Early run at 7 TeV, L=20$\mu b^{-1}$ (<$N_{PU}$>~0)

- Trigger: beam pick-ups (BPTX) + hit in BSC counters (on either side)

- Event selection:
  - high-quality primary vertex (ndof>4)
  - beam-halo and beam background rejection
  - calorimeter-noise cleaning




ξ=proton fractional momentum loss

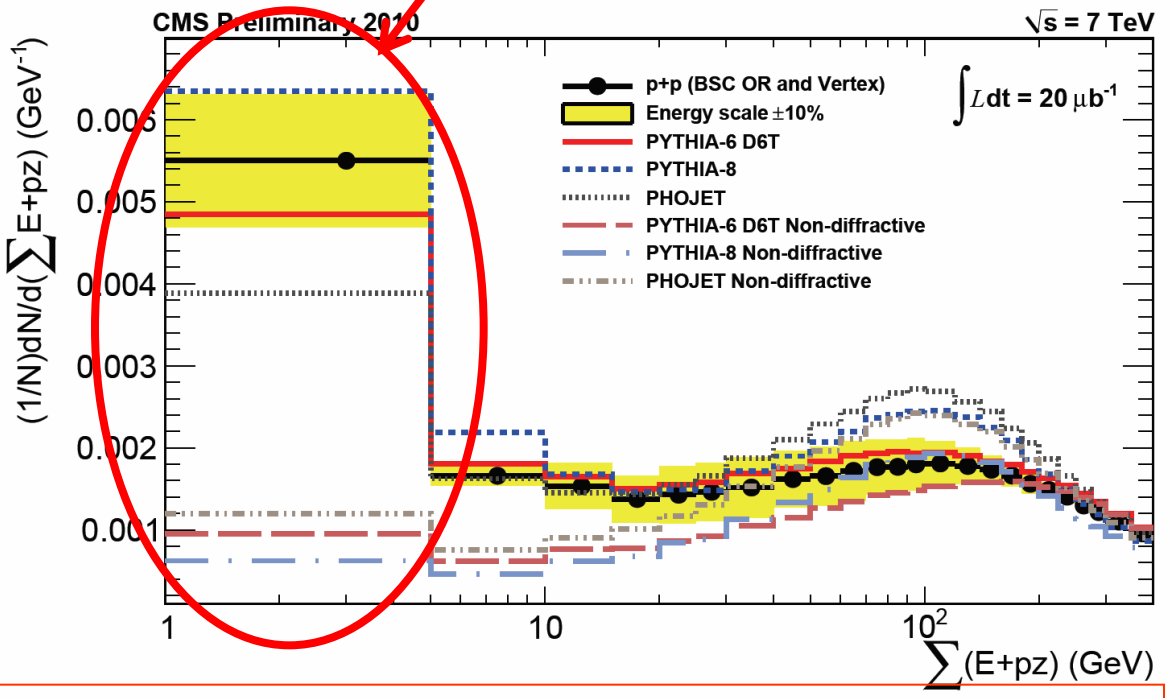
- Very low ξ events rejected by vertex requirement

- Large discrepancy between generators (more to come)

# Evidence of inclusive diffraction (I)

- **Inclusive diffractive cross section peaks at small proton momentum loss: $\sigma \sim 1/\xi$**

- **$\xi \sim \Sigma (E + p_z)$ for scattered p in +ve z direction**
- **$\xi \sim \Sigma (E - p_z)$ for scattered p in -ve z direction**




**Uncorrected !**

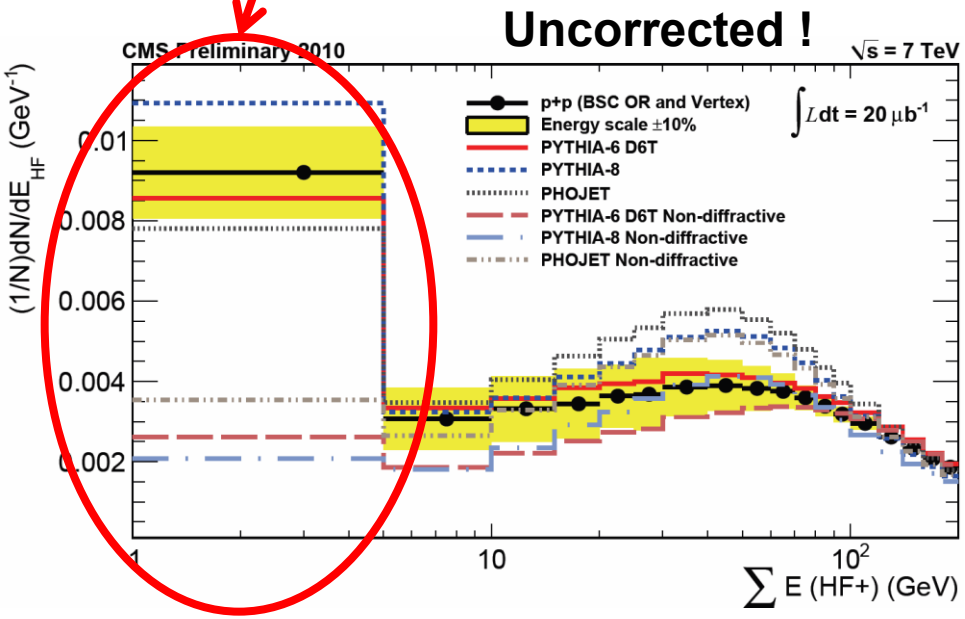
**Observed diffraction via diffractive peak**

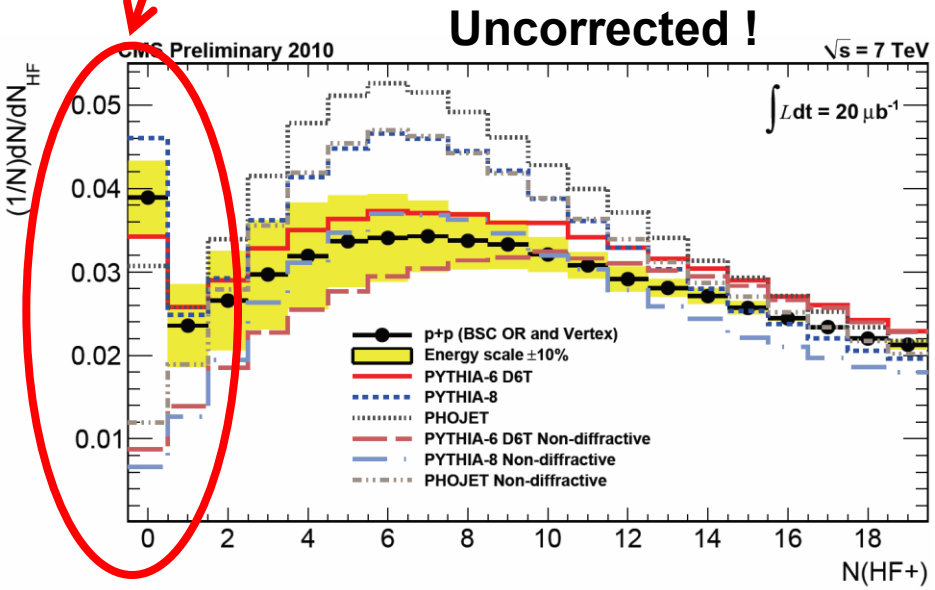
# Evidence of inclusive diffraction (II)

- **Inclusive diffraction characterised by large rapidity gap**

**No energy deposition in HF**
**ie gap over HF**

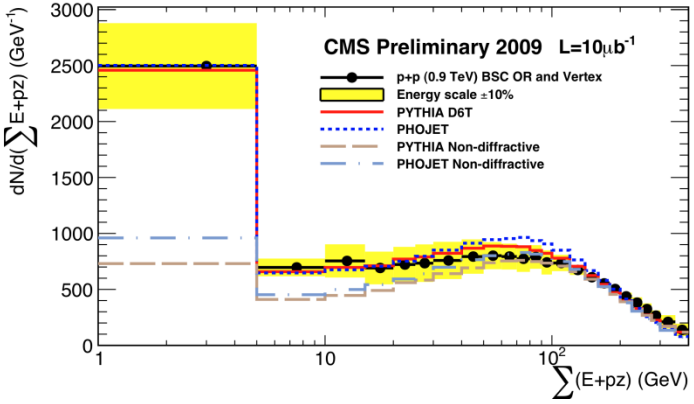
**Zero tower multiplicity in HF**
**ie gap over HF**



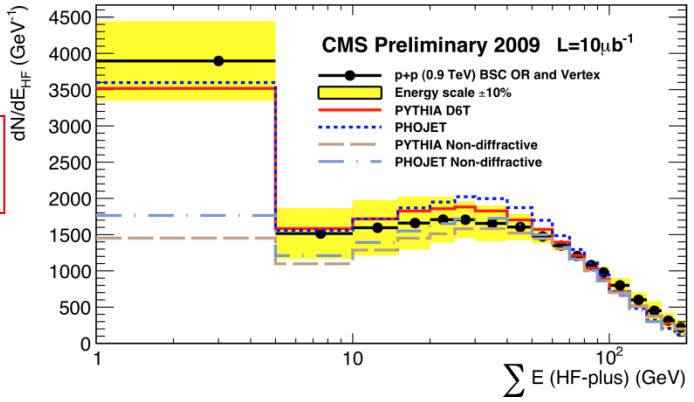



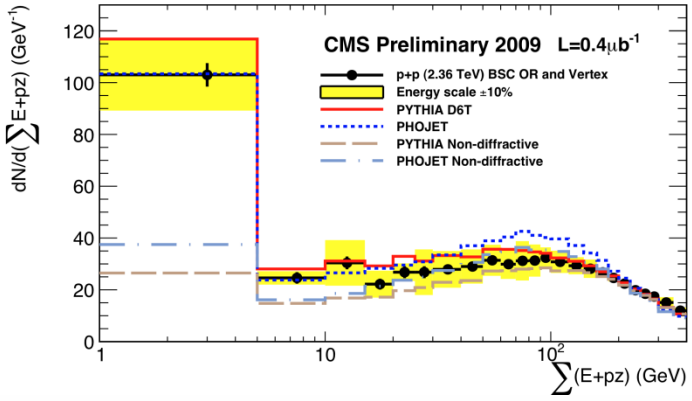

**Observed diffraction via large rapidity gap**

# Inclusive diffraction vs √s

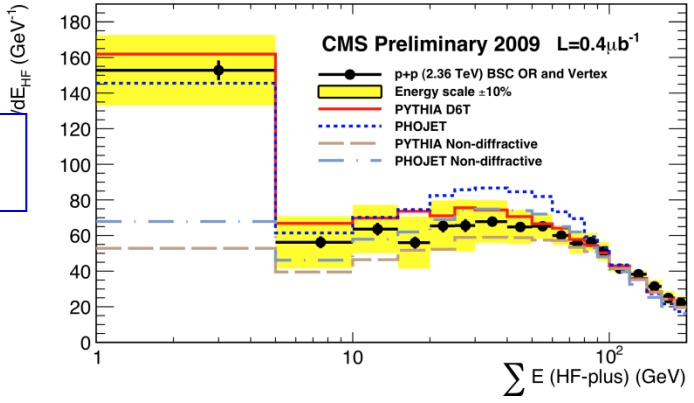


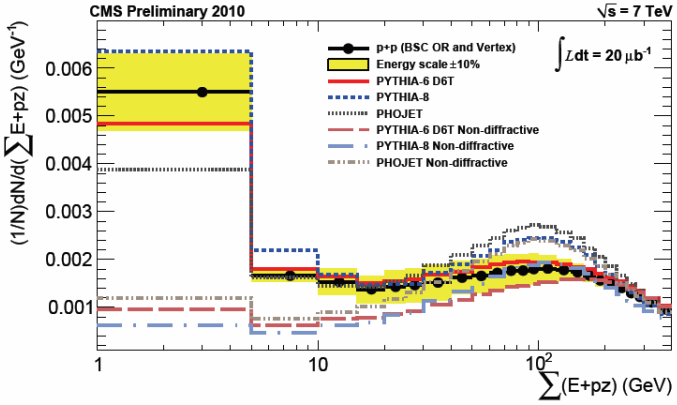

900 GeV



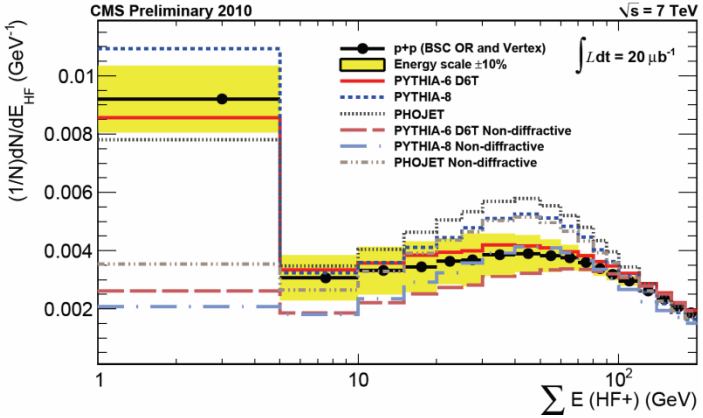




2.36 TeV



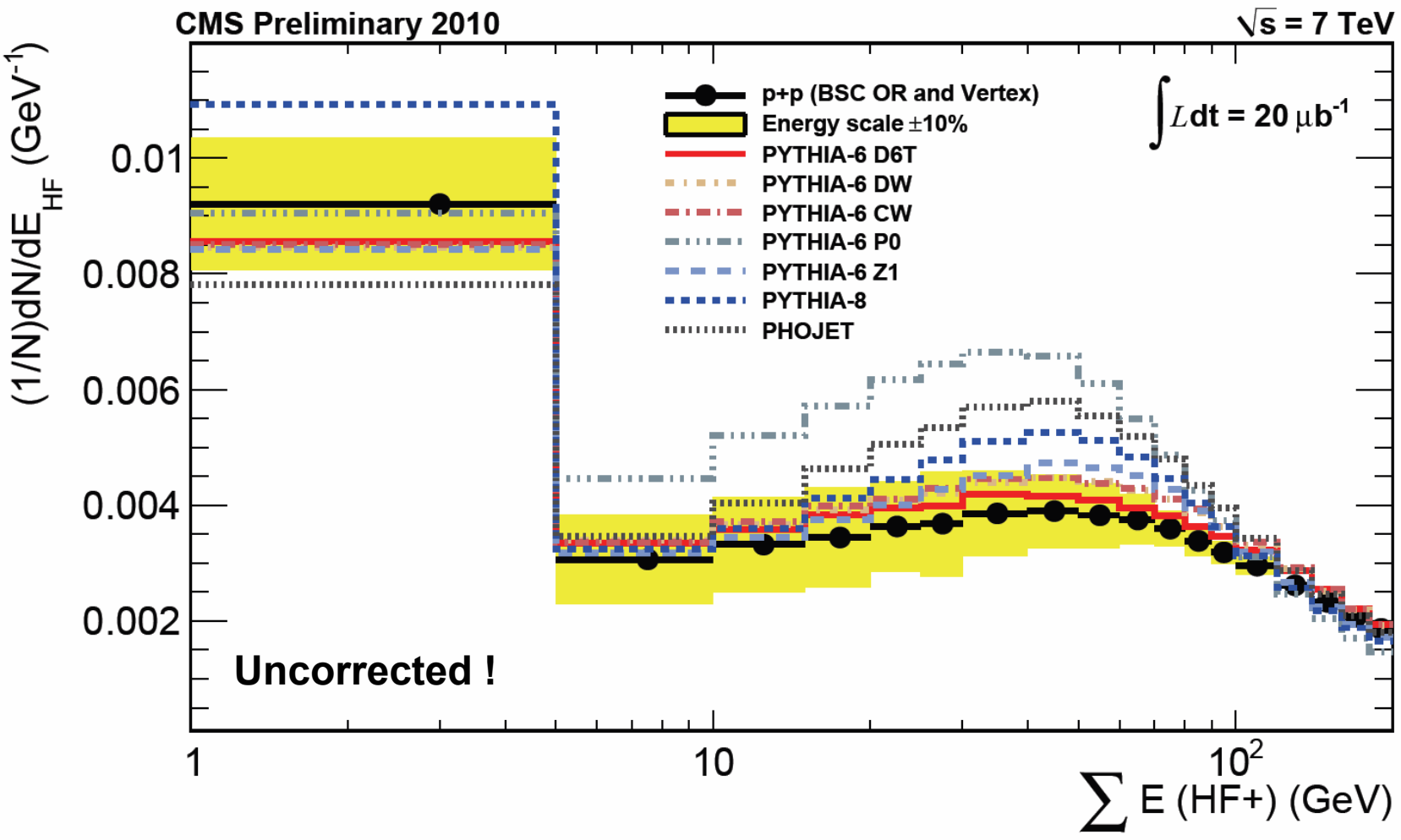




7 TeV



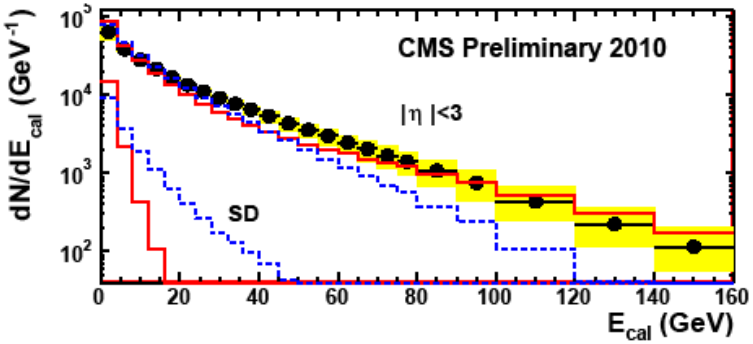
# Data vs MC

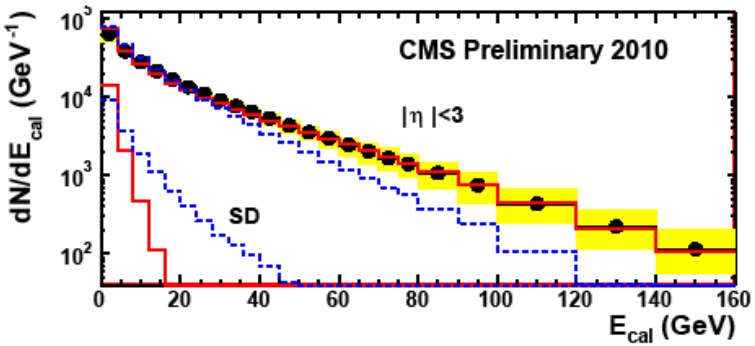
# Data vs MC (forward: 3<|η|<5)

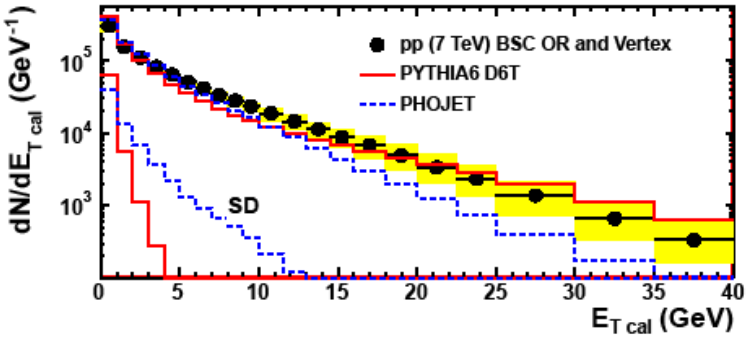


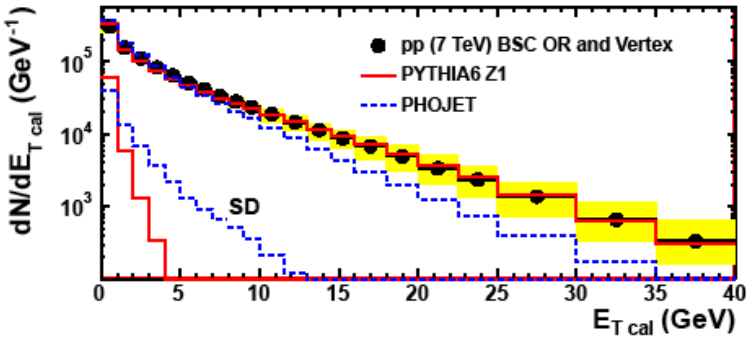

| Pythia6 | D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|---|
| | ok | ok | ok | very bad | ok | bad | very bad |

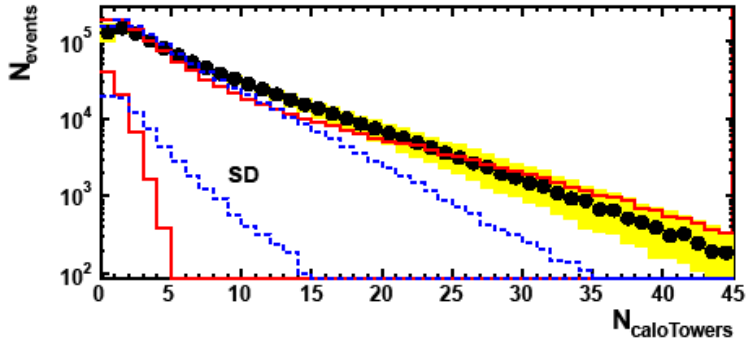
# Data vs MC (cal |η|<3)

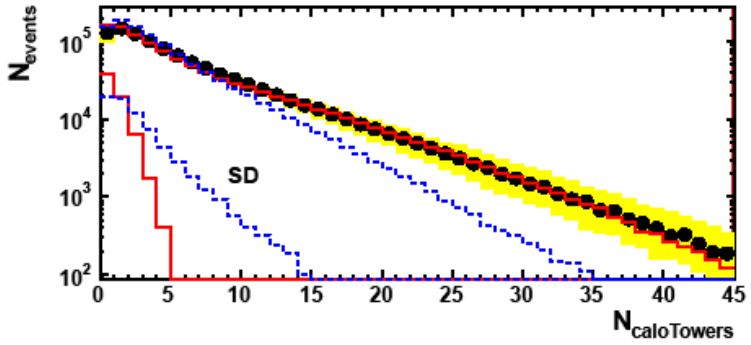


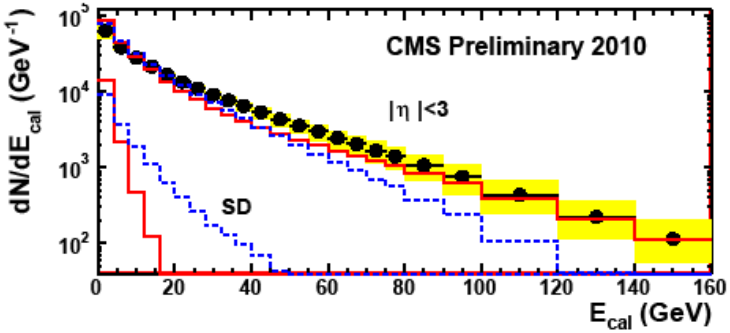



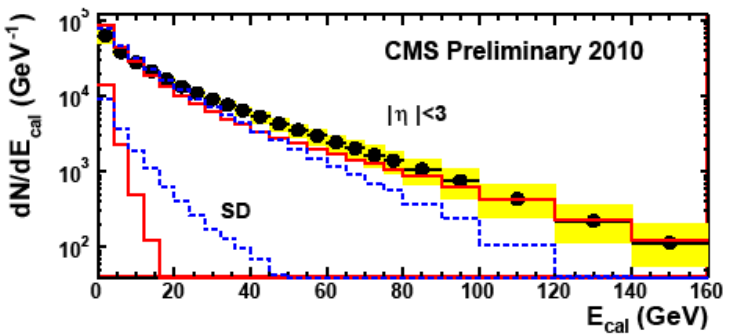



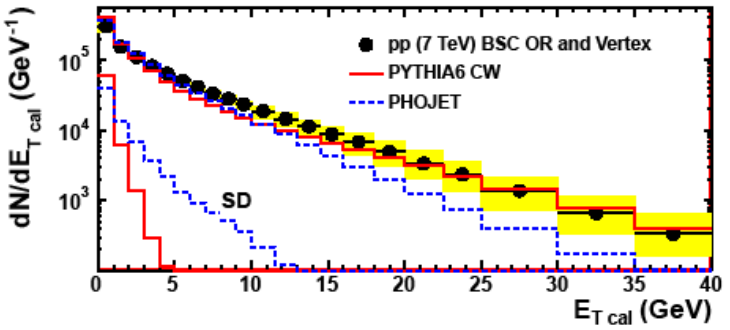

Uncorrected !

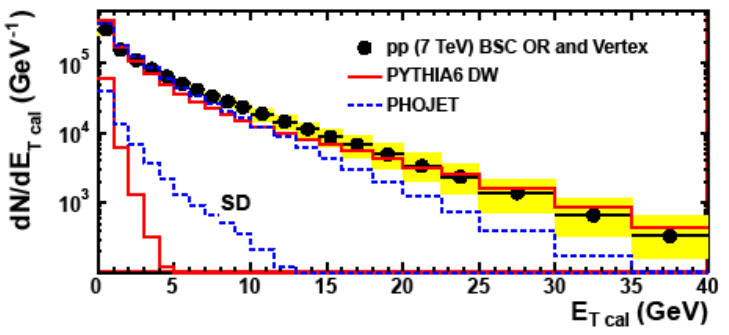
Pythia6 D6T fair DW fair CW fair P0 bad Z1 ok Pythia 8 fair Phojet very bad

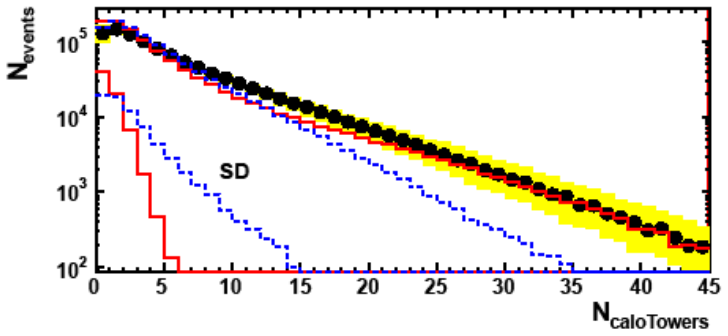
# Data vs MC (cal |η|<3)

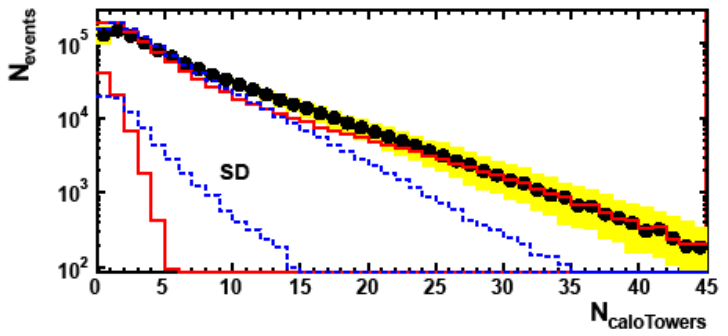


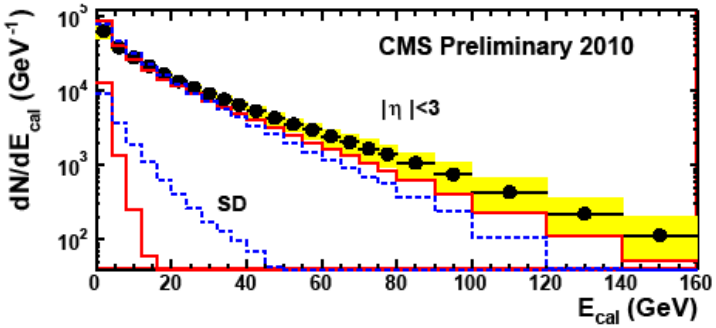



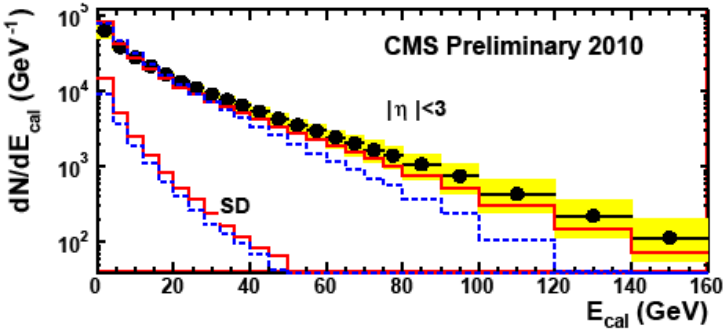



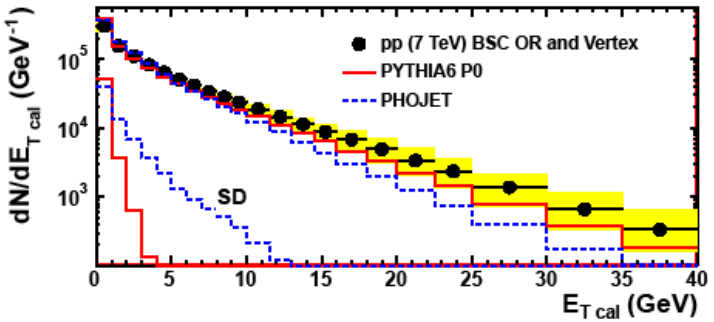

Uncorrected !

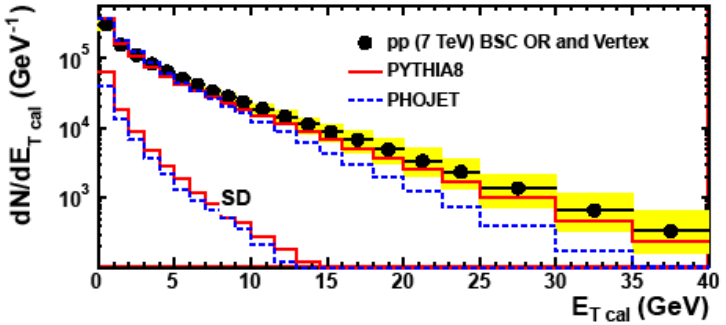
Pythia6 D6T fair DW fair CW fair P0 bad Z1 ok Pythia 8 fair Phojet very bad

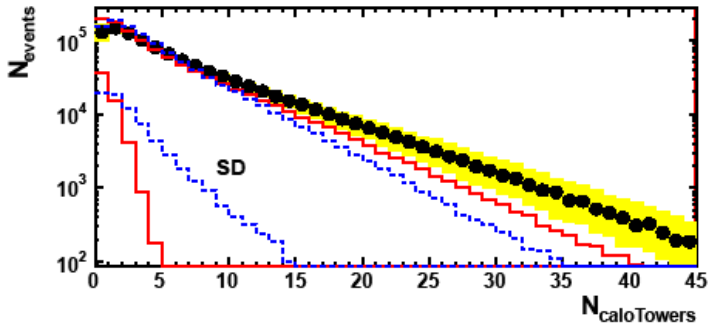
# Data vs MC (cal |η|<3)

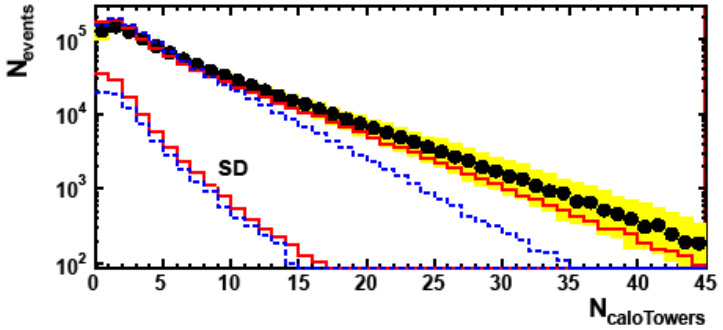


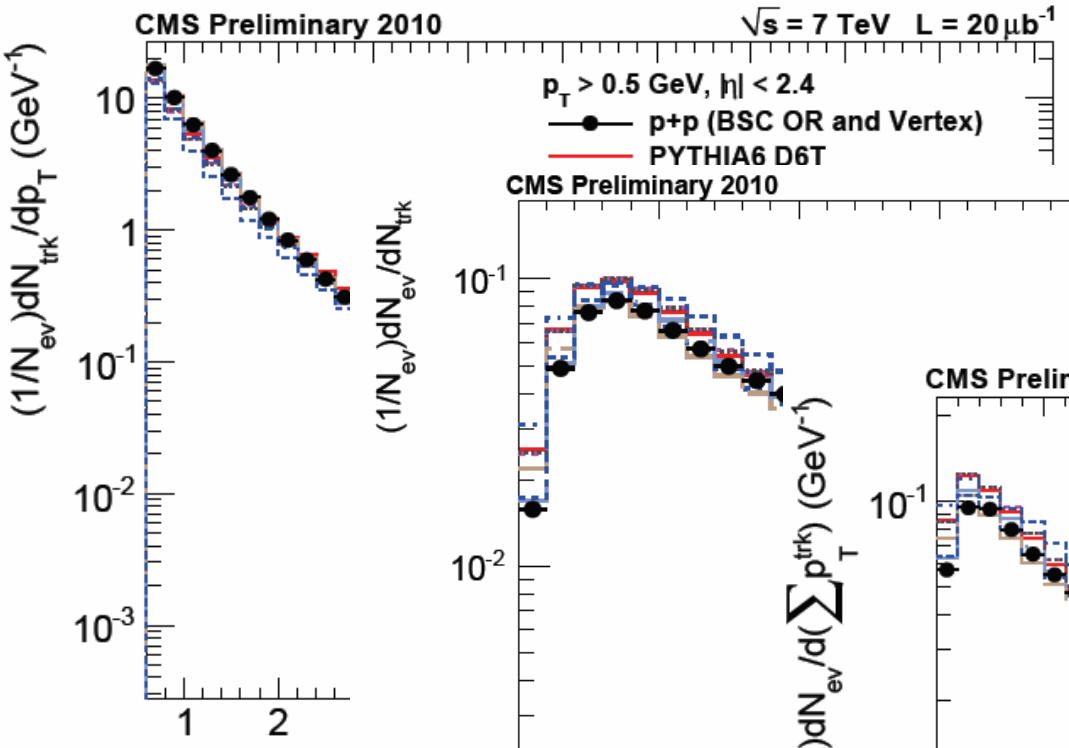



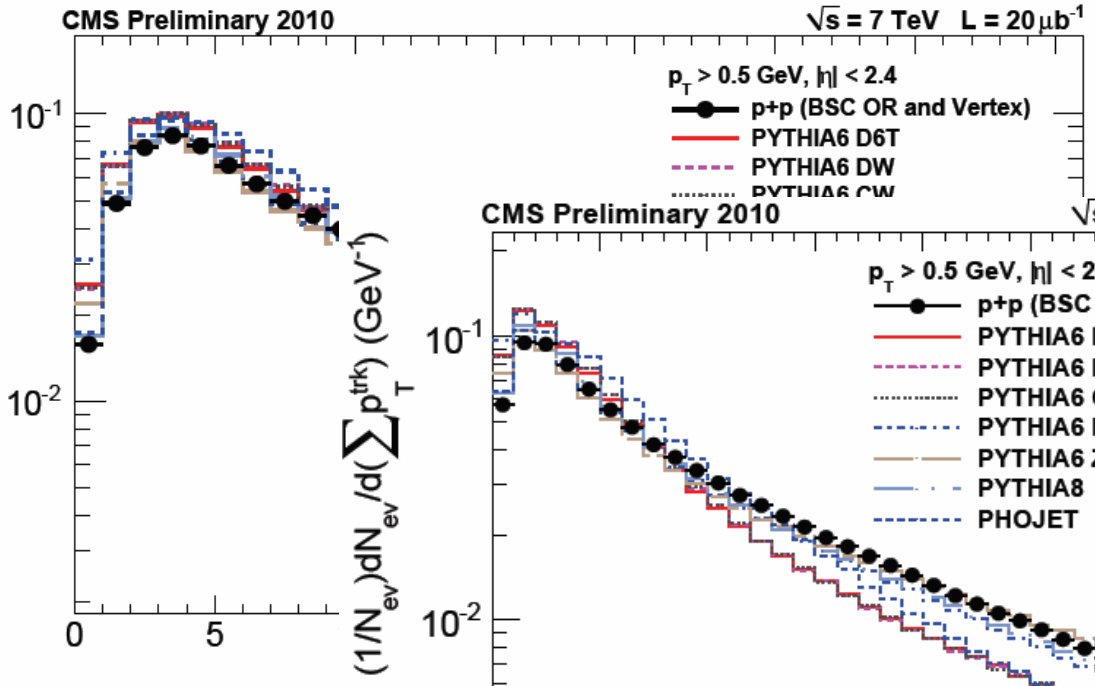




Uncorrected !

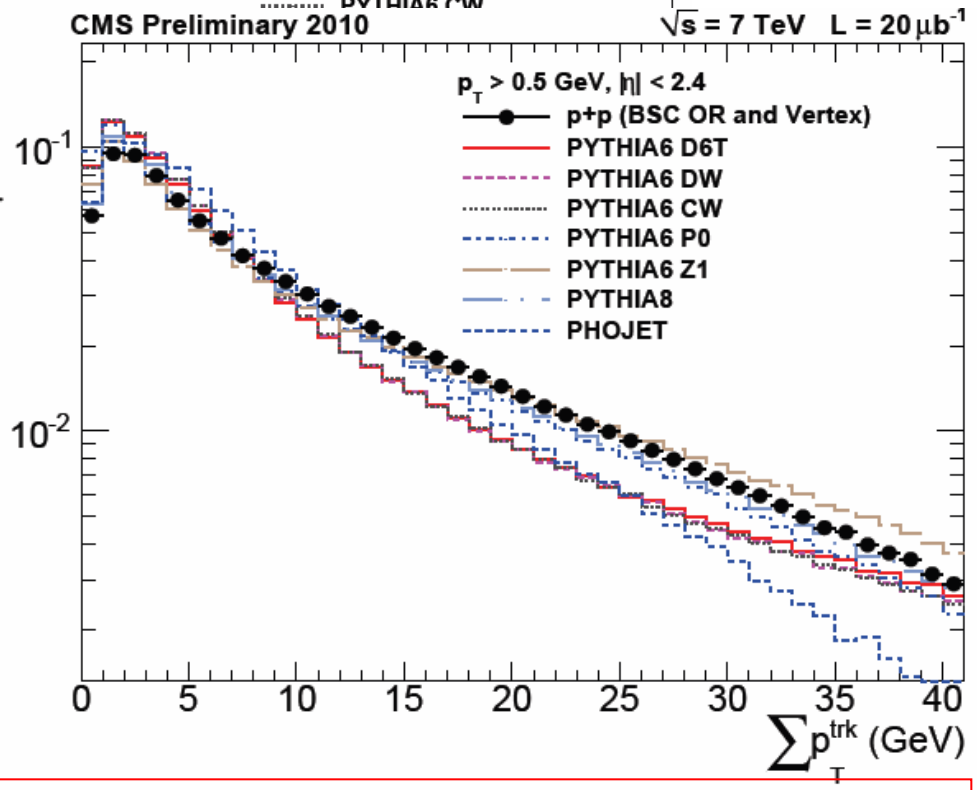
| Pythia6 | D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|---|
| | fair | fair | fair | bad | ok | fair | very bad |

# Data vs MC (tracking |η|<2.4)




**Uncorrected !**

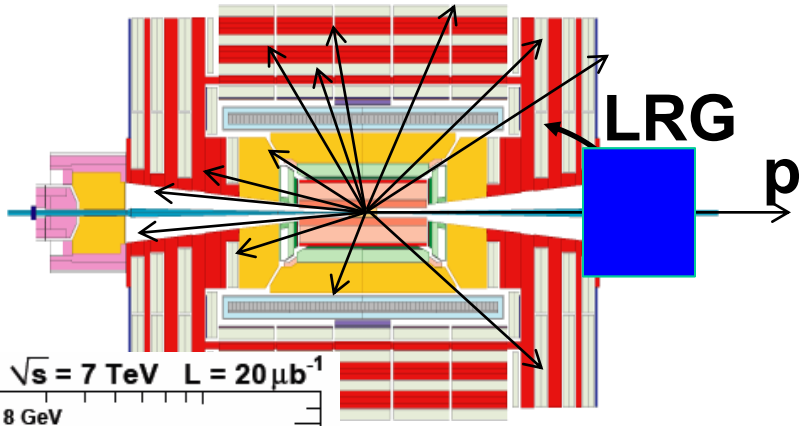


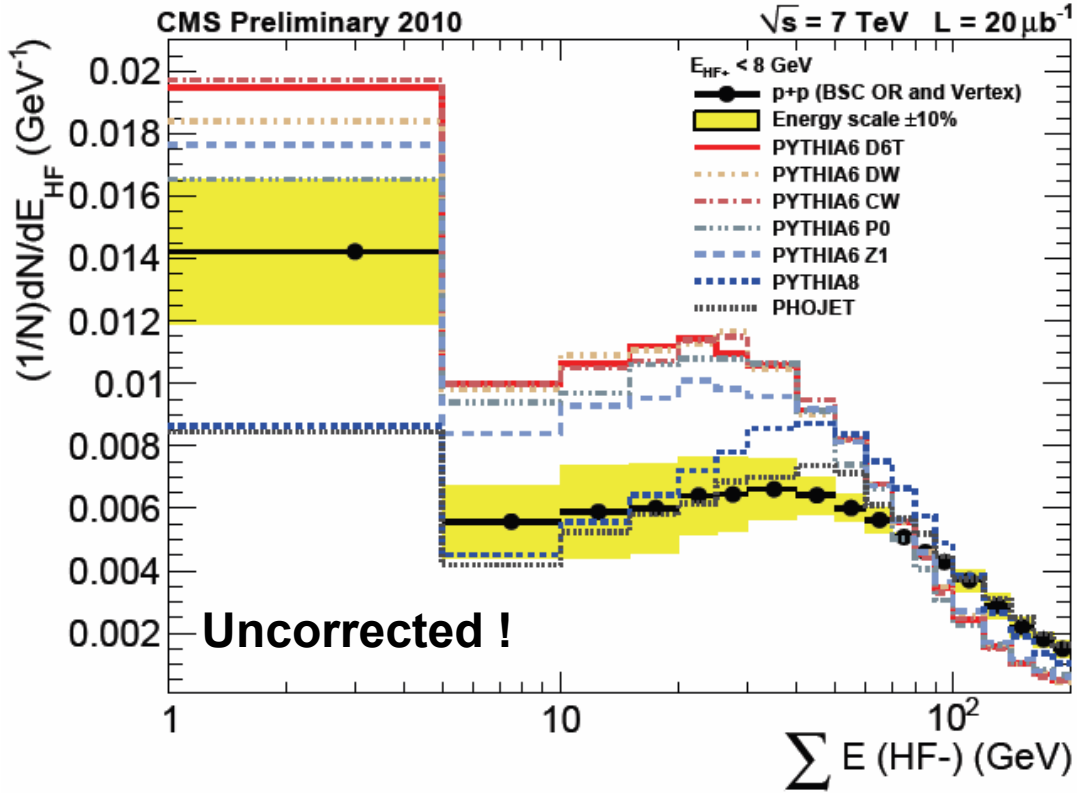

**$p_T$>0.5 GeV**

| Pythia6 D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|
| bad | bad | bad | fair | fair | ok | bad |

# Enhance diffr. component: data vs MC (forward)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

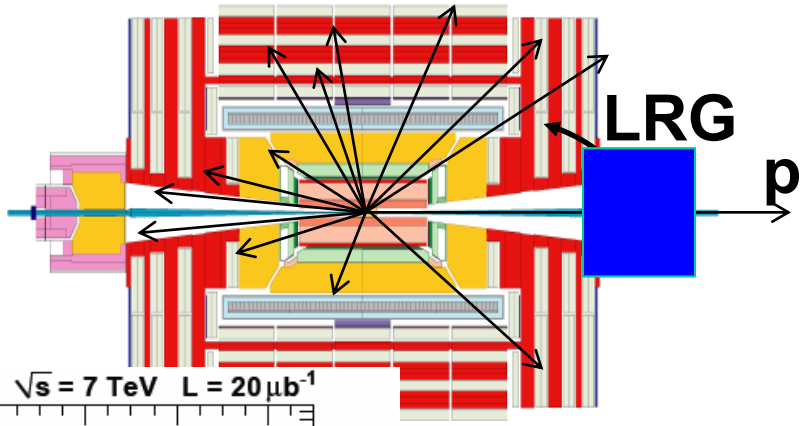


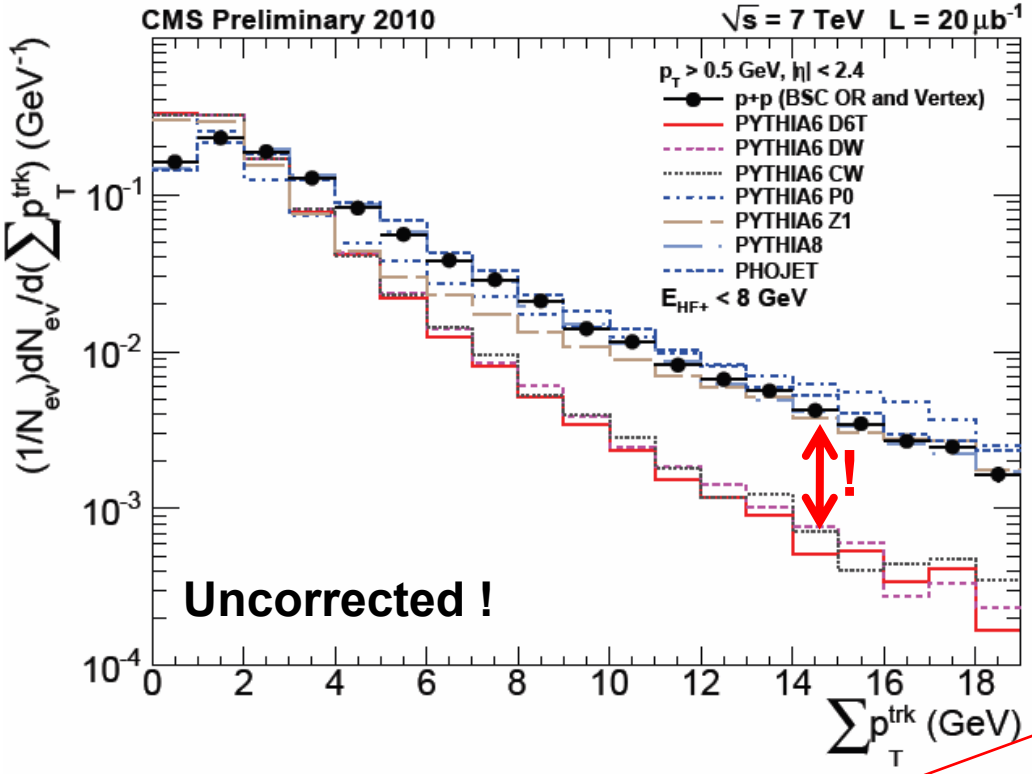




| Pythia6 D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|
| bad | bad | bad | bad | bad | bad | fair (but not low E) |

# Enhance diffr. component: data vs MC (tracking)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**




(only at high $p_T$)

| Pythia6 D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|
| bad | bad | bad | fair | fair | ok | fair |

# Summary of data vs MC comparison

1) Distributions without diffractive enhancement:

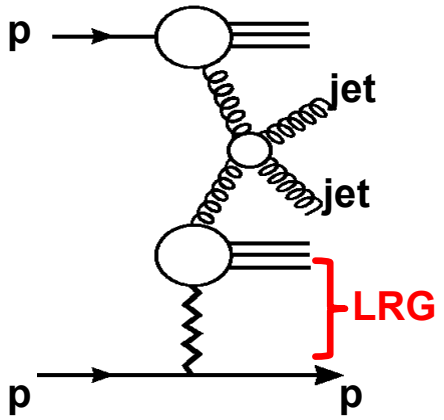
| | Pythia6 | D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|---|---|
| CAL $\|\eta\|<3$ | | fair | fair | fair | bad | ok | fair | very bad |
| Tracking | | bad | bad | bad | fair | fair | ok | bad |
| Forward | | ok | fair | fair | bad | fair | bad | bad |

2) Distributions with diffractive enhancement

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Tracking | bad | bad | bad | fair | fair | ok | fair |
| Forward | bad | bad | bad | bad | bad | bad | fair |

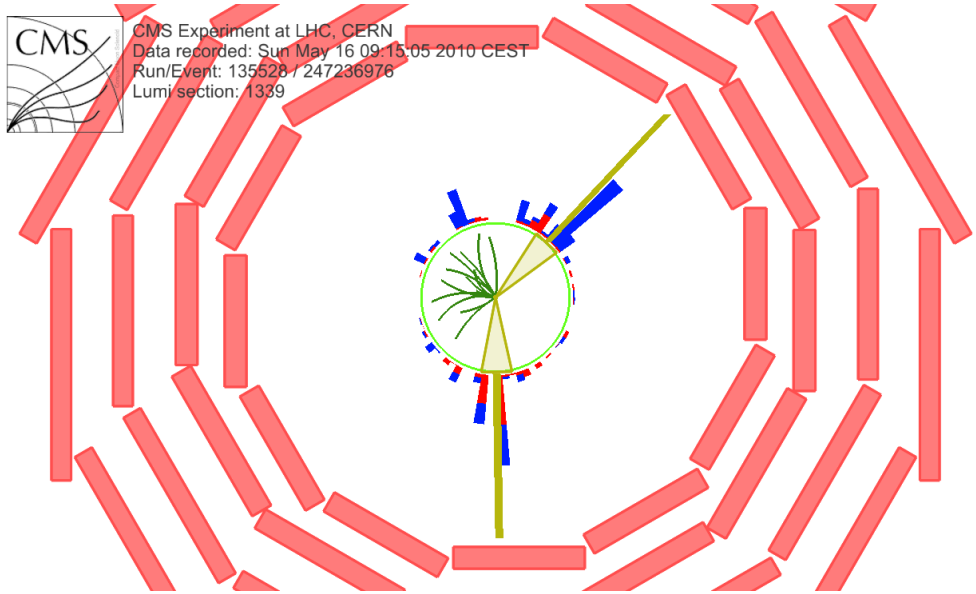
- No single MC describes the data in their entirety
- Diffraction best reproduced by Phojet and Pythia8 (in central region)
- Inclusive distributions best reproduced by Pythia6 (Z1 in central region, D6T in forward) and Pythia8

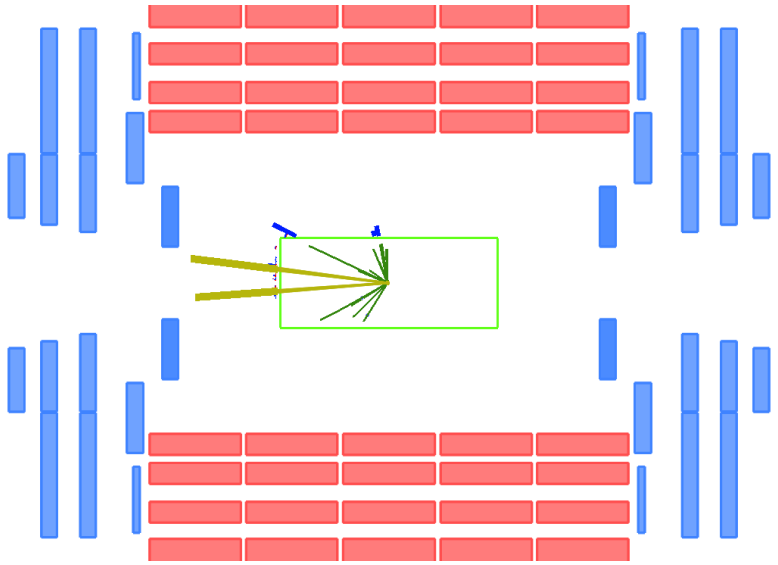
# Diffractive dijet production

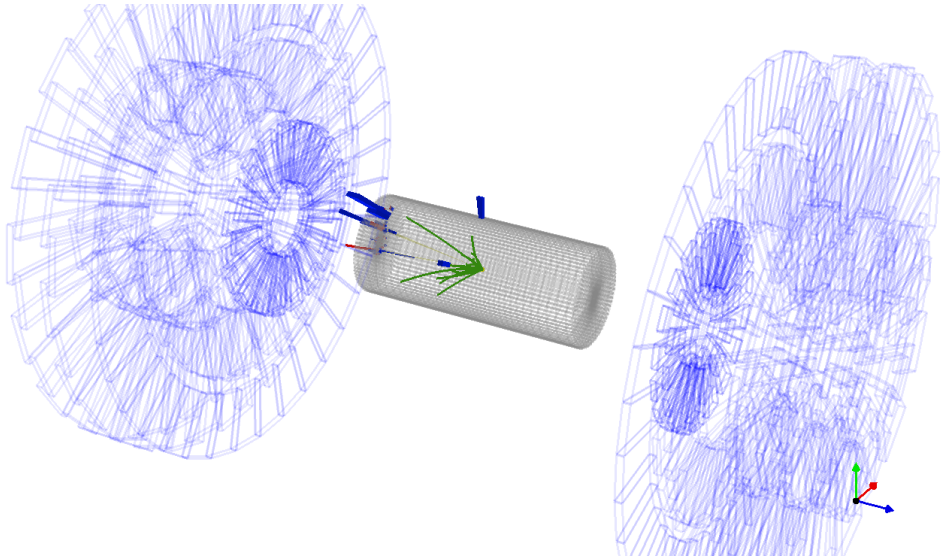


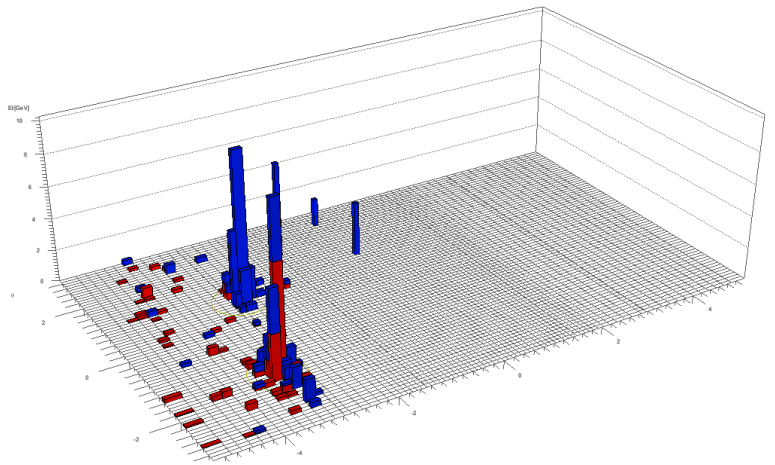

**Event Displays: DPS note DP-2010-036**

# Diffractive dijet candidate at 7 TeV





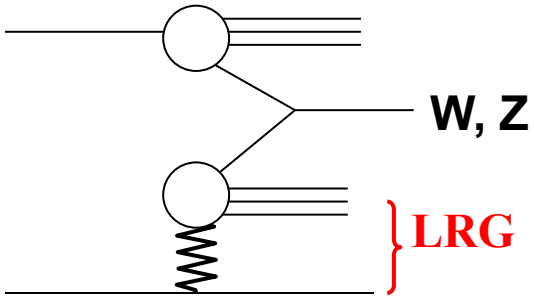


DPS note DP-2010-036

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

$p_T$ (jet1) = 41.2 GeV, $p_T$ (jet2) = 31.9 GeV
$\eta$ (jet1) = -2.8, $\eta$ (jet2) = -3.3

# Diffractive W & Z production



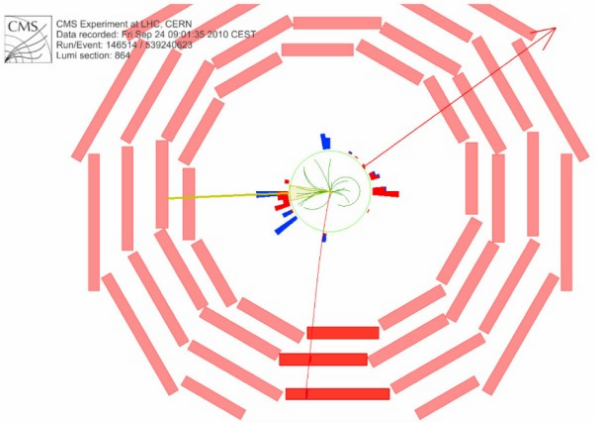

**Event displays [DPS note DP-2011-01 ]**

# Diffractive W candidate at 7 TeV

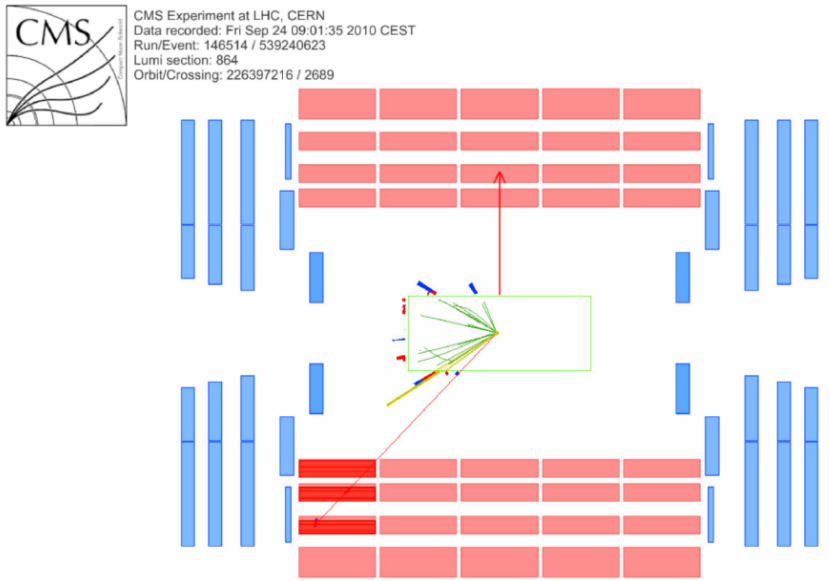
## W -> mu nu

Run: 146514
Event: 539240623
Lumi Section: 864

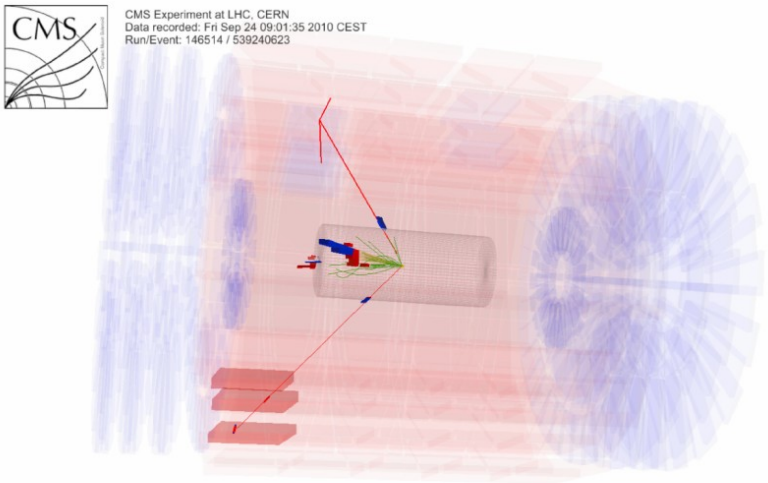
Muon: $p_T = 40.3$ GeV
Muon: $\eta = -0.85$
MET: $\not{E}_T = 49.4$ GeV
Transverse mass: $m_T = 82.1$ GeV/$c^2$

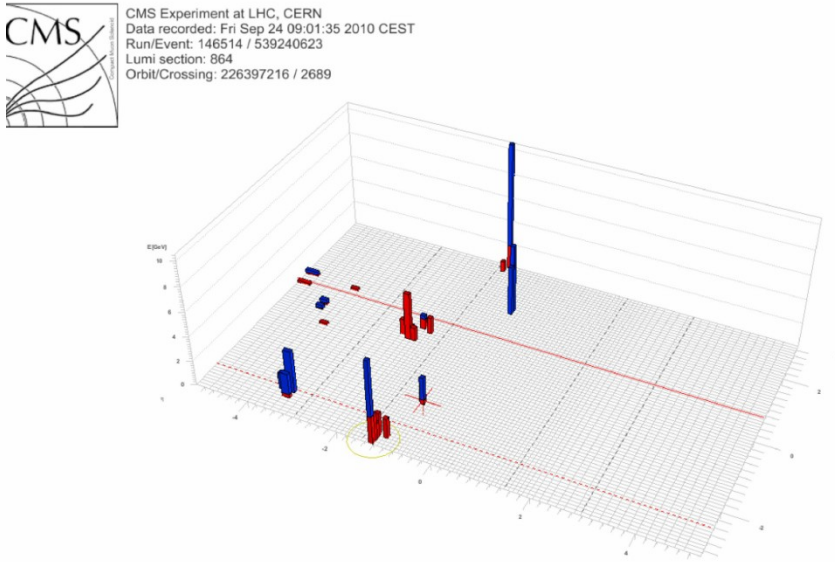



## W -> mu nu




## W -> mu nu



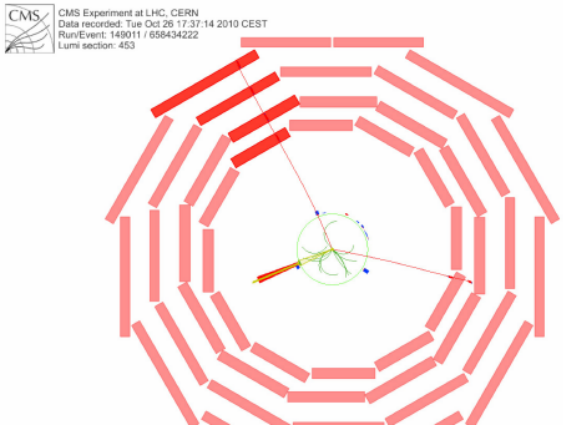

DPS note DP-2011-01

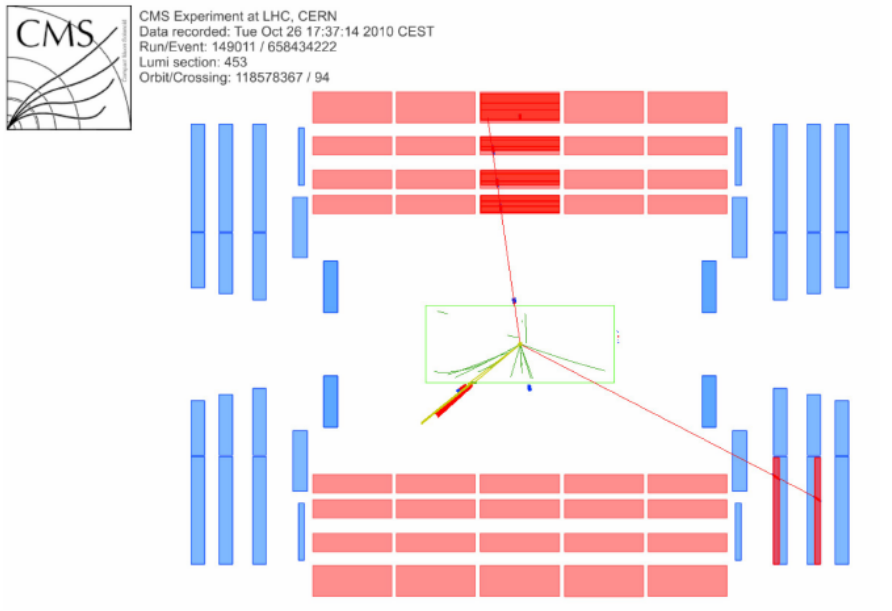
# Diffractive Z candidate at 7 TeV

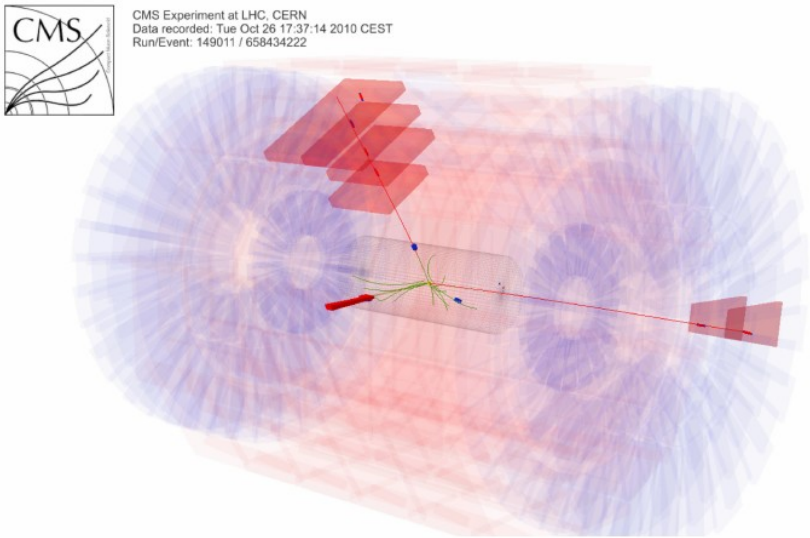
Z -> mu mu

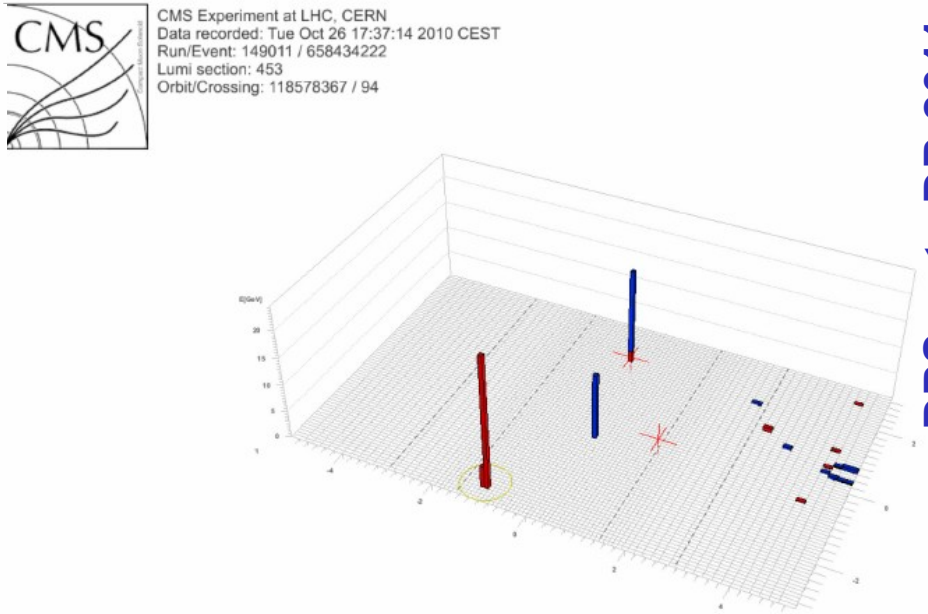
Run: 149011
Event: 658434222
Lumi Section: 453

Muon 1: $p_T = 42.6$ GeV
Muon 2: $p_T = 28.1$ GeV
Muon 1: $\eta = -1.4$
Muon 2: $\eta = -0.1$
Invariant mass: $m_{ll} = 84.8$ GeV/$c^2$



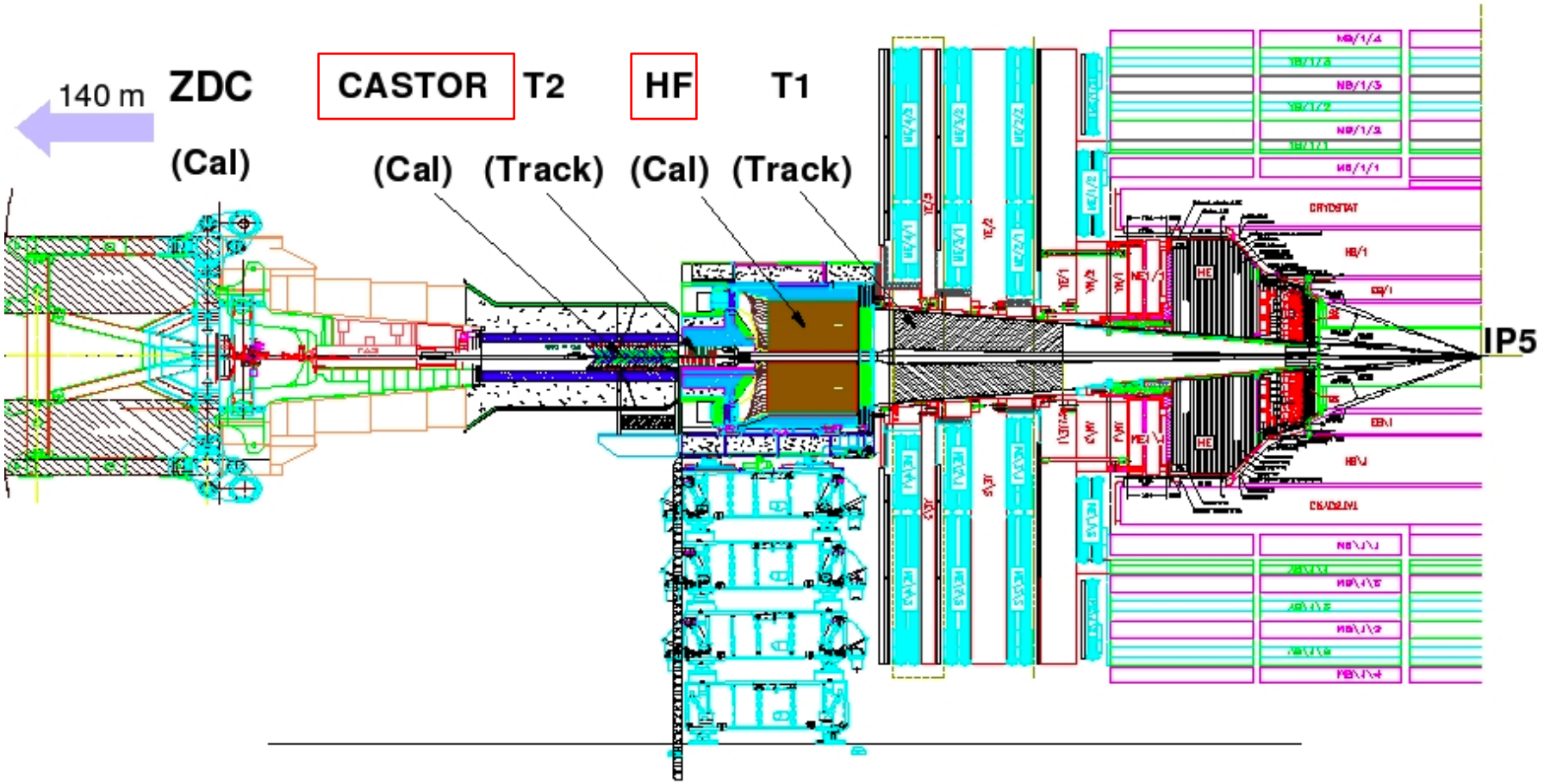

DPS note DP-2011-01

# Summary

- Diffraction “re-discovered” at 7 TeV – results complement those at 900 and 2360 GeV from 2009
- Uncorrected data compared with Pythia6, Pythia8 and Phojet in central (calorimeter and tracking) and forward regions
- Phojet/Pythia8 give better description of diffractive-enhanced distributions
- Pythia6 does not describe the diffractive component
- Hard diffraction there…

# BACKUP

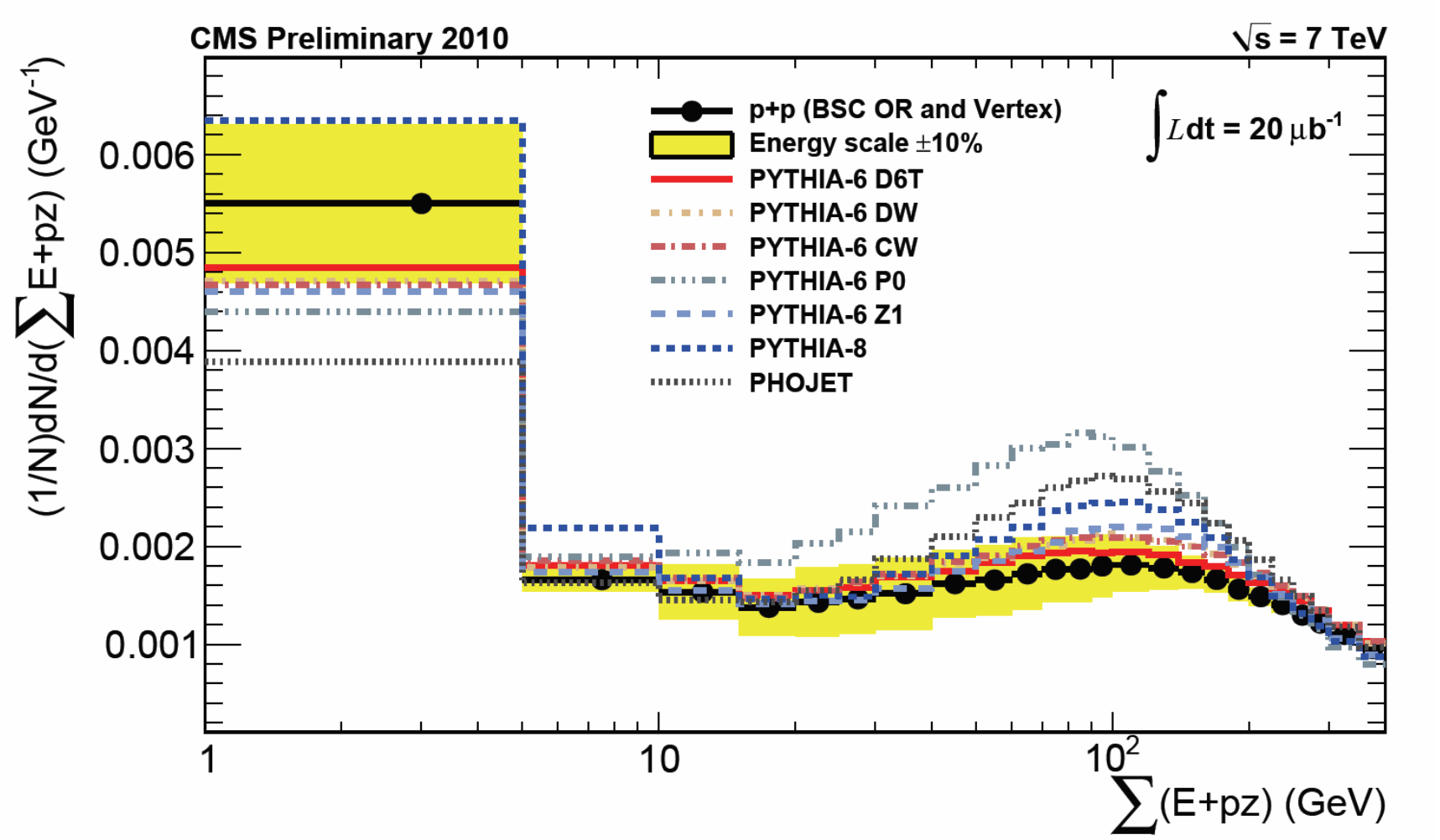
# Forward instrumentation at CMS




HF $3 \leq |\eta| \leq 5$ (CMS)

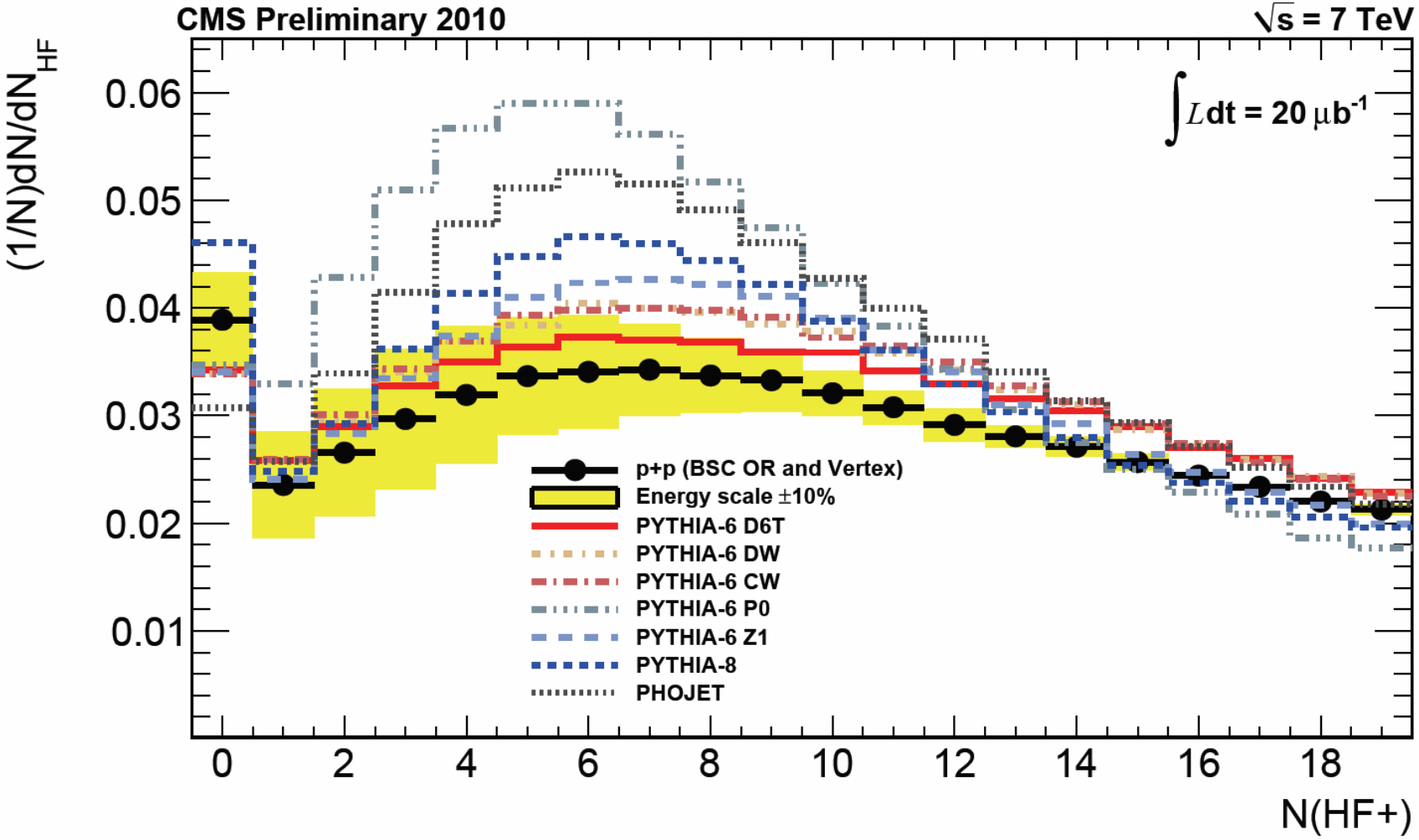
Castor $5.3 \leq |\eta| \leq 6.6$ (CMS)

# Data vs MC (forward: 3<|η|<5)



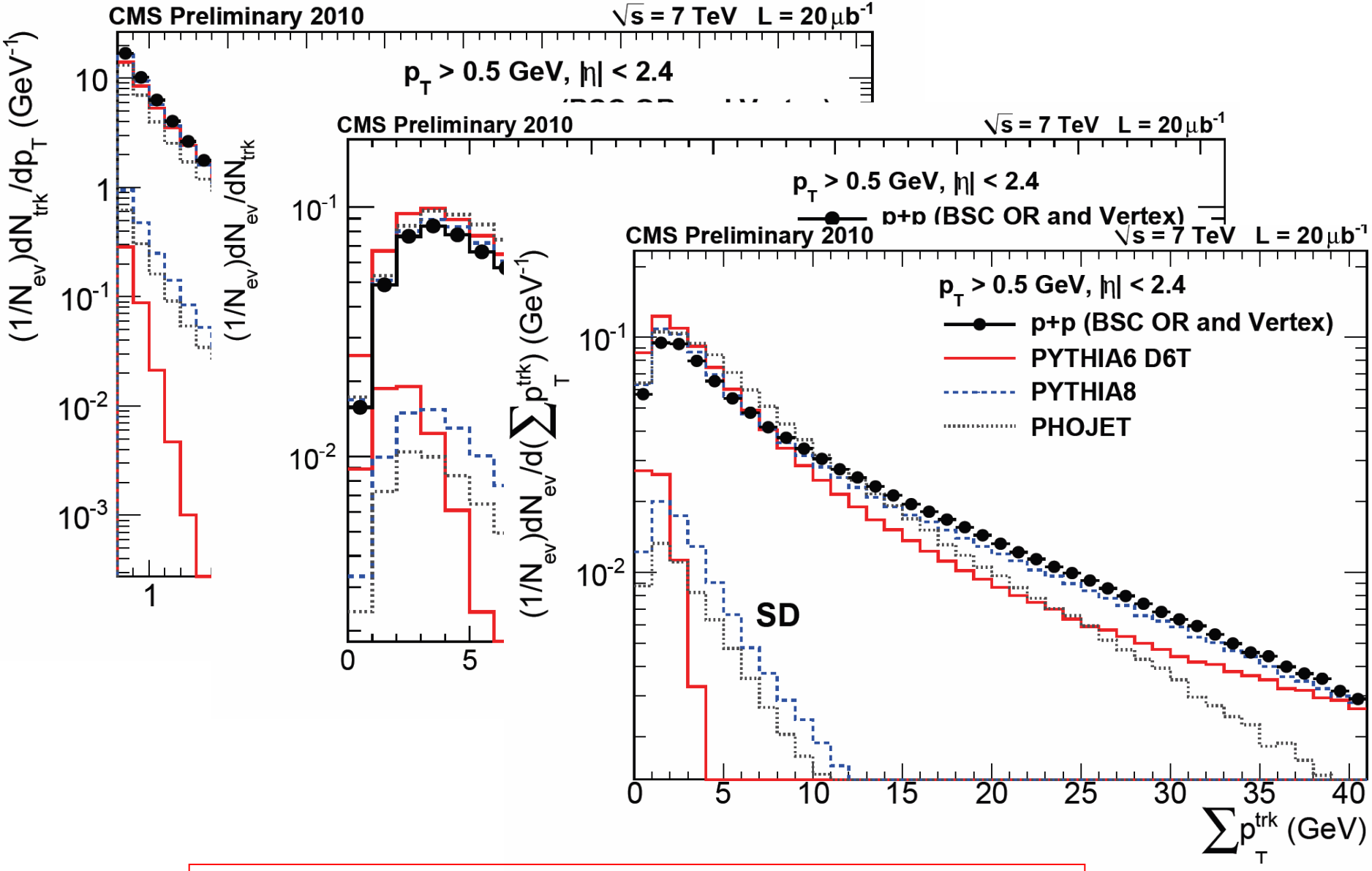

Pythia6 D6T ok DW ok CW ok P0 very bad Z1 ok Pythia 8 bad Phojet very bad

# Data vs MC (forward: 3<|η|<5)




| Pythia6 | D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|---|
| | fair | fair | fair | very bad | fair | bad | very bad |

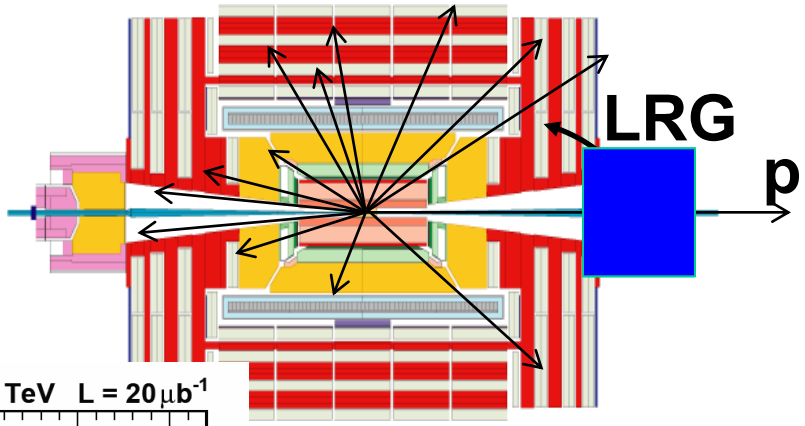
# Data vs MC (tracking |η|<3)

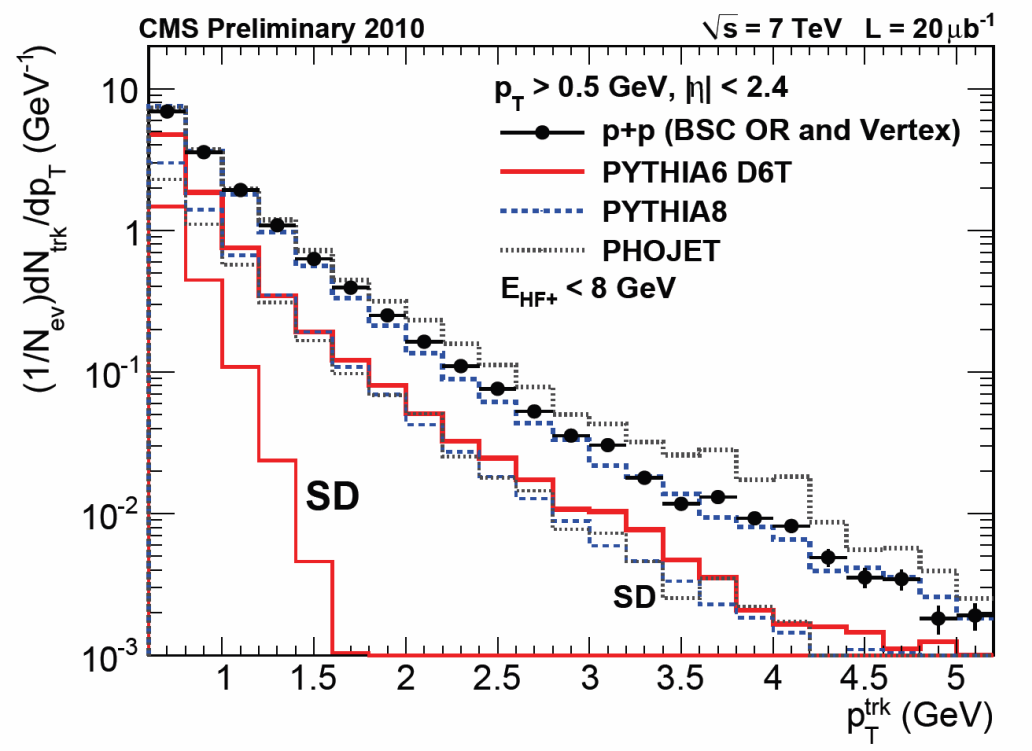



**SD dominates at small values of $p_T$, $N_{track}$, $\Sigma p_T$**

# Enhance diffr. component: data vs MC (tracking)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

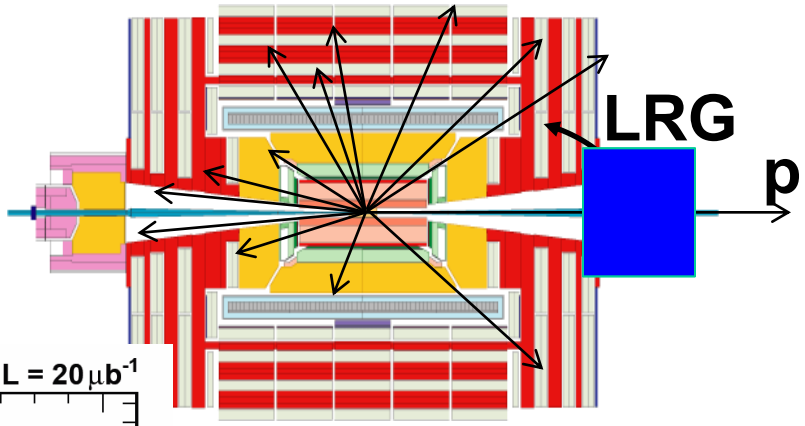


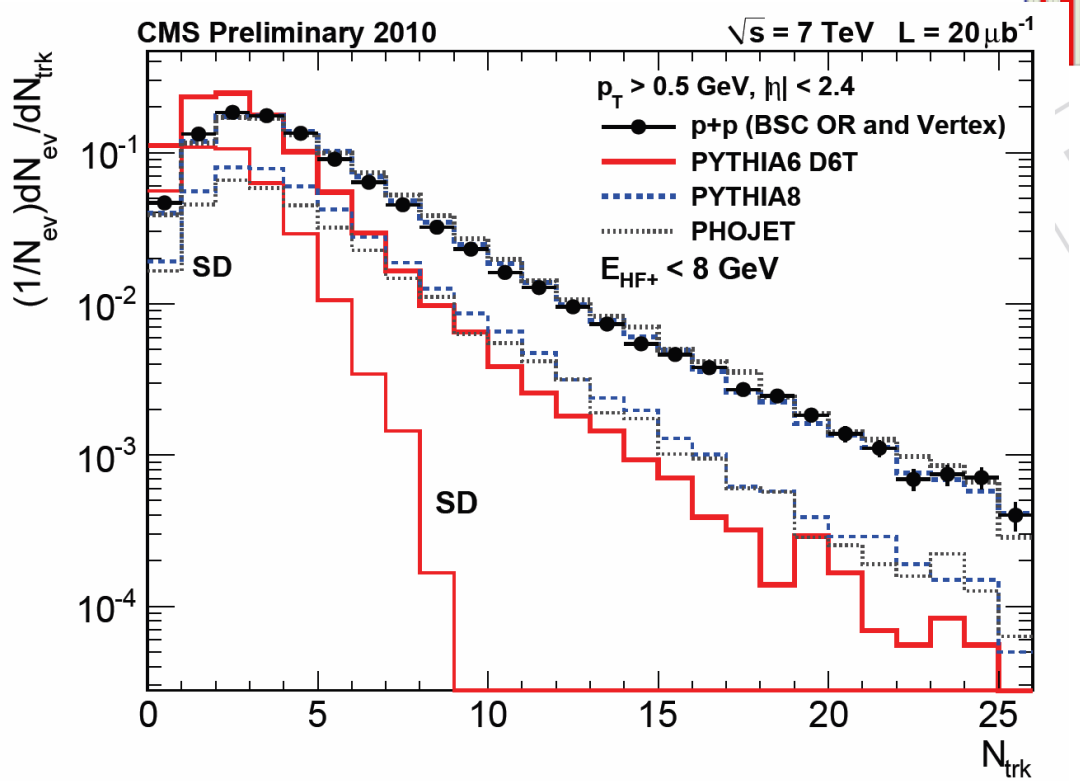




| Pythia6 D6T | Pythia 8 | Phojet |
|---|---|---|
| bad | ok | fair |

# Enhance diffr. component: data vs MC (tracking)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**




**Pythia6 D6T bad** **Pythia 8 ok** **Phojet fair**

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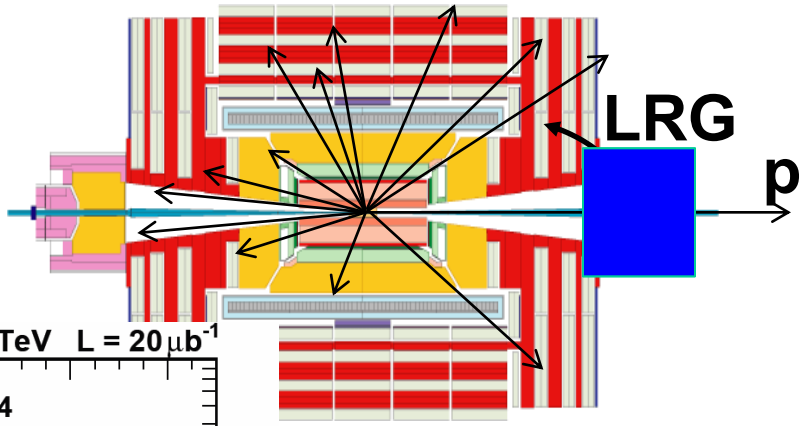


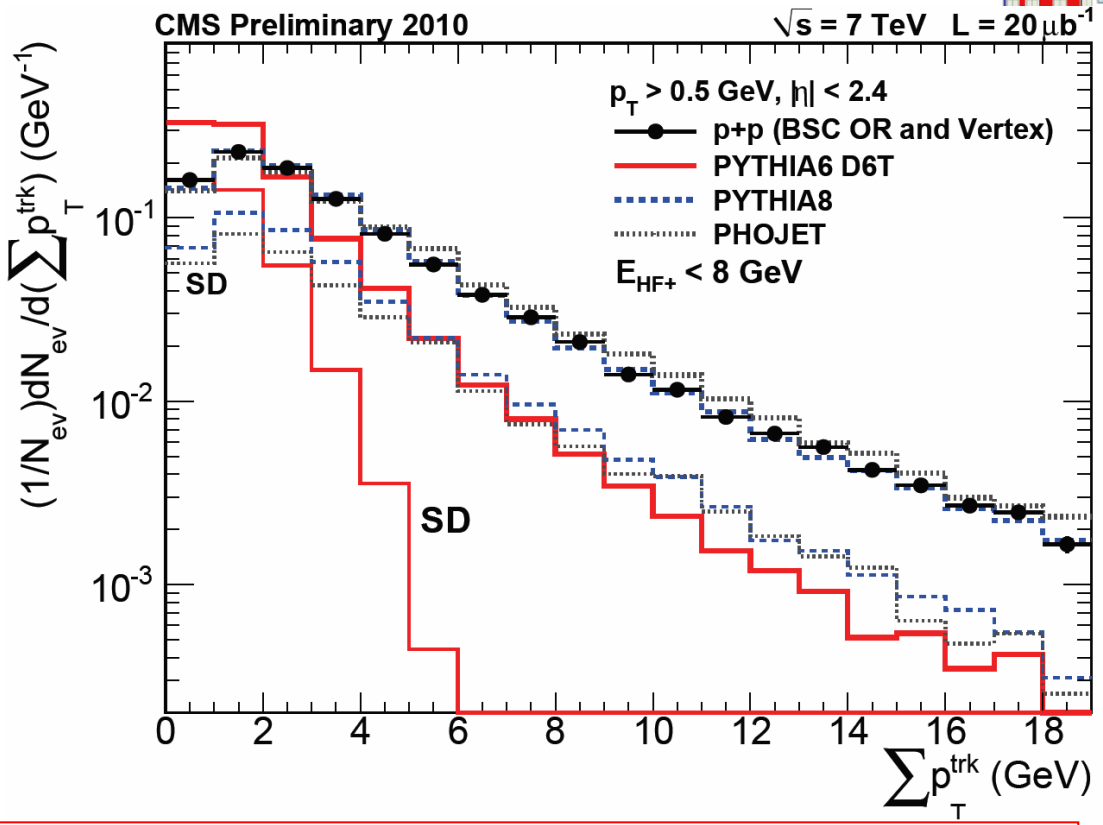


**Pythia6 D6T bad** **Pythia 8 ok** **Phojet fair**

# Enhance diffr. component: data vs MC (tracking)

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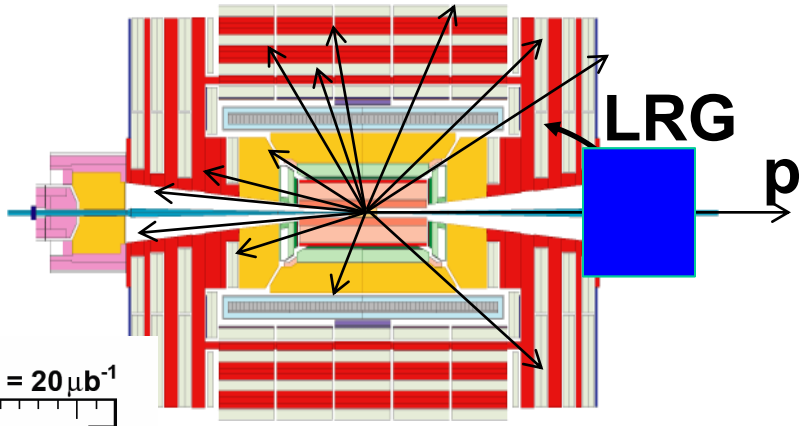


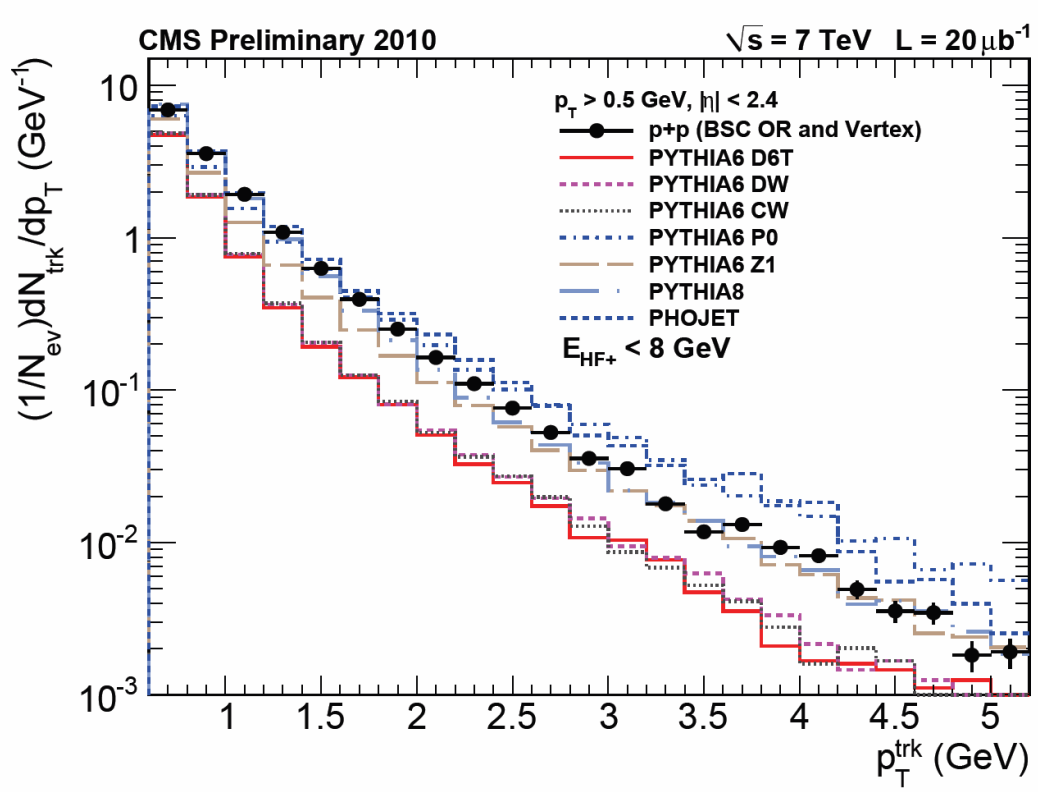


Pythia6 D6T bad DW bad CW bad P0 fair Z1 fair Pythia 8 ok Phojet fair

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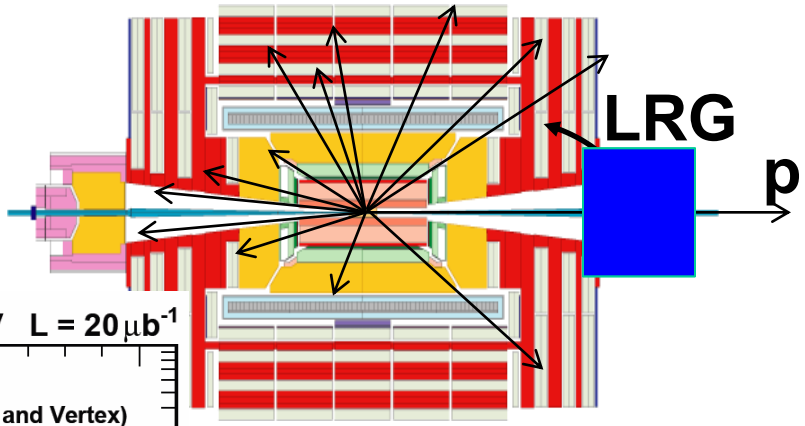
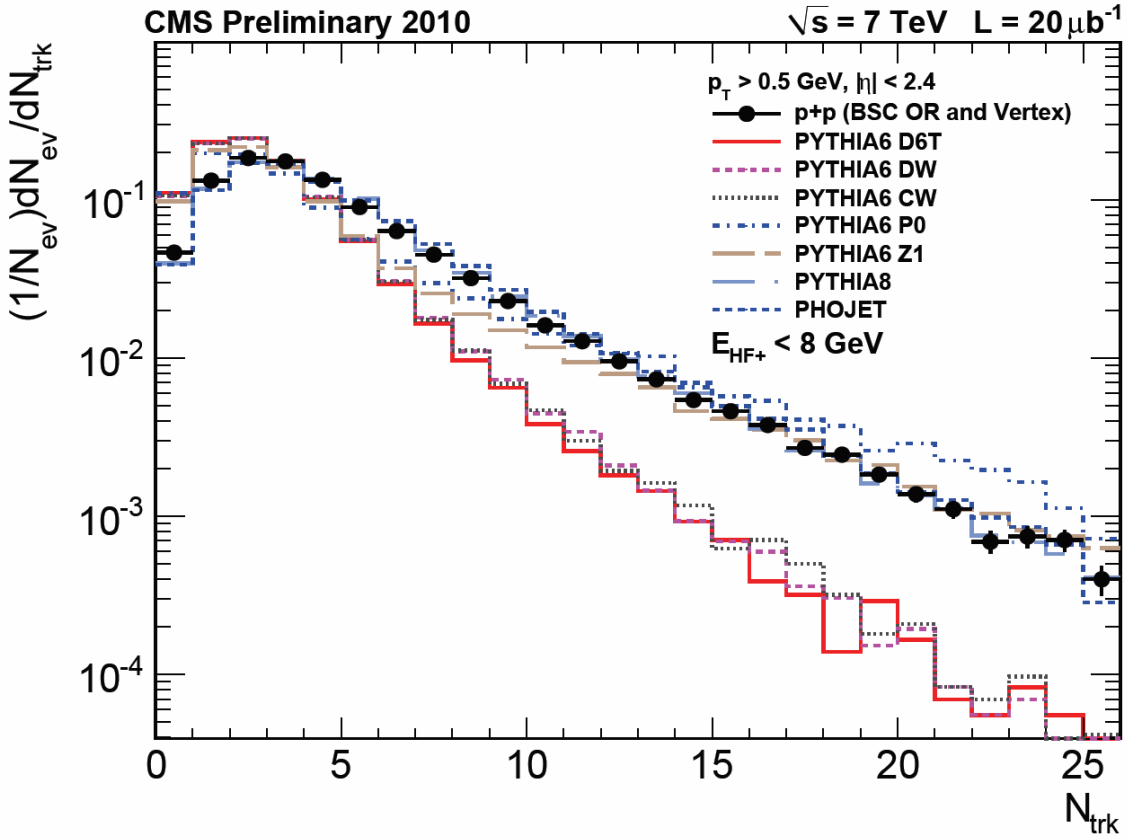
**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

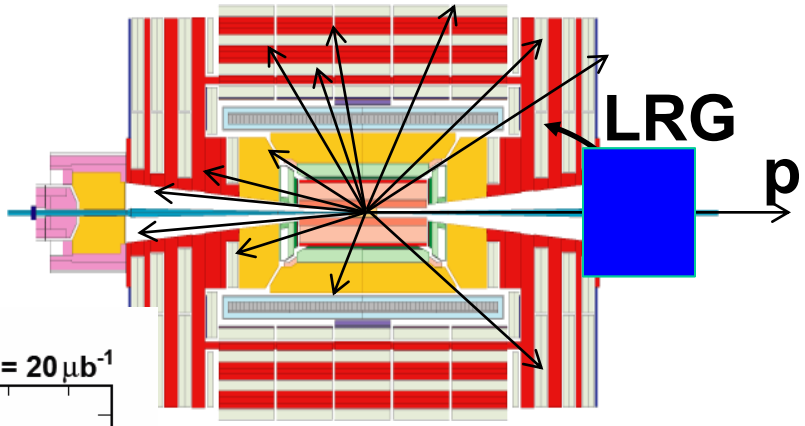


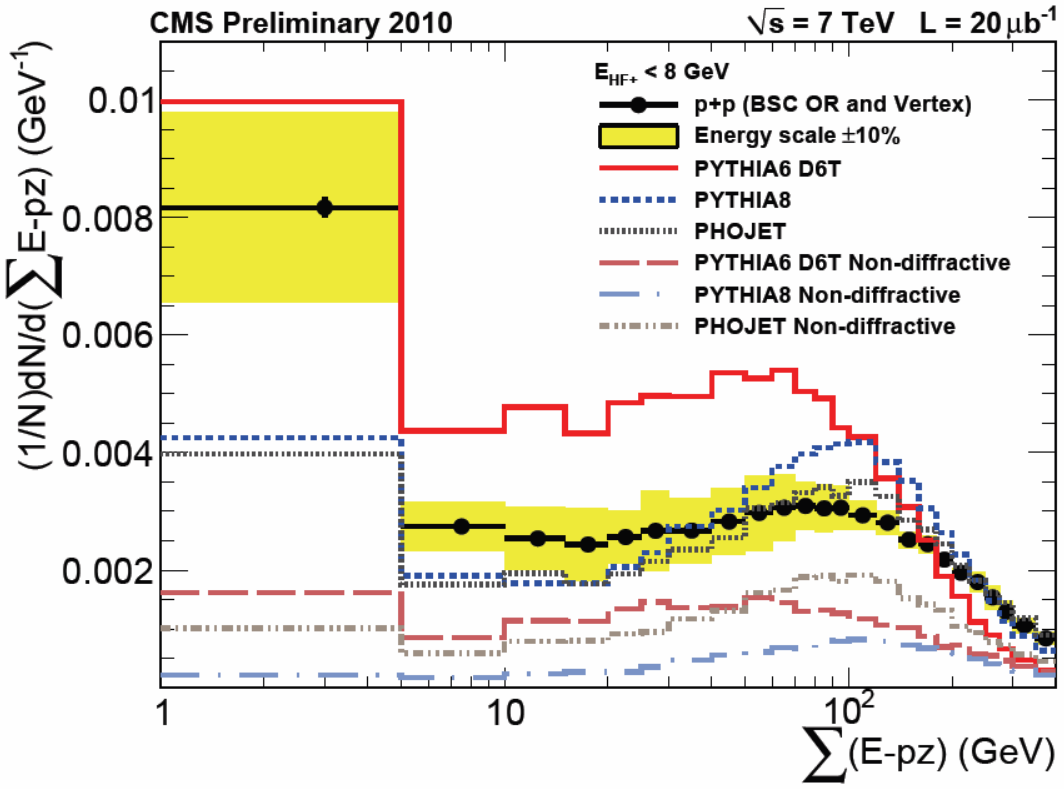




Pythia6 D6T bad DW bad CW bad P0 fair Z1 fair Pythia 8 ok Phojet fair

# Enhance diffr. component: data vs MC (forward)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

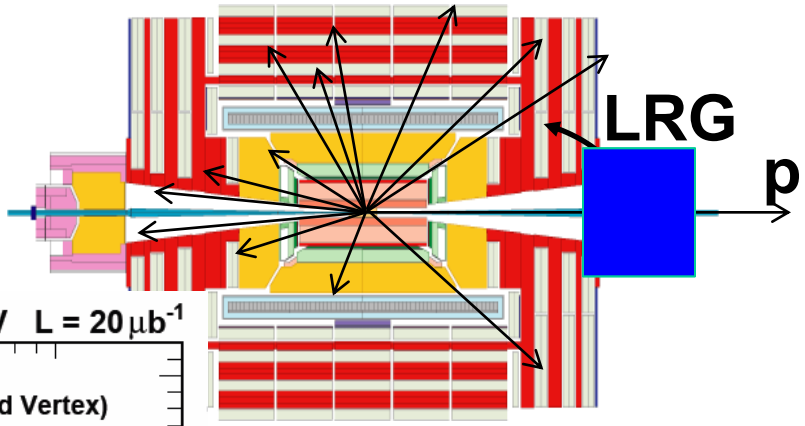


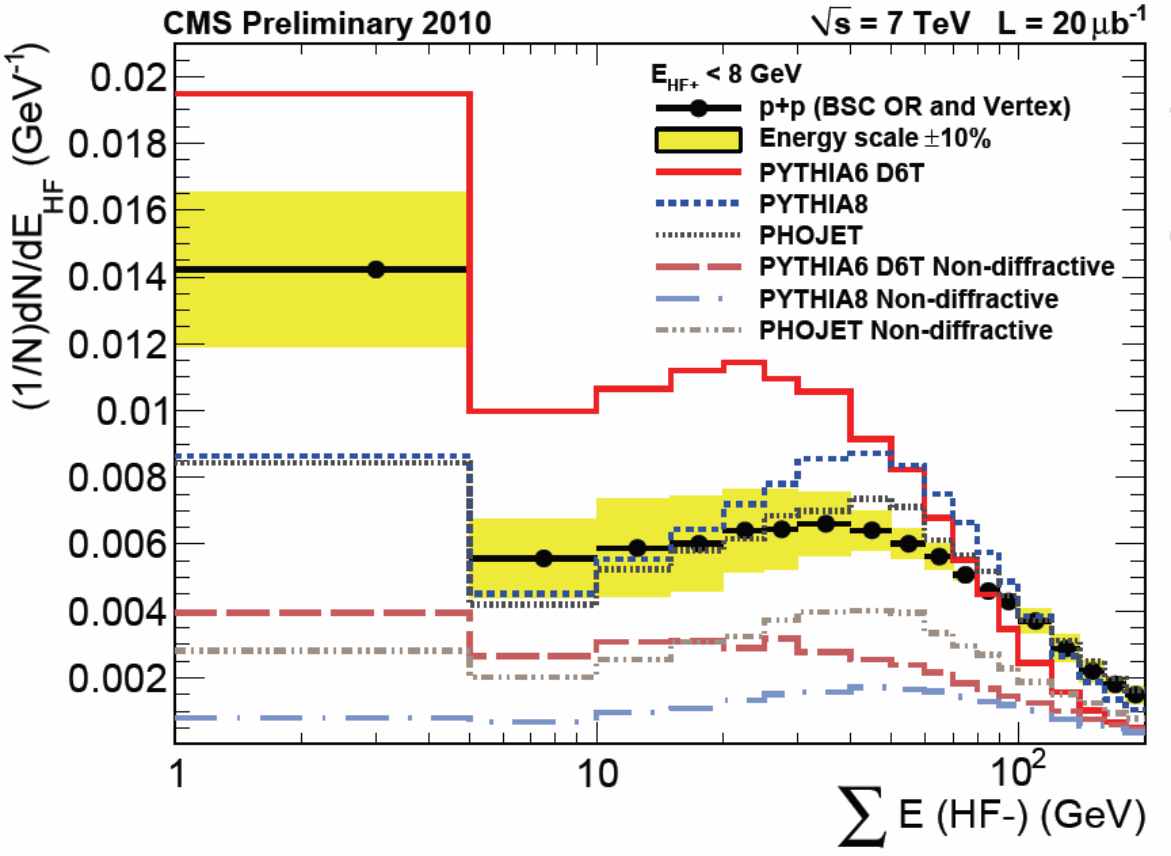




**Non-diffractive contribution suppressed**

# Enhance diffr. component: data vs MC (forward)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

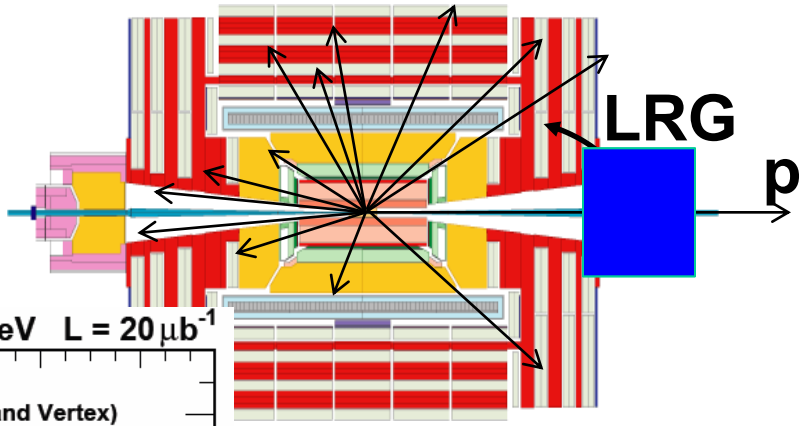


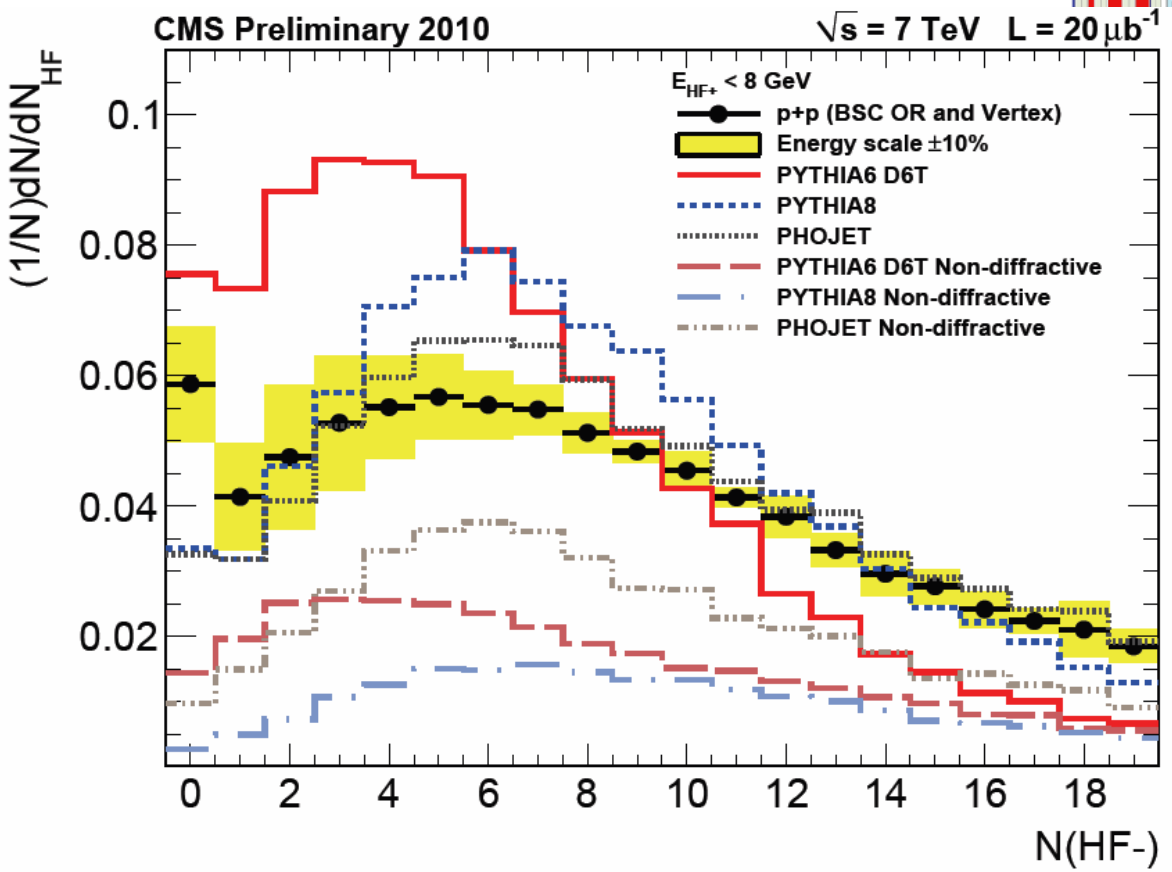




**Non-diffractive contribution suppressed**

# Enhance diffr. component: data vs MC (forward)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

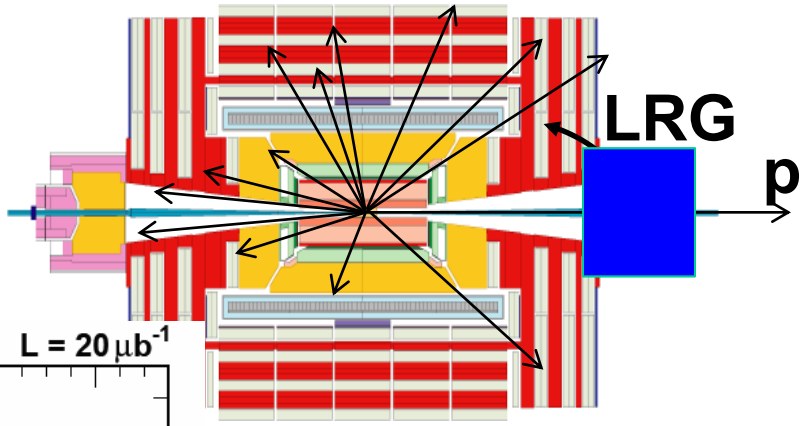


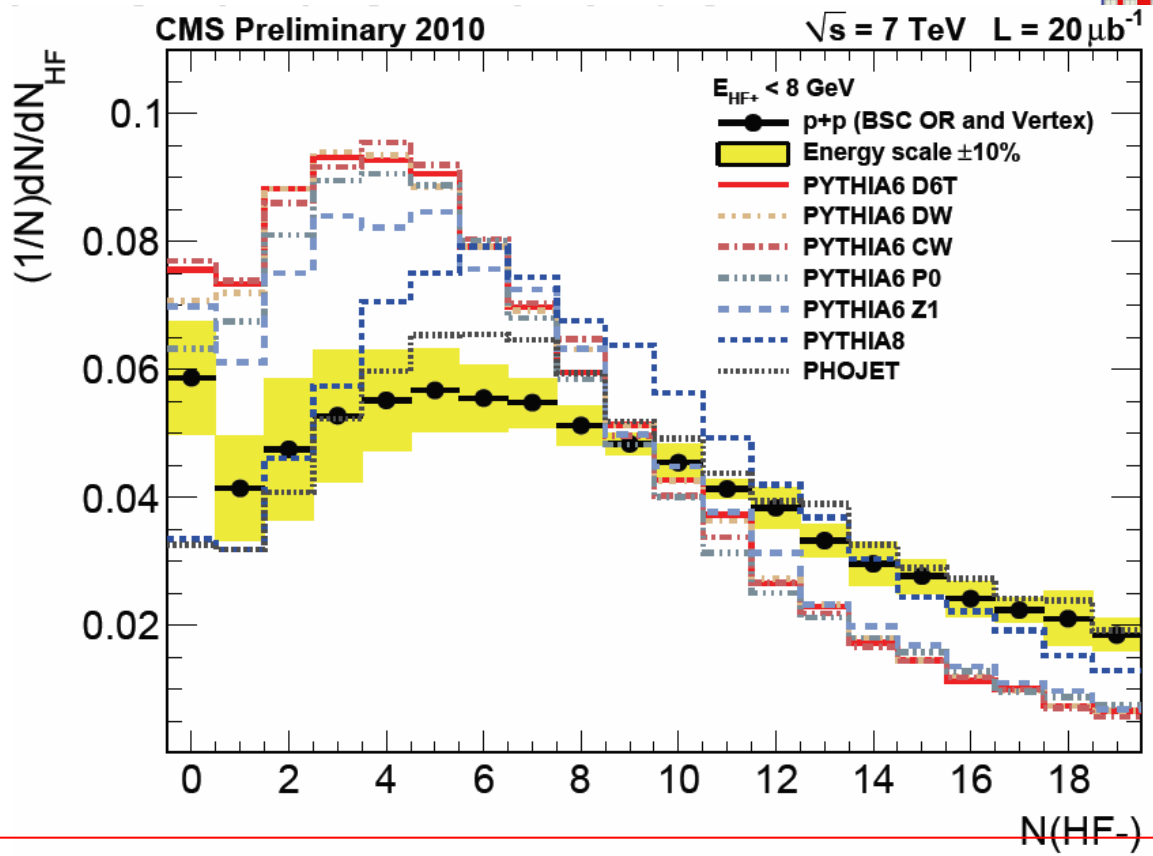




**Non-diffractive contribution suppressed**

# Enhance diffr. component: data vs MC (forward)

**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

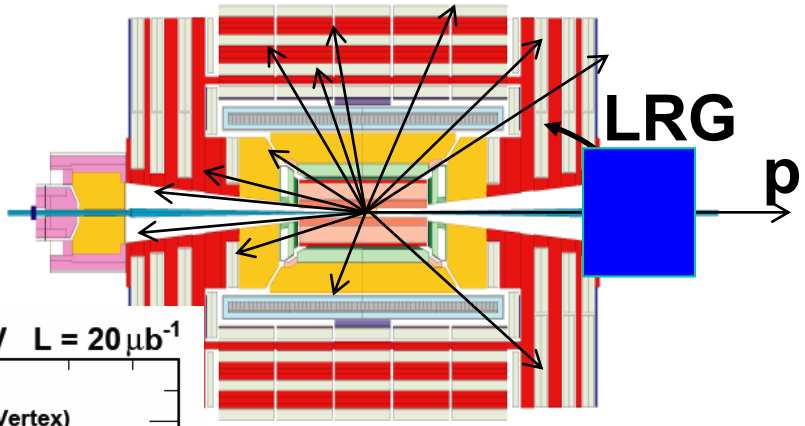


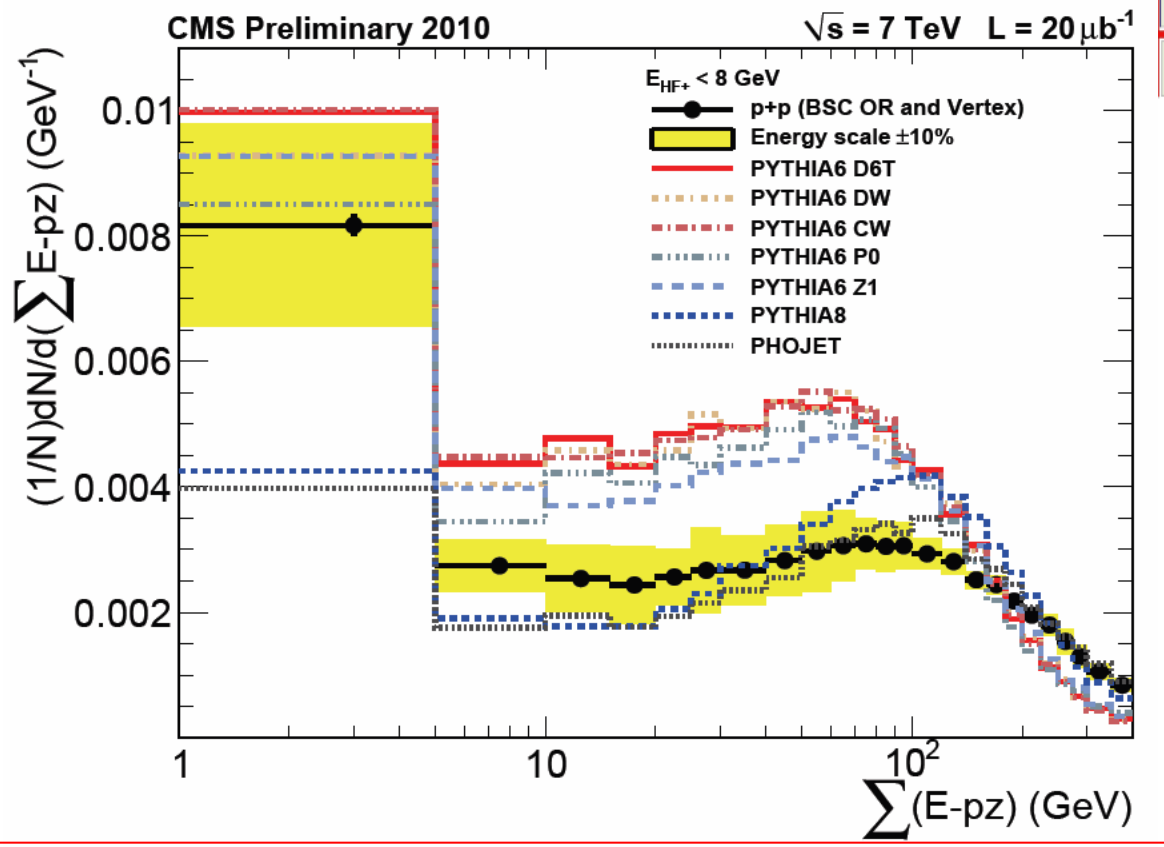




| Pythia6 D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|
| bad | bad | bad | bad | bad | bad | fair (but not low E) |

# Enhance diffr. component: data vs MC (forward)

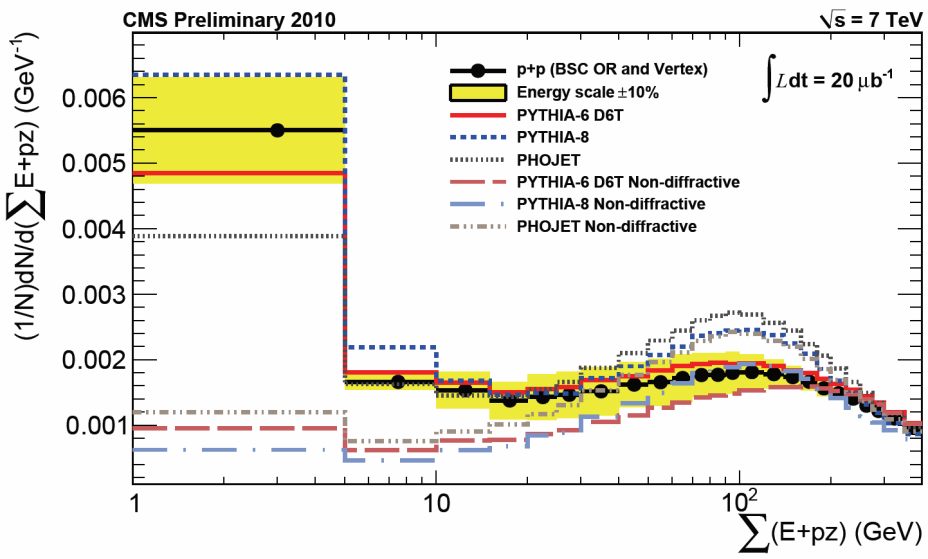
**Look at events with eg no activity in HF+ (ie rapidity gap over HF, E(HF+) < 8 GeV)**

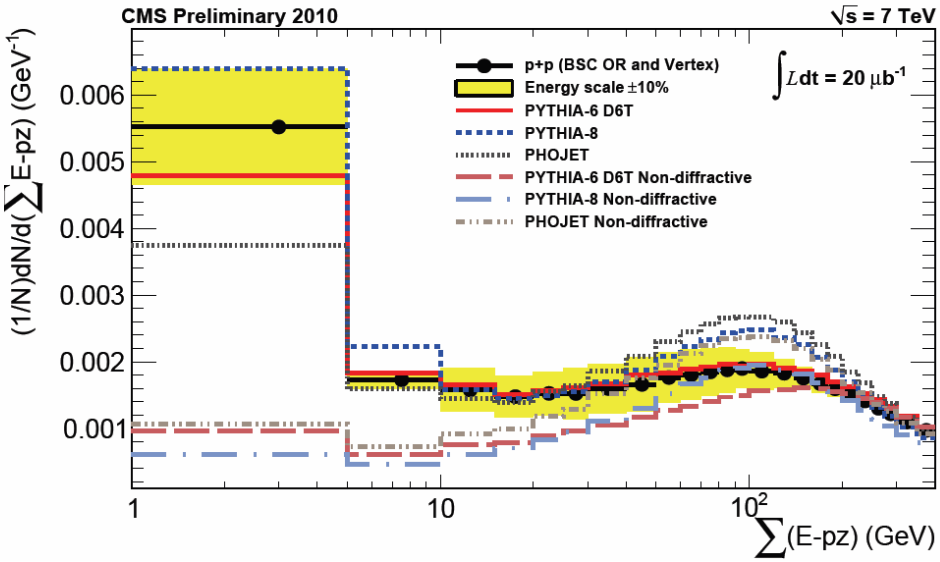


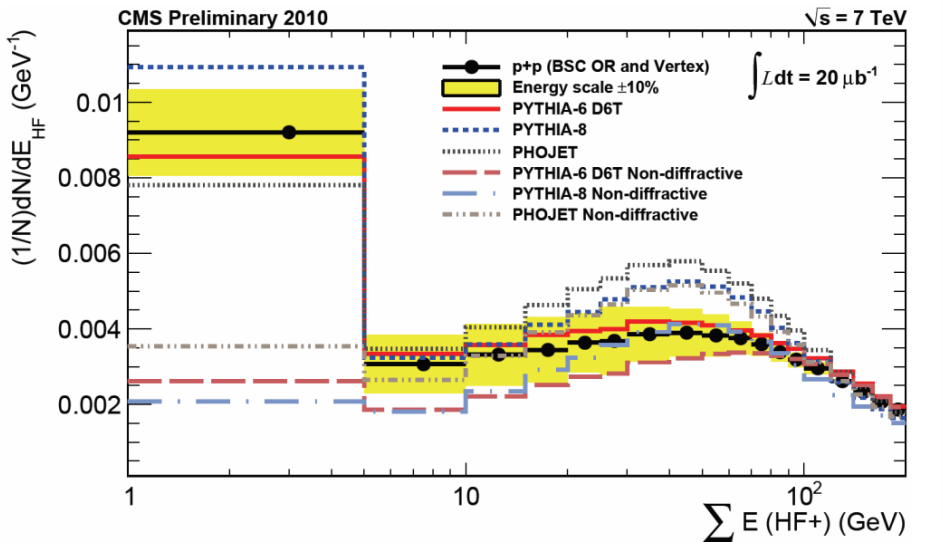

| Pythia6 | D6T | DW | CW | P0 | Z1 | Pythia 8 | Phojet |
|---|---|---|---|---|---|---|---|
| | bad | bad | bad | bad | bad | bad | fair (but not low E) |

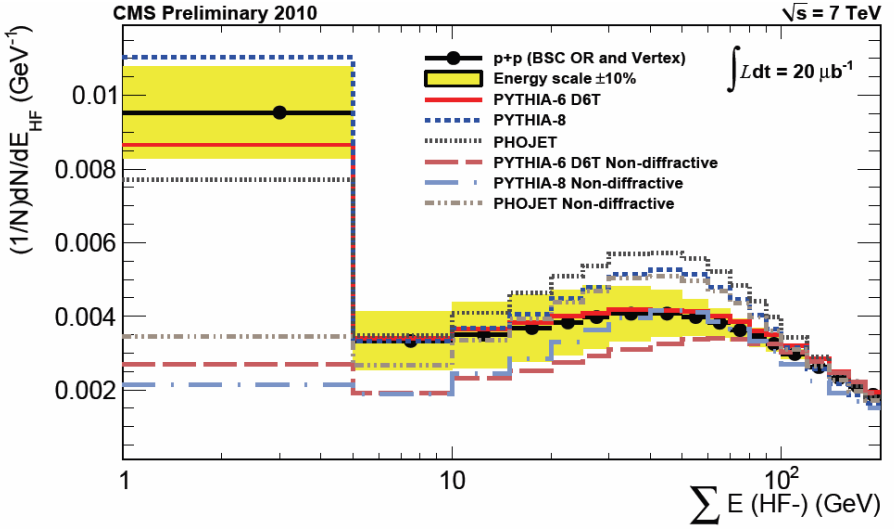
# E+pz vs E-pz

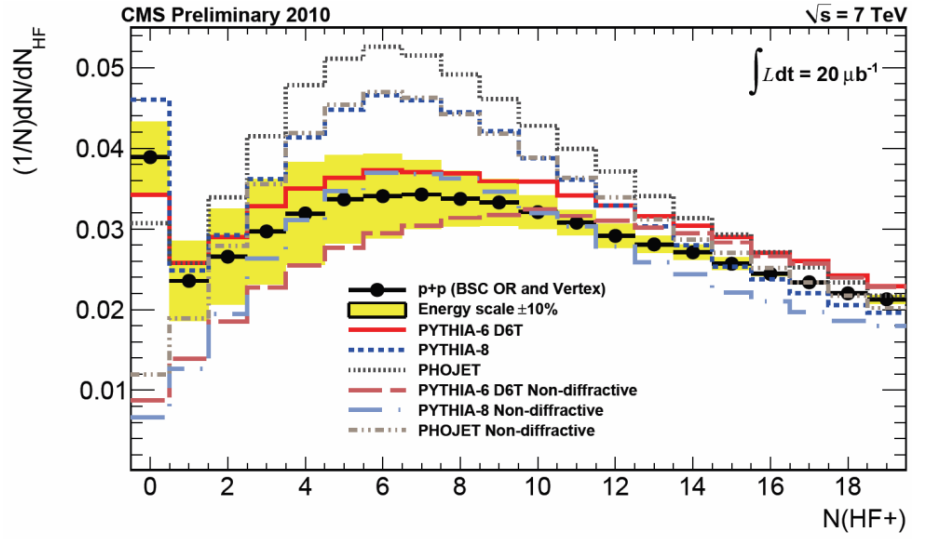

CMS Preliminary 2010
√s = 7 TeV
∫Ldt = 20 μb-1
p+p (BSC OR and Vertex)
Energy scale ±10%
PYTHIA-6 D6T
PYTHIA-8
PHOJET
PYTHIA-6 D6T Non-diffractive
PYTHIA-8 Non-diffractive
PHOJET Non-diffractive
(1/N)dN/d(∑E+pz) (GeV-1)
0.006
0.005
0.004
0.003
0.002
0.001
1
10
10^2
∑(E+pz) (GeV)

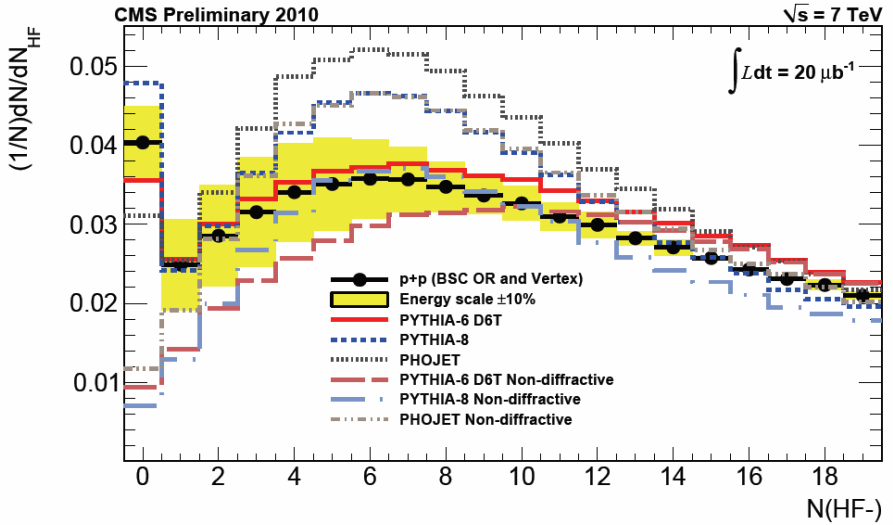

CMS Preliminary 2010
√s = 7 TeV
∫Ldt = 20 μb-1
p+p (BSC OR and Vertex)
Energy scale ±10%
PYTHIA-6 D6T
PYTHIA-8
PHOJET
PYTHIA-6 D6T Non-diffractive
PYTHIA-8 Non-diffractive
PHOJET Non-diffractive
(1/N)dN/d(∑E-pz) (GeV-1)
0.006
0.005
0.004
0.003
0.002
0.001
1
10
10^2
∑(E-pz) (GeV)

# HF+ vs HF-

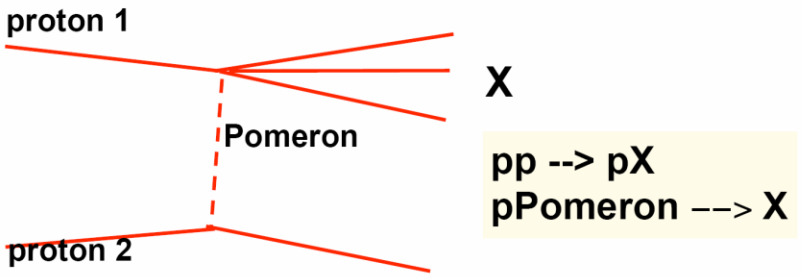

CMS Preliminary 2010
√s = 7 TeV
∫Ldt = 20 μb⁻¹
p+p (BSC OR and Vertex)
Energy scale ±10%
PYTHIA-6 D6T
PYTHIA-8
PHOJET
PYTHIA-6 D6T Non-diffractive
PYTHIA-8 Non-diffractive
PHOJET Non-diffractive
(1/N)dN/dE_HF (GeV⁻¹)
∑ E (HF+) (GeV)


CMS Preliminary 2010
√s = 7 TeV
∫Ldt = 20 μb⁻¹
p+p (BSC OR and Vertex)
Energy scale ±10%
PYTHIA-6 D6T
PYTHIA-8
PHOJET
PYTHIA-6 D6T Non-diffractive
PYTHIA-8 Non-diffractive
PHOJET Non-diffractive
(1/N)dN/dE_HF (GeV⁻¹)
∑ E (HF-) (GeV)


CMS Preliminary 2010
√s = 7 TeV
∫Ldt = 20 μb⁻¹
p+p (BSC OR and Vertex)
Energy scale ±10%
PYTHIA-6 D6T
PYTHIA-8
PHOJET
PYTHIA-6 D6T Non-diffractive
PYTHIA-8 Non-diffractive
PHOJET Non-diffractive
(1/N)dN/dN_HF
N(HF+)


CMS Preliminary 2010
√s = 7 TeV
∫Ldt = 20 μb⁻¹
p+p (BSC OR and Vertex)
Energy scale ±10%
PYTHIA-6 D6T
PYTHIA-8
PHOJET
PYTHIA-6 D6T Non-diffractive
PYTHIA-8 Non-diffractive
PHOJET Non-diffractive
(1/N)dN/dN_HF
N(HF-)

# Meaning of $E \pm p_z$




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

Momentum and energy conservation:
$E(\text{Pomeron}) + E(\text{proton 1}) = E(X)$
$p_z(\text{Pomeron}) + p_z(\text{proton 1}) = p_z(X)$

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

If proton 1 moves in positive z direction: $E(\text{proton 1}) - p_z(\text{proton 1}) \approx 0$ (and proton 2, and Pomeron, move in the negative z direction)

Hence:
$E(\text{Pomeron}) - p_z(\text{Pomeron}) \approx 2E(\text{Pomeron}) \approx E(X) - p_z(X)$

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

Conversely, if proton 1 moves in the negative z direction (and proton 2, and Pomeron, in the positive z direction), $E(\text{proton 1}) + p_z(\text{proton 1}) \approx 0$, hence:

$E(\text{Pomeron}) + p_z(\text{Pomeron}) \approx 2E(\text{Pomeron}) \approx E(X) + p_z(X)$

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