Diffraction at CMS

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ETH Zurich

Zurich PhD Seminar

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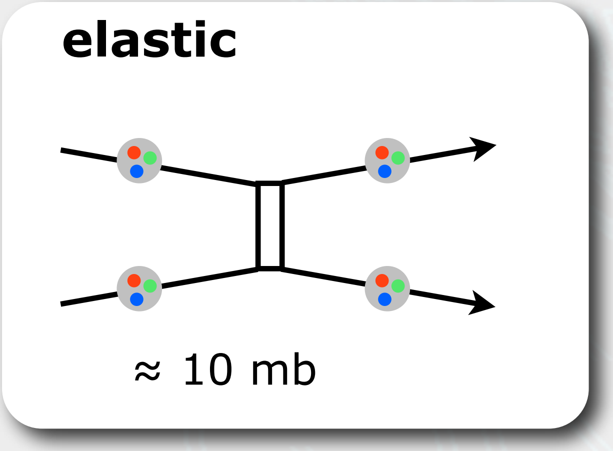
ETH Institute for Particle Physics

CMS

PP-INTERACTIONS AT THE LHC

$\sigma_{tot} =$



+ .....

PP-INTERACTIONS AT THE LHC

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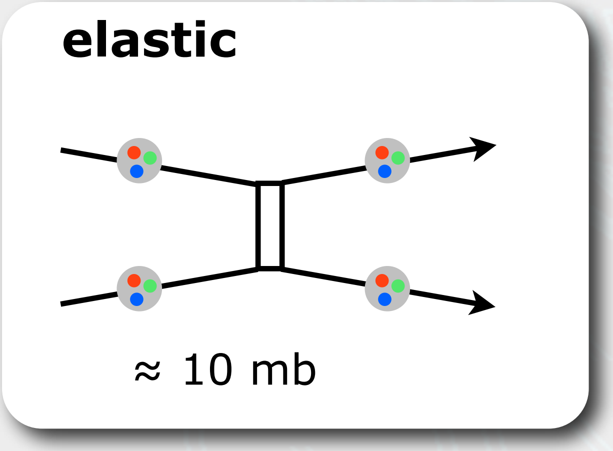

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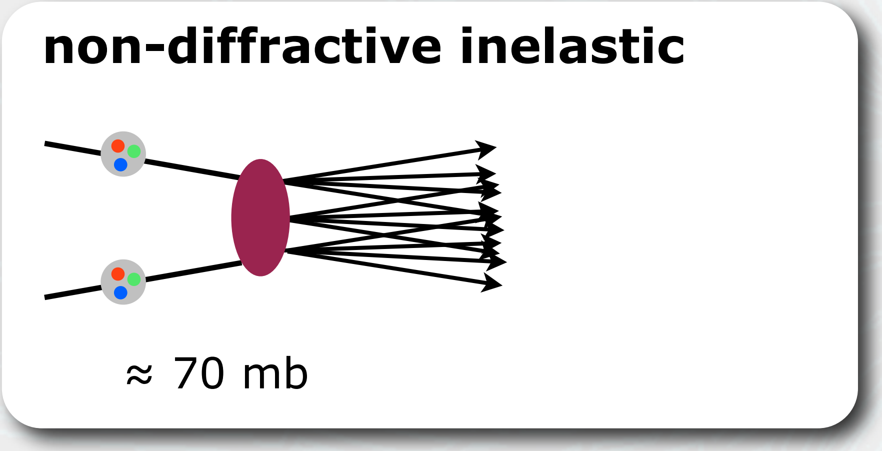
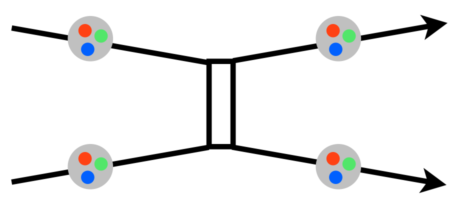


+ .....

PP-INTERACTIONS AT THE LHC

$\sigma_{tot} =$

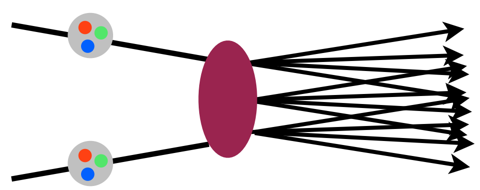
elastic



≈ 10 mb

+

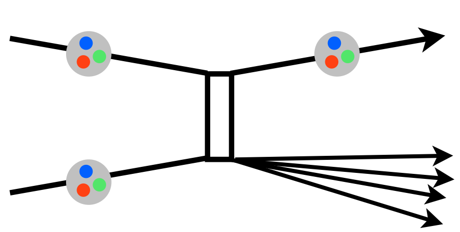
non-diffractive inelastic



≈ 70 mb

+

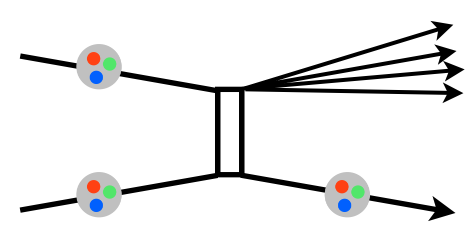
single-diffractive



≈ 10 mb

+

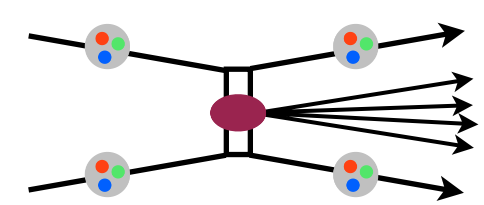
single-diffractive



≈ 10 mb

+

central-diffractive



≈ "small"

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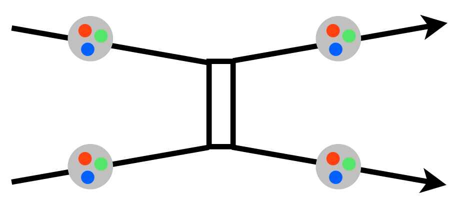
PP-INTERACTIONS AT THE LHC

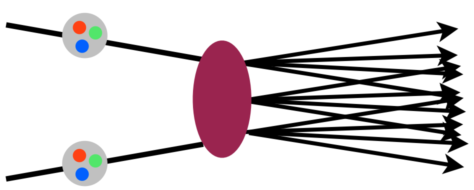
$\sigma_{tot} =$

elastic



≈ 10 mb

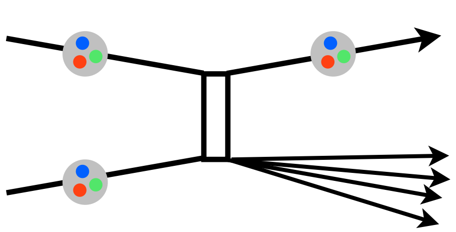
\+ **non-diffractive inelastic**



≈ 70 mb

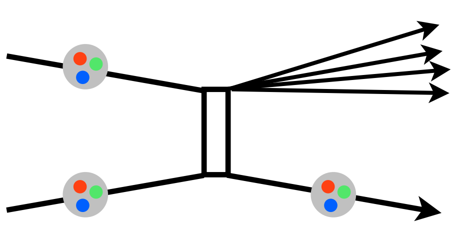
processes (still) lack a complete understanding and modeling in MC

\+ **single-diffractive**



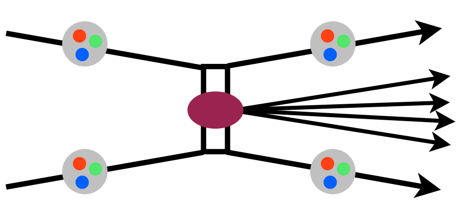
≈ 10 mb

\+ **single-diffractive**



≈ 10 mb

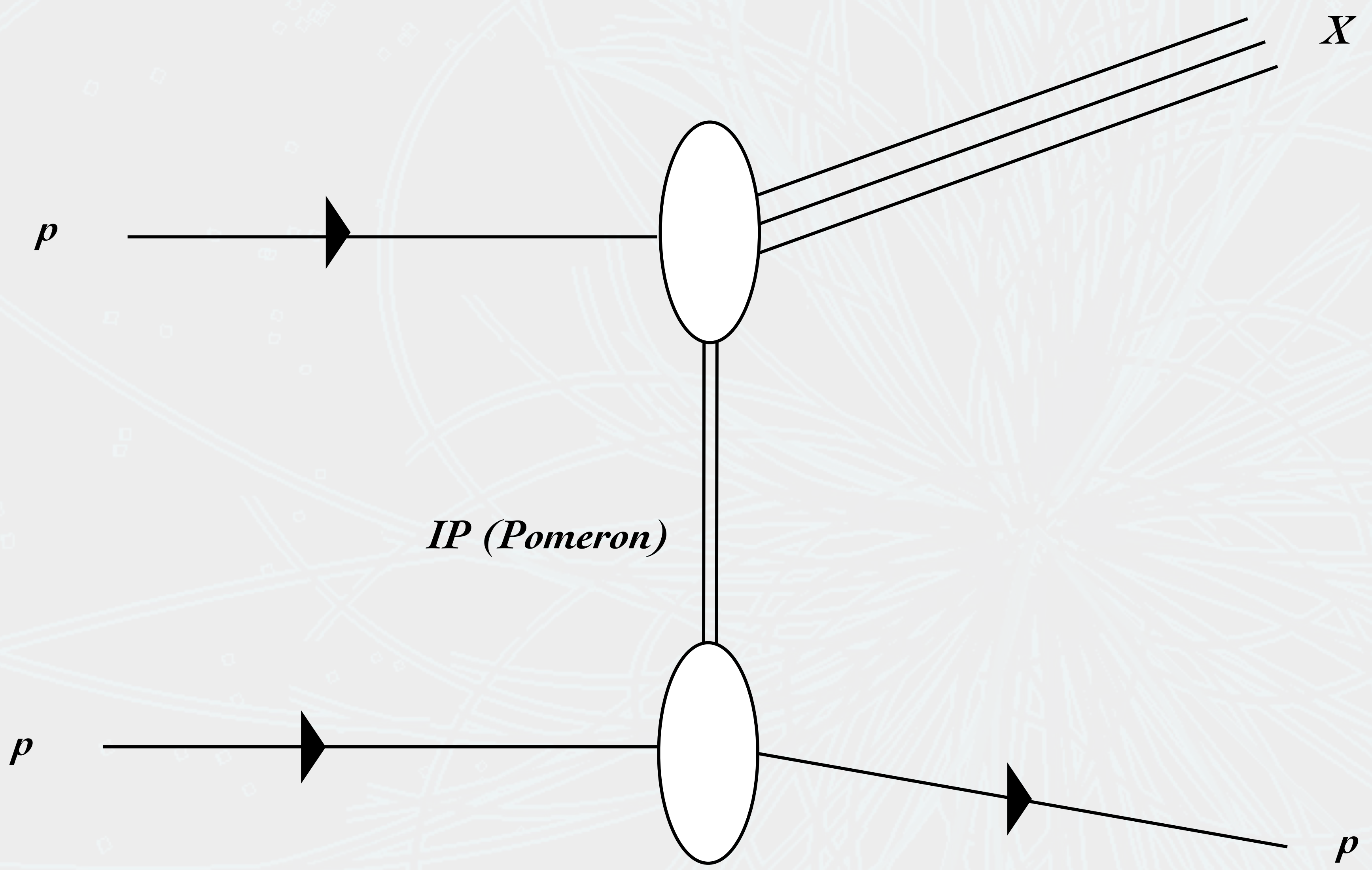
\+ **central-diffractive**



≈ "small"

What is Diffraction?

SIGNATURE OF (SINGLE) DIFFRACTION



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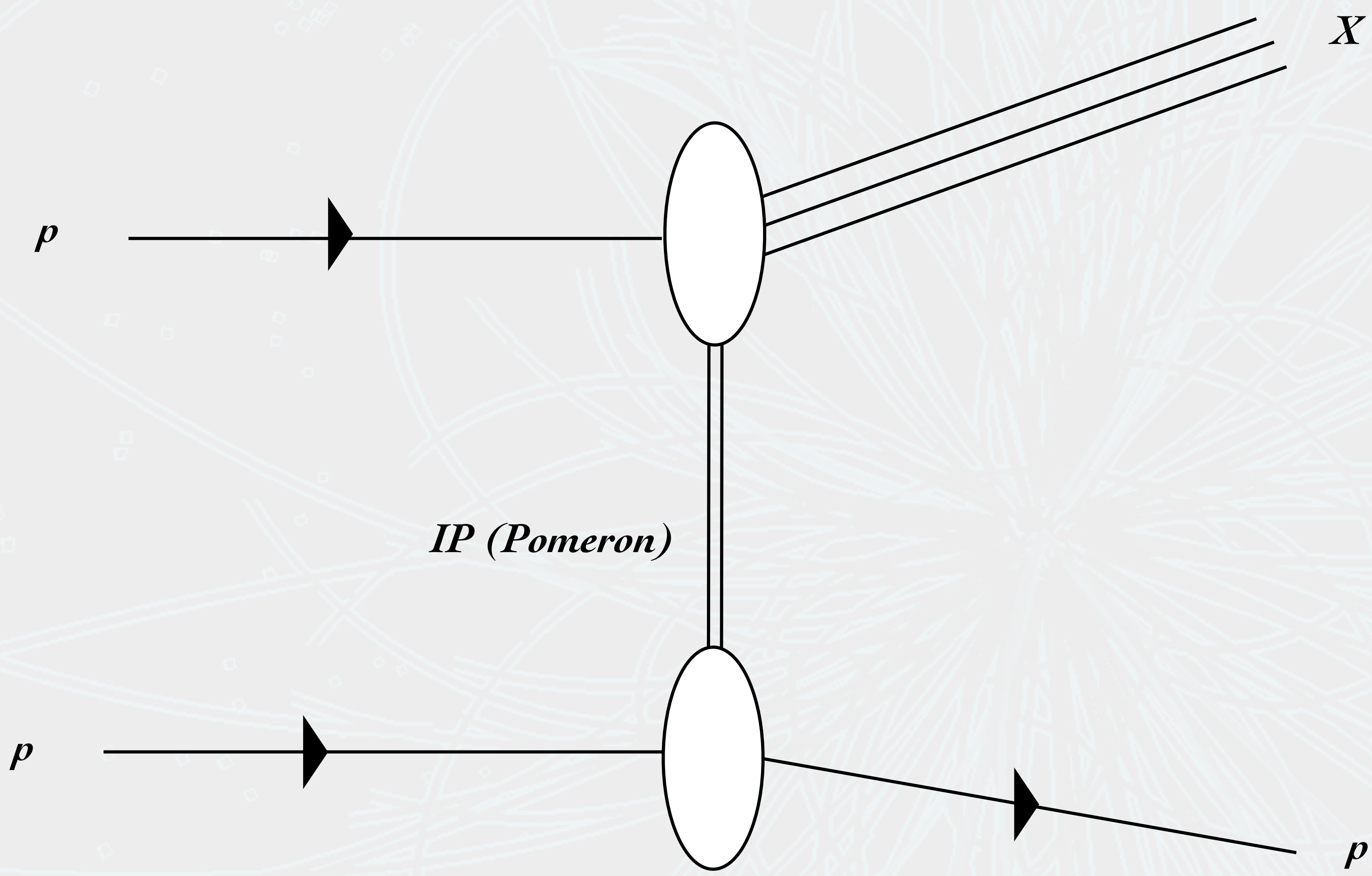
SIGNATURE OF (SINGLE) DIFFRACTION



one proton emerges intact from interaction

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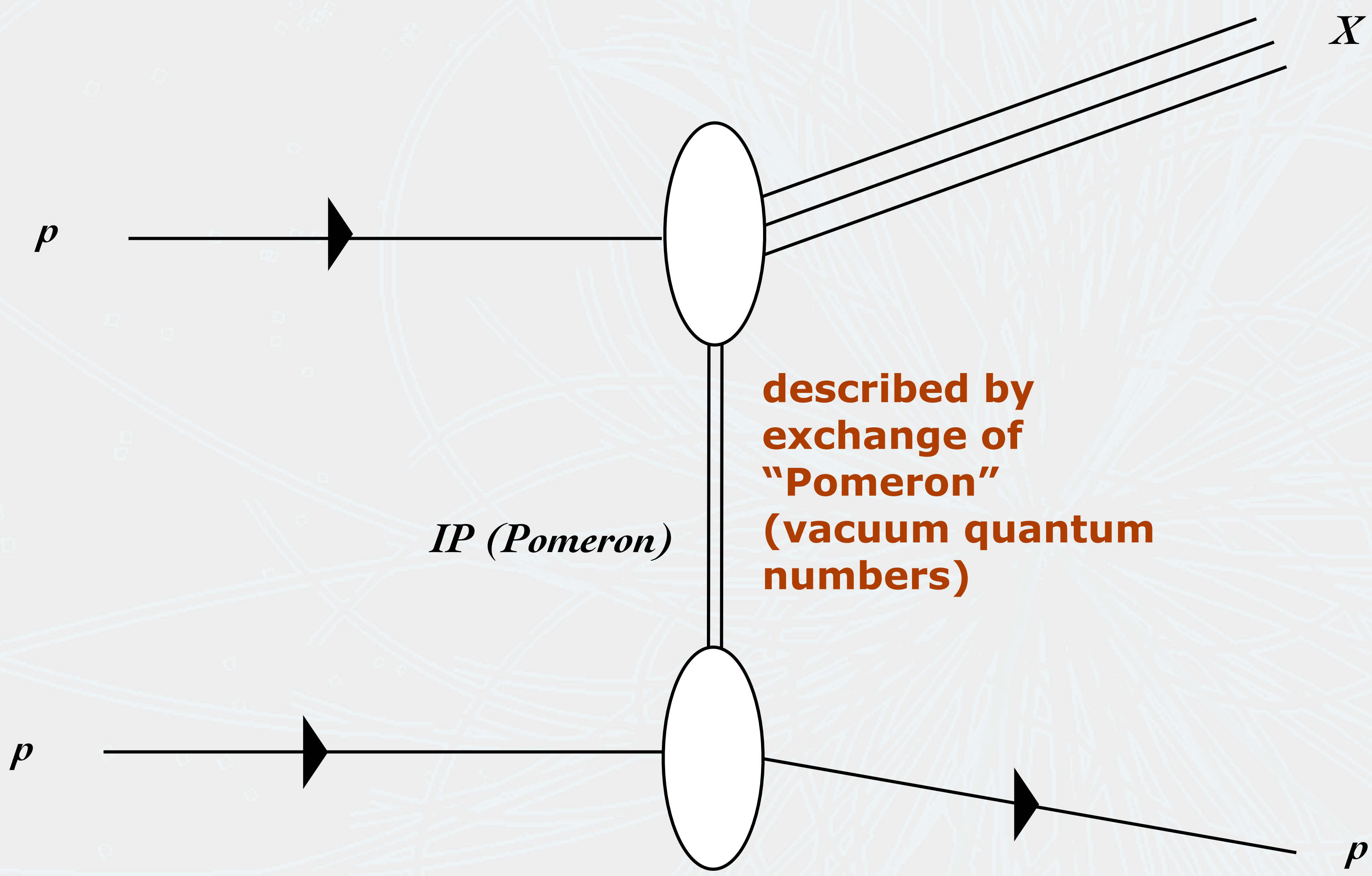

described by exchange of "Pomeron" (vacuum quantum numbers)

one proton emerges intact from interaction

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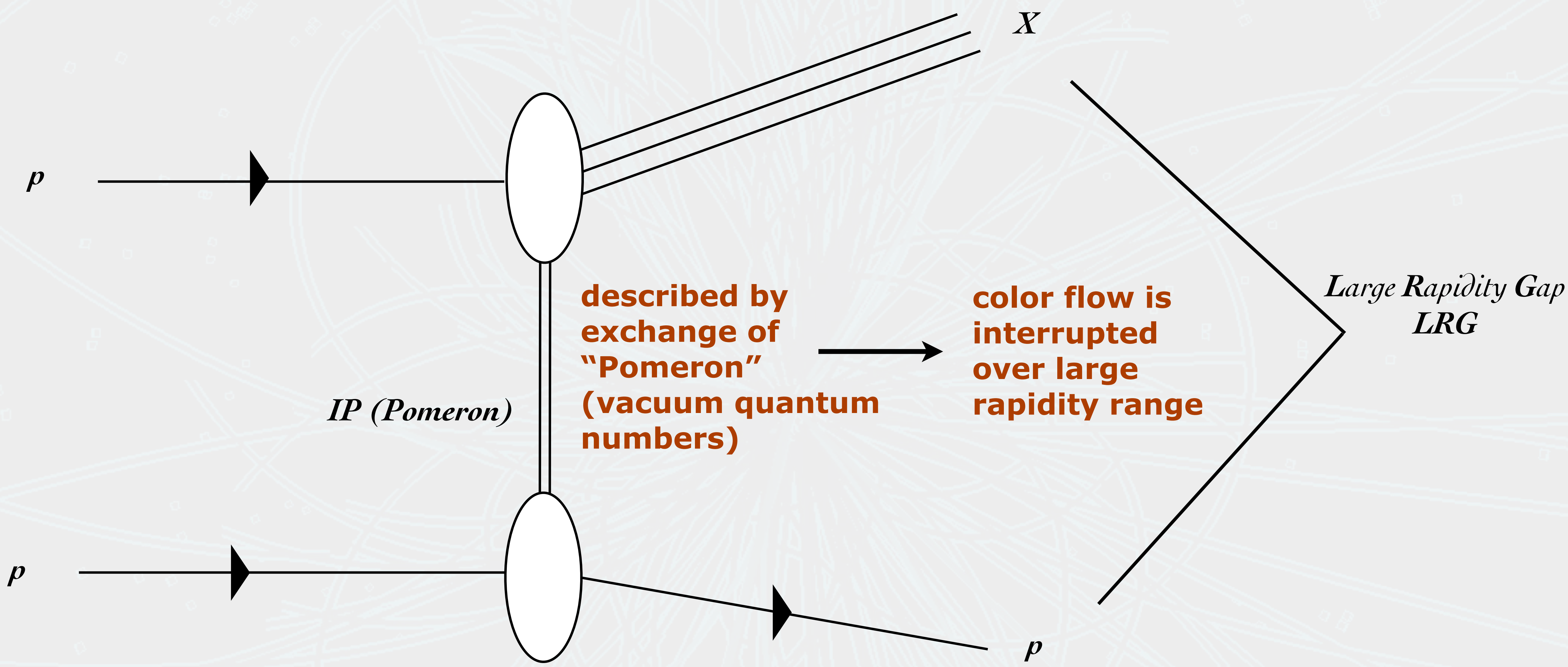
SIGNATURE OF (SINGLE) DIFFRACTION



described by exchange of "Pomeron" (vacuum quantum numbers) → color flow is interrupted over large rapidity range

one proton emerges intact from interaction

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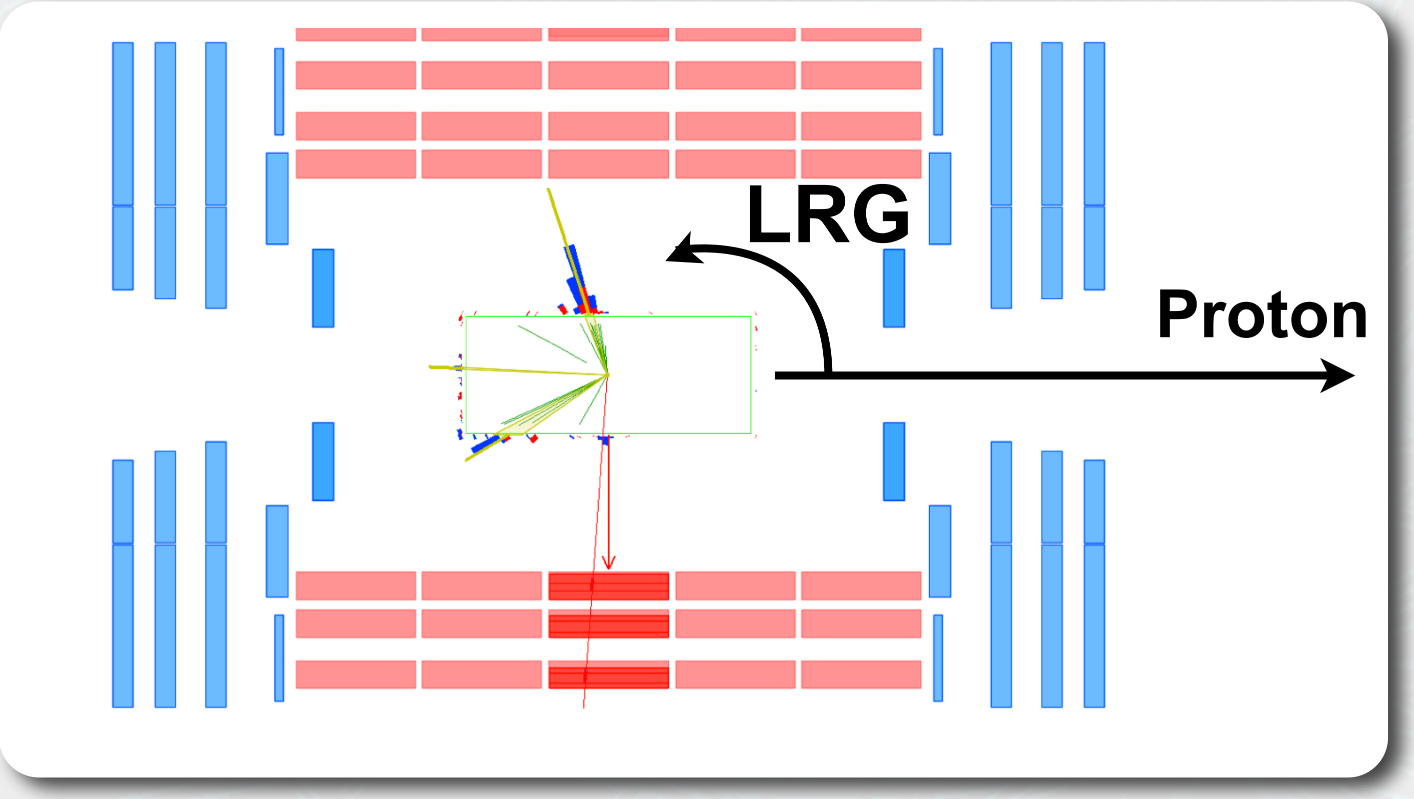
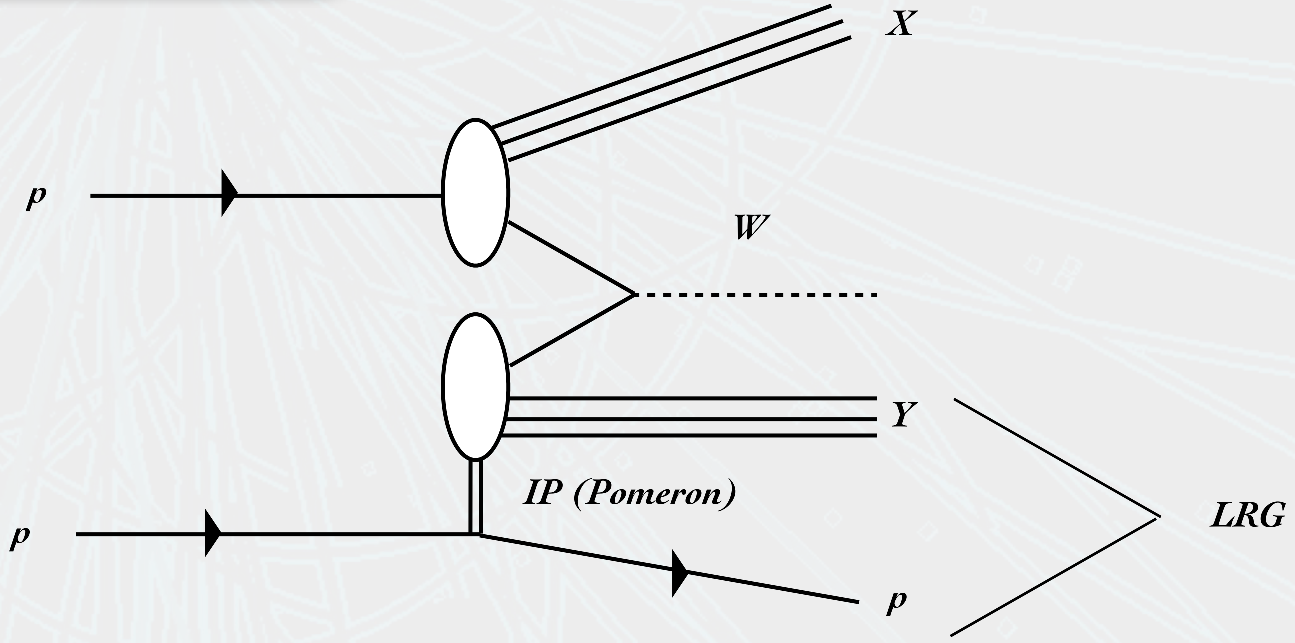
OBSERVATION OF DIFFRACTION



- Soft scale
  - minimum-bias
- Hard scale
  - jets
  - **W/Z bosons**



- This analysis: W/Z bosons
  - signature is **centrally** produced W/Z with a LRG in the **forward** region

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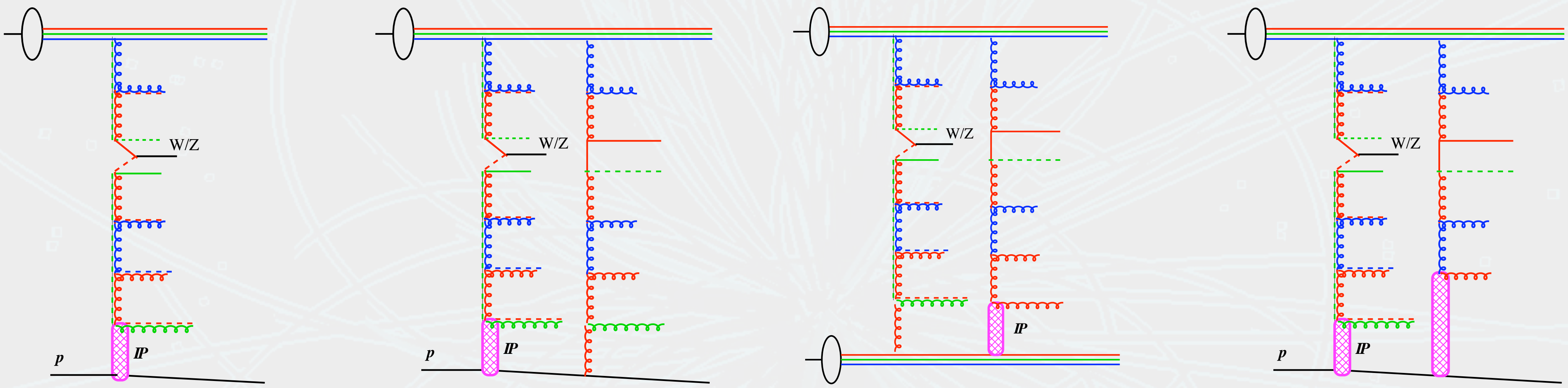
Why measure Diffraction?

MOTIVATION

- pp scattering: factorize in hard process + underlying event
- both produced diffractively and non-diffractively

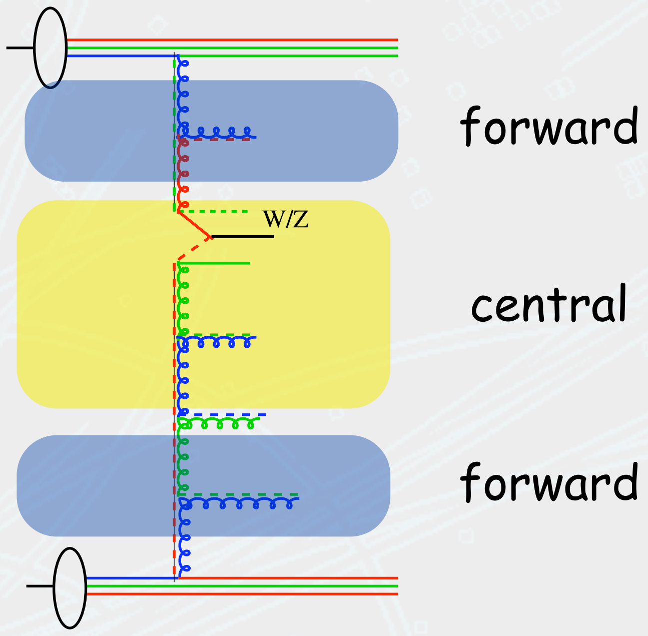


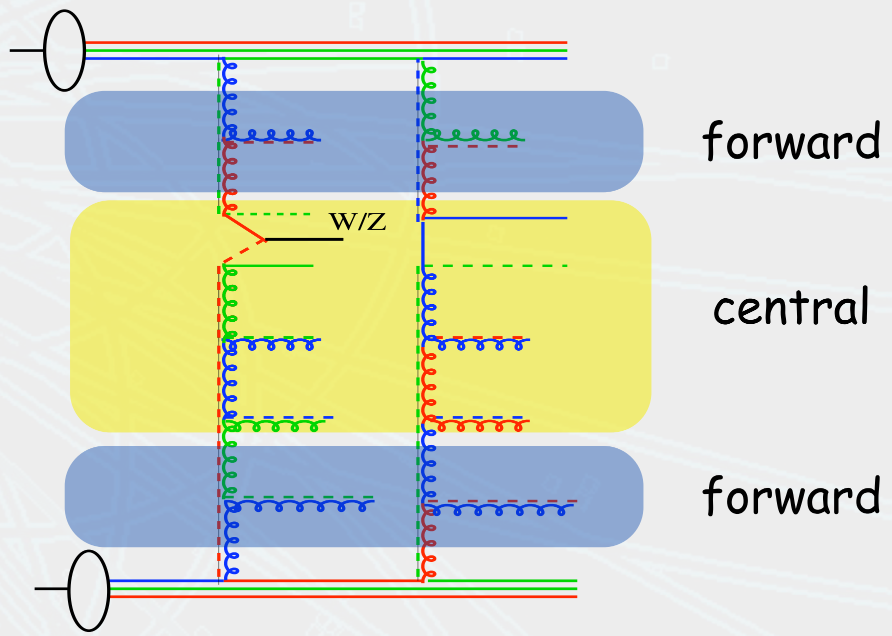
hard diffractive production | *hard diffractive production + non-diffractive MPI* | *hard non-diff. interaction + diffractive MPI* | *hard diffractive production + diffractive MPI*

- Large center-of-mass energies → high parton densities
  - increased probability for underlying multi-parton interactions (MPI)
  - observation of diffraction strongly influenced by MPI

MOTIVATION

- MPI events not well understood theoretically, phenomenological approach needs parametrized models
  - study models over large phase-space
- Models tuned on central underlying event data
  - extrapolation to larger phase space (forward region) and higher c.m.s challenging: parton showers and MPI significant
  - measurements in forward calorimeters at CMS allows to study large phase space and high c.m.s, improving the understanding of basic processes and providing input for model tuning

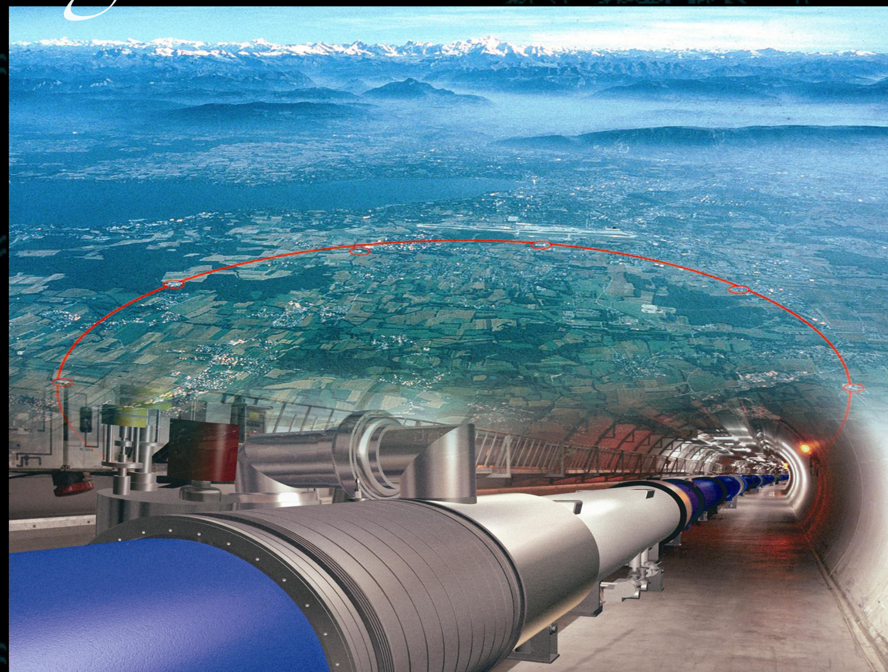




- GOALS:
  - first measurement of diffractive W/Z events in pp collisions
  - energy flow measurement as a function of pseudorapidity in the forward region $3.15 < \eta < 4.9$

How to measure Diffraction?

The Large Hadron Collider: LHC



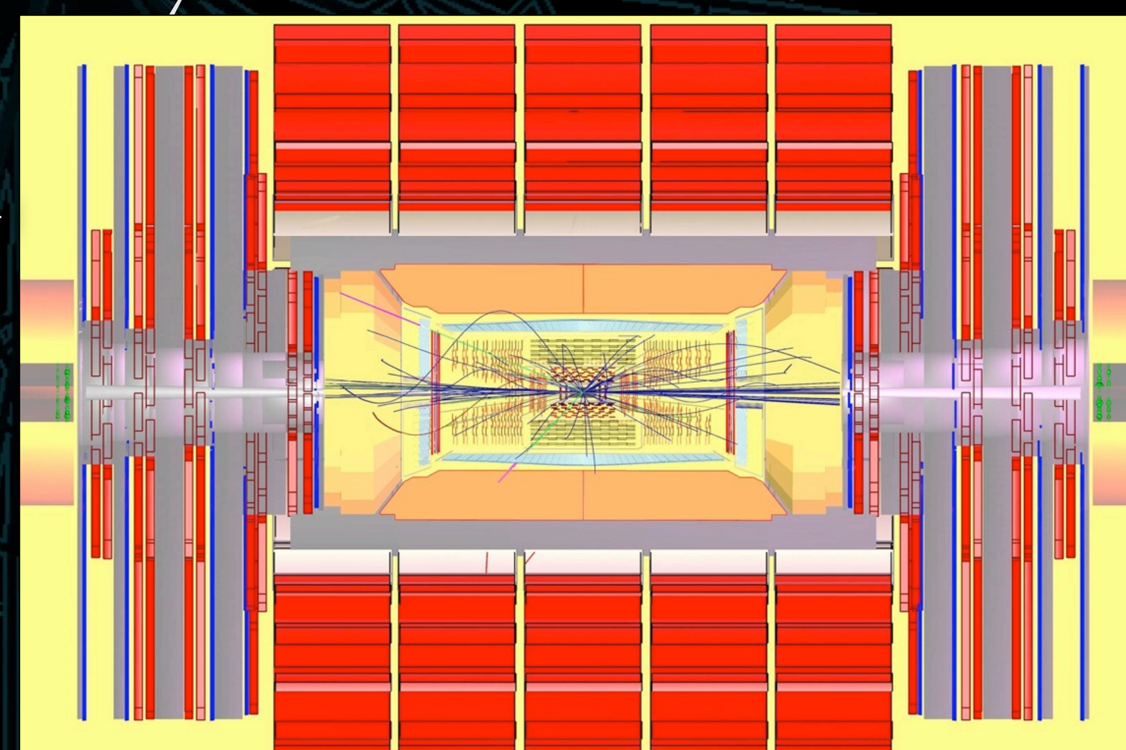
- Restart of the machine in November 2009
- First 7 TeV collisions in March 2010
- Integrated luminosity 2010 recorded by CMS: XX pb^{-1}
- Integrated luminosity 2011 recorded by CMS: XX pb^{-1}

The Compact Muon Solenoid: CMS

- Pixel: 66M channels for ~1m^2
- Tracker: 9.6M channels for ~210 m^2
- ECAL: 76k $PbWO_4$ crystals
- HCAL: interleaved scintillator/brass
- Muons: redundant DT (CSC) and RPC
- HF: steel absorbers / quartz fibers

Solenoid coil: 4 T

Total weight: 12'500 t



Overall length: 21.6 m

Overall diameter: 15 m

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SAMPLE SELECTION

1 Selection of subsample by triggering events with **centrally produced W or Z boson**

Electron and muon selection:

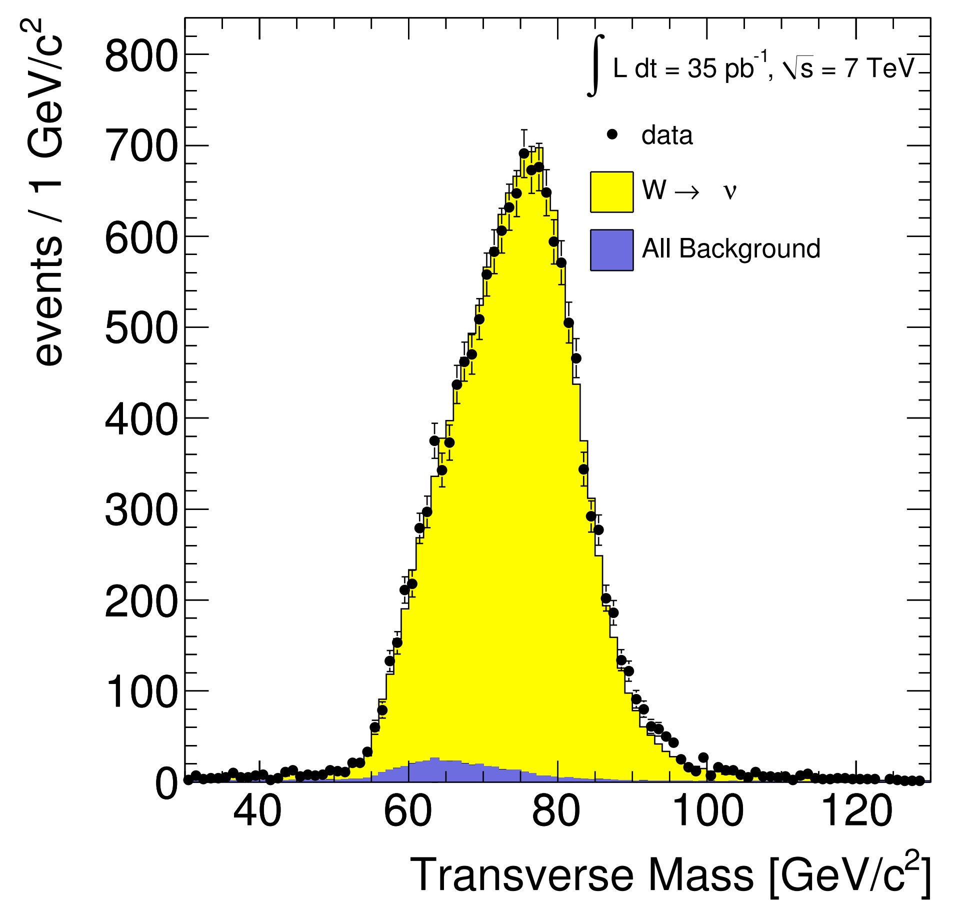
- isolated
- good track quality
- high transverse momentum

W selection:

- 1 electron or 1 muon
- large missing transverse energy
- transverse mass > 60 GeV

Z selection:

- 2 opposite sign electrons or muons
- 60 GeV < invariant mass < 120 GeV



➡ **well understood, almost background free sample (< 1 %)**

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SAMPLE SELECTION

1. Selection of subsample by triggering events with **centrally produced W or Z boson**

2. Removal of **pile-up** from the selected sample

particles coming from pile-up fill up the LRG!

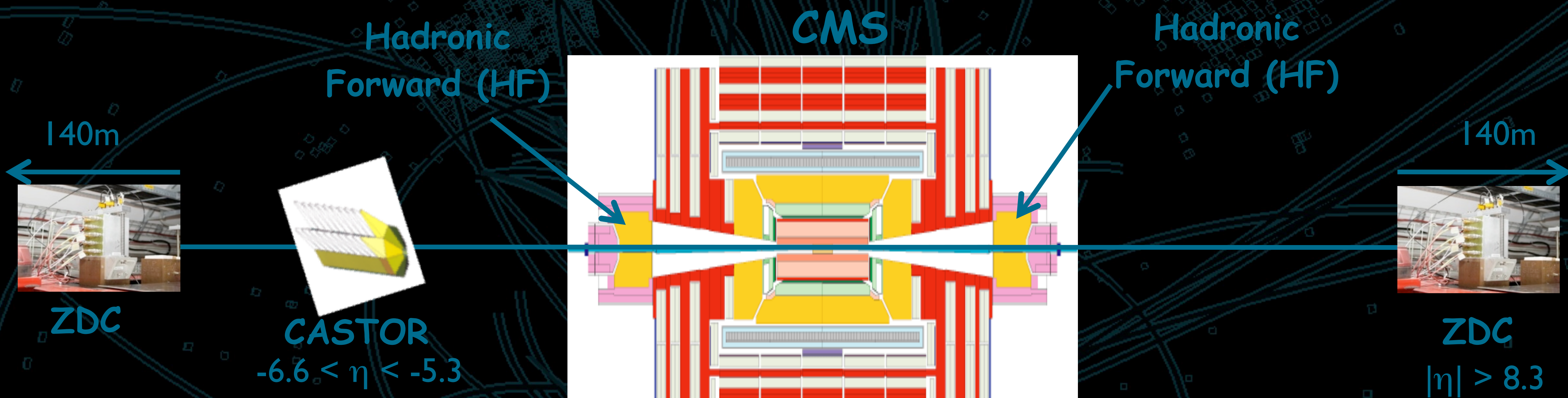
→ "only" technical problem, but makes the measurement unfeasible with increasing inst. luminosity

→ up to 2010 data taking (~36 pb^{-1}) corrections with zero bias data

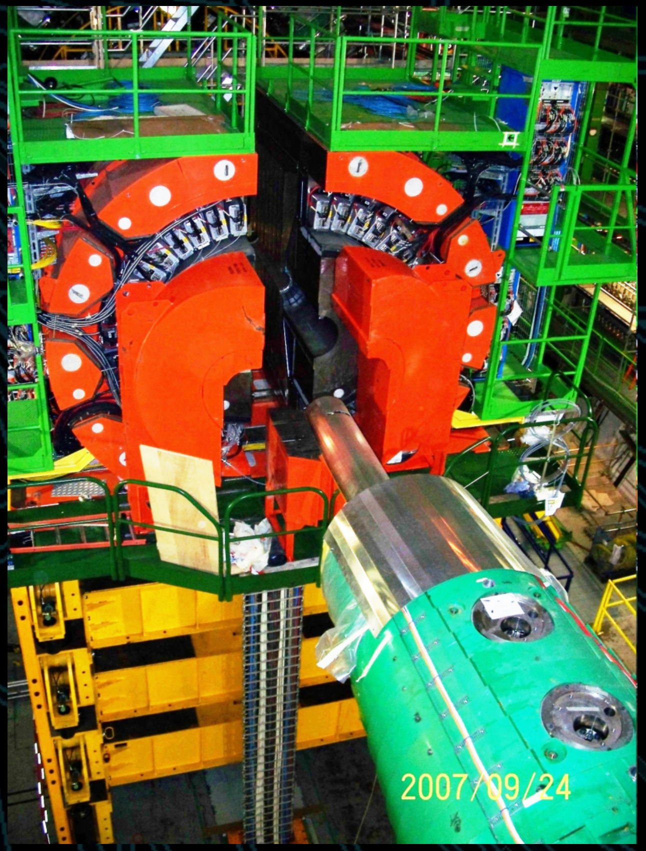
DIFFRACTION SIGNATURE

1. Select a clean and robust subsample by triggering events with **centrally produced W or Z boson**
2. Removal of **pile-up** from the selected sample
3. Dedicated forward detectors to study the particle flow in the **forward region**

The Hadron Forward Detector: HF



- Located at 11.2 m from the interaction point
- Rapidity coverage: 2.9 < |η| < 5.2
- Steel absorbers and embedded radiation hard quartz fibers



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DIFFRACTION SIGNATURE

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3. Dedicated forward detectors to study the particle flow in the **forward region**

Variables reflecting a LRG:

E_{HF}: energy deposit in the HF calorimeter

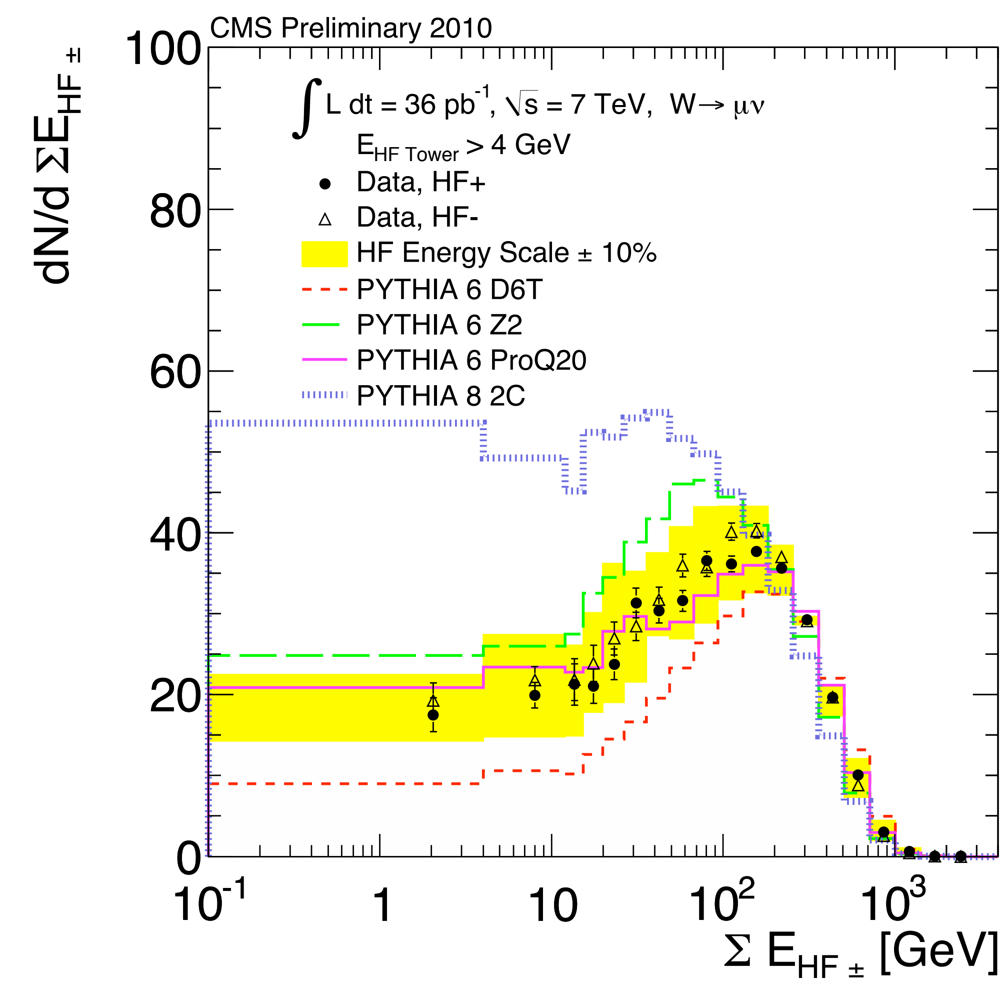
- select events with no energy deposit above noise threshold in one of the forward detectors HF
- noise threshold in HF ~ 4 GeV

NT_{HF}: number of calorimeter towers in HF

- select events with NT = 0 in HF+ or HF-
- count towers above a threshold of 4 GeV

η_{max}, η_{min}:

- pseudo-rapidity of most forward/backward particle



MC models without diffractive component!

DIFFRACTION SIGNATURE

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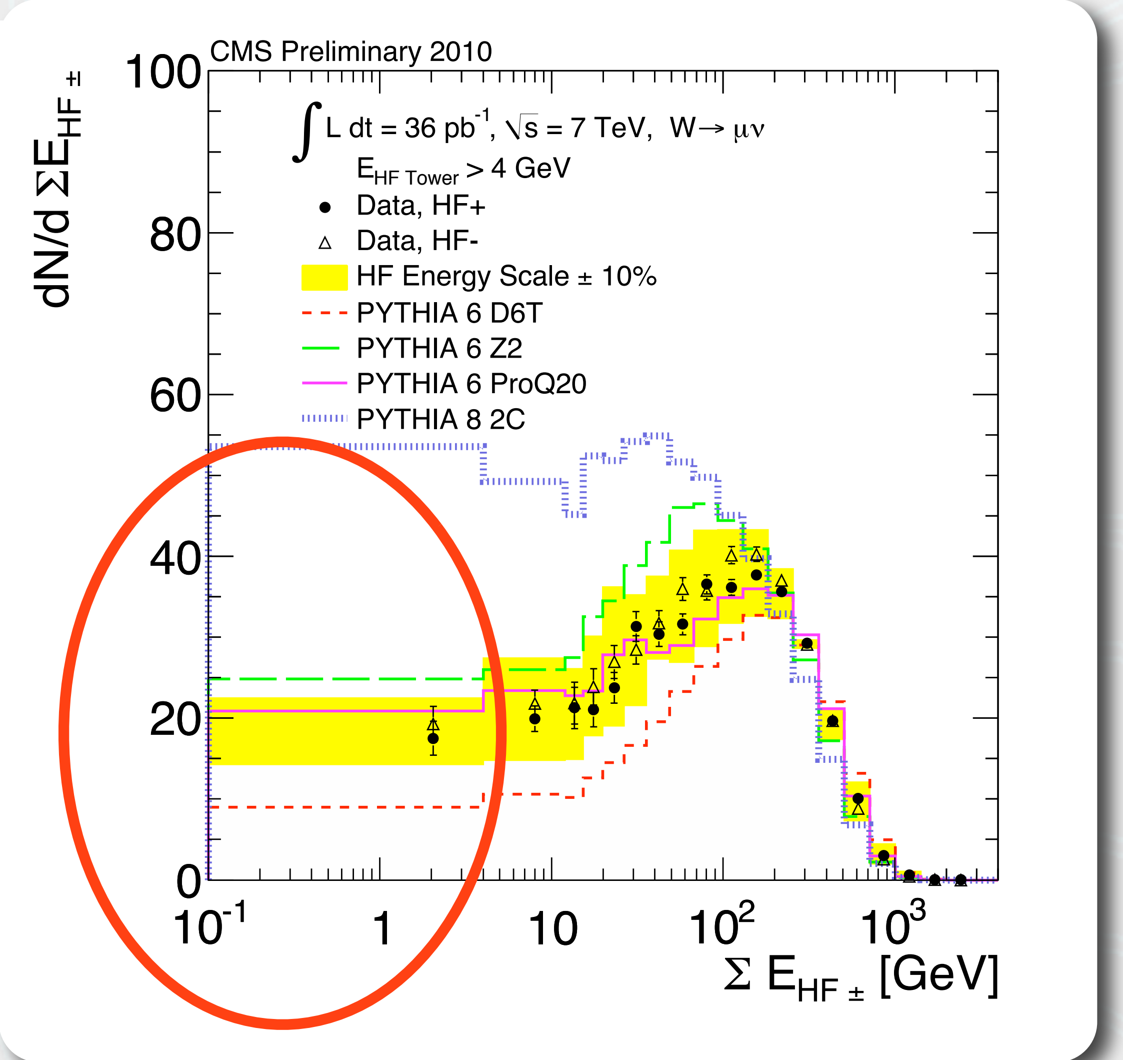


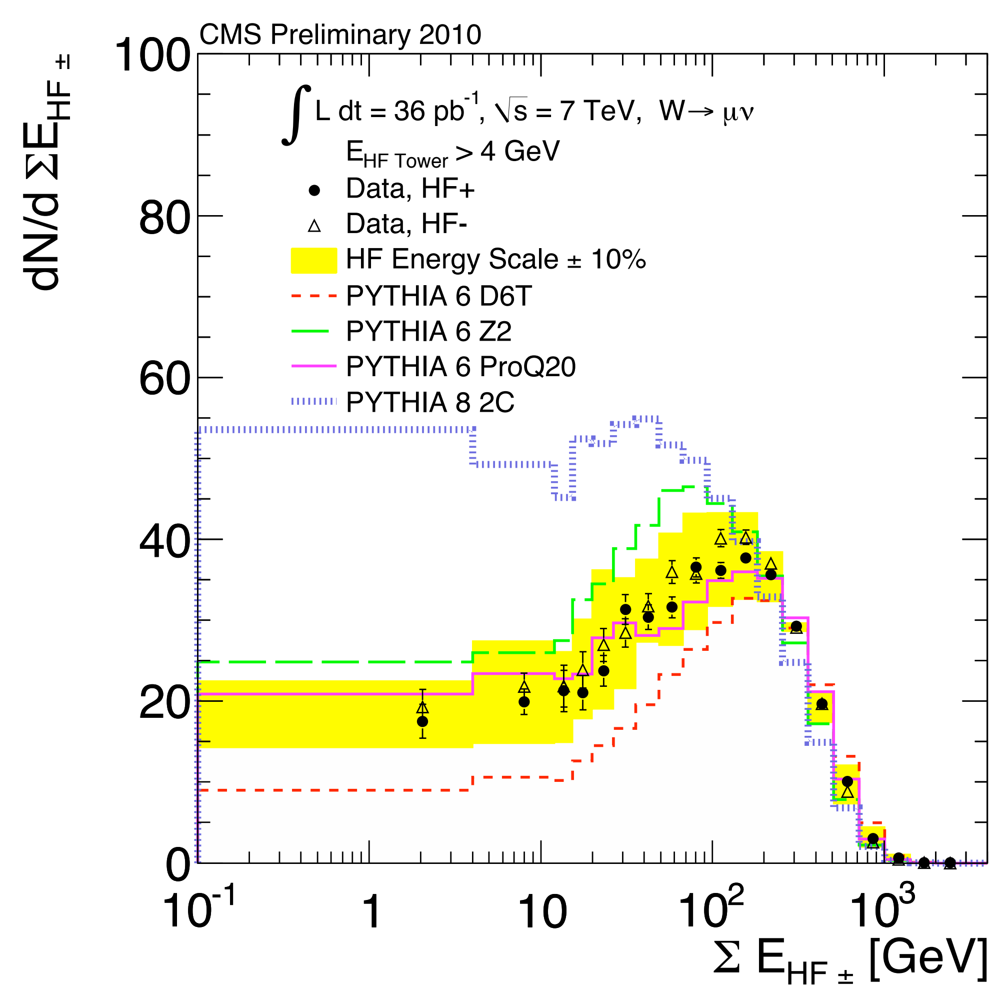
➡ **no diffractive peak can be observed**

➡ **forward energy flow is strongly tune dependent**

FORWARD ENERGY FLOW

- Underlying multi-parton interactions (MPI) fill the LRG reducing the observed yields of hard diffractive events

➡ "gap survival probability"

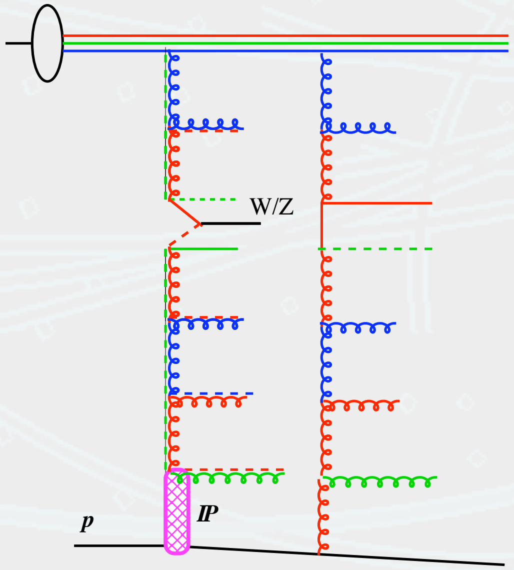


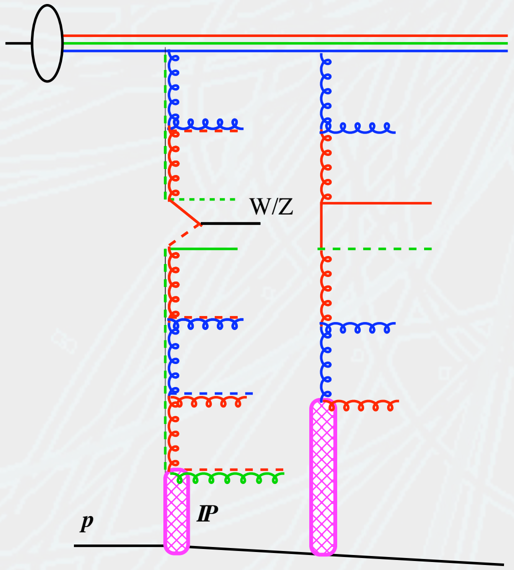
Fraction of LRG events after corrections for undetectable pile-up (e and μ combined):

W: 1.46 ± 0.09 (stat.) ± 0.38 (syst.) %

Z: 1.57 ± 0.25 (stat.) ± 0.42 (syst.) %

consistent with Tevatron results

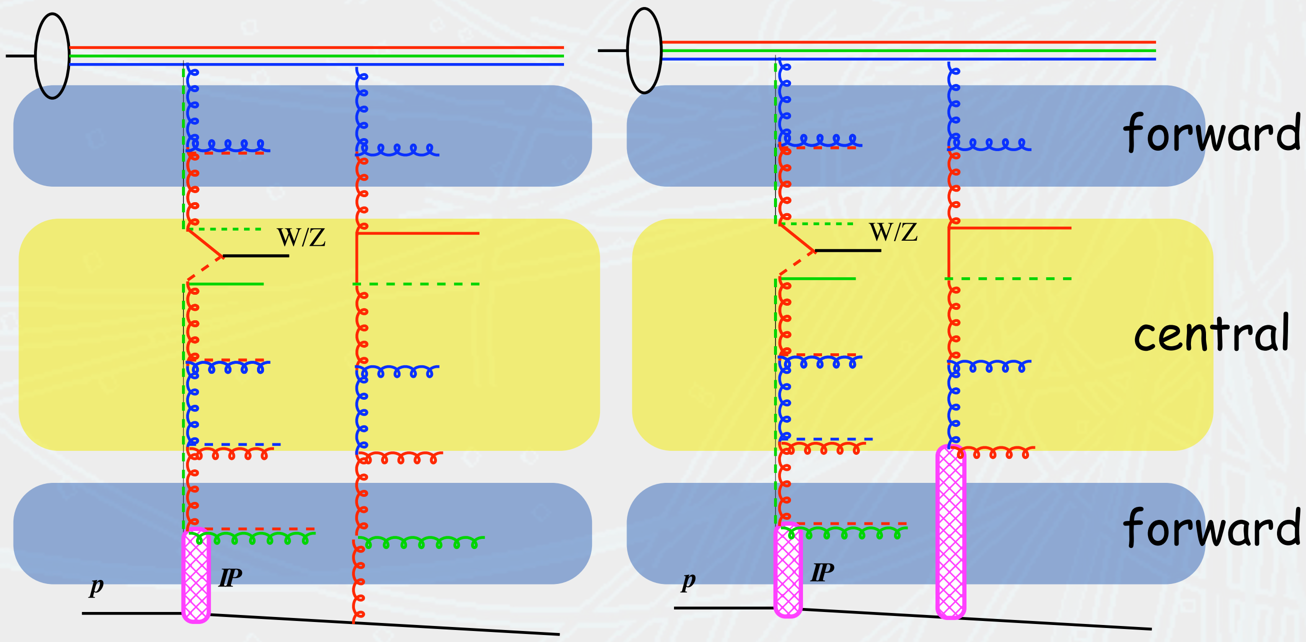


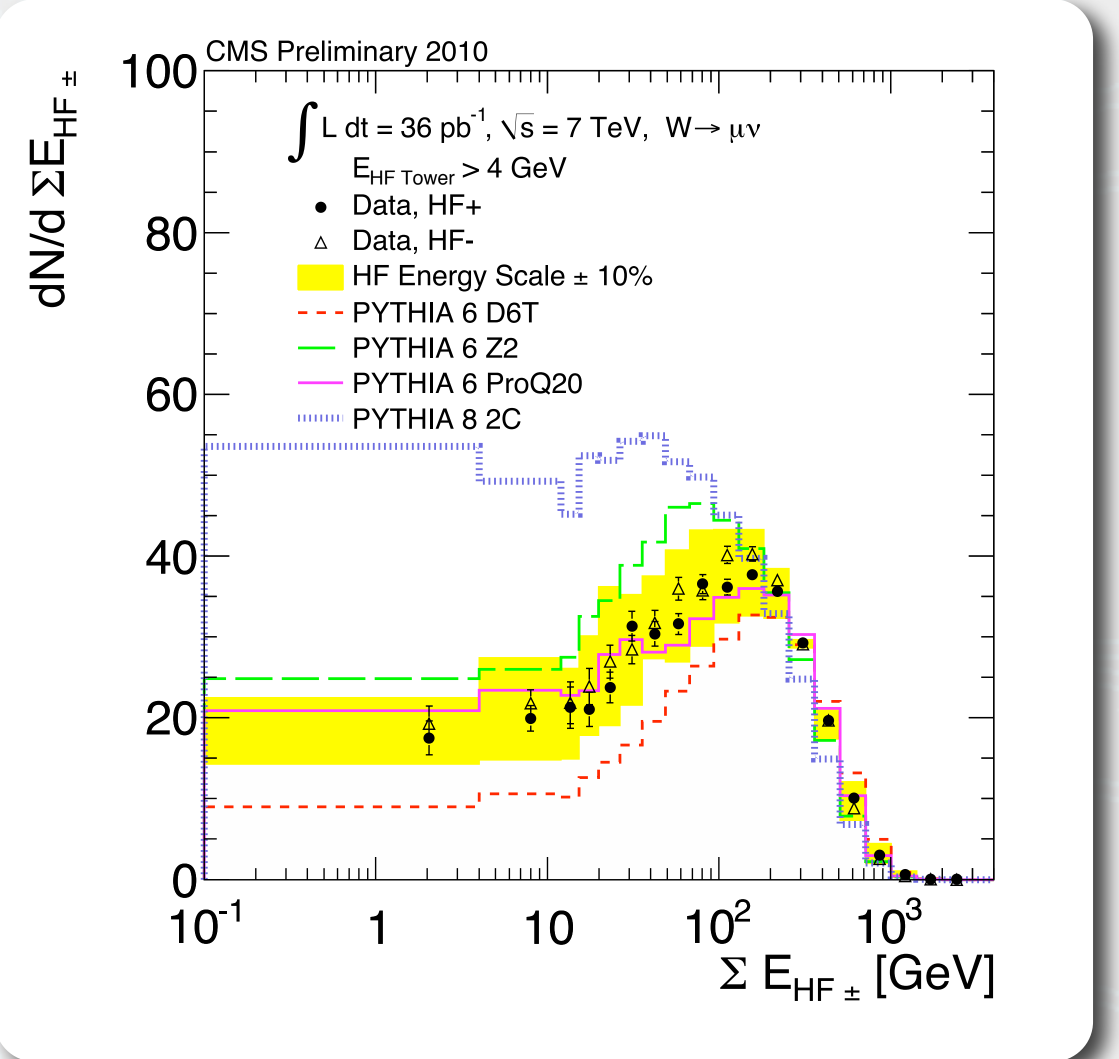


Analysis Strategy

FORWARD ENERGY FLOW

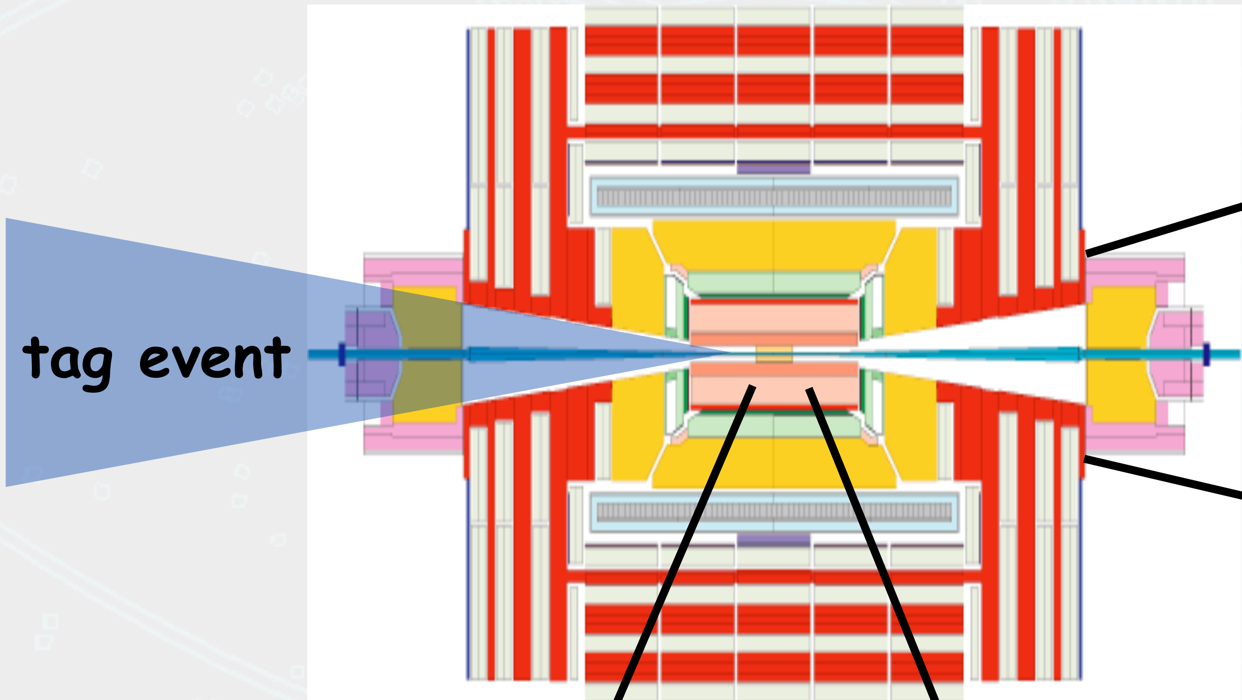
- Underlying multi-parton interactions (MPI) fill the LRG reducing the observed yields of hard diffractive events
  - ➡ "gap survival probability"
- MPI is MC tune dependent (so far tuned to central observables in minimum bias)
- MC has so far no diffractive MPI component
  - ➡ expect different Forward/Backward and Forward/Central correlations



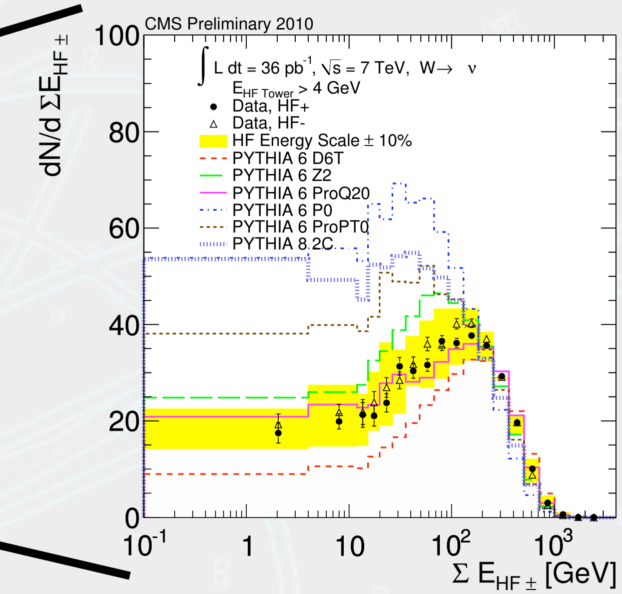


CORRELATION STUDIES

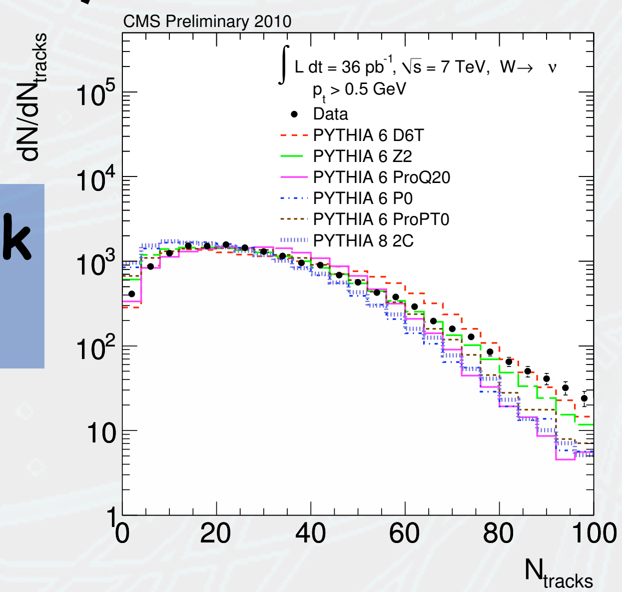
study opposite side



tag event



study central track multiplicity



Split in 3 different energy regions, tagging on HF–

1) **low** (20 GeV < E_{HF-} < 100 GeV)

2) **medium** (200 GeV < E_{HF-} < 400 GeV)

3) **high** (E_{HF-} > 500 GeV)

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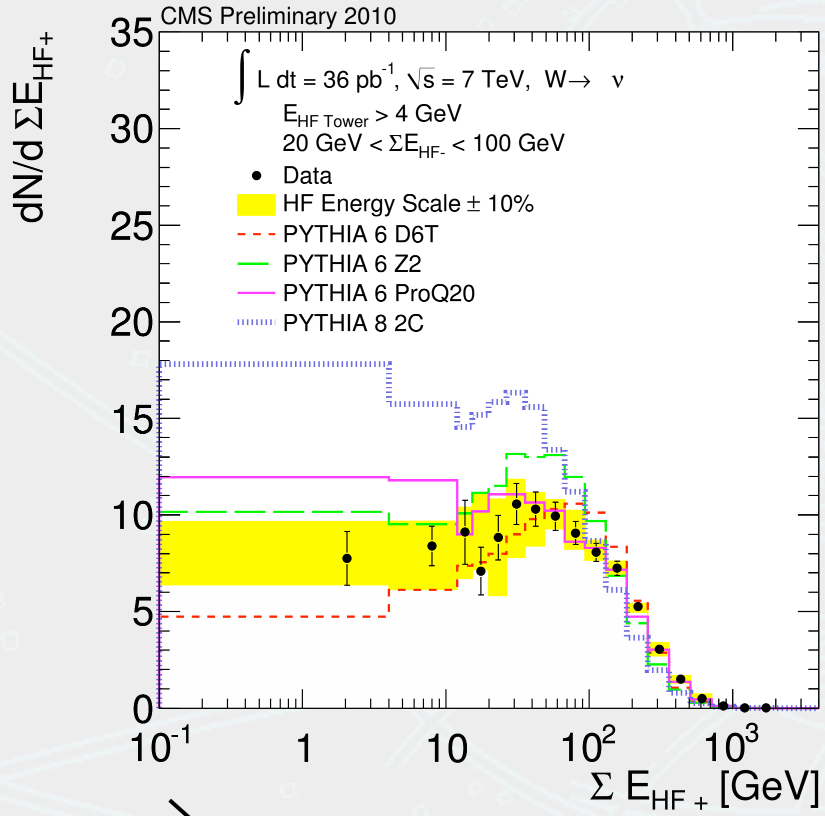
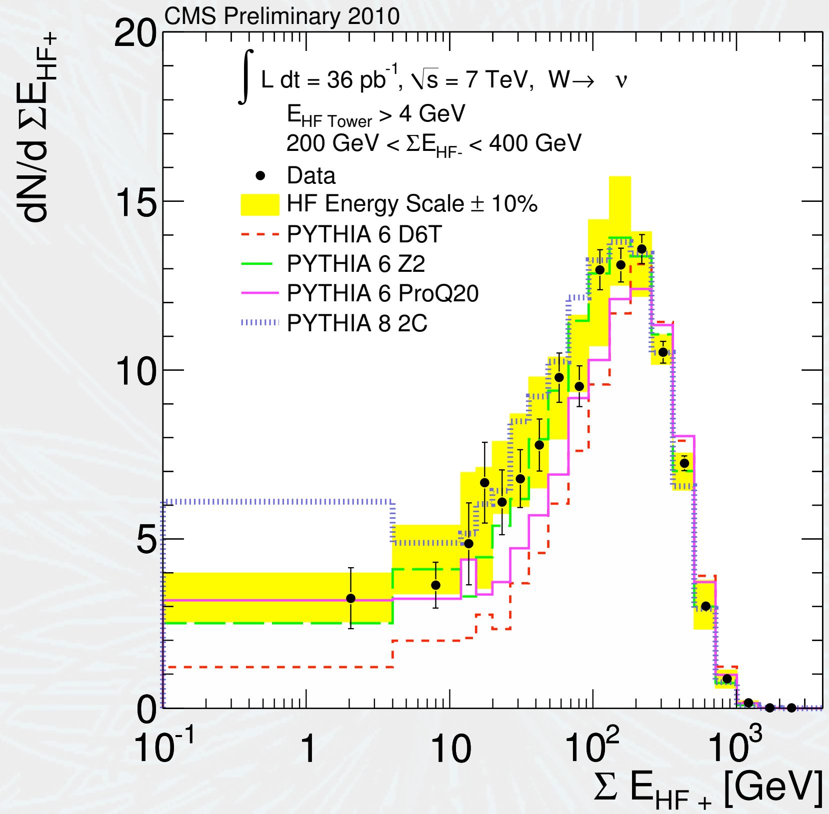
FORWARD/BACKWARD CORRELATION

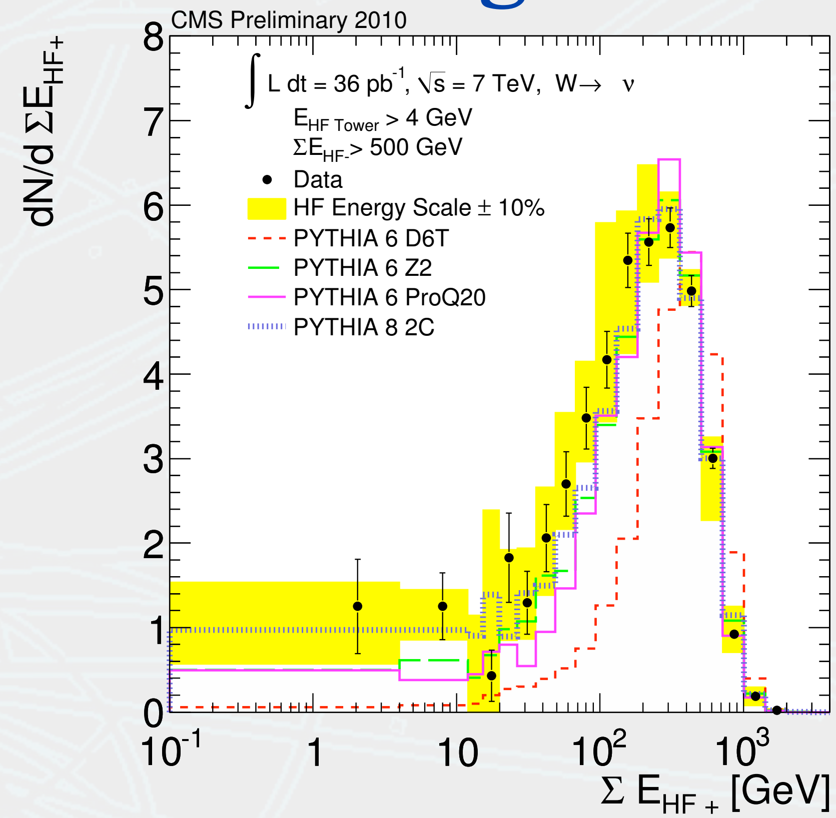
low

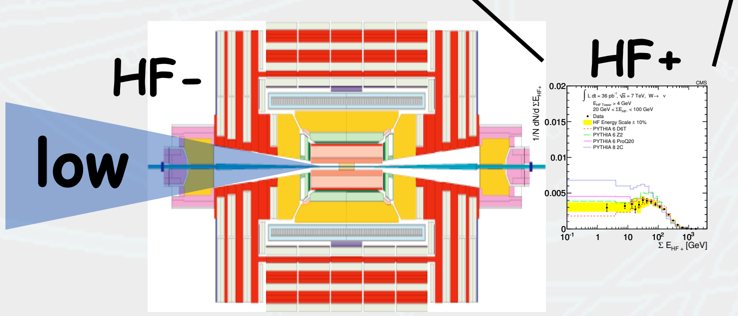


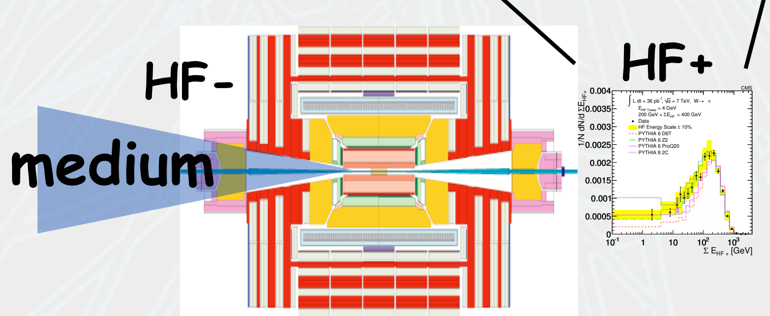
medium

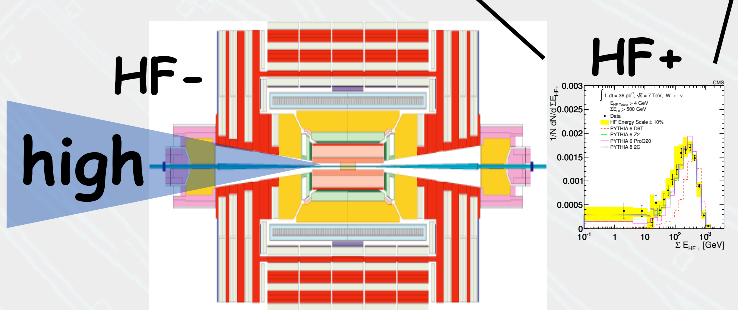


high



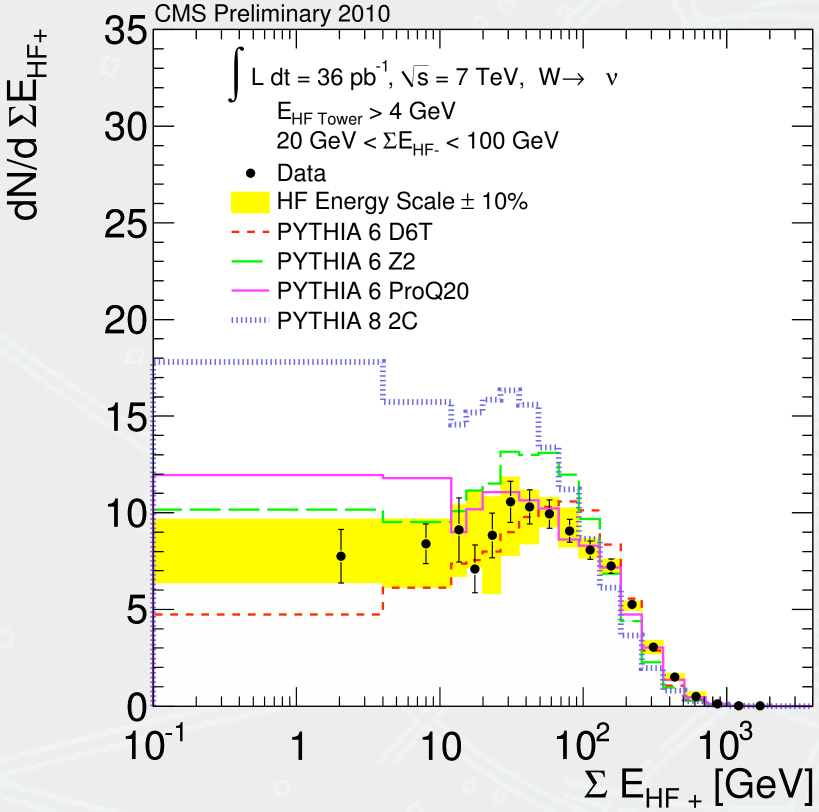




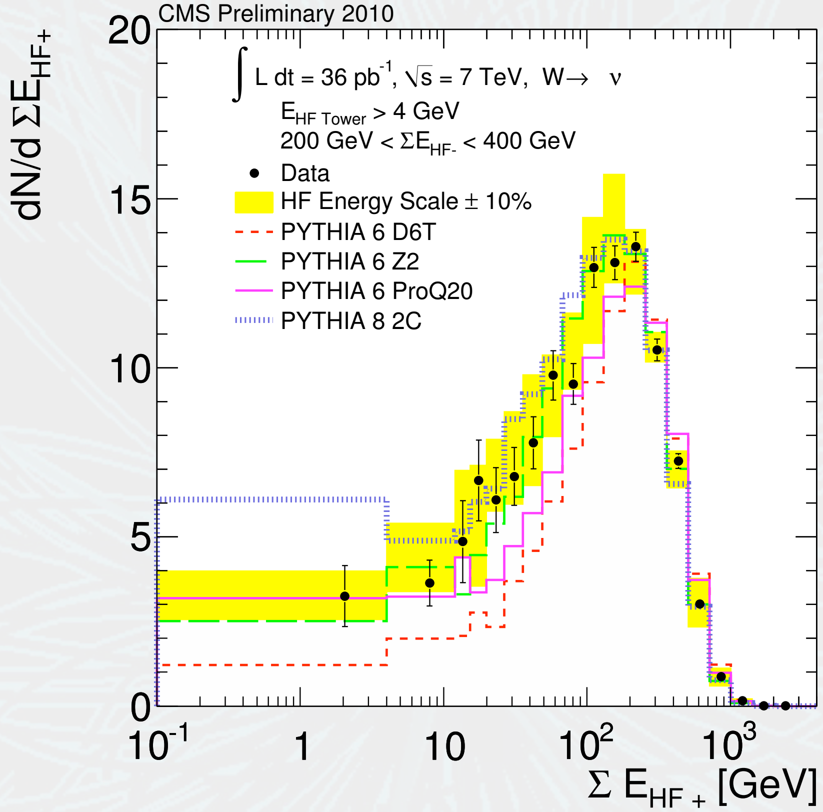


FORWARD/BACKWARD CORRELATION

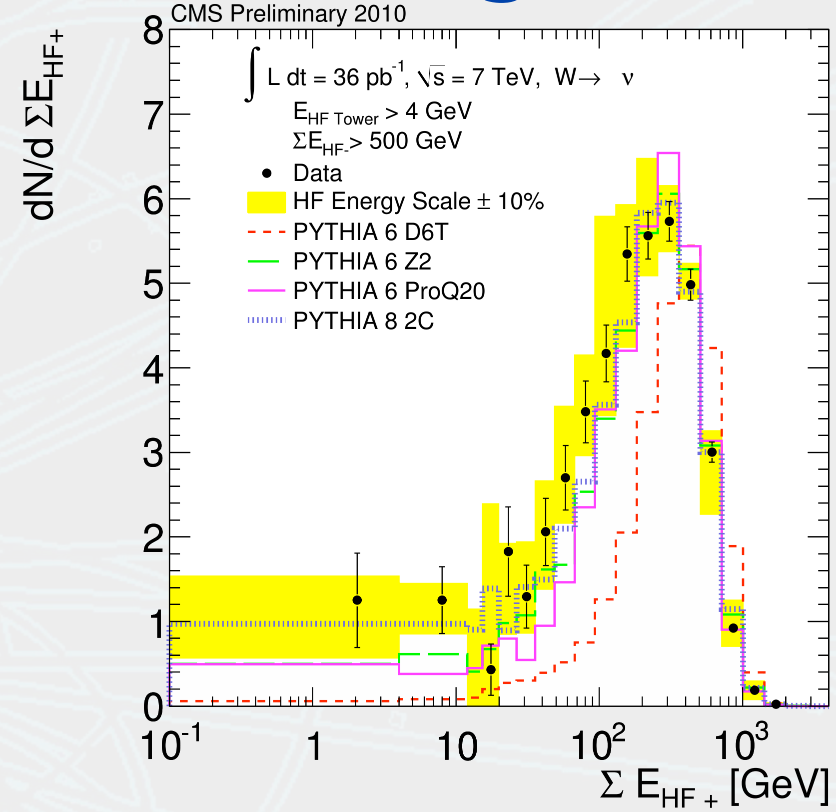
low



medium



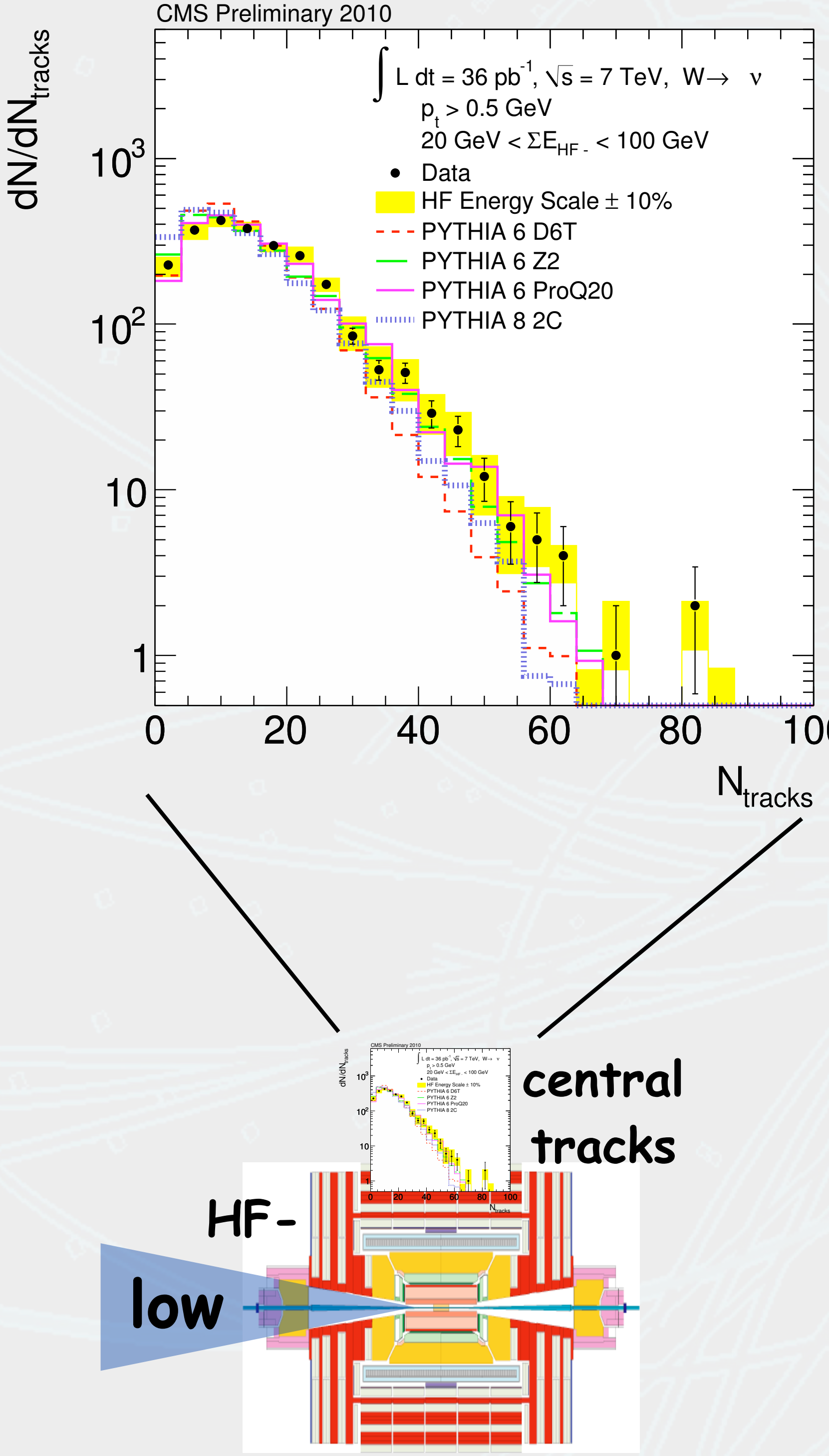
high



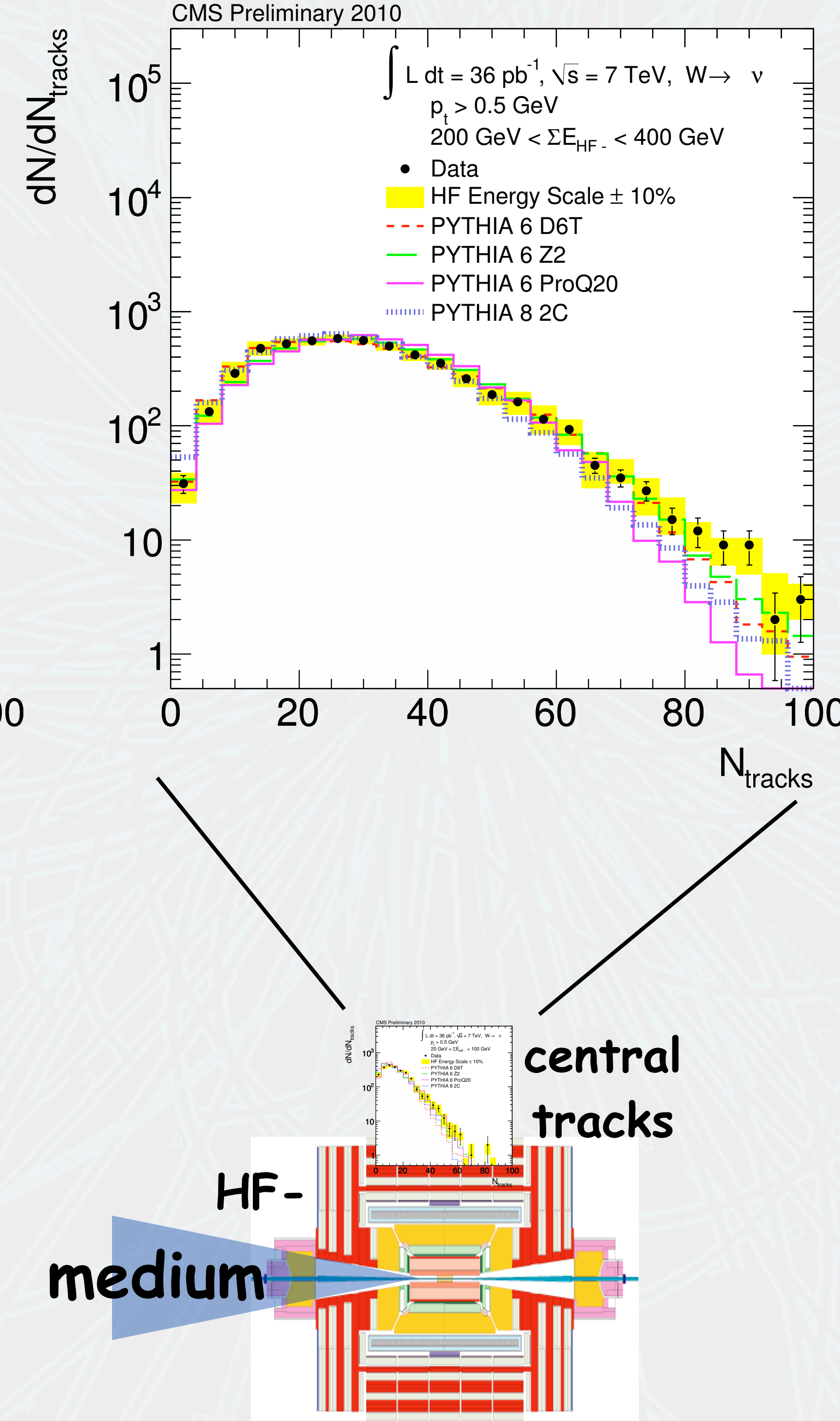
- strong positive correlations are observed in data and MC
- but none of the MC tunes describes data in their entirety

FORWARD/CENTRAL CORRELATION

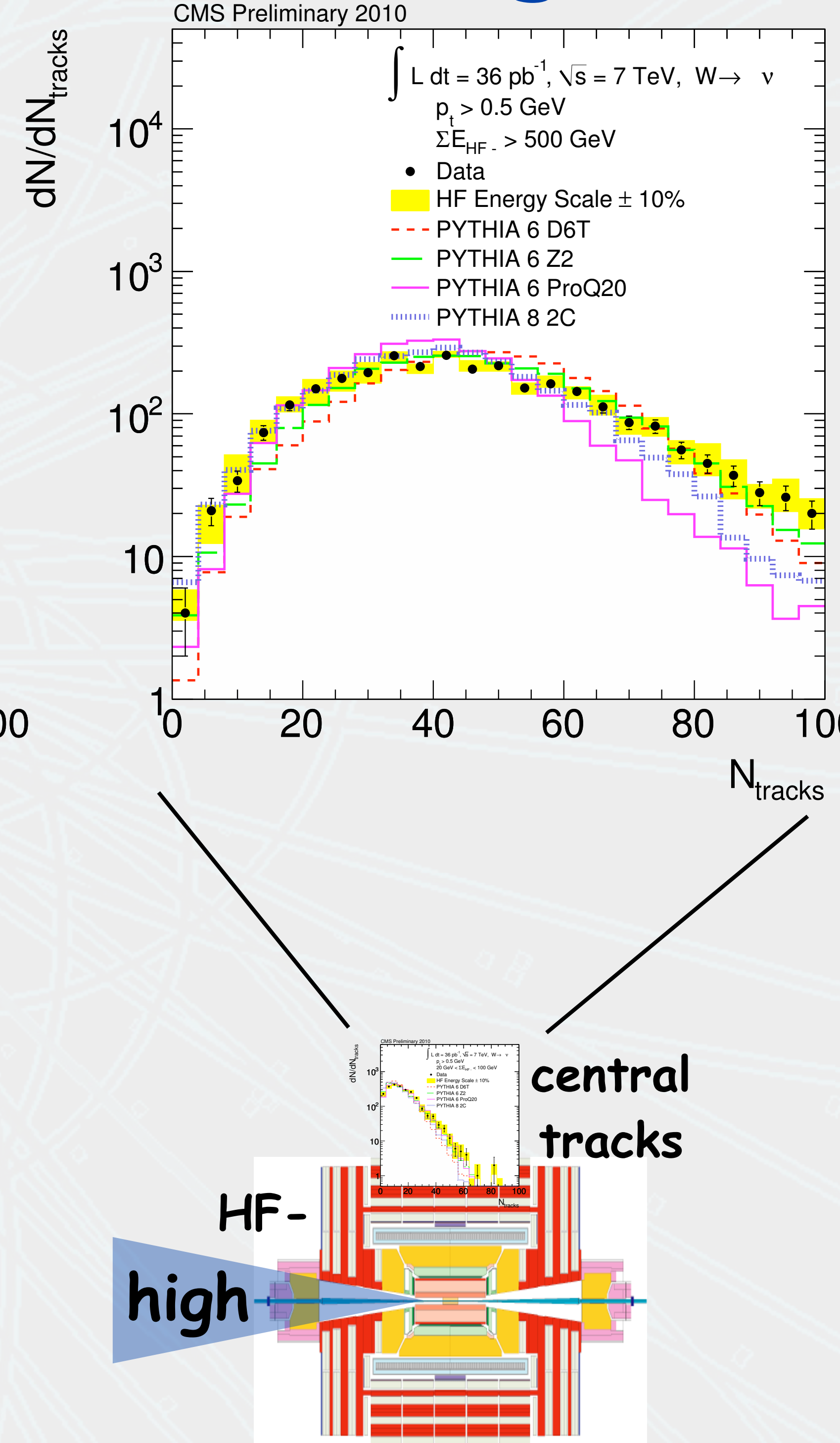
low



medium



high



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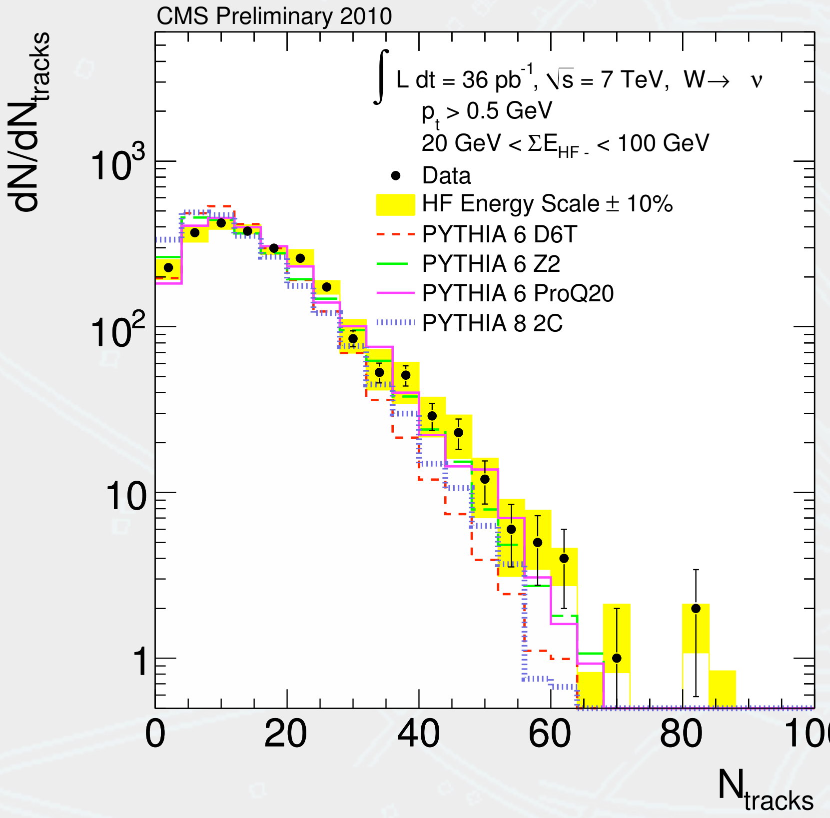
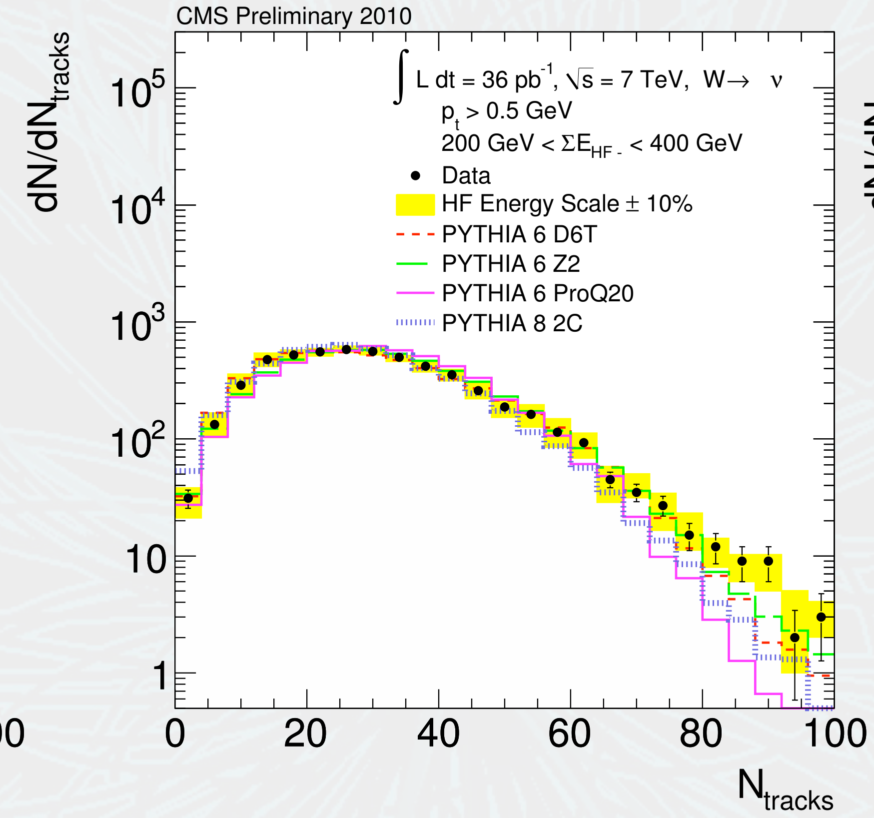
FORWARD/CENTRAL CORRELATION

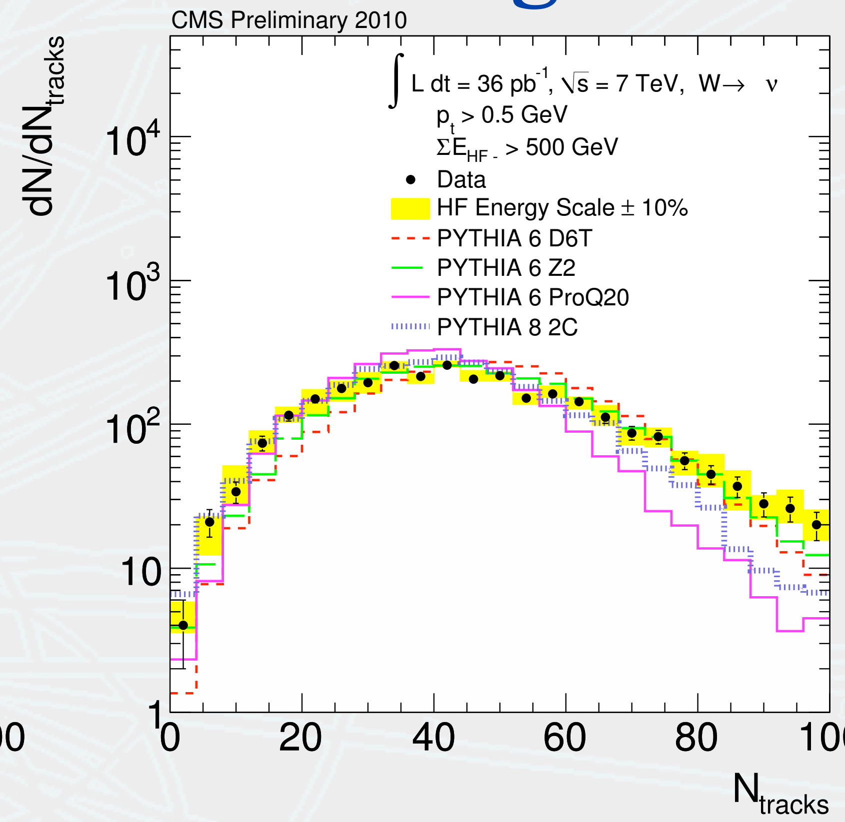
low



medium



high



- strong positive correlations are observed in data and MC
- but none of the MC tunes describes data in their entirety

OBSERVATION OF DIFFRACTION

$$A = \frac{N^{pos}_{evts} - N^{neg}_{evts}}{N^{tot}_{evts}}$$

- An asymmetry of events where the lepton is in the opposite rapidity hemisphere to the gap is observed in data:

A = - 0.22 ± 0.06 for W tagged events and

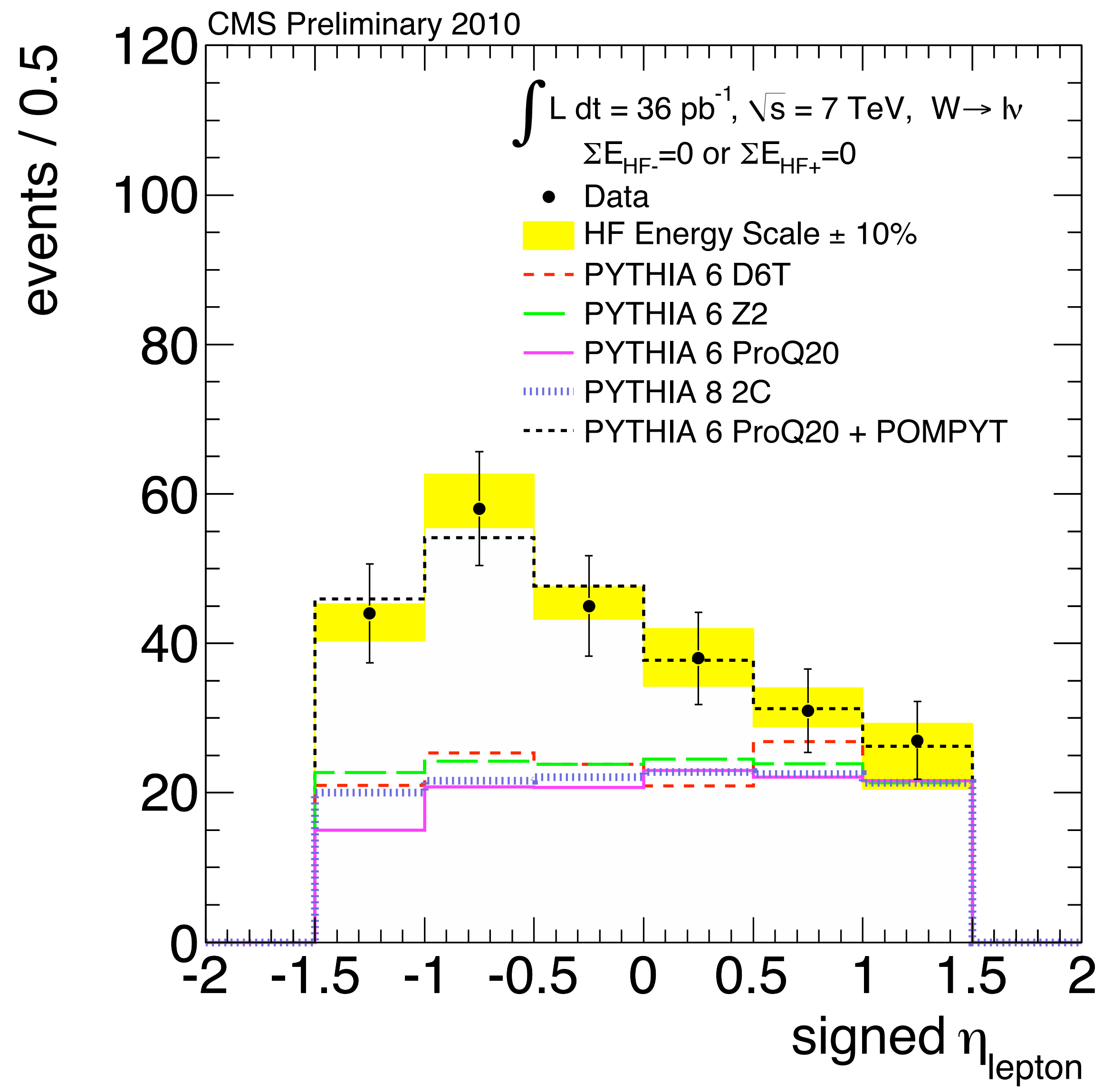
A = - 0.20 ± 0.16 for Z tagged events

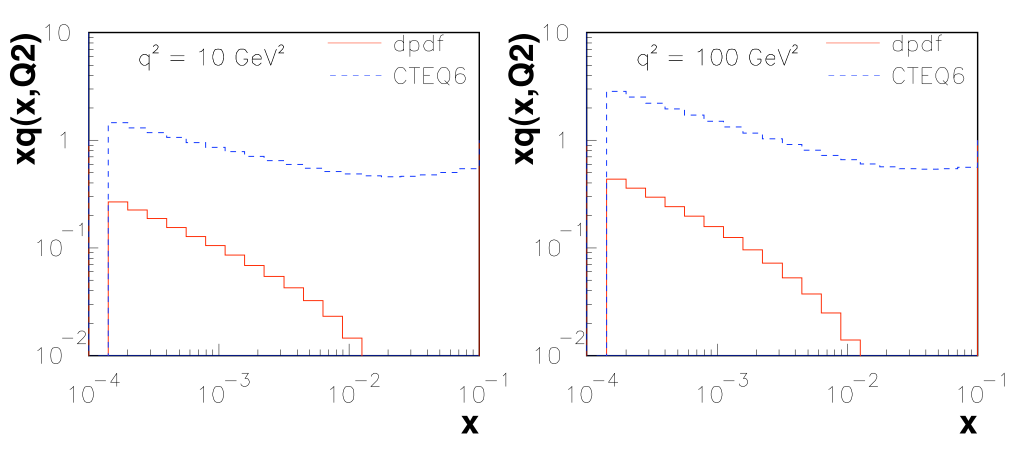
- The same variable is flat for non-diffractive MC whereas diffractive MC shows an asymmetry

- The fraction of single diffractive MC component which describes the observed asymmetry is

50 ± 9.3 (stat.) ± 5.2 (syst.) %

- Such an asymmetry can be understood looking at the diffractive PDF component which on average has a lower x then the quark PDF





$$\text{signed } \eta_{lepton} = \eta_{lepton} * (\text{sign of gap side})$$

Conclusions

- Hard diffraction with W or Z events has been observed through an asymmetry in data
- A 50 % single diffractive component in MC can describe this asymmetry
- Results indicate importance of multi-parton interaction in description of data
- Large efforts needed towards a simultaneous description of forward and central variables with MC models
- Measurements can be used for further constraints of the models with multi-parton interaction