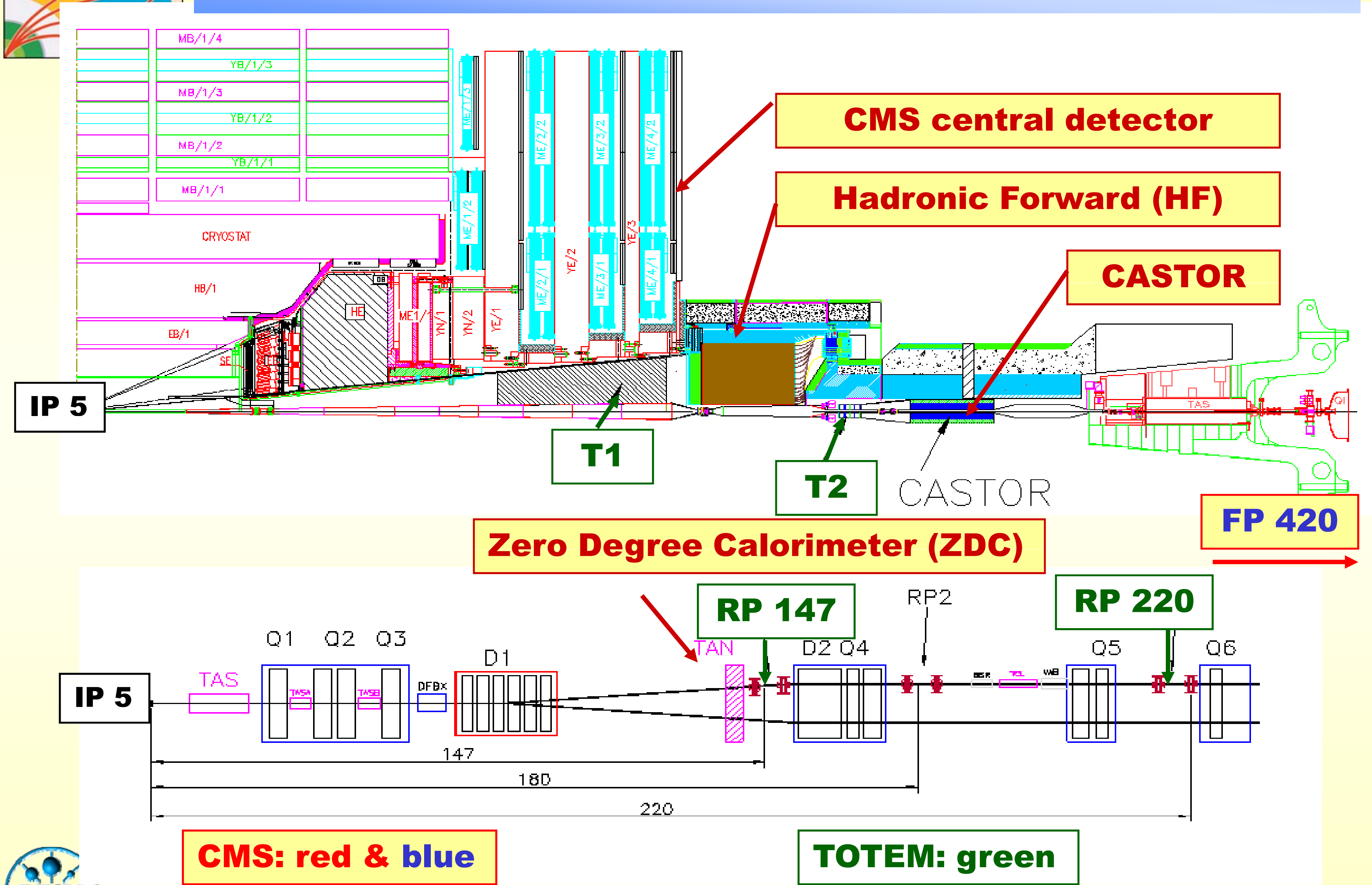
Status of Forward Physics Projects at CMS

Kerstin Borras (DESY)
on behalf of the
CMS Collaboration

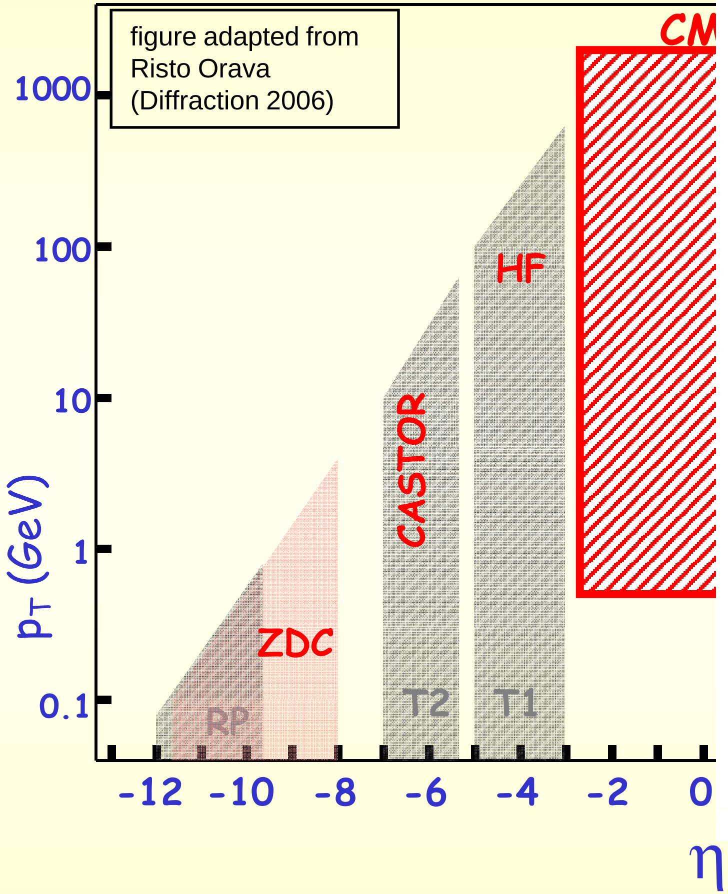
- **Forward Detector Components in CMS Interaction Region**
- **Outline for Forward Physics**
- **Experimental Issues: Trigger & Pile Up**
- **Selected Physics Topics**
- **Summary**

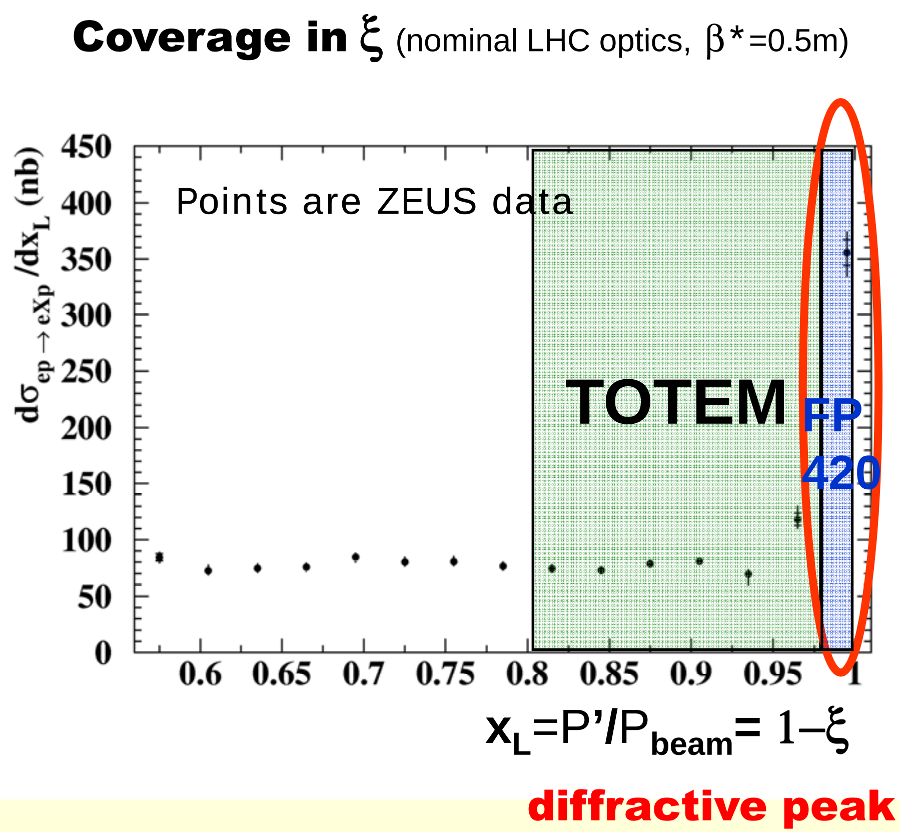
Forward Region around CMS IP



Coverage in p_T - η and ξ

CMS fwd calorimetry up to $|\eta| \approx 5$ + Castor + ZDC + FP420

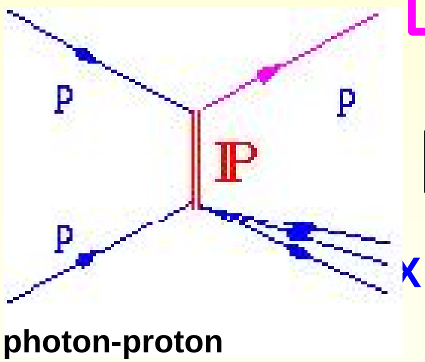




Unprecedented coverage at hadron colliders !

Experimental Signatures

Single Diffraction



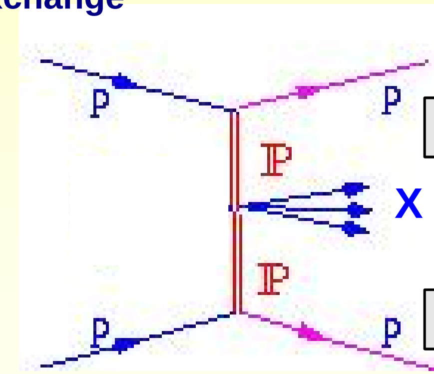
Roman Pot

gap

central + forw. det.

Similar for photon-proton

Double Pomeron Exchange



Roman Pot

gap

central + forw. det.

gap

Roman Pot

Similar for photon-photon or central exclusive production (CEP)

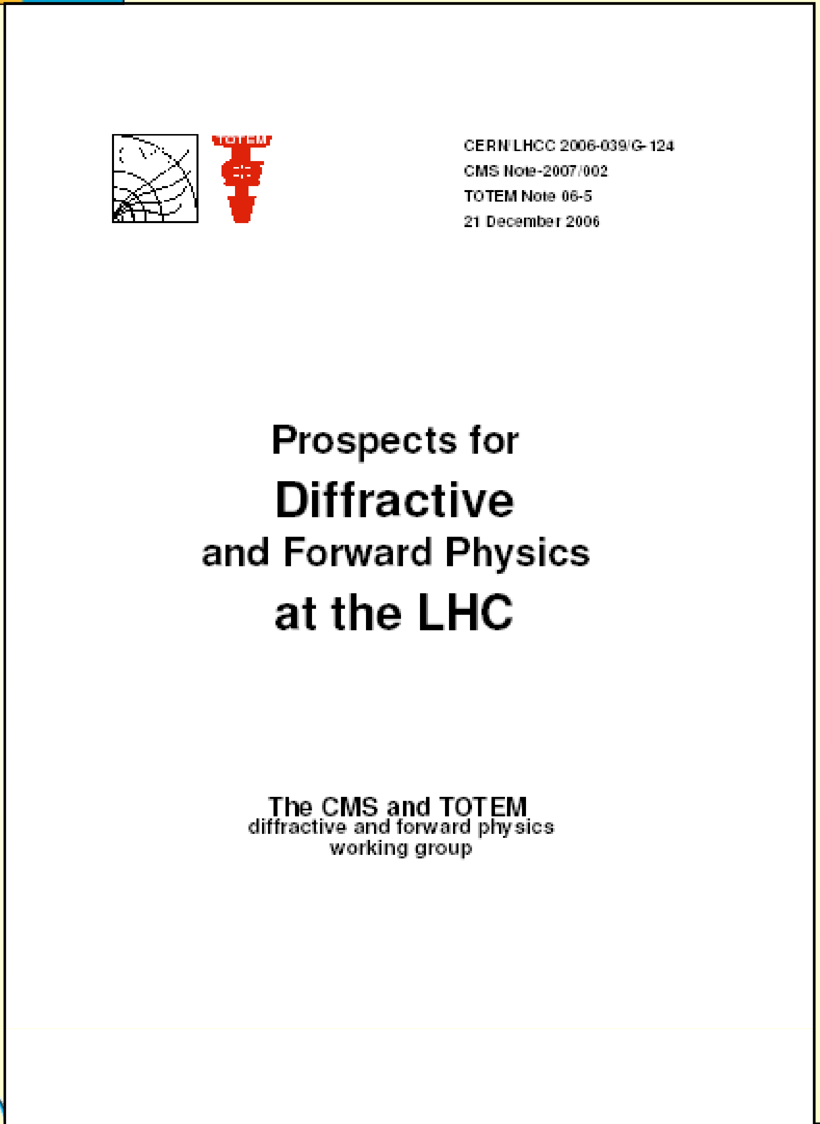
Experimental observables:

- large rapidity gaps
- tag in TOTEM RP and/or FP420: $\xi_1 \xi_2 s = M^2$
- reconstruction with central & forward detectors: $\xi_{1,2} = \frac{1}{\sqrt{s}} \sum_{\text{particles}} E_T e^{\pm\eta}$

Topics of soft and hard diffraction:

- Dependencies on ξ, t and Mx as fundamental quantities of non-pert. QCD
- Gap survival dynamics, multi-gap events
- Hard diffraction: production of jets, W; J/ψ ; b; t hard photons, diffr.PDF's
- Double Pomeron exchange events as a gluon factory
- Central exclusive Higgs production
- SUSY & other (low mass) exotics & exclusive processes
- Proton light cone studies (e.g. pp → 3jets + p)

Prospects with CMS & TOTEM



CERN/LHCC 2006-039/G-124
CMS Note-2007/002
TOTEM Note 06-5
21 December 2006

Prospects for
Diffractive
and Forward Physics
at the LHC

The CMS and TOTEM
diffractive and forward physics
working group

In a strong joint effort both

CMS and TOTEM

studied the prospects for forward physics with pp collisions @ LHC for various analysis topics

→ common CMS & TOTEM note

published in December 2006.

Different processes assessed for:

- **standard luminosity optics,**
- **high luminosity optics and**
- **special low luminosity optics.**

Tools for triggering and pile-up rejection studied and discussed.

Together CMS and TOTEM have an unprecedented coverage in rapidity.

Here emphasis is put on the CMS part
(see talk from Karsten Eggert for TOTEM, also FP420 was studied → see separate talk).

Map to diffraction and fwd physics in CMS

Low lumi
Rapidity gap selection possible
HF, Castor, BSCs, T1, T2
Proton tag selection optional
RPs at 220m and 420 m

Diffraction is about 1/4 of σ_{tot}
High cross section processes
"Soft" diffraction
Interesting for start-up running
Important for understanding pile-up

Low lumi

High lumi

High lumi
No Rapidity gap selection possible
Proton tag selection indispensable
RPs at 220m and 420 m

Central exclusive production
Discovery physics:
Light SM Higgs
MSSM Higgs
Extra dimensions

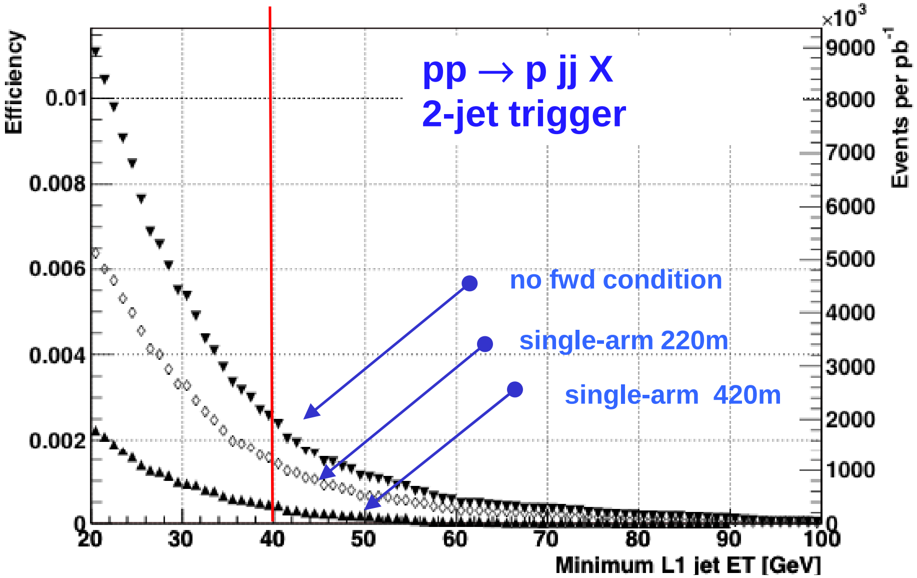
Gamma-gamma and gamma-proton interactions
Forward energy and particle flow:
- underlying event structure & multiple parton interactions
- input to cosmic shower simulation

QCD: Diffraction in presence of hard scale
- Low-x structure of the proton
- High-density regime (color glass condensate)
- Diffractive PDFs and generalized PDFs
- Drell-Yan

CMS alone | **CMS with Totem and/or FP420**

(M.Grothe HERA-LHC Workshop 2007)

Experimental Issue: Trigger for Diffraction



Usual trigger thresholds too high for diffractive events

- **use tag from forward detectors to lower the rate**
- **dedicated diffractive trigger stream: 1% of total bandwidth 1kHz @ L1 and 1Hz @ HLT**
- **can decrease E_T threshold from 100 GeV down to 40 GeV**

Luminosity $[cm^{-2}s^{-1}]$	# Pile-up events per bunch crossing	L1 2-jet rate [kHz] for $E_T > 40$GeV per jet	Total reduction needed	Reduction when requiring track in RP detectors at 220 m	$\xi < 0.1$
1×10^{32}	0	2.6	2	370	
1×10^{33}	3.5	26	20	7	15
2×10^{33}	7	52	40	4	10

single-sided 220m condition without and with cut on ξ

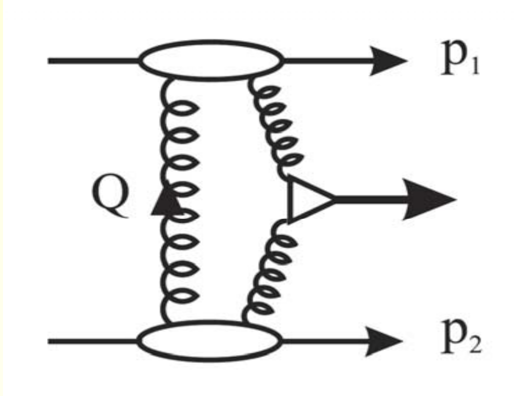
Achievable total reduction: 10 (single-sided 220m) x 2 (jet iso) x 2 (2 jets same hemisphere as p) = 40

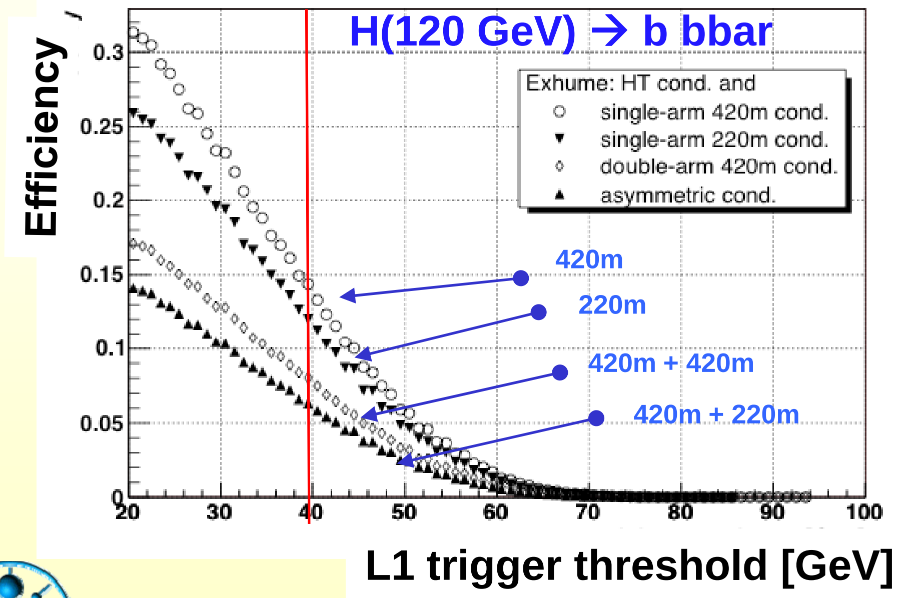
Experimental Issue: Trigger for CEP

Central exclusive production of pp → pHp with H(120GeV) → b bbar

- **large QCD dijet background → observation in non-diffractive production challenging**
- **selection with quantum numbers J^{PC}=0++ for CEP → improves signal to background ratio dramatically**
- **in certain MSSM scenarios: signal cross section three orders of magnitude larger than in SM**

→ Trigger is a major limiting factor





Level-1:
~12% efficiency with 2-jets (E_T>40GeV) & single-sided 220 m condition

HLT:
~7% jet trigger efficiency
for max. 1 Hz output rate → prescale b-tag or add 420 m condition

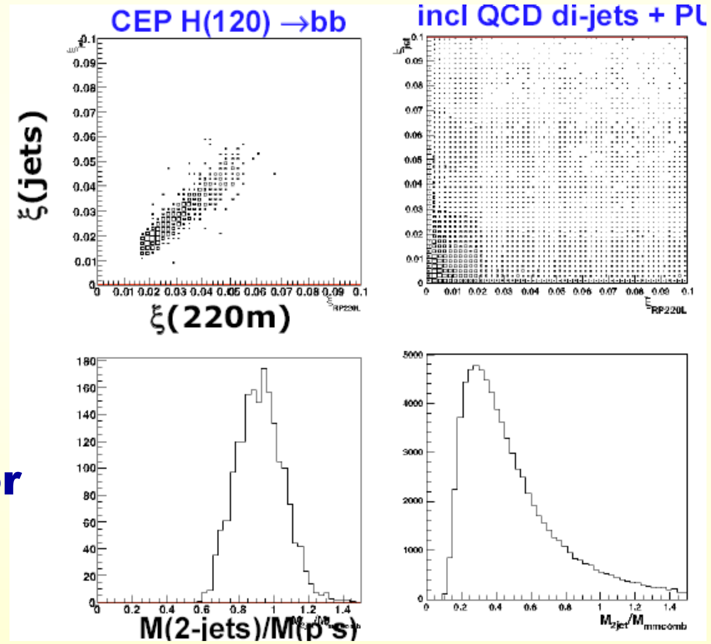
In addition:
~10% efficiency by requesting
1 jet & 1 μ (40GeV, 3GeV) condition

Experimental Issue: Pile-Up

DPE signature:

lumi	$\langle N^{PU} \rangle$	420+420	220+220	220+420	Total
$1 \cdot 10^{33}$	3.5	0.003	0.019	0.014	0.032
$2 \cdot 10^{33}$	7.0	0.008	0.052	0.037	0.084

at 2 x 10^{33} $cm^{-2}s^{-1}$: independent of process type (with dijet or b bar production ....)
→ 10% get DPE signature through pile up



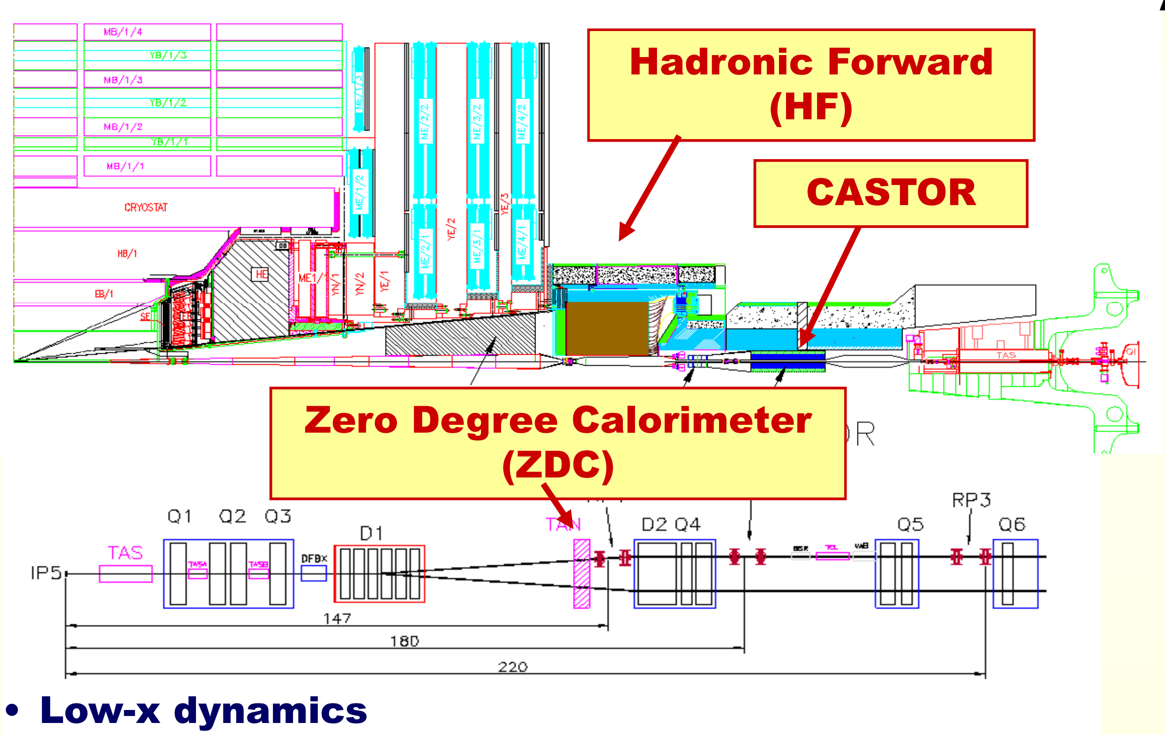
Reduction with:

- **correlation between ξ and M as measured in the central and in the near beam detectors**
- **add fast timing detectors → proton has same vertex as hard interaction**

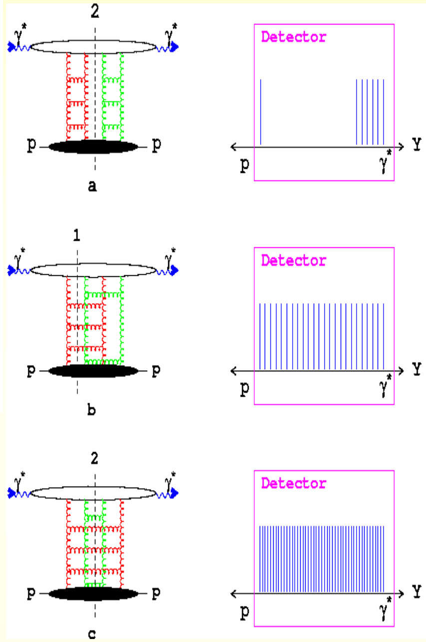
→ retain for example O(10%) of the signal for CEP H(120 GeV) → b bbar @ 2 x 10^{33} $cm^{-2}s^{-1}$

→ sufficient signal / background ratio achievable for SM Higgs, even much better for MSSM Higgs

Physics with CMS Forward Calorimeters



AGK-Cutting rules relate



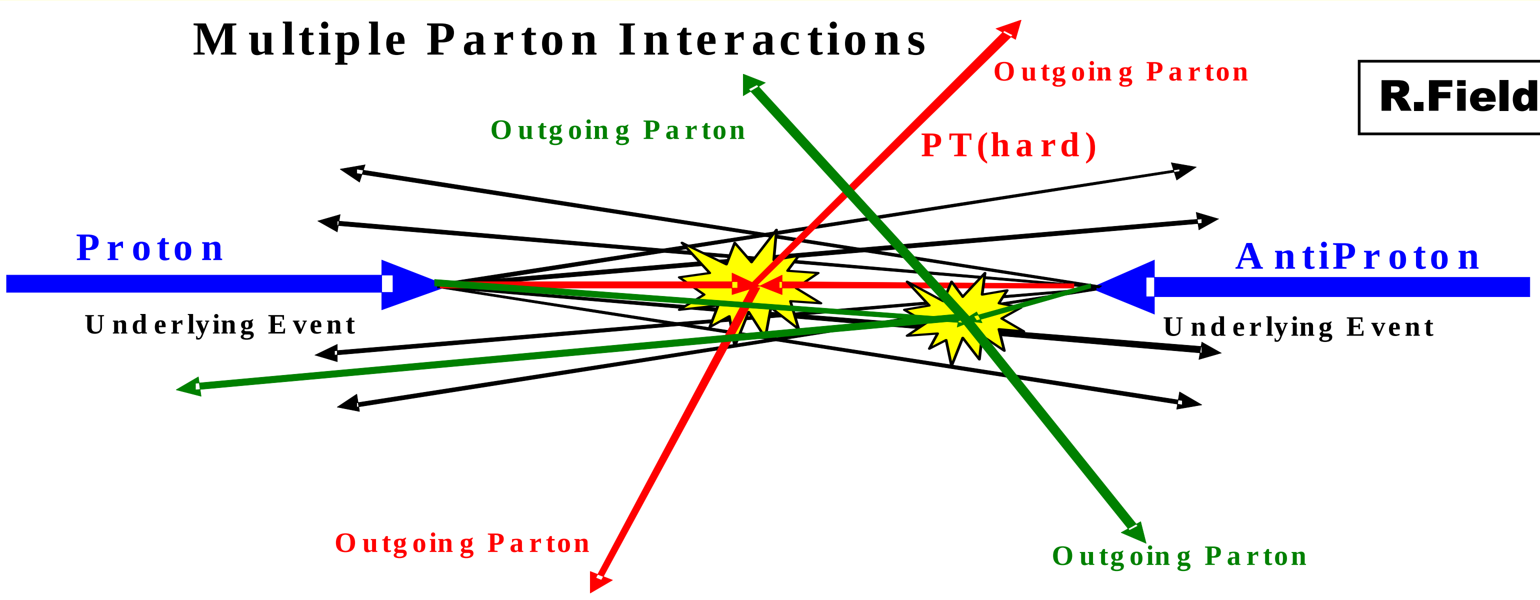
diffraction

saturation

multi-parton interactions

- **Low-x dynamics**
  - **Parton saturation, BFKL/CCFM dynamics, proton structure, multi-parton scattering.**
- **Measurements for cosmic ray data analysis**
  - **Forward energy and particle flows, minimum bias event structure**
- **Two-photon interactions and peripheral collisions**
- **QED processes to determine the luminosity to O(1%),e.g. pp → pp ee and pp → pp $\mu\mu$**
- **Forward physics in pA and AA collisions**
- **New forward physics phenomena**
  - **New phenomena such as Disoriented Chiral Condensates, incoherent pion emission, Centauro's, Strangelets.**

Multiple Interactions and Underlying Event



In addition to the single **hard interaction with large p_T**:

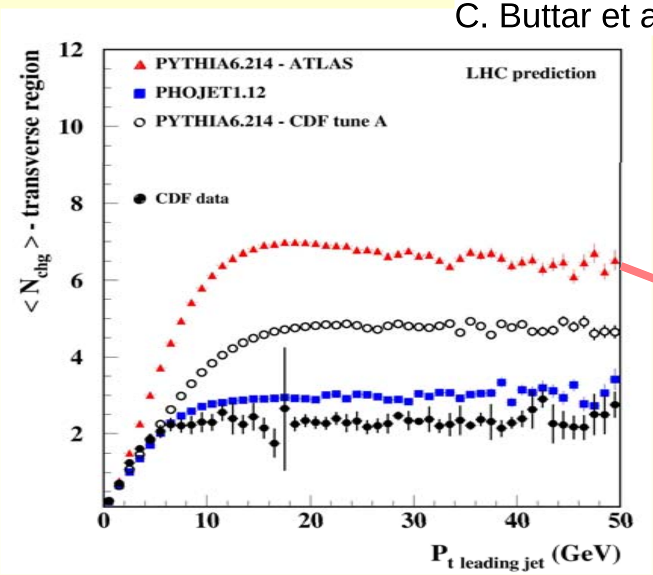
- (soft) interactions with low p_T → Underlying Event
  (remnant-remnant interactions and parton showers ...
  → additional energy offset)
- more hard interactions → Multi – Parton Interactions
  (see evidence from CDF 1997: need > 50% double parton interaction for γ + 3 jet)

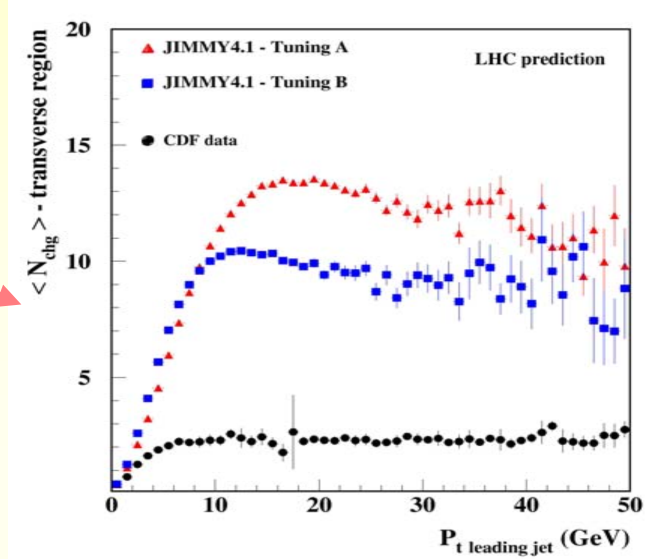
→ important for jet analyses (additional UE energy) or
$pp \to W+H+X$ with $W \to l+\nu$ and $H \to b\bar{b}$ (MI: $pp \to W+X_W + b\bar{b}+X_b$ without any Higgs!)

Underlying event and Multi – Parton Interactions crucial for all precision measurements !

Studies for LHC

C. Buttar et al in HERA – LHC workshop proceedings hep-ph/0601012





➔ **huge differences for the different generators and tunes !**

➔ **better understand multiple interaction dependencies :**

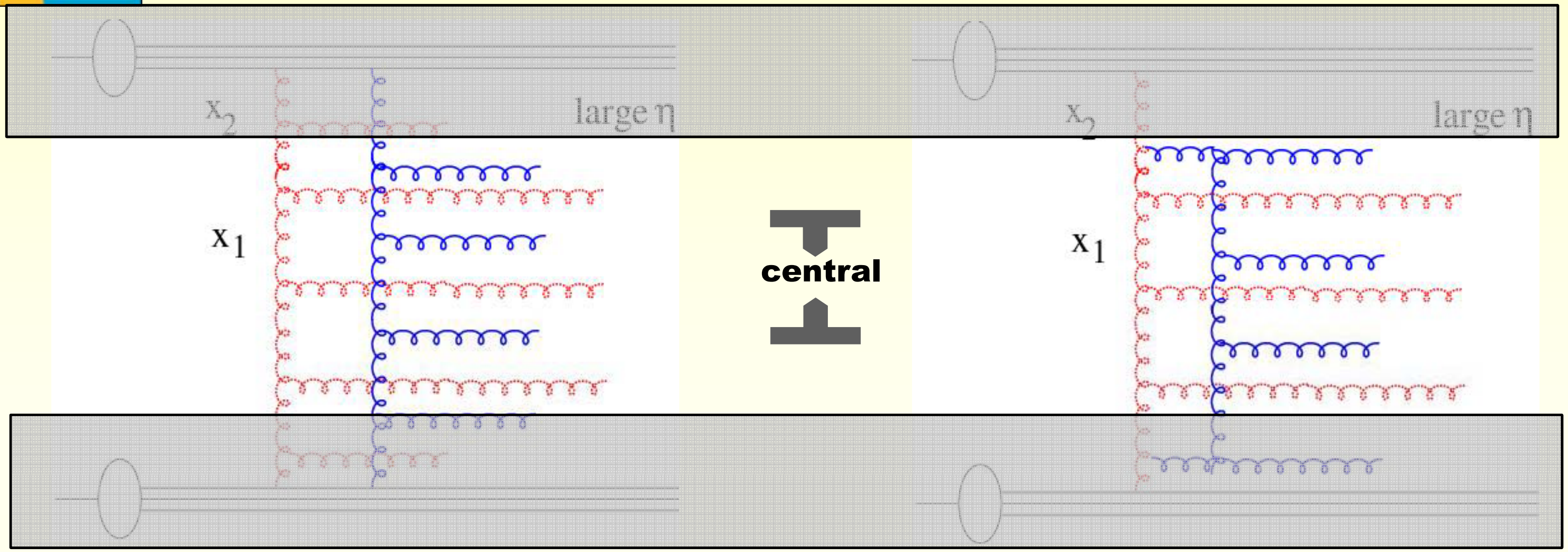
parton densities ← → factorization scheme

parton evolution (DGLAP/BFKL) / color correlations ...

Strategy for the first measurements:

- **pursue the same analysis strategy as @ CDF (tracking, central $|\eta| < 1$)**
  (➔ MB & UE study group (P. Bartalini, R. Field et al. ➔ CMS Note 2006/067)
- **prepare for early measurements in forward direction**
  (calorimeter, CASTOR: $5.2<|\eta|<6.6$, or even further down: close to the ZDC)

Why into the forward region ?



Central region does not distinguish between processes.

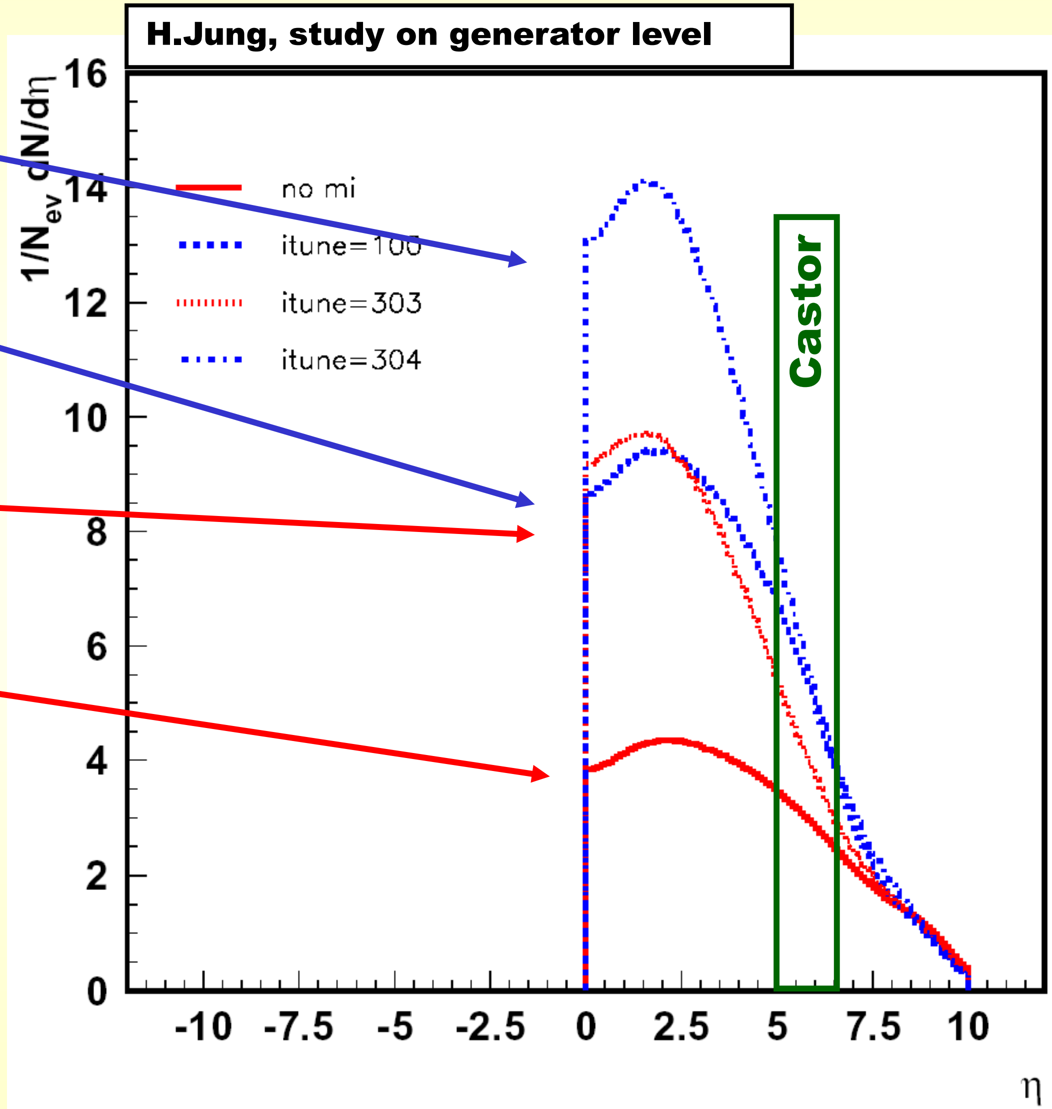
→ need to look forward :

- **jets in forward region 5 < |η| < 7 (CASTOR)**
- **correlations over large rapidity ranges (forward ←→ central)**
- **differences most clearly visible in the p-fragmentation region (energy taken differs)**
  → go to largest rapidities |η|~10 (→ possibly more fwd detectors near ZDC)

Particle Flow

Different models:

- extreme model (energy dependence of p_T – cut)
- realistic models:
  - Pythia: Tune A (Rick Field)
  - new Pythia: ~Tune A (Sandhoff-Skands) new parton shower → new MI treatment
- no Multiple Interactions
- Multiplicities in CASTOR differ by a factor of 1.5 – 2
- Multiplicities in central region pretty similar → enhancement by triggering on CASTOR ?



Long Range Correlations

central **forward**

no correlation

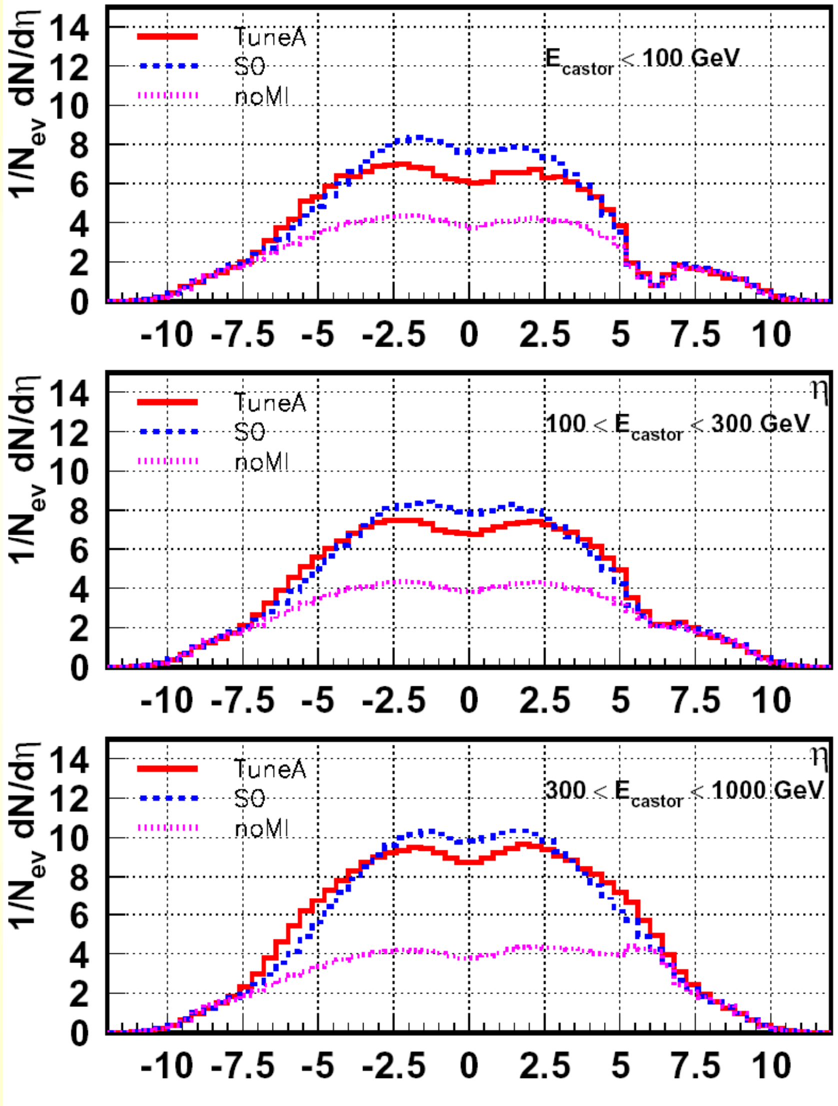
long range correlation

Pythia without MI → no correlation

Pythia with MI:

➔ long range correlations, trigger enhancing differences in the central region

➔ discriminative power

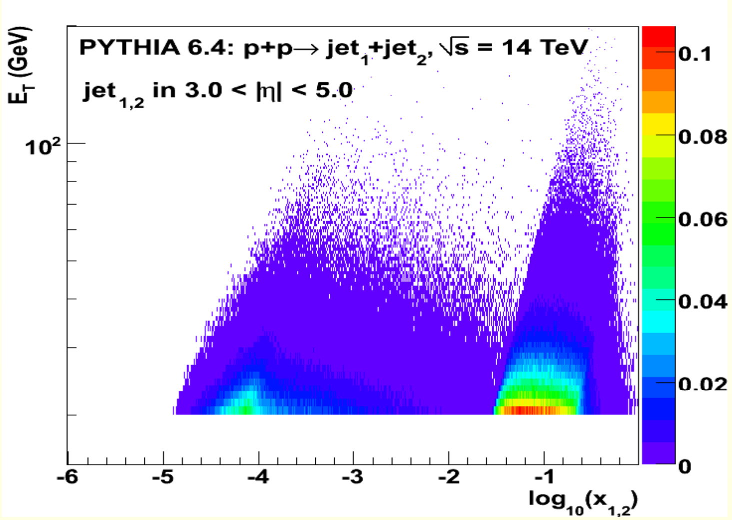


H.Jung, study on generator level

Small – x and Saturation

Goal:

study the parton evolution at small-x
→ DGLAP, BFKL, CCFM
→ investigate possible saturation effects



Forward Jets in HF (3<η<5):

→ dijet events with at least one jet in HF probe $x_1 \approx 10^{-4}$-10^{-5} and $x_2 \approx 10^{-1}$
(two units in η → one order of magnitude in x)

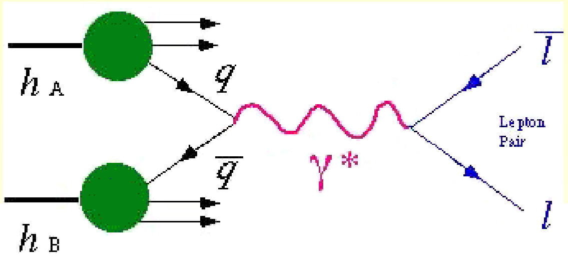
• single inclusive jet cross section with low E_T ~ 20GeV – 100 GeV constrain the low-x proton pdf

• Mueller-Navelet dijet cross section with one jet in each of the two HF are sensitive to BFKL dynamics and saturation effects.

Small – x and Saturation

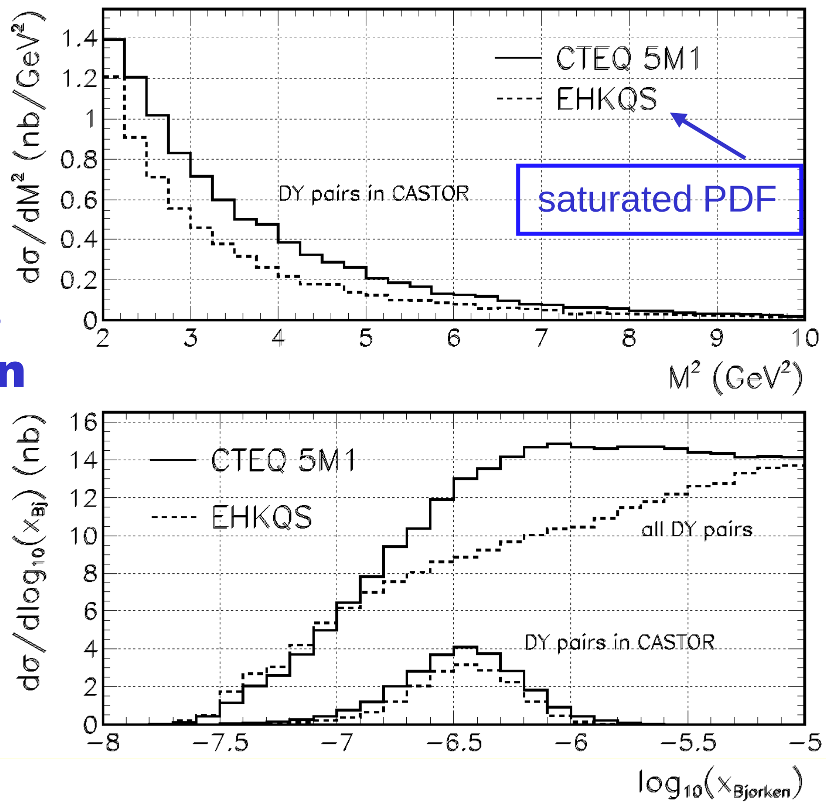
Forward Drell-Yan in CASTOR (5.3<η<6.6):

→ probes the pdf down to $x_1 \approx 10^{-7}$ when a large enough mass M is produced

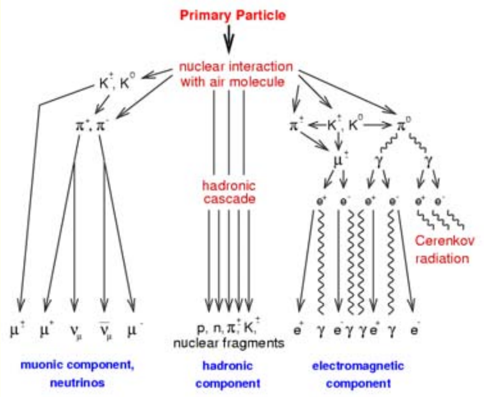


→ Drell-Yan pairs are suppressed by about 30 % when using a a saturated pdf like EHKQS

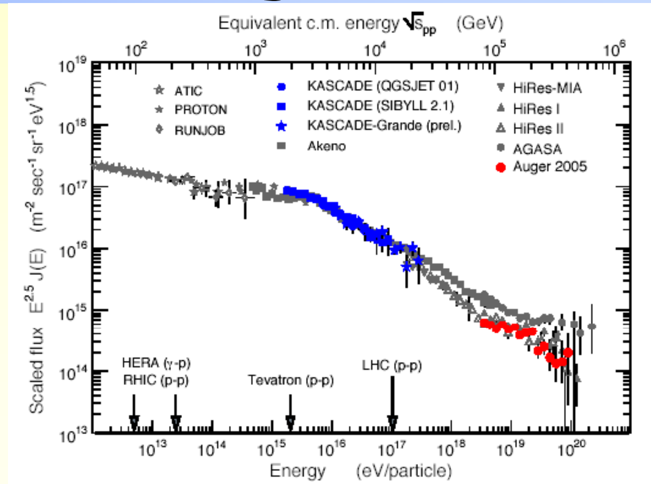
Angle measurement of the electrons with T2 will give valuable information



Hadronic Shower Models for Cosmic Ray Data Analyses



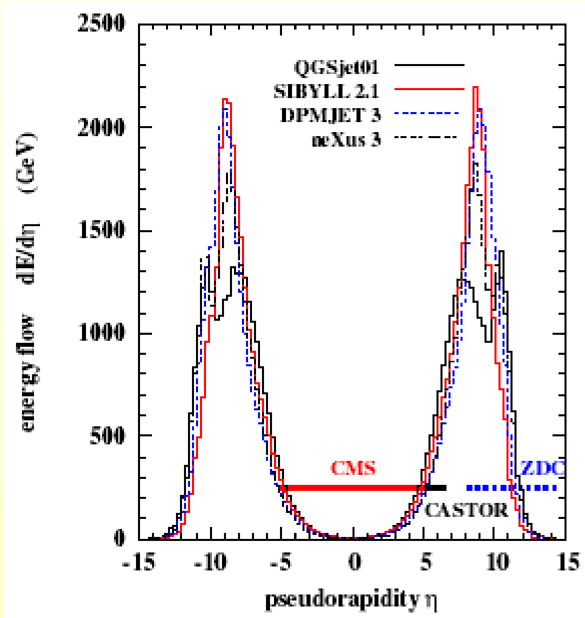
Dynamics of the high energy particle spectrum is crucial for the understanding of cosmic ray data. But models differ significantly !



Statistics for 100 PeV in fixed target frame is too low for reliable analysis ($O(10^{-4})$ particles per m^2 per year).

High momenta are needed
→ only available in the forward region

→ measurement of energy (HF, CASTOR, ZDC) and particle flow (T1, T2) in the forward regions will help to tune the models and the generators.



Strategy for First Data Taking

Program based on large rapidity gap selection

(TOTEM RP analyses will need time for alignment etc.)

→ concentrate on data with negligible pile up

- **Explore hard diffraction in the new kinematic regime of 14 TeV**
  (similar studies as performed at Tevatron)
- **Measure rapidity gap survival probability in single diffraction and DPE topology events**
- **Measurement of jet – gap – jet events**
- **Measurement of energy and particle flow (CASTOR, ZDC, possibly T1 & T2)**
- **Measurement of forward jets and forward Drell—Yan electrons**
- **Study of gamma—gamma and gamma—proton interactions**
- **Study possibly interesting observations … ☺**

Summary

- CMS forward detector components provide the possibility for a rich program for forward physics. Negotiations to include FP420 into the CMS experiment in progress.
- Comprising different physics topics for special low, standard and highest luminosity optics the forward and diffractive physics program spans the full lifetime of the LHC.
- In Diffraction:
  - <u>low luminosity:</u> standard measurements exploring traditional observables and processes in the new kinematic regime.
  - <u>nominal luminosity:</u> unprecedented statistics for processes presently studied at the TeVatron at lower center of mass energies.
  - <u>highest luminosity:</u> enabling the discovery of a Higgs Boson with a mass close to the exclusion limit constituting a special challenge for the central LHC experiments.
- Forward detector components make it possible to study underlying event structure and multi-parton interactions, representing a crucial input for all precision measurements. They open the window to a new region in the area of small-x, giving insight to parton evolution and saturation effects.

Thanks to Monika Grothe & Hannes Jung for fruitful discussions