Prospects for diffractive and forward physics at the LHC: Standard optics running

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Carry out a program of diffractive and forward physics as integral part of the routine data taking at the LHC, i.e. at nominal beam optics and up to the highest available luminosities.

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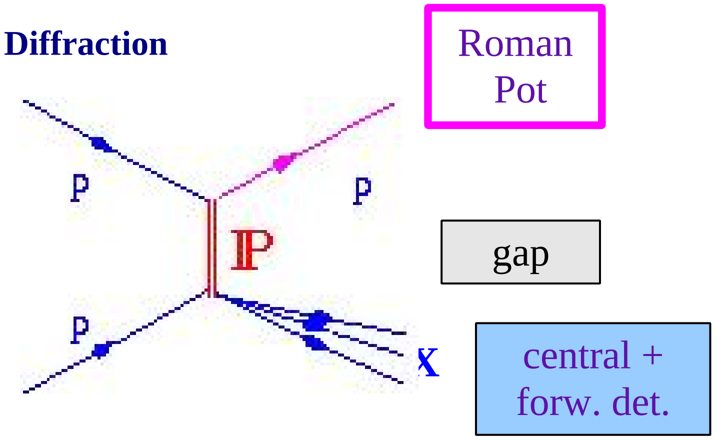
Prospects for
Diffractive
and Forward Physics
at the LHC

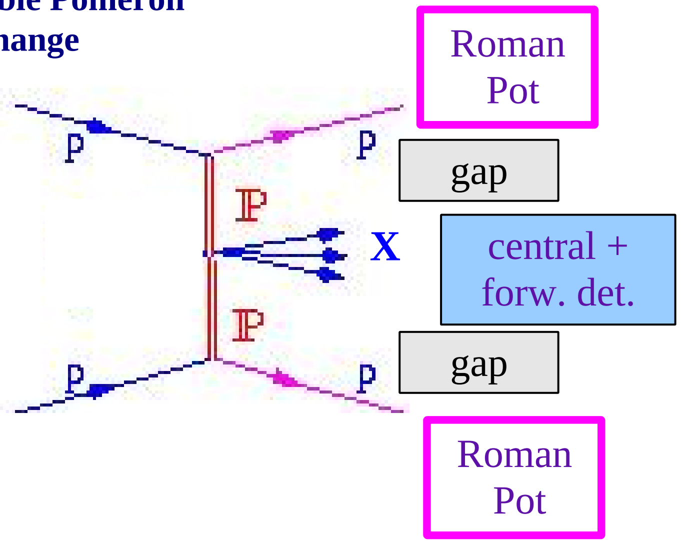
The CMS and TOTEM
diffractive and forward physics
working group

Program on diffractive and forward physics
1. Diffraction

Single Diffraction



Double Pomeron Exchange



X=anything : dominated by soft physics

- **Measure fundamental quantities of soft QCD:**
  SD and DPE inclusive cross sections, their s, t, M_X dependences are fundamental parameters of non-perturbative QCD.
- **Contributes to the pile up.**

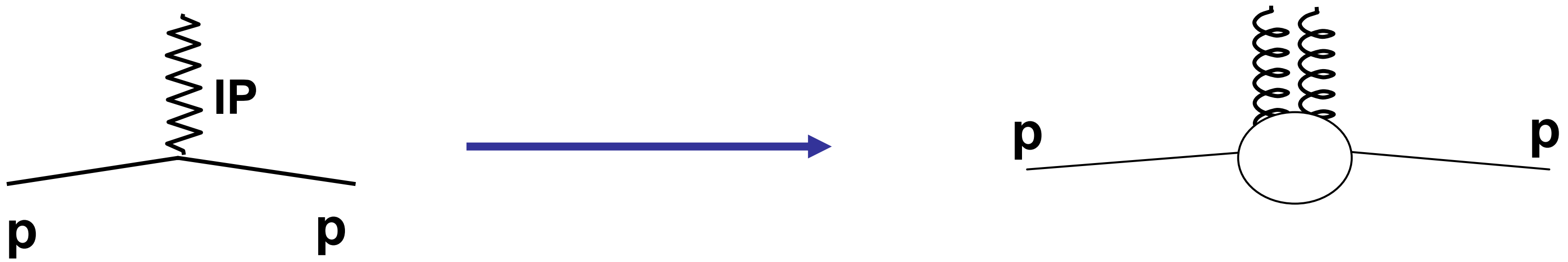
see previous talk, by V. Avati

X includes jets, W's, Z's, Higgs (!): hard processes calculable in pQCD

- **Give info on proton structure (dPDFs and GPDs), QCD at high parton densities, multi-parton interactions, discovery physics**

Diffraction ? - A way to probe the proton

In diffractive events look at the proton constituents through a lens that filters out all parton combinations except those with the vacuum quantum numbers



2-gluon exchange:
LO realisation of vacuum quantum numbers in QCD

→Tool to investigate low-x partons through diffractive PDFs and generalized parton densities (GPDs)

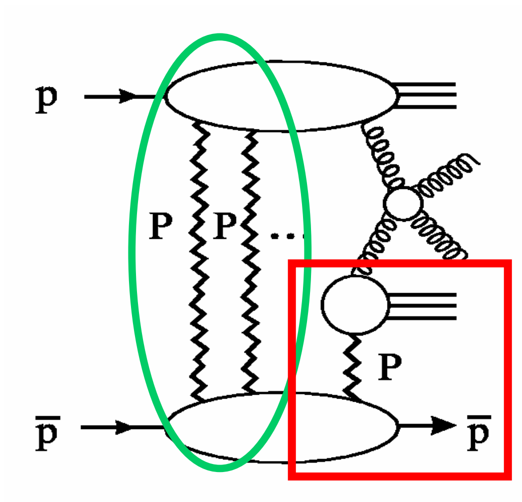
→Window on QCD at high parton densities (saturation, AA)

→Diffractive production may be a discovery channel for a light Higgs boson

Program on diffractive and forward physics

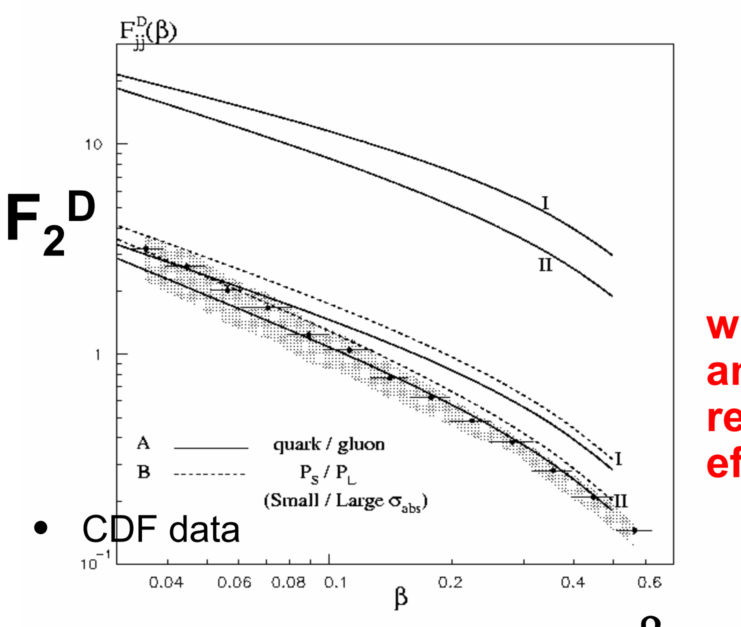
Rapidity gap survival probability

- Proton and anti-proton are large objects, unlike pointlike virtual photon
- In addition to hard diffractive scattering, there may be soft interactions among spectator partons. → Fill rapidity gap & slow down outgoing protons → Hence reduce the rate of diffractive events.
- Quantified by rapidity gap survival probability.



dPDF

Closely related to the underlying event at the LHC



β

without and with rescattering effects

Predictions based on HERA diffractive PDFs

“Prospects for diff and fwd physics at the LHC” - Part I: Diffractive part

Experimental issues in selecting diffractive events at the LHC

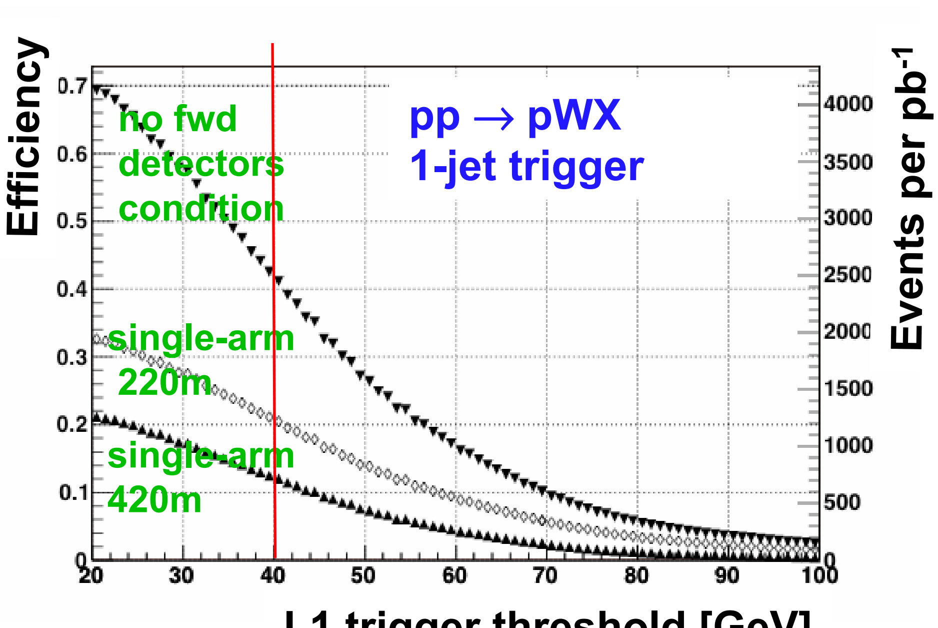
1. Trigger is a major limiting factor for selecting diffractive events

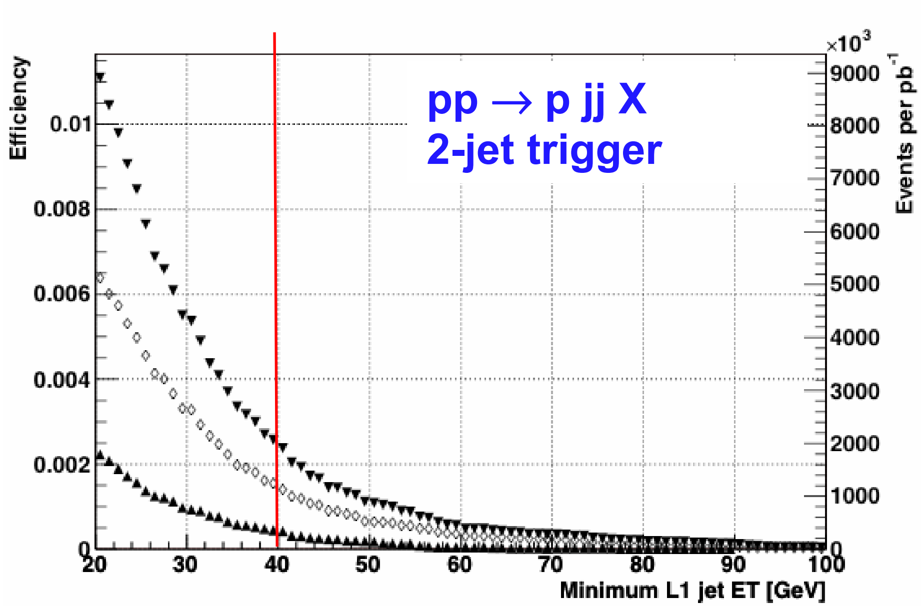
2. Background from non-diffractive events that mimic diffractive events because of protons from pile-up events

Exercised these issues at a number of exemplary processes

Note: Took into account as an option also near-beam detectors at 420 m from the IP (R&D project)

Trigger (I)





Attention: Gap survival probability not taken into account
Normalized to number of events with $0.001 < \xi < 0.2$
for proton and, in 2-jet case, with jets with p_T>10GeV

At 2×10^{33} cm^{-1} s^{-1} without any additional condition on fwd detectors:

L1 1-jet trigger threshold O(150 GeV)

L1 2-jet trigger threshold O(100 GeV)

Trigger (II)

→ CMS trigger thresholds for nominal LHC running too high for diffractive events

→ Use information of forward detectors to lower in particular CMS jet trigger thresholds

→ The CMS trigger menus now foresee a **dedicated diffractive trigger stream with 1% of the total bandwidth on L1 and HLT** (1 kHz and 1 Hz)

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

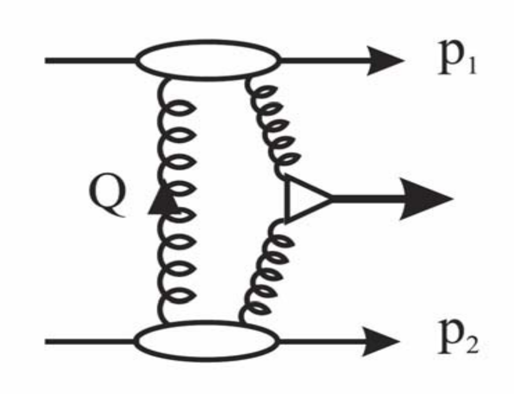
Achievable total reduction: 10 (single-sided 220m) x 2 (jet iso) x 2 (2 jets same hemisphere as p) = 40

Adding L1 conditions on the near-beam detectors provides a rate reduction sufficient to lower the 2-jet threshold to 40 GeV per jet while still meeting the CMS L1 bandwidth limits for luminosities up to 2x 10^{33} cm^{-1} s^{-1}

Much less of a problem is triggering with muons, where L1 threshold for 2-muons is 3 GeV

Trigger (III)

Central exclusive production pp →pHp with H (120GeV) → bb



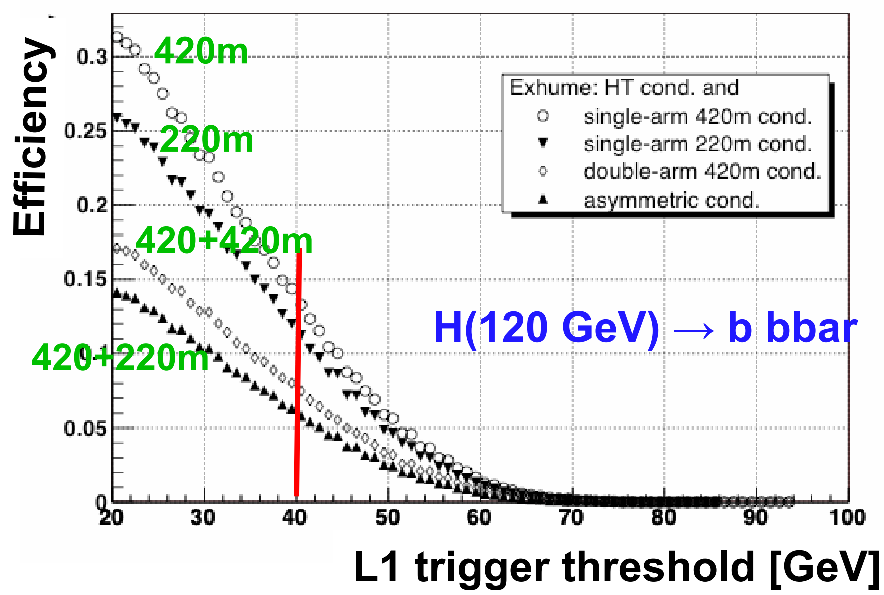
- In non-diffractive production hopeless, signal swamped with QCD dijet background
- Selection rule in CEP (central system is $J^{PC} = 0^{++}$ to good approx) improves S/B for SM Higgs dramatically
- In certain MSSM scenarios the signal cross section is three order of magnitude higher than for the SM case

Trigger is a major limiting factor !

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

HLT: Jet trigger efficiency ~7%
To stay within 1 Hz output rate, needs to either prescale b-tag or add 420 m detectors in trigger

Additional ~10% efficiency by introducing a 1 jet & 1 μ (40GeV, 3GeV) trigger condition

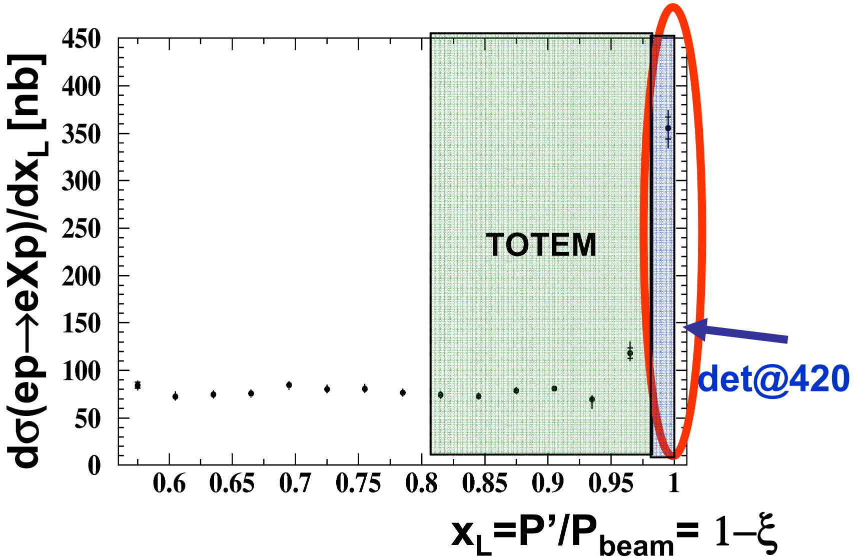


Pile-up background

Number of PU events with protons within acceptance of near-beam detectors on either side:

~2 % with p @ 420m

~6 % with p @ 220m



Translates into a probability of obtaining a fake DPE signature caused by protons from PU:

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

Eg at 2x 10^{33} $cm^{-2}s^{-1}$ 10% of any signal event one wants to select have a fake DPE signature
This is independent of the type of signal.

Depends critically on the leading proton spectrum at the LHC which in turn depends on size of soft rescattering effects (rapidity gap survival factor) !

Pile-up background (II)

Can be reduced by:

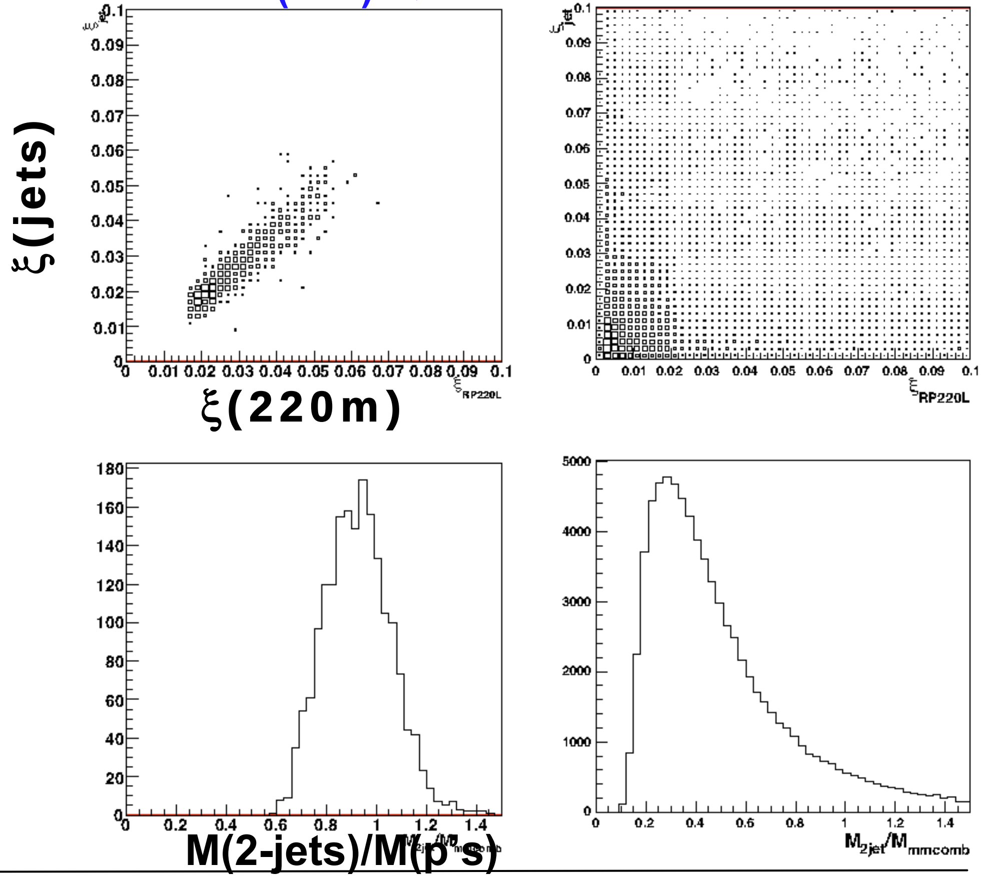
Requiring correlation between
ξ, M measured in the central detector and
ξ, M measured by the near-beam detectors

Fast timing detectors that can determine whether the protons seen in the near-beam detector came from the same vertex as the hard scatter (currently R&D project)

$$\xi_{1,2} = \frac{1}{\sqrt{s}} \sum_{\text{particles}} E_T e^{\pm\eta} \quad ; \quad \xi_1 \xi_2 s = M^2$$

CEP H(120) →bb

incl QCD di-jets + PU



CEP of **H(120 GeV) → b bbar:**

Possible to retain O(10%) of signal up to 2 x 10^{33} cm^{-2} s^{-1} in a special forward detectors trigger stream

S/B in excess of unity for a SM Higgs and up to 1000 for a MSSM Higgs appears achievable

Program on diffractive and forward physics

2. Forward physics

Cosmic ray physics

→ Models for showers caused by primary cosmic rays (PeV = 10^{15} eV range) differ substantially

→ Fixed target collision in air with 100 PeV center-of-mass E corresponds to pp interaction at LHC

→ Hence can tune cosmic ray shower models at the LHC

Study of the underlying event at the LHC:

→ Multiple parton-parton interactions and rescattering effects accompanying a hard scatter

→ Closely related to gap survival and factorization breaking in hard diffraction

Heavy-ion and high parton density physics:

Proton structure at low xBj → saturation → Color glass condensate

Photon-photon and photon-proton physics:

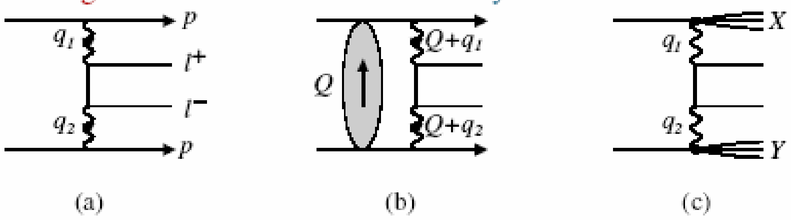
Also there protons emerge from collision intact and with very low momentum loss

Multiple connection points to other areas in High-Energy-Physics !

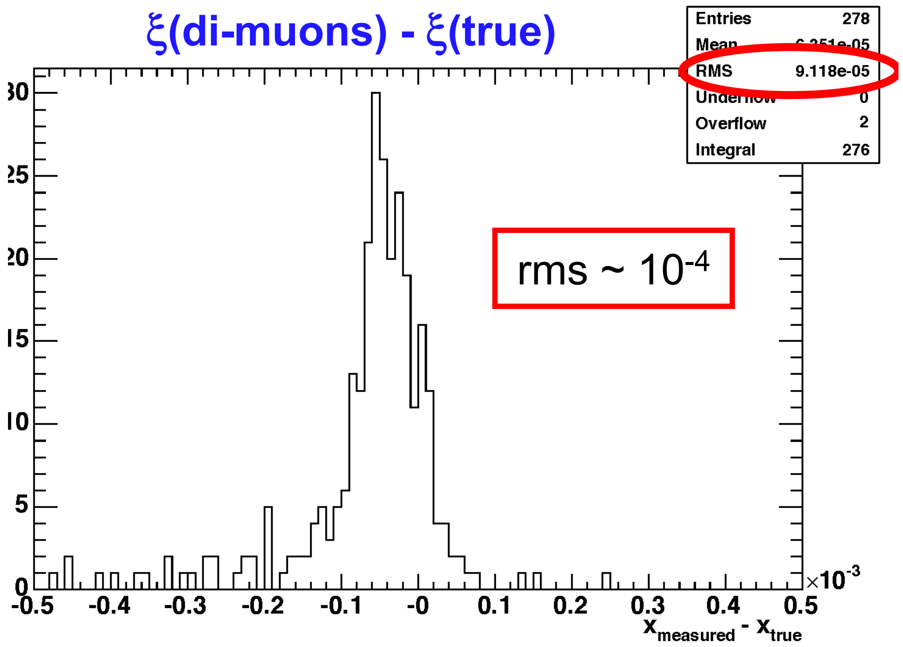
Photon-mediated processes: Exclusive μμ production

- QED process (a) production σ precisely known

event generator LPAIR based on ME by Vermaseren



- Hadronic corrections [(b) (c)] small.



→**Calibration process** both for luminosity and energy scales of near-beam detectors

→ Striking signature: acoplanarity angle between leptons

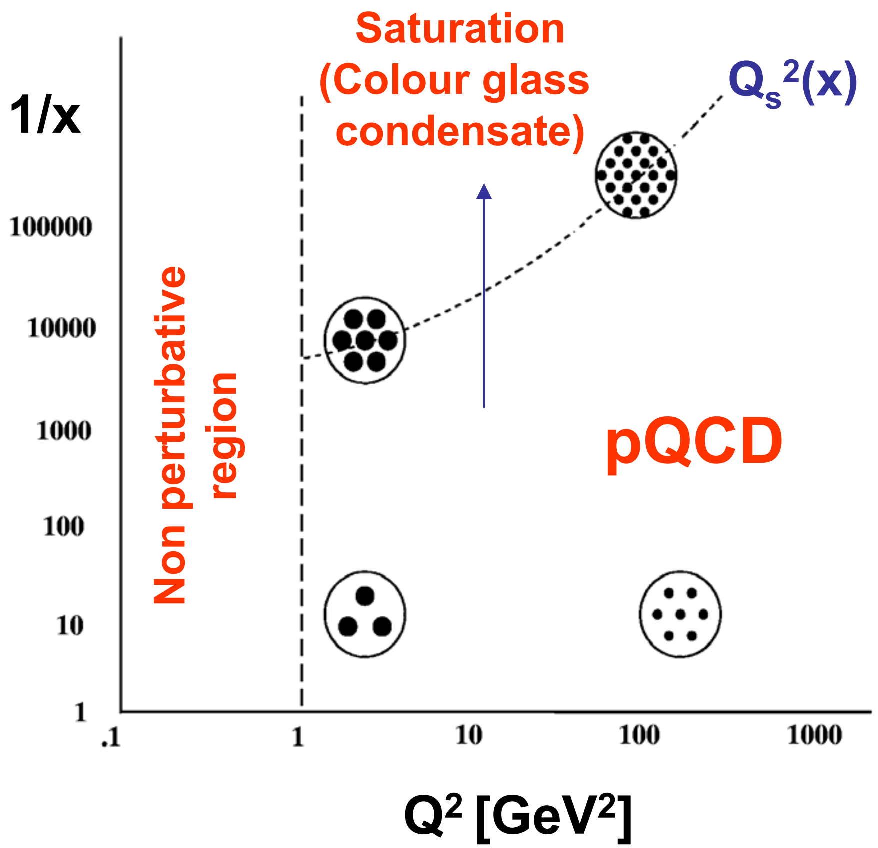
→Allows reco of proton ξ values with resolution of 10^{-4}, i.e. smaller than beam dispersion

→ Expect ~300 events/100 pb^{-1} after CMS muon trigger

Low-x QCD

- When $x \rightarrow 0$ at Q2 > a few GeV2 DGLAP predicts steep rise of parton densities
- At small enough x, this violates unitarity
- Growth is tamed by gluon fusion: saturation of parton densities at Q2=Qs2(x)

So far not observed in pp interactions

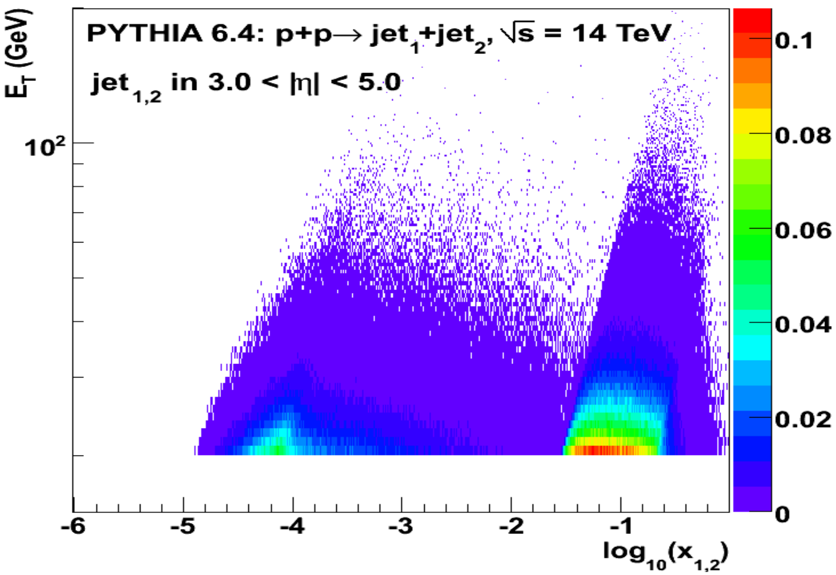


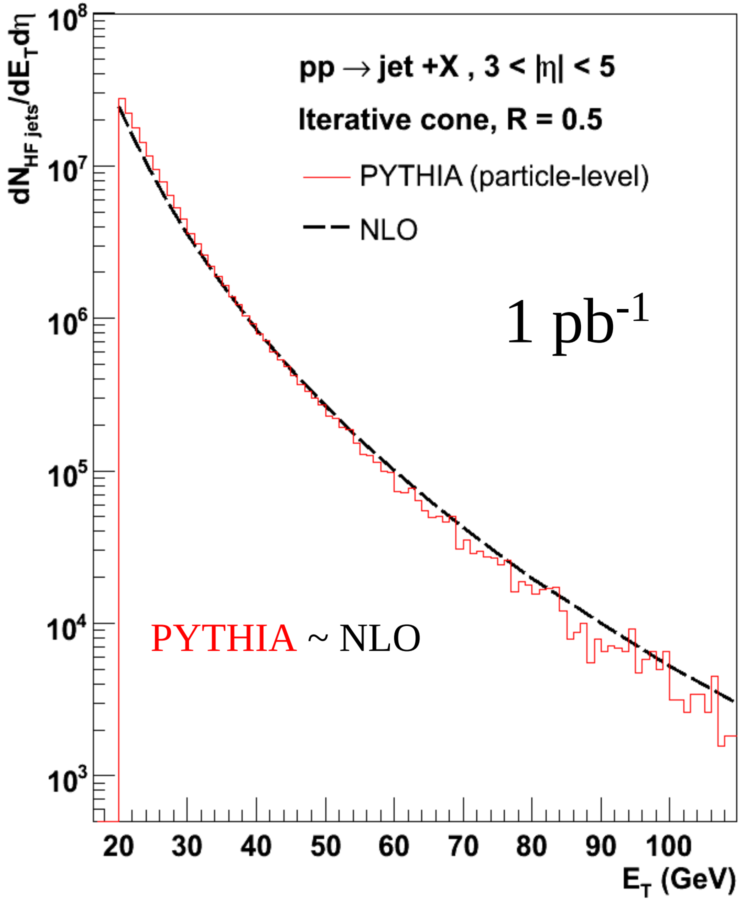
Low-x QCD: Forward jets

Inclusive forward “low-E_T” jet (E_T ~20-100 GeV) production:

$$p + p \rightarrow jet1 + jet2 + X$$

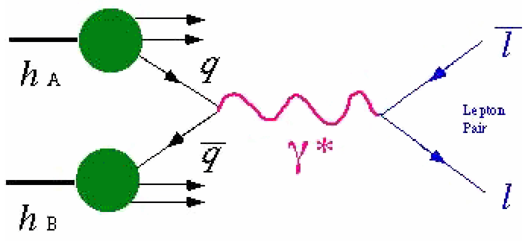
Sensitive to gluons with: $x_2 \sim 10^{-4}$, $x_1 \sim 10^{-1}$

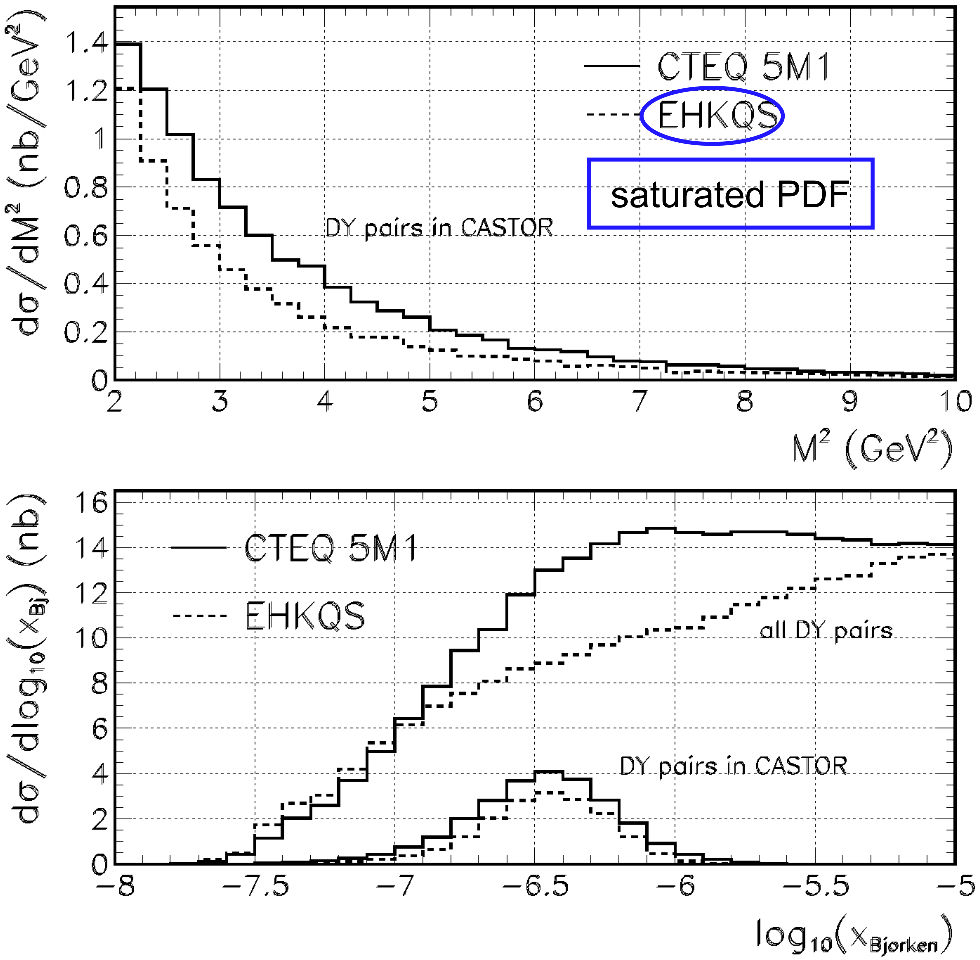




Large expected yields (~10^7 at ~20 GeV) !

Low-x QCD: Forward Drell-Yan





Gives access to low-x_{BJ} quarks in proton in case of large imbalance of fractional momenta $x_{1,2}$ of electrons, which are then boosted to large rapidities

→CASTOR with $5.3 \leq |\eta| \leq 6.6$ gives access to **x_{BJ}~10^{-7}**

→ Measure angle of electrons with T2

DY pairs suppressed in saturated PDF

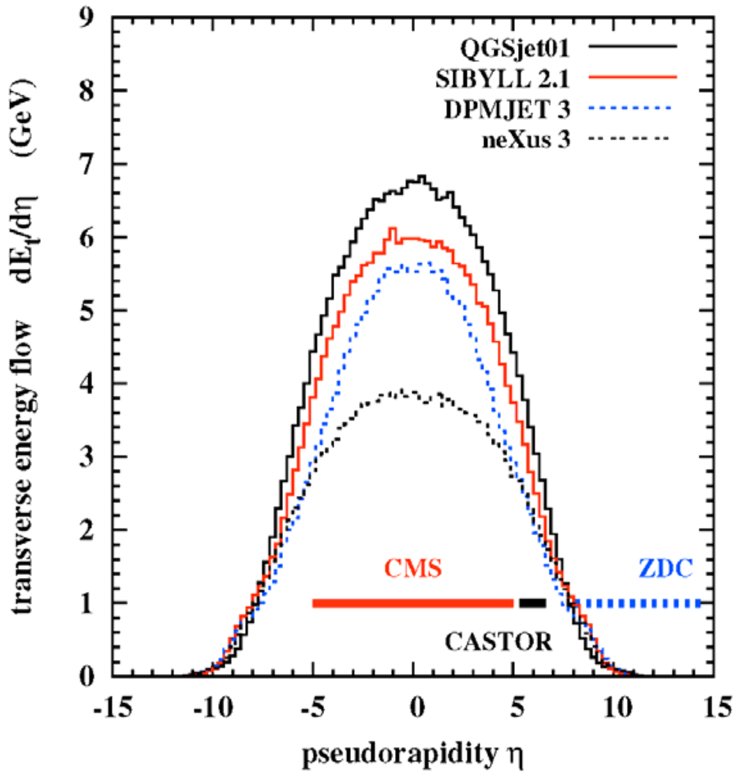
“Prospects for diff and fwd physics at the LHC” - Part 2: “Forward physics” part

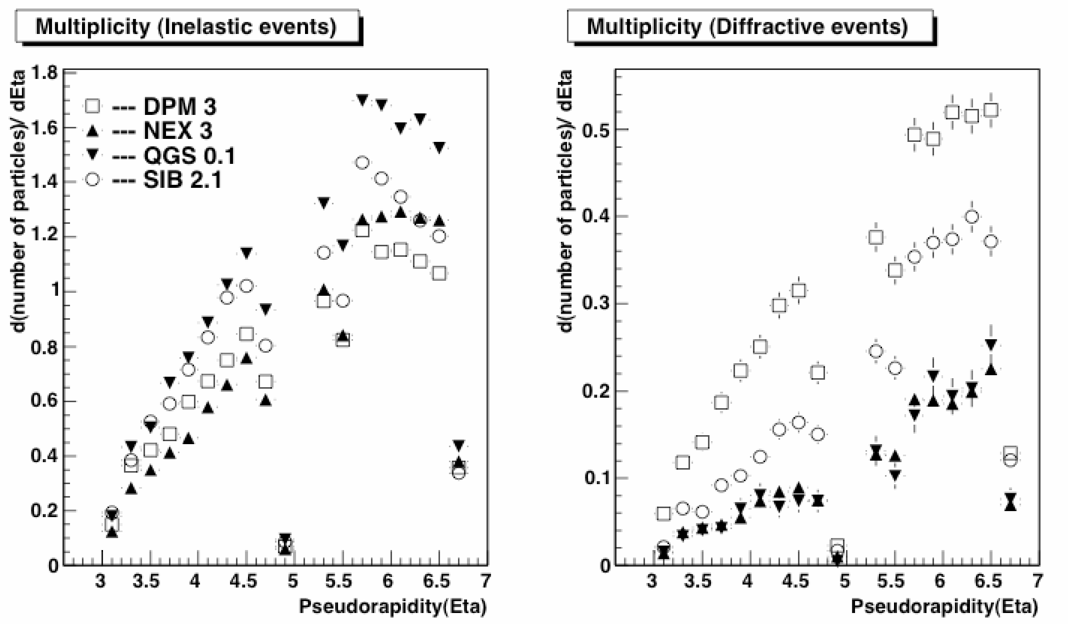
Validation of hadronic shower models in cosmic ray physics

→ Models for showers caused by primary cosmic rays (PeV = 10^{15} eV range) differ substantially

→ Fixed target collision in air with 100 PeV center-of-mass E corresponds to pp interaction at LHC

→ Hence can tune shower models by comparing to measurements with T1/T2, CASTOR, ZDC





T2 in front of CASTOR

Conclusions

Low Luminosity ($\leq 10^{32}$ cm^{-2}s^{-1}): low & high β^*

- Measure inclusive SD and DPE cross sections: (t, M_X dependence, topology)
- Measure semi-hard SD and DPE: (Onset of jet activity)
- Inclusive fwd jets, Muller-Navelet dijets
- Forward Drell-Yan
- Validation of Cosmic Ray generators

High Luminosity (> 10^{32} cm^{-2}s^{-1}) : low β^*

- Measure SD and DPE in presence of hard scales (dijets, vector bosons, heavy quarks): dPDF, GPD
- $\gamma\gamma$ and γp phyics

Highest Luminosity (> 10^{33} cm^{-2}s^{-1}) : low β^*

- Discovery physics in central exclusive production (SM or MSSM Higgs, other exotic processes)

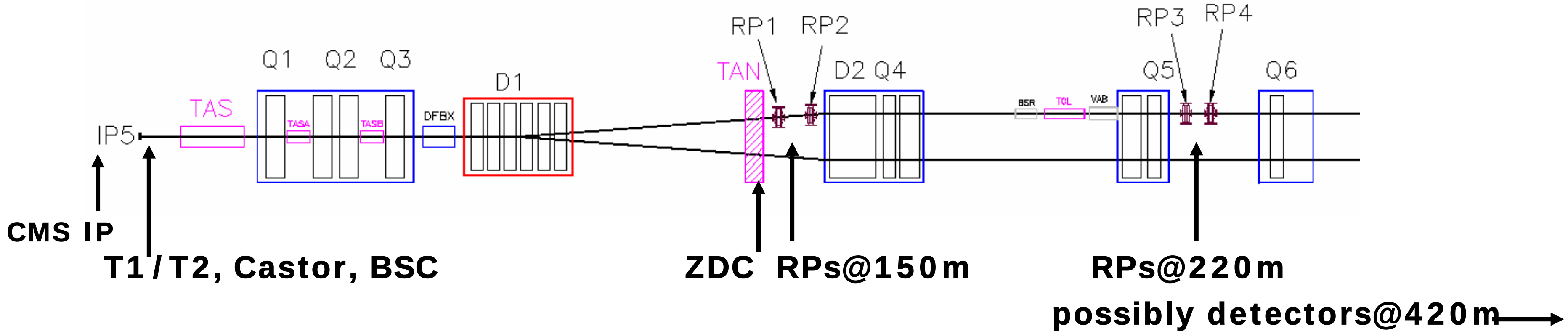
The CMS and TOTEM collaborations intend to carry out a joint diffractive and forward physics program with an unprecedented rapidity coverage. The document outlines some aspects of this physics program.

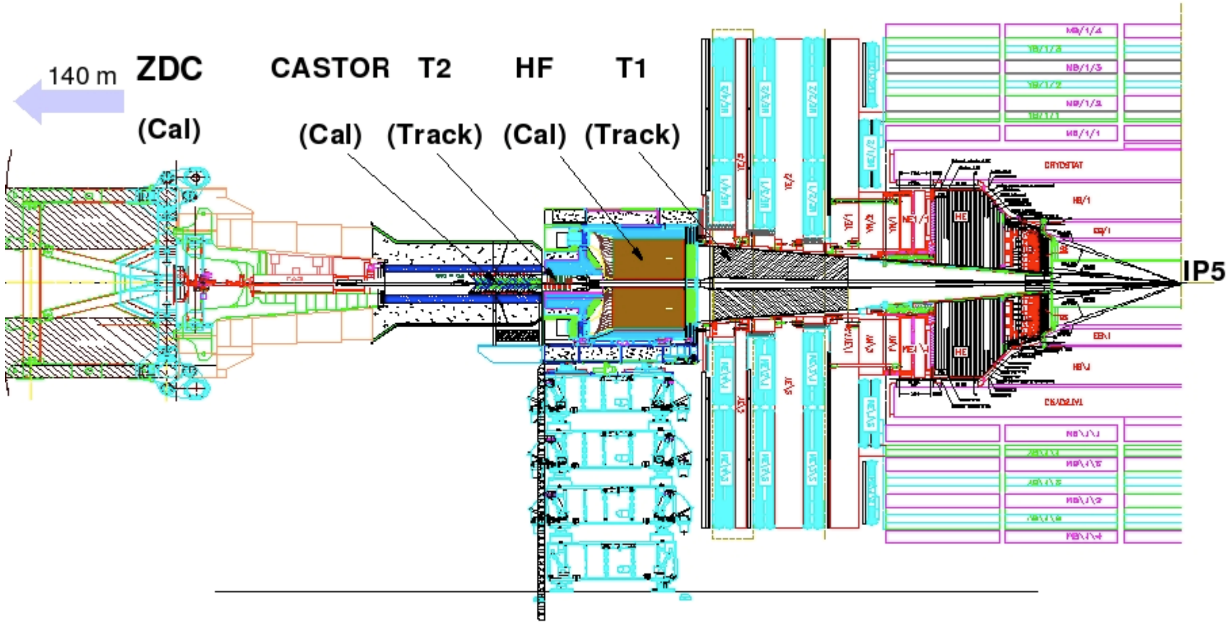
The document addresses,
for the first time at the LHC,
the central experimental issues
in measuring fwd and diffractive
physics by way of a number of
exemplary processes

A worthwhile program and we are optimistic that it can be done

BACKUP

CMS + TOTEM: Unprecedented Coverage in η



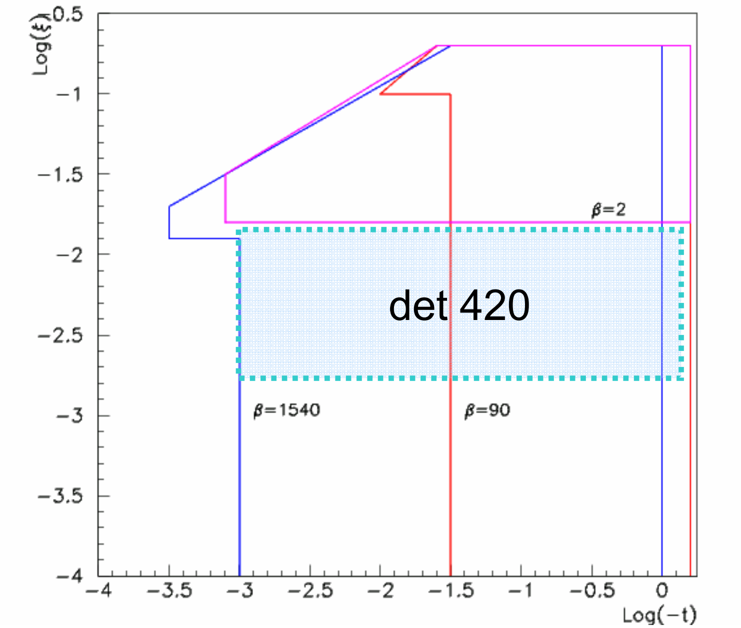


T1 (CSC) 3.1 ≤ |η| ≤ 4.7
HF 3 ≤|η| ≤ 5
T2 (GEM): 5.3 ≤ |η| ≤ 6.6
Castor 5.3 ≤ |η| ≤ 6.6

Possible addition FP420:
Near-beam detectors at 420 m

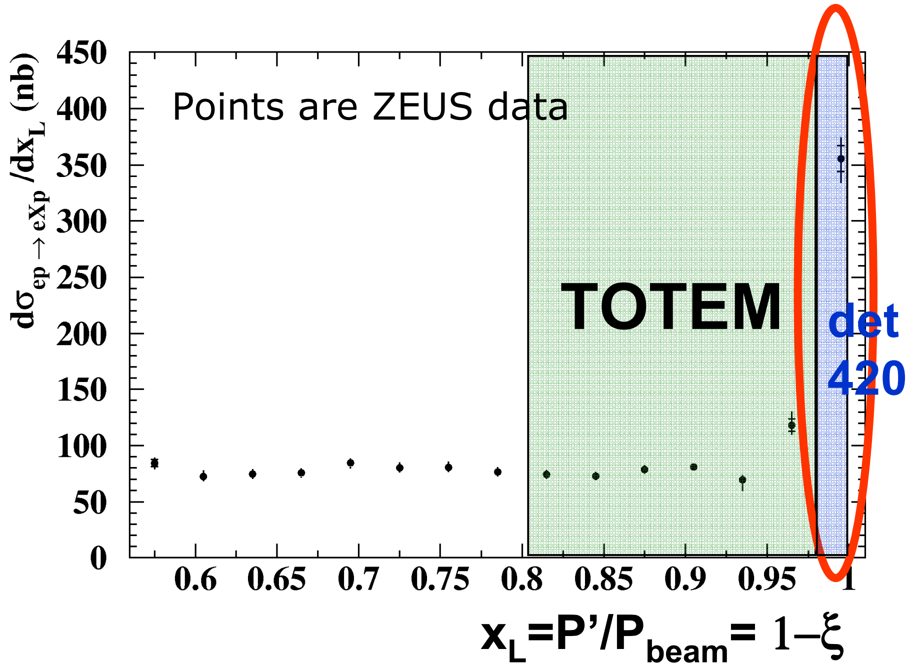
CMS + TOTEM: Coverage in ξ

Depends on value of β*



ξ: fractional momentum loss of proton
t: 4-momentum transfer squared at proton vertex

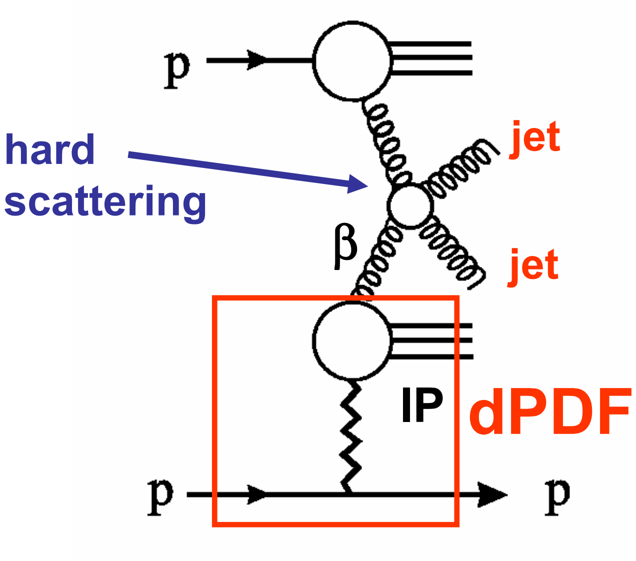
At nominal LHC optics, β*=0.5m



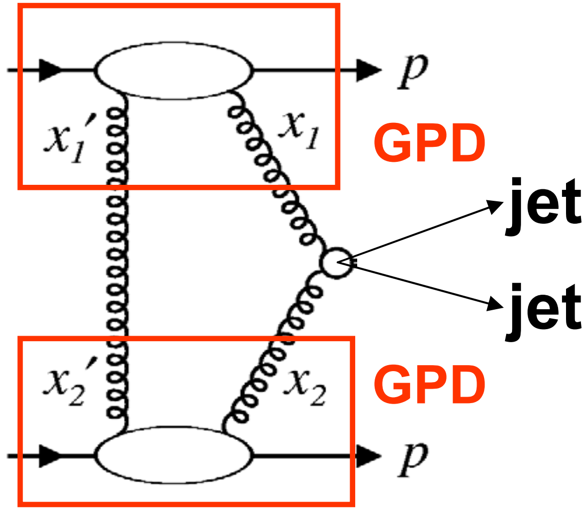
diffractive peak

Note: Totem RP's optimized for special optics runs at high β*
β* is measure for transverse beam size at vertex
Consider 3 different optics, at β*=0.5m, 90m and 1540m

Diffractive PDFs and GPDs



- **Diffractive PDFs:**
  probability to find a parton of given x under condition that proton stays intact – sensitive to low-x partons in proton, complementary to standard PDFs



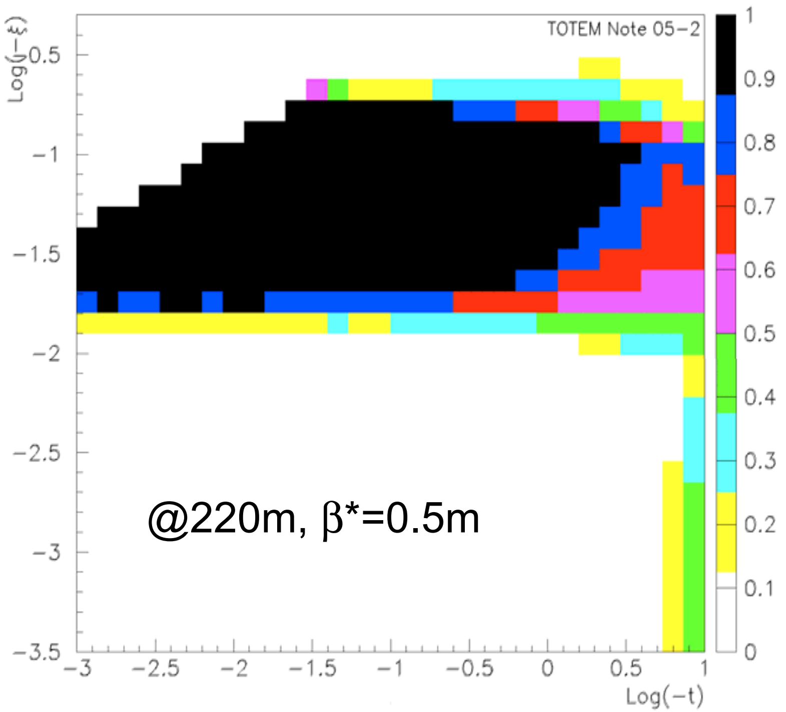
- **Generalised Parton Distributions (GPD)**
  quantify correlations between parton momenta in the proton
  t-dependence sensitive to parton distribution in transverse plane

  When x'=x, GPDs are proportional to the *square* of the usual PDFs

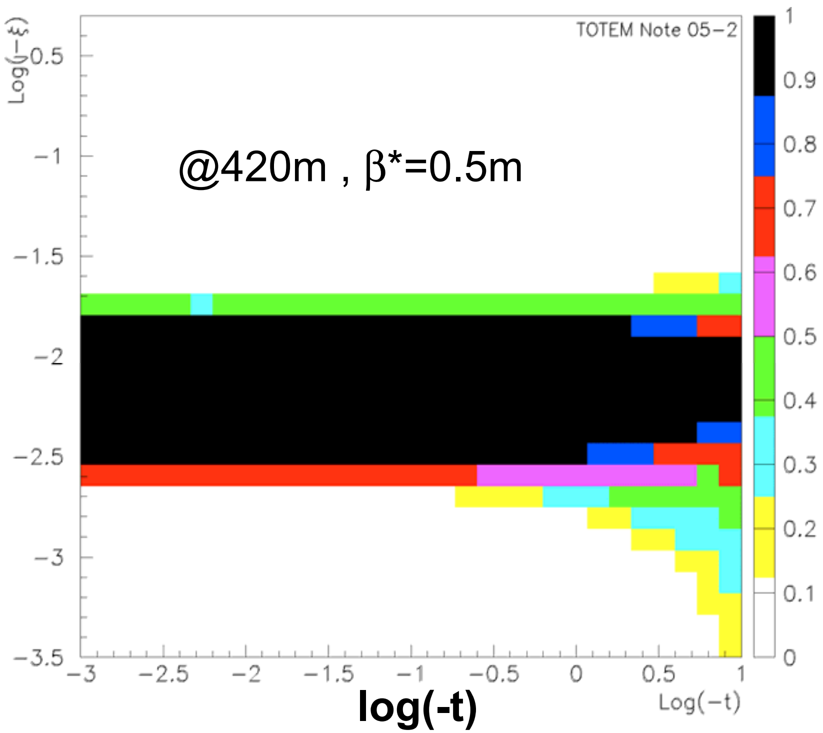
Detecting leading protons: Acceptance

- Determined by tracking protons through the LHC accelerator lattice with the program MAD-X
- Smearing of both transverse vertex position and scattering angle at the IP according to transverse beam size and beam momentum divergence
- Assume that near-beam detectors are 100% efficient, i..e. assume all protons that reach 220/420m location outside of cutout for beam (1.3mm @220m, 4mm @420m) are detected

All studies in document use these acceptance calculations



log(ξ)



log(-t)