Towards a diffractive and forward physics program in CMS with TOTEM and FP420

Monika Grothe
Wisconsin/Turin
Hera-LHC workshop meeting
CERN June 2006

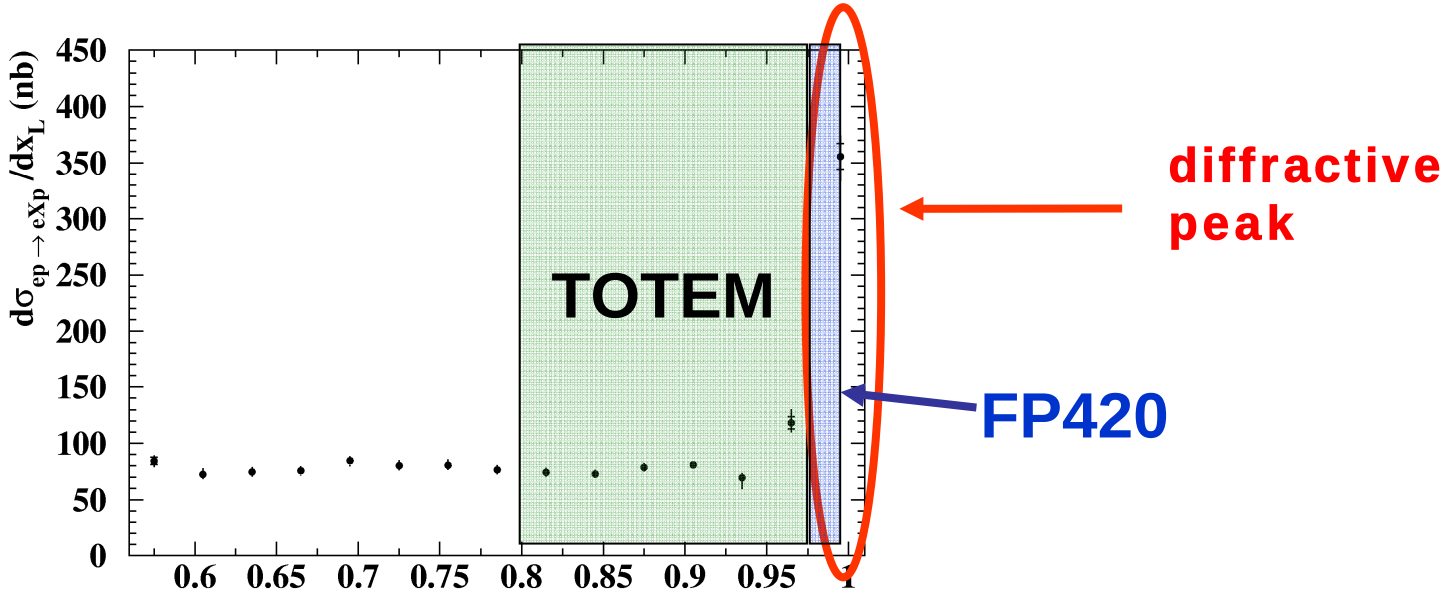
A snapshot of the current activities in the CMS fwd and diff working group

Short-term goal: Document, jointly written with Totem, that shows the potential of CMS + TOTEM (+ FP420)

See also in this workshop:
Totem talks by R. Orava (Tues) and J. Kaspar (Wed)
FP420 talk by B. Cox (Thur)

CMS + TOTEM + FP420: Coverage in ξ

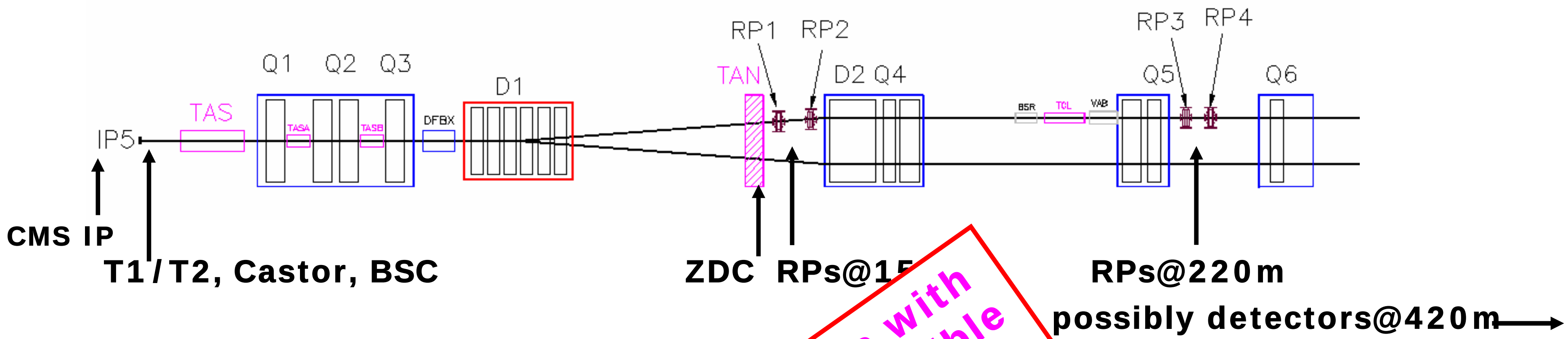
At nominal LHC optics, β^*=0.5m



$x_L = P'/P_{beam} = 1-\xi$

Note: Totem RP's optimized for special optics runs at high β^*

CMS + TOTEM + FP420: Coverage in η not as seamless



CMS detectors along beam line:
Cal with $|\eta| \leq 3$, **HF** with $3 \leq |\eta| \leq 5$
Castor calorimeter, behind T2, onl ... 5.3 ≤ |η| ≤ 6.6
Beam Scintillation counters **BCS**
Zero-degree calorimeter **ZDC**

TOTEM detectors:
T1 (CSC) in CMS en
T2 (GEM) in shi
T1: 3.1 ≤ |η| ≤ 4 ... |η| ≤ 6.6
Roman pots with ... s on 2 sides at up to **220 m**

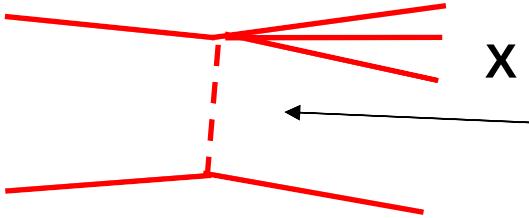
Possible addition **FP4** ... : **Detectors at 420 m** in cold region of LHC

Selection of diffractive events with rapidity gap selection only possible at luminosities below $10^{32}\ cm^{-2}s^{-1}$, where event pile-up is absent

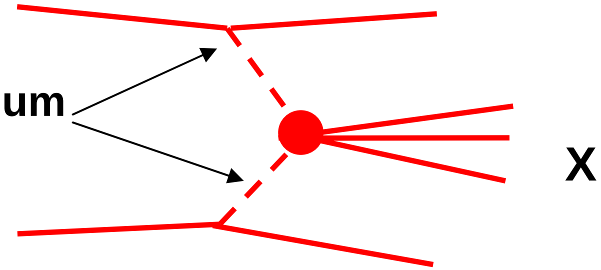
Possibilities to fill in "cracks" under investigation in CMS

A survey of the accessible diffractive and forward processes

Single diffraction:



Double Pomeron exchange:



2 gluon exchange with vacuum quantum numbers "Pomeron"

- X is measured in the central CMS apparatus
- Scattered protons may be visible in Roman Pot detectors along beam line
- Note large rapidity gap(s) between the scattered proton(s) and X

o) If X = anything – then dominated by soft physics; contributes to pile-up, i.e. soft events that overlay signal events at LHC (3.5 @ 10^{33} $cm^{-2}s^{-1}$, 35 @ 10^{34} $cm^{-2}s^{-1}$)

Inclusive Single Diffraction (SD) ~ 15 mb, Double Pomeron Exchange (DPE) ~ 1 mb

1 mb = 100 events/s @ 10^{29} cm^{-2} s^{-1}

o) If X includes jets, W's, Z's, Higgs (!): hard processes, calculable in QCD. Give info on proton structure, QCD at high parton densities, discovery physics etc

The accessible physics is a function of instantaneous and integrated luminosity

“Low”:

Lumi low enough that pile-up is negligible, i.e $<10^{32}$ $cm^{-2}s^{-1}$, and integrated lumi a few 100 pb^{-1} to < 1 fb^{-1}

- Measure inclusive SD and DPE cross sections and their Mx dependence
- In addition to running at nominal LHC optics:
  TOTEM suggests few days of running with $\beta^*=90m$ @ 10^{31} $cm^{-2}s^{-1}$, with much improved coverage for diffractive events compared to $\beta^*=0.5m$ (see R. Orava talk)

Program envisaged as part of the routine CMS data taking at $\beta^*=0.5m$:

“Intermediate”:

Lumi $> 10^{32}$ $cm^{-2}s^{-1}$, pile-up non-negligible and integrated lumi 1 to a few fb^{-1}

- Measure SD and DPE in presence of hard scale (dijets, vector bosons, heavy quarks)

“High”:

Lumi $> 10^{33}$ $cm^{-2}s^{-1}$, pile-up substantial and integrated lumi several tens of fb^{-1}

- Discover the SM or MSSM Higgs in central exclusive production

- At intermediate to high lumi also rich program of $\gamma\gamma$ and γp physics (QED)

A (non-exhaustive) snapshot of the on-going activities in CMS

CMS diffractive and forward physics working group,
for RP detectors in collaboration with TOTEM

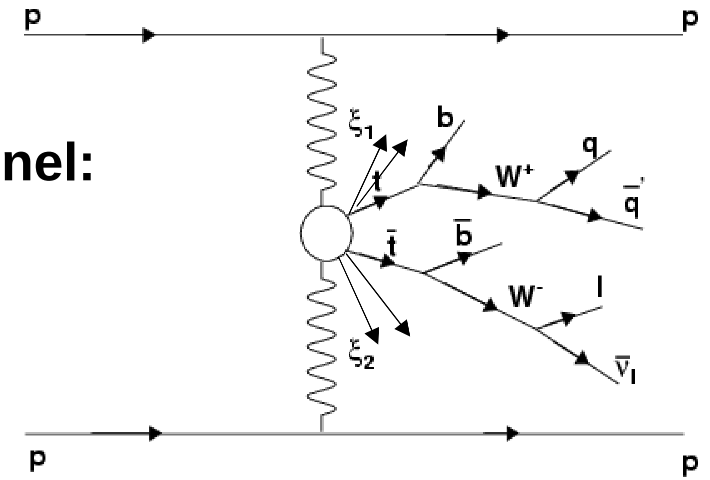
Note: Results of studies independent of specific detectors
In particular assume all protons are detected that make it within beampipe to 220/420m location and are outside a 10σ+0.5 mm cutout around the beam axis (~1.3mm @220m, ~4mm @420m)

Detectors at 420m included as option, are still in R&D stage by FP420 project, but could be installed in first long LHC shutdown period

Assume nominal LHC optics (β*=0.5m) and 25ns bunch spacing in the following, unless stated otherwise

Inclusive DPE and SD ttbar production

A. Vilela, D. J. Damião, , A. Sznadjer, A. Santoro
UERJ/Brasil



Detect ttbar in semileptonic decay channel:

$$pp \rightarrow p+X+(tt)+X+p$$

$$tt \rightarrow bbqq\mu\nu_\mu$$

Event yield after cuts:
DPE case between 1 and 100 per 10 fb^{-1}, depending on theoretical model

Backgrounds under study
diffractive: other ttbar decay channels, W + jets
non-diffractive: inclusive ttbar in coincidence with protons from diff pile-up events

CMS muon trigger thresholds not a limiting factor in event yield

Diffractive Production of B mesons decaying into J/ψ

D. J. Damião, A. Vilela, A. Sznadjer, A. Santoro
UERJ/Brasil

$\downarrow$

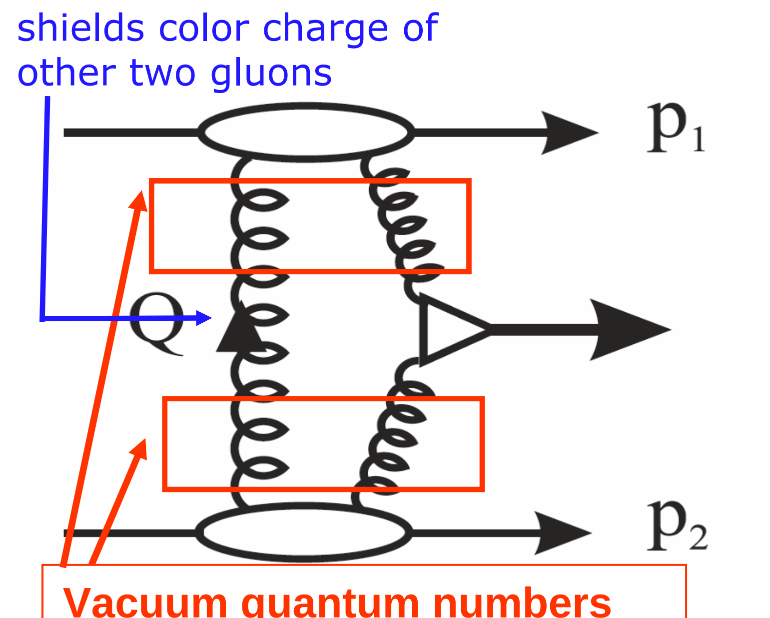
$J/\Psi \rightarrow \mu^+\mu^-$.

Inclusive DPE and SD production of B mesons
Event yields:
DPE case - a few events per pb^{-1}
SD case - a few 1000 events per pb^{-1}

Backgrounds under study

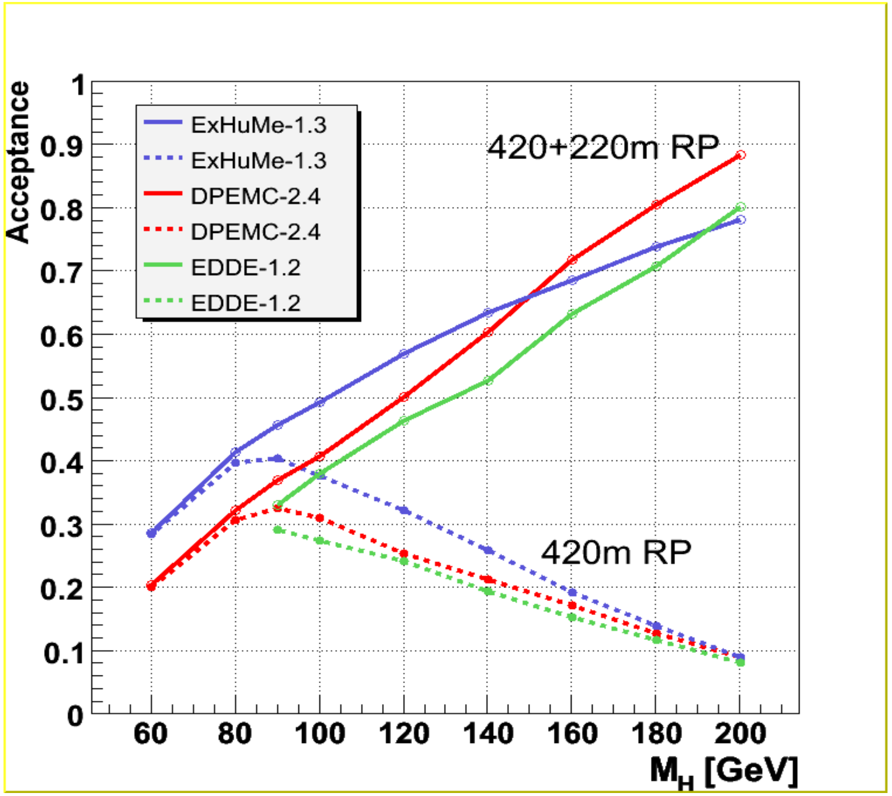
CMS muon trigger thresholds one limiting factor in event yield

Detecting a light SM/MSSM Higgs in central exclusive production pp → pHp



Vacuum quantum numbers "Double Pomeron exchange"

Calculate mass from fractional momentum loss of protons: $\xi_1 \xi_2$ **s = M²**
With √s=14TeV, M=120GeV on average:
$\xi \approx$ 0.009 $\approx$ 1%



Nominal LHC beam optics, β* =0.5m:
TOTEM: 0.02 < ξ < 0.2
FP420: 0.002 < ξ < 0.02

CEP of a light SM/MSSM Higgs

- Selection rules result in the central system being (to good approx) $J^{PC} = 0^{++}$, thereby reducing the dominant gg $\rightarrow$ b bbar background to H $\rightarrow$ bbar decay

- For SM Higgs: Fighting chance with S/B~1, though low event yield
But proton tagging may be the discovery channel in the MSSM

Studies by Marek Taševský (Physics Inst. Prague + Univ.Antwerp)

H->WW in SM	**hep-ph/0505240**
H->WW(bb,tautau) in MSSM	**Ongoing**
H->bb	**Tuning of cuts**
Comparison of models	**Proceed. HERA-LHC**
Models vs. Data	**Ongoing**

Background from coincidence of non-diff events with diff pile-up under study

(See Marek's talk on Thursday)

Trigger major limiting factor, see further down

Photon physics with roman pots

Krzysztof Piotrzkowski
Université Catholique de Louvain

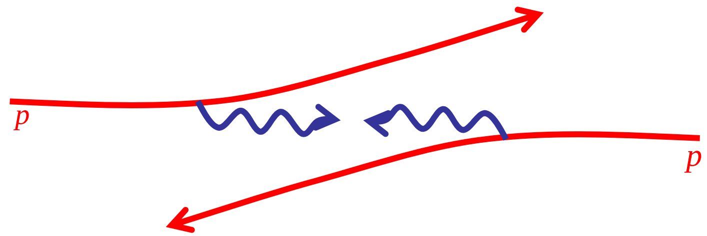
Louvain group

J. de Favereau, V. Lemaître, Y. Liu, S. Ovyn, T. Pierzchała, K. Piotrzkowski, X.Rouby

Investigate potential of studying in CMS high-energy photon interactions

Three main areas:

- SM tests in $\gamma\gamma$ interactions
- SM tests in γp (γA) interactions
- Luminosity with lepton pairs (+ diffractive meson photoproduction)



Note: Significant fraction of *pp* collisions involves <u>high-energy</u> photon exchanges; e.g. at LHC effective luminosity of $\gamma\gamma$ collisions is about 1% (of *pp* luminosity) for $\gamma\gamma$ cms energies above 100 GeV, and for γq and γg collisions is about 10% for γq and γg cms energies above 1 TeV!

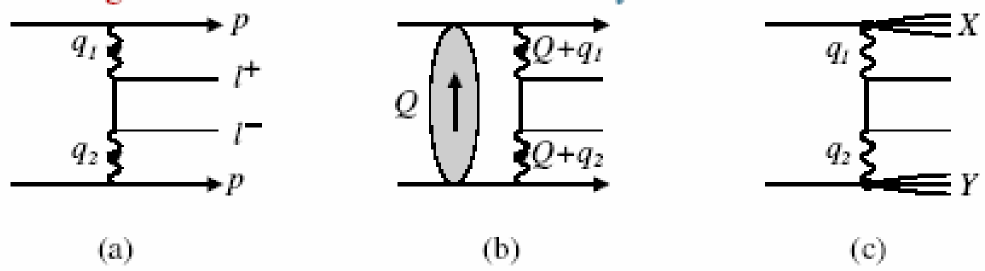
Areas of activity

- Calibration candle: Muon pairs two-photon production (Y.Liu)
- WW (and ZZ) case (J. de Favereau + T. Pierzchala)
- Single W photoproduction (J. de Favereau)
- WH photoproduction (M. vander Donckt et al.)

Exclusive lepton pairs

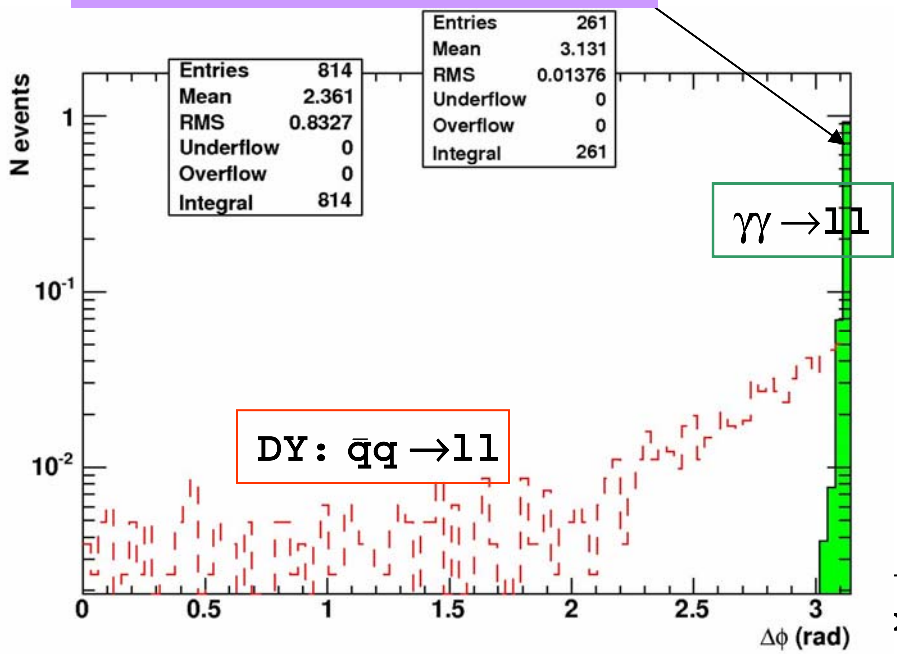
- QED process (a) production σ precisely known

event generator LPAIR based on ME by Vermaseren



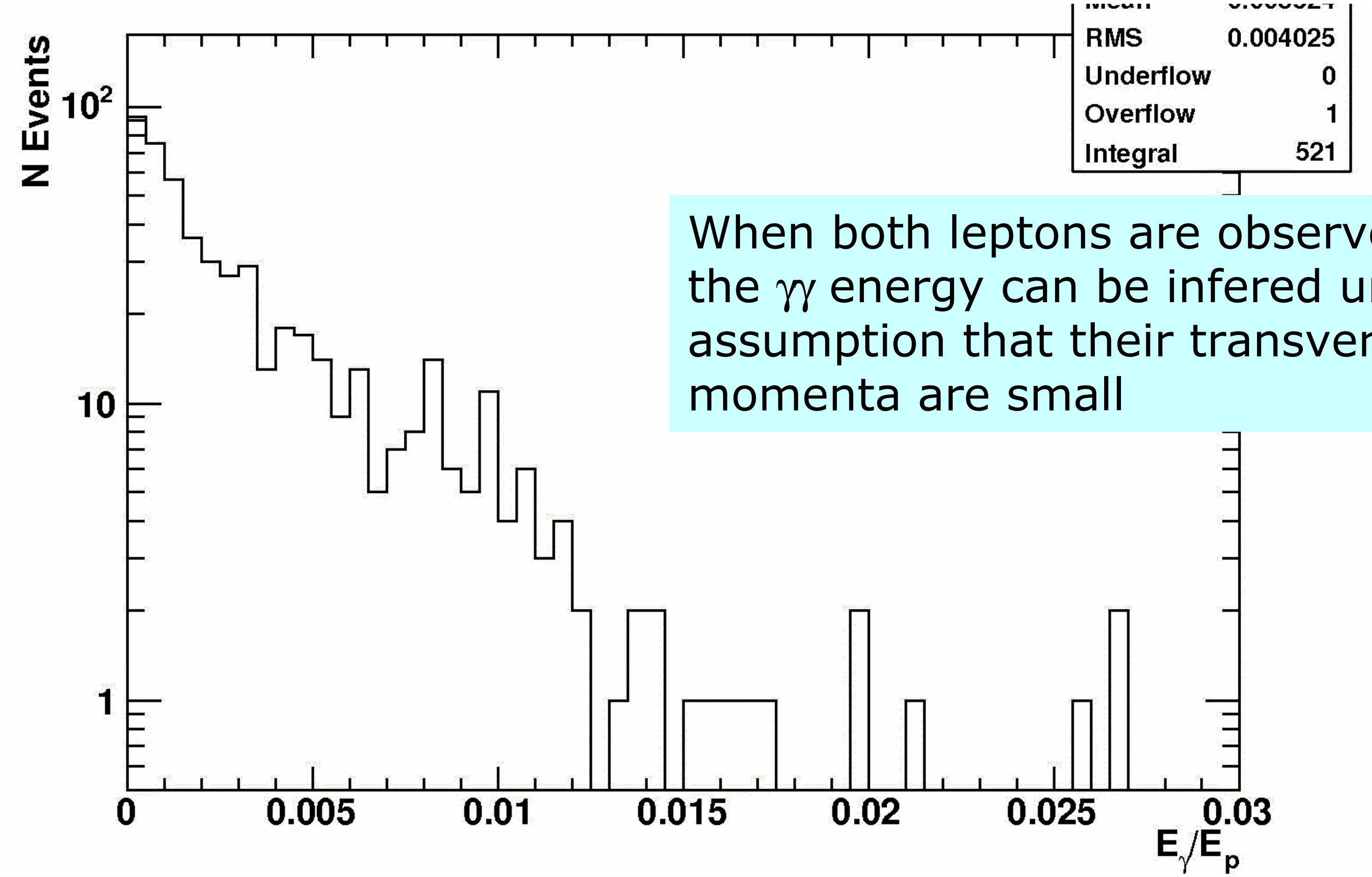
- Hadronic corrections [(b) (c)] small.

Key signature:
Acoplanarity angle
for dileptons



Calibration process both for luminosity and energy scales, has striking signatures and can be well triggered and reconstructed by CMS

Distribution of the proton energy loss for the reconstructed (and triggered) dimuon pairs:

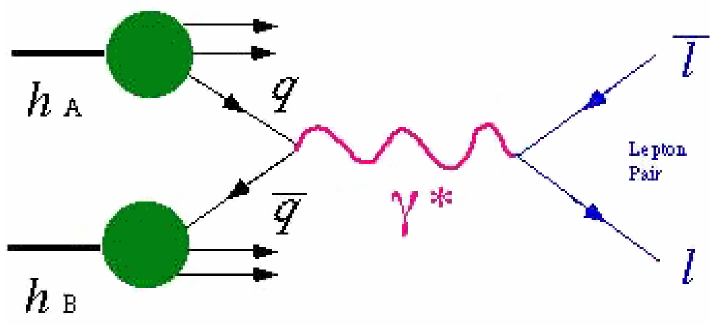


When both leptons are observed, the $\gamma\gamma$ energy can be infered under the assumption that their transverse momenta are small

Perfectly suited for FP420 calibration, but still some efficiency for TOTEM pots (-> high lumi)

Drell –Yan process with CASTOR

P. van Mechelen, S. Ochesanu (Antwerp), E. Sarkisyan-Grinbaum (Manchester)



$M^2_{ll}=s\,x_+x_-$

$$x_\pm = \frac{M}{\sqrt{s}} \exp^{\pm y}$$

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

CMS CASTOR calorimeter range $5.3 \leq |\eta| \leq 6.6$ gives access to $x_{BJ}{\sim}10^{-7}$
CASTOR has 16 segments in azimuth and logitudinally has electromagnetic and hadronic section

CASTOR alone can provide crude estimate of M_{ll}
Can be much improved with information from Totem tracker T2 in front of CASTOR

Triggering on Drell –Yan with CASTOR

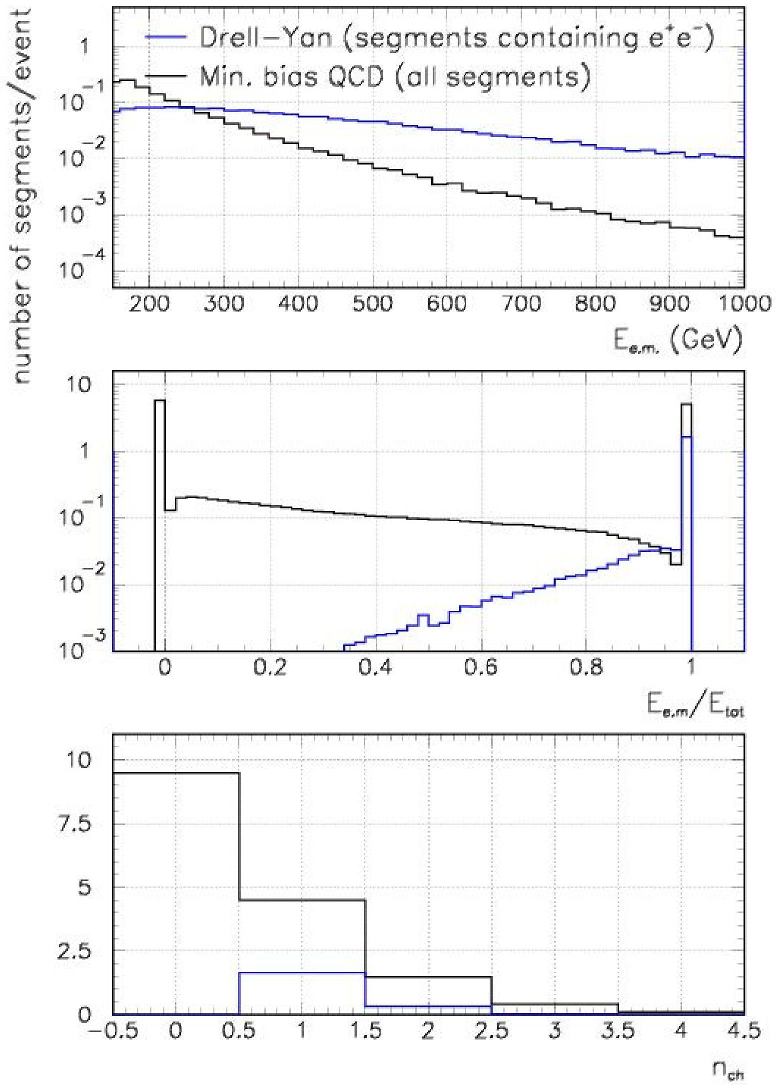
P. van Mechelen, S. Ochesanu (Antwerp), E. Sarkisyan-Grinbaum (Manchester)

- Drell–Yan signal
  - High electromagnetic energy
  - Small hadronic energy fraction
  - One charged track

- QCD background
  - Rapid decrease of number of segments with large electromagnetic energy
  - Symmetric electromagnetic and hadronic energy depositions
  - Low charged multiplicity

→ separation between signal and background possible at L1 ?

Under study



Major issues in selecting diffractive events with CMS + TOTEM + FP420

1. Background from non-diffractive events that are overlaid with diffractive pile-up events (1/5 of pile-up events are diffractive)

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

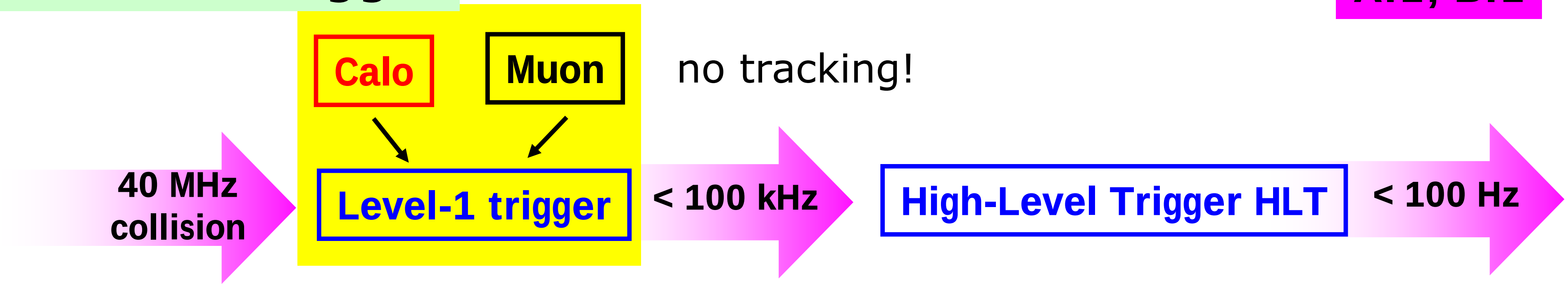
The CMS trigger menus now foresee 1% of the trigger bandwidth on L1 and HLT for a dedicated diffractive trigger stream
where the combination of forward detector information with the standard CMS trigger conditions (jets, muons) makes it possible to lower the jet/muon thresholds substantially and still stay within the CMS bandwidth limits

This is the completion of the trigger studies presented in the proceedings of the HERA-LHC workshop of 2004/2005
Now available as CMS note 2006/054 and TOTEM note 2006/01:
"Triggering on fwd physics", M.Grothe et al.

The difficulty of triggering on a light Higgs

The CMS trigger

A.1, B.1



120GeV Higgs has L1 jet trigger signature: 2 jets (E_T < 60 GeV) in CMS Cal

- Measured L1 jet E_T on average only ~60% of true jet E_T
- L1 trigger applies jet E_T calibration and cuts on calibrated value
- Thus: 40 GeV (calibrated) ~ 20 to 25 GeV measured
- Cannot go much lower because of noise

→ **Use rate / efficiency @ L1 jet E_T cutoff of 40 GeV as benchmark**

L1 2-jet rate for central jets ($|\eta|<2.5$) @ L1 jet E_T cutoff of 40 GeV for Lumi 2 x 10^{33} cm^{-2} s^{-1}: ~**50 kHz**, while considered acceptable: **O(1 kHz))**

Need additional conditions in trigger: Forward detectors !

L1 output rate reduction with fwd detectors

→ Very good reduction of rate in absence of pile-up both with T1/T2 veto and with near-beam detectors at 220/420m

→ However, reduction decreases substantially in the presence of pile-up because of diffractive component in pile-up

Richard Croft, Bristol

Luminosity $[cm^{-2}s^{-1}]$	# Pile-up events per bunch crossing	L1 2-jet rate [kHz] for $E_T > 40GeV$ per jet	Total reduction needed	Reduction when requiring track in RPs					
				at 220 m	at 220 m $\xi < 0.1$	at 420 m	at 220 & 420 m (asymmetric)	at 220 & 420 m (asymmetric) $\xi < 0.1$	at 420 & 420 m
1×10^{32}	0	2.6	2	370					
1×10^{33}	3.5	26	20	7	15	27	160	380	500
2×10^{33}	7	52	40	4	10	14	80	190	150
5×10^{33}	17.5	130	100	3	5	6	32	75	30
1×10^{34}	35	260	200	2	3	4	17	39	10

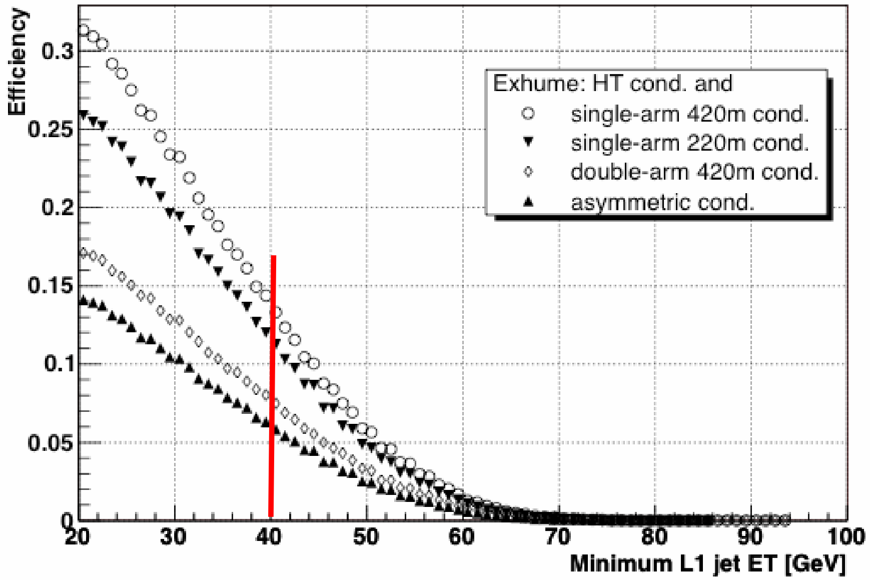
Achievable total reduction: 10 x 2 (H_T cond) x 2 (topological cond) = 40

Jet isolation criterion

Can win additional factor ~2 in reduction when requiring that the 2 jets are in the same η hemisphere as the RP detectors that see the proton

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

L1 diffractive signal efficiencies - examples



Central exclusive prod. of H(120) → b bbar:

2-jets (E_T>40GeV) & single-sided 220m cond. results in efficiency ~12%

Can add another ~10% efficiency by introducing a 1 jet & 1 μ (40GeV, 3GeV) trigger cond.

Richard Croft, Bristol

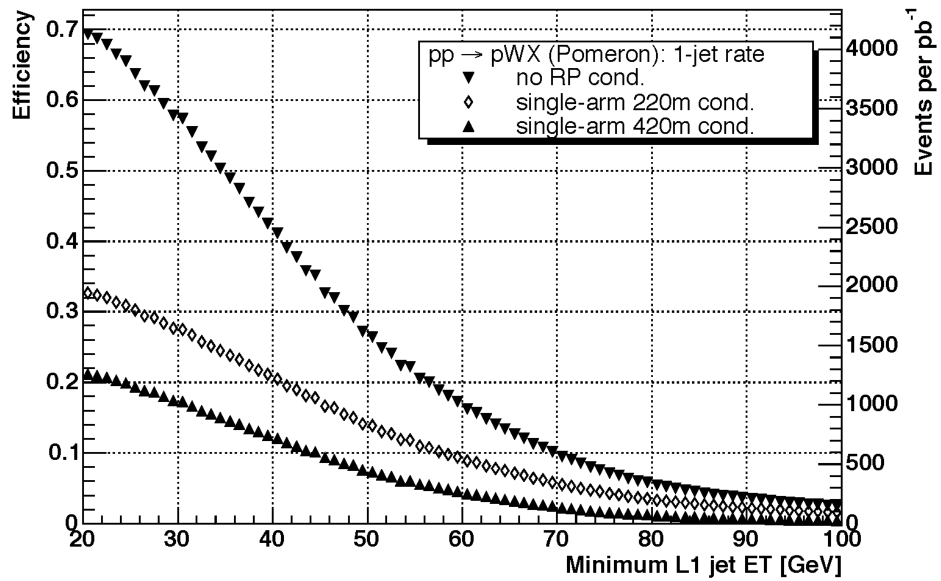
Example for single-diffractive process: SD production of W's

y-axis left: efficiency

y-axis right: #events per pb^{-1}

At 2x 10^{33} cm^{-2} s^{-1} 1 jet & single-sided 220m cond with ξ<0.1 cut would lead to 1kHz L1 output rate for jet threshold E_T > 70GeV, which means several 100 SD W's per pb^{-1}

Also looked at SD prod of Z's and dijets



HLT strategies for fwd detectors trigger stream

Conditions:

A: L1 di-jets with E_T>40 GeV & single-arm 220 m cond. with ξ<0.1 cut

B: Central ($|\eta|$<2.5) HLT di-jets with:
2.8 < |phi1 - phi2| < 3.5 & $(E_T(1) - E_T(2))/(E_T(1) + E_T(2)) < 0.4$ & $E_T(1,2) > 40$ GeV

C: Compare fractional momentum loss of proton as calculated from jets to ξ measured with near-beam detectors at 220m:

$\xi_{+(-)} = s^{-1/2} \sum Et_i \exp(-(+)\eta_i)$, where +/- denotes the two hemispheres

Select events where two ξ values match within 2σ

D: Either one of 2 jets is b-tagged.

E: A proton is seen at 420m.

Richard Croft, Bristol

HLT selection condition	A+B+C	A+B+D	A+B+C+E
HLT rate at 1×10^{33} cm^{-2} s^{-1}	15 Hz	20 Hz	< 1 Hz
HLT rate at 2×10^{33} cm^{-2} s^{-1}	60 Hz	80 Hz	1 Hz
Signal eff. $H(120\text{GeV}/c^2) \to b\bar{b}$	11%	7%	6 %

In order to keep the HLT rate below 1Hz, needs either prescale, double b-tag or near-beam detectors at 420m in addition to 220m ones

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

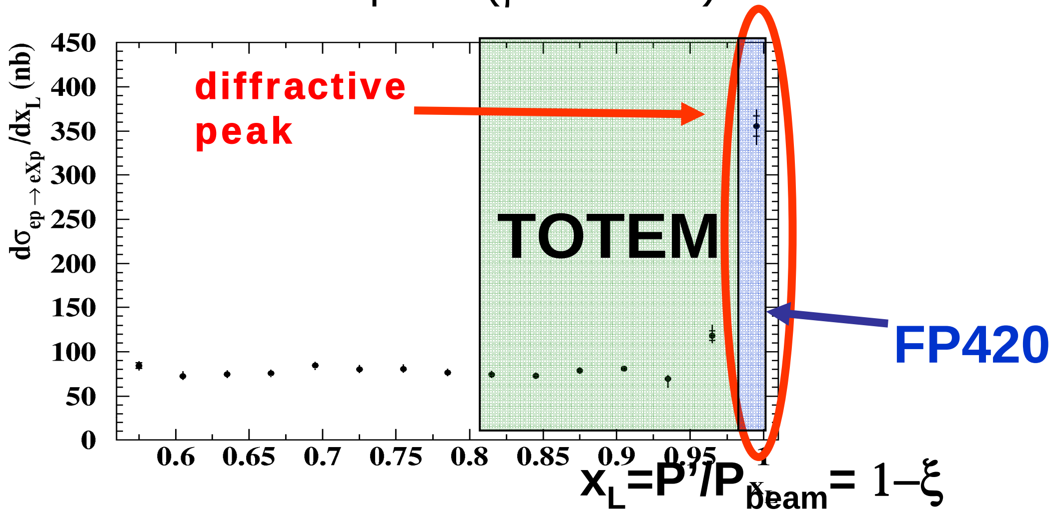
Central exclusive production
Discovery physics:
Light SM Higgs
MSSM Higgs
Extra dimensions

Gamma-gamma and gamma-proton interactions (QED)
Forward energy flow - input to cosmics shower simulation
QCD: Diffraction in presence of hard scale
- Low-x structure of the proton
- High-density regime (Color glass condensate)
- Diff PDFs and generalized PDFs
- Diffractive Drell-Yan

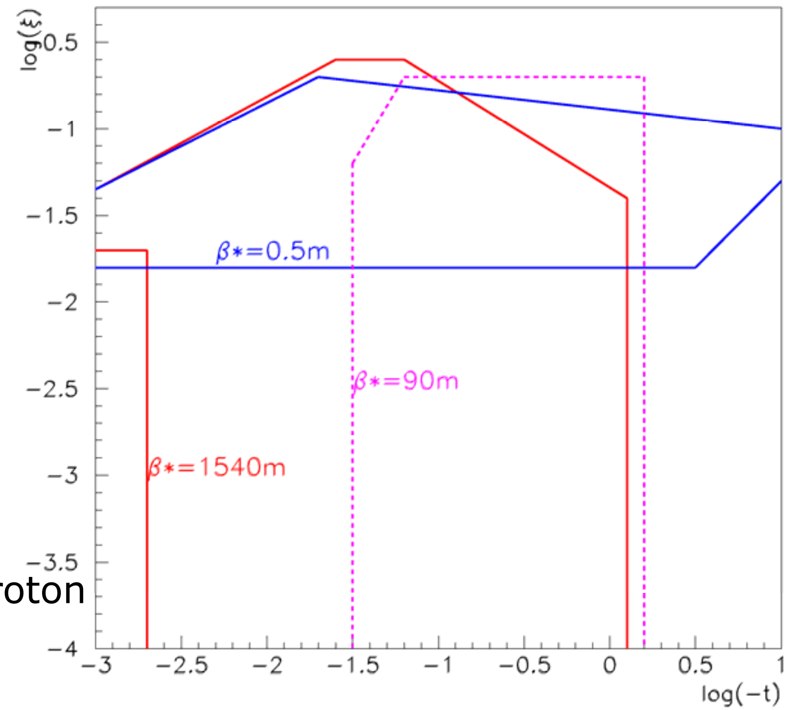
CMS alone | **CMS with Totem and/or FP420**

Proton tagging with TOTEM

At nominal LHC optics (β*=0.5m):



K.Eggert, Blois 05 proceed.



ξ - fractional momentum loss of proton
t - 4-momentum transfer squared from proton

TOTEM:

An approved experiment at LHC for measuring σ_{tot} and $\sigma_{elastic}$, uses same IP as CMS

TOTEM's trigger and DAQ system will be integrated with those of CMS , i.e. **common data taking CMS + TOTEM possible**

220m detector loc. optimal for **special optics runs** (β*=1540m) @ 10^{28} - 10^{29}cm^{-2}s^{-1}
TOTEM suggests few days of running with β*=90m @ 10^{31} cm^{-2}s^{-1}, with much improved coverage for diffractive events compared to β*=0.5m (@ 10^{33} - 10^{34} cm^{-2}s^{-1})