Forward Physics with CMS

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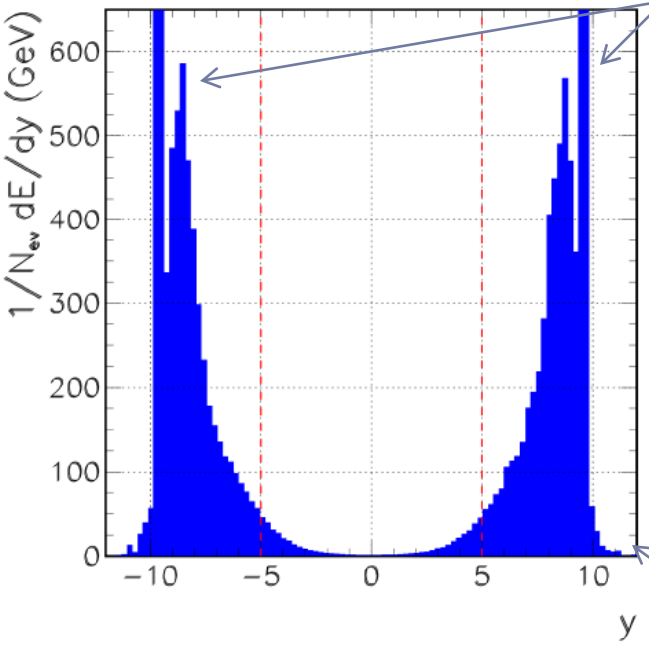
Forward physics

- Most energy deposited between $8 < |y| < 9$
- Main CMS/ATLAS calorimeters: $|y| < 5$

Energy flow at LHC



Elastic and diffractive protons

$$y_{max} = \ln \frac{\sqrt{s}}{m} \approx 11.5$$

Low-x QCD & BFKL dynamics studies

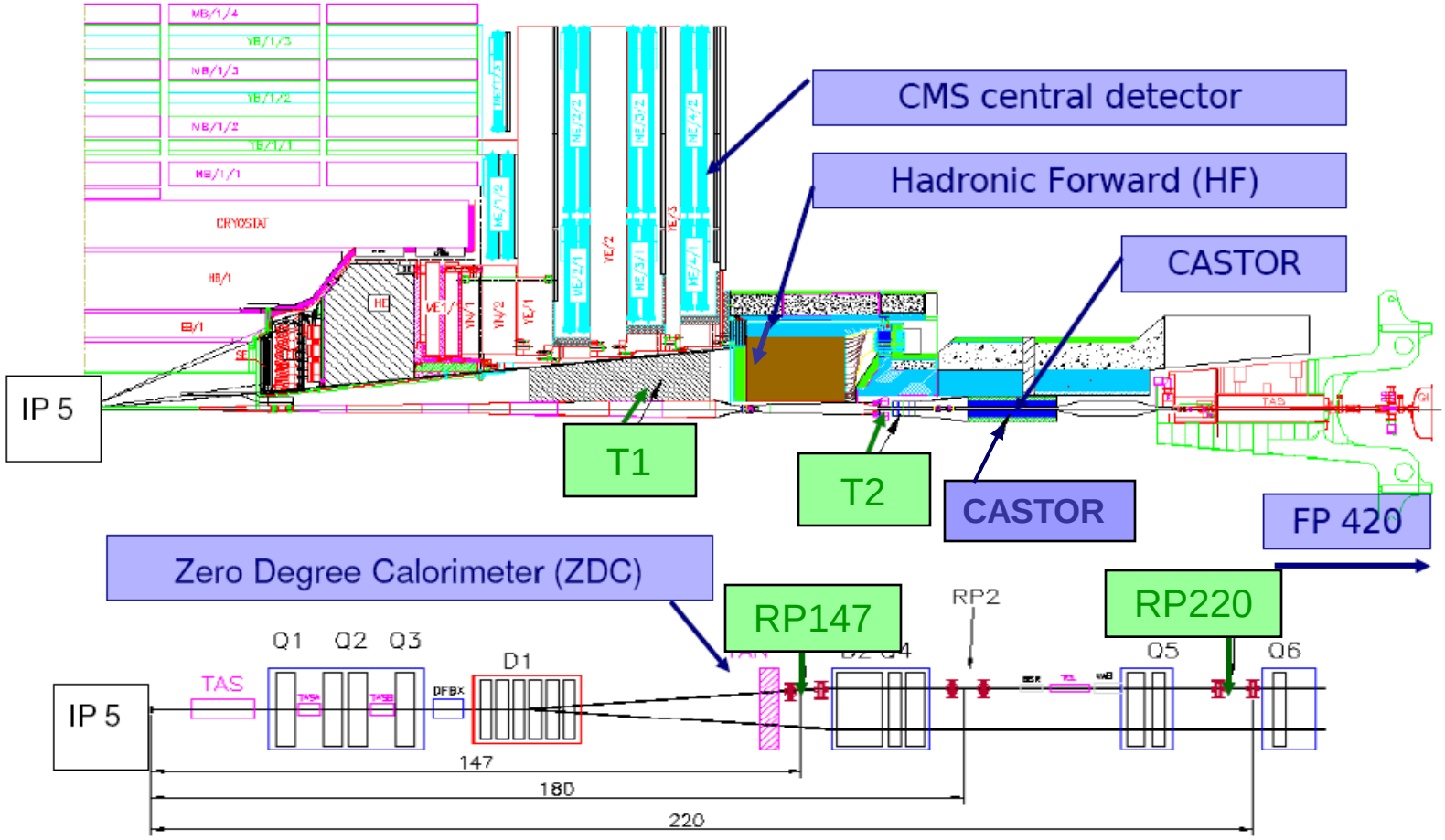
Monte Carlo tuning

γ-mediated processes & absolute luminosity determination

Hard diffraction and rapidity gap survival determination

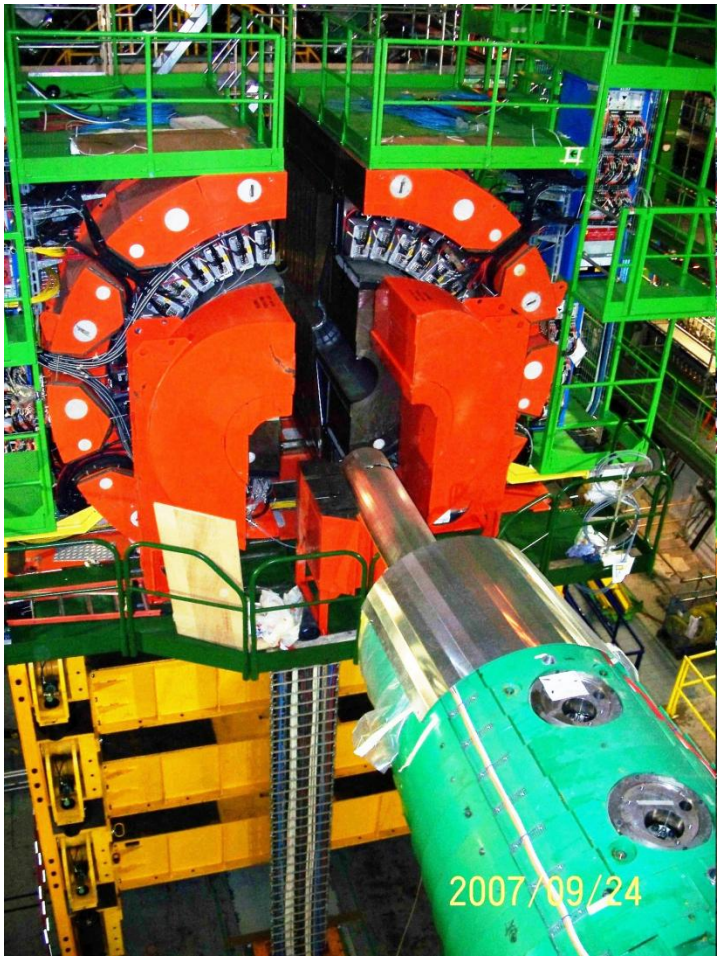
Discovery physics w/ near beam detectors

Forward detectors @ IP5

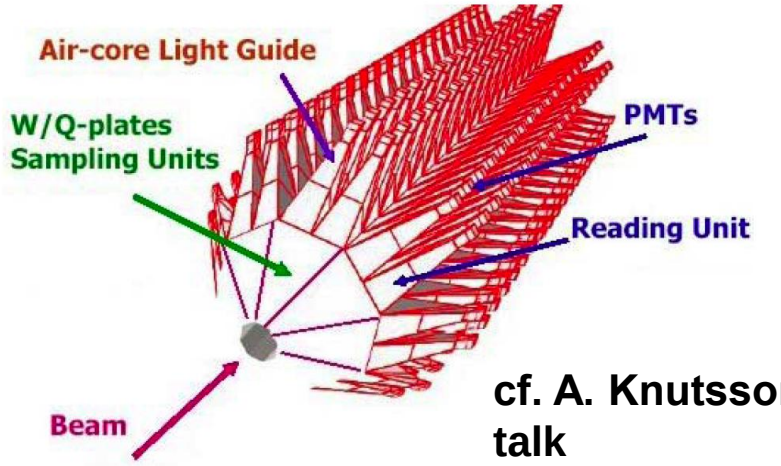


Hadron Forward calorimeter

- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers and embedded radiation-hard quartz fibers for fast collection of Cherenkov light
- Long (1.65m) and short (1.43m) fibers are placed alternately and run parallel to the beam axis along the iron absorbers

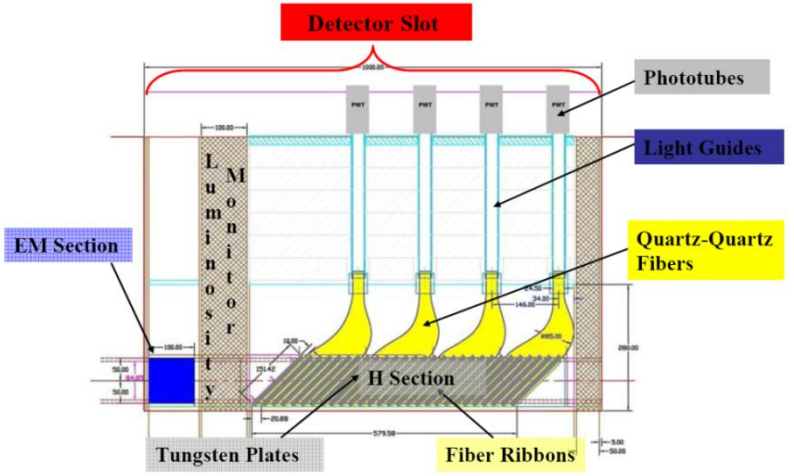


CASTOR & ZDC



cf. A. Knutsson's talk

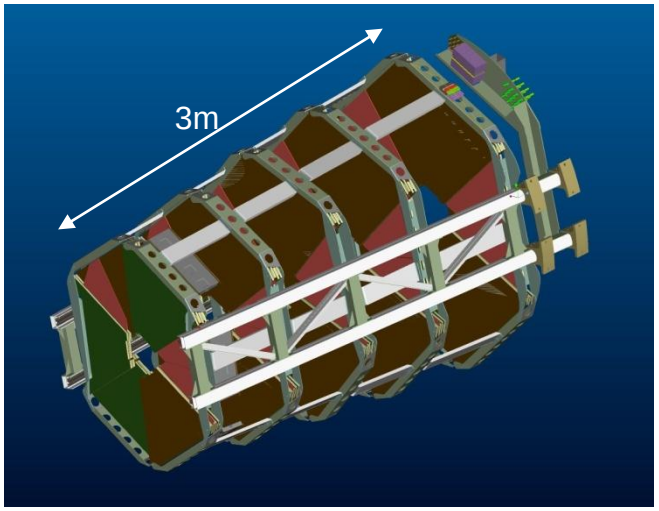
- W absorber & quartz plates sandwich
- @14m from IP – coverage $5.2 < \eta < 6.6$
- 16 segments in φ, 2 (EM) + 12 (HAD) segments in z
- No η segmentation
- signal collection through Cherenkov photons transmitted to PMTs through air-core lightguides
- At start-up, available on only one side

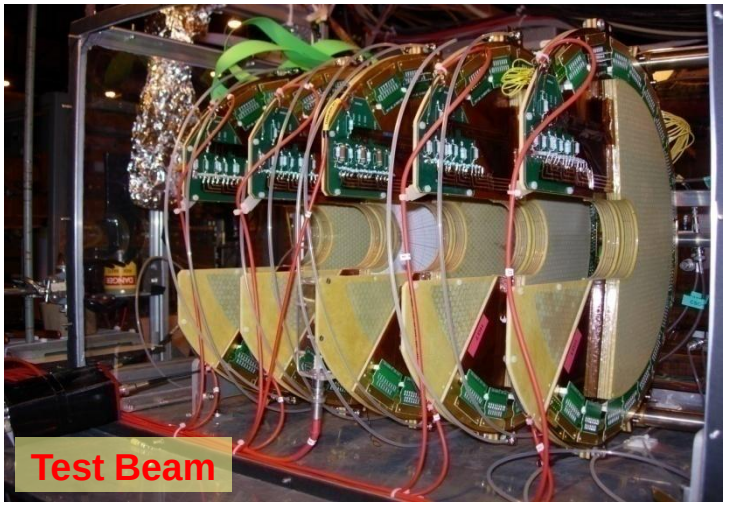


- @140 m from interaction point
- Tungsten/quartz Cherenkov calorimeter with separate EM and HAD sections
- Acceptance for neutrals (γ, π^0, n) from $\eta > 8.1$, 100% for $\eta > 8.4$
- Ready for start-up

cf. M. Murray's talk

TOTEM T1 & T2





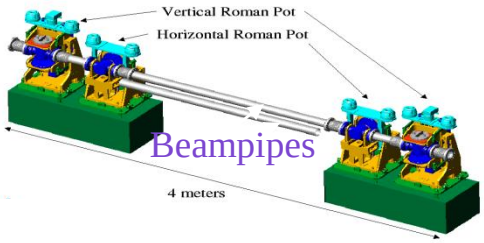
- Cathode Strip Chambers (CSC)
- Mounted in front of HF
- $3.1 < |\eta| < 4.7$
- 5 planes with 3 coordinates/plane
- 6 trapezoidal CSC detectors/plane
- Resolution: $\sigma \sim 0.8$mm

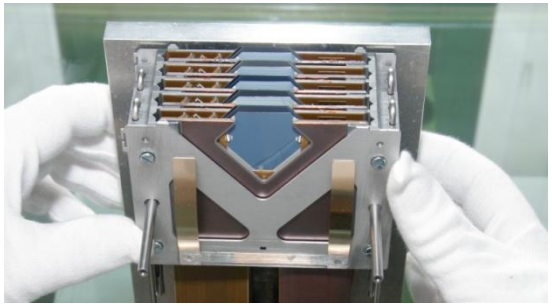
- Gas Electron Multiplier (GEM)
- Mounted in front of CASTOR
- $5.3 < |\eta| < 6.5$
- 10 planes formed by 20 GEM semi-circular modules
- Resolution: $\sigma_{strip} \sim 70\mu m$

TOTEM: Total Cross Section, Elastic Scattering and Diffraction Dissociation at the LHC

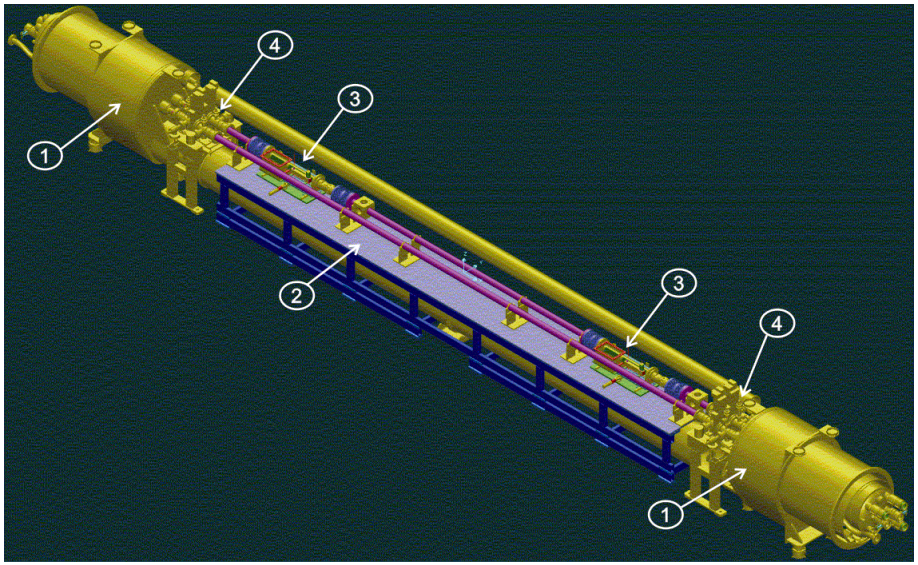
Proton taggers around IP5

TOTEM: Roman pot technique with Si detectors @ 147, 220 m from IP





- Installation of Si detectors in cryogenic region of LHC, i.e. cryostat redesign needed
- Strict space limitations rule out Roman Pot technology, use movable beampipe instead
- Radiation hardness required of Si is comparable to those at SLHC, use novel 3-D Silicon technology
- To control pile-up background use very fast timing detectors (σ ~ 10ps)

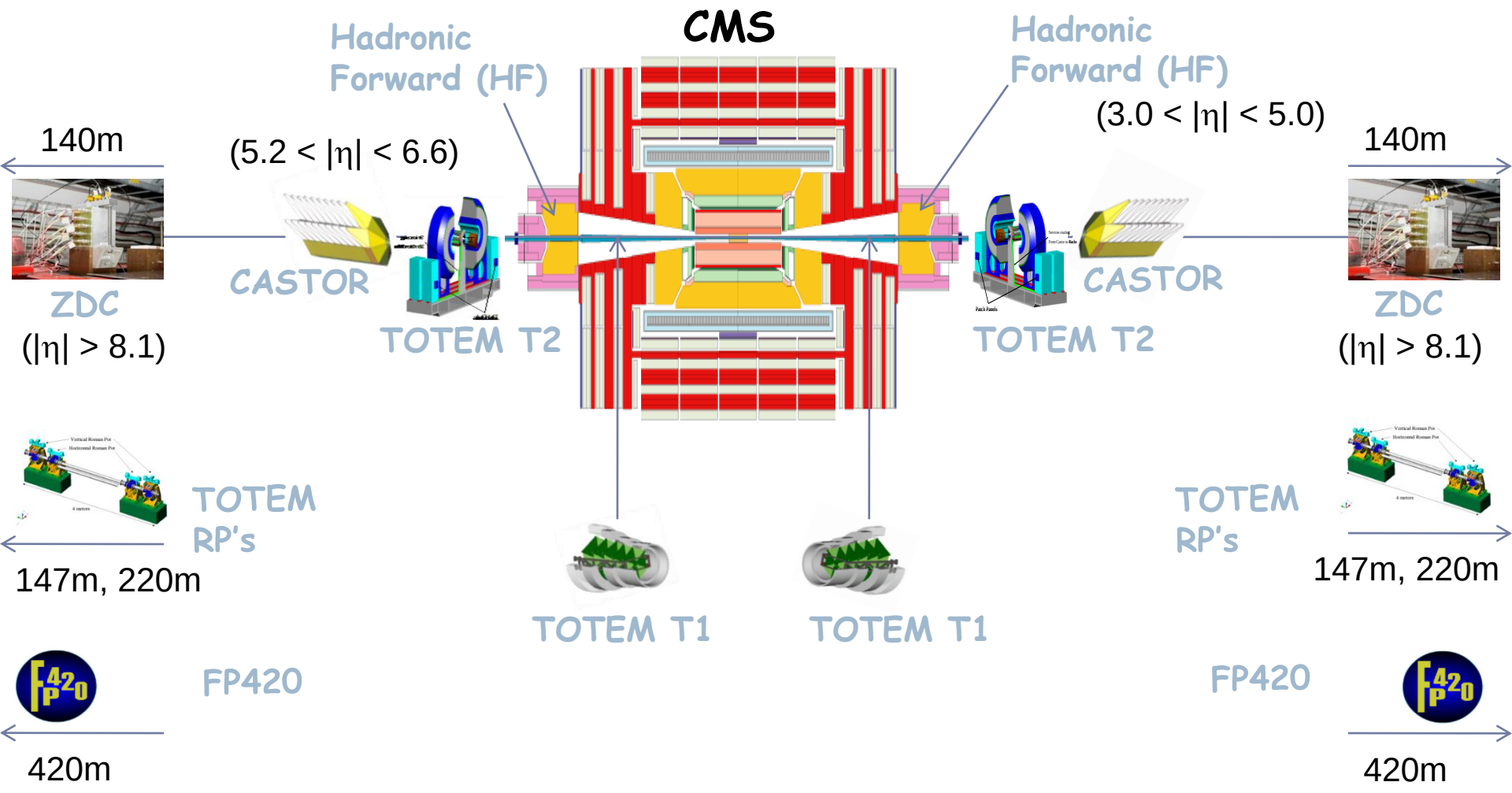


cf. A. De Roeck's talk

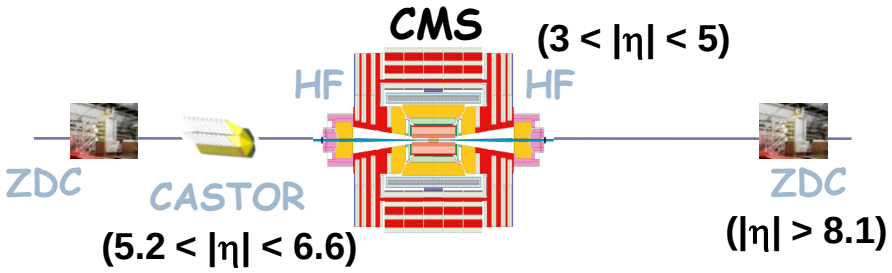
Acceptance: (At nominal LHC beam optics -- $\beta^* = 0.5$ m)

$0.02 < \xi < 0.2$ with **TOTEM** + **$0.002 < \xi < 0.02$** with **FP420**

Forward detectors @ IP5



Forward physics @ CMS



Low-x QCD with forward jets

Underlying event tuning & cosmic rays shower modeling

Exclusive di-muon production & absolute luminosity measurements

Vector meson photoproduction

Observation of hard-diffraction

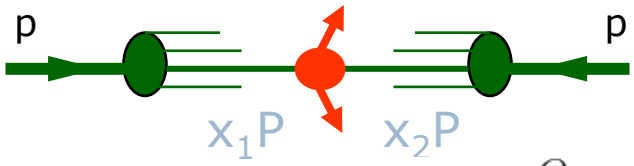
Physics with 1 pb^{-1} - 100 pb^{-1}

N.B. No pile-up assumed

All results assume $\sqrt{s}$ = 14 TeV

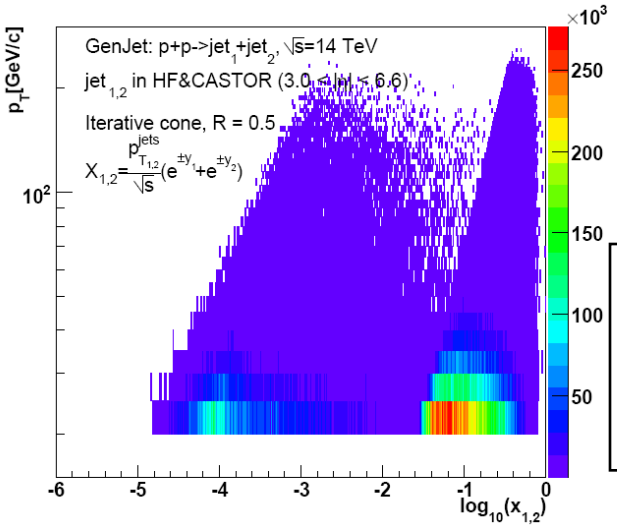
Physics with proton taggers @ high-luminosity

Low-x physics: proton pdf

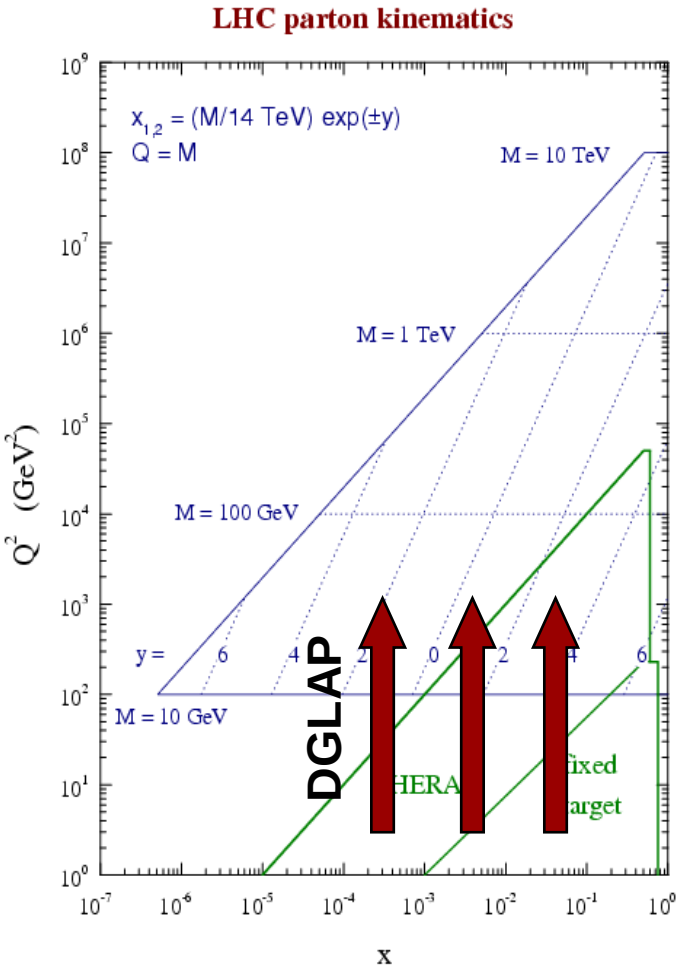


$$x_{Bj} = \frac{Q}{\sqrt{s}} e^{-\eta}, \qquad Q = p_T, M, \ldots$$

Low-x partons from forward jets, DY,…



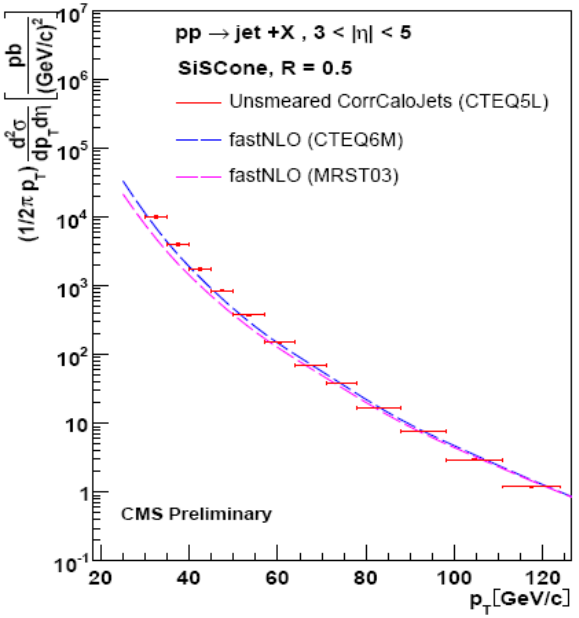
Jets in HF ($3 < |\eta| < 5$): $x \sim 10^{-4}$
Jets in CASTOR ($5.1 < |\eta| < 6.6$): $x \sim 10^{-5}$



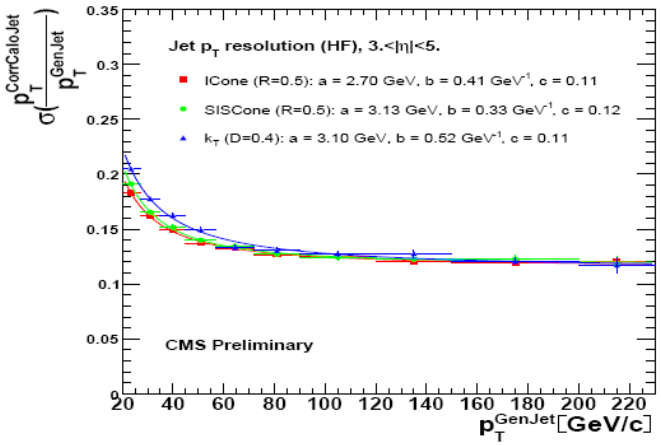
Forward Jets

CMS PAS FWD-08-001

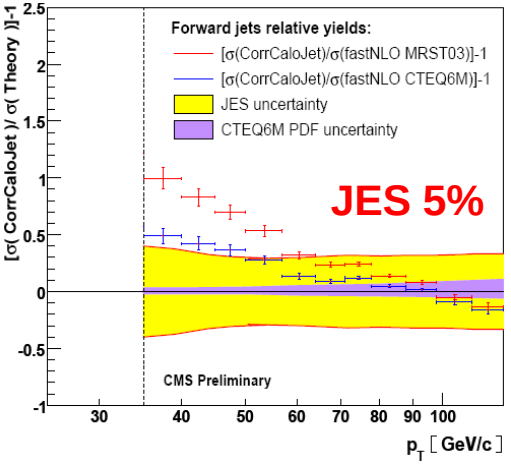
- Single inclusive forward jet spectrum with 1 pb^{-1}
- Jets reconstructable in HF from p_T ~ 35 GeV
- Very good (better than at mid-rapidities) energy and position resolutions (due to large forward boost)
- Main systematic source from jet energy scale (JES)



Jet energy resolution in HF

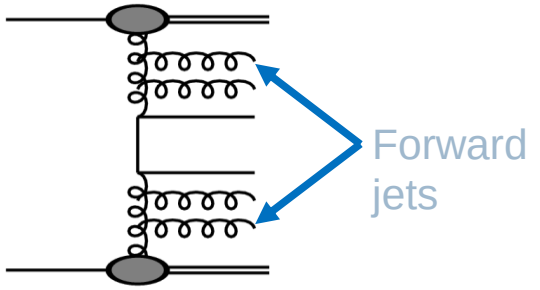


With improved JES, possible to constrain low-x gluon density

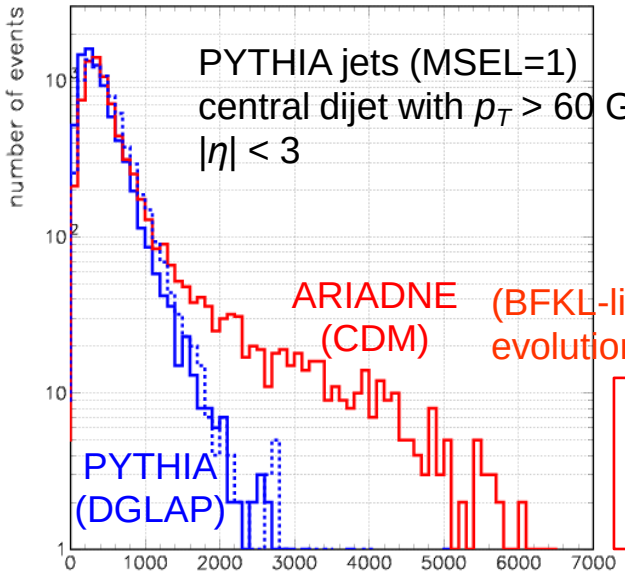


Forward jets from QCD evolution

- Forward jets: test the low-x QCD evolution
- Sensitivity to BFKL dynamics
- Mueller-Navelet di-jets with large y separation
- Jets separated by large rapidity gaps

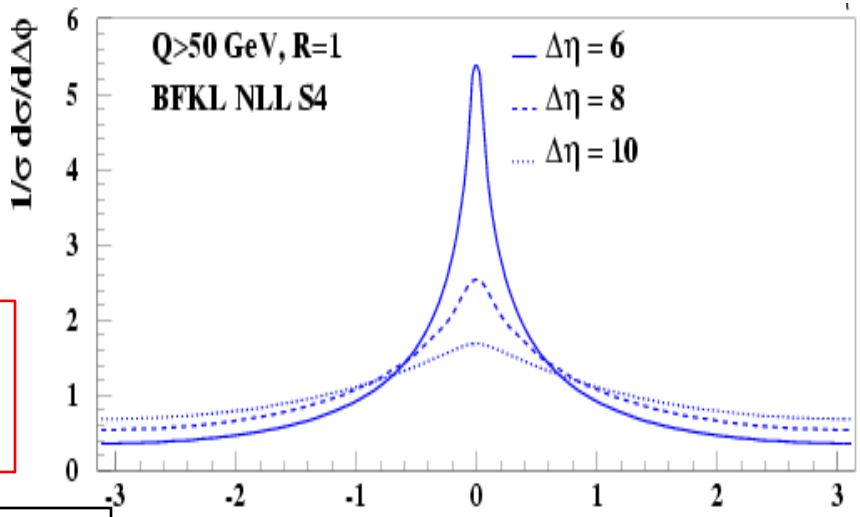


Enhanced azimuthal decorrelation with increasing Δy



"Jet energy" in CASTOR

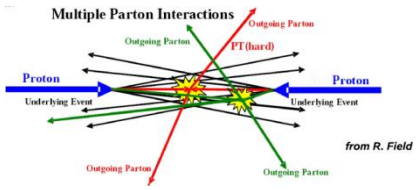
BFKL: large yield of high E forward jets



Generator level

[A.Sabio-Vera, F.Schwennsen]
[C.Marquet, Royon]

Underlying event tuning and cosmic rays shower modeling



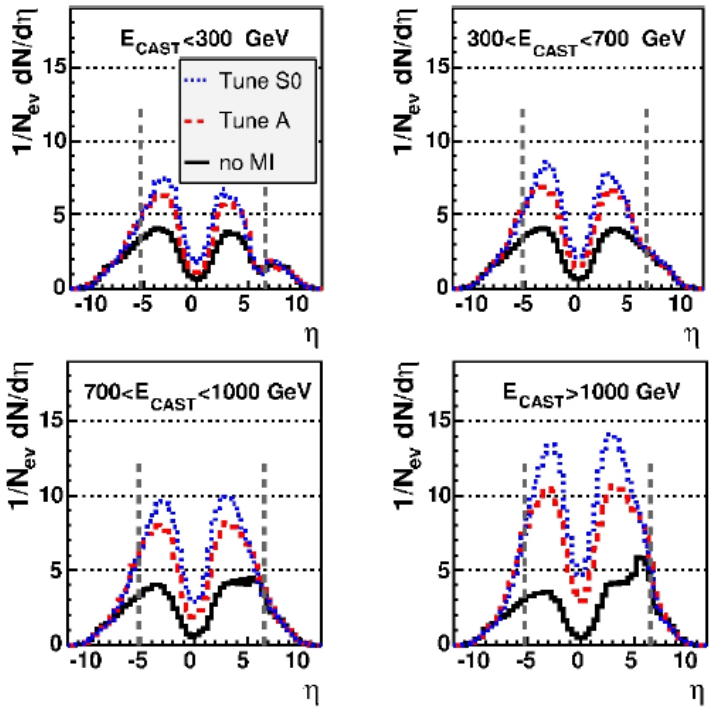
Tuning of underlying event models

- 100 PeV fixed target collision in air corresponds to pp interaction at LHC

→ Tune shower models by measurement of forward particle and energy flow with CASTOR, ZDC, T1/T2

Long-range correlations in CASTOR vs central detector

E_{CAST}: deposited energy in CASTOR



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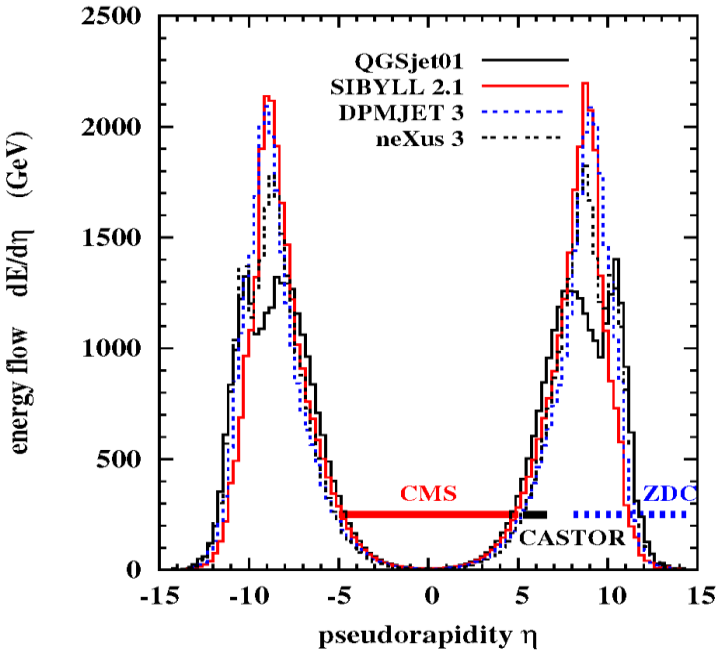
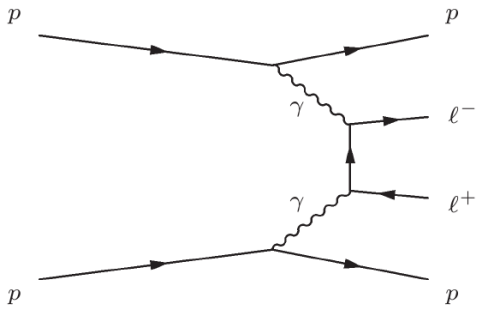


Zurikova et al, HERALHC, May 2008

CERN-LHCC-2006-039 G124

Exclusive di-muon production

CMS PAS DIF-07-001

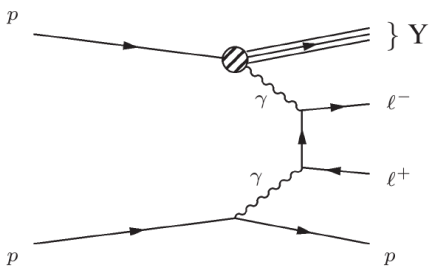


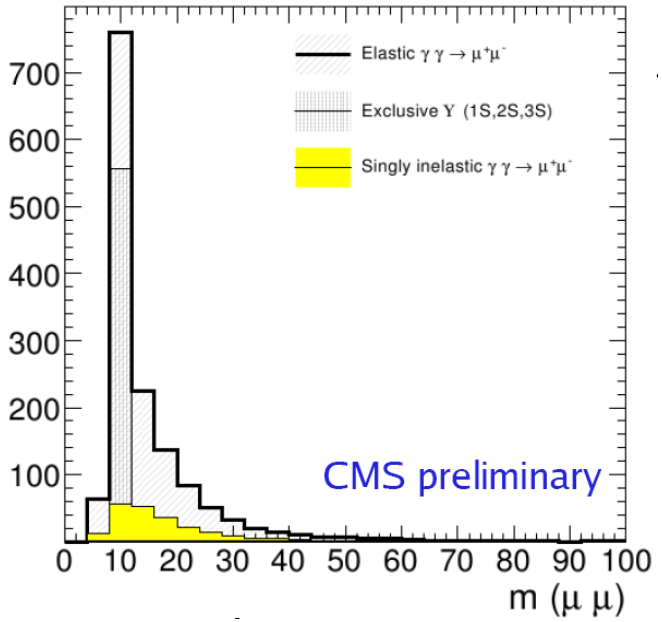
pp → pp l^+l^-

- Nearly pure QED process
- Absolute luminosity measurement with O(5%) feasible after 100 pb^{-1} of single-interaction data
- Calibration/alignment of proton taggers
- Selection via exclusivity conditions in central detector + veto on CASTOR & ZDC activity

- ~ 700 μμ events in 100 pb^{-1} of single-interaction data
- Main background from p-dissociative events (~ 200) with large rejection (2/3) from veto on CASTOR/ZDC

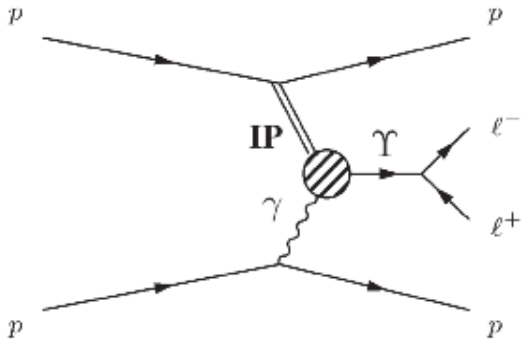
cf. K. Piotrzkowski's talk





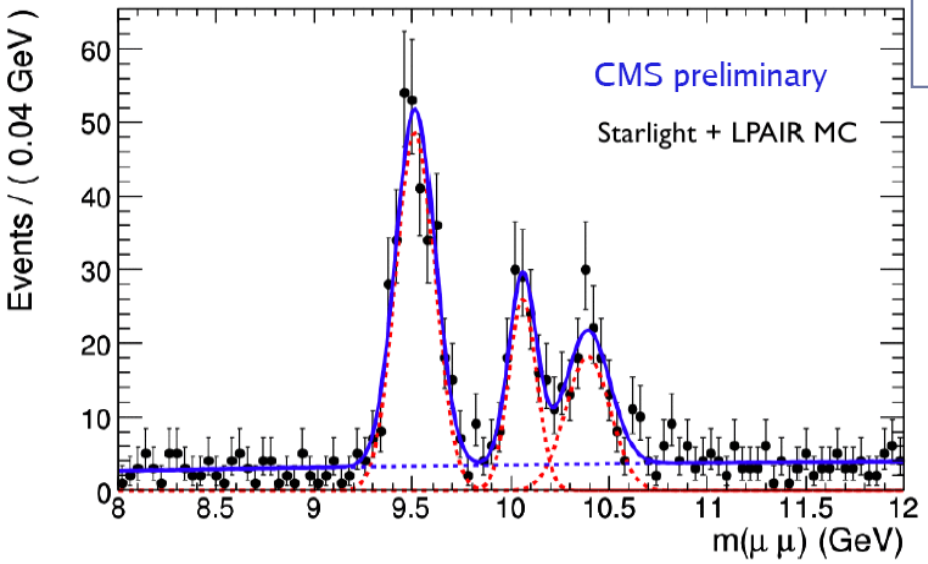
Vector meson photoproduction

CMS PAS DIF-07-001



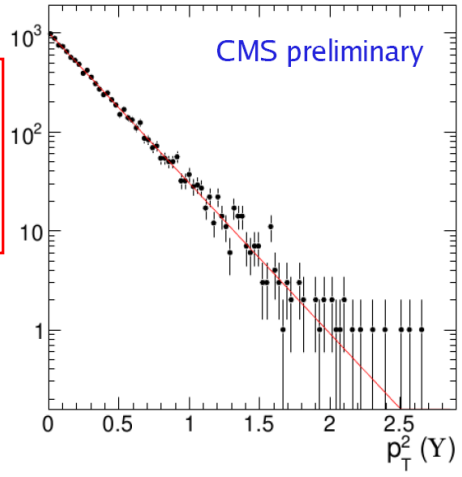
- Allows testing of QCD models
- Sensitive to Generalized Parton Distributions (GPD's)
- Dependence on $W_{\gamma p}$ (γp center-of-mass energy) and t (4-momentum transfer squared at IP-p vertex) sensitive to gluon density in the proton

$pp \rightarrow pp\Upsilon$, $\Upsilon \rightarrow l^+l^-$

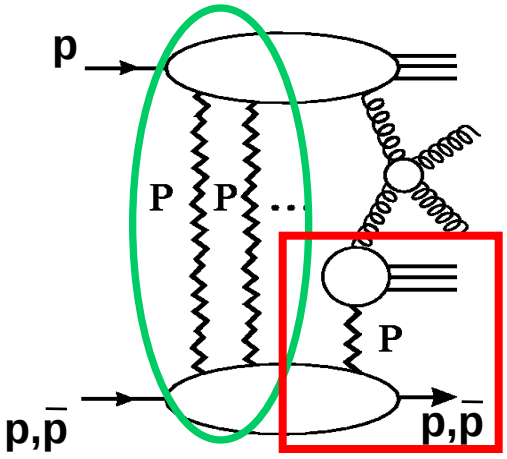


Feasible to separate 1S,2S,3S with 100 pb^{-1}

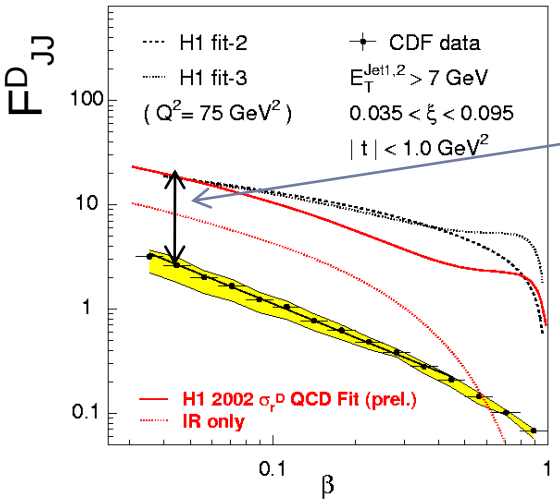
p_T^2 ($\mu\mu$) as estimator of true t



Hard-diffraction at LHC



dPDF



• From Tevatron to LHC: Factorization broken in diffractive hadron-hadron collisions due to soft interactions/rescatterings among spectator partons

→Which fill rapidity gap and slow down the p,pbar

→ Hence suppress visible σ_{diffr}

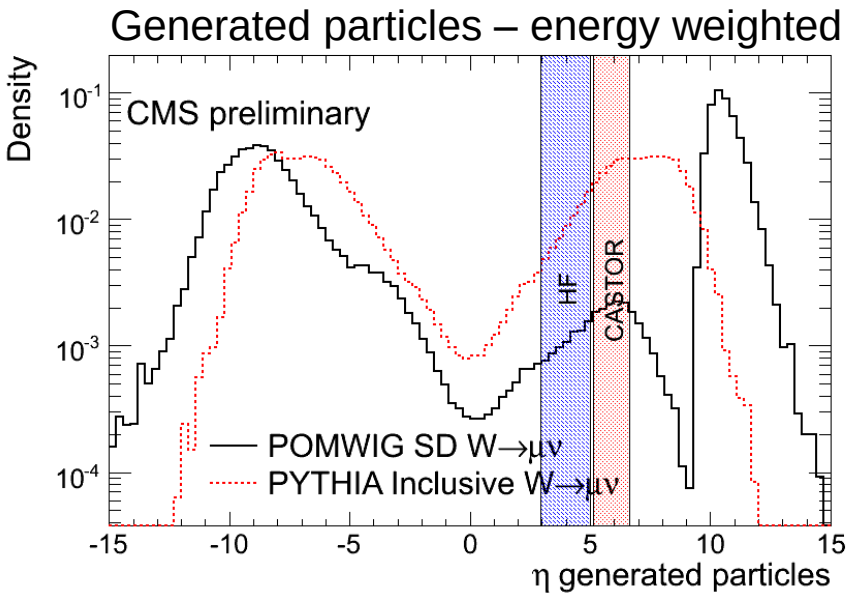
• Often quantified by rapidity gap survival probability $\langle S^2 \rangle$ ($\sigma_{diffr} \propto \langle S^2 \rangle$)

• At Tevatron: supression of O(10%) compared to HERA

• At LHC: predictions at $\langle S^2 \rangle$ ~ 5% (but values between 0.004 and 0.23 proposed)

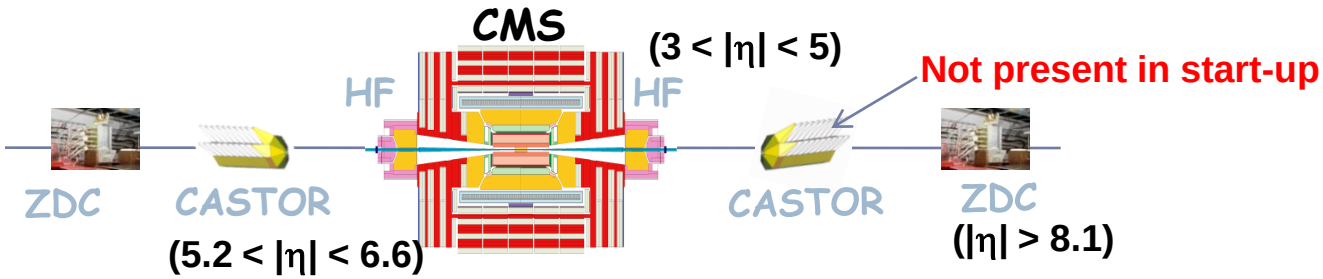
cf. K. Goulianos's talk

Observing hard-diffraction



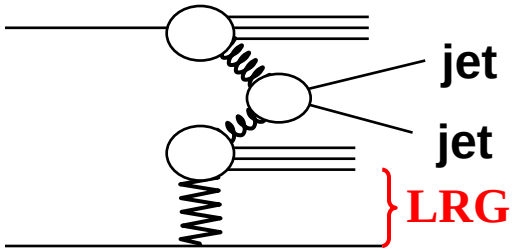
Sub-sample generated with gap in η-plus side

- At early LHC running: no proton taggers → rely on Large Rapidity Gap (LRG) identification in forward hadronic final state
- Use multiplicities in HF and/or CASTOR in gap side to select diffractive events
- In addition, exploit lower central activity



Feasibility studies

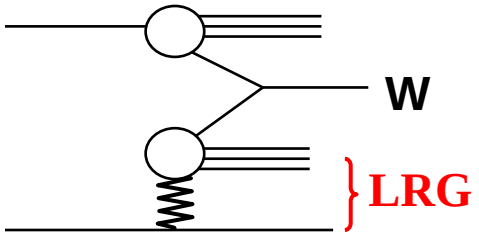
CMS PAS FWD-08-002



Single-diffractive di-jet production

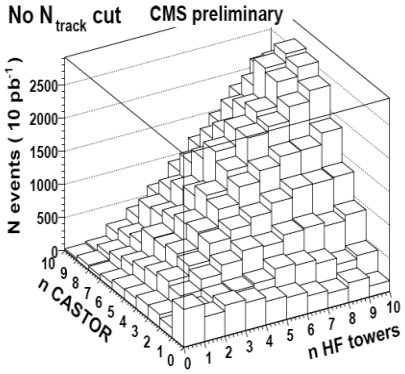
O(300) evts/10 pb^{-1} in [n(Castor), n (HF)] = [0,0] bin

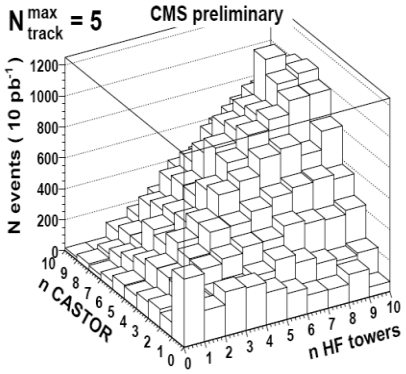
CMS PAS DIF-07-002



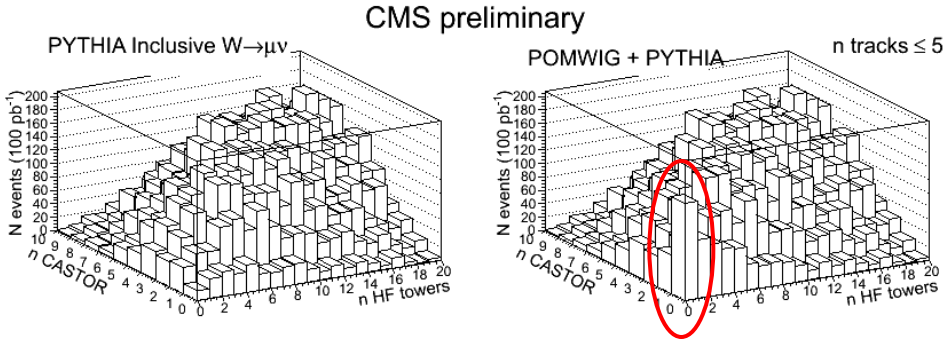
Single-diffractive W production

O(100) evts/100 pb^{-1} in [n(Castor), n (HF)] = [0,0] bin





cf. F. Silva's talk



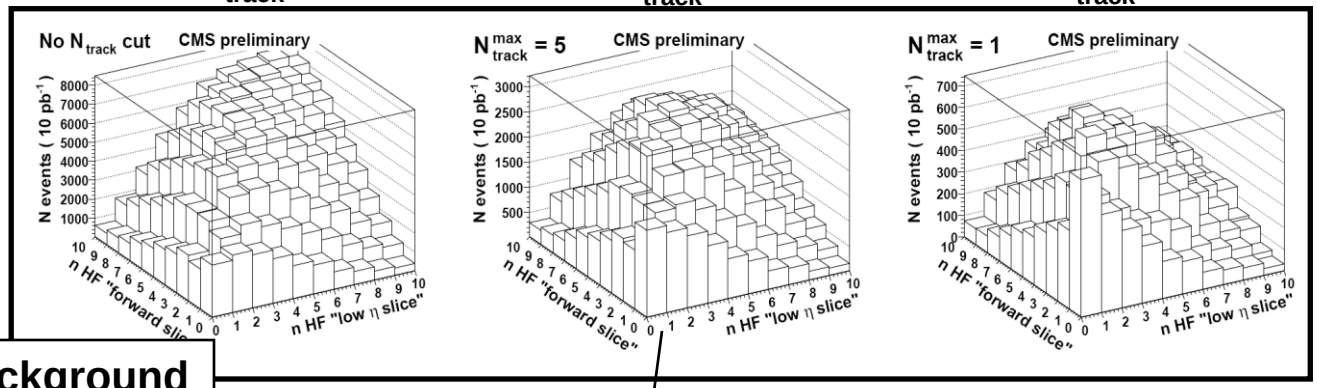
N.B. Assumes single-interaction data

Establishing diffractive signal in data

Single-diffractive di-jets

Significance is higher when the N_{track} cut is stricter

no N_{track} cut | **$N_{track} \leq 5$** | **$N_{track} \leq 1$**

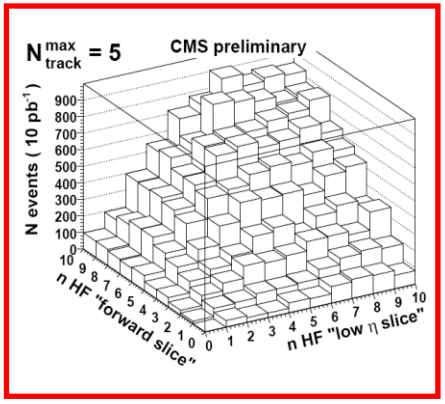


Signal + background

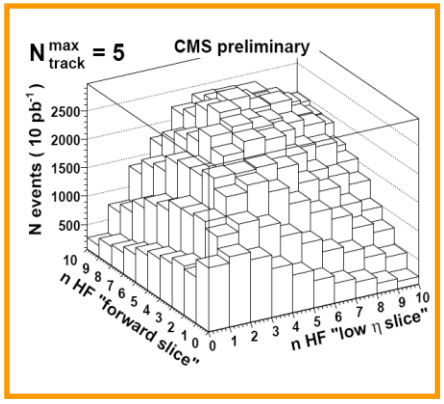
HF "low η slice" (3 < |η| < 4) vs HF "forward slice" (4 < |η| < 5)

No zero-multiplicity enhancement visible

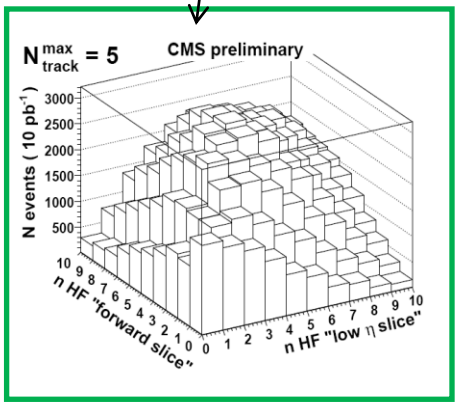
Signal reduced by factor ~ 2



SIDE OPPOSITE TO THE GAP



RANDOM GAP SELECTION

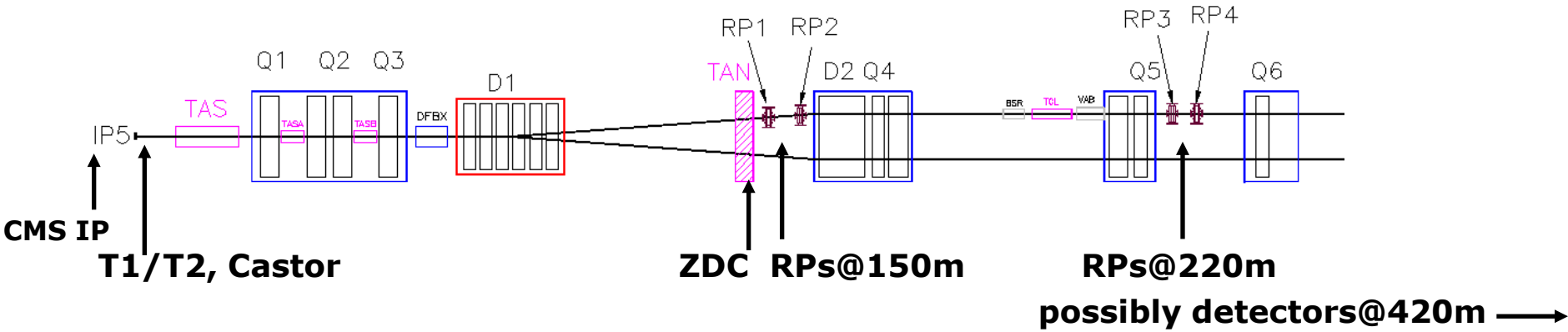


GAP SIDE

Size of SD signal can be controlled in a predictable way when changing diffractive selection cuts

cf. F. Silva's talk

Physics w/ proton taggers:

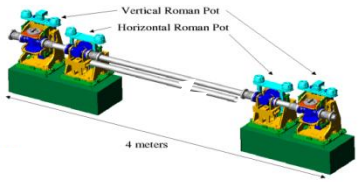


0.02 < ξ < 0.2 (TOTEM) + **0.002 < ξ < 0.02** (FP420) **at high-luminosity optics**

Expression of wish of **CMS + TOTEM to carry out a joint physics program**, with joint CMS+TOTEM data taking:

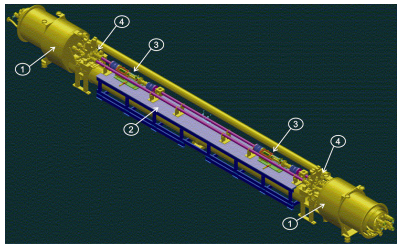
"Prospects for diffraction and forward physics at the LHC"

CERN LHCC 2006-039 G124, **CMS note 2007-02**, **TOTEM note 06-5**



FP420: Proposal to install high precision silicon tracking and fast timing detectors close to the beams at 420m from the CMS IP

R&D report recently published (**arXiv:0806.0302v1 [hep-ex]**)



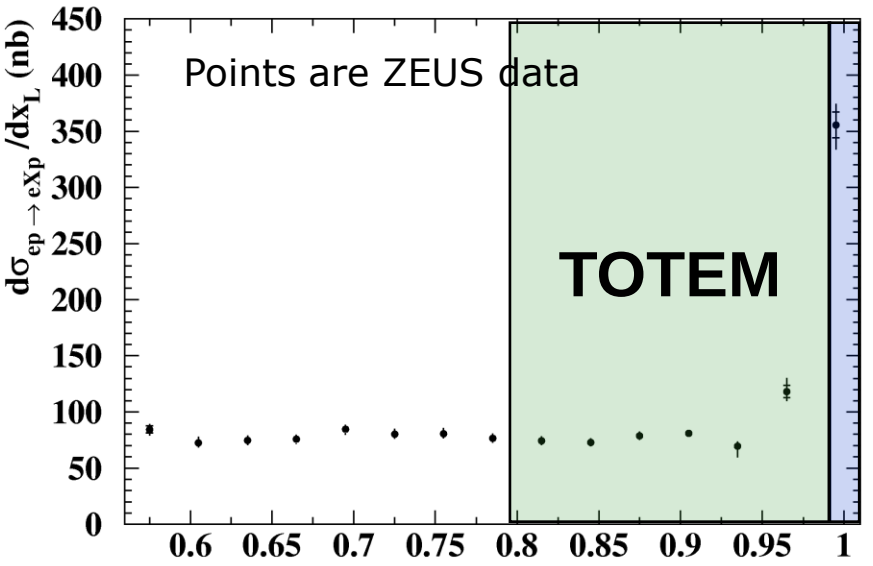
Physics with proton taggers

• At higher luminosities, due to pile-up, proton tagging only way to look at a wide range of physics topics:

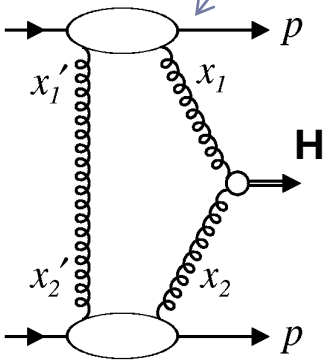
  • Unique QCD program, diffractive pdf's, parton correlations & GPD's

  • γ-mediated processes, e.g., anomalous gauge boson couplings, SUSY,…

  • Central Exclusive Production (CEP): tool for discovery physics and unique precision measurements



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



• May be Higgs discovery channel in certain regions if MSSM

• Excellent mass resolution from protons (2-3 GeV), independent of decay channel

• CP quantum numbers and CP violation from azimuthal asymmetry of the protons

cf. A. De Roeck's talk

Summary

- **Forward instrumentation around CMS IP provides unprecedented kinematic coverage**
- **Which makes possible a wide and rich program of forward physics:**
  - **Low-x QCD**
  - **γ-mediated processes**
  - **absolute luminosity measurements**
  - **diffraction**
  - **Monte Carlo tuning**
- **Accessible in good part already from start-up**
- **The addition of FP420 proton taggers would allow the study of central exclusive production processes with potential for discovery physics and precision measurements otherwise not possible at LHC**
- **Proton taggers would also allow to extend the study of diffractive and γ-mediated physics to high luminosities, where pile-up will be abundant**

References

"Prospects for diffraction and forward physics at the LHC"
CERN LHCC 2006-039 G124, **CMS note 2007-02**, **TOTEM note 06-5**

"The FP420 R&D Project: Higgs and New Physics with forward protons at the LHC"
(**arXiv:0806:0302 [hep-ex]**)

Public CMS notes at https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults:

http://cms-physics.web.cern.ch/cms-physics/public/DIF-07-001-pas.pdf
http://cms-physics.web.cern.ch/cms-physics/public/DIF-07-002-pas.pdf
http://cms-physics.web.cern.ch/cms-physics/public/FWD-08-001-pas.pdf
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