Outline

- Motivations
- CMS forward detectors
- ATLAS forward detectors
- Forward proton taggers at 420m
- Early physics example
Introduction

Half of full LHC cross section is very soft physics

\[ \sigma_{\text{tot}}(\text{LHC}) = 111.5 \pm 1.2(\text{stat})^{+4.1}_{-2.1}(\text{syst}) \text{ mb} \]

COMPETE Coll [PRL 89 (2002) 201801]

Rapidity

\[ y = \frac{1}{2} \ln \left( \frac{E + p_z}{E - p_z} \right) \]

Pseudo-rapidity

\[ \eta = -\ln \left( \tan \frac{\theta}{2} \right) \]

CMS / ATLAS + forward detectors: largest \( \eta \) coverage ever!
Forward physics

Elastic scattering and diffraction (including hard scale $\rightarrow$ pQCD)

Low-$x$ QCD: forward jets, DY

- Constraining proton PDFs at low $x$ ($x \sim 10^{-4}$)

Large rapidity gaps between forward jets

- HERA and Tevatron observed events with hard scale and LRGs

Validation of cosmic ray generators

- LHC pp c.m. energy 14 TeV $\leftrightarrow$ Fixed target collision energy 100 PeV

Luminosity monitoring or normalization
Forward detectors around IP5
Forward detectors around IP5

- CASTOR (calorimeter)
- ZDC (calorimeter)
- TOTEM (tracking) $T_1, T_2, RP$
- FP420 (tagging + timing)

CMS tracking: $0 < |\eta| < 2.5$
CMS calorimetry: $0 < |\eta| < 5$

Common physics programme for CMS + TOTEM

Joint data taking $\rightarrow$ nominal optics
Compatible TOTEM/CMS DAQ for trigger

CMS & TOTEM Coll [CERN/LHCC 2006-039/G-124]
Forward detectors around IP5

CASTOR:
(*) First one installed in 2008
Second one in 2009 if funded

CALORIMETRY
neutrals

TRACKING

FP420

TOTEM Coll [CERN/LHCC 2004–002]
Physics programme

- Possible at various LHC luminosities: already from start-up
- **Diffraction**: SD+DPE (dijets, W, Z, heavy flav., SM & MSSM Higgs)
  - Trigger studies with fwd detectors included, as well as pile-up impact
  - **Hard diffraction** program carried out, following HERA and Tevatron

**probe of the proton structure at low-x**

- **Photon** physics:
  - $\gamma\gamma$: lepton pairs, SUSY, WW and ZZ
  - $\gamma p$: $W$ associated productions of $H$ or single top; anomalous top, ...

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CMS & TOTEM Coll [CERN/LHCC 2006–039]

Moriond - QCD 2008 - X. Rouby
Physics programme

Low-x dynamics:
Parton saturation, BFKL/CCFM dynamics, proton structure, multi-parton scattering
- Forward jets & Drell-Yan

Rapidity gaps

Cosmic rays
Forward energy and particle flows
→ underlying events
→ multiple interactions
Forward detectors around IP1
Forward detectors for ATLAS

- LUCID: relative luminosity (*cerenkov*)
- ALFA: luminosity normalization, diffraction (*tracking*)
- ZDC: neutrals (*calorimeter*)
- Option: RP220 (*tracking*)
- Option: FP420 (*p tagging*)
- *LHCf* (*calorimeter*) **Independent experiment**

Luminosity measurement

→ ALFA
→ LUCID

Forward neutrals

→ ZDC
Forward detectors for ATLAS

Adapted from Rouby, de Favereau, Piotrzkowski [JINST 2 P09005]

Outline
Motivations
CMS fwd det.
ATLAS fwd. det.
R&D FP420
Early physics
Conclusions

~2009
~2010

FP420
Si + Cerenkov

TRACK & TIMING

~2009

LUMI
LUCID

Cerenkov

Quartz-W

CALORIMETRY
neutrals

ZDC

ZDC modules

TAN

ALFA

TRACKING

Scintillating fibers

R-Dipole
S-Dipole
V-Quadrupole
H-Quadrupole
H-Kicker
V-Kicker
RCollimator

Beam

Beam

~2009

0 100 200 300 400 500 [m]

x [mm]

0 50 100

ATLAS

IP1

ZDC

RP220

~2009
Zero Degree Calorimeter

- Quartz (fibers) tungsten sampling calorimeter
- $|\eta| > 8.1$ for n & $\gamma$; 140 m from IP1

LUCID
LUminosity measurement using a Cerenkov Imaging Detector

- 5x40 counters
- $5.4 < |\eta| < 6.1$;
- 17m from IP1

Counts tracks from minbias, diffractive events, ...

Reconstruction of $\pi^0$, $\eta$, $\eta'$, $\Delta$, $\Sigma$, $\Lambda$

pp programme, but also in AA

ATLAS Coll. [CERN/LHCC/2007-001]
ALFA

Absolute Luminosity For ATLAS

Roman pots at 237 m from IP1 – tracking with scintillating fibers

Elastic scattering parameters

- 1\textsuperscript{st}) Measurement of luminosity in optimal conditions: goal \(\sim 3\%\)
- 2\textsuperscript{nd}) Calibration of lumi monitors

Measurement of the total cross section

Study hard diffraction in nominal optics runs in conjunction with main ATLAS detector and proton taggers possibly after upgrade of ALFA

Luminosity from Coulomb scattering

\[
\frac{dN}{dt} = L \pi \left| f_C + f_N \right|^2 \approx L \pi \left\{- \frac{2\alpha}{|t|} + \frac{\sigma_{tot}}{4\pi} (i + p)e^{-b|t|/2} \right\}^2
\]

Elastic rate measurement & Fit of this distribution \{ Lumi \}

Relies on total cross section

Luminosity from optical theorem

\[
\frac{1}{L} = \frac{1}{16\pi dR_{el}/dt}\bigg|_{t=0}
\]

TOTEM @ CMS : also measuring \(\sigma_{tot}\) and calibrating lumi

RP220 : possible radiation hard upgrade of ALFA
R&D program with ATLAS and CMS contribution: FP420
Common R&D: FP420

Proton tagging at 420 m from IP5 or IP1

Common R&D for CMS & ATLAS coll
Installation ~ 2010

Discovery physics

Central Exclusive productions:

- Higgs or BSM particles
- Higgs production $pp \rightarrow p \ H \ p$
  - $\sim 3 \text{ fb (SM)}$
  - $\sim 10-100 \text{ fb (MSSM)}$

R&D programme under review by CMS & ATLAS

Missing mass method

$$M^2 = \xi_1 \xi_2 s$$

Proton taggers
Central detector
Proton taggers

CERN-LHCC-2005-025

Moriond - QCD 2008 - X. Rouby
Early forward physics
Exclusive dimuons

LHC as a photon collider  photon – photon interactions

\[ pp(\gamma\gamma \rightarrow \mu^+\mu^-)pp \]

Similar final states:

- photon-photon (LPAIR)
  - no cut:
    - \(1.47 \times 10^8\) fb (elastic)
    - \(p_T > 2.5\) GeV
    - \(74.7 \times 10^3\) fb (elastic)
    - \(76.2 \times 10^3\) fb (inelastic)

Upsilon (Starlight)

- \(Y(1S)\): 39 \times 10^3\) fb
- \(Y(2S)\): 13 \times 10^3\) fb
- \(Y(3S)\): 10 \times 10^3\) fb

Large well known cross section (QED)
Very clean final state

Exclusive \(Y\) photoproduction
Exclusive dimuons

After 100 pb$^{-1}$:

$$N_{\text{elastic}}(\gamma\gamma \rightarrow \mu^+\mu^-) = 709 \pm 27 \text{(stat)}$$

$$N_{\text{inelastic}}(\gamma\gamma \rightarrow \mu^+\mu^-) = 636 \pm 25 \text{(stat)} \pm 121 \text{(model)}$$

CMS Coll. [CMS PAS DIF-07-001]

Using CASTOR & ZDC to veto inelastic events

- Luminosity normalization ~ 4%
- Forward detector calibration

Cuts on
- acoplanarity
- $p_T$ balance
- calo exclusivity
- tracker exclusivity

$$N_{\text{w/veto inelastic}}(\gamma\gamma \rightarrow \mu^+\mu^-) = 223 \pm 15 \text{(stat)} \pm 42 \text{(model)}$$

No pile-up

$\mathbb{L} = 100 \text{ pb}^{-1}$
Upsilon: measurement

Selection of the dimuon pairs as for $\gamma\gamma$ events

Observation of the three resonances
- cross section measurement
- low $p_T$ track calibration
- detector alignment
- sensitivity to $t$ distribution slope

CMS Coll. [CMS PAS DIF-07-001]
Conclusions

ATLAS / CMS + forward detectors:
largest $\eta$ coverage ever

Dedicated instrumentation:
CMS : CASTOR/ZDC + TOTEM + FP420
ATLAS: LUCID/ZDC/ALFA +RP220/FP420

Many different fields covered by forward physics:
- low-x QCD
- exclusive QED
- Higgs/SUSY/BSM
Back-up slides
CASTOR
Centauro And Strange Object Research

- Quartz tungsten sampling calorimeter
- $5.25 < |\eta| < 6.5$
- 14.38m from IP
- 0.65m long cylinder
- 0.36m diameter
- Separate EM + HAD units

Access to low-x
→ multiple descriptions of parton showers available
→ distinction possible with CASTOR?
→ study of underlying events

Constraining cosmic ray MC models

Drell Yann events
Forward jets; Energy flow; rap-gap veto

1 CASTOR installed in 2008
a second one later if fundings are ok
ZDC

Zero Degree Calorimeter

- Quartz (fibers) tungsten sampling calorimeter
  - 140m from IP in TAN neutral absorber
  - 1000mm (l) x 96mm (w) x 607mm (h)
- $|\eta| > 8.1$ neutrons ; photons
- Separate EM + HAD sections

Contribution to the evaluation of rapidity gaps
  - pomeron induced physics
  - veto condition for proton dissociation
Energy flow in forward region

Complementary measurement for
  - luminosity calibration of online monitors
  - beam crossing angle

Cosmic ray physics
Heavy ion physics
TOTEM

TOTEM: T1 3.1< η <4.7
TOTEM T2 5.3< η <6.7
RP : 100 < ξ < 1000

**Totem T1** : in front of HF, 7.5m from IP, Cathode Strip Chambers, 2.8m long, 5 planes of CSC

**Totem T2** : in front of CASTOR, 13.6m from IP, Gas Electron Multiplier sensors

**Totem RP** : Roman Pots at (147&149)m and (216&220)m, edgeless Si microstrip

- Total LHC cross section (dedicated LHC runs)
- Luminosity normalization
- Diffraction programme

\[ \sigma_{tot} = \frac{16\pi}{(1 + \rho^2)} \frac{(dN_{el}/dt)_{t=0}}{(N_{el} + N_{inel})} \]

\[ \mathcal{L} = \frac{1 + \rho^2}{16\pi} \frac{(N_{el} + N_{inel})^2}{(dN_{el}/dt)_{t=0}} \]
CASTOR + TOTEM

Backup
- CASTOR
- ZDC (CMS)
- TOTEM
- dimuons
- LUCID
- ZDC (ATLAS)
- ALFA (ATLAS)
- RP220
- SD
Applications

- Luminosity normalization: offline calibration of lumi monitors
  - Low reducible background
  - Irreducible (inelastic) background manageable
- Forward detector calibration + alignment

Exclusive dimuons

Rouby, de Favereau, Piotrzkowski

\[ pp(\gamma\gamma \rightarrow H)pp \]
LUCID

- LUminosity measurement using a Cerenkov Imaging Detector
  - Dedicated luminosity monitors
  - Cerenkov counters
  - $5.4 < |\eta| < 6.1$ ; 17m from IP1
  - 5 rings of 40 tubes (1.5 m long)
  - Counts tracks from minbias, diffractive events, ...

Backup
- CASTOR
- ZDC (CMS)
- TOTEM
- dimuons
- LUCID
- ZDC (ATLAS)
- ALFA (ATLAS)
- RP220
- SD

ATLAS Collab. [CERN-LHCC/2004-010]
Zero Degree Calorimeter

- Quartz (fibers) tungsten sampling calorimeter
- $|\eta| > 8.1$ neutrons & photons
  - 140 m from IP in neutral absorber
  - 850 mm (l) x 91mm (w) x 620mm (h)

Reconstruction of $\pi^0$, $\eta$, $\eta'$, $\Delta$, $\Sigma$

Backup
- CASTOR
- ZDC (CMS)
- TOTEM
- dimuons
- LUCID
- ZDC (ATLAS)
- ALFA (ATLAS)
- RP220
- SD

Status : approved (2007)
ALFA

Absolute Luminosity For ATLAS

237m from IP1 tracking with scintillating fibers elastic scattering parameters

- 1\textsuperscript{st} Measurement of luminosity in optimal conditions: goal \sim 3\% 
- 2\textsuperscript{nd} Calibration of lumi monitors 
- Single Diffractive events 

Roman pots

Lumi calibration: Runs with dedicated LHC optics

Backup
- CASTOR 
- ZDC (CMS) 
- TOTEM 
- dimuons 
- LUCID 
- ZDC (ATLAS) 
- ALFA (ATLAS) 
- RP220 
- SD
Option : RP220

- Roman pots at 216+224 m from IP1
- Movable beampipe at 224m for timing detectors
- RP similar to TOTEM
- Same technology as for FP420

Missing mass method:
measuring the momentum loss of both final state protons $\xi_1$ and $\xi_2$ gives an access to the central system mass

$$M = \frac{\xi_1 \xi_2}{\sqrt{s}}$$
Single diffraction

The X system is accessible by ATLAS + forward detectors

The forward proton is measured by RP/ALFA/FP420