The background is a nighttime photograph of a large, open square, likely Plaza Mayor in Madrid. The square is paved with cobblestones and is surrounded by multi-story buildings with many windows. Some windows are lit up. In the foreground, there are some green bushes and white plastic chairs. A large, 3D, white text overlay is positioned diagonally across the center of the image. The text reads "The ATLAS Forward Physics Program DIS 2009".

The ATLAS Forward Physics Program DIS 2009

James L Pinfold

University of Alberta

ATLAS-The Forward System

Detectors

**QCD Physics
Low lumi**

**$\gamma\gamma/\gamma p$ Physics
Low lumi**

ZDC physics

**QCD
High lumi**

**$\gamma\gamma/\gamma p$ Physics
High lumi**

See talk by Laura Fabbri for details of ATLAS Forward Detectors

ATLAS-The Forward Detectors

Detectors

**QCD Physics
Low lumi**

**$\gamma\gamma/\gamma p$ Physics
Low lumi**

ZDC physics

**QCD
High lumi**

**$\gamma\gamma/\gamma p$ Physics
High lumi**

ALFA at 240 m

**Absolute Luminosity
for ATLAS**

ZDC at 140 m

Zero Degree Calorimeter

LUCID at 17 m

**Luminosity Cerenkov
Integrating Detector**

See talk by Laura Fabbri for details of ATLAS Forward Detectors

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

Plans for the Forward Region

- **THE AFP PROJECT** aims to create a precise forward proton spectrometer using Si trackers and fast-timing detectors deployed close to the beam at 220m & 420m from the IP.
 - Moveable beam pipe are used to locate detectors
- See talk by Laura Fabbri for details of ATLAS Forward Detectors

Forward Physics Program - QCD

- **INSTRUMENTATION OF THE FORWARD REGION** opens up a new window on QCD physics at the LHC - *Diffractive and Elastic - 40% of total p - p cross-section ($\sigma_{tot} \sim 100$ mb)*

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

– Elastic
(25% of σ_{tot})

– Single diffractive
(10% of σ_{tot})

– Double diffractive
($\sim 1\%$ if σ_{tot})

– Central diffractive
DPE ($\sim 1\%$ if σ_{tot})

– Inelastic
(non diffractive)
(60% of σ_{tot})

Absolute Lumi & σ_{tot}

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

- **USE ALFA TO STUDY ELASTIC SCATTERING** in the Coulomb Nuclear Interference CNI region: $L \sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$, large β^* optics (beam div. $\sim 0.2 \mu\text{rad}$)

Fit of data gives $\rightarrow \sigma_{\text{tot}}, L, \rho, b (\Delta L/L \sim 3\%)$

$$\left. \frac{dN}{dt} \right|_{t=\text{CNI}} = L\pi |f_C + f_N|^2 \approx L\pi \left| -\frac{2\alpha_{\text{EM}}}{|t|} + \frac{\sigma_{\text{tot}}}{4\pi} (i + \rho) e^{-\frac{b|t|}{2}} \right|^2$$

- **USE THE OPTICAL THEOREM** as a complementary solution

$$\begin{cases} L = \frac{(1 + \rho^2)}{16\pi} \frac{N_{\text{tot}}^2}{\left. \frac{dN_{\text{el}}}{dt} \right|_{t=0}} \\ \sigma_{\text{tot}} = \frac{N_{\text{tot}}}{L} \end{cases}$$

- $N_{\text{tot}}, dN_{\text{el}}/dt|_{t=0} \rightarrow L$ and σ_{tot}
 - ☹ Need MC for η extrapolation
 - ☺ Straightforward to determine ρ

- **Provide high precision (2-3%) LUCID CALIBRATION**

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

Diffraction

- **HARD DIFFRACTION: $X = \text{jets}, Ws, Zs, \text{Higgs}, \text{etc.}$**
 - Hard processes calculable in pQCD
 - Info on proton structure: dPDFs and GPDs
 - Discovery physics (!)
- **SOFT DIFFRACTION: $X = \text{anything}$, dominated by soft physics, Important insights on npQCD:**
 - Gap survival probability,
 - Multi-parton interactions
 - Pile-up contributions at high-luminosity.

Diffraction - Detector Inputs

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

- **FORWARD PROTON TAG** in special runs with ALFA
 - Elastic + SD measurement
- **FORWARD RAPIDITY GAP** requirement in FCAL ($3.2 < |\eta| < 4.9$), LUCID ($5.6 < |\eta| < 6.0$) and ZDC ($|\eta| > 8.3$).
- **CENTRAL RAPIDITY GAP** in hadronic/ EM calorimeters ($|\eta| < 3.2$) and inner detector ($|\eta| < 2.5$).
- ☹ **PILE-UP** will kill rapidity gaps

Soft SD with ALFA

Detectors

QCD Physics
Low Lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

- *ALFA has good acceptance (in special runs) for single diffractive (SD) events.*

– *Measure forward proton spectrum in region $6.3 \text{ TeV} < E_{\text{prot.}} < 6.993 \text{ TeV}$*

- *SD measurement for $\xi < 0.01$.*
 - *Non-diffractive forward proton spectrum measurement for $0.01 < \xi < 0.1$.*
- *Expect 1.2-1.8M events in 100hrs at $L = 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$.*

Hard Single Diffraction

Detectors

QCD Physics
Low Lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

- Look for hard scatter event with gap on one side of the detector.
- Compare gap/non-gap ratio to determine soft-survival.
- Gap defined by LUCID/ZDC + FCAL

• FCAL gap needed to restrict event to diffractive region ($x_{pom} < 0.01$). e.g. di-jet production

$p_T(\text{GeV})$	x_{pom}	σ (pb)	gap type	efficiency	Events in 100 pb^{-1}
20	< 0.01	7.2×10^5	FCAL	0.4	2.9×10^7
20	< 0.1	3.6×10^6	FCAL	0.08	2.9×10^7
40	< 0.1	2.1×10^5	FCAL	0.05	1.0×10^6
40	< 0.1	2.1×10^5	LUCID,ZDC	0.44	9×10^6

• Approximately 5000 (8000) SD di-jet events in 100 pb^{-1} with jet transverse energy > 20 (40) GeV after trigger pre-scale.

Detectors

QCD Physics
Low Lumi

$\gamma\gamma/\gamma p$ Physics
Low Lumi

ZDC physics

QCD
High Lumi

$\gamma\gamma/\gamma p$ Physics
High Lumi

DPE/CEP

DPE

- Two central jets with $|\eta| < 2.5$.

- Gap imposed on both sides of IP in FCAL, LUCID, ZDC.

- Expect CEP cross section to be 50 times larger than DPE for these criteria.

CEP

- Measurement of CEP dijet production at 14TeV. Compare with CDF measurement to constrain theoretical model.

- CDF has already observed DPE/CEP production of photon-photon, di-jet and χ_c

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

Gaps Between Jets

- *Di-jet production via colour singlet exchange*
 - (background from single gluon exchange process).
- *Require two jets, one in each forward calorimeter.*
- *Require gap in central calorimeter.*
- *ATLAS can make an improved measurement with increased E_{cm} and available phase space.*
- *D0 performed similar measurements at the Tevatron-PLB 440, 189 (1998).*

Photon Induced Muon Pairs

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

• *EXCLUSIVE Dileptons*

- Two isolated leptons back-to-back in ϕ , balanced in P_T
- Leptons derive from an exclusive vertex (no other tracks can join)
- Protons remain intact not other activity in the detector (use FCAL, LUCID, ZDC)

• *PROCESSES:*

- Two photon production $\rightarrow$ non-resonant lepton pairs from $\gamma\gamma \rightarrow l^+l^-$
- Photoproduction - lepton pairs through J/ψ & upsilon resonances - $\gamma IP \rightarrow J/\psi, Y \rightarrow l^+l^-$

Photon Induced Muon Pairs

- *In MC, several hundred two-photon and Upsilon events pass the final selection in the dimuon channel, for 100 pb^{-1} :*

709 ± 27 (stat) elastic events

223 ± 15 (stat) ± 42 (model) singly inelastic events

636 ± 25 (stat) ± 121 (model) singly inelastic events, no ZDC/Castor

CMS

- *QED process - minimal uncertainties on the cross-section, highly constrained 4-body final state*
- *Startup applications - candidate for:*
 - *Luminosity calibration*
 - *Low p_T lepton ID studies*
- *High-luminosity applications:*
 - *Alignment sample for forward proton taggers*
 - *“Standard candle” for BSM physics in high energy interactions: $\gamma\gamma \rightarrow \gamma\gamma$, $\gamma\gamma \rightarrow$ slepton pairs, Higgs pairs, W-pairs etc.*

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

ZDC - Physics

- **HEAVY-ION PHYSICS:**
count spectator neutrons

- Determine the event centrality
- Trigger for ultra-peripheral collisions

- **VERY FORWARD CROSS-SECTIONS**

- New energy range explored
- Input for high energy cosmic ray MCs (Modeling air showers)
- Improve hermiticity

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

QCD at Hi Lumi - the AFP Project

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

Double
Pomeron
(Photon)
Exchange

- *AFP - Forward Proton Spectrometers to tag protons at 220m & 420m.*
- *Use fast timing to reduce pile-up background at high luminosity*
- *Good acceptance and mass resolution for the DPE Higgs*

Higgs Production

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

- SM $h \rightarrow WW^*$, $140 < M_h < 180$ GeV
- *Higgs boson studies* - Higgs mass, quantum numbers, discovery in certain regions of MSSM/NMSSM:
 - Standard Model $h \rightarrow WW^*$, for $M_h > 140$ GeV.
 - MSSM $h, H \rightarrow bb$ and $h, H \rightarrow \tau\tau$ for $M_h/H < 240$ GeV.
 - NMSSM $h \rightarrow aa \rightarrow 4\tau$, $90 \text{ GeV} < M_h < 110 \text{ GeV}$.
- *Slepton pair production.*
- *Gluino pair production for split-SUS models.*

Cox et. al. JHEP 0710:090 (2007)

Rich $\gamma p + \gamma\gamma$ Physics via p-Tagging

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

Detectors

QCD Physics
Low lumi

$\gamma\gamma/\gamma p$ Physics
Low lumi

ZDC physics
rationale

QCD
High lumi

$\gamma\gamma/\gamma p$ Physics
High lumi

Summary & Conclusions

- **LUMINOSITY:**

- *LUCID and ALFA will provide the luminosity to ATLAS to better than 5% accuracy.*

- **FORWARD PARTICLE SPECTRUM:**

- *ZDC (and LHCf experiment) will measure forward particle production for MC tuning.*
- *ZDC will measure forward spectators for heavy ion collisions; provide trigger, luminosity and centrality measurements.*

- **LOW LUMINOSITY PHYSICS:**

- *Elastic scattering and σ_{tot} using ALFA*
- *Single diffractive forward proton spectrum (ALFA).*
- *Single diffractive di-jet and W production, DPE and CEP of di-jets (with rapidity gap veto in FCAL, LUCID, ZDC).*
- *Gaps between jets as a probe of colour singlet exchange.*

- **POSSIBLE HIGH LUMI UPGRADE AT 220M and 420M:**

- *Proton tagging gives access to CEP Higgs production and SUSY physics as well as $\gamma\text{-}\gamma$ and $\gamma\text{-}IP$ physics, at high luminosity*

- **THE LHC WILL BE 4 COLLIDERS IN 1: $p\text{-}p$, $IP\text{-}IP$, $\gamma\text{-}IP$, $\gamma\text{-}\gamma$!**