LowX – 2011

Santiago de Compostela, 3-7 June 2011

Small-x and Forward Measurements in ATLAS

Sara Valentinetti – University of Bologna & INFN

On behalf of ATLAS Collaboration

Summary

- The **ATLAS Forward Detectors** **LUCID, ALFA, ZDC + MBTS.**

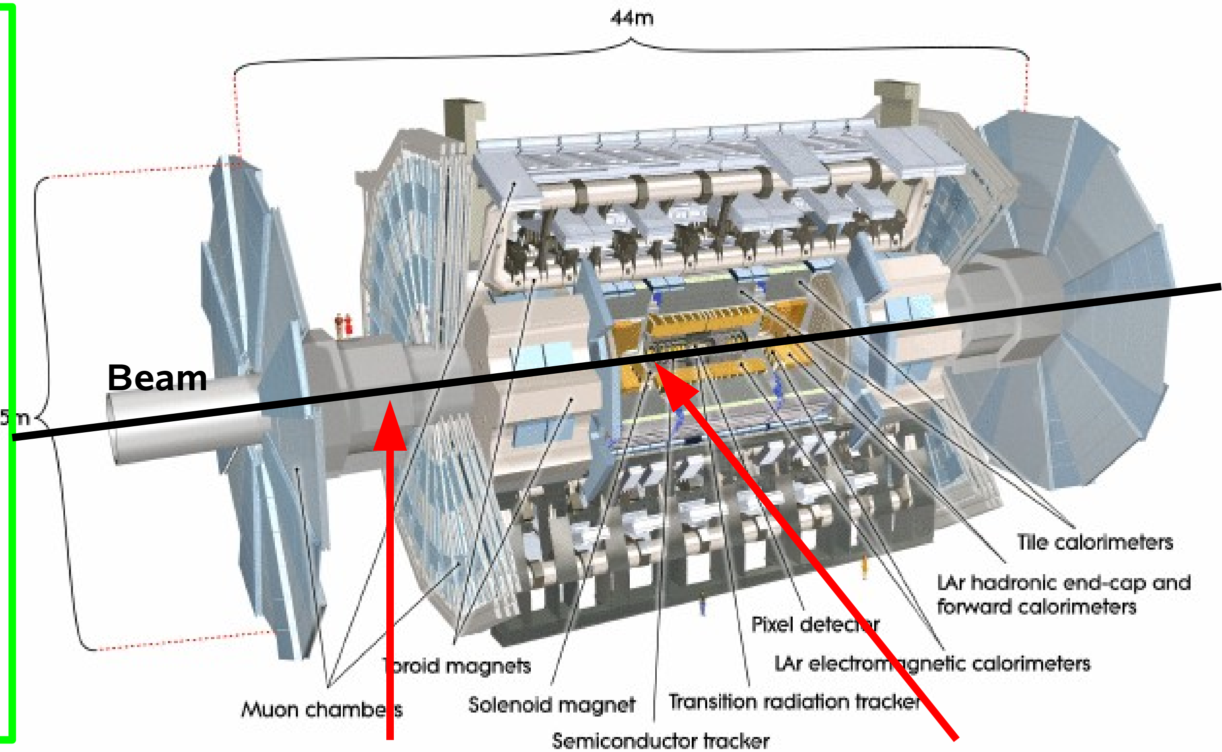
- **Forward Measurements:**
  - **- Luminosity Measurements;**
  - **- Forward Physics:**

    Soft Diffraction;
    Hard Diffraction;
    Central Exclusive Production;
    Gaps Between Jets.

- **Conclusions.**

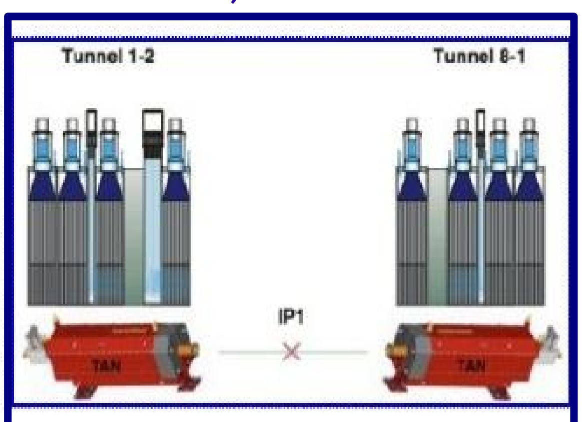
ATLAS Rapidity Coverage

Detector	Pseudorapidity
Inner Detector	$\lvert\eta\rvert < 2.5$
EM Calorimeter	$\lvert\eta\rvert < 3.2$
HAD Calorimeter	$\lvert\eta\rvert < 4.9$
Muon Chambers	$\lvert\eta\rvert < 2.7$
MBTS	$2.1<\lvert\eta\rvert<3.8$
LUCID	$5.6<\lvert\eta\rvert< 5.9$
ZDC	$\lvert\eta\rvert > 8.3$
ALFA	$10.6<\lvert\eta\rvert<13.5$

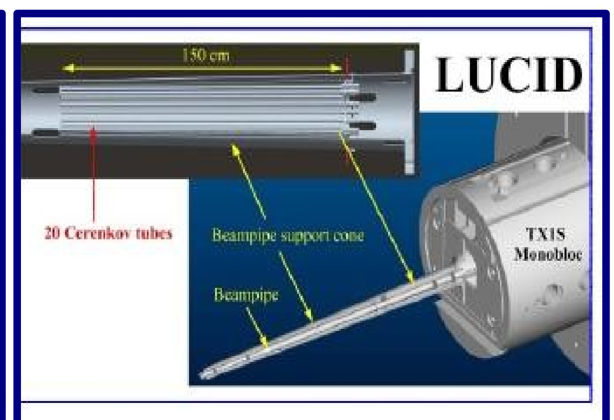


ALFA (Absolute Luminosity for ATLAS) at 240 m

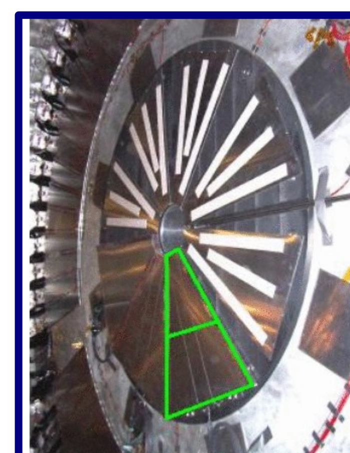
ZDC (Zero Degree Calorimeter) at 140 m



LUCID (Luminosity measurements Using Cherenkov Integrating Detector) at 17 m

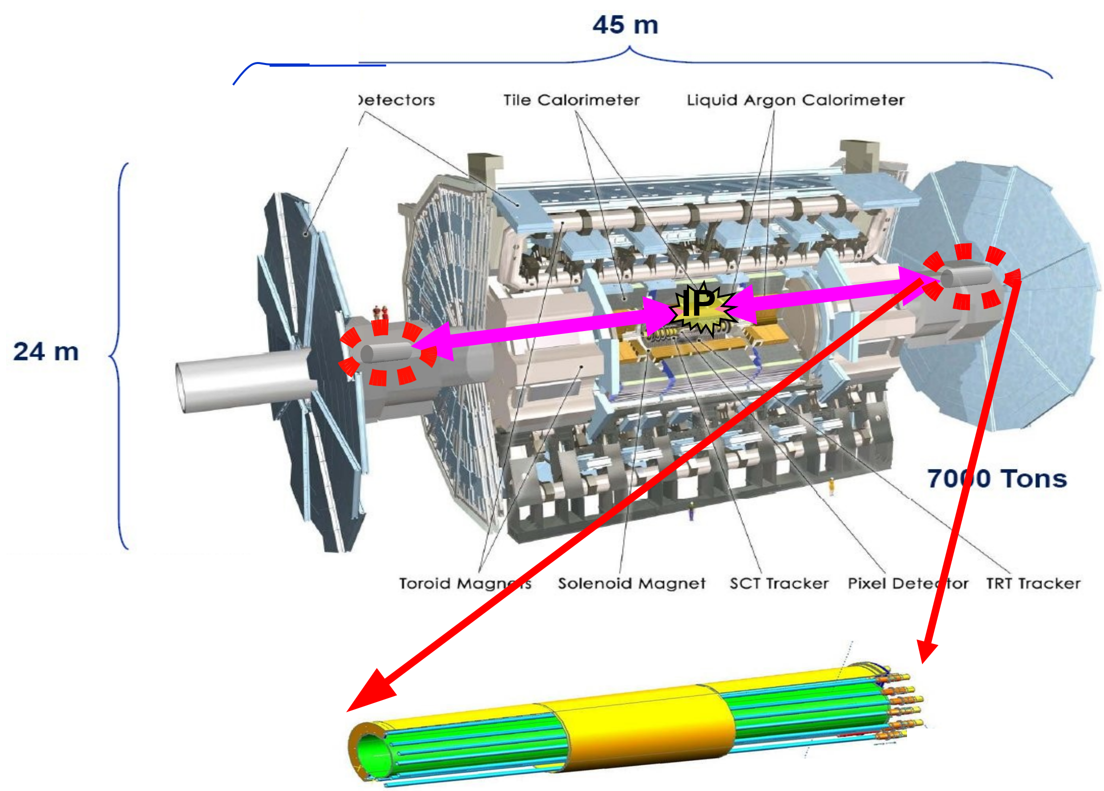


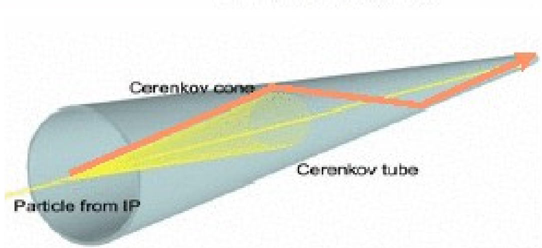
MBTS (Minimum Bias Trigger Scintillator) at 3.6 m



On both side of the IP

LUCID: Luminosity measurement Using Cherenkov Integrating Detector





- Forward detector using Cherenkov effect.
- Sensitive to charge particles coming from IP.
- 2 symmetrical modules at 17 m from IP.
- For each module, 20 reflective Al tubes pointing to the IP.
- Each tube, filled with C_4F_{10} at 1.1 bar.
- 16 tubes directly coupled with PMT (*); 4 tubes read out by fiber boundle coupled to a MAPMT. (2 different designs to test the electronics for LUCID in LHC at high luminosity).
- Designed to measure luminosity from $L \sim 10^{27} cm^{-2} s^{-1}$ to $L \sim 4*10^{33} cm^{-2} s^{-1}$

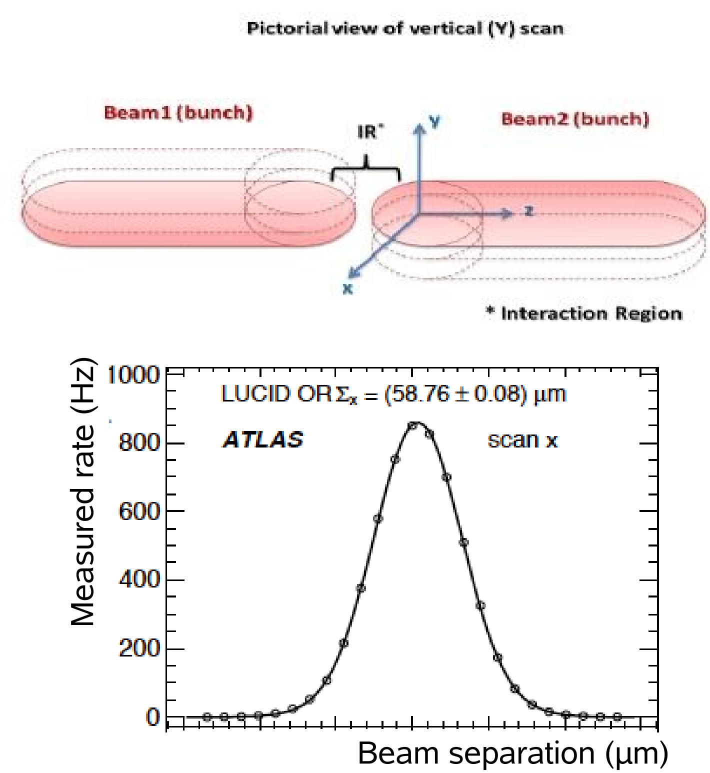
Luminosity Dedicated Monitor: LUCID

- LUCID measures the relative instantaneous luminosity.

- The detector fulfills the following fundamental requirements:
  - signal duration shorter than 25 ns (no pile up between signals coming from different BC);
  - fast response of electronics (bunch by bunch structure);
  - radiation hard (gas detector using Cherenkov effect);
  - low sensitivity to background (projective geometry);
  - stable signal definition (no Landau fluctuations);
  - independent of trigger and DAQ.

- Absolute luminosity if calibration is available:
  - at LHC start up from MC simulation;
  - in 2010 from **Van der Meer scan** results;
  - in future from physics channel rates (e.g. W and Z production) and ALFA (currently in commissioning phase).

- Forward Physics contribution:
  - provide minimum bias trigger at high η



$$L = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$

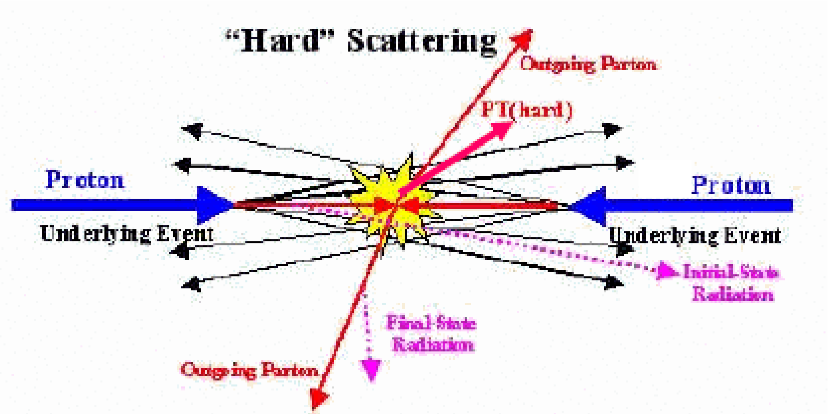
MBTS: Minimum Bias Trigger Scintillator

- Segmented plastic scintillator paddles quite close to the beam pipe;

- 32 scintillators paddles, 2 cm thick, organised into 2 disks, one on each side of the IP;

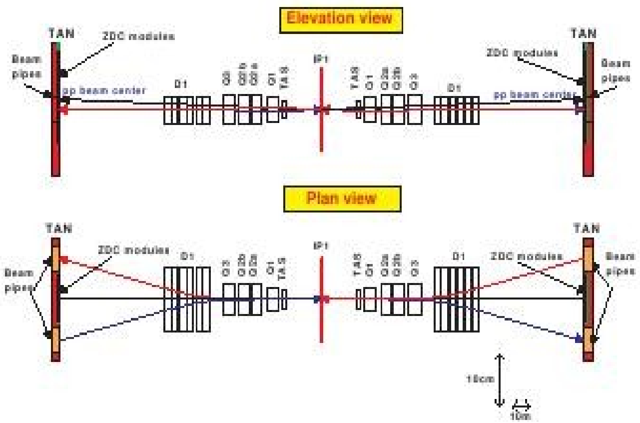
- AIM: triggers on minimum collision activity during the proton-proton collisions at low luminosity (up to $L = 10^{32}\ cm^{-2}\ s^{-1}$);

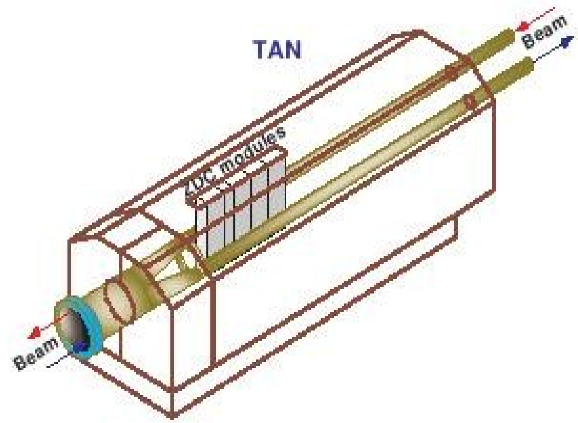
- Used for: - relative luminosity measurements;
  - trigger on minimum bias events (underlying events)
  - topologies with η gaps.



Underlying events:
- events with low-pt;
- everything except the two outgoing hard scattered jets;
- background we need to subtract to extract new physics

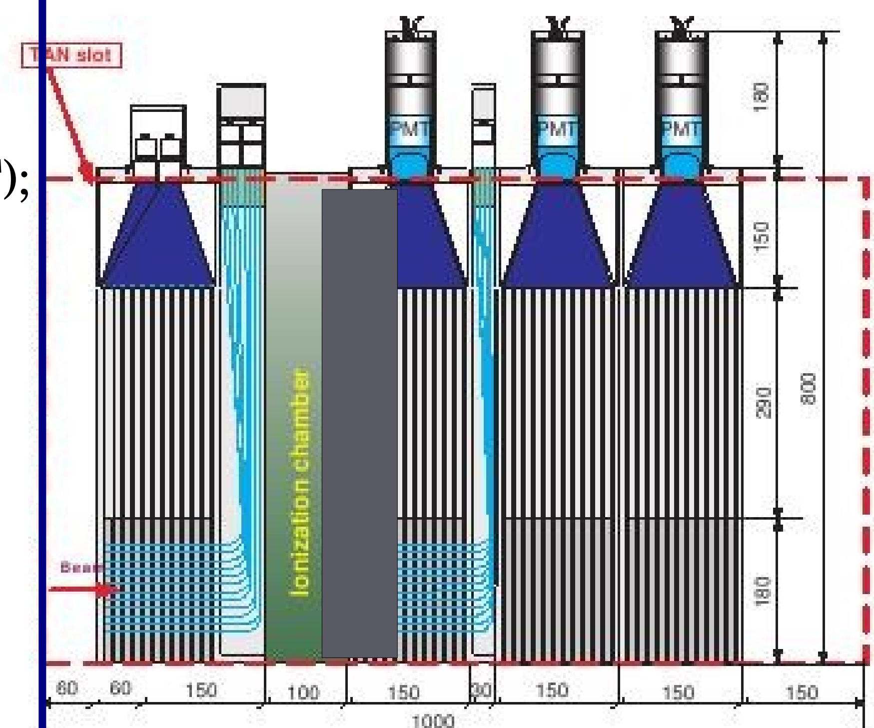
ZDC: Zero Degree Calorimeter





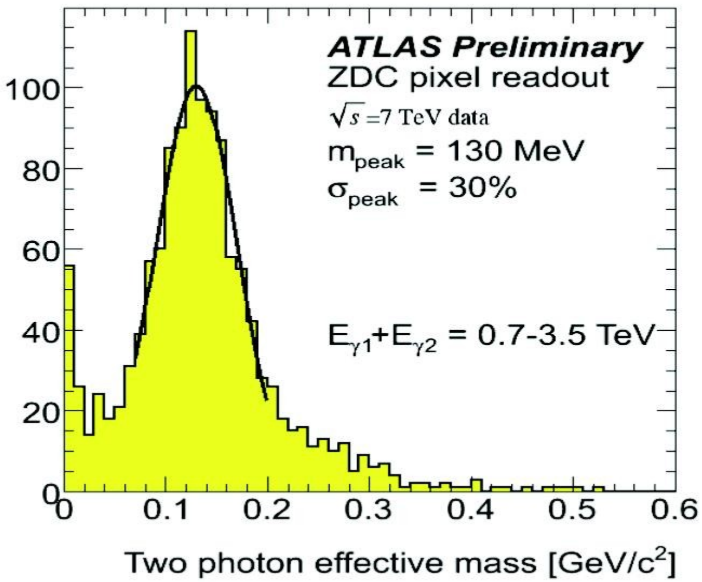
- ZDC sits in a slot in the TAN (Target Absorber Neutral) at 140 m from the IP.
- It measures the neutral particles at zero degree.

- 4 modules/arms: 1 EM (29 X_0) + 3 HAD (1.14 λ_{int})
- EM calorimeter:
  - 11 Tungsten plates in beam region;
  - 1 mm quartz rods parallel to the beam for coordinates measurements (read out by MAPMT);
  - 1.5 mm vertical quartz rods for energy measurements (read out by PMT).
- HAD calorimeter:
  - similar to EM.
- Radiation hardness:
  - small degradation up to 5 Grad;
  - at $10^{33} cm^{-2} s^{-1}$ survive for few years;
  - at $10^{34} cm^{-2} s^{-1}$ survive for few months.



ZDC Physics

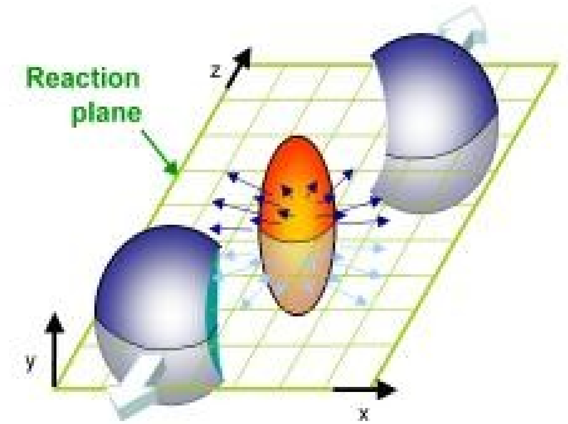
p-p collisions



- Hadronic x-y
- calibration ZDC not yet optimized

- Very forward cross sections:
  - new energy range explored (p_T from 0 to 3.3 GeV);
  - detection and reconstruction of π^0 and η in two γ, measurements of production cross section and energy;
  - input for high energy cosmic rays (forward direction and soft scattering, protons with E>10^{17} eV)

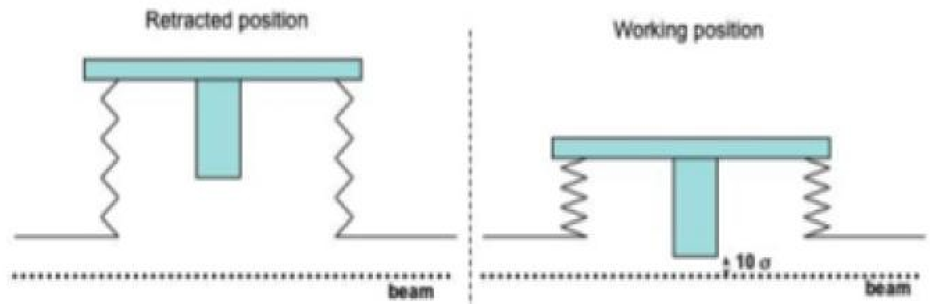
HI collisions



- Counting of the number of the spectator neutrons throught the measurement of the energy (20% energy resolution sufficient to resolve peaks from 1 or 2 neutrons).
- Measurement of the centrality of the collision.
- Trigger for ultra-peripheral collisions:
  - hard photo-production;
  - quasi elastic vector meson production.
- Minumum bias trigger using coincidence.
- Absolute luminosity monitoring using the theoretically-predicted Coulomb dissociation cross section.

ALFA: Absolute Luminosity For ATLAS

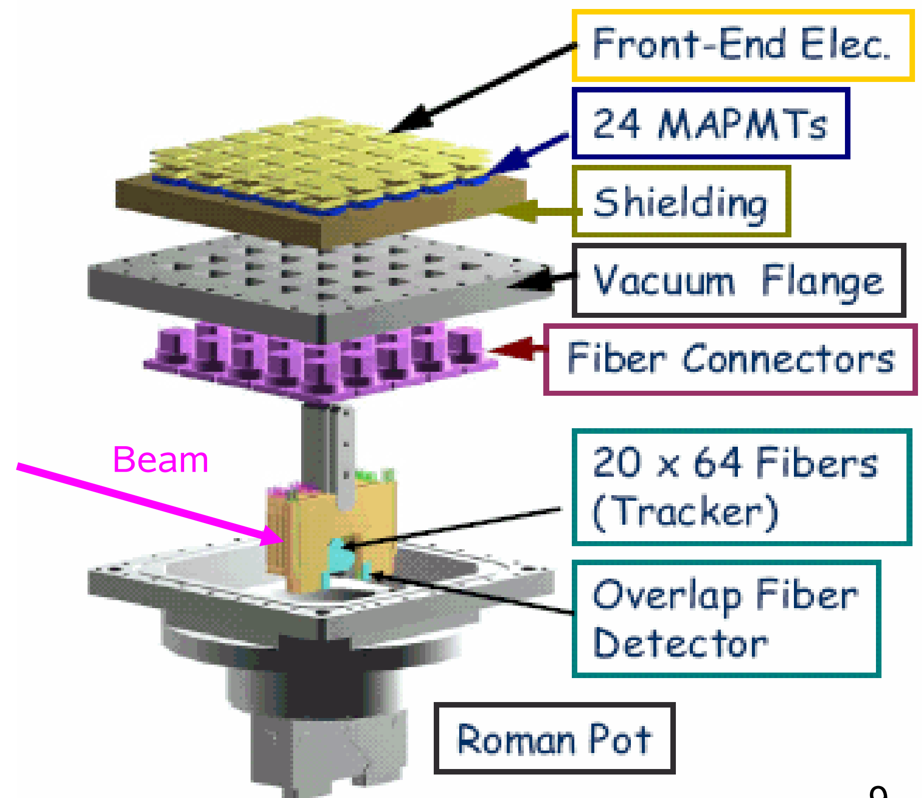
- Goal: measurement the elastic scattering rate in the Coulomb-nuclear Interference region
  - run at high β^* optics (β^*=2600 m);
  - low luminosity;
  - parallel-to-point focusing.



- Roman pots at 240 m from IP1 equipped with dedicated detector.
  - approach the beam to ~5σ.

- Detector requirements:
  - measure $|t| \sim 6*10^{-4}$ ($\theta \sim 3$ μrad);
  - detector spatial resolution << beam size (130 μm) $\Longrightarrow$ $\sigma_{xy} \sim 30$ μm;
  - vacuum tight;
  - radiation-tolerant in very hostile beam environment.

- Solution $\Longrightarrow$ scintillating fibers detector:
  - <30 μm of inactive region.
  - 10 x 64 U + 10 x 64 V fibers at 90°;
  - MAPMT read out fibers;
  - planes staggered by 70.7 μm;
  - effective fiber pitch 50 μm.



Luminosity Measurements with ALFA

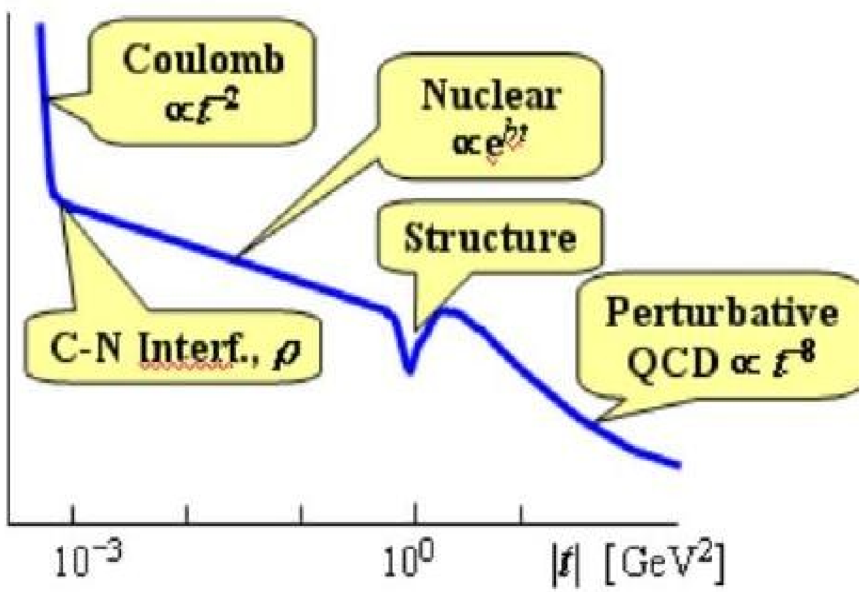
- Measurement of the elastic scattering at **very small angles** (**3 μrad**) and small t-values so that the cross section becomes sensitive to the electromagnetic amplitude through the Coulomb-Nuclear Interference term.

- Total rate of scattering events:

$$\frac{dN}{dt} \sim \mathcal{L}\pi \left| \left(-\frac{2\alpha_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2} \right) \right|^2$$

Coulomb amplitude

Strong interaction amplitude

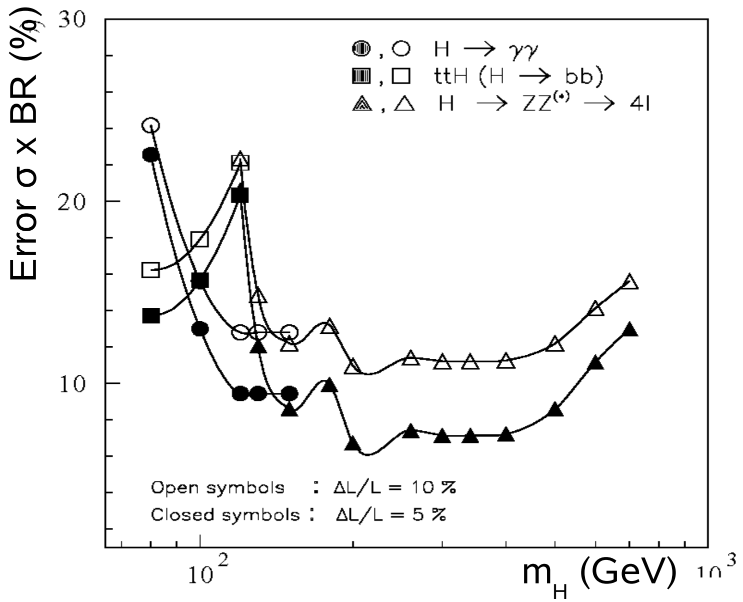


Fit in the CNI region of the function: simultaneous evaluation of absolute luminosity and total cross section without any a priori knowledge.

Absolute Luminosity Measurements

Why precise measurements needed?

$$L = \frac{R_{inel}}{\sigma_{inel}} = \frac{\mu n_b f_r}{\sigma_{inel}} = \frac{\mu^{vis} n_b f_r}{\epsilon \sigma_{inel}}$$



- Cross section for standard processes:
  top pair production, jet production…
- New physics:
  manifesting in deviation of σ x BR relative to the Standard Model predictions
- Precision measurements:
  Higgs production σ x BR, measurements for MSSM Higgs, …

Methods to measure absolute luminosity

- At LHC start up with MC predictions:

$$L = \frac{\mu^{vis} n_b f_r}{\sigma_{DD}\epsilon_{DD} + \sigma_{SD}\epsilon_{SD} + \sigma_{ND}\epsilon_{ND}}$$

SD=single diffractive
DD = double diffractive
ND=non diffractive

20% systematic error due to extrapolation to a not yet explored center-of-mass energy.

- During 2010 with Van der Meer scans (using machine paramenters):

$$L = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$

3.4% systematic error (main contribution: uncertainty on bunch current measurements)

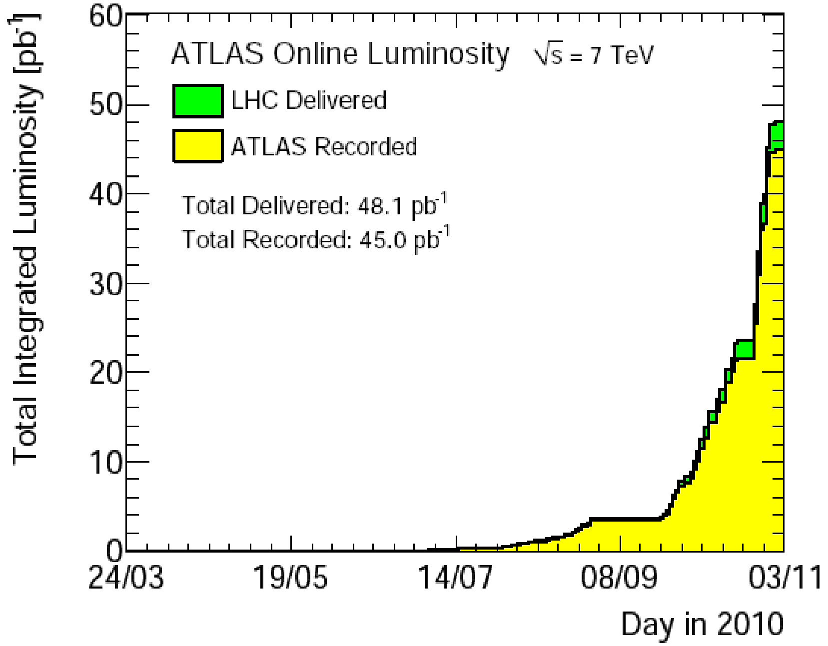
- In future:

- when sufficient statistics is reached, with well known physics processes (W/Z production): accuracy of 5% due to PDF uncertainty;

- with ALFA results (without using machine parameters): accuracy of 2-3%.

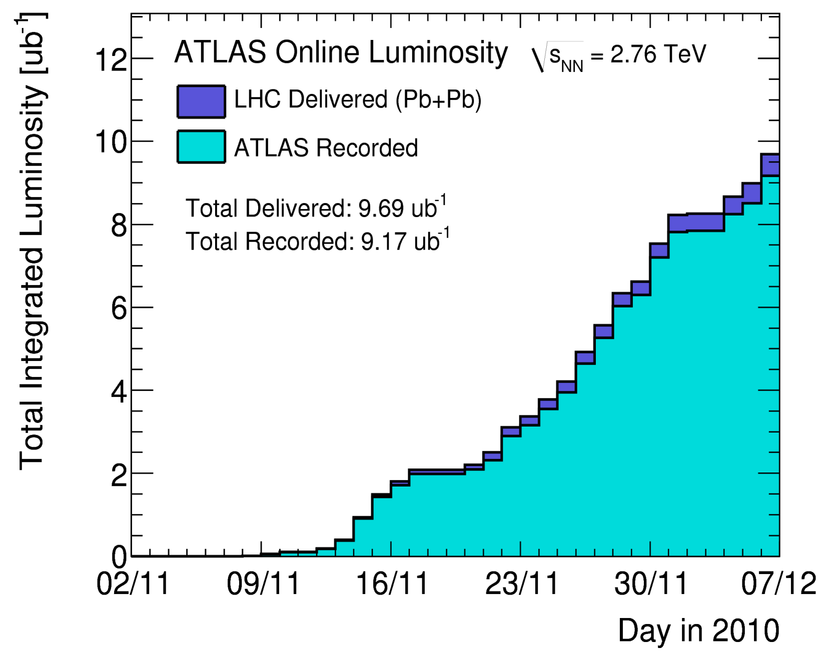
2010 Luminosity Performance

pp running



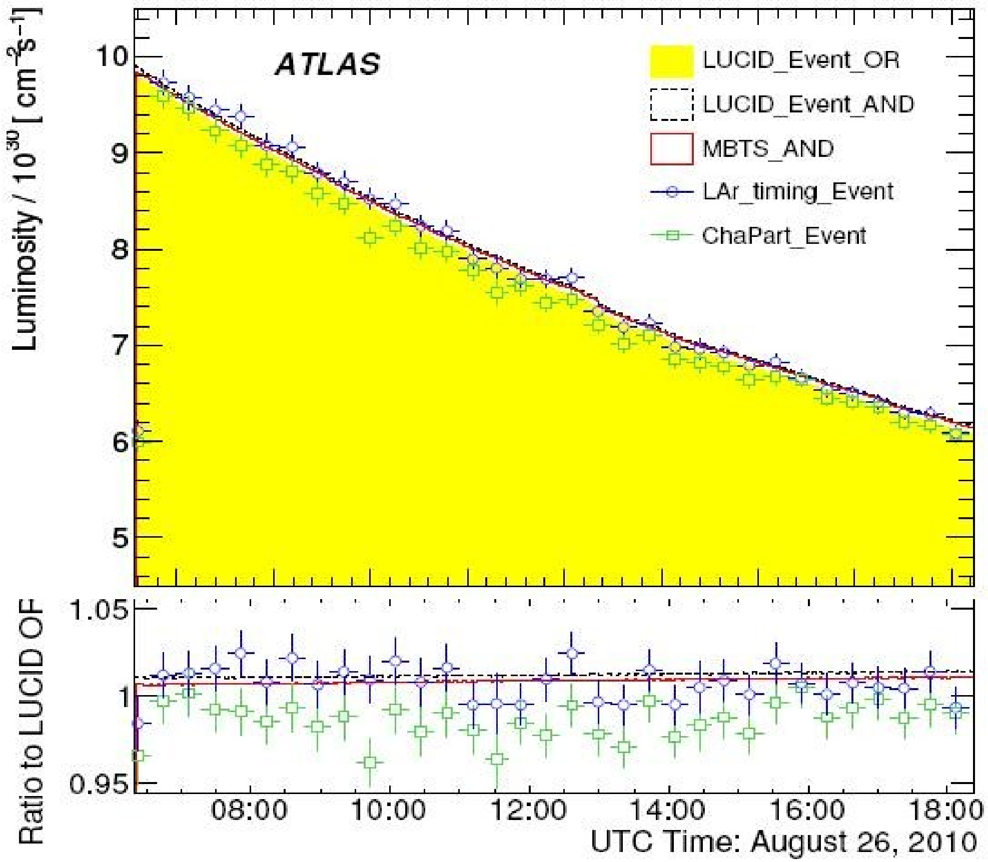
- Cumulative luminosity vs time during stable beam for pp collision.
- Online luminosity from LUCID detector calibrated via Van der Meer scan results.
- Delivered luminosity: before ATLAS trigger.
- Systematic uncertainty: 3.4% (dominated by beam current).
- ATLAS recording efficiency: 93.6%.
- Peak delivered lumi = 2.07 x 10^{32}; Max colliding bunches = 348; Max number of events per BX = 3.78.

Pb-Pb running



- Cumulative luminosity vs time during stable beam for Pb-Pb collision.
- Online luminosity from LUCID detector.
- ATLAS recording efficiency: 94.6%.
- Peak delivered lumi = 3.04 x 10^{25}; Max colliding bunches = 129.

2010 Luminosity Performance: Comparison between Detectors



(a)

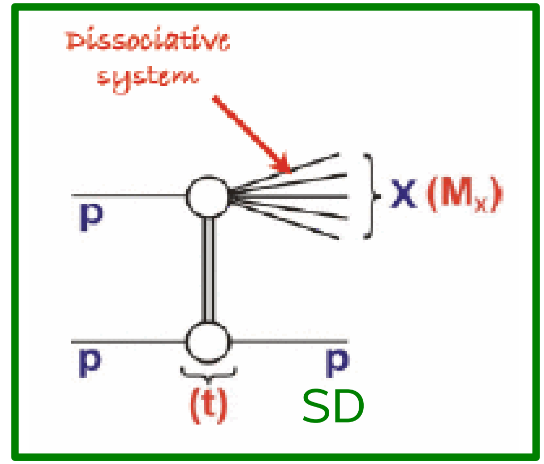
- Top: ATLAS instantaneous luminosity for Run 162882 from different detectors.
- Each detector calibrated with VdM calibration results.
- Bottom: ratio of the luminosity obtained with each algorithm to that obtained with LUCID Event OR.
- Statistical uncertainties for the online algorithms (LUCID Event OR, LUCID Event AND and MBTS Event AND) negligible.
- Statistical uncertainties for the offline algorithms displayed.

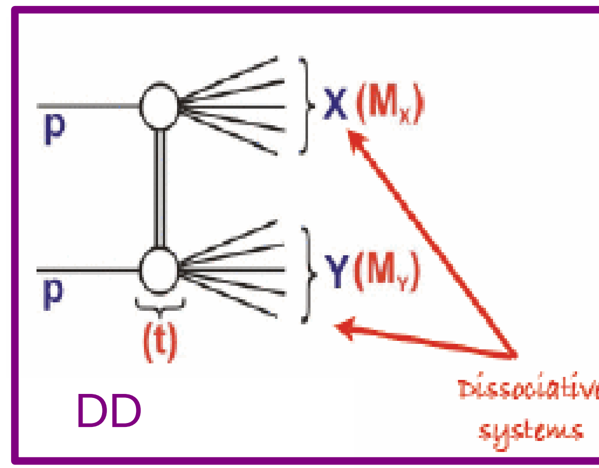
Good agreement between different detectors.

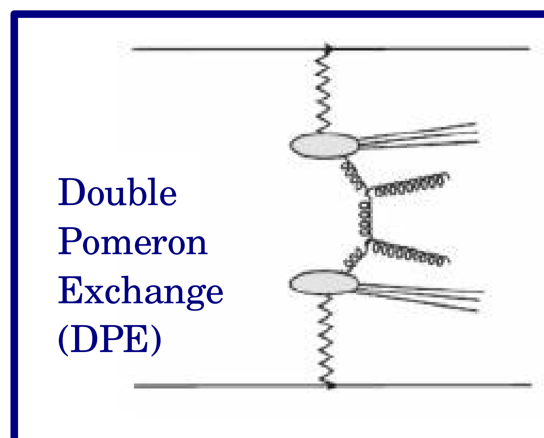
ATLAS Forward Physics: Processes

- **Soft diffraction**:
  - single/double diffraction,
  - diffractive mass distribution,
  - multi parton interactions;
- **Hard diffraction**:
  - diffractive di-jet production;
  - double pomeron exchange (DPE).
- **Central exclusive production** (CEP).
- **Gap between jets**
  - di-jets production via colour singlet exchange.

Diffractive cross section ~30% of total pp cross section







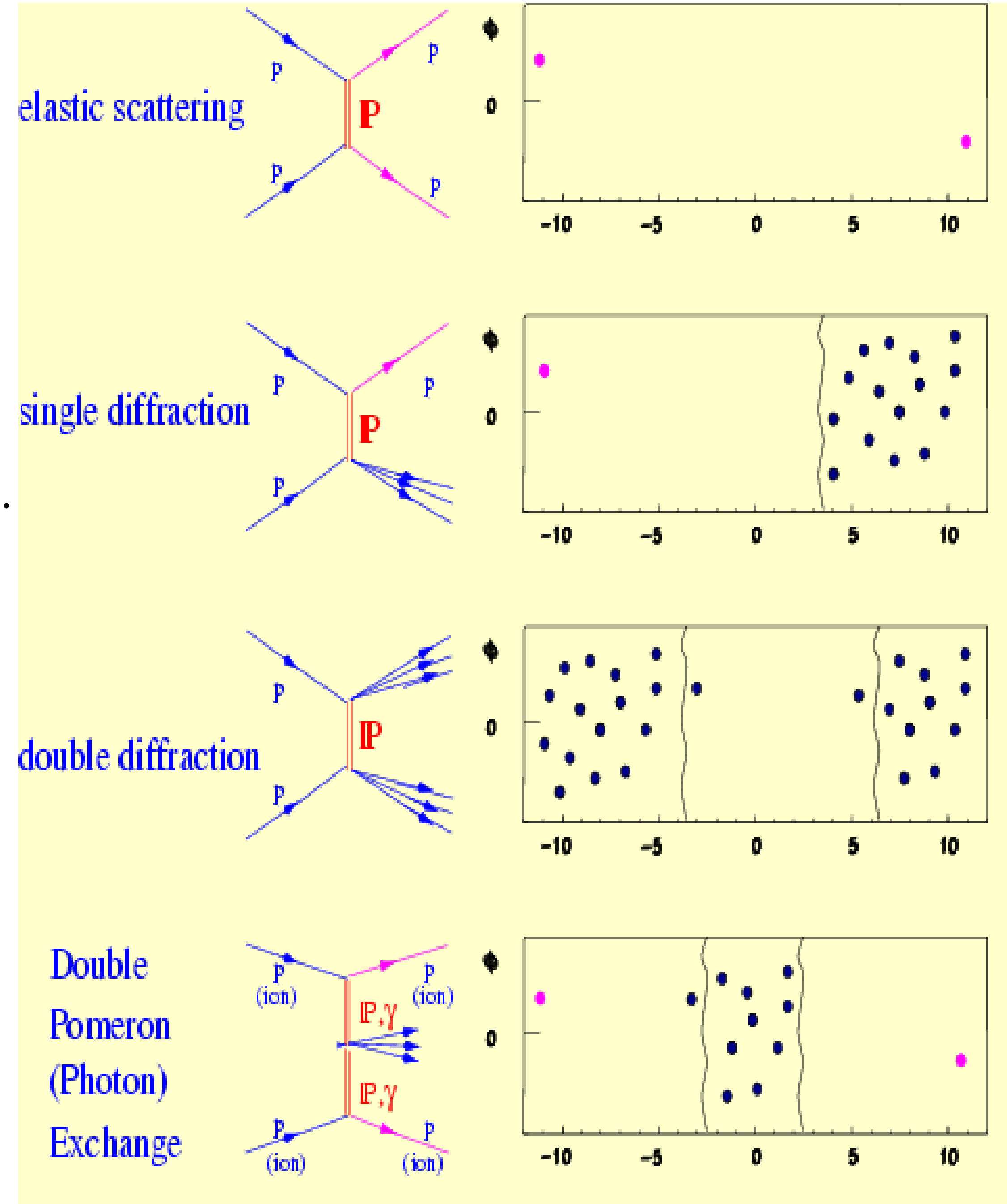
ATLAS Forward Physics: Strategy

- ATLAS good coverage in the forward region.

- Diffractive events: low-t processes in which a colour singlet (Pomeron) is exchanged between the two protons. One or both of protons break up into a dissociative system (SD/DD diffractive) or produce a central system (DPE/CEP).

- Tag of diffractive events: identifying a rapidity gap
  study rapidity gaps in different η regions and with different configuration and/or measurements of forward protons.

- Dedicated detectors with low noise and sensitive to single event:
  - forward detector for SD and DD events;
  - central calorimeters for DPE.



Soft (Single/Double) Diffraction

With central and forward detectors

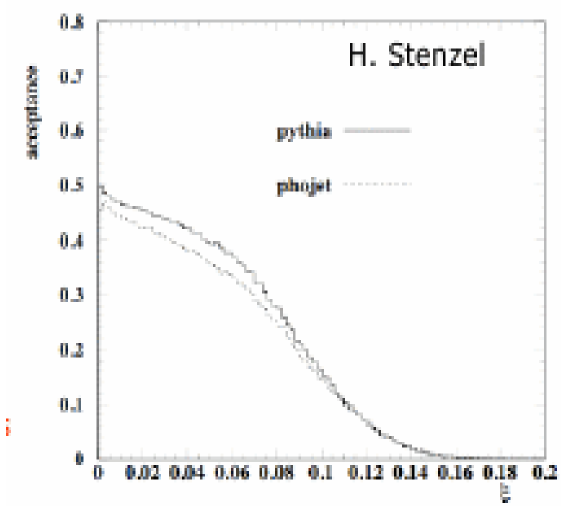
- Measured using central detectors by imposing a pseudo-rapidity gap in LUCID, MBTS and ZDC;
- Requirement: register little hadronic activity;
- Diffractive mass M_x of the dissociative system measured using calorimeter clusters and tracking information;
- Fractional momentum loss of the intact proton defined by:

$$\xi = \frac{M_x^2}{s}$$

- Aim: reconstruct ξ on a event-by-event basis.

With ALFA detector

- ALFA has good acceptance in dedicated runs for SD events (tagging outgoing p).



- Accuracy on fractional momentum loss ~8% for ξ~0.01 and ~2% for ξ~0.1 where

$$\xi = 1 - \frac{p'_z}{p_z}$$

p = longitudinal momenta of the outgoing and incoming proton

- Expected 1.2-1.8 million events in 100 hrs at L = 10^{27} cm^{-2} s^{-1}.

Hard Single Diffraction - Double Pomeron Exchange

- Processes: one (SD) or two (DD) protons remains intact and remnant from exchanged particles are present;

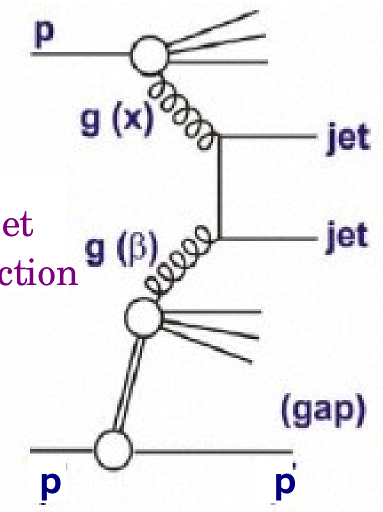
- Look for hard scattering events with (smaller) gap;

- Aim to study:
  - diffractive parton density function;
  - ratio of single diffractive di-jets to non diffractive di-jets;
  - ratio of double pomeron exchange to single diffractive di-jets;

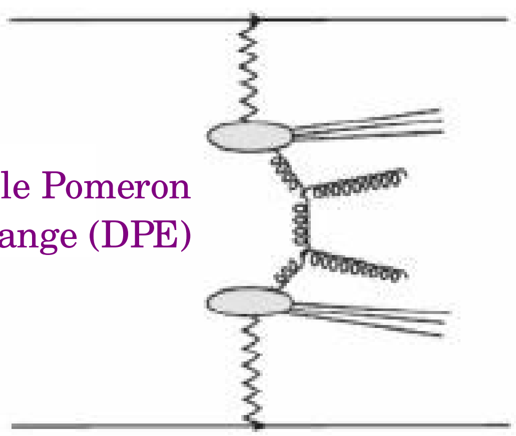
- Trigger for low transverse energy jets and gap requirements using LUCID, ZDC and MBTS (veto);

- Conclusions about gap survival probability at LHC energy + improvement in theoretical uncertainty.

SD dijet production



Double Pomeron Exchange (DPE)



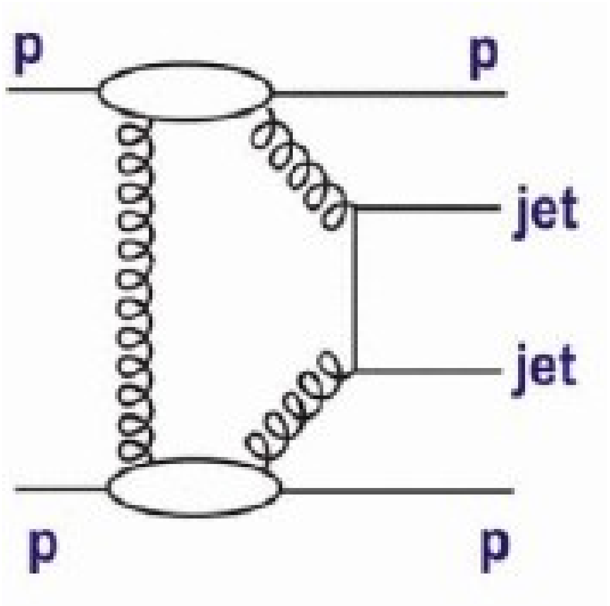
Central Exclusive Di-jet Production

- Process pp → p+Φ+p: all the energy lost by the protons goes into the production of a hard central system (maybe Higgs boson?);

- Look for: two high pt jets and little extra hadronic activity, (large) gaps between jets and protons;

- Necessary to reduce the L1 prescale using the forward detectors (MBTS veto on one side + LUCID/ZDC gaps);

- Aim: to measure cross section as function of E_T to constraint the uncertainty on theoretical model and to study CEP di-jet production as background for other interesting processes;



- Idea: measure the dijet mass fractional

$$R_{jj} = \frac{M_{jj}}{M_{calo}}$$

M_{jj}: invariant mass of the di-jets

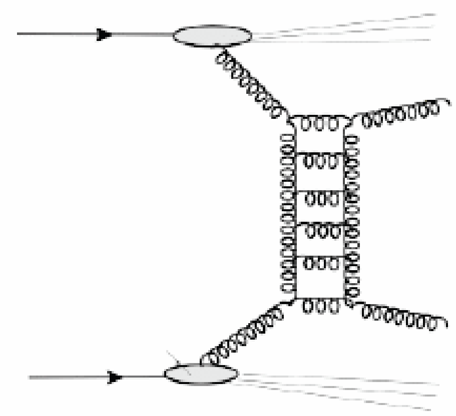
M_{calo}: mass of all energy deposit in the calorimeter

For CEP $R_{jj} \sim 1$

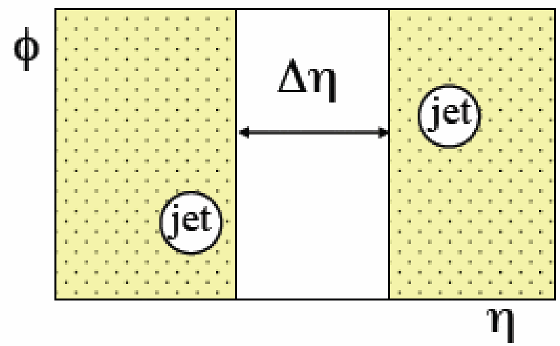
For DD events $R_{jj} << 1$ (background suppression)

Rapidity Gaps Between Jets

- Processes: 2 → 2 scatters via a colour singlet exchange;



- Typical signature: two high-pt jets separated in the detector by a large rapidity gap ($\Delta\eta>3$);
- Aim: to measure the gap fraction, ratio of events containing no or small radiation in the center of the detector to inclusive di-jet events;
- Fraction of events with suppressed activity in central region rises with rapidity gap between jets;



- Separation of jets in pseudo-rapidity increases with center-of-mass energy: $\Delta\eta = \ln\frac{s}{t}$;
- ATLAS should reach a gap fraction up to $\Delta\eta \sim 9 \rightarrow 9.5$;
- Experimentally: veto on radiation between jets (veto-scale on maximum transverse energy deposited between jets).

Conclusions

- ATLAS has several **Forward Detectors** **LUCID, ZDC** and **ALFA + MBTS**.

- During all 2010 data taking LUCID, MBTS and ZDC provided **relative instantaneous luminosity** measurements and, if calibrated, **absolute** luminosity, with **good performances** (final accuracy 3.4%).

- Once commissioned, ALFA will provide absolute luminosity measurements with accuracy of 2-3%.

- Forward detectors are involved in **Diffractive Physics** as **trigger on rapidity gap:** - MBTS already included in the trigger menu;
  - use of LUCID and ZDC yet under study.

BACK-UP SLIDES

Luminosity Measurements with LUCID

$$L = \frac{R_{inel}}{\sigma_{inel}} = \frac{\mu n_b f_r}{\sigma_{inel}}$$

$$L = \frac{\mu^{vis} n_b f_r}{\epsilon \sigma_{inel}}$$

f_r = bunch crossing rate = 2808/3564 * 40 Mhz

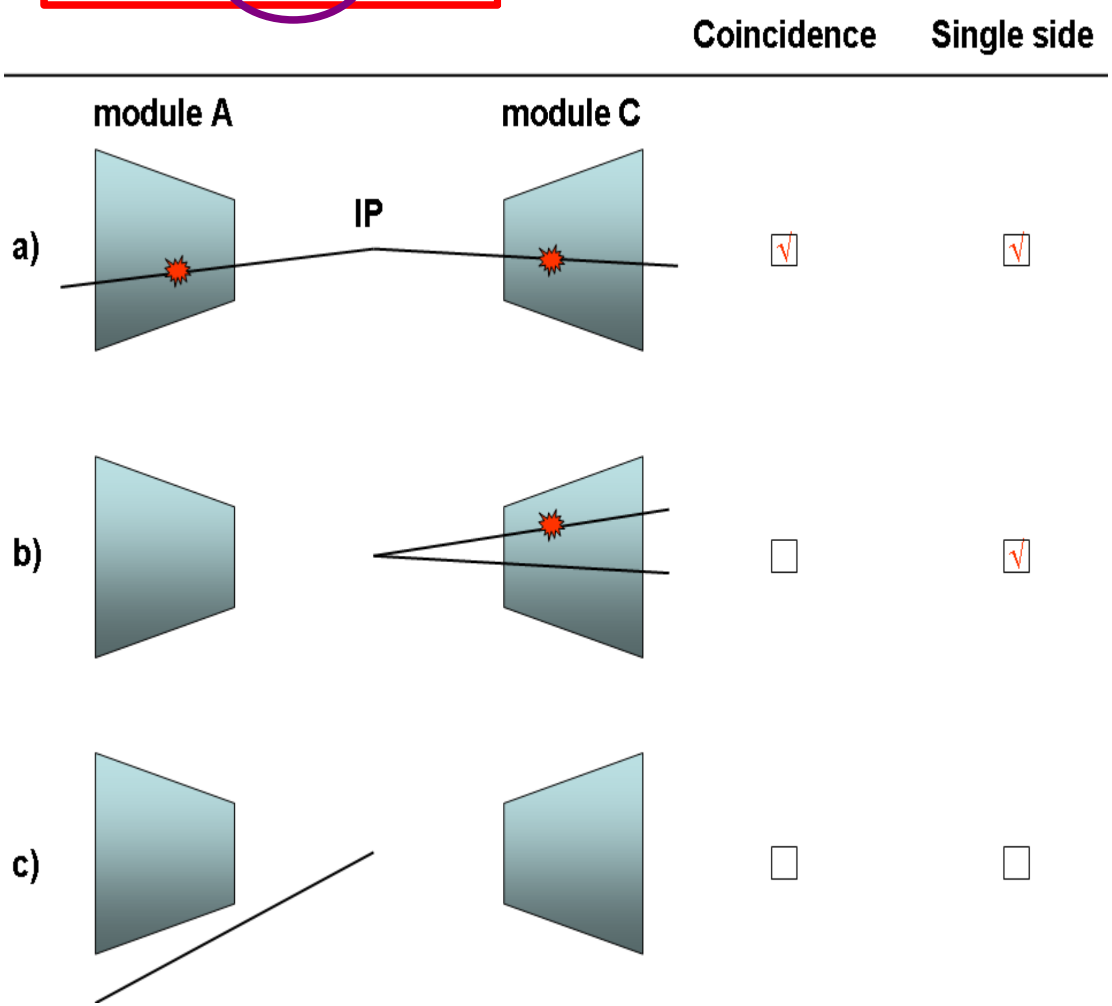
n_b = number of bunches

$\mu = \mu^{vis}/\varepsilon$

μ^{vis} = number of pp interactions per bunch crossing as measured by LUCID

ε = efficiency and acceptance of LUCID (35% single side and 14% coincidence)

$\varepsilon\sigma_{inel} = \sigma_{vis}$ calibration constant



Assumption: number of collisions at the IP follows Poisson statistics.

Hit definition: one signal above threshold.

Choise of a logic:
Single side: at least one hit in any of the two vessels (case a or b)
Coincidence: at least one hit in both vessels (case a)

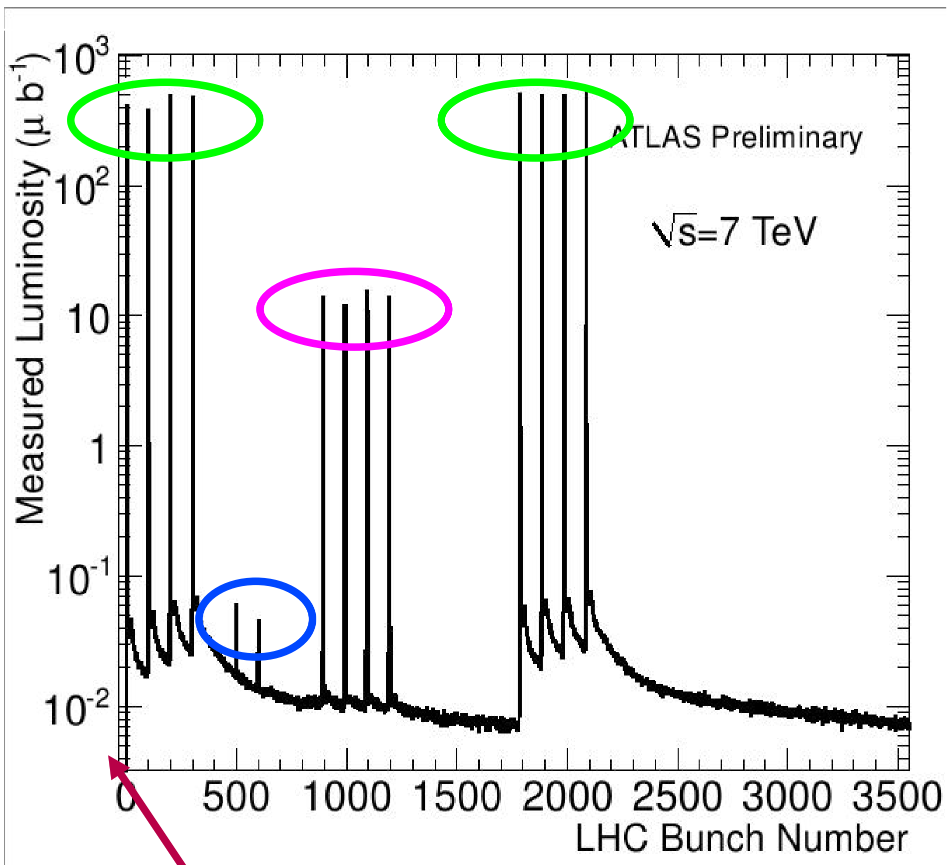
Algorithms:
Event counting: number of events with at least one hit (up to $\mu \sim 10$);
Hit counting: mean number of hits per bunch crossing ($\mu > \sim 10$).

LUCID Performance with 2010 Data

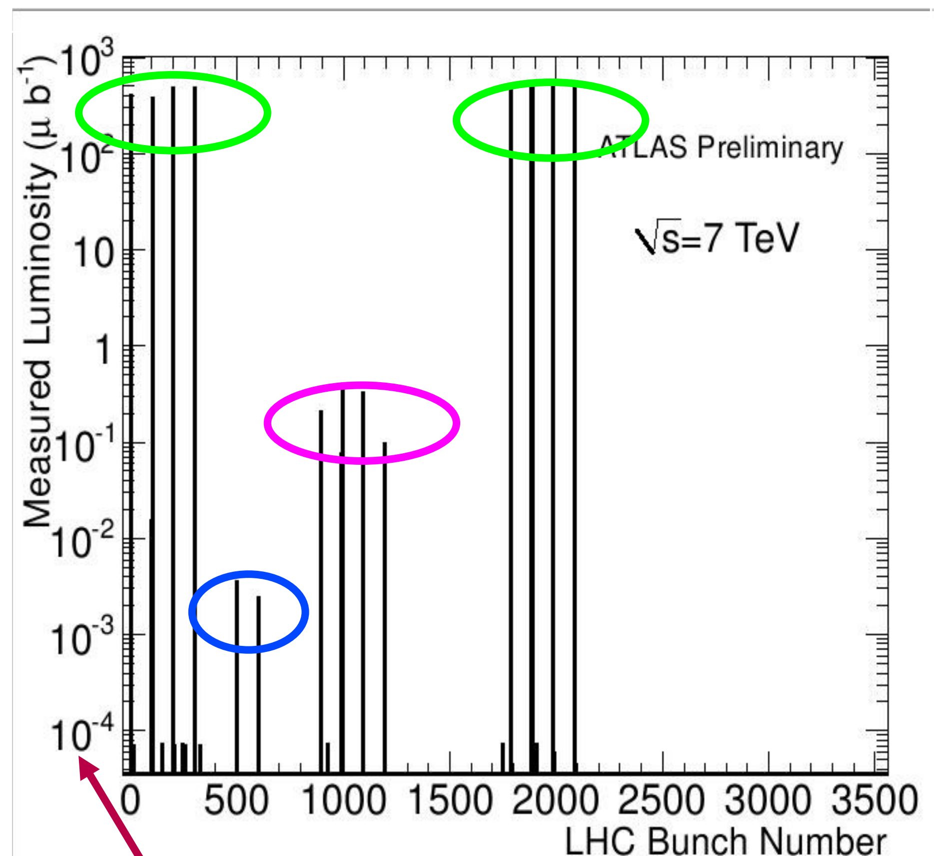
Run 155697 (24-25 May 2010) <μ> = 0.188 Luminosity = 3.942 μb^{-1}

14 bunches: 8 colliding at IP1 + 4 colliding at 11 m (displaced) + 2 non colliding (unpaired)

Event OR



Event AND



Background of single side mode reduced by a factor 100 in coincidence mode.

Luminosity Calibration: MonteCarlo

$$L = \frac{\mu^{vis} n_b f_r}{\sigma_{vis}} = \frac{\mu^{vis} n_b f_r}{\epsilon_{SD}\sigma_{SD} + \epsilon_{DD}\sigma_{DD} + \epsilon_{NN}\sigma_{NN}}$$

ND = non diffractive
SD = single diffractive
DD = double diffractive

Inelastic cross section (σ)

	7 TeV	
Process	**PYTHIA**	**PHOJET**
ND	48.5	61.6
SD	13.7	10.7
DD	9.3	3.9
Total:	71.5	76.2

Efficiency for different algorithms (ε)

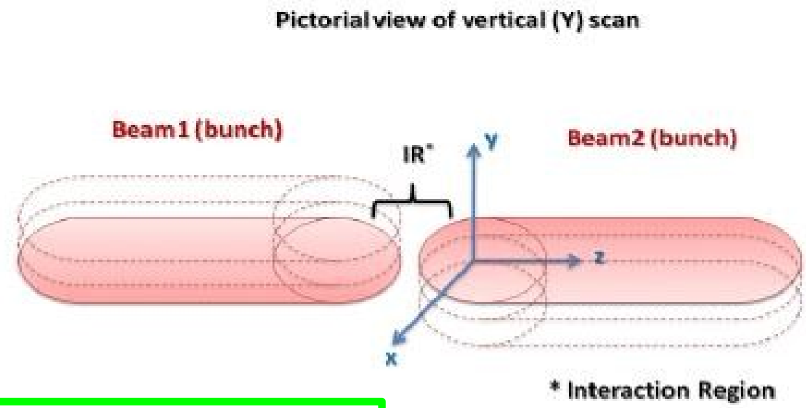
Event AND	$\sqrt{s} = 7\ TeV$	
Process	**PYTHIA**	**PHOJET**
ND	30.8	25.5
SD	1.2	2.4
DD	4.4	14.8
σ_{vis}	15.5	16.4

Event OR	$\sqrt{s} = 7\ TeV$	
Process	**PYTHIA**	**PHOJET**
ND	79.2	74.2
SD	28.7	44.8
DD	39.4	62.0
σ_{vis} (mb)	46.1	52.9

Systematic uncertainty	$\sqrt{s} = 7\ TeV$
Source	%
σ_{vis}	20.0
Detector responce	5.0
Background	negligible
Trigger Efficeincy	n.a
Total	20

20% uncertainty on σ*ε due to extrapolation to unexplored energy range.
Ungoing studies to lower the uncertainty.

Luminosity Calibration: Van der Meer Scan



- Dedicated runs → calibration not available during physics runs.
- 5 Van der Meer scans in 2010
- Beam displacement of ±6σ wrt beam size.
- For each step: - relative displacement;
  - relative luminosity from all active luminosity monitors.

$$L = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$

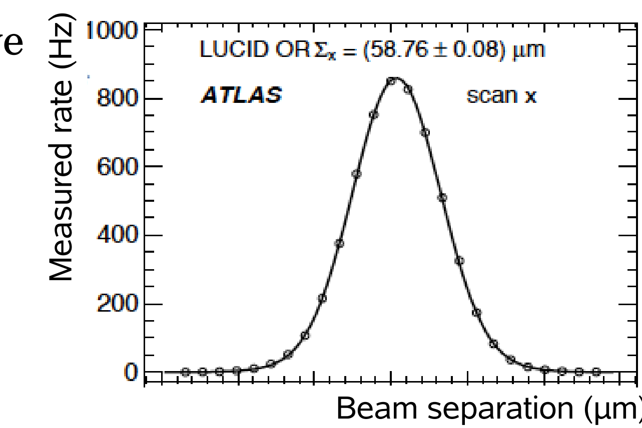
$$\frac{1}{\Sigma_{(x,y)}} = \sqrt{(2\pi)} \frac{(R_x(0))}{\int (R_x(x)\,dx)}$$

Σ = related to the area under the curve and the peak position (independent from the form of the curve itself)

n_b = bunch numbers

I = bunch current

f_r = revolution frequency



RESULTS

Source	Uncertainty on σ_{vis} (%)
Beam intensities	10
Lenght scale	2
Imperfect beam centering	2
Transverse emittance changes	3
mu dependence	2
Total	11

Algorithm	Scan number	σ_{vis} (mb)
Event AND	1	12.15 ± 0.14
	2	12.55 ± 0.10
	3	12.73 ± 0.10
Event AND	1	39.63 ± 0.32
	2	40.70 ± 0.13
	3	40.77 ± 0.14

Uncertainty improved to 3.4% with analysis of latest VdM scans

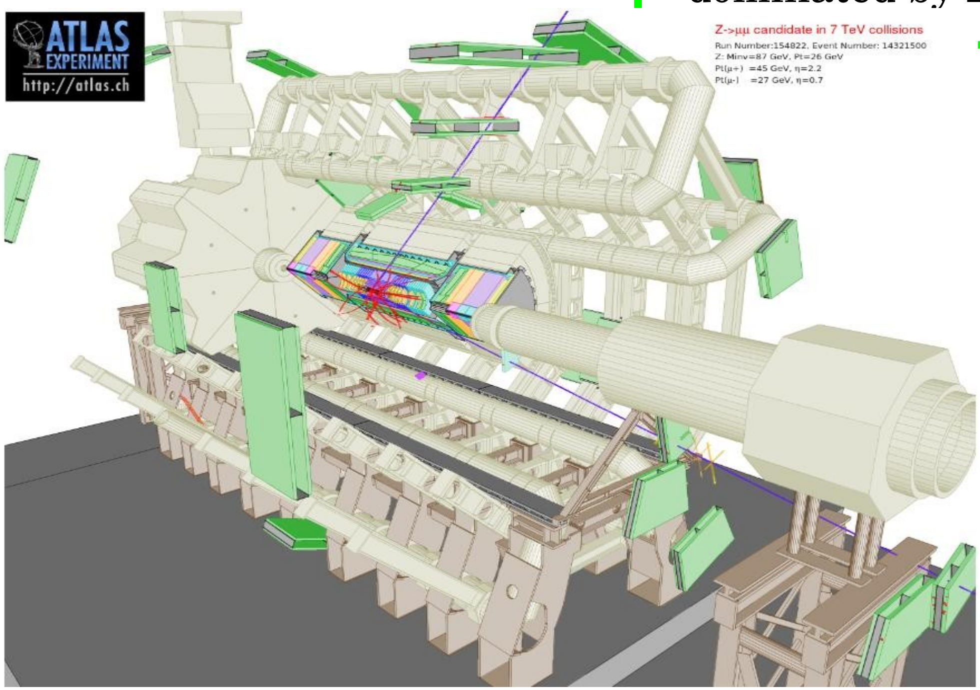
Luminosity Calibration: Physics Processes

$\sigma(Z) * BR(Z \rightarrow \mu^+\mu^-)$

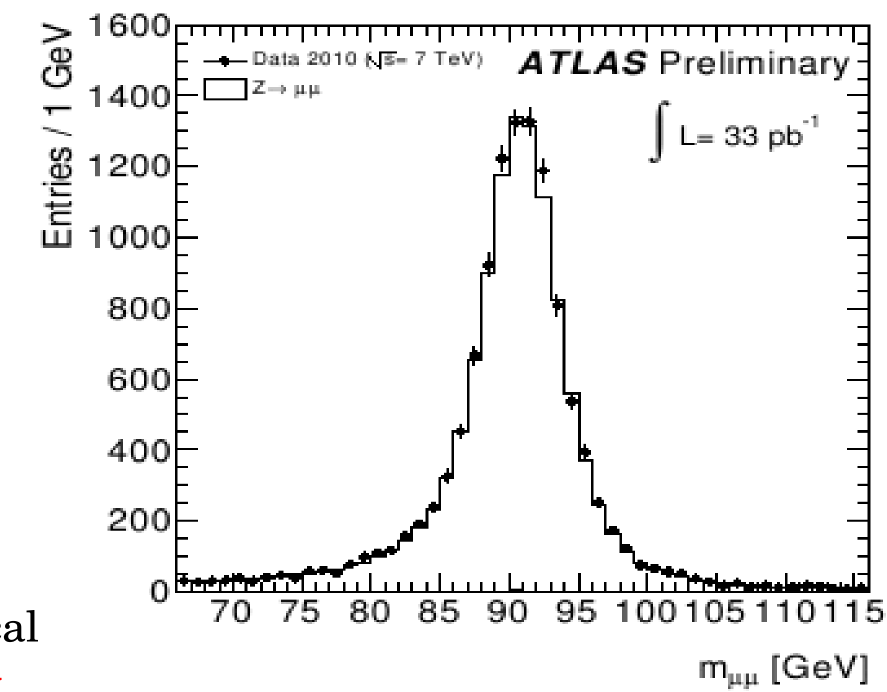
$L = R / \sigma$

Theoretical cross section (NNLO)
$\sigma(pp \rightarrow Z/\gamma^* \rightarrow \mu\mu) = 0.99$ nb
Uncertainty 5%
dominated by PDF.

Experimental cross section uncertainty:
- detector efficieny and acceptance 6.6%;
- luminosity 3.4%;
- background marginal.



Integrated luminosity = ~35 Pb^{-1}
Z candidate events = 11669
Expected background = 66 ± 21

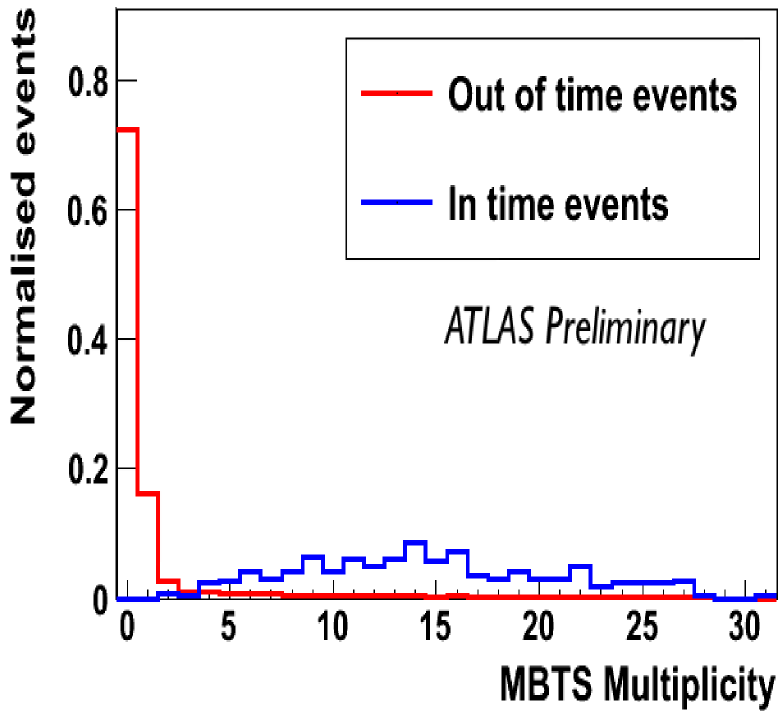


Sperimental cross section ($66 < m_{\mu\mu} < 116$ GeV)

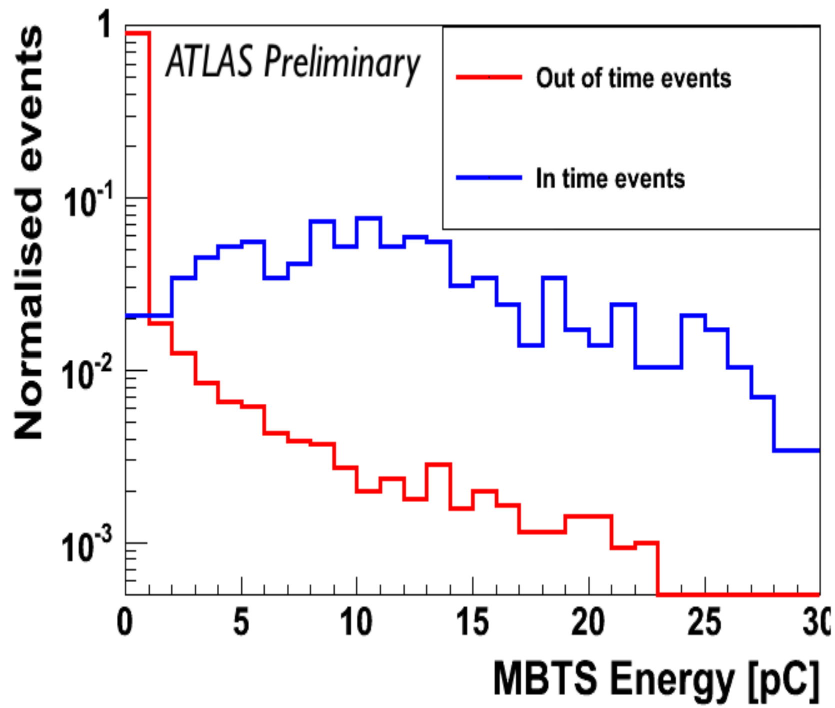
$$\sigma_{qq\rightarrow Z} \times BR_{Z\rightarrow\mu\mu} = 0.941 \pm 0.008_{stat} \pm 0.011_{sys} \pm 0.032_{lumi} \pm 0.037_{acc} \text{ nb}$$

Compatible within the uncertainties with the theoretical value → **Z production used as relative luminosity monitor**

MBTS Performance with 2010 p-p Data

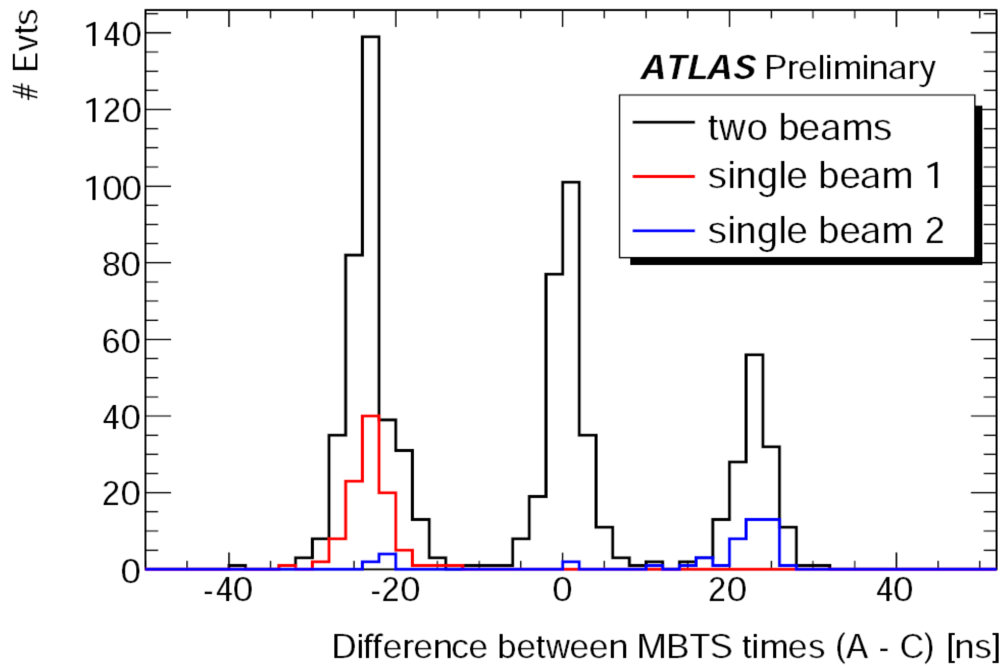


MBTS counter multiplicity for events with time difference t_A – t_C < 7.5 ns (blue) and for events with t_A – t_C > 7.5 ns (red). The red curve is not compatible with collision timing



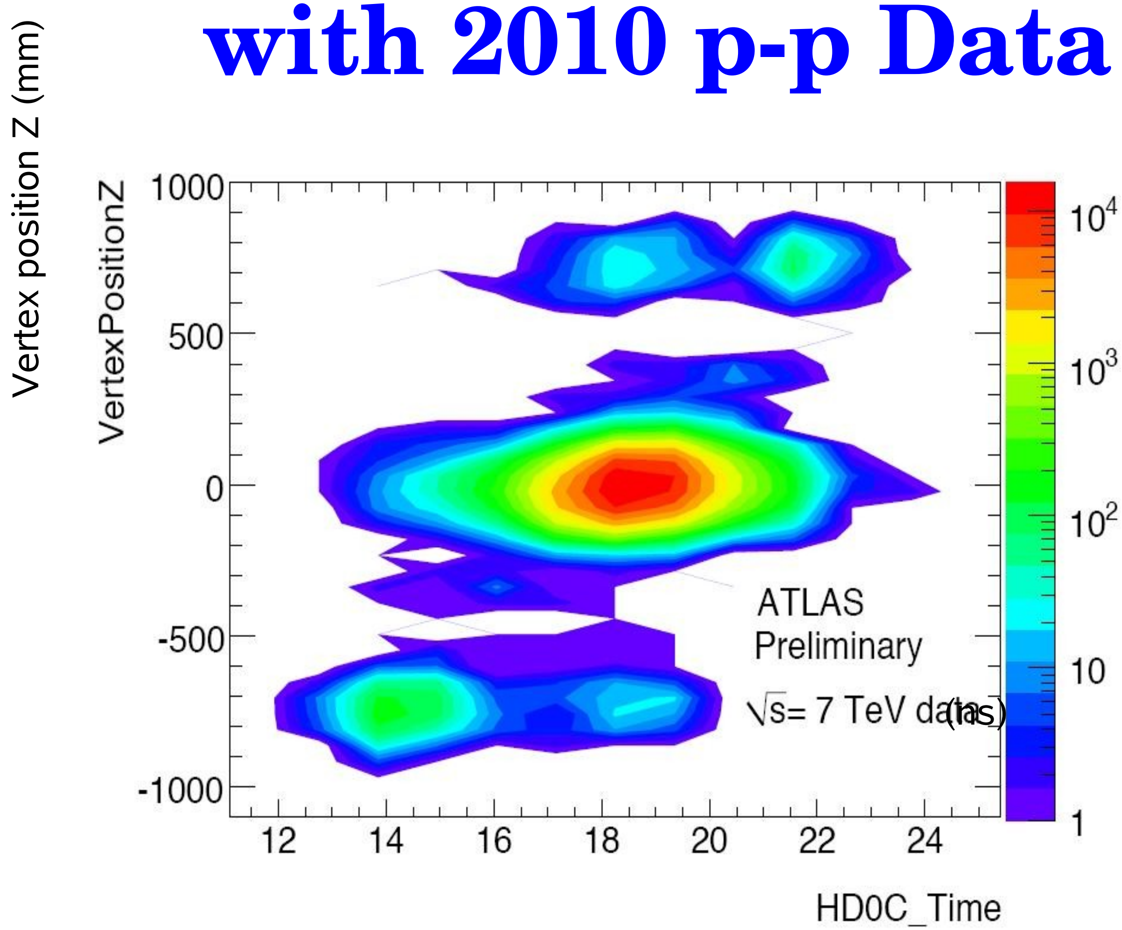
The total raw energy deposited in the MBTS counters for events with time difference t_A – t_C < 7.5 ns (blue) and for events with t_A – t_C > 7.5 ns (red). The red curve is not compatible with collision timing

MBTS Performance with 2010 p-p Data



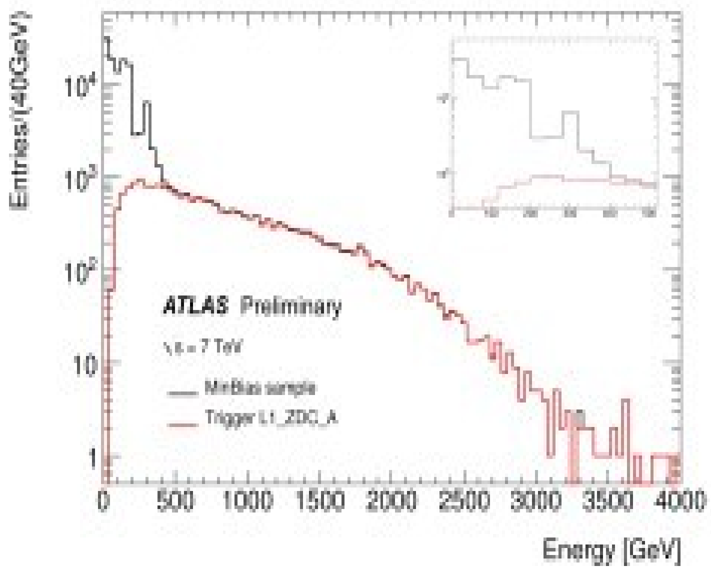
The difference between the time measured by the MBTS side A and that measured by MBTS side C for 3 runs: one with two beams (black), one with beam 1 only (red) and one with beam 2 only (blue).

ZDC Performance with 2010 p-p Data

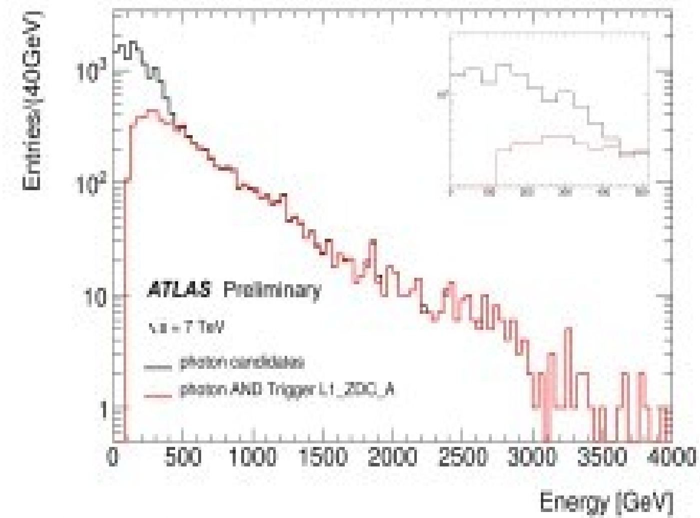


The Z (reconstructed) vertex distribution from inner tracker vs. the time of arrival of showers in ZDC-C relative to the ATLAS clock.
Typical time resolution is ~200 ps per PMT.
The two areas outside the main high intensity area are due to satellite bunches (2.5 ns).

ZDC Performance with 2010 Data

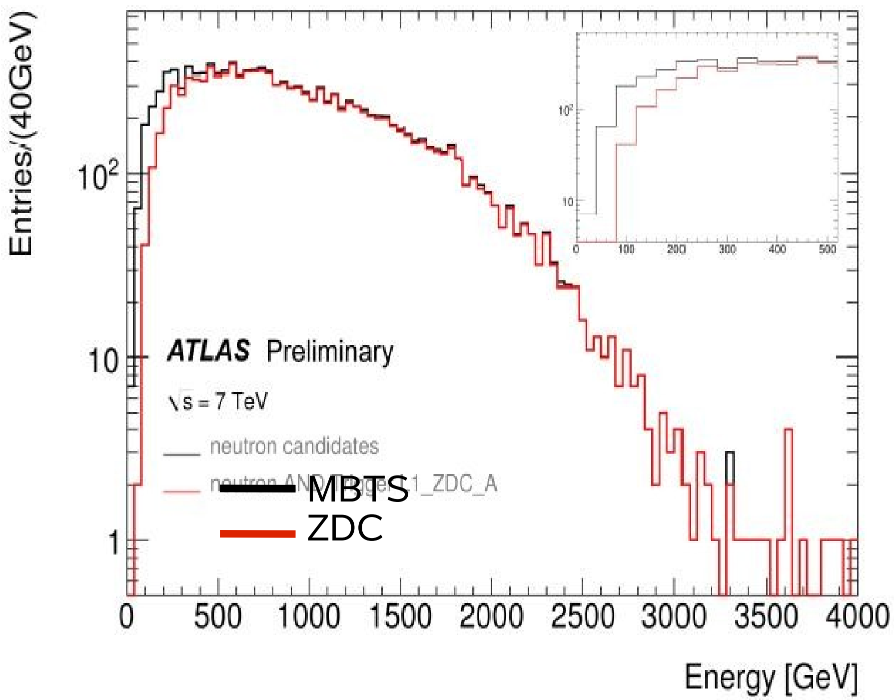


Energy distribution as measured by the ZDC-A. Black curve is total events triggered by the ATLAS minimum bias trigger. Red curve is events triggered by the Constant Fraction Discriminator (CFD). The inset is the lower energy part of this figure showing the threshold effect of the CFD. The threshold for full efficiency is approximately 400 GeV.



Energy distribution as measured by the ZDC-A for photon candidates. Black curve is events triggered by the ATLAS minimum bias trigger. Red curve is events triggered by the Constant Fraction Discriminator trigger. A photon event is defined by the longitudinal shower development, i.e., less than 17 GeV deposited in module 2 and less than 13 GeV deposited in module 3. Inset is the lower energy part of the figure showing threshold effect of the discriminator. The threshold for full efficiency is approximately 420 GeV. The energy scale for photons was obtained by adjusting the end point of the distribution to 3.5 TeV.

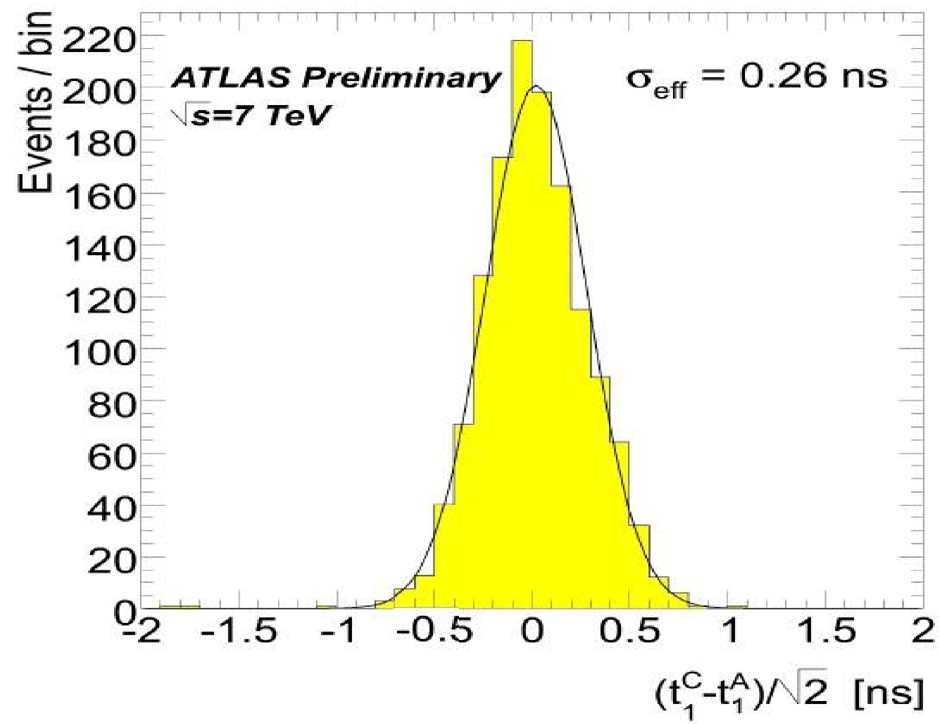
ZDC Performance with 2010 Data



Energy distribution measured by ZDC-A for neutron candidates.

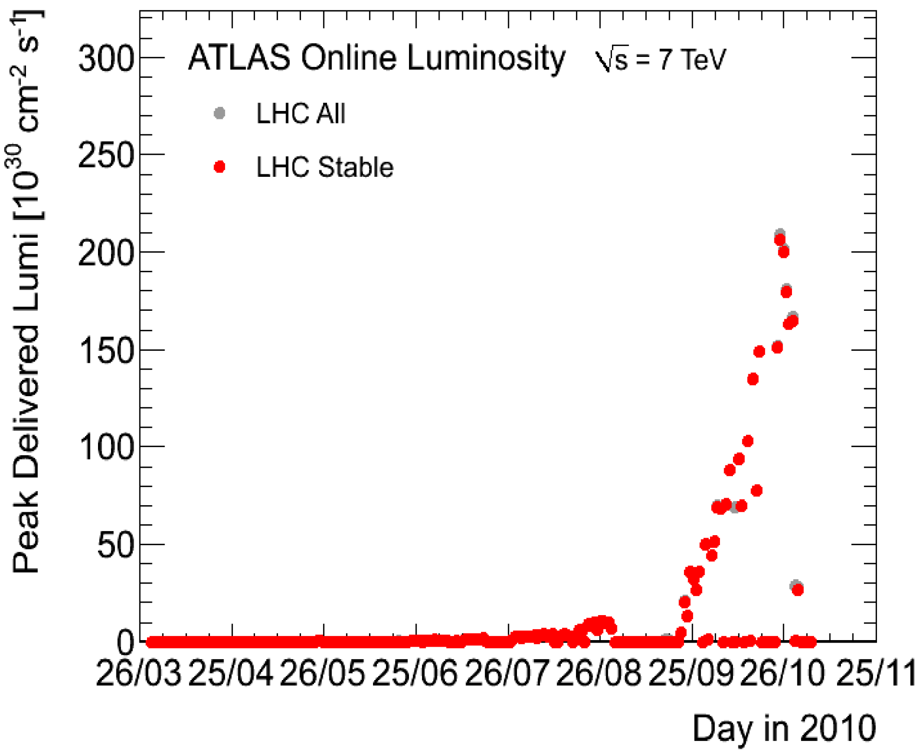
Neutron defined by longitudinal shower development (>17 GeV in module 2 and >13 GeV in module 3).

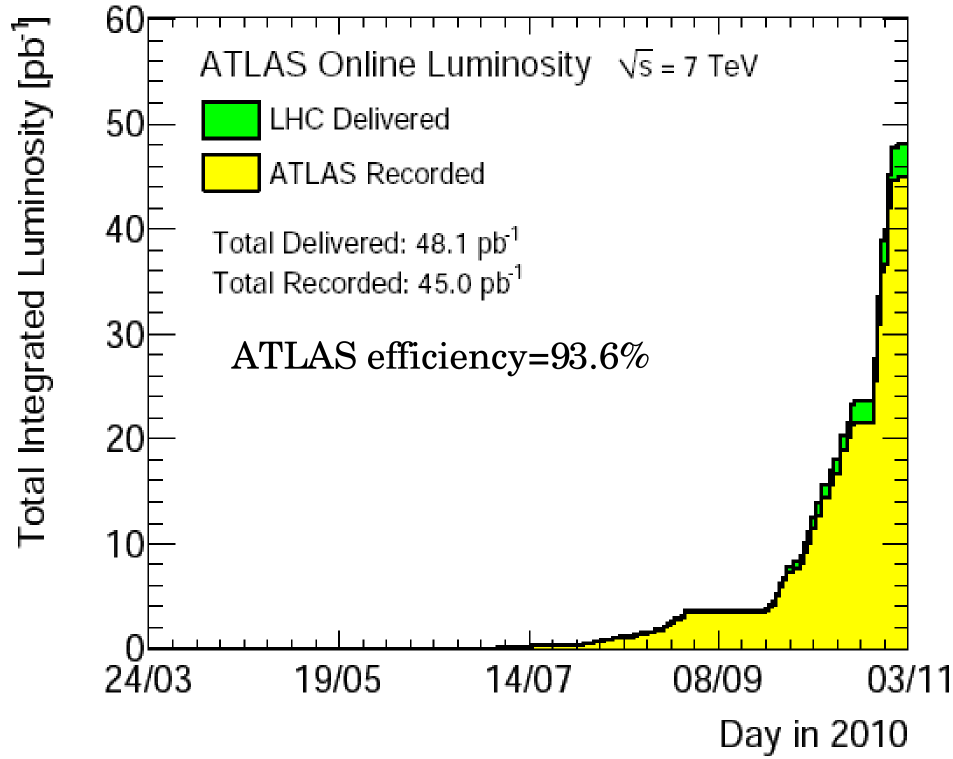
From the energy of the spectator neutrons is possible to determine their number ⟹ measurement of the number is equivalent to measuring the centrality.



Distribution in time of events in ZDC-C minus that in ZDC-A, divided by the square root of 2. This two arm width of 0.26 ns is larger than the single width shown in the figure above, (0.21 nsec) which is consistent with a 4 cm rms in the distribution of p-p interactions along the beam.

2010 pp Luminosity Performance

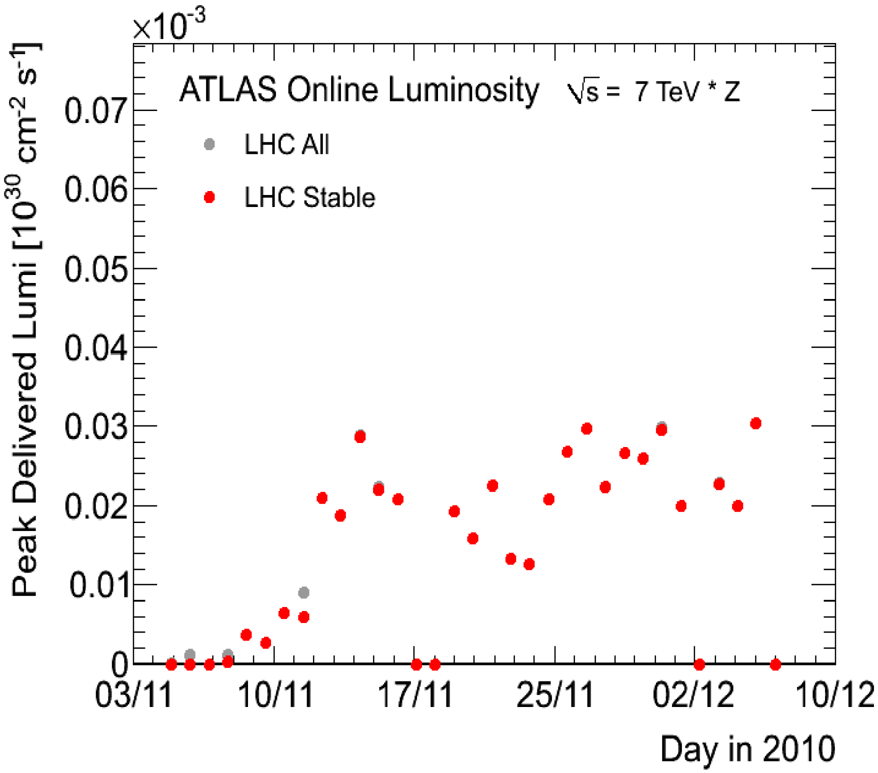


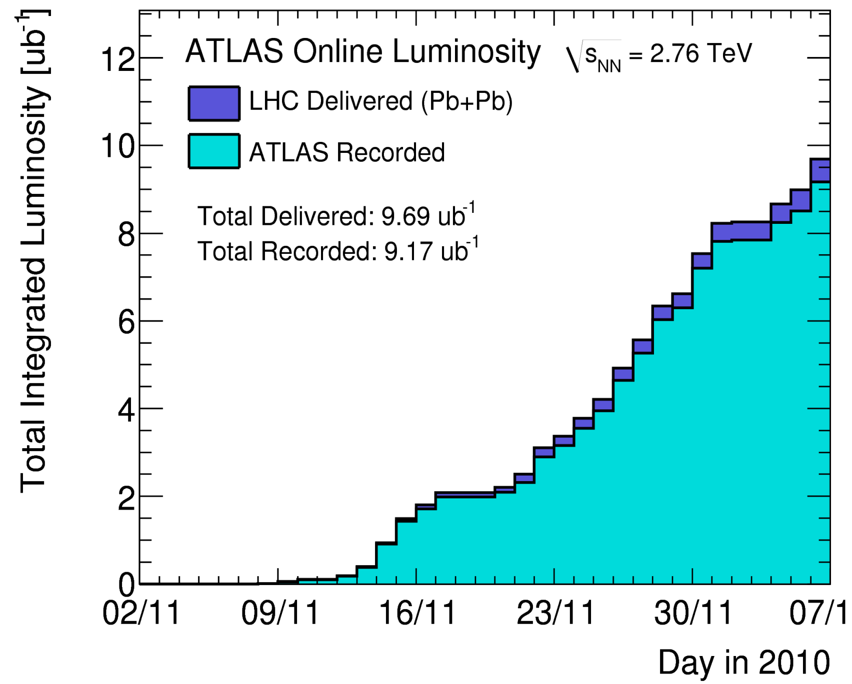


Collision energy per beam	3.5 TeV
Peak Stable Luminosity Delivered	$2.07 \cdot 10^{32}$
Maximum Luminosity Delivered in one fill	$6304.61\ nb^{-1}$
Maximun Luminosity Delivered in one day	$5983.78\ nb^{-1}$
Maximum Colliding Bunches	348
Maximum Average Events per Bunch Crossing	3.78
Longest Time in Stable Beams for one fill	30.3 hours
Longest Time in Stable Beams for one day	22.8 hours
Longest Time in Stable Beams for 7 days	69.9 hours

- Cumulative luminosity vs time during stable beam for pp collision.
- Luminosity from LUCID detector calibrated via Van der Meer scan results.
- Delivered luminosity: before ATLAS trigger.
- Systematic uncertainty: 3.4% (dominated by beam current).
- ATLAS recording efficiency: 93.6%

2010 HI Luminosity Performance

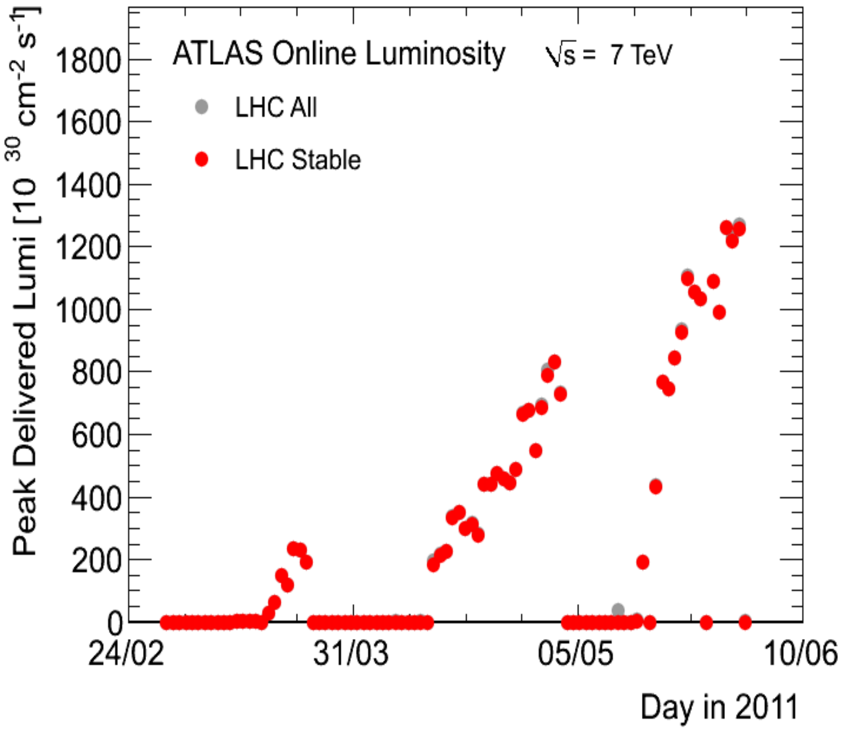


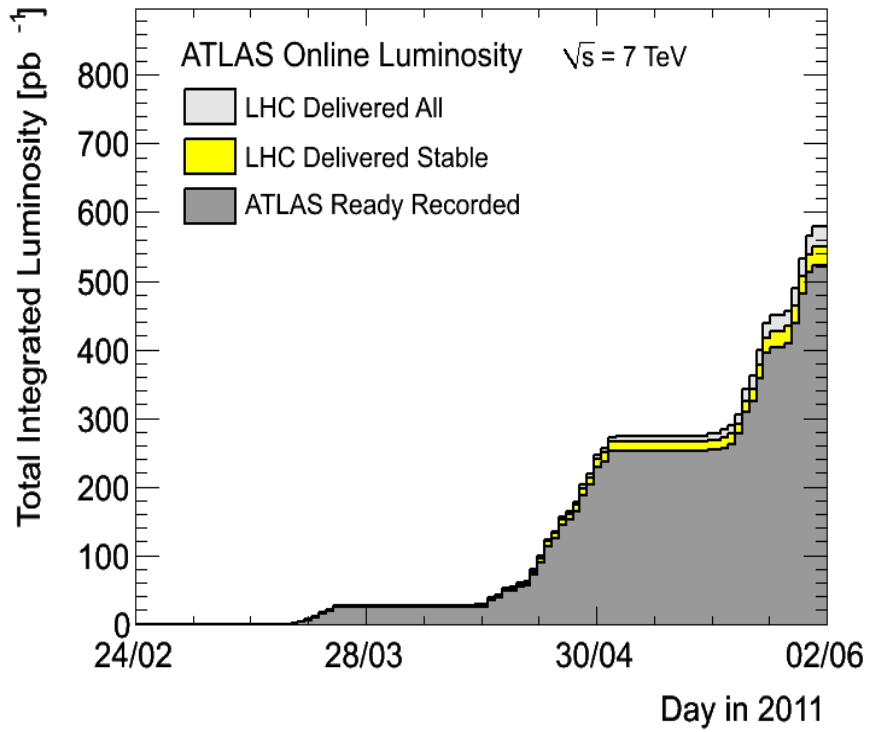


Collision energy per nucleon	2.76 TeV
Peak Stable Luminosity Delivered	$3.04 \cdot 10^{25}$
Maximum Colliding Bunches	129
Longest Time in Stable Beams for one fill	13.9 hours
Longest Time in Stable Beams for one day	15.6 hours
Longest Time in Stable Beams for 7 days	79.0 hours

- Cumulative luminosity vs time during stable beam for Pb-Pb collision.
- Luminosity from ZDC detector.
- ATLAS recording efficiency: 94.6%.

2011 pp Luminosity Performance





Peak Stable Luminosity Delivered	1.26×10^{33}
Maximum Luminosity Delivered in one fill	37.65 pb^{-1}
Maximum Luminosity Delivered in one day	43.12 pb^{-1}
Maximum Luminosity Delivered in 7 days	165.61 pb^{-1}
Maximum Colliding Bunches	1042
Maximum Peak Events per Bunch Crossing	14.01
Maximum Average Events per Bunch Crossing	8.93
Longest Time in Stable Beams for one fill	17.9 hours
Longest Time in Stable Beams for one day	19.7 hours (82.1%)
Longest Time in Stable Beams for 7 days	93.0 hours (55.4%)

- Cumulative luminosity vs time during stable beam for pp collision.
- Luminosity from BCM detector, calibrated using Van der Meer scan results.
- Delivered luminosity: before ATLAS trigger.
- Systematic uncertainty: 3.4% (dominated by beam current).