ATLAS and forward physics

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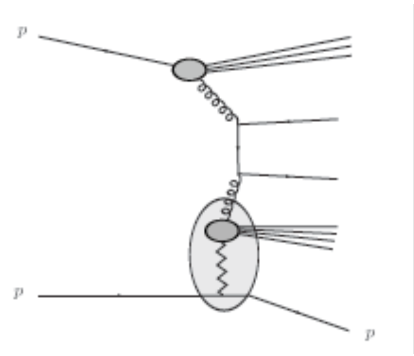
On behalf of the ATLAS Collaboration

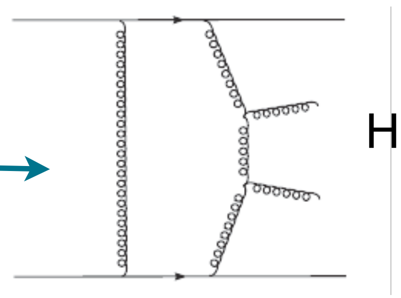
Outline

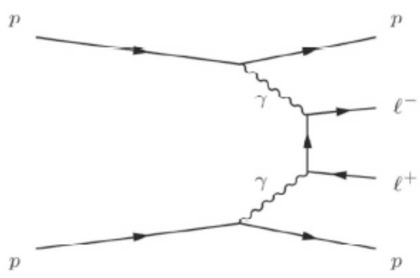
- Forward Physics and strategy
- The ATLAS forward detectors
- Forward Physics with the present detectors
- Possible future
- Conclusions

Forward Physics topics

- Soft Diffraction
  - Single Diffraction (SD)
  - Diffractive mass distribution
- Hard Diffraction
  - Diffractive di-jet production
- Central Exclusive Production (CEP)
- Gaps Between jets

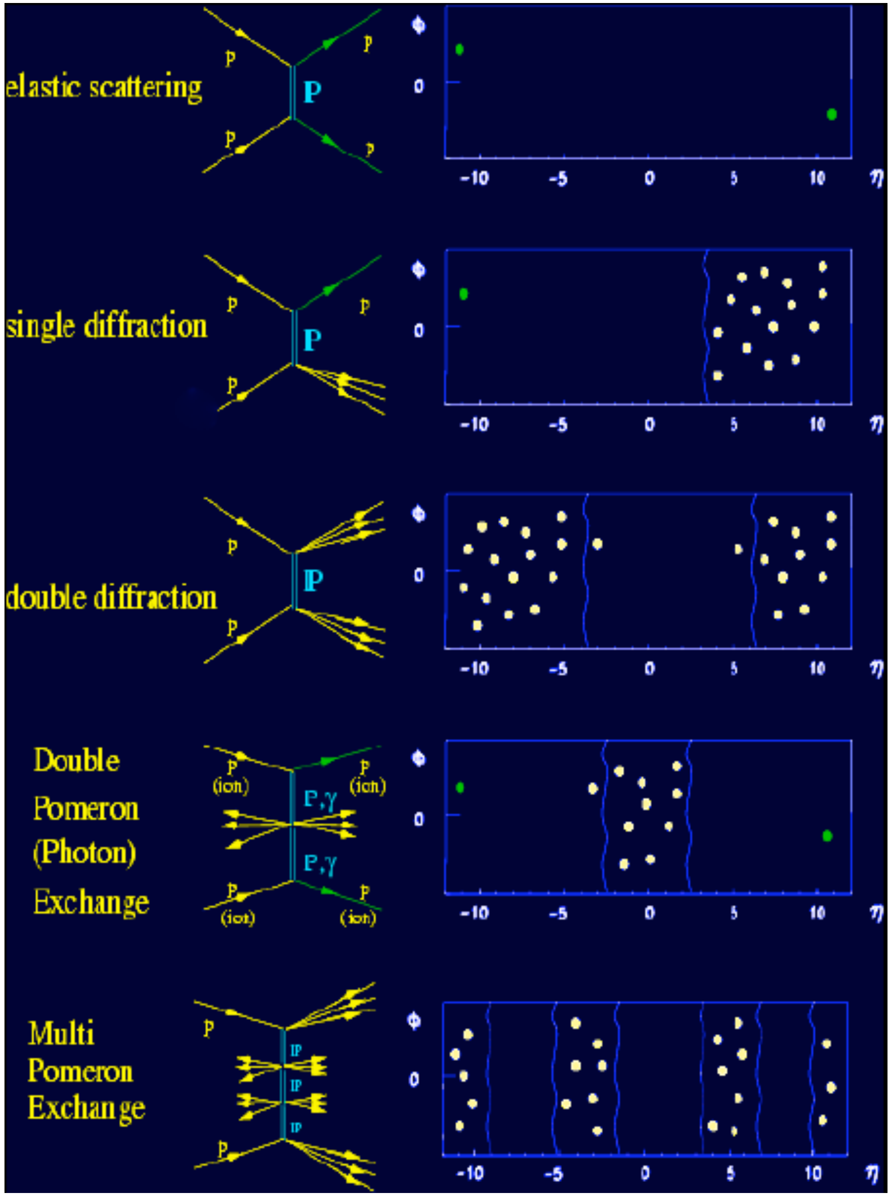




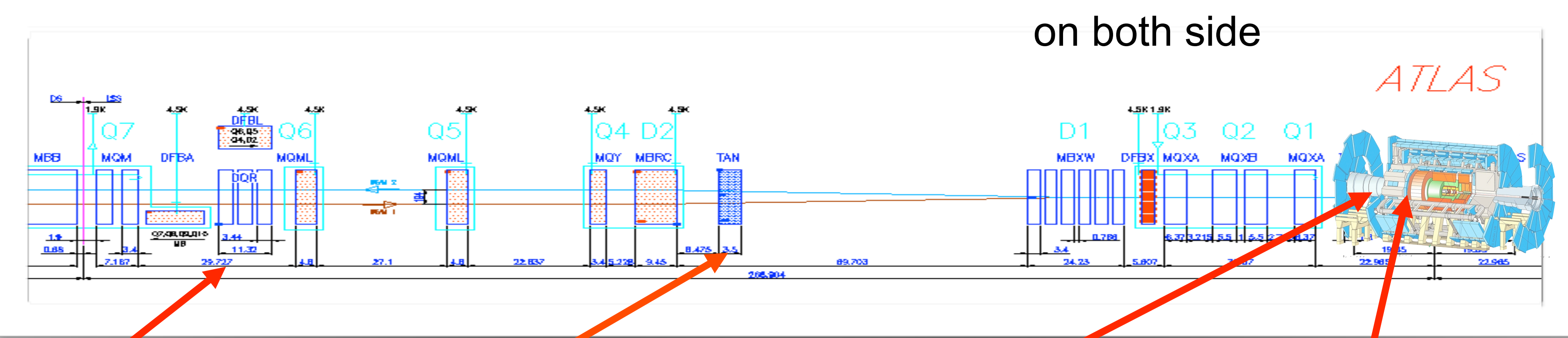


Strategy

- Rapidity Gaps in different η regions and with different configurations and/or measurement of forward protons:
  - forward regions for Single Diffractive (SD), double diffractive and Central Exclusive Production (CEP)
  - central calorimeter (jet-jet) (DPE)
- Requirements:
  - Dedicated detectors
  - Low noise in detectors
  - Single event, no pile-up!



ATLAS Forward Detectors

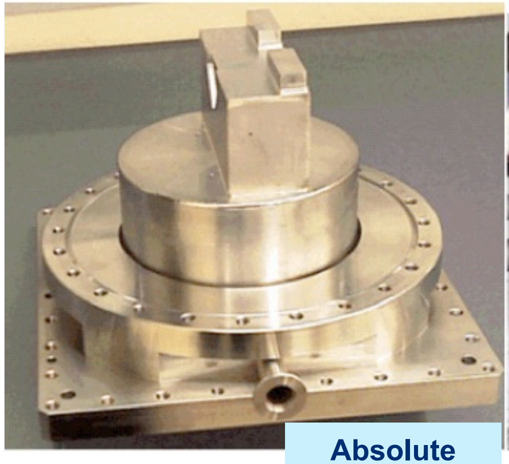


ALFA at 240 m

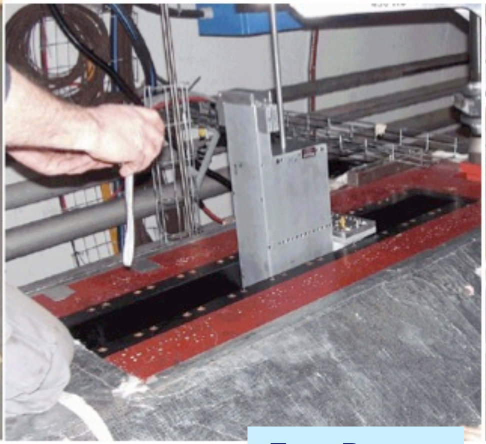
ZDC at 140 m

LUCID at 17 m

MBTS at 3.6 m



Absolute Luminosity for ATLAS



Zero Degree Calorimeter

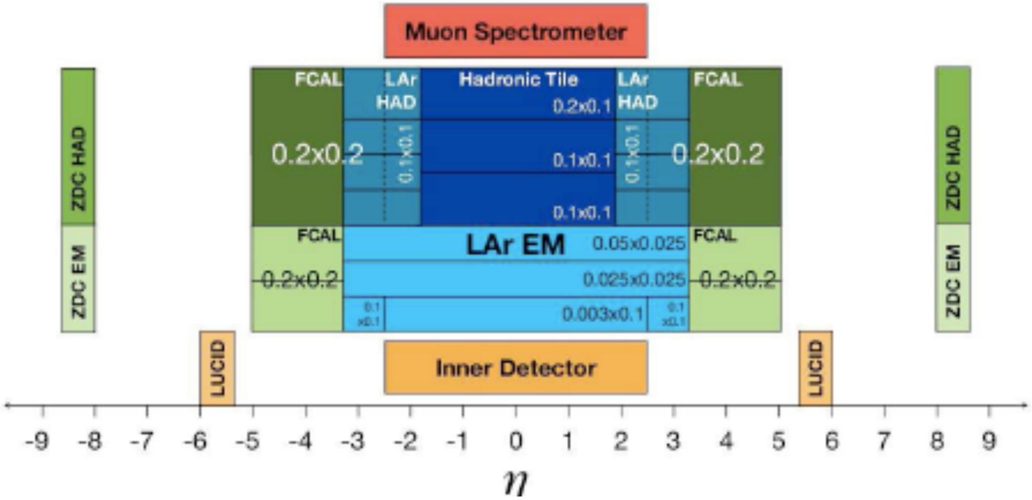
Luminosity Čerenkov Integrating Detector

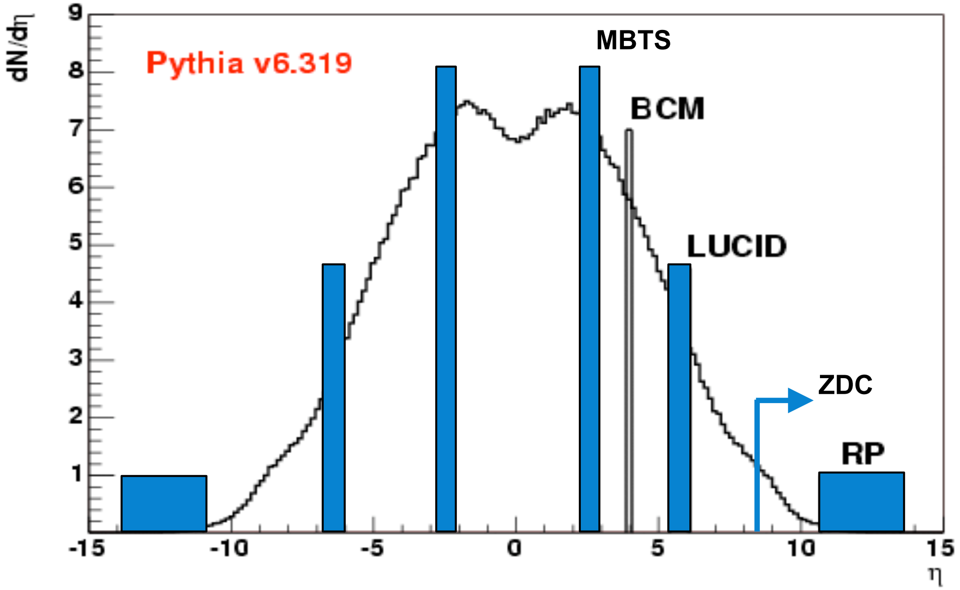
Minimum Bias Trigger Scintillator

2010

ATLAS pseudo-rapidity coverage

Atlas consists of a number of detectors that are useful for diffractive studies:





The central detector covers the following η ranges:

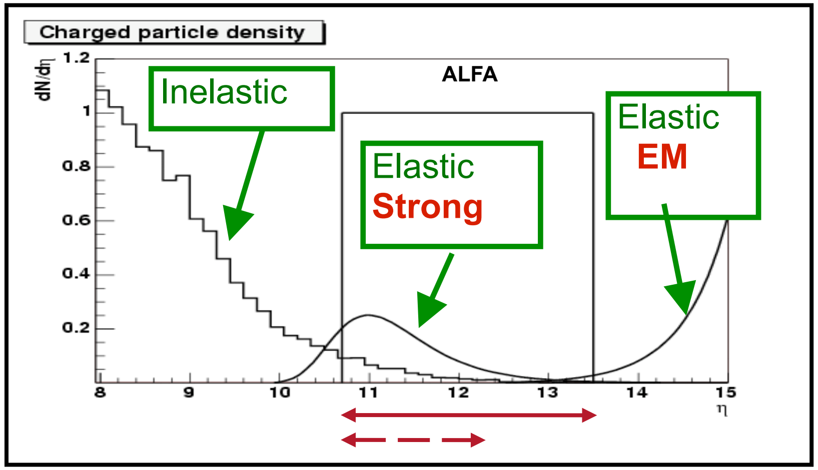
- Inner tracker |η| < 2.5
- EM calorimeters |η| < 3.2
- Hadronic calorimeters |η| < 4.9
- Muon spectrometer |η| < 2.7

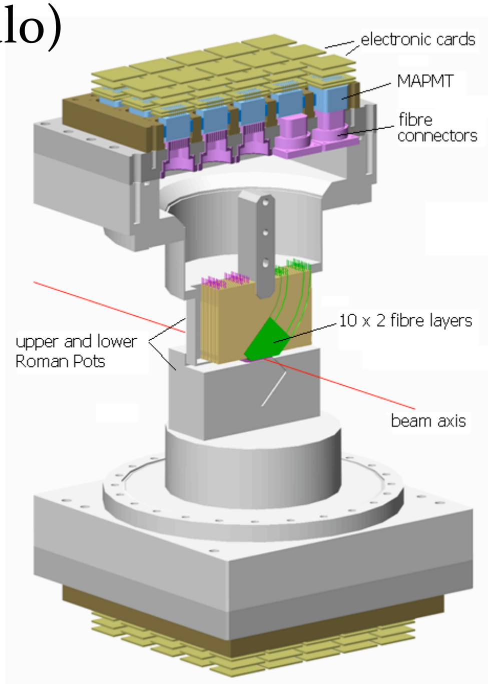
The forward detectors cover the following

- MBTS 2.1 < |η| < 3.8
- LUCID 5.6 < |η| < 5.9
- ZDC |η| > 8.3
- ALFA 10.6 < |η| < 13.5

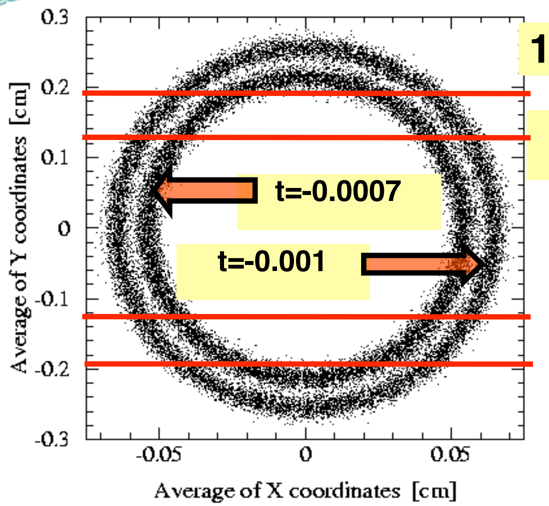
The ALFA Roman Pots

- Aim to measure elastic pp-scattering down to very small angles
- Need special (High β*) optics
  - Low luminosity special runs ($L=10^{27}$ cm^{-2} s^{-1})
  - Parallel-to-point focussing
- detector resolution σ_d = 30 μm (t-resolution dominated by beam divergence)
- radiation tolerance 100 Gy/yr (dominated by beam halo)



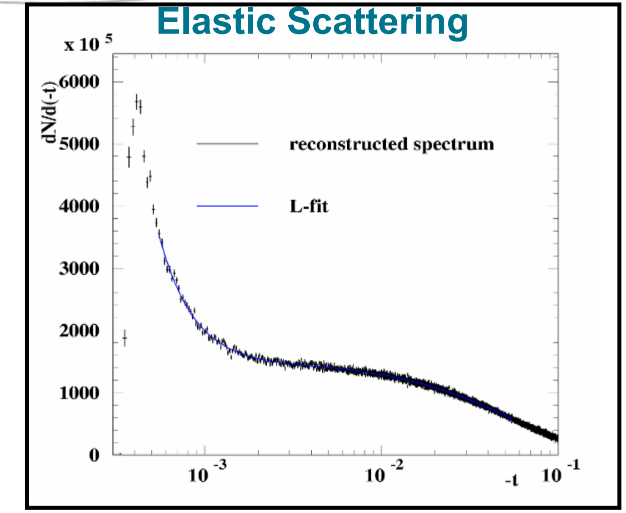


ALFA performance



$$-t = (p\theta^*)^2 = p^2(\bar{\theta}_x^2 + \bar{\theta}_x^2)$$

$$= p^2\left(\left(\frac{\bar{x}}{L_{eff,x}}\right)^2 + \left(\frac{\bar{y}}{L_{eff,y}}\right)^2\right)$$



Fit to simulated dN/dt data corresponding to ~ 1 week (10M events) of running at L = 10^{27} $cm^{-2}s^{-1}$

(H. Stenzel ATL-LUM-PUB-2007-001)

	input	fit	Stat. error
L	8.10 10^{26}	8.151 10^{26}	1.77 %
σ_{tot}	101.5 mb	101.14 mb	0.9%
b	18 Gev^{-2}	17.93 Gev^{-2}	0.3%
ρ	0.15	0.143	4.3%

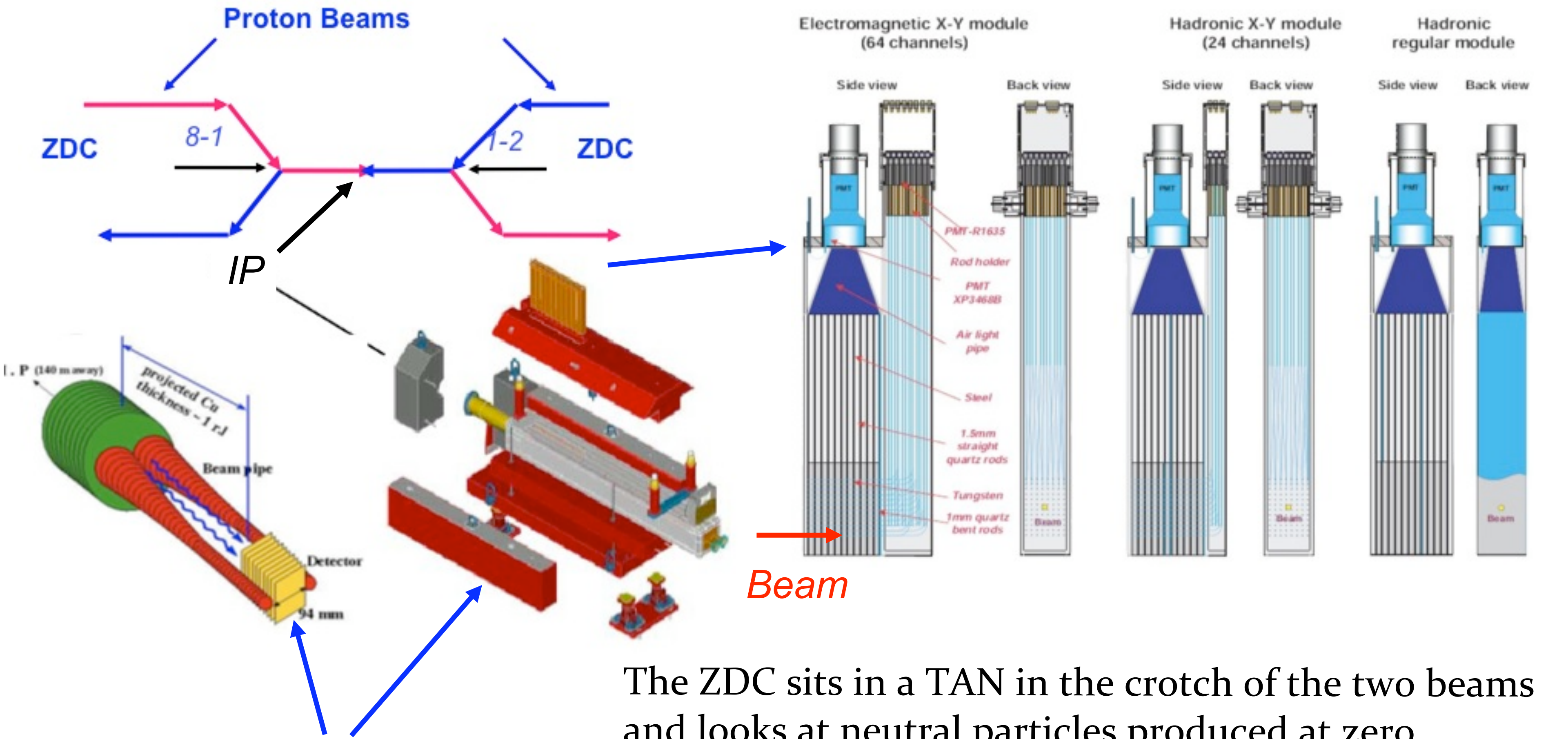
Systematics on L:

- beam divergence and optics
- detector acceptance, resolution & alignment
- background from halo (beam-gas, off-momentum, betatron oscillations)
- Background from non-elastic interactions

Δ L/L ~ 3% - after 2010

The Zero Degree Calorimeter

The ZDC will measure production of neutral particles in the forward direction.

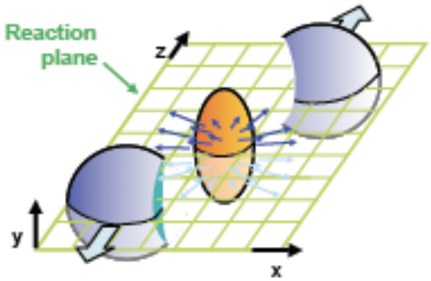


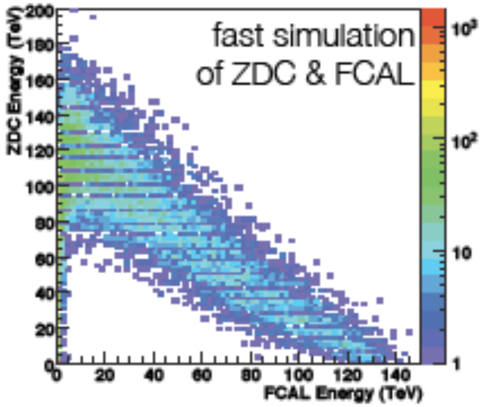
TAN housing, beam pipe, and ZDC

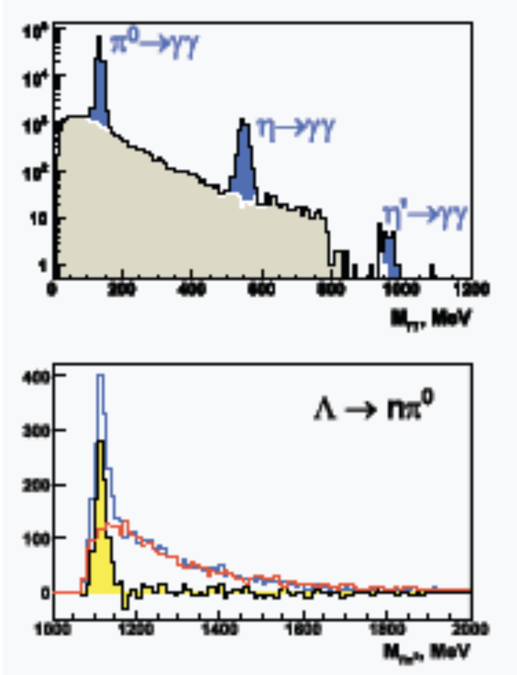
The ZDC sits in a TAN in the crotch of the two beams and looks at neutral particles produced at zero degrees. The TAN is a shielding box that is 140m from the IP. Three types of modules compose the ZDC detector

ZDC goals

Will perform studies both with Heavy Ions and pp collisions by measuring neutral particles at 0° (n, γ, π^0)





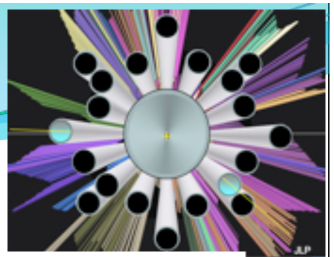


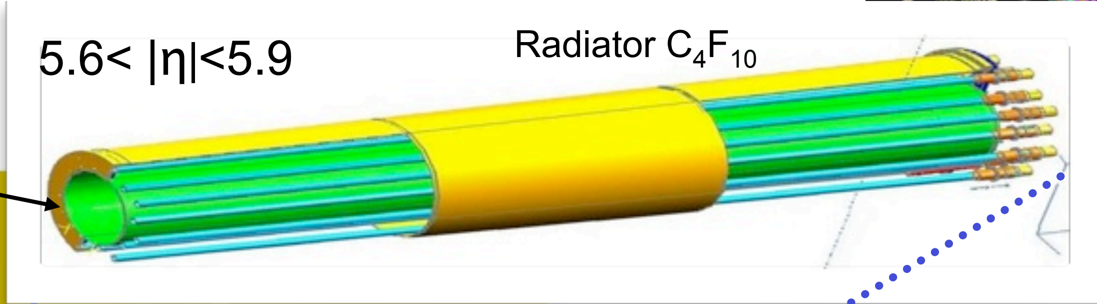
- Centrality of the events
- Minimum Bias Trigger
- Luminosity measurement

- MC constraints from forward particle production
- Rapidity gap trigger/veto

LUCID: Luminosity Monitor

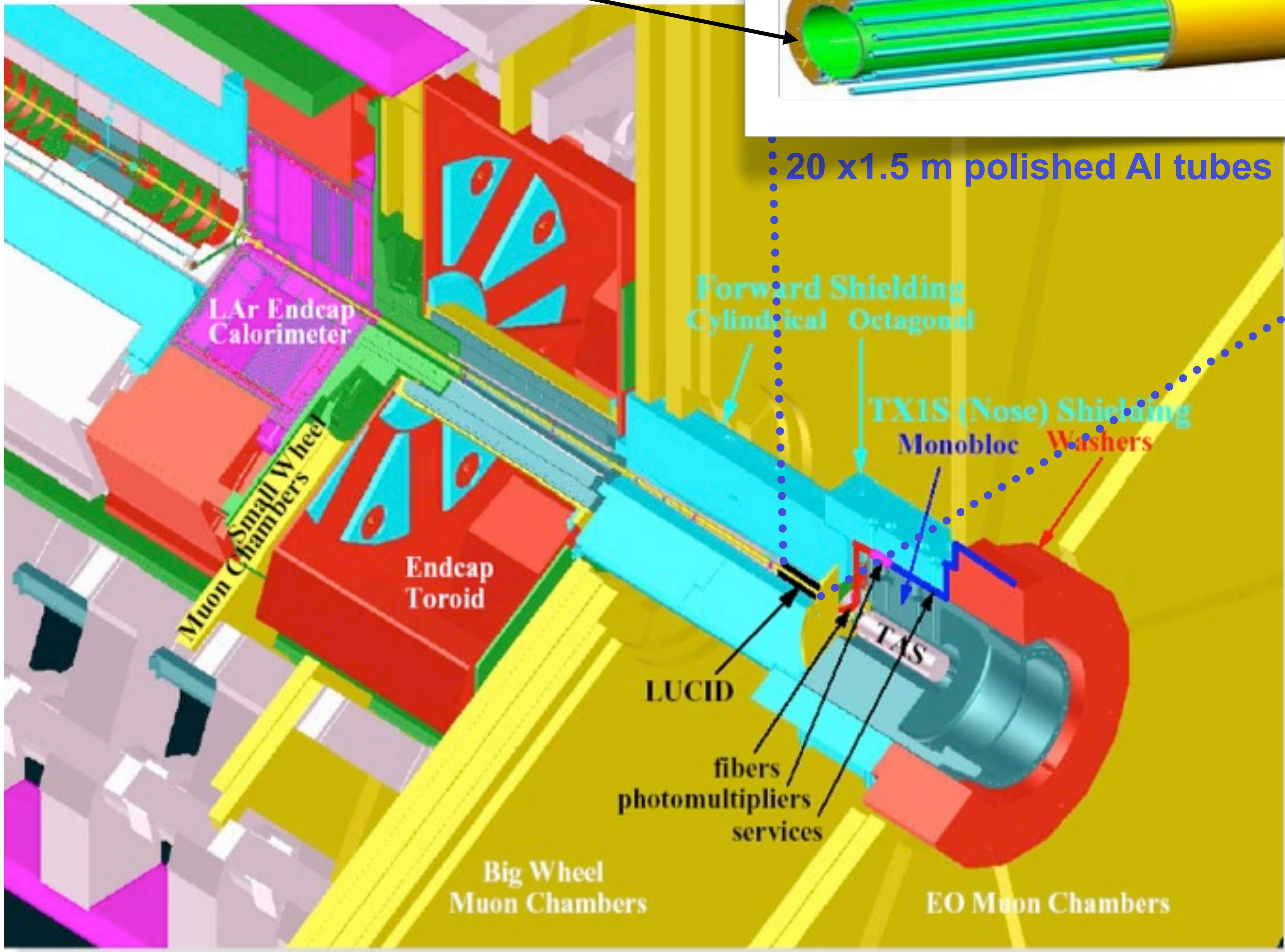
LUCID : "LUminosity measurement using Čerenkov Integrating Detector





Beam pipe

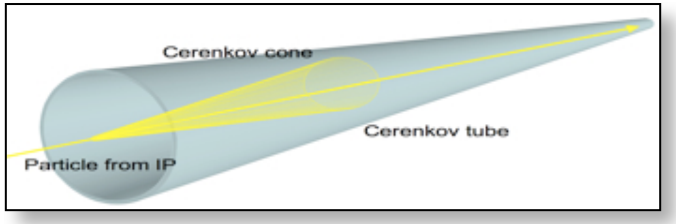
20 x1.5 m polished Al tubes (∅=1.5cm)

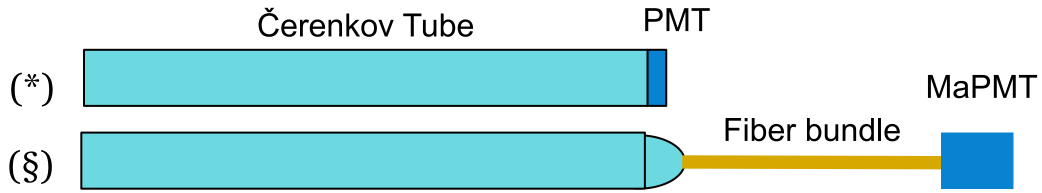


LUCID:

- is made of 2 modules located at 17 m from the interaction point on each side
- is sensitive to charged particles pointing to the primary pp collisions
- is designed to measure luminosity up to $L \sim 4\ 10^{33}\ cm^{-2}\ s^{-1}$

LUCID:Pointing Gas Čerenkov Counters





- Monitor instant. Luminosity:
  - Bunch-to-Bunch structure
  - beam degradation
  - indep. of LVL1 trigger
  - indep. of TDAQ
- Measure absolute Luminosity:
  - Needed for phys. analysis
  - final precision ~ 3-5%
- Forward Physics contribution
  - provide minimum bias trigger at high eta (Rapidity Gap)

Main parameters per module	
η coverage	±[5.6, 5.9]
N. Tubes	20
Material	Mechanic. polished Al
Gas	C4F10
Pressure	1.1-1.5 bar
Cherenkov angle	3°
<N. reflections>	3
Ch. threshold	*e*-: 10 MeV π: 2.8 GeV
Signal duration	Few *ns*
Read-out	16 PMTs (*) + 4 fibres (§)
Expected dose	7 Mrad/y @ 10^{34} cm^{-2}s^{-1}

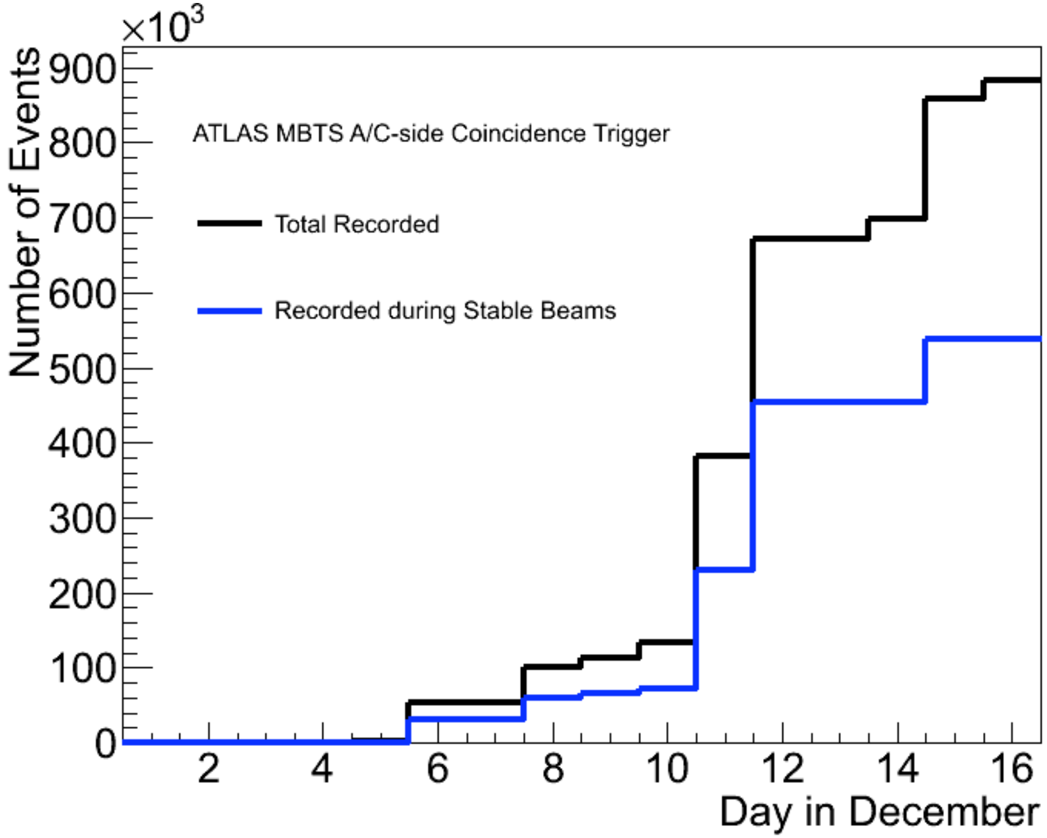
Lucid performances with the early data

- LUCID is in a stable working condition
- The response of the two modules are equalised
- The OR trigger signal is sensitive to the beam background
  - good for background studies
- The AND trigger signal is quite insensitive to the beam background
  - good to monitor luminosity

Minimum Bias Trigger Scintillator

- Wedge-shaped plastic scintillators installed on the front face of LAr end-cap cryostat
- Each scintillator cover $\Delta\phi = 2\pi/8$ and consist of two separated sections
- AIM: triggers on minimum bias events and vetos halo events during the commissioning phase
- Provides LVL1 trigger information and data to the ROS for triggered events
- Is able to count the minimum bias trigger rate (sensitive to 1 MIP)

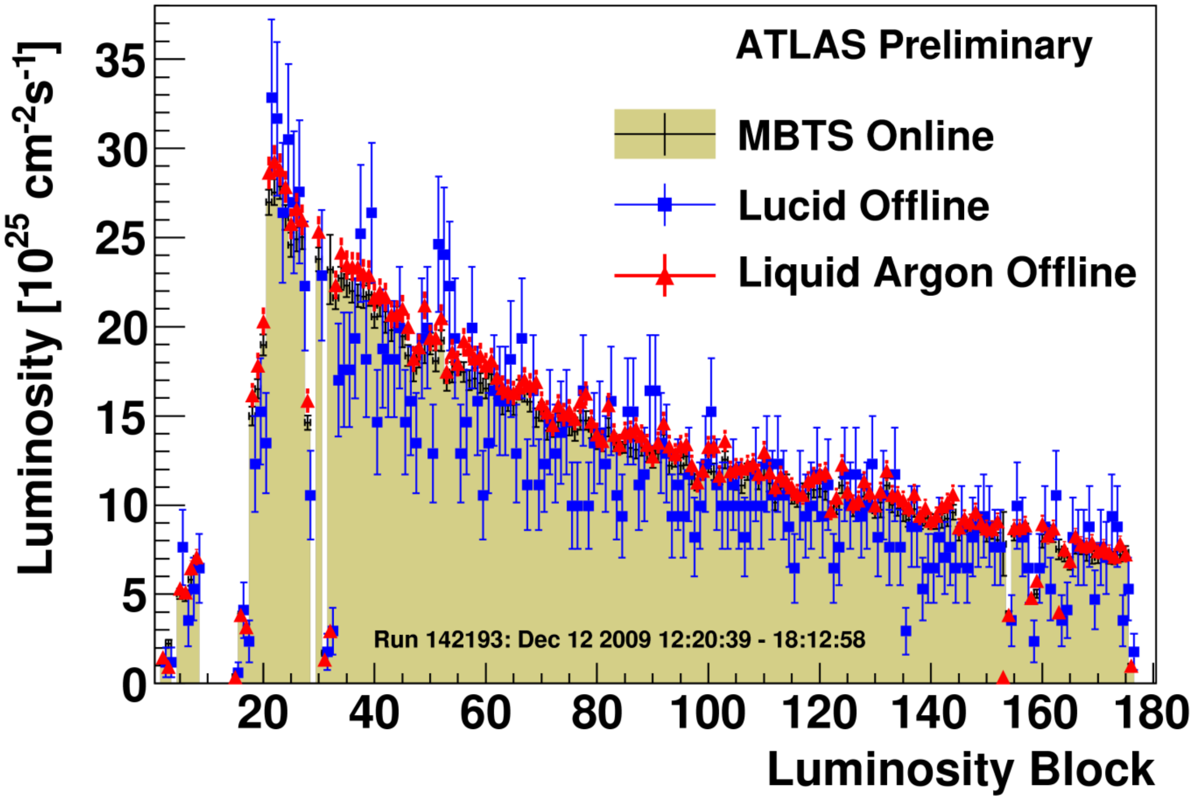
MBTS performances with the early data



- Efficiency of L1_MBTS_1_1 for collisions about 85%
- Background from non-collision events about 10%

First Luminosity measurements

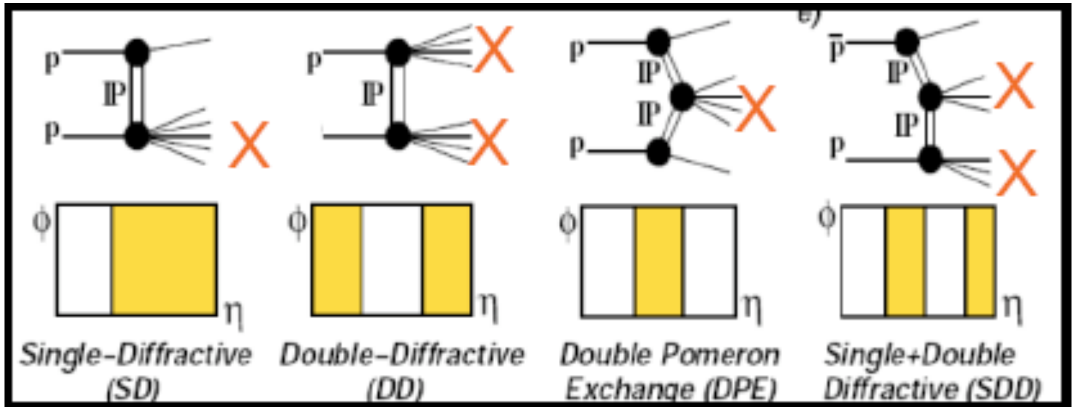
Instantaneous Luminosity for Run 142193: Comparison of 3 Methods



- See Jacob's talk for details
  (J. Groth-Jensen at this workshop)

Integrated Luminosity recorded by ATLAS: 20 μb^{-1}
During stable beams: 12 μb^{-1}
Max peak luminosity 7 10^{26} cm^{-2} s^{-1} Uncertainty about 30%

Diffraction



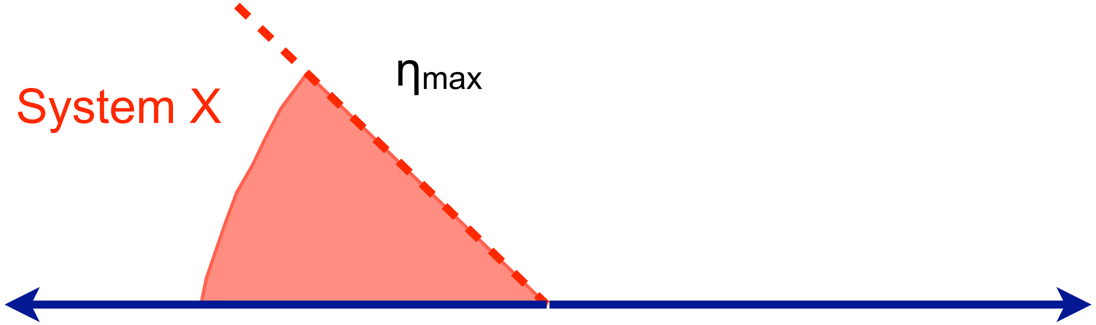
- SOFT Diffraction (SD)
  - Multi – parton interactions
- HARD Diffraction (HD): jets, W/Z, Higgs, etc.
  - Hard processes calculable with pQCD
  - Proton structure (PDF and GPD)
  - Discovery physics

Rapidity gaps pile-up contributions at high-luminosity

Soft diffraction

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

- The event is characterised by the ξ variable
- The aim is to reconstruct ξ on an event-by-event basis.
  - Appropriate gap definition
  - Noise suppression
  - Careful triggering ⇒ MBTS, LUCID, ZDC
  - Study of variables correlated with ξ ⇒ the minimum η of the system

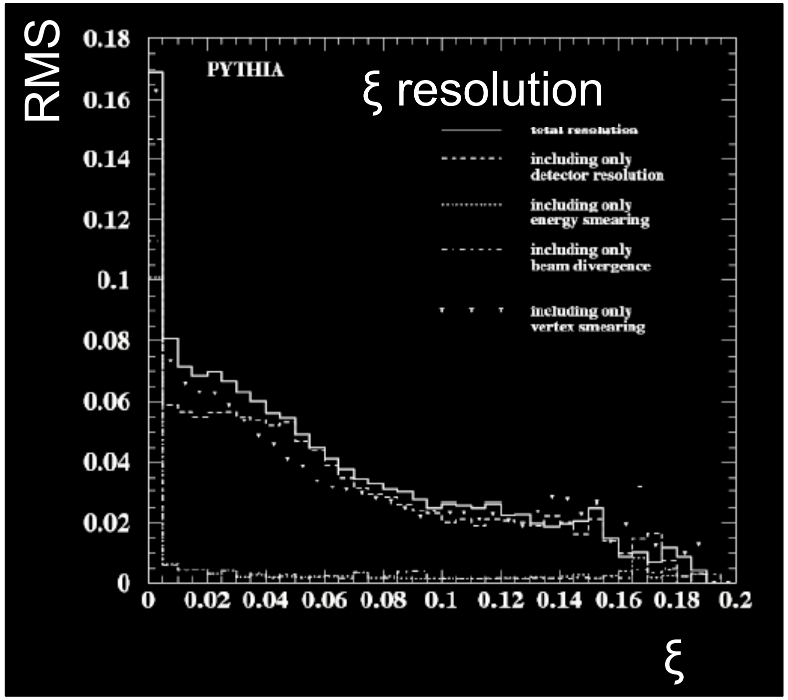


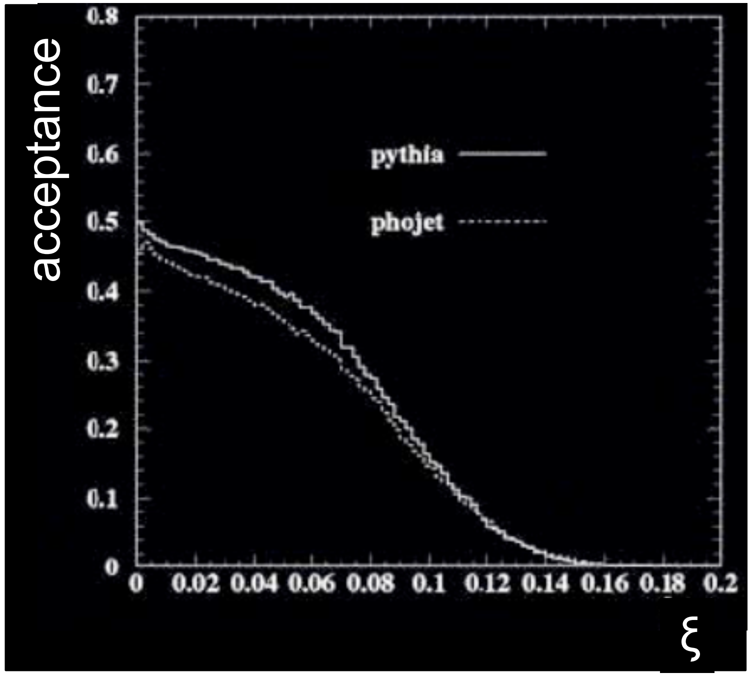
Studies at generator level, using the η ranges covered by forward detectors suggest a significant trigger efficiency even at low ξ and a good separation between single and double diffractive events.
However, even with low efficiency, we expect million of events!

~ 10^5 just recorded

Soft SD measurement with ALFA

- ALFA has good acceptance in dedicated runs for SD events
- Measure forward proton spectrum in the region 6.3 TeV < Ep < ~7 TeV

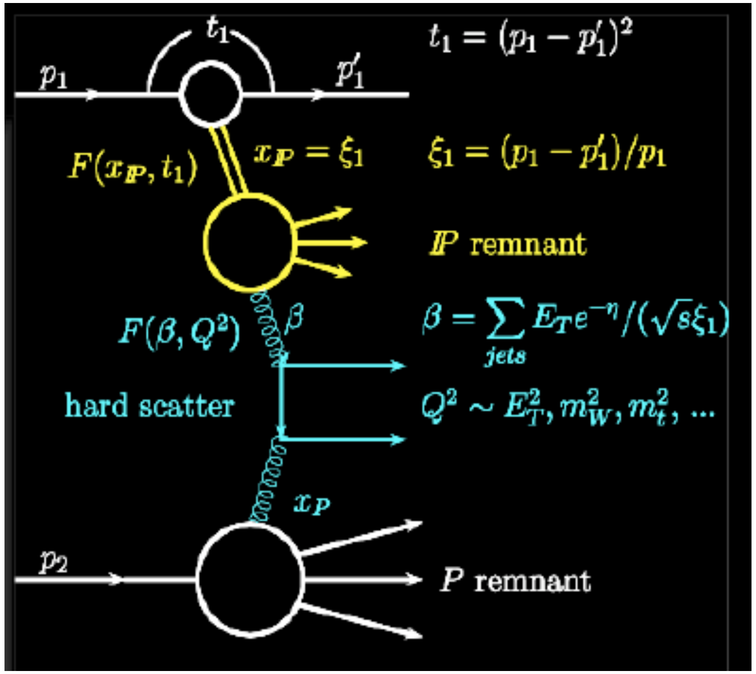




- SD measurements for $\xi < 0.01$
- Non-diffractive forward protons spectrum measurement for $0.01 < \xi < 0.1$
- Expect 1.2-1.8 M events in 100 hrs at $L=10^{27}$ $cm^{-2}s^{-1}$

Hard Single Diffraction

- Look for hard scattering events with gap on one side of the detector. Compare gap/non-gap ratio for soft survival
- Gap: LUCID/ZDC+ FCAL
- FCAL gap needed to restrict event to diffractive region (ξ<0.01)

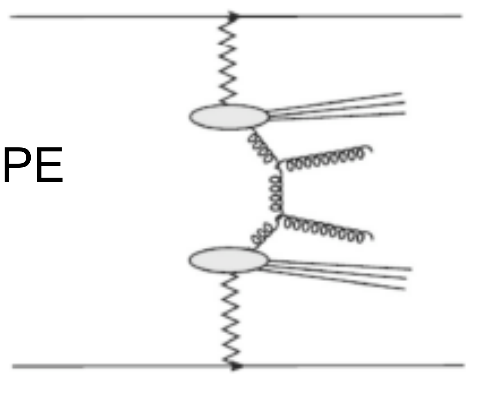


Simulations performed with the different Gap vetos (FCAL, LUCID, ZDC) as a function of Pt and cross section values.
Approximately 5000 (8000) SD di-jet events in 100 pb^{-1} with jet transverse energy > 20 (40) GeV after trigger pre-scale.

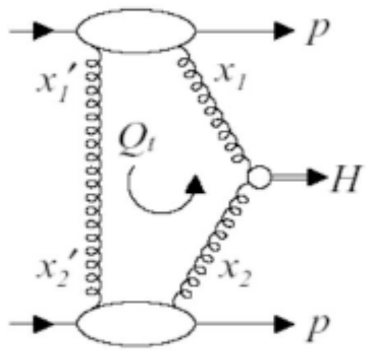
DPE and CEP measurements

- Look for two central jets with $|\eta| < 2.5$.
- Gap imposed on both sides of IP in MBTS, LUCID, ZDC
- Expect CEP cross section to be much larger than DPE for these criteria.
- Measurement of CEP di-jet production at 14TeV
  - to understand the structure of diffractive exchange by comparison with prediction from electron-proton data
  - to compare with Tevatron measurement to constrain theoretical model

DPE



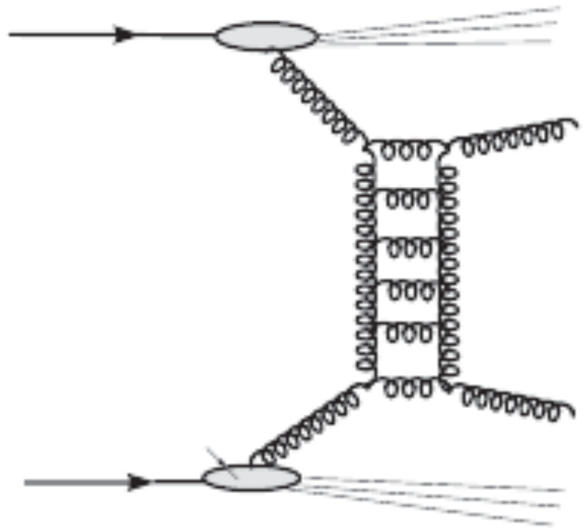
CEP

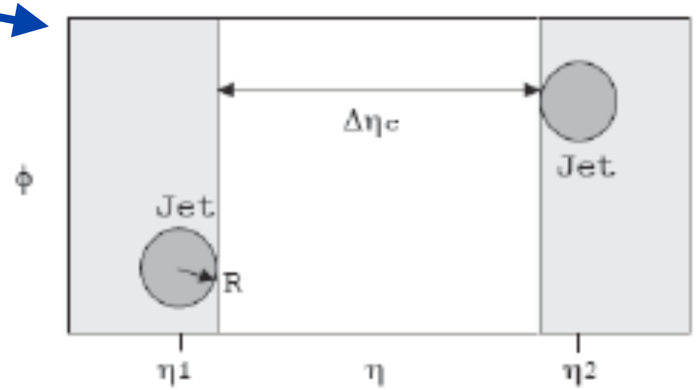


Few hundred events expected in 100 pb^{-1} with $E_T > 20GeV$

Gaps between jets

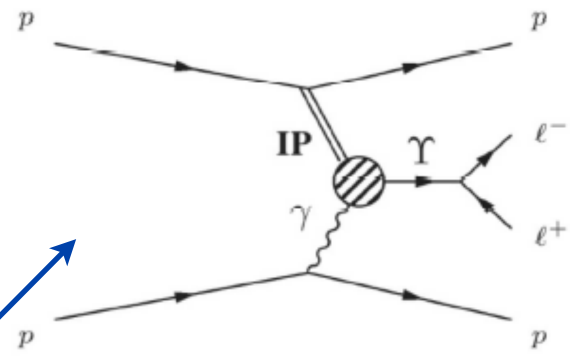
- Di-jet production via colour singlet exchange
  - background from single gluon exchange process.
- Require two jets, one in each forward calorimeter.
- Require gap in central calorimeter.
- ATLAS can make an improved measurement with increased CM energy and available phase space.

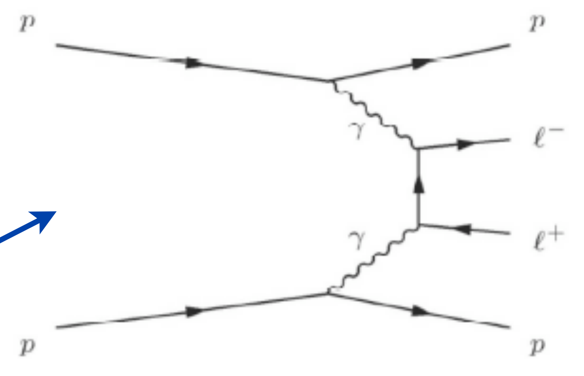




Photon induced muon pairs

- EXCLUSIVE Dileptons
  - Two isolated leptons back-to-back, balanced in p_T
  - Leptons derive from an exclusive vertex
  - Protons remain intact no other activity in the detector (FCAL, LUCID, ZDC)
- PROCESSES:
  - Photoproduction - lepton pairs through J/Ψ & ϒ resonances
  - Two photon production → non-resonant lepton pairs from $\gamma\gamma \rightarrow l^+l^-$



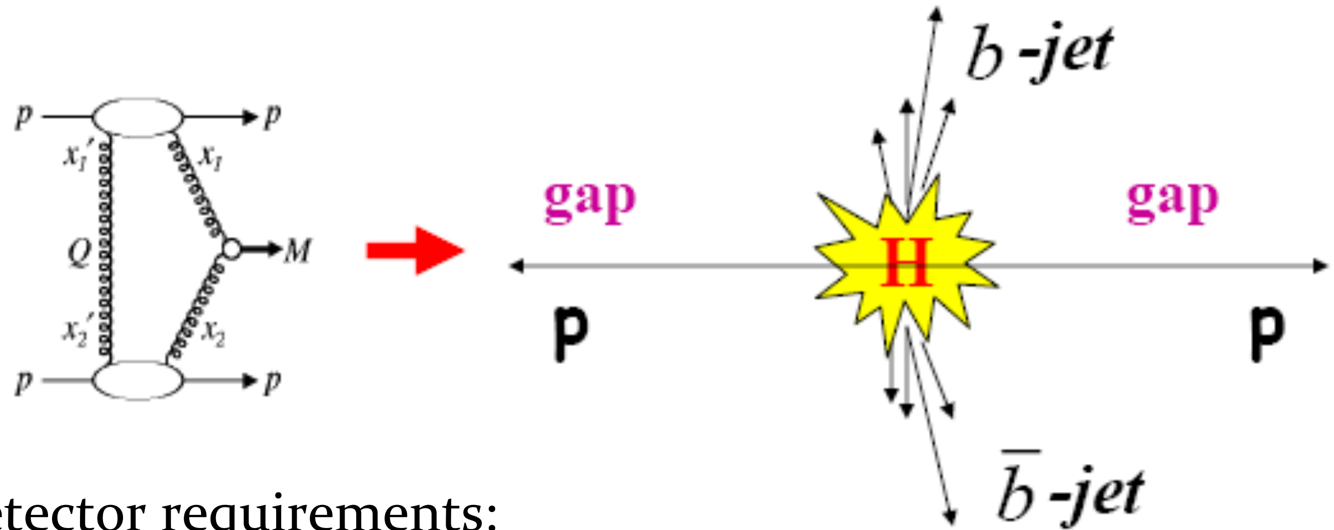


Simulation predict several hundreds two-photon and Upsilon events in the di-muon channel final selection for 100 pb^{-1}

AFP Upgrade: the idea

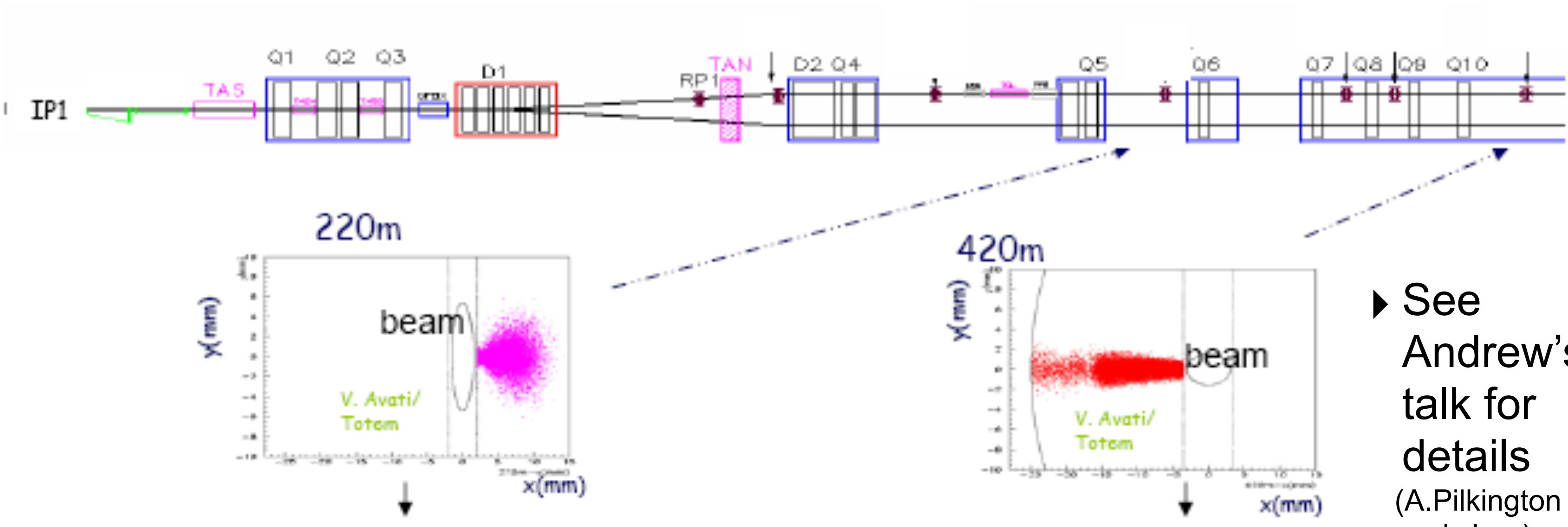
Measure forward protons on both side of the detector for CEP and DPE studies

Provide a trigger for the diffractive physics (LVL1 + HLT)



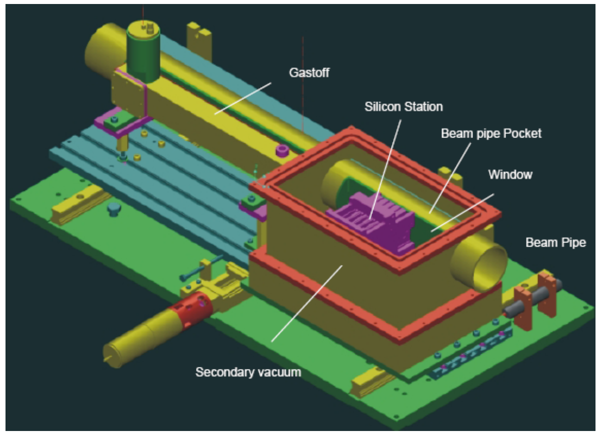
- Detector requirements:
  - Tracking system to detect and reconstruct the 2 leading protons (1μrad. angular resolution) ⇒Si detector
  - Timing system (10-20ps resolution) to identify the primary vertex ⇒Cerenkov photon detectors
  - Beam proximity ⇒ Radiation hardness

AFP a future possible Detector



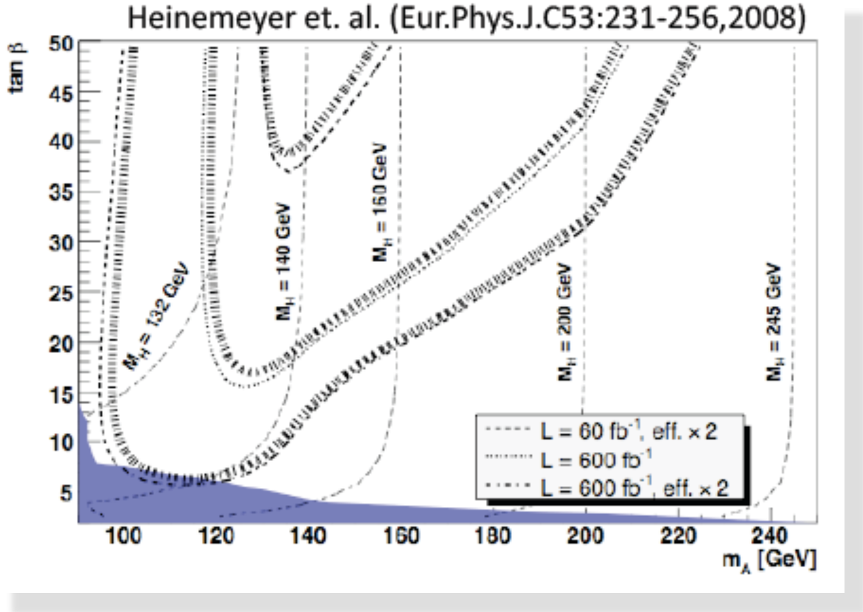
- See Andrew's talk for details
(A.Pilkington at this workshop)

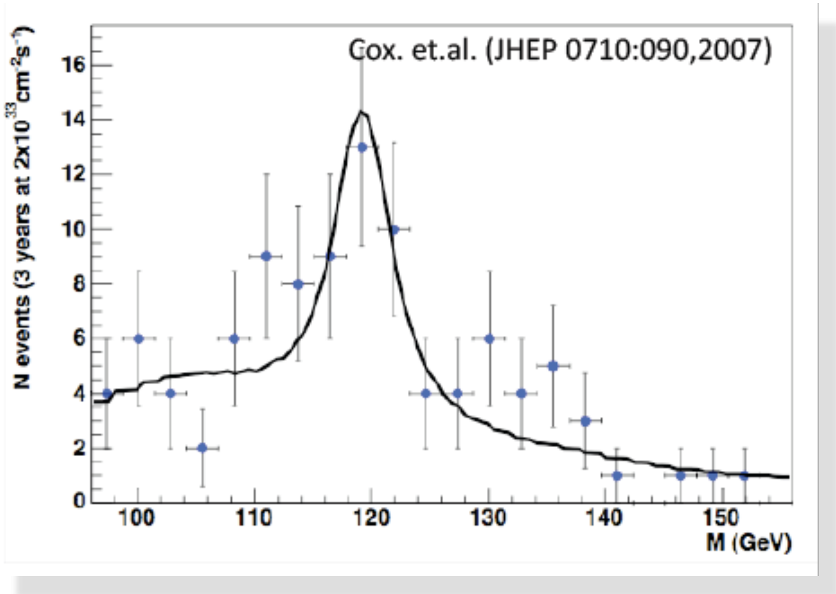
- Two stations at 220 and 420 m to detect leading protons, integrated in LHC
- Very good mass resolution for forward protons



VERY CHALLENGING!

AFP: the physics





- Main topics:
  - CEP Higgs Physics (H decays in SM, MSSM, NMSSM and other exotic models)
  - Photon-photon physics (slepton pair production, Anomalous gauge couplings, etc.)

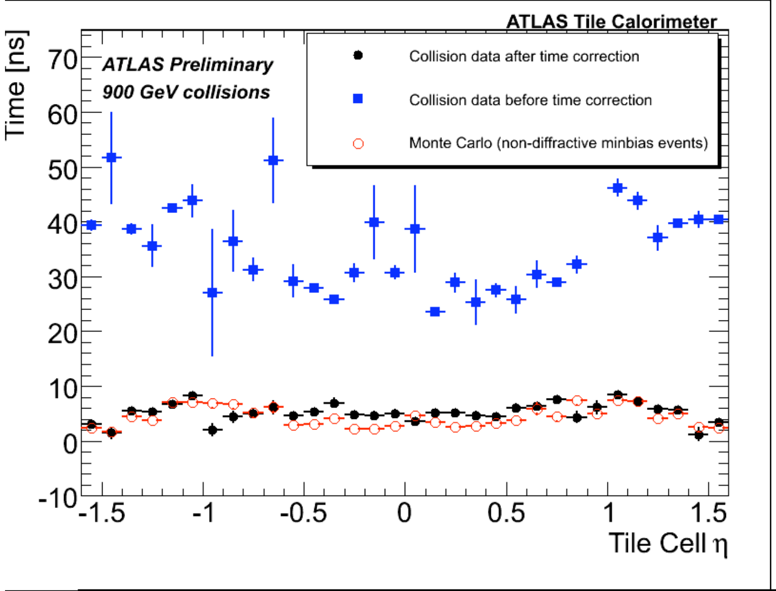
Trigger capabilities and final performances under investigation

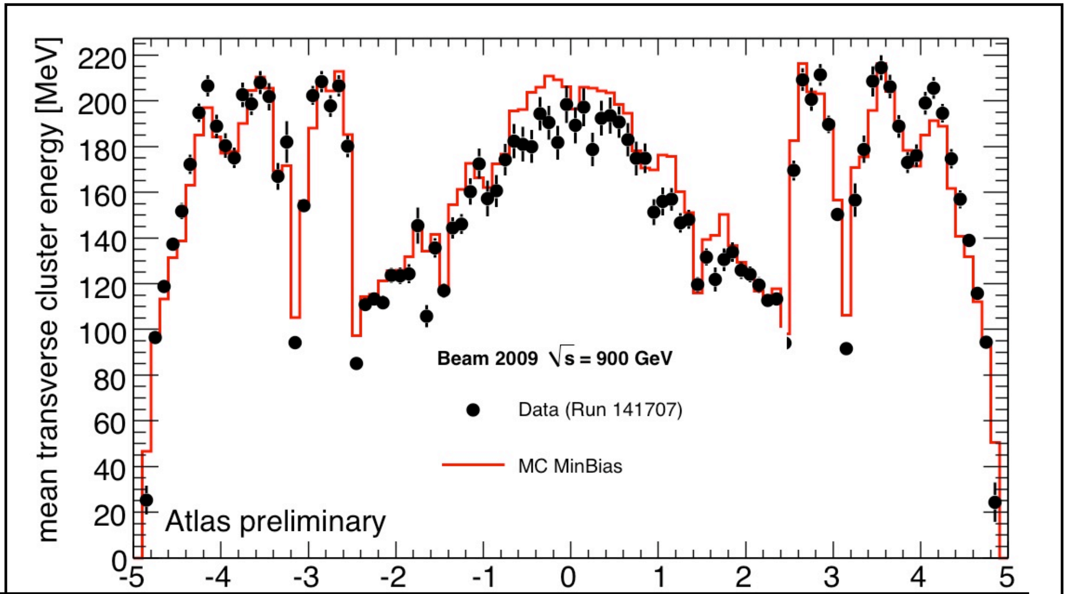
Conclusions

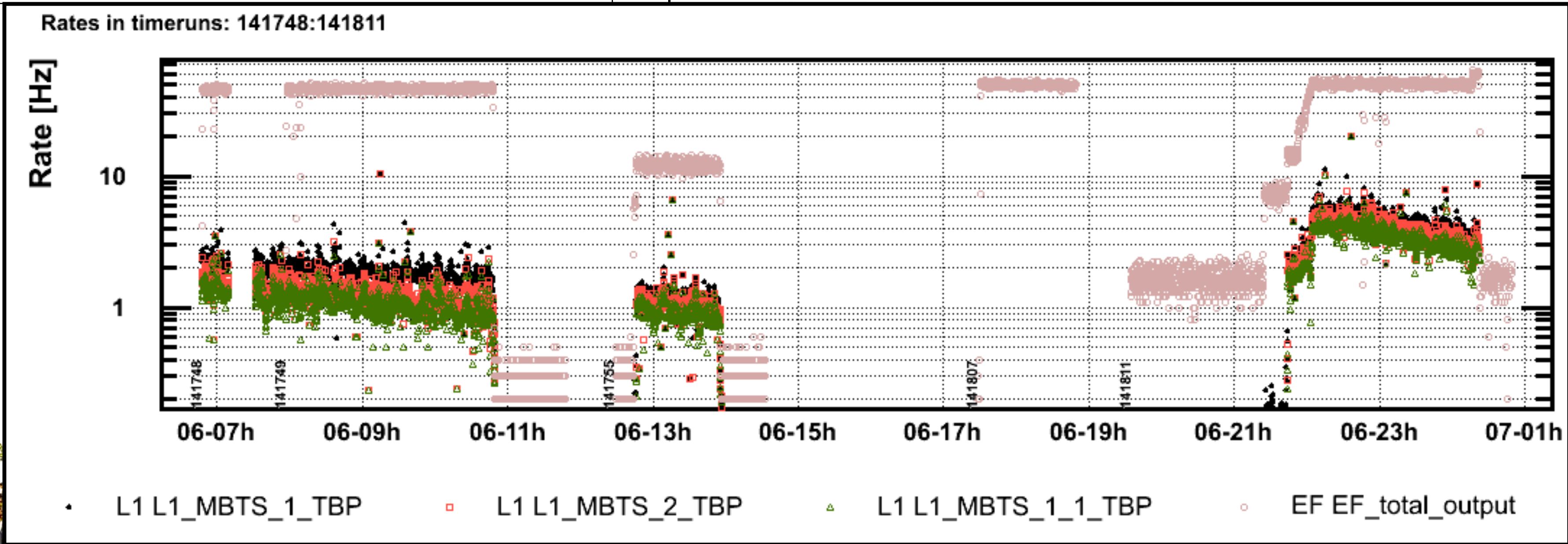
- First collisions produced by LHC detected with success. ATLAS is ready for physics!
- First measurements of luminosity are done, LUCID and ALFA will reach 5% accuracy.
- Forward Particle Spectrum:
  - ZDC → forward particle production
  - ZDC → forward spectators for heavy ion collisions and centrality measurements.
- Low luminosity physics:
  - Elastic scattering with ALFA
  - Single diffractive forward proton spectrum (ALFA).
  - Single diffractive di-jet and W production, double pomeron exchange and central exclusive production of di-jets (with rapidity gap veto in MBTS, LUCID, ZDC).
  - Gaps between jets as a probe of colour singlet exchange.
- High luminosity upgrade:
  - Possible upgrade (AFP project) installing photon and tracking detectors at 220m and 420m for CEP and DPE (under study)

Backup slides

ATLAS DATA



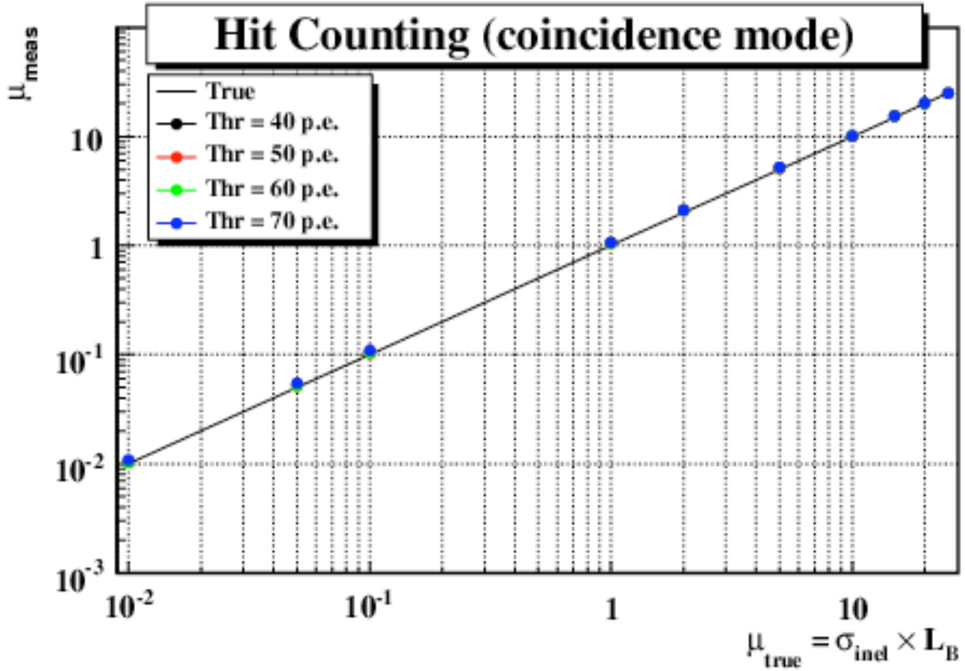




X vertex position, mm

Luminosity monitoring

- Average number of tracks per tube per event proportional to luminosity.
- Monitor bunch by bunch stability.
- Measure relative luminosity
- Calibration needed:
    - LHC machine parameters
    - Know reactions e.g. Z,W
    - ALFA calibration in special runs



$$\mu_{MEAS} = \frac{\langle M \rangle}{\langle N \rangle \bullet \varepsilon} = L \times \sigma_{inel} \Rightarrow L = \frac{\langle M \rangle}{\langle N \rangle \bullet \varepsilon \bullet \sigma_{inel}}$$

μ = average number of interactions per bunch crossing

<*M*> = average # of charged particles per bunch crossing

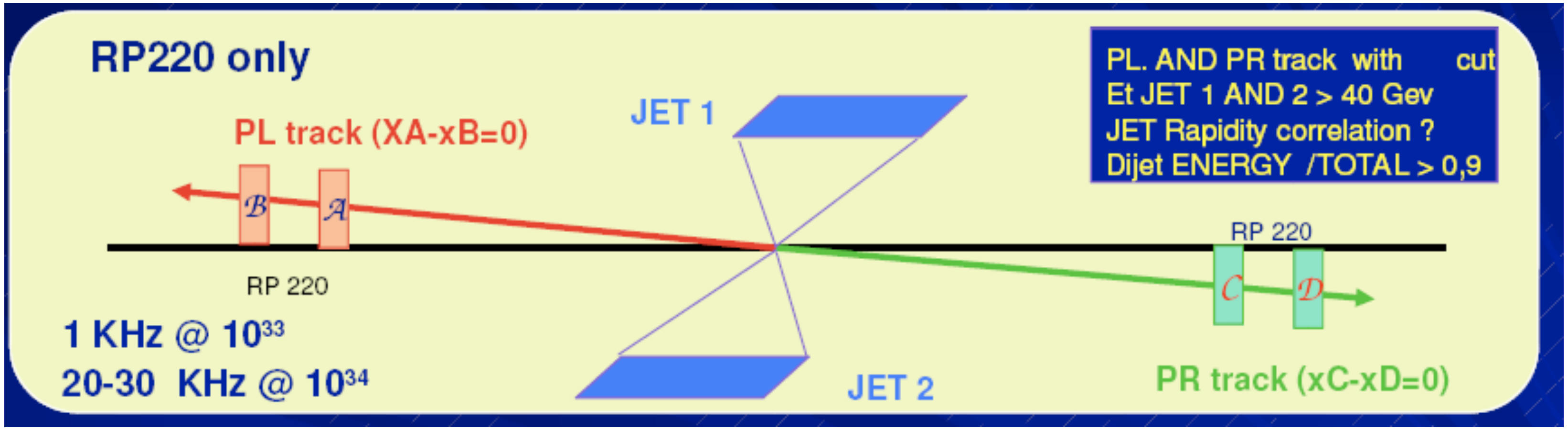
<*N*> = average number of particles per interaction

ε = interaction efficiency

σ_{inel} = inelastic cross section

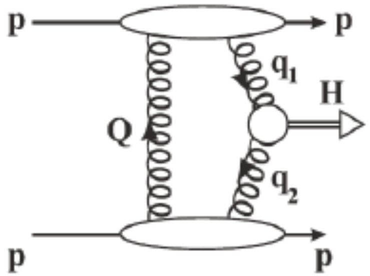
AFp Trigger

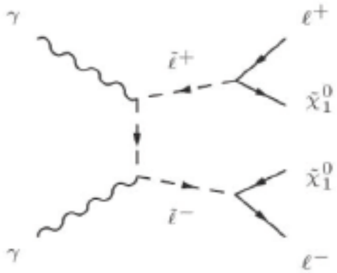
Trigger scheme (LVL1 + HLT):
LVL1: high Pt in central region + signals at both 220 stations



Quoted latency for LVL1 trigger: 1921 ns (with some uncertainties) → At the limit
Large LVL1 bandwidth (~30%) @ 10^{34} $cm^{-2}s^{-1}$

Physics case





- Two new-physics production processes : CEP and γγ

- CEP leads to quantum number selection rules / high precision mass measurement irrespective of decay channel / bb channel open in wide range of MSSM scenarios

- In MSSM, very important that pseudo-scalar production heavily suppressed, important in scenarios where scalar and pseudo-scalar masses are close

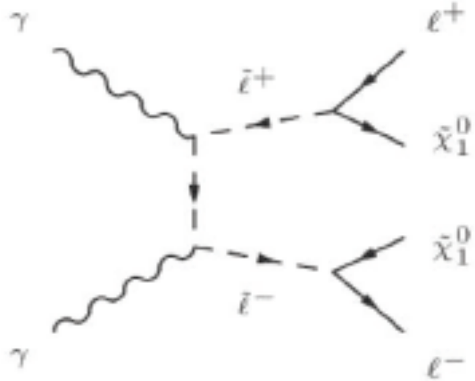
- γγ production very large, theoretically well known cross sections for SM and BSM processes: SUSY production, anomalous gauge couplings

- Wide "bread and butter" physics program in QCD and photoproduction

- Useful service tasks including high precision calibration of jet energy scale

Other Physics goals

• Two new-physics production processes : CEP and γγ
• CEP leads to quantum number selection rules / high precision mass measurement irrespective of decay channel / bb channel open in wide range of MSSM scenarios



• In MSSM, very important that pseudo-scalar production heavily suppressed, important
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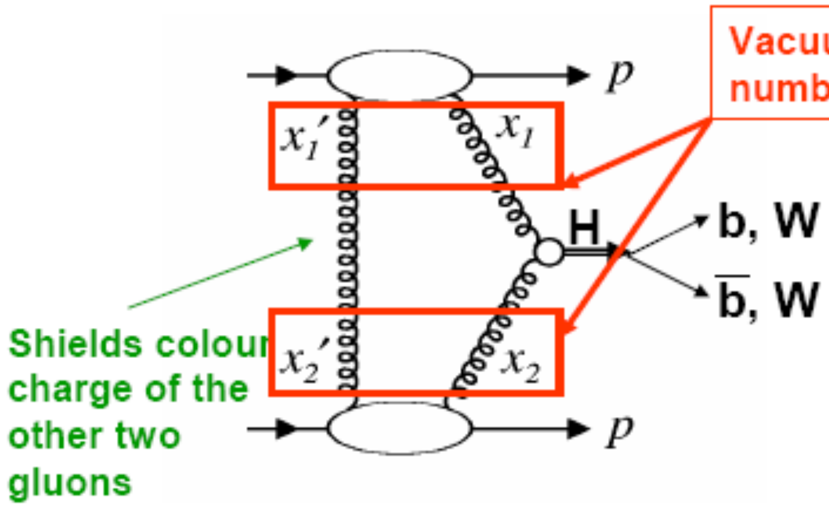
• γγ production very large, theoretically well known cross sections for SM and BSM processes: SUSY production, anomalous gauge couplings
• Wide "bread and butter" physics program in QCD and photoproduction
• Useful service tasks including high precision calibration of jet energy scale

Initial physics case

Central Exclusive Production (CEP) of the Higgs

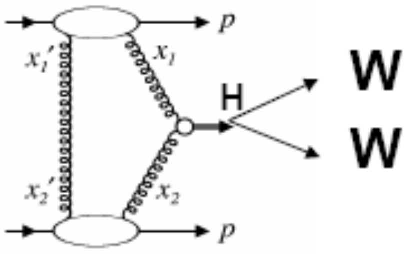


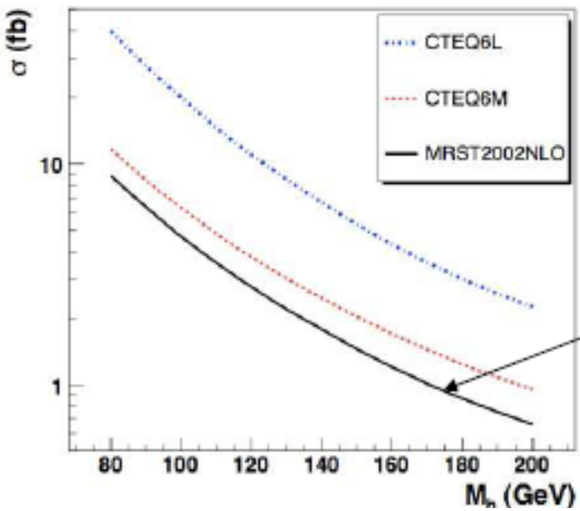
ξ: fractional momentum loss of proton – for 120 GeV Higgs, ξ~ 1%

- Khoze, Martin, Ryskin hep-ph/0002072
- J_z=0, C-even, P-even selection rule → central system is (to a good approx) 0^{++}
- If observe a new particle produced exclusively with proton tags its quantum numbers are known
- Missing mass from protons: excellent mass resolution (~ GeV) irrespective of decay products of the central system
- Attractive for M_H=120-250 GeV

•Look at SM, MSSM, NMSSM -- W, t, b decay channels

Higgs Physics





Take more conservative MRST PDFs

σ= 3 fb for M_H=120 GeV

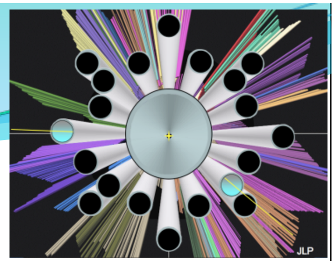
CEP calculation uncertain by a factor of 2-3

- CDF measurements in both di-photon and di-jet channels imply CEP cross section is at upper end of the theoretical uncertainty
- Overlap background has uncertainty due to lack of knowledge regarding underlying event activity at the LHC, total cross section, single-diffractive cross section

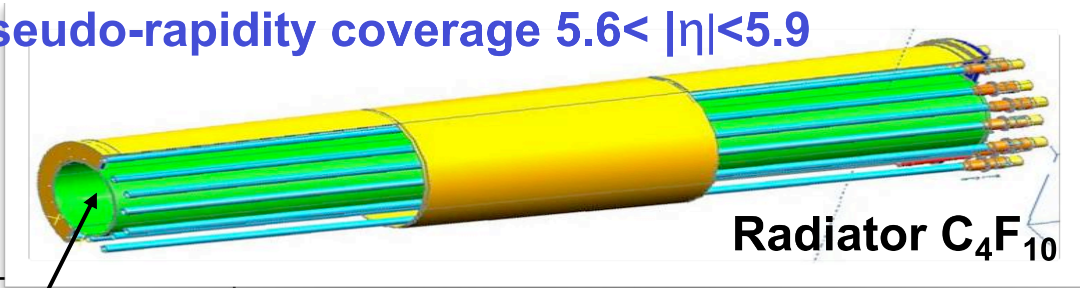
Forward Physics

- Beside the baseline "classic" physics program of the ATLAS experiment (Higgs, SM, etc.) there are many topics in forward physics which can be addressed
- In general to be effective, dedicated detectors and a data taking strategy (parallel running or dedicated runs, priority etc.) are needed
- Physics achievable in the present configuration
- Possible future measurements →Upgrade

LUCID: where and why

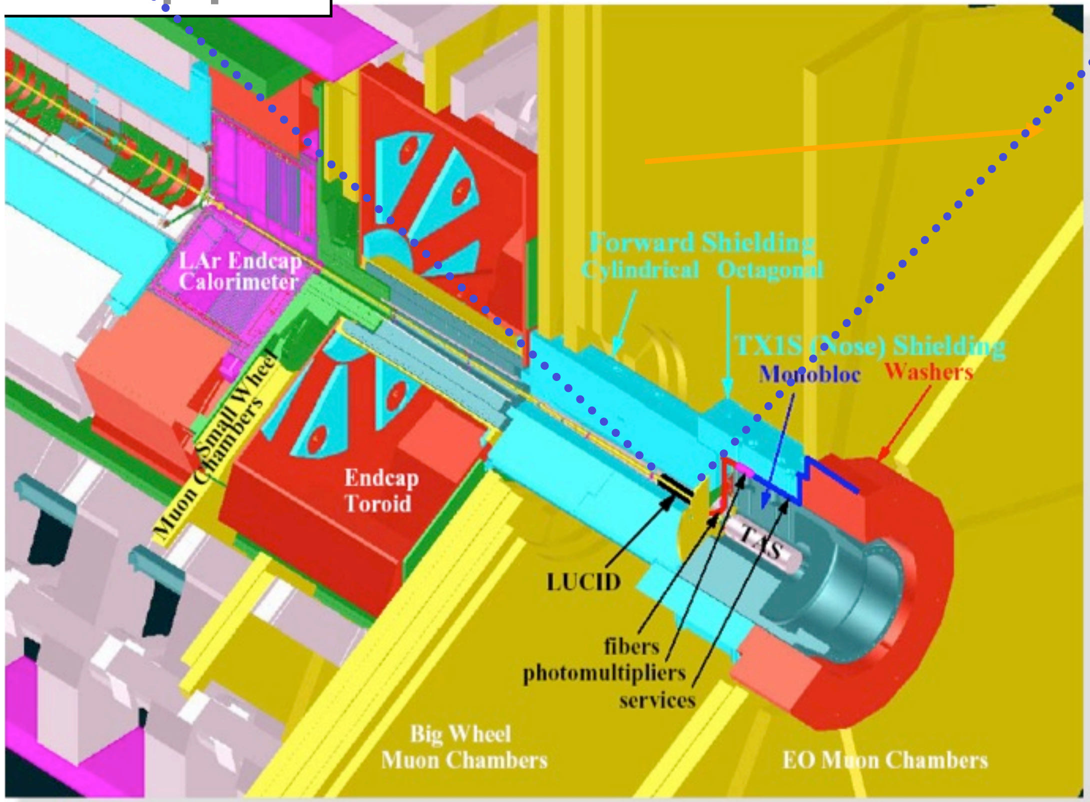


Pseudo-rapidity coverage 5.6< |η|<5.9



Beam pipe

20 x1.5 m polished Al tubes (∅=1.5cm)



Monitor instant. L:
- BC-to-BC structure
- beam degradation
- indep. of LVL1 trigger
- indep. of TDAQ

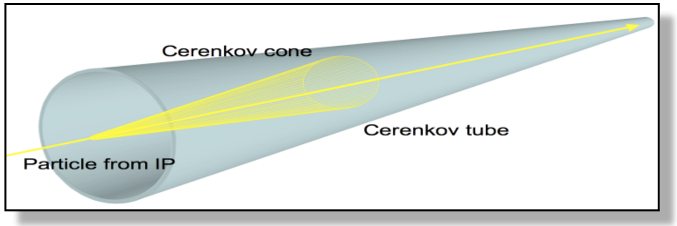
➡Requirements:
- relative L sufficient
- fast response (single BC)
- online monitoring

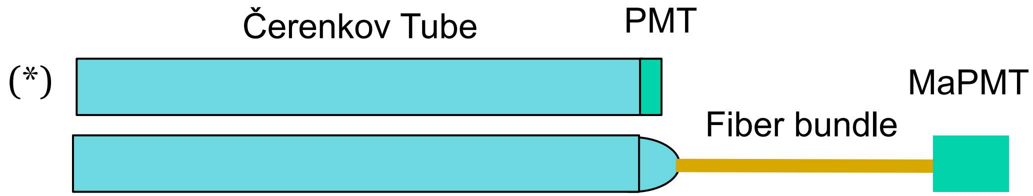
Measure absolute L :
- Needed for phys. analysis

➡Requirements:
- calibration needed
- final precision ~ 2-3%

Physics capability:
- provide trigger for MB and Forw.Phys. (Rapidity Gap)

LUCID:Pointing Gas Čerenkov Counters





- 2 modules located at 17 m from the IP.
- Cherenkov tubes sensitive to charged particles pointing to the pp collisions.
- Two different readout techniques.
- Designed for up to L ~ 4 10^{33} cm^{-2} s^{-1}
- Need to be upgraded to work @ high lumi
  - → Rad hardness
  - → More η coverage

Forward Physics topics

- Elastic scattering
- Single diffraction (soft and hard)
  - Diffractive W/Z production
- Double diffraction
- Double Pomeron exchange
- Multi Pomeron exchange
- Central Exclusive Production (CEP)
- P-γ physics
- γ-γ physics