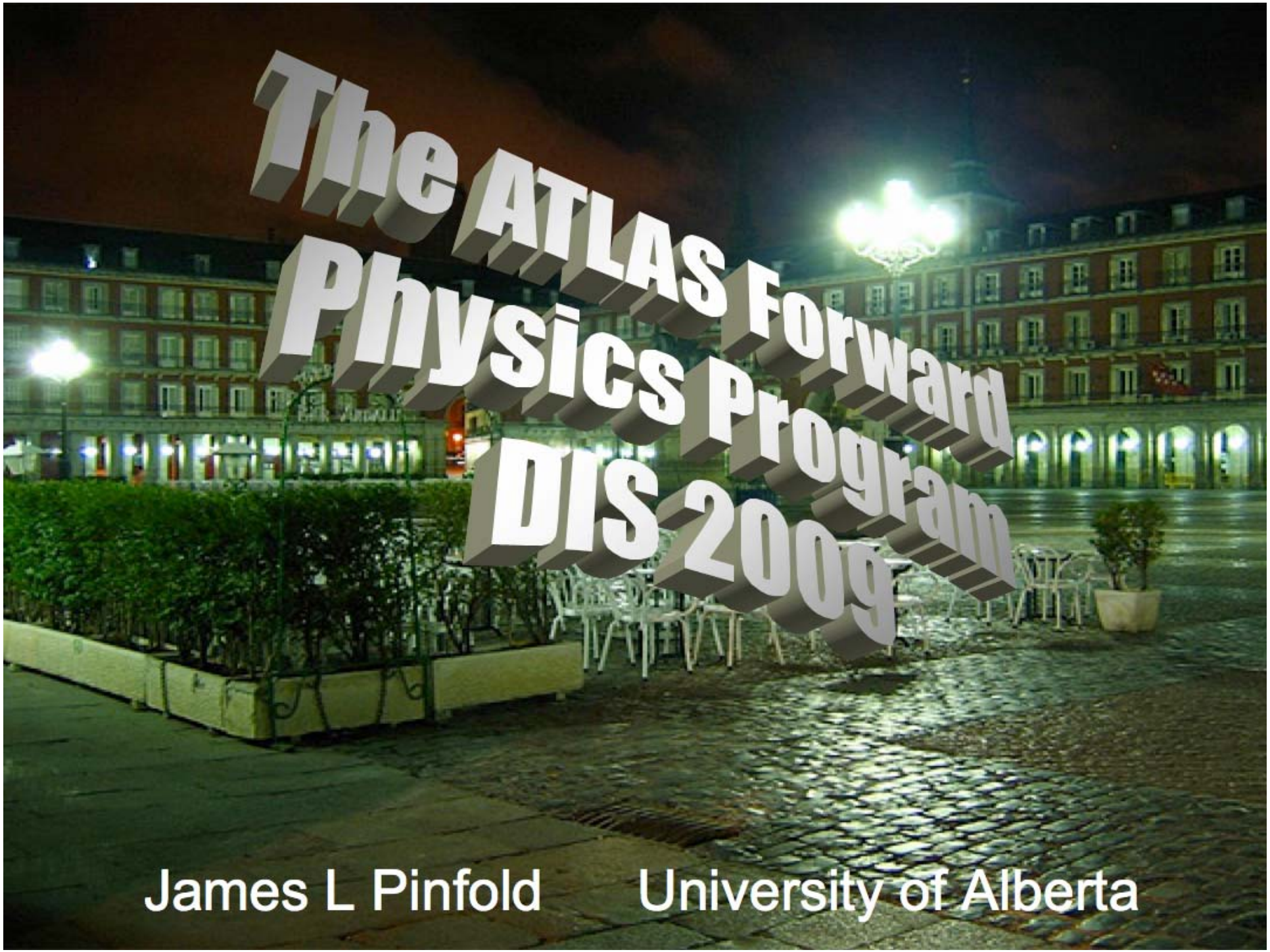
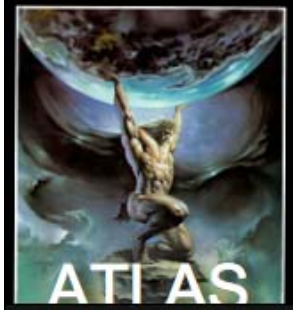
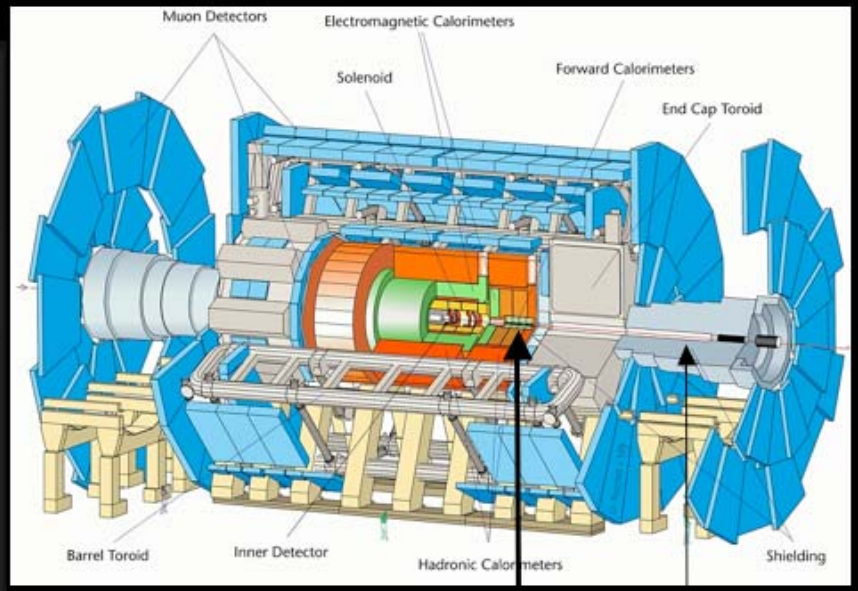
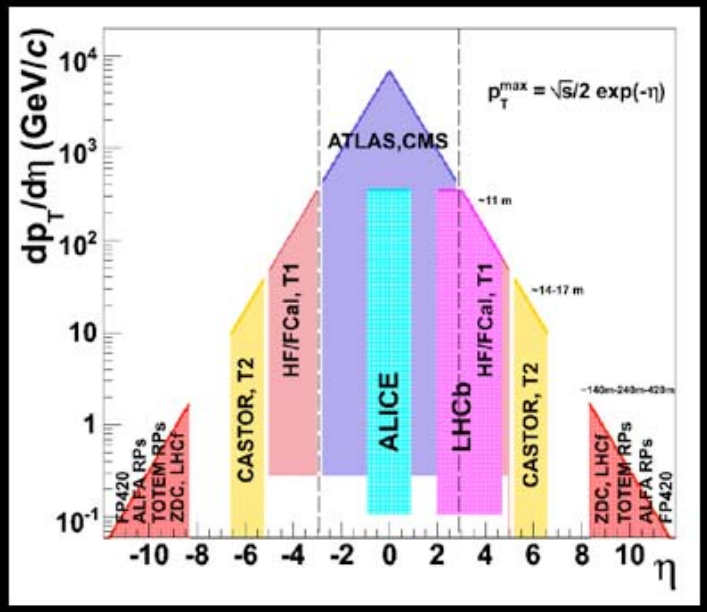

The ATLAS Forward Physics Program
DIS 2009
James L Pinfold
University of Alberta

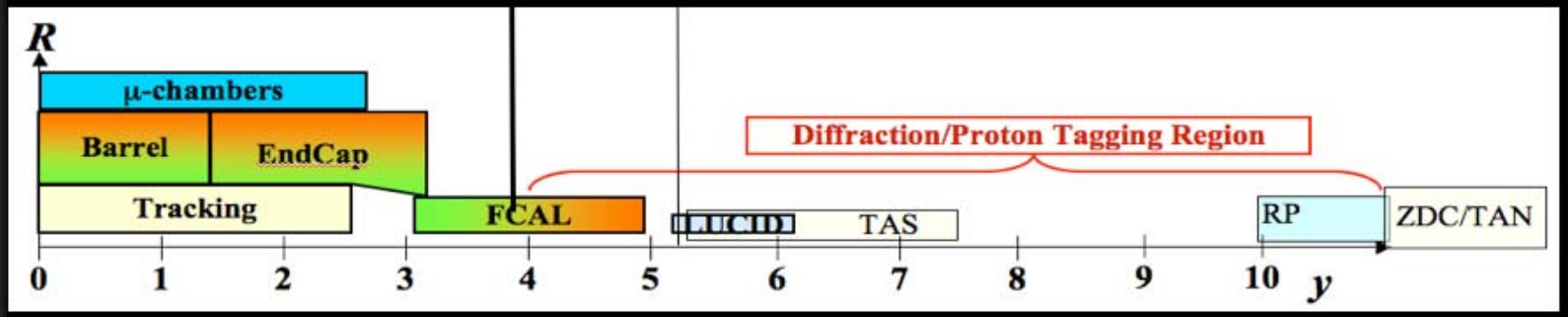
ATLAS-The Forward System



- Detectors
- QCD Physics Low lumi
- γγ/γp Physics Low lumi
- ZDC physics
- QCD High lumi
- γγ/γp Physics High lumi

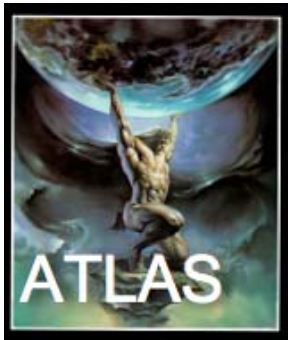




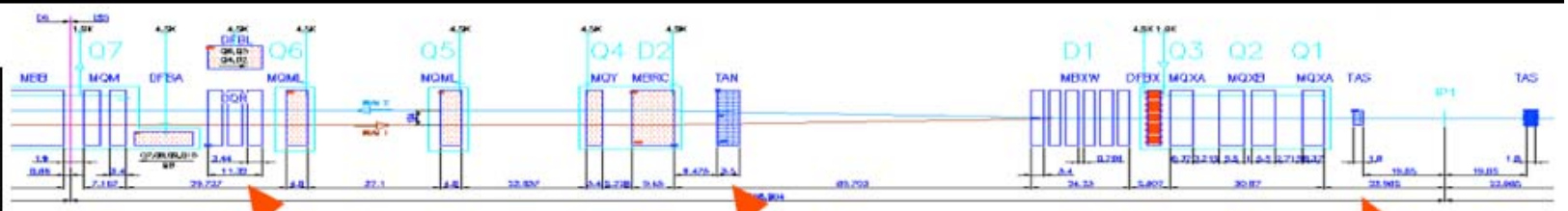


See talk by Laura FABBRI for details of ATLAS Forward Detectors

ATLAS-The Forward Detectors



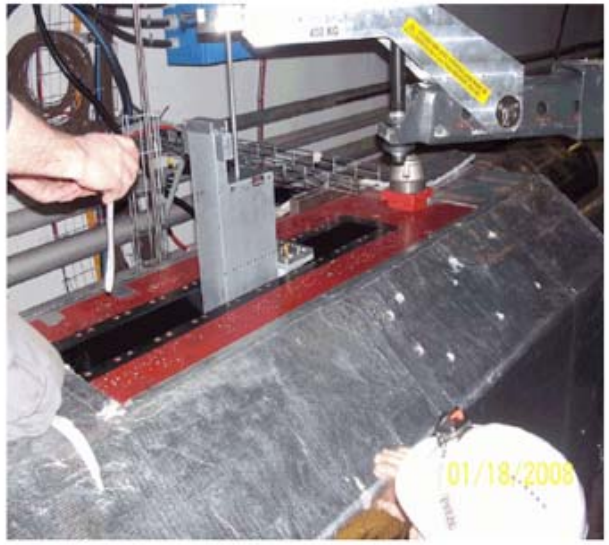
- Detectors
- QCD Physics Low lumi
- γγ/γp Physics Low lumi
- ZDC physics
- QCD High lumi
- γγ/γp Physics High lumi



ALFA at 240 m

Absolute Luminosity for ATLAS

ZDC at 140 m

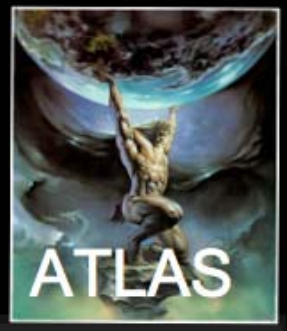


Zero Degree Calorimeter

LUCID at 17 m

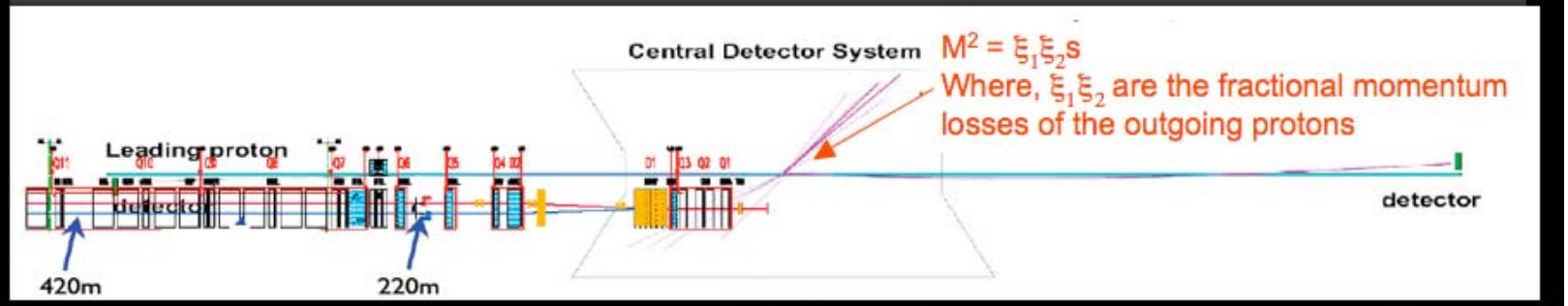
Luminosity Cerenkov Integrating Detector

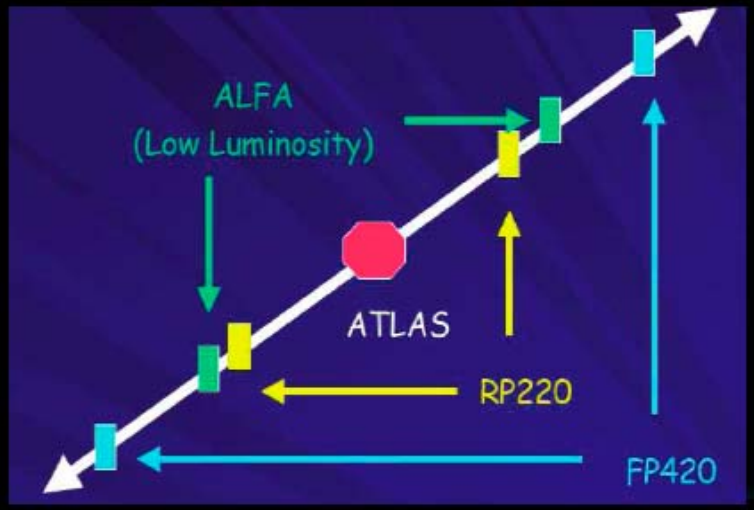
See talk by Laura FABBRI for details of ATLAS Forward Detectors

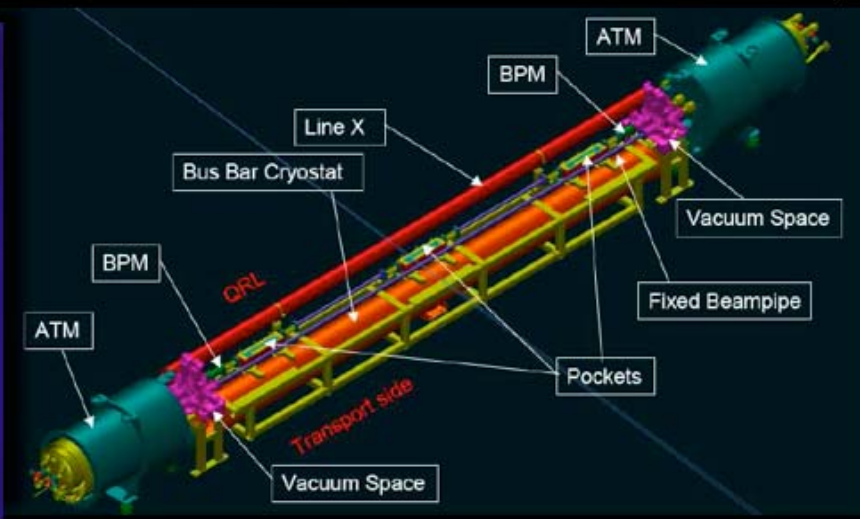


Plans for the Forward Region

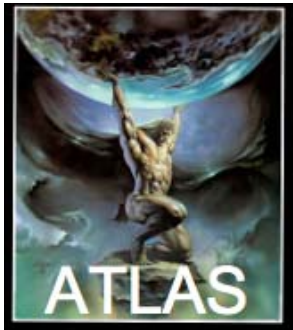
- Detectors
- QCD Physics Low lumi
- γγ/γp Physics Low lumi
- ZDC physics
- QCD High lumi
- γγ/γp Physics High lumi







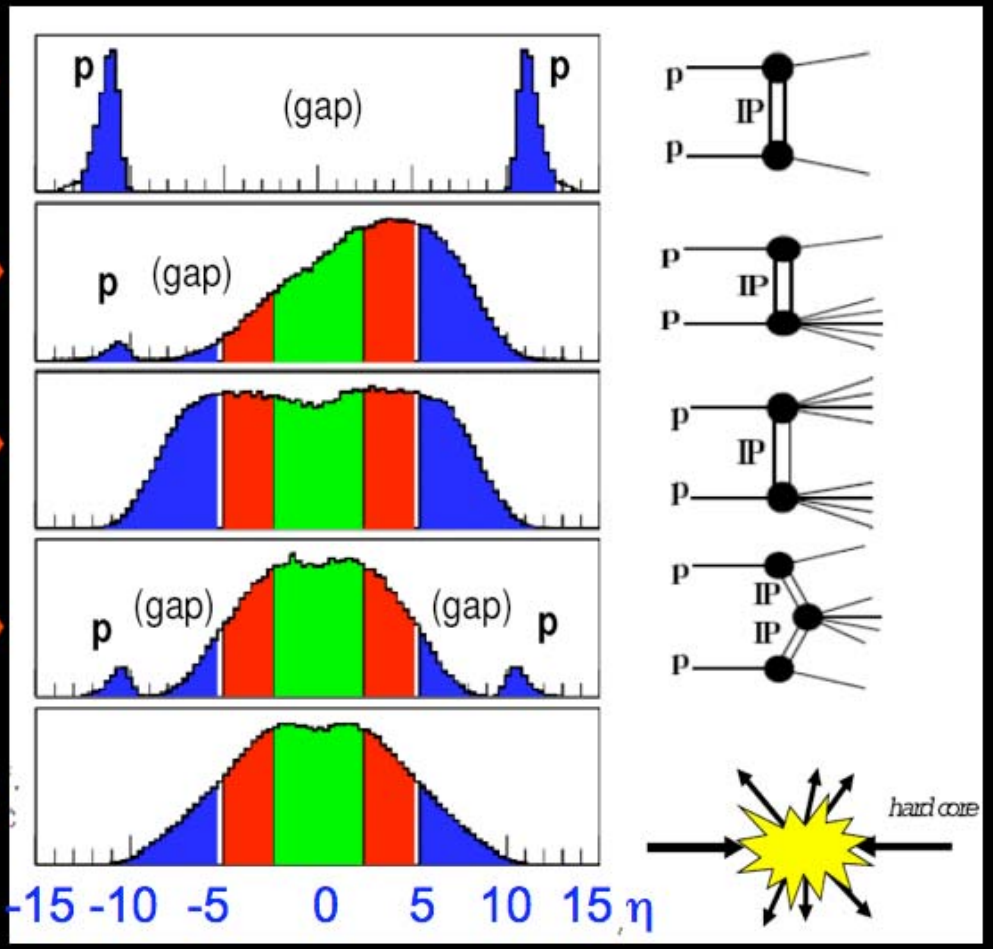
- *THE AFP PROJECT aims to create a precise forward proton spectrometer using Si trackers and fast-timing detectors deployed close to the beam at 220m & 420m from the IP.*
  - *Moveable beam pipe are used to locate detectors*



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 (σ_{tot} ~100 mb)*

  - *Elastic (25% of σ_{tot})*
  - *Single diffractive (10% of σ_{tot})*
  - *Double diffractive (~3% if σ_{tot})*
  - *Central diffractive DPE (~1% if σ_{tot})*
  - *Inelastic (non diffractive) (60% of σ_{tot})*



Detectors

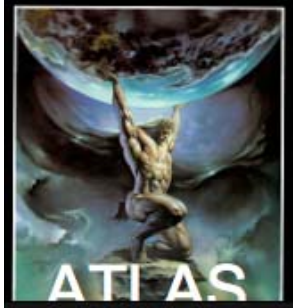
QCD Physics Low lumi

γγ/γp Physics Low lumi

ZDC physics

QCD High lumi

γγ/γp Physics High lumi



Detectors

QCD Physics Low lumi

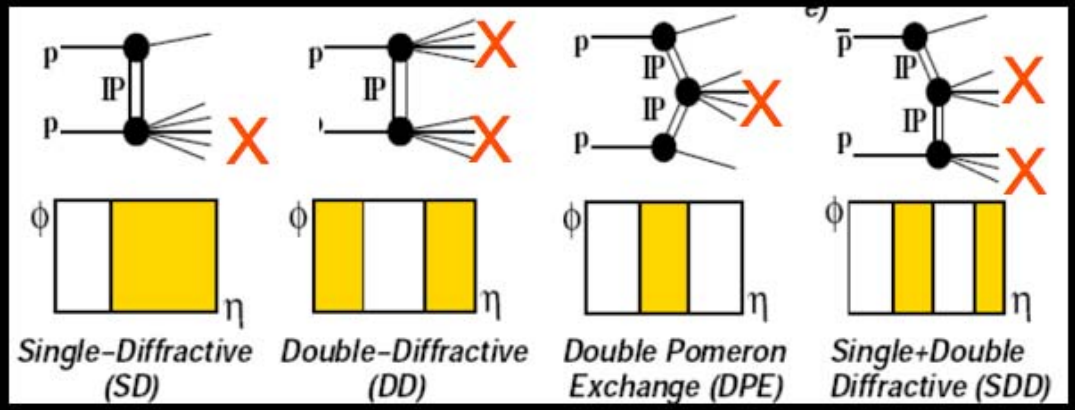
γγ/γp Physics Low lumi

ZDC physics

QCD High lumi

γγ/γp Physics High lumi

Diffraction

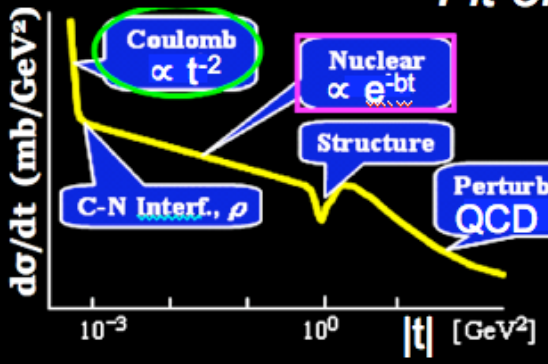


- *HARD DIFFRACTION: X = jets,Ws, Zs,Higgs, etc:*
  - *Hard processes calculable in pQCD*
  - *Info on proton structure: dPDFs and GPDs*
  - *Discovery physics (!)*
- *SOFT DIFFRACTION: X = anything, dominated by soft physics, important insights on npQCD:*
  - *Gap survival probability,*
  - *Multi-parton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

Absolute Lumi & σ_{tot}

- *USE ALFA TO STUDY ELASTIC SCATTERING in the Coulomb Nuclear Interference CNI region: L ~10^{27} $cm^{-2}s^{-1}$, large β^* optics (β^*=2625m, beam div.~0.2μrad)*

Fit of data gives --> σ_{tot}, L, ρ, b(ΔL/L ~3%)



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

CNI region: $|f_C| \sim |f_N| \rightarrow$ @ LHC: $-t \sim 6.5 \times 10^{-4}$ GeV²;
θ_{min}~3.4 μrad (θ_{min}~120 μrad @ SPS, UA4, precision 3%)

- *USE THE OPTICAL THEOREM as a complementary solution*

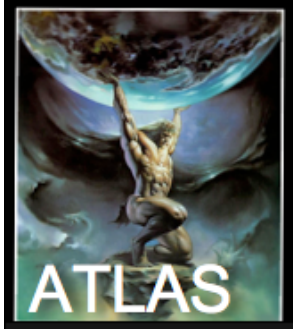
$$\begin{cases} L = \dfrac{(1+\rho^2)}{16\pi}\dfrac{N_{tot}^2}{\left.\frac{dN_{el}}{dt}\right|_{t=0}} \\ \sigma_{tot} = \dfrac{N_{tot}}{L} \end{cases}$$

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

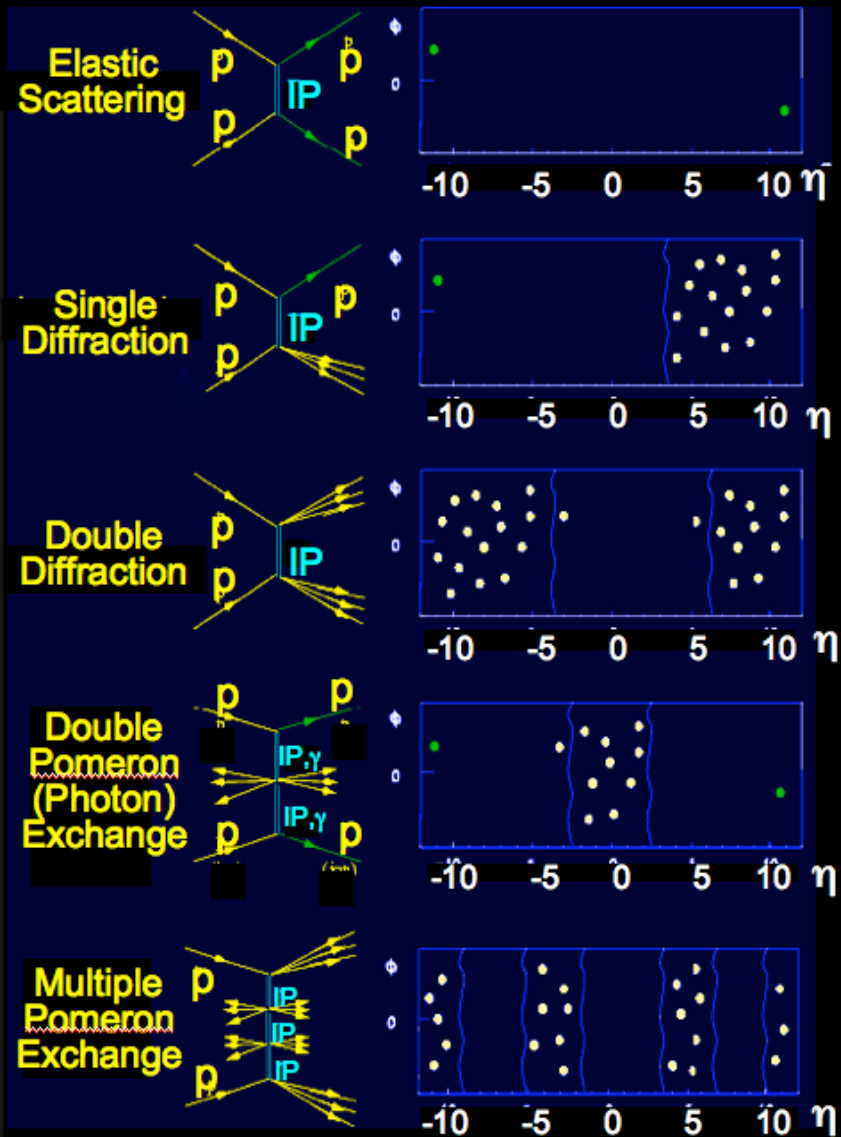
- *Provide high precision (2-3%) LUCID CALIBRATION*

N_{tot} is the total interaction rate

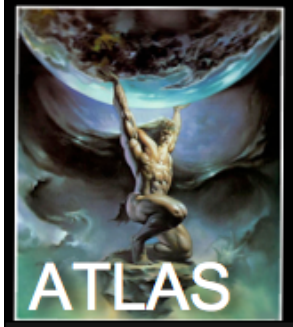
Diffraction - Detector Inputs



- Detectors
- QCD Physics Low lumi
- γγ/γp Physics Low lumi
- ZDC physics
- QCD High lumi
- γγ/γp 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*



Detectors

QCD Physics Low Lumi

γγ/γp Physics Low lumi

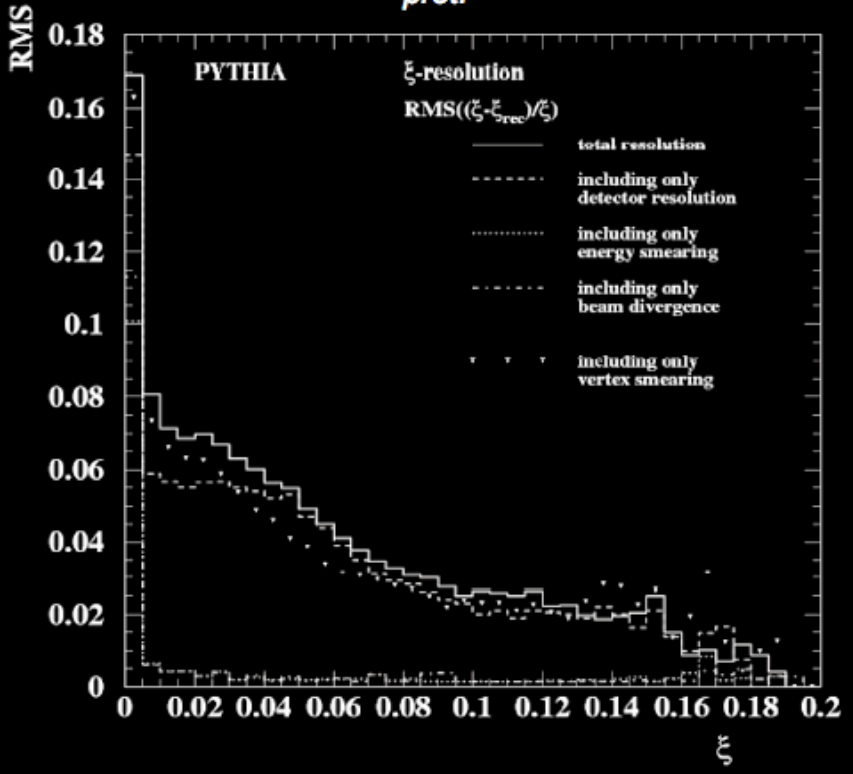
ZDC physics

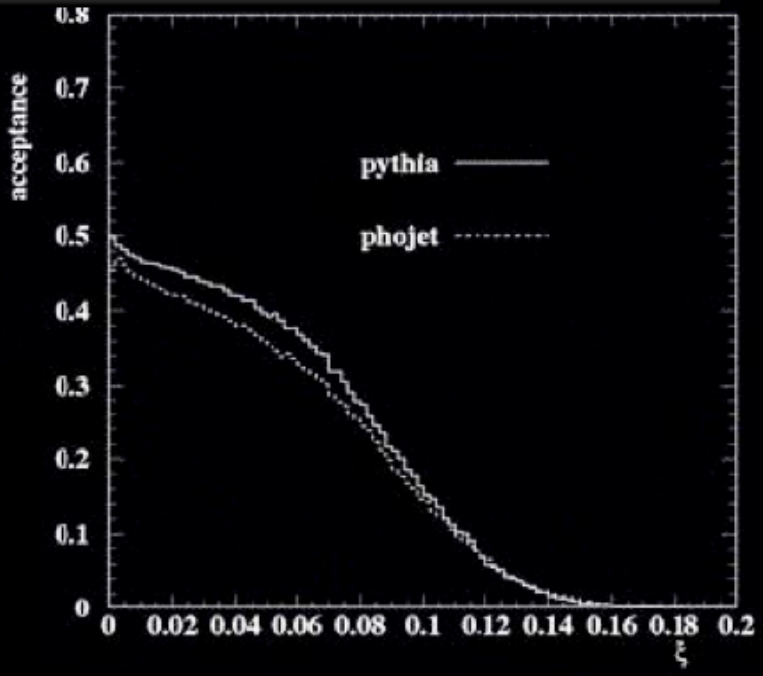
QCD High lumi

γγ/γp Physics High lumi

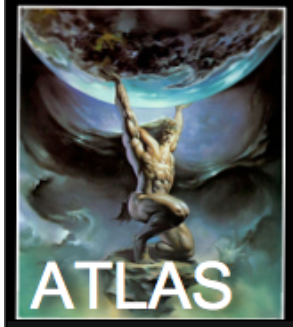
Soft SD with ALFA

- *ALFA has good acceptance (in special runs) for single diffractive (SD) events.*
  - *Measure forward proton spectrum in region 6.3 TeV < $E_{prot.}$ < 6.993 TeV*



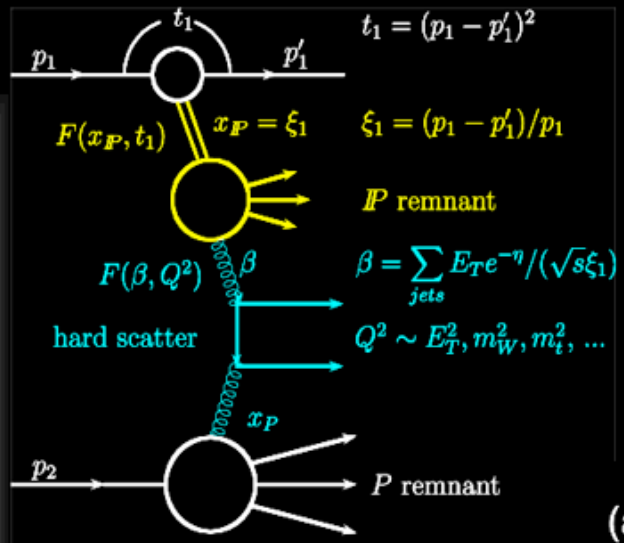


- *SD measurement for ξ<0.01.*
  - *Non-diffractive forward proton spectrum measurement for 0.01 < ξ < 0.1.*
- *Expect 1.2-1.8M events in 100hrs at L = 10^{27} cm^{-2} s^{-1}.*

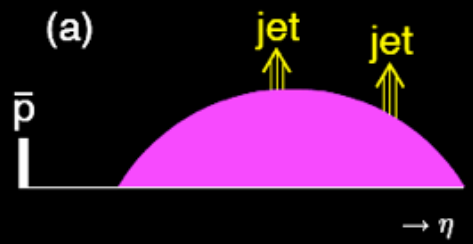


Hard Single Diffraction

Detectors
QCD Physics Low Lumi
γγ/γp Physics Low lumi
ZDC physics
QCD High lumi
γγ/γp Physics High lumi

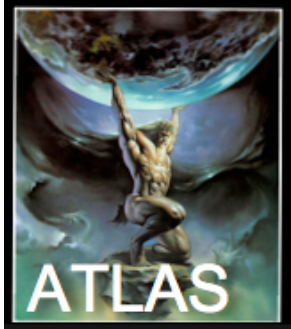


- *Look for hard scatter event with gap on one side of the detector.*
- *Compare gap/non-gap ratio to determine soft-survival.*
- *Gap defined by LUCID/ZDC + FCAL*



- *FCAL gap needed to restrict event to diffractive region (x_{pom}<0.01). e.g. di-jet production*
- *Of the order of 10K SD di-jet events in 100 pb^{-1} (~1.5 years at 10^{31} cm^{-2} s^{-1}) with jet transverse energy > 20 (40) GeV after trigger pre-scale.*

Trigger prescale 6000 (100) at L=10^{31} cm^{-2} s^{-1} for jet E_T > 10(42) GeV



Detectors

QCD Physics Low Lumi

γγ/γp Physics Low lumi

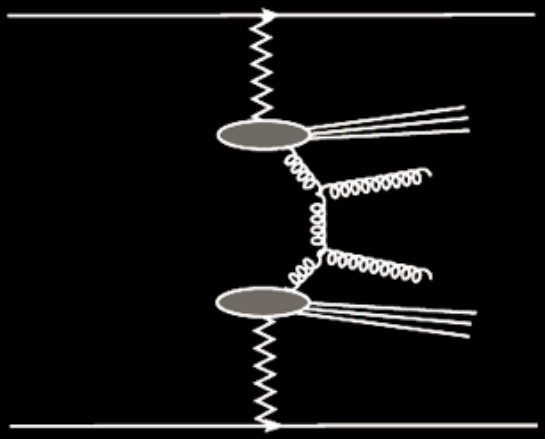
ZDC physics

QCD High lumi

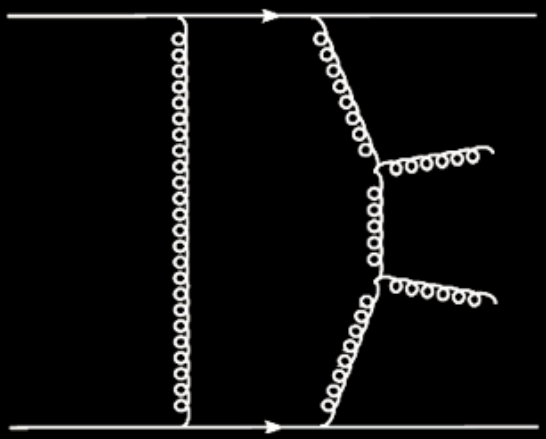
γγ/γp Physics High lumi

DPE/CEP

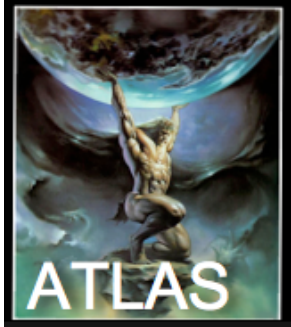
DPE



CEP



- *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.*
- *Measurement of CEP dijet production at 14TeV. Compare with CDF measurement to constrain theoretical model.*
  - *Expect ~ 100 events in 100pb^{-1}*
- *CDF has already observed DPE/CEP production of photon-photon, di-jet and χ_c*



Detectors

QCD Physics Low lumi

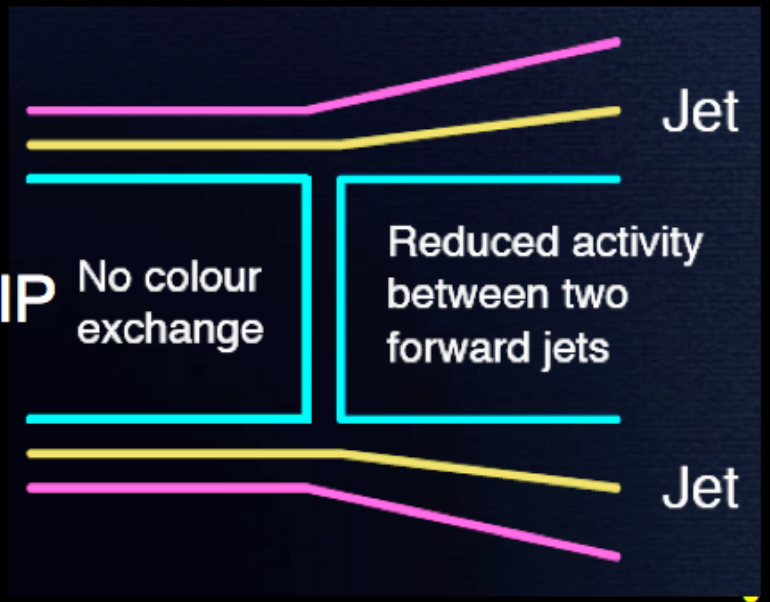
γγ/γp Physics Low lumi

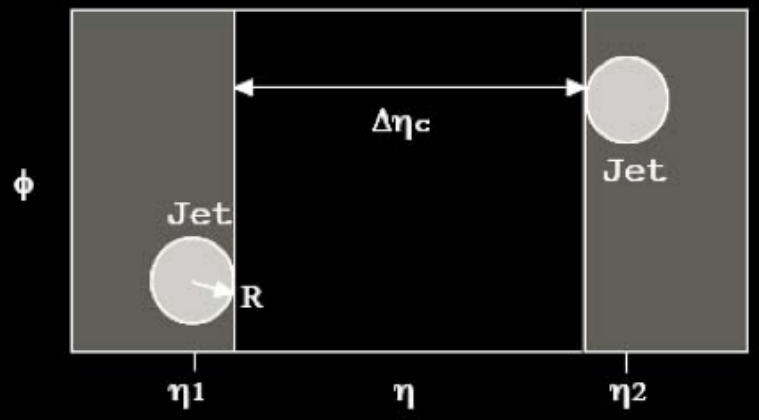
ZDC physics

QCD High lumi

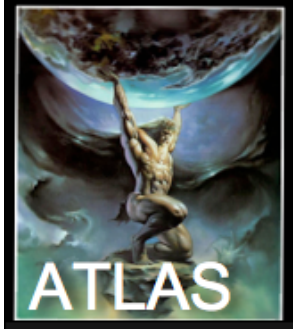
γγ/γp Physics High lumi

Gaps Between Jets





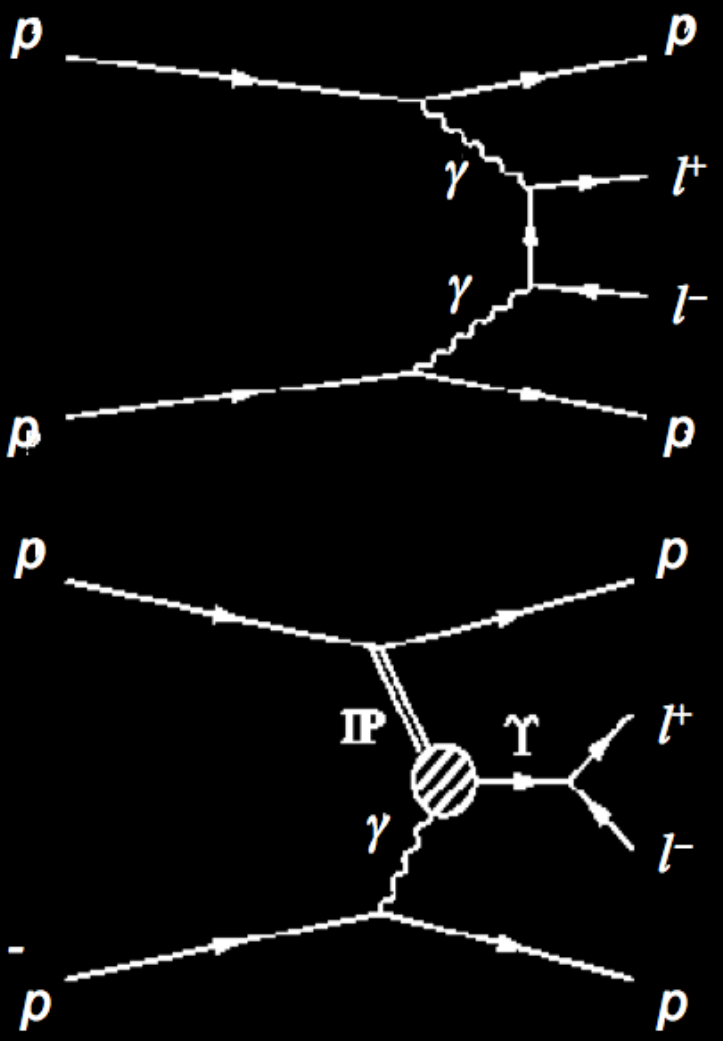
- *Di-jet production via colour singlet exchange*
  - *(background from single gluon exchange process).*
- *Require two jets, one in each forward calorimeter.*
- *Require gap in central calorimeter.*
- *ATLAS can make an improved measurement with increased E_{cm} and available phase space.*
  - *Test BFKL prediction that the fraction of events with little activity between jets should rise with jet separation*
- *Similar measurements were performed at the Tevatron (D0/CDF) & HERA (H1/ZEUS)*

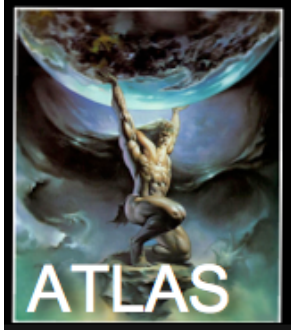


Photon Induced Muon Pairs

- Detectors
- QCD Physics Low lumi
- γγ/γp Physics Low lumi
- ZDC physics
- QCD High lumi
- γγ/γp 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 no other activity in the detector (use FCAL, LUCID, ZDC)*
- *PROCESSES (Observed by CDF):*
  - *Two photon production → non-resonant lepton pairs from $\gamma\gamma \rightarrow l^+l^-$*
  - *Photoproduction - lepton pairs through J/ψ & upsilon resonances - γ IP → J/ψ, Υ → 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

CMS

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

- *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 & calibration of 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

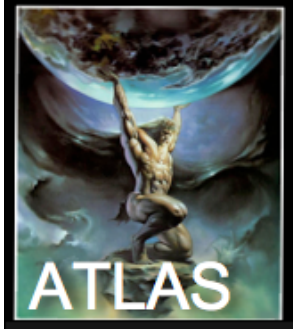
QCD Physics Low lumi

γγ/γp Physics Low lumi

ZDC physics

QCD High lumi

γγ/γp Physics High lumi



Detectors

QCD Physics Low lumi

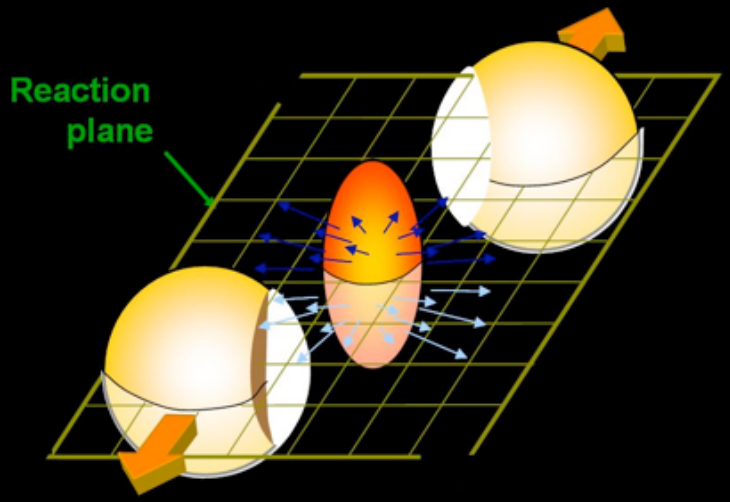
γγ/γp Physics Low lumi

ZDC physics

QCD High lumi

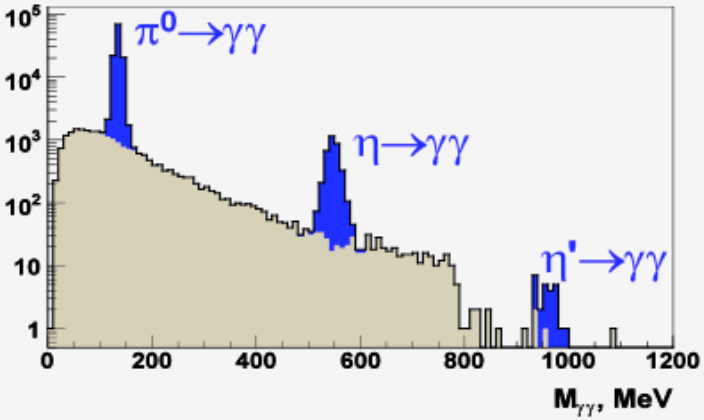
γγ/γp Physics High lumi

ZDC - Physics

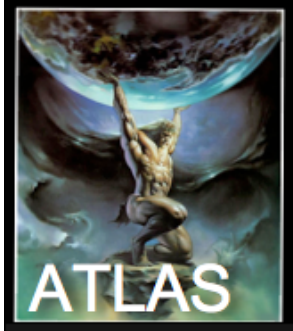


- *VERY FORWARD CROSS-SECTIONS*
  - *New energy range explored*
  - *Study particle production*
  - *Input for high energy cosmic ray MCs (Modeling air showers)*
  - *Improve hermiticity*

- *HEAVY-ION PHYSICS: count spectator neutrons*
  - *Determine the event centrality*
  - *Trigger for ultra-peripheral collisions ($b > 2R_{nucleus}$)*



- *BEAM MONITORING & LUMINOSITY Using Van Der Meer Scans*



QCD at Hi Lumi - the AFP Project

Detectors

QCD Physics Low lumi

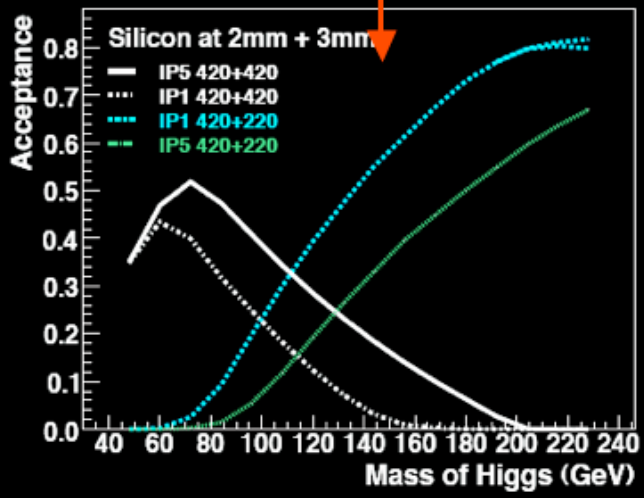
γγ/γp Physics Low lumi

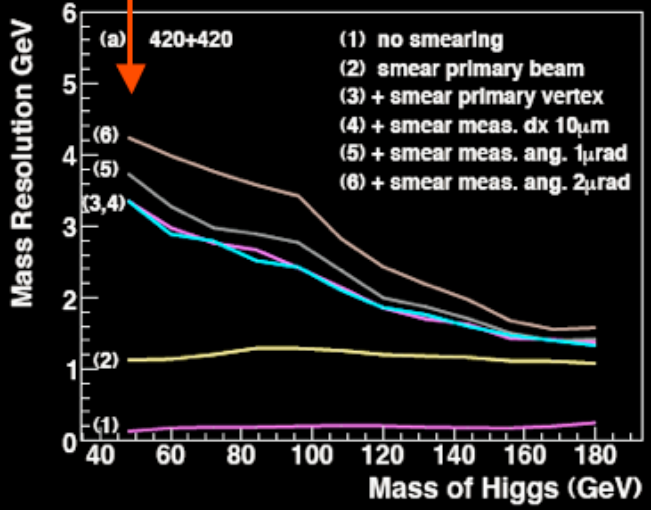
ZDC physics

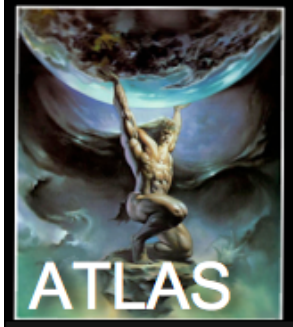
QCD High lumi

γγ/γp Physics High lumi

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







Detectors

QCD Physics Low lumi

γγ/γp Physics Low lumi

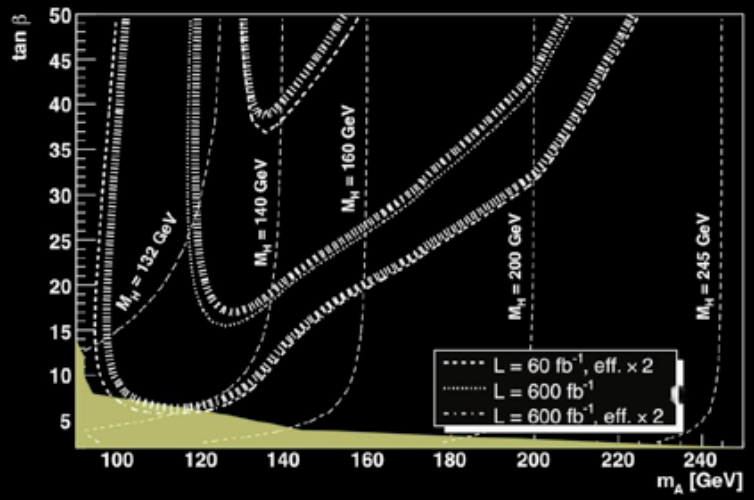
ZDC physics

QCD High lumi

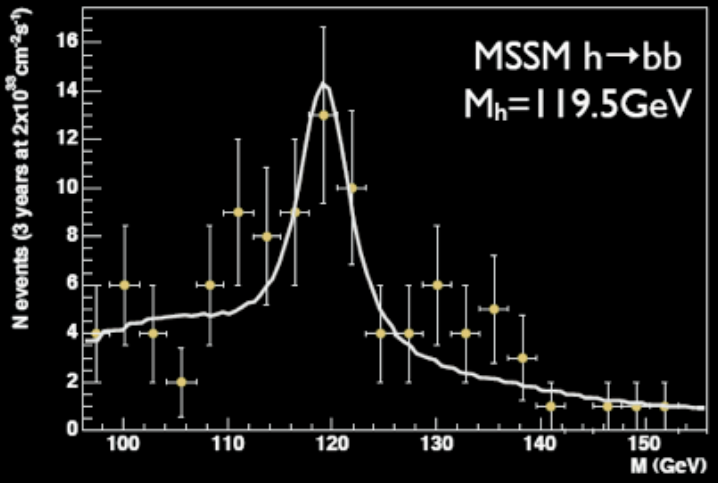
γγ/γp Physics High lumi

Higgs Production

- 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-SUSY models.*

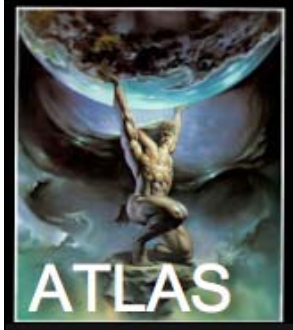


Cox et. al. JHEP 0710:090 (2007)

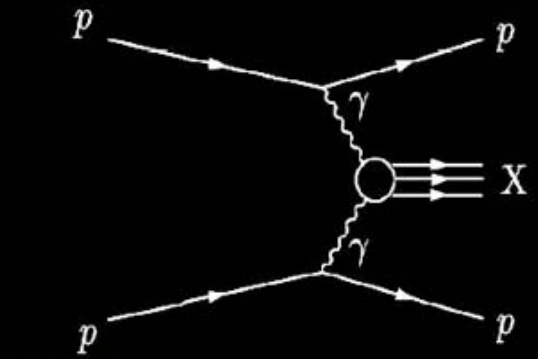


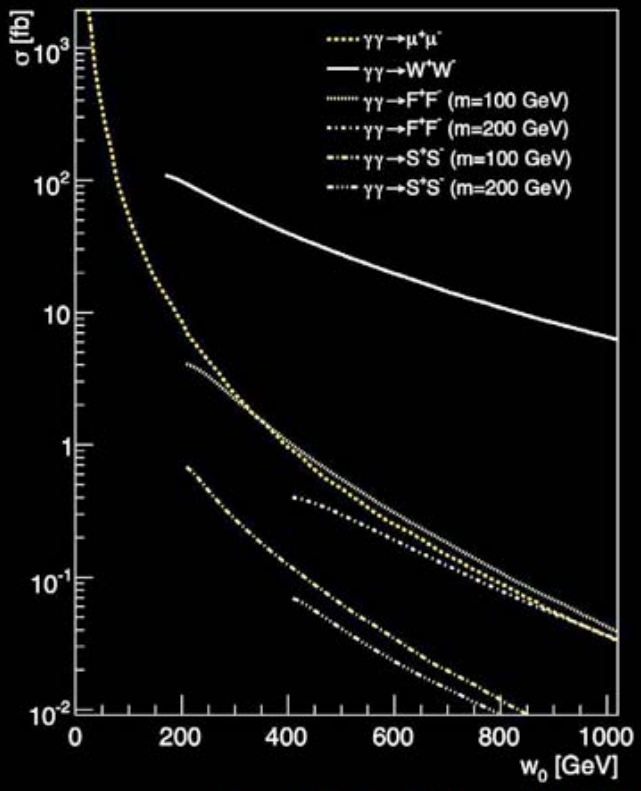
See the talks of Krzysztof PIOTRZKOWSKI Valeri KHOZE in this session

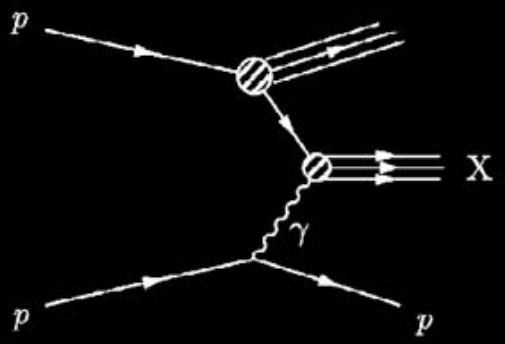
Rich γp+γγ Physics via p-Tagging

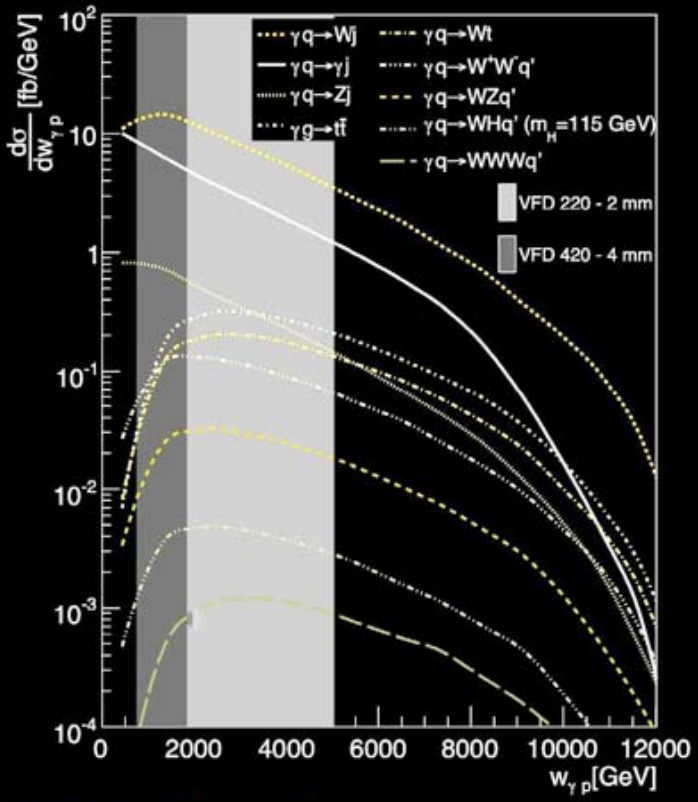


- Detectors
- QCD Physics Low lumi
- γγ/γp Physics Low lumi
- ZDC physics
- QCD High lumi
- γγ/γp Physics High lumi

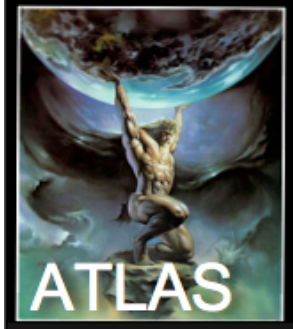








See talk by Krzysztof PIOTRZKOWSKI in this session



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, centrality measurements and a luminosity measurement.*
- *LOW LUMINOSITY PHYSICS:*
  - *Elastic scattering and σ_{tot} (at the 2-3% level) 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 AFP (HIGH LUMI) UPGRADE AT 220M and 420M:*
  - *Proton tagging gives access to CEP Higgs production and SUSY physics as well as γ-γ and γ-IP physics, at high luminosity*
- *THE LHC WILL BE 4 COLLIDERS IN 1: p-p, IP-IP, γ-IP, γ-γ!*

Detectors

QCD Physics Low lumi

$\gamma\gamma$/γp Physics Low lumi

ZDC physics rationale

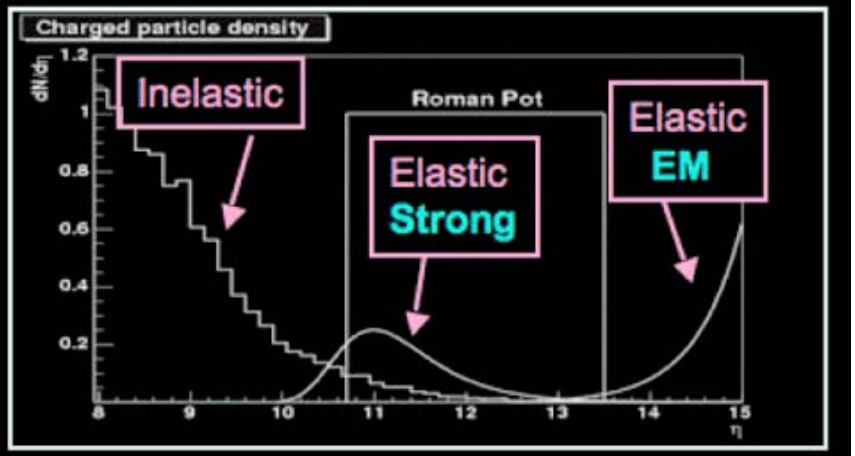
QCD High lumi

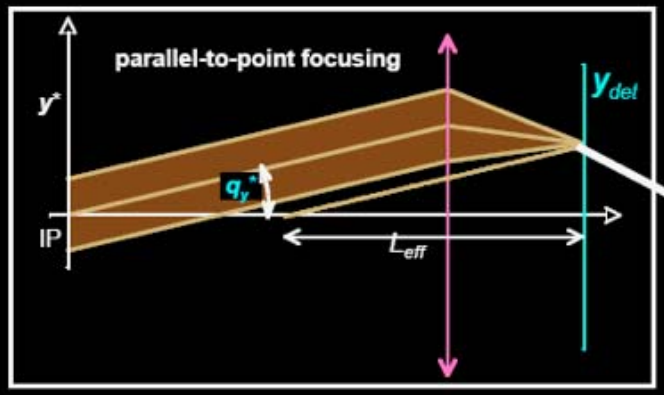
$\gamma\gamma$/γp Physics High lumi

Extra Slides

The ALFA Roman Pots

- Aim to measure elastic scattering using Roman Pot spectrometers.
- Need special (High β^*) optics to measure scattering angle:
  - Parallel-to-point focussing
  - Low luminosity special runs ($L=10^{27}\,cm^{-2}\,s^{-1}$)



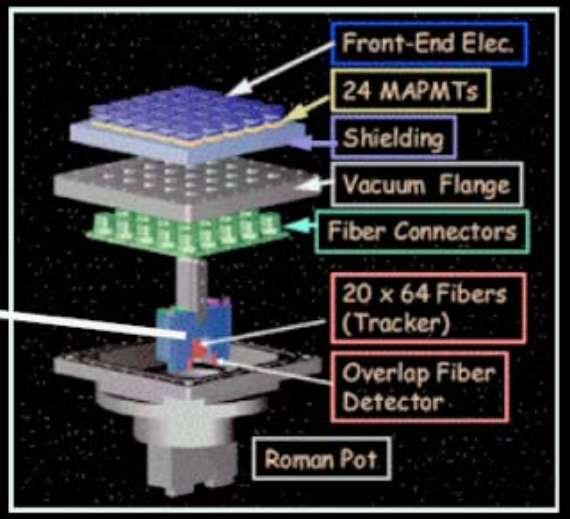


Detector requirements:

dead edge < 100μm

σ_{xy}<30μm

Achieved with scintillating fibres.



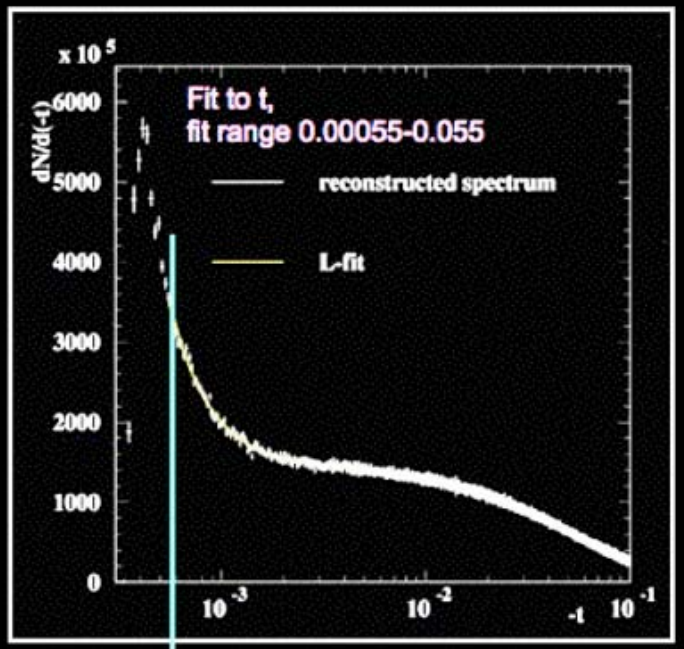
Absolute Luminosity Determination

- Elastic scattering rate given by nuclear and EM (Coulomb) terms:

$$\frac{dN}{dt} = L\pi\left|F_C + F_N\right|^2$$
$$= L\left(\frac{4\pi\alpha^2(\hbar c)^2}{|t|^2} - \frac{\alpha\rho\sigma_{tot}e^{-B|t|/2}}{|t|} + \frac{\sigma_{tot}^2(1+\rho^2)e^{-B|t|}}{16\pi(\hbar c)^2}\right)$$

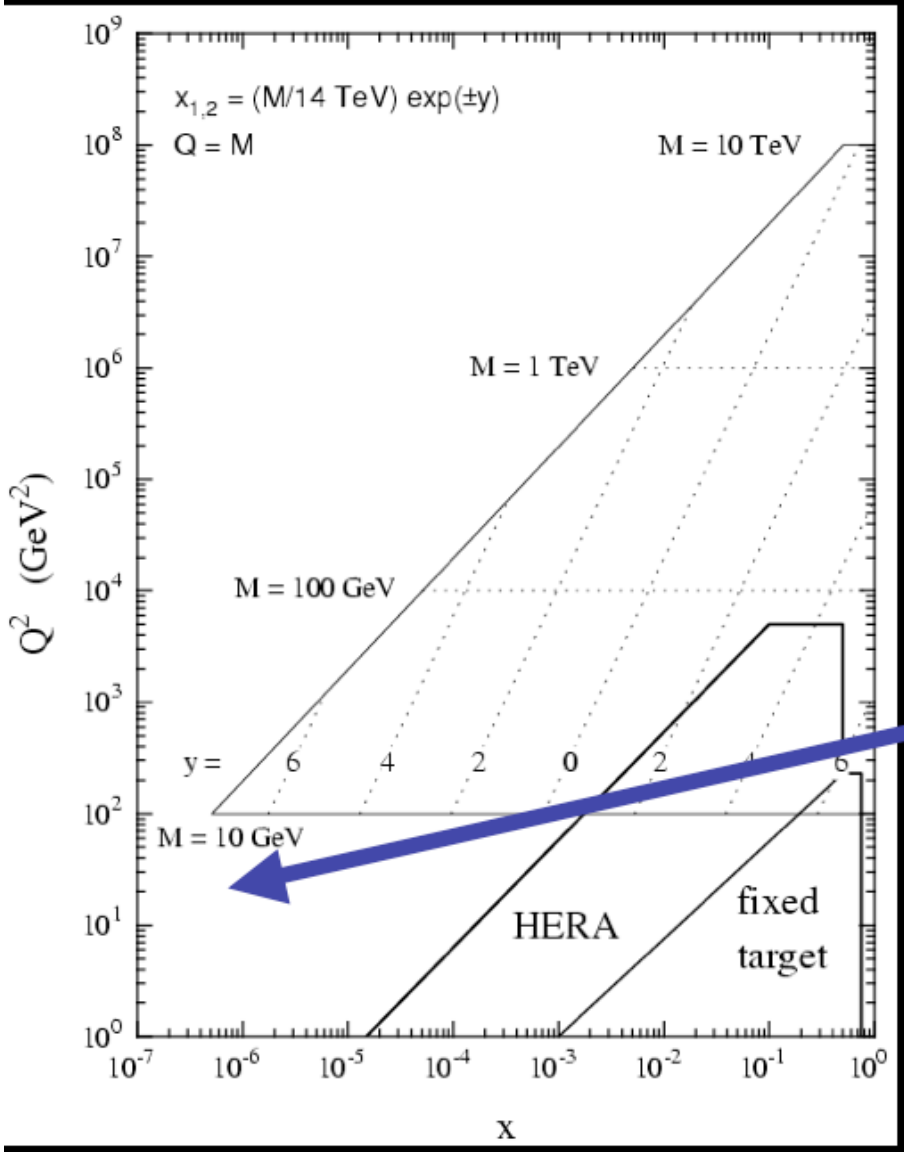
- Fit to ALFA data gives luminosity to ~3% (inc. systematics).

	Input	Linear fit	Error [%]
L [10^{26} cm^{-2} s^{-1}]	8.10	8.151	1.77
σ_{tot} [mb]	101.511	101.14	0.9
b [GeV^{-2}]	18	17.93	0.25
ρ	0.15	0.143	4.3
Fit range		$0.00055 < -t < 0.055$	
Fit quality [χ^2/Ndof]		2845/2723	



- Detector edge 1.5mm from beam:
- θ_{min} = 2.7μrad
- t_{min} = 0.00055

Low-x at the LHC



LHC: due to the high energy can reach small values of Bjorken-x in structure of the proton $F(x,Q^2)$

Processes:

- Drell-Yan
- Prompt photon production
- Jet production
- W production

If rapidities above 5 and masses below 10 GeV can be covered ⇒ x down to 10^{-6}-10^{-7}

Proton structure at low-x !!

Parton saturation effects?

Trigger conditions

- For the special run (~100 hrs, L=1027cm-2s-1)

- 1. ALFA trigger
  - coincidence signal left-right arm (elastic trigger)
  - each arm must have a coincidence between 2 stations
  - rate about 30 Hz

- 2. LUCID trigger
  - coincidence left-right arm (luminosity monitoring)
  - single arm signal: one track in one tube

- 3. ZDC trigger
  - single arm signal: energy deposit > 1 TeV (neutrons)

- 4. Single diffraction trigger
  - ALFA.AND.(LUCID.OR.ZDC)
  - central ATLAS detector not considered for now

Efficiency [%]	Pythia	Phojet
Preselection		
ξ<0.2	97.1	94.8
ZDC [E>1 TeV]	51.5	38.7
LUCID [1 track]	45.1	57.3
[Central ATLAS E> 100 GeV]	24.9	38.7
Total preselection	75	74
RP selection		
ALFA **(Relative to preselection)**	60.1	54.2
Total acceptance	44.9	40.1