ATLAS and the Forward Physics

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On behalf of the
ATLAS Collaboration

Outline

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

Forward physics

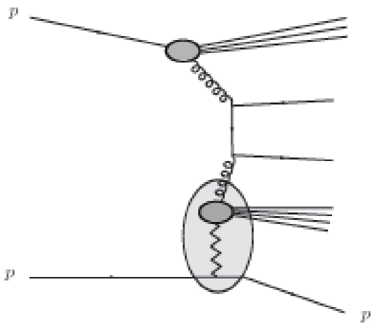
Beside the baseline “classic” physics program of the ATLAS experiment (Higgs, SM, etc.) there are many topics in forward physics which can be addressed

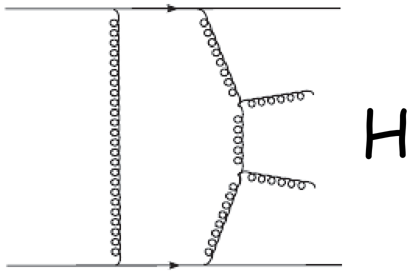
In general to be effective, dedicated detectors and a data taking strategy (parallel running or dedicated runs, priority etc.) are needed

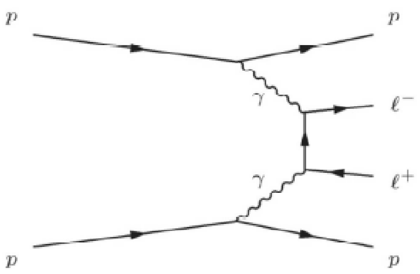
Physics achievable in the present configuration
Possible future measurements → Upgrade

Forward physics topics

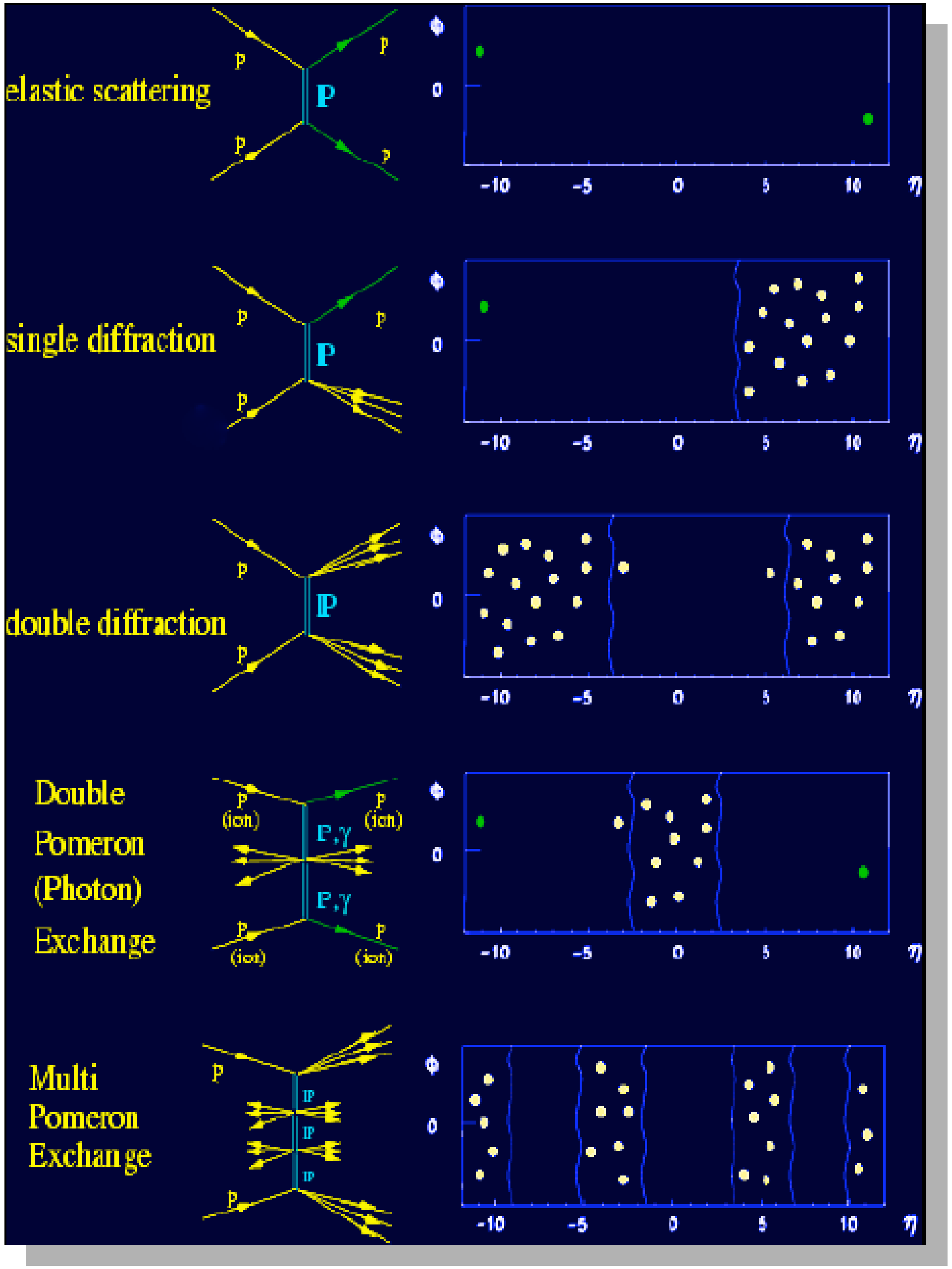
- Elastic scattering
- Single diffraction (soft and hard)
  - Diffractive W/Z production
- Double diffraction
- Double Pomeron exchange
- Multi Pomeron exchange
- Central exclusive production
- P-γ physics
- γ -γ physics







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 (DPE) and Central Exclusive Production (CEP)

- central calorimeter (jet-jet)

Gaps study still ongoing

Requirements:

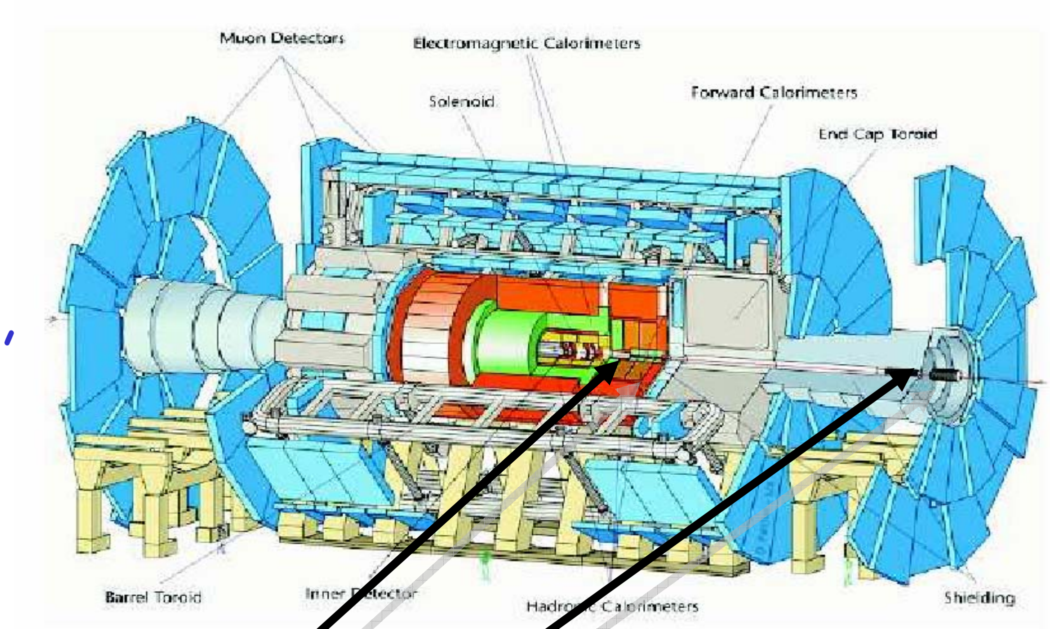
-Dedicated detectors

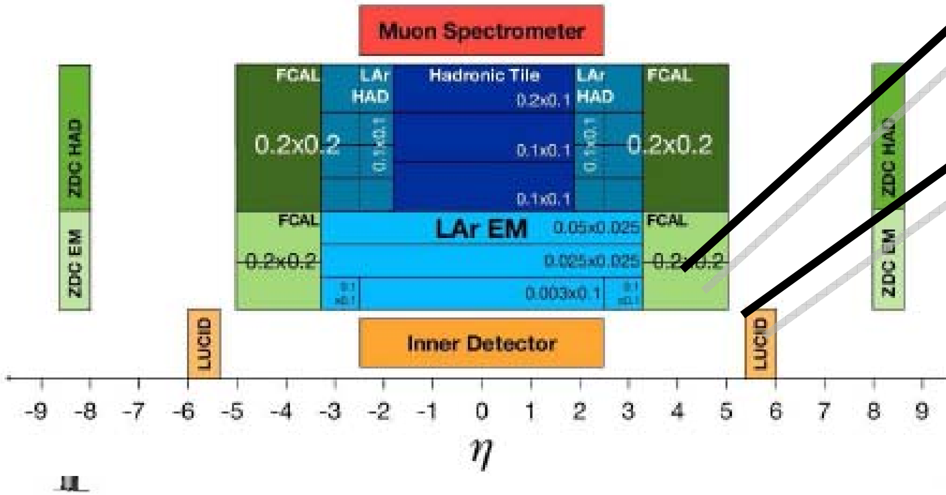
-Low noise in detectors

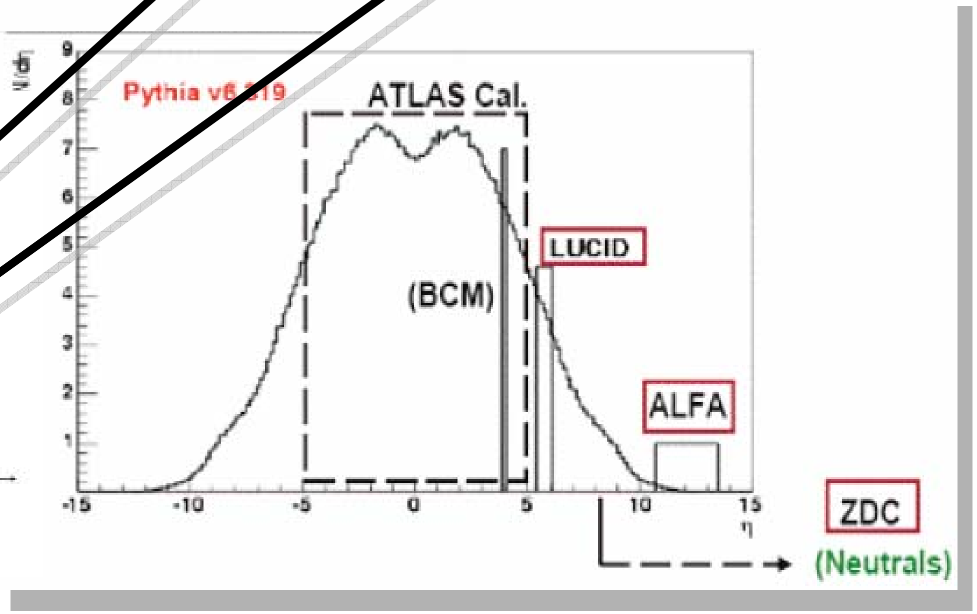
-No pile-up !

Atlas detectors for forward physics

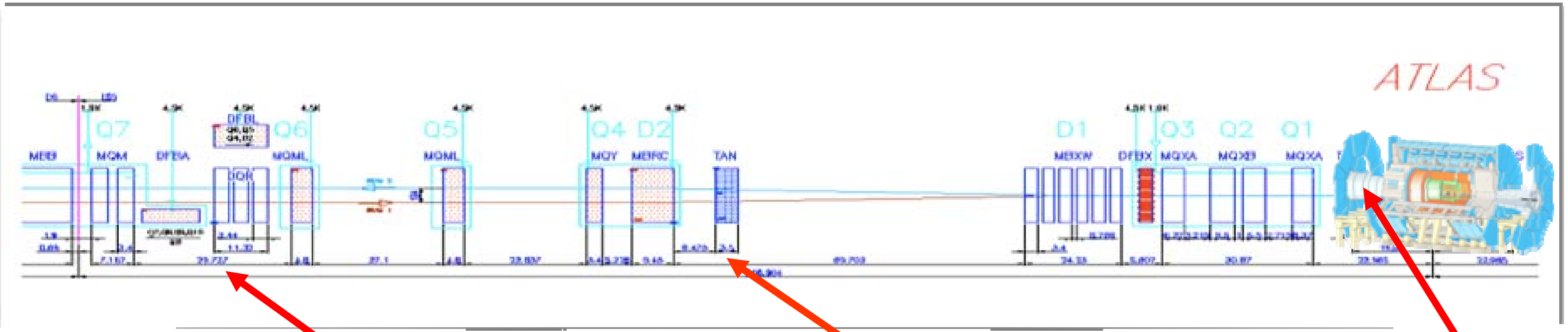
Originally designed with different goals (e.g. luminosity determination), they can provide useful information for forward physics.







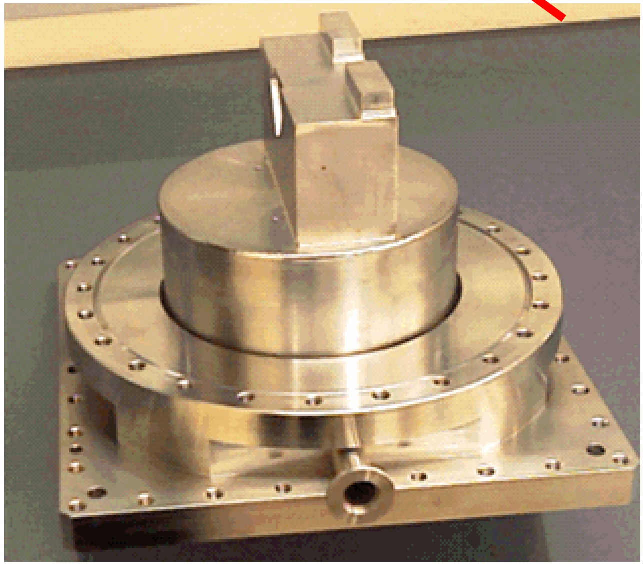
ATLAS Forward Detectors



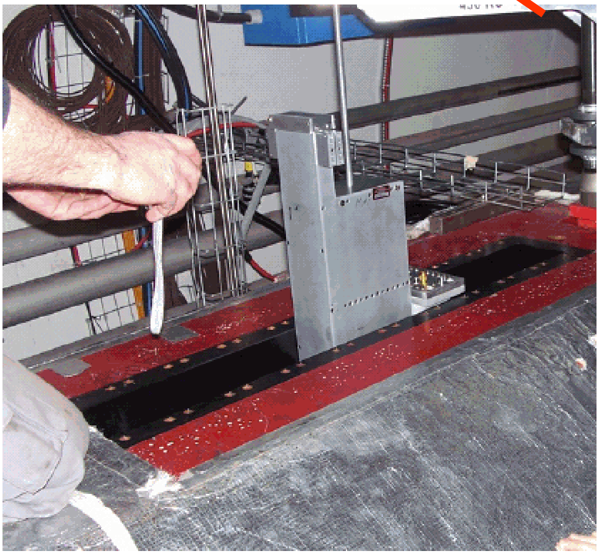
ALFA at 240 m

ZDC at 140 m

LUCID at 17 m



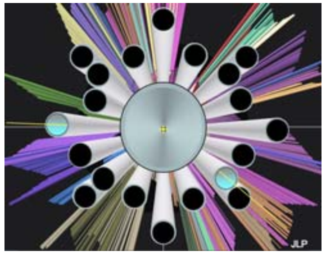
Absolute Luminosity for Atlas



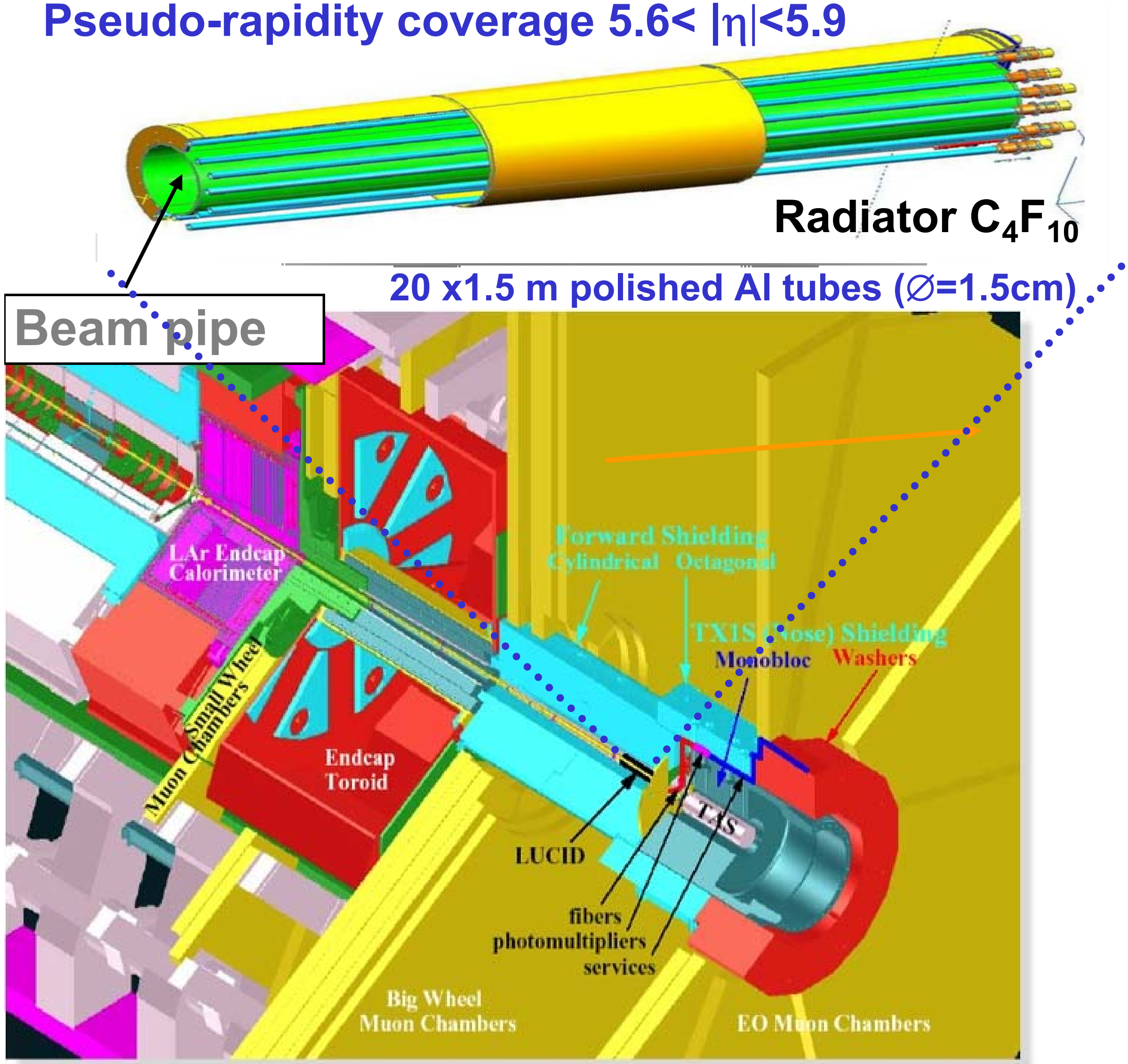
Zero Degree Calorimeter

Luminosity Cerenkov Integrating Detector

LUCID: where and why



Pseudo-rapidity coverage $5.6 < |\eta| < 5.9$



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

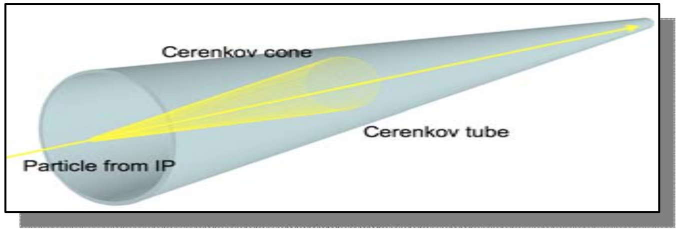
⇒ Requirements:

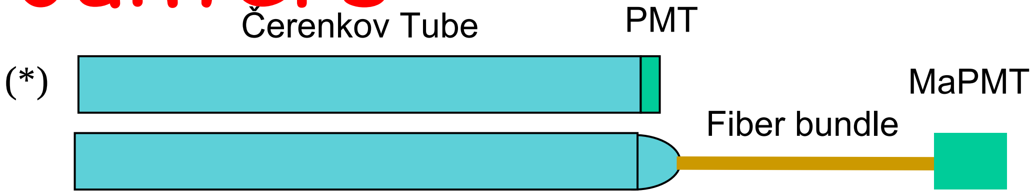
- calibration needed
- final precision ~ 2-3%

Physics capability:

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

LUCID:Pointing Gas Čerenkov Counters





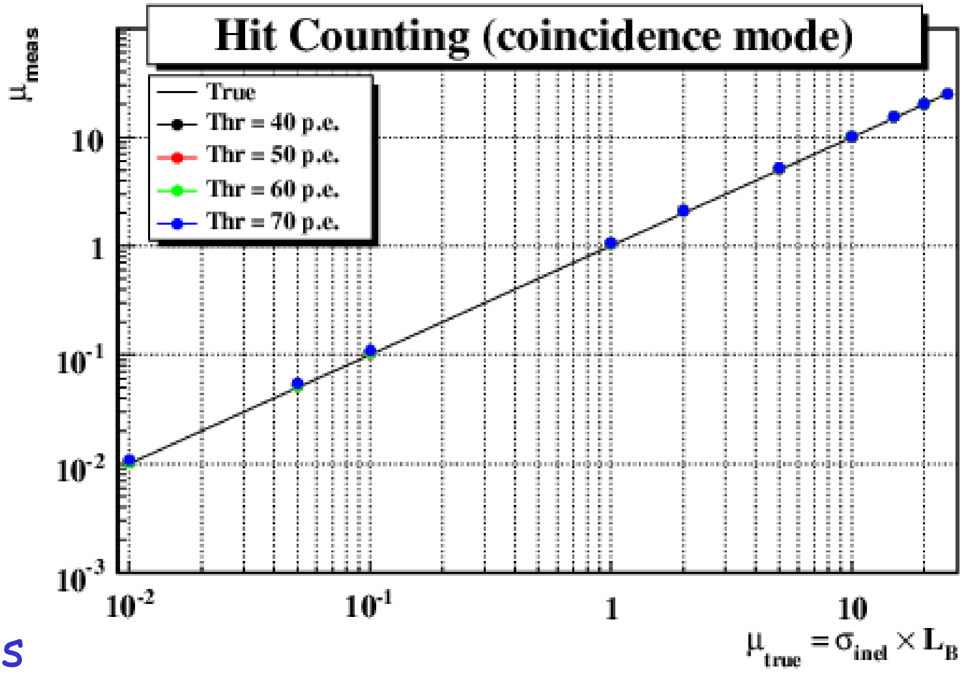
- 2 modules located at 17 m from the IP.
- Cherenkov tubes sensitive to charged particles pointing to the pp collisions.
- Two different readout techniques.
- Designed for up to L ~ 4 10^{33} cm^{-2} s^{-1}
- Need to be upgraded to work @ high lumi

  → Rad hardness

  → More η coverage

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



$$\mu_{MEAS} = \frac{\langle M \rangle}{\langle N \rangle \cdot \varepsilon} = L \cdot \sigma_{inel} \Longrightarrow L = \frac{\langle M \rangle}{\langle N \rangle \cdot \varepsilon \cdot \sigma_{inel}}$$

μ = average number of interactions per bunch crossing

$<M>$ = average number of charged particles per bunch crossing

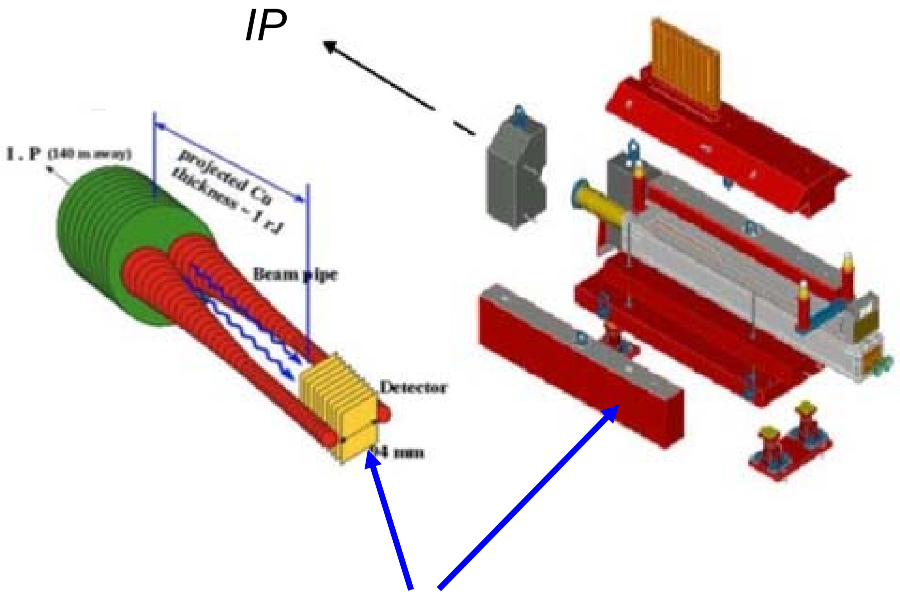
$<N>$ = average number of particles per interaction

ε = interaction efficiency

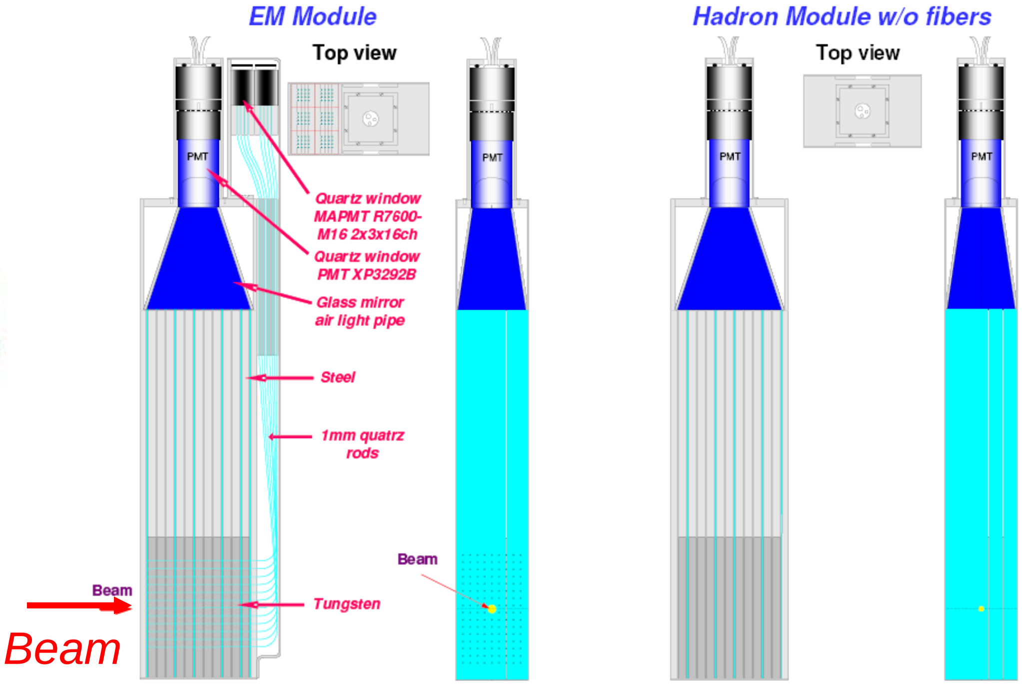
σ_{inel} = inelastic cross sec.

Zero Degree Calorimeter (ZDC)

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



TAN housing beam pipe, and ZDC



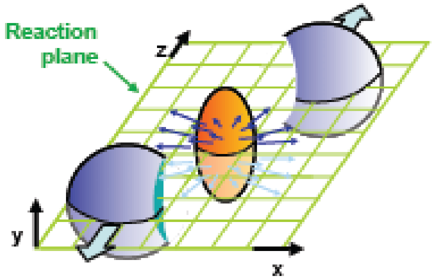
1 EM and 3 hadronic calorimeters

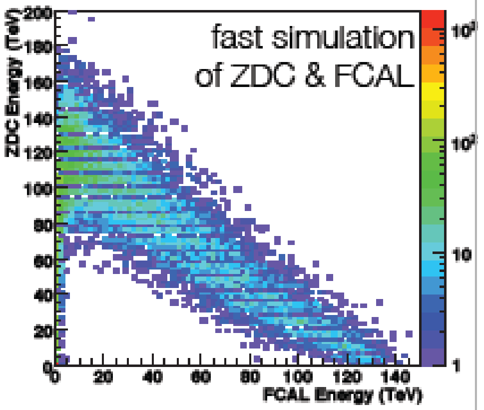
Tungsten/Quartz calorimeter covering |η| > 8.3 for neutrals

- quartz strips for energy measurement
- Horizontal rods for coordinates RO

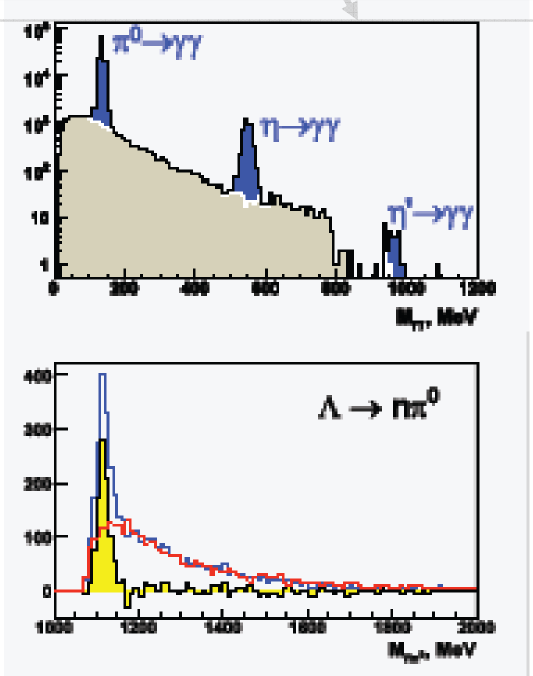
ZDC goals

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





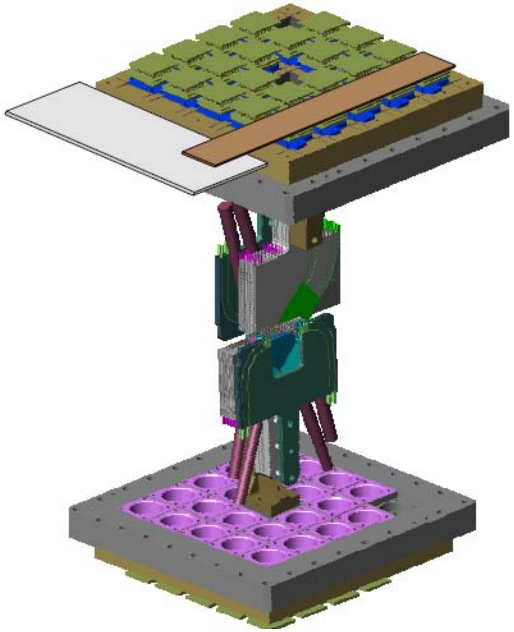
- Centrality of the events
- Minimum Bias Trigger
- Luminosity measurement

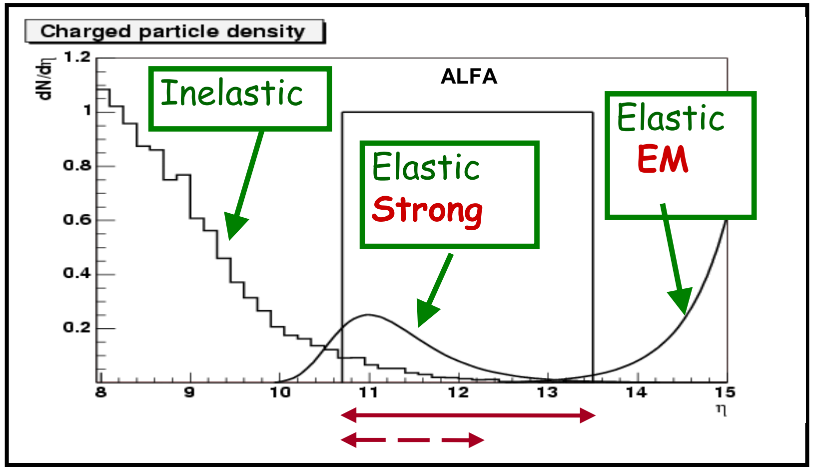


- MC constraints from forward particle production
- Rapidity gap veto

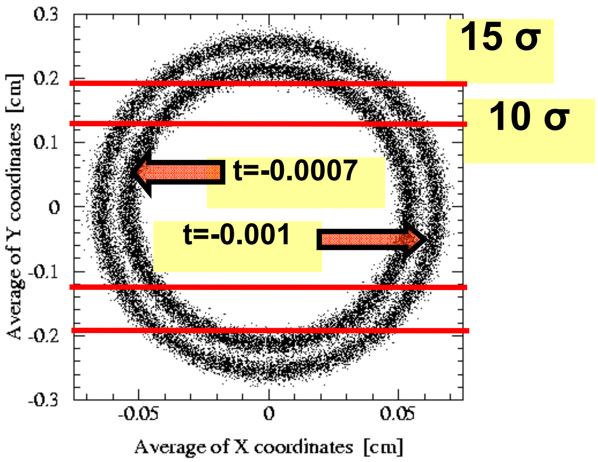
The ALFA Roman Pots

- Aim to measure elastic pp-scattering down to very small angles
- Need special (High β*) optics
  - Low luminosity special runs ($L=10^{27}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$)
  - 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)

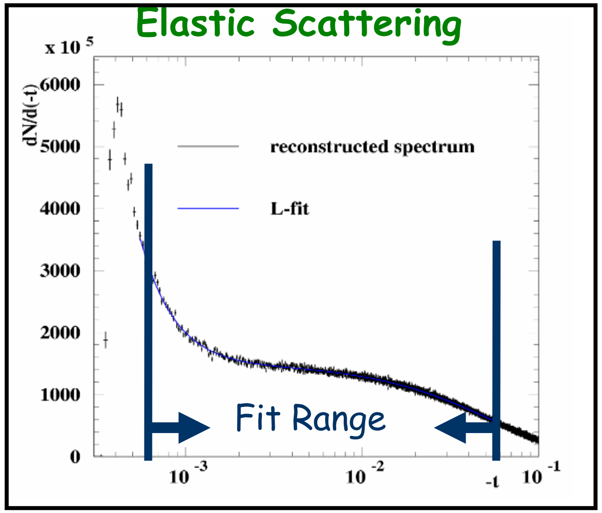




ALFA performance



$$-t = \left(p\,\theta^*\right)^2 = p^2\left(\overline{\theta}_x^2 + \overline{\theta}_x^2\right)$$
$$= p^2\left(\left(\frac{\overline{x}}{L_{eff,x}}\right)^2 + \left(\frac{\overline{y}}{L_{eff,y}}\right)^2\right)$$



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

	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%

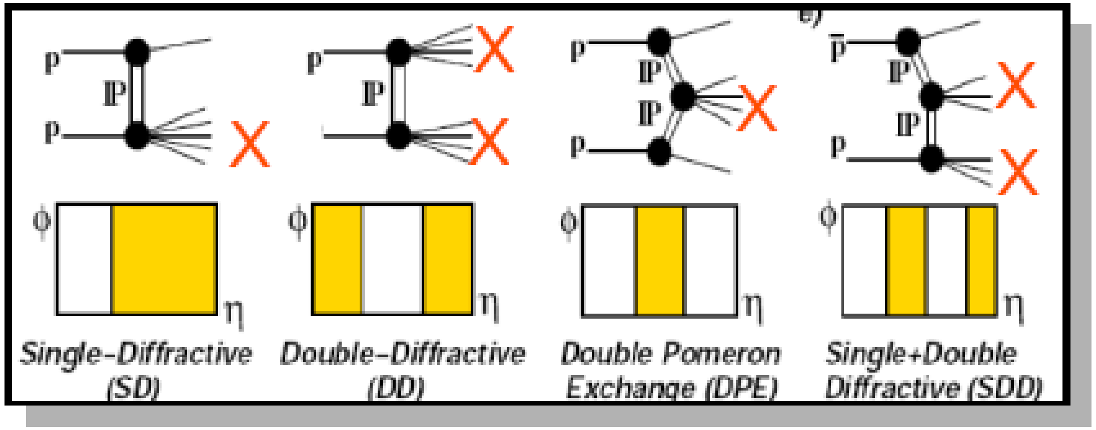
Systematics on L

- 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

→ for more details see M. Heller presentation

Diffraction



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

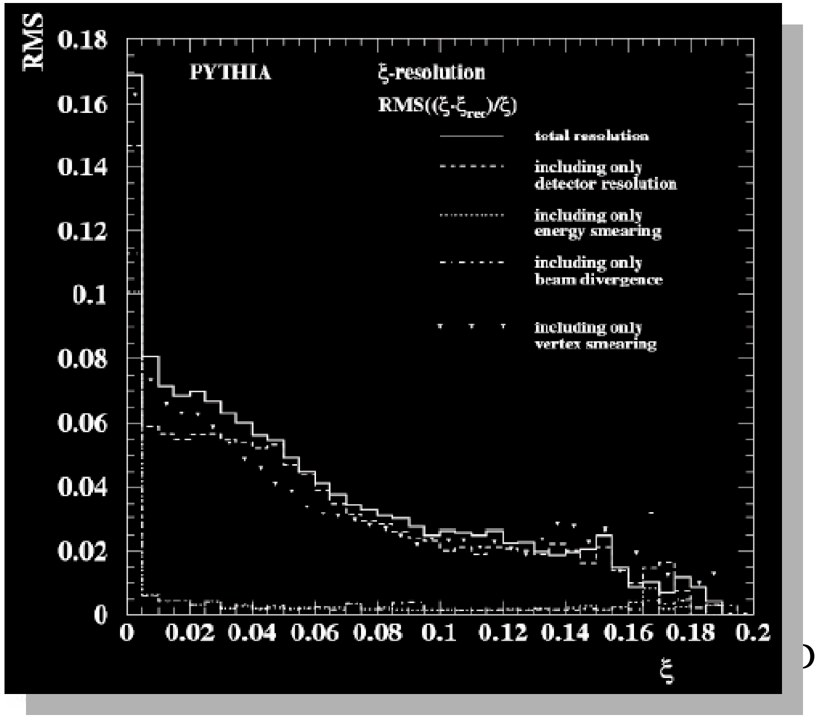
- SOFT Diffraction (SD)
  - Multi – parton interactions

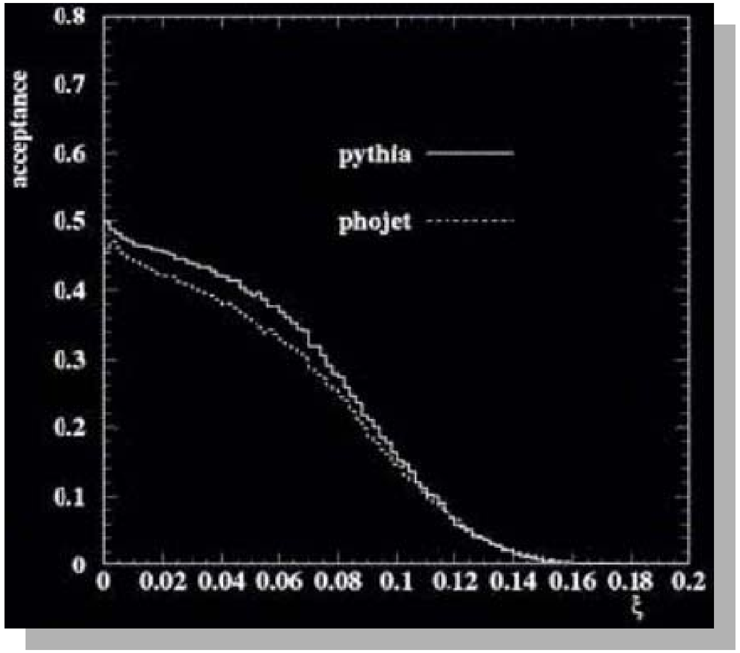
Rapidity gaps pile-up contributions at high-luminosity

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 < E_{prot} < ~7 TeV





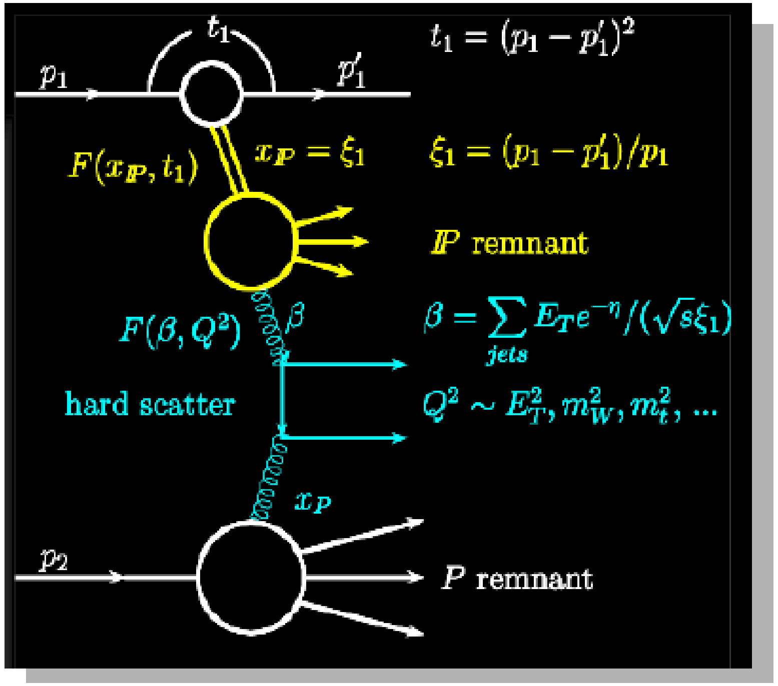
-SD measurements for ξ < 0.01

- Non-diffractive forward protons spectrum measurement for 0.01 < ξ < 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 (x_{POM}<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.

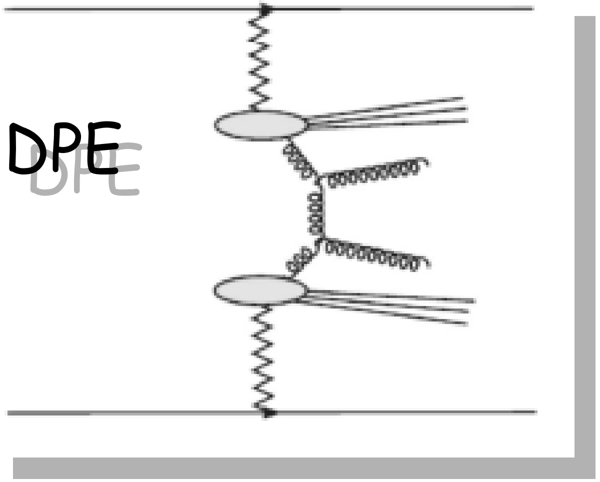
DPE and CEP measurements

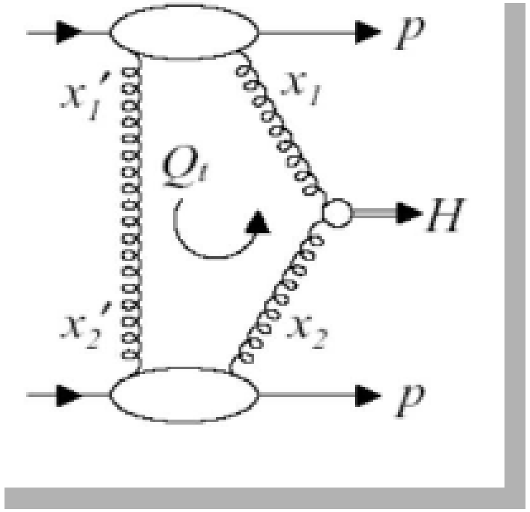
- Look for two central jets with $|\eta|<2.5$.

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

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

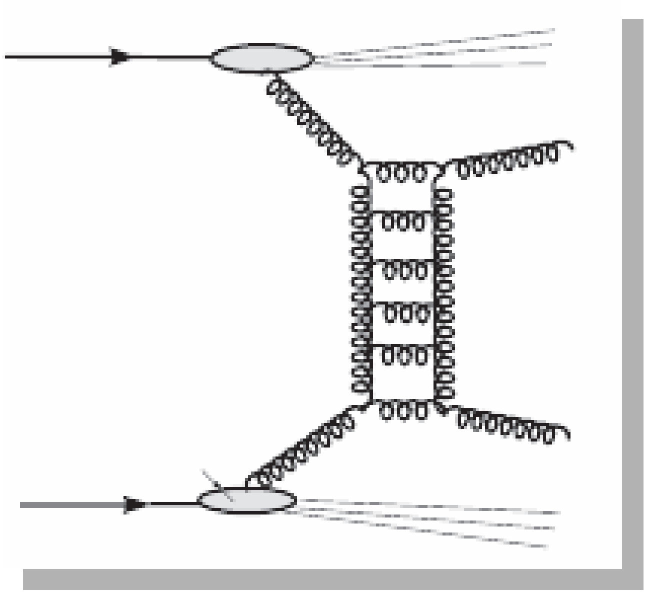
- Measurement of CEP dijet production at 14TeV. Compare with CDF measurement to constrain theoretical model.

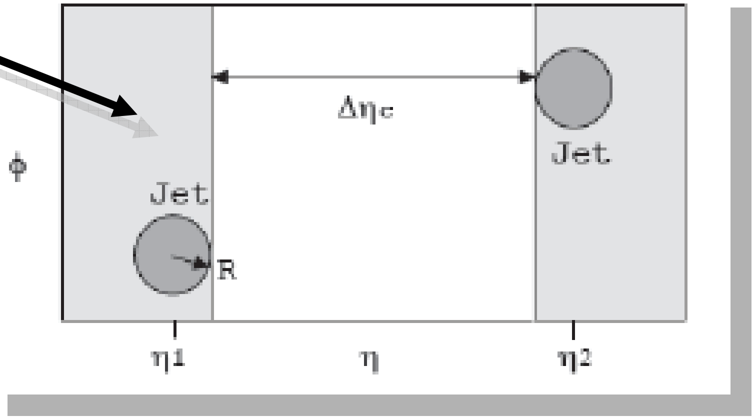




Gaps between jets

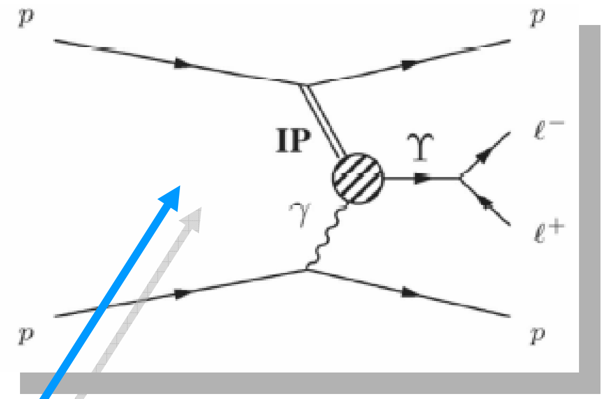
- Di-jet production via colour singlet exchange
    - background from single gluon exchange process.
- Require two jets, one in each forward calorimeter.
- Require gap in central calorimeter.
- ATLAS can make an improved measurement with increased CM energy and available phase space.

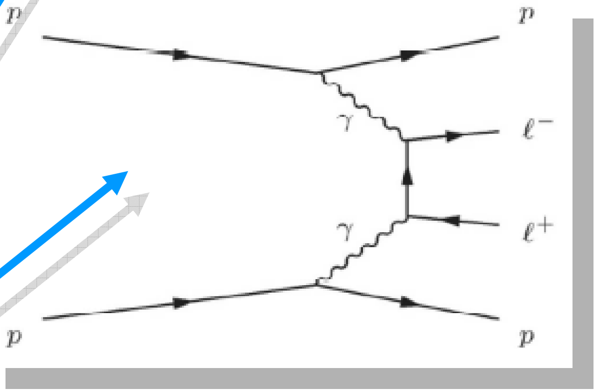




Photon induced muon pairs

- EXCLUSIVE Dileptons
  - Two isolated leptons back-to-back, balanced in PT
  - 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 & upsilon resonances
  - Two photon production → non-resonant lepton pairs from $\gamma\gamma \to l^+l^-$



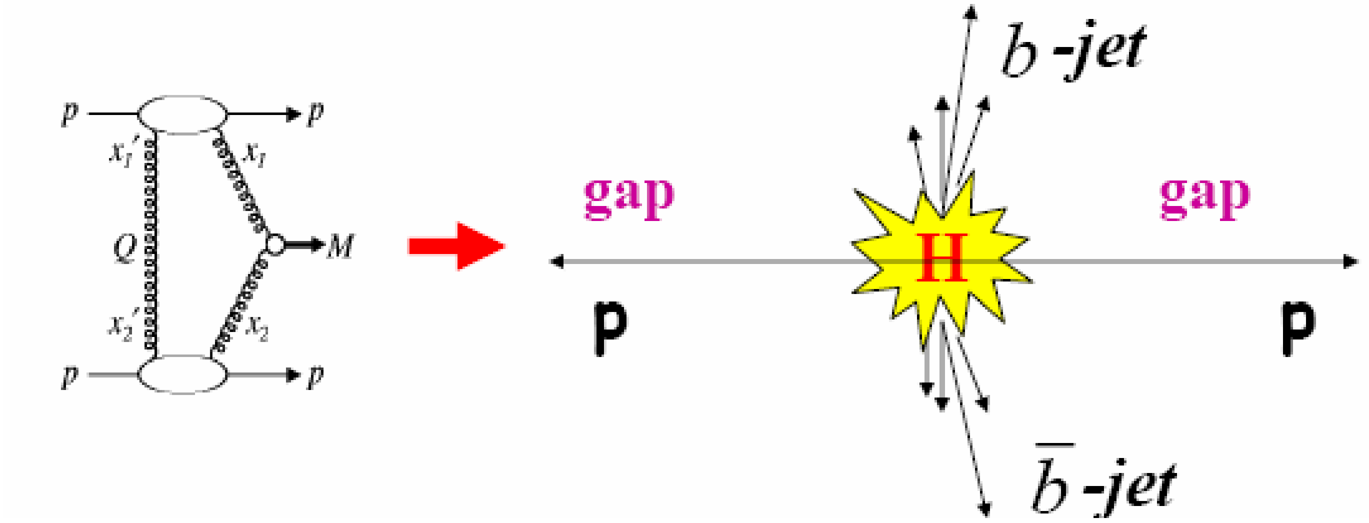


Simulation predict several hundreds two-photon and Upsilon events in the di-muon channel final selection for $100 pb^{-1}$

Afp Upgrade: the idea

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

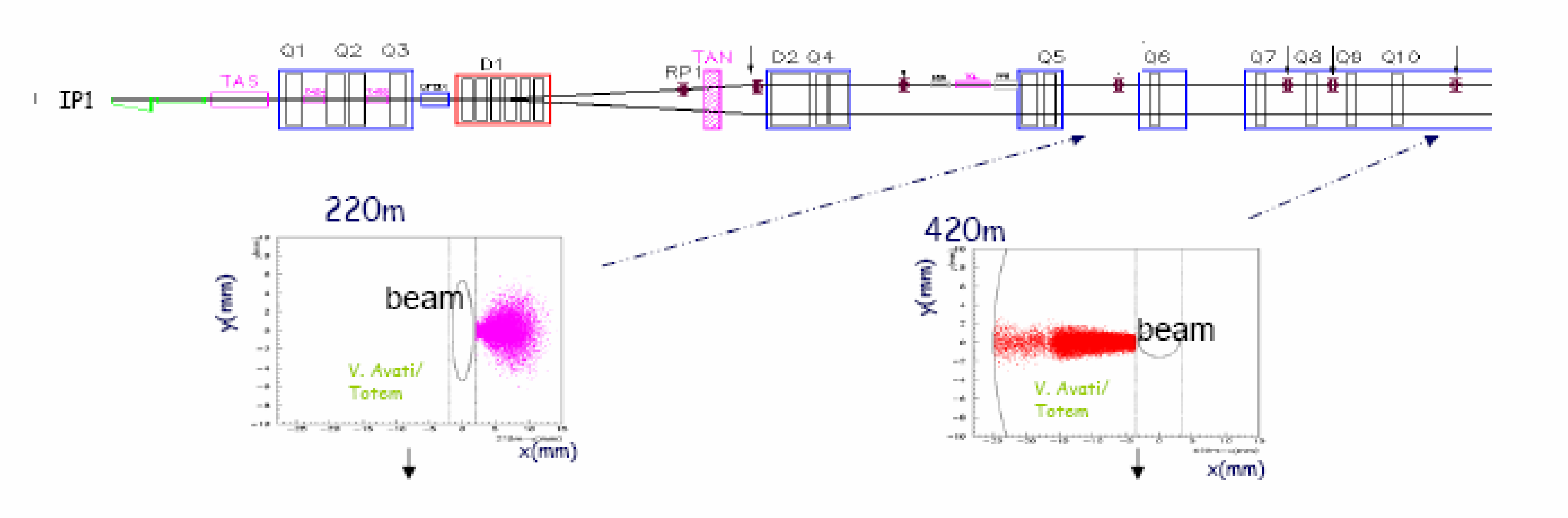
Provide a trigger for the diffractive physics (LVL1 + HLT)



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

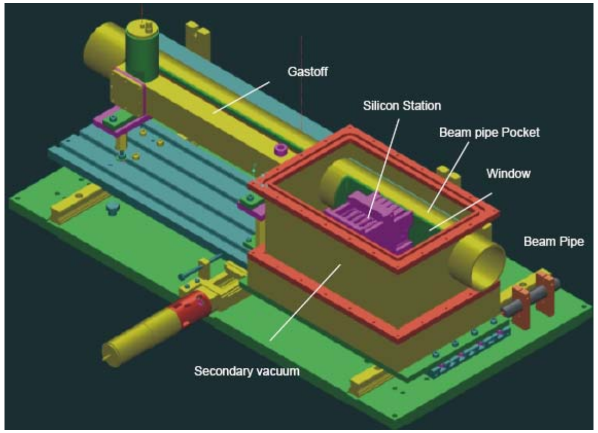
AFP a future possible Detector



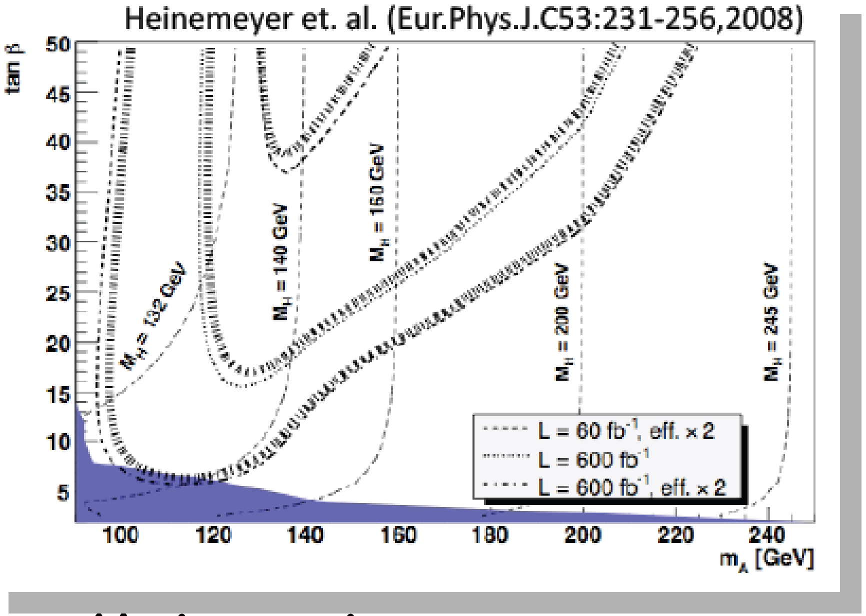
Two stations at 220 and 420m to detect leading protons, integrated in LHC

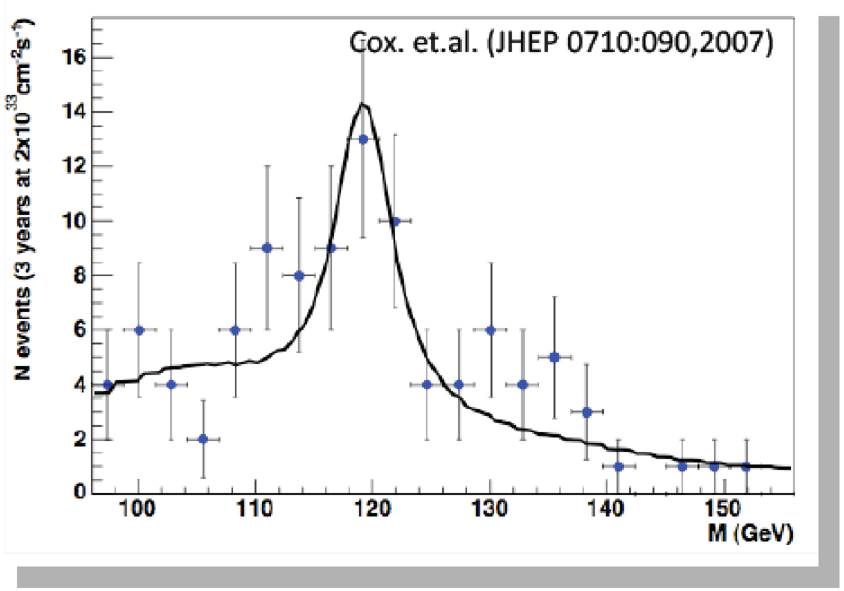
Very good mass resolution for forward Protons

VERY Challenging !



AFP : the physics


Heinemeyer et. al. (Eur.Phys.J.C53:231-256,2008)


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

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

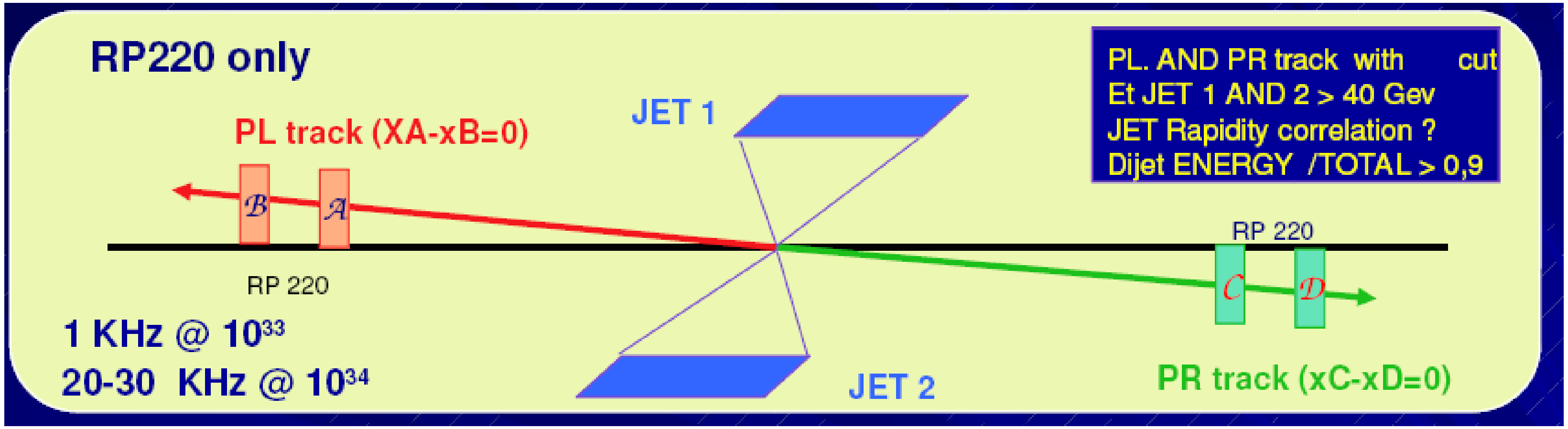
Conclusions

- Luminosity from existing forward detectors LUCID and ALFA at 5% accuracy.
- Forward Particle Spectrum:
  - ZDC → forward particle production.
  - ZDC → forward spectators for heavy ion collisions and c 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 FCAL, 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

Afp Trigger

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



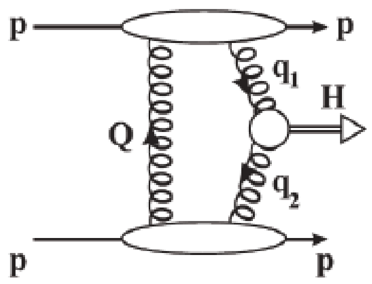
PL. AND PR track with cut
Et JET 1 AND 2 > 40 Gev
JET Rapidity correlation ?
Dijet ENERGY /TOTAL > 0,9

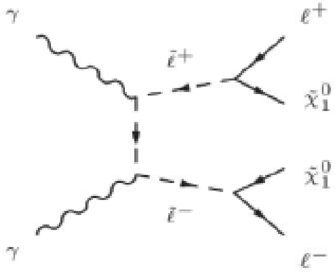
1 KHz @ 10^{33}
20-30 KHz @ 10^{34}

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 $\gamma\gamma$

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

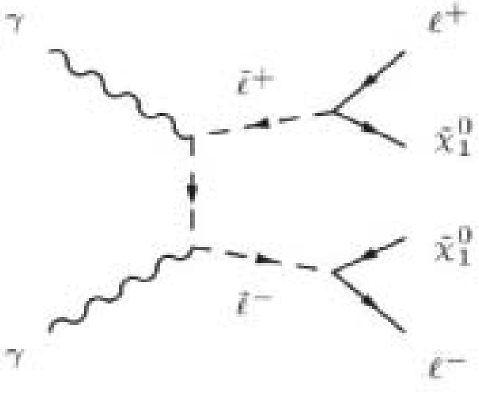
- In MSSM, very important that pseudo-scalar production heavily suppressed, important in scenarios where scalar and pseudo-scalar masses are close

- $\gamma\gamma$ 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



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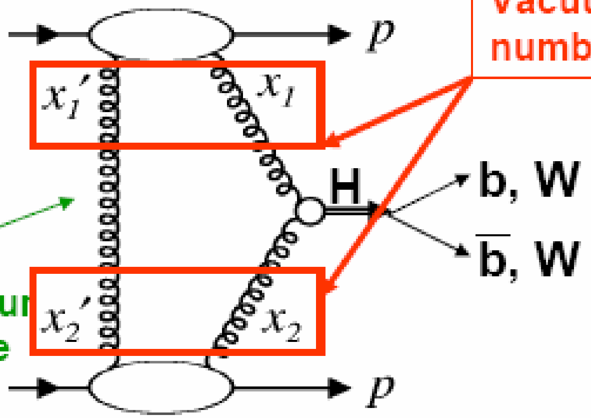
Initial physics case

Central Exclusive Production (CEP) of the Higgs



Vacuum quantum numbers !

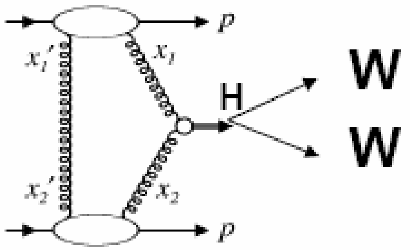
Shields colour charge of the other two gluons

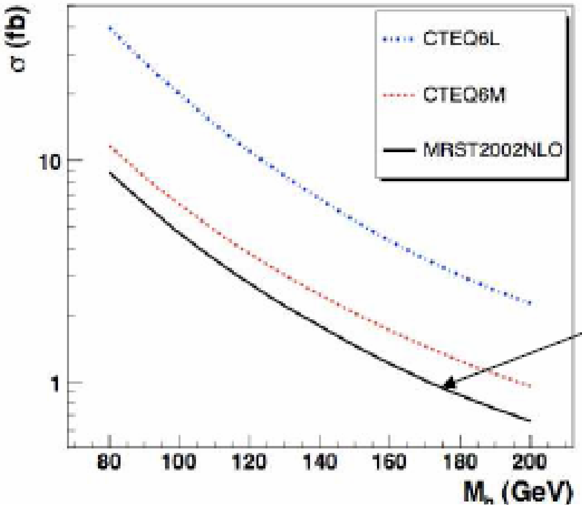
ξ: fractional momentum loss of proton – for 120 GeV Higgs, ξ~ 1%

- 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