Luminosity measurements and diffractive physics in ATLAS

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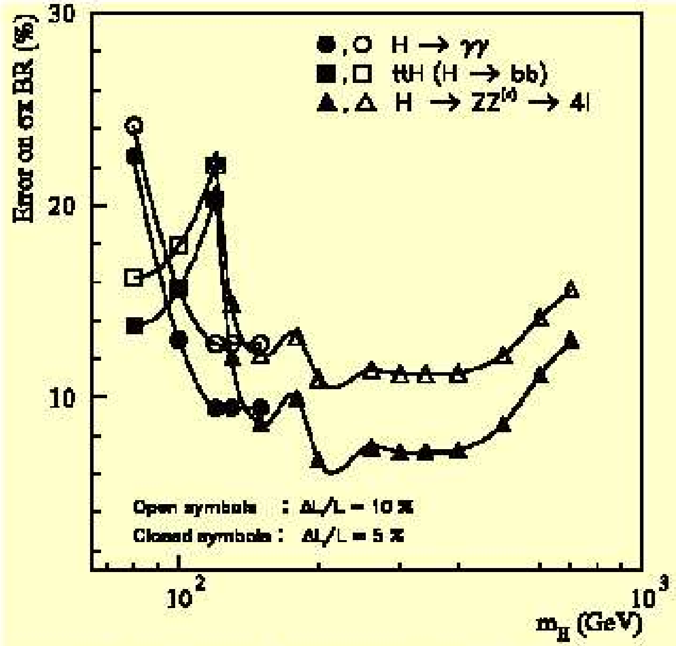
Contents:

- ATLAS Luminosity project
  - Absolute luminosity: roman pots
  - Relative luminosity: LUCID
  - Other methods
- Hard diffraction program in ATLAS (still in project status, not yet widely discussed within ATLAS)

Precise measurement of luminosity?

Precise measurement of luminosity needed: leading uncertainty for potential measurements like measurement of Higgs boson production cross section and $\tan\beta$

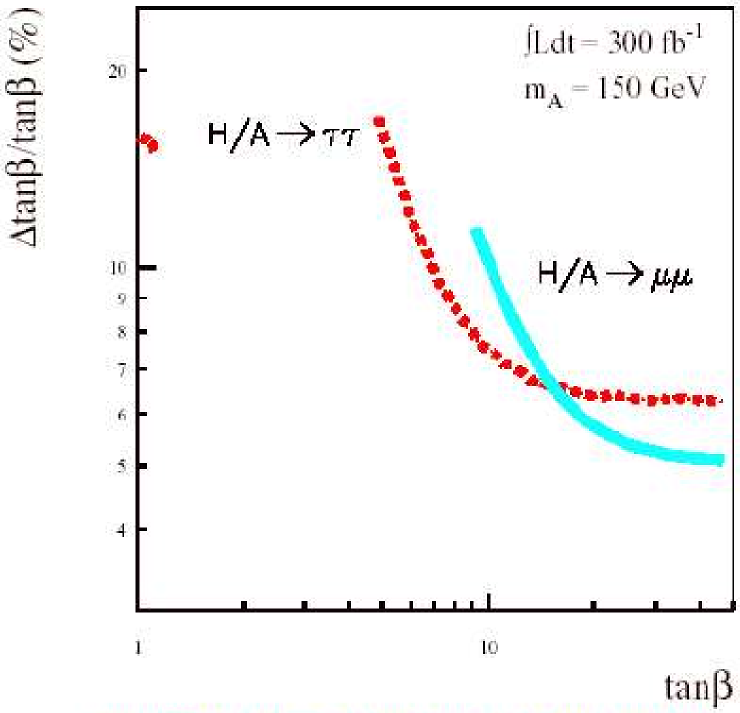
Higgs coupling



Relative precision on the measurement of $\sigma_H \times$BR for various channels, as function of m_H, at $\int Ldt = 300$ fb^{-1}. The dominant uncertainty is from Luminosity: 10% (open symbols), 5% (solid symbols).

(ATLAS-TDR-15, May 1999)

tanβ measurement

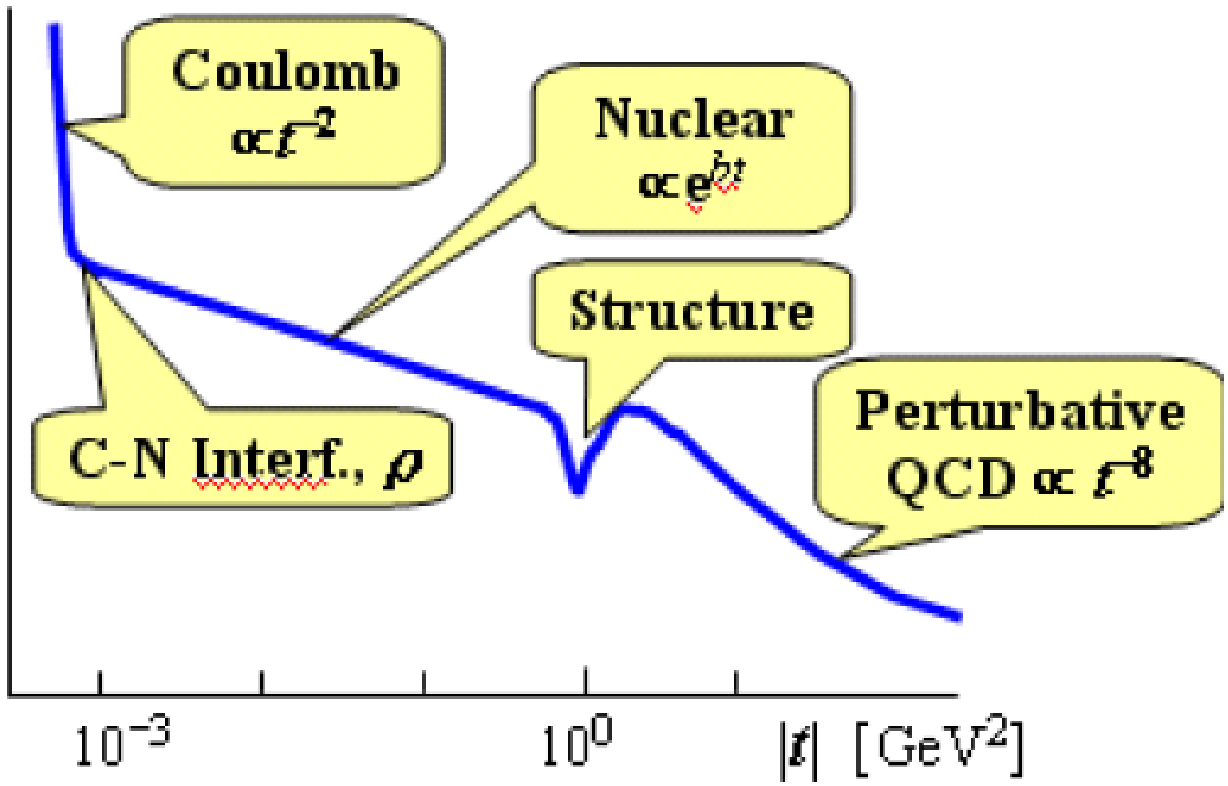


Systematic error dominated by luminosity (ATLAS Physics TDR)

Luminosity measurement options

- Relative luminosity measurement: LUCID
- Absolute luminosity measurement:
  - Goal: Luminosity measurement with 2-3% accuracy
  - LHC beam parameter measurement: extrapolation from measurements outside the experimental area, accuracy of 5-10%, improving with time
  - Known cross section in QED: (production of a muon pair by double photon exchange): small observable cross section), QCD (W production...): Theoretical prediction of the order of 5%, in progress with NNLO calculations, dependence on PDFs...
  - Optical theorem (inelastic and elastic cross sections): use of total cross section measured by TOTEM, needs good rapidity coverage (not perfect for ATLAS), and roman pot detectors
  - Luminosity from Coulomb scattering: need roman pots
- ATLAS will pursue all these options
- More emphasis put on roman pot option in the following

Elastic scattering in the Coulomb region



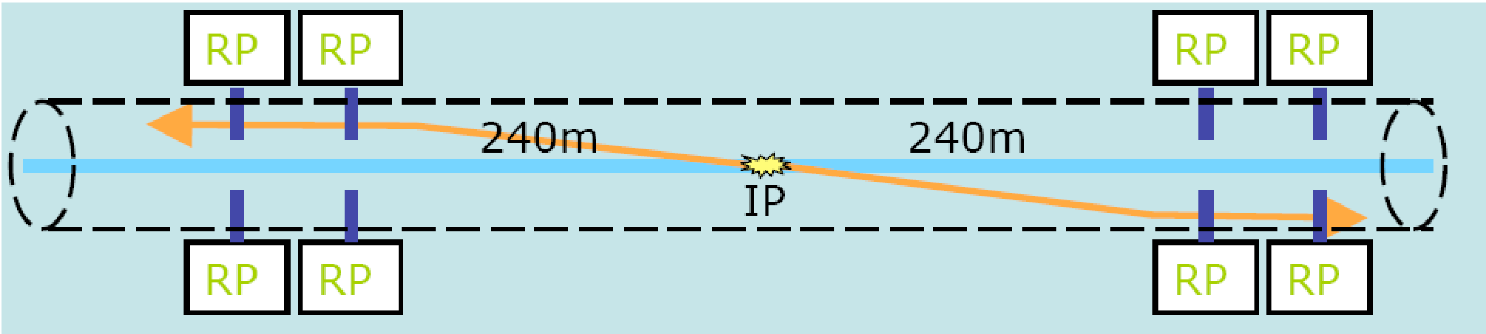
- Measurement of dN/dt:

$$\frac{dN}{dt}(t \to 0) = L\pi \left(\frac{-2\alpha}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2} \right)^2$$

- From the fit, we get σ_{tot}, ρ, b and L

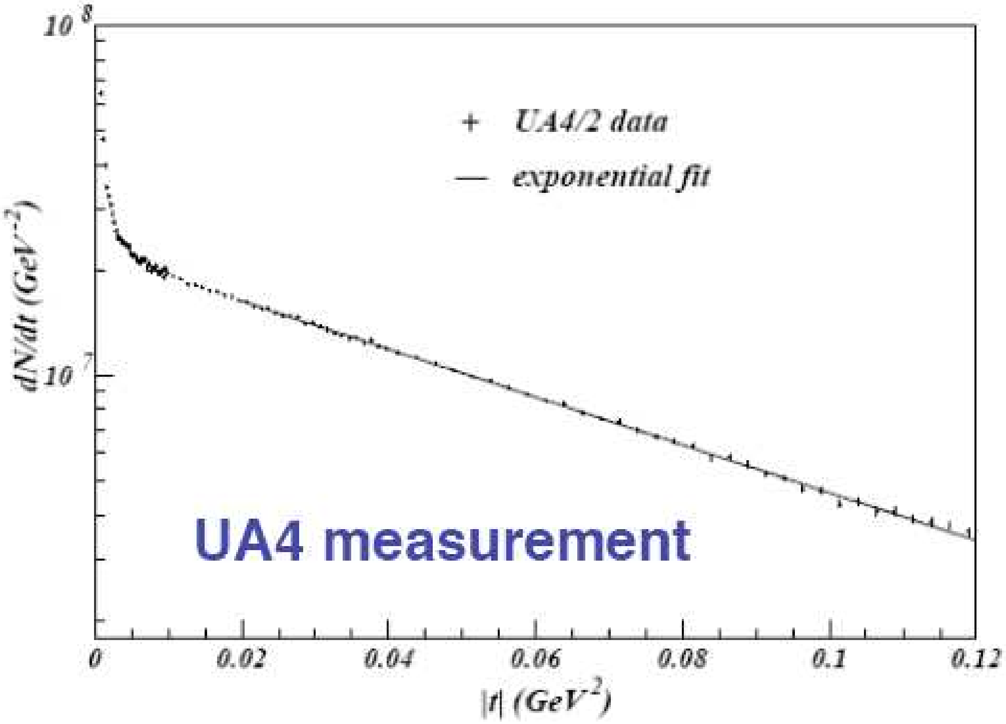
Elastic scattering in the Coulomb region: How technically?

- Goal: Understanding lumi with a precision better of 2-3%
- Measure elastic rate dN/dt in the Coulomb interference region: Necessity to go down to $t \sim 6.5\ 10^{-4}$ GeV^2, or $\theta \sim$ 3.5 μrad (when the strong amplitude equals the electromagnetic one)
- This requires:
  - Special high β^* beam optics
  - Detectors at $\sim$ 1.5 mm from LHC beam axis
  - Spatial resolution well below 100 μm
  - No significant inactive edge ($< 100\mu$m)



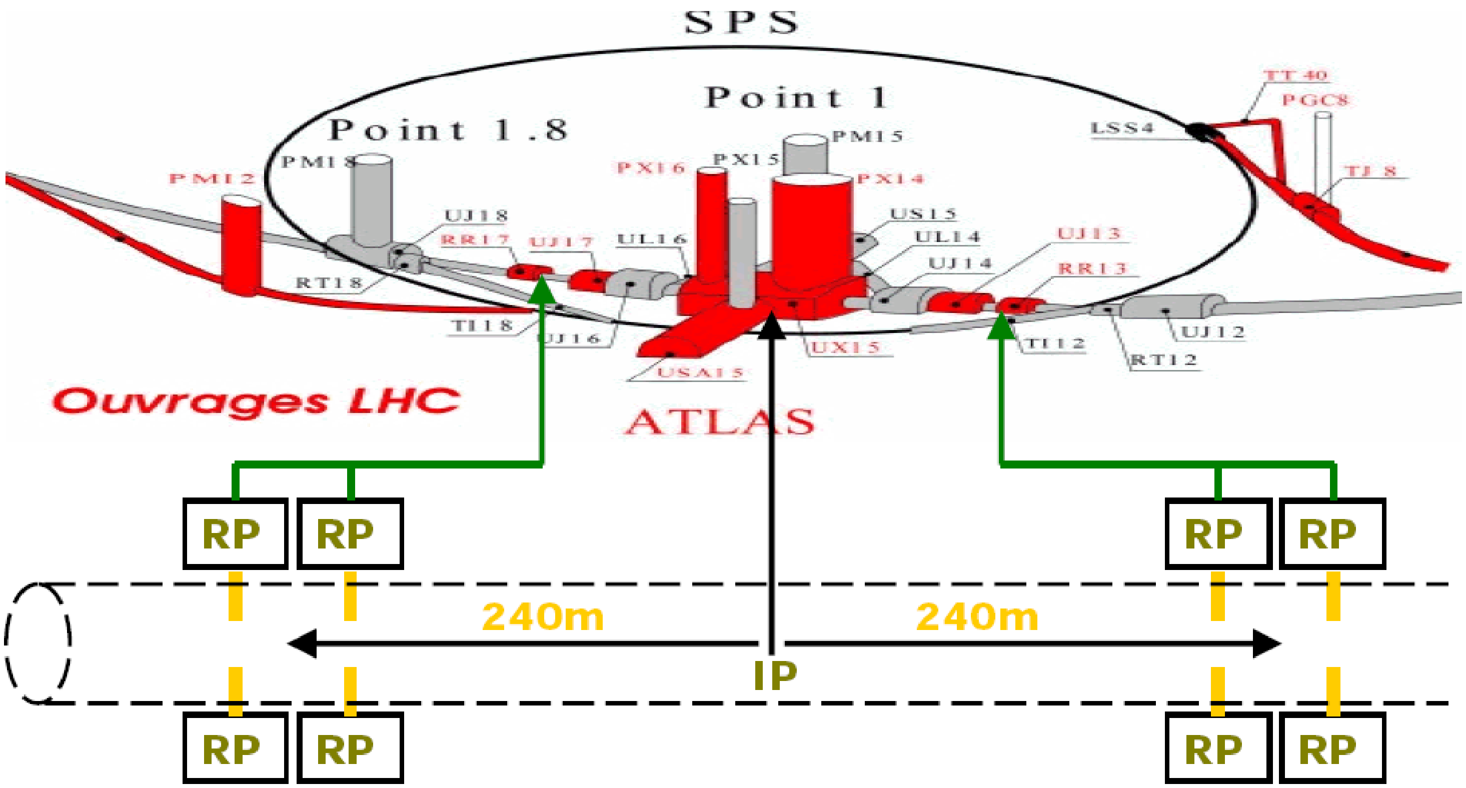
Elastic scattering in the Coulomb region: UA4 result

- Measurement of dN/dt from the UA4 collaboration: precision reached on absolute luminosity of the order of 3%
- Follow the same idea within the ATLAS collaboration (measurement going down to 120 μrad at UA4 whereas we need to go to 3.5 μrad at the LHC!): requires special beam optics (parallel-to-point optics from the interaction point to the roman pot), large β^*



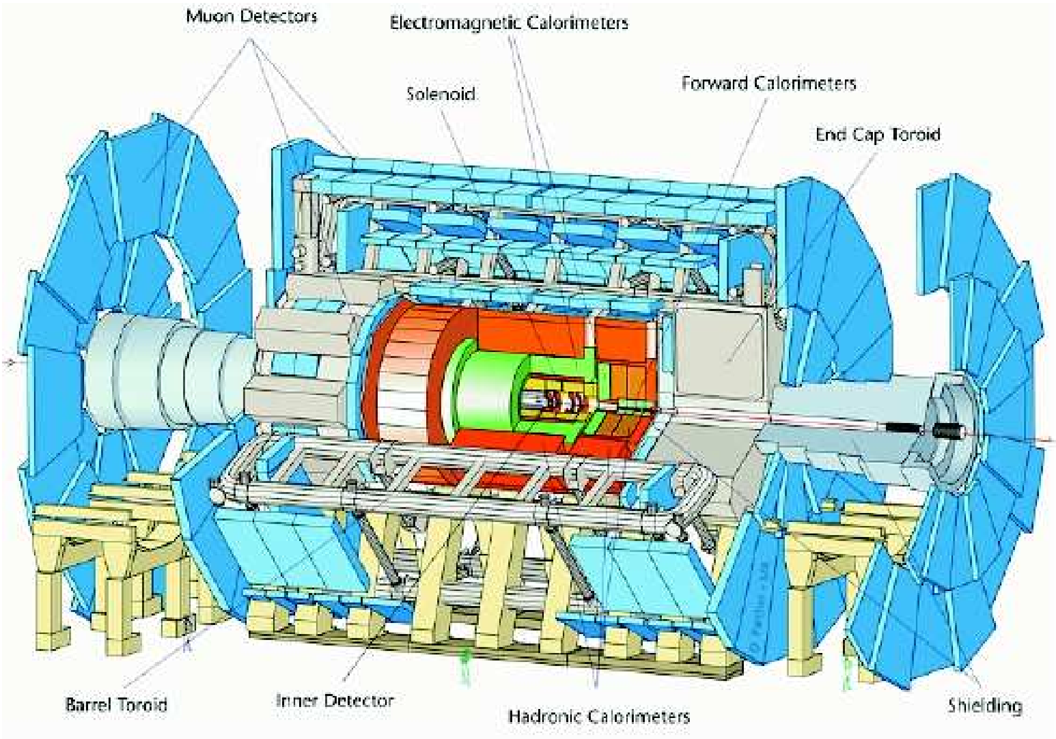
Roman pot location in ATLAS

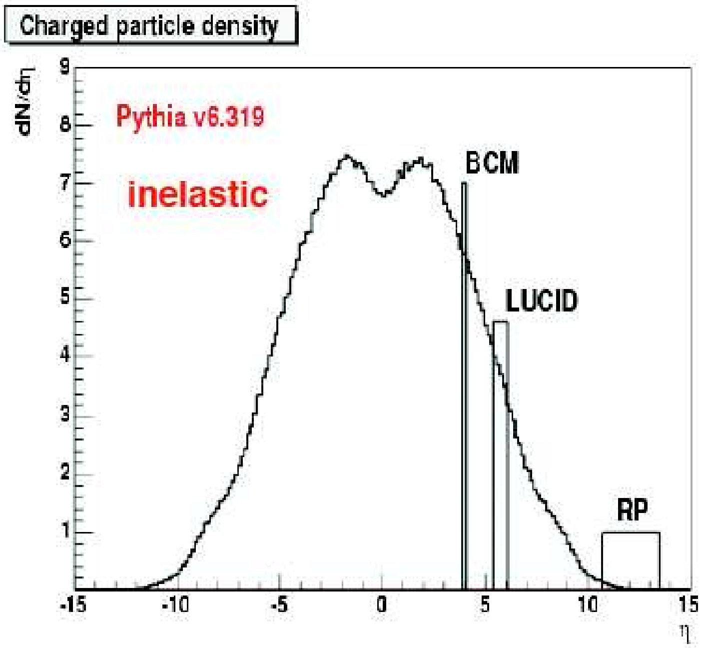
Installation of two sets of roman pot detectors on each side of ATLAS

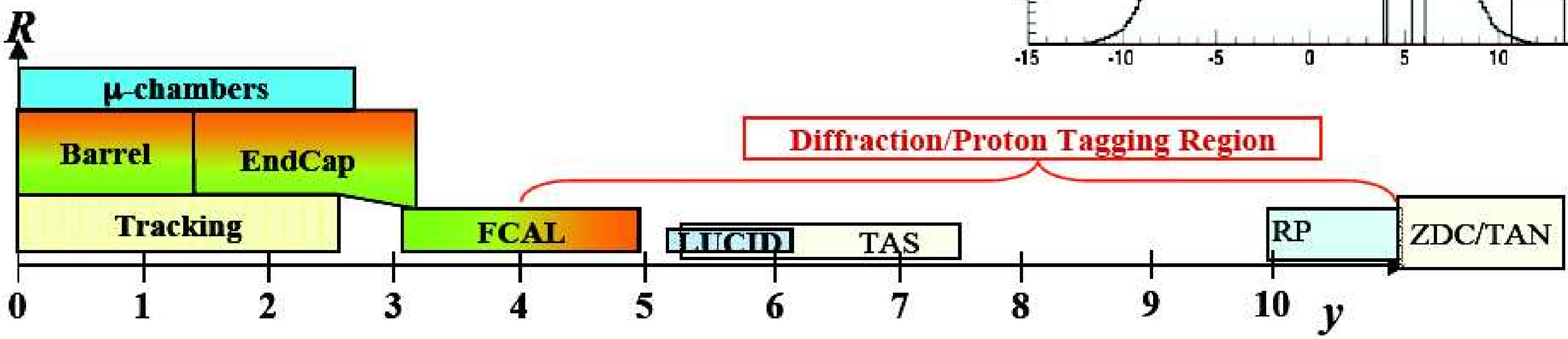


ATLAS detector

Forward region of ATLAS covered by LUCID, roman pot detectors

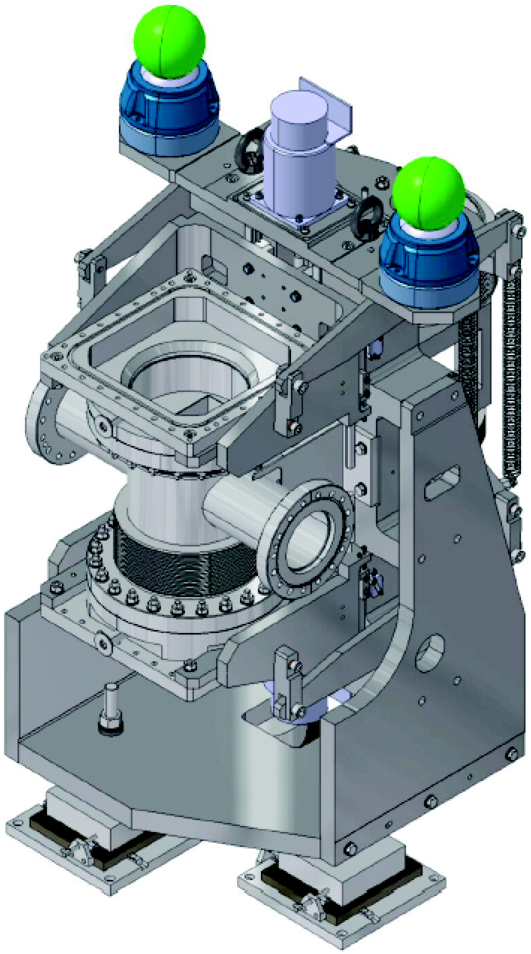






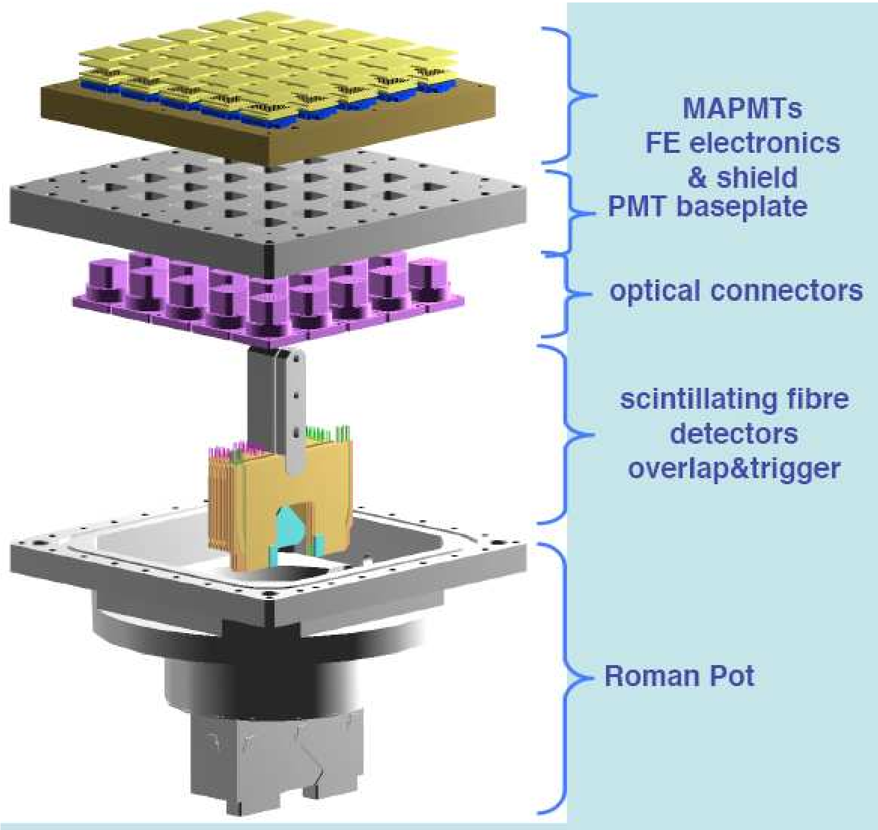
Roman pots

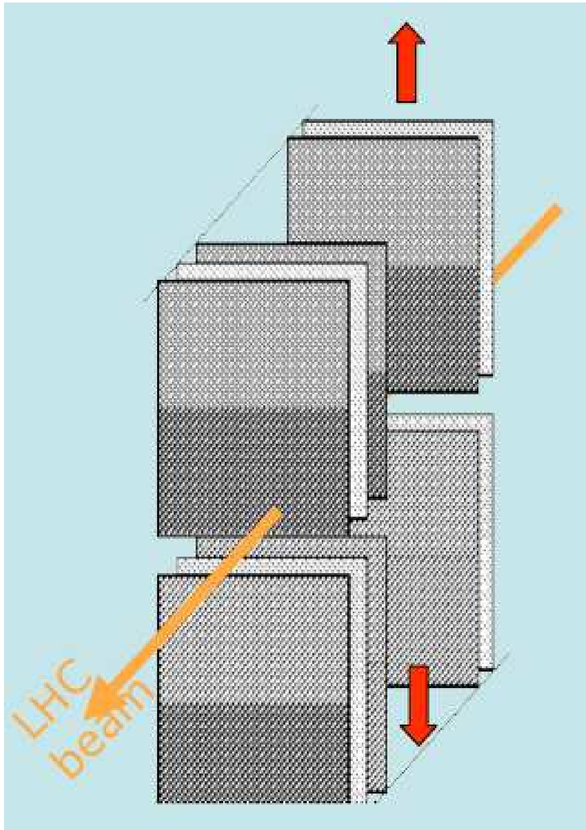
- Final roman pot design inspired by TOTEM roman pots
- Changes with respect to TOTEM: no horizontal pots, modify the geometry of flanges where pots are mounted, modify bases to allow different beam height



Detector design

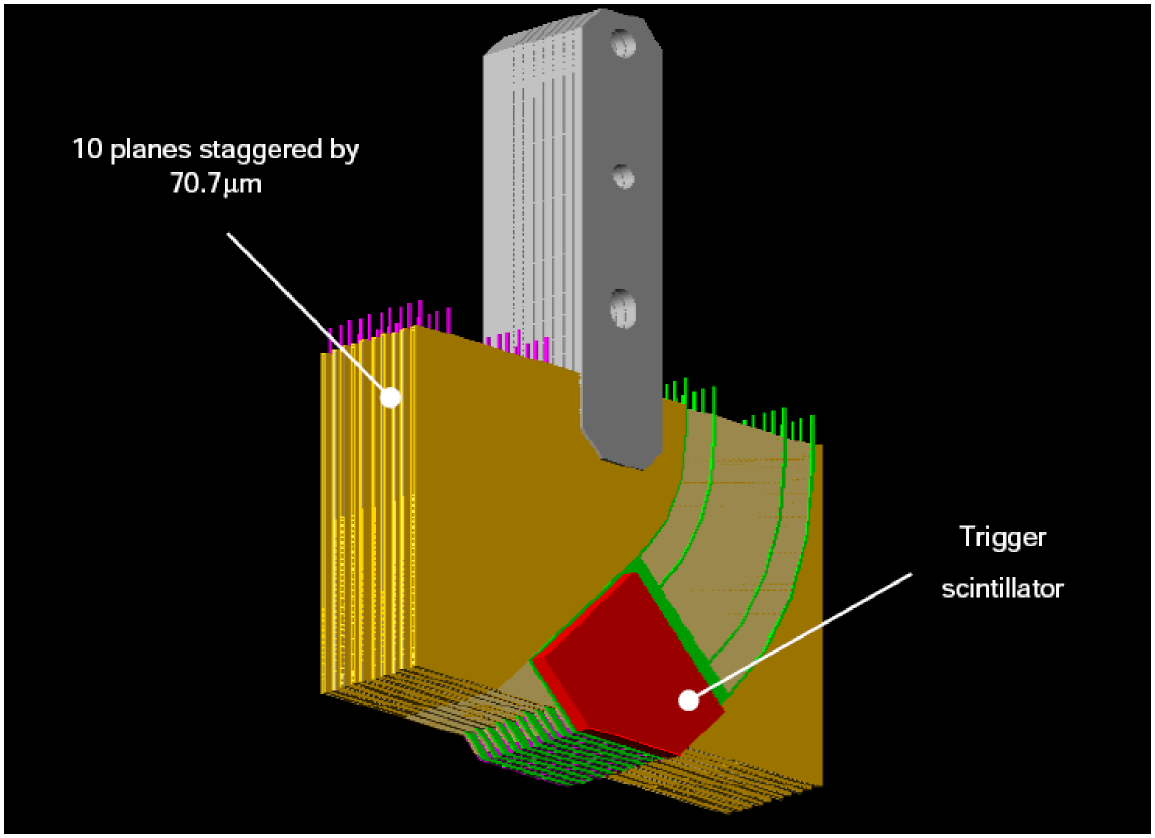
- 24 MAPMTs (64 channels) and readout cards on top
- Detector: 20×64 scintillating fibers on ceramic substrates





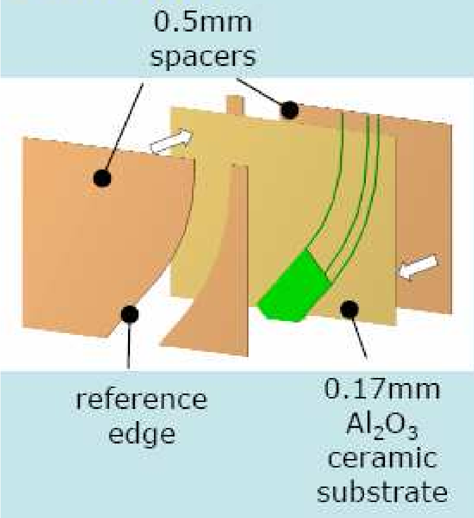
Detector design: main characteristics

- Square scintillating fibers 0.5×0.5 mm^2
- U/V geometry 45 degree stereo layers
- 64 fibers per module plane
- 10 double sided modules per pot
- Trigger scintillator in the crossing area
- Overlap detectors for relative vertical alignment



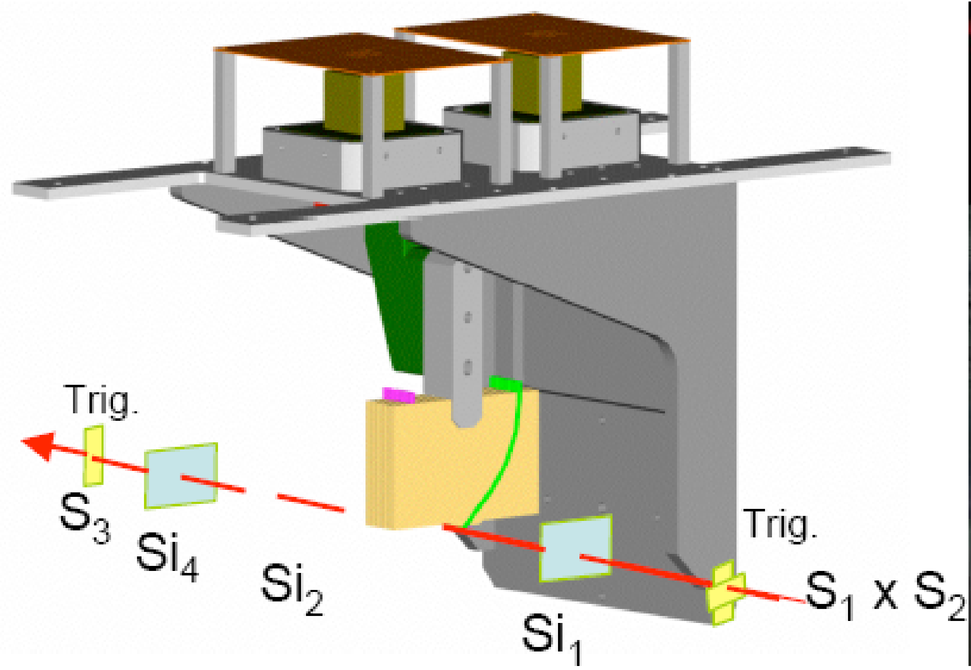
Detector prototype

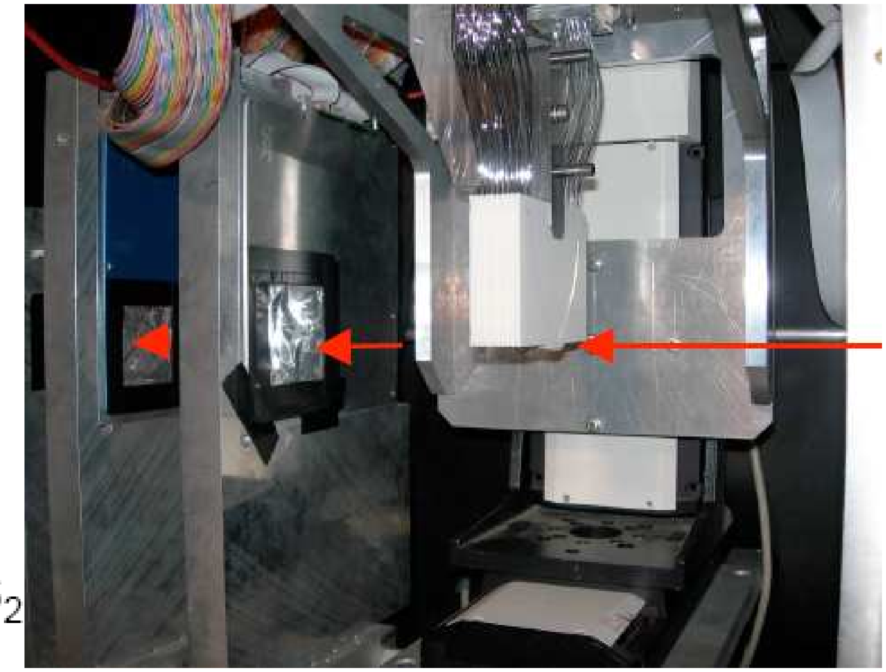
Principle



Protoype: 20 Planes u and v of 6 fibres

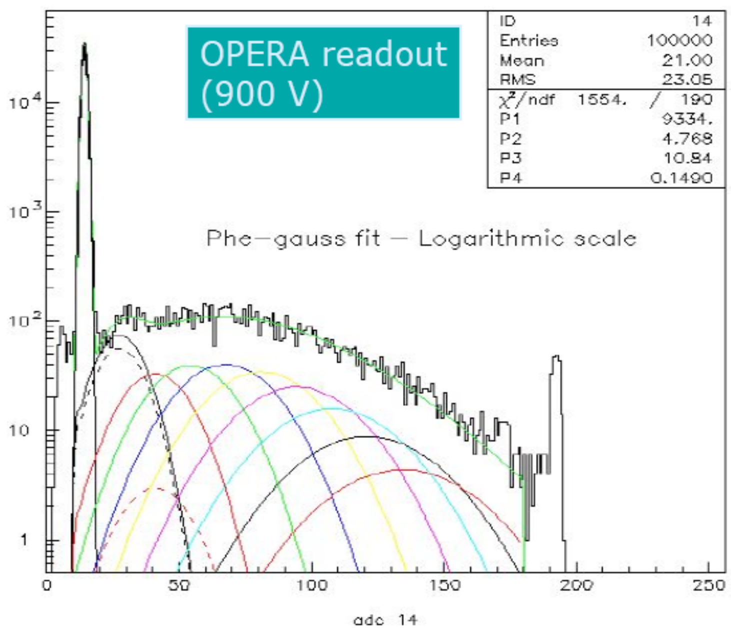
Beam tests of ALFA prototypes





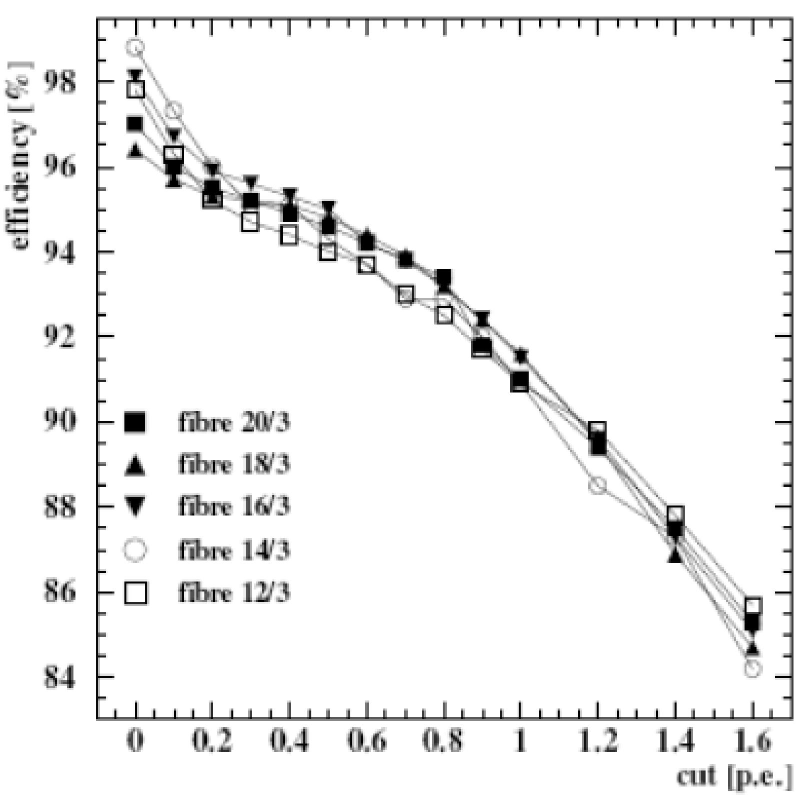
- Beam tests performed at DESY using 6 GeV e beams
- Aim of beam tests: photeelectric yield, efficiency, cross talk, edge sensitivity, track resolution

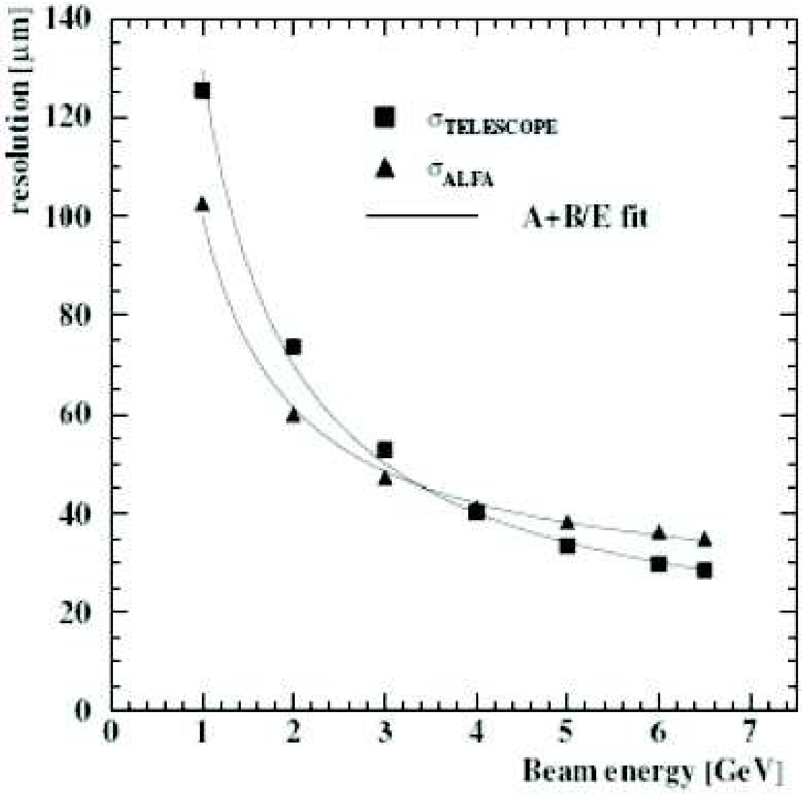
Photoelectric yield and cross talk



- Fits of multi-photoelectron spectra: two step process, first fit the position and width of pedestal with a Gaussian, and then fit the contribution from 0 to 12 photoelectrons using a convolution between a Poisson and Gauss functions
- Results:
  - Average number if photoelectrons: 4.1
  - cross-talk: 3 to 4%
- Of course, tests at higher beam energy need to be performed

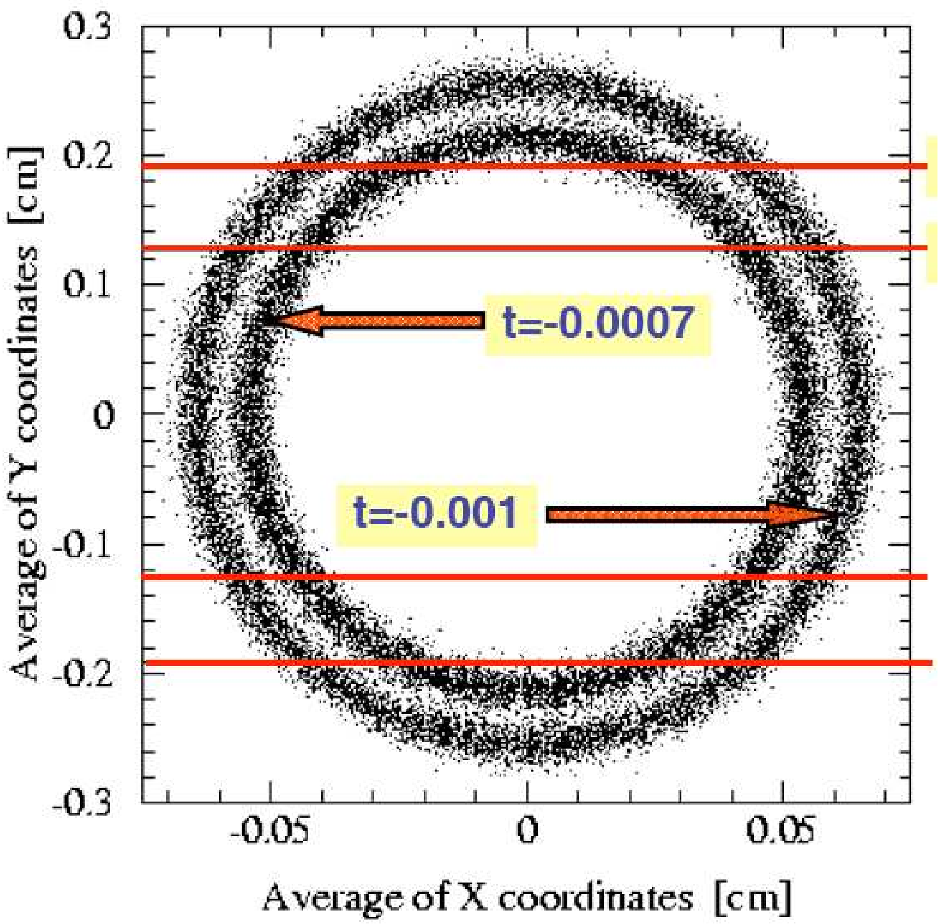
Fiber efficiencies and detector resolution





- Single fiber efficiencies: 90-94 % (depends on cuts)
- Space resolution: scales like $1/E$, expected to be of the order of 20 μm at LHC energies
- Insensitive area at the edge of detector less than 30 μm

Simulation of elastic scattering

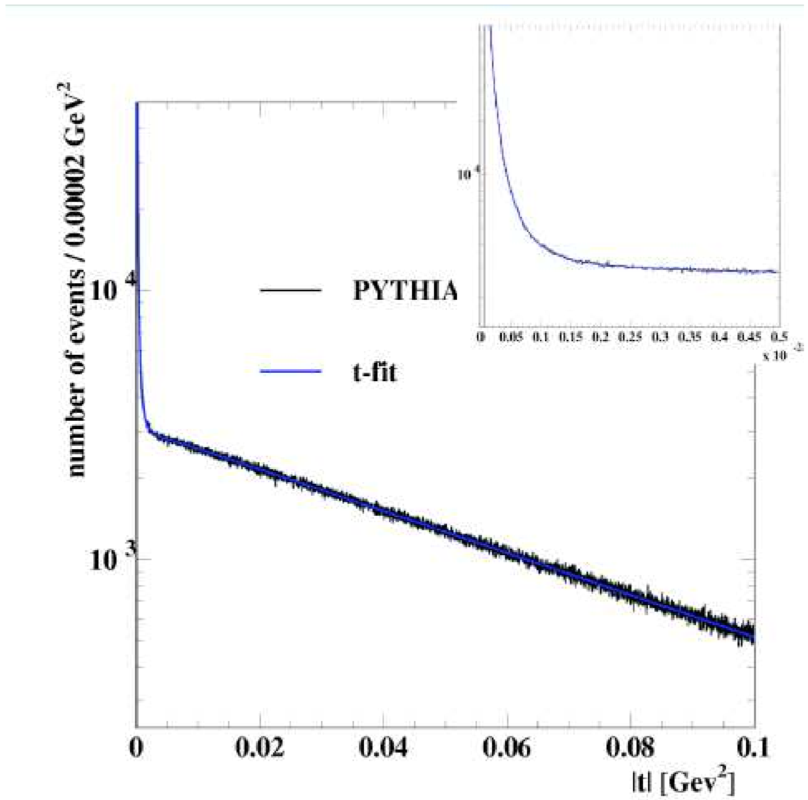


- Simulation of elastic events in real detector
- Simulation performed for two t values: $t = 7.10^{-4}$ and $t = 10^{-3}$ GeV^2, the two horizontal lines indicating respectively the 15 and 10 σ from the beam

Luminosity extraction from a fit to the t-distribution

Aim: showing the feasibility of a fit to dN/dt to extract luminosity information after a full simulation of 10 million events

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



Luminosity extraction from a fit to the t-distribution

Comparison between fitted parameters and input ones

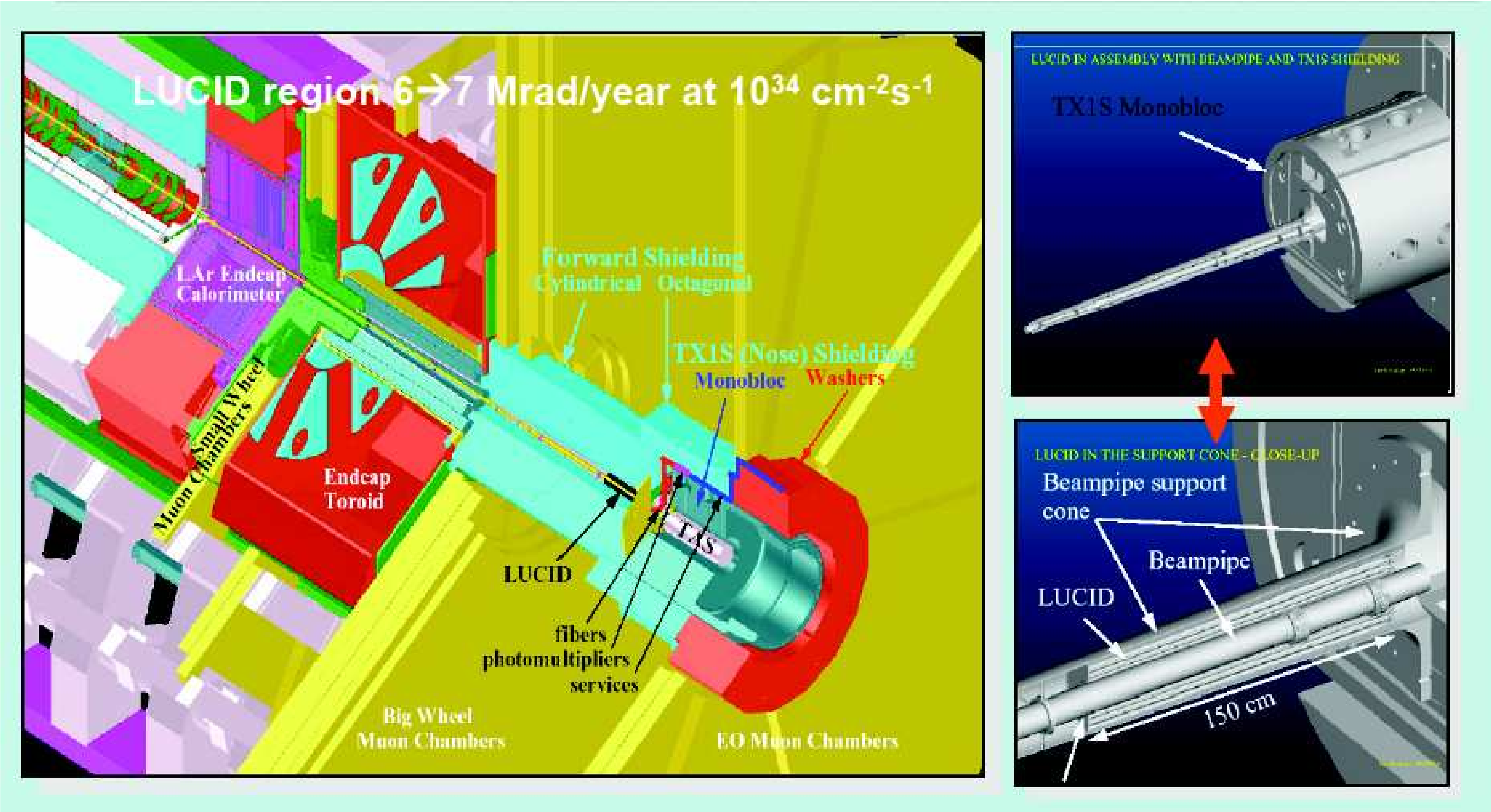
$$\frac{dN}{dt} = L\left(\frac{4\pi\alpha^2}{|t|^2} - \frac{\alpha\rho\sigma_{tot}e^{-b|t|/2}}{|t|} + \frac{\sigma_{tot}^2(1+\rho^2)e^{-b|t|}}{16\pi}\right)$$

Parameters	input	fitted	error	correlation
L	8.124 10^{26}	8.162 10^{26}	1.5%	
σ_{tot}	100 mb	101.1 mb	0.74%	99%
b	18 GeV^{-2}	17.95 GeV^{-2}	0.59%	64%
ρ	0.15	0.1502	4.24%	92%

Large statistical correlations between L and other parameters in the fit

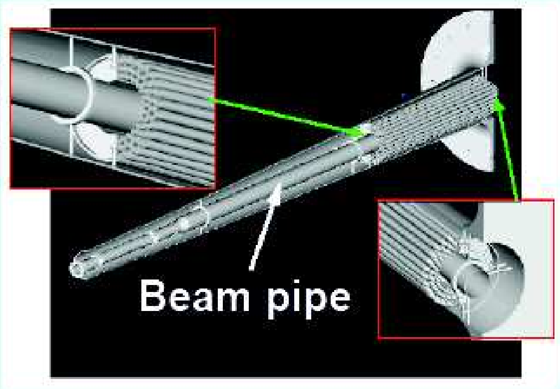
Relative luminosity measurement: LUCID

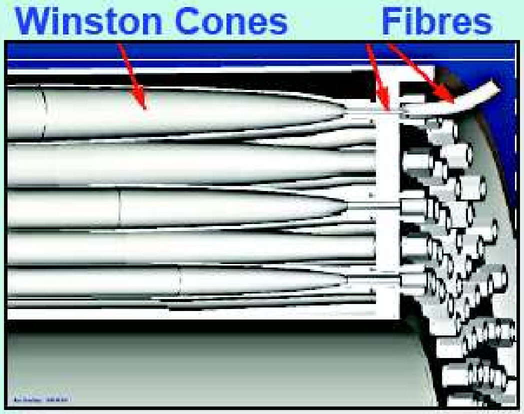
- LUCID: Luminosity measurement using Cerenkov integrating detectors
- The front face of LUCID end is about 17 m from the IP, covering $5.4 < |\eta| < 6.1$

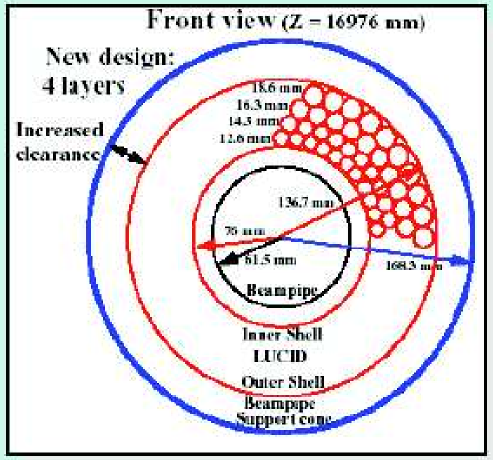


LUCID principle

Two detectors x 168 Al tubes filled with C_4F_{10} or Isobutane at 1 or 2 Bar pressure

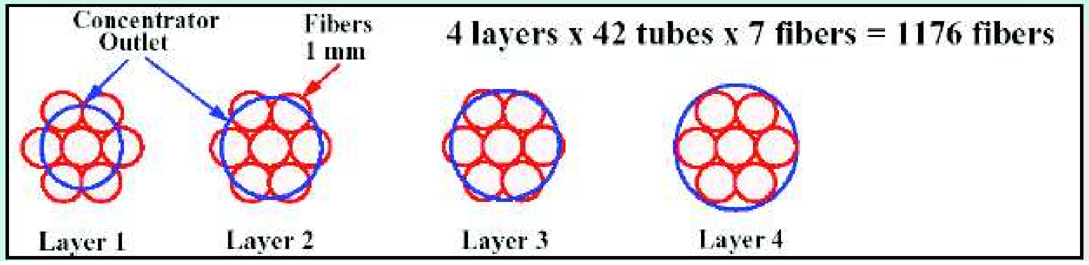






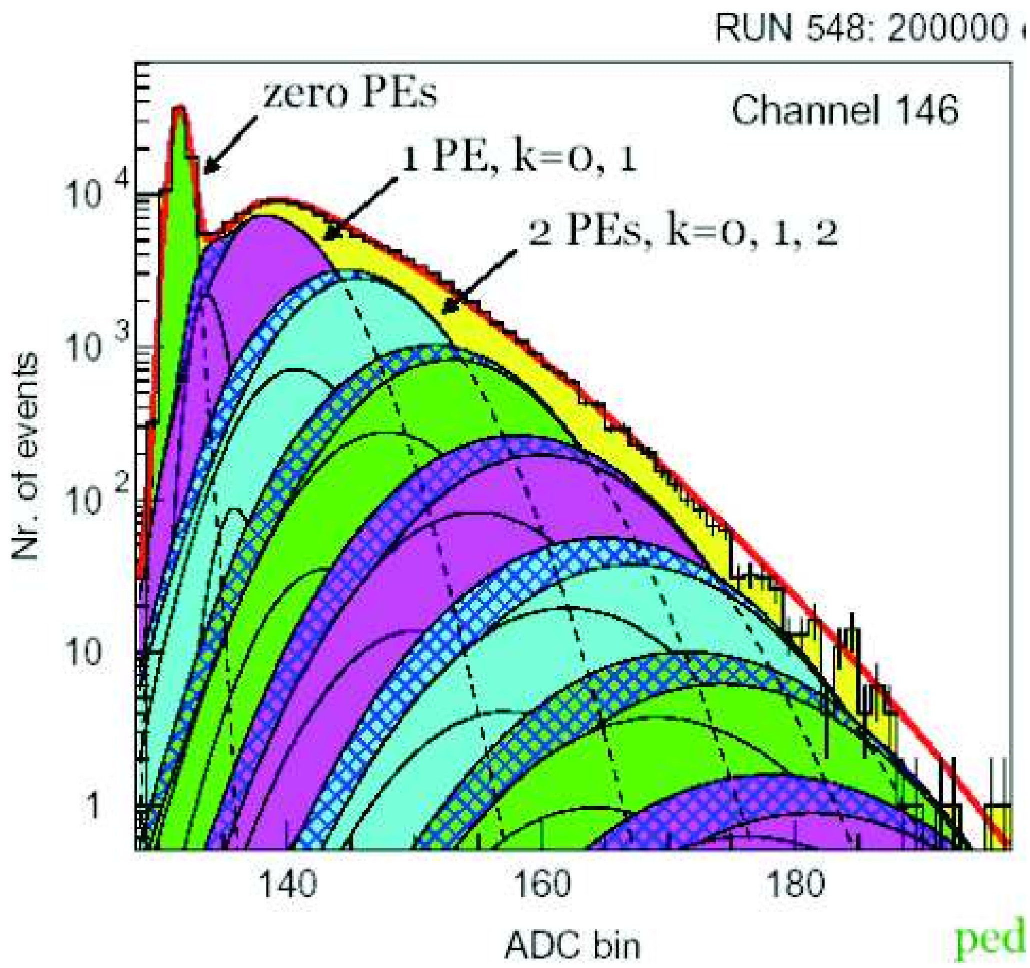
LUCID Cross-section

Winston cones at the end of the tubes bring the Cerenkov light onto quartz fibers.

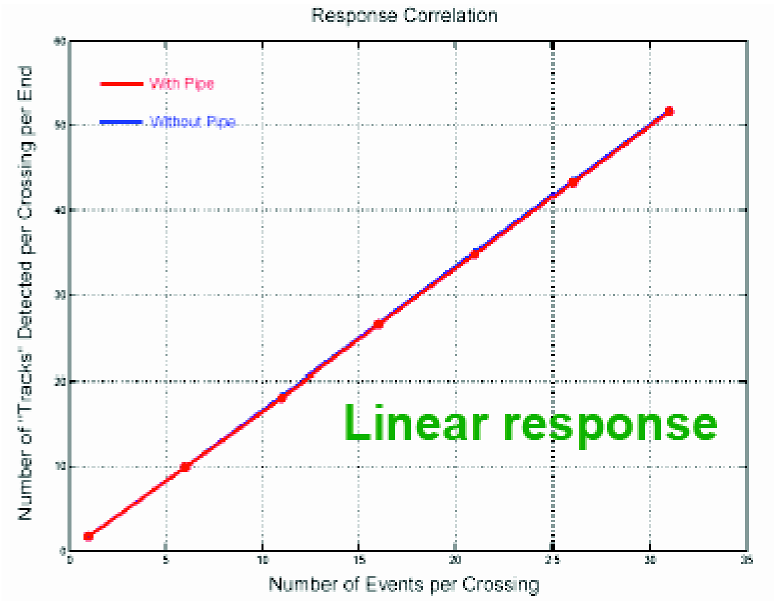


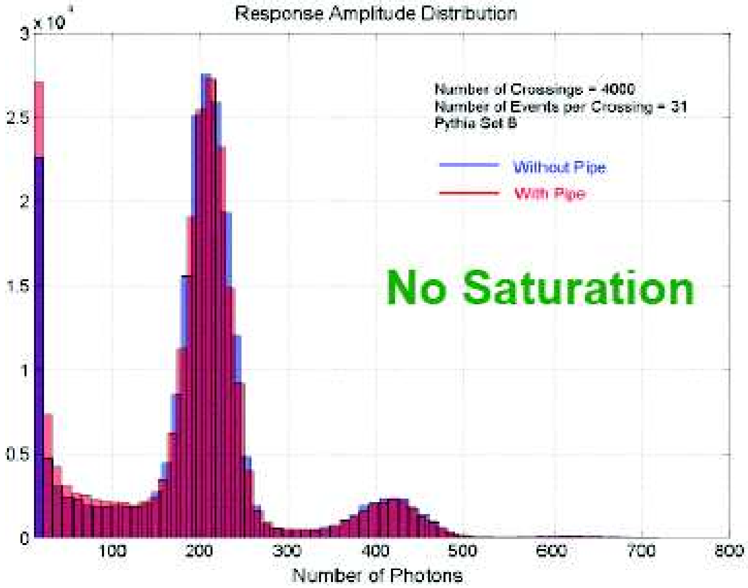
LUCID test beam performance

- Number of photoelectrons by Cerenkov tube $\sim$ 5.3: a bit lower than foreseen by simulation
- Improvement in progress (specially the coupling tube/fiber)



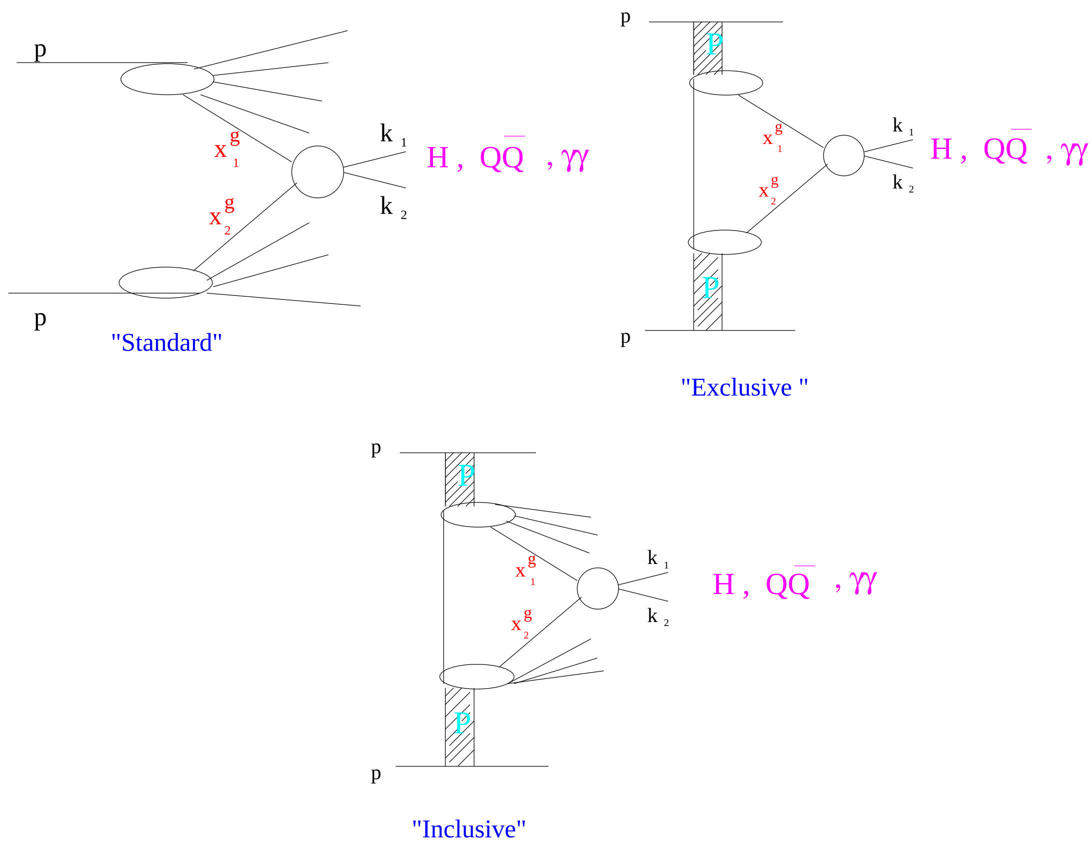
LUCID luminosity monitoring





- Excellent time resolution: 140 ps at CDF, allows determination of luminosity bunch by bunch
- Linear relationship between Lumi and track counting
- Radiation hard, compact detector
- Sensitive to primary particles: much more light coming from primary particles than from secondaries or soft particles
- Excellent amplitude resolution: possible to count multiple tracks per tube, no saturation even at highest lumi

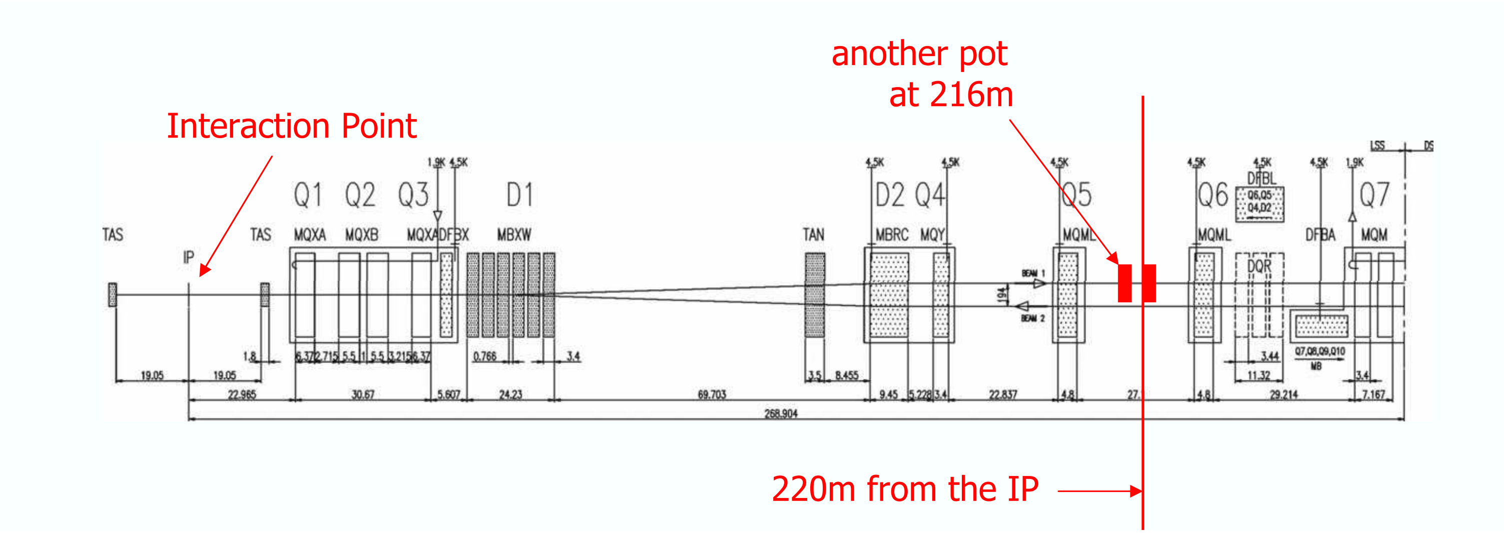
Hard diffraction in ATLAS



- Diffractive program under discussion inside ATLAS collaboration as a natural follow up of the luminosity studies
- Two options considered: roman pots at 220 m, and at 420 m (FP420 project, not mentioned here)

Roman pots at 220 m

- Roman pot location: assume roman pots at 216 and 224 m on both side of ATLAS
- Study the acceptance of the detectors at 216-224 m

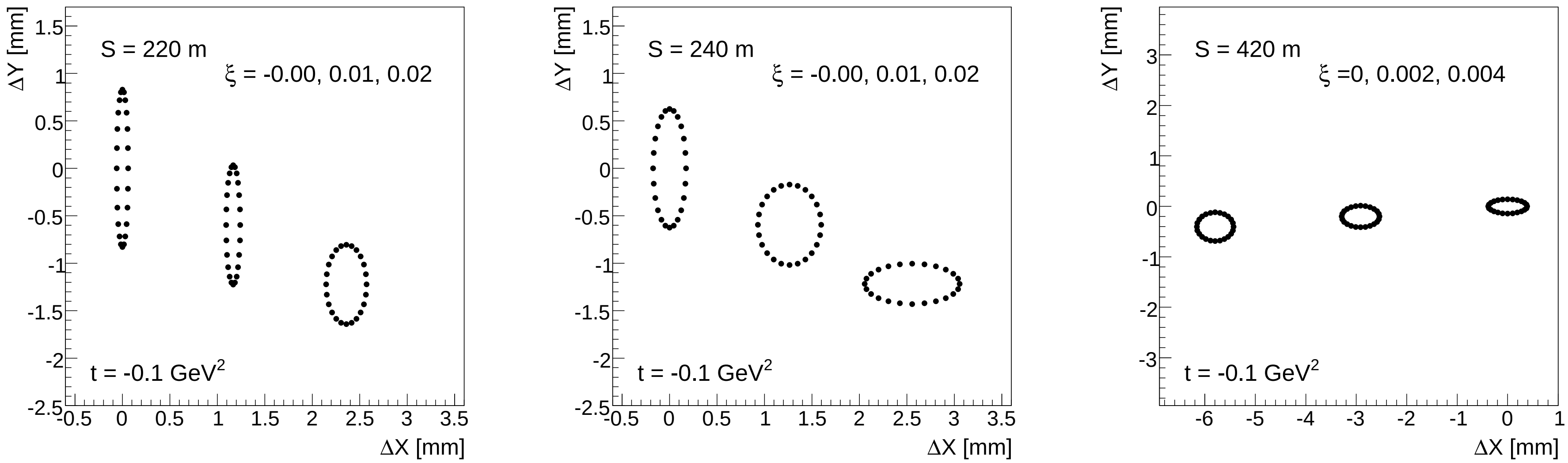


Hard diffraction in ATLAS

- Measurement of diffractive events in double pomeron exchanges possible even at highest luminosity
- Physics motivation: Higgs and SUSY event production, high β gluon density measurement, W production via γ or pomeron exchanges, QCD... See talks by Jeff Forshaw and Christophe Royon on Saturday
- Roman pot characteristics: good acceptance event for low masses (down to a Higgs mass of 110 GeV or so, $M = \sqrt{\xi_1 \xi_2 S}$), and good space resolution to get a good resolution on t, ξ and then on mass
- At highest luminosity, up to 40 interactions by bunch crossing: necessity to have a very good timing detector (resolution $\sim$ 5 ps) to know if protons are coming from the same vertex, and also from the primary one

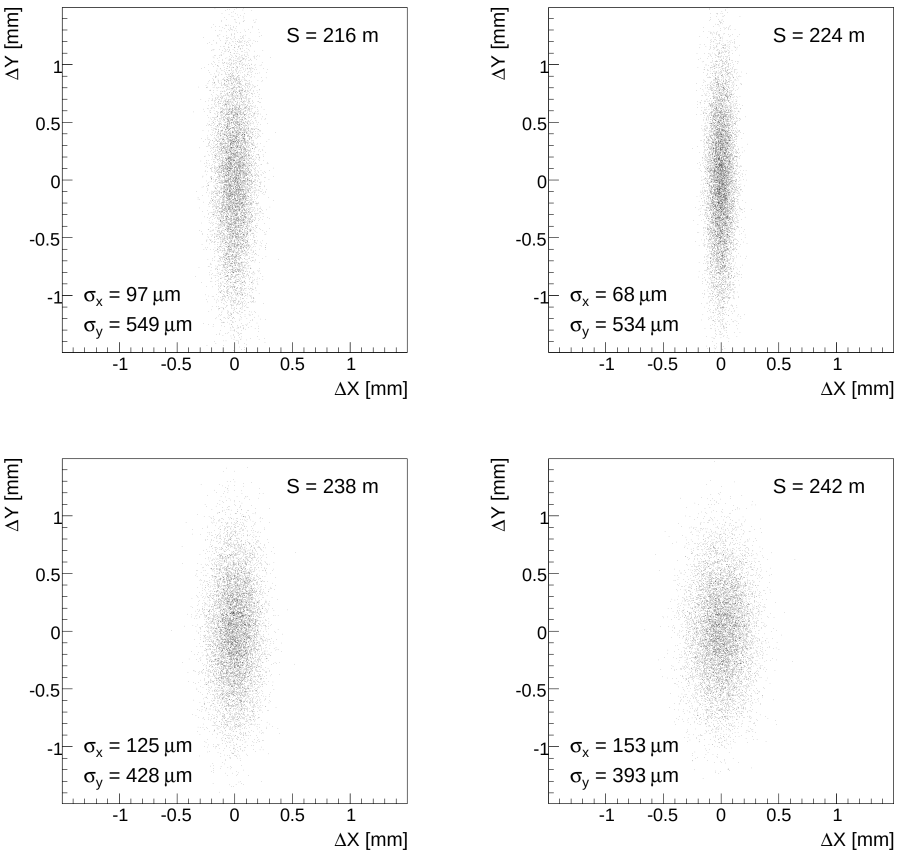
Acceptance for diffractive events

- Acceptance for diffractive events ($\xi \sim 0, 0.01, 0.02$) at 220, 240, and 420 m
- Note the difference of sign between 220-240 m and 420m



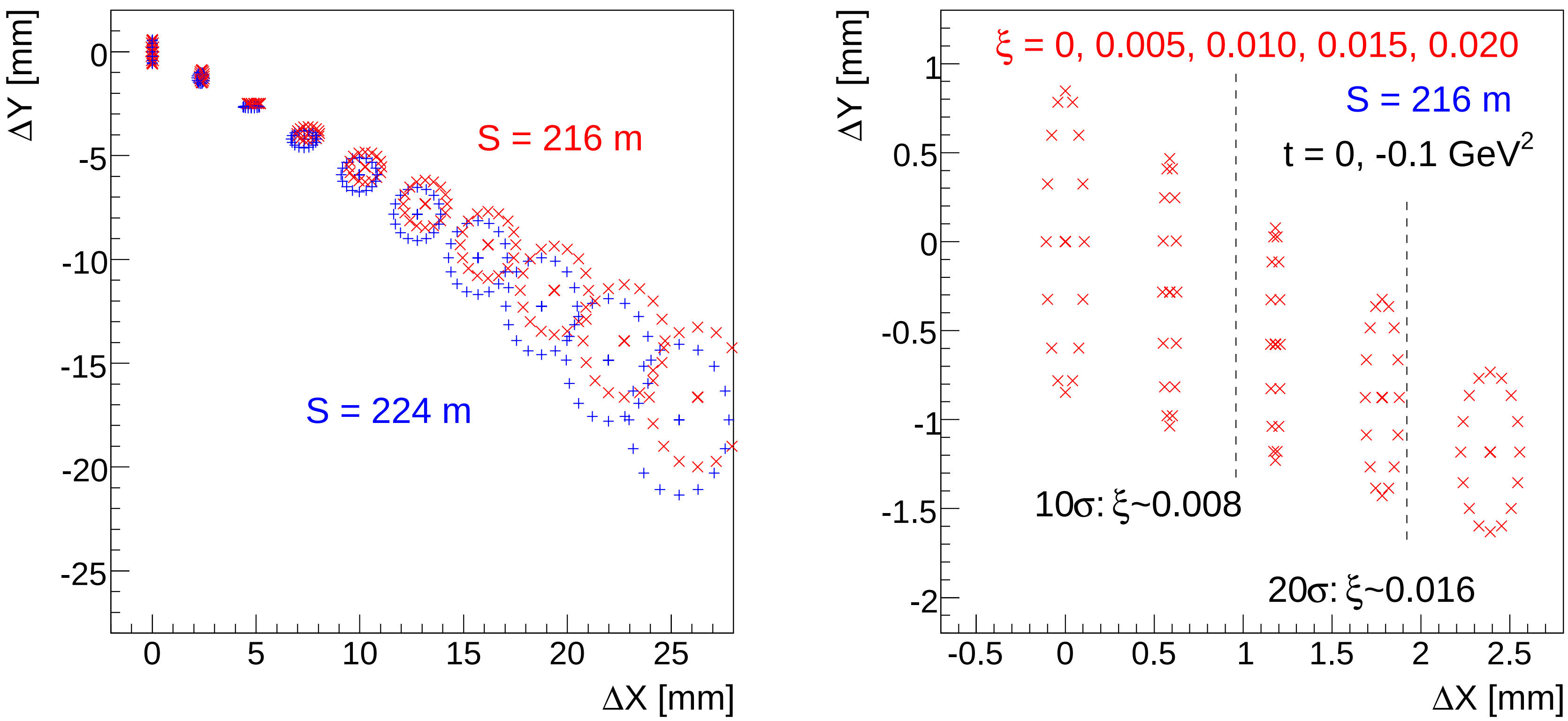
Beam spots

- Use full beam simulation to compute beam spots
- Obtain beam spots, useful to determine what is the beam size at the 220 m location: needed to know what 10 or 15 σ from the beam means
- Difference in time between 2 protons coming from the same vertex with different t and ξ less than 50 μm



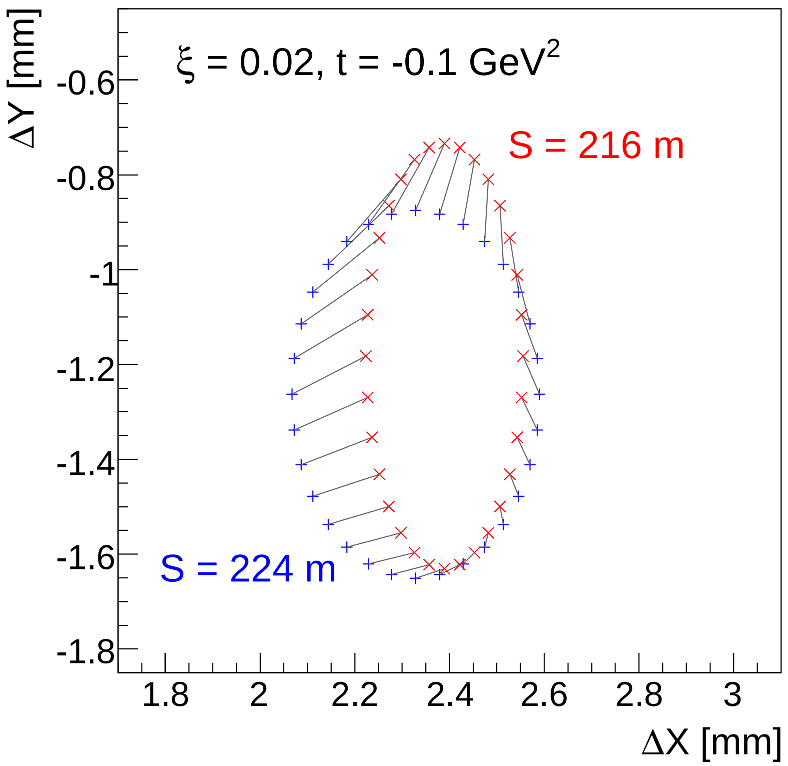
Acceptance for 220 m pots

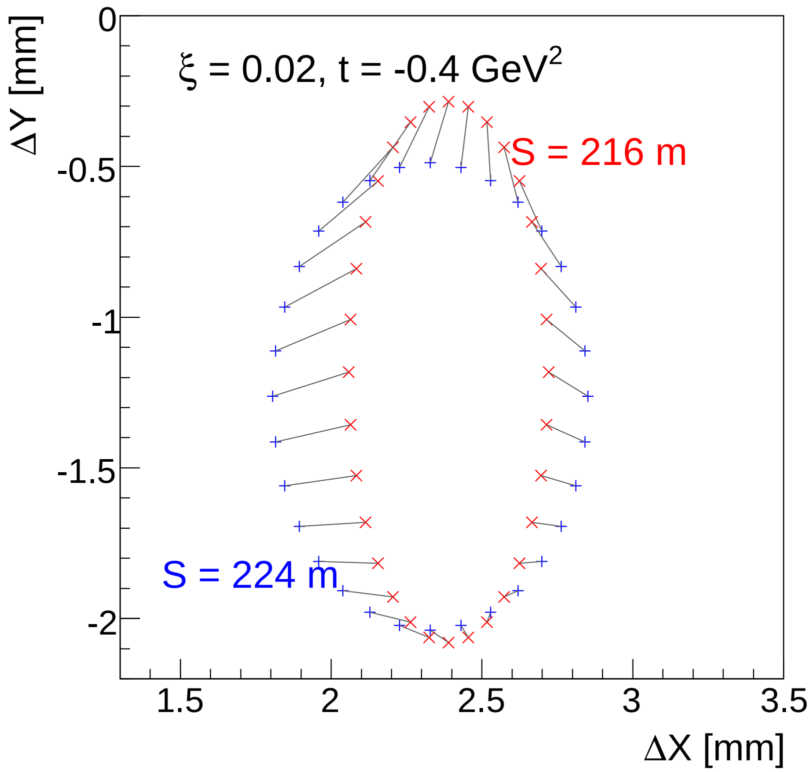
- Steps in ξ: 0.02 (left), 0.005 (right), $|t|$=0 or 0.05 GeV^2
- Detector of 2 cm $\times$ 2 cm will have an acceptance up to $\xi \sim 0.16$, down to 0.008 at 10 σ, 0.016 at 20 σ
- As an example Higgs mass acceptance using 220 m pots down to 112 GeV and upper limit due to cross section and not kinematics



Hit maps at 216 and 224 m

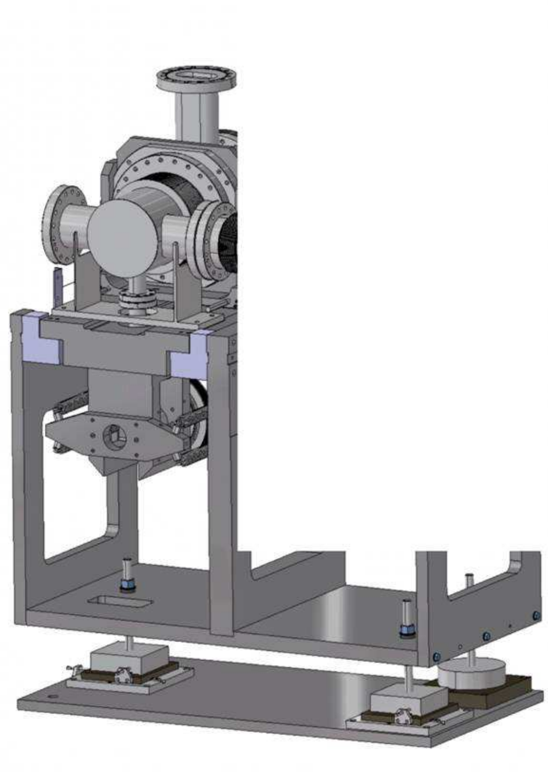
- Study difference between hit maps at 216 and 224 m: test the idea of using displacement at the trigger level to distinguish with halo
- No unique shift direction between 216 and 224 m

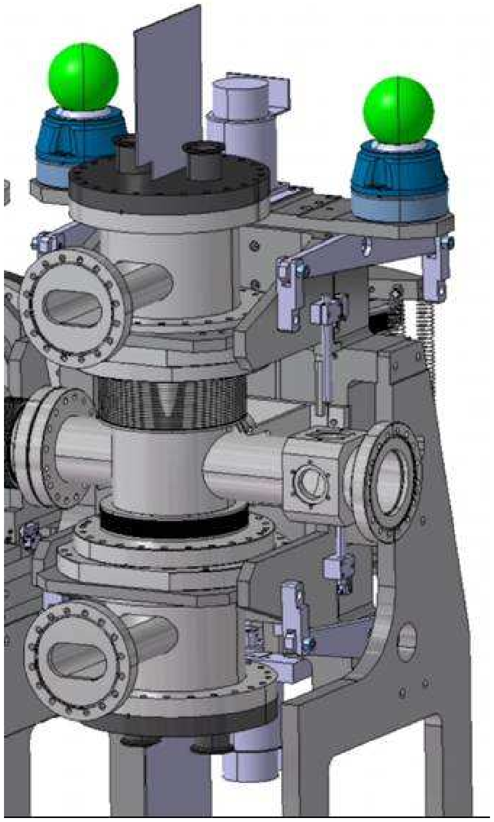




Roman pots at 220 m

Schematic view of 220 m pots: keep horizontal pots only
from the TOTEM pots





Si strip detectors

- 10 planes of Si 50 μm strip detectors per pot (in the sequence: vertical- U-V - horizontal- vertical- U-V- horizontal- vertical, two U, V, and vertical planes being spaced by 25 μm)
- Good space resolution: of the order of 50 μm per plane, leads to a few μm per detector, useful if one wants to see (and use) the displacement from one station to another to distinguish halo from real event
- Good timing resolution: of the order of 5 ns to know from which beam crossing the event is coming
- Little dead material at the edge: of the order of 100 μm, to minimize the distance between the beam and the active part
- Very good timing resolution (5 ps) of a dedicated timing detector: to say from which vertex the protons are coming, Cerenkov counters under study
- Readout or integration time: of the order of 5 ns to avoid pile up (we expect at high lumi 0.3 diffractive event by bunch crossing plus halo)

Conclusion

- Absolute luminosity measurement: Use the Coulomb method, roman pots being built and detectors on test, well advanced
- Relative luminosity measurement: LUCID detector, in progress
- Measurement of hard diffraction in ATLAS: project of installing 220 m pots under discussion within ATLAS, as a natural follow-up of the luminosity project, complementary to the FP420 project