The ATLAS Experiment

ALFA - absolute luminosity for ATLAS

Luminosity measurements and forward physics in ATLAS

- forward detectors
- luminosity calibration and monitoring
- forward physics beyond luminosity

Hasko Stenzel

on behalf of the

ATLAS Luminosity

& forward physics WG

HERA AND THE LHC

2nd workshop on the implications of HERA for LHC physics

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Forward physics in ATLAS

ATLAS proposes a two-stage program:

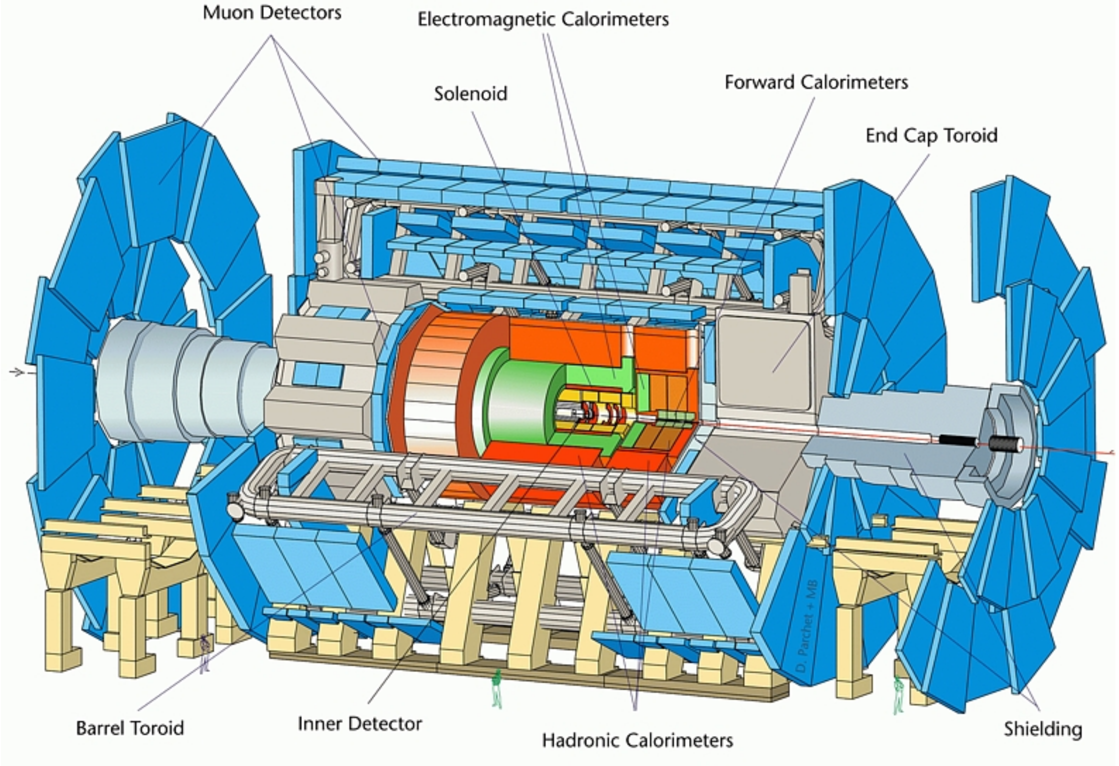
1: Luminosity calibration with Roman Pot detectors from elastic scattering in the Coulomb region using special beam optics with high β^*.

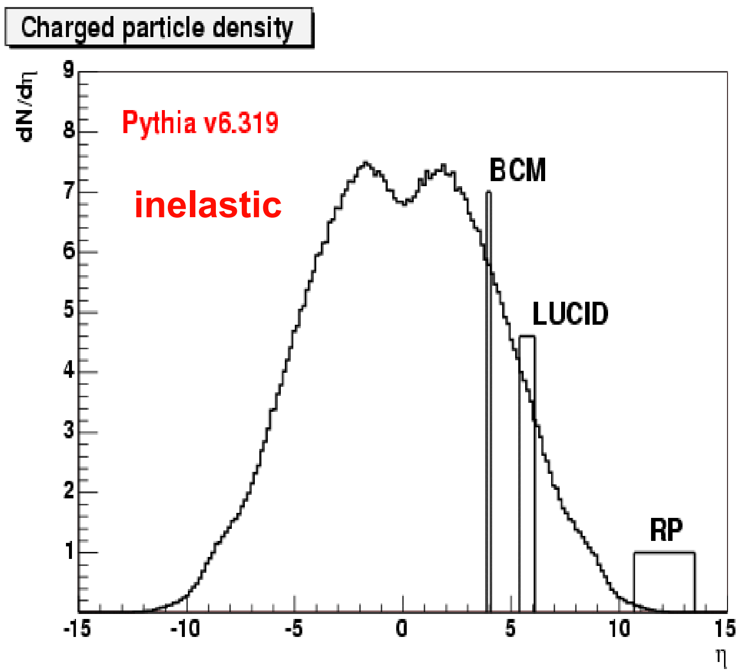
Relative luminosity monitoring by an integrated Cerenkov detector LUCID up to highest luminosity.

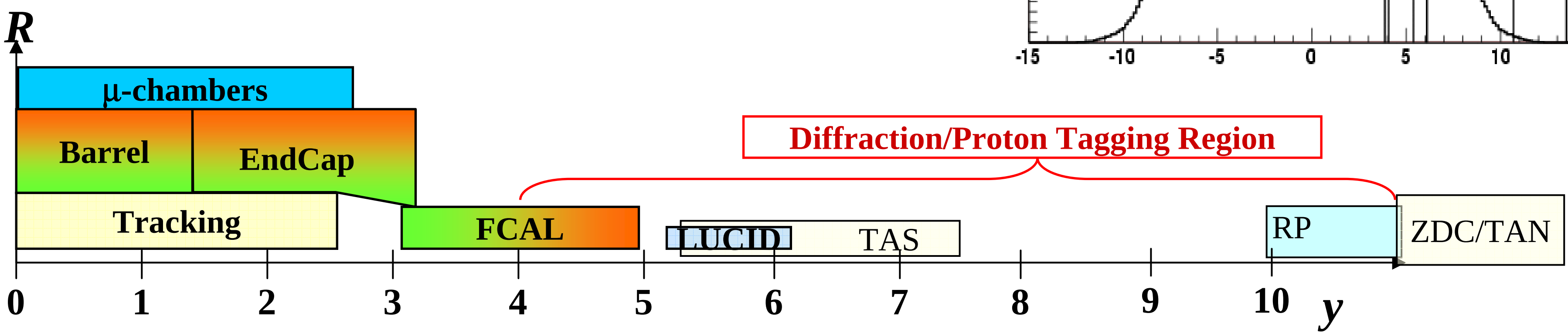
2: Hard diffractive physics, exclusive central diffraction, double-Pomeron exchange, requiring proton tagging and momentum-loss measurements at collision optics.

Studies for radhard RP detectors at 220m are ongoing, complementing FP420 studies.

The ATLAS detector







Motivation for a precise Luminosity determination

$$\sigma_{\exp} = \frac{N_{obs} - N_{bgd}}{A \cdot \varepsilon \cdot L_{pp}}$$

Determination of Standard Model cross sections

- heavy quark production
- W/Z production
- QCD jet cross sections

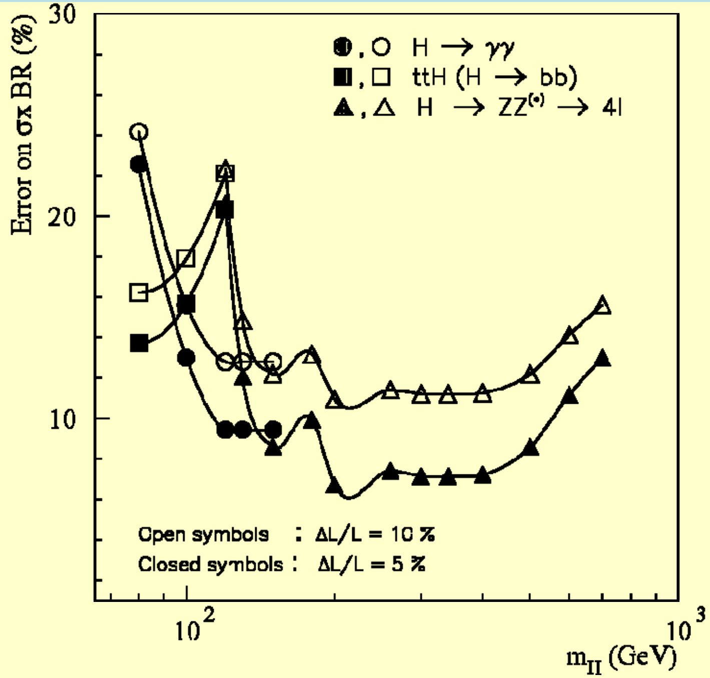
→Background for searches, constraints of PDFs

Theorectical predictions at the level of 5% with prospect for improvements (NNLO).

New physics manifesting in deviation of σ x BR relative to the Standard Model predictions

Important precision measurements

- Higgs production σ x BR
- tanβ measurement for MSSM Higgs



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

(ATLAS-TDR-15, May 1999)

Methods of Luminosity measurements

Absolute luminosity

- from the parameters of the LHC machine
- rate of $pp \rightarrow Z^0 / W^{\pm} \rightarrow l^+ l^- / l\nu$
- rate of $pp \rightarrow \gamma\gamma \rightarrow \mu^+ \mu^-$
- Optical theorem: forward elastic+total inelastic rate, extrapolation $t \rightarrow 0$ (but limited |η| coverage in ATLAS)
- cross-check with ZDC in heavy ion runs
- from elastic scattering in the Coulomb region
- combinations of all above

Relative luminosity

- LUCID Cerenkov monitor, large dynamic range, excellent linearity

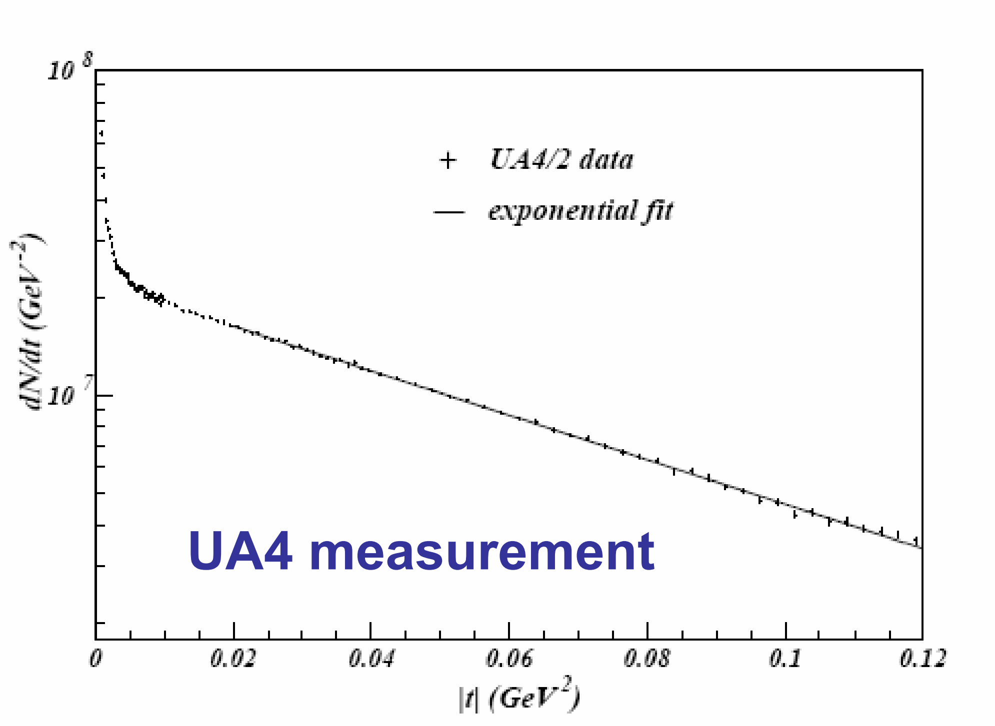
ATLAS aims for 2-3% accuracy in *L*

Luminosity from elastic scattering

Measure elastic pp-scattering down to very small angles (~3 μrad)

- operate tracking detectors very close to the beam, 10 σ = 1.2 mm
- high β* optics
  parallel-to-point focusing
- reconstruct the t-spectrum
- fit L to the t-spectrum

$$\left.\frac{dN}{dt}\right|_{t\approx 0} = L\pi\left|F_C + F_N\right|^2 \approx L\pi\left|-\frac{2a_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-B|t|/2}\right|^2$$



Coulomb region: $F_C \approx F_N$ $\quad -t_{\min} \leq\approx \frac{8\pi a_{EM}}{\sigma_{tot}} \approx 6\times 10^{-4}\ GeV^2 \Rightarrow \theta_{\min} \leq 3.5\mu rad$

Detector requirements

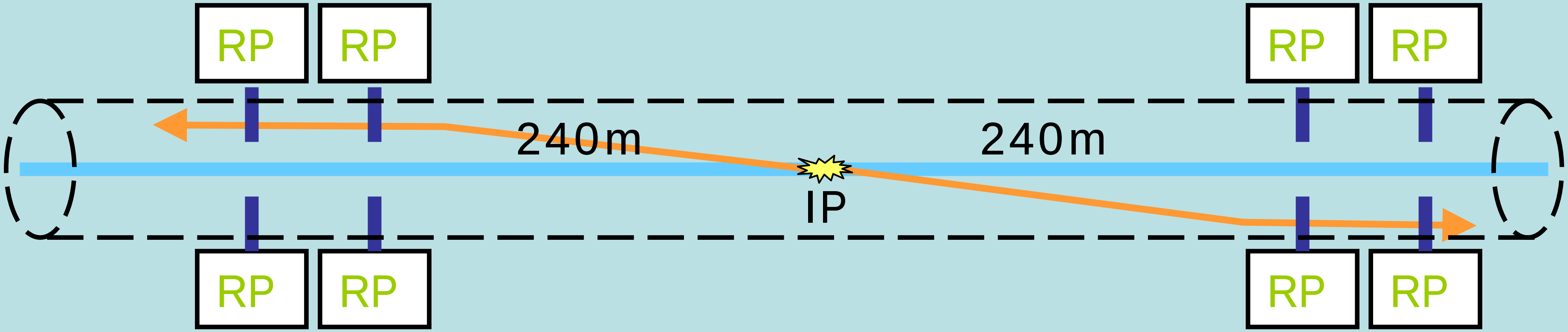
Physics & operation requirements

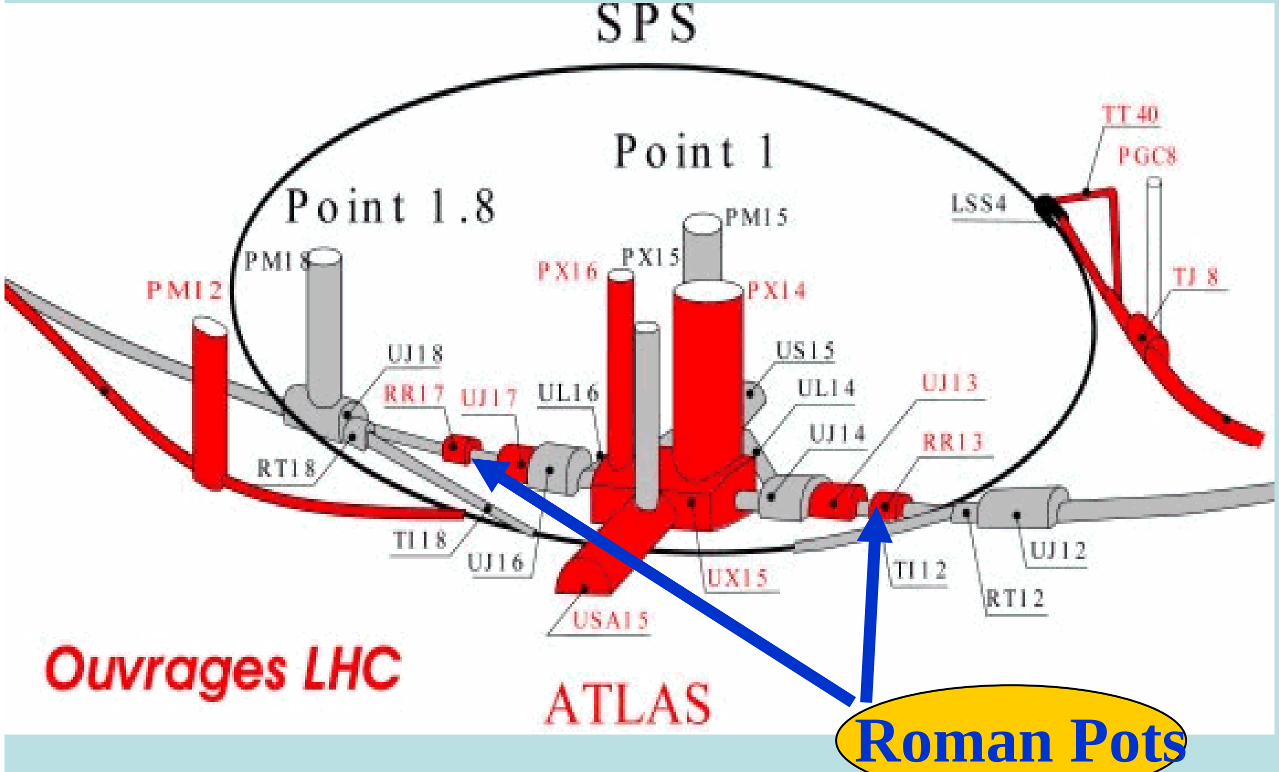
- **detector resolution σ_d = 30 μm , beam spot size =120 μm at RP (*t*-resolution dominated by beam divergence)**
- **detector sensitivity up to the edge towards the beam ('edgeless detector', insensitive region $d_0 \lesssim 100\mu$m at the edge)**
- **position accuracy ~ 10 μm relative between top and bottom detector (stringent survey and metrology requirements)**
- **radiation tolerance 100 Gy/yr (dominated by beam halo)**
- **rate capability O(1 MHz) and time resolution O(5 ns)**
- **insensitive to EM pulse from the bunched beam**

Integration & construction constraints

- **integration in the readout/DAQ/trigger scheme of ATLAS**
- **LHC safety, control and interlock requirements**
- **limited resources and tight schedule**

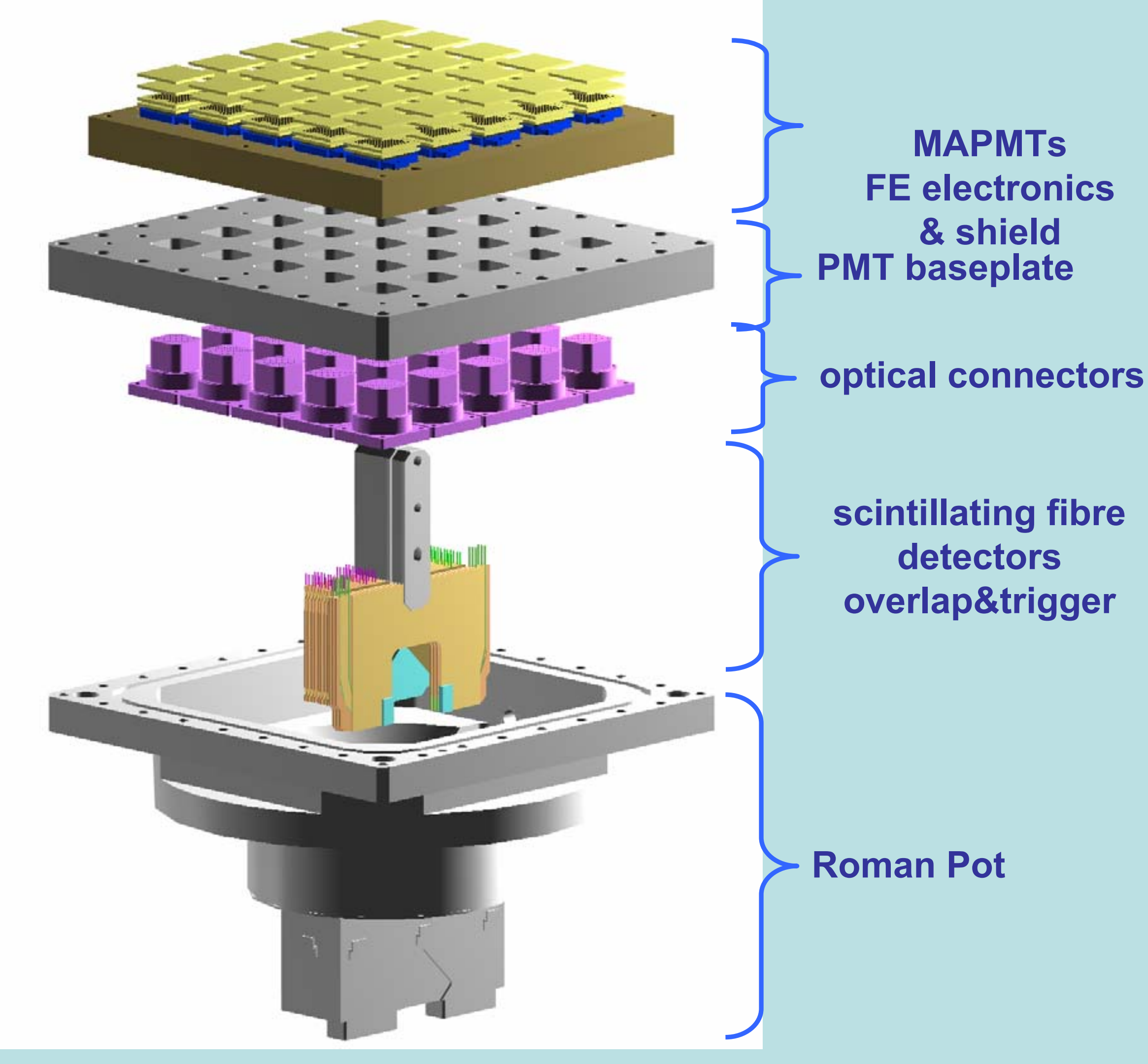
Roman Pots for ATLAS



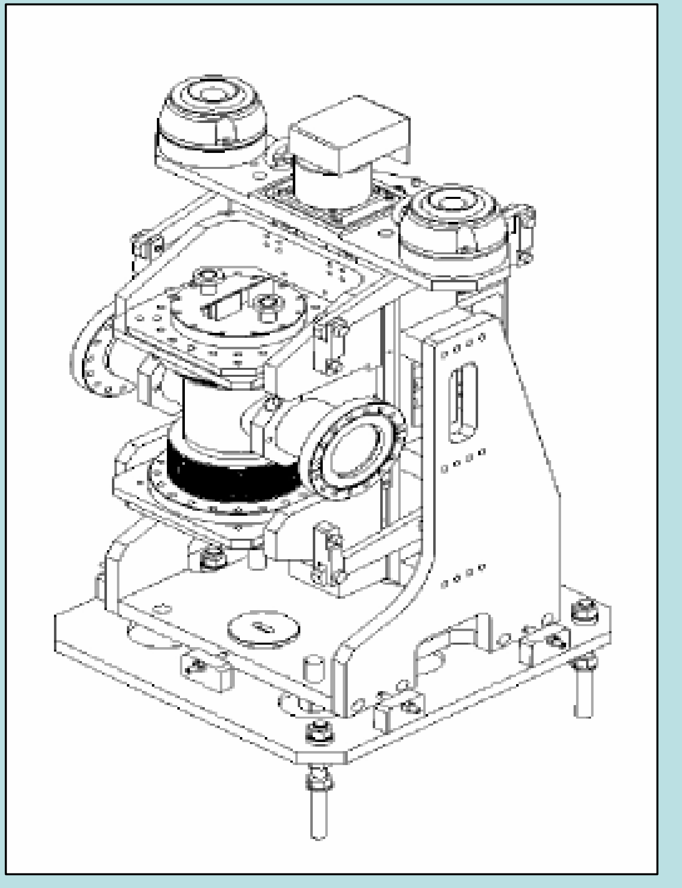


Two RP stations with top and bottom vertical pots, separated by 4 m, at each side 240 from IP1

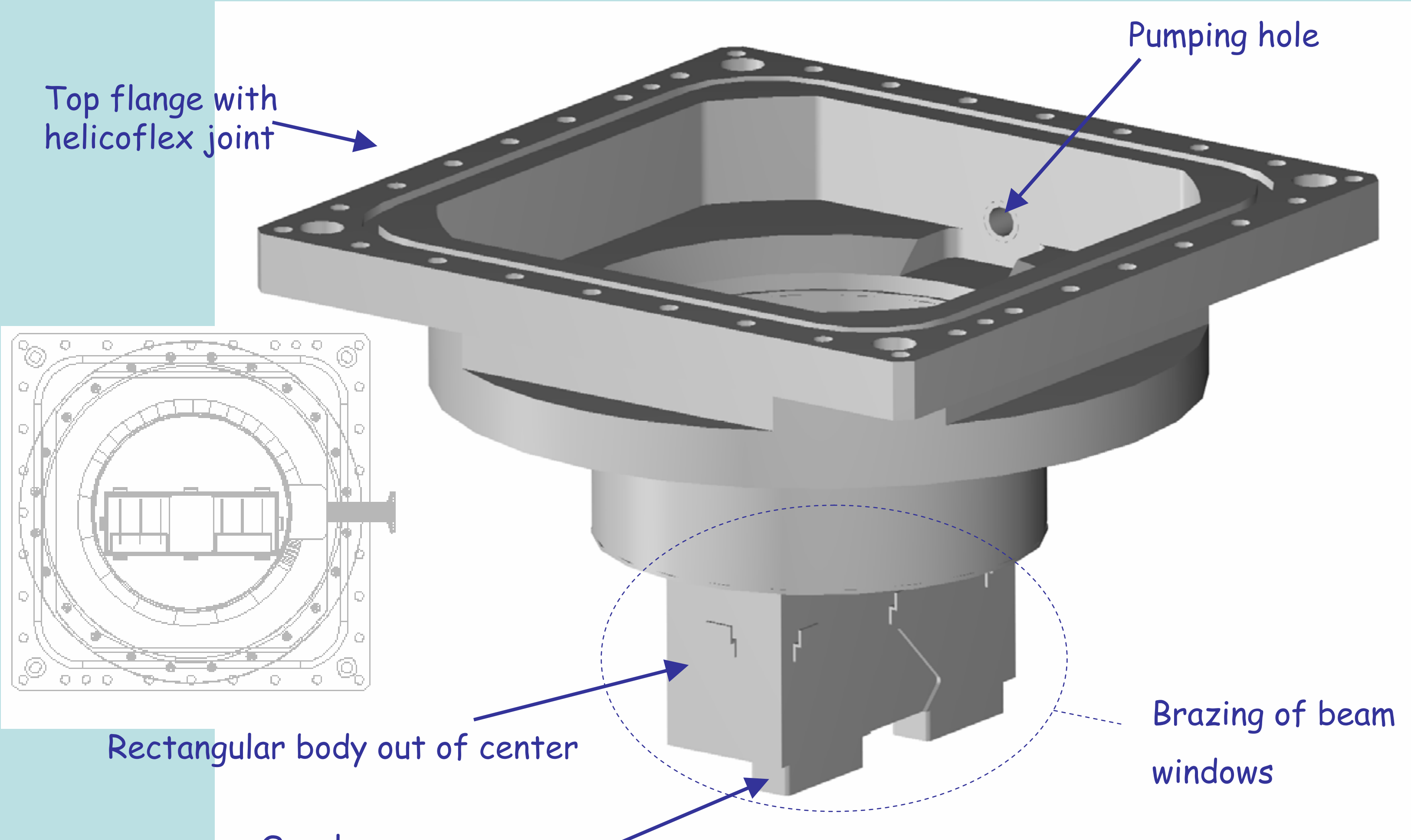
Roman Pot detectors



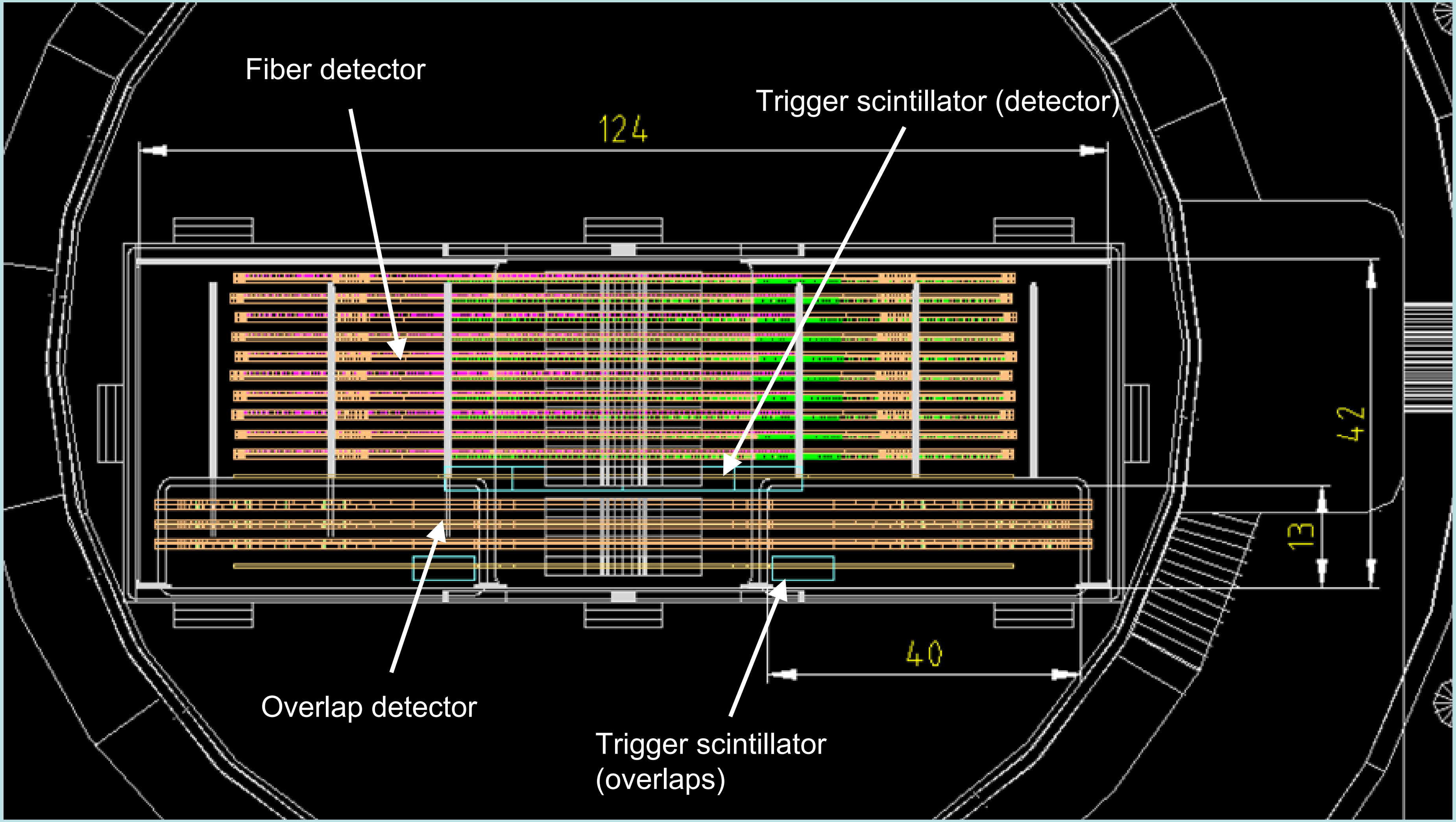
Roman Pot mechanics (TOTEM design)



The Roman Pot (modified TOTEM design)

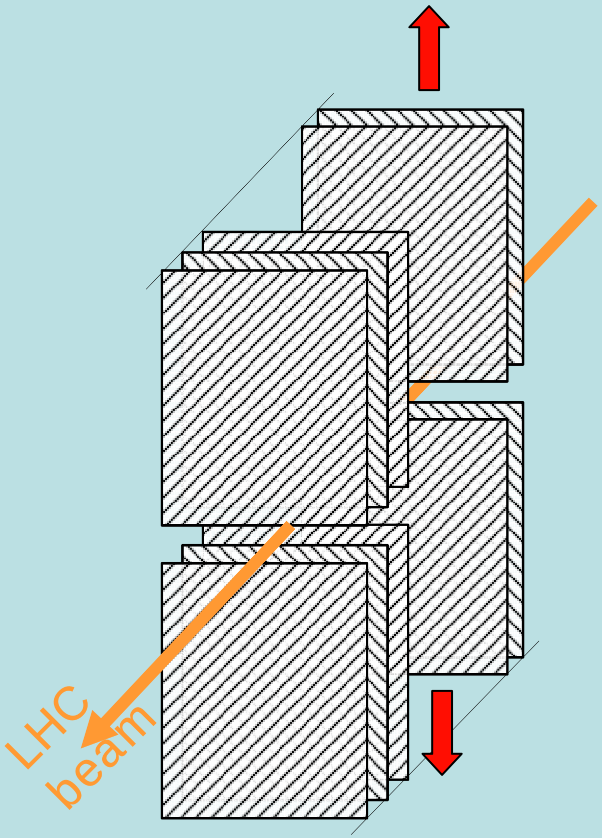


Top view



Fiber detector
Trigger scintillator (detector)
124
42
13
40
Overlap detector
Trigger scintillator
(overlaps)

detector principle



key features:

- **square scintillating fibres 0.5x0.5 mm^2**
- **U/V geometry 45^o stereo layers**
- **64 fibres per module plane**
- **10 double sided modules per pot**
- **staggering of modules by n√2x0.5mm/10**
- **trigger scintillator in the crossing area**
- **overlap detectors for relative vertical alignment**
- **overlap triggers in the beam halo**

Fiber detector: 10 plates of

2x64 fibers

Overlap detector: 3 plates of

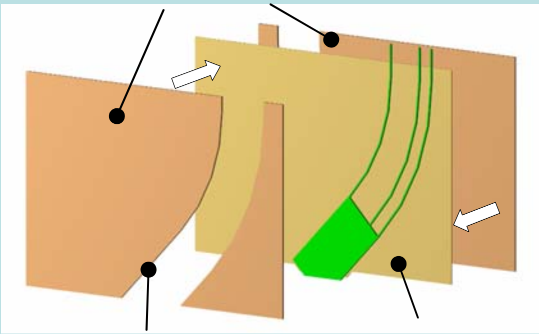
2x30 fibers

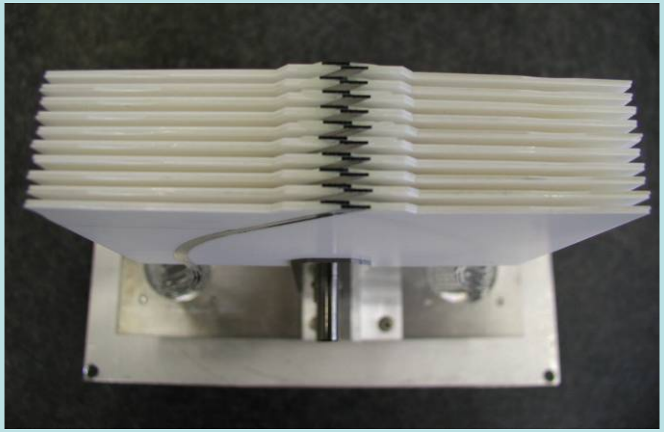
Trigger for detector: 1 plastic scintillator 3mm thick

Trigger for overlap detector: 2 plastic scintillator 3mm thick

detector prototypes

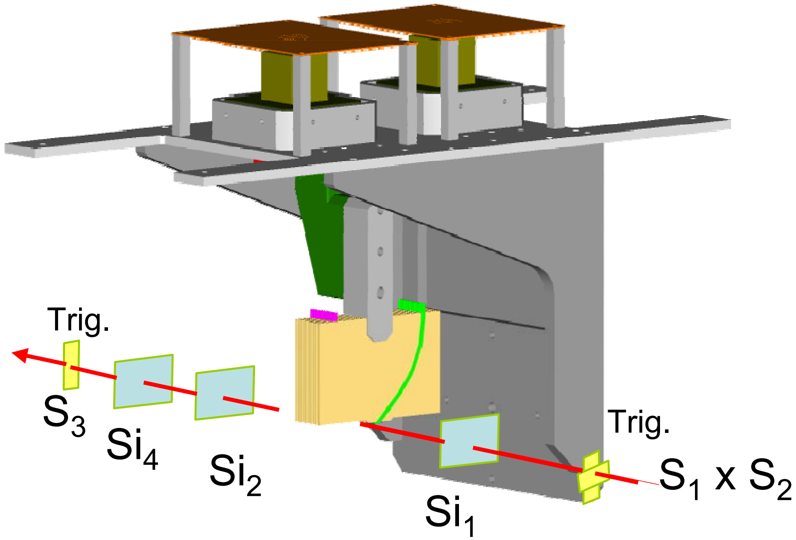
Principle

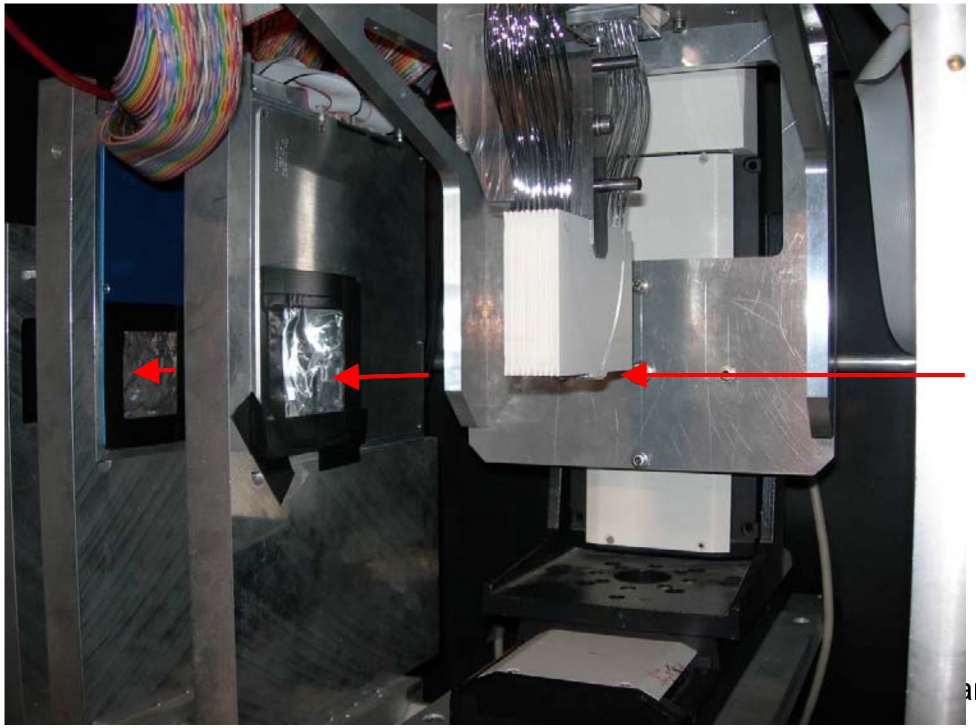




Protoype: 20 Planes u and v of 6 fibres

Beam tests of ALFA prototypes





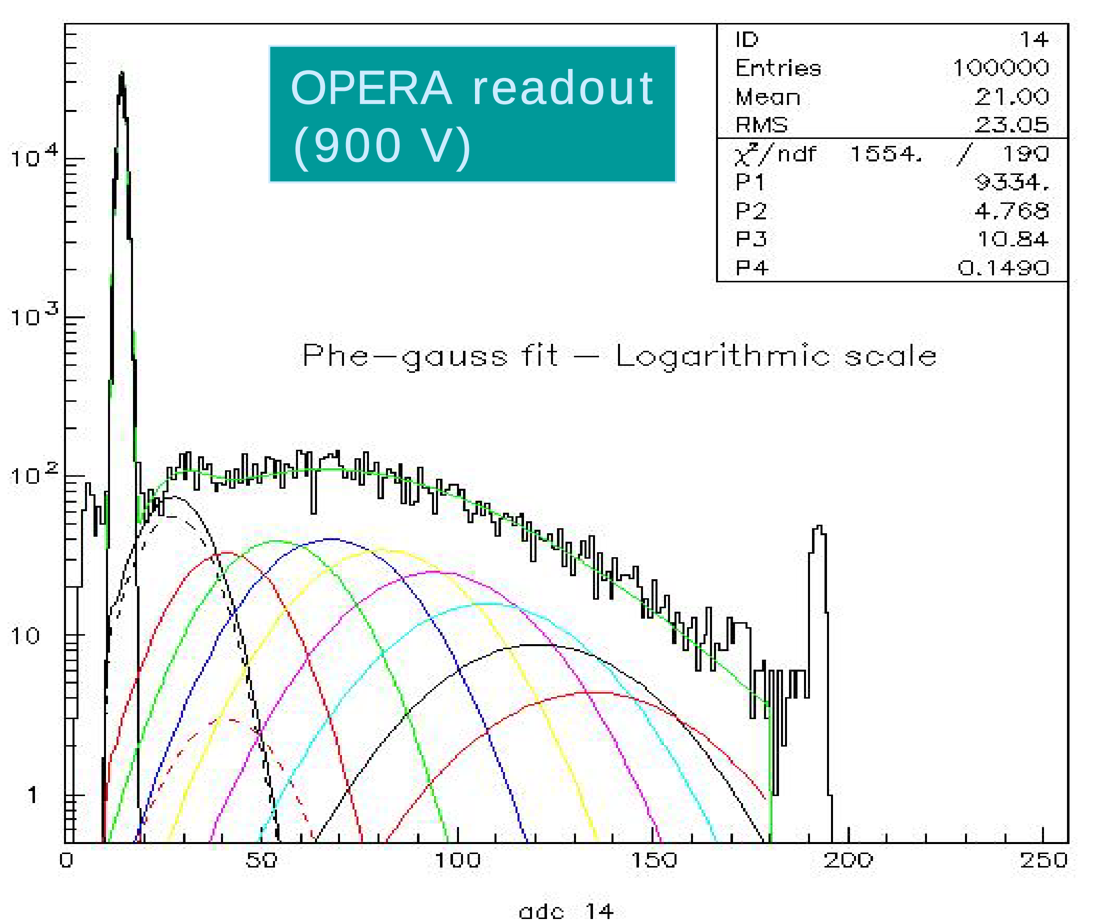
Purpose of the testbeam:

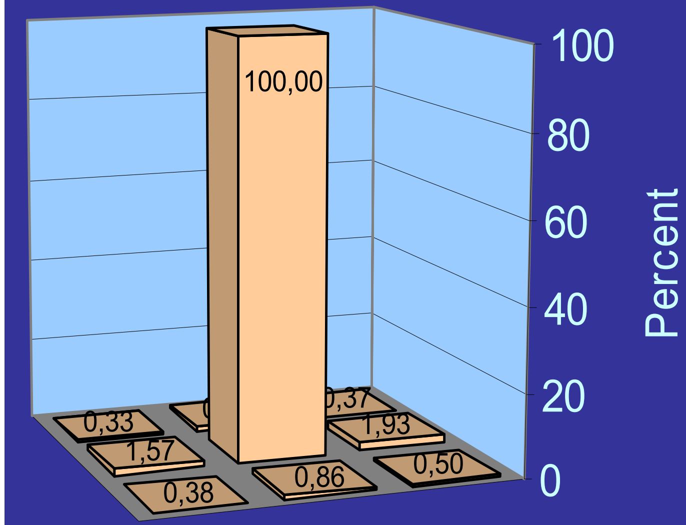
- **photoelectric yield**
- **efficiency**
- **cross talk**
- **edge sensitivity**
- **track resolution**

proof of principle

At DESY22, 6 GeV e^-
October/November 2005

testbeam results: photoelectric yield and cross talk

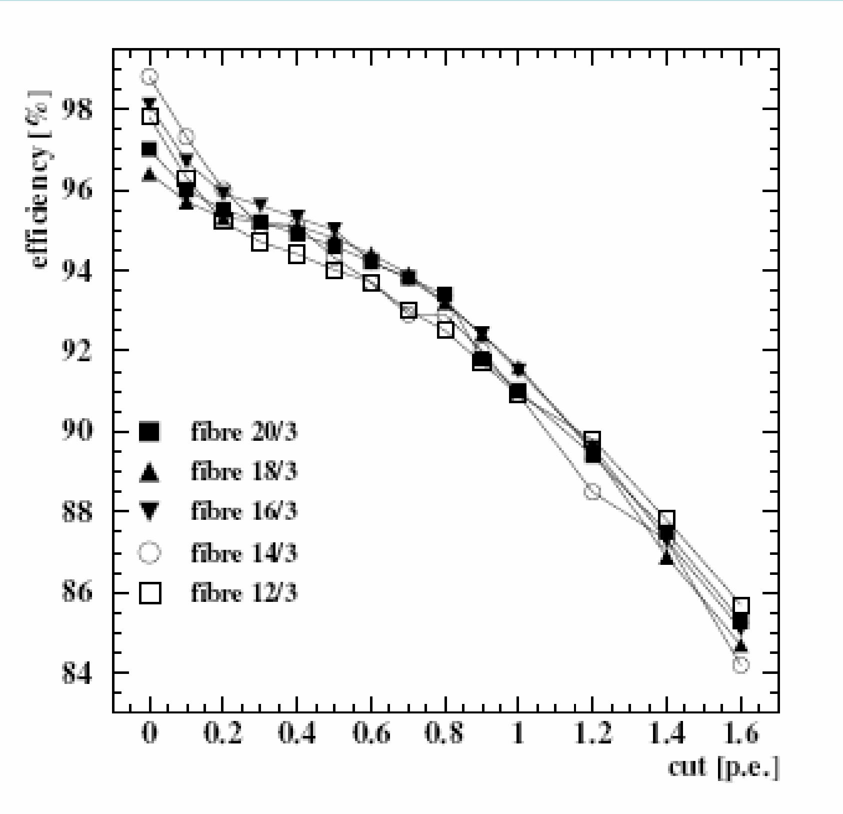


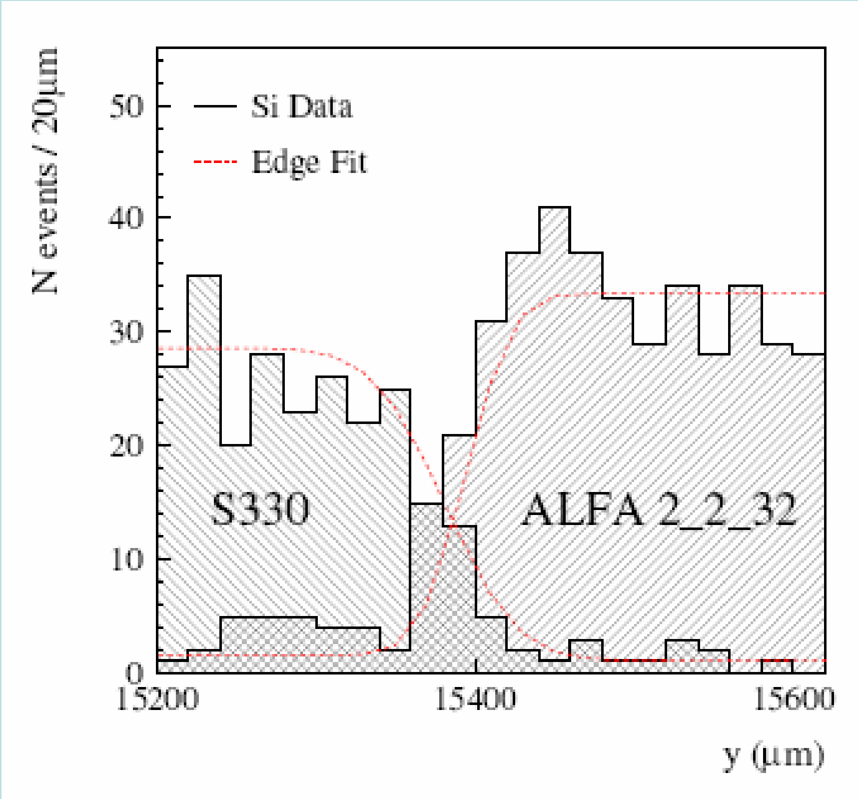


total optical cross talk = 4%

<Npe>/MIP=4-4.5

testbeam results: efficiency

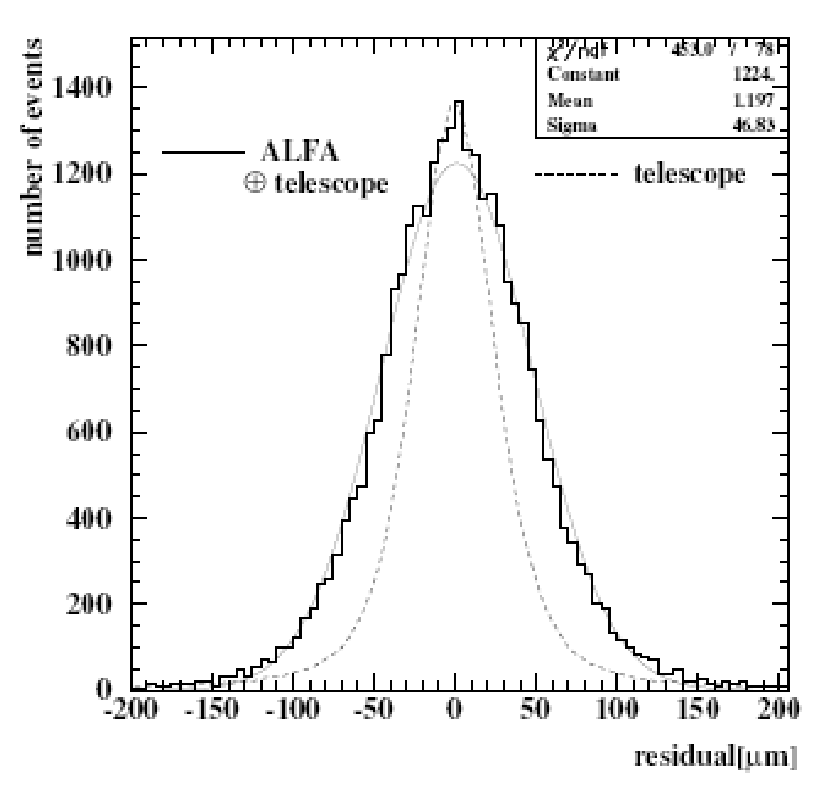


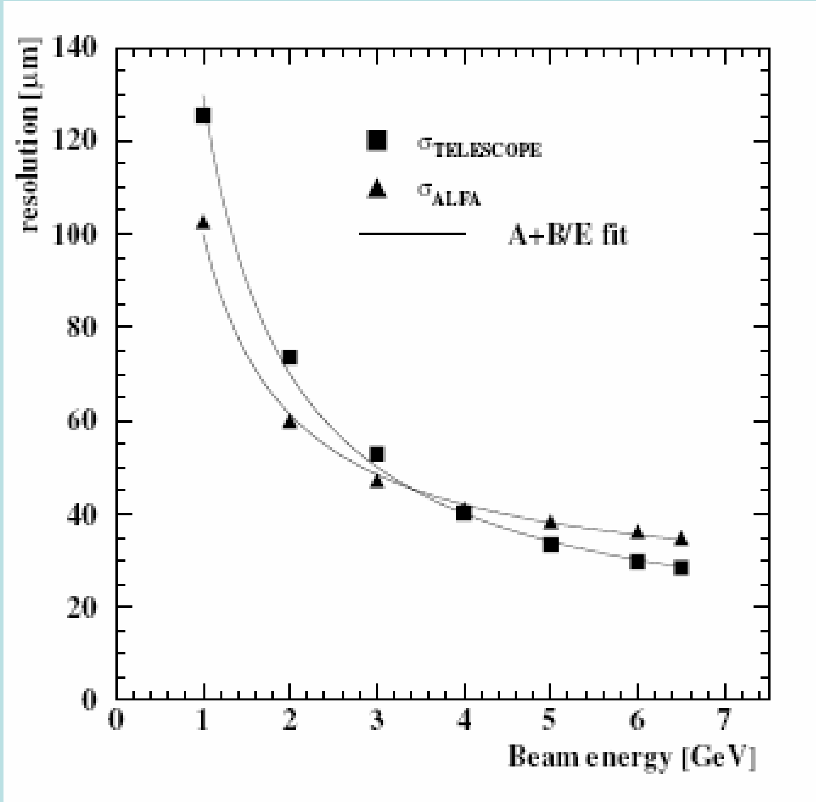


single fibre efficiency 90-94%
(depends on cut)

insensitive area
at the edge < 30 µm
(limited by resolution)

testbeam results





At E_e = 6 GeV	σ_x[μm]	σ_y [μm]	ε[%]
Si telescope	29.9	29.5	?
ALFA	36.00	36.56	98.99

- **resolution scales like 1/E**
- **large multiple scattering contribution**
- **expect $\sigma_{x,y}$≈20μm from MC at LHC**

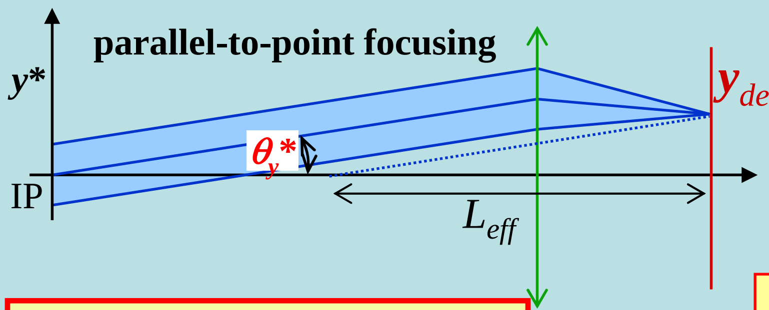
Beam optics: high ß*

Transversal displacement of particles in the ring away from the IP:

$$y = \sqrt{\frac{\beta}{\beta^*}}\left(\cos\Psi + \alpha^* \sin\Psi\right) y^* + \sqrt{\beta\beta^*}\sin\Psi\,\theta_y^*$$

Special optics with high β^* and parallel-to-point focusing:

$$\beta^* = 2625 \text{ m}$$
$$\beta_y = 119 \text{ m}$$
$$\alpha^* \approx 0$$
$$\Psi \approx 90^\circ$$
$$L \approx 10^{27}\, cm^{-2} s^{-1}$$



independent of the vertex position

$$y_{\text{det}} = \sqrt{\beta\beta^*}\,\theta_y^* = L_{eff,y}\,\theta_y^* \; ; -t = \left(p\,\theta^*\right)^2$$

parallel - to - point, 90° phase advance

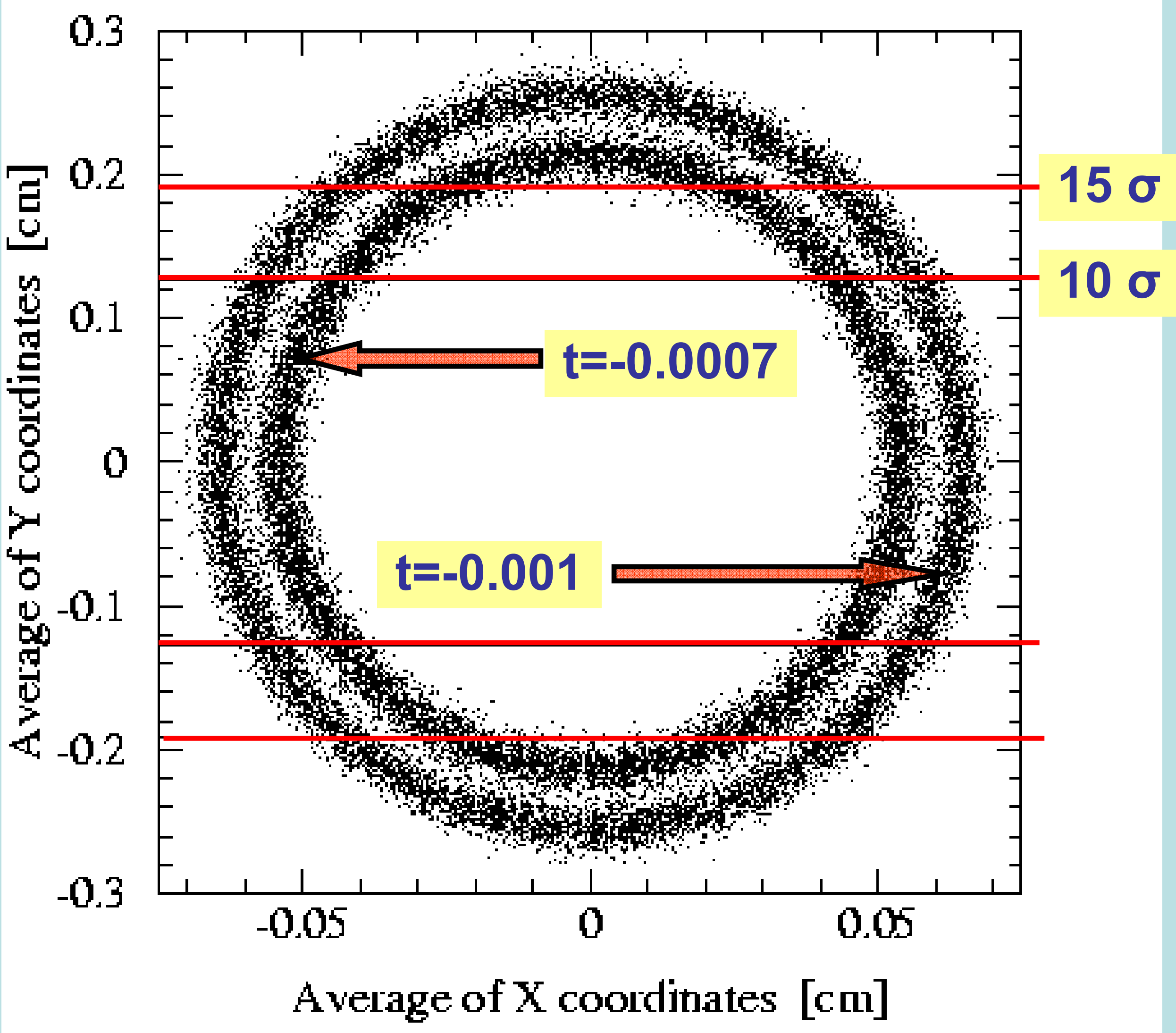
$$\sigma_{\text{d}} = 0.12\,\text{mm}$$
$$\theta_{\text{min}} = 2.7\,\mu\text{rad}$$
$$\theta_{\text{max}} = 44.7\,\mu\text{rad}$$
$$t_{\text{min}} = 0.0004\,\text{GeV}^2$$
$$t_{\text{max}} = 0.098\,\text{GeV}^2$$

properties at the roman pot (240m)

Simulation of elastic scattering

t reconstruction

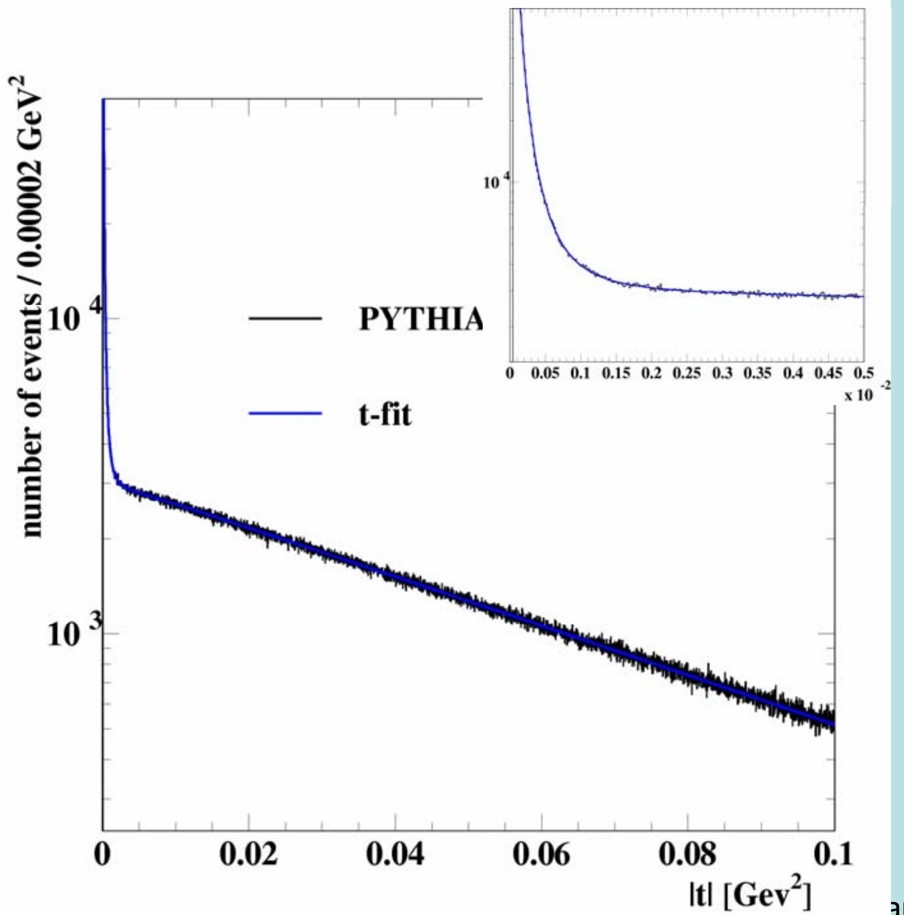
$$-t = \left(p\theta^*\right)^2 = p^2\left(\overline{\theta}_x^2 + \overline{\theta}_x^2\right)$$
$$= p^2\left(\left(\frac{\overline{x}}{L_{eff,x}}\right)^2 + \left(\frac{\overline{y}}{L_{eff,y}}\right)^2\right)$$



L from a fit to the t-spectrum

$$\frac{dN}{dt} = L\pi\left|F_C + F_N\right|^2$$

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



Simulating 10 M events,
running 100 hrs
fit range 0.00055-0.03

	input	fit	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%

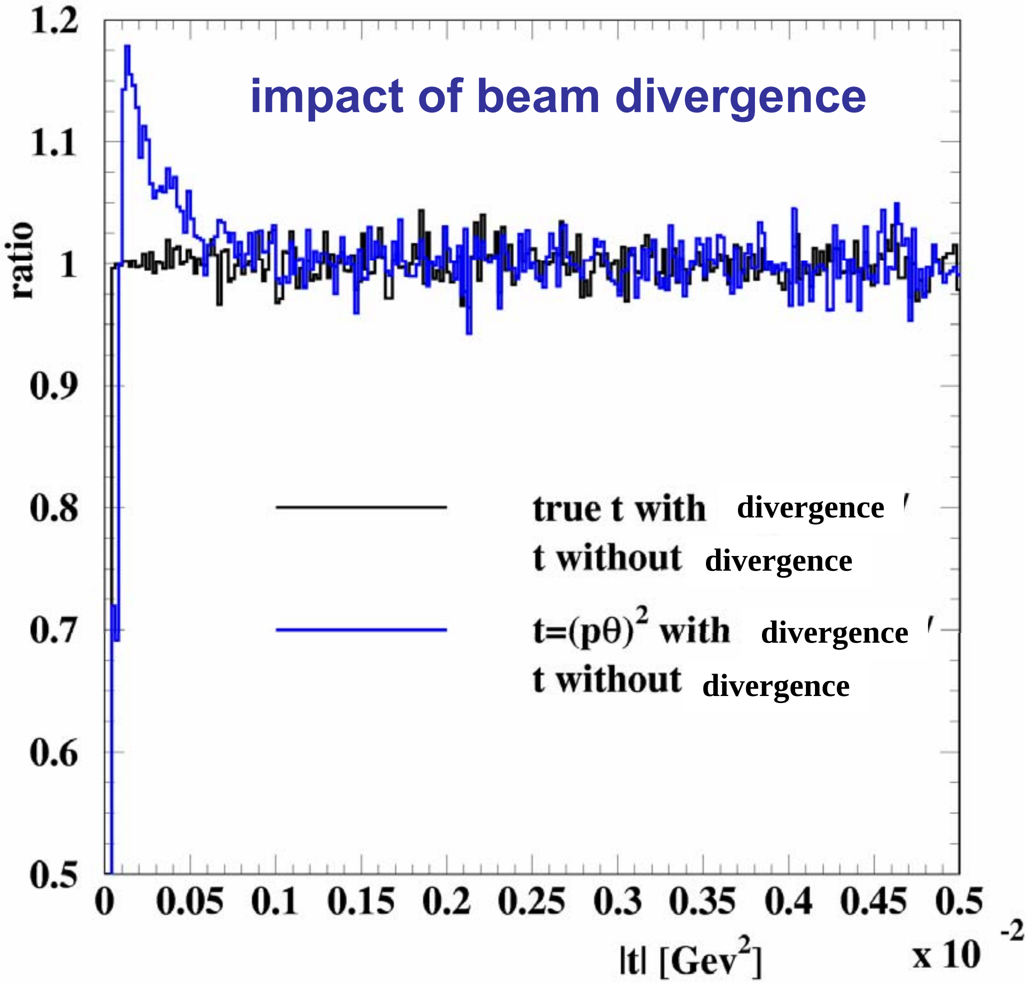
large stat.correlation between L and other parameters

experimental systematic uncertainties

Currently under re-evaluation

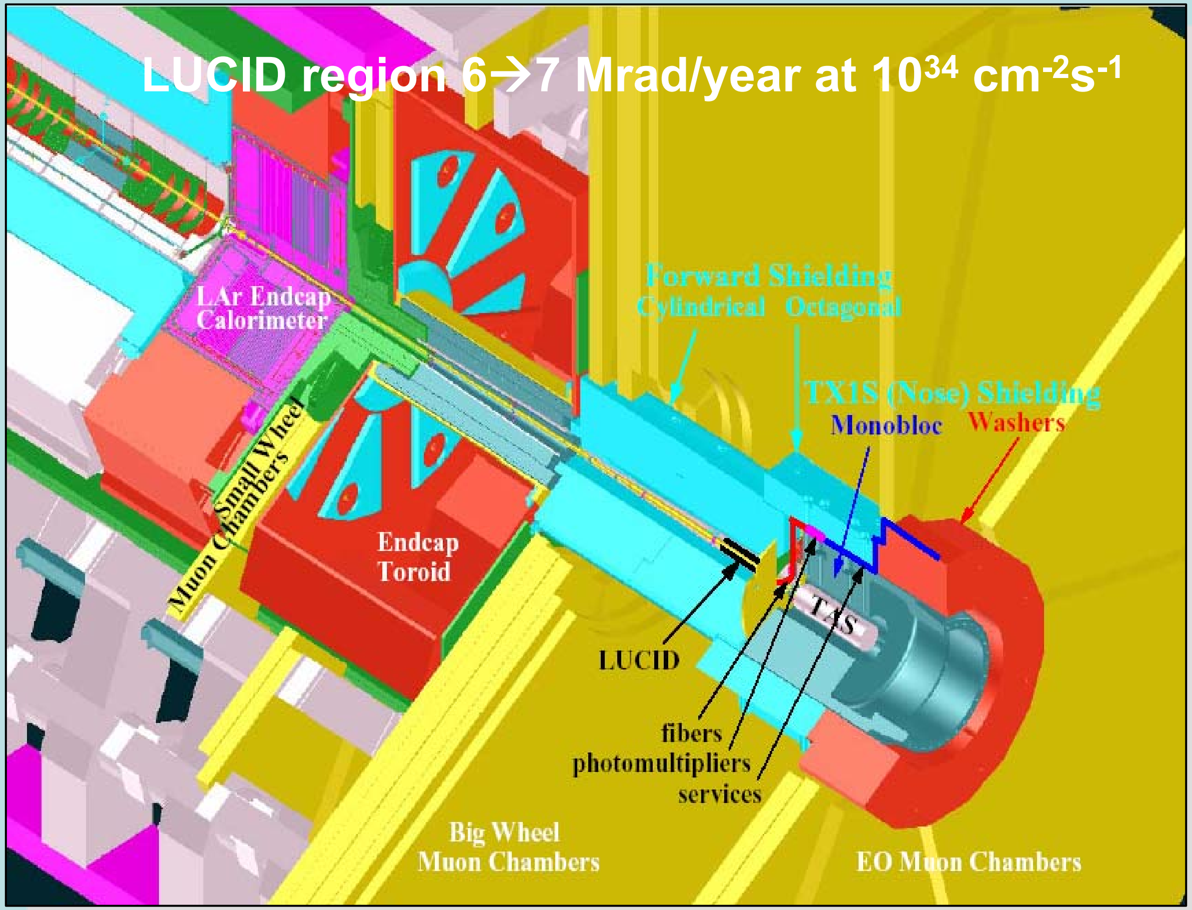
- **beam divergence σ’=0.23μrad**
- **detector resolution**
- **detector alignment**
- **background from**
  - **Halo**
  - **beam-gas**
  - **beam-wall**
  - **non-elastic**
- **beam optics uncertainties**

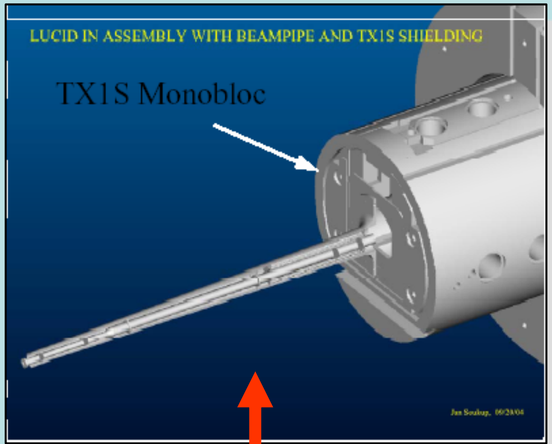
Δ_{exp}≈2-3 %

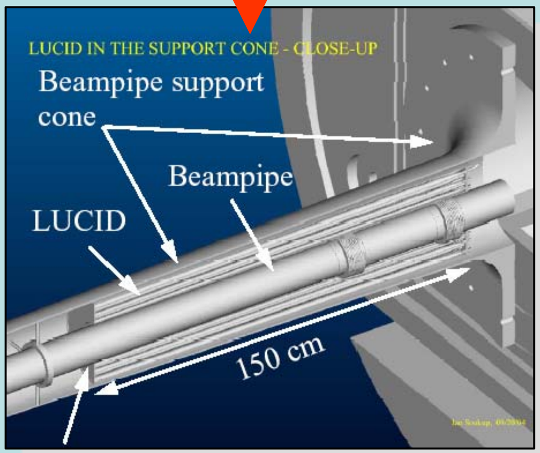


LUCID:Luminosity measurement using Cerenkov integrating detector

Front face of LUCID end is ~17m from the IP - covering 5.4 <|η|< **6.1**



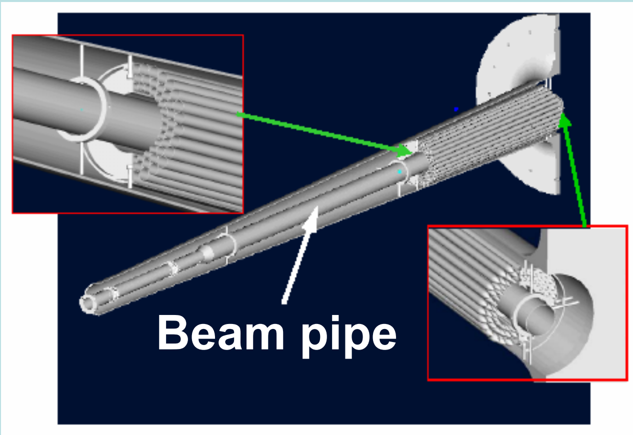


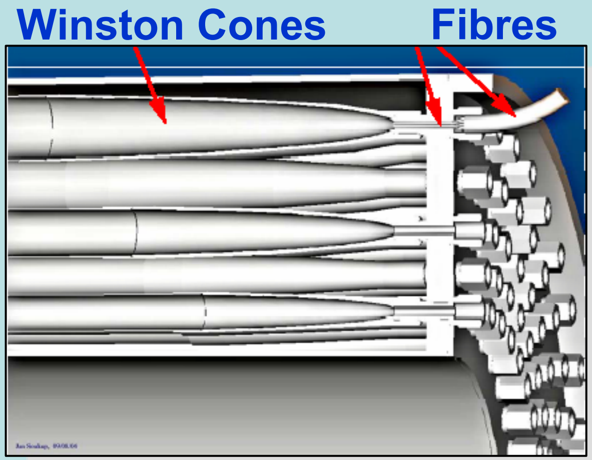


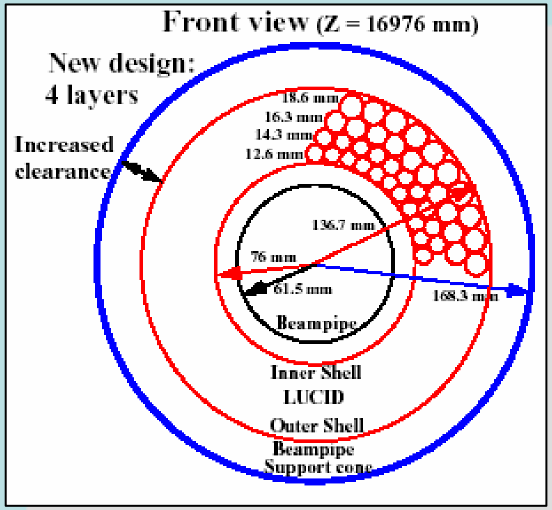
from J.Pinfold

LUCID detector principle

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

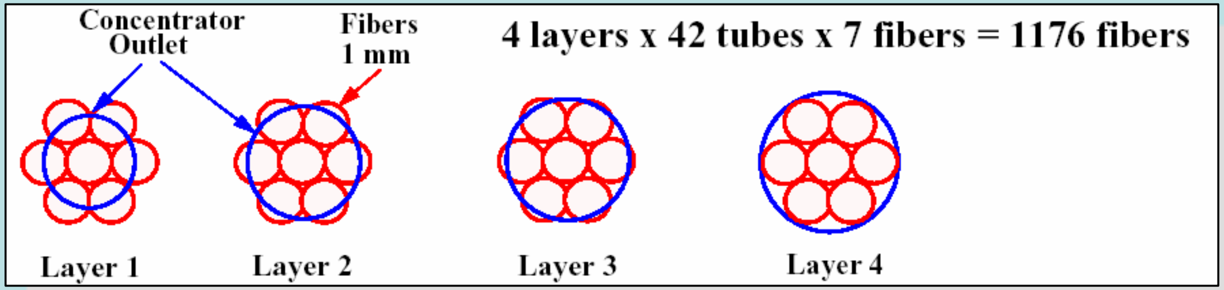




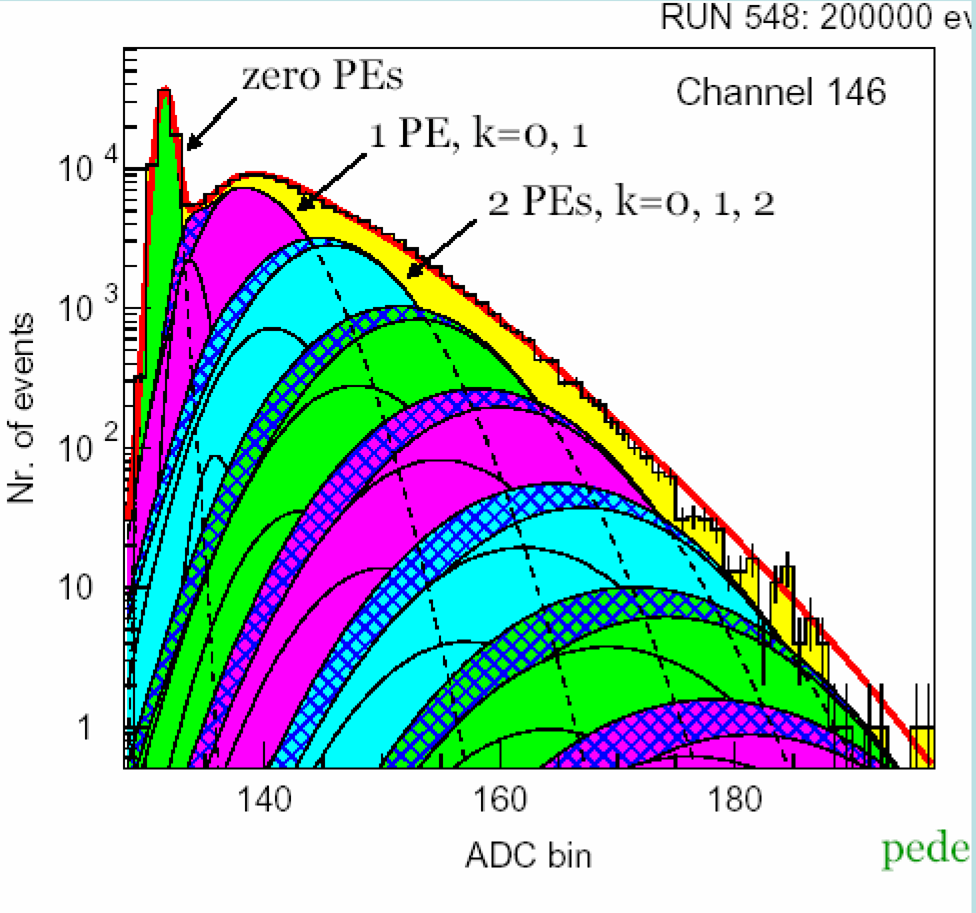


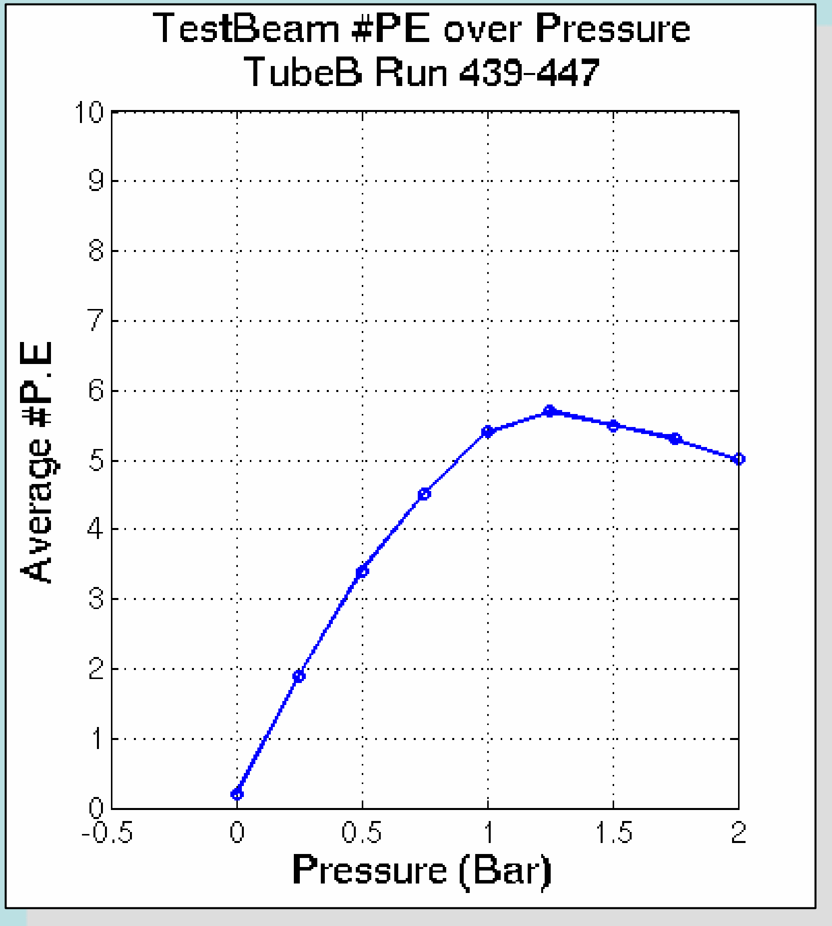
LUCID Cross-section

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



LUCID test beam performance





- **<Npe>/Cerenkov tube = 5.3, a bit lower than anticipated from simulation**
- **triggered design improvements for tubes/winston cones/fibre coupling**

LUCID luminosity monitoring

Sensitive to primaries – projective geometry – smaller signals for secondaries & soft particles:
- **shorter paths length for secondaries**
- **Cerenkov thresholds**

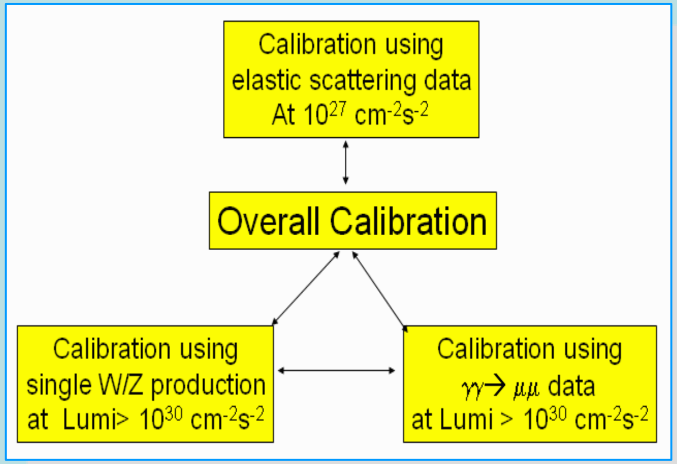
No Landau fluctuations in Cerenkov emission counting multiple tracks/tube – no saturation

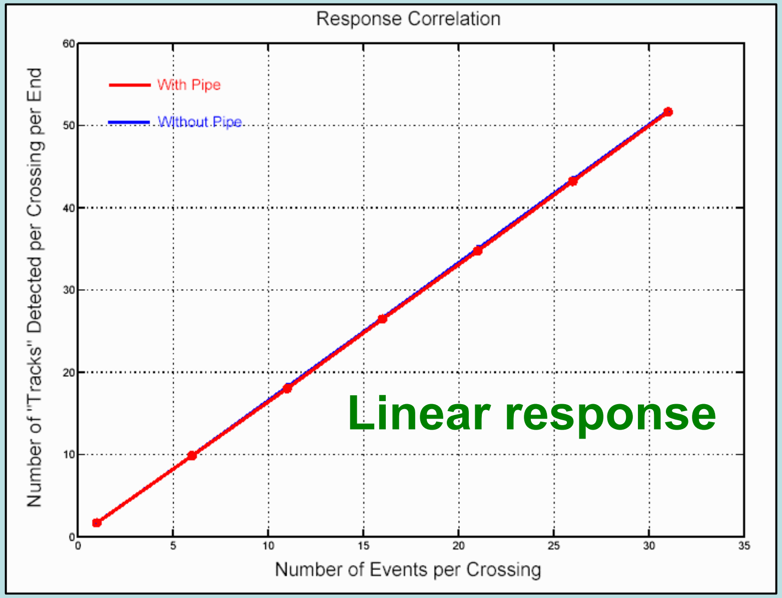
Excellent time resolution
- **~140ps @ CDF**
- **Luminosity bunch-by-bunch**

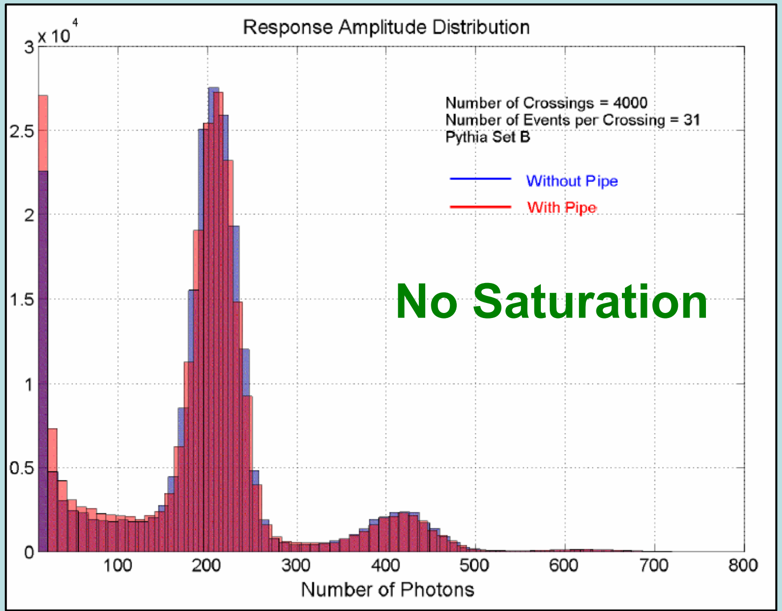
Linear relationship between lumi & track counting

Segmentation in tubes gives position sensitivity

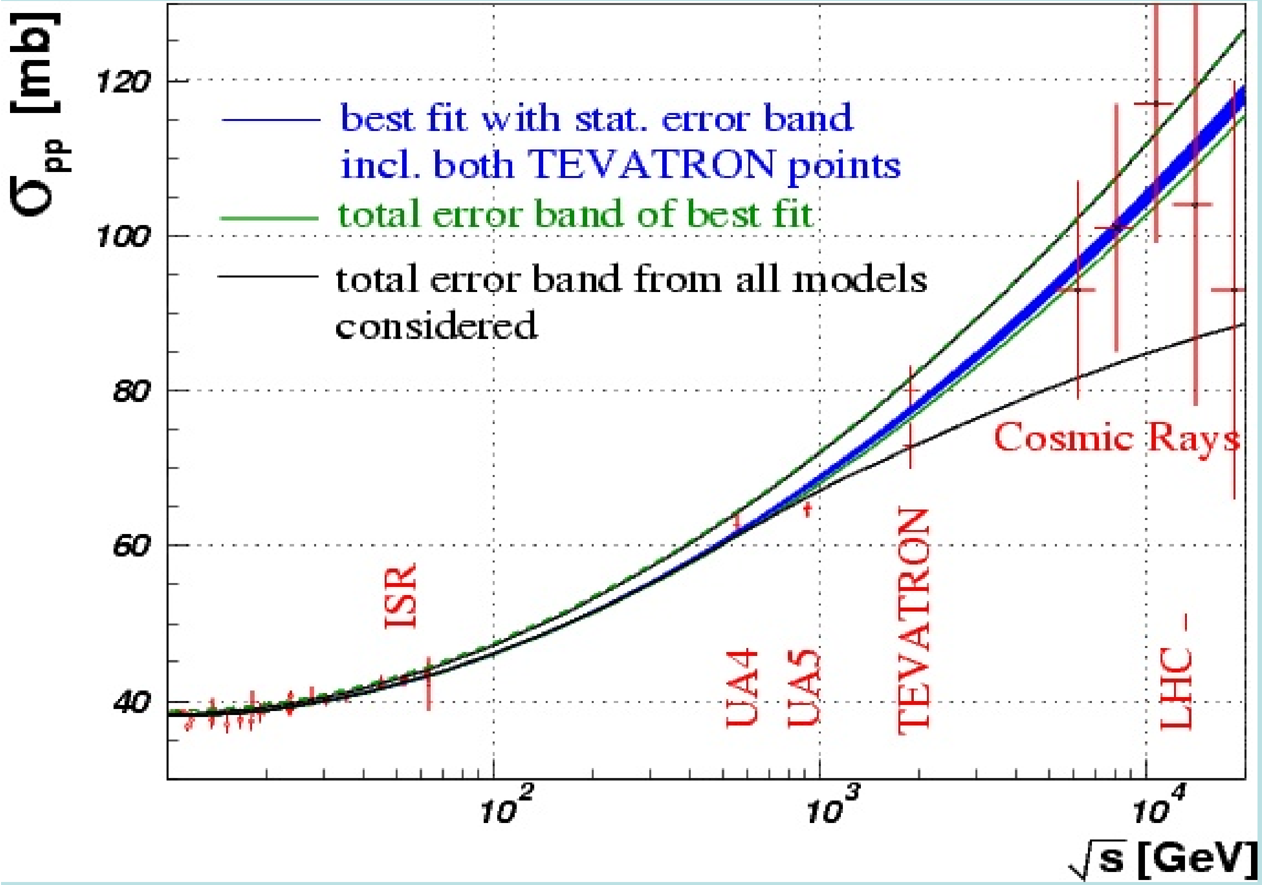
Radiation hard – light – compact







Forward physics beyond luminosity

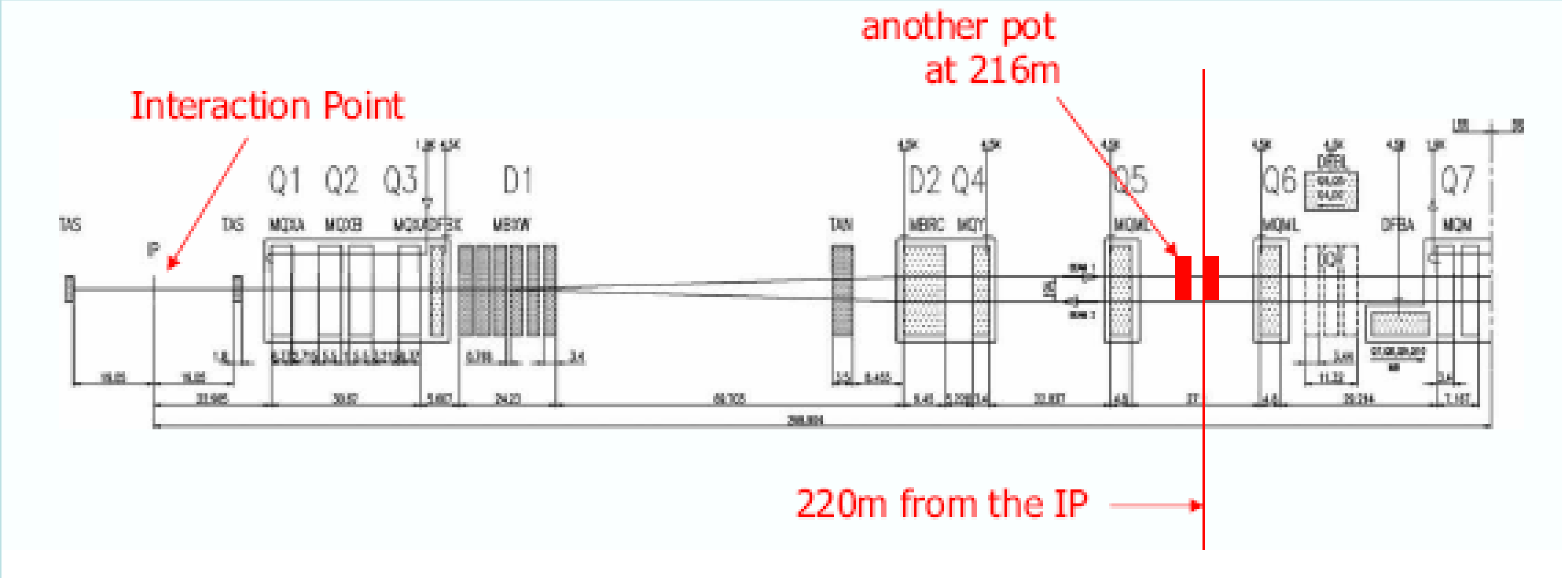


From the luminosity run and elastic scattering we get

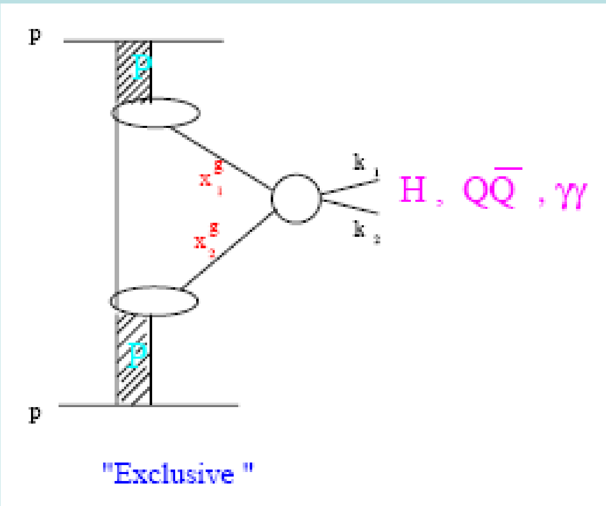
- **the total cross section σ_{tot}**
- **the nuclear slope *B***
- **the ρ-parameter**

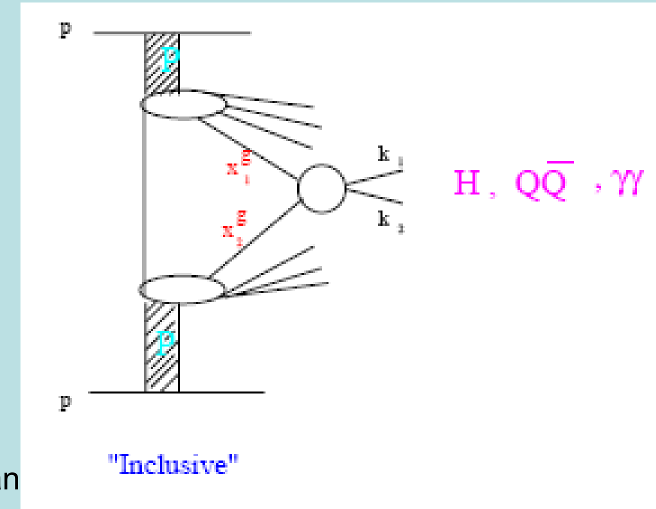
... to some accuracy

hard diffraction with ATLAS ?



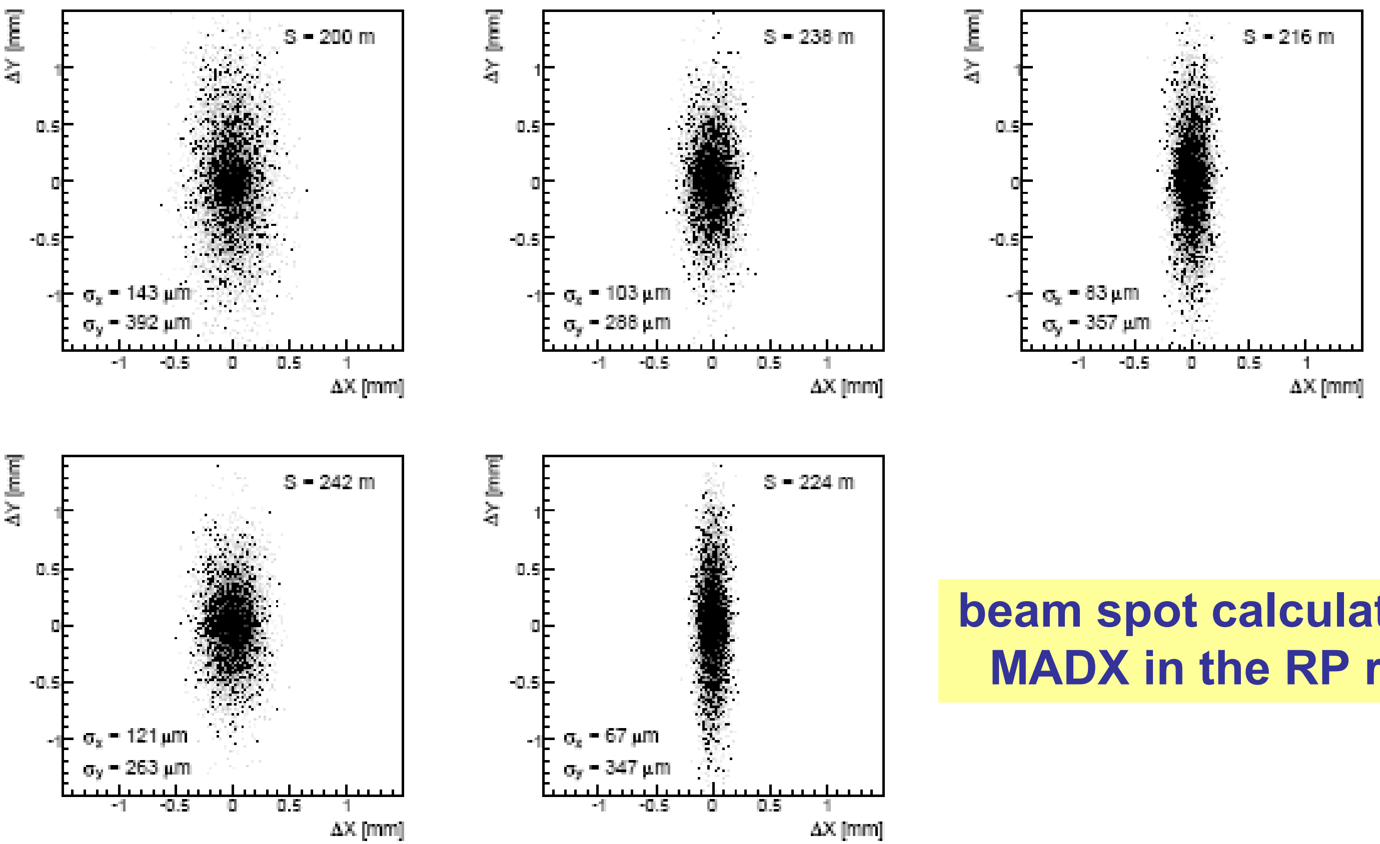
A new study for RP detectors at ~220 m for DPE at high luminosity has started





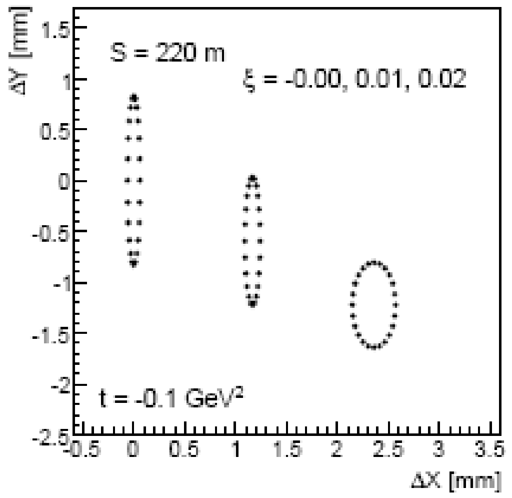
acceptance study

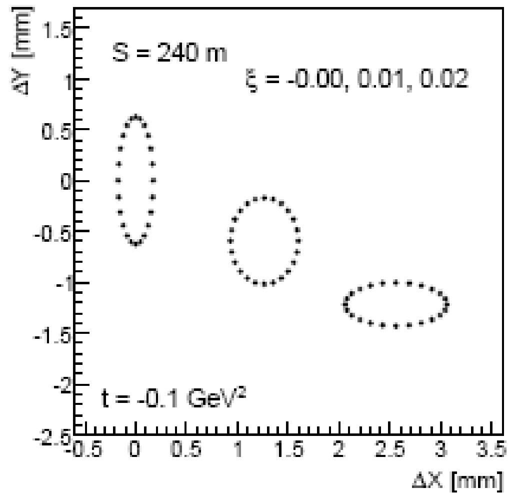
- Place two horizontal RP stations around 220m
- Run at high luminosity with collision optics
- Si strip / micromegas detectors studied
- Cerenkov counters for timing considered
- extension of the luminosity program, complementary to FP420

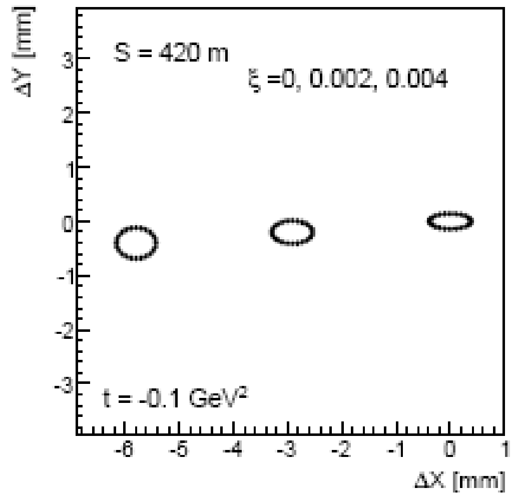


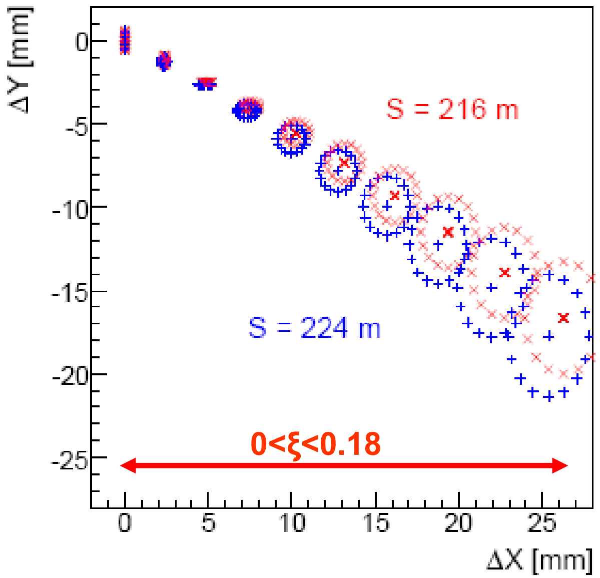
beam spot calculated with MADX in the RP region

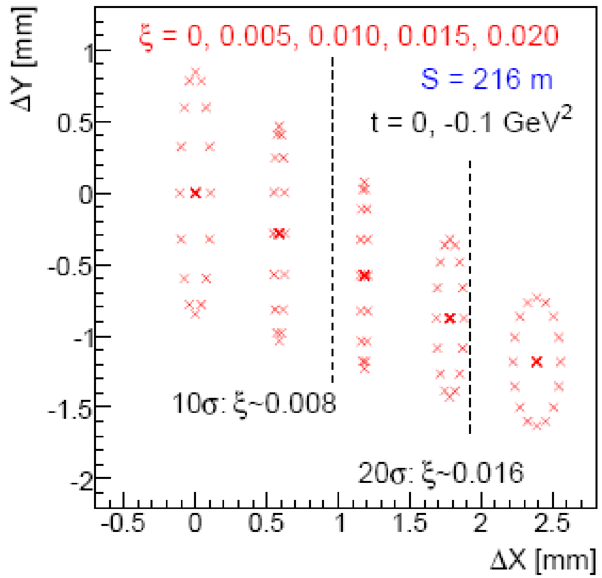
acceptance for t and ξ











acceptance for ξ from ~0.01 to ~0.16

conclusion

ATLAS luminosity program

- **with roman pot detectors from elastic scattering for absolute calibration**
- **complemented by W/Z counting and γγ-processes**
- **and machine parameters**
- **with LUCID for luminosity monitoring**
- **gaining experience in operation close to the beam**
- **2006: testbeams for ALFA and LUCID, final design**
- **construction 2006/2007, installation 2007/2008**

Upgrade options

- **RP220 under study to explore hard diffraction & DPE**
- **complementing/extending FP420**
- **time scale 2008-2009**