ATLAS Forward Detectors for Measurement of Elastic Scattering and Luminosity

ATLAS Collaboration

Technical Design Report

LHCC open meeting
7th May 2008

ATLAS Collaboration

(Status April 2008)

- 37 Countries
- 167 Institutions
- 2200 Scientific Authors total
- (1750 with a PhD, for M&O share)

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Yale, Yerevan

Outline

- Motivation

- Elastic Scattering and Luminosity

- ATLAS Roman Pot system (ALFA)
  - Special beam conditions
  - The detectors
  - The electronics
  - The mechanics

- Performance simulation

- Machine induced background

- Machine protection

- Conclusion

Motivation-why we need to measure the luminosity

- Measure the cross sections for "Standard " processes
  - Top pair production $\longleftarrow$ Theoretically known to ~ 10 %
  - Jet production
  - ......

- New physics manifesting in deviation of σ x BR relative to the Standard Model predictions. Precision measurement becomes more important if new physics not directly seen. (characteristic scale too high!)

- Important precision measurements
  - Higgs production σ x BR
  - tanβ measurement for MSSM Higgs
  - ....

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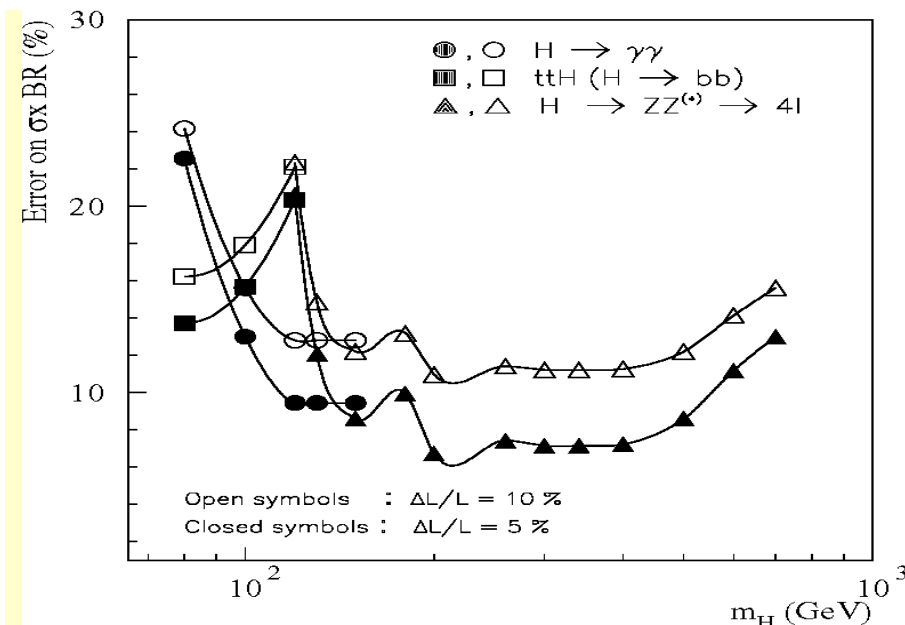
Relative precision on the measurement of $\sigma_H \times$ BR for various channels, as function of m_H, at $\int L dt = 300$ fb^{-1}. The dominant uncertainty is from Luminosity: 10% (open symbols), 5% (solid symbols).

(ATLAS Physics TDR , May 1999)

Relative versus absolute luminosity

With *relative luminosity* we mean a measurement of L which is proportional to the actual luminosity in a constant but unknown way.

LUCID dedicated
relative monitor

Cerenkov cone

Cerenkov tube

Particle from IP
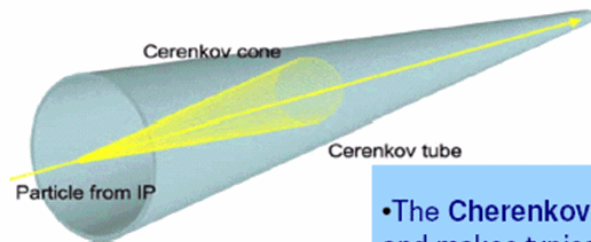
LUminosity measurement
with a **C**herenkov
Integrating **D**etector

• The **Cherenkov light** is produced at a 3° angle and makes typically 3 reflections while passing down the tube.
• The **Cherenkov light** is read out by Photo Multipliers (PMT) at the end of the tubes
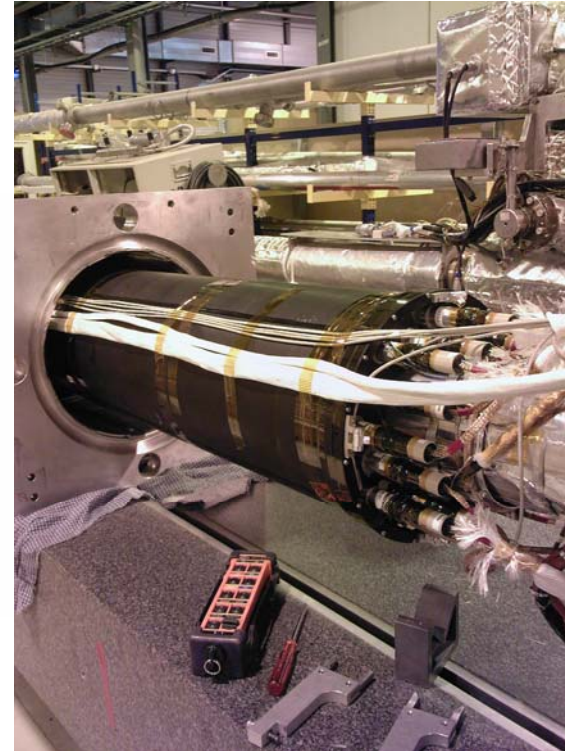
Other possible
relative monitors
• Min. Bias Scint
• LAr/Tile current
• Beam Cond. Monitor.
• Zero Degree Cal.

Absolute Luminosity measurement implies to determine the calibration constants for any of those monitors.

The ATLAS strategy for absolute luminosity

Ultimate goal: Measure L with ~ 3 % accuracy

How do we get there?

- **To start with we will work with LHC Machine parameters**
  - In the beginning 20-25 % precision.
  - Special calibration runs with simplified conditions will improve :
    maybe 10 % after some time and even better
- **Rates of well-calculable processes will be next step:**
  - EW processes like W/Z production are good candidates:
    high cross section and clean signature
  - QCD NNLO corrections to the partonic cross section have been
    calculated and the scale error is less than 1 %
  - PDF's more problematic 5-8 %
  - Taking into account experimental error a precision of 10 % in L might be reached
    quite early
  - Aiming at 5 % after some time - LHC data itself might constrain the PDF
- **Third step: Elastic scattering**

Elastic scattering and luminosity

Elastic scattering has traditionally provided a handle on luminosity at colliders.

Can be used in several ways.

The optical theorem relates the total cross section to the forward elastic rate

$$\sigma_{tot} = 4\pi \, \text{Im} \; f_{el}(0) \quad \rightarrow \quad L = \frac{1+\rho^2}{16\pi} \frac{N_{tot}^{\,2}}{\left.\dfrac{dN_{el}}{dt}\right|_{t=0}}$$

Thus we need

■ Extrapolate the elastic cross section to t=o

■ Measure the total rate

■ Use best estimate of ρ ($\rho \sim 0.13$ +- 0.02 $\Rightarrow$ 0.5 % in $\Delta L/L$)

ATLAS will use this method. However the η coverage in the forward direction is not optimal.

Elastic scattering and luminosity (cont.)

Other options:
• Extrapolate to t=0 and use the optical theorem in combination with and independent measurement of σ_{tot} (TOTEM)
• Combine machine parameters with optical theorem

ATLAS will also pursue the above options

In addition we will aim at the Coulomb Interference region

■ Measure elastic scattering at such small t-values that the cross section becomes sensitive to the Coulomb amplitude

■ Effectively a normalization of the luminosity to the exactly calculable Coulomb amplitude

■ No total rate measurement and thus no additional detectors near IP necessary

■ UA4 used this method to determine the luminosity to 2-3 %

ATLAS Roman Pots
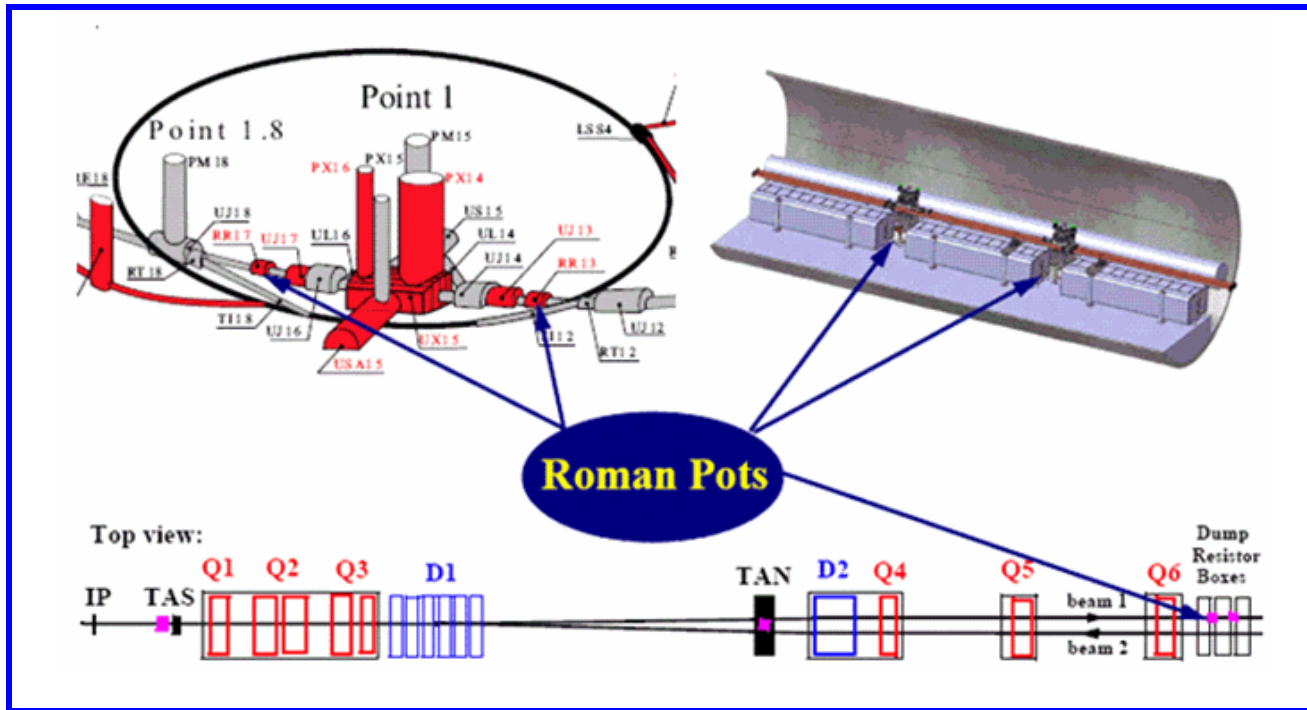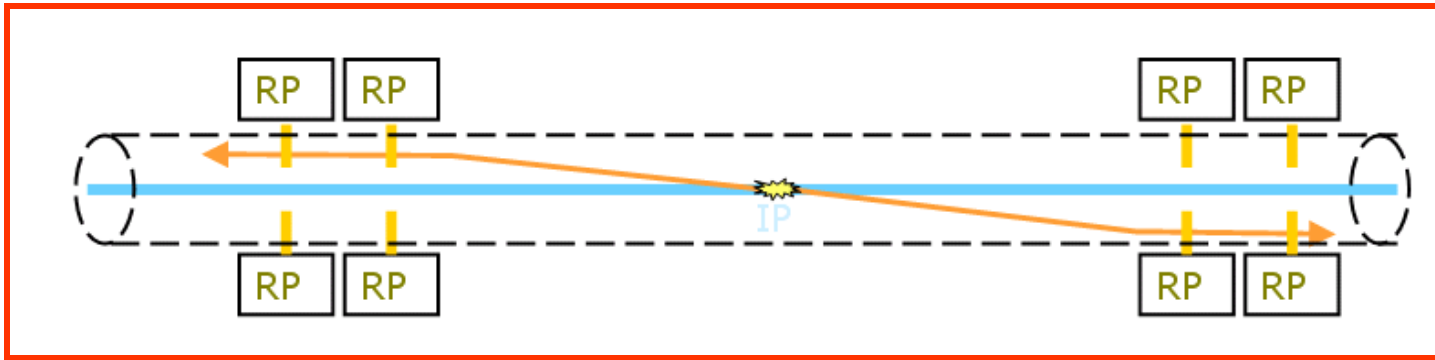
- **A**bsolute
- **L**uminosity
- **F**or
- **A**TLAS

ATLAS Forward Detectors

ALFA at 240 m
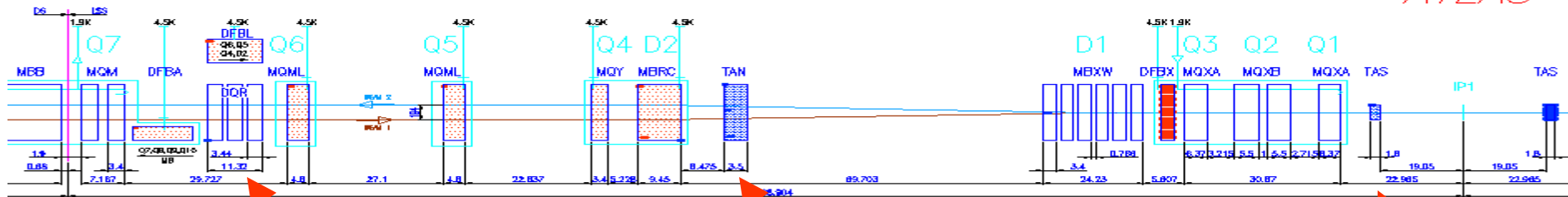
ZDC at 140 m
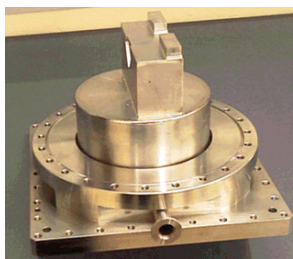
LUCID at 17 m

Absolute Luminosity for ATLAS

TDR submitted CERN/LHCC/2008-004
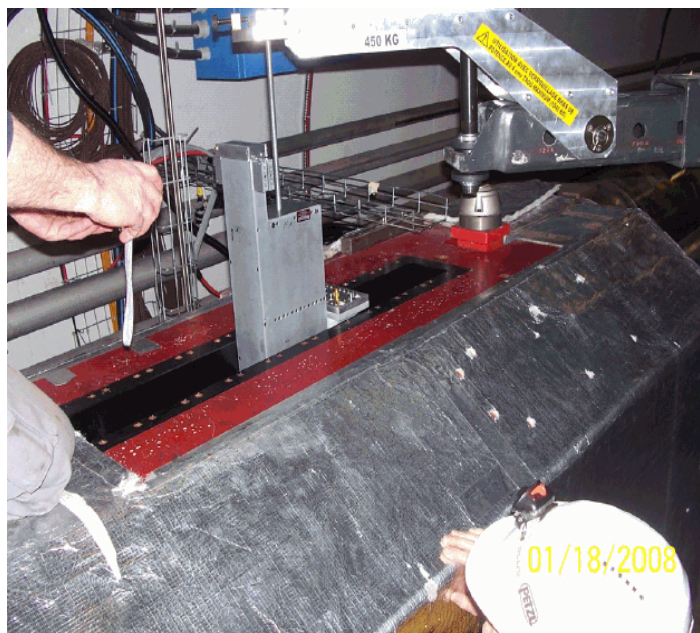
Zero Degree Calorimeter

Phase I (partially) installed
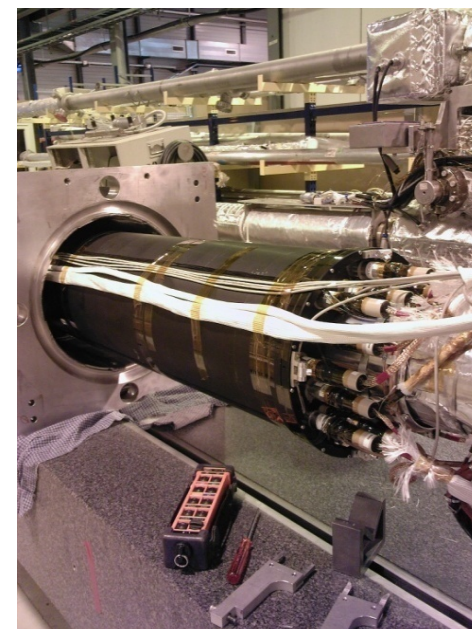
Luminosity Cerenkov Integrating Detector

Phase I ready for installation

What is needed for the elastic scattering measurement?

- Special beam conditions

- "Edgeless" Detector

- Compact electronics

- Precision Mechanics in the form of Roman Pots to approach the beam

The beam conditions

Nominal divergence of LHC is 32 μrad
We are interested in angles ~ x 10 smaller
$\Rightarrow$ high beta optics and small emittance
(divergence $\propto \sqrt{\varepsilon}/\sqrt{\beta^*}$)

To reach the Coulomb interference region we will
use an optics with $\beta^* \sim 2.6$ km and $\varepsilon_N \sim 1$ μm rad

Zero crossing angle $\Rightarrow$ fewer bunches

High β^* and few bunches $\Rightarrow$ low luminosity

Insensitive to vertex smearing
large effective lever arm L_{eff}

Very High-beta Optics   LHC Version 6.4
Unix version 8.51/13   05/02/04 12.31.50

β_x β_y D_x

β [m]

D [m]

s (m)

Compatible
with TOTEM

parallel-to-point focusing

y^*

y_{det}

θ_y^*

IP

L_{eff}
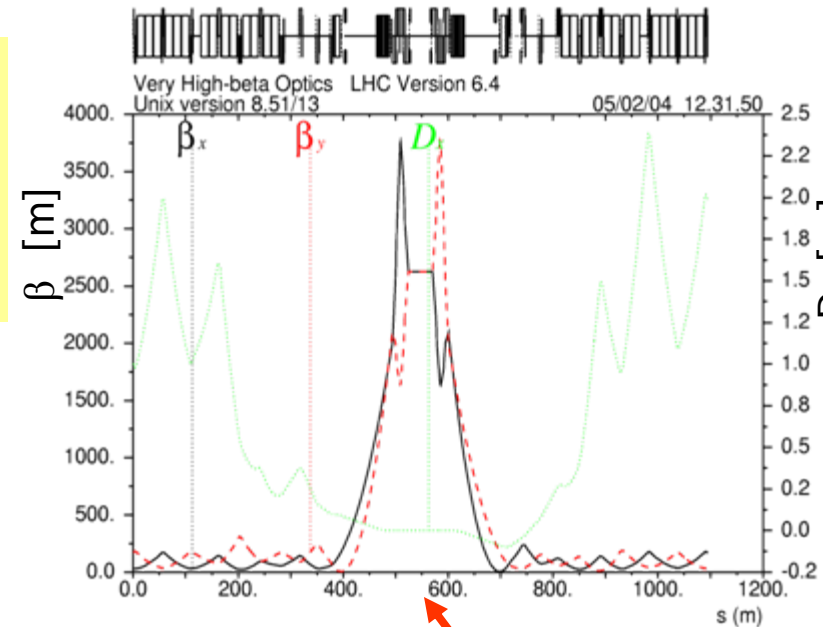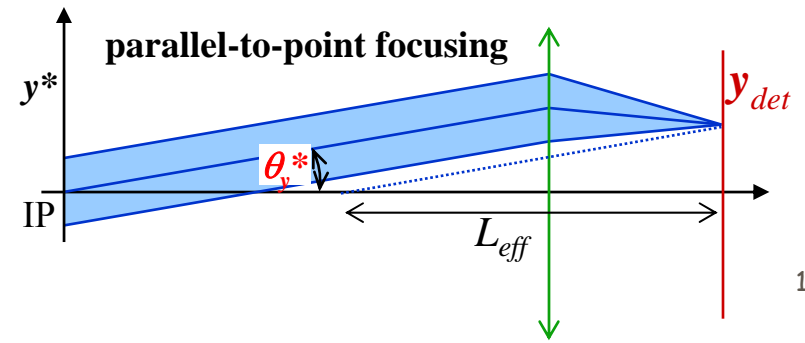
The detectors-fiber tracker

Choice of technology:
- minimum dead space
- no sensitivity to EM induction from beam
- resolution $\sigma \sim 30\ \mu m$

Concept
- 2x10 U planes
  2x10 V planes
- Scintillating fibers
  0.5 mm² squared
- Staggered planes
- MAPMT readout
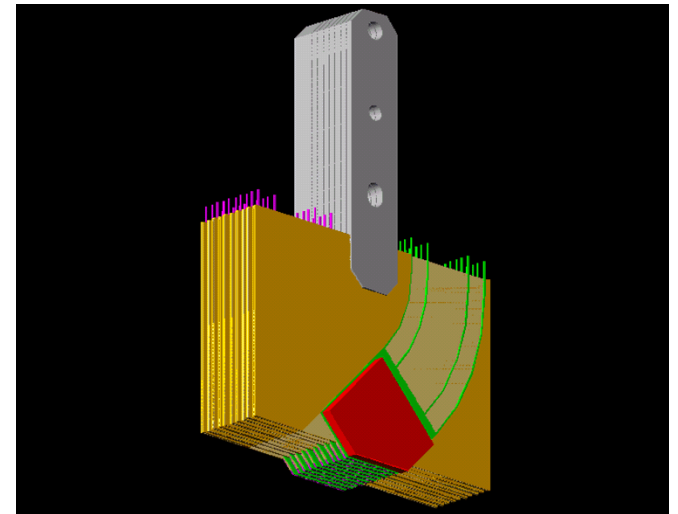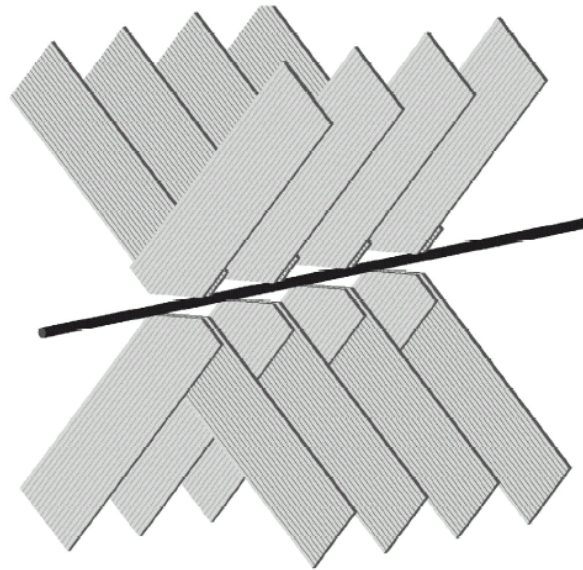
Test beam campaigns-DESY and CERN

ALFA
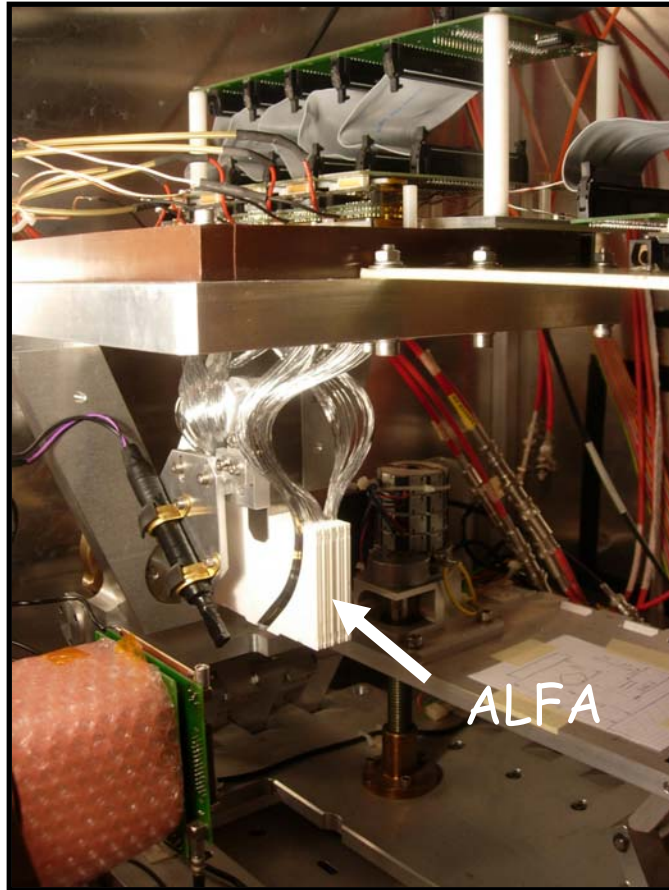
A number of prototypes with
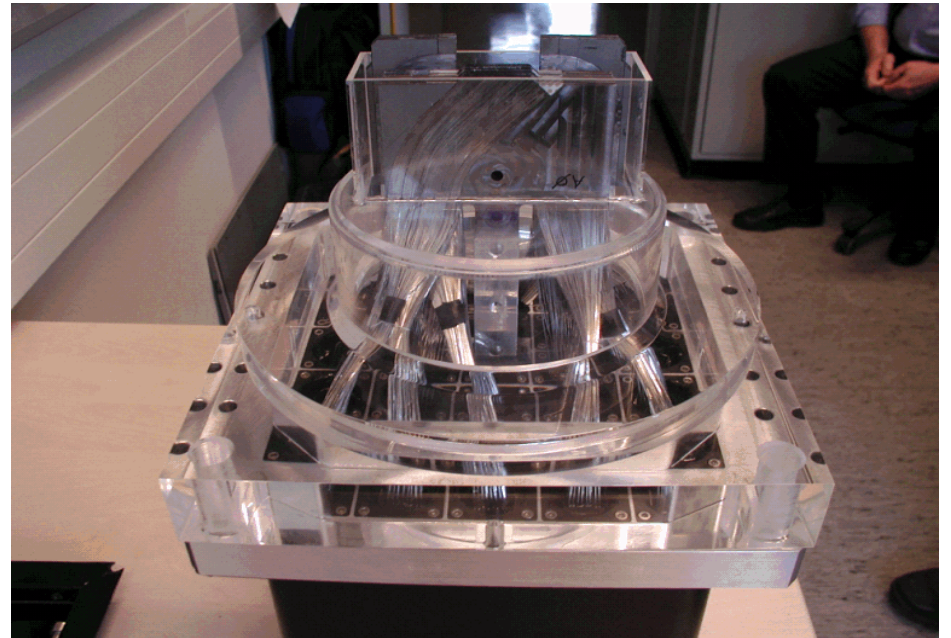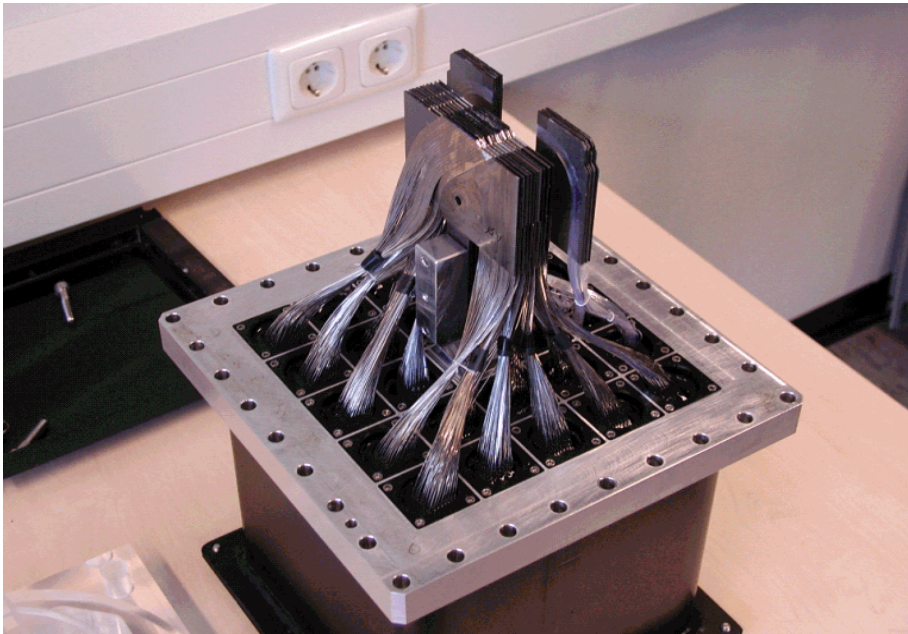limited amount of fibers were tested
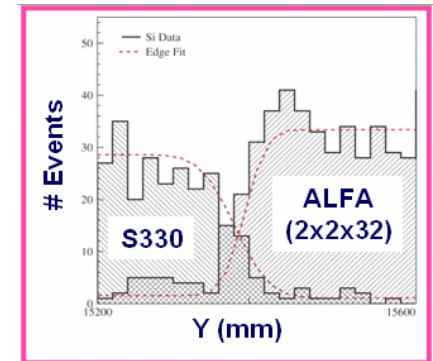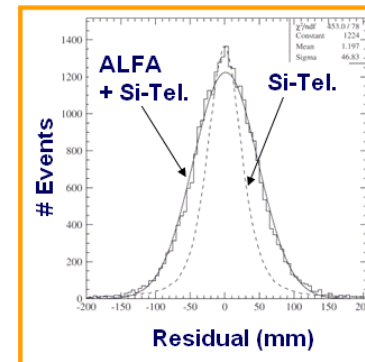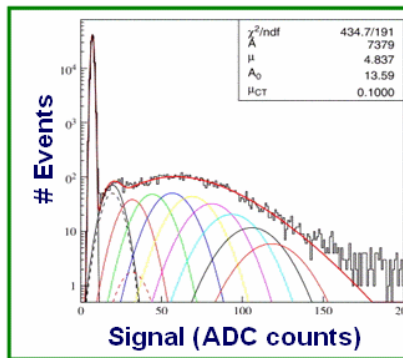
Main results:
* Light yield ~ 4 p.e.
* resolution σ ~ 25 μm
* non-active edge << 100 μm

S. Ask et al., *NIM* A568, 588 (2006)
F. Anghinolfi et al., *Jinst* 2 P07004 (2007)
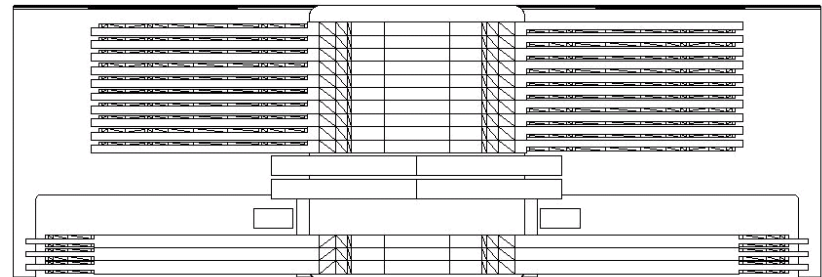
Test beam-this summer
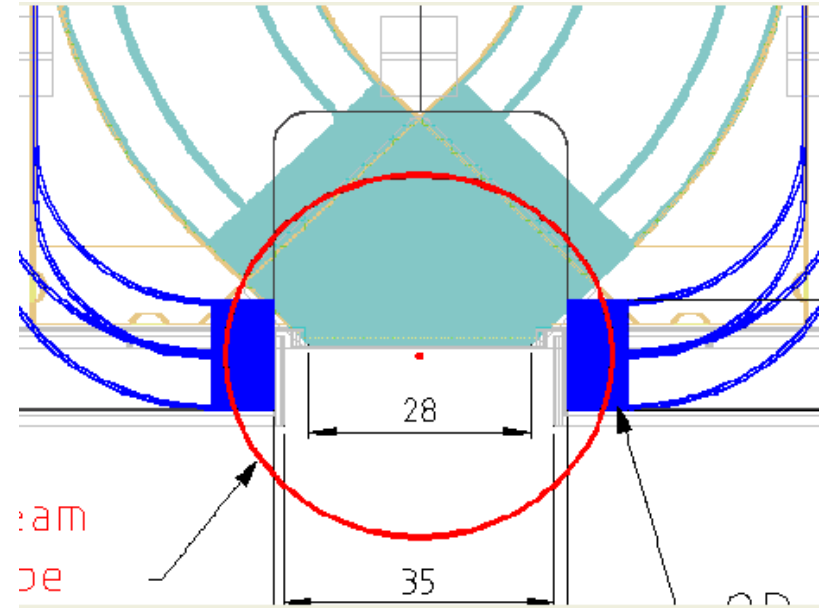
Complete detector for one Roman Pot i.e. 1460 channels
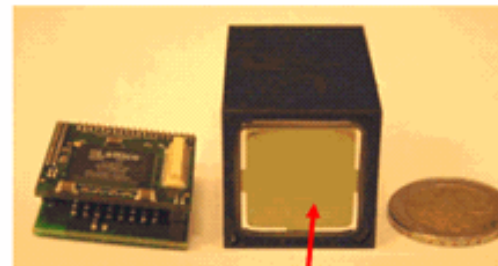
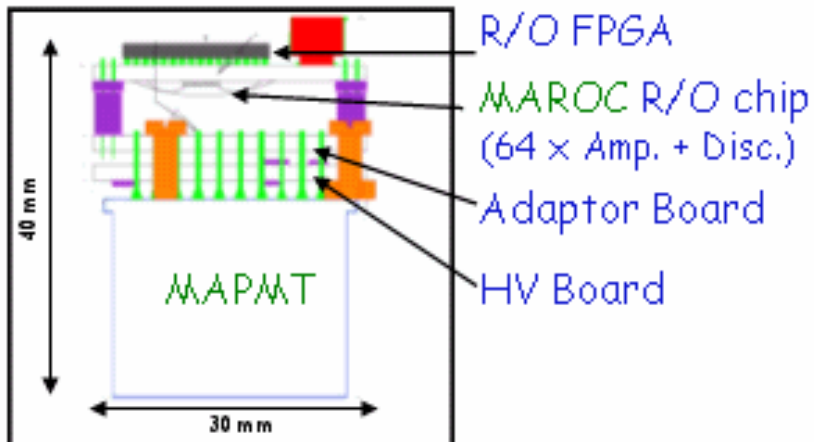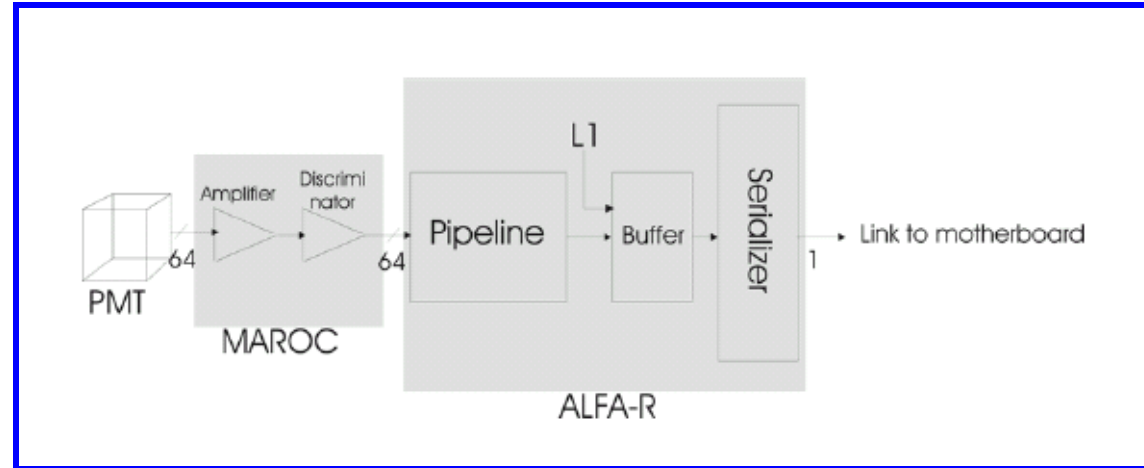# The overlap detector concept
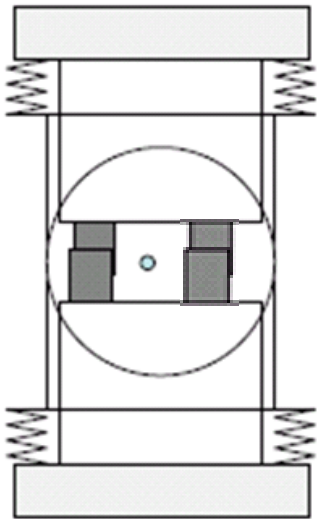
Front view

Side view

particle
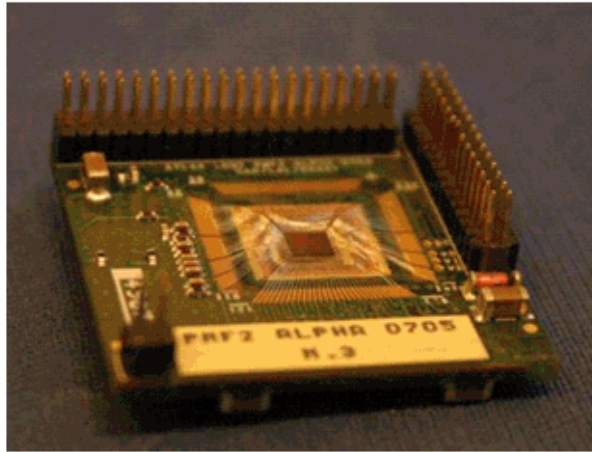
28

35
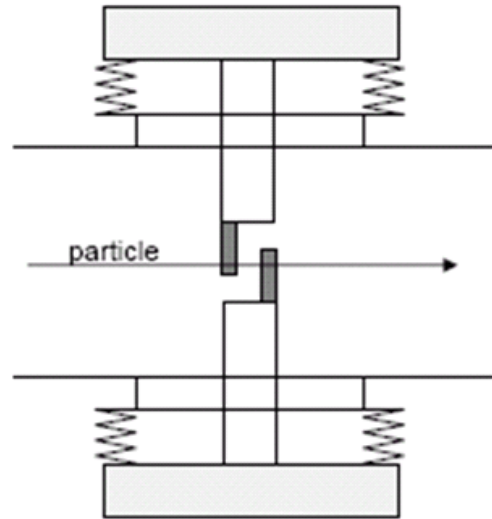
The ALFA electronics – front end - PMF

Requirements

Adjustable amplifier-MAPMT
Adjustable threshold
High speed
Small cross talk
Compact

R/O FPGA
MAROC R/O chip (64 × Amp. + Disc.)
Adaptor Board
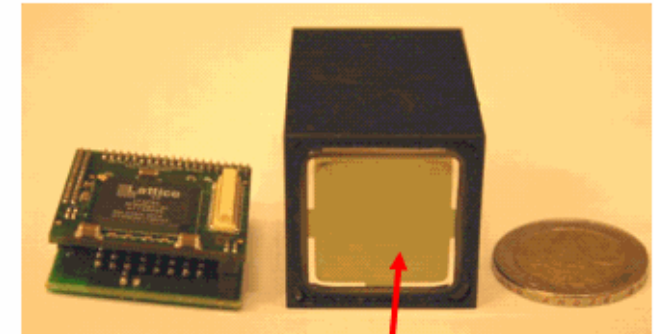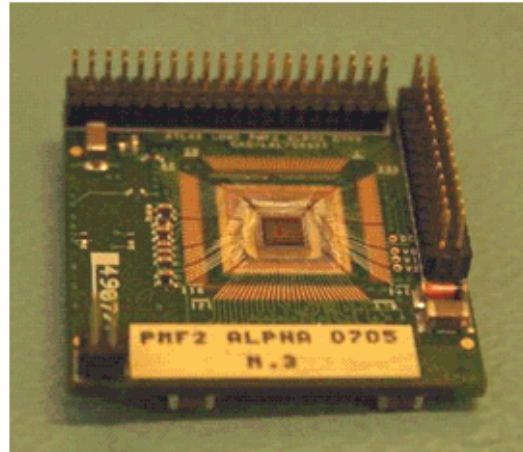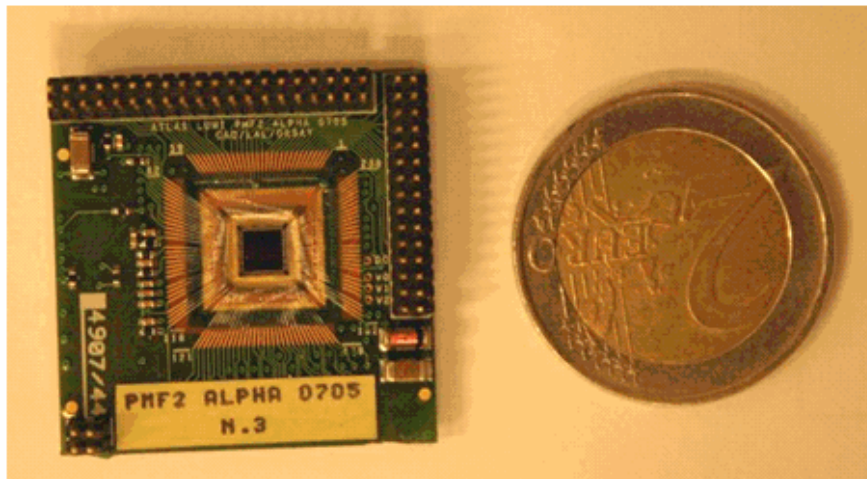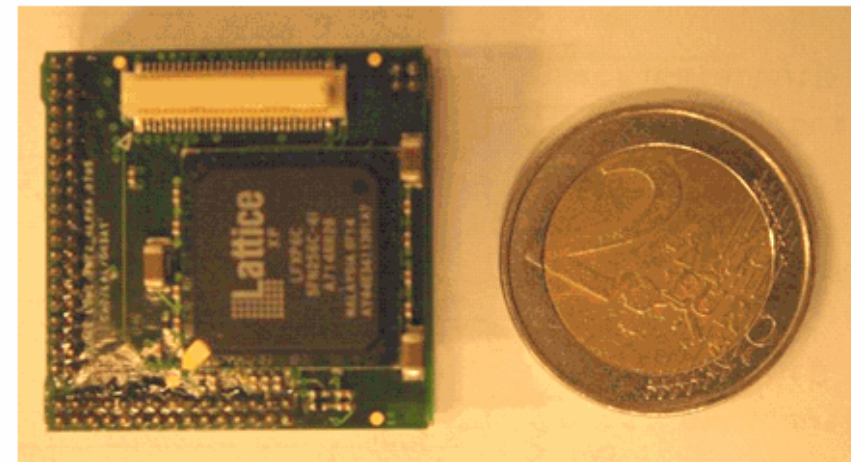HV Board
MAPMT
40 mm
30 mm

64 ch PMT

Active board pictures

MAROC2 chip bonded at CERN
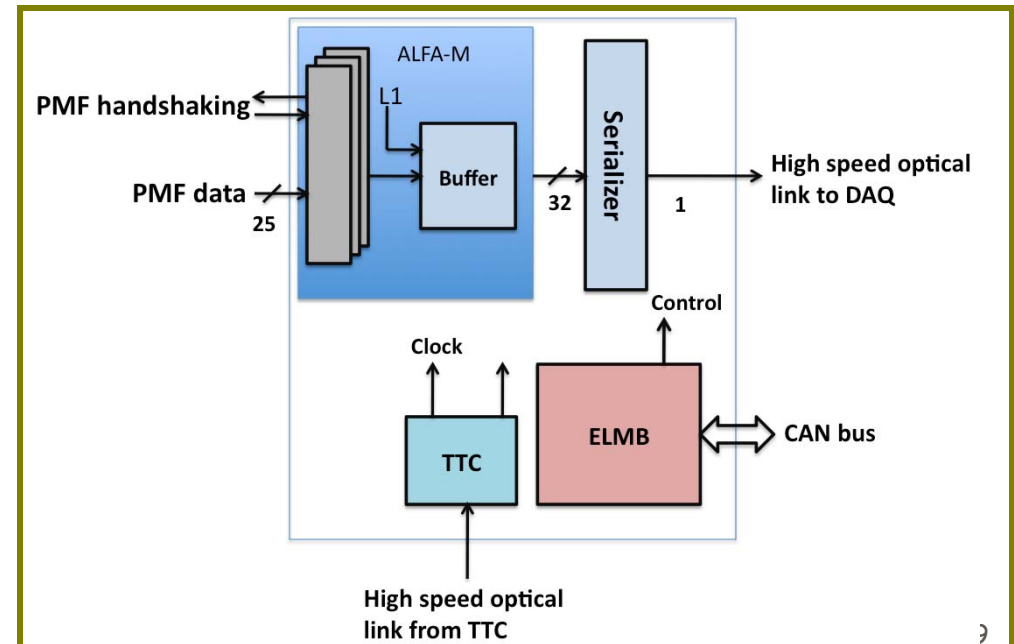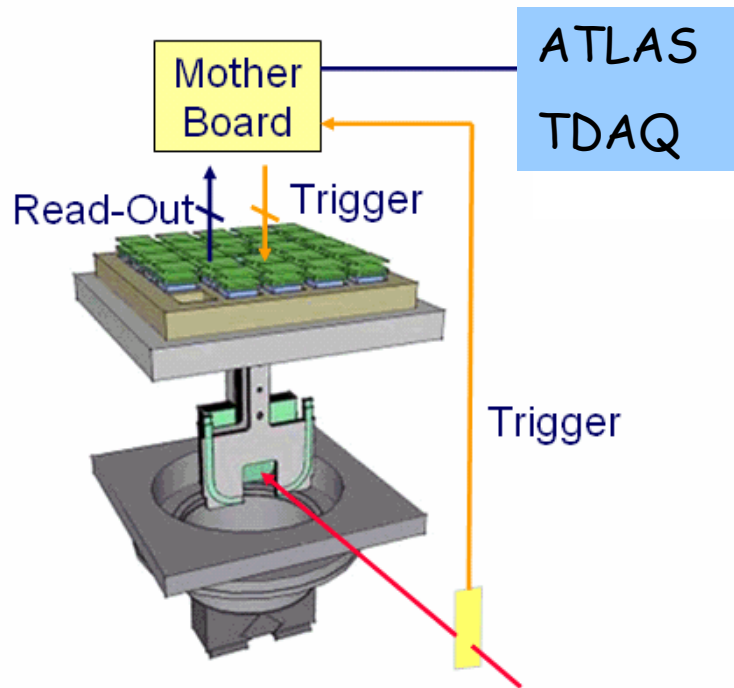

64 ch PMT

MAROC side

Lattice side

The ALFA electronics – the mother board
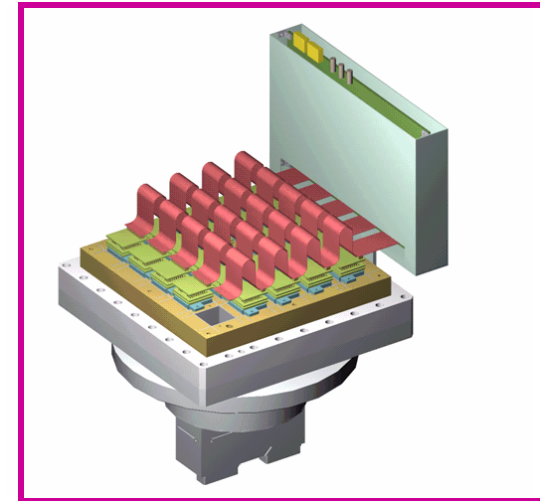
Mechanics - the pot itself
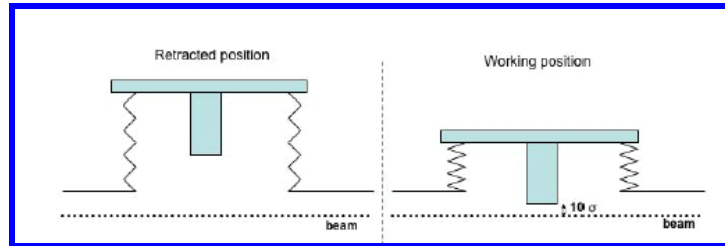
Roman Pot concept

Profiting from Serge Mathot/ TS and TOTEM R&D. Espec. thin window

ATLAS specific

Top flange

Rectangular spacer

Bottom flange

Cylindrical fan-out

Rectangular detector housing

Overlap extrusions

Thinner wall
Thin window
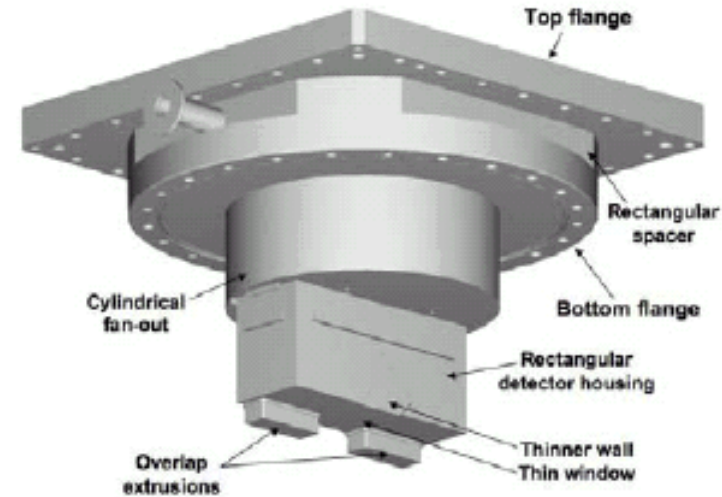
Mechanics - the Roman Pot unit

Reproducible and precise movements required

Profiting from AB collimation group

deviation

Performance simulation

elastic generator PYTHIA6.4
with coulomb- and ρ-term
SD+DD non-elastic
background, no DPE

beam properties at IP1
size of the beam spot $\sigma_{x,y}$
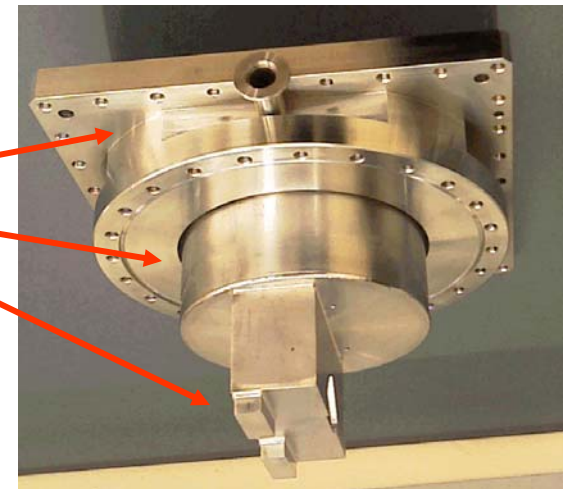beam divergence $\sigma'_{x,y}$
momentum dispersion

beam transport MadX
tracking IP1$\rightarrow$RP
high β^* optics V6.5
including apertures
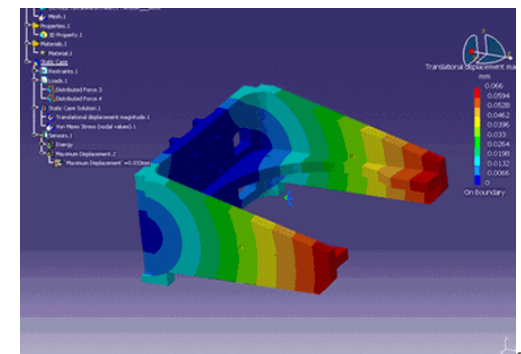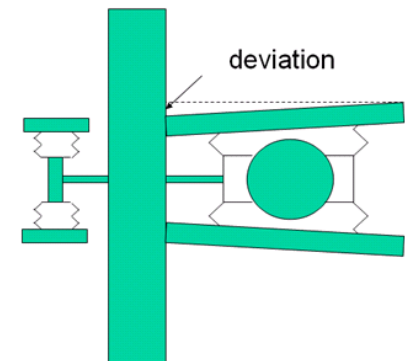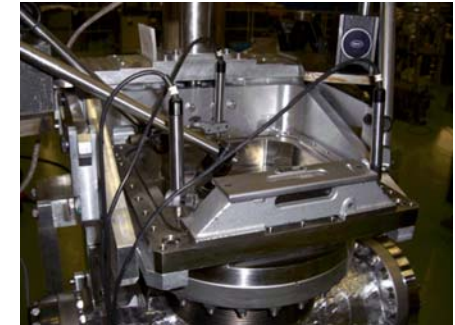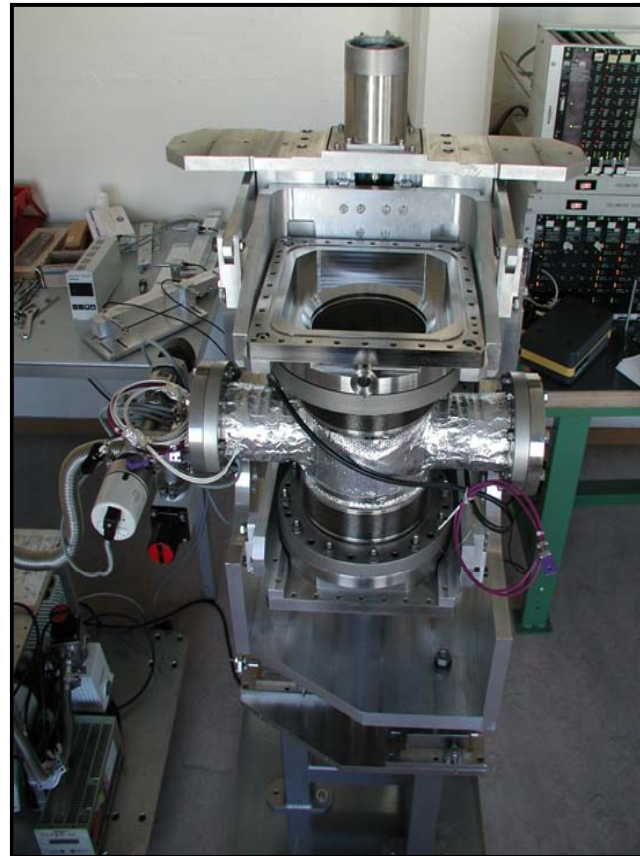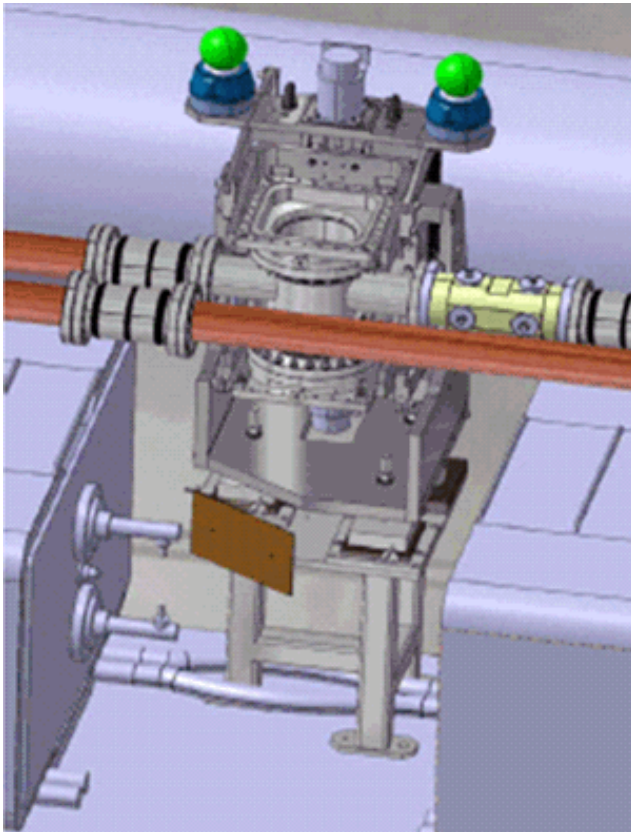
ALFA simulation
track reconstruction
t-spectrum
luminosity determination
later: GEANT4 simulation
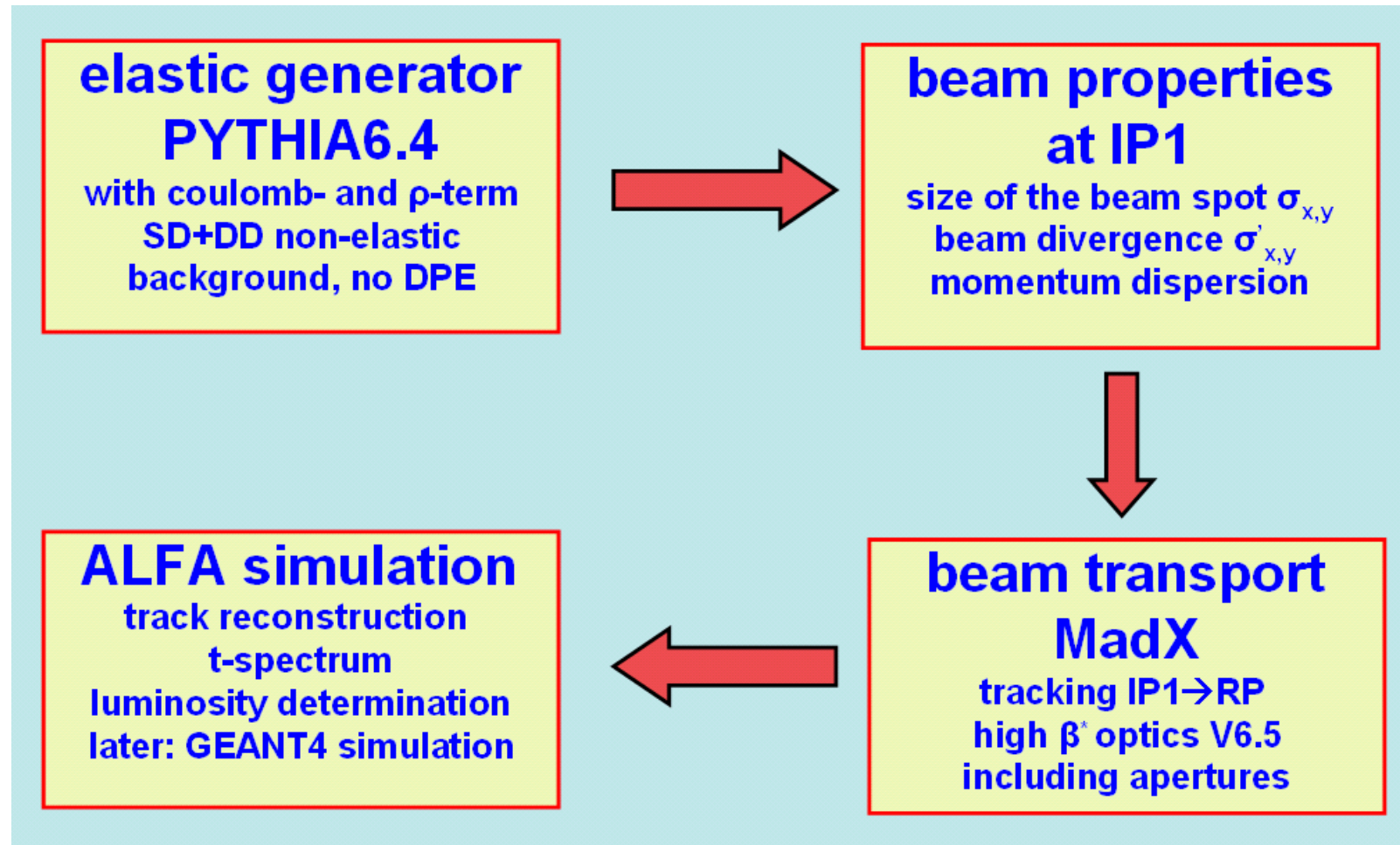
Hit pattern and acceptance
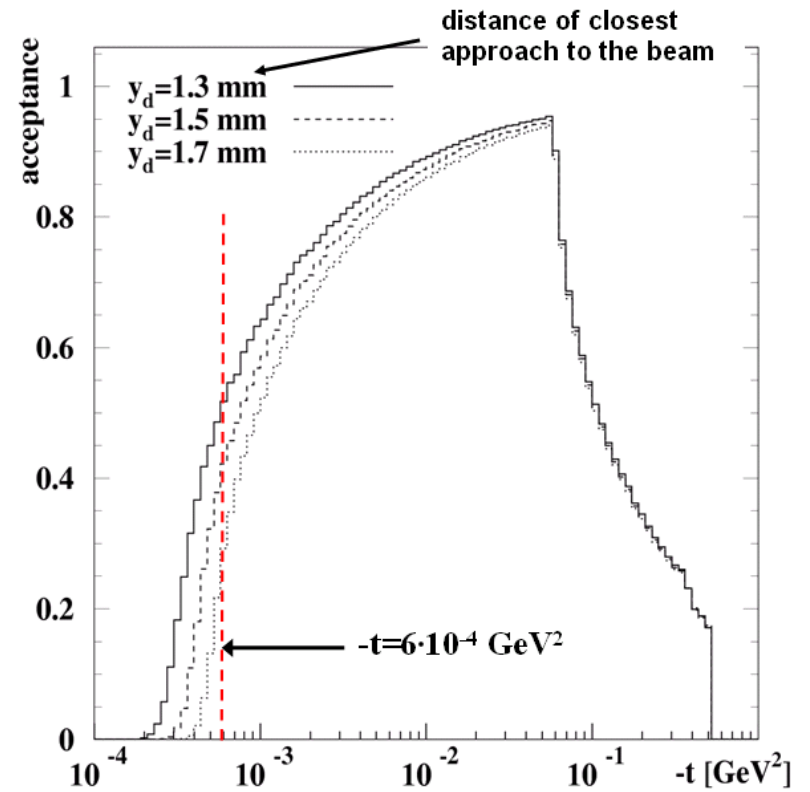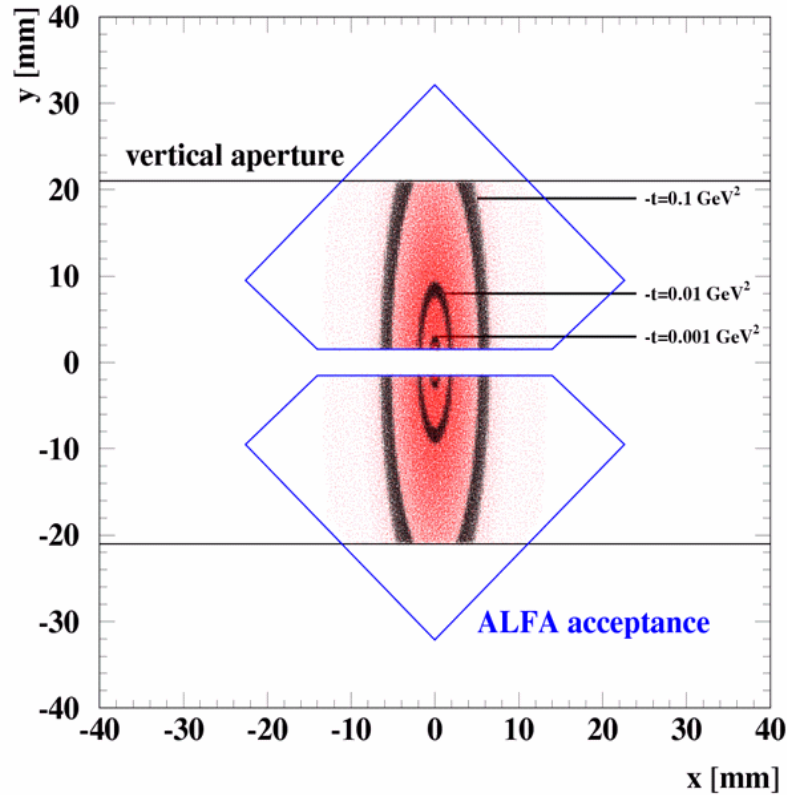
Statistical results from fit
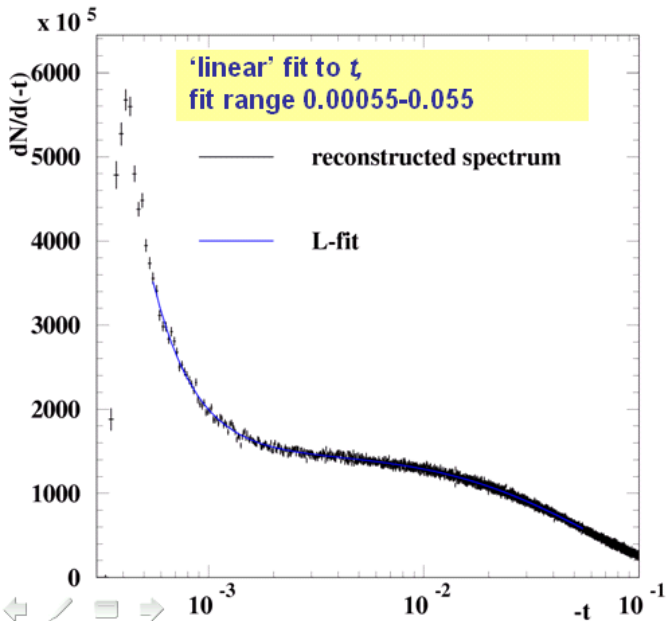
$$\frac{dN}{dt}\bigg|_{t\approx 0} = L\pi\left|f_C + f_N\right|^2 \approx L\pi\left|-\frac{2a_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2}\right|^2$$

'linear' fit to t,
fit range 0.00055-0.055

—— reconstructed spectrum

—— L-fit

- 10 M events corresponding to 100 hours at L= 10²⁷
- Edge 1.5 mm from beam

	Input	Lin.fit	Error (%)
L (10^{26} cm^{-2} s^{-1})	8.10	8.15	1.8
σ_{tot} (mb)	101	101.1	0.9
B (Gev^{-2})	18	17.9	0.25
ρ	0.15	0.14	4.3

Machine induced background

Multiple Sources

- Beam gas scattering in the arcs
- Local beam gas
- Inefficiencies of collimation system
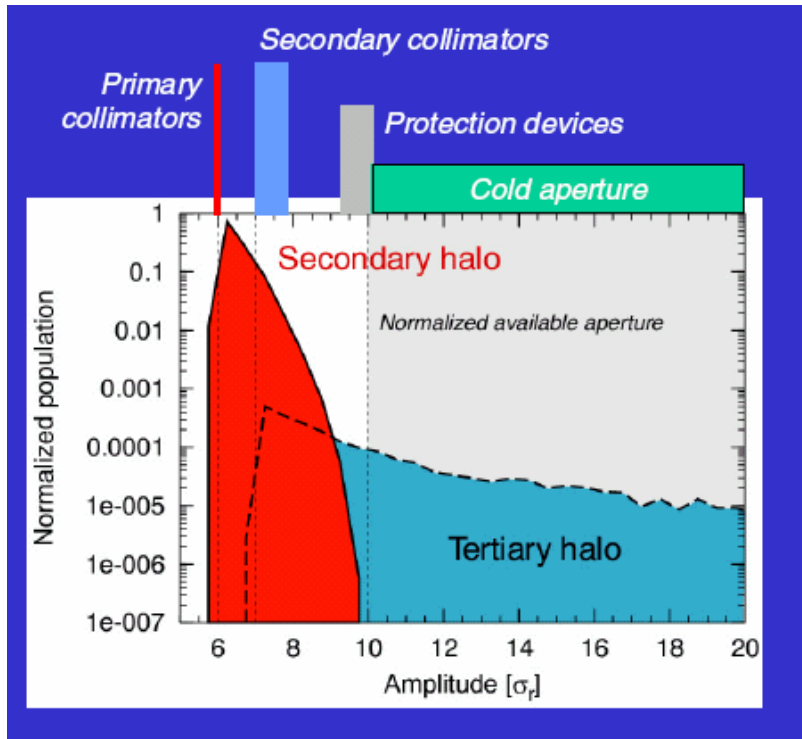
Important and difficult
- determines how close we can come
- backgrounds estimate often wrong
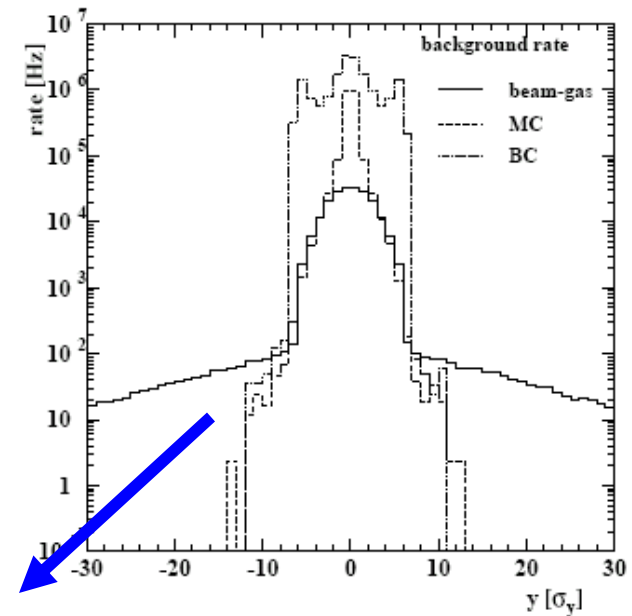
Summary: 2kHz integrated above 10 σ

25

Machine induced background (cont.)

Main handles:

Elastic signature:
- left –right coincidence
- acollinearity cut

Vertex cut
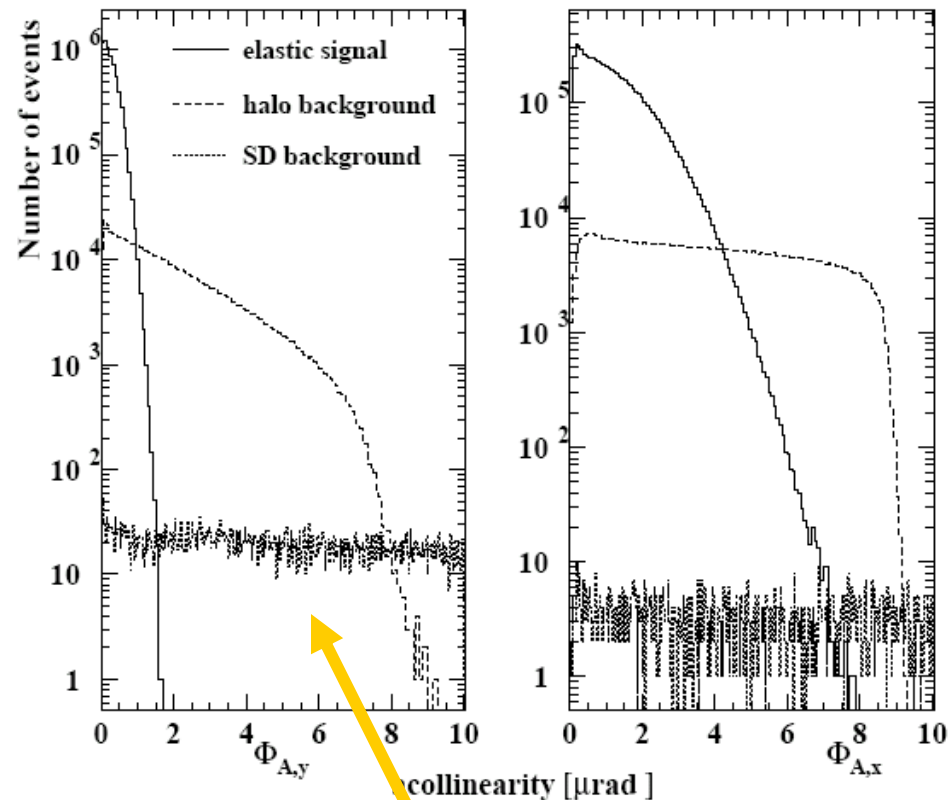
Background reduced to 2 % of the elastic signal

Single diffractive background (generated with PYTHIA) negligible : << 1 permille

Vertex reconstruction for background rejection
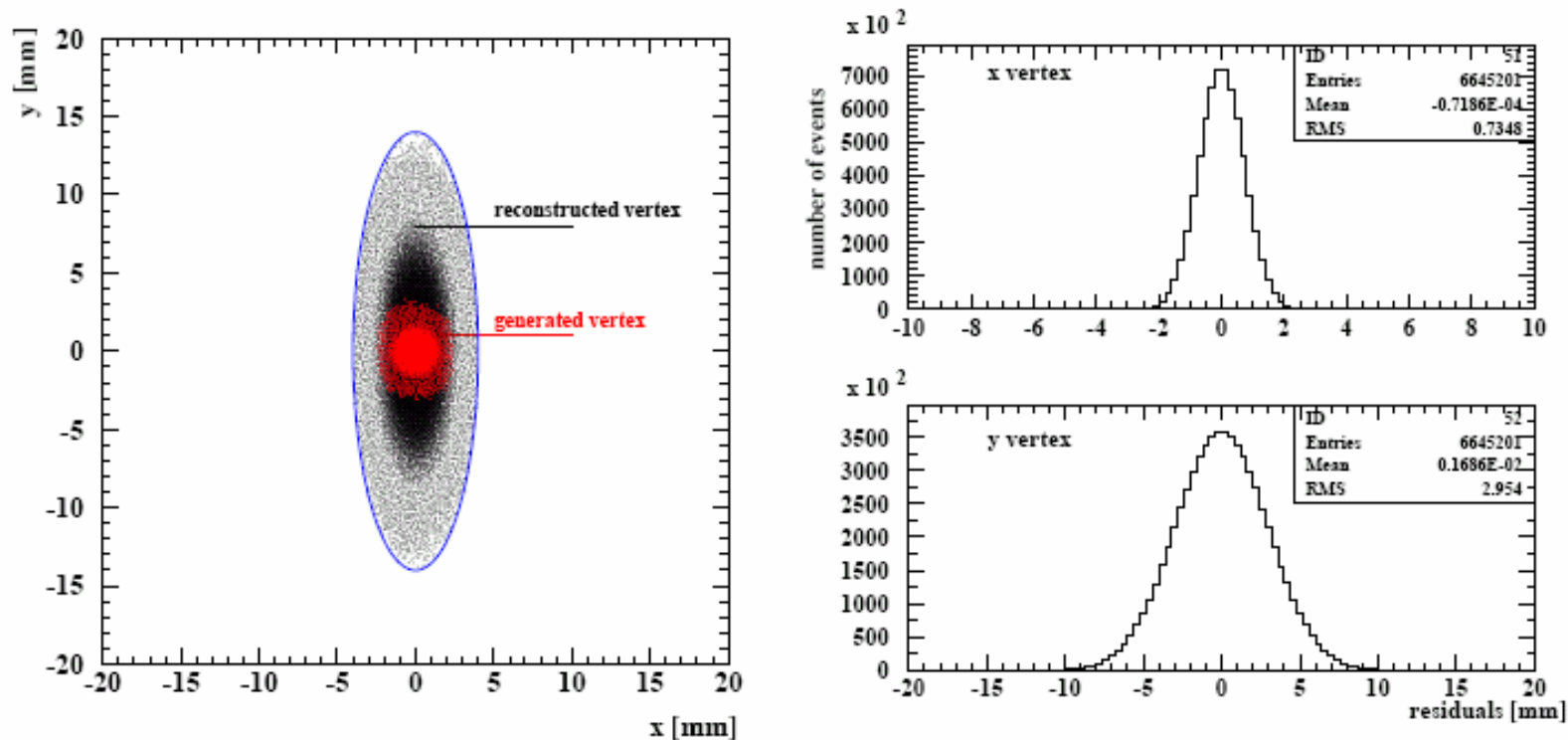
Figure 9-6 The reconstructed vertex position (black dots) compared to the true vertex (red dots), where the blue ellipse indicates the rejection cut (left). The vertex resolution in *x* and *y* (right).

Systematic errors

Systematic uncertainties [%]	Linear fit
Nominal result for L	8.15
Statistical error	1.77
Beam divergence	0.31
Crossing angle	0.18
Optical functions	0.59
Phase advance	1.0
Detector alignment	1.3
Geometrical detector acceptance	0.52
Detector resolution	0.35
Background subtraction	1.10
Total experimental systematic uncertainty	2.20
Total uncertainty	2.82

Machine protection

- Uniform treatment of all movable devices in LHC $\Rightarrow$ the ATLAS Roman Pots will be controlled from the CCC. The ATLAS Roman Pots will be an integrated part of the global LHC collimator control system.

- The Collimator Supervisor System will ensure that all Roman Pots are positioned in the shadow of the collimators.

- The Roman Pots will only be allowed to move to data taking position during the STABLE BEAM operational mode of LHC.

- BLM's have been installed close to the Roman Pots. The BLM's are connected to the LHC Beam Interlock System.

- The Roman Pots moves out automatically in case of power failure

Participating institutes, schedule and costs

Participating ATLAS institutes

Czech Republic	Charles University
	Academy of Science
	Palacky University
France	LAL Orsay
Germany	DESY
	University of Giessen
	Humboldt University
Great Britain	University of Manchester
Poland	University of Science and Technology, Cracow
	Institute of Nuclear Physics, Cracow.
Portugal	Laboratorio de Fisica, Lisbon
Spain	IFIC, Valencia
Sweden	University of Lund
USA	Stony Brook University
CERN	

Estimated cost	(kCHF)
ALFA detector with PMS	600
Electronics and read out	375
Roman Pot mechanics	300
Infrastructure	300
Total	1575

The detector will be ready for installation earliest spring 2009 and will most likely be installed in the shutdown 2009/2010.

Conclusion

- ATLAS proposes to use scintillating fibers in Roman Pots to measure Elastic Scattering at small angles.

- The ultimate goal is to reach the Coulomb interference region. This will be extremely challenging due to the small angles and the required closeness to the beam.

- Main challenge is not so much in the detectors but rather in the required beam properties. Especially the level of beam halo at small distances will be important.

- The ALFA project will be an important part of the luminosity determination in ATLAS even if the Coulomb Interference region is not completely reached.

- In addition, ALFA opens up the door for a Forward Physics program in ATLAS. Experience with working close to the beam will prepare us for expanding towards a Forward Physics program as a future upgrade.