Novel detection techniques in FP420

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Intro: Detectors at 420m (for high lumi)

HECTOR: LHC beamline simulation

Detection system: Hamburg pipes

Detectors: Tracking and timing

Outlook

FP420 R&D issues (NB. Report in preparation):

- **Modification of LHC connecting cryostat to allow for near-beam detectors at ~420 m**

- **Optimization of detector setup for resolutions and acceptances**

- **Design detector system to allow for reliable and precise close approach to beam**

- **Study and tests detectors for precise proton tracking and timing**

- **Study and design required infrastructure in LHC tunnel**

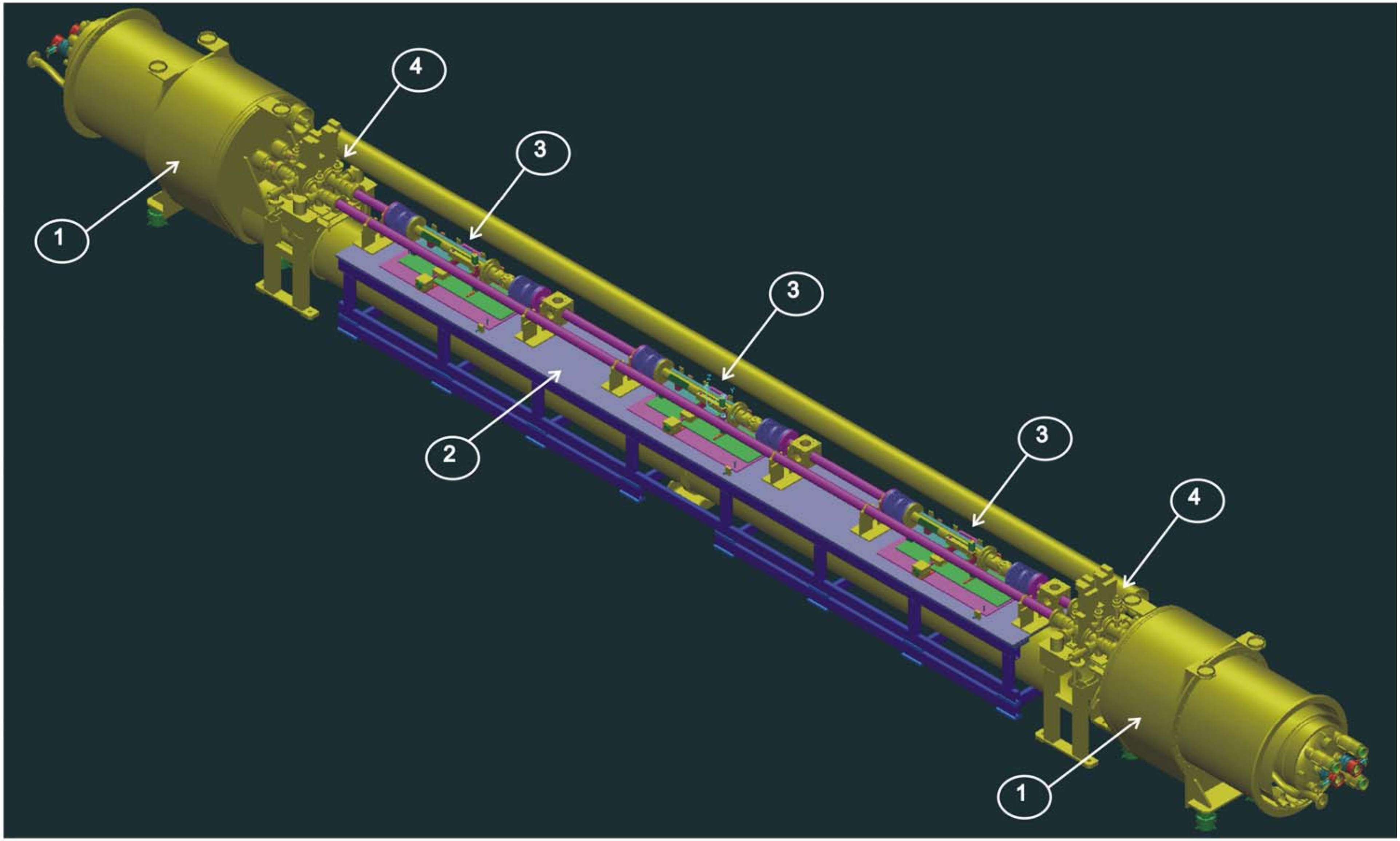
- **Study backgrounds and radiations hardness**

B. Florins, K. Piotrzkowski, G. Ryckewaerts
UCLouvain

Moving Hamburg pipe detector system

1. Introduction

Detection of diffractive protons at 420 m from the IP is particularly challenging since it has to be done between two LHC beam pipes, which are separated mechanically only by about 140 mm (the distance between the pipe axes is of nominal 194 mm). In addition, the nearby cryo-lines limit strongly the available free space. This is why the traditional Roman Pot technique is not possible to use, and another concept for near beam detectors, pioneered at DESY is proposed. This technique of moving Hamburg pipes was developed within the ZEUS collaboration in 1994/5 in the context of photoproduction tagging at HERA using very forward-scattered electrons [1], and was inspired by the moving pipes used in the PETRA wiggler line to allow for the beam-line aperture changes. Electron detectors (as small sandwich calorimeters) attached to the moving pipe some 44 m from the IP could approach the coasting beam and register off-beam energy electrons, which left the pipe by special exit windows. The detectors could be easily maintained and were successfully and routinely run for six years, providing data essential for several publications [2]. Each time after setting HERA in the collision mode, HERA shift crew remotely inserted detectors at the working position; about 15 mm from the coasting electron beam, using the HERA slow control system. Before installation, the Hamburg pipe system was tested by making several thousands displacement operations. Finally, no significant RF effects on the electron beam were observed due to the changed beam-pipe geometry. It should be noted that no special RF screening was used, only the inclined at 45° exit windows and the so-called RF fingers providing good electrical contact across the connecting bellows.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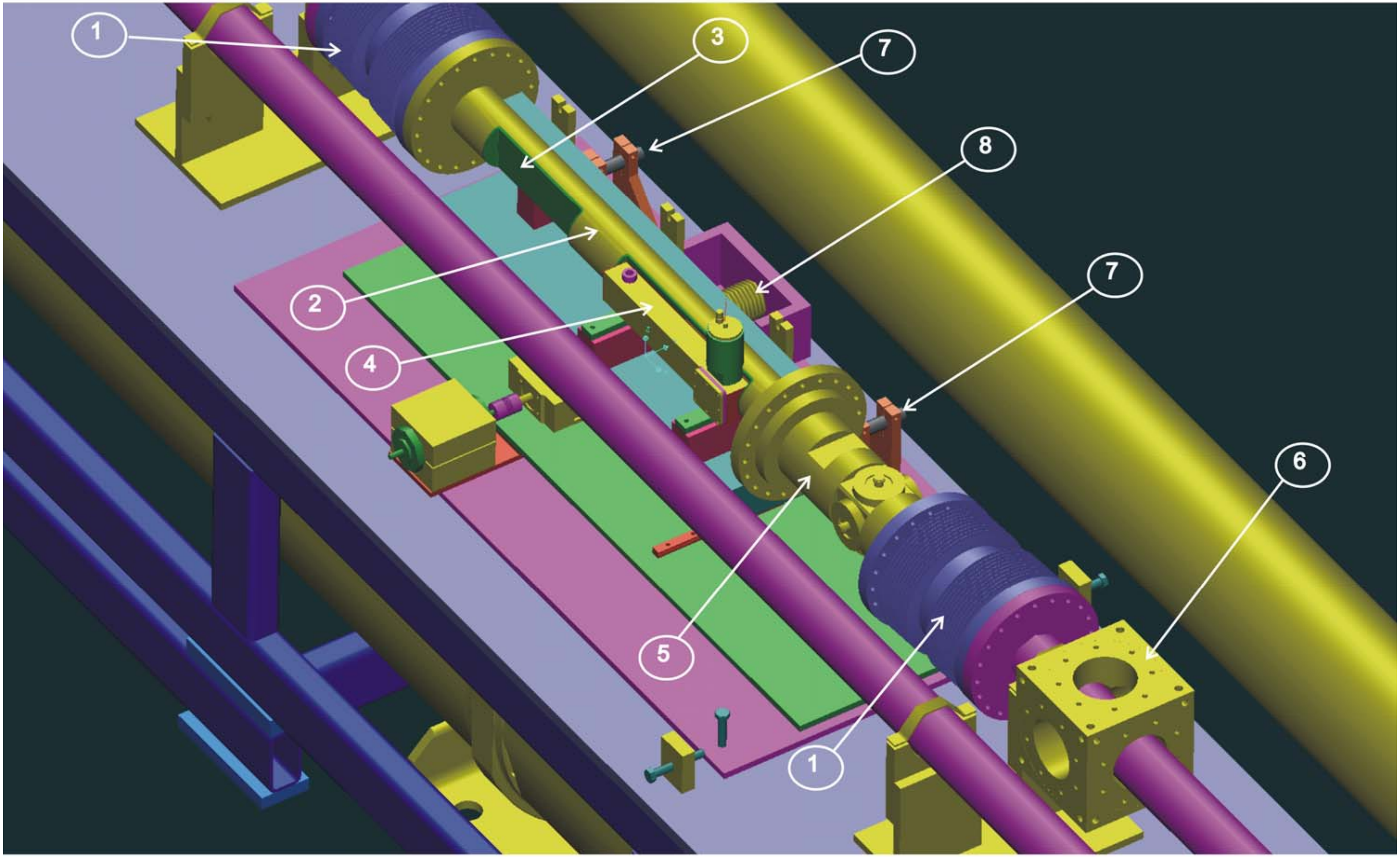
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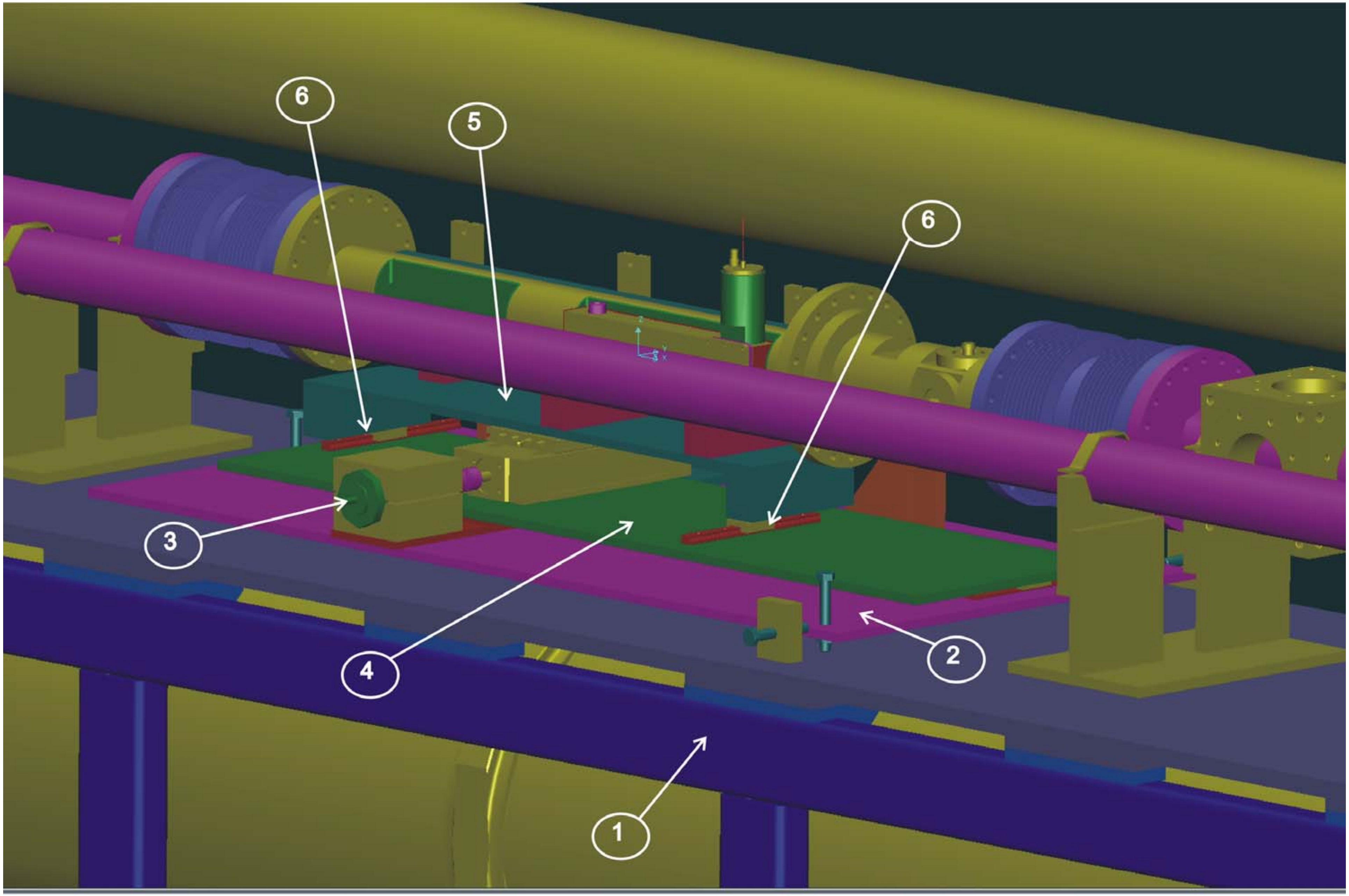
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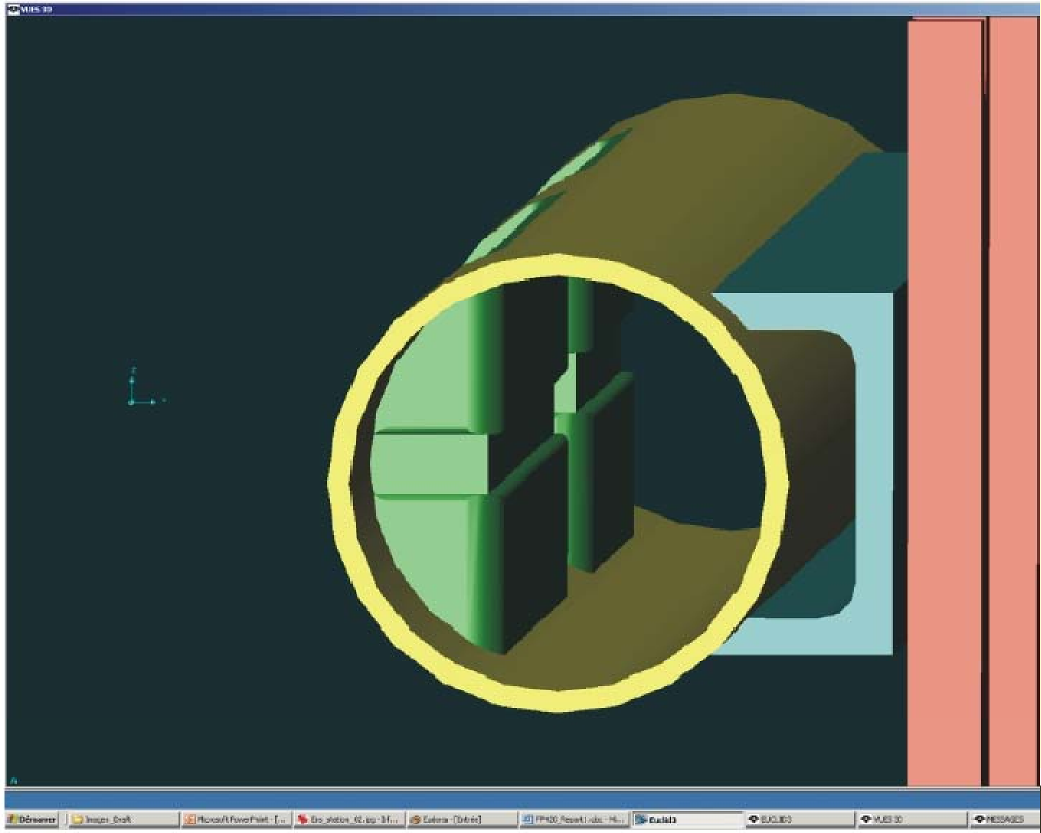


Figure 4: interior of the moving beam pipe as seen by the particles.

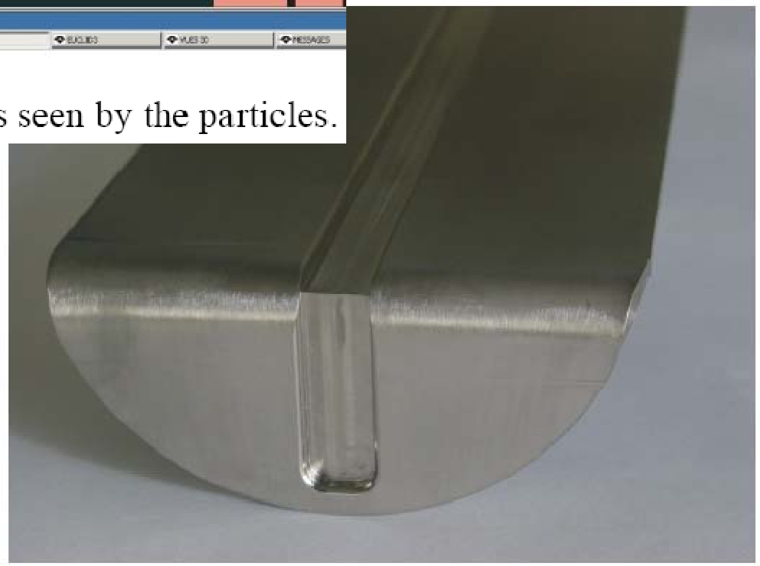
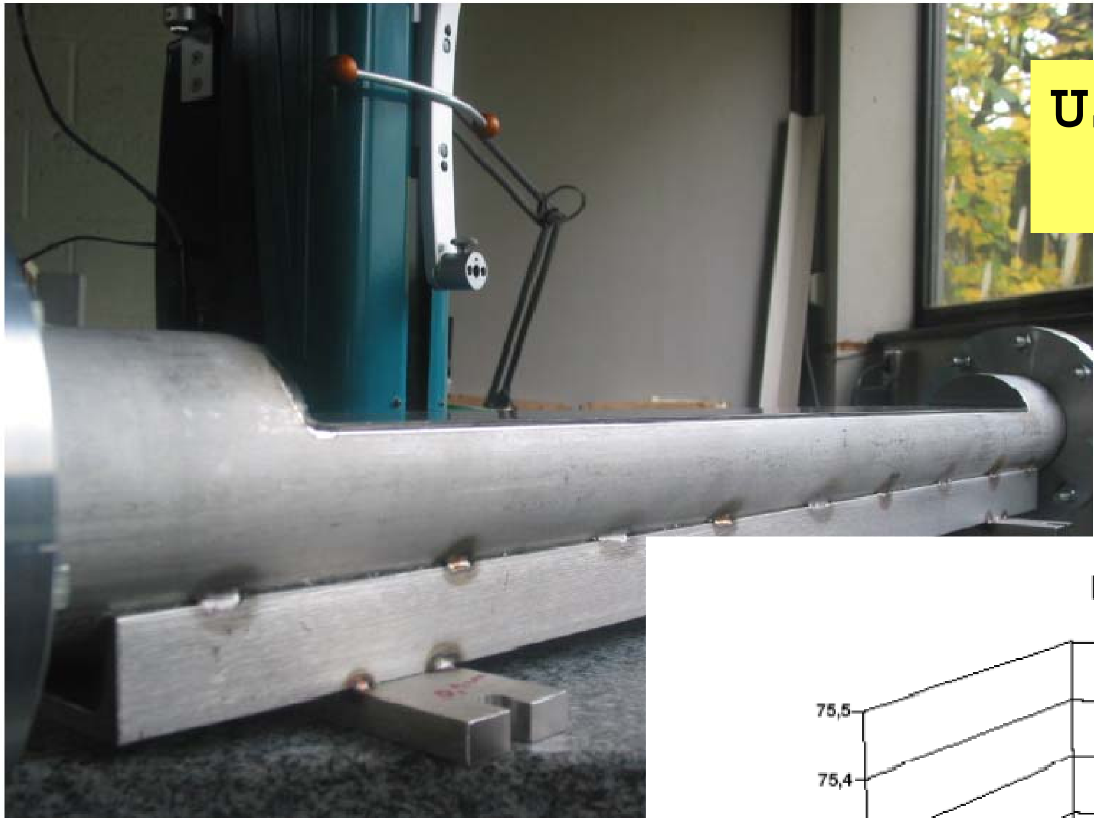
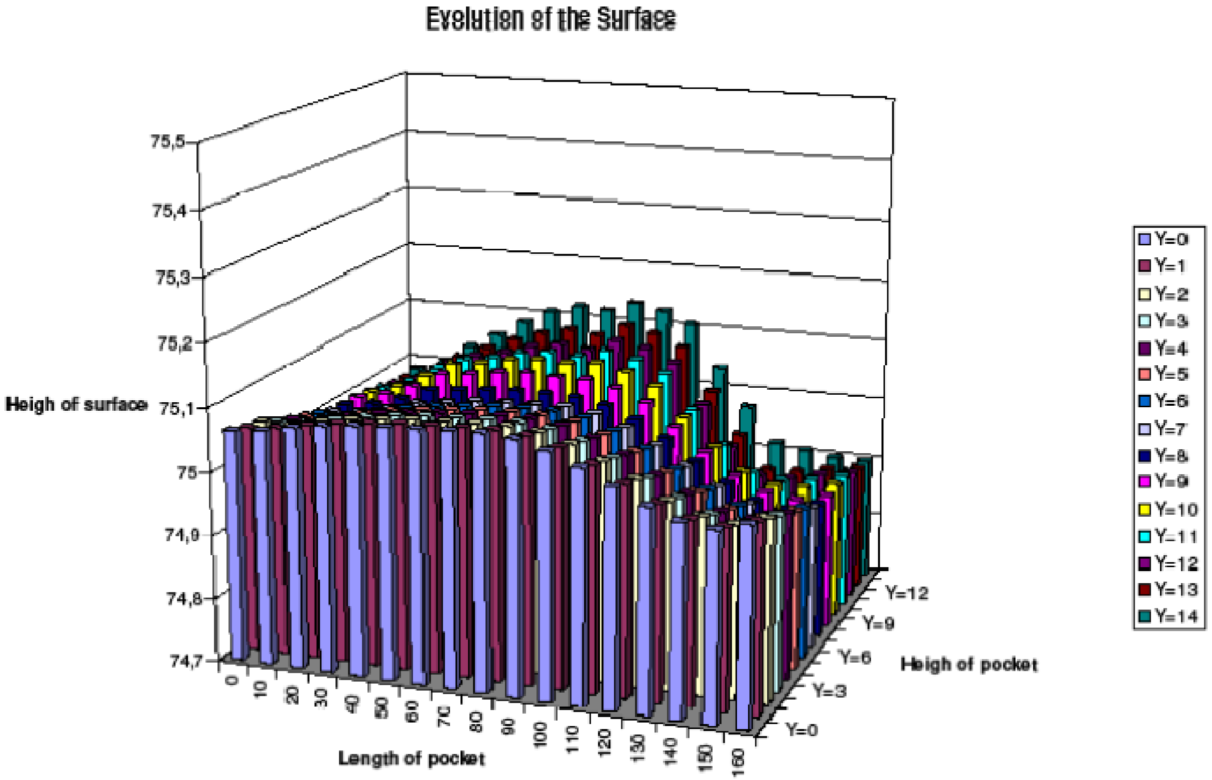


Figure 5: end view of a machined window before welding on the beam pipe slo

Figure 8: fabrication drawing for 600 mm long pocket welded in a reinforced tube.



Used for RF tests at Cockroft



Aim at < 50 µm pocket surface flatness

Hector, a fast simulator for the transport of particles in beamlines

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Abstract

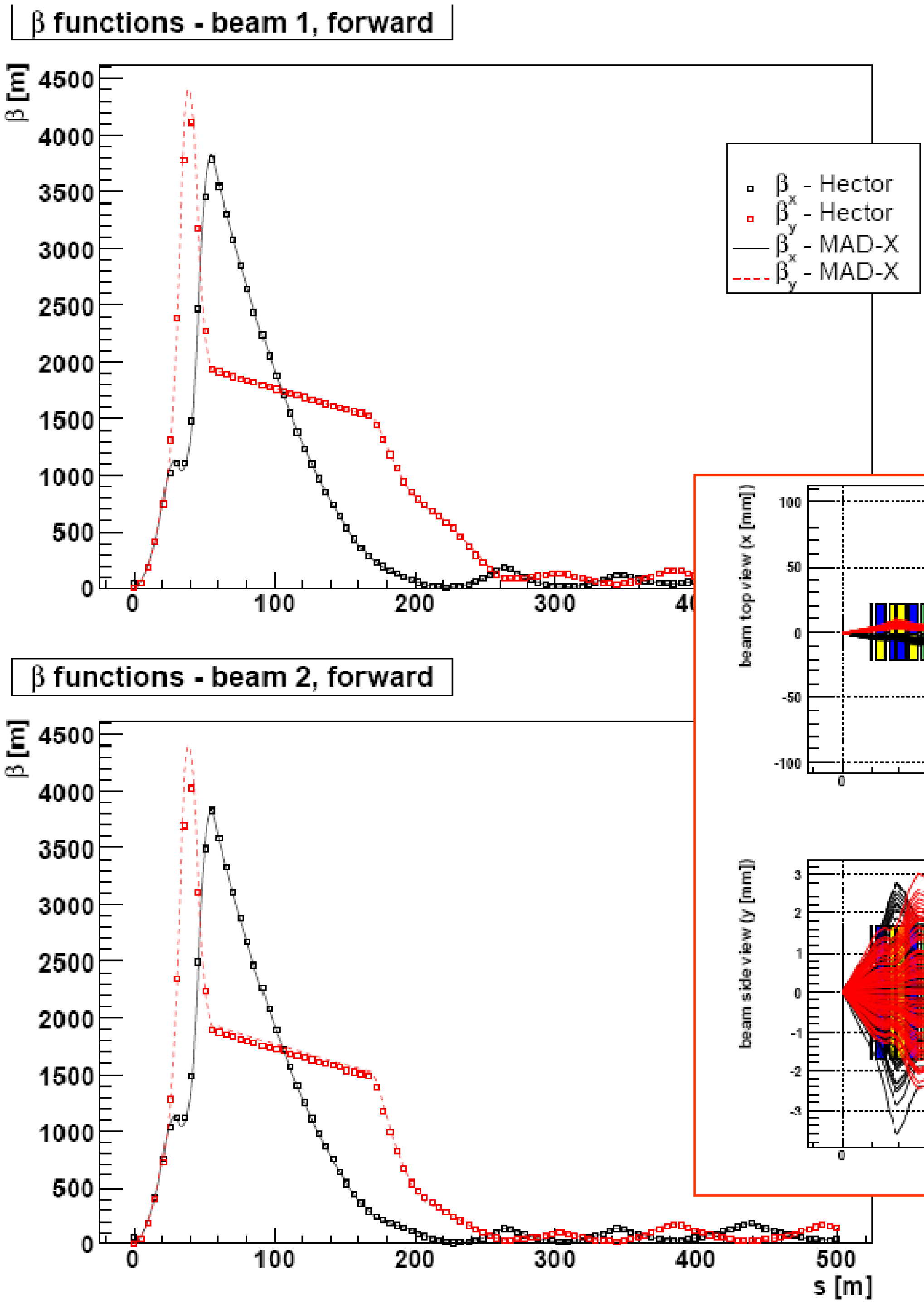
Computing the trajectories of particles in generic beamlines is an important ingredient of experimental particle physics, in particular regarding near-beam detectors. A new tool, Hector, has been built for such calculations, using the transfer matrix approach and energy corrections. The limiting aperture effects are also taken into account. As an illustration, the tool was used to simulate the LHC beamlines, in particular around the high luminosity interaction points (IPs), and validated with results of the Mad-X simulator. The LHC beam profiles, trajectories and beta functions are presented. Assuming certain forward proton detector scenarios around the IP5, acceptance plots, irradiation doses and chromaticity grids are produced. Furthermore, the reconstruction of proton kinematical variables at the IP (energy and angle) is studied as well as the impact of the misalignment of beamline elements.

PACS: 29.27.-a ; 41.85.Ja

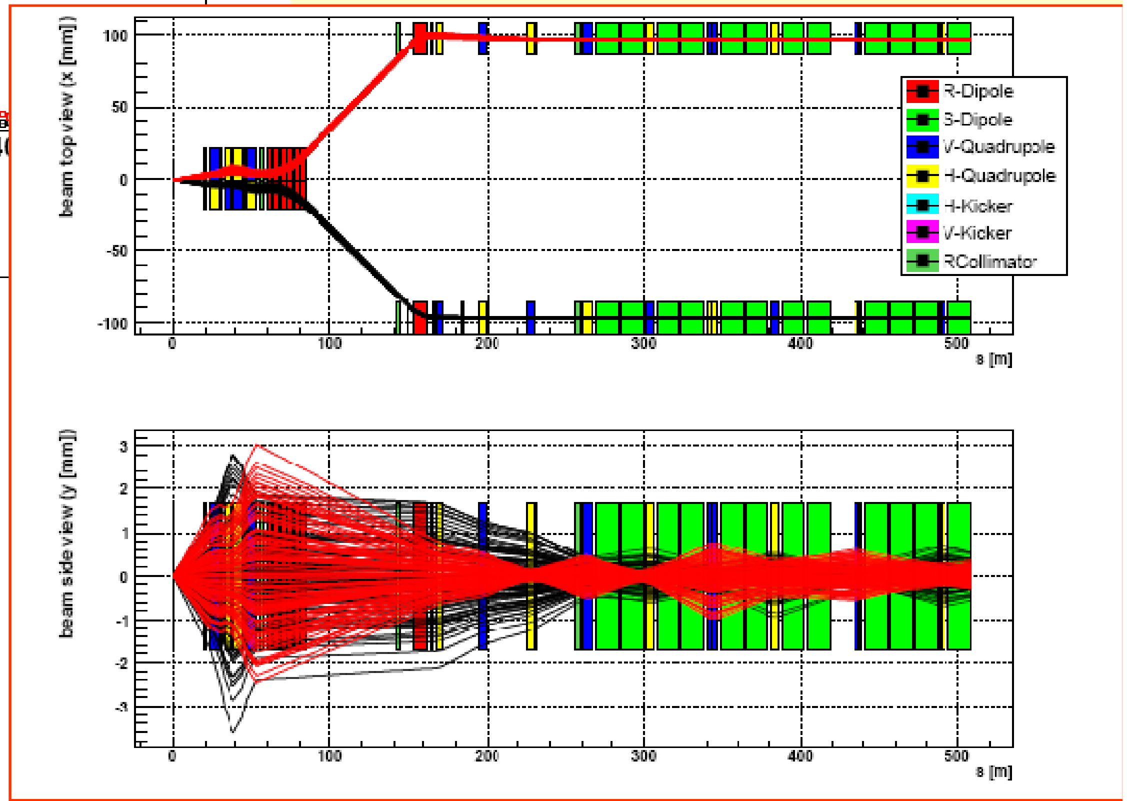
Keywords: Particle transport, transfer matrix, LHC beamline, forward detectors, misalignment

1 Introduction

In the context of the LHC beamlines and in particular of very forward, near beam detectors, we introduce a new fast simulator, called Hector, for the transport of single particles through generic beamlines, although primarily dedicated to the LHC. The simulator is based on a linear approach of the beamline optics, implementing transport matrices from the optical element magnetic effective length, and with correction factors on magnetic strength for particles with non nominal energy. Hector deals with the computation of the position and angle of beam particles, and the limiting aperture of the optical elements. It has been designed to be fast, light and user friendly and its object oriented structure, using the Root framework [1], helps its usage, its maintenance and the future improvements.



Hector **verified with Mad-X: it is fast, versatile, precise tool for FP420/220/LHC studies**



Acceptance driven mostly by p energy loss, and by detector/beamline geometry/aperture

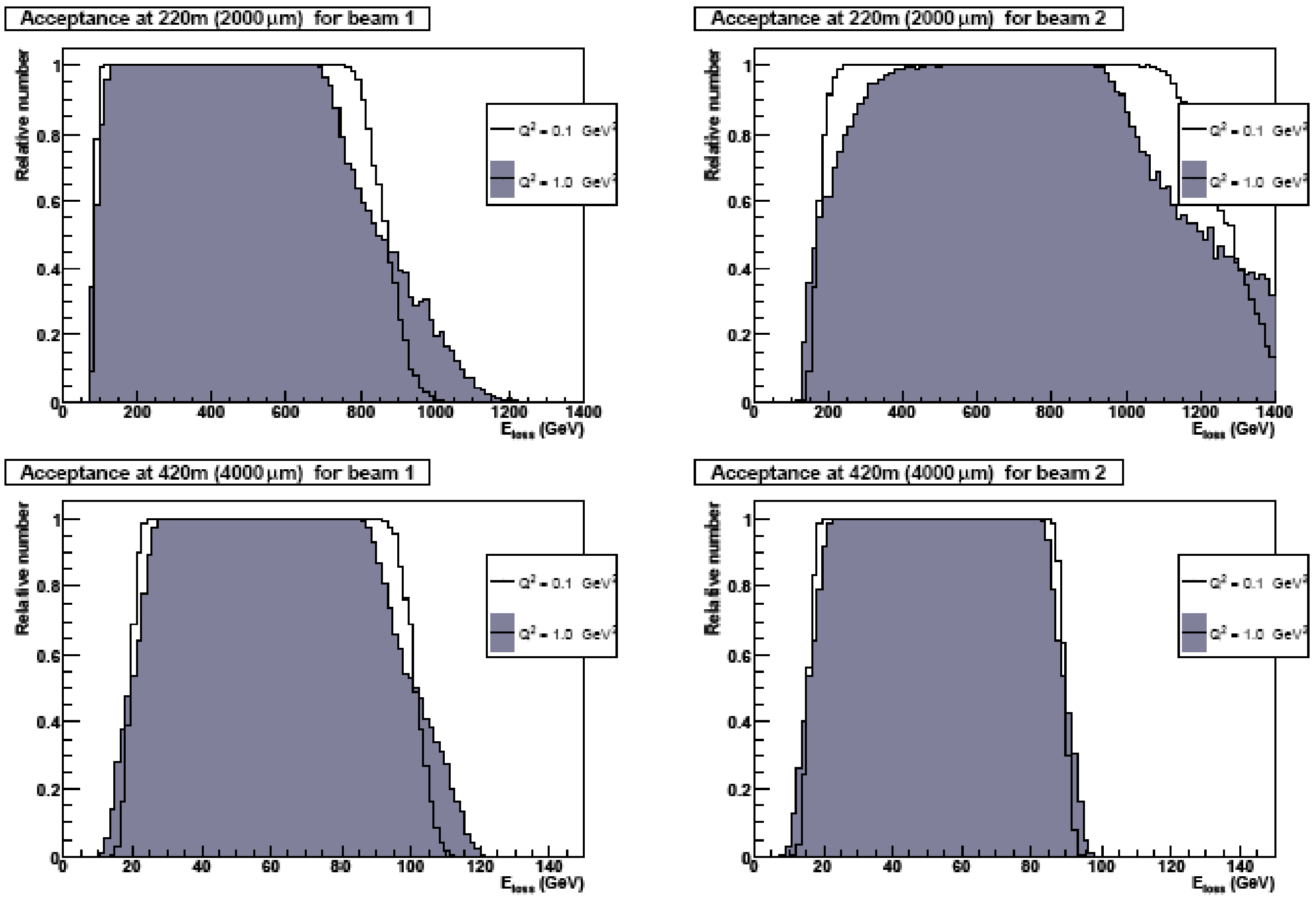
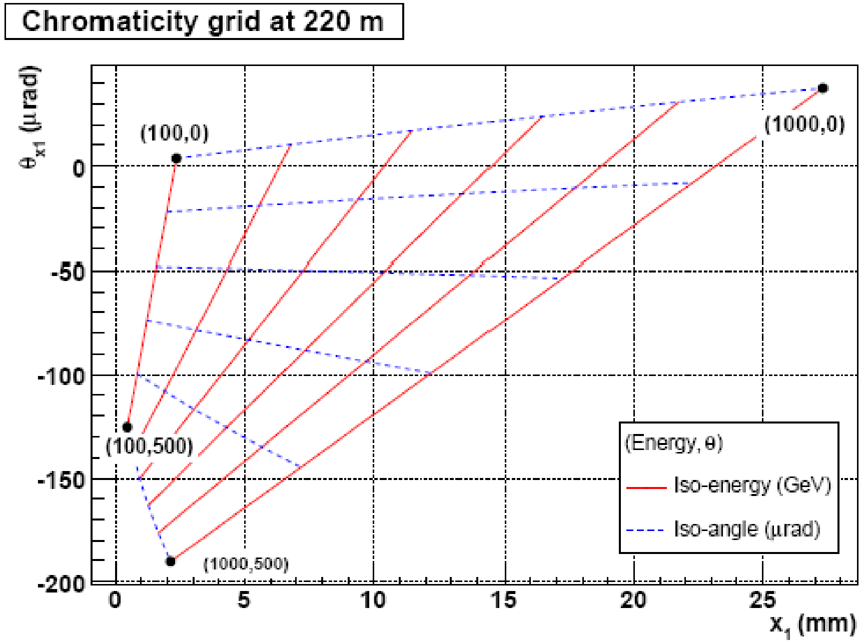
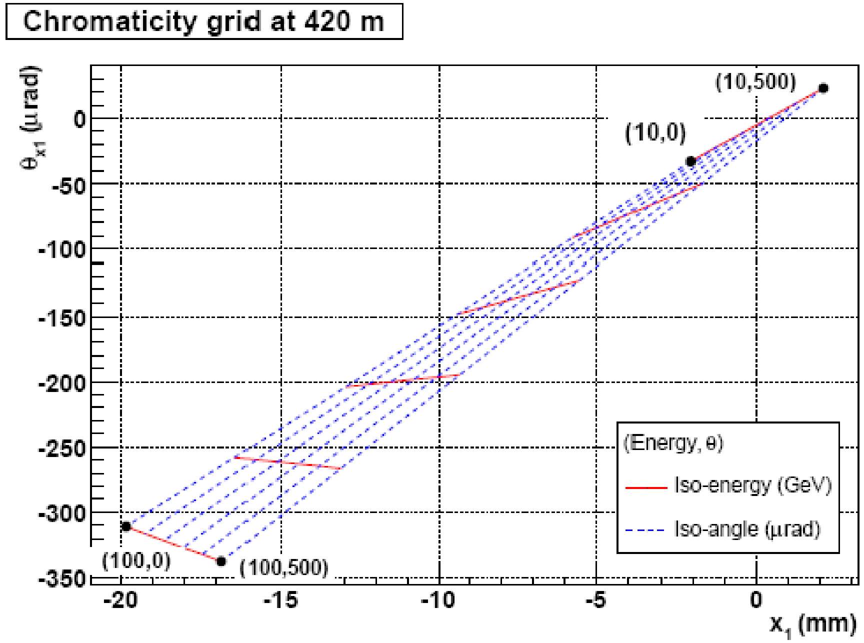
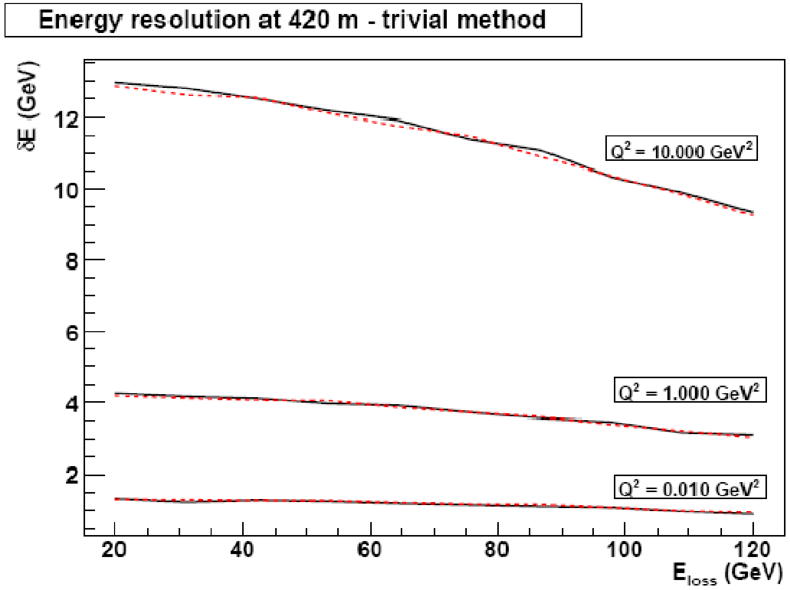


Figure 9: VFD acceptance as a function of energy loss, for two fixed virtualities (Reminder: $Q^2 = -t$). See previous figure for more details.





- **Optics non-linear**
- **Effects of energy and angles mixed**
- **Transverse momentum measurement difficult**



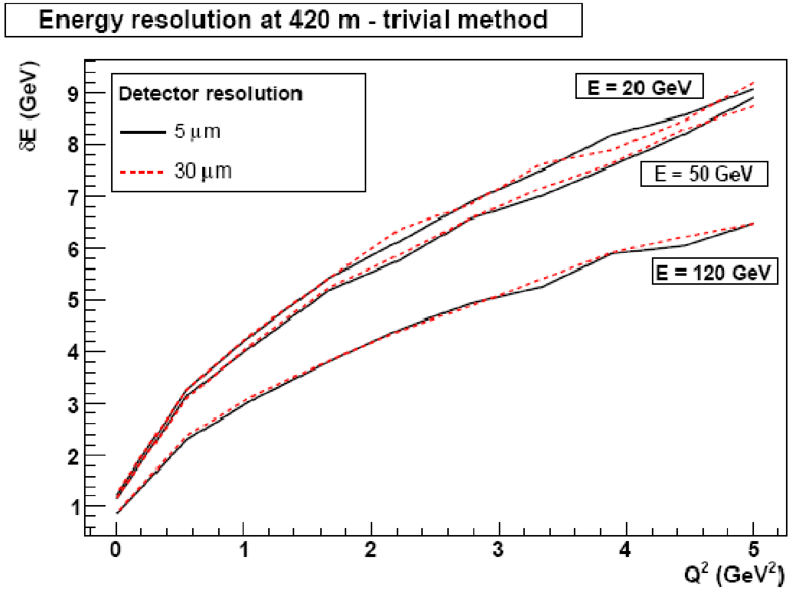


Figure 13: Energy resolution for the trivial reconstruction, for protons measured at 220 m and 420 m from the IP5. The protons have exchanged a particle taking away some energy, at a given virtuality. The resolution is shown as a function of the energy loss and the virtuality. The effects of some error on position measurement, due for instance to the spatial resolution of the detector stations (5 μm and 30 μm), are taken into account. The beam energy dispersion is not included.

However, energy measurement is good at 420 m even for poor spatial resolutions ~100 µm (for scattering angles not too large)

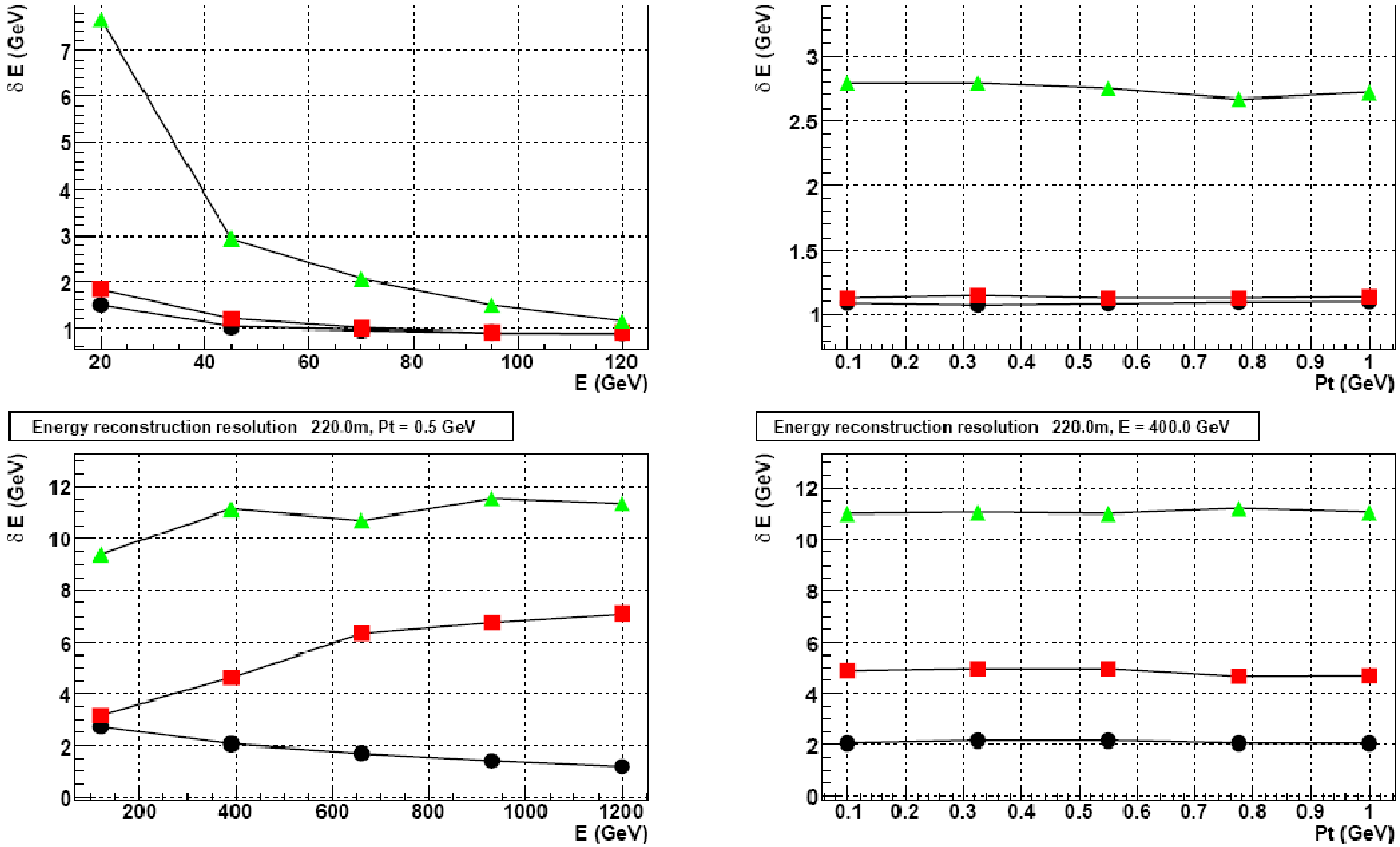


Figure 18: Resolution of the reconstruction of the particle energy loss E, as a function of the energy loss (*left*) and of the transverse momentum (*right*), for VFDs at 420 (*upper plot*) and 220 m (*lower plot*) from IP5. The advanced method, using full detector information, is used. Dots correspond to different scenarios of detector resolutions, namely perfect detectors (*circles*), 5 μm (*squares*) and 30 μm (*triangles*) spatial resolution.

Ultimate full reconstruction requires extremely good resolutions and alignment (esp. at 220 m), below 10 µm

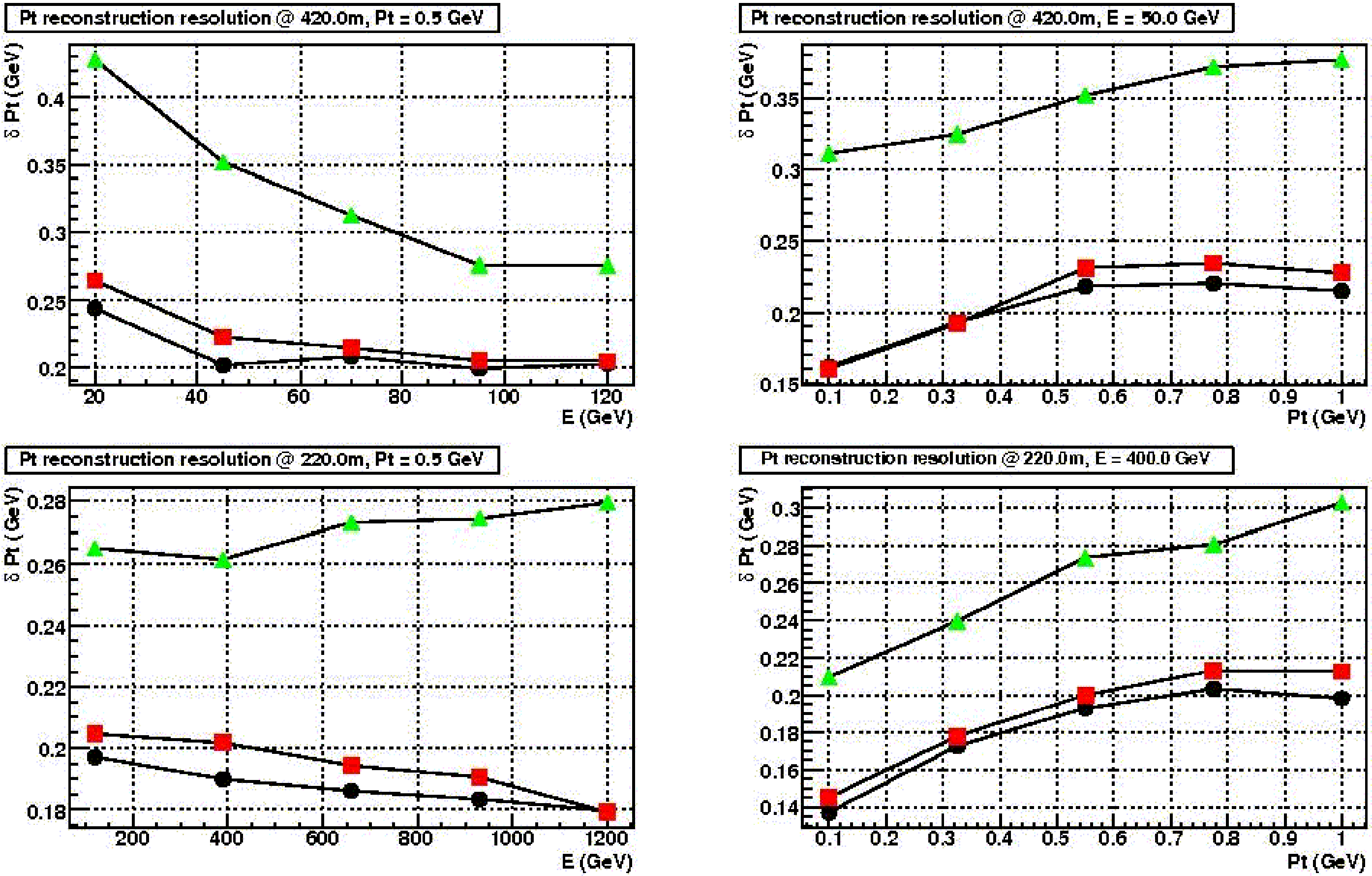


Figure 17: Resolution of the reconstruction of the particle transverse momentum p_T, as a function of the energy loss (*left*) and of the transverse momentum (*right*), for VFDs at 220 (*upper plot*) and 420 m (*lower plot*) from IP5. The advanced method, using full detector information, is used. Dots correspond to different scenarios of detectors resolutions, namely perfect detectors (*circles*), 5 μm (*squares*) and 30 μm (*triangles*) spatial resolution.

Ultimate full reconstruction requires extremely good resolutions and alignment, below 10 μm; p_T better measured at 220 m

Misalignment impact on Higgs mass reconstruction

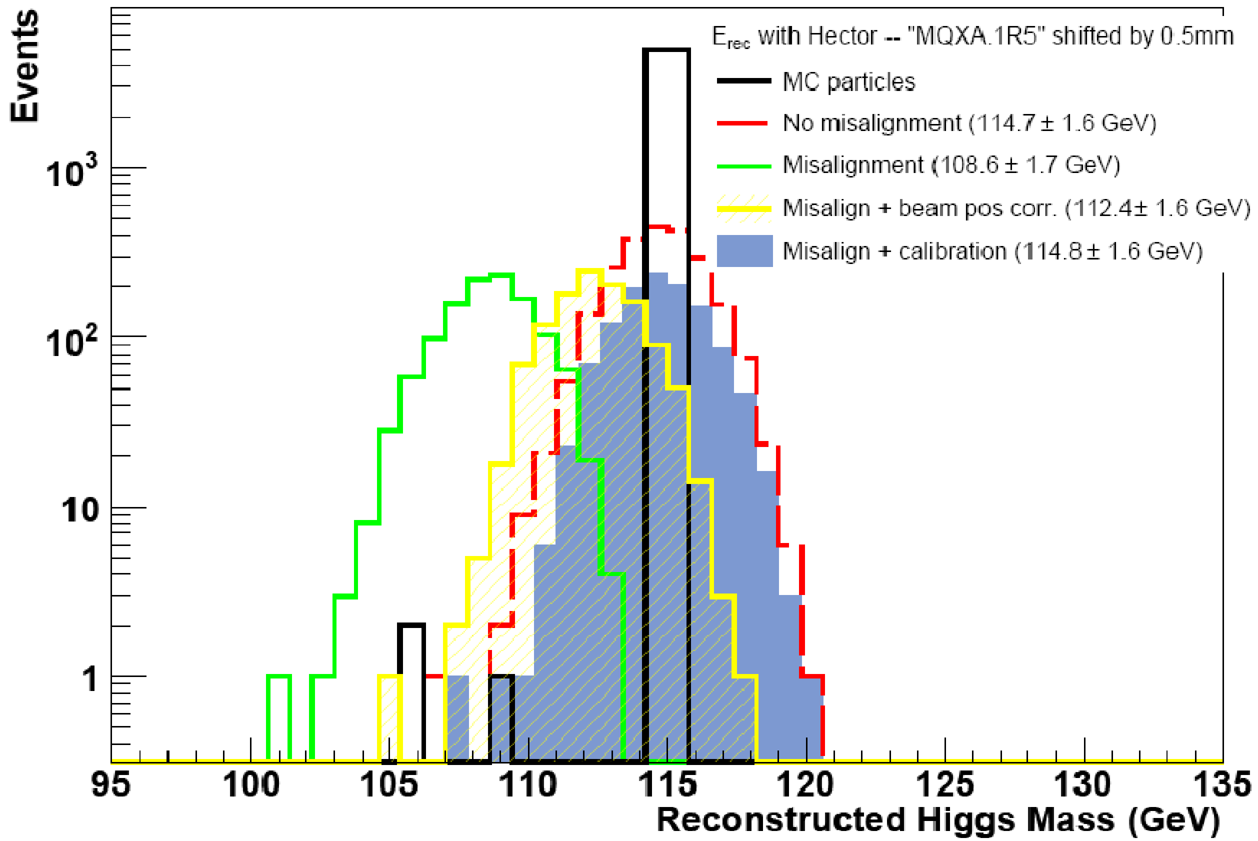


Figure 20: Illustration of the effects in the energy reconstruction due to the misalignment of LHC quadrupoles. The graphs show the reconstructed Higgs boson mass in the two-photon exclusive production, using energy of two forward scattered protons. In the upper plot, a quadrupole (MQM9R5, $s = 347$ m) close to the detector has been shifted by 100 μm. Misaligning an optical element (MQXA1R5, $s = 29$ m) close to the IP leads to a loss of acceptance (lower plot). The reconstructed values including the correction due to the dimuon calibration is also plotted. In brackets, the average reconstructed mass and its resolution are given, without including the beam energy dispersion.

Standard Candle: Exclusive di-muons
Y. Liu (UCLouvain)

Reconstruction & trigger efficiencies:

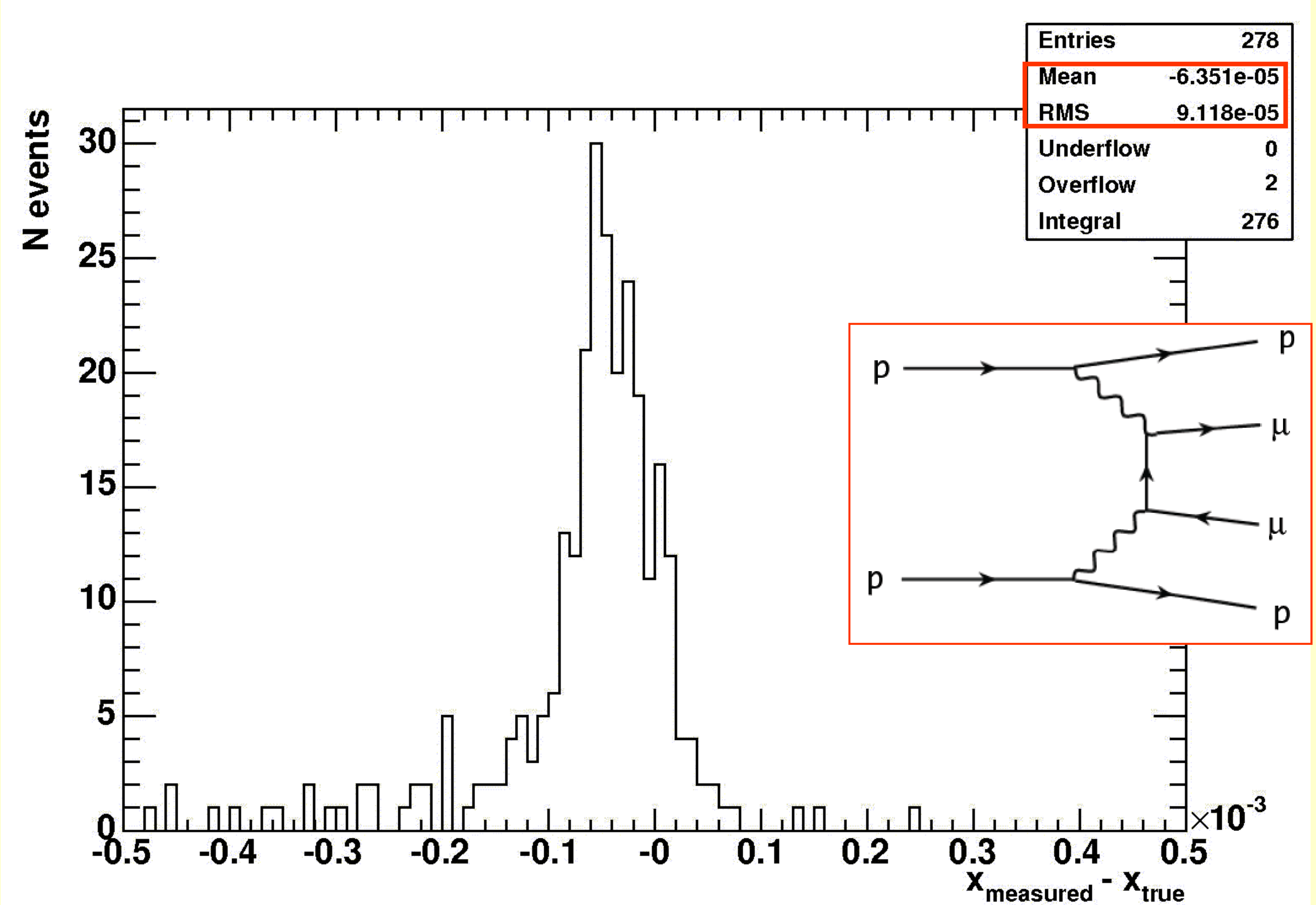
- Sample of 5000 μμ pairs at p_T > 3 GeV generated with LPAIR ($\sigma \approx 50$ pb)

- Reconstructed with ORCA – efficiency for muons reaches plateau of 90% at p_T = 7GeV (at p_T=5 GeV it is 60%)

- Cross-section for reconstructed pairs is 6 pb, L1 efficiency is high but high p_T cuts at HLT results in 40% global trigger efficiency

Note: Roman Pots are NOT used for trigger!

Resolution of the proton energy loss for the reconstructed dimuon pairs:



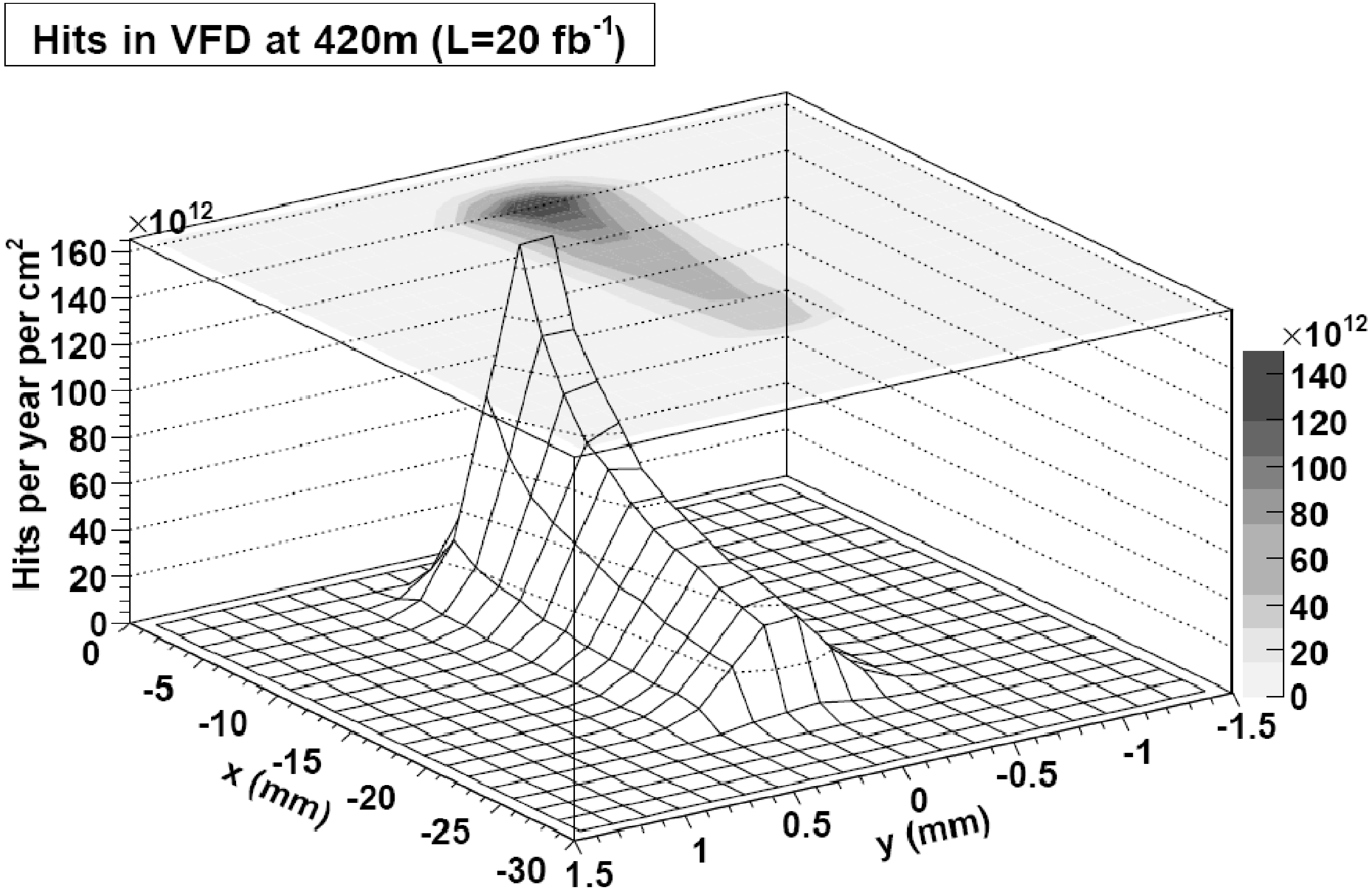


Figure 12: Irradiation levels due to pp $\rightarrow$ pX processes, of VFDs located at $s = 220$ m (*above*) and $s = 420$ m (*below*) from the IP5. The horizontal position of the detector edge is respectively $x = 2$ mm and $x = 4$ mm from the nominal position of the center of the corresponding beam. The fluence is given per year and square centimeter. The integrated luminosity of $L = 20$ fb^{-1} was assumed. For this analysis, HECTOR has propagated protons with 4-momentum generated by PYTHIA 6.2.10 (process number 93). The irradiation levels can locally exceed 1×10^{14} protons per square centimeter.

Conclusions from Hector:

- Radiation hard detectors are needed

- Spatial resolution is essential for p_T reconstruction

- Di-muon essential for understanding energy scales, acceptances and luminosity of FP420 events

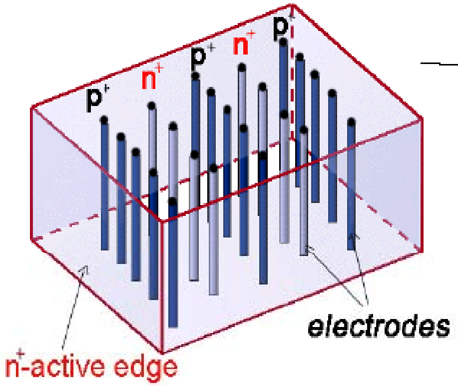
- Absolute energy resolution worse but p_T resolution better at 220m

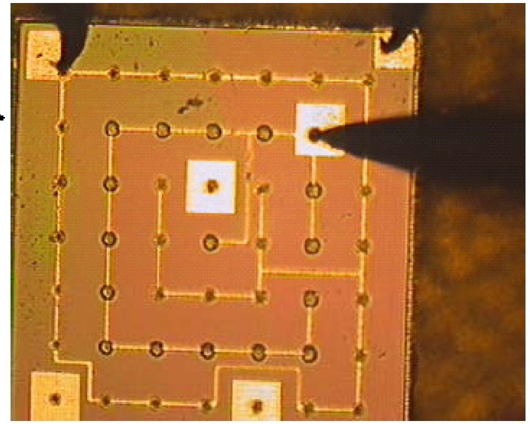
- Calibration of detectors at 220m more tricky: need to study electron pairs with forward CALs, and bremsstrahlung in ZDCs

3D Si Tracking + Cerenkov Fast Timing

3D DETECTORS AND ACTIVE EDGES

Brunel, Hawaii, Stanford



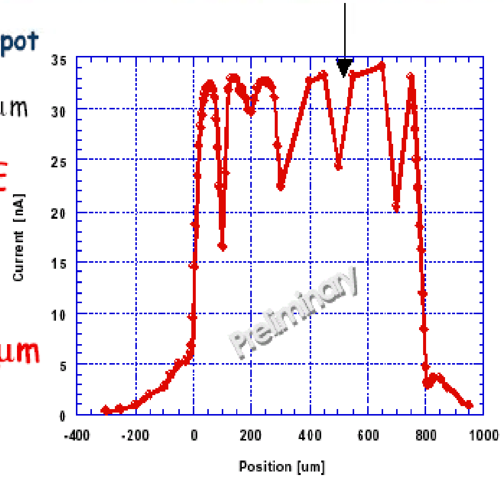


❖EDGE SENSITIVITY	‹10 µm
❖COLLECTION PATHS	~50 µm
❖SPATIAL RESOLUTION	10-15 µm
❖DEPLETION VOLTAGES	‹ 10 V
❖DEPLETION VOLTAGES at 10^{15}n/cm^2	~105 V
❖SPEED AT RT	3.5 ns
❖AREA COVERAGE	3X3 cm^2
❖SIGNAL AMPLITUDE before Irradiation	24 000 e
❖SIGNAL AMPLITUDE at 10^{15}n/cm^2	15 000 e$^-$

❖15 µm InfraRed beam spot
❖FWHM = 772 µm
❖Edge Al strip width = 16 µm

INSENSITIVE EDGE (INCLUDING 16 µm Al STRIP):

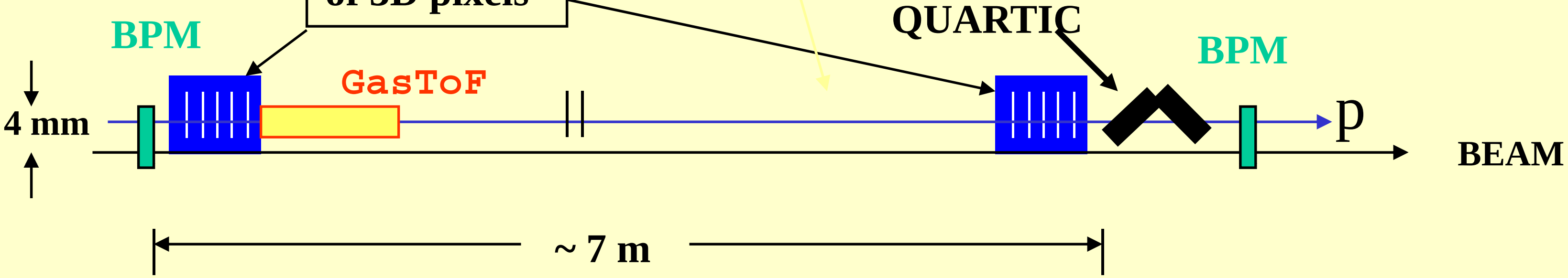
(813 - 772) / 2 = 21 µm



❖CERN Courier, Vol 43, Number 1, Jan 2003

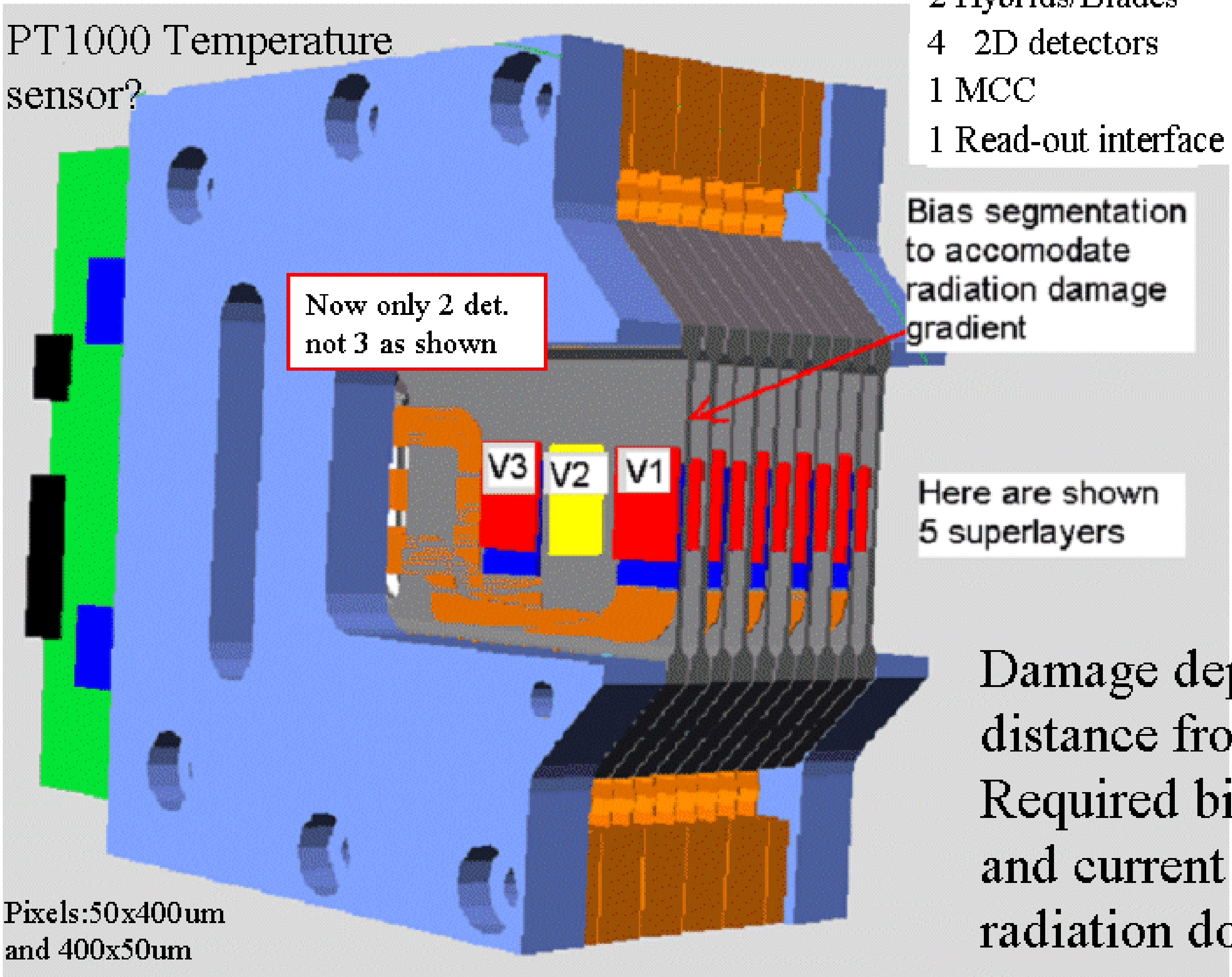
6mm(y) x 24mm (x) covers distribution

~ 8 layers of 3D pixels



HV-LV supply segmentation

1 Superlayer =
2 Hybrids/Blades
4 2D detectors
1 MCC
1 Read-out interface



Drawing: From Ray Thompson

Damage depends on distance from the beam. Required bias voltage and current increase with radiation dose.

MCC: Module Controller Chip

Why need s(uperfast)TOF?

Z-by-timing is <u>crucial</u> for running at high LHC luminosity, by suppressing accidental backgrounds:

If δt = 10 ps can be achieved for a single ToF, then z-vertex resolution is 2 mm (from time difference for two arms) to be compared with >50 mm RMS of IR!

Note: Background suppression power is ~ inversely proportional to resolution of ToF!

gastof: Basic idea

Consider gas Cerenkov as complementary solution to Quartic:

- Very simple and robust design
- Very thin and light detector - can be used before the tracking part
- (Very) radiation hard
- High energy threshold

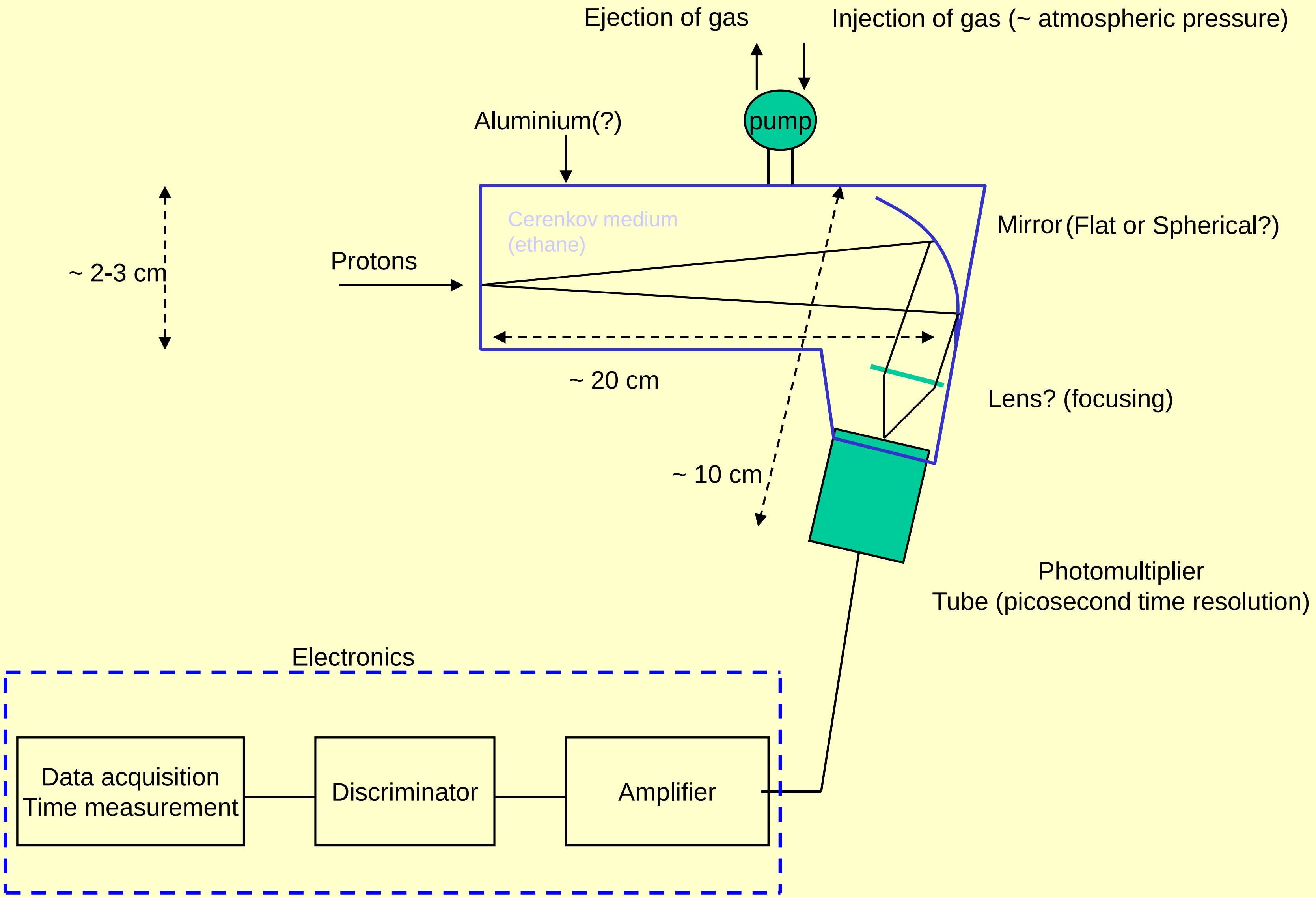
Basic formula: $N_{pe} \approx 100 \sin^2\theta_c \, L[\mathrm{cm}]$

To estimate position sensitivity estimate average light spot radius $\langle r \rangle$, at radiator exit:

$$\langle r \rangle \approx 0.5 \, L \tan\theta_c \approx \sin\theta_c \, L/2$$

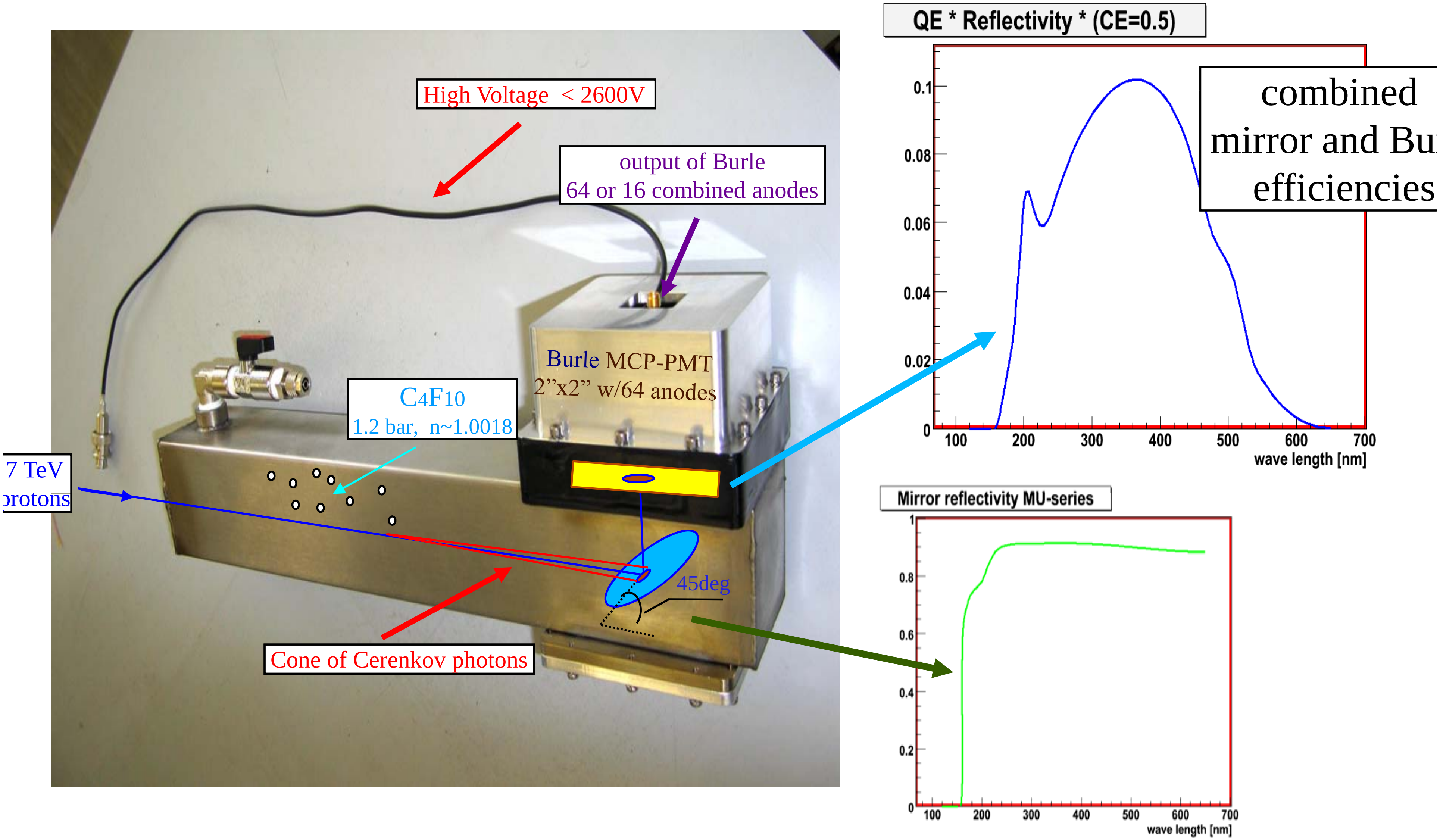
$$N_{pe} \approx 200 \, \langle r \rangle[\mathrm{cm}] \, \sin\theta_c$$

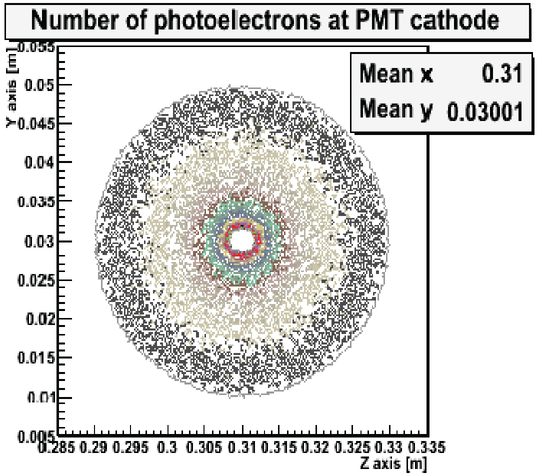
gastof

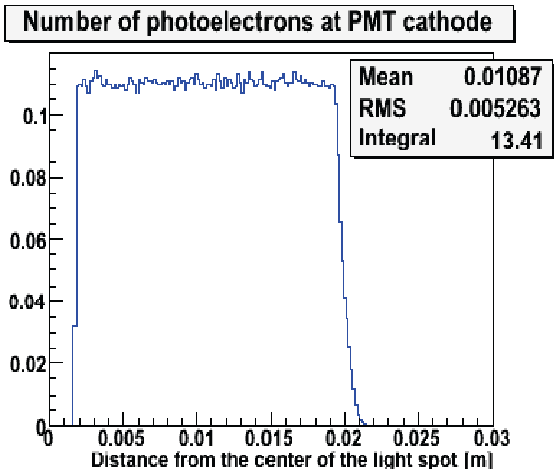


Ejection of gas
Injection of gas (~ atmospheric pressure)
Aluminium(?)
pump
Cerenkov medium
(ethane)
Protons
~ 2-3 cm
Mirror (Flat or Spherical?)
~ 20 cm
Lens? (focusing)
~ 10 cm
Photomultiplier
Tube (picosecond time resolution)
Electronics
Data acquisition
Time measurement
Discriminator
Amplifier

gastof **prototyping**

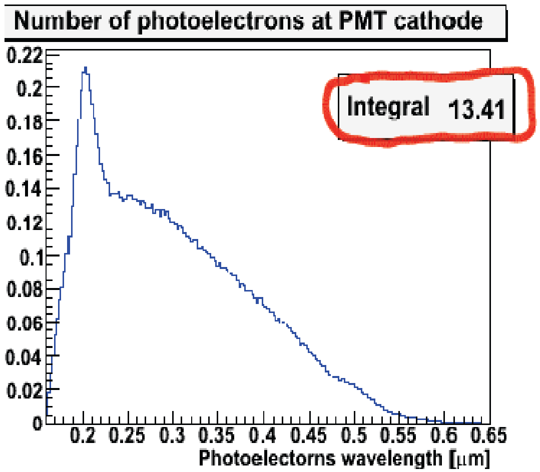


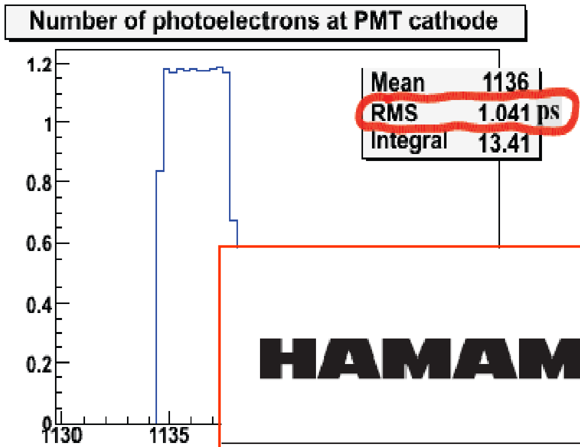




simulation input :

- length 31cm
- C4F10 at 1.2 bar
- protons at 6.9 TeV





results :

- Arrival Time RMS ~ 1ps ! (without PMT
- Spot Size < 2 cm
- Avg. number of photoelectrons = 13.4

Prototype 1 with Hamamatsu MCP-PMT:

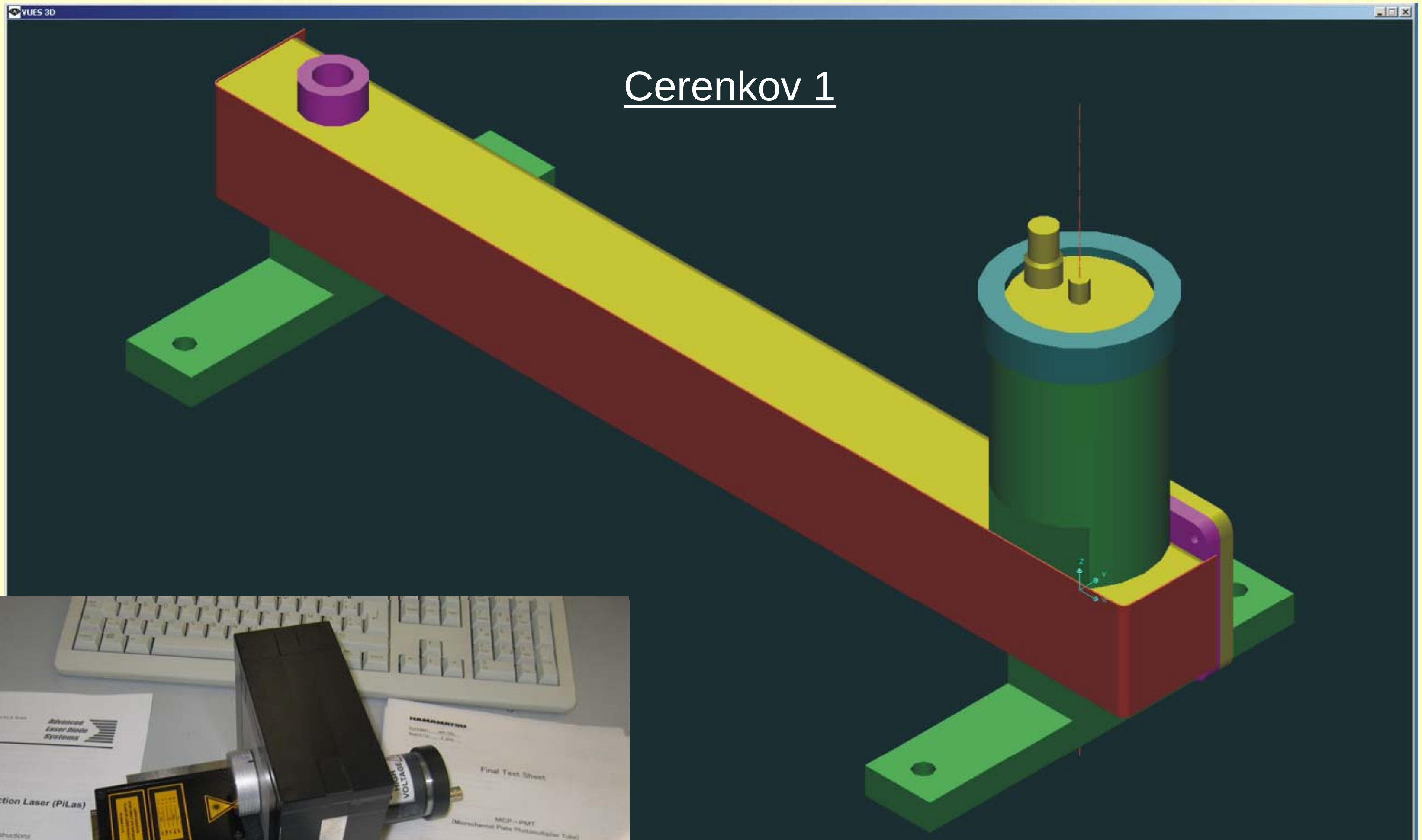
HAMAMATSU

MICROCHANNEL PLATE PHOTOMULTIPLIER TUB (MCP-PMTs)
R3809U-50 SERIES

Compact MCP-PMT Series Featuring
Variety of Spectral Response with Fast Time Response

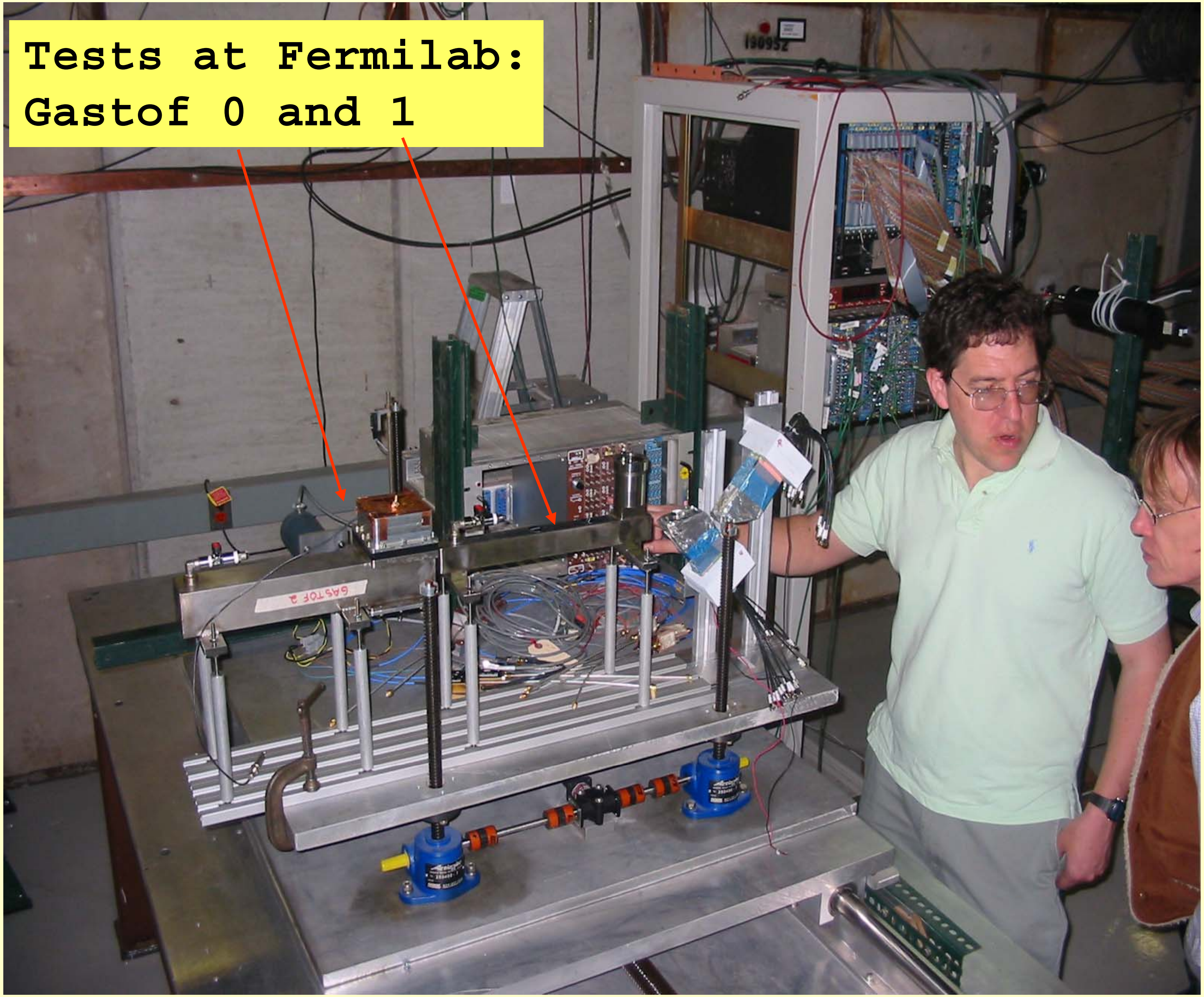
FEATURES
- High Speed
  Rise Time: 150ps
  T.T.S. (Transit Time Spread)1): ≤ 25ps(FWHM)
- Low Noise
- Compact Profile
  Useful Photocathode: 11mm diameter
  (Overall length: 70.2mm Outer diameter: 45.0mm)

GasToF

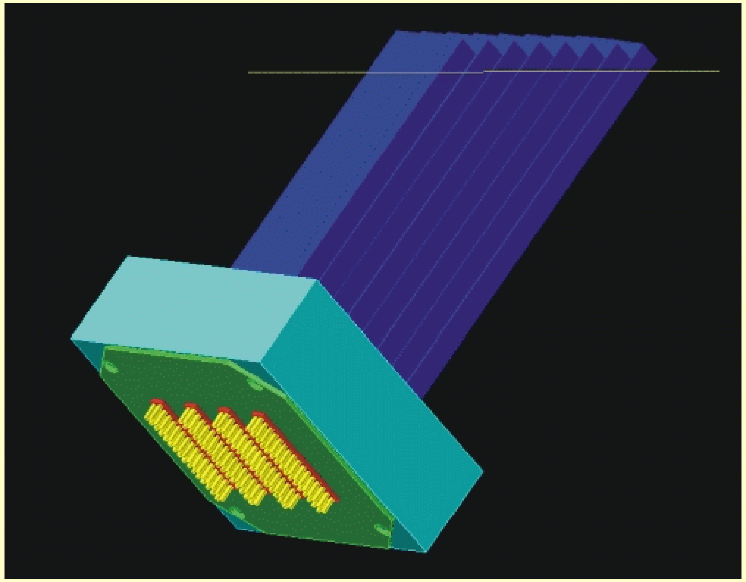


CRC
Louvain-la-Neuve

Tests at Fermilab: Gastof 0 and 1



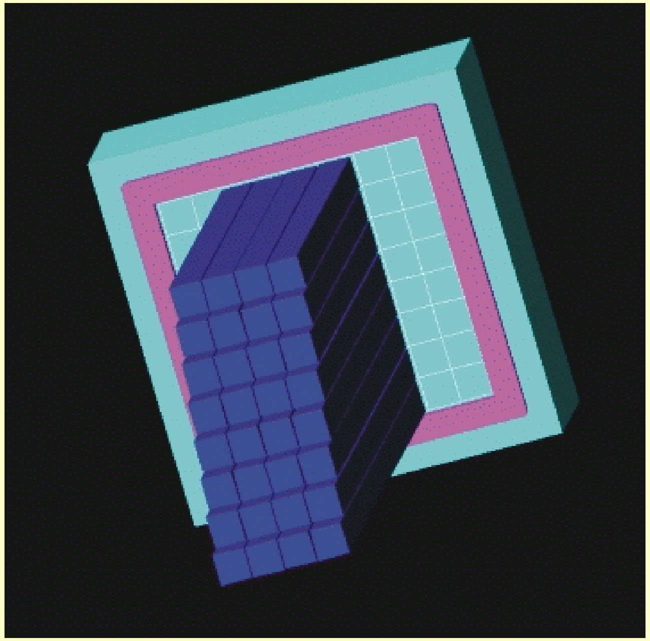
The Detectors : 2) QUARTIC

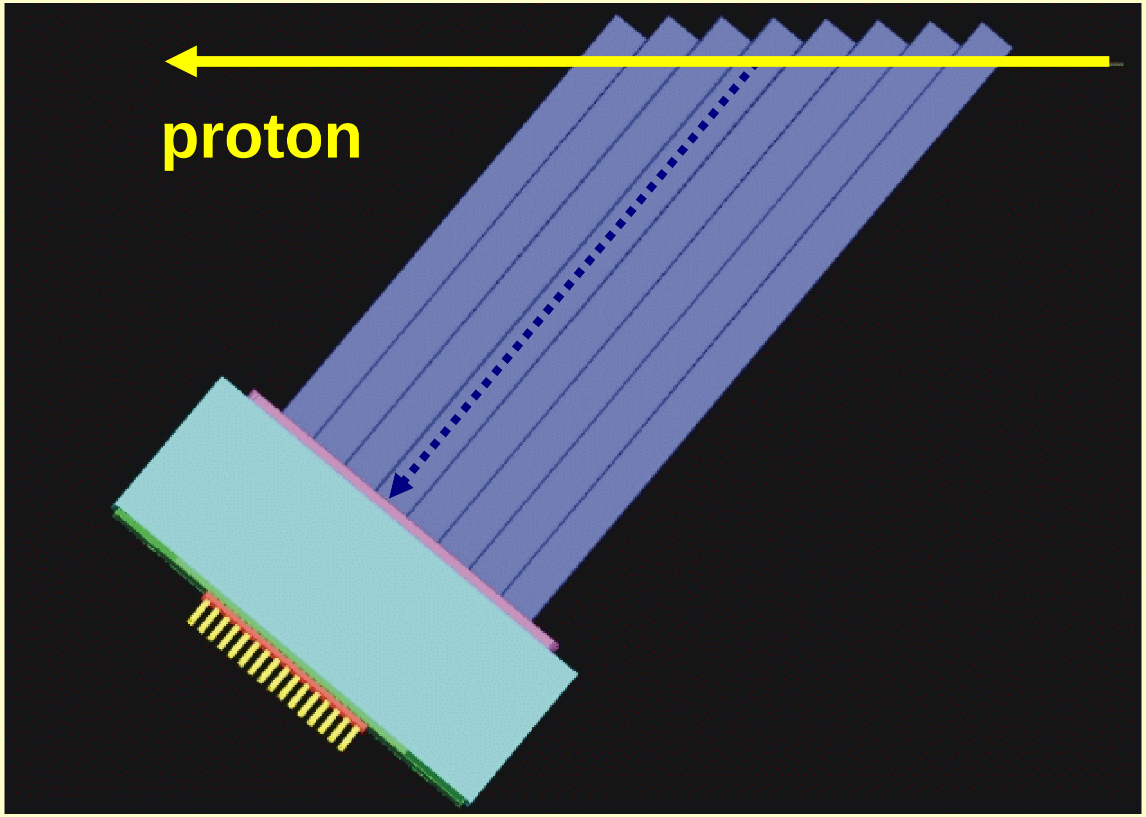


Mike's idea

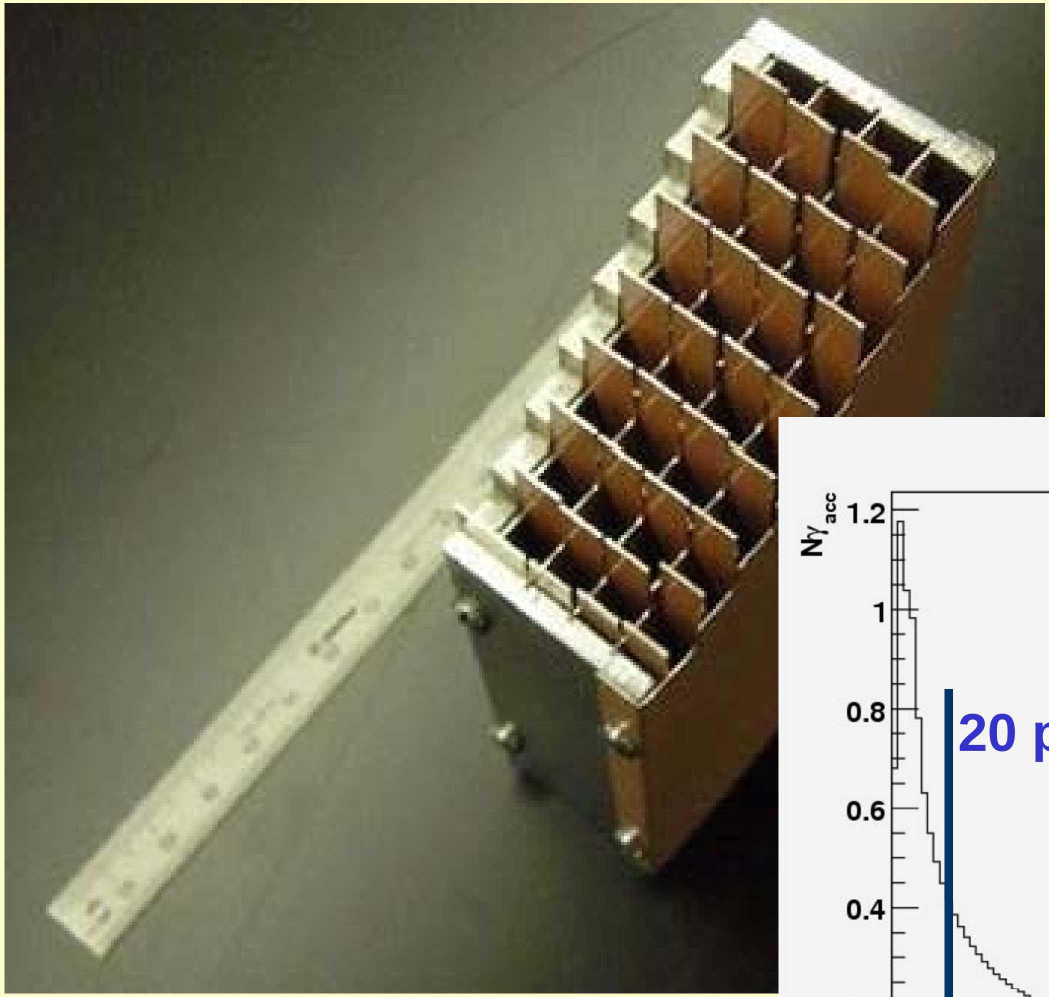
Jaak's drawing

8 fused silica rods in z (my fused silica!)





QUARTIC (V2)

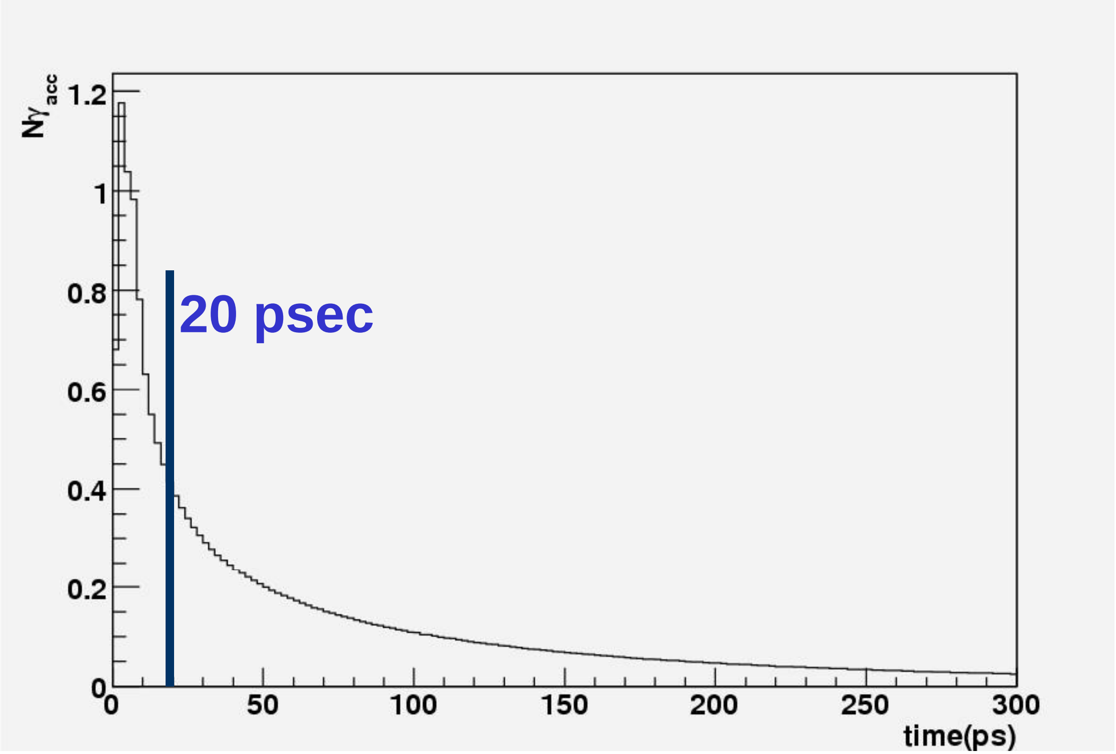


Advantages:

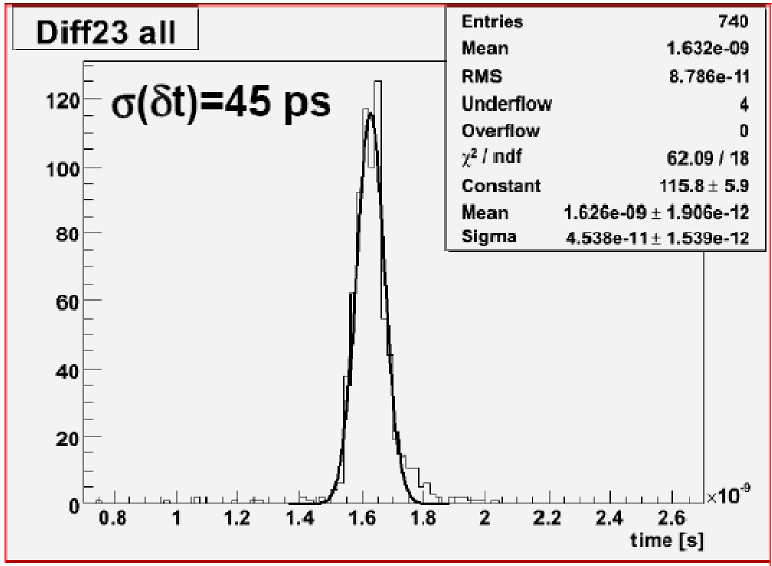
- **Segmentation (8 x 4)**
- **Compact**

Disadvantages:

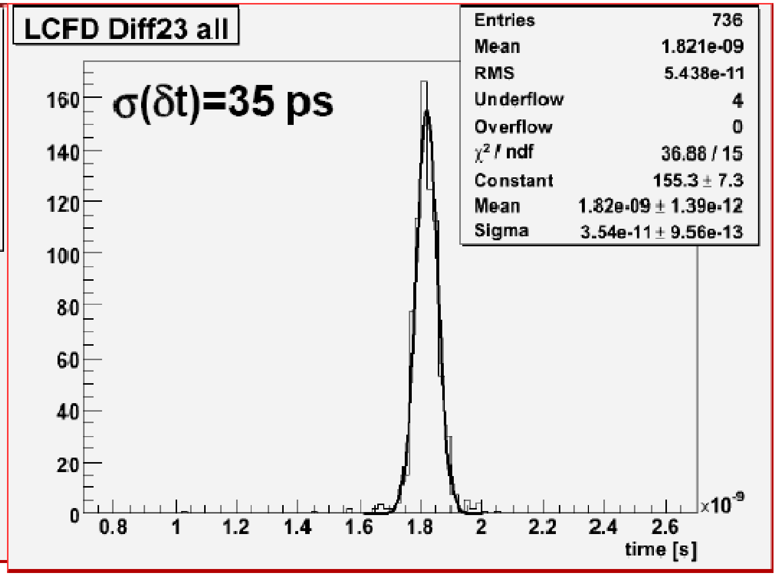
- **More material**
- **Not as fast**



Scope Analysis (G1-G2)



Threshhold discriminaton

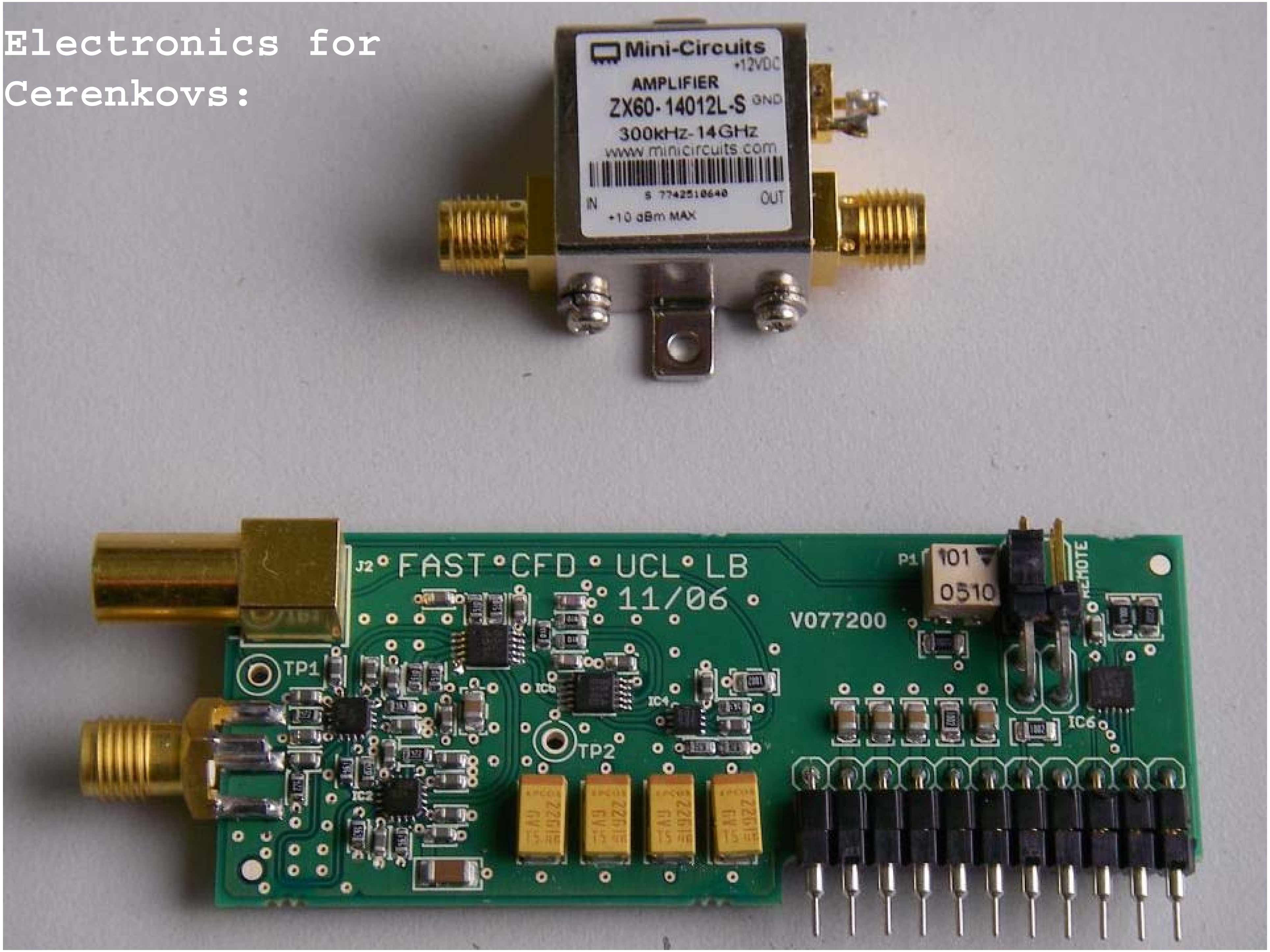


CFD algo simulated

Individual detectors	
$\sigma(G01)$	32 ps
$\sigma(G02)$	13 ps
$\sigma(QBE)$	68 ps
$\sigma(QBD)$	52 ps

Target detector resolutions achieved. Still have to study efficiencies, and tune front-end electronics…

Electronics for Cerenkovs:

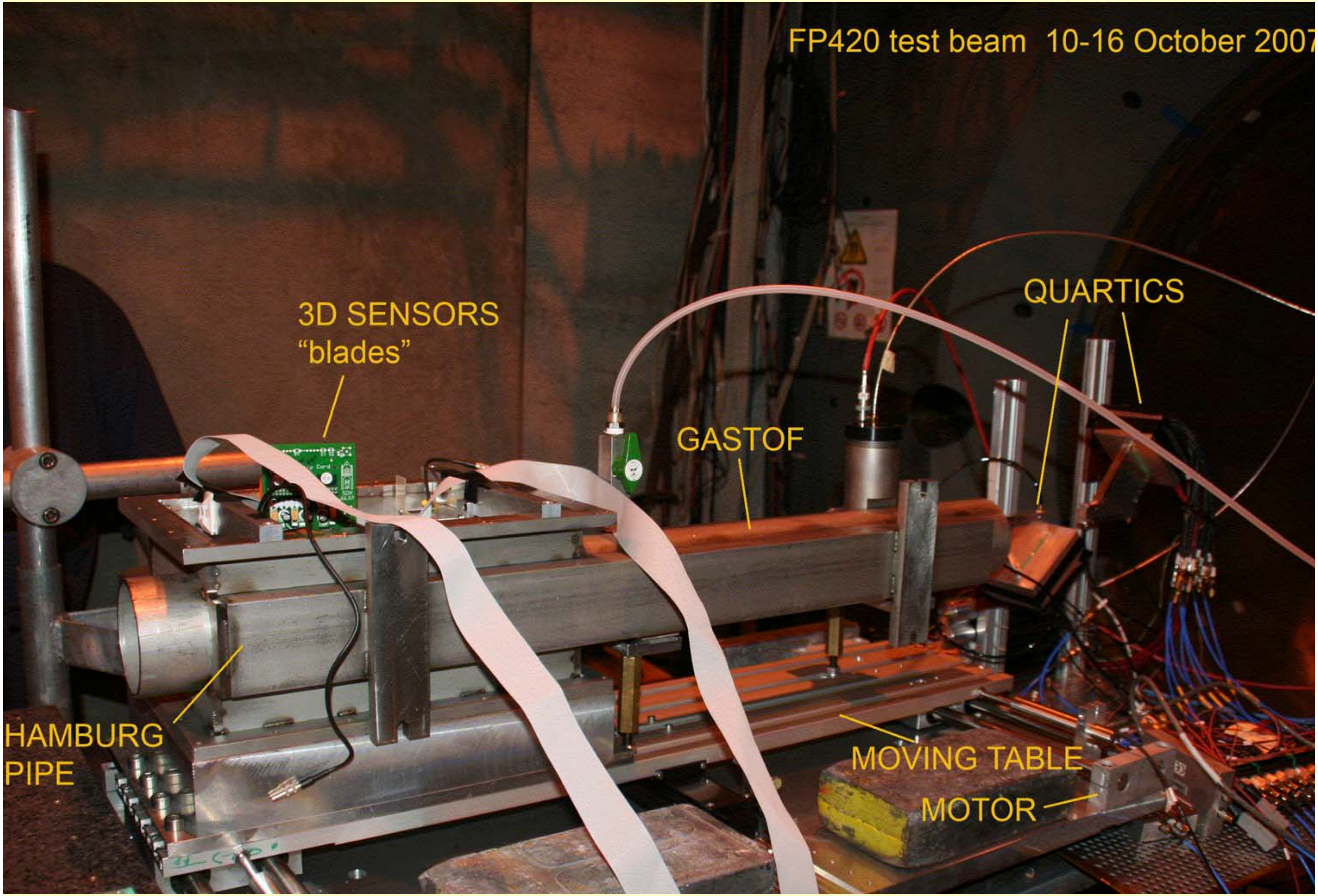


Example of NIM module with mini-modules

Two such modules with ~8 CFD mini-modules were built and are under tests

Note:

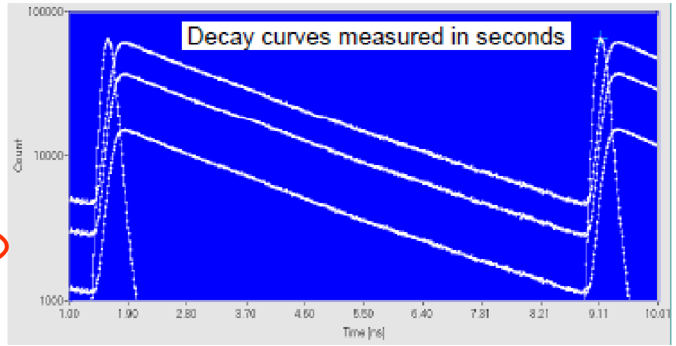
- **It has remote control**
- **It is tuned for Burle&Hamamatsu MCP-PMTs**
- **It has double output**

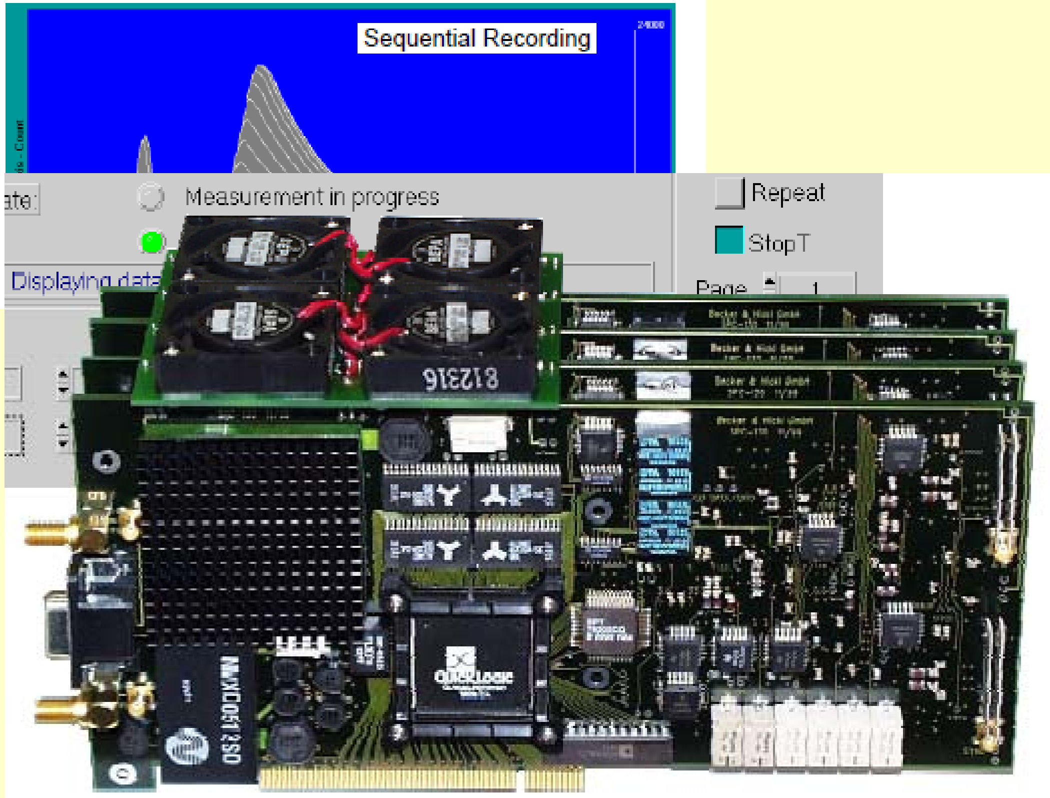

FP420 test beam 10-16 October 2007
3D SENSORS
"blades"
QUARTICS
GASTOF
HAMBURG
PIPE
MOVING TABLE
MOTOR

The TCSPC Power Package SPC-134

Four Channel Time-Correlated Single Photon Counting Module

- Four Completely Parallel TCSPC Channels
- Ultra-High Data Throughput
- Overall Count Rate 32 MHz
- Channel Count Rate 8 MHz (Dead Time 125ns)
- Dual Memory Architecture: Readout during Measurement
- Reversed Start/Stop. Repetition Rates up to 200 MHz
- Electrical Time Resolution down to 8 ps FWHM / 5 ps rms
- Channel Resolution down to 813 fs
- Up to 4096 Time Channels / Curve
- Measurement Times down to 0.1 ms
- Software Versions for Windows 95 / 98 / NT
- Direct Interfacing to most Detector Types
- Single Decay Curve Mode
- Oscilloscope Mode
- Seqential Recording Mode
- Spectrum Scan Mode with 8 Independent Time Windows
- Continuous Flow Mode for Single Molecule Detection
- FIFO / Time Tag Mode for Single Molecule Detection



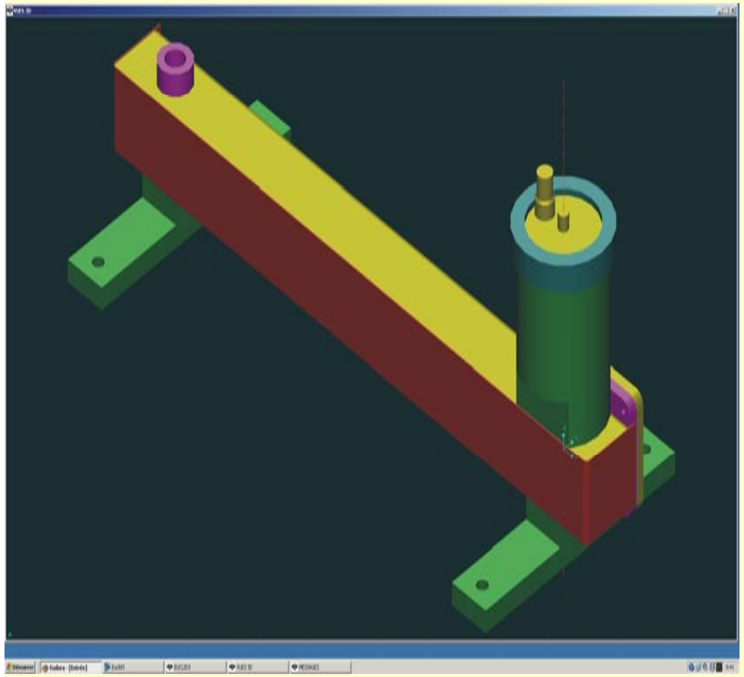


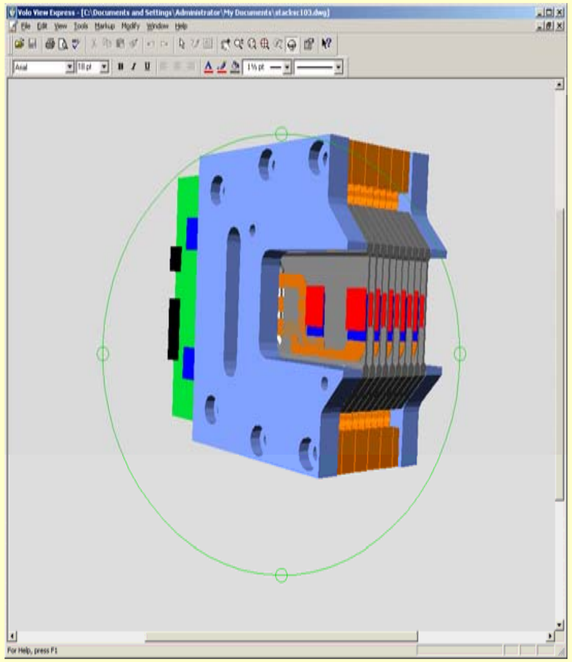
Baseline Plan

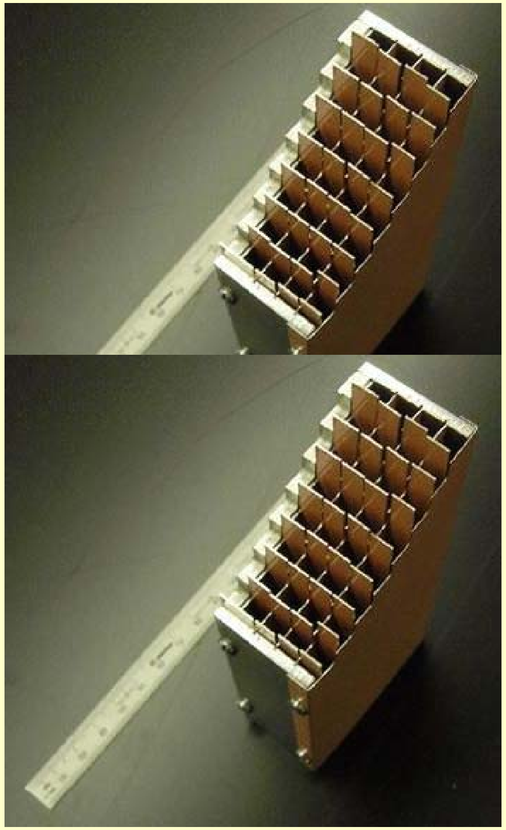
1 GASTOF

Lots of silicon

2 QUARTICs







Summary/Outlook

• Final cryostat design should be ready this Fall, and production could start early 2008… If accepted and allowed by LHC schedules installation in 2008/9 of one cryostat very profitable! Aim for full system installation in 2009/10.

• Moving HH pipe system well advanced; first irradiation tests underway; this October tests at CERN of a motorized and fully equipped (3D silicon + Cerenkov) section; complete RF studies show full compatibility with LHC

• Both Gastof and Quartic detector designs well advanced and with target resolutions (~10 and 50 ps per channel, respectively) achieved

Summary/Outlook

• Need to finalize FE electronics and DAQ studies; complete background estimates/radiation hardness studies should be available by this Fall

• Tunnel infrastructure preparations has started as it requires long lead time for cabling and shieldings!

• All these studies in very close contact with machine vacuum, RF, collimator, instrumentation, … LHC groups

• Many (all?) of these developments are very interesting and applicable at 220m!

Thanks