Gas sTOF, or GasToF™

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Intro: Why GasToF

GasToF prototyping

Irradiations and cosmic rays tests

Outlook

http://www.uclouvain.be/fynu

Why need s(uperfast)ToF?

Z-by-timing **is <u>crucial</u> for running at high LHC luminosity, for 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!

sToF: LHC challenges

Achieve best possible resolution in harsh LHC environment:

- **very high event rate – up to and above 10 MHz**
- **high irradiation levels – up to 10^{14} p/cm^2/y**
- **at high LHC luminosity have to face multi-hit conditions (>1 particle to detect every 25 ns)**
- **(possibility to provide trigger)**

Good news: Small area detectors (~3x1 cm^2) with limited number of channels are needed -> push performances to limits

Measurement Principle

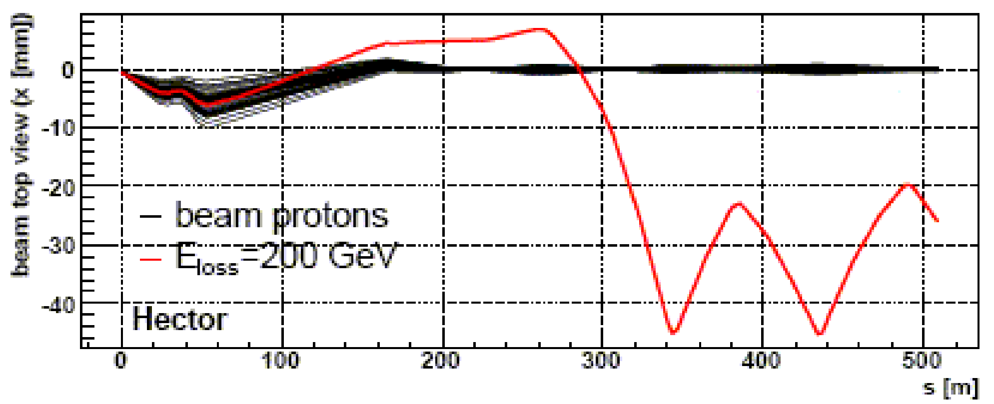
$\vec{P}, E, x_0, x'_0, y_0, y'_0$

IP5
CMS

x_1, x'_1, y_1, y'_1

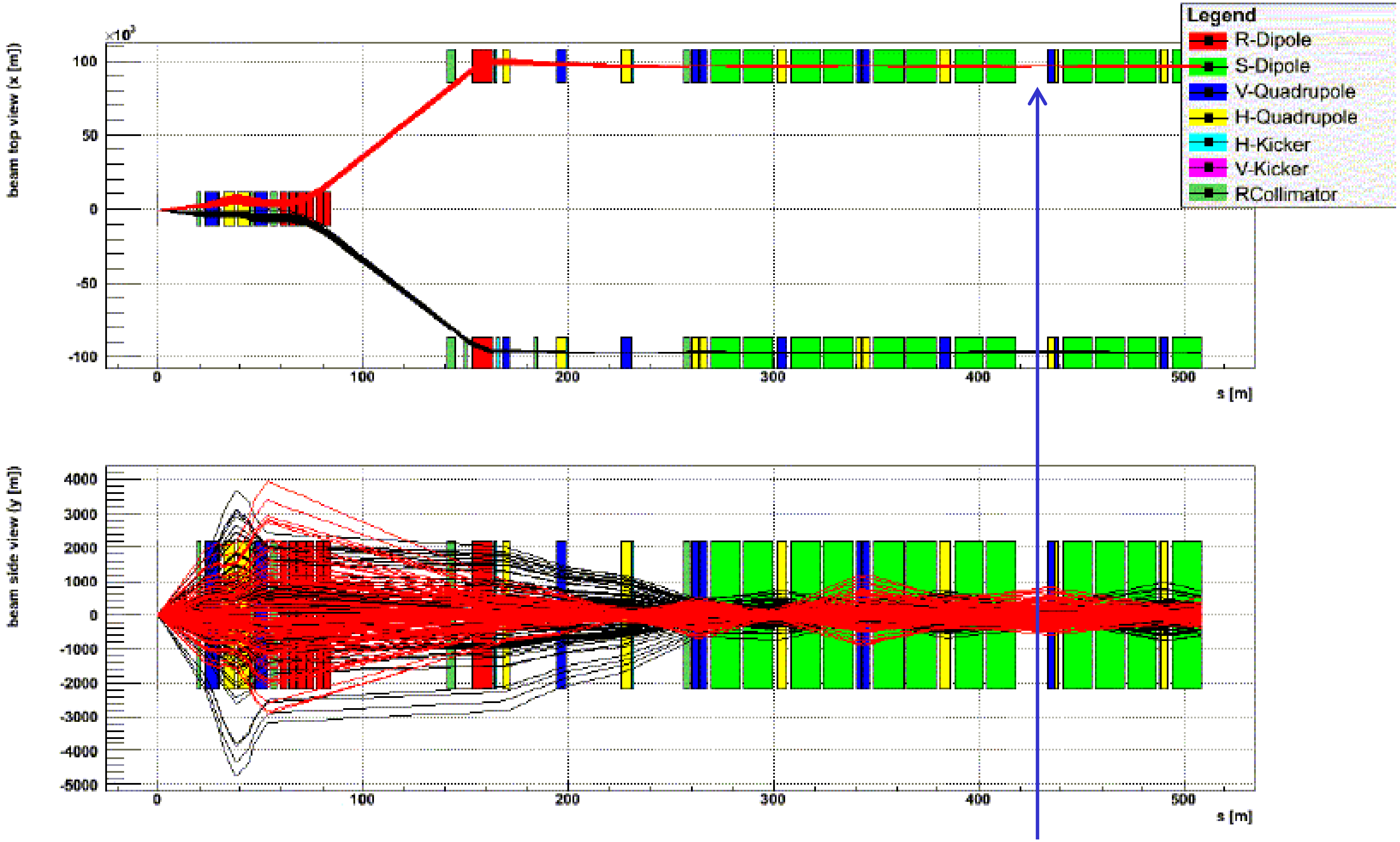
@ FP420

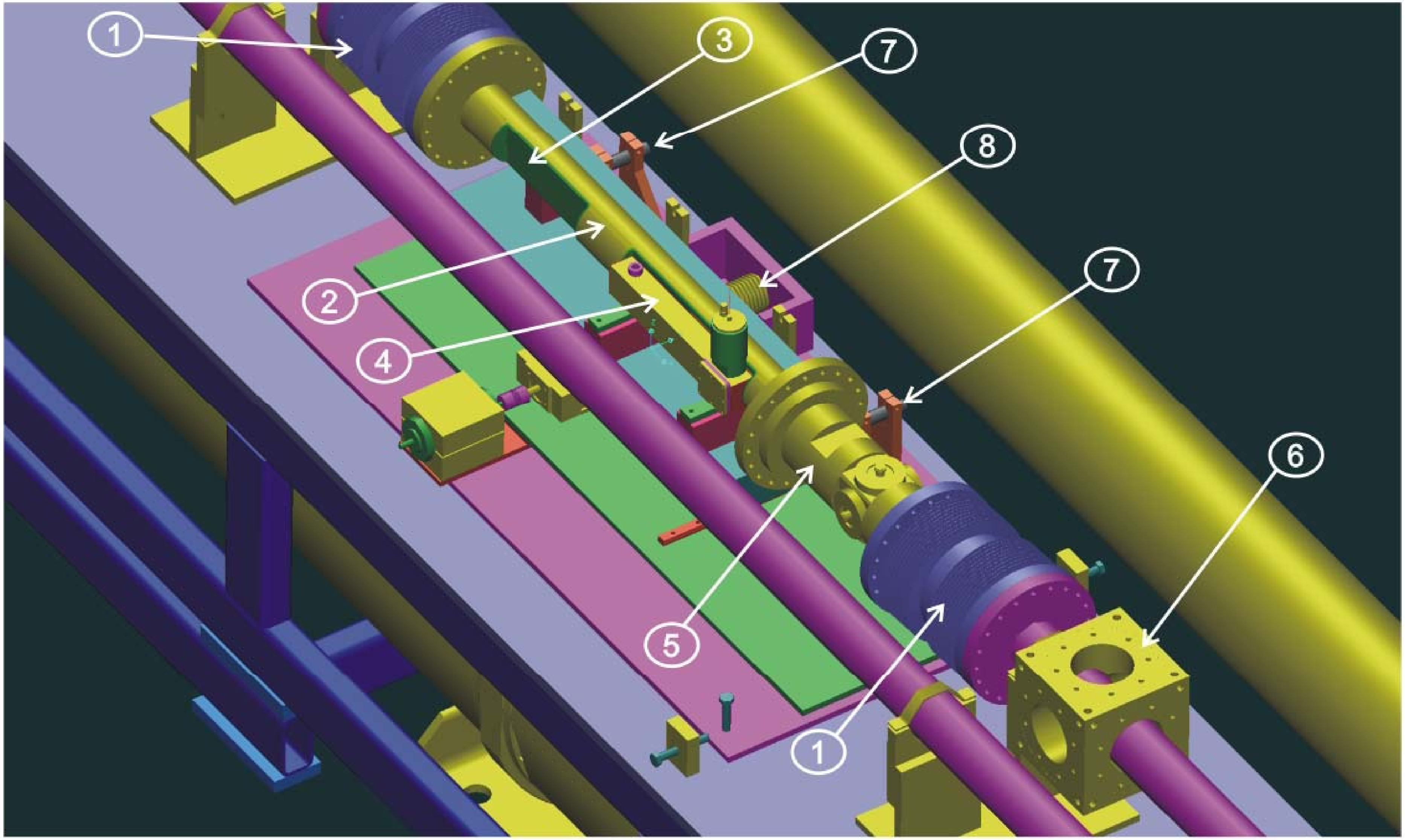
- **Use LHC beam-line as spectrometer**
- **Proton energy loss results in proton trajectory horizontal departure**
- **Low losses require close approach to beam of 4-5 mm**



J.de Favereau, X.Rouby & KP
published JINST 2 (2007) P09005

The LHC beams (on the right of CMS) :





Propose to use moving (Hamburg) pipe concept. First pre-prototype produced for CERN tests (*B.Florins, UCLouvain*).

gastof: Basic idea

Consider gas Cerenkov:

- **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:

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

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

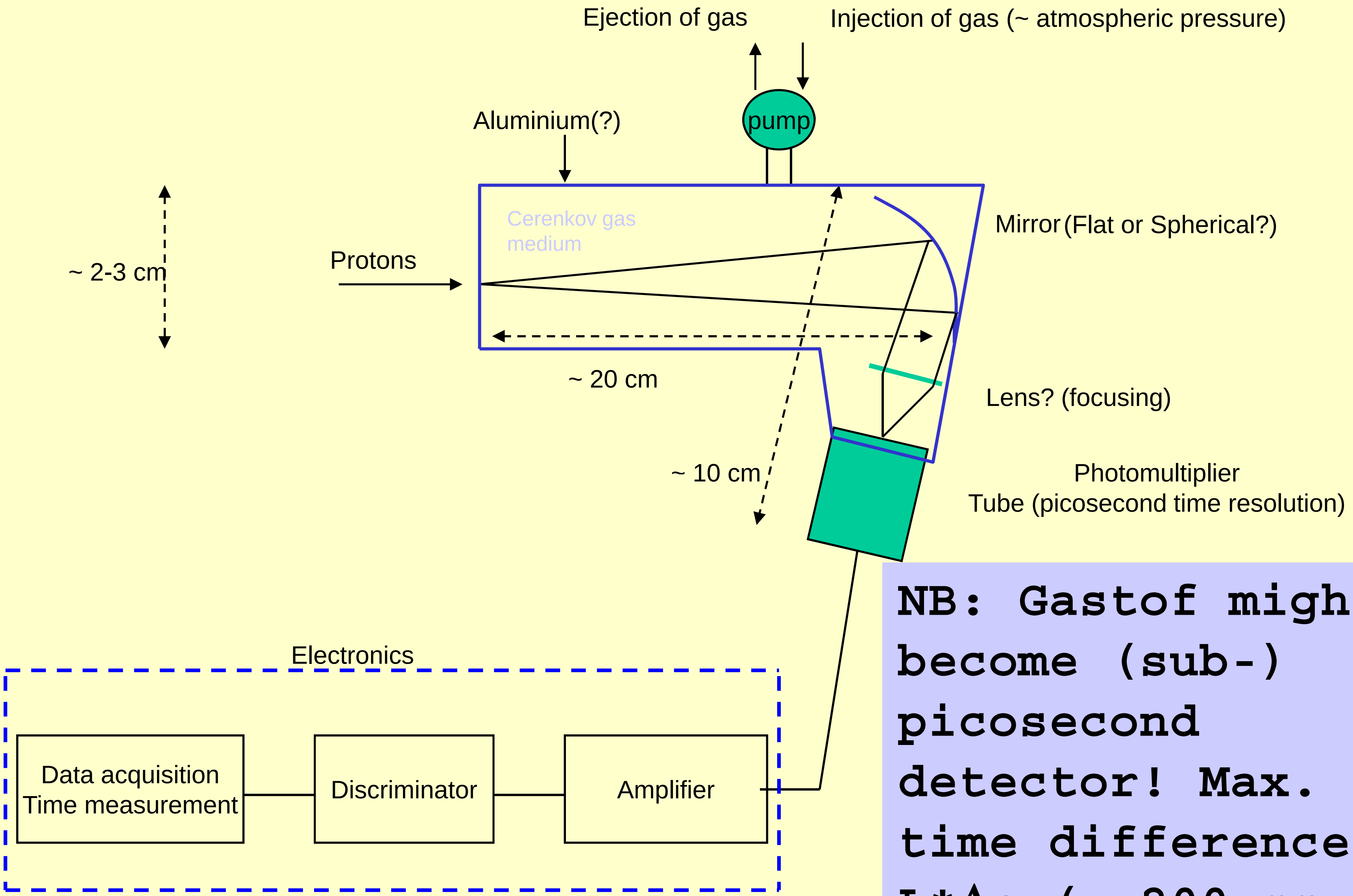
gastof: Favorite radiator

Use dense gas as C_4F_{10}:

- $n = 1.002$, $\sin\theta_c = \sqrt{(n^2-1)}/n \approx 0.06$
- So, if
  $\langle r \rangle$ = 2 mm then we get $N_{pe} = 2.5$ ~OK
- Then $L = 2\langle r \rangle/\tan\theta_c \sim 7$ cm
- 'Free' parameters: radiator length + gas pressure

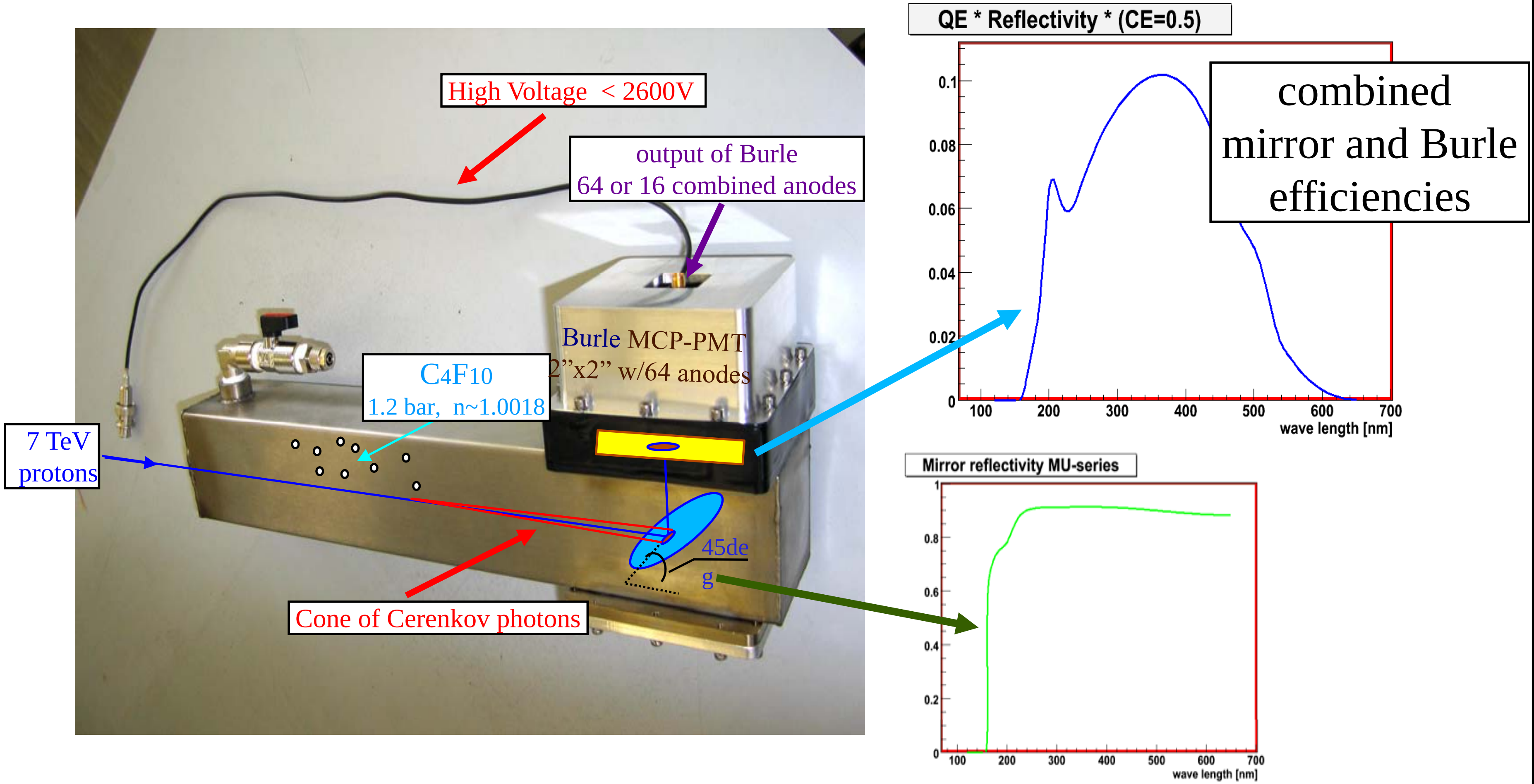
FAVORITE SOLUTION

GasTof

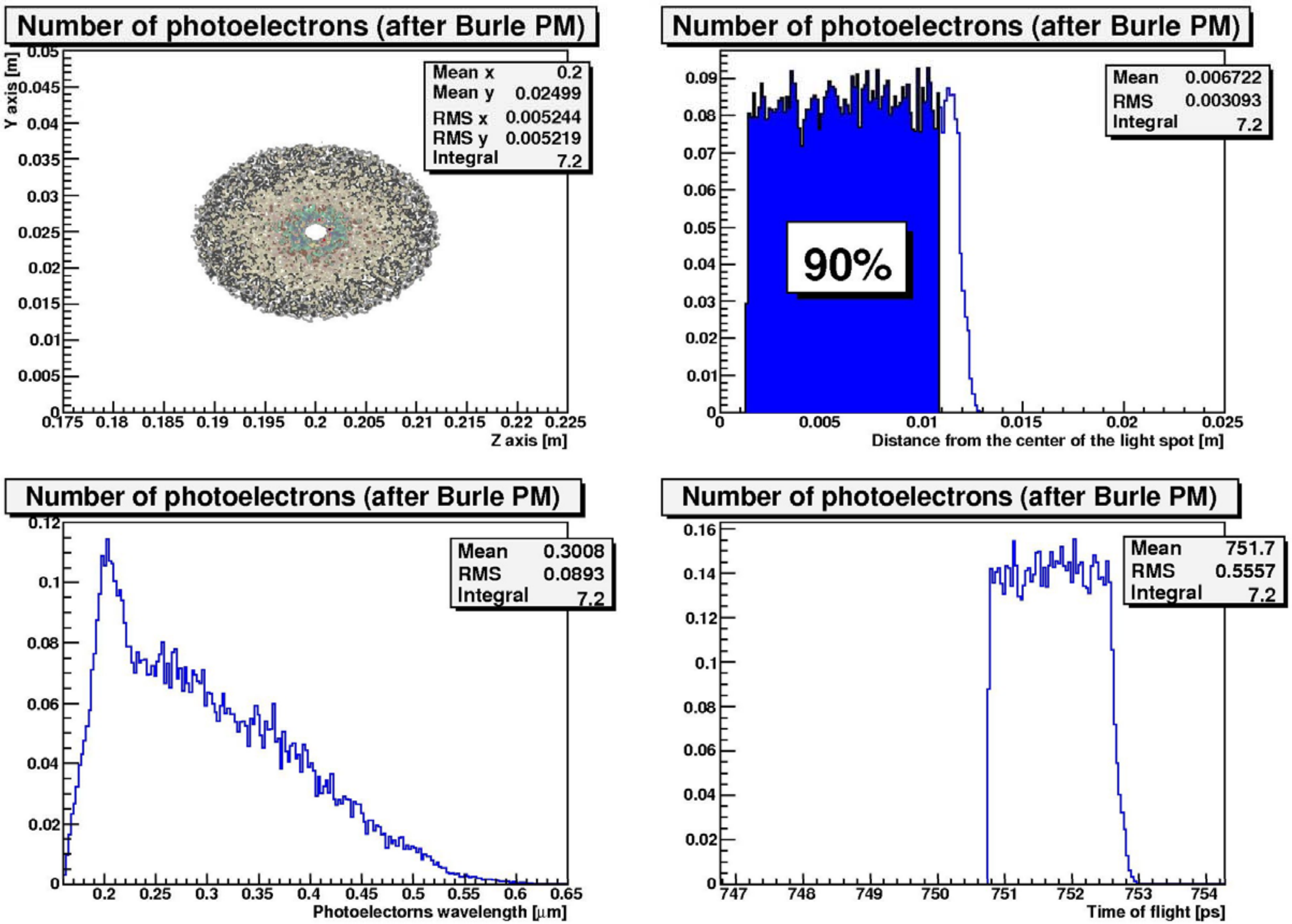


NB: Gastof might become (sub-) picosecond detector! Max. time difference = L*Δn (= 200 mm * 0.002 = 0.4 mm !)

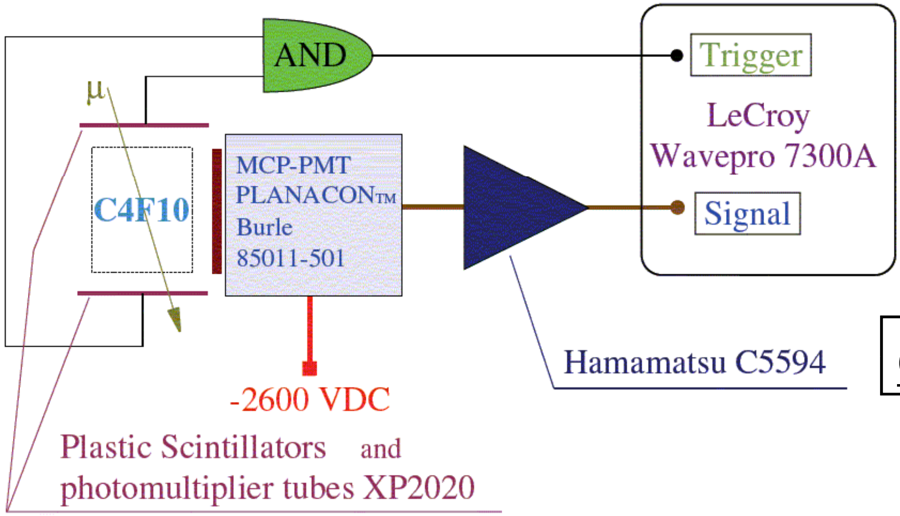
gastof **prototyping**

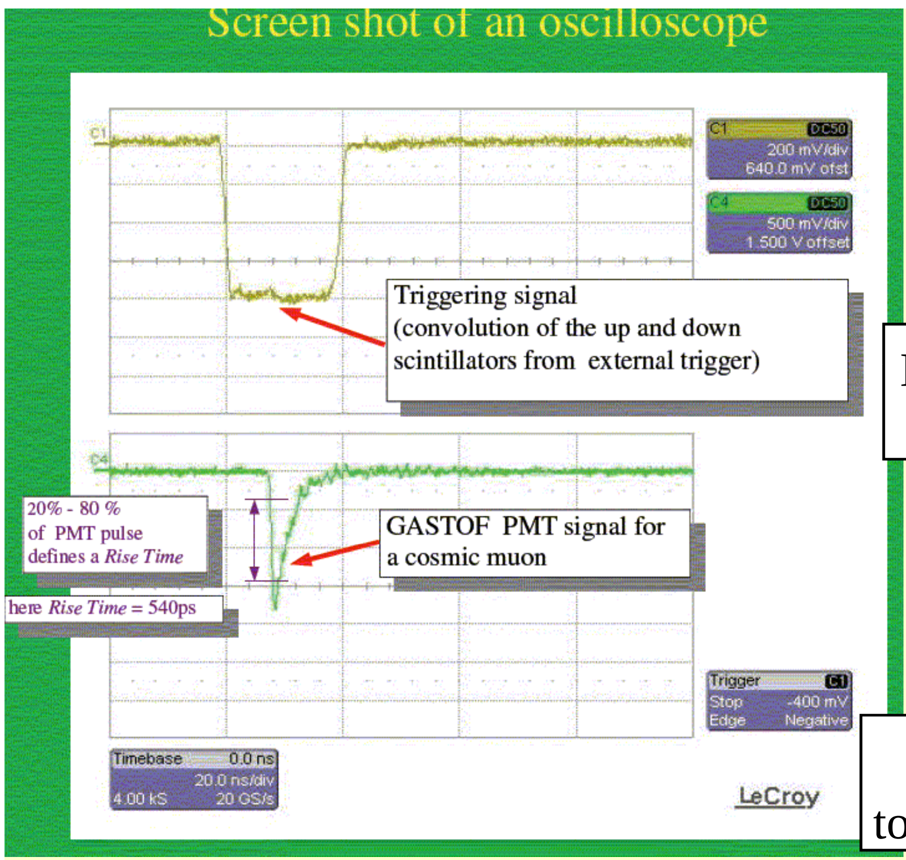


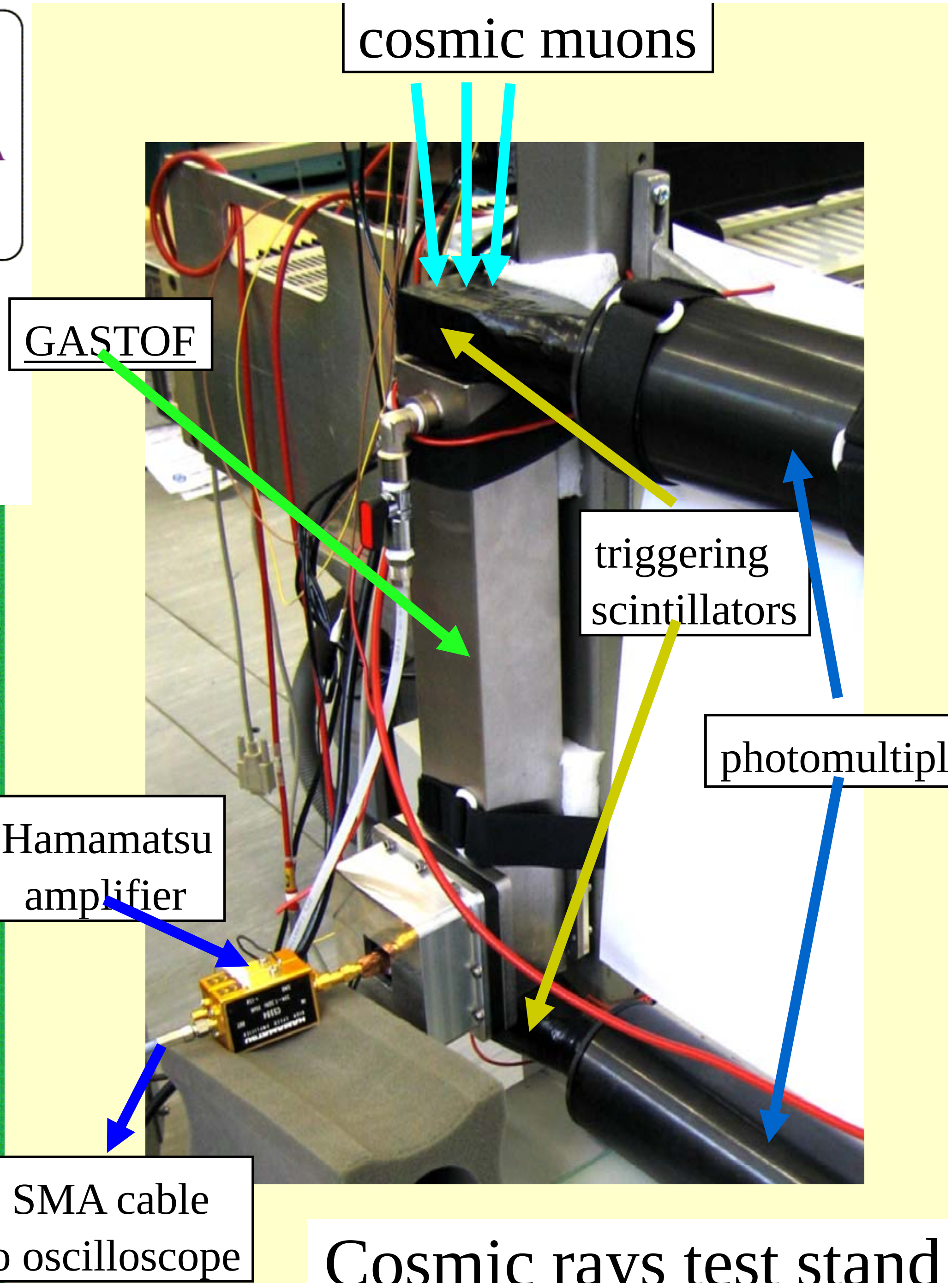
Simulations with Burle (raytracing)



20cm C_4F_{10} + Flat mirror + central protons + 50% CE

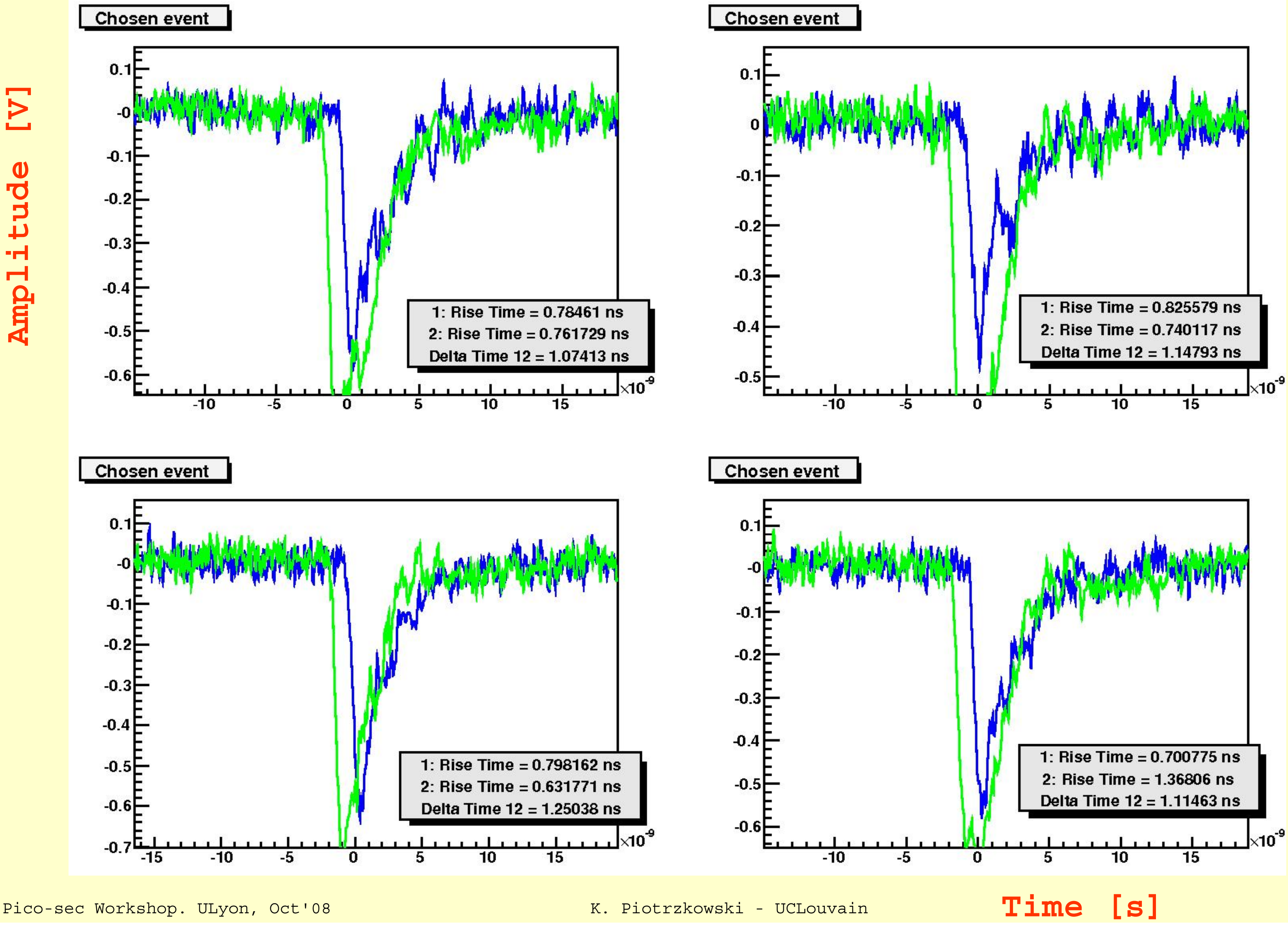






Cosmic rays test stand

Finally two detectors (in sequence, each with 16 anodes combined) put into comics - some real four events in GASTOFs:



Conclusions from Photonis 1st prototype:

- **Very robust and solid detector, regularly used as a test-beam 'working horse'**

- **Limited time resolution ~ 35 ps (for ~8 pe) because only 25 μm pore tubes available…**

- **Very interested by 10 μm pore tubes -> run Gastof as a Cerenkov image detector: read out 64 anode pads and reconstruct Cerenkov spot – eg. for $\langle N_{pe} \rangle = 9$ and 30 ps per channel per 1 pe might get 10 ps resolution, and have multi-hit capability!**

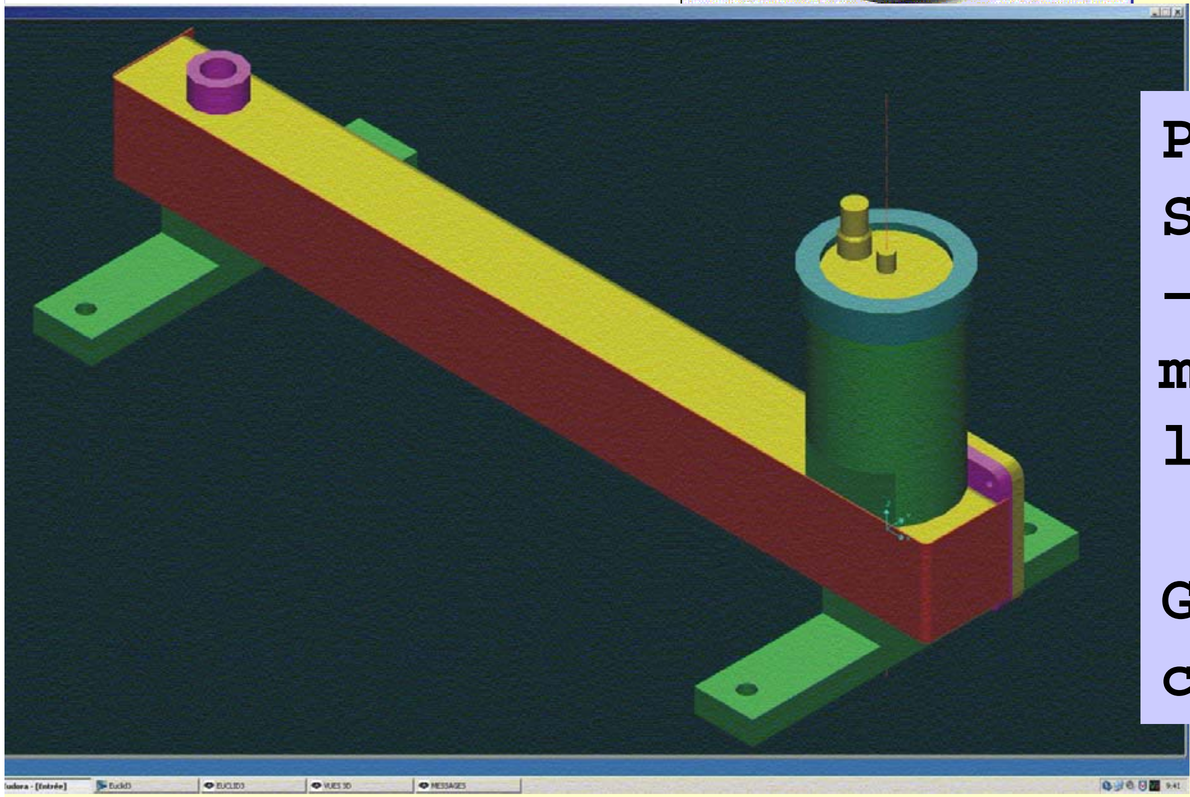
HAMAMATSU

MICROCHANNEL PLATE-PHOTOMULTIPLIER TUBE (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)

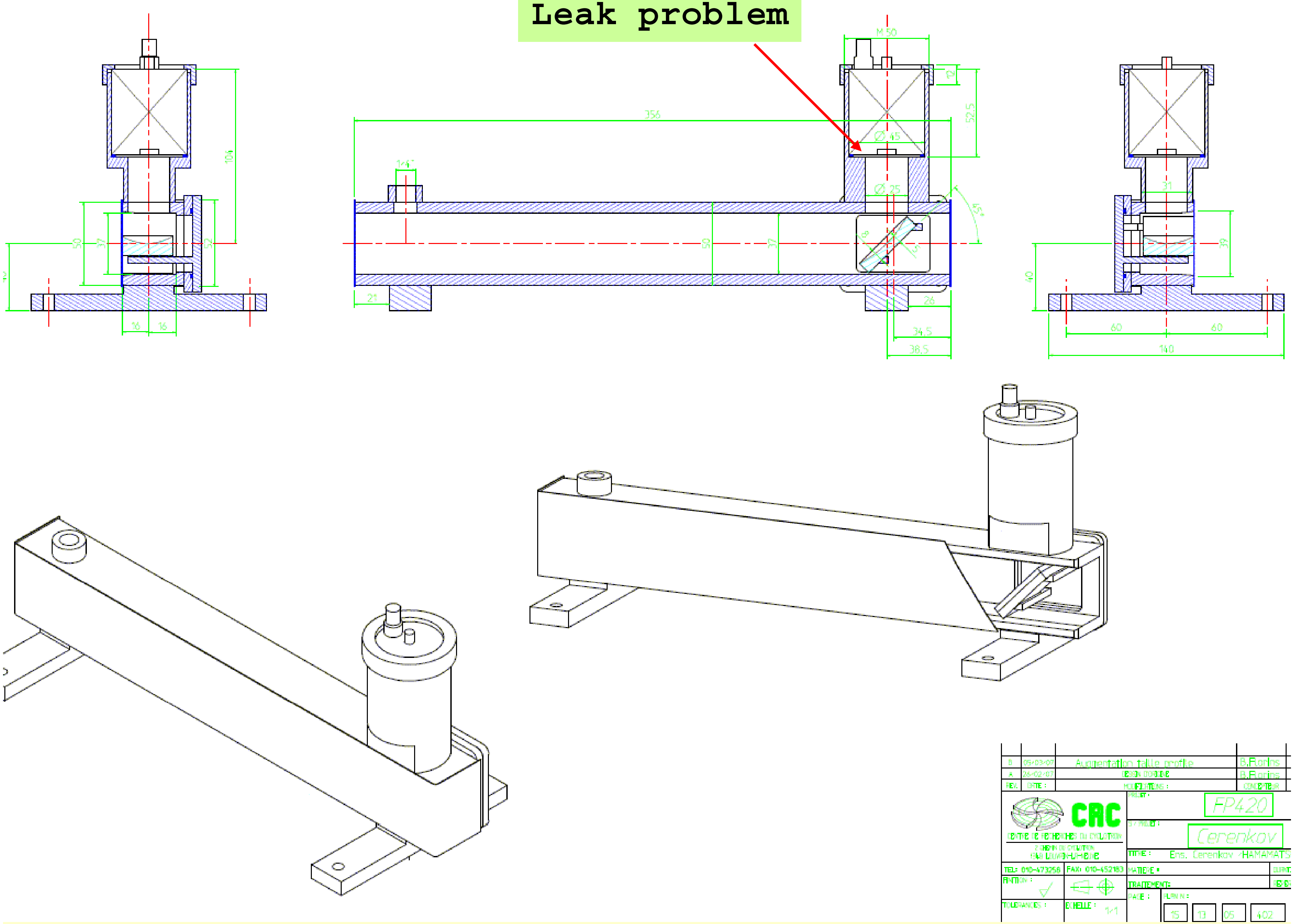
Gastof **with 6 µm pore MCP PMT**



Problems:
Small 11 mm cathode -> use spherical mirror to focus light on MCP-PMT;

Gas tightness – PMT case leaks.

Leak problem



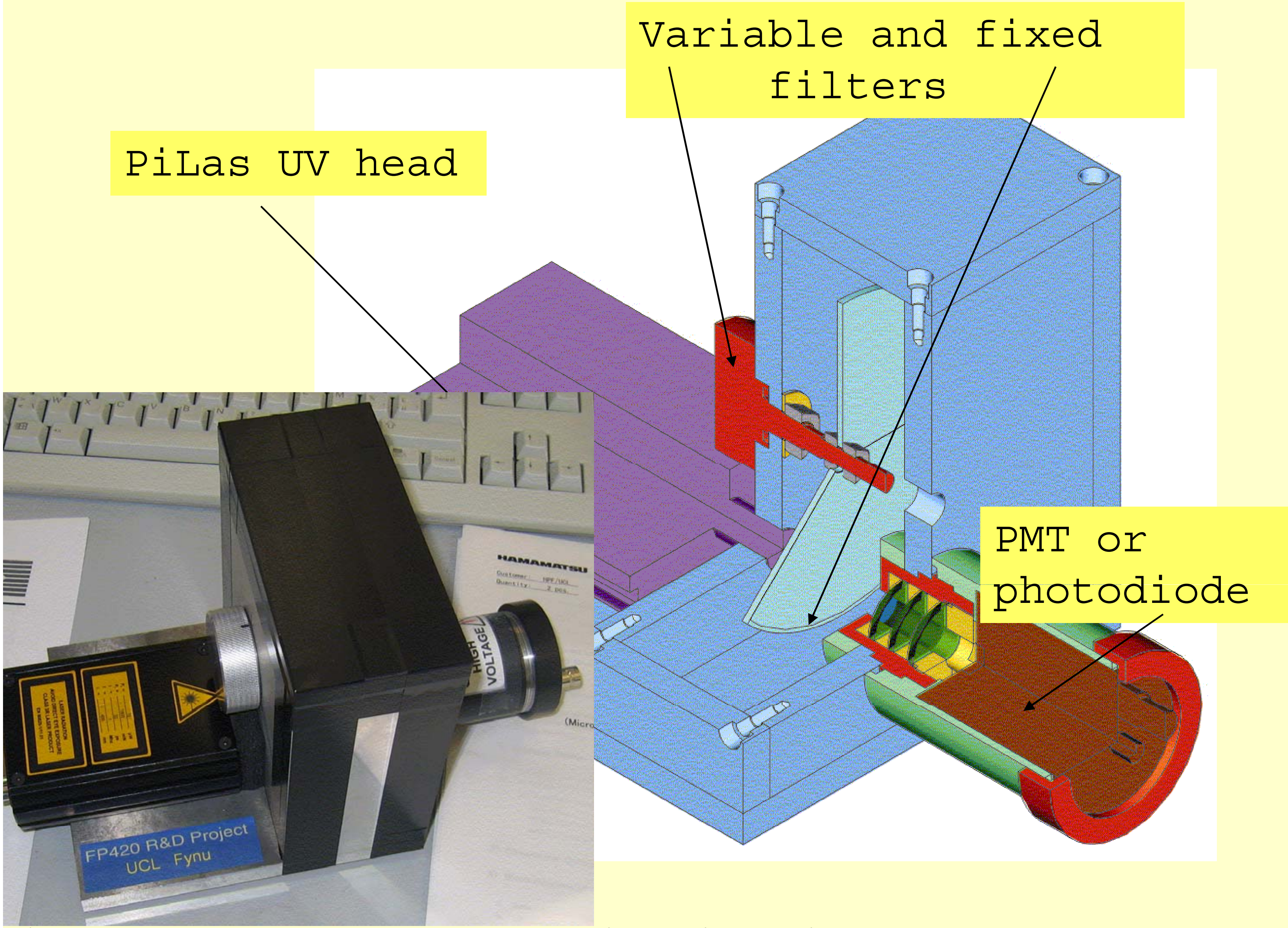
Laser stand

- **Picosecond laser driver (PiLas) with UV laser head PIL040 - 408 nm, 32 ps pulse FWHM and 3 ps jitter according to specs…**

EIG1000D with PIL063SM (fiber coupler and fiber)

- PiLas Digital Control Unit (EIG1000D)
- Optical Heads (PILxxx) for 375 nm – 1550 nm)

Crucial also for design and development of electronics as amplifiers, CFDs and DAQ. Good for simulating LHC high event rates - runs up to 1 MHz repetition rate.



Variable and fixed filters
PiLas UV head
PMT or photodiode
HIGH VOLTAGE
HAMAMATSU
FP420 R&D Project
UCL Fynu

Unavoidable irradiation due to *diffractive protons* simulated with Hector **: J.de Favereau and X. Rouby + KP (Louvain):**

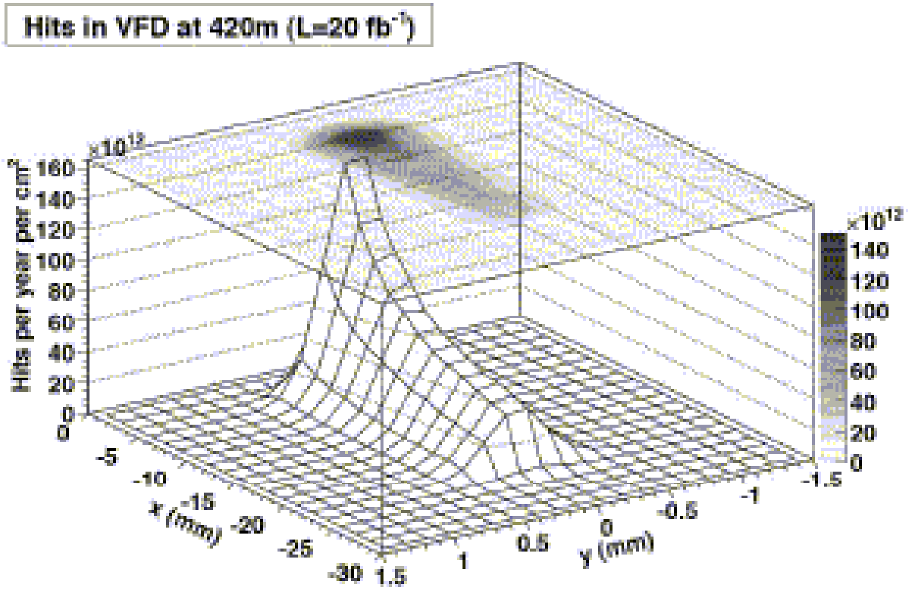
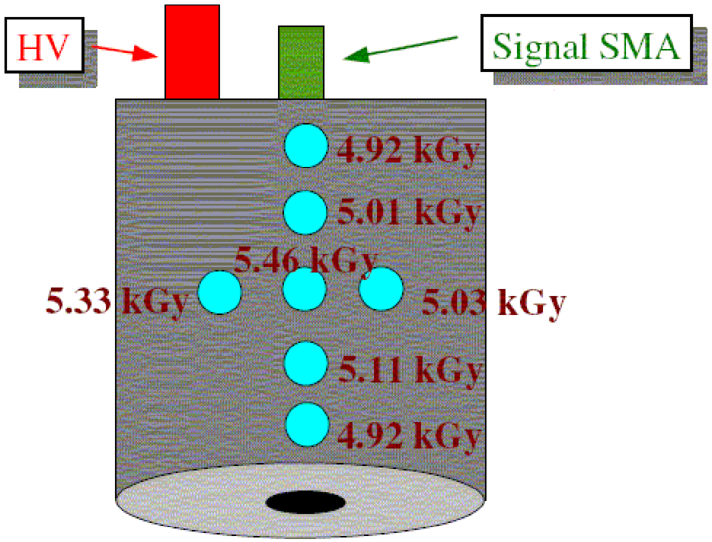


Fig. 27: Number of proton hits per year due to the process pp → pX for 20 fb^{-1} integrated luminosity. Protons were generated with PYTHIA 6.2.10 (single diffraction process 93) and tracked through the beam lattice with HECTOR.

Irradiation of Hamamatsu PMT

The last - 4th irradiation of PMT R3809U-50 #XC0113 with neutron

at UCL (spring 2008)



The average measured dose of 4th irradiation :

5.11kGy +/- 0.08 kGy ~ 2.21E+14 n/cm2 (1MeV)

Finally the total dose :

9.62kGy +/- 0.11 kGy ~ 4.16E+14 n/cm2 (1MeV)

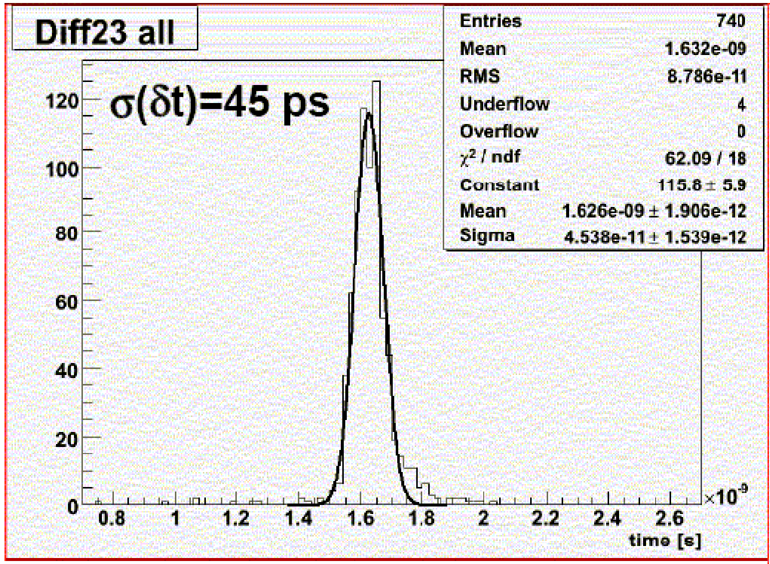
Intense fast neutron beam

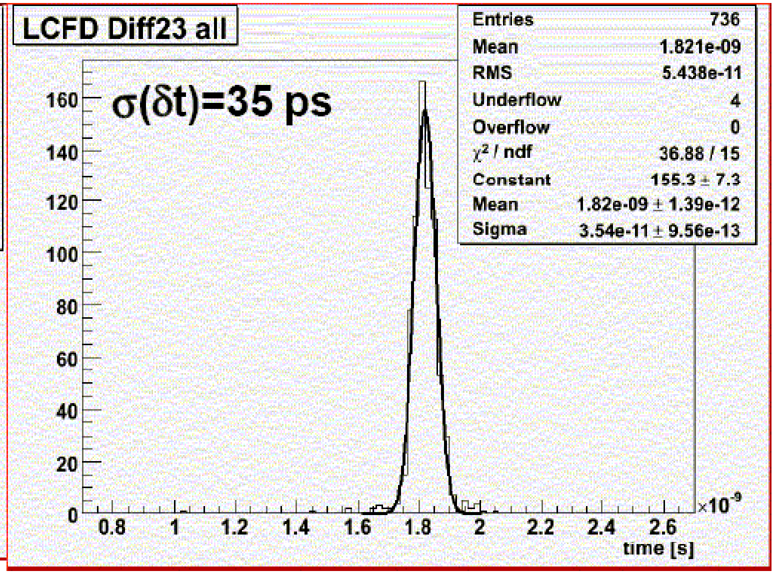
No degradation observed up to 10^{13} n/cm^2

Gain drops by 50%, rise-time unchanged at 2.10^{14} n/cm^2

Final dose of at 4.10^{14} n/cm^2, results in preparation but have problems with jitter measurement -> plan to split light and measure 2 PMTs at a time

Scope Analysis (G1-G2)



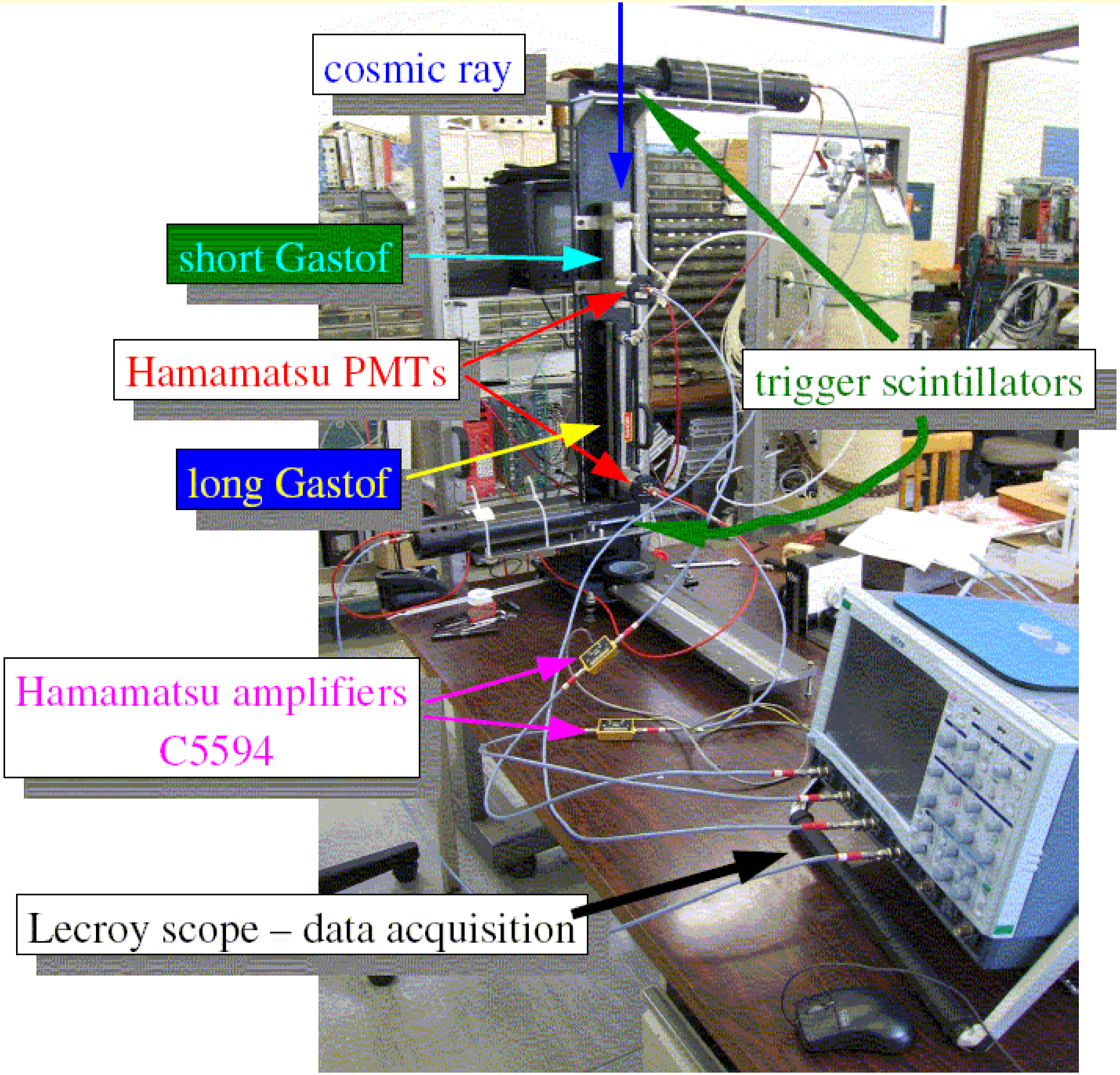


Threshhold discriminaton **CFD algo simulated**

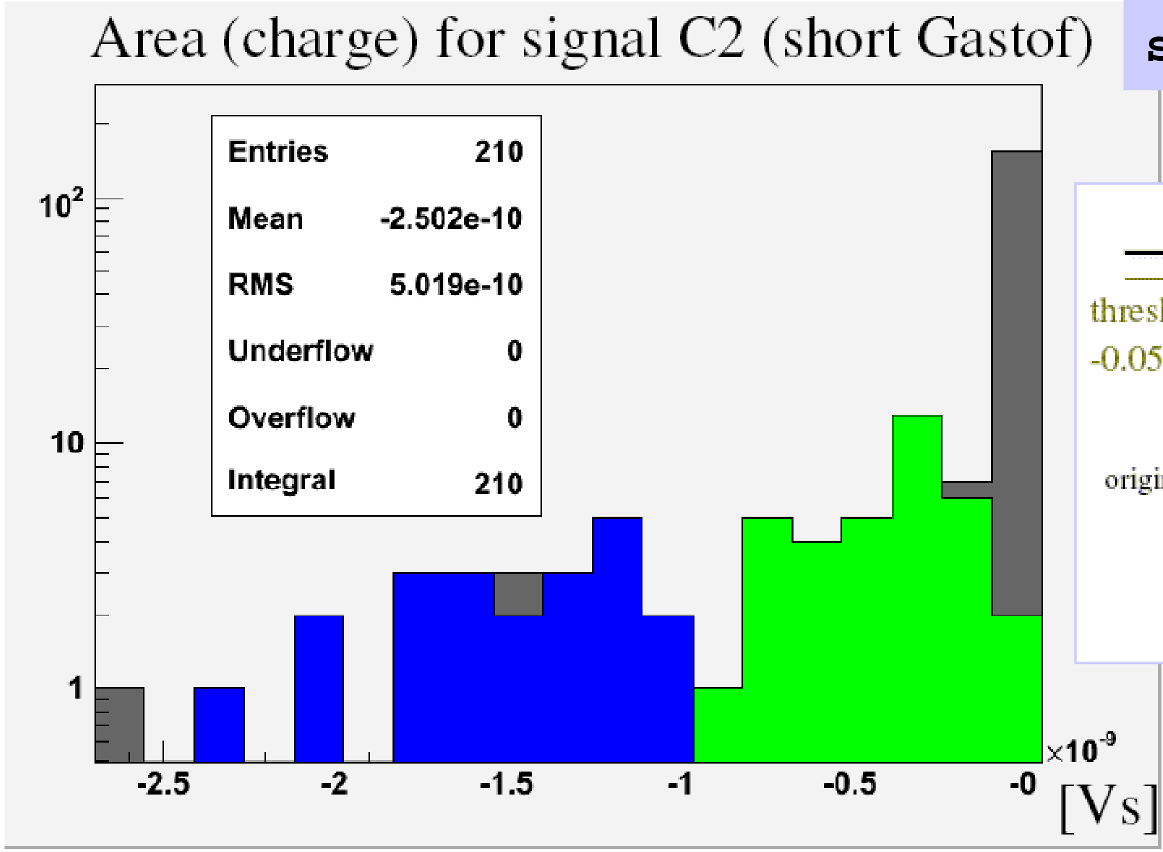
Individual detectors	
$\sigma(G01)$	32 ps
$\sigma(G02)$	13 ps
$\sigma(QBE)$	68 ps
$\sigma(QBD)$	52 ps

Target detector resolutions achieved?

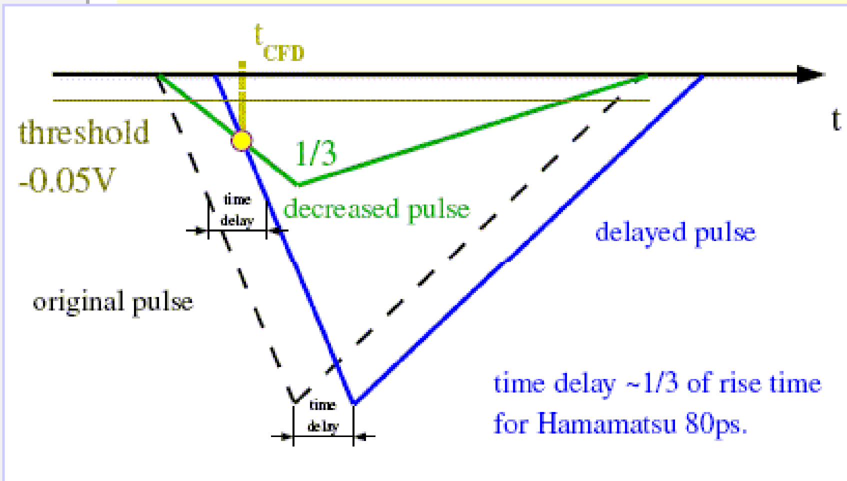
Cosmic rays test stand



Charge distributions for the cosmic ray events

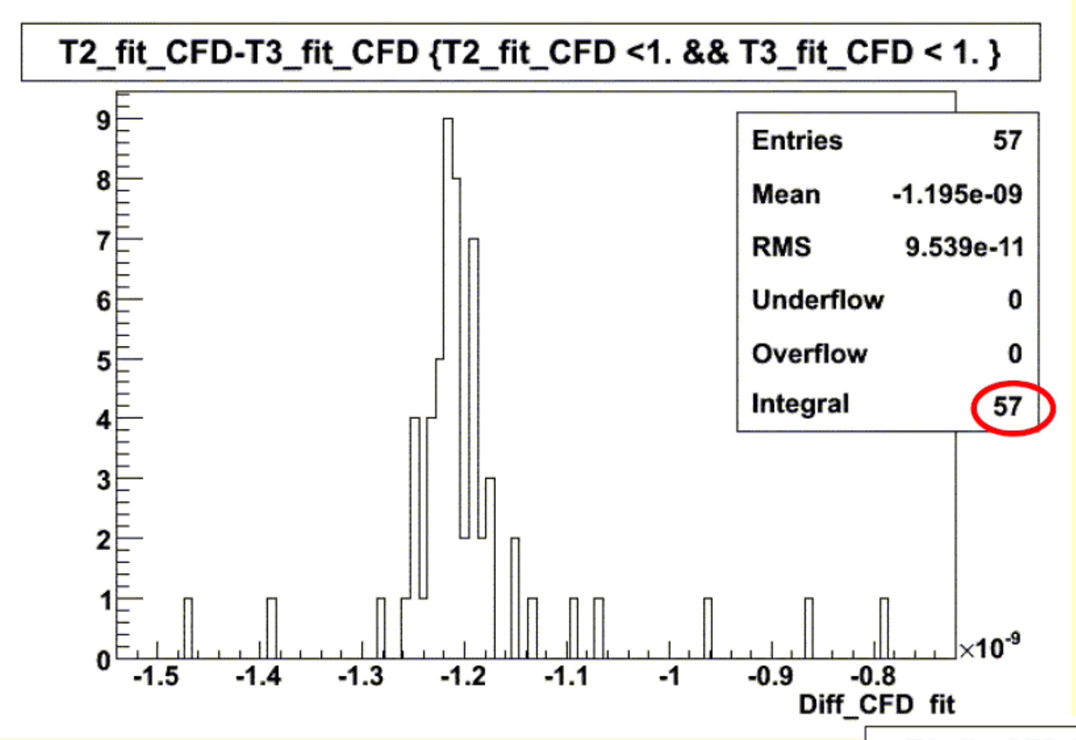


First, start with air-filled detectors -> 1 pe signals

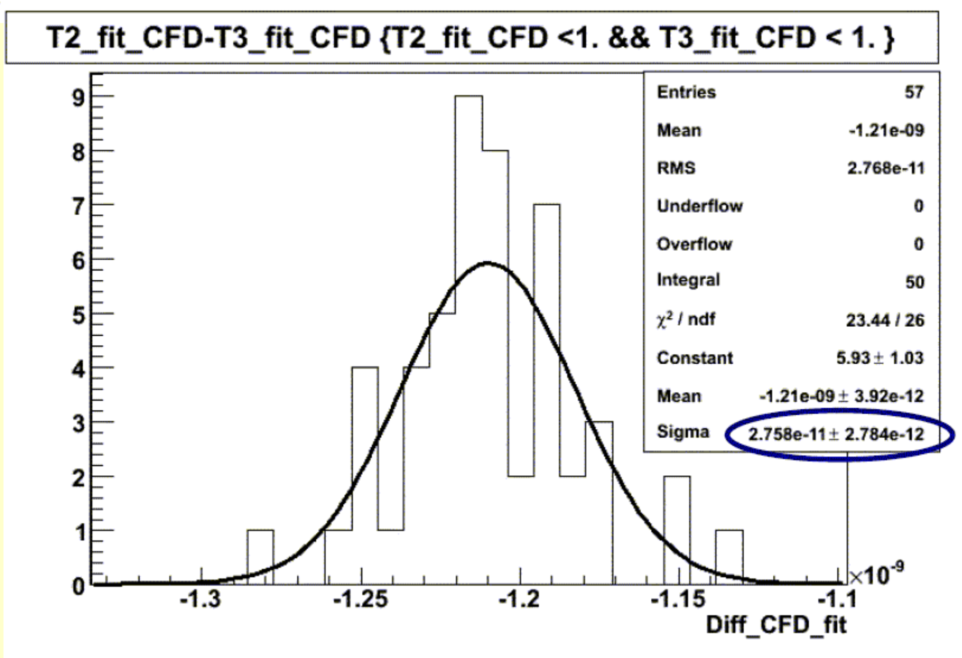


Store 20 GS/s waveforms and run CFD algo offline

1 pe, 2 pe, …



From CFD algo:
Measure spread of time difference (= distance between PMTs)

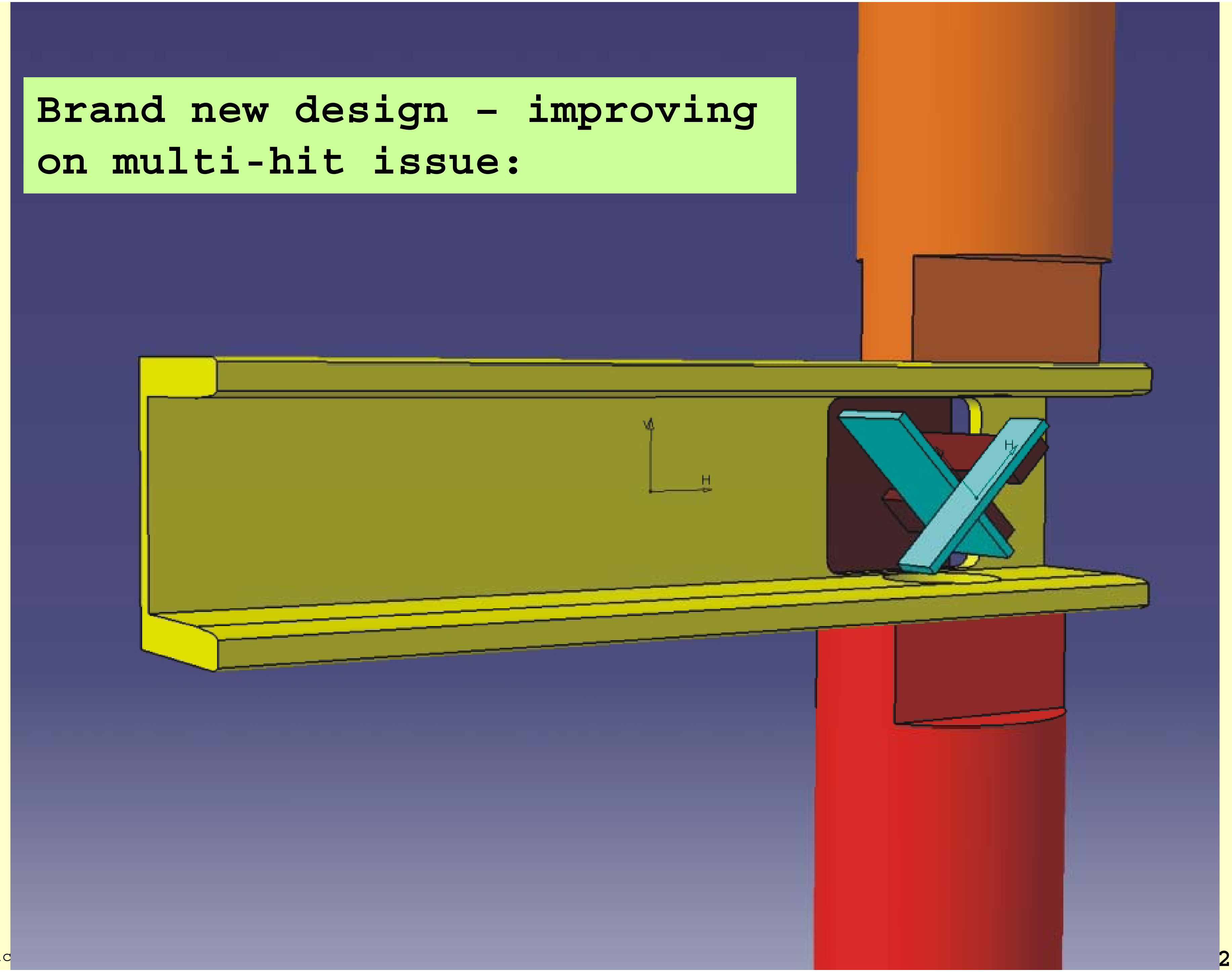


Single Gastof resolution (for ~1 pe):

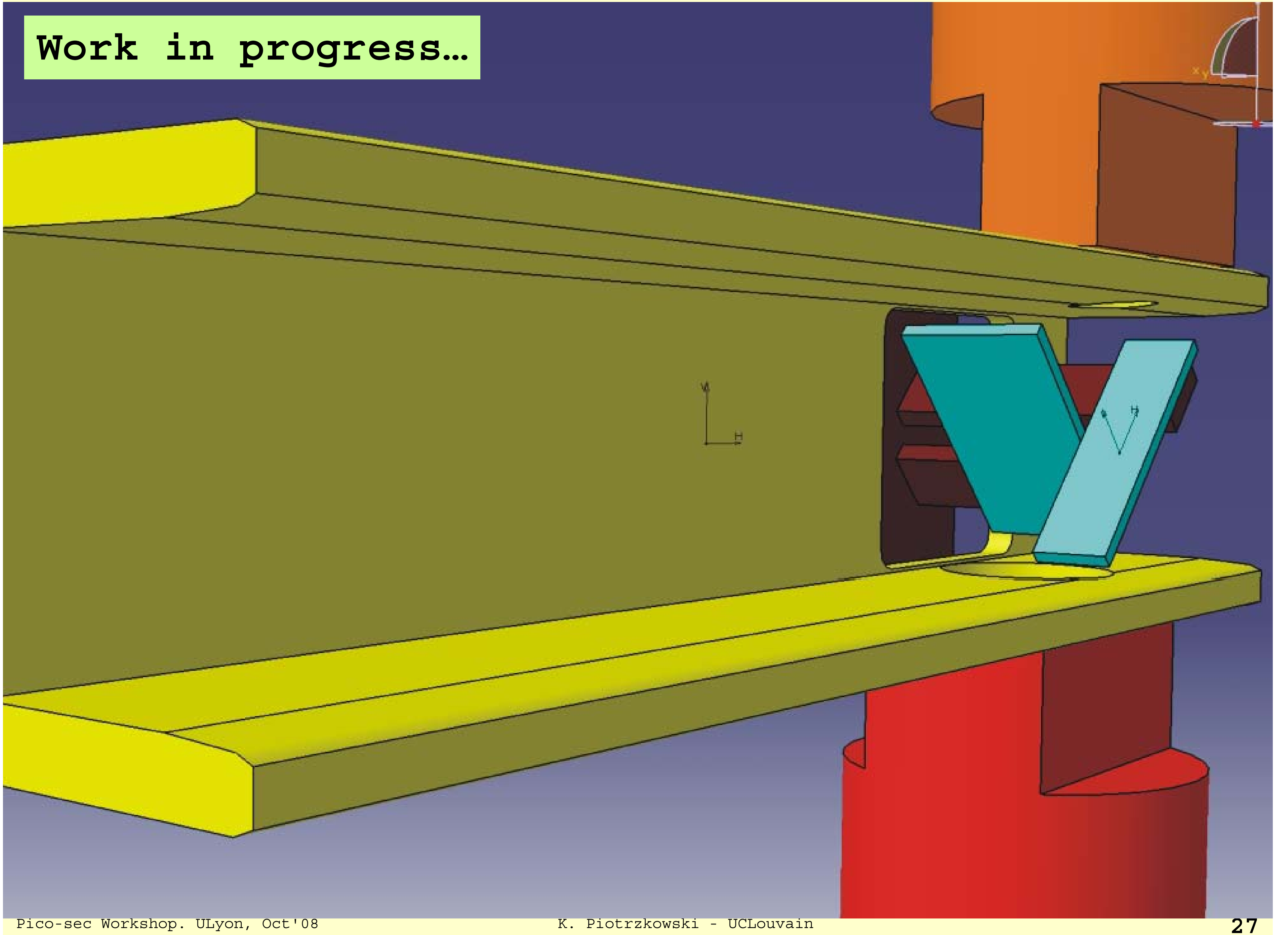
$28\ \text{ps}/\sqrt{2} = 19.5 \pm 2\ \text{ps}$

δΔt (jitter)	short Gastof 1 photoelectron	short Gastof more than 1 photoelectrons
long Gastof 1 photoelectron	25.1±4.6ps 16 events	31.6±4.5ps 25 events
long Gastof more than 1 photoelectrons		20±6ps 9 events

Brand new design – improving on multi-hit issue:



Work in progress…



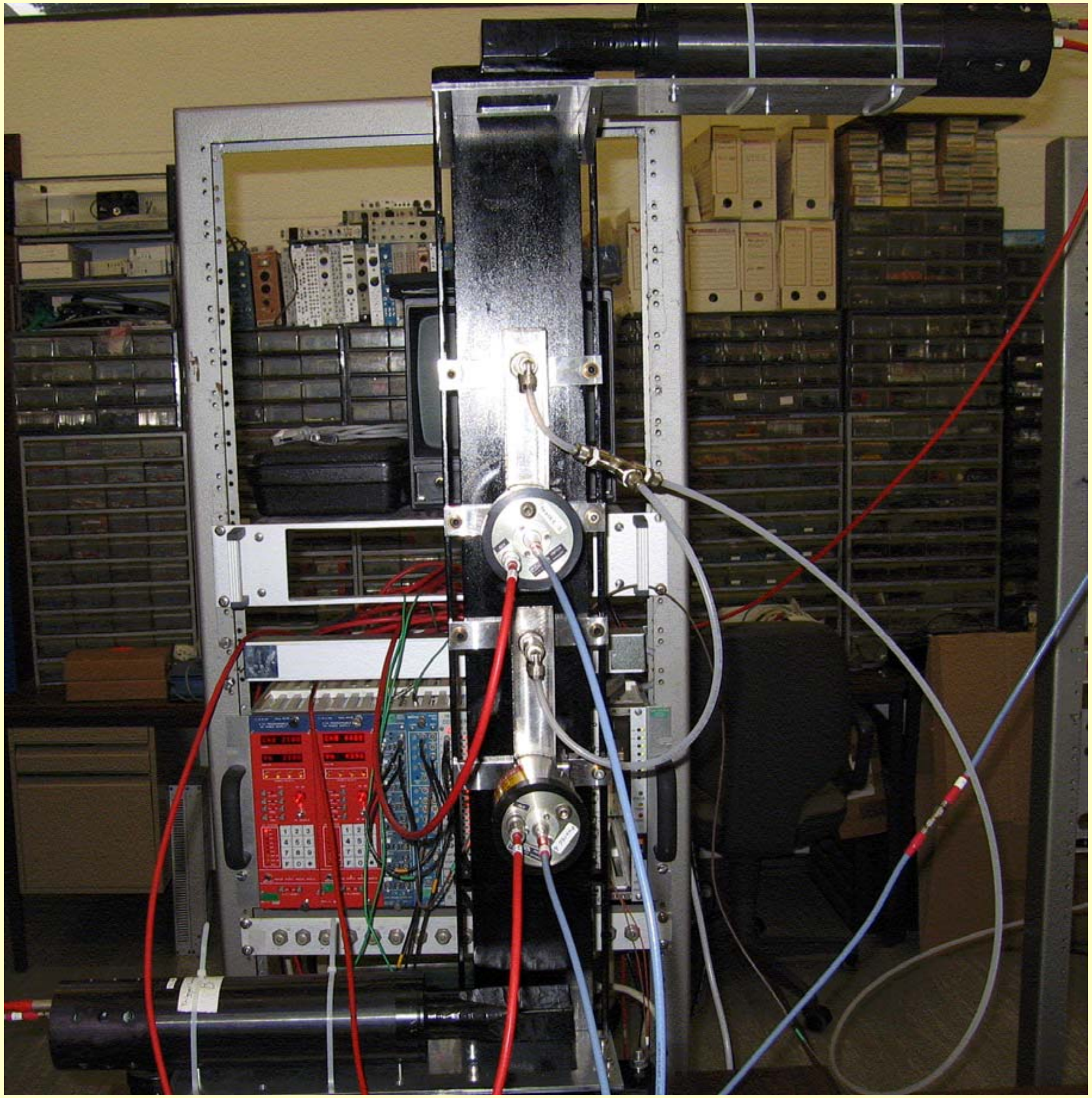
ULTRA FAST PHOTOMULTIPLIERS Photek

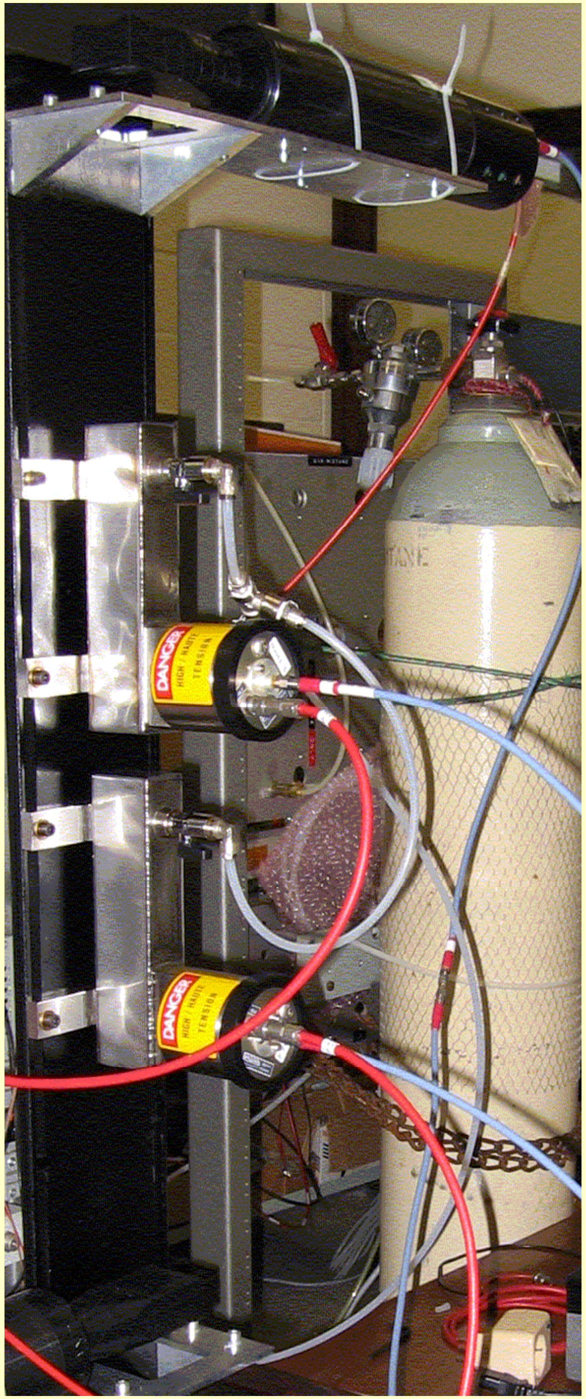
New collaboration with PHOTEK:

- Received two tubes (no gas leak!)

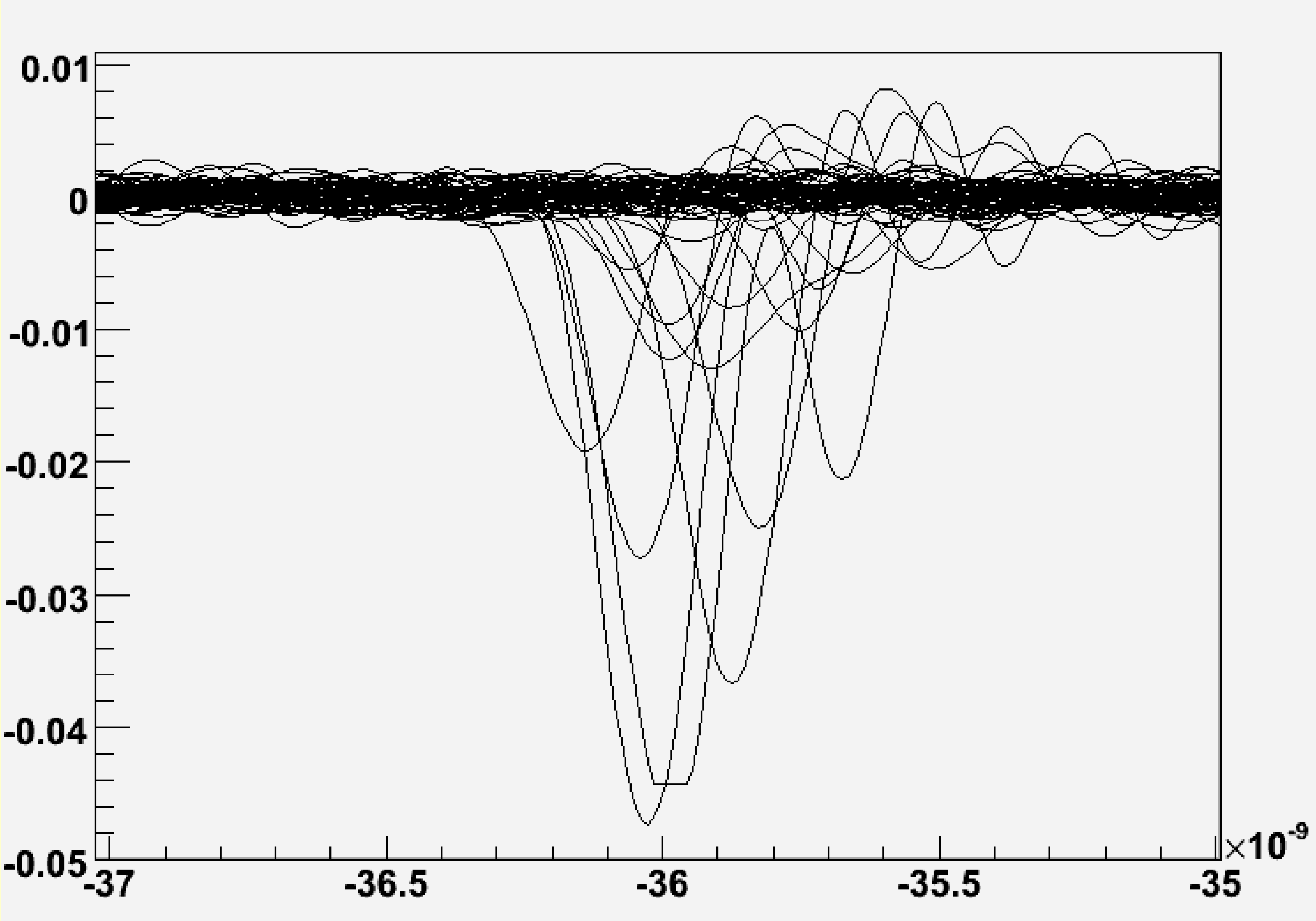
	PMT210	PMT212	PMT325	PMT340
Anode Size	10 mm	12 mm	25 mm	40 mm
Electron Gain	10^6	10^6	10^7	10^7
Peak/Valley	2:1	1.5:1	2:1	2:1
Dynamic Range cps	40,000	40,000	40,000	40,000
Pulse Rise Time	100 ps	100 ps	300 ps	500 ps
Pulse FWHM	170 ps	170 ps	800ps-1 ns	1 ns
Transit Time Jitter	30 ps	30 ps	100 ps	100 ps
MCP Pore Size	5/6	5/6	10/12	10/12

Gastofs **with Photek PMTs**





Hot off the press – first waveforms from Gastof with Photek tubes – very fast signals with rise time determined by 3 GHz scope BW…



By end of year 2008 two new (one 2 x HPK + one 2 x Photek) prototypes characterized:

-> R&D for initial set of Gastof detectors will be finalized, incl. irradiations

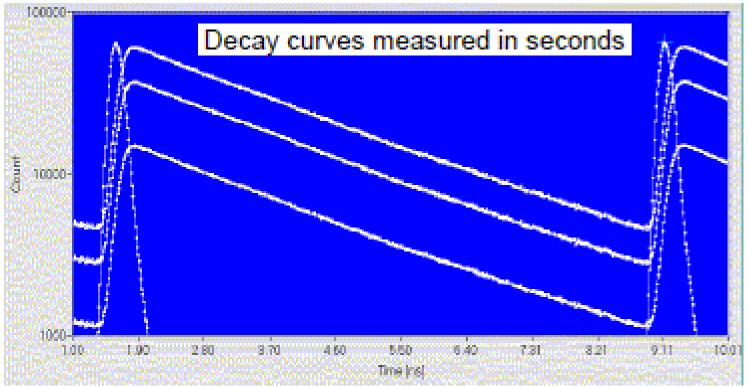
-> focus then mostly on the electronics/DAQ aspects for Gastof (including Photonis PMT based multi-anode system)

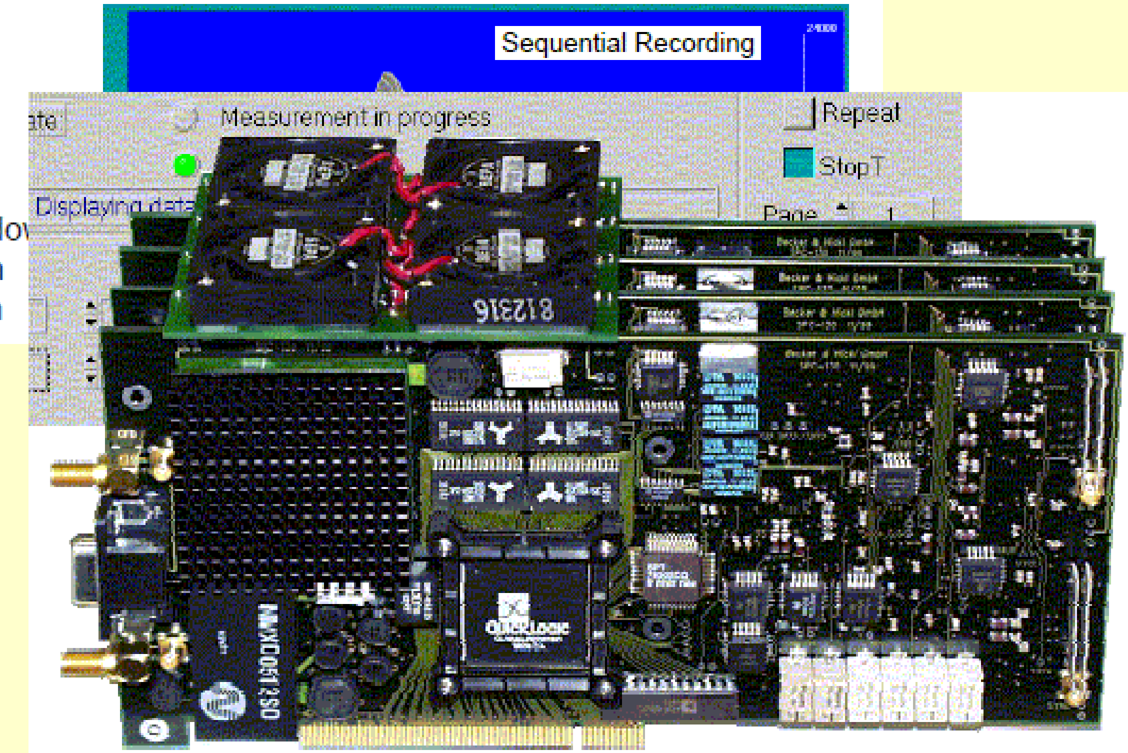
-> continue with Photek towards longer term R&D for sub 10 ps resolution detectors

The TCSPC Power Package SPC-134

Four Channel Time-Correlated Single Photon Counting Module

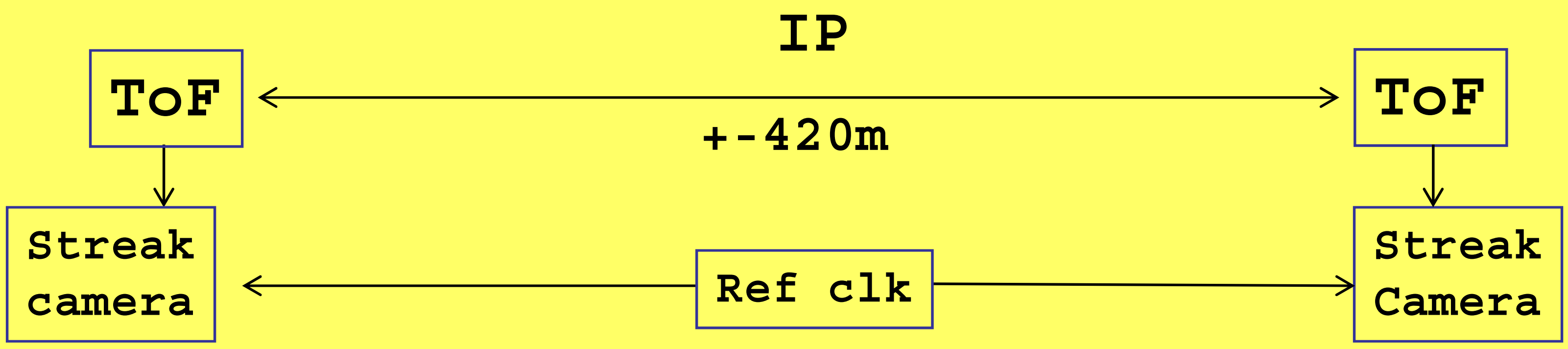
- Four Completely Parallel TCSPC Channels
- Ultra-High Data Throughput
- Overall Count Rate 32 MHz
- Channel Count Rate 8 MHz (Dead Time 125ns)
- Dual Memory Architecture: Readout during Measurement
- Reversed Start/Stop: Repetition Rates up to 200 MHz
- Electrical Time Resolution down to 8 ps FWHM / 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 Windo
- Continuous Flow Mode for Single Molecule Detection
- FIFO / Time Tag Mode for Single Molecule Detection





Longer perspectives

- Is ~ 1 ps all-inclusive resolution possible? Can use streak cameras?



Note: Need <u>very high</u> precision reference clock distribution. NO need for segmented detectors – multi-hit events no problem but has to run at high 40 MHz repetition rate… and large light yield mandatory.