GasToF: Pico-second Gas Čerenkov Time-of-Flight Detectors

K. Piotrzkowski (UCLouvain – CP³ Center)

Introduction and LHC Motivation

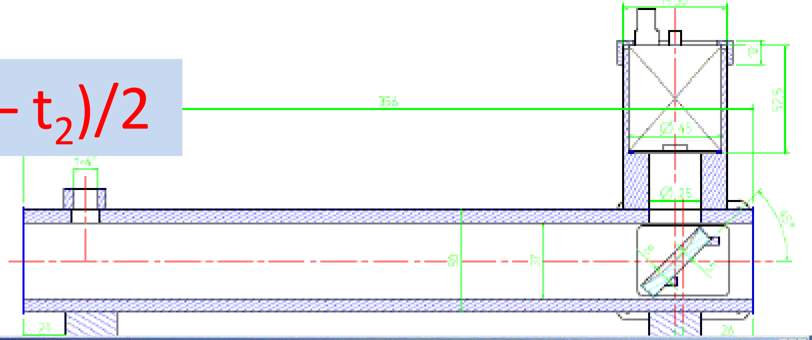
GasToF: Final test beam results

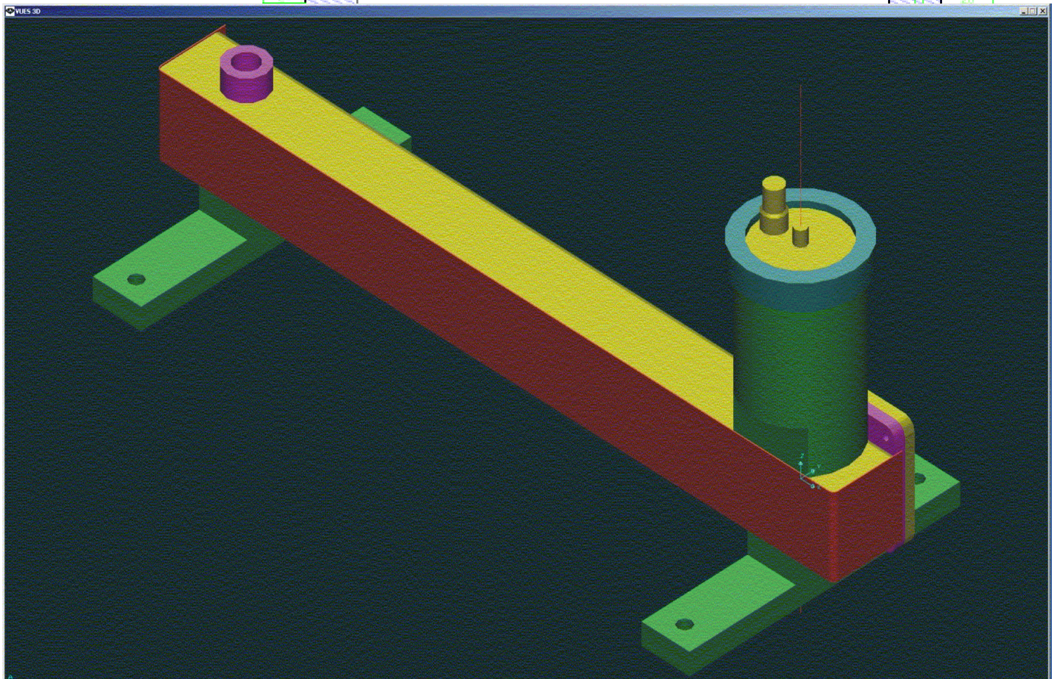
One photoelectron principle

Next steps

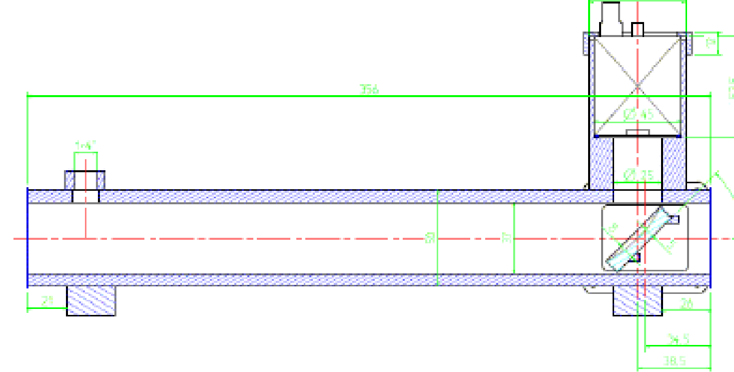
ps timing workshop
LPC (Clermont-Ferrand)

$z = c\,(t_1 - t_2)/2$



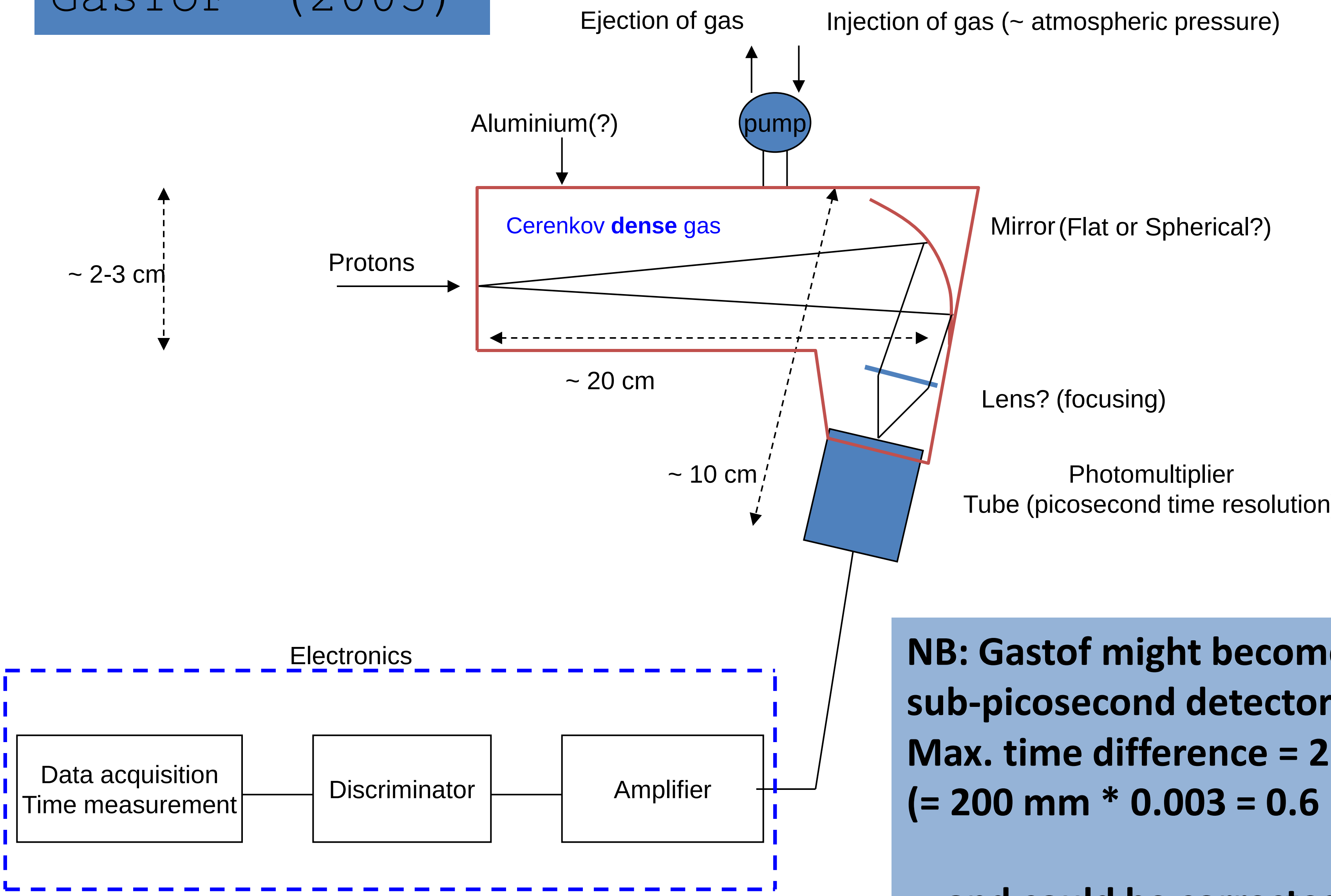


GasToF Concept



- Gas Čerenkov – direct, very forward light propagation (no internal reflections) – intrinsically very fast, excellent resolutions with single photons
- Very simple "optics" thanks to small chromatic dispersion; light spectrum peaking at deep UV
- Robust and radiation hard (light reflected away by thin mirrors)
- Light detector (just thin walls) – can be used within tracking
- *Needs some space though, length…*

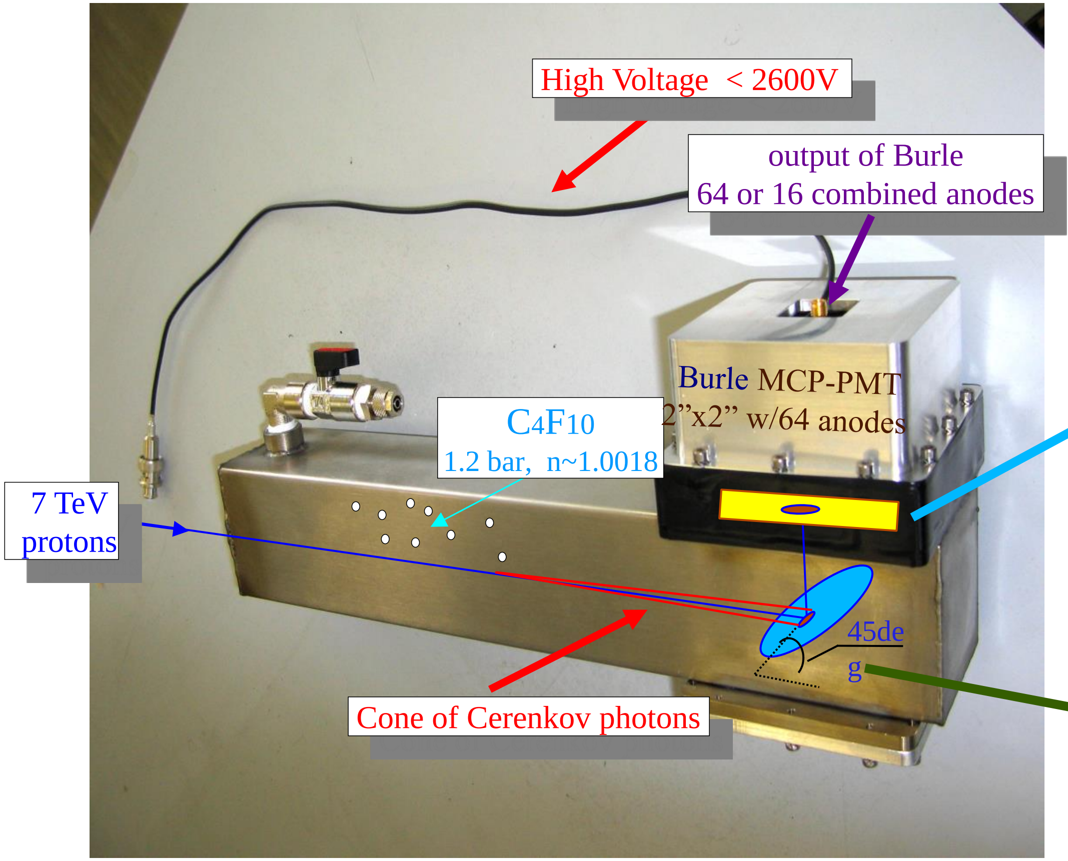
GasToF™ (2005)

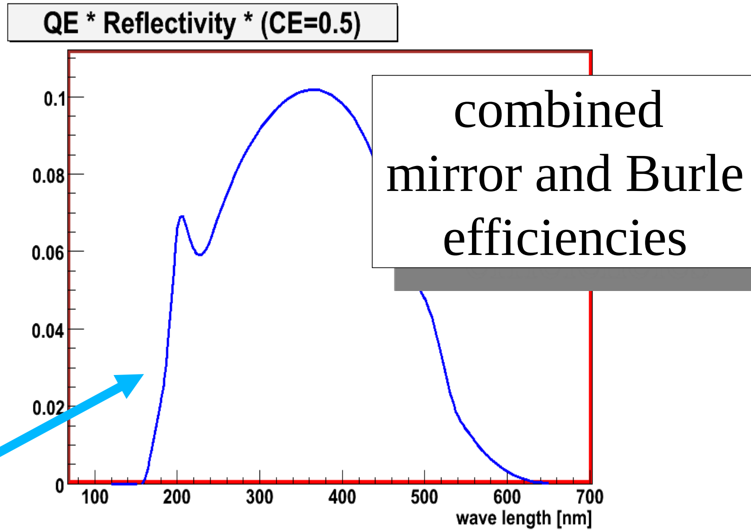


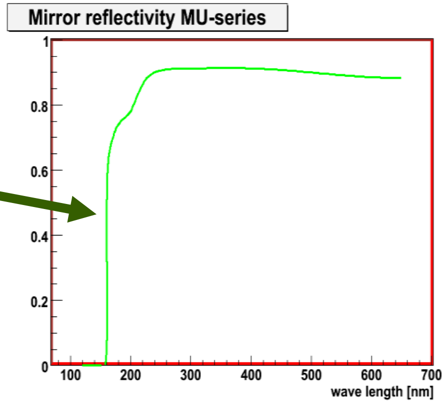
NB: Gastof might become sub-picosecond detector!
Max. time difference = 2*L*Δn
(= 200 mm * 0.003 = 0.6 mm)

… and could be corrected for !

GasToF **prototyping** with PHOTONIS/Burle 25 μm MCP-PMTs

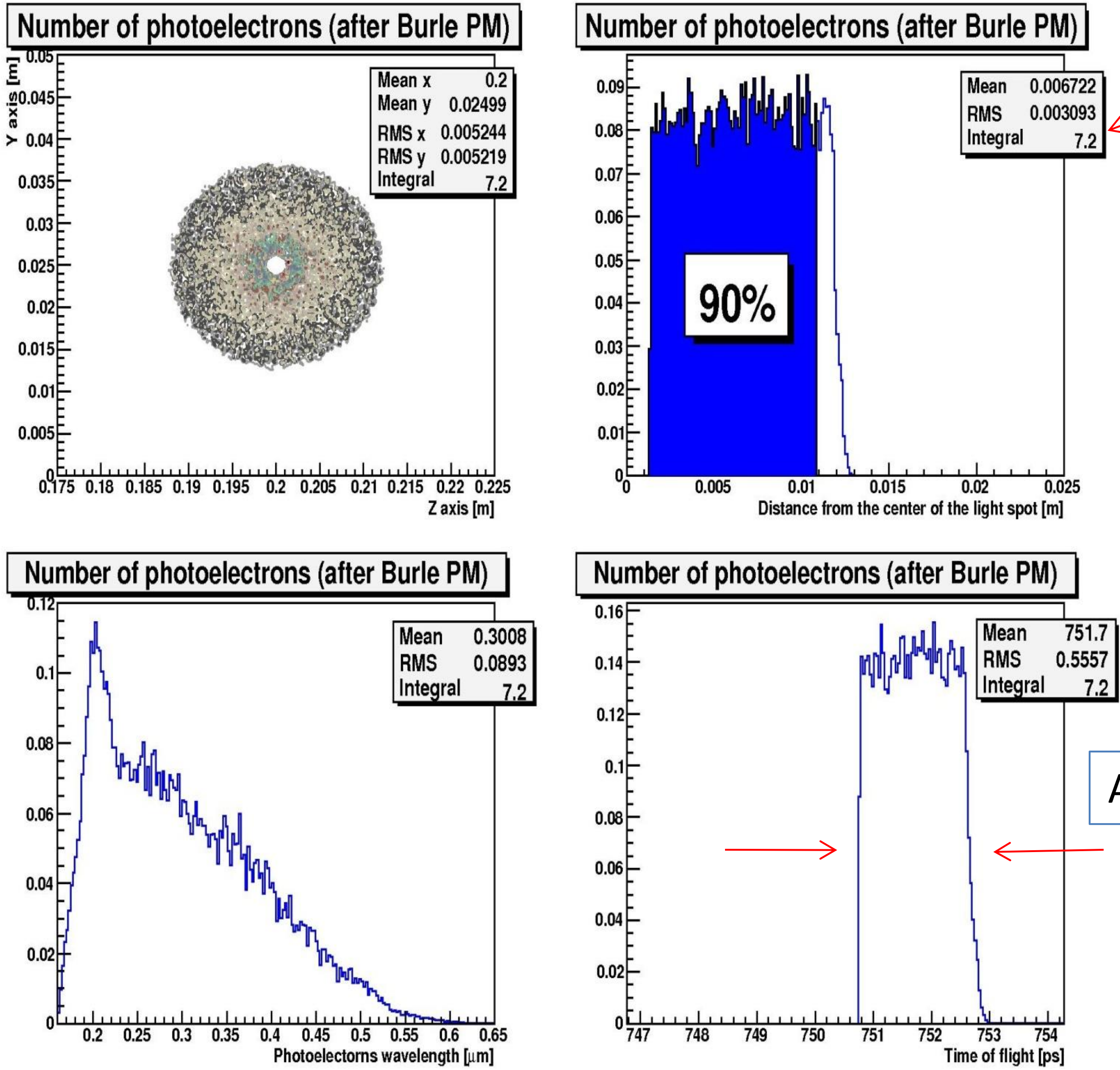






Our 'workhorse': very robust with timing resolution of ~30 ps (due to TTS) → L. Bonnet *et al.* Acta Phys. Pol. B38 (2007) 447; FP420 Collab., JINST 4 (2009) T10001

Simulations with PHOTONIS 25 μm MCP-PMT **(T. Pierzchala: raytracing)**

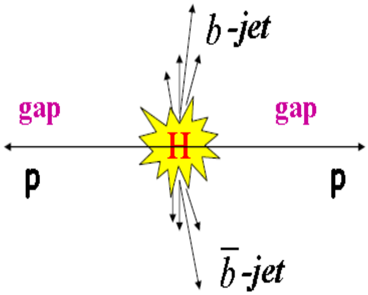


All in 2ps !!

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

Picosecond ToF detectors @ LHC

Plan to run forward proton detectors at nominal luminosity – event rates are so high that triple accidental coincidence (an interesting event in central detector + two protons from single diffraction) becomes major background, therefore relatively, it rises quadratically with luminosity!



Use very fast ToF detectors to reduce it by matching *z-vertex* from central tracking with *z-by-timing* from proton arrival time difference:
LHC vertex spread is ~50 mm → to reduce significantly backgrounds one needs < 10ps time resolution (→ 2 mm *z-vertex* resolution)!

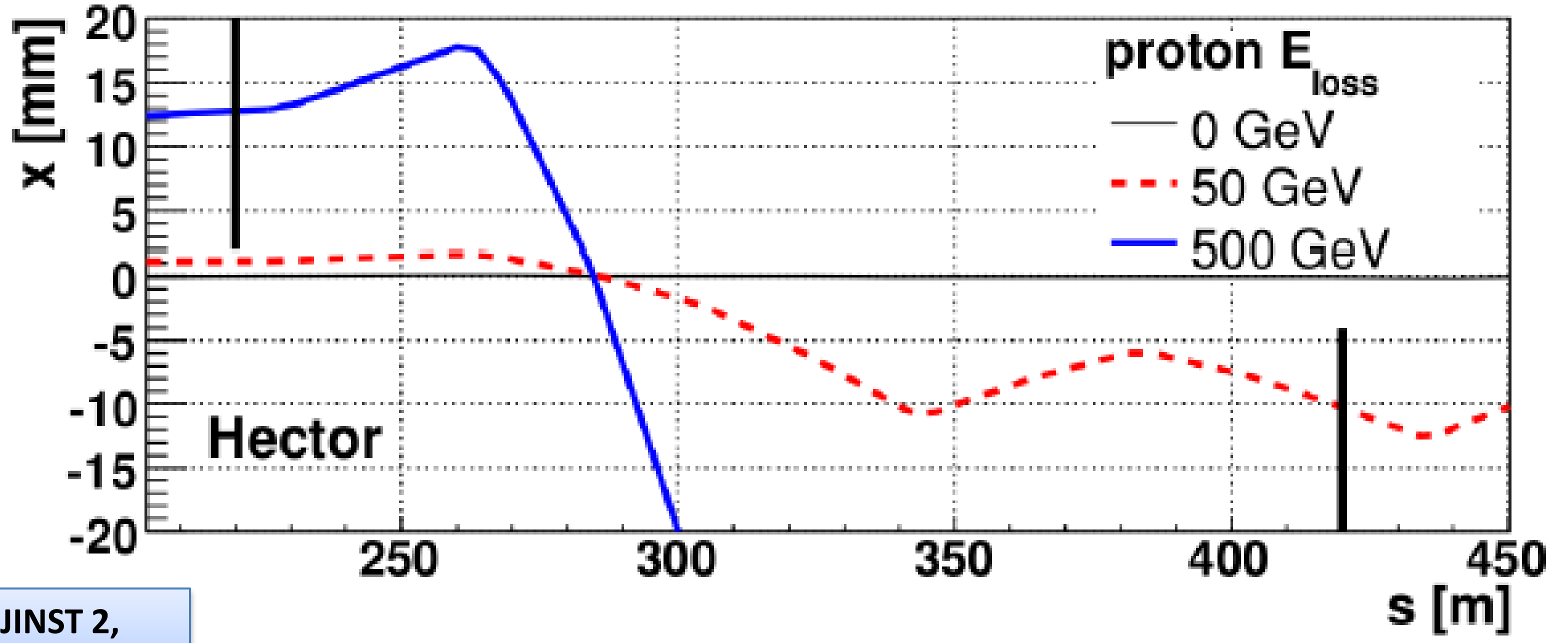
$z = c\,(t_1 - t_2)/2$

Proposed fast (& small ~10 cm^2 cross-sections) timing detectors: Čerenkov radiators + fastest MCP-PMTs

Challenging conditions → pushing MCP-PMT performances to limits:
→ High event rates, up to several MHz
→ Running MCP-PMTs at (above?) maximal anode currents
→ Large total collected anode charges (at least few C/cm^2)

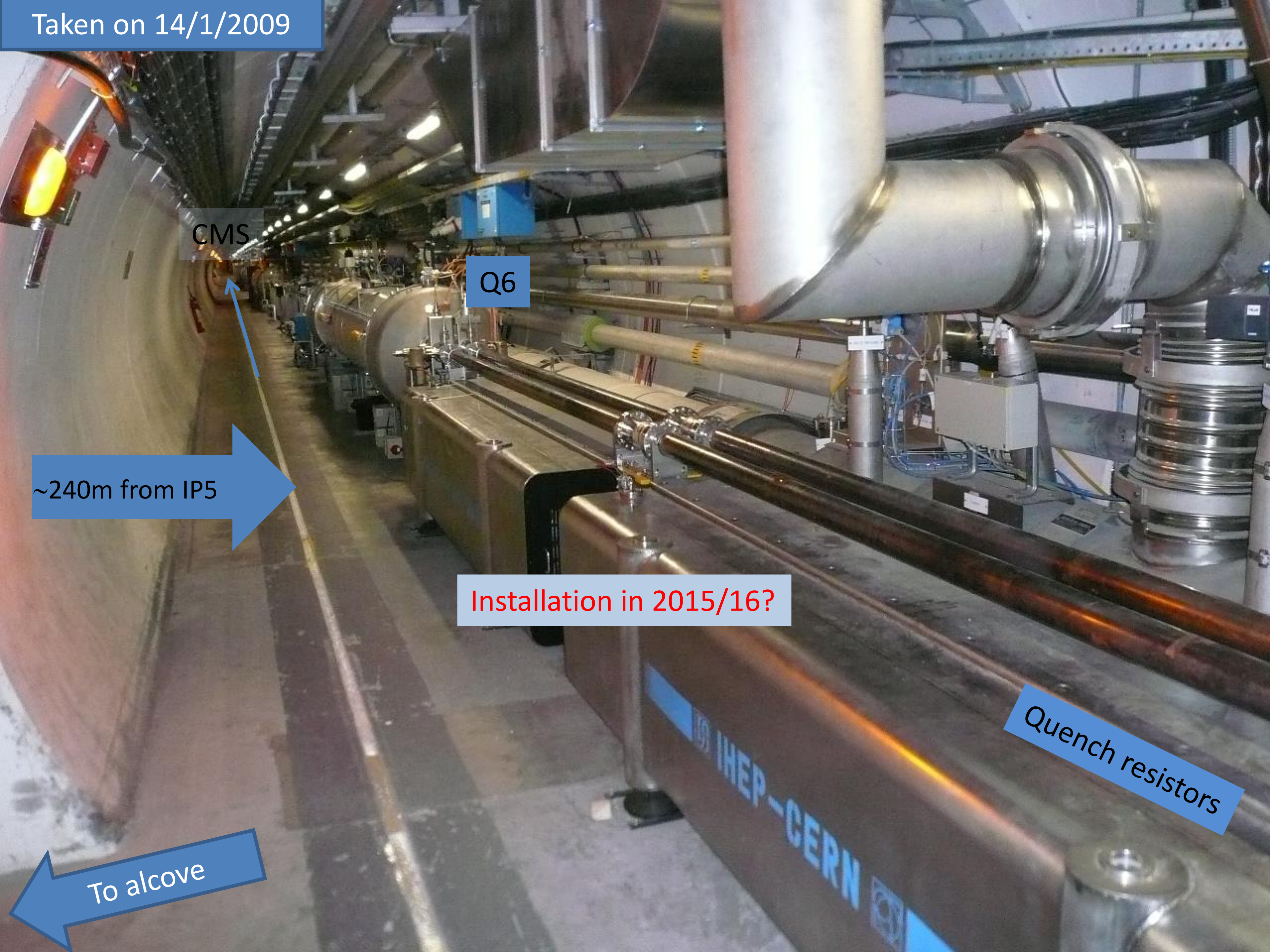
GasToF: Gas (C_4F_{10}) Čerenkov detector with very fast light pulse (< 1 ps spread!) → resolution limited by TTS of MCP-PMTs and electronics

Forward proton trajectories @ LHC

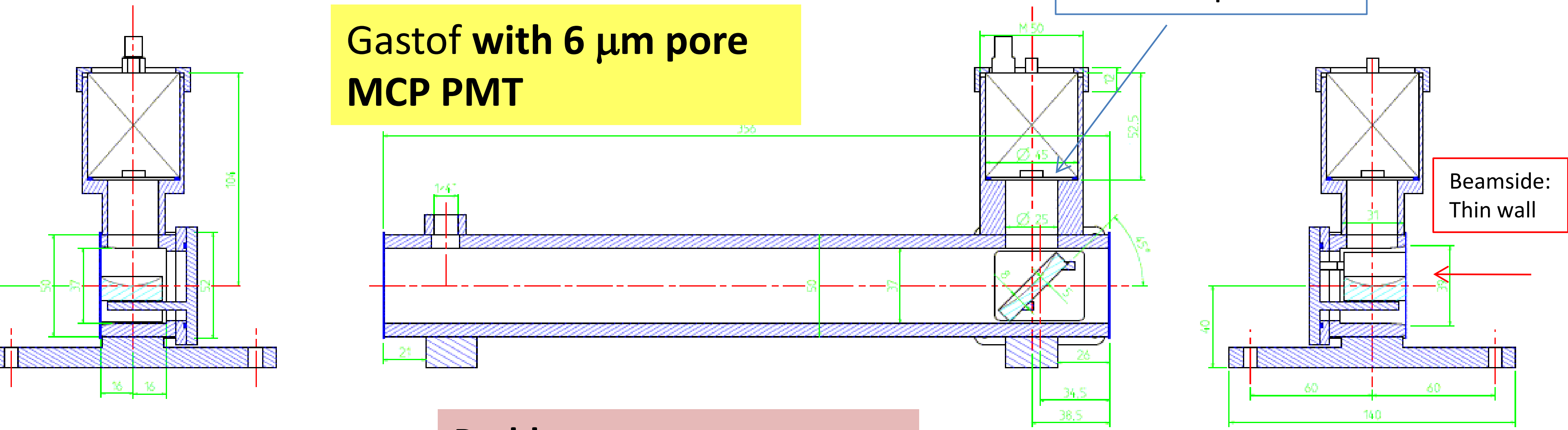


HECTOR: **JINST 2, P09005 (2007)**

Thanks to very high energy and low scattering angles path length differences are very small for forward protons, below 100 μm! It means that it starts affecting *z-by-timing* only for sub-picosecond measurements!

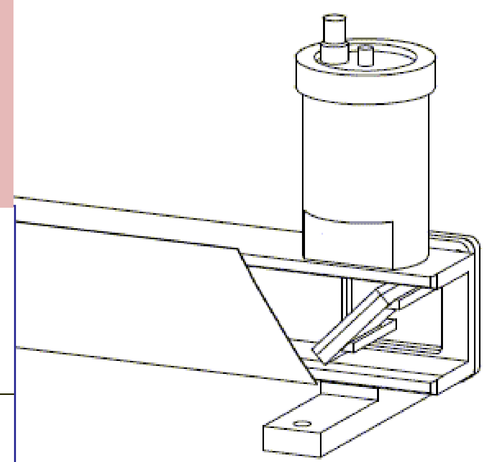


Taken on 14/1/2009
CMS
Q6
~240m from IP5
Installation in 2015/16?
Quench resistors
IHEP-CERN
To alcove



Gastof **with 6 µm pore MCP PMT**

Problem:
Small 11 mm cathode → use spherical mirror to focus light on MCP-PMT

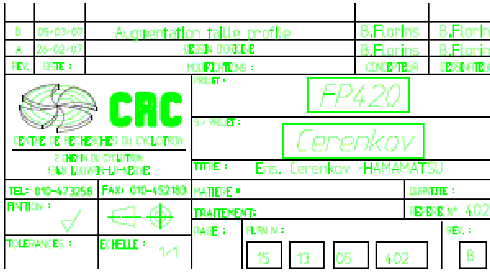


HAMAMATSU

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

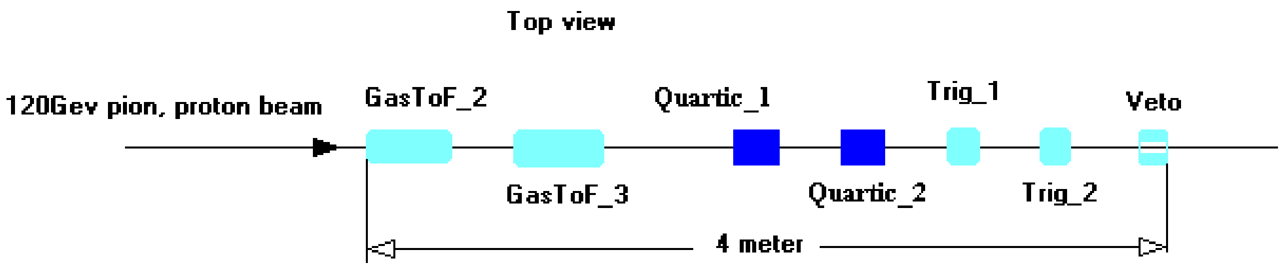
Compact MCP-PMT Series Featuring Variety of Spectral Response with Fast Time Response

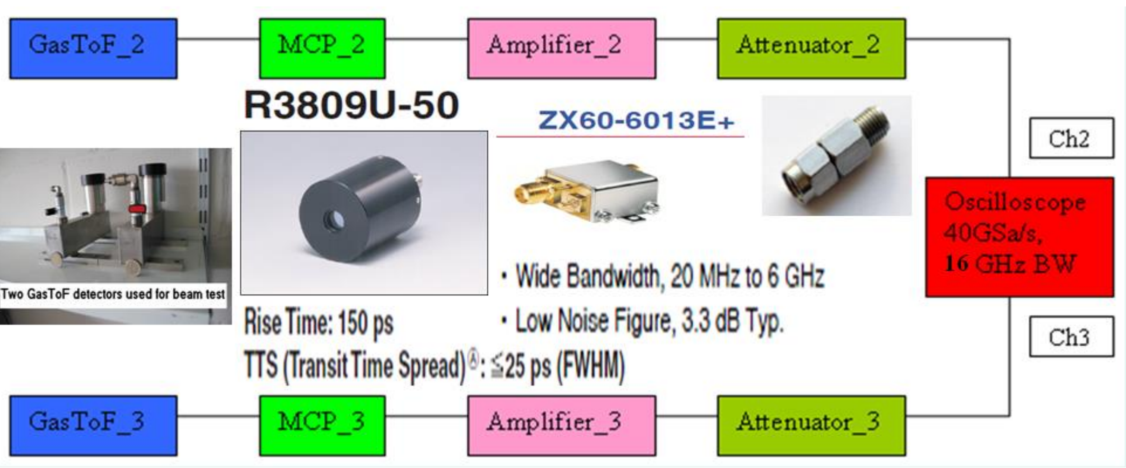
FEATURES
- High Speed
  Rise Time: 150ps
  T.T.S. (Transit Time Spread)[1]: ≦ 25ps(FWHM)
- Low Noise
- Compact Profile
  Useful Photocathode: 11mm diameter
  (Overall length: 70.2mm Outer diameter: 45.0mm)

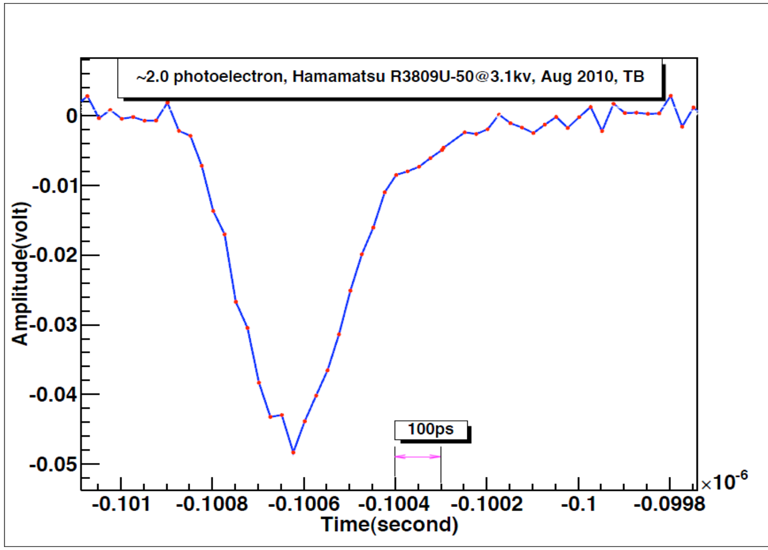


GasToF @ CERN test beam

- Two short GasToF prototypes with HPK tubes and readout with 40 (80) GSa/s 14 GHz BW scope (thanks to UTA and AFP!)
- Quartz windows were added to seal gas volume

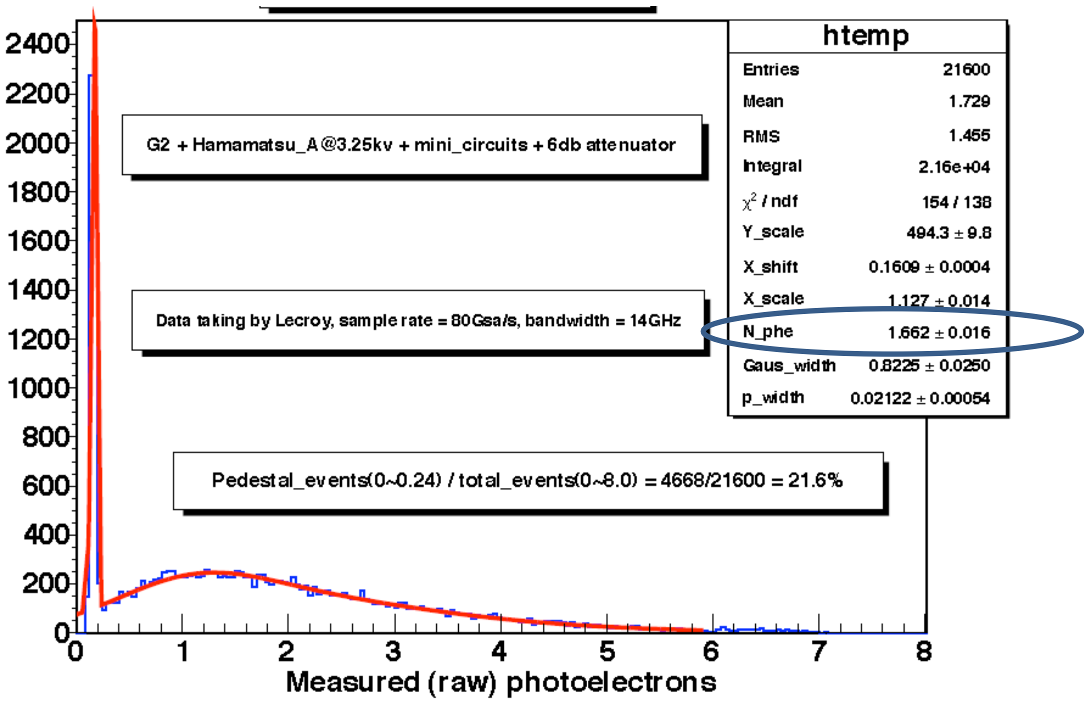




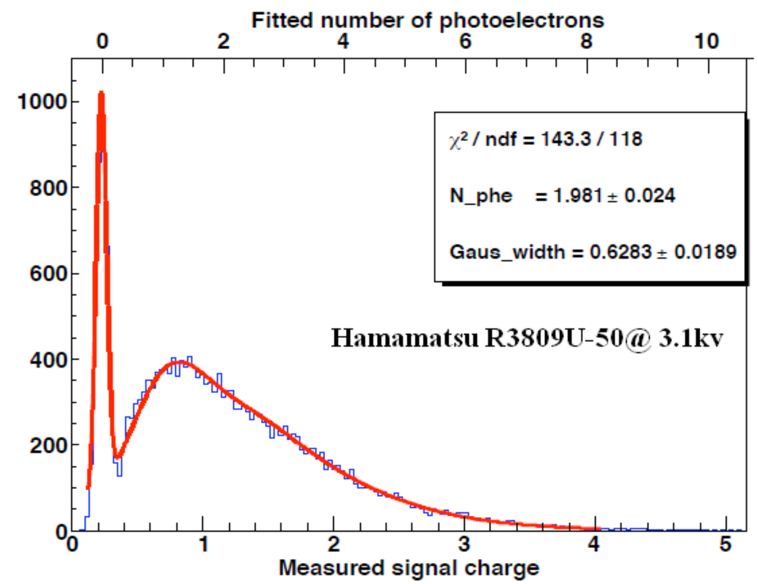


GasToF@TB: Final results

- Two short GasToF prototypes with HPK tubes at 3.1 and 3.25 kV, this corresponds to gains of about 4.10^5
- Use fast amplifiers and 6 dB attenuators (should simulate well long cables)
- Expected (low) signals are observed (would increase by ~2 for final design)



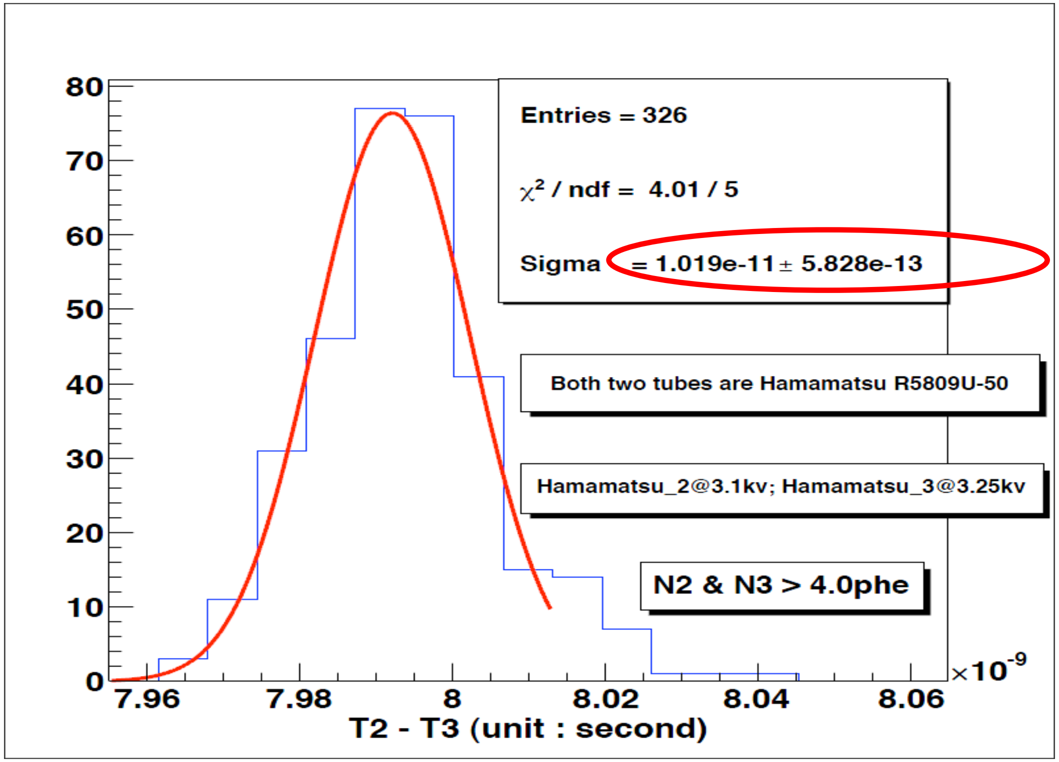
J. Liao



GasToF@TB: Final results

- Time difference between two GasToF detectors:

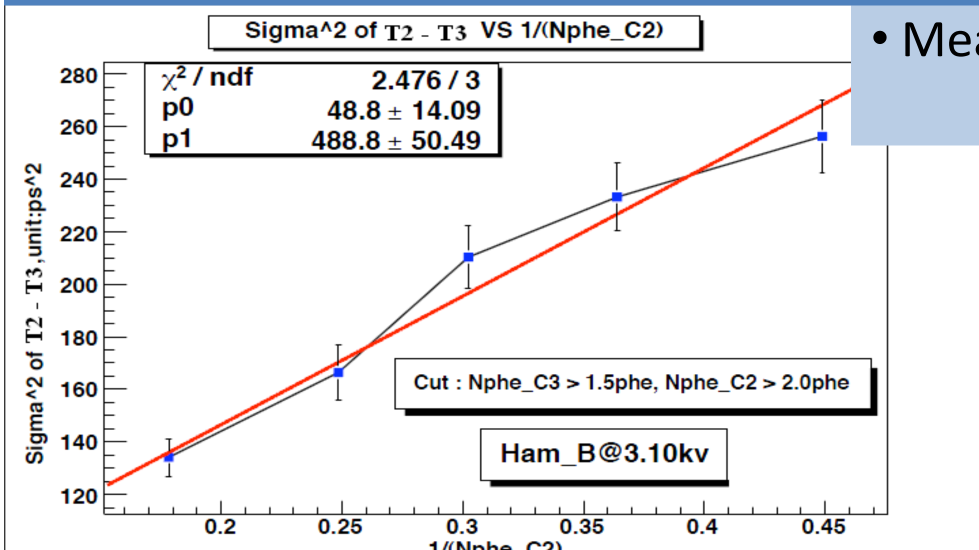
J. Liao

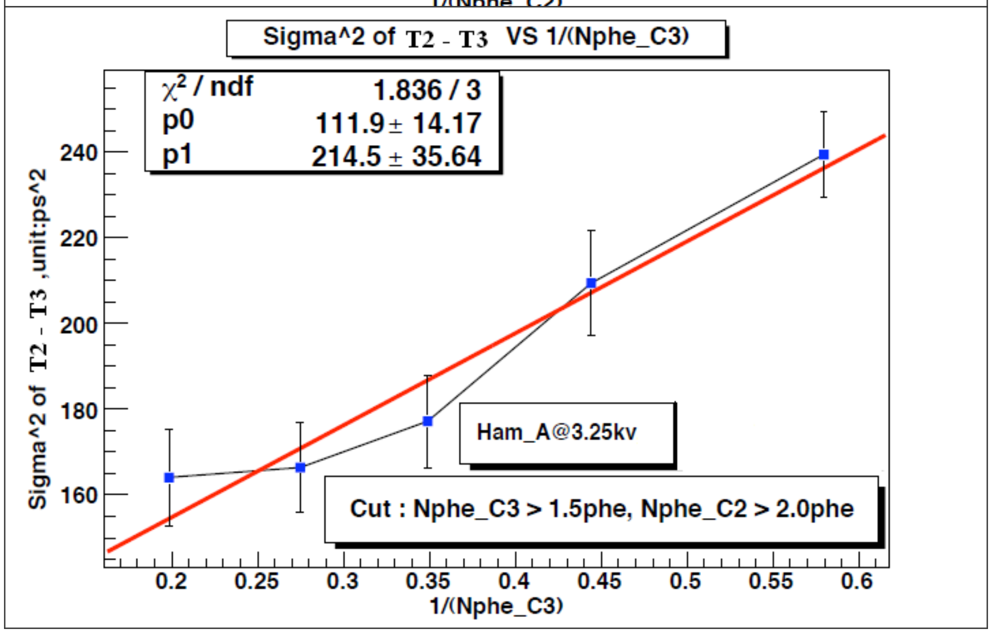


10 ps width corresponds to average **7 ps** detector resolution measured for signals > 4 photoelectrons

… can also study this difference as a function of number of photoelectrons…

GasToF@TB: Final results





- Measure time difference width vs # photoelectrons

$$\sigma^2 = (\sigma_{ref})^2 + (\sigma_{1phe})^2/N_{phe}$$

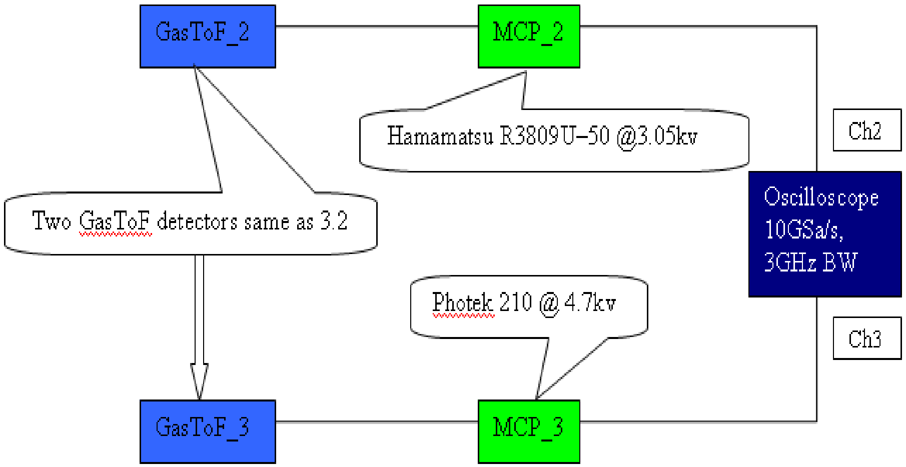
From linear fits to σ^2 vs $1/N_{phe}$ one can extract resolutions for 1 photoelectron signals !

Measured resolution for 1 phe signal is about **15 ps**

(as expected from TTS)

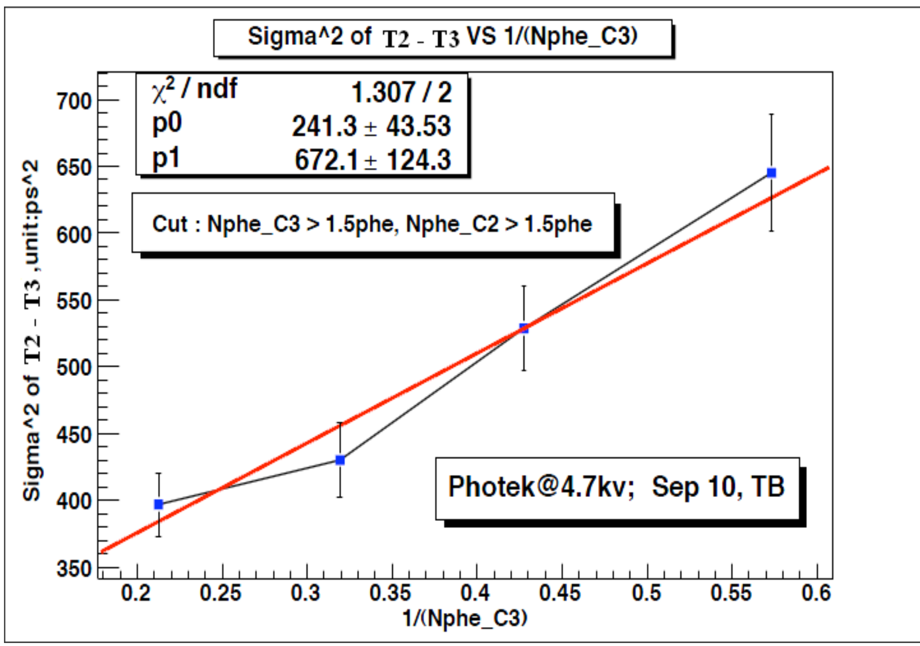
J. Liao

GasToF@TB: Final results



- Another measurement of time difference width vs # photoelectrons, with **PHOTEK** and HPK tubes

J. Liao



$$\sigma^2 = (\sigma_{ref})^2 + (\sigma_{1phe})^2/N_{phe}$$

Measured PHOTEK PMT210 resolution for 1 phe signal is about **25 ps**

(note different setup; it is expected < 15 ps for the previous one)

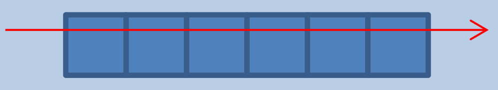
GasToF: One photoelectron mode

- **GasToF** test prototypes have two problems in view of running them at LHC:

1. Lack of multiple hit capability;
2. Very high anode currents + lifetime issues

Solution: To run GasToF detectors in "single photoelectron mode"! Two, each ~30 cm long, configurations possible: a) several very short, single anode detectors in a row – each with an average signal of about 0.7 phe; b) one long detector with fast ~20 cm^2, 8x8 multi-anode MCP-PMT – with total signal of about 16 phe, and up to ~0.5 phe per anode.

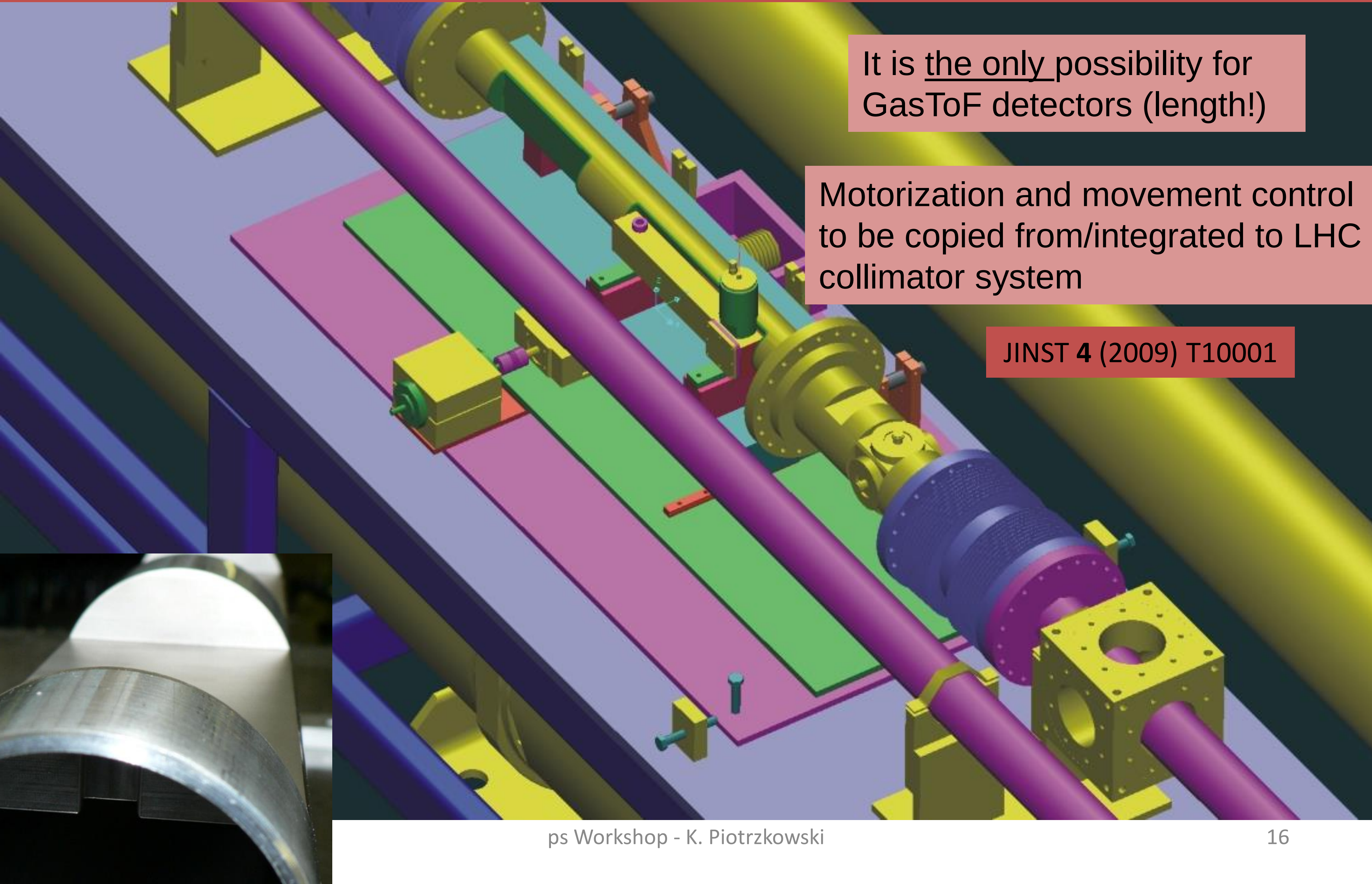
a) 6x1



b)

- To increase lifetime, enhance UV part – use MgF_2 windows + photocathodes <u>only</u> sensitive in deep UV ('solar blind') – have already one such PHOTEK PMT210; and then apply other solutions – HPK offers MCP-PMTs with thin foil ion barrier; one can hope for ALD MCPs too…

A must@LHC: Movable Hamburg pipe



It is <u>the only</u> possibility for GasToF detectors (length!)

Motorization and movement control to be copied from/integrated to LHC collimator system

JINST **4** (2009) T10001

GasToF: ~~R~~&D and Outlook

- Should put *asap* in the LHC tunnel existing, tested **GasToF** prototypes; to study and verify near-beam background conditions + make first measurements already in 2015?

- For running in 2016 can prepare first 4-in-row detector(s) with PHOTEK (MgF_2/solar blind) and HPK MCP-PMTs + first multi-anode **GasToF** with PHOTONIS 10 μm MCP-PMT XP85112 with 35 ps TTS

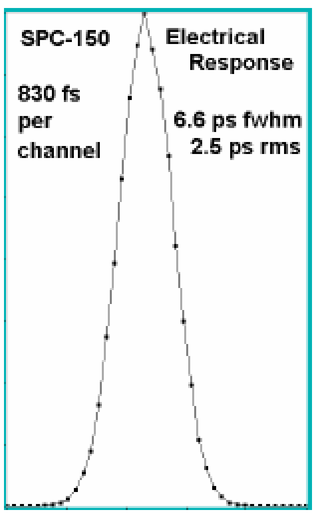
- Beyond 2018 one needs to use some of lifetime fixes discussed earlier – expected annual anode charge is 2-5 C/cm^2 for 100 fb^{-1}

- Note that multi-anode detectors have large potential; timing resolution driven by TTS – if 15 ps can be reached there too, an overall resolution of 5 ps is then possible…

- … provided a very performing DAQ…

Single channel **GasToF** & SPC-150 modules

Picosecond resolution
Ultra-high sensitivity
Multi-detector / multi-wavelength capability
High-speed on-board data acquisition
Photon distribution and time-tag modes
Image acquisition by synchronisation with ext. scanner
Unlimited sequential recording of curves or images
Imaging in histogram mode and in time-tag mode
Works at any scan rate of CLSMs or MPLSMs
Time channel width down to 813 fs
Electrical time resolution (Jitter) 6.6 ps fwhm / 2.5 ps rms
Reversed start/stop: Laser repetition rates up to 150 MHz
Saturated count rate 10 MHz
Total useful recorded count rate up to 5 MHz
Dead time 100 ns



Note: This system provides timing resolution < 3 ps !

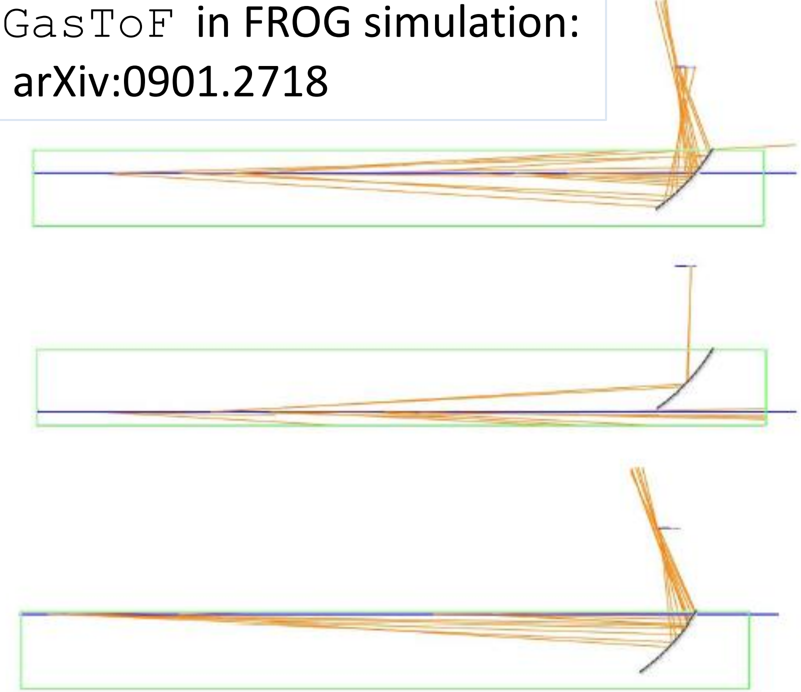
It is designed/ready for (analog) input signals directly from Hamamatsu R3809…
UCLouvain has a one channel PCI card successfully tested → could be used for initial/reference measurements at LHC

For final configuration a multi-channel custom made TDC DAQ system is necessary. Based on HPTDC?

To fully profit from `GasToF` performance a DAQ time resolution of (at least) 5 ps is required.

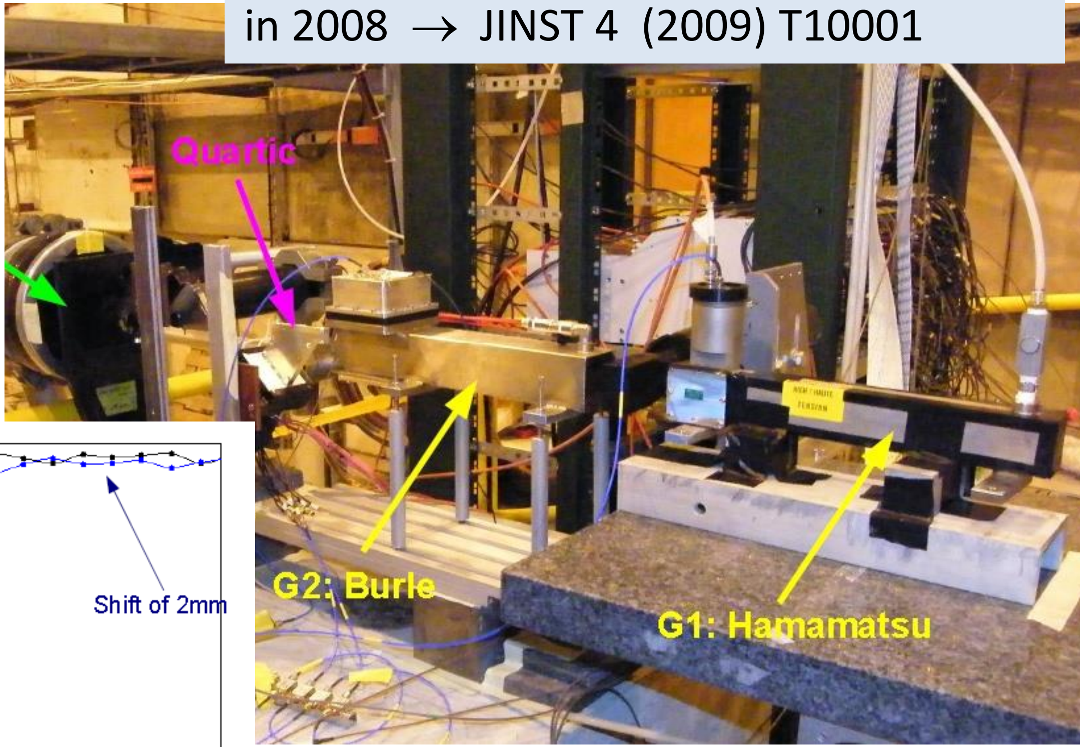
Extra slides

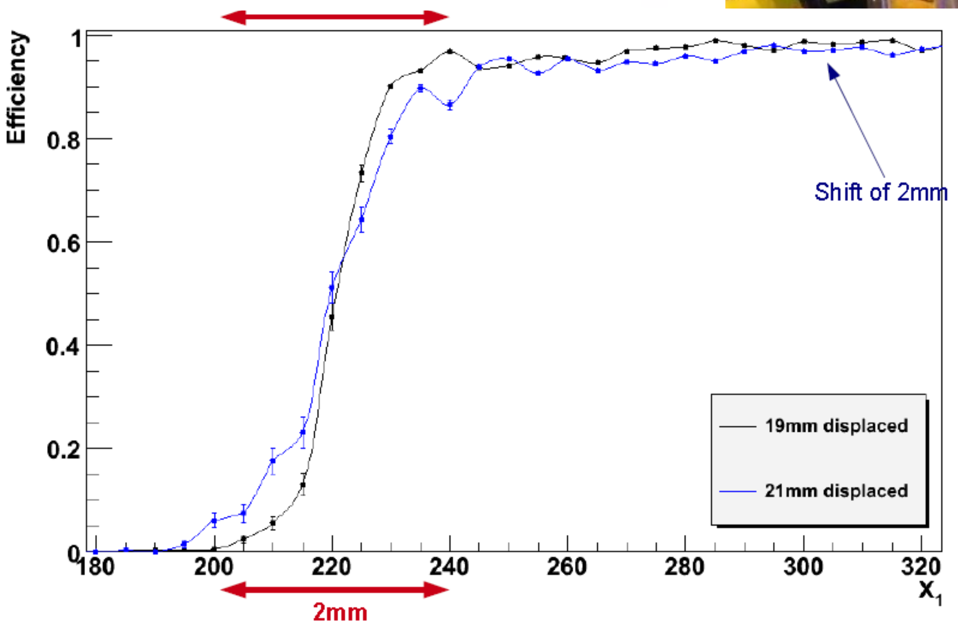
GasToF in FROG simulation:
arXiv:0901.2718



N. Schul

Two GasToF detectors at CERN test beam in 2008 → JINST 4 (2009) T10001

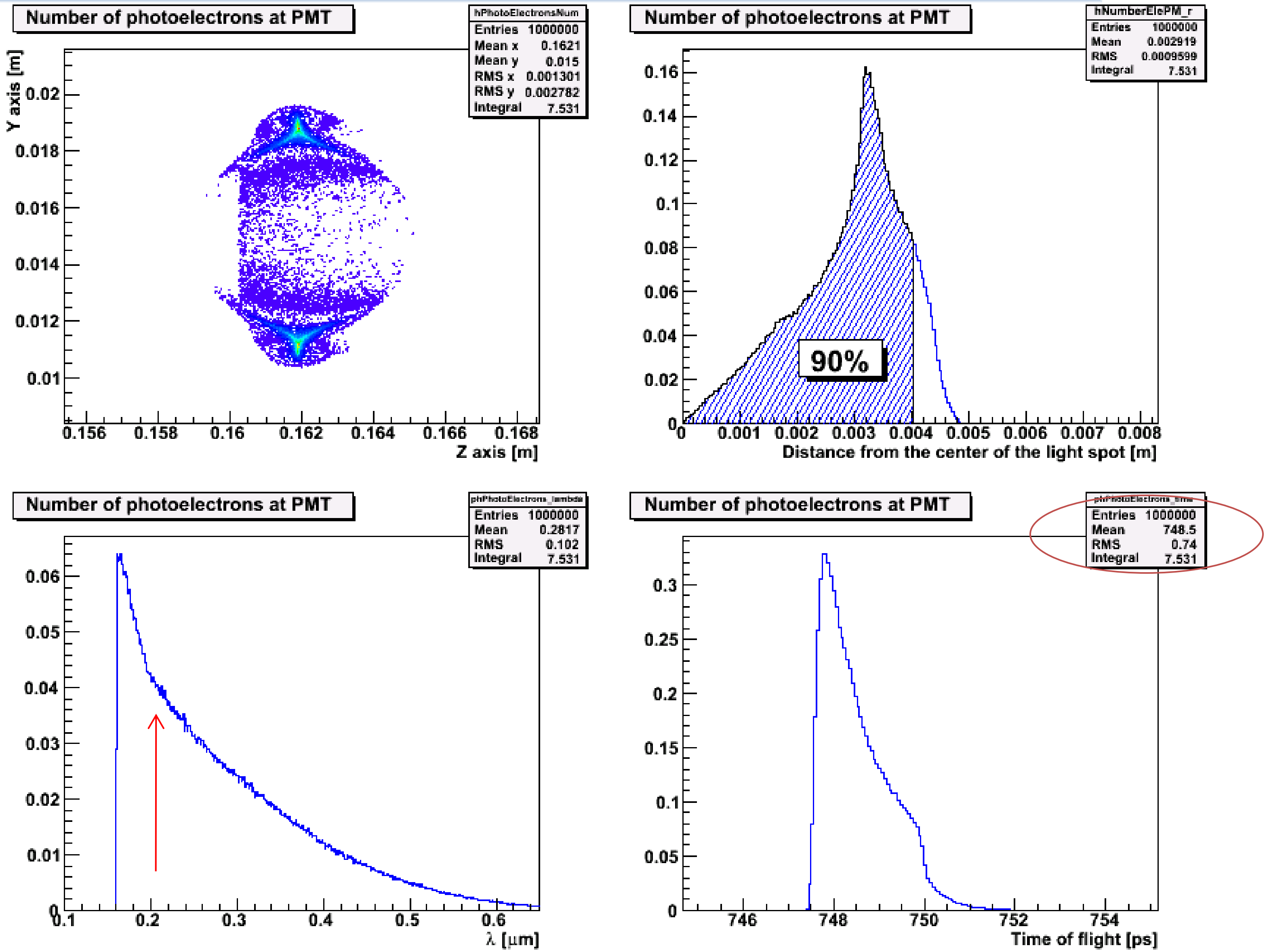




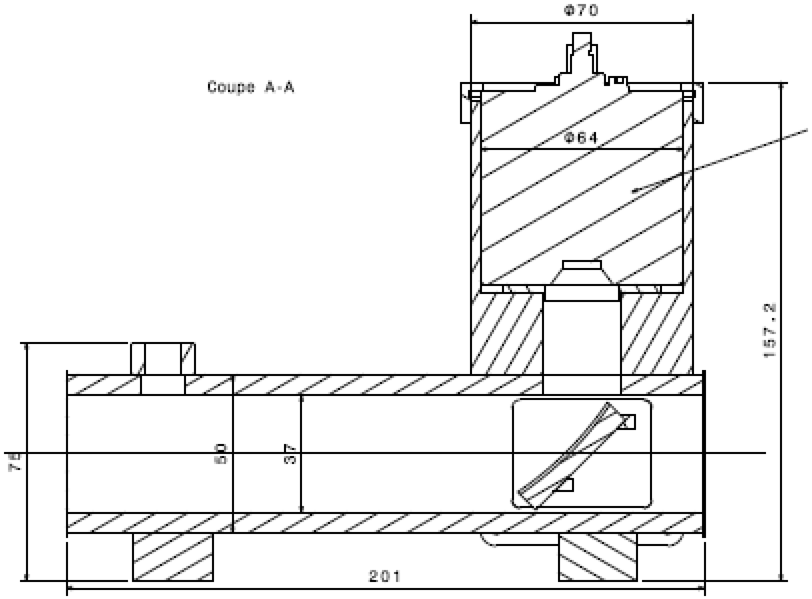
High statistics beam test results:
- High efficiency (~98%), down to close mechanical edge
- Good description by MC

Short GasToF (20cm), reflective beam-wall, R3809U-58 PMT, protons on axis:

Nicolas Schul



ULTRA FAST PHOTOMULTIPLIERS Photek



	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

Received from PHOTEK two 3 μm pore MCP-PMTs…

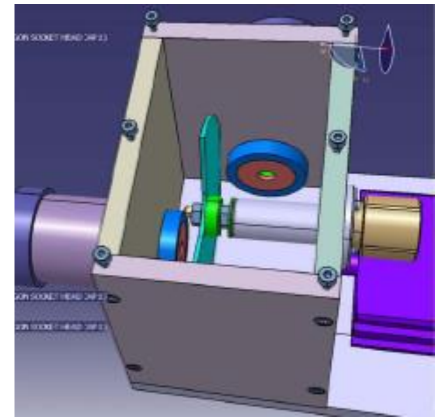
…so fast that had to upgrade to yet faster scope…

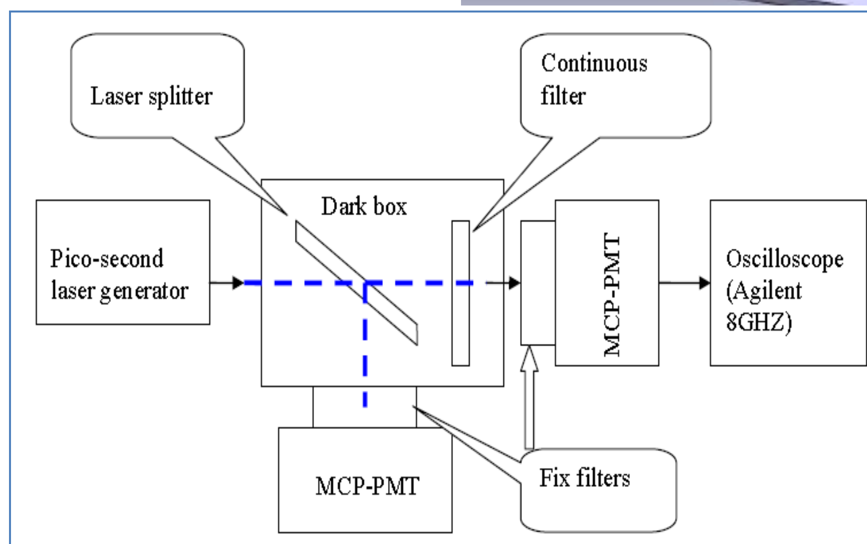
Dedicated picosecond laser test setup was developed to characterize fastest MCP-PMTs from Photek and Hamamatsu – using Agilent scope with 8 GHz BW and 40 GSamples/s

PILxxx	wavelength (nm)	tolerance (nm)	spectral width (nm)	pulse width (ps)
PIL037	375	± 10	< 7	< 60
PIL040	408	± 10	< 7	< 45

FWHM

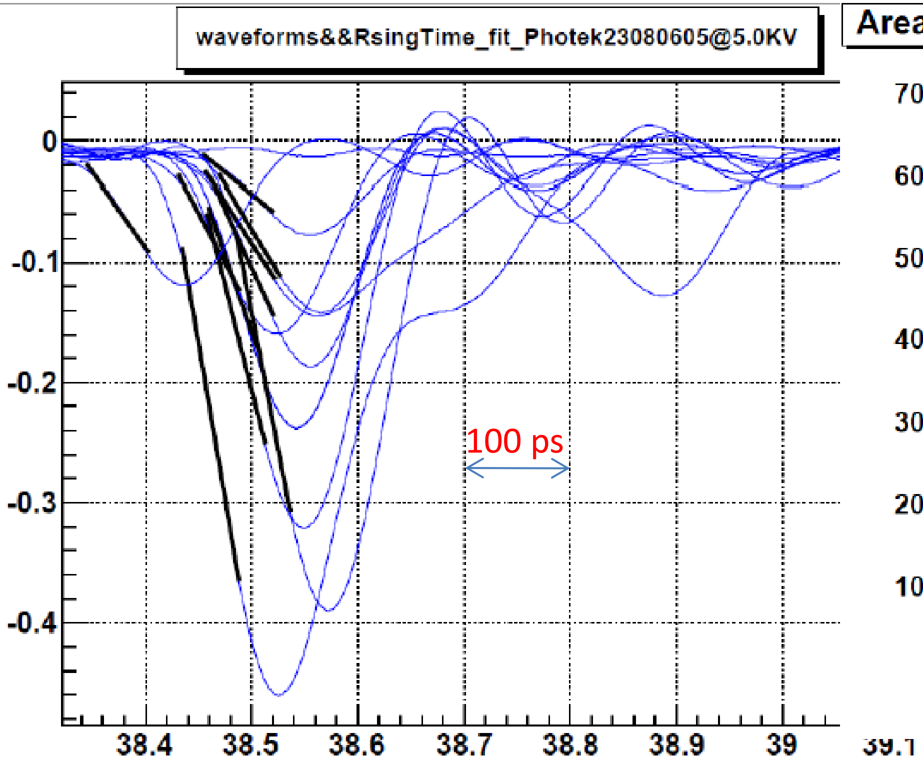
PiLas 408 nm



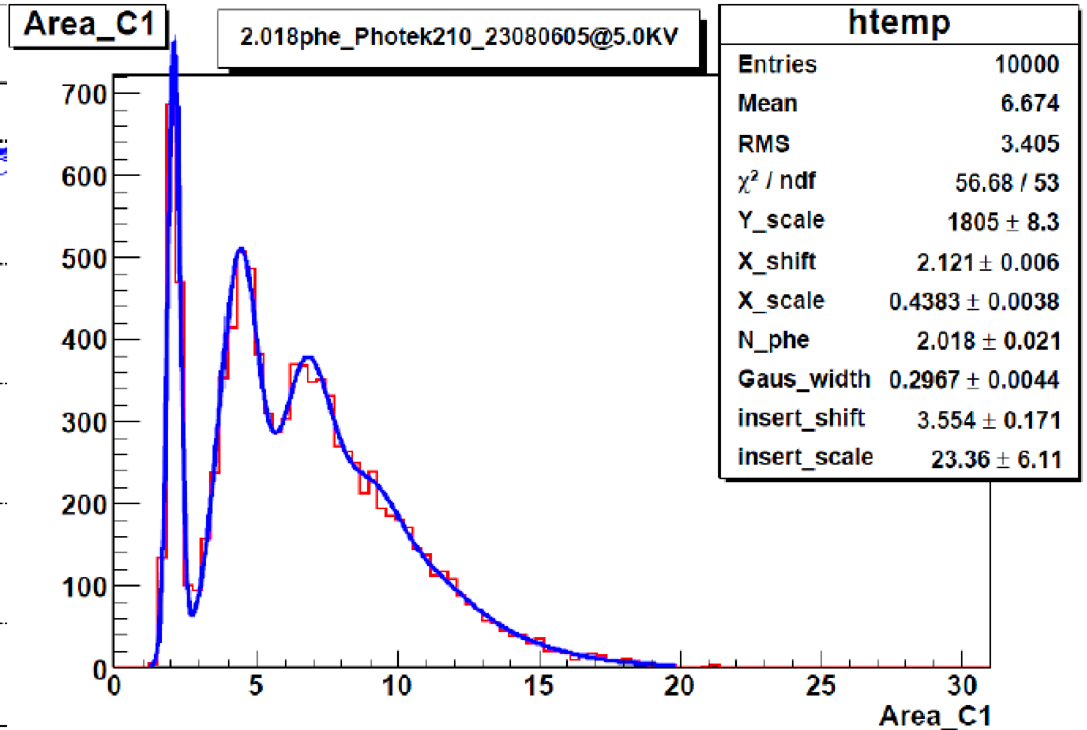


PiLas laser test setup runs up to 1 MHz repetition rate at 408 nm and using 8 GHz Agilent scope with 40 GSa/s

J. Liao



Photek23090605_2.5phe

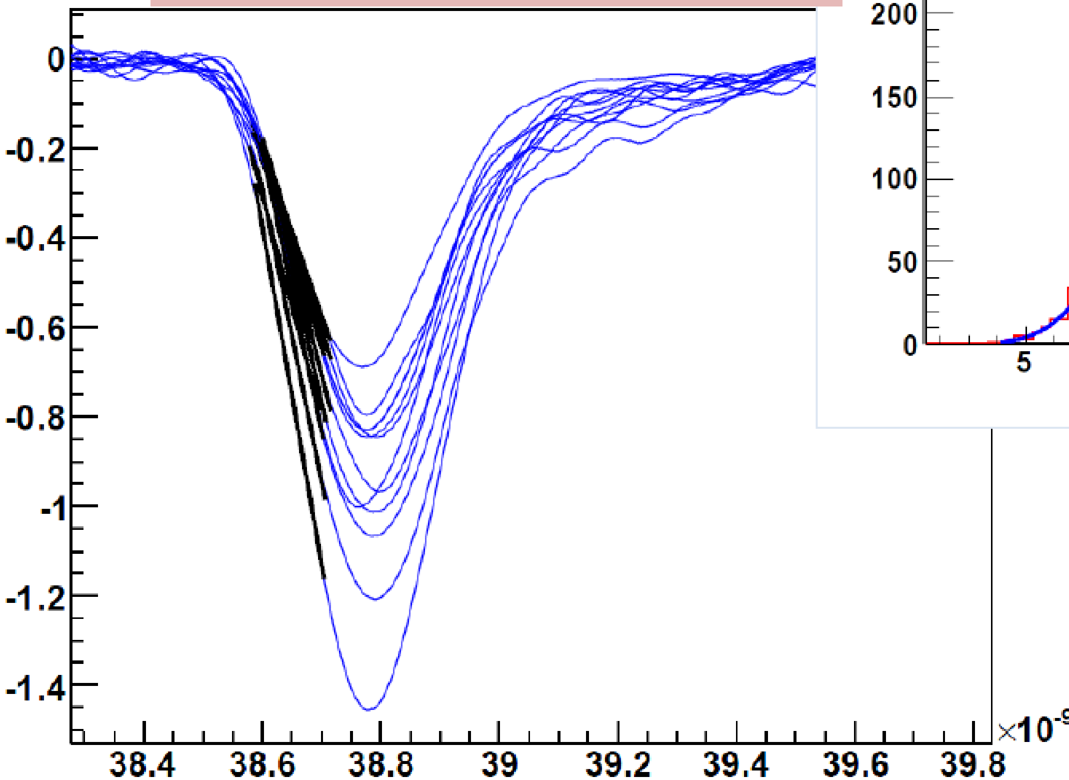


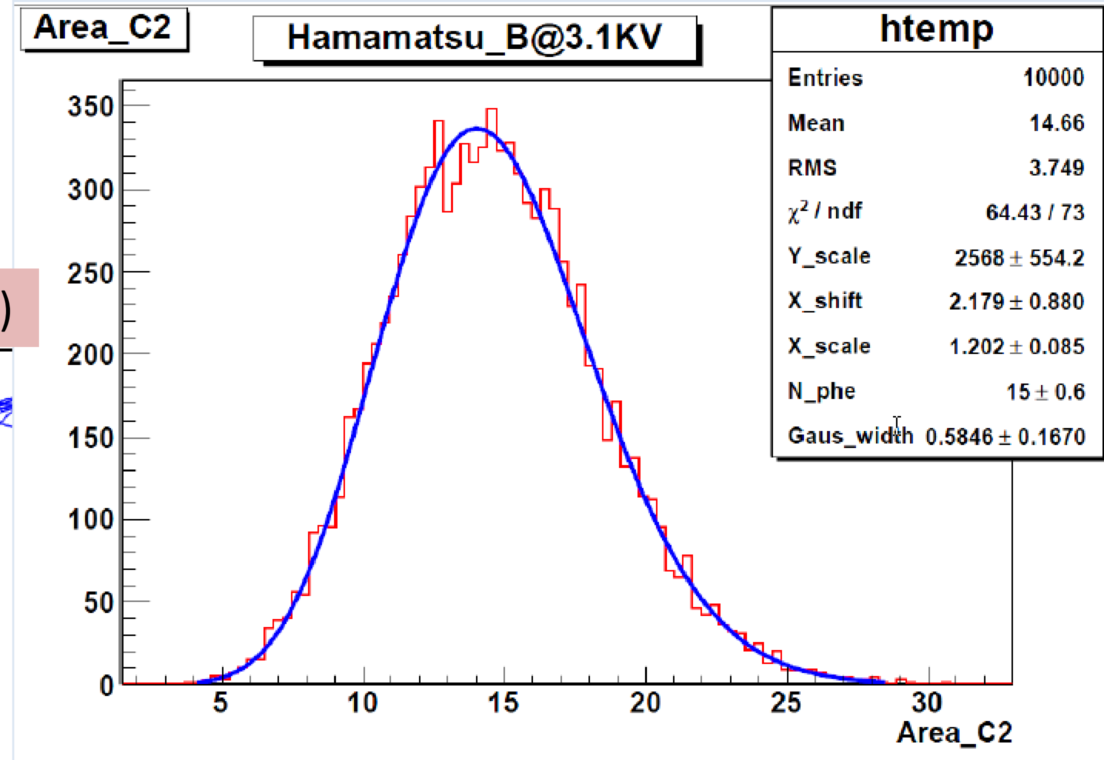
Impressive rise time (10→90%) measured: 80 ps for PHOTEK 3 μm pore **PMT210** (and 150 ps for R 3809U-50)

Example of anode charge distribution for low light pulse; 0, 1 and 2 phe peaks are clearly visible; line shows fitted detector response model

Waveforms and anode charge distribution from Hamamatsu R 3809U-50

Laser test measurements (J. Liao)





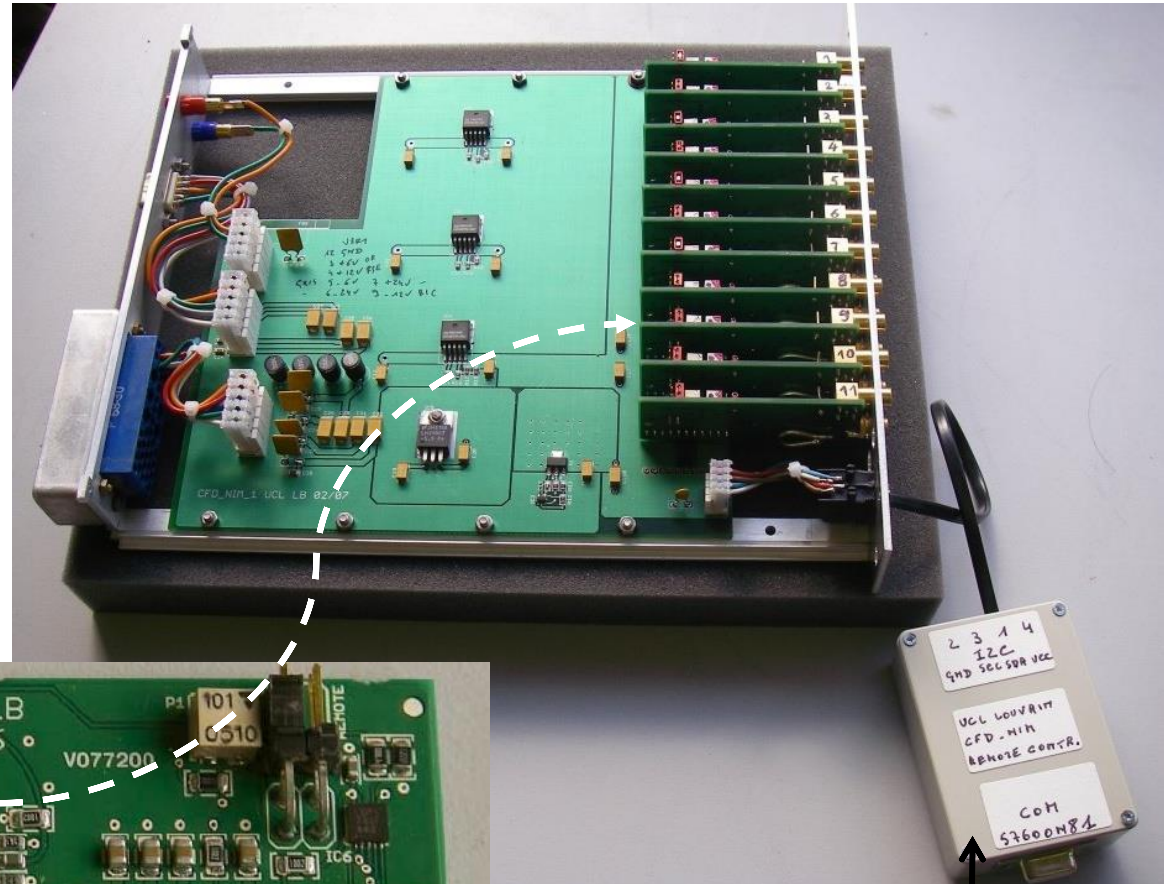
Good understanding of laser tests:
→ Reliable modeling of waveforms (mostly charge)
→ Input to MC simulations

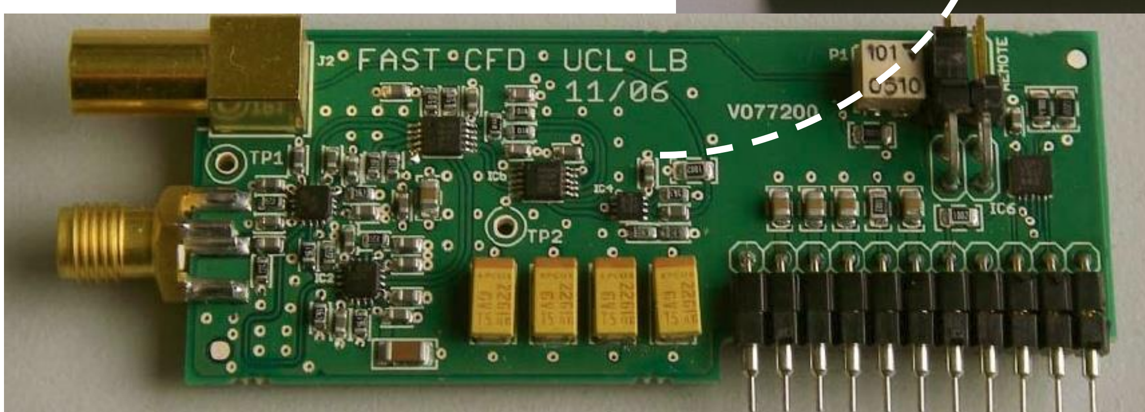
Fast Constant Fraction Discriminator

L. Bonnet (UCLouvain)

Development of LCFD

- 12 channel NIM units
- mini-module approach tuned to PMT rise time (HPK/Photek vs Photonis)
- Good performance: < 10 ps resolution for 4 or more phe's (A. Brandt)

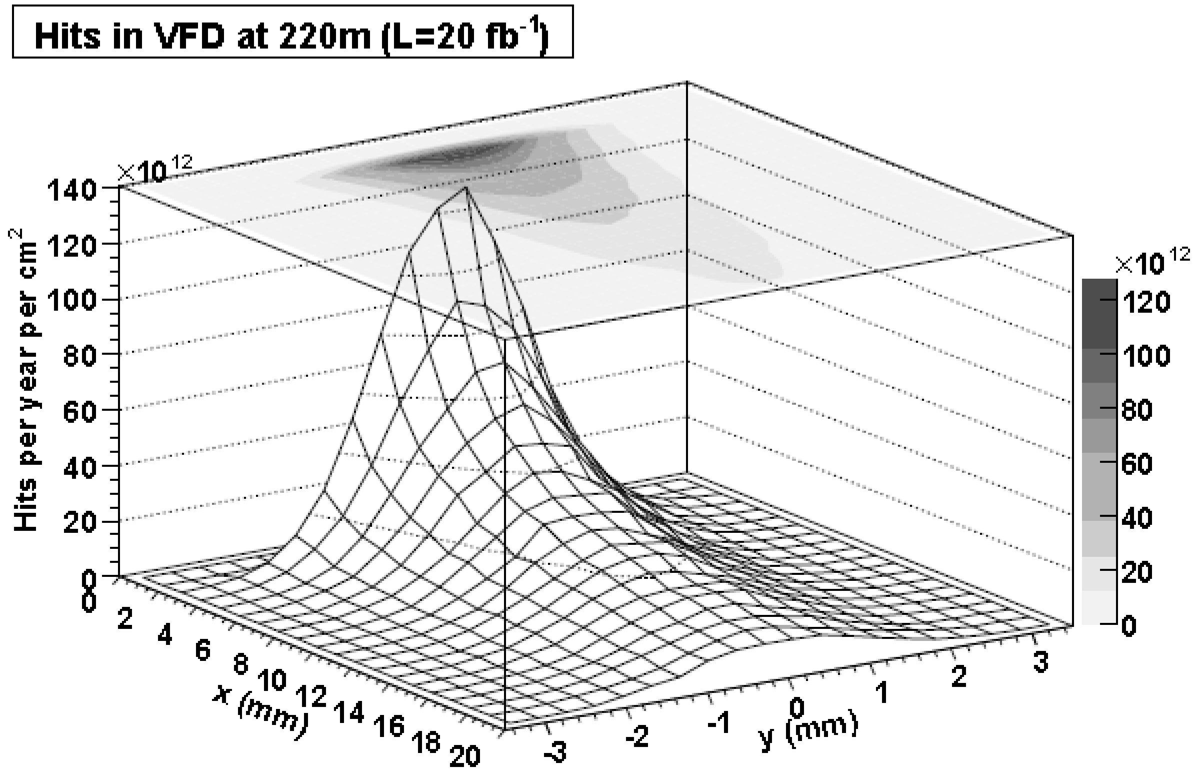


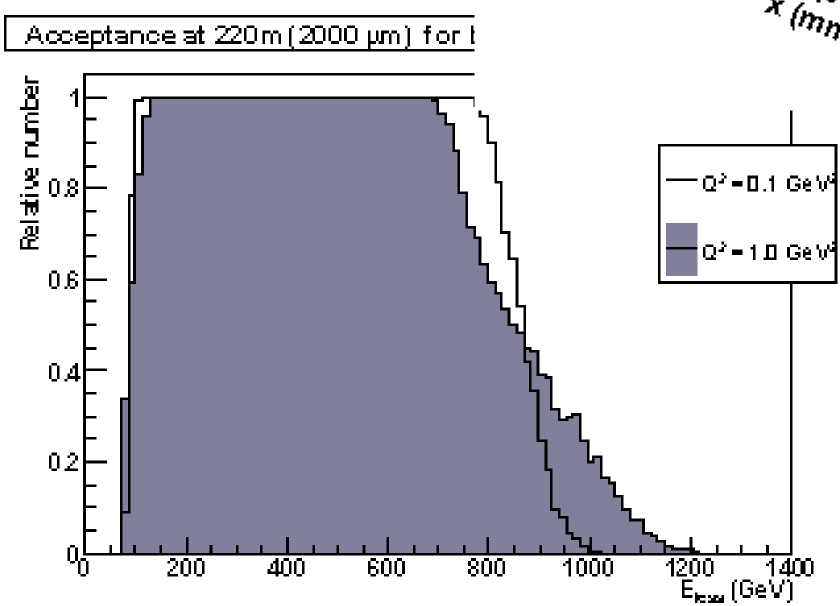


Remote control for threshold

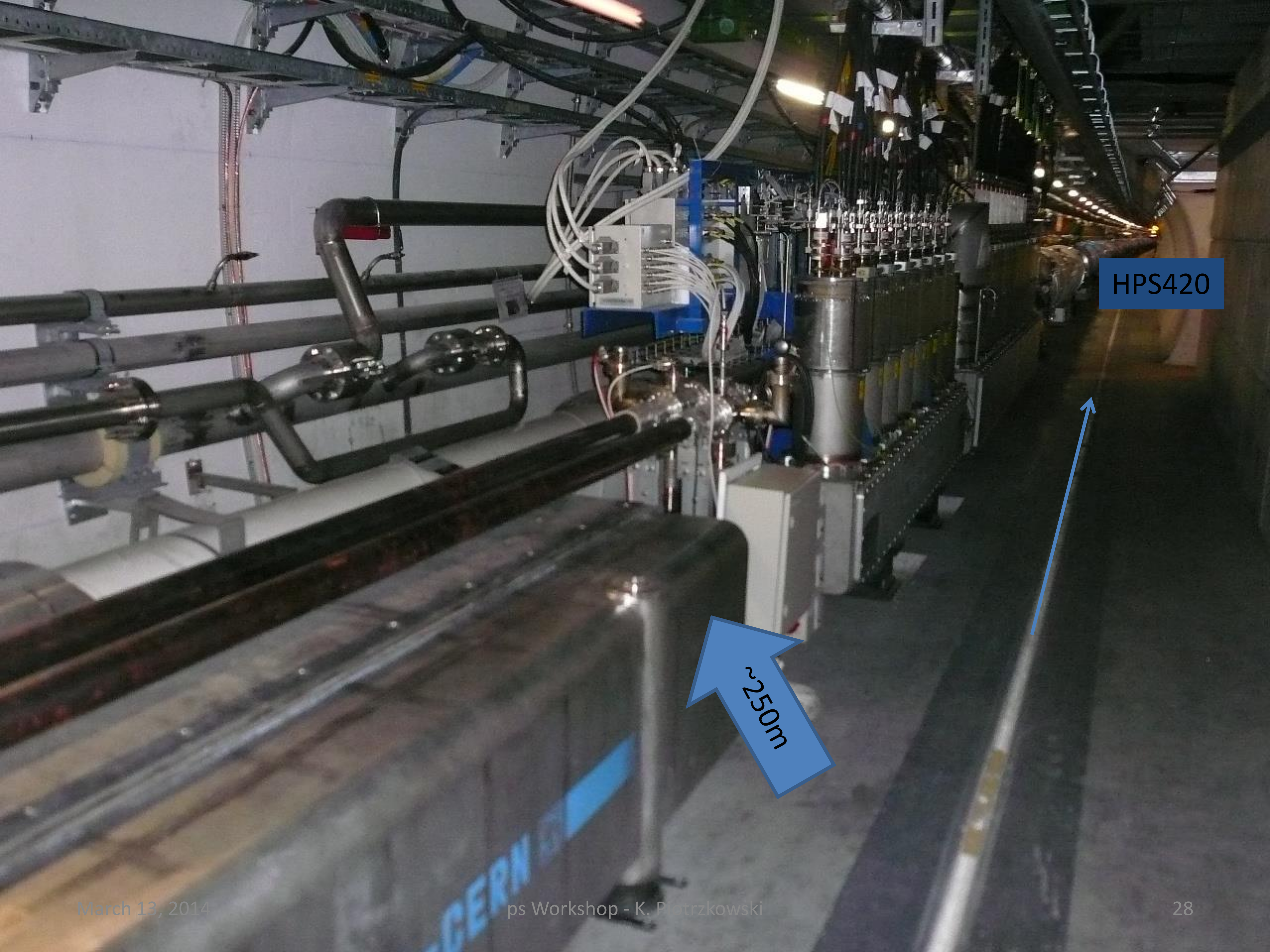
Forward proton acceptance @ $\beta^* = 0.5$ m

HECTOR: **JINST 2, P09005 (2007)**

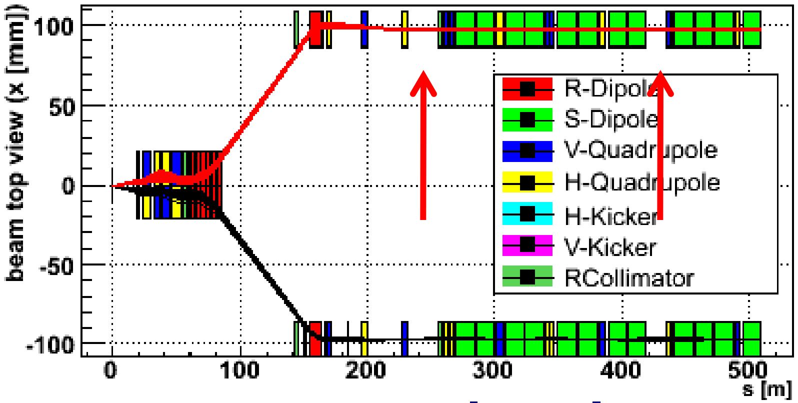




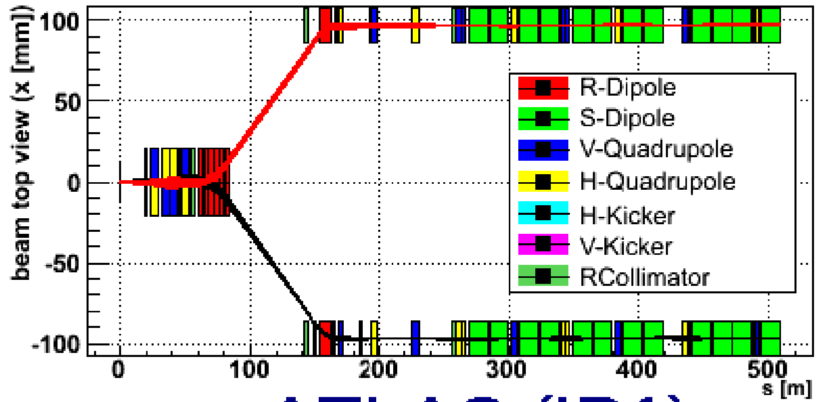
Similar proton lateral distributions to HPS420


HPS420
~250m
CERN

Optimal places for tagging Central Exclusive Production (CEP) at LHC: @ 220/240m and 420m from IP

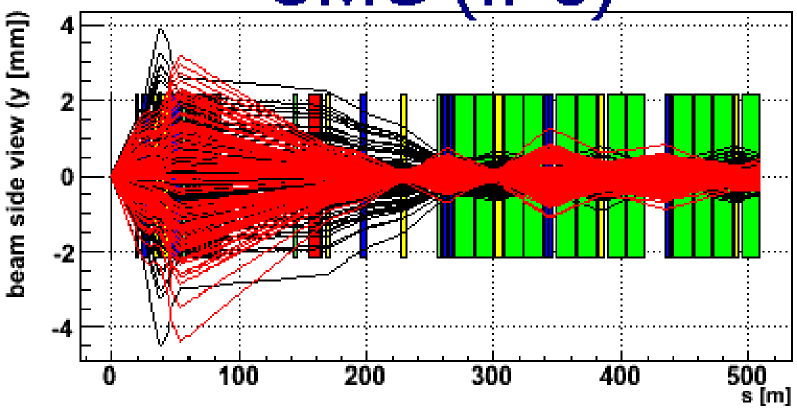


top

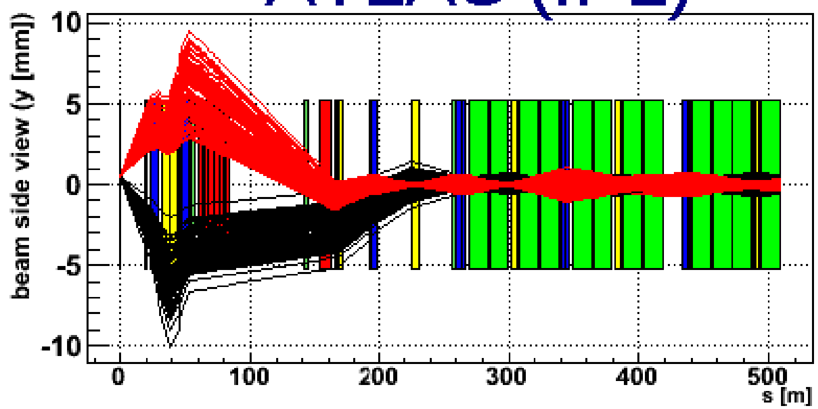


CMS (IP5)

ATLAS (IP1)



side



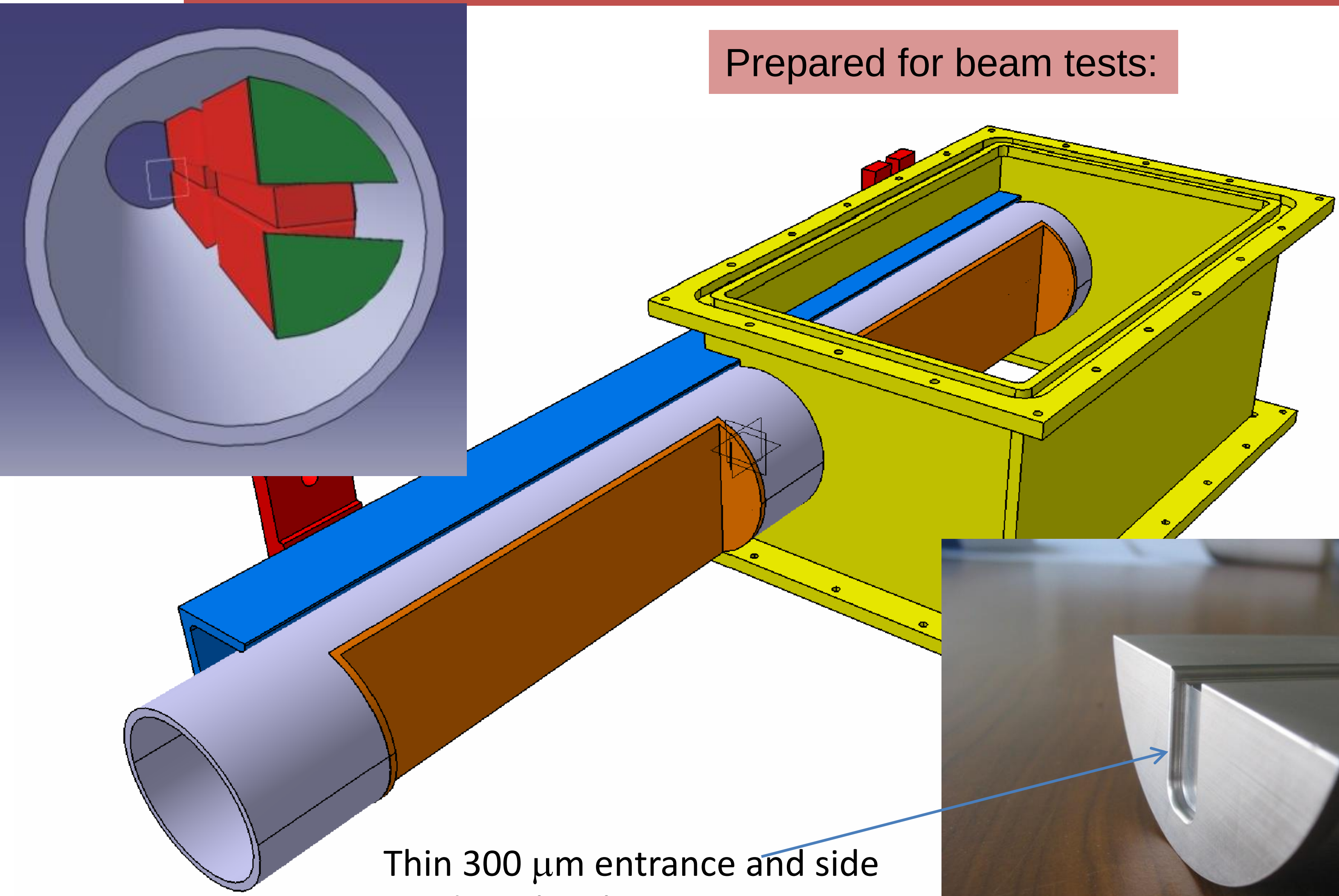
Horizontal crossing plane

Vertical crossing plane

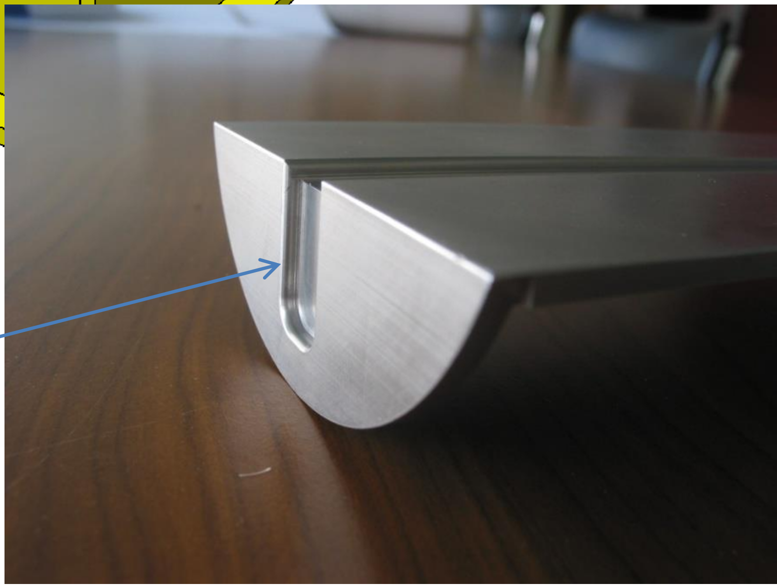
HECTOR: **JINST 2, P09005 (2007)**

For <u>nominal</u> low-β LHC optics

Moving pipe: Detector ‘pockets’



Prepared for beam tests:



Thin 300 μm entrance and side windows by electro-erosion