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

K. Piotrzkowski (UCLouvain – CP[3] Center)

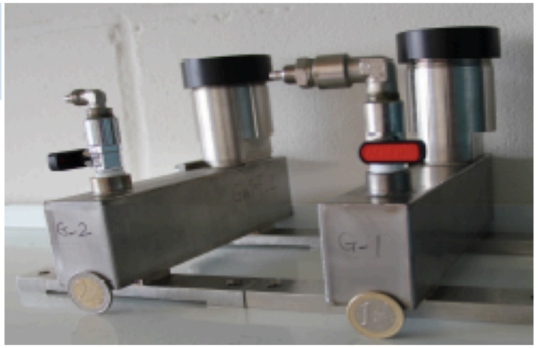
Introduction and LHC (Fast) Motivation

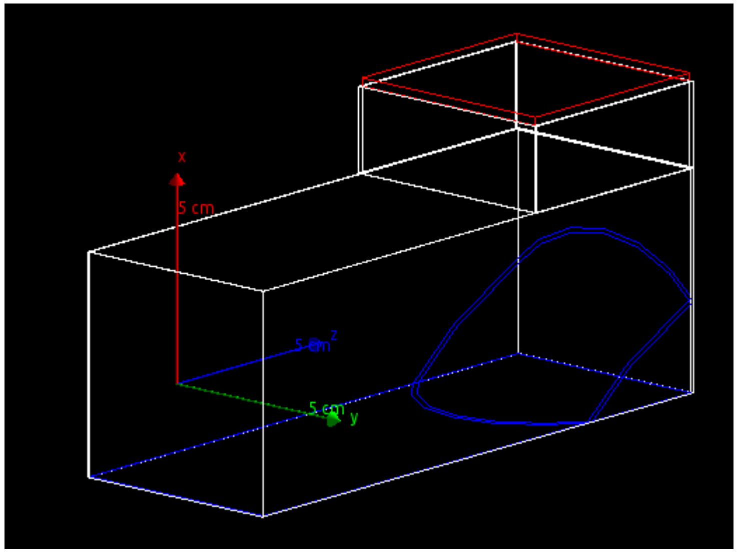
GasToF: One anode paper (reminder)

One photoelectron principle and multi-anode design

Next steps

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

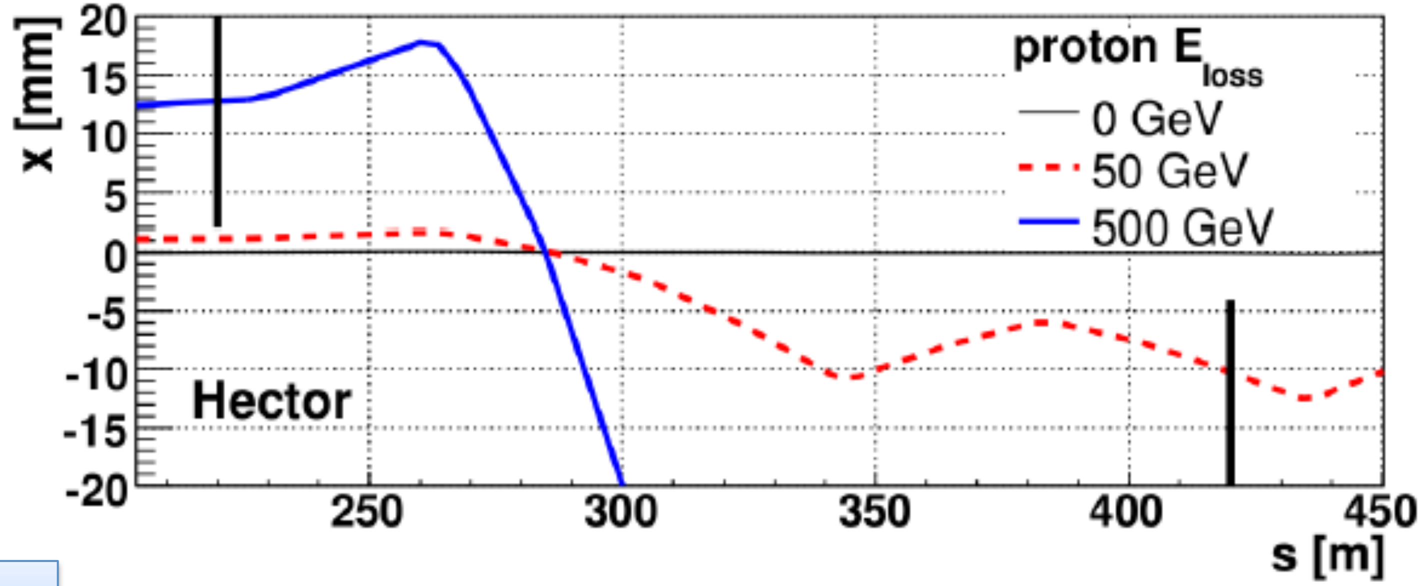




ps timing workshop

Institute of Physics (Praha)

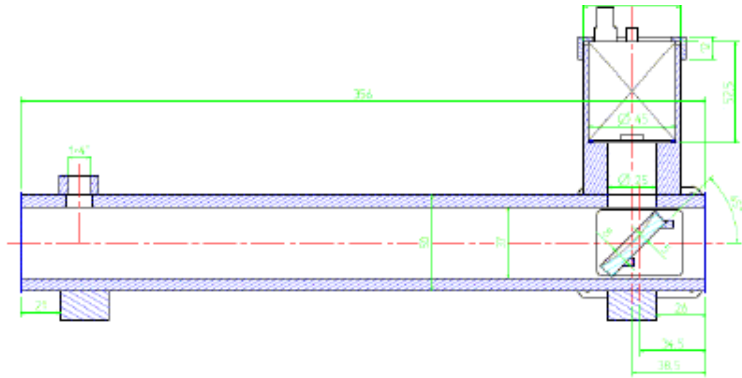
Forward proton trajectories @ LHC



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!

GasToF™ Concept



- Gas Čerenkov – direct, very forward light propagation (no internal reflections) – intrinsically very fast, excellent resolutions with single photons

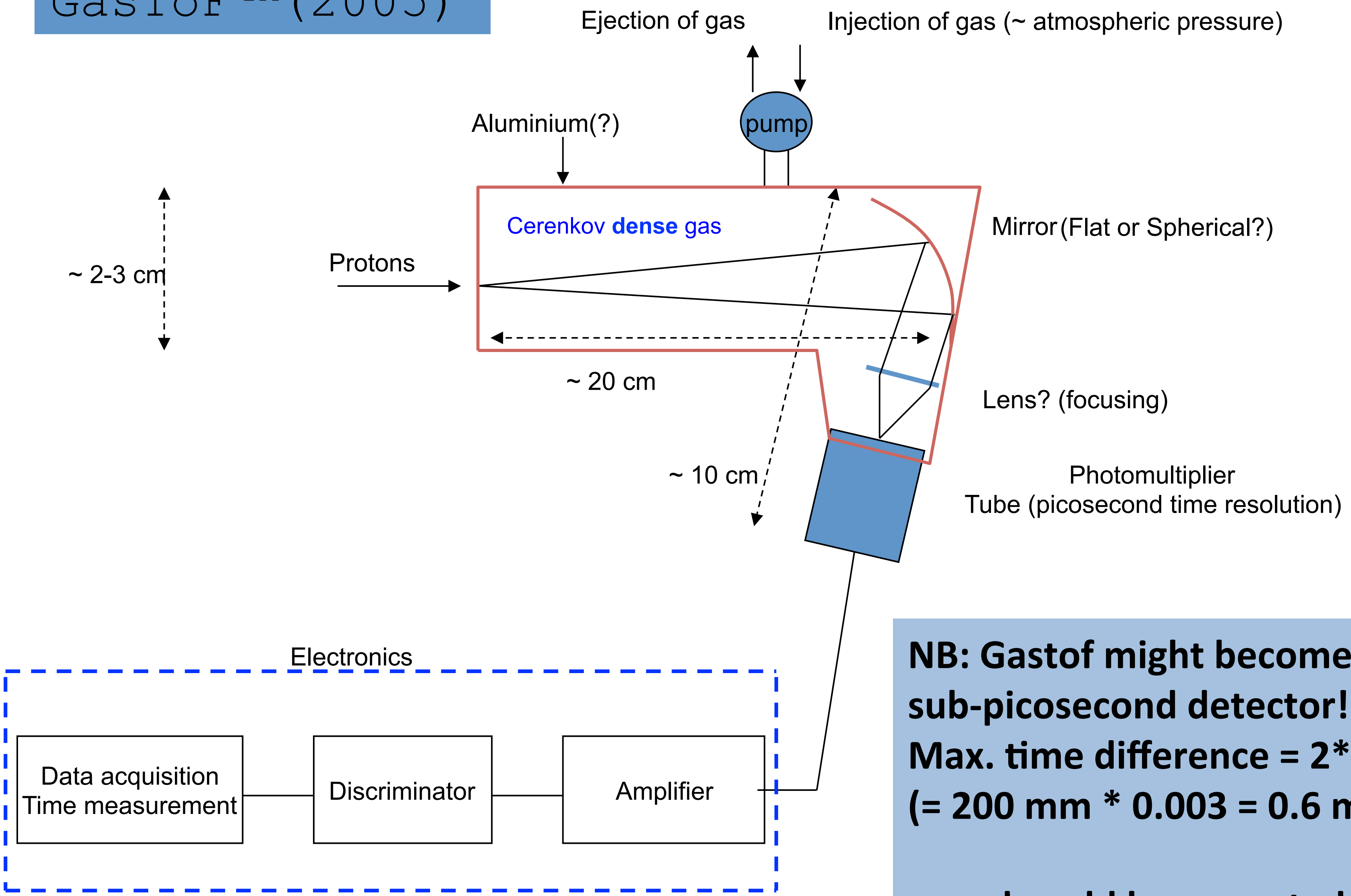
- Very simple "optics" thanks to small chromatic dispersion; light spectrum peaking at deep UV

- 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)

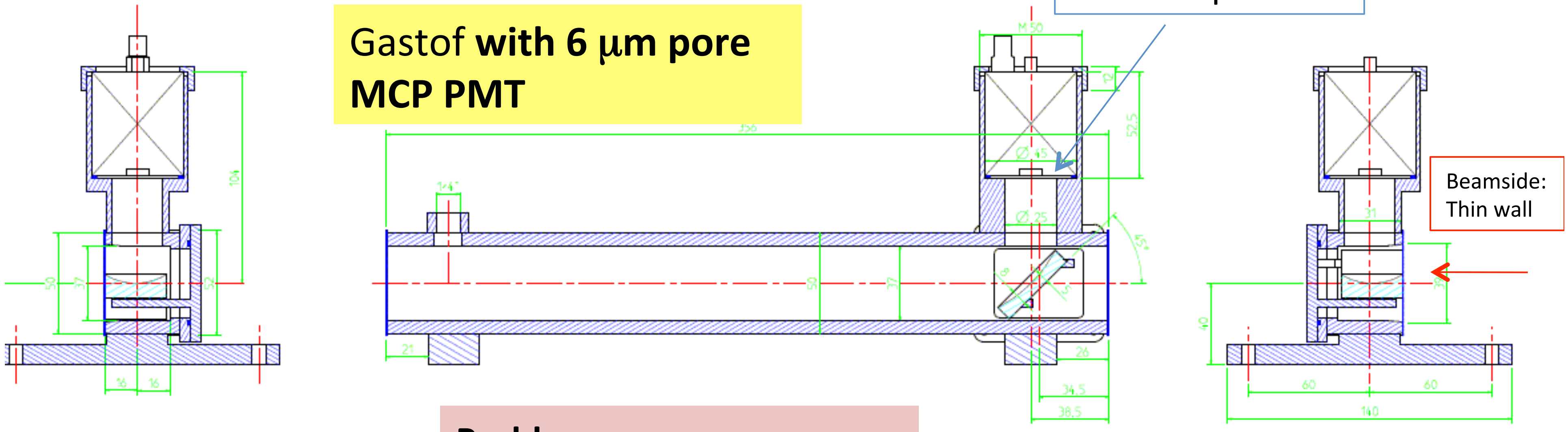


NB: Gastof might become sub-picosecond detector!
Max. time difference = 2*L*Δn
(= 200 mm * 0.003 = 0.6 mm)

… and could be corrected for !

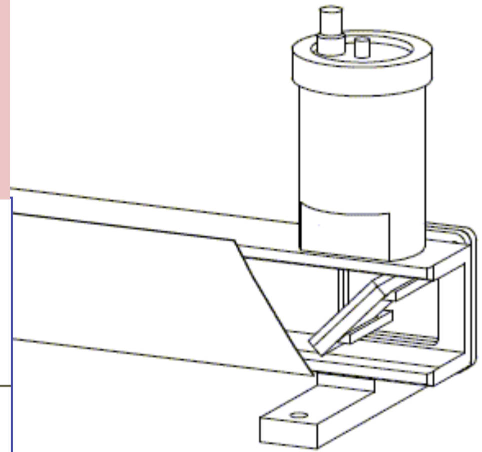
Gastof **with 6 μm pore MCP PMT**

Gas leak problem



Beamside: Thin wall

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

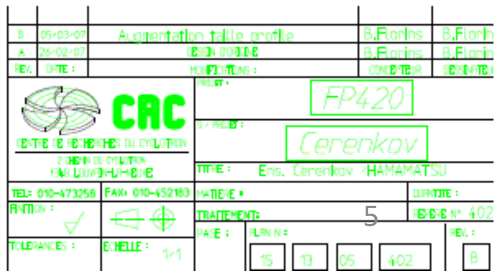


HAMAMATSU

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

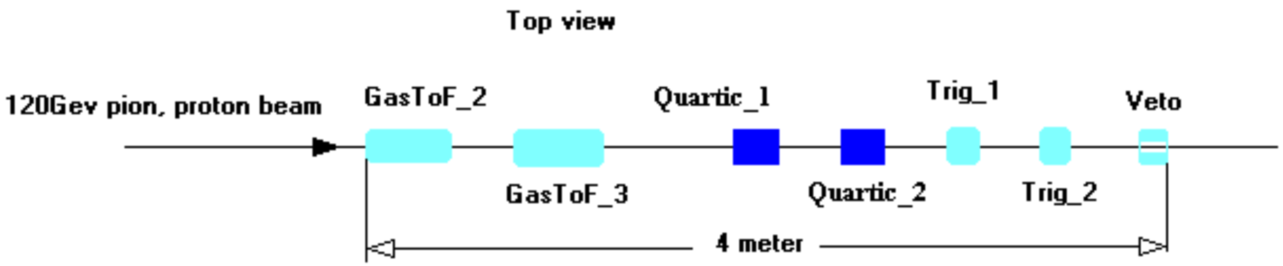
Compact MCP-PMT Series Featuring
Variety of Spectral Response with Fast Time Response

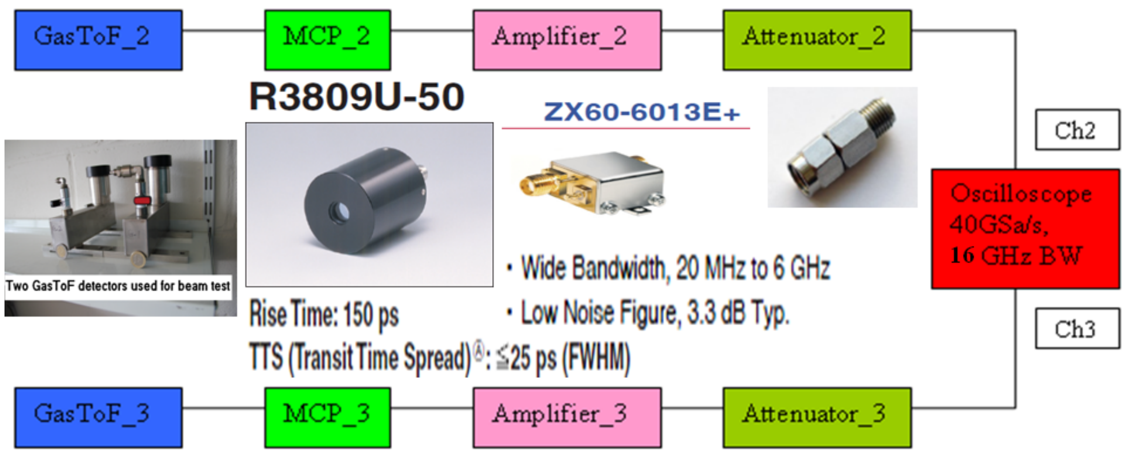
FEATURES
- High Speed
  Rise Time: 150ps
  T.T.S. (Transit Time Spread)[1]: ≤ 25ps(FWHM)
- Low Noise
- Compact Profile
  Useful Photocathode: 11mm diameter
  (Overall length: 70.2mm Outer diameter: 45.0mm)

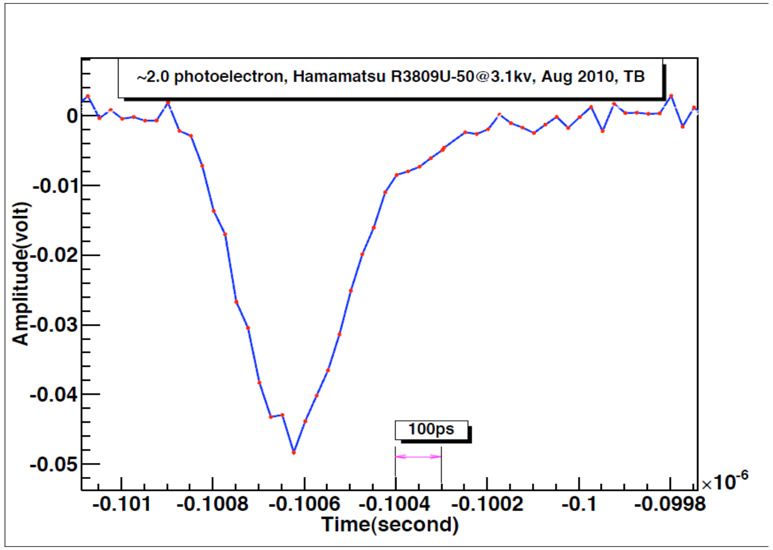


GasToF @ CERN test beam

- 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

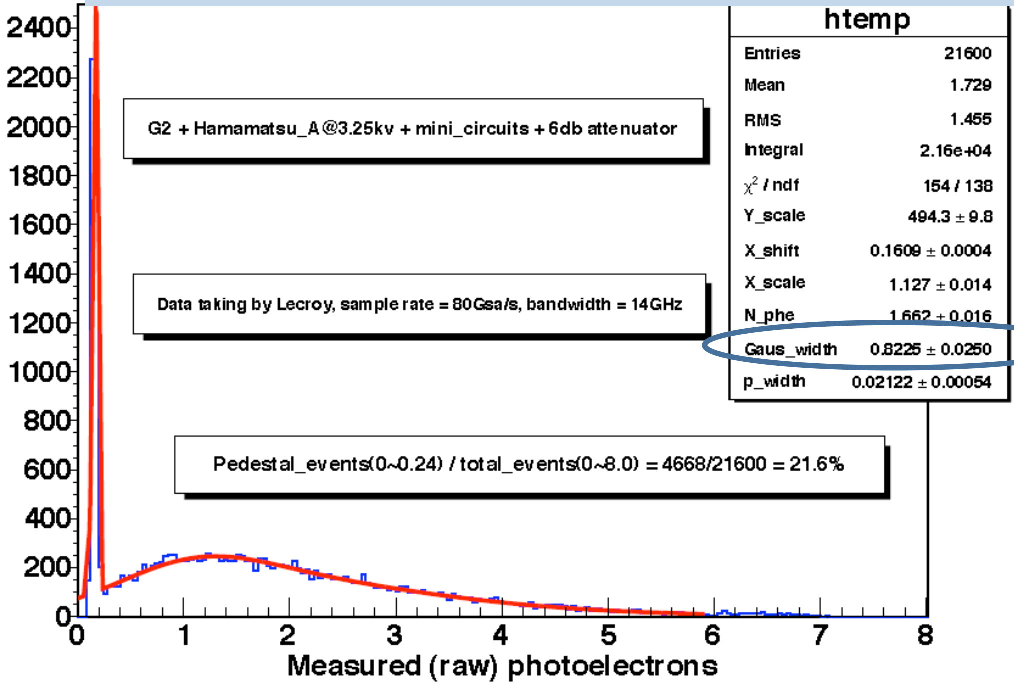




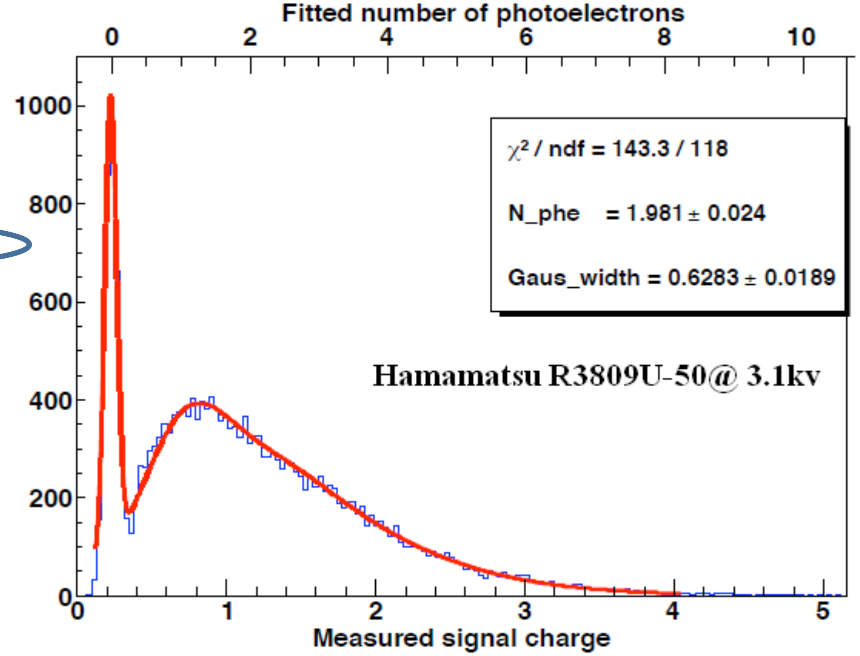


GasToF@TB: Published results

- 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

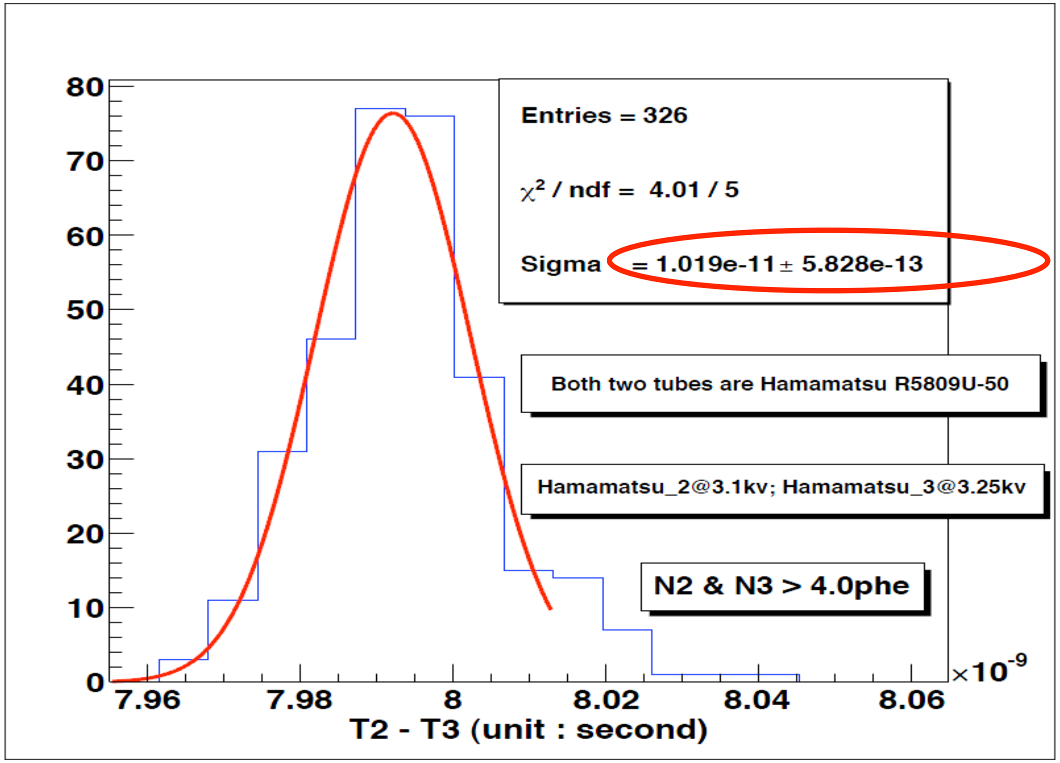


Published in NIM **A762** (2014) 77

GasToF@TB: Published results

- Time difference between two GasToF detectors:

J. Liao

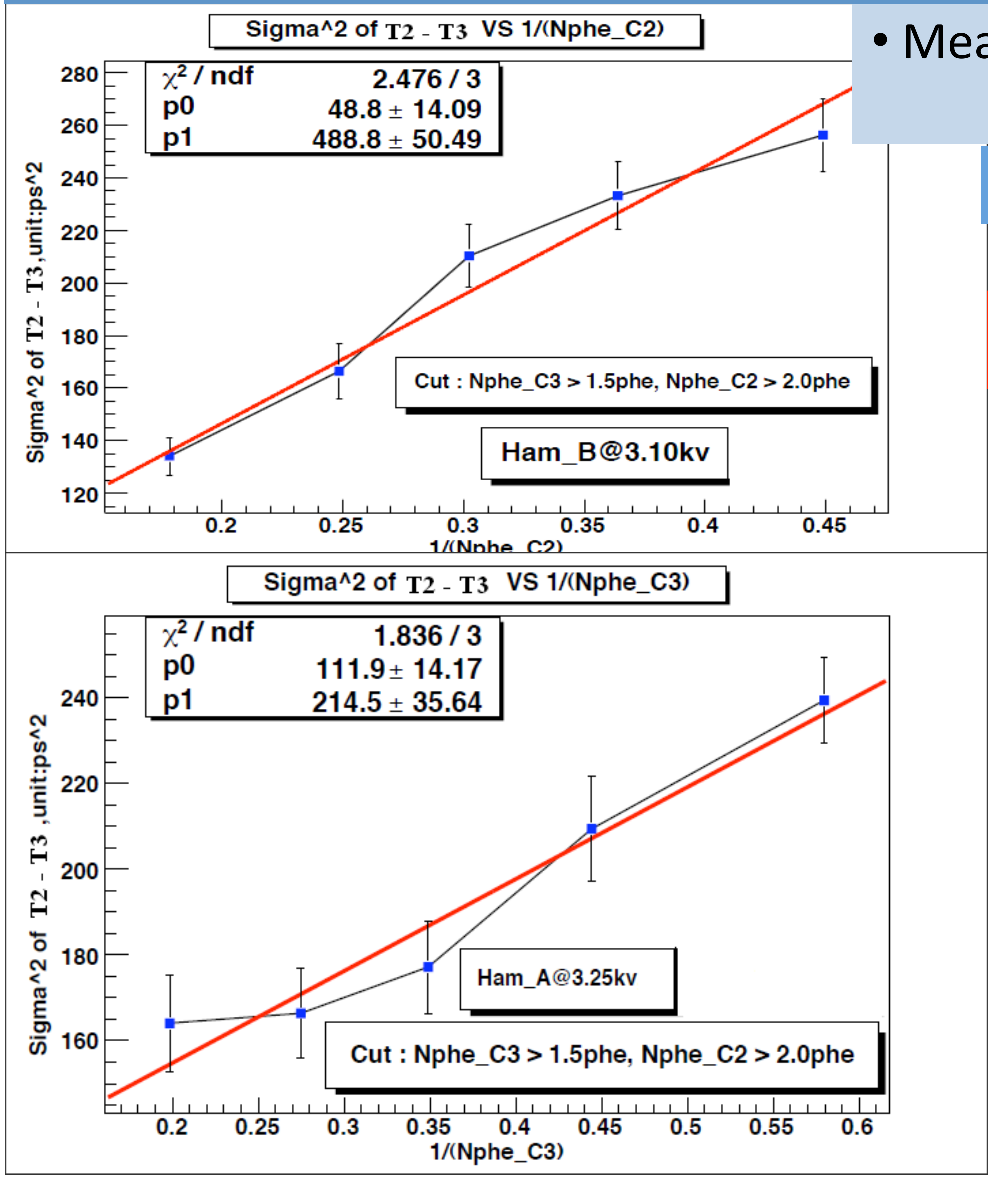


10 ps width corresponds to average **7 ps** detector resolution measured for signals > 4 photoelectrons

Published in NIM **A762** (2014) 77

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

GasToF@TB: Published results



- Measure time difference width vs # photoelectrons

J. Liao

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

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)

Published in NIM **A762** (2014) 77

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

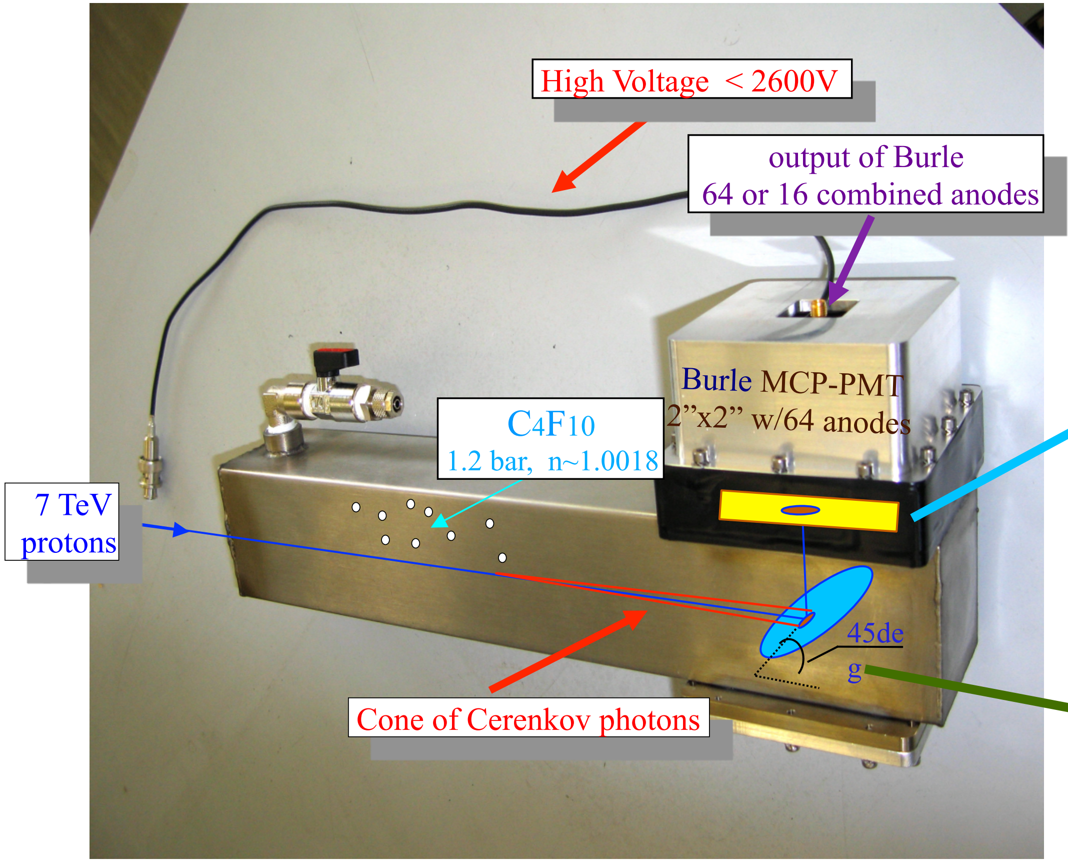
Solution: detector with fast 8x8 multi-anode MCP-PMT – with total signal of about 16 phe, and up to ~0.5 phe per anode.

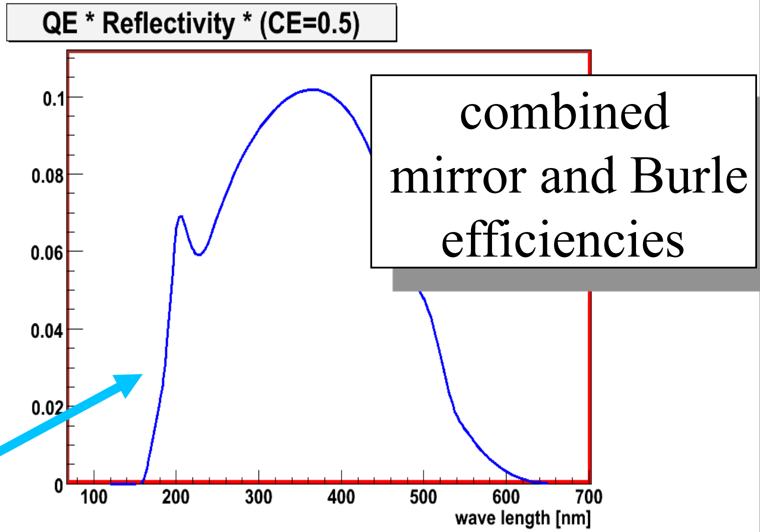
• To increase lifetime, enhance UV part – use MgF_2 windows + photocathodes only sensitive in deep UV ('solar blind') – and eventually ALD treated MCPs.

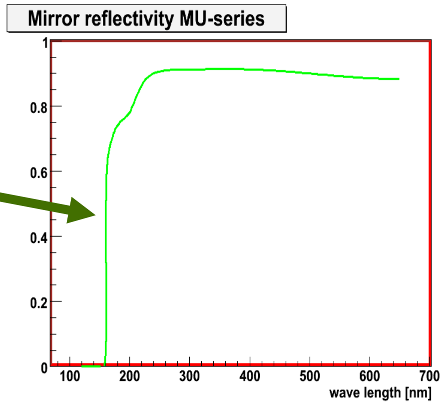
Caveat: For multi-hit case the time measurement is feasible but there is no position sensitivity, so one cannot associate time to tracks

Example solution: Run together with pixel detectors of good (but inferior) time resolution

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

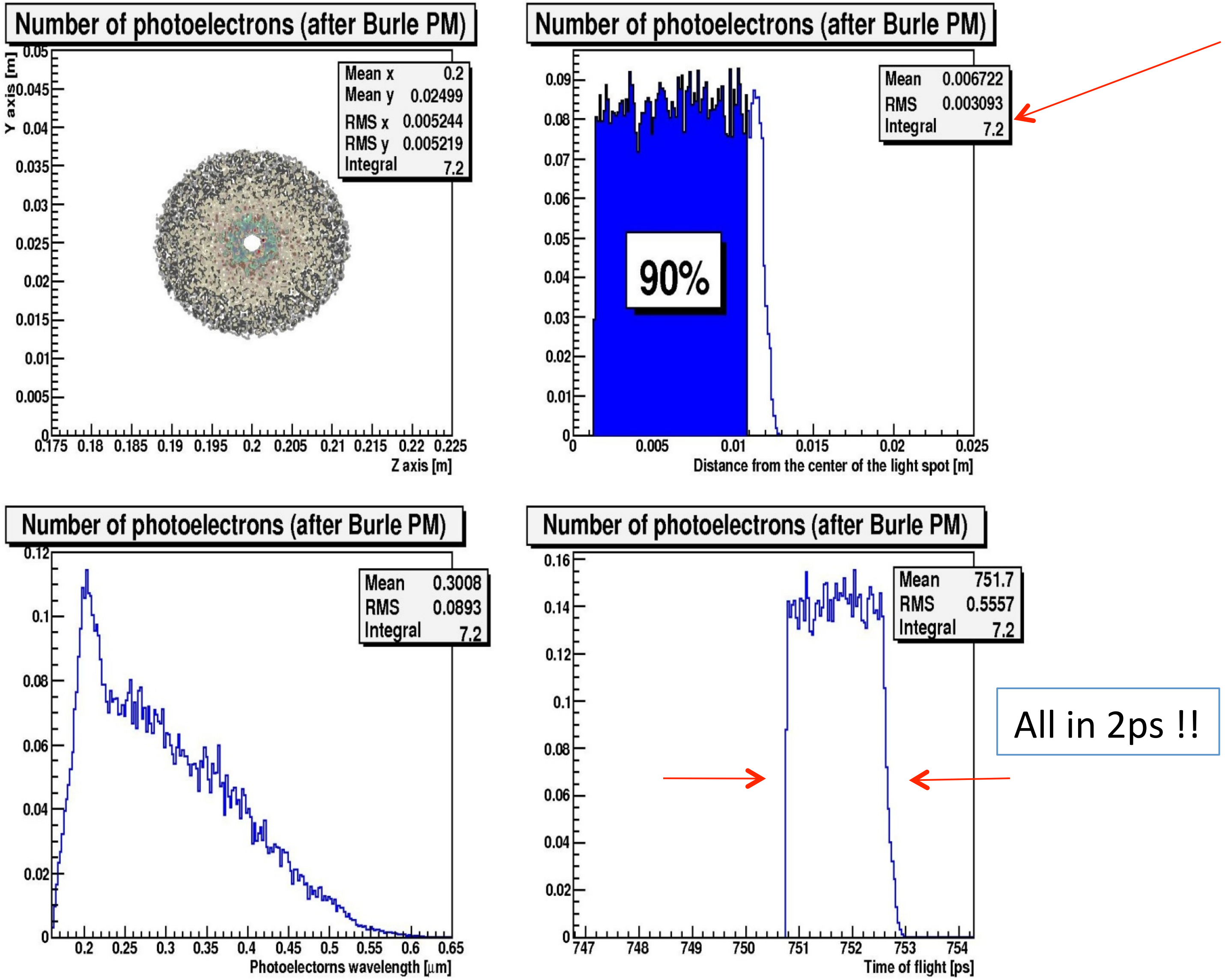






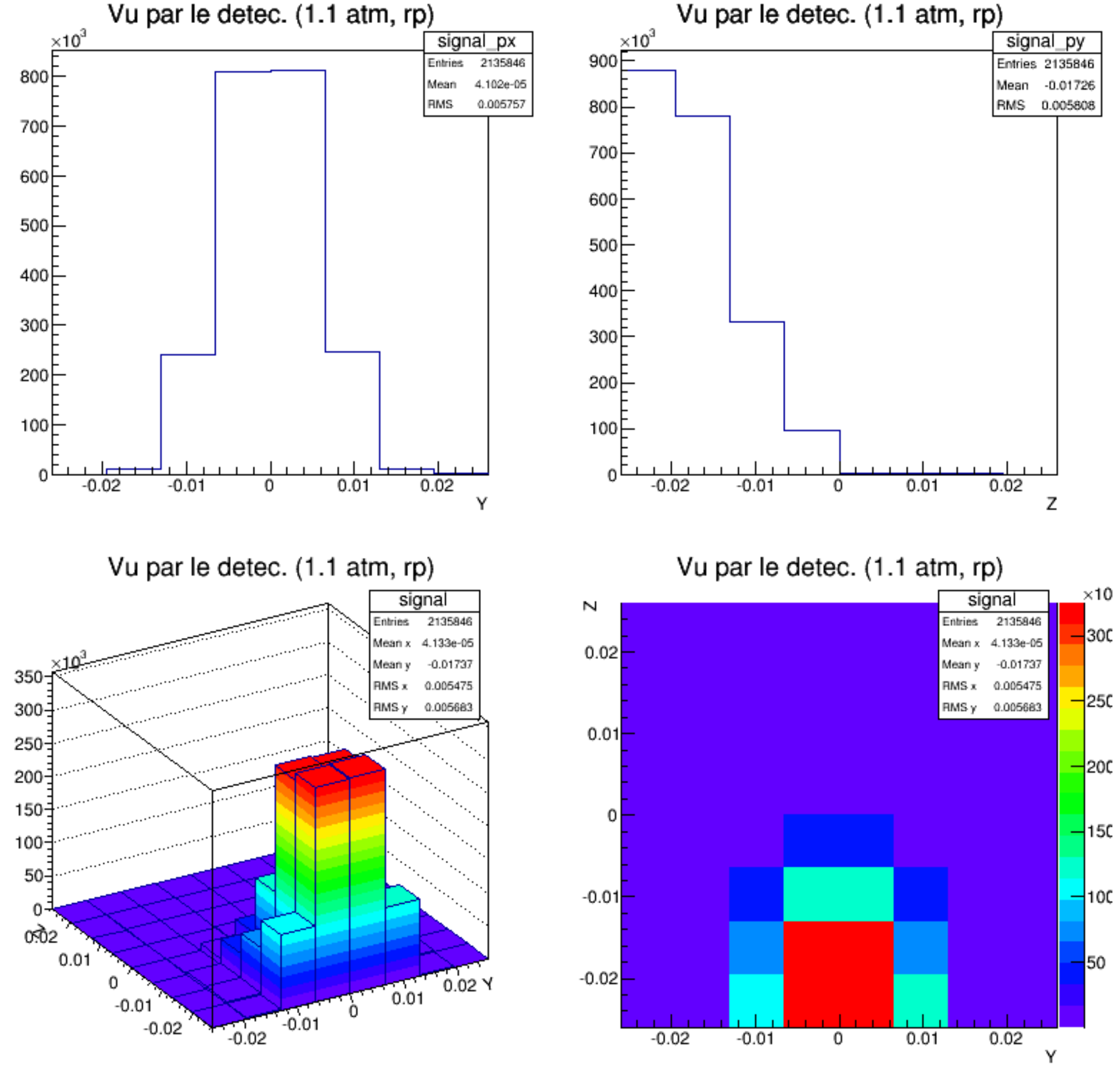
Our 'workhorse': very robust with timing resolution of ~30 ps (due to TTS) → L. Bonnet *et al.* Acta Phys. Pol. B38 (2007) 447; FP420 Collab., JINST 4 (2009) T10001

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



20cm C_4F_{10} + Flat mirror + <u>central protons</u> + 50% CE

New short GasToF (flat mirror) for LHC



M. Renaud

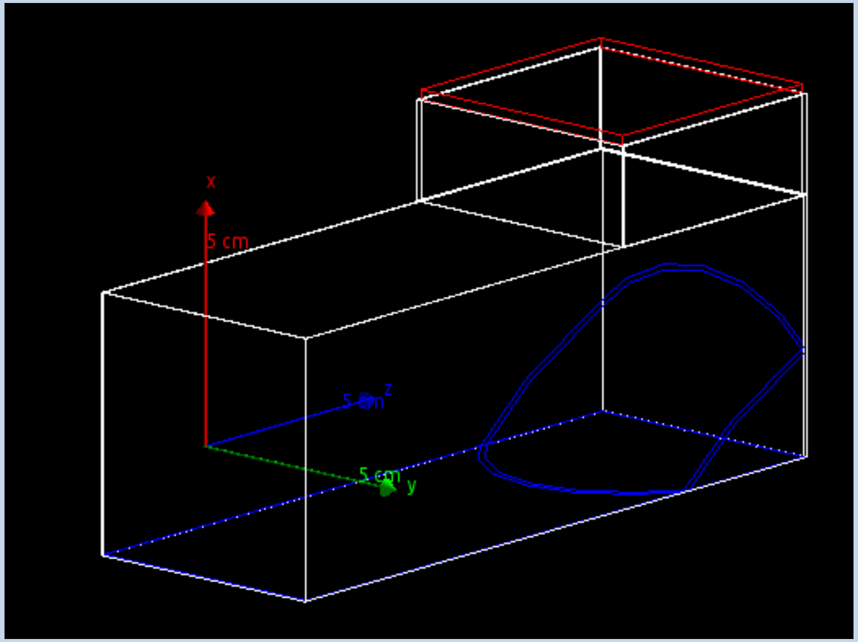
LHC distribution highly non-uniform

One needs to distribute the light

GasToF in G4 & mirror design

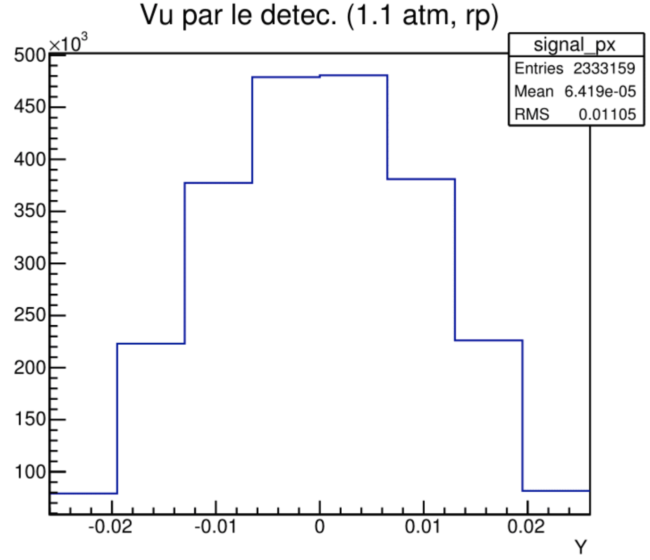
Changed base-line from a "vertical" design to a short, horizontal one, Roman Pot compatible, fitting in its volume.

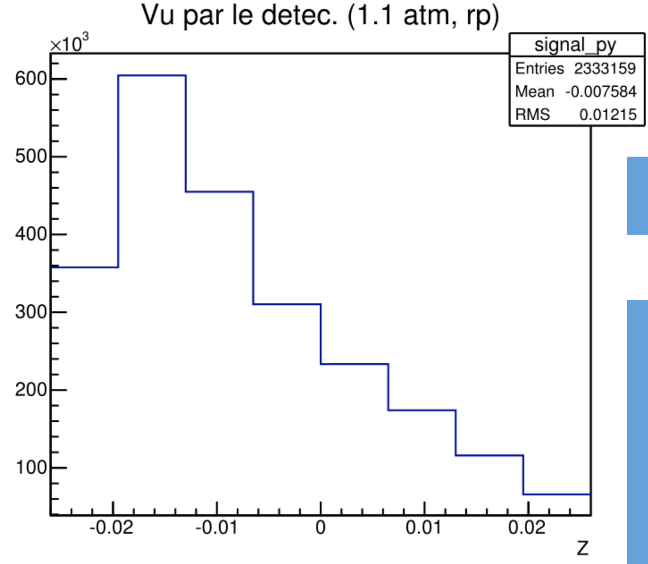
- Started with a simplest, toroid deformation with three free parameters:
  - Two radiuses
  - Position of the "origin of curvature"



- Studies of the "ultimate" mirror shape ongoing

New GasToF with toroid mirror

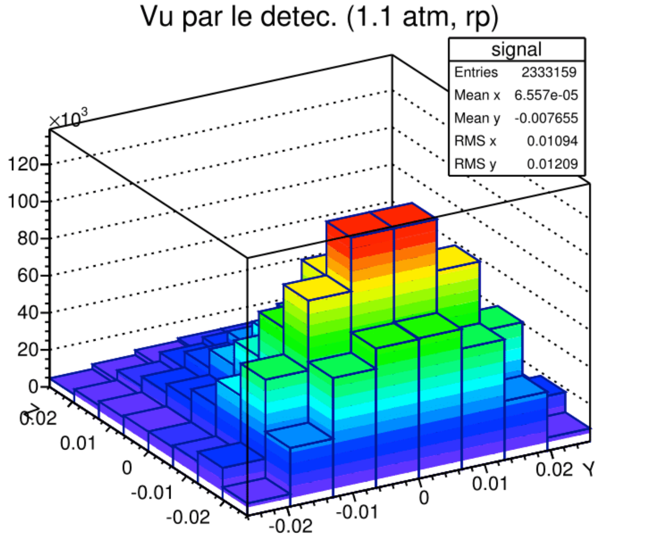


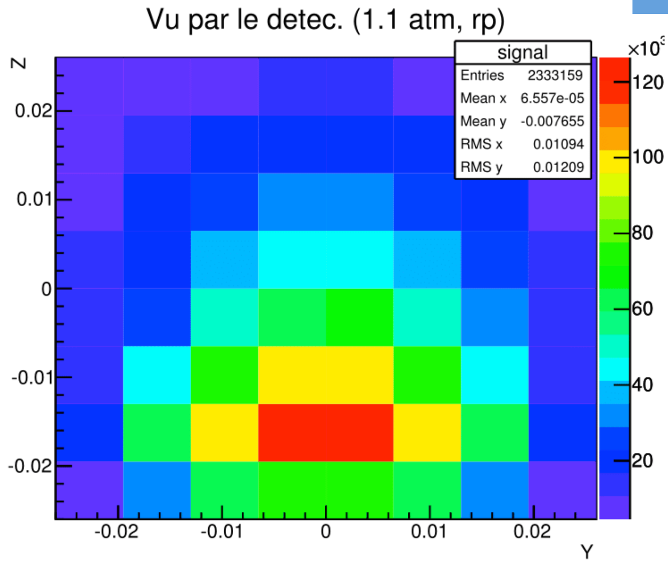


M. Renaud

Good result: max:min occupancy ratio obtained **5:1**

Work in progress…





Multianode **GasToF**: Test beam

We continue GasToF development within R&D for CT-PPS

- First, we would like to test (understand) multi-channel, single-photon operation and performance, including the DAQ system based on the NINO+HPTDC chips

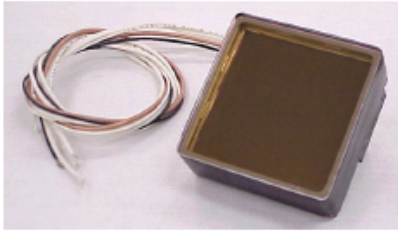
- A detector with a flat mirror is being equipped for the TB in August with a Photonis XP85112 tube:

Photon Detector

XP85112

PLANACON®

10µm MCP-PMT
53 mm Square, 8x8 Anode
- Superior Magnetic Field Immunity
- Enhanced Timing Performance



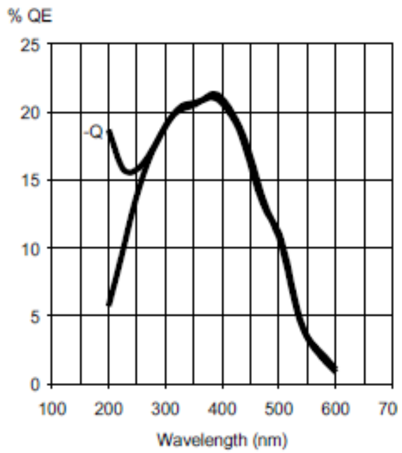
Applications

- ✓ Specialized Medical Imaging
- ✓ Cherenkov – RICH, TOF, TOP, DIRC
- ✓ High Energy Physics Detectors
- ✓ Homeland Security

Description	
Window options	Schott 8337B or equivalent, UVFS (-Q)
Photocathode	Bialkali
Multiplier structure	MCP chevron (2), 10 µm pore, 60:1 L:D ratio
Anode structure	8×8 array, 5.9 / 6.5 mm (size / pitch)
Active area	53×53 mm
Package open-area-ratio	80%

Photocathode characteristics	Min	Typ	Max	Unit
Spectral range:	200		650	nm
Peak Quantum Efficiency at 380 nm*	18	22		%
Operating Characteristics	**Min**	**Typ**	**Max**	**Unit**
Overall Voltage for 10^5 Gain *		FIG	2800	V
Total anode dark current @ 10^5 gain *		2	10	nA
Spatial Uniformity		2:1		
Rise time**		0.5		ns
Pulse width**		0.7		ns
Transit time spread (σ_{tts})**		35	60	ps
Maximum Magnetic Field Operation		2		T

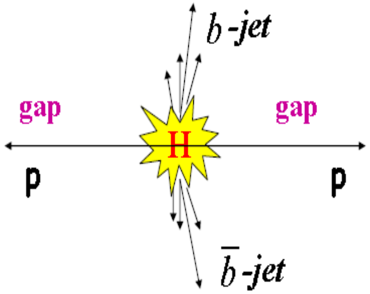
Typical spectral response



Extra slides

Picosecond ToF detectors @ LHC

Plan to run forward proton detectors at <u>nominal</u> 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)!

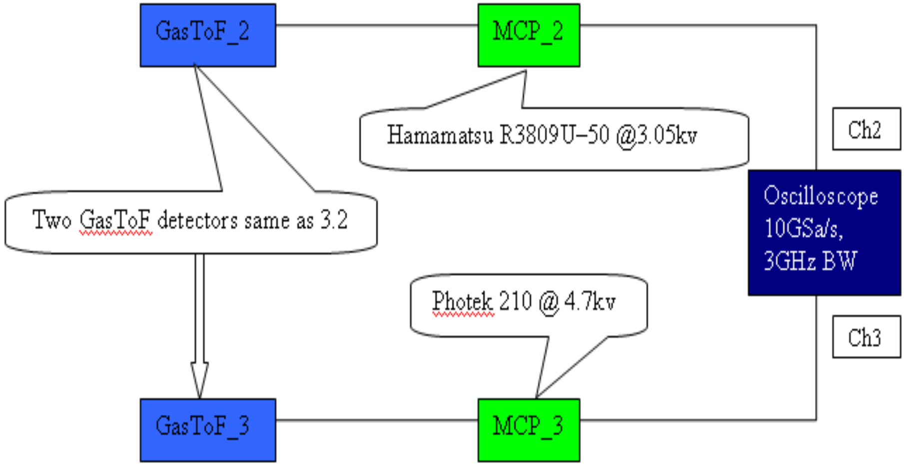
$z = c\,(t_1 - t_2)/2$

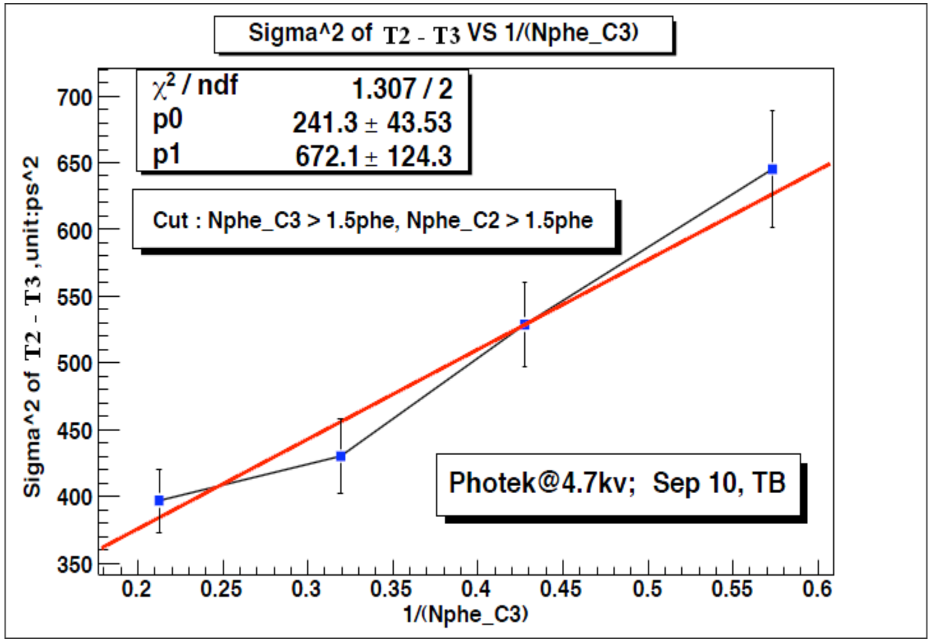
Proposed fast (& small ~10 cm^2 cross-sections) timing detectors: Čerenkov radiators + fastest MCP-PMTs

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

GasToF@TB: Published results





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

J. Liao

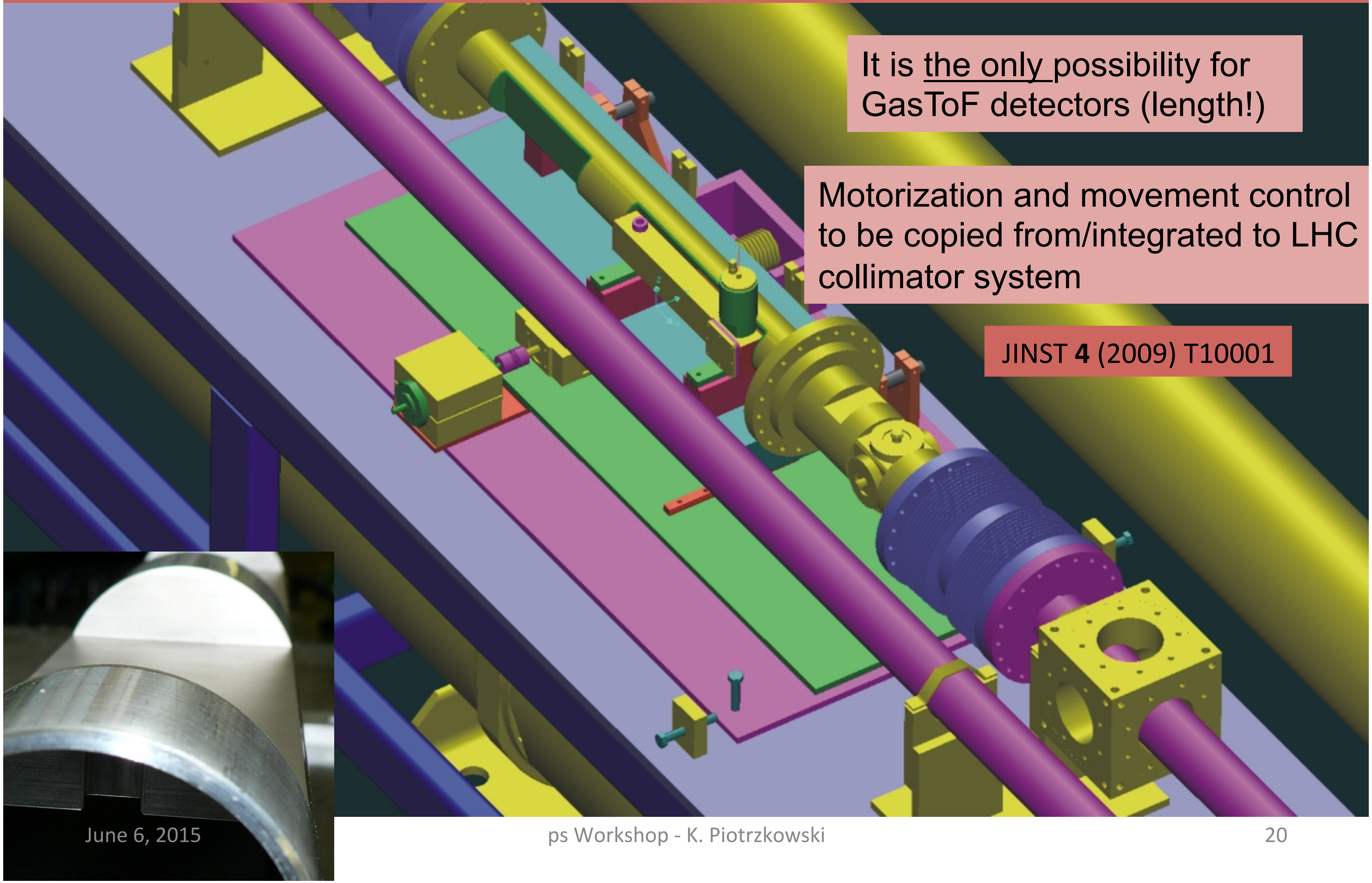
$$\sigma^2 = (\sigma_{ref})^2 + (\sigma_{1phe})^2/N_{phe}$$

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

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

Published in NIM **A762** (2014) 77

A must@LHC: Movable Hamburg pipe

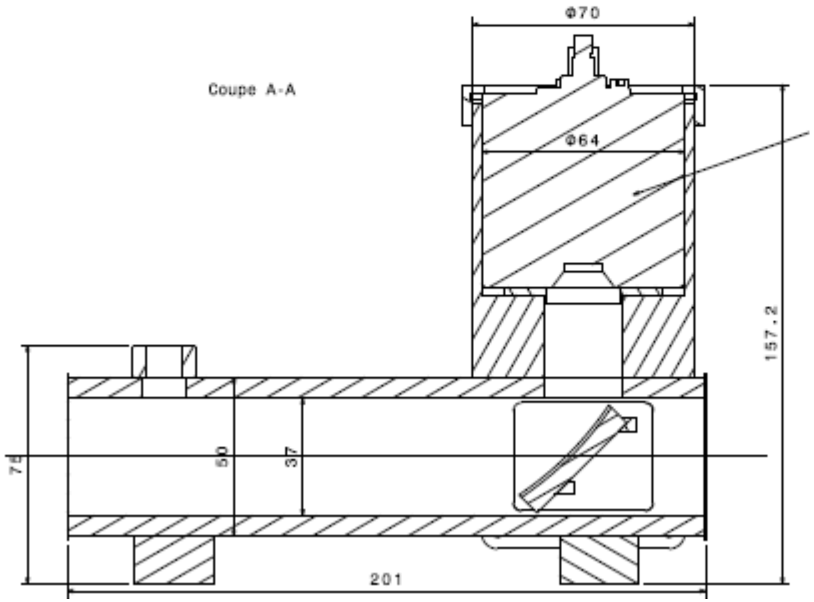


It is the only possibility for GasToF detectors (length!)

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

JINST **4** (2009) T10001

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…

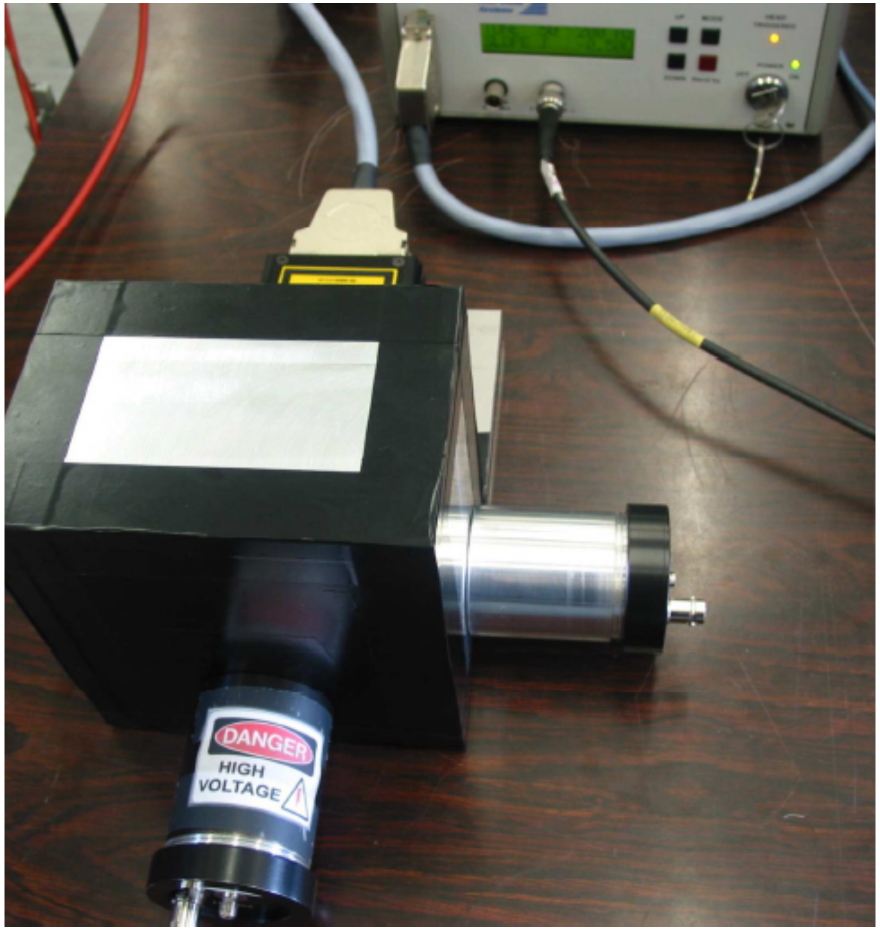
…so fast that had to upgrade to yet faster scope…

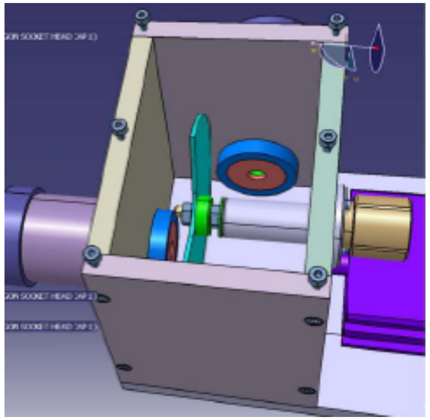
Dedicated picosecond laser test setup was developed to characterize fastest MCP-PMTs from Photek and Hamamatsu – using Agilent scope with 8 GHz BW and 40 GSamples/s

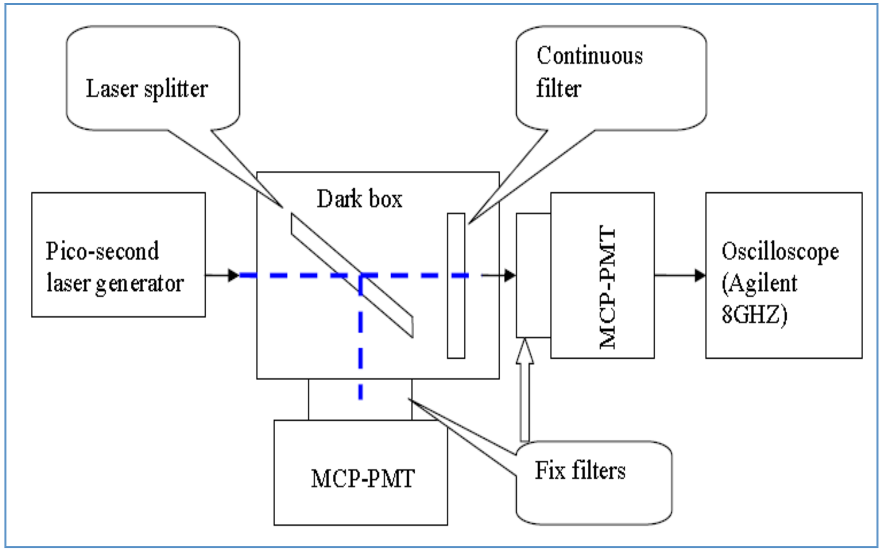
PILxxx	wavelength (nm)	tolerance (nm)	spectral width (nm)	pulse width (ps)
PIL037	375	± 10	< 7	< 60
PIL040	408	± 10	< 7	< 45

FWHM

PiLas 408 nm

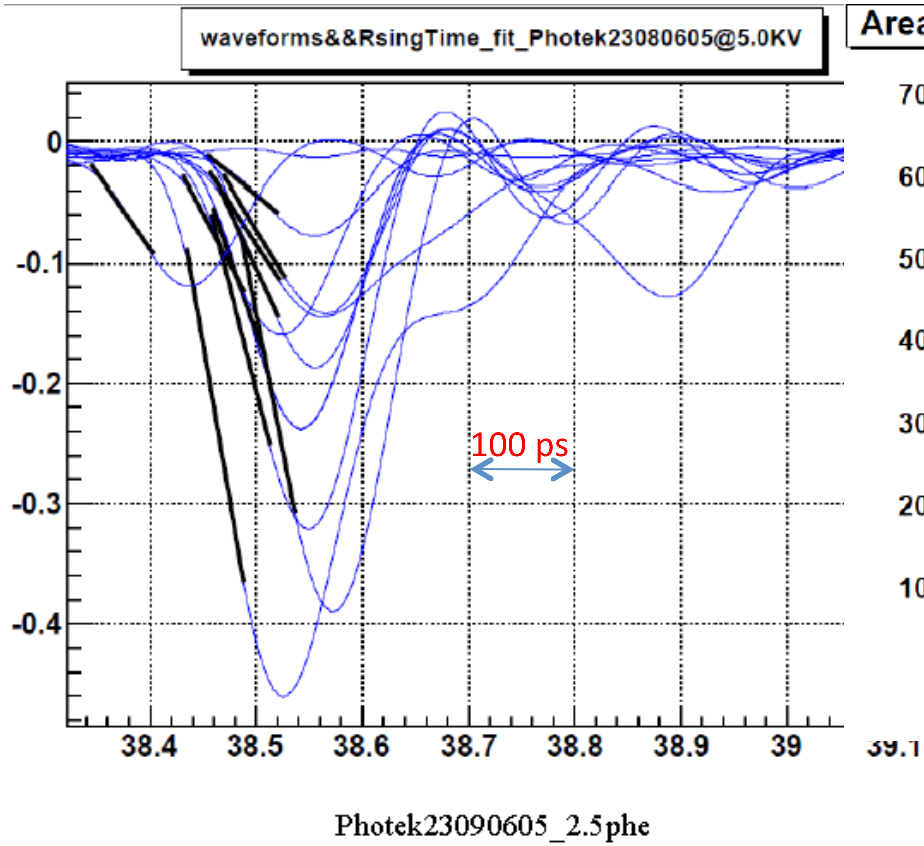


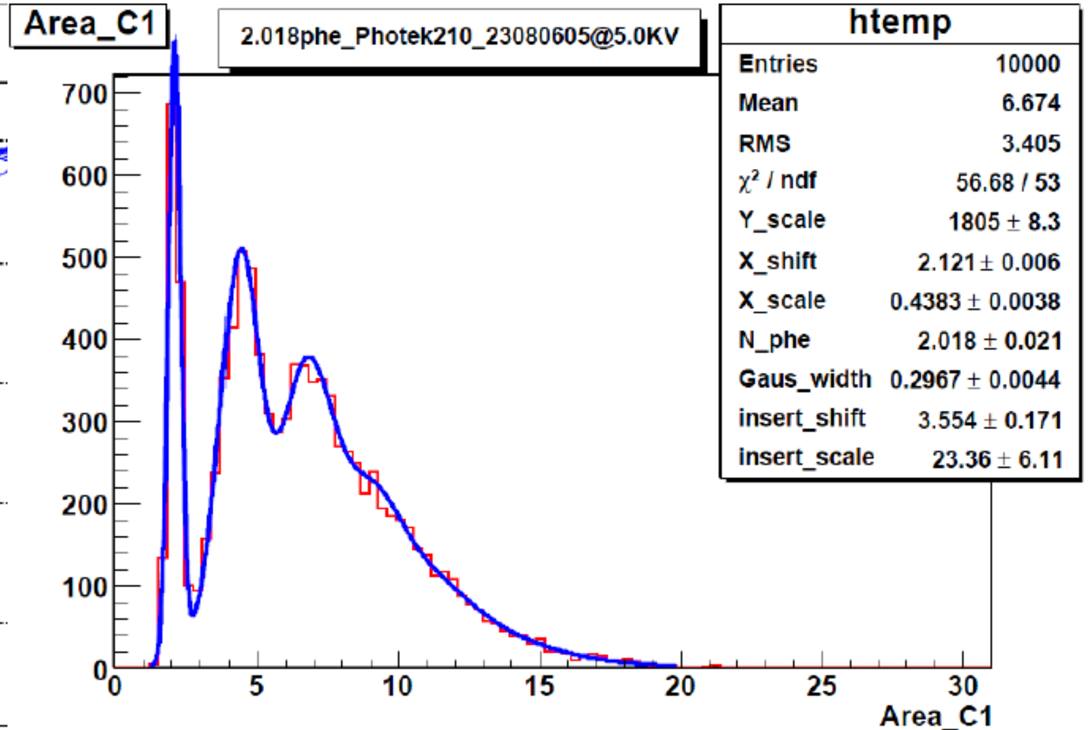




PiLas laser test setup runs up to 1 MHz repetition rate at 408 nm and using 8 GHz Agilent scope with 40 GSa/s

J. Liao

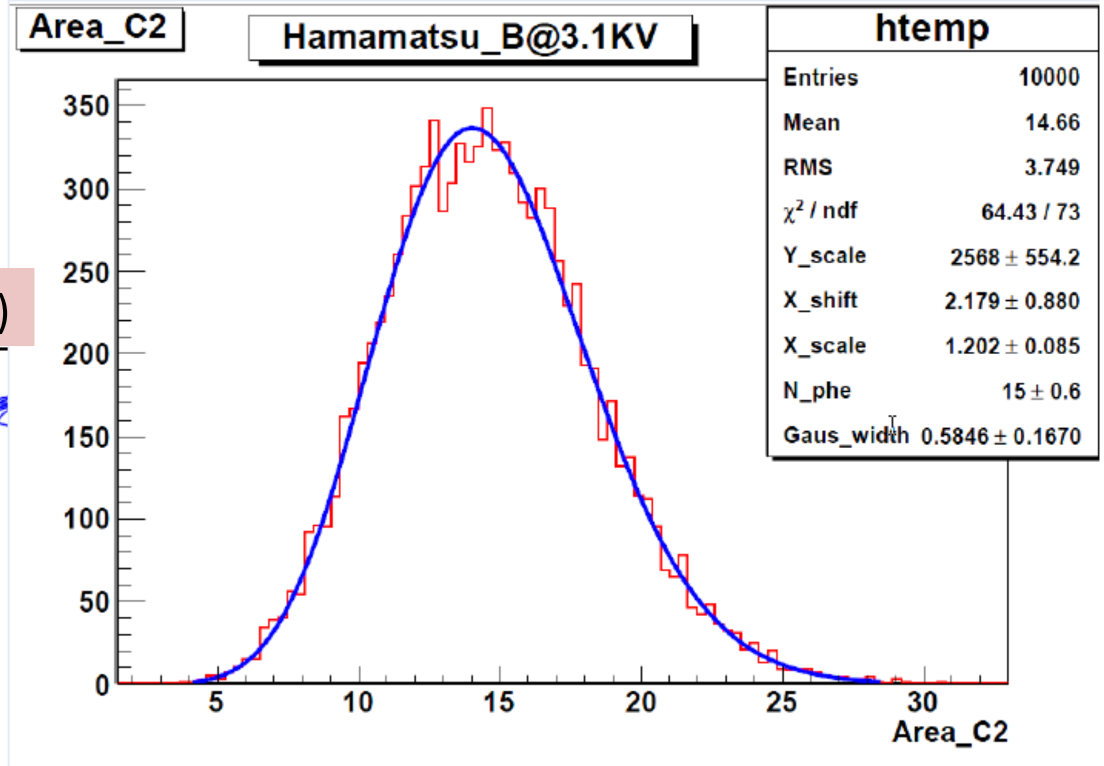




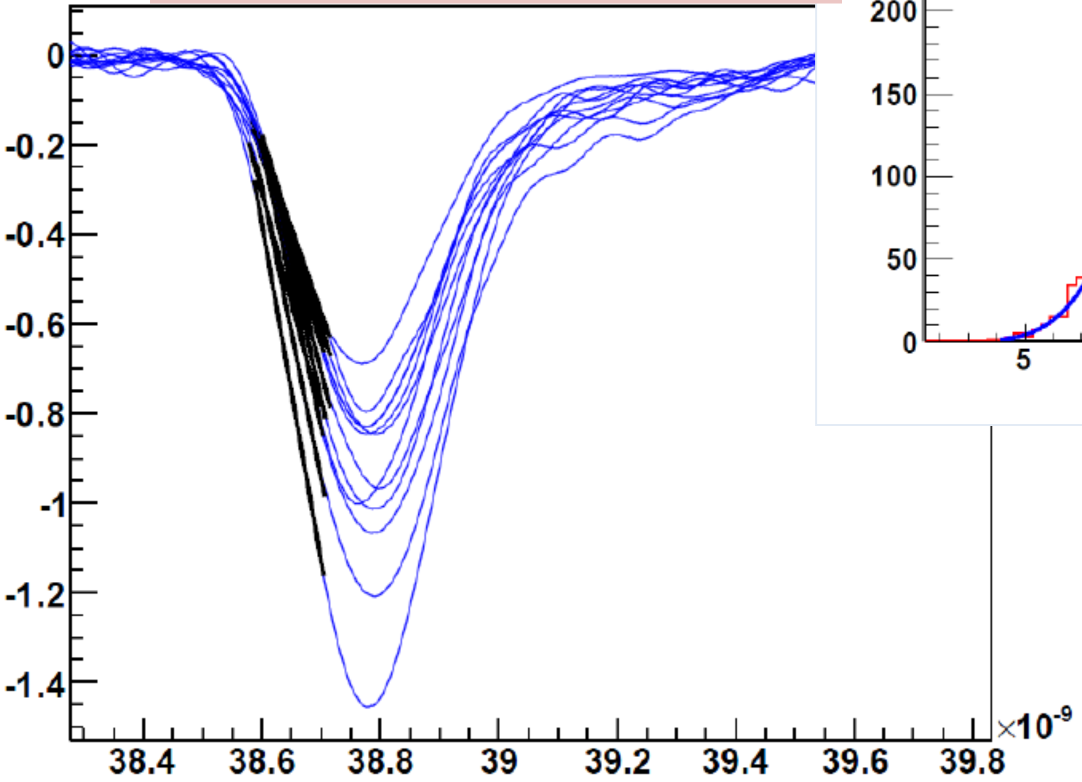
Impressive rise time (10→90%) measured: 80 ps for PHOTEK 3 μm pore **PMT210** (and 150 ps for R 3809U-50)

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