HPS and Ultra Fast Time-of-Flight (Forward) Detectors for CMS

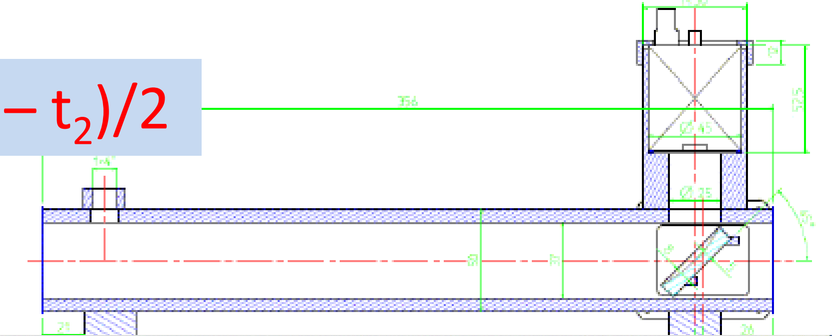
K. Piotrzkowski,UCLouvain

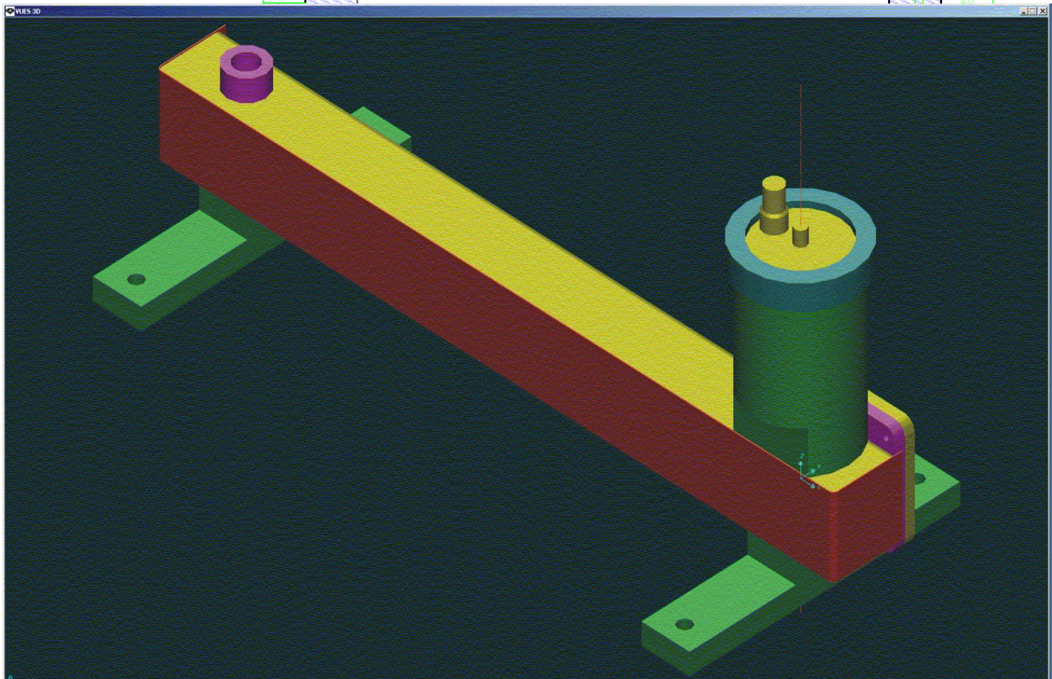
Forward proton timing at LHC

GasToF & QUARTIC detectors

TDC needs

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





Meeting on new HPTDC
CERN

New forward detectors

Brief history:

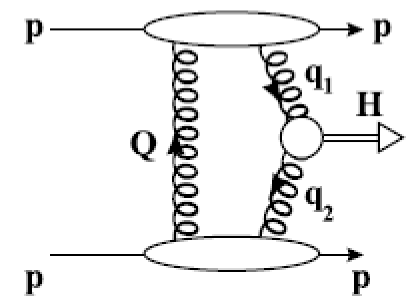
May’05: R&D proposal acknowledged by LHCC

June’08: FP420 Report

Fall’08: First proposals to CMS/ATLAS

In 2009: Adding detectors @220/240 m

HPS project in CMS



FP420

FP420

: Central Exclusive Production (CEP): $pp \to p + H + p$

The FP420 R&D Project: Higgs and New Physics with forward protons at the LHC

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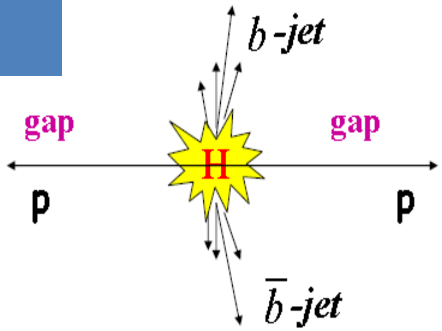
FP420 R&D Collaboration

JINST **4** (2009) T10001

High Precision Spectrometers: Motivation

(1000 Tm bending power $\rightarrow$ $\delta p/p \sim 2.10^{-4}$)

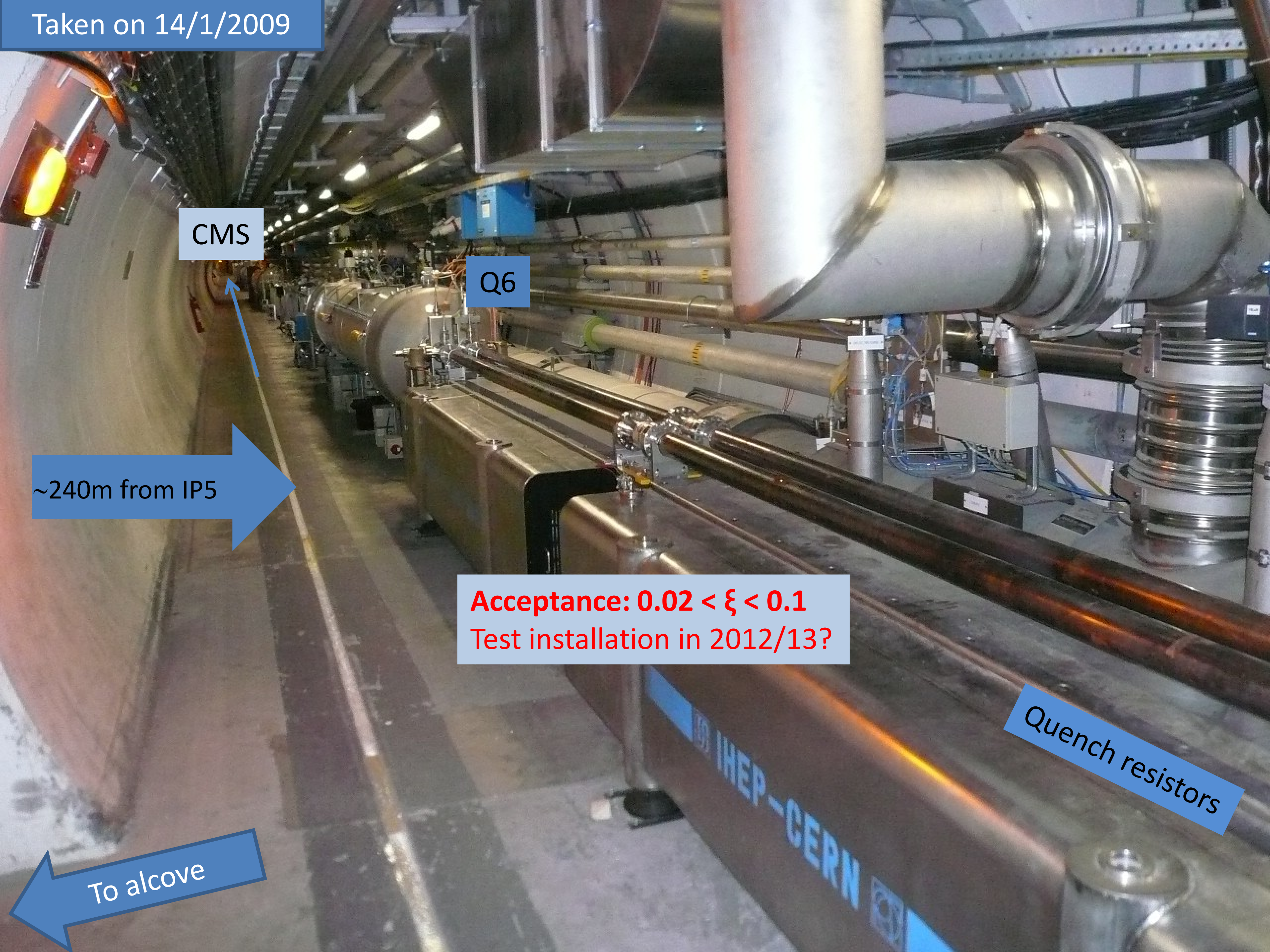


Light Higgs boson case is compelling more than ever – exclusive production provides unique information:

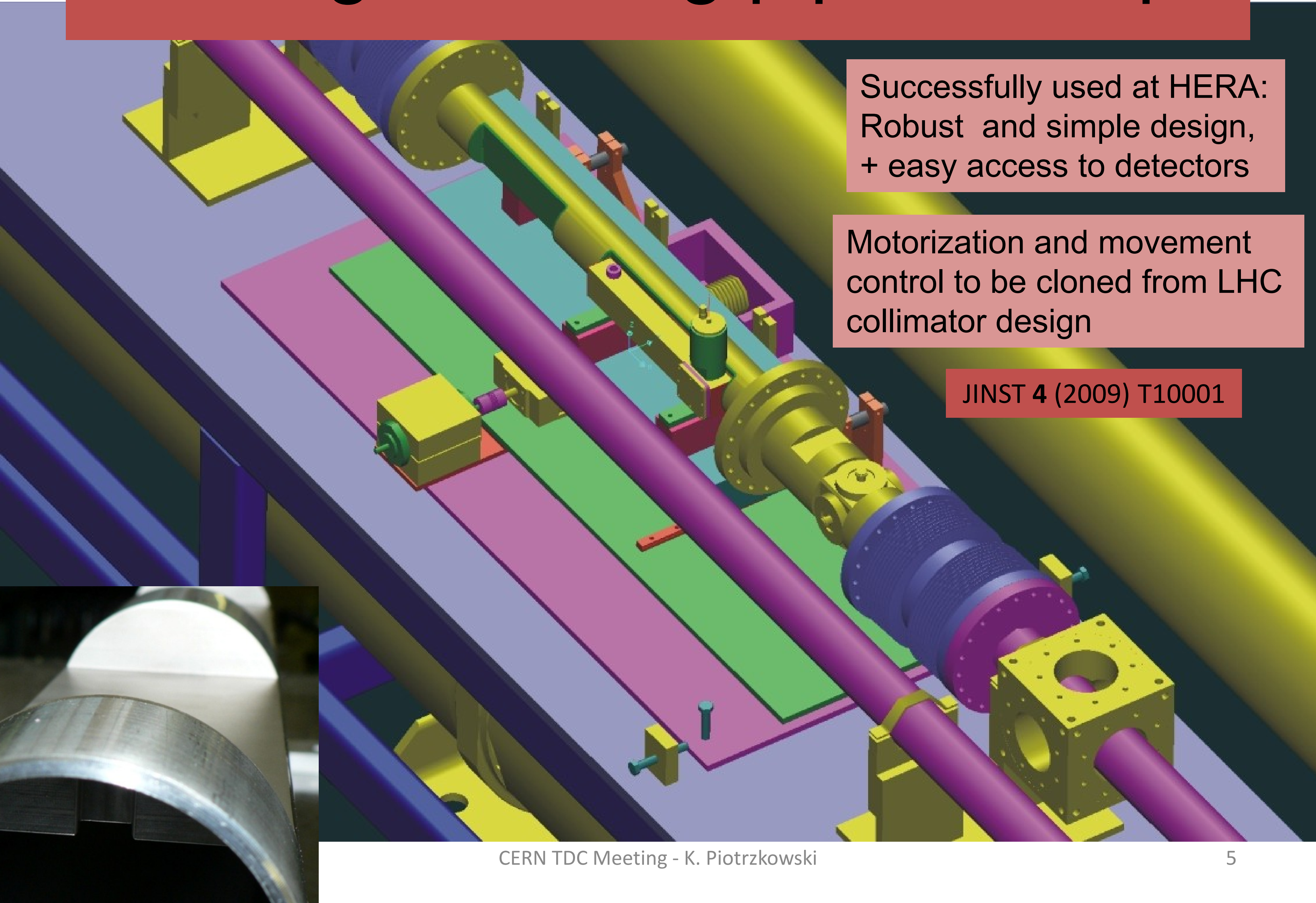
- Higgs quantum numbers (spin-parity filter)
- Direct & precise H mass measurement (event-by-event);
  M_H resolution of ≈ 2 GeV $\rightarrow$ direct limits on Higgs width
- Possibility of detecting H $\rightarrow$ $b\bar{b}$ mode

Detection of SM Higgs boson requires (very) large luminosity ($\sigma_{obs} \approx 0.1$–0.2 fb) and challenging timing detectors to keep backgrounds low ($S/B \approx 1{:}2$); in case of BSM physics HPS could provide discovery channels for Higgs bosons

In addition, HPS offers access to 'guaranteed' and unique studies like electroweak physics in two-photon interactions, or new QCD phenomena in exclusive production, for example.


Taken on 14/1/2009
CMS
Q6
~240m from IP5
Acceptance: 0.02 < ξ < 0.1
Test installation in 2012/13?
Quench resistors
To alcove
IHEP–CERN

Moving Hamburg pipe concept



Successfully used at HERA: Robust and simple design, + easy access to detectors

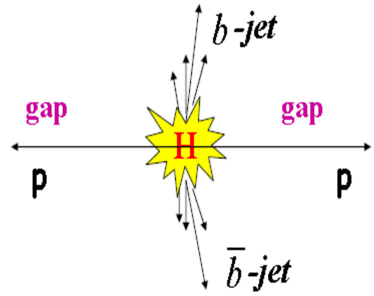
Motorization and movement control to be cloned from LHC collimator design

JINST **4** (2009) T10001

Picosecond ToF detectors @ LHC

At nominal luminosity event rate so high @ HPS that accidental overlays (= triple coincidence of an interesting event in central detector + two protons from single diffraction) become major background!

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)!



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

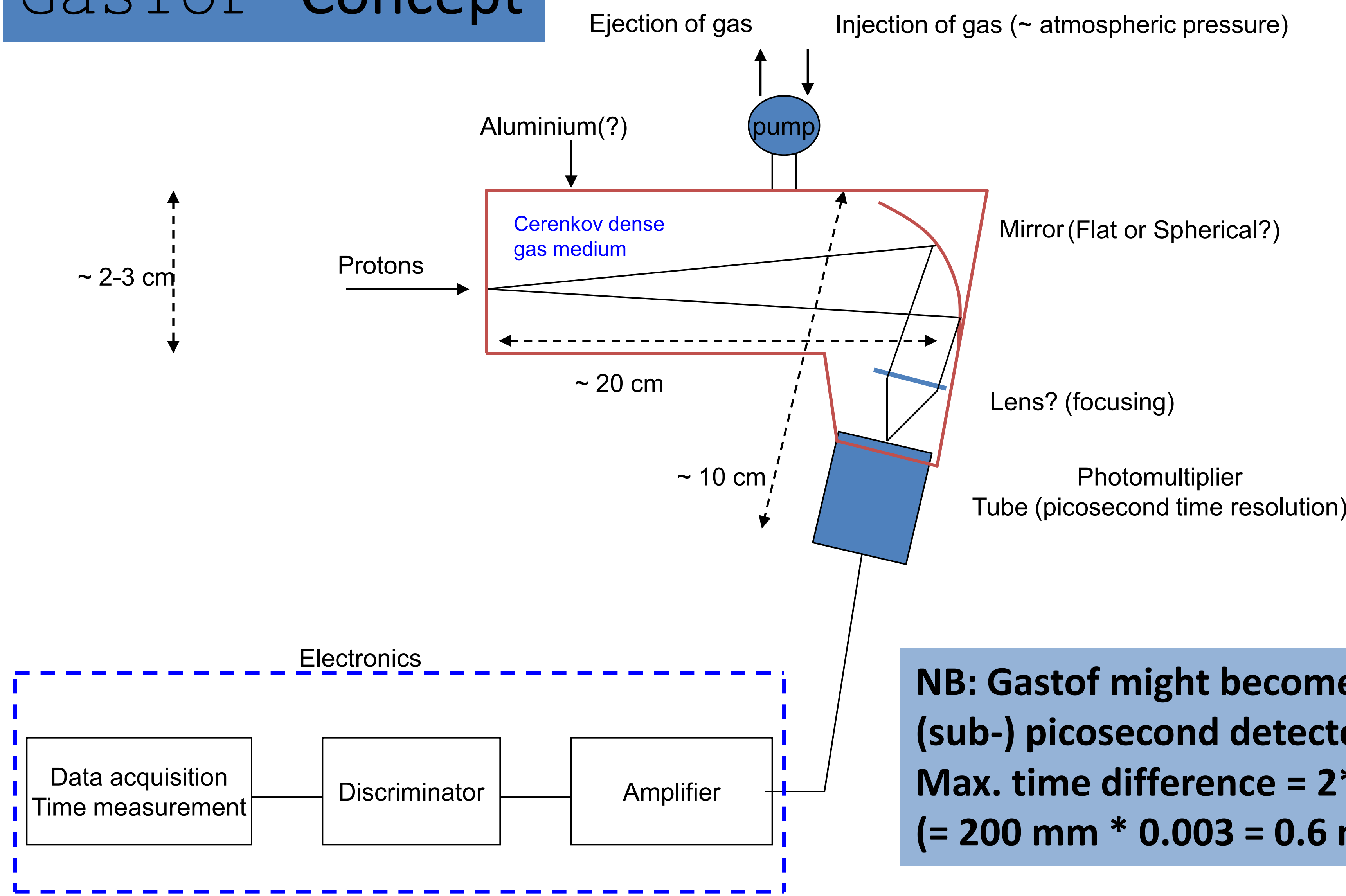
Proposed fast (& small ~10 cm^2) timing detectors: Čerenkov radiators + fastest MCP-PMTs

Challenging environment → pushing MCP-PMT performances to limits:
→ High event rates, up to several MHz
→ Running MCP-PMTs close to maximal anode currents
→ Large annual total collected anode charges (up to 10 C/cm^2)

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

Quartic: Quartz based Čerenkov with fine segmentation – multi-hit capability

GasToF Concept

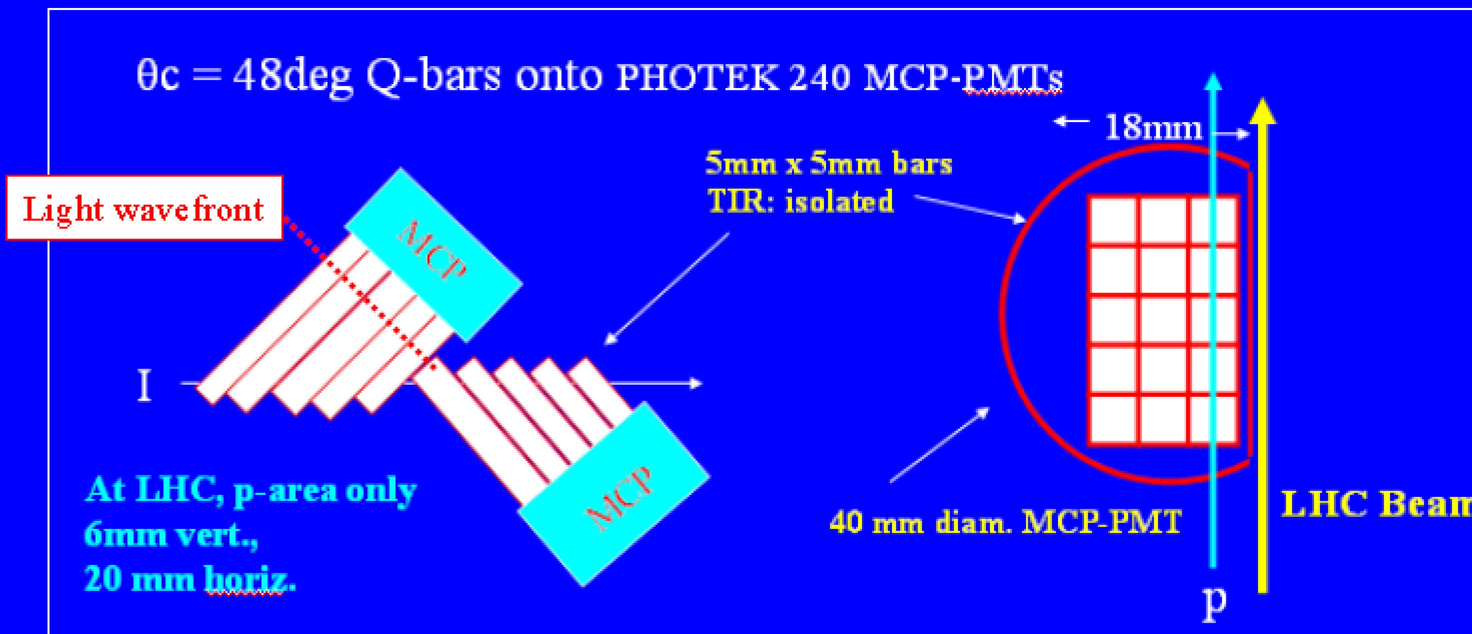


NB: Gastof might become (sub-) picosecond detector!
Max. time difference = 2*L*Δn
(= 200 mm * 0.003 = 0.6 mm !)

QUARTIC Concept

Edgeless design: QUARTIC = QUARtz TIming Cherenkov

Principle of QUARTIC: Cherenkov light in quartz at θ ~ 48°
Incline Q-bars at 48° & normal to PMT
Light from all bars arrives simultaneously at PMT window
Can have bars to individual pads (Photonis), or single anode (Photek)
Cross-talk, sharing does not matter. Can be "edgeless" (thin foil)

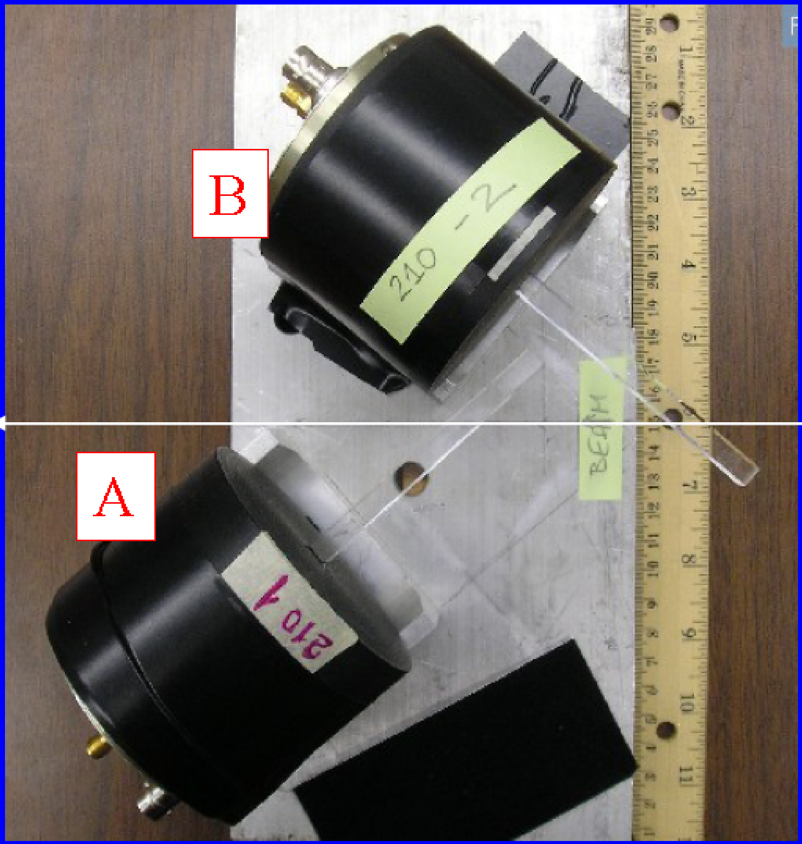


Mike Albrow Fast Timing Detectors for Forward Protons at the LHC Cracow Timing Workshop – Dec 2010

QUARTIC Test beam

Double Q-bar

Quartz (fused silica) bars 6mm x 6mm x 90mm → PHOTEK 210
Mounted at Cherenkov angle θc ~ 48 deg. on opposite sides.
dz = 6 mm/sin(48) = 8.1 mm. Some light direct to PMT, ~1/2 TIR to PMT
Black "sock" over bars just to avoid light sharing



Unfold:
σ(A) = 22.3 ps
σ(B) = 30.5 ps

Includes electronics (~3 ps)
and 2 mm beam width smear (A,B)
Δt = 2 mm x (10 ps/2 mm)

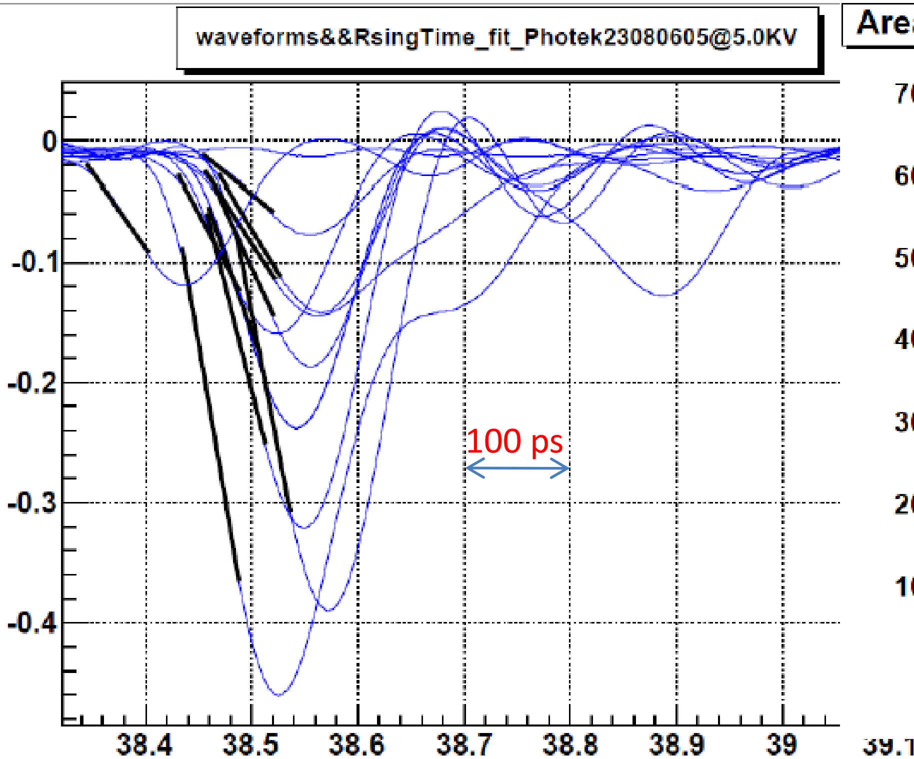
$$\sigma_A \approx \sqrt{22.3^2 - 3^2 - 10^2} = 19.7 \text{ ps}$$

$$\sigma_B \approx \sqrt{30.5^2 - 3^2 - 10^2} = 28.7 \text{ ps}$$

Combining [AB] removes beam spread (later, tracking)

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

J. Liao



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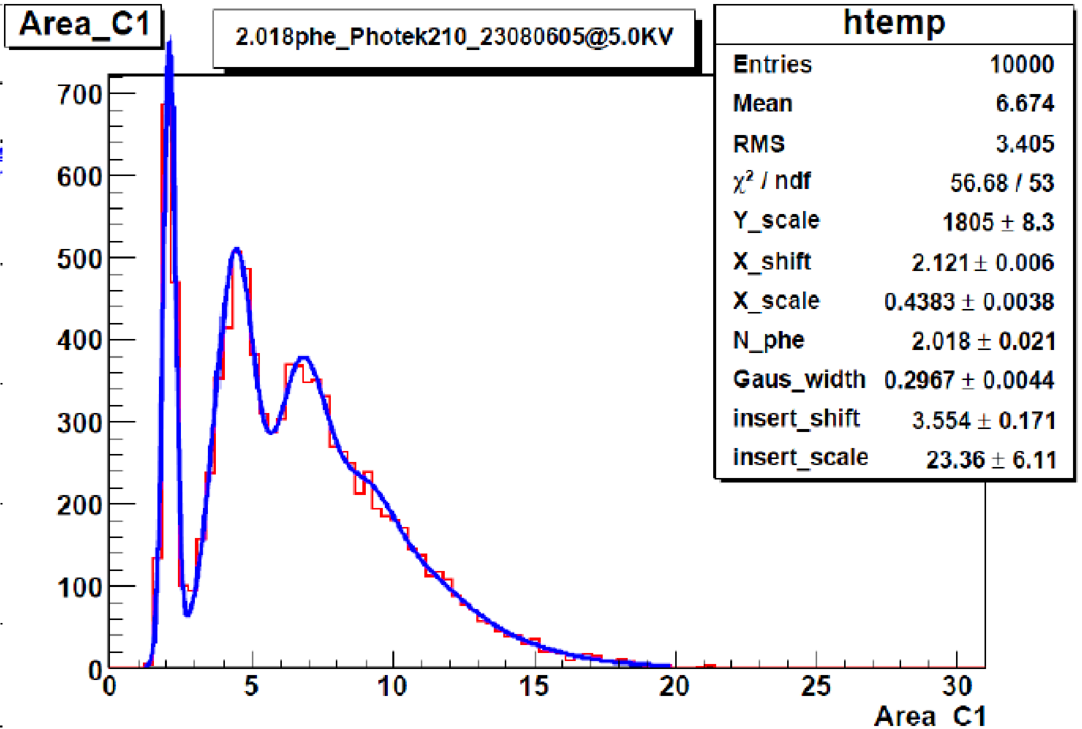
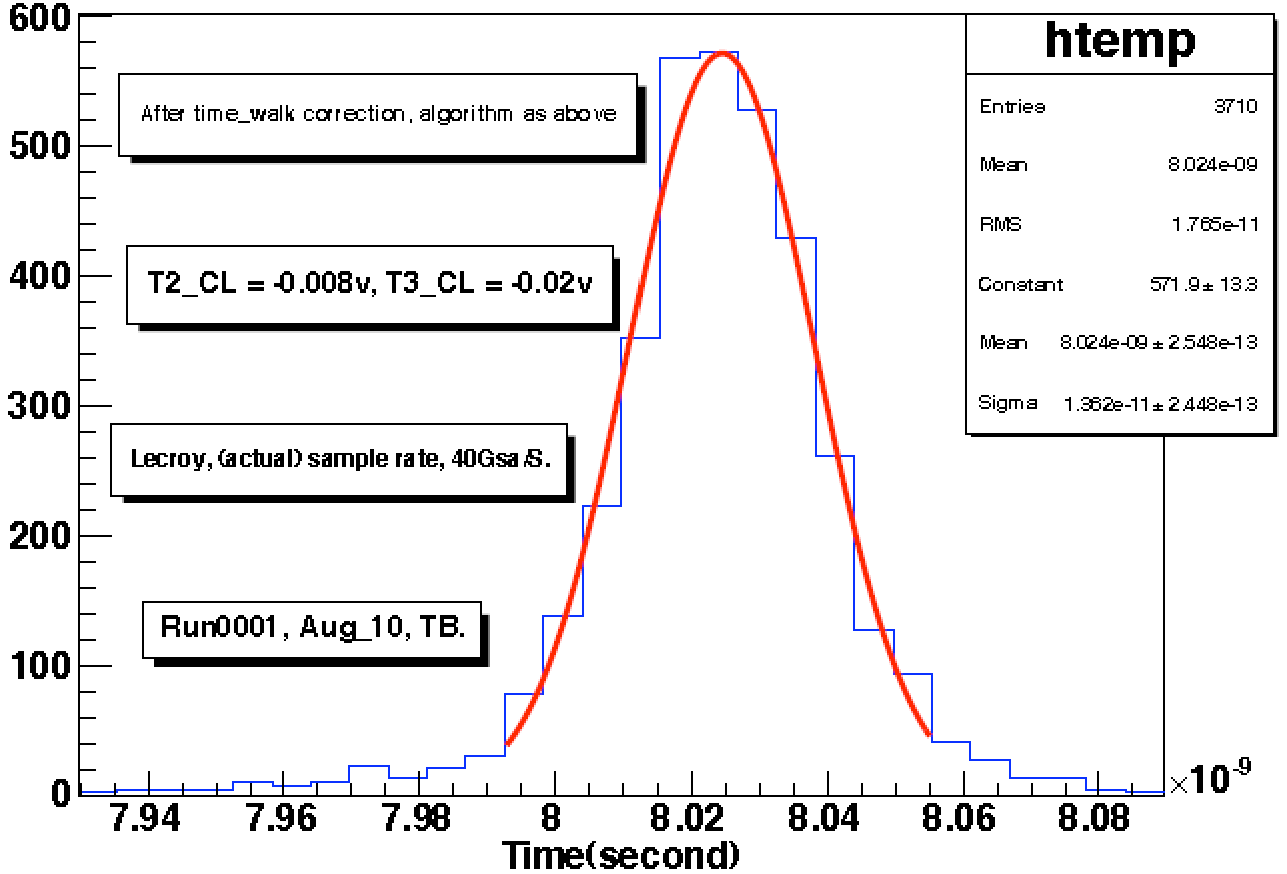


Impressive rise time (10→90%) measured: 80 ps for PHOTEK 3 μm pore **PMT210** (and 150 ps for HPK R3809U-50)

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

GasToF at CERN test beam

J. Liao, Aug'10



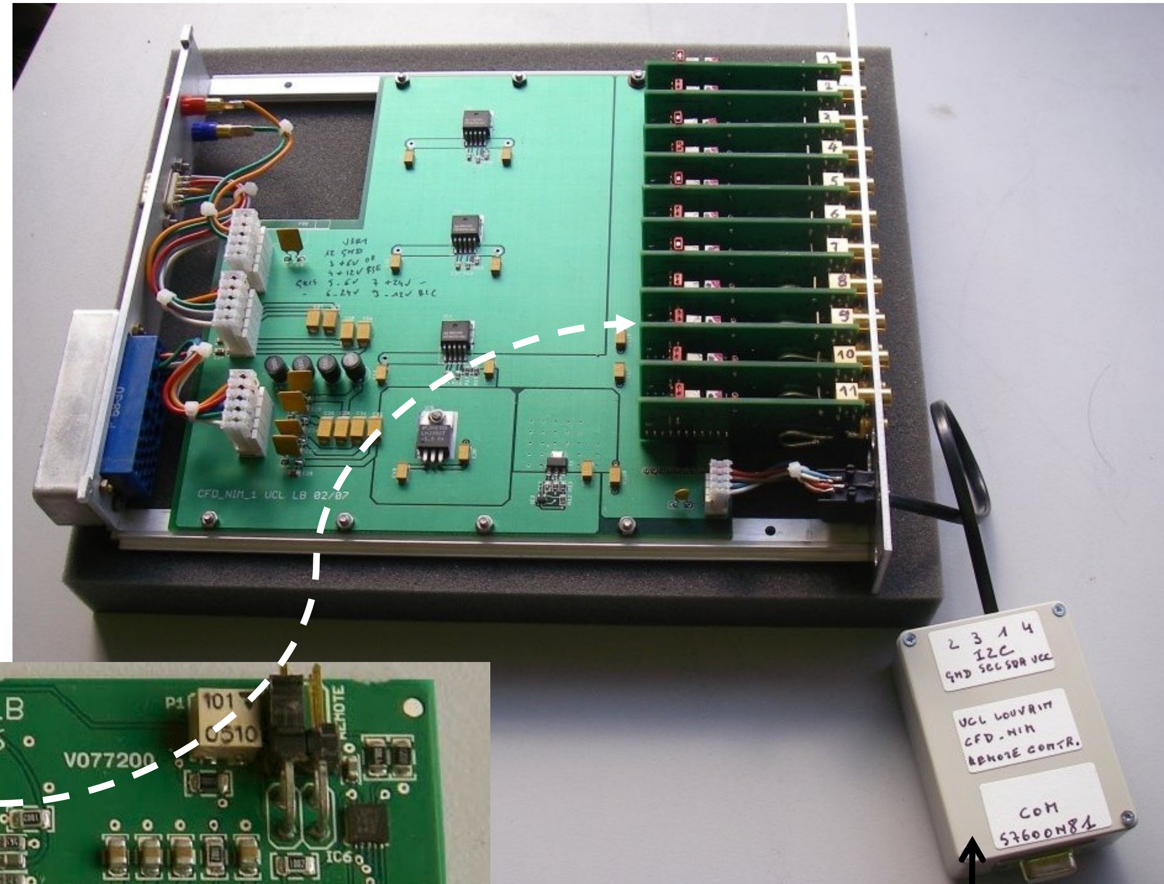
- Two (short) GasToF prototypes with HPK tubes and readout by 40 GSa/s scope
- Offline analysis: threshold discrimination and simple time-walk correction
- Measured time differences show < 10 ps time resolution per detector

Fast Constant Fraction Discriminator

L. Bonnet (UCLouvain)

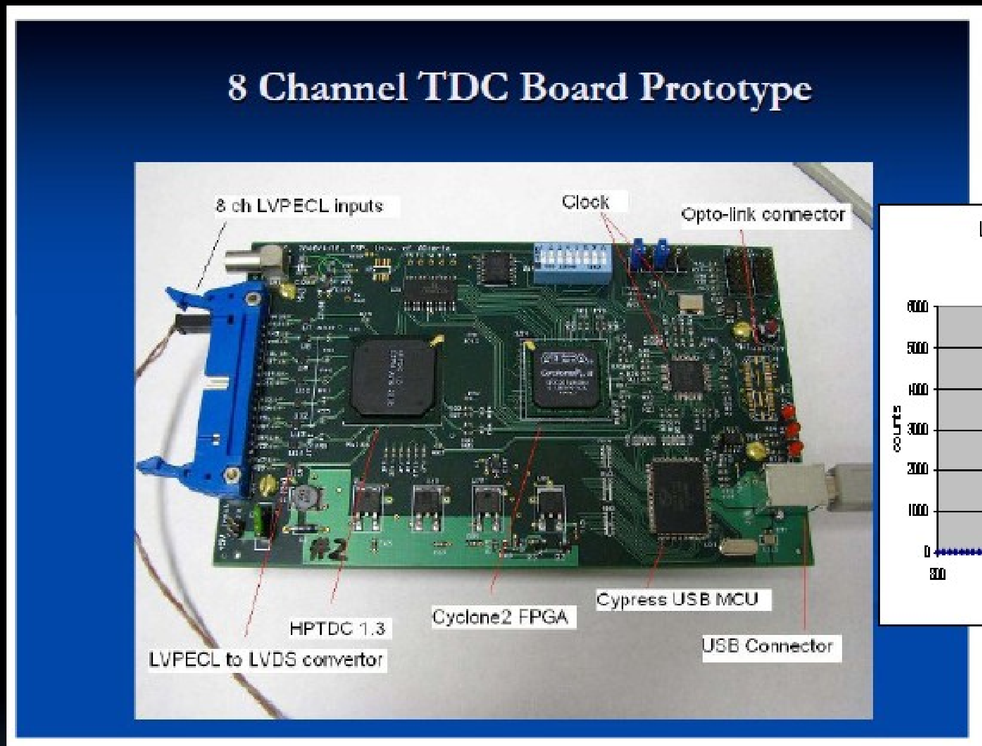
Development of LCFD

- 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)

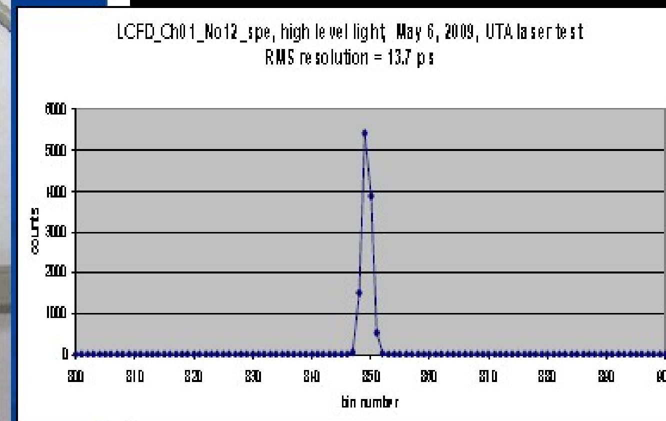


Remote control for threshold

QUARTIC Electronics – the HPTDC



J. Pinfold (U. Alberta)
Dec'10, Krakow Workshop



- 12 ps resolution obtained with pulser
- Successfully tested at UTA laser test stand with laser /10 μm tube/ZX60 amp/CFD - 13.7ps resolution obtained with CFD
- ~30 ps resolution obtained with real pulses at test beam

HPS: status and plans

HPS is part of the CMS R&D program

• In 18 months we will finalize developments for Stage One HPS:

- Finalize QUARTIC and GasToF detector prototyping;
- Development of ps precision clock distribution system (J. Gronberg + SLAC)
- Design TDC cards based on present 25 ps HPTDC chips

• In 2013 (assuming approval by CMS) will install Stage One HPS detectors ('proof-of-principle' experiment)

• Continue R&D on <u>multi-anode</u> MCP-PMTs and fast electronics in preparation for the final HPS system installation (in 2018?)

HPS: need for new HPTDC

- Even for Stage One (with the goal of at least 20 ps overall resolution per detector) performance of the HPS timing system is compromised by electronics – in particular HPTDC is not well suited for GasToF…

- For final HPS at least 10 ps resolution is aimed for – each improvement of resolution directly reduces background (rising with luminosity^2…)

- HPS wish-list/ultimate conditions:
  - TDC chip with ~ 5 ps bin/resolution
  - ~ 1K channels
  - double threshold useful
  - up to 1 MHz hit rate/channel
  - ~ 100 KHz trigger rate
  - ~ 100 ns trigger window
  - ~ 3.2 μs trigger latency
  - SEU protection (at least) for controls
  - NINO?