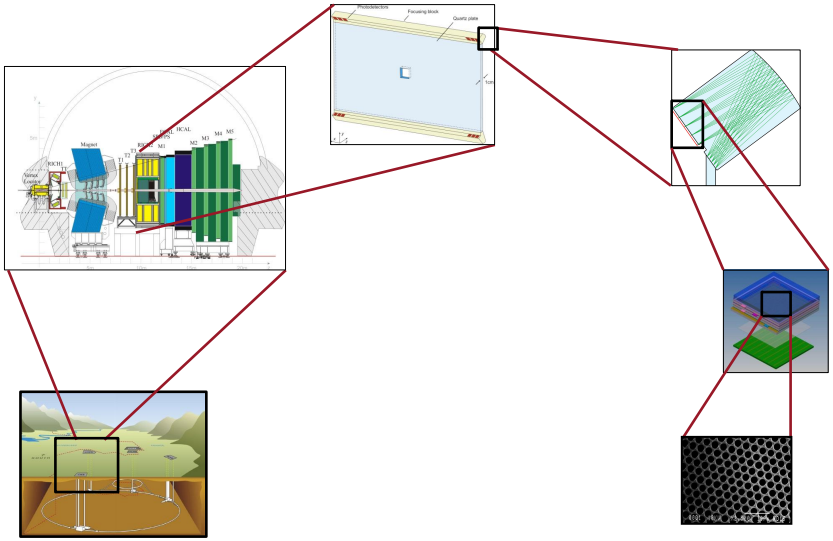
Test-beam and laboratory characterisation of the TORCH prototype detector

Ana Ros García

on behalf of the TORCH Collaboration
(University of Bristol, CERN, UCL, University of Oxford, with industrial partner Photek)

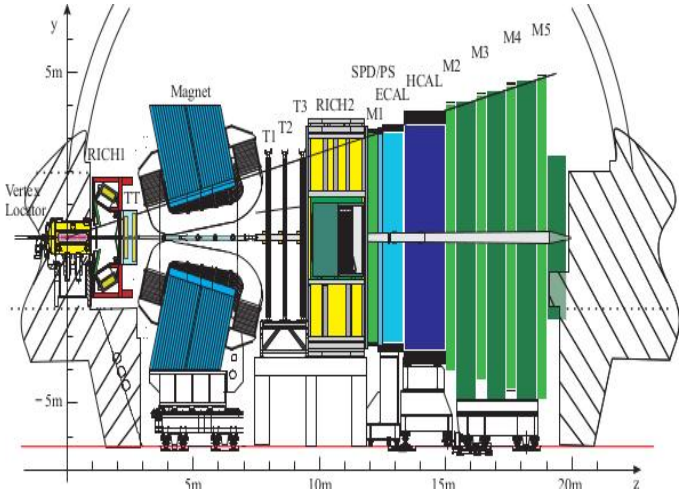


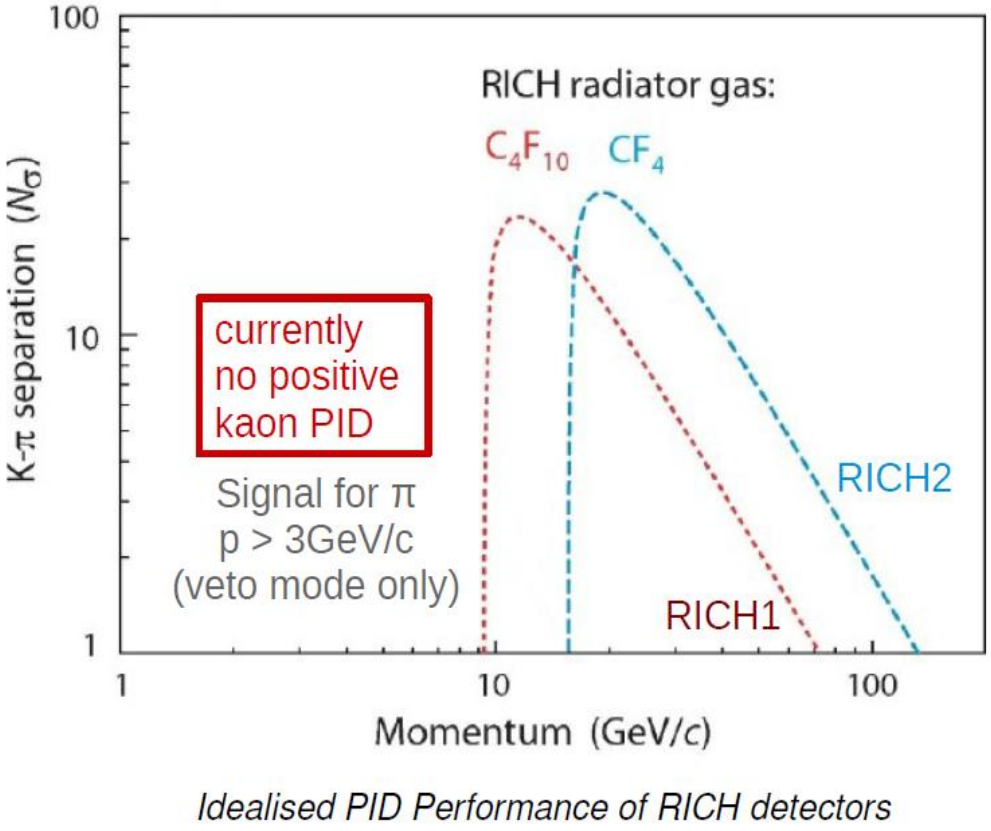
CONTENTS

- **TORCH project**
- **Detector characterisation**
  - Charge-sharing and spatial resolution
  - Electronics calibration
- **SPS test-beam results**
  - Hit-map & time projection results
- **PS test-beam preliminary results**
  - Timing reference measurements & time projection results

MOTIVATION FOR TORCH 1

TORCH in LHCb (future upgrade - LS3)





Idealised PID Performance of RICH detectors

TORCH

Time of Internally Reflected Cherenkov Light

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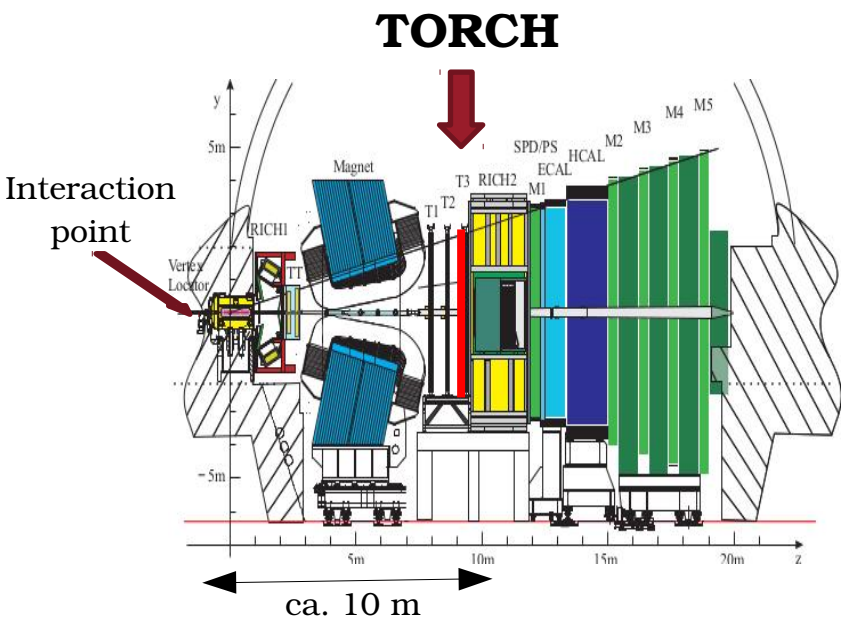
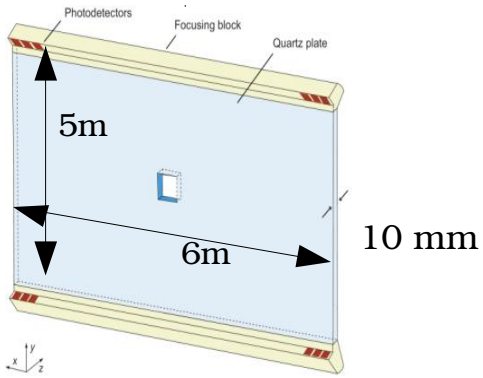
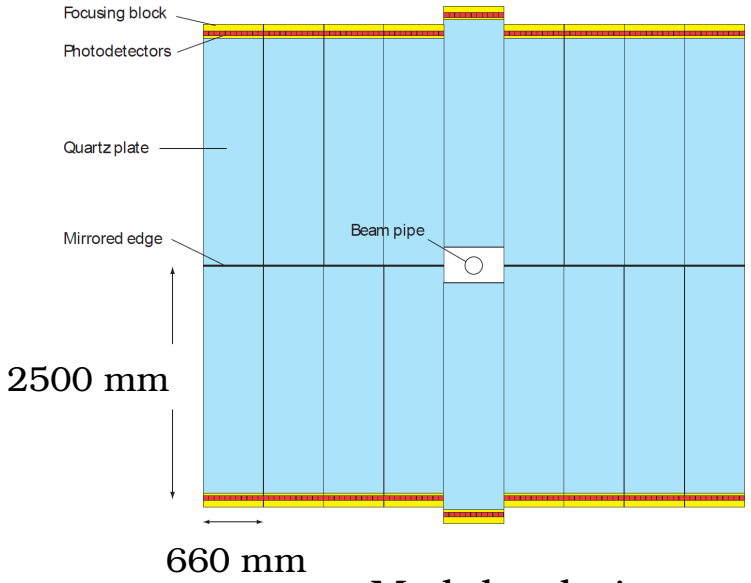
TORCH OVERALL GEOMETRY





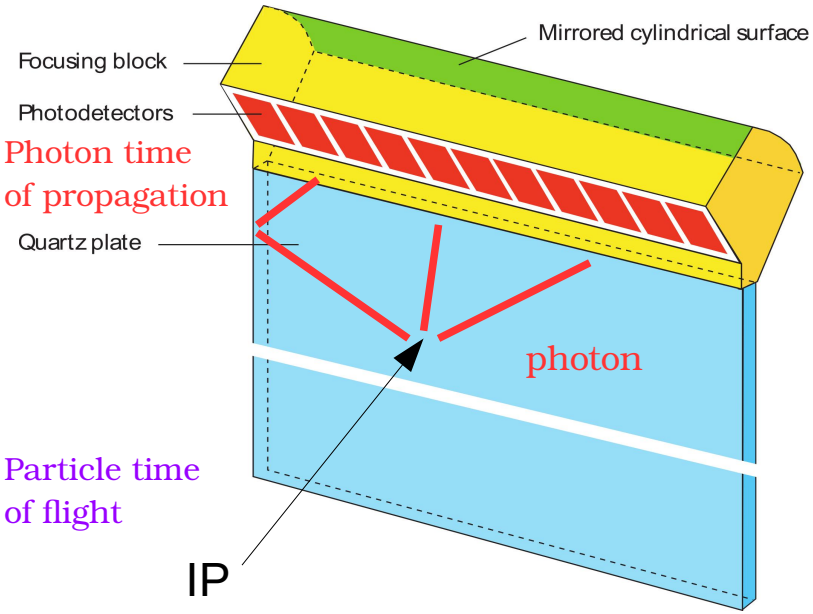
Single plate design

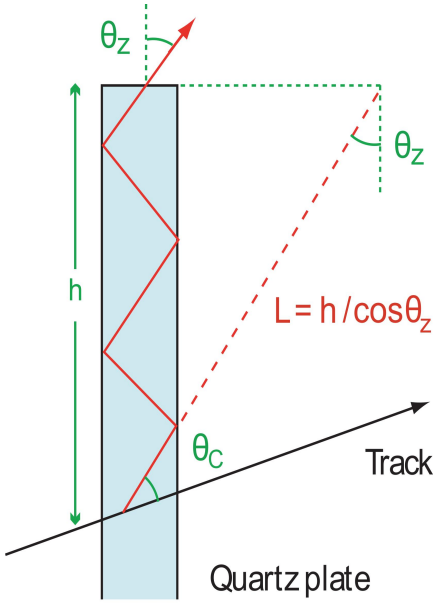
- Overall area about 6 x 5 m²
- Plate thickness ca. 10 mm
- 18 tiles of 660 x 2500 mm² in modular design

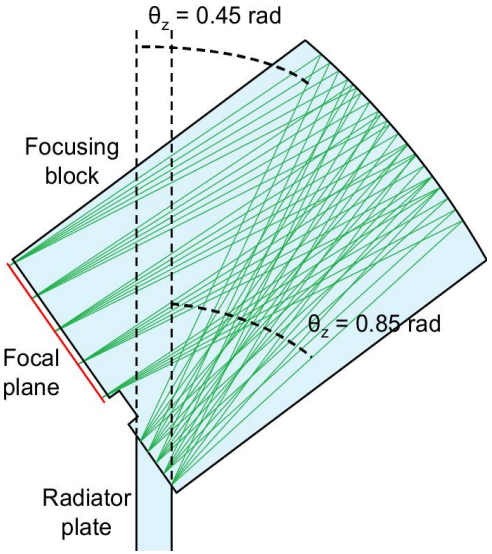


Modular design
Easier to manufacture!

TORCH DESIGN

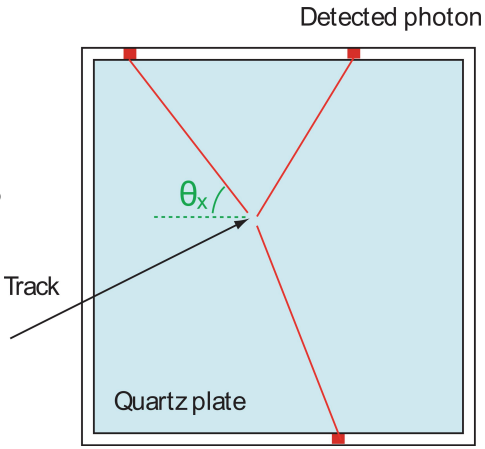






θx measured via horizontal position on MCP sensors

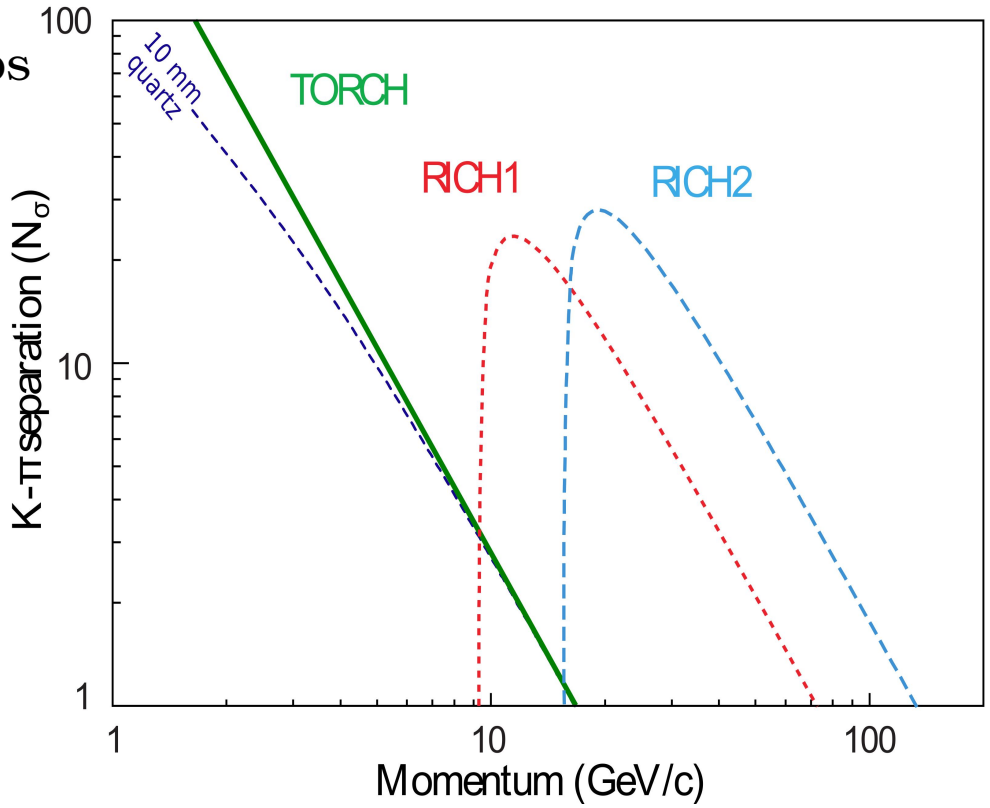
θz measured via cylindrical mirror focussing



MOTIVATION FOR TORCH 2

- **Basic principle:** Measure time of flight & tracking
- Reconstruct time-of-propagation of individual photons, and combine time information
- Goal is to provide 3σ K-π separation for momentum range 1-10 GeV/c
  - ~15 ps time resolution/track
  - ~30 photons observed/track
  - single photon resolution: 70 ps

For kaons positive PID in the range p=1-10GeV/c can be achieved by adding the TORCH detector



Foehl K. [IV]
Van Dijk M. [V]
Charles M.J. [VI]

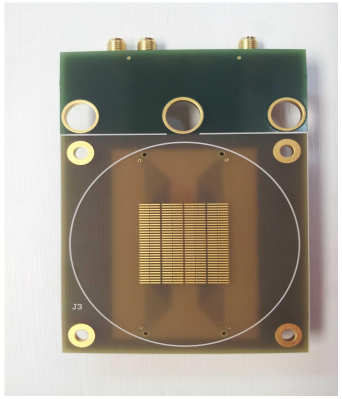
PHOTODETECTOR

Photek* phase 2 tube prototype:

- Quarter-size customized circular-shape ***MCP*** (Micro-channel plate) with finely segmented anode (26.5x26.5 mm² area)

- Backplane anode:
  - metallic pads connected to an interface PCB and merging channels by groups of 8 in horizontal direction
  - **asymmetric segmentation** 4x32 channels (6.625x0.828 mm² area per channel)

- Charge sharing technique:
  - to **reduce number of readout channels** and improve spatial resolution



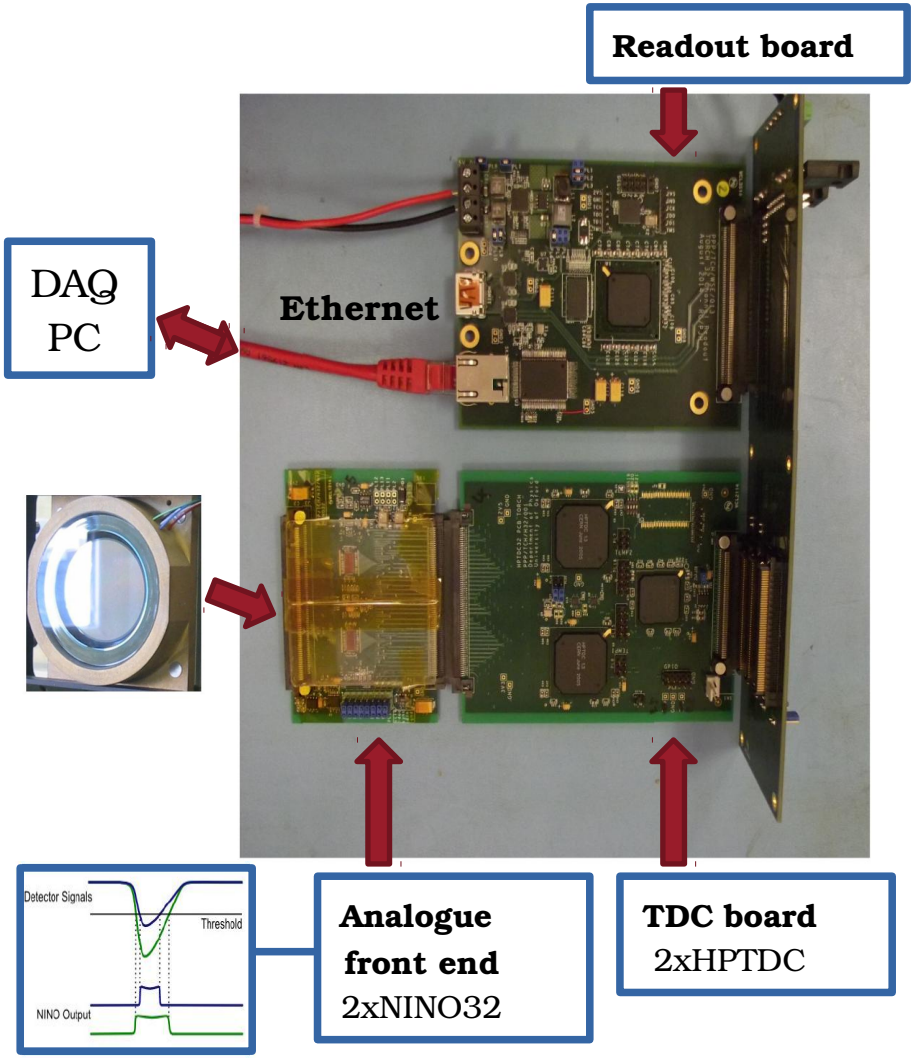
Tube phases:

- Long life time
- Spatial resolution
- Large area

* ***The development of a MCP with this layout is a focus of the R&D with industrial partner Photek (UK).***

Photek will be available to discuss their latest detector developments on Thursday & Friday in the Industrial Exhibition.

READOUT



Readout chain:

- NINO32 board
  - ASIC NINO32 developed at CERN (TOF for ALICE project) reads the output signal of the MCP and converts it to a square signal whose width is related to the input charge

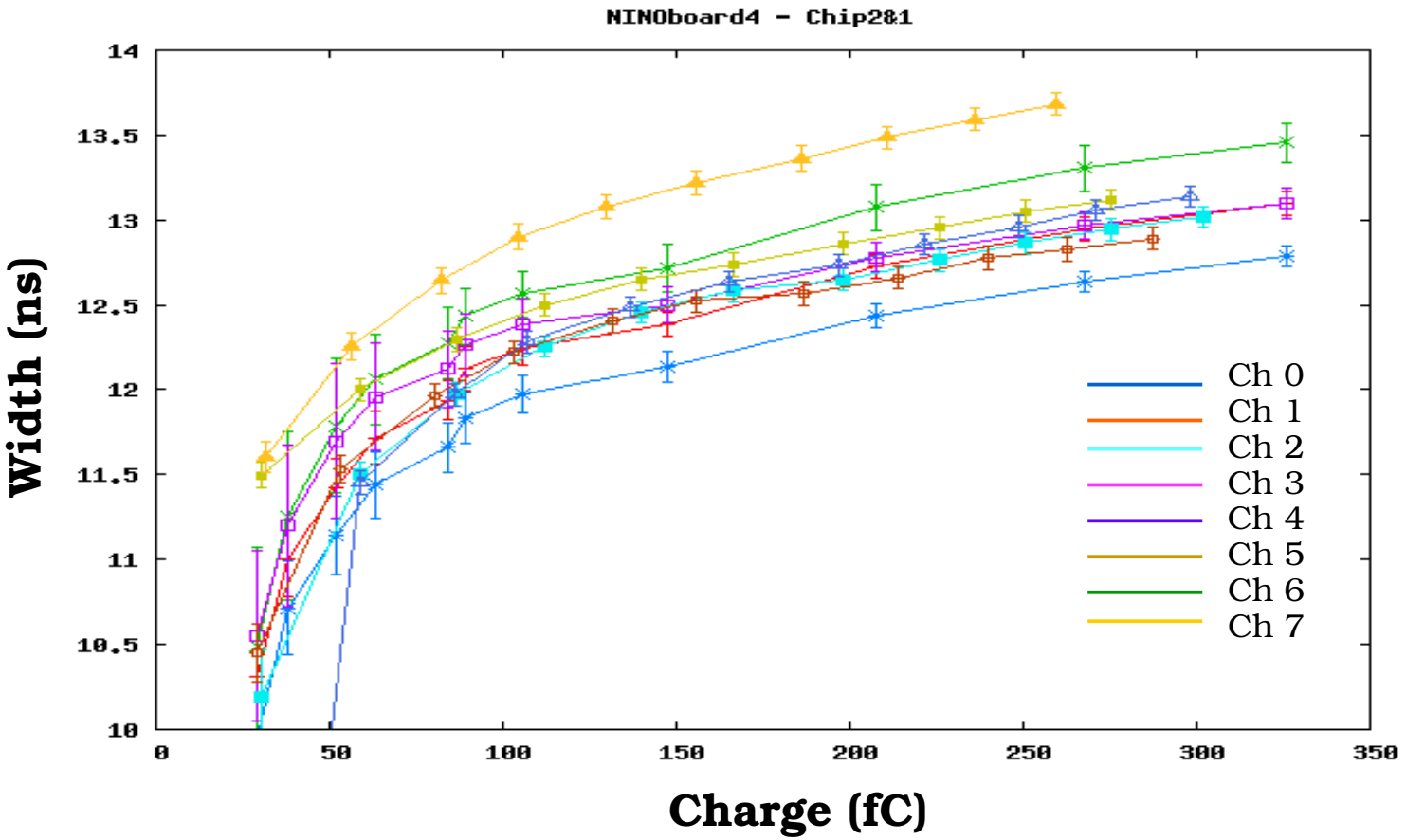
    F. Anghinolfi et al.,[I]

- HPTDC board:
  - HPTDC developed at CERN reads the output signal of the NINO32 and digitises the leading and trailing edges of the signal

    A.V. Akindinov et al., [II]

NINO32

- The Charge to Width calibration of the NINO32 is mandatory:
  - Non-linear behaviour
  - Different from channel to channel



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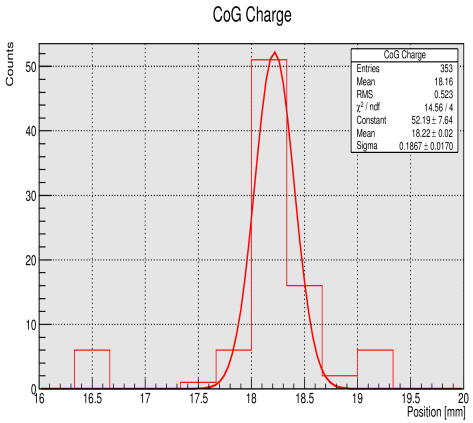
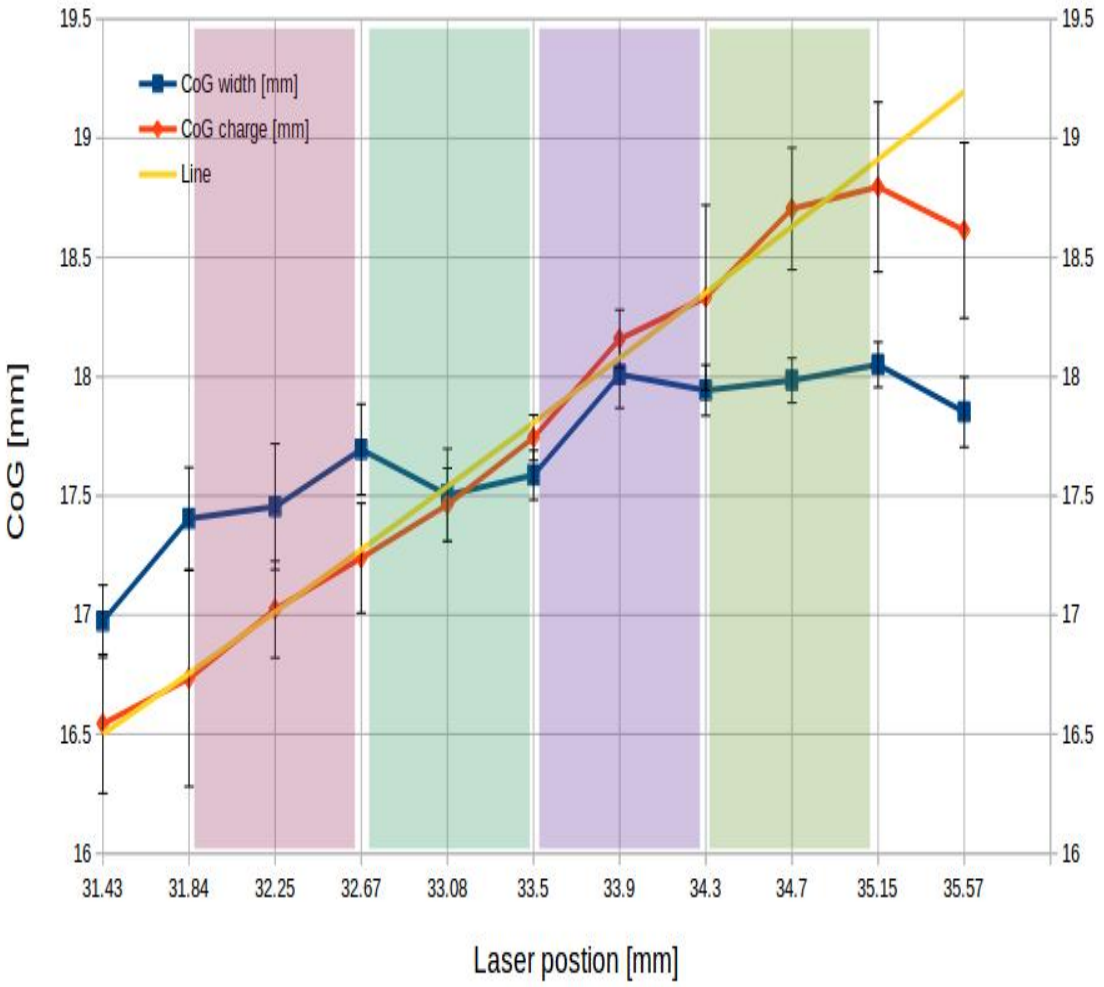
PHASE 2 TUBE + NINO32

- Position estimation by using the Centre of Gravity (CoG) algorithm

Pulsed laser

From 31.43 mm
to 35.57 mm
in 0.414 mm steps





PHASE 2 TUBE + NINO32 + HPTDC

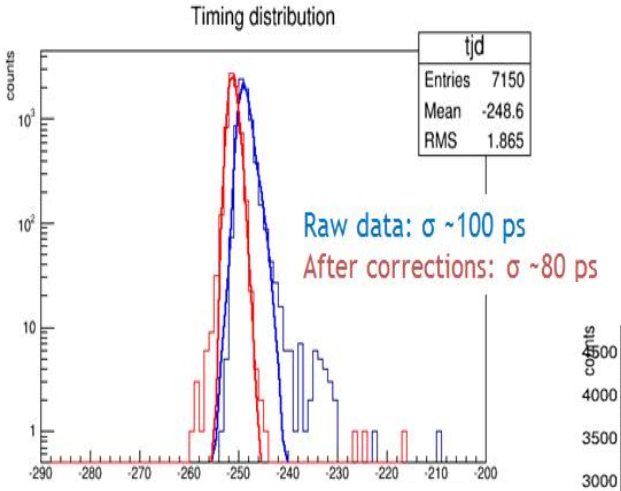
- Position estimation by using the Center of Gravity (CoG) algorithm & timing resolution

Required spatial resolution:

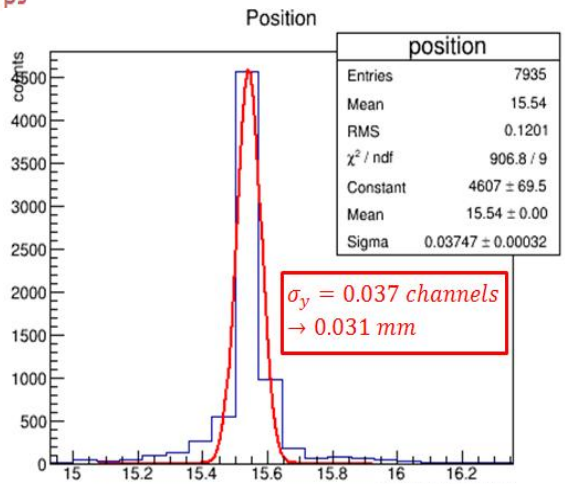
$$\frac{53\ mm}{128\ channels} = 0.414\ mm \rightarrow$$

$$\frac{0.414\ mm}{\sqrt{12}} = 0.12\ mm$$

Required timing resolution:



Signal-Ref [100ps]

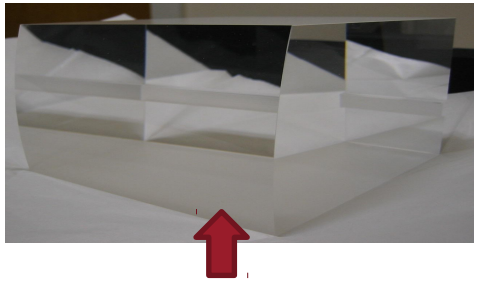


Position [channels]

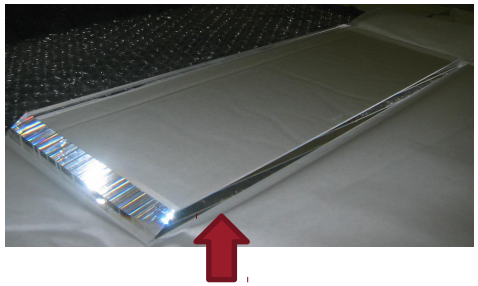
~ 50 ps resolution per single photon
(only electronics + MCP)

Castillo-Garcia L. [III]

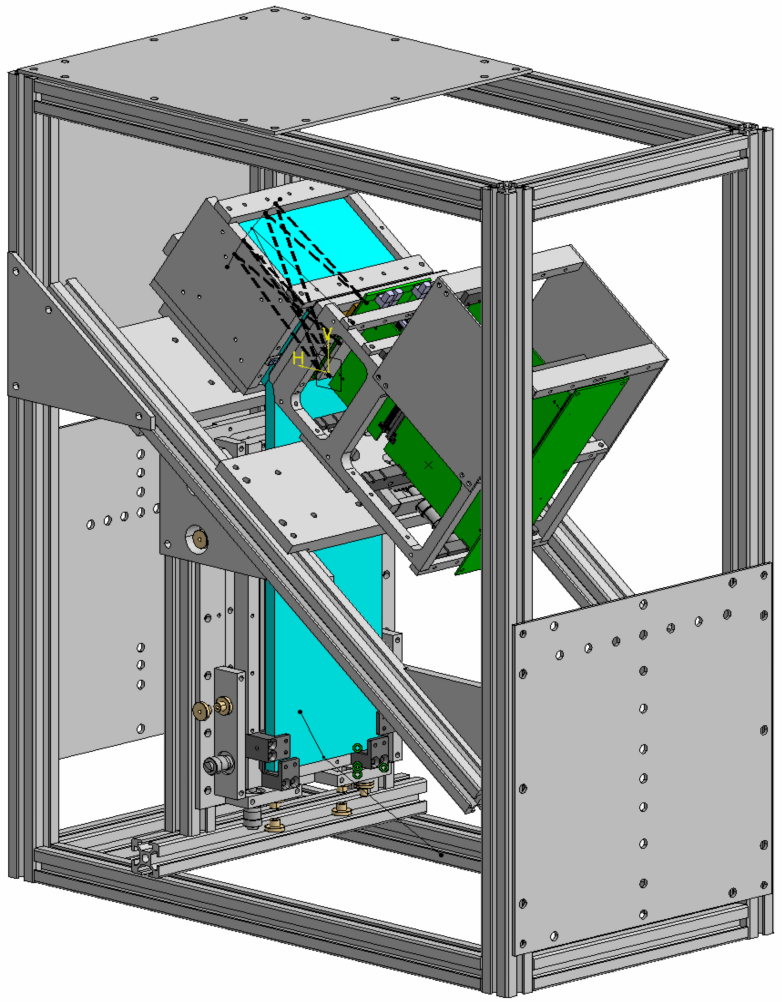
TEST BEAM SETUP



Focussing block



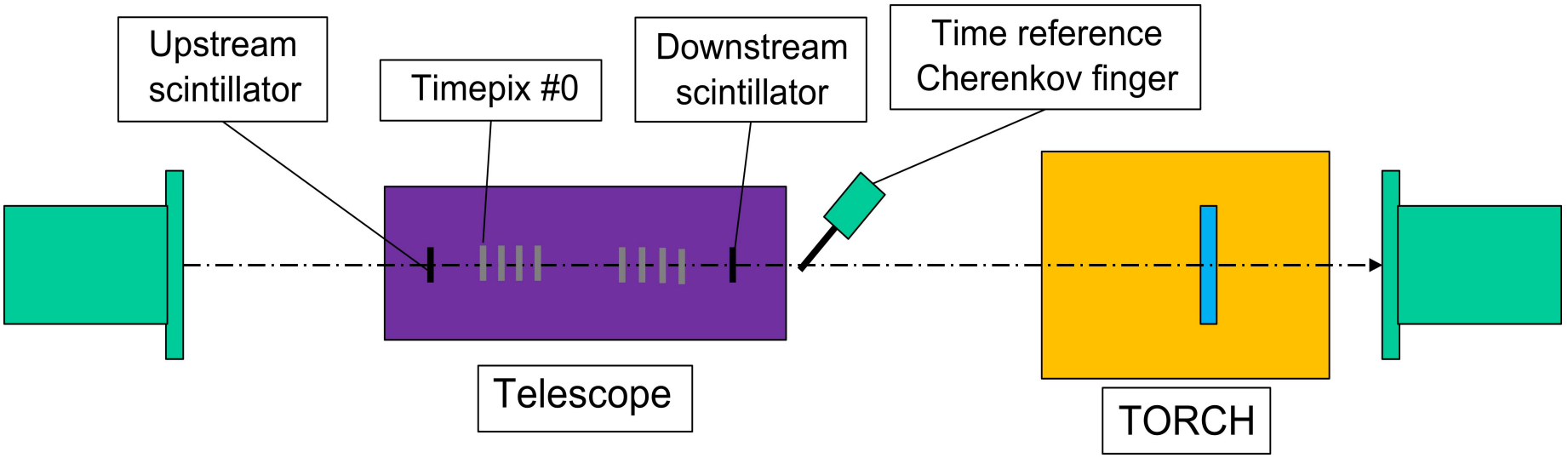
Radiator



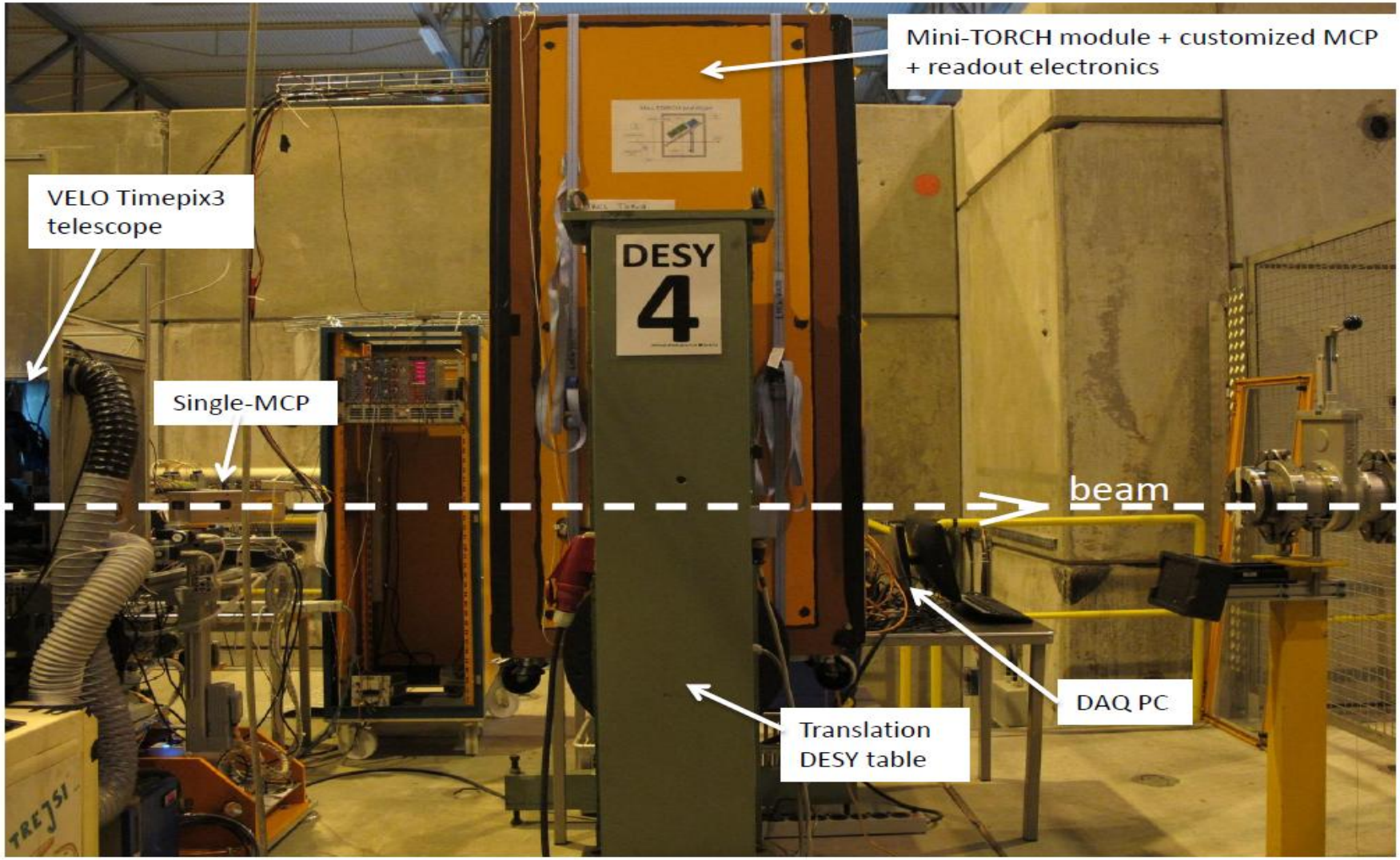
- Beam tests at CERN (SPS-H8 and PS-T9)
- Scaled down version of TORCH module:
  - Quartz radiator plate 12x35x1 cm^3
  - Focussing block
- Photek phase 2 Prototype MCP

TEST BEAM FACILITY SPS

- Beam conditions:
  - p → 180GeV/c charged hadrons (essentially protons)
- Pixel telescope from LHCb VELO group to provide particle track information
- Coincidence signal from scintillators of the VELO telescope used as trigger
- A trigger logic unit synchronized the telescope with the TORCH electronics



TEST BEAM FACILITY SPS

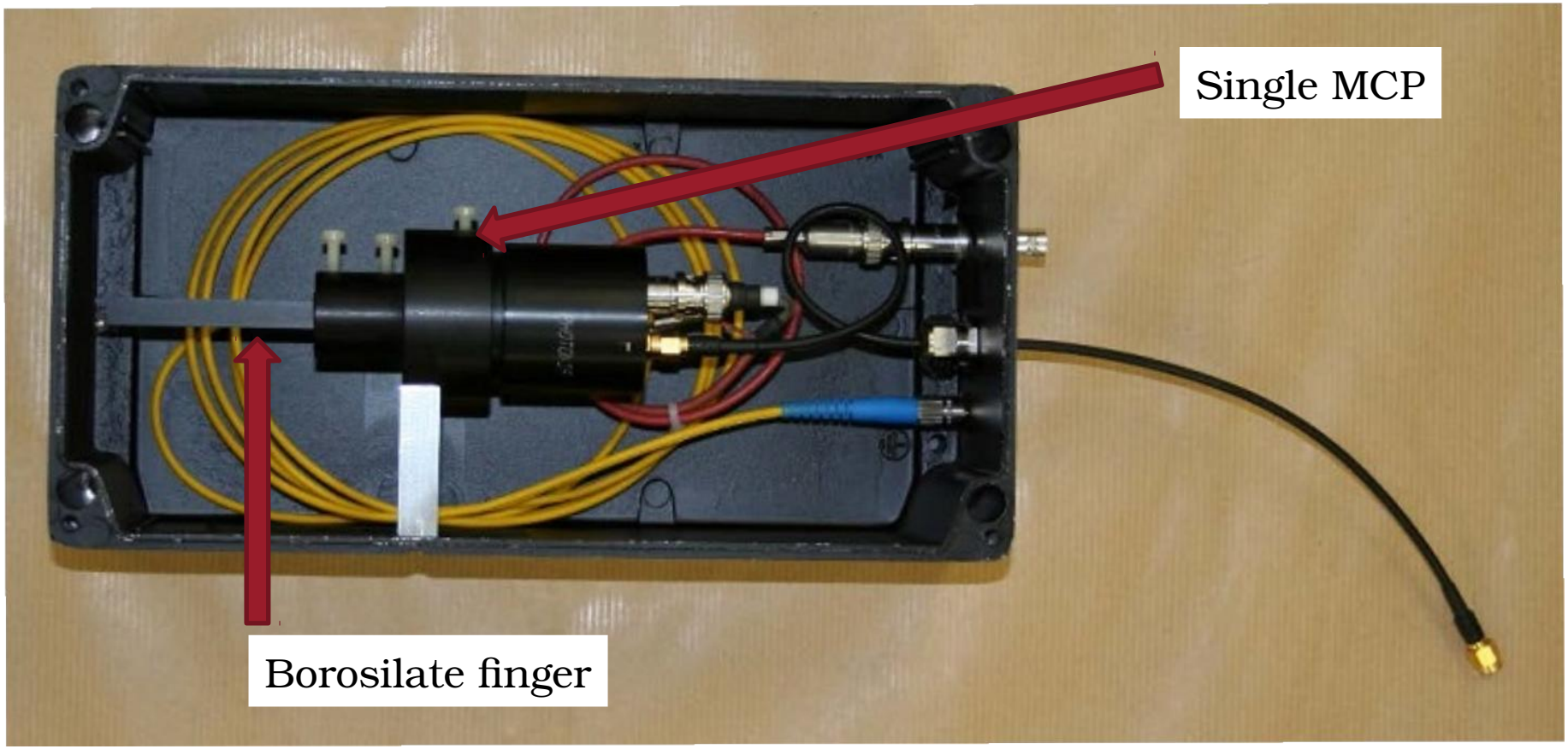


TEST BEAM TIMING & TRIGGERING

Mini-TORCH borosilicate finger used as a timing reference:

Blackened borosilicate finger + single channel MCP

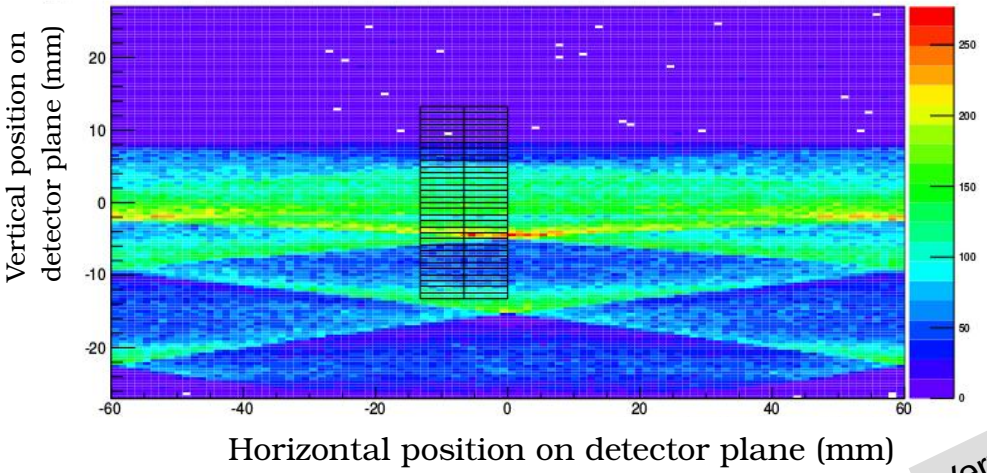
(Lab. measurements ->50 ps timing resolution for borosilicate fingers)



GEANT4 Simulations

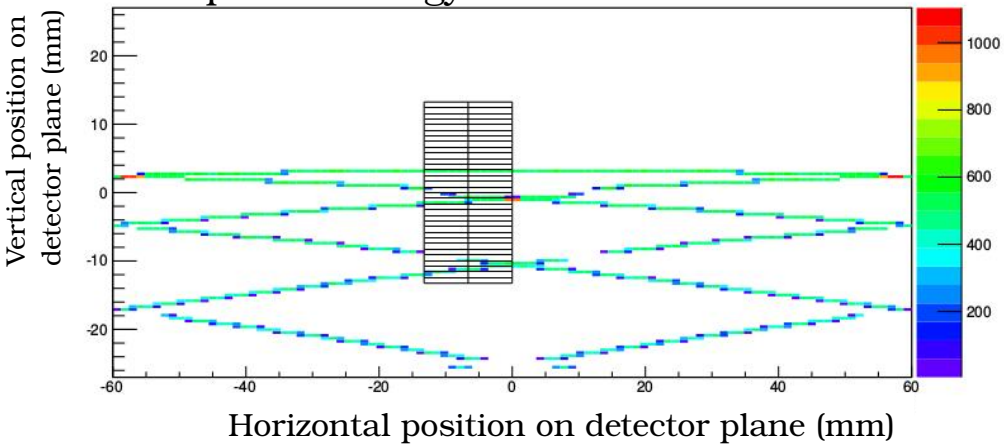
HITMAP Full TORCH SETUP

Cherenkov angle changes with energy



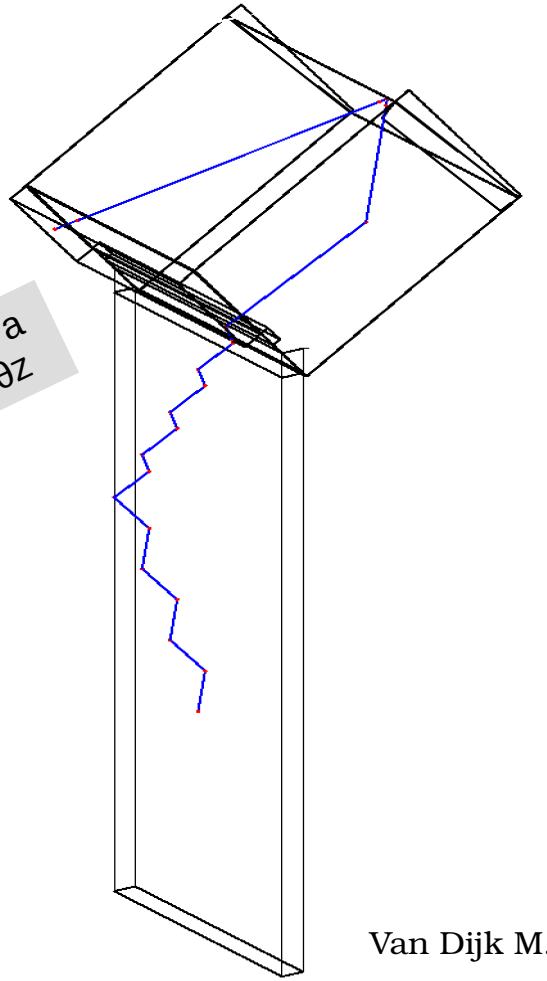
HITMAP Full TORCH SETUP

5 eV photon energy



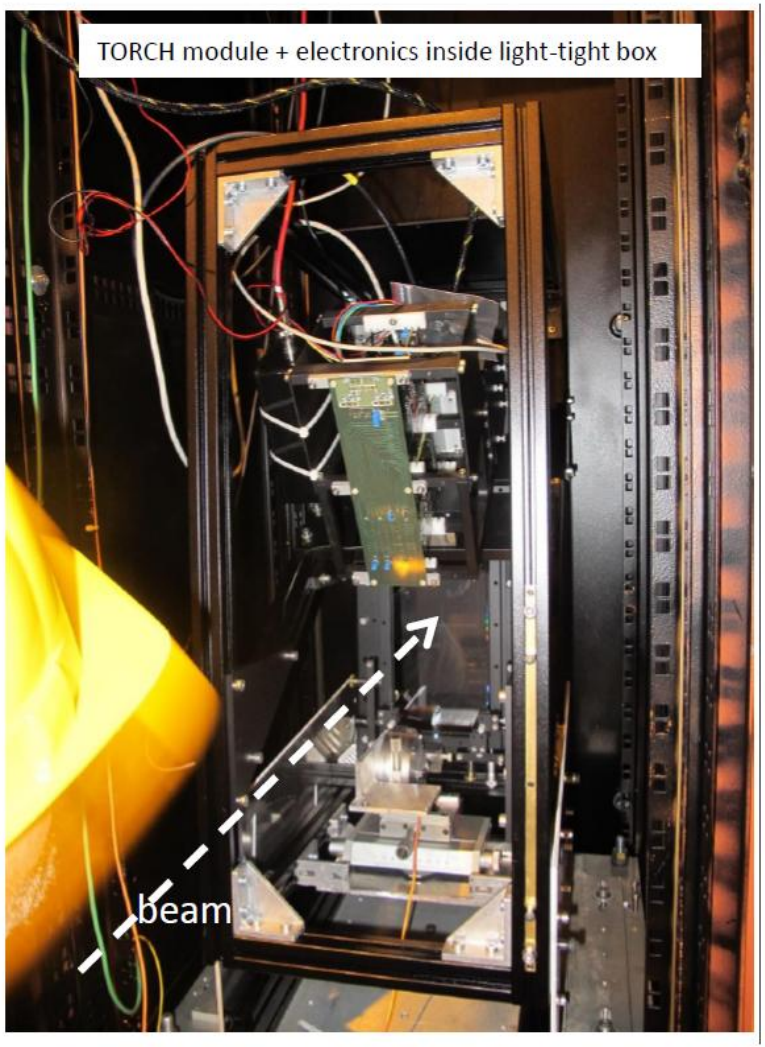
Light reflections

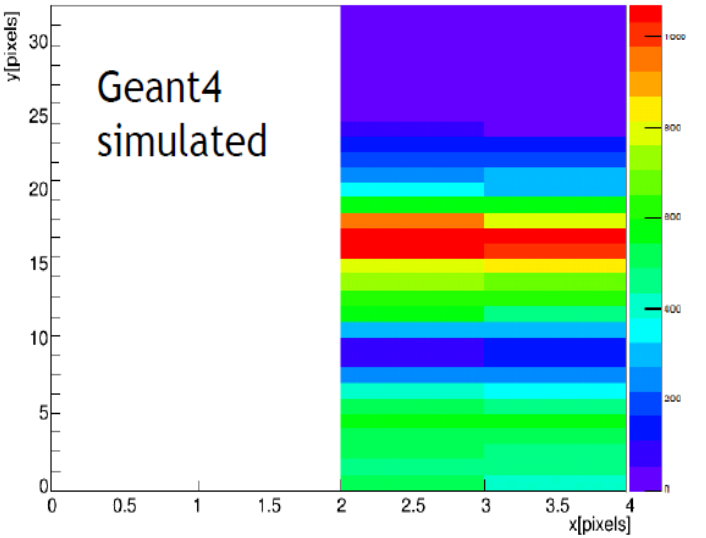
Vertical position is a measurement of θz

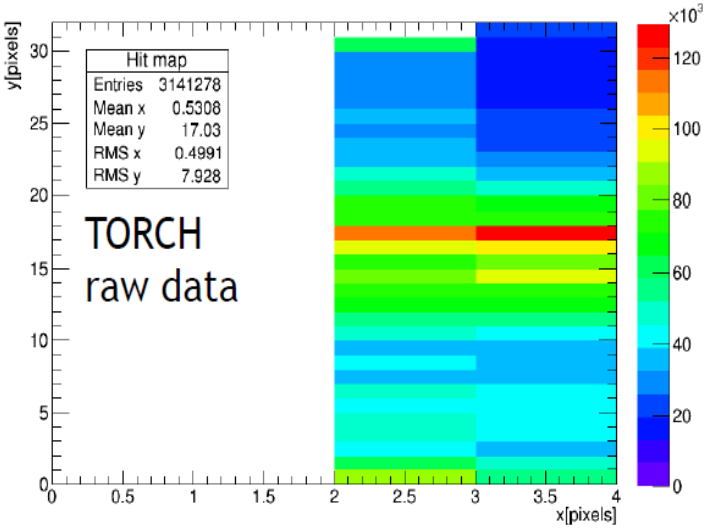


Van Dijk M. [V]

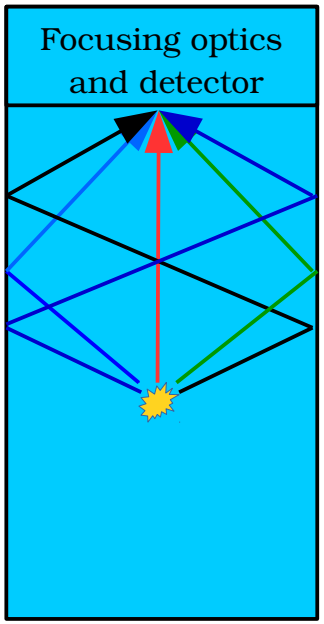
TEST BEAM Measurements SPS

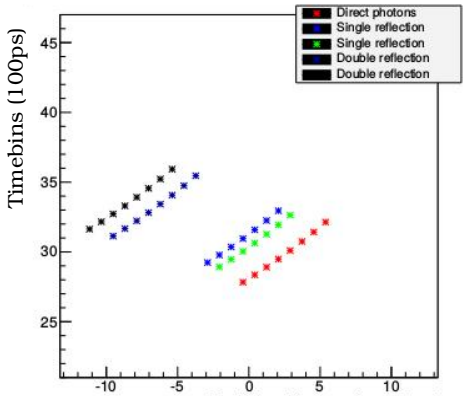


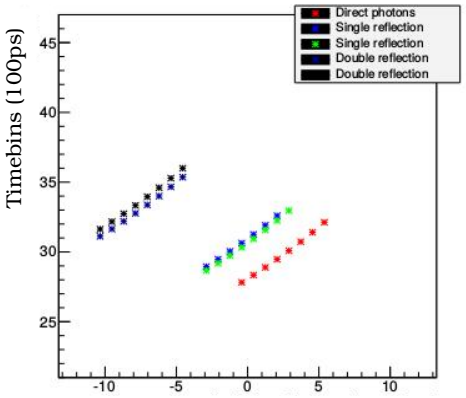


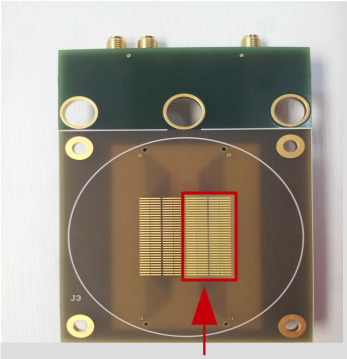


TEST BEAM Measurements SPS

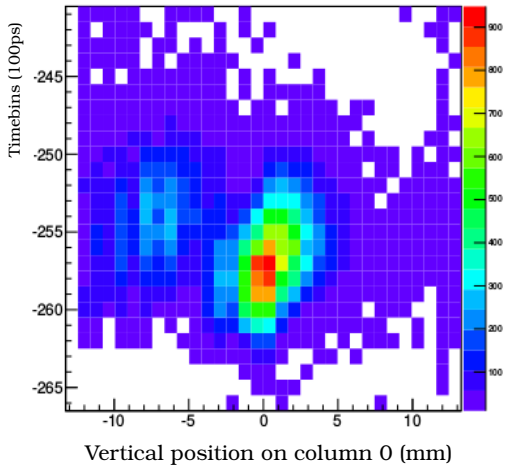


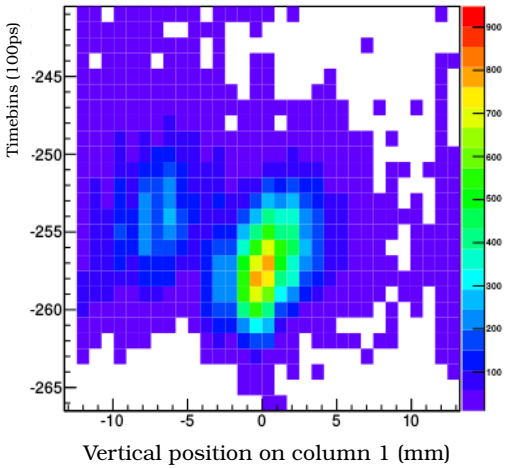




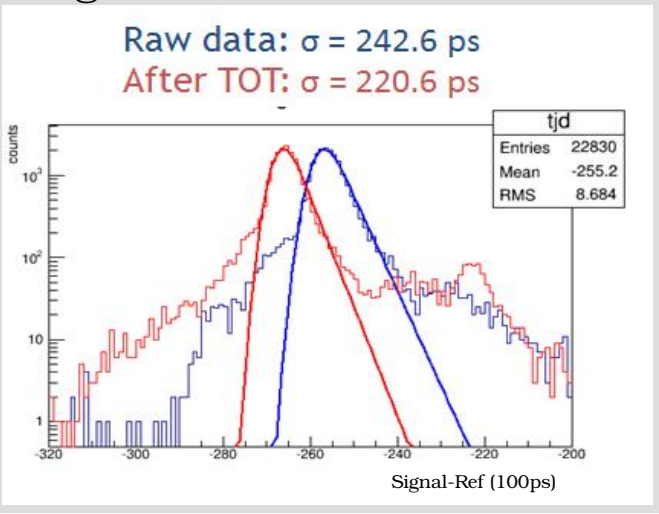


Half of the tube instrumented

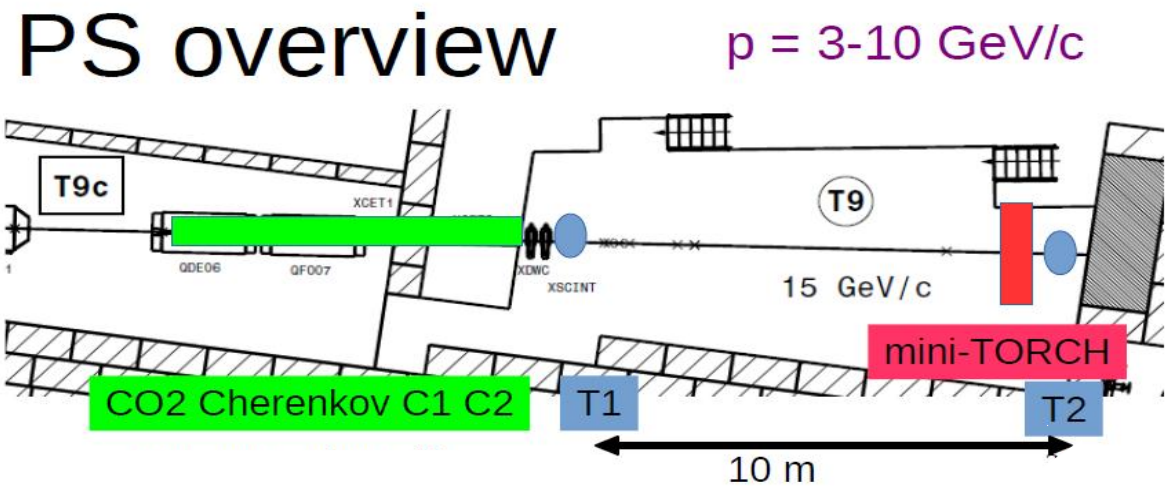


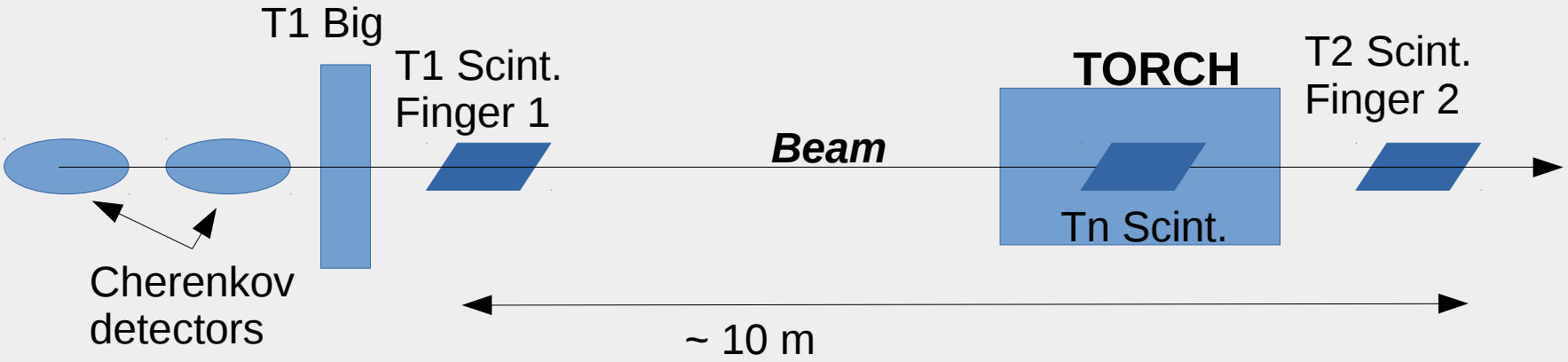


Single channel time resolution



TEST BEAM FACILITY PS

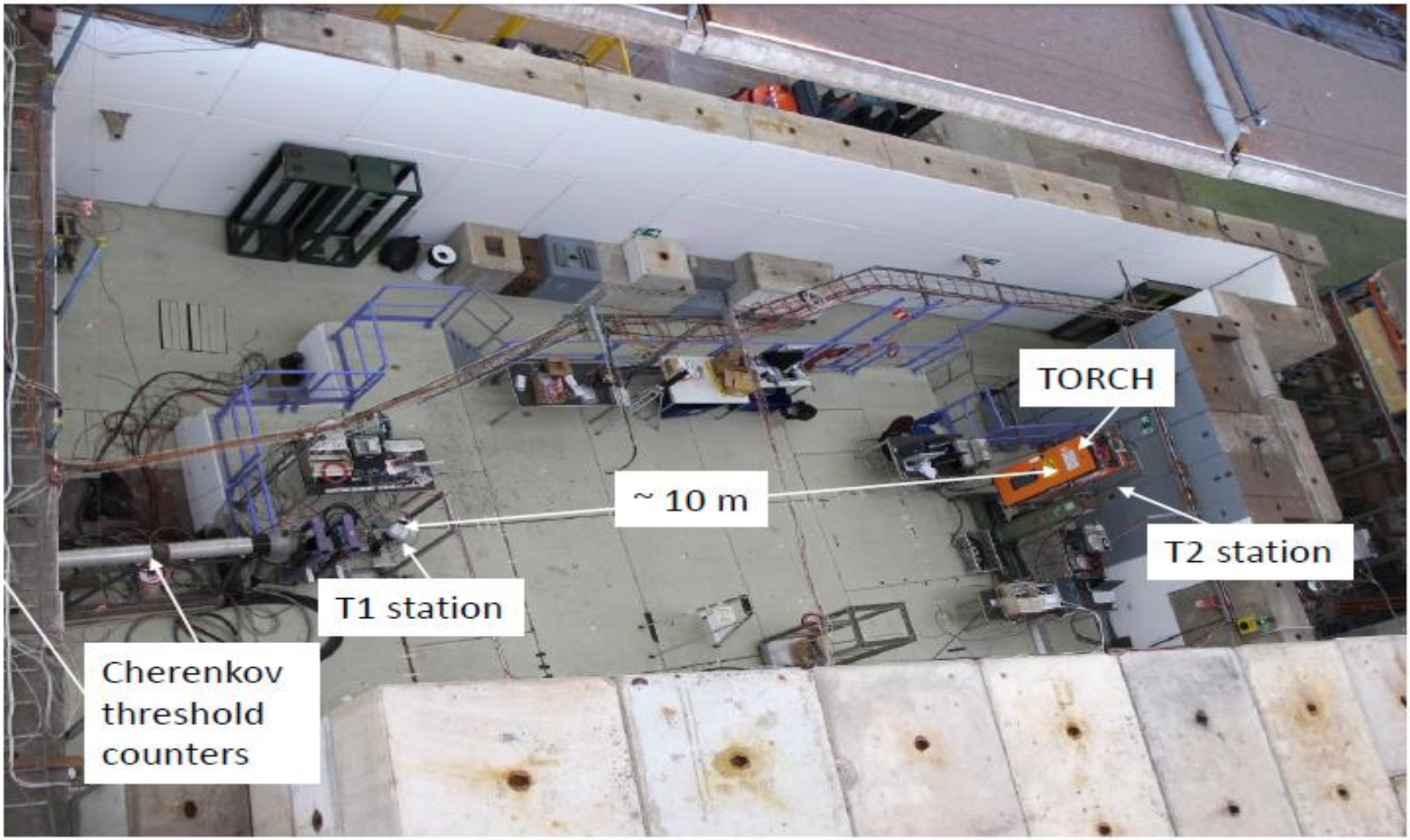




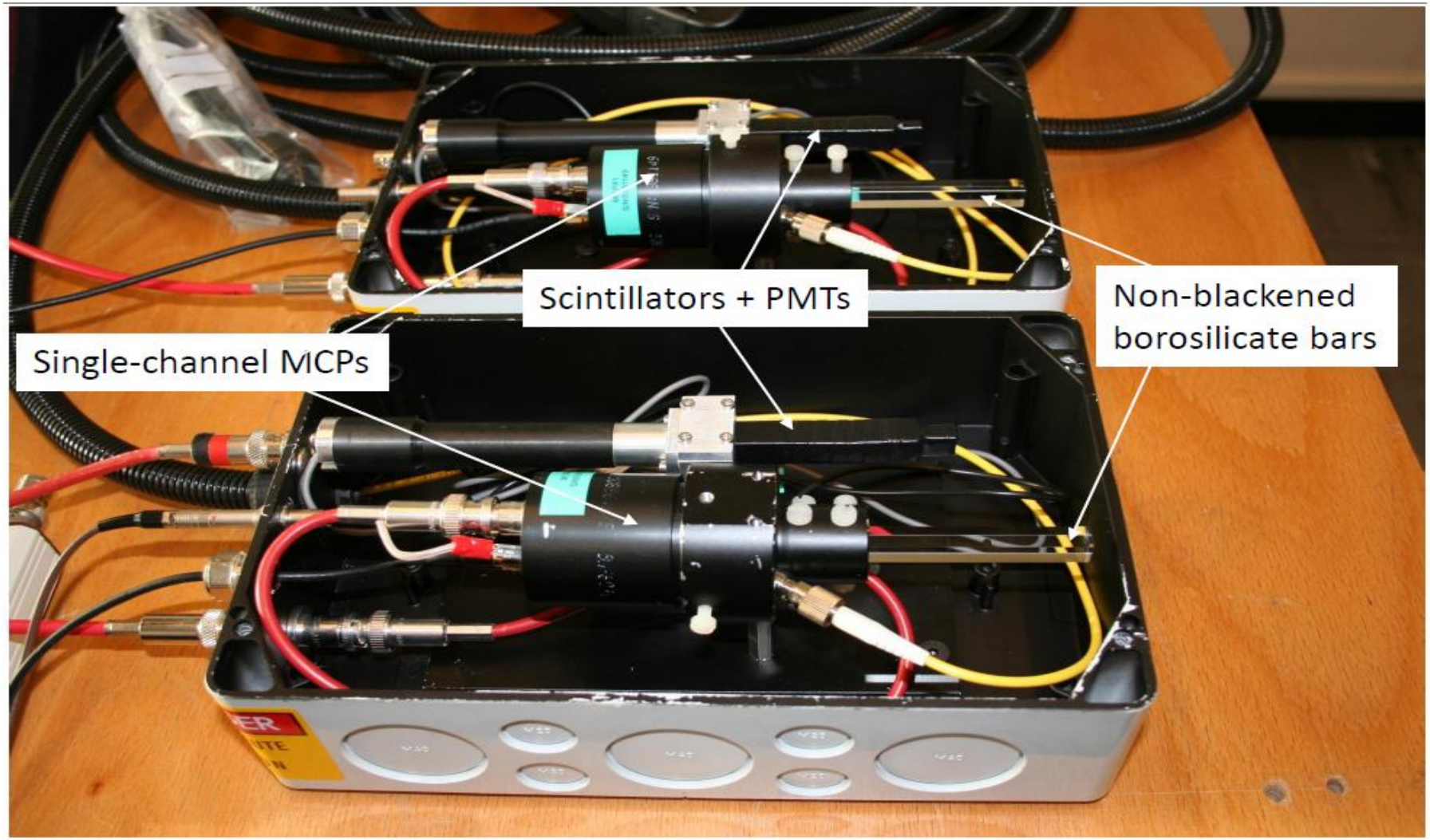
Time references: Fingers 1 & 2 (Two signals instead of just one)

Trigger: Scintillation coincidences

TEST BEAM FACILITY PS-T9



TEST BEAM TIME REFERENCE & TRIGGERING



TEST BEAM FACILITY

PS-T9 beam composition

- **3 GeV/c**
  - about 1/3 protons, 2/3 π, kaons at the % level

3 GeV/c → [p → 33%] & [π → 67%]

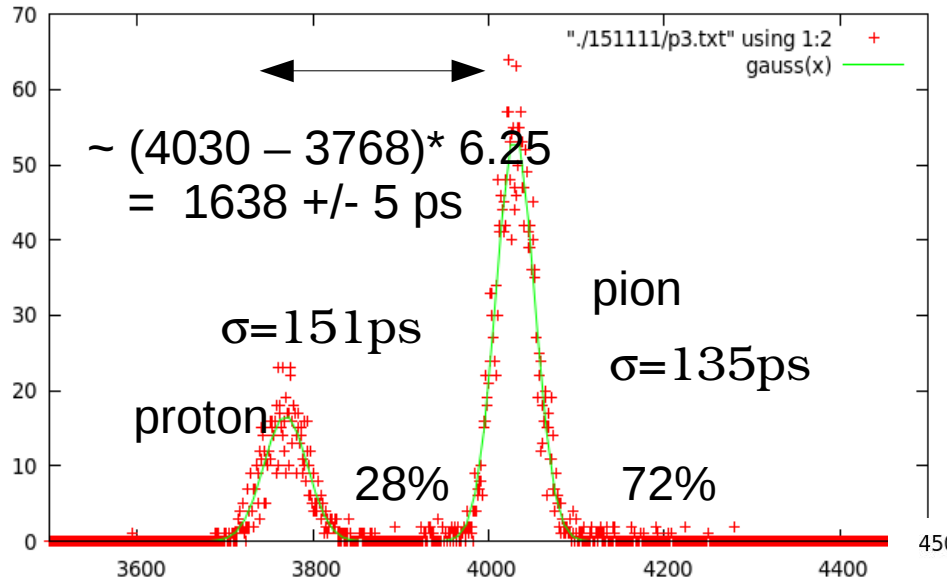
Commercial timing module:

- Difference in time of flight of the reference signal for particles in beam
- T1-T2 reference in TORCH through commercial module

TORCH fingers timing:

- Difference in time of flight of the reference signal for particles in beam
- T1-T2 reference in TORCH through TORCH electronics

Reference signal TOF – Measurements - 3GeV

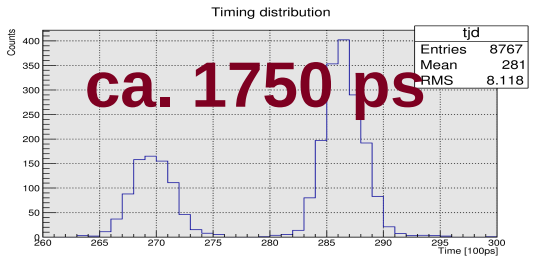


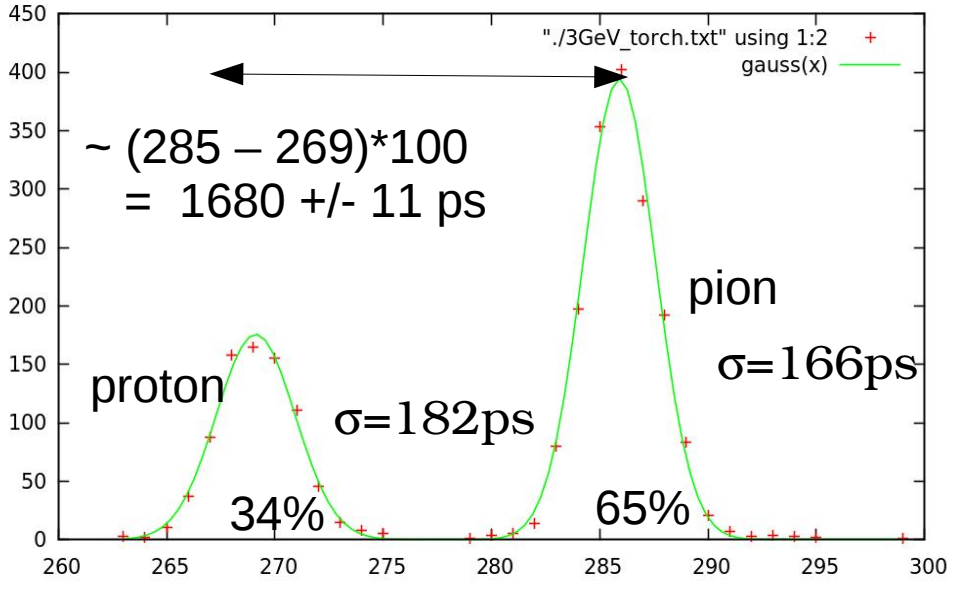
Commercial timing module

6.25 ps timing binning

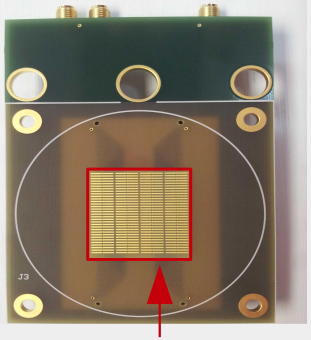
TORCH fingers timing

100 ps timing binning

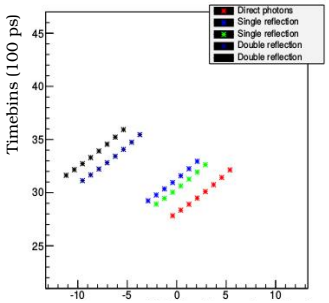




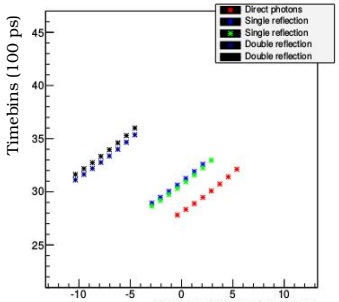
3GeV Beam Measurements – PS - Preliminary Results



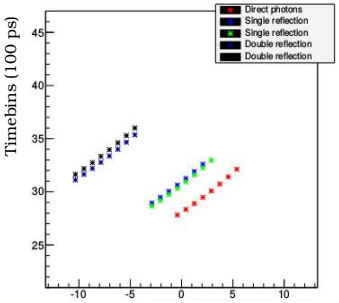
Full tube instrumented



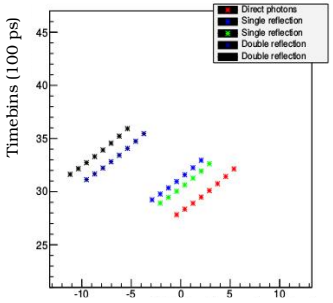
Vertical position on column 0 (mm)



Vertical position on column 1 (mm)

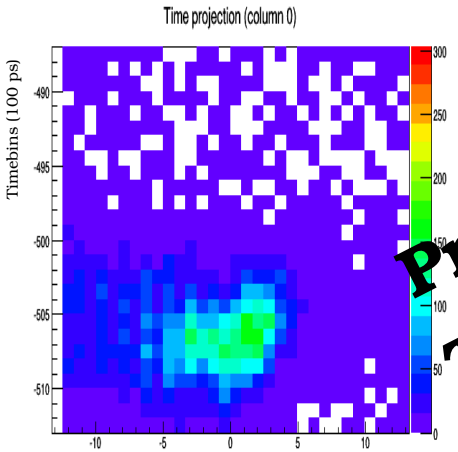


Vertical position on column 2 (mm)

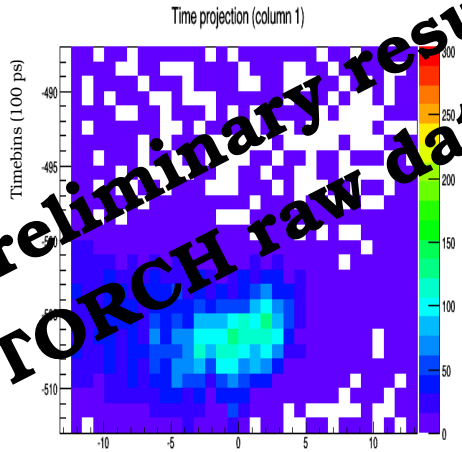


Vertical position on column 3 (mm)

Preliminary results ! TORCH raw data



Position Column 0 (mm)



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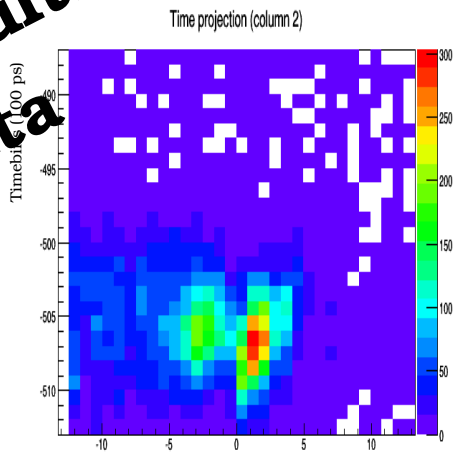
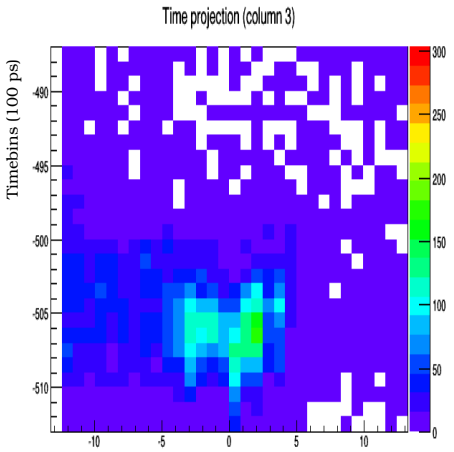


Position Column 2 (mm)



Position Column 3 (mm)

Conclusions and future work

- Laboratory measurements show that it is necessary to do the full channel charge-to-width calibration for NINO32
- Charge sharing of Phase 2 tube has been proven
- Spatial resolution σ~*0.031mm* and temporal resolution σ~*80ps* was obtained for the full readout chain

- SPS - Test-beam timing results show a good pattern, and separate reflections can be identified. Timing resolution of σ~*221ps* was obtained for one channel
- PS - Test-beam timing reference studies show that the TORCH prototype is able to distinguish between protons and pions
- PS - Test-beam timing results show a good pattern, and separate reflections can be identified

- The new generation of MCP tubes will be tested in the next months (phase 3)
- Work on data analysis and reconstruction will continue over the coming months with the full calibration for NINO32

I. *F. Anghinolfi et al.,* **NINO: an ultra-fast and low-power front-end amplifier/discriminator ASIC designed for the multigap resistive plate chamber** Nuclear Instruments and Meth. in Phys. Research Section A,Vol. 533, Issues 1–2, 1 November 2004, Pages 183–187

II. *A.V. Akindinova et al.,* ***Design aspects and prototype test of a very precise TDC system implemented for the Multigap RPC of the ALICE-TOF*** Nuclear Instruments and Meth. in Phys. Research Section A, Vol. 533, Issues 1–2, 1 November 2004, Pages 178–182

III. *Castillo-Garcia L. et al.,* ***Development, Characterization and Beam Tests of a Small-Scale TORCH Prototype Module*** presented at DIRC2015: Workshop on fast Cherenkov detectors

IV. *Foehl K. et al.,* ***TORCH - Cherenkov and Time-of-Flight PID Detector for the LHCb upgrade*** presented at DIRC2015: Workshop on fast Cherenkov detectors

V. Van Dijk M. **PhD. Thesis** - ***Design of the TORCH detector: A Cherenkov based Time-of-Flight system for particle identication***

VI. *Charles M.J. et al.,* ***TORCH: Time of flight identification with Cherenkov radiation*** Nuclear Instruments and Meth. in Phys. Research Section A, Vol. 639, Issue 1, 21 May 2011, Pages 173–176

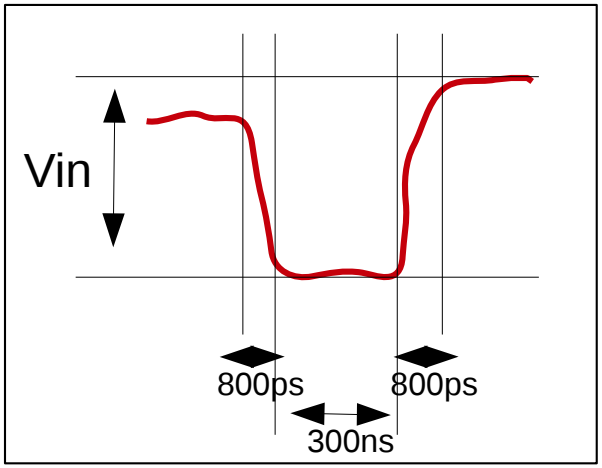
THANK YOU FOR YOUR TIME !

NINO32

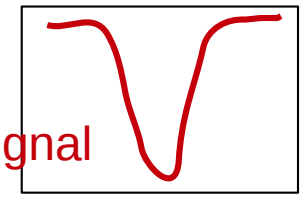
- The Charge to Width calibration of the NINO32 is mandatory:
  - Non-linearity
  - Different from channel to channel

R(RC circ.)	C(RC circ.)	Att.	Width	Lead & Trailing
50 Ω	10 pF	26 dB	300 ns	0.8 ns

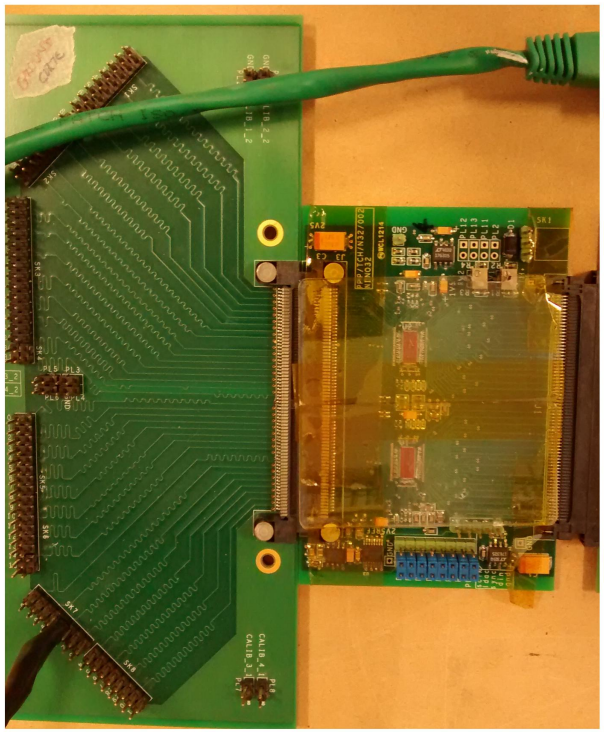
Table 1: *Input signal characteristics*



Att + RC circuit



Input signal



SCOPE

Output signal

Timing summary

	Time diff (ps)	σ proton (ps)	σ pion (ps)	Percent proton	Percent pion
Maestro 3GeV	1601 +/- 5	151	135	28%	72%
Maestro 5GeV	594 +/- 3	127	127	36%	64%
Beam 3GeV	1680 +/- 11	182	166	34%	65%
Beam 5GeV	613 +/- 8	132	166	32%	68%