The “DIRC-like TOF”: a time-of-flight Cherenkov detector for particle identification at SuperB

Laboratoire de l Accélérateur Linéaire (CNRS/IN2P3), Université Paris-Sud 11
N. Arnaud, D. Breton, L. Burmistrov, J. Maalmi, V. Puill, A. Stocchi

SLAC National Accelerator Laboratory
J. Va'vra, D. Aston

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Outline

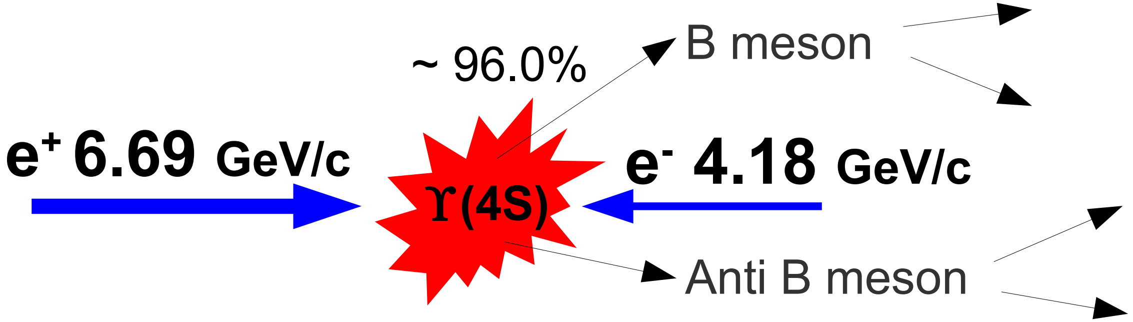
- SuperB project
- DIRC-like TOF detector in forward region: the FTOF (similar to Belle2 TOP counter)

- First prototype of the FTOF
- Test at SLAC Cosmic Ray Telescope
- Results and conclusions

SuperB project

SuperB project

- Electron positron asymmetric collider



- Energy in the center of mass is ~10.58 GeV/c, corresponding to mass of the ϒ(4S).

- Boost $\beta\gamma$=0.237 (reduced w.r.t BaBar 0.56)

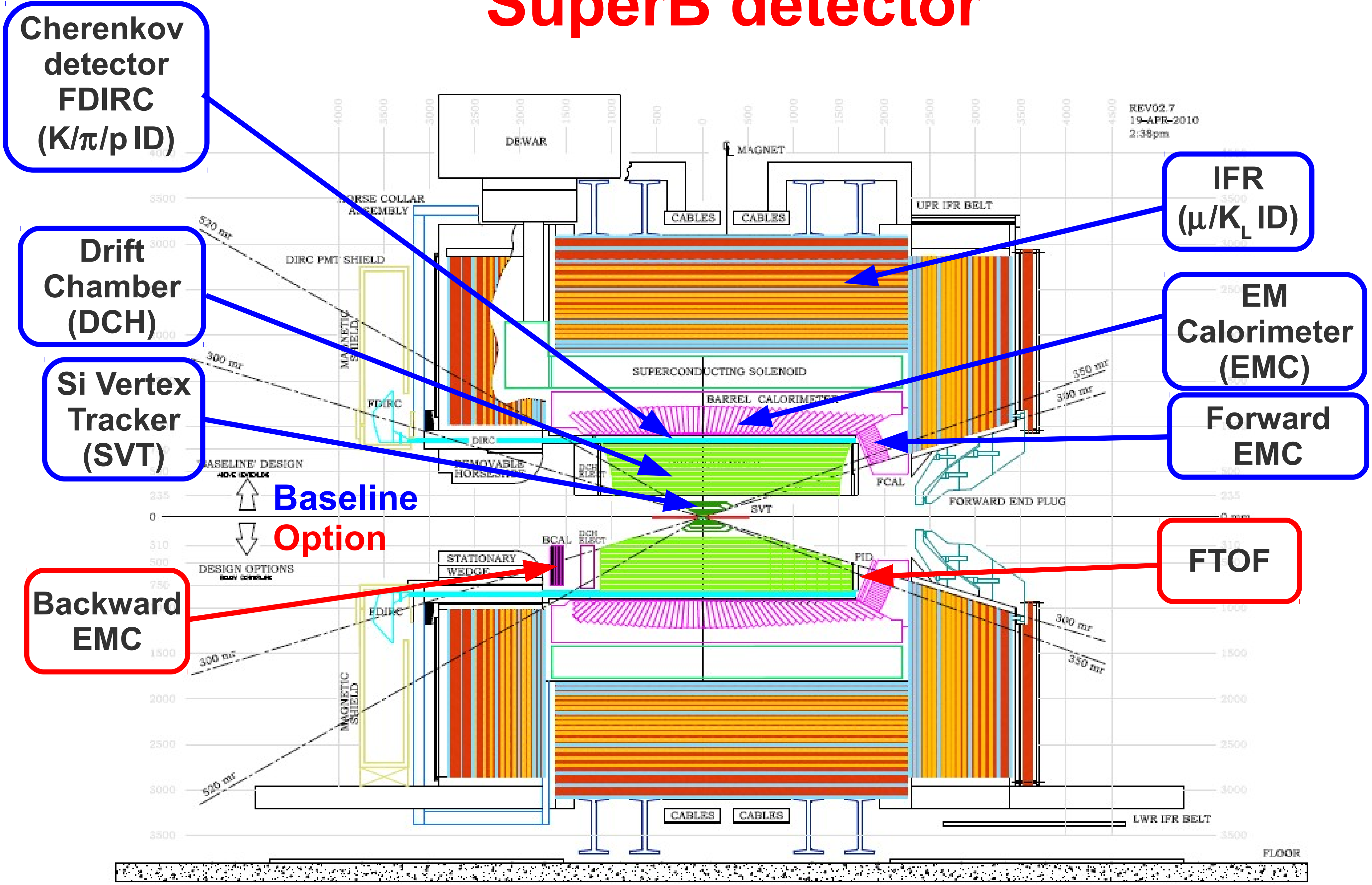
- Peak Luminosity goal: 10^{36} $cm^{-2}s^{-1}$ (15 ab^{-1} per year). 100 times more than BaBar and Belle

- Use new crab waist bunch crossing scheme, tested at DAΦNE (2008-2009)

- SuperB detector based on BaBar but substantially improved.

- Physics motivations:
  - test of the Standard Model (SM) in fermion sector
  - construction of the New Physics (NP) Lagrangian

SuperB detector



Cherenkov detector FDIRC ($K/\pi/p$ ID)

Drift Chamber (DCH)

Si Vertex Tracker (SVT)

Backward EMC

IFR (μ/K_L ID)

EM Calorimeter (EMC)

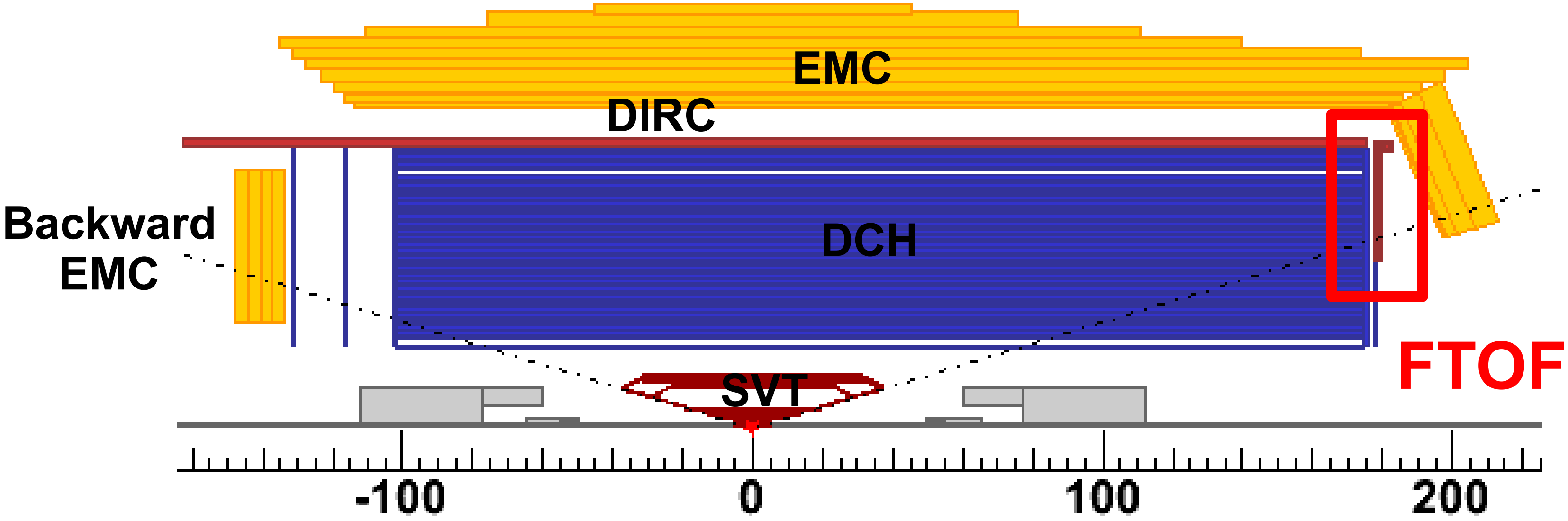
Forward EMC

FTOF

Baseline

Option

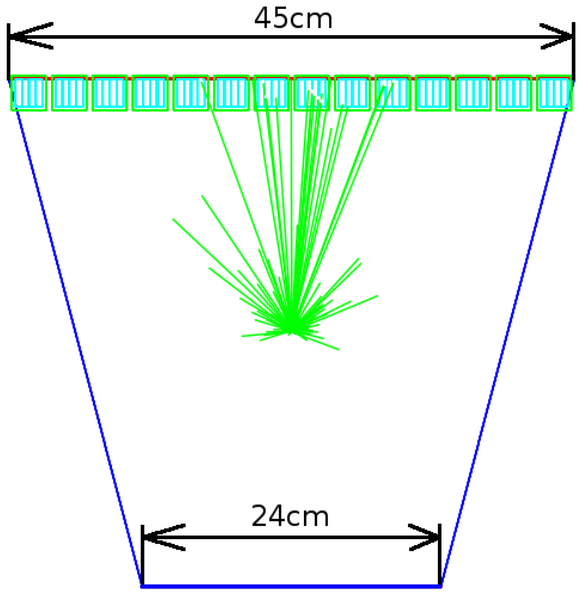
Requirements for forward PID

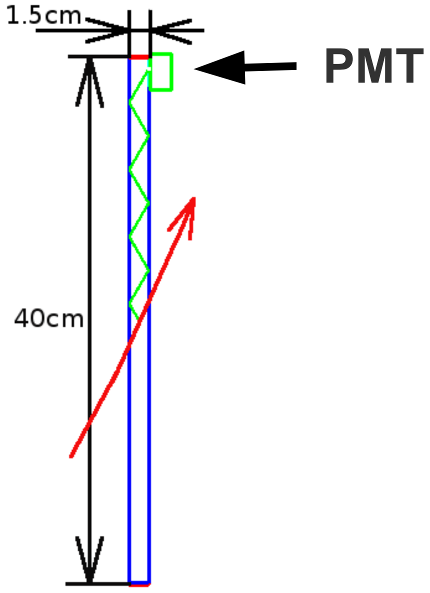


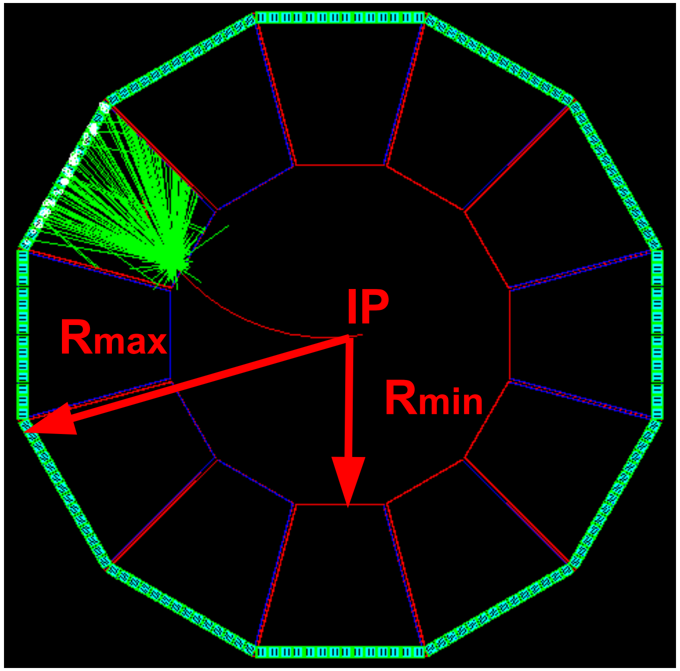
- Compact device (limited space between DCH and forward EMC)
- Small amount of material (in front of the EMC)
- Radiation hard (close to the IP)
- Good K/π separation in (0.8-3.5) GeV/c momentum range

Candidate detector: DIRC-like TOF with 30 ps time resolution

DIRC-like TOF detector in forward region







- Detector made of 12 quartz sectors
- The quartz used as radiator of Cherenkov photons and as a light guide (DIRC technique)
- Each sector is readout by 14 MCP – PMT SL10 (TTS~40 ps).
- Thickness of the detector is 1.5 cm (12 % of X_0)
- Located at ~2 m from interaction point (IP)
- Rmin ~ 50 cm, Rmax ~ 90 cm
- Very similar to the TOP counter in Belle-II.

Time resolution of the FTOF detector

The total time resolution of this detector is sum of different contributions:

$$\sigma_{tot}^2 \sim \left(\frac{\sigma_{electronics}}{\sqrt{N_{p.e.}}}\right)^2 + \left(\frac{\sigma_{detector}}{\sqrt{N_{p.e.}}}\right)^2 + \left(\frac{\sigma_{TTS}}{\sqrt{N_{p.e.}}}\right)^2 + \sigma_{trk}^2 + \sigma_{t_0}^2$$

Number of the detected photoelectrons (N_{pe}) within 4 ns time window is 10 for low momentum kaons (0.8 GeV/c) and ~18 for high momentum (3 GeV/c) estimated with Geant4.

Contribution	Resolution (ps)	Comment
Electronics	<10	Measured
Detector	70	Estimated with Geant4 sim.
TTS for SL10	40*	arXiv:1010.1057v1
trk	10	Estimated with fast sim.
t_0	20	$\sigma_t = \sigma_z / c$ σ_z – longitudinal size of the bunch

Total time resolution per track will be between 30 – 40 ps

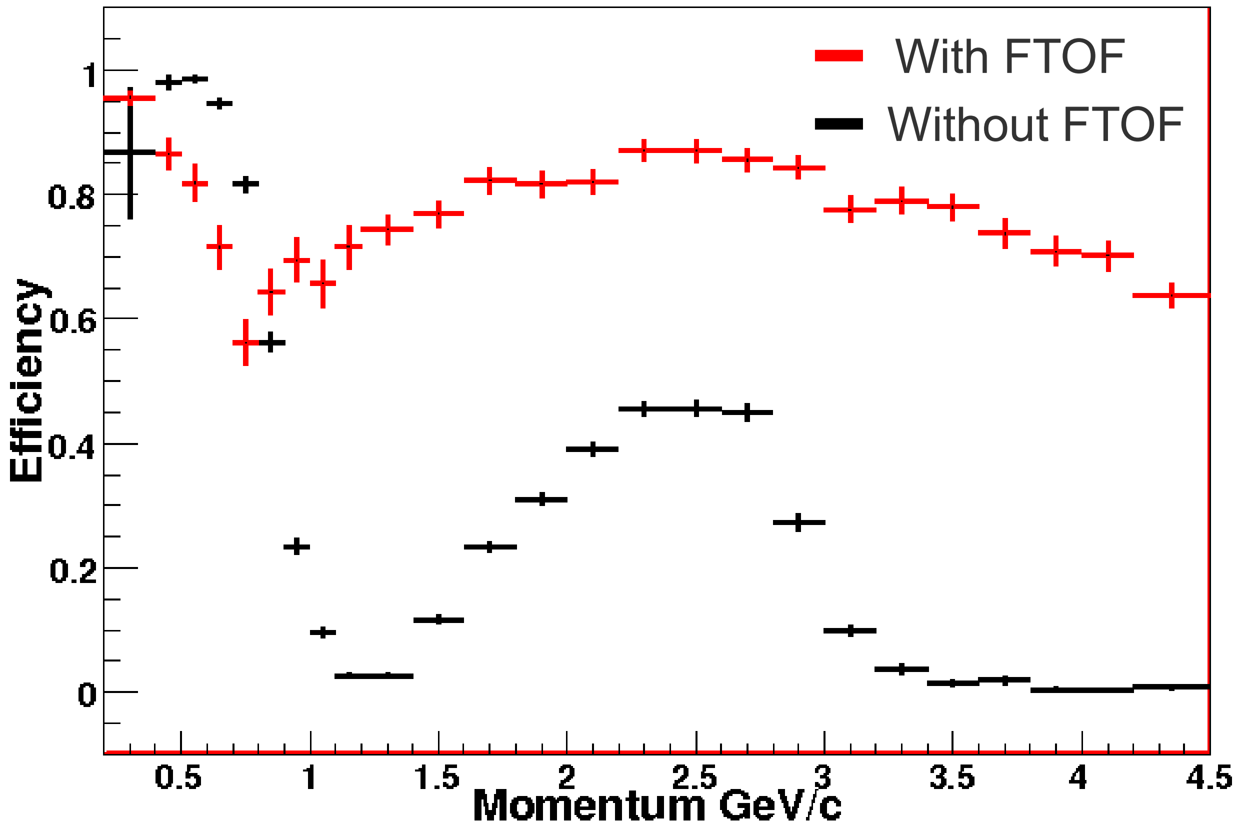
*This is narrow component of the TTS. Howerer within full simulation we take into account the wide component of the TTS and background hits.

K/π Separation in forward region of SuperB

- Fast parameterized simulation (FastSim) was developed by SuperB collaboration for detector optimization and physics reach studies.

- FTOF detector response **(**based on full simulation**)** have been implemented within FastSim.

Kaon identification efficiency vs momentum

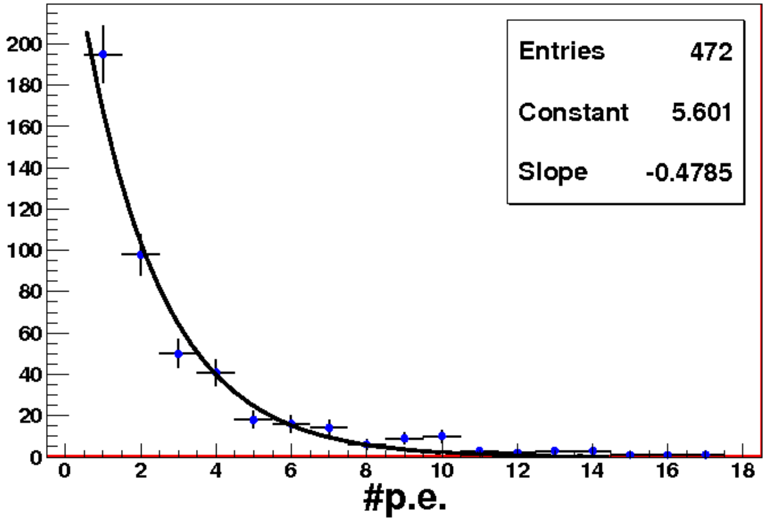


Background studies

Radiative Bhabha is the dominant source of background for FTOF detector

→ Using Full Geant4 Simulation of the SuperB detector (Bruno), background rate coming from Radiative Bhabha was estimated.

Number of back hit in 1 sector



→ Background particles are:

In forward region:
Gammas – 87%
Neutrons – 10%
Electrons, positrons < 3%

→ ~10 gammas with average momentum = 1.6 MeV entering the FTOF detector region per bunch crossing. This correspond to a p.e. rate of **460 kHz/cm^2**.

→ Currently we are trying to reduce this background by increasing tungsten shield around beam pipe and by tuning parameters of the magnets in the final focus region. This work is in progress.

→ **The DIRC-like TOF is background tolerant device. We should understand and have the main sources under control.**

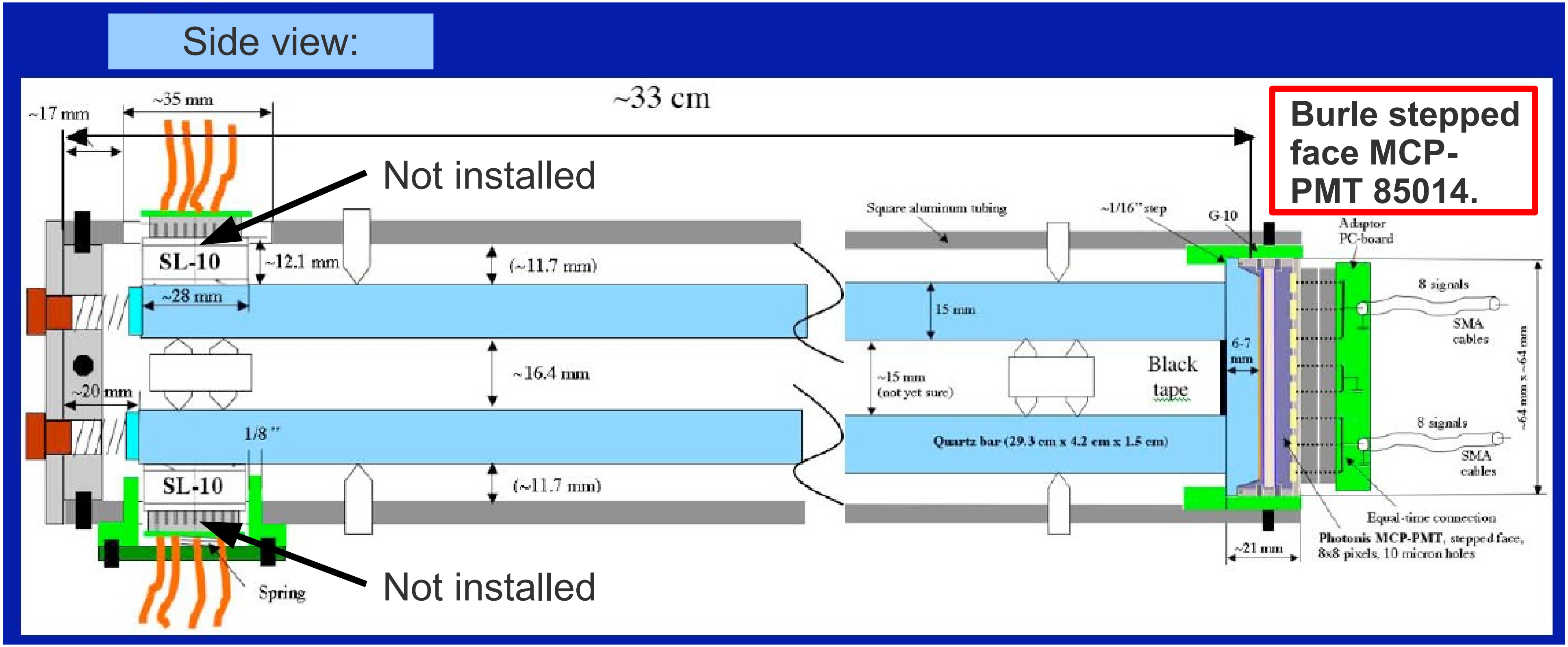
Test of the first FTOF prototype at SLAC cosmic ray telescope

Main goals are:

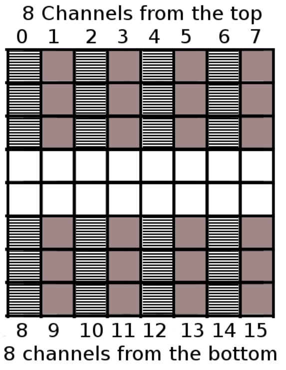
1) Test of the electronics
2) Estimate time resolution per channel
3) Prove the principles of DIRC-like TOF detector for SuperB project

Note: within following experiment we did not apply yet any correction on the time of the p.e. arriving. The cosmic ray telescope have been used just to obtain clean sample of muons and restrict their angles.

First prototype of the DIRC-like TOF detector

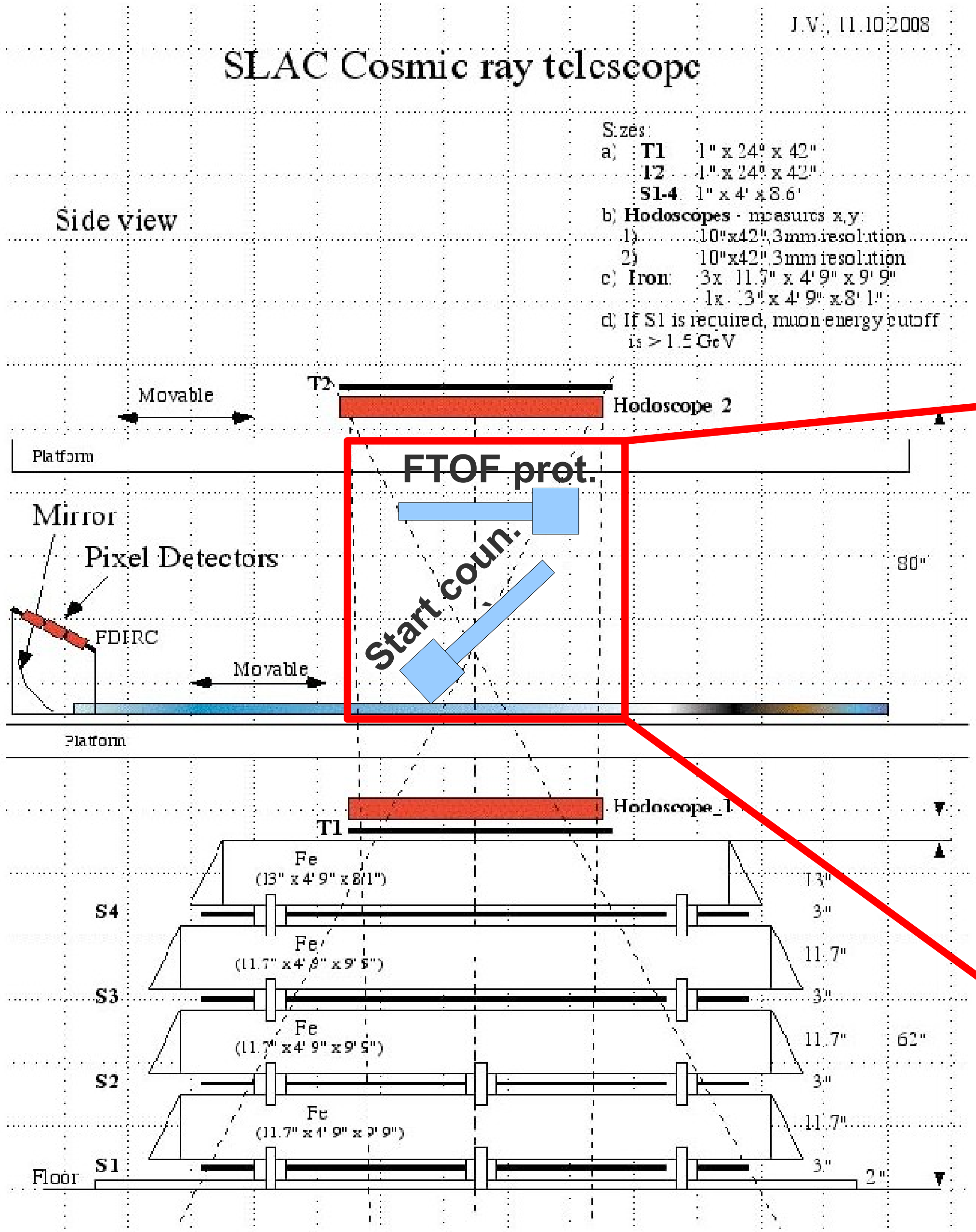


- Two quartz bars connected to one Photonis MCP-PMT (8x8 pixels, 10 micron holes).
- Mylar sheets inserted between quartz bars and MCP-PMT (reduction of light by factor of 5).
- Tube operate at -2.7kV (gain ~ 7x10^5).
- 16 channels (see top right picture) connected to the USB-Wave Catcher (USBWC) electronics developed by LAL electronics team.
- Amplifiers (40dB).
- Filters (600MHz bandwidth).
- All connections done with SMA cables.
- Constructed at SLAC and installed in cosmic ray telescope.



MCP-PMT channel map

SLAC Cosmic Ray Telescope (CRT)

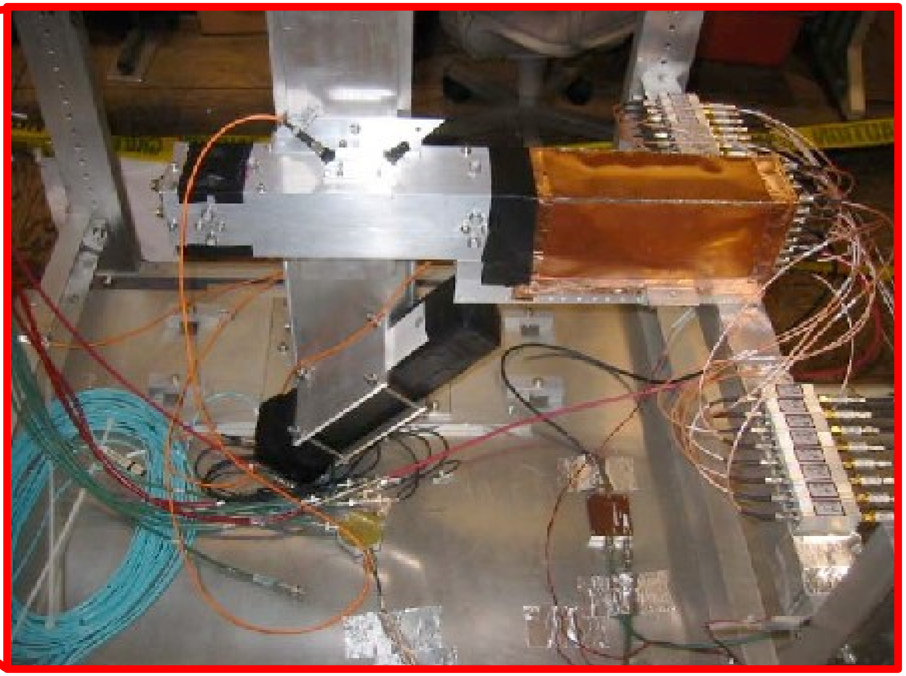


Sizes:
a) **T1** 1" x 24" x 42"
T2 1" x 24" x 42"
S1-4 1" x 4' x 8.6'
b) **Hodoscopes** - measures x,y:
1) 10"x42",3mm resolution
2) 10"x42",3mm resolution
c) **Iron**: 3x 11.7" x 4' 9" x 9' 9"
1x 13" x 4' 9" x 8' 1"
d) If S1 is required, muon energy cutoff
is > 1.5 GeV

Two hodoscopes (T1, T2), allow reconstruction of the muon tracks.

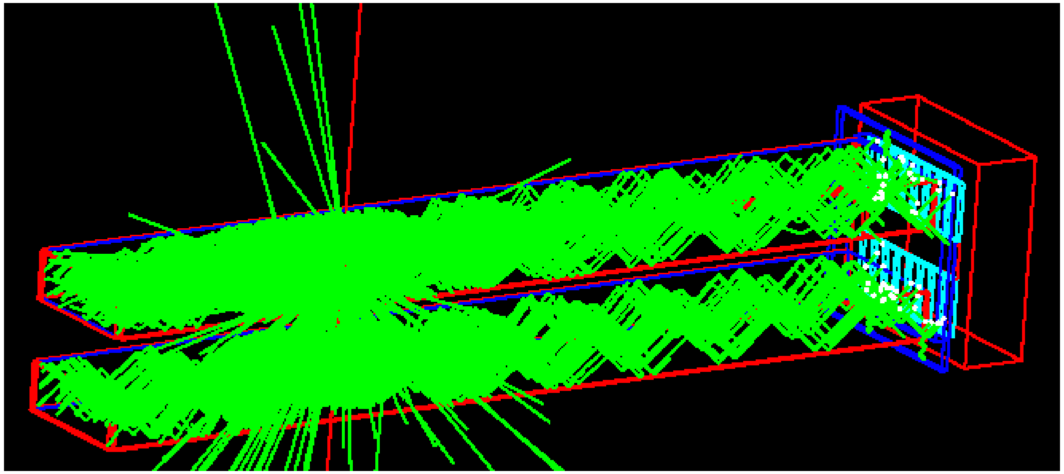
Quartz start counter gives precise timing of the muon arrival.

Stack counters (S1, S2, S3, S4) define muon energy.



We use reconstructed muons which cross the FTOF prototype and the start counter

Geant4 Simulation of the FTOF prototype



- Precise geometry description
- Optical properties of the quartz
- Transit Time Spread of the MCP – PMT (TTS) = 35 ps / channel
- Electronics resolution = 10 ps / channel
- Bialkali photocathode
- p.e. collection efficiency 14% = 70.0%(coll eff of the PM) * 1/5(mylar sheets)

Time measurements:

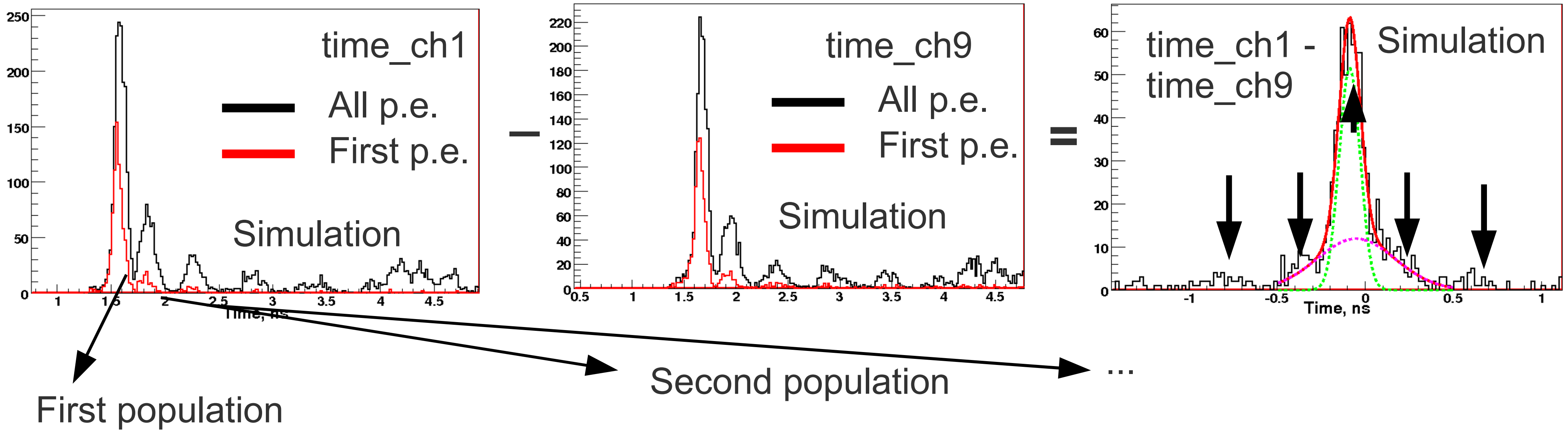
Time of first p.e. arriving is taken as a time measurement for a given channel.

Simulation of the waveform based on the MCP-PMT response on single p.e. (laser run)

- Simple muon generator developed

What we learn from full simulation

Fix position and direction of the muon



- Several possible paths exist to reach same channel => several different times (peaks on the histogram above).
- Due to geometry of the prototype (bars with 29.3 x 4.2 x 1.5 cm) the time distances between different peak are small, unlike in the real FTOF detector.
- Time difference between two channels have two components: narrow and wide. Narrow component corresponds to time difference between p.e. from same populations, while wide component corresponds to time difference between p.e. from different populations.

A simple way to estimate time resolution per p.e.

We consider the RMS(of narrow component)/sqrt(2) as the time resolution per channel.

Data analysis

We store all waveform (256 points with period 312.5 ps) from 16 channels

→ **Calculate parameters of the stored waveform**

a) Amplitude
b) Change
c) Constant fraction time at 50% of the amplitude
d) Classify shape of the waveform (single peak, multi peak, crosstalk like)

→ **Apply sanity cuts on muon track and waveform**

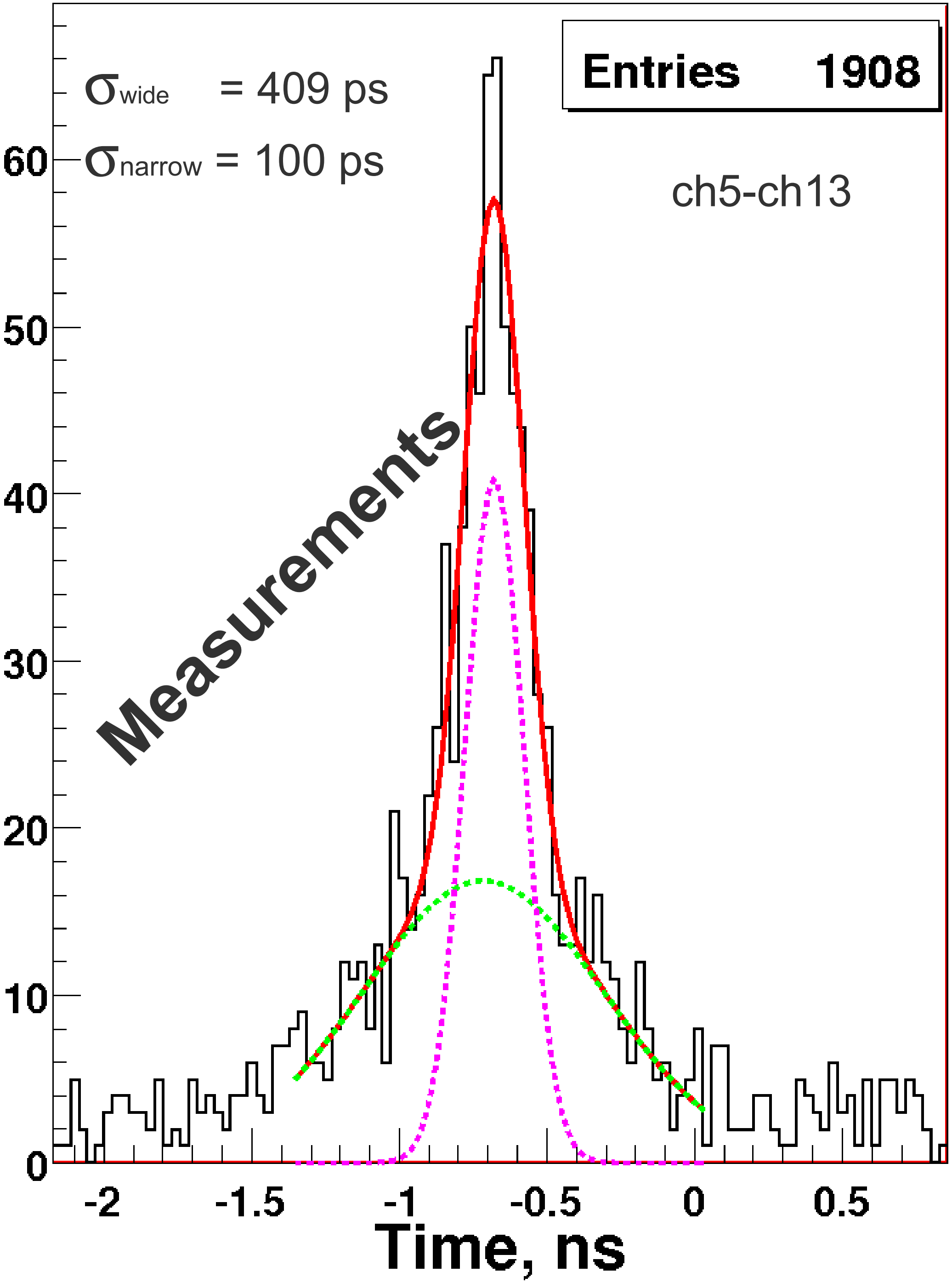
a) muon track to be reconstructed
b) coincidence between CRT and FTOF prototype
b) Amplitude of the signal > 80mV
c) Shape of the signal should be single peak
d) total number of firing channels < 6

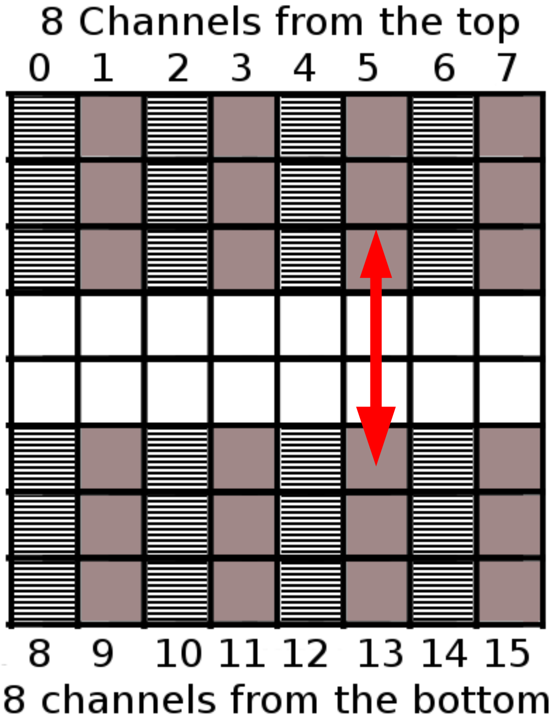
→ **Construct time difference between different channels**

→ **Accumulate statistics**

→ **Fit time resolution**

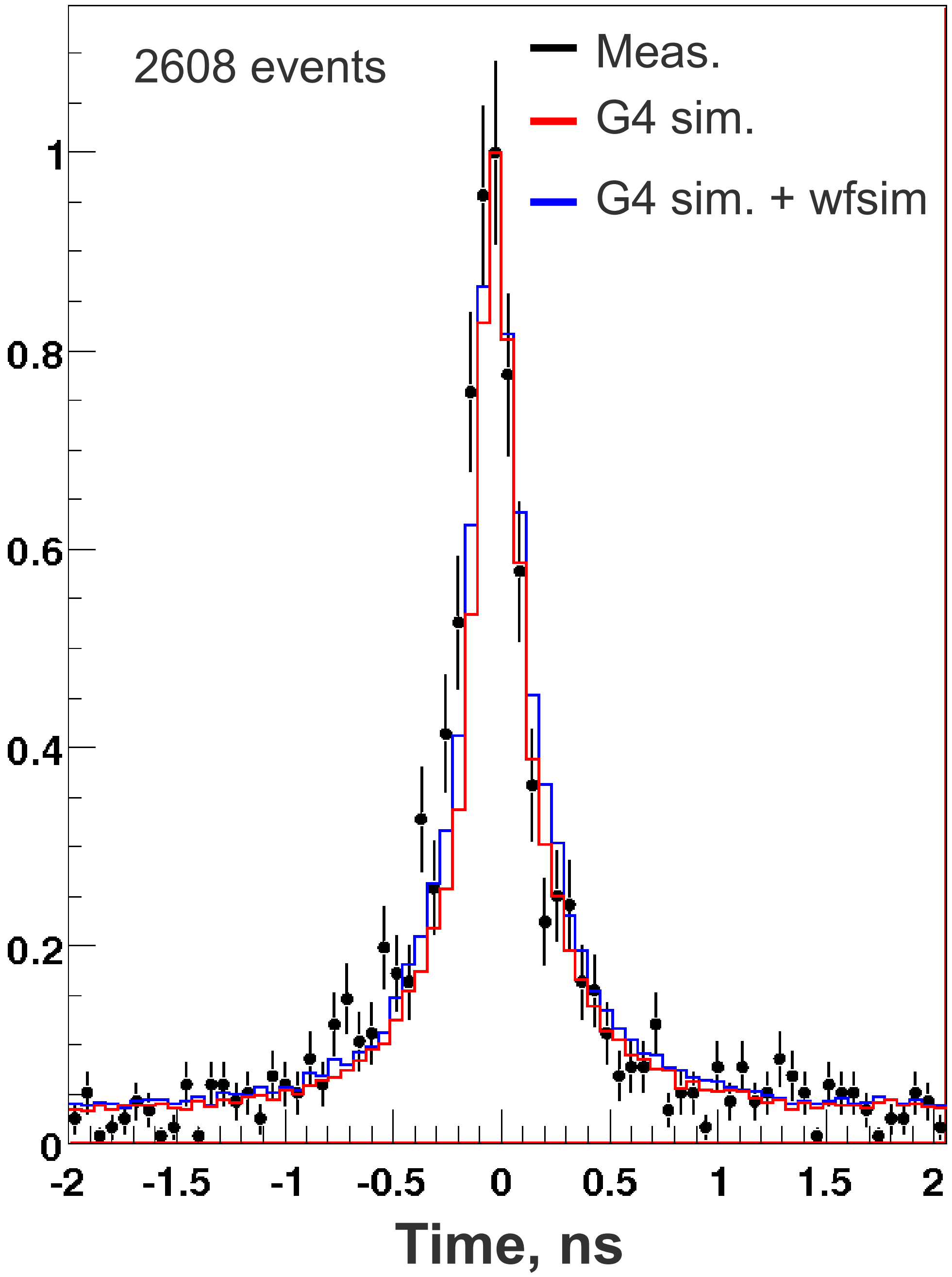
Example of time resolution per channel

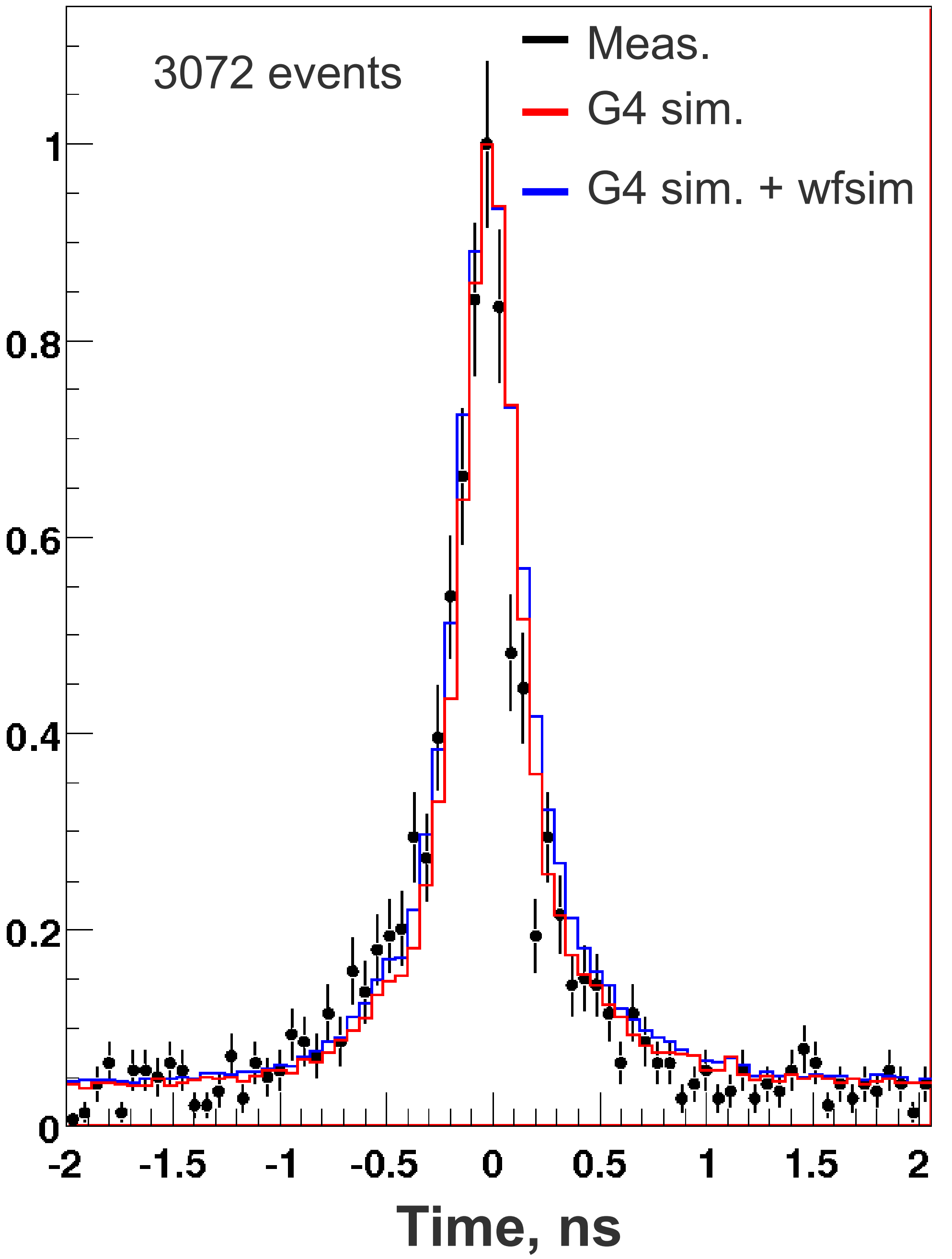




$\sigma_{\text{narrow}}/\text{sqrt}(2) \sim 70$ ps per p.e.

Measurement vs simulation


Time difference between channel 5 and 13


Time difference between channel 5 and 10

Discussion of the results

First FTOF prototype presented in this paper.

$$70\ \text{ps} = \sigma_{\text{narrow}}/\text{sqrt}(2) = \sigma_{\text{det}} \oplus \sigma_{\text{trk correction}} => \sigma_{\text{det}} < 70\text{ps}$$

We do not use the 3D tracking information. Which contribute to the narrow component and is the origin of the wide component. **We are planning to do it later.**

Final FTOF detector at SuperB

Contribution	Resolution (ps)
Electronics	<10
Detector	**70**
TTS for SL10	40
trk	10
t_0	20

Into detector term many different effects contribute (chromatic, channel size and many others) and they can not be corrected.

Conclusions

→ The FTOF is a promising device for particle ID in the forward region of SuperB.

→ 30 ps time resolution of the FTOF would allow to perform a good K/π separation.

→ This technology (detector + PMT + electronics) has been tested in the SLAC CRT (2010 - 2011).

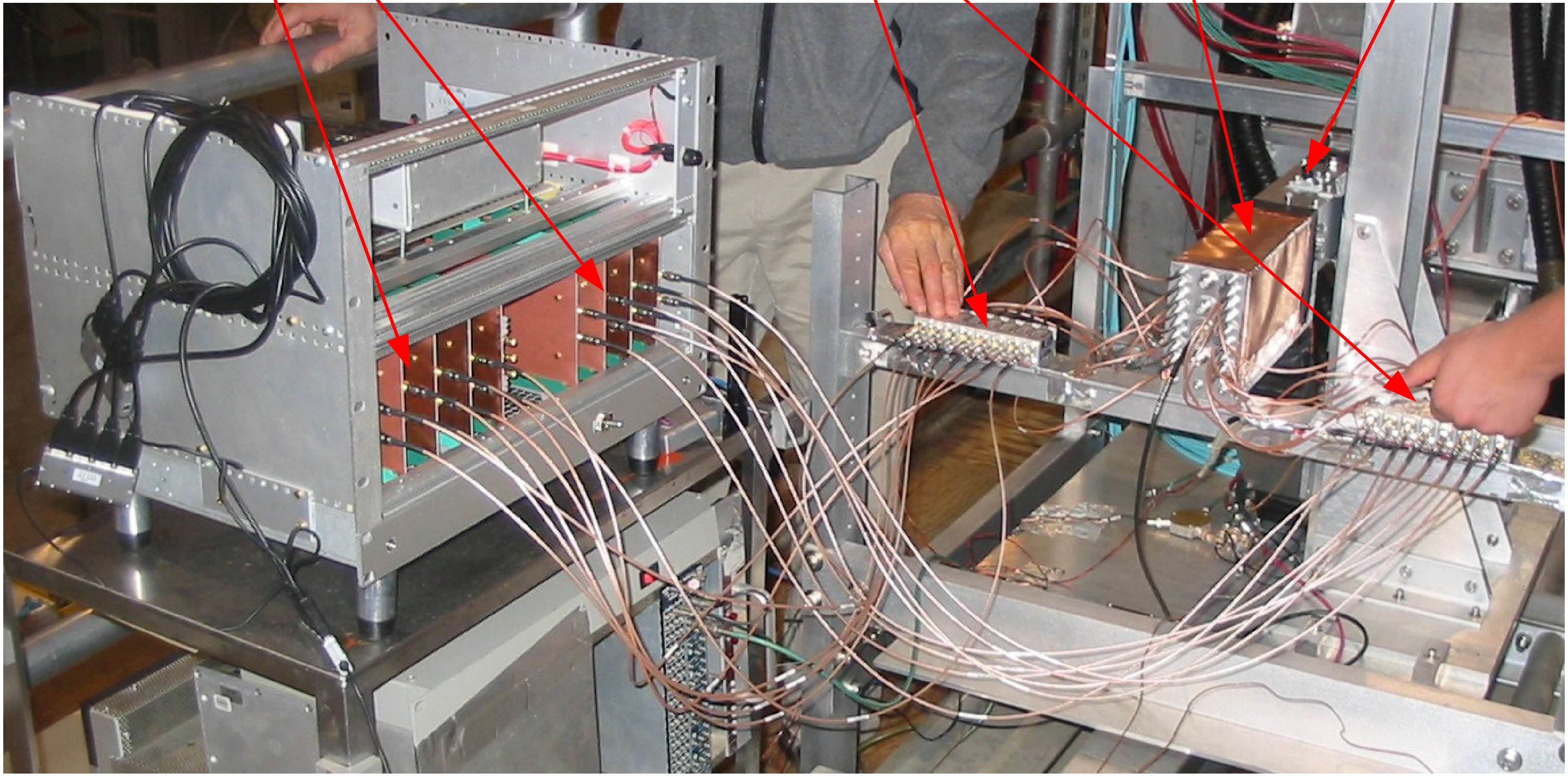
→ Next important step is to development the fast algorithm which will define the expected time of the p.e. arriving.

→ The FTOF has recently been identified by SuperB collaboration as the best candidate for forward particle ID.

→ This test encourage us to construct one full-size prototype sector of a DIRC-like TOF detector.

Backup

Experimental Setup



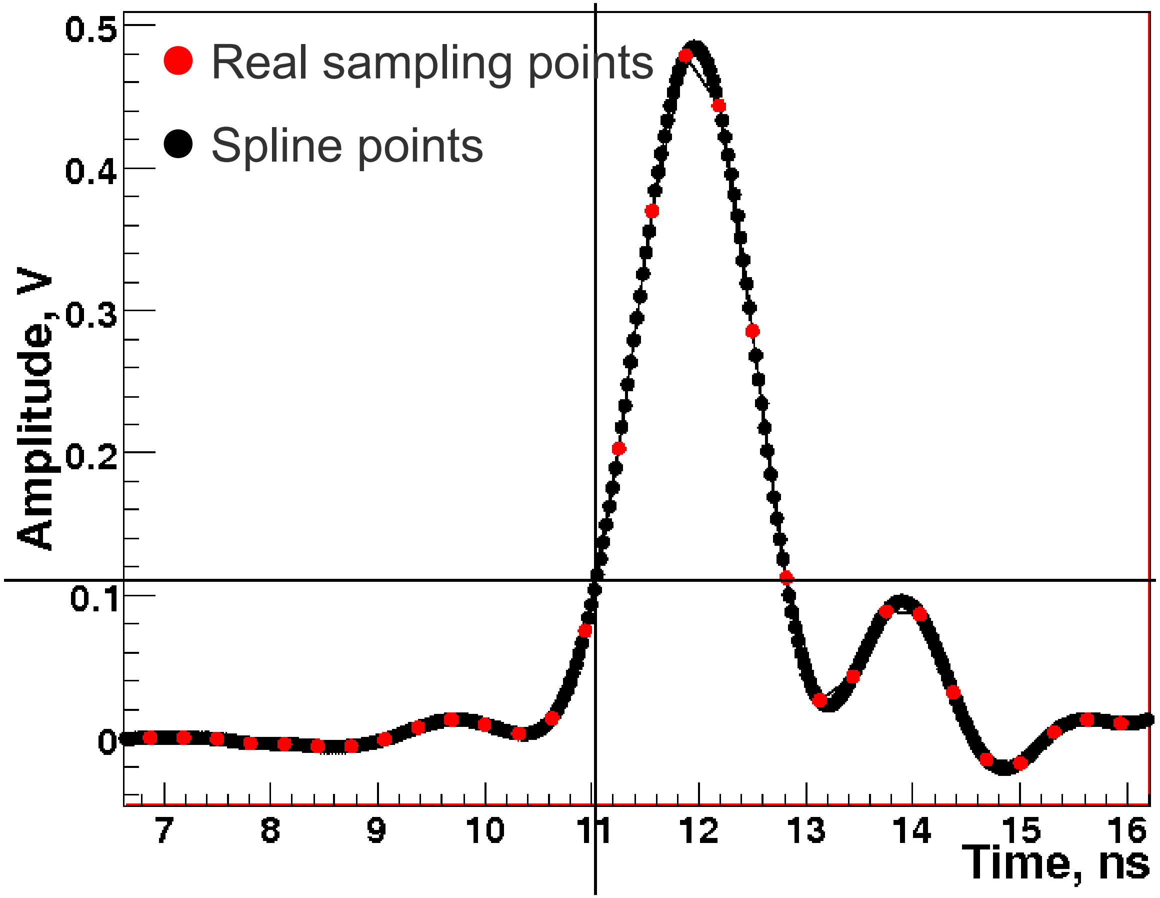
8 USBWC = 16 Channels

Filters (600MHz bandwidth)
and Amplifiers (40dB)

MCP-PMT
-2.7kV

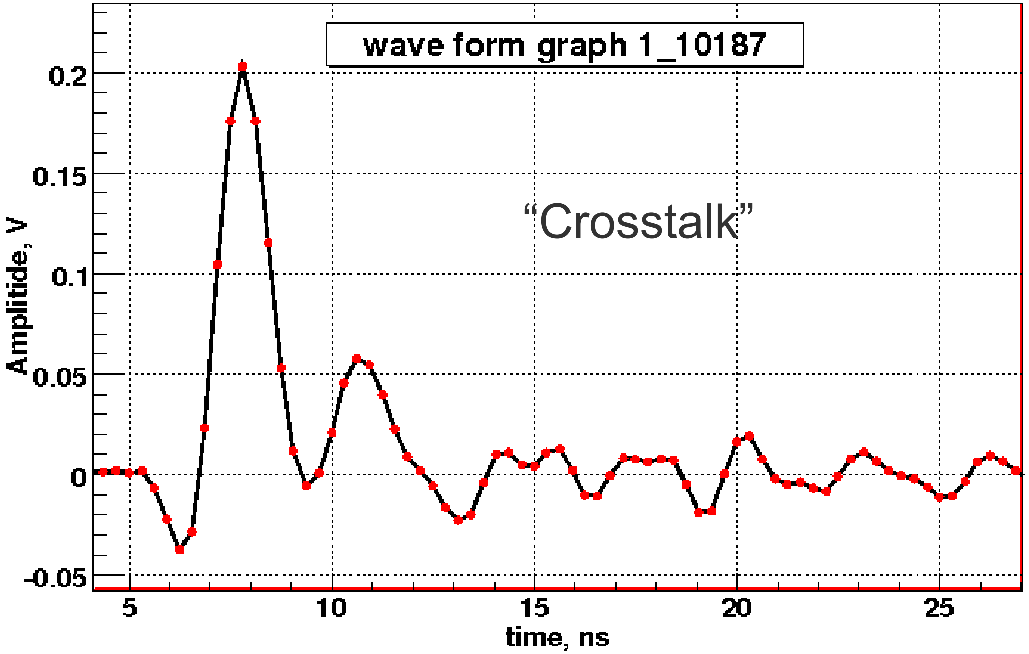
Quartz Bars

Waveform analysis

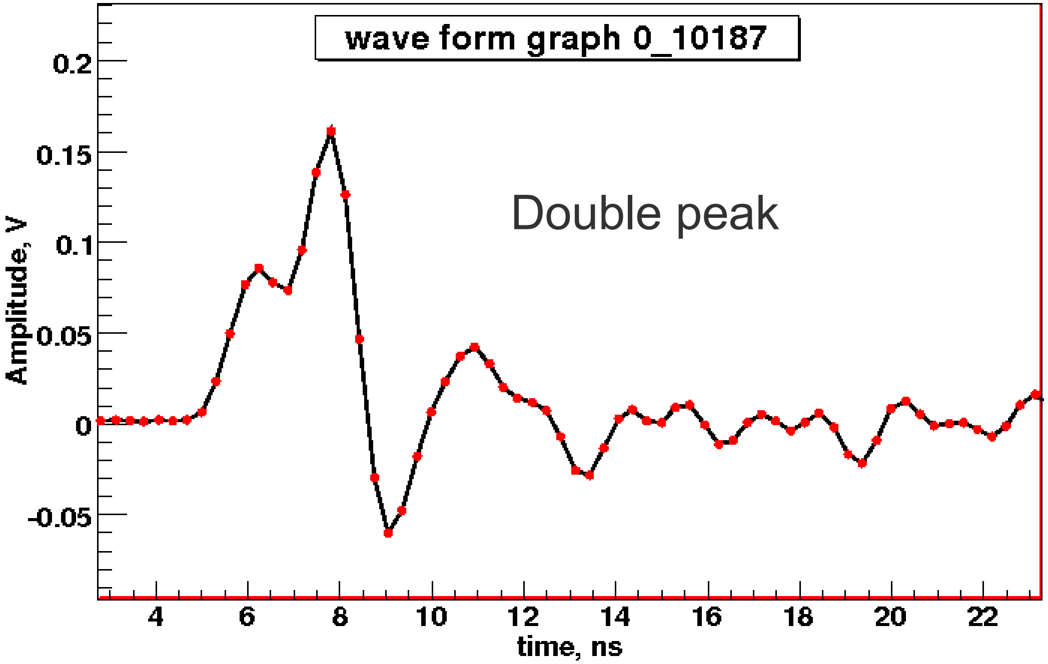


- Add points from spline interpolation
- Find first positive peak
- Find time at 23% or 50% of the peak amplitude
- We ask for amplitude more then 80mV
- We ask waveform to be not crosstalk or multi-peak

Waveform classification

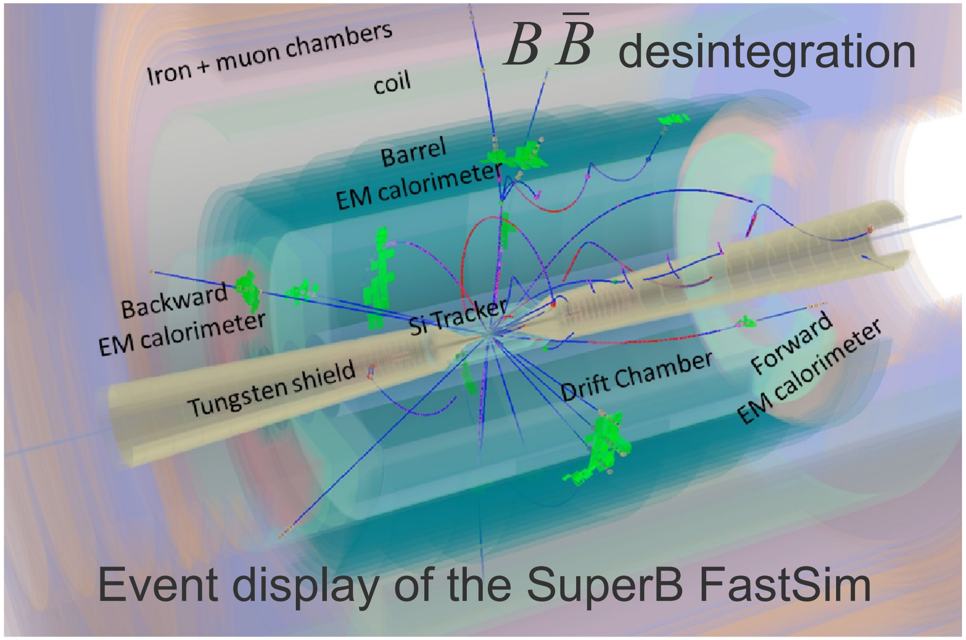


“Crosstalk”



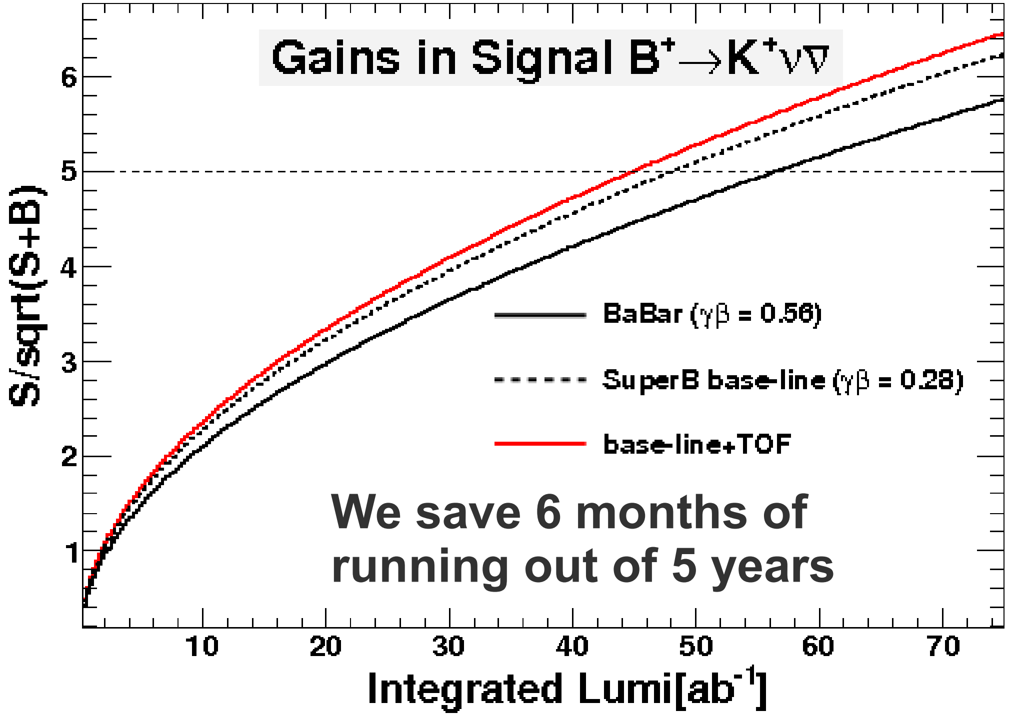
Double peak

Physics gain with FTOF system



Event display of the SuperB FastSim

- Parameterized fast simulation (FastSim) for detector optimization and physics reach studies was developed by SuperB collaboration
- Based on Geant4 simulation the FTOF subsystem was implemented within FastSim
- K/π separation ability in forward region was studied
- Effect of FTOF on physics analysis was studied

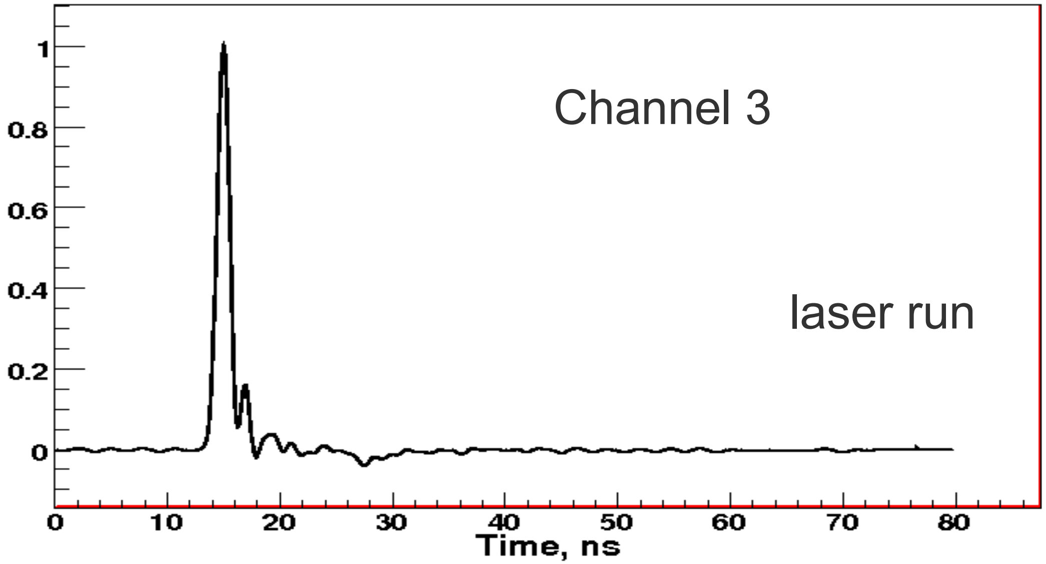


We save 6 months of running out of 5 years

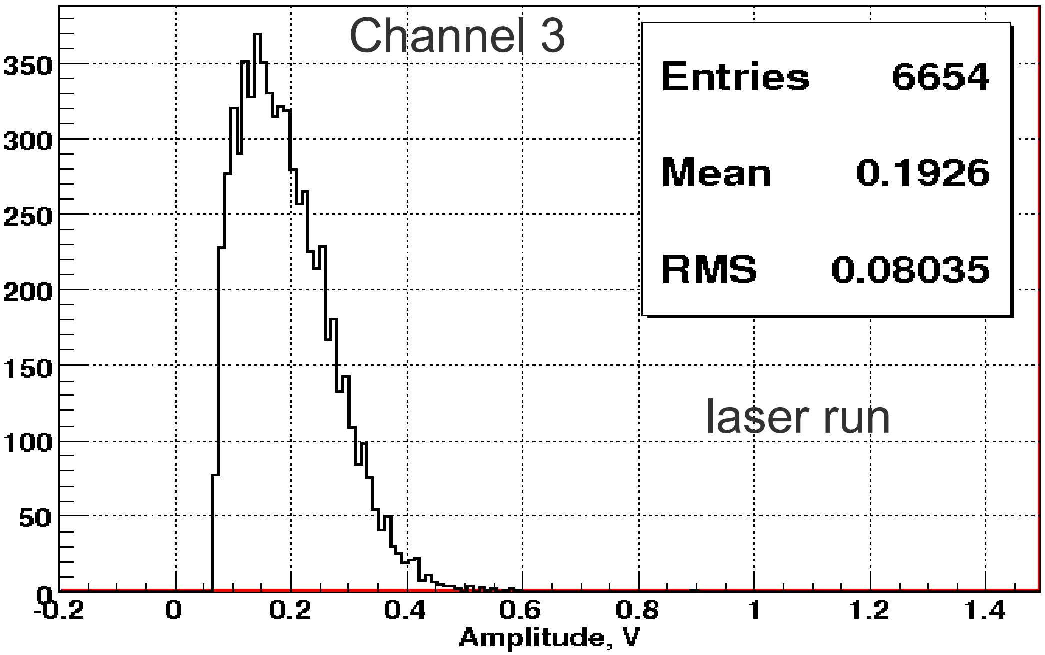
Waveform simulation

- From laser run we extract information about MCP-PMT response on single p.e. (average waveform shape and amplitude distribution)

Average shape of the signal from single p.e



Amplitude distribution of the signal from single p.e.



- Each p.e. in the simulation creates a signal with the shape and amplitude drawn above. The time of the p.e. defined by Geant4 ⊕ 35 ps (TTS) smearing. The total waveform (wf) is the sum of wf's from all p.e.

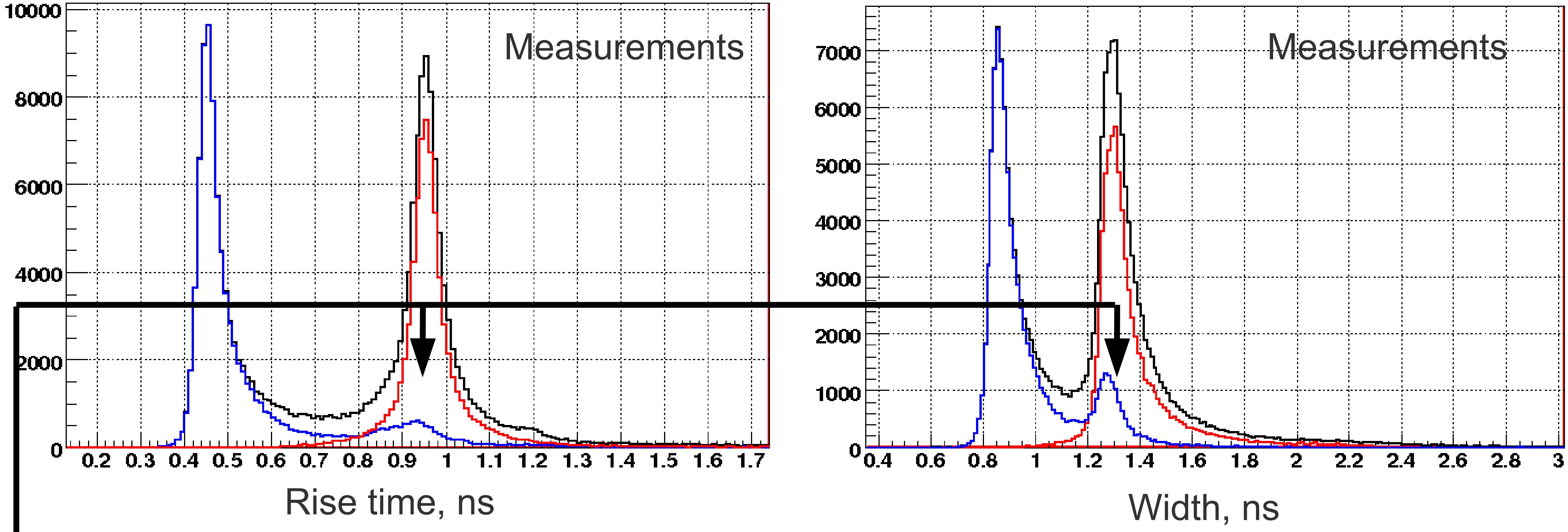
- White noise generated on top of the total wf. The amplitude of the noise is generated as a Gaussian with mean = 0, RMS 1.3- 1.5 mV (values taken from the data) .

- Crosstalk and charge sharing are not taken into account (yet?).

Test of the waveform analysis algorithm

▬ Signals with all shapes
▬ Crosstalk - like shape
▬ Single peak - like shape

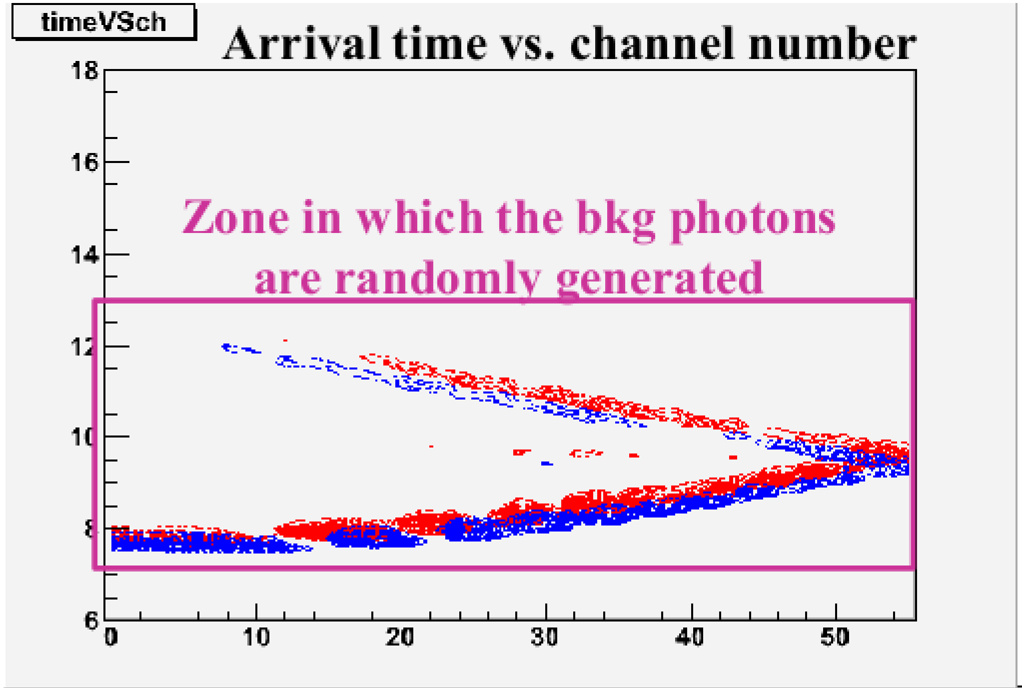
▬ Signals with all shapes
▬ Crosstalk - like shape
▬ Single peak - like shape



Crosstalk - like and single peak - like signals have their own typical values of the rise time and width. As we can see from the histograms above these quantities can be used for distinguishing between Crosstalk - like and single peak - like signals.

Signals with a normal rise time and width can have crosstalk ahead and so recognized as a crosstalk -like signals.

Could we work with complicated configurations in presence of background ?



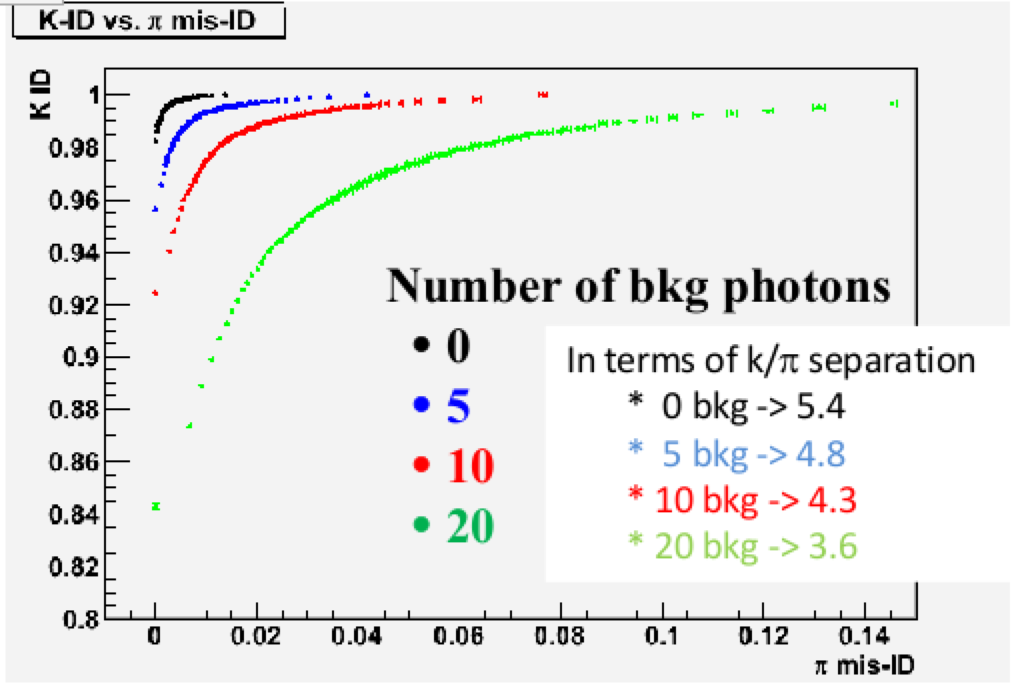
Preliminary answer

p = 2 GeV/c
θ = 20 degrees
ϕ = 0 degrees

Kaon map, 10 photons/track
Pion map, 13 photons/track

Preliminary studies (Annecy) shown that we expect ~1 event of background in FPID

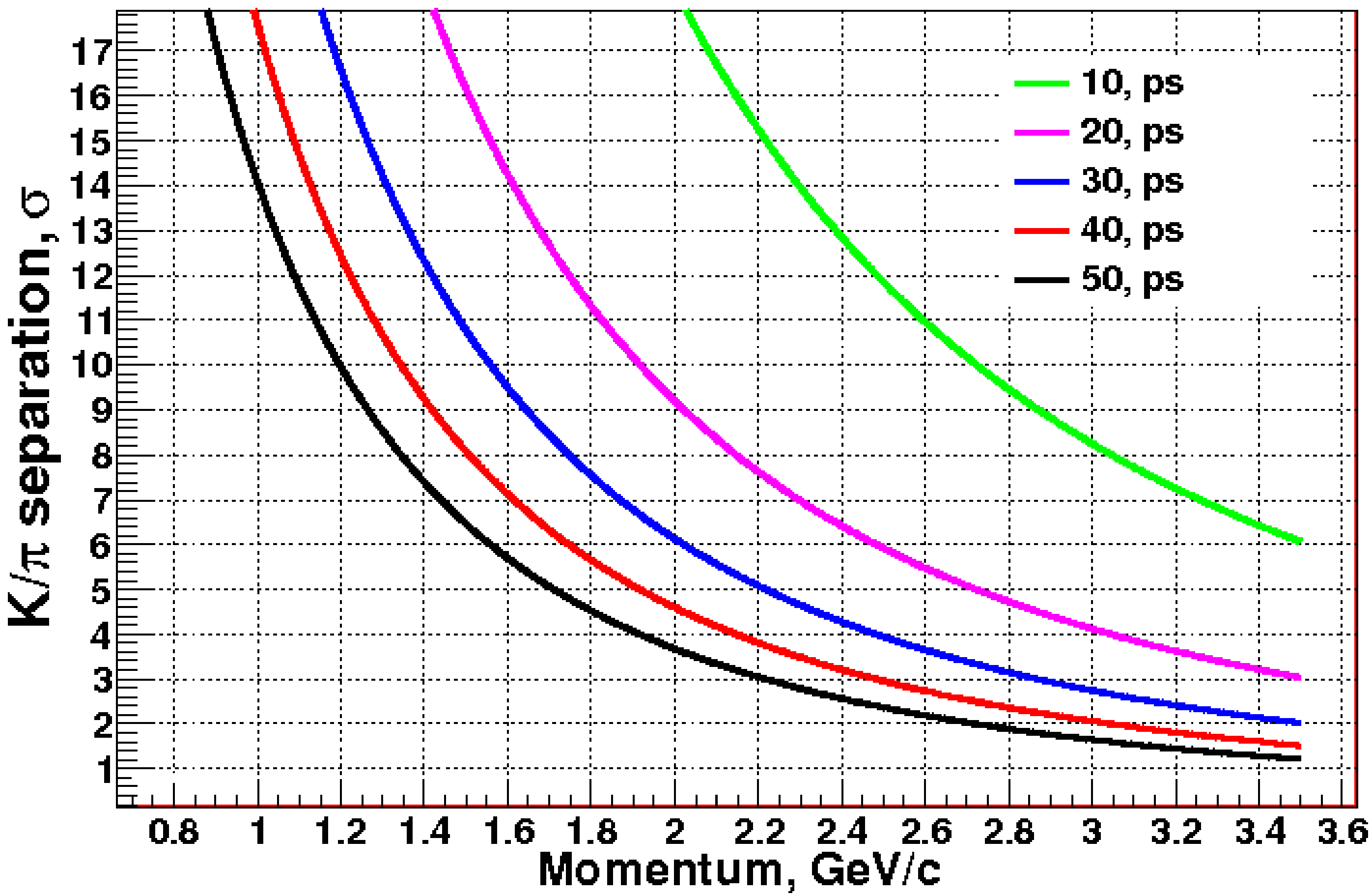
It seems that the PID starts to really suffer if background is ~20events



In terms of k/π separation
* 0 bkg -> 5.4
* 5 bkg -> 4.8
* 10 bkg -> 4.3
* 20 bkg -> 3.6

K/π separation

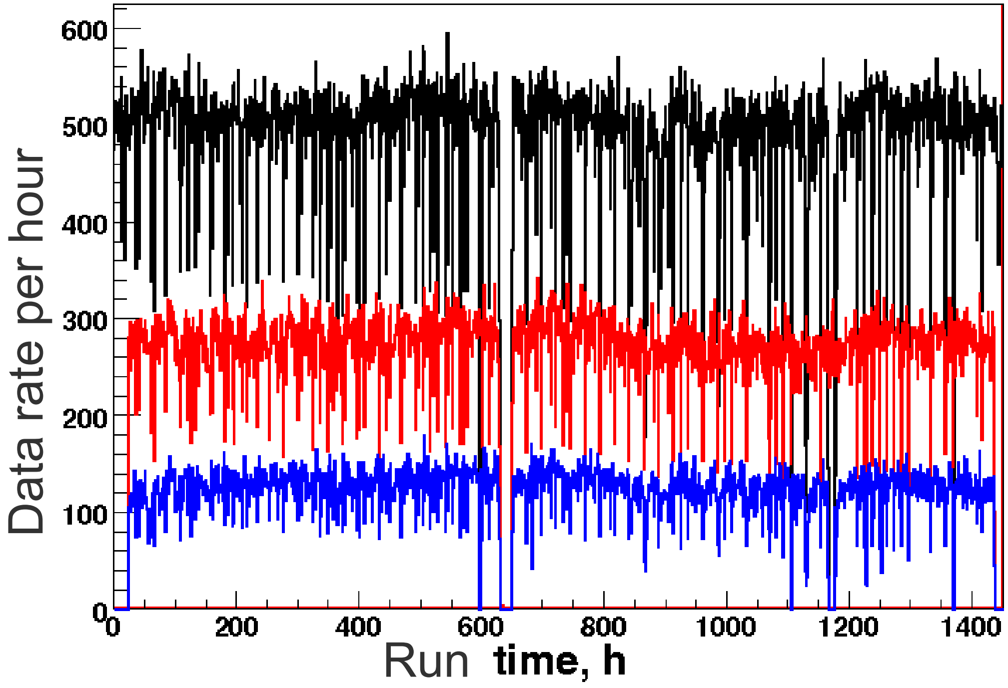
L = 2 m



Data taking

- In total we have 6 different runs. First three were dedicated for commissioning the experimental setup.
- During Run4 we collect the cleanest dataset.
- Our results are based on Run4

RUN4

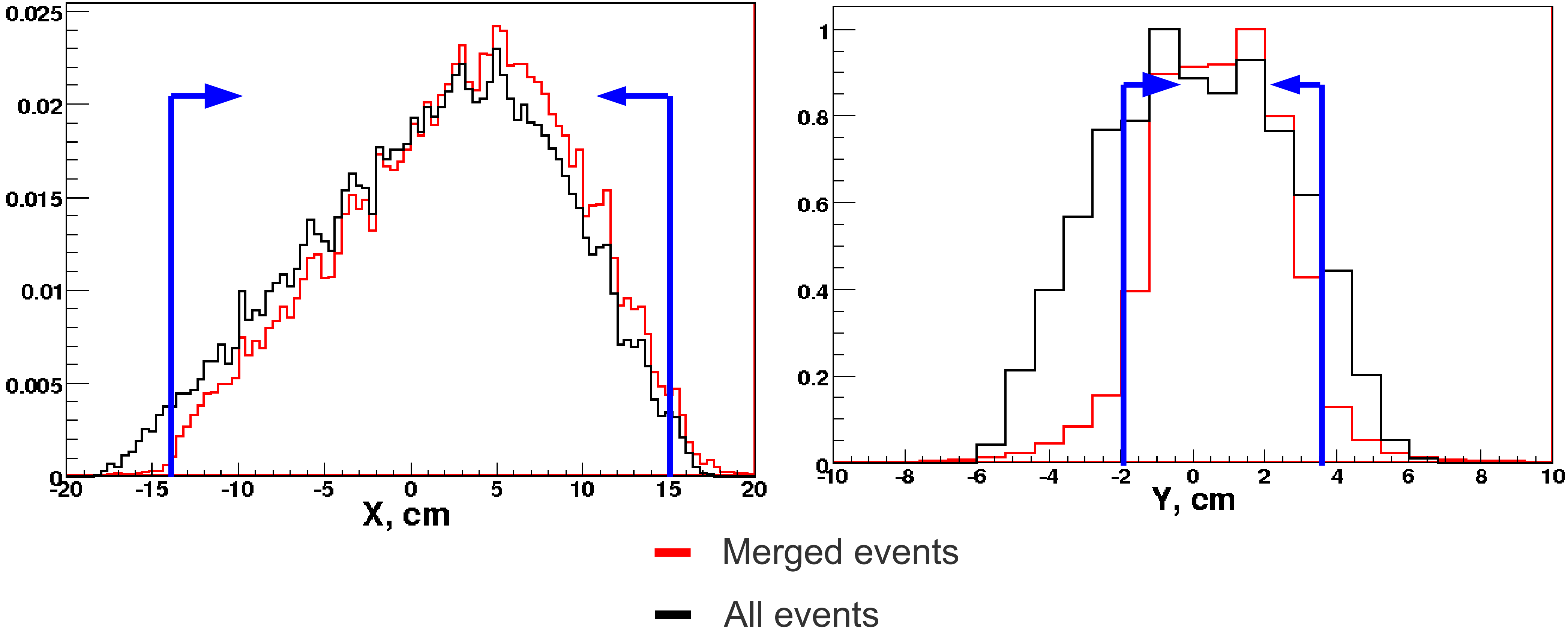


Color in the plots	System	Rate events/h
⬛	CRT	490
🟥	FTOF prot	275
🟦	Coincidence	130

total run time 1414 hours
total number of entries USBWC 378347
GMT time START run : 28.01.2011 18:21:19
GMT time END run : 28.03.2011 16:37:34

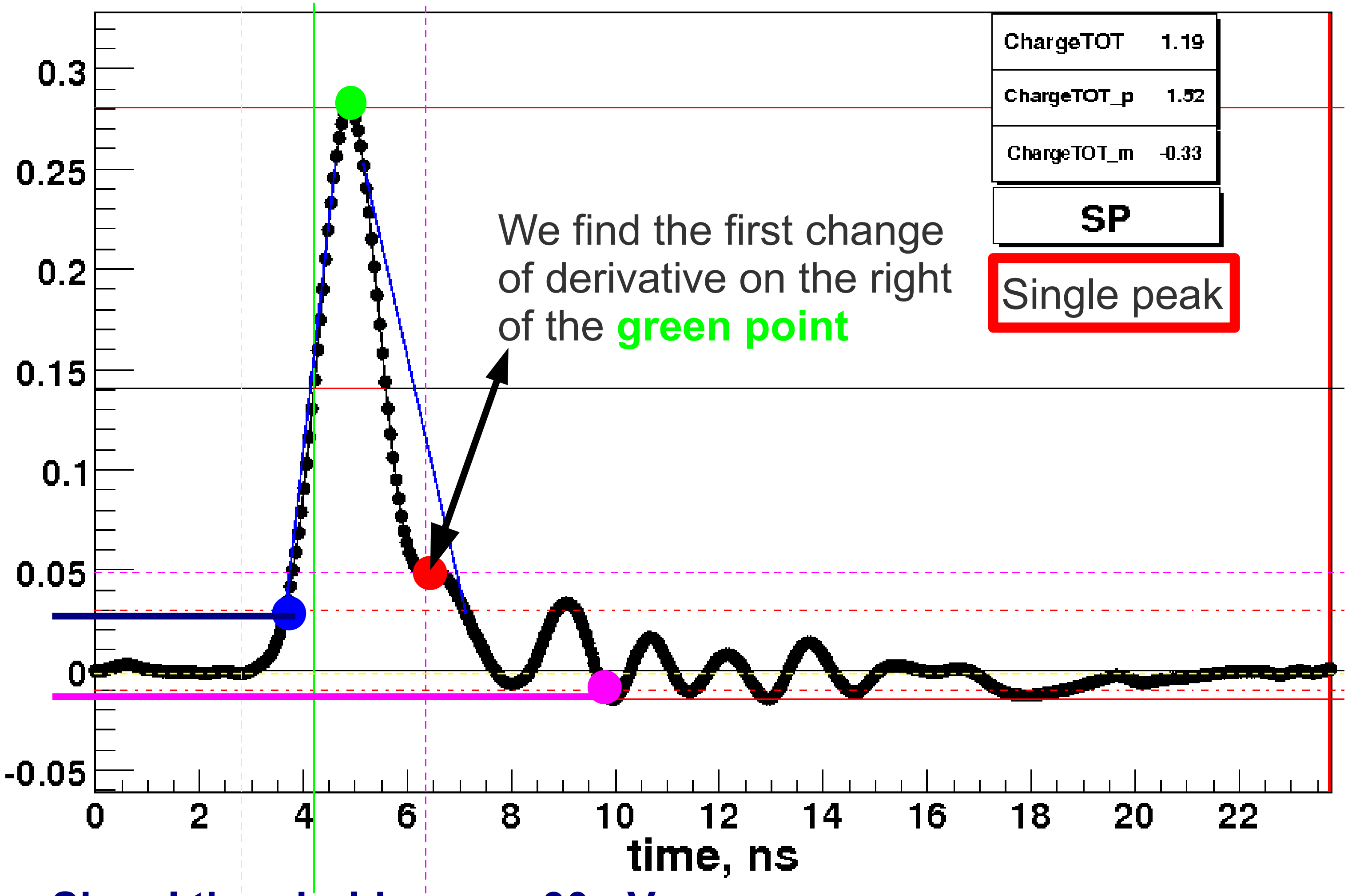
Test of the merging USBWC and CRT DAQ systems

X_{FTOF}, Y_{FTOF} coordinates of the intersection with FTOF prototype



Additional sanity cuts are applied on X_{FTOF} and Y_{FTOF} coordinates:
-14 < X_{FTOF} < 15 && -2 < Y_{FTOF} < 3.5

Waveform analysis algorithm



We find the first change of derivative on the right of the **green point**

Single peak

● **Signal threshold = 30mV**

● **Crosstalk threshold = -10mV**

● **Multi peak fraction = 0.8**

The definition of the single peak:

(Time of the Signal threshold < Time of the Crosstalk threshold) && (Not a multi peak*)

*Defined later