Status of FTOF wall detectors

Petersburg Nuclear Physics Institute (PNPI)

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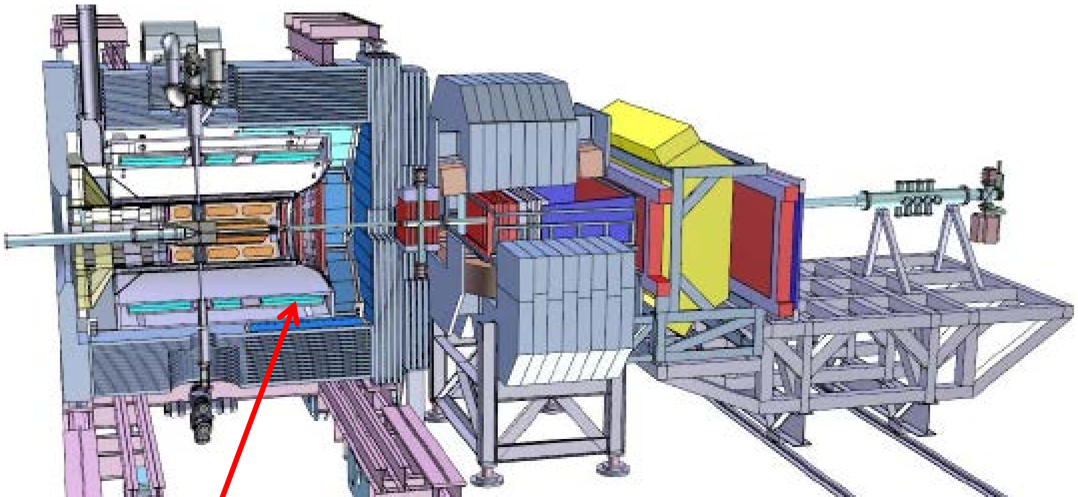
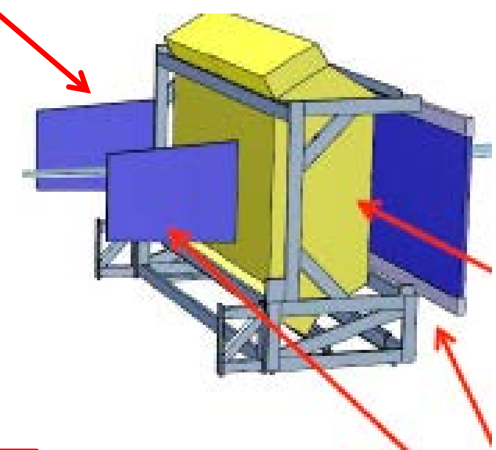
Time-of-Flight PANDA detectors



Barrel TOF
SciTil

FS TOF

Left Side
DipoleTOF



RICH

Right Side
Dipole TOF

FTOF
wall

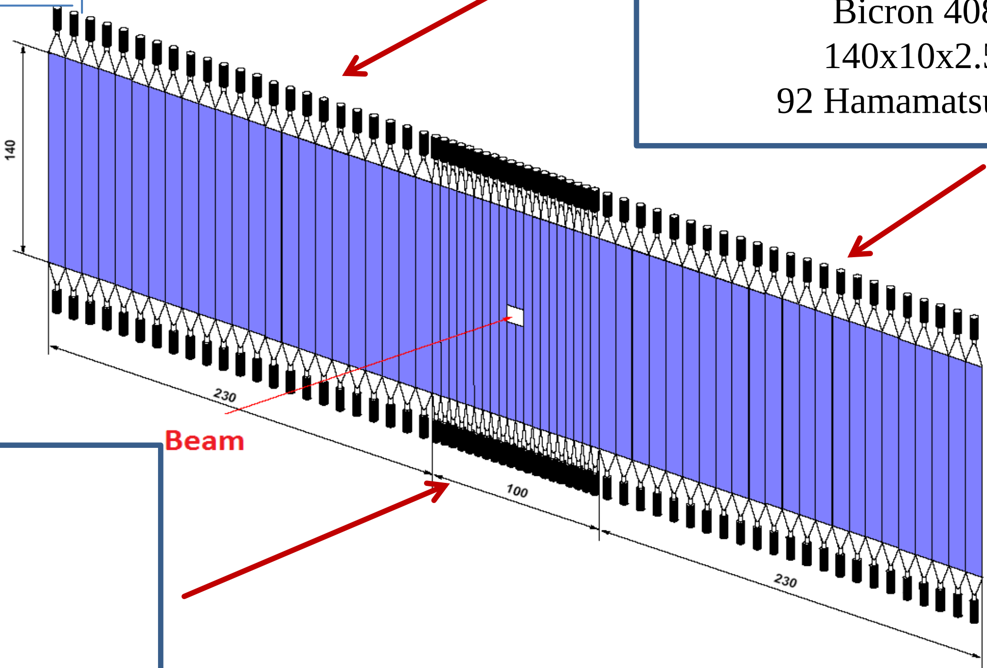
Motivations for FTOF wall

- PID of forward emitted particles with timing resolution of 50-100ps
- Event start reference time with timing resolution
- A good strangeness or charm (offline) trigger
- Can be used for determination of the drift time in DCs

FTOF wall

positioned at 7.5 m from the IP

Side parts
2x23 counters
46 plastic scintillators
Bicron 408
140x10x2.5 cm
92 Hamamatsu R2083 (2”)



Central part
20 counters
20 plastic scintillators
Bicron 408
140x5x2.5 cm
40 Hamamatsu R4998 (1”)

Bicron 408
(recommended for large TOF counters)

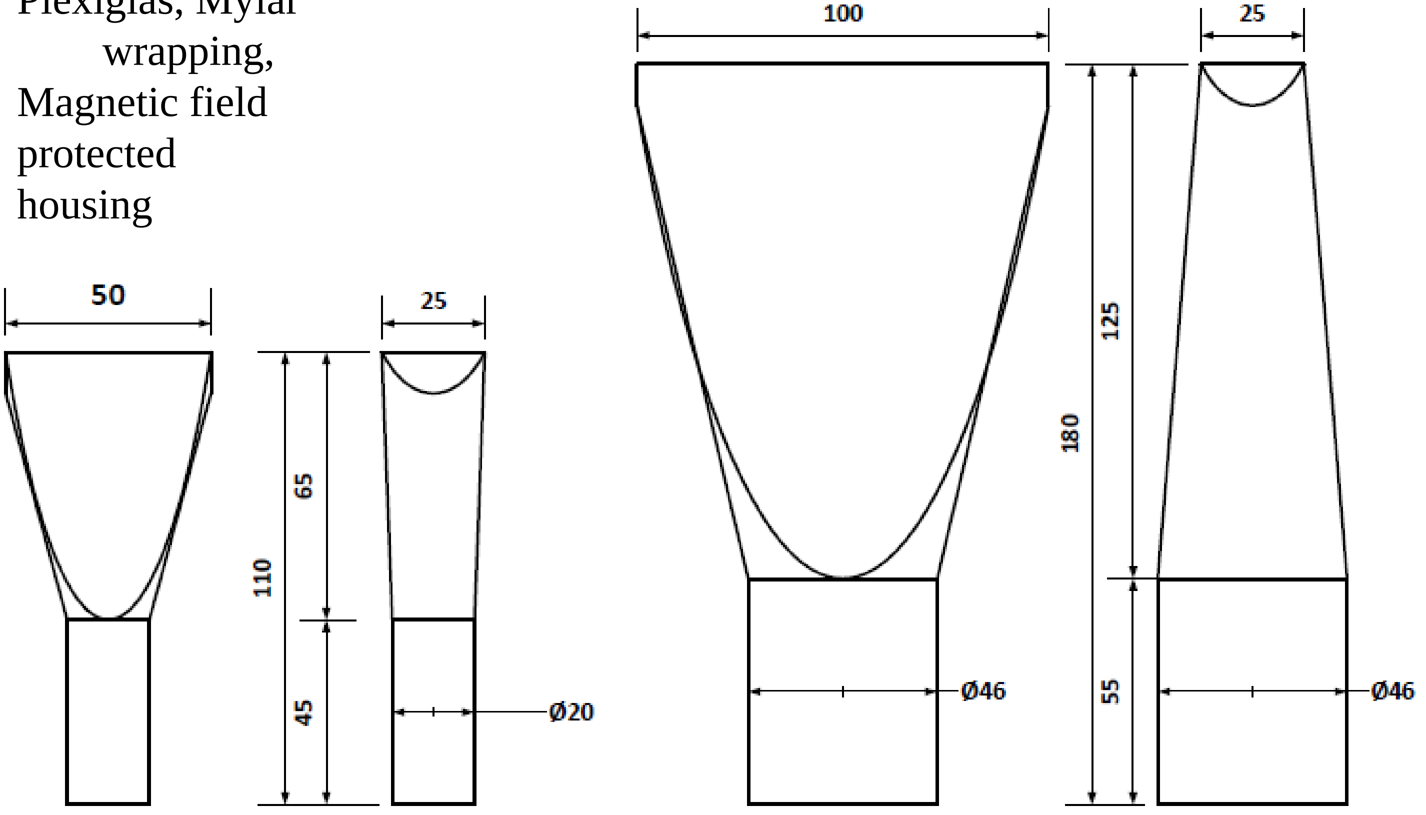
Rise time	0.9 ns
Decay time	2.1 ns
1/e light attenuation length	210cm
Wavelength of max emission	425nm

***Fast PMTs** (hamamtsu)*
R4998 1” (R9800) , R2083 2” (R9779)

Anode pulse rise time	0.7-1.8ns
TTS	250-370ps (FWHM)
Gain	$1.1\text{-}5.7\text{x}10^6$
W.m. emission	420nm
HV	1500-3500v

LIGHT GUIDES FOR 1” AND 2” PMTs

Plexiglas, Mylar wrapping, Magnetic field protected housing



Count rates in frame of DPG

Number of events selected from 100 generated $\bar{p}p$ *collisions chosen arbitrarily, at 10 GeV*

$\bar{p}p \to \bar{p}p$	24	$\bar{p}p \to \bar{p}p\pi^0$	5
$\bar{p}p \to \bar{n}n\pi^0$	3	$\bar{p}p \to \bar{p}n\pi^+$	3
$\bar{p}p \to \bar{p}p\pi^+\pi^-$	2	$\bar{p}p \to \bar{n}p\pi^0\pi^-$	2
$\bar{p}p \to \bar{p}n\pi^+\pi^0$	2	$\bar{p}p \to \bar{p}p\pi^0\pi^+\pi^-$	9
$\bar{p}p \to \bar{n}p\pi^0\pi^+\pi^-\pi^-$	4	$\bar{p}p \to \bar{p}p\pi^0\pi^+\pi^-\pi^+\pi^-$	4
$\bar{p}p \to \bar{\Lambda}n\bar{K}^0\pi^0\pi^+\pi^-$	1		

Hadron count rate by TOF wall at 10 GeV, 15 GeV, 10^7/s interactions in target

$\bar{p}$ beam momentum, GeV/c	Pion rate, 1/s	Kaon rate, 1/s	Proton rate, 1/s	Antiproton rate, 1/s
2	3.9×10^5	2×10^3	1.2×10^4	1.07×10^6
5	6×10^5	7.8×10^3	3.8×10^4	9.5×10^5
15	9.6×10^5	4.7×10^4	3.2×10^4	8.2×10^5

High rate of π^0

Bgr expected from

$\pi\to2\gamma$ $\gamma\to e^+e^-$

Count rates of TOF wall and $e^+ e^-$ background @ 10 GeV

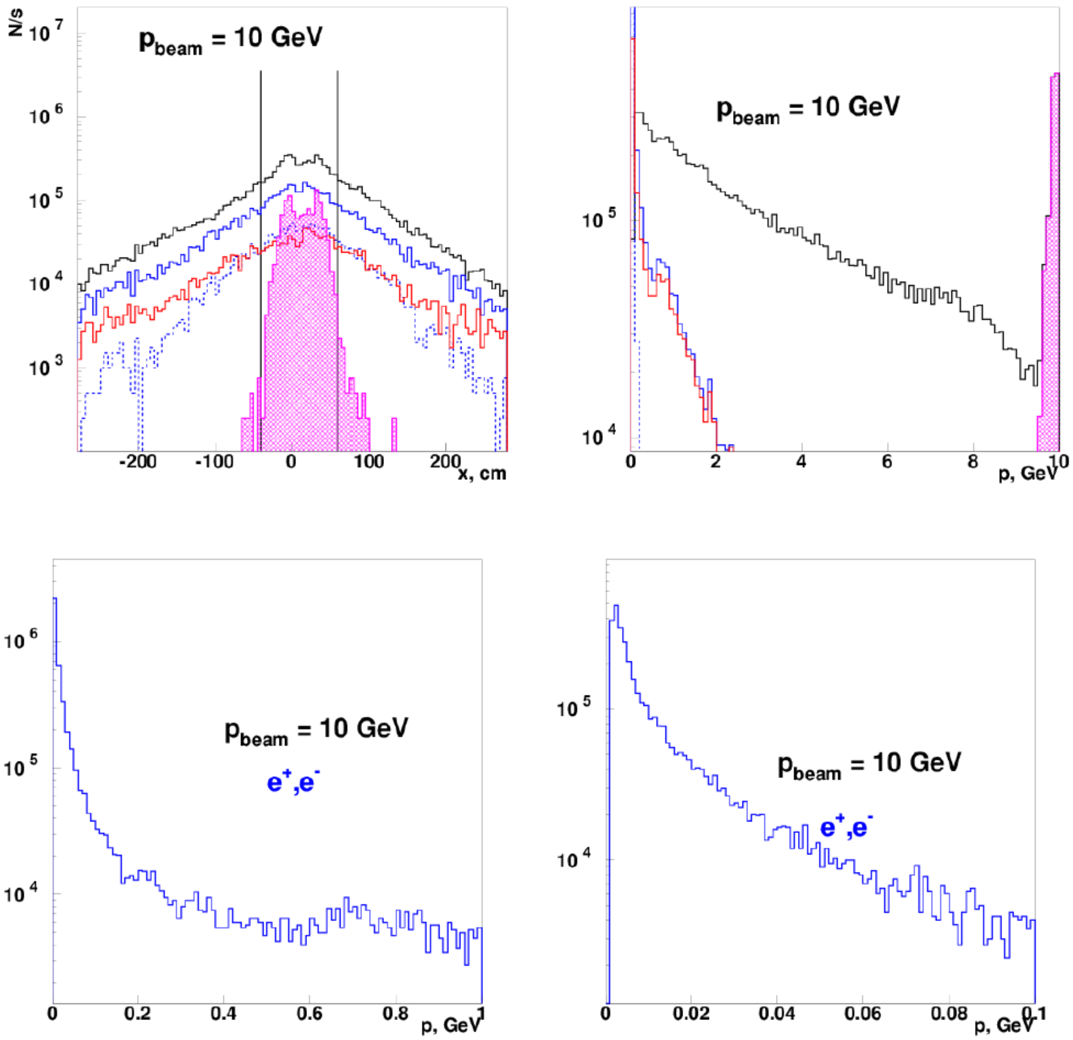
All

Pbar forward peak

$e^+ e^-$ all

$e^+ e^-$ produced in vacuum pipe

$e^+ e^-$ backward scattering from EMC (dashed)



Count rates of TOF wall and $e^+ e^-$ background @ 5 GeV

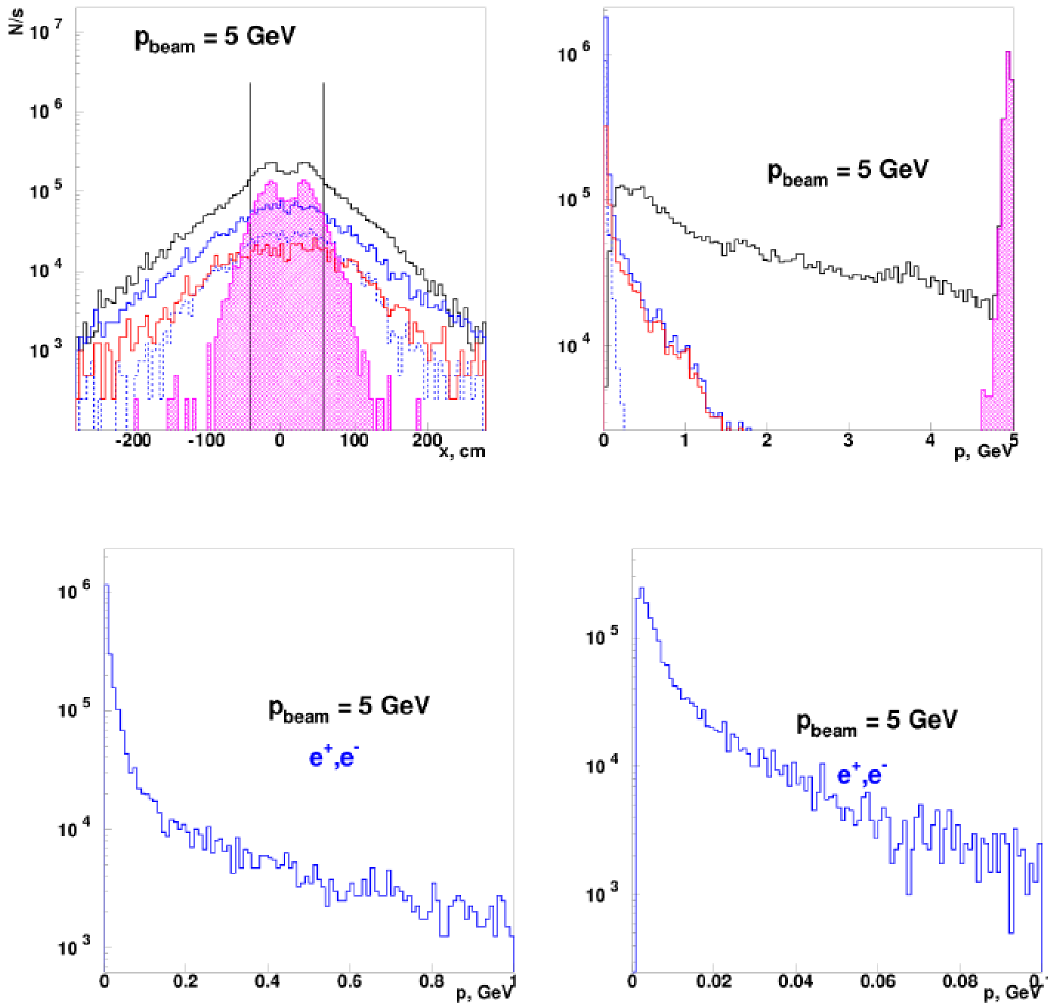
All

Pbar forward peak

$e^+ e^-$ all

$e^+ e^-$ produced in vacuum pipe

$e^+ e^-$ backward scattering from EMC (dashed)

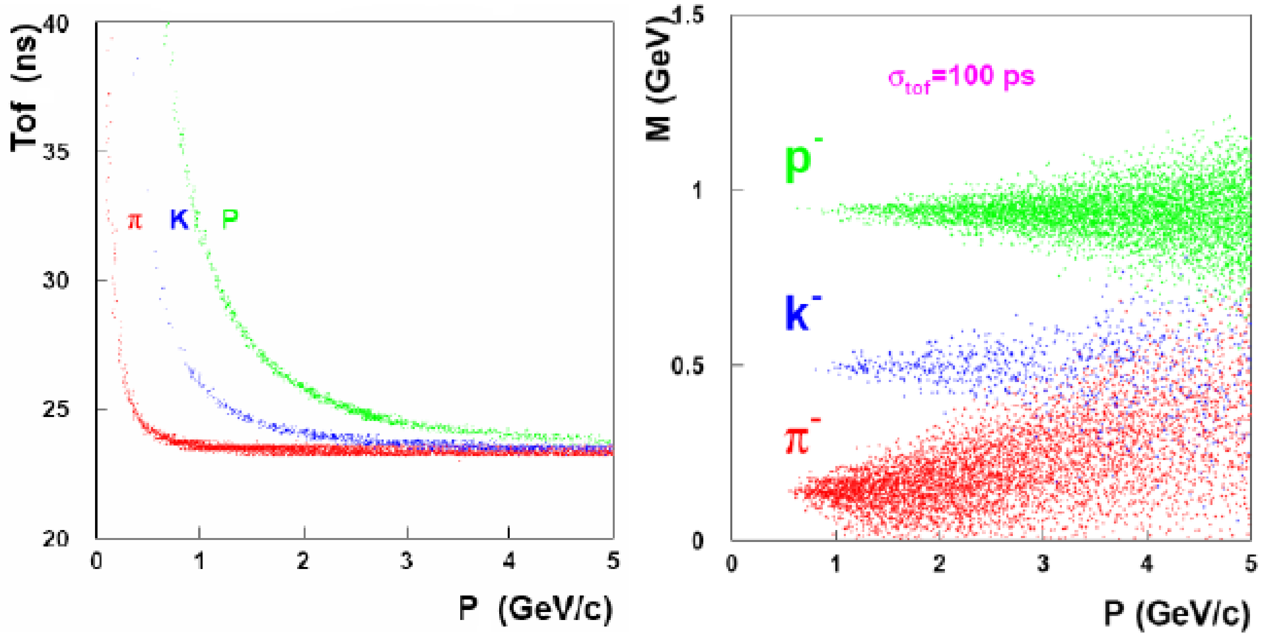


PID with TOF wall using Forward Tracking information

$$m = p\sqrt{\frac{t^2}{t_c^2} - 1}$$

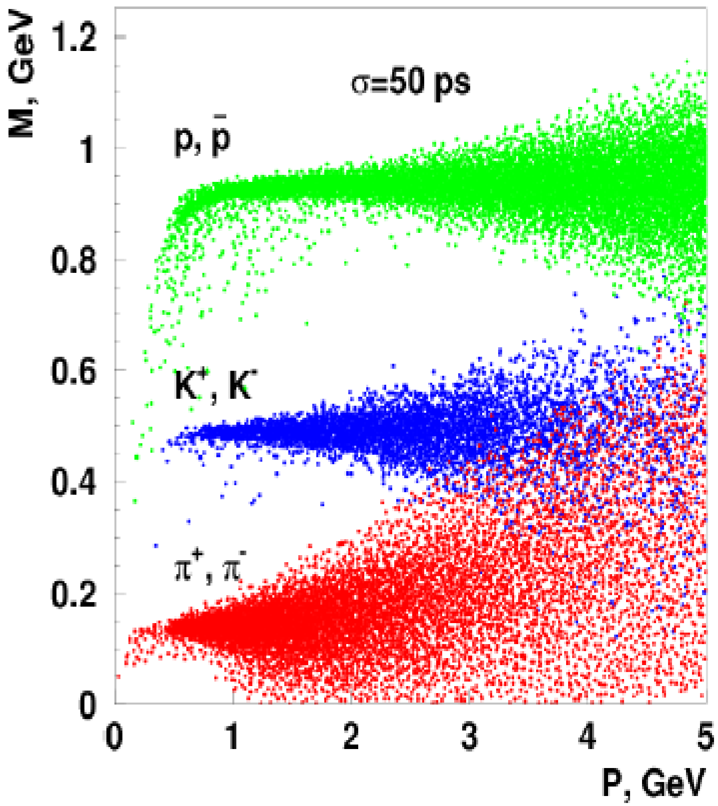
$$\frac{\delta m}{m} = \sqrt{\left(\frac{\delta p}{p}\right)^2 + \gamma^4 \left(\frac{\sigma_{TOF}}{t}\right)^2}$$

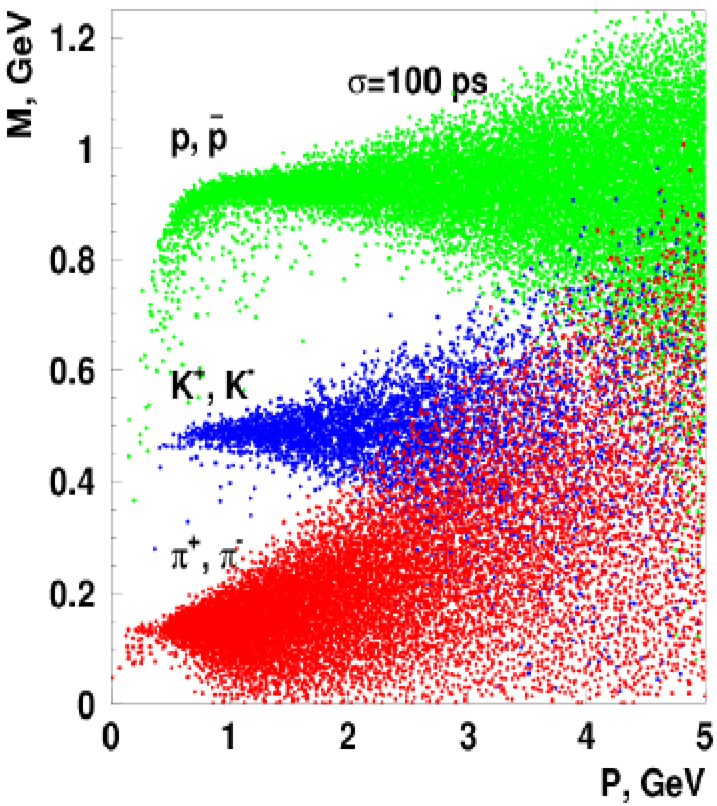
$$t_c = L_{track} / c \quad \sigma(TOF) = 50 - 100 \text{ ps} \quad \frac{\sigma(p)}{p} = 0.01$$



- **Good separation of hadrons up to 3-5 GeV**
- **Good event start reference**

PID with TOF wall using Forward Tracking information





Detection Efficiency of FTOF wall

$0.72\times10^{6}\ \bar{p}p$ interactions @10 GeV, $\frac{\sigma(p)}{p}=0.01$, $\sigma(TOF)=50\,ps$

acceptance of FS ±10 deg. hor. ±5 deg. ver. $\rightarrow\ \Omega_{FS}=0.09\,sr$

	Generated by DPM	Detected by FTOF wall	detection efficiency
π^{-}	880346	172188	0.195
π^{+}	877255	150440	0,171
K^{-}	30179	5820	0.192
K^{+}	26811	2863	0.107
$\bar{p}$	453293	202174	0.446
p	398323	51241	0.129
$\bar{\Lambda}\rightarrow\bar{p}+\pi^{+}$	19874	3840	0.193
$\Lambda\rightarrow p+\pi^{-}$	19518	≈100	$\approx5\cdot10^{-3}$

Both proton and pion detected with FTOF

Lambda_bar and Lambda Event Selection

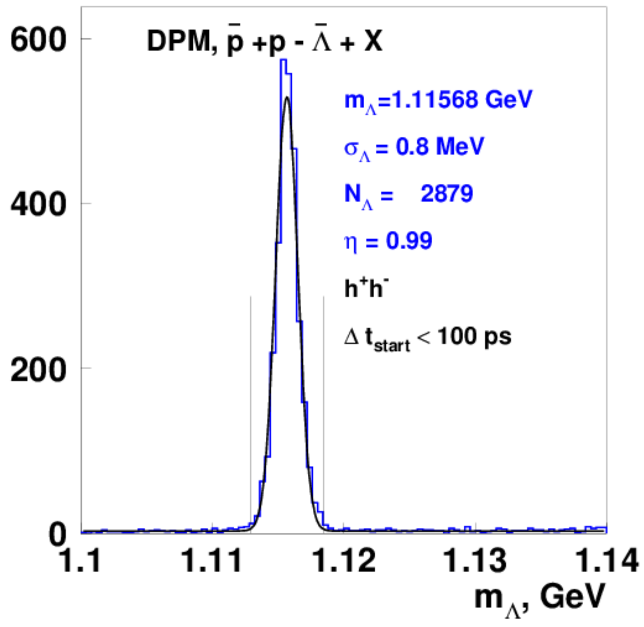
$\bar{p} + p \rightarrow \bar{\Lambda} + X$

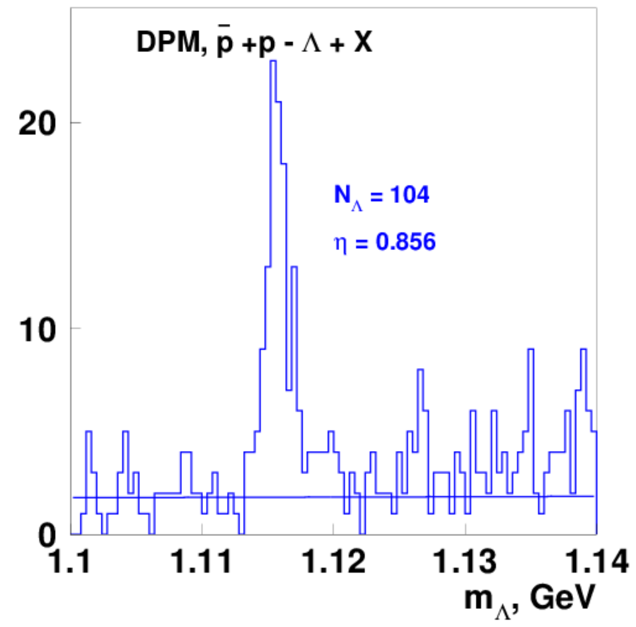
$\bar{p} + p \rightarrow \Lambda + X$

Event selection criteria

$m(h^-) = m_p \quad m(h^+) = m_\pi \text{ and } \Delta t_{start}^{\bar{p}\pi^+} > 100\text{ps}$

$m(h^+) = m_p \quad m(h^-) = m_\pi \text{ and } \Delta t_{start}^{p\pi^-} > 100\text{ps and } z2 > 6\text{mm}$





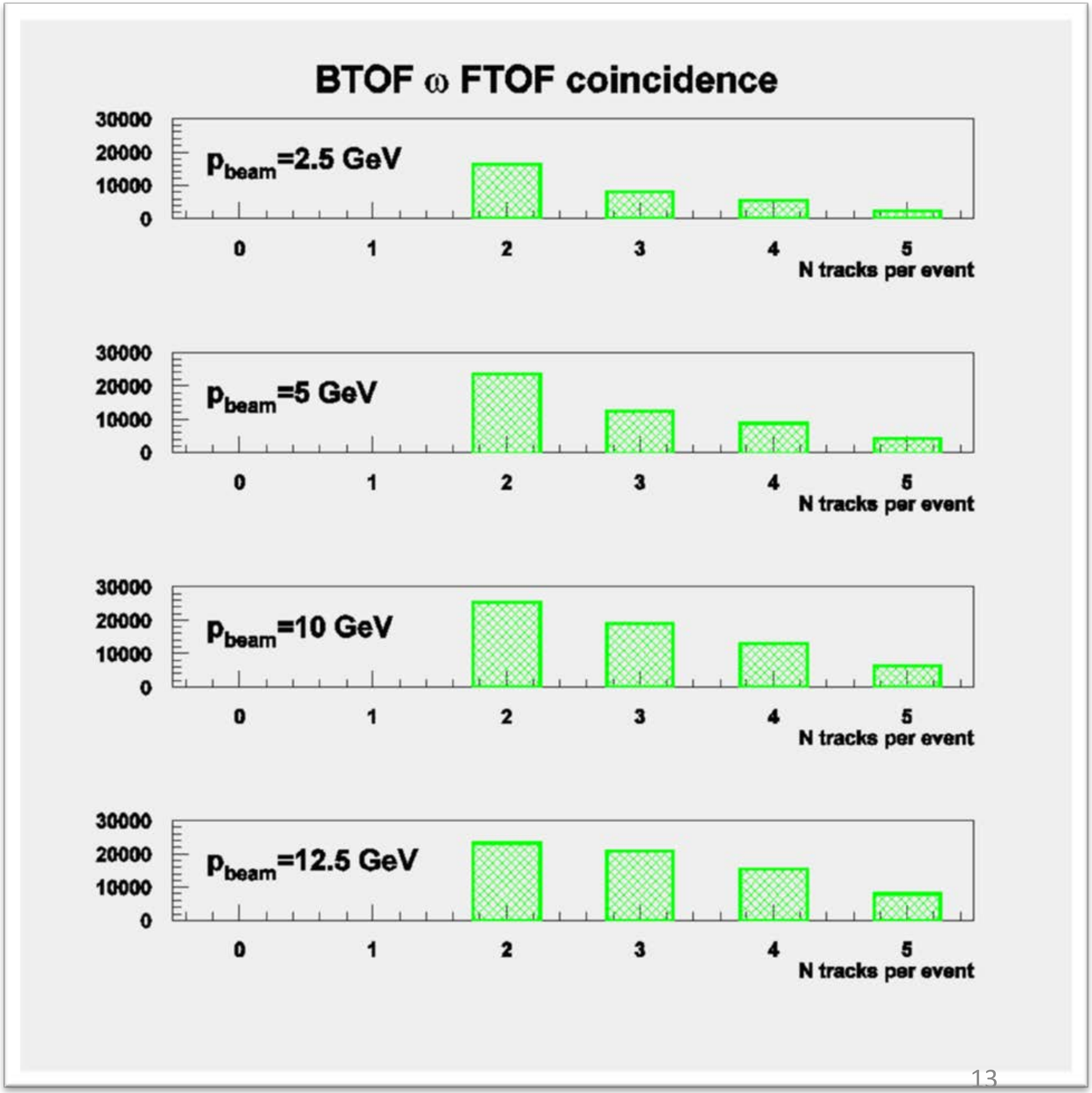
$\bar{\Lambda}$ detected with high efficiency (20%) at weak selection criteria

$N_\Lambda / N_{\bar{\Lambda}} \simeq 1/40$ Λ events also well detected

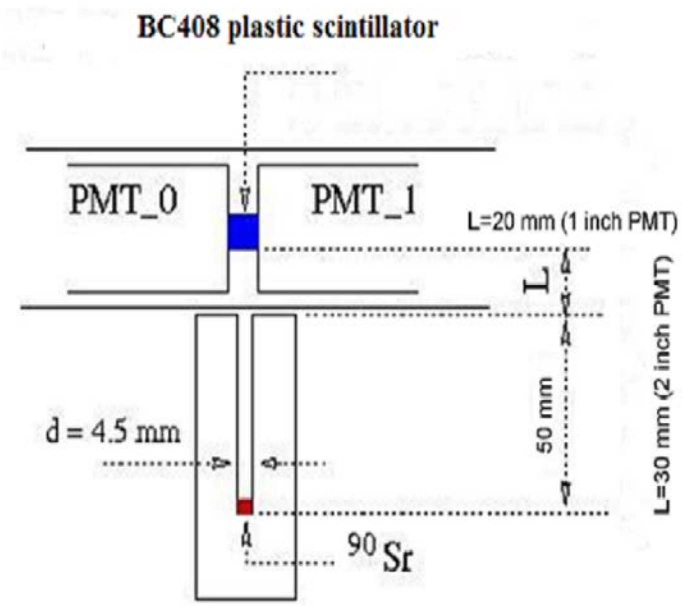
FTOF wall and barrel TOF interplay

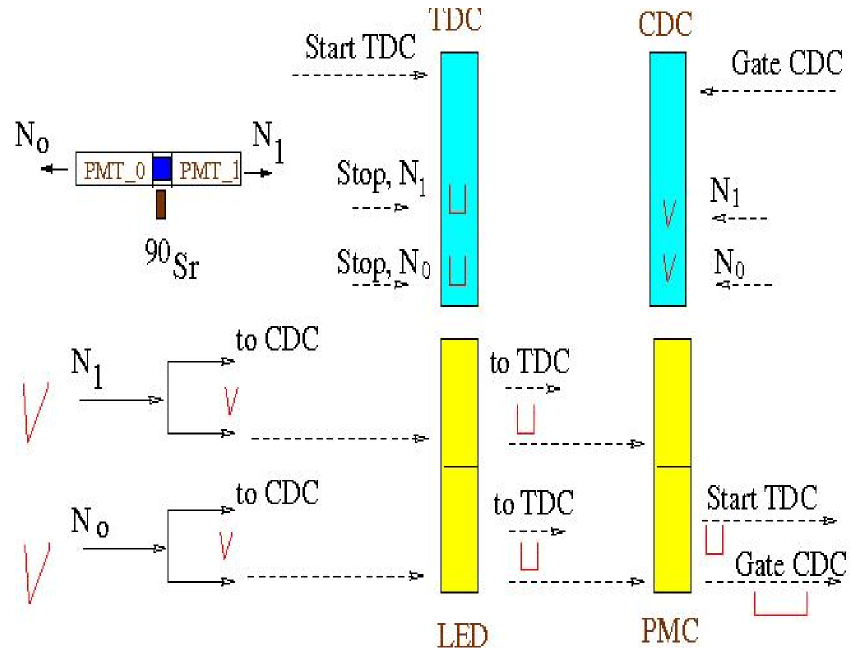
FTOF/BTOF coincidence probabilities

2.5 GeV	23.6%
5.GeV	35.1%
10.GeV	45.4%
12.5GeV	48.3%



Test stand layout and electronics

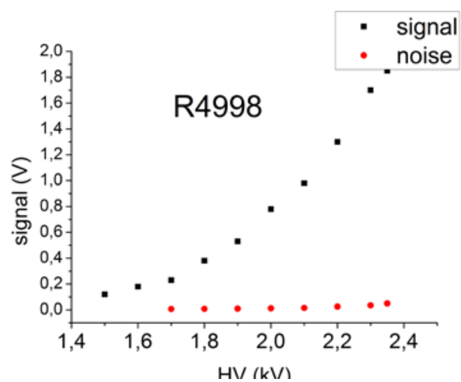


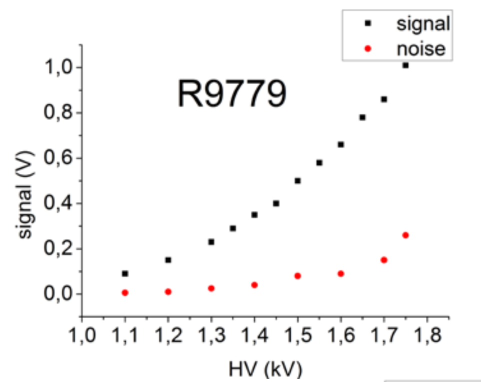


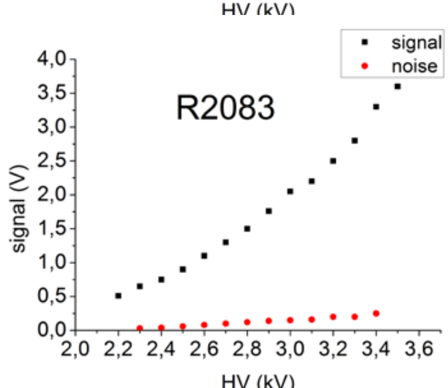
Measured are TDC_1, TDC_0, QDC_1, QDC_0

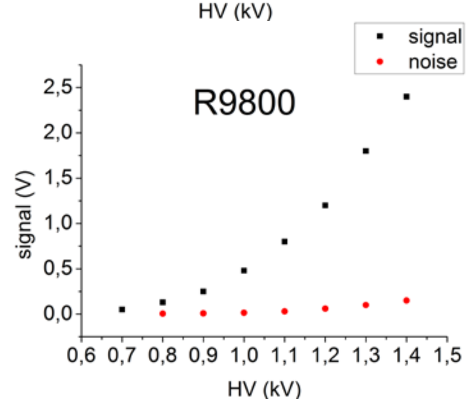
PMT characteristics

PMT	Photocathode diameter (mm)	Anode pulse rise time (ns)	Electron transition time (ns)	Transition time spread (ps)	Gain / 10^6	Typical voltage (V)
R4998	25 (1 inch)	0.7	10	160	5.7	2250
R9800	25 (1 inch)	1.	11	270	1.1	1300
R2083	51 (2 inch)	0.7	16	370	2.5	3000
R9779	51 (2 inch)	1.8	20	250	0.5	1500
XP2020	51 (2 inch)	1.6	28	??	30	2000



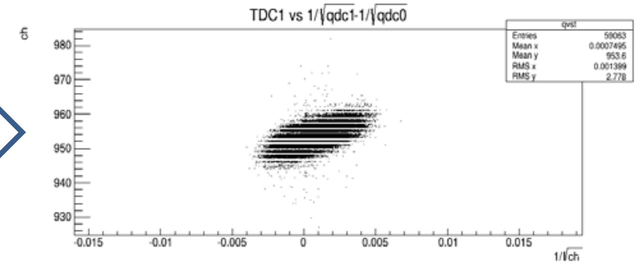






Test station results

After offline amplitude corrections

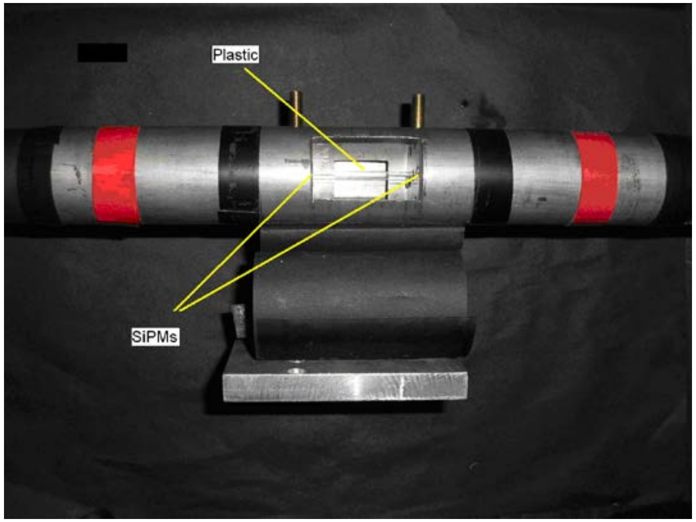


$$\frac{1}{\sqrt{Q_i}} - \frac{1}{\sqrt{Q_k}}$$

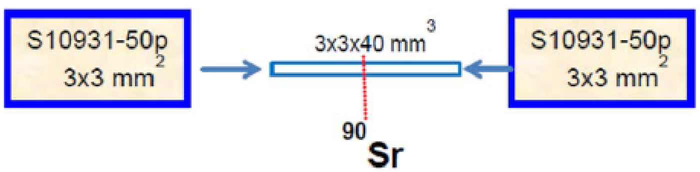
PMT_1	σ_{TDC_1} (ps)	σ_{PMT} (ps)
R4998 (4998/4998)	72.	44.4
R9800 (4998/9800)	86.	64.6
R2083 (2083/2083)	72.6	44.9
R9779 (2083/9779)	64	56.5
XP2020 (2.5, 2.36kV)	82	52,3

After offline corrections
For elecronics and track walk

SiPM timing resolution

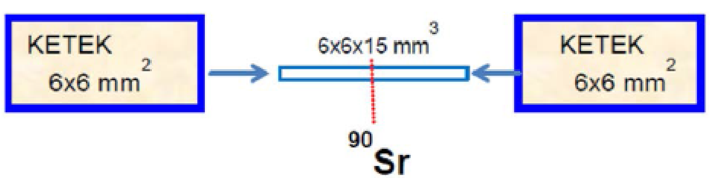


Variant A



Variant B

mm



Amplitude correction $\Delta t = \Delta t_0 - a\left(\frac{1}{\sqrt{q_1}} - \frac{1}{\sqrt{q_2}}\right) - b$

Results variant A S10931

After corrections $\sigma = 103$ ps

Results variant B KETEK 6660

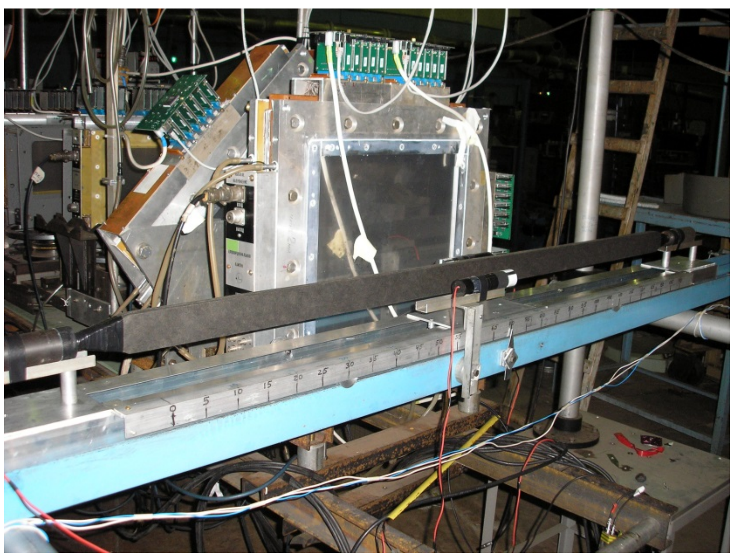
Table 4. Main parameters and time resolution of KETEK 6660.

Supply voltage (V)	Signal amplitude (mV)	Noise amplitude (mV)	Current without ^{90}Sr (mkA)	Current with ^{90}Sr (mkA)	σ_{TDC_1} (ps)	$\frac{\sigma_{TDC\_1}}{\sqrt{2}}$ (ps)	σ_{KETEK} (ps)
26.35	20÷30	~ 0.3	7.5	9	120	84.8	81.1
26.85	70÷90	~ 0.5	11	13	100	70.7	66.1

PMT timing resolution using proton beams

PNPI 1 GeV synchrocyclotron

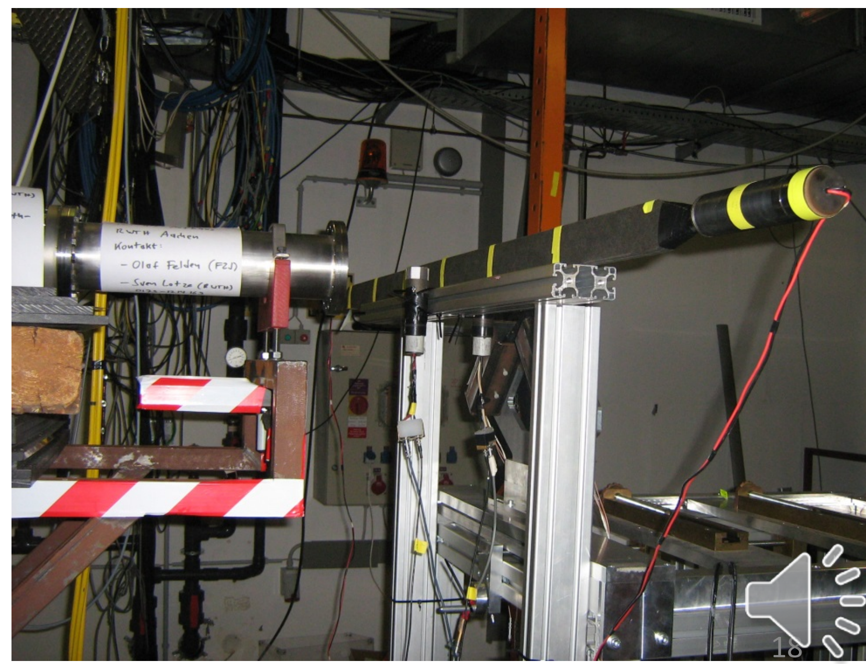
April 2009.
Optimization of slab thickness to 2.5 cm
Nov. 2012
Time resolution better 100ps
June 2013
Time resolution better 80 ps
Dec. 2013 , June 2014
Final results on prototyping



PMTs: R4998, R2083, Electron 187

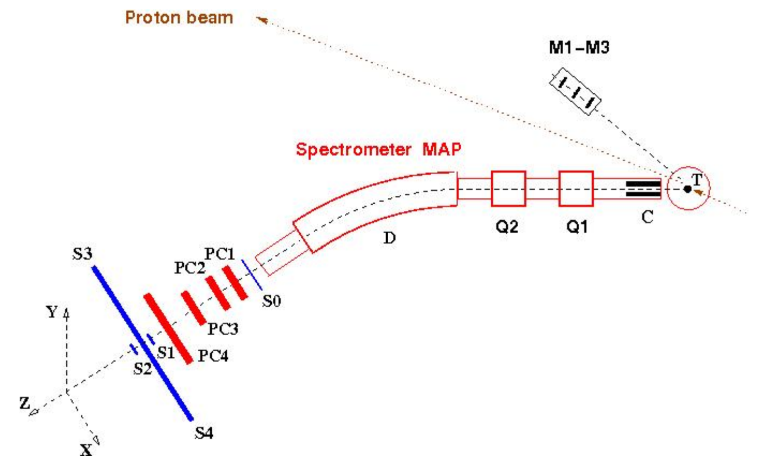
COSY test beam in Juelich

Dec. 2012 test with TRB-2 readout.
First “Electron” PMT187 test

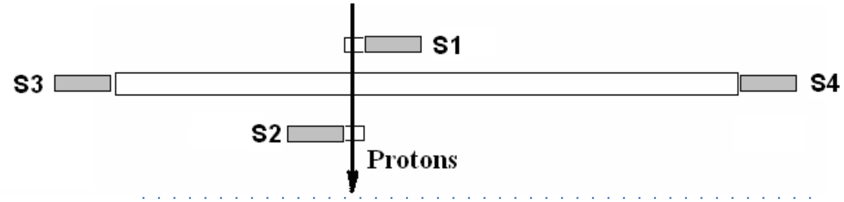


Timing resolution measurements at 1 GeV PNPI SC

1 GeV proton beam



Scattered protons up to 10^6 / cm^2



S_3S_4 scintillation slabs B408:
length 100, 140cm
width 2.5, 5,10cm
thickness 1.5, 2.5cm
S_1S_2 1x1x1cm
R4998, R2083, Electron187

Hit position and pulse amplitude correction equation

calculated are $\tau_{13}, \tau_{14}, \tau_{34}$

$$\tau_{nk} = t_n - t_k - a\left(\frac{1}{\sqrt{q_n}} - \frac{1}{\sqrt{q_k}}\right) - bx - c,$$

x hit position along the scintillation slab,

$\sigma(x) \simeq 0.5\text{mm}$ defined by MWPCs

t_n, t_k measured with TDC, q_n, q_k measured with QDC,

a,b,c fitting parameters,

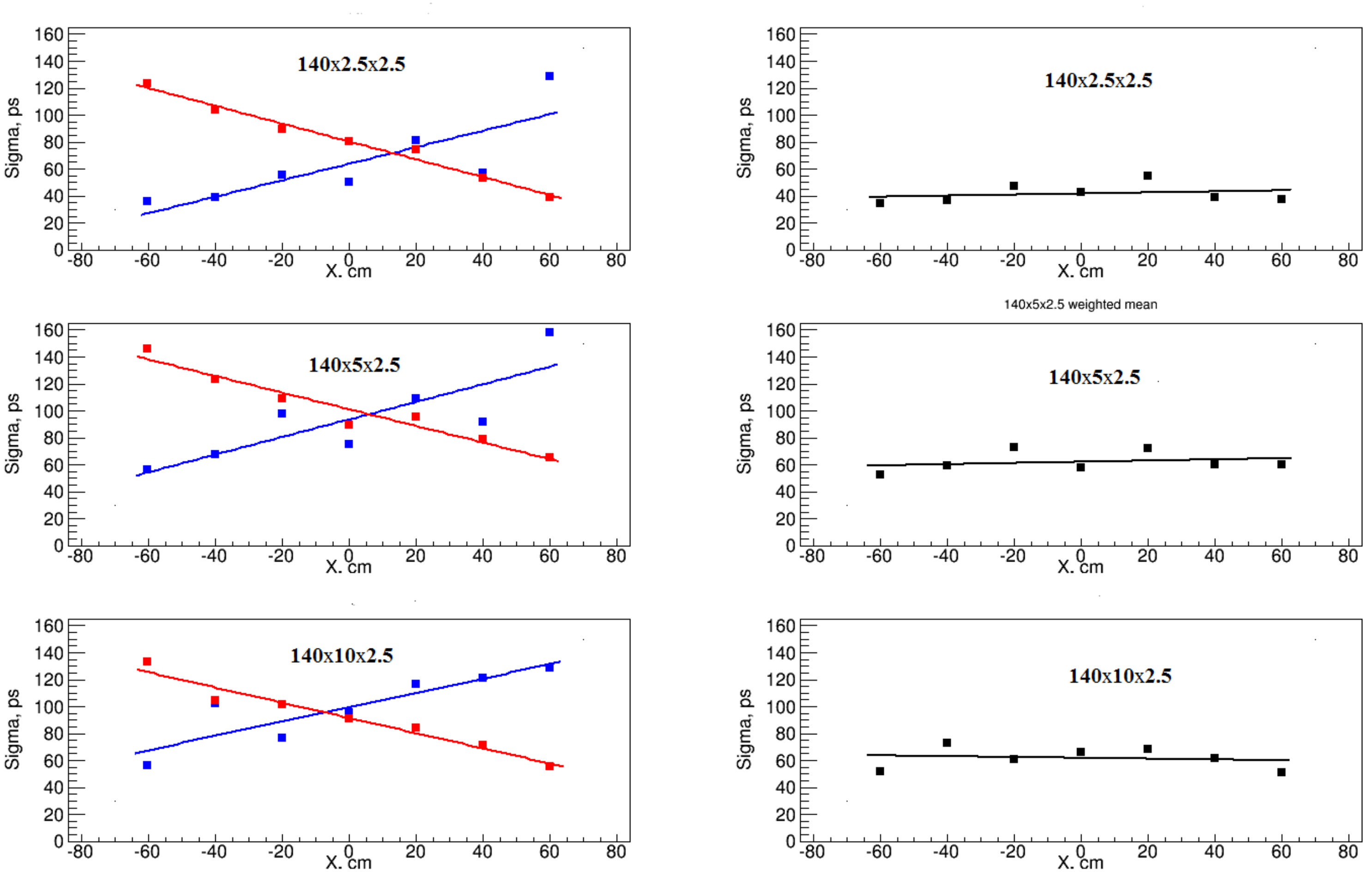
$\delta\tau_{nk}$ timing resolution (sigma of τ-distribution).

Proton energy E_p=730 and 900MeV, $\sigma(E_p)$ about 0.5%

B408 thickness 2.5cm
Energy deposition 5MeV

Scintillation Efficiency
several 10^3 photons/MeV

Timing resolution measurements at 1 GeV PNPI SC



Prototyping summary

Off line time resolutions obtained as weighted means with amplitude and hit position correction using 920 MeV protons

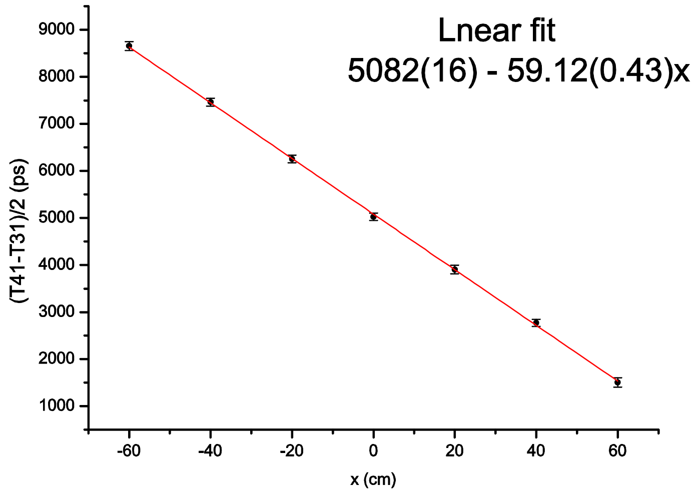
scintillation slab dimensions (cm)	PMT	timing resolution σ (ps)	comment
140 × 10 × 2.5	Hamamatsu R2083 (both ends)	63	Recommended for a prototype for the FTOF wall.
140 × 5 × 2.5	Hamamatsu R4998 (both ends)	60	Recommended for a prototype for the FTOF wall.
140 × 2.5 × 2.5	Hamamatsu R4998 (both ends)	43	a variant of a prototype with smaller stintillator width
140× 5 × 1.5	Hamamatsu R4998 (both ends)	≈ 88	projected originally for the FTOF wall
140 × 2.5 × 2.5	Electron PMT 187 (both ends)	78	magnetic field protected, tentatively projected for the dipole TOF
1×1×1	Electron PMT 187, Hamamatsu R4998	49	“net” timing resolution of one PMT

Importance of hit position measurements

$$2\Delta t^{+}_{431} = (T_3 - T_1) + (T_4 - T_1) \quad \textit{sensitive to TOF, not sensitive to hit position}$$

$$2\Delta t^{+}_{432} = (T_3 - T_2) + (T_4 - T_2) \quad \textit{sensitive to hit position, not sensitive to TOF}$$

x	$(T_{41}-T_{31})/2$	$\sigma_{431}-$	$(T_{41}+T_{31})/2$	$\sigma_{431}+$	$(T_{42}-T_{32})/2$	$\sigma_{432}-$	$(T_{42}+T_{32})/2$	$\sigma_{432}+$
cm	ps	ps	ps	ps	ps	ps	ps	ps
60	1504	99	11950	148,5	1503,5	100,5	11580	**120,5**
40	2770,5	74	11865	138,5	2770,5	74,5	11510	**102**
20	3904	90,5	11975	145,5	3904	90,5	11630	**114**
0	5025	76	11920	136,5	5025	75,5	11580	**103,5**
-20	6255	81,5	11940	150	6255	82,5	11630	**115,5**
-40	7460	84	11895	143,5	6890	85	11560	**112,5**
-60	8655	93,5	11945	148,5	8655	93,5	11600	**121**



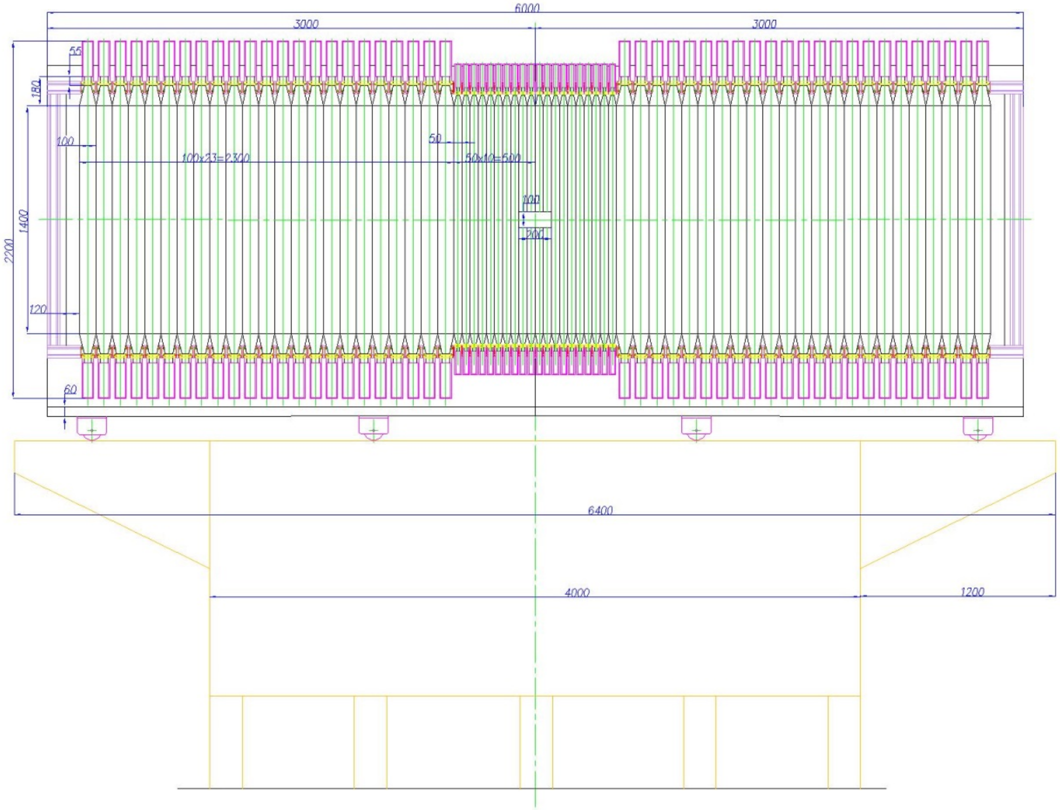
Hit position measurement σ = 15 mm   FT gives 5-10 mm
Time resolution σ = 120 ps vs 60-70 ps
with independent hit position measurement

Summary

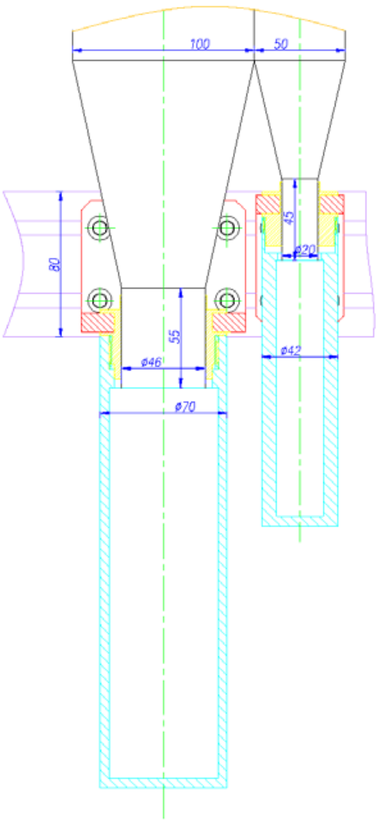
- The time resolution of 60–65 ps was obtained for the scintillation counters recommended for prototypes for the FTOF wall.
- The time resolution of 50 ps was obtained for the slabs of 2.5 cm width. Practical application of such slabs however would result in increase of number of channels which may confront the detector cost limitation.
- The time resolution of 80 ps was obtained for the scintillation counter based on the slab of 2.5 cm width viewed with the Electron PMT 187. These mesh PMTs can operate in magnetic fields up to 0.5 T without deterioration of time resolution.
- Samples with slabs of 1.5 cm thickness originally projected for the FTOF wall showed essentially worse time resolution than those of 2.5 cm thickness.
- A precise measurement of the hit position is crucial to get the timing resolution on the level of 60 ps. It has been demonstrated that without independent information on hit position the best timing resolution which can be achieved is twice worse.
  - A satisfactory result was obtained for KETEK PM6660 samples at test station. A raw timing resoluton of σ = 71 ps (per a SiPM sample) was directly measured , and after corrections it was obtained σ_{PM6660} = 66 ps. The measurements with large scintilltors has not yet been done.
  - A very tentative test of radiation hardness of SiPMs has been made in PNPI using not powered S0931-50p SiPM (3x3 mm^2) sample exposed to 1 GeV proton beam. It was found that the radiation dose equivalent to 0.45 x 10^{11} protons having passed through the active area of the sample is crucial for its operation capabilities.

Supporting slides

FTOF wall mechanics.



FTOF wall front view



Scintillation counter mechanical components

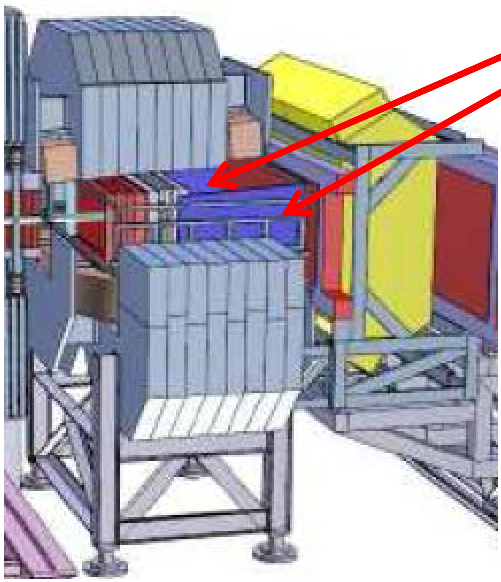
Cost estimation update

FTOF wall

Plastic scintillators	
B408 20u.140x5x2.5cm+46u.140x10x2.5cm	40 k€
PMTs 1” 760 € 40u. +5u.(spare)	42
PMTs, 2” 1270 € 92u.+20u.(spare)	155
FEE+DAQ	35
HV power supply	22
Monitoring/calibration system	25
Supporting structure , mechanical items	75
Test stand for mass production	35
Transportation, custom expenses	42
…………………………………………………………………………	
	471 k€

From RRB February 2014 470 k€

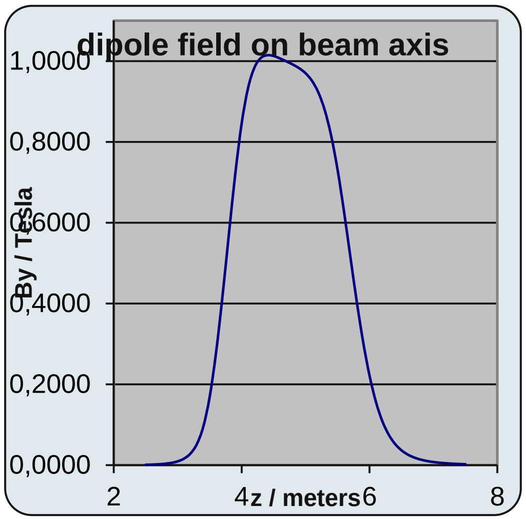
Dipole TOF positioned inside the dipole magnet gap as planned for TDR



Projected 2x10 scintillation slabs 80÷100x10x2.5cm readout from each end with Electron PMT 187

Diameter	30mm
Photocathode	20mm
Anode pulse rise time	1.4ns
TTS	≈500ps
Gain	$5x10^5$
W.m. emission	380nm
	(80% at 420nm)
HV	1800v

tested in magnetic field up to 0.5T



Alternative solution SiPMs provided timing resolution better than 100ps

radiation hardness??

Not sensitive to mag. F.(!)

SiPMs*(hamamatsu)*

S10931-50p, S10931-100p

active area	3x3mm
Pixels	3600
Gain	$7.5x10^5 – 2.4x10^6$
W.m. emission	440nm
TTS	0.5-0.6ns(FWHM)