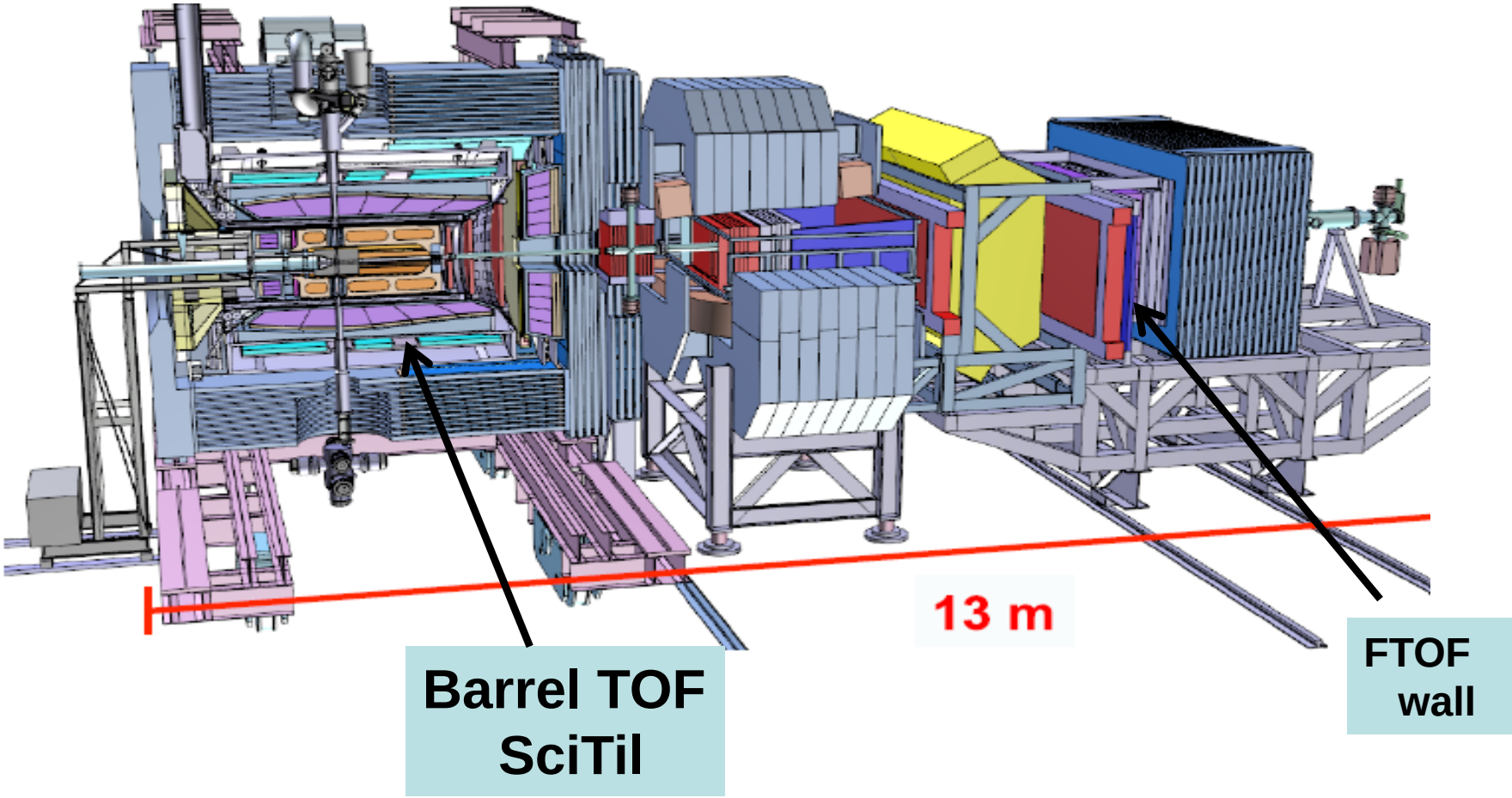
Status of FTOF wall detector

Petersburg Nuclear Physics Institute (PNPI)

S.Belostotski

Wien, December 2015

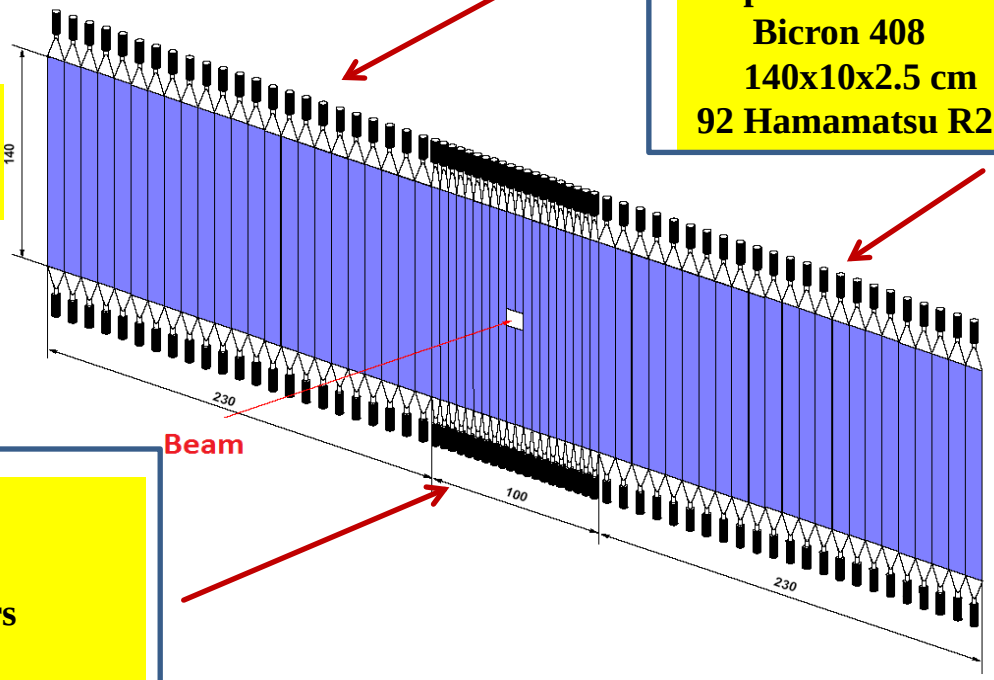
PANDA Time-of-Flight detectors



Forward TOF wall configuration

positioned at 7.5 m from 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")

Sensitive area
width = 5600 cm
height= 1400 cm

Bicron 408
(recommended for large TOF counters)

Rise time	0.9 ns
Decay time	2.1 ns
1/e light attenuation length	210cm

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

Anode pulse rise time	0.7-1.8ns
TTS	250-370ps (FWHM)
Gain	1.1-5.7x10^6

Forward TOF wall functions

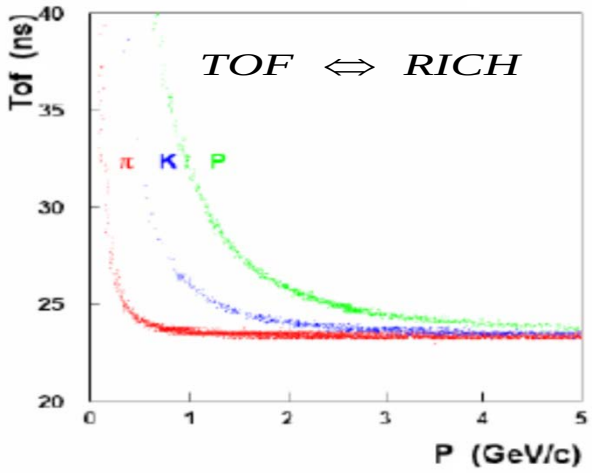
- **PID of forward emitted particles** using time-of-flight information:
  protons < 4.5 GeV, kaons < 3.5 GeV, pions < 3. GeV
  where forward RICH is not effective
  time resolution of 50-100 ps required
  FS momentum resolution 0.01

- **Event start stamp reference time**

- **Possibility to use Λbar for detector calibration**

- Can be used as start for determination of the drift time in DCs

FTOF wall hadron ID

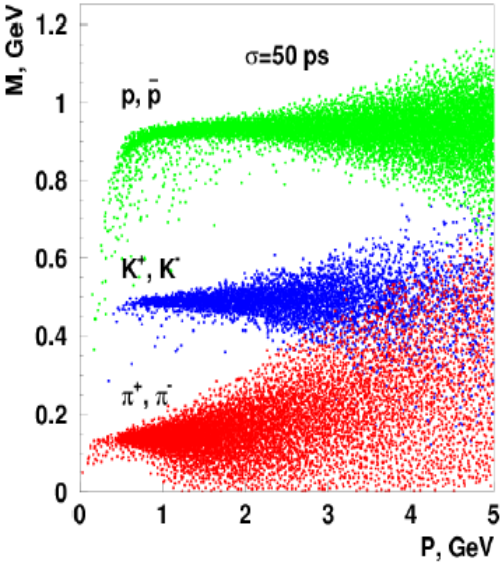


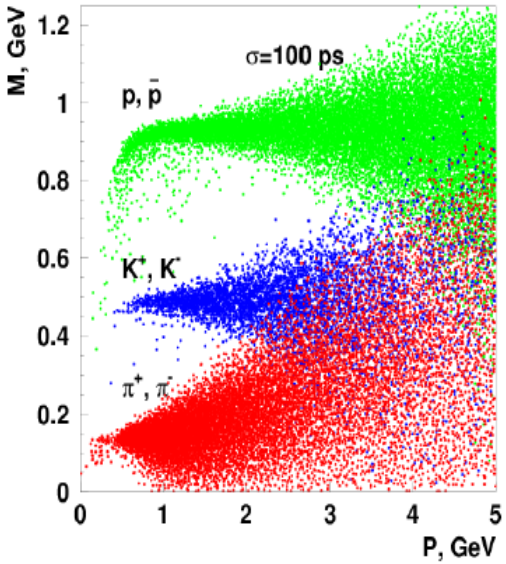
TOF resolution σ_{TOF} = 50 or 100 ps

FS momentum resolution $\Delta p/p = 0.01$

$$m = p\sqrt{\frac{t^2}{t_c^2} - 1}\,, \qquad t_c = L_{track}/c$$

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



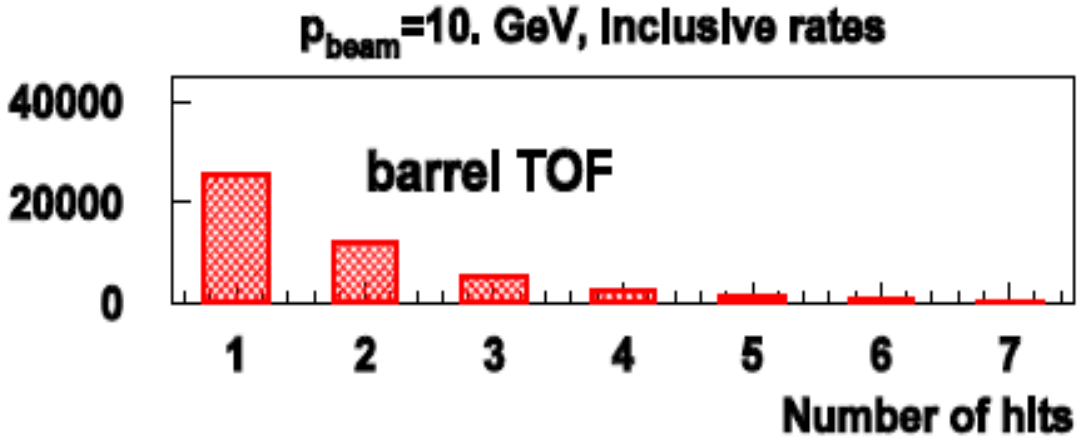


Track multiplicity/event in TOF detectors at 10 GeV

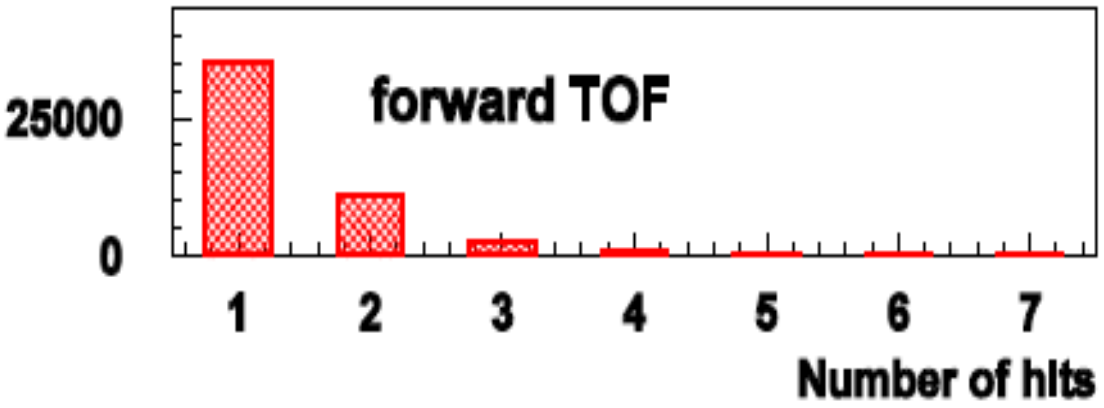
No dedicated start counter

coincidence efficiency

SciTil ≈ 50%



FTOF wall ≈ 31%

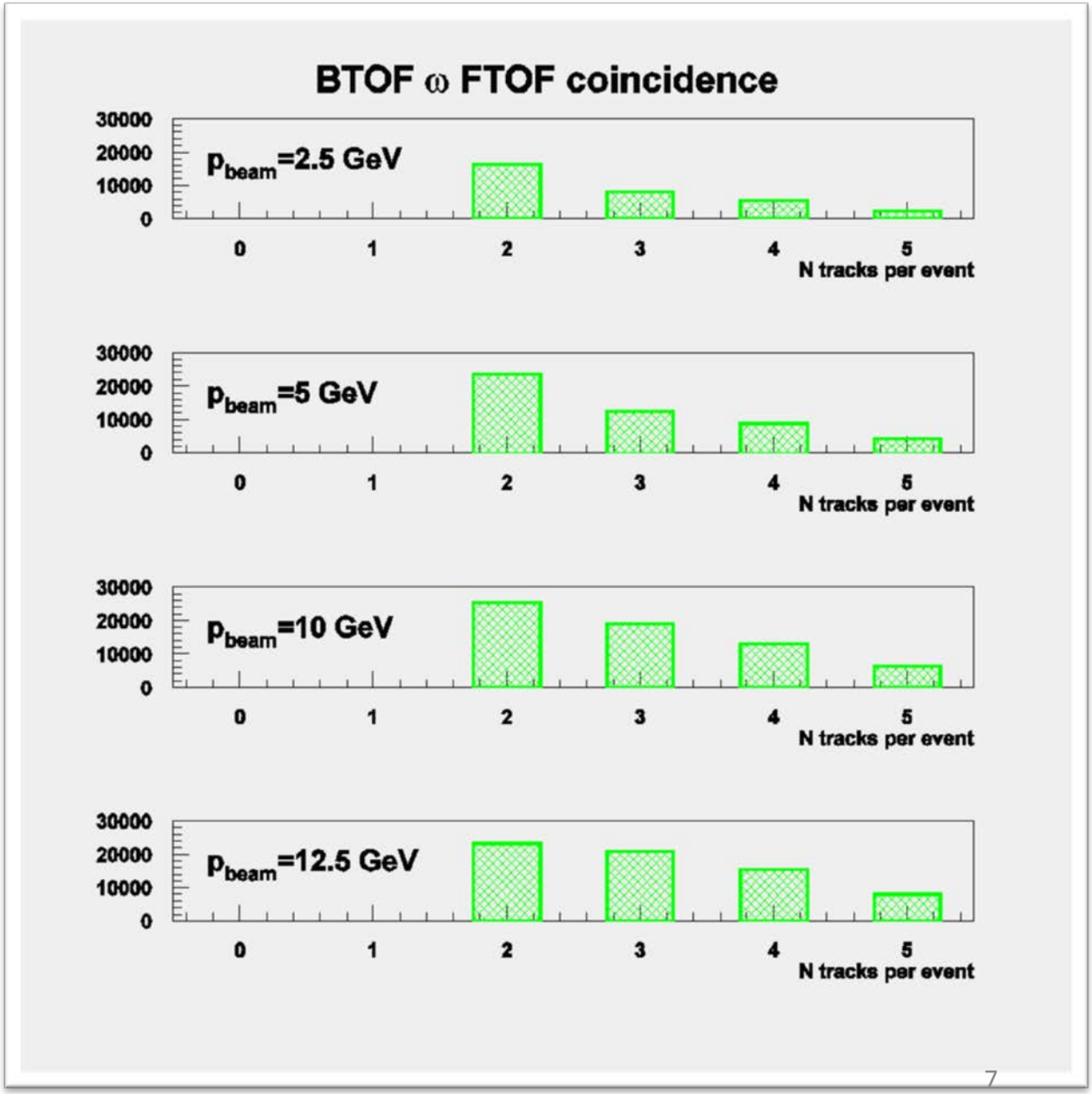


FTOF wall and barrel TOF interplay

No dedicated start counter

FTOF•BTOF coincidence probabilities

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



Count rates of FTOF wall and e^+ e^- background at 5 GeV (3.5 MHz)

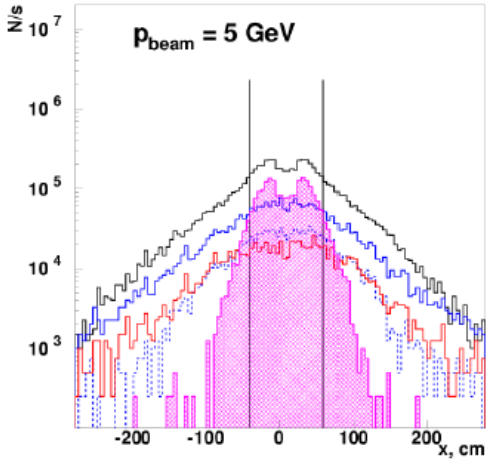
All

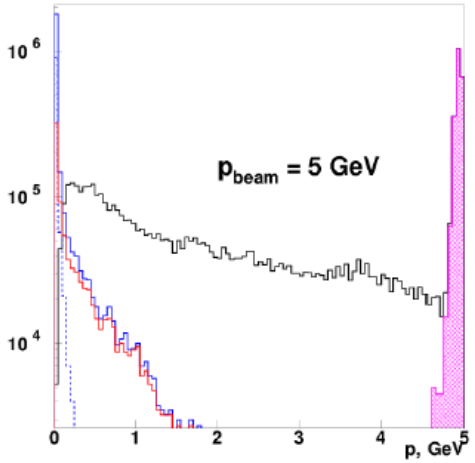
Pbar forward peak

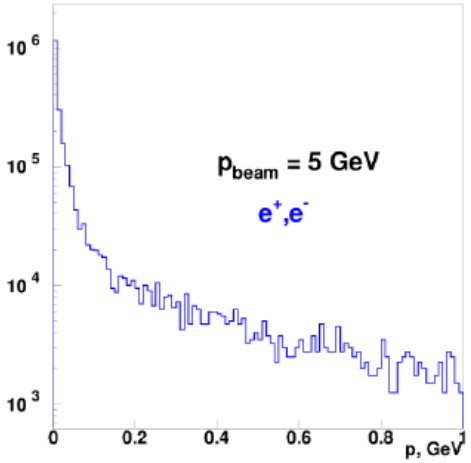
e^+ e^- all

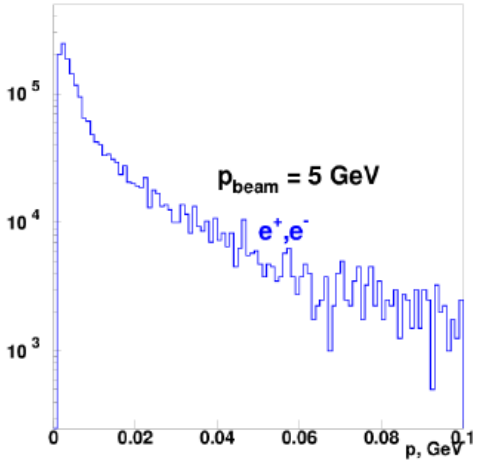
e^+ e^- produced in vacuum pipe

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









Count rates of FTOF wall and e^+ e^- background at 10 GeV (3.5 MHz)

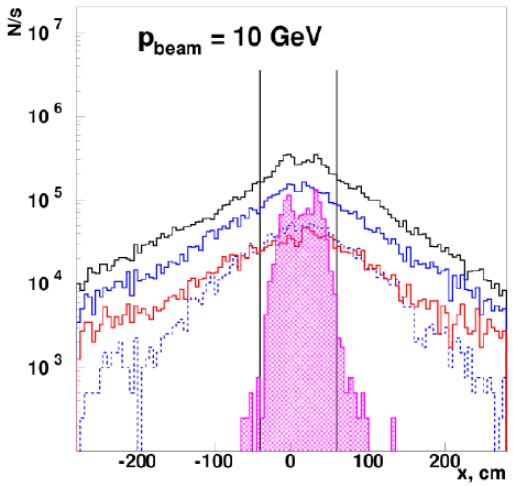
All

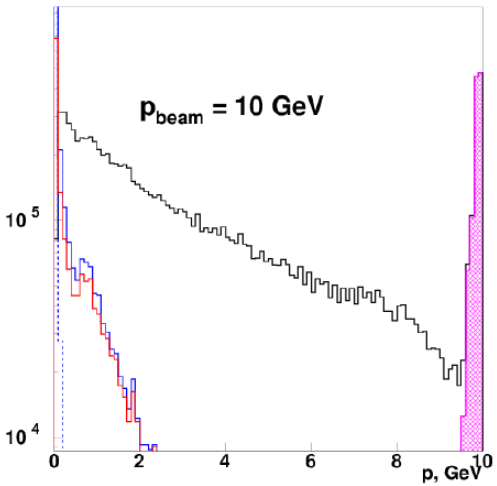
Pbar forward peak

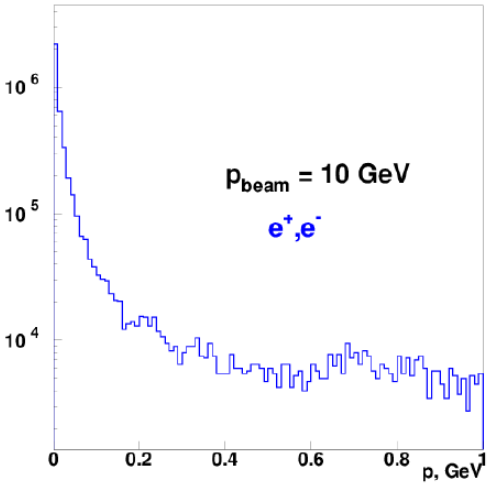
e^+ e^- all

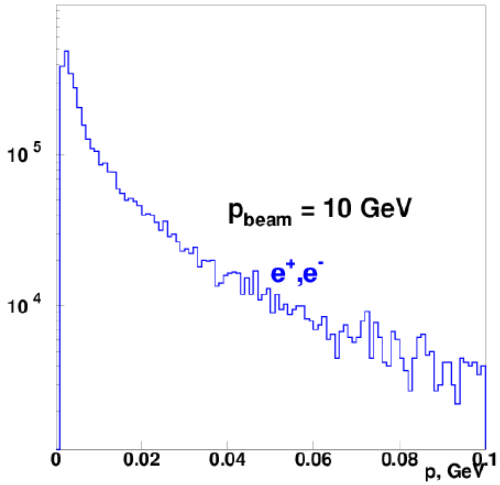
e^+ e^- produced in vacuum pipe

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









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

Λbar detection

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

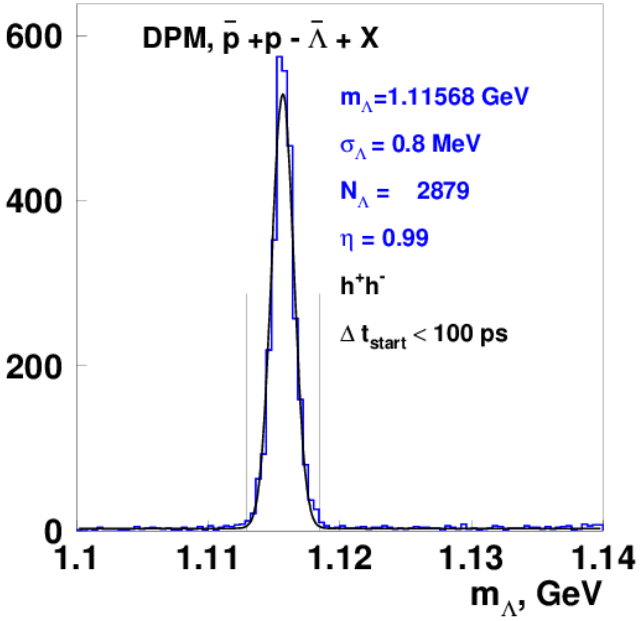
$\bar{p}+p\rightarrow\bar{\Lambda}+X$

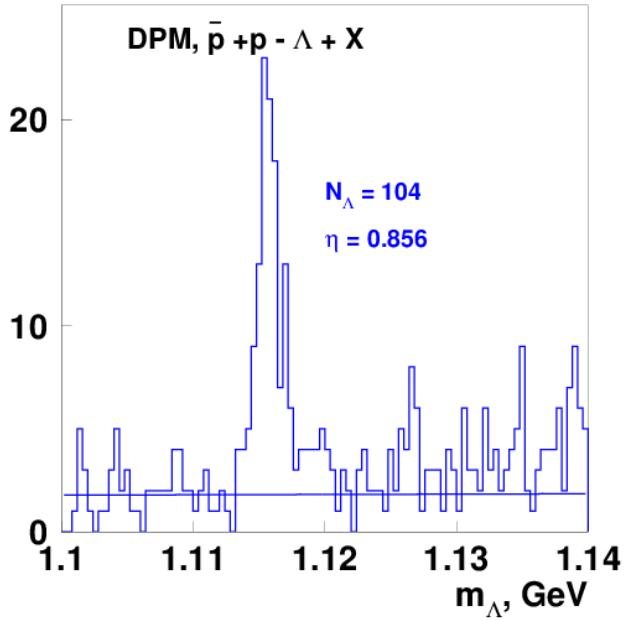
$\bar{p}+p\rightarrow\Lambda+X$

Event selection criteria

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

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





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

$N_\Lambda / N_{\bar{\Lambda}} \simeq 1/40$

Λ events also well detected

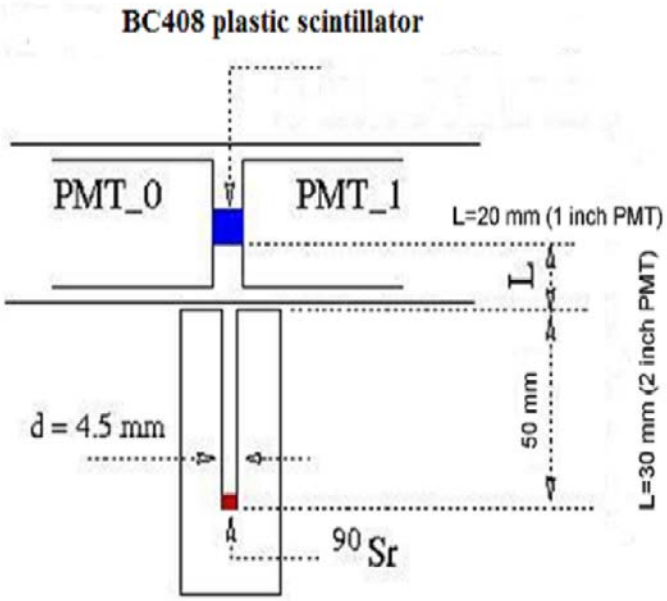
@$10^6 s^{-1}$target interactions ($L\approx10^{31}s^{-1}cm^{-2}$)

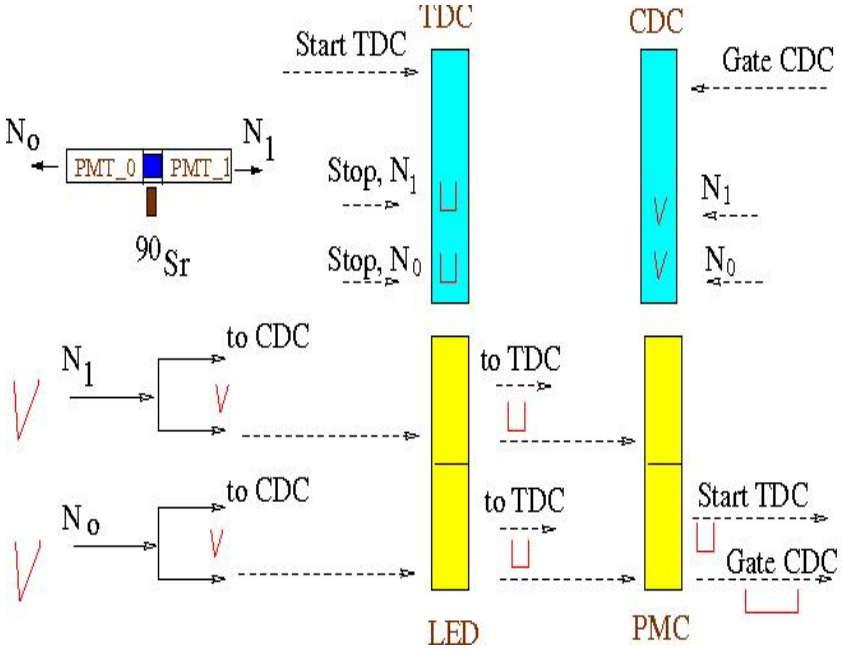
$N_{\bar{\Lambda}}=4\times10^3\ s^{-1}$!!

can be used to tag exclusive

$\bar{p}p\rightarrow\bar{\Lambda}\Lambda$ production 25×10^6 events / 7days

Prototyping. Test stand layout and electronics



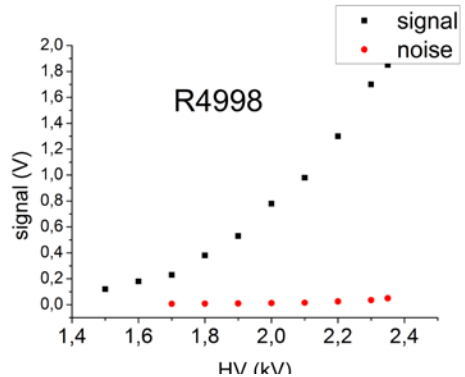


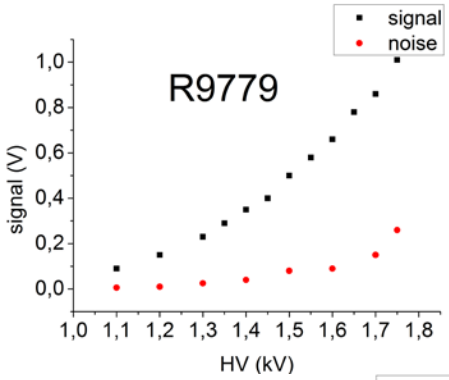
2 MeV energy deposition, 2×10^4 photons
Track walk in scintillator $\sigma_{tr.w.} = 15$ ps
Electronics contribution $\sigma_{el} = 30$ ps

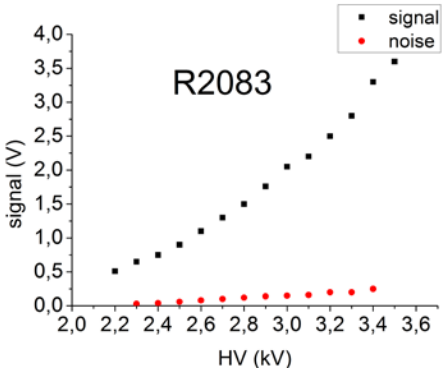
Measured are TDC_1, TDC_0, QDC_1, QDC_0

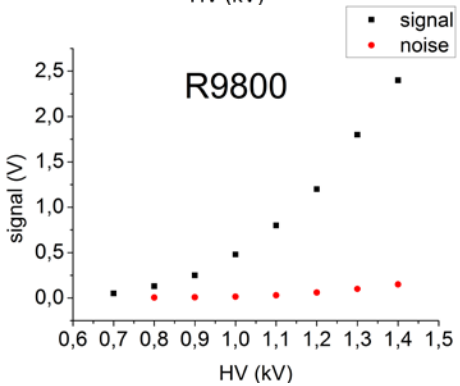
PMT characteristics

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

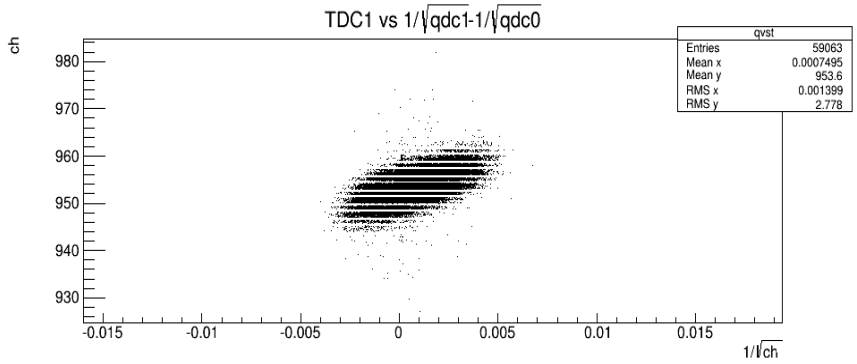








Test station results



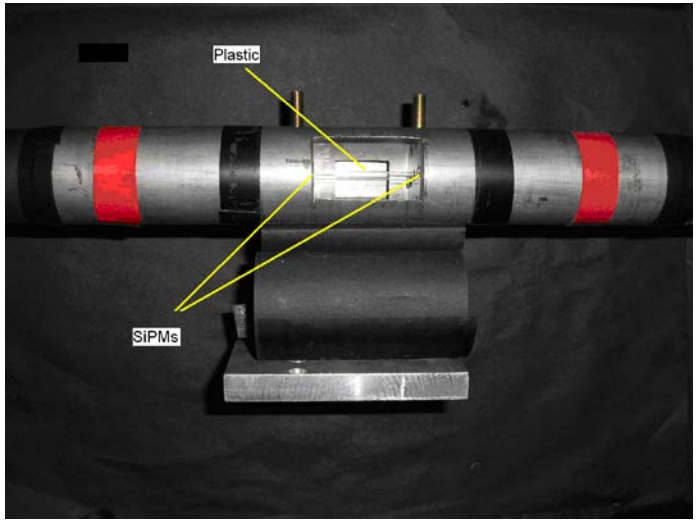
$$\frac{1}{\sqrt{Q_i}} - \frac{1}{\sqrt{Q_k}}$$

After offline amplitude corrections

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 corrections for electronics and track walk

SiPM timing tests



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

variant A S10931

after corrections **σ =103 ps**

variant B KETEK 6660

after corrections **σ =65 ps**

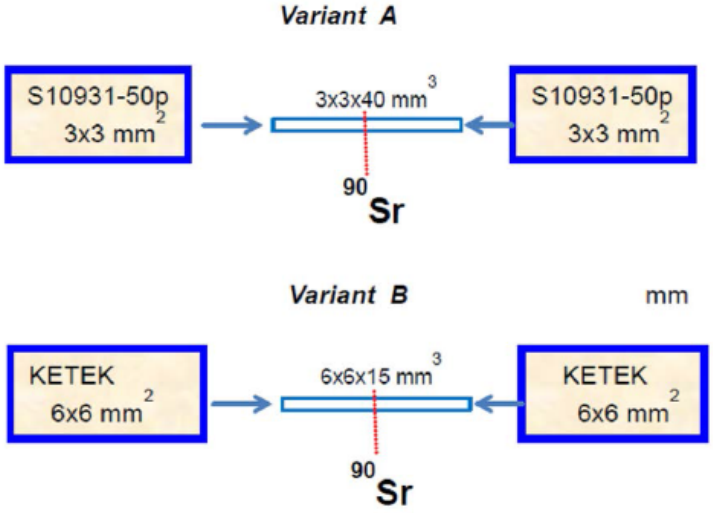
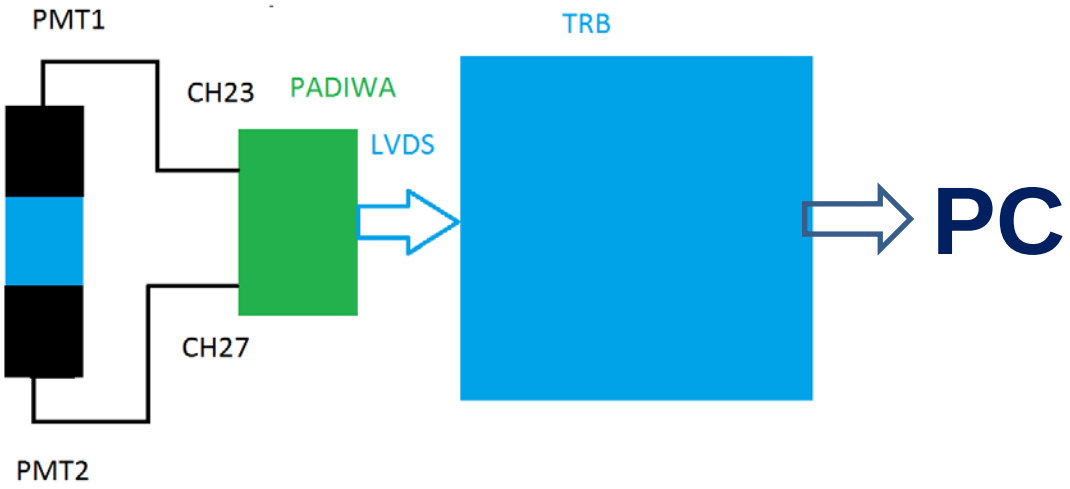
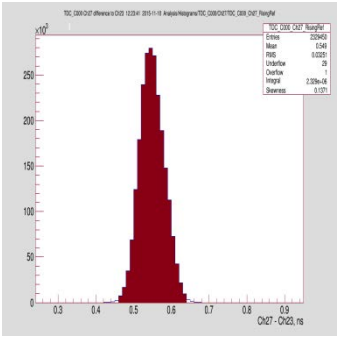


Table 4. Main parameters and time resolution of KETEK 6660.

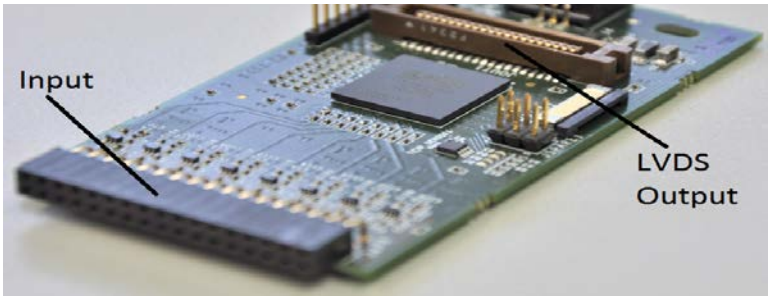
Supply voltage (V)	Signal amplitude (mV)	Noise amplitude (mV)	Current without ^{90}Sr (mkA)	Current with ^{90}Sr (mkA)	σ_{TDC_1} (ps)	$\frac{\sigma_{TDC\_1}}{\sqrt{2}}$ (ps)	σ_{KETEK} (ps)
26.35	20÷30	~ 0.3	7.5	9	120	84.8	81.1
26.85	70÷90	~ 0.5	11	13	100	70.7	66.1

Application of TRB-3 readout underway in PNPI





generator



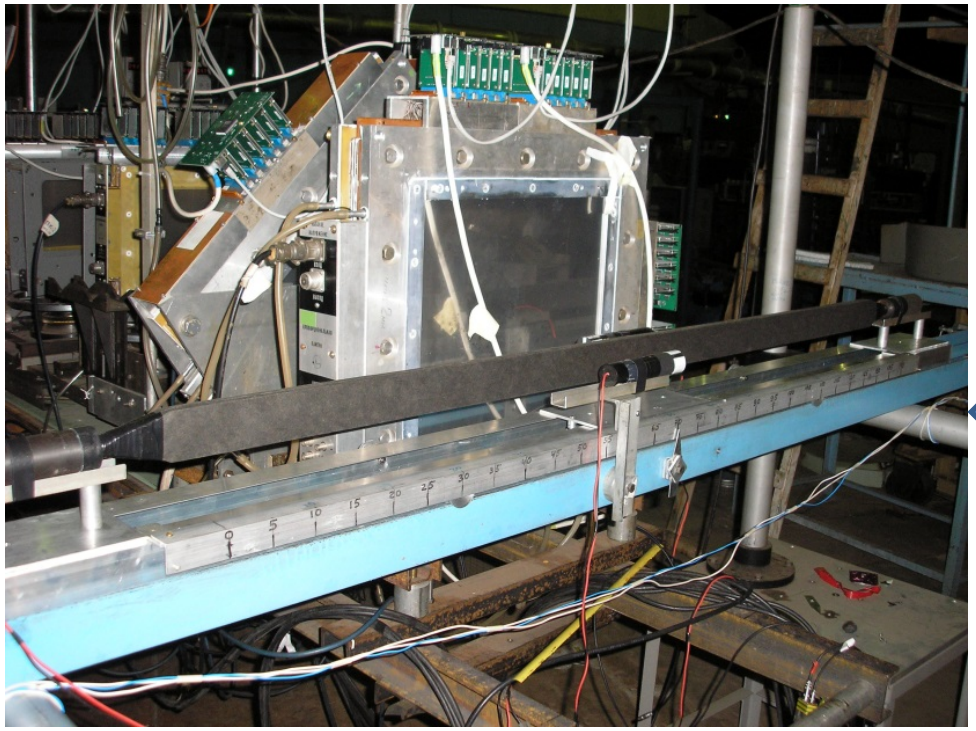
mV	Peak posit.	σ ps
100	540	31.5
75	530	31.5
50	520	33.
40	520	34.
30	520	36.
25	510	36.

Needs more expertise

Prototyping using proton beams

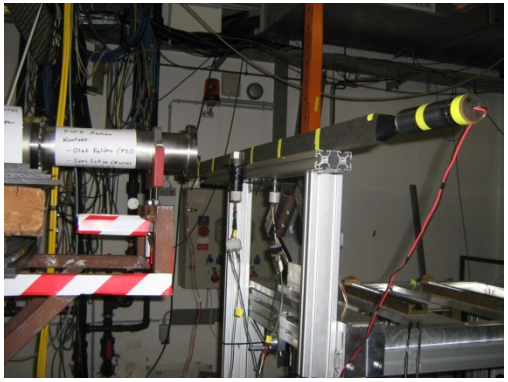
PNPI 1 GeV synchrocyclotron

740 and 920 Mev protons selected with magnetic spectrometer



COSY test beam in Juelich 2 GeV

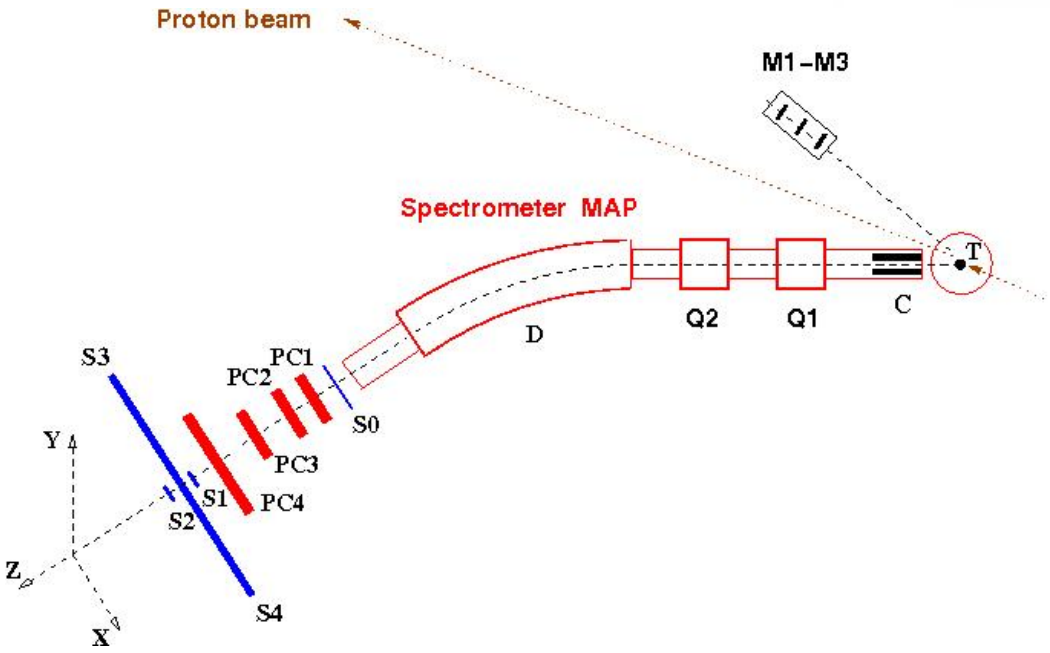
MIP protons

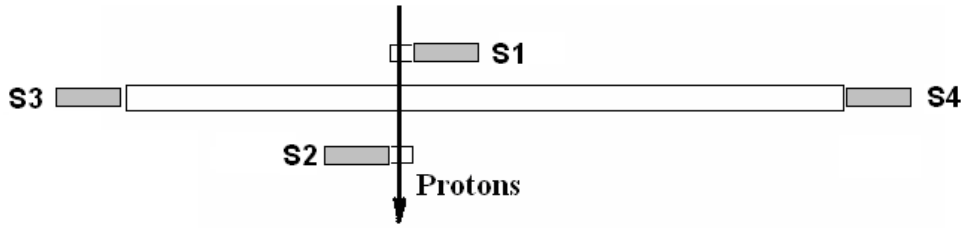


Slab put horizontally
in spectrometer focal plane
at movable frame.
MWPCs provide hit position
with $\delta x \approx 1$ mm

Beam tests at 1 GeV PNPI SC

1 GeV proton beam





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

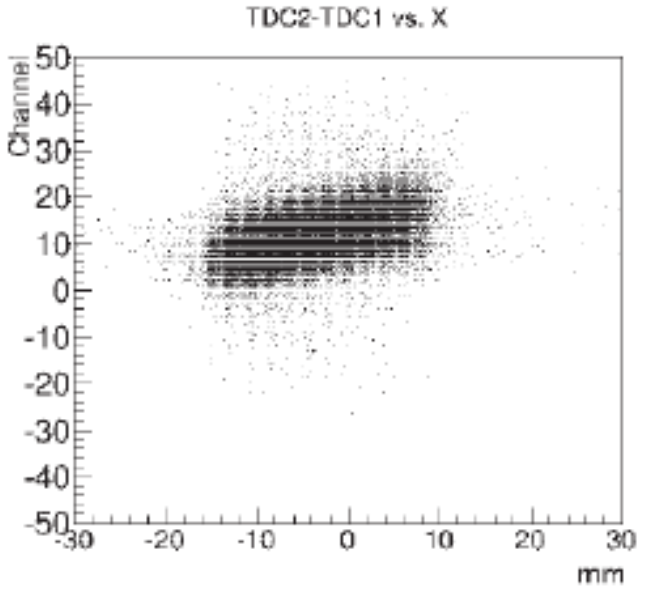
Scattered protons up to 10^6 / cm^2

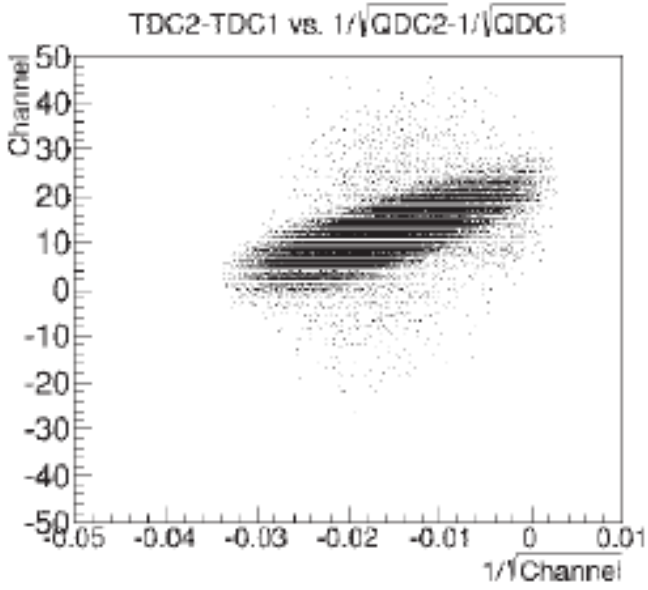
Proton energy E_p=740 and 920MeV, $\sigma(E_p)$ about 0.5%

B408 thickness 2.5cm
Energy deposition ≈ 5MeV

Scintillation Efficiency
several 10^4 photons/MeV

Off-line time resolution





Hit position and pulse amplitude corrections

on event basis calculated are

$$\tau_{13}, \tau_{14}, \tau_{23}, \tau_{24}, \tau_{34}$$

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

x hit position along the scintillation slab,

t_n, t_k time stamp measured with TDC,

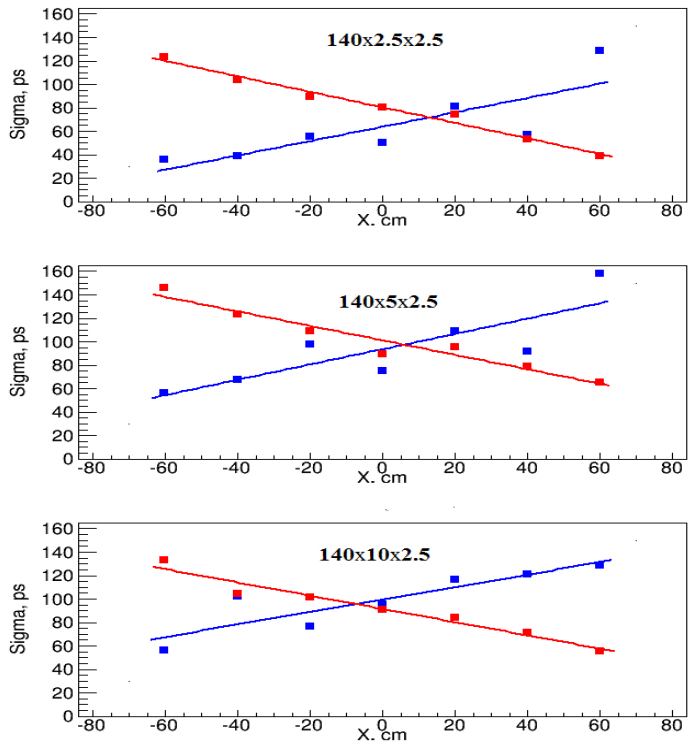
q_n, q_k measured with QDC,

a,b,c free parameters to minimize τ_{nk}

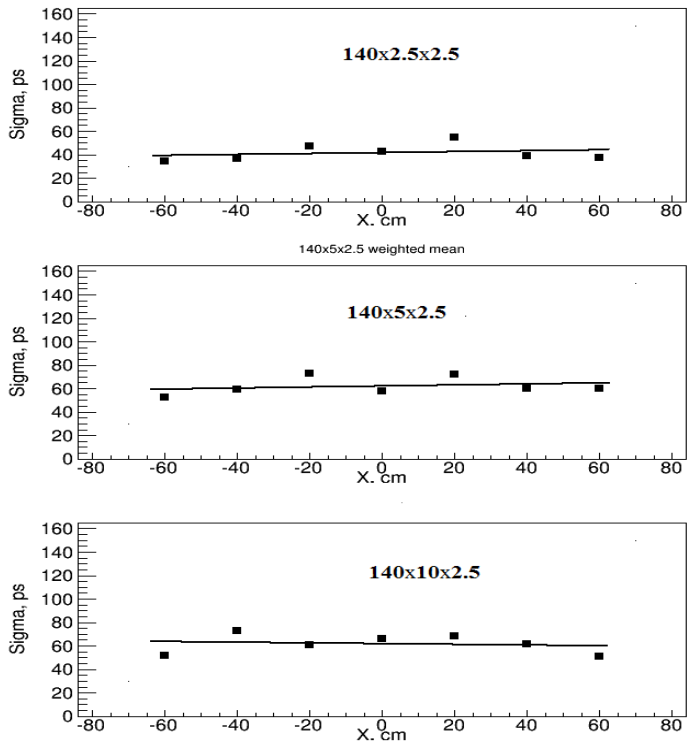
timing resolution is σ of

(corrected) τ_{nk} distribution.

Timing resolution results from 1 GeV PNPI SC



σ_{TOF} vs hit position



σ_{TOF} weighted means

weighted mean

$$\frac{1}{\sigma_{TOF}^2} = \frac{1}{\sigma_{TDC3}^2} + \frac{1}{\sigma_{TDC4}^2}$$

in the middle of slab $\quad \sigma_{TOF} \approx \frac{\sigma_{TDC3}}{\sqrt{2}} \approx \frac{\sigma_{TDC4}}{\sqrt{2}}$

Prototyping 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 seems crucial to get the timing resolution on the level of 60 ps. Without independent information on hit position, the timing resolution of 80 ps has been measured. .
  - 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.

Open questions

- **MC simulation.**

  - time dependent event reconstruction analysis

- **Related to FSTT.**

  - FS momentum resolution Δp/p must be 1%

  -vertical hit position uncertainty ? Δy=1 mm corresponds 5.3 ps (BC-408)

  expected at present design FSTT Δy=5-10 mm → up to Δ(tof) ≈ 60 ps

  -uncertainty in track reconstruction? $\Delta L_{track} / L_{track}$ = 0.1% → Δ(tof) ≈ 30 ps

- **FTOF wall position behind RICH.**

  - RICH width is smaller than sensitive area of FTOF wall, deterioration of track information at FTOF wall side slabs

- **FTOF wall width is 5.6 m while FSTT last station width is 3.9 m, thus side parts of FTOF wall are out of FSTT acceptance.**

  reduce FTOF wall width ??

- **Hardware:**

  - finalize TRB-3 readout tests

  - definitive decision on Hamamatsu PMs (type, housing, divider, price,.).

  - on-line laser calibration system (??)

  - HV-power supply: commercial or

  PNPI production HVDS3200 designed for Nustar R3B FAIR (neutron detector)

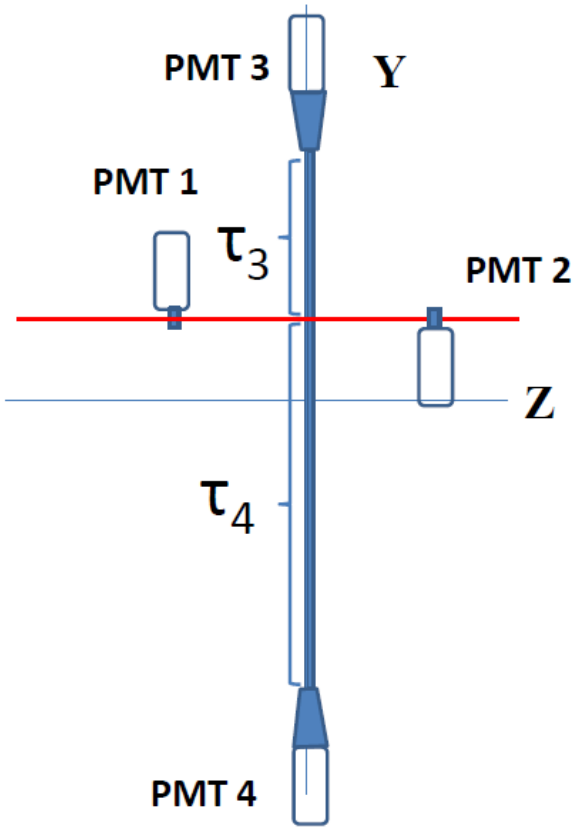
Conclusion

- MC simulation demonstrates important functions of FTOF wall:
  - PID of forward emitted particles with momenta below 3-4 GeV
  - determination of event start time stamp
  - possibility to use Λbar for detector calibration
- Maximum count rate in central part of FTOF wall at $L = 10^{32}$ cm^{-2} s^{-1} is below 3×10^{6} s^{-1} . Background related to $e^{+}e^{-}$ pairs production peaked at very low momenta is small.
- Prototyping is completed. Timing resolution of 60 ps is measured. The measurements were performed using 920 MeV protons selected by the magnetic spectrometer.
- Without hit position precise information, timing resolution of 80 ps has been obtained.

- TDR drafting has not yet been finished. It is planned to circulate within Collaboration in March.

Supporting slides

Time resolution without hit position correction



$\tau_3 + \tau_4 = \tau$ constant

light propagation

time through slab

$$T_3 = T_1 + t + \tau_3 \qquad T_4 = T_1 + t + \tau_4$$

$$(T_3 - T_1) + (T_4 - T_1) = T_{31} + T_{41} = 2t + \tau$$

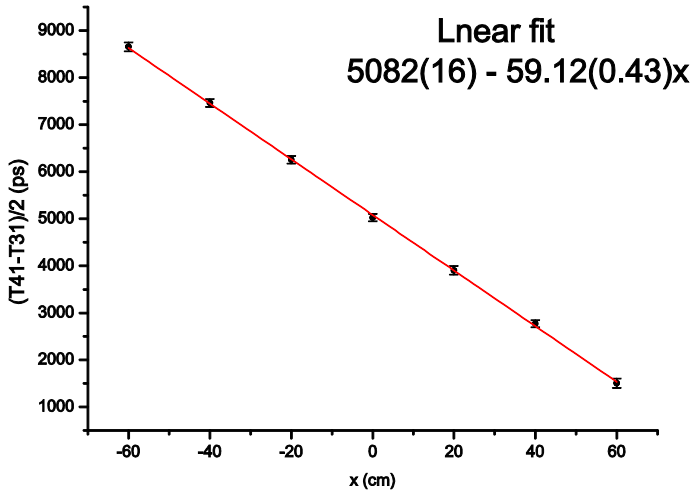
sensitive to measured time, not sensitive to hit position

$$(T_3 - T_1) - (T_4 - T_1) = T_3 - T_4 + \tau - 2\tau_4$$

sensitive to hit position, not sensitive to measured time

Time and hit position measurements using TDC information only

x	$(T_{41}-T_{31})/2$	σ_{431}^-	$(T_{41}+T_{31})/2$	σ_{431}^+	$(T_{42}-T_{32})/2$	σ_{432}^-	$(T_{42}+T_{32})/2$	σ_{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



$$\tau = 59.12\,\text{ps/cm} \times 140\,\text{cm} = 8276.8\,\text{ps}$$

v_{BC408} = 1/59.12 = 0.17mm/ps
speed of light in BC408 = 0.19 mm/ps

hit position resolution
80ps x 0.17mm/ps = 13.6 mm

Summary table of beam tests

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,
1×1×1	Electron PMT 187, Hamamatsu R4998	49	“net” timing resolution of one PMT

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 0.35×10^7/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

$\pi \to 2\gamma$ $\gamma \to e^+ e^-$

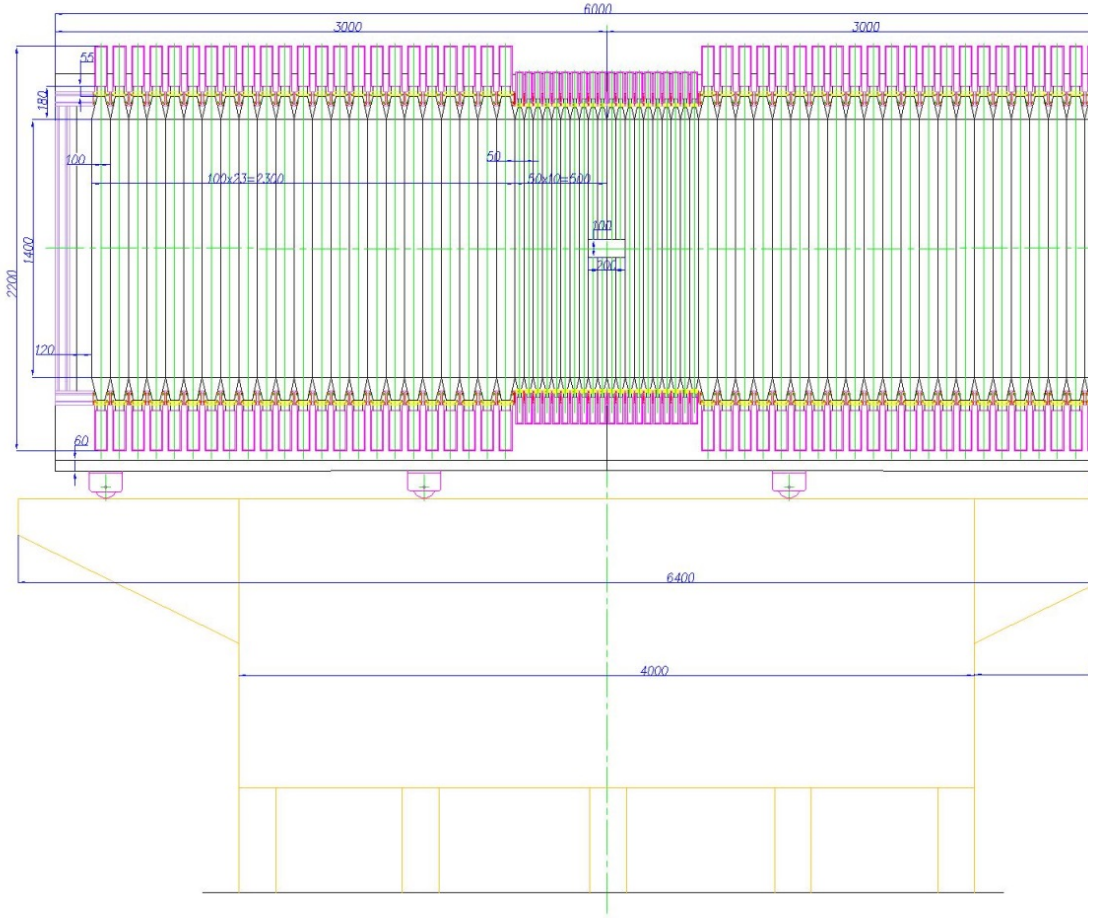
Cost estimation update

FTOF wall

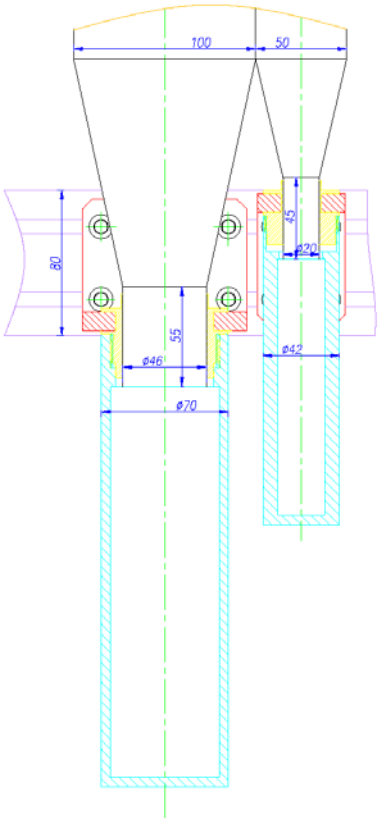
Plastic scintillators	
B408 20u.140x5x2.5cm+46u.140x10x2.5cm	40 k€
PMTs 1” 760 € 40u. +5u.(spare)	42
PMTs, 2” 1270 € 92u.+20u.(spare)	155
FEE+DAQ	35
HV power supply	22
Monitoring/calibration system	25
Supporting structure , mechanical items	75
Test stand for mass production	35
Transportation, custom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

From RRB February 2014 470 k€

FTOF wall mechanics.



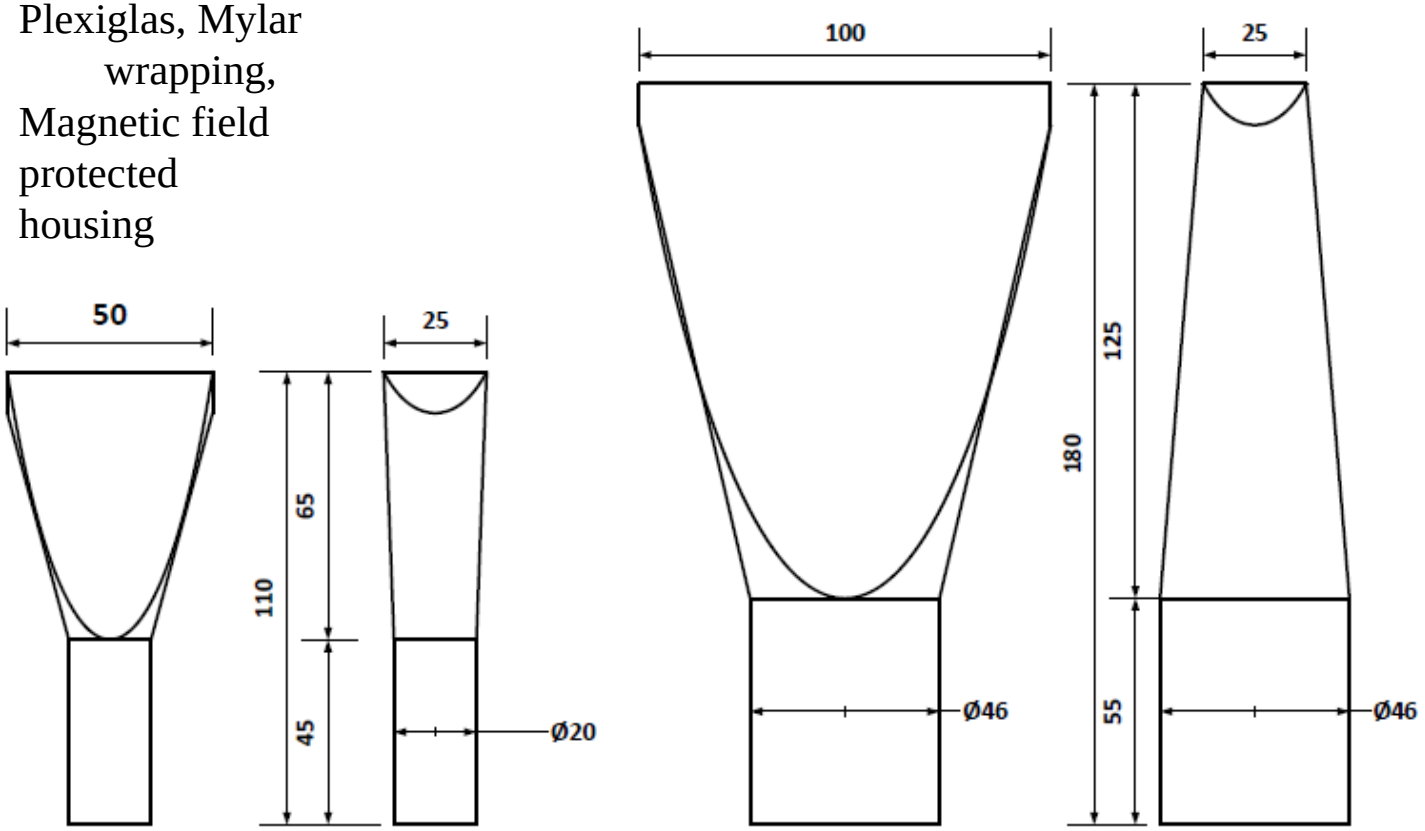
FTOF wall front view



Scintillation counter mechanical components

LIGHT GUIDES FOR 1” AND 2” PMTs

Plexiglas, Mylar wrapping, Magnetic field protected housing

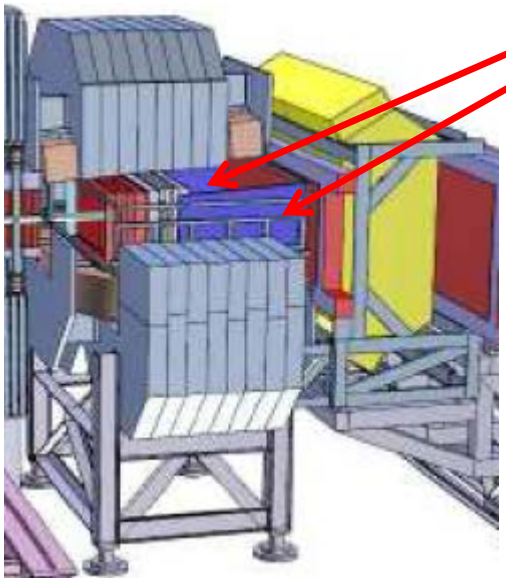


FSTT impact on FTOF

Tracking station	$z_{min} - z_{max}$ [mm]	Active area w [mm]	Active area h [mm]	Number of modules	Number of straw tubes
1	2954-3104	1338	640	4x10=40	4x288=1152
2	3274-3424	1338	640	4x10=40	4x288=1152
3	3945-4245	1782	690	4x12=48	4x384=1536
4	4385-4685	2105	767	4x14=56	4x448=1792
5	6075-6225	3923	1200	4x27=108	4x824=3296
6	6395-6545	3923	1200	4x27=108	4x824=3296

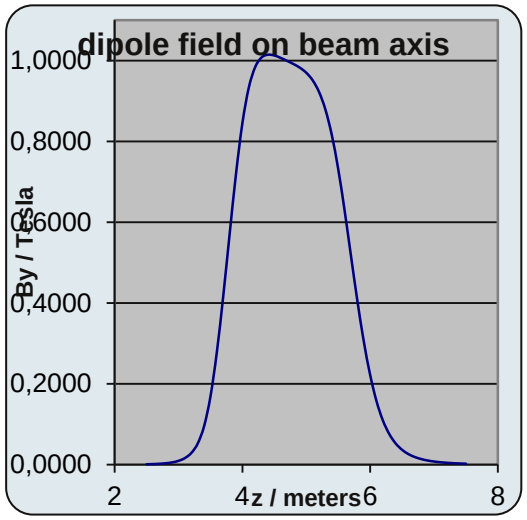
Table 1.1: Positions, width and height of active area, number of modules and number of straw tubes in the Forward Tracker stations. In the second column z-coordinate of the first and forth double layers are given. The indicated width and height of active area corresponds to dimensions of the first double layer with vertical straws in individual tracking stations.

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)

TDR TABLE OF CONTENT

1. EXECUTIVE SUMMARY

1.1 INTR0DUCTION: THE PANDA EXPERIMENT AT HESR, GSI

1.2.FORWARD TIME-OF-FLIGHT DETECTORS

1.3 EXPERIMENTAL TESTS OF PROTOTYPES

1.4.CONCLUSION

2. PHYSICS CASE OF FTOF, MC STUDY

2.1 FORWARD SPECTROMETER TOF PID

2.2 FTOF WALL COUNT RATES, BACKGROUND

2.3 HADRON DETECTION WITH FTOF WALL

2.4 STRANGE HYPERONS DETECTION

2.6 INTERPLAY OF FTOF WALL AND BARELL TOF

3. TECHNICAL DESIGN CONSIDERATIONS OF FTOF WALL

3.1 PLASTIC SCINTILLATORS AND PHOTO DETECTORS

3.2 DIGITIZATION OF SCINTILLATION COUNTER RESPONSE

4.EXPERIMENTAL STUDY OF PROTOTYPES

4.1 STUDY OF PHOTODETECTORS USING TEST STATION

4.2 PROTPTYPING AT PROTON BEAMS

4.3 FTOF PROTOTYPING SUMMARY

5. MECHANICS, CABLING AND INTEGRATION

6. CALIBRATION AND MONITORING

7. PROJECT MANAGEMENT (SCHEDULE, RISK ASSESMENT, CONTRACT, ETC.)

8. CONCLUSION