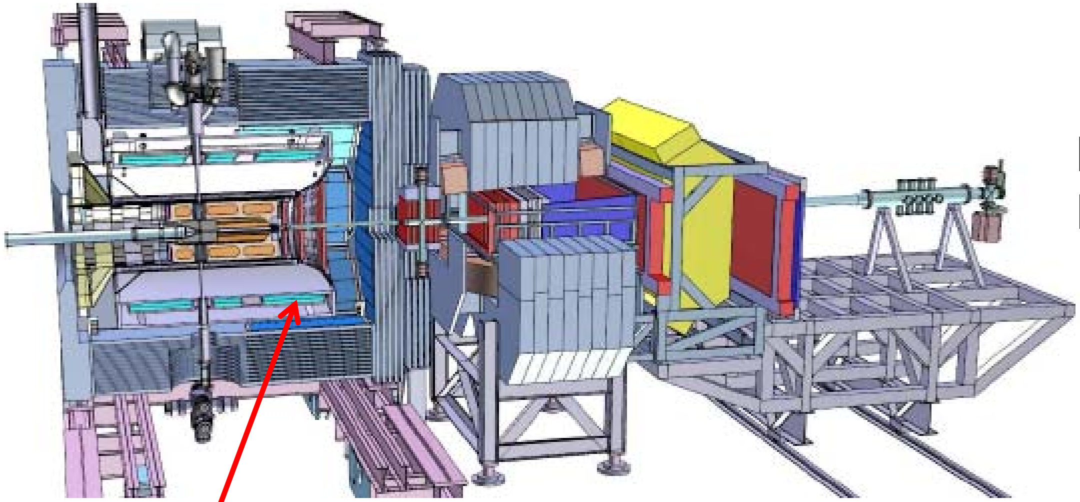
Status of FTOF detectors

Petersburg Nuclear Physics Institute (PNPI)

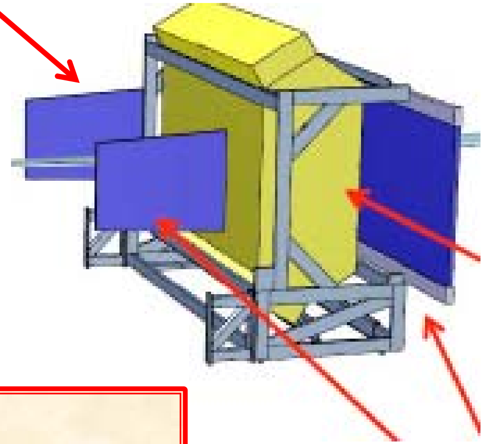
S.Belostotski

PANDA collaboration meeting March 2014

Time-of-Flight PANDA detectors



FS TOF

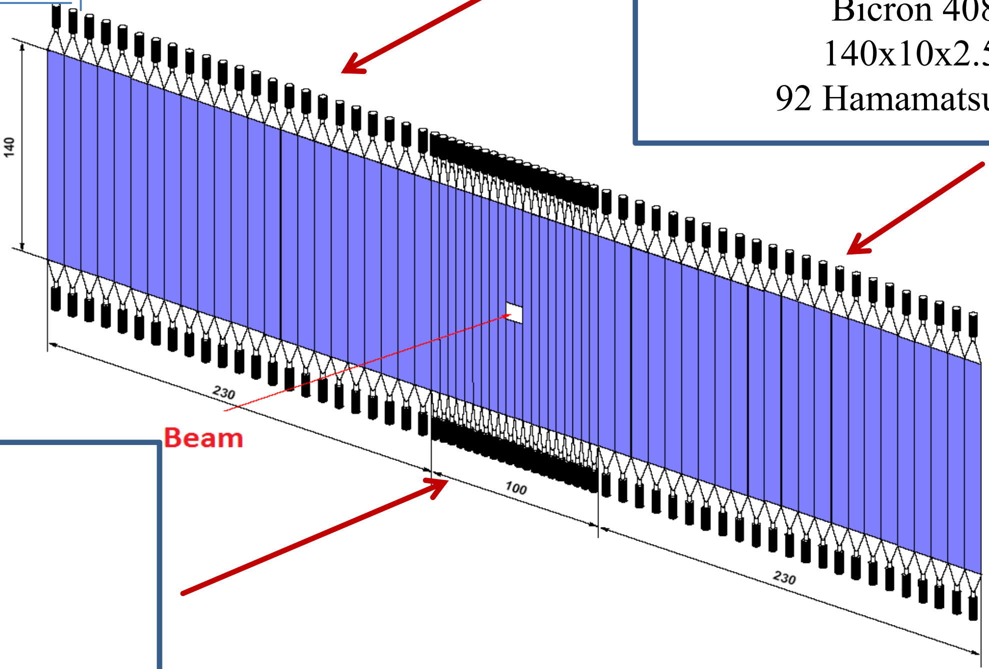


Motivations for FTOF

- PID of forward emitted particles with timing resolution of 50ps
- Work in coincidence with Barrel TOF
- Event start reference time with timing resolution of 50ps
- A high efficiency to detect anti hyperons, 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

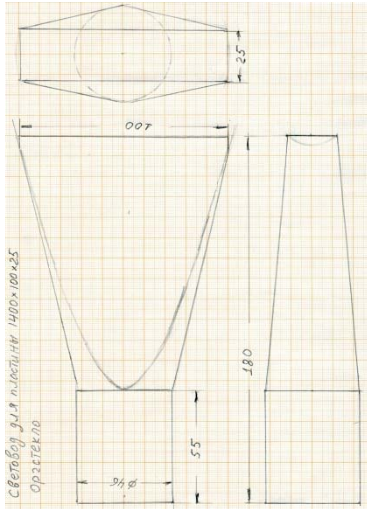


Side parts
2x23 counters
46 plastic scintillators
Bicron 408
140x10x2.5 cm
92 Hamamatsu R2083 (2”)

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

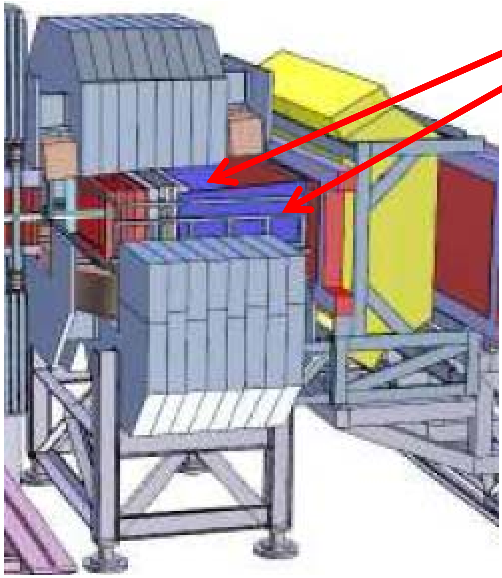
light guides

Plexiglas, Mylar wrapping



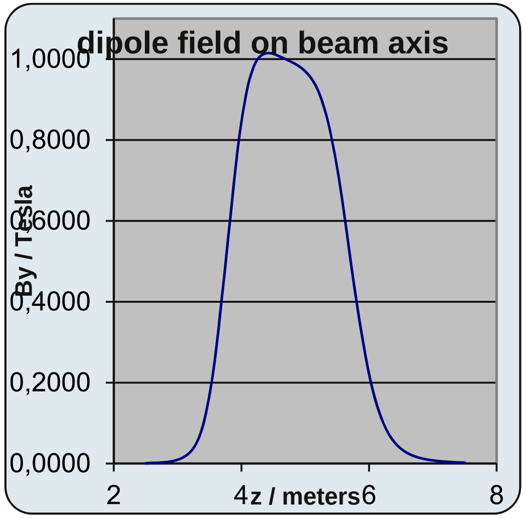
Bicron 408 (recommended for large TOF counters)		***Fast PMTs** (hamamtsu)* **R4998 1” (R9800) , R2083 2” (R9779)**	
Rise time	0.9 ns	Anode pulse rise time	0.7-1.8ns
Decay time	2.1 ns	TTS	250-370ps (FWHM)
1/e light attenuation length	210cm	Gain	$1.1\text{-}5.7\text{x}10^6$
Wavelength of max emission	425nm	W.m. emission	420nm
		HV	1500-3500v

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



Caveat: have been tested in magnetic field less 0.5T

Alternative solution SiPMs provided timing resolution better than 100ps

Caveat: 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)

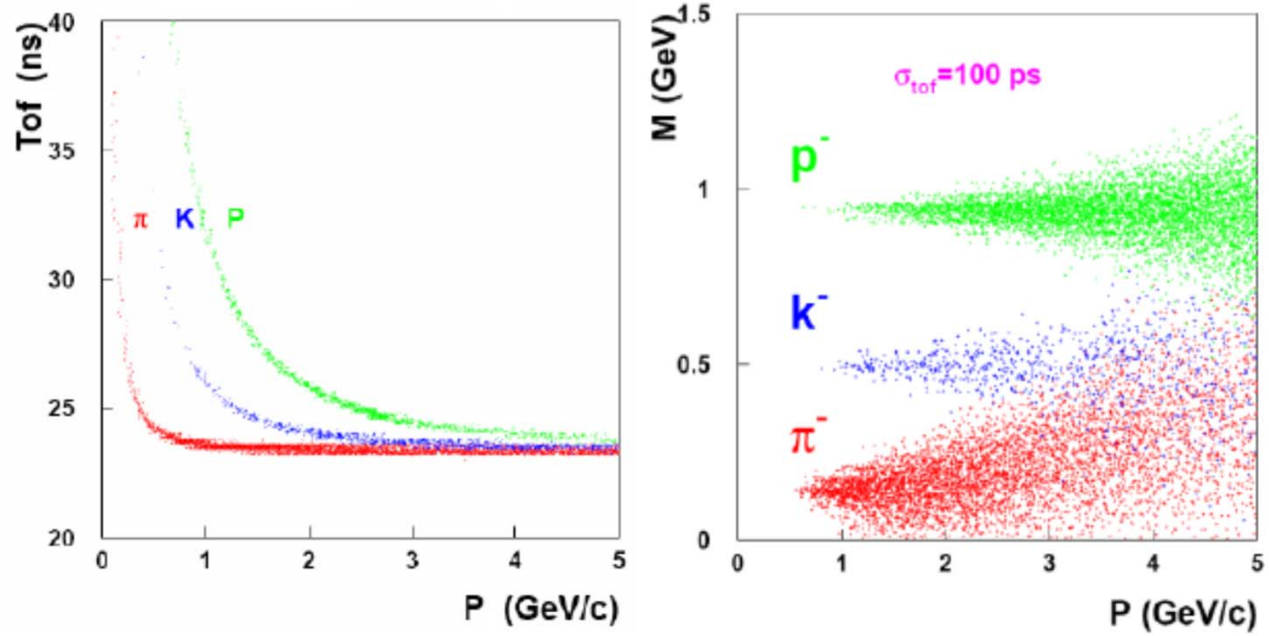
Selected aspects of Monte Carlo Studies

Time-of-flight PID with tracking and momentum analysis

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

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

$t_c = L_{track}/c$ $L_{track} \simeq 7.5\,\mathrm{m}$ (TOF wall position) $\sigma(TOF) = 50 - 100\,\mathrm{ps}$

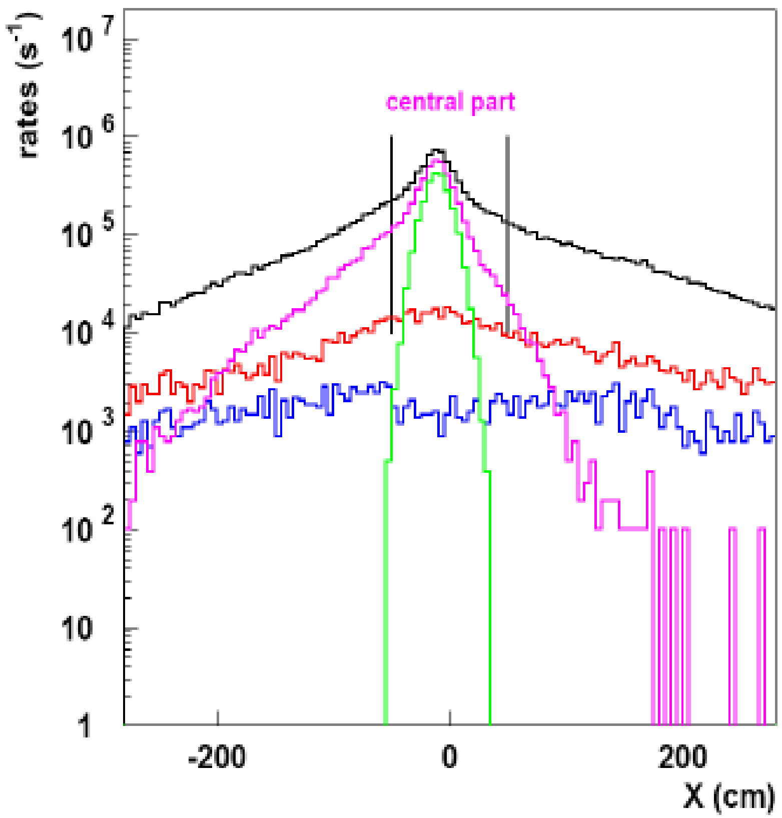


Comment: a good event start of 50ps provides if:
independent start counter available (no momentum info needed)
or RICH info or kinematical criteria

FTOF wall slab count rates

$\bar{p}$ 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

@ HESR cycle averaged
Luminosity 10^{32} cm^{2}s^{-1}



@ 15 GeV/c pbar beam
normalized to 10^7/s interactions

all charged particles

total pbar rate

pbar from elastic scattering

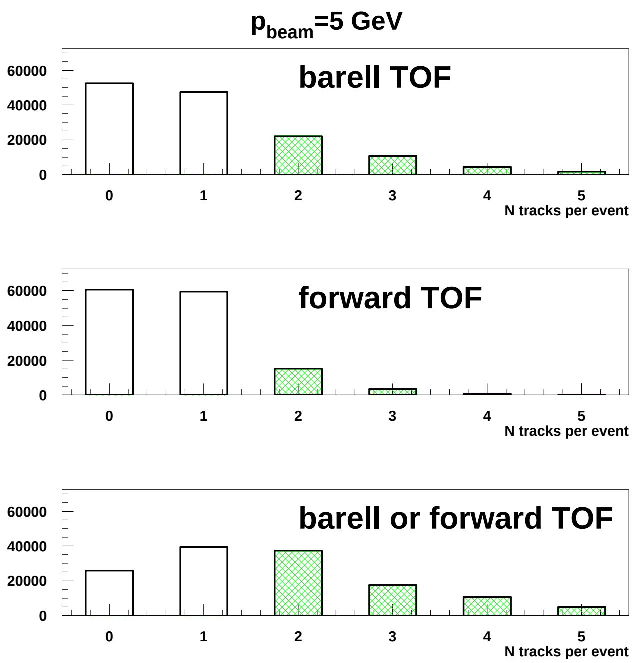
charged particles produced in vacuum pipe

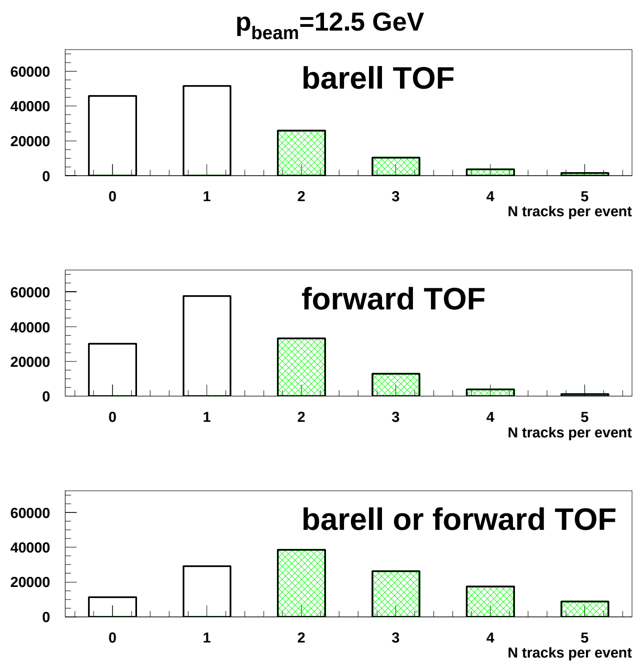
e^+e^- pairs produced by gammas from pi^0 decay in the target

FTOF wall and barrel TOF multiplicities

0.14×10^6 $\bar{p}p$ interactions generated

No dedicated start counter !

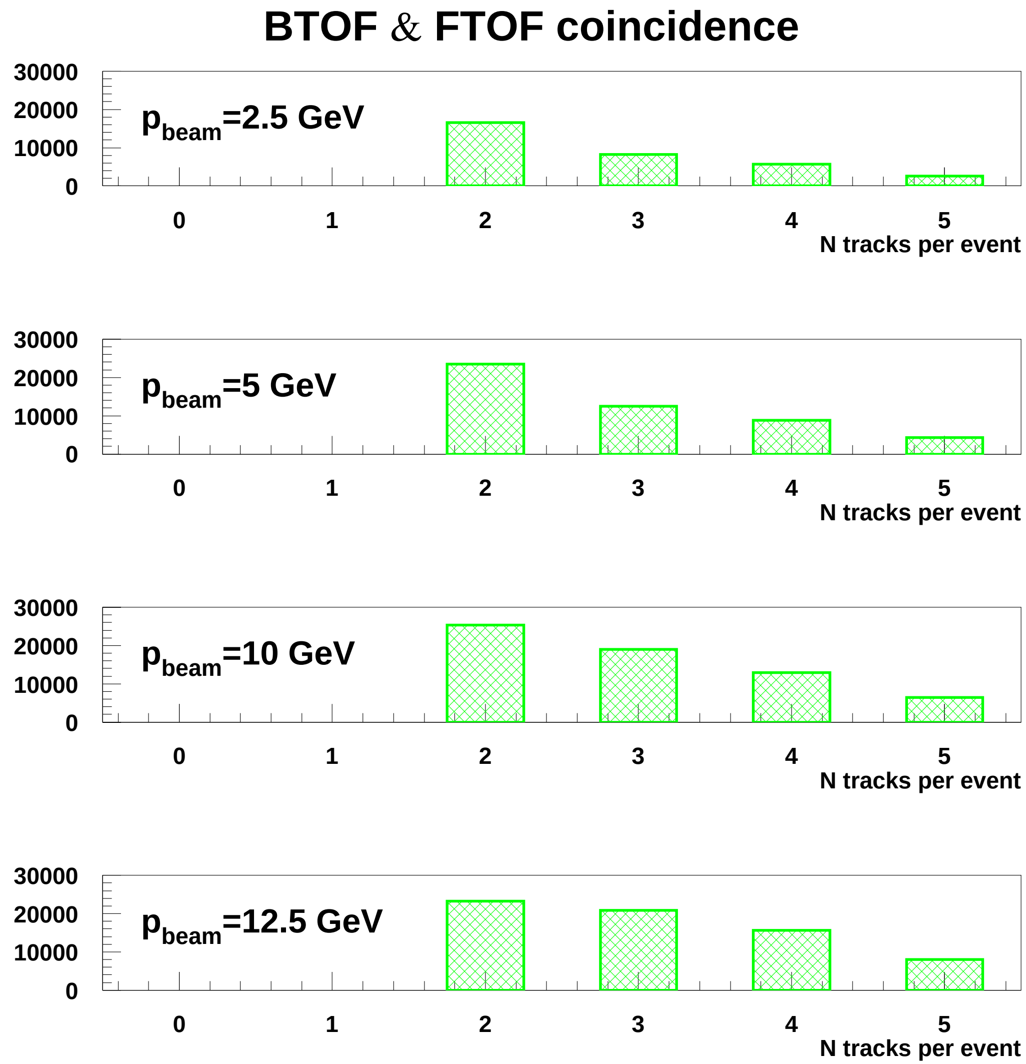




FTOF wall and barrel TOF interplay

FTOF/BTOF coincidence probabilities

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



MC Simulation of $\bar{\Lambda}$, Λ event selection

Under study are $\bar{p} + p \rightarrow \bar{\Lambda} + X, \; \bar{\Lambda} \rightarrow \bar{p} + \pi^{+}$

and $\bar{p} + p \rightarrow \Lambda + X, \; \Lambda \rightarrow p + \pi^{-}$

- DPM generator, PANDA root framework

0.72×10^{6} $\bar{p}p$ interactions @10 GeV

- Generated are

$$\pi^{-}, \pi^{+}, K^{-}, K^{+}, \bar{p}, p, \bar{\Lambda}, \Lambda$$

- Produced particles are tracked through the solenoid and dipole magnetic fields and detected with FTOF wall scintillation counters

with

Particle momentum smearing of

$$\frac{\sigma p}{p} = 0.01$$

Time-of-flight smearing of

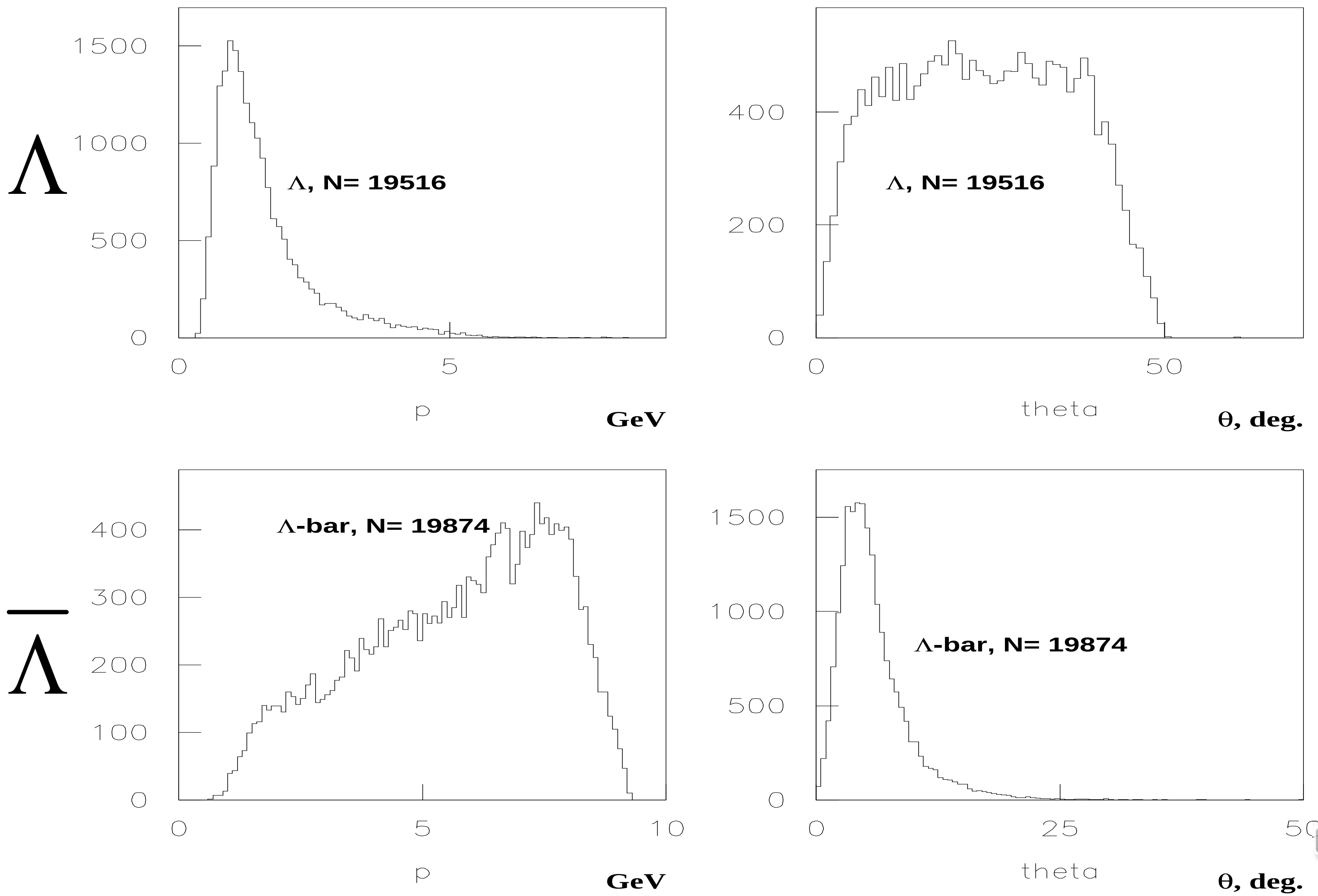
$$\sigma TOF = 50\, ps$$

Track length smearing of

$$\sigma L = 1 cm$$

Production/decay vertex separation

Generated Lambda hyperons



Detection Efficiency of FTOF wall

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

	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	$\approx 5 \cdot 10^{-3}$

Lambda Hyperon Event Selection

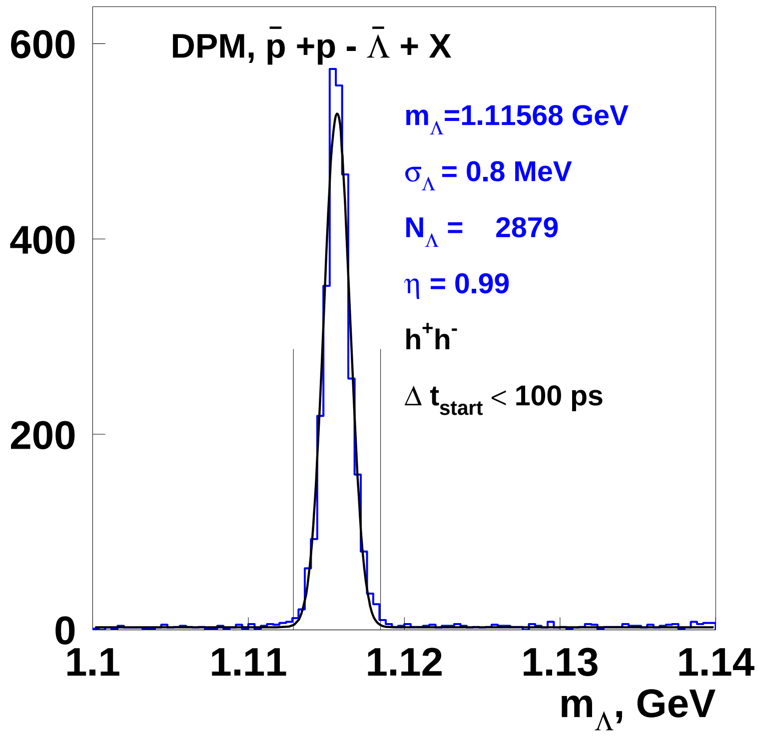
$\bar{p} + p \to \bar{\Lambda} + X$

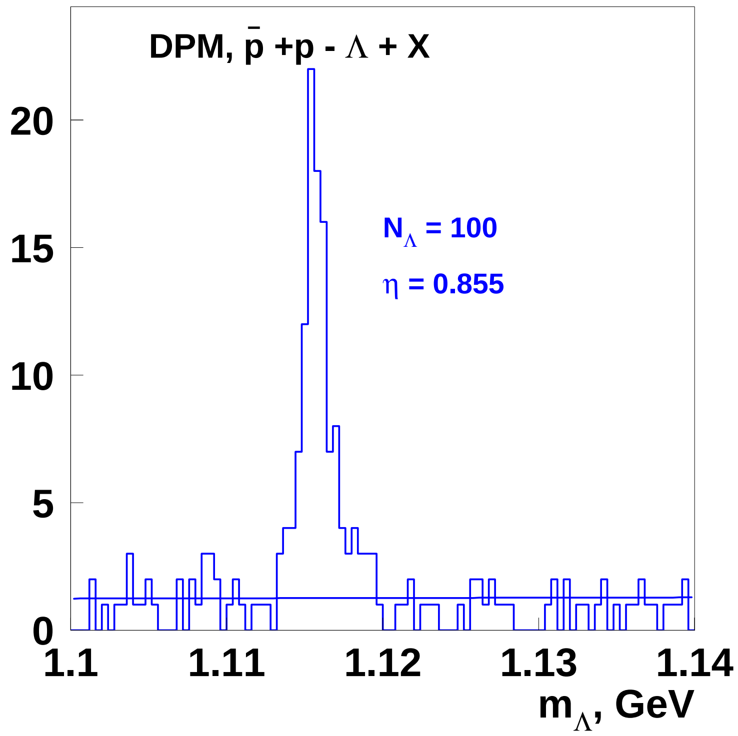
$\bar{p} + p \to \Lambda + X$

Event selection criteria

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

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





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

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

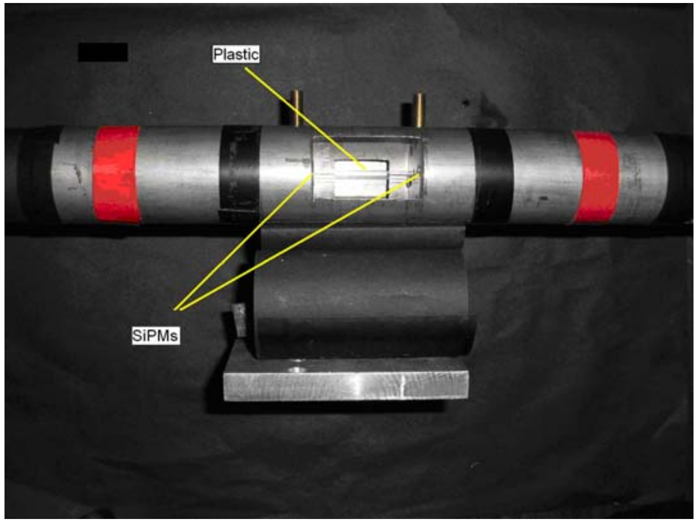
Experimental Study

of Timing Resolution

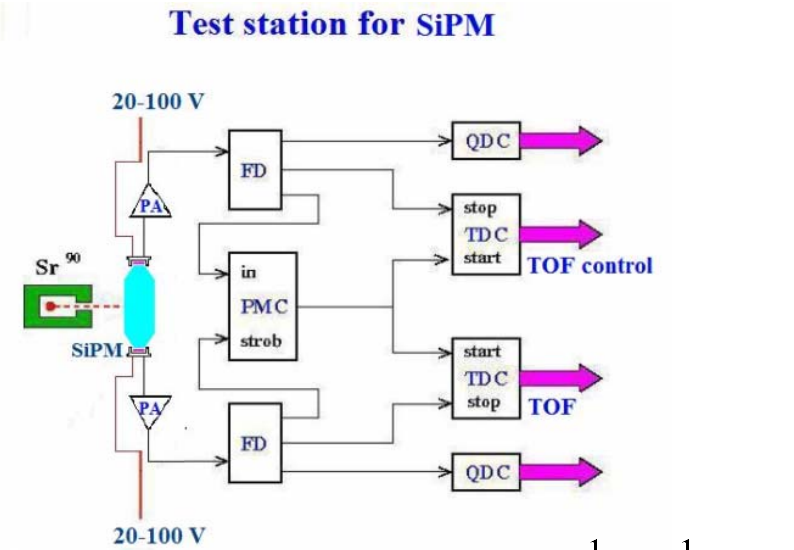
and

Prototyping

SiPM timing resolution

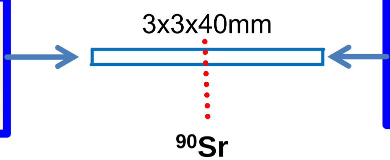


Variant A



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

S10931-50p 3x3mm



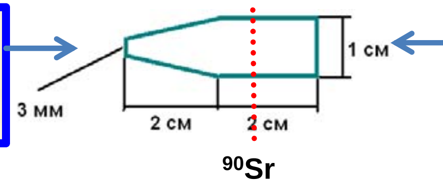
S10931-50p 3x3mm

Variant B

Results variant B

Run	σ_0	σ_1	σ_2
40366	326	168	149
40367	497	170	142
40368	486	176	147

S10931-50p 3x3mm



R4998 1”

Results variant A

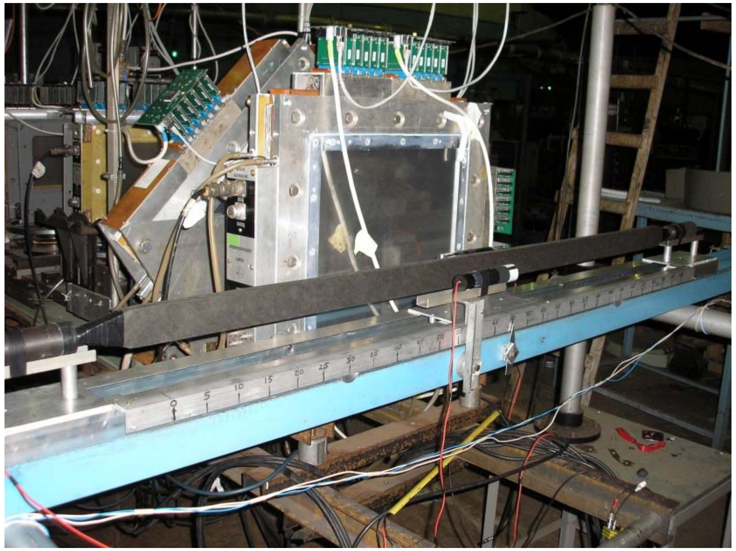
Run	σ_0	σ_1	σ_2
40366	608	195	157
40367	543	199	151
40368	557	193	150

SiPM timing resolution is about 150ps

PMT timing resolution using proton beams

PNPI 1 GeV synchrocyclotron

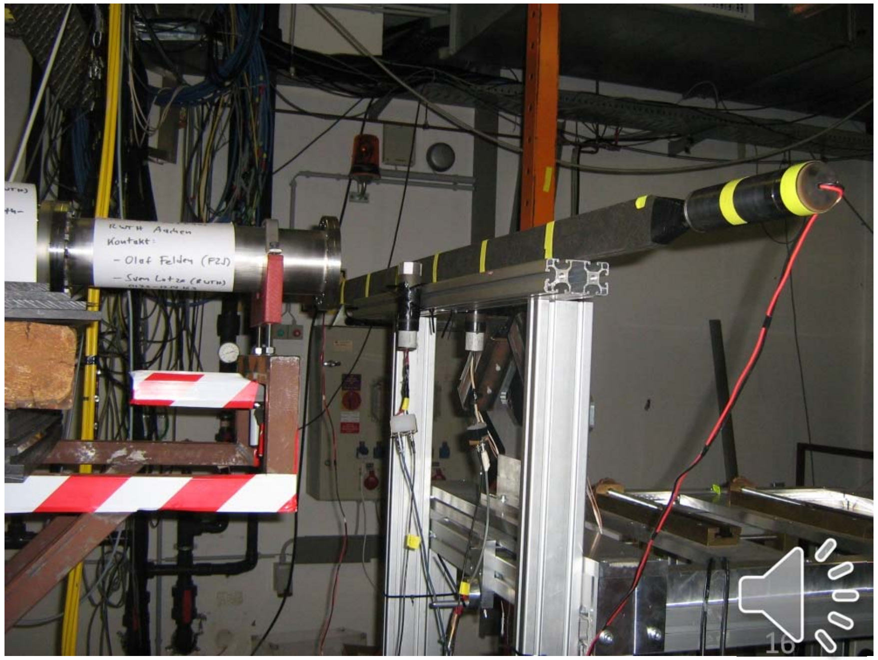
April 2009.
Optimization of slab thickness to 2.5 cm
Nov. 2012
Time resolution better 100ps
June 2013
Time resolution better 80 ps
Dec. 2013
Final results on prototyping



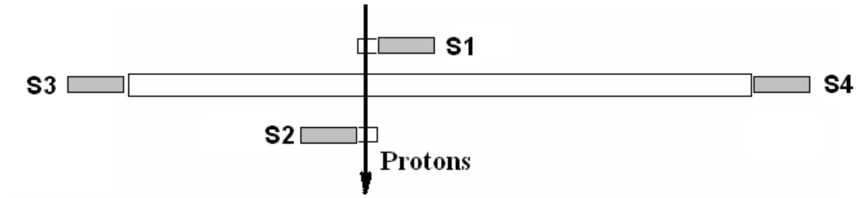
PMTs: R4998, R2083, Electron 187

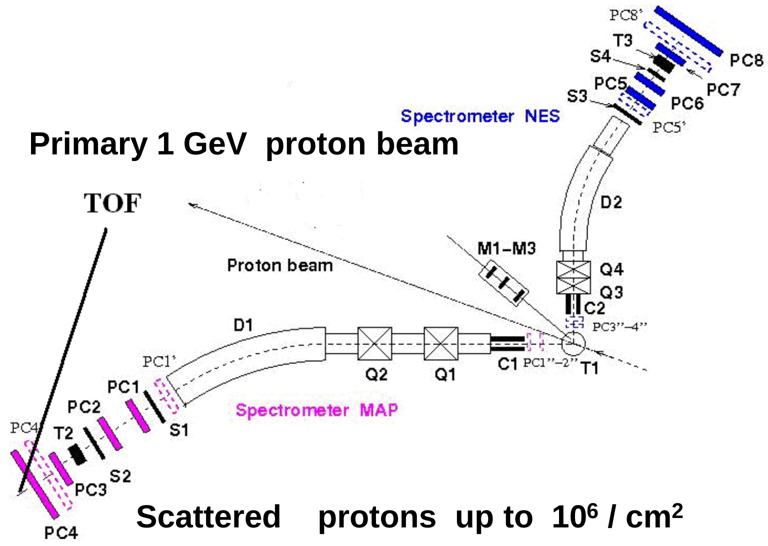
COSY test beam in Juelich

Dec. 2012 test with TRB readout.
First "Electron" PMT187 test



Timing resolution measurements at 1 GeV PNPI SC





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,

$\sigma(x) \simeq 0.5$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).

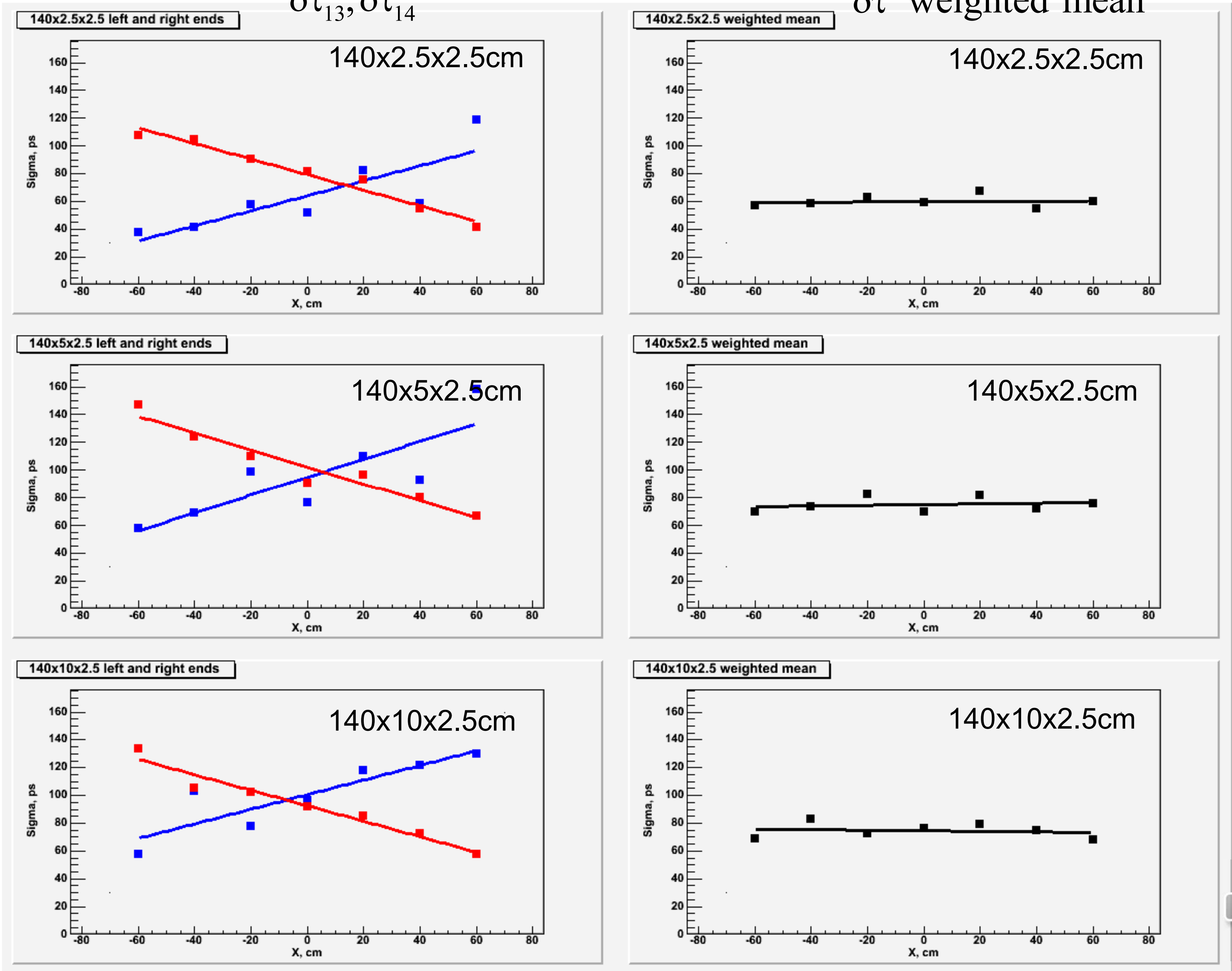
Proton energy E_p=730 and 900MeV, $\sigma(E_p)$ about 0.5%

B408 thickness 2.5cm
Energy deposition 5MeV

Scintillation Efficiency
10^4 photons/MeV

Timing resolution with R4998 and R2083

$\delta\tau_{13}, \delta\tau_{14}$ $\delta\tau$ weighted mean

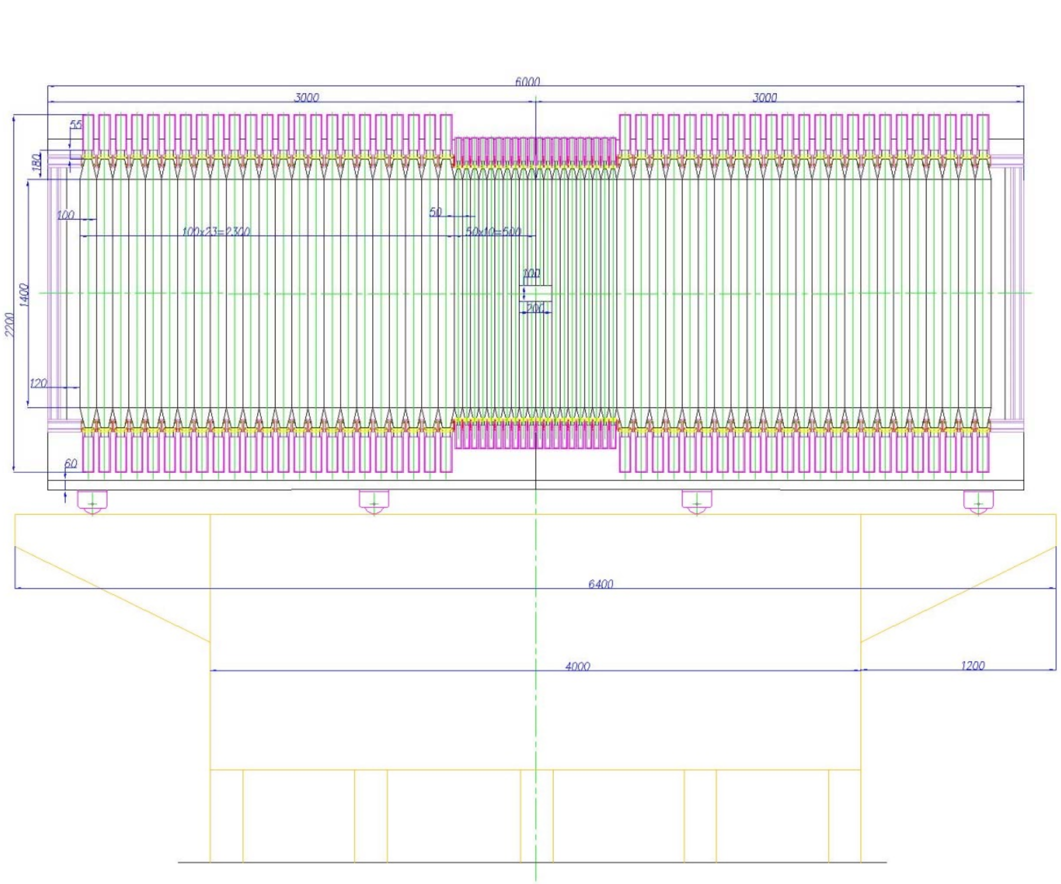


Summary of tests using proton beam

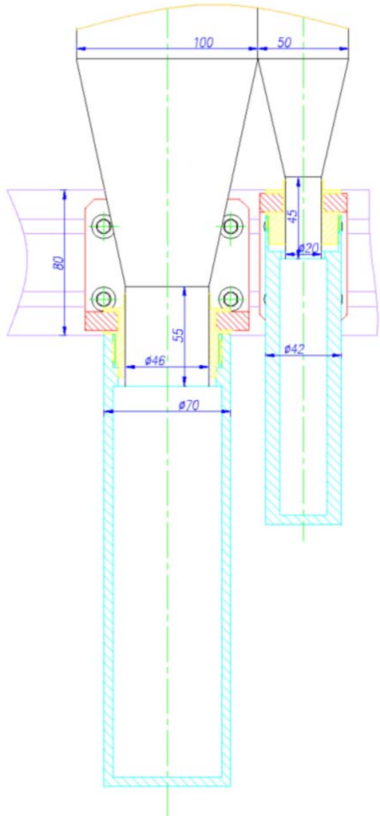
Scintillation slab dimensions	**Photo multiplier tube**	**Comments**
140 cm × 10 cm × 2.5 cm	Hamamatsu R 2083	**75ps** **Accepted as a prototype for the FTOF wall**
140 cm × 5 cm × 2.5 cm	Hamamatsu R 4998	**70ps** **Accepted as a prototype for the FTOF wall**
140 cm × 2.5 cm × 2.5 cm	Hamamatsu R 4998	60ps Variant of a prototype with smaller slab width
140 cm × 10 cm × 1.5 cm	Hamamatsu R2083	150ps Projected originally for the FTOF wall
140 cm × 5 cm × 1.5 cm	Hamamatsu R4998	120ps Projected originally for the FTOF wall
140 cm × 2.5 cm × 2.5 cm	Electron PMT 187	**80ps** **Magnetic field protected, tentatively projected for the dipole TOF**
100 cm × 10 cm × 2.5 cm	Electron PMT 187	150ps Magnetic field protected, tentatively projected for the dipole TOF

Time resolution R4998 and Electron187 with small scintillator (2x2x2cm) is 50 and 70ps, respectively.

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	60 k€
PMTs R9800 1" 600€ 40u. +5u.(spare)	27
PMTs, R9779 2" 900€ 92u.+10u.(spare)	92
Caveat: PMT R9800, , R9779 not on beam tested	
FEE electronics	30
HV power supply	22
Gain monitoring system	9
Supporting structure (design, fabrication)	40
Test stand for mass production	35
Transportation, custom expenses	25
…………………………………………………………………	
	340 k€

Dipole TOF

Plastic scintillators B408 20u.	15
PMTs Electr.187 1.5" 1400€ 40u. +5u.(spare)	63
Caveat: PMT 187, to be tested at 2T magnetic field	
FEE electronics	5
HV power supply	9
Gain monitoring system	5
Supporting structure (design, fabrication)	35 ??
…………………………………………………………………	
	132 k€

Infrastructure

- PNPI test beam
- PNPI design department (mechanical components drawings)
- PNPY electronic department (expertise, HV)
- PNPI Workshop (fabrication of mechanical components)
- Test station/preassembly in Juelich

From RRB February 2014 471 k€

PNPI group in PANDA

S.Belostotski	Stanislav	Prof.	Group leader
Gavrilov	Gennadij	Scient.	hardware
Izotov	Anton	Scient	R&D ,hardware, data analysis
Manaenkov	Sergej	Scient	theory, analysis
Miklukho	Oleg	Sen. Scient	R&D instrumentation
Naryshkin	Yuri	Scient	MC, data analysis
Suvorov	Kirill	PhD stud	MC, hardware
Veretennikov	Denis	PhD stud	MC, hardware, data analysis
Zhdanov	Andrey	Scient	R&D, hardware

Work Package 2014

Monte Carlo simulation
In PANDAROOT Framework

- *Study various PID options using TOF/DTOF/BTOF/ChTOF detectors;*
- *Optimize configuration of FTOF and DTOF in the dipole using benchmark reactions;*
- *Update rate calculations of Individual FTOF/DTOF slabs at max luminosity;*

TDR approval September

Design and prototyping

- Finalize prototyping FTOF counters with TRB;
- Complete study of PM-187 in strong magnetic field for DTOF prototyping, investigate SiPM variant
- Work out project of GMS
- Work out project of supporting mechanical structures and cabling

Supporting slides

Global plan for FTOF / DTOF design, fabrication and installation 2014-2018

1. TDR approval, funding, tender, agreement, manufacturing concept. from 01.01.2014 to 31.05.2015 17 months

2. Material procurement, manufacturing and final prototype tests, manufacturing all components, detector pre-assembly. from 01.06.2015 to 31.03.2017 22 months

3. Shipment to FAIR: good inspection , test inspection, approval for installation, shipment from 01.04.2017 to 31.12.2017 9 months

4. Installation at HESR from 01.01.2018 to 30.09.2018 9 months

5. Commisioning from 01.10.2018 to 31.12.2018 3 months

M3 9/2014	M8 04/2016	M10 06/2017	M11 10/2018
Approval of TDR	Prototype tested pre-series accepted	Approval for installation	Ready for bean

SiPM Radiation Hardness Test @ 1GeV PNPI Proton Beam.

- The absolute beam intensity was determined in a standard way by measuring induced radioactivity of irradiated aluminum foils.
- The beam intensity during the tests was varied in the range 1.3 - 2.1x10^8 cm^{-2}s^{-1} .
- The SiPM sample was not powered!
- Radiation was exposed in 10 successive periods about 10 minutes each. The integrated number of protons passing through the sensitive surface of the SiPM sample with the cross-section of 3x3 mm^2 was 0.9*10^{11}SiPM parameters (dark noise, amplitude and time characteristics for different values of high voltage) were measured before and after the radiation test using test station with ^{90}Sr electron source.

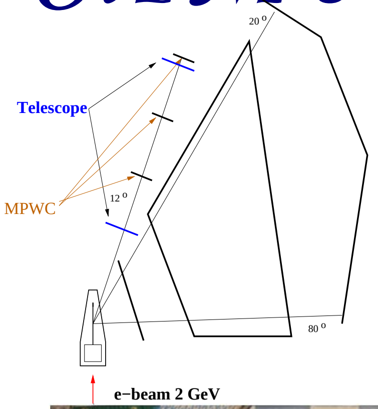
U,V	I, µA	A, mV	Noise	Noise+^{90}Sr
72.06	0.15	40	1550	8700
72.53	0.30	80	4230	18500
72.06	81.0	4	2800	6200
72.53	113.0	6	99000	102000

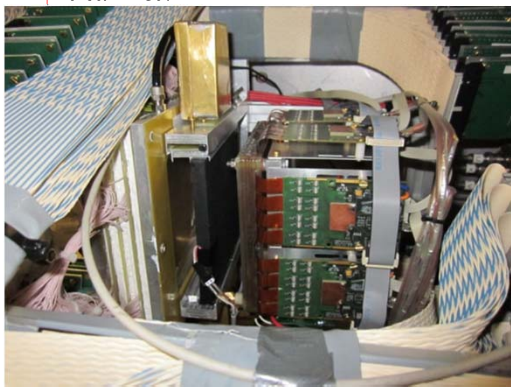
As it is seen from the table the SiPM was practically killed by this dose the value of which can be taken as upper limit,

- Yet it is important to find out at which dose the sample start malfunctioning,
- It is also important to compare irradiation effect on unpowered and powered samples,
- All this will constitute our experimental program with SiPM samples.

$\Delta T = 0.056\ C^o$ *this is not heat!*

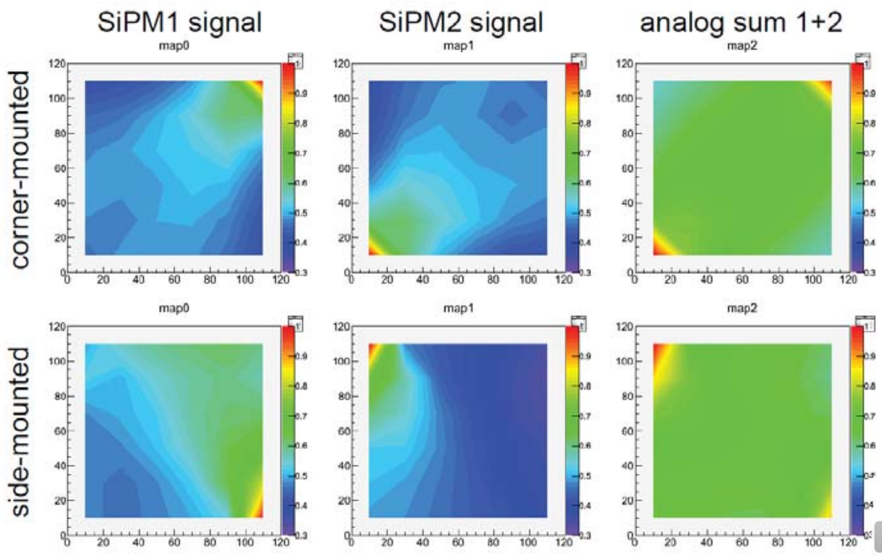
SiPM's @ OLYMPUS. DESY TB22.





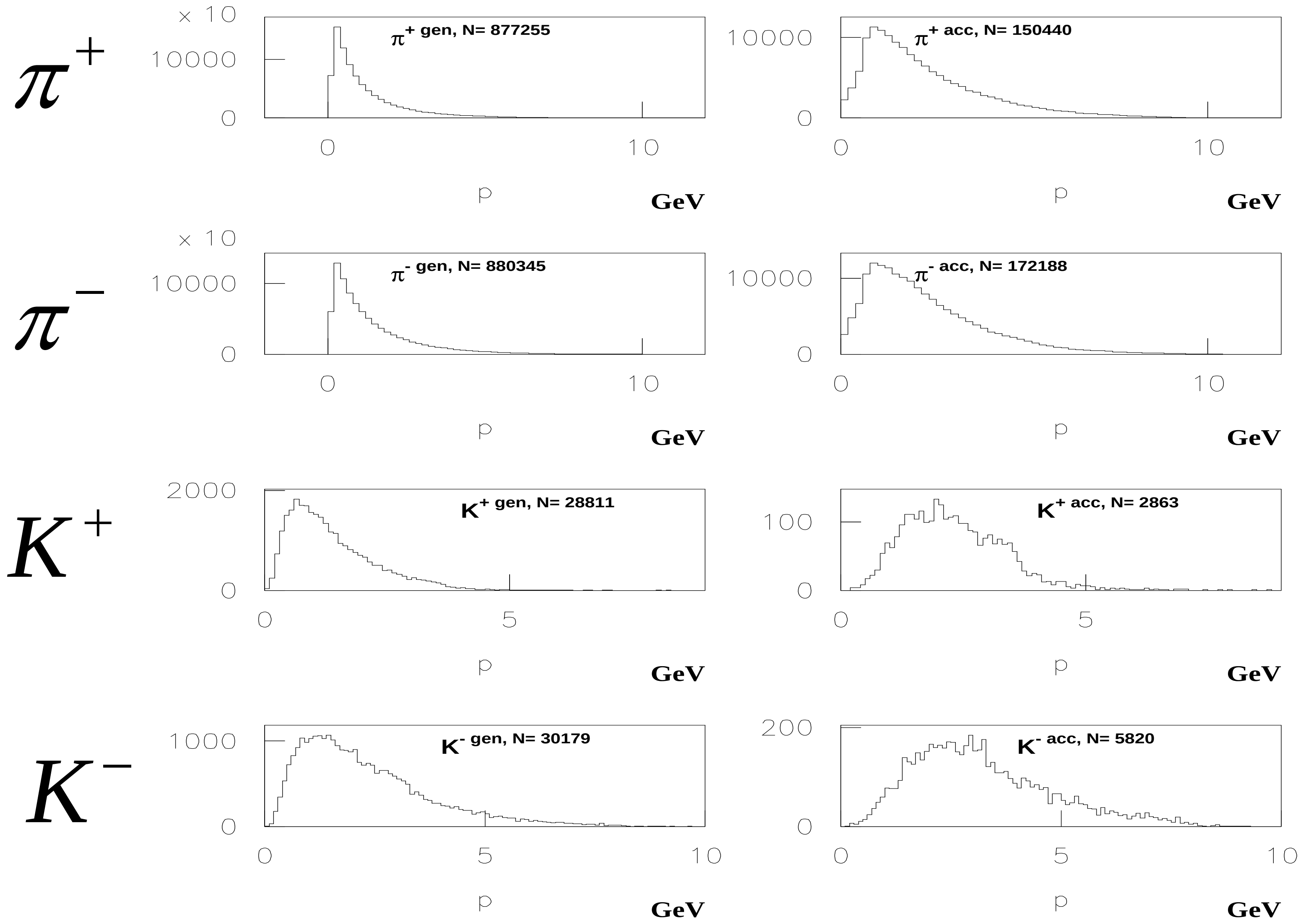
Counters:8mm/2SiPM's, 4mm/2SiPM's (corners), 4mm/2SiPM's (sides),
Readout: 25x preamp (electronics workshop, KPH Mainz)

- QDC spectra to see light yield,
- QDC spectra with prescaled baseline triger mixed into determine gain for each spectrum,
- Triple coincidence from beam trigger finger conciliators (2 with PMT's, 1 with SiPM)
- Quadruple coincidence (3 PMT's, 1 SiPM and single SiPM
  - efficiency scan,
  - maximum efficiency reachable with single SiPM

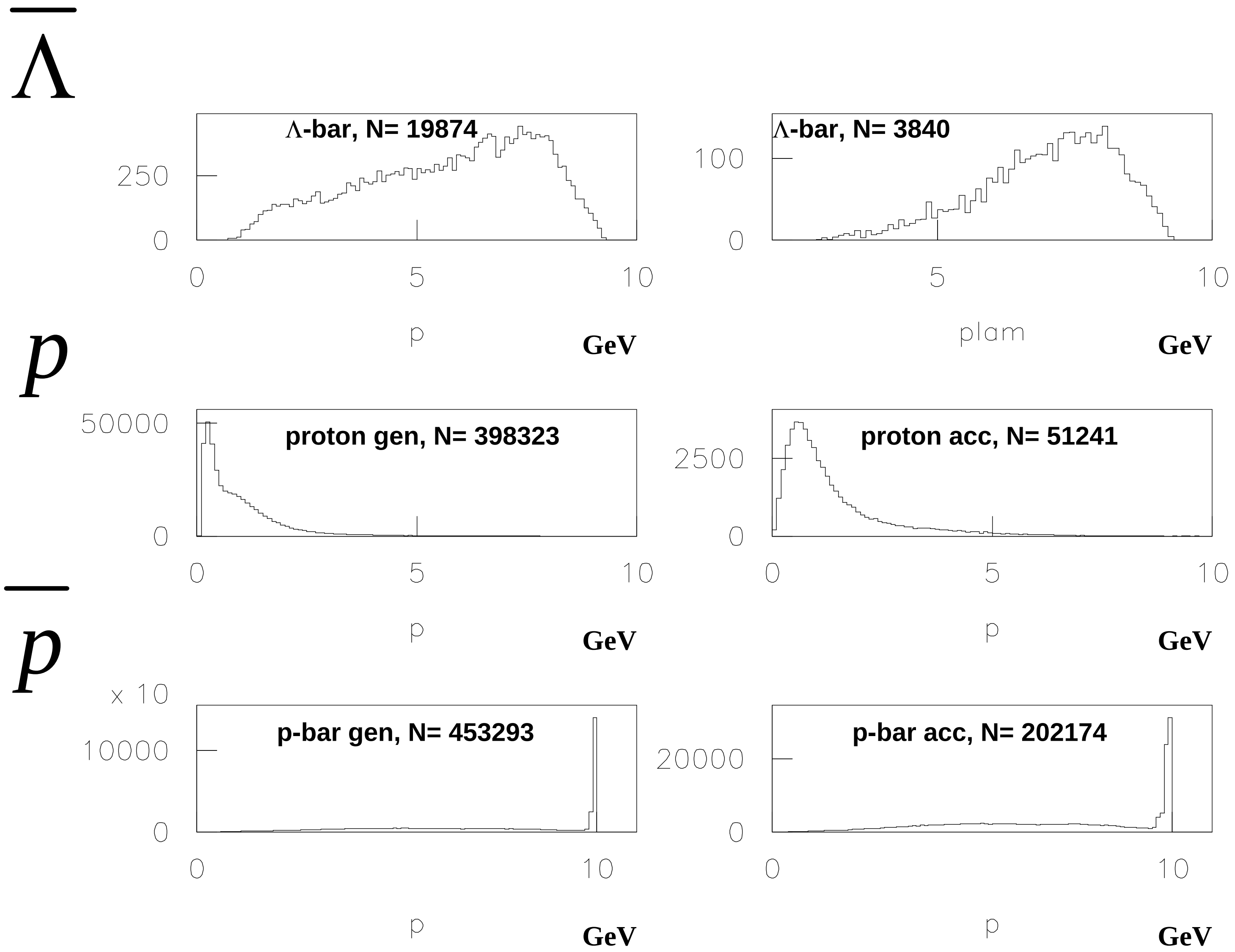


- Both side-mounting and corner-mounting, counters have similar yields,
- Blind spots exist in both configurations,
- Side-mounting is easier,
- Trigger scan shows, that even one SiPM is enough with proper threshold

Generated/detected with FTOF wall

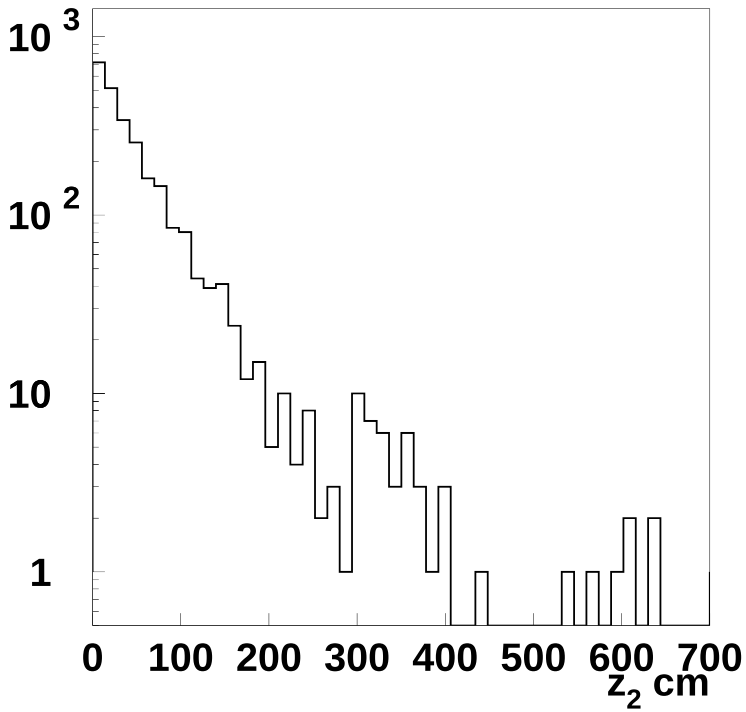


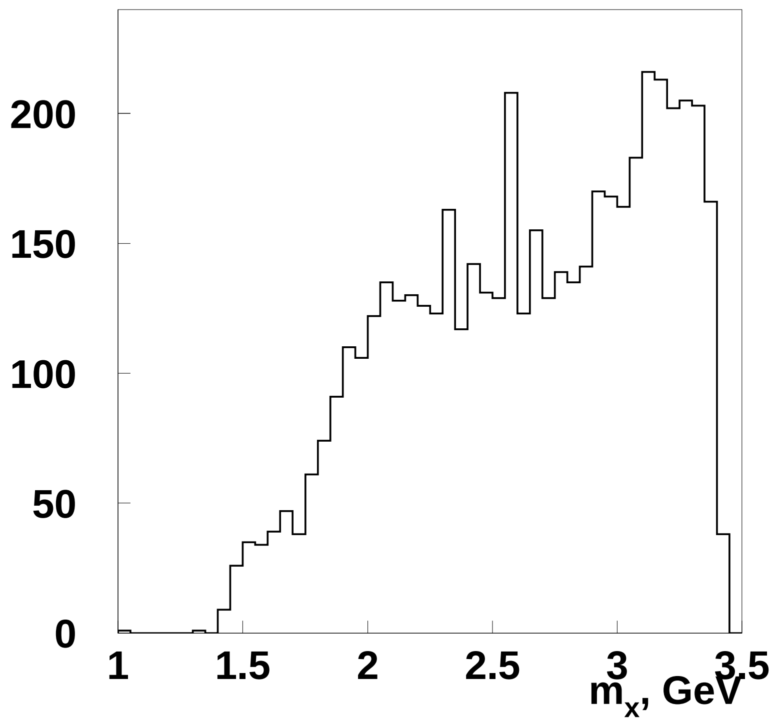
Generated/detected with FTOF wall



Decay length and m_X for Lambda-bar

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



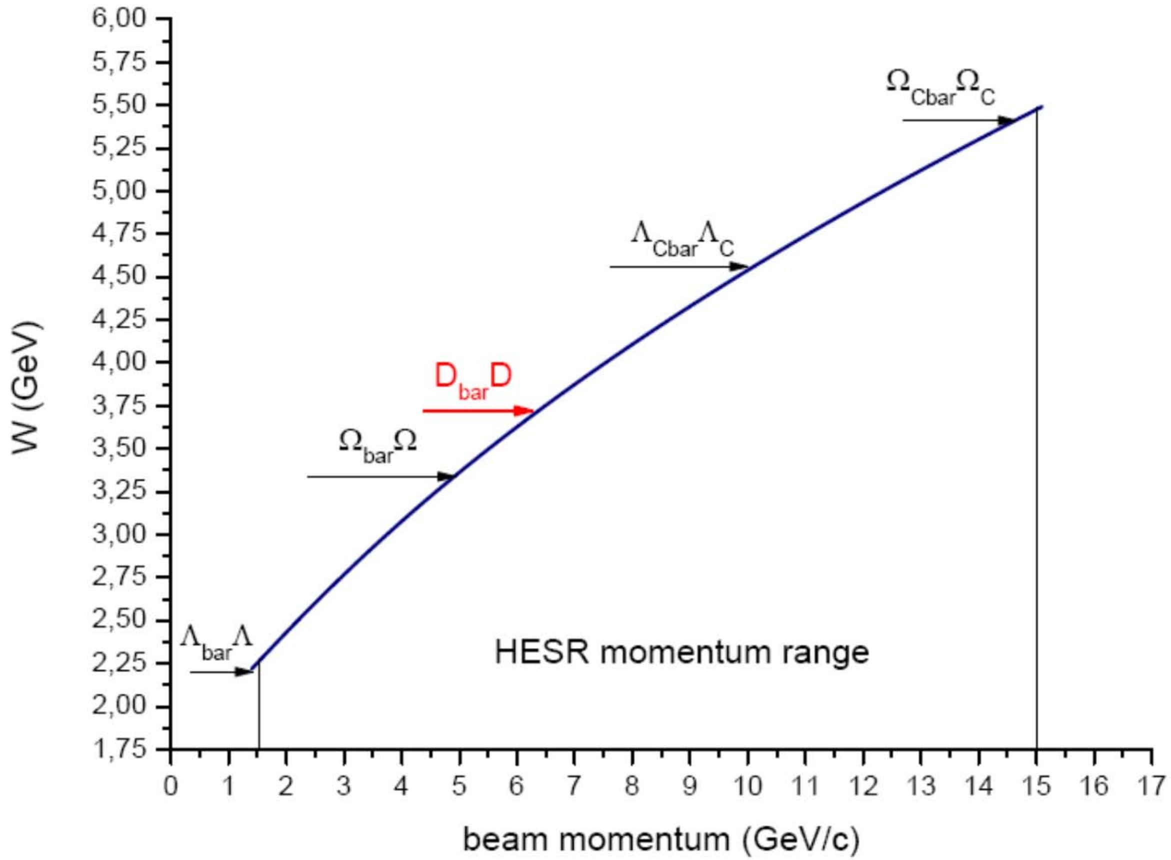


Binary reactions

$$\bar{p} + p \rightarrow \bar{h} + h$$

$$h = \text{hyperons} : \Lambda, \Sigma, \ldots \Omega_C$$

$$h = \text{mesons} : \ldots D \ldots$$



Selection of inclusive Λ and anti Λ

$$\bar{p} + p \to \bar{\Lambda} + X \qquad \bar{p} + p \to \Lambda + X$$

$$\bar{\Lambda} \to \bar{p} + \pi^{+} \qquad \Lambda \to p + \pi^{-}$$

Selection criteria

- pair of hadrons detected with the FTOF wall
- hadrons in a pair are of opposite charge: $H^{+}H^{-}$
- invariant mass calculated under assumption

$$m(H^{-}) = m_p \quad m(H^{+}) = m_\pi \quad for \quad \bar{\Lambda} \qquad m(H^{-}) = m_\pi \quad m(H^{+}) = m_p \quad for \quad \Lambda$$

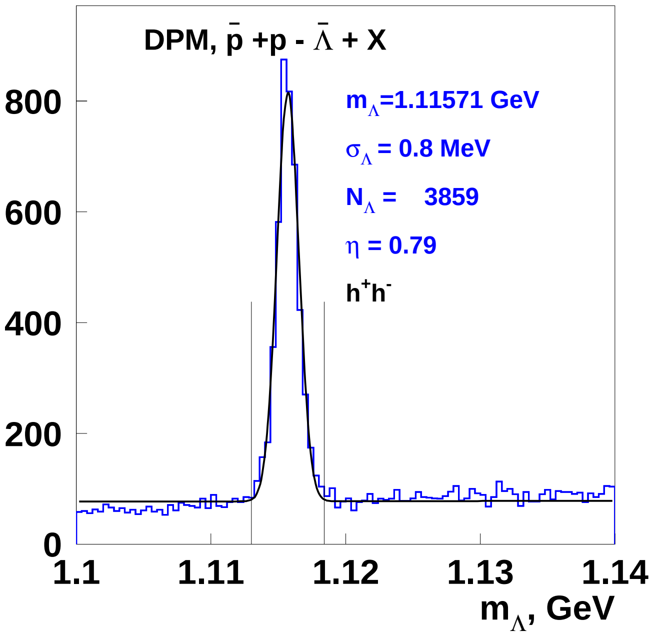
- time-of-flight from decay vertex to FTOF calculated

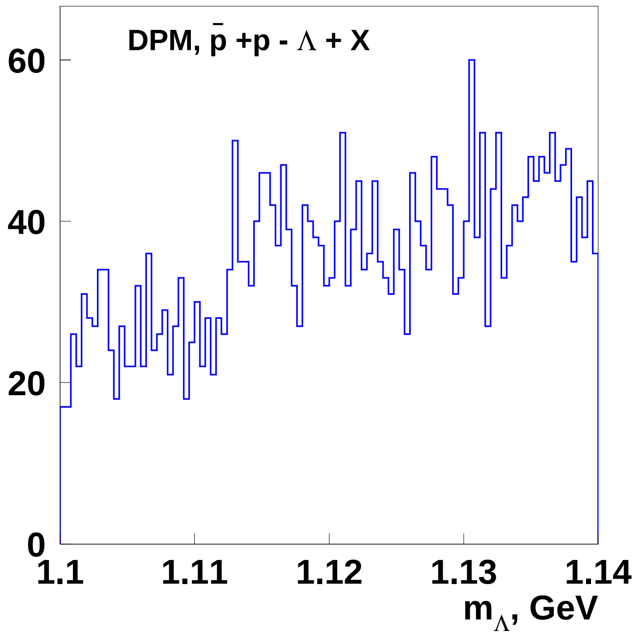
$$t = t_c\sqrt{\frac{m^2}{p^2}+1} \quad t_c = \frac{L}{c} \qquad \left|t(H^{+}) - t(H^{-})\right| < 100\,ps$$

- Kinematic criterion

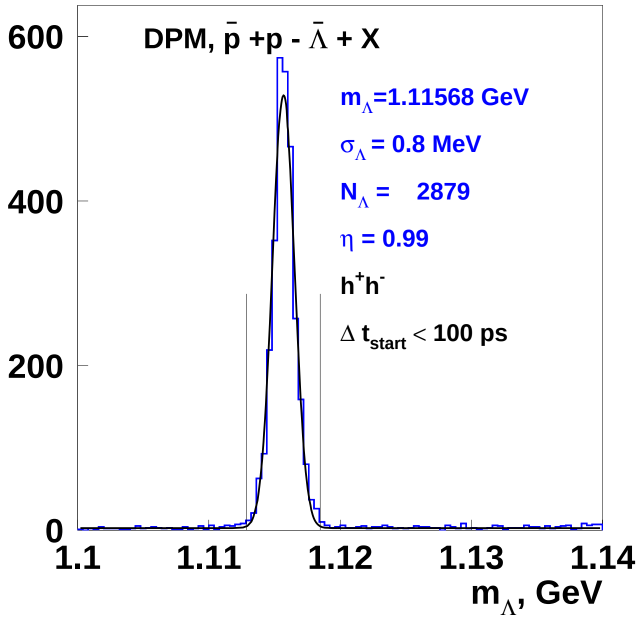
$$p(H^{-}) > p(H^{+}) \quad for \quad \bar{\Lambda} \qquad p(H^{-}) < p(H^{+}) \quad for \quad \Lambda$$

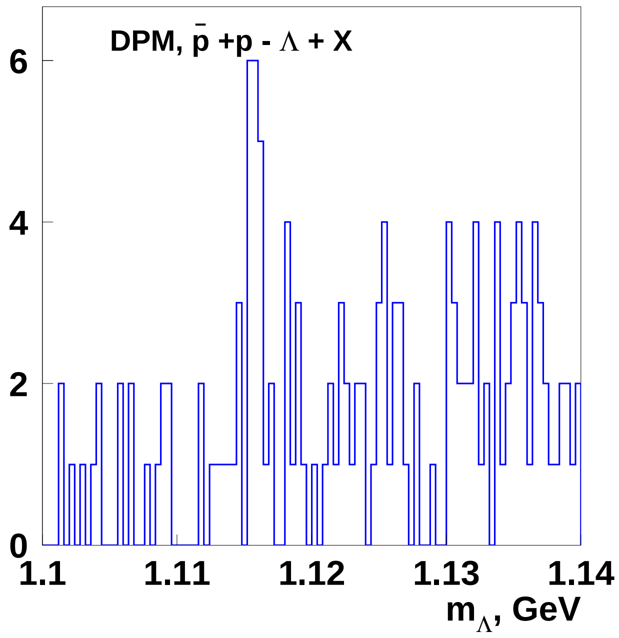
Λ and anti Λ invariant masses, hadrons of opposite charge



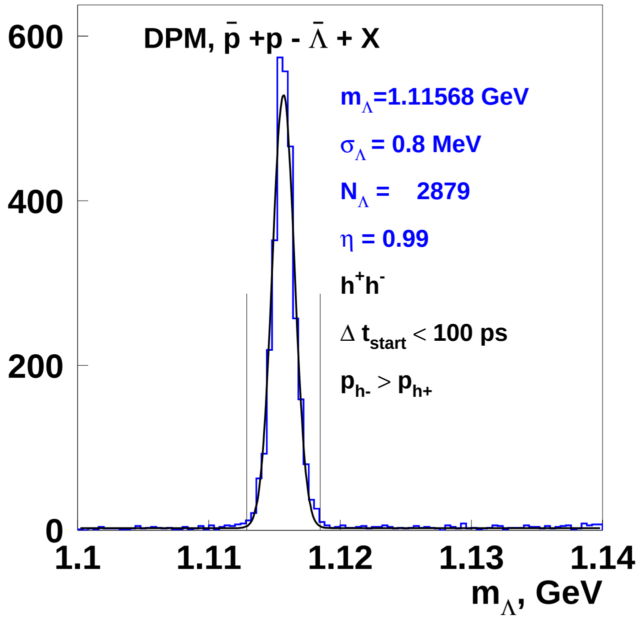


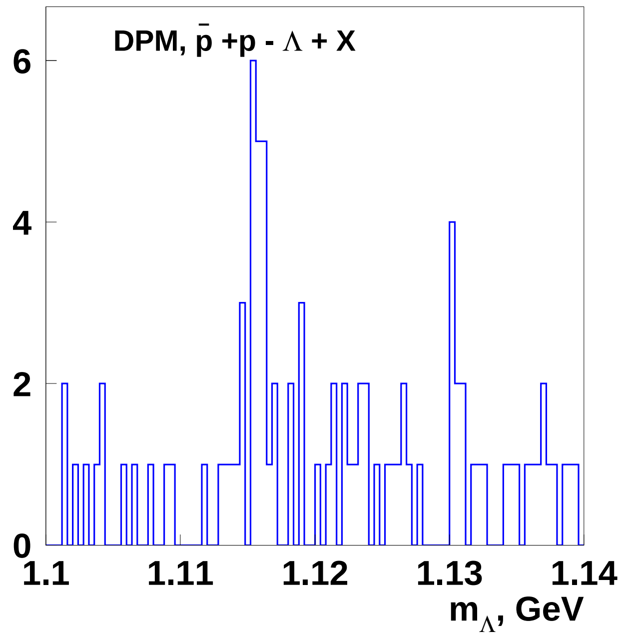
Λ and anti Λ invariant masses, hadrons of opposite charge, time-of-flight criterion





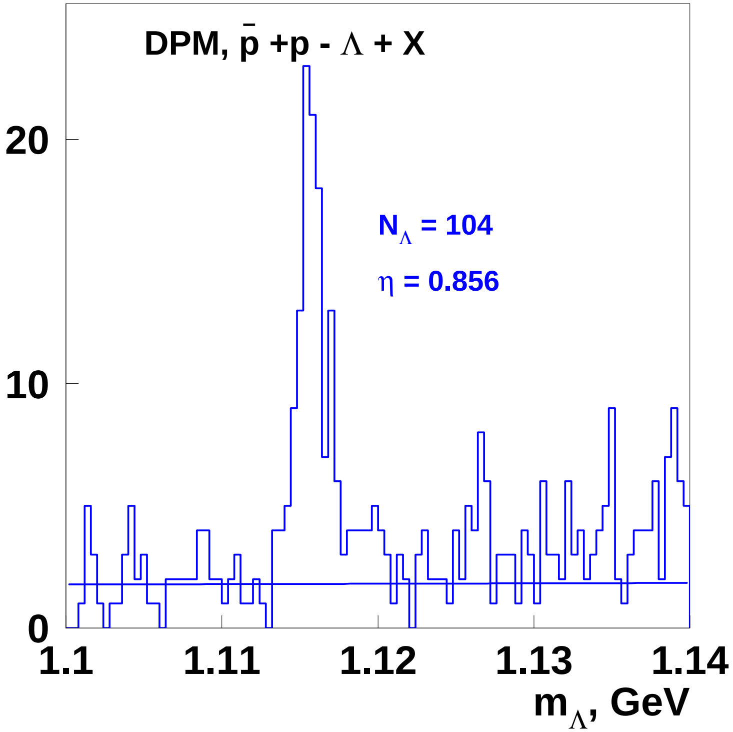
Λ and anti Λ invariant masses, hadrons of opposite charge, time-of-flight criterion, kinematic criterion



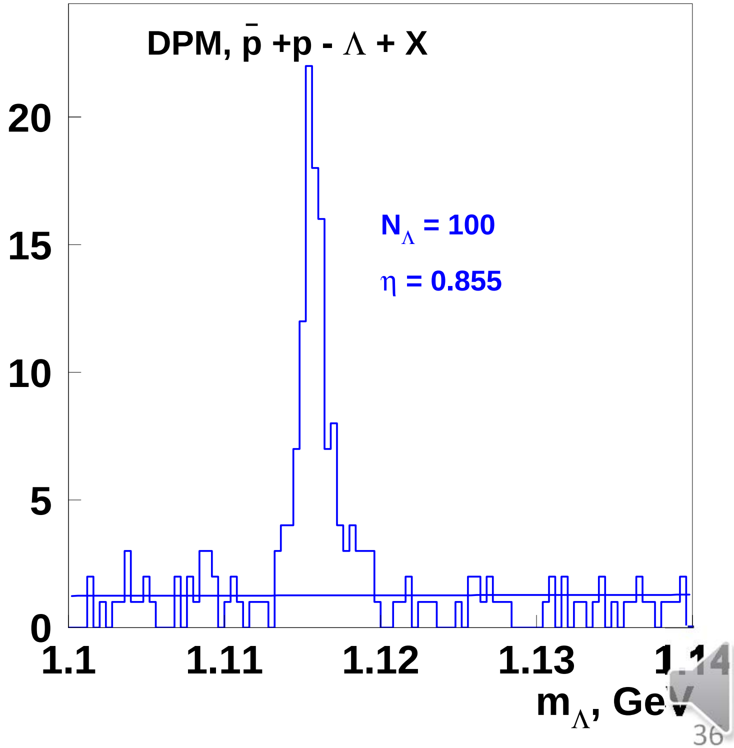


$$\bar{p} + p \rightarrow \Lambda + X$$

Pairs of hadrons with opposite charge and calculated Δt start <100 ps



Pairs of hadrons with opposite charge and calculated Δt $_{start}$ <100 ps and z_2>0.066 cm



FTOF wall and barrel TOF multiplicities

$$0.14\times10^{6}\ \bar{p}p\ \text{interactions generated}$$