Feasibility studies for the Forward Spectrometer

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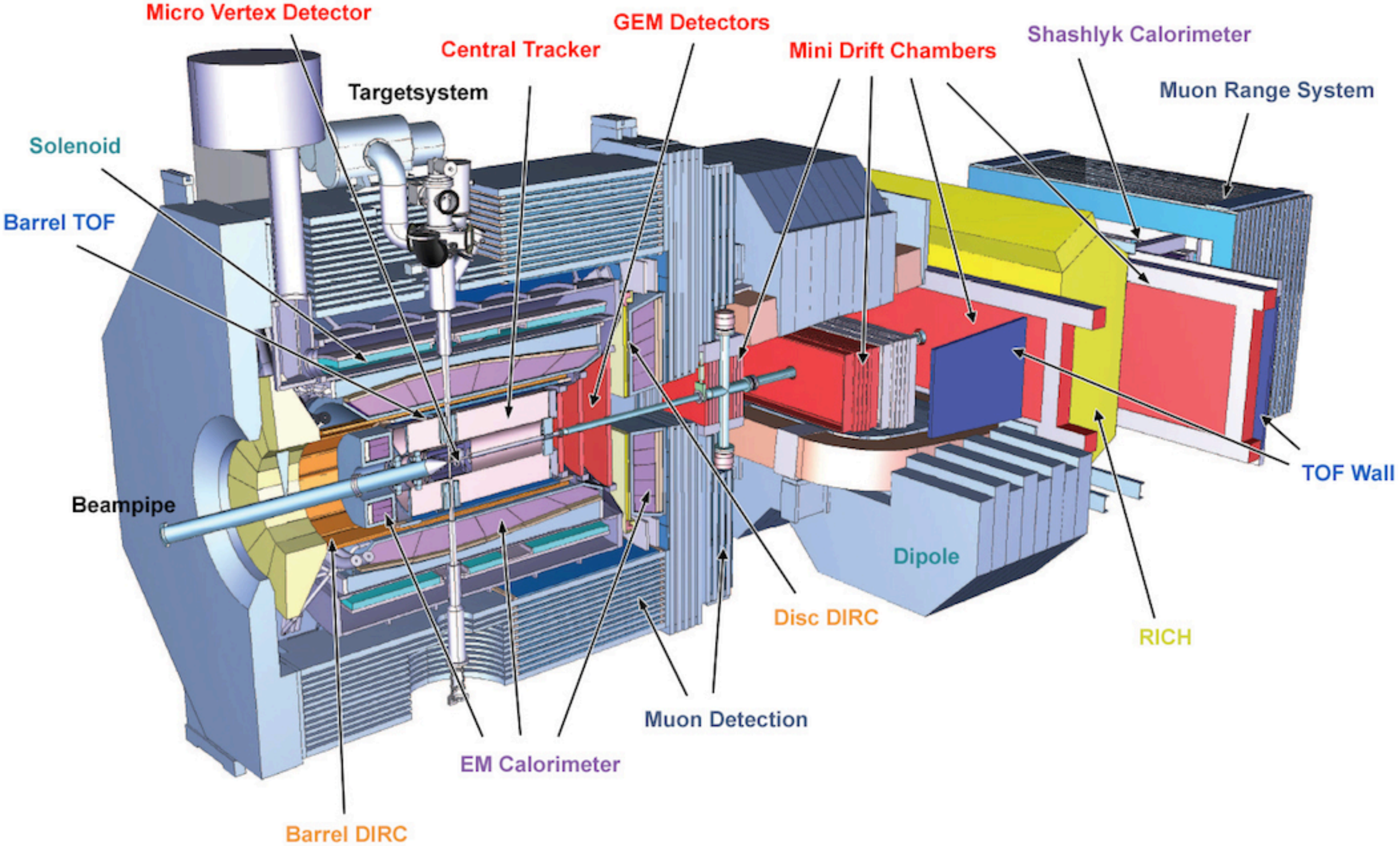
FAIRNESS 2014

The Menu:

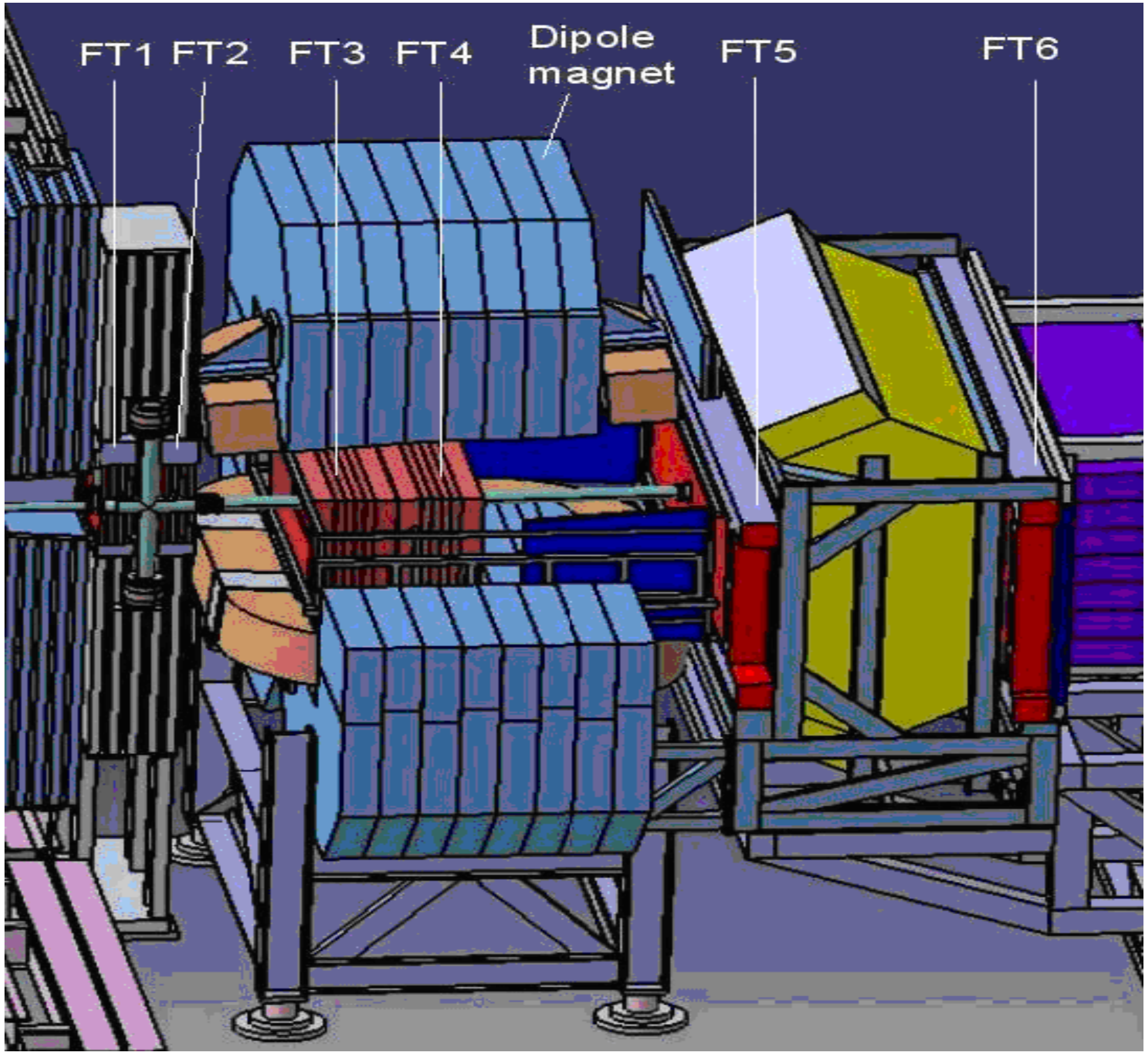
- The PANDA detector
- The Forward Tracking System of PANDA
- Results from simulations:
- Background study
- Physics channel reconstruction
- Results from ongoing test of the STT prototype at Forschungzentrum Juelich

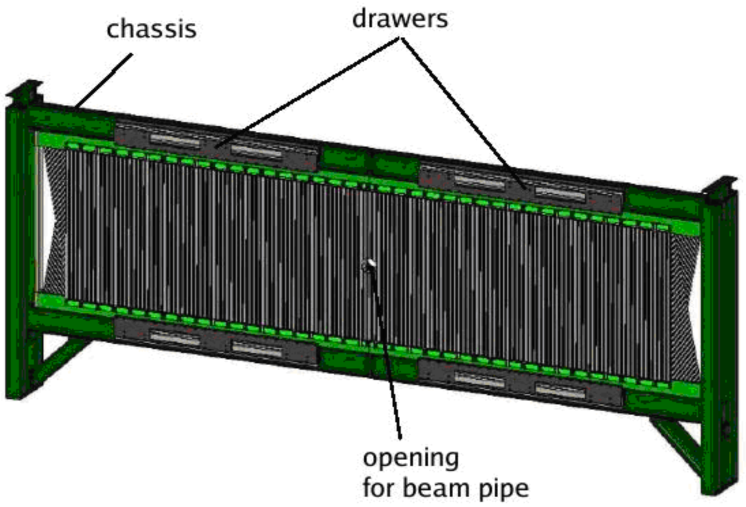
The PANDA detector



The Forward Tracker

- Momentum analysis of charged particles
- Angular acceptance ±10° horizontally and ±5° vertically with respect the beam direction
- Consists of six tracking stations FT1 up to FT6
- The tracker will consist of about 13056 straws
- Designed to withstand high counting rates $2 \cdot 10^7\ s^{-1}$
- 90% Ar + 10% CO_2 gas mixture is considered at 2 bar





The Simulation -> Rate studies

The 1st simulation:

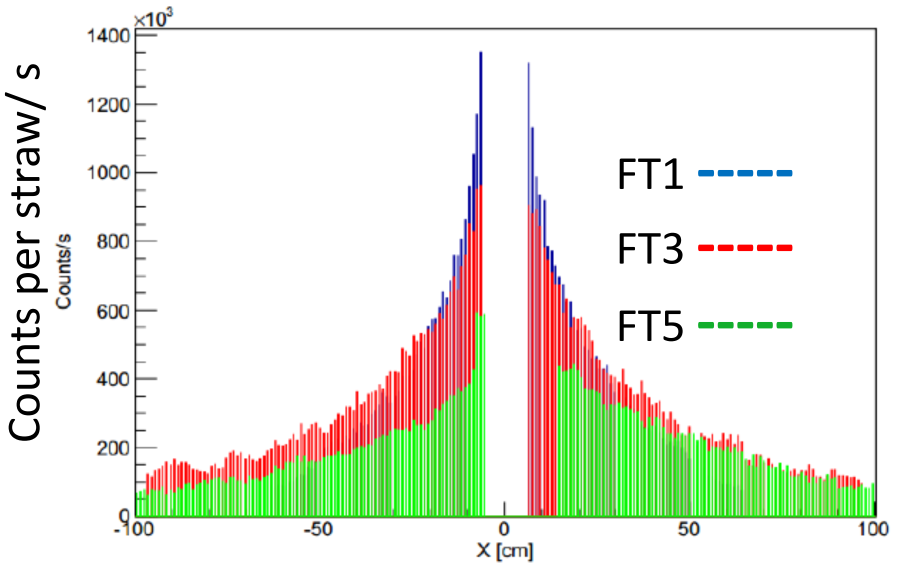
- dual parton model pbar-p@15 GeV/c
- 20 000 events were simulated
- Assuming 2 x 10^7 reactions/s

The 2nd simulation:

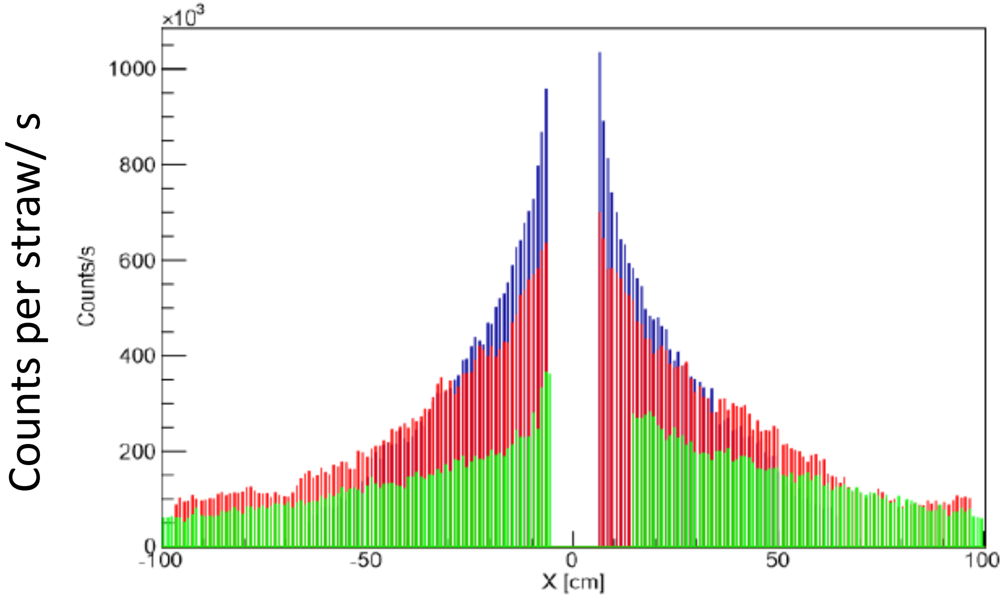
- urQMD pbar- N@15 GeV/c
- 12 000 events simulated
- Assuming 10^7 reactions/s

Rates in different tracking stations

pbar-p@15 GeV/c

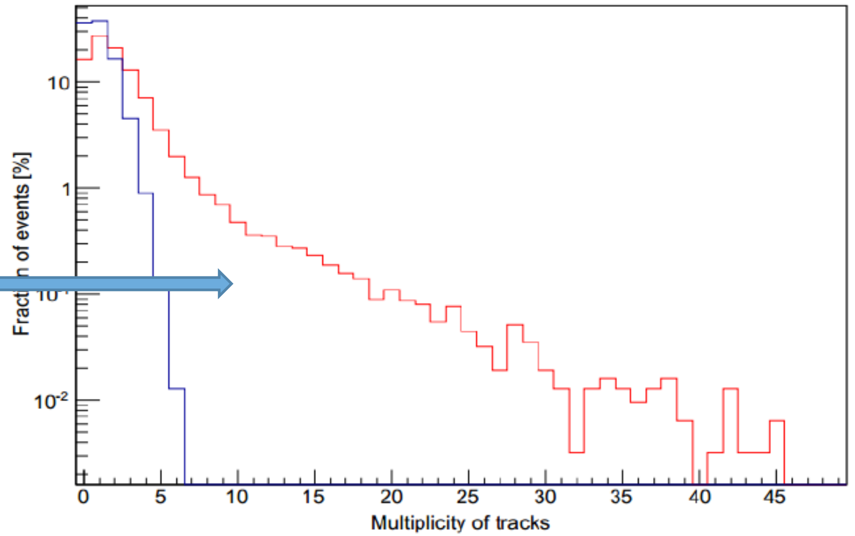


pbar-N@15 GeV/c



High count rates for straws near the beam pipe.
Significant lower counting rates after the dipole

One can see that there is a big influence in the count rate coming from secondary particles



Benchmark channels for PANDA

List of selected channels reflect the application of the tracking detectors of PANDA, like high precision track reconstruction and momentum measurement in the region of 100 MeV/c up to 15 GeV/c.

Channel	Final state	Related to detector
$\bar{p}p \to (n)\pi^+\pi^-$	$(n)\pi^+\pi^-$	CT
$\bar{p}p \to \psi(3770) \to D^+D^-$	$2K\,4\pi$	MVD, CT
$\bar{p}p \to \psi(4040) \to D^{*+}D^{*-}$	$2K\,4\pi$	MVD, CT
$\bar{p}p \to \bar{\Lambda}\Lambda$	$p\pi^-\bar{p}\pi^+$	MVD, CT, FT
$\bar{p}p \to \bar{\Xi}\Xi$	$p\bar{p}4\pi$	MVD, CT, FT
$\bar{p}p \to \eta_c \to \phi\phi$	4K	CT
$\bar{p}A \to J/\Psi X$	$2lX$	MVD, CT
$\bar{p}p \to \bar{p}p$	$\bar{p}p$	MVD, CT, FT

List of selected benchmark channels for PANDA

Physics motivation

Working horses:

BESIII, BaBar, Belle, Cleo, LHC, CDF,..

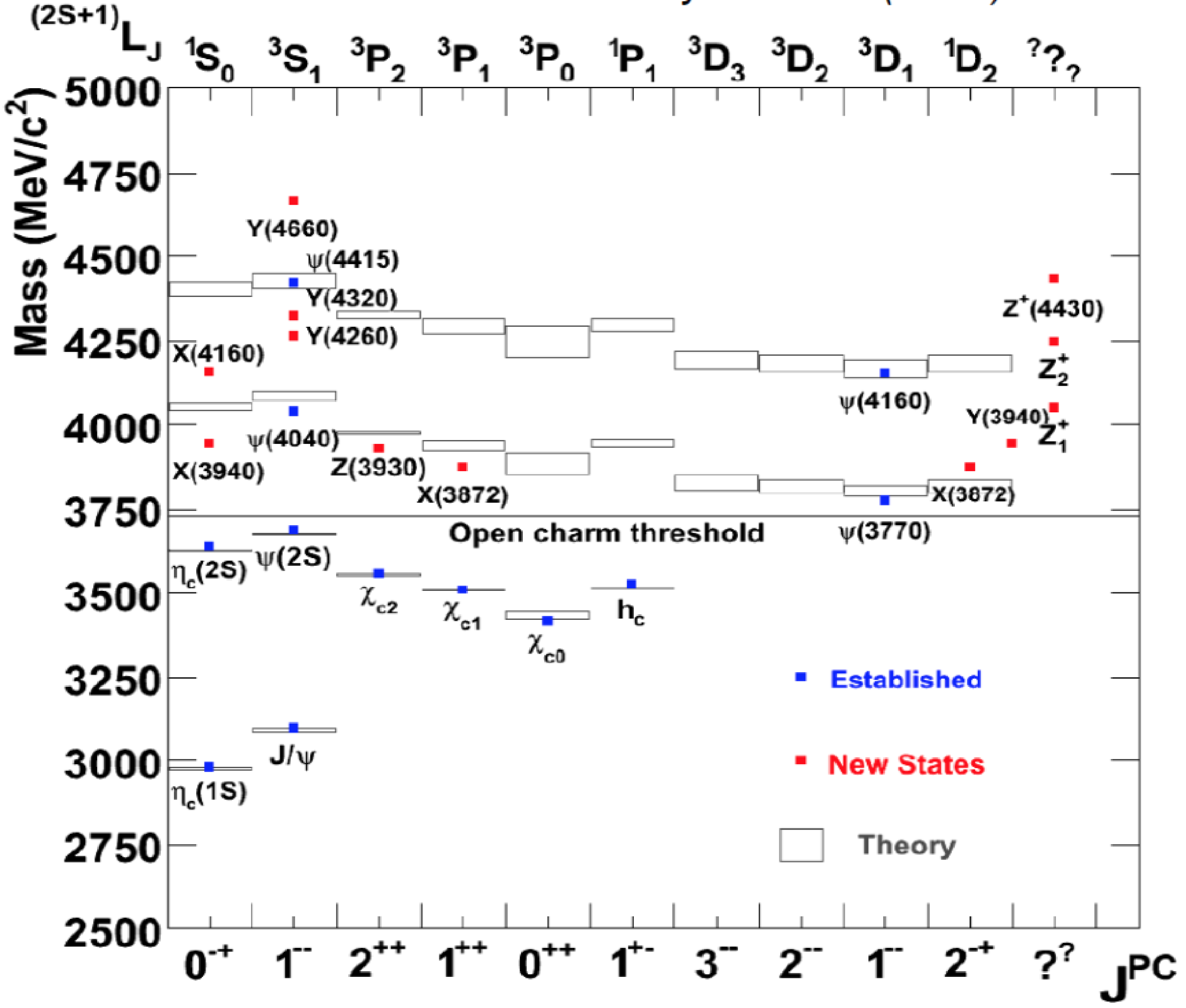
- Charmonium spectrum below open charm threshold is well understood and complete
- Above D Dbar threshold new states observed:
- **Some of them have features not expected for pure cc :**

1) Charged Z states decaying to cc (charged pion)

2) Very narrow though above DD

3) More states than expected from the potential model

Eur.Phys.J. C71 (2011) 1534



Physics channels reconstruction

- Full FTS geometry
- pbar-p@7.71GeV/c
- Simulated channels:

$$\bar{p} + p \to D^{*+} D^{*-} \to D^0 \overline{D^0} \pi^+ \pi^- \to K^+ K^- \pi^+ \pi^- \pi^+ \pi^-$$

$$\bar{p} + p \to D^0 \overline{D^0} \to K^+ K^- \pi^+ \pi^-$$

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

ψ(4040) ➔ D*(2010)$^+$ D*(2010)$^-$

$D^*(2010)^{\pm}$

$I(J^P) = \frac{1}{2}(1^-)$

I, *J*, *P* need confirmation.

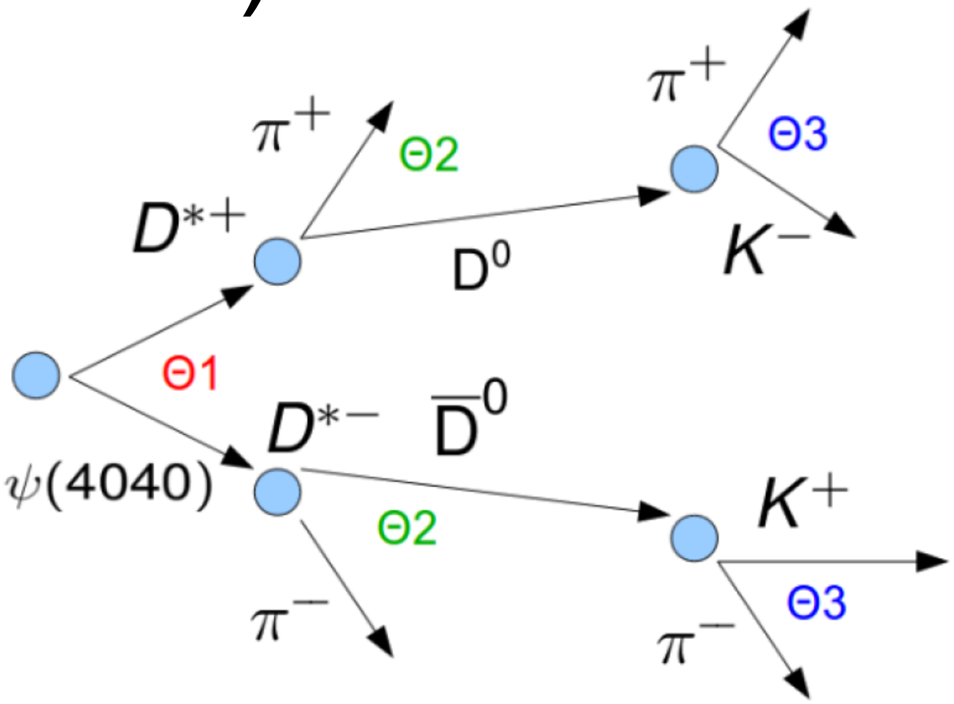
Mass $m = 2010.22 \pm 0.14$ MeV

$m_{D^*(2010)^+} - m_{D^+} = 140.66 \pm 0.10$ MeV (S = 1.1)

$m_{D^*(2010)^+} - m_{D^0} = 145.421 \pm 0.010$ MeV (S = 1.1)

Full width $\Gamma = 96 \pm 22$ keV

$D^*(2010)^-$ modes are charge conjugates of the modes below.



$D^*(2010)^{\pm}$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0\pi^+$	(67.7 ± 0.5) %	39
$D^+\pi^0$	(30.7 ± 0.5) %	38
$D^+\gamma$	(1.6 ± 0.4) %	136

D* decay will emit low momentum pion`s witch will go to the Forward Spectrometer !!

D^0

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1864.80 \pm 0.14$ MeV

$m_{D^\pm} - m_{D^0} = 4.77 \pm 0.10$ MeV (S = 1.1)

Mean life $\tau = (410.1 \pm 1.5) \times 10^{-15}$ s

$c\tau = 122.9\ \mu$m

$\left|m_{D_1^0} - m_{D_2^0}\right| = (2.39^{+0.59}_{-0.63}) \times 10^{10}\ \hbar\ s^{-1}$ [j]

$(\Gamma_{D_1^0} - \Gamma_{D_2^0})/\Gamma = 2y = (1.66 \pm 0.32) \times 10^{-2}$ [j]

$\left|q/p\right| = 0.86^{+0.18}_{-0.15}$

$A_\Gamma = (1.4 \pm 2.7) \times 10^{-3}$

$K^+\pi^-$ relative strong phase: $\cos\delta = 1.03^{+0.32}_{-0.18}$

$K^-\pi^+\pi^0$ coherence factor $R_{K\pi\pi^0} = 0.78^{+0.11}_{-0.25}$

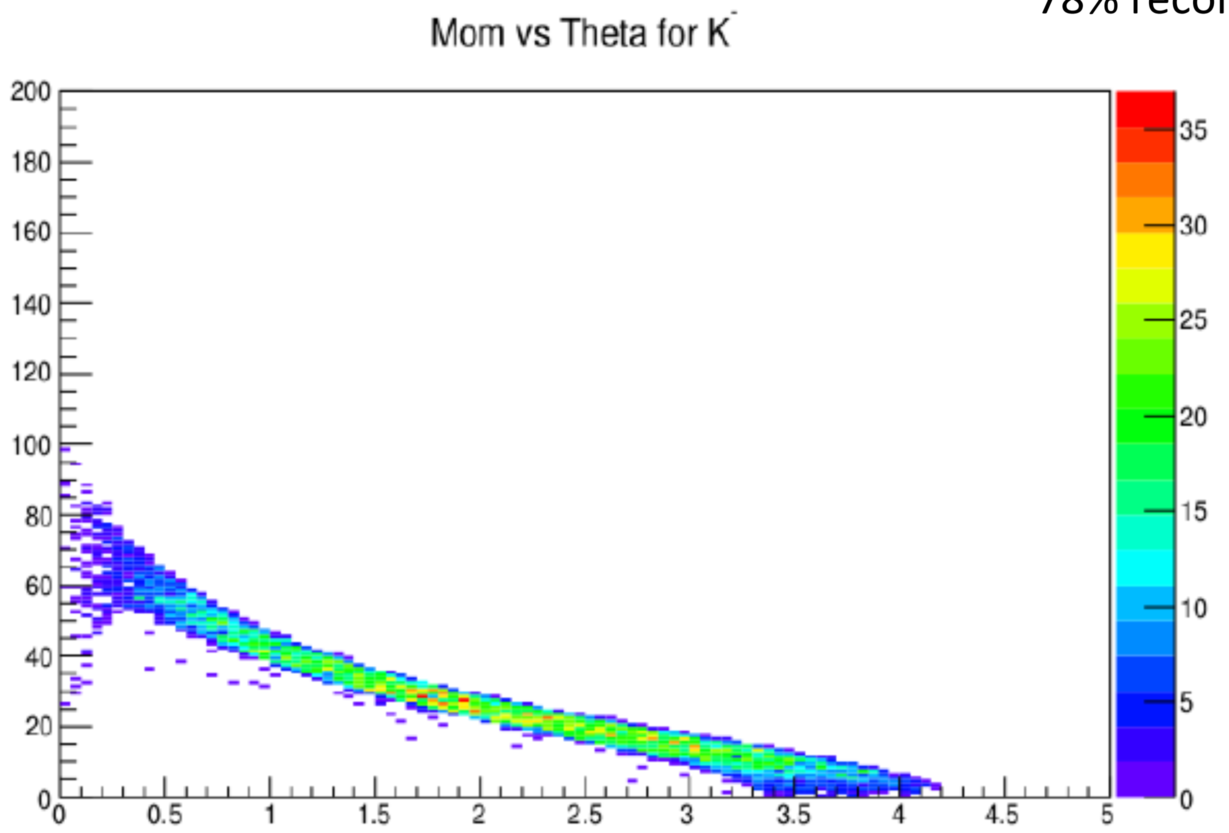
$K^-\pi^+\pi^0$ average relative strong phase $\delta^{K\pi\pi^0} = (239^{+32}_{-28})^\circ$

Theta vs momentum for Kaons (generated and reconstructed)

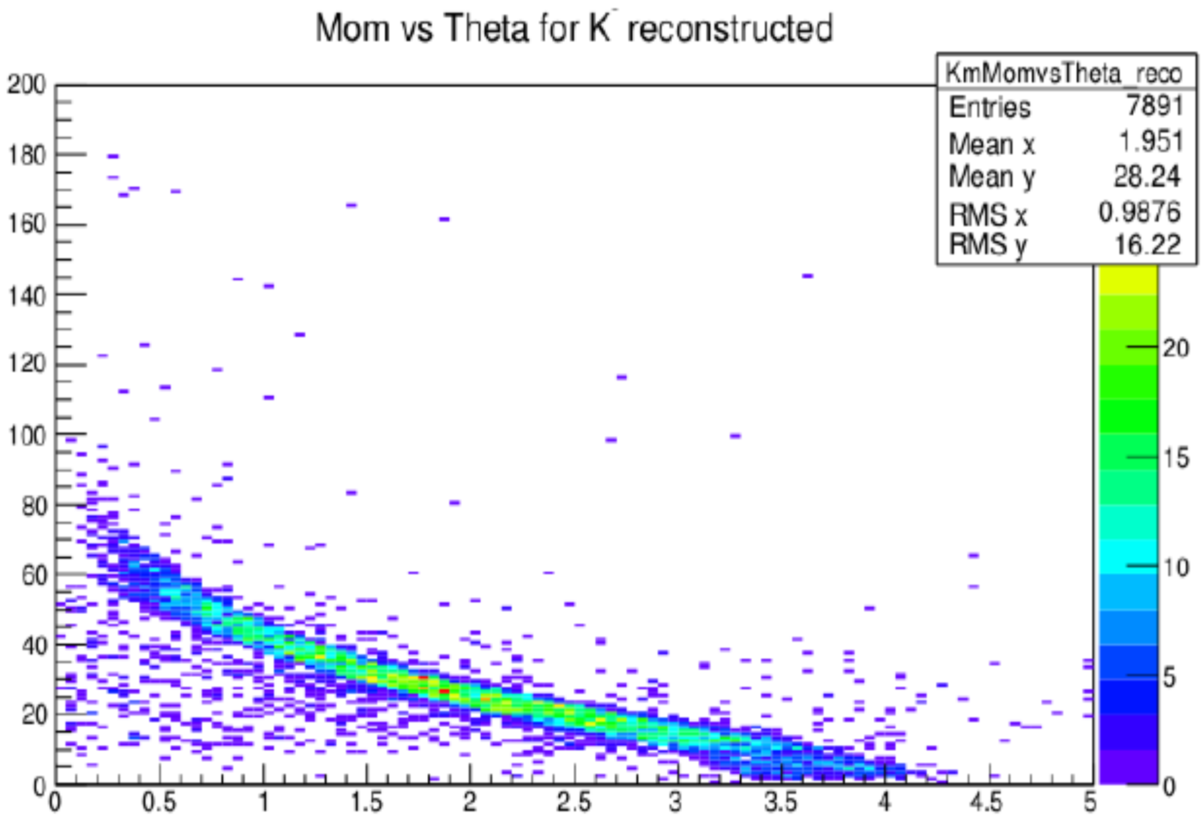
Reconstructed

78% reconstructed

θ



Momentum GeV/c

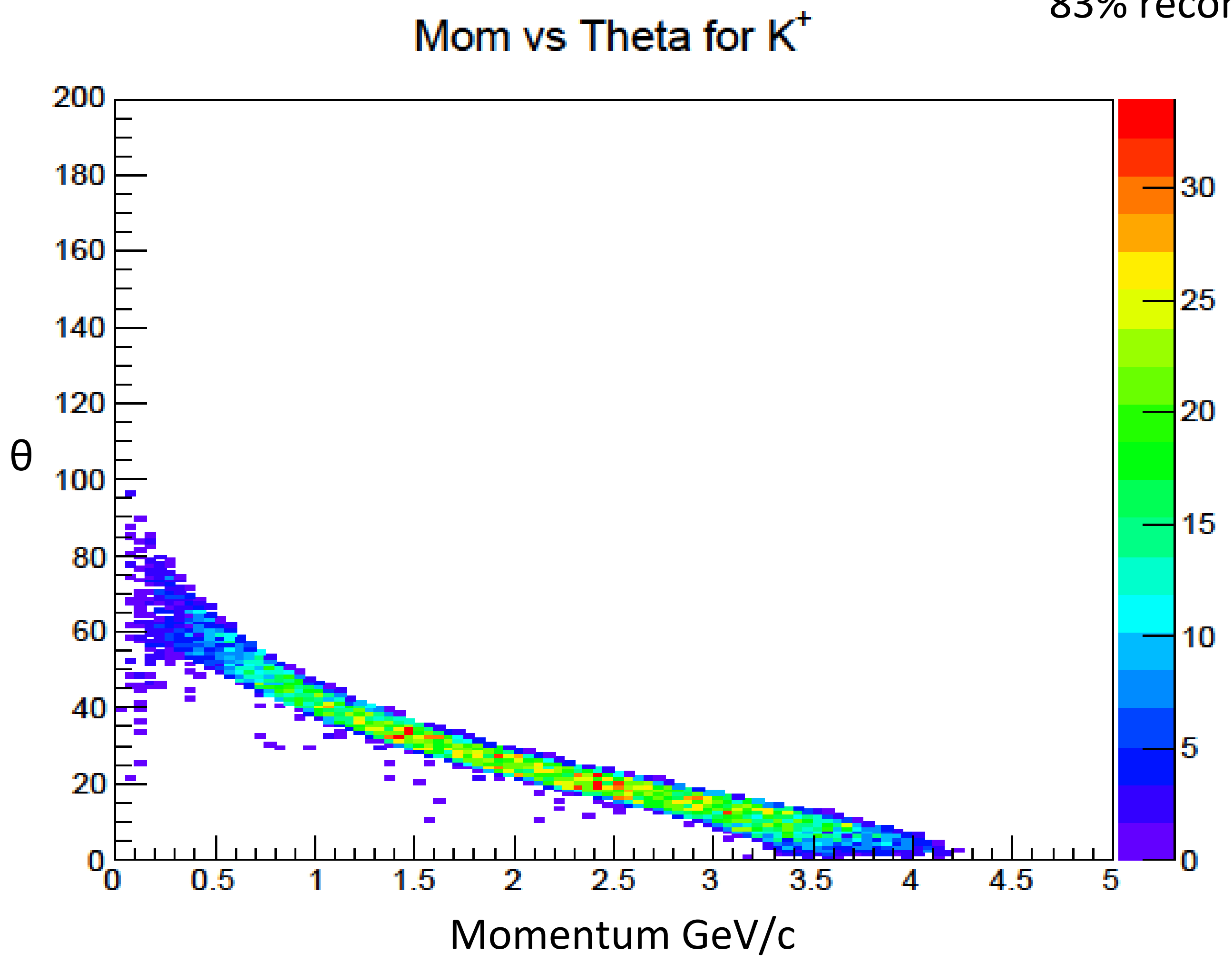


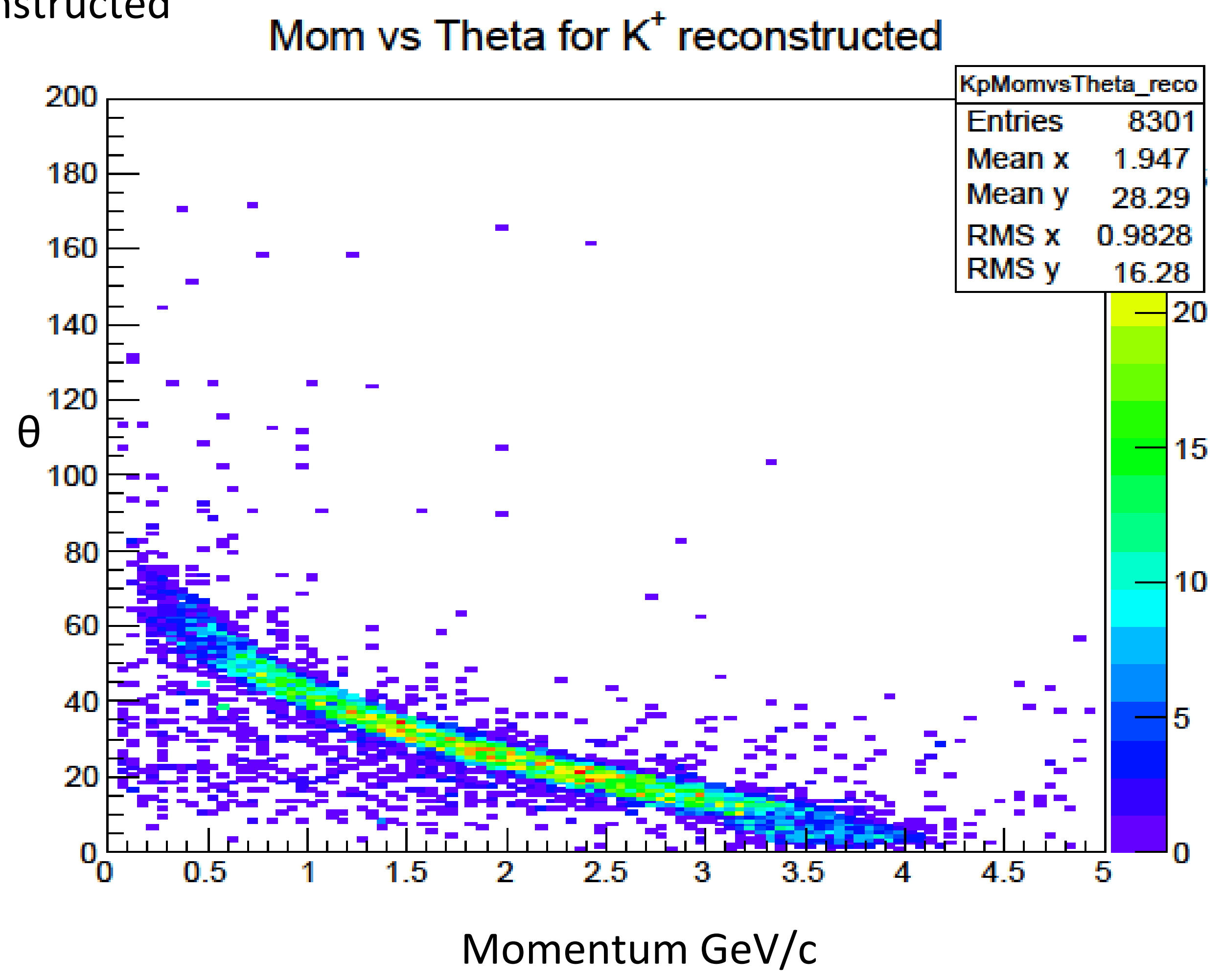
Momentum GeV/c

Theta vs momentum for Kaons (generated and reconstructed)

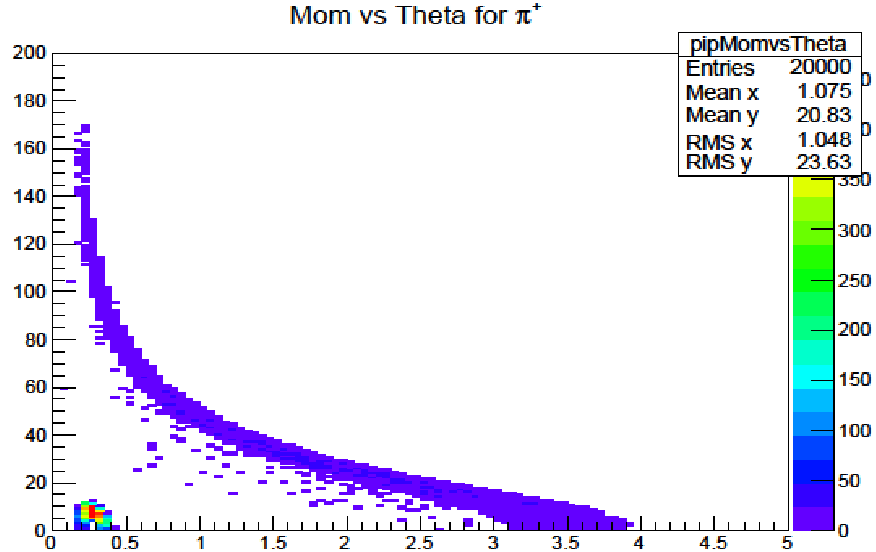
Reconstructed

83% reconstructed



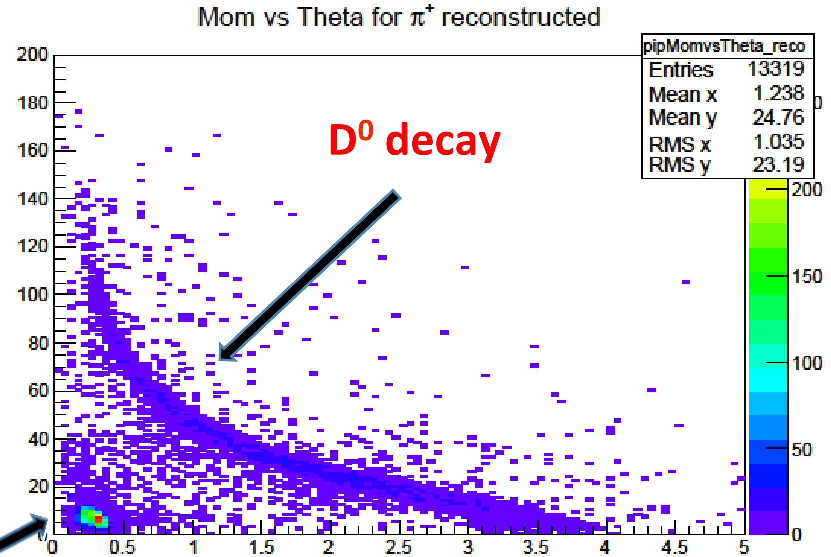


Theta vs momentum for π (generated and reconstructed)



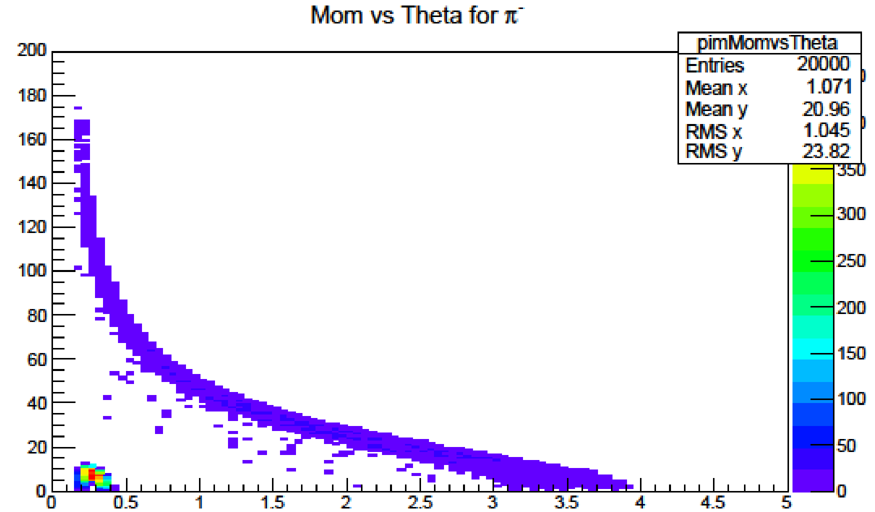
Reconstructed

→ 80% reconstructed

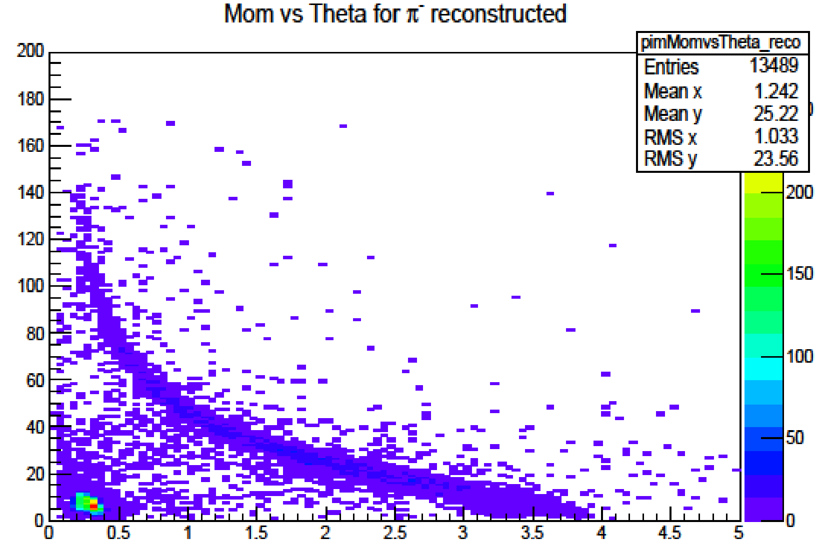


D^0 decay

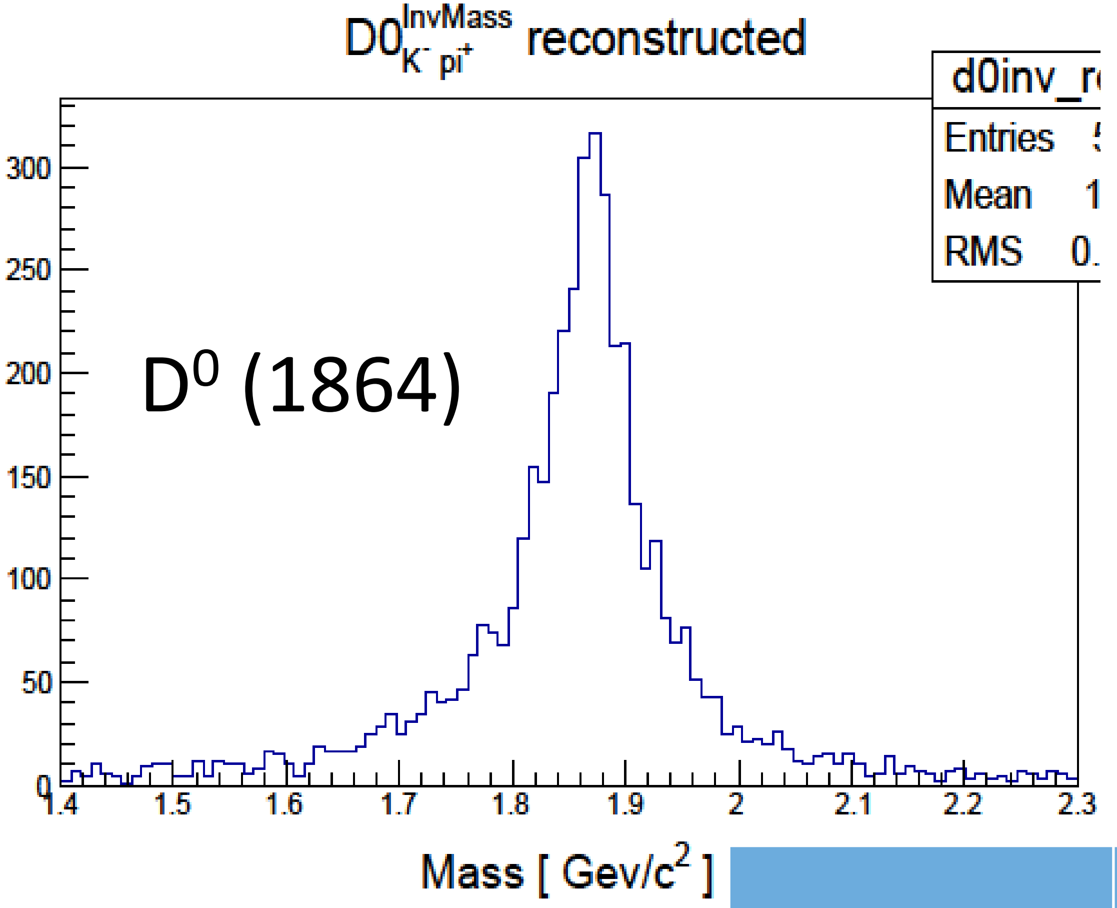
D* decay

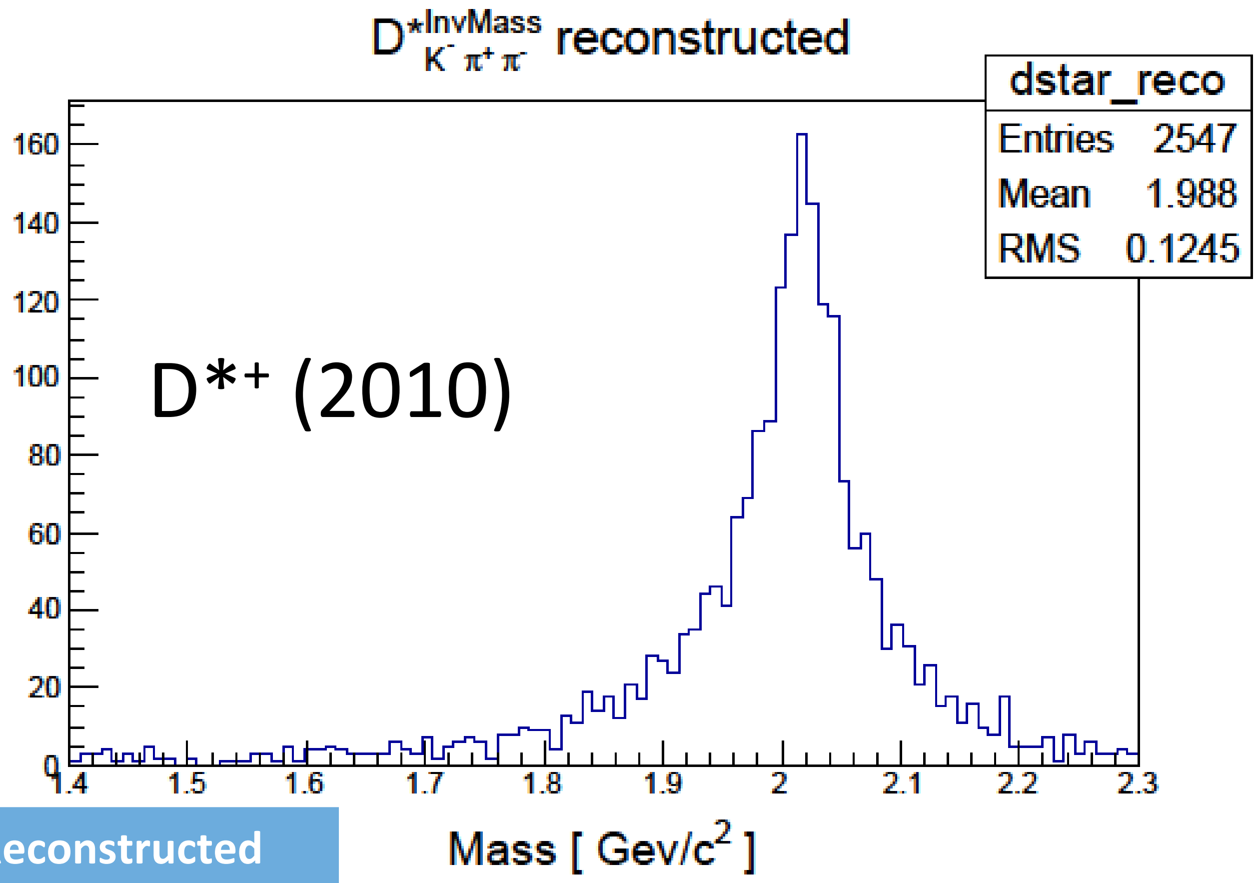


Reconstructed



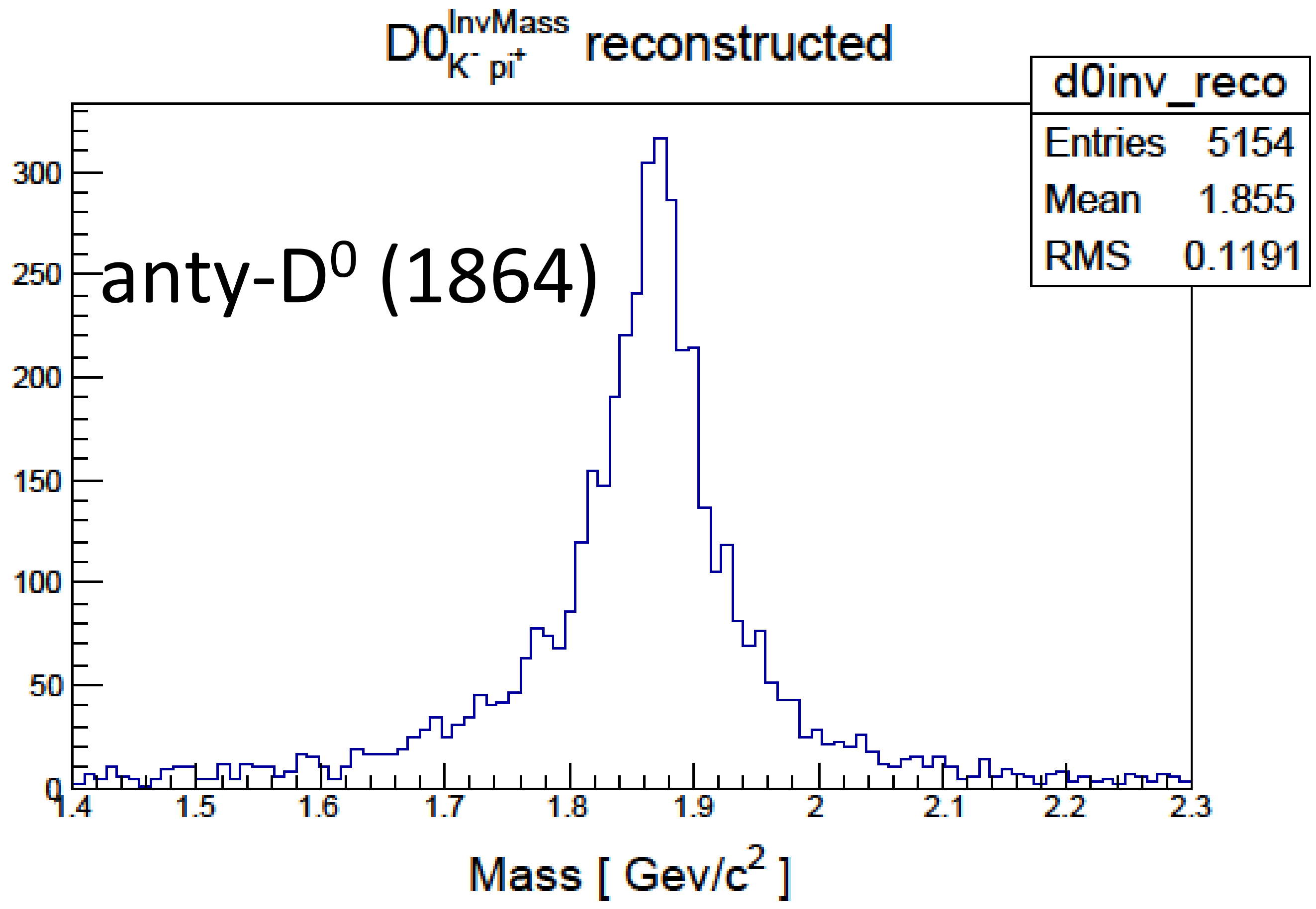
Invariant mass reconstruction

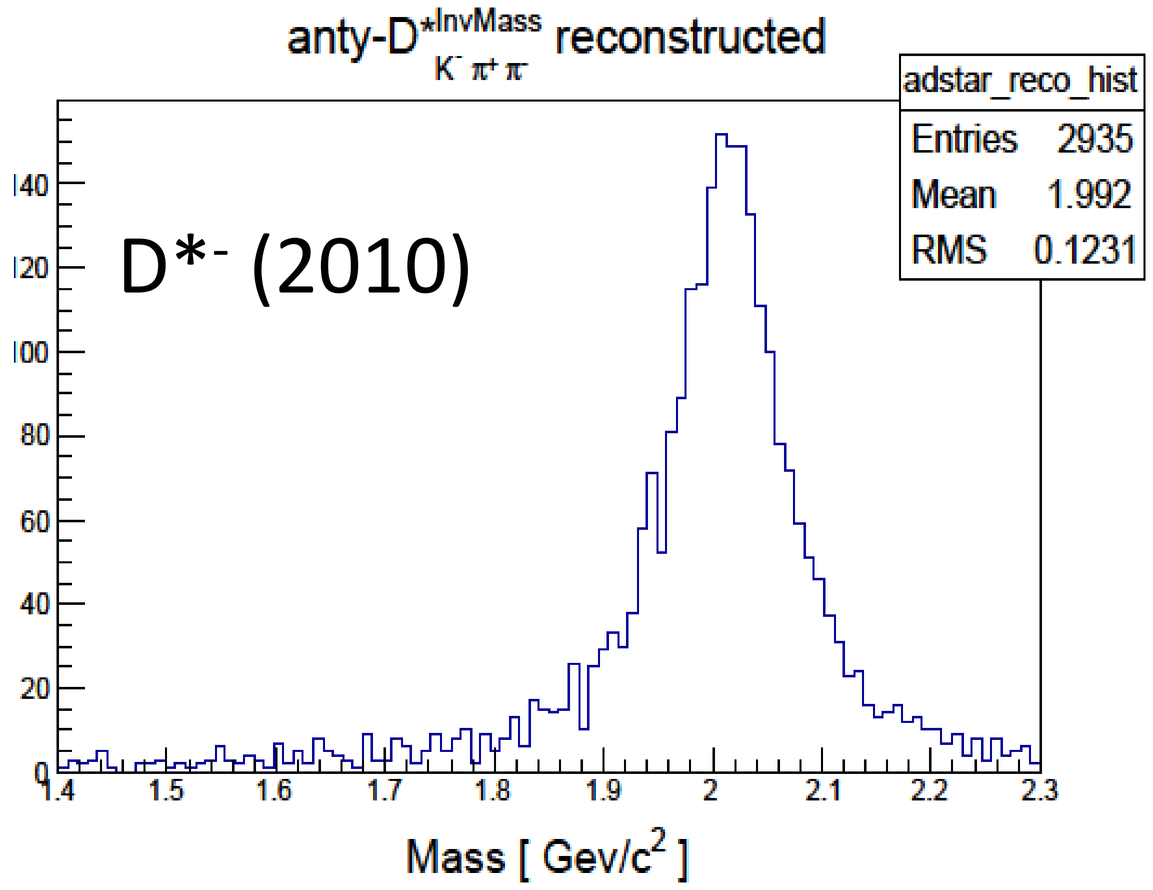




	Reconstructed
D^0	51%
anti-D^0	51%
D^{*+}	25%
D^{*-}	29%

invariant mass reconstruction



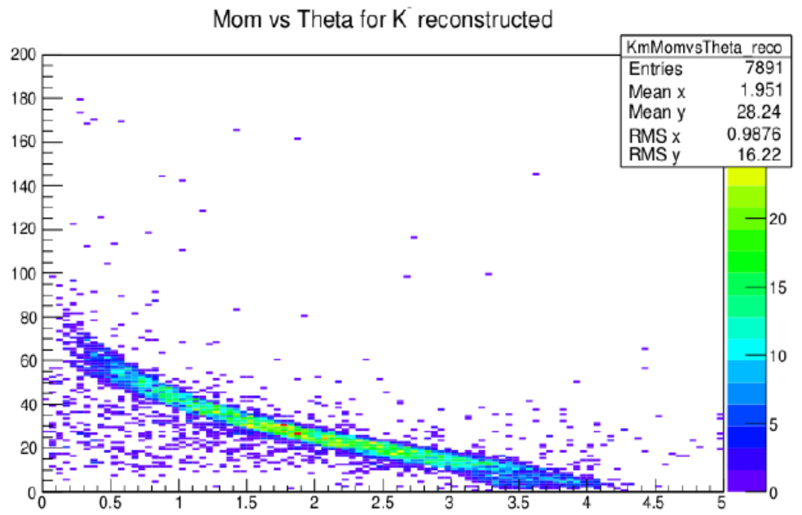


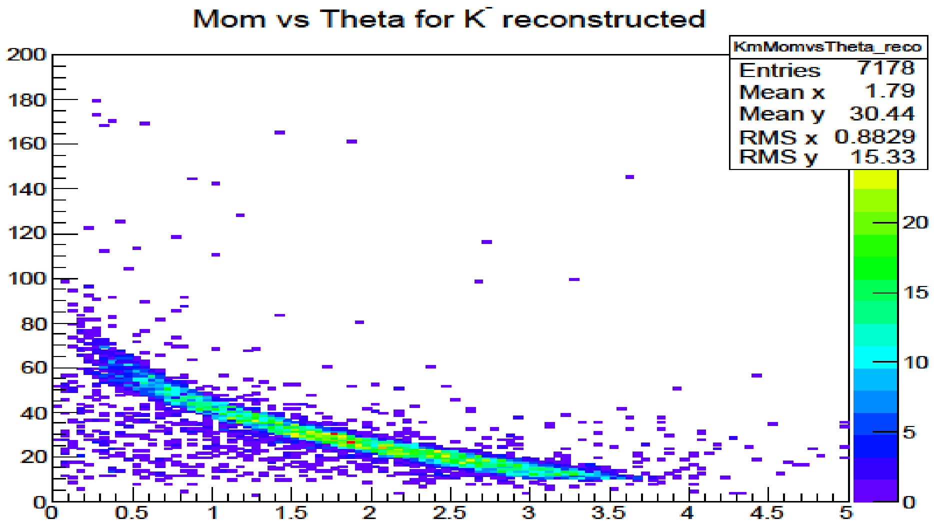
What happens when one switches off the FTS ?!

Full setup

Kaons

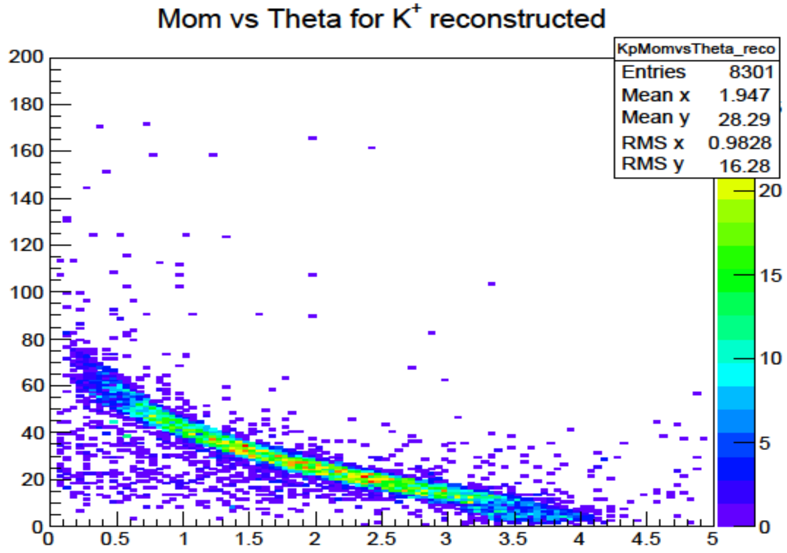
FTS off

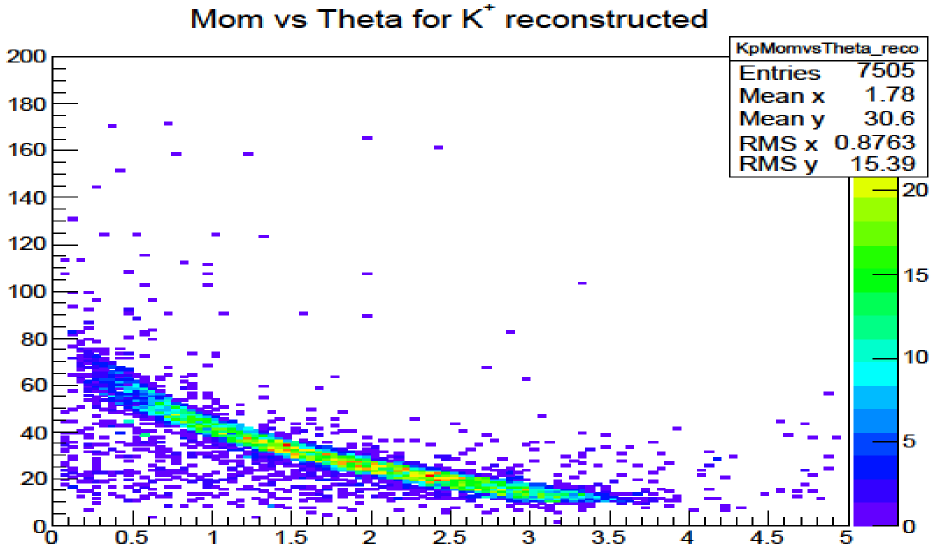




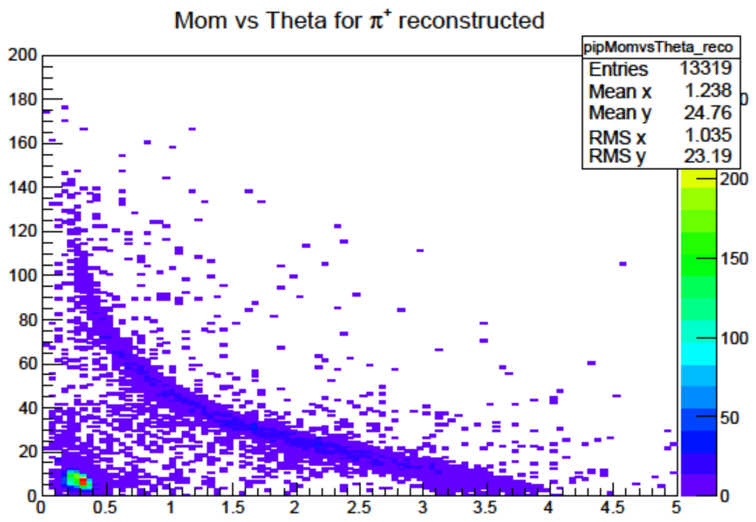
Some of the K`s emitted at low theta are lost

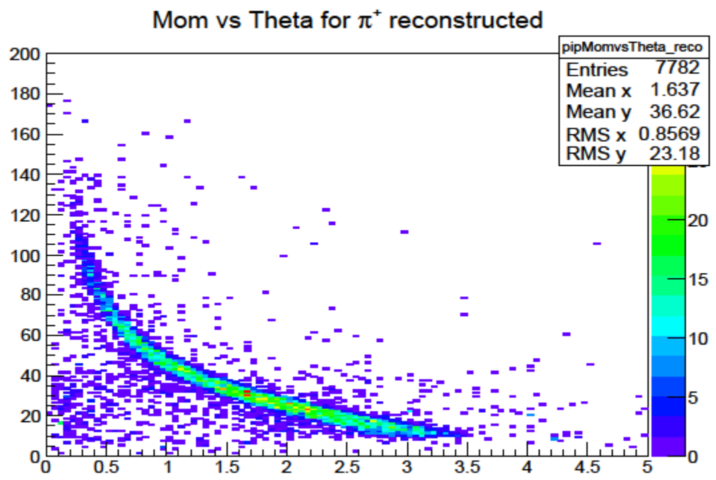
Full Setup		FTS OFF	
K^+	K^-	K^+	K^-
79%	83%	71%	75%



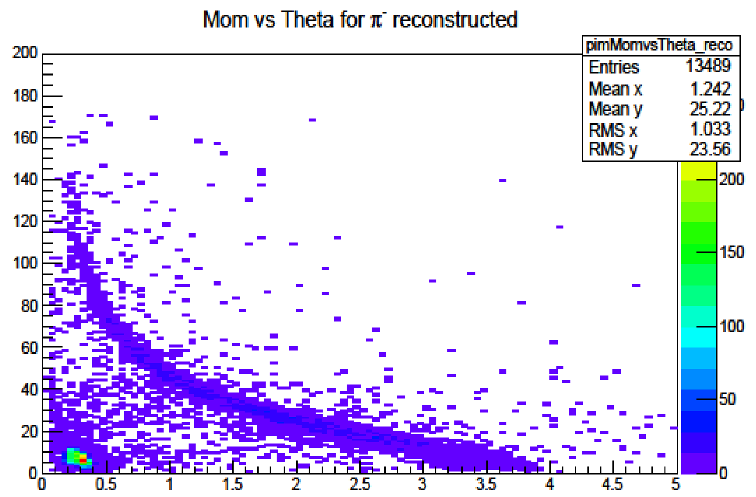


Theta vs momentum for $\pi^{-/+}$

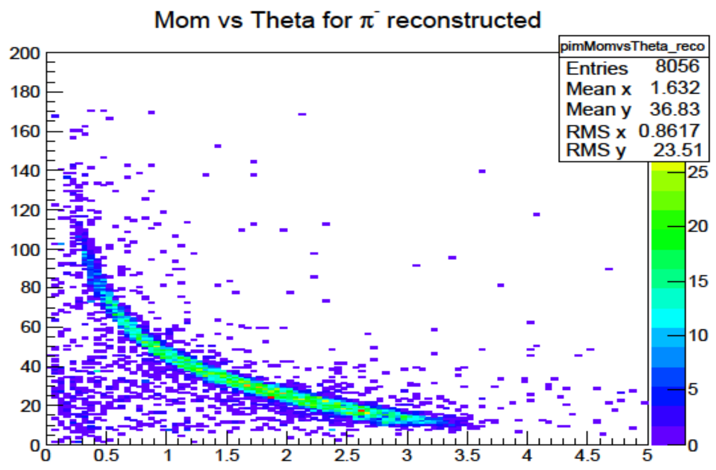




Full Setup		FTS OFF	
π^+	π^-	π^+	π^-
64%	65%	37%	40%

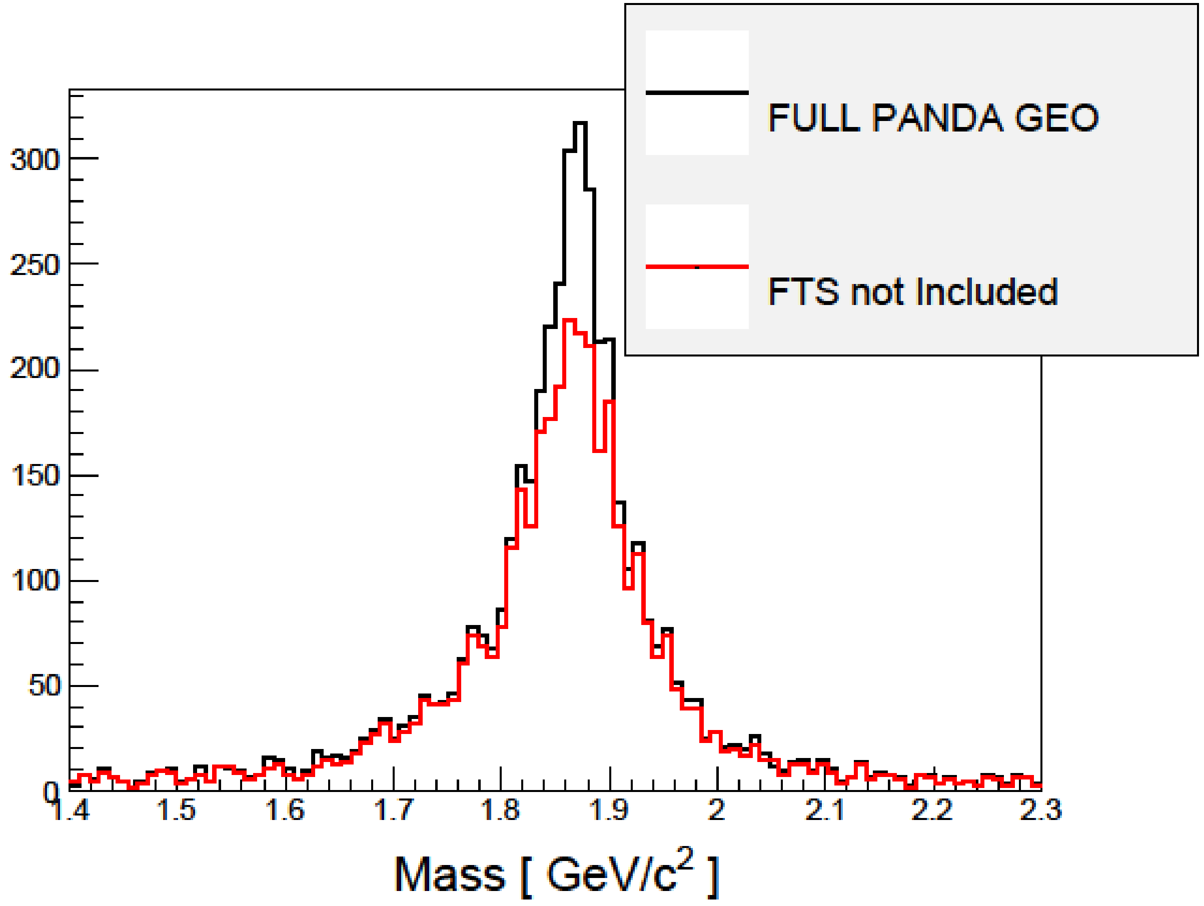


Pions coming form D* decay are not visible ☹
Pions at low theta are lost

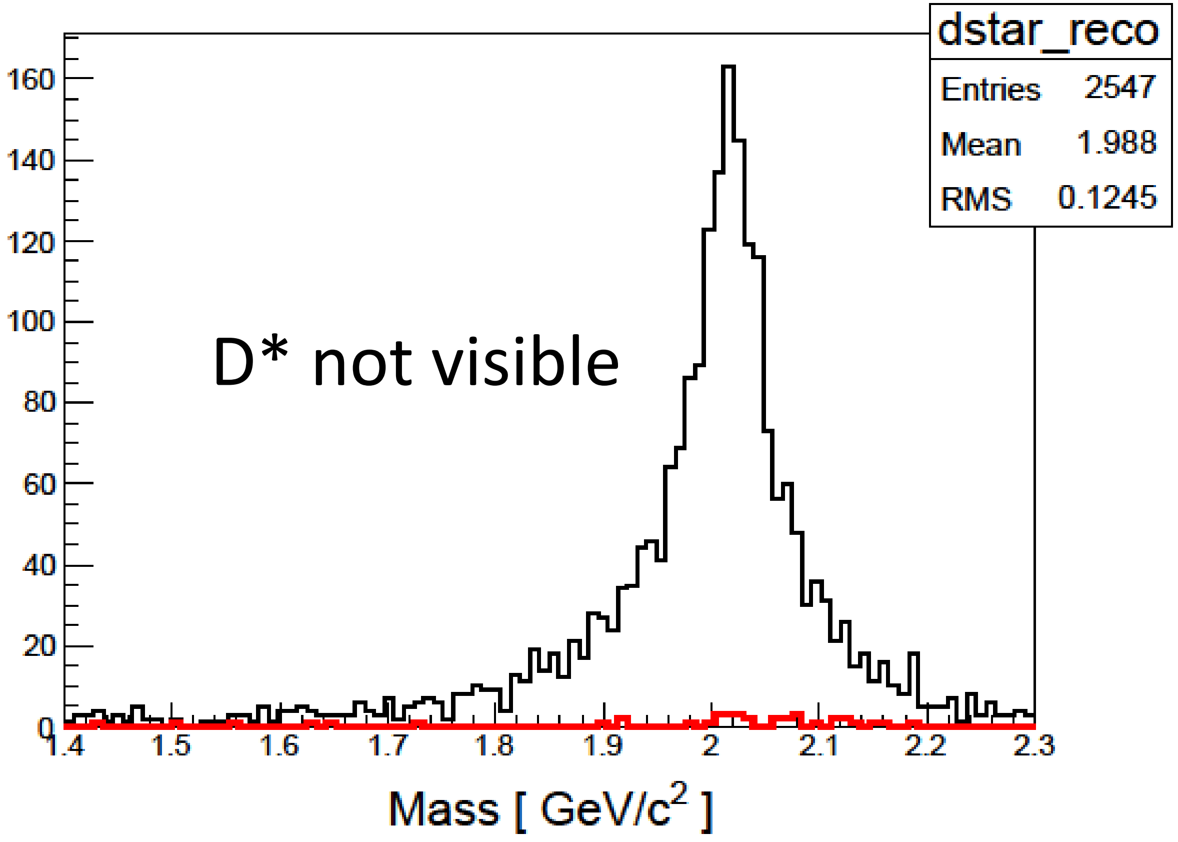


Invariant mass reconstruction

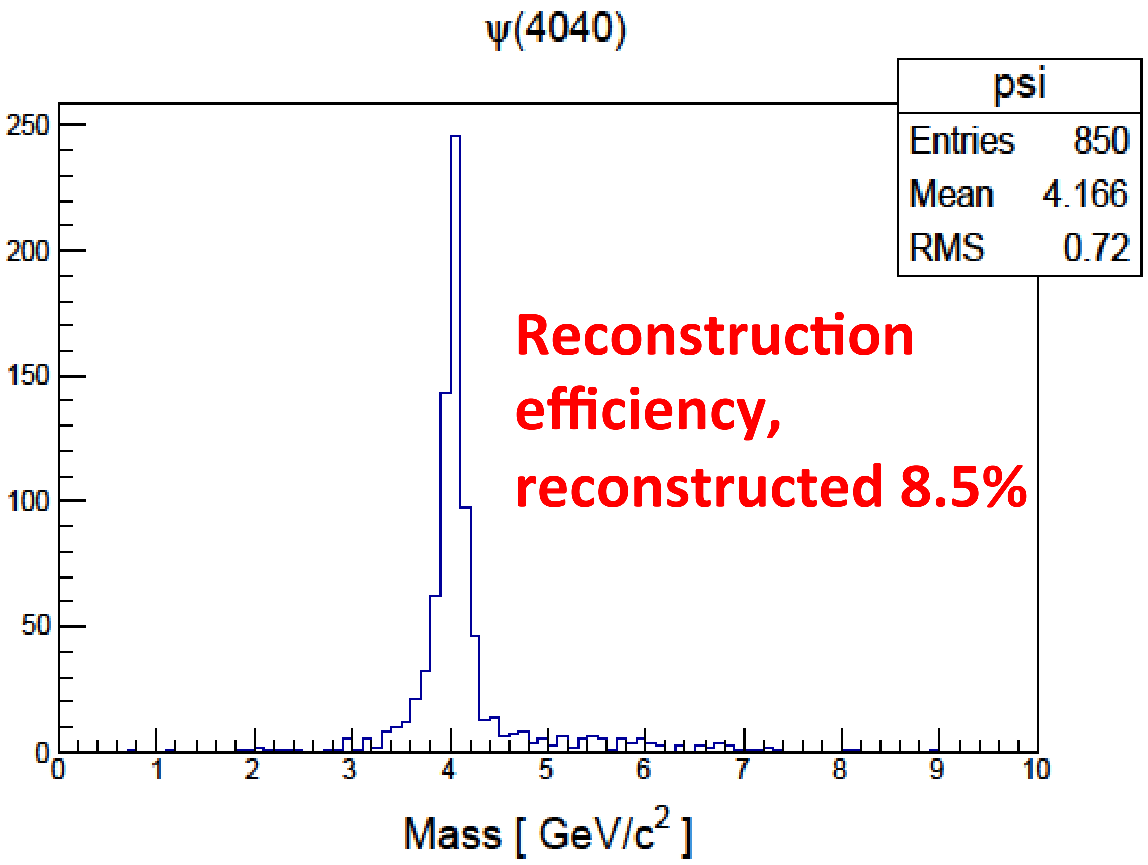
D^0 (1864)

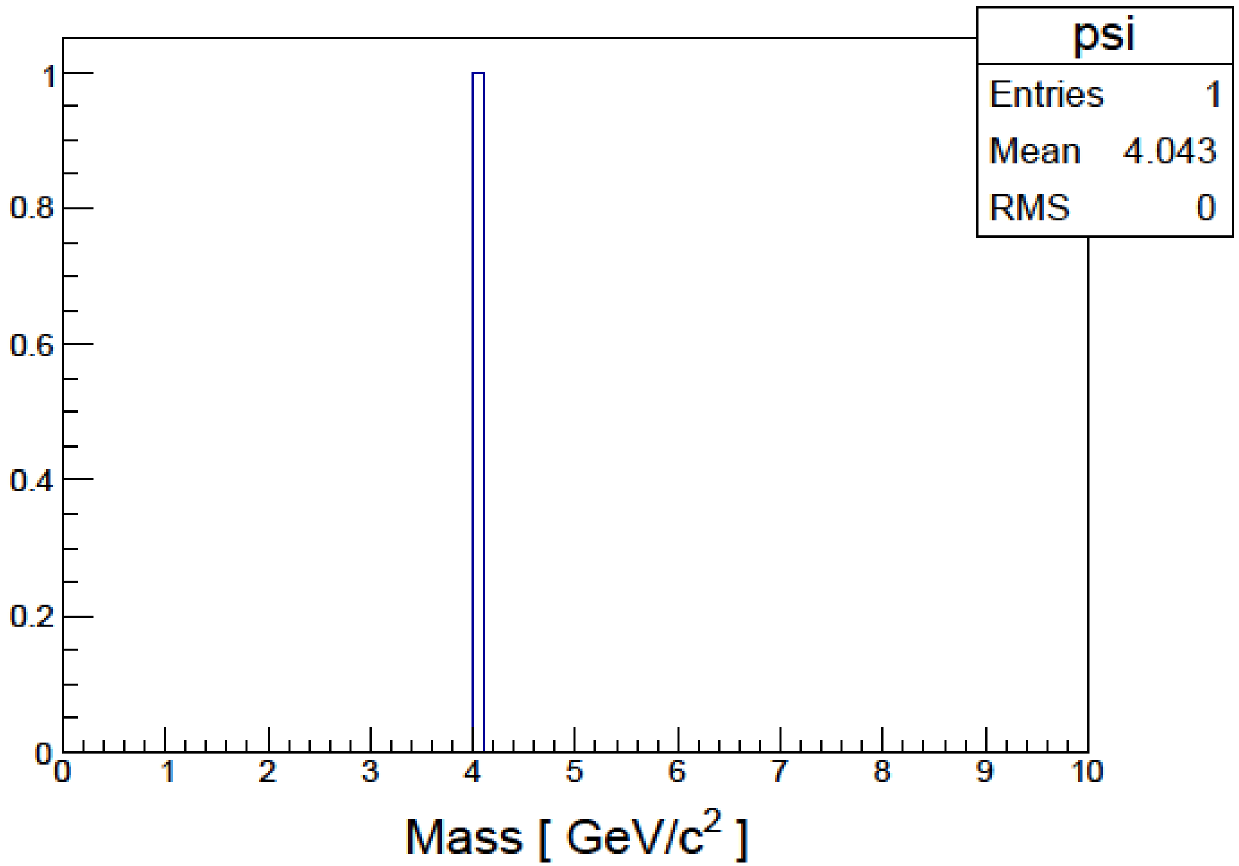


D* (2010)



Ψ(4040) expected results

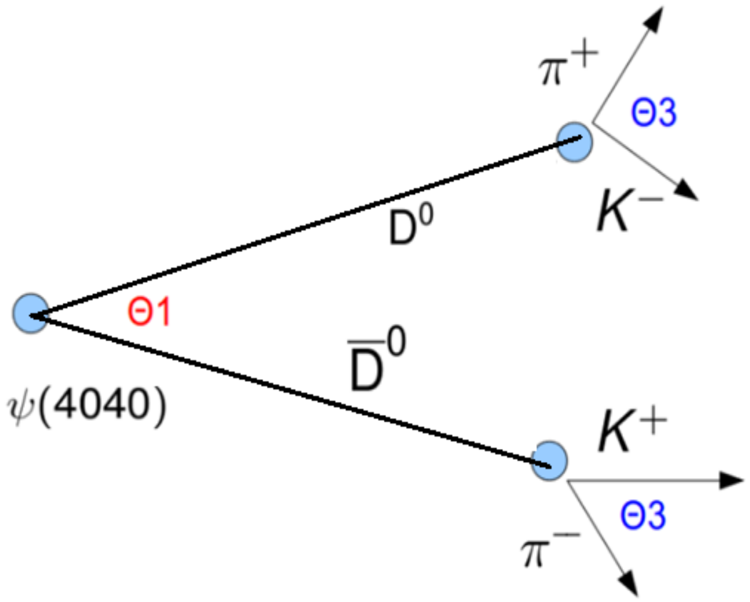




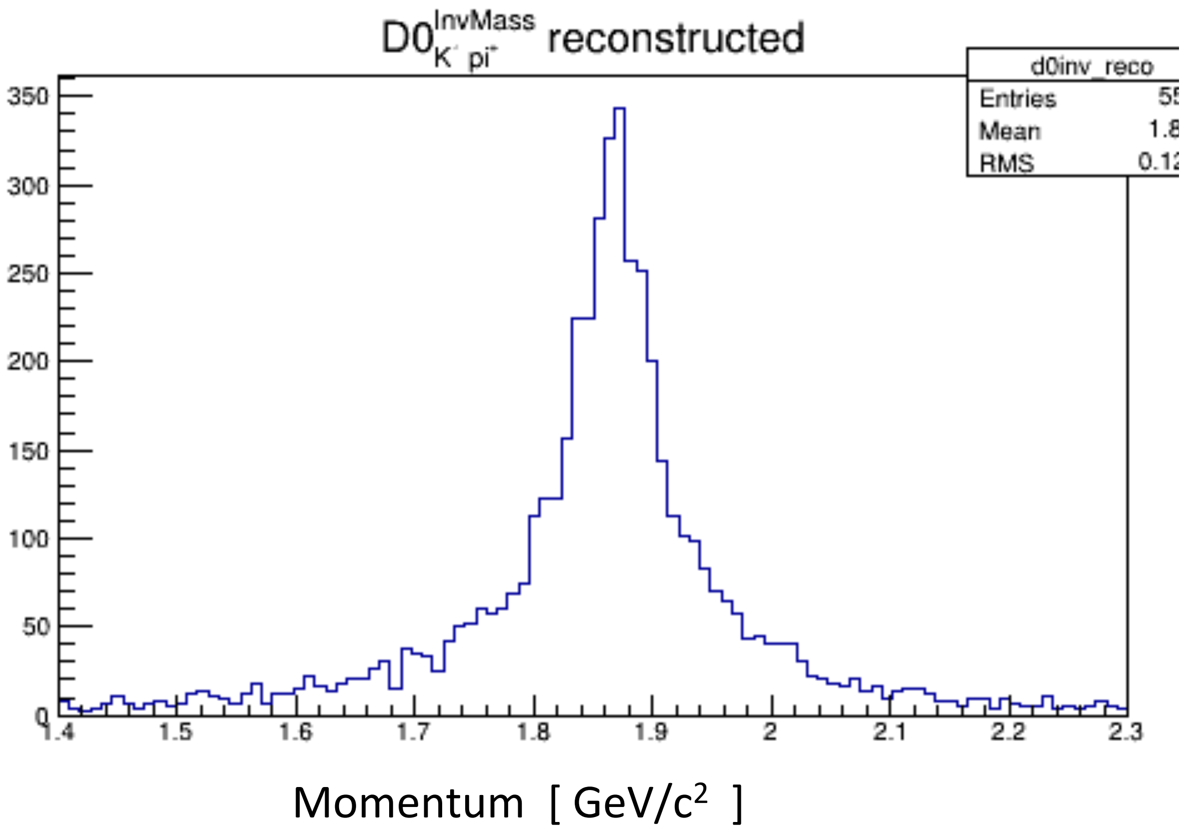
One can see that full reconstruction of the Ψ(4040) requires the Forward Spectrometer, due to low momentum pion`s coming form D* decay!

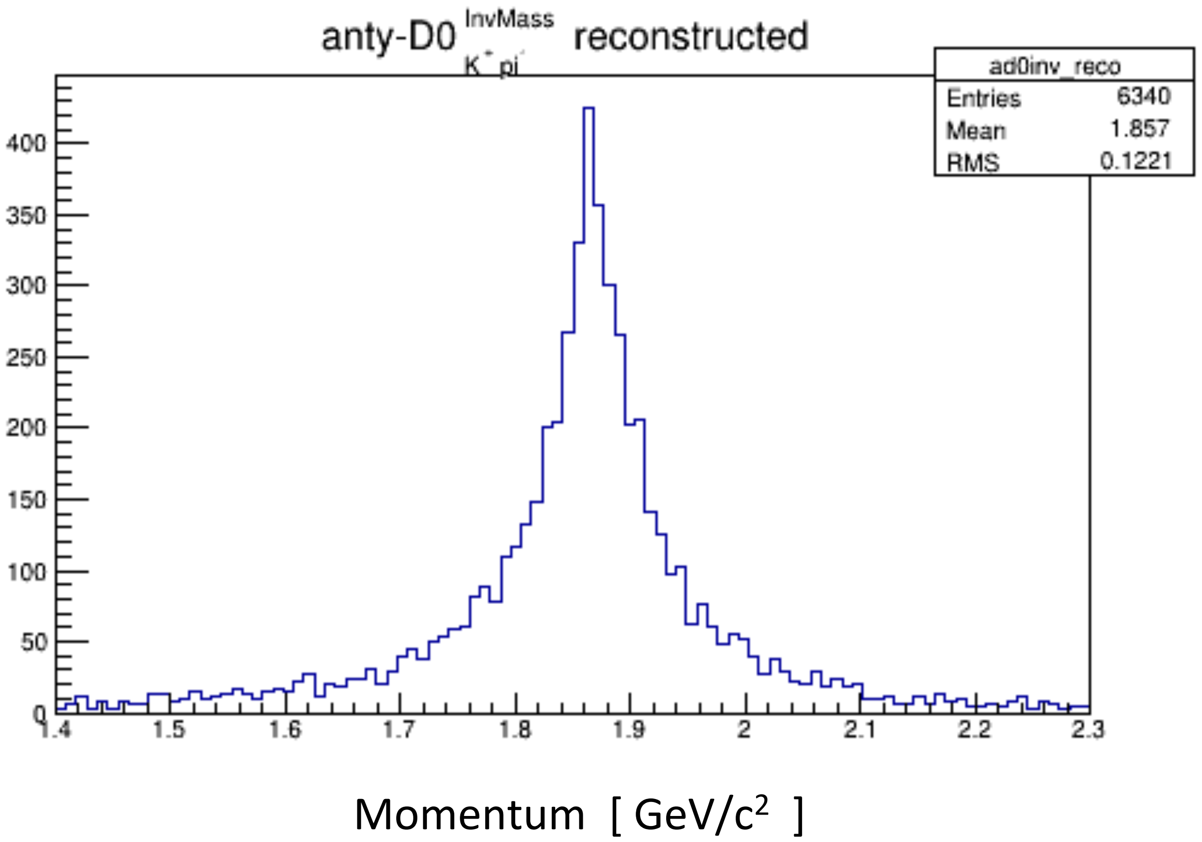
ψ(4040) ➔ $D(1864)^0$ anti-$D(1864)^0$

- As a comparison, a reconstruction of a „central case” (pion`s and kaon`s go to the Central Tracker)



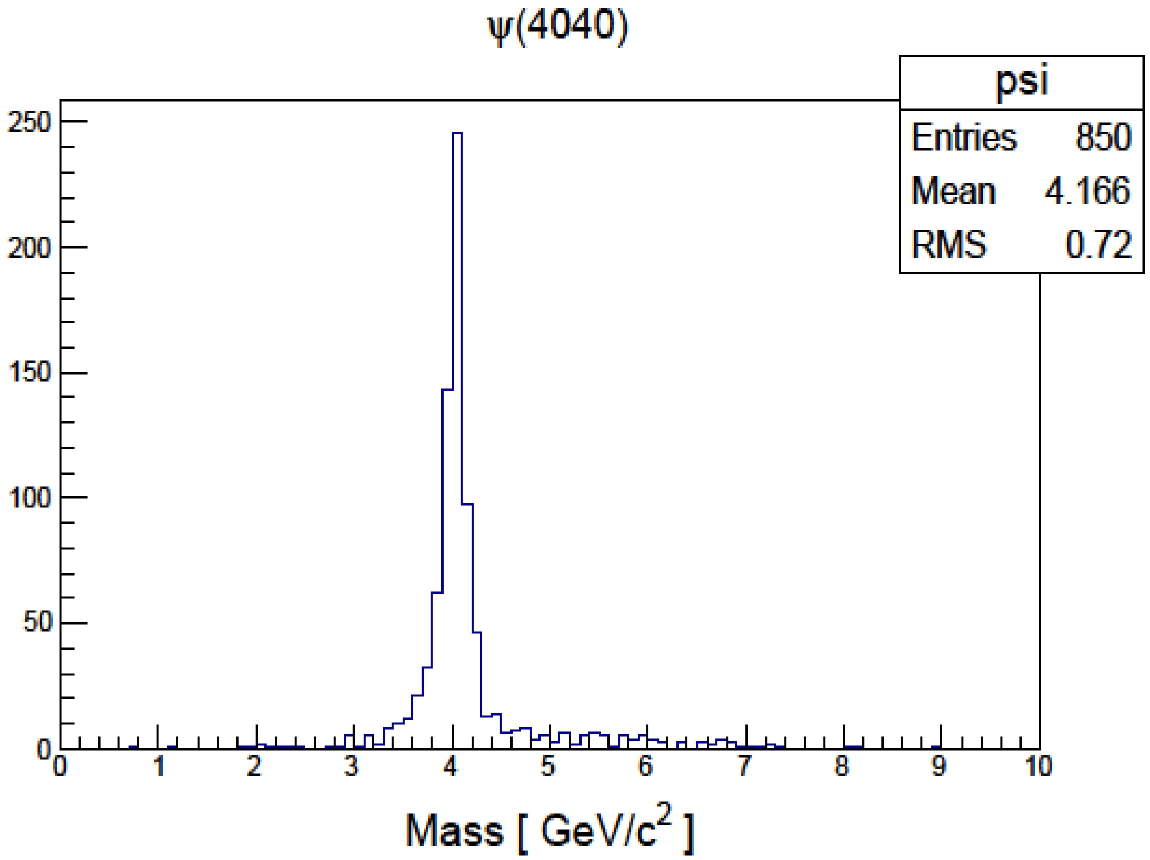
Invariant mass reconstruction

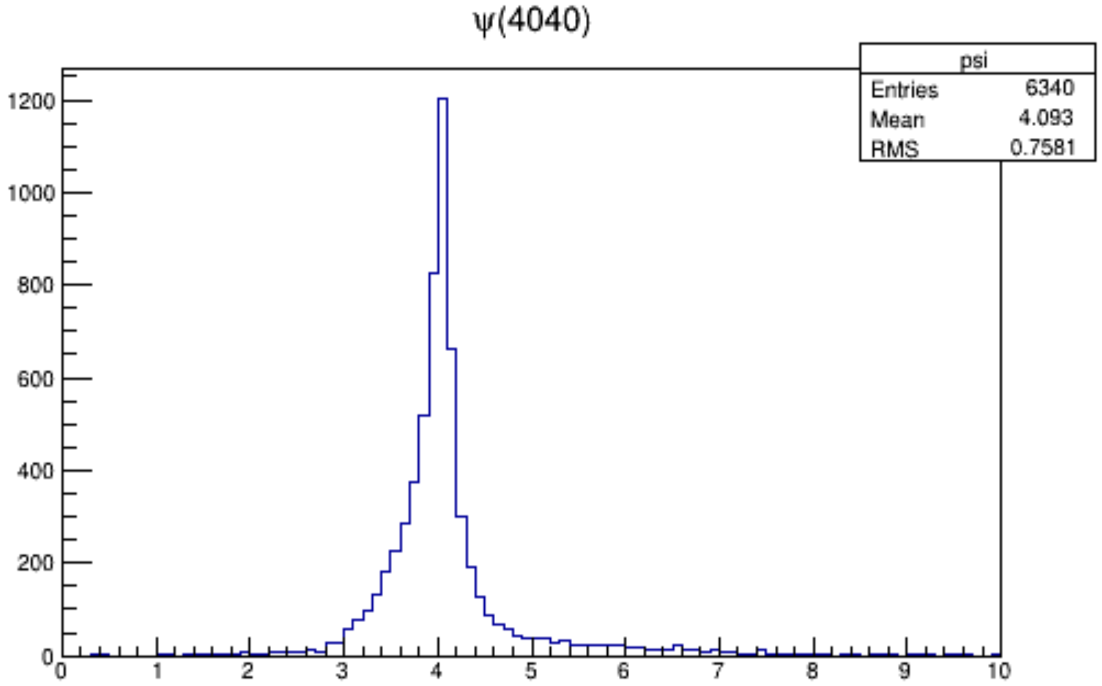




Particle	First case	Second case
D^0	51%	55%
anti-D^0	51%	60%

Ψ(4040) invariant mass, expected results





Mass [GeV/c^2]

$$\bar{p} + p \rightarrow \Lambda\bar{\Lambda} \rightarrow p\bar{p}\pi^{+}\pi^{-}$$

- Important from the point of baryon spectroscopy
- The study of double Λ is one of the major physics topic within the program of PANDA
- Perfect case to benchmark the FTS due the fact that all products go mostly at low Theta

Λ

$I(J^P) = 0(\frac{1}{2}^+)$

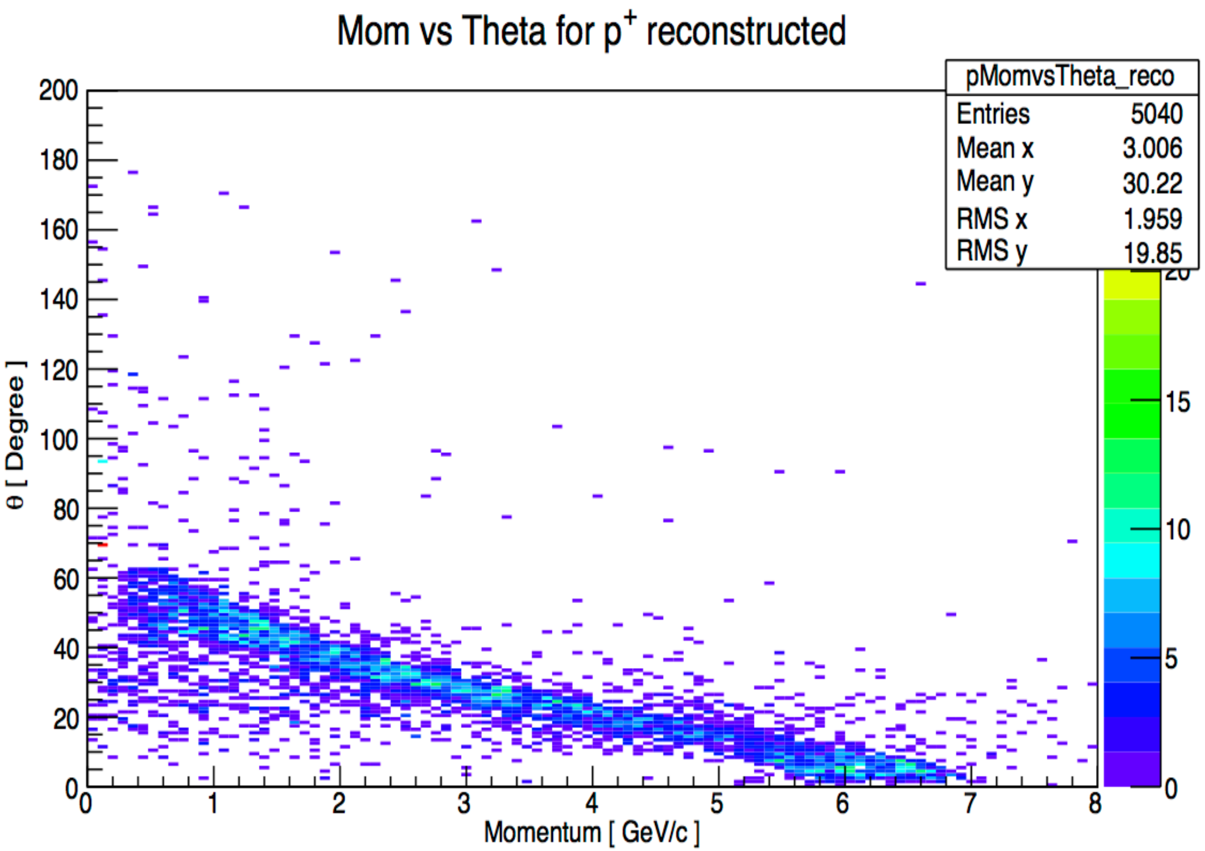
Mass $m = 1115.683 \pm 0.006$ MeV
$(m_\Lambda - m_{\overline{\Lambda}}) / m_\Lambda = (-0.1 \pm 1.1) \times 10^{-5}$ (S = 1.6)
Mean life $\tau = (2.632 \pm 0.020) \times 10^{-10}$ s (S = 1.6)
$(\tau_\Lambda - \tau_{\overline{\Lambda}}) / \tau_\Lambda = -0.001 \pm 0.009$
$c\tau = 7.89$ cm
Magnetic moment $\mu = -0.613 \pm 0.004\ \mu_N$
Electric dipole moment $d < 1.5 \times 10^{-16}\ e$ cm, CL = 95%

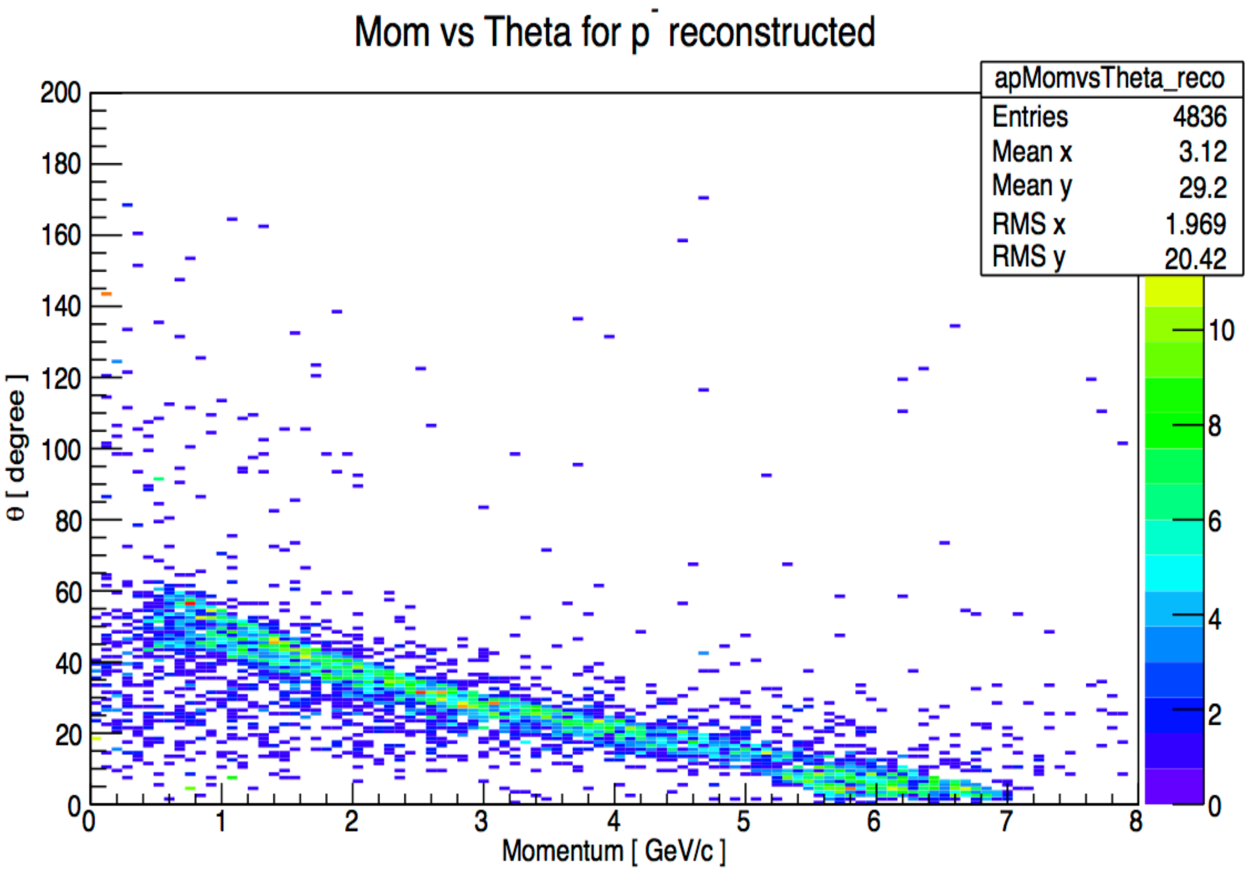
Decay parameters

$p\pi^-$	$\alpha_- = 0.642 \pm 0.013$
$\overline{p}\pi^+$	$\alpha_+ = -0.71 \pm 0.08$
$p\pi^-$	$\phi_- = (-6.5 \pm 3.5)^\circ$
"	$\gamma_- = 0.76$ [a]
"	$\Delta_- = (8 \pm 4)^\circ$ [a]
$n\pi^0$	$\alpha_0 = 0.65 \pm 0.04$
$pe^-\overline{\nu}_e$	$g_A/g_V = -0.718 \pm 0.015$ [b]

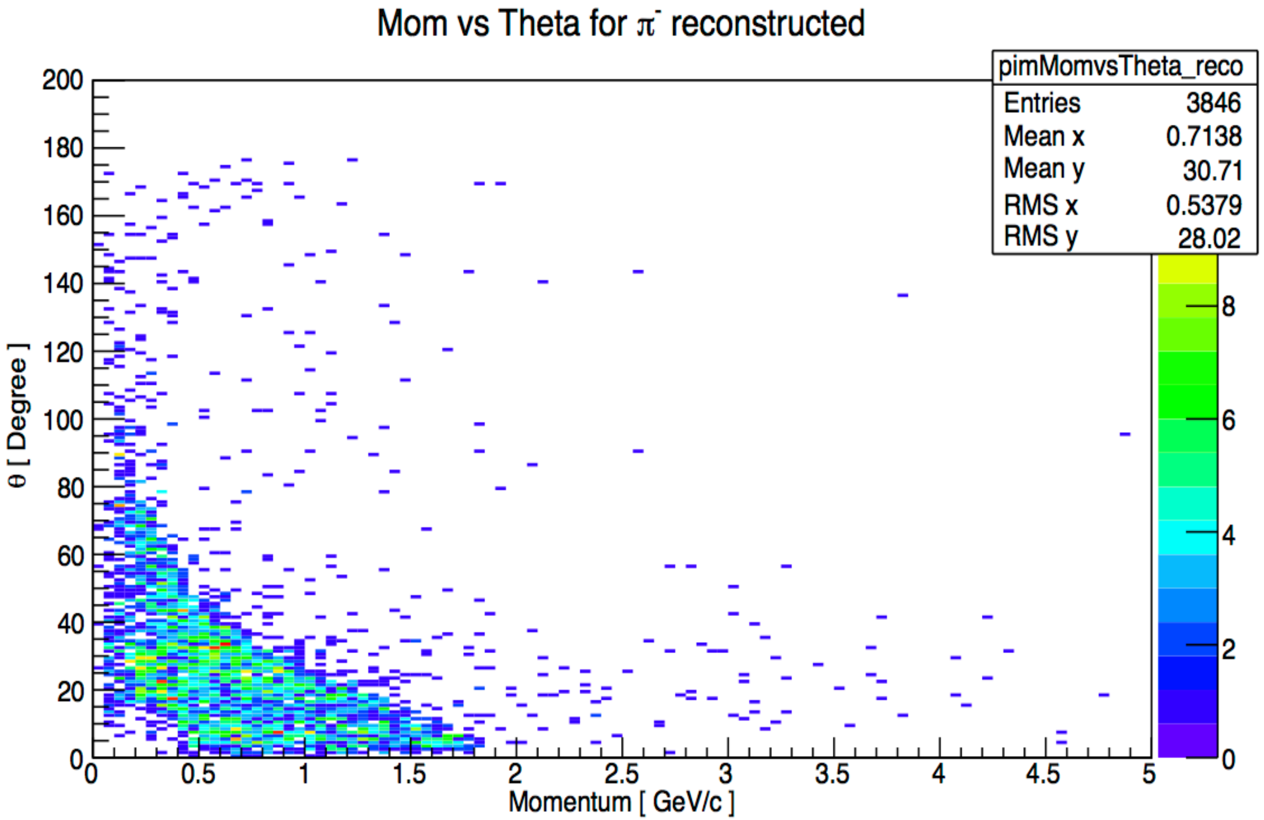
Λ DECAY MODES		Fraction (Γ_i/Γ)	p (MeV/c)
$p\pi^-$		(63.9 ± 0.5) %	101
$n\pi^0$		(35.8 ± 0.5) %	104
$n\gamma$		$(1.75 \pm 0.15) \times 10^{-3}$	162
$p\pi^-\gamma$	[c]	$(8.4 \pm 1.4) \times 10^{-4}$	101
$pe^-\overline{\nu}_e$		$(8.32 \pm 0.14) \times 10^{-4}$	163
$p\mu^-\overline{\nu}_\mu$		$(1.57 \pm 0.35) \times 10^{-4}$	131

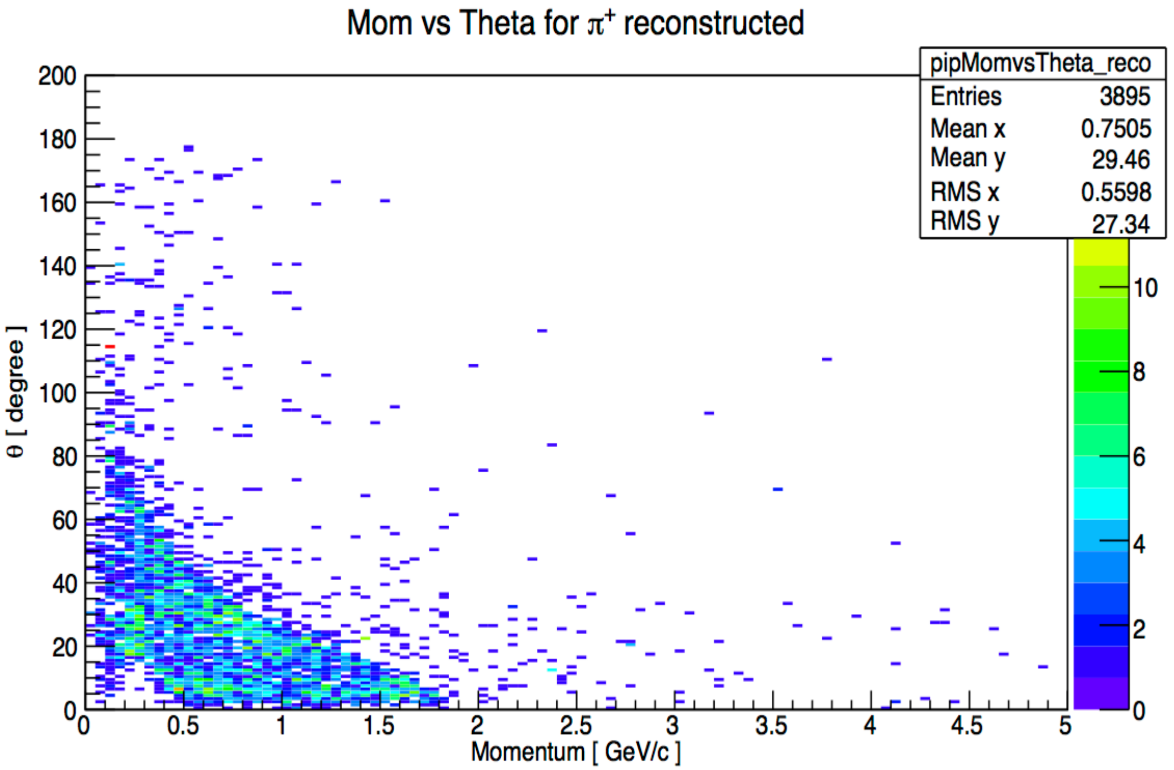
Momentum vs theta





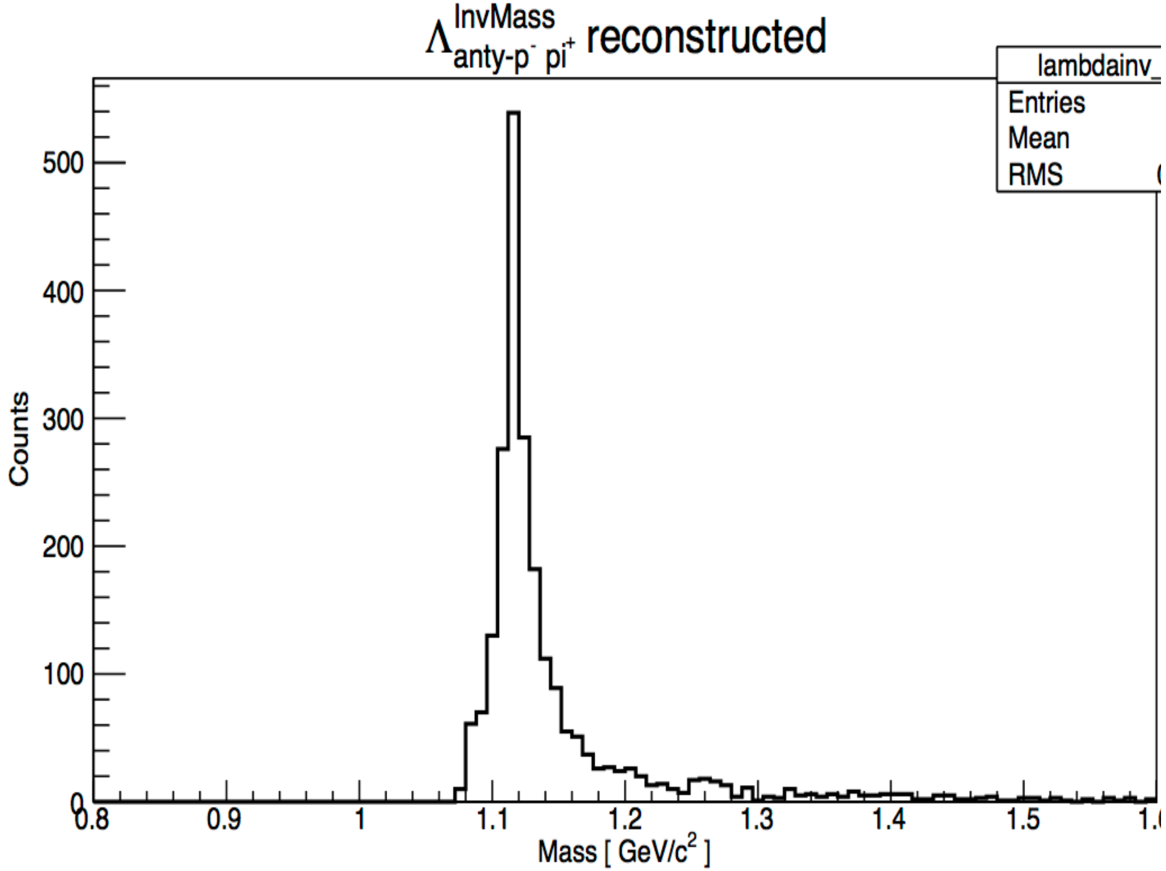
Momentum vs theta

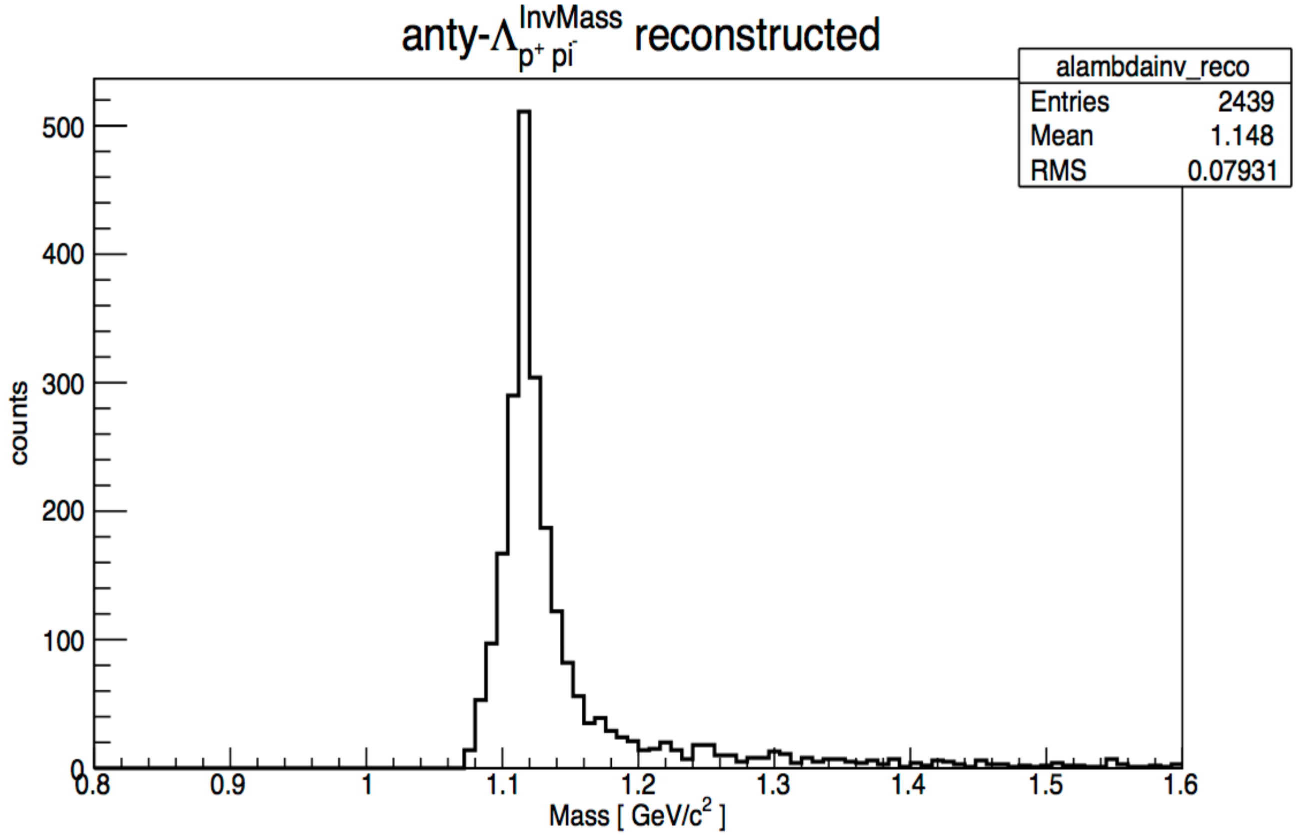




The pions and protons go at low theta angle

Invariant mass reconstruction



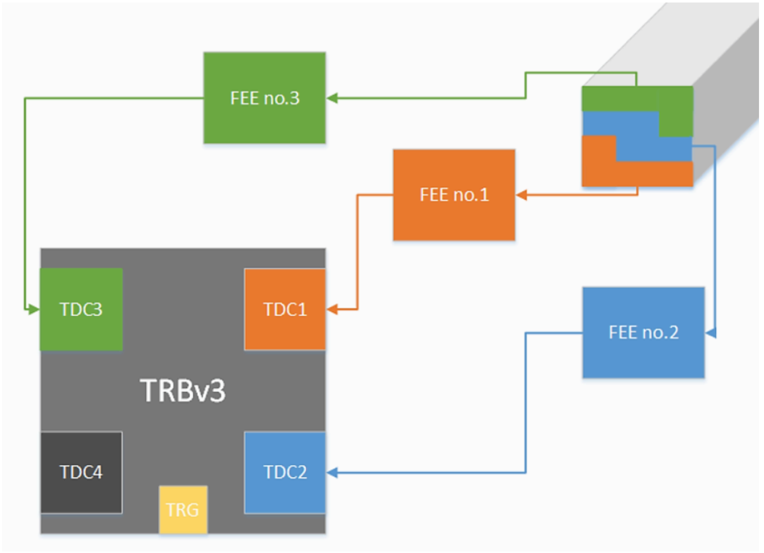


25% of Lambdas reconstructed

1st Conclusions

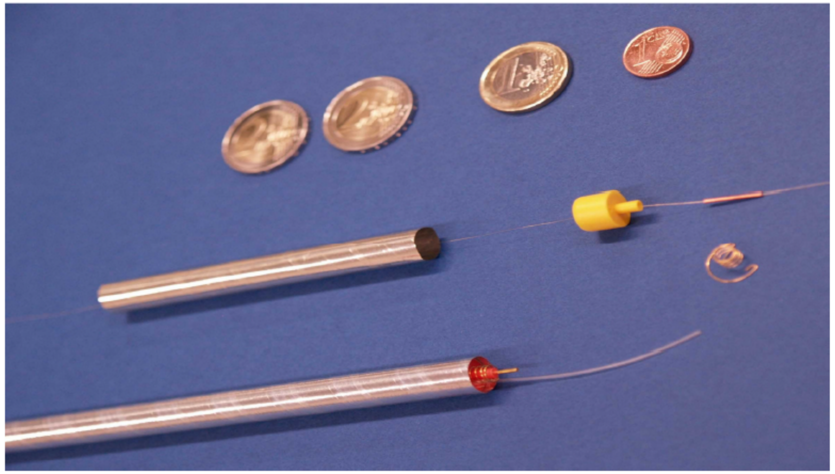
- Necessary to reconstruct states above the open charm threshold
- High momentum resolution
- Important for double lambda production etc.

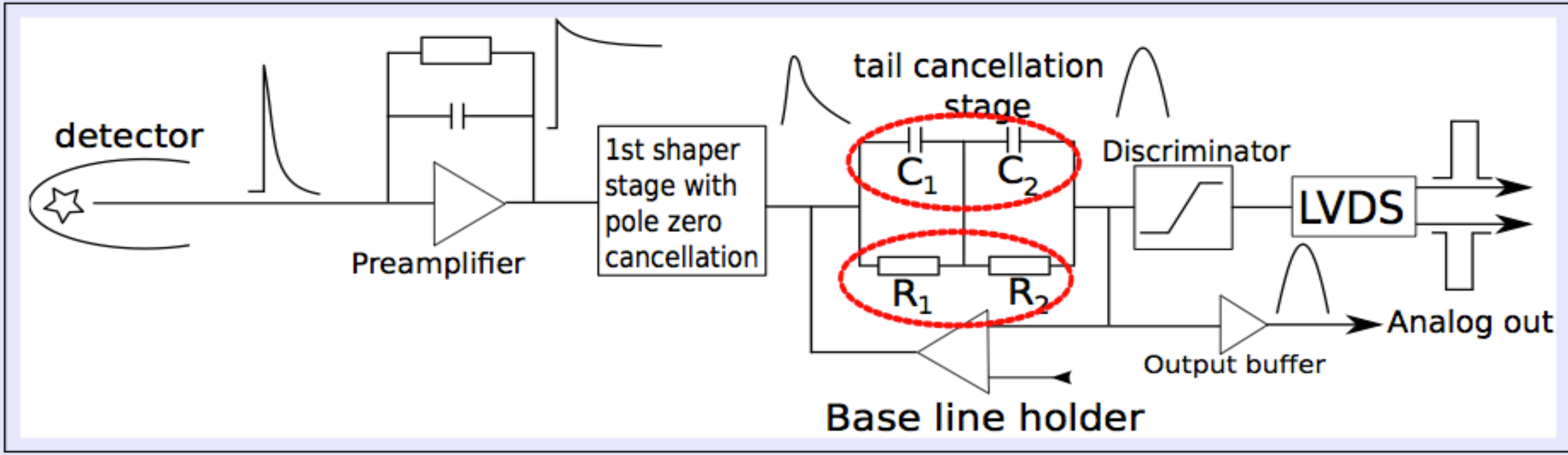
Straw tube tracker prototype tests at Forschungzentrum Juellich



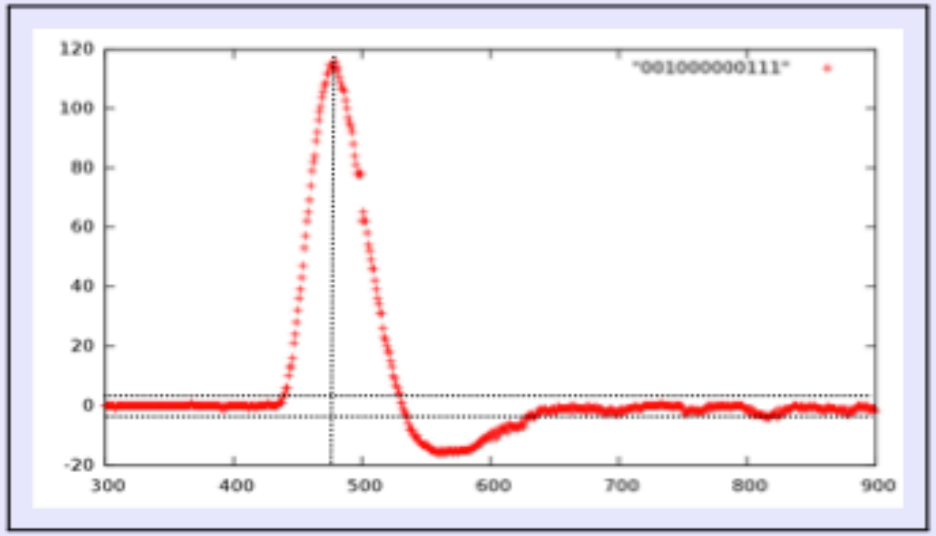
The Detector:

- Consists of 96 straw tube detectors
- Arranged in 8 layers each layer consists of 12 straws
- Each straw is filled witch a Ar / CO_2 (90%/10%) gas mixture at 2 bar overpressure
- Each straw tube operates in „proportional counter" mode
- A setup of 3x ASIC boards (developed by AGH Cracow) and one TRBv3 HADES board



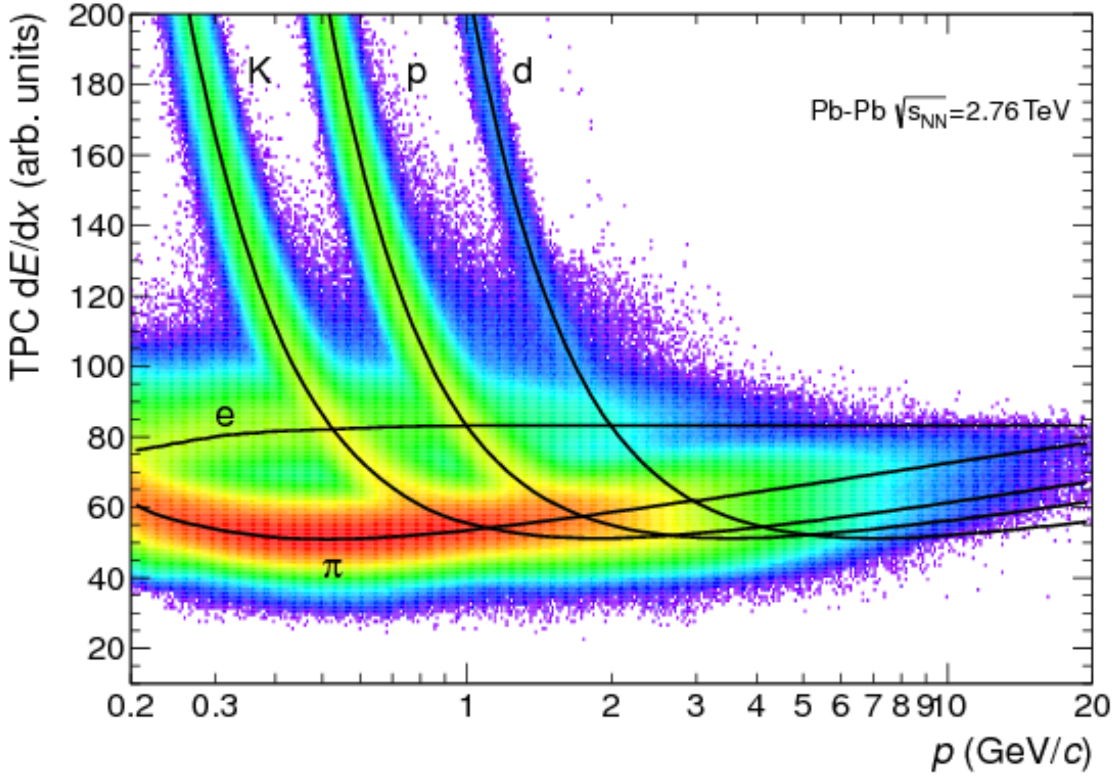


- Threshold 1.28 V, base line 1.20 V
- Tail cancellation $Rt_1 = 31k\Omega; Rt_2 = 11k\Omega; Ct_1 = 6pF; Ct_2 = 1.2pF$



Goals of the measurement

- Can we use the straw tube tracker to identify different particles?
- Can we measure energy loss by Time over Threshold ?

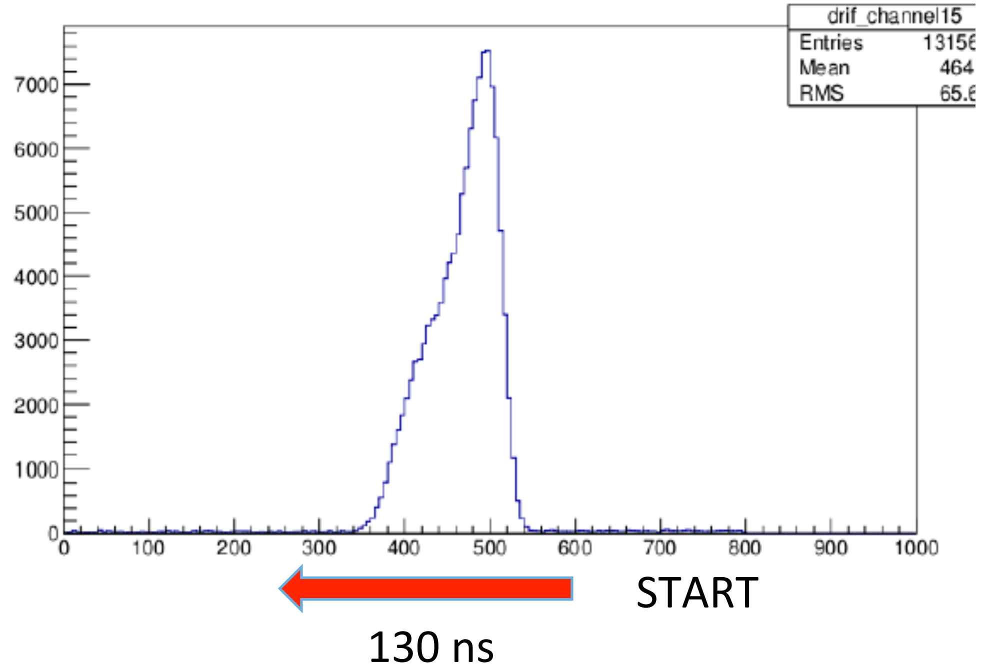


The collected data

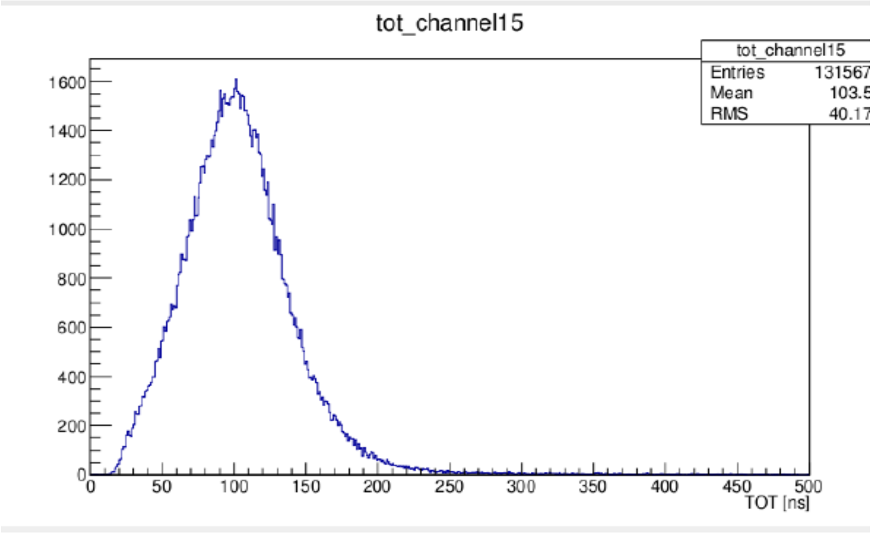
- HV on the detector was set at 1700V up to 1900V
- Intensity of the proton beam at COSY from 10kHz up to 1MHz per bunch
- Beam momenta starting from 0.6 GeV/c up to 2.95 GeV/c

Data taken for 0.9 GeV/c at HV 1900V will be presented

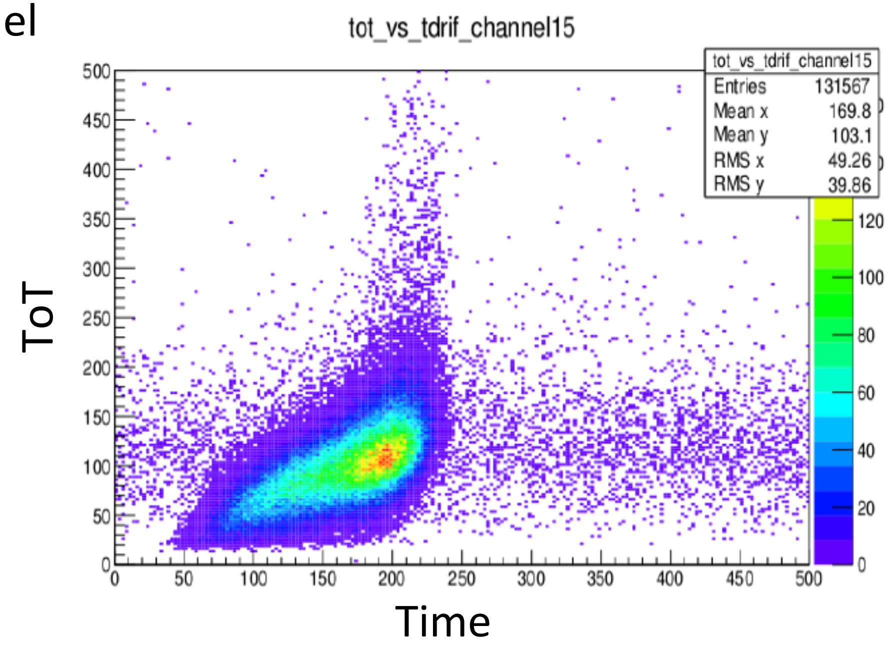
Time over threshold & electron drift time distributions



Electron drift time spectrum in a expected time range



Quasi Gaussian ToT distribution from a single channel

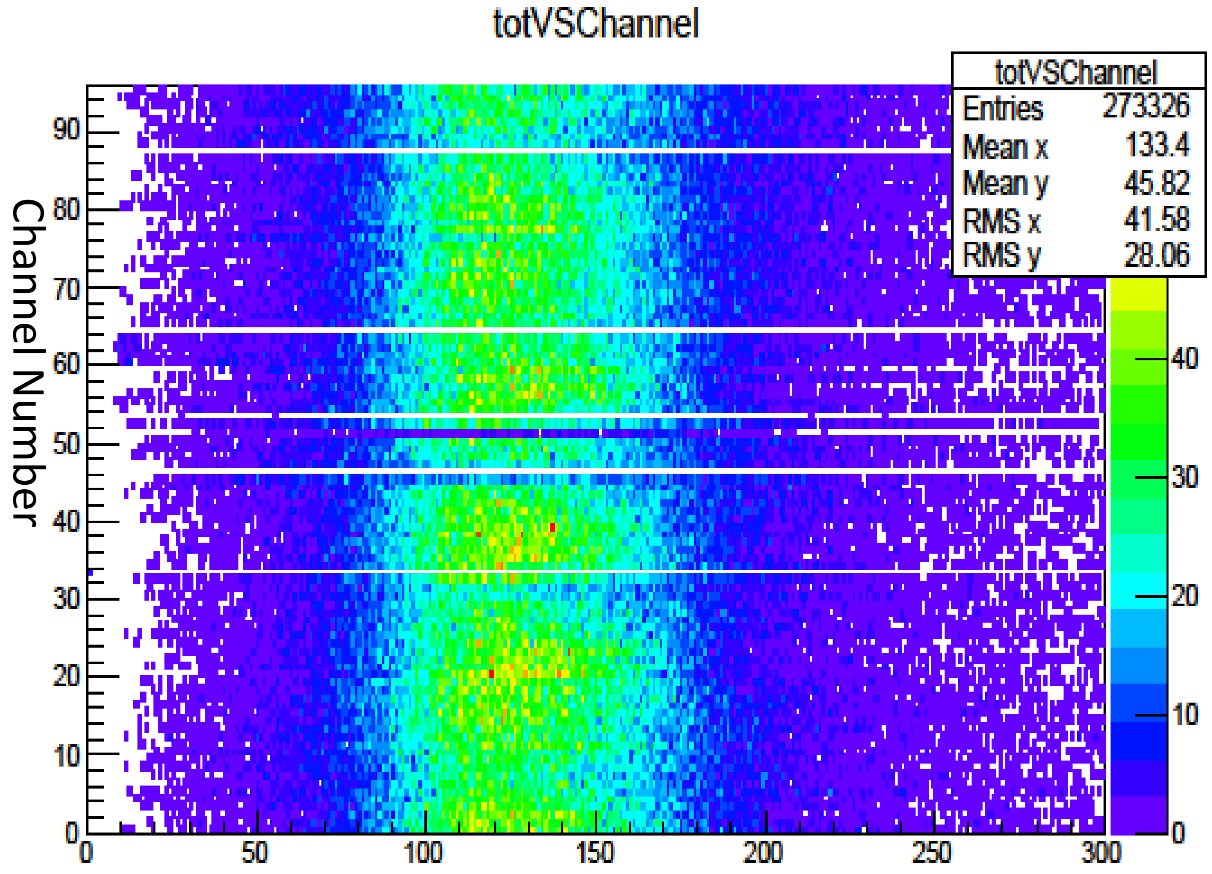


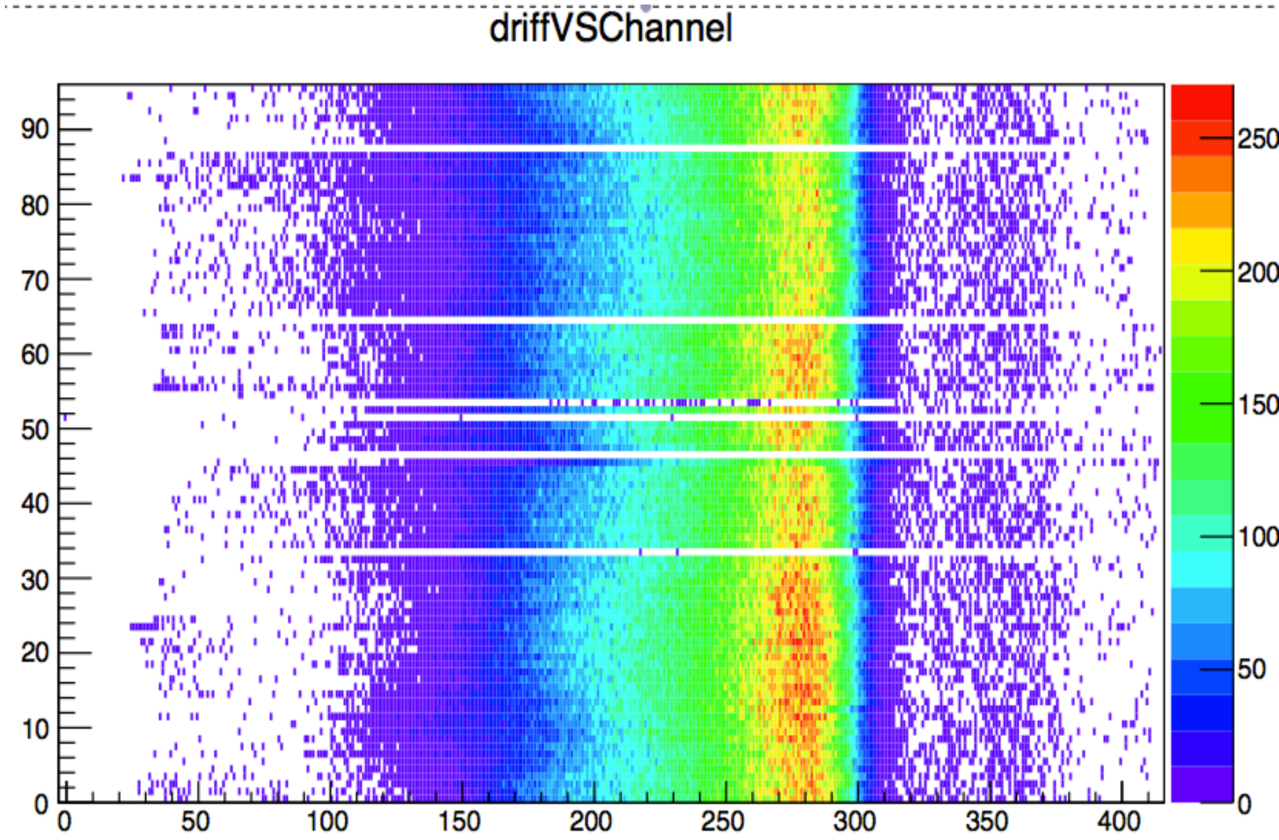
Sr^{90} tests, December 2013

Preparing Data

- Electron drift spectra were calculated for all channels
- Each channel was fitted with a 8 parameter function to calculate the rise time of the spectrum (later referred as „walk”), the function was not used to calibrate the detector (values of start and „end” time of the spectrum was selected manually)
- Spectra from all channels were aligned to start at time 0 (to compensate the error in threshold setting of each channel)

Alignment correction

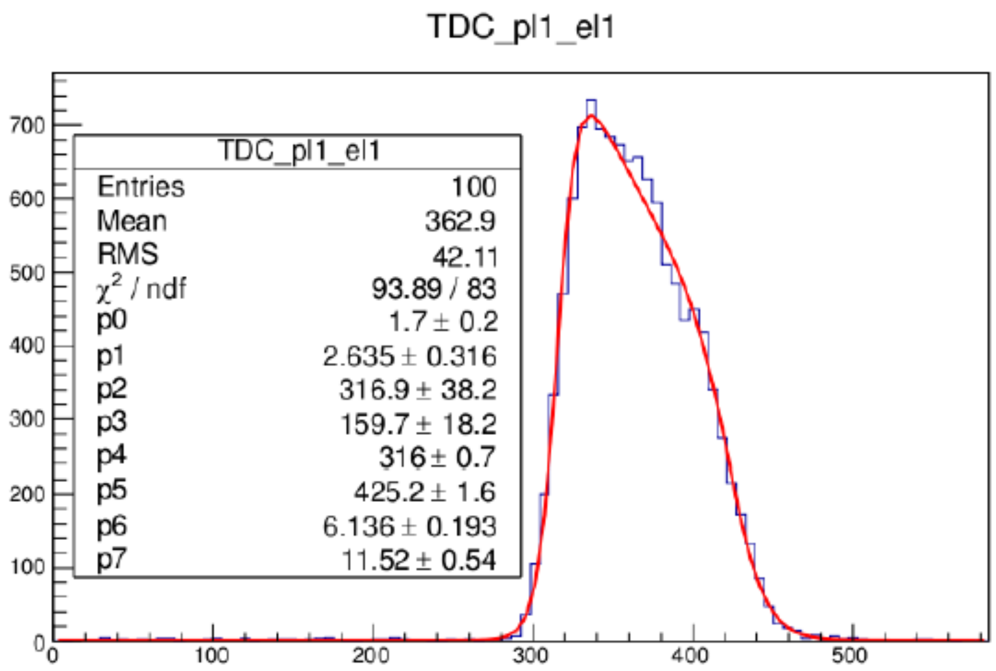




The 8 parameter Fermi like function

$$\frac{\mathrm{d}n}{\mathrm{d}t} = P_1 + \frac{P_2\left[1 + P_3 \exp((P_5 - t)/P_4)\right]}{\left[1 + \exp((P_5 - t)/P_7)\right]\left[1 + \exp((t - P_6)/P_8)\right]},$$

- P1- noise
- P2- normalization factor
- P3-related to the shape
- P4- related to the shape
- P5- t0
- P6- t max
- P7- leading edge raise time
- P8- trail time



2^{nd} step, preforming the D(t) calibration

A D(t) curve was obtained using the uniform irradiation method, as it is described by the formula below:

$$D(t) = R_{wire} + (R_{tube} - R_{wire}) \cdot \frac{\int_0^t n(t)dt}{\int_0^{T_{max}} n(t')dt'}$$

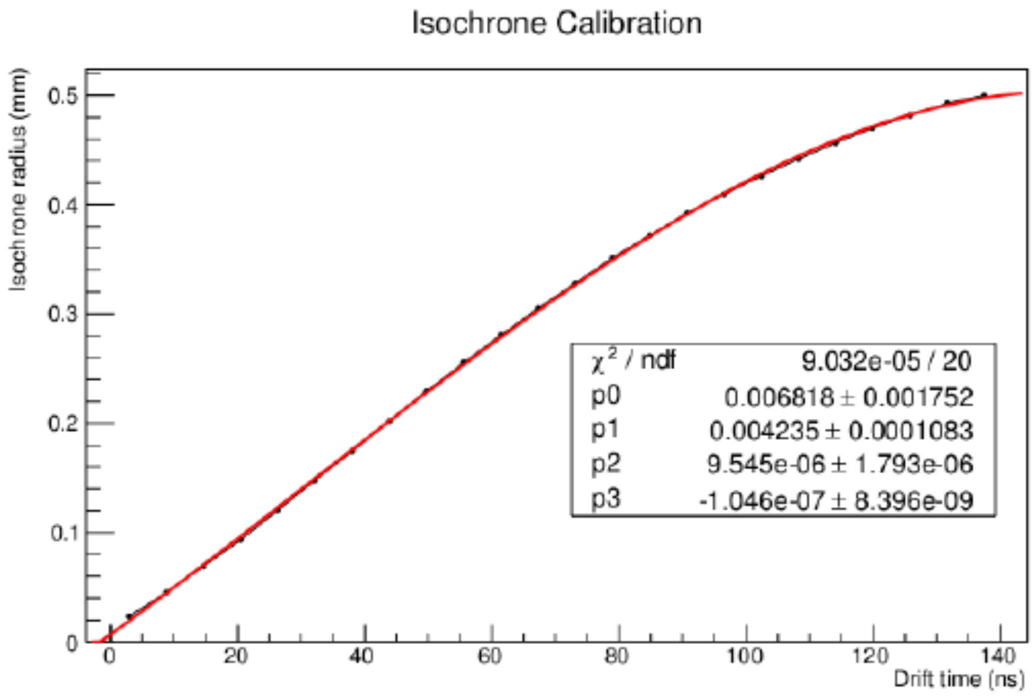
R_{wire} - anode diameter

R_{tube} – tube diameter.

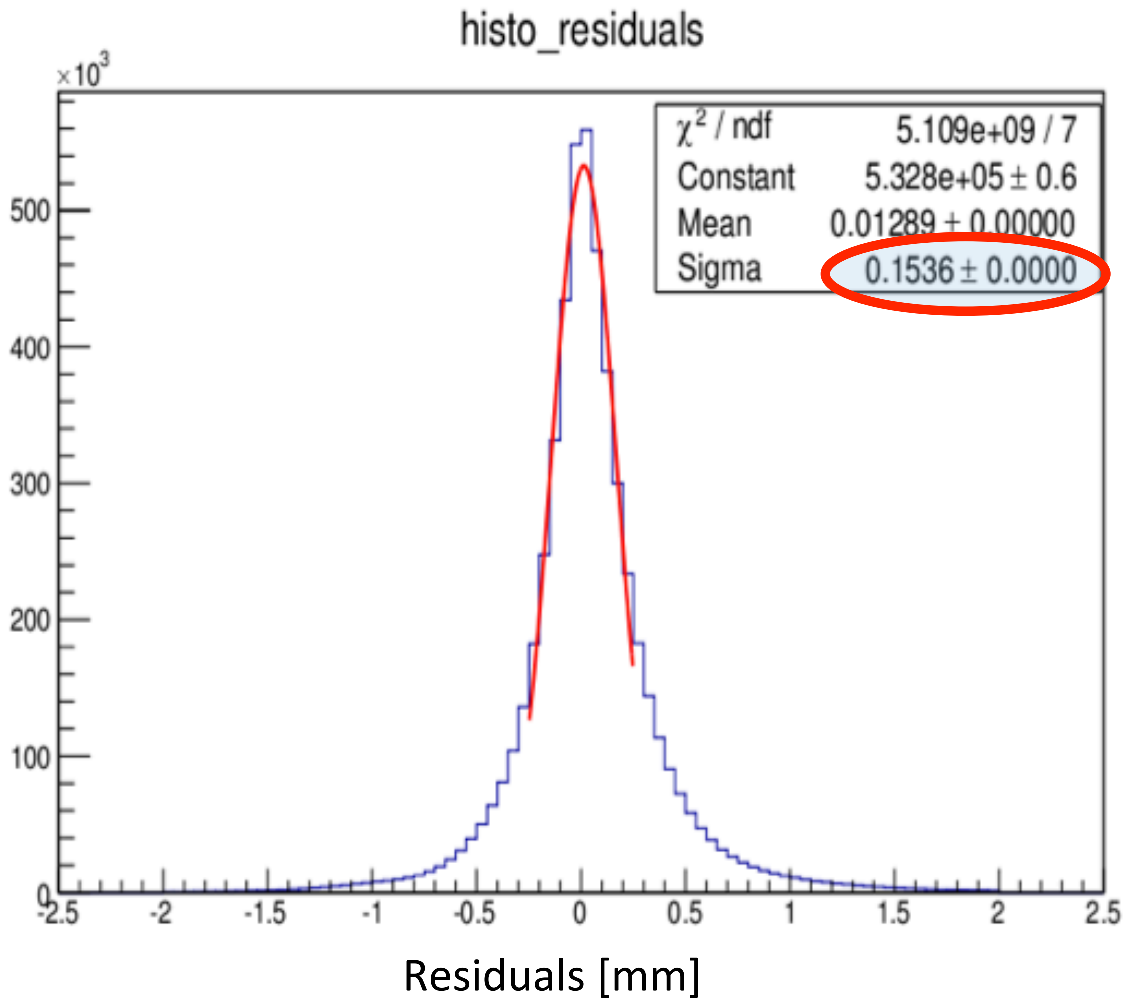
t – time in with the spectrum was measured

n(t) – number of events registered at time t.

T_{max} – maximum drift time.



80% of track were reconstructed (10 straw track taken in to consideration),tracks are lost due to high threshold setting (signals coming form particles crossing the tube close the anode wire are lost), sigma calculated from the Gaussian fit represents the spatial resolution



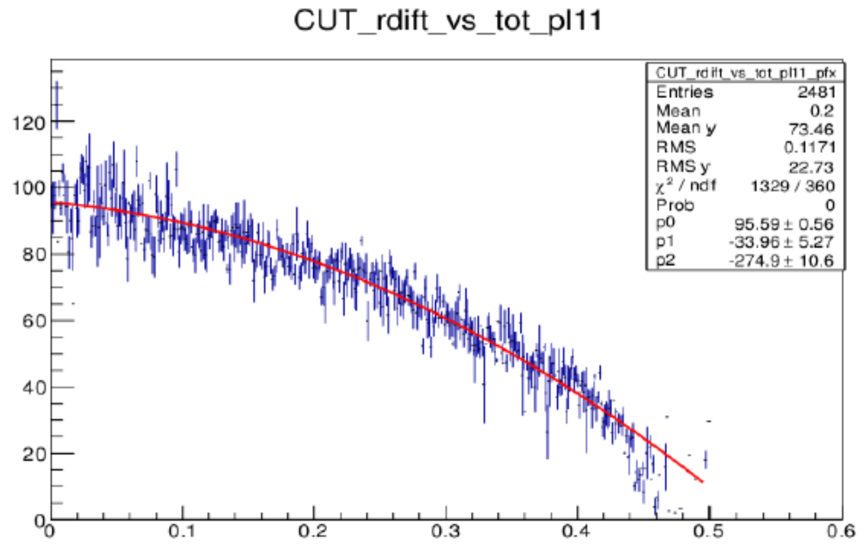
Time over Threshold analysis

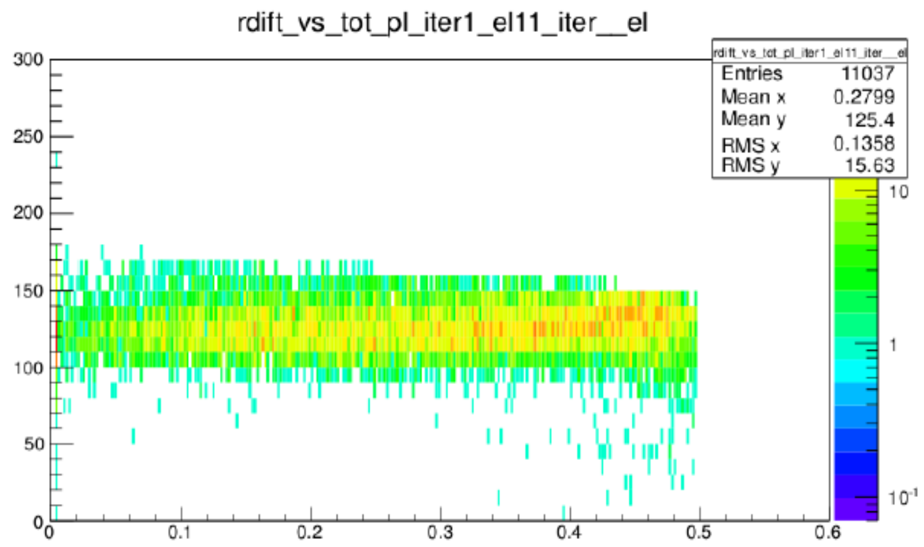
- After tracking one can calculate the ToT vs drift radius distributions (as shown below)

- To lose the dependency of ToT to the distance from the anode wire one can calibrate via 2nd degree polynomial

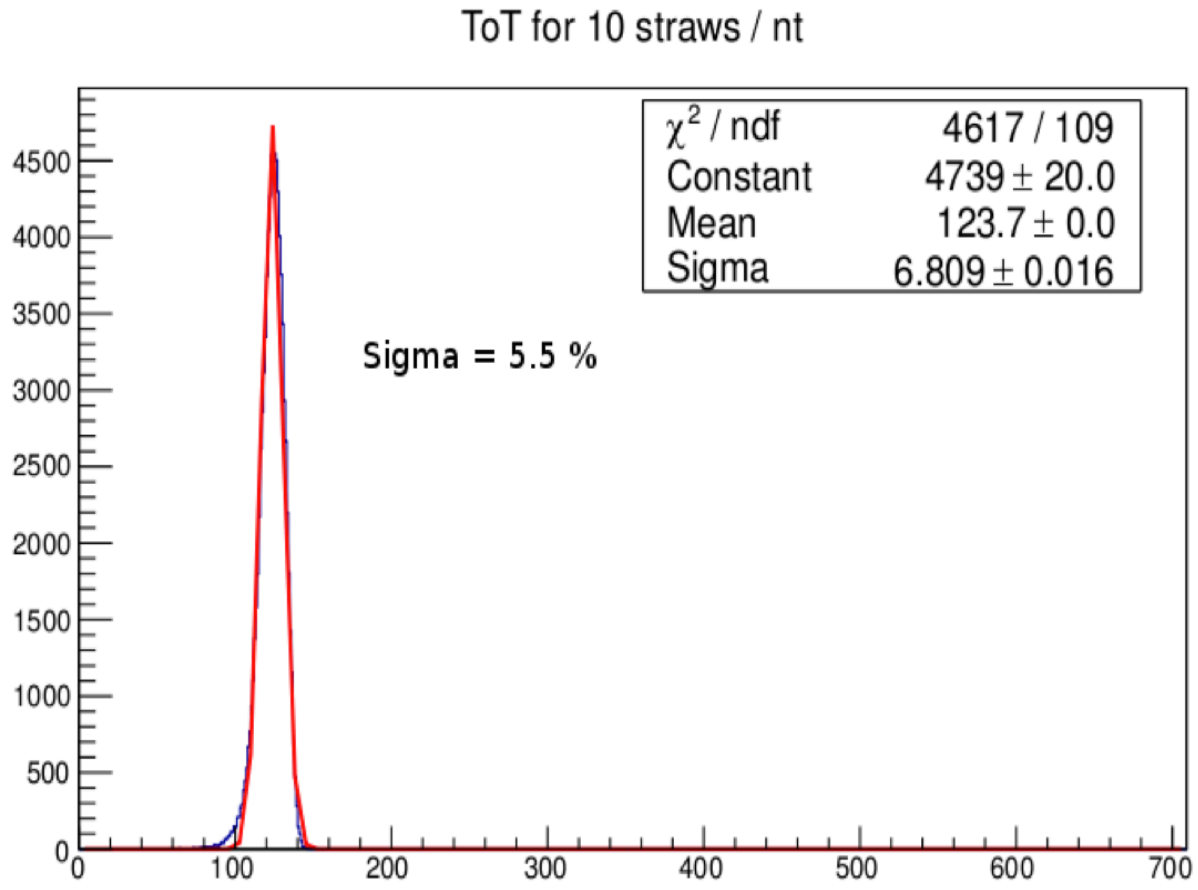
By fitting a 2nd degree poly to the ToT vs. rdrift plot one obtains a function of ToT(tdrif) with is used to calibrate the ToT and in effect one drops the dependence of ToT from the center of the tube

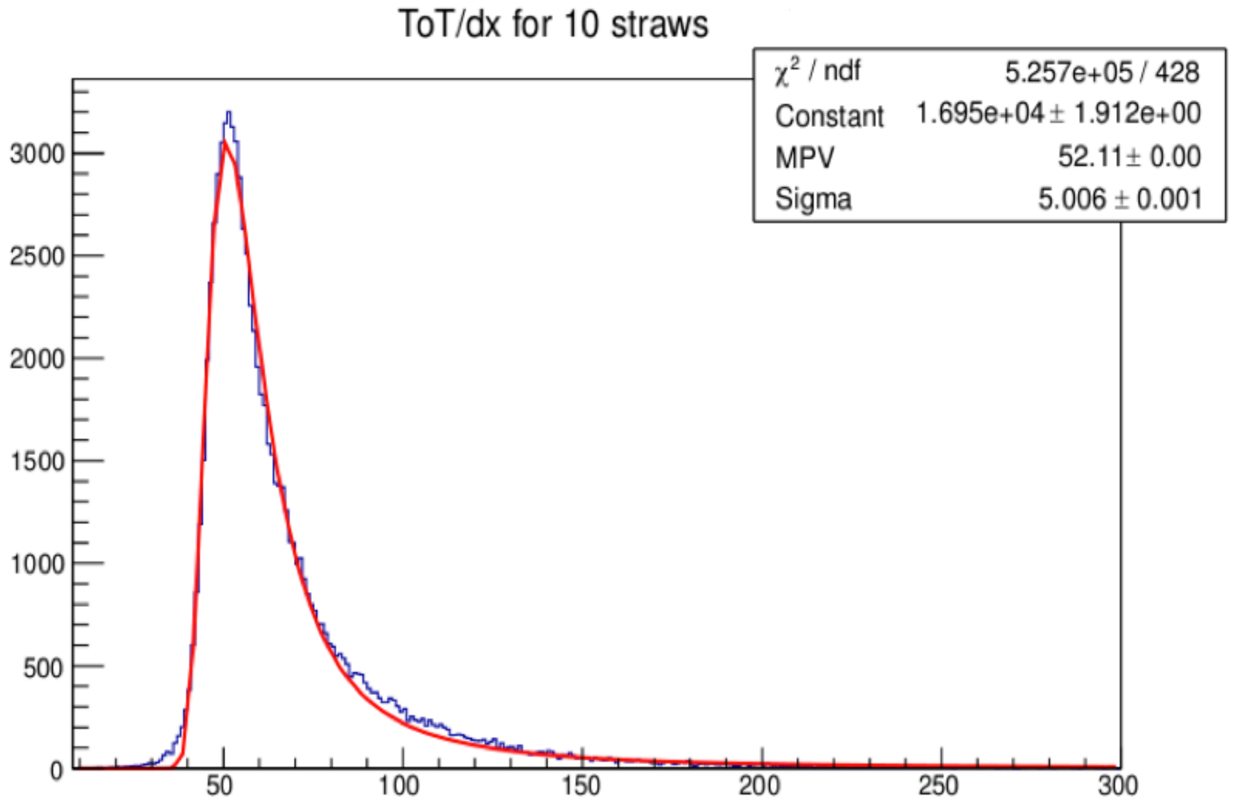
- As a result one obtains a distribution shown on the second figure





- Spectra for 10 straw tracks were calculated
- ToT/dx and ToT distributions were made
- Landau like shape of ToT/dx (expected due to the fact of linear relation between ToT vs dE at 1900V (4 pC for 900 MeV/c protons)) shows that dx is calculated as it should be



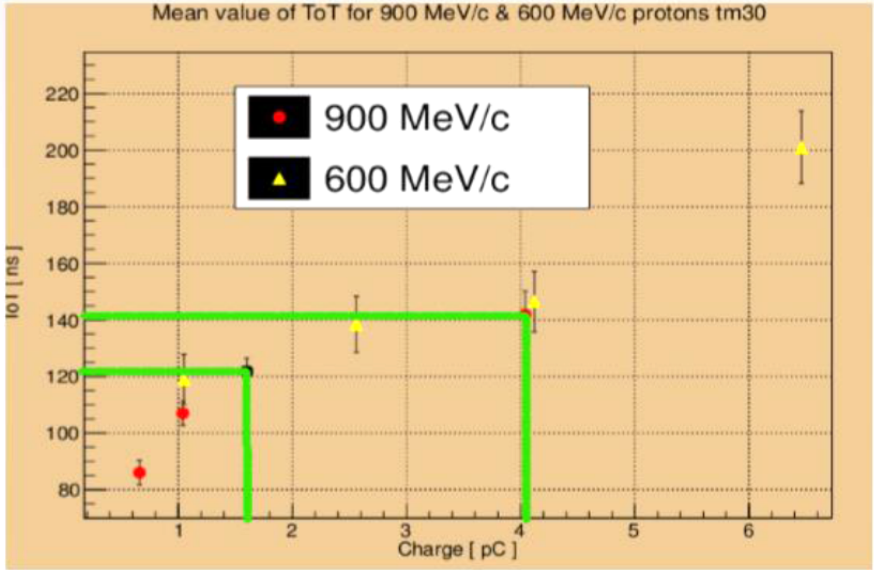


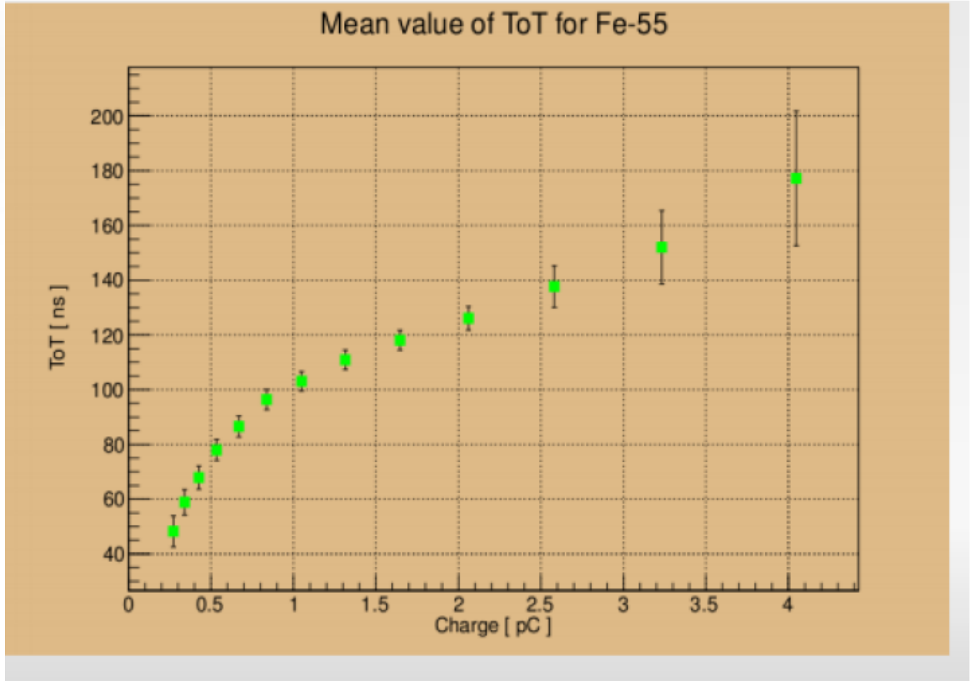
ToT vs Energy loss calculations

Reminder: ToT vs Energy Loss distributions (dE with the Bethe- Bloh formula)

on the left data from the proton beam and on the right data coming form the Fe-55 source

$$\frac{\delta E}{E} = \frac{\sigma ToT_1}{ToT_2 - ToT_1} * \left(\frac{Q_2 - Q_1}{Q_1}\right)$$

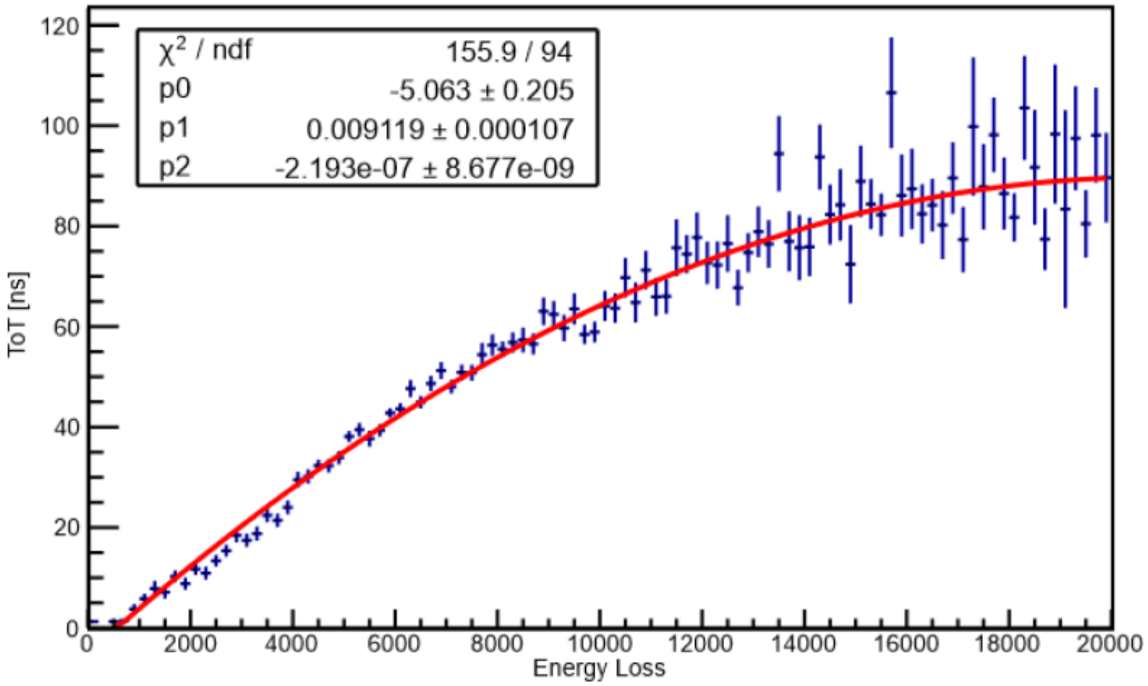




ToT (R = 9.8% for Fe-55 and 11% for 900 MeV/c protons)

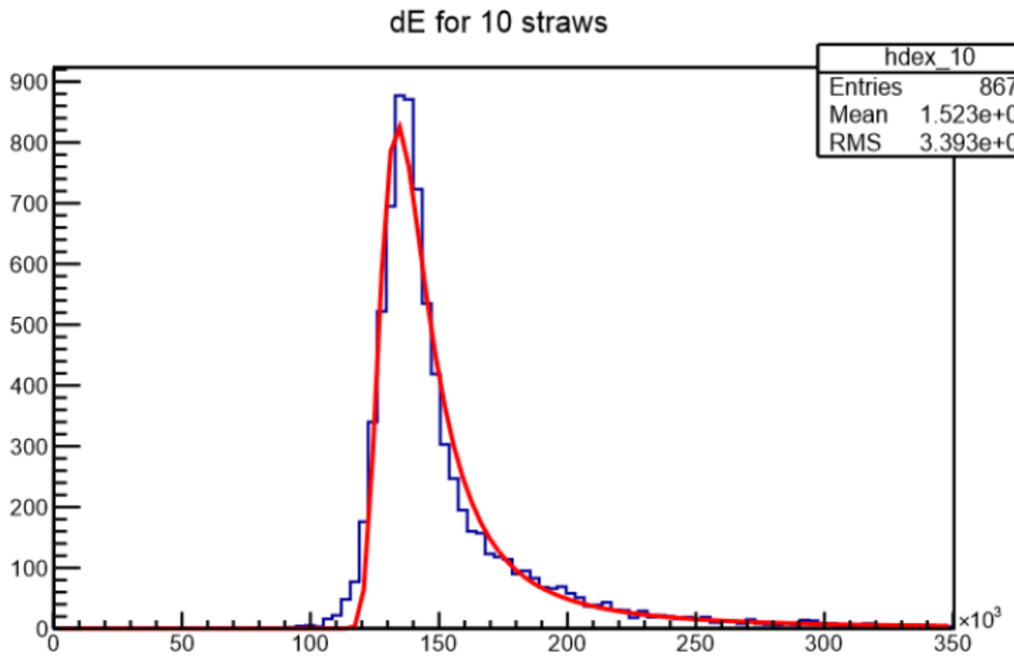
Energy resolution study

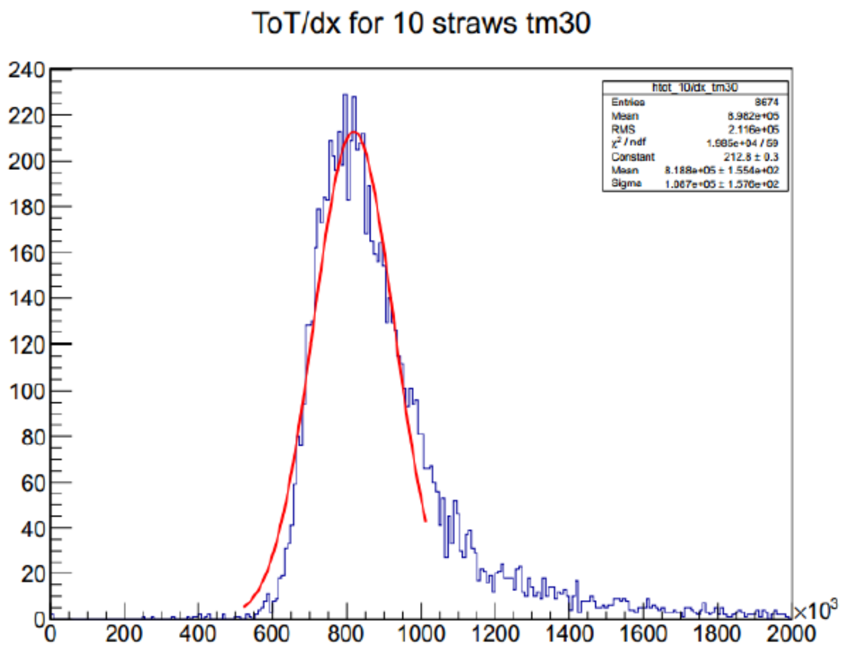
- Data coming from the Flash ADC, ToT (done by software) vs Energy Loss distributions were made for each channel.
- The plot was fitted with a second degree polynomial to obtain the calibration function



Tracking results-> Energy Resolution

- dE/dx distributions were made for the TRB + ASIC data with the use of the obtained function
- The distribution follows the expected Landau shape
- Truncated mean was preformed (30% „cut off”)
- R = 12% (for 10 straw tracks)

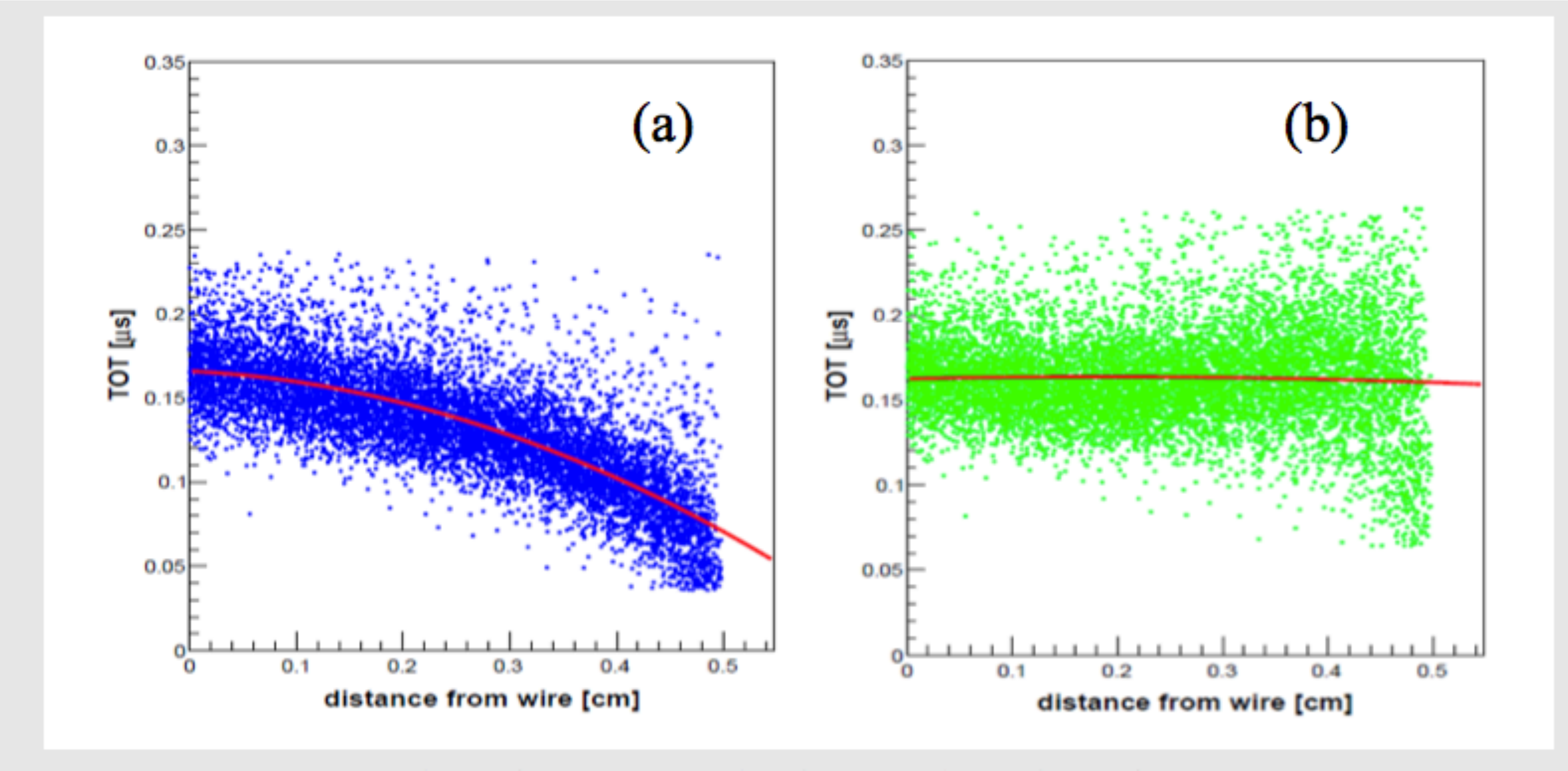




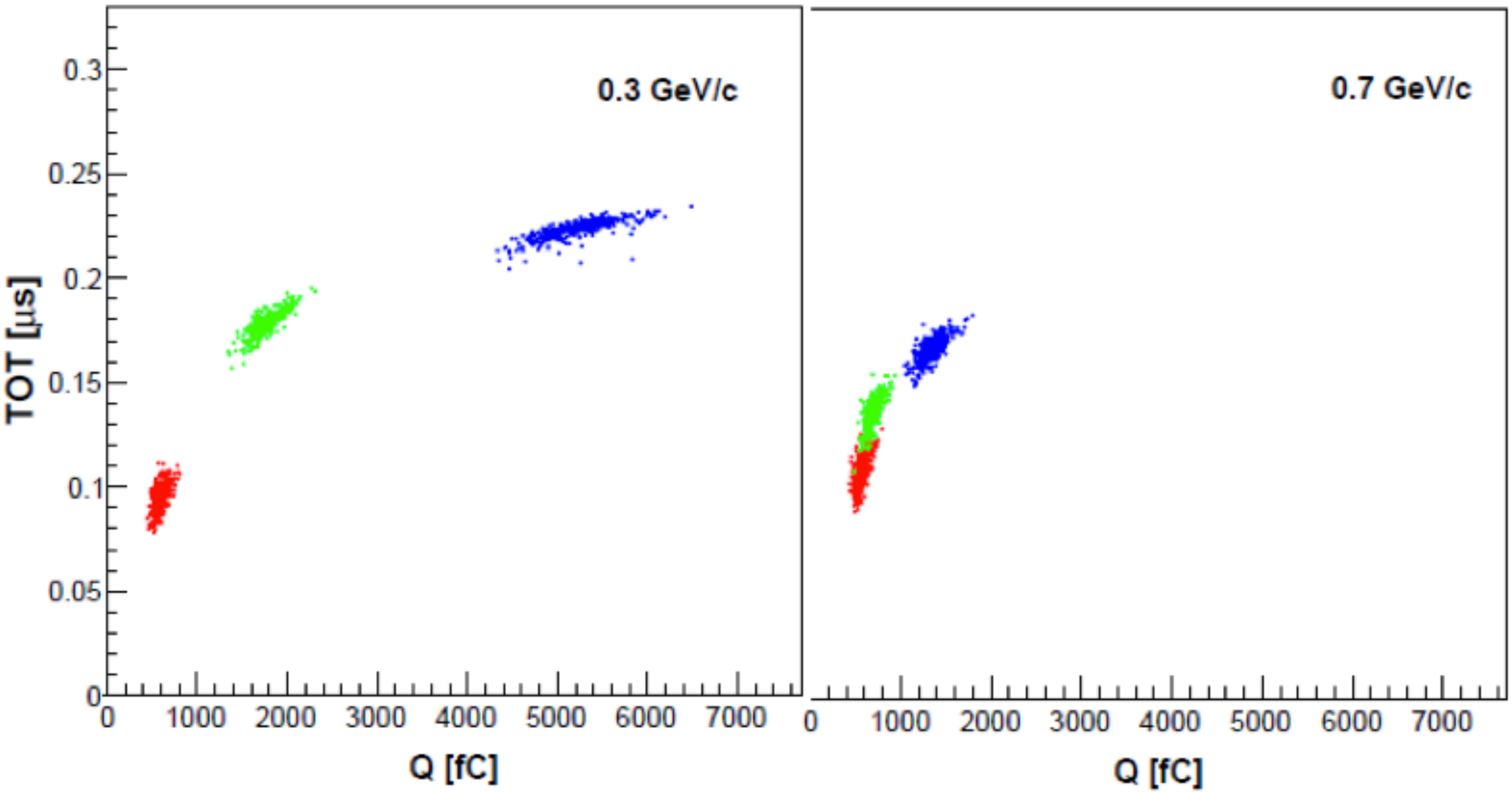
Conclusions

- Spatial resolution is at a acceptable ~153 um
- Reconstruction efficiency is at 80%
- ToT measurements show reasonable time resolution at 5%
- One can measure energy loss with ToT
- Different energy loss calibration show consistent results with a resolution of 10% to 12%

Backup



(a)
TOT [µs]
distance from wire [cm]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
(b)
TOT [µs]
distance from wire [cm]


0.3 GeV/c
0.7 GeV/c
TOT [µs]
Q [fC]
Q [fC]
0
0.05
0.1
0.15
0.2
0.25
0.3
0
1000
2000
3000
4000
5000
6000
7000