Mitglied der Helmholtz-Gemeinschaft

JÜLICH FORSCHUNGSZENTRUM

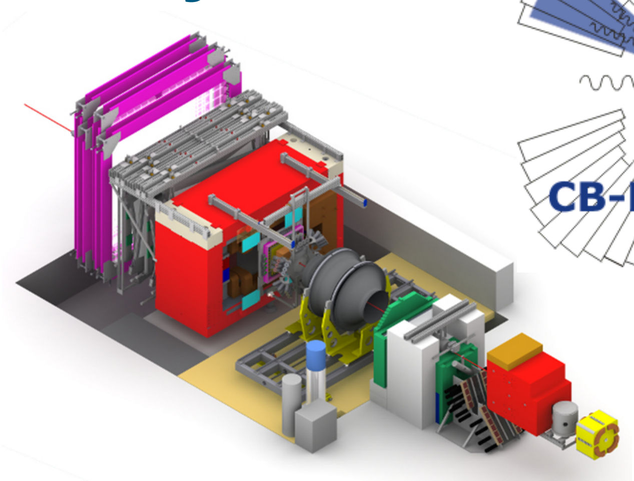
The Potential for Baryon Spectroscopy at PANDA and the „Day-1 Setup“

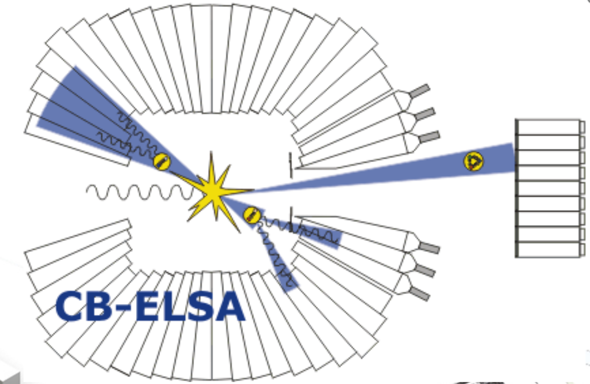
Sep 14, 2016 | Albrecht Gillitzer, IKP Forschungszentrum Jülich

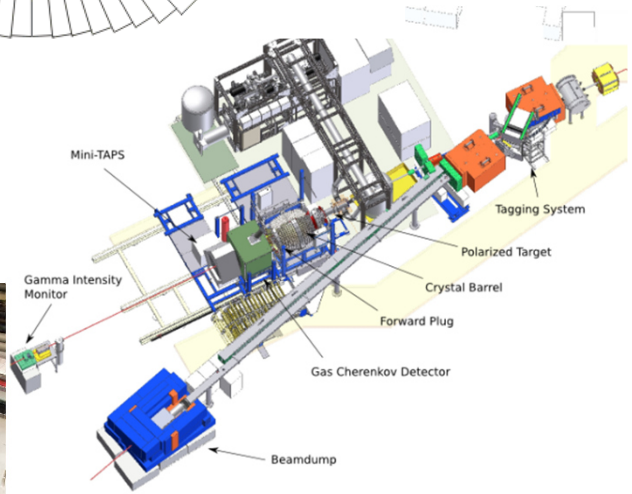
LVIII PANDA Meeting, Mainz, September 2016

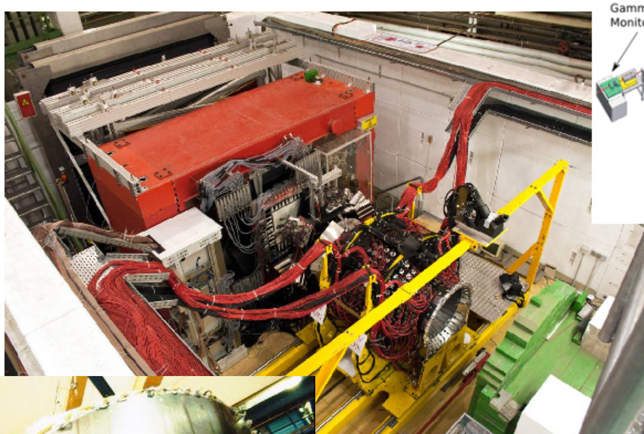
Why to be Interested in Baryons?

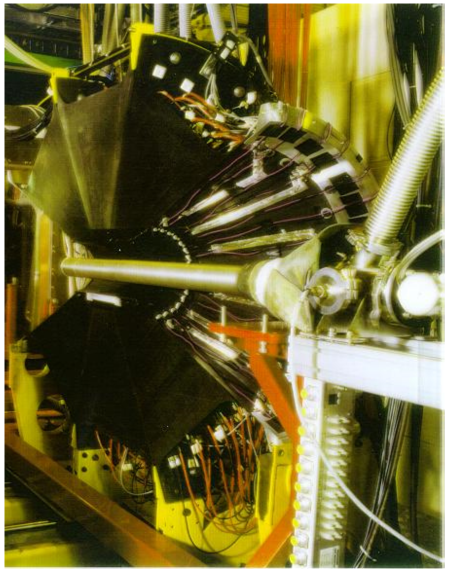
- No understanding of strong interaction without understanding the excitation pattern of baryons!
- Strong worldwide activity in „Baryon Spectroscopy“ with photo-induced reactions

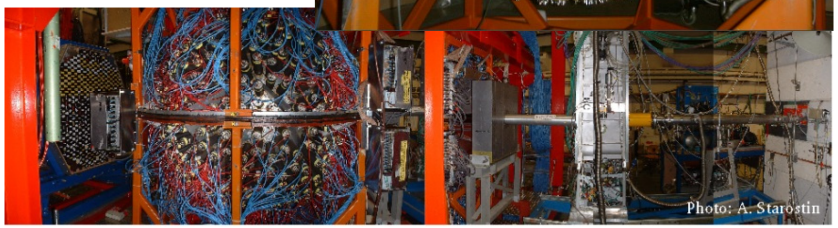












Achievements in N* Spectroscopy

$N(1875)\frac{3}{2}^-$ or $N(1875)D_{13}$

$N(1875)\frac{3}{2}^-$ pole parameters (MeV)			
M_{pole}	1860±25	Γ_{pole}	200±20
Elastic pole residue	2.5±1.0	Phase	not defined
$2\,\text{Res}_{\pi N\to\Lambda K}/\Gamma$	1.5±0.5%	Phase	not defined
$2\,\text{Res}_{\pi N\to\Sigma K}/\Gamma$	4±2%	Phase	not defined
$2\,\text{Res}_{\pi N\to N\sigma}/\Gamma$	8±3%	Phase	−(170±65)°
$A^{1/2}$ ($\text{GeV}^{-\frac{1}{2}}$)	0.018±0.008	Phase	−(100±60)°
$A^{3/2}$ ($\text{GeV}^{-\frac{1}{2}}$)	0.010±0.004	Phase	(180±30)°
$N(1875)\frac{3}{2}^-$ Breit-Wigner parameters (MeV)			
M_{BW}	1880±20	Γ_{BW}	200±25
$\text{Br}(N\pi)$	3±2%	$\text{Br}(N\eta)$	5±2%
$\text{Br}(\Lambda K)$	4±2%	$\text{Br}(\Sigma K)$	15±8%
$\text{Br}(N\sigma)$	60±12%		
$A^{1/2}_{BW}$ ($\text{GeV}^{-\frac{1}{2}}$)	0.018±0.010	$A^{3/2}_{BW}$ ($\text{GeV}^{-\frac{1}{2}}$)	−0.009±0.005

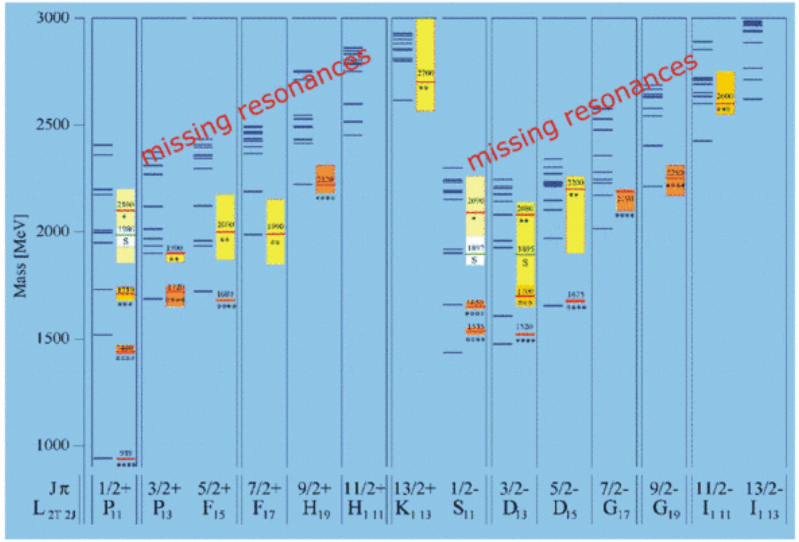
	All	πN	γN	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\sigma$
$N(1875)\frac{3}{2}^-$	★★★	★	★★★		★★★	★★		★★★

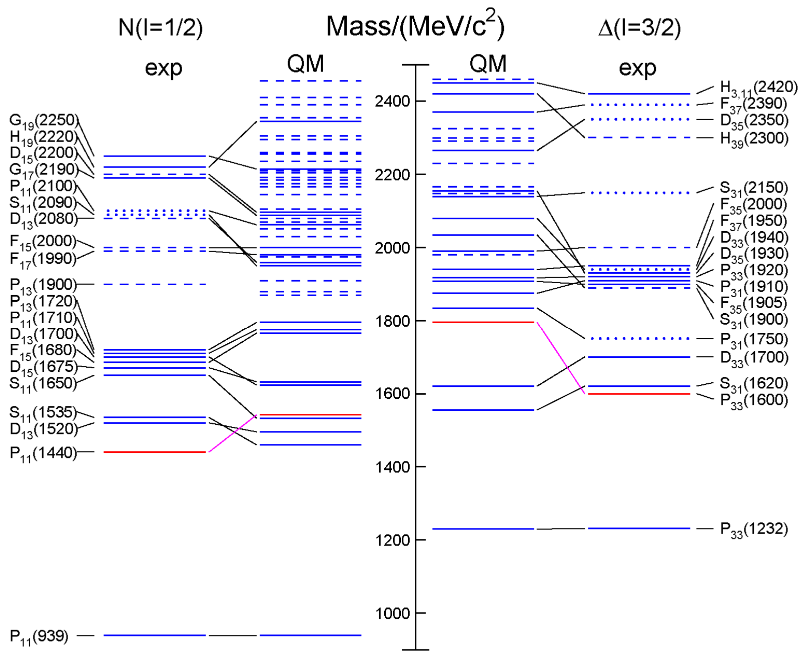
BnGa PWA:
A.V. Anisovich *et al.*, EPJA 48 (2012) 15

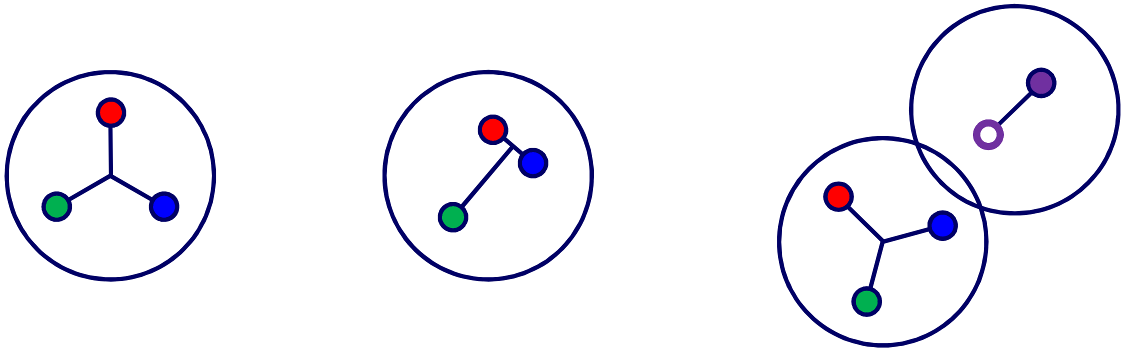
N^*	J^P ($L_{2I,2J}$)	2010	2014
N(1440)	$1/2^+$ (P_{11})	* * **	* * **
N(1520)	$3/2^-$ (D_{13})	* * **	* * **
N(1535)	$1/2^-$ (S_{11})	* * **	* * **
N(1650)	$1/2^-$ (S_{11})	* * **	* * **
N(1675)	$5/2^-$ (D_{15})	* * **	* * **
N(1680)	$5/2^+$ (F_{15})	* * **	* * **
N(1685)			*
N(1700)	$3/2^-$ (D_{13})	* * *	* * *
N(1710)	$1/2^+$ (P_{11})	* * *	* * *
N(1720)	$3/2^+$ (P_{13})	* * **	* * **
N(1860)	$5/2^+$		**
N(1875)	$3/2^-$		* * *
N(1880)	$1/2^+$		**
N(1895)	$1/2^-$		**
N(1900)	$3/2^+$ (P_{13})	**	* * *
N(1990)	$7/2^+$ (F_{17})	**	**
N(2000)	$5/2^+$ (F_{15})	**	**
~~N(2080)~~	D_{13}	**	
~~N(2090)~~	S_{11}	*	
N(2040)	$3/2^+$		*
N(2060)	$5/2^-$		**
N(2100)	$1/2^+$ (P_{11})	*	*
N(2120)	$3/2^-$		**
N(2190)	$7/2^-$ (G_{17})	* * **	* * **
~~N(2200)~~	D_{15}	**	
N(2220)	$9/2^+$ (H_{19})	* * **	* * **

Open Questions

- Missing resonances
- Wrong masses, wrong sequence
- Relevant degrees of freedom?
  - 3-quark?
  - quark-diquark?
  - meson-baryon dynamics





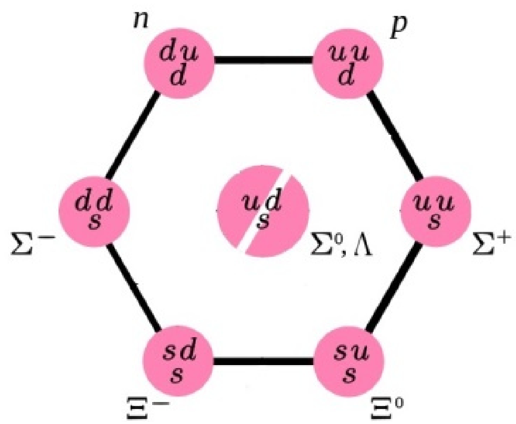


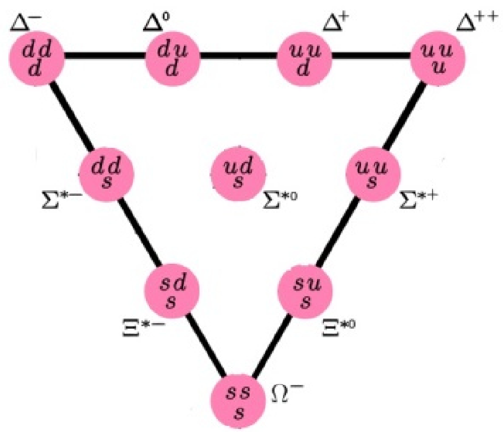
from RPP 2014 / QM: S. Capstick, W. Roberts

Strange Partners

- Approximate SU(3) flavor symmetry
- N* & Δ states have partners in the strange sector
- focus on Ξ and Ω
  - Ξ: as many states as N* & Δ together (1)
  - Ω: as many states as Δ
- scrutinize our understanding of the baryon excitation pattern

(1) in case of SU(3) symmetry !





Quark Model for Ξ & Ω

Ξ:

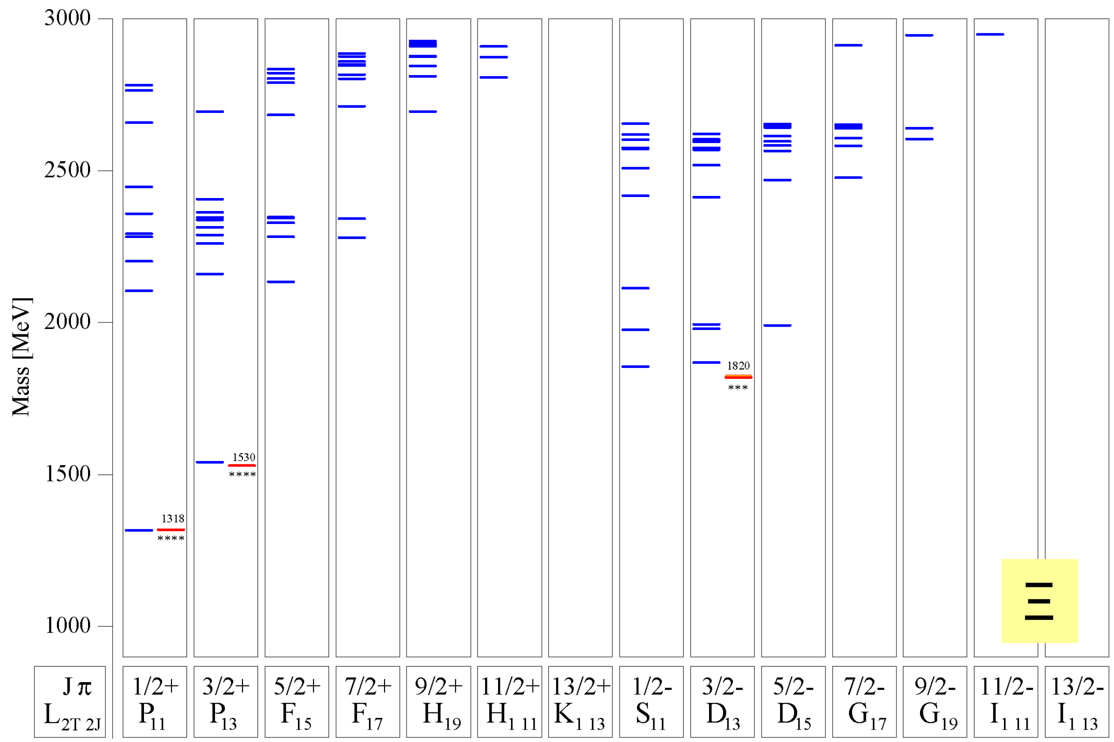
- many states predicted below 3 GeV
- compare $1/2^+$ and $1/2^-$ excitation

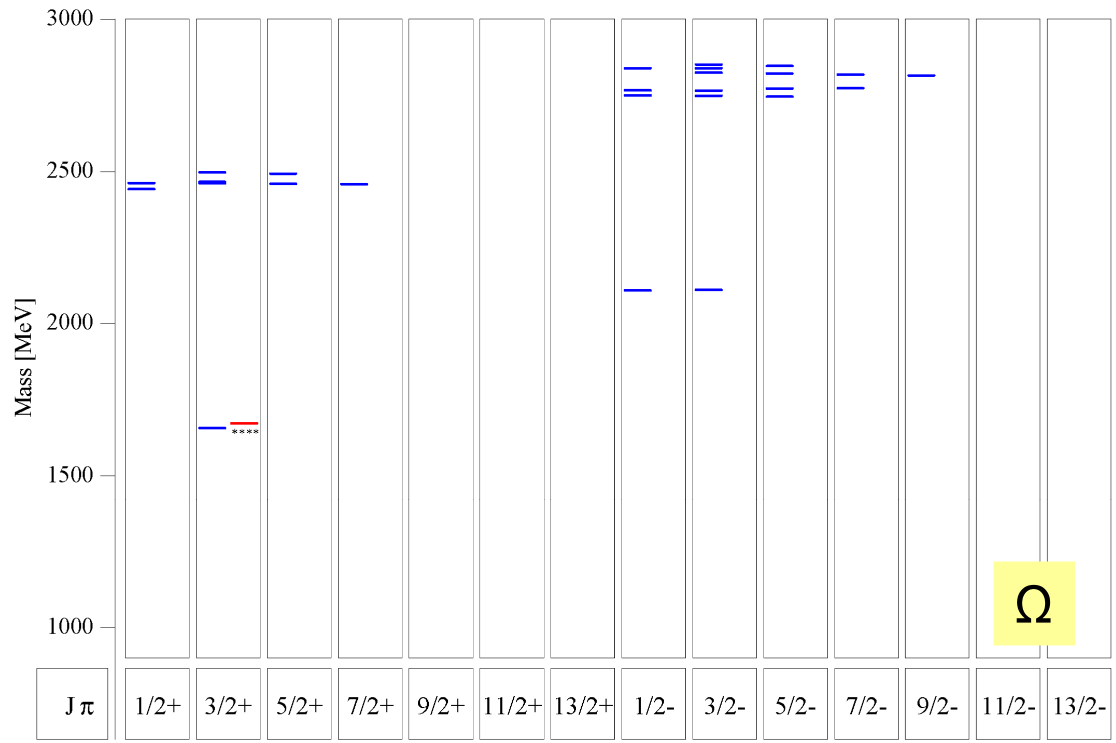
Ω:

- several states predicted between 2 GeV and 3 GeV
- compare $3/2^+$ and $3/2^-$ excitation

U. Löring *et al.*, EPJA 10 (2001) 447

s.a.: M. Pervin, W. Roberts, PRC 77 (2008) 025202





Most Promising: Study Ξ Resonances

- very little known ←→ rather high cross section
- find missing resonances
- determine branching to various decay modes:
  $\Xi\pi,\ \Xi\pi^+\pi^-,\ \Xi\pi^0\pi^0,\ \Lambda K^-,\ \Sigma\bar{K},\ \Xi\eta,\ \Xi\eta\pi,\ \Xi\eta',\ \Xi\omega,\ \Xi\phi, \ldots$
- determine J^P quantum numbers if possible

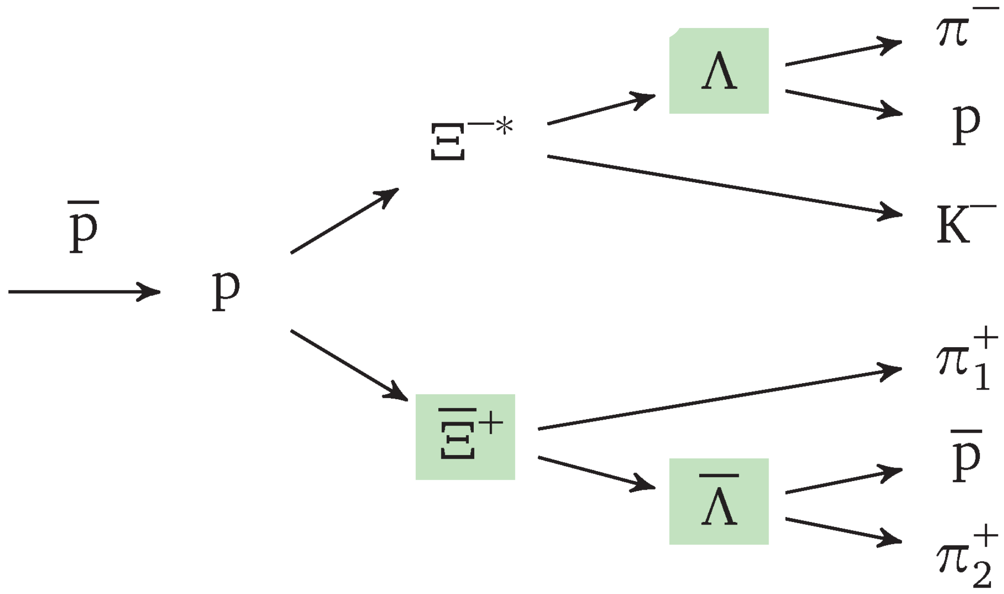
recent progress:
PAWIAN now includes baryons

see talk by Bertram Kopf

strategy:

select $\bar{p}$ momentum to produce a specific resonance close to threshold

Recent Simulation & Analysis



new MC simulations & analyses:

- André Zambanini, completed, PhD thesis U Bochum 2015
- 4.1 GeV/c $\bar{p}p \rightarrow \Xi(1690)^-\bar{\Xi}^+ \rightarrow K^-\Lambda\bar{\Xi}^+$
- ~$0.5 \cdot 10^6$ signal events, ~$50 \cdot 10^6$ DPM background events

- Jennifer Pütz, PhD thesis fully devoted to Ξ spectroscopy
- 4.6 GeV/c $\bar{p}p \rightarrow \Xi(1820)^-\bar{\Xi}^+ \rightarrow K^-\Lambda\bar{\Xi}^+$ & c.c.
- $1.5 \cdot 10^6$ signal events, $15 \cdot 10^6$ DPM background events so far

reco eff. 2.2 %

Early Physics: Expected Rates for Strange Baryons

- initial phase: $L \cong 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ instead of $L \cong 2 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- nevertheless the $\Xi\bar{\Xi}$ production rate will be $R_{\Xi\bar{\Xi}} \cong 10/s \cong 10^6/\mathrm{d}$
- for $\Omega\bar{\Omega}$ production we expect $R_{\Omega\bar{\Omega}} \cong 0.3/s \cong 3 \cdot 10^4/\mathrm{d}$
- for excited states the cross section should be of the same order of magnitude as for the ground state for given $\sqrt{s} - \sqrt{s_{\mathrm{thr}}}$
- the *detected* rate depends on the specific decay mode (branching & reconstruction efficiency)
- e.g. $\bar{p}p \rightarrow \bar{\Xi}^+\Xi^{*-} \rightarrow \bar{\Xi}^+\Xi^-\pi^0 \rightarrow \bar{\Lambda}\pi^+\Lambda\pi^-\pi^0 \rightarrow \bar{p}\pi^+\pi^+p\pi^-\pi^-\pi^0$
  assume $b = 0.5 \cdot 0.64^2 = 0.2$ and $\epsilon = 5\%$ → $R_{det} \cong 10^4/\mathrm{d}$

Current Version of the PANDA ‚Start Setup'

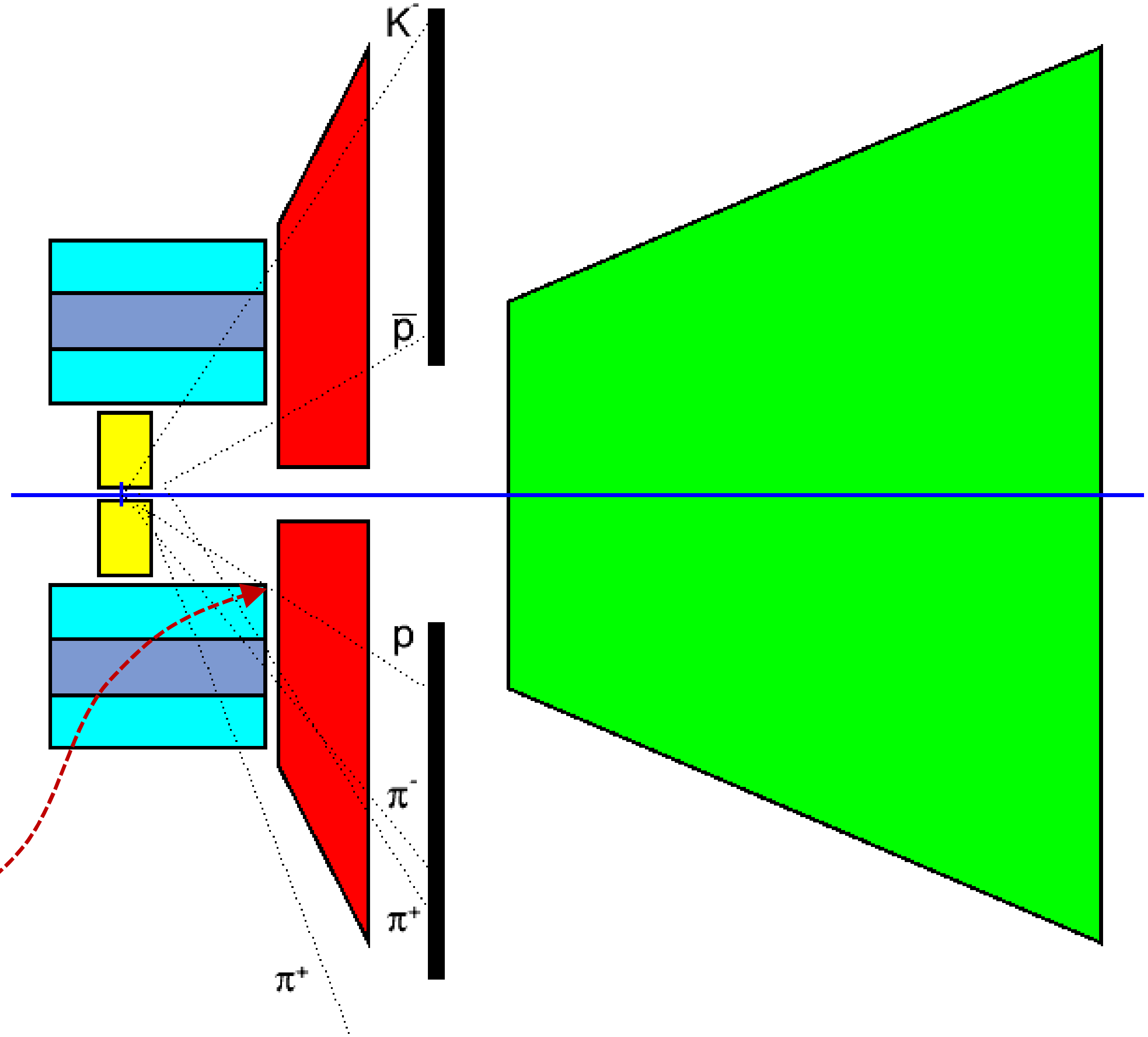
Day-1 master macros distributed by Stefano July 25 as basis for the physics simulation and analysis studies:

- Cluster Jet Target
- No GEM planes → need MVD or STT_{stereo} for p_z
- No Disc DIRC → no K/π separation
- FTS planes 1 2 3 4 (no 5 6) → poor p resolution
- No RICH

➤ How does this affect Hyperon Spectroscopy & Hyperon Spin Physics?

Fast Geometric Analysis with Straight Tracks

- EvtGen events
- 4.1 GeV $\bar{p}p \rightarrow \bar{\Xi}^{+}\Lambda K^{-}$
- $\bar{p}\pi^{+}\pi^{+}p\pi^{-}K^{-}$ final state
- simplified geometry of MVD, STT, GEM, FTS
- neglect magnetic field (conservative)
- evaluate path length in each sub-detector volume & R(z_{STT})

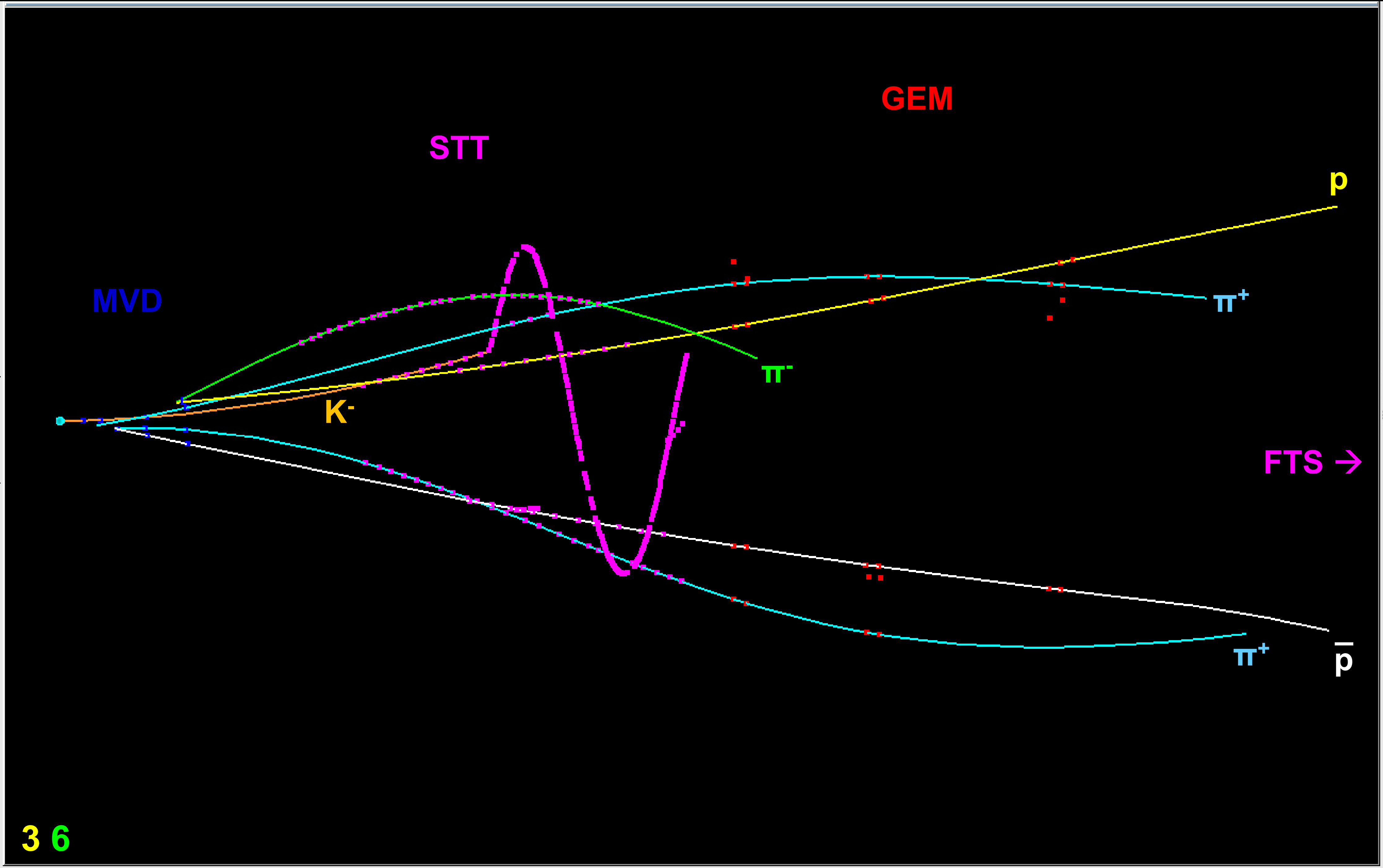


Scan of 100 Events in Event Display

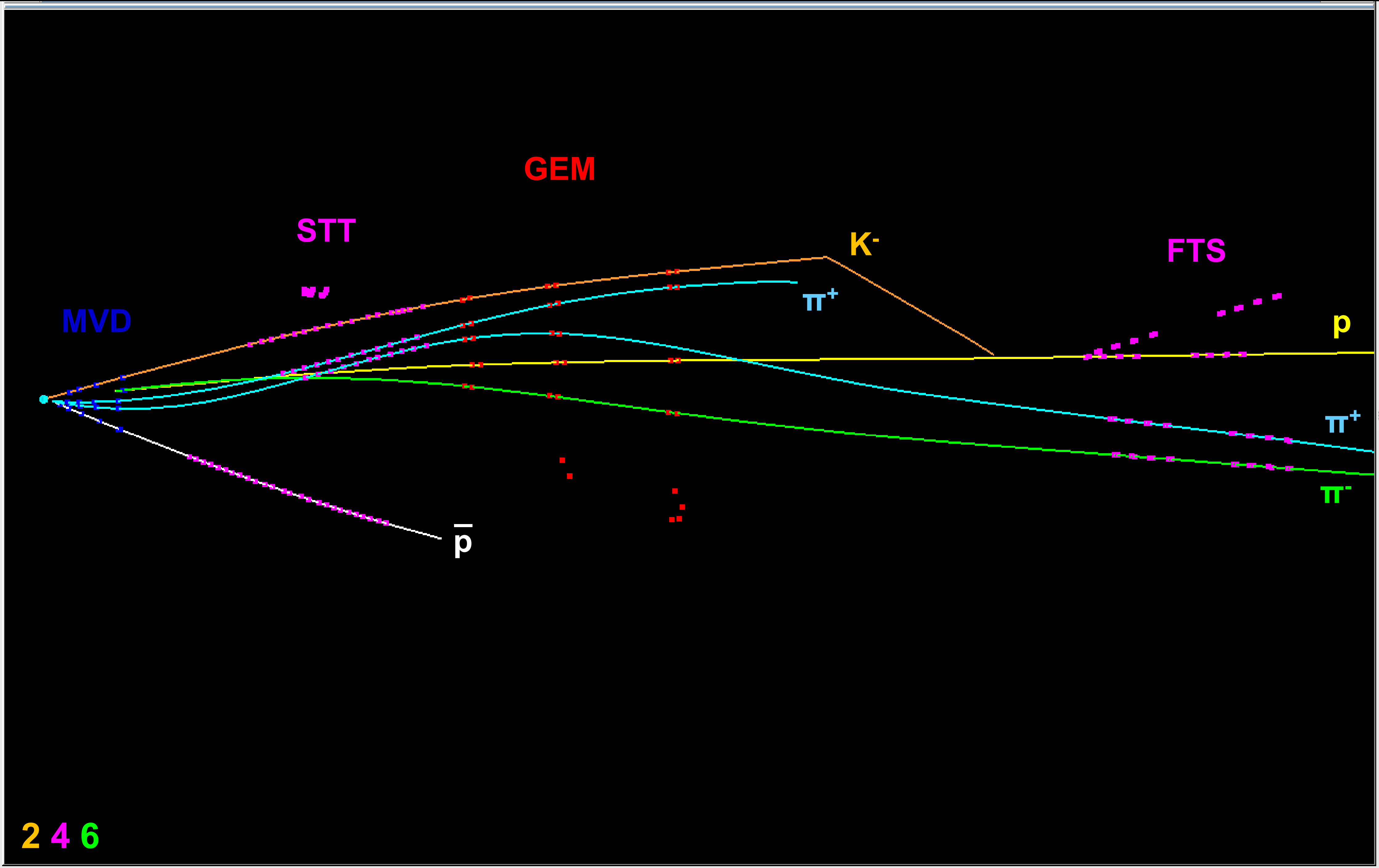
- display primary particles only
- display MVD, STT, GEM, FTS points only
- minimum requirement: all 6 tracks visible on ‚global' scale
- how „straight" are the tracks?
- what is the event topology?
  - 1 : both p & $\bar{p}$ in FTS
  - 2 : one of p, $\bar{p}$ in FTS
  - 3 : both p & $\bar{p}$ in GEM
  - 4 : one of π, K in FTS
  - 5 : both p & $\bar{p}$ vertex ‚beyond' MVD
  - 6 : one of p, $\bar{p}$ vertex ‚beyond' MVD

any of these disfavors recostruction with MVD & STT only

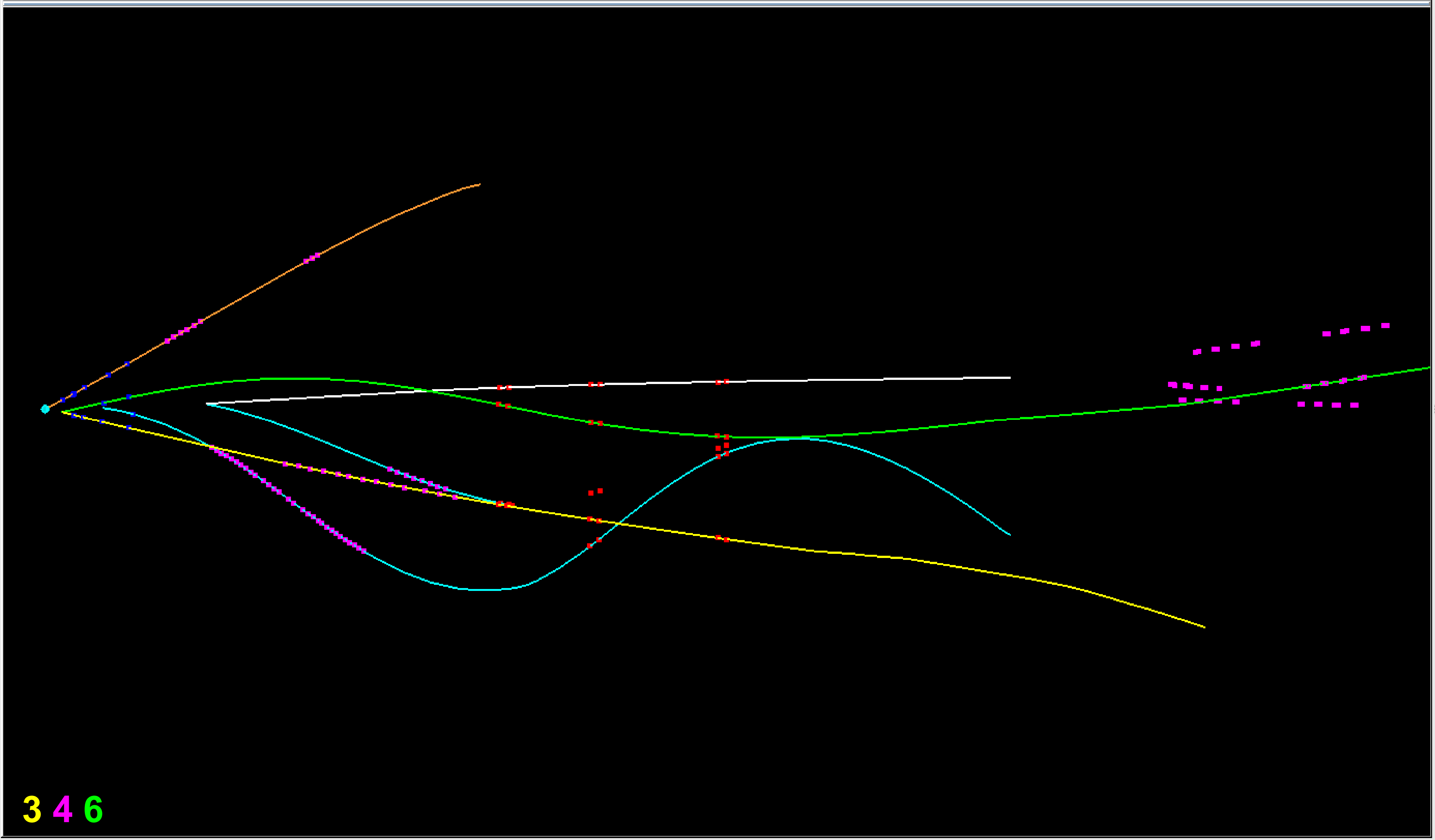
event #04



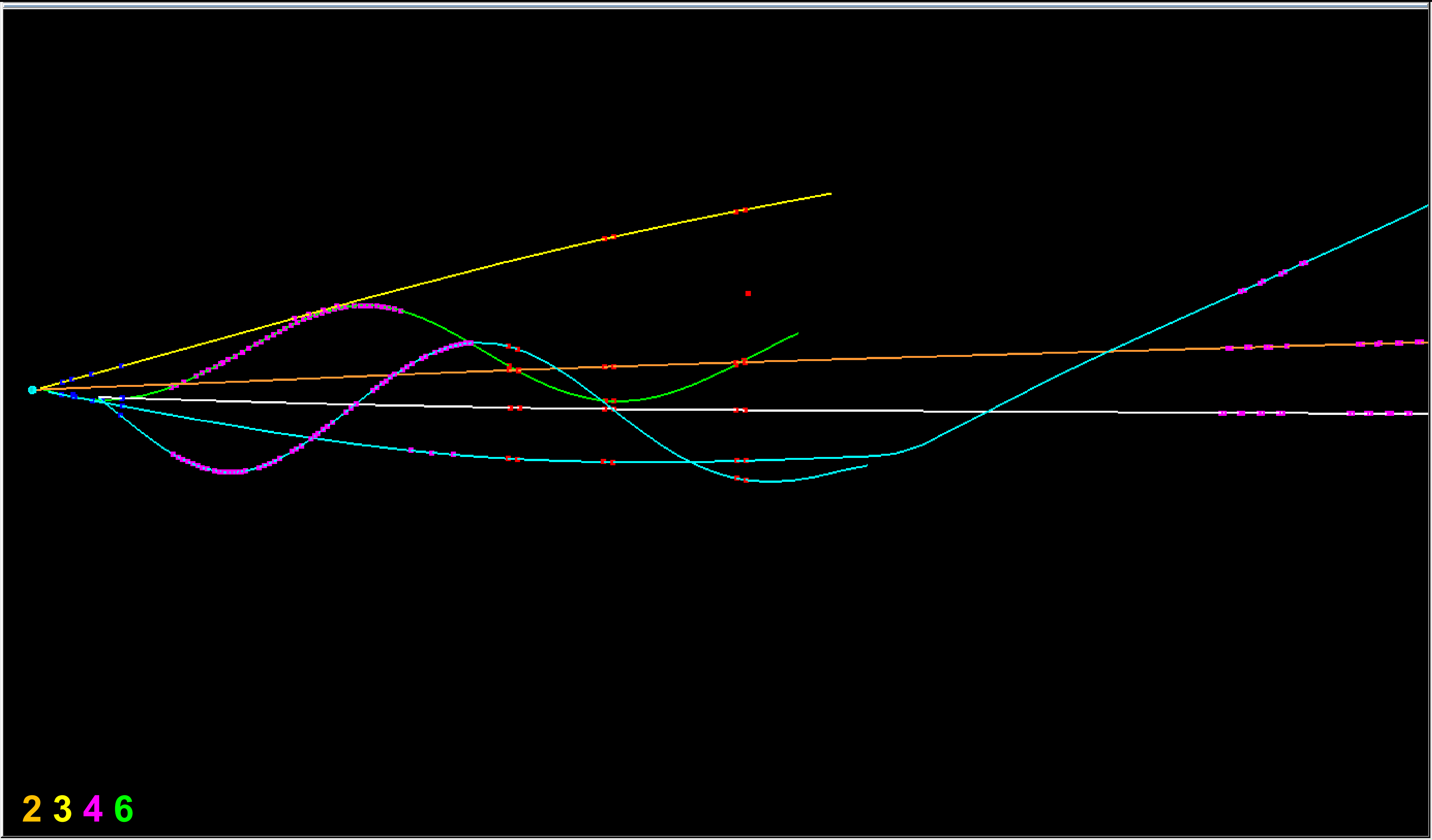
event #15



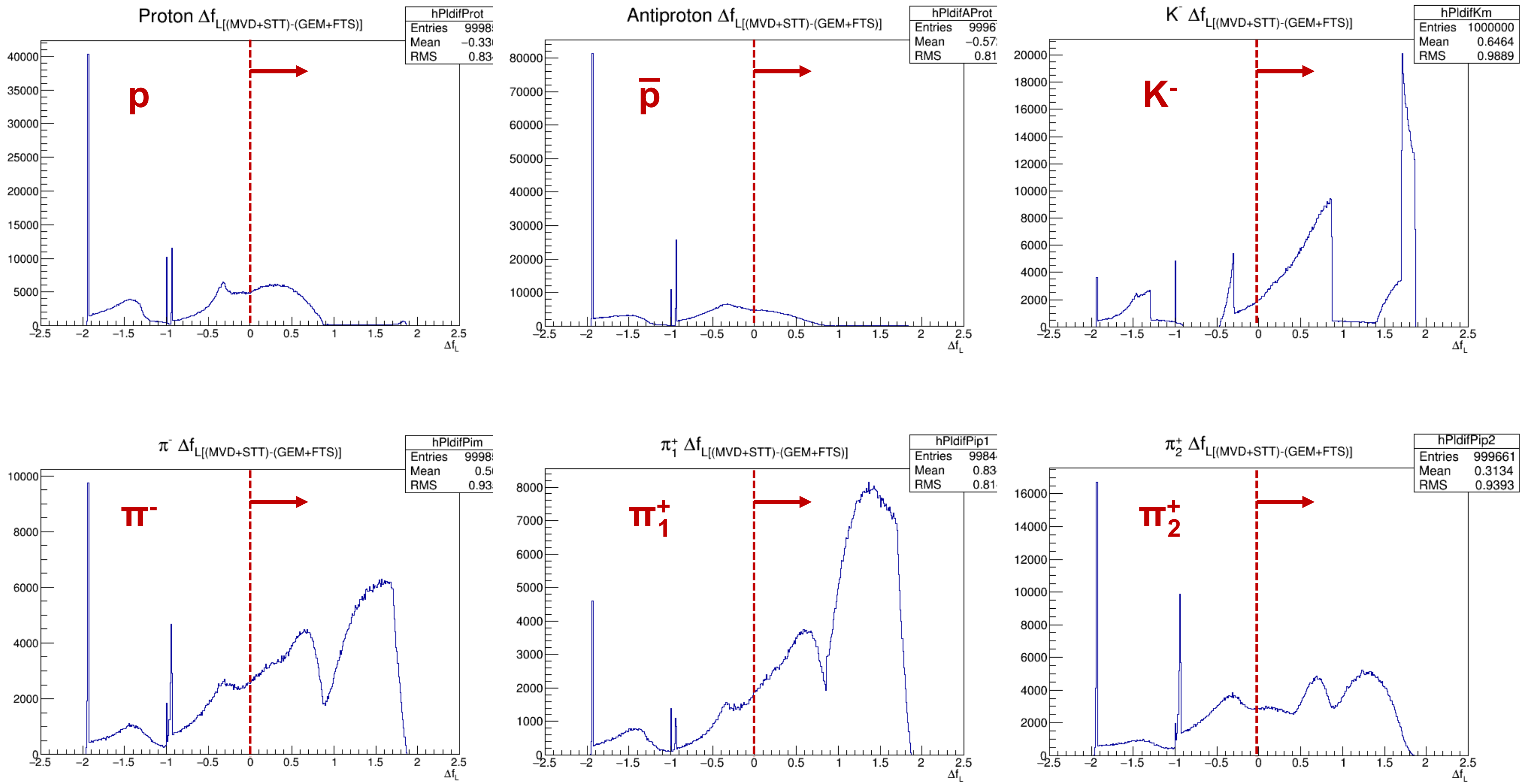
event #17



event #34

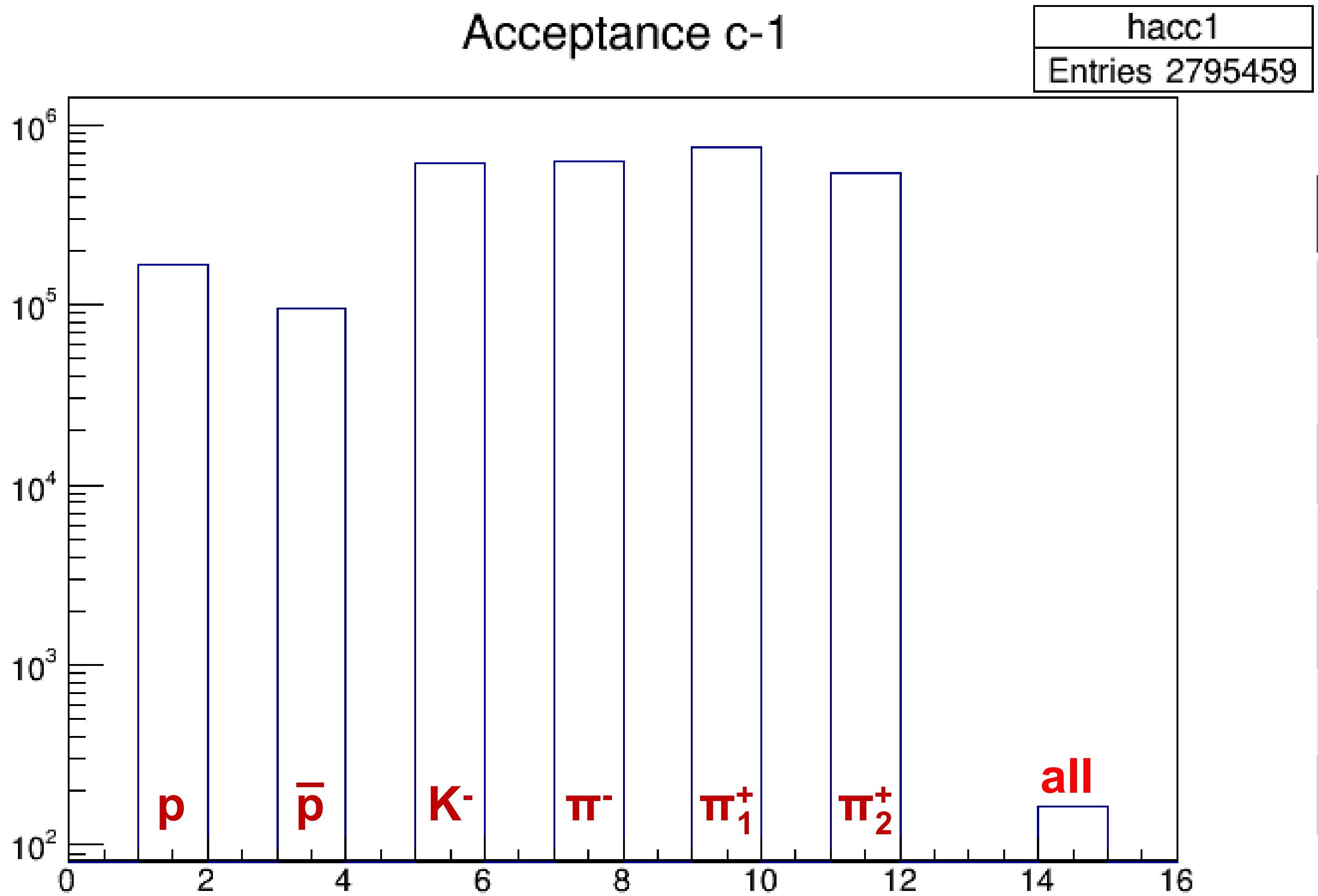


Fractional Path Length Difference (MVD+STT) – (GEM+FTS)



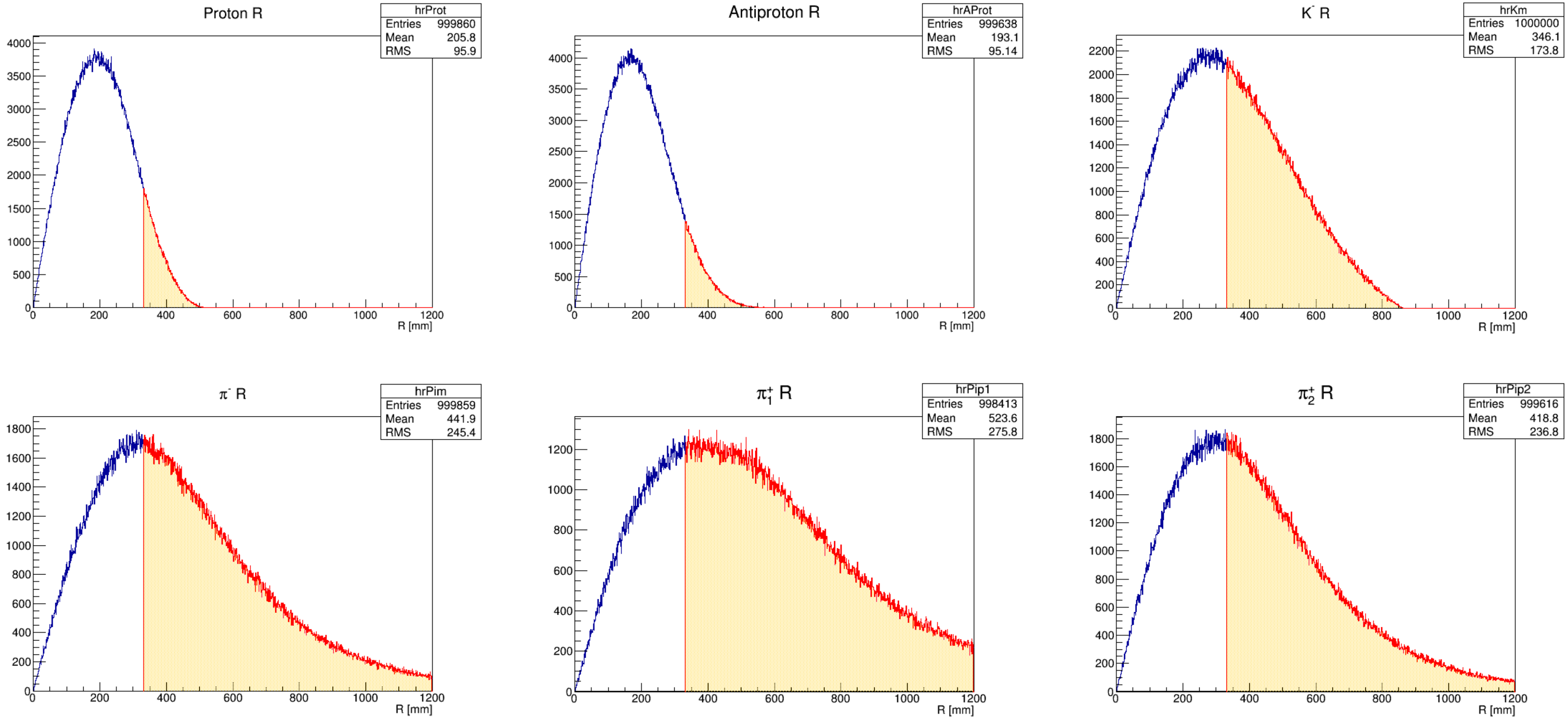
$$\Delta f_L = f_L(MVD) + f_L(STT) - f_L(GEM) - f_L(FTS); \quad f_L = L/L_{max}$$

Acceptance ($\Delta F_L > 0$)

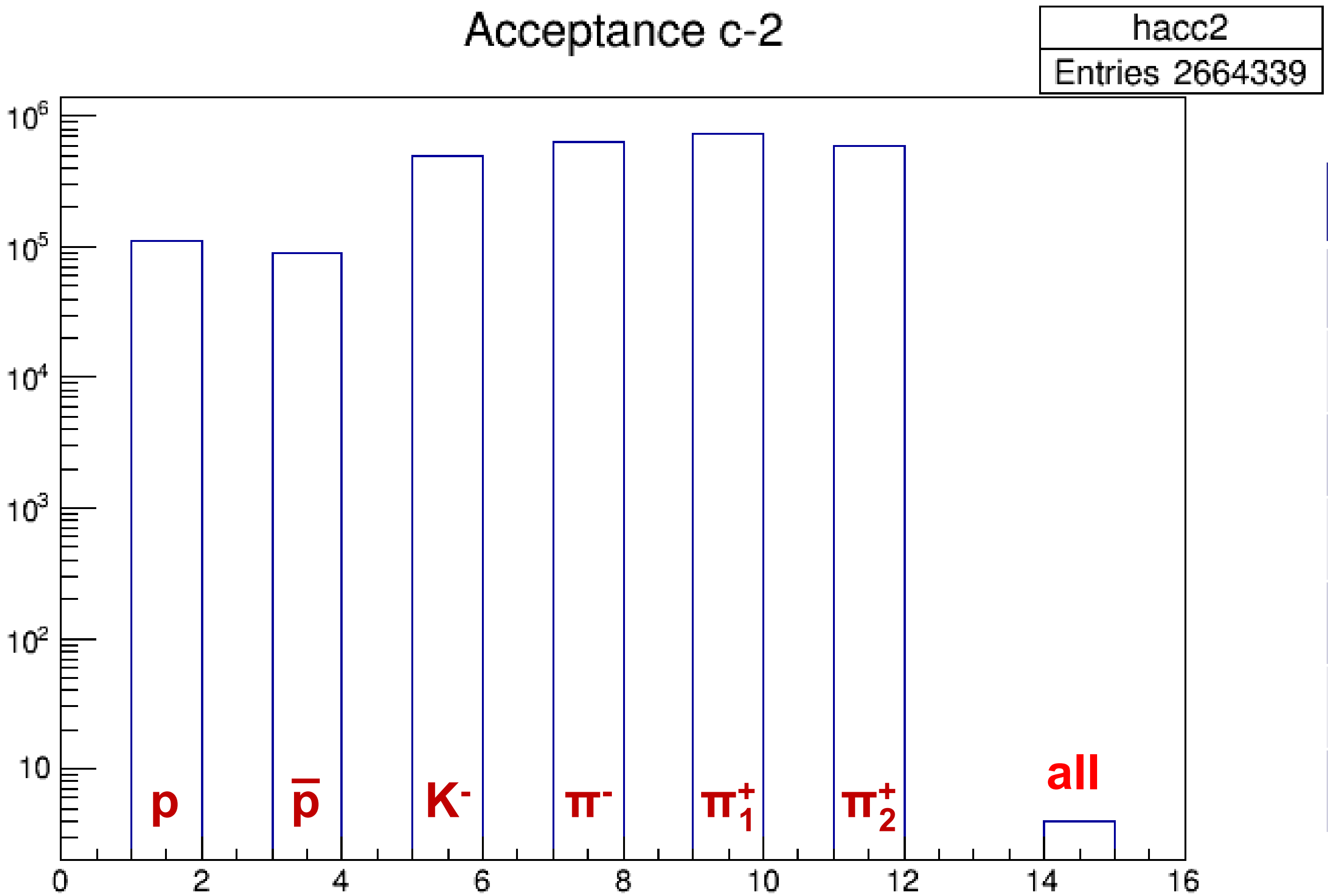


particle	f_{acc}
p	0.425
$\bar{p}$	0.265
K^-	0.808
π^-	0.743
$\pi^+{}_1$	0.856
$\pi^+{}_2$	0.635
all	0.034

Radial Distribution at STT End Plane



Acceptance (R > R_{crit})



R_{crit} = 331 mm

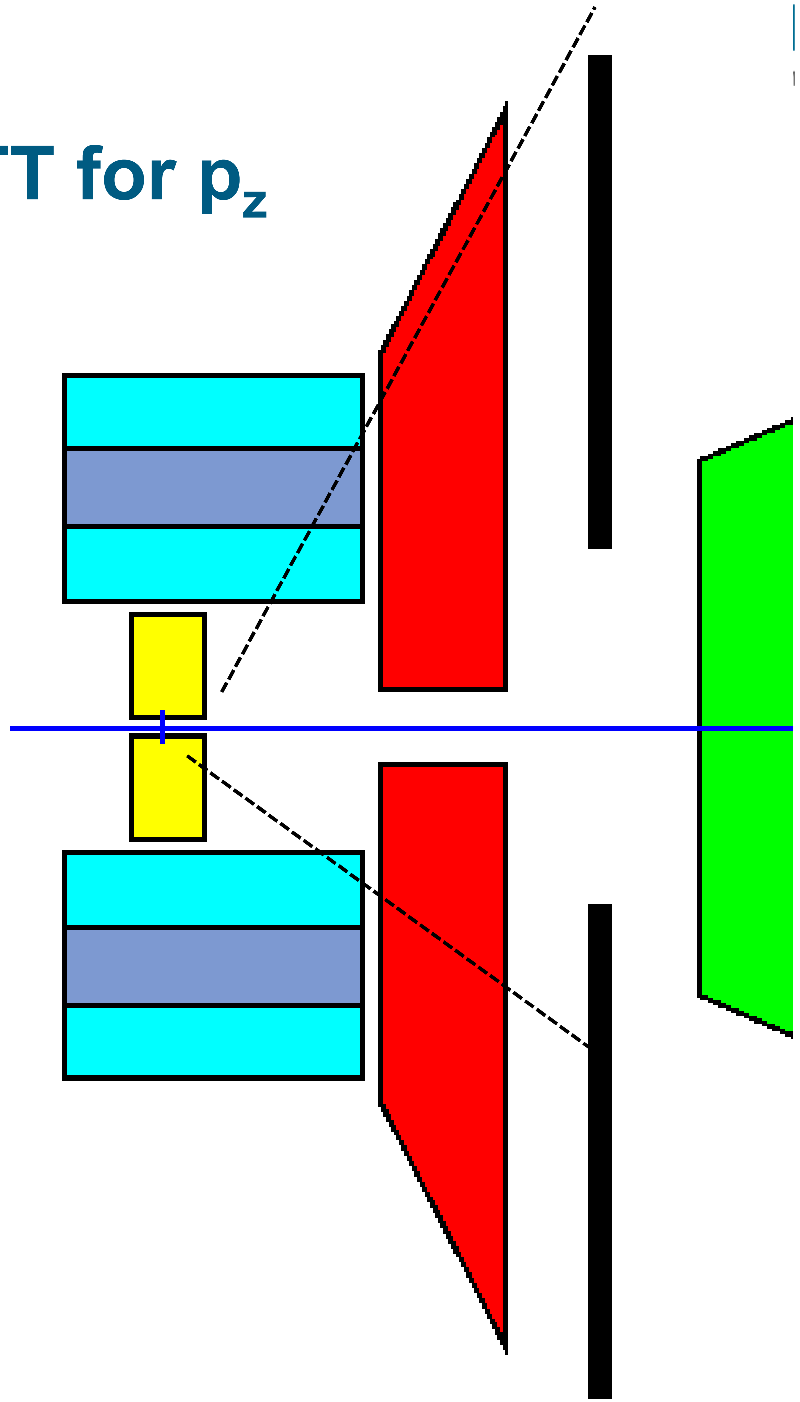
particle	f_{acc}
p	0.109
$\bar{p}$	0.088
K^-	0.498
π^-	0.630
$\pi^+{}_1$	0.745
$\pi^+{}_2$	0.594
all	$4\cdot10^{-6}$

→ almost zero efficiency if p_z information from STT is required !

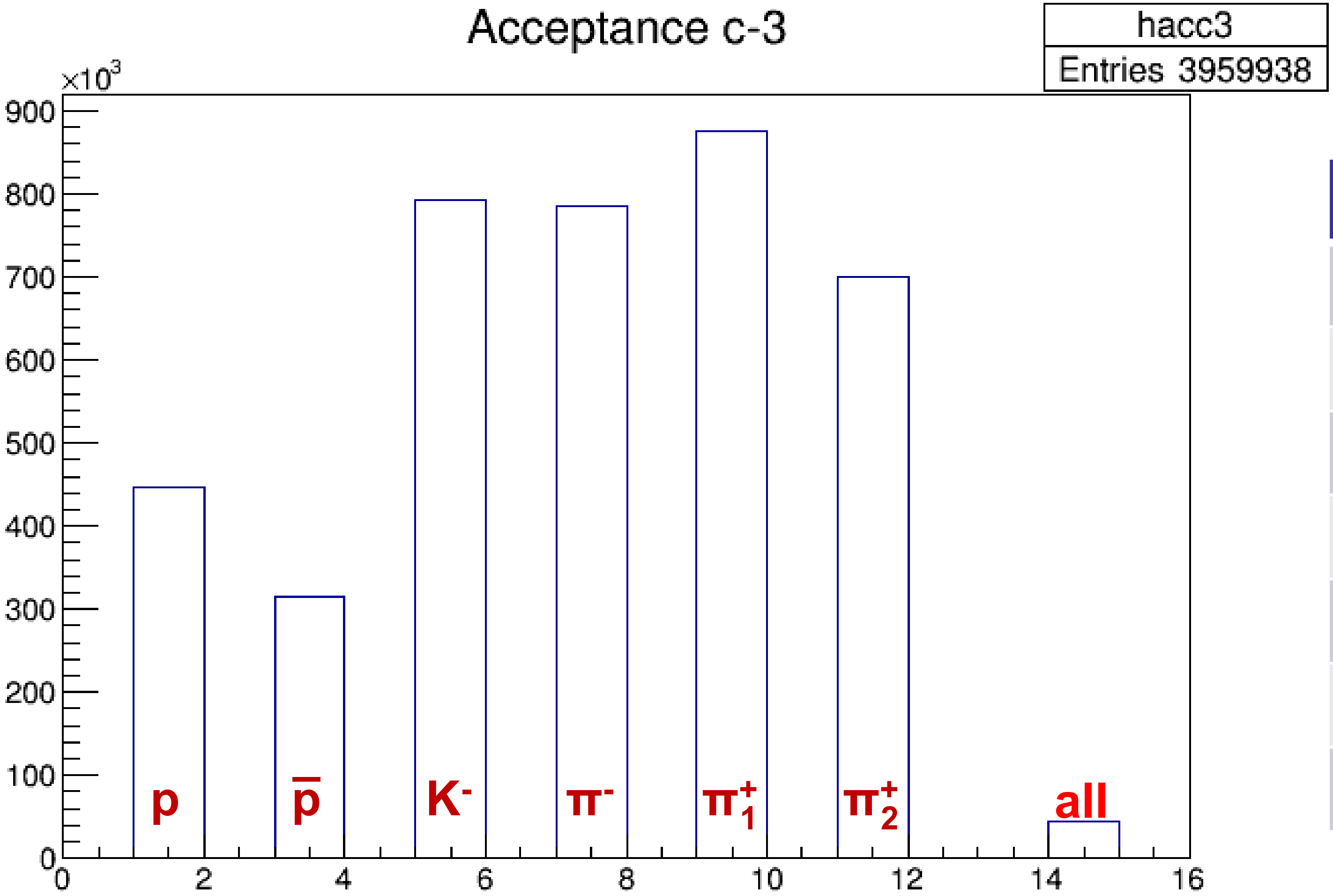
More Realistic: Combine MVD & STT for p_z

- need both p_z and p_T information from central detector
- a track starting downstream of MVD must pass the STT stereo layer
- a track starting inside MVD must at least pass the last two MVD discs and two axial STT double-layers

➢ $L_{MVD} \cdot \cos\theta > 70$ mm
$L_{STT} \cdot \sin\theta > 40$ mm



Acceptance $(R > R_{crit}) \,||\, ((L_{MVD} > L_{c1})\ \&\&\ (L_{STT} > L_{c2}))$

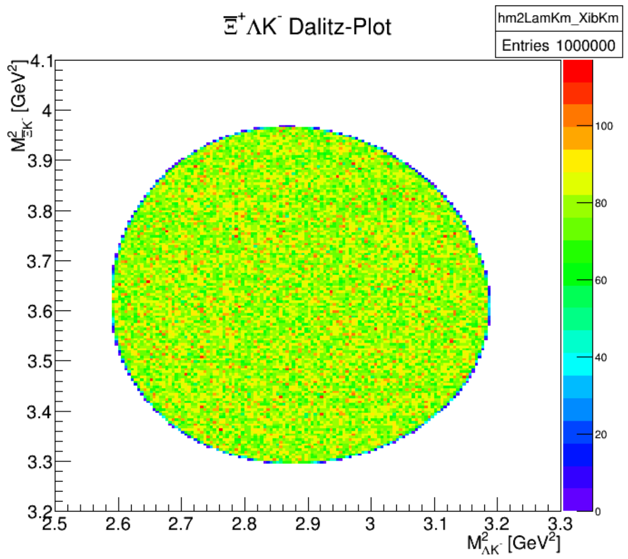


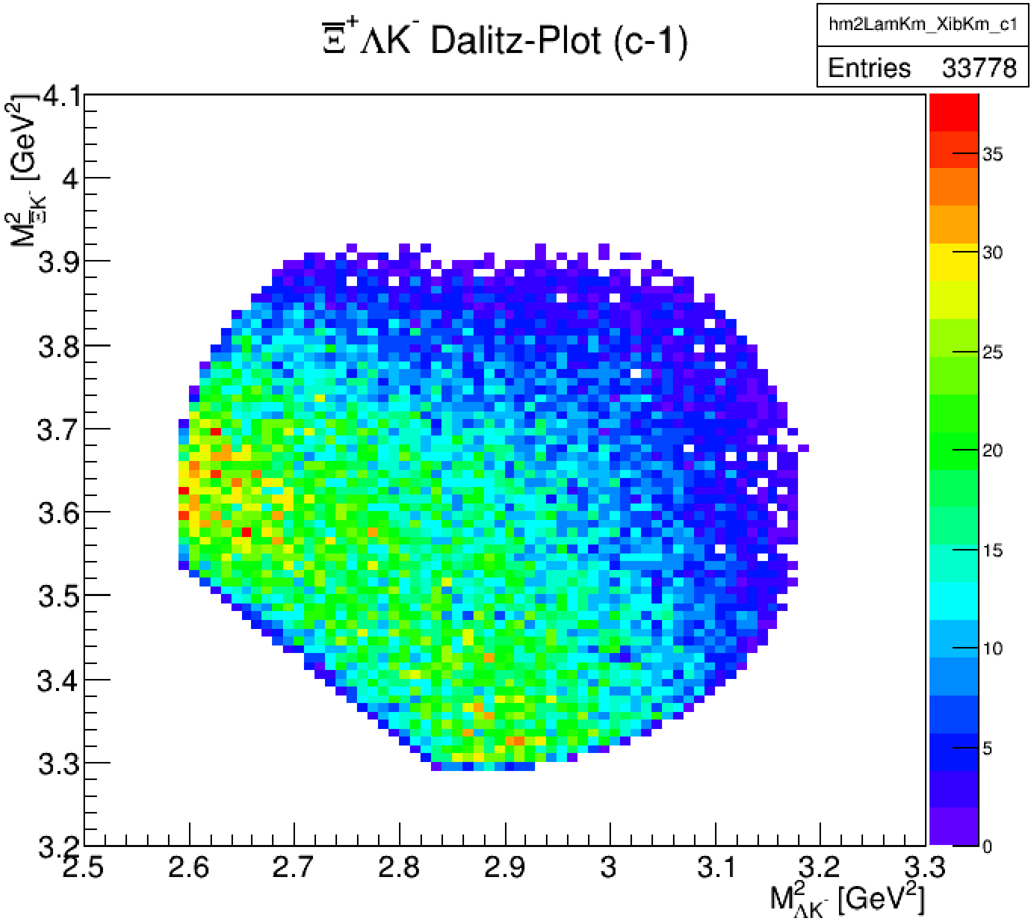
particle	F_{acc}
p	0.447
$\bar{p}$	0.314
K^-	0.793
π^-	0.785
$\pi^+{}_1$	0.876
$\pi^+{}_2$	0.700
all	0.045

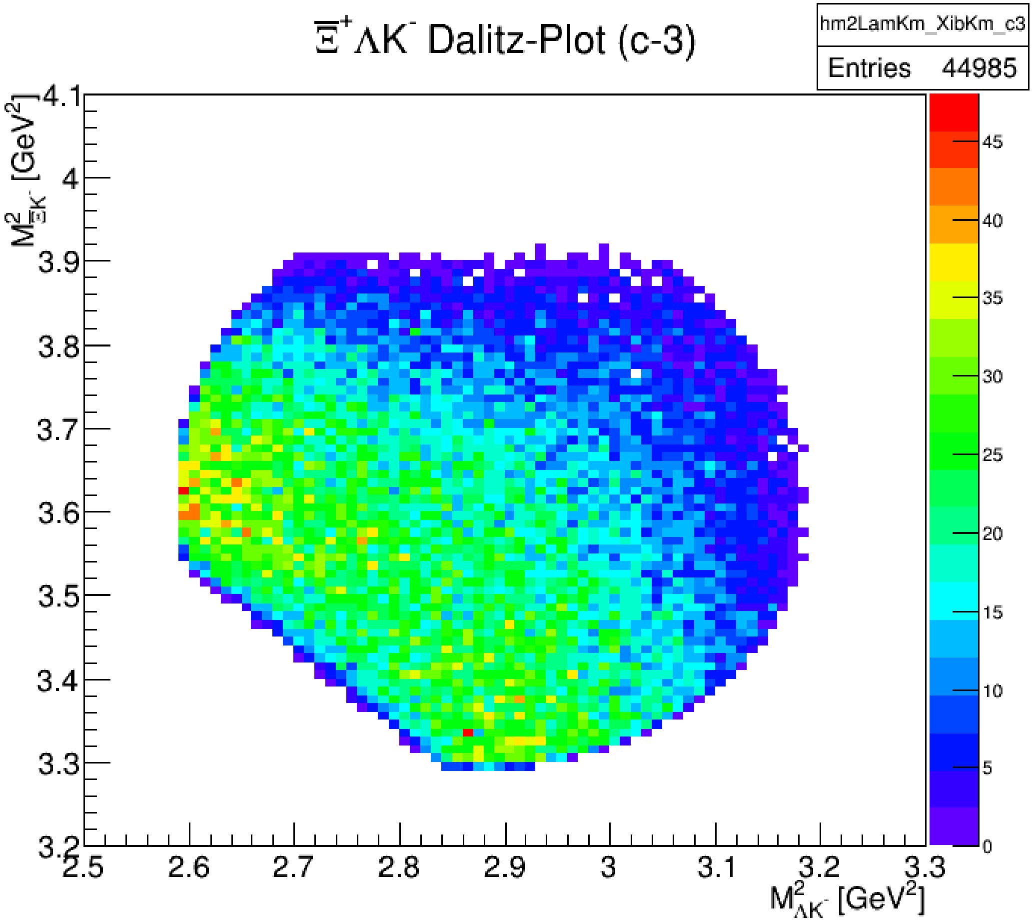
L_{c1} > 70 mm / cosθ : hits in last 2 discs

L_{c2} > 40 mm / sinθ : hits in inner two double layers

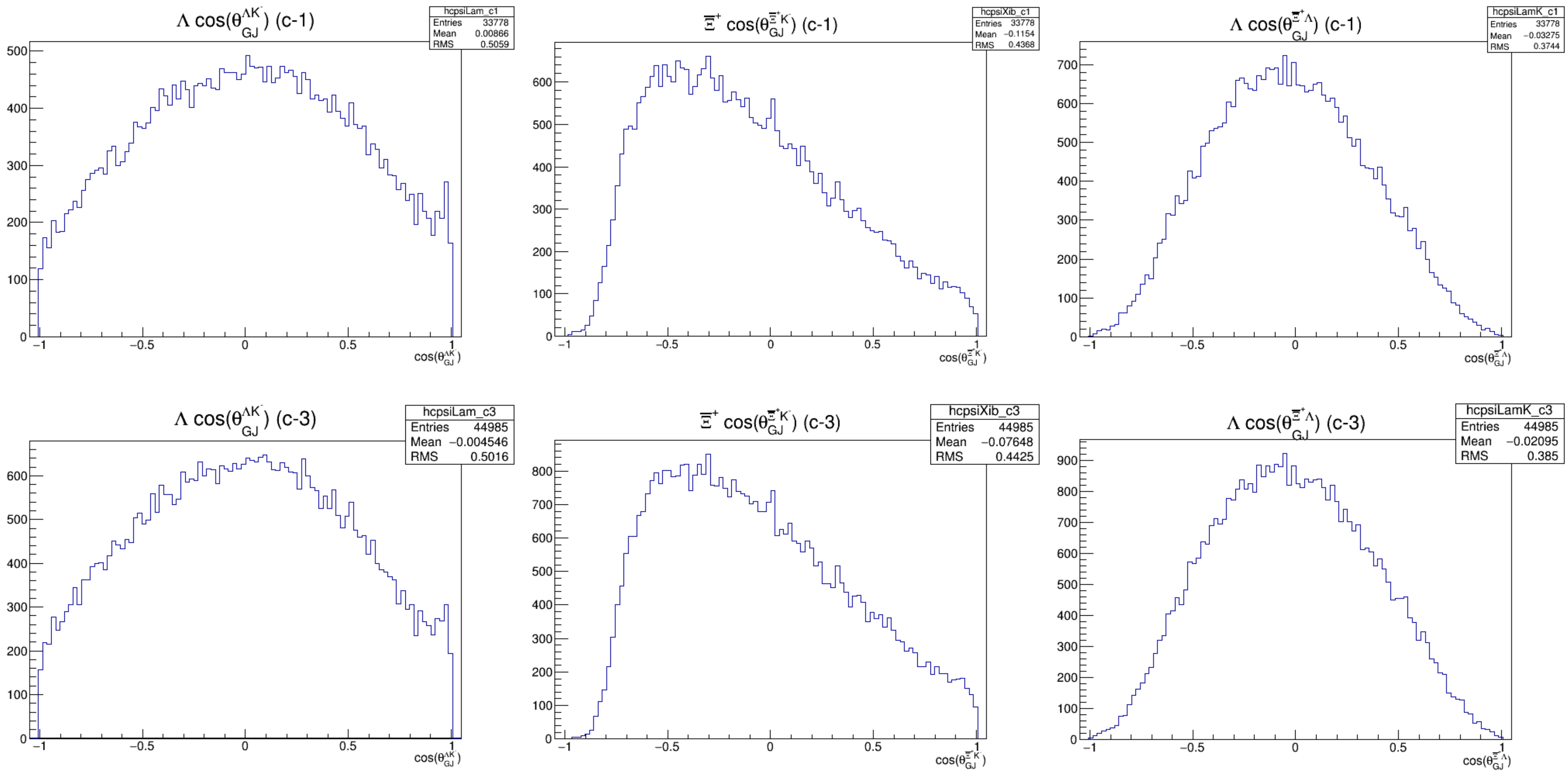
Effect on $\Xi^+ \Lambda K^-$ Dalitz Plot







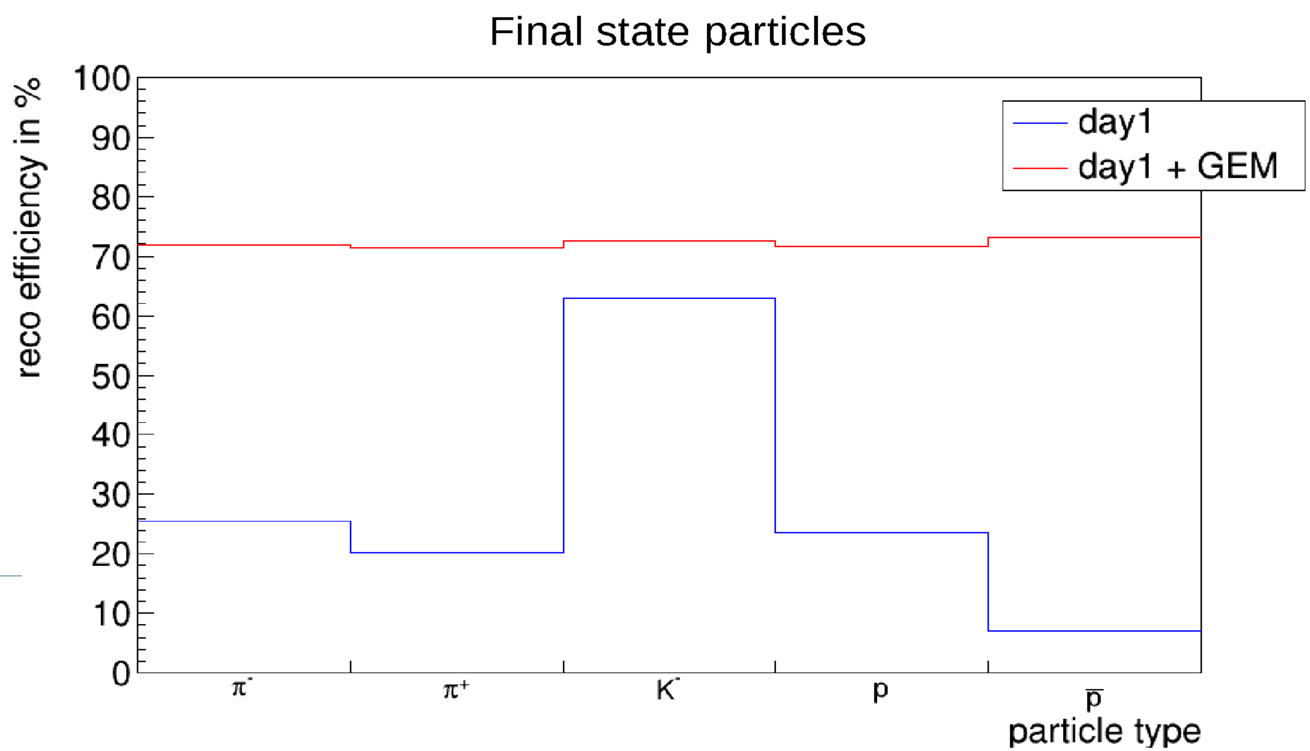
Effect on Angular Distribution (GJ Frame)



Simulation & Reconstruction Efficiency

Simulation:

10,000 events for
$\bar{p}p \rightarrow \bar{\Xi}^{+}\ \Xi(1820)^{-}$
@4.6 GeV/c PHSP



Particle type	Reco. Efficiency [%]	
	Day1	Day1+GEM
Λ	7.7	25.9
$\bar{\Lambda}$	1.5	22.2
$\bar{\Xi}^{+}$	0.6	11.5
$\Xi(1820)^{-}$	5.1	19.4
$\Xi(1820)^{-}\ \bar{\Xi}^{+}$	0.01	1.06

Jenny Pütz:
full PandaRoot simulation

Conclusion

- Hyperon spectroscopy is an important topic in hadron physics which has not received the deserved attention in the past
- PANDA is the ideal instrument for a comprehensive Ξ and Ω spectroscopy program
- A large part of the program can already be pursued at reduced luminosity

❖ **However:** for these studies the GEM detector and the FTS (preferrentially including a detector *behind* the dipole) are required