Measuring Hiperon Dalitz decays with PANDA & HADES

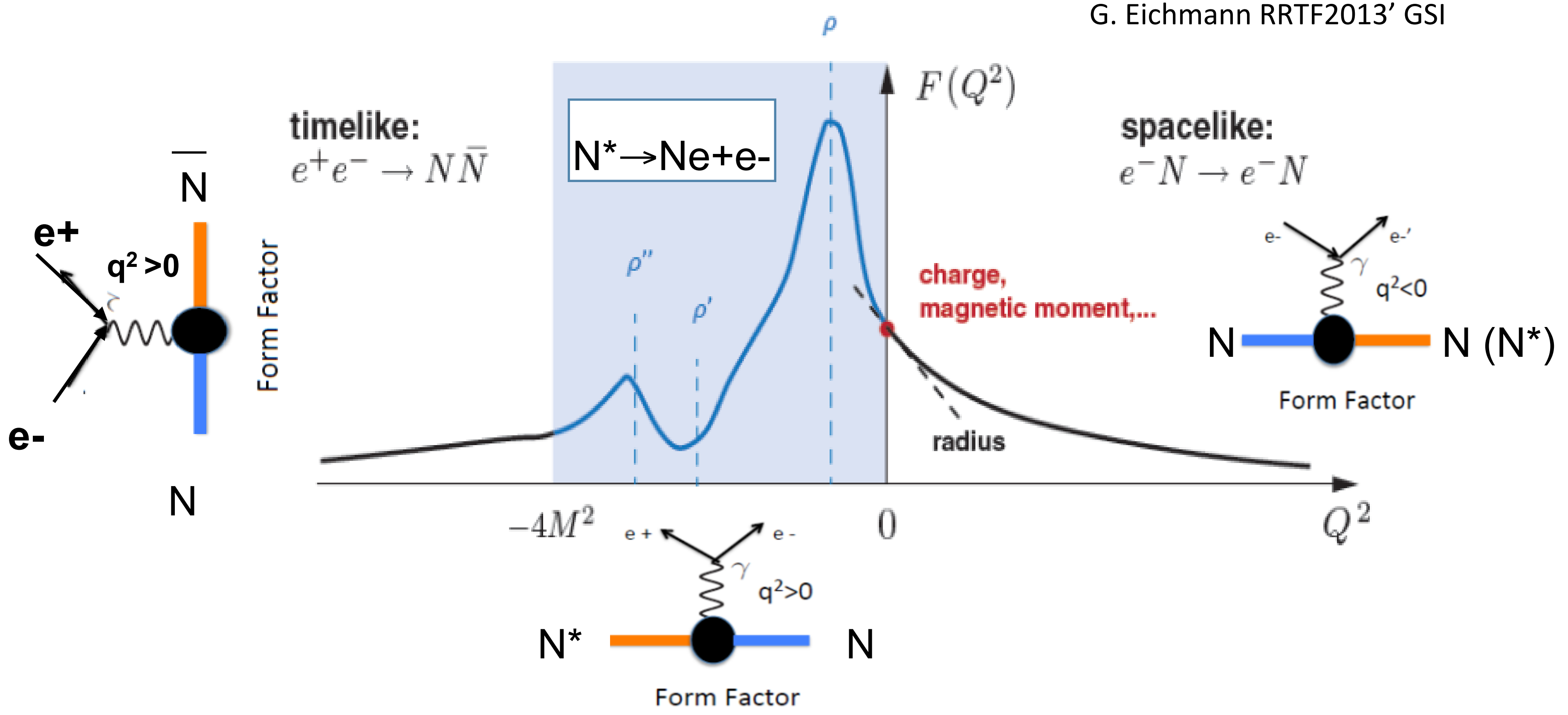
Jacek Biernat

The Menu

- Motivation
- Experimental setup
- Analysis
- Comparison with HADES simulation results
- Conclusions

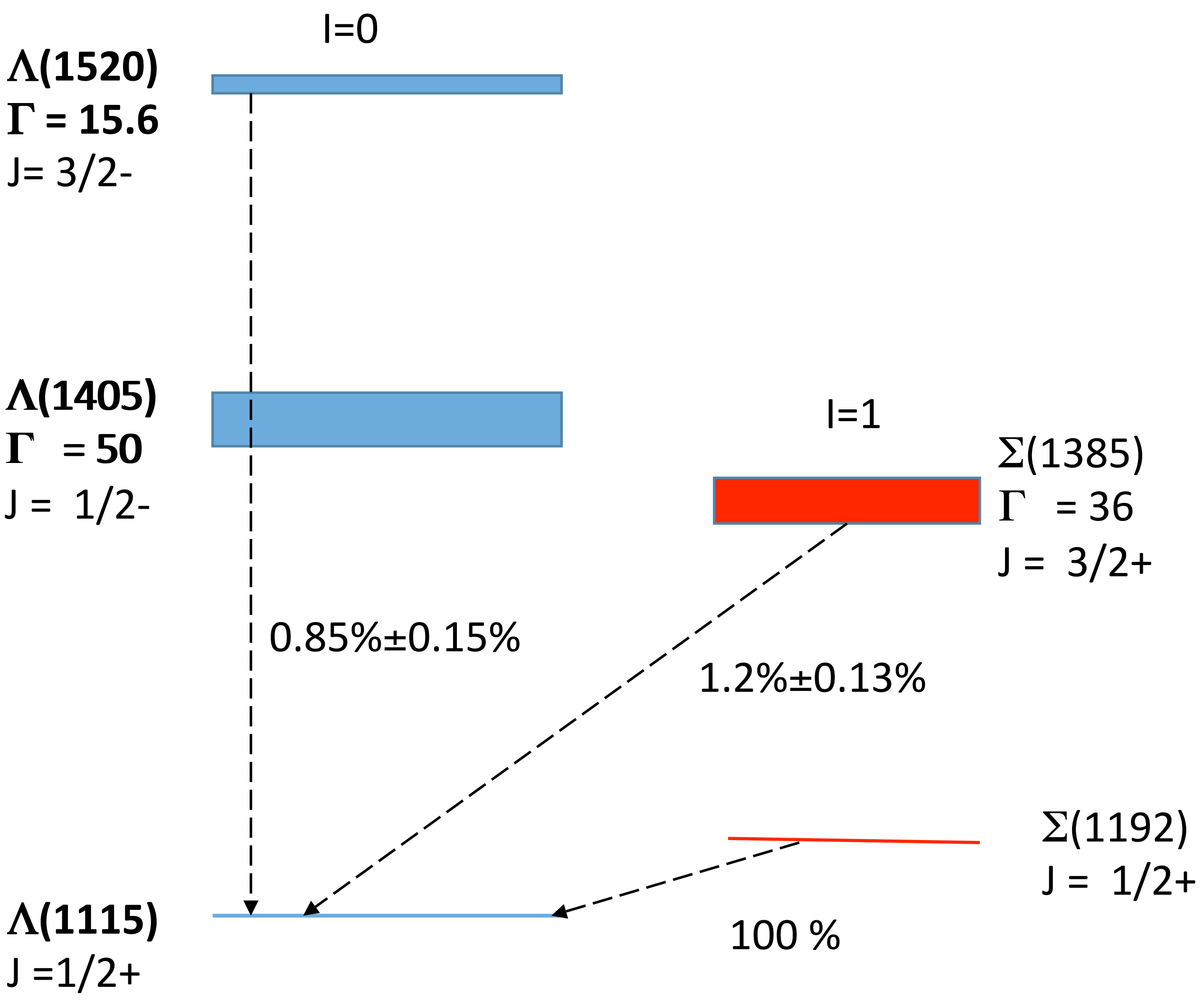
Electromagnetic structure of baryons

G. Eichmann RRTF2013' GSI



- Dalitz decays N* →Ne+e- probe electr-magnetic structure of baryons-> Form Factors
- Nucleon em.FF, Resonance Transition FF

Radiative hyperon decays



- Other radiative decays badly or not know
- Very strong model dependency (quark models) of BR(γ)

related to quark structure of excited states, in particular quark

correlation effects

see E.Kaxiras, J Moniz, M.Soyeur PRD32(1985) 695:

Λ(3/2-)→Λ(1/2+) γ/ Λ(3/2-)→Σ(1/2+) γ (isospin changing)
Λ(1/2-) →Λ(1/2+) γ/ Λ(1/2-)→Σ (1/2+) γ ?
(baryon vs pentaquark) !

- Measured BR (Λγ) are large! (comparable to Δ→Nγ)
- Hyperon states are narrow !

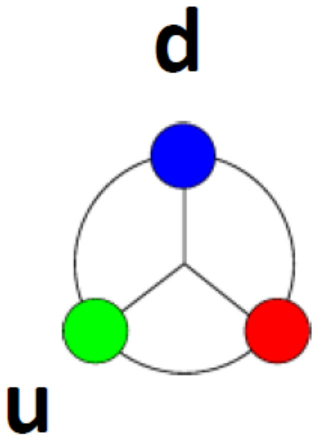
Results on hyperon Form Factors in time- like region

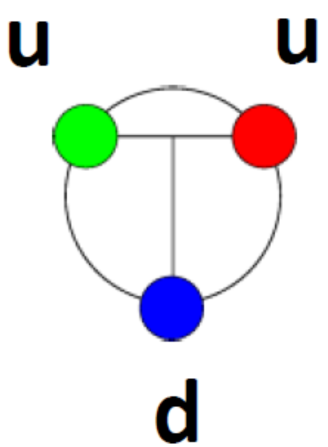
- Electromagnetic Form Factors (eFF) contain information about hadron charge and currents distributions. For J>1/2 there are 3 eFF (usually G_M,G_E,G_C)

Annihilation experiments :
e+e- → hyp anty-hyp (**$q^2 > 4*m^2_{hyp}$**)

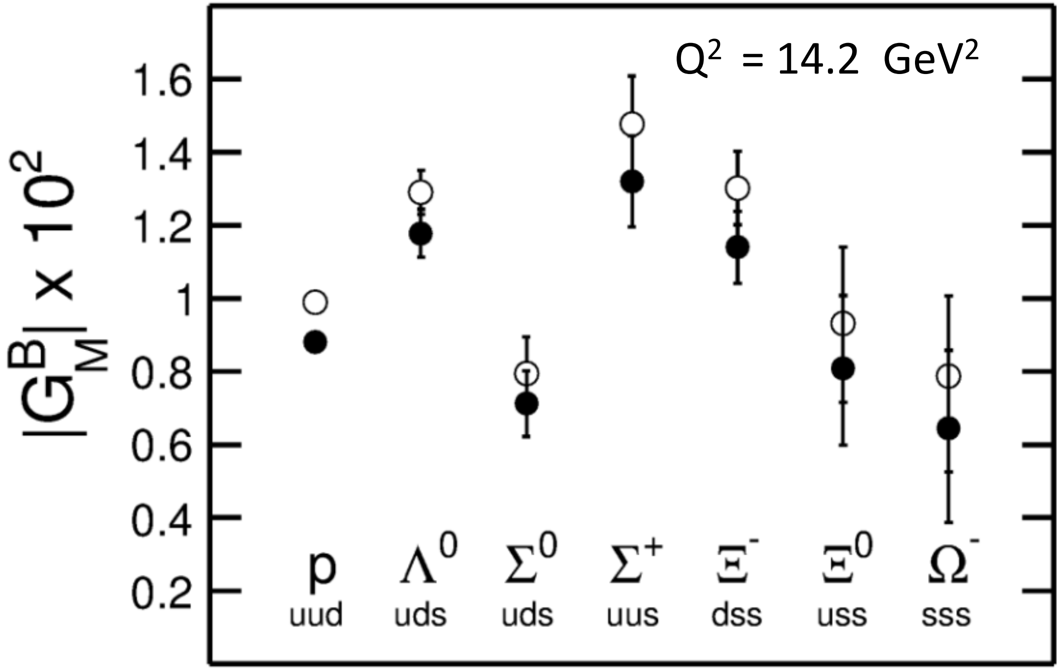
$$\sigma(s) = (4\pi\alpha^2\beta_B/3s)[|G_M(s)|^2 + \tau/2|G_E(s)|^2].$$

- eFF sensitive to hyperon structure (for example di-quark correlations)
- Are eFF for hyperons equivalent to their counterpartners in baryon sector –N*,Δ (SU(3)-symmetry)?
- Measured eFF (CLEO) are larger by factor 10 from early predictions based on VDM





CLEO; K. Seth ICNFP 2014: Crete



Closed circles : $G_E = G_M$, Open circles: $G_E = 0$

Di-quark correlations

- Λ^0 (I = 0) and Σ^0 (I = 1) have the same quark content |uds > but the obtained results show a difference in the G_m value
- it is important to note that only u and d quarks carry isospin

Two-body (fermion) correlations are known to play an important role in many aspects of physics, ranging from Cooper pairs in superconductivity, to pairing interactions in nuclear physics. Diquark-quark models of nucleons have been proposed to explain many observations in hadron physics, particularly the observed G_M(timelike) / G_M(spacelike) ≈ 2 for the proton.

Recently, Wilczek and colleagues [17] have drawn attention to the fact that "it is plausible that several of the most profound aspects of low-energy QCD dynamics are connected to diquark correlations." Wilczek goes on to actually state that

– "The Λ is isosinglet, so it features the good diquark [ud], while Σ, being isotriplet, features the bad diquark (ud)."
– "the good diquark would be significantly more likely to be produced than the bad diquark", and that "this would reflect in a large Λ/Σ ratio."

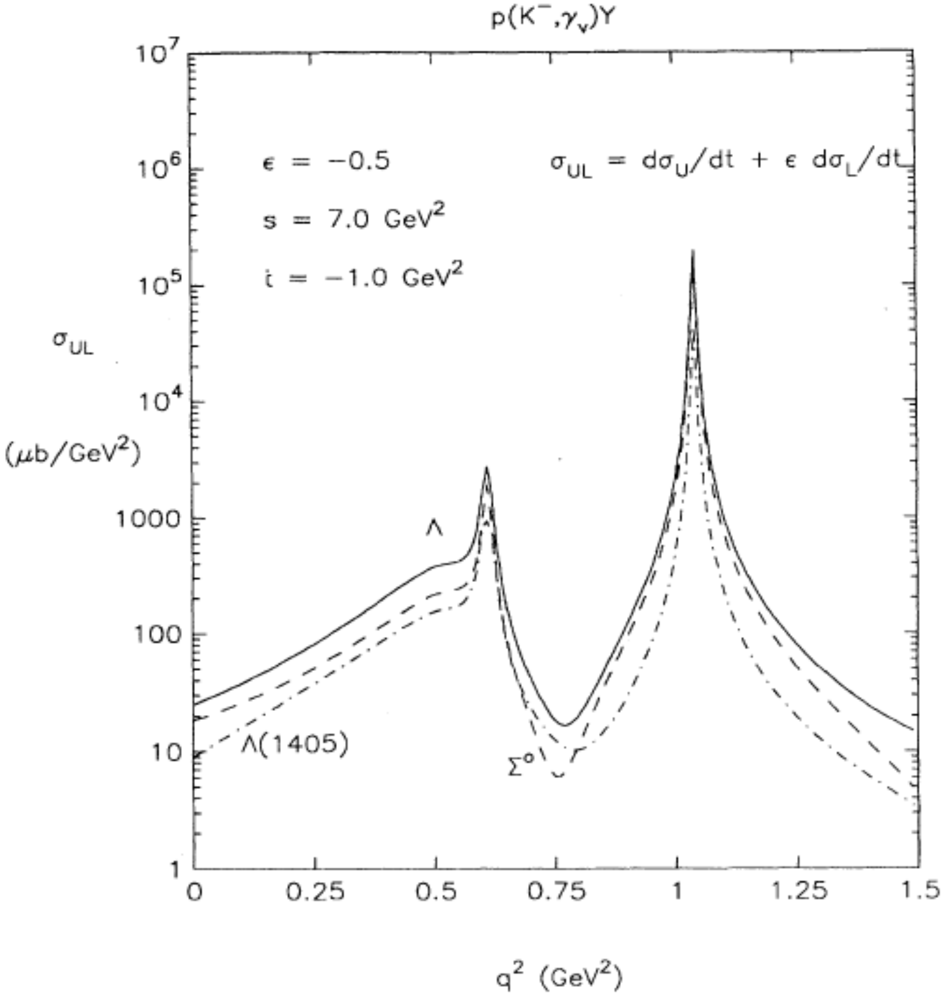
http://www.epj-conferences.org/articles/epjconf/pdf/2015/14/epjconf_icnfp2014_03033.pdf

Dalitz decays

- Dalitz decays; for example $\Lambda^{3/2-}(1520) \rightarrow \Lambda^{1/2+}$ e+e- probe etransitionFF in time like region at low $Q^2 = (4m_l\ ;\ m_{\Lambda(1520)} - m_{\Lambda})$ –complementary to annihilation experiments

- Predictions based on VDM shows rich structure due to intermediate vector meson states ρ,ω,ϕ..

  for example R. Williams et. al. PRC48(1993)1381 $\longrightarrow$



- As compared to Dalitz decays of baryon resonances (for example counterpartner decay N(1520) $^{3/2-} \longrightarrow p^{1/2+}$ e+e-) are easeier to identify because hyperons are narrow states
- PANDA & HADES can measure

Hyp*->Hyp γ (radiative decays), Dalitz decays into leptons and muons and hadronic decays as well !

Dalitz decays - formalism

Generally we can express differentia decay width of such transition as:

$$\frac{d\Gamma}{dM} = \text{"QED"} \otimes eTFF(Q^2 = M^2)$$

where „QED" parts accounts for description of point like particles with given spin, parity
eTFF are Electromagnetic transition FF which depends on lepton inv. mass (M) and contain information on hyperon structure

„QED" part has been calculated for various baryonic tranistions in
M.I. Krivouchenko et.al Ann.Phys.296(2002)299 , M. Zetenyi and G. Wolf Phys.Rev.C67(2003)044002 (arxiv:02020471)

$$d\Gamma(N^* \to N e^+ e^-) = \Gamma(N^* \to N\gamma^*) M\Gamma(\gamma^* \to e^+e^-) \frac{dM^2}{\pi M^4},$$

$$M\Gamma(\gamma^* \to e^+e^-) = \frac{\alpha}{3}(M^2 + 2m_e^2)\sqrt{1 - \frac{4m_e^2}{M^2}}$$

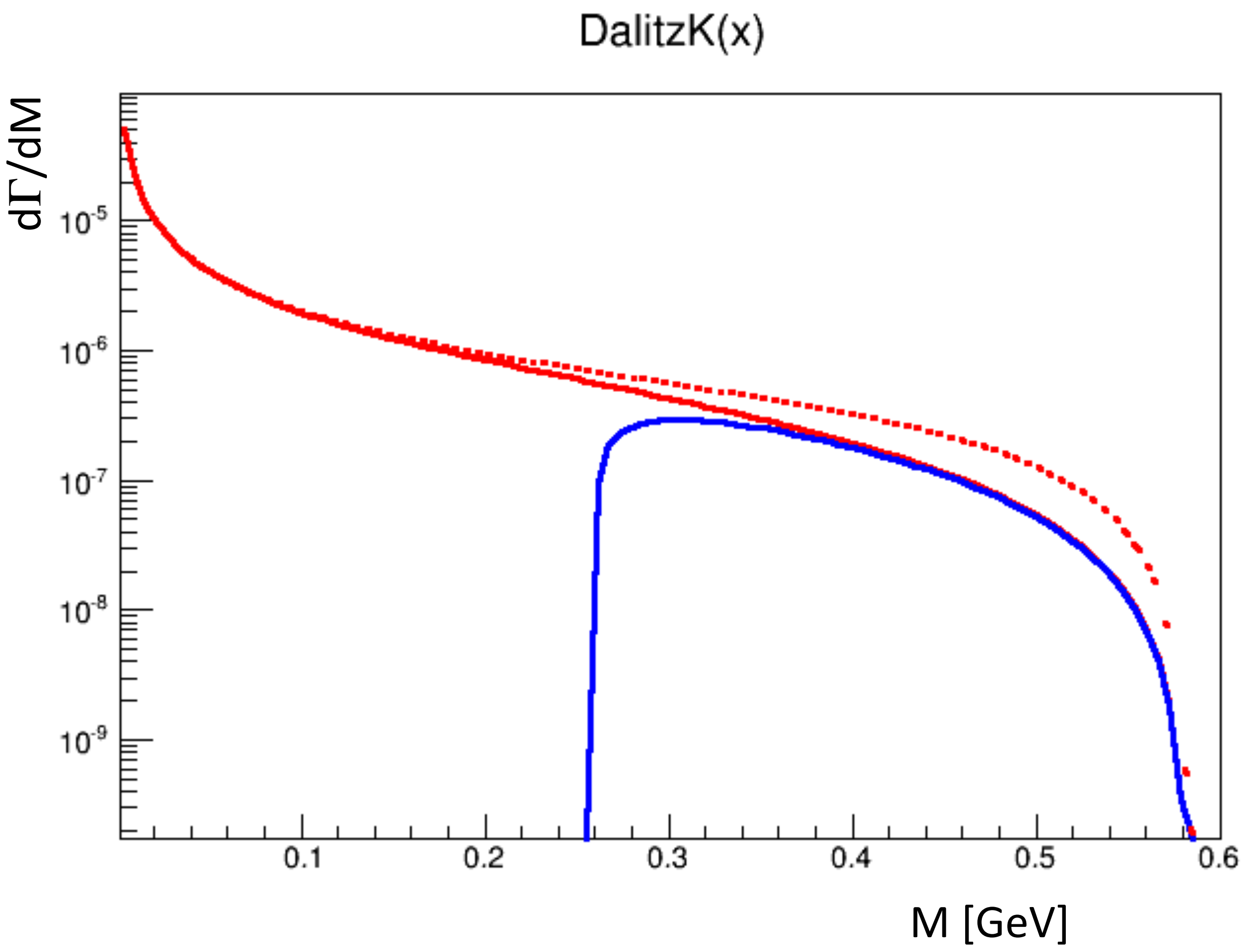
$$\Gamma(N^*_{(\pm)} \to N\gamma^*) = \frac{9\alpha}{16} \frac{(l!)^2}{2^l(2l+1)!} \frac{m_\pm^2(m_\mp^2 - M^2)^{l+1/2}(m_\pm^2 - M^2)^{l-1/2}}{m_*^{2l+1} m^2}$$

$$\left(\frac{l+1}{l}\left|G^{(\pm)}_{M/E}\right|^2 + (l+1)(l+2)\left|G^{(\pm)}_{E/M}\right|^2 + \frac{M^2}{m_*^2}\left|G^{(\pm)}_{C}\right|^2\right).$$

M. Krivoruchenko for J≥3/2 ± transitions

eTFF

Example of $\Lambda(1520)^{3/2-} \rightarrow \Lambda^{1/2+}\ l^+l^-$



- „QED" forumla with constant FF . FF values adjusted to restore known radiative decay width of $\Lambda(1520)$ $\Gamma(\Lambda(1520)\text{->}\Lambda\gamma)$ =132 keV

l – electrons

l – muons

Dashed line –
effect of simple eTFF of the „dipole" form :
$1/(1-(M/0.71)^2)$
Effect is most visible at high masses

Integrated $\Gamma_{\Lambda e+e-} \cong 1$ keV (BR= 6.8e-5)

Note that $\Gamma_{\Lambda e+e-}/\Gamma_{rad} \cong 1/132 \cong \alpha$

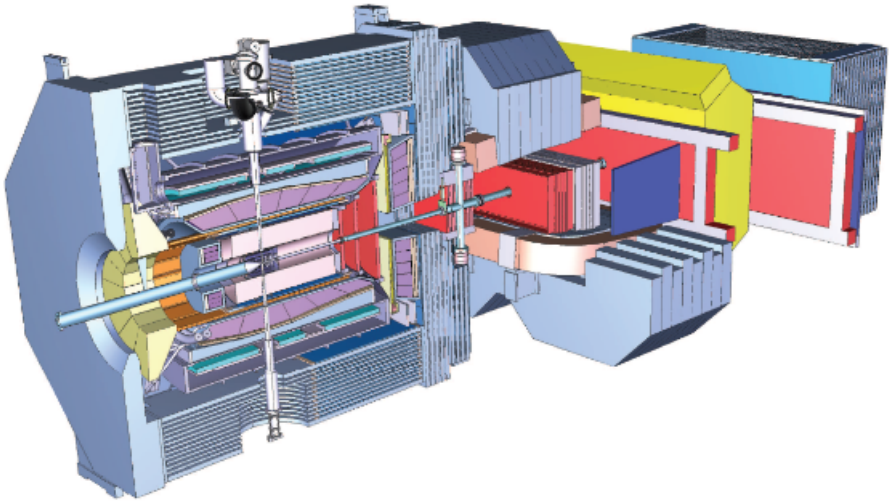
PANDA: Anti-Proton ANnihilation at DArmstadt (450 physicists, 17 countries)

future experiment at new international FAIR facility at GSI
(German national lab for heavy ion research near Darmstadt)

FAIR Facility for Antiproton and Ion Research

High-intensity anti-proton beam on internal pellet/cluster target.

- Average production rate: 2×10^7/sec;
- Beam momentum 1.5 ... 15 GeV/c; $\Delta p/p$ as good as 10^{-5};
- Luminosity up to 2×10^{32} $cm^{-2}s^{-1}$.



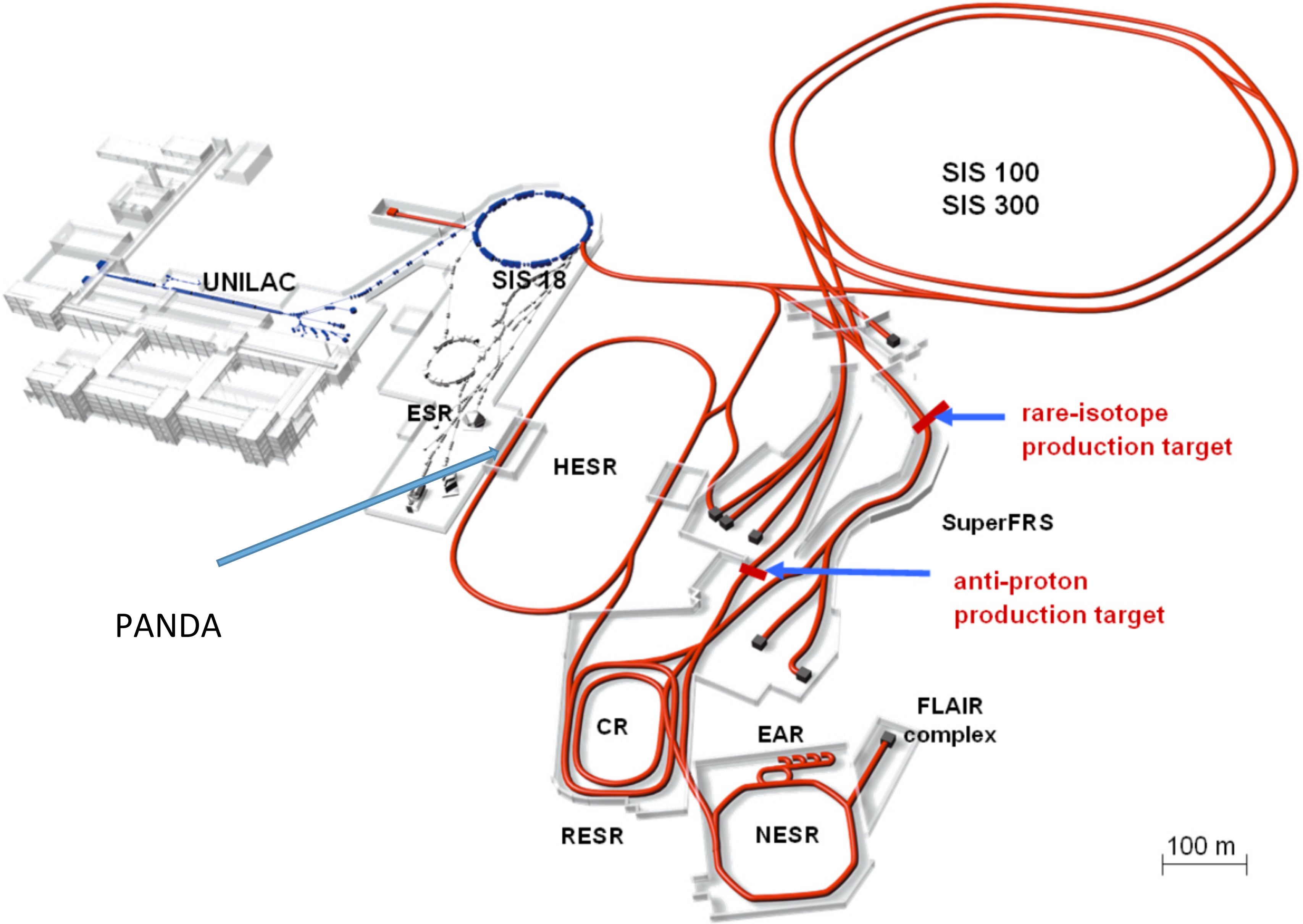
Study of QCD with Antiprotons

- Charmonium Spectroscopy;
- Search for Exotics; Hadrons in Medium;
- Nucleon Structure; Hypernuclear Physics.

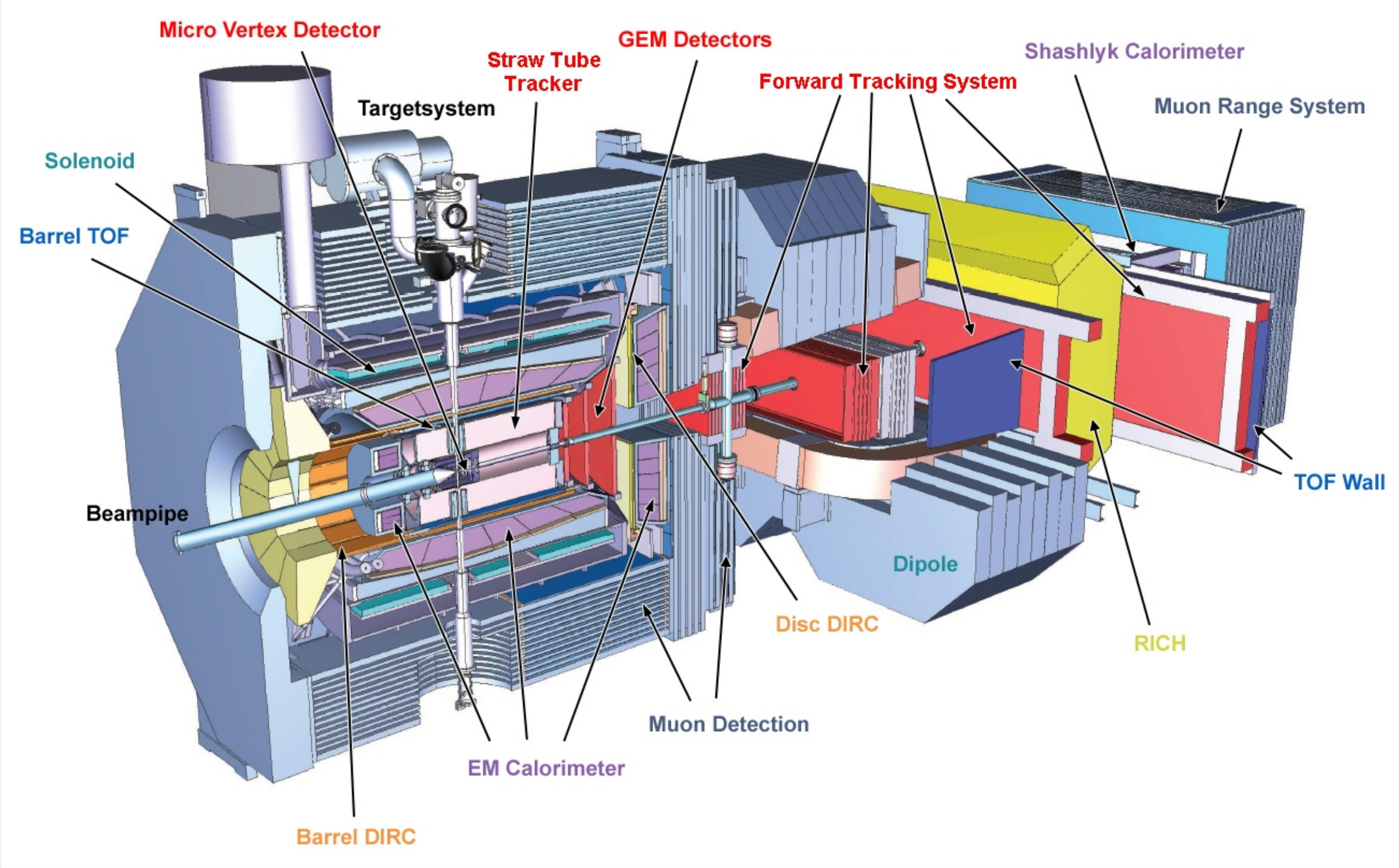
Particle identification essential

- Momentum range 200 MeV/c – 10 GeV/c.
- Several PID methods needed to cover entire momentum range.
- dE/dx, EM showers, Cherenkov radiation in forward & target spectrometer configuration.

The Accelerator Facility



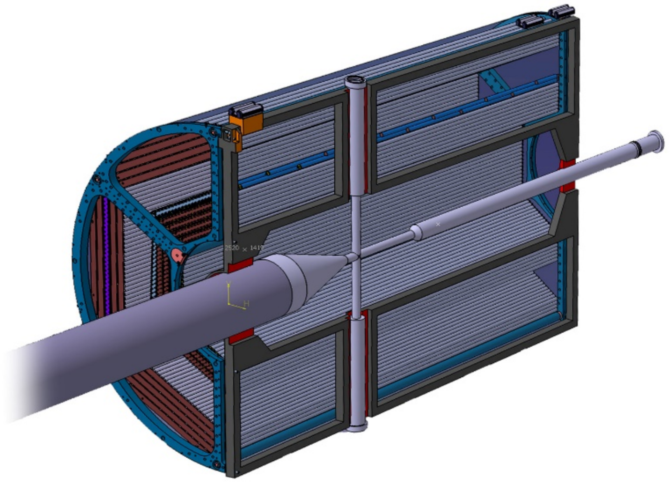
Particle Identification at PANDA



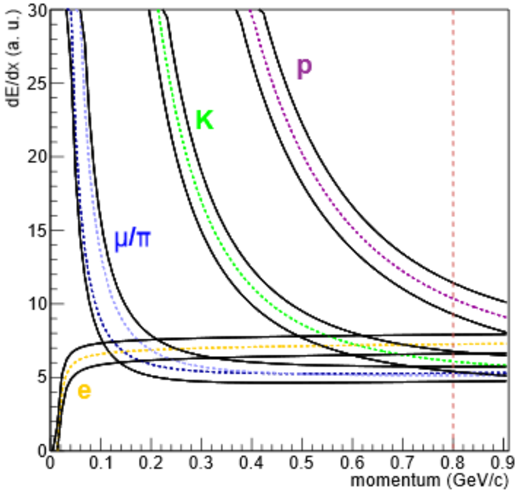
Particle Identification at PANDA

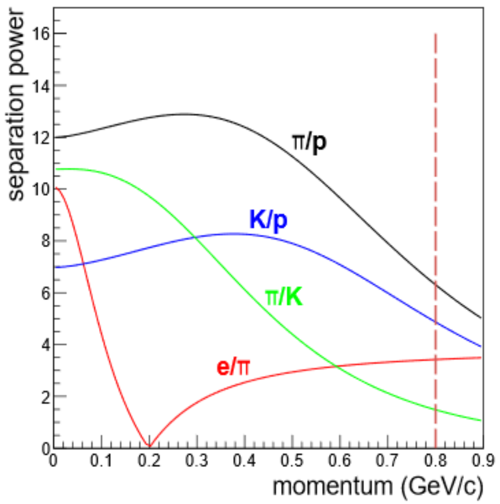
Straw tube tracker (STT)

PID method

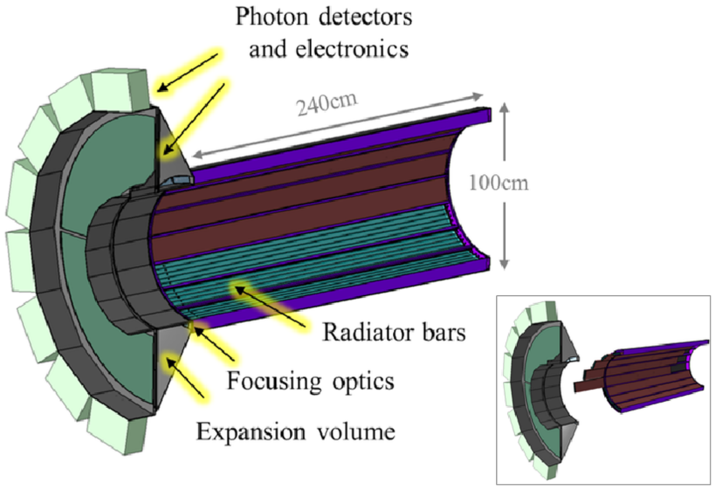


dE/dx

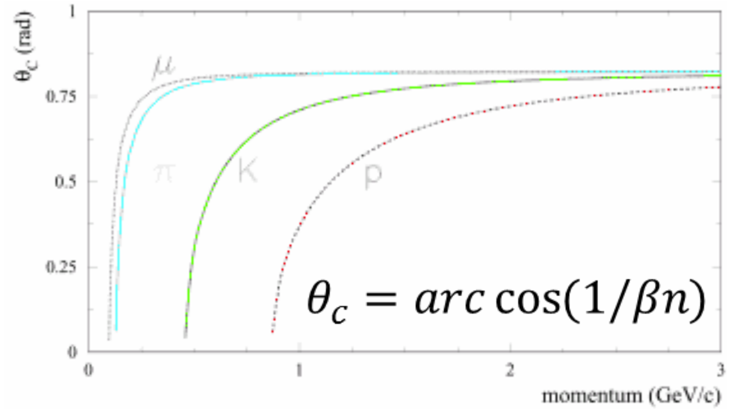




Barel DIRC

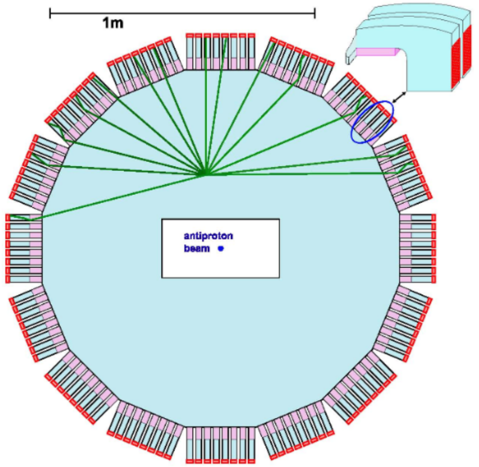


Cherenkov

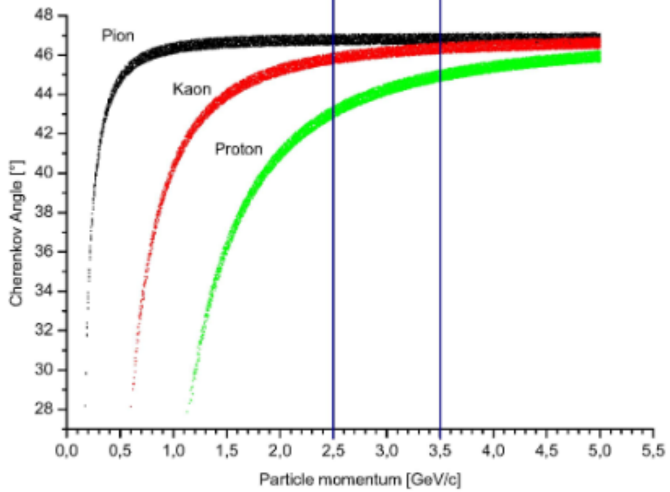


Particle Identification at PANDA

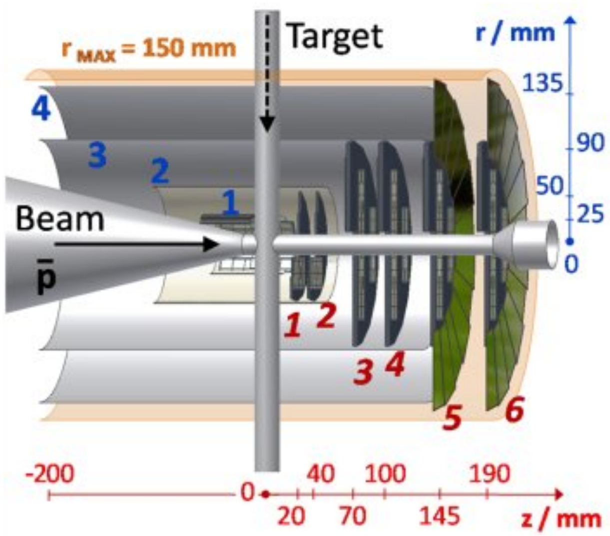
Disc DIRC



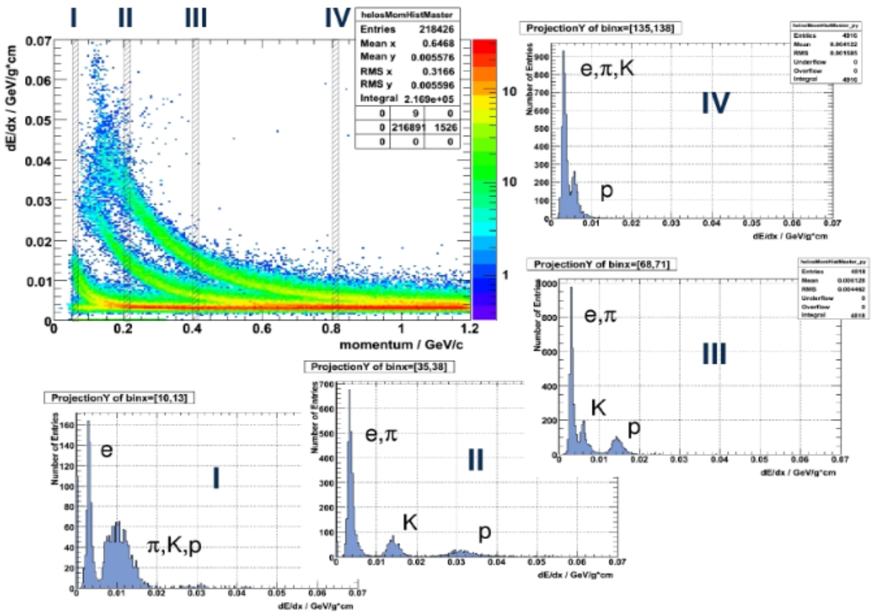
Cherenkov



MVD



dE/dx

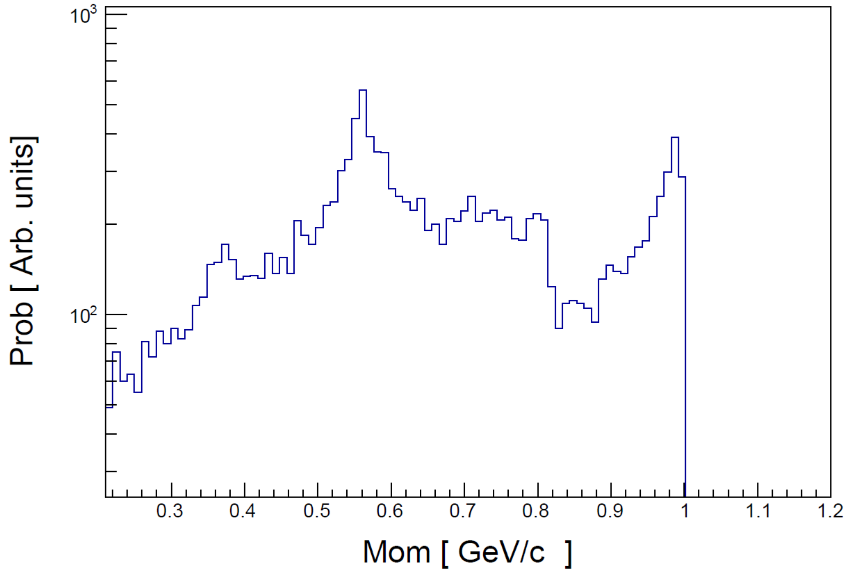


PID in simulation

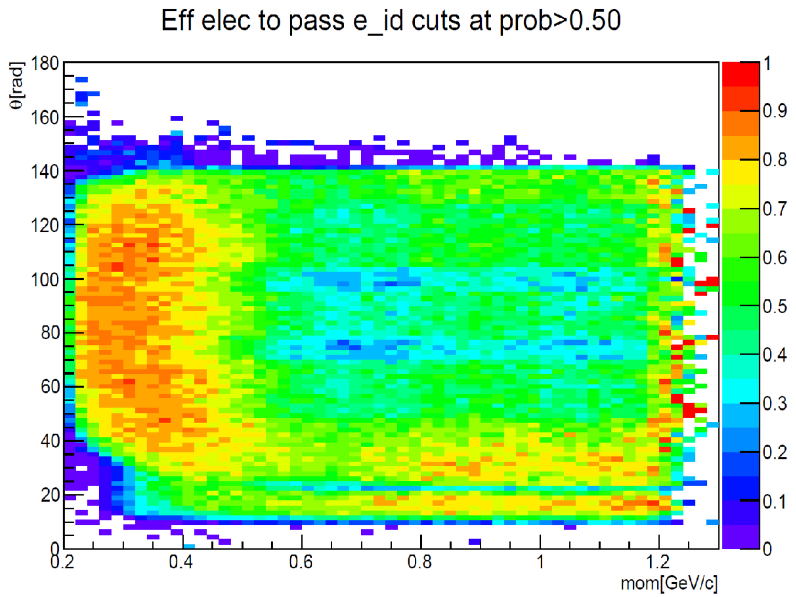
- The parametrization was produced as follows:

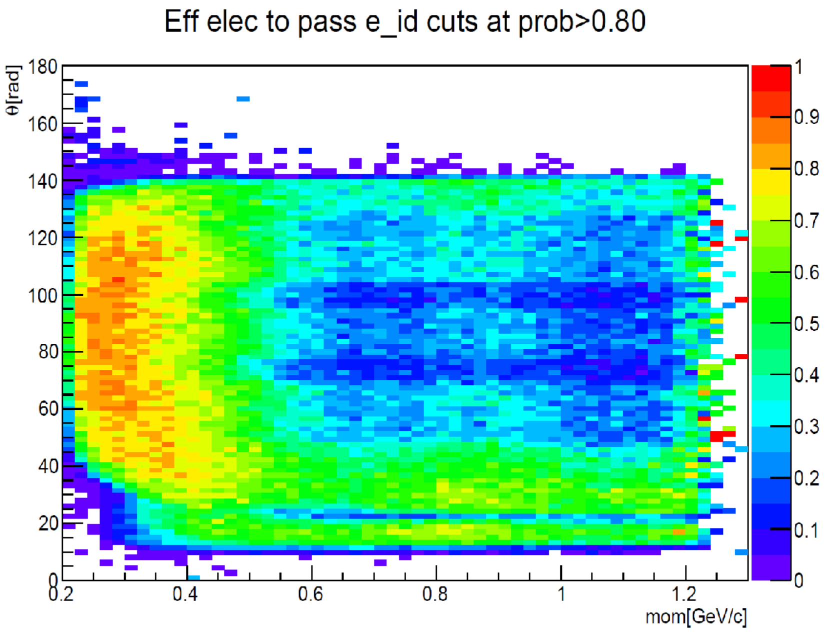
$$p(k) = \frac{\prod_i p_i(k)}{\sum_j \prod_i p_i(j)}$$

where the product with index “i” runs over all selected sub detectors and the sum with index “j” over the particle types e, μ, π, K and p.



Efficiency is reasonable above 200 MeV/c !

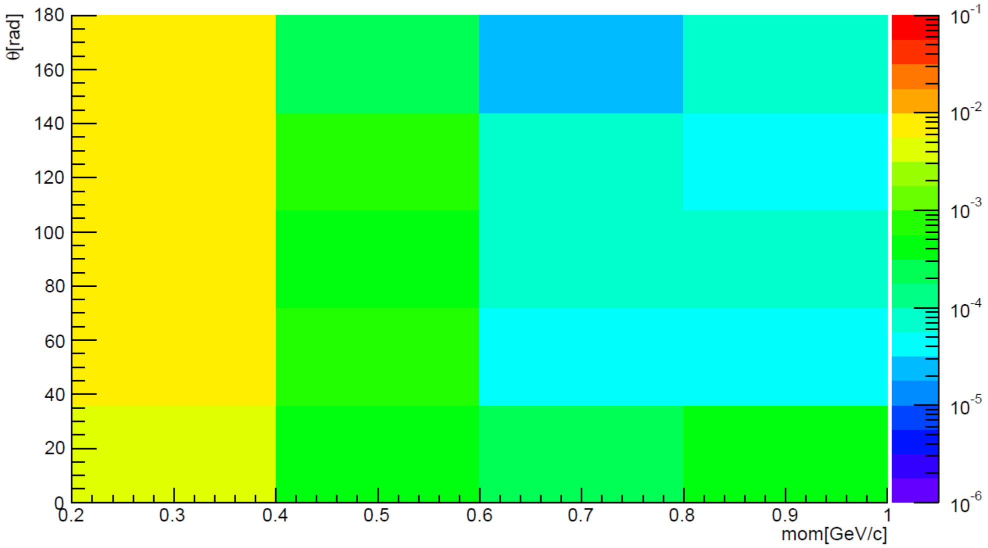




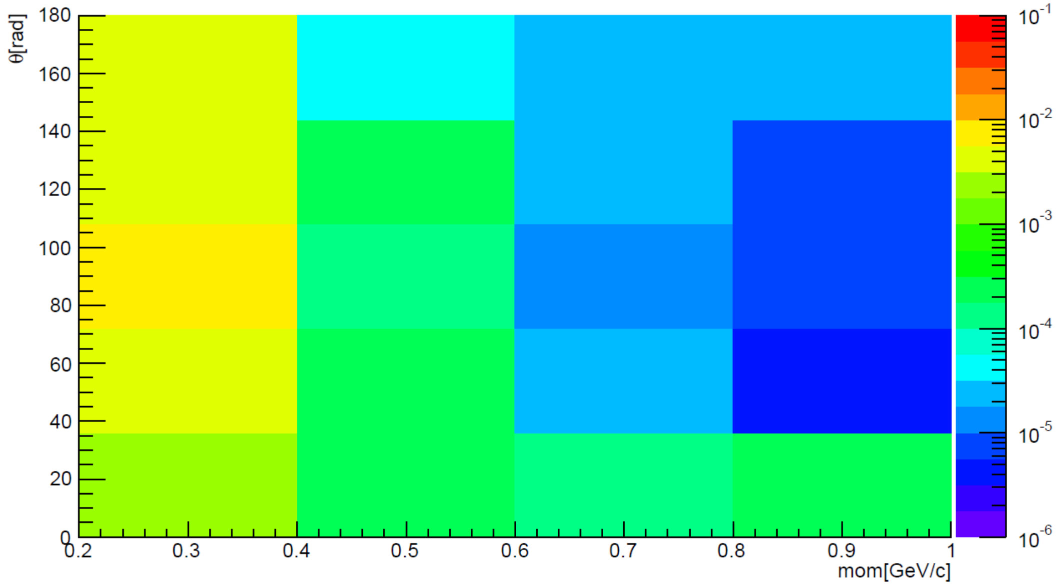
Background study

- The background contribution will be originating from $\pi^+\pi^-$
- There is a probability to miss identify pions as electrons, simulations of PID were produced to show this effect

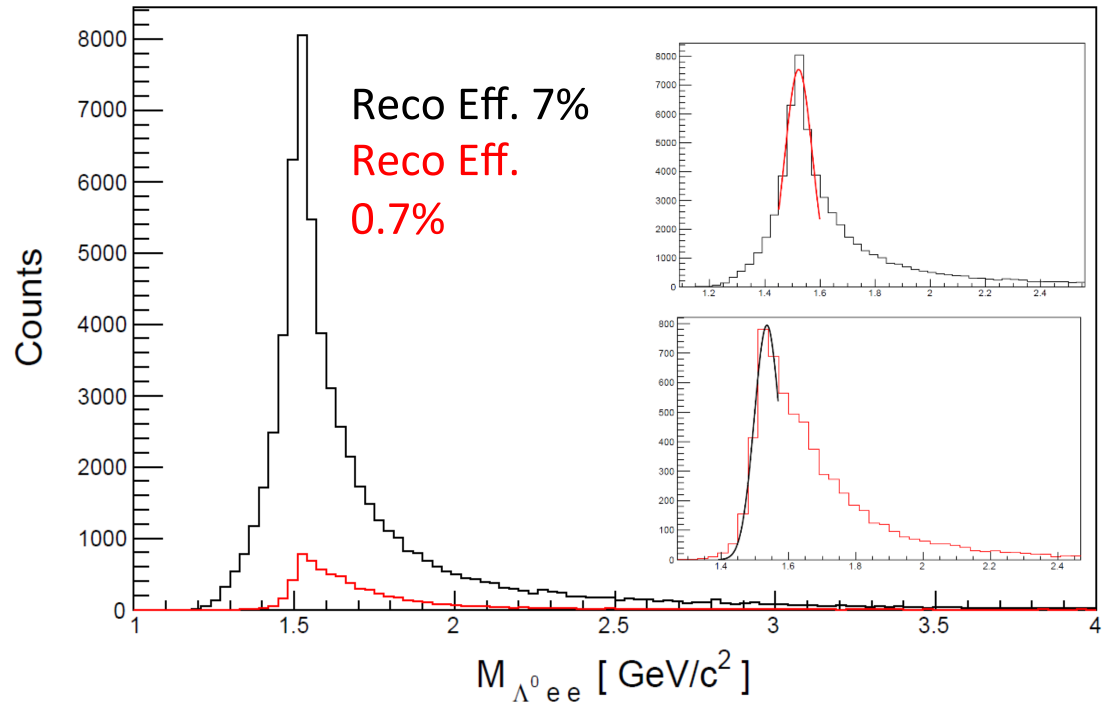
Eff pion to pass e_id cuts at prob > 0.50



Eff pion to pass e_id cuts at prob > 0.80

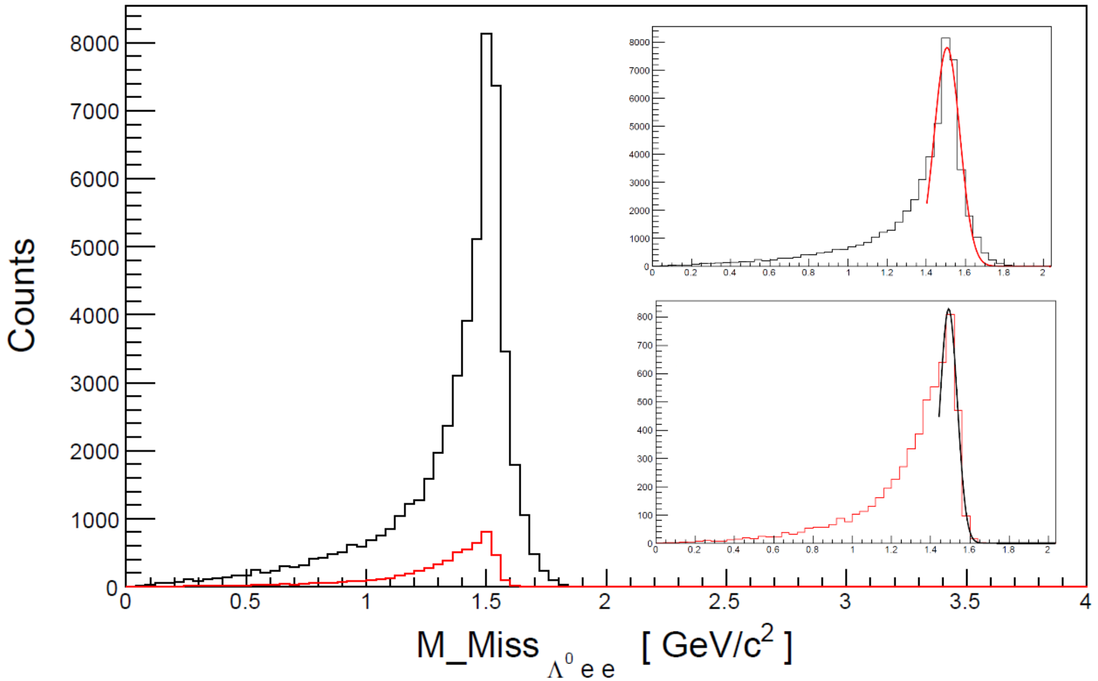


Λ(1520) reconstruction



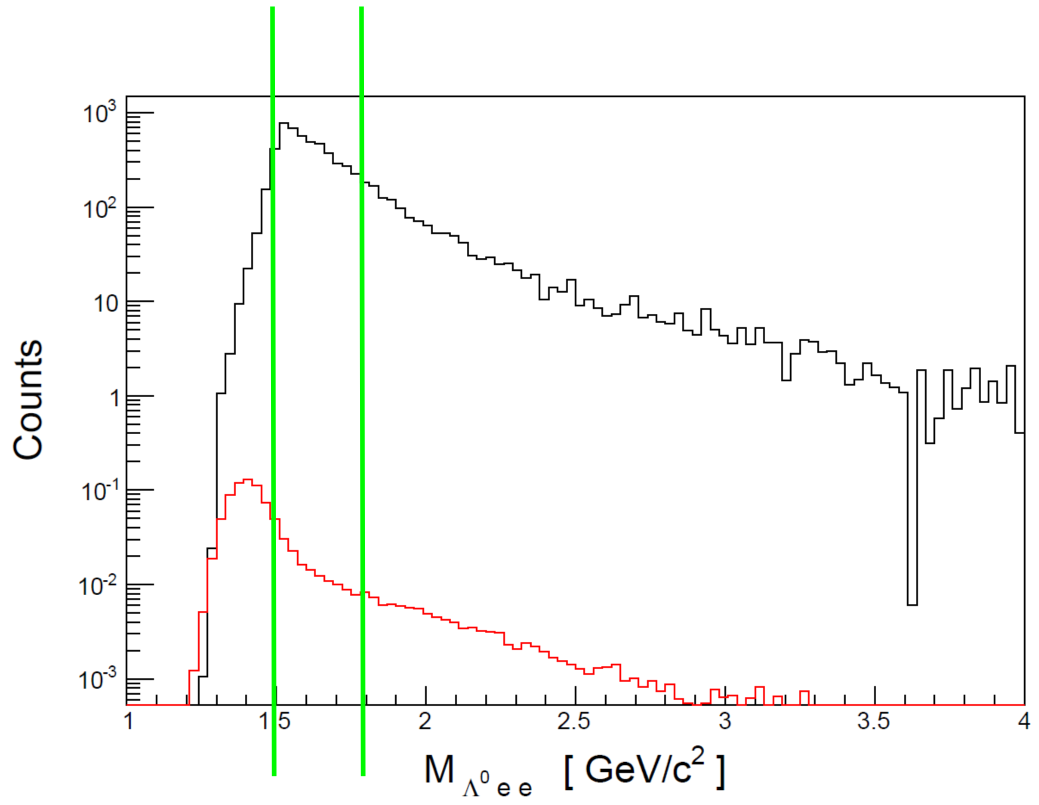
particle	Fraction form 4π
lambda MC Reco	7%
lambda MC PID	0.65%

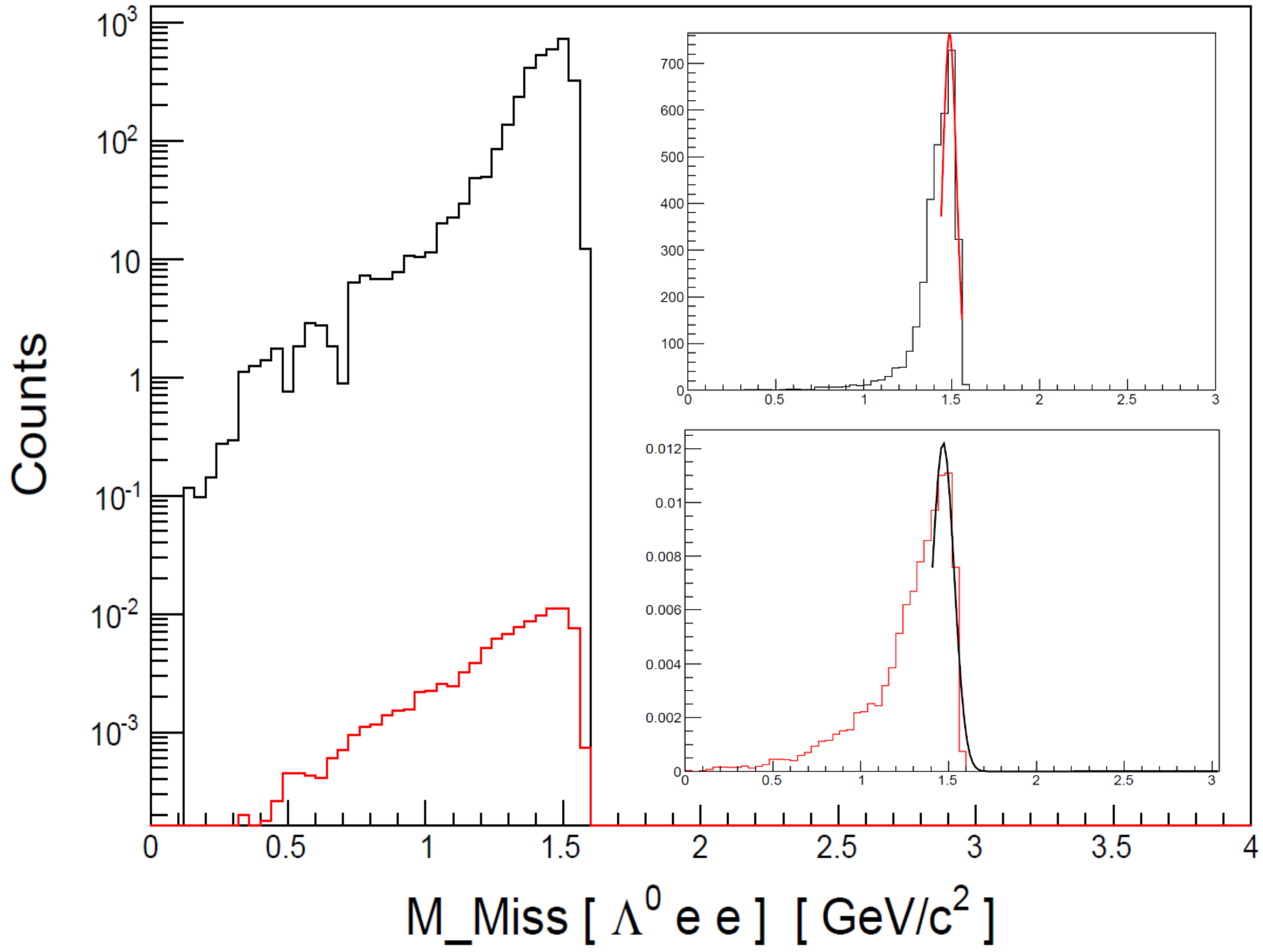
particle	peak position	sigma
lambda MC Reco	1.522	0.05
lambda MC PID	1.539	0.049



particle	peak position	sigma
lambda MC Reco	1.504	0.062
lambda MC PID	1.5	0.043

Final signal calculation



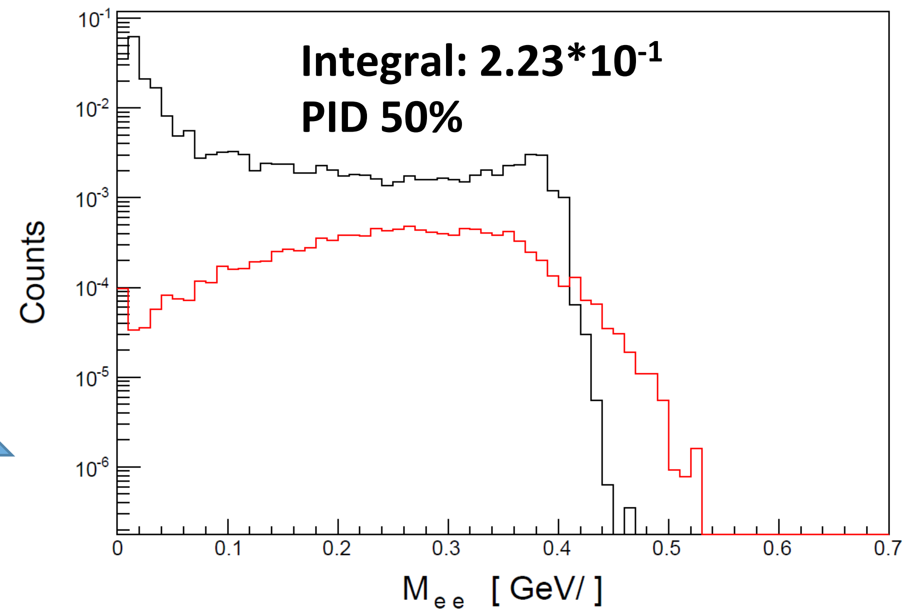


A cut on the Λ(1520) Inv Mass from 1.5 GeV/c^2 to 1.67 GeV/c^2

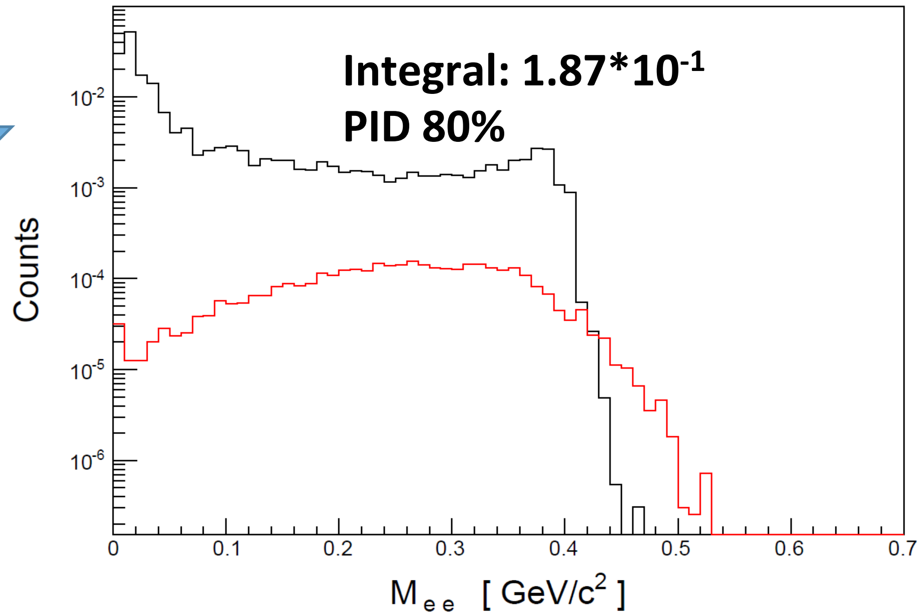
particle	mean	sigma	Fraction form 4π
lambda epem PID	1.508	0.060	0.36%
lambda pipim PID	1.49	0.23	1.16e-9 %

Signal to background ratio

- The $e^+ e^-$ signal was parametrized with the Zeteni & Wolf formula and scaled to the BR = $6.8*10^{-5}$
- The $\pi^+\pi^-$ was scaled to BR = 0.1
- $\bar{p}-p \rightarrow \Lambda(1520)\bar{\Lambda}(1520)(stable) \rightarrow e^+e^-\pi^-p$
- $\bar{p}-p \rightarrow \Lambda(1520)\bar{\Lambda}(1520)(stable) \rightarrow \pi^+\pi^-\pi^-p$

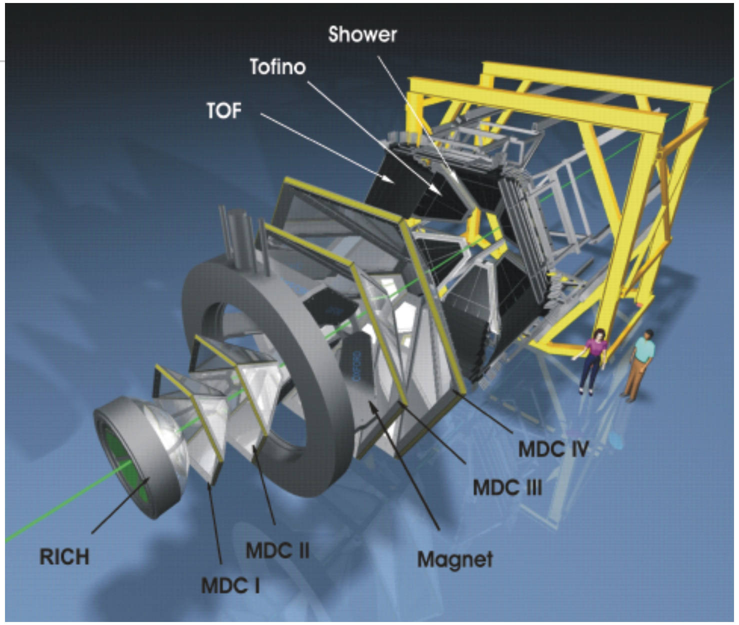


16% difference



High luminosity mode	Low luminosity mode
$L = 2 *10^{32}/ cm^2 *s$	$L = 2 *10^{31}/ cm^2 *s$
Branching ration 6.8 * 10^{-5}	
σ = 43 μb*	
e+ e- pair reconstruction efficiency (within mass window)	
180 / 24 h	18 / 24 h

The HADES spectometer

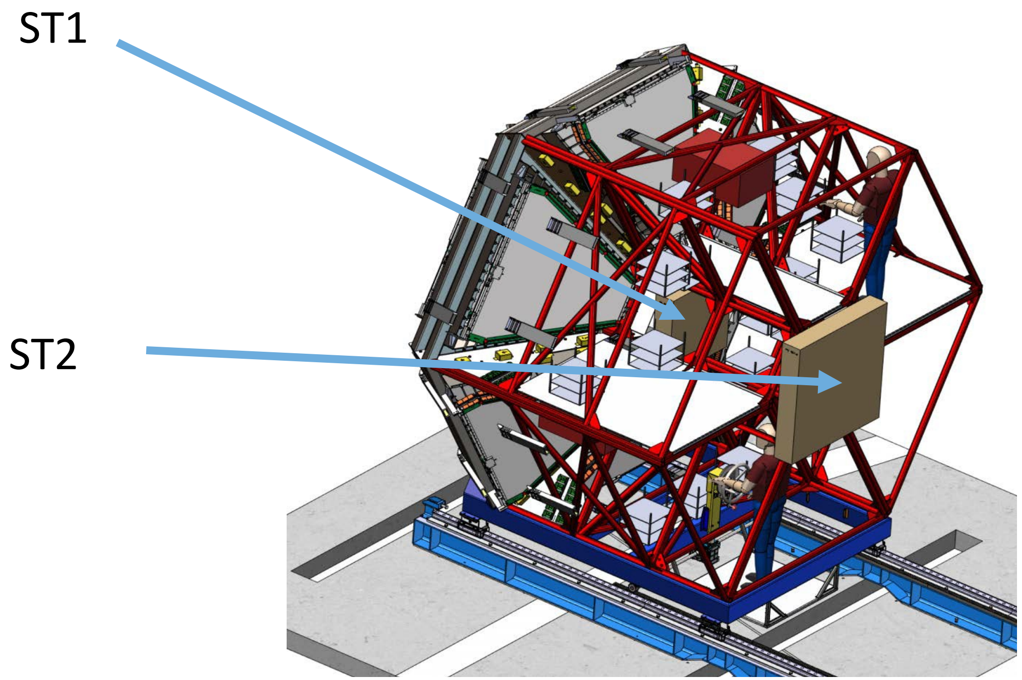


• **Detector geometry**
full azimuthal range covered, 6 sectors
polar angle: $16^{o}<\theta<84^{o}$

• **Tracking**
Superconducting coils, toroidal field
24 Mini Drift Chambers

• **Particle identification (e, p, K)**
RICH, MDC, TOF, TOFINO, Shower (RPC)

• **Resolutions**
$\Delta M\omega/M\omega \sim 2.1\%$ at ω peak
$\Delta p/p \sim 2\text{-}3\%$ for proton and π



Planed Upgrade :
•RICH (hadron blind) with new PMT`s
•New Daq
•ECAL (form γ tagging)
•FW detector (straw tube + TOF)

Current HADES

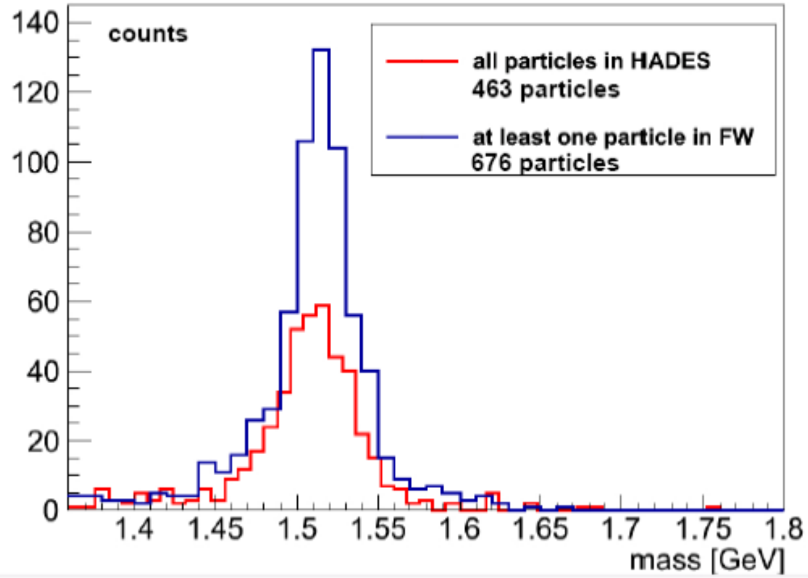
10^8 p/s $5*10^5$ π/s

	Proton Beam	Pion Beam
HADES only		
Carbon Target	52/day	0.2/day
Hydrogen Target	13.2/day	0.2/day
HADES and FW		
Carbon Target	128.3/day	0.5/day
Hydrogen Target	32.6/day	0.7/day

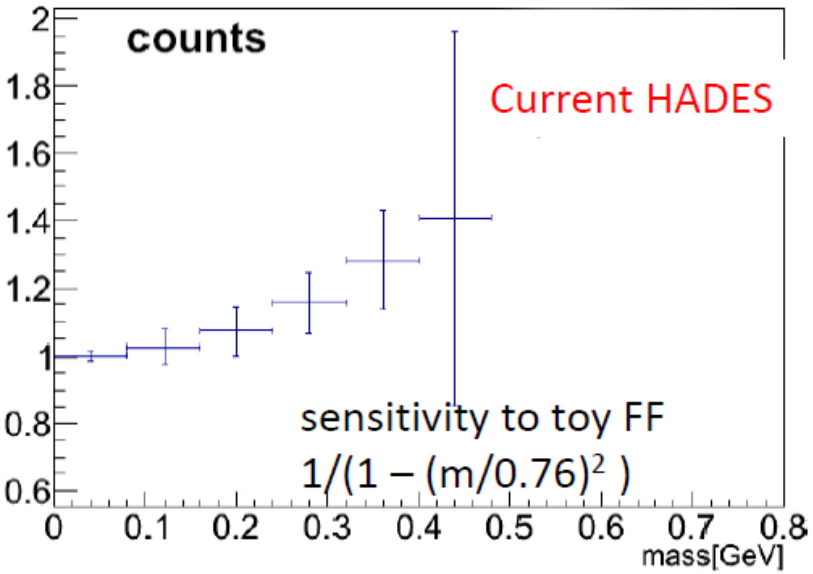
„Future” (2018) HADES

- Improved DAQ (~200 KHZ) – factor 5 for pp (luminosity ~ 4-6x 10^{31} 1/(s*cm^2)
- Imrpoved RICH (gain for e+e- -factor 5), + FW detector (gain ~2) = gain 10 ~

Total Gain 50 !~



10 days run with C target

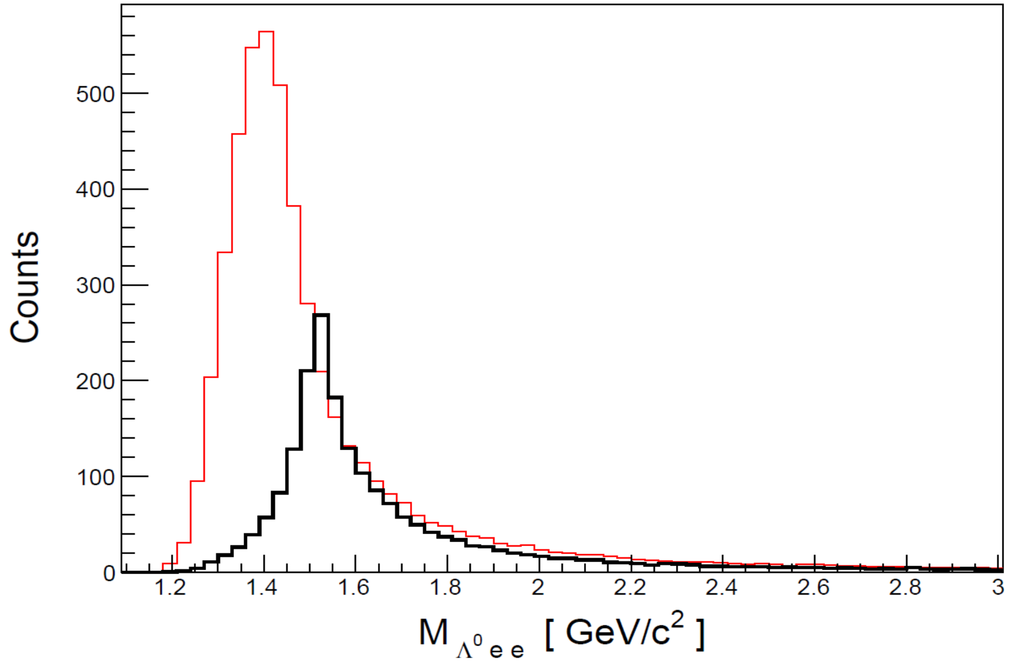


Conclusions

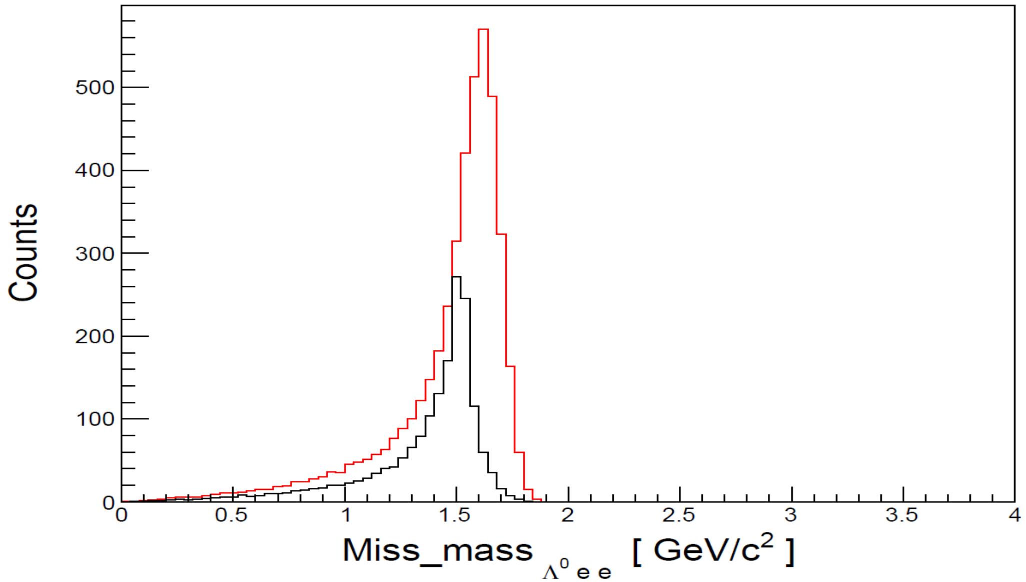
PANDA:
•There is a factor 10 difference between signal and background
•Λ(1520) e+ e- reconstruction rates are low.
HADES:
•Obtained production rates are promising (especially p+C)
•Planed upgrade will increase the reconstruction rate by factor 50 and enable gamma tagging (ECAL)

Backup Slides

Λ(1520) reconstruction



particle	mean	sigma
lambda epem Reco	1.523	0.05
lambda pippim RECO	1.4	0.049



particle	mean	sigma
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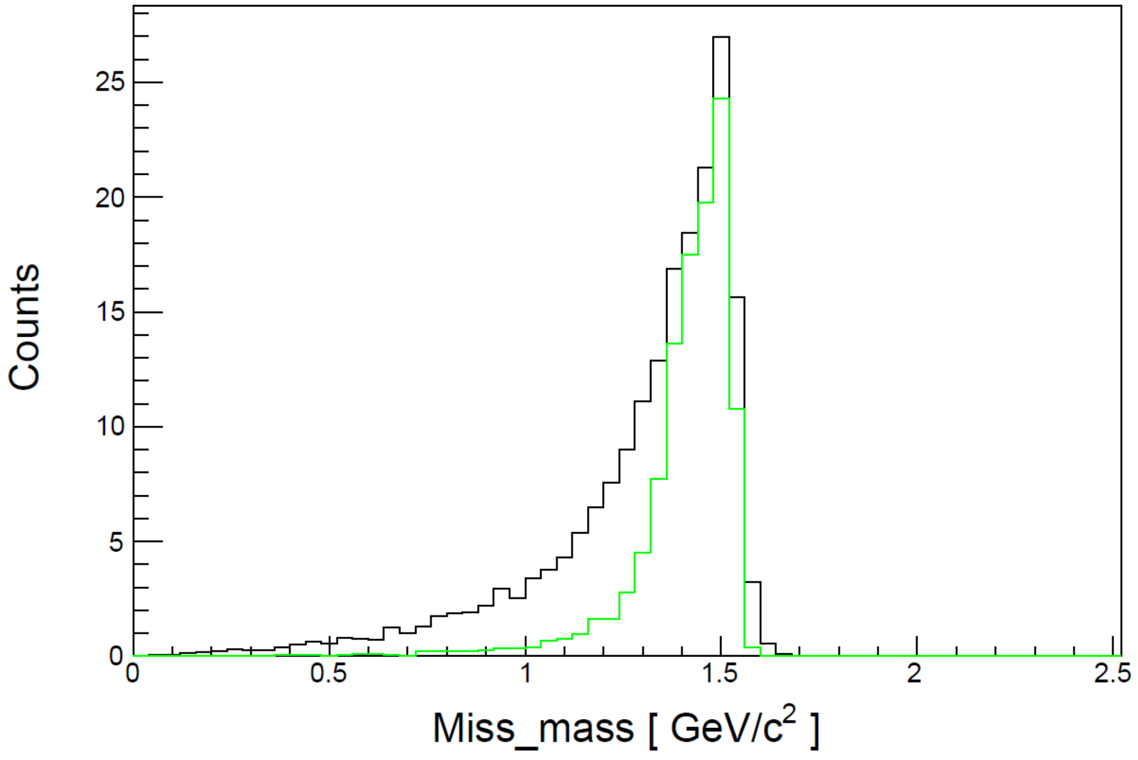
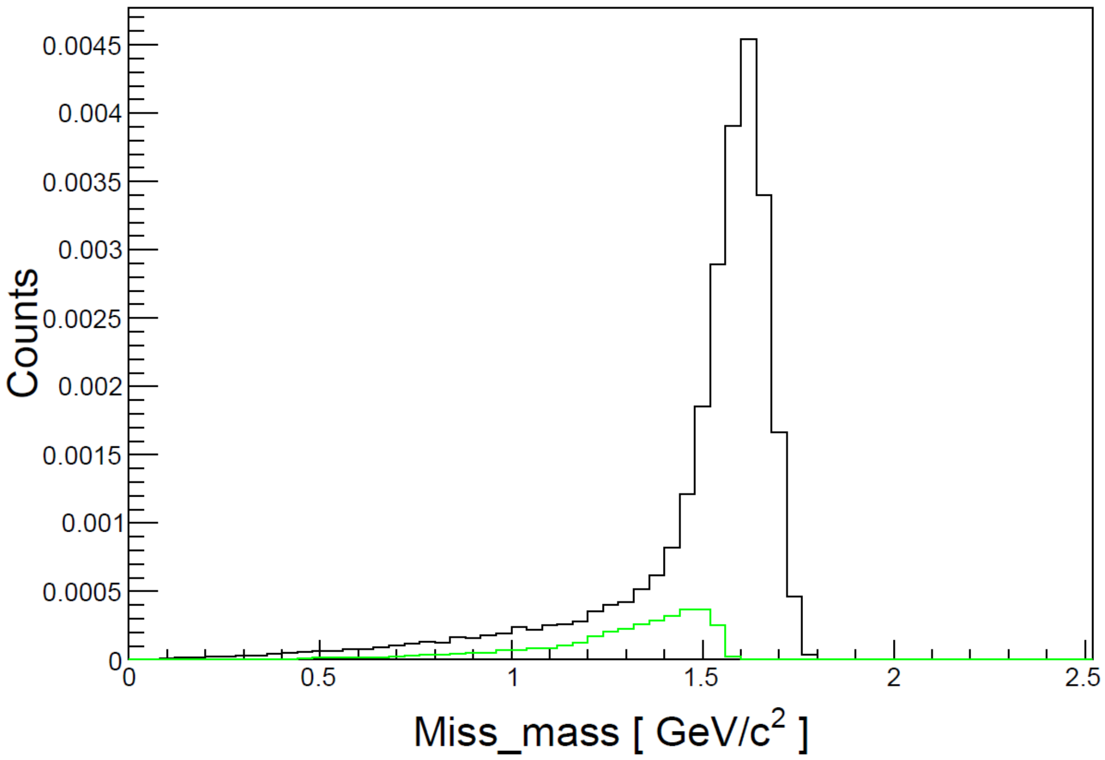
Missing mass

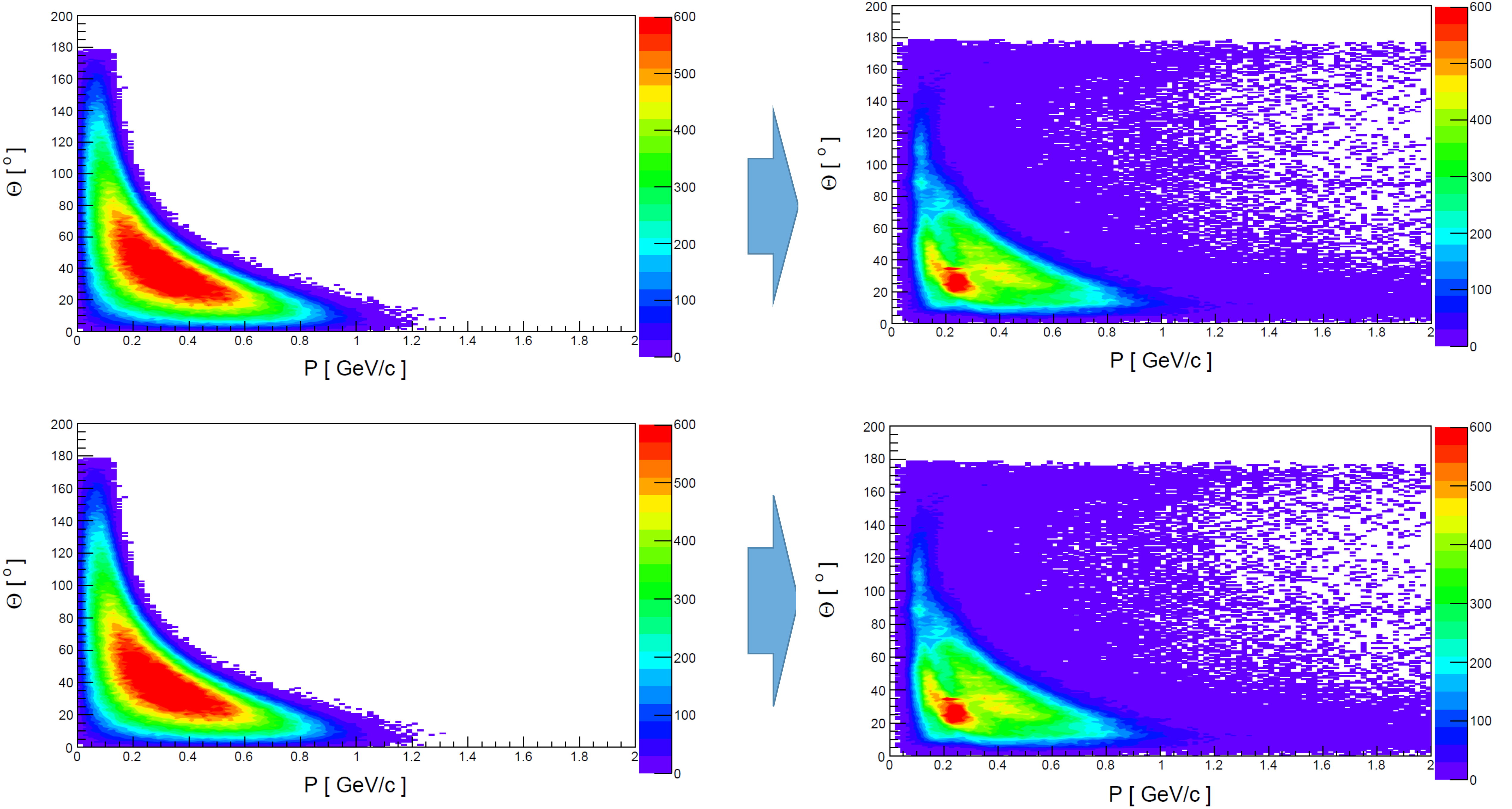
Leptonic

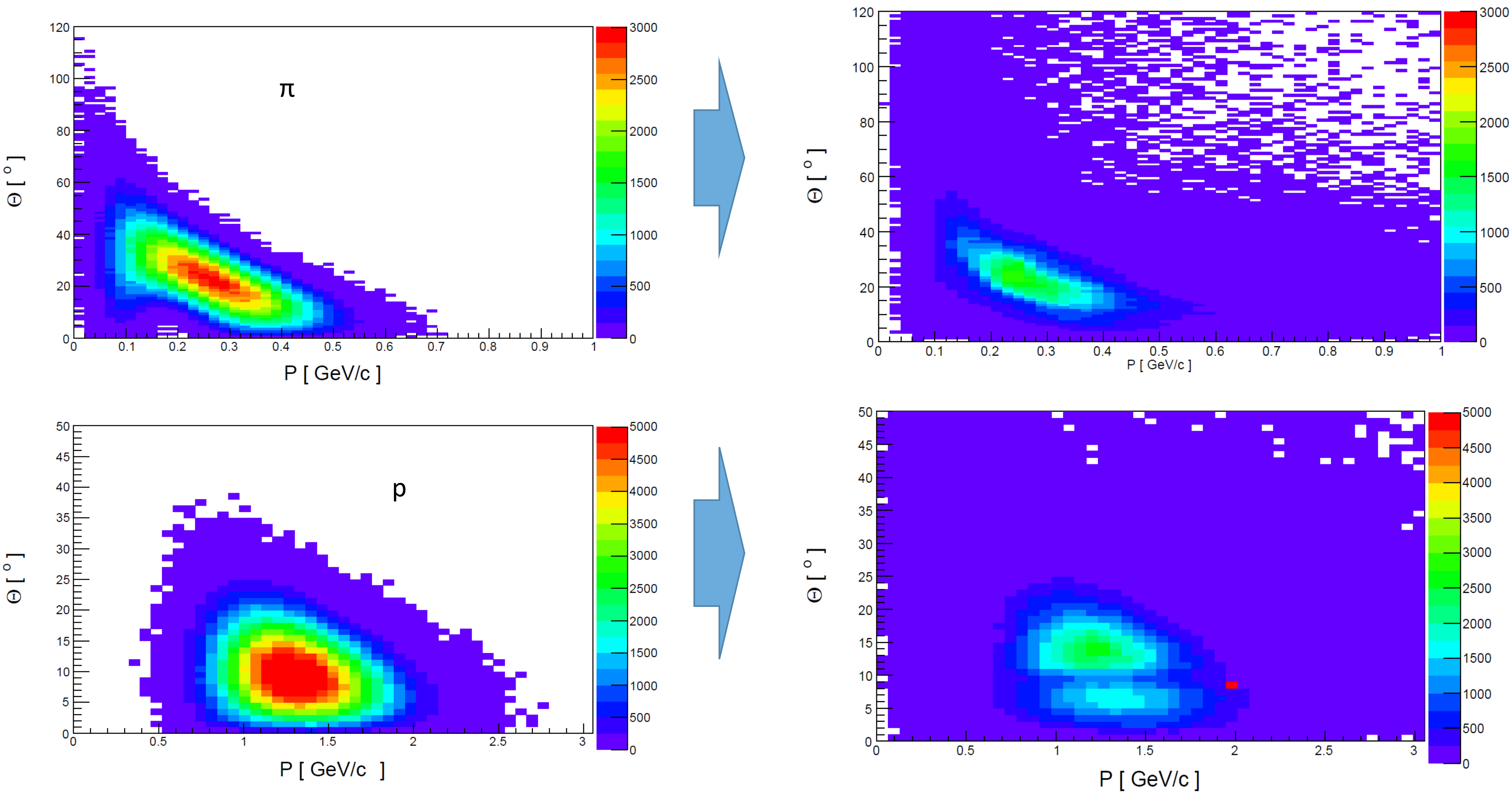


Hadronic

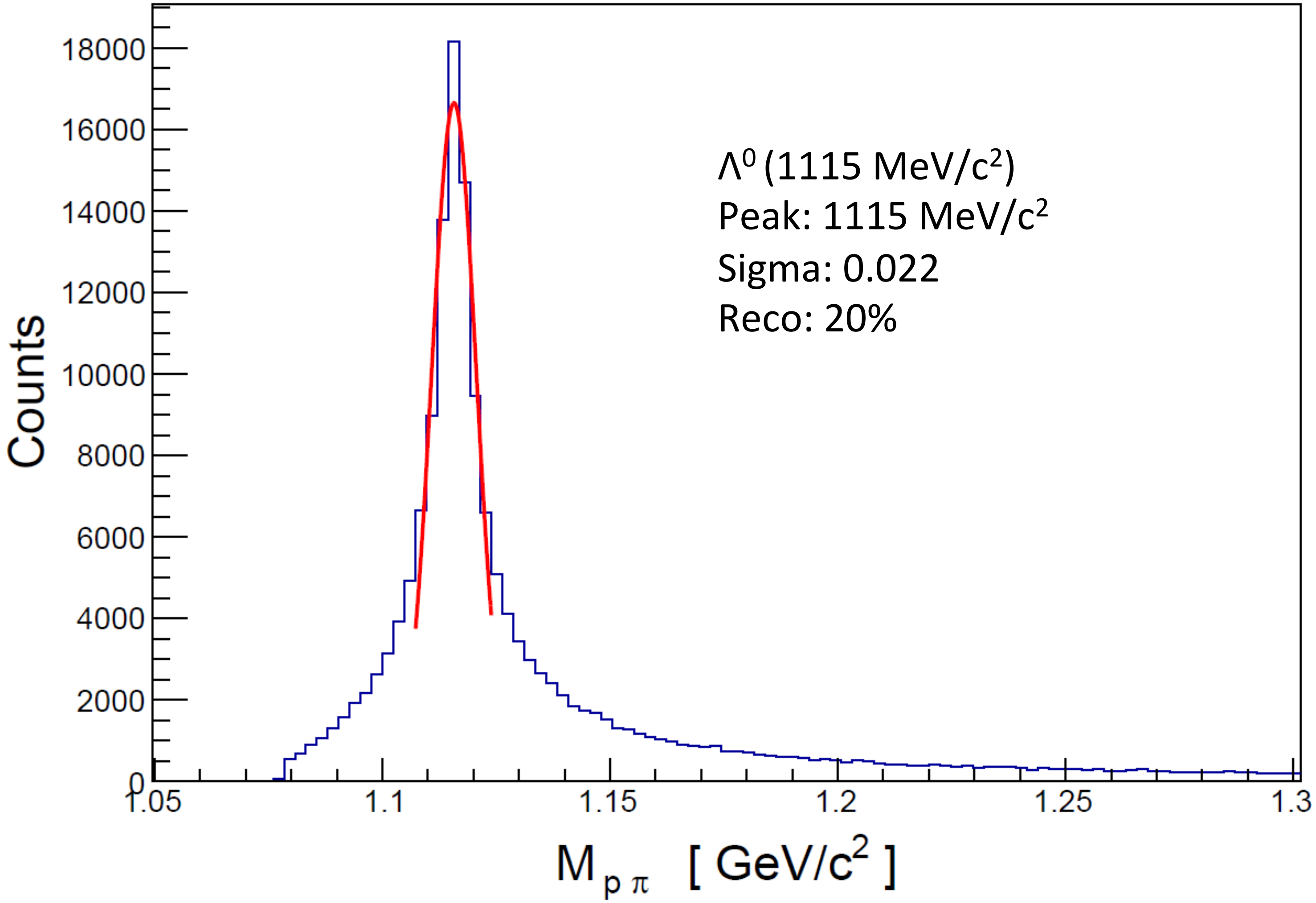


Electrons/Positrons

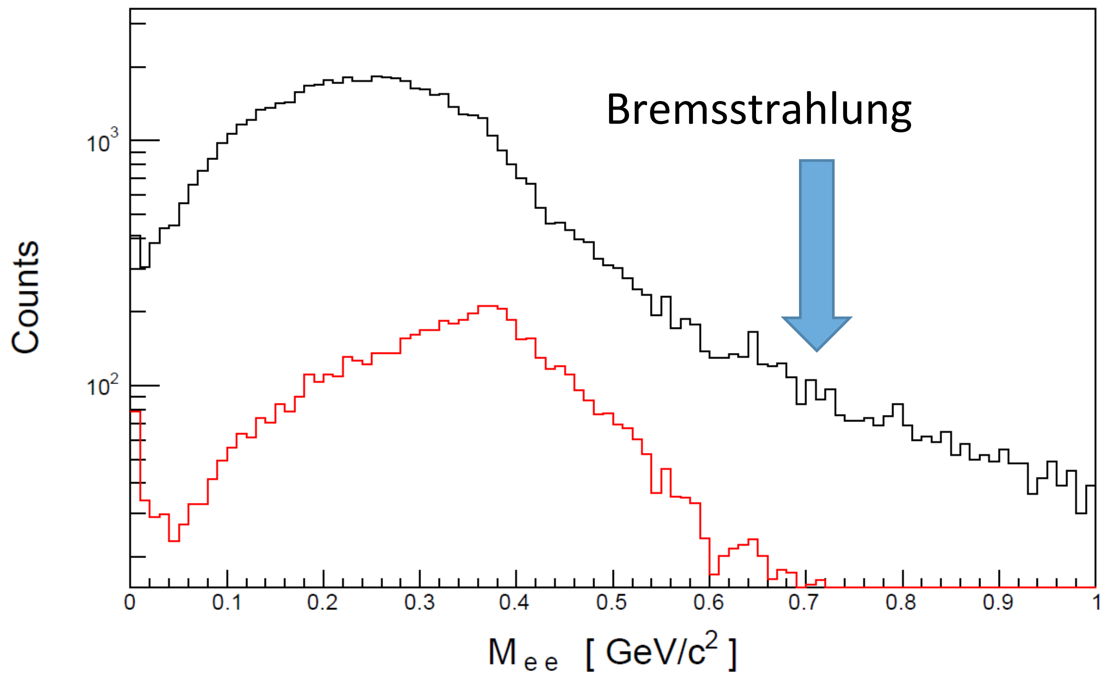



π
p
Θ [°]
P [GeV/c]
P [GeV/c]
Θ [°]
P [GeV/c]
Θ [°]
P [GeV/c]
Θ [°]

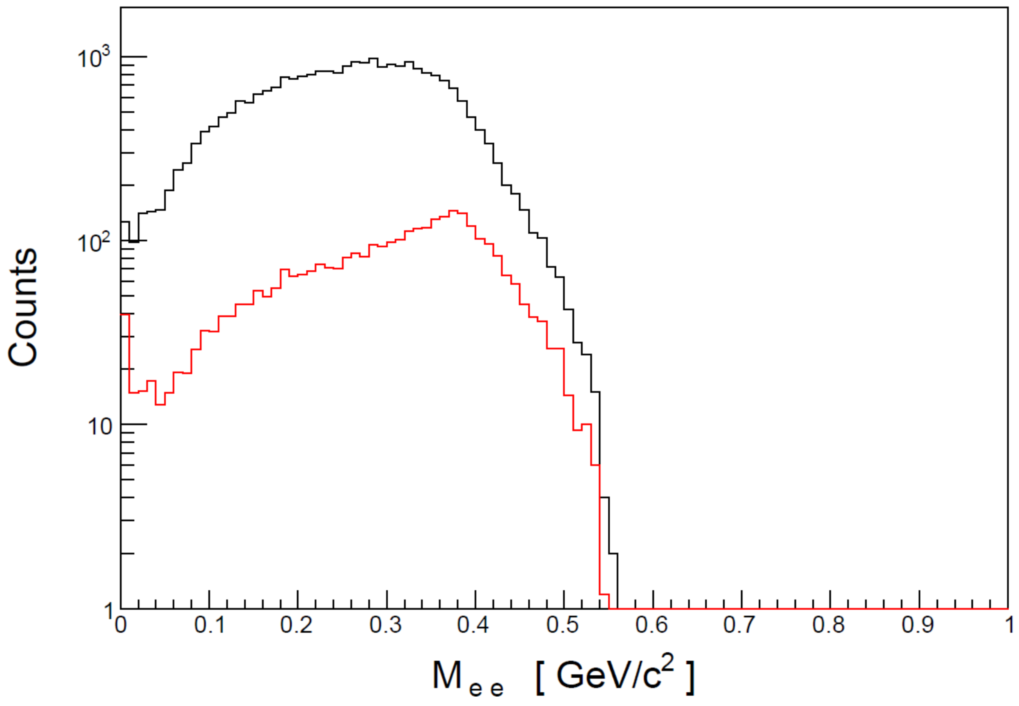
Λ^0 reconstruction



Signal e+ e-

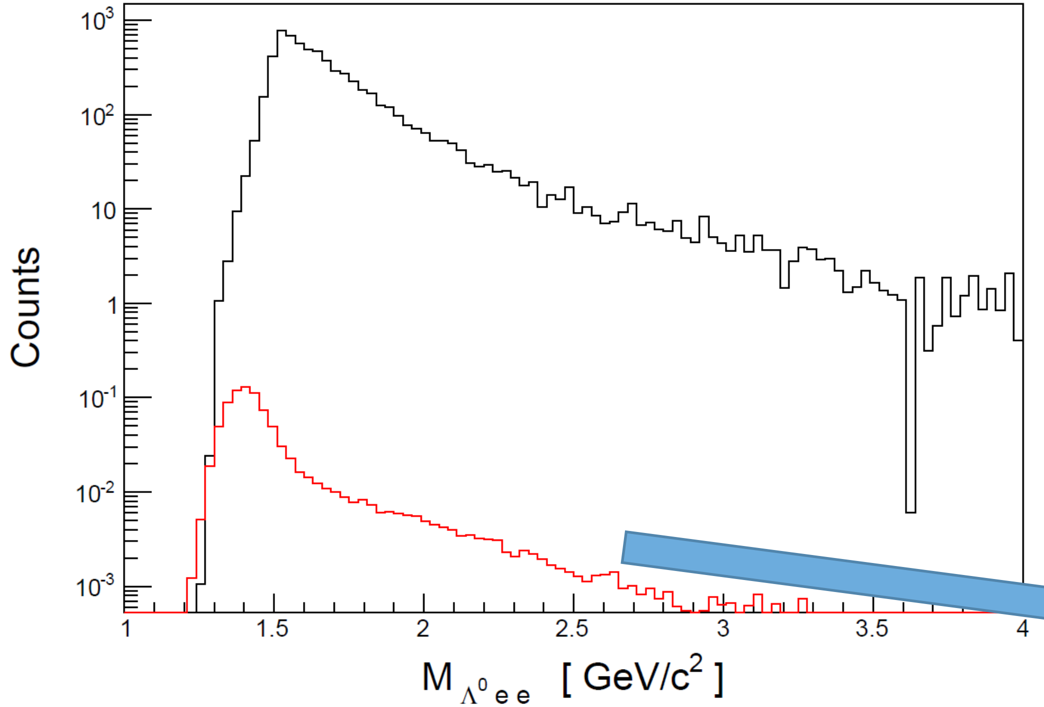


A cut on the Λ(1520) Inv Mass from 1.5 GeV/c^2 to 1.67 GeV/c^2



particle	Fraction form 4π
Signal Reco	26280
Signal PID	3300

Λ(1520) reconstruction with PID



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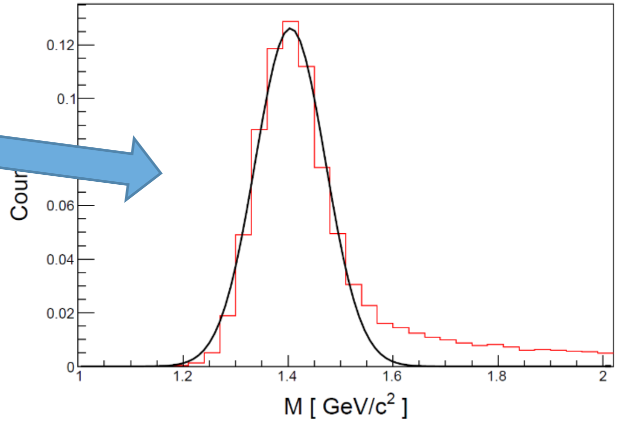
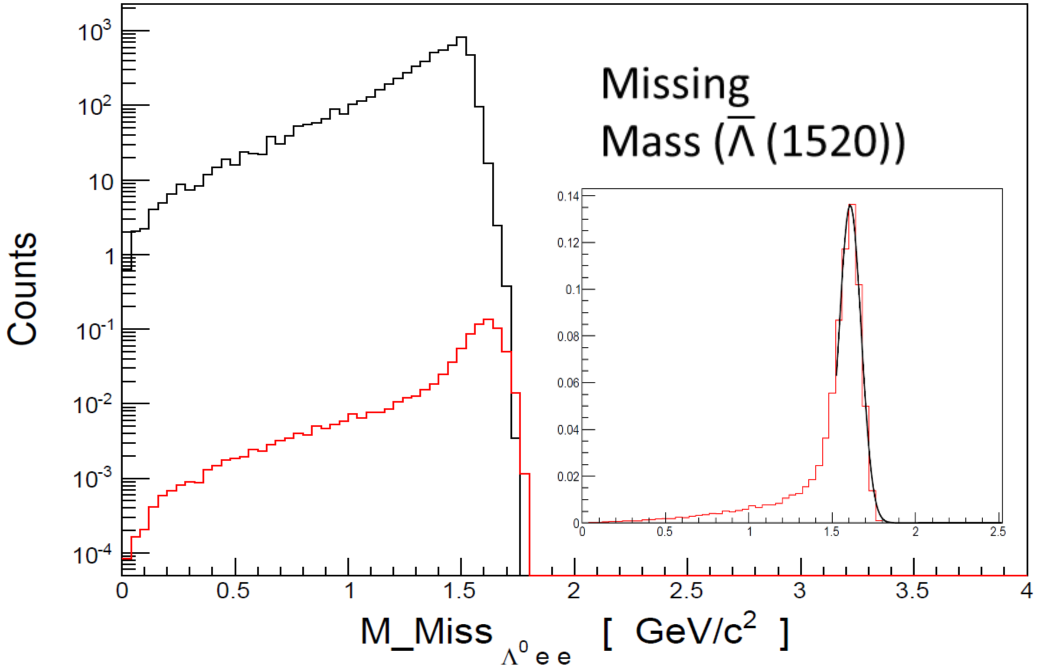
lambda epem PID	1.539	0.05
lambda pippim PID	1.4	0.049



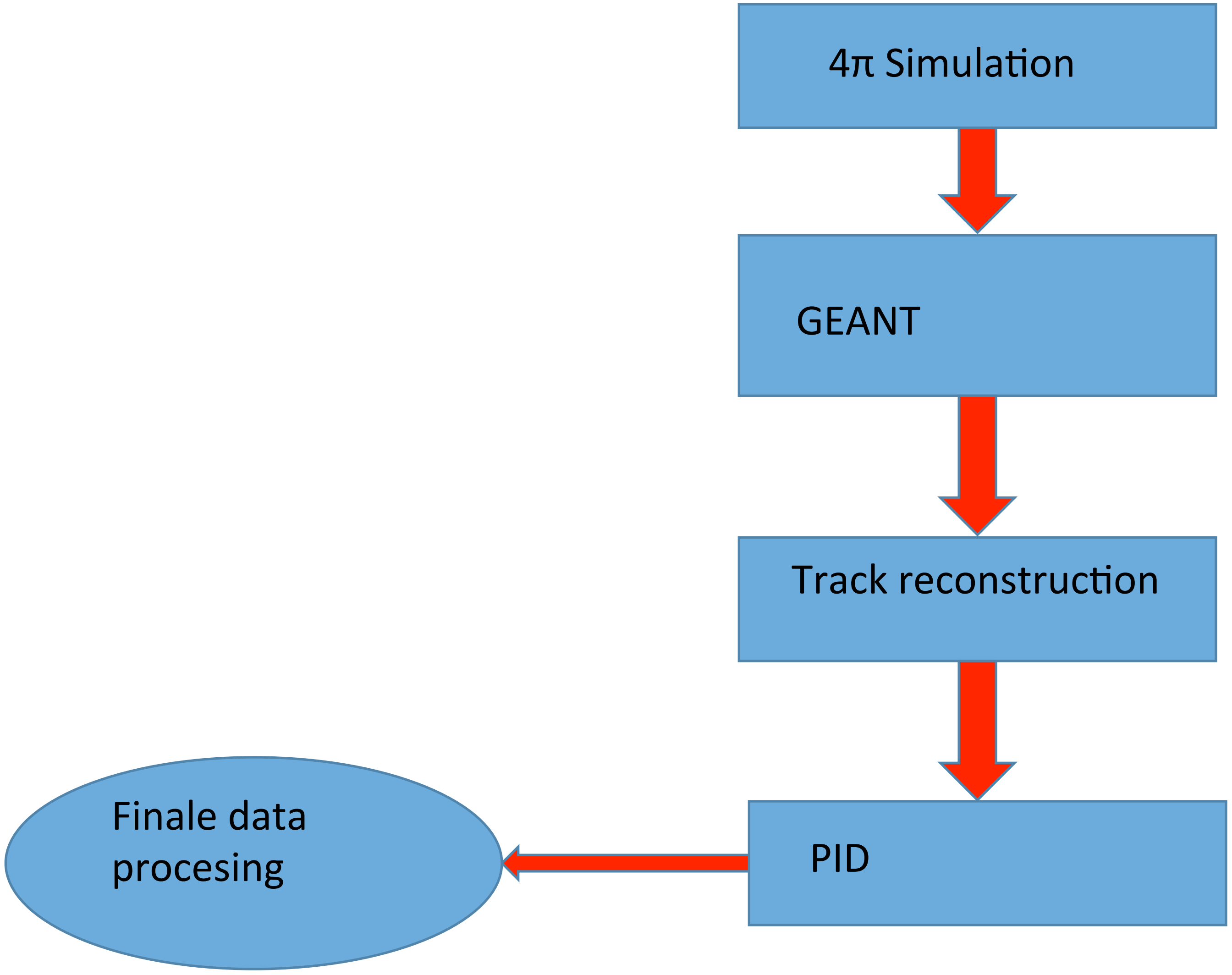


Λ(1520) e+ e- / Λ(1520) π+ π- = 1

particle	peak position	sigma
lambda epem PID	1.508	0.062
lambda pipim PID	1.622	0.043

Symulacja

- anti- proton collisions (beam momentum 4 GeV/c) with proton target
- 0.9 M events simulated in 4π
- Two channels included in simulation



Reconstruction rates

Particle	Reconstructed [%]
e+/e-	71%
π+/π-	47%
proton/ anti-proton	49%