Dalitz decays of Hyperons

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Motivation

- 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)
- Generally eFF depends on q^2 and can be probed in scattering experiments (space like region), annihilation experiments (see below) AND Dalitz decays (topic of my talk)- (time like region)

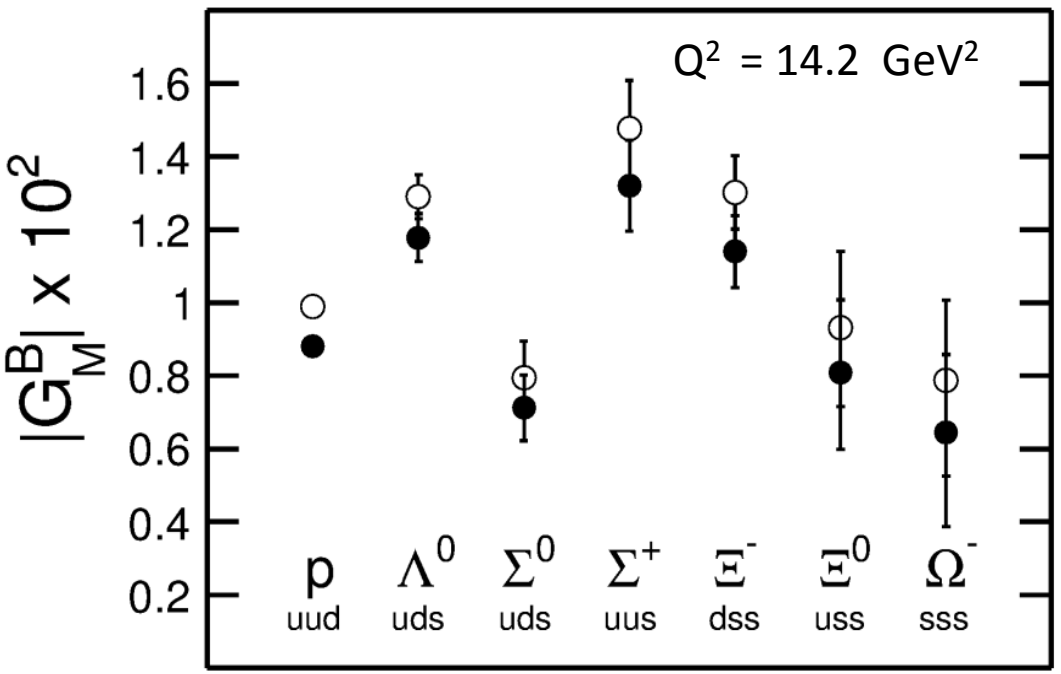
Annihilation experiments :

e+e- $\rightarrow$ hyp anty-hyp (**$q^2 > 4*m^2_{hyp}$**)

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

- 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



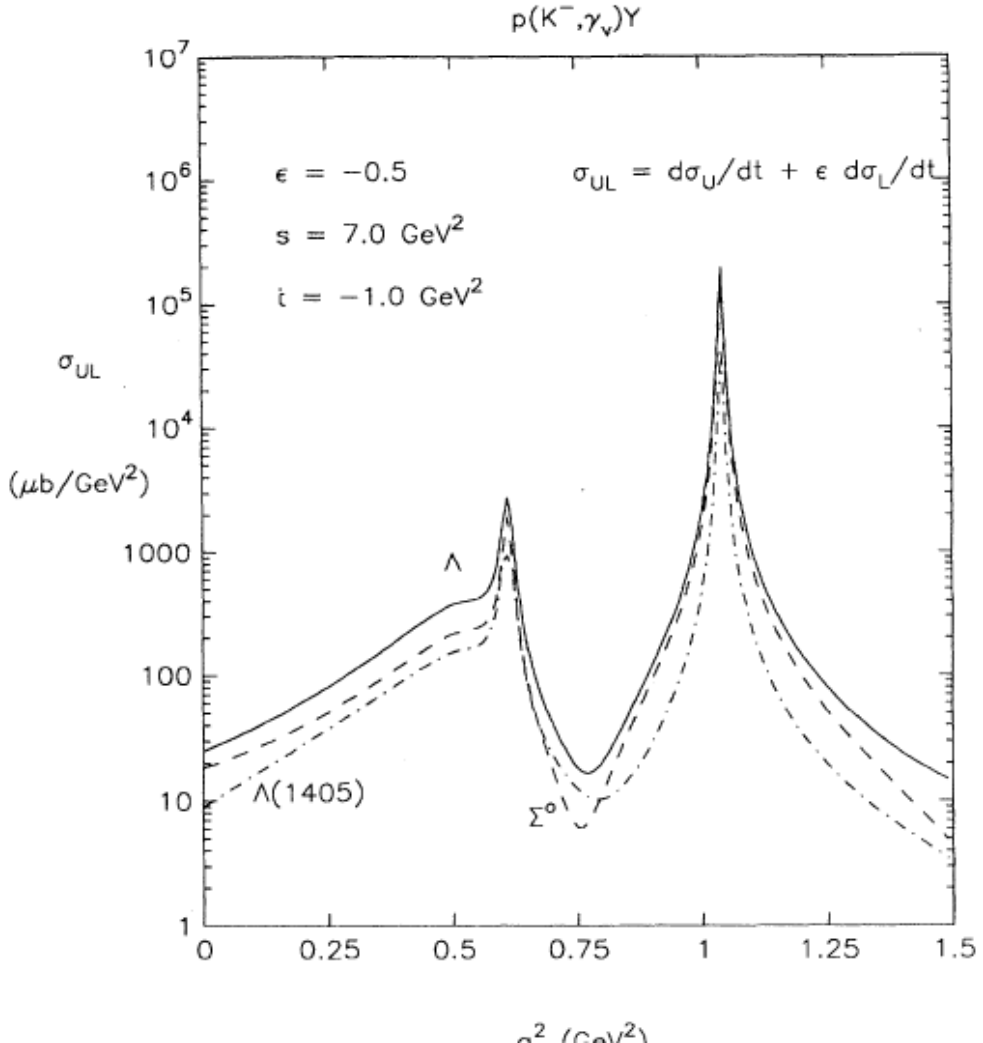
Closed circles : $G_E = G_M$, Open circles: $G_E = 0$

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 $\rightarrow$



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

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

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

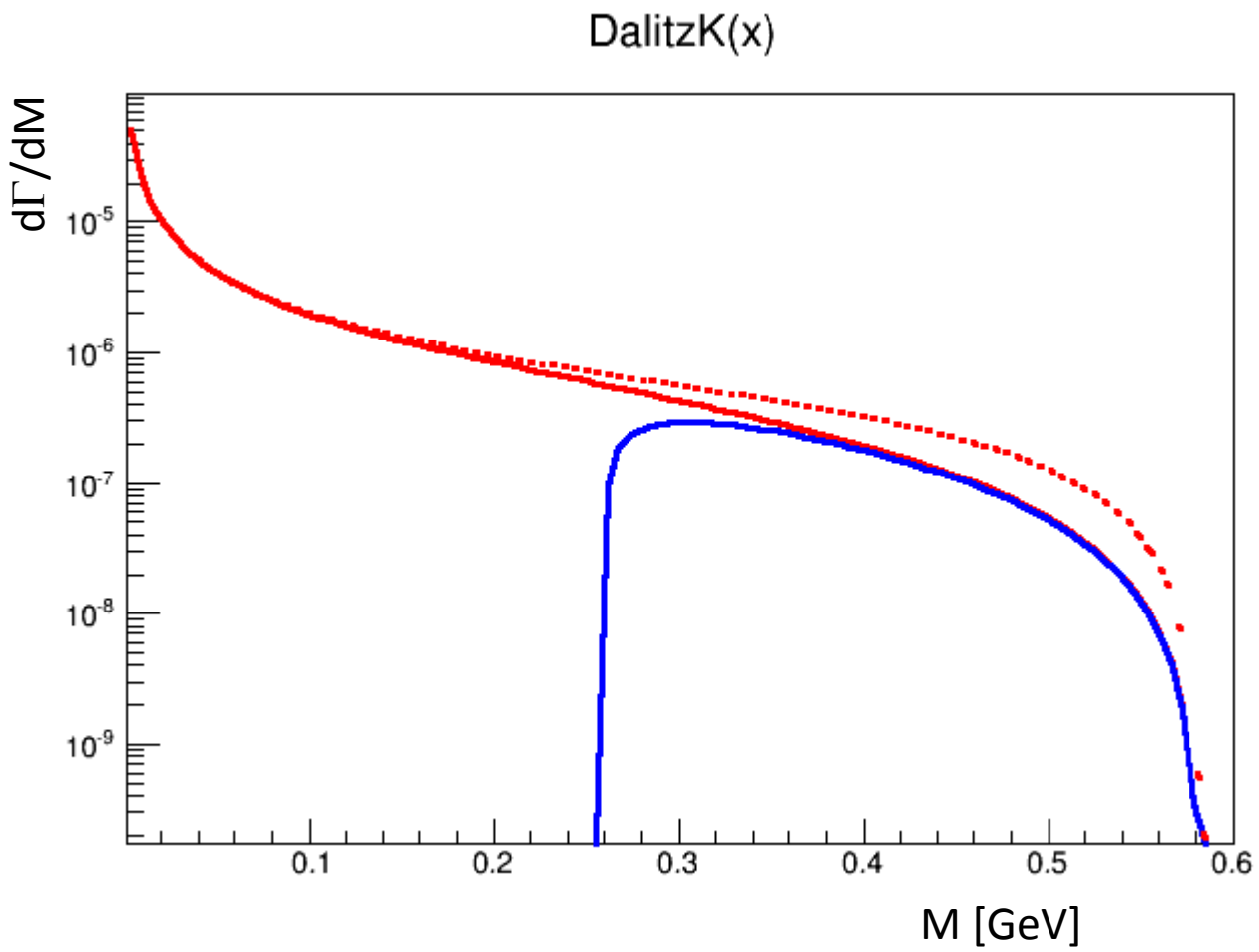
$$\Gamma(N^*_{(\pm)} \to N\gamma^*) = \frac{9\alpha}{16} \frac{(l!)^2}{2^l(2l+1)!} \frac{m_\pm^2(m_\mp^2 - M^2)^{l+1/2}(m_\pm^2 - M^2)^{l-1/2}}{m_*^{2l+1} m^2}$$

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

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)

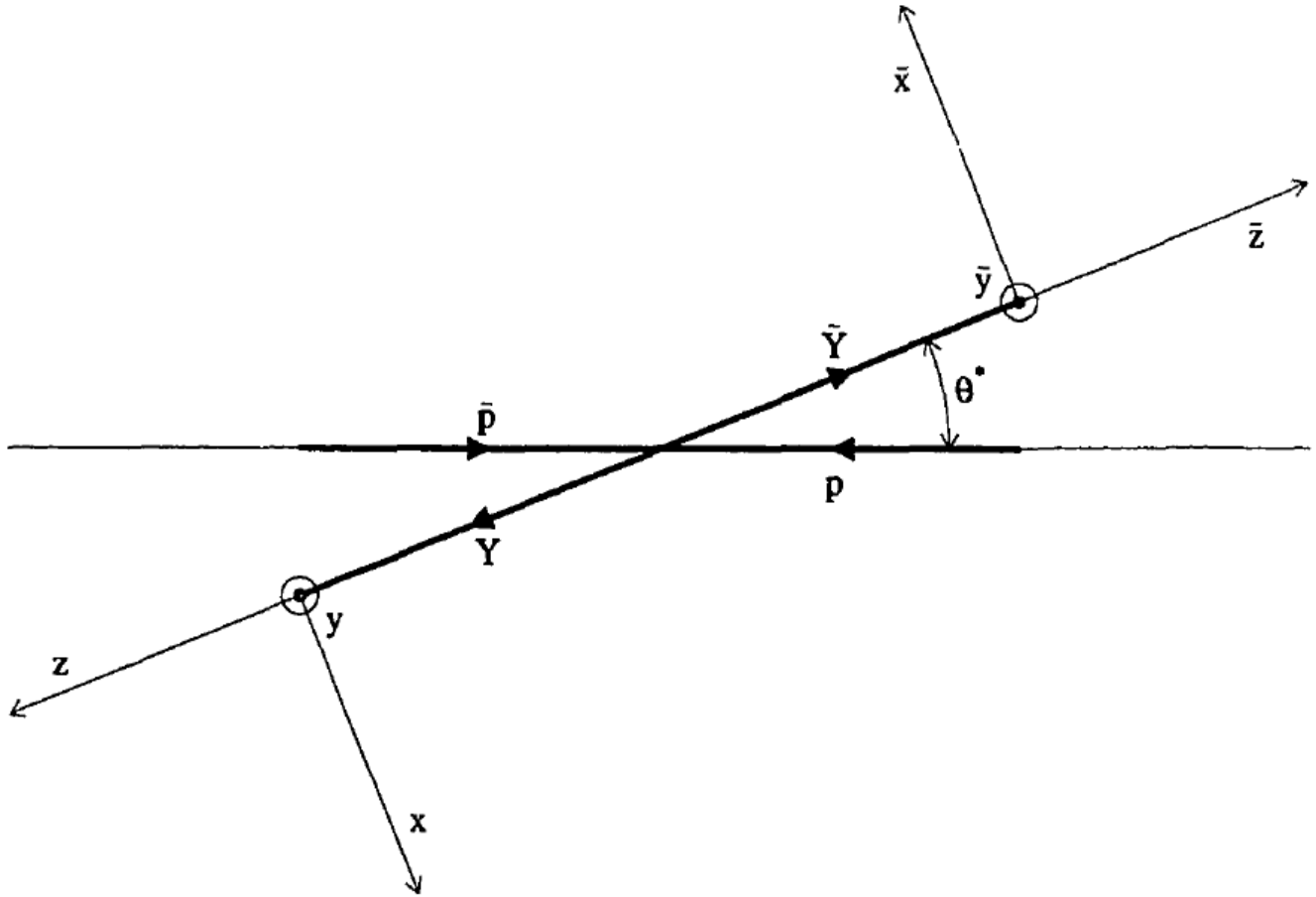
Note that $\Gamma_{\Lambda e+e-} / \Gamma_{rad} \cong 1/132 \cong \alpha$

Simulation:

Anisotropic LEAR parametrization!

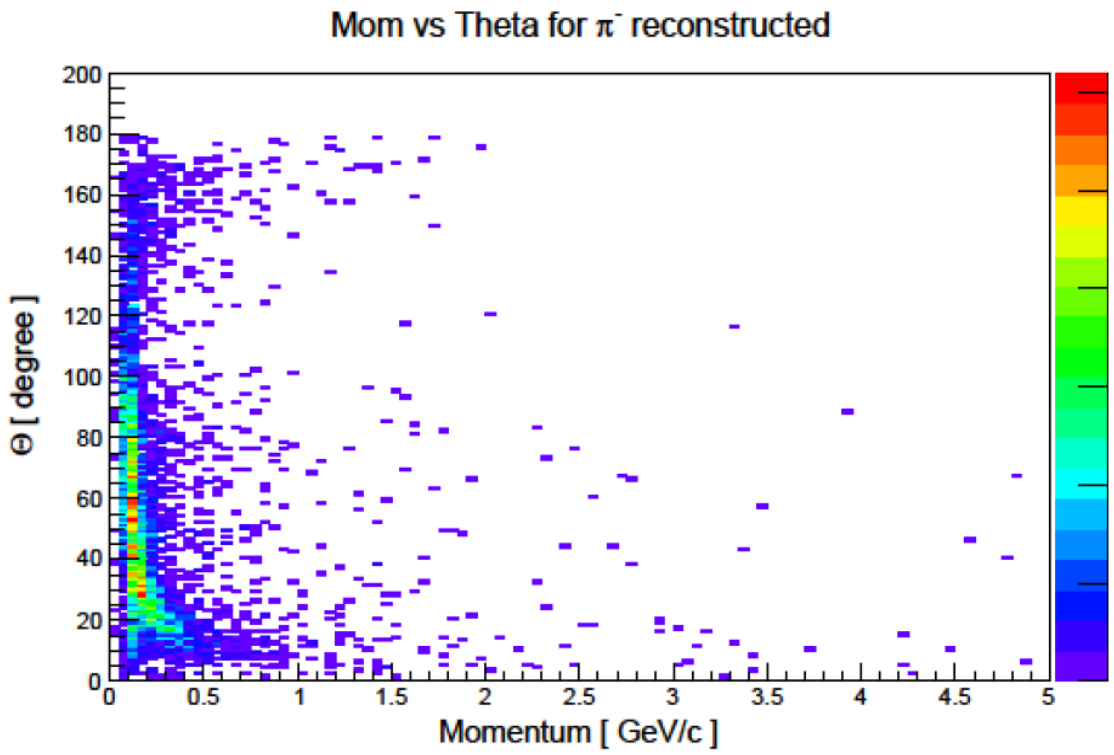
- pbar-p@4GeV/c
- Full Panda geometry included
- channels:
- $pbar - p \rightarrow \Lambda\bar{\Lambda} \rightarrow \mathrm{p}\,\bar{p}\,\pi^{+}\,\pi^{-}$
- $pbar - p \rightarrow \Lambda(1520)\bar{\Lambda}(1520)(stable) \rightarrow e^{+}e^{-}\pi^{-}\mathrm{p}$
- $pbar - p \rightarrow \Lambda(1520)\bar{\Lambda}(1520)(stable) \rightarrow \mu^{+}\mu^{-}\pi^{-}\mathrm{p}$

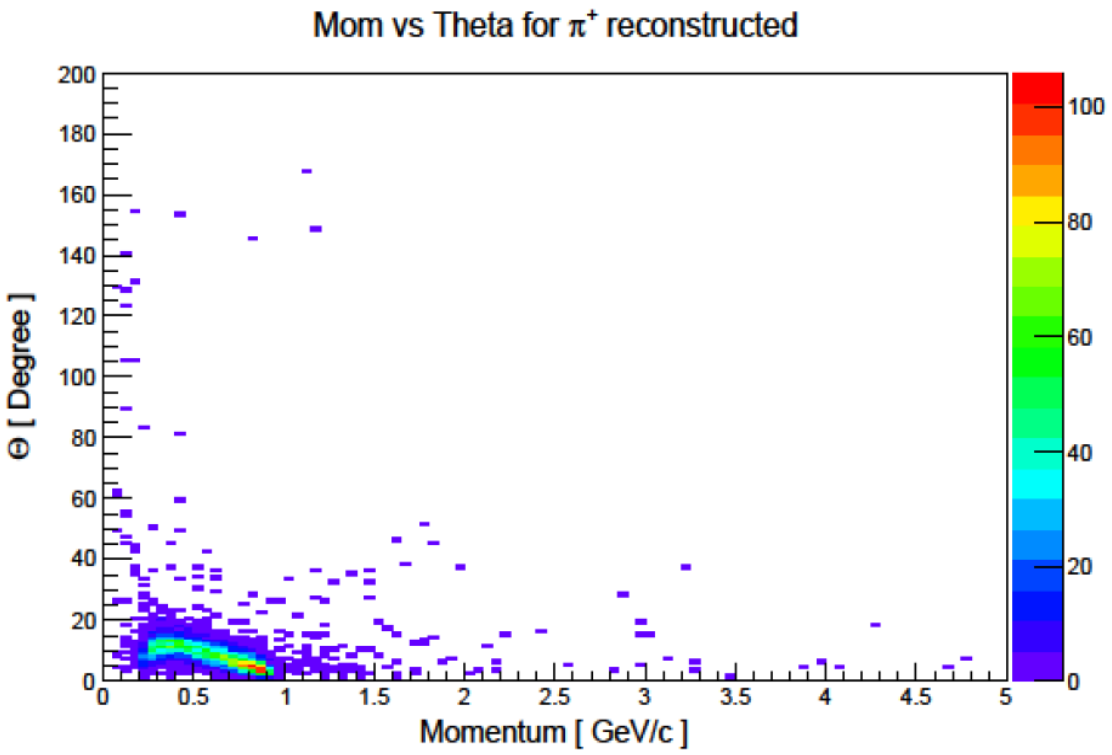
$\bar{p}p \rightarrow Y\bar{Y}$



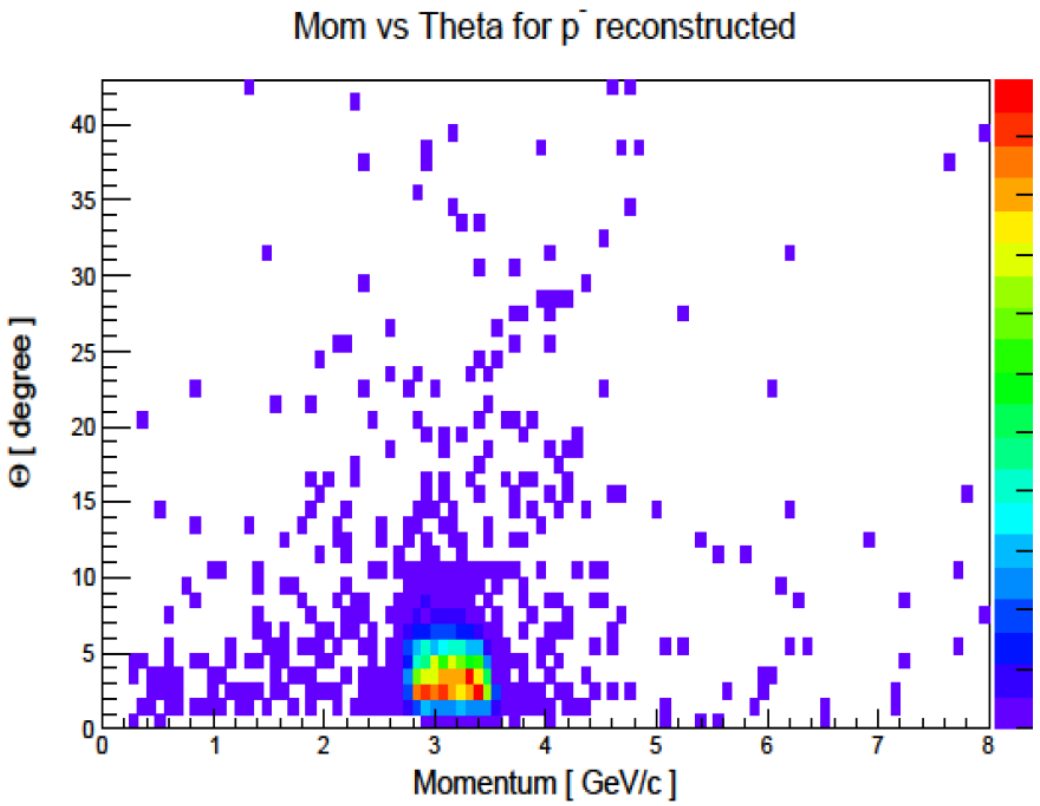
https://www.ideals.illinois.edu/bitstream/handle/2142/22932/9543744.pdf?sequence=2

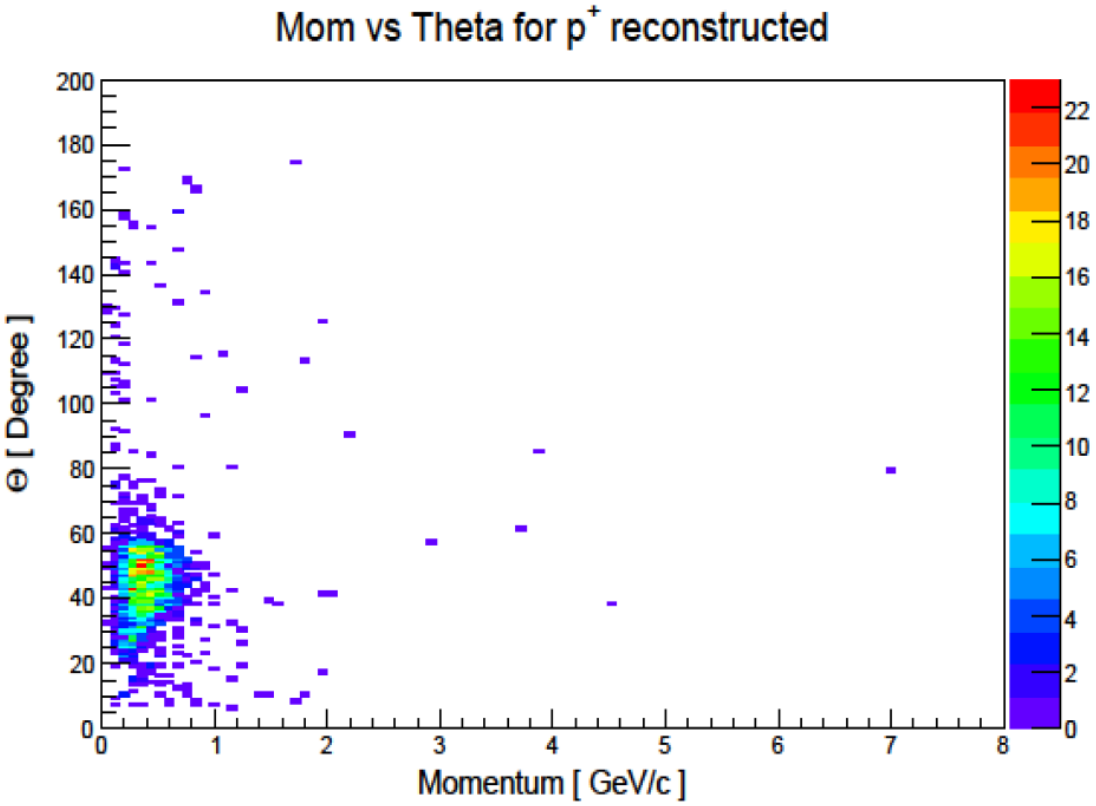
Reconstructed proton/anti-proton pi+/pi-





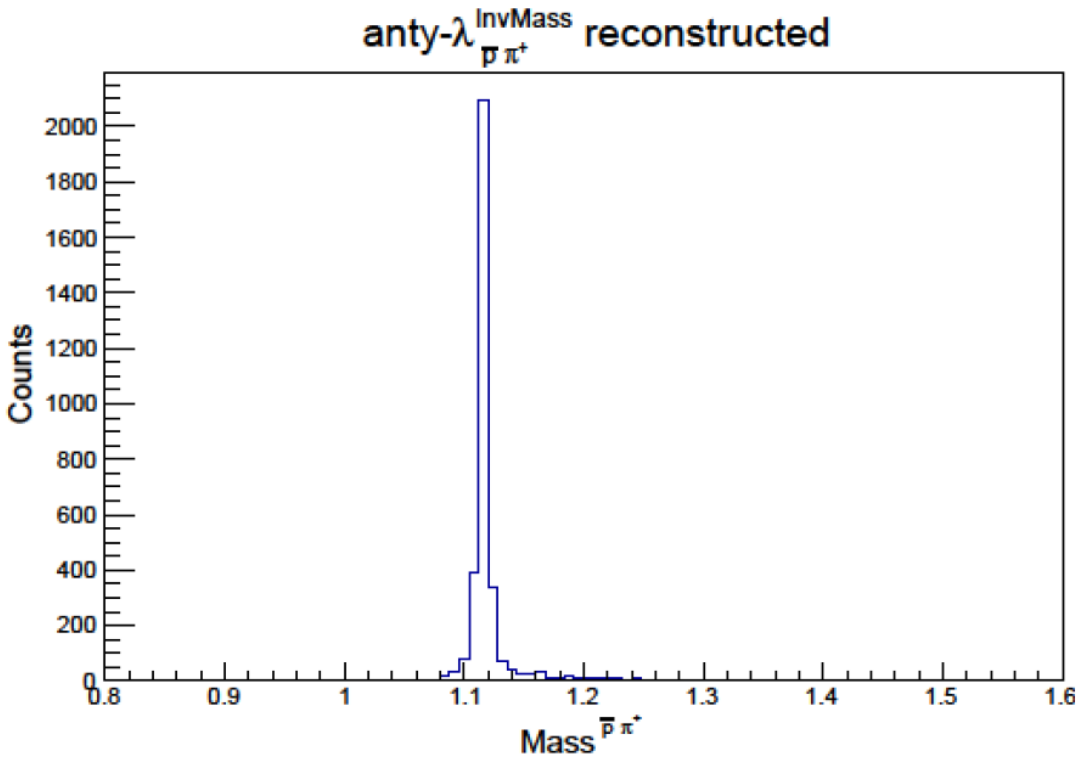
pi+	pi-
52%	53%

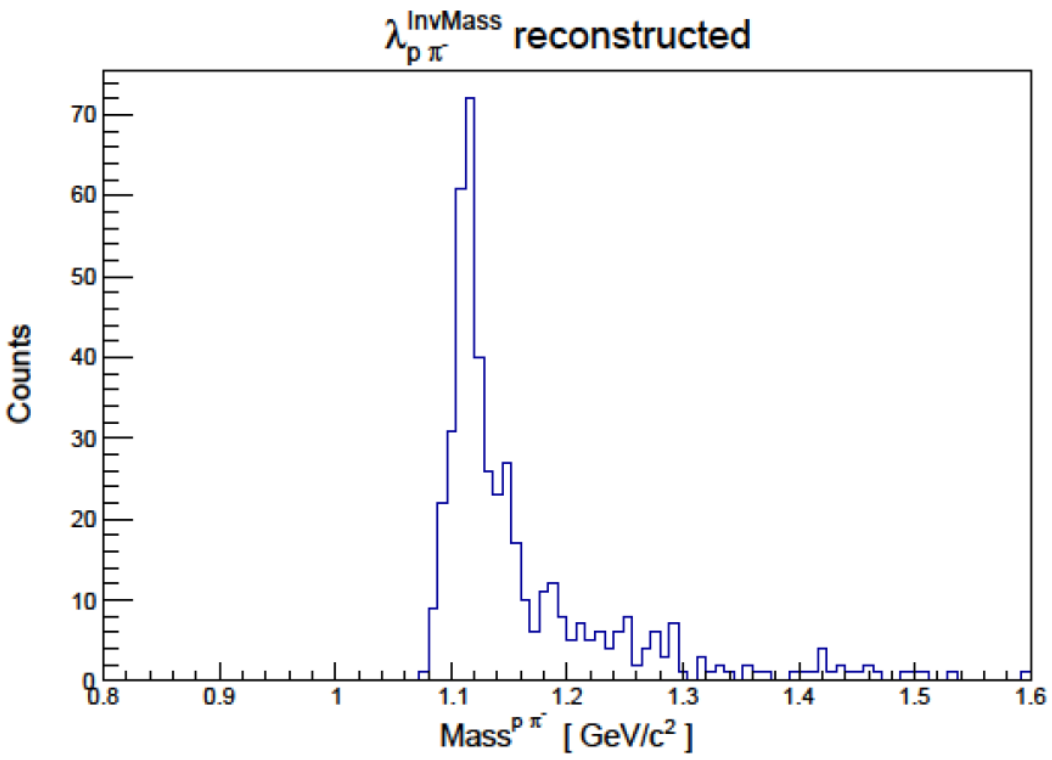

Mom vs Theta for p⁻ reconstructed
Θ [degree]
Momentum [GeV/c]


Mom vs Theta for p⁺ reconstructed
Θ [Degree]
Momentum [GeV/c]

p	pbar
20%	65%

Invariant mass reconstruction



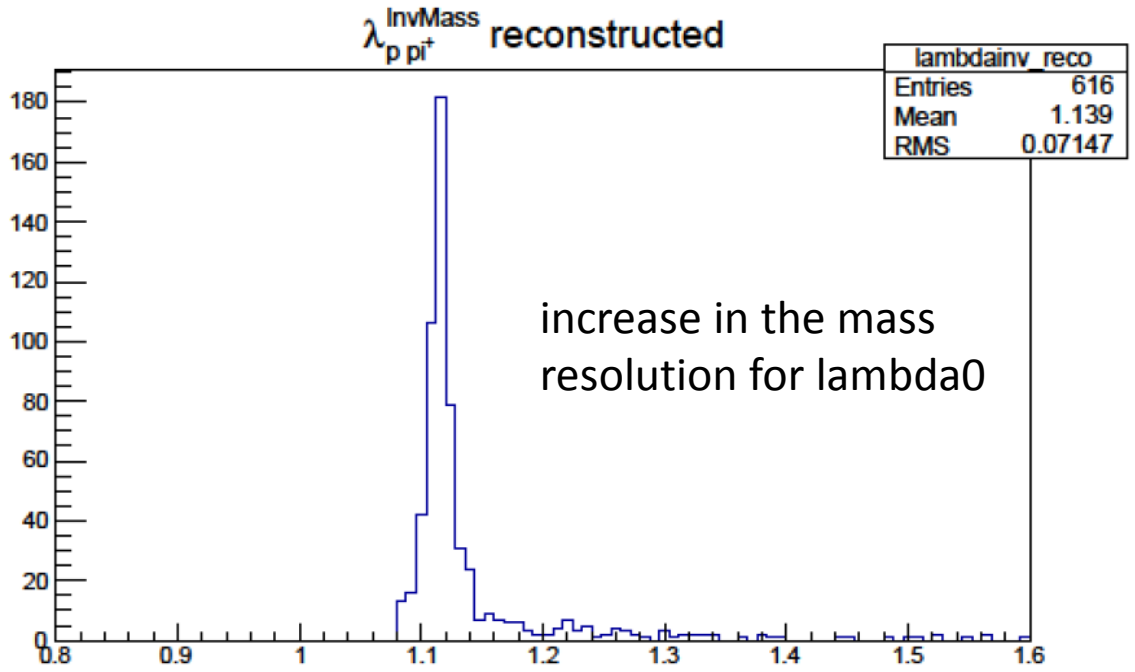


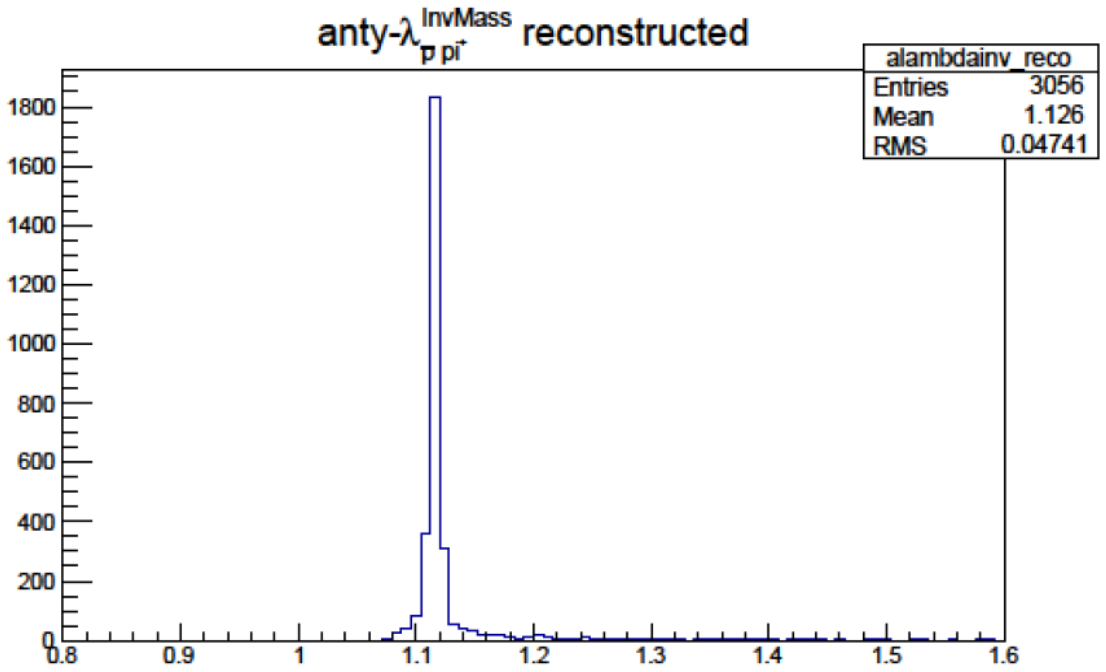
Anti-lambda	Lambda
34%	5%

Conclusion

- 50% of the pions are reconstructed, 62% of anti-protons and only 20% of protons reconstructed !
- 34% of lambda0bar reconstructed, and only 6% of lambdas with a poor mass resolution
- What to do next ? Preform the same study with the reduced field by a factor of 2 in solenoid and dipole.

Field setting	p	p-bar	pi+	pi-
Full	20%	65%	52%	53%
Half	21%	65%	46%	45%

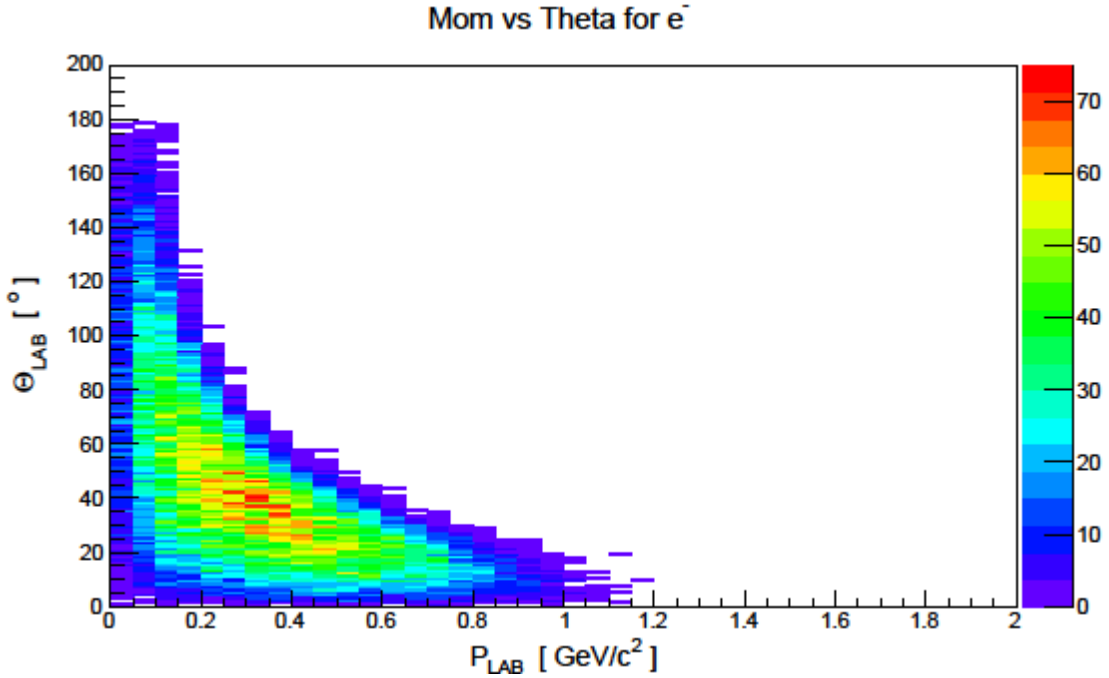


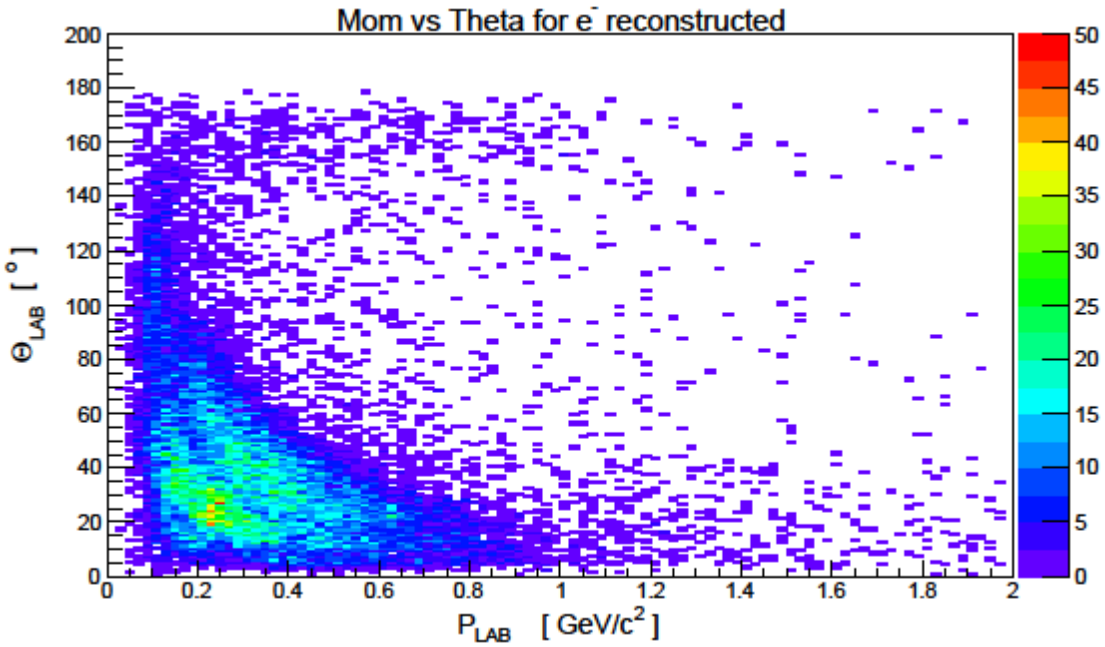


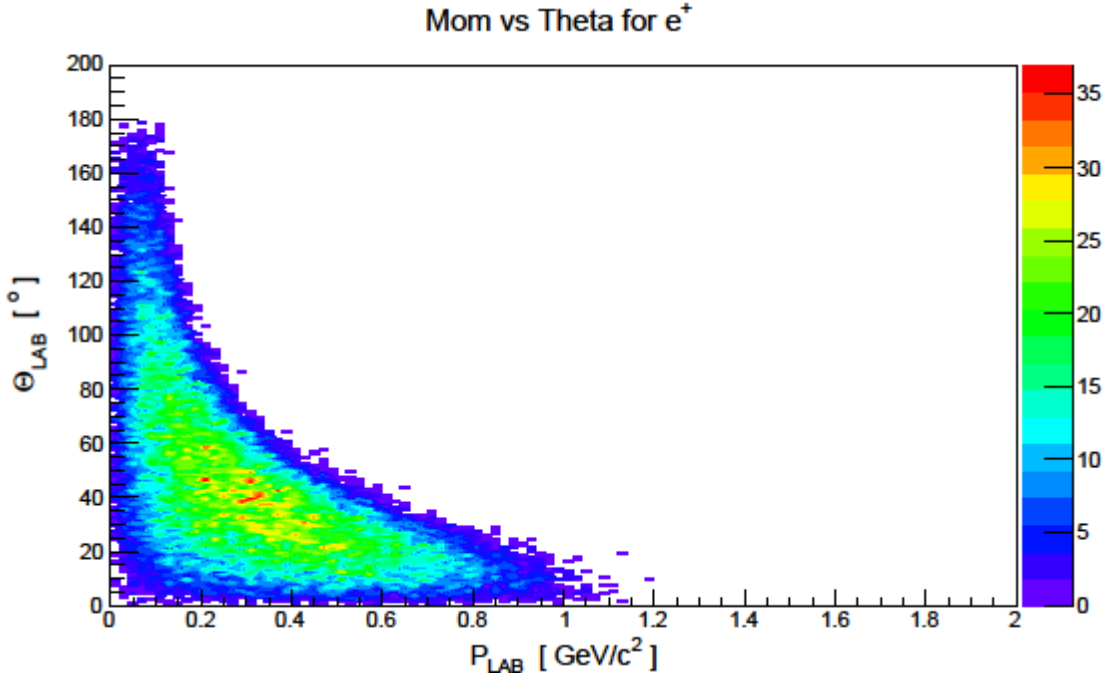
$\Lambda(1520)\,\overline{\Lambda}(1520)$ study

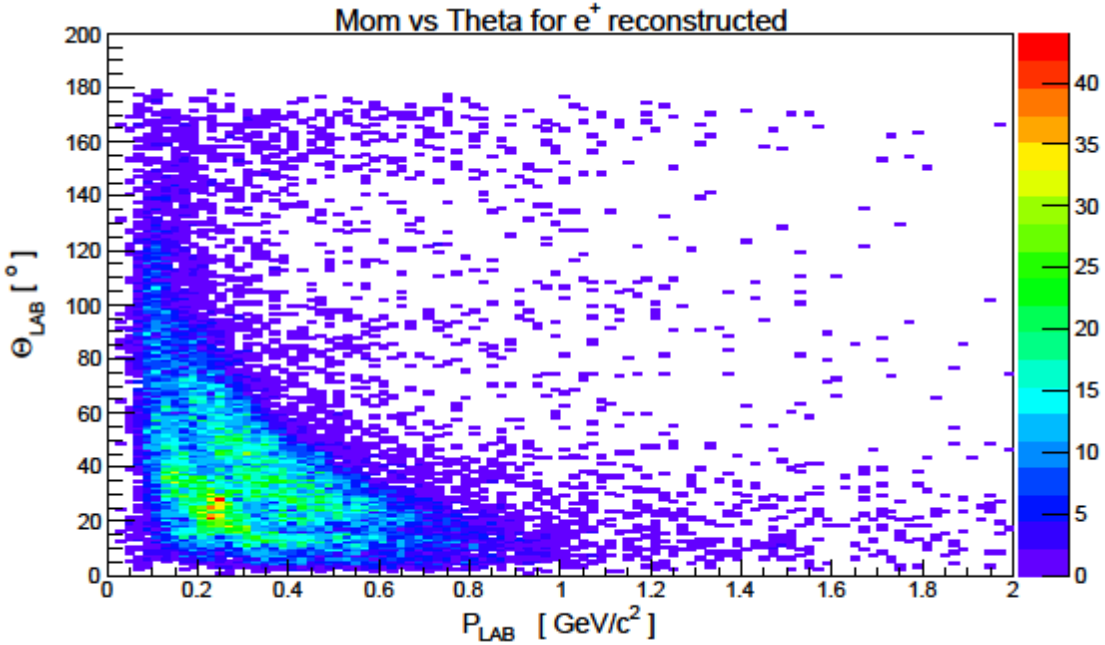
- 30000 events simulated
- only $\Lambda(1520)$->Λe+e- reconstructed (decay according to phase space), $\overline{\Lambda}(1520)$ is marked as a stable particle

Electrons/Positrons







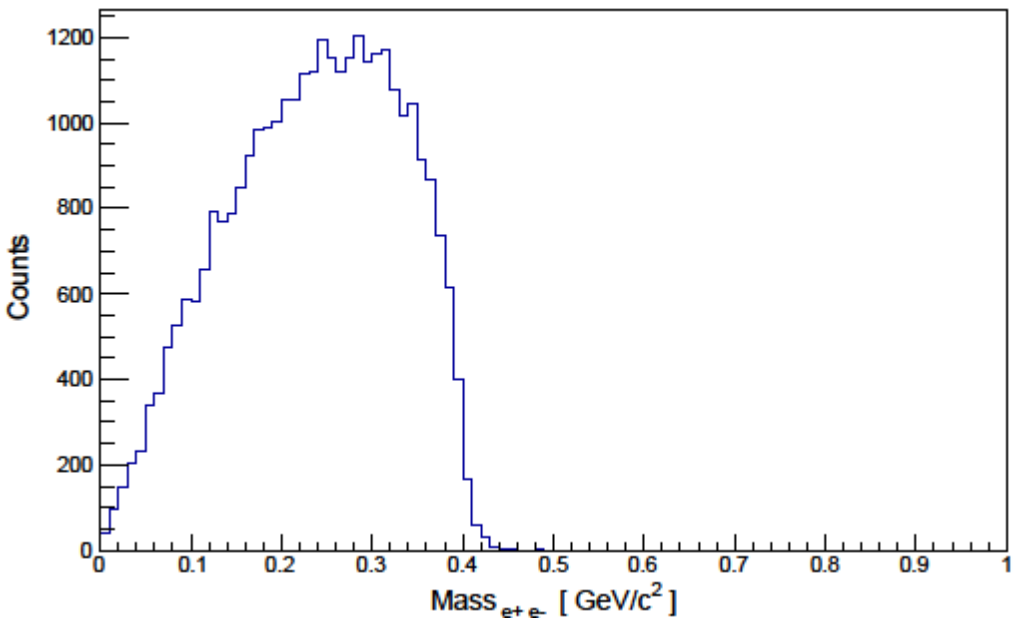


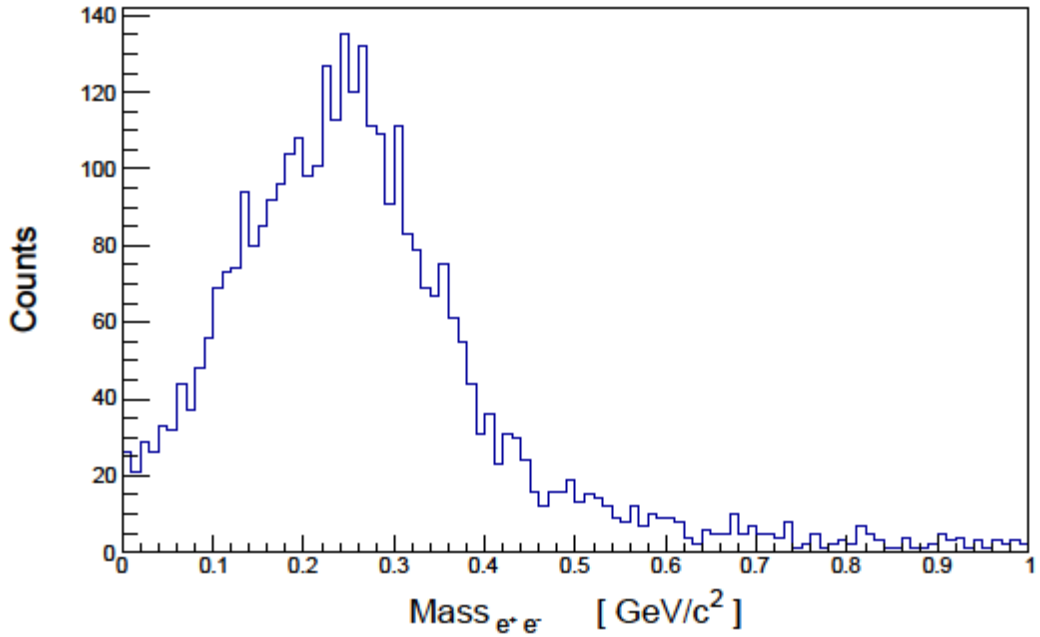
Facts & Figures

Reconstructed e+	Reconstructed e-
76%	74%

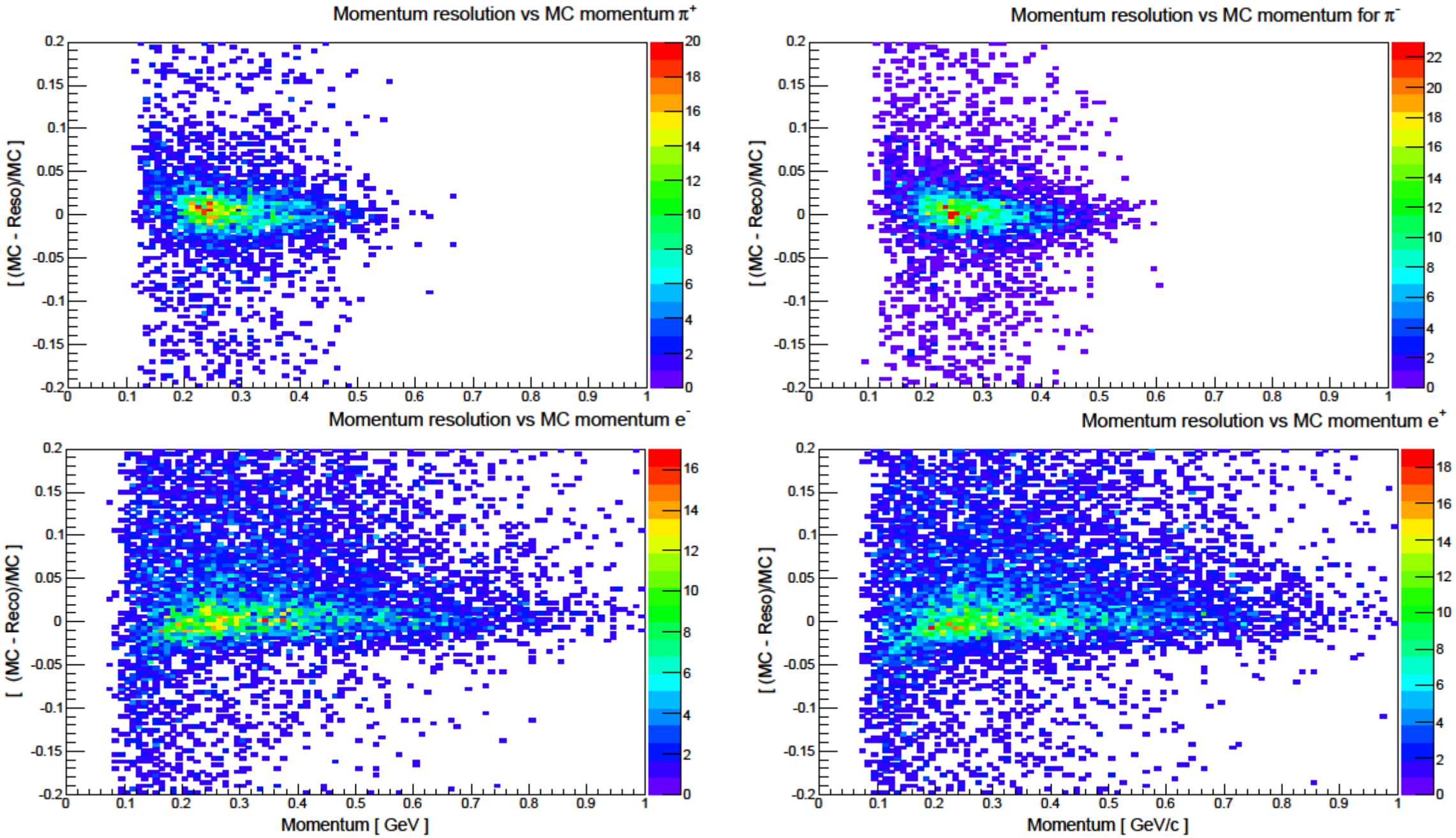
Possible problems:

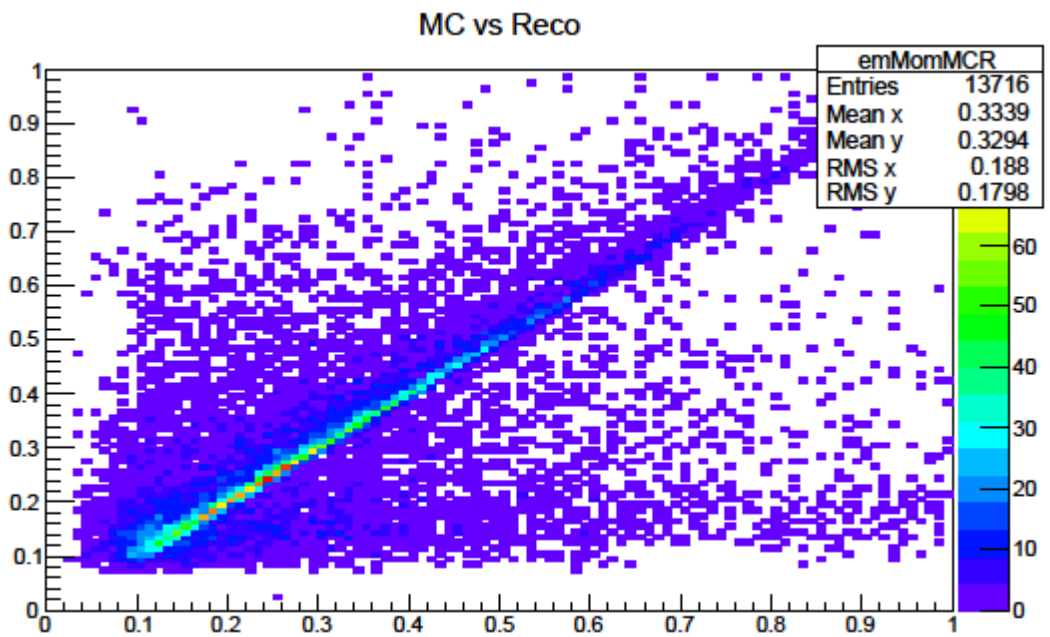
- low momenta electrons/positrons can be hard to reconstruct
- bremsstrahlung contribution visible in the e+ e- invariant mass distribution (no correction for bremsstrahlung photons in EMC included- to be done)

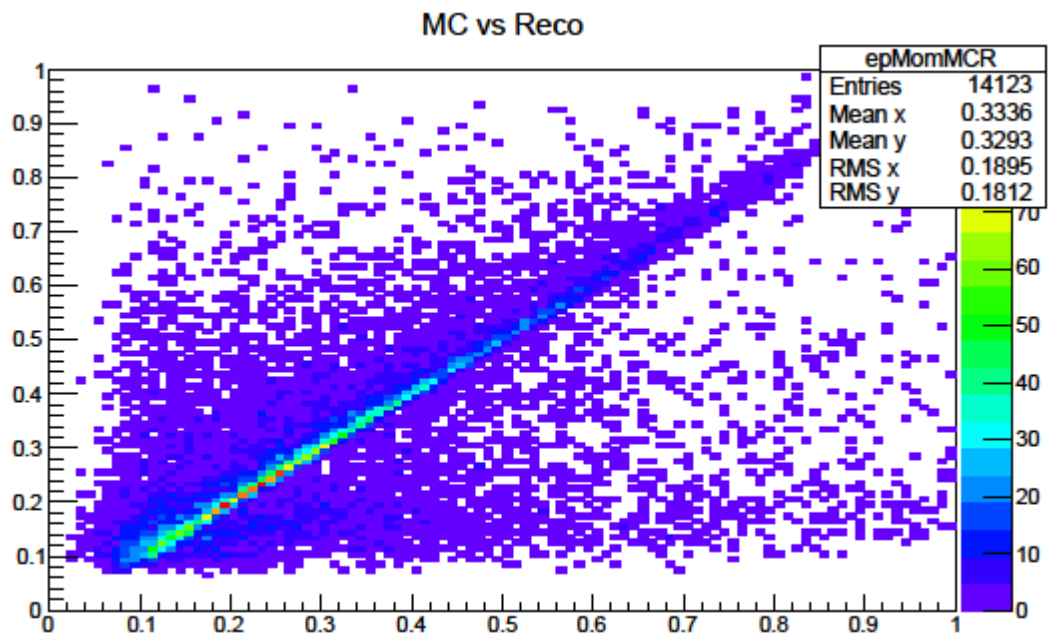




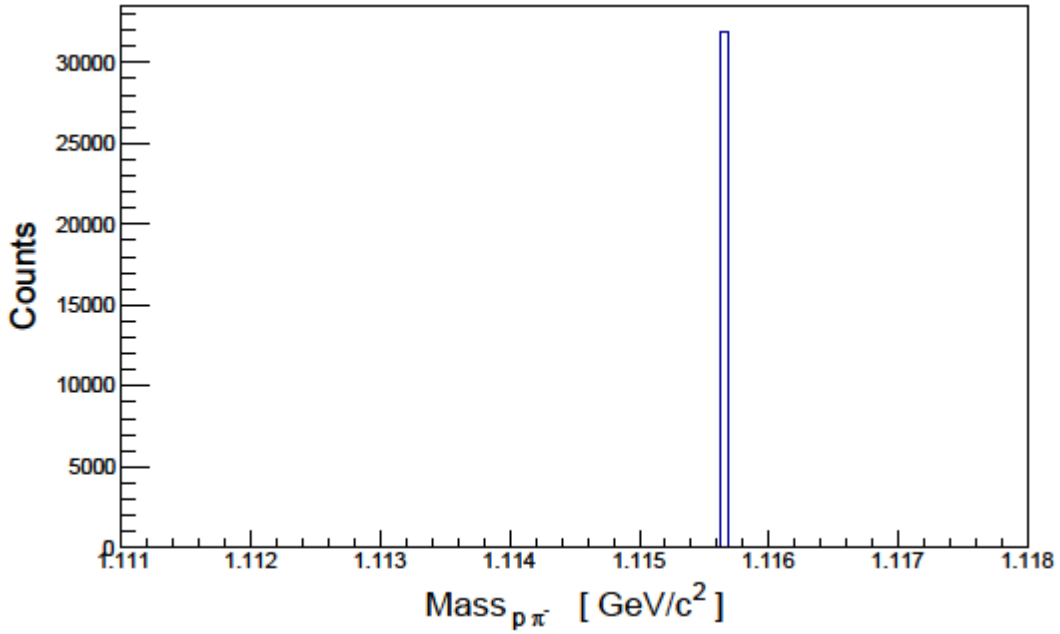
Reconstruction resolution

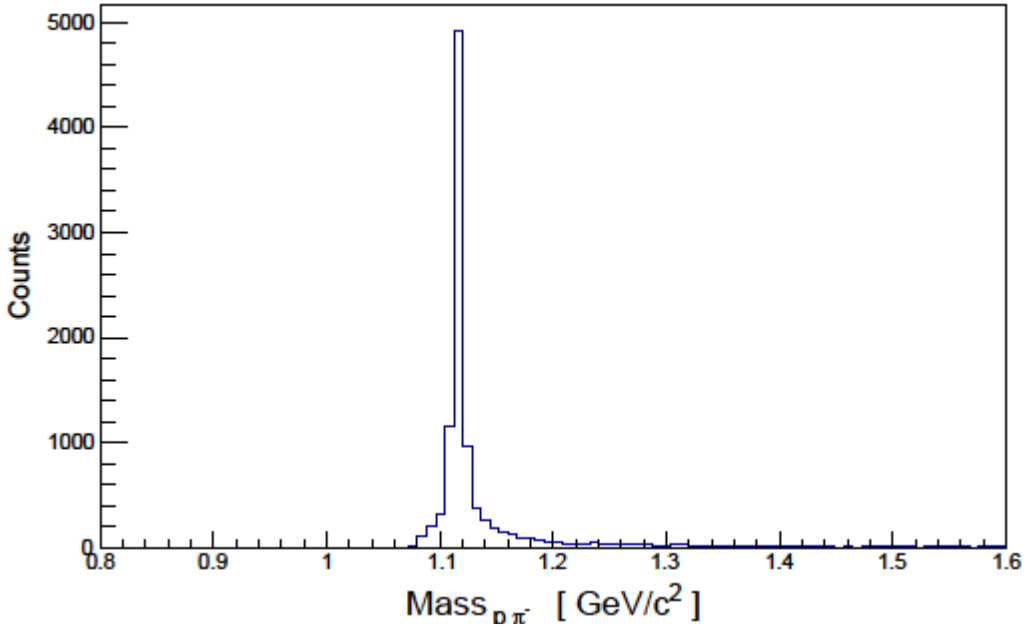


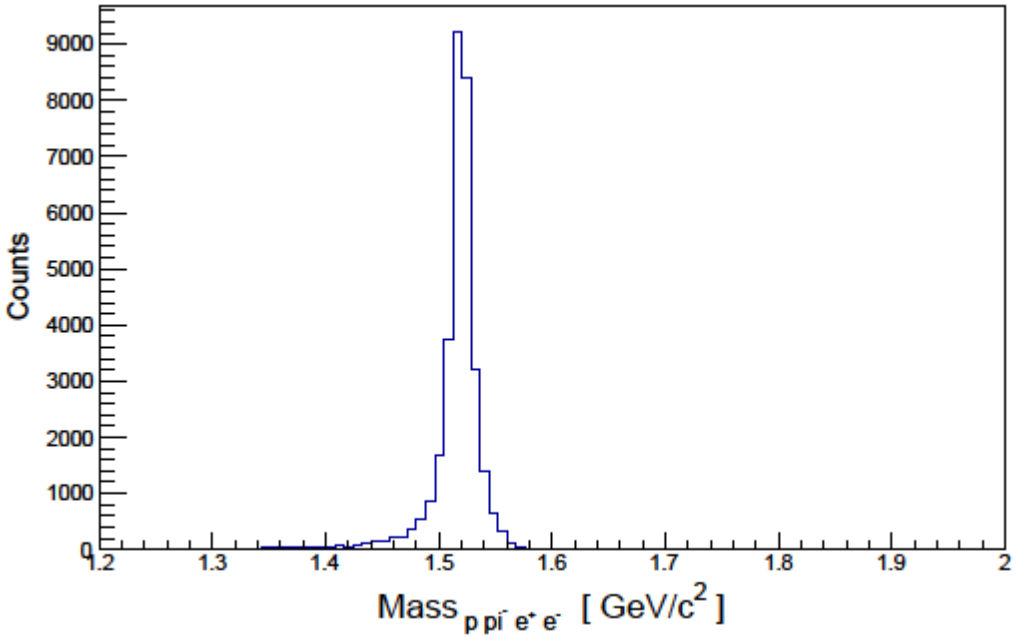

MC vs Reco
emMomMCR
Entries 13716
Mean x 0.3339
Mean y 0.3294
RMS x 0.188
RMS y 0.1798


MC vs Reco
epMomMCR
Entries 14123
Mean x 0.3336
Mean y 0.3293
RMS x 0.1895
RMS y 0.1812

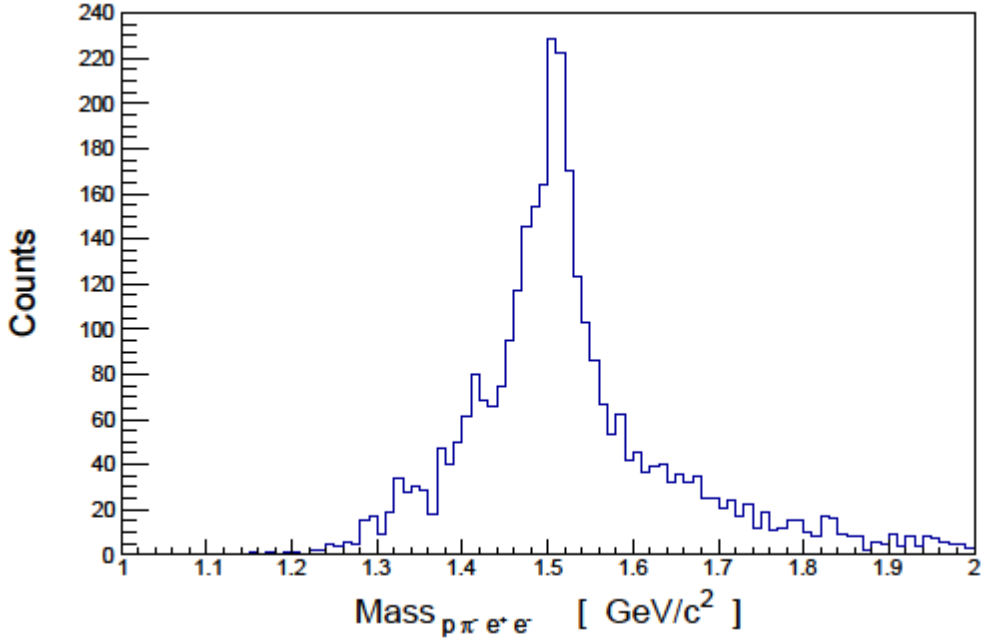
Reconstruction of $\Lambda^0 (p\,\pi^-)$ $\Lambda(1520)^0 (p\,\pi^-\,e^+\,e^-)$ (Phase space)







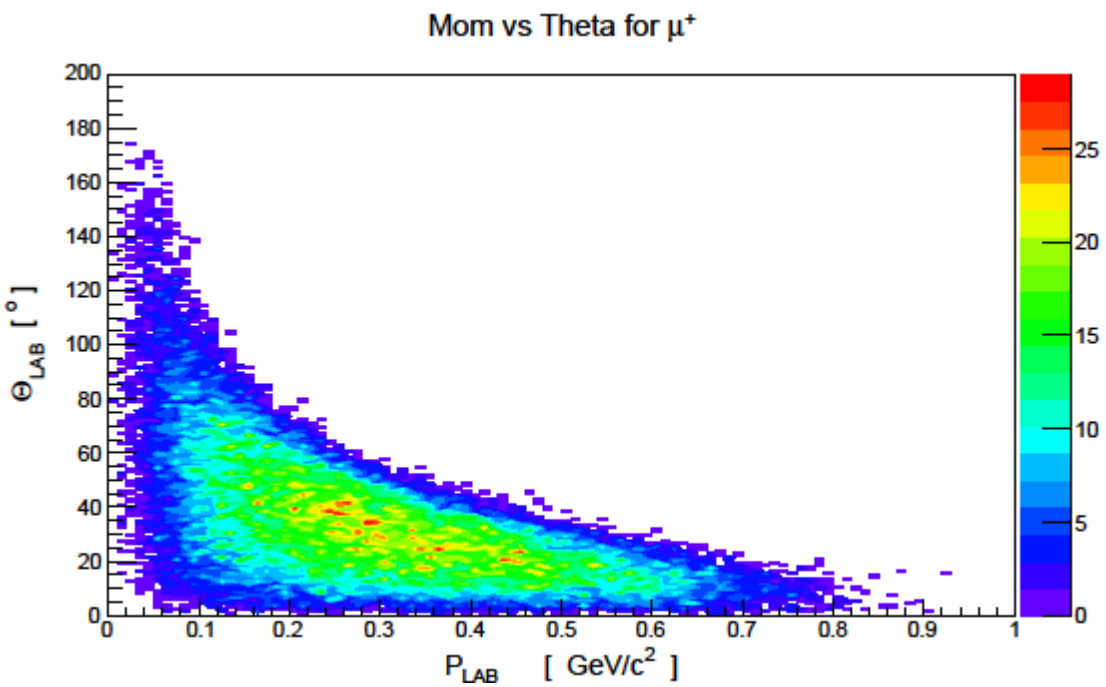
11%

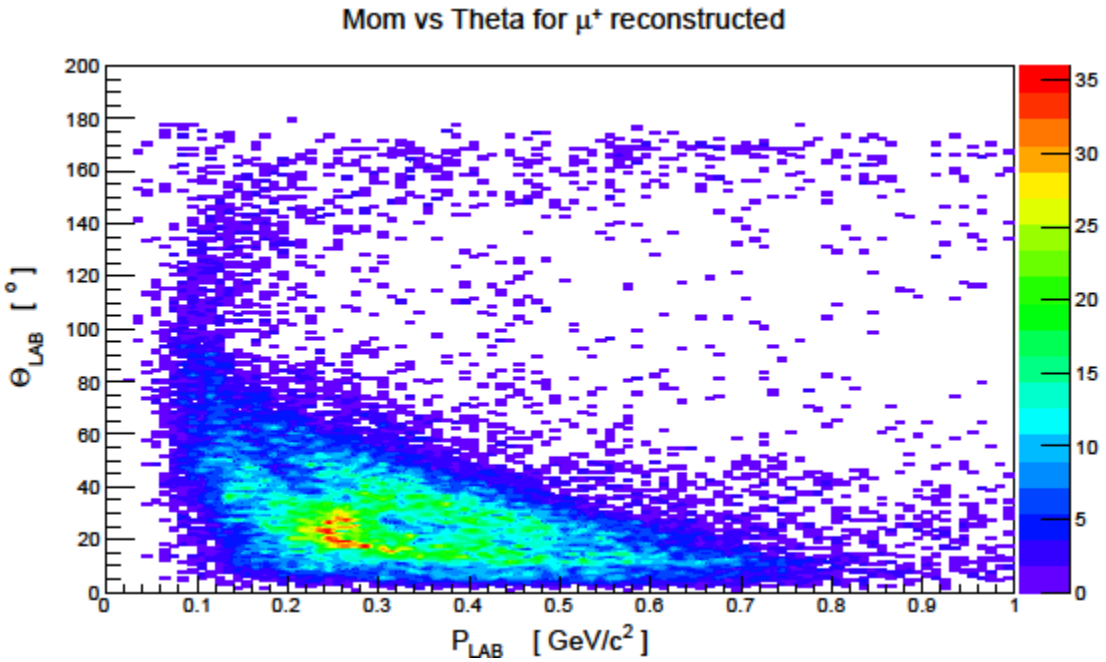


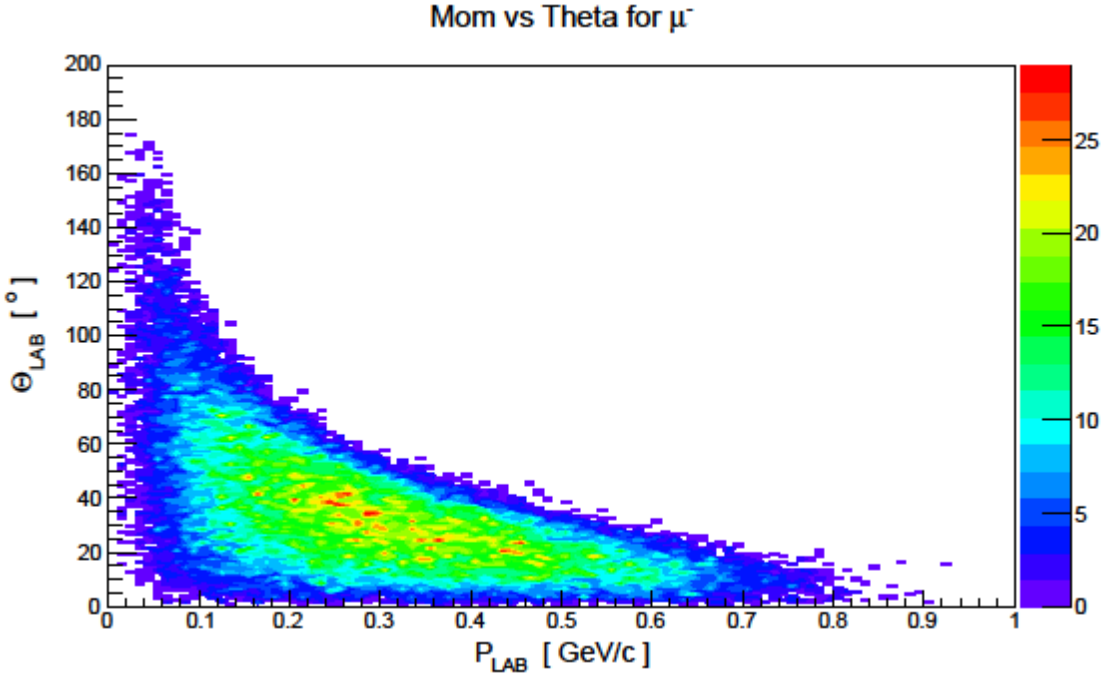
Conclusion

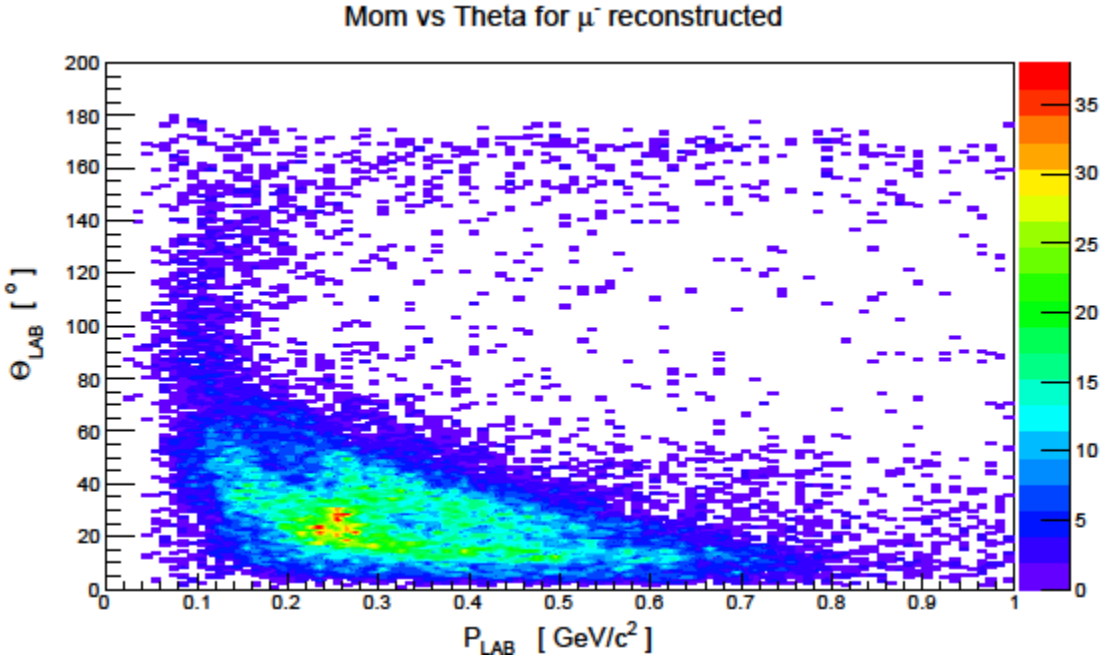
- Bremsstrahlung and problem with low momenta electron is visible in reconstruction
- Low reconstruction efficiency and low mass resolution
- A possibility to reconstruct $\boldsymbol{\Lambda(1520)^0}$ from the $\mu^+\mu^-$ channel ?

$\mu^+\mu^-$

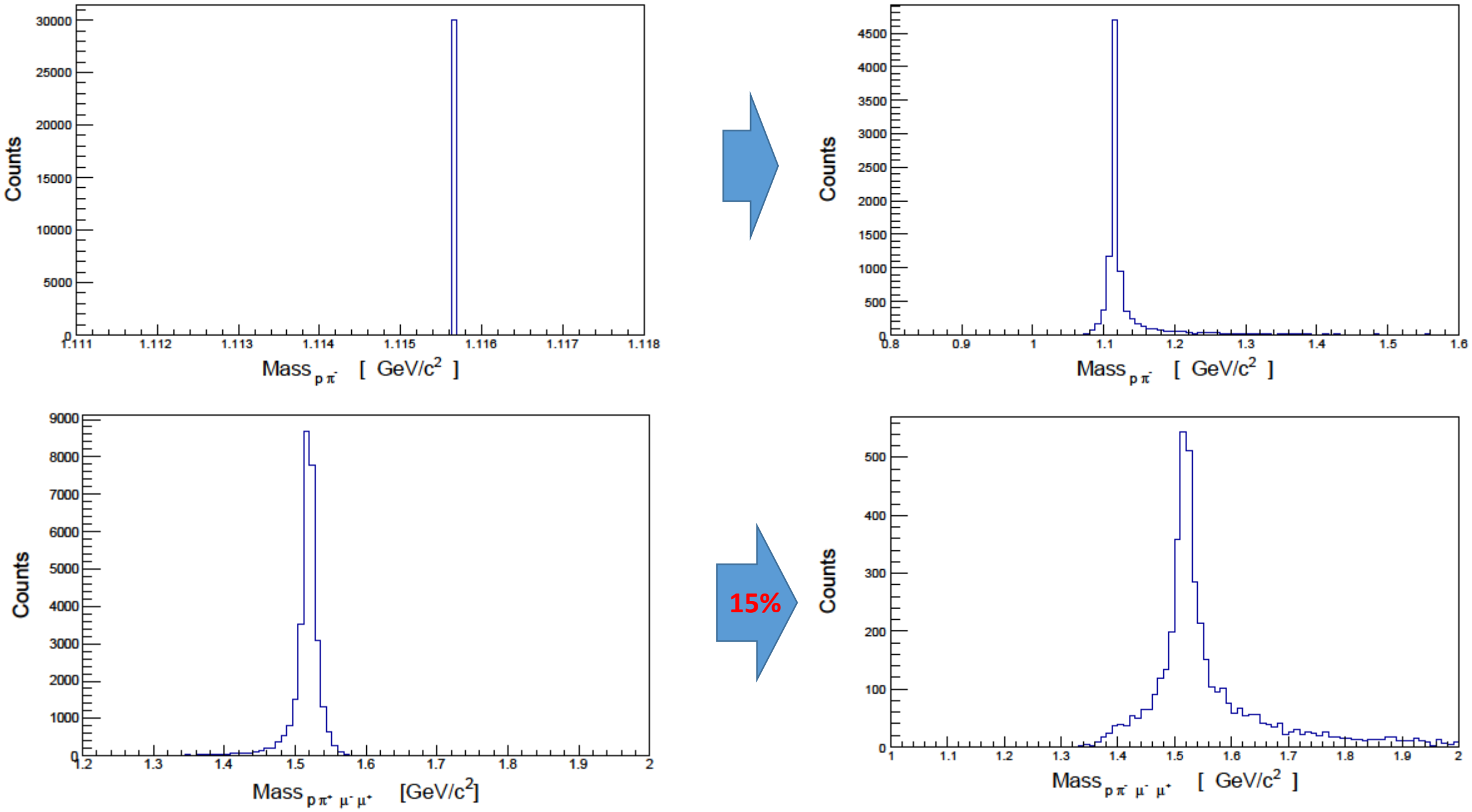

Mom vs Theta for μ+
Θ_LAB [°]
P_LAB [GeV/c²]


Mom vs Theta for μ+ reconstructed
Θ_LAB [°]
P_LAB [GeV/c²]


Mom vs Theta for μ-
Θ_LAB [°]
P_LAB [GeV/c]


Mom vs Theta for μ- reconstructed
Θ_LAB [°]
P_LAB [GeV/c²]

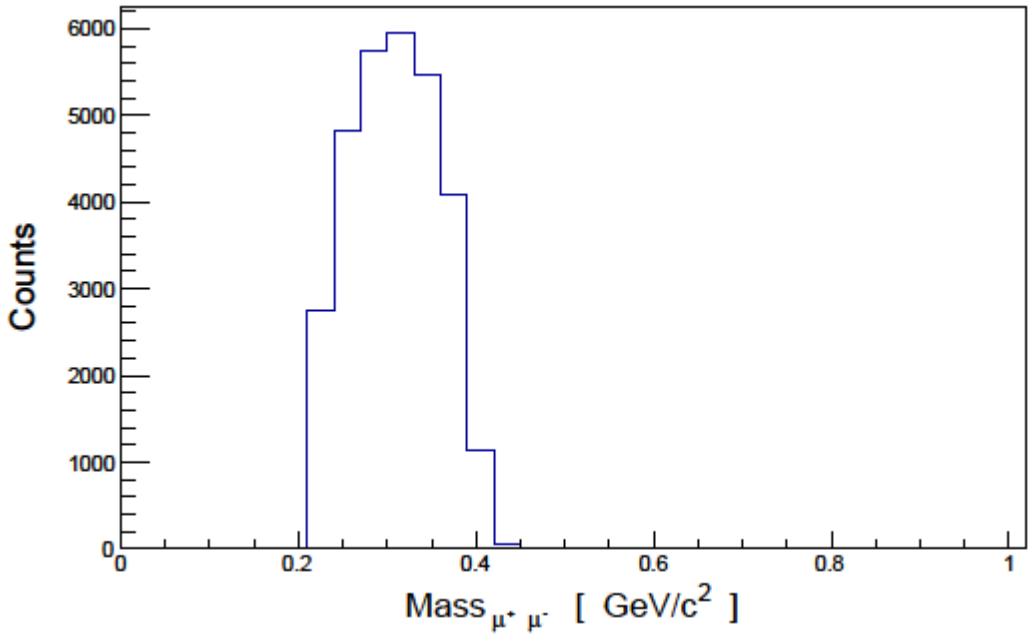
Reconstruction of $\Lambda^0 (p\,\pi^-)$ $\Lambda(1520)^0 (p\,\pi^-\,\mu^+\,\mu^-)$ (phase space)

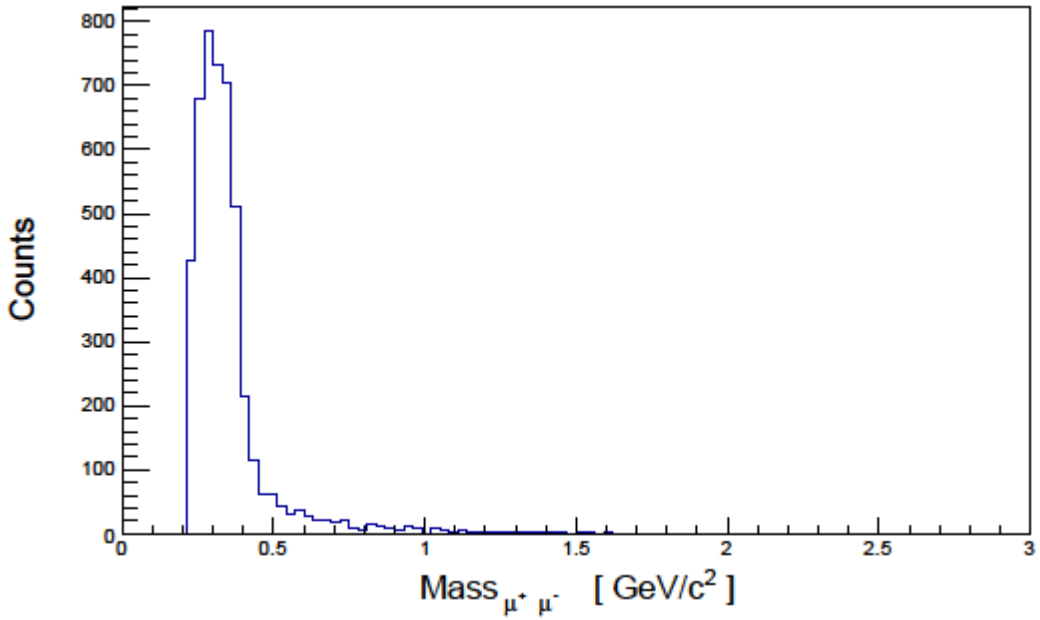


Results

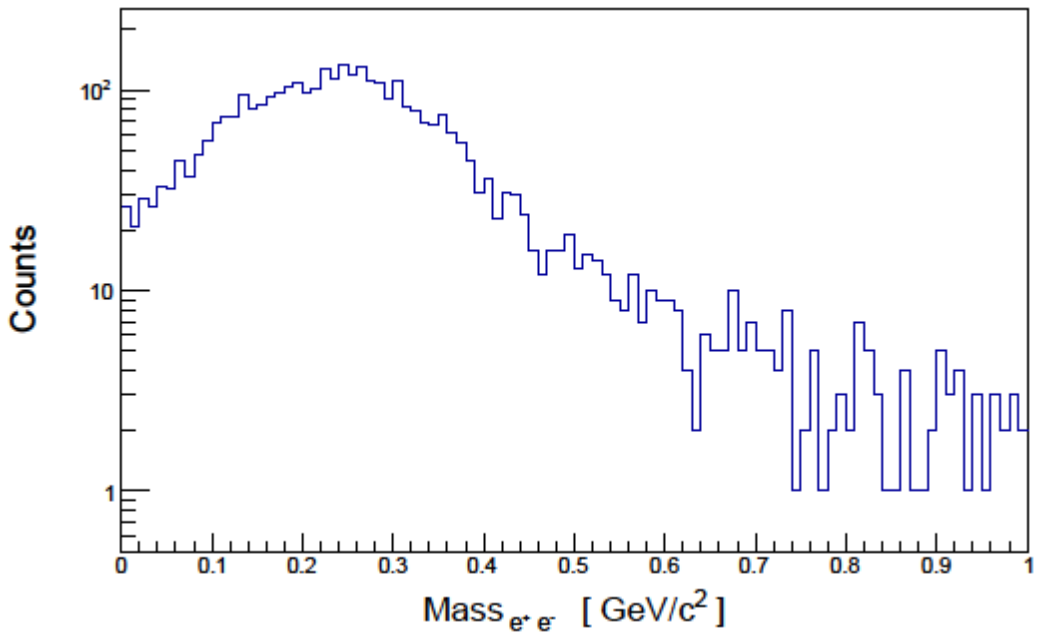
- increased reconstruction efficiency
- better energy resolution
- Bremsstrahlung is negligible (~1/m^2)

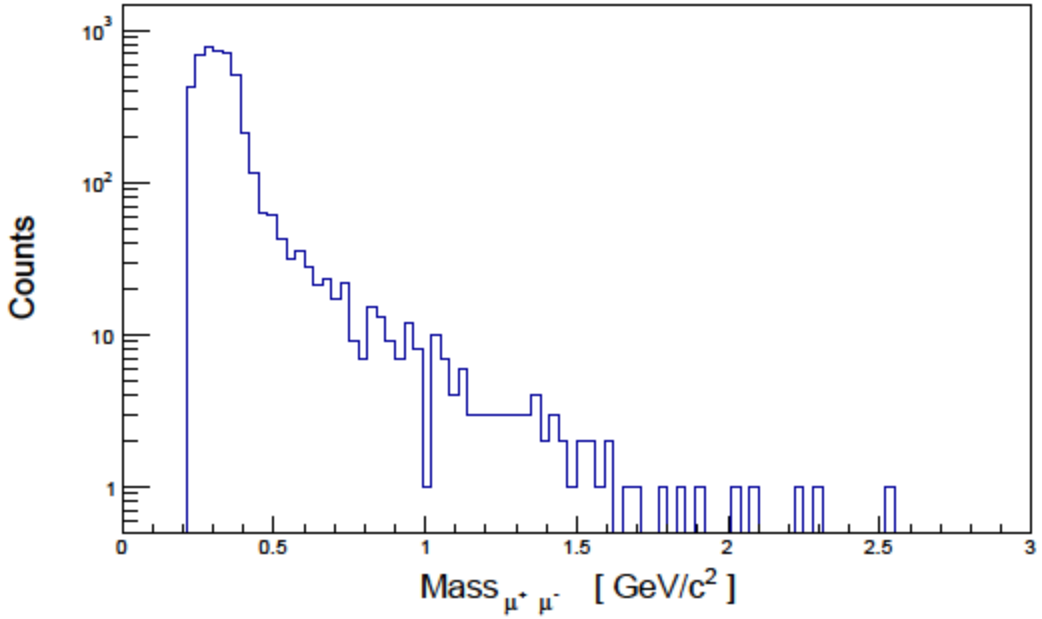
Reconstructed μ^+	Reconstructed μ^-
88%	87%





$e^+ e^-$ vs $\mu^+ \mu^-$

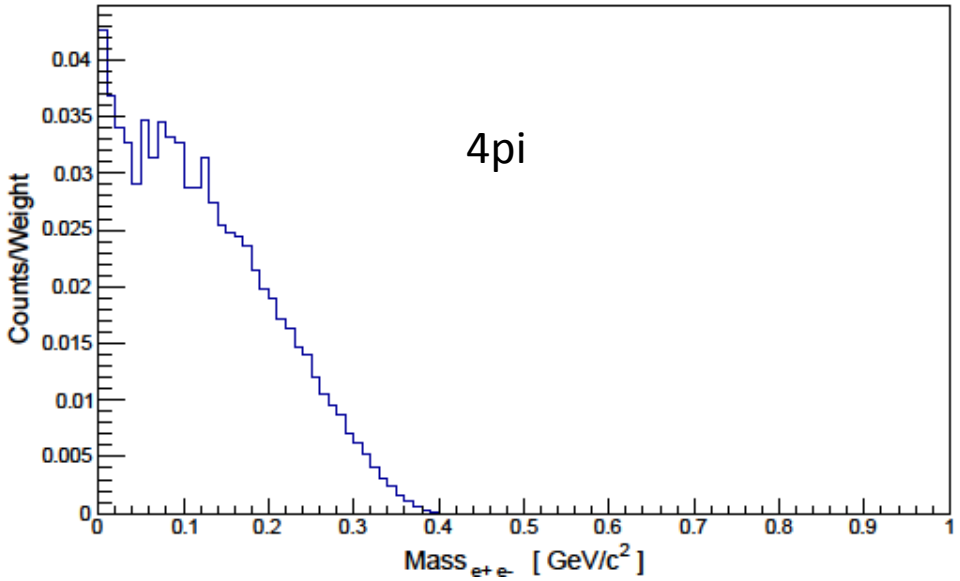


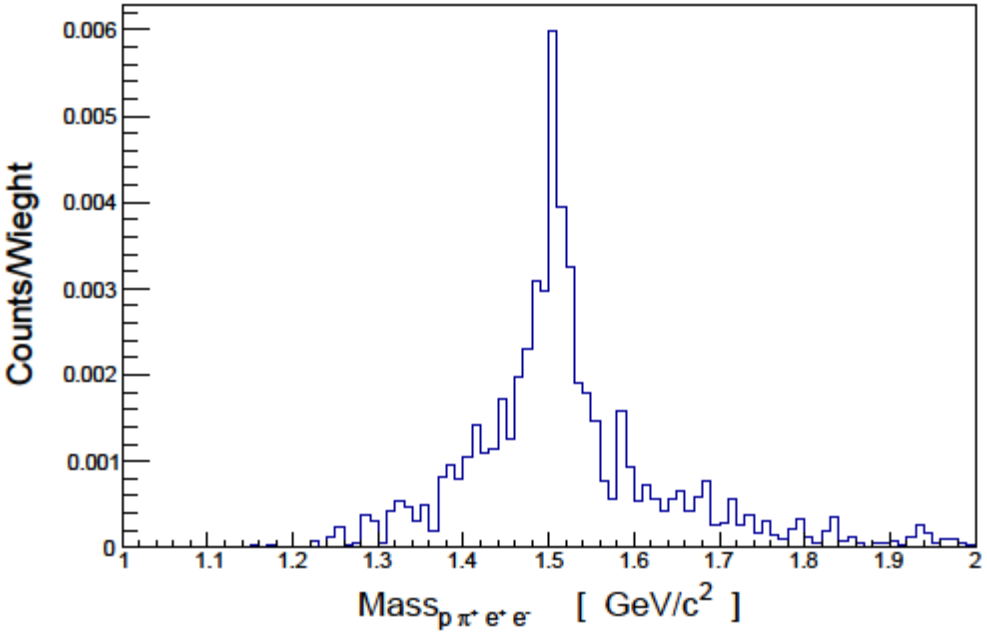


- Di-muons cut at 2*mμ but sensitive to effects of eFF on di-lepton mass which are important at high values
- Bremsstrahlung correction must be apllied for electrons

Modification of (e+ e-) distributions according to "QED" dΓ/dm

Each event weighted according to calculated (see slide 4) dΓ/dm (formula from Krivoruchenko for $\Lambda(1520)^{3/2-} \rightarrow \Lambda^{1/2+}\, e^+e^-$ transition





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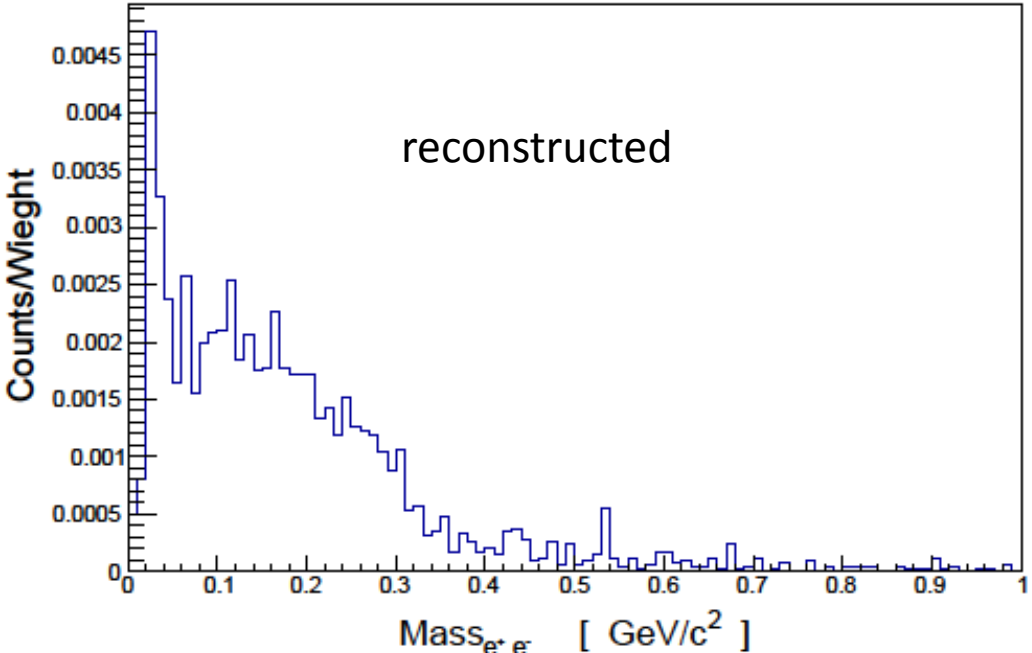
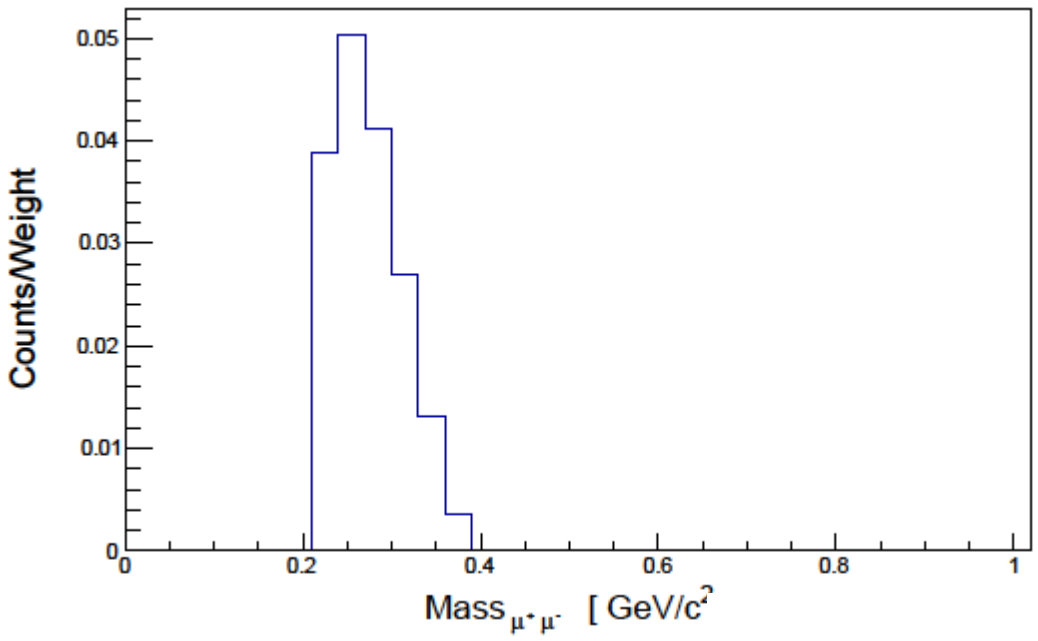
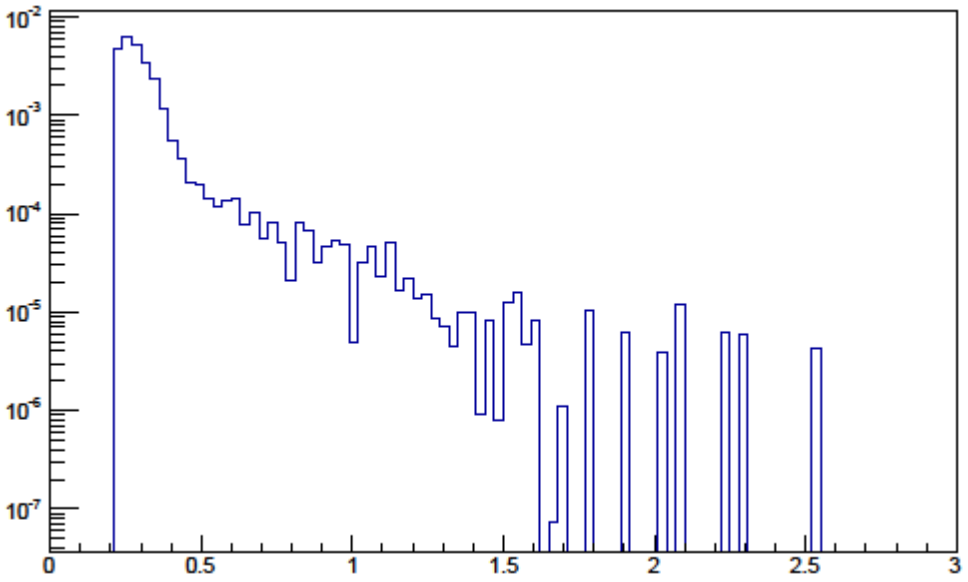
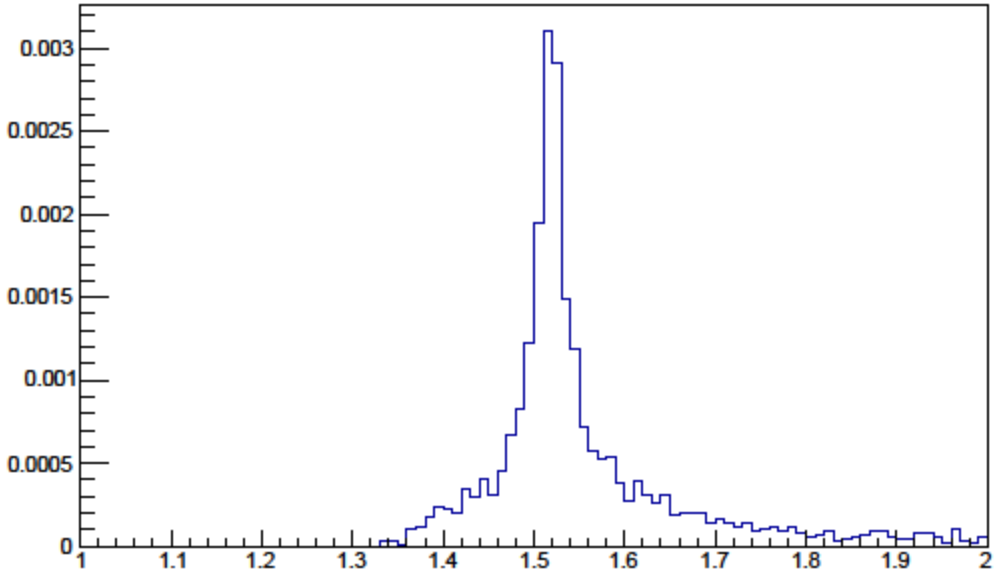


Same for dimuon channel (mu+ mu-)







Baryon spectroscopy @ PANDA startup version

Assumption: 10x lower luminosity (J. Ritman Panda overview talk)

	$\bar{\Lambda}\Lambda$	$\bar{\Xi}\Xi$	$\Omega^+\Omega^-$	$\bar{\Lambda}_c^+\Lambda_c^-$
1.64 GeV/c	$2x10^5$ h^{-1}			
4 GeV/c	$4x10^4$ h^{-1}	2500 h^{-1}		
15 GeV/c	$2x10^4$ h^{-1}	(≈ 1000 h^{-1})	(30 h^{-1})	((5 day^{-1}))

Assuming Λ(1520) Production rates of similar order as Λ we can expect
~ few e+e-/hour

Final conclusions

- Bremsstrahlung and problem with low momenta electron is visible in reconstruction- correction for energy loss is needed – to be done in next

- Low reconstruction efficiency and low mass resolution for e+ e-

- A possibility to reconstruct $\Lambda(1520)^0$ from the $\mu^+\mu^-$ channel yields in:

- increased reconstruction efficiency
- better energy resolution
- Bremsstrahlung is negligible