Thomas Jefferson National Accelerator Facility

Source size measurments in the $eHe \rightarrow e'p\Lambda X$ reaction

(for CLAS collaboration)

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OutLine

- Physics Motivation of $p\Lambda$ femtoscopy
- STAR experimental results
- CLAS setup and experimental conditions
- Details of CLAS $p\Lambda$ experiment
- Comparison with theory
- Conclusions

Physics motivation

- It was shown by Wang and Pratt that an enhancement of the $p\Lambda$ correlation function at low relative momentum allows one to infer the size of the emitting source

[F. Wang and S. Pratt PRL 83,3138,1999]

- The low-energy $p\Lambda$ parameters can be estimated using the Migdal-Watson approach to FSI (reformulated taking the Jaffe-Low P-Matrix) .

[B.Kerbikov et al., Sov.J.Nucl.Phys. 43, 982 (1986), Nucl.Phys. A480, 585 (1988);

R.L.Jaffe and F.E.Low, Phys. Rev. D19, 2105 (1979)]

Our knowledge on pΛ interaction is far from being complete

Table 2: Λp scattering length and effective ranges in fm. The subscripts s and t correspond to spin singlet and triplet states, the first and second columns display the spin-blind values

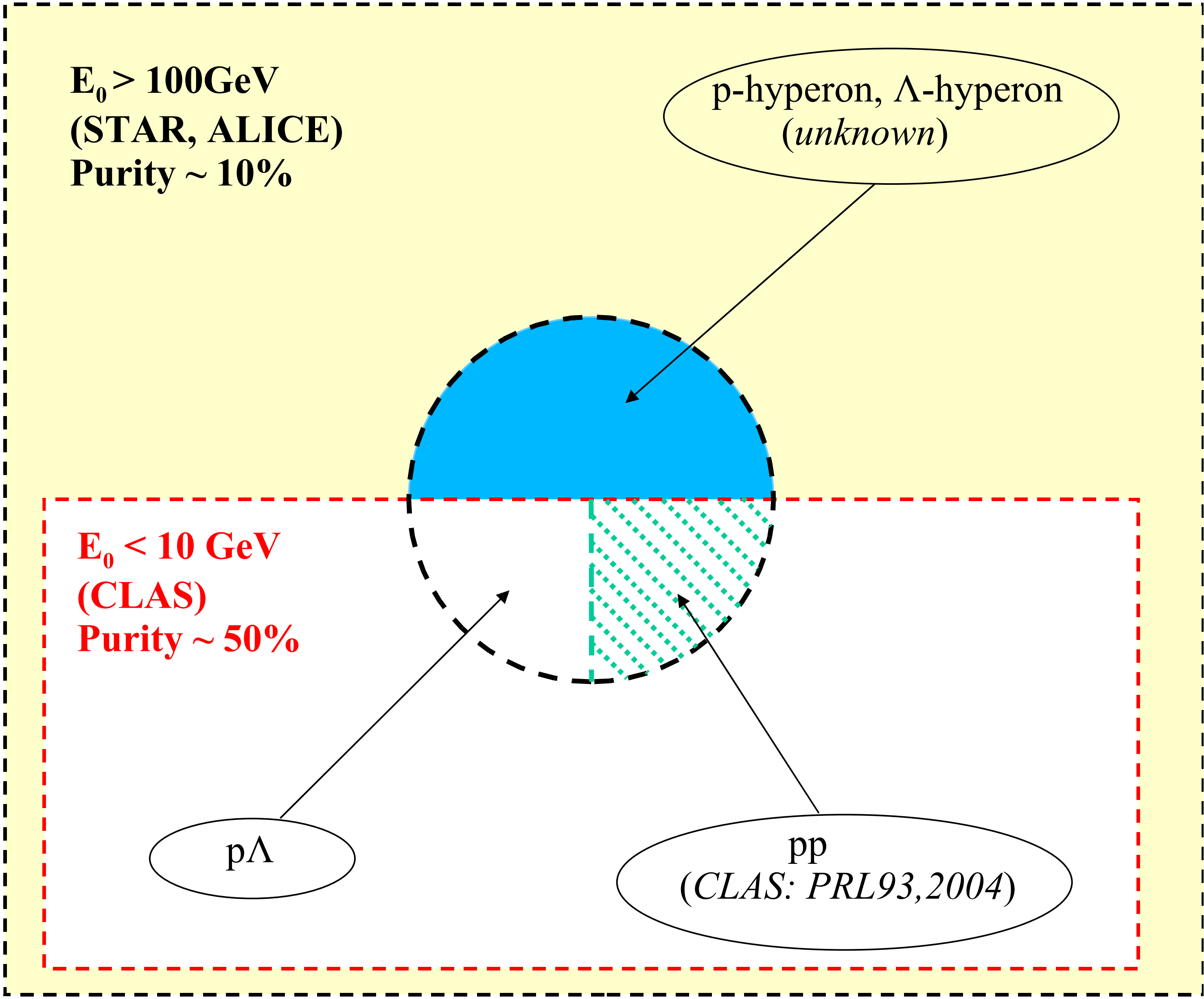
	a	r	a_s	a_t	r_s	r_t
[38]	-1.5					
[39]	-1.8	2.8				
[40, 41]	-2.44	2.64				
[36]			-0.71	-2.18		
[36]			-2.51	-1.75		
[42]			-1.941	-1.858	3.570	3.133
[38]			-1.80	-1.23	1.73	2.29
[43]			-2.18	-1.93	3.19	3.35
[9]			-2.88	-1.66	2.92	3.78
[44]			-(2.4-2.6)	-(1.3-1.7)		
[37]			-2.59	-1.60	2.83	3.00

Contribution to the measured pΛ c.f.

Misidentified pΛ

Residual correlation (example $p\Lambda_{\Sigma}$)

p-pπ correlations



STAR: pΛ (p$\bar{\Lambda}$) correlation in central Au+Au collisions at Sqrt(s_NN)=200GeV

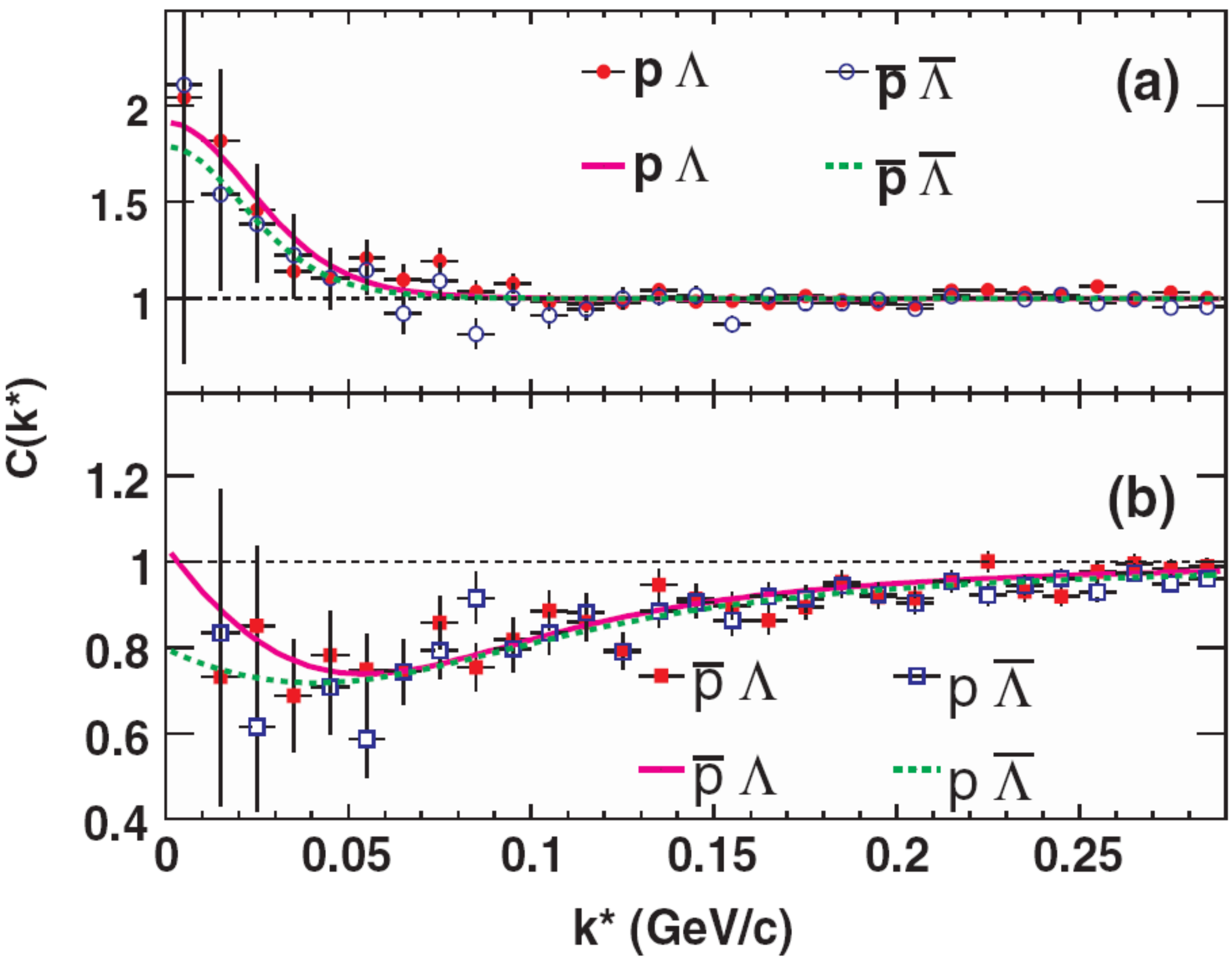
PRC 74, 064906 (2006)

Source size parameter: r_0 (pΛ) = 3.09 ± 0.3 fm, r_0 (p$\bar{\Lambda}$) = 1.56 ±0.08 fm

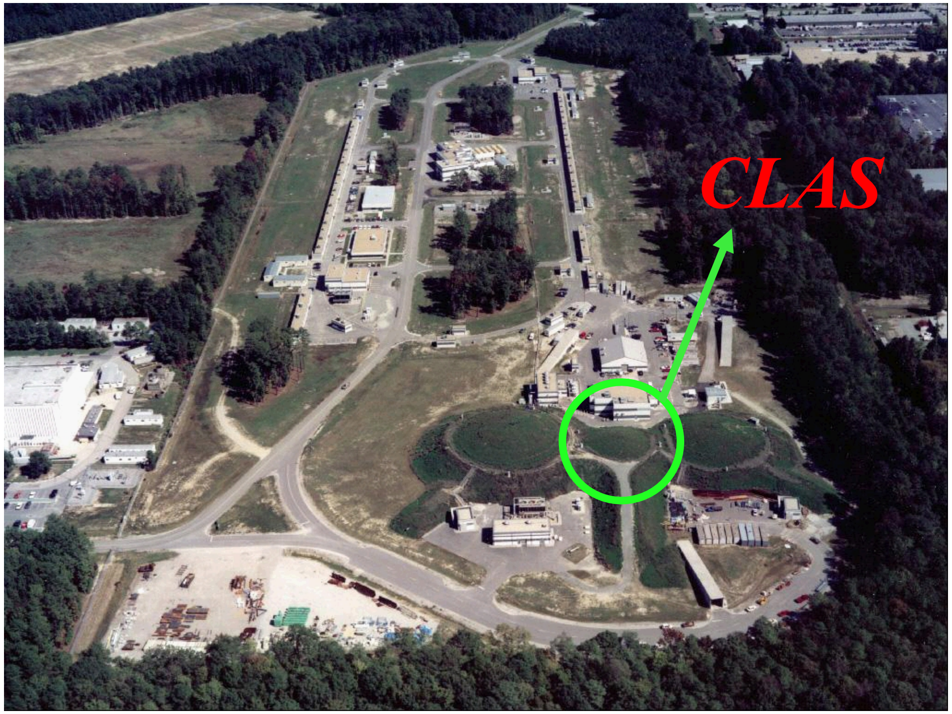
Drawback: Most Λ hyperons and protons are from the decay of hyperons (low “purity”):

TABLE III. Summary of the main fractions of pairs containing particles from particle decays included in p-Λ, p-$\overline{\Lambda}$, $\overline{p}$-Λ, and $\overline{p}$-$\overline{\Lambda}$ correlation functions assuming the absence of residual correlations. Λ_Ξ are Λ ($\overline{\Lambda}$) decay products of Ξ^-, Ξ^0 ($\overline{\Xi^-}$, $\overline{\Xi^0}$), Λ_{Σ^0}, are Λ ($\overline{\Lambda}$) decay products of Σ^0 ($\overline{\Sigma^0}$), p_Λ are p ($\overline{p}$) decay products of Λ ($\overline{\Lambda}$), p_{Σ^+} are p ($\overline{p}$) decay products of Σ^+ ($\overline{\Sigma^+}$), $\Lambda_{\rm prim}$ and $p_{\rm prim}$ represent primary Λ ($\overline{\Lambda}$) and p ($\overline{p}$). The remaining 29% represents misidentified p ($\overline{p}$) and reconstructed fake Λ ($\overline{\Lambda}$).

Pairs	Fractions (%)
$p_{\rm prim}$-$\Lambda_{\rm prim}$	15
p_Λ-$\Lambda_{\rm prim}$	10
$p_{\Sigma+}$-$\Lambda_{\rm prim}$	3
$p_{\rm prim}$-Λ_{Σ^0}	11
p_Λ-Λ_{Σ^0}	7
$p_{\Sigma+}$-Λ_{Σ^0}	2
$p_{\rm prim}$-Λ_Ξ	9
p_Λ-Λ_Ξ	5
$p_{\Sigma+}$-Λ_Ξ	2
$p_{\rm prim}$-$p_{\rm prim}$	7



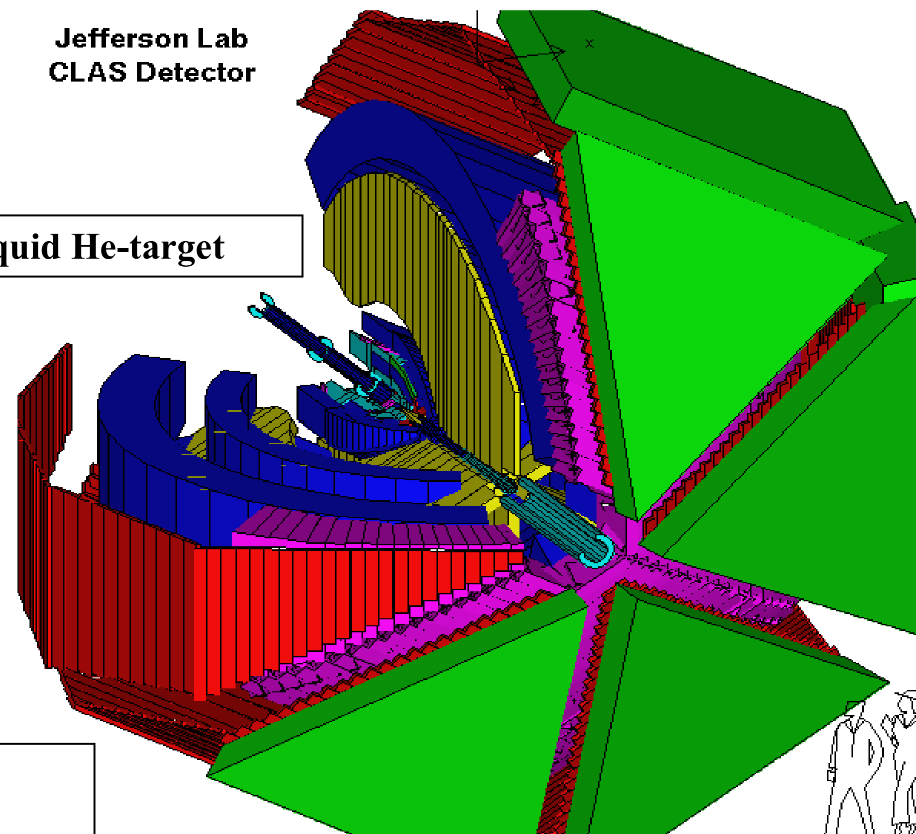
Jefferson Lab CLAS detector



Torus magnet
6 superconducting coils, B=5T

Drift chambers
argon/CO_2 gas, 35,000 cells

Time-of-flight counters
plastic scintillators, 684 PMTs



Liquid He-target

Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

Gas Cherenkov counters
e/π separation, 216 PMTs

Large angle calorimeters
Lead/scintillator, 512 PMTs

CLAS experiment: pΛ interactions at low relative momentum

Reaction and run condition

- The reaction: e^3He, $^4He \rightarrow e'p\Lambda X$
- The data : e2a (1999) and e2b (2002) runs, 2430 millions triggers on **^{3}He** and 440 millions on **^{4}He.** The beam energy was 4.7 GeV and 4.46 GeV respectively.

Identification of Λ

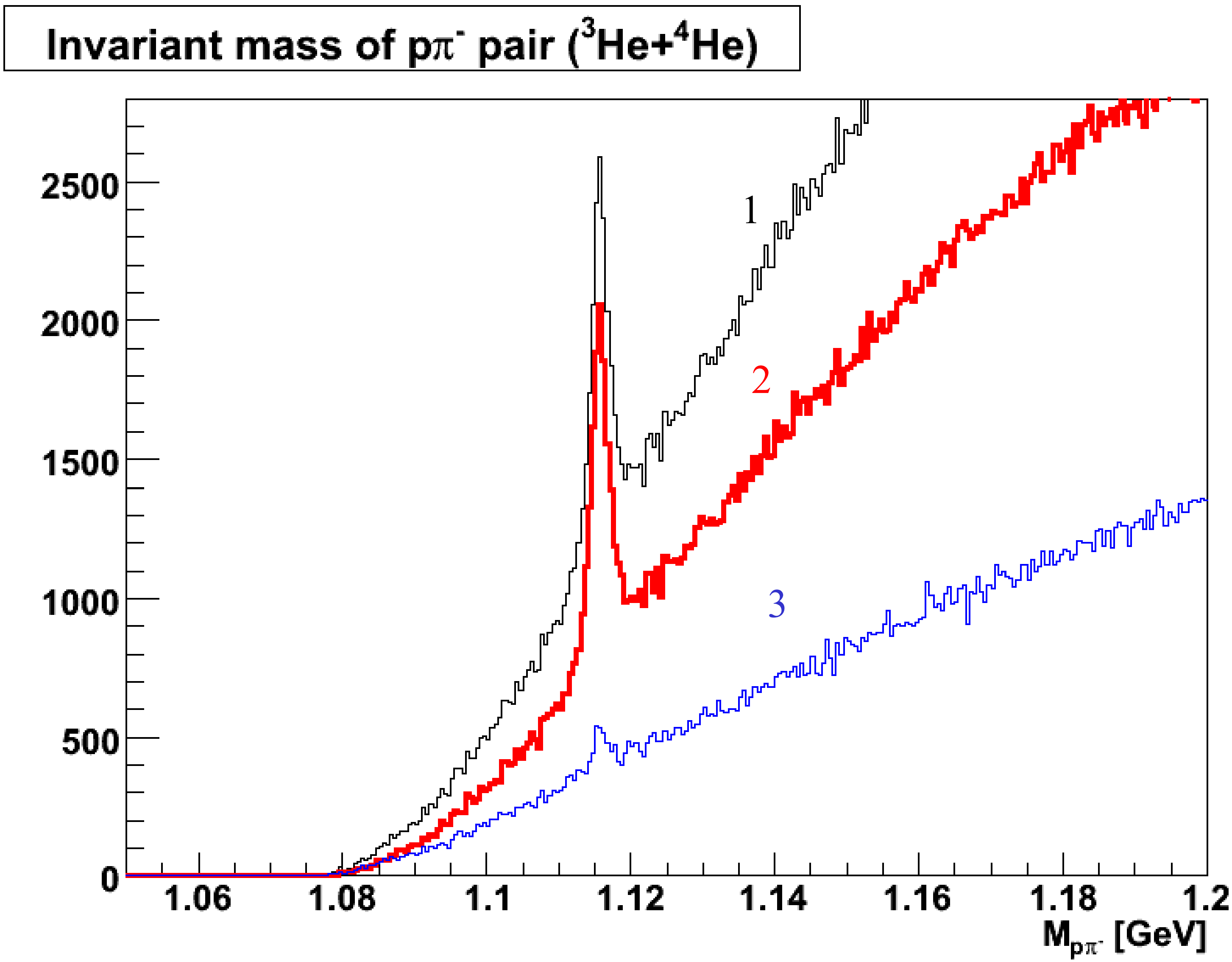
- Λ-hyperons were identified by proton – pion decay: M(pπ) = 1115.5±2MeV
- Cuts: Vertex (target walls), track quality, same TOF, transferred energy ν, missing mass ($eHe \rightarrow e'pp\pi X$)
- Proton momentum range : 0.3 to 2.0 GeV/c
- π momentum range : 0.1 to 0.7 GeV/c
- Due to kinematical restrictions (K-meson production at least) the minimal energy transferred (ν) is not negligible. The cut ν> 0.8 GeV was applied as a compromise of data reduction and purity.

Λ id: invariant mass of proton-pion

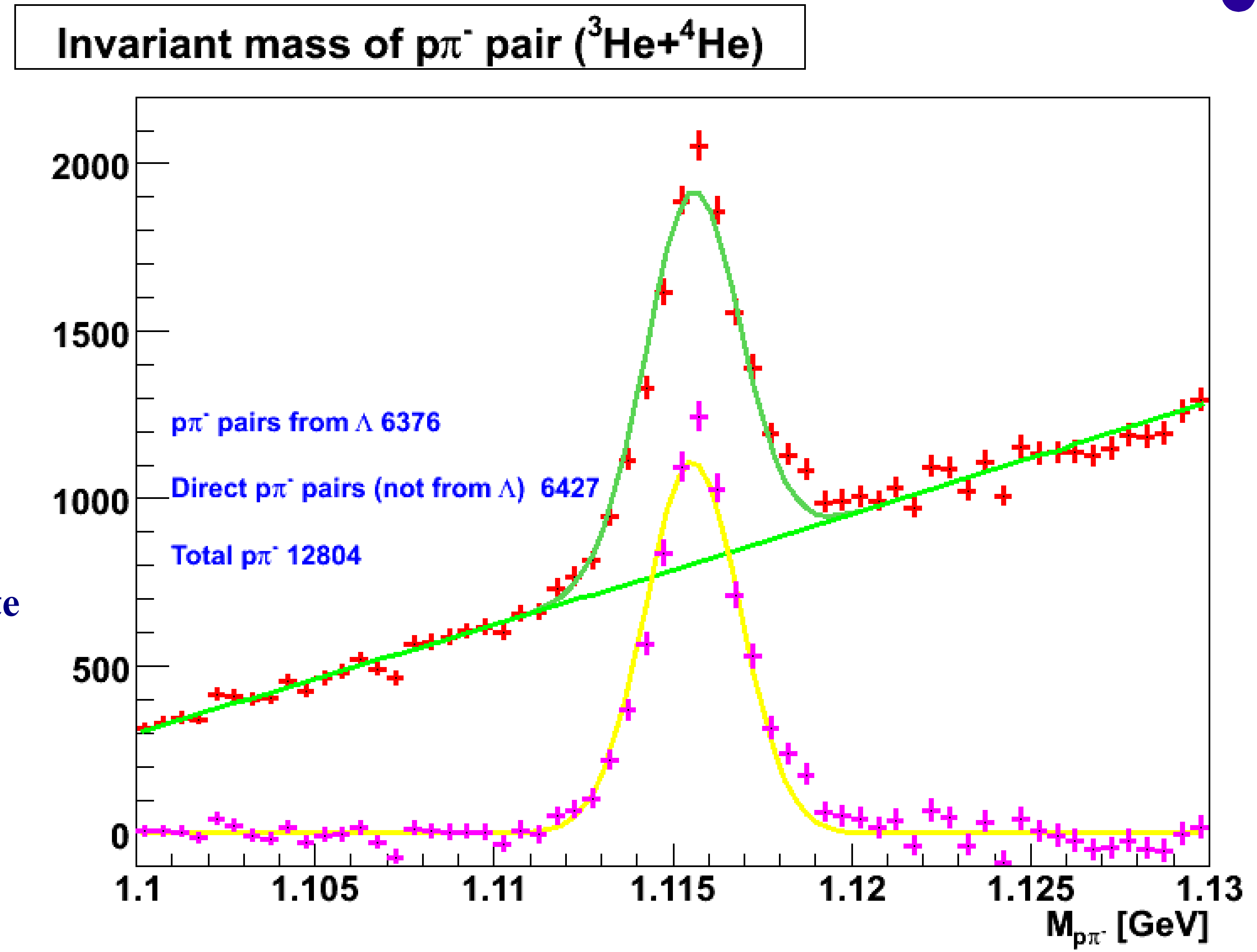
1 – all pairs

2 – cut: $\nu-\nu_{min} > 0.8$ GeV and $M^2_{miss} > 2.1$ GeV^2

3 – difference (1) – (2)



Λ id: subtract background



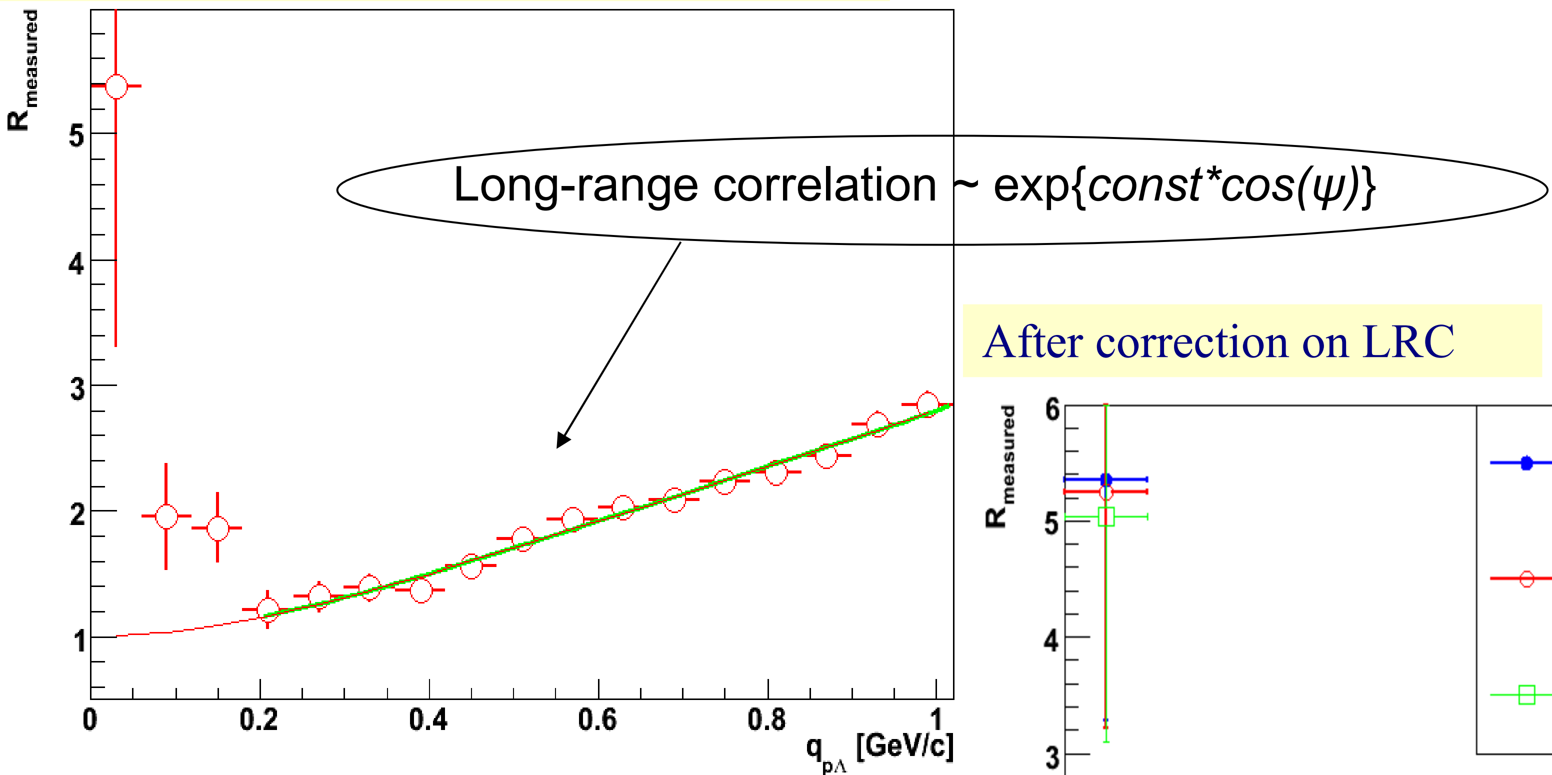
Events with $M_{p\pi}$:1.1135-1.1175 GeV is used to calculate pΛ correlation function

Events which is out of Λ-peak is used to calculate correlated p-pπ background

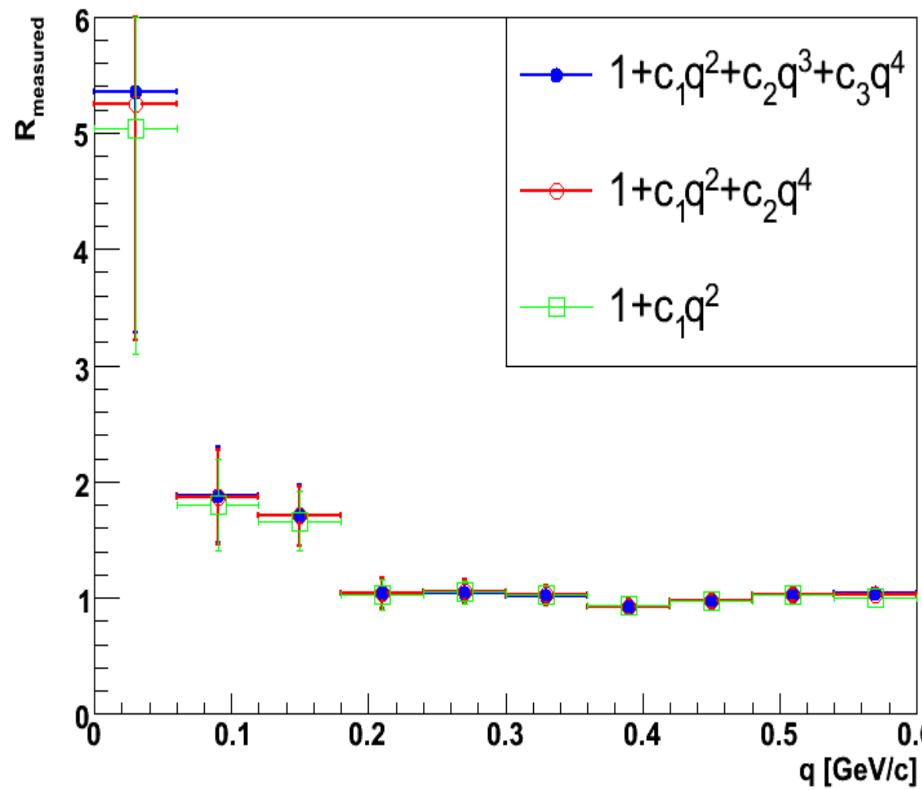
Measured corr. function: $R_{p\Lambda+pp\pi} = \alpha R_{p\Lambda} + (1-\alpha) R_{pp\pi}$,where $\alpha \approx 0.5$

Measured correlation function(LRC)

$R_{measured} = N_{real} / N_{mix}$ ($\mathbf{q=p_p-p_\Lambda}$)

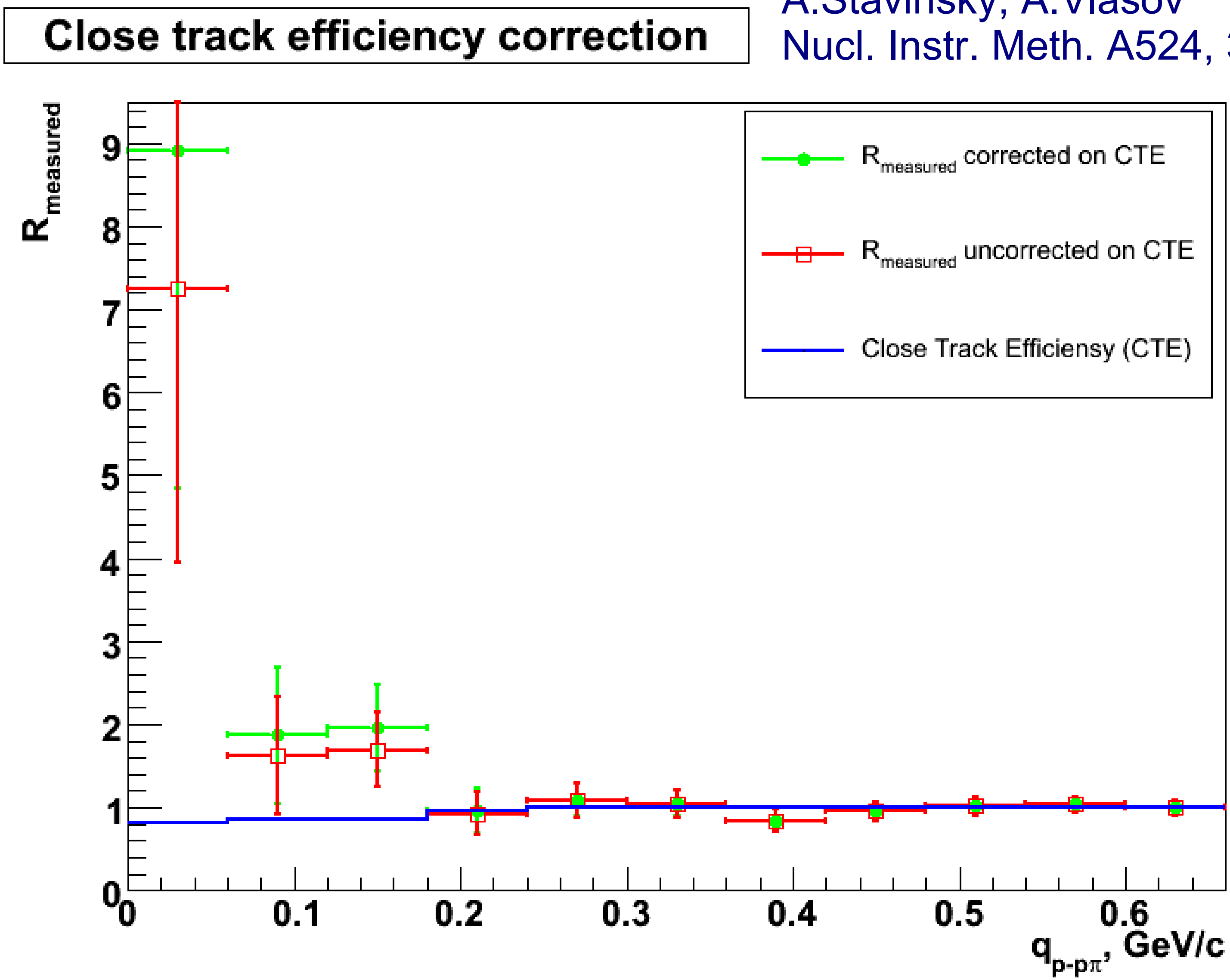


After correction on LRC



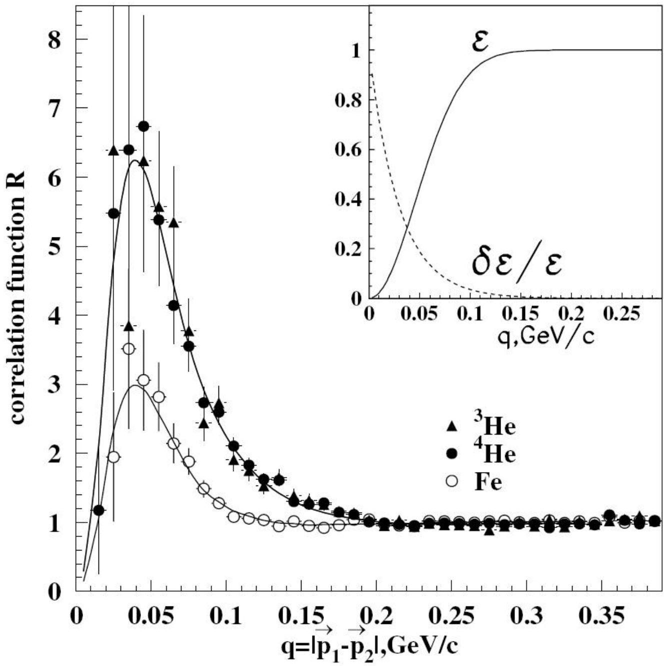
Close track efficiency correction

Methods: M.Mestayer, K.Mikhailov, A.Stavinsky, A.Vlasov
Nucl. Instr. Meth. A524, 306 (2004)

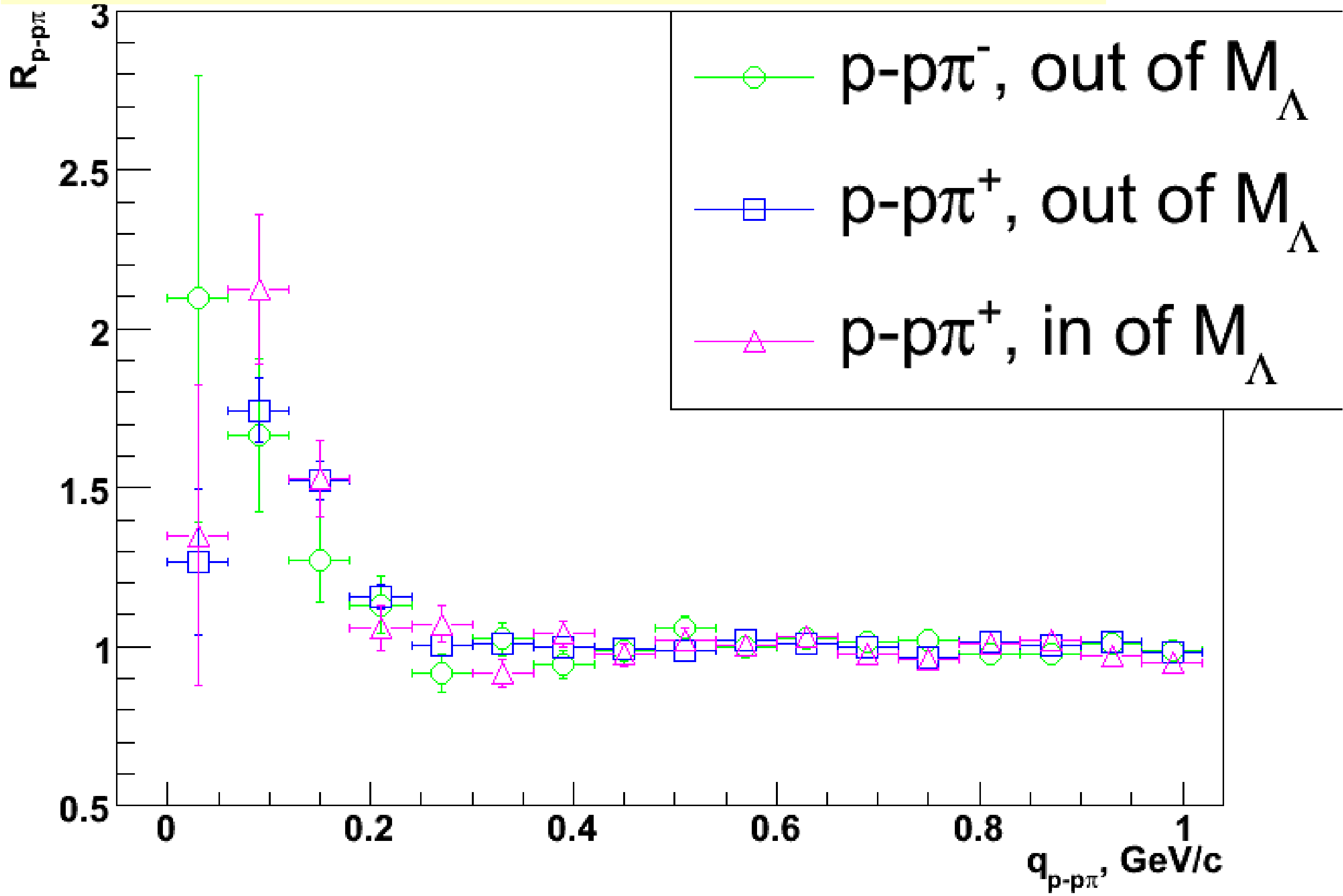


p-pπ contribution to pΛ

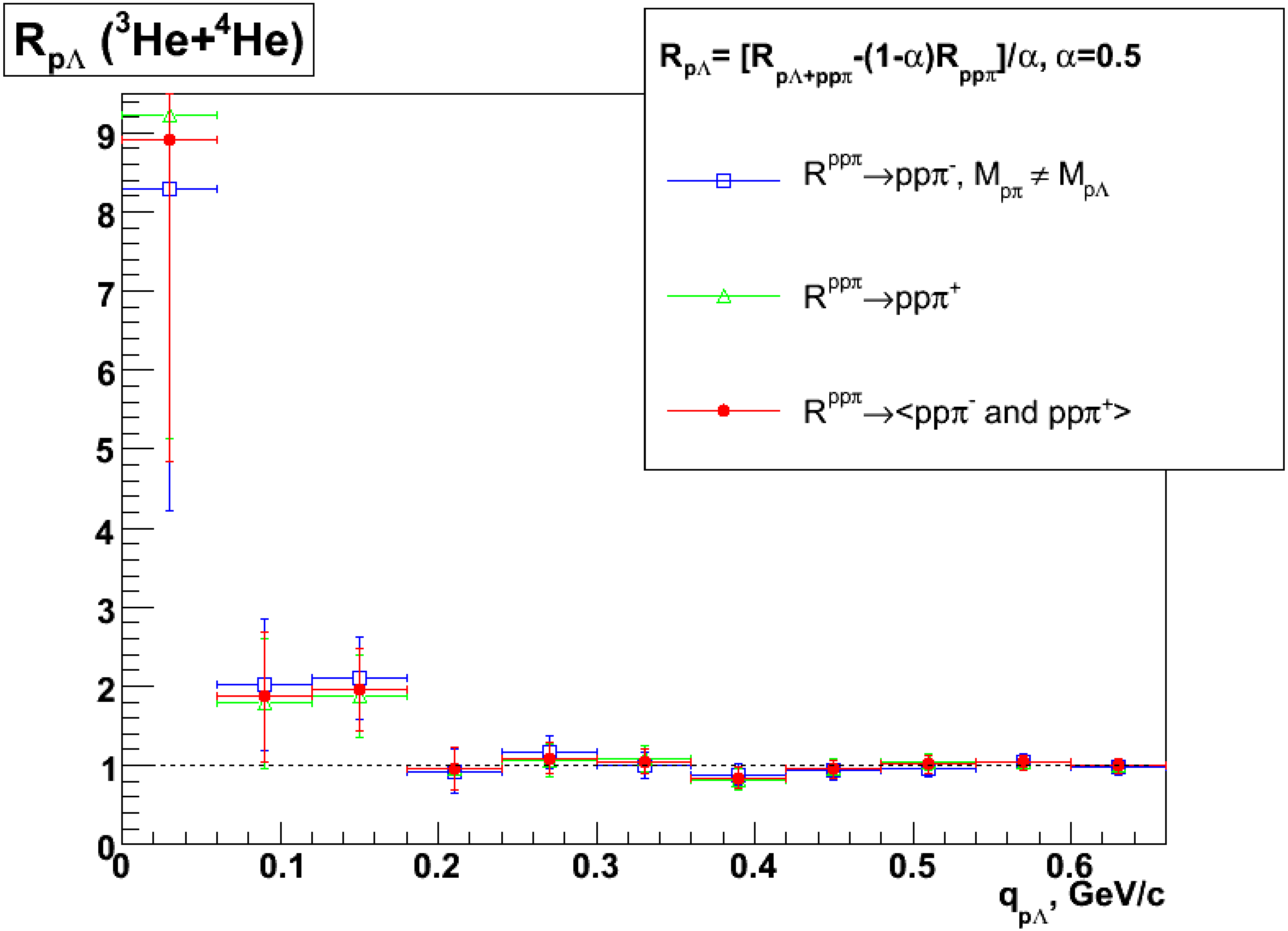
eHe→e'ppX [CLAS:PRL93,2004]
$r_0 \sim 1$ fm, r_{rms}=sqrt(3)r_0



p-pπ correlation function, when $m_{p\pi} \sim m_\Lambda$



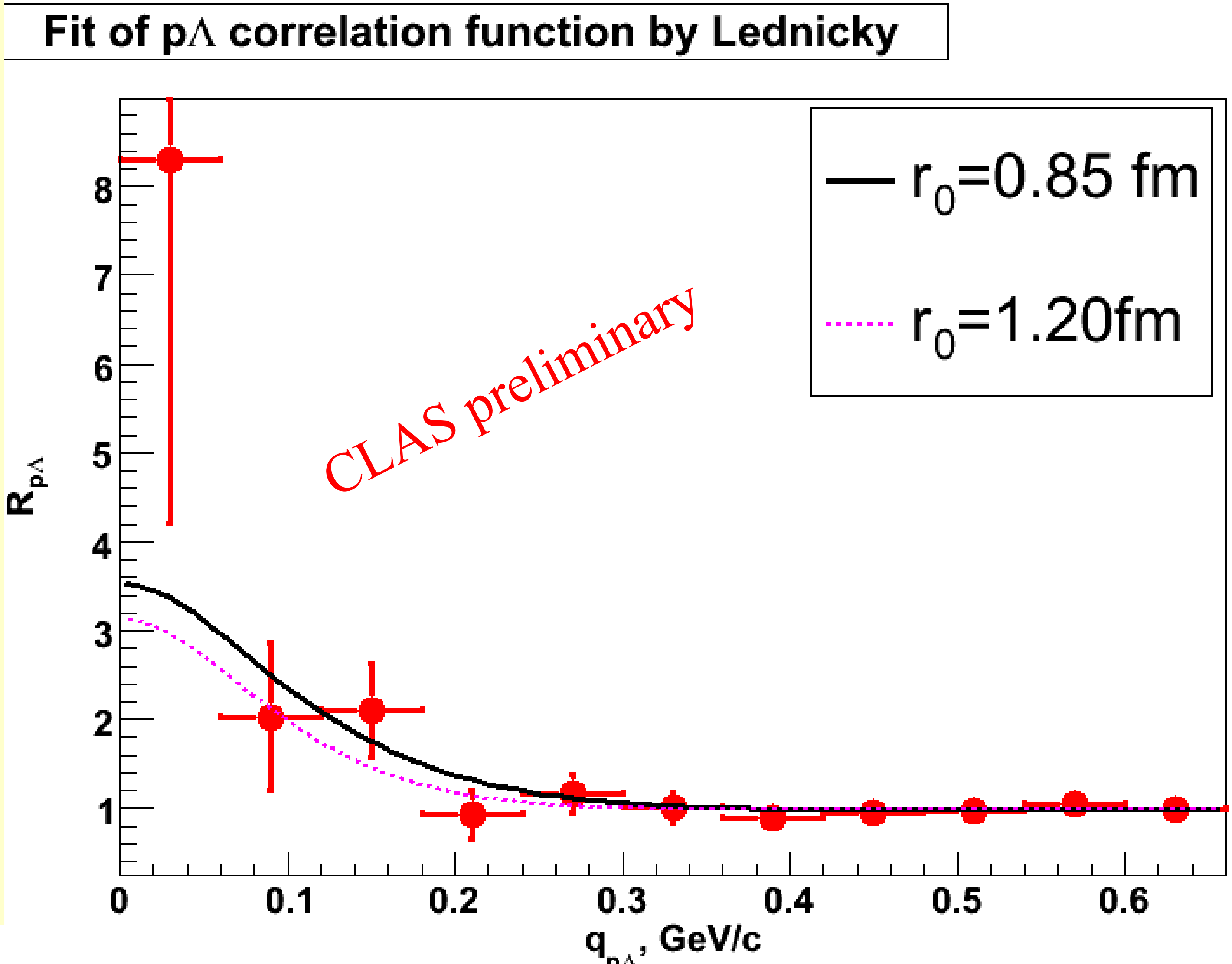
After correction on p-pπ contribution



pΛ source size

• Lednicky and Lyuboshitz analytical model, Sov. J. Nucl. Phys. 35, 770 (1982): Two particle CF is given by square of wave function elastic transition ab→ab averaged over distance r^* of emitters [Gaussian dist $d^3N/d^3r^* \sim \exp(r^{*2}/4r_0^2)$] and over spin projections

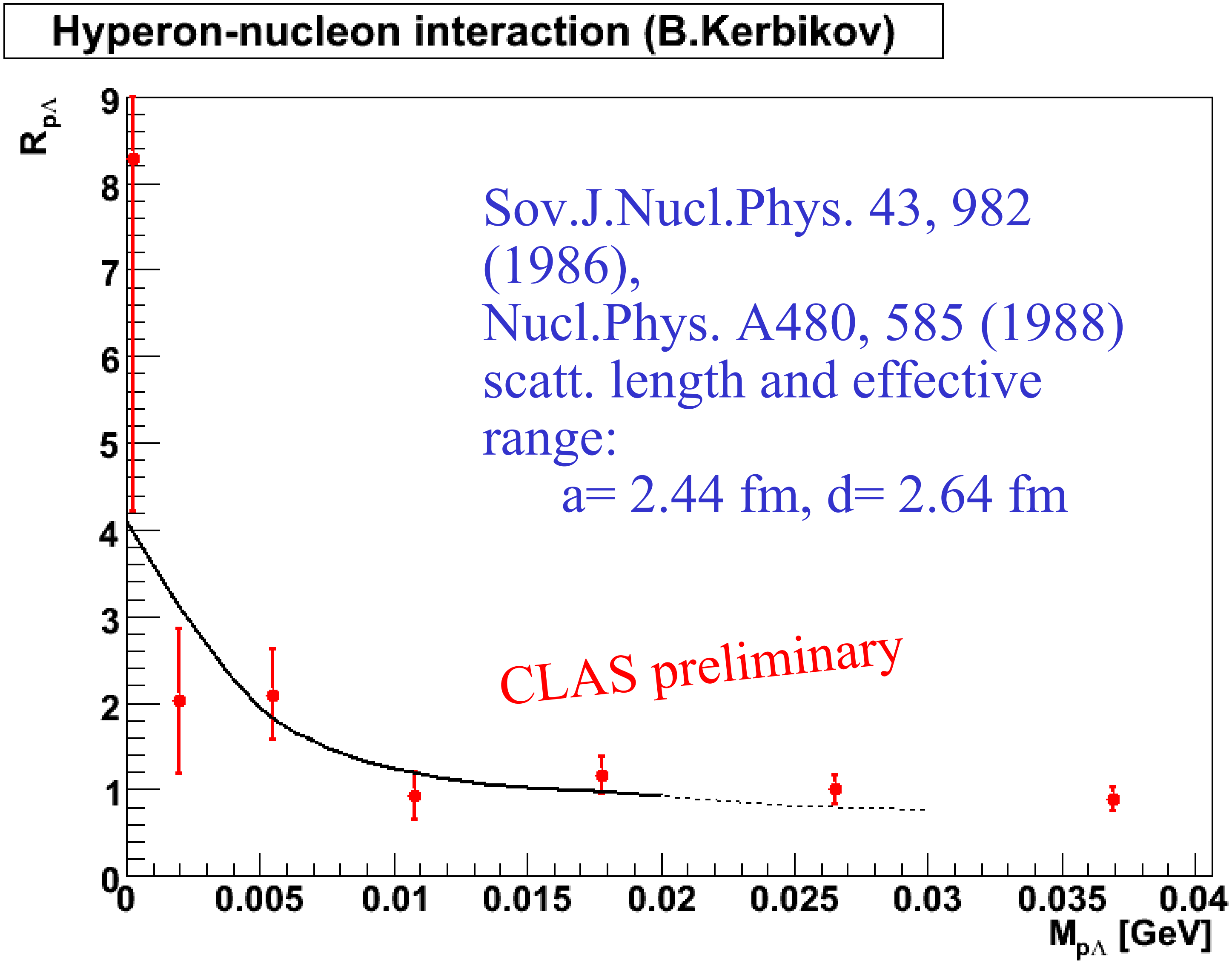
•Scatt. length and effective range (as in STAR fit):
a^0=2.88 fm, a^1=1.66 fm, d^0=2.92 fm and d^1=3.78fm (0-singlet, 1-triplet)



P-matrix

• Jaffe-Law P-matrix: connection between scatt. data and multiquark states

• Scatt. length and effective range:
a=2.64 fm, d=2.64 fm



Conclusions

- The data show a narrow structure in the correlation function in the region of small relative momenta ($q<0.2$ GeV/c), which is in qualitative accordance with theoretical expectations.
- The important p-pπ correlations were studied. It was shown that p-pπ pairs in the region of mass pπ around mass of lambda are correlated.
- The source size for strangeness production reaction proved to be consistent with one measured in semi-inclusive two proton production reaction.
- The proton-lambda correlation function is compatible with P-matrix fit of the hyperon-nucleon data.
- Small relative momentum pΛ correlations both for He target and for electro-production reaction was studied for the first time.

Thank you for your attention!

Extra slides

Vertex cut

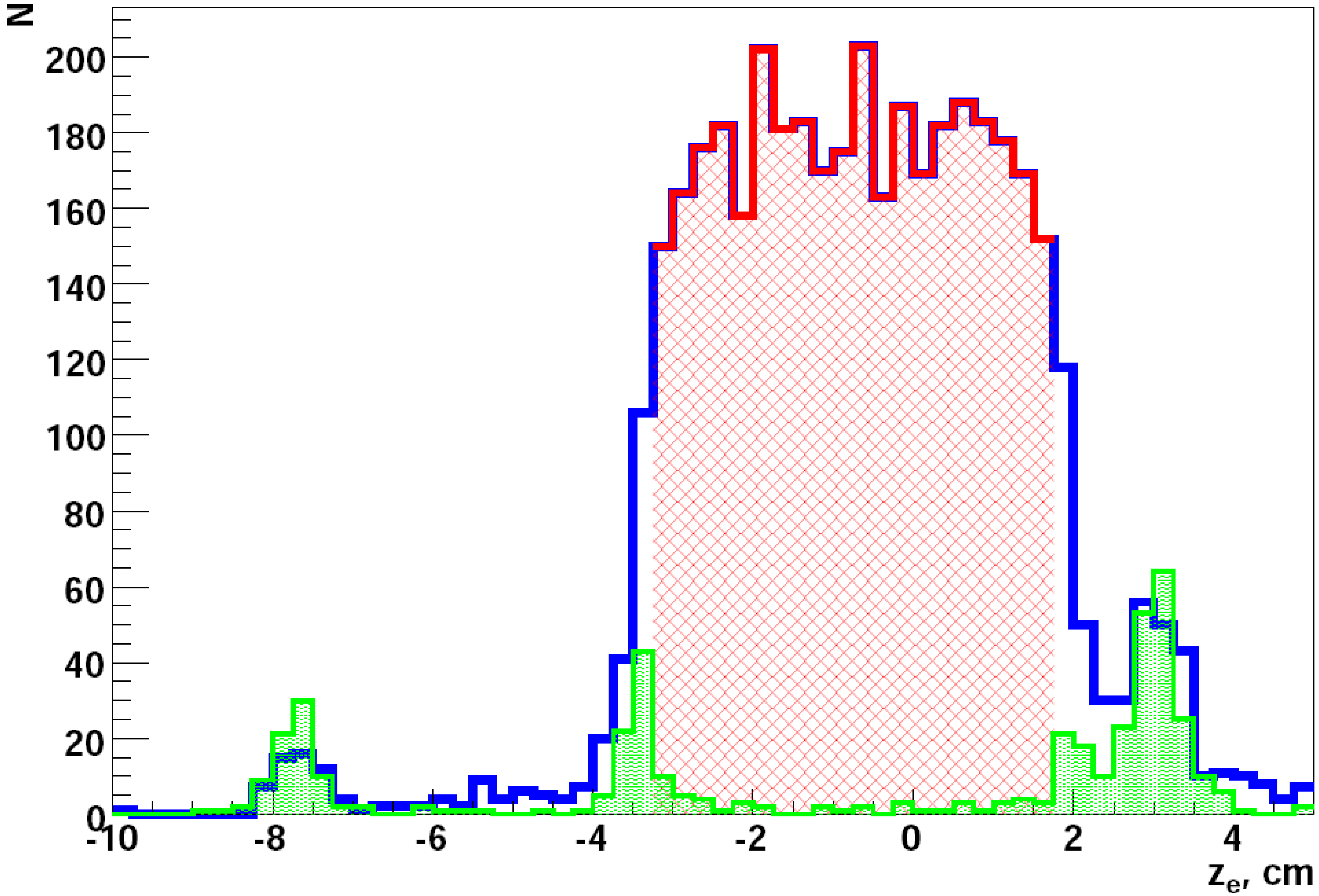


Figure 2: Vertex z-position distribution for reconstructed scattered electron in $e^4He \rightarrow e'pp\pi^-X$. Blue line corresponds to full target He run period. Green shadowed histogram is for empty run period normalized for tha same number of events at z=-8cm and z=3cm peaks. The red histogram corresponds to events which are taken into analysis.

Missing Mass

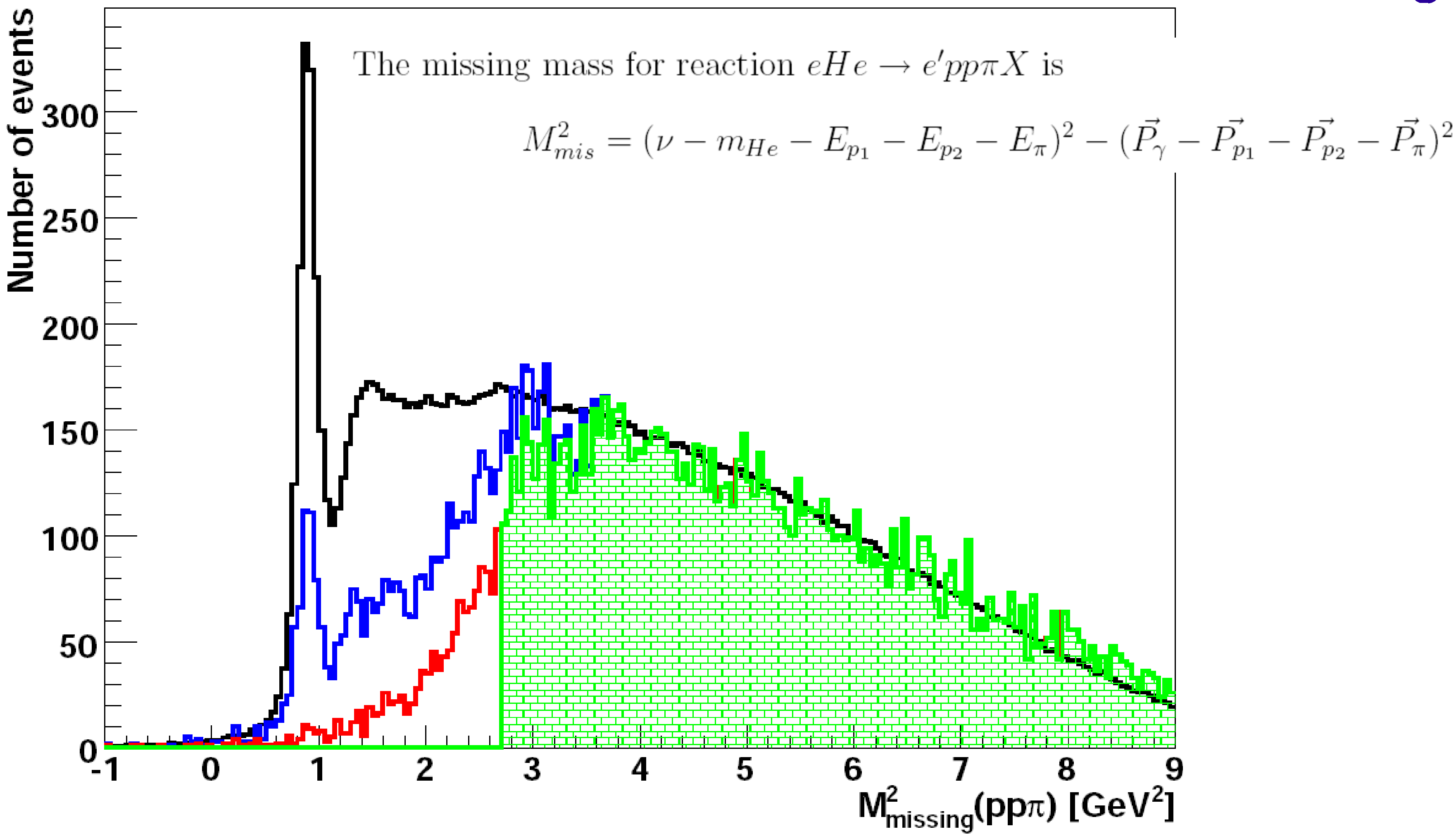
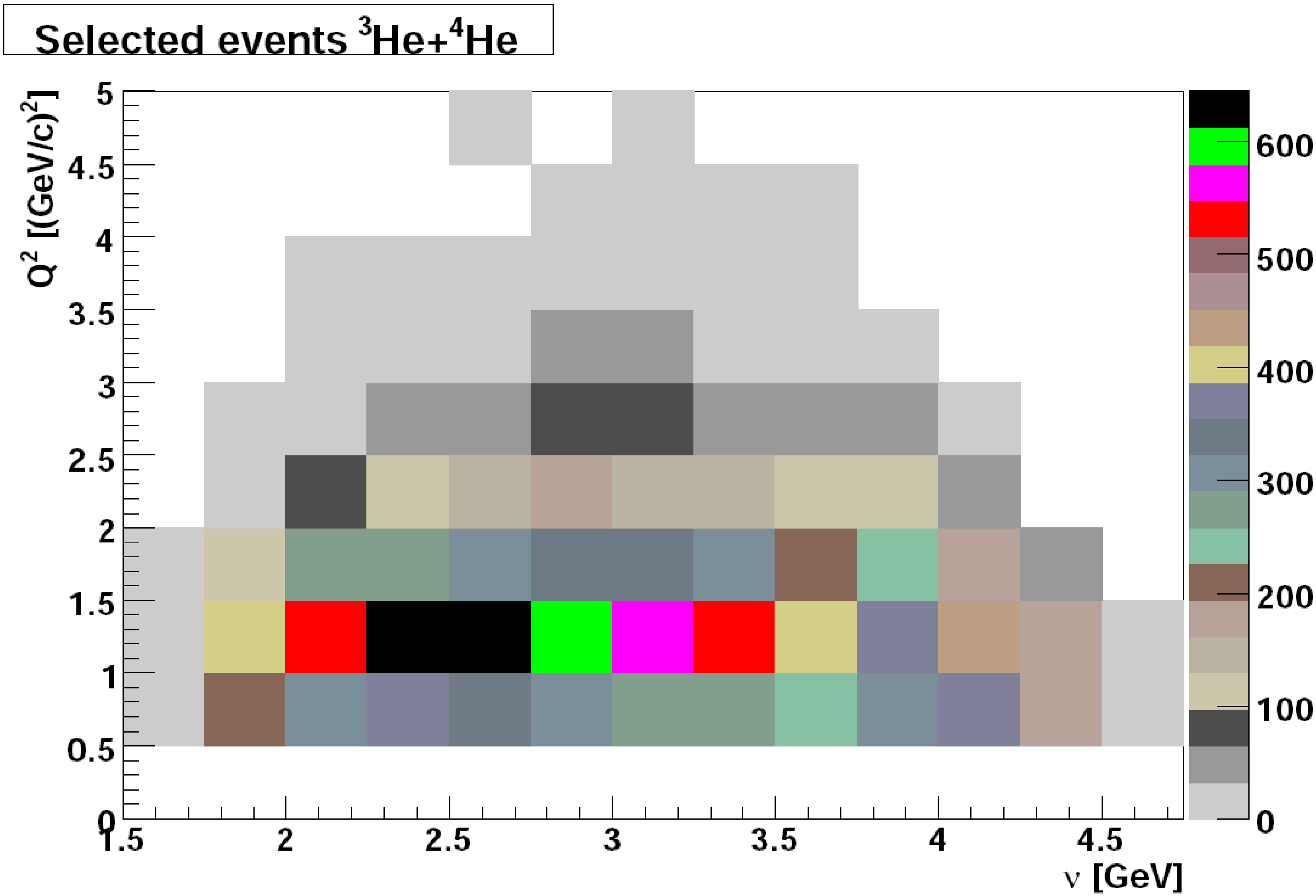


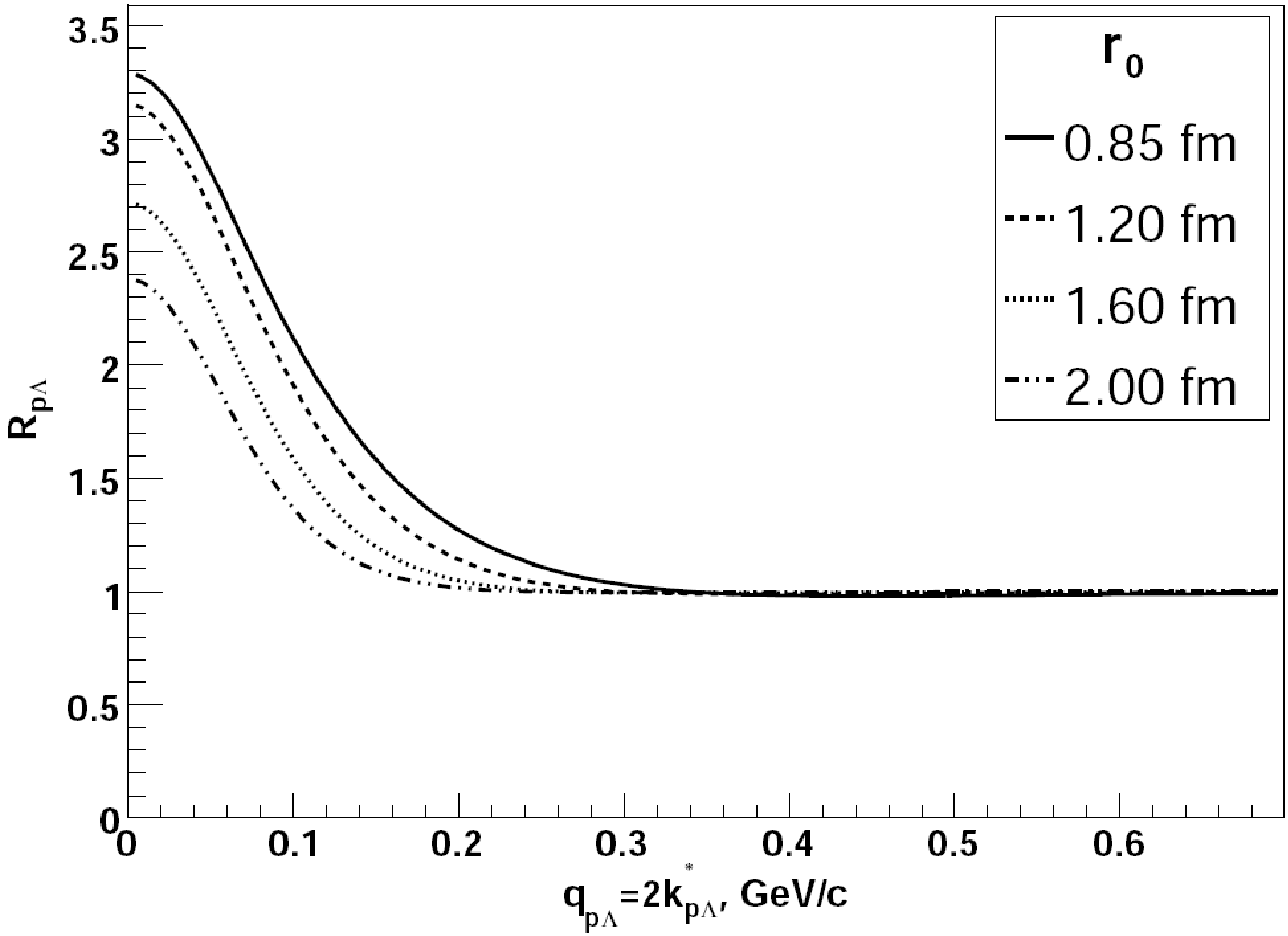
Figure 5: Missing mass squared distributions for reaction $e^3He(^4He) \to e'pp\pi^- X$. Black histogram is for all events, blue is for events from Λ-peak, and red-green is for events from Λ-peak with cut $\nu - \nu_{min} > 0.8$ GeV. Green histogram represents events accepted for the analysis.

Q^2 versus ν



ν - Q^2 plot for selected events which are taken into analysis.

Theoretical pΛ cor.fun.



P-matrix

Jaffe and Low identified P-matrix is a tool which allows to reveal the connection between the scattering data and the multiquark states.

The excess energy:

$$\varepsilon = s_{p\Lambda}^{1/2} - (m_p + m_\Lambda)$$

The cross secton of eHe->e'pΛX reaction:

$$d\sigma/d\varepsilon = const^* \varepsilon^{1/2} |T|^2,$$

where the amplitude T in the narrow enegry region close to pΛ threshold (ε<30MeV) may be factorized:

$$|T|^2 = |T_0|^2 / |f(-k^*)|^2$$

T_0 is a production amplitude (independent of k*) and $f(k^*)$ is the Jost function (enhaacement factor) corresponding to the low-energy pΛ interaction which may be expressed in term of scattering length (a) and effective range (r):

$$f(k^*) = (k^* - i\beta) / (k^* + i\alpha) \text{ with } r(\alpha-\beta)=2,\ r\alpha\beta = -2/a$$

In case of correlation function the phase space factor $\varepsilon^{1/2}$ eliminates:

$$R_{p\Lambda}(\varepsilon) = const\ \{(k^*)^2 + \alpha^2\} / \{(k^*)^2 + \beta^2\}$$

P-matrix(2)

Two channel ΛN-ΣN S-matrix is connected to the P-matrix via relation

$$\hat{S} = \hat{Q}^{1/2} e^{-i\hat{Q}b} (\hat{P} - i\hat{Q})^{-1} (\hat{P} + i\hat{Q}) e^{-i\hat{Q}b} \hat{Q}^{-1/2}$$

Here Q is the diagonal matrix momenta k_1=k*(Λp) and k_2=k*(Σp), b is YN separation at which the quark degrees of freedom come into play.
In the YN channel with *I*=1/2, $J^P=1^+$ the bag model predicts a six-quark state with M_n=2.34GeV ($E_n=M_n - m_p - m_\Lambda$ = 0.286Gev above the ΣN threshold). The poles of the S-matrix the quark-hadron coupling is introduced with coupling constants λ_i(i=Λp,Σp). P-matrix:

$$P_{ij} = \delta_{ij} P_i + \frac{\lambda_i \lambda_j}{E - E_n}, \qquad i, j = 1, 2$$

The set of parameters was: $\lambda^2 = 0.014\ \mathrm{GeV}^2, \quad P_1 = 0.11\ \mathrm{GeV}, \quad P_2 = 0.13\ \mathrm{GeV}$

Expressions for the Λp scattering length (*a*) and effective range (*r*):

$$a = -\left\{ P_1 - \frac{\lambda^2}{E_n - \frac{\lambda^2}{H}} \right\}^{-1} + b\,,$$

$$r = 2b - \frac{b^2}{a} + \frac{P_1}{\lambda^2 \mu a} \left[P_1 (b - a) - 1 \right]\,,$$

$$H = P_2 + \Delta\,, \frac{1}{\mu} = \frac{1}{\mu_1} + \frac{\lambda^2}{H^2 \Delta}\,, \Delta^2 = 2\mu_1 E_0$$