II Workshop on Dense Cold Matter and Cumulative Processes.
St. Petersburg State Polytechnical University
June 15, 2011

Femtoscopy with Dence Cold Matter

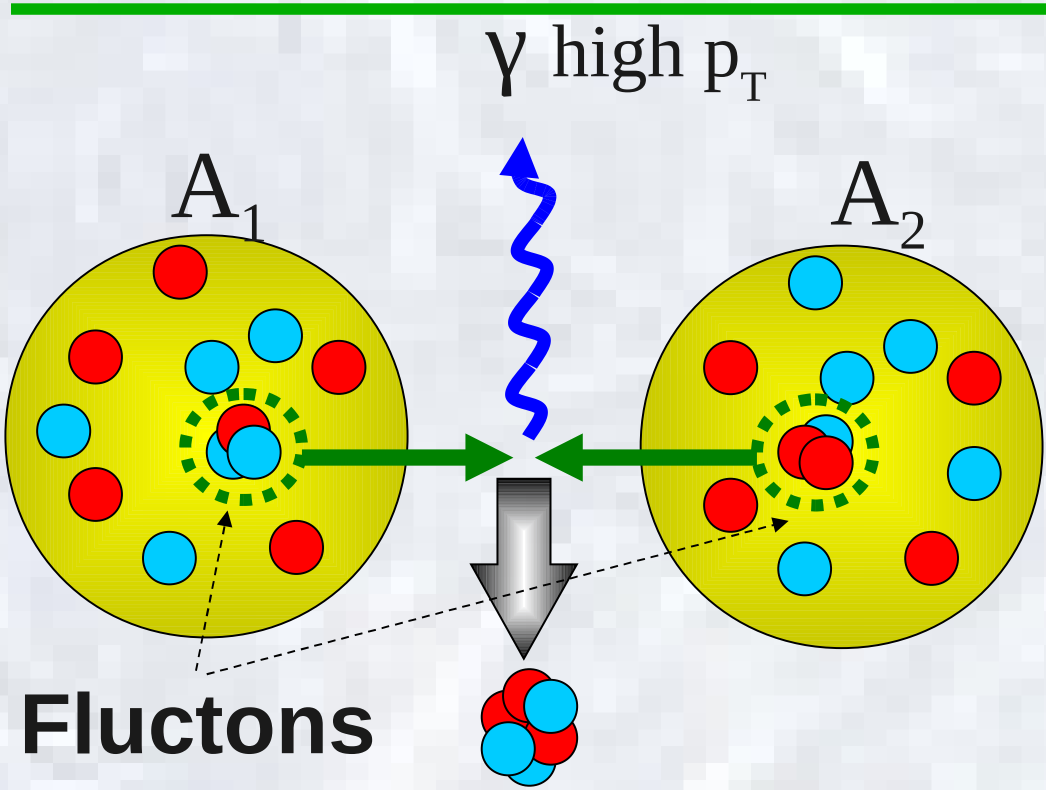
Konstantin Mikhailov for FLINT collaboration

ITEP, Moscow

Outline

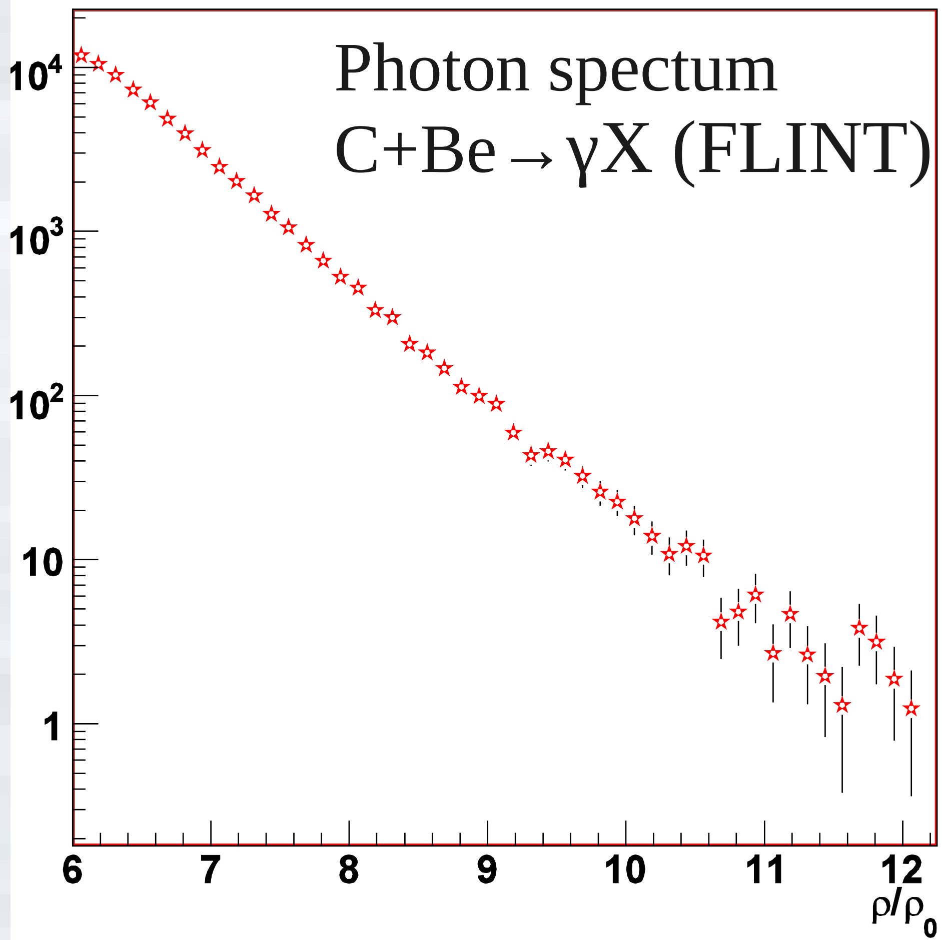
- How can we measure density of matter?
- Femtoscopy as tool to measure sizes
- First cumulative femtoscopy experiment
- CEBAF – size of flucton
- FLINT and femtoscopy
- List of problems
- Conclusion

Density of cold matter



Dense baryon system

$\rho \sim m_N (X_1 + X_2)/r^3_f$,
r_f=1.3fm flucton radius



What is the dencity?

What is the density of cold matter?

- Transferred momentum

ρ=Mass/Volume
Volume ~ size^3, size ~ 1/p_T

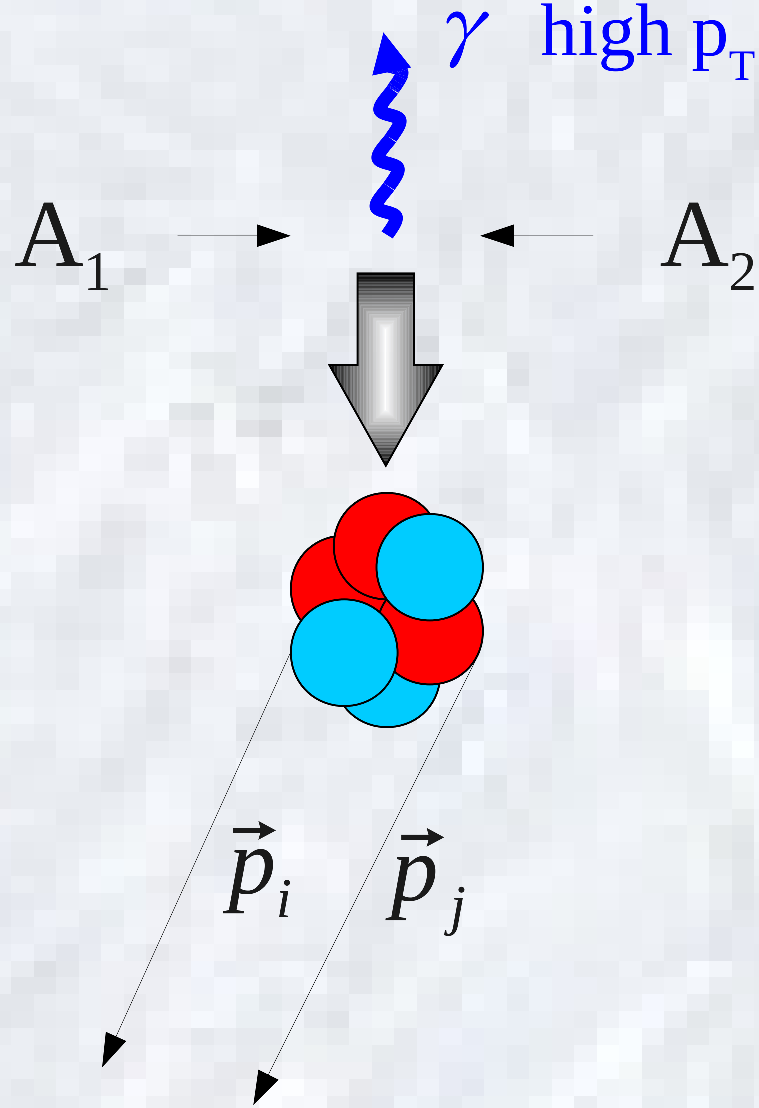
$p_T(\gamma)$ ~ 2 GeV/c
Size ~ **0.1 fm** ?
or
4 nucleons 0.5GeV/c
Size ~ 0.4*sqrt(4) ~ **1fm**?

- Femtoscopy

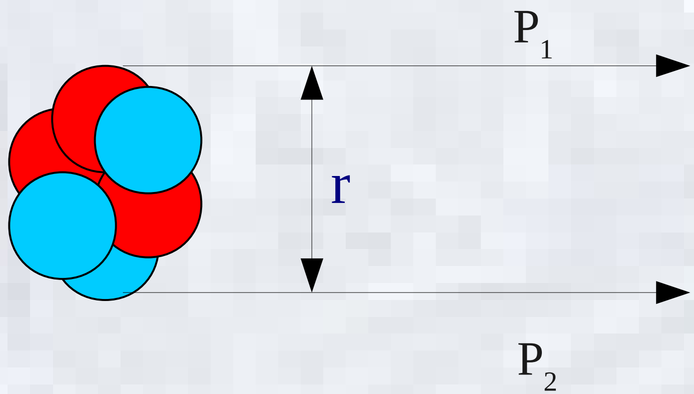
$$R_{ij}(\vec{p}_i,\vec{p}_j)=\frac{f_{ij}(\vec{p}_i,\vec{p}_j)}{f_i(\vec{p}_i)f_j(\vec{p}_j)}$$

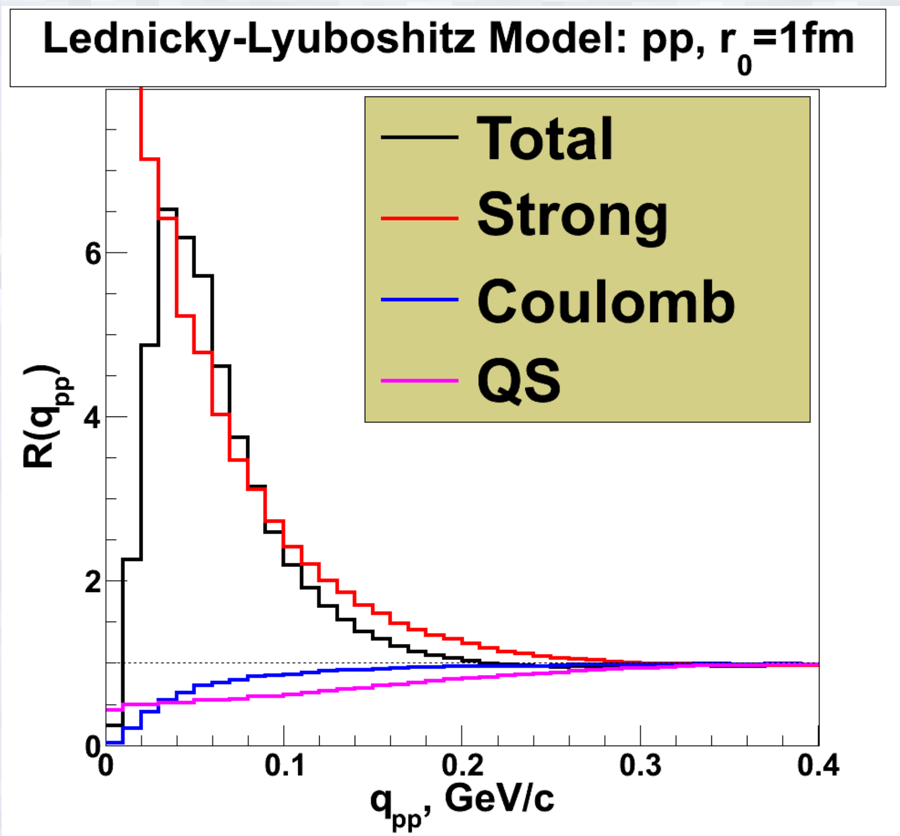
space-time characteristics of source

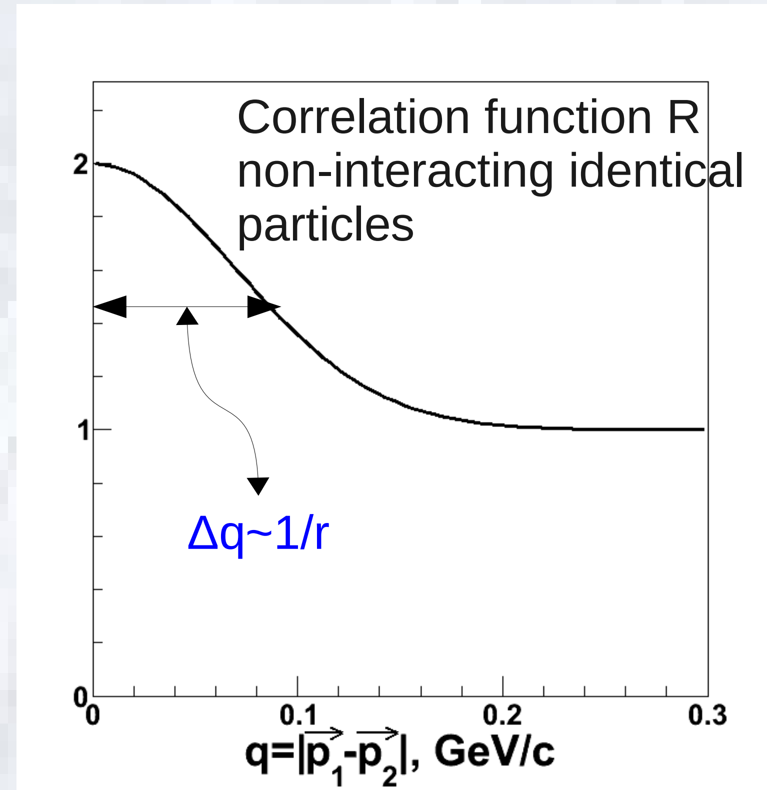
- Other methods ?



Femtoscopy as tool





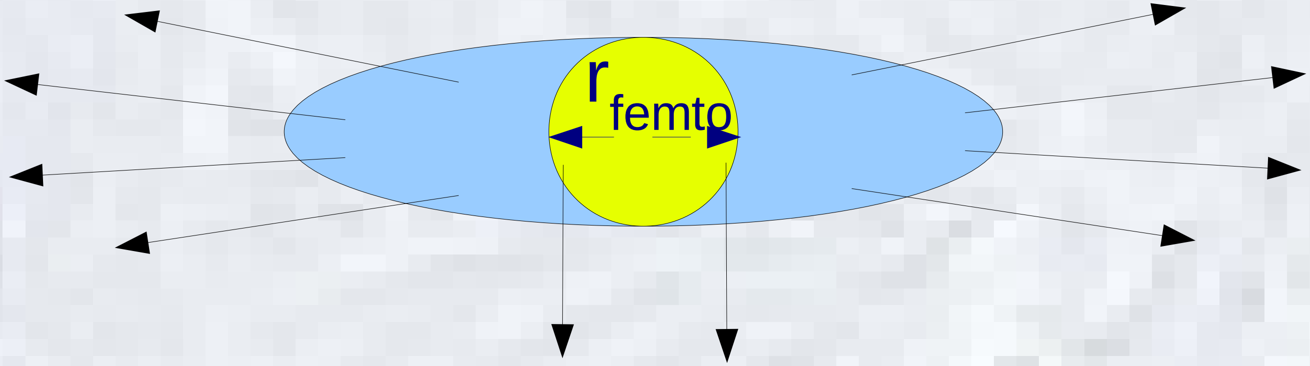


$$R_{ij}(\vec{p}_i,\vec{p}_j) \approx \frac{N_{same\,event}(q_{ij})}{N_{different\,event}(q_{ij})} \qquad [Kopylov, PL\,50B, 1974]$$

In common case Correlations are due to:

- Quantum Statistics
- Strong FSI
- Coulomb FSI

Measured size = Geometrical size?



Particles with similar momenta (small q) are preferentially emitted from close-by regions

length of homogeneity (Yu.M. Sinyukov, 1988):

$$r_{femto} \approx \tau_f \sqrt{\frac{T_f}{m_t}}, \quad m_t = \sqrt{(m^2 + k_t^2)}$$

radii depend on m_t

$$r_{femto} = min(r_{geom}, r_{thermal})$$

First Cumulative Femtoscopy

ЯФ, т.36, вып.4(10),1982, с.915.

ПОПЫТКА ОПРЕДЕЛЕНИЯ ФОРМЫ ОБЛАСТИ, ИЗ КОТОРОЙ ВЫЛЕТАЮТ КУМУЛЯТИВНЫЕ ПРОТОНЫ

ВЛАСОВ А. В., ГАВРИЛОВ В. Б., ДЕГТЯРЕНКО П. В., ЗАЙЦЕВ Ю. М., КОСОВ М. В., ЛЕКСИН Г. А., СТАВИНСКИЙ А. В., СУЧКОВ Д. А.

ИНСТИТУТ ТЕОРЕТИЧЕСКОЙ И ЭКСПЕРИМЕНТАЛЬНОЙ ФИЗИКИ ГКИАЭ

(Поступила в редакцию 1 марта 1982 г.)

Путем анализа распределений пар кумулятивных протонов, вылетающих из ядра Pb, по продольной и поперечной составляющим разности их импульсов изучалась форма области образования кумулятивных частиц. Получены указания, что эта область несферическая: размер продольный относительно направления налетающей частицы больше поперечного.

Transverse source size of cumulative protons is about **1.5 fm at X~3.7**

p(8.3 GeV/c)Pb->ppX, p_0=0.37-0.9GeV/c, θ=110-160^0

$X_{pp}=(E_0E-p_0p\cos\theta-0.5m_N)/(E_0-E+m_N)$, where E,p,m,θ corresponds to two protons

Mean cumulative number of two protons: X_{pp}~3.7

Estimated source size r_L=4.5fm, r_T=1.5fm

CEBAF: eA → e'ppX, PRL 93(2004)192301

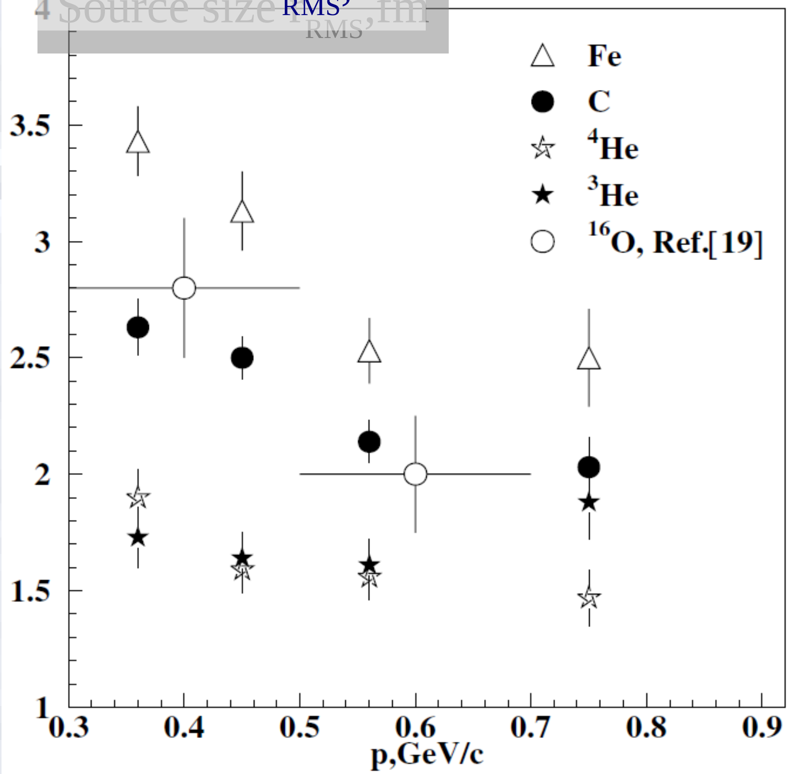
Cumulative number for

$e + X_s m_p \rightarrow e' + p + m_c$

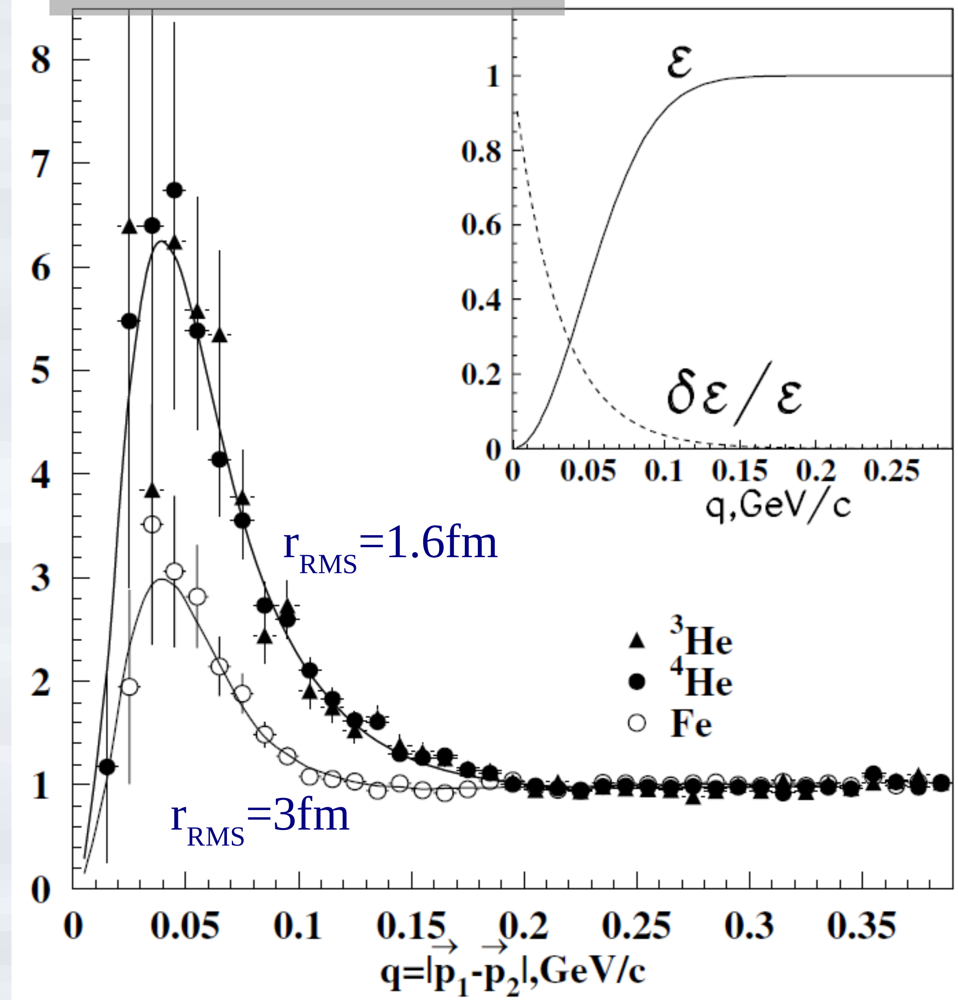
$$X_S = \frac{\frac{Q^2}{2\nu} + E_p - P_p \cos\theta_{p\gamma}\sqrt{1 + Q^2/\nu^2}}{(1 - T_p/\nu)m_p}$$

Proton pairs with $X_s > 2$

Source size r_{RMS},fm



Correlation function



The flucton size $r_f = 1.3 \pm 0.3$fm

What we learn from eHe → e'ppX

- The Lednicky-Luboshitz analytical model still work for such a small source sizes as we get for He.
- The results of calculation within this model slightly depend on the proton-proton potential if r_{RMS}<2fm.
- The best fit for He data were for Reid (with core) and Tabakin (without core) potential.
- Long-range correlation is important in case of small multiplicity (He case).
- Close track efficiency is very important for correlation study.

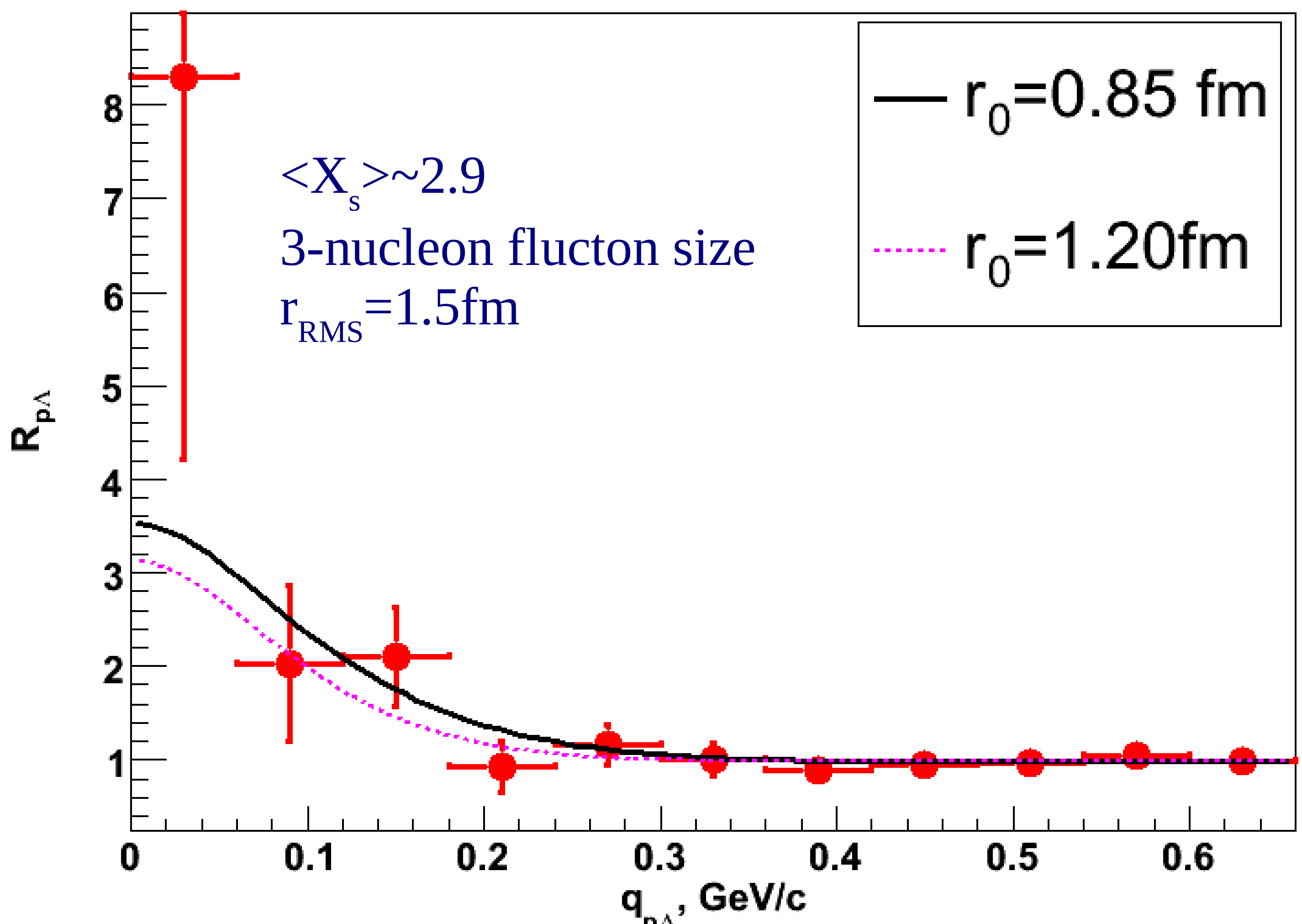
CEBAF: $eHe \rightarrow e'p\Lambda X$, Yad.Fiz., 72 (2009) 668

$$X_S \cdot m_N = M_0 = \frac{E - p\cos\Theta\sqrt{1 + \frac{Q^2}{\nu^2}} + \frac{Q^2}{2\nu} + \frac{\Delta m}{2\nu}\left(\frac{\Delta m}{2} - M\right)}{1 - \frac{T+\Delta m}{\nu}}$$

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

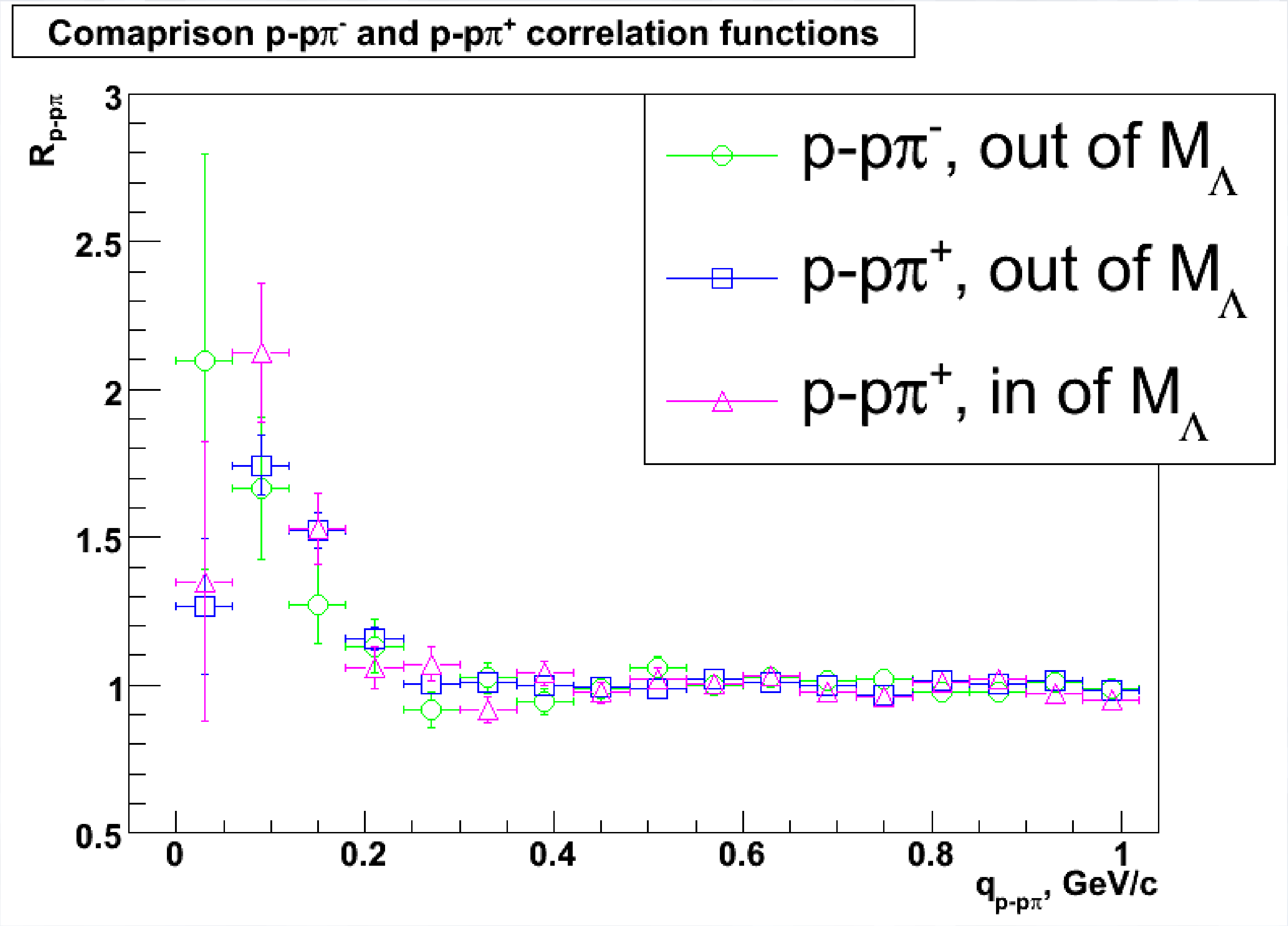
- Scatt. length and effective range (as in STAR fit): a^0=2.88 fm, a^1=1.66 fm, d^0=2.92 fm and d^1=3.78fm (0-singlet, 1-triplet)

Fit of pΛ correlation function by Lednicky



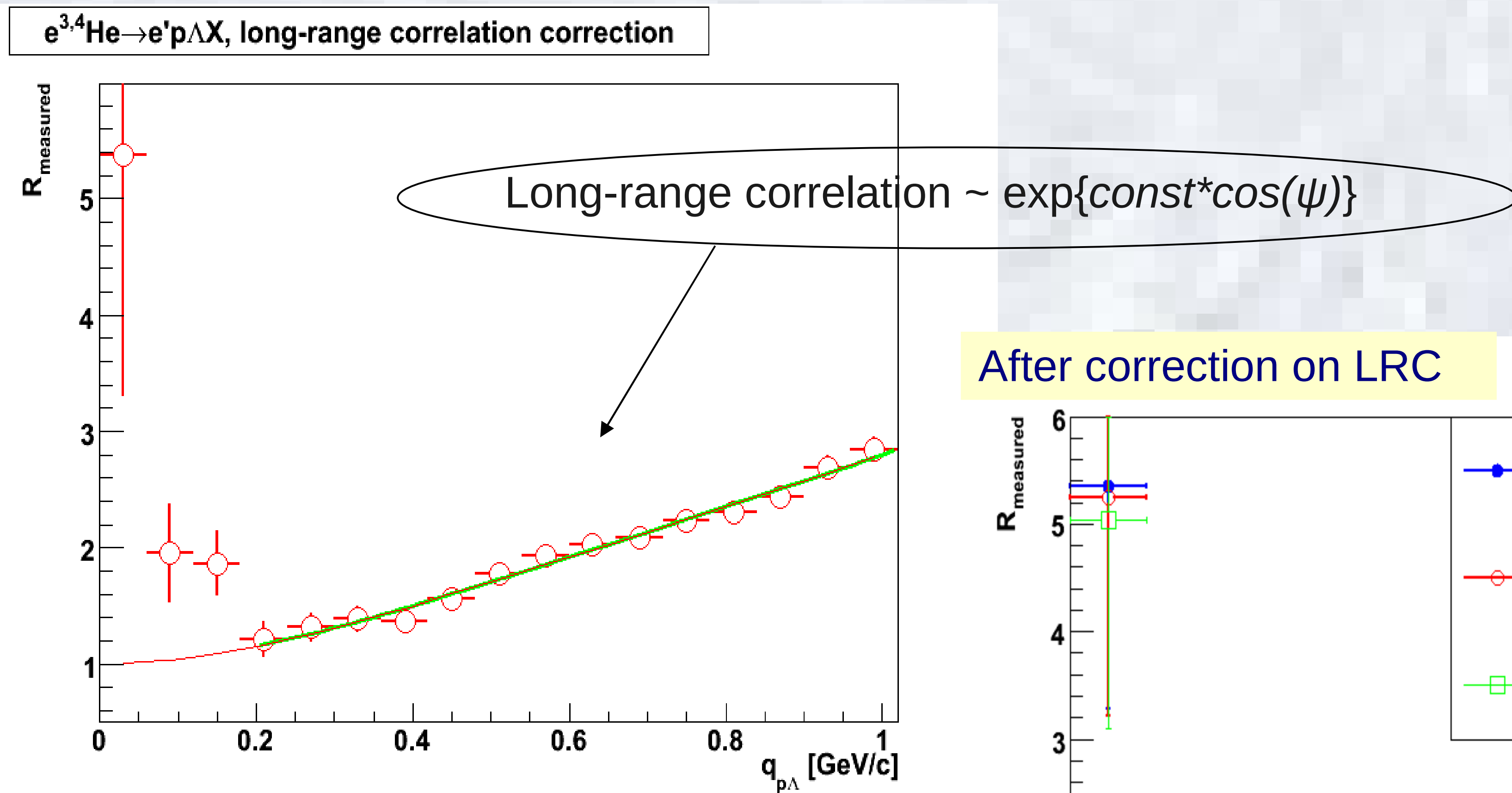
What we learn from eHe → e'pΛX

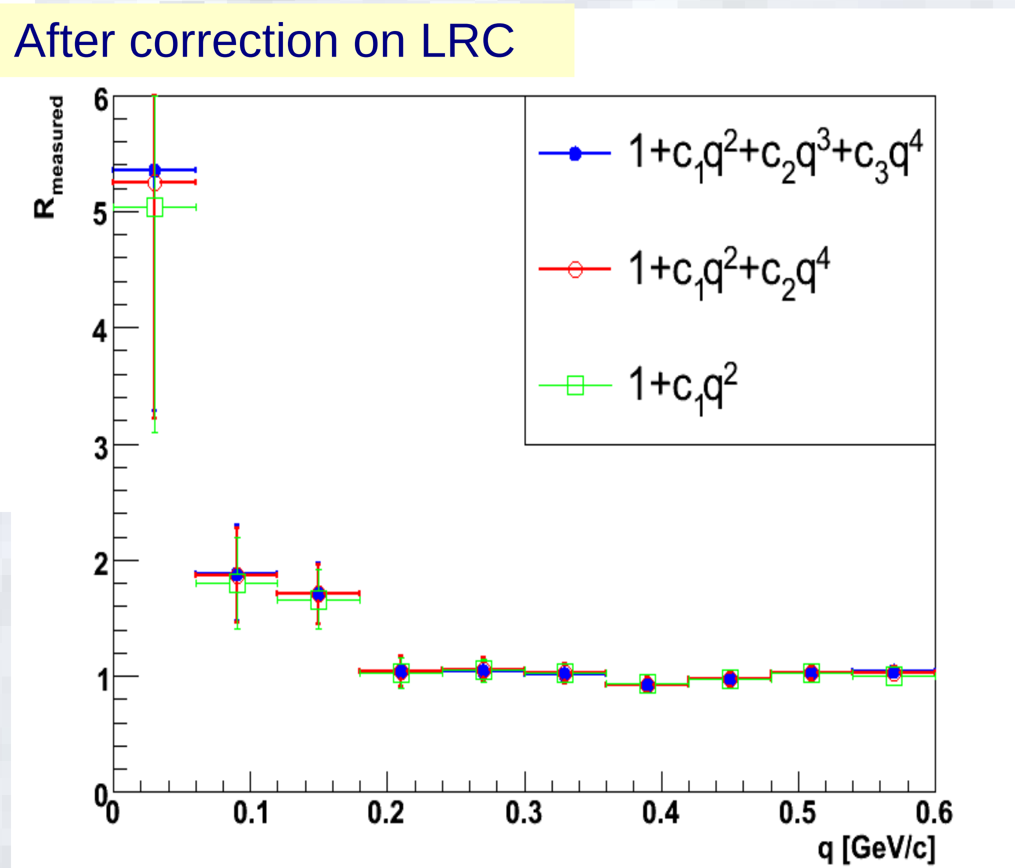
The p-pπ pairs in the region of mass pΛ around mass of lambda are correlated (**three particle correlations**).



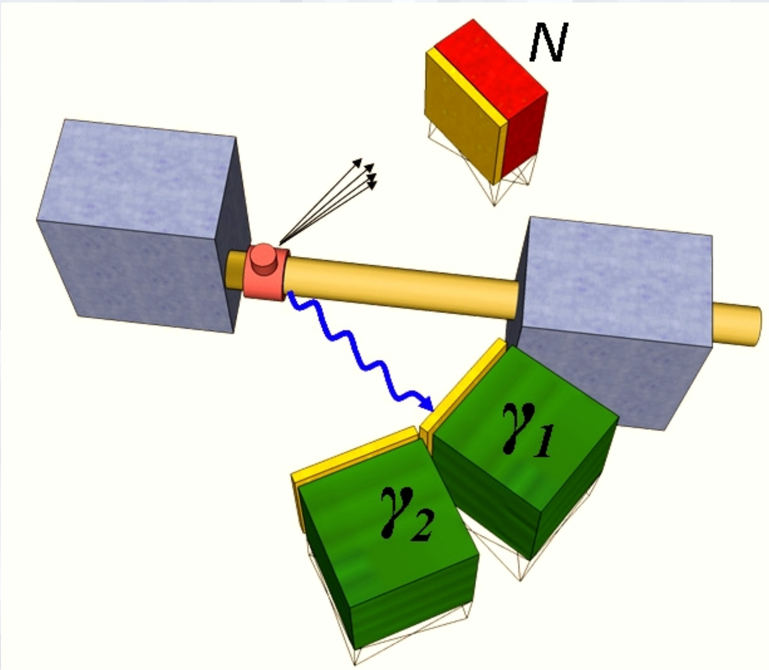
What we learn from eHe → e'pΛX

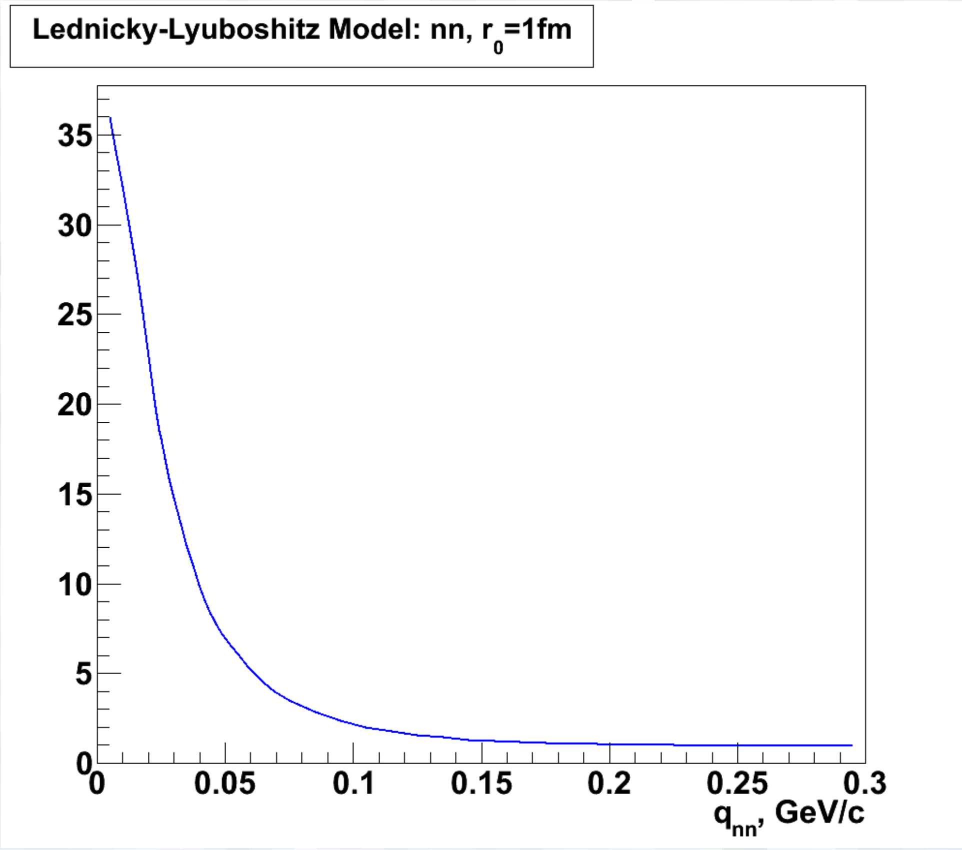
The correction on long-range correlation is very important.





FLINT and femtoscopy





Expect larger size for identical particles:

$r_{nn} \sim r_{pp} > r_{np}$, r_{dd}, …

Neutron femtoscopy:
TOF distance 2m
En=50-500 MeV
Resolution:
$\Delta q \sim 15$ MeV/c -> Δt=300ps $\Delta r \sim 3$cm
FLINT proposed position sensitive neutron detector
(see for details Stavinskiy's talk at: http://x4u.lebedev.ru/che2011/program.html)

List Problems

- Does we measure size of flucton in FLINT experiment?
- Alternative measurements of flucton size?
- Femtoscopy and small sizes?
- Size of flucton or homogeneity length?
- Flucton radius of freese-out radius?
- Residual correlations, 3-particale correlations?

Conclusions

- It seems femtoscopy is most powerful method to estimate the density of cold nuclear matter.

- It is important to have another method for cross check.

- One can estimate the flucton radius as about 1 fm looking at the experimental data on cumulative particle correlation.

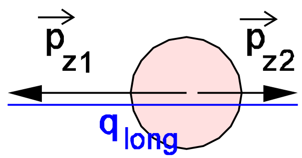
- The femtoscopy study of dense cold matter in FLINT (and other experiments) experiment could provide an information about the density of the matter.

Thank you for your attention!

Bertsch-Pratt Parametrization

$$\vec{p}_1 - \vec{p}_2 = \vec{q} = (q_{long}, q_{side}, q_{out}) \quad \rightarrow \quad R_{long}, R_{side}, R_{out}$$

longitudinal:

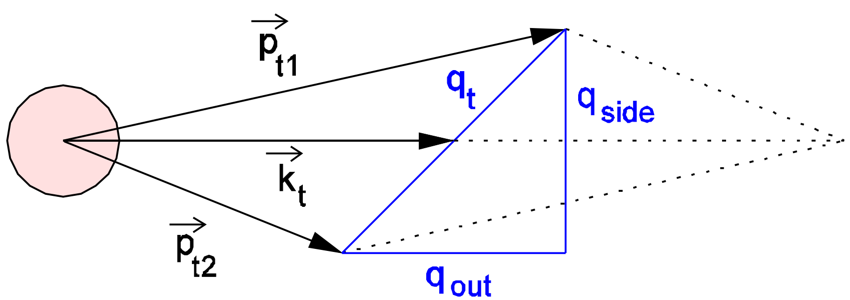


$$q_{long} = \vec{p}_{z1} - \vec{p}_{z2}$$

in LCMS:

$$\vec{p}_{z,1} + \vec{p}_{z,2} = 0$$

transverse:



$$\vec{k}_t = \frac{1}{2}(\vec{p}_{t1} + \vec{p}_{t2})$$

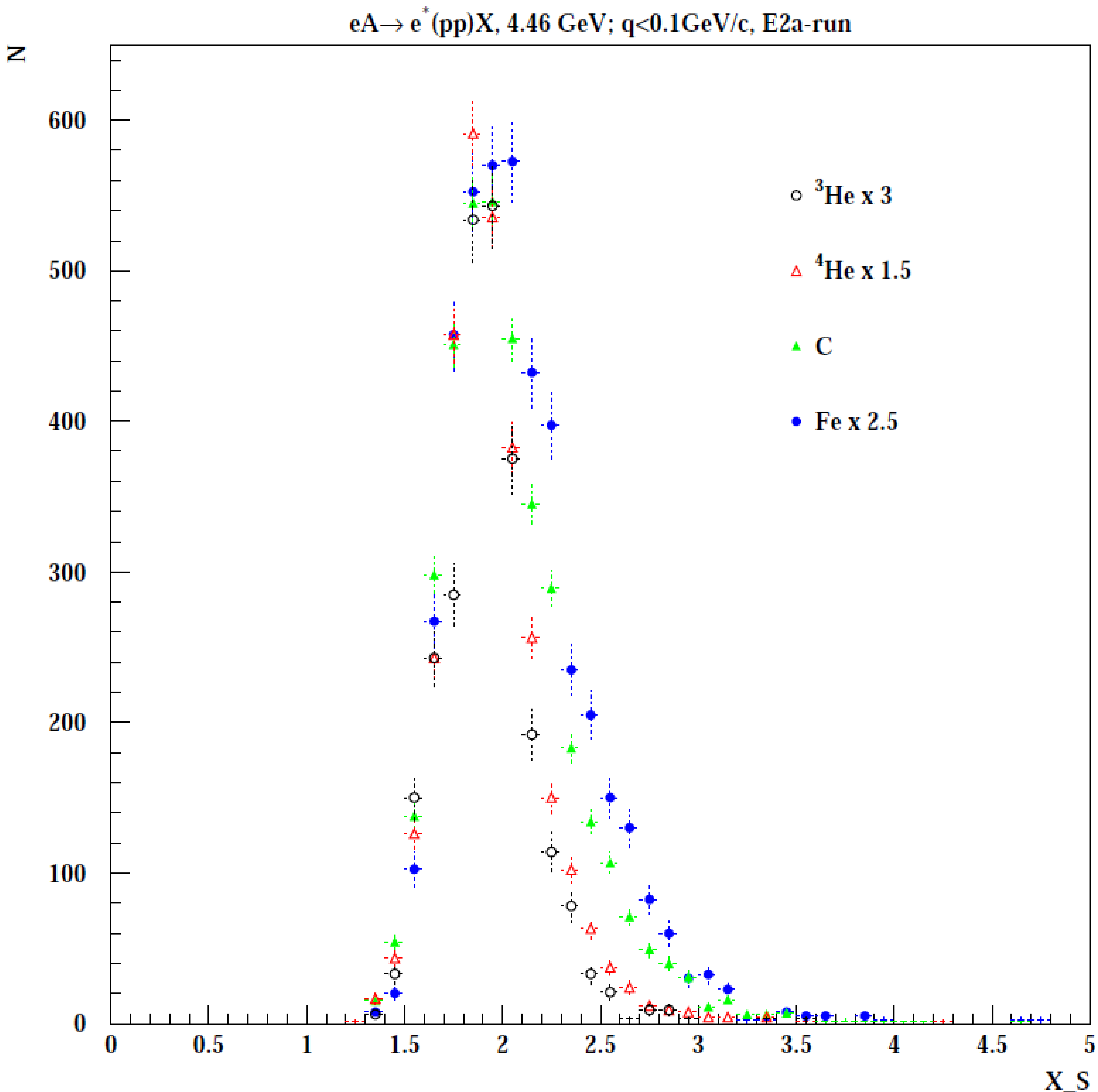
$$q_t = |\vec{p}_{t1} - \vec{p}_{t2}|$$

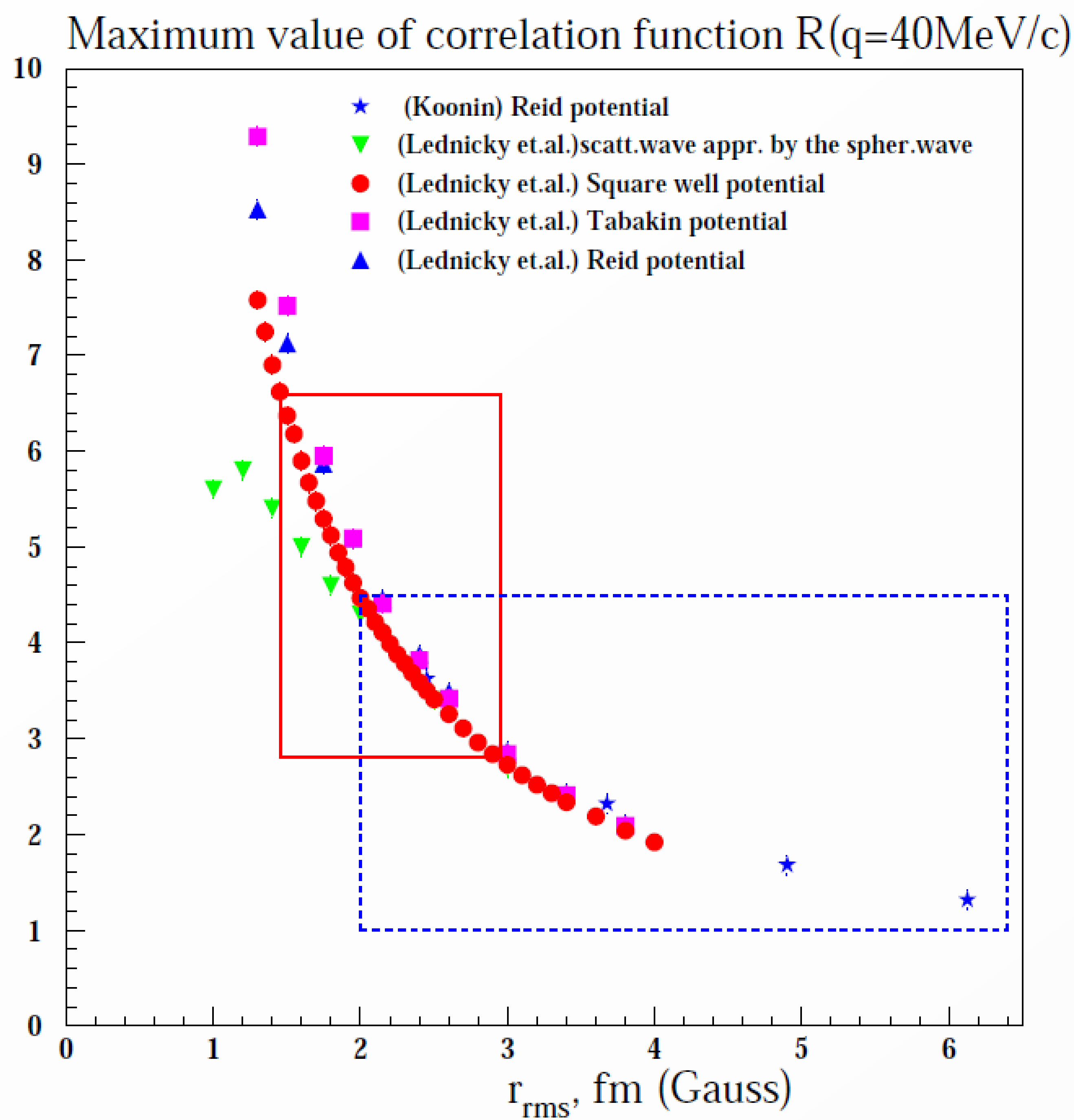
$$q_{side} \perp \vec{k}_t \,, \quad q_{out} \,||\, \vec{k}_t$$

R_{long} : longitudinal expansion and lifetime τ_f

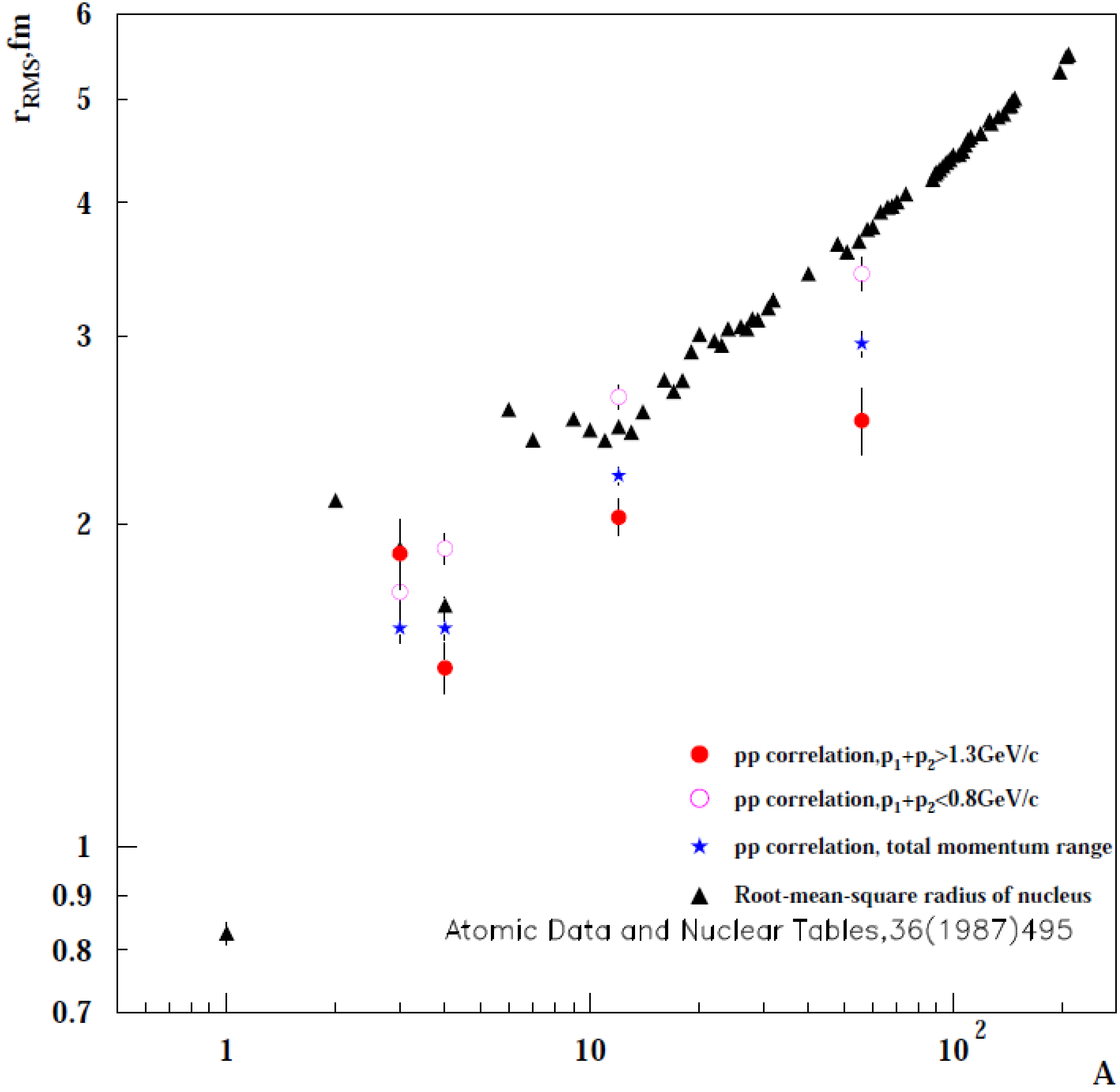
R_{side} : transverse size, radial expansion

R_{out} : as R_{side} but also duration of emission $\Delta\tau$

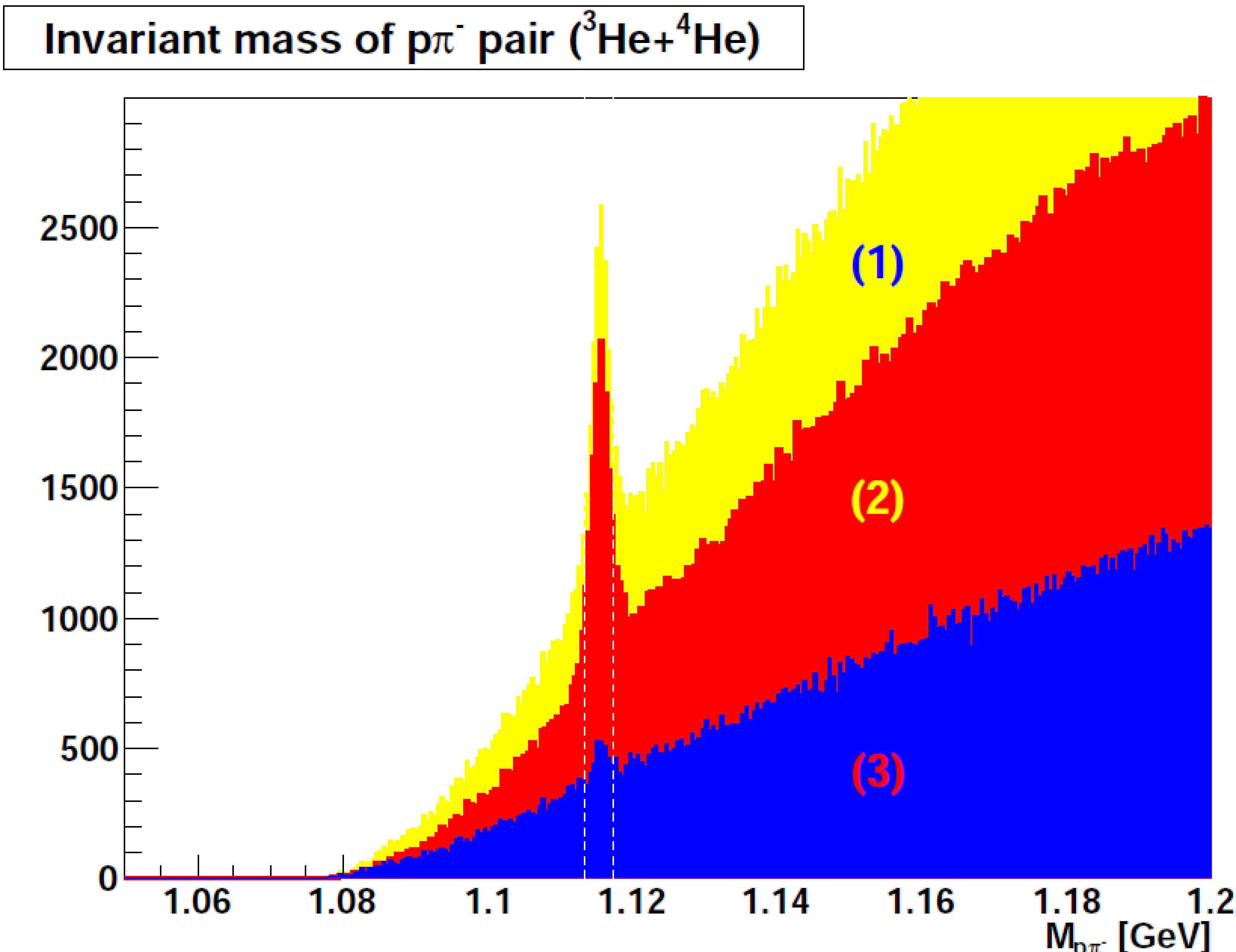

eA→ e*(pp)X, 4.46 GeV; q<0.1GeV/c, E2a-run
N
^{3}He x 3
^{4}He x 1.5
C
Fe x 2.5
X_S
0
100
200
300
400
500
600
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5



Maximum value of correlation function R(q=40MeV/c)
(Koonin) Reid potential
(Lednicky et.al.)scatt.wave appr. by the spher.wave
(Lednicky et.al.) Square well potential
(Lednicky et.al.) Tabakin potential
(Lednicky et.al.) Reid potential
0
1
2
3
4
5
6
7
8
9
10
0
1
2
3
4
5
6
r_rms, fm (Gauss)



r_{RMS},fm
6
5
4
3
2
1
0.9
0.8
0.7
1
10
10^2
A
pp correlation,$p_1+p_2>1.3$GeV/c
pp correlation,$p_1+p_2<0.8$GeV/c
pp correlation, total momentum range
Root-mean-square radius of nucleus
Atomic Data and Nuclear Tables,36(1987)495



Invariant mass of pπ⁻ pair (³He+⁴He)
(1)
(2)
(3)
0
500
1000
1500
2000
2500
1.06
1.08
1.1
1.12
1.14
1.16
1.18
1.2
$M_{p\pi^-}$ [GeV]

CEBAF: eHe → e'pΛX

Reaction and run condition

- The reaction: e^3He, $^4He \rightarrow e'p\Lambda X$
- The data : e2a and e2b 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: $M(p\pi) = 1115.5\pm2$MeV
- 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.