POSSIBLE DEVELOPMENT of CUMULATIVE PARTICLE EXPERIMENTS

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Short History

1957 Leksin G A, Azhgirey L S et al — P, T=660 MeV

$P+d \rightarrow p$ in backward direction,

Blokhintsev D I — $P+He \rightarrow d$

Short-range few-nucleon correlation **flukton**

1971 Baldin A M

1974 Stavinskiy V S — Cumulative effect, **quark structure**

1974 - …

Burov V V, Lukianov V K, Titov A I

Efremov A V

Baldin A A

…

Short-range few-nucleon correlation

Frankfurt L L, Strikman M I

Direct measurement of momentum-space wave function squared

$$d^3\sigma / d^3 p \simeq c\sigma_{tot}\psi^2{}_D(p)$$

$$E_p d^3\sigma / d^3 p \simeq c\sigma_{tot} E_p \psi^2{}_D(p) \simeq c\sigma_{tot}\psi^2{}_{l.c.}$$

Cross- section describes knockout of n from d. Spectator p rushes into detector with speed it had in d before collision

Experimental verification

2-nucleon correlation:

Spectrometer EVA

A.Tang et al Phys. Rev. Lett. 90, 042301(2003)

2- and 3-nucleon correlation:

CLAS Collaboration

K.S. Egiyan et al Phys. Rev. Lett. 96, 082501(2006)

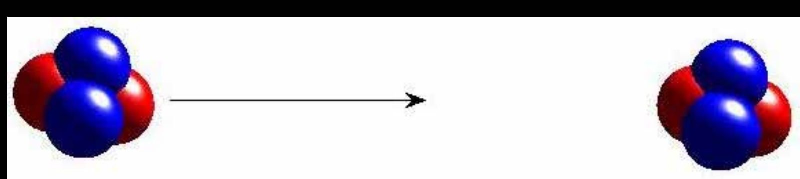
Formation of quark bag

1. Pre-existent quark bag

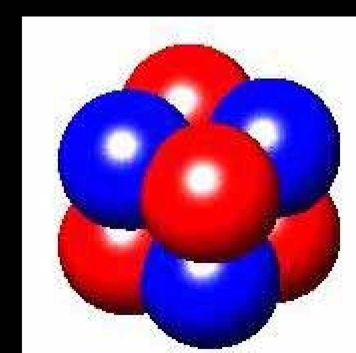
2. Chiral phase transition in few-nucleon systems:

SRC → multibaryon

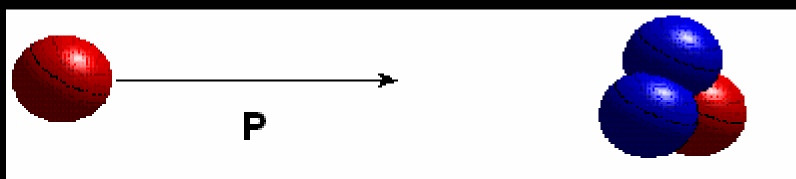
IN:



OUT:



Kinematics



$$M_{MB}^2 = (E - E_\pi + M_{SRC})^2 - P_\pi^2 - P^2 + 2PP_\pi \cos\theta_\pi$$

$$M_{MB} = f(M_{SRC})$$

$$M_{SRC} = f^{-1}(M_{MB})$$

Kinematics (continuation)

a priori: $M_{SRC, min} = n*0.94$

Exp. masses of SRC: $M_n \geq n$ GeV

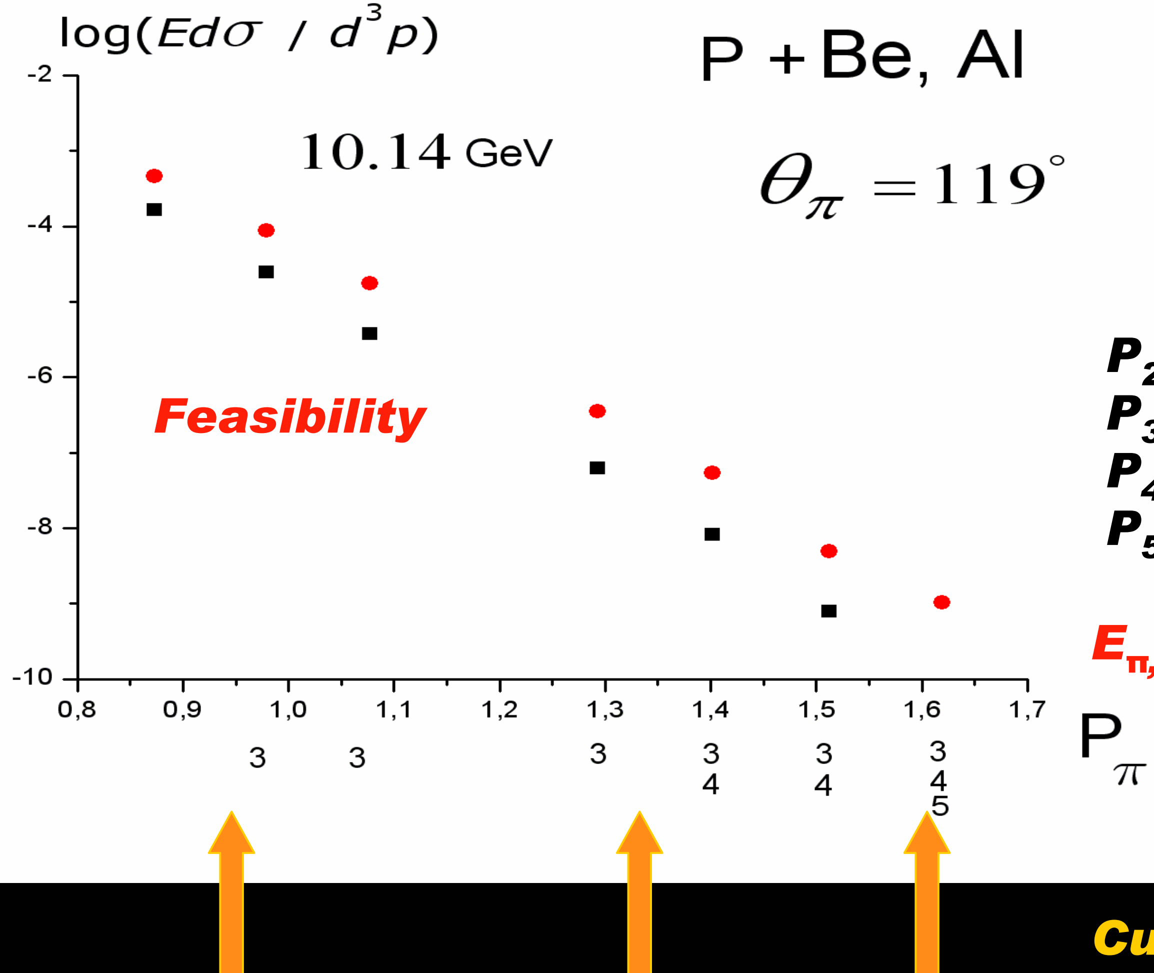
Theor. masses of MB: $M_3^* = 3.62, M_4^* = 4.76, M_5^* = 6.07$ GeV

Possibility of transition

(p + n-nucleon SRC) → (n+1) MB + cumulative π

Experimental proposal to find multibaryons with B=2, 3, 4, 5

S.V.Boyarinov et al., Yad. Fiz. 46,1472(1987); 57, 1452(1994)



$P_{2,min}$=0.494
$P_{3,min}$=0.942
$P_{4,min}$=1.328
$P_{5,min}$=1.602

$E_{\pi,bind}$ ≈ 0.025

CMM

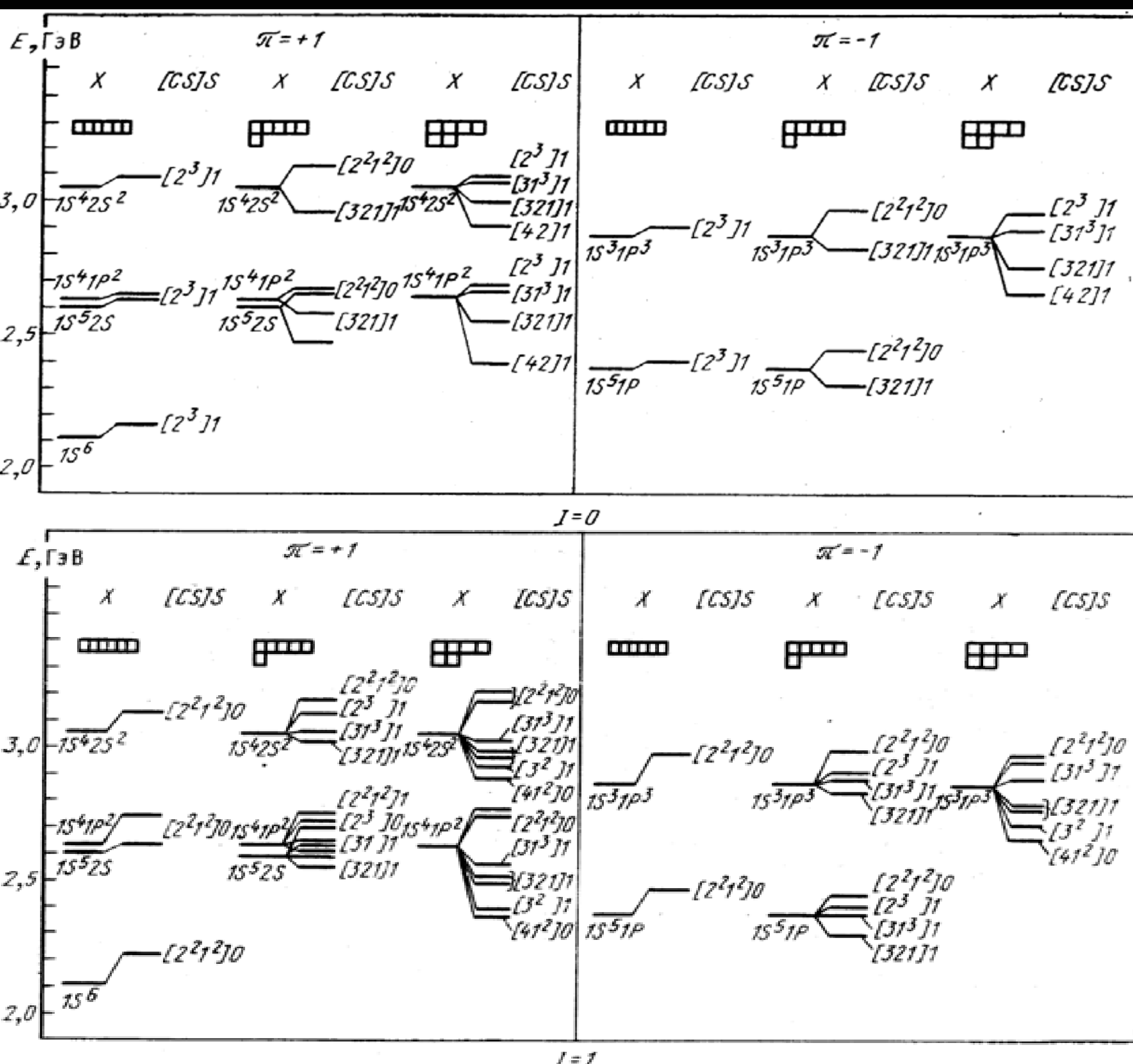
Cumulative particle is π

Denominations

1 monobaryon
2 dibaryon
3 tribaryon
4 tetrabaryon
5 pentabaryon
6 hexabaryon
7 heptabaryon
8 octabaryon
9 nonabaryon
10 decabaryon

Experimental proposal :

p+p → dibaryon + π*



6-q system, spectrum in MIT bag framework

Dorkin SM, Reznik BL, Titov AI, Yad Fiz 36, 1244 (1982)

CMM

Momentum of the trigger cumulative meson can be precisely calculated since M_1=0.94

Experimental proposal

CMM

Investigation of dibaryon production in different nuclei (including hydrogen target) may give information on intranuclear pion – nucleus potentials in different nuclei:

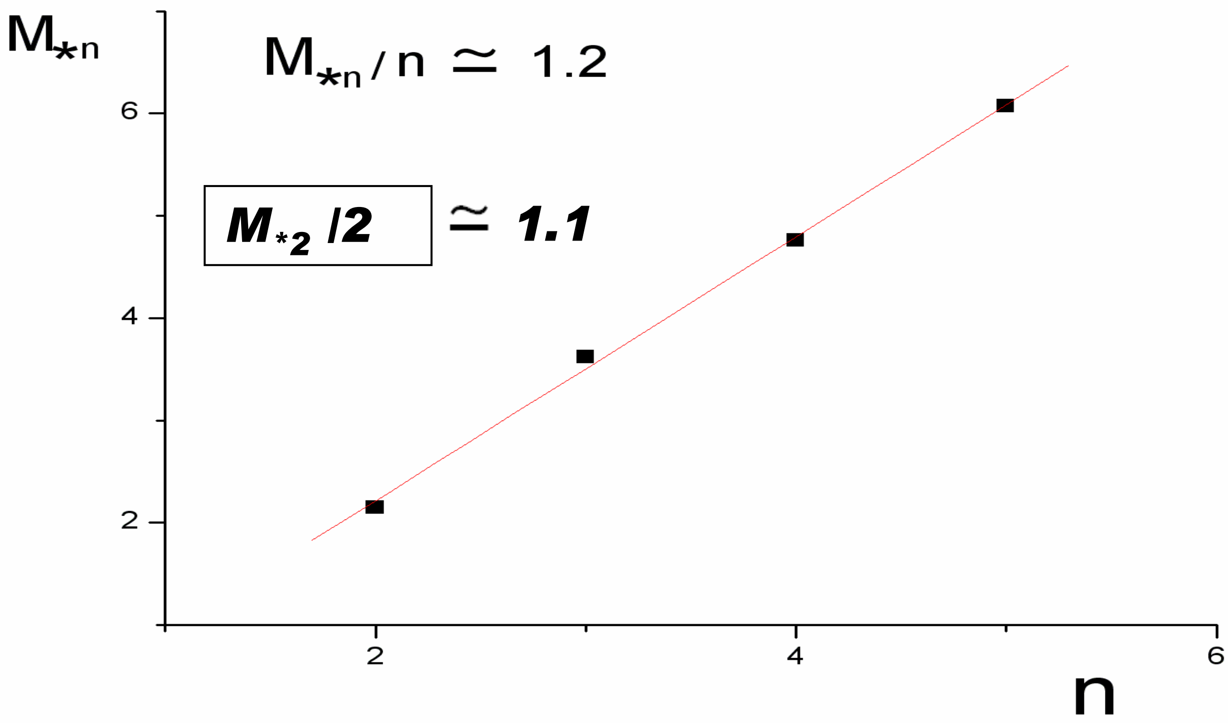
P + nucleus → dibaryon + π + …

Alternative explanation:

in-medium effect on dibaryon

Finite size effects

1. Shell effects : 2—3 %



E. Farhi, R.L. Jaffe, Phys. Rev. D 30, 2379(1984)
J.J. de Swart, Phys. Rev.D 17, 260(1978)
V.K. Lukyanov, A.I. Titov, PEPAN 10, 815(1979)

Finite size effects

2. ***Surface tension*** ***coefficient for quark bag : 70 MeV^3≈ 8,8 MeV / Fm^2***

See E. Farhi, R.L. Jaffe, Phys. Rev. D 30, 2379(1984)

For M_3^* this gives 2– 3 % correction given R ≈ 0.8 Fm

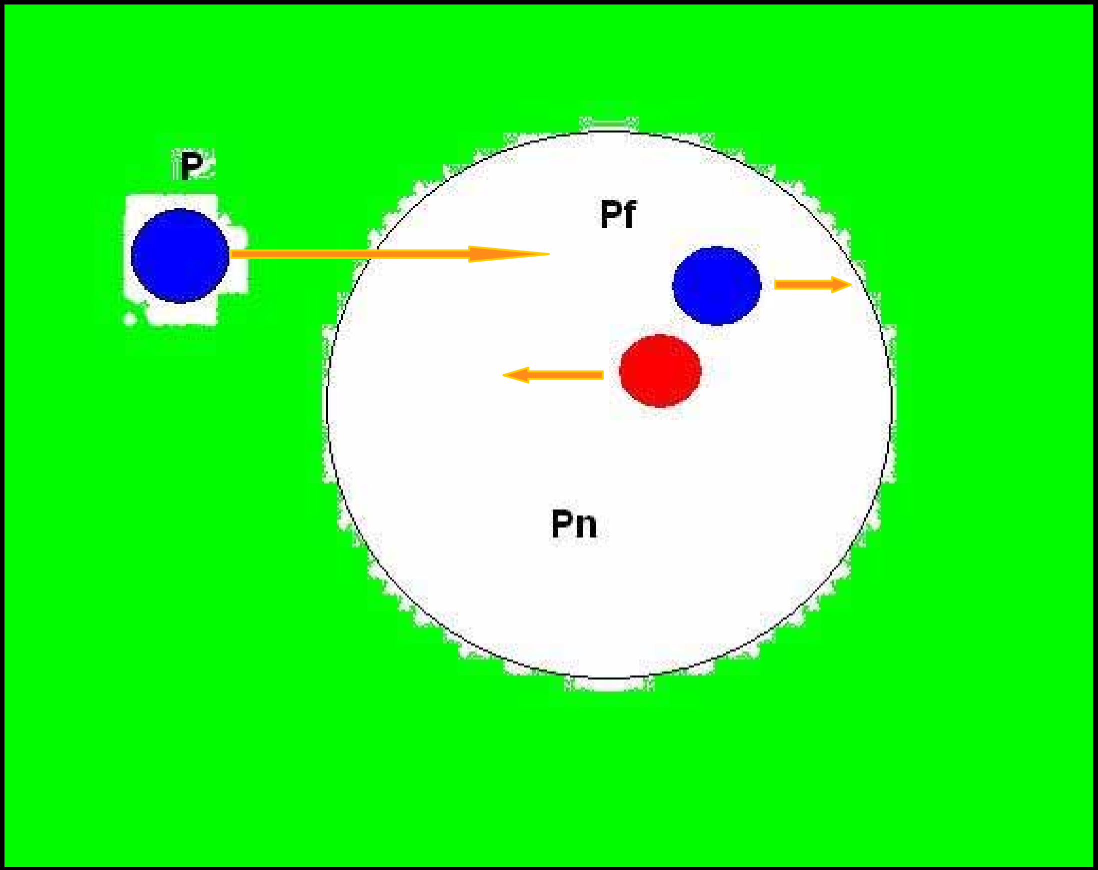
Estimation of Casimir energy in chiral bag model,

see L. Vepstas, A.D. Jackson, Phys. Rep. 187, 109(1990)

gives the same

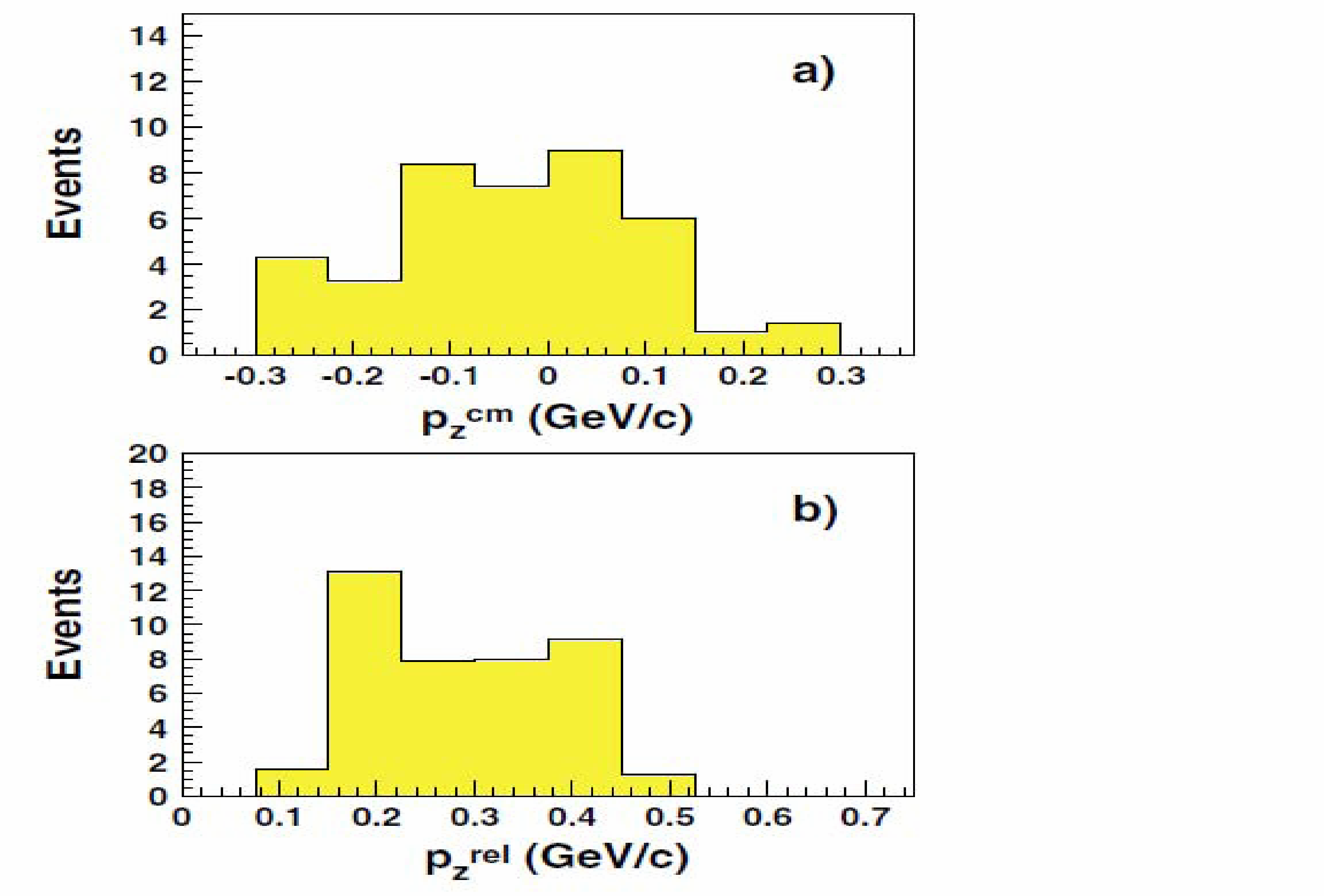
3. ***Coulomb repulsion : less 0.2 %***

Experiment at BNL with EVA spectrometer



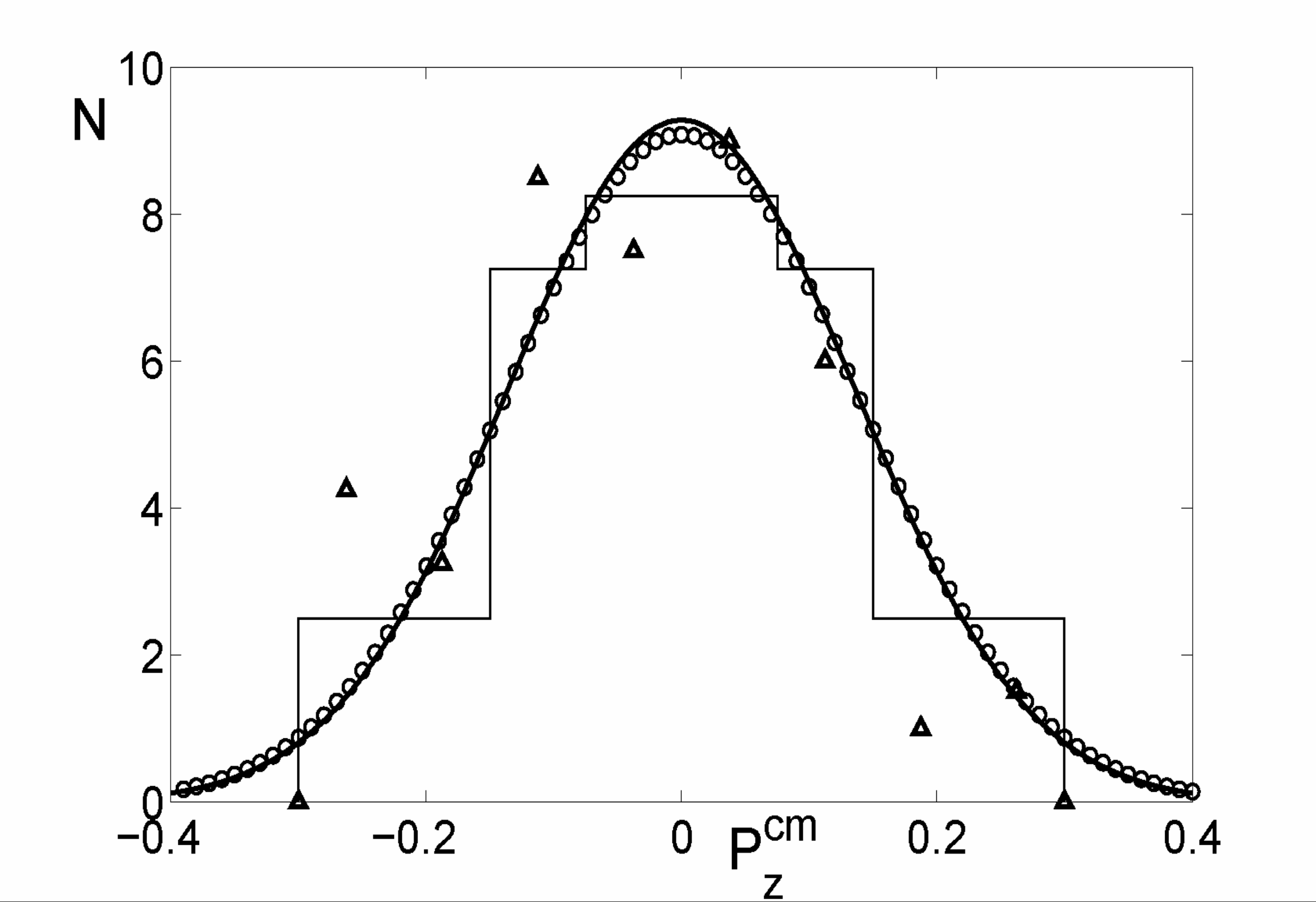
J. Aclander et al Phys. Lett. B 453, 211 (1999)
A. Tang et al Phys. Rev. Lett. 90, 042301 (2003)

Experimental evidence for 2-nucleon SRC



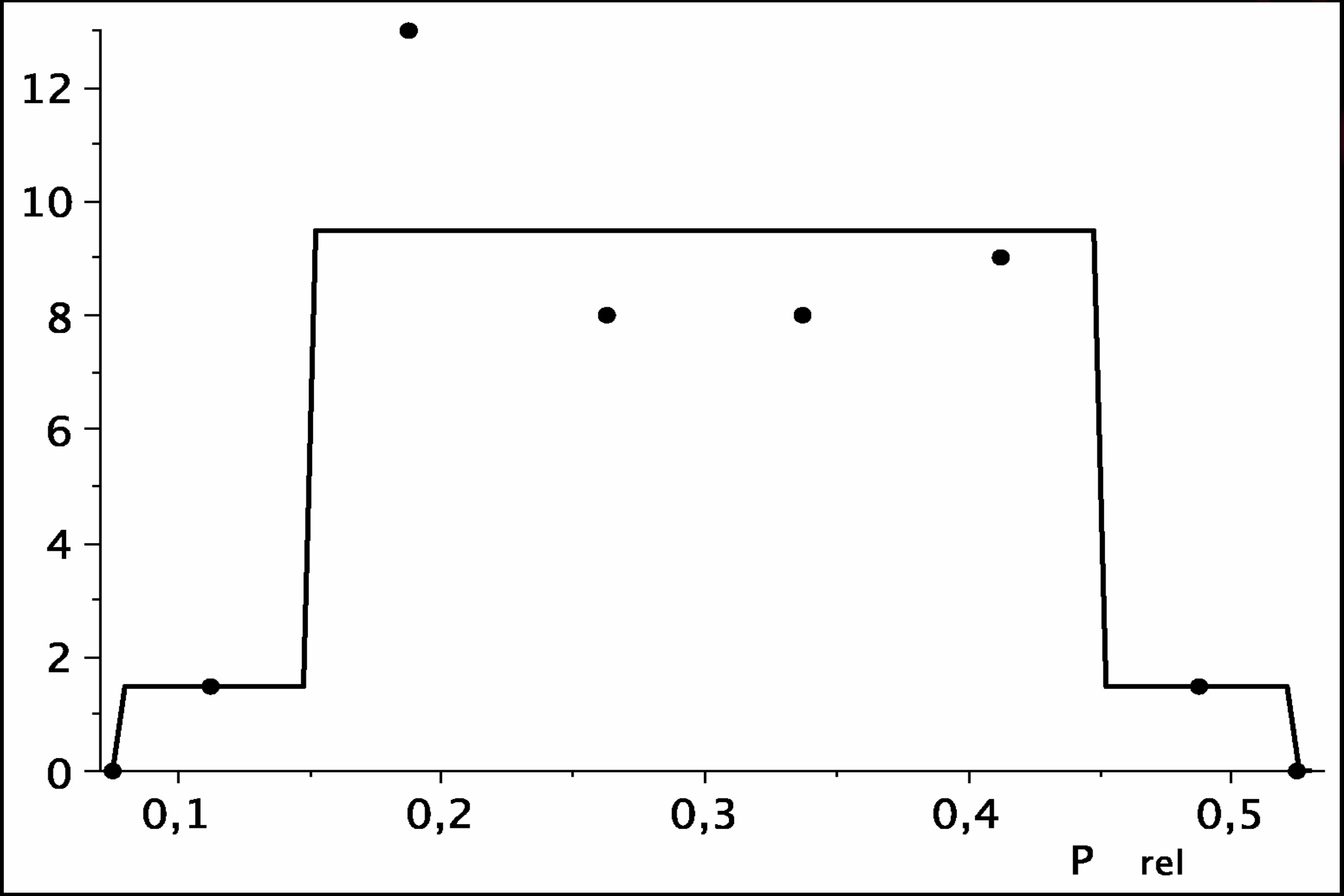
A. Tang et al Phys. Rev. Lett. 90, 042301 (2003)

CM motion in longitudinal direction

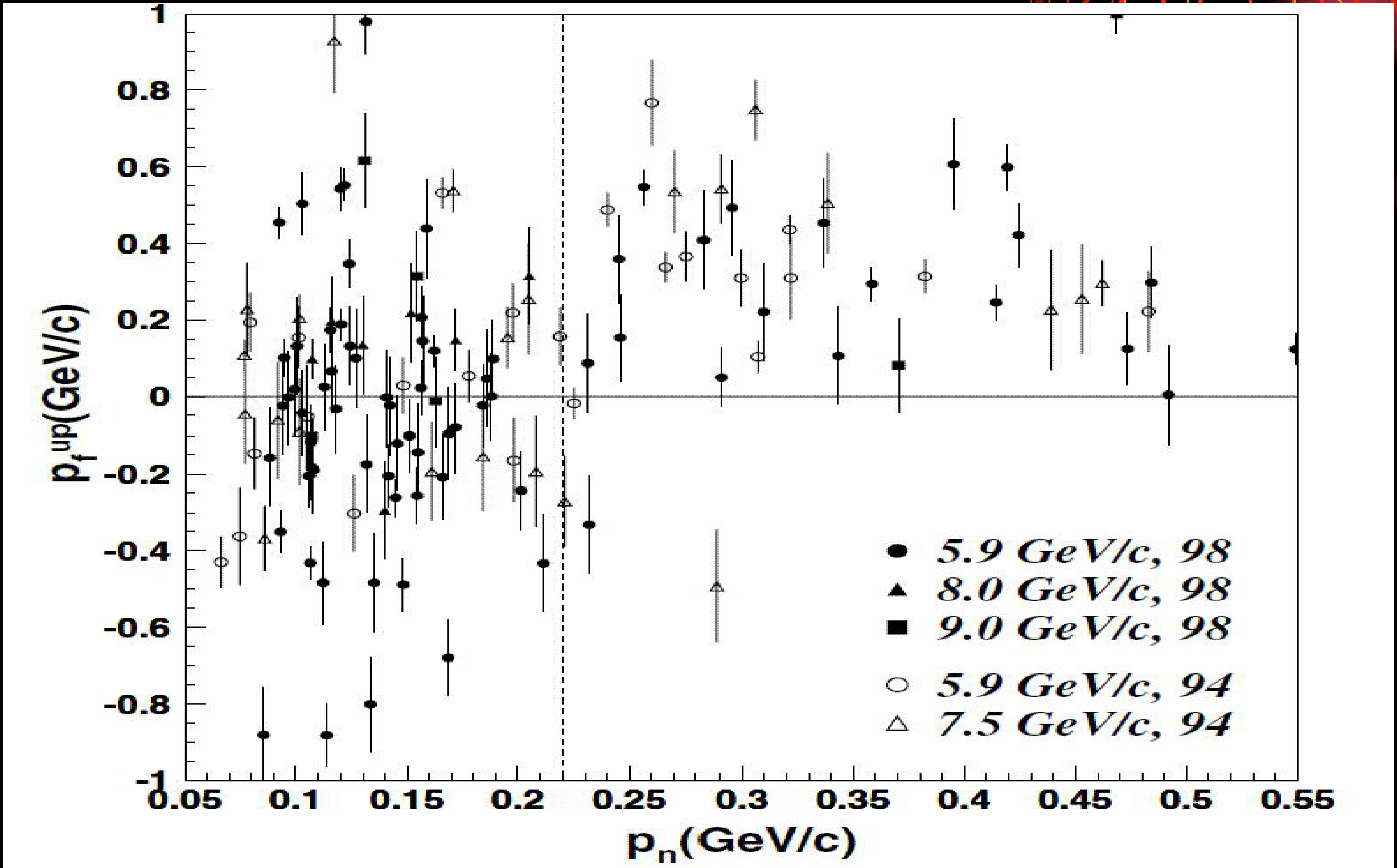


Σ = *0.14*

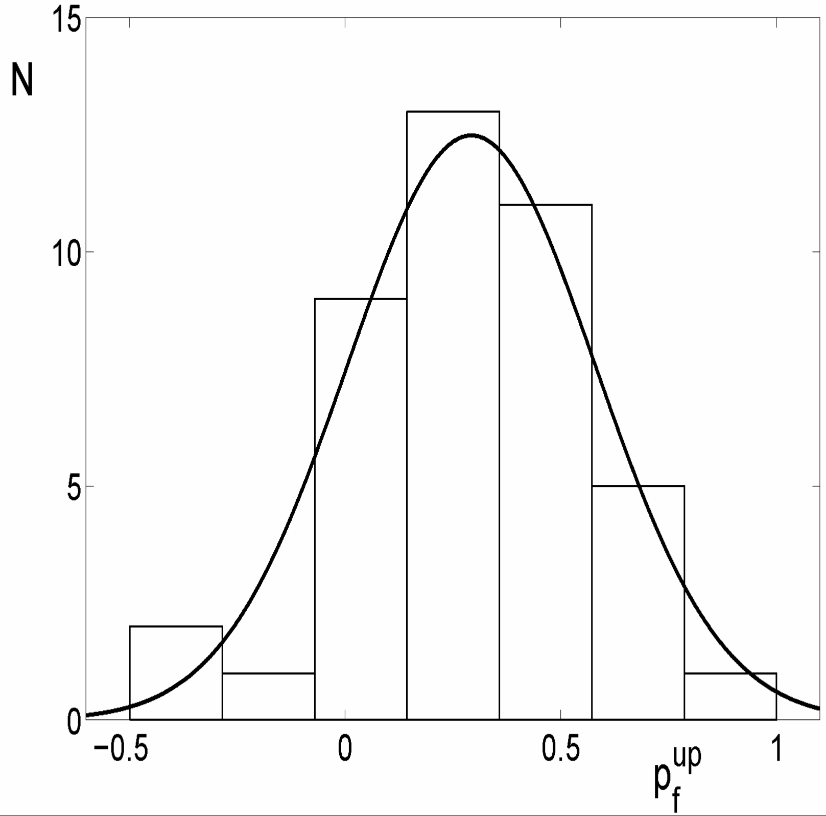
Relative motion in longitudinal direction

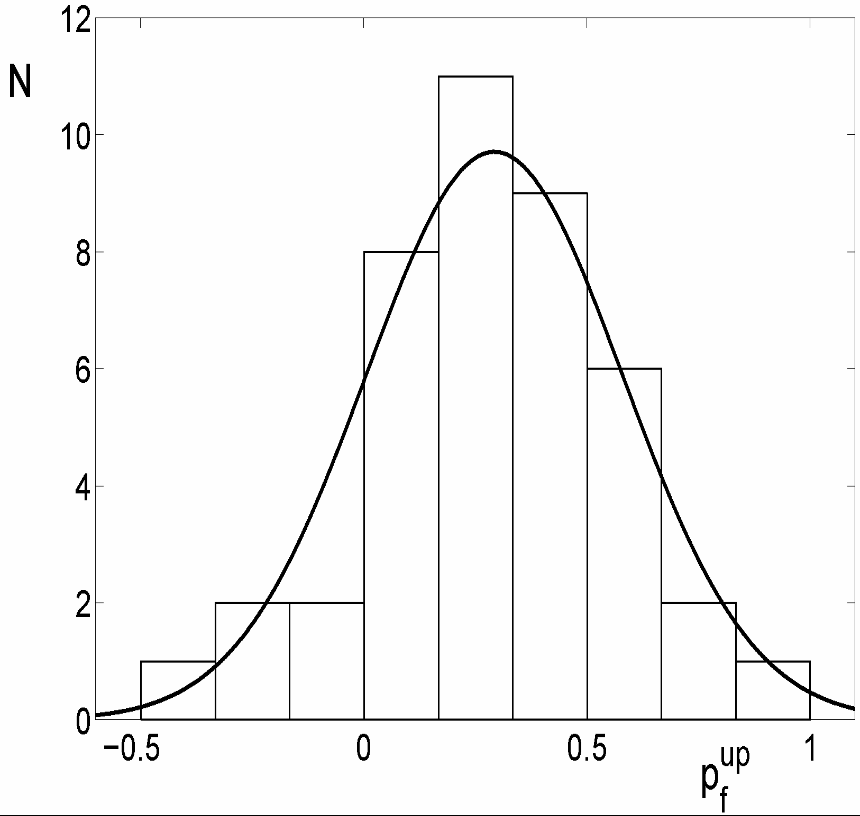


Motion in transversal direction

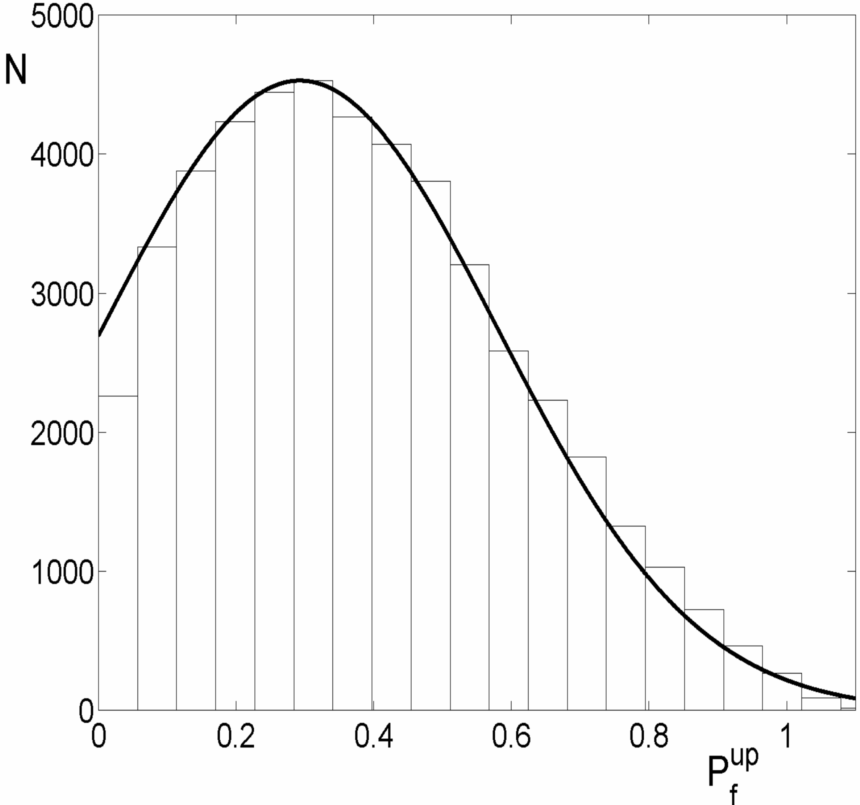


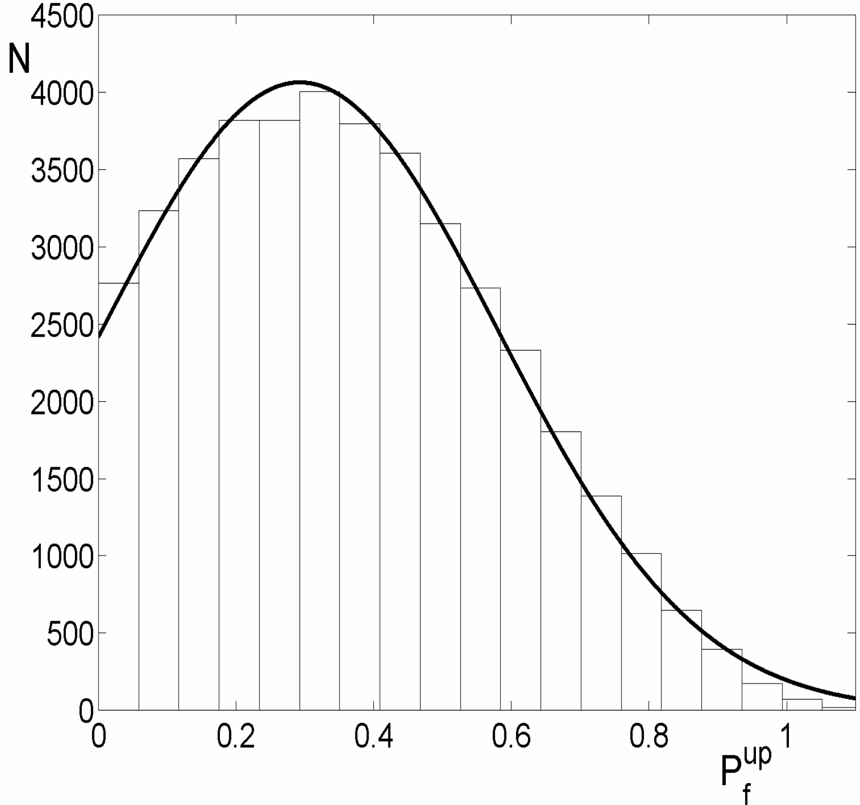
Distributions of P_x





Summation of relative and CM motion

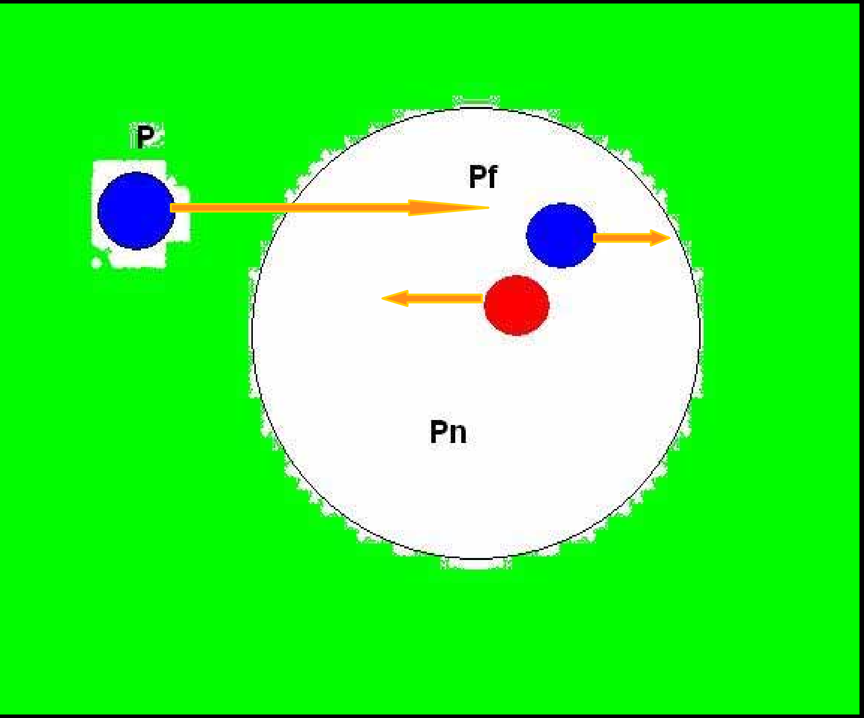


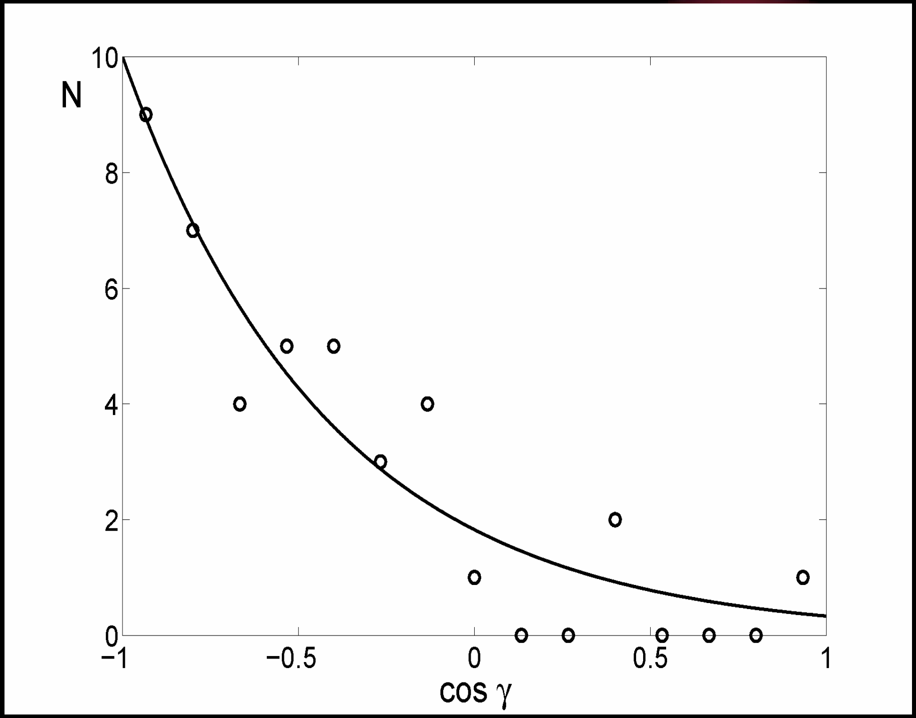


1. $\Sigma^{cm}=0.136$, $\Sigma^{rel}=0.586$

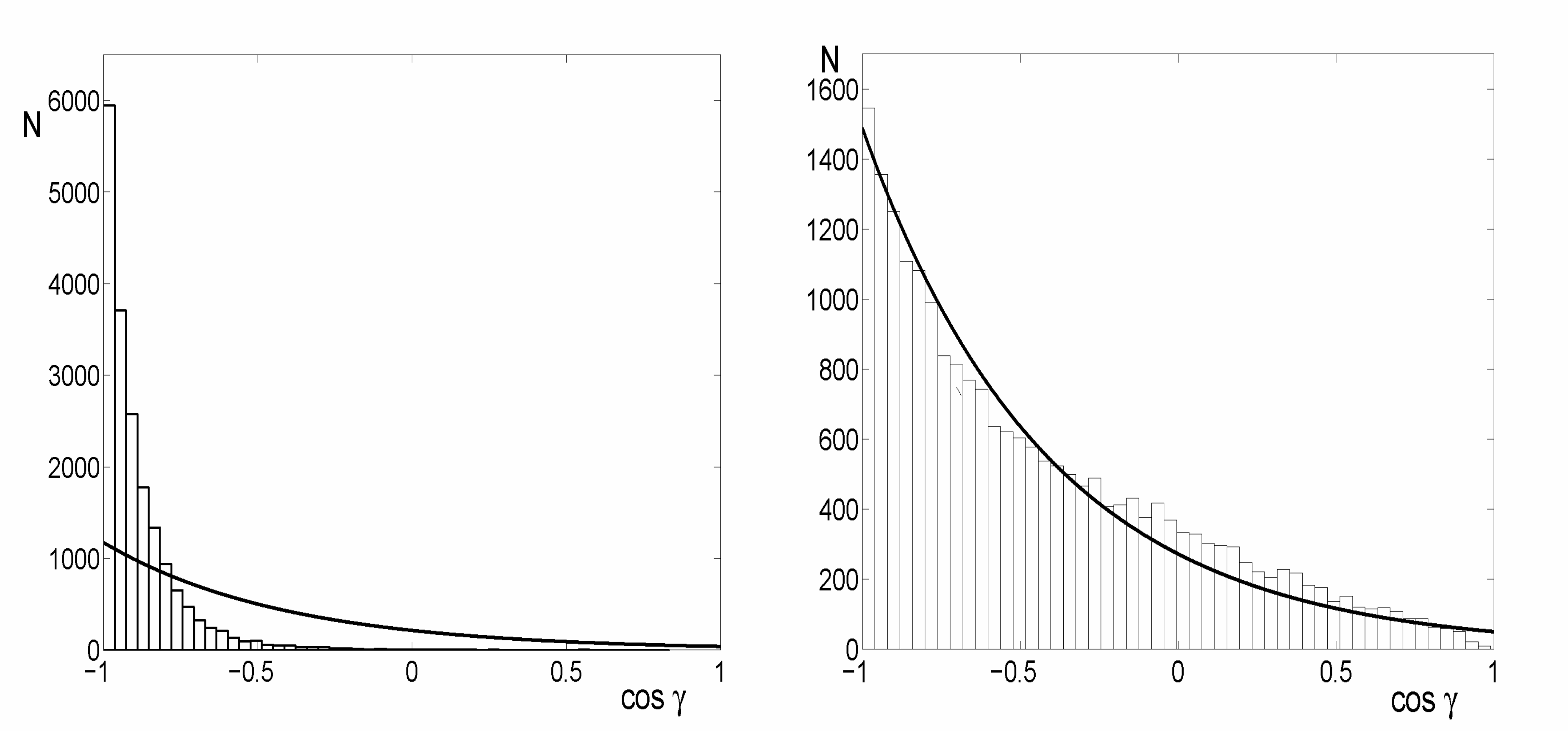
2. $\Sigma^{cm}=0.570$, $\Sigma^{rel}=0.212$

Model of quasi-elastic knockout





Recognition of CM motion

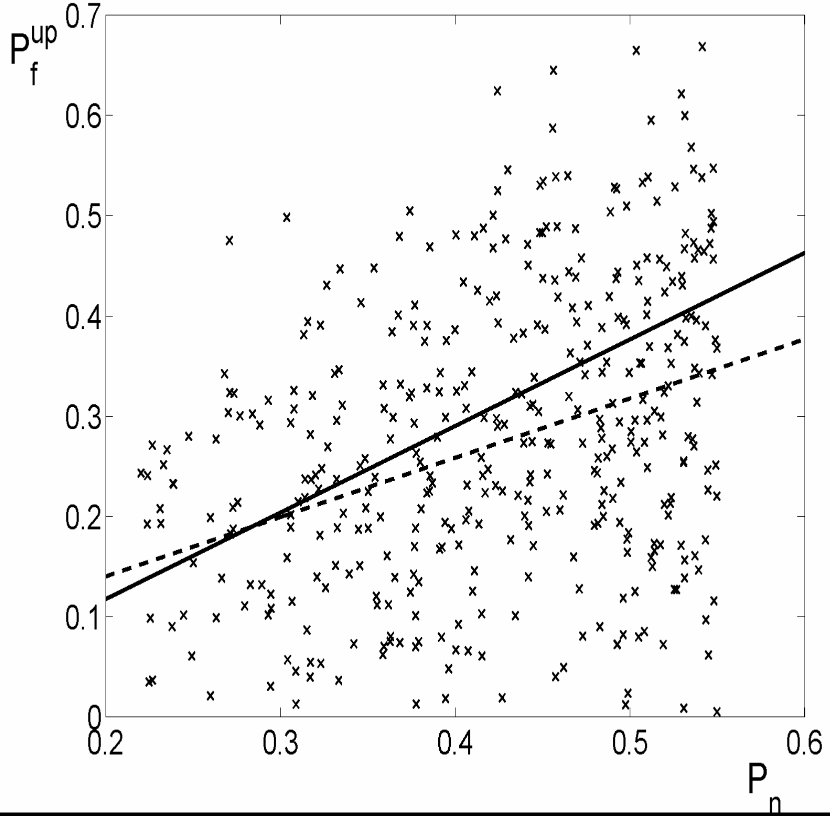


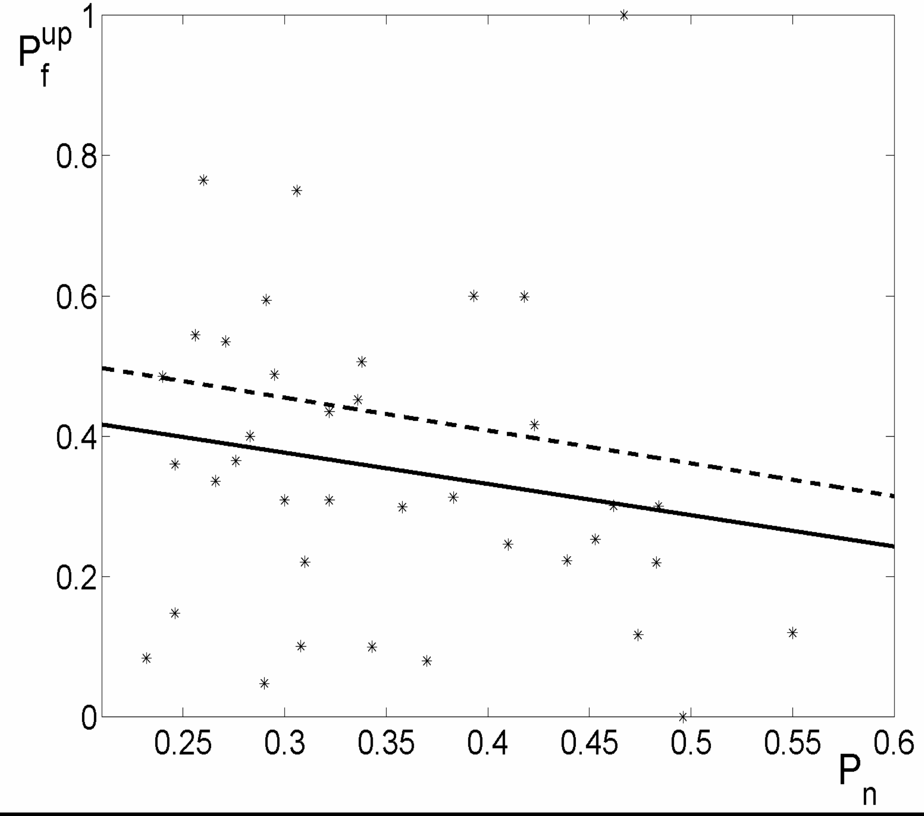
1. $\Sigma^{cm}=0.136$, $\Sigma^{rel}=0.586$

2. $\Sigma^{cm}=0.570$, $\Sigma^{rel}=0.212$

Additional evidence: correlation analysis

J. Aclander et al Phys. Lett. B 453, 211 (1999)





1. $\Sigma^{cm}=0.136$, $\Sigma^{rel}=0.586$

2. $\Sigma^{cm}=0.570$, $\Sigma^{rel}=0.212$

Reason for difference

Linear regression :

$$\left\langle p_f^{up}(p_n)\right\rangle = \left\langle p_f^{up}\right\rangle + \rho_{fn}^{\exp}\frac{\Sigma_f^{up}}{\Sigma_n^{\exp}}\left(p_n - \left\langle p_n^{\exp}\right\rangle\right)$$

The difference is due to the initial approximation of P_f^{up} distribution

Theoretical and experimental parameters Σ_n agree without special fitting, as well as correlation coefficients

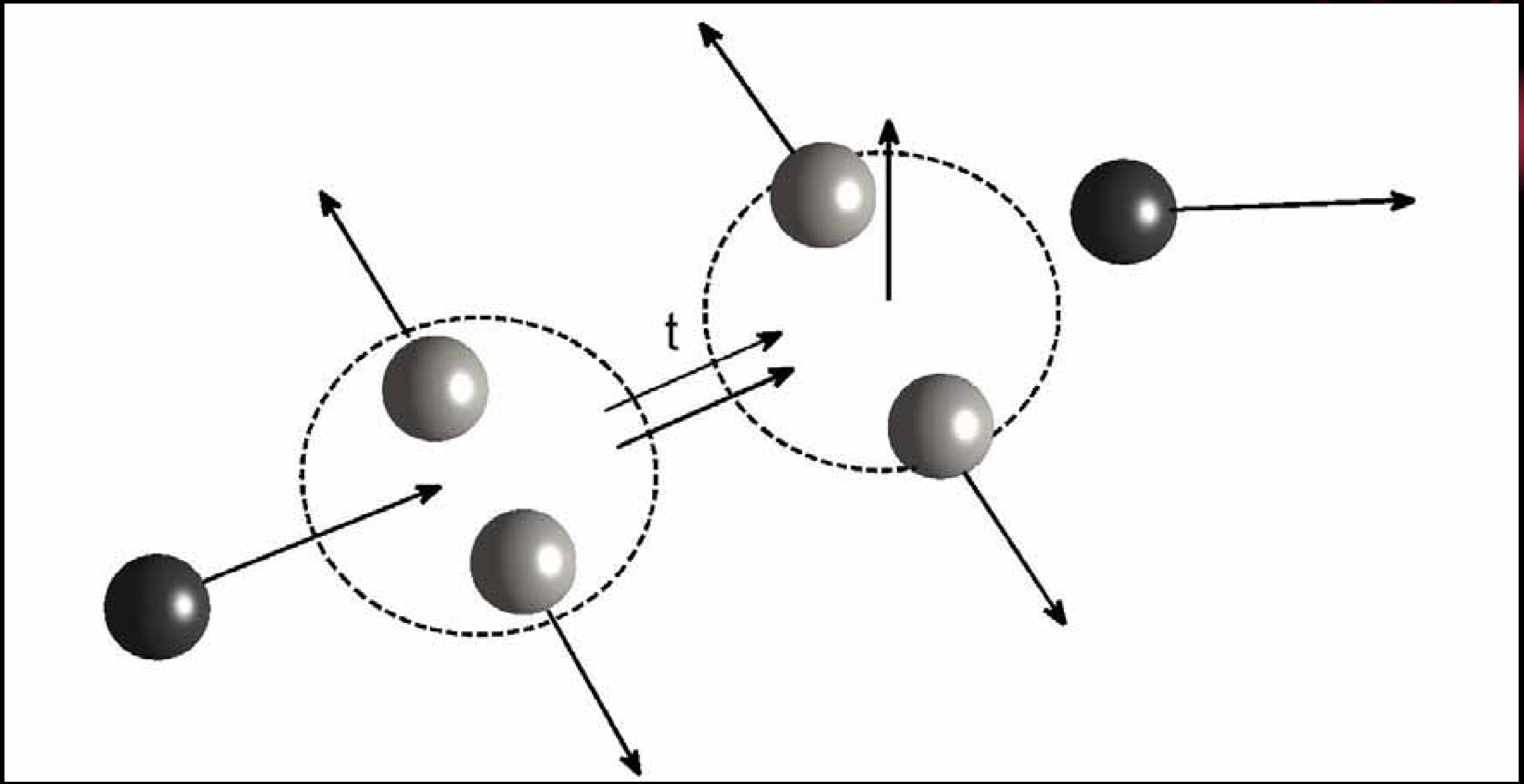
Summary of our study of EVA results

1 We confirm EVA results for momentum distributions of SRC, P^{cm} and P^{rel}, along z axis

2 EVA results permit also to establish distributions for P^{cm} and P^{rel} along the transversal directions

3 Distributions P^{cm}_z , P^{rel}_z and P^{cm}_x, P^{rel}_x are very different

Evident, but wrong explanation



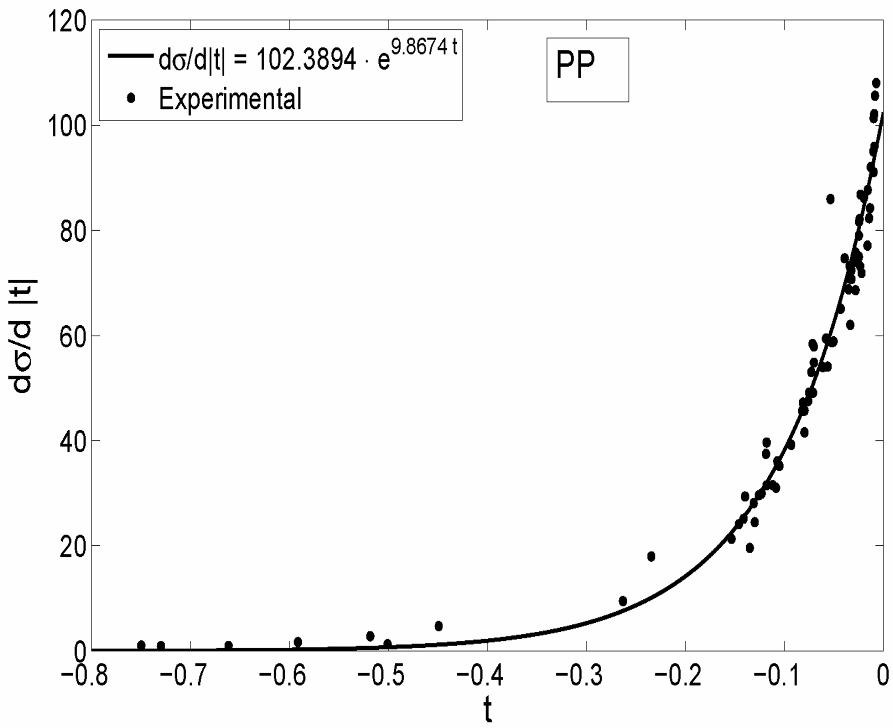
Beyond the quasi-elastic knockout

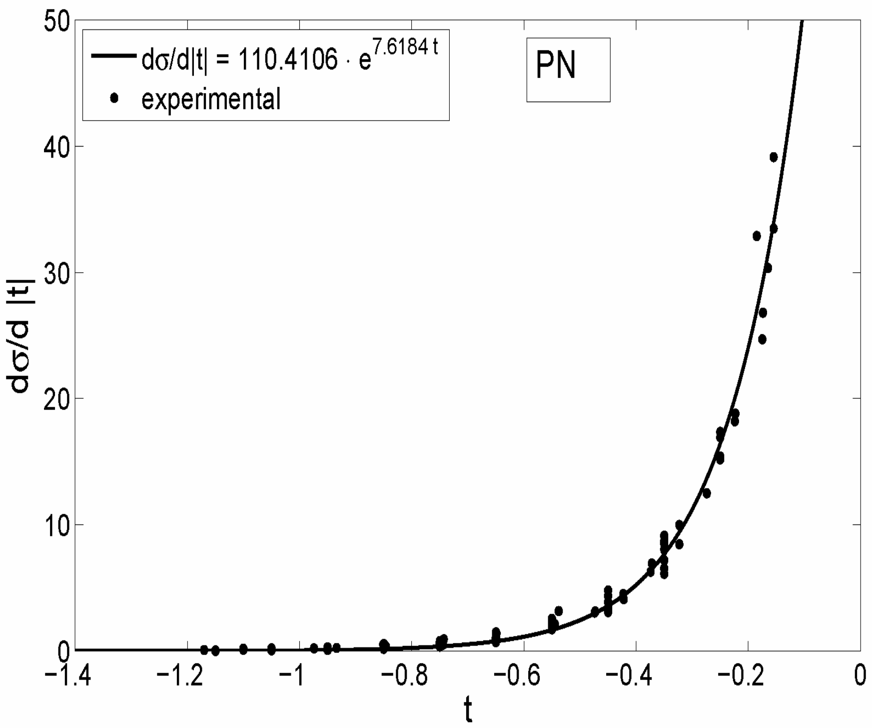
$$\vec{p}_0 + \vec{p}_{p,f} + \vec{p}_{n,b} = \vec{p}_1 + \vec{p}_2 + \vec{p}_n + \Delta\vec{p}$$

$$\vec{p}_f \equiv \vec{p}_1 + \vec{p}_2 - \vec{p}_0 = \vec{p}_{p,f} + \vec{p}_{n,b} - \vec{p}_n - \Delta\vec{p}$$

$$\vec{p}^{cm} \equiv \vec{p}_f + \vec{p}_n = \vec{p}_{p,f} + \vec{p}_{n,b} - \Delta\vec{p}$$

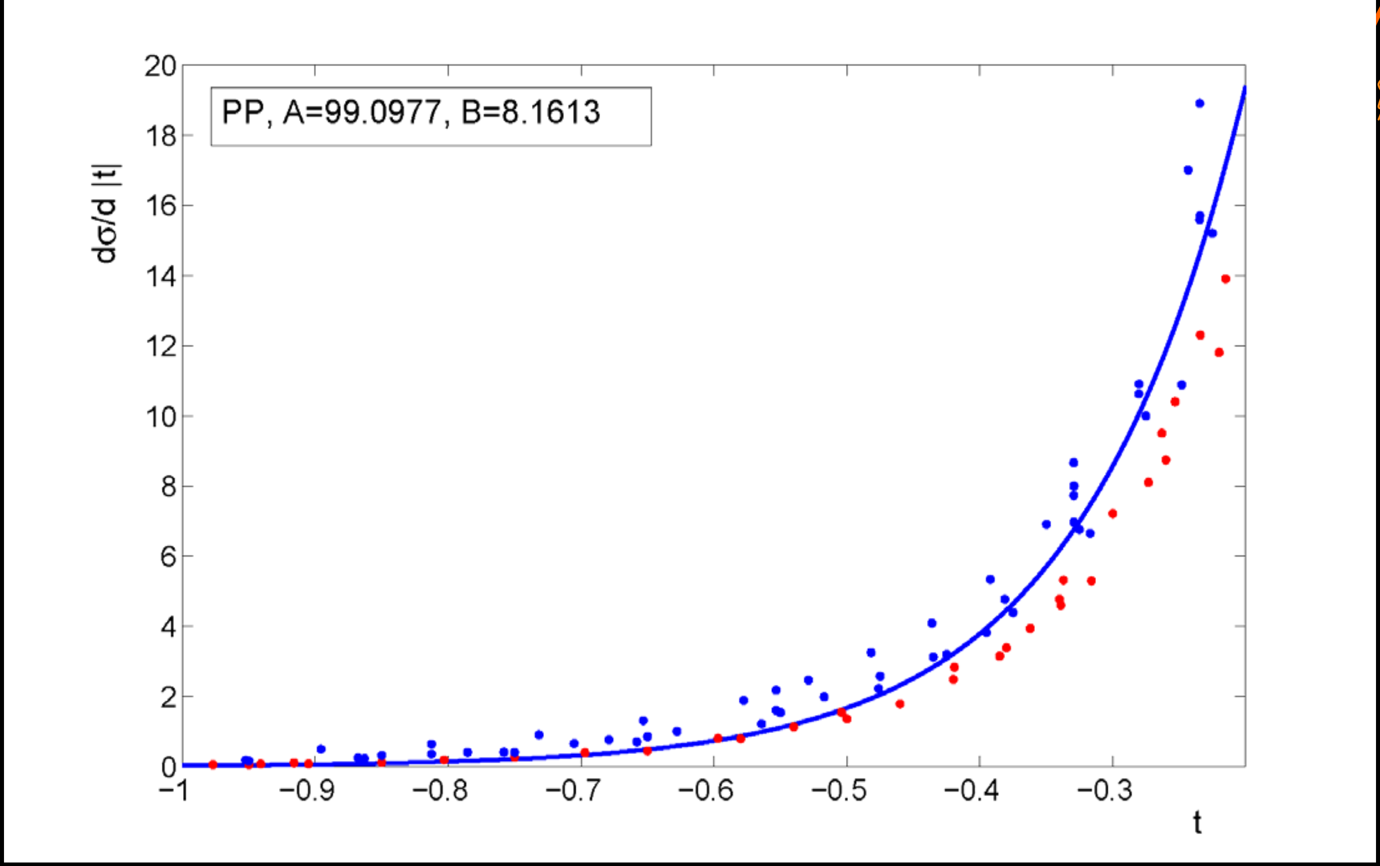
May ΔP arise from elastic scattering of projectile ?





Compilation exp data from the LANDOLT - BËRSTEIN tables

t- and s- dependence

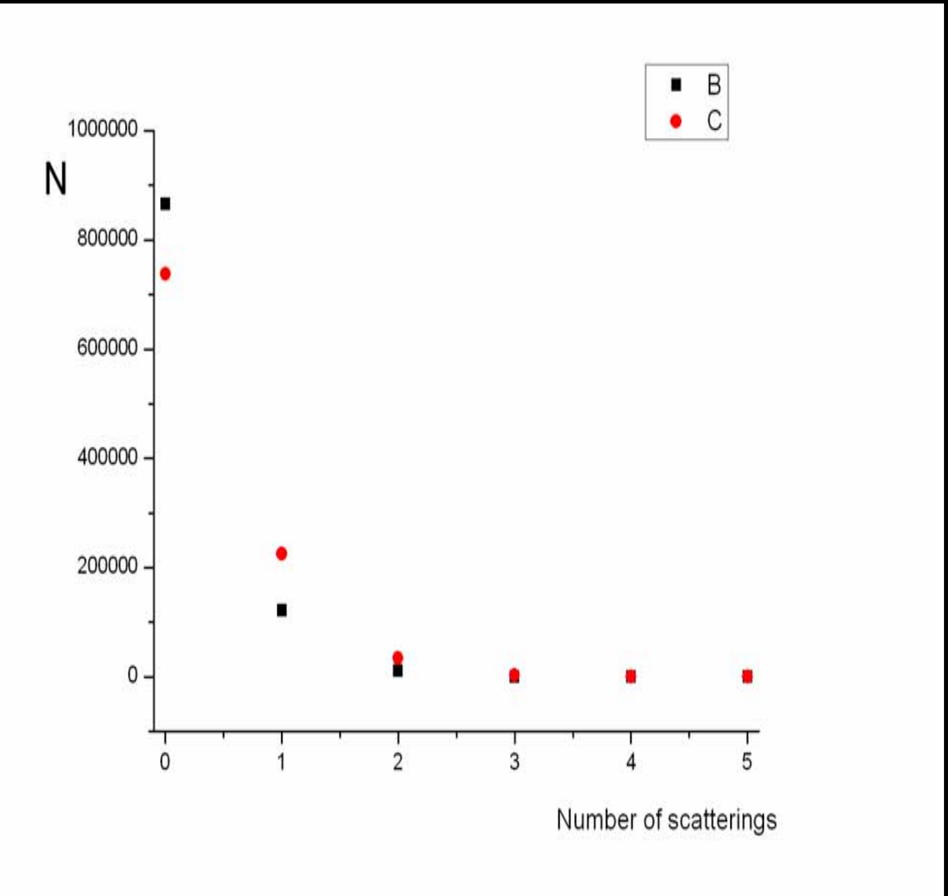


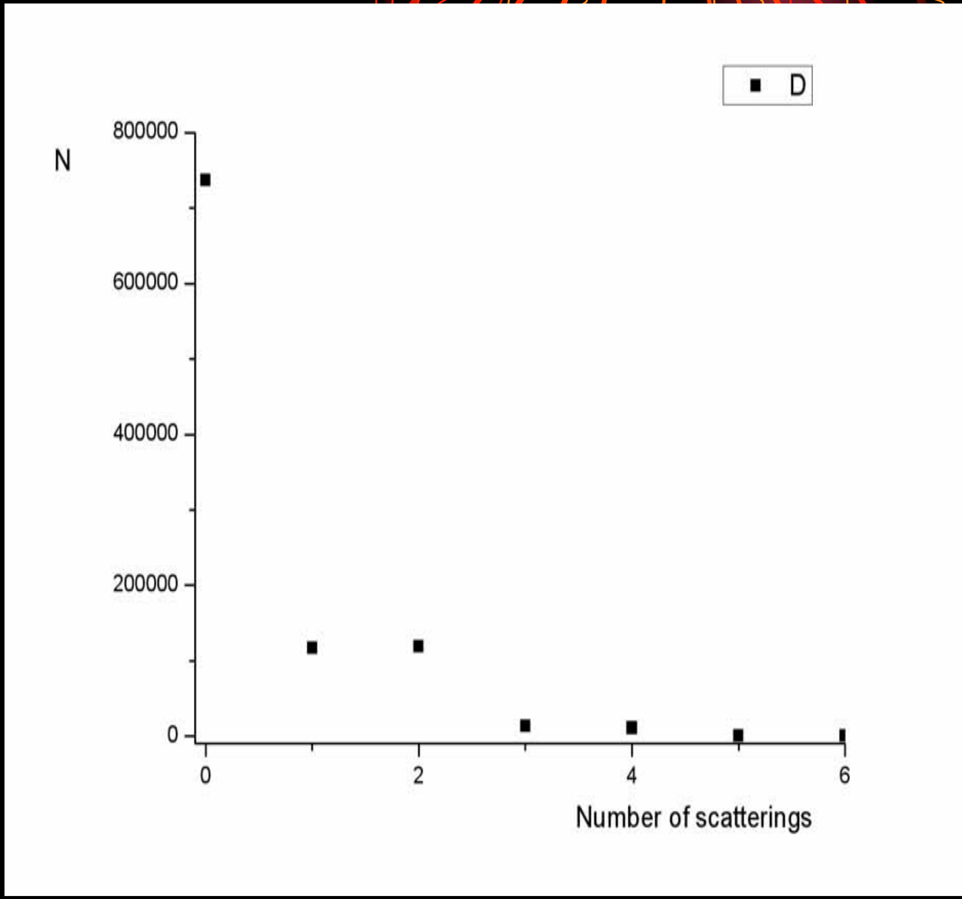
Experimental data from the LANDOLT – BËRSTEIN compilations

Main suggestions of simulation program

1. ***Nuclear density ρ : Woods-Sakson shape, $r_N \approx 0.2$ Fm, $E_{N,bind} = .006$***
2. ***Probability to find 2-nucleon SRC is ~ ρ^2***
3. ***Respect for the Pauli principle with $P_{Fermi} = 0.22$ GeV / c***
4. ***There were no π-mesons accompanying secondary nucleons in the final state***
5. ***Only elastic scattering of projectile <u>before and after</u> collision with SRC is taken into account (main contribution to P_{tr})***

How often scatterings take place ?



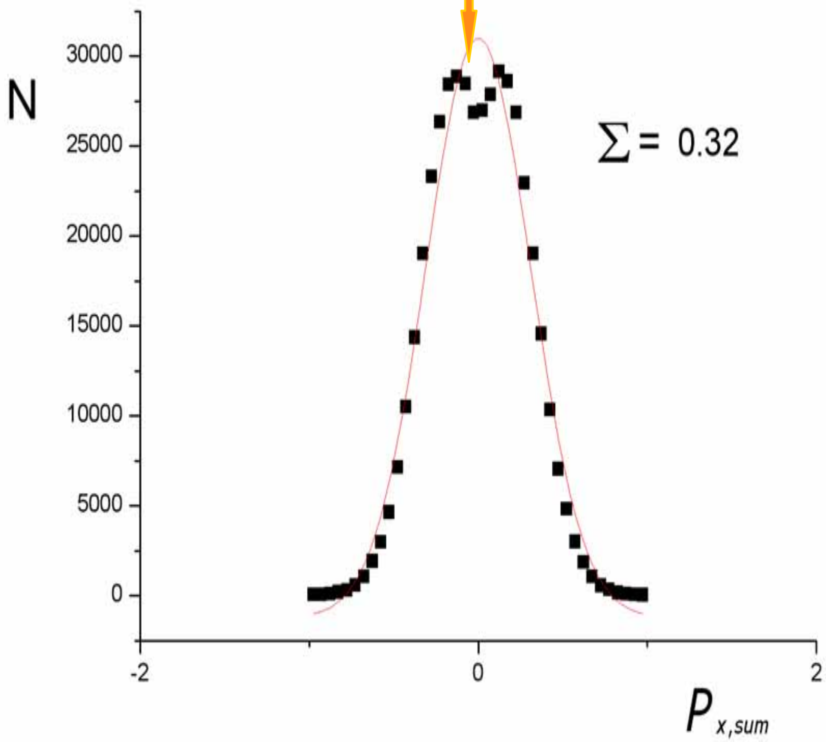


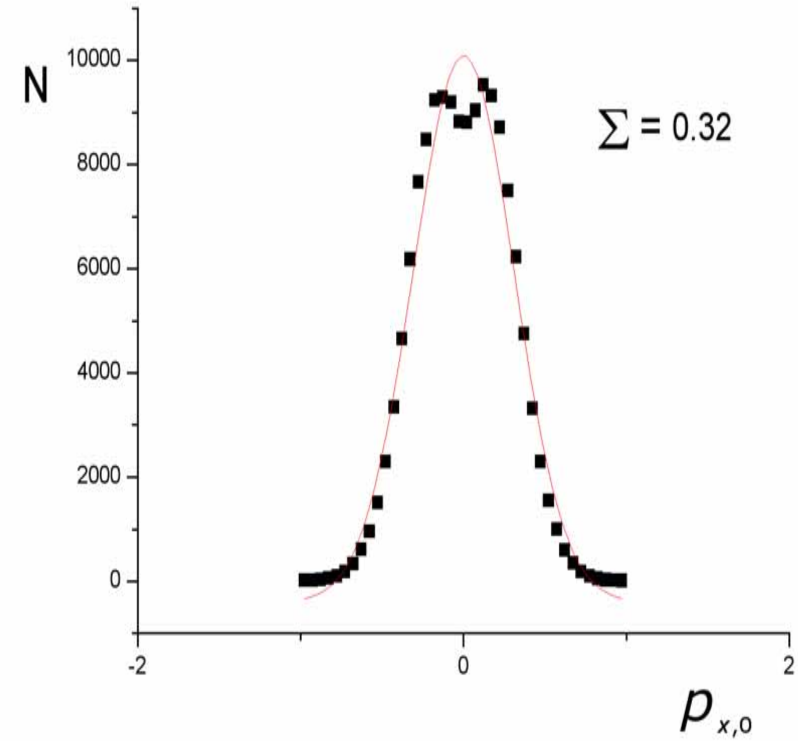
Scattering of 0 and 1 particles. Effective anticorrelation

Scattering at least one of them.
Events without additional scattering dominate : P0 = 0.74

Contribution of additional scattering to P_{tr}

Depression due to the Pauli principle





Is this enough ?

$$\left\langle (\xi_1-\langle\xi_1\rangle)^2+(\xi_2-\langle\xi_2\rangle)^2\right\rangle=\Sigma_1^2+\Sigma_2^2+2\rho_{12}\Sigma_1\Sigma_2$$

$$\rho_{12}=0$$

$$\Sigma_{sum}=\sqrt{\Sigma_1^2+\Sigma_2^2}=\sqrt{\Sigma_{cm,z}^2+\Sigma_{scatt}^2}=\sqrt{0.14^2+0.32^2}=0.35<0.57$$

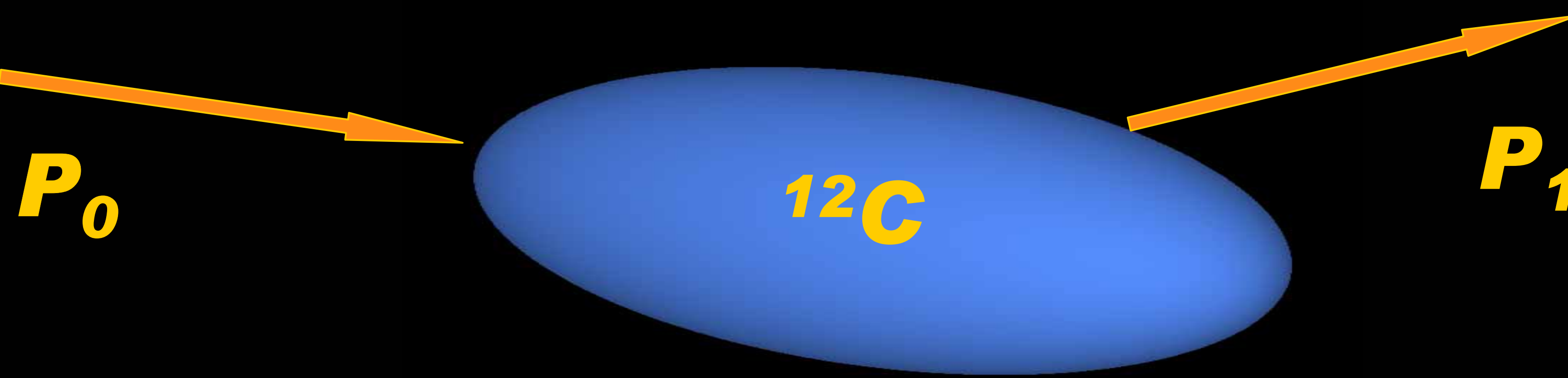
No! Even in the case $P_0=0$!

Summary of our study of intranuclear scattering

Contribution of the intranuclear scattering is insufficient for description of the observed motion of SRC along the transversal direction

More intensive Fermi motion ?

Nuclear states squeezed in transversal direction



Unconsidered possibilities:

1) **Experimental mistake**: there were missing (lost) π – mesons in each relevant experimental event
2) **Theoretical mistake**: colour **anti** - transparency was observed (instead of expected colour transparency)

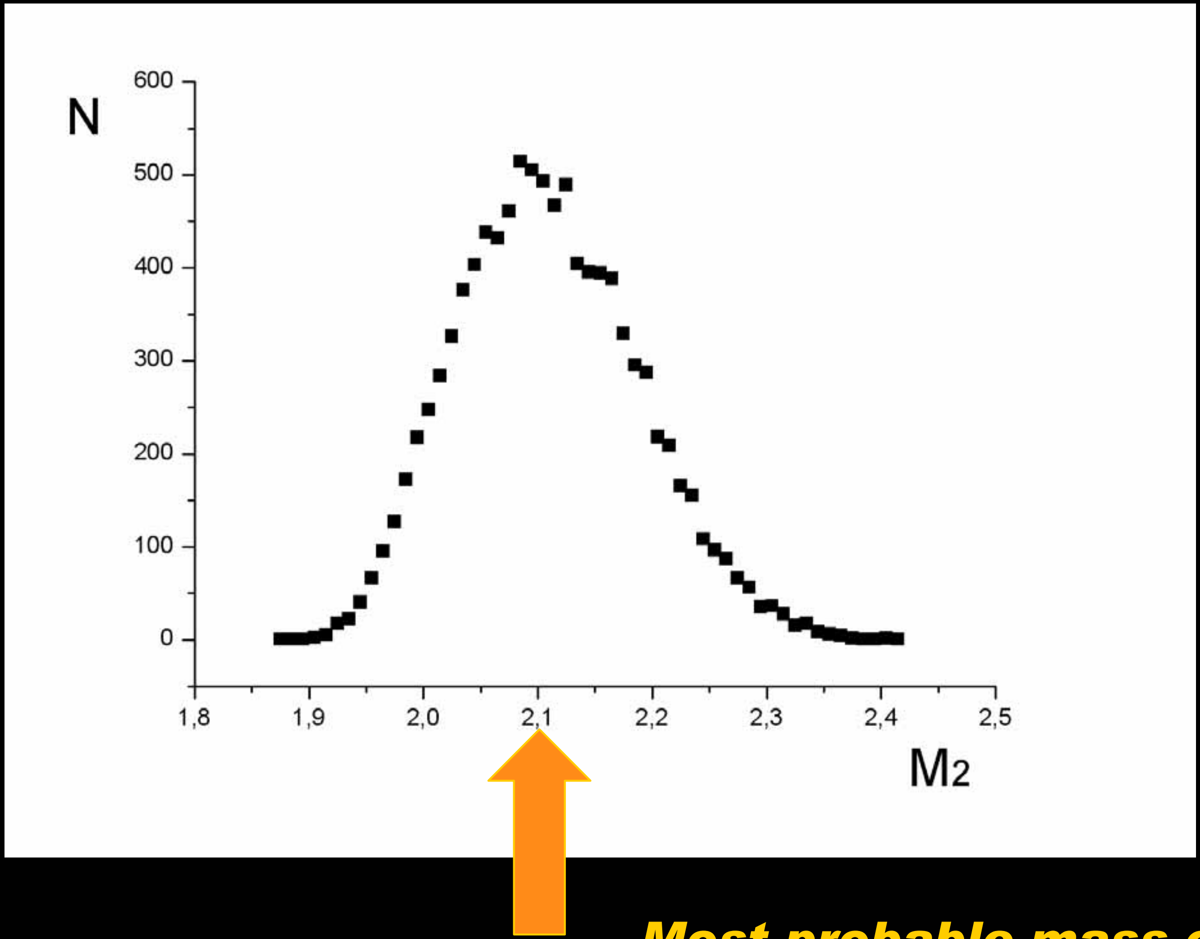
Possible wave function of ^{12}C

$$\left|\Psi\right\rangle = \ldots + \alpha \left|\Psi_{\perp}\right\rangle \otimes \left|\Psi_{\parallel}\right\rangle$$

Independent measurement of transversal size (large momentum transfer) and longitudinal size (low momentum transfer)

SRC appears only inside a squeezed state of nucleus ?

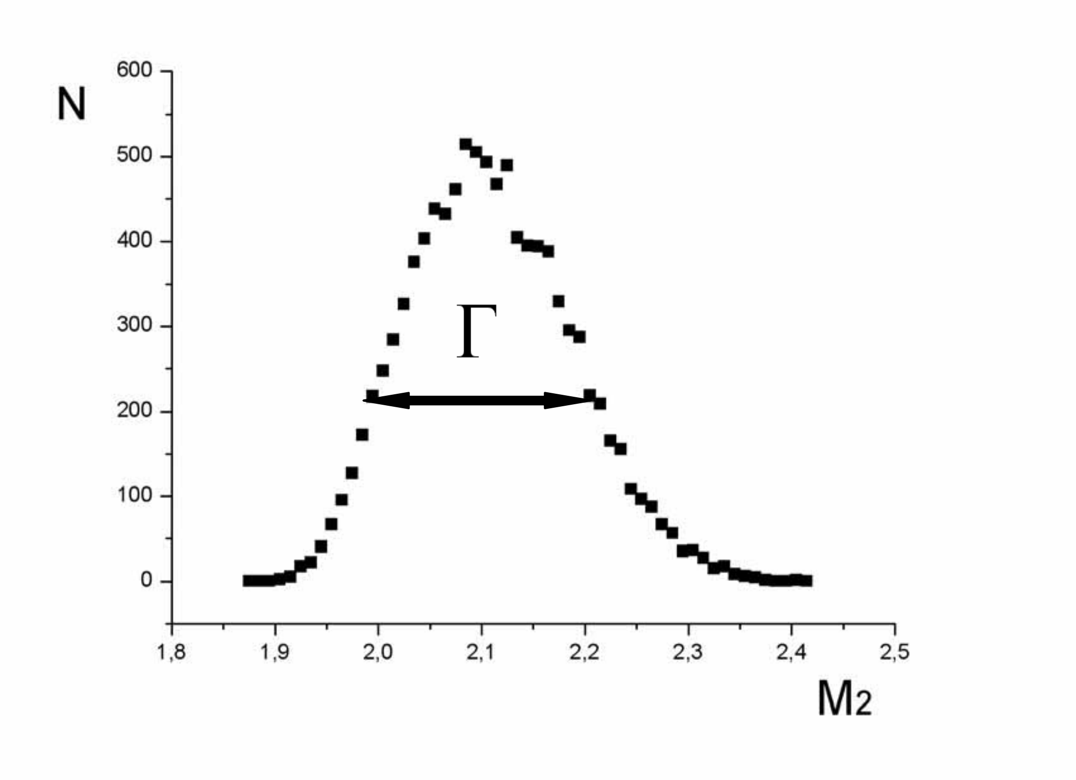
Mass distribution



Most probable mass of SRC measured with EVA spectrometer

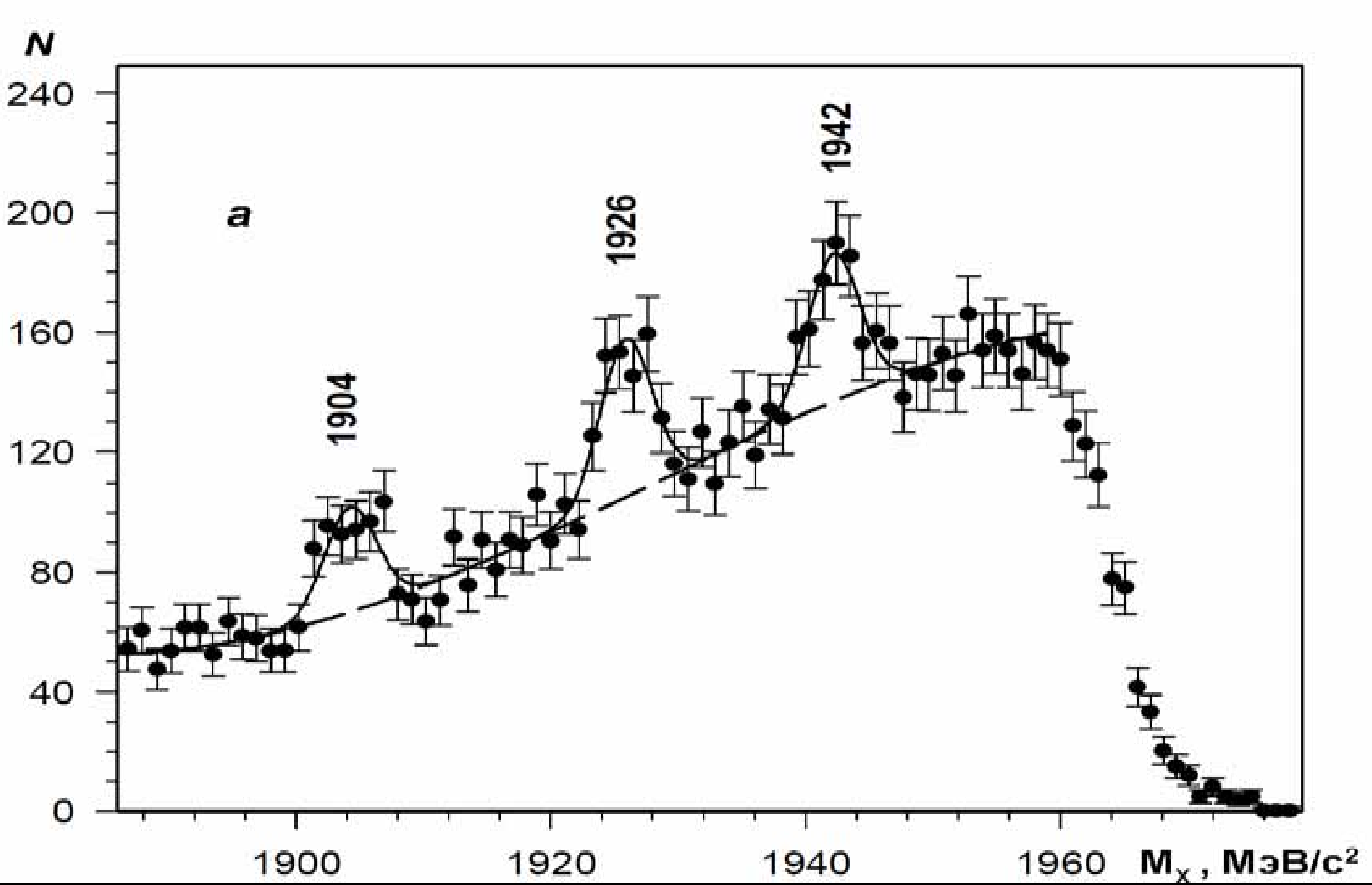
May it be dibaryon production ?

p_0 + SRC → dibaryon + p_1
dibaryon → p_2 + n



$M_{dibaryon} \approx 2.15$

Experimental proposal: to increase resolution

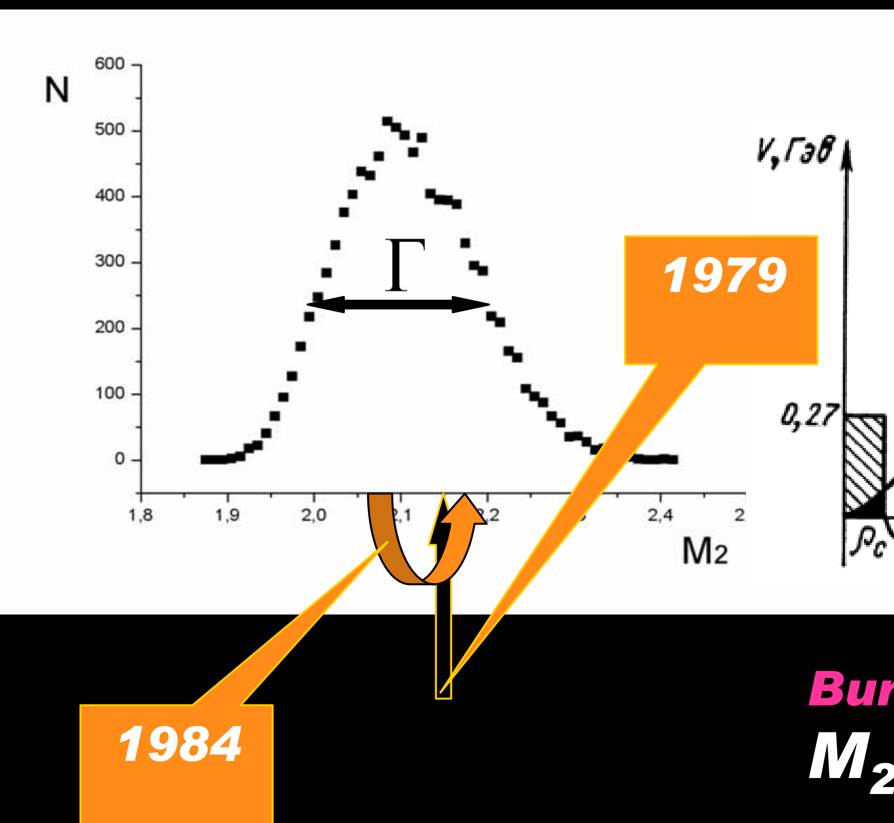


p d → p + p X

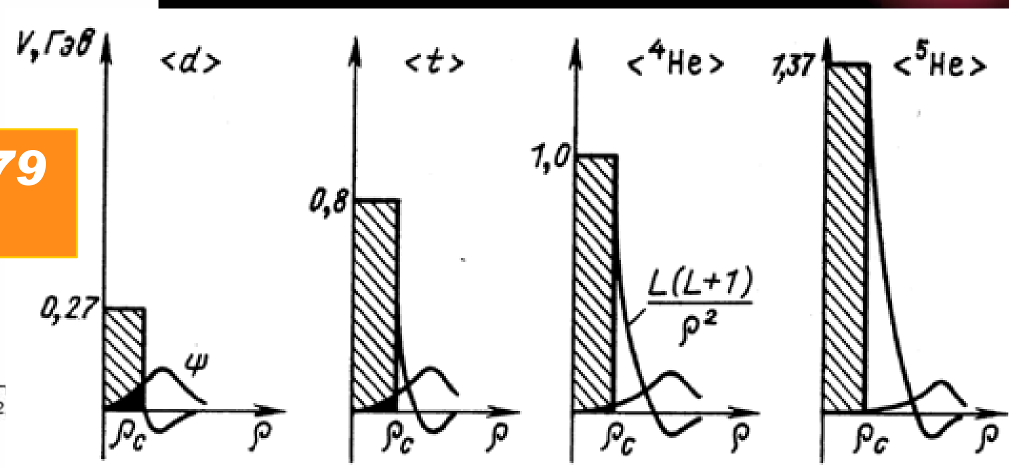
Method:
invariant mass M_{pX} spectra

LV Fil'kov et al (Lebedev Institute + JINR)
Baldin ISHEPP XV, 2000

May it be flucton existing before interaction?



Lukyanov, Titov, PEPAN 1979



Burov, Lukyanov, Titov, PEPAN 1984

M_2 = 0.208 — 0.218

How created and pre-existing MB may be discriminated ?

CNM versus CMM

p0 + SRC → dibaryon + p1

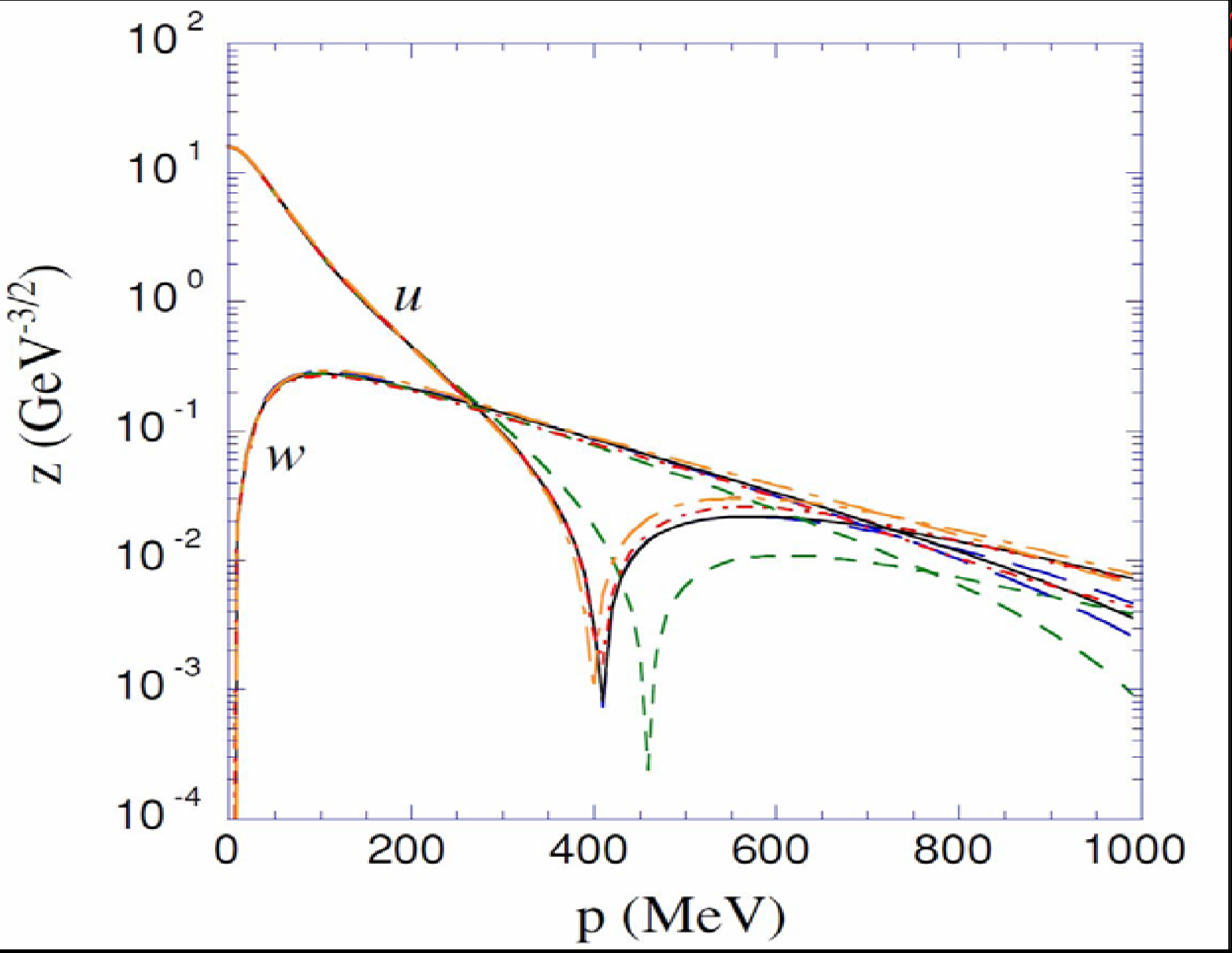
dibaryon → p2 + n

Measurement of the projectile particle momentum transfer

p1 - p0

May it be SRC ?

R. Gilman, F. Gross, J Phys G 28 (2002) R37



$P_S = 0.24$

$P_D = 0.76$

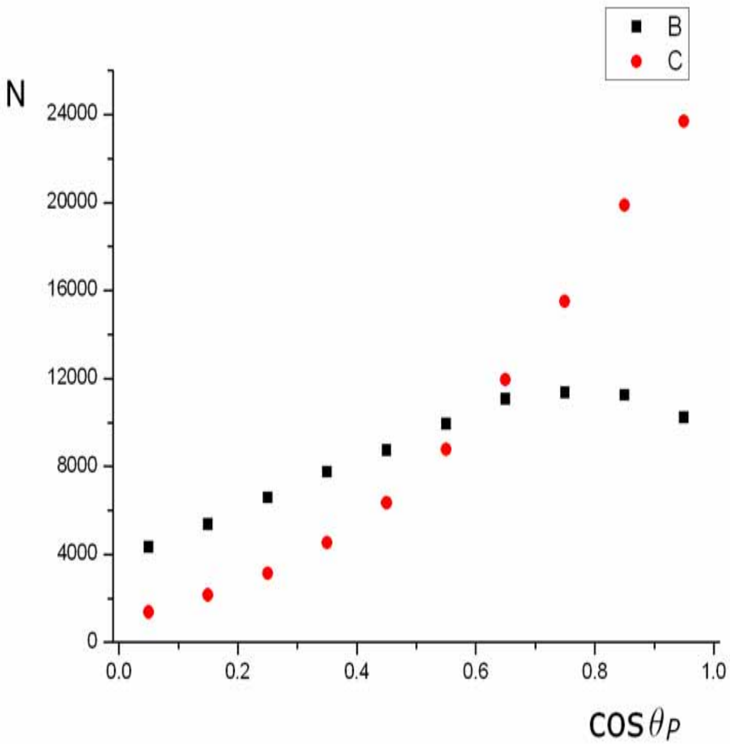
$0.45 < P < 1.1$

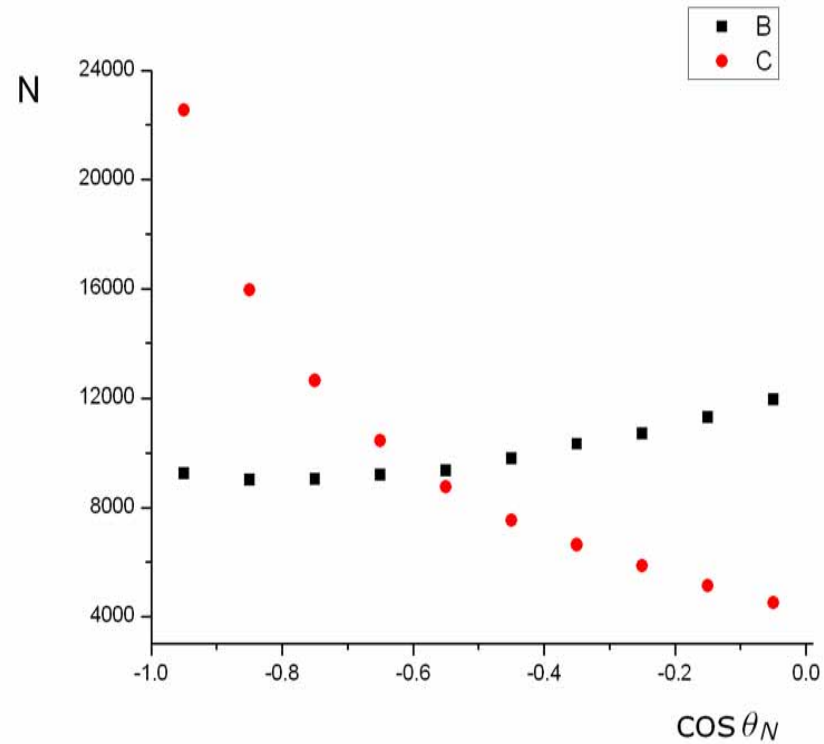
May it be SRC ?

Influence of quark counting rules

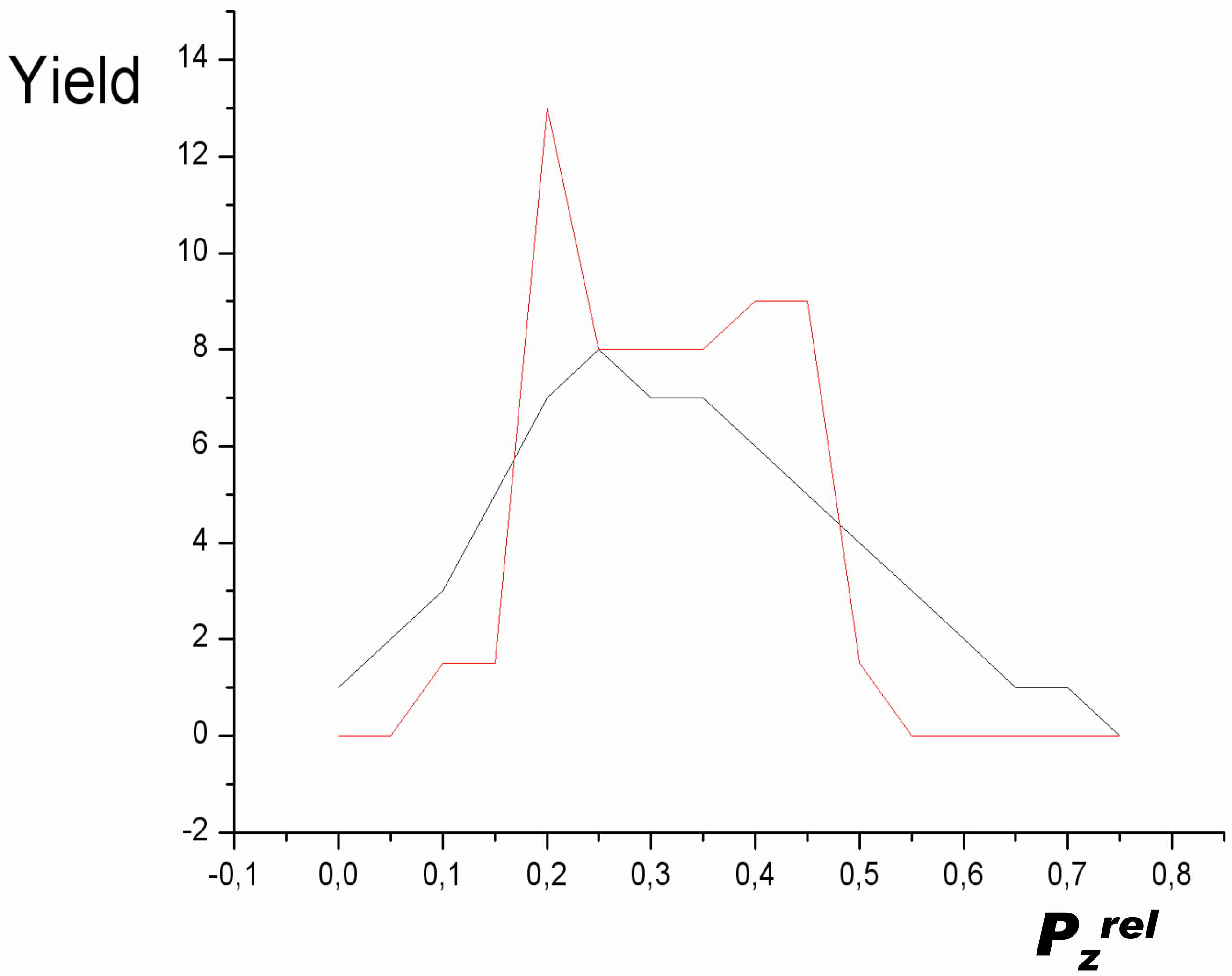
$$d\sigma/d\Omega=(s-4m^2)(4\pi)^{-1}d\sigma/dt$$

$$d\sigma/dt\sim s^{-9}$$





May it be SRC ?



Experimental cut-offs: Neutron moves downward and backward, 0.05 < Pn < 0.55 GeV

Probability for tails to be cut ≈ 0.84

Experimental proposal : knockout or creation of MB

Cumulative particle is nucleon

Search for 6 – q bag : to improve statistics in an experiment of EVA type for the purpose of to refine P^{rel}_{z} distribution

Toward true cumulative effect

P_p	SRC	EXP
0.715	0.33 ±4%	0.33 ±10%
0.888	0.12 ±6%	0.06 ±10%
1.026	0.031 ±12%	0.012 ±10%

EVA:
$P_n < 0.55$

ITEPh :
$0.58 < P_p < 2.215$

S.V.Boyarinov et al Yad. Fiz. 57, 1452(1994)

P+Be,

$\Theta_p = 97°$

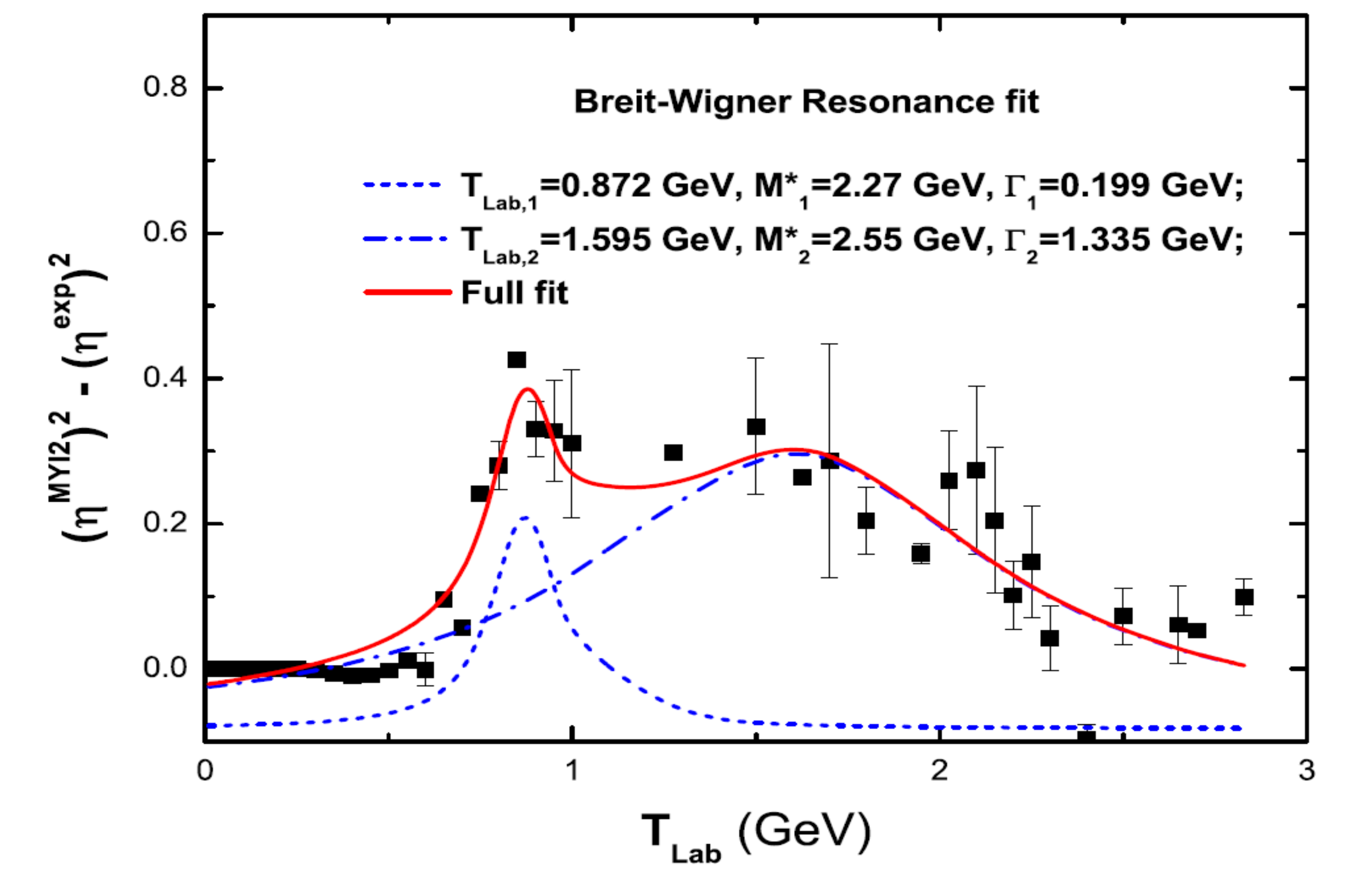
Signature of N N fusion

Covariant Bethe – Salpeter approach

S. G. Bondarenko et al Nucl Phys A 848, 75 (2010)

MY6 model

Experimental proposal



SG Bondarenko,
VV Burov,
EP Rogochaya
PL B705(2011)264

Search for 2.27 and 2.55 GeV resonances in CMM experiments

p+p → (quasi) dibaryon + π

The main experimental proposal: registration of chiral phase transition

$$M_{MB}^2 = (E - E_\pi + M_{SRC})^2 - P_\pi^2 - P^2 + 2PP_\pi \cos\theta_\pi$$
$$M_{MB} = f(M_{SRC})$$
$$M_{SRC} = f^{-1}(M_{MB})$$

CMM

Either SRC or q-bag model is true

$$\left\{ \begin{array}{l} \theta_\pi = 119°: \\ P_\pi = 1.008 \end{array} \right.$$

$$\left\{ \begin{array}{l} \theta_\pi = 97°: \\ P_\pi = 1.285 \end{array} \right.$$

Resolution is desirable to be high

$$M_3^* = 3.62, M_4^* = 4.76, M_5^* = 6.07$$

+ account for $E_{\pi,bind} \approx 0.025$

Feasibility

P_π, /c	f, Be	f, Al
0.873	$1.65\ 10^{-4}$	$4.61\ 10^{-4}$
0.979	$2.47\ 10^{-5}$	$8.62\ 10^{-5}$
1.077	$3.72\ 10^{-6}$	$1.72\ 10^{-5}$
1.293	$6.23\ 10^{-8}$	$3.56\ 10^{-7}$
1.402	$8.21\ 10^{-9}$	$5.32\ 10^{-8}$
1.512	$7.94\ 10^{-10}$	$4.95\ 10^{-9}$
1.619		$1.03\ 10^{-9}$

P_π, /c	f, Be	f, Al
1.192	$1.95\ 10^{-5}$	$7.09\ 10^{-5}$
1.370	$1.20\ 10^{-6}$	$6.34\ 10^{-6}$
1.523	$9.36\ 10^{-8}$	$6.37\ 10^{-7}$
1.635	$1.40\ 10^{-8}$	$1.26\ 10^{-7}$
1.790	$1.21\ 10^{-9}$	$1.42\ 10^{-8}$

$mb \cdot GeV^{-2} \cdot c^3 \cdot sr^{-1} \cdot nucleon^{-1}$

S.V.Boyarinov et al., Yad. Fiz. 46,1472(1987); 57, 1452(1994)

Last experimental proposal

CMM may also be applied to double cumulative processes for search of heavy multibaryons

Cumulative π-meson may be replaced by cumulative K-meson to create strange MB

CMM