Simulation of the reaction of deuteron fragmentation into cumulative and double cumulative pions

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Outline

- ☐ Introduction
  - ✓ definitions
  - ✓ motivation
- ☐ Simulation
  - ✓ structure
  - ✓ contribution of the various mechanisms
- ☐ Results for cumulative pions
  - ✓ comparison with experimental data
  - ✓ conclusion I
- ☐ Simulation for double cumulative pions
  - ✓ results
  - ✓ conclusion II

Cumulative particle (**c**) definition

1. subthreshold

$$B + A = c + X \qquad \xcancel{p + p = c + X}$$

$$P_c = \{E_c, \vec{p}_c\}$$

2. Produced in the fragmentation region of one of the primary particles

$$|Y_A - Y_c| << |Y_B - Y_c|$$

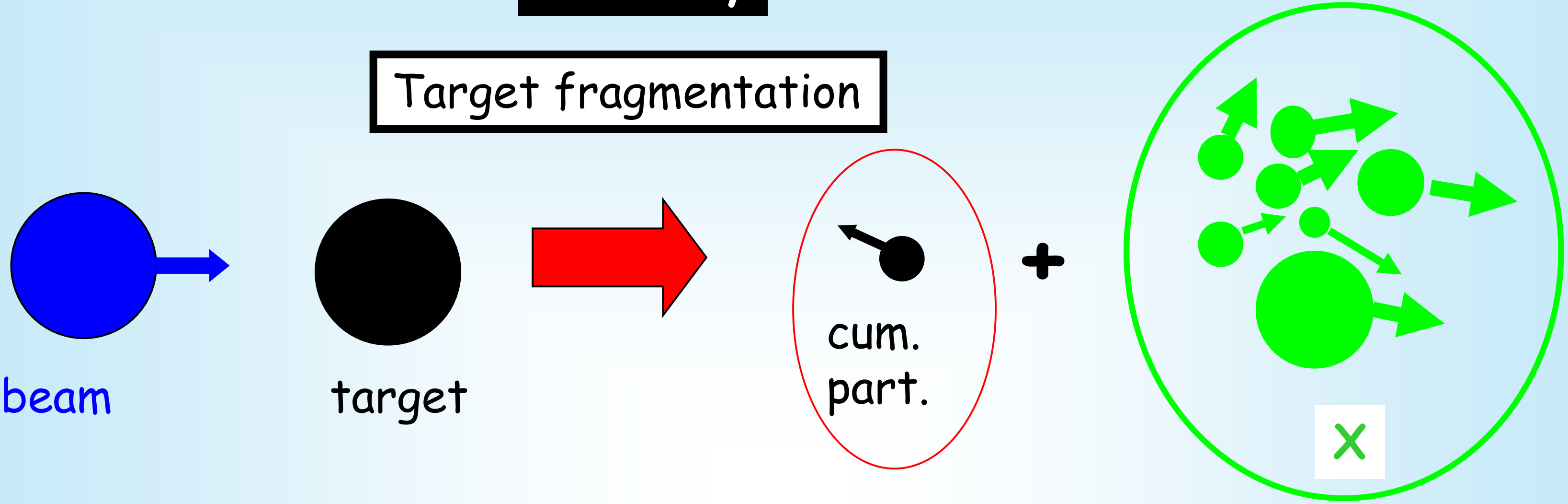
$$|\mathbf{Y_B} - \mathbf{Y_A}| \geq 2 \qquad T_b \approx \ 4 - 5 \ \mathrm{GeV/N}$$

Colliding particles are included in the definition asymmetrically!

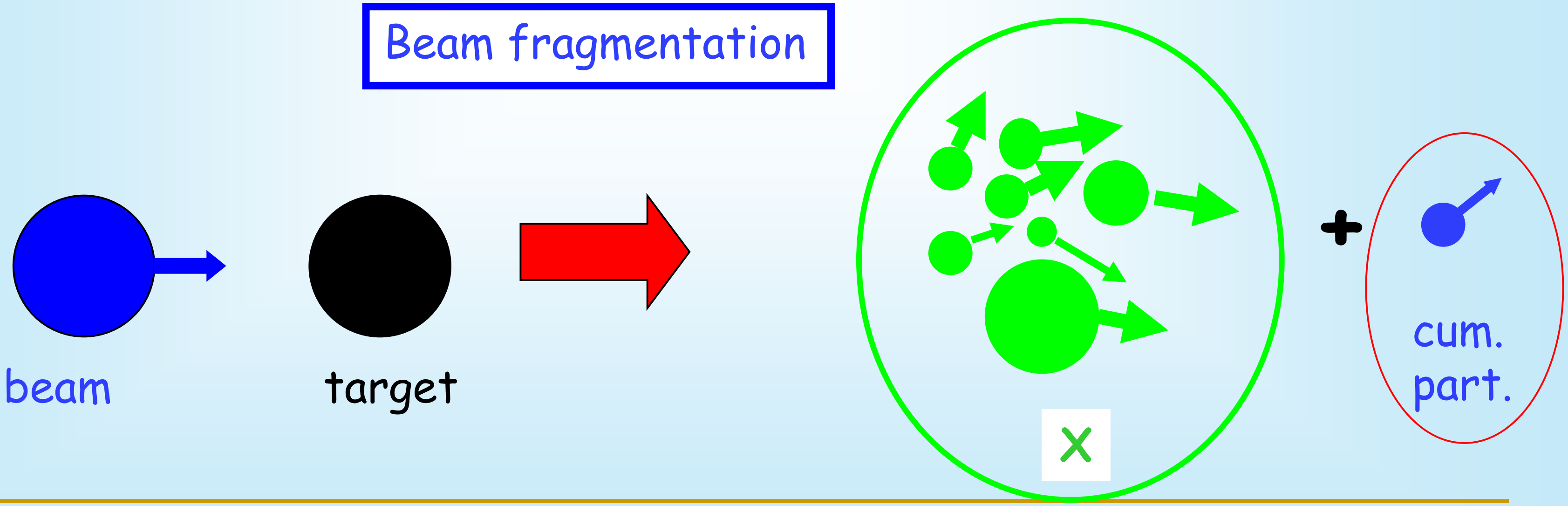
Colliding particles are included in the definition of asymmetric!

Geometry

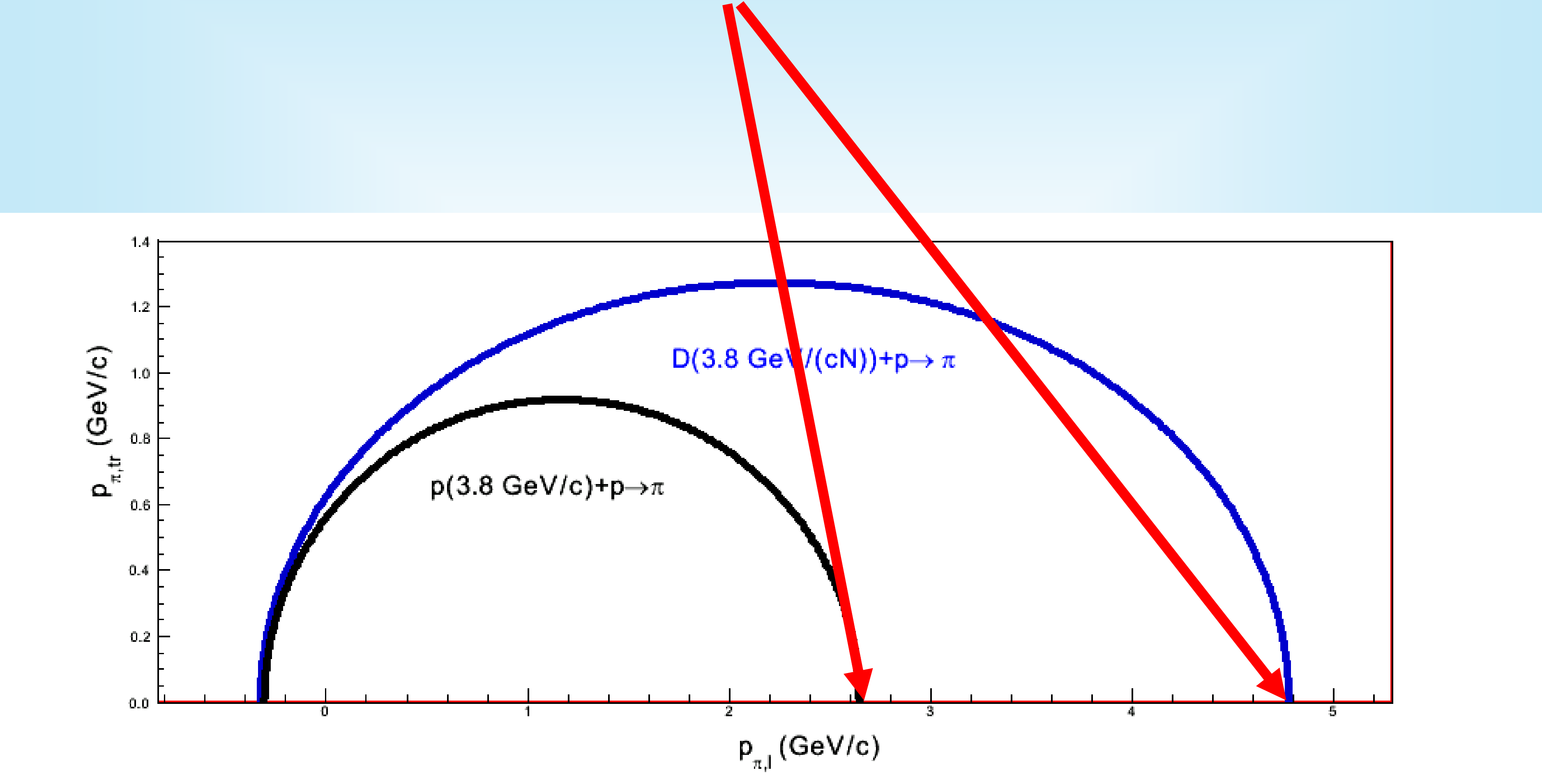
Target fragmentation



Beam fragmentation



Cumulative region (beam fragmentation)



Colliding particles are included in the definition asymmetrically

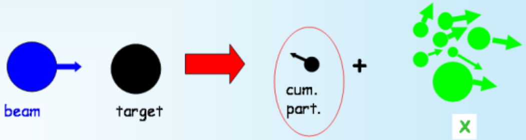
observed effect

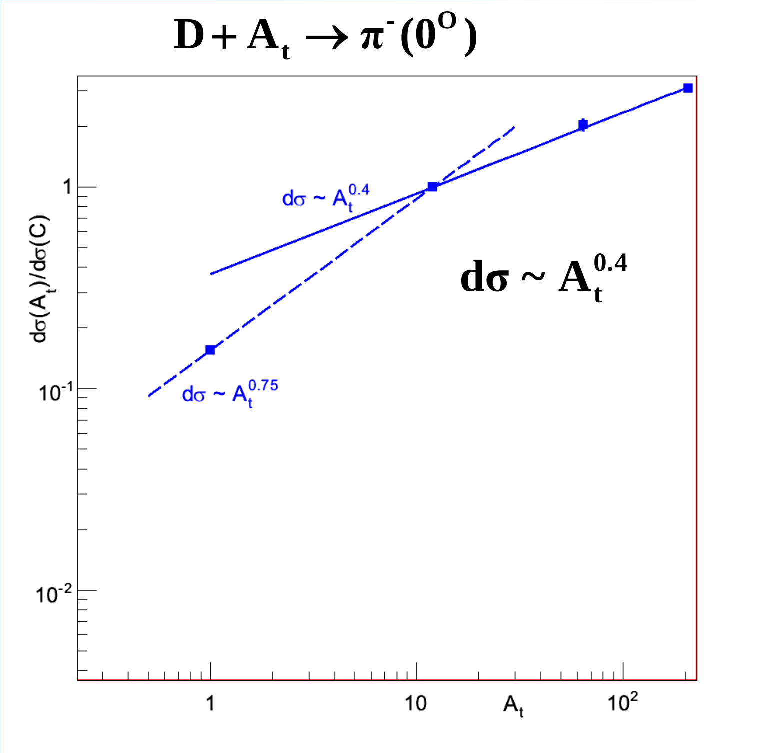
Dependence from the atomic mass of the colliding nuclei

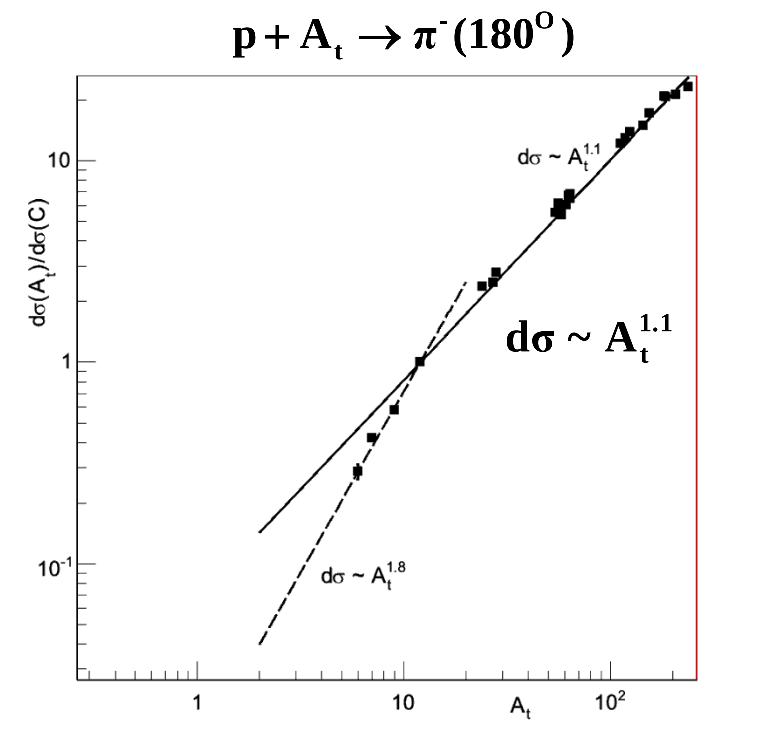
Not fragmenting nucleus

$$d\sigma \sim A_t^n f(X_c, \theta)$$

fragmenting nucleus





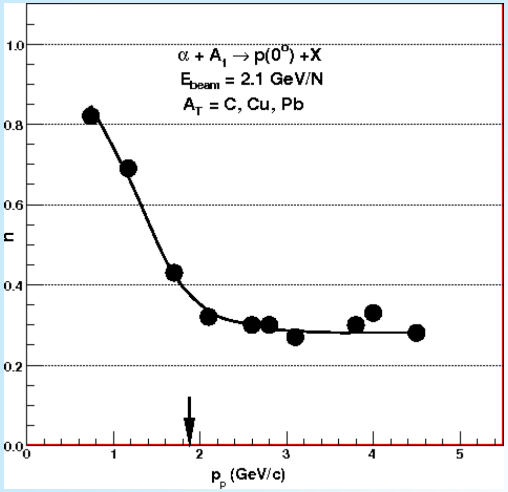


Yu.S.Anisimov at al., Nucl.Phys., 60, 1070, (1997).

V.K.Bondarev et al., JINR Rapid Comm., No.4,4, (1984)

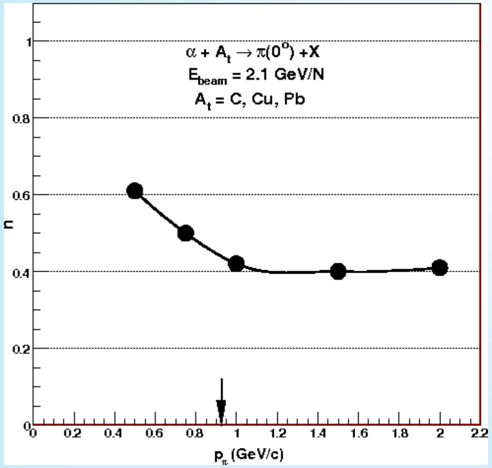
Experimental data

$$E\frac{d\sigma}{d^3p} = C \cdot A_t^n\ ;\ A_t = C, Cu, Pb$$



$$(D, {}^4He, C) + A_t(C, Cu, Pb) \rightarrow p(0^O)$$

L.Anderson et al., Phys.Rev.C, C28, 1224, (1983).



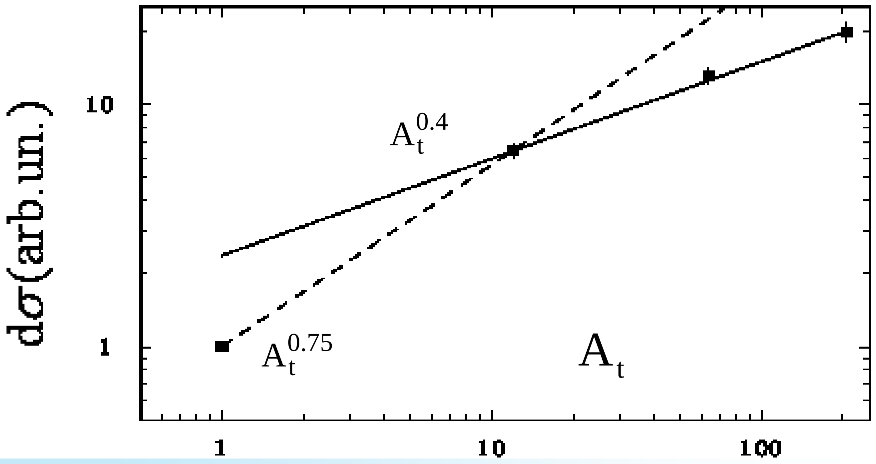
$$(D, {}^4He, C) + A_t(C, Cu, Pb) \rightarrow \pi(0^O)$$

E.Moeller et al., Phys.Rev.C, C28, 1246, (1983).

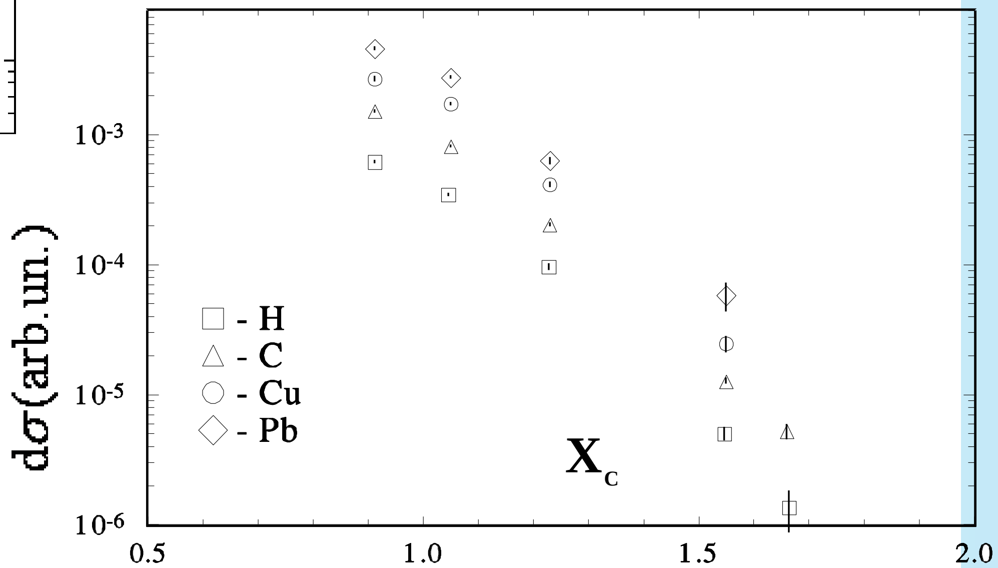
Experimental data

$$D(4.5\ \text{GeV/N}) + A_t(H, C, Cu, Pb) \rightarrow \pi(0^O)$$

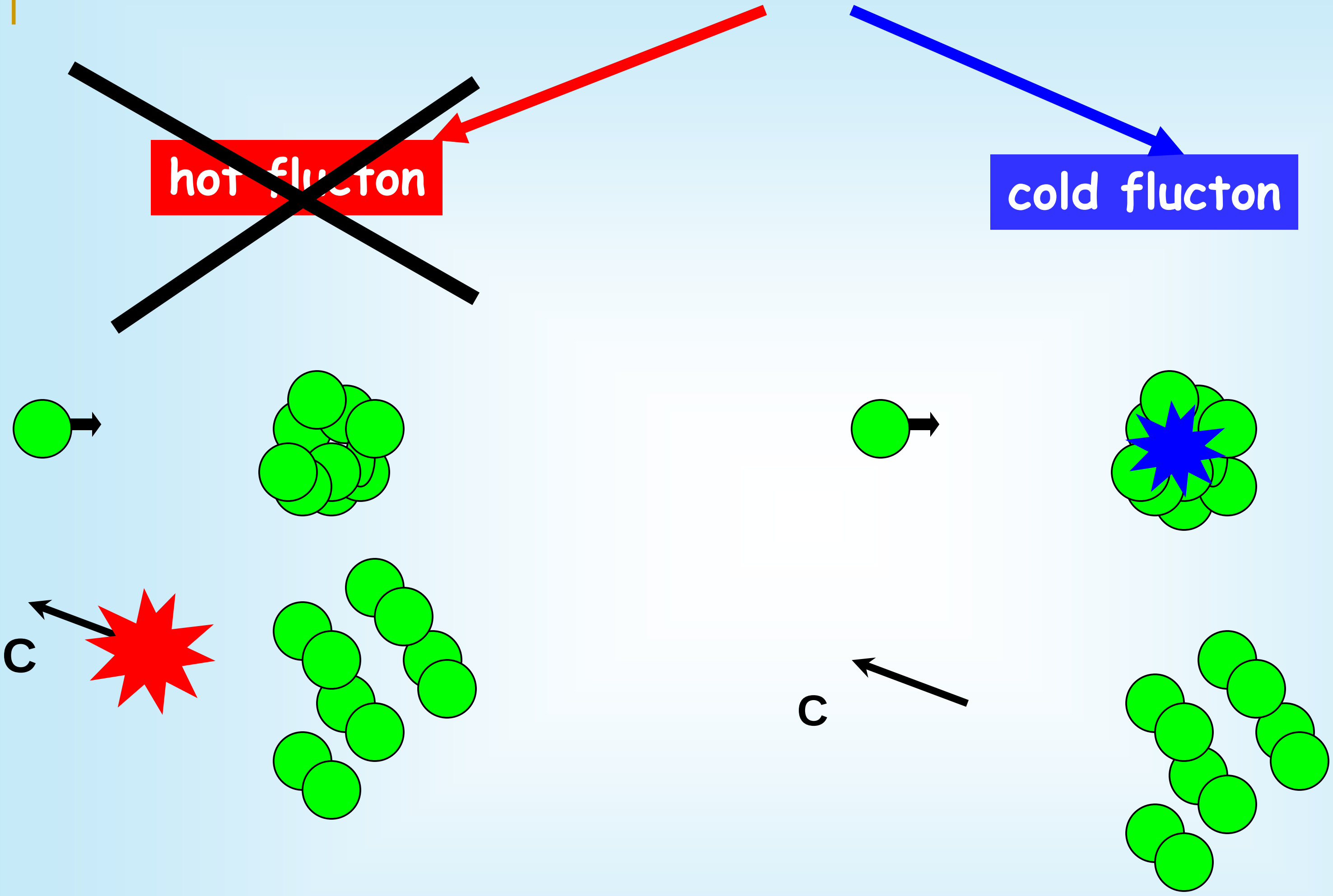
Yu.S.Anisimov at al., Nucl.Phys., 60,1070,(1997).



$$E\frac{d\sigma}{d^3p}\ ; A_t = H, C, Cu, Pb$$



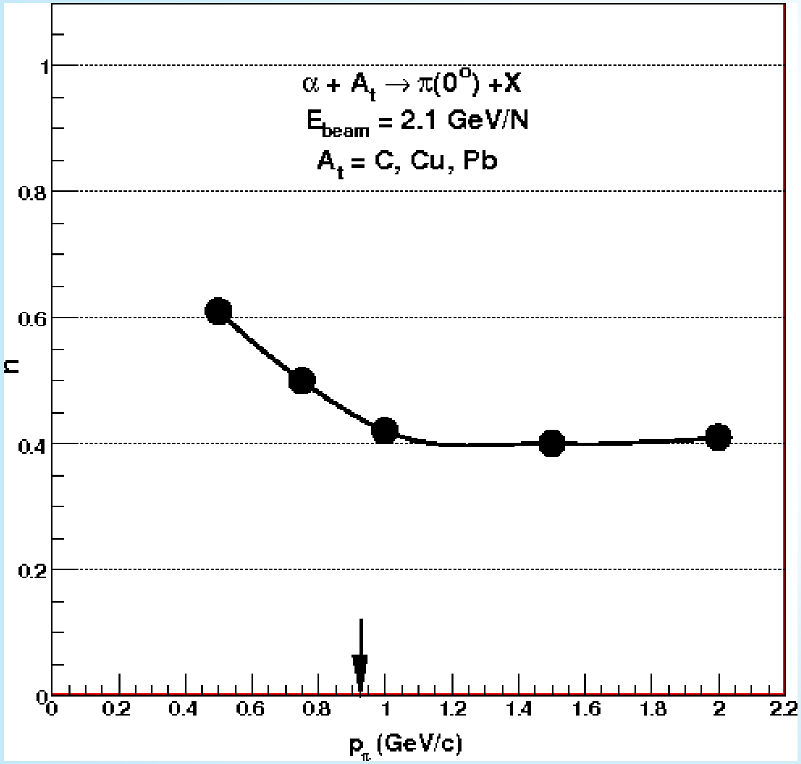
Models of cumulative particles production

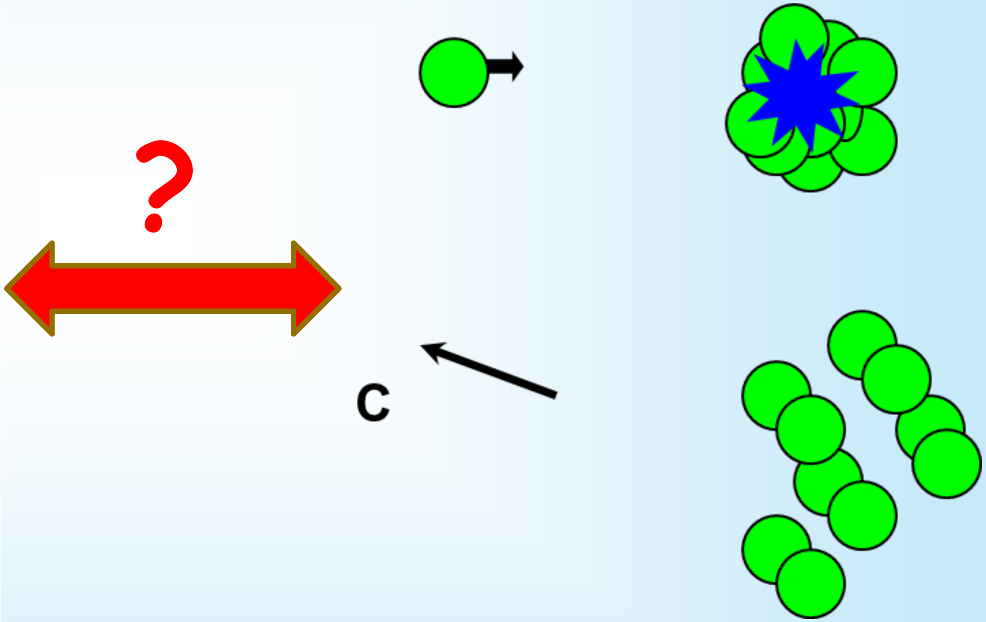


A.V. Efremov, PEPAN, **V.13(3)**, 613, (1982)

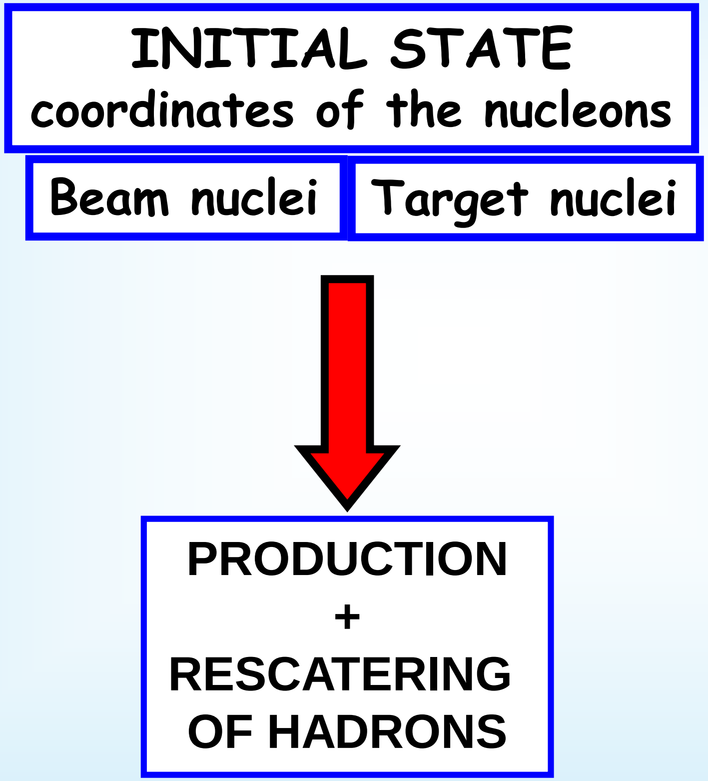
Motivation of the simulation of cumulative particle production

"How relate the experimental data and the models with cold flucton?"





Simulation (structure)



INITIAL STATE

coordinates of the nucleons

Beam nuclei

Target nuclei

PRODUCTION

+

RESCATERING OF HADRONS

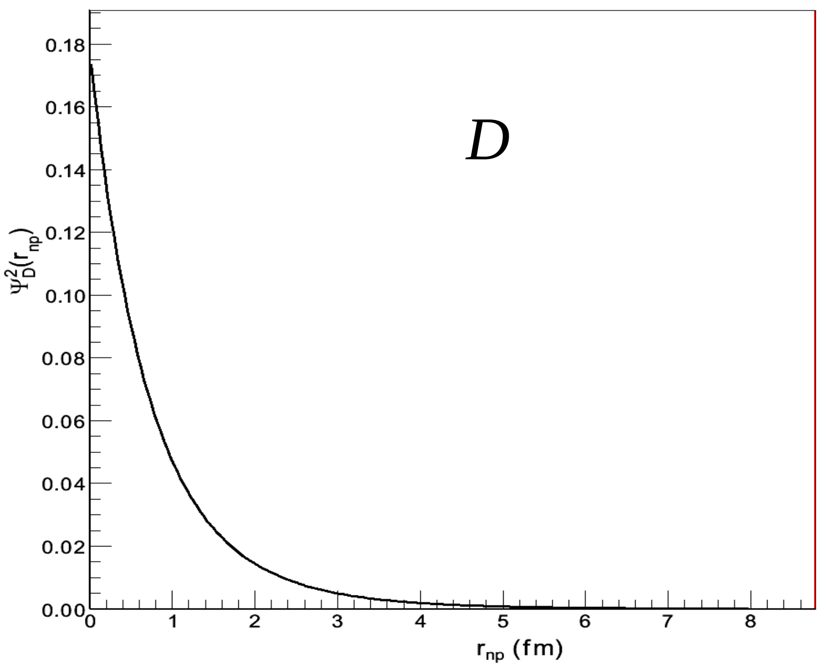
INITIAL STATE
coordinates of the nucleons

DEUTERON
Hulthen DWF

M.Sagavara L.Hulthen. Handb. Phys., 39, 1, (1957).

$$P(r) = \frac{ab(a+b)}{2(a-b)}\left(\frac{\mathrm{exp(\text{-}2ar)} + \mathrm{exp(\text{-}2br)} - 2\,\mathrm{exp(\text{-}(a+b)r)}}{\mathrm{r}^2}\right)$$

$$a = 0.228\ fm^{-1}, b = 1.18\ fm^{-1}$$



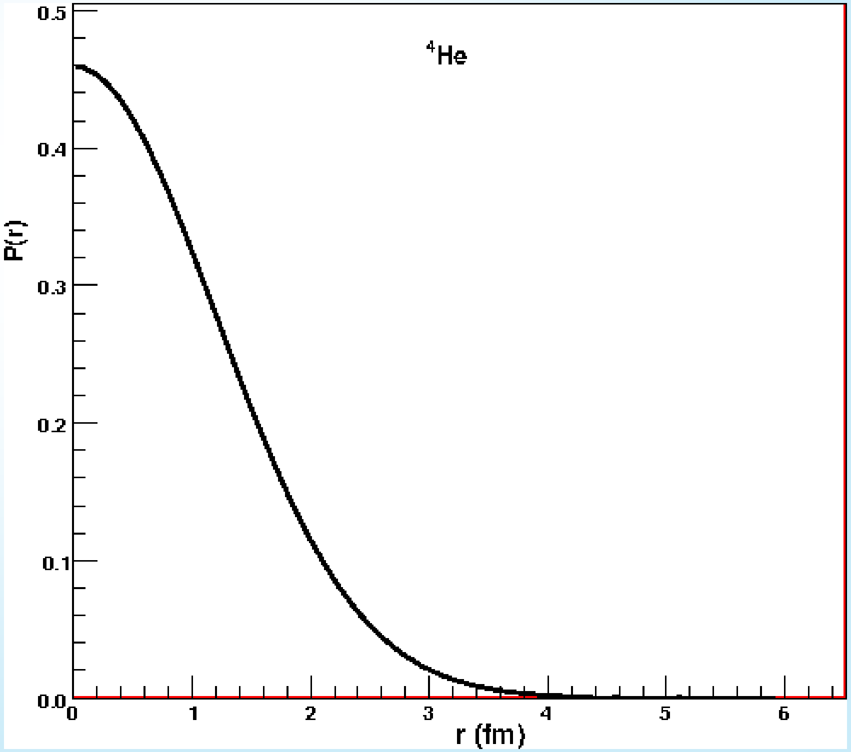
INITIAL STATE
coordinates of the nucleons

$^{4}\mathrm{He}$

Barlet R.C., Jakson D.F.Nuclea Sizes and Structure N.Y.: Oxford Univ.Press., (1997)

$$P(r) = \frac{4}{\sqrt{\pi} d^3} \exp(-r^2 / d^2)$$

$$d = 1.7 \ fm$$



INITIAL STATE
coordinates of the nucleons

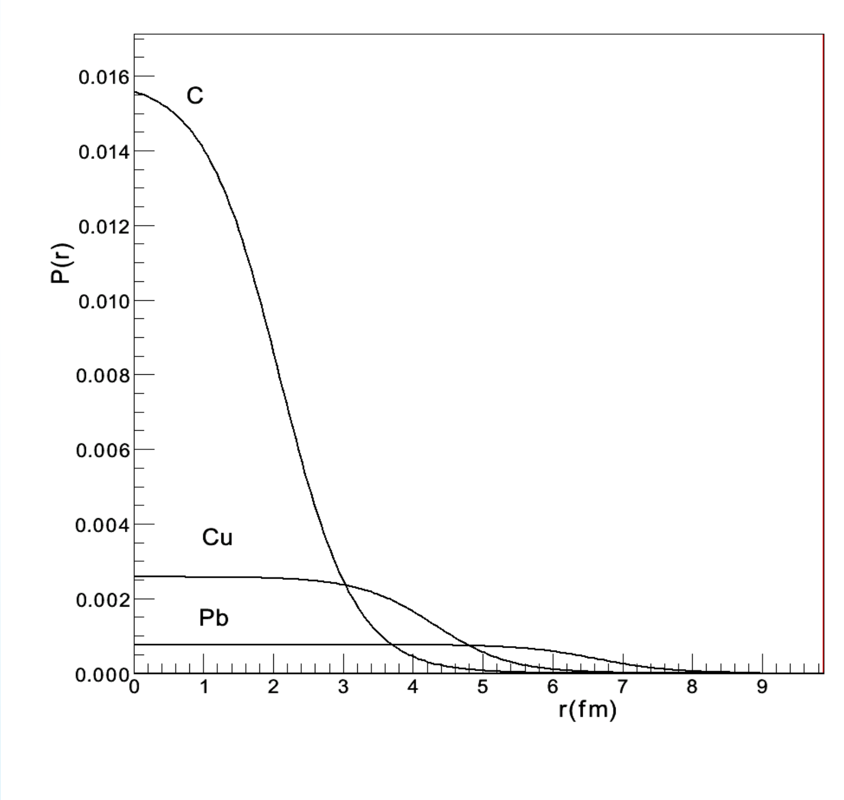
$A_t \geq 12$

Barlet R.C., Jakson D.F.Nuclea Sizes and Structure N.Y.: Oxford Univ.Press., (1997)

$$P(r) = \frac{N}{1 + \exp((r - R_A)/d)}$$

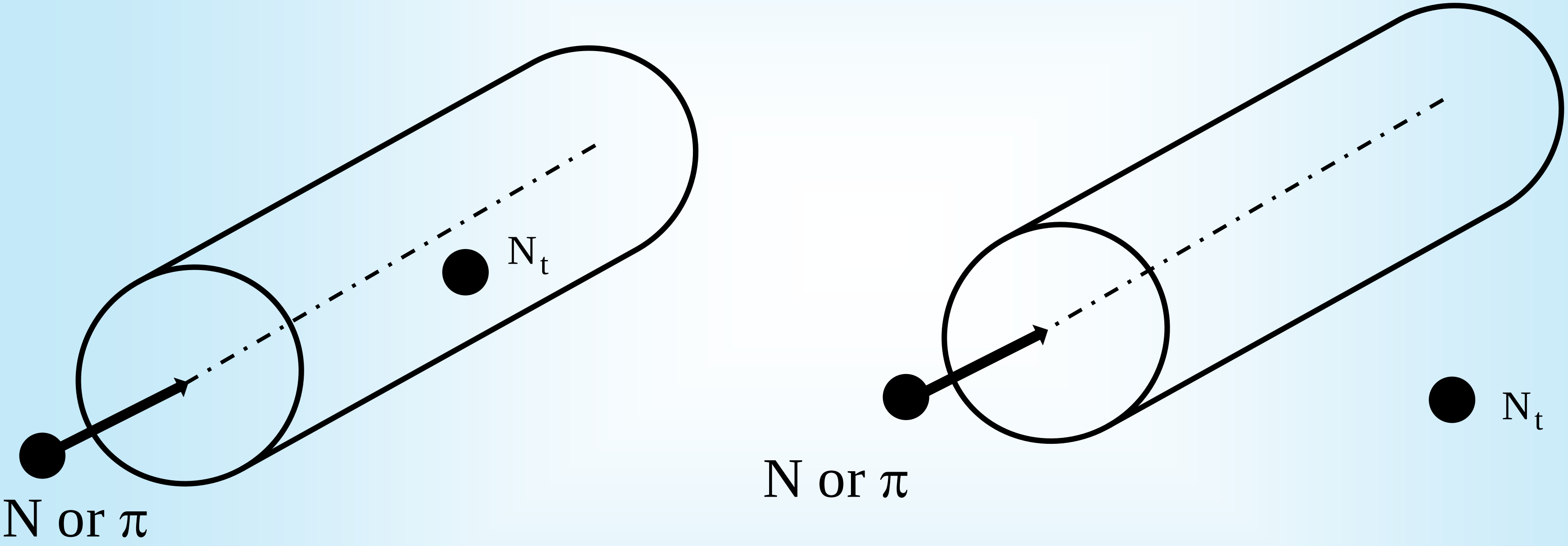
$$d = 0.54\ \text{fm};$$

$$R_A = 1.16(1 - 1.16A^{-1/3})A^{1/3}$$



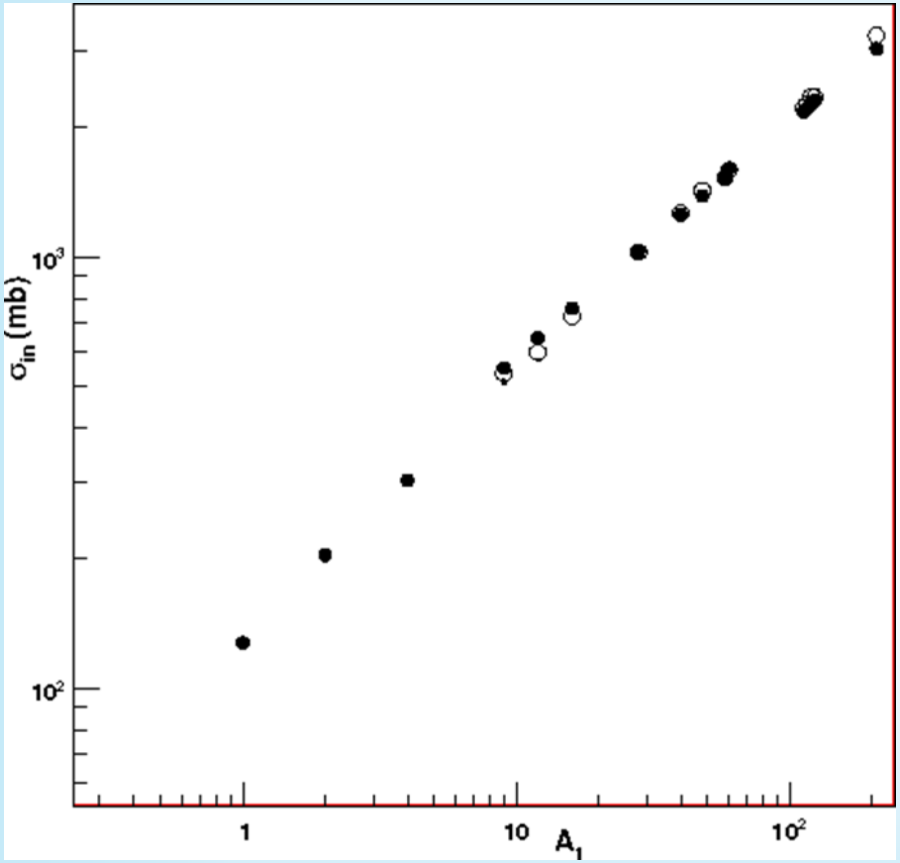
Scattered particles == inside of the cylinder was another particle

$R = \sqrt{\sigma(\mathrm{mb})/(10\cdot\pi)}$; $\sigma_{NN} = 45\ \mathrm{mb};\ R_{NN} = 1.197\ \mathrm{fm}$ $\sigma_{\pi N} = 30\ \mathrm{mb};\ R_{\pi N} = 0.977\ \mathrm{fm}$



S.G. Mashnik et al., nucl-th/0210065v2.

Simulation of inelastic deuteron-nuclei cross section



closed circles – simulated data

open circles –experimental data

A.Auce and et al.,
Phys.Rev.C, C53, 2919, (1996).

Simulation of the pion production

$$D + A_t \rightarrow \pi(0^O)$$

«direct» mechanism

$$D + N_t \rightarrow \pi(0^O)$$

$$d\sigma_c \sim \int \sigma(NN \rightarrow \pi) n_N(b,z) \overline{W}_D(b,[-\infty,z]) \overline{W}_\pi(b,[z,\infty]) dzbdb$$

$\overline{W}_D(b,[-\infty,z])$ - probability deuteron reach a point with coordinates $\{b,z\}$

$\overline{W}_\pi(b,[z,\infty])$ - probability that pion leave the target without scattering

$$L = \lambda_d + \lambda_\pi$$

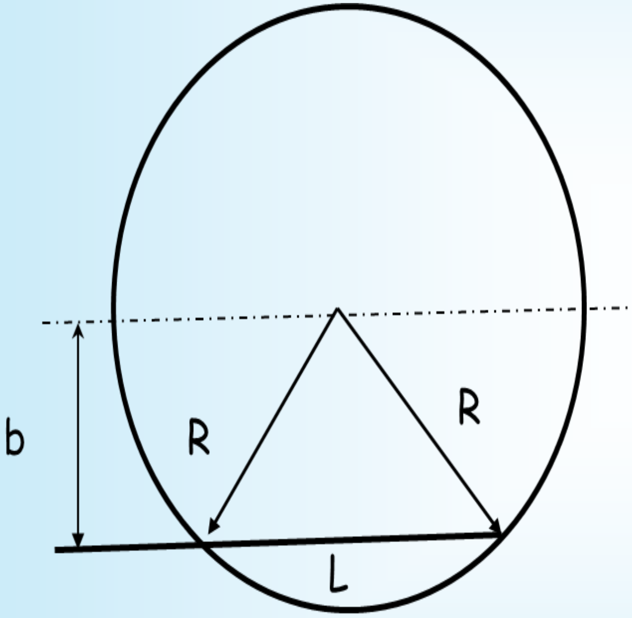
$$\lambda_d = 1\ \mathrm{fm}$$

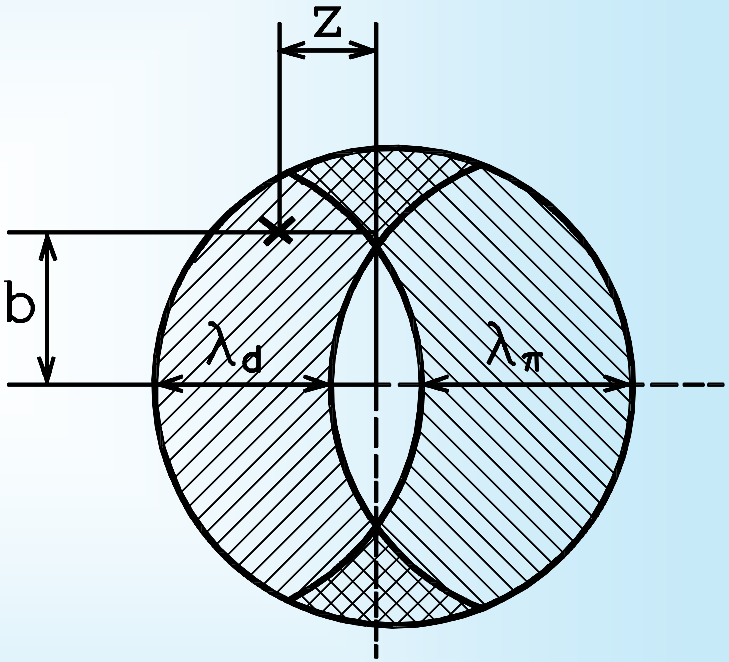
$$\lambda_\pi = 2.4\ \mathrm{fm}$$

$$L = 3.4\ \mathrm{fm}$$

Pions production

«direct» mechanism



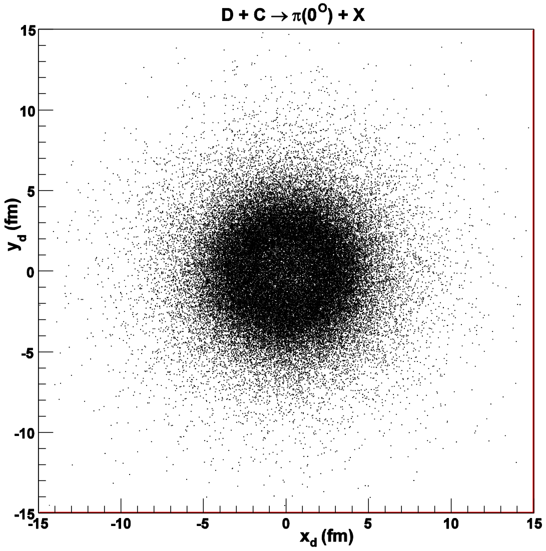


$$b = \sqrt{R^2 - (L/2)^2}$$

Pions production

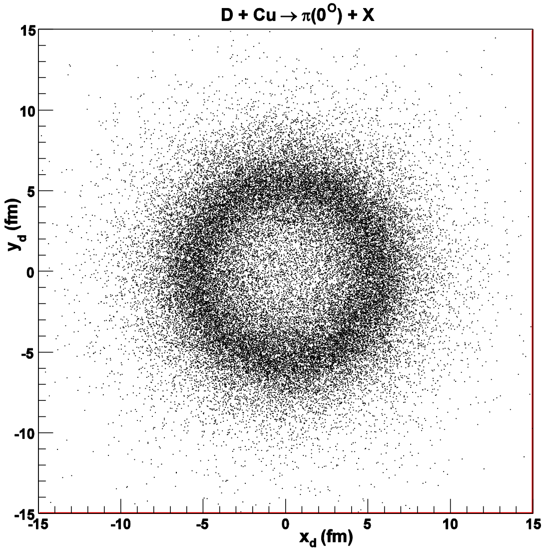
«direct» mechanism

C



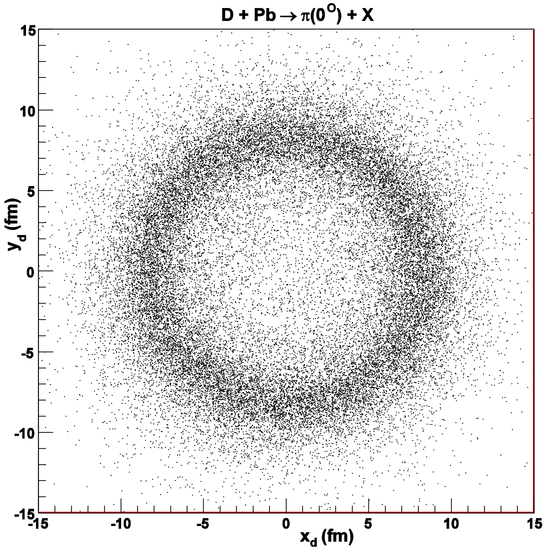
$$b = \sqrt{R^2 - (L/2)^2} = 2.1\,\text{fm}$$

Cu



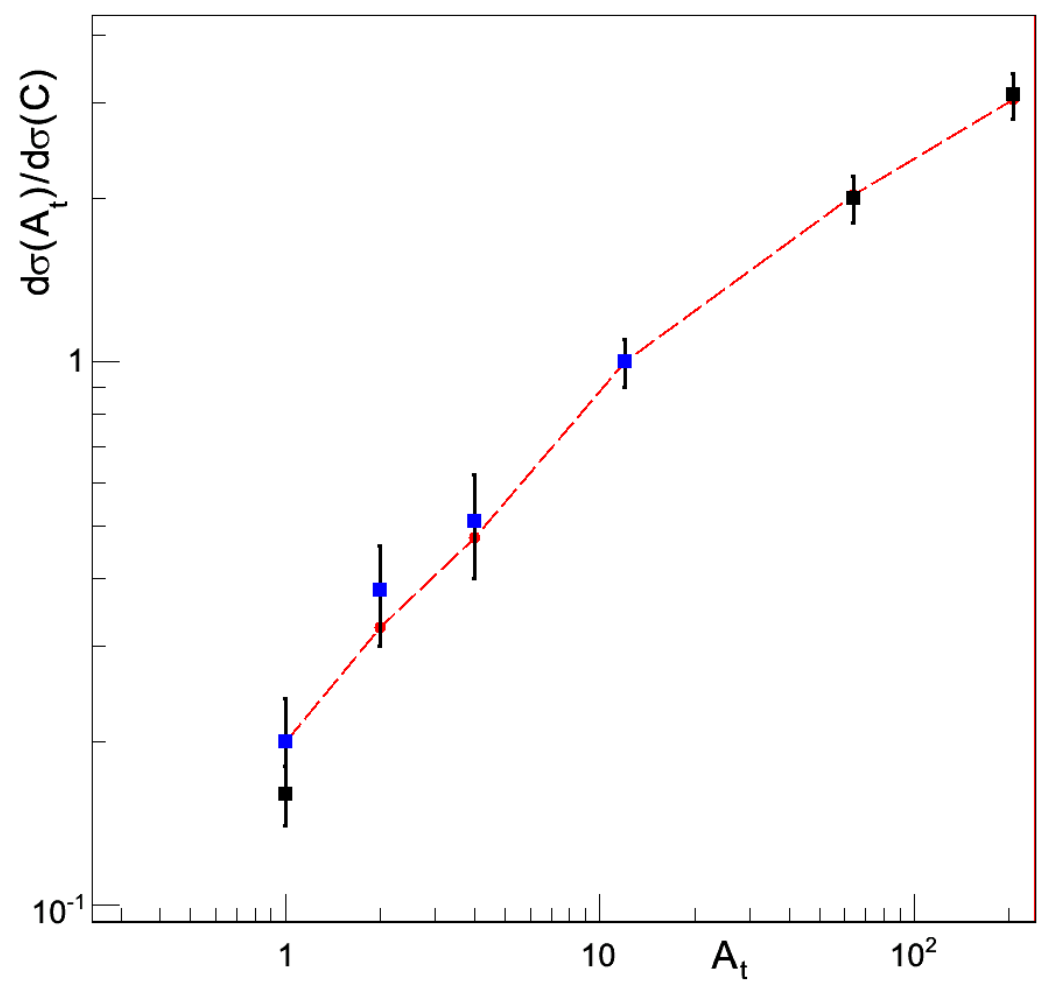
$$b = \sqrt{R^2 - (L/2)^2} = 4.4\,\text{fm}$$

Pb



$$b = \sqrt{R^2 - (L/2)^2} = 6.9\,\text{fm}$$

experiment vs theory



- 🟦 $C + A_t \rightarrow \pi(3^o) + X$

V.K.Bondarev at al.,JINR Communication, E93-84, (1984)

- ■ $D + A_t \rightarrow \pi(0^o) + X$

Yu.S.Anisimov at al., Nucl.Phys., 60, 1070, (1997).

- 🟥 - - - - - Simulation

Pions production

2 «cascades»

$$D + N_t \to \tilde{\pi} + X_1$$

$$\downarrow$$

$$\tilde{\pi} + \mathrm{N_t} \to \pi(0^O) + X_2$$

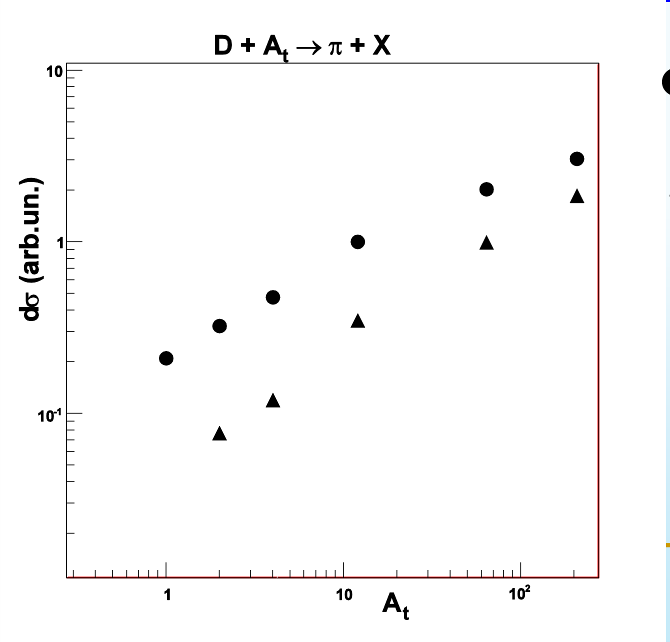
$$\frac{\text{cascade\#1}}{\text{direct}} < 1\%$$

$$D + N_t \to \tilde{p} + X_1$$

$$\downarrow$$

$$\tilde{\mathrm{p}} + \mathrm{N_t} \to \pi(0^O) + X_2$$

$$\frac{\text{cascade\#2}}{\text{direct}} < 0.5\%$$



● - direct

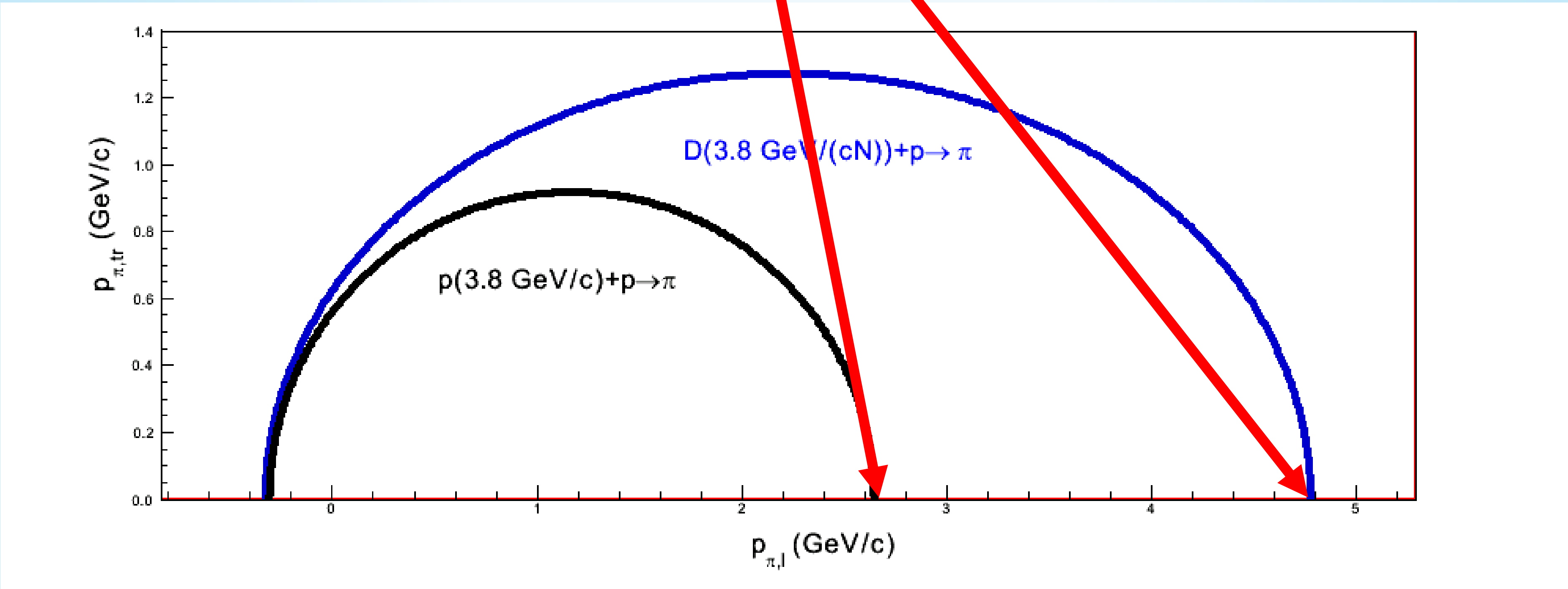
▲ - cascades (#1+#2) x 100

Conclusion I

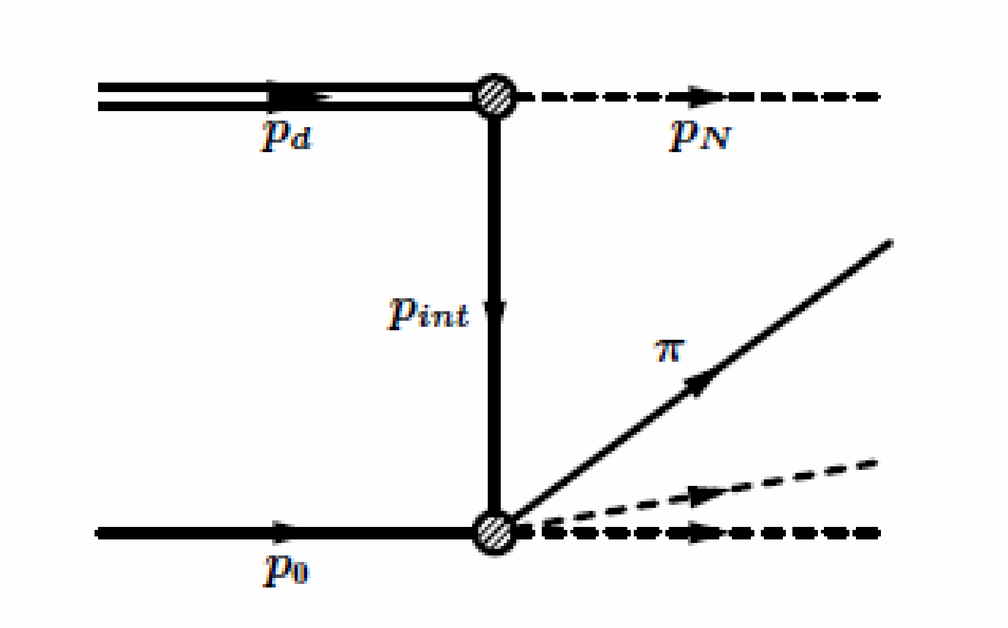
- The reaction of the fragmentation of the incident deuterons into cumulative pions on targets with different atomic mass was discussed. The simulation based on the hadron- hadron scattering gives a good description of the experimental data on the dependence of the cross-section from atomic mass of the target.

- The contribution of the cascade mechanism was studied. It was shown that even for the heaviest nuclei this contribution does not exceed one percent.

Cumulative region

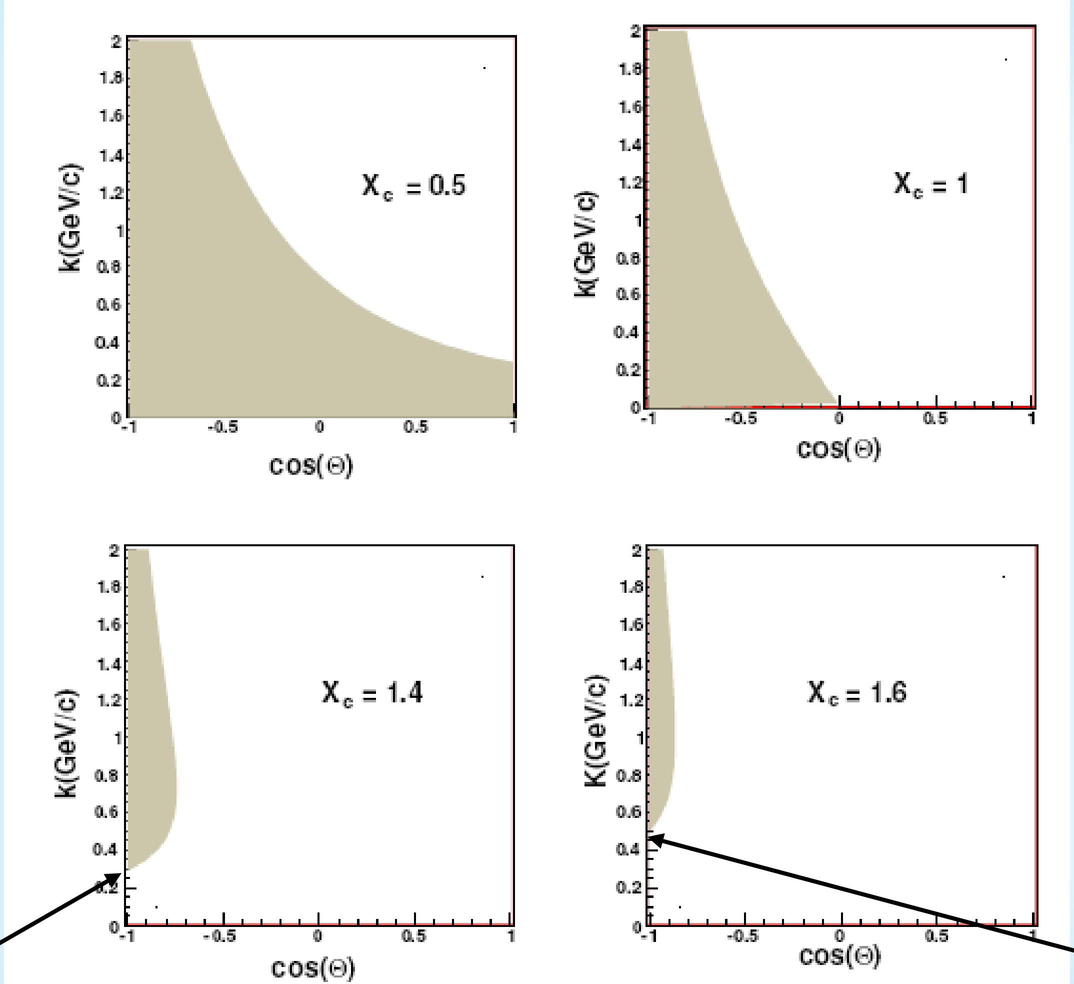


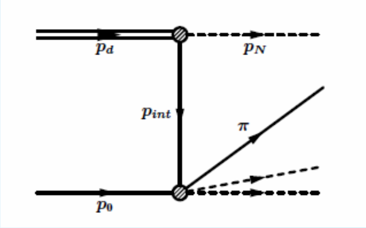
Impulse approximation for pion production in deuteron proton scattering



$$d\sigma = \left| \int \Psi_D f_{NN}(\ldots) d\vec{p}_{int} \right|^2$$

Integration over internal momentum





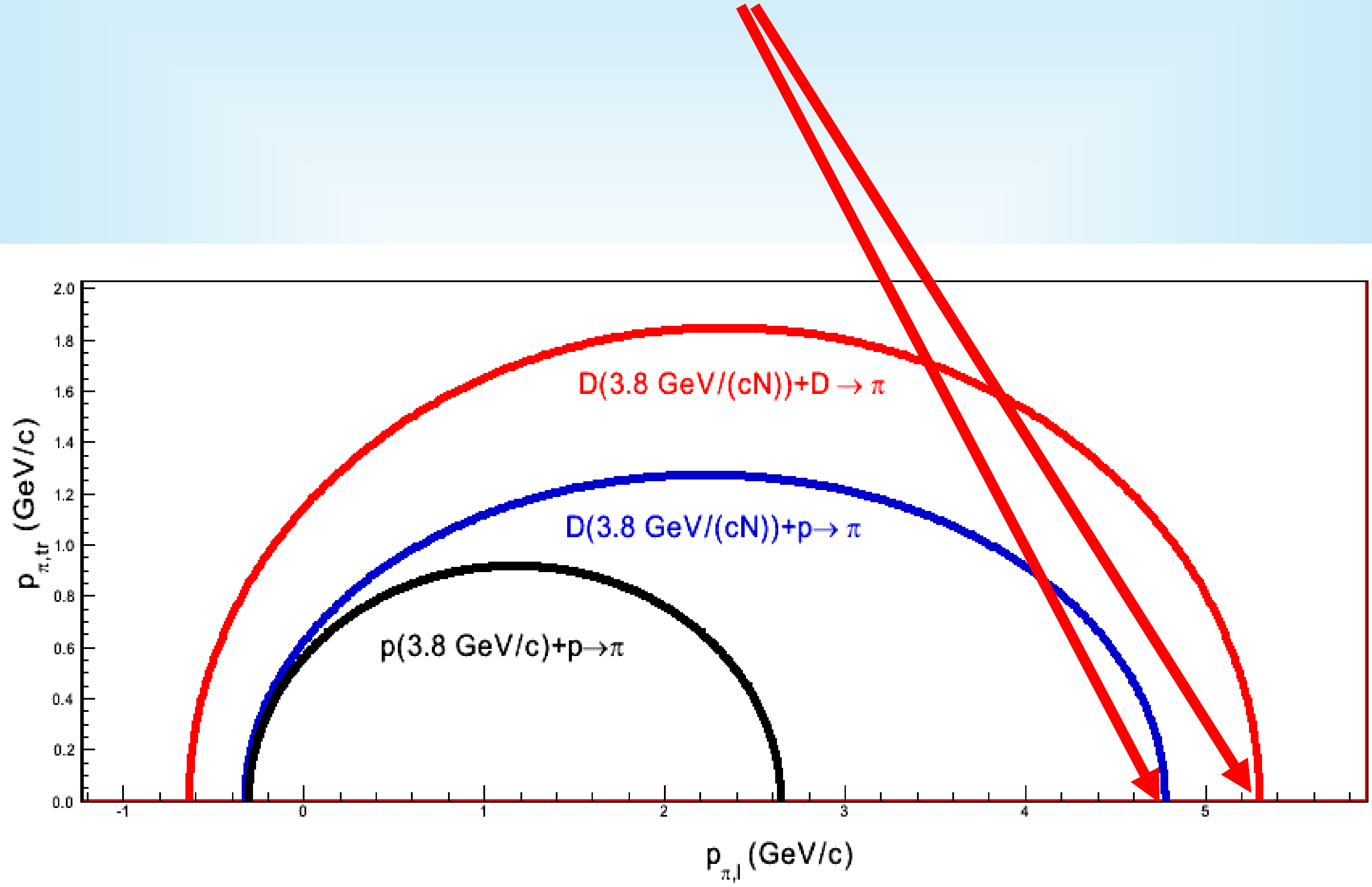
$\vec{p}_{int} \equiv \vec{k}$

$(p_{int})_{min}$

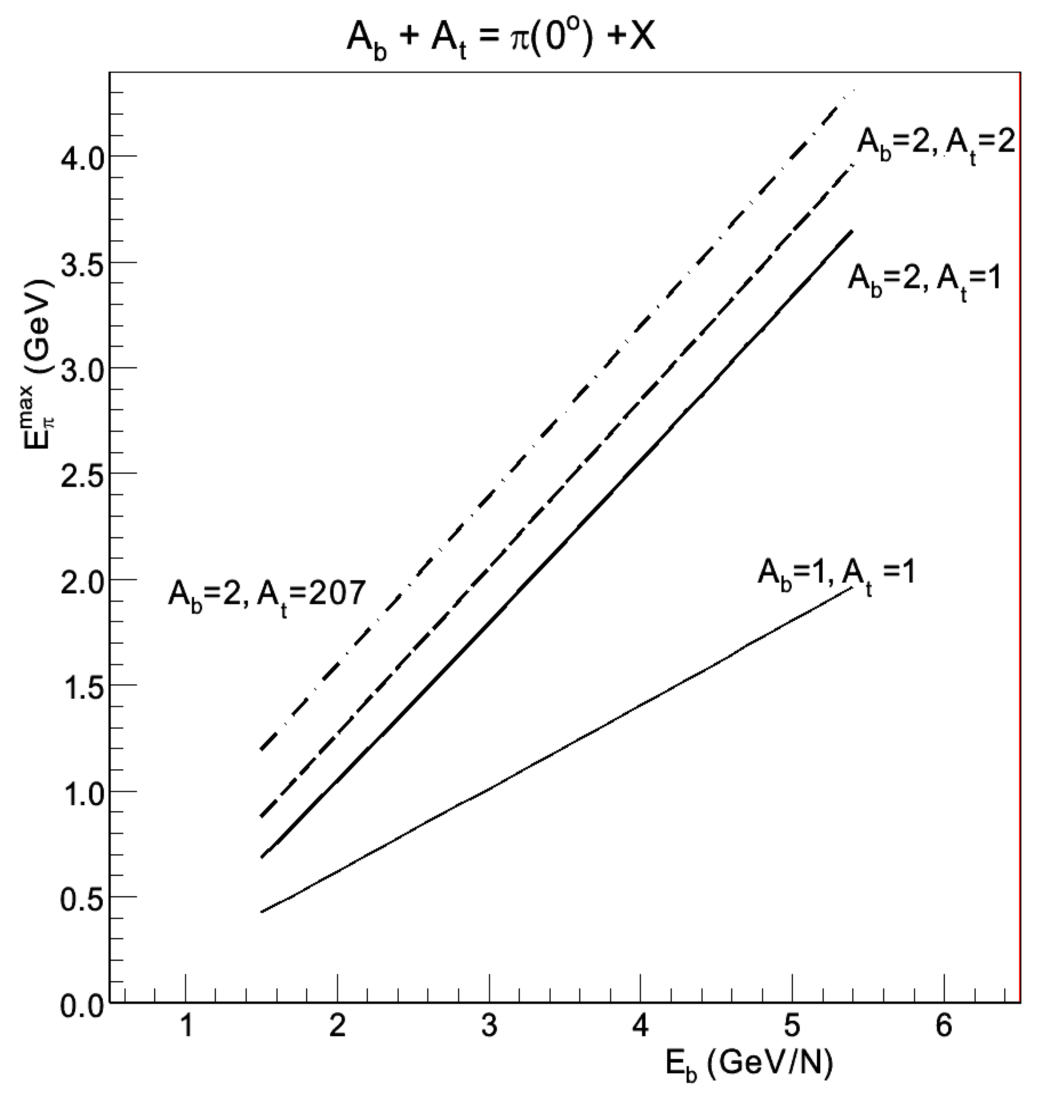
$(p_{int})_{min}$

$$d\sigma = \left| \int \Psi_D f_{NN}(\ldots) d\vec{p}_{int} \right|^2$$

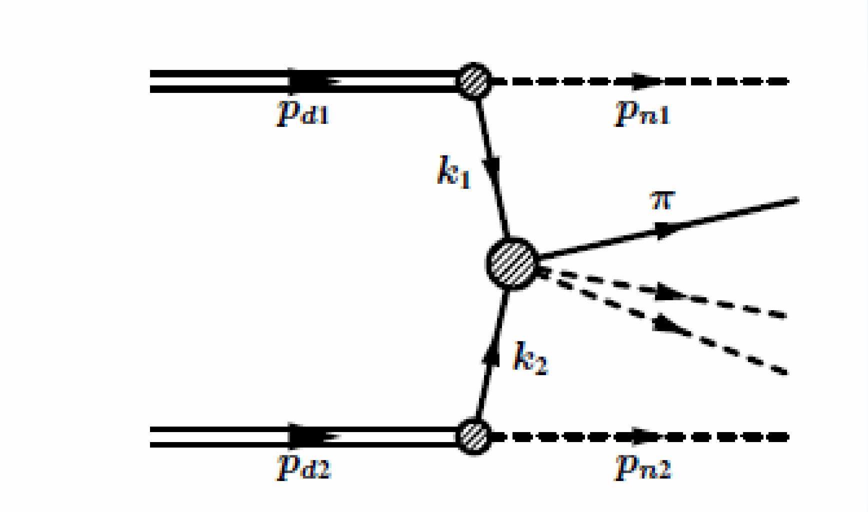
Double cumulative region



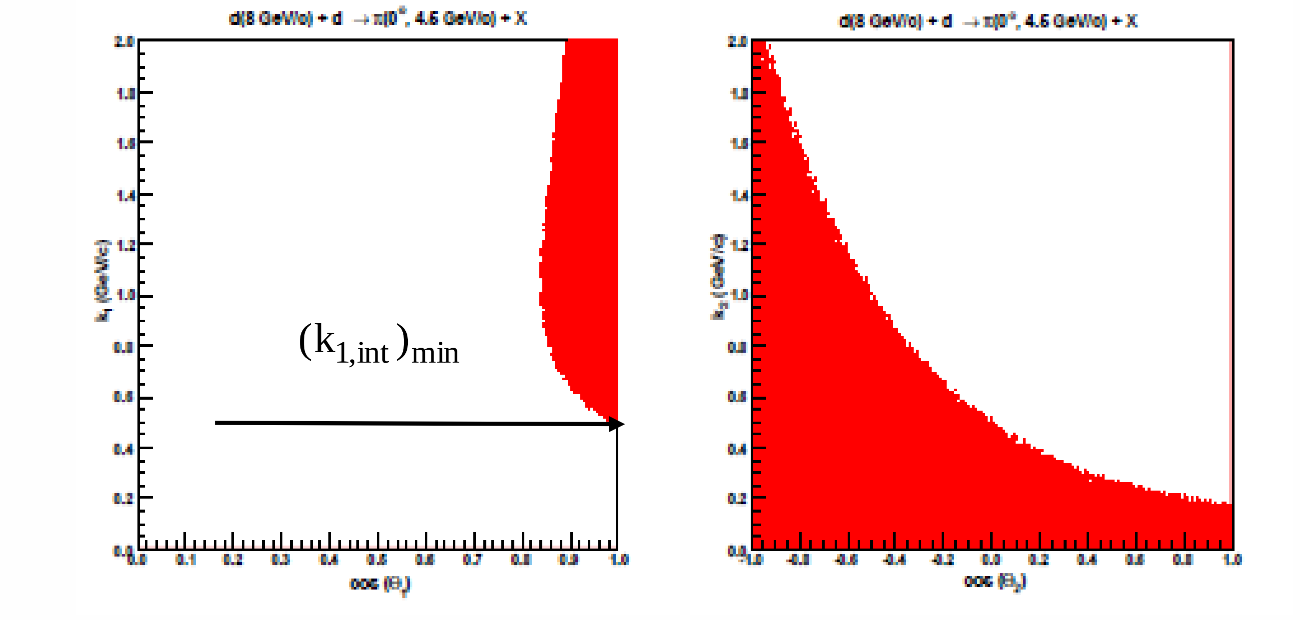
Double cumulative region



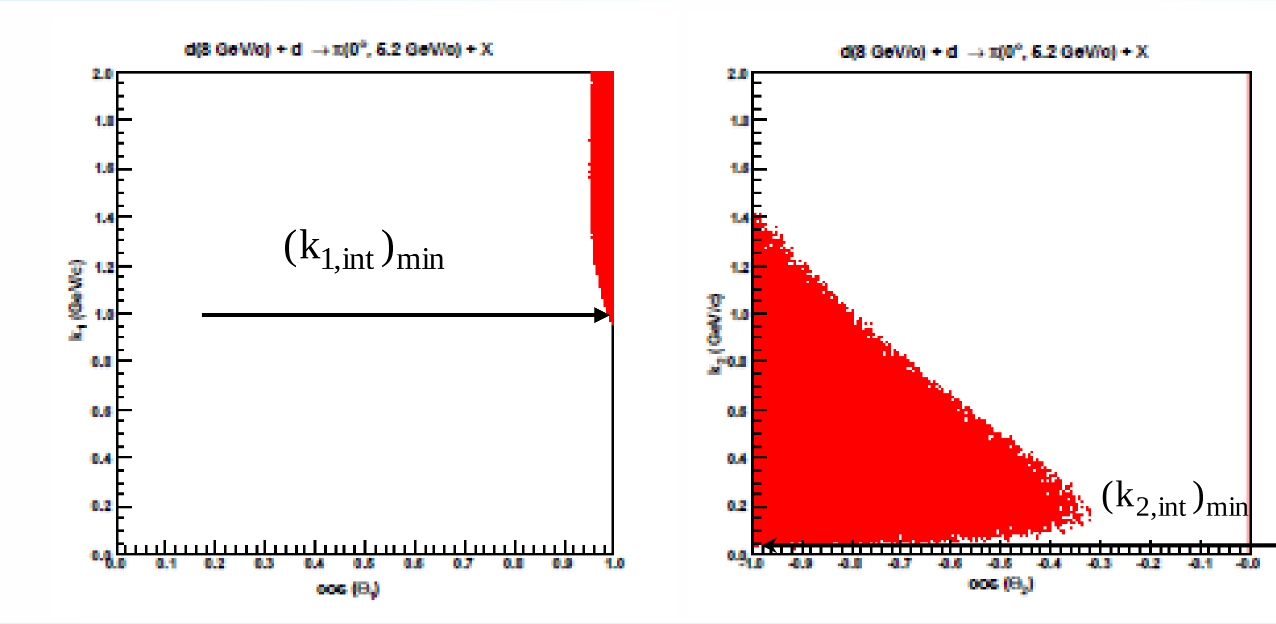
Impulse approximation for pion production in deuteron deuteron scattering



$$d\sigma = \left| \int \Psi_D(k_1)\Psi_D(k_2) f_{NN}(\ldots) d\vec{k}_1 d\vec{k}_2 \right|^2$$



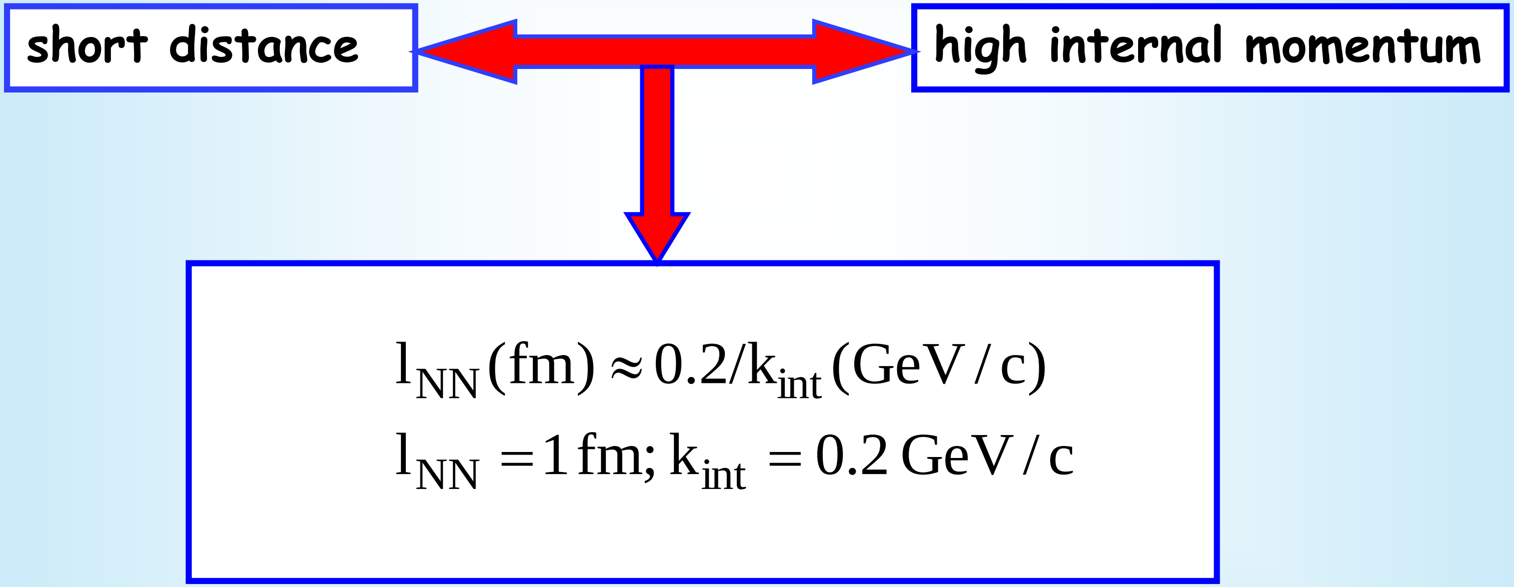
Cumulative region



Double cumulative region

Blokhintsev D.I., JETF (RUS), 33, 1295, (1957) :

«flucton – two (or more) nucleons at short distance»



short distance

high internal momentum

$$l_{NN}(\mathrm{fm}) \approx 0.2/k_{int}\,(\mathrm{GeV/c})$$

$$l_{NN} = 1\,\mathrm{fm};\ k_{int} = 0.2\,\mathrm{GeV/c}$$

Simulation.

Difference between production of cumulative and double cumulative pions

cumulative ~ density of nucleon n_N

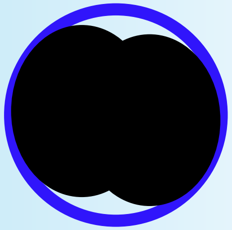
$$d\sigma_c \sim \int \sigma(N\underline{N} \to \pi)\,\underline{n_N(b,z)}\,\overline{W}_D(b,[-\infty,z])\,\overline{W}_\pi(b,[z,\infty])\,bdbdz$$

double cumulative ~ density of fluctons n_F

$$d\sigma_{d-c} \sim \int \sigma(N\underline{F} \to \pi)\,\underline{n_F(b,z)}\,\overline{W}_D(b,[-\infty,z])\,\overline{W}_\pi(b,[z,\infty])\,bdbdz$$

for simulation one needs a model of flucton

Volume model of flucton
A.M.Baldin, PEPAN, 8(3), 429, (1977)



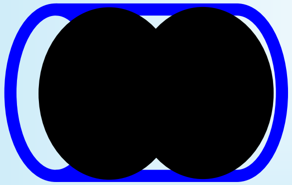
$R_f = 0.8\,\text{fm}$

$R_{Au} = 7\,\text{fm}$

$V_f \approx 2.1\,\text{fm}^3$

$V_{Au} \approx 1\,400\,\text{fm}^3$

Tube model of flucon
Berlad G., Dar A., and Eilam G., Phys.Rev., **D13**, 161, (1976)



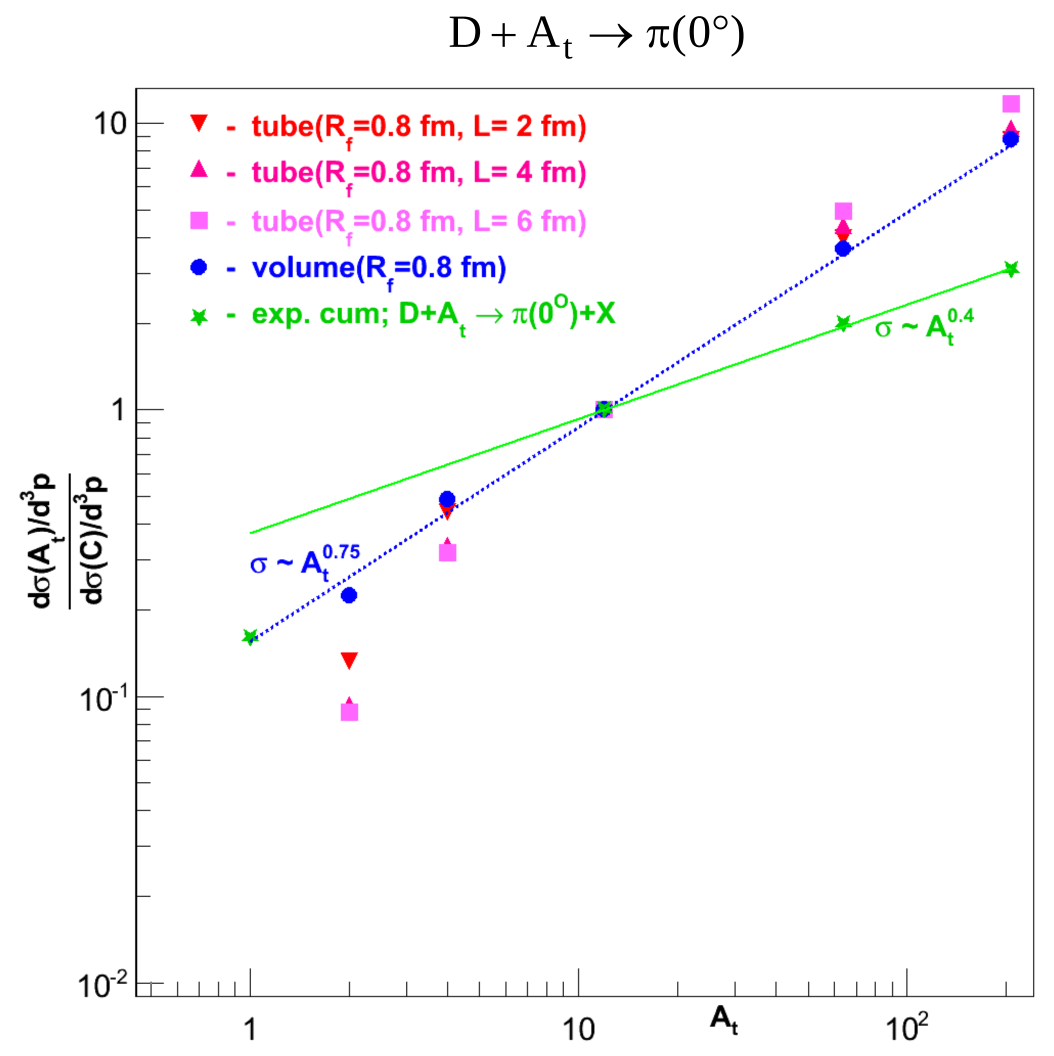
$R_f = 0.8\,\text{fm},\ L = 2\,\text{fm}$

$R_{Au} = 7\,\text{fm}$

$V_f \approx 4.0\,\text{fm}^3$

$V_{Au} \approx 1\,400\,\text{fm}^3$

Dependence of the cross section from atomic mass of target nuclei in cumulative and **double cumulative** pions (volume and tube model of fluctons)

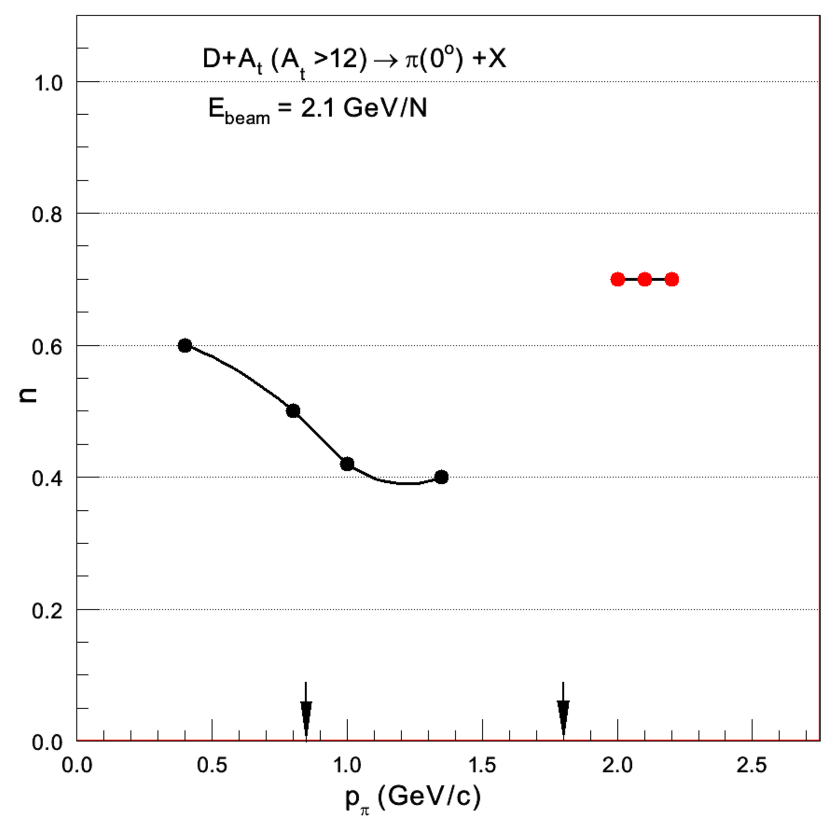


★ exp. data (cum)

Yu.S.Anisimov at al., Nucl.Phys., 60, 1070, (1997).

Dependence of the cross section from atomic mass of target nuclei in cumulative and **double cumulative** (volume model of flucton)

$$D + A_t \to \pi(0°) \qquad E\frac{d\sigma}{d^3p} = C \cdot A_t^n\ ;\ A_t = C, Cu, Pb$$



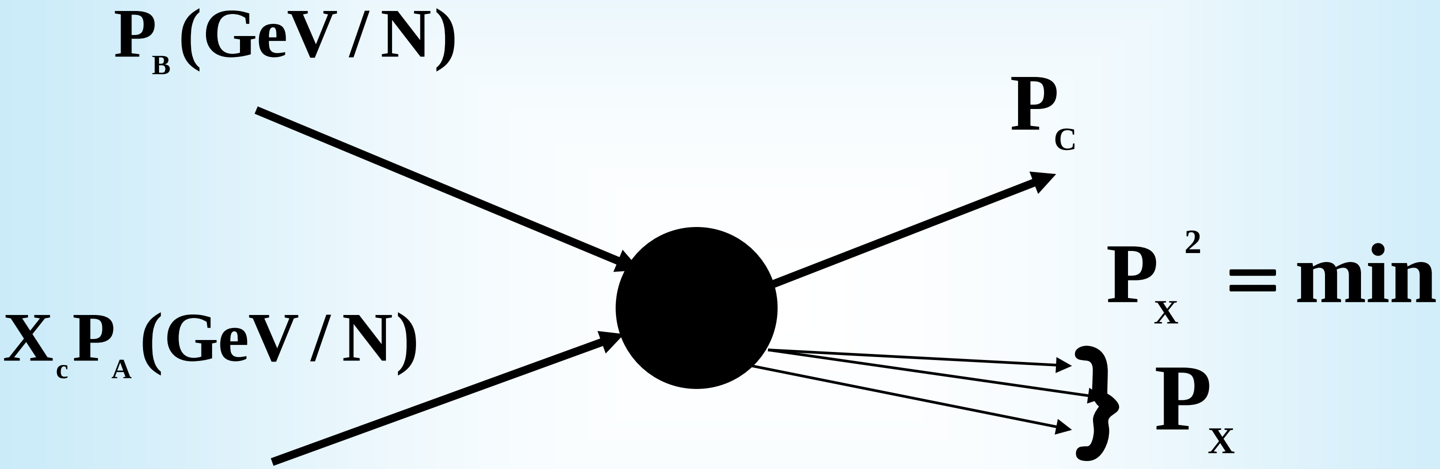
Conclusion II

- The reaction of the fragmentation of the incident deuterons into double cumulative pions on targets with different atomic mass was discussed. The simulation based on the hadron- hadron scattering shows that cross section dependence from atomic mass is sensitive to the model of flucton.

- The simulation with volume and tube models of flucton was performed. From this simulation it was obtained that dependence from the target atomic mass in the double cumulative region is much stronger than in the cumulative region.

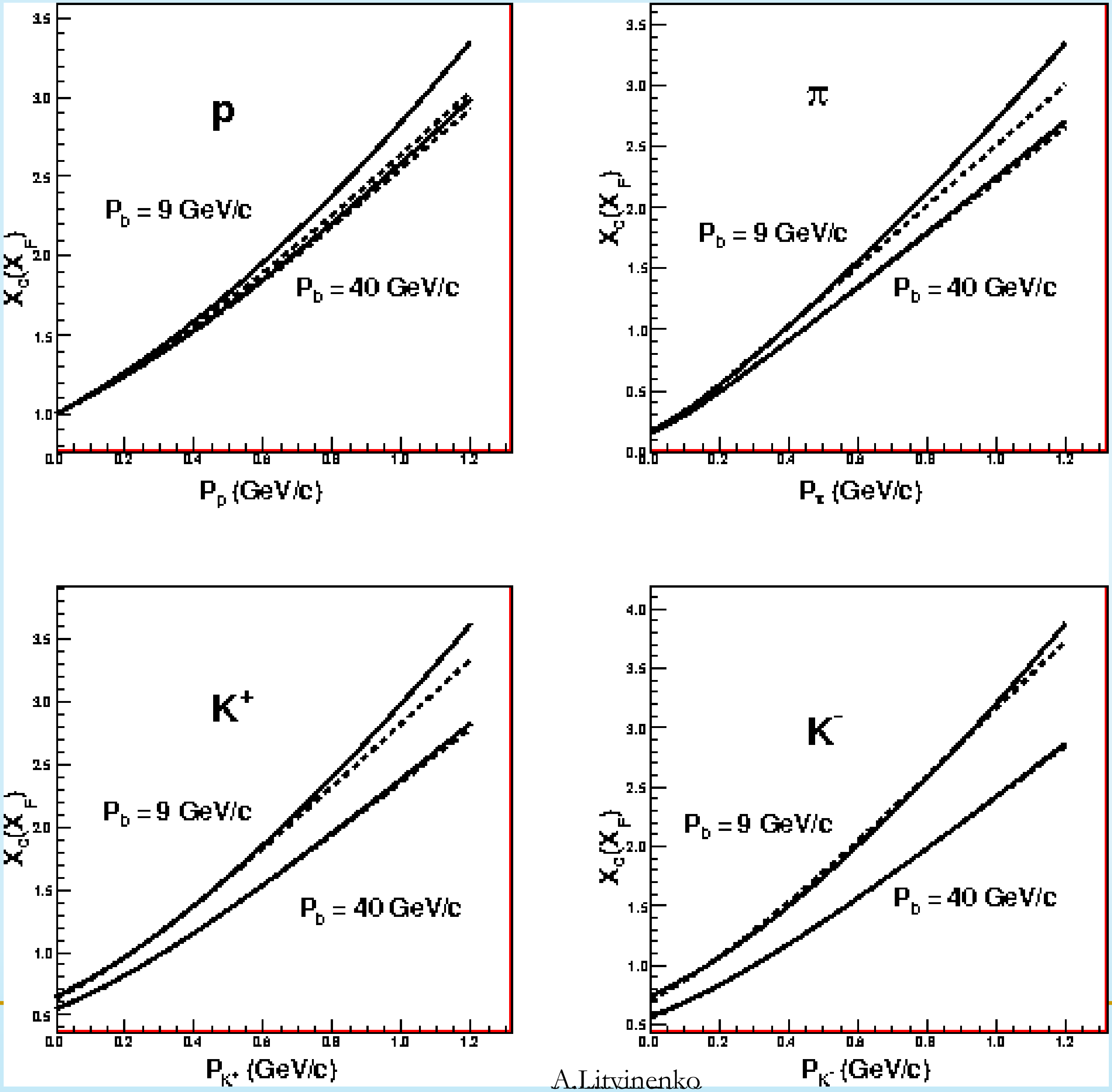
Backup Slides

Cumulative number (Scale variable)



$$X_C = \frac{(P_b P_\pi) - m_\pi^2/2}{(P_b P_t) - (P_t P_\pi) - m_N^2}$$

Cumulative number (Scale variable)



$$d\sigma \sim \exp(-X_c / X_0)$$

Скейлинг (Суперскейлинг?):

- ✓Независимость от начальной энергии;
- ✓Независимость от типа детектируемой (кумулятивной) частицы;
- ✓Независимость от типа налетающей частицы;
- ✓Независимость от ядра мишени для средних и тяжелых ядер;

$$E_В - 5 - 400 \text{ GeV} \qquad c = \pi^{\pm}, K^{\pm}, p^{\pm}, d$$

Налетающие частицы: лептоны, мезоны, ядра

Ядра мишени: дейтрон - свинец

$$d\sigma \sim \exp(-X_c / X_0)$$

Scaling (Superscaling):

(For brevity, it is assumed target fragmentation)

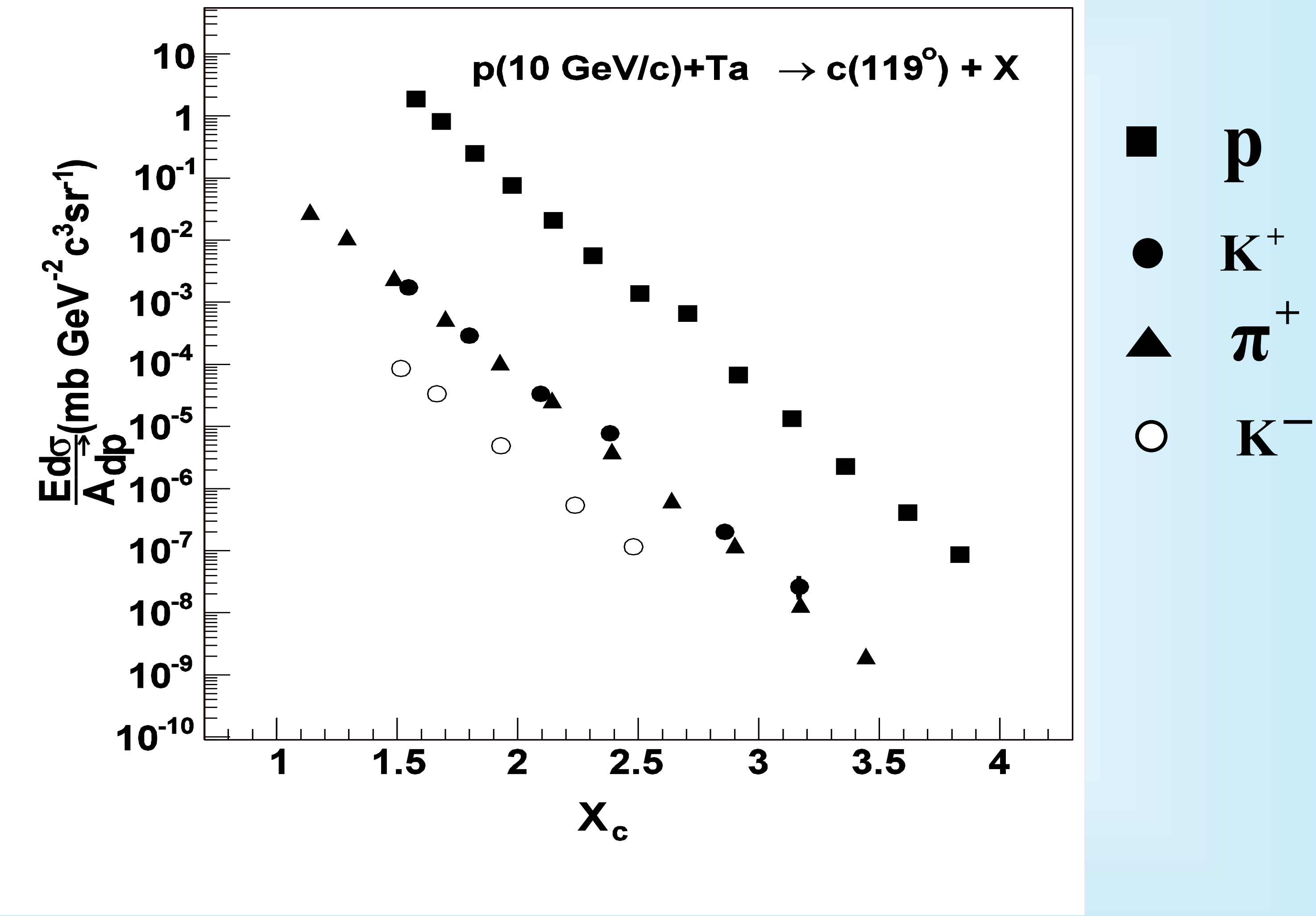
- ✓ Independence from the initial energy
- ✓ Independence from the detected (cumulative) of the particle
- ✓ Independence from the incident particle
- ✓ Independence from the target nucleus for medium and heavy nuclei

$$E_B - 5 - 400\ \mathrm{GeV} \qquad c = \pi^{\pm}, K^{\pm}, p^{\pm}, d$$

incident particle : leptons, mesons, nuclei

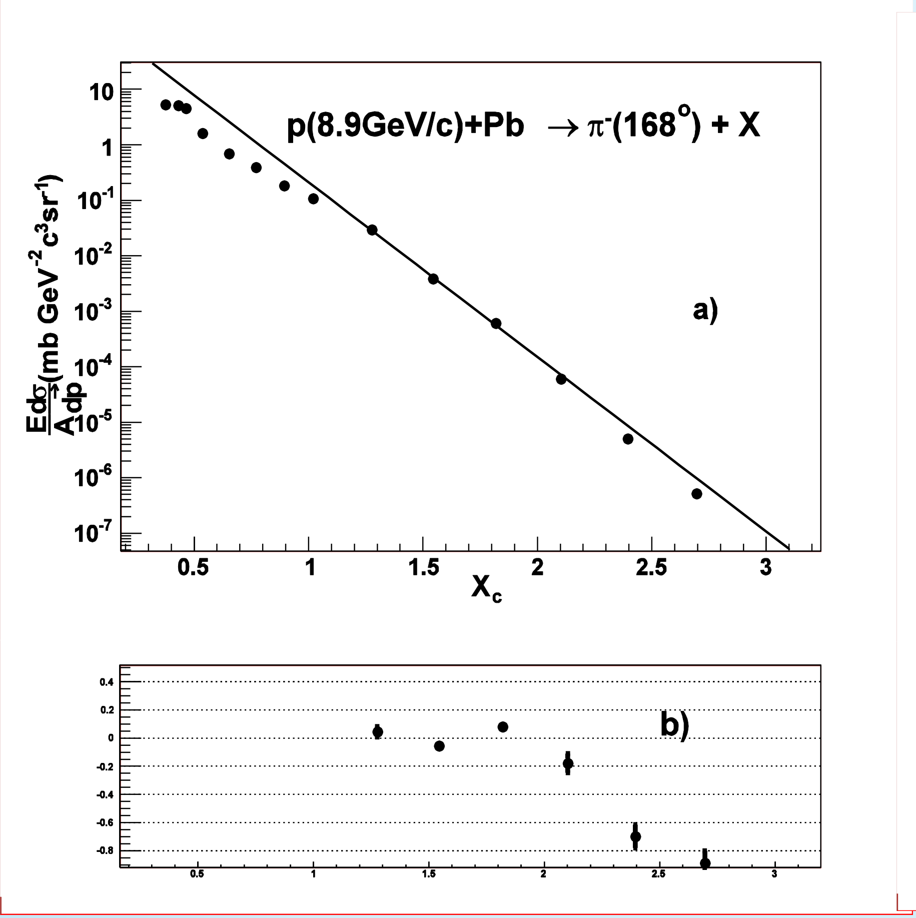
targets: D - … - Pb

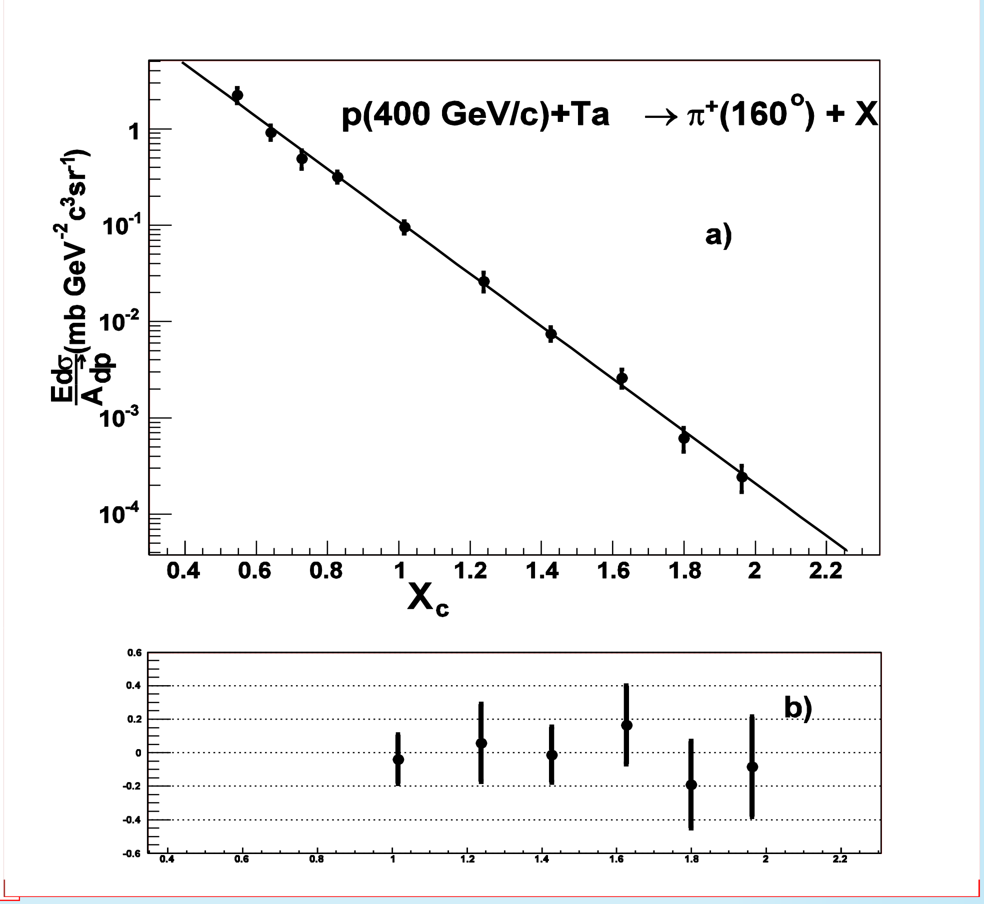
Independence of the cross section behavior from cumulative particle



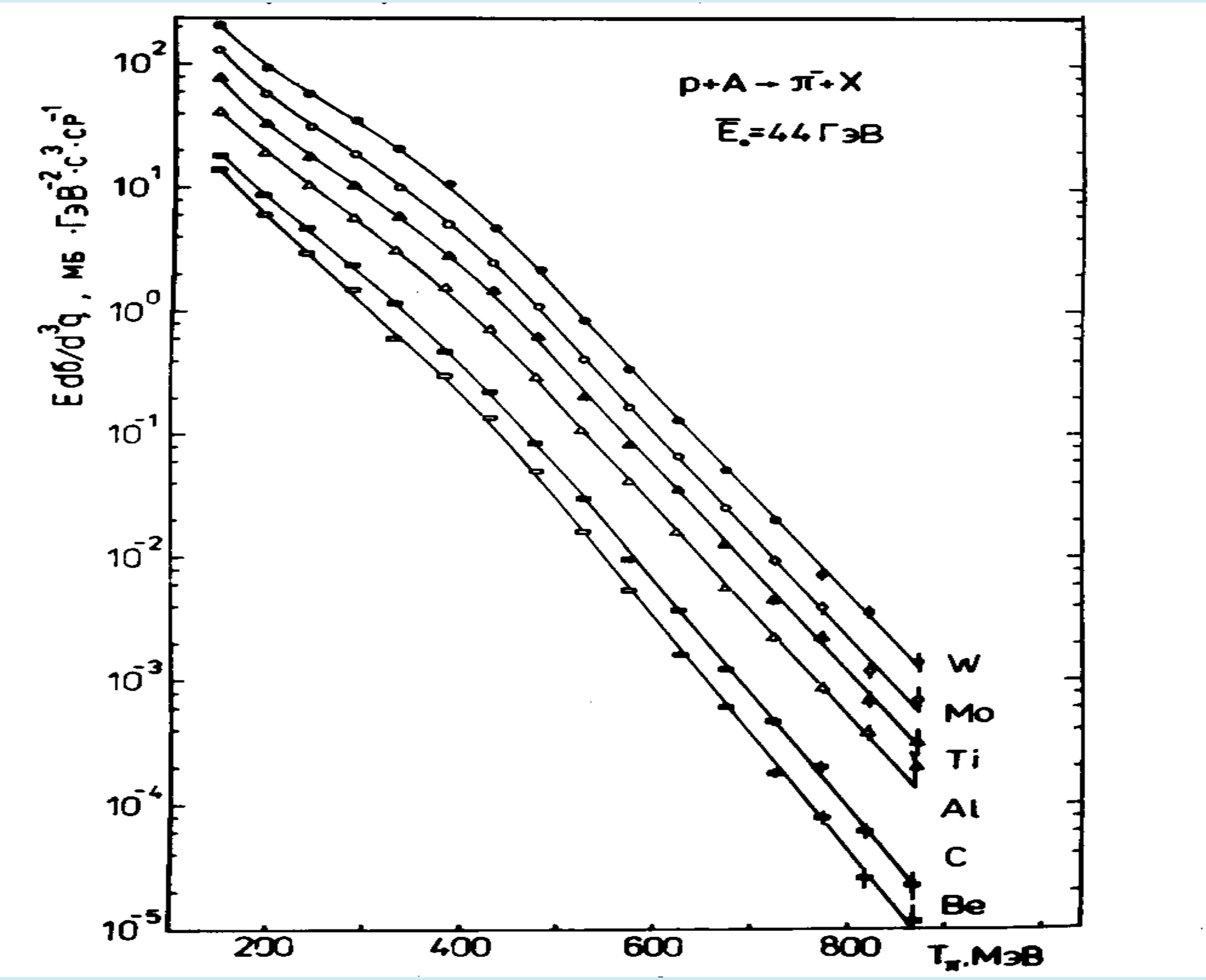
Independence from initial energy.

30-40 %





Independence from fragmenting nuclei



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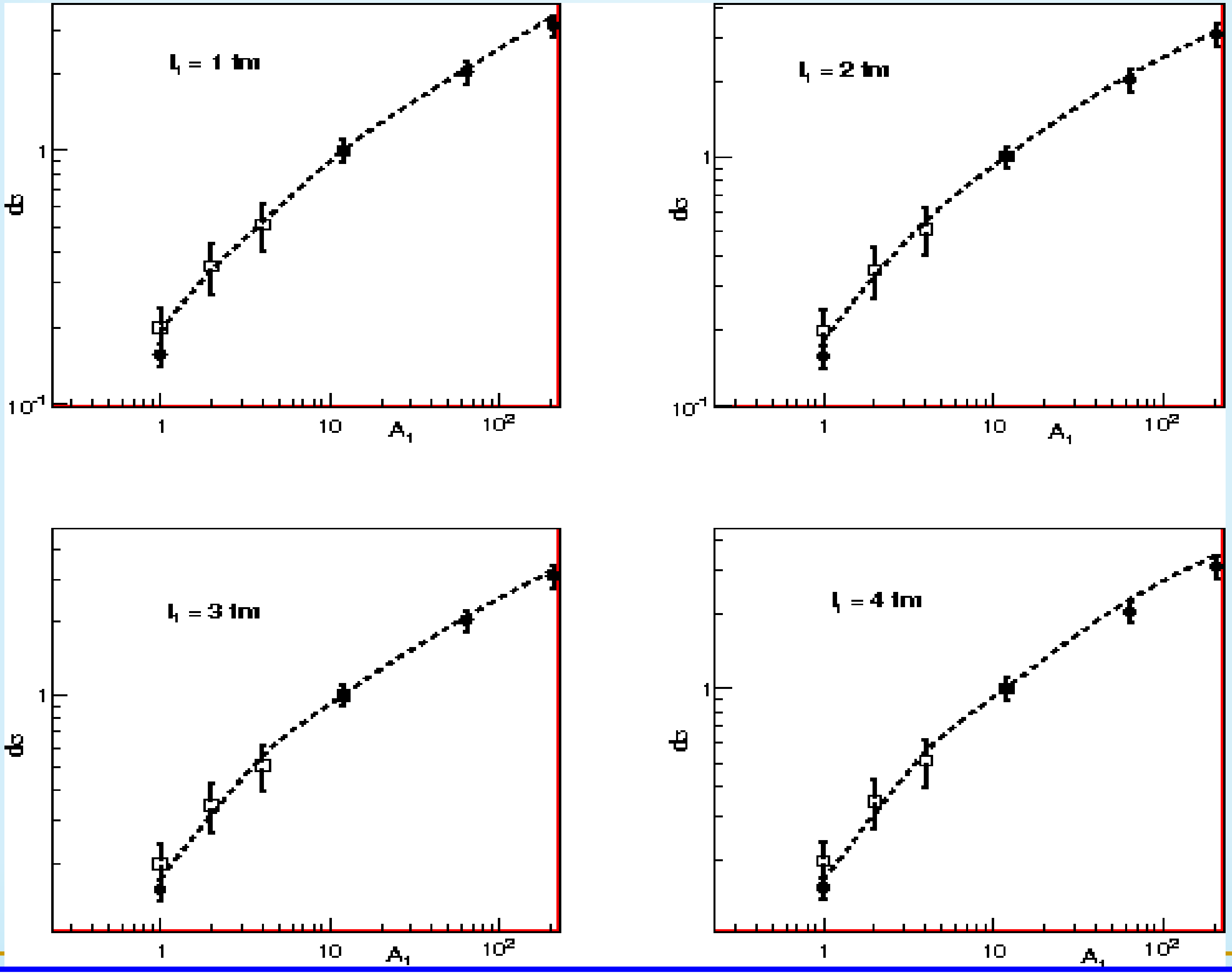
V.K.Bondarev et al., JINR Communication,E1-93-84,Dubna, (1993).



$B(p,D,{}^4He,C)(4.5\,\mathrm{GeV/(cN)}) + C \to \pi(0.5\,\mathrm{GeV},120^\circ)$ ➡ $C(4.5\,\mathrm{GeV/(cN)}) + (p,D,{}^4He,C) \to \pi(4.6\,\mathrm{GeV},3^\circ)$

Theory

$$p_{int} > 0.2$$

$$l_{NN} < 1\text{фм.}$$

$$l_{NN}(\text{фм.}) \sim 0.2/p_{int}(GeV/c)$$

Non nucleon degrees of freedoms

Empirical approaches

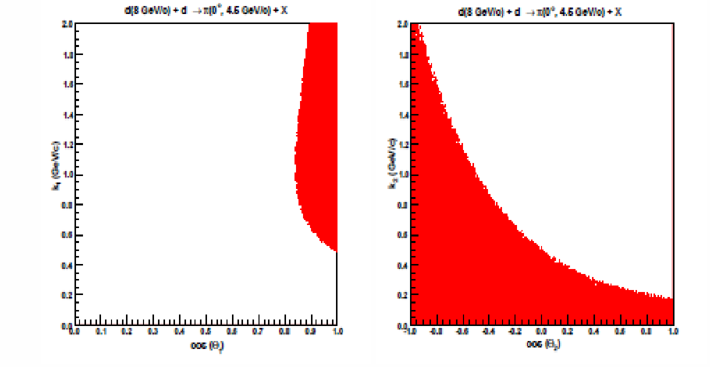
$$(6q);\quad (9q);\quad (N^*N^*);\ (\Delta\Delta);\quad \ldots$$

$$d\sigma \sim F_q(q)$$

Simulation.
Difference between production of cumulative and double cumulative pions

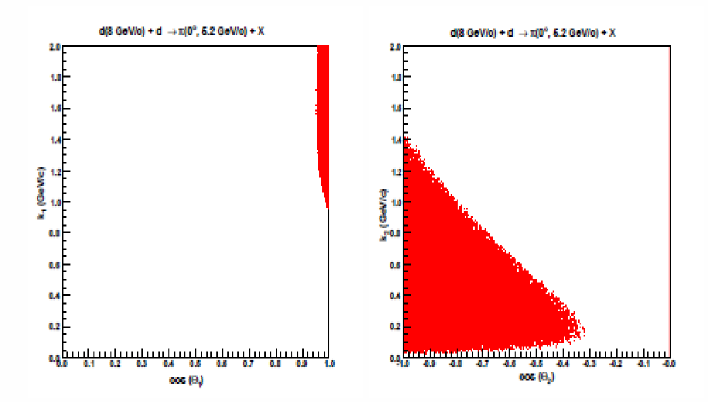
cumulative ~ density of nucleon $\boxed{n_N}$

$$d\sigma_c \sim \int (\sigma \boxed{n_N}) W_D(b)\overline{W}_\pi(b)\,b\,db$$



double cumulative ~ density of fluctons $\boxed{n_F}$

$$d\sigma_c \sim \int (\sigma \boxed{n_F}) W_D(b)\overline{W}_\pi(b)\,b\,db$$

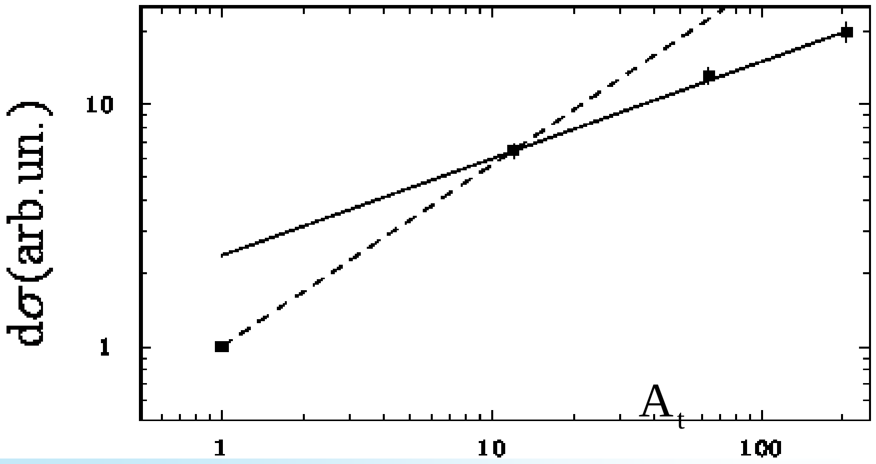


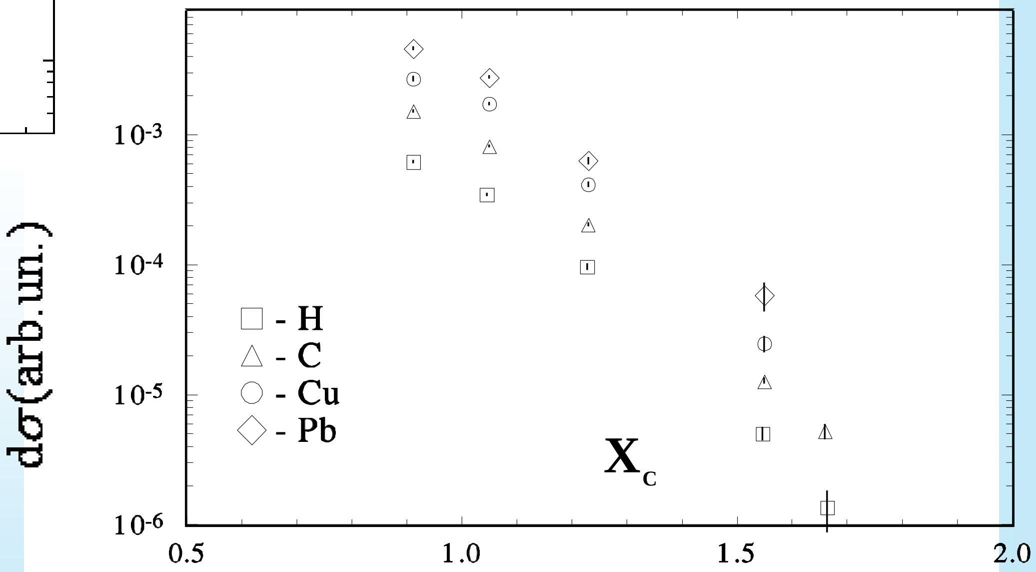
$$d\sigma = \left| \int \Psi_D(k_1)\Psi_D(k_2) f_{NN}(\ldots) d\vec{k}_1 d\vec{k}_2 \right|^2$$

$$E\frac{d\sigma}{d^3p}\ ;\ A_t = H, C, Cu, Pb$$

$D + A_t(H, C, Cu, Pb) \rightarrow \pi(0^O)$

Yu.S.Anisimov at al., Nucl.Phys., 60, 1070, (1997).





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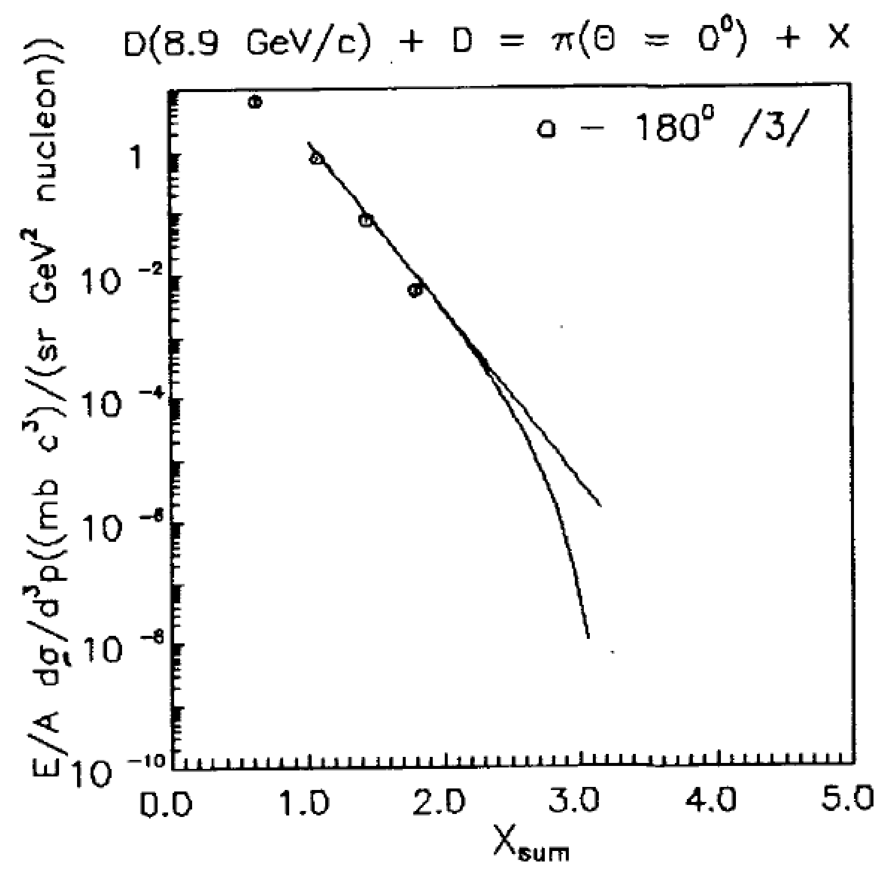
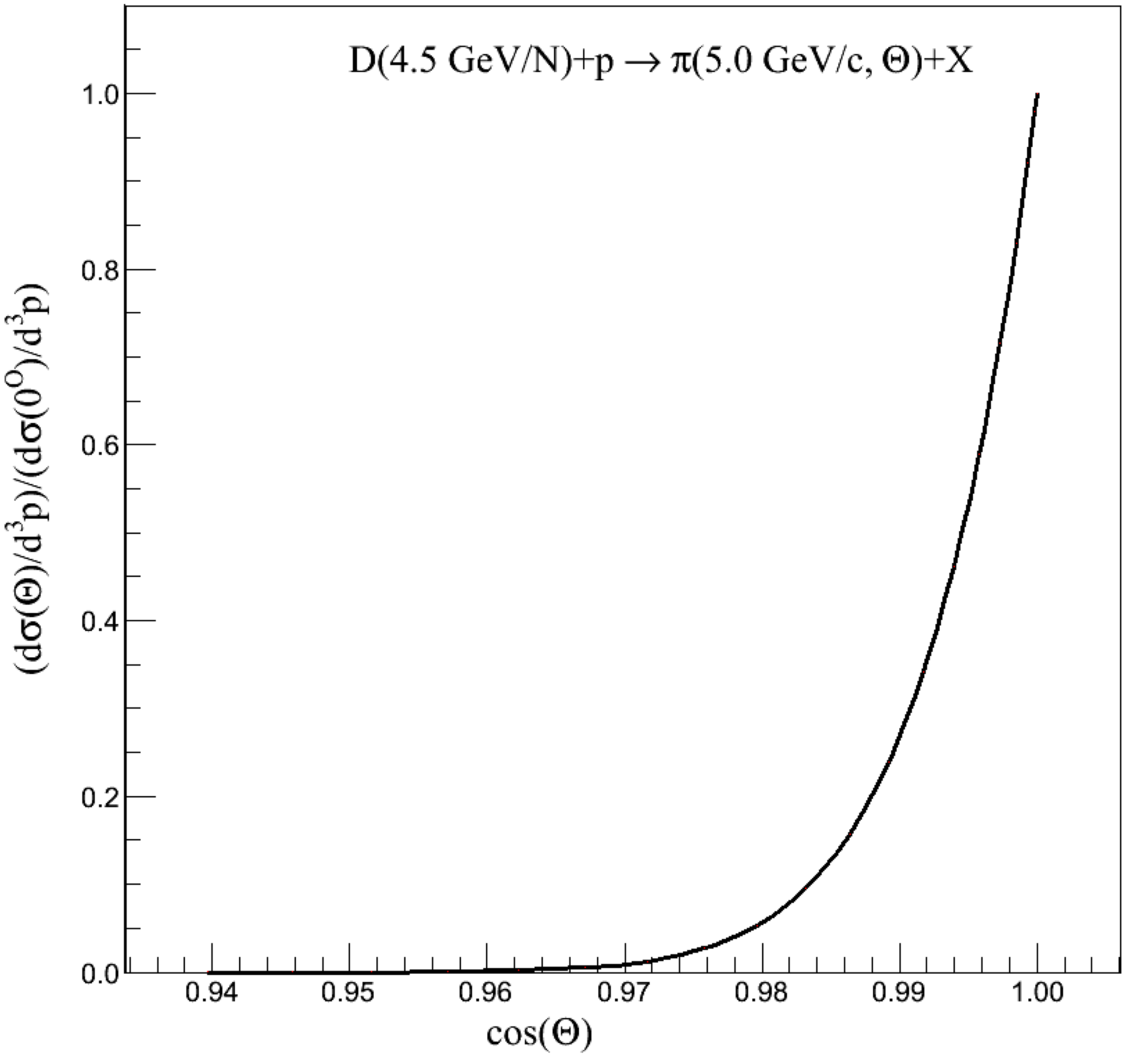
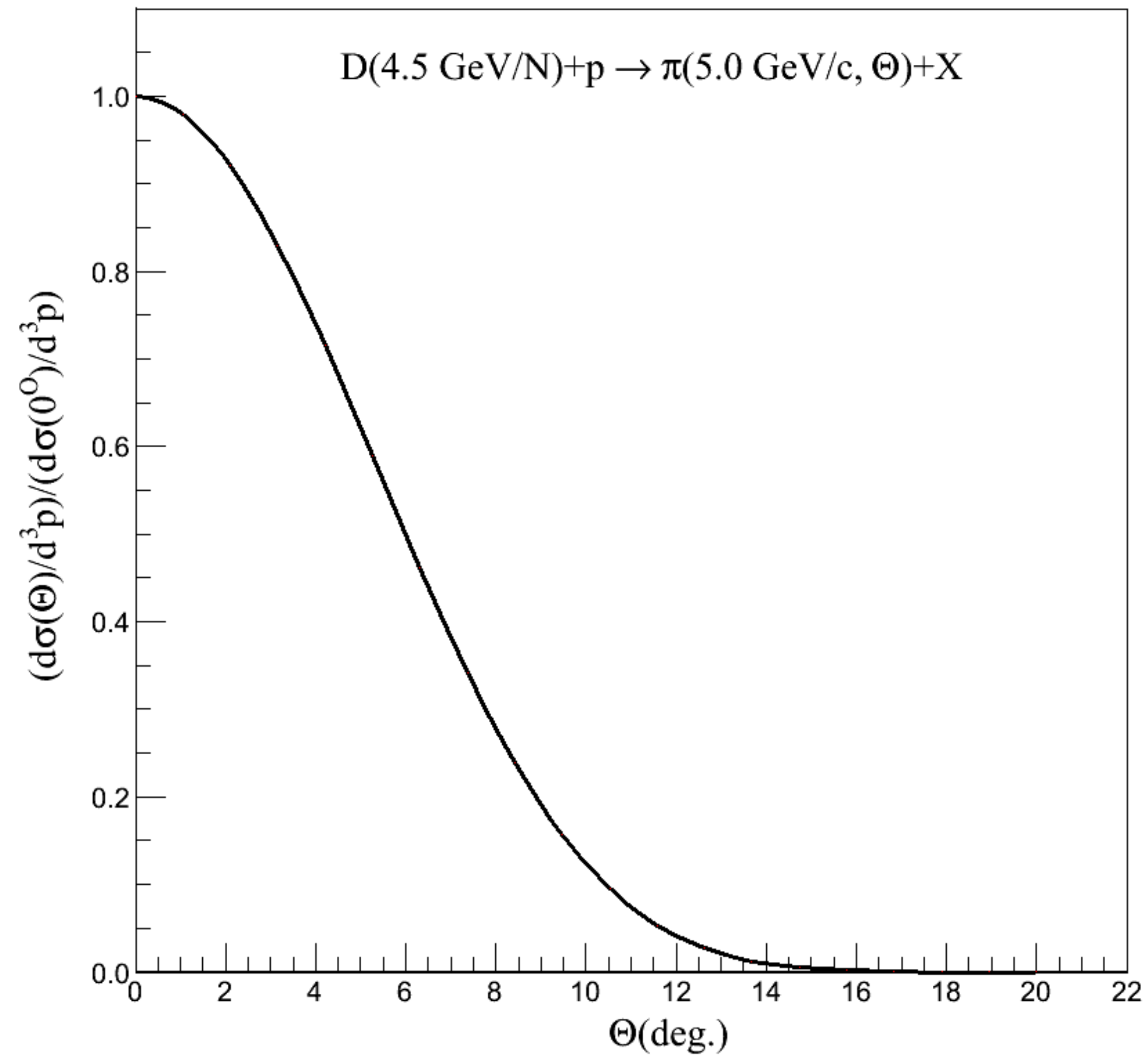


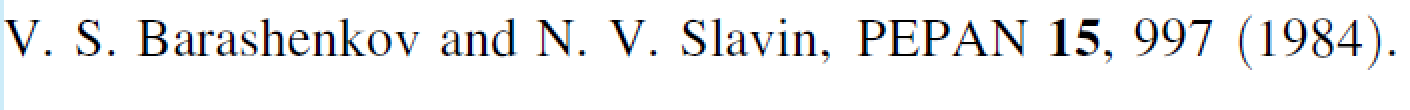

D(4.5 GeV/N)+p → π(5.0 GeV/c, Θ)+X
$(d\sigma(\Theta)/d^3p)/(d\sigma(0^O)/d^3p)$
1.0
0.8
0.6
0.4
0.2
0.0
0.94
0.95
0.96
0.97
0.98
0.99
1.00
cos(Θ)


D(4.5 GeV/N)+p → π(5.0 GeV/c, Θ)+X
(dσ(Θ)/d³p)/(dσ(0°)/d³p)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
18
20
22
Θ(deg.)

$$(N,\pi) + N_t \to (N,\pi) + X$$

$$E\frac{d\sigma}{d\vec{p}} = C \cdot \exp(\beta t);\ t = (P - P_0)^2 \qquad \sigma_{tot} = \int E \frac{d\sigma}{d\vec{p}} \frac{d\vec{p}}{E}$$

$$N + N_t \to \pi + X$$



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duality- HOW IT IS LOOKS LIKE