Fritiof (FTF) model in Geant4, latest improvements

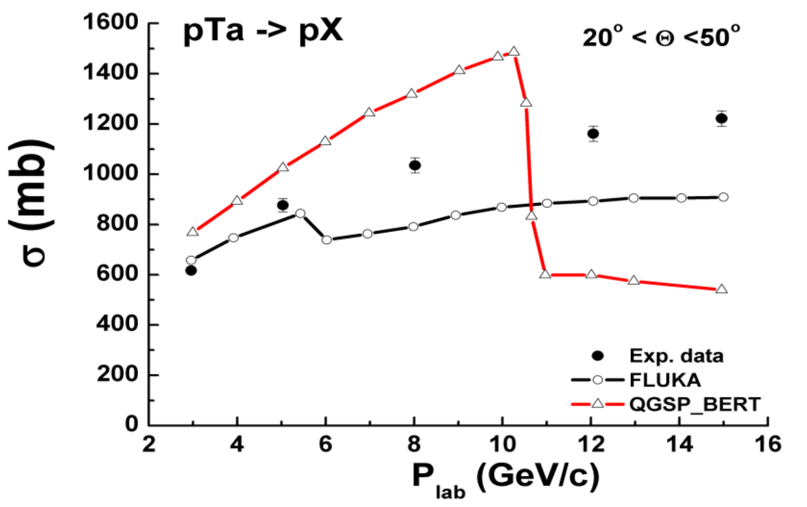
V. Uzhinsky (Geant4 hadronic working group)

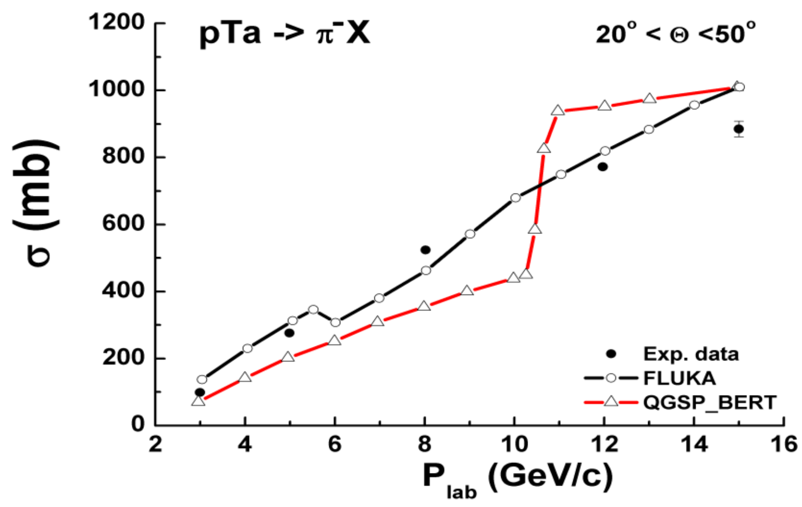
EUDET Annual meeting, 29-09-2010

HARP-CDP hadroproduction data: Comparison with FLUKA and GEANT4 simulations.

HARP-CDP Collaboration (A. Bolshakova *et al.*) CERN-PH-EP-2010-017, Jun 2010. 21pp.

Submitted to Eur.Phys.J.C, e-Print: arXiv:1006.3429 [hep-ex]





All MC models (Geant4, LAQGSM, DPMJET, UrQMD) assume that there is a change in the hadron-nucleus interaction mechanism at Plab ~4 – 10 GeV/c.

Questions:

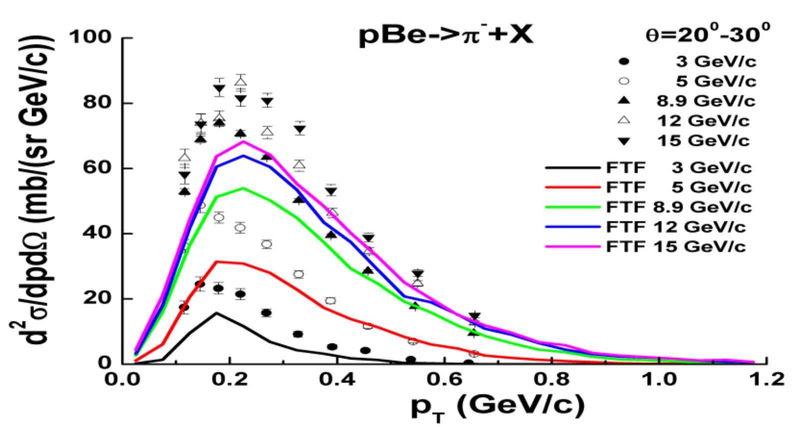
1. Is there a real transition in the nature? What is its physics?
2. What can we do to improve the MC models?

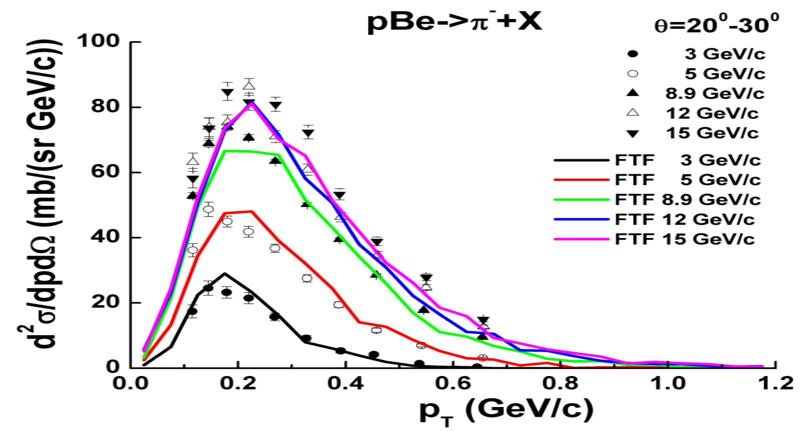
Why does not the HARP-CDP group use the FTF-BERT Physics List announced as one of the best PL for LHC collaborations?

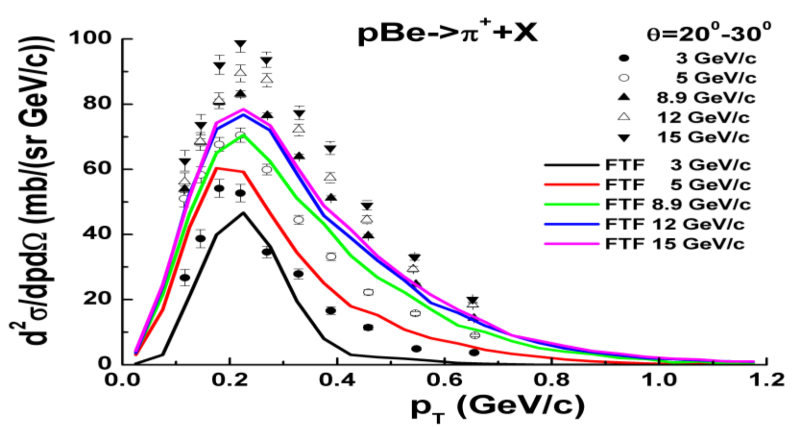
How well does the FTF model evolve.

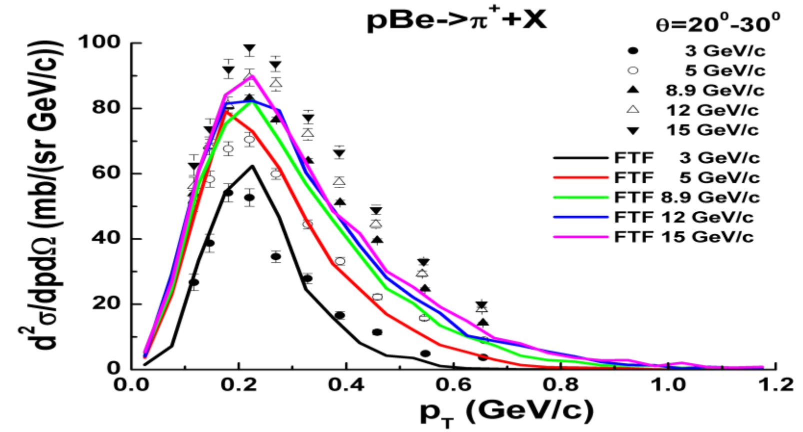
FTF, June 2010

FTF, September 2010









FTF model is going in the right direction! But it was very heavily to improve it.

New things have been implemented in FTF last time!

1. Phase space restrictions at low mass string fragmentation
2. Correction of intra-nuclear interaction number
3. Tuning of reggeon cascading parameters

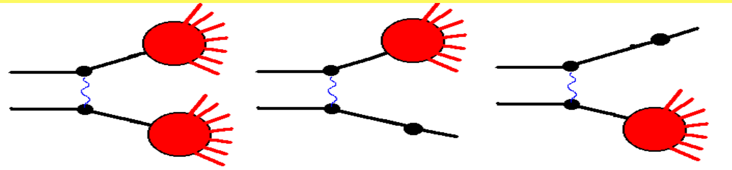
Short description of the models

B. Andersson et al., Nucl. Phys. B281 (1987) 289;
B. Nilsson-Almquist and E. Stenlund, Comp. Phys. Comm. 43 (1987) 387.

Hadron-hadron interactions are modeled as binary kinematics

$a + b \rightarrow a' + b'$, $m_a' > m_a$ $m_b' > m_b$

where a' and b' are excited states of the initial hadrons a and b.

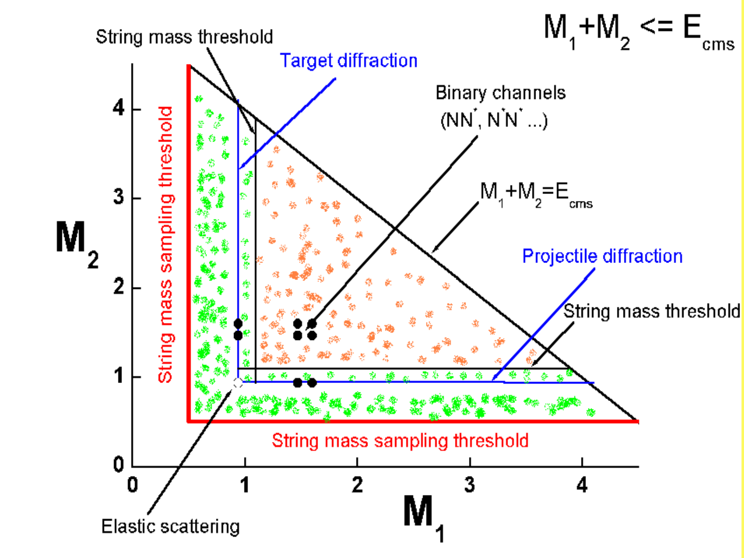


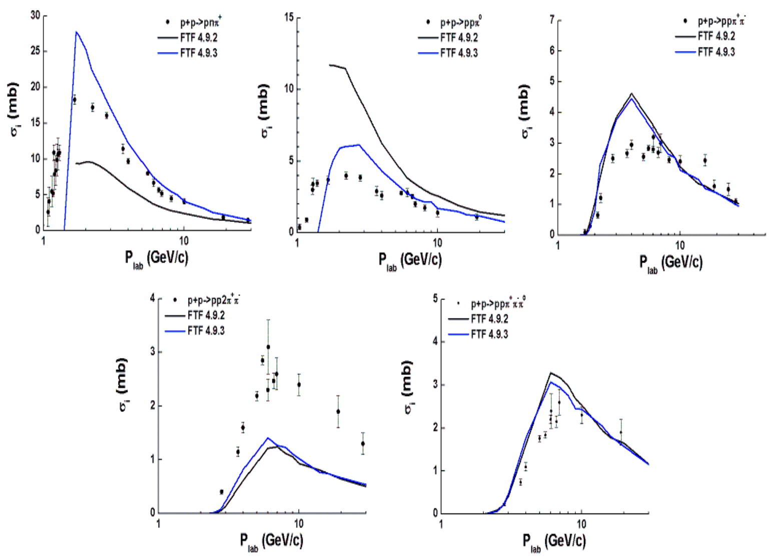
$$dW \propto \frac{dM_1}{M_1}, \qquad dW \propto \frac{dM_2}{M_2}$$

Key parameters

$$M_{string} = 1.1\ GeV\ (N),\quad 1\ GeV\ (\pi),\quad 1.1\ GeV\ (K)$$

$$M_{sampling} = 0.94\ GeV\ (N),\ 0.75\ GeV\ (\pi),\ 0.85\ GeV\ (K)$$

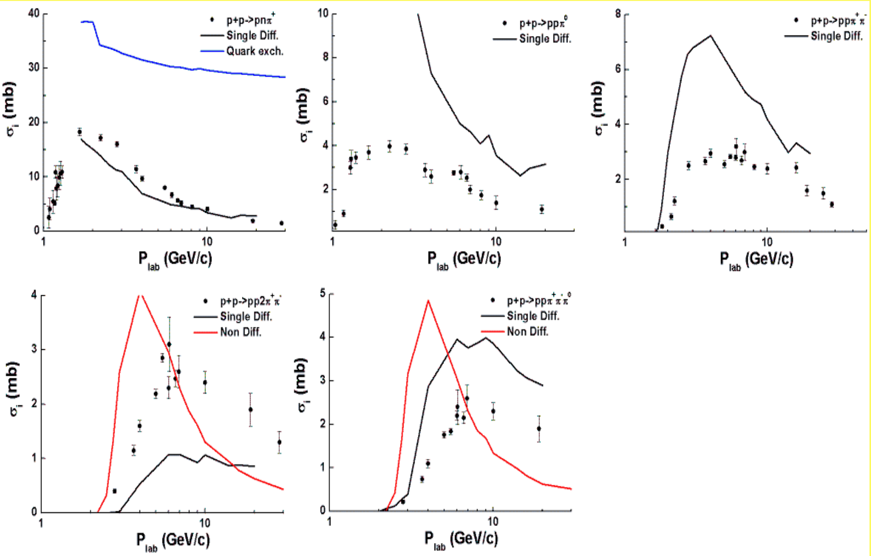




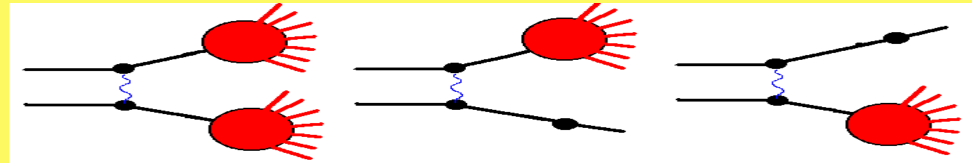
Quark exchange was introduced. It improved the results.

More adequate description of PP and PiP interactions is needed!

Phase space restrictions at low mass string fragmentation



Separate simulation of the single diffraction and non-diffraction interactions.



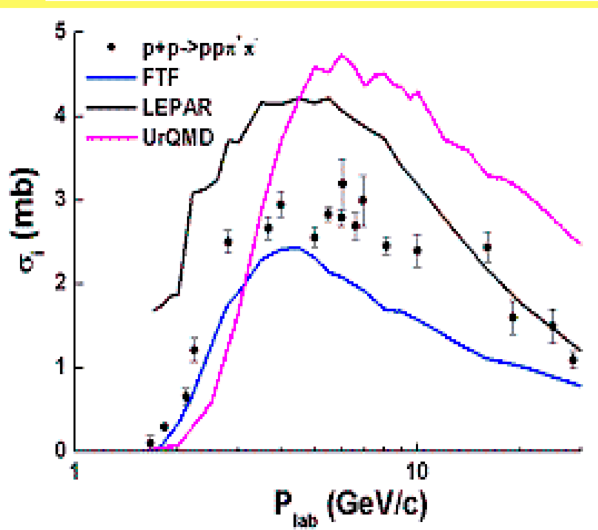
pp→ppπ⁺π⁻

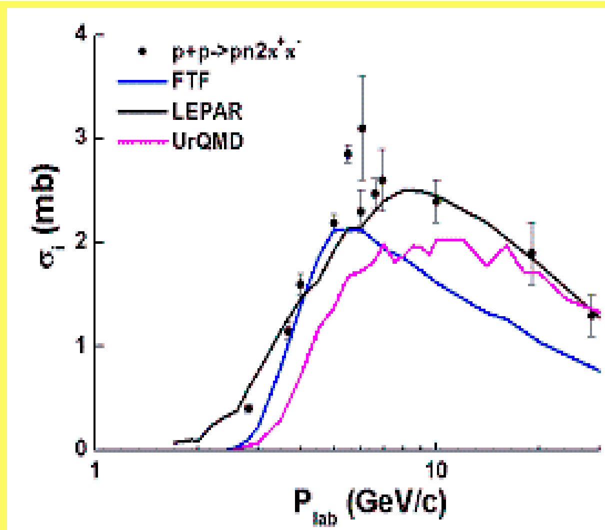
Final state: single diffraction

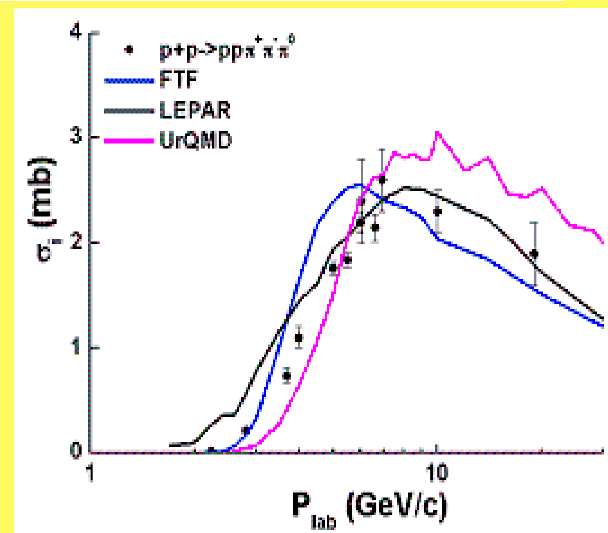
P(Δ⁺⁺π⁻)	XXX
P(Δ⁰π⁺)	X
P(Pπ⁺π⁻)	3

SplitLast
Too many delta's!
P(B3/2)=P(B1/2)?

Solution: probability of a final state is proportional to PS~$q_{2\ \text{part. decay}}$





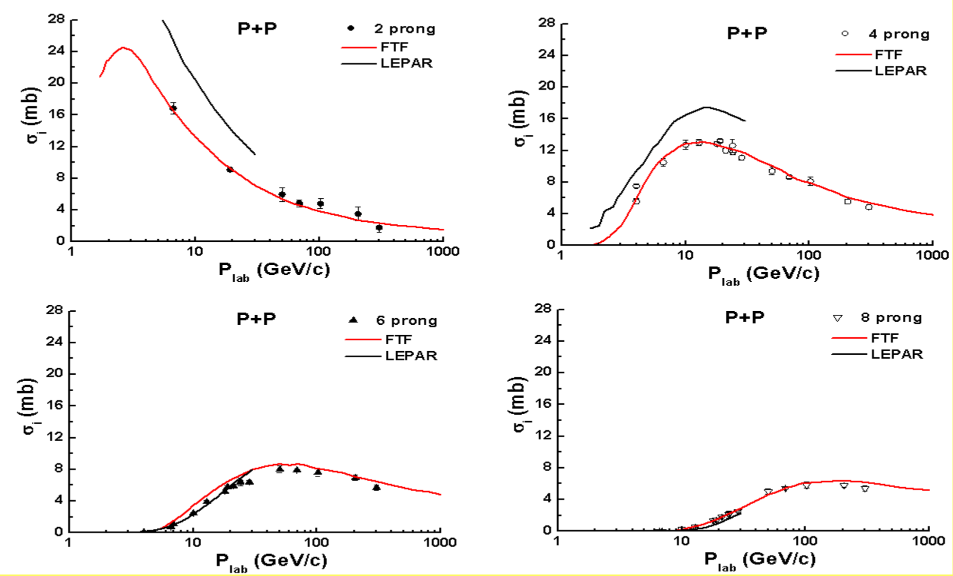


PP interaction, channel cross sections

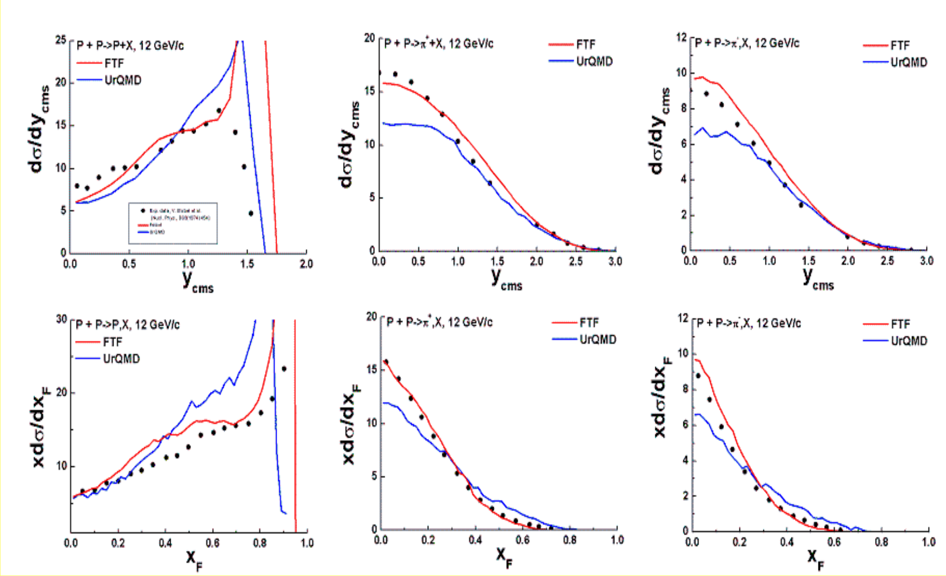
Phase space restrictions at low mass string fragmentation

Excellent results for PP interactions!

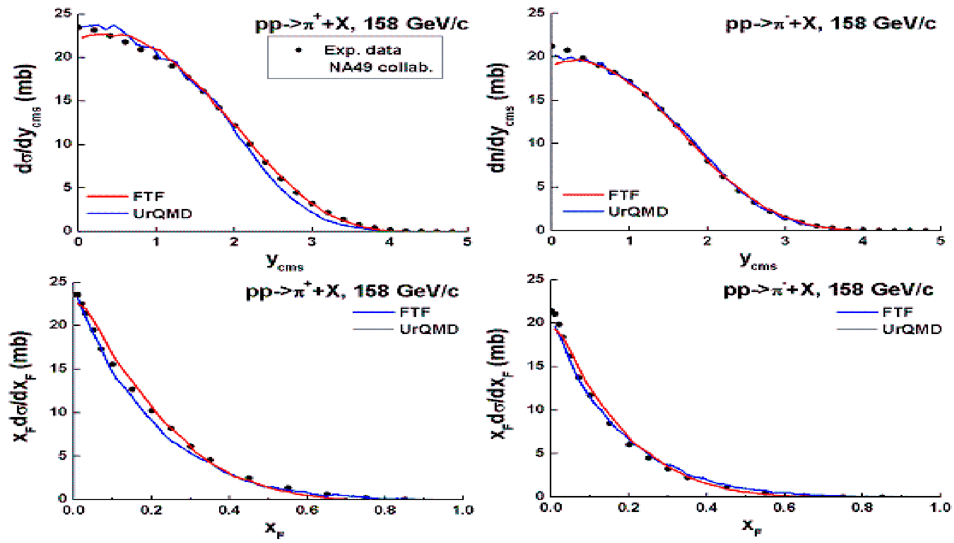
PP interaction, topological cross sections



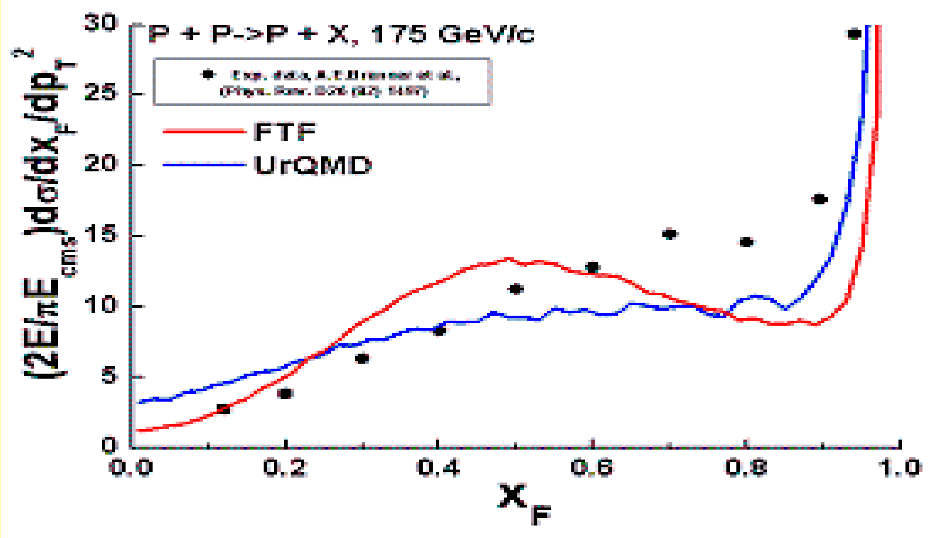
PP interaction, inclusive cross sections



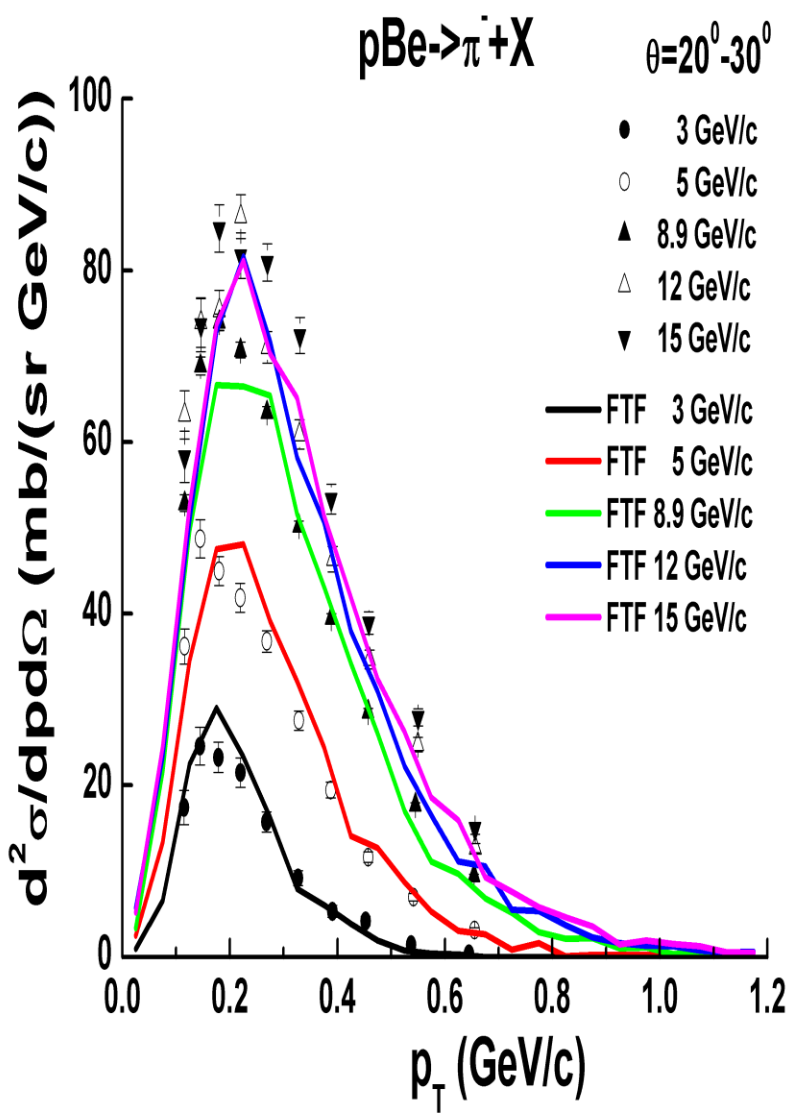
PP interaction, inclusive cross sections

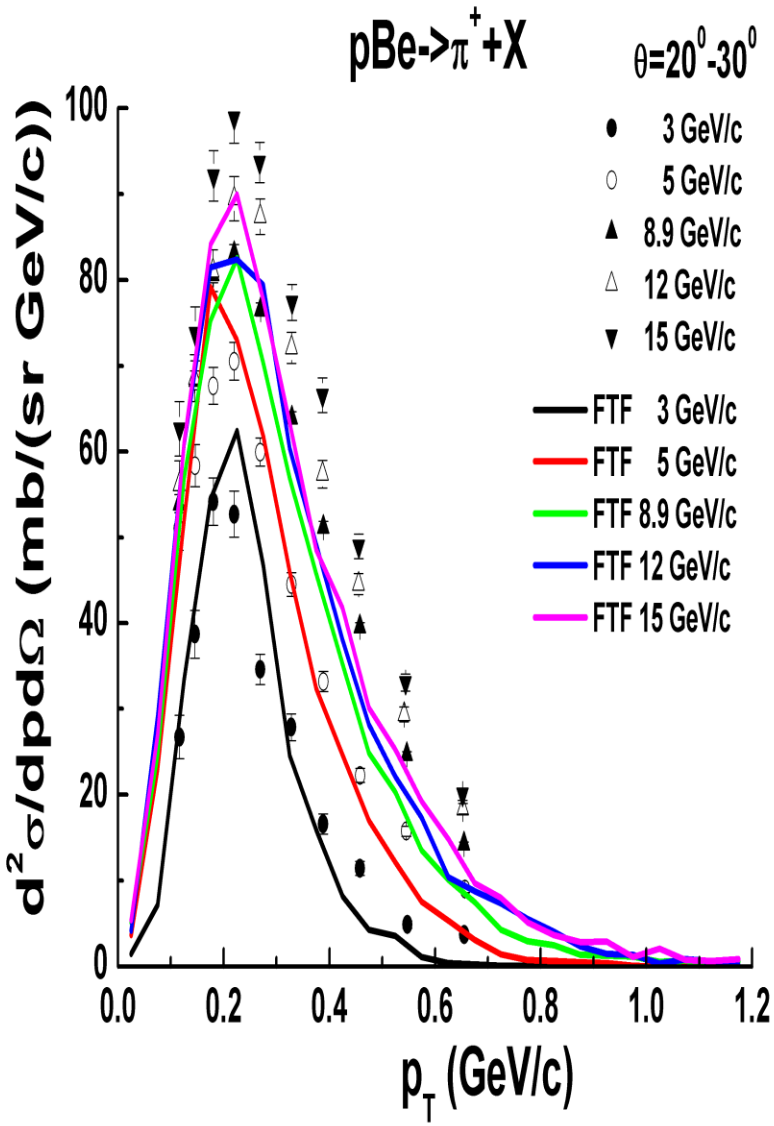


Some problems with proton spectra



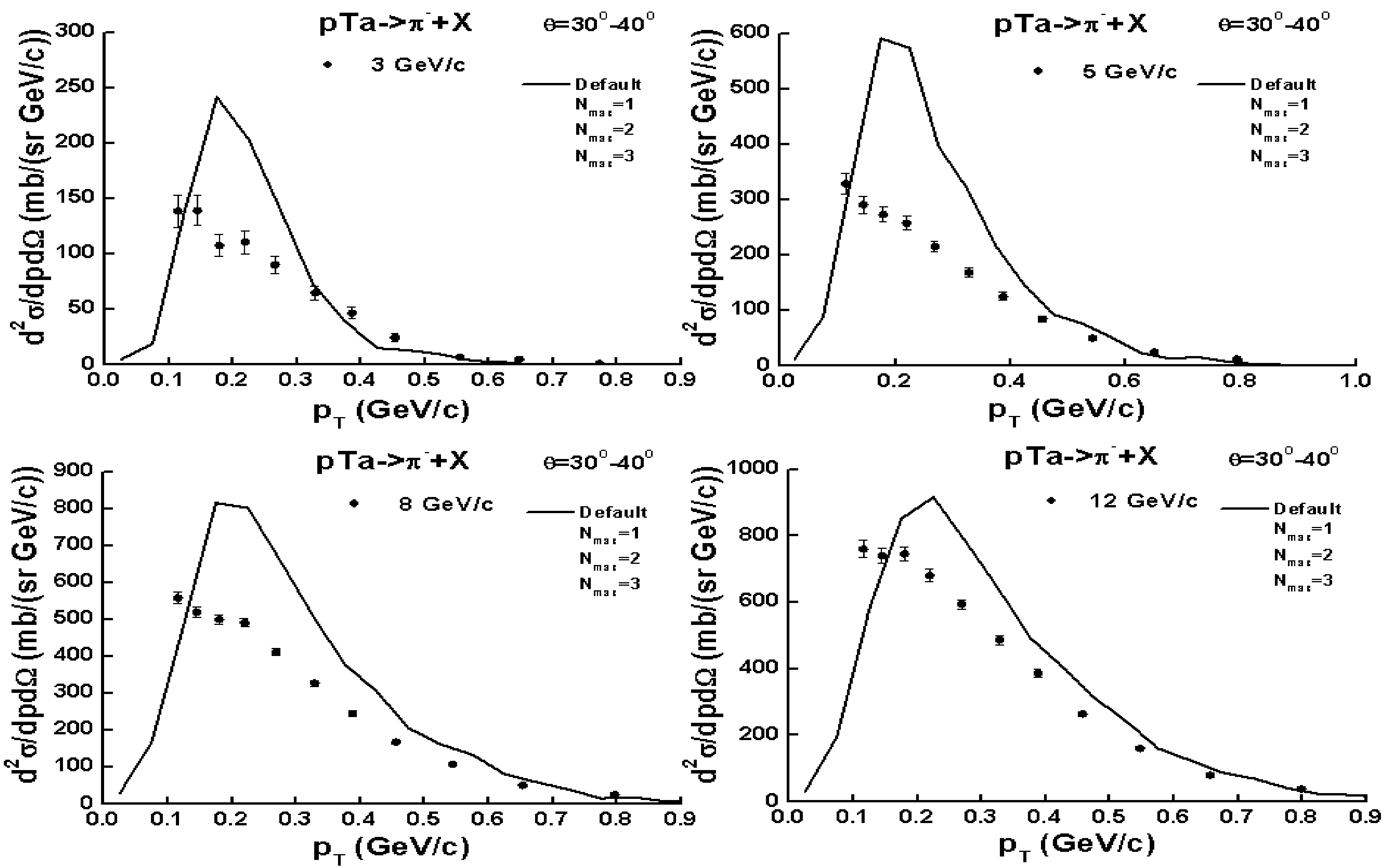
Phase space restrictions at low mass string fragmentation





Check of inclusive cross sections for PN interactions, HARP-CDP data

Correction of intra-nuclear interaction number



PROBLEM!

What can we do?

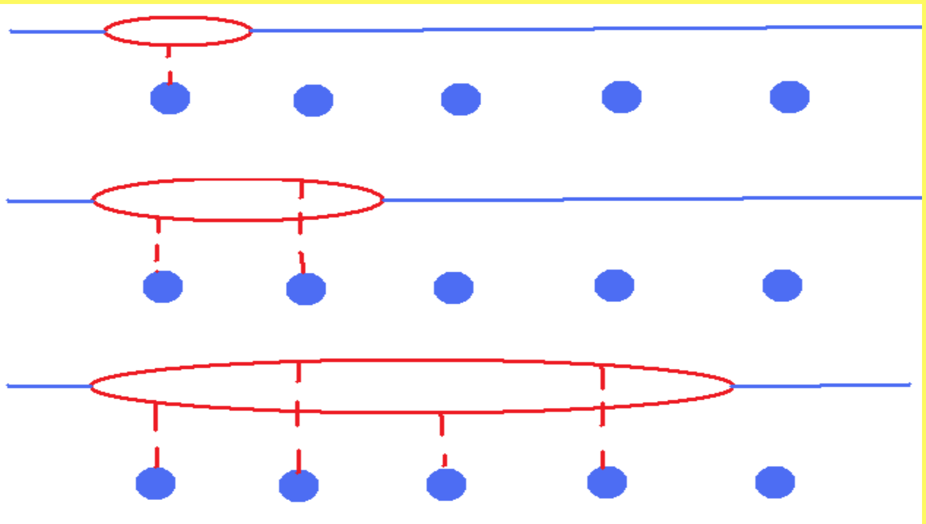
Change string fragmentation.
Change string mass distribution.
Change cross sections.
Correct interaction number.

Correction of intra-nuclear interaction number

Source of the problem: the AGK cutting rules are asymptotical ones!

Glauber cross section | **AGK rules**

$$\sigma_{pA}^{in} = \int d^2b[1 - e^{-\sigma_{pn}^{in}T(\vec{b})}] = \sum_{\nu=1}^{\infty}\int d^2b\frac{[-\sigma_{pn}^{in}T(\vec{b})]^{\nu}}{\nu!}e^{-\sigma_{pN}T(\vec{b})}$$



Low energy, Std. cascade.

Cascade+ QGS

High energy, Std. QGS.

Competition of planar and non-planar diagrams. There was only 1 paper on the subject by K. Boreskov and A. Kaidalov.

Glauber cross section

$$N_{max} = \sigma\rho <\tau> v\gamma = \sigma\rho <\tau> P_{lab}^{proj}/m_{proj} = P_{lab}/P_0$$

$$\sigma_{pA}^{in} = \int d^2b[1 - e^{-\sigma_{pn}^{in}T(\vec{b})}] = \int d^2b[1 - e^{-N_{max}\frac{\sigma_{pn}^{in}}{N_{max}}T(\vec{b})}] =$$

$$\sum_{\nu=1}^{N_{max}} C_{N_{max}}^{\nu}\int d^2b[1 - e^{-\frac{\sigma_{pn}^{in}}{N_{max}}T(\vec{b})}]^{\nu}e^{-(N_{max}-\nu)\frac{\sigma_{pn}^{in}}{N_{max}}T(\vec{b})}$$

Nmax=Plab/4 (GeV/c)

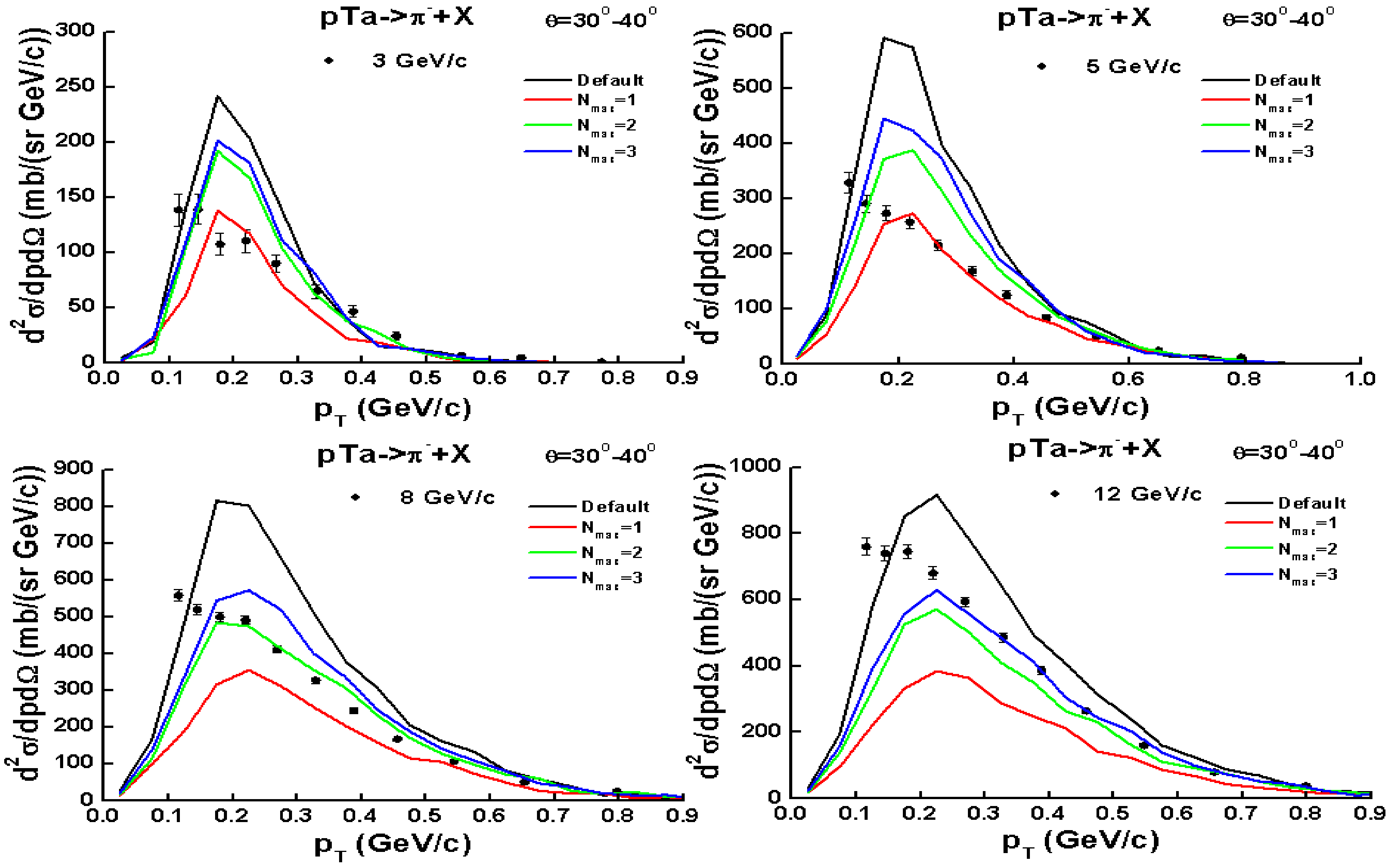
Uzhi rules

S.Yu. Shmakov, V.V. Uzhinsky, Zeit. fur Phys. C36:77,1987.

Max. cross section method:

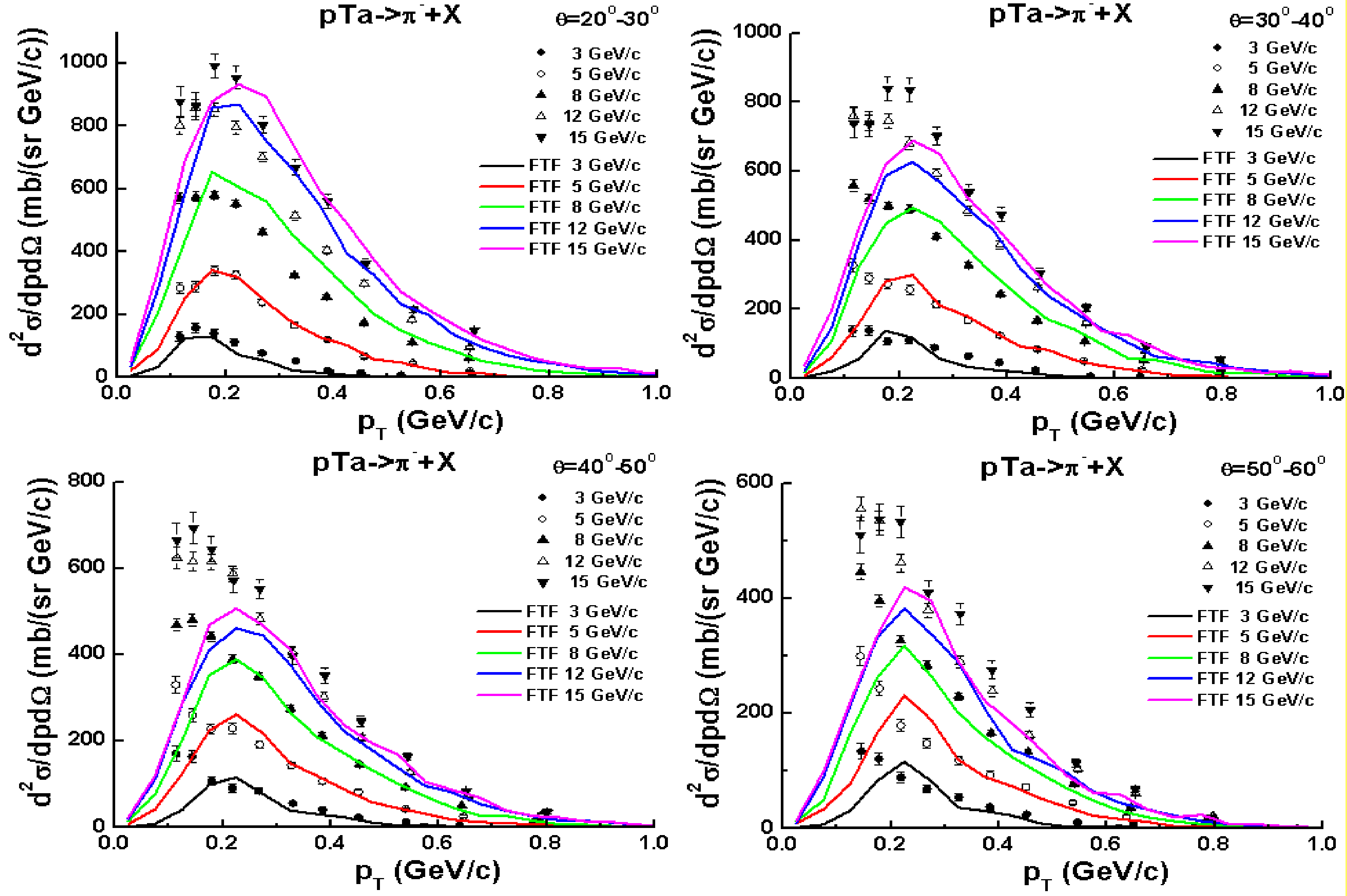
W.A. Coleman: Nucl. Sci. Eng. 32 (1968) 76

Correction of intra-nuclear interaction number



Nmax=1, Plab=3, 5 GeV/c: Nmax=2, Plab=8 GeV/c: Nmax=3, Plab=12

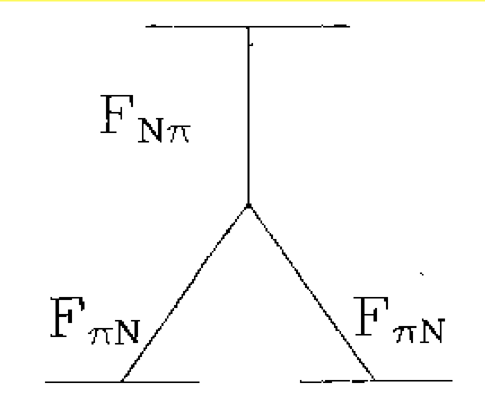
Correction of intra-nuclear interaction number

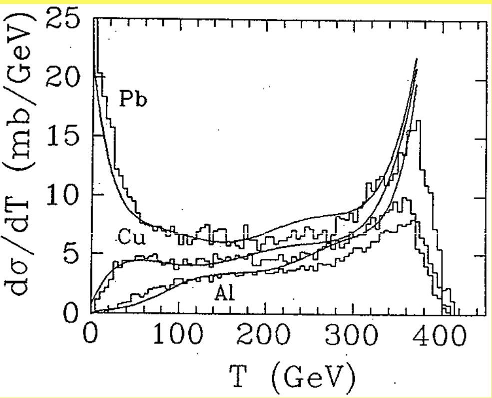


All O.K. with Pi-mesons!

Nmax=Plab/4 (GeV/c)

Tuning of reggeon cascading parameters





Si+A, 14.7 GeV/N
T – energy in ZDC

Model of nuclear disintegration in high-energy nucleus nucleus interactions.
K. Abdel-Waged, V.V. Uzhinsky
Phys.Atom.Nucl.60:828-840,1997, Yad.Fiz.60:925-937,1997.

$$Y = G\int d\xi' d^2b' F_{N\pi}(\vec{b}-\vec{b}',\xi-\xi')\times$$
$$\times\; F_{\pi N}(\vec{b}'-\vec{s}_1,\xi')F_{\pi N}(\vec{b}'-\vec{s}_2,\xi'),$$

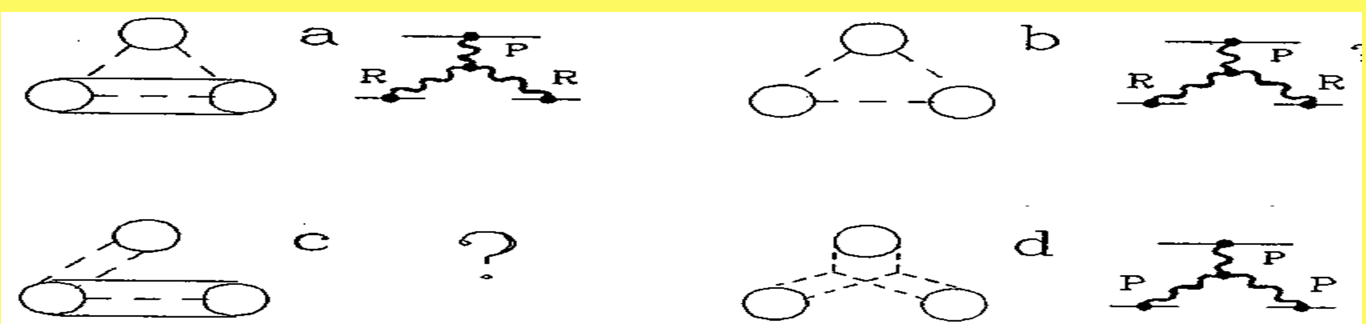
G is 3-pomeron vertex constant, $\vec{b}$- impact parameter of incident hadron, $\vec{s}_1$, $\vec{s}_2$- impact co-ordinates of nuclear nucleons. $\vec{b}'$ is the position of pomeron interactions vertex in the impact parameter plane, ξ'-its rapidity.

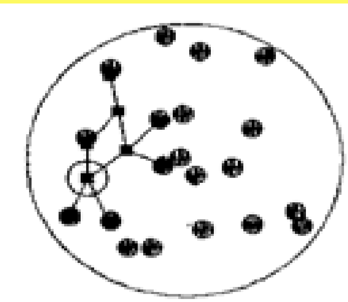
Using Gaussian parameterization for $F_{\pi N}$ ($F_{\pi N} = exp(-(|\vec{b}|^2)/(R^2_{\pi N}))$ and neglecting its dependence on energy, we have

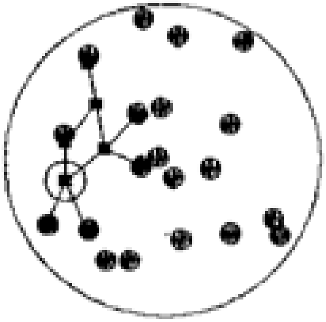
$$Y \simeq G(\xi_0 - 2\epsilon)\frac{R^2_{\pi N}}{3}exp(-(\vec{b}-(\vec{s}_1+\vec{s}_2)/2)^2/3R^2_{\pi N})\times$$
$$\times\; exp(-(\vec{s}_1-\vec{s}_2)^2/2R^2_{\pi N}),$$

where $R_{\pi N}$ is the pion-nucleon interaction radius. According to (2) the contribution reaches a maximum if the nucleon coordinates $\vec{s}_1$ and $\vec{s}_2$ coincide and decreases very fast with increasing the distance between the nucleons. For reproduction of this behavior we choose ϕ as

$$\phi(|\vec{s}_i-\vec{s}_j|) = C exp(-\frac{|\vec{s}_i-\vec{s}_j|^2}{r_c^2}).$$







Tuning of reggeon cascading parameters

Complex analysis of gold interactions with photoemulsion nuclei at 10.7-GeV/nucleon within the framework of cascade and FRITIOF models.

By EMU-01 Collaboration (M.I. Adamovich *et al.*). 1997.

Zeit. fur Phys.A358:337-351,1997.

In case of dissociation of two compound systems A and B containing A and B constituents respectively, the i-th constituent of system A will be described by

$$x_i^+ = (E_{Ai} + p_{iz})/W_A^+ \quad and \quad \mathbf{p}_{i\perp},$$

and the j-th constituent of system B

$$y_j^- = (E_{Bj} + q_{jz})/W_B^- \quad and \quad \mathbf{q}_{i\perp}.$$

Here, $E_{A_i}(E_{B_i})$ and $\mathbf{p}_i(\mathbf{q}_i)$ are energy and momentum of i-th constituent from $A(B)$.

$$W_A^+ = \sum_{i=1}^{A}(E_{Ai} + p_{iz}); \quad W_B^- = \sum_{i=1}^{B}(E_{Bi} - q_{iz}).$$

Using these variables, let us write the conservation law as

$$\frac{W_A^+}{2} + \frac{1}{2W_A^+}\sum_{i=1}^{A}\frac{m_{i\perp}^2}{x_i^+} + \frac{W_B^-}{2} + \frac{1}{2W_B^-}\sum_{i=1}^{B}\frac{\mu_{i\perp}^2}{y_i^-}$$
$$= E_A^0 + E_B^0,$$
$$\frac{W_A^+}{2} - \frac{1}{2W_A^+}\sum_{i=1}^{A}\frac{m_{i\perp}^2}{x_i^+} - \frac{W_B^-}{2} + \frac{1}{2W_B^-}\sum_{i=1}^{B}\frac{\mu_{i\perp}^2}{y_i^-}$$
$$= P_A^0 + P_B^0,$$
$$\sum_{i=1}^{A}\mathbf{p}_{i\perp} + \sum_{i=1}^{B}\mathbf{q}_{i\perp} = 0, \qquad (15)$$

where $m_{i\perp}^2 = m_i^2 + \mathbf{p}_{i\perp}^2$, $\mu_{i\perp}^2 = \mu_i^2 + \mathbf{q}_{i\perp}^2$, and $m_i(\mu_i)$ - mass i - th constituent from system $A(B)$.

System (15) allows us to determine W_A^+, W_B^- and kinematic characteristics all the particles in the finite sets $\{x_i^+, \mathbf{p}_{i\perp}\}$, $\{y_i^-, \mathbf{q}_{i\perp}\}$.

$$W_A^+ = (W_0^- W_0^+ + \alpha - \beta + \sqrt{\Delta})/2W_0^-; \qquad (16)$$
$$W_B^- = (W_0^- W_0^+ - \alpha + \beta + \sqrt{\Delta})/2W_0^+; \qquad (17)$$
$$W_0^+ = (E_A^0 + E_B^0) + (P_{Az}^0 + P_{Bz}^0);$$
$$W_0^- = (E_A^0 + E_B^0) - (P_{Az}^0 + P_{Bz}^0);$$
$$\alpha = \sum_{i=1}^{A}\frac{m_{i\perp}^2}{x_i^+}; \quad \beta = \sum_{i=1}^{B}\frac{\mu_{i\perp}^2}{y_i^-};$$
$$\Delta = (W_0^- W_0^+)^2 + \alpha^2 + \beta^2 - 2W_0^- W_0^+ \alpha -$$
$$- 2W_0^- W_0^+ \beta - 2\alpha\beta;$$

$$p_{iz} = (W_A^+ x_i^+ - \frac{m_{i\perp}^2}{x_i^+ W_A^+})/2; \quad q_{iz} = -(W_B^- y_i^- - \frac{\mu_{i\perp}^2}{y_i^- W_B^-})/2.$$

To reproduce this result the values of $\mathbf{p}_{i\perp}$ for knocked-out nucleons are simulated according to distribution

$$dW \propto \exp(-\mathbf{p}_{i\perp}^2/<p_\perp^2>)d^2p_{i\perp}, \sqrt{<p_\perp^2>} = 0.05. \qquad (18)$$

The sum of transverse momenta (with sign "minus") was ascribed to the residual nucleus.

The chose of x_i^+ is carried out by

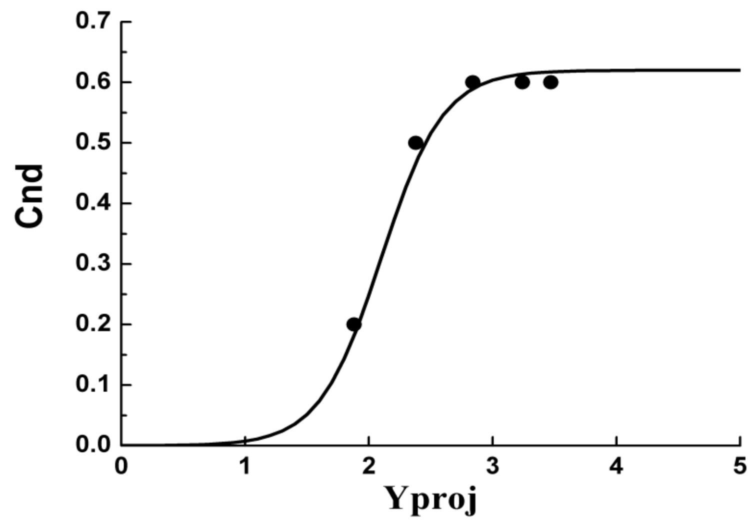
$$dW \propto \exp[-(x_i^+ - 1/A)^2/(d_x/A)^2]dx_i^+, \quad d_x = 0.05. \qquad (19)$$

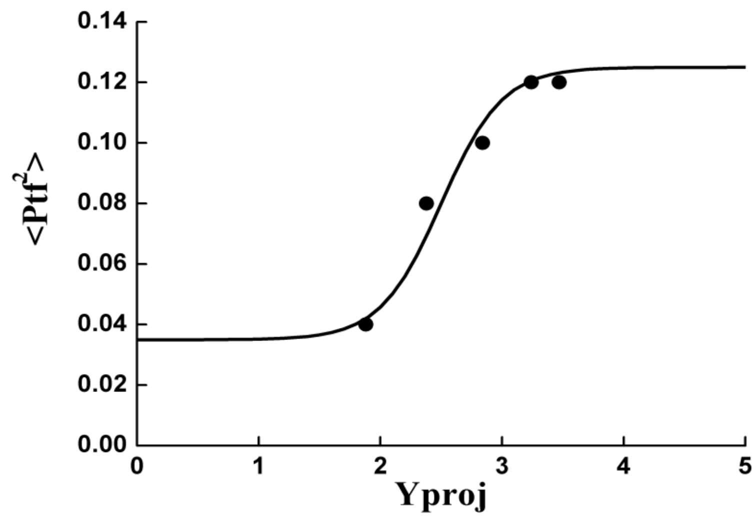
The dispersion of the distribution was defined by fitting the average emission angle of b-particles. x^+ of the residual nucleus was included as $1 - \sum x_i^+$.

Main parameters: Cnd, d_x, p_T^2

Tuning of reggeon cascading parameters

Unexpected results of the tuning!





$$C_{nd} = 0.62\frac{e^{4(y-2.1)}}{1+e^{4(y-2.1)}}$$

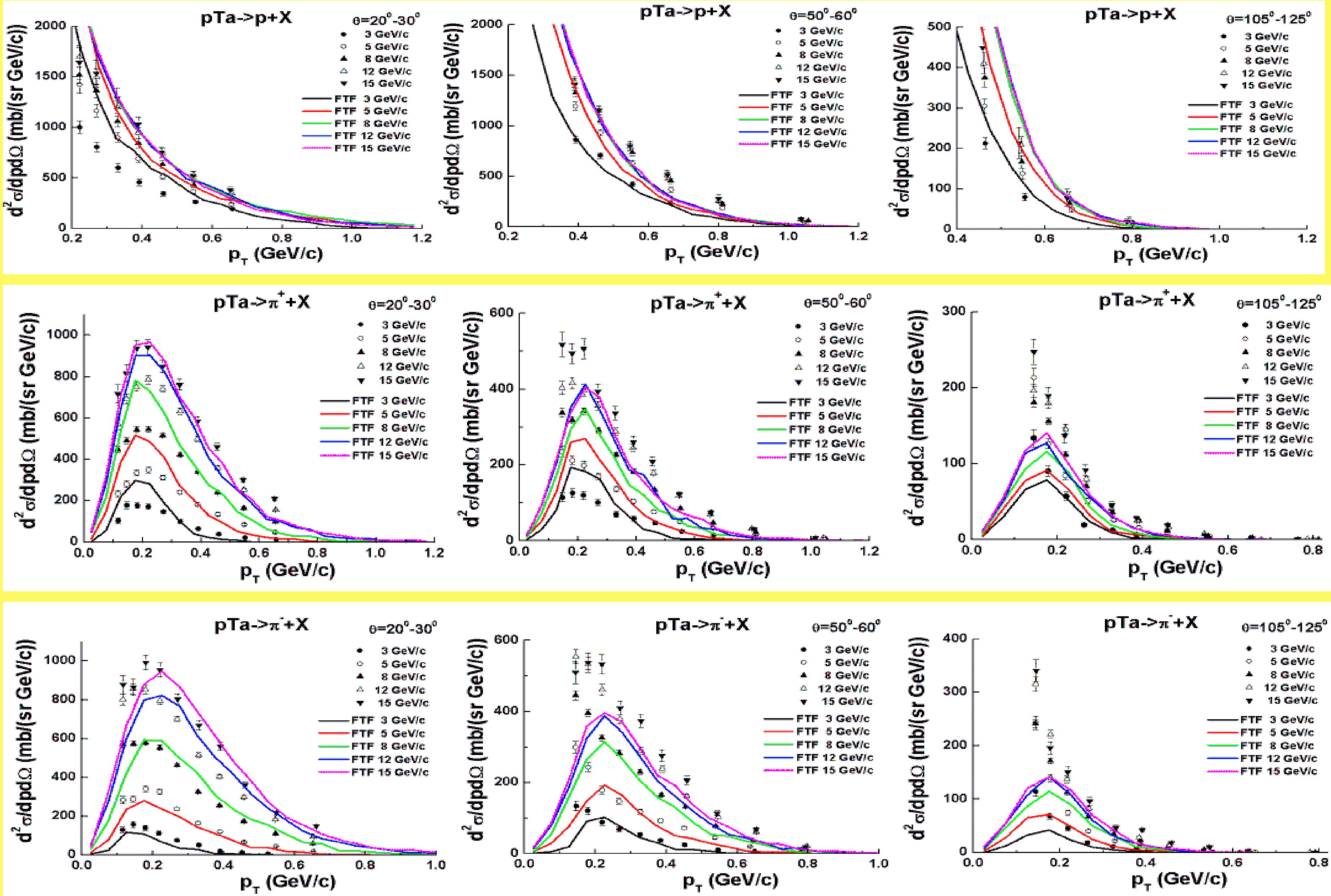
$$y = 2.1 \; at \; p_{lab} \simeq 4 \; GeV/c$$

$$< P_T^2 >= 0.035 + 0.09\frac{e^{4(y-2.5)}}{1+e^{4(y-2.5)}} \; (GeV/c)^2$$

$$y = 2.5 \; at \; p_{lab} \simeq 5.5 \; GeV/c$$

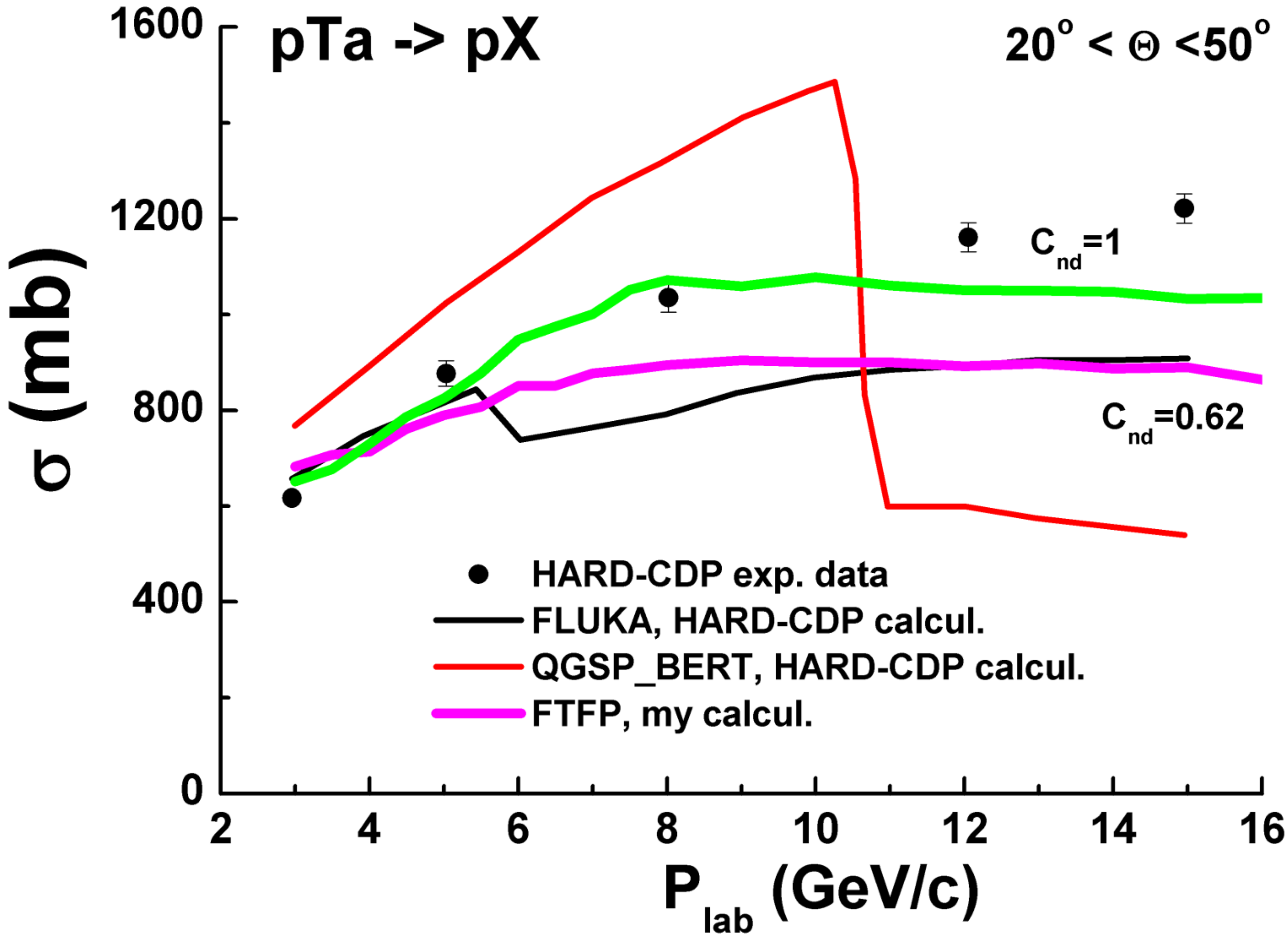
Clear signal of a transition regime!
The transition takes place at Plab= 4-5 GeV/c

Tuning of reggeon cascading parameters - Results

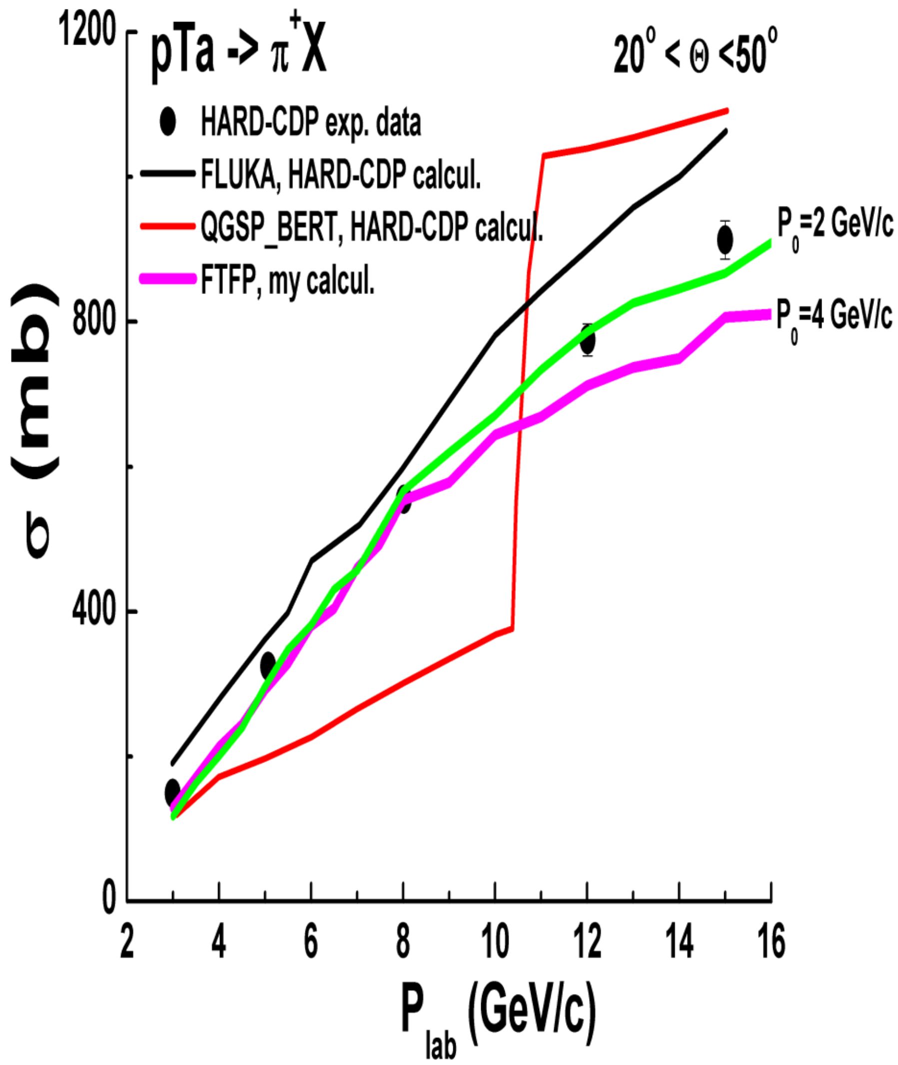


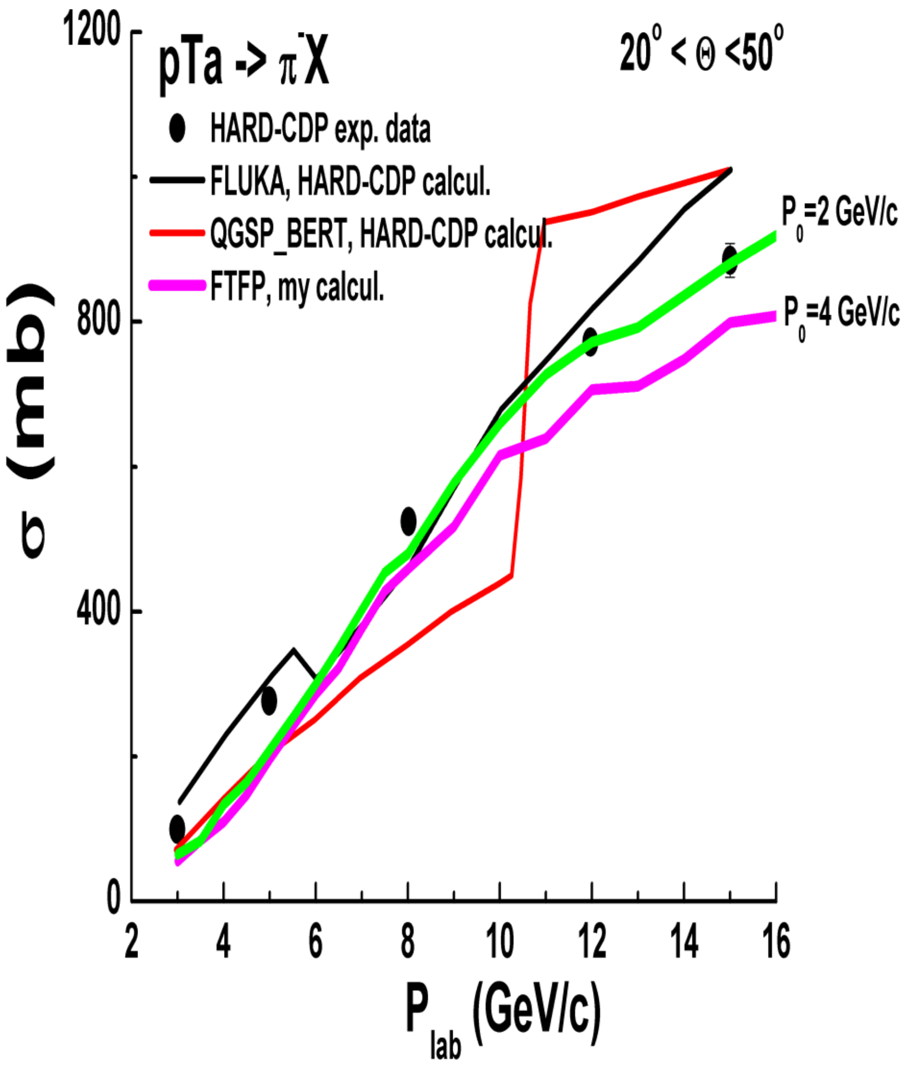
All is beautiful!

Smooth transition

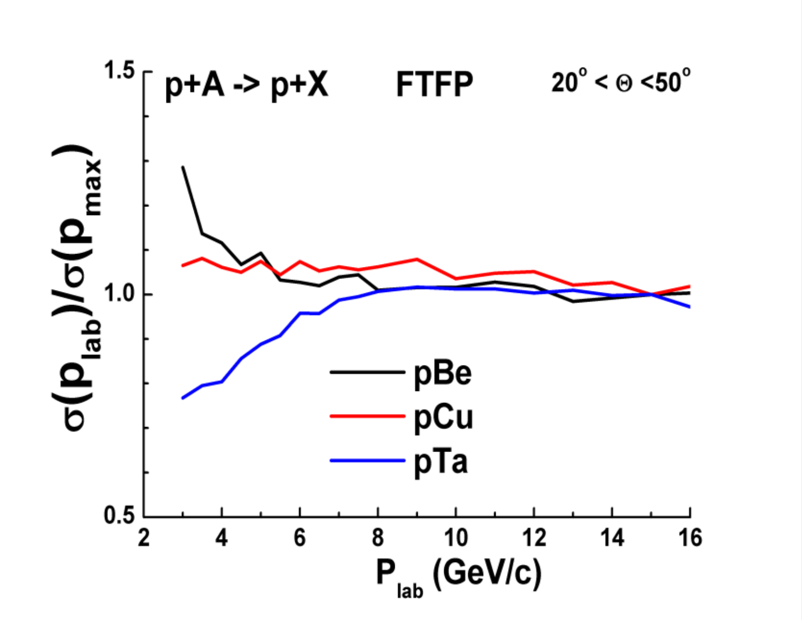


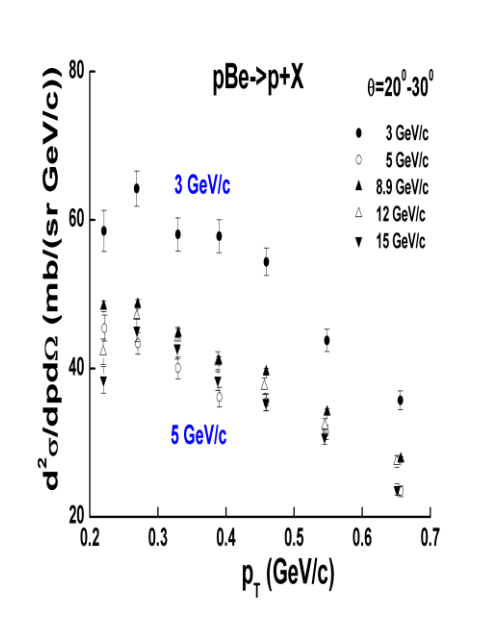
Smooth transition

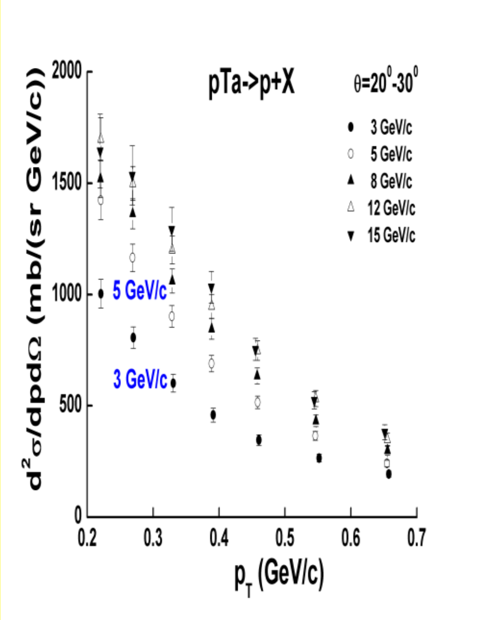


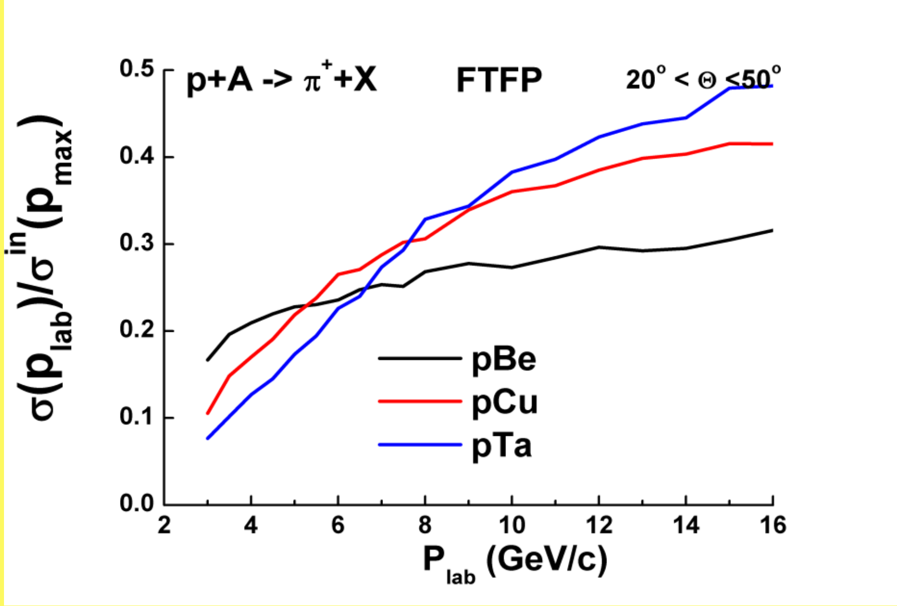


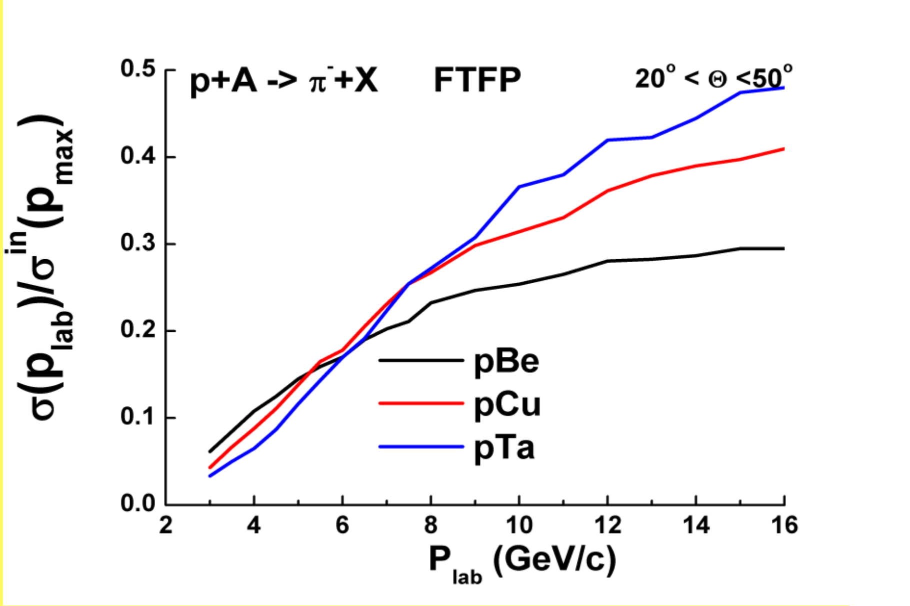
Possible experimental check











Summary

1. 3 new things are introduced in FTF for pp- and pA-interactions:
   a) Phase space restrictions at low mass string fragmentation
   b) Correction of multiplicity of intra-nuclear collisions
   c) Tuning of RTIM parameters

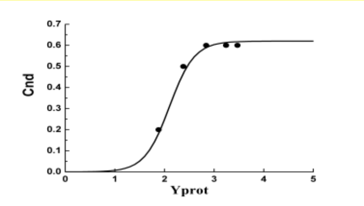
2. Good results are obtained for pp- and pA-interactions, especially for description of HARP-CDP data. **The description of HARP-CDP data on pA-interactions (Be, C, Cu, Ta, Pb) is the best among other models!**

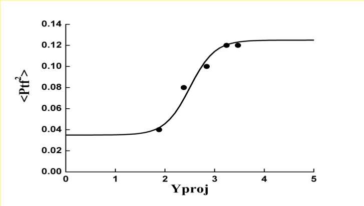
3. The best low energy partner of FTF is the Bertini model. The corresponding transition region is 3 – 8 GeV/c.

4. It would be well to improve the Bertini model. **Improving of the Binary model is heavily desirable!**

5. **A strong indication on transition regime realization is obtained!**

Nmax=Plab/4 (GeV/c)





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