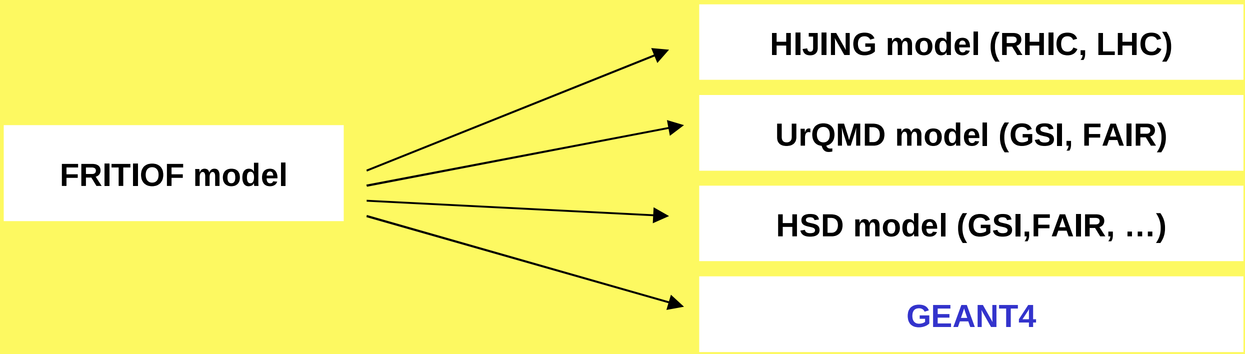
Development of the Fritiof Model in Geant4

Vladimir Uzhinsky, (On behalf of the Geant4 Hadronics Working Group)

MC-2010. Tokyo, Japan

B. Andersson et al., Nucl. Phys. {\bf B281} (1987) 289;
B. Nilsson-Almquist and E. Stenlund, Comp. Phys. Commun. 43 (1987) 387.

The well established Fritiof model is in the core of modern MC codes: HIJING, UrQMD, HSD, ART. Now it is adapted in Geant4 also!



Our aim – extension of Geant4 string models to low energy domain

Content

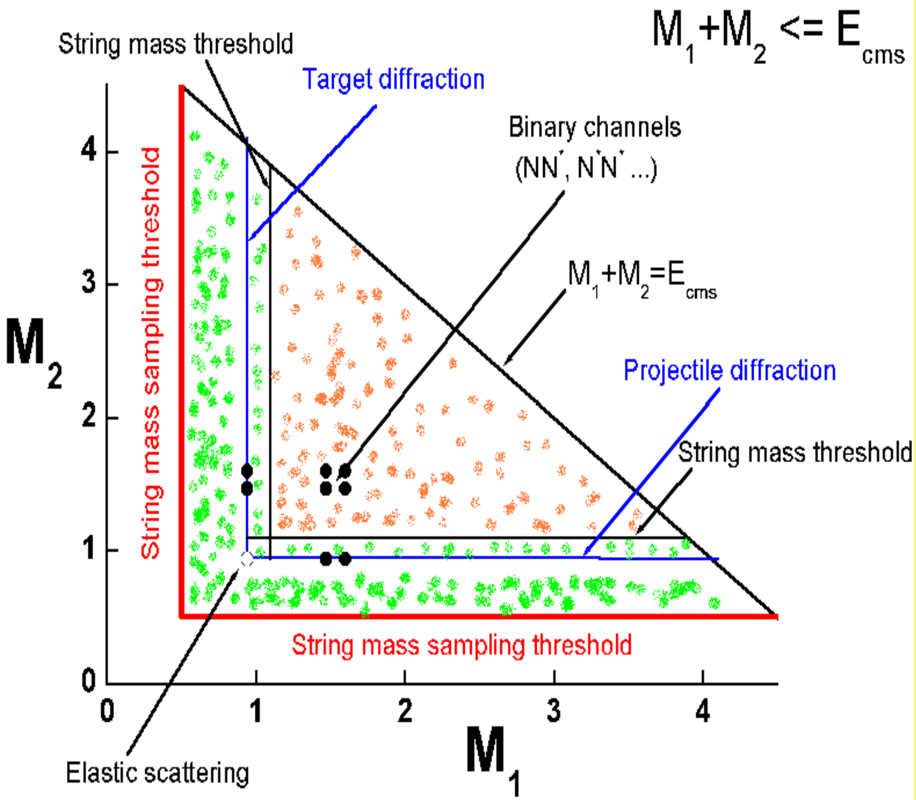
1. Short description of the models;
2. Separate simulation of diffraction dissociation;
3. Simulation of binary reactions and low mass string frag.;
4. Correction of multiplicity of intra-nuclear collisions;
5. Fit of RTIM parameters;
6. Results;
7. Conclusion

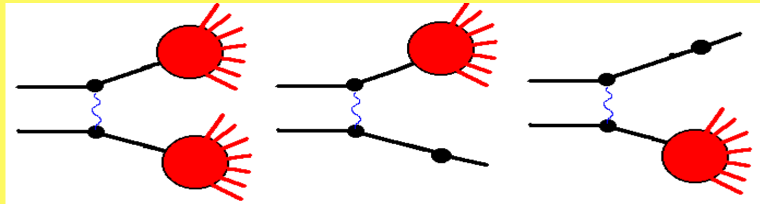
1. FRITIOF model

It is assumed binary kinematics of hadron-hadron interactions

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

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





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

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

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

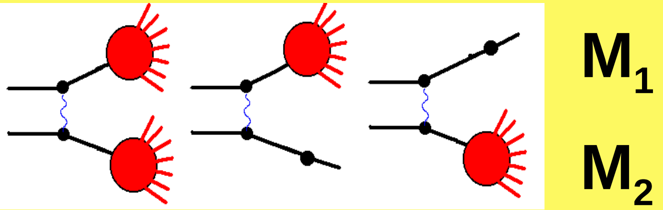
$$dW \propto dP^-_{proj}/P^-_{proj}$$

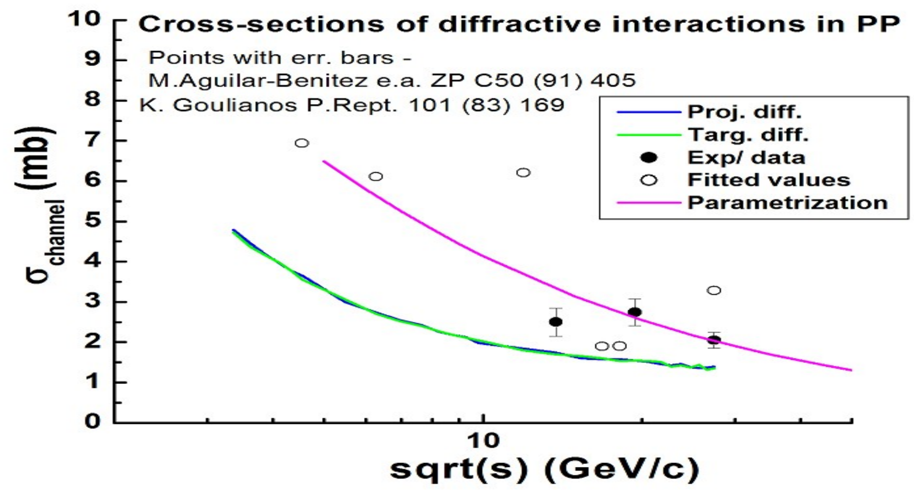
$$dW \propto dP^+_{tar}/P^+_{tar}$$

In hadron-nucleus interactions the excited hadrons can interact with other nucleons of nucleus and increases mass. The probability of multiple collisions is calculated in Glauber approach. The used variant of model Fritiof is enlarged with elastic re-scatterings of hadrons. The excited states are considered as QCD-strings and LUND model are used for their fragmentation.

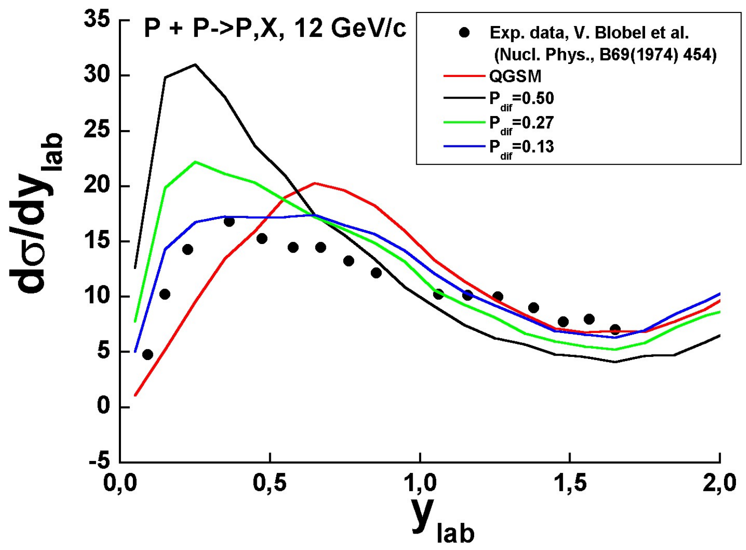
2. Separate simulation of diffraction dissociation

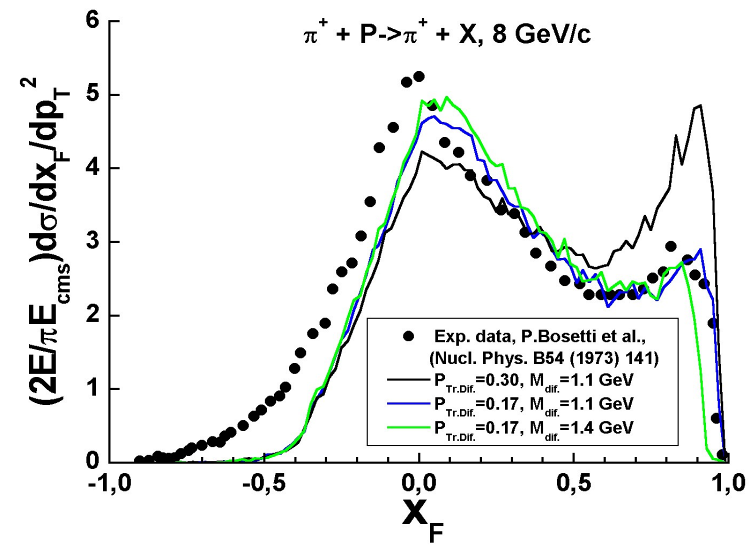
We simulate separately diffractive and non-diffractive interactions.



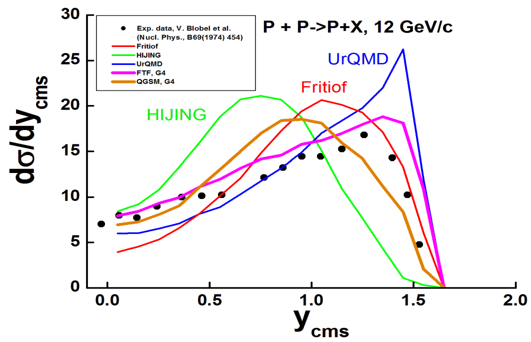


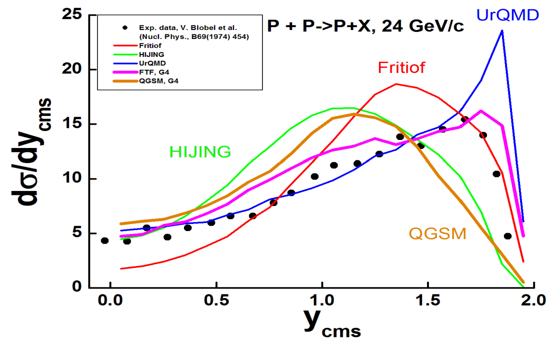
Probabilities of diffractions in Fritiof are not right! The separation allows to fit the probabilities.

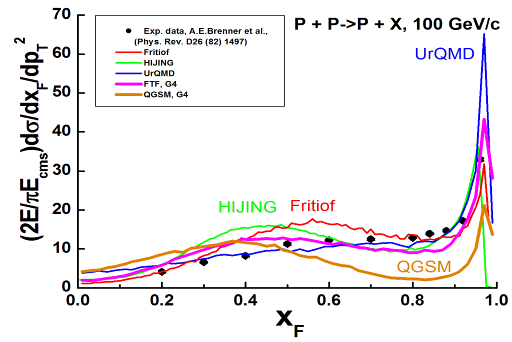




Description of baryon spectra is the problem in all MC models

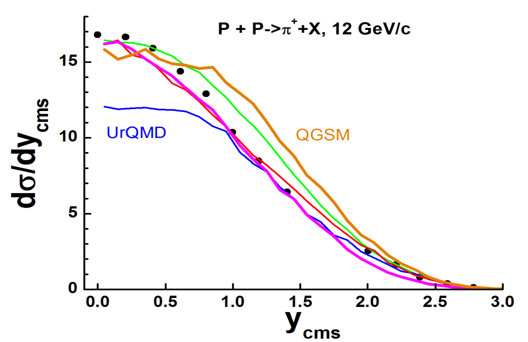


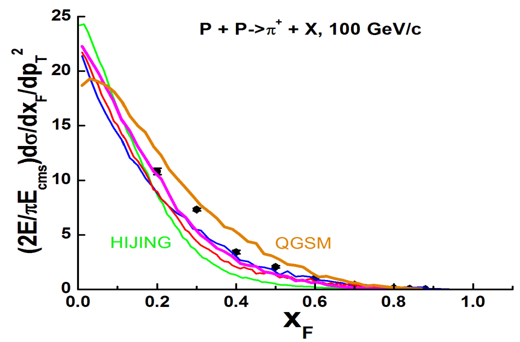


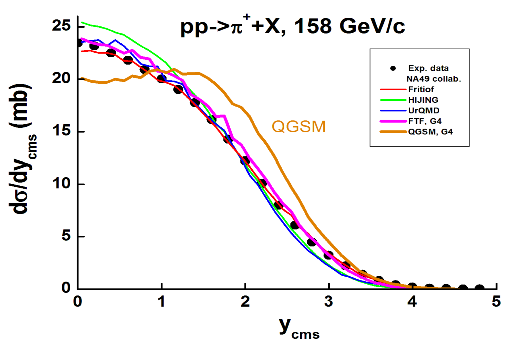


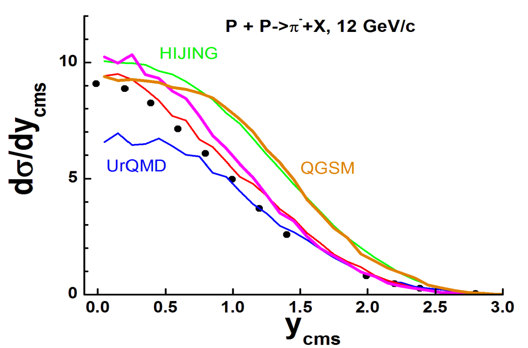
Exp. Data: V. Blobel et al., Nucl. Phys., B69(1974) 454.

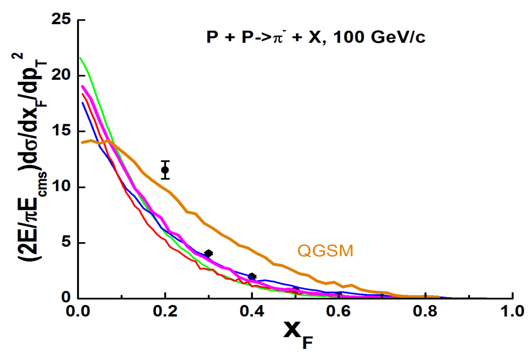
There are some problems with a description of meson spectra

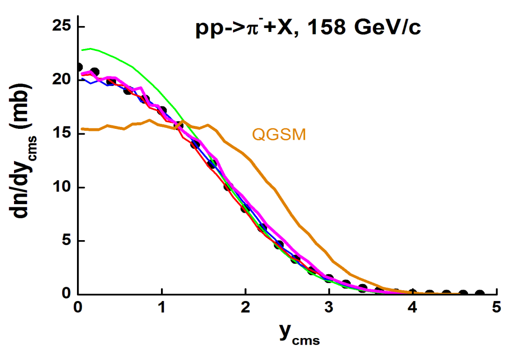




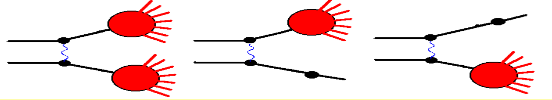




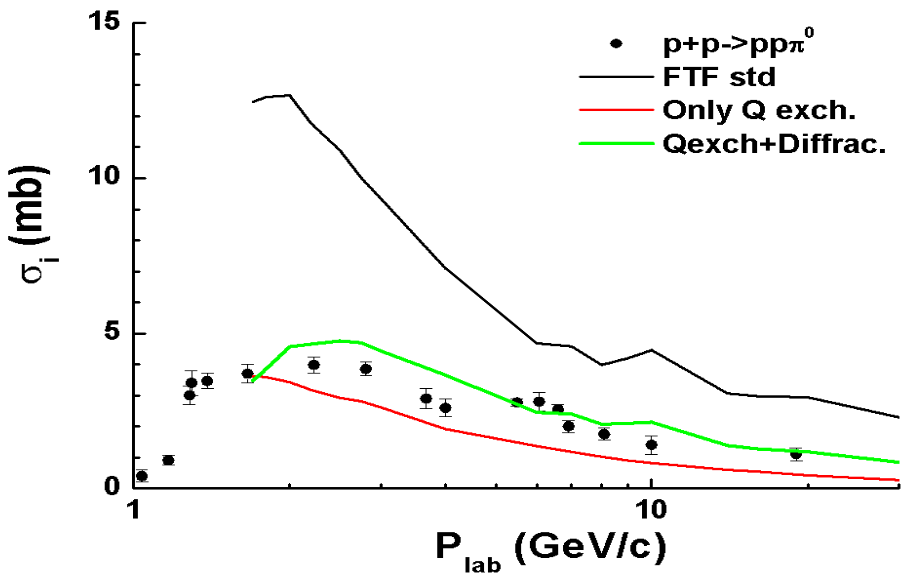


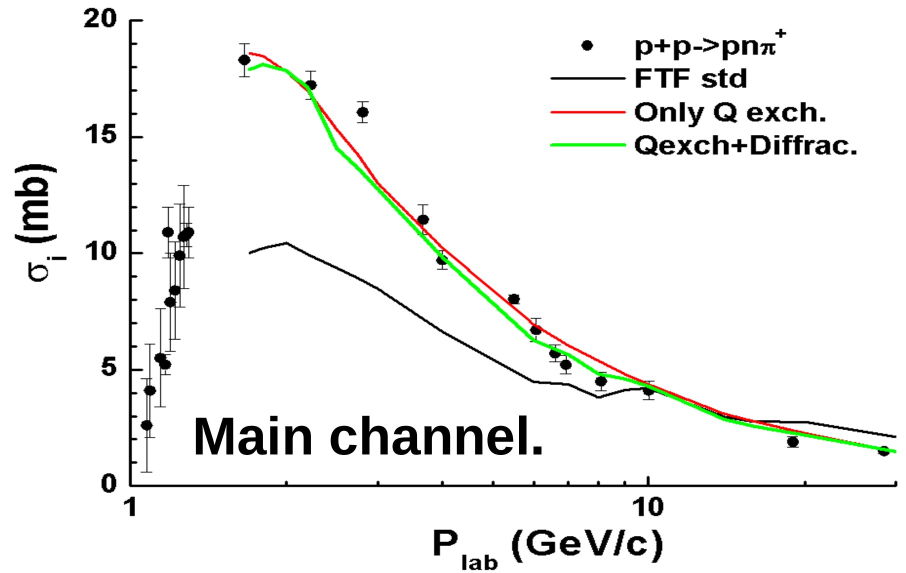


3. Simulation of binary reactions



Standard FTF approach does not give positive results





P+P->P+P*

- 2/3 ud-u string
  - 1/3 $P\pi^0$
  - 1/3 $N\pi^+$
- 1/3 uu-d string
  - 1/6 $P\pi^0$
  - 1/6 $\Delta^{++}\pi^-$

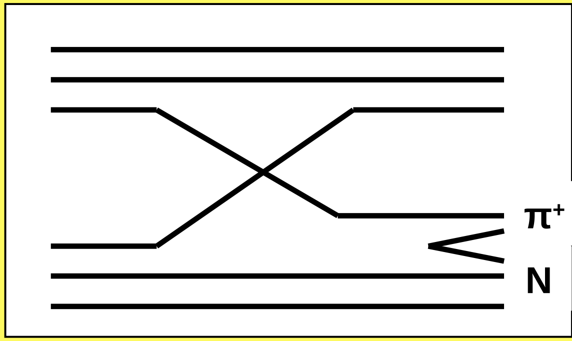
→

1/3 $N\pi^+$

1 /2 $P\pi^0$

1/6 $P\pi^+\pi^-$

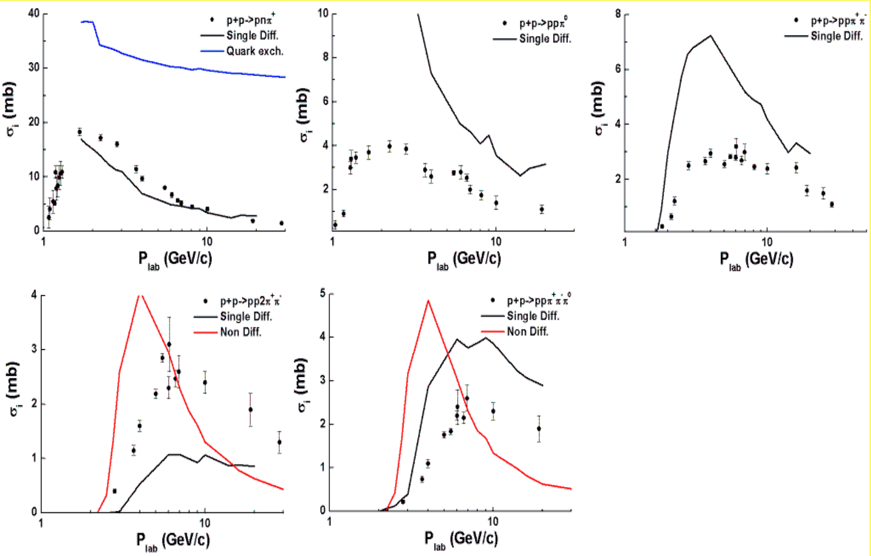
Solution – quark exchange



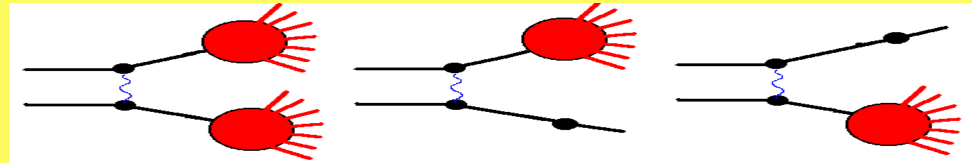
$$W_{q.exc.} \sim 3.4\; e^{-1.2\cdot(y_{pr}-y_{tr})}$$

P+P-> ~~PΔ⁺~~, NΔ⁺⁺, ~~ΔΔ~~

Phase space restrictions at low mass string fragmentation



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



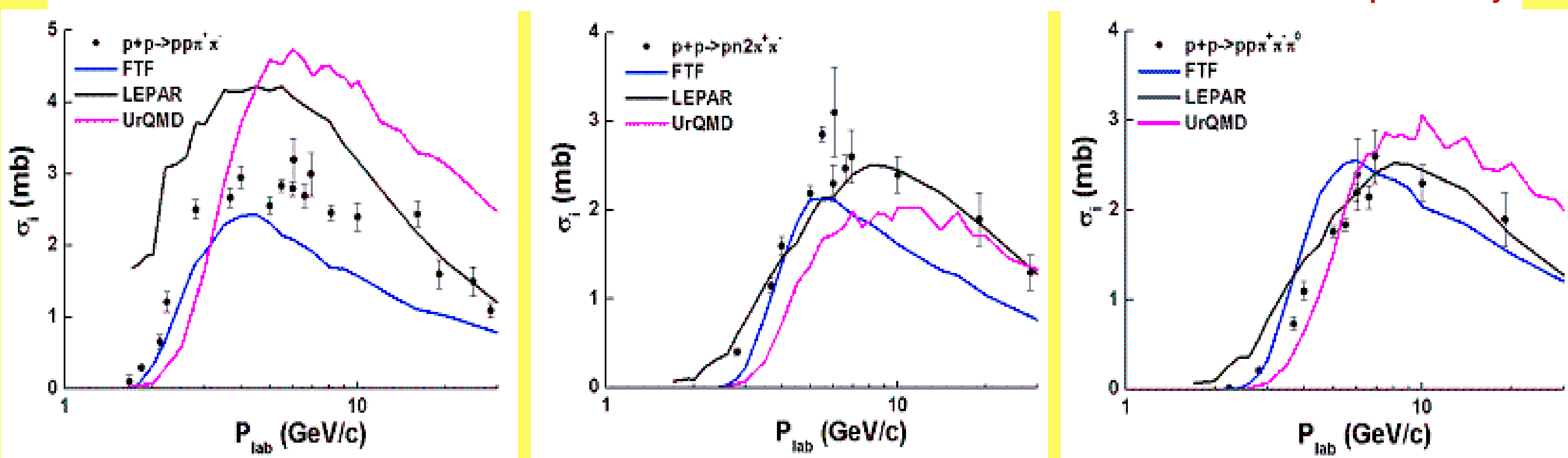
$pp \to pp\pi^+\pi^-$

Final state: single diffraction

$P(\Delta^{++}\pi^-)$ XXX
$P(\Delta^0\pi^+)$ X
$P(P\pi^+\pi^-)$ 3

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

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

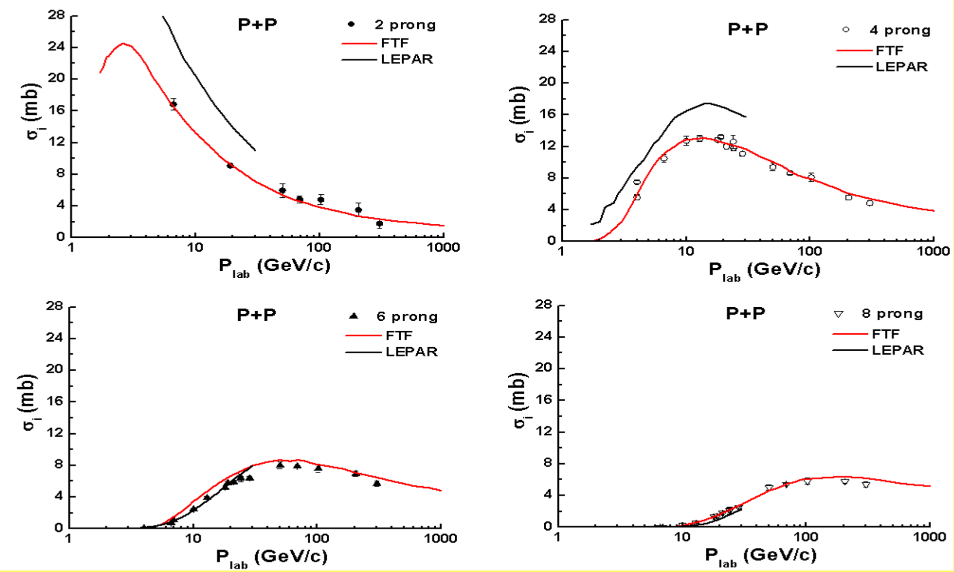


PP interaction, channel cross sections

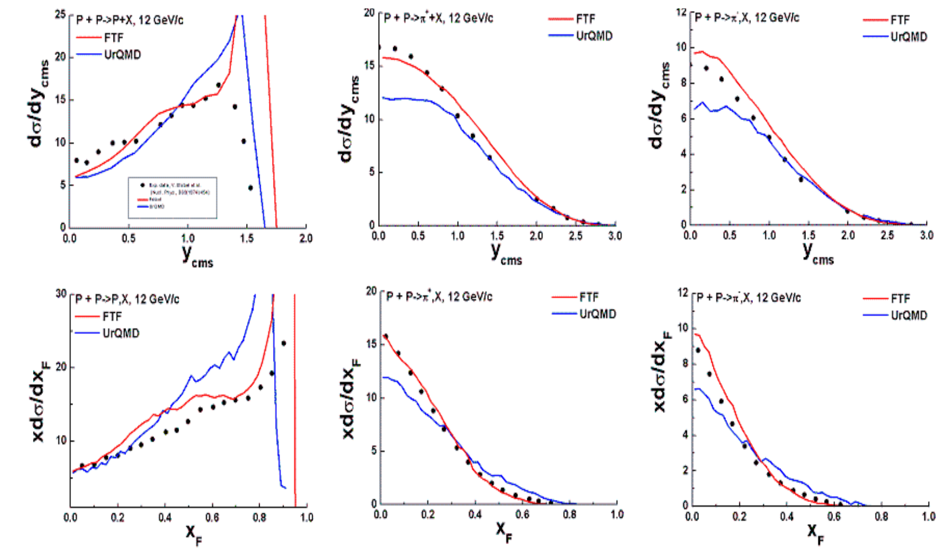
Phase space restrictions at low mass string fragmentation

ults for PP

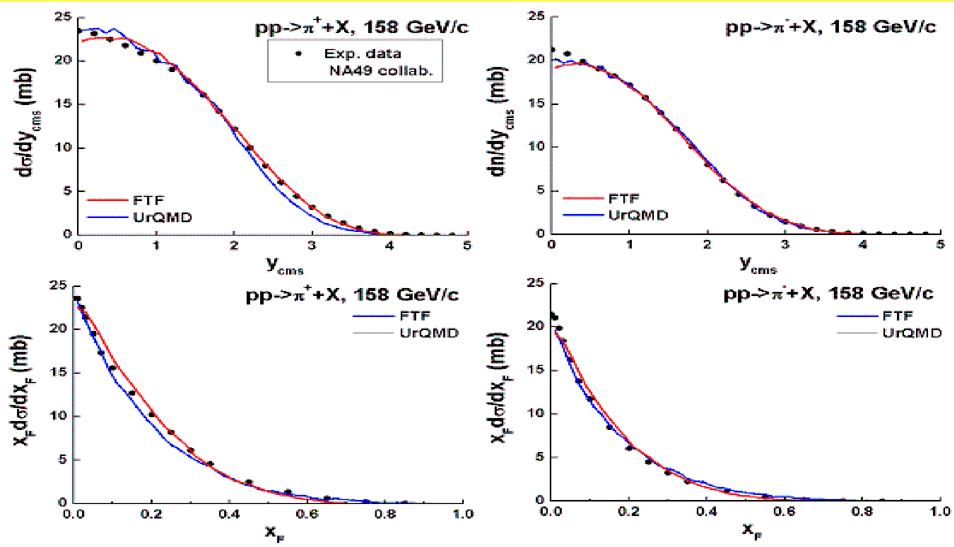
PP interaction, topological cross sections



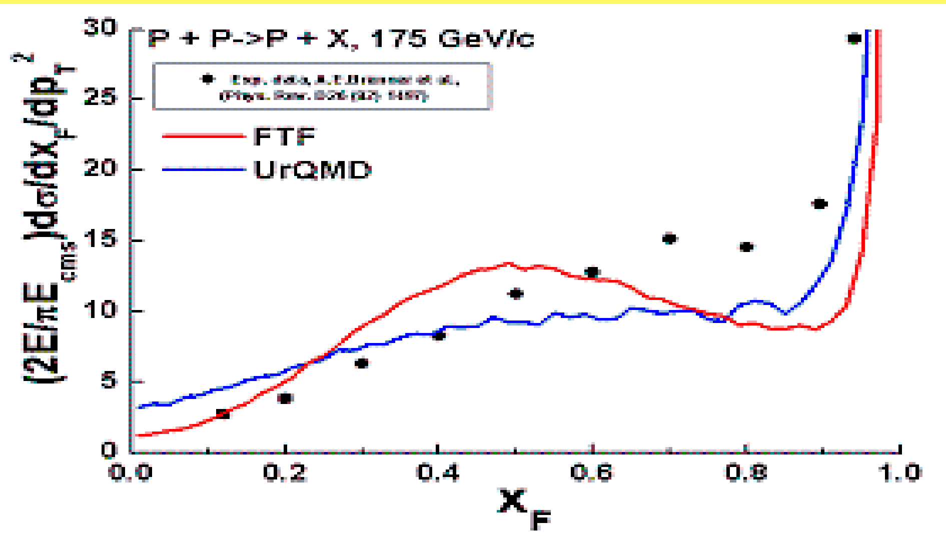
PP interaction, inclusive cross sections



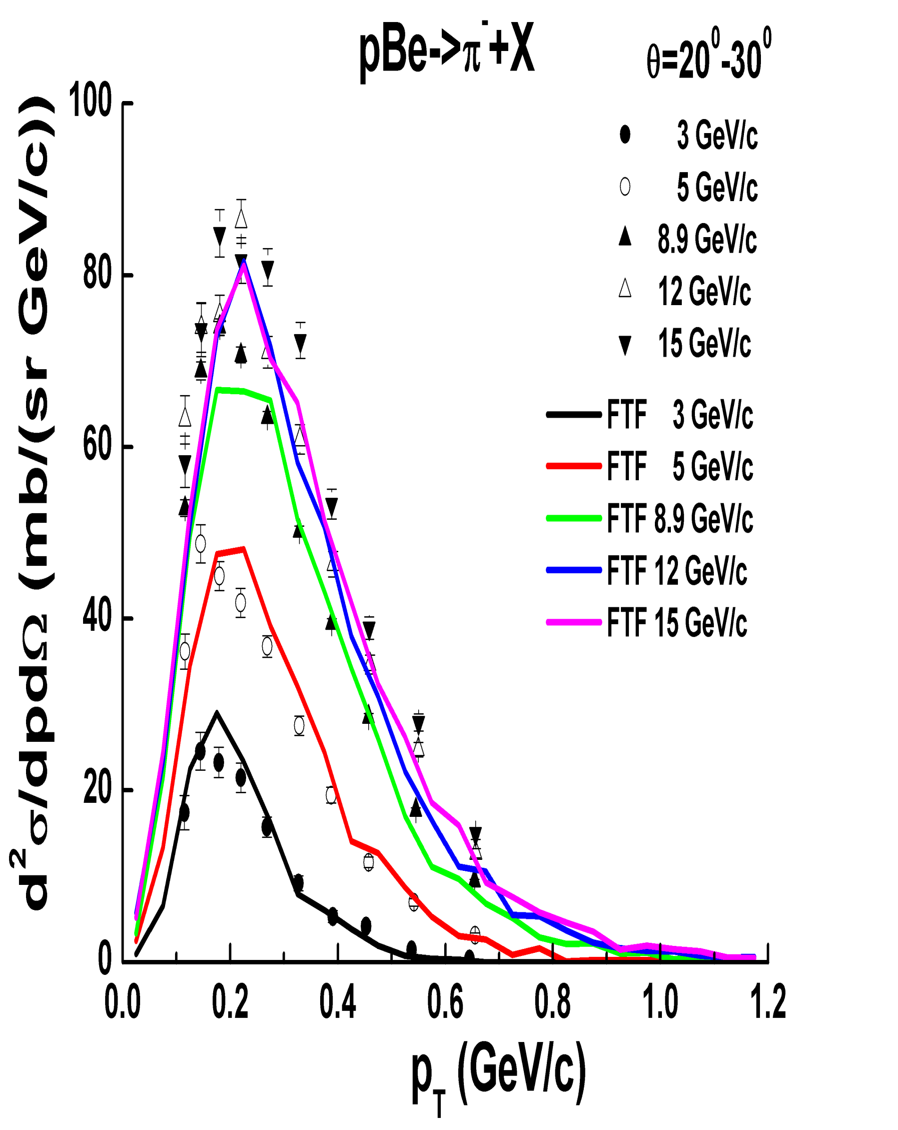
PP interaction, inclusive cross sections

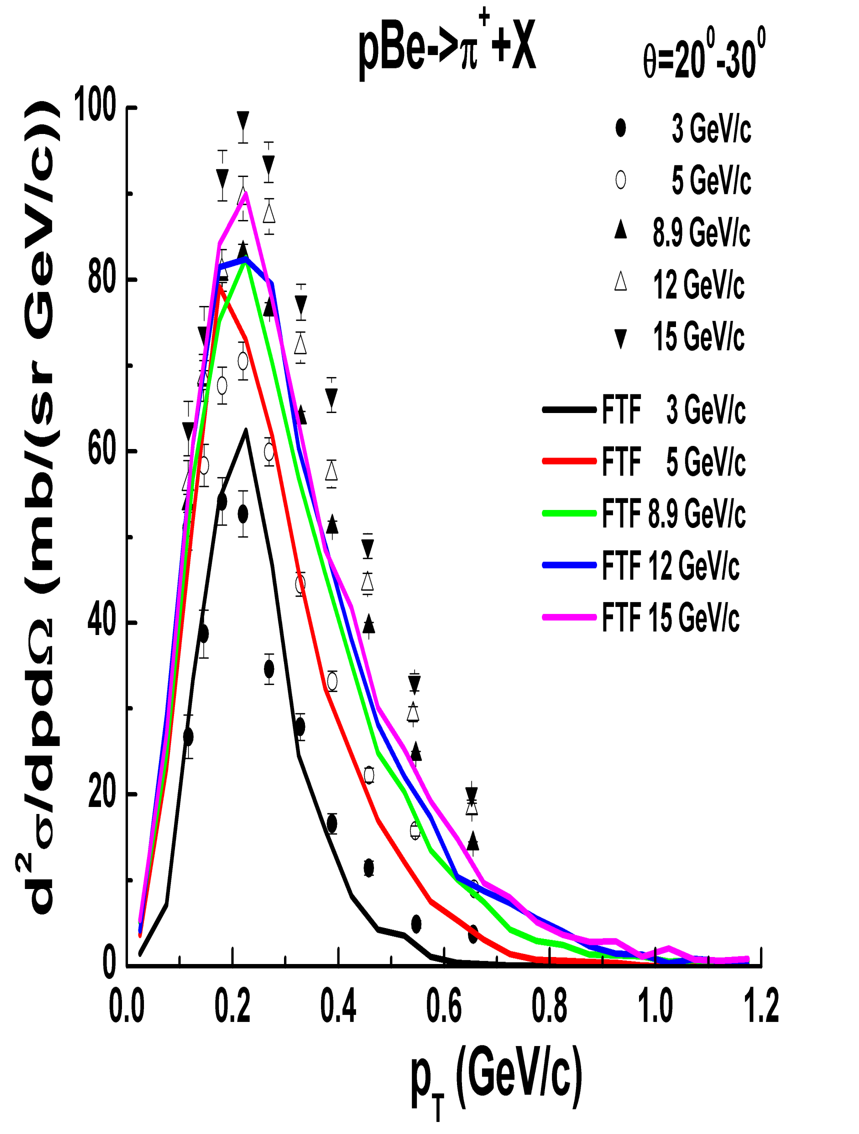


Some problems with proton spectra



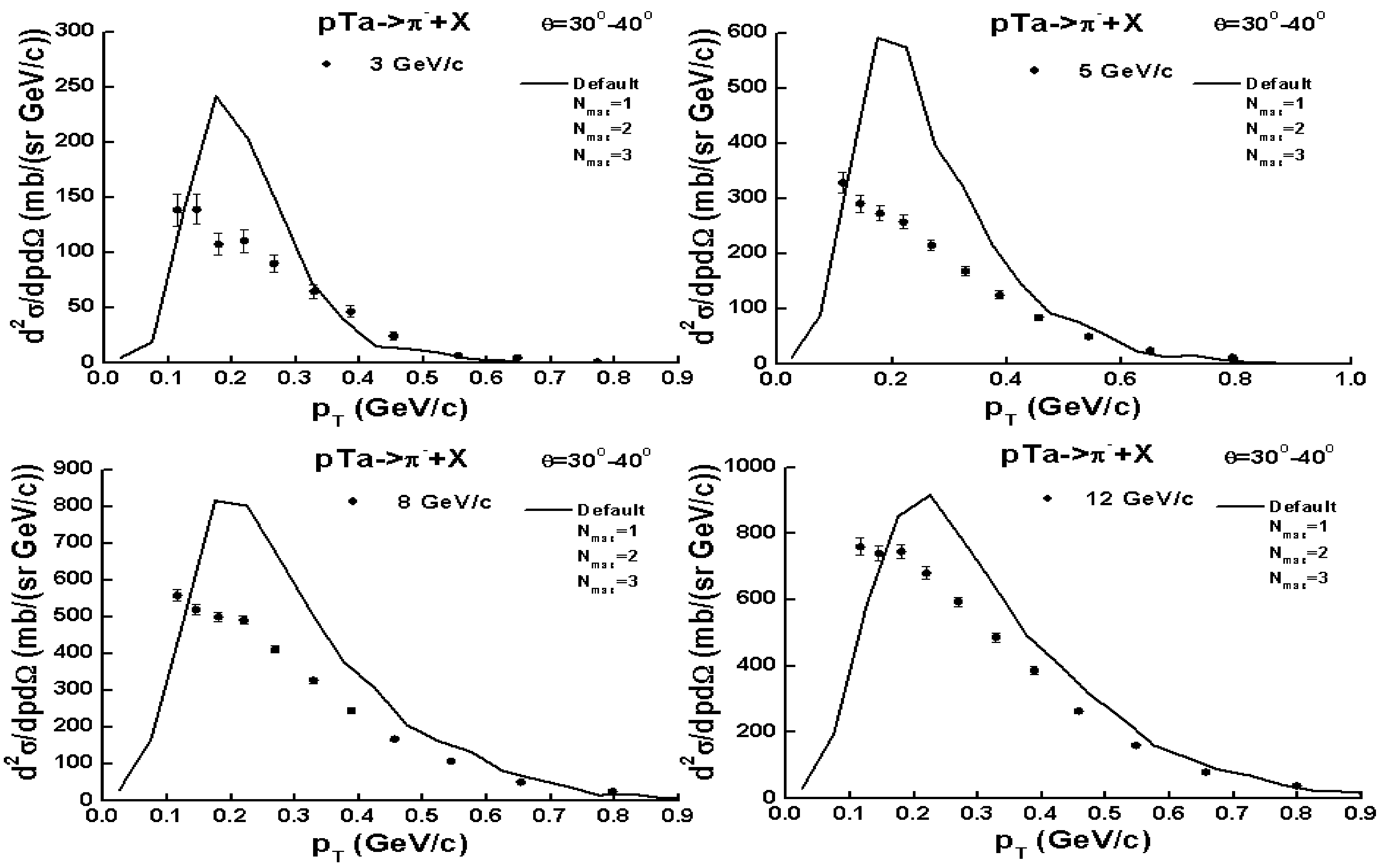
Phase space restrictions at low mass string fragmentation





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

Correction of multiplicity of intra-nuclear collisions



PROBLEM!

What can we do?

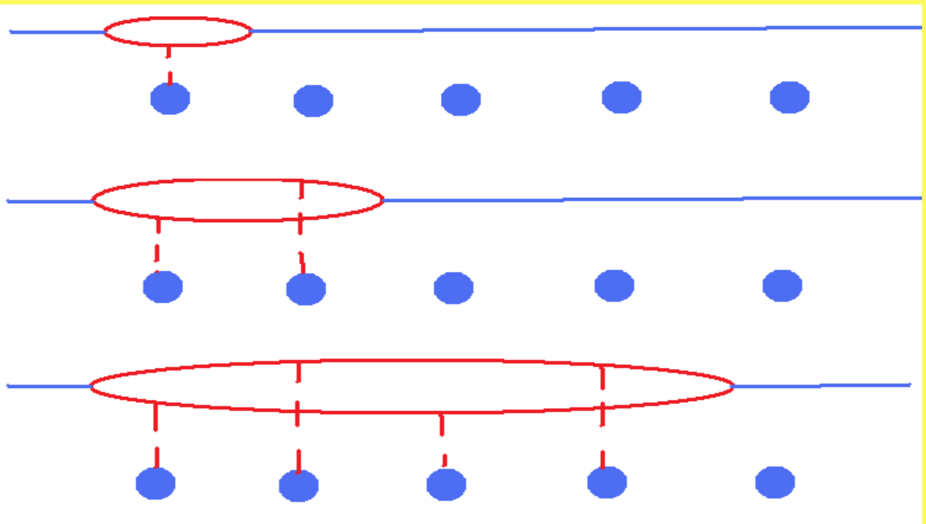
Change string fragmentation.
Change string mass distribution.
Change cross sections.
Correct interaction number.

Correction of multiplicity of intra-nuclear collisions

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.

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

Glauber cross section

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

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

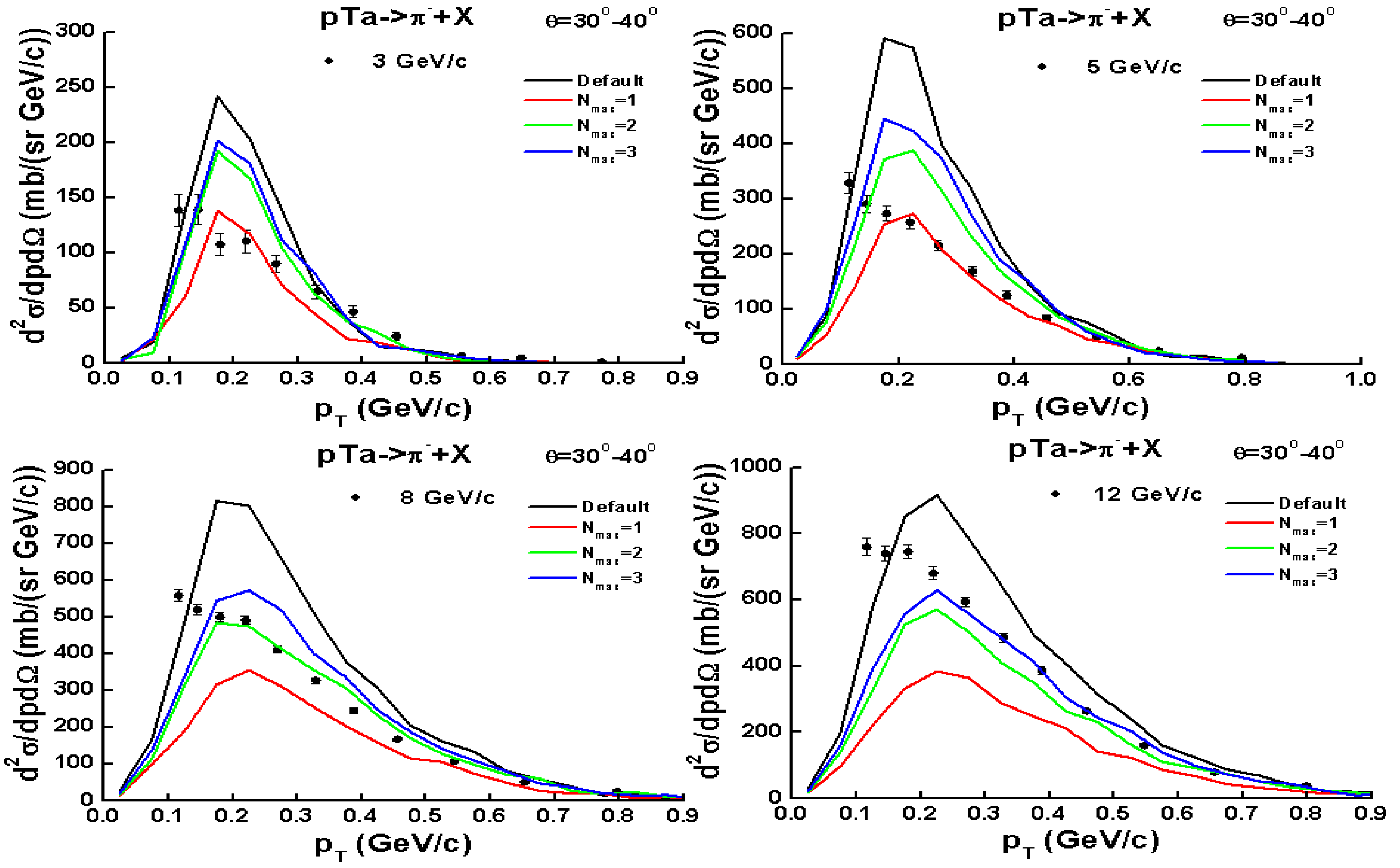
Uzhi rules

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

Max. cross section method:

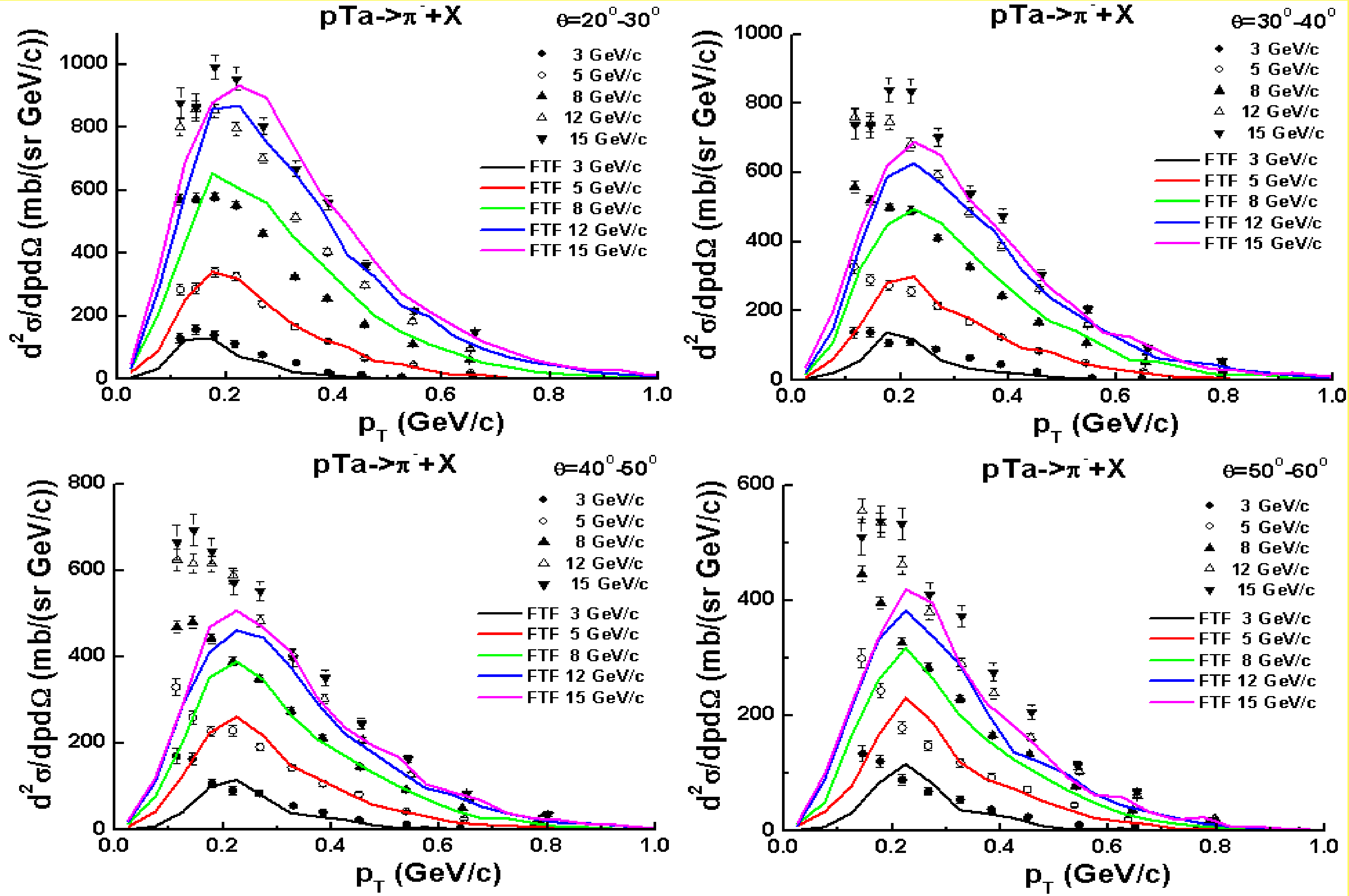
W.A. Coleman: Nucl. Sci. Eng. 32 (1968) 76

Correction of multiplicity of intra-nuclear collisions



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

Correction of multiplicity of intra-nuclear collisions

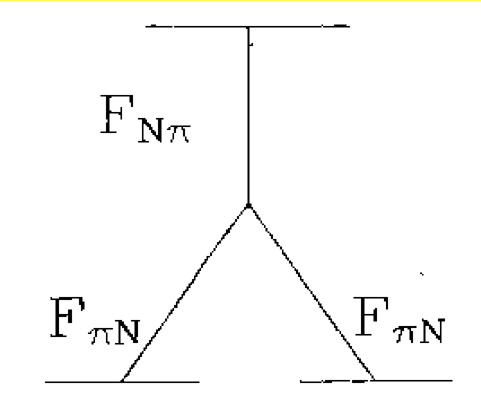


All O.K. with Pi-mesons!

Nmax=Plab/4 (GeV/c)

Tuning of reggeon cascading parameters

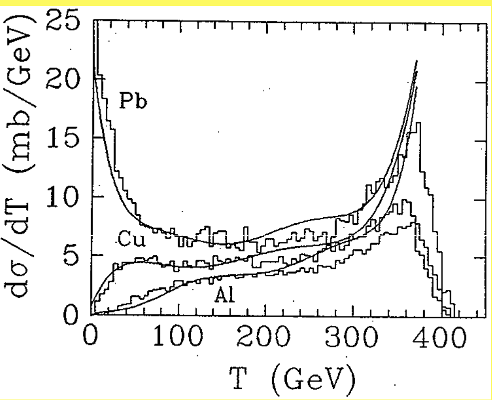
Glauber approach implemented in FTF and QGS is not sufficient for a destruction of a nucleus. Thus a reggeon cascading model of nuclear destruction was applied.



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



Si+A, 14.7 GeV/N
T – energy in ZDC

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

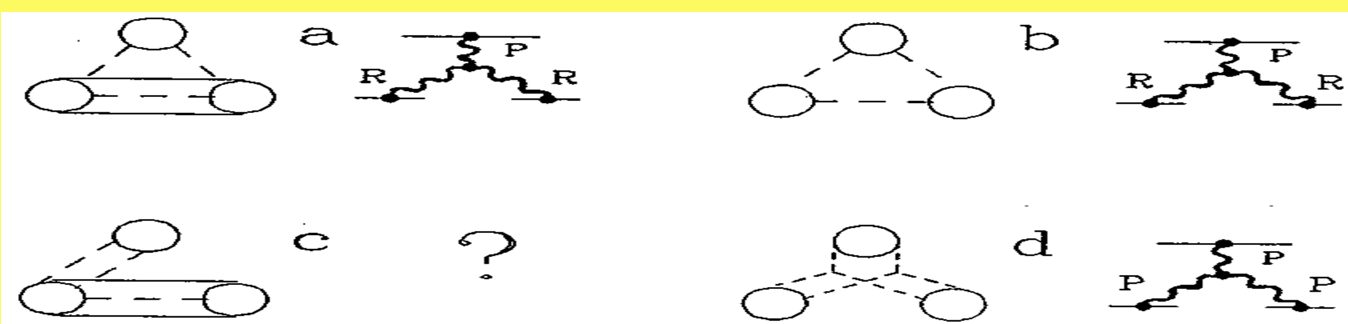
G is 3-pomeron vertex constant, $\vec{b}$- impact parameter of incident hadron, $\vec{s}_1$, $\vec{s}_2$- impact co-ordinates of nuclear nucleons. $\vec{b}'$ is the position of pomeron interactions vertex in the impact parameter plane, ξ'-its rapidity.

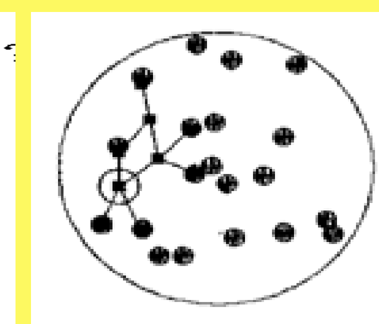
Using Gaussian parameterization for $F_{\pi N}$ ($F_{\pi N} = exp(-(|\vec{b}|^2)/(R^2_{\pi N}))$ and neglecting its dependence on energy, we have

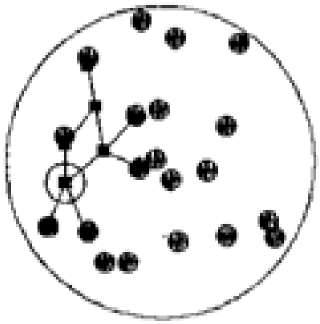
$$Y \simeq G(\xi_0 - 2\epsilon)\frac{R^2_{\pi N}}{3}exp(-(\vec{b}-(\vec{s}_1+\vec{s}_2)/2)^2/3R^2_{\pi N}) \times$$
$$\times\ exp(-(\vec{s}_1-\vec{s}_2)^2/2R^2_{\pi N}),$$

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

How have we to determine momentum spectra of nucleons?

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

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

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

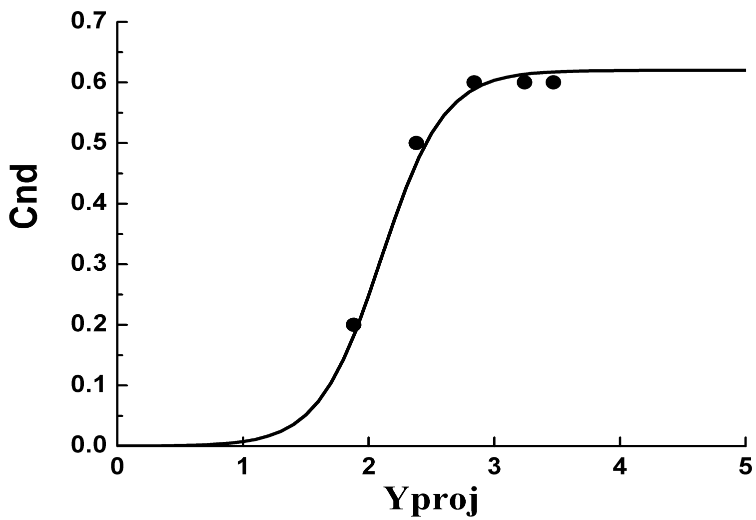
$$dW \propto \exp[-(x_i^+ - 1/A)^2/(d_x/A)^2]dx_i^+, \quad d_x = 0.05. \qquad (19)$$

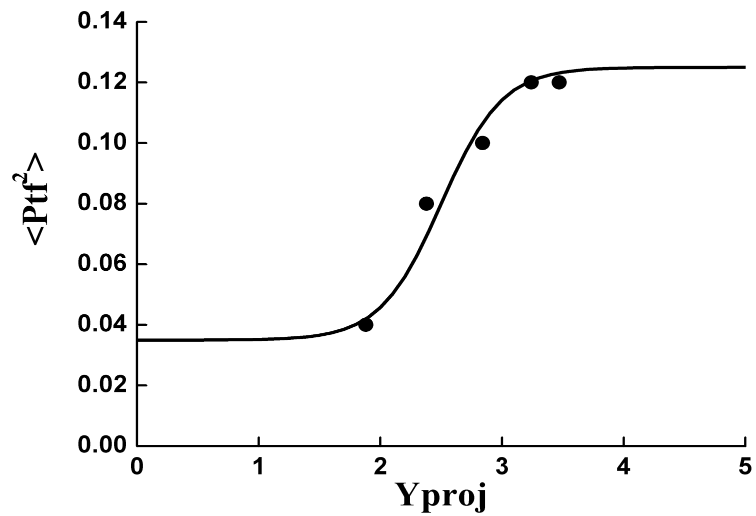
The dispersion of the distribution was defined by fitting the average emission angle of b-particles. x^+ of the residual nucleus was included as $1 - \sum x_i^+$.

Main parameters: Cnd, d_x, p_T^2

Tuning of reggeon cascading parameters

Unexpected results of the tuning!





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

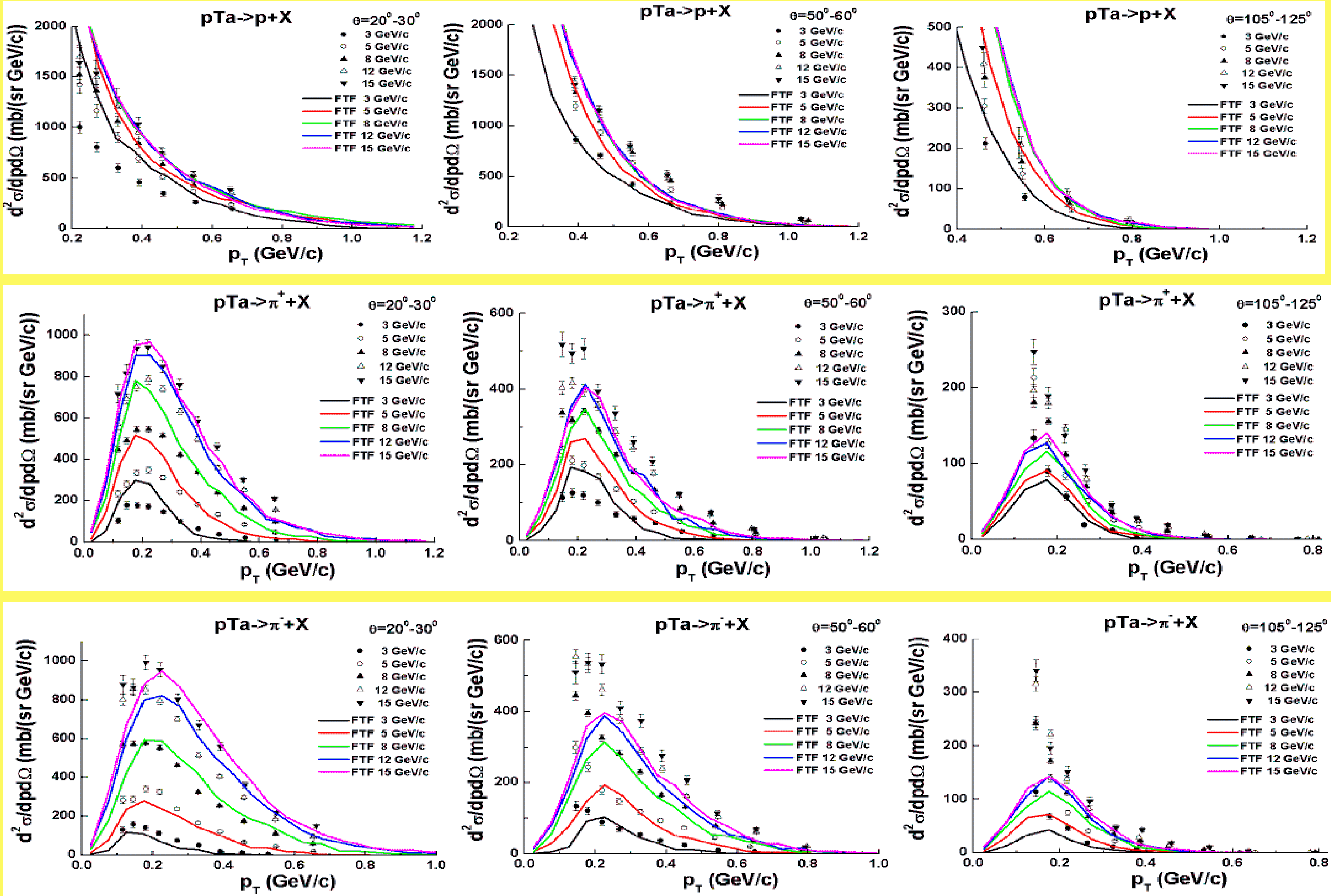
$$y = 2.1 \; at \; p_{lab} \simeq 4 \; GeV/c$$

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

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

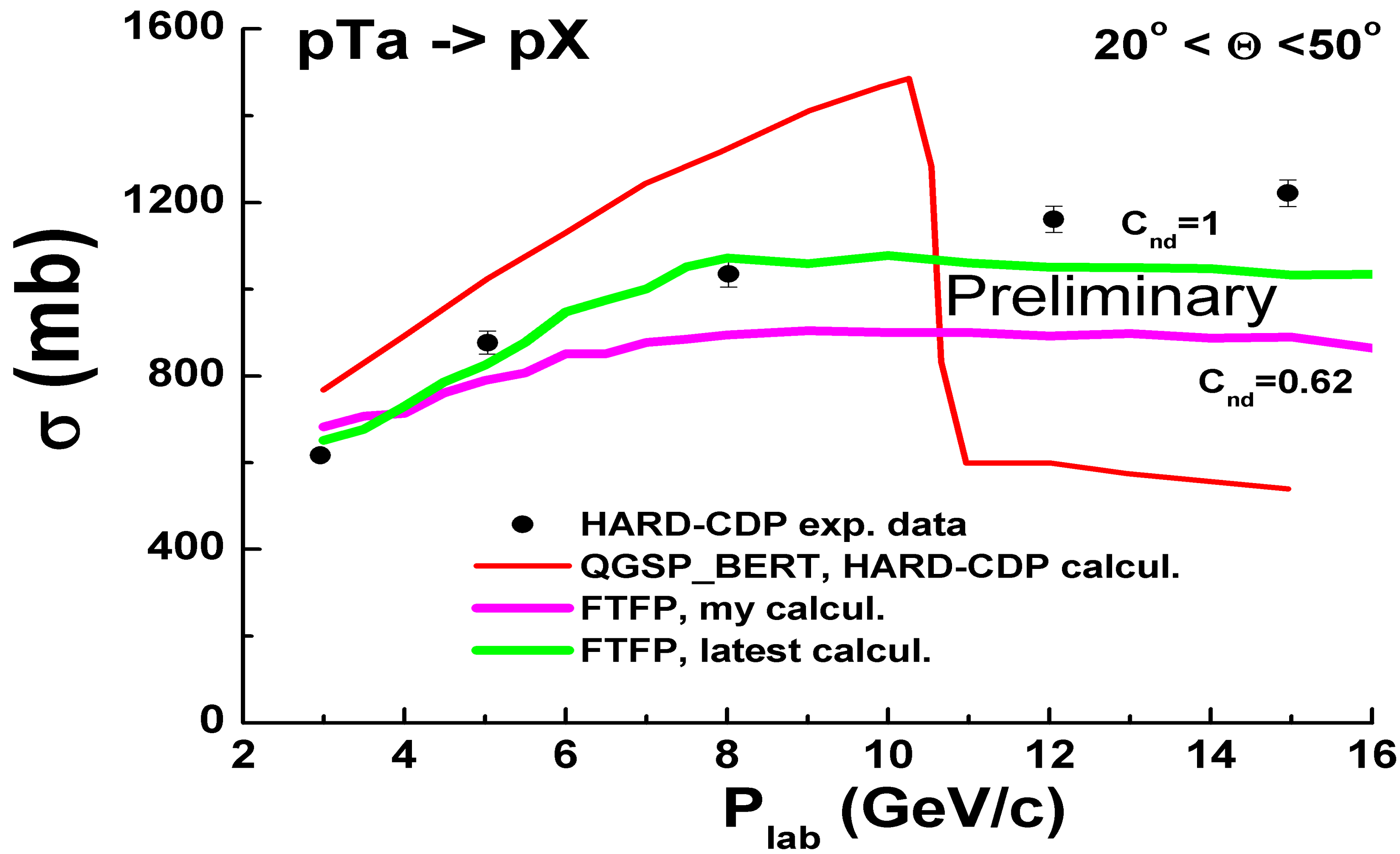
Clear signal of a transition regime!
The transition takes place at Plab= 4-5 GeV/c

Results – Description of the HARP-CDP exp. data



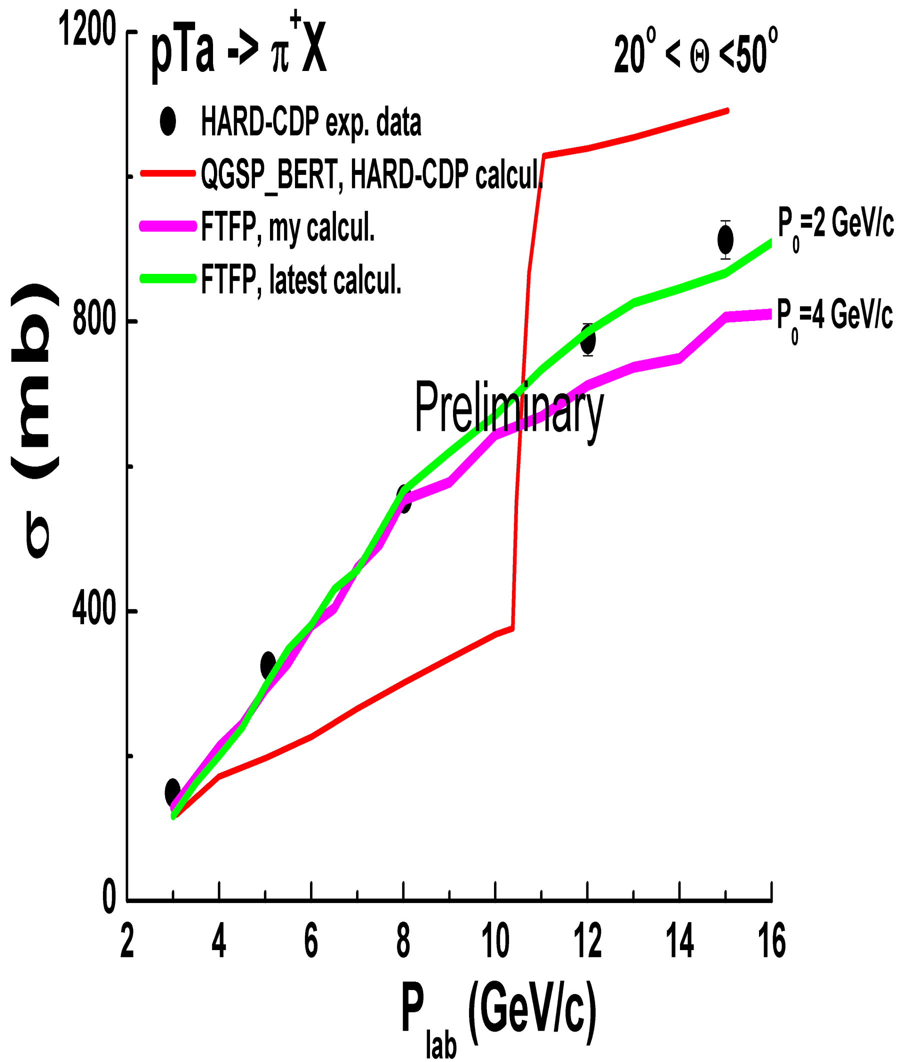
All is beautiful!

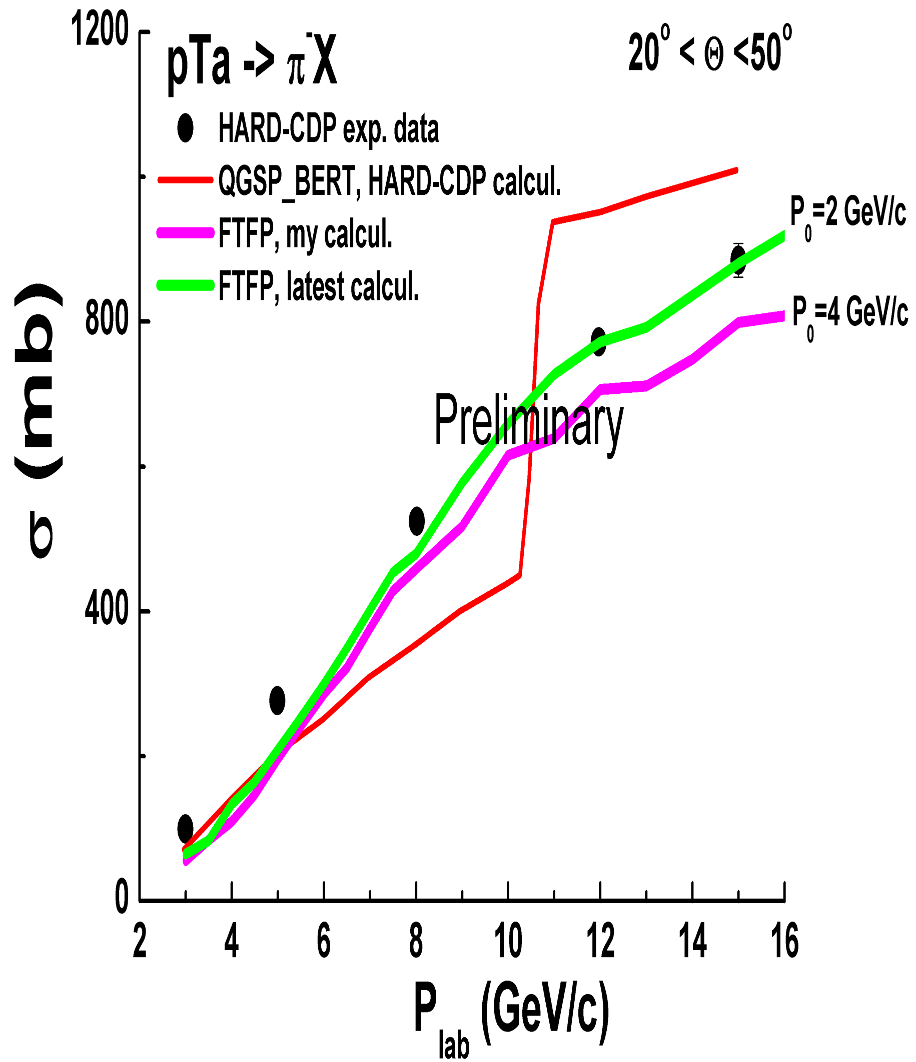
Results - Smooth transition



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]

Results - Smooth transition



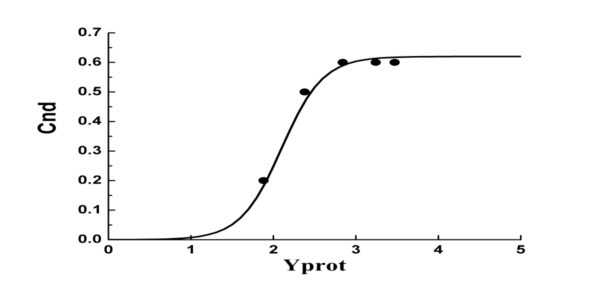


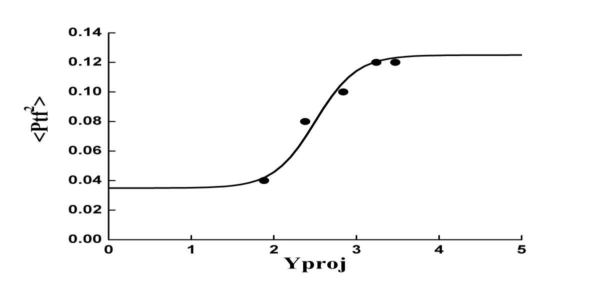
Summary

1. New things are introduced in FTF for pp- and pA-interactions:
   a) Separate simulation of diffractive and non-diffractive interactions
   b) Phase space restrictions at low mass string fragmentation
   c) Quark exchange for simulation of binary reactions
   d) Correction of multiplicity of intra-nuclear collisions
   e) RTIM was implemented and its parameters were tuned

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

3. A strong indication on transition regime realization is obtained!





Improved FTF model will be in December release of Geant4. It will be considered as production model.

Possible experimental check