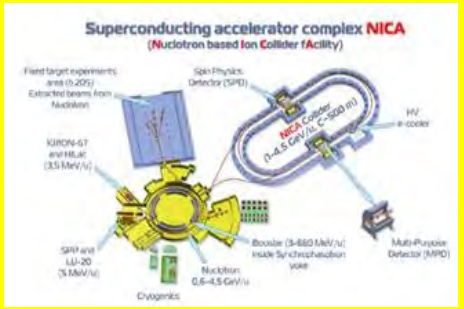
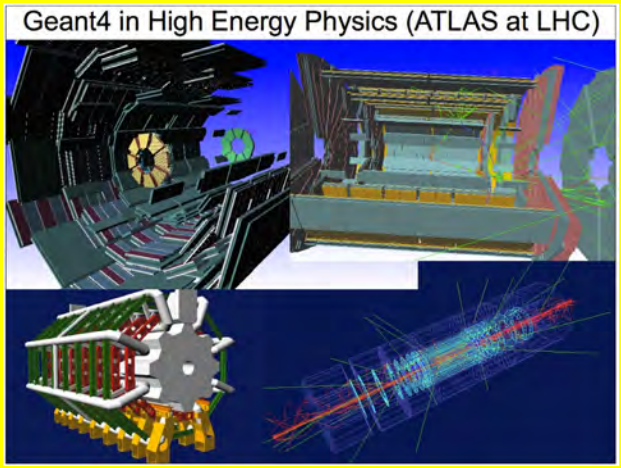
Geant4 hadronic models

V. Uzhinsky, A. Galoyan, N. Chalyi 24.10.2024
JINR Dubna and Tomsk Univ.





Geant4 для медицины

Four major use cases

- Beam therapy
- Brachytherapy
- Imaging
- Irradiation study

Geant4 is a component of muon tomography

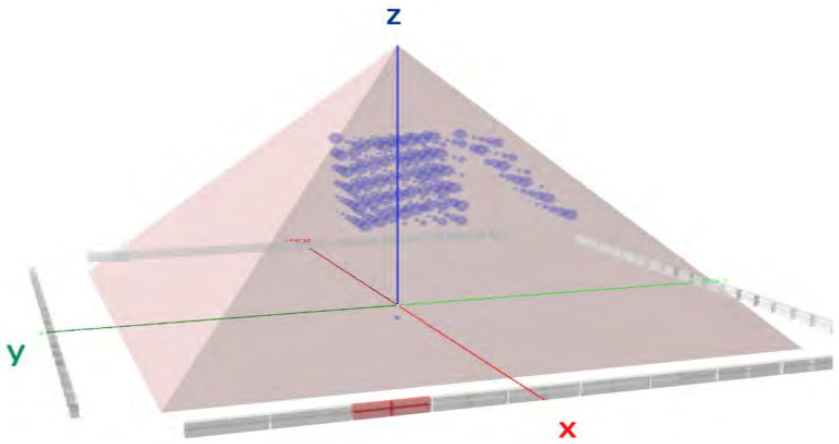


Figure 1: GEANT4 model. The model consists of a solid pyramid with voids with diameters between 1 and 6 m

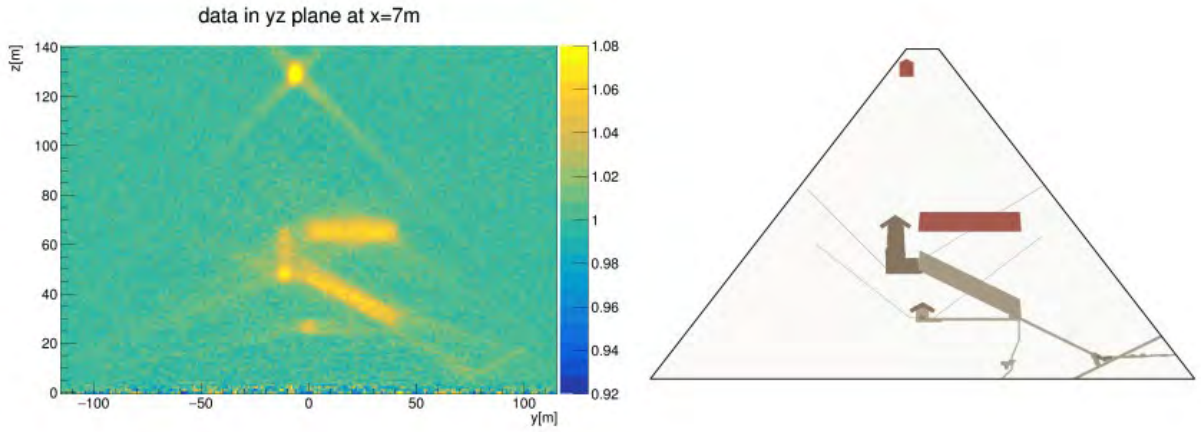
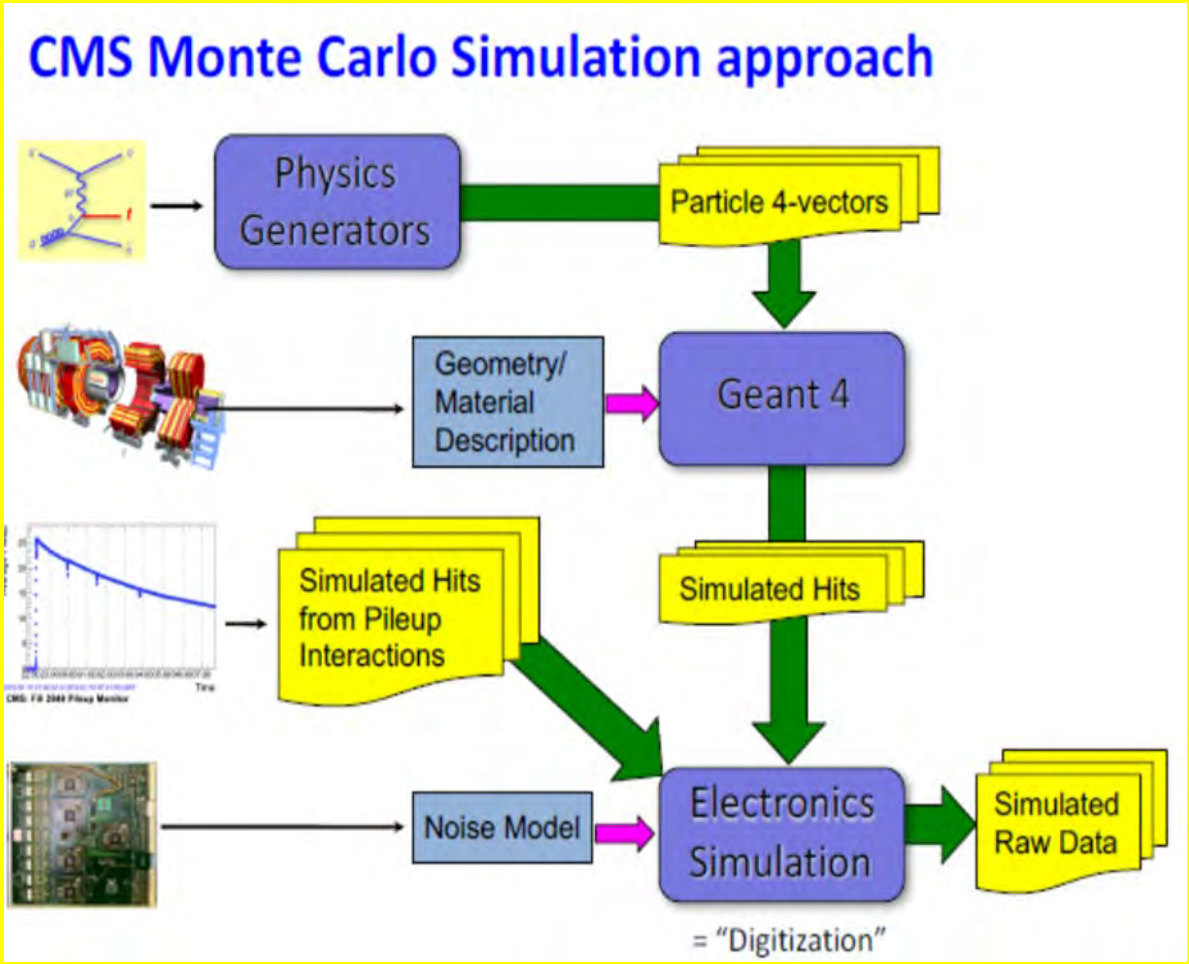


Figure 9: Left: yz slice from the 3D histogram. Right: Khufu model.

Geant4 for HEP experiments

- Monte Carlo simulation of particle interaction in pp collision at LHC or collisions at other accelerators is performed by special Monte Carlo tools
  - For example, PHYTHIA
- Geant4 is responsible for Monte Carlo simulation of particle transport in experimental setup
  - Hits in detectors
- Simulation of electronics and pileup is performed by specialized user code
  - DIGI step



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analysis	g3tog4	materials	readout
CMakeLists.txt	geometry	parameterisations	run
digits_hits	global	particles	track
error_propagation	graphics_reps	persistency	tracking
event	intercoms	physics_lists	visualization
externals	interfaces	processes	

$G4INSTALL/ /source//processes

biasing	decay	History	parameterisation	transportation
CMakeLists.txt	electromagnetic	management	scoring	
cuts	hadronic	optical	solidstate	

$G4INSTALL/ /source/processes/ hadronic/ models/

$G4INSTALL/ /source/processes/ hadronic/ models/

abla	de_excitation	inclxx	pre_equilibrium
abrasion	em_dissociation	lend	qmd
binary_cascade	fission	lepto_nuclear	quasi_elastic
cascade	gamma_nuclear	particle_hp	radioactive_decay
coherent_elastic	im_r_matrix	parton_string	theo_high_energy

$G4INSTALL/ /source/processes/ hadronic/ models/parton_string

diffraction hadronization History management qgsm

FTF model String fragm. Quark-gluon string model

Fritiof model

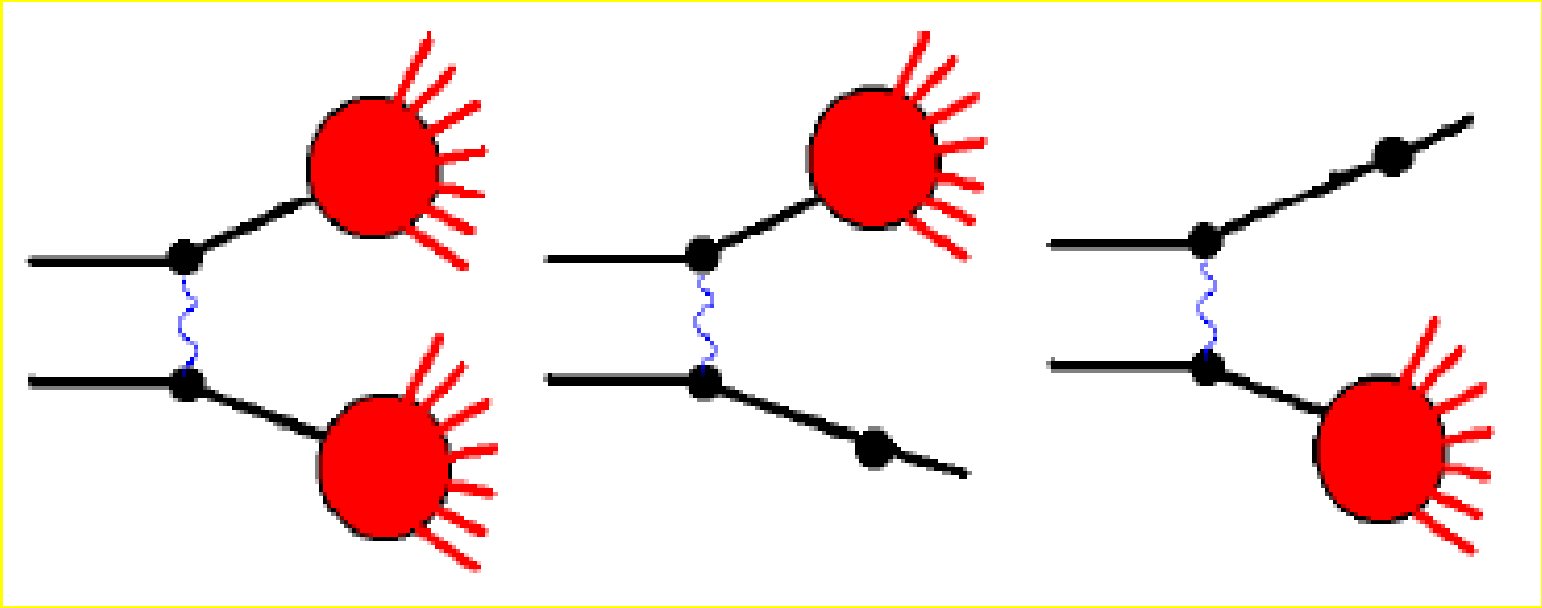
B.Andersson et al. Nucl. Phys. B281 289 (1987);
B.Nilsson-Almquist, E.Stenlund, CPC 43 387 (1987).

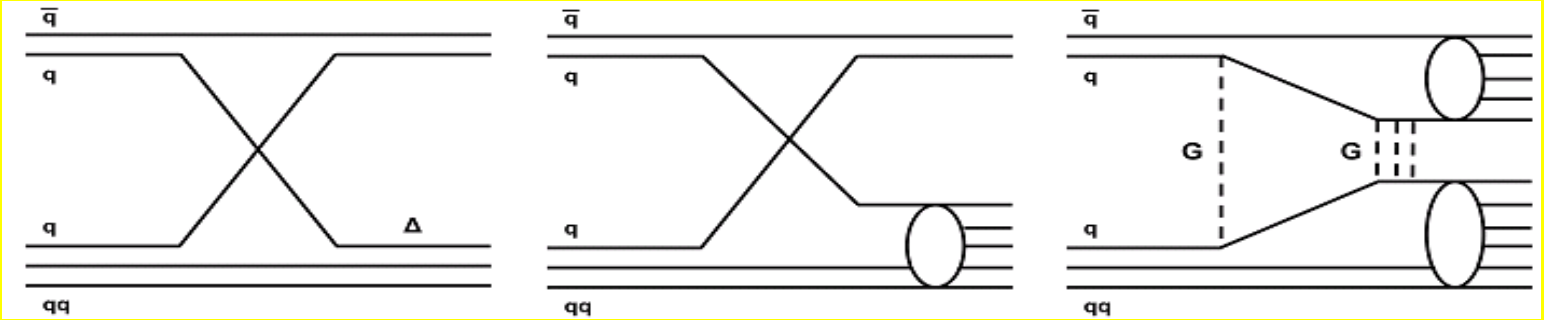
Hadron-hadron interactions are modeled as binary reactions

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

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

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





Fritiof model

B.Andersson et al. Nucl. Phys. B281 289 (1987);
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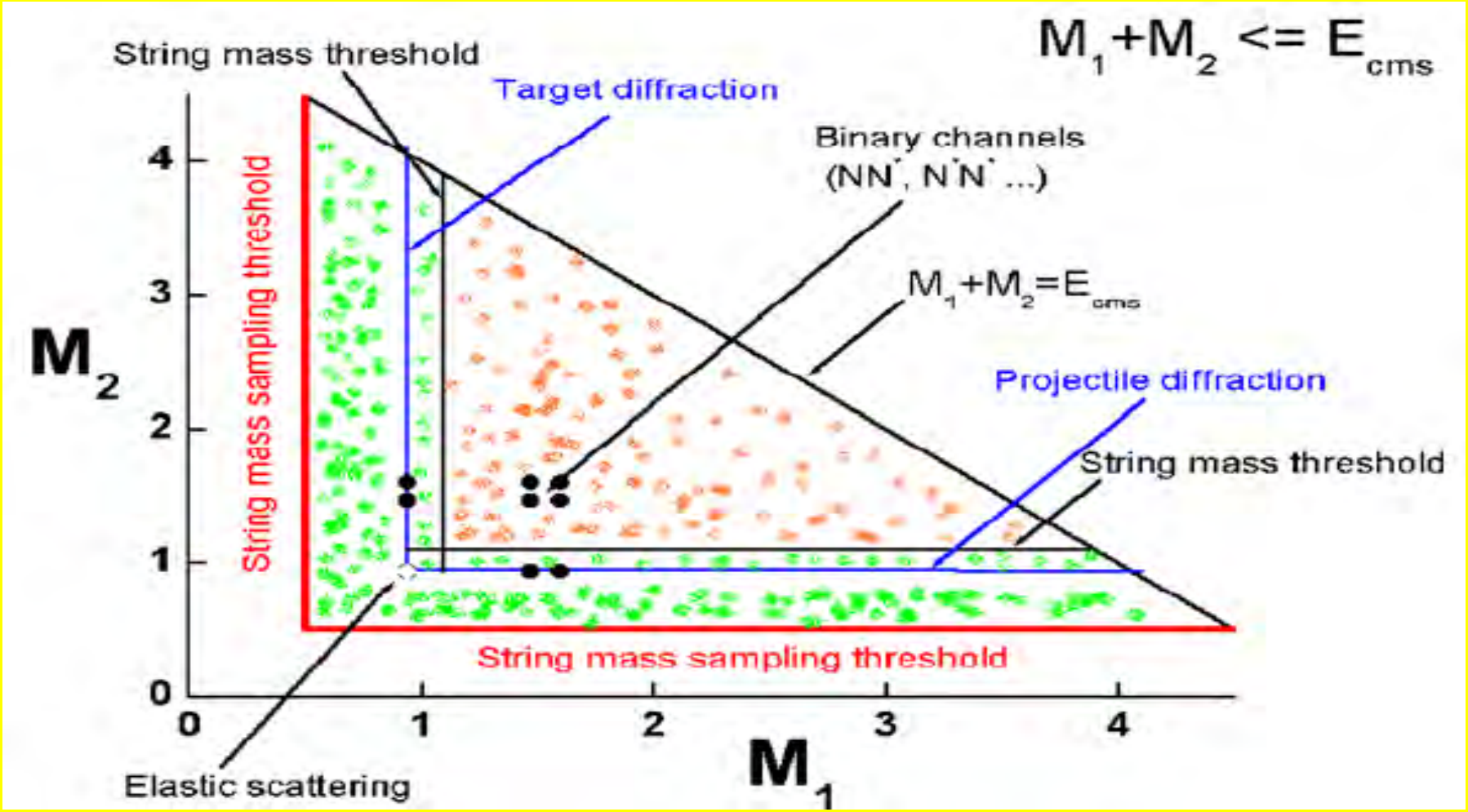


$NN \to N\Delta_{1232}$ $NN \to NN^*$

FTF model: string fragmentation details

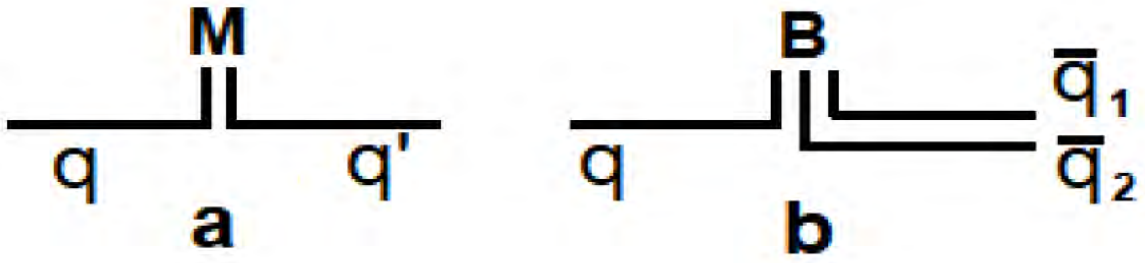


Figure 9: Vertexes of quark fragmentations.

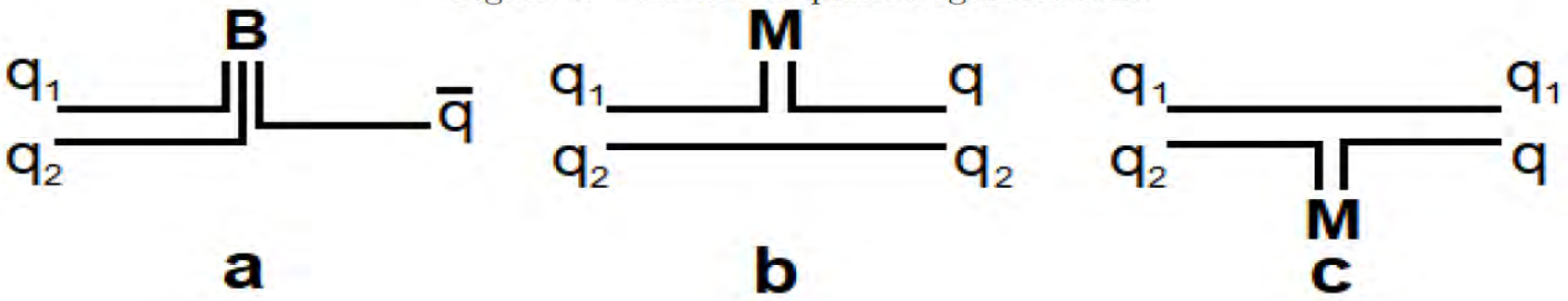


Figure 10: Vertexes of diquark fragmentations.

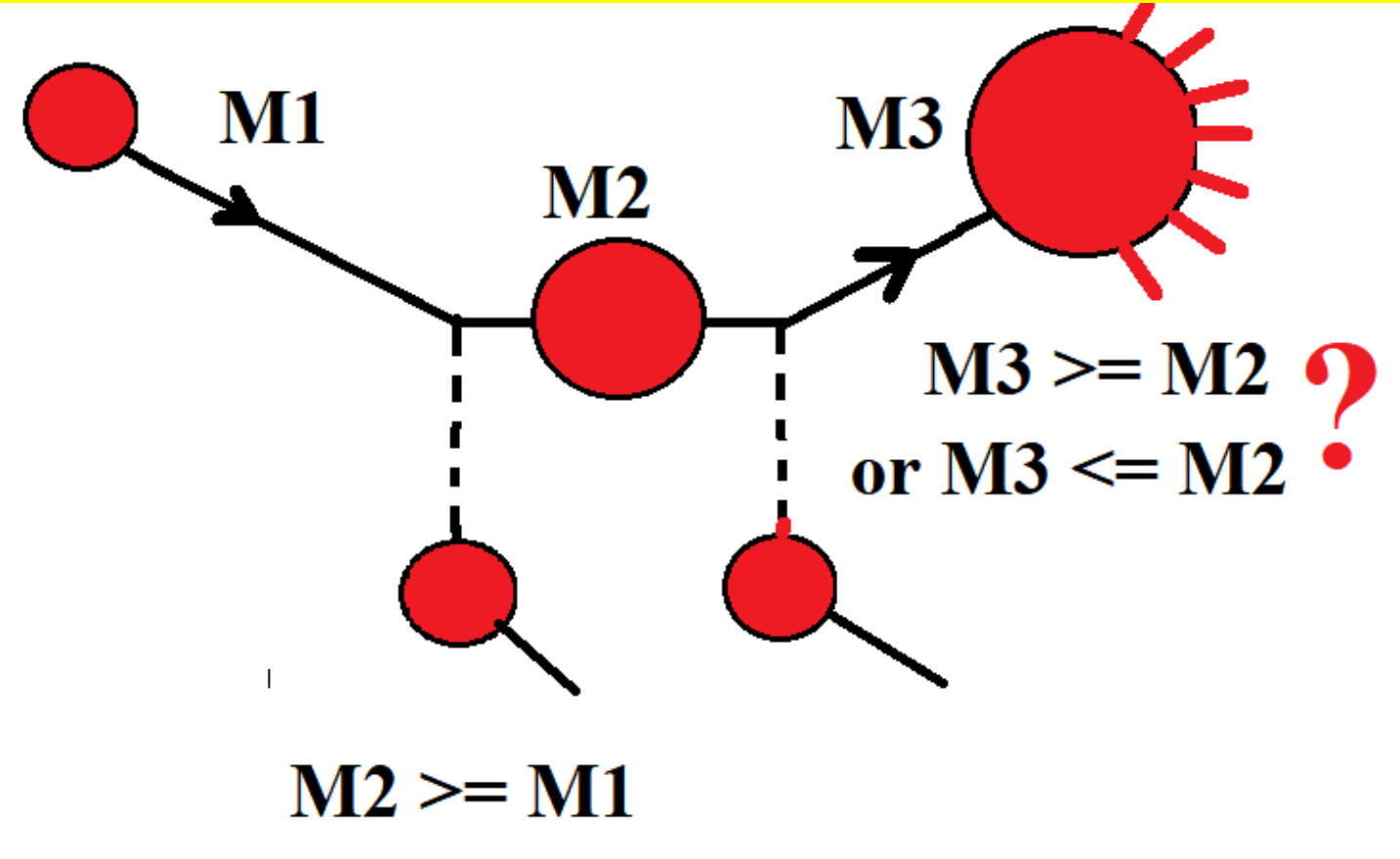
For mesons

$$f(z) \propto z^{-1}\ (1-z)^{a}\ \exp\left(-b\ m_T^2/z\right), \quad a=1, \quad b=0.7\ (GeV)^{-2}, \quad m_T^2 = m_h^2 + P_T^2.$$

For baryons, a'la Kaidalov

$$f(z) = \frac{c}{(z_{max}-z_{min})^{c}}\ (z-z_{min})^{c-1}, \quad c = 2 + P_T^2.$$

hA and AA interactions?



36 years old question!

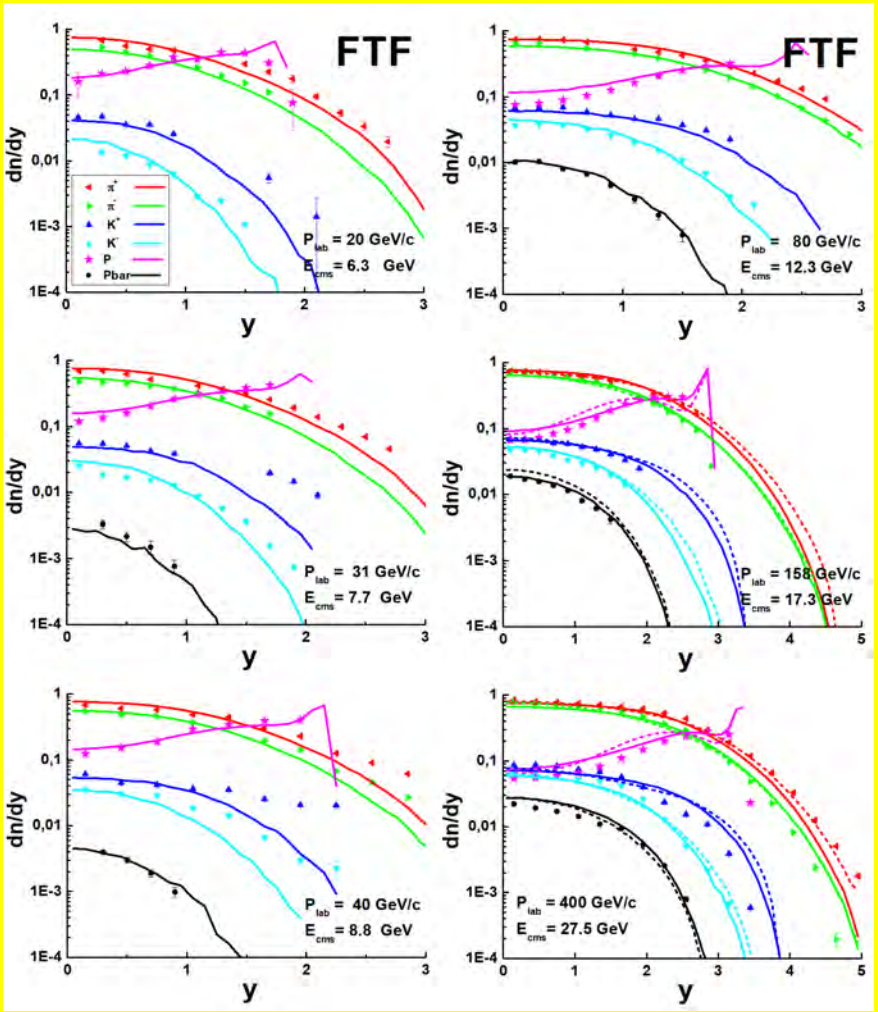
Now, M3 => M2 !

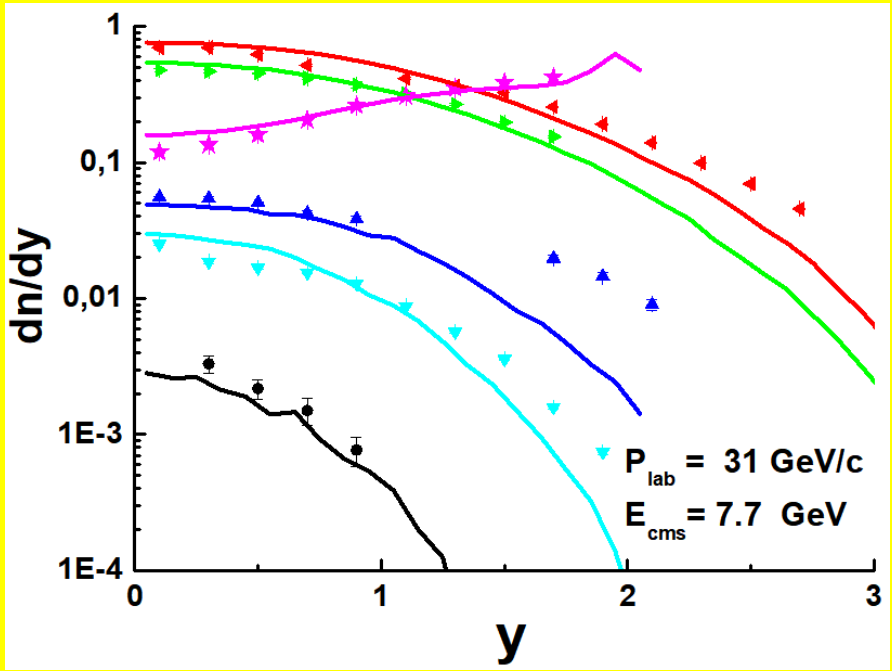
FTF model description of inclusive one-particle distributions …

Measurements of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/*c* with the NA61/SHINE spectrometer at the CERN SPS

NA61/SHINE Collaboration

Eur. Phys. J. C (2017) 77:671



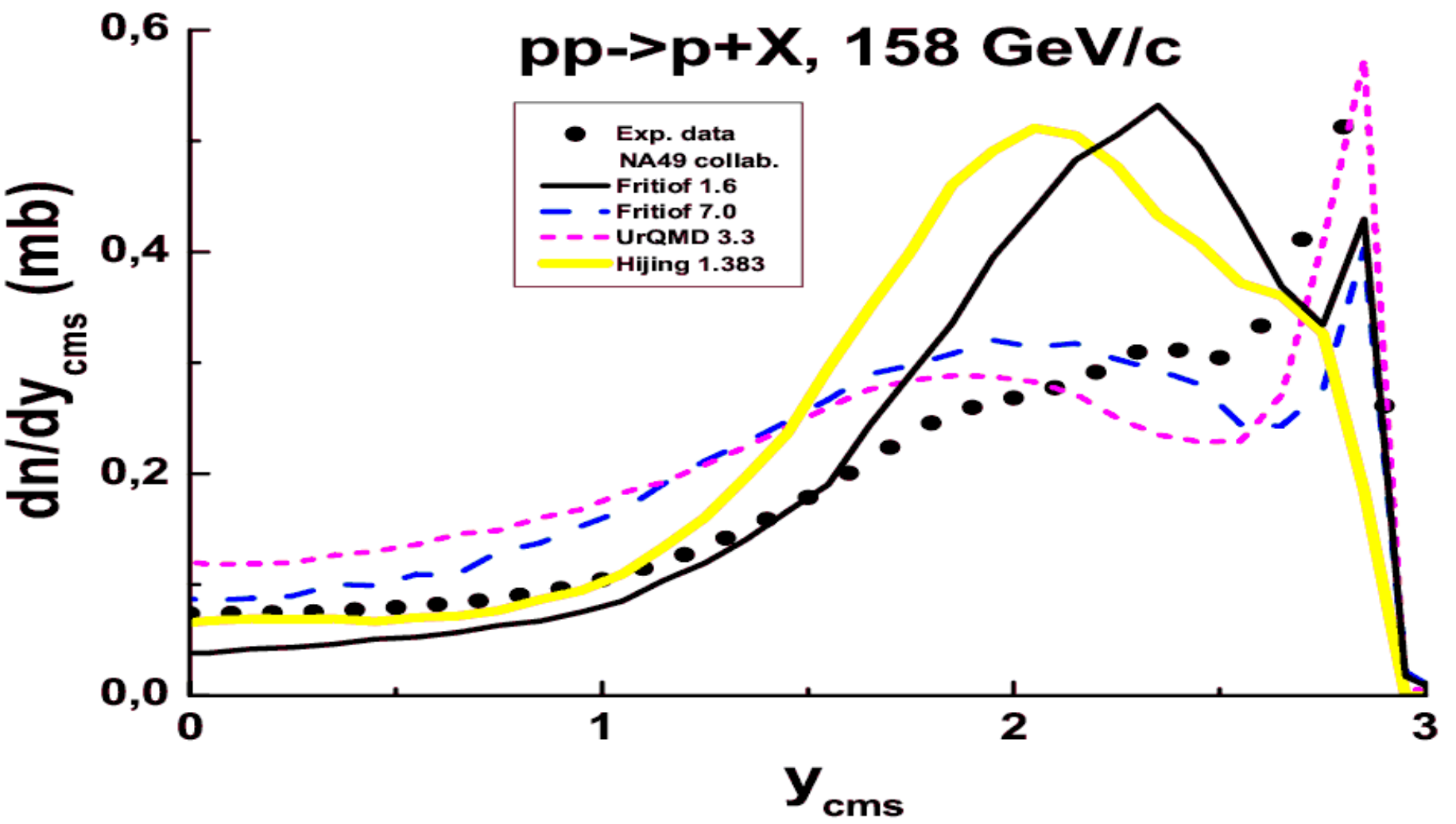


FTF cannot describe K+, K- production at 20, 31 and 40 GeV/c. At higher energies all O.K.

Are exp. data correct?

Problem

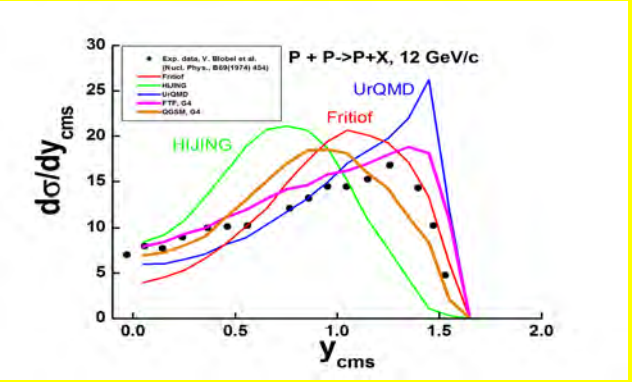
Fritiof 1.6, Fritiof 7.0, Hijing, UrQMD 3.3, pp-interactions NA49 exp. data

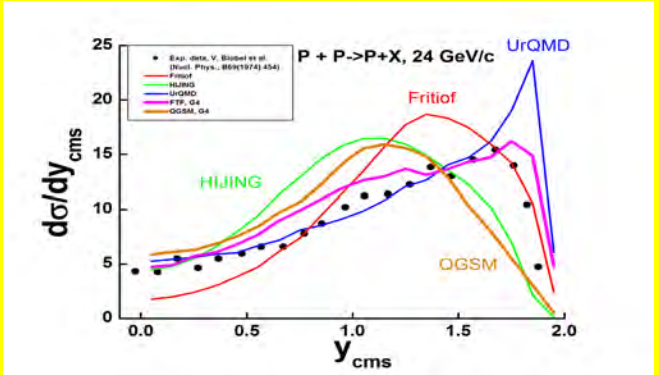


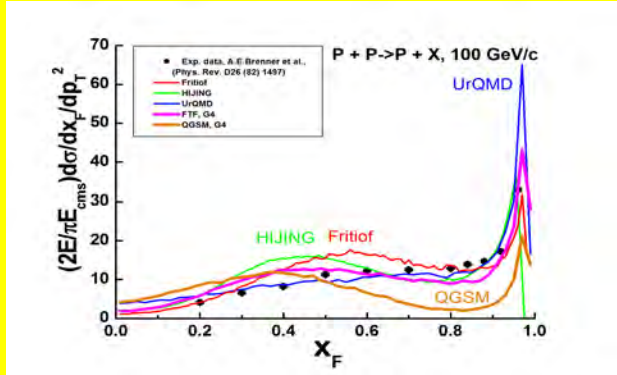
Arxiv: 1404.2026 [hep-ph] Toward Description of pp and pC Interactions at High Energies:

Problems of Fritiof-based Models, V.

Description of baryon spectra is the problem in all MC models

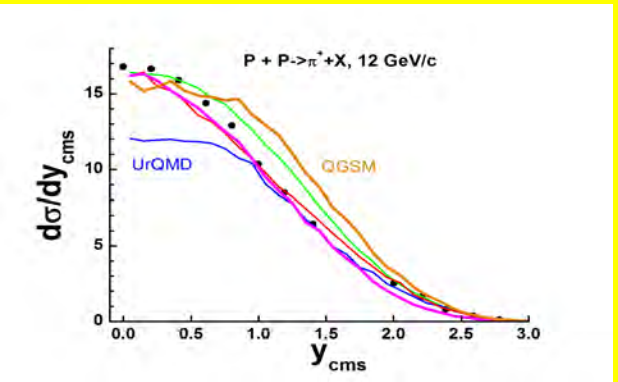


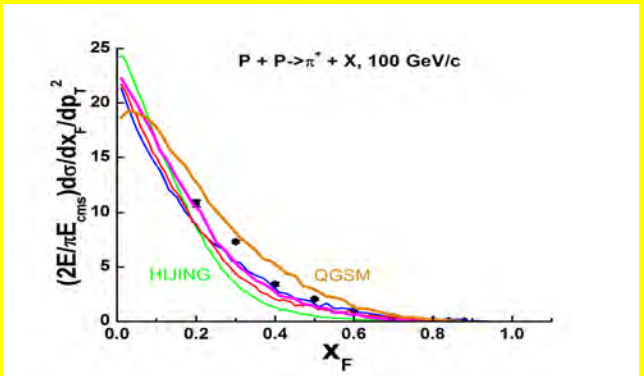


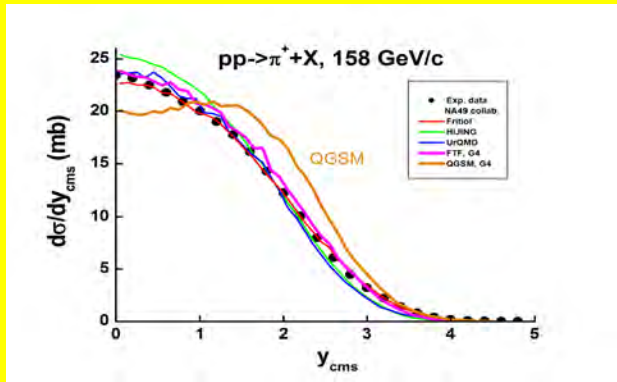


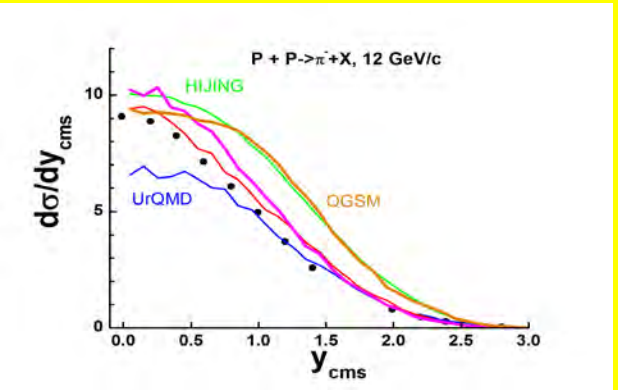
Exp. Data: V. Blobel et al., Nucl. Phys., B69(1974) 454.

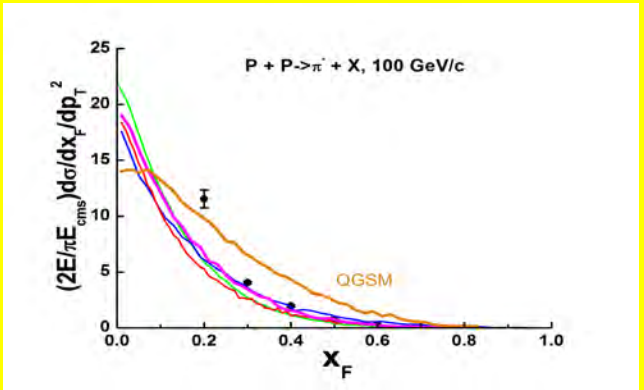
There are some problems with a description of meson spectra

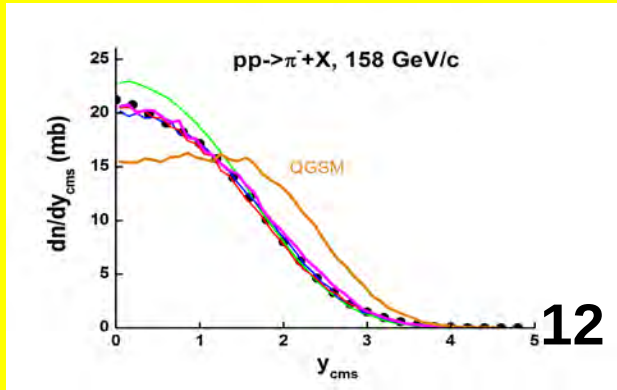


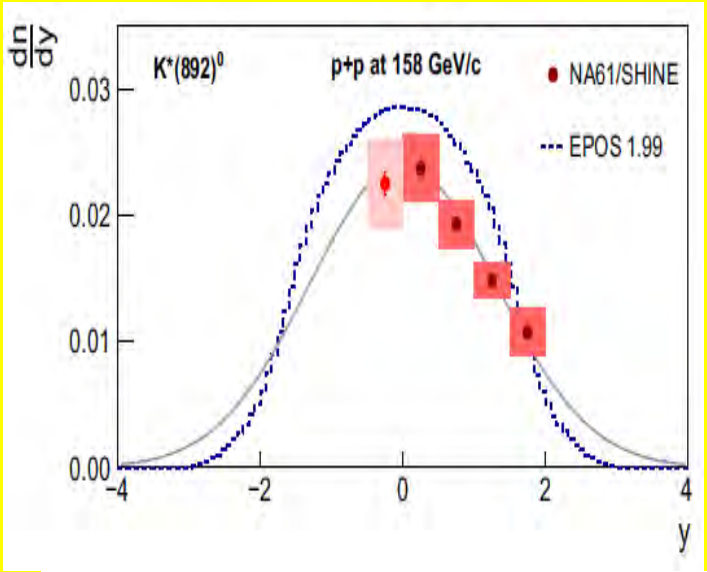












$K^*(892)^0$ meson production in inelastic p+p interactions at 158 GeV/*c* beam momentum measured by NA61/SHINE at the CERN SPS

NA61/SHINE Collaboration Eur. Phys. J. C (2020) 80:460

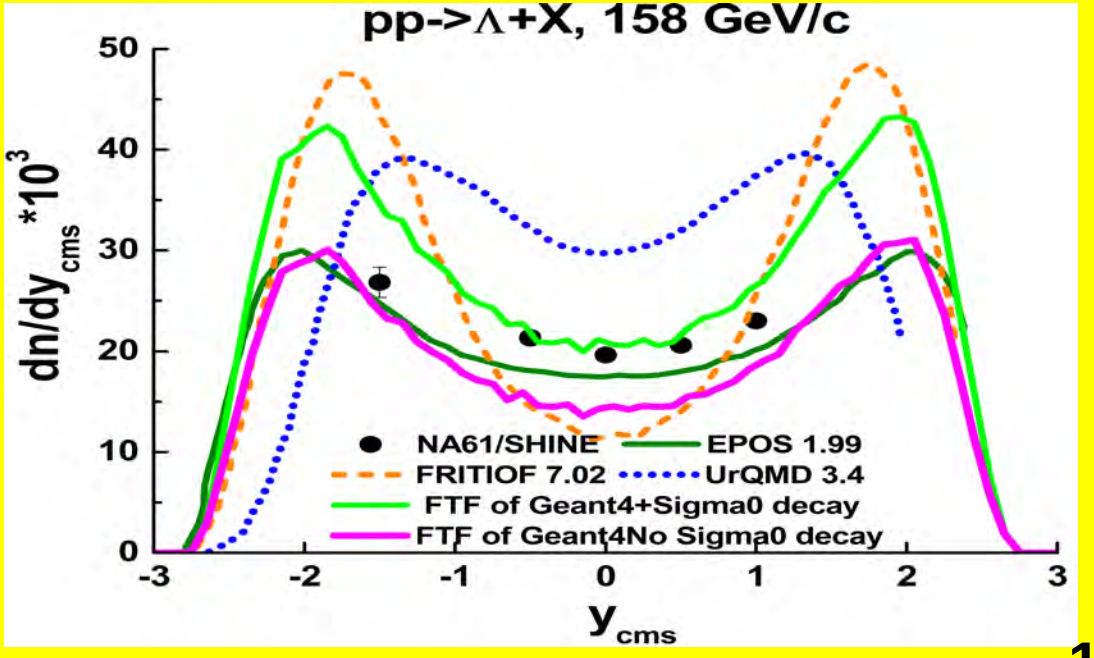
Monte Carlo Event Generators must be validated!

Production of Λ-hyperons in inelastic p+p interactions at 158 GeV/*c*

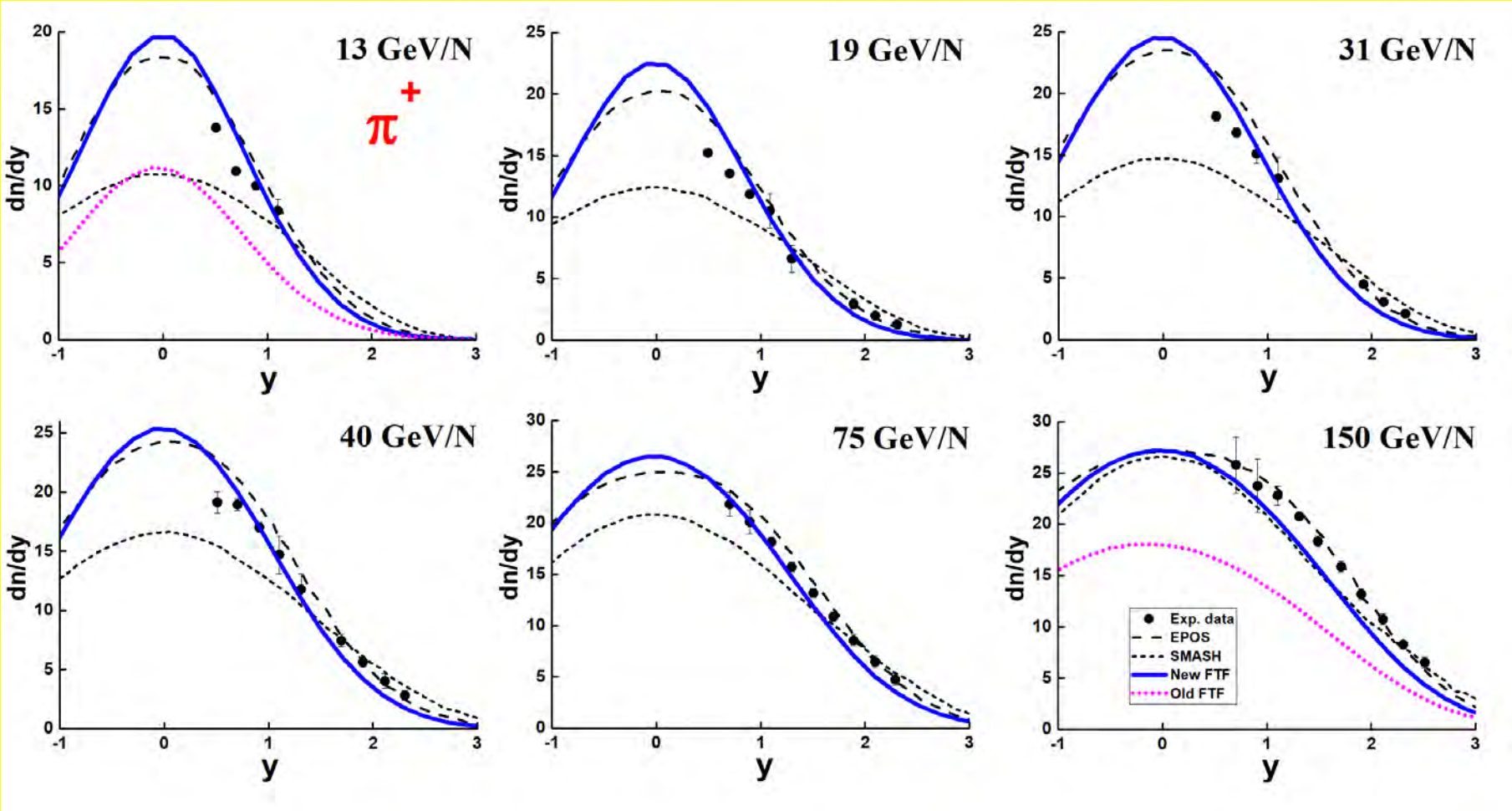
NA61/SHINE Collaboration

Eur. Phys. J. C (2016) 76:198

Fritiof 1.6, Fritiof 7.0, Hijing, UrQMD 3.3, pp-interactions



New exp. data by NA61/SHINE collab. On Ar-40 + Sc-45 interactions at high energies (2024) 0 – 10 % centrality

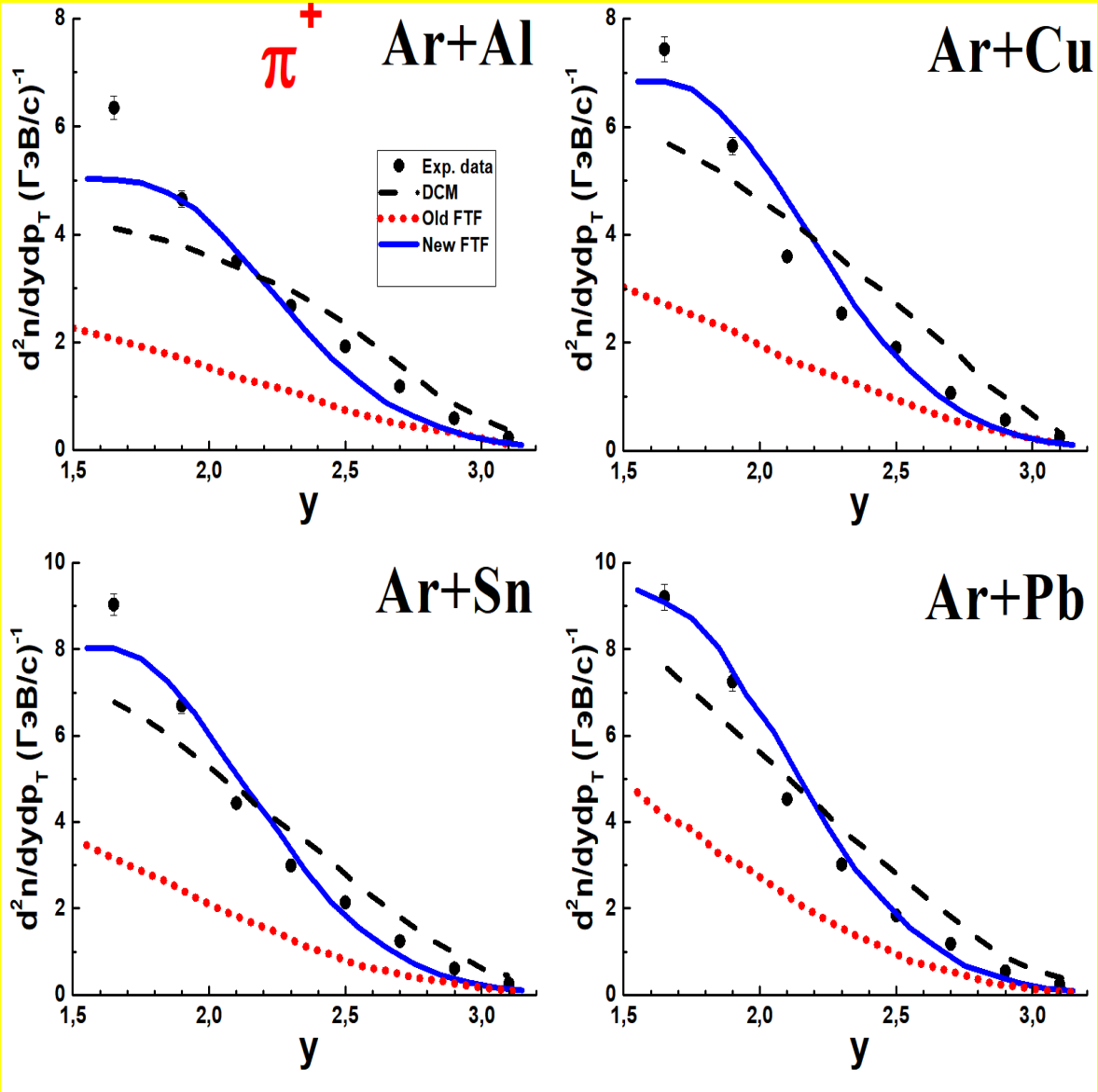


New FTF:

К теоретической интерпретации данных о взаимодействиях ядер аргона с ядрами при высоких энергиях

В. В. Ужинский[+*1)], *А. С. Галоян*[+], *Н. А. Чалый*[*]

Совершенно неожиданным для нас оказалось то, что предлагаемый подход дает хорошие результаты в применении к данным (2023) коллаборации NICA BM@N о выходах π+ мезонов во взаимодействиях ядер аргона с ядрами при энергии 3,2 А ГэВ.



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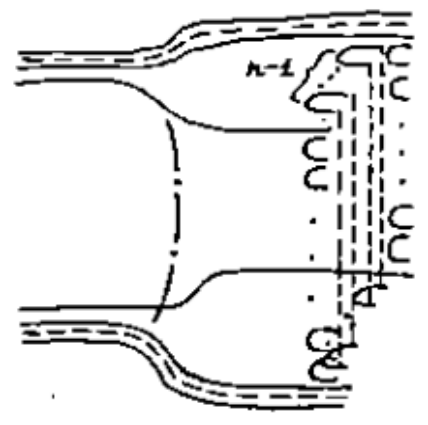
Quark-gluon string model –QGSM, a'la Kaidalov

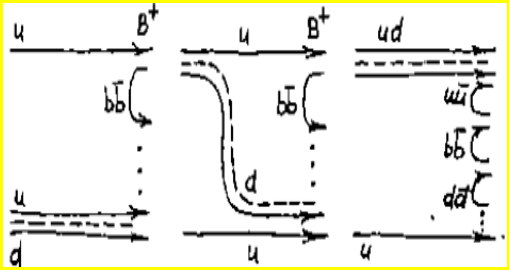


$$1/\sigma_{inel} d\sigma/dx = \sum_{n=1}^{\infty} w_n \phi_n^h(x)$$

$$\Delta = 0.139\ ,\ \alpha' = 0.21\ \mathrm{GeV}^{-2}\ ,\ \gamma_{pp} = 1.77\ ,\ \gamma_{\pi p} = 1.07\ ,$$
$$R_{pp}^2 = 3.18\ \mathrm{GeV}^{-2}\ ,\ R_{\pi p}^2 = 2.48\ \mathrm{GeV}^{-2}\ ,\ C_{pp} = 1.5\ ,\ C_{\pi p} = 1.65$$

$$\phi_n^h(x) = f_{qq}^h(x_+, n) f_q^h(x_-, n) + f_q^h(x_+, n) f_{qq}^h(x_-, n) + 2(n-1) f_s^h(x_+, n) f_s^h(x_-, n)$$

$$f_q^h(x_+, n) = \int_{x_+}^1 u_q(x_1, n) G_q^h(x_+/x_1) dx_1$$



$$f_p^{u_v(n)}(x) = C_n^{u_v} x^{-\alpha_R(0)} (1-x)^{\alpha_R(0) - 2\alpha_N(0) + n - 1}, \qquad (10)$$

$$G_d^{D^-}(x/x_1) = G_{\bar{u}}^{D^0}(x/x_1) = (1-x/x_1)^{\lambda - \alpha_\psi(0)} [1 + a_1 (x/x_1)^2], \qquad (11)$$

where $\alpha_R(0) = 0.5$, $\alpha_N(0) = -0.5$, $\lambda = 2 < p_\perp^2 > \alpha_R' = 0.5$, and the coefficient $C_n^{u_v}$ is determined by normalization

WEB resources

Main Geant4 web https://geant4.web.cern.ch/ includes references to

- Download page
- Documentation
- Main Geant4 publications
  - we ask to cite these publications in your articles
- User forum
  - This is a place to discuss problems with developers and other users
- Bug report system
- Announcements
- Open-source license

Geant4 virtual machine https://geant4.lp2ib.in2p3.fr/

- It is possible to install a player and ready to use virtual machine to your PC

How to start?

Read documentation

Install Geant4 according to manual

- Compile Geant4 and examples of interest

Alternatively install virtual machine

- Geant4, ROOT, and QT visualization driver will be pre-installed for you

Try to use Geant4 examples

- **Basic $G4INSTALL/example/basic**
- Electromagnetic
  - $G4INSTALL/examples/extended/electromagnetic/TestEm5
    - It is possible to used macro files from the example directory or use you own
    - Study penetration of particles via target – various histograms built-in
  - $G4INSTALL/examples/extended/electromagnetic/TestEm7
    - Study profile of energy deposition in the target for various particle type
    - Observe the Bragg peak of ionization
- Hadronic
  - $G4INSTALL/examples/extended/hadronic/Hadr01
    - Study profile of energy deposition in the target
    - Study production of secondary particles
    - Study neutron flux after the target

https://geant4.web.cern.ch/docs/getting-started

Physics Reference Manual **describes physics interactions simulated in Geant4.**

geant4/examples/basic

B1 B2 B3 B4 B5

geant4/examples/extended/hadronic

CMakeLists.txt Hadr01 Hadr04 Hadr07 Hadr10 ParticleFluence
FissionFragment Hadr02 Hadr05 Hadr08 History README
Hadr00 Hadr03 Hadr06 Hadr09 NeutronSource

Monte Carlo Event Generators must be validated!