高エネルギー宇宙線におけるハドロンカスケード模型

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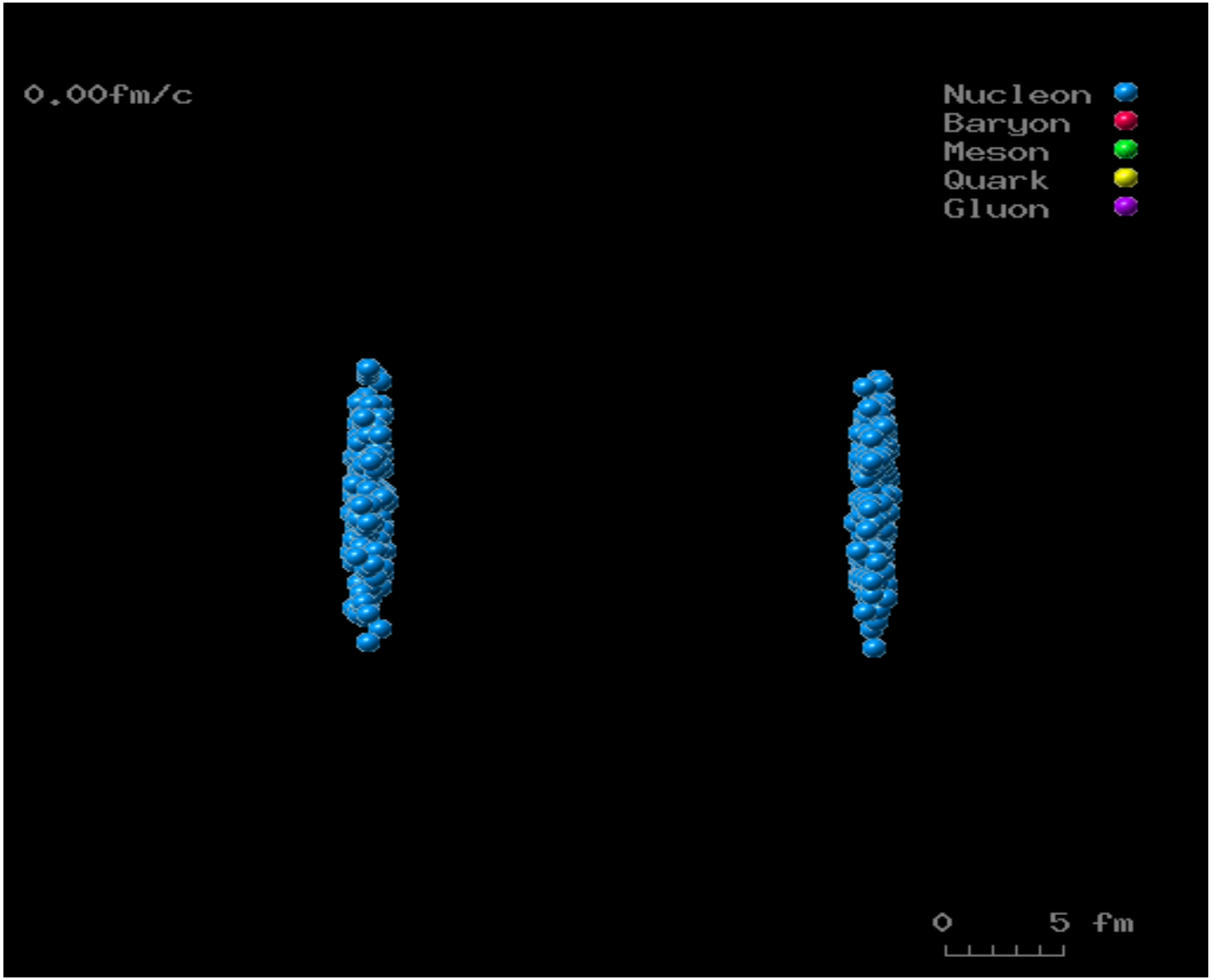
- 高エネルギー重イオン衝突におけるハドロンカスケード模型
- モデルの説明: インプット (ハドロン散乱レベルでの素過程)
- 応用例
- まとめ

超高エネルギー宇宙線とハドロン構造2008　KEK , Apr. 25-26 2008

High energy heavy ion collision

Pb+Pb collision at E=200 AGeV

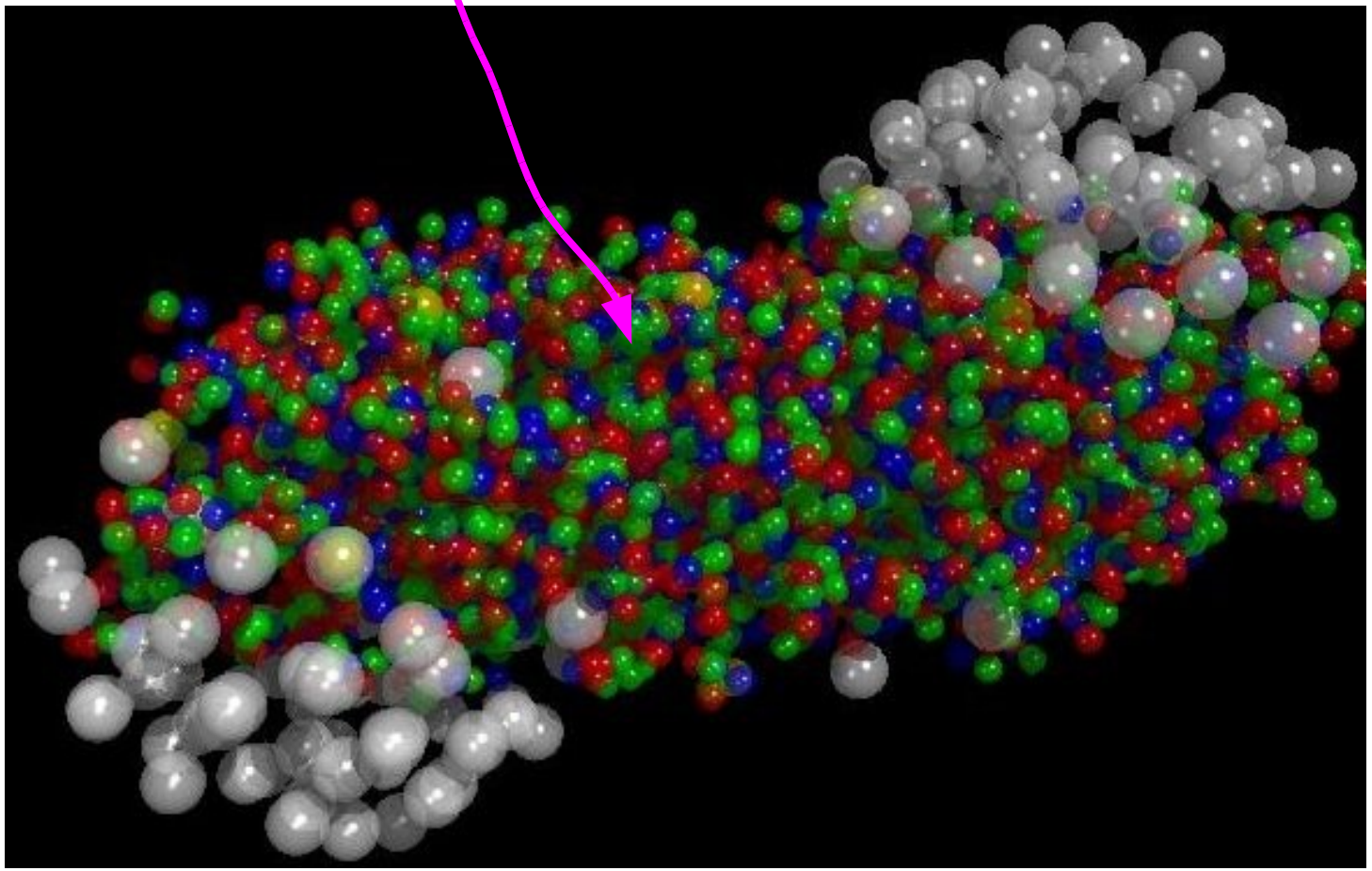
Animation from Hdronic Cascade model JAM



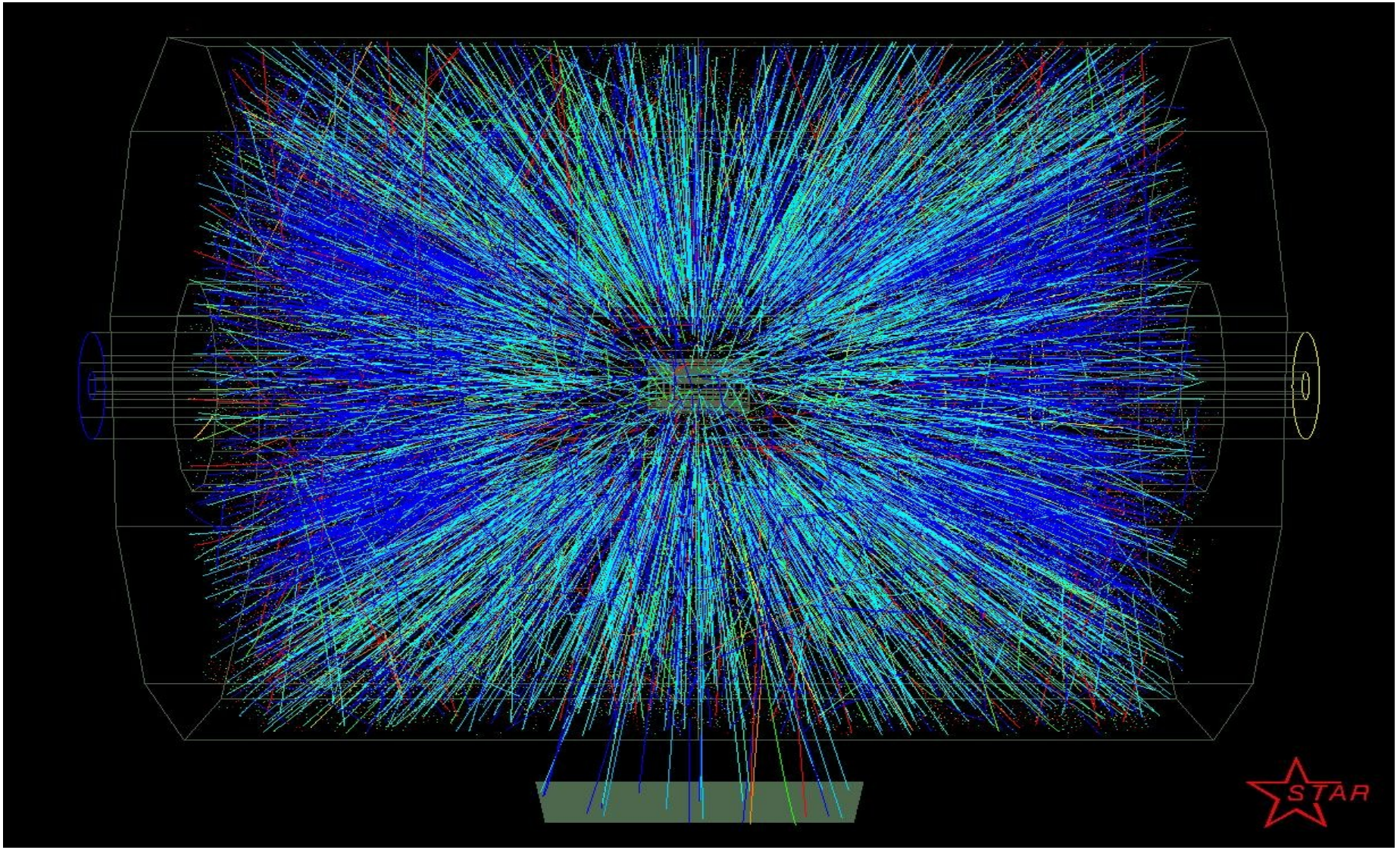
After the collision, matter looks like this.

UrQMD simulation

Hot and dense matter created!

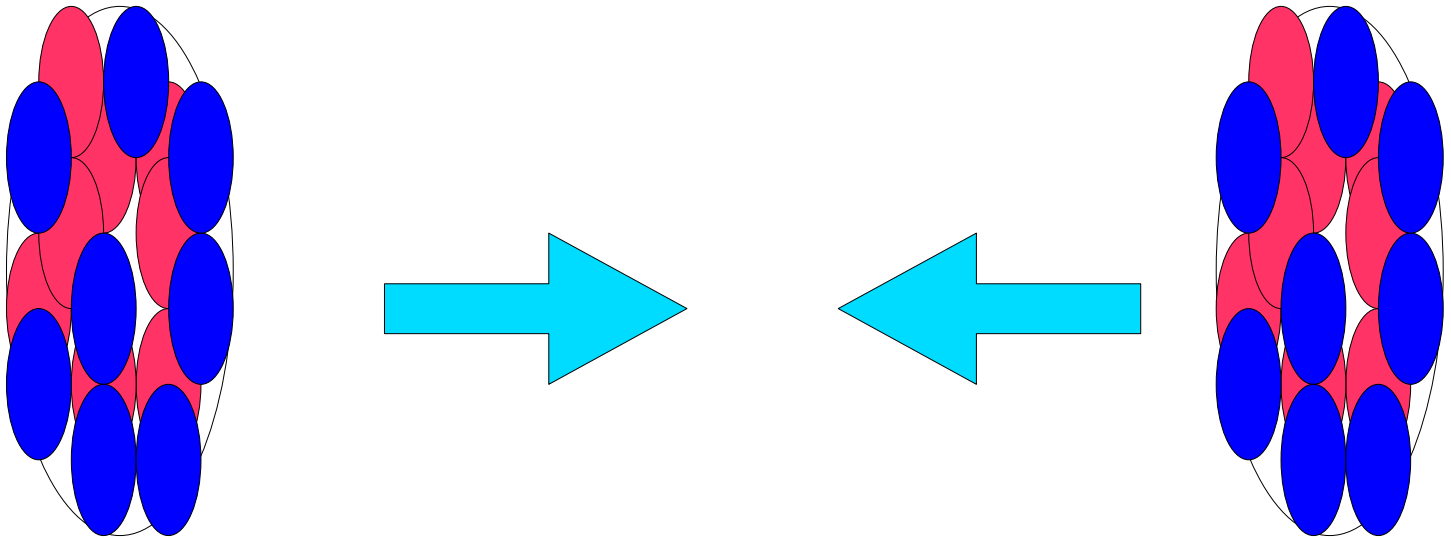


Gold beam-beam collision event at RHIC experiment



Hadron cascade の簡単な説明

1. Initial state (before collision): Nucleons are sampled according to Woods-Saxon distribution, momentum of each nucleon is sampled by Fermi momentum
   ,boost two nucleus according to the corresponding incident energy.

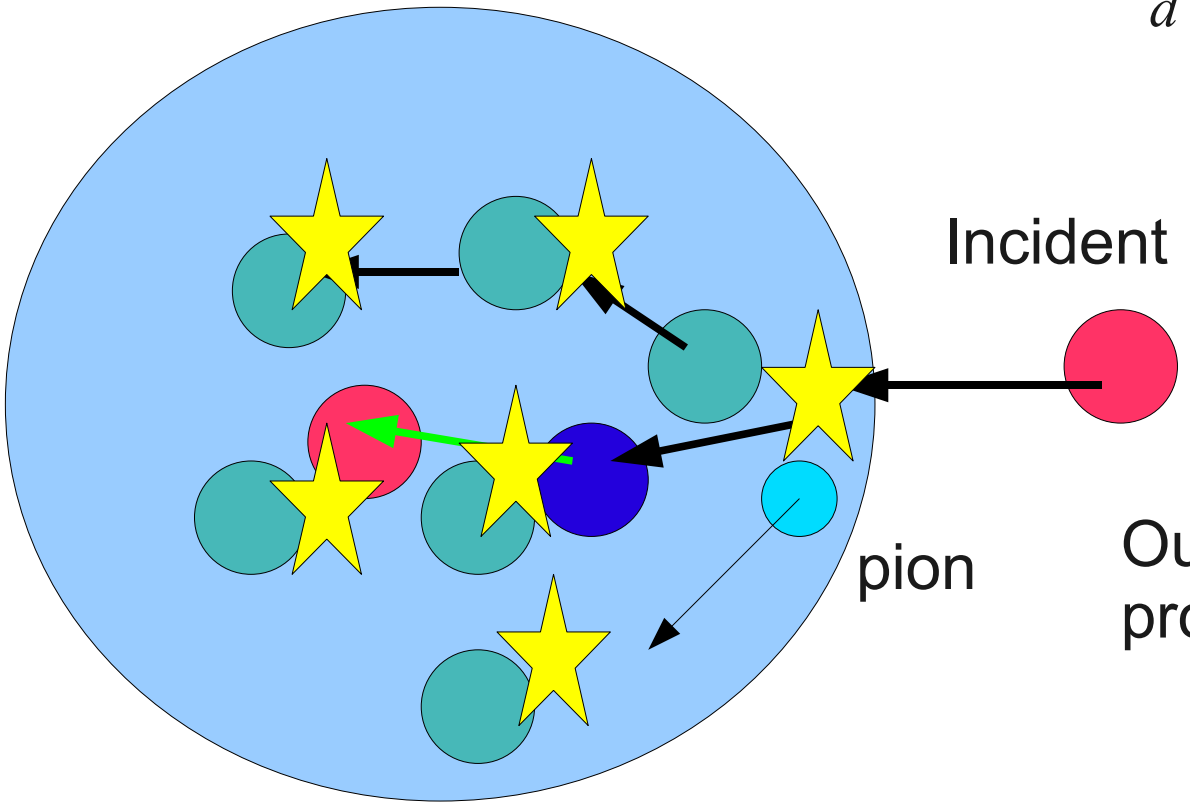


ハドロン-ハドロン散乱の インコヒーレントな重ね合わせ

2. Straight line trajectories until particles interact

3. Collision at closest approach

$$d < \sqrt{\sigma_{tot}/\pi}$$

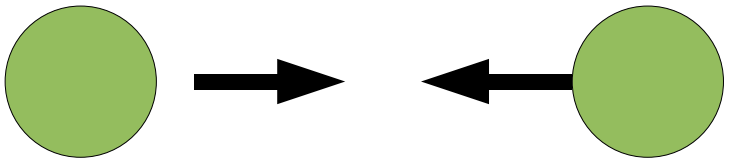


Incident hadron

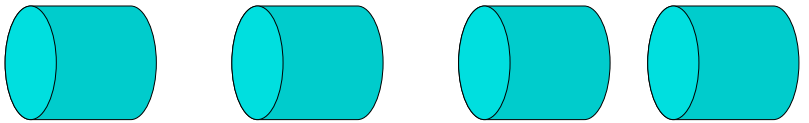
pion

Outgoing channel selection:
prob. of elastic = $\frac{\sigma_{el}}{\sigma_{tot}}$

- すてべの可能な素過程
- 粒子発生の時空発展



String excitation of hadrons



String decay into hadrons

Hadronic transport models

OSCAR (Open Standard Codes and Routines)

http://nt3.phys.columbia.edu/OSCAR/

RQMD
UrQMD Frankfurt group: http://th.physik.uni-frankfurt.de/~urqmd/

GiBUU The Giessen Boltzmann-Uehling-Uhlenbeck project
http://gibuu.physik.uni-giessen.de/GiBUU/

JAM http://quark.phy.bnl.gov/~ynara/jam/

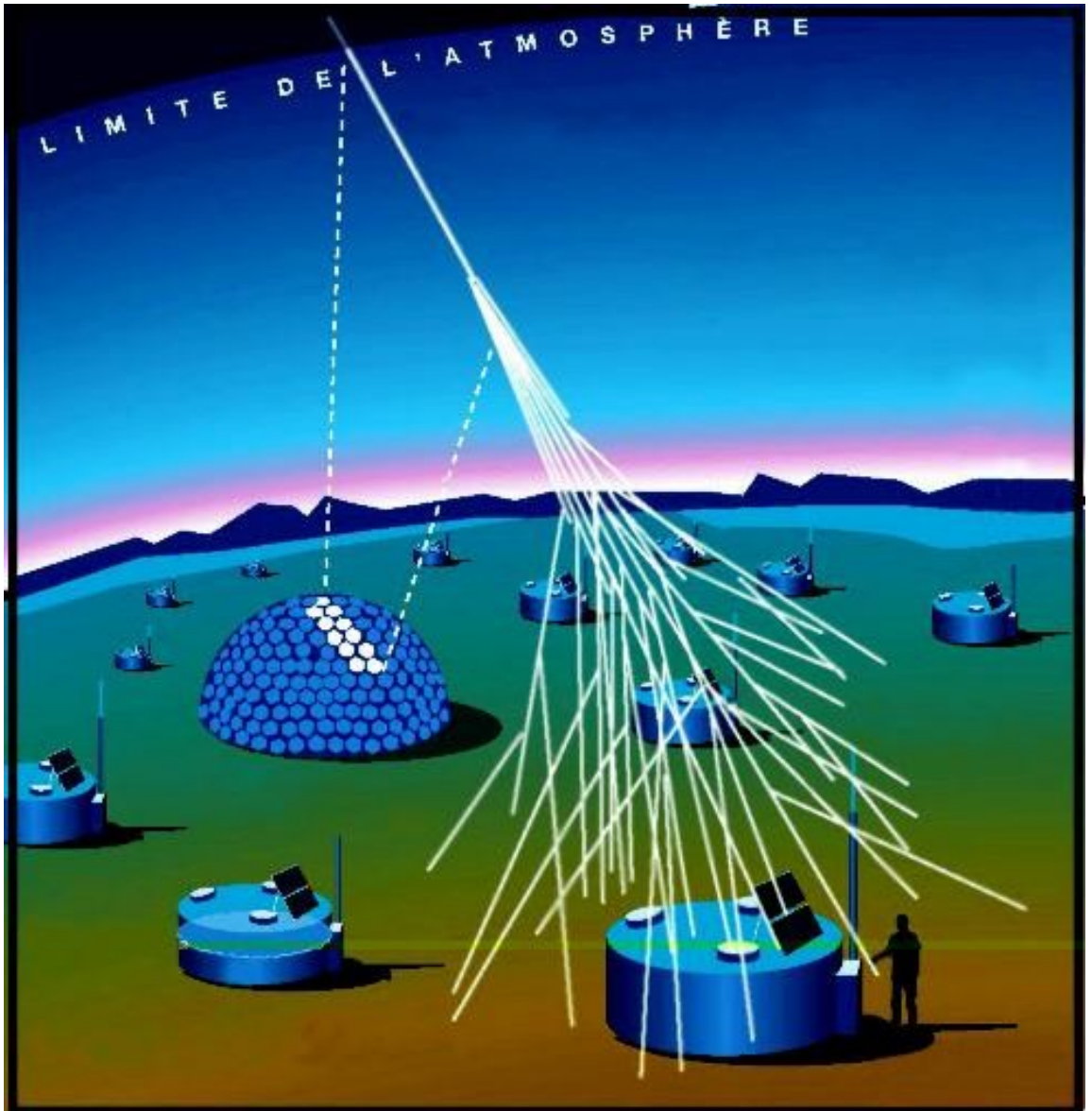
Y.Nara, N.Otuka, A.Ohnishi, K.Niita and S.Chiba,
``Study of relativistic nuclear collisions at AGS energies from p + Be to Au + Au with hadronic cascade model,"
Phys. Rev. C61, 024901 (2000) [arXiv:nucl-th/9904059].

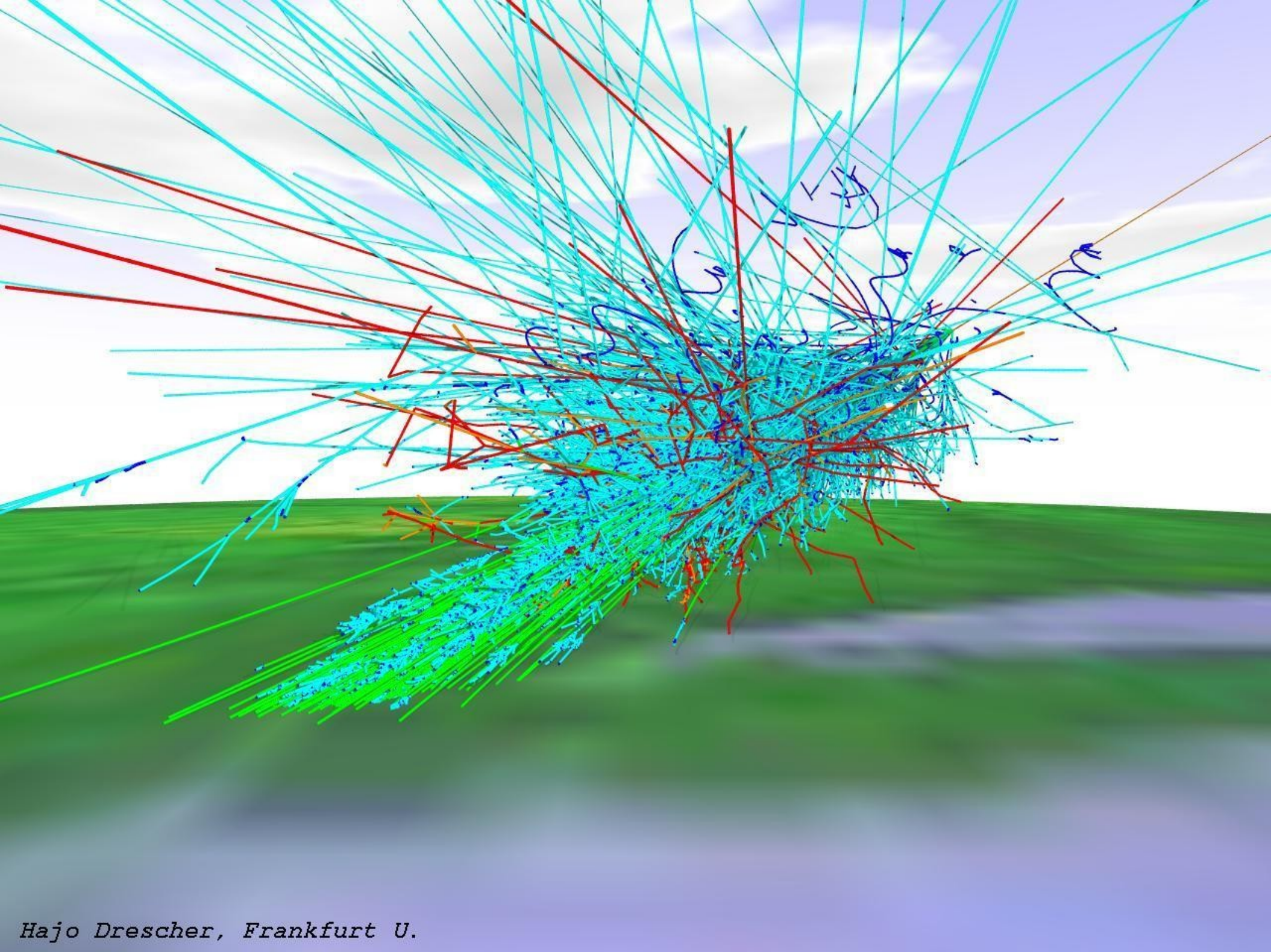
Applications of hadronic cascade code

- hadron-nucleus collisions (proton, pion, kaon,....)
- Nucleus-nucleus collisions
- Gamma-nucleus collisions

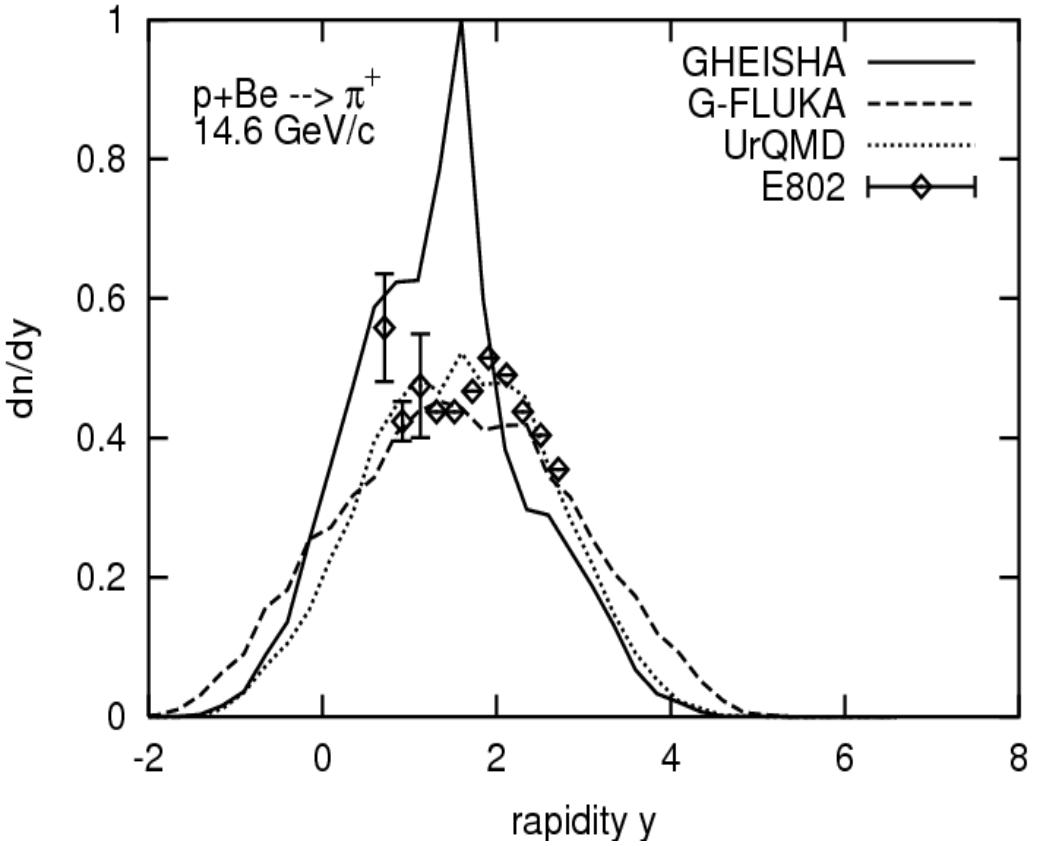
  - Hydrodynamics + hadron cascade
  - Parton cascade + hadron cascade
  - GIANT4
  - Air shower model of cosmic ray

Air shower simulations needed for analysis and interpretation of data

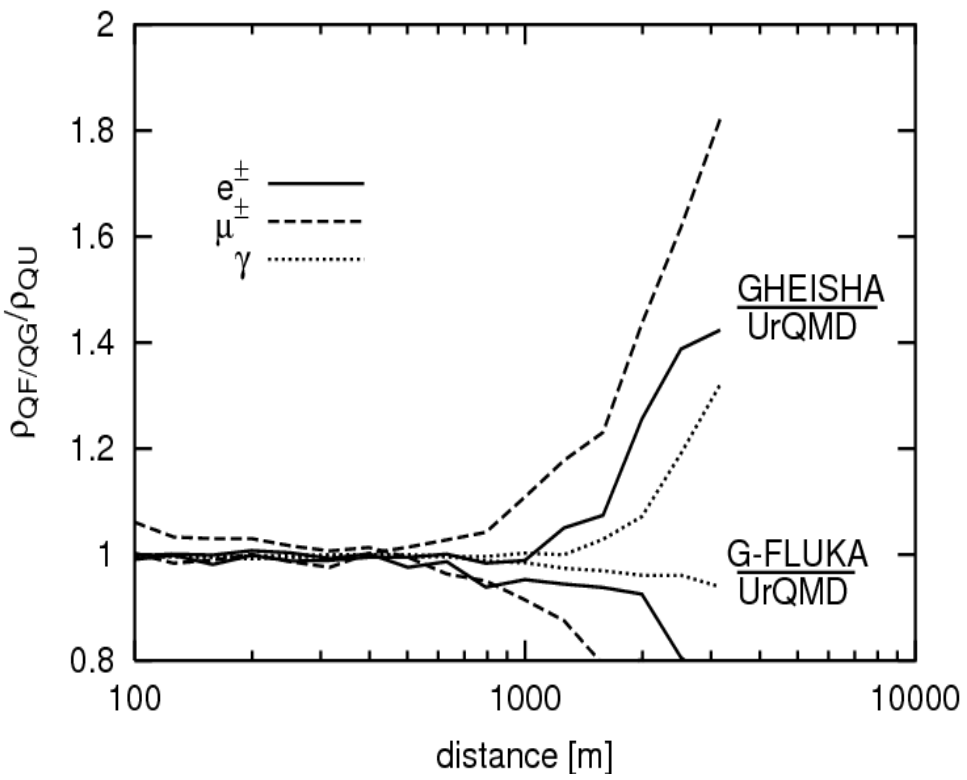



Hajo Drescher, Frankfurt U.

Model dependence of rapidity distribution

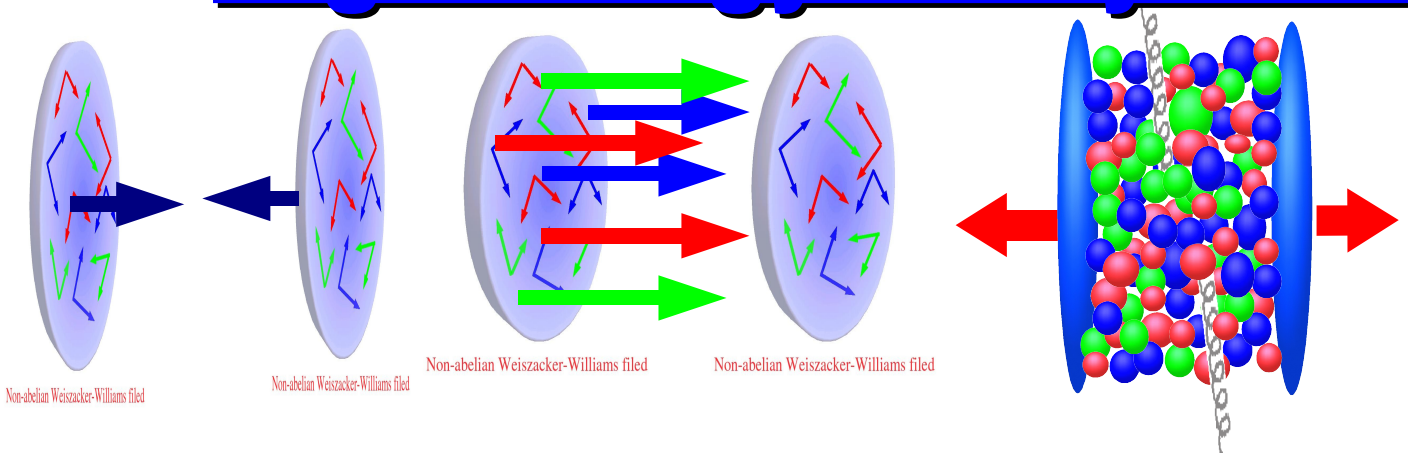


Dependence of LDF



H. J. Drescher, M. Bleicher, S. Soff and H. Stoecker, Astropart. Phys. 21, 87 (2004)

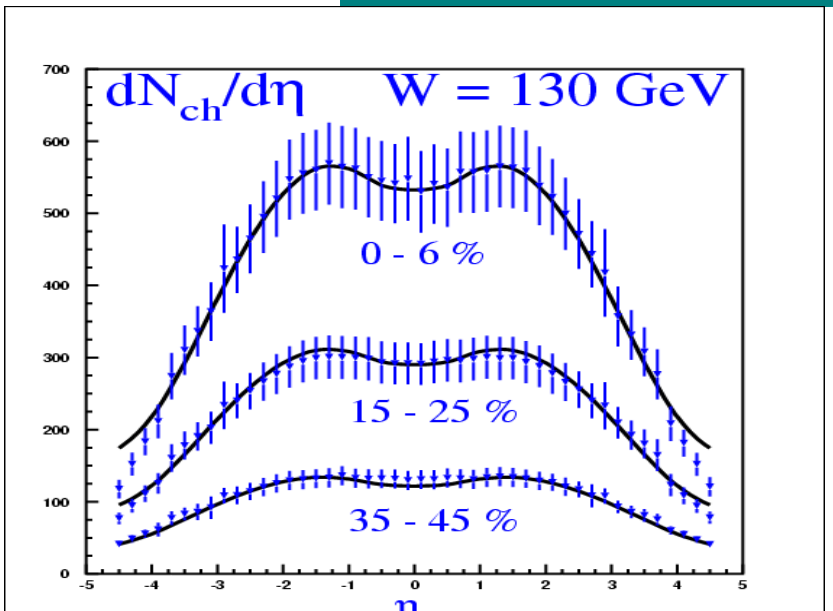
High energy heavy ion collisions



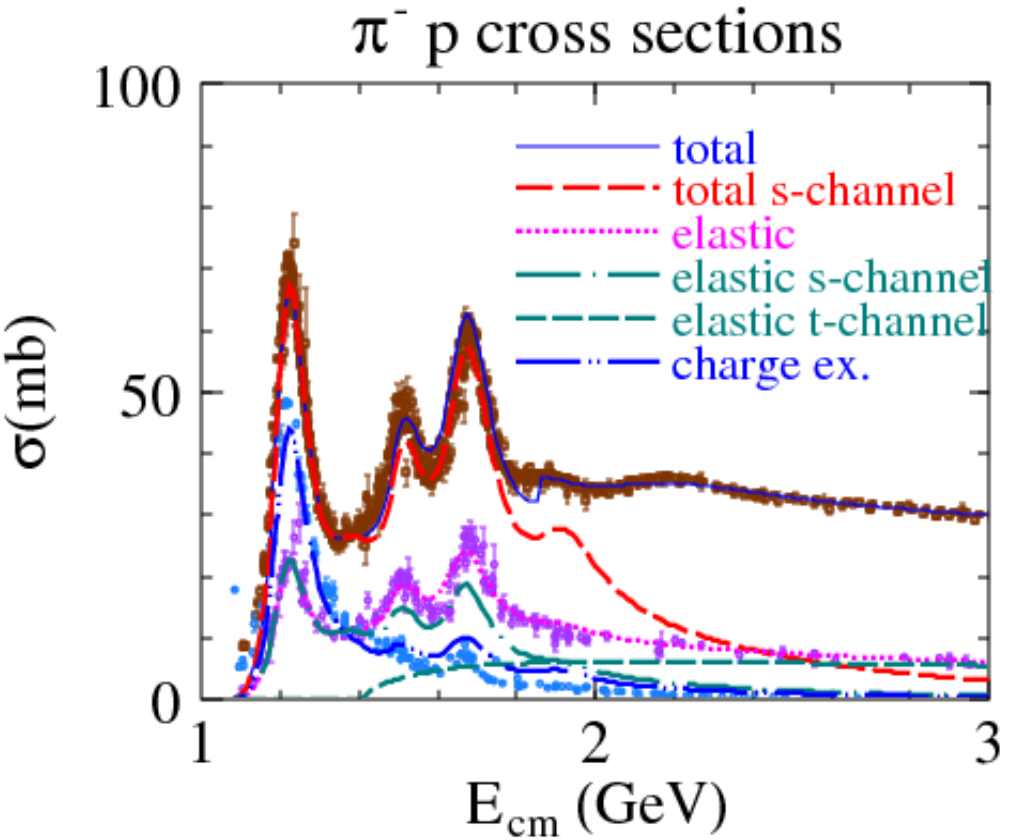
$\tau = 0 \qquad \tau \approx 1/Q_s \qquad \tau \approx 1 \sim 2\ fm/c$

CGC | Non equilibrium | Hydro evolution | Hadron gas

time



Modeling low energy π-p cross sections



- S-channel inelastic:
  pi-p -> resonance (or string)
- T-channel inelastic:
  pi-p -> resonance + resonance
- Elastic
- Charge exchange: $\pi^- p \rightarrow \pi^0 n$

Hadronic Cross sections in JAM

$$\sigma_{tot}(s) = \sigma_{el}(s) + \sigma_{ch}(s) + \sigma_{ann}(s)$$
$$+ \sigma_{t-R}(s) + \sigma_{s-R}(s) \quad : \text{Resonance}$$
$$+ \sigma_{t-S}(s) + \sigma_{s-S}(s) \quad : \text{String}$$

Resonance production (absorption)

$$\sigma_{t-R}(s) : NN \leftrightarrow N\Delta, \quad NN \leftrightarrow N^*\Delta^*, \cdots$$
$$\sigma_{s-R}(s) : \pi N \leftrightarrow \Delta, \quad \bar{K}N \leftrightarrow Y^*, \cdots$$

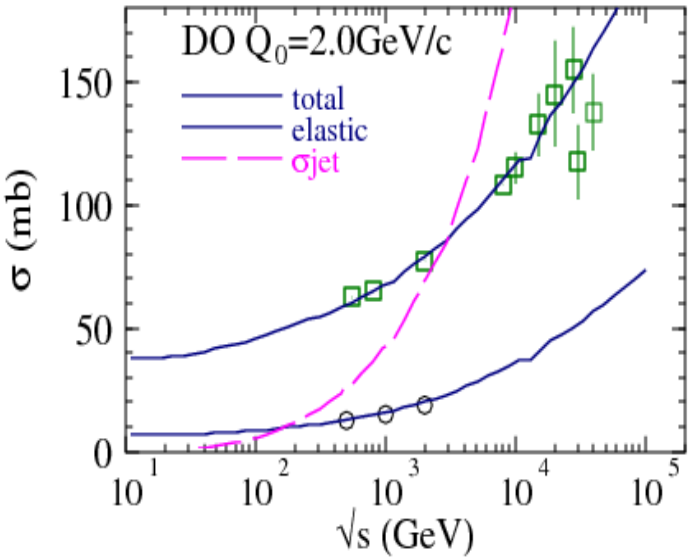
String formation

$$\sigma_{t-S}(s) : NN \rightarrow \text{String} + \text{String},$$
$$\sigma_{s-S}(s) : \pi N \rightarrow \text{String}$$

Eikonal Formulation for pQCD (HIJING)

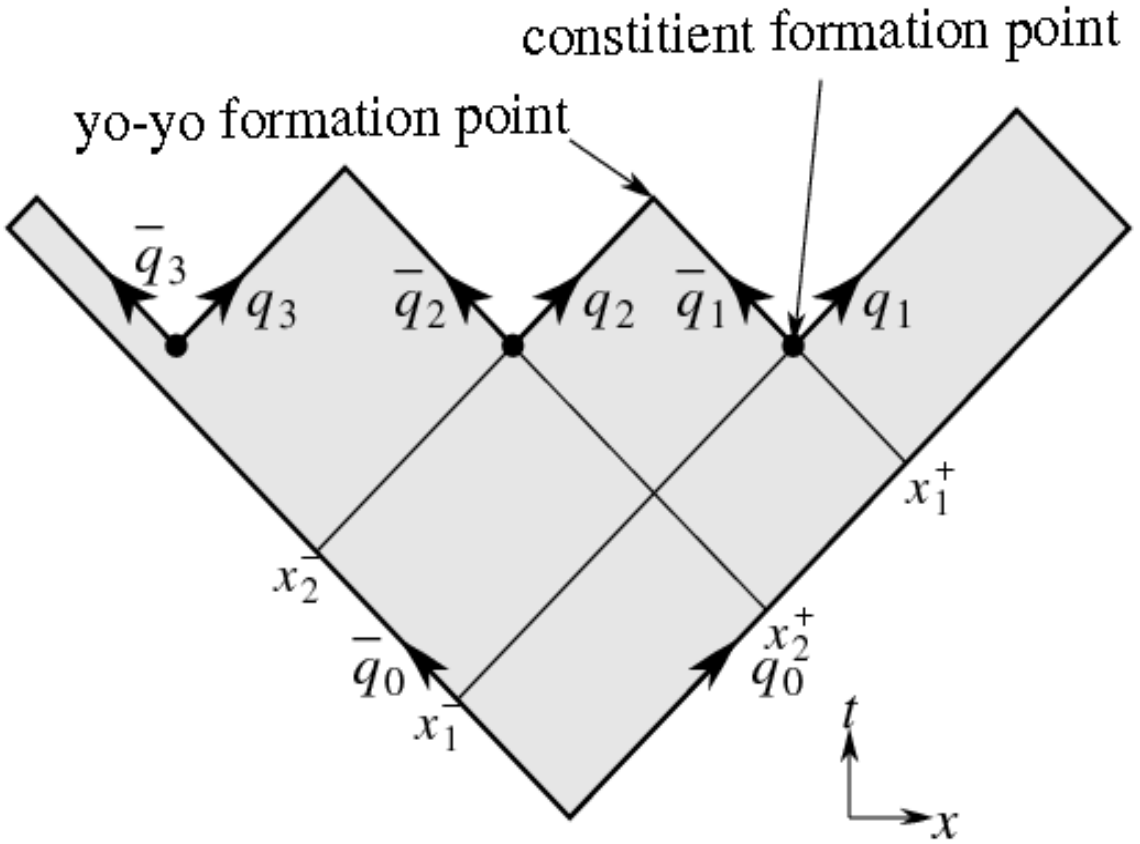
$$\sigma_{t-S}(s) = 2\pi \int_0^\infty db^2 \left[1 - \exp(\chi(b,s))\right],$$

$$\chi(b,s) = \frac{1}{2}\left(\sigma_{jet}(s) + \sigma_{soft}(s)\right) A(b,s)$$



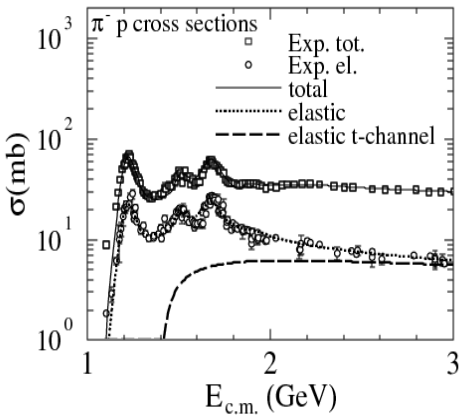
$$\sigma_{jet} = \int_{p_0^2}^{s/4} dp_T^2 dy_1 dy_2 \frac{1}{2} K \sum_{a,b} x_1 x_2 f_a(x_1, P_T^2) f_b(x_2, P_T^2) \frac{d\sigma^{ab}(\hat{s}, \hat{t}, \hat{u})}{d\hat{t}}$$

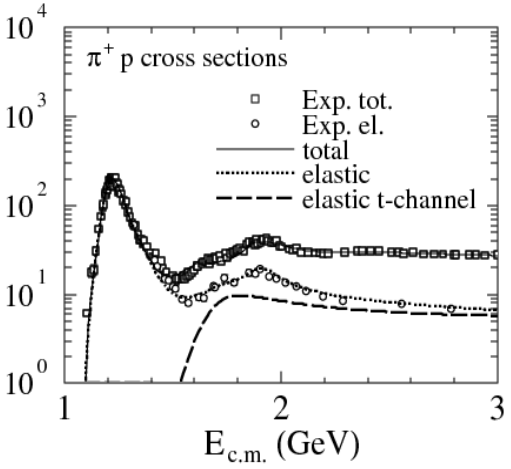
Hadron formation point from string decay

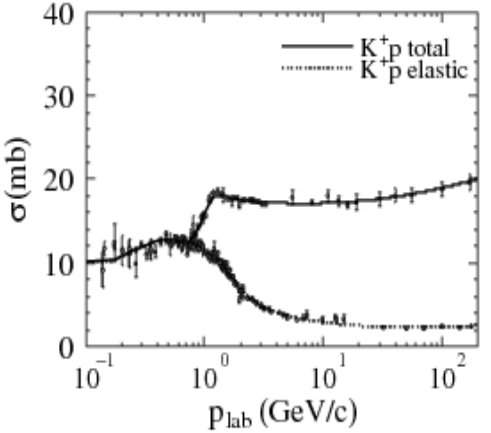


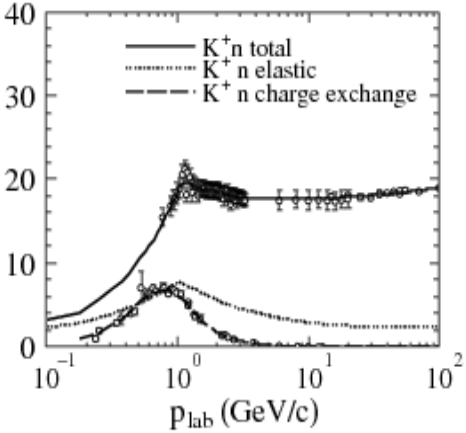
Spacetime picture
of q-qbar string motion

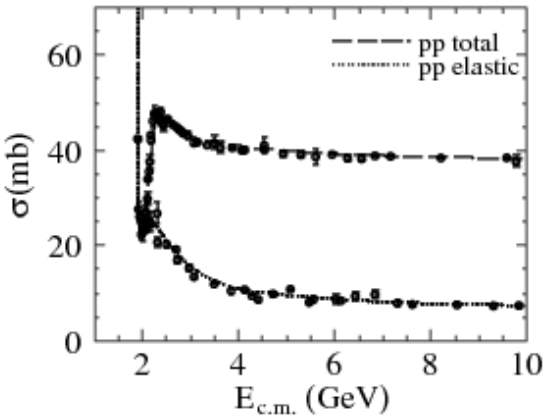
JAM: total cross sections

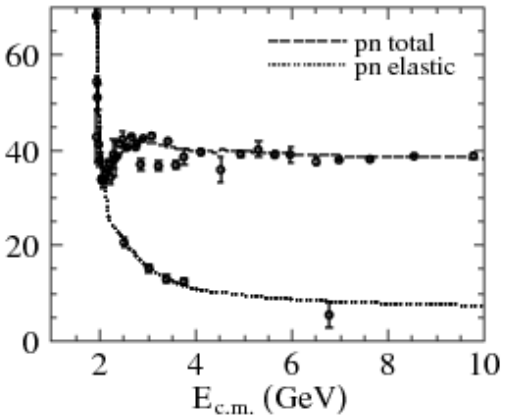


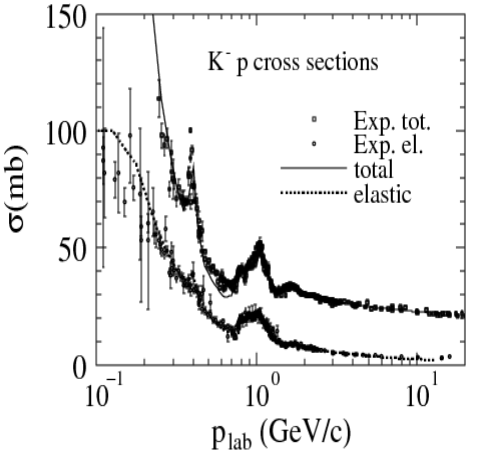


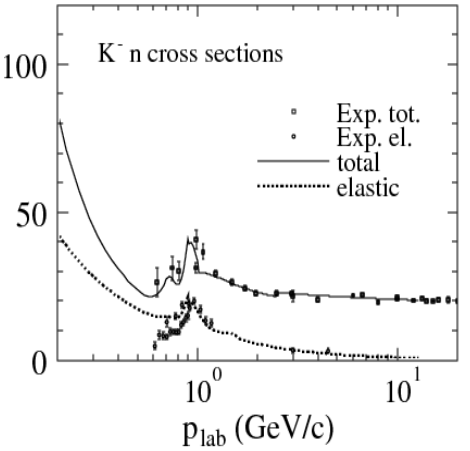




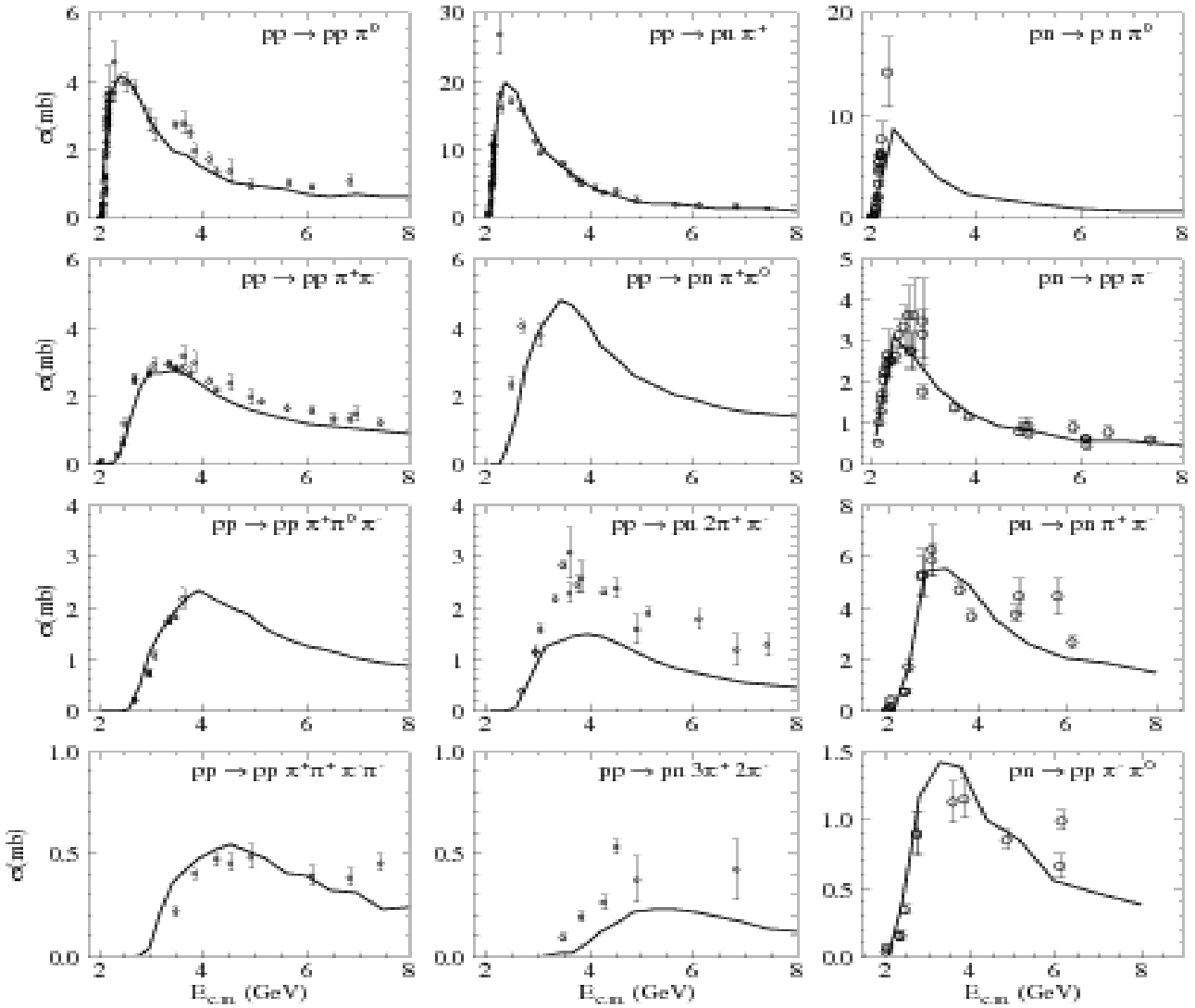




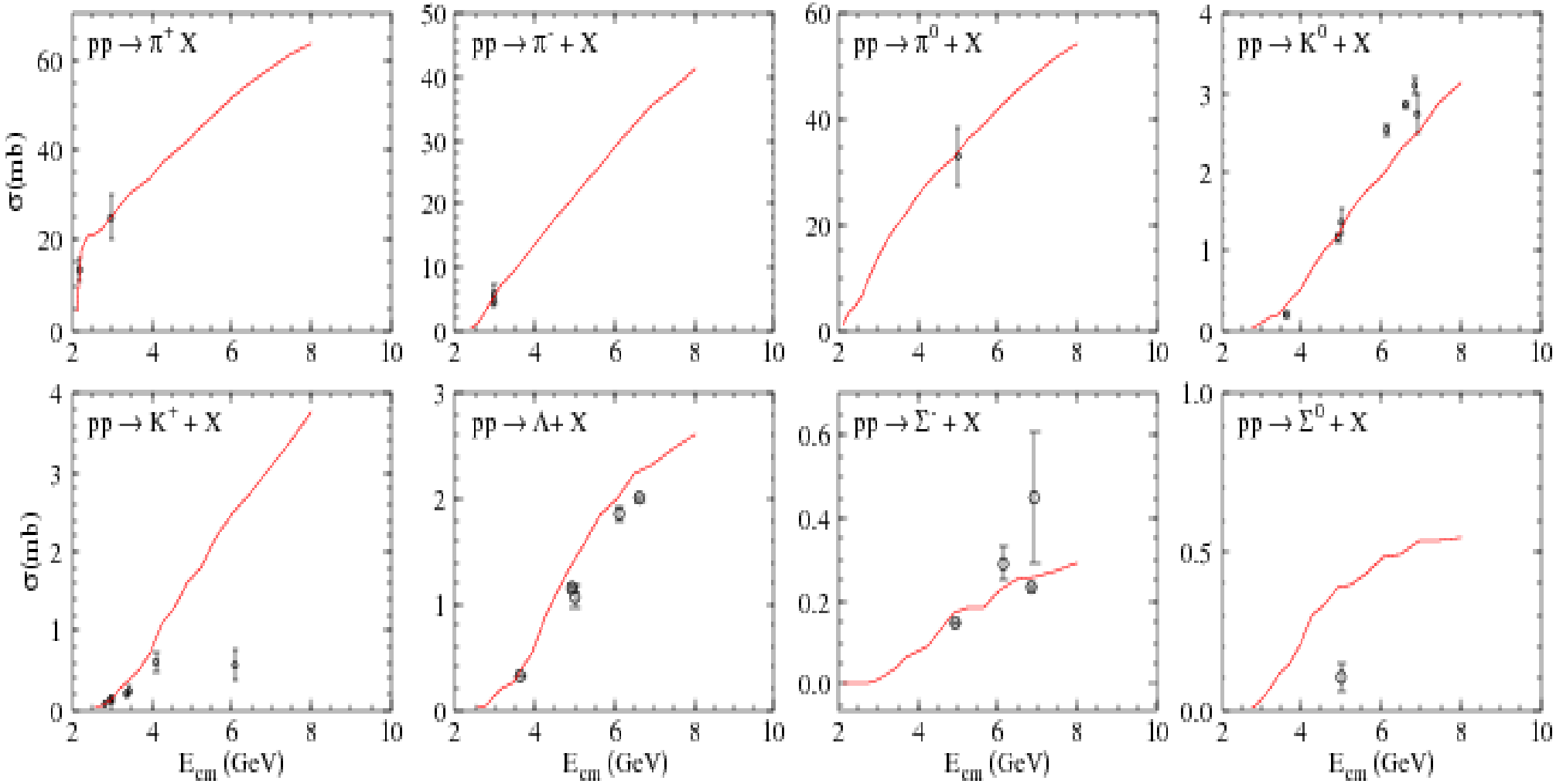


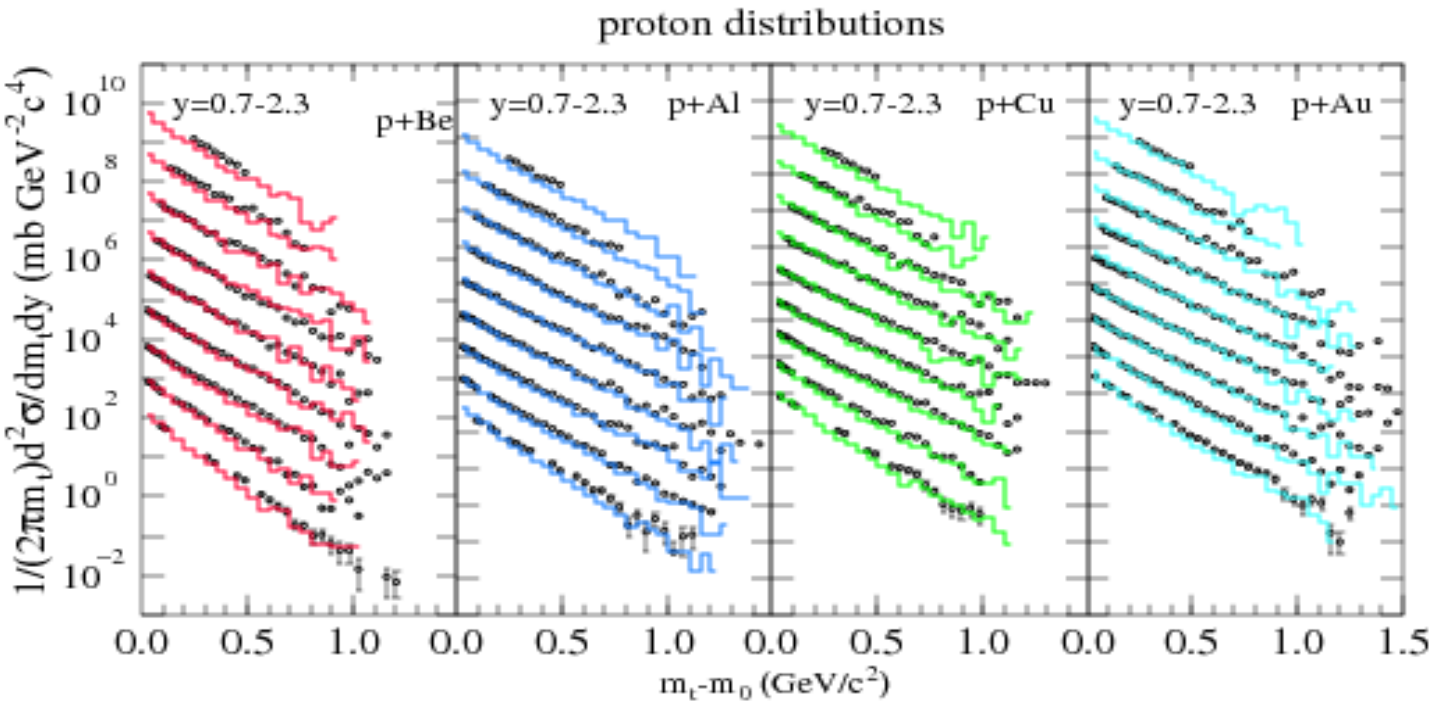


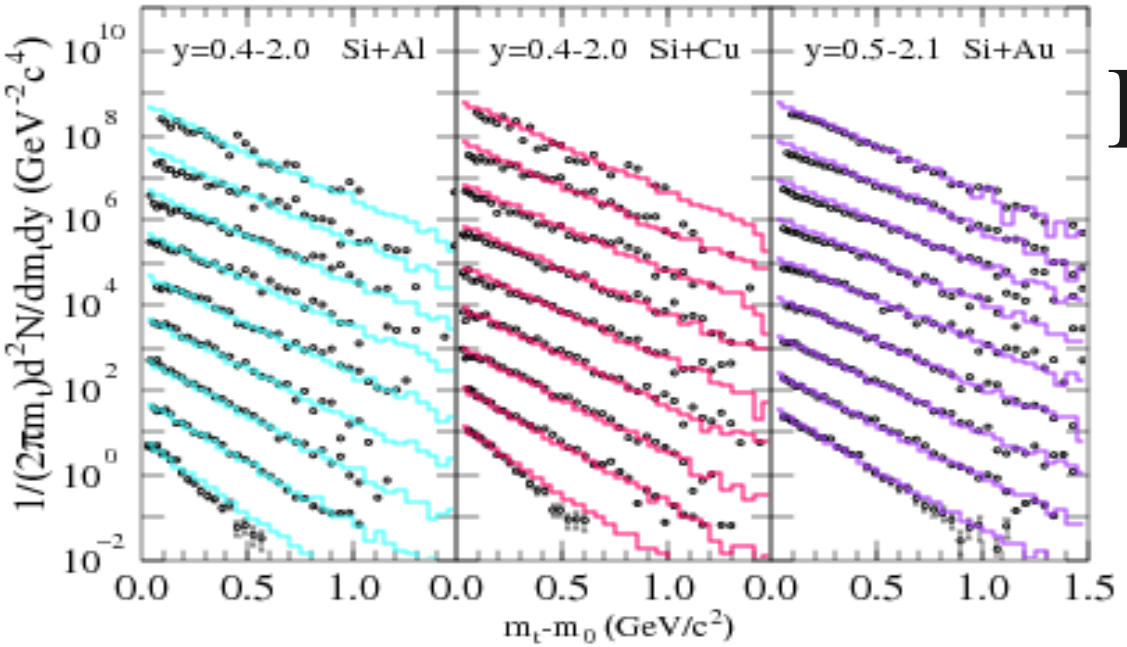
Pion production cross sections in JAM



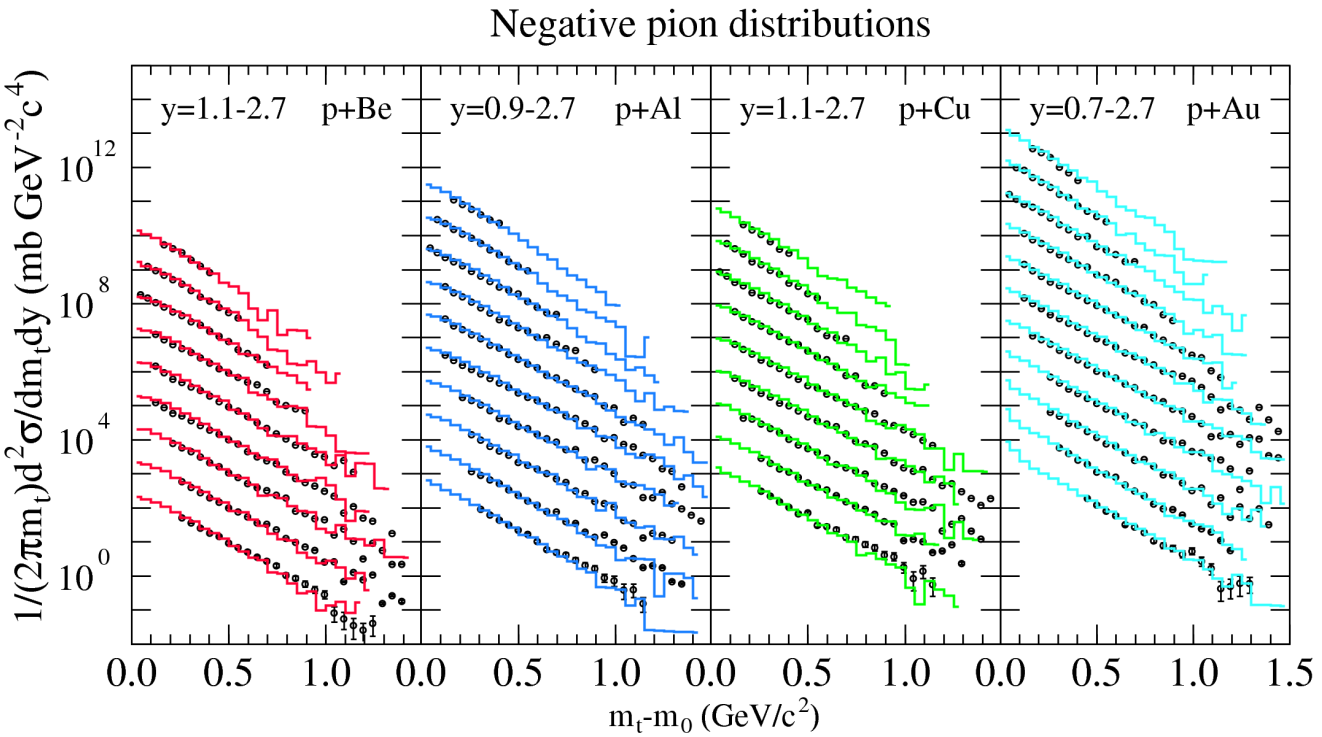
Excitation function of p+p -> x in JAM

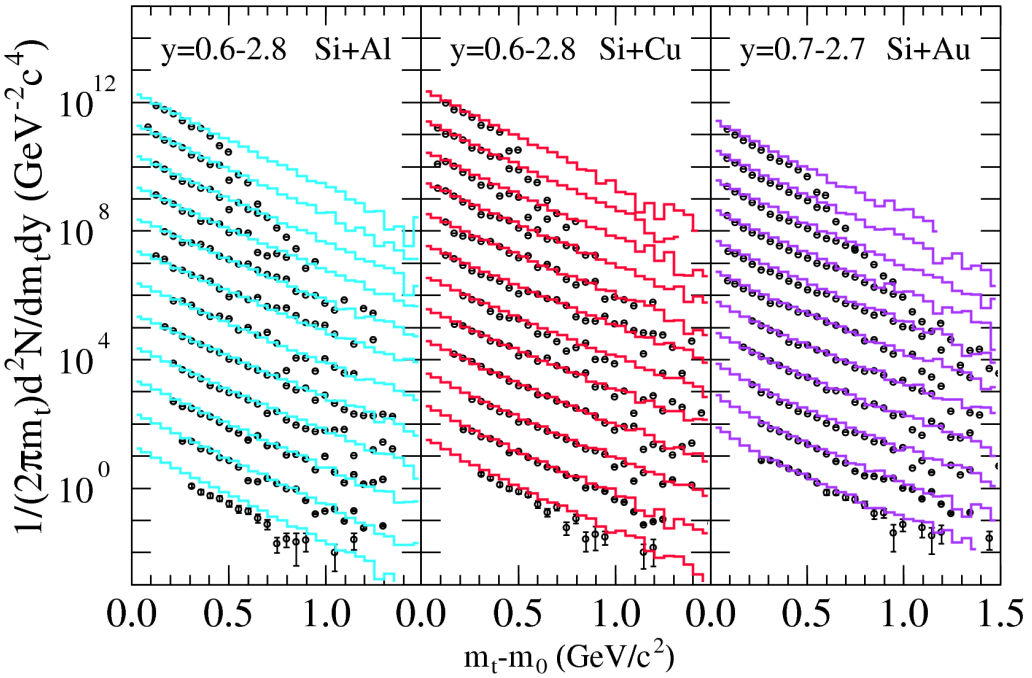






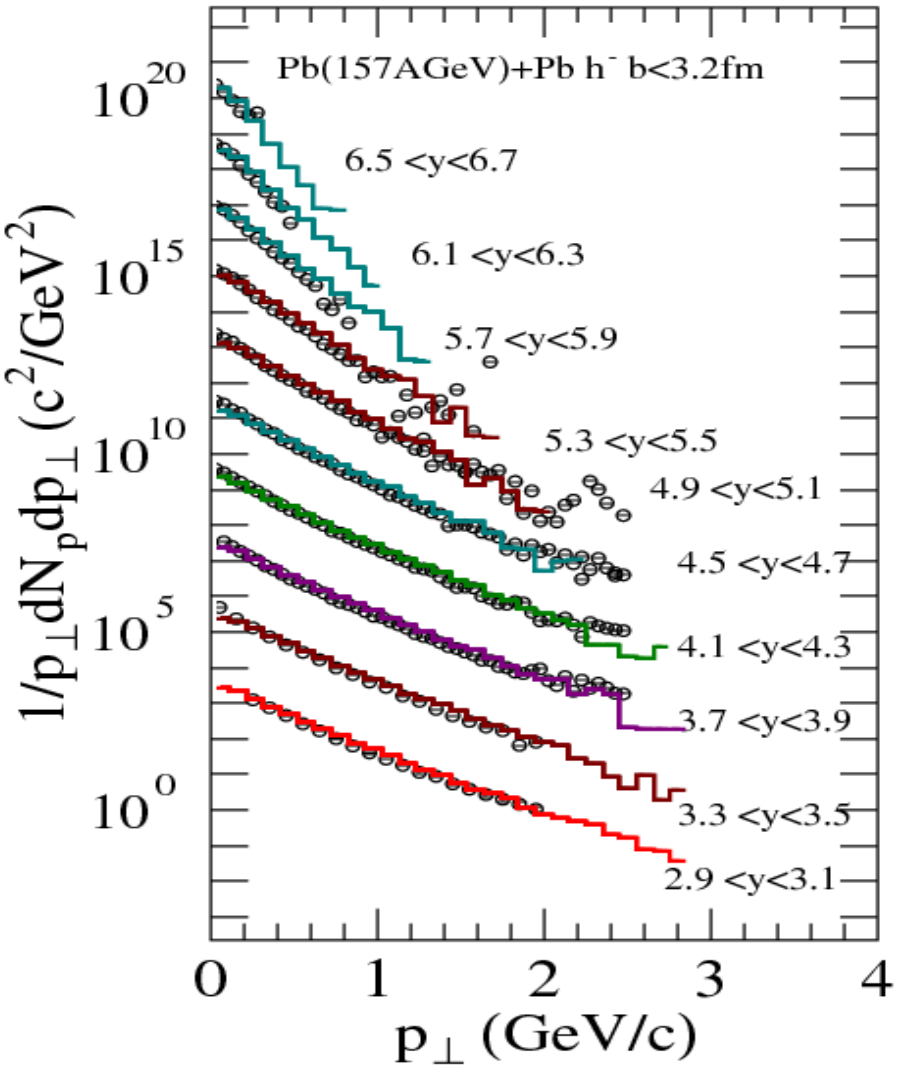
Proton distribution at AGS energy

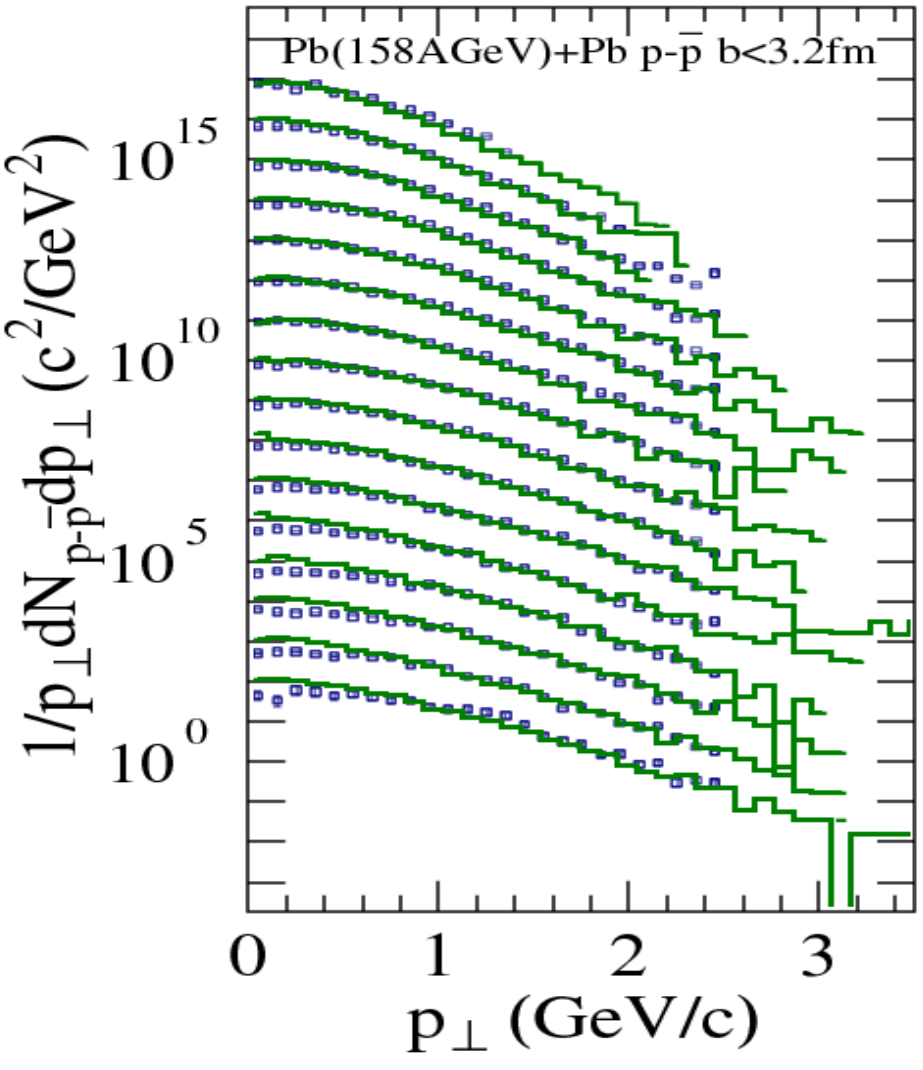




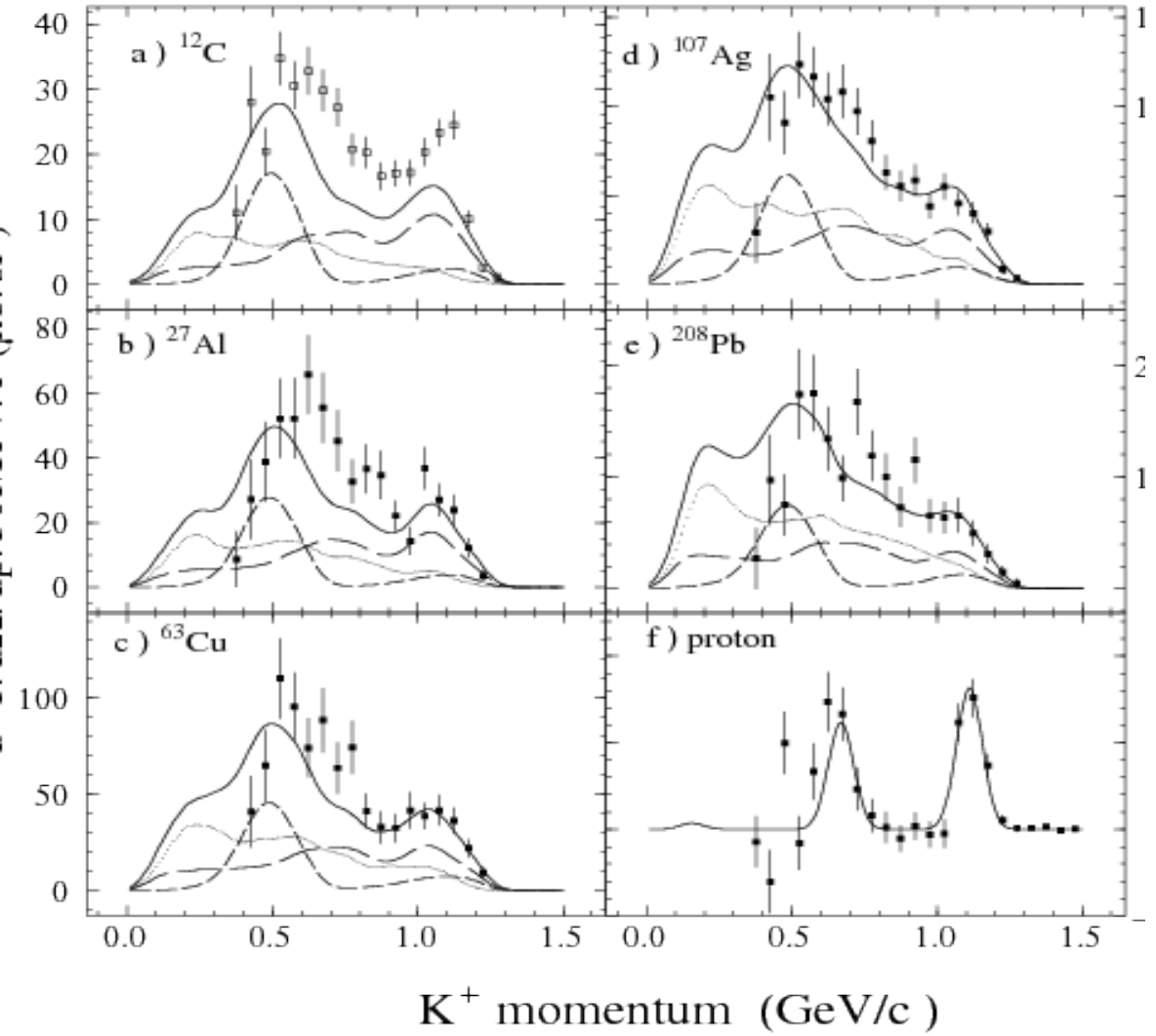
pion distribution at AGS energy (E=14GeV)

Transverse momentum distribution at SPS energy (160AGeV)





(K^-,K^+) reactions



$\bar{K}N \rightarrow K\Xi, K\Xi^*(1530)$

$\bar{K}N \rightarrow (\phi, a_{0,} f_0)\Lambda$

$(\phi, a_0, f_0) \rightarrow K^+K^-$

$\bar{K}N \rightarrow (\pi, \rho, \eta, \omega, \eta')(Y, Y^*)$

$(\pi, \rho, \eta, \omega, \eta')N \rightarrow$

$(K, K^*)(Y, Y^*), \phi N$

まとめ

- ハドロニックカスケードモデルは、重イオン衝突や、ハドロン-原子核反応の時空発展をミクロに記述するものである。

- 現在最高エネルギーで原子核を衝突できるRHIC energy まで、粒子の multiplicity などのバルクな観測量はよく再現できるが、集団効果,例えば楕円形フローなどは再現できない。