Multiparton interaction and exotic resonance production

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Outline:

- **Motivation: multiparton interactions (MPI):**
  - multiparton correlations (MPC)
  - multiparton scattering (MPS)

- **Diquarks and large pT-baryon production**

- **Multiparton interaction as a source of multiquark hadronic systems at NICA energies**

- **Diquark model based on Pythia 8.3**

- **Summary**

Hard processes in QCD

Perturbative QCD for hard processes

$Q^2/s = x$ – fixed, $s \to \infty$ (Bjorken limit)

→

- Factorization of hard and soft contributions in leading twist

A.Efremov & A.Radyushkin (78-81)
A.Mueller, J.Collins, D.Soper, G. Sterman, ...

DIS: $\sigma_{HARD} = \sigma_{parton} \times F(x, Q^2) + (1/Q^2)^n$

DY-MMT: $\sigma_{HARD} = F(x, Q^2) \times \sigma_{parton} \times F(x, Q^2) + (1/Q^2)^n$

- $F(x, Q^2)$: PDF with GLAPD $\log[Q^2]$-evolution

V.Gribov & L.Lipatov (71-72,74), G.Altarelli & G.Parisi (77), Yu.Dokshitzer (77)

- $\sigma_{parton} \sim 1/Q^4$: partonic subprocess

- $(1/Q^2)^n$-terms: higher twists

Large-pT hadron production

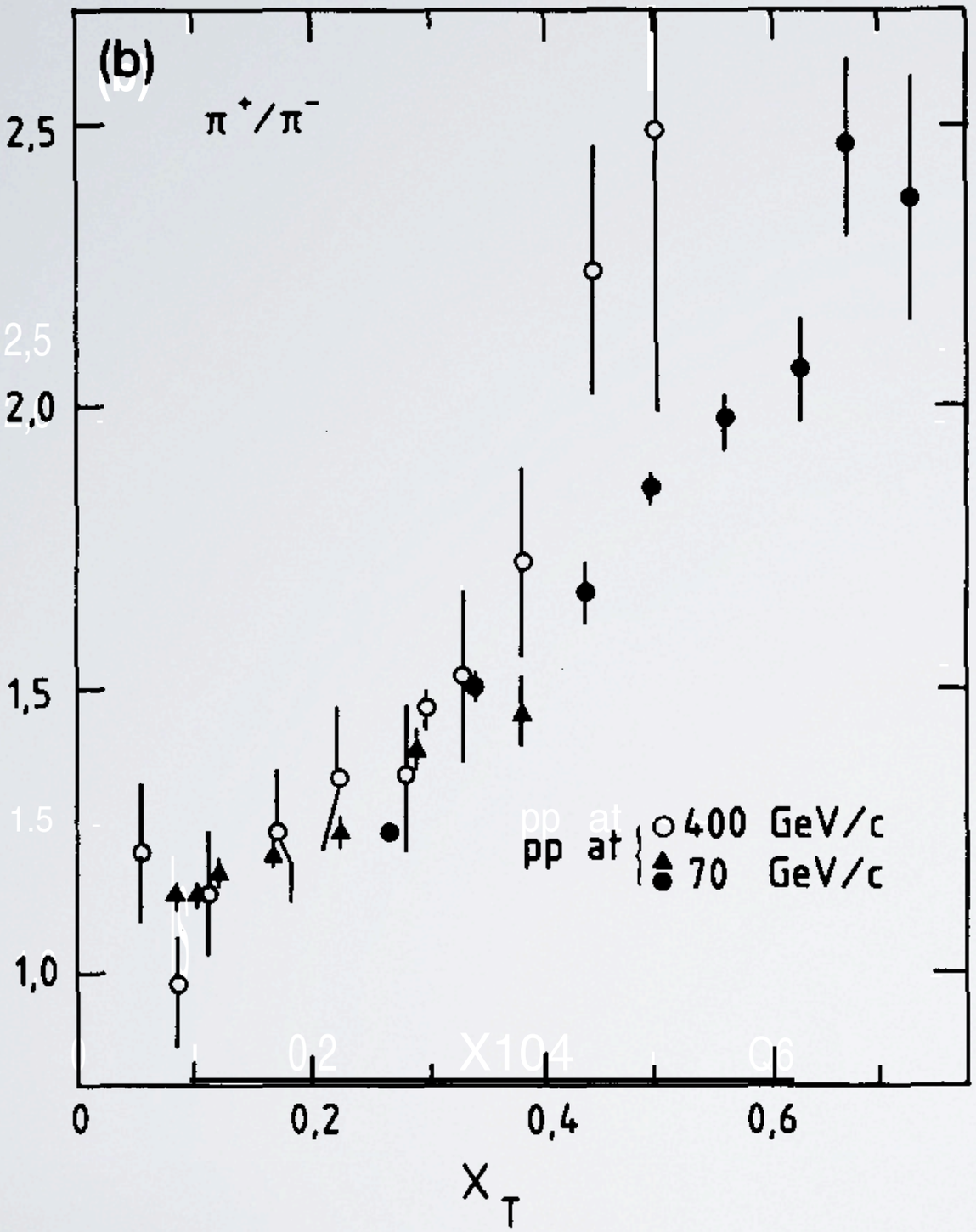
Factorization of hard and soft contributions for inclusive large-pT hadron production in pp-collisions:

$$\sigma_{HARD}\,(NN\to hX) = F_N(x, Q^2) \times \sigma_{parton} \times F_N(x, Q^2) \times D_h\,(x, Q^2) \;+\; (1/Q^2)^n$$

Ratio of different hadron production:
$\sigma_{HARD}\,(NN\to h_1X)/\sigma_{HARD}\,(NN\to h_2X)$

should exhibit scaling behaviour at high $\sqrt{s}$ and at high pT

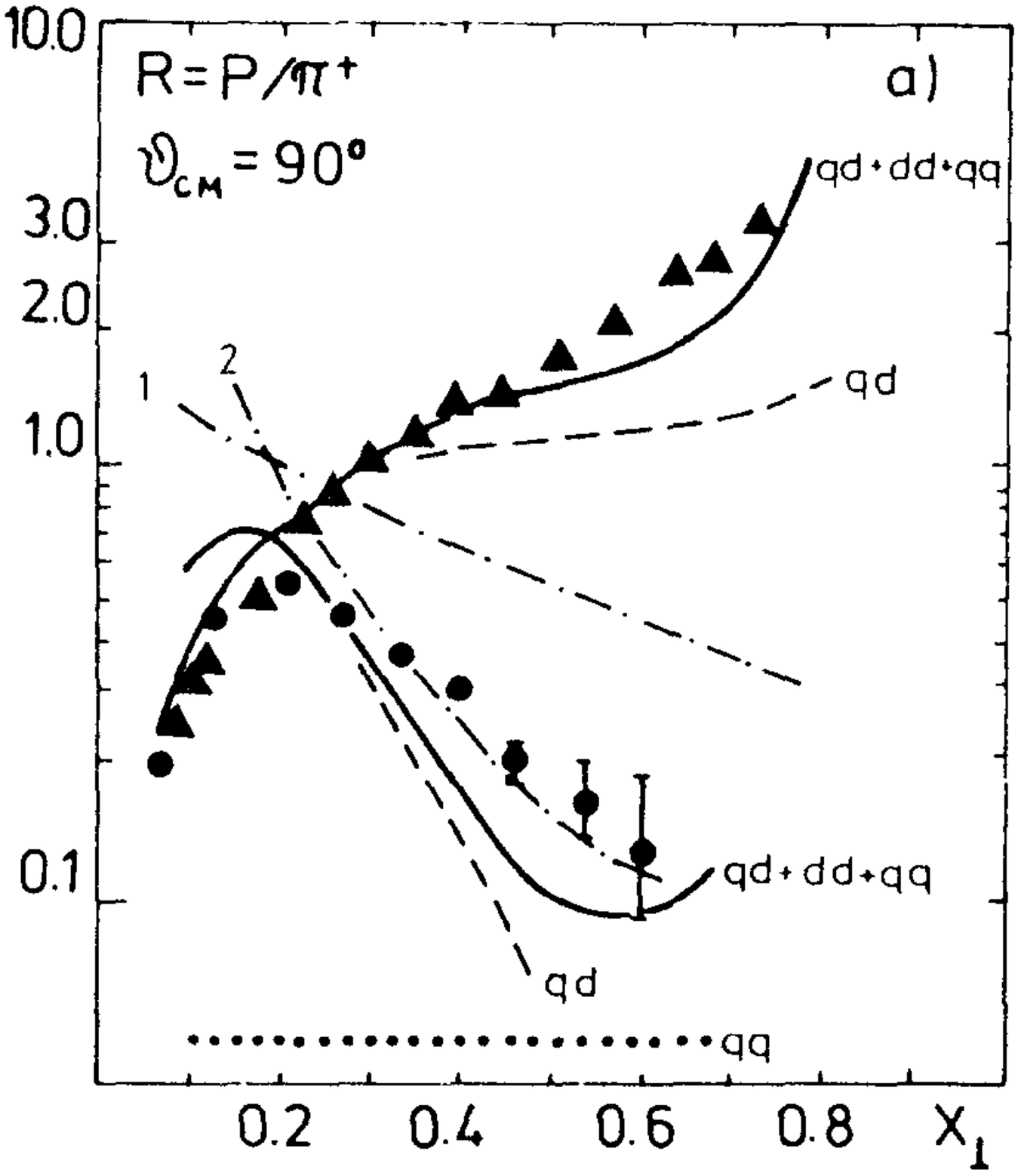
Large-pT meson production: scaling behaviour



400 GeV: CP, J. Cronin et al (1977-79)

70 GeV: FODS, R.M. Sulyaev et al (84-87)

Large-pT proton production: non-scaling behaviour

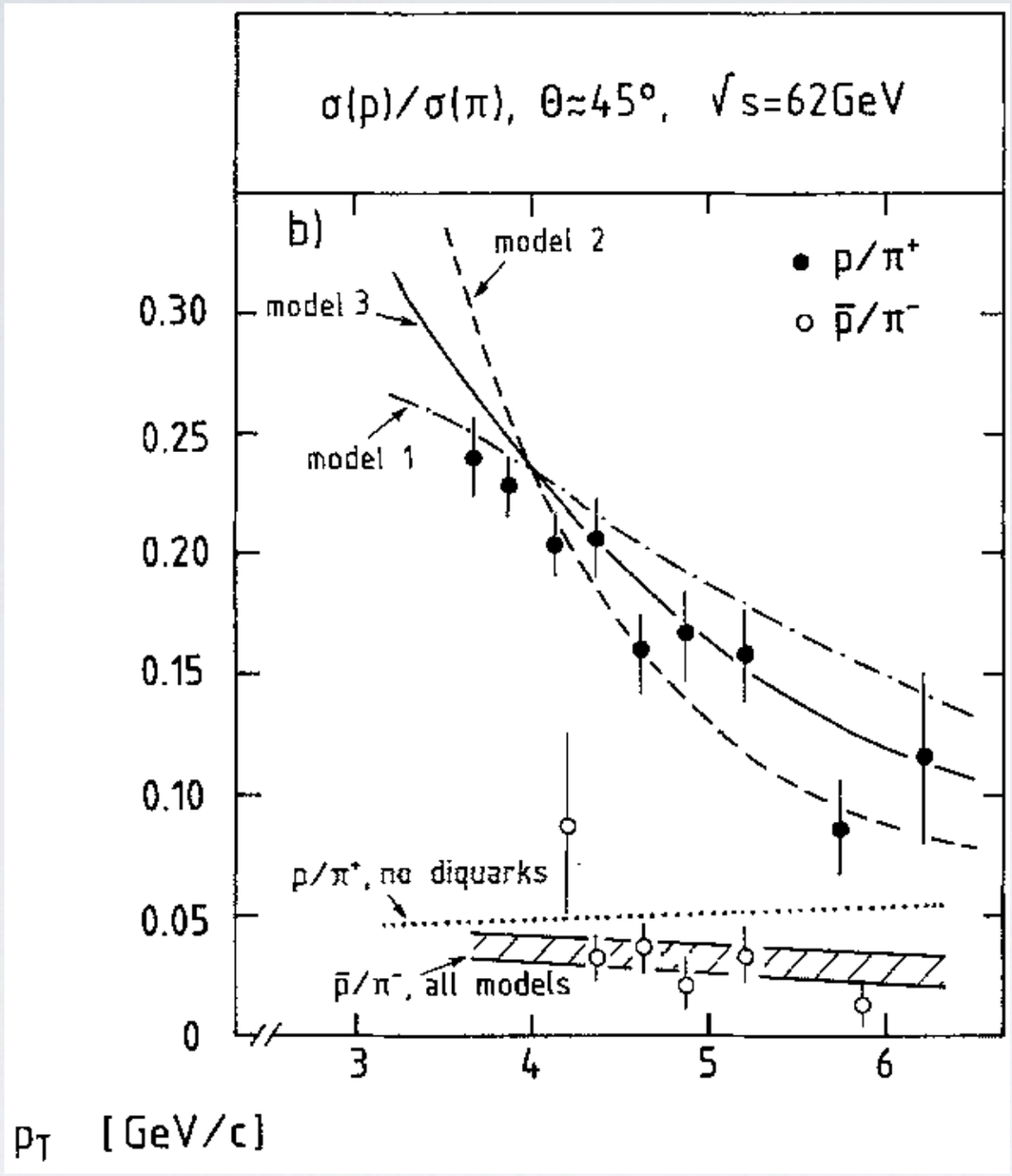


▲ $\sqrt{s}$ = 11.5 GeV (E = 70 GeV).

● $\sqrt{s}$ = 23.4 GeV (E = 300 GeV)

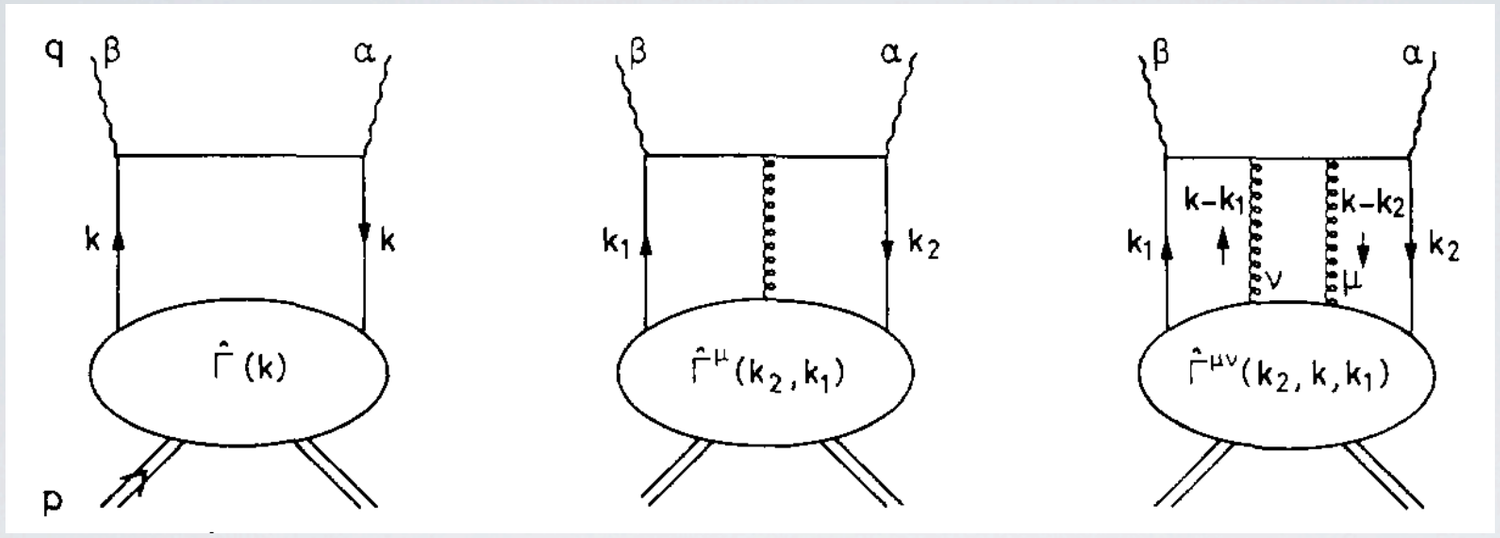
VK (1987-88)

Large-pT proton production: non-scaling behaviour



ABCDHW Coll.:
A.Breakstone et al. (1985) $\sqrt{s}$ = 62 GeV

Higher twists in DIS



A.De Rujula, H.Georgi, H.Politzer (197-77),
R.Jaffe (1981-82)
K.Ellis, Furmanski & Petronzio (1982-83)
E.Shuryak & A.Vainshtein (1982-83)

higher twists at large x are enhanced by factor $1/(1-x)^m$:

$$F_N(x, Q^2) \sim (1-x)^3 \; [1+C/(Q2\,(1-x)^2)]$$

since $F^D{}_N(x, Q^2) \sim (1-x)^1$
due to quark counting rules
V.Matveev, R.Muradyan & A.Tavkhelidze (1971-72)
S.Brodsky & G.Farrar (1972)

Higher twists:
Two-parton correlation as diquark

$$\sigma_{HARD}\,(NN\to PX) = F^{D}_{N}(x, Q^2) \times \sigma_{parton}\, f^2(Q^2) \times F_N(x, Q^2)$$

$f^2(Q^2)=1/(1+M^2/Q^2)^2$ – diquark form factor
$F^{D}_{N}(x, Q^2)$ – diquark distribution in proton

V.Anisovich (1975), V.Anisovich, P.Volkovitski & Povzun (1976)
L.Laperashvili (1982), Larson (84)
S.Ekelin & S.Fredriksson (1984), V.A. Bednyakov (1984)
VK (1987-88)

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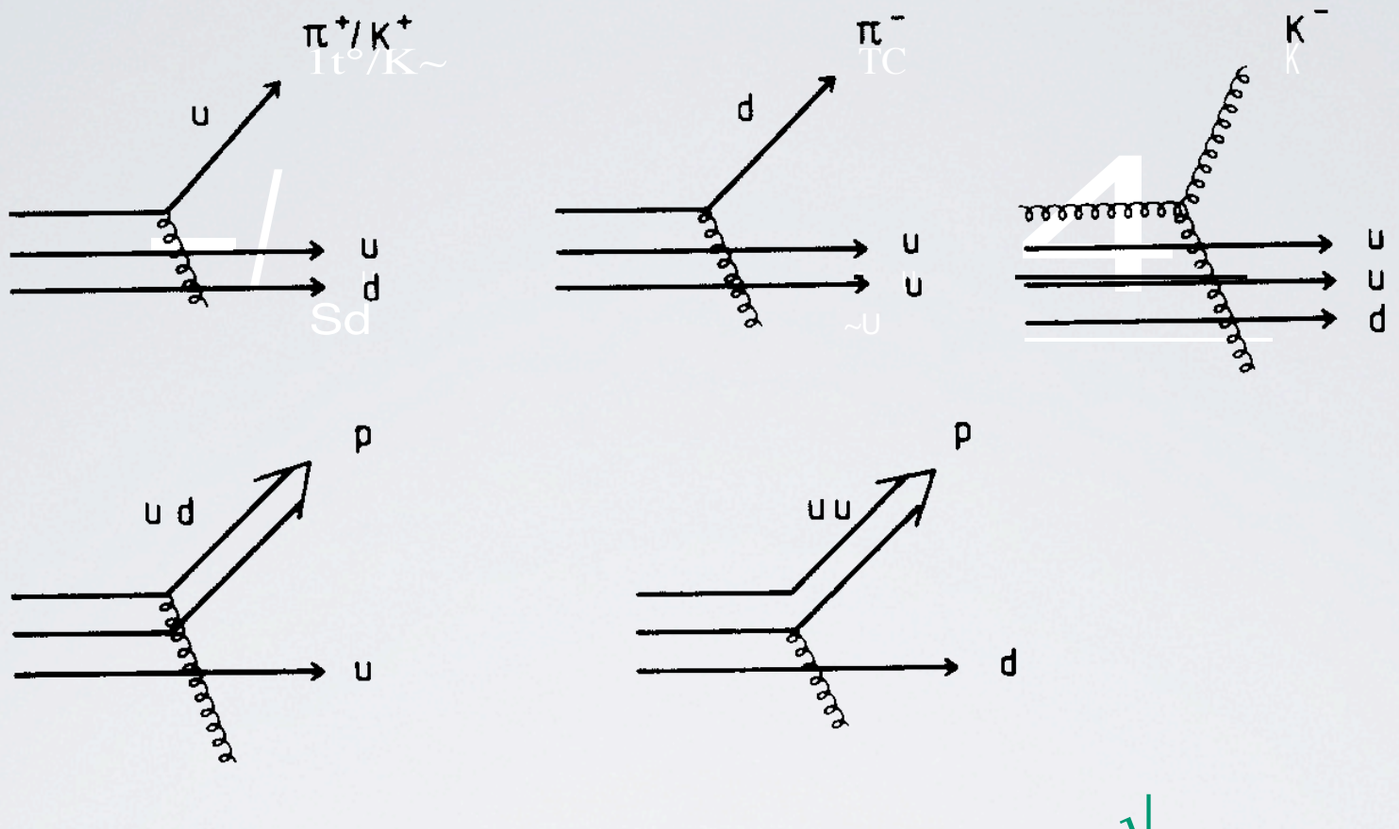
Diquarks in large-pT proton production in pp-collisions: two-hadron correlations in final state



ABCDHW Coll.: A.Breakstone et al (1987) $\sqrt{s}$ = 62 GeV

Correlations between high-pT proton and meson from toward jet

proton-meson correlations: favouring diquark scattering

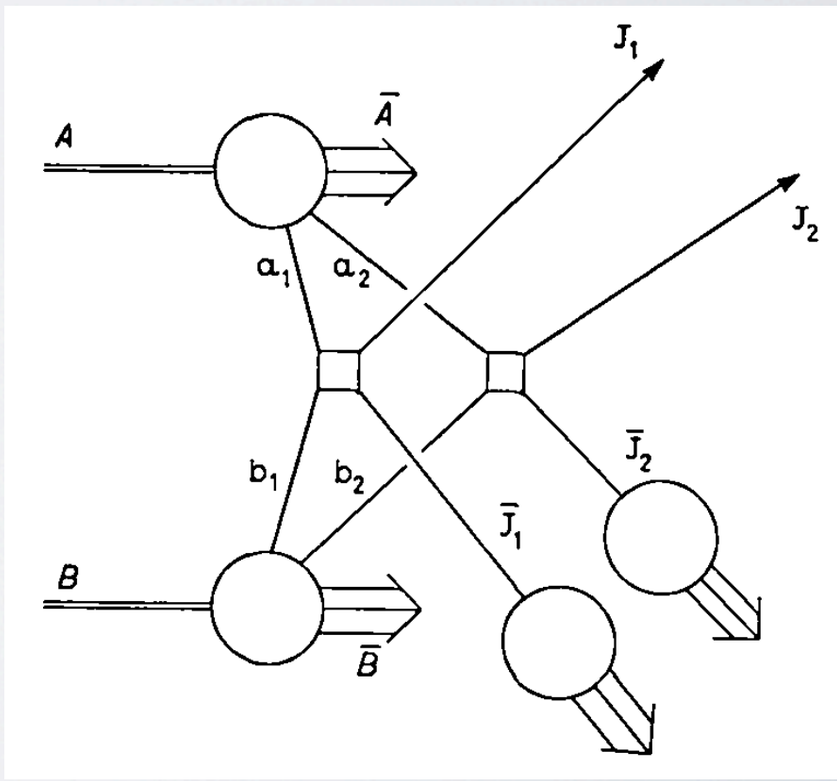
MPI as multi-parton scattering (MPS)

double parton scattering:

$$\sigma_{HARD}\,(NN\to PX) = F_N(x_1,x_2,Q^2) \times \sigma_{parton\ 1} \times \sigma_{parton\ 2} \times F_N(x_3,x_4,Q^2) \times r^2$$

$F_N(x_1,x_2,Q^2)$ – two-parton distribution in proton
r – "distance" in the impact parameter plane

P.Landshoff (1974)
N.Paver & D.Treleani (1982)
V.Shelest, A. Snigirev & G.Zinoviev (1982)
M.Jacob (1983), M.Mekhfi (1985)
A.Efremov & VK (1987)
....
recent study:
B.Blok, Yu.Dokshitzer & M.Strikman
M.Ryskin & A.Snigirev
M.Diehl et al.



MPI: both MPC and MPS involved

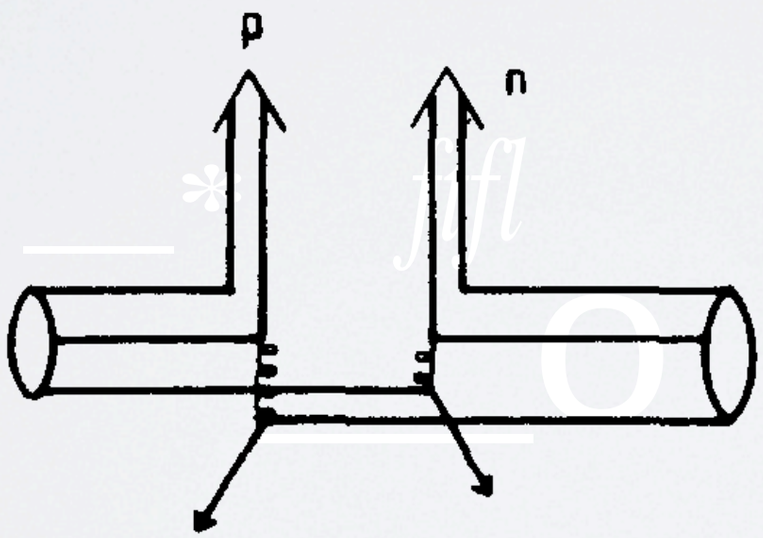
NN->DeutronX production via double diquark-quark scattering:

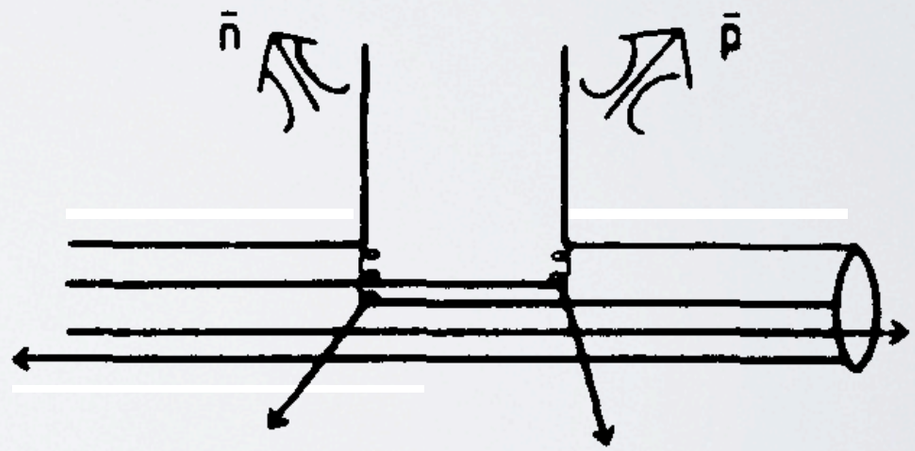
$$\sigma_{HARD}\,(NN\text{->}DX) = F^{D}_{N}(x_1,x_2,\,Q^2) \times \sigma_{parton\ 1} \times \sigma_{parton\ 2} \times F^{D}_{N}(x_3,x_4,\,Q^2)$$

$$\times f^4(Q^2)/r^2 \times K$$

A.Efremov & V.Kim (1987)

VK et al., in preparation

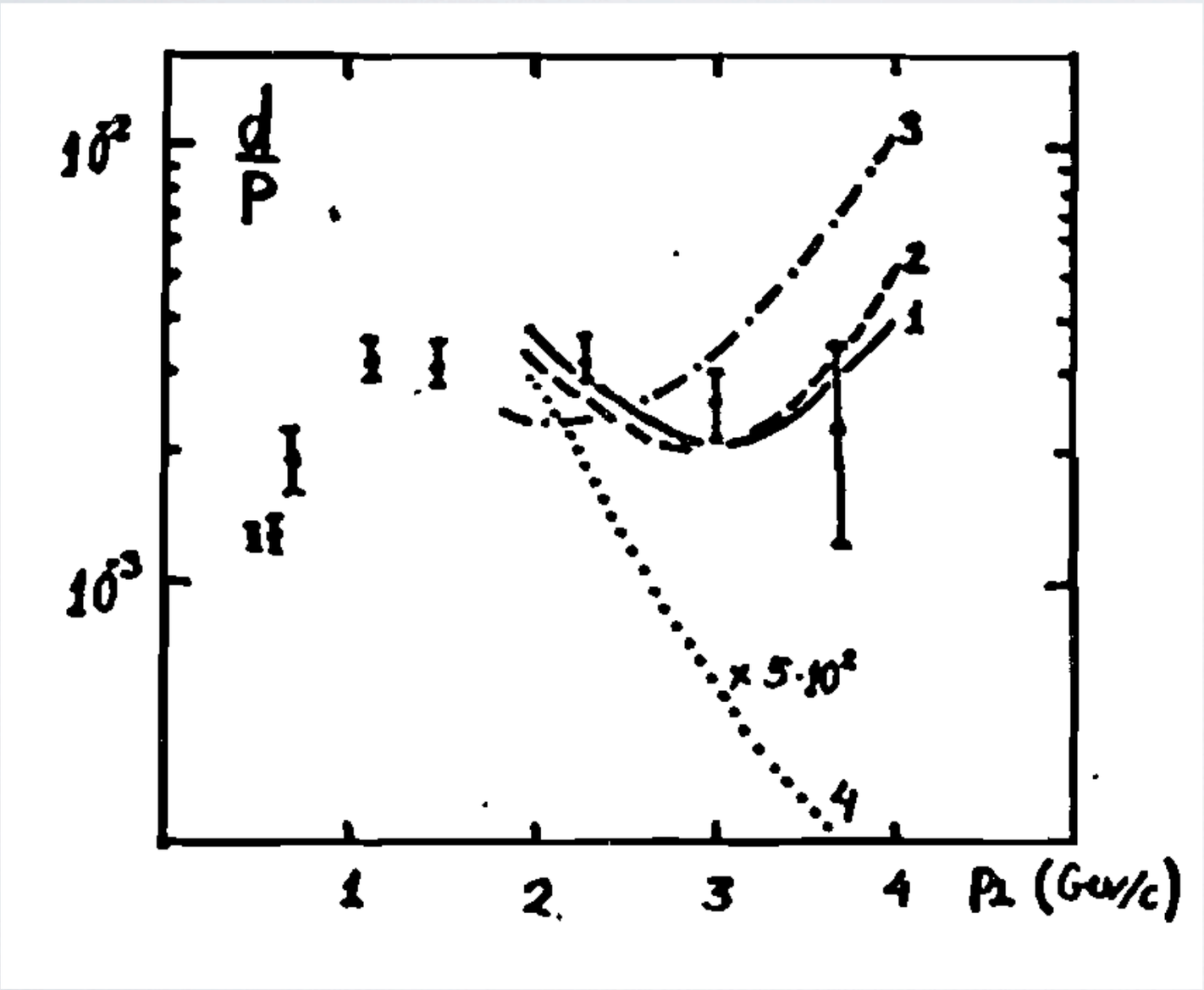




light nuclei: deuteron, etc. exotic multiquark resonances

MPI: both MPC and MPS involved

A.Efremov & V.Kim (1987)
VK et al., in preparation



$\sqrt{s} = 11.5$ GeV ($E = 70$ GeV).

MPI with MPC and MPS involved: compromise between pT and collision energy

MPI, when both MPC and MPS involved, needs optimal ranges in pT and collision energy:

- **Multi-parton correlations - MPC (higher twists): enhanced at large x as ~1/(1-x)^m, but suppressed at large pT as ~ 1/pT^n**

- **MPS is not suppressed at large collision energies: can enhance production of large-pT complex hadronic states (multiquark states and nuclei)**

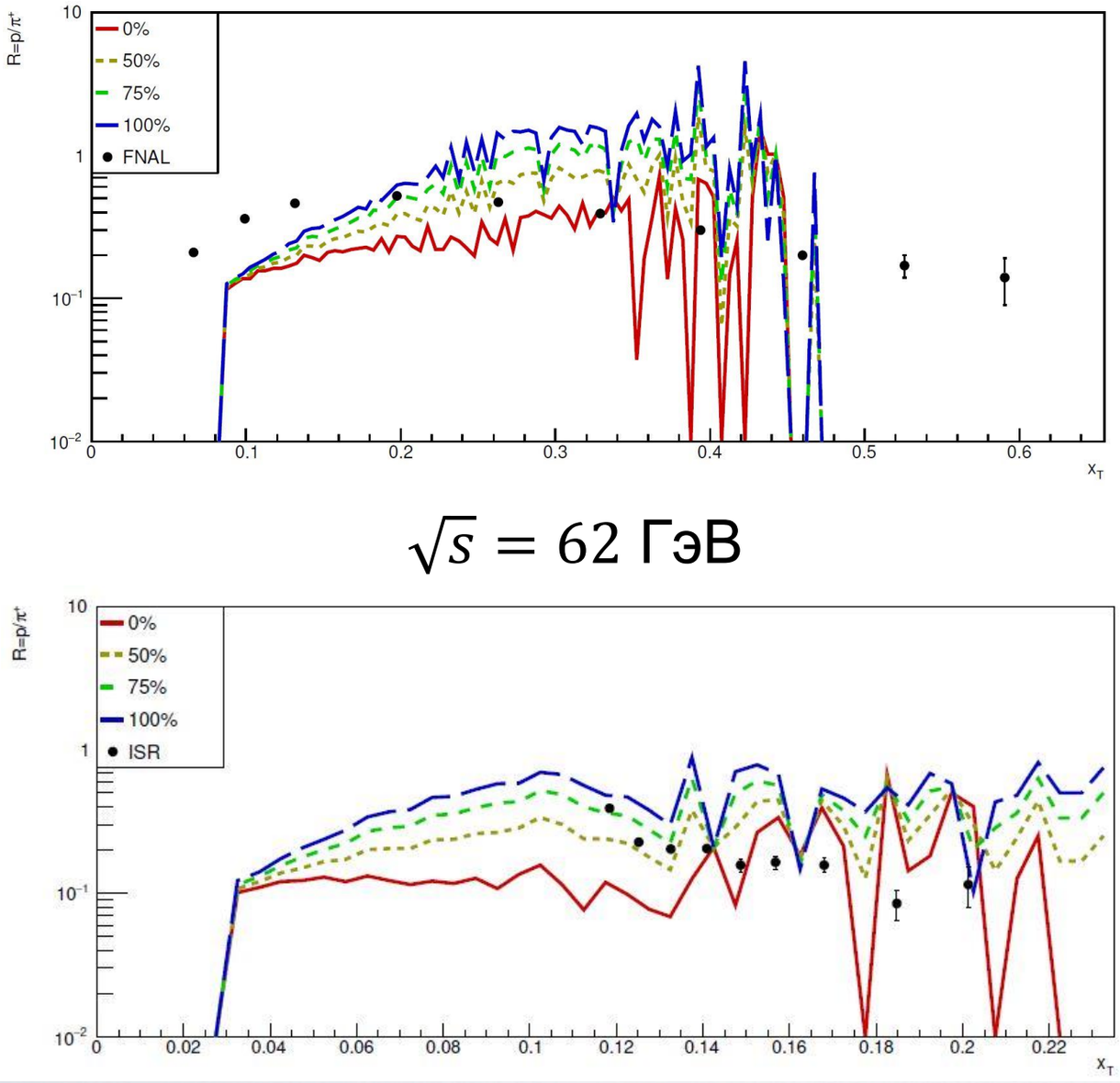
A.Efremov & V.Kim (1987)
VK et al., in preparation

MC event generator ULYSSES: Diquark model implementation to PYTHIA

- Diquark model implemented to PYTHIA 8

VK, A.S. Shavrin & A.V. Zelenov, in preparation

$\sqrt{s} = 23.4$ ГэВ



$\sqrt{s} = 62$ ГэВ

$$R(x_T) = \frac{\left(\frac{Ed^3\sigma}{dp^3}(x_T)\right)_p}{\left(\frac{Ed^3\sigma}{dp^3}(x_T)\right)_{\pi^+}} \qquad x_T = \frac{2p_T}{\sqrt{s}}$$

$\vartheta_{cm} = \pi/2$

MC event generator ULYSSES: Diquark model implementation to PYTHIA

- **Diquark model implemented to PYTHIA 8**
  VK, A.A. Shavrin & A.V. Zelenov, in preparation

When both MPC and MPS involved,
for the MPI processes there should be
an optimal region in pT and collision energy <– NICA SPD reach

ULYSSES for medium and large pT:
various two-particle correlations in pT and azimuthal plane
estimates for possible exotic resonances (tetraquarks, pentaquarks, etc)

Heavy pentaquarks and tetraquarks established at LHC
-> motivation for searches in light sector at NICA energies

Summary

Multiparton interaction (MPI):

- multiparton correlations (MPC) - higher twists - important for for baryon production

- multiparton scattering (MPS) – may be important for exotic resonances: tetraquarks, pentaquarks, etc.

There a lot of open interesting issues with MPC and MPS

NICA energies seem to be optimal for MPI studies !

MPI with both MPC & MPS involved would provide a rich physics study at NICA SPD !