Diquark role in baryon and exotic state production with large p_T in pp- and dd-collisions

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Introduction

The QCD parton model demonstrates a good description of mesons over a wide range of energies. But it can't describe an anomalously large yield of protons along with its strong scaling violation.

Taking into account the two-quark correlation (Diquark) allows us to describe the anomalous proton yield.

"Dynamical role of diquarks in processes of inclusive proton production" Laperashvili (Sov. J. Nucl. Phys. 35(3), 431-434,1982);

"Large-p_T protons from constituent diquark scattering" Ekelin et al (Physics Letters B, 149(6), 509-513, 1984);

"DIQUARKS AND DYNAMICS OF LARGE-P⊥ BARYON PRODUCTION" Kim (Modern Physics Letters A 03:09, 909-916,1988)

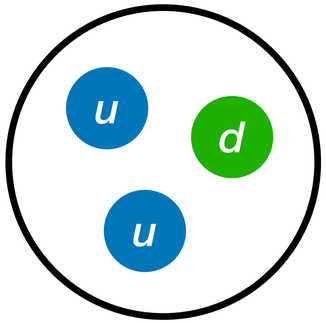
Being a higher-twist, the Diquark contribution can describe the strong scaling violation in deep inelastic scattering of nucleons observed in p/π^+ ratio.

"DIQUARKS AND DYNAMICS OF LARGE-P⊥ BARYON PRODUCTION" Kim (Modern Physics Letters A 03:09, 909-916,1988)

Two-quark correlations: Diquarks

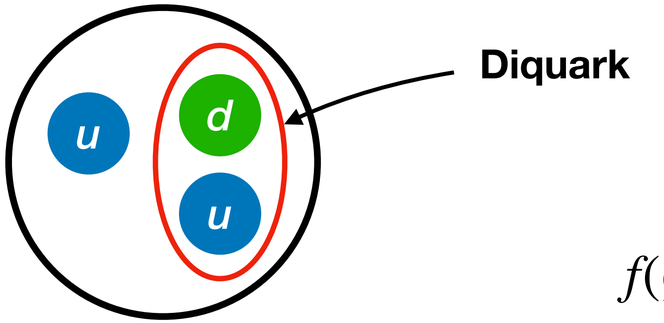
Diquark is a two-quark correlation in baryons.

$p\{uud\}$



Quark model of baryon

$p\{u(ud)\}$



Model of baryon with Diquark

Diquark is not a point-like object!

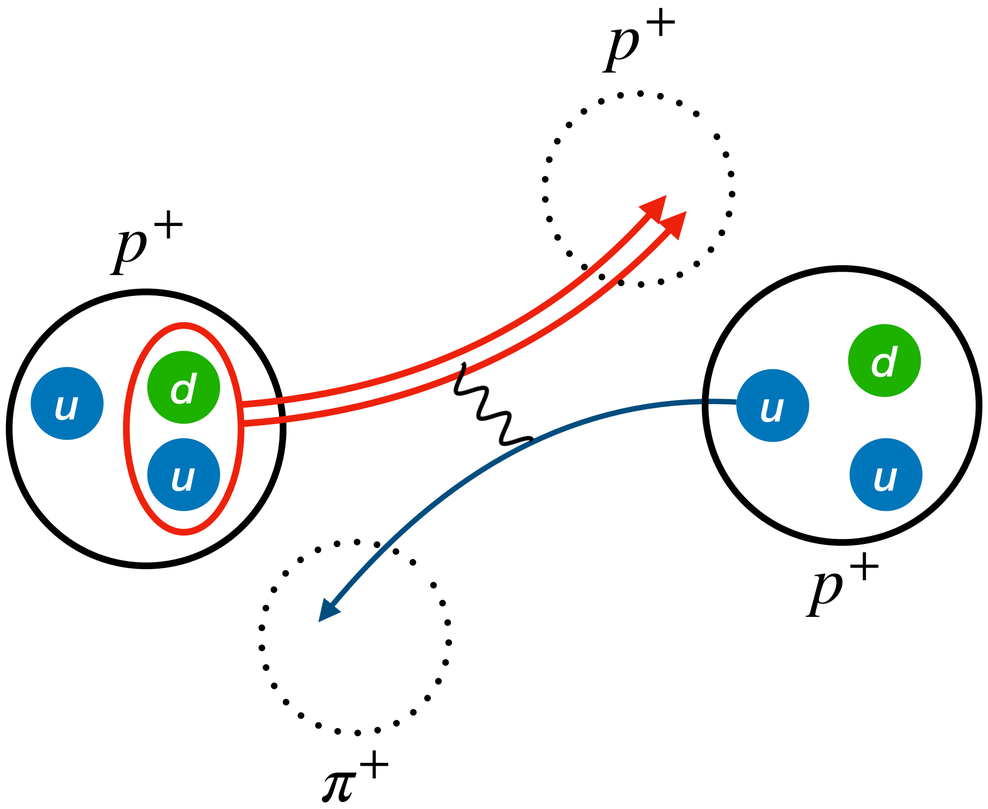
$$f(Q^2) = \frac{1}{1 + \frac{Q^2}{M^2}}$$ – **Diquark form-factor**

M^2 – **Diquark size parameter**

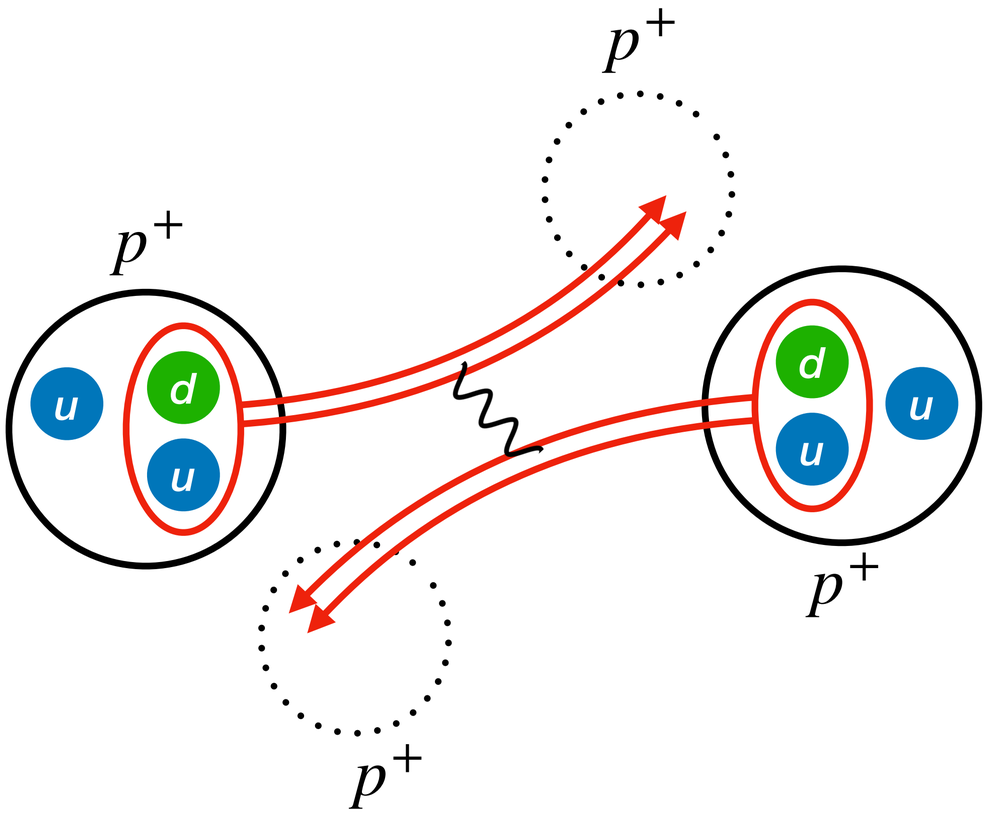
Baryon (proton) is in quark-Diquark state with probability W

Two-quark correlations: Diquarks

(ud) Diquark scatters on u quark



(ud) Diquark scatters on (ud) Diquark



$$\left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{qD} = \left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{qq} \cdot f^2(Q^2)$$

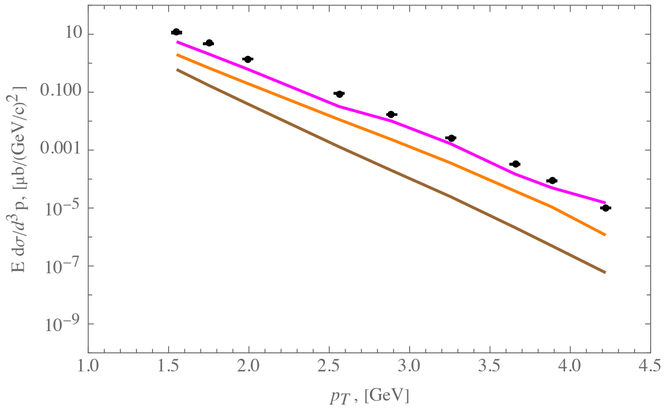
The main source of baryons with large p_T in pp collisions at NICA energies

$$\left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{DD} = \left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{qq} \cdot f^4(Q^2)$$

Large-p_T p production

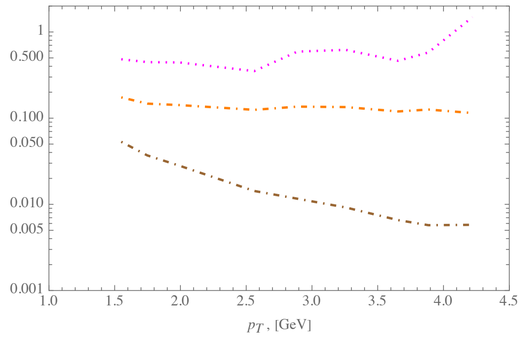
"Diquarks for Large- Baryon Production at High-Energy Collisions" V.T. Kim, A.V. Zelenov (Phys. Part. Nucl. 2025)

$\sqrt{s} = 11.5$ GeV



- Abramov, V.V., et al, p; $\sqrt{s}$ = 11.5GeV
- no Diquark; **FFHNKS**
- Diquark ($M_D{}^2$= 10, ν_0=2, λ = 4.1); **FFHNKS**
- PYTHIA 8.3, p; $\sqrt{s}$ = 11.5GeV

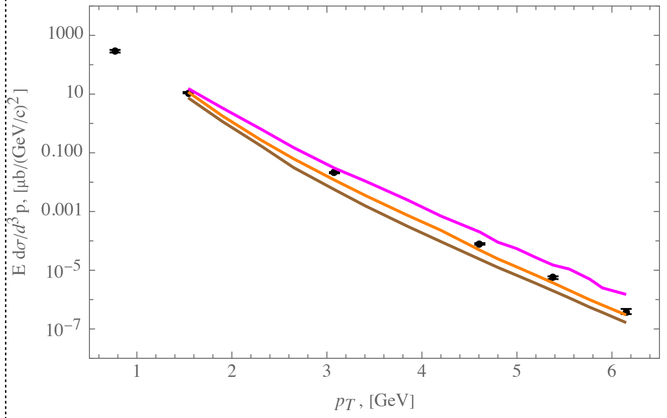
Theory/Data



- no Diquark; **FFHNKS** VS Data $\sqrt{s}$ = 11.5GeV
- Diquark ($M_D{}^2$= 10, ν_0=2, λ = 4.1); **FFHNKS** VS Data $\sqrt{s}$ = 11.5GeV
- PYTHIA 8.3 VS Data Ratio

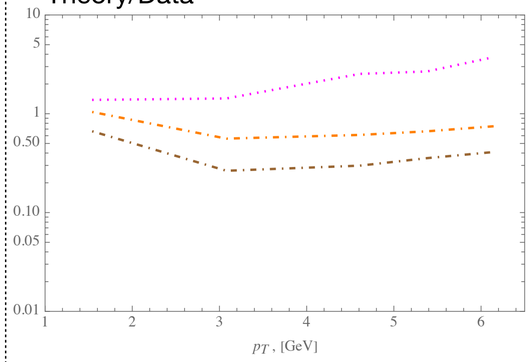
IHEP, Protvino, $\sqrt{s} = 11.5$ GeV
FODS, V.V. Abramov et al. (1985)

$\sqrt{s} = 23.4$ GeV



- Antreasyan, et al, p; $\sqrt{s}$ = 23.4GeV
- no Diquark; **FFHNKS**
- Diquark ($M_D{}^2$= 10, ν_0=2, λ = 4.1); **FFHNKS**
- PYTHIA 8.3, p; $\sqrt{s}$ = 23.4GeV

Theory/Data



- no Diquark; **FFHNKS** VS Data $\sqrt{s}$ = 23.4GeV
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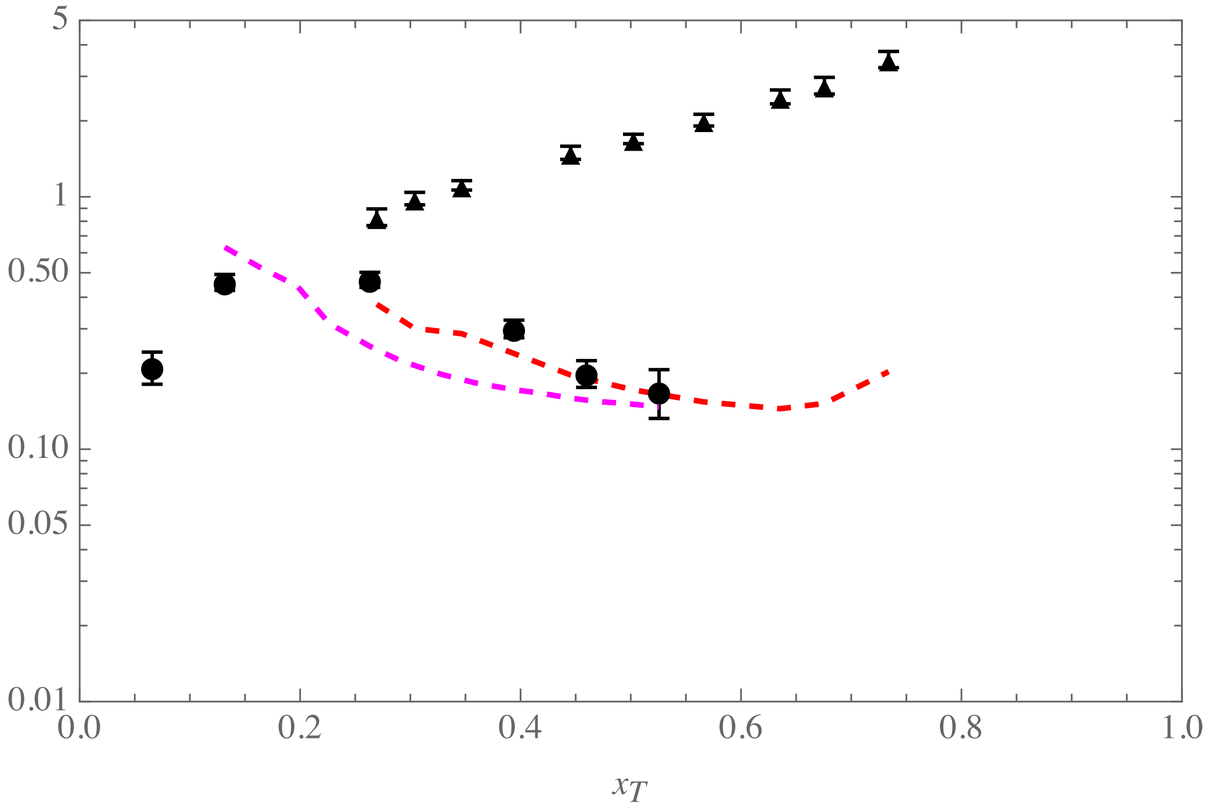
- PYTHIA 8.3 VS Data Ratio

collinear factorization improved by k_T dependence was used for calculation R.P. Feynman, R.D. Field and G.C. Fox Phys. Rev. D 18 (1978) 3320

FNAL, Batavia, $\sqrt{s} = 23.4$ GeV
D.Antreasyan et al. (1979)

Scaling violation: p/π^+ ratio without Diquark

p/π^+ Ratio



p/π^+ Ratio with $\theta_{\text{cms}} = 90^o$ in pp-collisions and also comparison with data

(▲) **IHEP**, Protvino for $\sqrt{s} = 11.5$ GeV
FODS, V.V. Abramov et al. (1985)

(●) **FNAL**, Batavia for $\sqrt{s} = 23.4$ GeV
D.Antreasyan et al. (1979)

Calculation results**:**

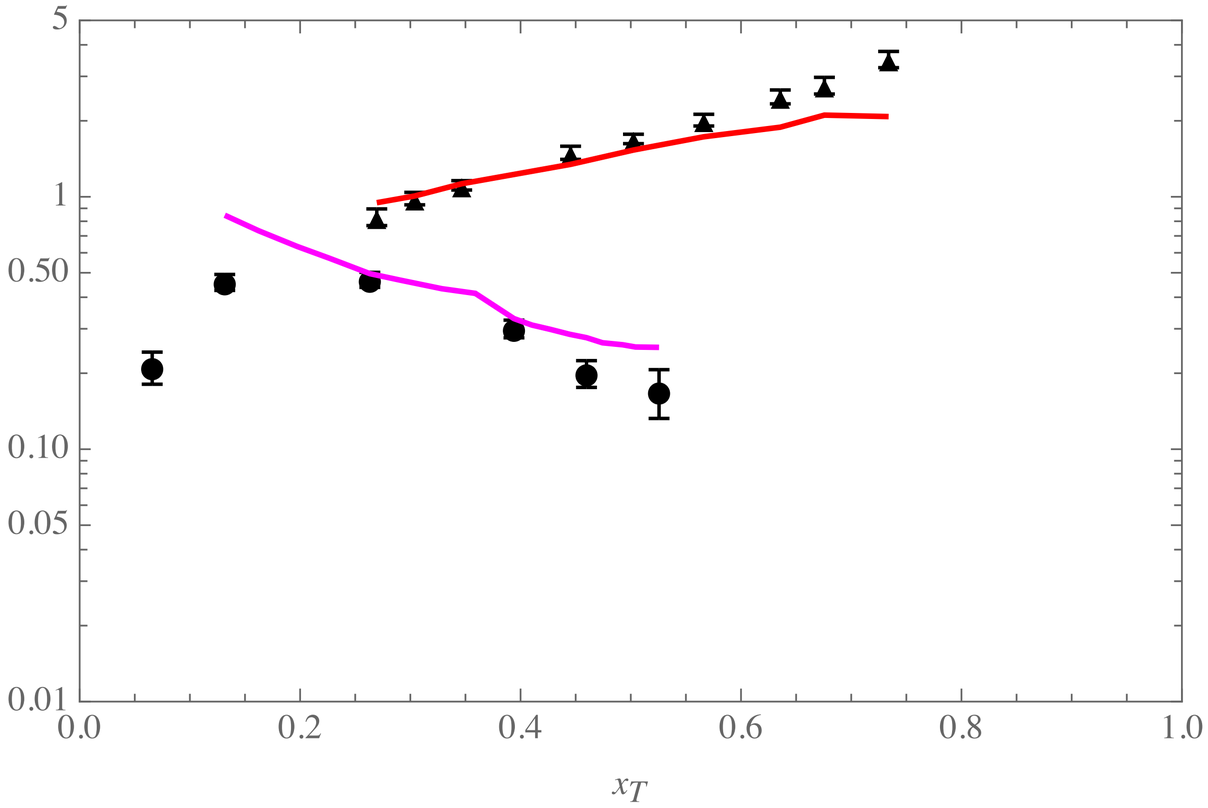
Red dashed line $-\sqrt{s} = 11.5$ GeV,

Magenta dashed line $-\sqrt{s} = 23.4$ GeV,

$x_T = 2p_T/\sqrt{s}$

Scaling violation: p/π^+ ratio with Diquark

p/π^+ Ratio



$x_T = 2p_T/\sqrt{s}$

"Diquarks for Large- Baryon Production at High-Energy Collisions" V.T. Kim, A.V. Zelenov (Phys. Part. Nucl. 2025)

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Calculation results**:**

Red solid line $-\sqrt{s} = 11.5$ GeV,

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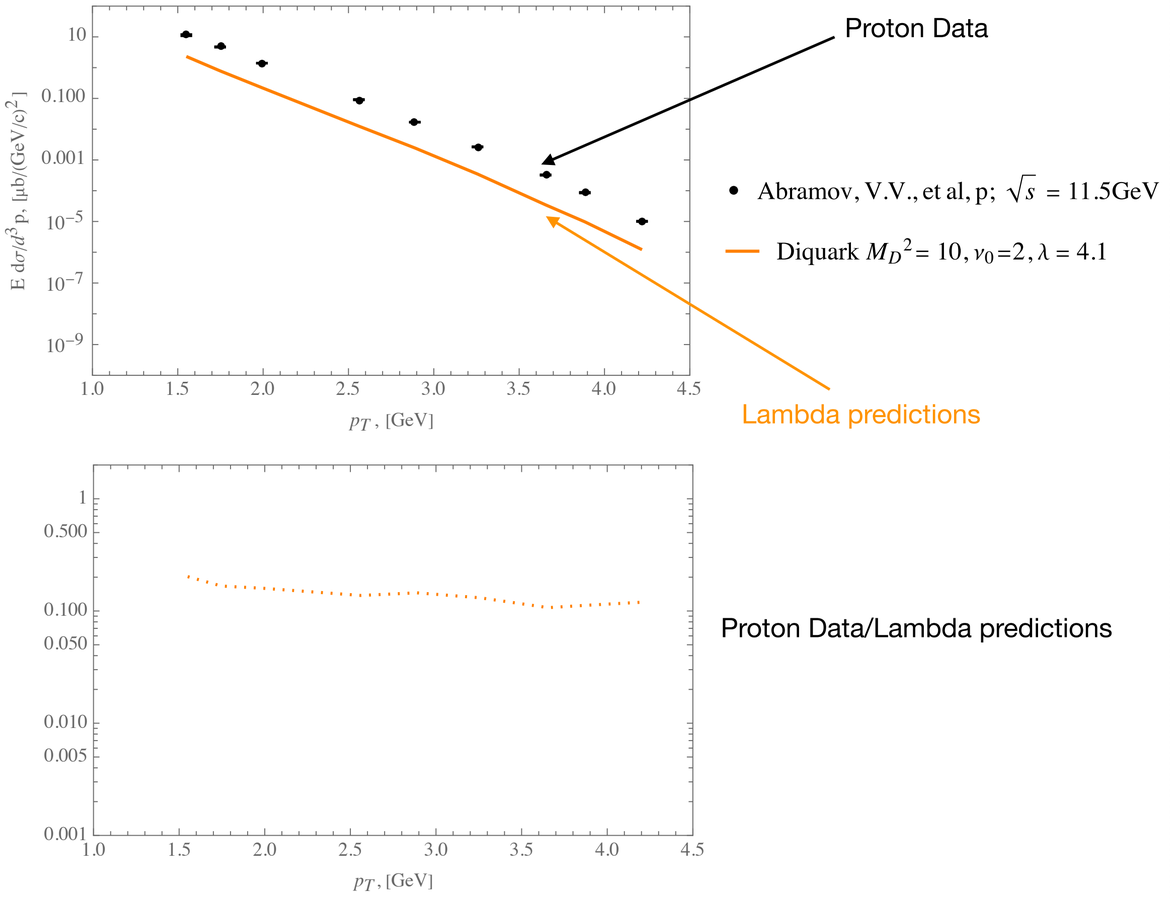
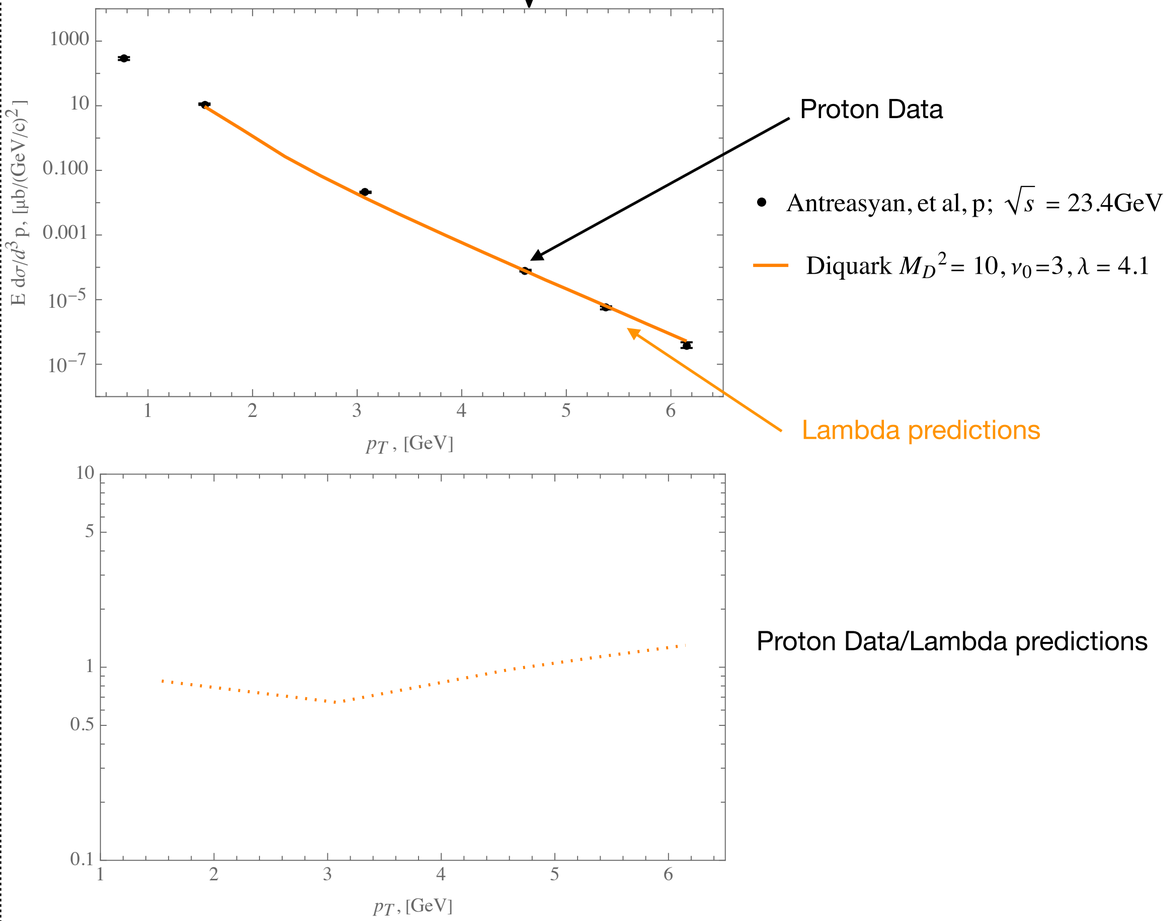
Large-p_T $\Lambda(uds)$ production

"Diquarks for Large- Baryon Production at High-Energy Collisions" V.T. Kim, A.V. Zelenov (Phys. Part. Nucl. 2025)

$\sqrt{s} = 11.5$ GeV



$\sqrt{s} = 23.4$ GeV



IHEP, Protvino, $\sqrt{s} = 11.5$ GeV
FODS, V.V. Abramov et al. (1985)

$\Lambda \to p\pi^-$

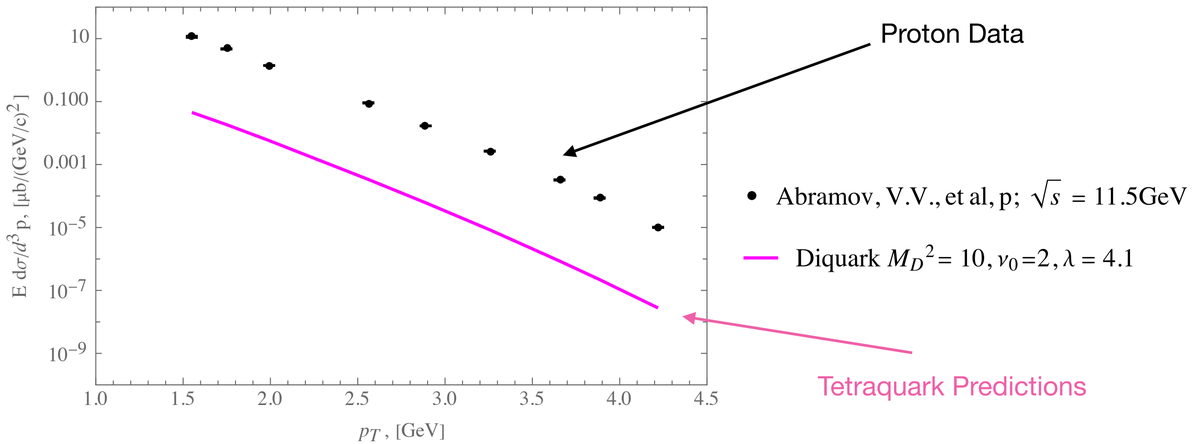
$L = 10^{31} cm^{-2} s^{-1};\ N = 10000 \qquad t = \dfrac{N}{\sigma \cdot L \cdot B \cdot \text{DetEff}} \simeq 1/2$ month

optimal data taking 3 months

FNAL, Batavia, $\sqrt{s} = 23.4$ GeV
D.Antreasyan et al. (1979)

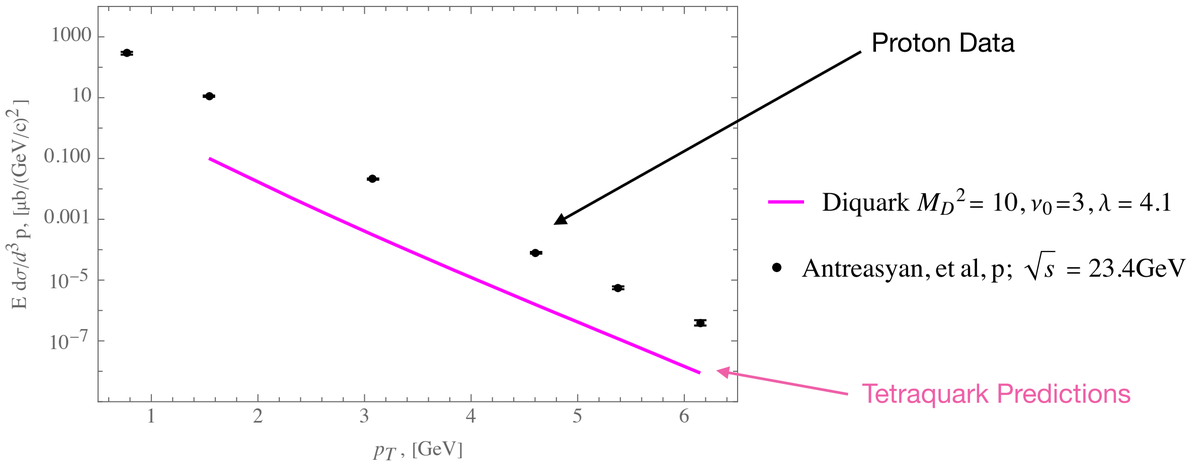
Exotic state production. Tetraquark $(qq\bar{q}\bar{q})$ $a_0(980)$: $\{(ud)\bar{u}\bar{d}\}$

$\sqrt{s} = 11.5$ GeV



IHEP, Protvino, $\sqrt{s} = 11.5$ GeV
FODS, V.V. Abramov et al. (1985)

$\sqrt{s} = 23.4$ GeV



FNAL, Batavia, $\sqrt{s} = 23.4$ GeV
D.Antreasyan et al. (1979)

$$a_0(980) \to K^0\bar{K}^0 \to \pi^+\pi^-\pi^+\pi^-$$

$$L = 10^{31} cm^{-2} s^{-1};\ N = 1000 \qquad t = \frac{N}{\sigma \cdot L \cdot B \cdot \text{DetEff}} \simeq 1 \text{ month}$$

optimal data taking 5 months

"Diquarks for Large- Baryon Production at High-Energy Collisions" V.T. Kim, A.V. Zelenov (Phys. Part. Nucl. 2025)

Assuming that Tetraquark consists at least 1 Diquark

R.L. Jaffe, Phys. Rev. D 15, 267 (1977);
R.L. Jaffe, Phys. Rev. D 15, 281 (1977);
R.L. Jaffe, Phys. Rep. 409, 1 (2005)

Summary

- Two-quark correlations (Diquarks) can describe the strong scaling violation in large-p_T proton production in hard nucleon collisions at **SPD** energies.
- The **SPD** at **NICA** collider provides a unique opportunity to improve understanding of Diquark role for large-p_T baryon production in pp-collisions.
- The **SPD** at **NICA** collider provides a unique opportunity to study possible production of exotic multi quark states (tetra) in light quark sector
- The role of multiparton dynamics in the production of hadrons with large-p_T momenta and exotic hadronic states in high-energy pp collisions has been investigated. “Diquarks for Large-p_T Baryon Production at High-Energy pp Collisions” V.T. Kim, A.V. Zelenov (Phys. Part. Nucl. 2025)
- Exotic multiquark hadron state production is included to the physic program of **SPD** at **NICA**: "Possible studies in the first stage of the NICA collider..." V.V. Abramov et al. (Phys. Part. Nucl. 2021)