Probing generalized parton distributions and color transparency in hard 2→3 processes

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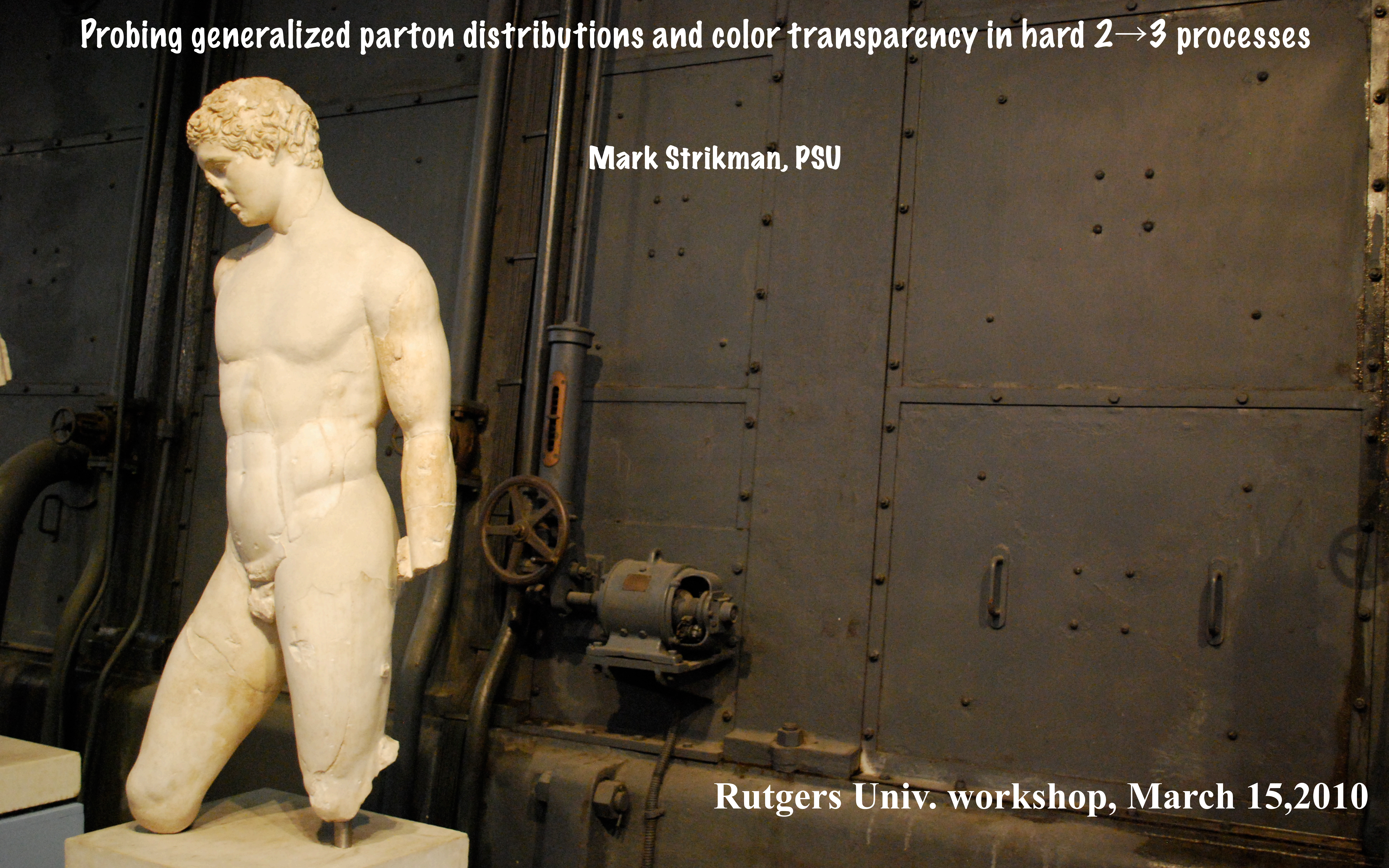


Rutgers Univ. workshop, March 15,2010

Outline

- **Introduction: Motivation and facilities**

- **Brief summary of color coherence and color transparency**

- ***Novel class of the processes hard 2→3 branching exclusive processes:***

  ☛ ***Measurement of GPDs of photons, nucleons in ep collider and various hadrons in hadron induced processes***

  ☛ ***More effective way to test color transparency for hard 2→2 processes***

Motivations for the hard exclusive hadron induced processes with nucleons and nuclei

- ✳ *Going beyond one dimensional image of nucleon - GPDs & correlations in the wave functions of baryons and mesons*

- ✳ *What is **the multiparton structure** of photons, hadrons and how they are different*

$$|baryon\rangle = |qqq\rangle + |qqq(q\bar{q})\rangle + |qqqg\rangle + ...$$
$$|meson\rangle = |q\bar{q}\rangle + |q\bar{q}g\rangle + ...$$

☛ Need probes with high resolution - in addition to virtual photon probe discussed in a number of talks. Natural candidate - large t / large angle photon/hadron - hadron scattering.

Need large W's but not too large - as many of discussed processes drop with energy

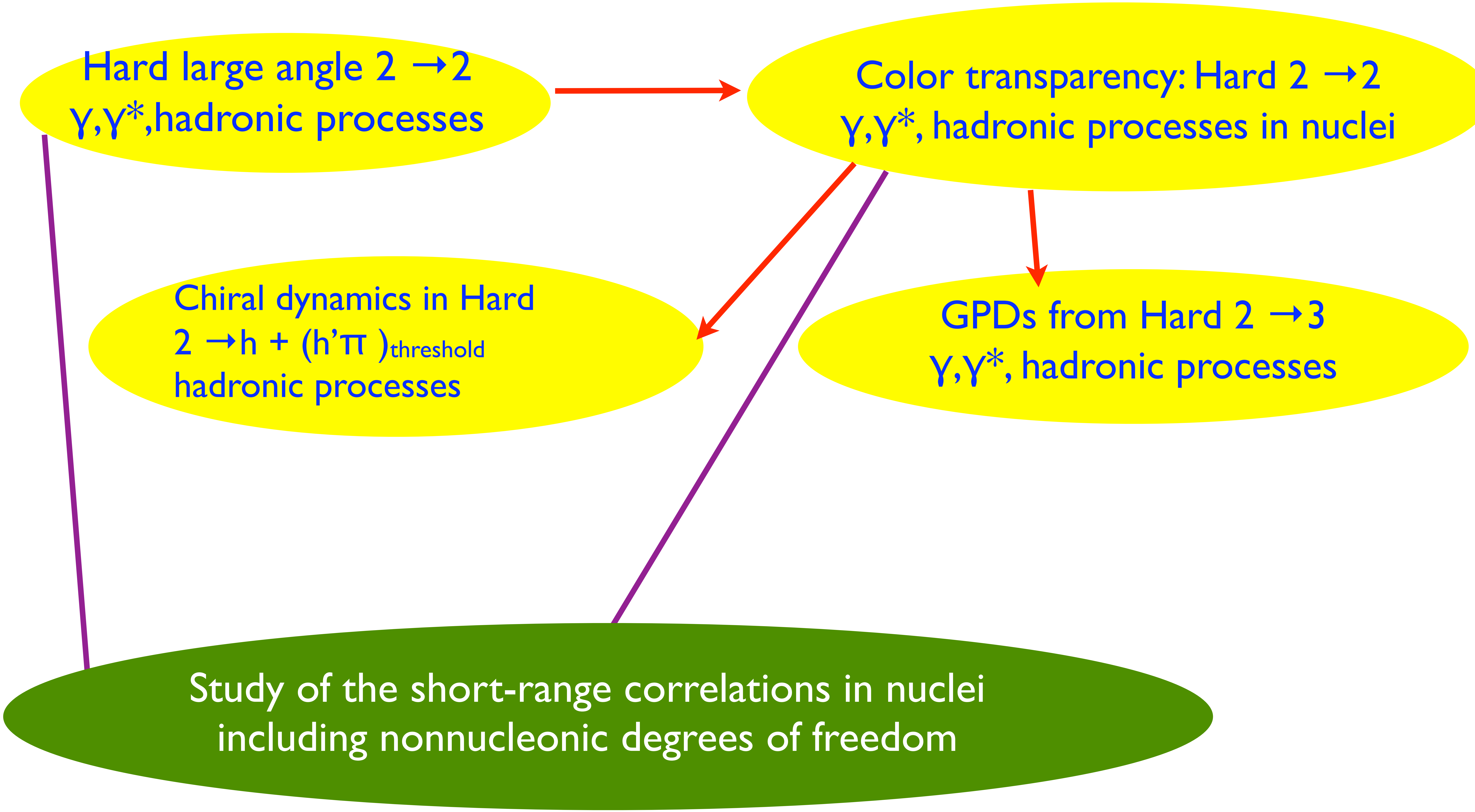
➠ Scan sizes involved in large t a+b → c+ d reaction, determine at what t point-like configurations dominate.

✳ Understand dynamics of 2 →2 reaction.

✳ *How fast do wave packets of quarks evolve into hadrons?*

☛ Use chiral degrees of freedom to probe dynamics

Starting at what t $2 \to 2$ large angle process allow to do analog of DIS - *select point - like configurations in hadrons*?



Facilities:

Jlab - 12 GeV upgrade (2015)

COMPASS detector at CERN (collected data, will run for few years)

PANDA detector at FAIR (GSI) (2017?)

EIC

Main tool for exclusive processes is color coherence (CC) property of QCD and resulting **Color transparency (CT)**

CT phenomenon plays a dual role:

- probe of the high energy dynamics of strong interaction
- probe of minimal small size components of the hadrons

at intermediate energies also a unique probe of the space time evolution of wave packages

Basic tool of CT: suppression of interaction of small size color singlet configurations = CC

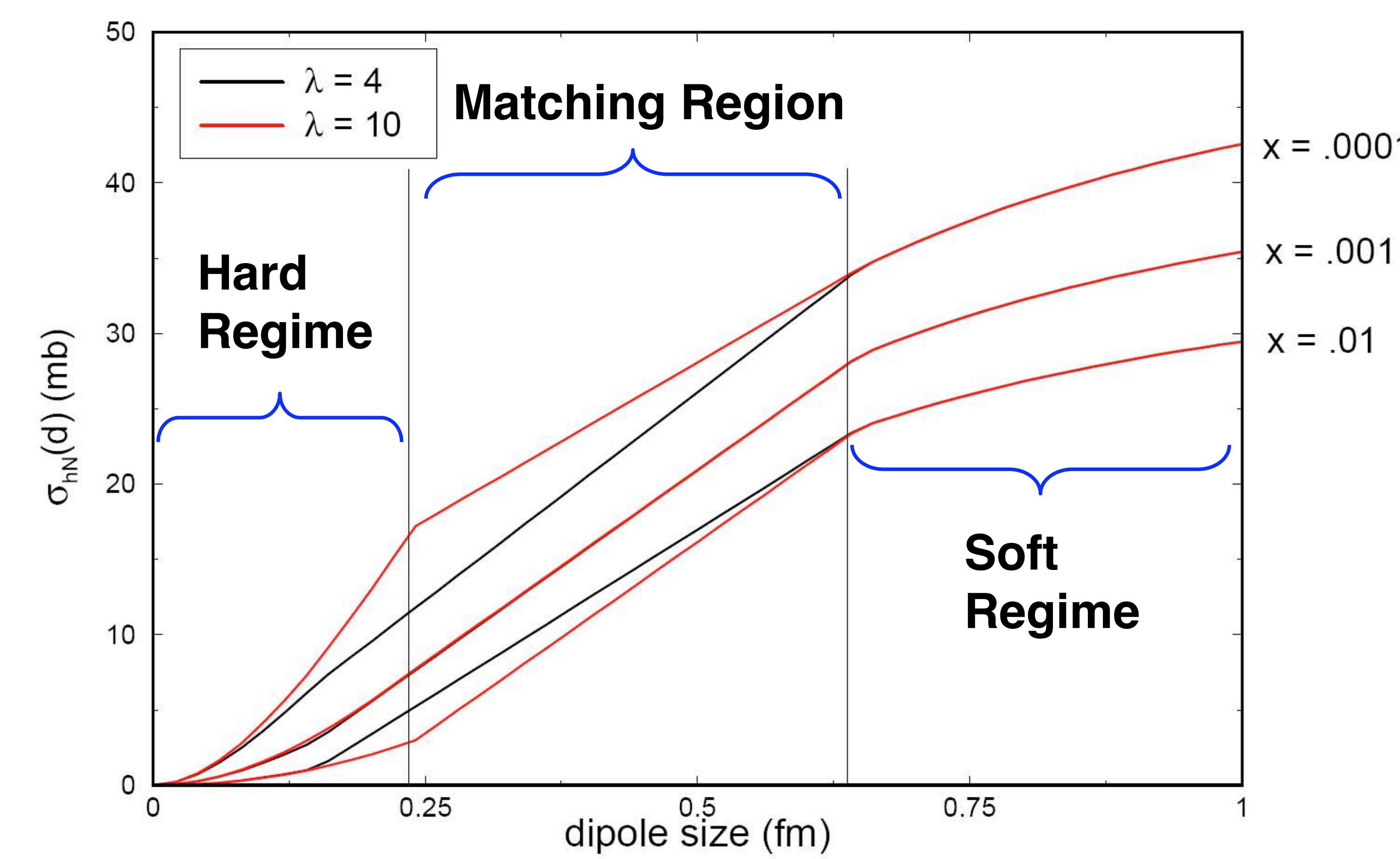
For a dipole of transverse size d:

$\sigma = cd^2$ *in the lowest order in* αs *(two gluon exchange F.Low 75)*

$$\sigma(d, x_N) = \frac{\pi^2}{3}\alpha_s(Q^2_{eff})d^2\left[x_N G_N(x_N, Q^2_{eff}) + 2/3 x_N S_N(x_N, Q^2_{eff})\right]$$

Important at E_{dipole} < 10 GeV

$Q^2 = 3.0\ GeV^2$



Here S is sea quark distribution for quarks making up the dipole.

(Baym et al 93, FS&Miller 93 & 2000)

Brief Summary of CT: squeeze and freeze

Squeezing: *(a) high energy CT*

- Select special final states: diffraction of pion into two high p_t jets: $d_{q\bar{q}} \sim 1/p_t$
- Select a small initial state: γ^*_L - $d_{q\bar{q}} \sim 1/Q$ in $\gamma^*_L + N \to M + B$

QCD factorization theorems are valid for these processes with the proof based on the CT property of QCD

(b) Intermediate energy CT

- Nucleon form factor
- γ^*_L (γ^*_T ?)+ $N \to M + B$
- Large angle (t/s = const) two body processes: $a + b \to c + d$ Brodsky & Mueller 82

↕ Problem: *strong correlation* between t (Q) and lab momentum of produced hadron

Freezing: ***Main challenge:*** |qqq> ($|q\bar{q}>$ is not an eigenstate of the QCD Hamiltonian. So even if we find an elementary process in which interaction is dominated by small size configurations - they are not frozen. They evolve with time - expand after interaction to average configurations and contract before interaction from average configurations (FFLS88)

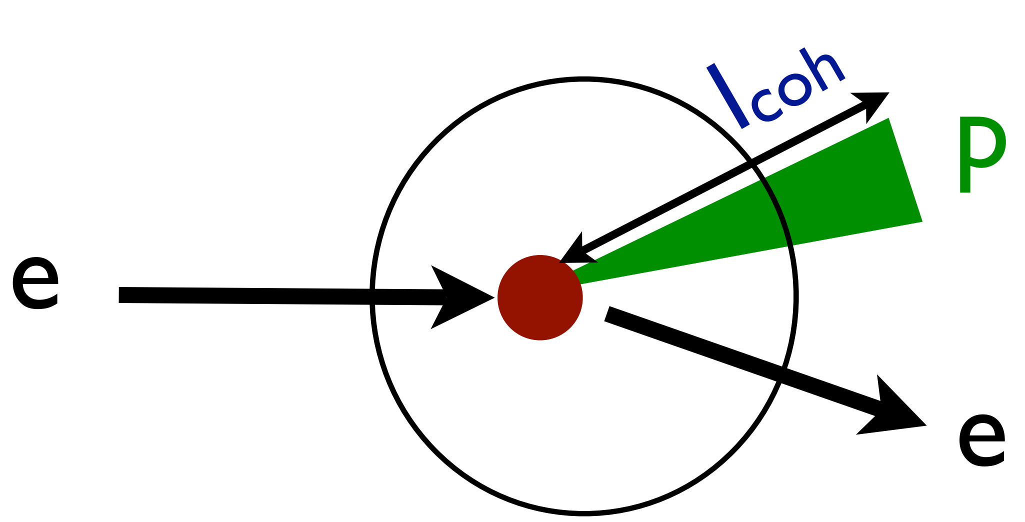
$$|\Psi_{PLC}(t)\rangle = \sum_{i=1}^{\infty} a_i \exp(iE_i t)\,|\Psi_i t)\rangle = \exp(iE_1) \sum_{i=1}^{\infty} a_i \exp\left(\frac{i(m_i^2 - m_1^2)t}{2P}\right) |\Psi_i t)\rangle$$

$$\sigma^{PLC}(z) = \left(\sigma_{hard} + \frac{z}{l_{coh}}\left[\sigma - \sigma_{hard}\right]\right)\theta(l_{coh} - z) + \sigma\theta(z - l_{coh})$$

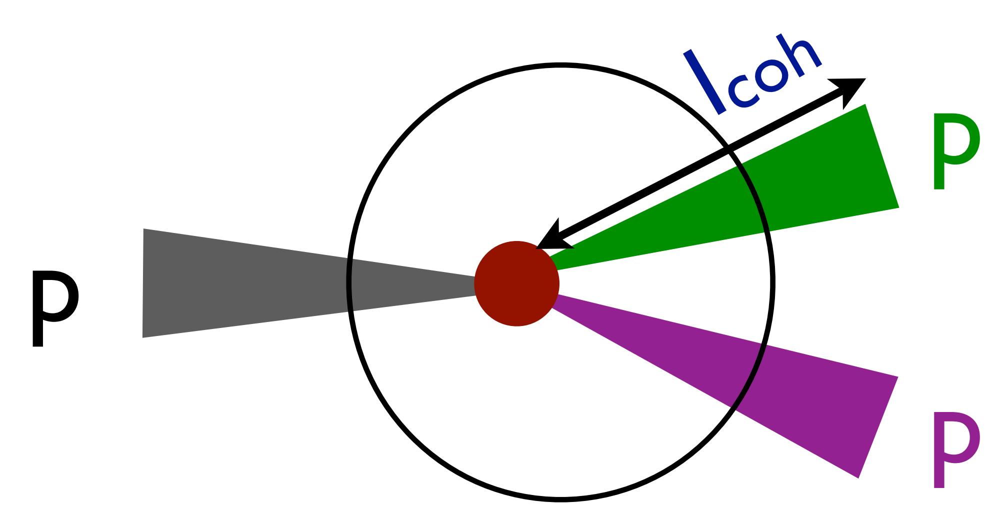
Quantum Diffusion model of expansion

$l_{coh}\sim$ (0.4- 0.8) fm E_h[GeV] *actually incoherence length*

The same expression with the same parameters describes production of leading hadrons in DIS - U.Mozel et al



eA→ ep (A-1) at large Q



pA→ pp (A-1) at large t and intermediate energies

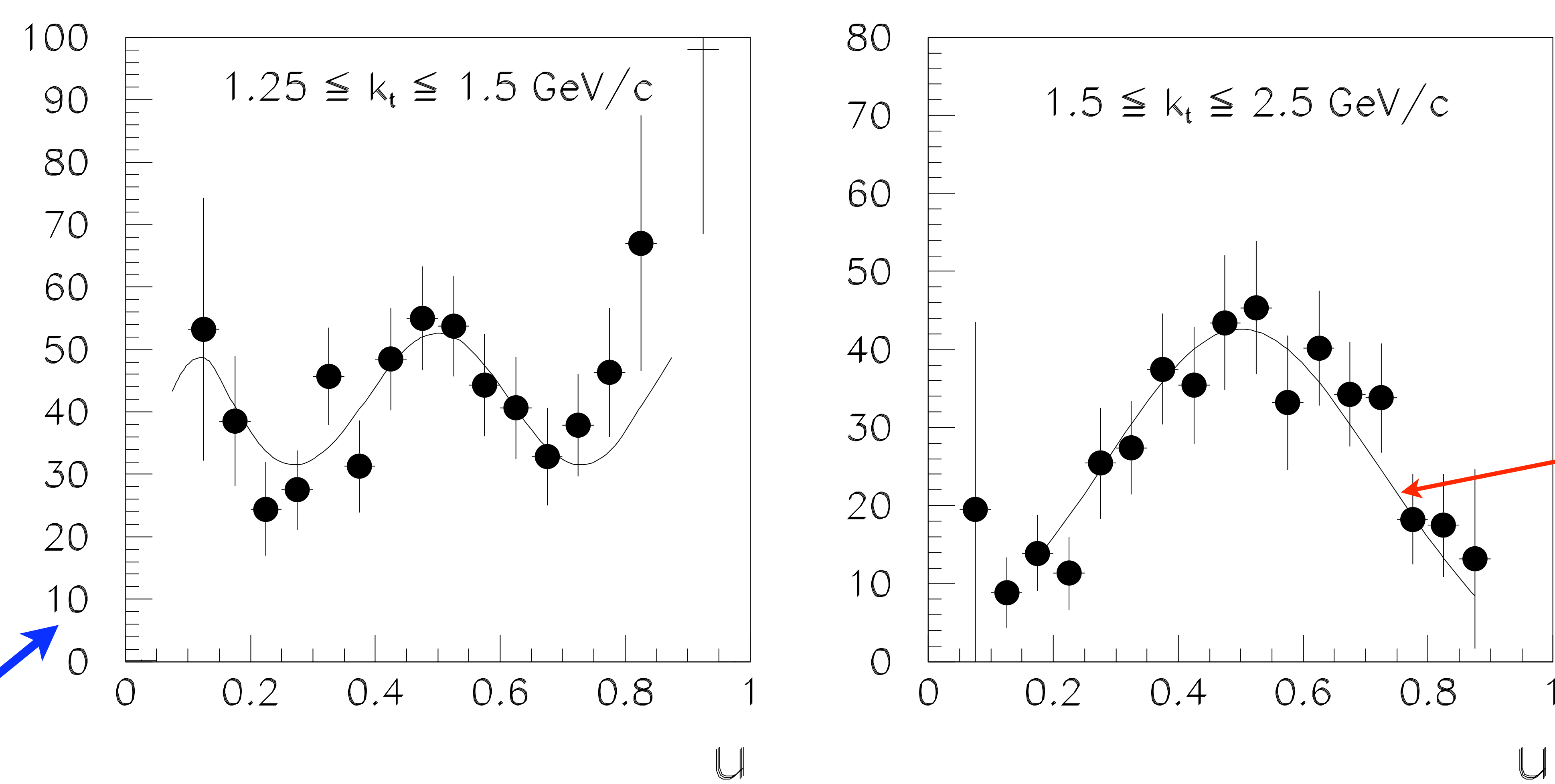
MC's at RHIC assume much larger l_{coh}= 1fm E_h/m_h;
for pions l_{coh}= 7 fm E_h[GeV] -
a factor of 10 difference !!!

Note - one can use multihadron basis with build in CT (Miller and Jennings) or diffusion model - numerical results for σ^{PLC} are very similar.

High energy color transparency is well established

At high energies weakness of interaction of point-like configurations with nucleons - is routinely used for explanation of DIS phenomena at HERA.

First experimental observation of high energy CT for pion interaction (Ashery 2000): π +A →"jet"+"jet" +A. Confirmed predictions of pQCD (Frankfurt ,Miller, MS93) for *A-dependence, distribution over energy fraction, u carried by one jet, dependence on p_t(jet), etc*



prediction

(π wave funct)^2

Squeezing occurs already before the leading term (1-z)z dominates!!!

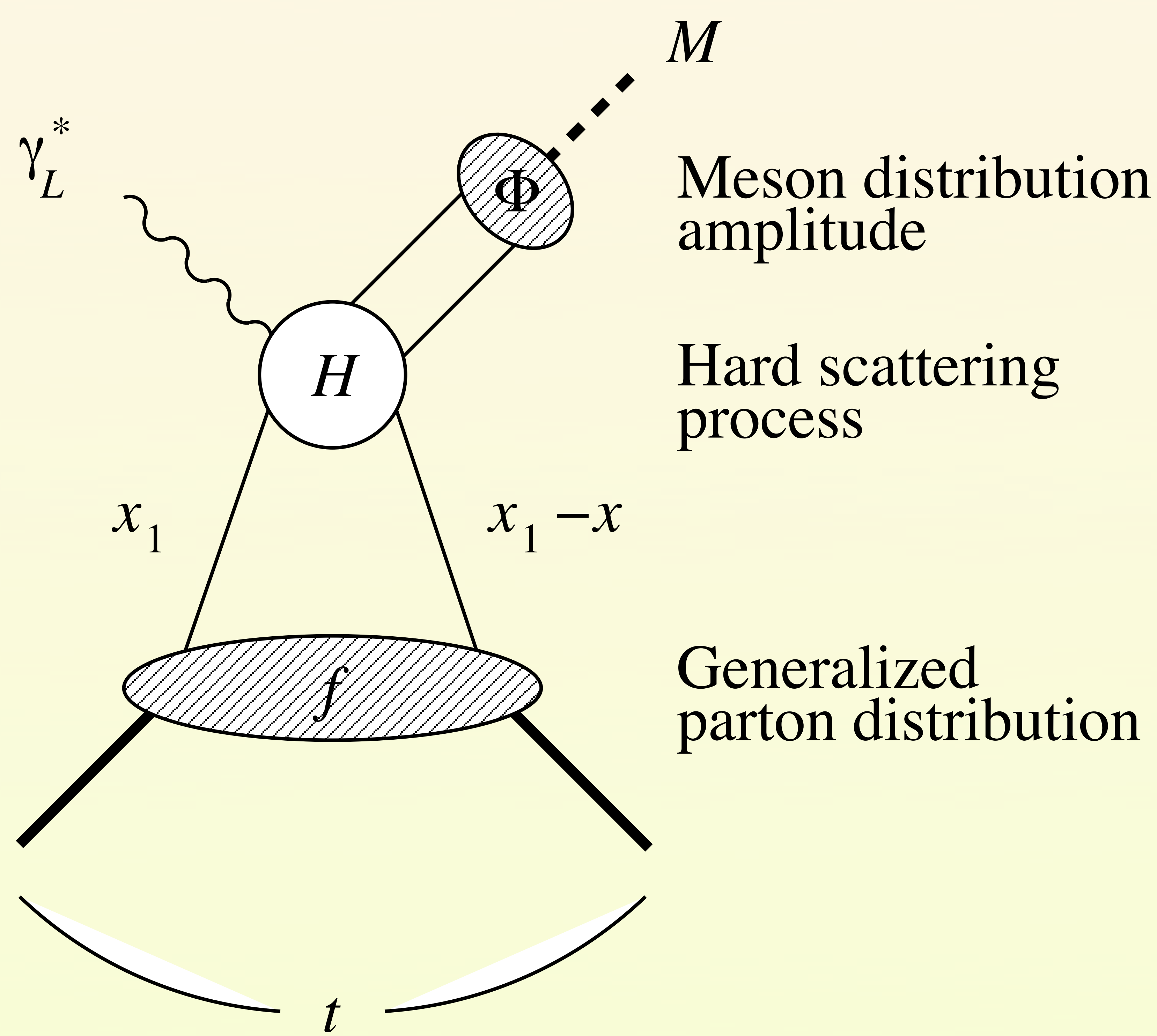
$$Q^2(\pi\ f.f.) \sim 4k_t^2(jet)$$

$$\Downarrow$$

strong squeezing in π form factor for Q^2=6 GeV^2

High energy CT = QCD factorization theorem for DIS exclusive meson processes

(Brodsky,Frankfurt, Gunion,Mueller, MS 94 - vector mesons,small x; general case Collins, Frankfurt, MS 97). The prove is based (as for dijet production) on the CT property of QCD not on closure like the factorization theorem for inclusive DIS.



- Presence of small size $q\bar{q}$ Fock componentss in light mesons is unambigously established
- At transverse separations $d \leq 0.3$ fm pQCD reasonably describes "small $q\bar{q}$ - dipole"- nucleon interaction for $10^{-4} < x < 10^{-2}$
- Color transparency is established for the interaction of small dipoles with nucleons and with nuclei (for $x \sim 10^{-2}$)

Intermediate energies

Main issues

☛ At what Q^2 / t particular processes select PLC - for example interplay of end point and LT contributions in the e.m. form factors, exclusive meson production.

☛ $l_{coh} = (0.4 \div 0.8$ fm $)\ p_h$ [GeV] ➜ p_h=6 GeV corresponds $l_{coh} = 4$ fm $\sim 1/\sigma_{NN}\rho_0$

need high energies to see large CT effect even if squeezing is effective at E~ few GeV

Experimental situation

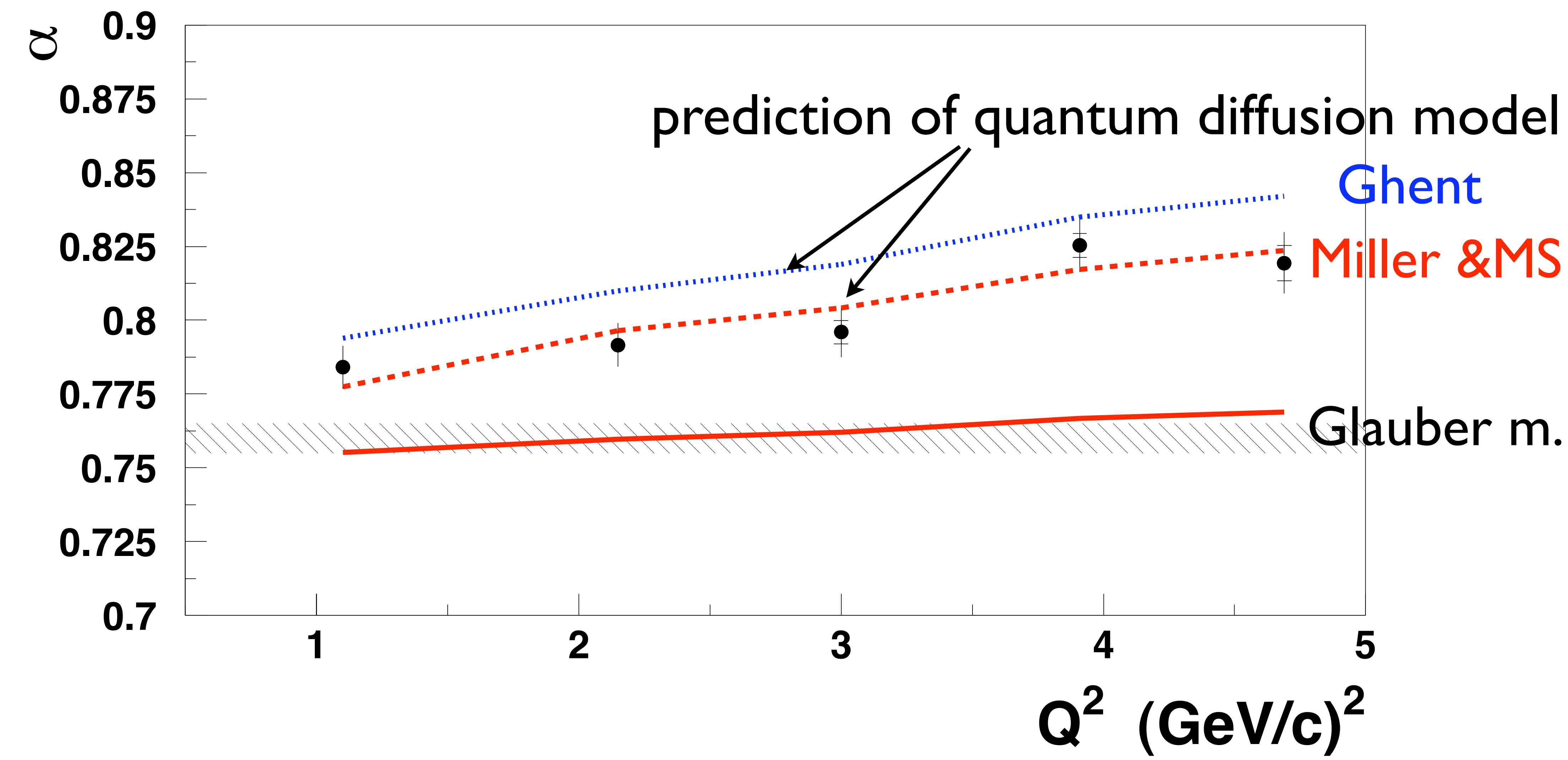
- Energy dependence of transparency in (p,2p) is observed for energies corresponding to $l_{coh} \geq$ 3 fm. Such dependence is impossible without freezing. But not clear whether effect is CT or something else? Needs independent study & new approaches.

- $\gamma^* + A \rightarrow \pi A^*$ evidence for increase of transparency with Q (Dutta et al 07)

Note that elementary reaction for Jlab kinematics is dominated by ERBL term so $\gamma^* N$ interaction is local. γ^* does not transform to $q\bar{q}$ distance $1/m_N x$ before nucleon

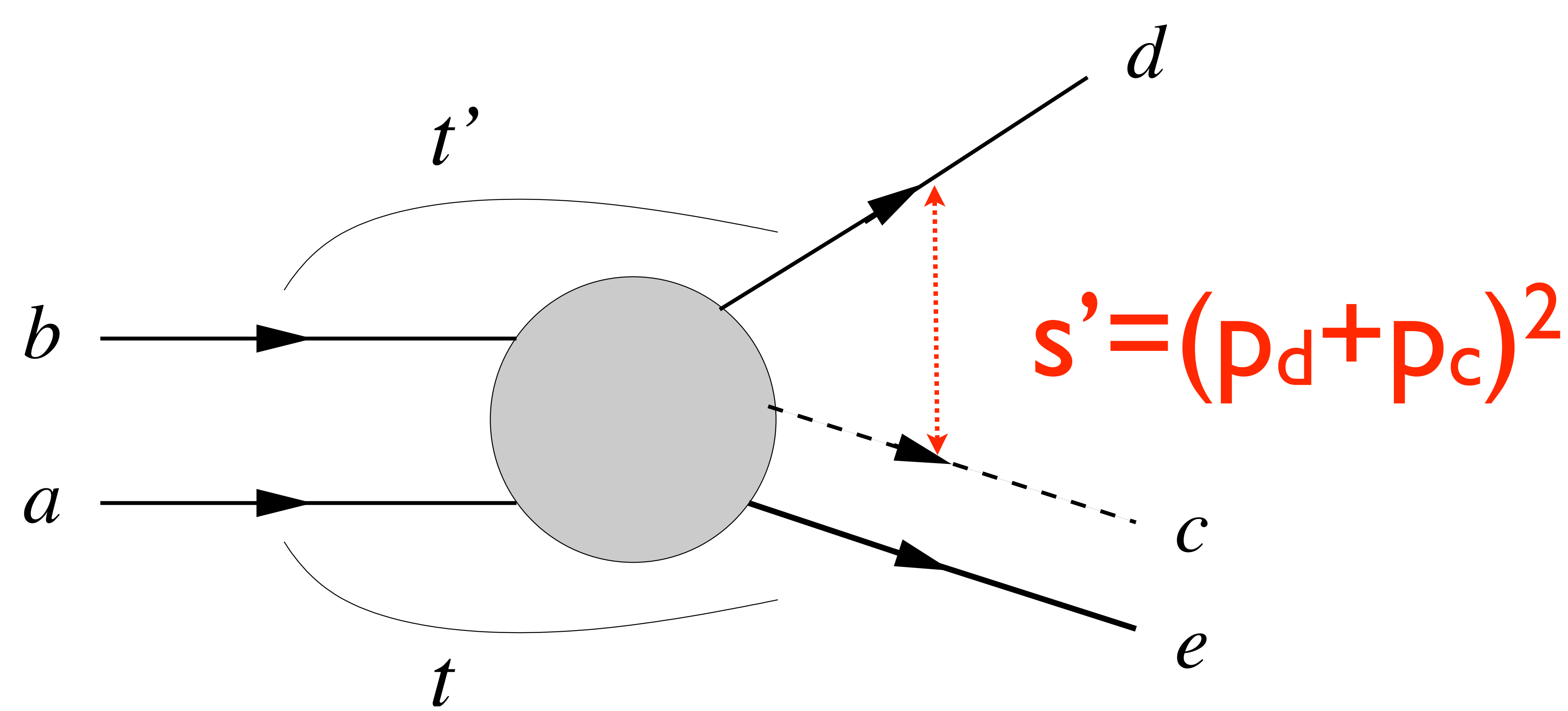
A- dependence checks not only squeezing but **small** l_{coh} as well

Also Jlab and HERMES ρ meson production data & FNAL J/ψ data indicate CT



Idea is to consider new type of hard hadronic processes - <u>*branching exclusive processes*</u> of large c.m. angle scattering on a "cluster" in a target/projectile (MS94)

to study both CT of 2 → 2 and hadron GPDs



Limit:

$-t' >$ few GeV^2, $-t'/s' \sim 1/2$

$-t = const \sim 0$

➠ $s'/s = y < 1$,

$t_{min} = [m_a^2 - m_b^2/(1-y)]y$

Two recent papers: Kumano, MS, and Sudoh PRD 09;
Kumano &MS arXiv:0909.1299, Phys.Lett. 2010

For hadron induced processes two kinematics - different detector strategies

"a" at rest - "d" and "c" in forward spectrometer, "e" in recoil detector
➠ can use neutron (^2H)/ transversely polarized target

"b" at rest - "d", "c" and "e" in forward spectrometer ➠ can use neutron target

For e p collider possible processes

$\gamma^* + p \rightarrow \underbrace{\pi^+ \pi^0}_{\text{current fragmentation}} n$

$\gamma^* + p \rightarrow \rho^0 \underbrace{\pi^+ n}_{\text{nucleon fragmentation}}$

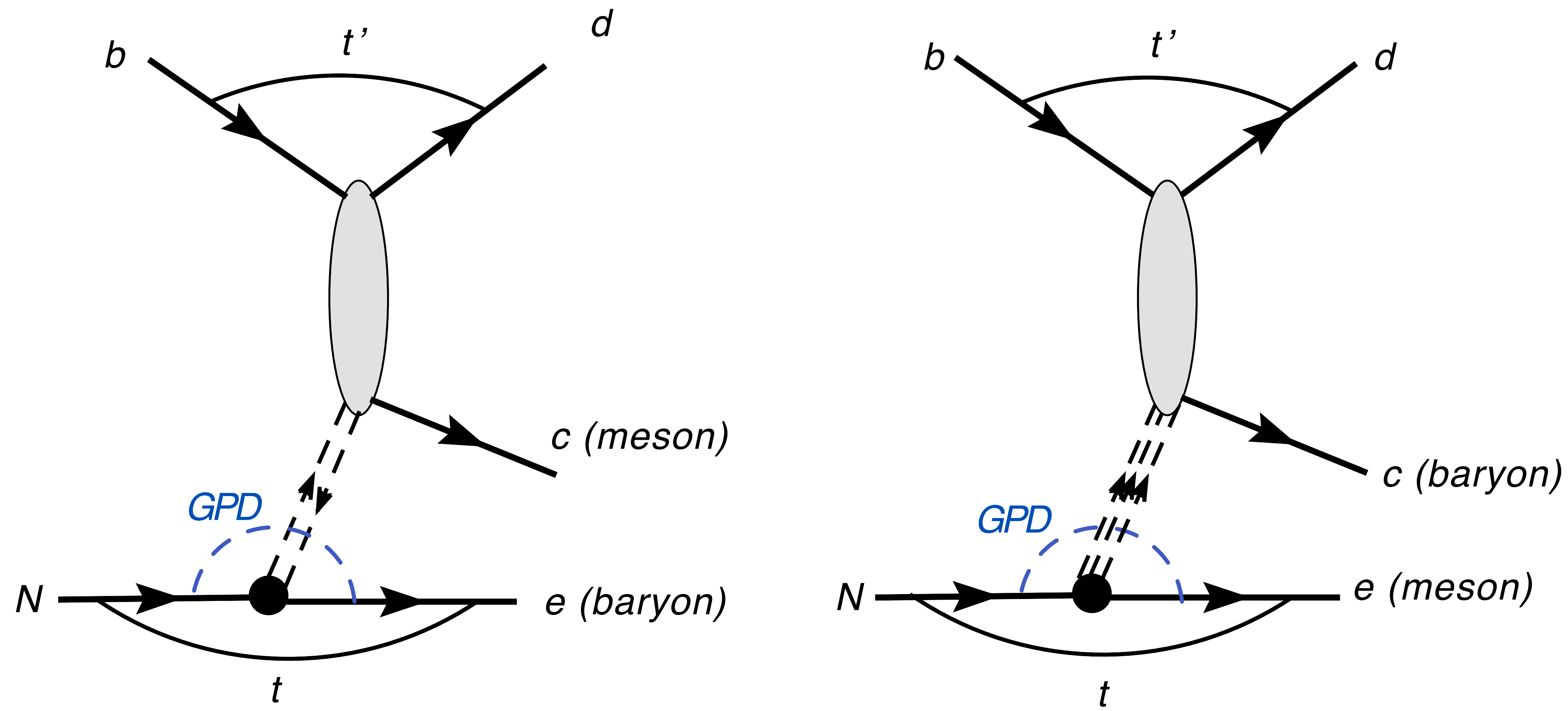
$2 \rightarrow 3$ branching processes:

- test onset of CT for $2 \rightarrow 2$ avoiding diffusion effects

For example at what s',t process $\gamma\pi \rightarrow \pi\pi$ is due to scattering in small configurations, when point -like component of photon starts to dominate.

- measure transverse sizes of b, d,c
- measure cross sections of large angle (γ)pion - pion (kaon) scattering
- probe 5q in nucleon and 4q in mesons
- measure GPDs of nucleons, photons, and mesons(!)
- measure pattern of freezing of space evolution of small size configurations

Factorization:



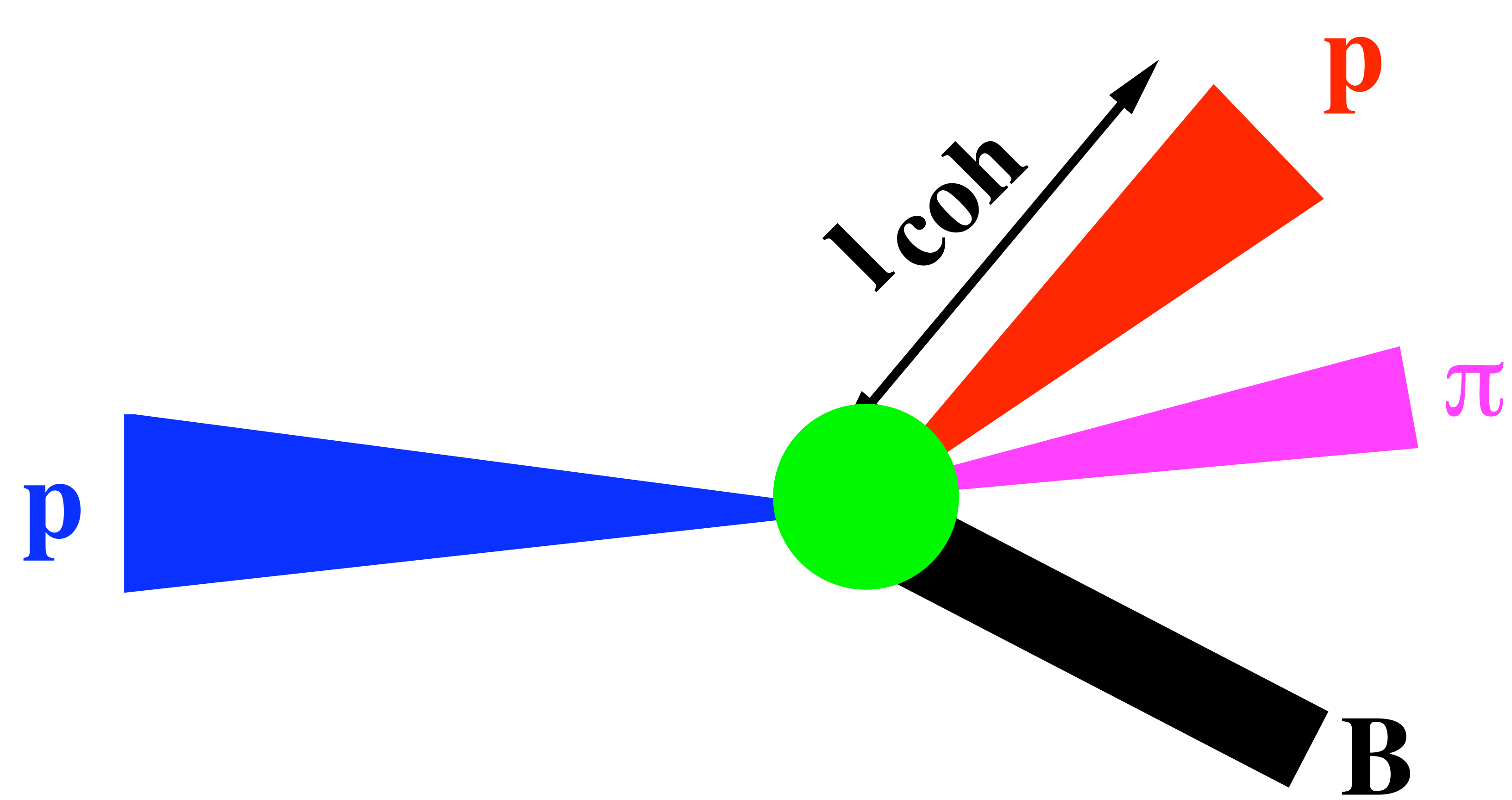
If the upper block is a hard (2 →2) process, "b","d","c" are in small size configurations as well as exchange system (qq, qqq). Can use CT argument as in the proof of QCD factorization of meson exclusive production in DIS (Collins, LF, MS 97)

⇓

$$\mathcal{M}_{NN\to N\pi B} = GPD(N \to B) \otimes \psi_b^i \otimes H \otimes \psi_d \otimes \psi_c$$

Minimal condition for factorization:

$$l_{coh} > r_N \sim 0.8 \text{ fm}$$



Time evolution of the 2 → 3 process

$$l_{coh} = (0.4 \div 0.6 \text{ fm}) \cdot p_h/(\text{GeV}/c)$$

easy to satisfy at EIC

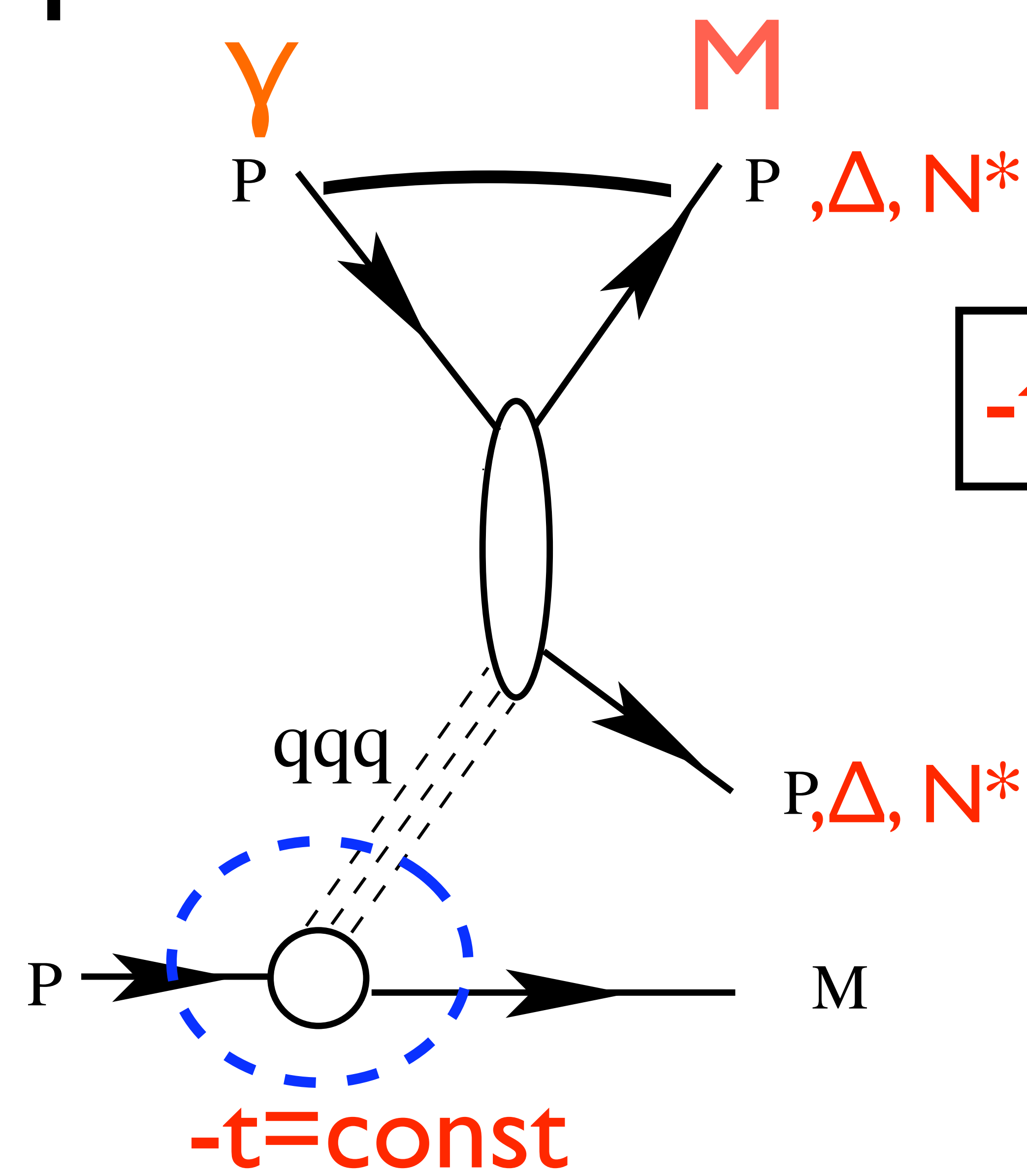
$$p_c \geq 3 \div 4 \text{ GeV}/c, \quad p_d \geq 3 \div 4 \text{ GeV}/c$$

$$p_b \geq 6 \div 8 \,\text{GeV}/\text{c}$$

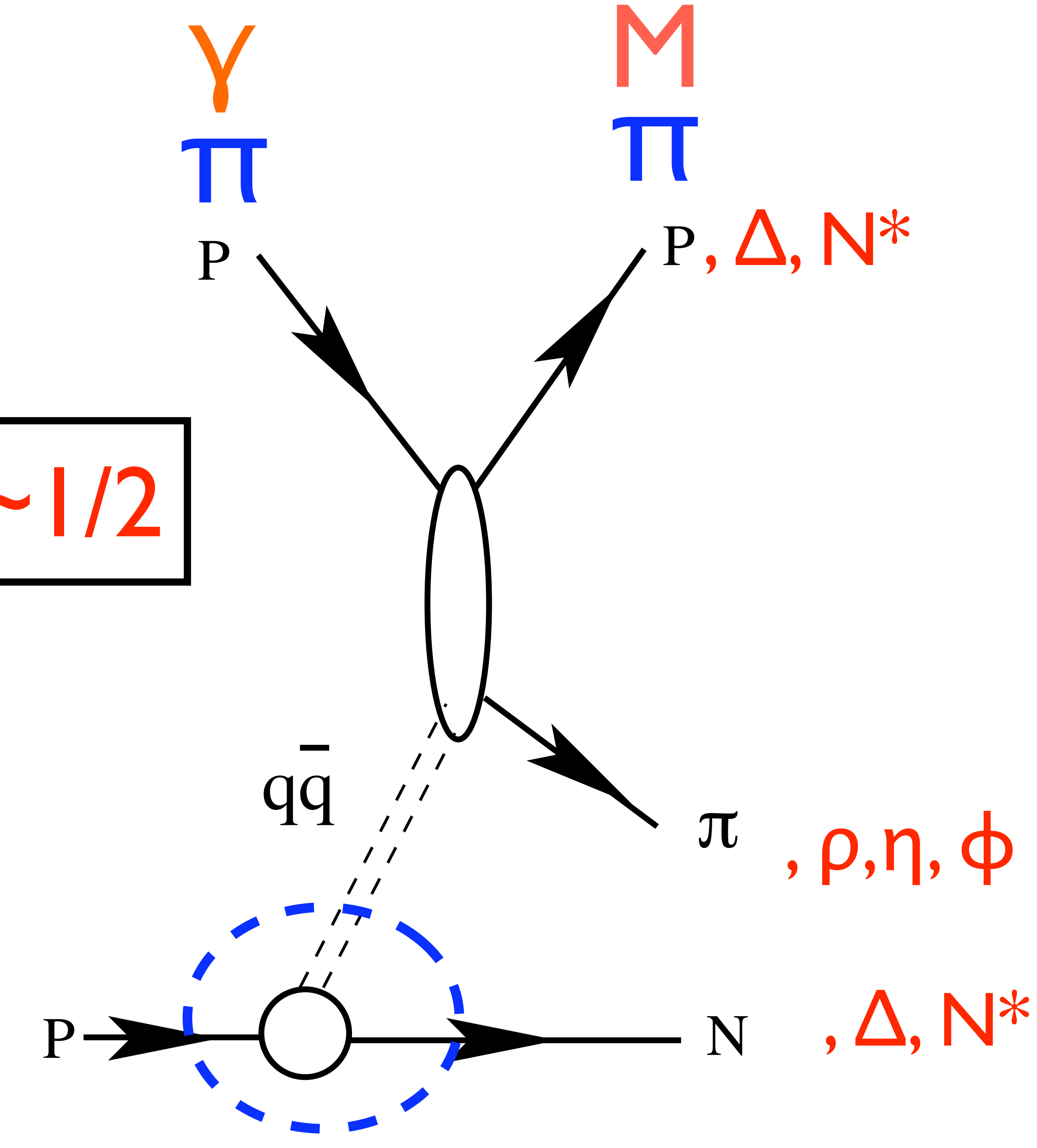
easier to reach than in CT reactions with nuclei

Examples

GPD (N→M)



-t/s'~1/2



GPD (N→B)

Λ,Σ

K,K*

$$pp \to pN + M(\pi, \eta, \pi\pi)$$

$$pp \to p\Delta + M(\pi, \eta, \pi\pi)$$

$$pp \to p\Lambda + K^+$$

$$\pi^- p \to p\pi + M$$

$$\pi^- p \to \pi^- \pi^- \Delta^{++},$$ COMPASS

$$\pi^- p \to \pi^- \pi^+ \Delta^0,$$

$$\pi^- p \to \pi^- \pi^0 p,$$

J-PARC if beams of pions with energies 20 -40 GeV are doable

$$\pi^- p \to \pi^- p + (\pi^0\pi^0 - forward\ low\ p_t)$$

Study of Hidden/Intrinsic Strangeness & Charm in hadrons

$\gamma p \rightarrow M + \Lambda_{sp}$ (any other strange baryon)+ $K^{+}(K^{*})$

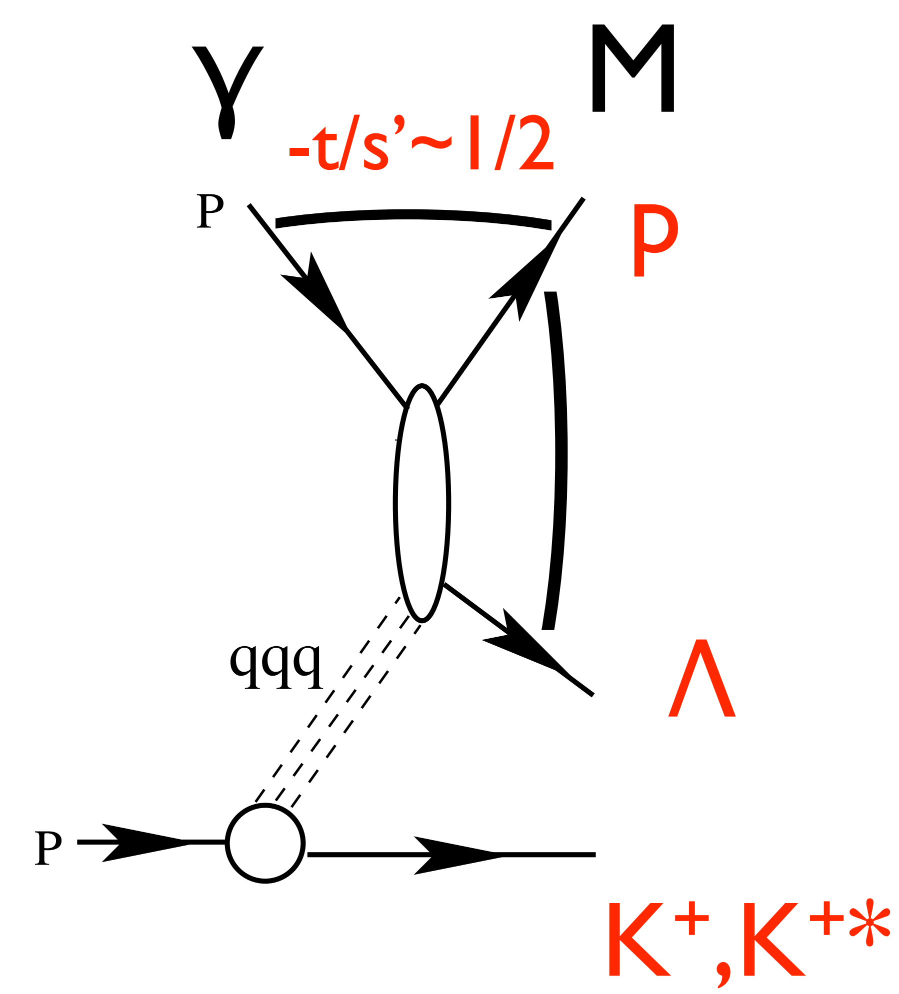
$pp \rightarrow K(K^{*})_{sp} + \Lambda + p$

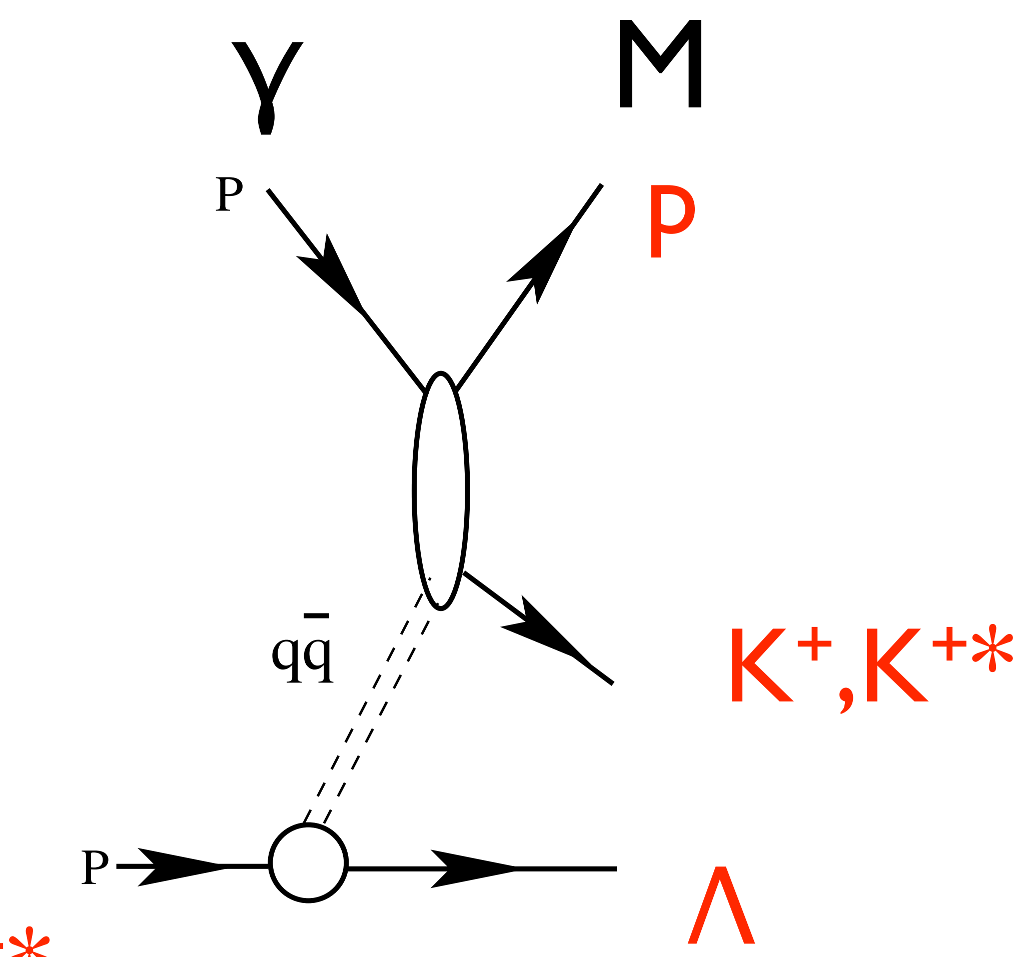
$pp \rightarrow \varphi_{sp} + p + p$

BNL experiment: EVA has few candidate events

$pp \rightarrow \bar{D}_{sp} + \Lambda_c + p$

$\gamma p \rightarrow M + \bar{D}_{sp} + \Lambda_c$

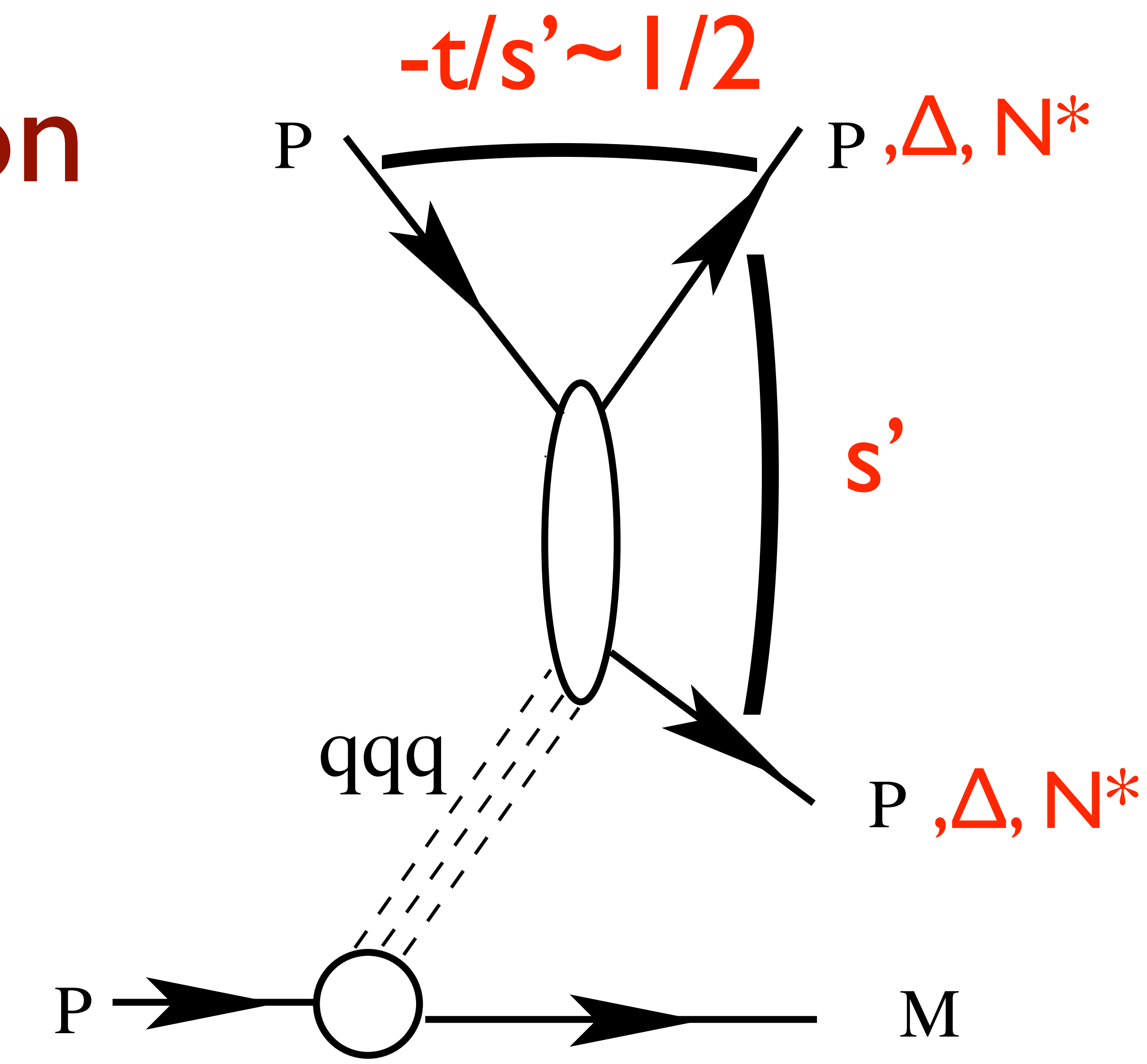




Study of the spin structure of the nucleon

use of polarized beams and/or targets

Can one gain from electron polarization?



$\vec{p}\vec{p} \to \Lambda_{sp}$ (any other strange baryon)+ $K^+(K^*)$ + p

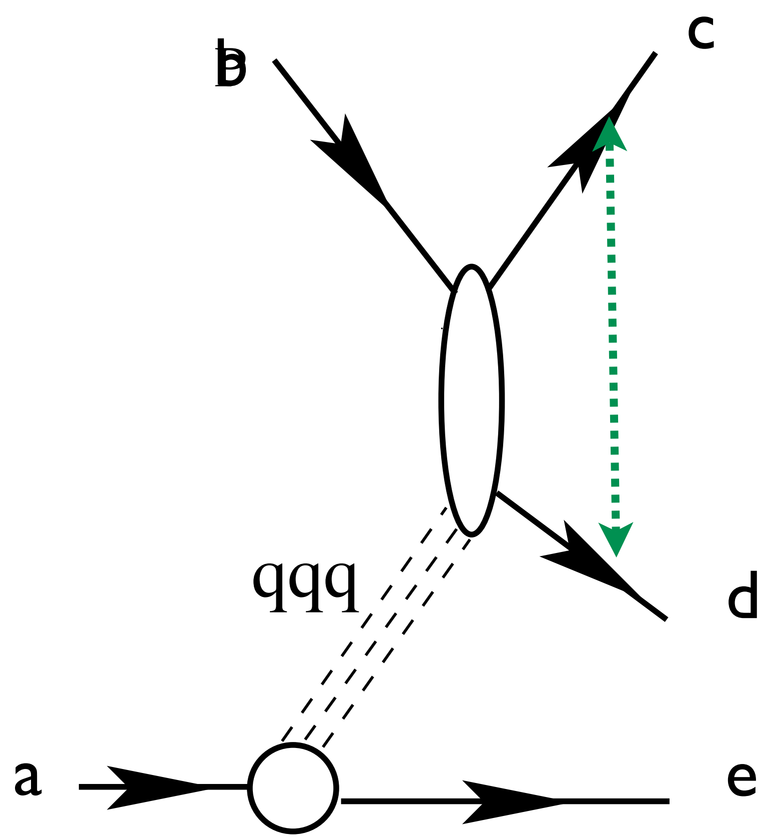
$\vec{p}\vec{p} \to K^+(K^*)_{sp} + \vec{\Lambda}$(any other strange baryon)+ p

$\vec{p}\vec{p} \to \Delta_{sp}$ (any other strange baryon)+ meson + p

study of the NΔ GPDs - more GPDs than for NN case - QCD chiral model - selection rules; single transverse spin asymmetries

Frankfurt, Pobilitsa, Polyakov, MS 98

Energy dependence of branching processes



$$s' = (p_c + p_d)^2 = (1 - \alpha_e)s_{ab}$$

$$\alpha_{spect} \equiv \alpha_e = p^e_- / p^a_-$$

$$\frac{d\sigma(a + b \to c + d + e)}{d\alpha_{sp} d^2 p_{t\ sp}/\alpha_{sp}} = \phi(\alpha_{sp}, p_{t\ sp}) R(\theta_{c.m.}) \left(s_o/s'\right)^n$$

$$n = n_q(a) + n_q(cluster) + n_q(c) + n_q(d) - 2.$$

e flies along A - slow if A is the target - fast if A is the projectile

Scaling relations between hadron and electron projectiles

$$\frac{\frac{d\sigma(p+p\to p+p+\pi^0)}{d\alpha_{\pi^0} d^2 p_t/\alpha_{\pi^0}}}{\frac{d\sigma(e+N\to e+N+\pi^0)}{d\alpha_{\pi^0} d^2 p_t/\alpha_{\pi^0}}} \approx \frac{\sigma(p + p \to p + p)}{\sigma(eN \to eN)},$$

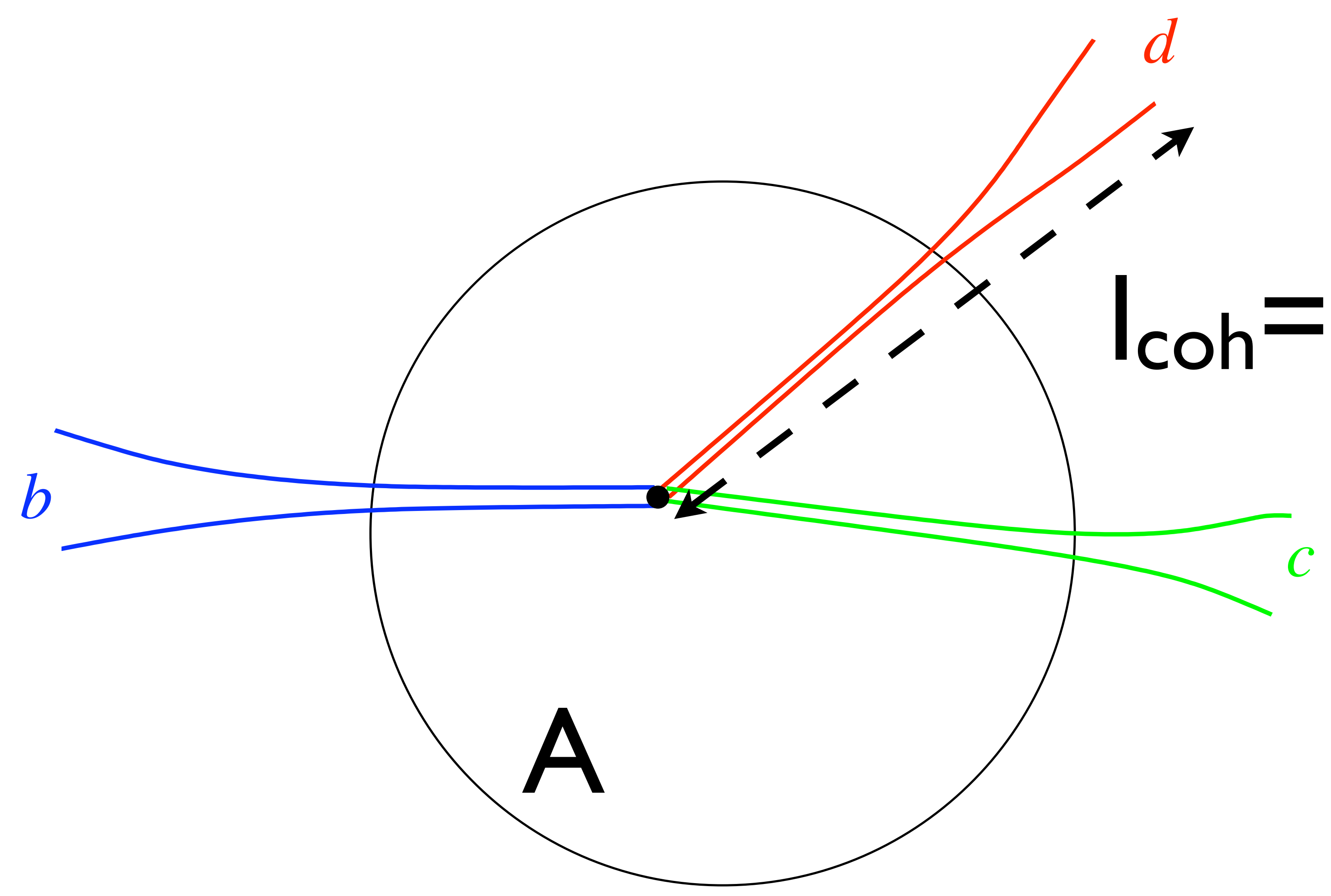
$$\frac{\frac{d\sigma^{pp\to p+\pi+B}}{d\alpha_B d^2 p_{tB} d\theta_{c.m.}(p\pi)}}{\frac{d\sigma^{p\pi\to p+\pi}}{d\theta_{c.m.}}(s_{p\pi})} = \frac{\frac{d\sigma^{\gamma^*_L+p\to\pi+B}(Q^2)}{d\alpha_B d^2 p_t}}{\sigma^{\gamma^*_L+\pi\to\pi}(Q^2)}$$

How to check that squeezing takes place and one can use GPD logic?

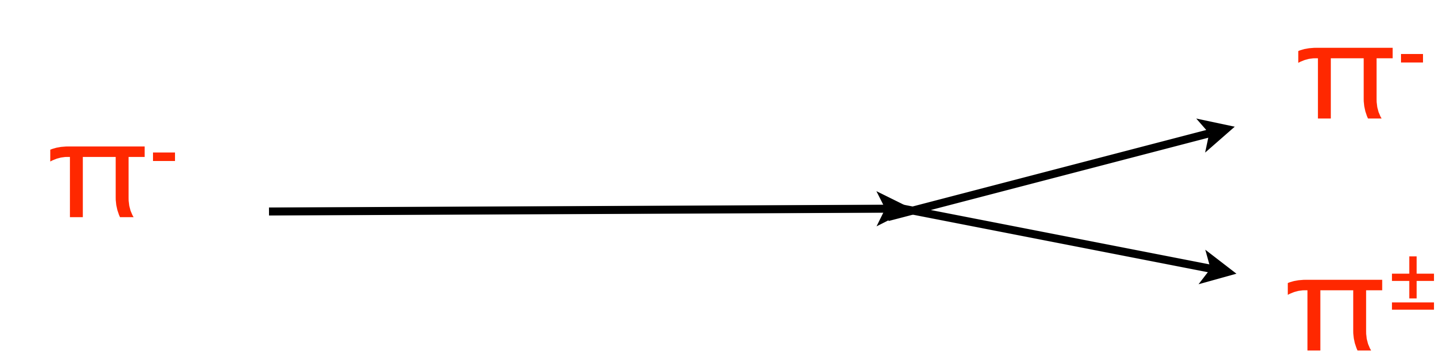
Use as example process $\pi^- A \to \pi^- \pi^\pm A^*$

- easier to squeeze
- COMPASS 190 GeV data on tape
- Early data from FNAL

$p_f(\pi) = p_i(\pi)/2$, vary $p_{ft}(\pi) = 1 - 2$ GeV/c; $p_{ft}(\pi^-) + p_{ft}(\pi^\pm) \sim 0$



l_{coh}=60 fm



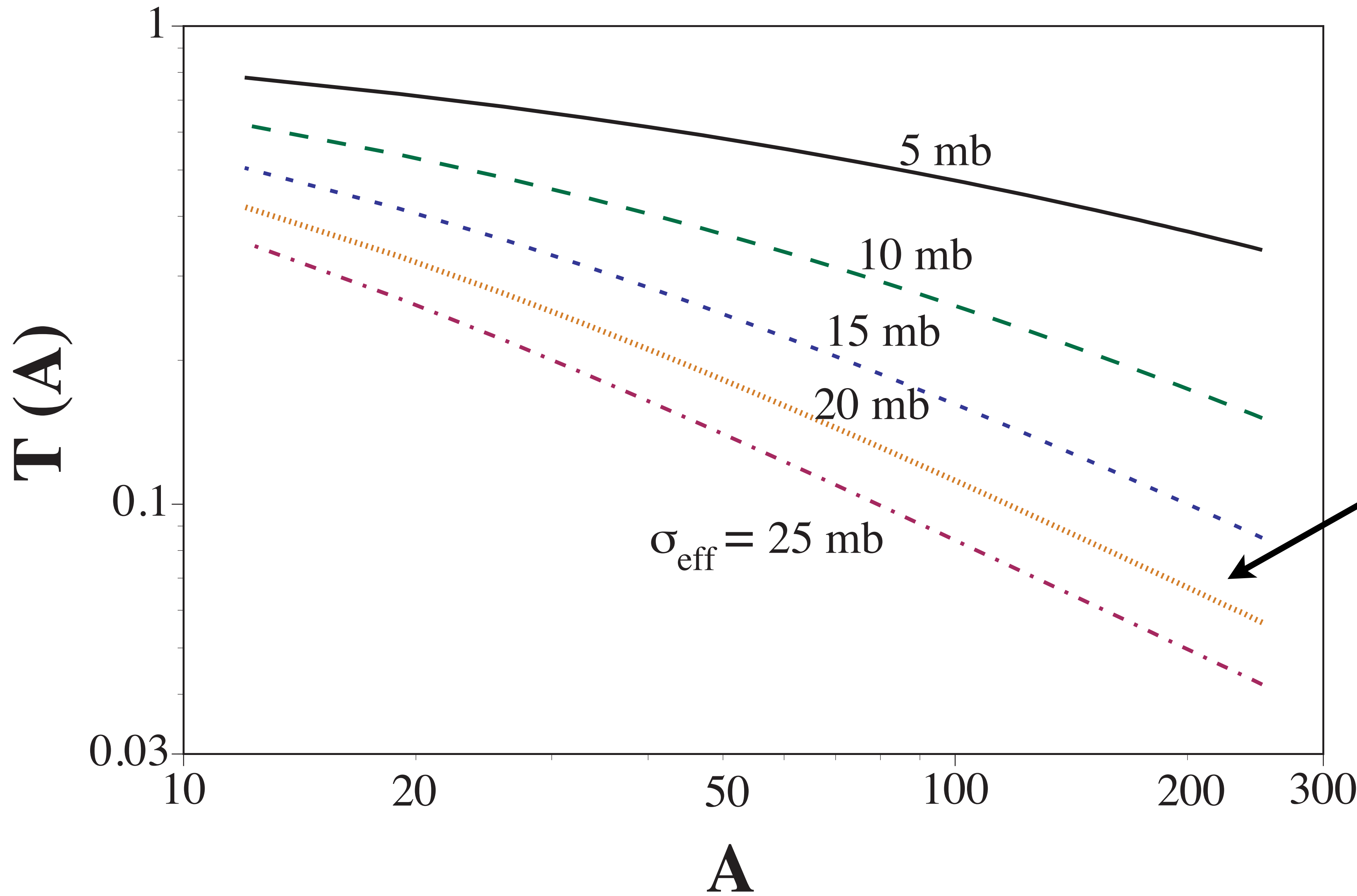
Branching (2→3) processes with nuclei - freezing is 100% effective for p_{inc} > 100 GeV/c - study of one effect only - size of fast hadrons

$$T_A = \frac{\frac{d\sigma(\pi^- A \to \pi^- \pi^+ A^*)}{d\Omega}}{Z \frac{d\sigma(\pi^- p \to \pi^- \pi^+ n)}{d\Omega}}$$

$$T_A(\vec{p}_b, \vec{p}_c, \vec{p}_d) = \frac{1}{A} \int d^3 r \rho_A(\vec{r}) P_b(\vec{p}_b, \vec{r}) P_c(\vec{p}_c, \vec{r}) P_d(\vec{p}_d,$$

where $\vec{p}_b, \vec{p}_c, \vec{p}_d$ are three momenta of the incoming and outgoing particles b, c, d; ρ_A is the nuclear density normalized to $\int \rho_A(\vec{r}) d^3 r = A$

$$P_j(\vec{p}_j, \vec{r}) = \exp\left(-\int_{\text{path}} dz\, \sigma_{\text{eff}}(\vec{p}_j, z) \rho_A(z)\right)$$



Large effect even if the pion radius is changed just by 20%

If there are two scales in pion (Gribov) - steps in $T(k_t^\pi)$ as a function of k_t^π

If squeezing is large enough can measure quark- antiquark size using dipole - nucleon cross sectio

If squeezing is large enough can measure quark- antiquark size using dipole - nucleon cross section which I discussed before

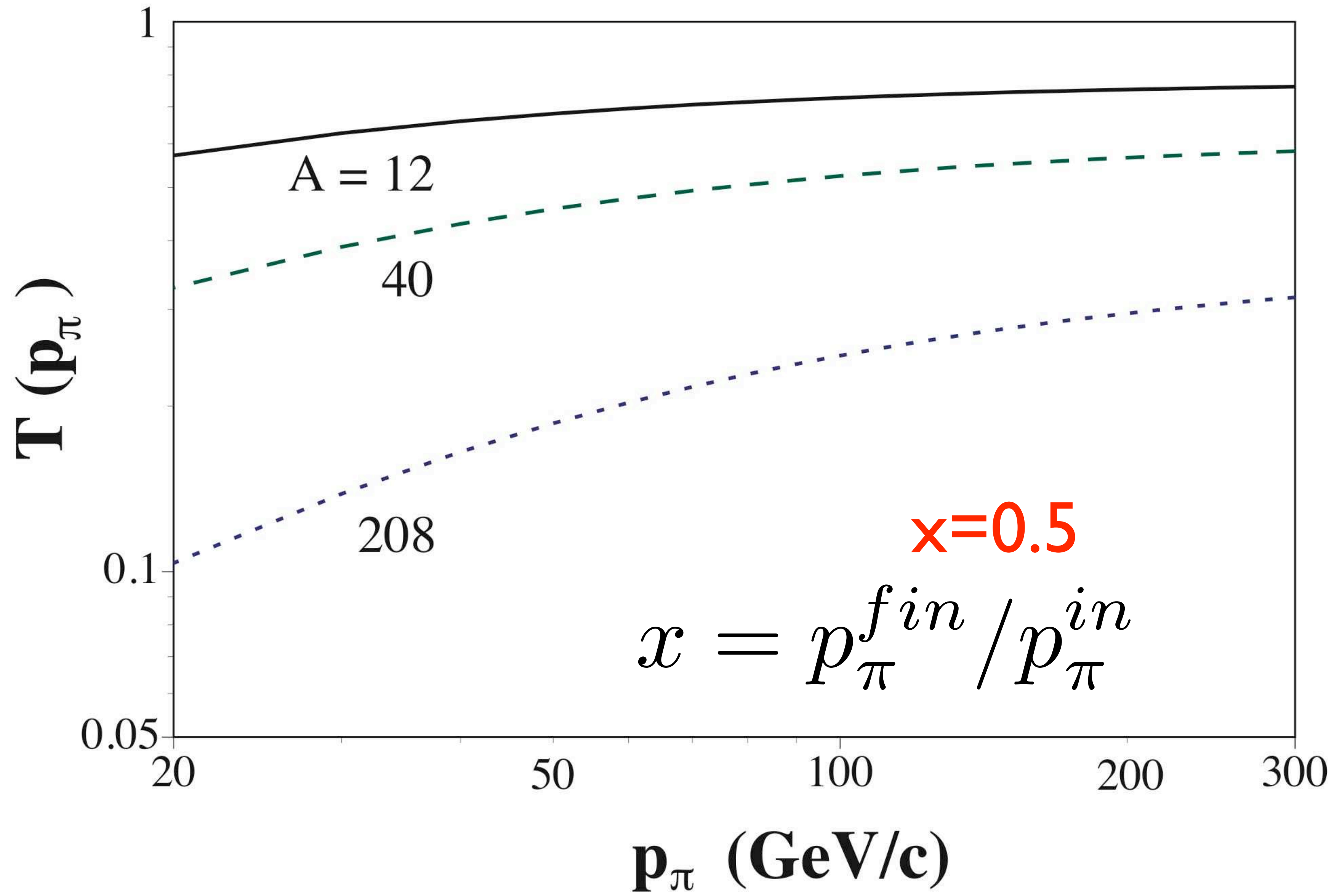
$$\sigma(d,x) = \frac{\pi^2}{3}\alpha_s(Q^2_{eff})d^2\left[xG_N(x,Q^2_{eff}) + \frac{2}{3}xS_N(x,Q^2_{eff})\right]$$

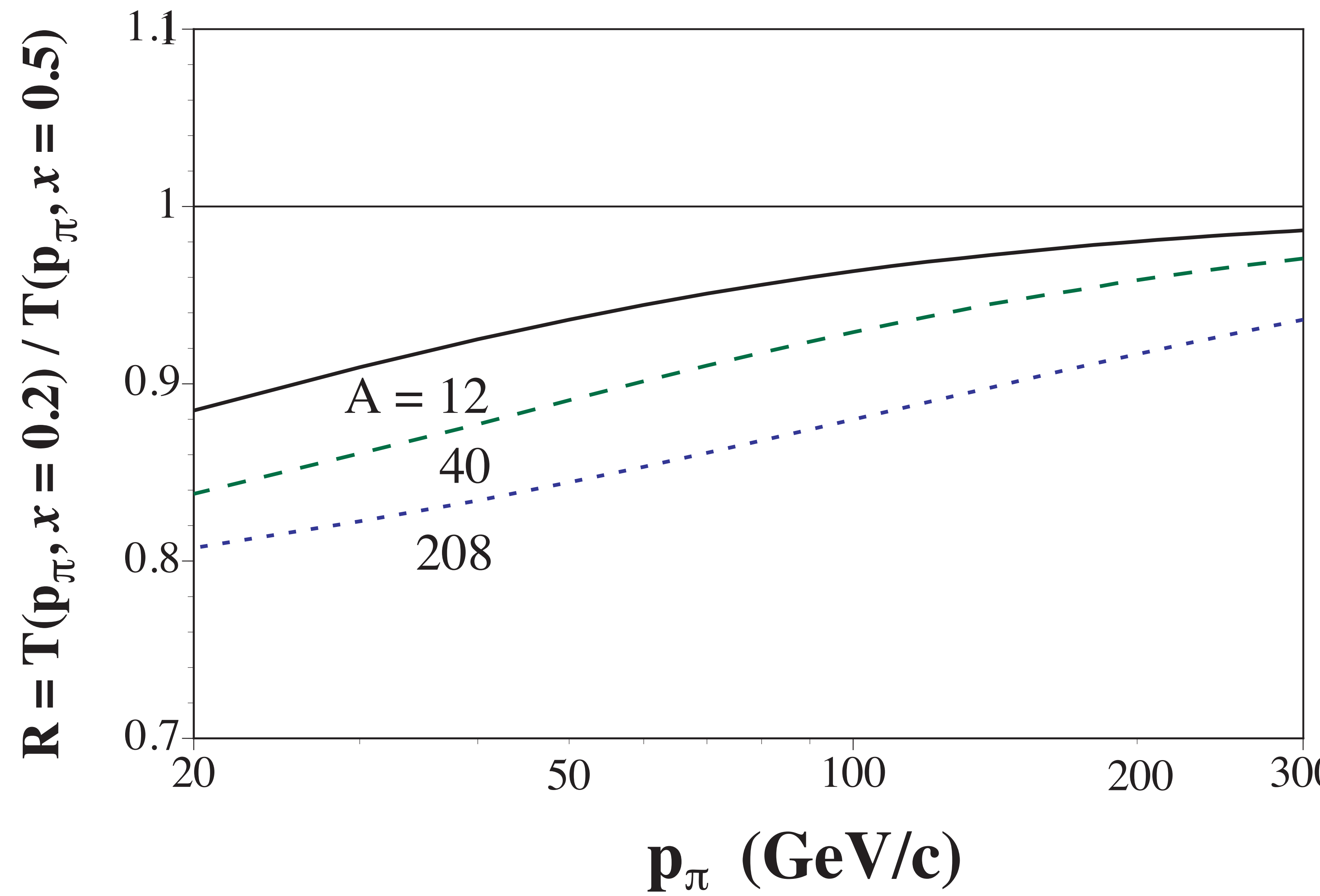
Defrosting point like configurations - energy dependence for fixed s',t'

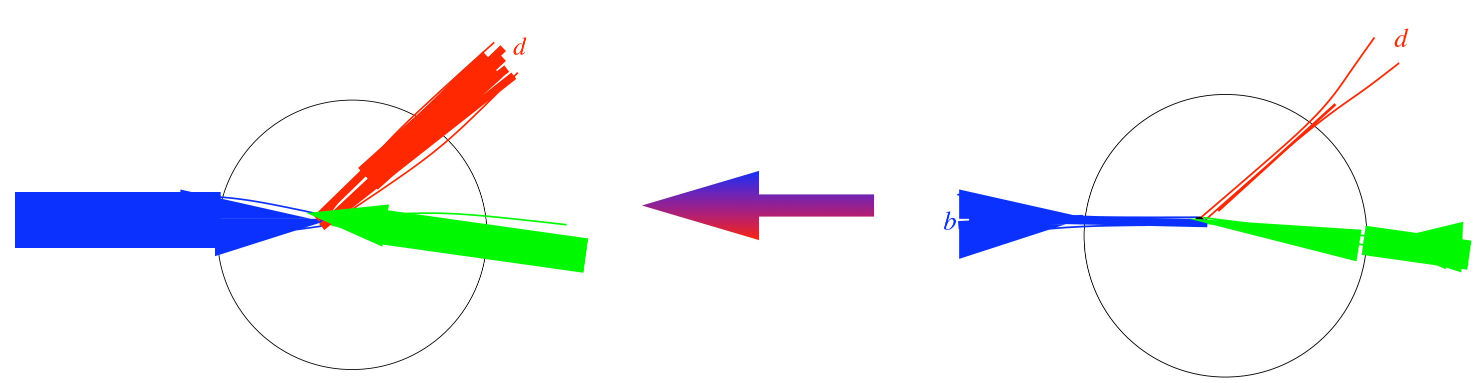
$$\sigma^{PLC}(z) = \left(\sigma_{hard} + \frac{z}{l_{coh}}\left[\sigma - \sigma_{hard}\right]\right)\theta(l_{coh} - z) + \sigma\theta(z - l_{coh})$$

Quantum Diffusion model of expansion

Use $l_{coh} \sim 0.6$ fm E_h[GeV]   which describes well CT for pion electroproduction



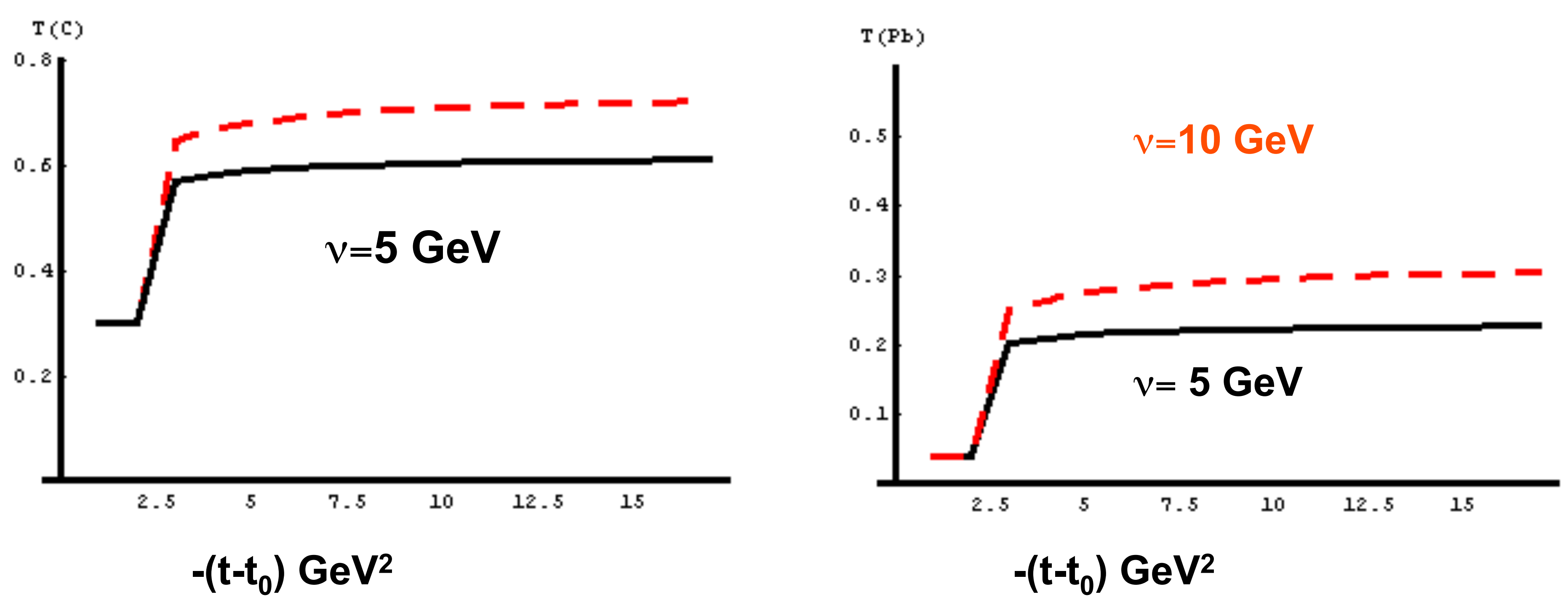




For photons in reaction $\gamma^* + A \rightarrow \pi^+\pi^0 + A^*$ one can scan as a function of Q^2 and p_t's of pions; other reactions $\gamma^* + A \rightarrow K^+\pi^0 + A^*$,...

Transition from VDM component of photon to point like - analogous to issues in $\gamma^* + A \rightarrow \pi^- p + (A-1)^*$

$\gamma N \rightarrow \pi N$ Transparency vs. A, ν



From G. Miller talk at Hall D workshop

Comment - the discussed reactions are optimal for studies GPDs corresponding to nonvacuum quantum numbers in t -channel at small x.

Interesting question is α'_R

Is it the same as for soft processes ~ 1 GeV^{-2} ?

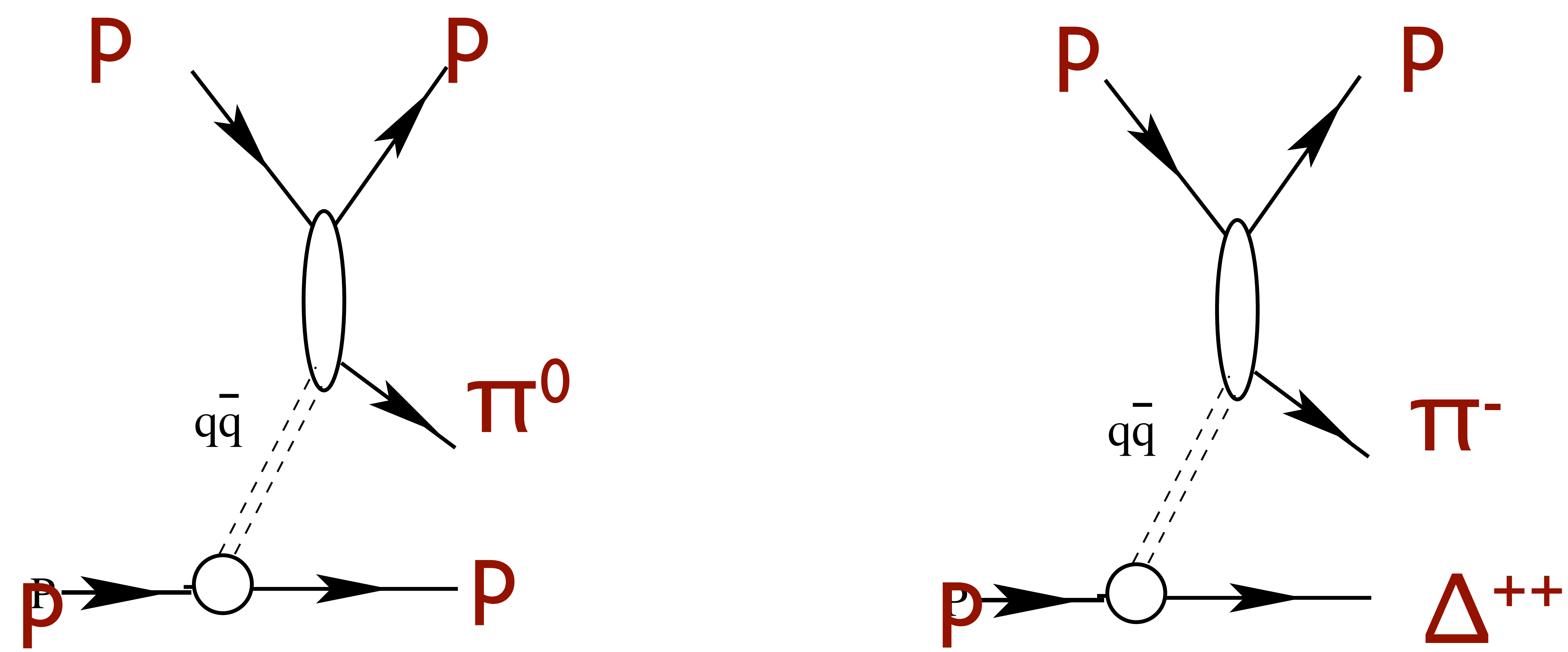
My guesses: $\alpha'_R(\text{pert}) << \alpha'_R(\text{nonperturb})$

$\alpha_R(\text{pert})$ (- t > 1 GeV^2) ~ -0.2

Presence of many channels allows to perform many cross checks

A detailed theoretical study of the reactions pp→NNπ, NΔπ was recently completed. Factorization based on squeezing

Kumano, Strikman, and Sudoh 09



Strategy of the first numerical analysis:

- account for contributions of GPDs corresponding to $q\bar{q}$ pairs with S=1 and 0

- Approximate the ERBL configurations by the pion and ρ-meson poles

- Use experimental information about

  $\pi^- p \to \pi^- p$, $\pi^- p \to \rho^- p$

  $\pi^+ p \to \pi^+ p$, $\pi^+ p \to \rho^+ p$

$$d\sigma = \frac{S}{4\sqrt{(p_a \cdot p_b)^2 - m_N^4}} \overline{\sum}_{\lambda_a,\lambda_b} \sum_{\lambda_d,\lambda_e} |\mathcal{M}_{NNN\pi B}|^2$$

$$\times \frac{1}{2E_c}\frac{d^3p_c}{(2\pi)^3}\frac{1}{2E_d}\frac{d^3p_d}{(2\pi)^3}\frac{1}{2E_e}\frac{d^3p_e}{(2\pi)^3}(2\pi)^4\delta^4(p_a + p_b - p_c - p_d - p_e)$$

$$\frac{d\sigma}{d\alpha d^2p_{BT}d\theta_{cm}} = f(\alpha, p_{BT})\phi(s', \theta_{cm})$$

$$\alpha \equiv \alpha_{spec} = (1-\xi)/(1+\xi)$$

$$s' = (1-\alpha)s$$

$$\phi(s', \theta_{cm}) \approx (s')^n \gamma(\theta_{cm})$$

$$\mathcal{M}_N^V = \int \frac{d\lambda}{2\pi} e^{i\lambda x} \left\langle N, p_e \left| \overline{\psi}(-\lambda n/2) \not{n} \psi(\lambda n/2) \right| N, p_a \right\rangle$$
$$= I_N \, \overline{\psi}_N(p_e) \big[H(x,\xi,t) \not{n} + E(x,\xi,t) \frac{i\sigma^{\alpha\beta} n_\alpha \Delta_\beta}{2m_N} \big] \psi_N(p_a)$$

$$I_N =< 1/2 || \widetilde{T} || 1/2 > \left\langle \tfrac{1}{2} M_N : 1m \middle| \tfrac{1}{2} M_N' \right\rangle / \sqrt{2}$$

$$\mathcal{M}_N^A = \int \frac{d\lambda}{2\pi} e^{i\lambda x} \left\langle N, p_e \left| \overline{\psi}(-\lambda n/2) \not{n} \gamma_5 \psi(\lambda n/2) \right| N, p_a \right\rangle$$
$$= I_N \, \overline{\psi}_N(p_e) \big[\widetilde{H}(x,\xi,t) \not{n} \gamma_5 + \widetilde{E}(x,\xi,t) \frac{n \cdot \Delta \gamma_5}{2m_N} \big] \psi_N(p_a)$$

N →Δ transitions

$$\mathcal{M}^V_{N\to\Delta} = \int \frac{d\lambda}{2\pi} e^{i\lambda x} \left\langle \Delta, p_e \left| \overline{\psi}(-\lambda n/2) \not{n} \psi(\lambda n/2) \right| N, p_a \right\rangle$$

$$= I_{\Delta N} \overline{\psi}^{\mu}_{\Delta}(p_e) \big[H_M(x,\xi,t) \mathcal{K}^M_{\mu\nu} n^\nu + H_E(x,\xi,t) \mathcal{K}^E_{\mu\nu} n^\nu$$

$$+ H_C(x,\xi,t) \mathcal{K}^C_{\mu\nu} n^\nu \big] \psi_N(p_a),$$

$$\mathcal{K}^M_{\mu\nu} = -i \frac{3(m_\Delta + m_N)}{2m_N[(m_\Delta + m_N)^2 - t]} \varepsilon_{\mu\nu\lambda\sigma} P^\lambda \Delta^\sigma,$$

$$\mathcal{K}^E_{\mu\nu} = -\mathcal{K}^M_{\mu\nu} - \frac{6(m_\Delta + m_N)}{m_N Z(t)} \varepsilon_{\mu\sigma\lambda\rho} P^\lambda \Delta^\rho \varepsilon^\sigma_{\nu\kappa\delta} P^\kappa \Delta^\delta \gamma^5,$$

$$\mathcal{K}^C_{\mu\nu} = -i \frac{3(m_\Delta + m_N)}{m_N Z(t)} \Delta_\mu (t P_\nu - \Delta \cdot P \Delta_\nu) \gamma^5,$$

where m_Δ is the Δ mass, and $Z(t)$ is defined by

$$Z(t) = [(m_\Delta + m_N)^2 - t][(m_\Delta - m_N)^2 - t].$$

$$
\begin{aligned}
\mathcal{M}^{A}_{N\to\Delta} &= \int \frac{d\lambda}{2\pi} e^{i\lambda x} \left\langle \Delta, p_e \left| \overline{\psi}(-\lambda n/2) \not{n} \gamma^5 \psi(\lambda n/2) \right| N, p_a \right\rangle \\
&= I_{\Delta N}\, \overline{\psi}^{\mu}_{\Delta}(p_e) \Big[\widetilde{H}_1(x,\xi,t) n_\mu + \widetilde{H}_2(x,\xi,t) \frac{\Delta_\mu (n\cdot\Delta)}{m_N^2} \\
&\quad + \widetilde{H}_3(x,\xi,t) \frac{n_\mu \not{\Delta} - \Delta_\mu \not{n}}{m_N} \\
&\quad + \widetilde{H}_4(x,\xi,t) \frac{P\cdot\Delta n_\mu - 2\Delta_\mu}{m_N^2} \Big] \psi_N(p_a)
\end{aligned}
$$

$$
\begin{aligned}
\phi_\pi(z) &= \sqrt{3} f_\pi z(1-z), \\
\phi_\rho(z) &= \sqrt{6} f_\rho z(1-z).
\end{aligned}
$$

$$\frac{d\sigma_{NN\to N\pi B}}{dt\,dt'} = \int_{y_{min}}^{y_{max}} dy \;\frac{s}{16\,(2\pi)^2\, m_N\, p_N}$$

$$\times \sqrt{\frac{(ys-t-m_N^2)^2-4m_N^2 t}{(s-2m_N^2)^2-4m_N^4}}\;\frac{d\sigma_{MN\pi N}(s'=ys,t')}{dt'}$$

$$\times \sum_{\lambda_a,\,\lambda_e} \frac{1}{[\phi_M(z)]^2}\left|\mathcal{M}_{N\to B}\right|^2$$

$$y \equiv \frac{s'}{s} = \frac{t + m_N^2 + 2(m_N E_N - E_B E_N + p_B p_N \cos\theta_e)}{s}$$

$$y_{min} = \frac{Q_0^2 + 2m_N^2 - t'}{s}, \quad -t' \geq Q_0^2$$

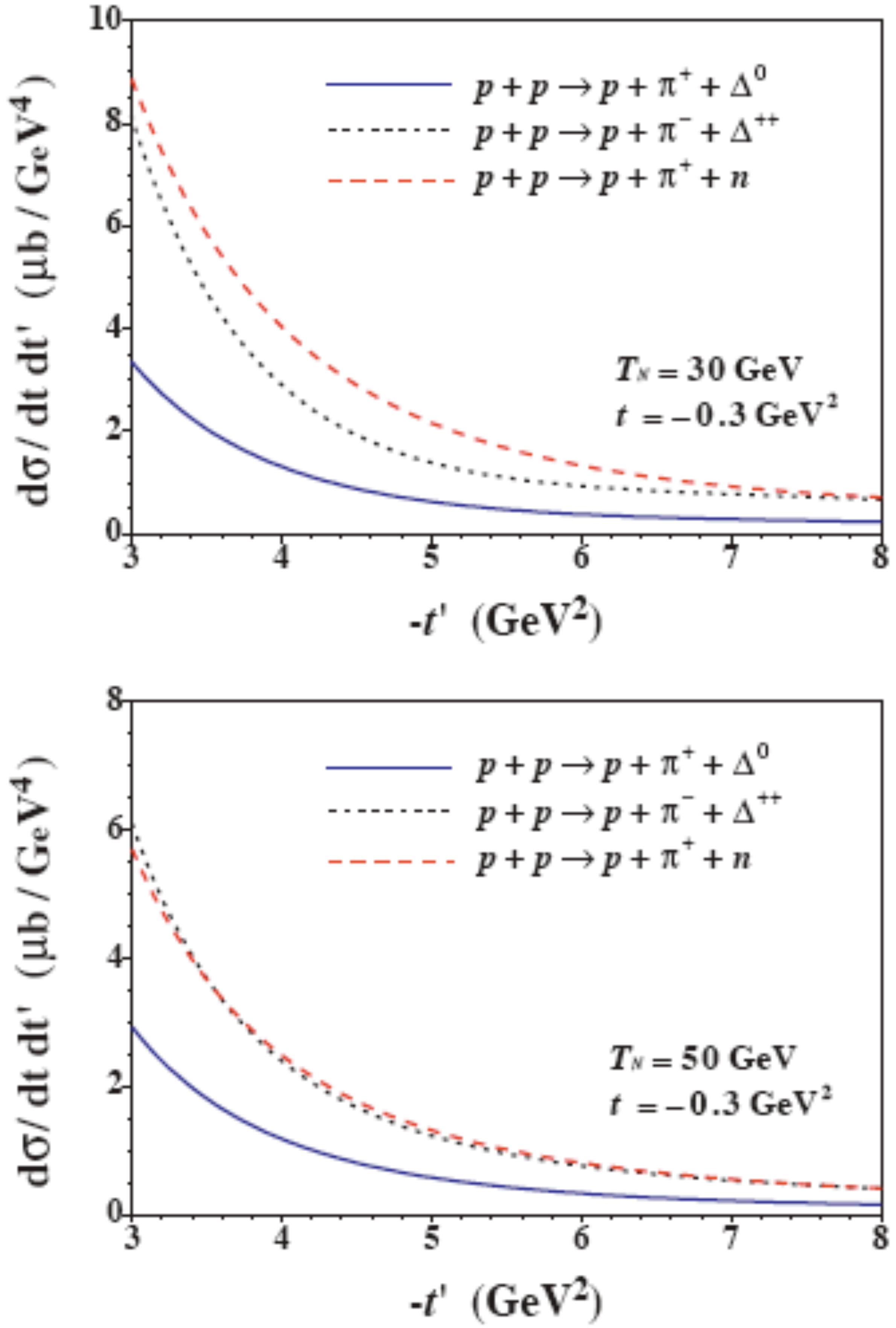


FIG. 11: Differential cross section as a function of t'. The incident proton-beam energy is 30 (50) GeV in the upper (lower) figure, and the momentum transfer is $t = -0.3$ GeV^2. The solid, dotted, and dashed curves indicate the cross sections for $p + p \to p + \pi^+ + \Delta^0$, $p + p \to p + \pi^- + \Delta^{++}$, and $p + p \to p + \pi^+ + n$, respectively.

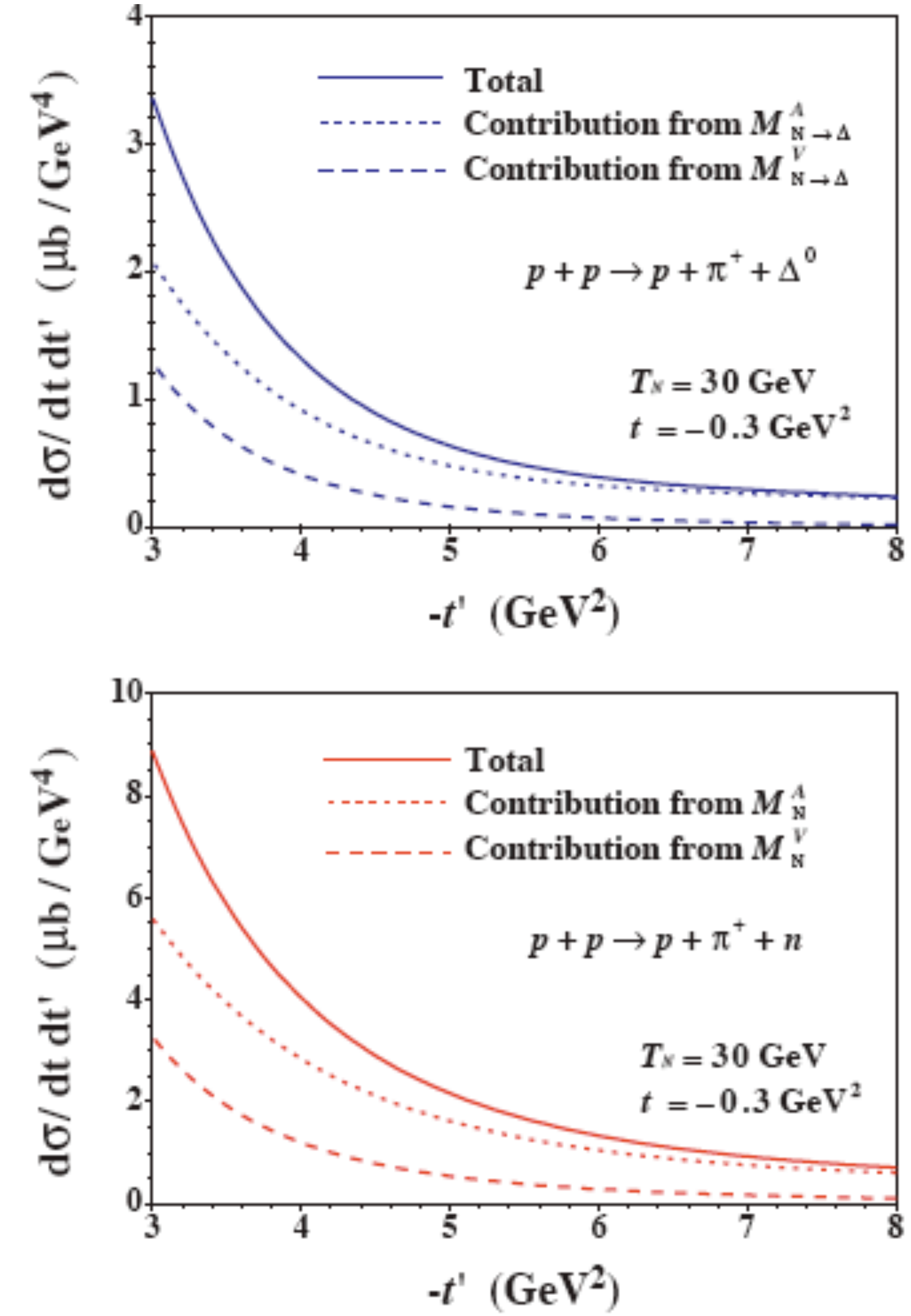


FIG. 12: Differential cross section as a function of t'. The incident proton-beam energy is 30 GeV, and the momentum transfer is $t = -0.3$ GeV^2. The upper (lower) figure indicates the cross section for the process $p+p \to p+\pi^+ +\Delta^0$ ($p+p \to p + \pi^+ + n$). The solid, dotted, and dashed curves indicate the cross sections for the total, axial-vector (π) contribution, vector (ρ) contribution, respectively.

Same cross section for antiproton projectiles!

Large enough cross sections to be measured with modern detectors

Strong dependence of σ on proton transverse polarization (similar to DIS case of pion production Frankfurt, Pobilitsa, Polyakov, MS)

Discussed processes will allow

- to discover that pattern of interplay of hard and soft physics in one of the most fundamental hadronic processes of large angle scattering

- compare wave function of different mesons and baryons

- map the space-time evolution of small wave packets at distances $1 < z < 6$ fm

- test the role of chiral degrees of freedom in hard interactions

Program which can be performed at COMPASS and also J-PARC (complementary - different beams, higher energies, etc).

EIC can follow up this program at higher energies and address issues of both the hadron and photon structure.