# On a way to GPDs (at large skewness)

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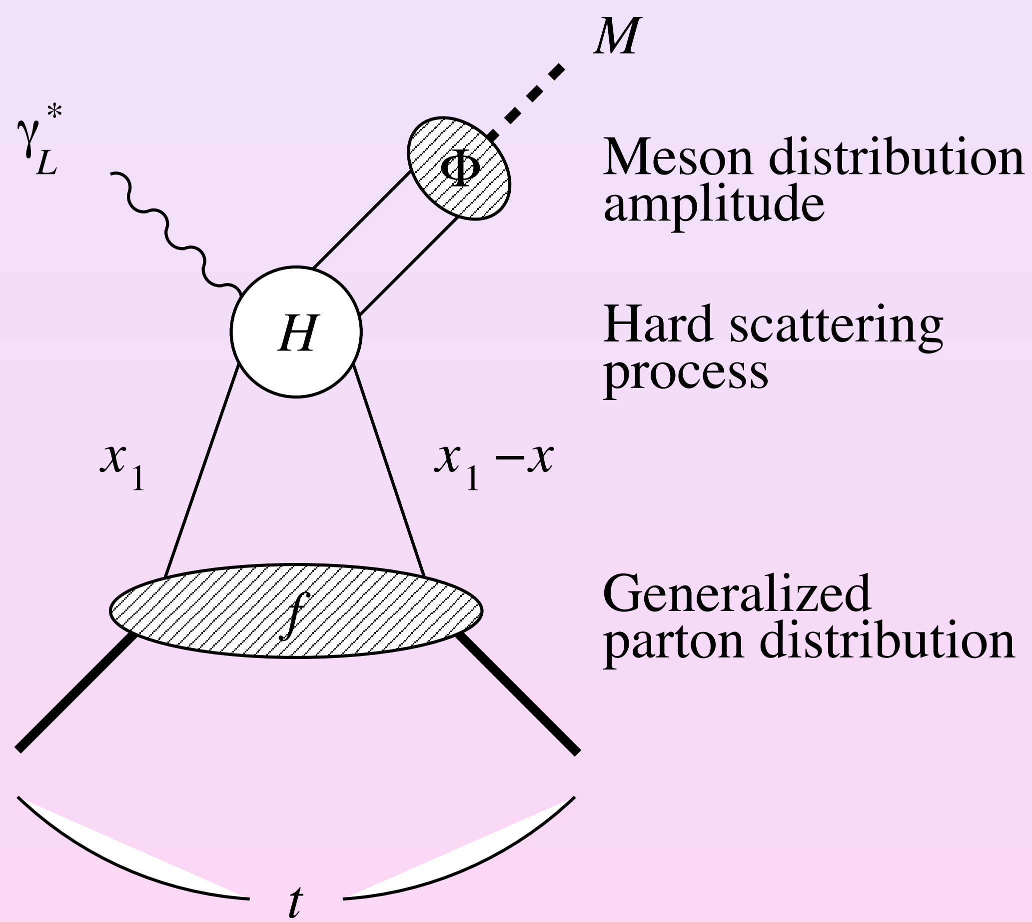
# Outline

- Introduction: factorization in eN→e+Meson + Baryon and eN→e+Baryon + Meson
- Pre-asymptotic(white cluster) regime in Factorization in eN→eBM
- Hadron induced hard semiexclusive (branching) processes
- Quark exchanges in pQCD via two body processes

## Before looking backward - lessons from looking forward

QCD factorization theorem for DIS exclusive meson production processes (Brodsky,Frankfurt, Gunion,Mueller, MS 94 - vector mesons, small x; general case Collins, Frankfurt, MS 97)




The proof of the factorization for the meson exclusive production (Collins, Frankfurt and MS) is essentially based on the observation that the cancellation of the soft gluon interactions is intimately related to the fact that the meson arises from a small size quark-antiquark pair generated by the hard scattering. Thus the pair starts as a small-size configuration and only substantially grows to a normal hadronic size, to a meson.

## Factorization requirement best seen in the Breit frame

### Before the interaction:

N

$\Longrightarrow$(P,P)

$\gamma^*_L$

• $q_\mu = (0, q_3)$

**squeezed qq pair**

### After photon absorption:

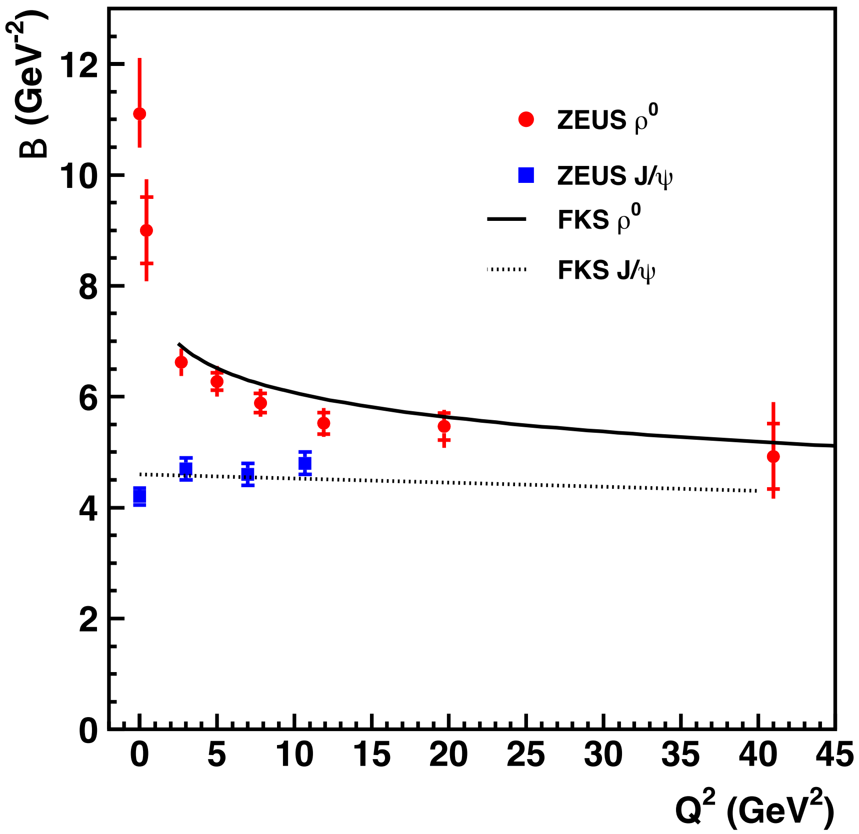
for $m^2_{meson\ \ syst.} = const, m^2_{baryon\ \ syst.} = const, Q^2, W^2 \rightarrow \infty.$

| Meson system | Baryon system |
| --- | --- |
| $\Leftarrow$ **Fast left movers** | **Fast right movers** |

**No soft interactions between left and right movers is possible provided left moving system (meson or baryon) was produced by γ* in a small transverse size configuration**

**Reaching color transparency regime is necessary (but not sufficient) condition for onset of leading twist factorization regime in which cross section can be expressed through GPDs, and the minimal Fock space hadron wave functions.**

# Lessons from study of the meson production




**The convergence of the t-slopes, B, of ρ and J/ψ electroproduction at high $Q^2$.**
**The data are from HERA; the curves are the predictions of Frankfurt, Koepf, MS 97**

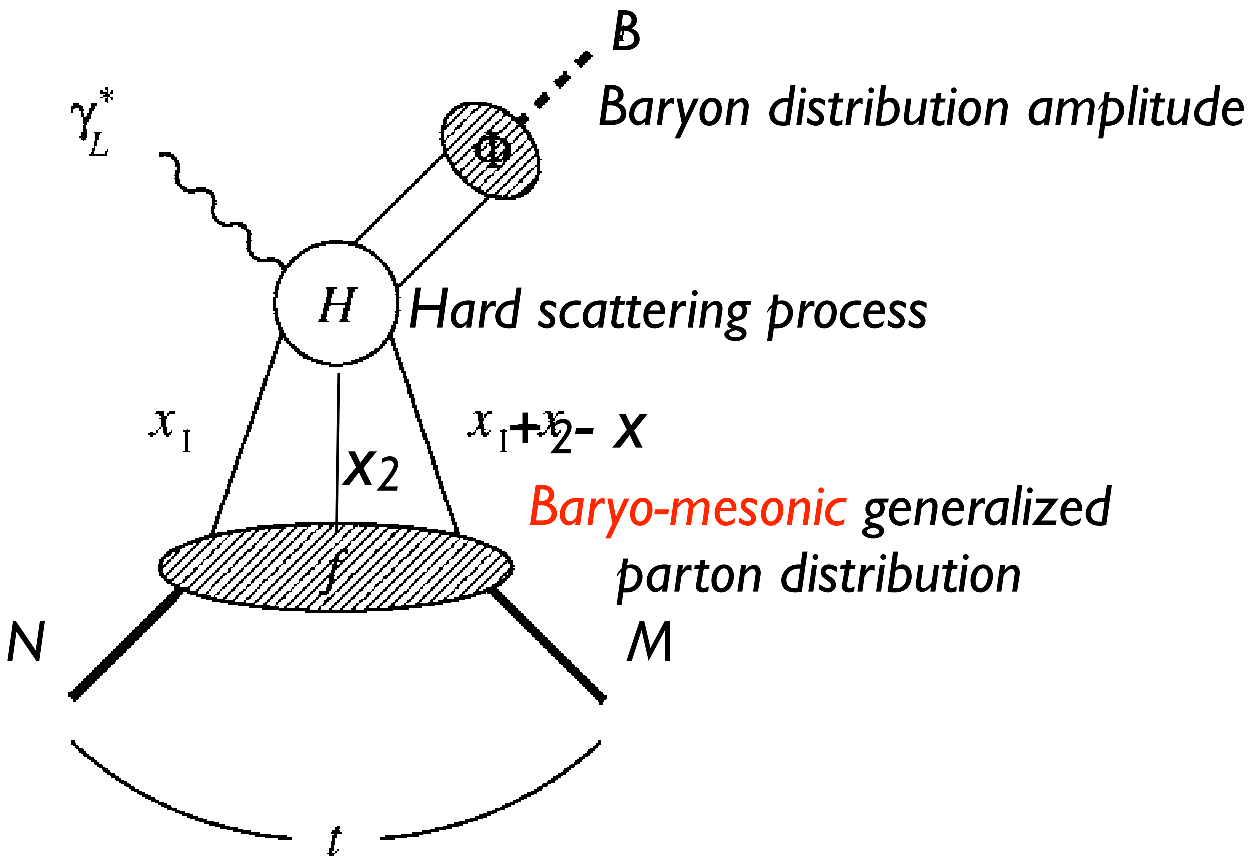
$$R^2(\text{dipole})(Q^2 \geq 3\ \text{GeV}^2)/R^2_\rho \leq 1/2 - 1/3$$

**squeezing starts rather early but asymptotic regime is reached only for $Q^2$ > 10 GeV$^2$**

***Consistent with observation of CT effect (rather weak as expected ) in***

$$\gamma^* + A \to \pi(\rho) + A^*$$

Conjecture (Frankfurt, Polyakov, Pobilitsa, FS 1999): the factorization theorem should be valid for a new class of reaction the production of leading baryon as well.




For large enough x (x>0.3?) the configuration in the nucleon which is likely to give the dominant contribution is when virtual photon hits a highly localized three quarks. So the minimal Fock component in N which contributes is $4q\bar{q}$ which is quite different from reactions with a leading meson.

**Need to introduce skewed distribution amplitude (SDA.) It is defined as a non-diagonal matrix element of the tri-local quark operator between a meson M and a proton:**

$$\int \prod_{i=1}^{3} dz_i^- \exp[i \sum_{i=1}^{3} x_i\,(p\cdot z_i)]\cdot \langle M(p-\Delta)|\varepsilon_{abc}\,\psi^a_{j_1}(z_1)\,\psi^b_{j_2}(z_2)\,\psi^c_{j_3}(z_3)|N(p)\rangle\Big|_{z_i^+=z_i^\perp=0} =$$

$$= \delta(1-\zeta-x_1-x_2-x_3)\,F_{j_1j_2j_3}(x_1,x_2,x_3,\zeta,t)\;,$$ Baryo-mesonic GPDs

**FPPS99**

where a,b,c are color indices, j, i are spin-flavor indices, and $F_{j1j2j3}(x_1,x_2,x_3,\zeta,t)$ are the new SDA.

$\zeta = 1 - \Delta^+/p^+$ skewness parameter

## Factorization is not proven so far?

Baryon system

⇐Fast left movers

Meson system

Fast right movers

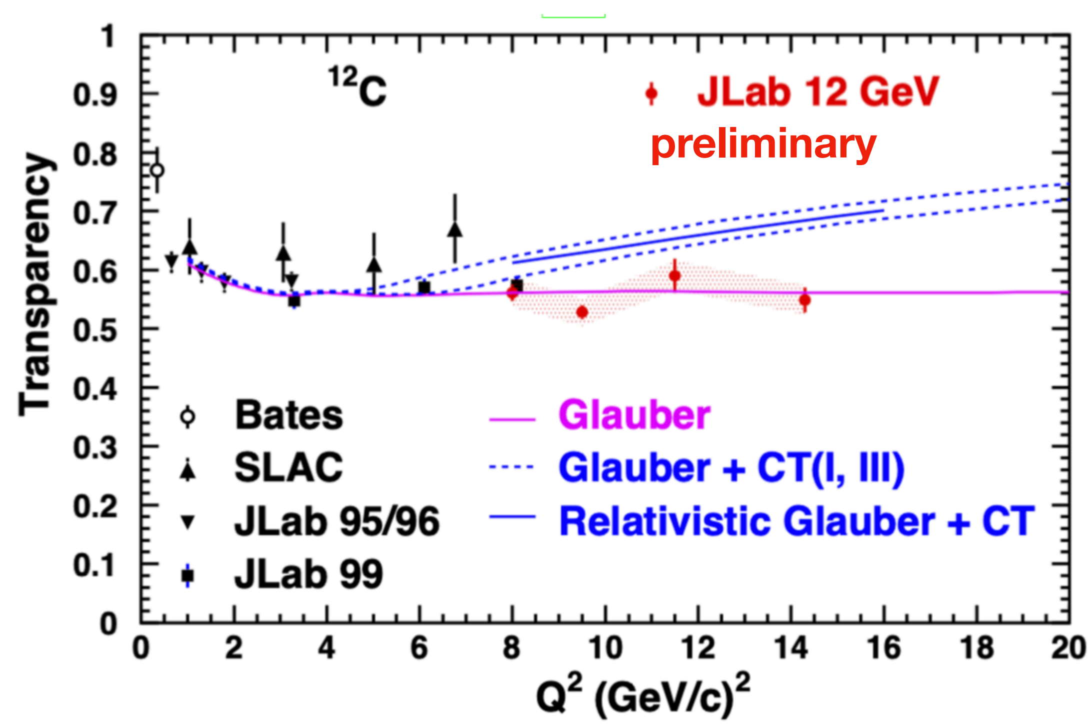
CT for nucleons is a minimal requirement for onset of factorization

need large enough W to avoid expansion. Difficult since

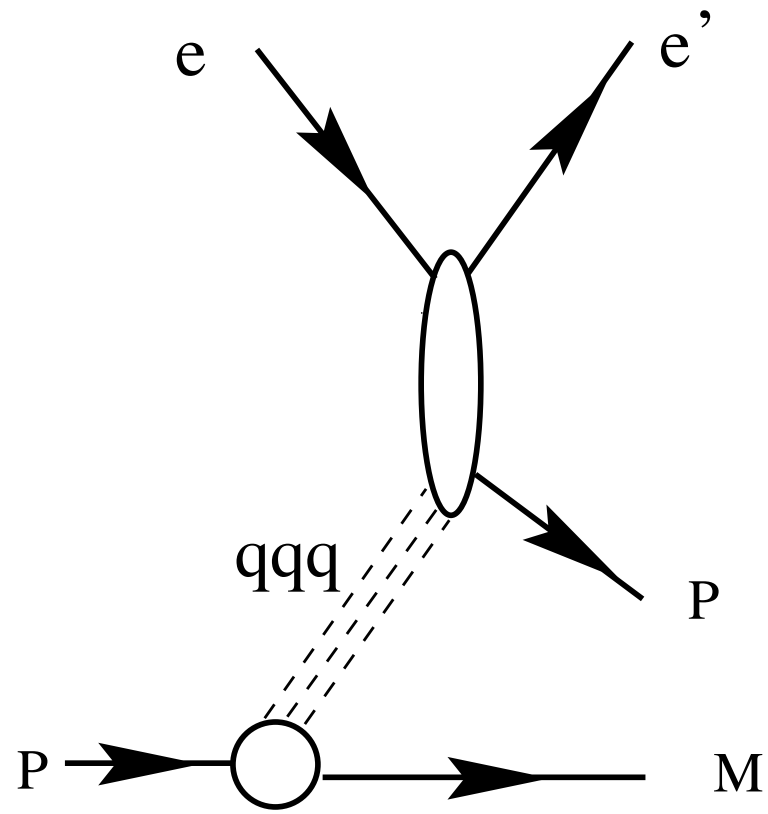
large x -kinematics = small W $W^2 = Q^2(1/x-1)+m_N^2$

no evidence significant CT effect in proton production: eA→ep(A-1)*

at least up to $Q^2$~ 6 $GeV^2$



**A natural conjecture : existence of preasymptotic regime where photon knocks out three quarks in a a somewhat squeezed configuration , but LT approximation is not valid yet.**




***Production of a fast baryon and recoiling mesonic system.***

**Addresses a question: does nucleon contain color singlet 3q, q\bar q clusters?**

**yes: in chiral quark soliton model like (Diakonov & Petrov),**
**no: in QED - positronium , MIT bag model**

**In the picture where electronscatteres off color clusters, FSI cannot be too large (reduction of cross section by a factor of at most 2). In 50% cases 3q behind $q\bar{q}$**

## *Kinematics (Bjorken limit)* $\alpha_M$ - light cone fraction of proton carried by M

$$\alpha_M = \frac{p_{M-}}{p_{N-}} = \frac{E_M - p_{3M}}{E_N - p_{N3}} = \frac{E_M - p_{3M}}{m_N} = 1 - x$$

**If requirement of the survival of a cluster as a baryon leads to a reduction of its size, the color transparency would suppress the FSI between the fast moving nucleon/baryon and the residual meson state early enough. In this case it would be natural to expect an early onset of the factorization of the cross into two blocks:**

$$\frac{d\sigma(e+N \to e+N+M)}{d\alpha_M d^2p_t/\alpha_M} = f_M(\alpha_M, p_t)(1-\alpha_M)\sigma(eN \to eN)$$

**where $(1 - \alpha_M)$ is the flux factor and $\sigma(eN \to eN)$ in the cross section of the elastic eN scattering in the appropriate kinematics.**

**Interesting channels** **in addition to** $\gamma^* p \to p\pi^0$

$\gamma^* p \to p\sigma$ **no strong suppression for x < 0.5 as compared to $\pi^0$ in the chiral soliton models**

***$\sigma$ meson mass is ~ 400 - 500 MeV,***

***Observation of the decay channel $\pi^0\,\pi^0$ (BR= 1/2) allows to to separate $\sigma$ - meson production from the tail of $\rho$- meson production***

## Very interesting channels: $\gamma^* p \to \Delta\pi$

**best to study** $\gamma^* p \to \Delta^{++}\pi^-$

- **The highest rates as $\Delta^{++}$ electric and magnetic form factors are a factor of ~ 2 larger than for proton (quark model) (enhance x-section by ~ 4).**

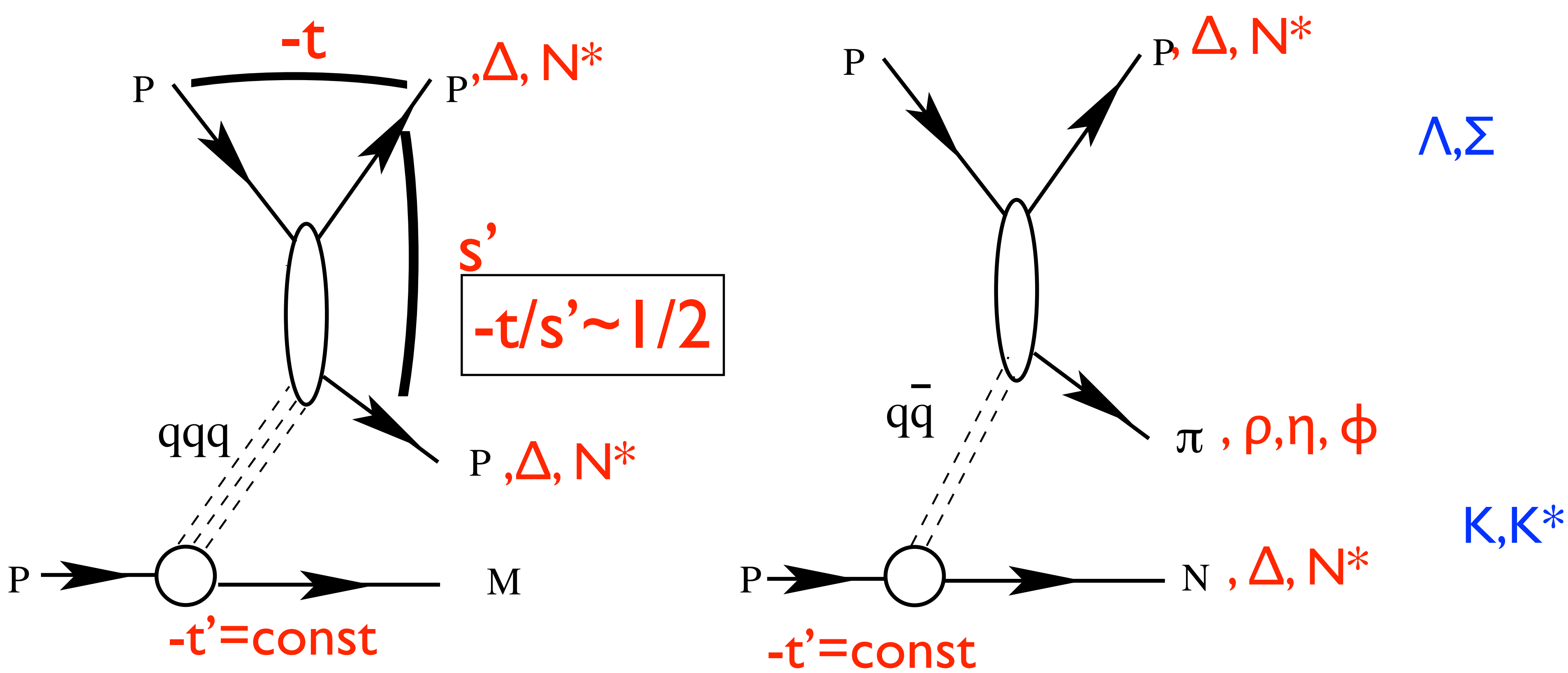
- **no contribution of the scattering off a πN cluster**

# Hadron induced hard semiexclusive (branching) processes (MS95)

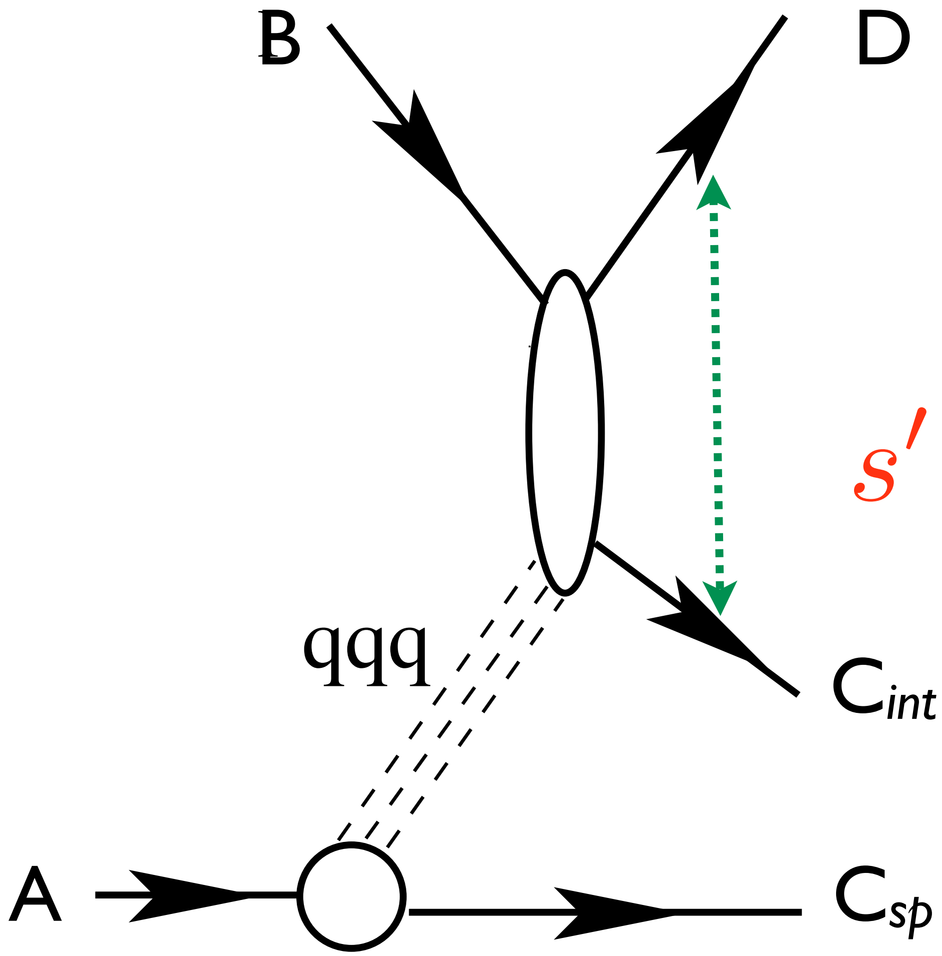
**A natural extension of the processes discussed for electron scattering is a photon/hadron scattering process:**

$$A + B \to C_{int} + C_{sp} + D,$$

**It is easier to reach high energies: Jlab (photon) , Jpark pions and nucleons, EIC**




Could a gluonium be left behind when three quarks in a nucleon come close (but not too close to remove the gluon field) and instantaneously knocked out.




# Energy dependence of branching processes

$$s' = (p_D + p_{C_{int}})^2 = (1 - \alpha_{C_{sp}}) s_{AB}$$

$$\alpha_{C_{sp}} = (E_{C_{sp}} - p_{3\,C_{sp}})/m_A$$

$$\frac{d\sigma(A + B \to C_{int} + C_{sp} + D)}{d\alpha_{sp} d^2 p_{t\ sp}/\alpha_{sp}} = \phi(\alpha_{sp}, p_{t\ sp}) R(\theta_{c.m.}) \, (s_o/s')^n$$

$$n = n_q(A) + n_q(cluster) + n_q(C_{int}) + n_q(D) - 2.$$

$C_{sp}$ flies along A - slow if A is the target - fast if A is the projectile

# Scaling relations between hadron and electron projectiles

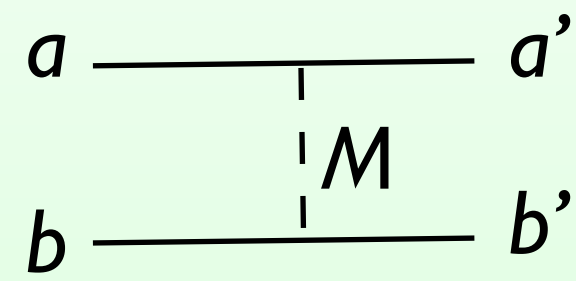
$$\frac{\dfrac{d\sigma(p+p\rightarrow p+p+\pi^0)}{d\alpha_{\pi^0}\, d^2p_t/\alpha_{\pi^0}}}{\dfrac{d\sigma(e+N\rightarrow e+N+\pi^0)}{d\alpha_{\pi^0}\, d^2p_t/\alpha_{\pi^0}}} \approx \frac{\sigma(p+p\rightarrow p+p)}{\sigma(eN\rightarrow eN)},$$

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

# *Quark exchanges in pQCD via two body processes*

Reminders: Regge theory - scattering at fixed t (u),and s $\to \infty$

*a) if interaction between two partiles is mediated by exchange of particle "M" with spin J*

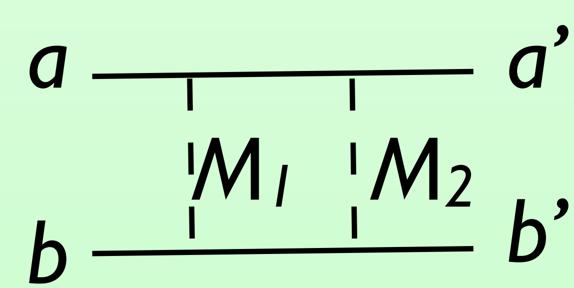



$$A(a+b \to a' + b') = f(t)s^J$$

$$d\sigma/dt = \frac{1}{s}|A(a+b \to a' + b')|^2 \propto s^{2J-1}$$

In Regge theory meson exchanges are "reggeized" $d\sigma/dt \propto f(t)s^{2J(t)-1}$

*b) Azimov displacement: if two (N) particles are exchanged*




$$A(a+b \to a' + b') = f(t)s^{J_1+J_2-1}$$

Two simplest types of processes with largest cross sections (except the ones where vacuum Pomeron exchange is allowed):

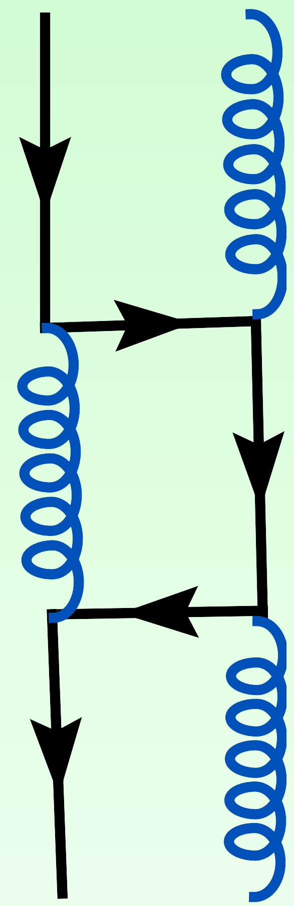
exchange by q$\bar{q}$ is allowed $\pi^- p \to \pi^0 + n$

exchange by qqq is allowed $\pi^- p \to p + \pi^-$

Processes where one needs an exchange by $qq\bar{q}\bar{q}$

are strongly suppressed though experimental information is very limited $\pi^- p \to K^+ \Sigma^-$

# pQCD - quark exchange is reggeized (Fadin and Sherman 1976, ...)



Important property of quark regge trajectory in pQCD

$\alpha_q(t)$ - weakly dependents on t

For quark antiquark exchange: $A \propto s^{2\alpha_q(t)-1}$

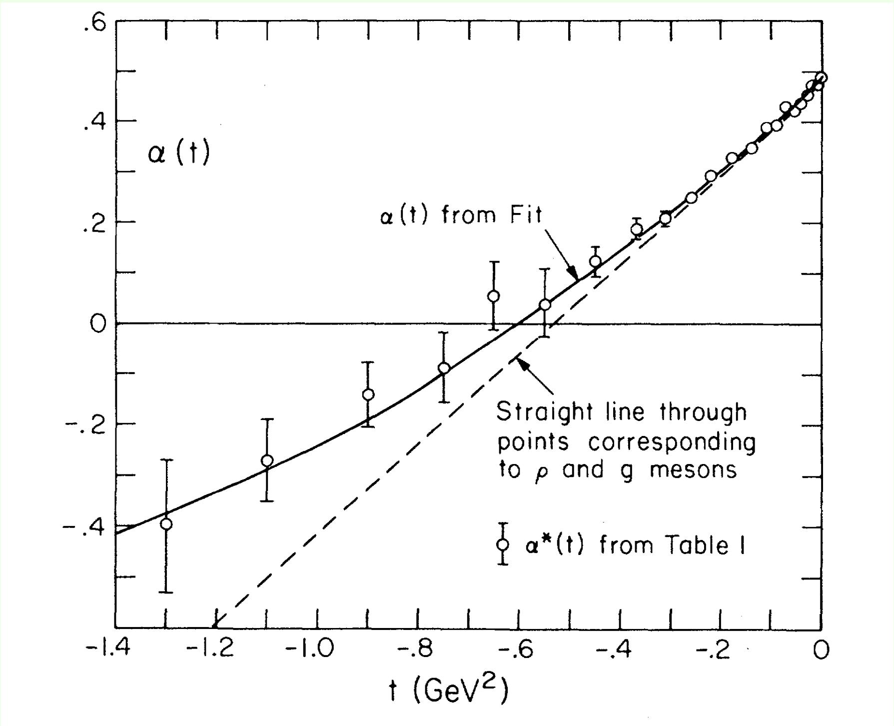
For three quark exchange: $A \propto s^{3\alpha_q(t)-2}$

$\downarrow$

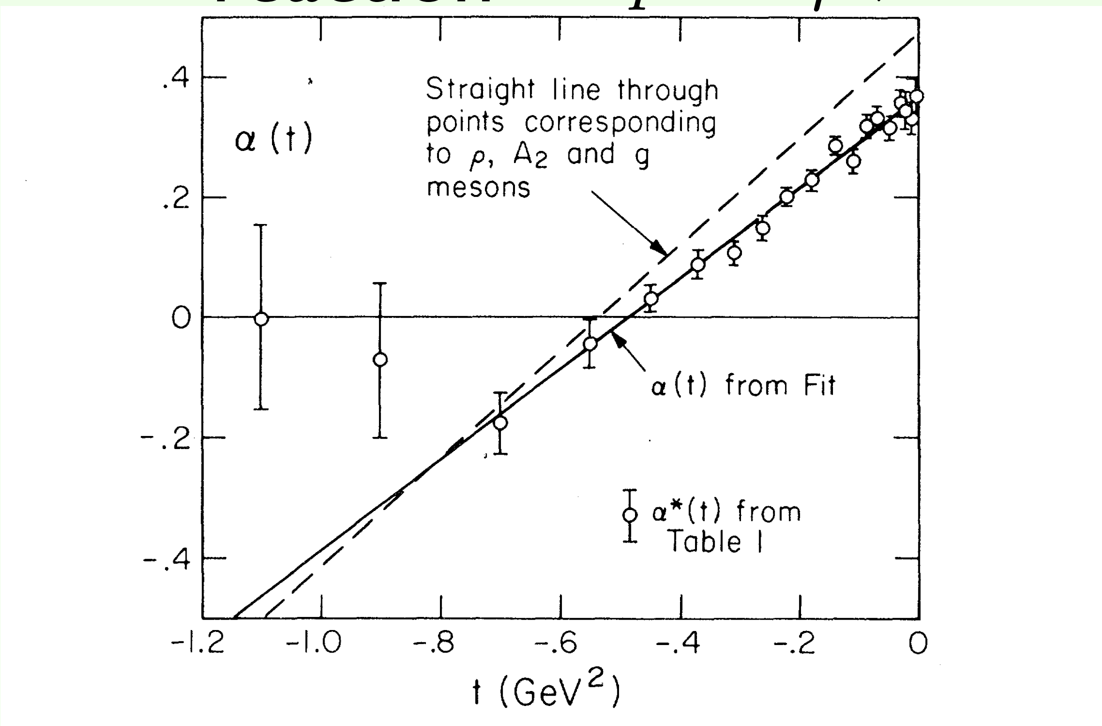
Relation between effective baryon and quark trajectories at large t

$$\boxed{\alpha_N(t) = 3\alpha_M(t)/2 - 0.5}$$

reaction $\pi^- p \to \pi^0 + n$




reaction $\pi^- p \to \eta + n$




$\alpha_M(-t > 1\ \mathrm{GeV}^2) = -(0.2 \div 0.4)$

$\alpha_q(-t > 1\ \mathrm{GeV}^2) = (0.3 \div 0.4)$

$\alpha_B(-t > 1\ \mathrm{GeV}^2) = -(0.8 \div 1.1)$

as compared to nonreggeized case of 0.5 - reggeization effect is rather small

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

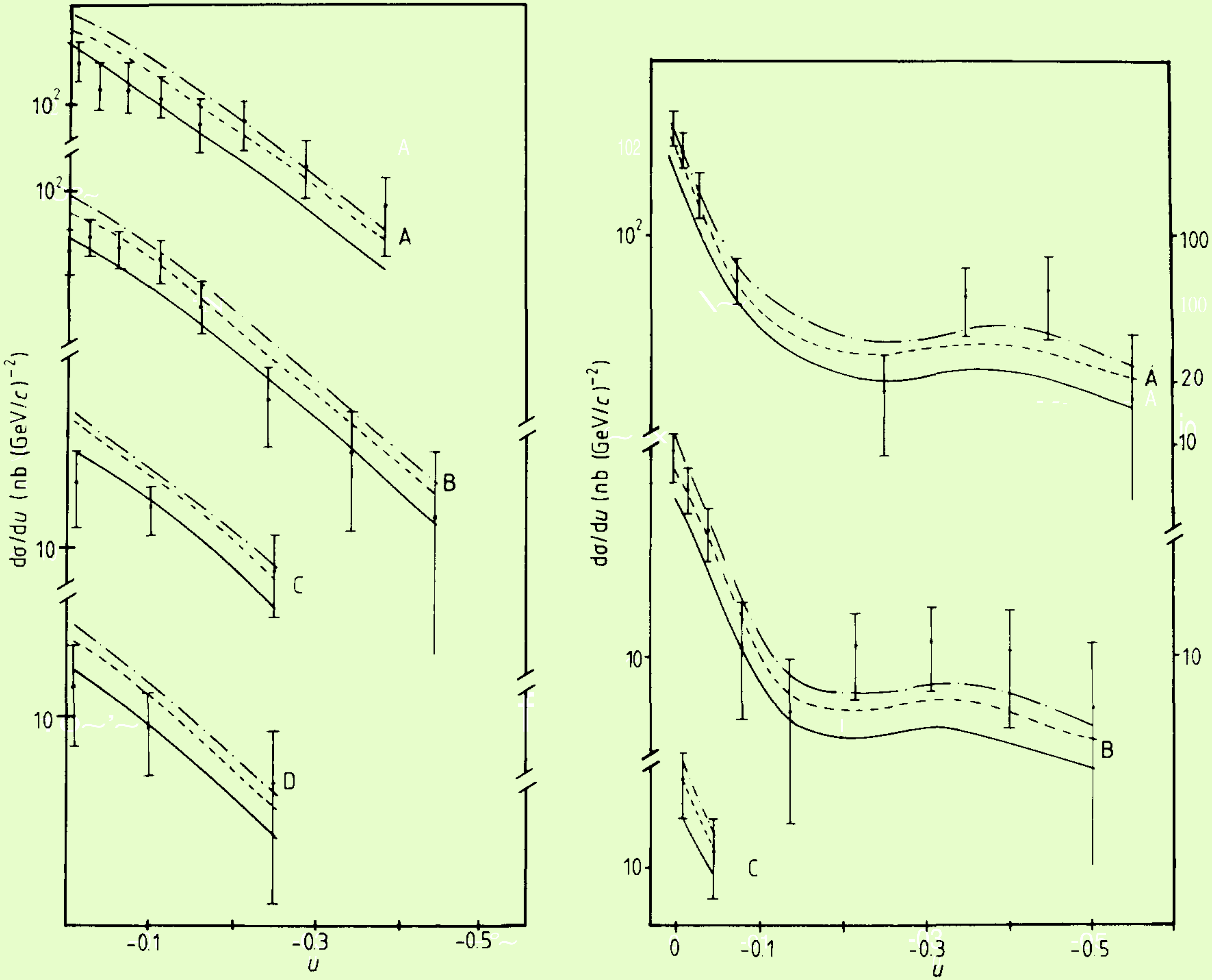
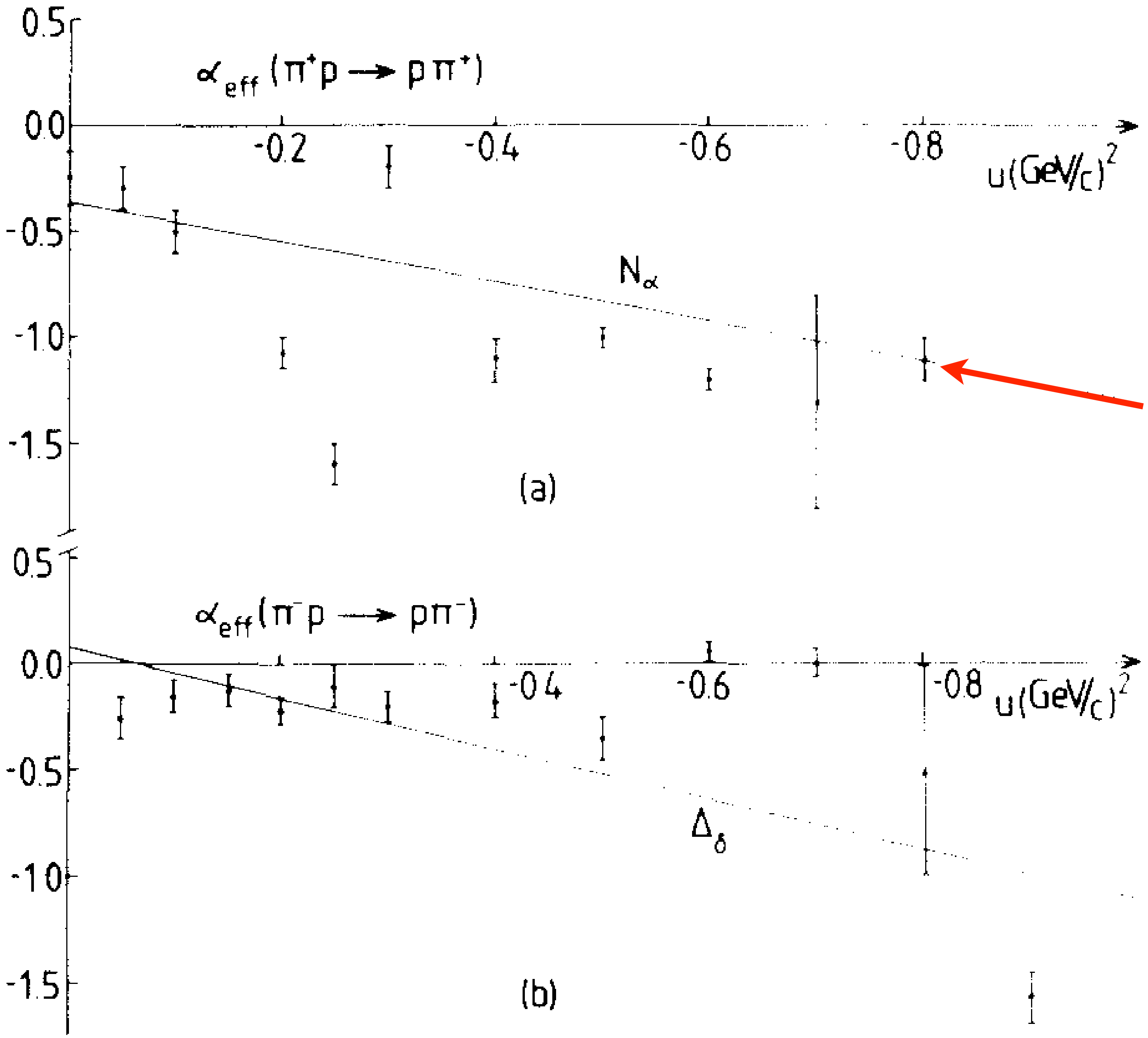
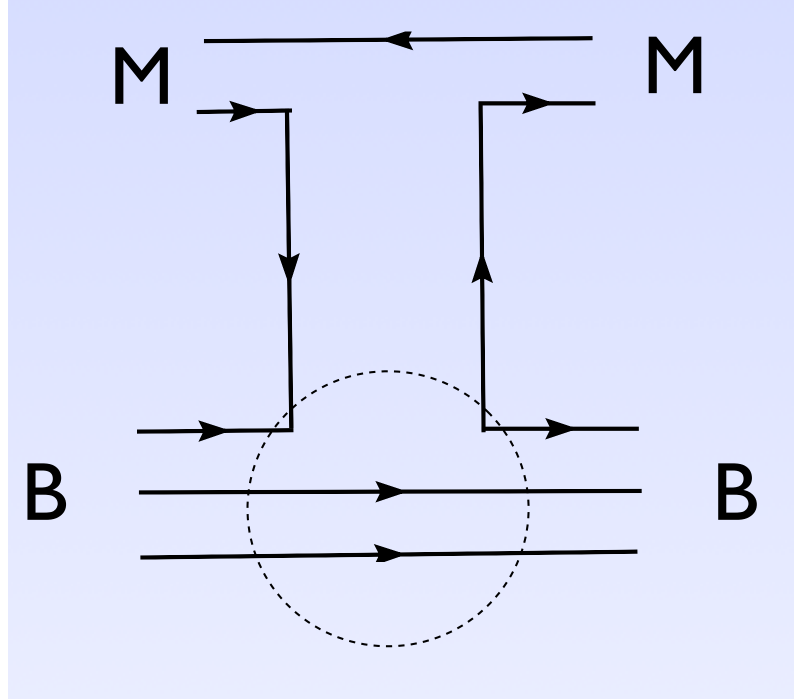



Fig. 11. FNAL backward cross section data for (a) $\pi^- p \to p\pi^-$ and (b) $\pi^+ \to p\pi^+$ at $p_L$ = 30 GeV/$c$ (A), 50 GeV/$c$ (B), 70 GeV/$c$ (C) and 90 GeV/$c$ (D) from ref. [64], compared to extrapolations of fits to lower energy data [158]. The different curves correspond to different choices of normalisation of the lower energy data [158].




close to pQCD expectation of $\alpha_B(-t > 1\ \text{GeV}^2) = -(0.8 \div 1.1)$

Fig. 5. Effective trajectories $\alpha_{eff}(u)$ plotted against $u$ for (a) $\pi^+ p \to p\pi^+$ and (b) $\pi^- p \to p\pi^-$. *All* data above $p_L = 5$ GeV/$c$ are included [80]: they are listed in ref. [158]. Solid lines are linear fits to (a) $N_\alpha$ and (b) $\Delta_\delta$ resonances given in eqs. (3.1a) and (3.1d). From ref. [158].[23]




Baryon GPD at large t?

Do not have time to discuss spin effects - obviously would help (target, projectile, produced mesons and baryons) as it allows to analyze properties of the vertices - due to quark-quark interaction there should be several nearly degenerate trajectories

# Conclusions

☞ It maybe possible to reach pre-asymptotic (white cluster) “backward” kinematics regime at Jlab

☞ Necessary to measure not only leading protons, but also Δ’s, etc

☞ Highly desirable to measure in parallel two body final states in ep scattering and 3 body final states in γ/h p scattering

☞ From Regge exchange regime to quark exchange regime (an important interface of soft and hard QCD to explore)