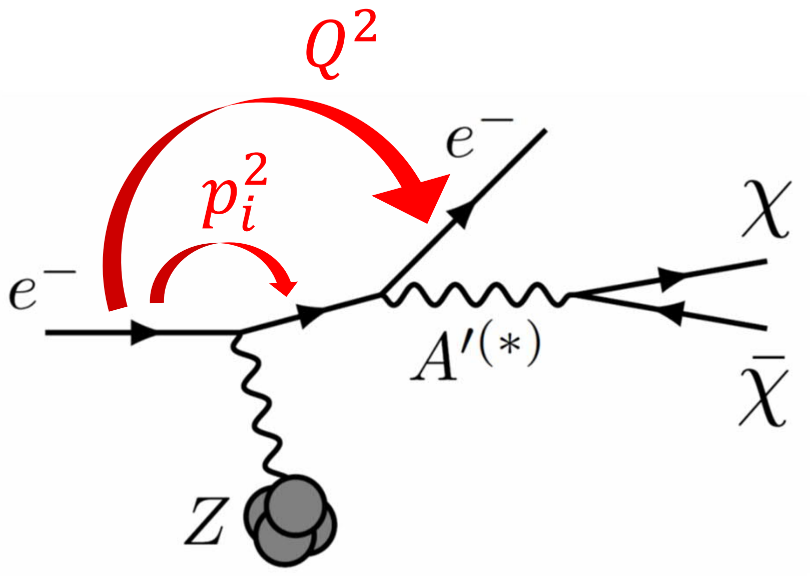
LDM events – understanding backgrounds



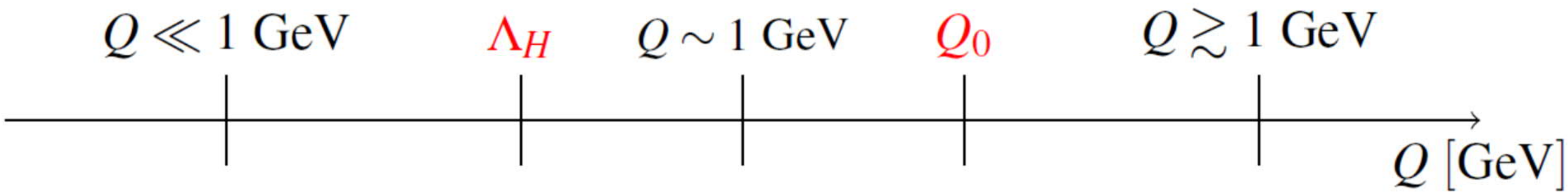
Momentum transfers

p_i^2 *internal scale for target interaction in signal event*

Q^2 *measured*
main scale in background events

$\Downarrow$

Momentum transfer scale



$\Downarrow$

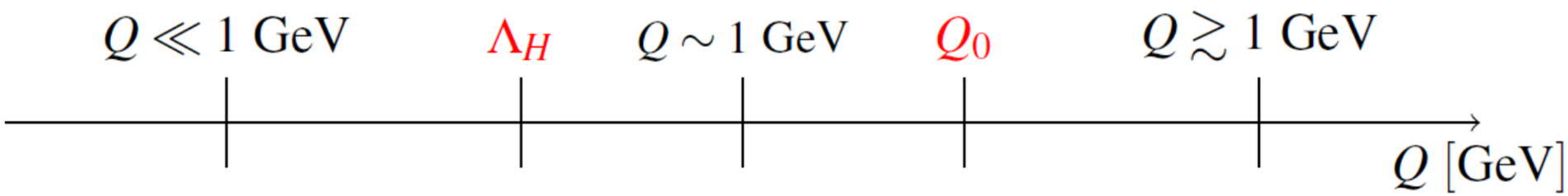
hadrons ChPT	hadrons → partons form factors + starting PDFs	partons pQCD	Quantum states & theory

Understanding PDFs and the proton spin puzzle

A. Ekstedt, H. Ghaderi, G. Ingelman, S. Leupold

arXiv:1807.06589 Nucleon parton distributions from hadronic quantum fluctuations

arXiv:1808.06631 Towards solving the proton spin puzzle



hadronic fluctuations

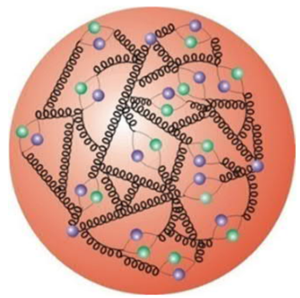
model for PDFs at Q_0

partonic fluctuations $|uud\ q\bar{q}\rangle$

$$|p\rangle = \alpha_0 |p_0\rangle + \alpha_{p\pi} |p\pi^0\rangle + \alpha_{n\pi} |n\pi^+\rangle + \ \ldots$$

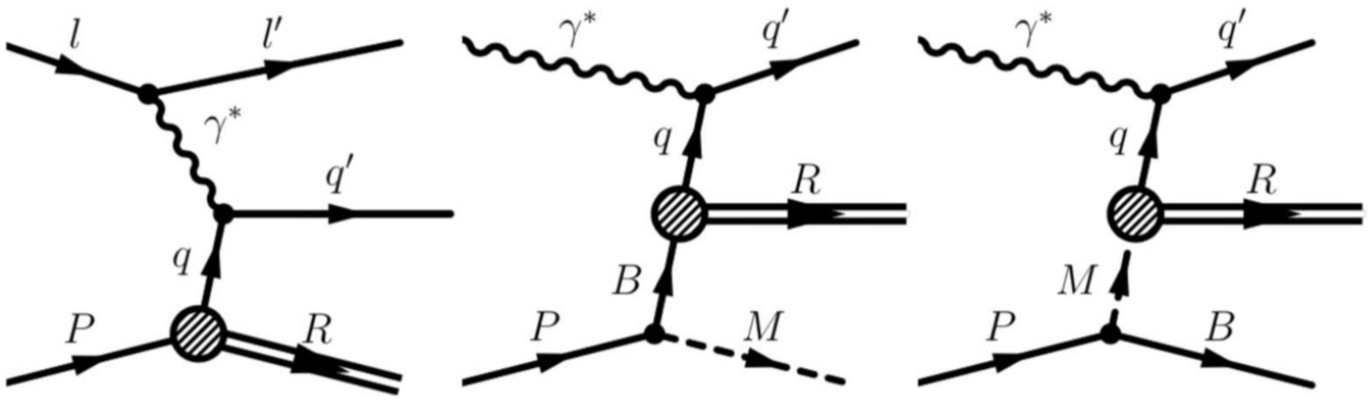
DGLAP Q^2 evolution of PDFs

p-wave → L=1 not observed in DIS



Fock expansion of proton state $|P\rangle = \sqrt{Z}\,|P\rangle_{\text{bare}} + \alpha_{n\pi^+}\,|n\pi^+\rangle + \alpha_{P\pi^0}\,|P\pi^0\rangle$

$$+ \alpha_{\Delta^{++}\pi^-}\,|\Delta^{++}\pi^-\rangle + \alpha_{\Delta^+\pi^0}\,|\Delta^+\pi^0\rangle + \alpha_{\Delta^0\pi^+}\,|\Delta^0\pi^+\rangle$$
$$+ \alpha_{\Lambda K^+}\,|\Lambda K^+\rangle + \cdots$$



$$f_{i/P}(x) = f_{i/P}^{\text{bare}}(x) + \sum_{\lambda, H\in\{B,M\}} \int \mathrm{d}y\,\mathrm{d}z\,\delta(x-yz)\,f_{i/H}^{\text{bare}}(z)\,f_{H/P}^{\lambda}(y)$$

- LO ChPT Lagrangian $\rightsquigarrow f_{H/P}^{\lambda}(y) = \frac{|g_{BM}|^2}{(2\pi)^3 2y(1-y)} \int \mathrm{d}^2 k_\perp \left| \phi \frac{S^\lambda(y, \boldsymbol{k}_\perp)}{m_P^2 - m^2(y, k_\perp^2)} \right|^2$

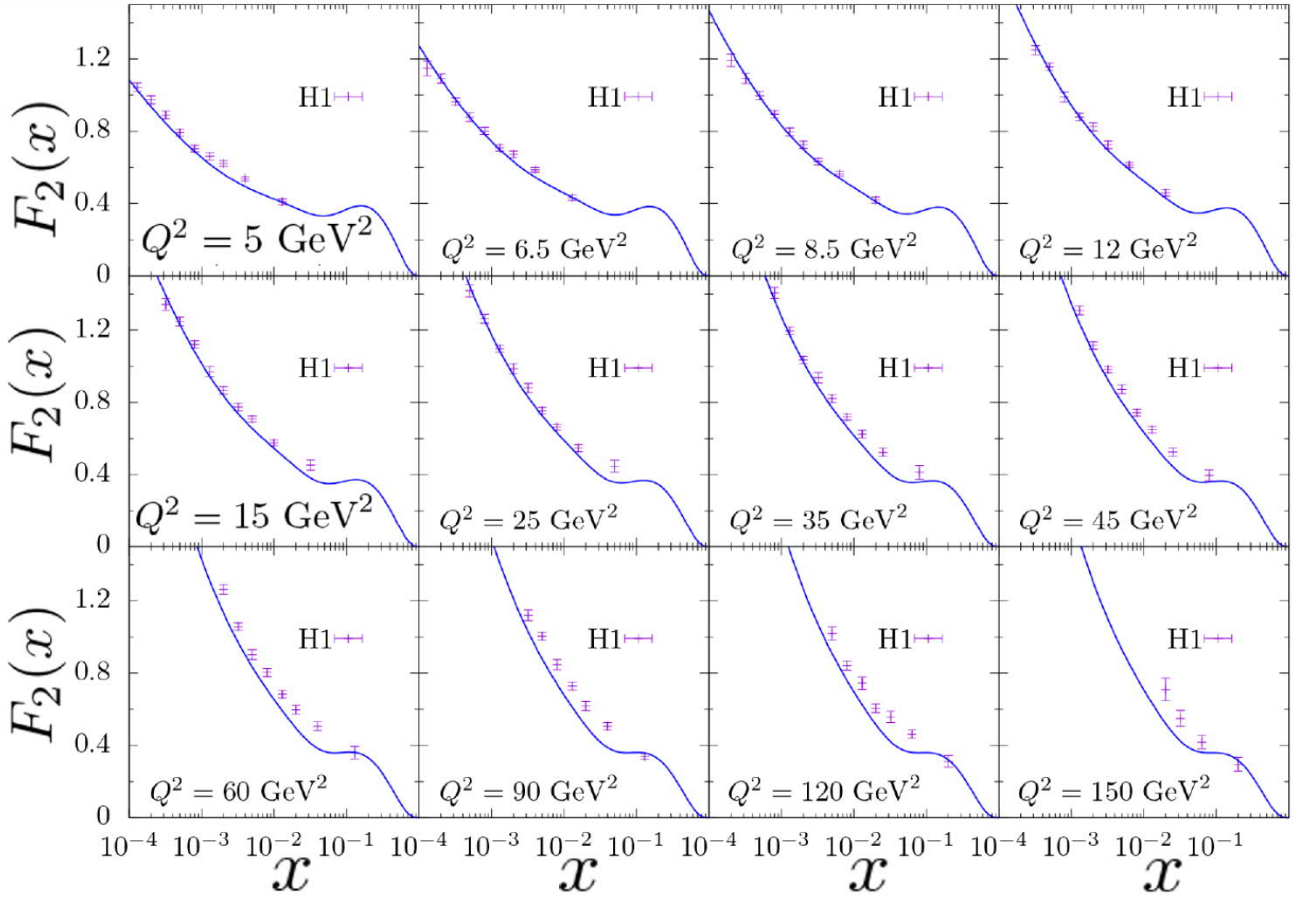
$$y = p_B^+/p_P^+ \qquad \phi(y, k_\perp^2, \Lambda_H^2) = \exp[-(\boldsymbol{p}_M^2 + \boldsymbol{p}_B^2)/(2\Lambda_H^2)]$$

- $f_{i/H}^{\text{bare}}(x) = \int \frac{\mathrm{d}^4 k}{(2\pi)^4}\,\delta\left(k^+/p_H^+ - x\right) \exp\left[-\frac{(k_0-m_i)^2 + k_x^2 + k_y^2 + k_z^2}{2\sigma_i^2}\right]$ at $Q = Q_0$

DGLAP $Q > Q_0$

- 'Free' parameters: σ_1, σ_2, σ_g and Λ_H, Q_0

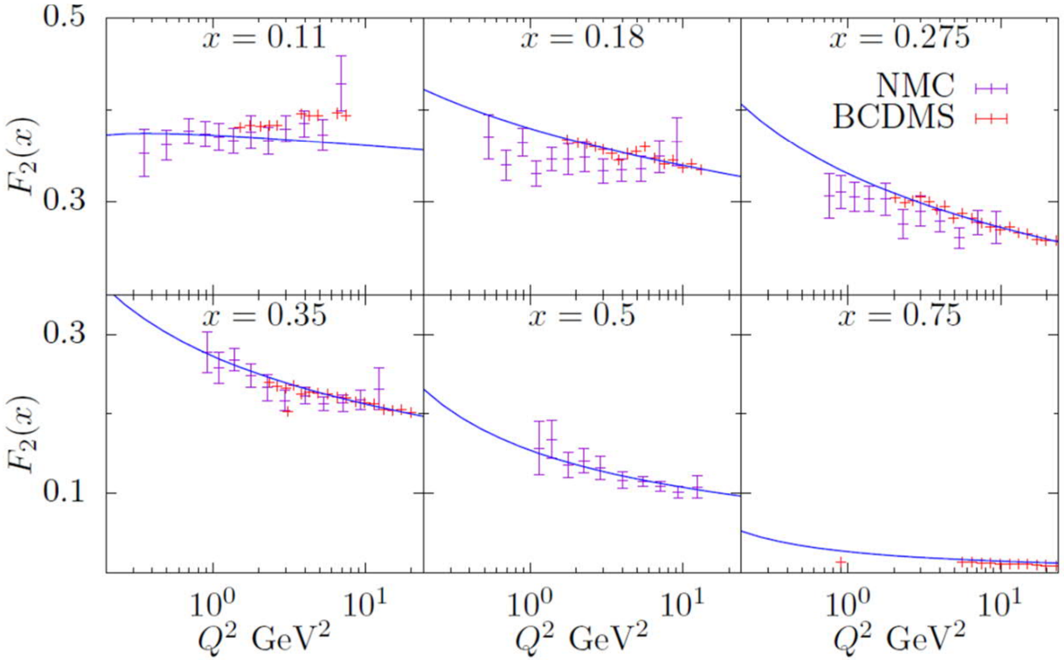
A priori expected value: $\sigma_i \sim 1/D_H \sim 0.1$ GeV and $\Lambda_H \sim Q_0 \sim 0.5$ GeV



Unpolarised structure functions ↓ parameter values

F_2 *at small* x
$\rightarrow \sigma_g, Q_0$

F_2, F_3 *at larger* x
$\rightarrow \sigma_1, \sigma_2, \Lambda_H$



$\sigma_g = 0.028$ GeV, !! ??

$\sigma_1 = 0.11$ GeV,

$\sigma_2 = 0.22$ GeV, Pauli principle !?

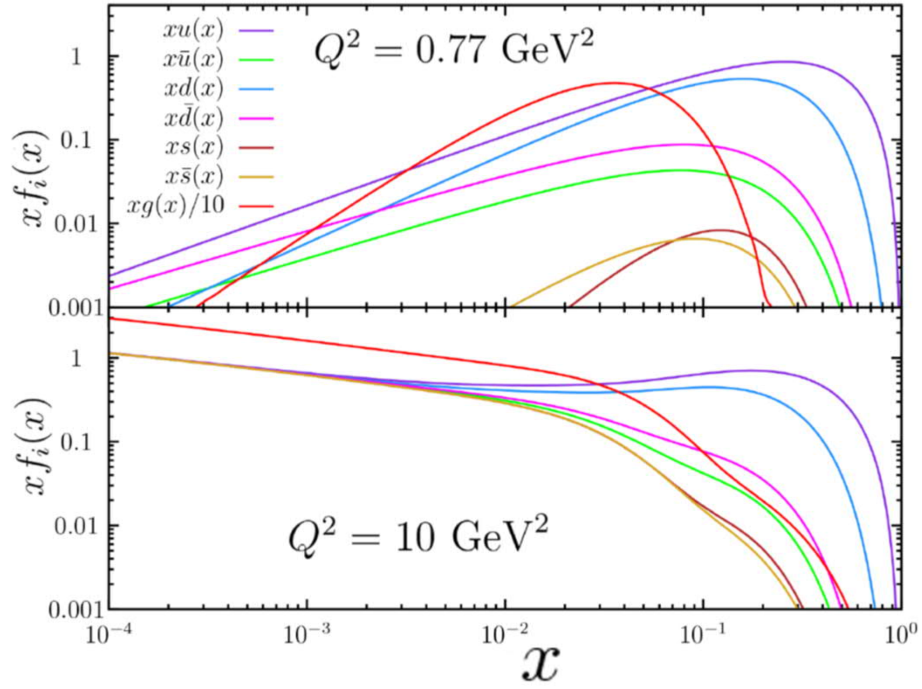
$\Lambda_H = 0.87$ GeV, hadron-parton transition !!

$Q_0 = 0.88$ GeV

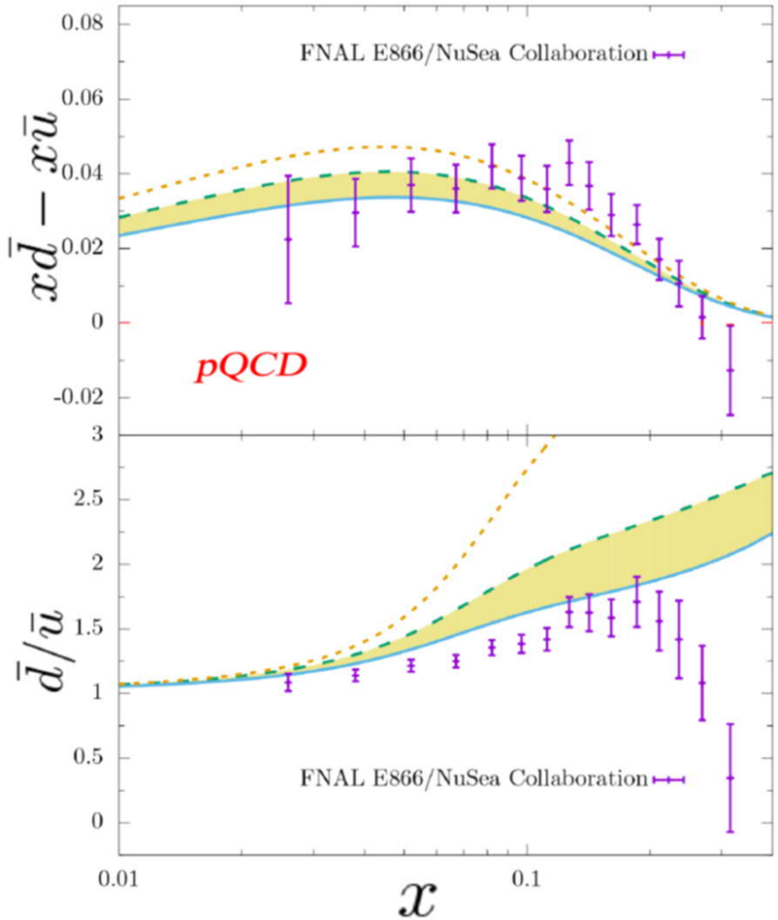
Resulting unpolarised PDFs

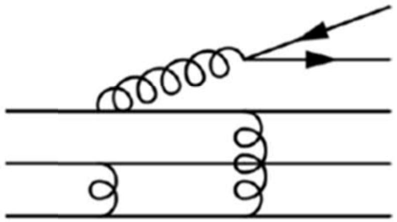
based on 5 physical parameters
→ understanding!

cf. conventional PDF fits with
~30 parameters



Also explains sea quark asymmetries:





- From pQCD point of view: since $m_u, m_d \ll \Lambda_{QCD}, Q_0 \rightsquigarrow$ the momentum distribution of the $\bar{d}$ and $\bar{u}$ sea in the proton should be similar
- $\rightsquigarrow$ pQCD $\Rightarrow x\bar{d} - x\bar{u} = 0$
- Hadronic fluctuations: (cheapest) $|n\pi^+\rangle$
- $\pi^+ \sim u\bar{d} \Rightarrow |n\pi^+\rangle \rightsquigarrow$ asymmetry
- Including $|\Delta\pi\rangle \rightsquigarrow$ even better agreement

The proton spin puzzle / "crisis"

1988 European Muon Collaboration:
measured polarization of quarks adds to only ~1/3 of proton spin 1/2

Unpolarised:

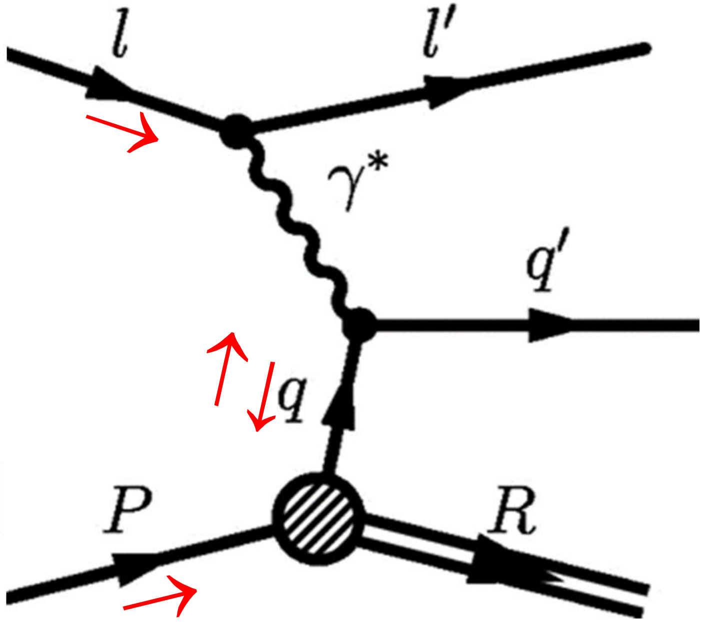
$$\frac{d^2\sigma}{dx dQ^2} \sim F_2(x,Q^2) = \sum_f e_f^2\, x[q_f(x,Q^2) + \bar{q}_f(x,Q^2)]$$

PDF: $q(x) \equiv q^{\uparrow}(x) + q^{\downarrow}(x)$

Polarised:

$$\frac{d^2\Delta\sigma}{dx dQ^2} \sim g_1(x,Q^2) = \sum_f e_f^2\, [\Delta q_f(x,Q^2) + \Delta\bar{q}_f(x,Q^2)]$$

Polarised PDF: $\Delta q(x) \equiv q^{\uparrow}(x) - q^{\downarrow}(x)$

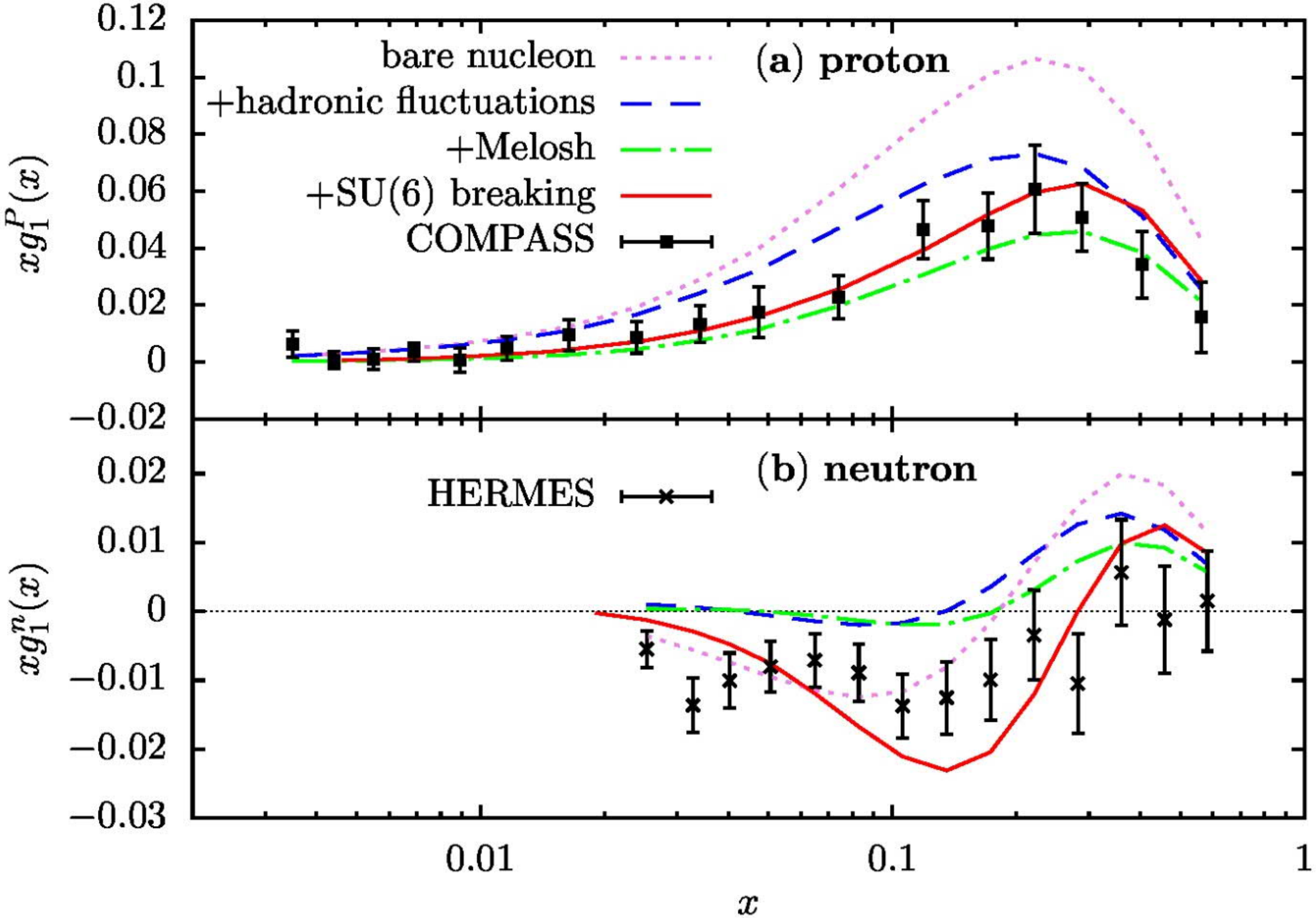


$\rightarrow\ \Delta\Sigma = \int_0^1 dx\, \sum_f \Delta q_f(x) \approx = 0.3$!?

proton spin $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L_q + L_g$

Polarised PDFs: $\Delta f_{q/H}^{\text{bare}}(x) = \Delta f_{q/H}^{SU(6)} f_{q/H}^{\text{bare}}(x)$

$$|p\uparrow\rangle = \frac{1}{\sqrt{2}}|u\uparrow(ud)_{S=0}\rangle + \frac{1}{\sqrt{18}}|u\uparrow(ud)_{S=1}\rangle - \frac{1}{3}|u\downarrow(ud)_{S=1}\rangle - \frac{1}{3}|d\uparrow(uu)_{S=1}\rangle + \frac{\sqrt{2}}{3}|d\downarrow(uu)_{S=1}\rangle$$



Melosh = relativistic spin transformation

p spin OK !
But not *n* spin ?

Solutions …?

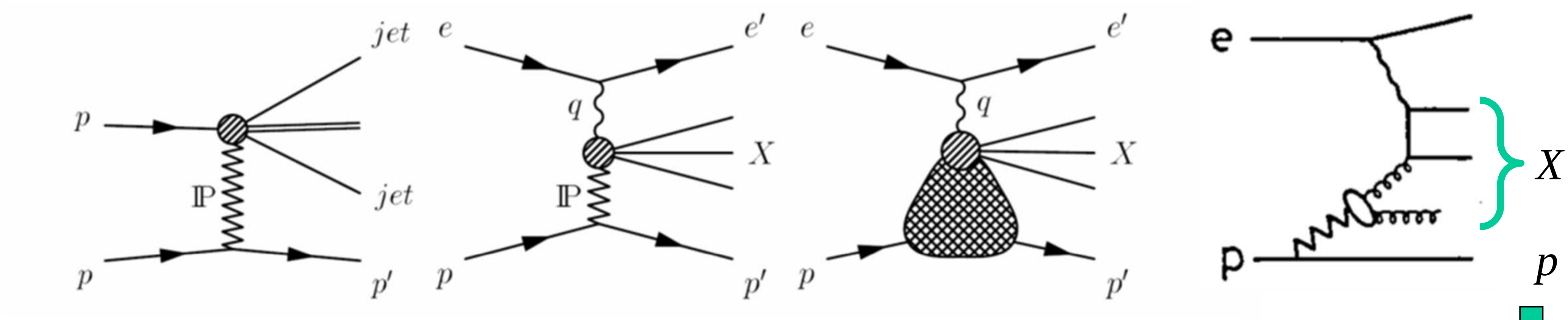
- SU(6) breaking available range $-2 \leq \Delta f_{u/p} \leq 2$, $-1 \leq \Delta f_{d/p} \leq 1$ $\Rightarrow \Delta f_{u/P} = 2,\ \Delta f_{d/P} = -1 \ \rightarrow |p\rangle \approx |u^{\uparrow}u^{\uparrow}d^{\downarrow}\rangle$

in constrast to SU(6) quark model !!??

- Problem in extracting neutron state from deuterium state ??

Possible effects of soft gluon fields missing !!

Information available from diffractive scattering

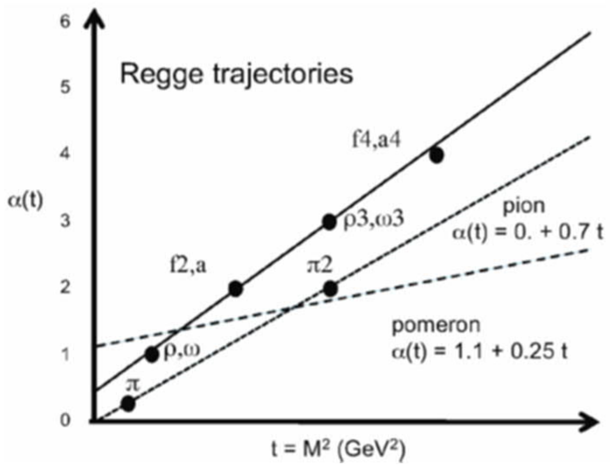


Regge theory (soft pre-QCD):

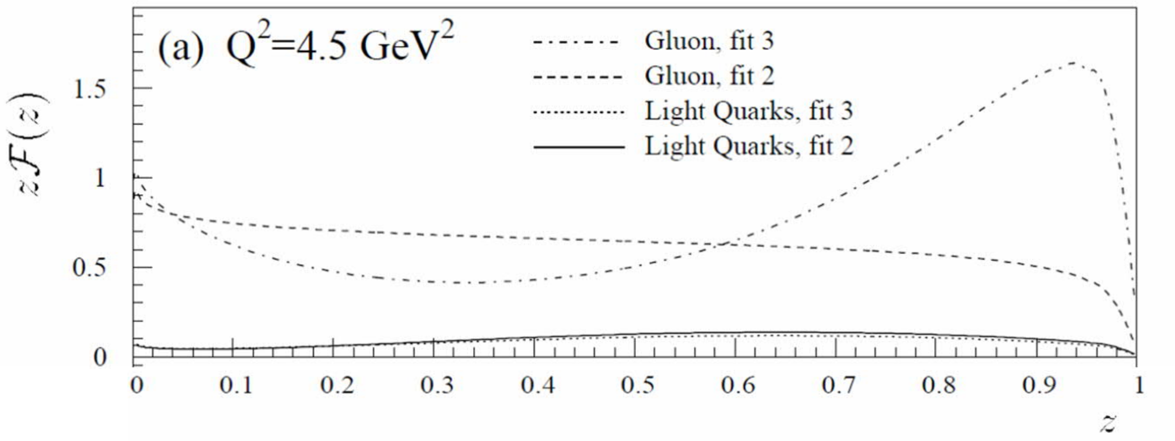
pomeron factorization $d\sigma(a+p \to p+X) = f_{I\!P/p}(x_{I\!P},t)\, d\sigma(a+I\!P \to X)$

pomeron flux $f_{I\!P/p}(x_{I\!P},t) = \frac{9\beta_0^2}{4\pi^2}\left(\frac{1}{x_{I\!P}}\right)^{2\alpha_{I\!P}(t)-1}[F_1(t)]^2$ $\quad a = p, e, \gamma$ ...

pomeron trajectory $\alpha_{I\!P}(t) \simeq 1.08 + 0.25t$



Pomeron as color singlet gluon field



Extra material

More info in spin sum rules: $\Gamma^{P\pm n}(x_{\min}) = \int_{x_{\min}}^{1} \mathrm{d}x \left(g_1^P(x) \pm g_1^n(x)\right)$

$\Gamma_{Bj}^{p-n}(x_{min}=0) = 0.187 \rightarrow$

i.e. Bjorken sum rule

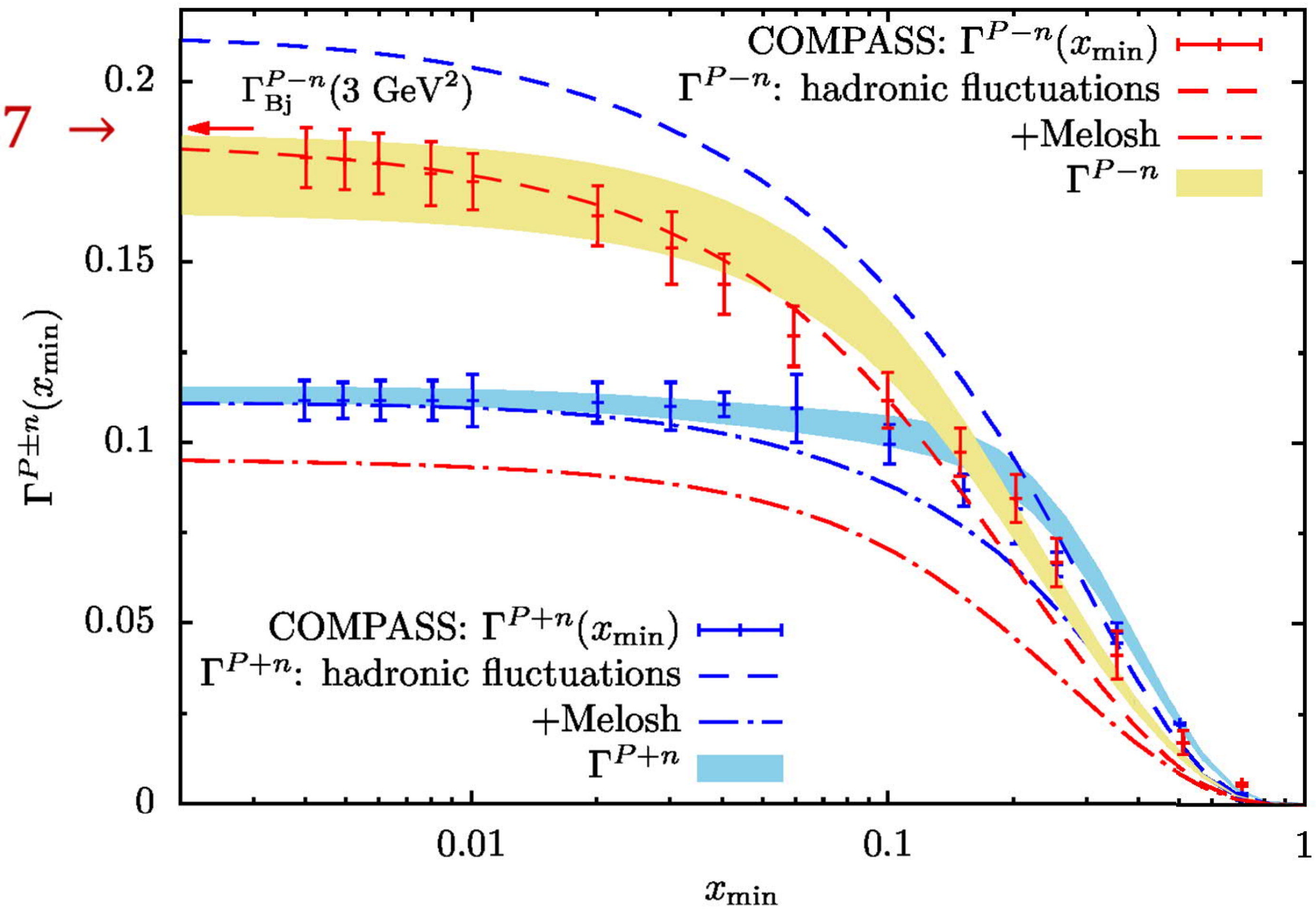
& $g_1^n(x)$ forces

SU(6) breaking,

available range:

$-2 \leq \Delta f_{u/p} \leq 2$

$-1 \leq \Delta f_{d/p} \leq 1$



Data $\rightarrow$ $\Gamma^{P-n}(0) \Rightarrow \Delta f_{u/P} = 2,\ \Delta f_{d/P} = -1$

$\rightarrow |p\rangle \approx |u^{\uparrow}u^{\uparrow}d^{\downarrow}\rangle$ in constrast to SU(6) quark model !!??

Conclusion

Hadron fluctuations (ChPT) + non-pQCD parton fluctuations
+ pQCD DGLAP evolution + SU(6) quark flavor-spin symmetry
$\rightarrow$ repoduce data on

- proton spin structure function
- Ellis-Jaffe sum rule
- proton quark spin sum $\Delta\Sigma$

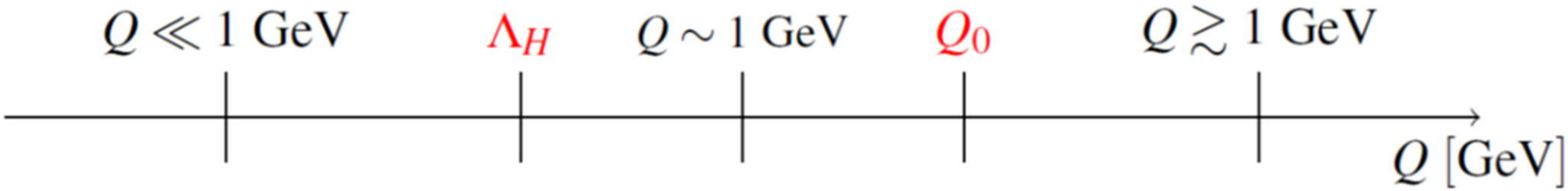
	bare	hadronic fluct.	Melosh	SU(6) break.	$\Delta\Sigma^{exp}$
$\Delta\Sigma$	0.95	0.75	0.39	0.39	0.26–0.36

+ SU(6) breaking $\rightarrow$ reproduce data on

- neutron spin structure function
- Bjorken sum rule

QCD established as *the* theory for strong interactions,

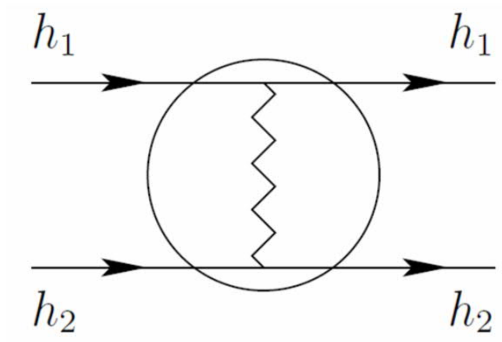
but *soft non-pQCD is the major unsolved problem* within the Standard Model



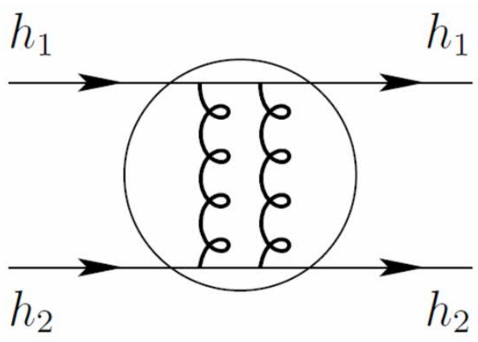
ChPT hadrons ← ??? → partons pQCD

Soft gluon fields !?

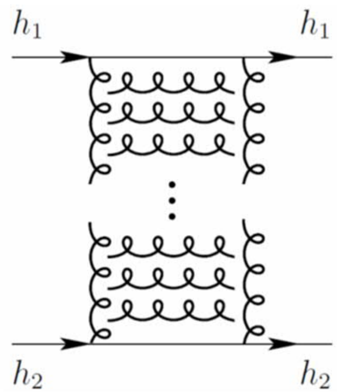
Consider information from soft elastic/diffractive hadron scattering



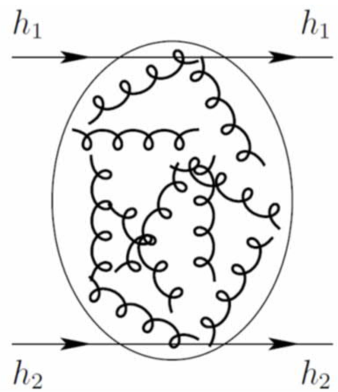
Pomeron theory/phenomenology



2-gluon exchange



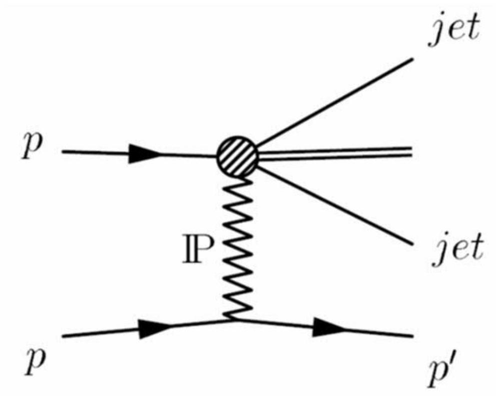
reggeized gluon ladder



gluon field vacuum fluctuation

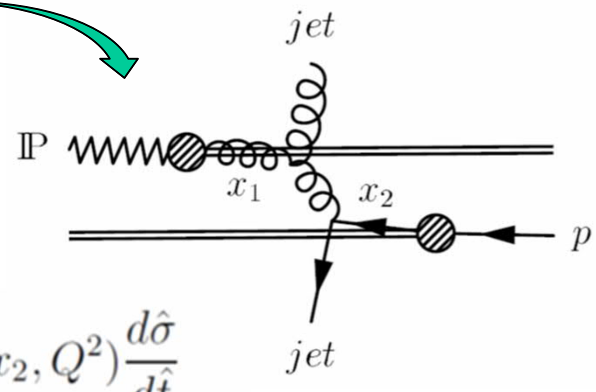
Possible effects of soft gluon fields missing !!

Information available from diffractive hard scattering:



$$\frac{d\sigma_{jj}}{dt dM_X^2} = \frac{d\sigma_{SD}}{dt dM_X^2} \frac{\sigma(I\!\!Pp \to jj)}{\sigma(I\!\!Pp \to X)}$$

$$\sigma(I\!\!Pp \to jj) = \int dx_1\, dx_2\, d\hat{t} \sum_{ij} f_{i/I\!\!P}(x_1, Q^2) f_{j/p}(x_2, Q^2) \frac{d\hat{\sigma}}{d\hat{t}}$$



Based on:

pomeron factorization $\quad d\sigma(a + p \to p + X) = f_{I\!\!P/p}(x_{I\!\!P}, t)\, d\sigma(a + I\!\!P \to X)$

$a = p, e, \gamma$ ...

pomeron flux $\quad f_{I\!\!P/p}(x_{I\!\!P}, t) = \frac{9\beta_0^2}{4\pi^2} \left(\frac{1}{x_{I\!\!P}}\right)^{2\alpha_{I\!\!P}(t)-1} [F_1(t)]^2$

pomeron trajectory $\quad \alpha_{I\!\!P}(t) \simeq 1.08 + 0.25t$

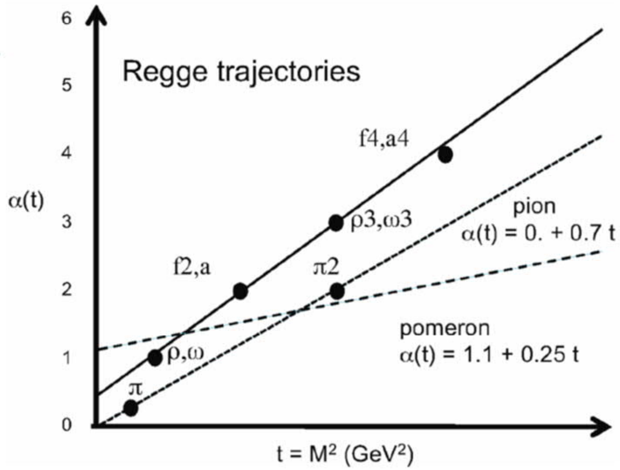
from Regge phenomenology with

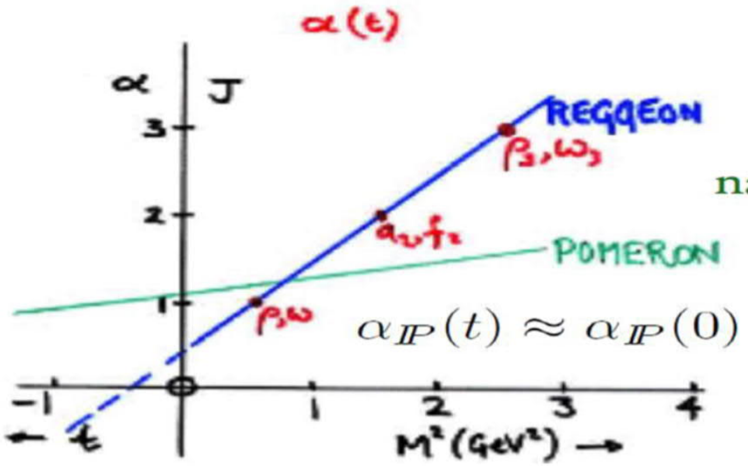
$\beta = 3.24\, GeV^2$ is the mentioned effective pomeron-quark coupling and $F_1(t) = (4m_p^2 - At)/(4m_p^2 - t) \cdot (1 - t/B)^{-2}$ is a proton form factor with m_p the proton mass and parameters $A = 2.8,\ B = 0.7$.

Reggeon Field Theory before QCD

P.D.B. Collins, *An introduction to Regge theory and high energy physics*, Cambridge University Press, Cambridge, 1977.

- V. N. Gribov introduce in the 60´s
- Scattering amplitude at high energies for hadrons is according Regge Theory
- The exchange are "quasi particles" characterized by its Regge trajectories :





named after Pomeranchuk

$$\alpha_{I\!P}(t) \approx \alpha_{I\!P}(0) + \alpha'_{I\!P}\, t \approx 1.08 + (0.25\ \mathrm{GeV}^{-2})\, t$$

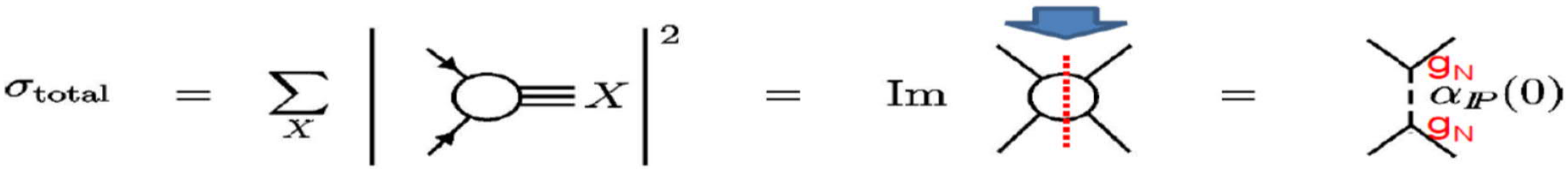
- According to the Regge theory the contribution to the total Cross section, is given by:

$$\sigma_T = A_i s^{\alpha_i(0)-1}$$

- Leading Pole: is Called Pomeron with vacuum quantum numbers

$\alpha(t) = \alpha_0 + \alpha' t$ α_0 is the Pomeron intercept and α' is the slope

optical theorem



Diffractive hard scattering

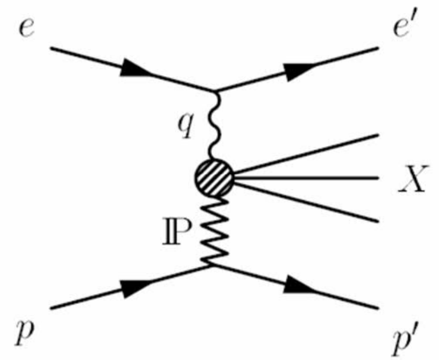
Idea:
Ingelman-Schlein 1984 $\rightarrow$ Blois -85!!
- hard scale probes parton level
- $I\!P$ flux
- $I\!P$ structure function

Predicted:
- jets etc. in hadronic diffraction
- diffractive deep inelastic scatering

Discovery: UA8 at S$p\bar{p}$S 1988
- jets in single diffraction $\simeq$ model
- hard gluons $xg(x) \sim x(1-x)$ in $I\!P$
- 'superhard' $\delta(1-x)$ component

More exp's: HERA ep, Tevatron $p\bar{p}$

Diffractive DIS



$$\frac{d\sigma}{dx\, dQ^2\, dx_{I\!P}\, dt} =$$

$$\frac{2\pi\alpha^2}{xQ^4}\left(1+(1-y)^2\right) F_2^{D(4)}$$

$$F_2^{D(4)}(x,Q^2,x_{I\!P},t) =$$

$$\underbrace{f(x_{I\!P},t)}_{I\!P\text{ flux}}\ \underbrace{F_2^{I\!P}(\beta,Q^2)}_{I\!P\text{ structure}}$$

Fits HERA rapidity gap data