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Hadron single spin asymmetry and polarization relation in reactions involving photons

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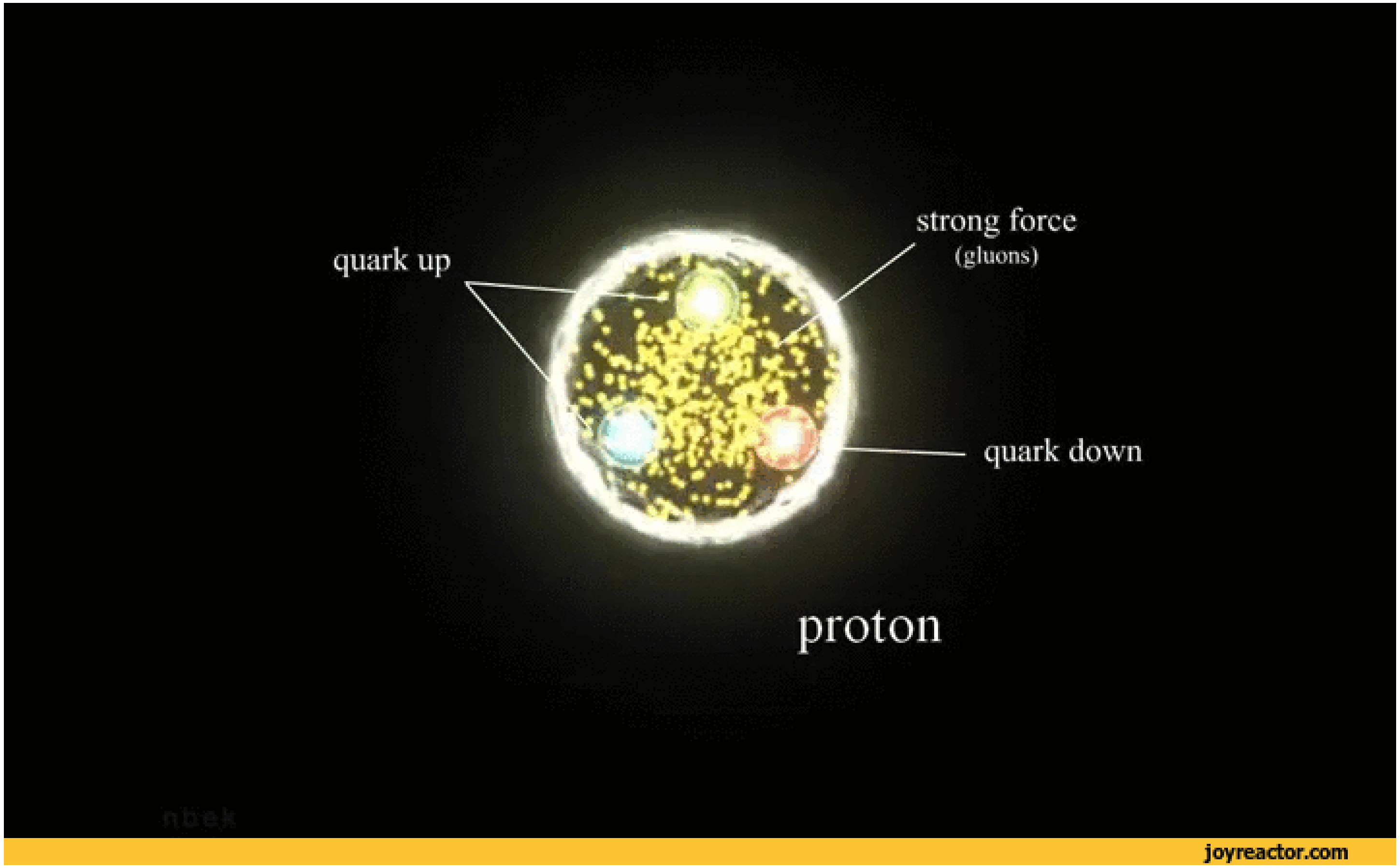
MOTIVATION

SOME PROTON CONUNDRUMS:



SIZE OF THE PROTON

BEFORE:

Proton's radius was about 0,88 femtometers (10^{-15} m)

LAST MEASUREMENTS:

Bernauer, MAMI particle accelerator in Mainz, Germany, using electron scattering: proton's radius ~ 0,88 fm

Randolf Pohl, Max Planck Institute of Quantum Optics in Garching, Germany, a new more precise method. They created muonic hydrogen and studied the muon transitions: proton's radius ~ 0,841 fm

NEW PHYSICS???

LIFE-TIME OF THE PROTON

t = 0 **Big Bang**

t < 10^6 seconds **Quarks and gluons roam freely**

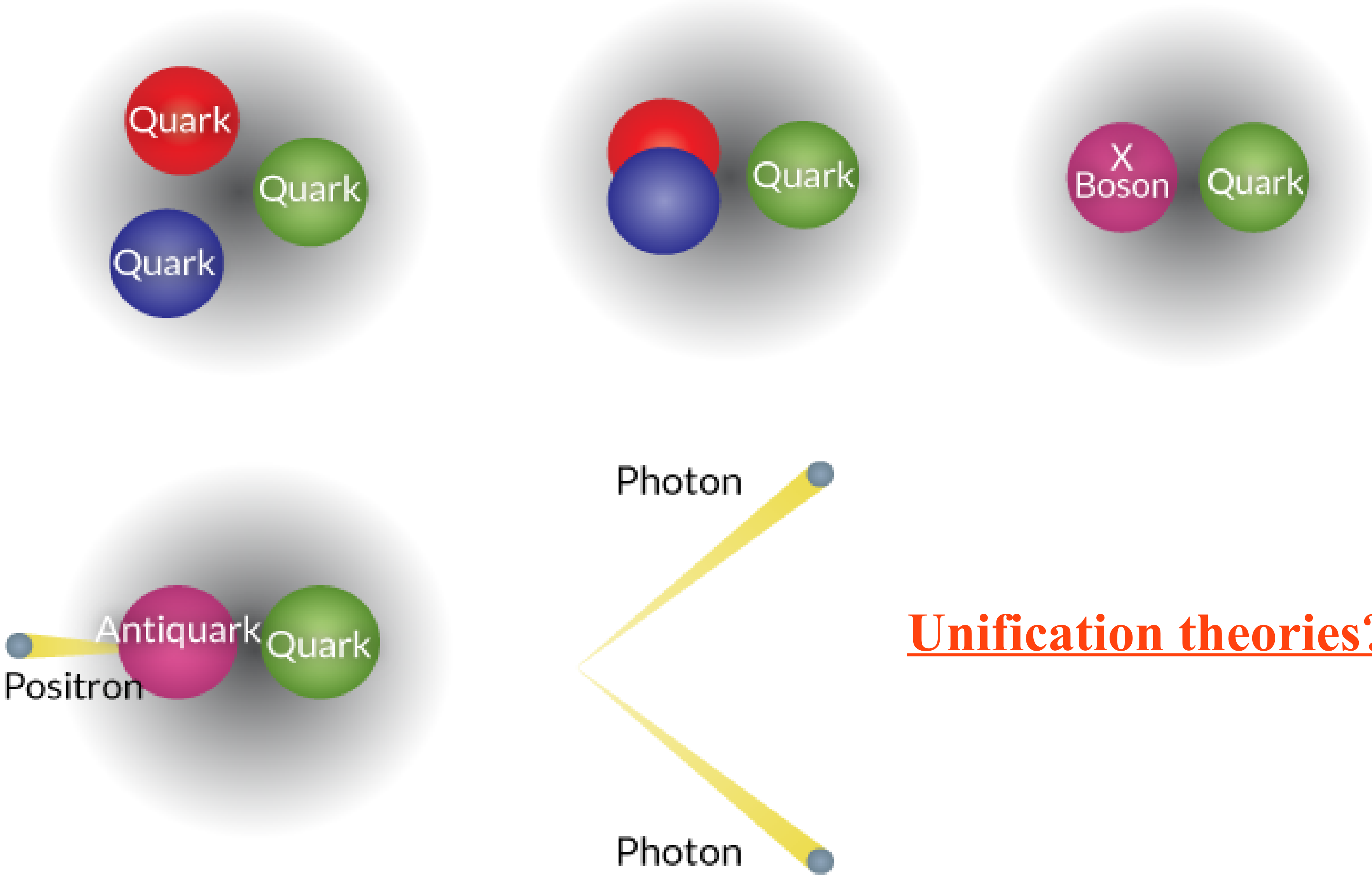
t = 10^6 seconds **Protons and neutrons form**

t = 10 s **Protons and neutrons begin to form atomic nuclei**

t = 13.8 billion years **In today's universe, atoms have formed into stars, planets and intelligent life.**

t = 10^{34} years or later **A substantial portion of protons may have decayed.**

LIFE-TIME OF THE PROTON (cont.)

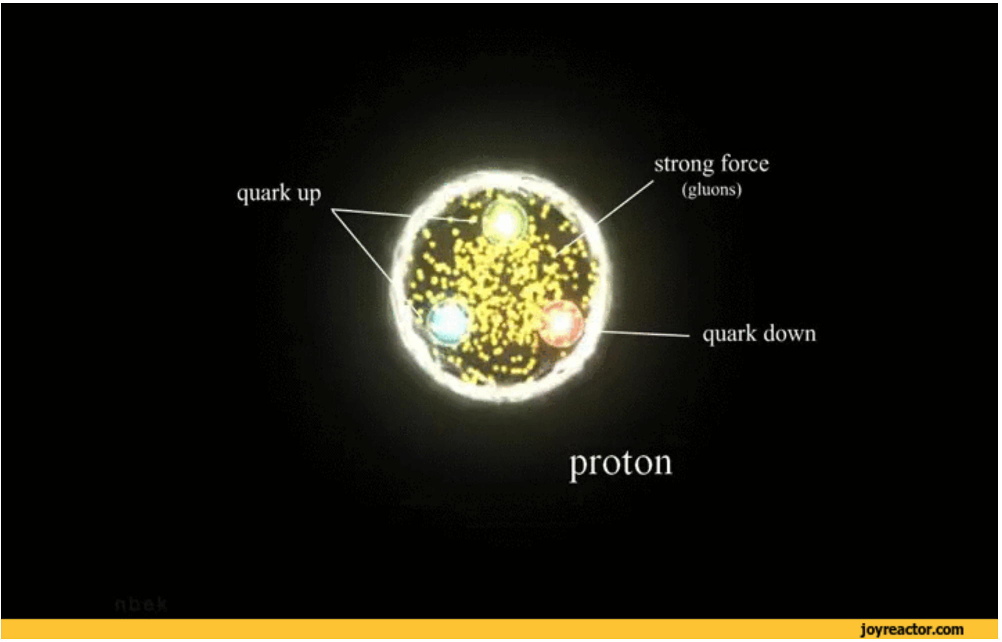


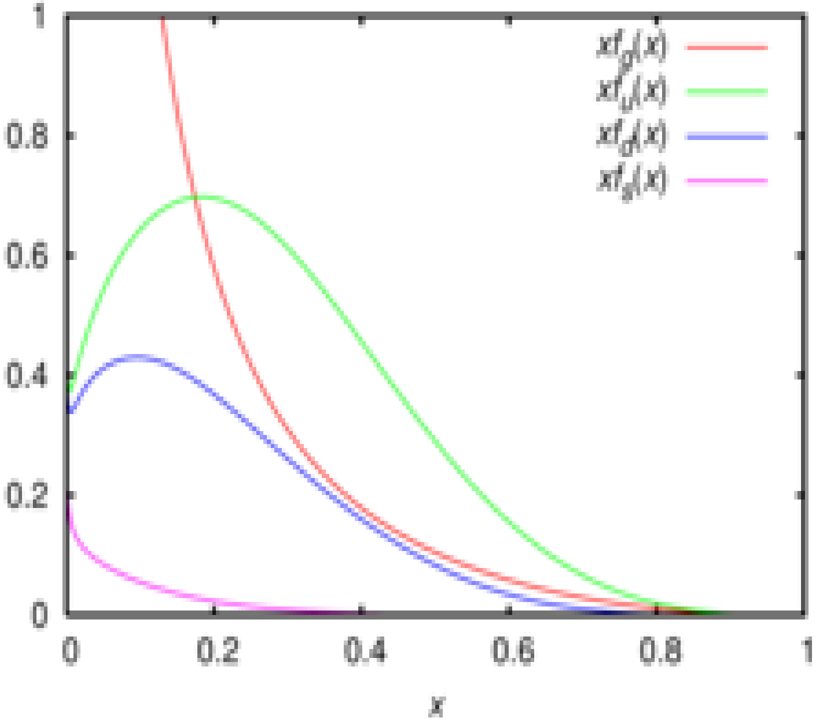
Unification theories???

PROTON CONFINEMENT

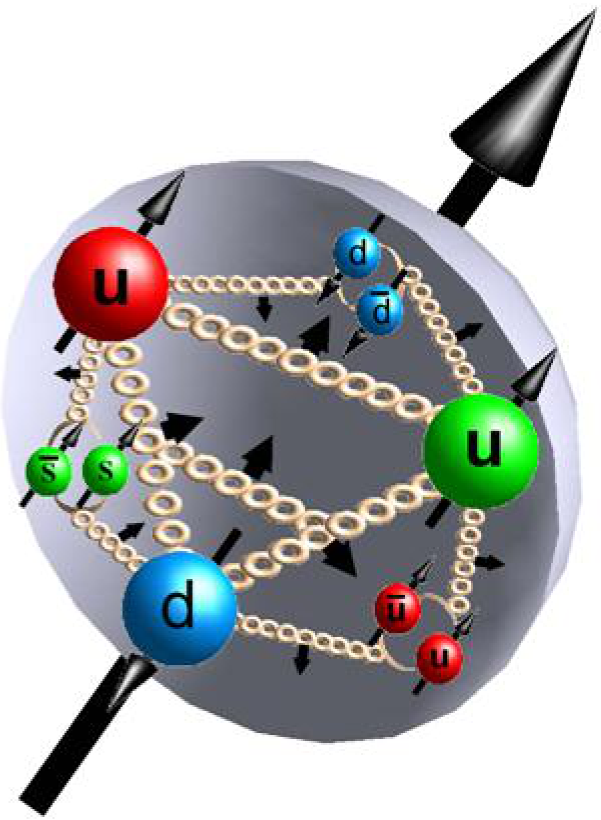
DIVISION OF PROTON ENERGY

Much bigger gluon density intensity close to border





SPIN OF THE PROTON



SPIN CRISIS (1997)

SPIN OF THE PROTON (cont.)

Contributions to Proton Spin:

- Spin of valence quarks
- Orbital motion of valence quarks
- Contribution of gluons
- Contribution of sea quarks ???

Rojo et al, RHIC-Brookhaven:

gluons (35%), valence quarks (25%), unaccounted (40%)

KehFei Liu, Lattice QCD:

gluons (25%), valence quarks (25%), orbital valence quarks motion (50%)

Alternative studies

Hadron single spin (Left-Right) asymmetry and polarization relation in reactions involving photons

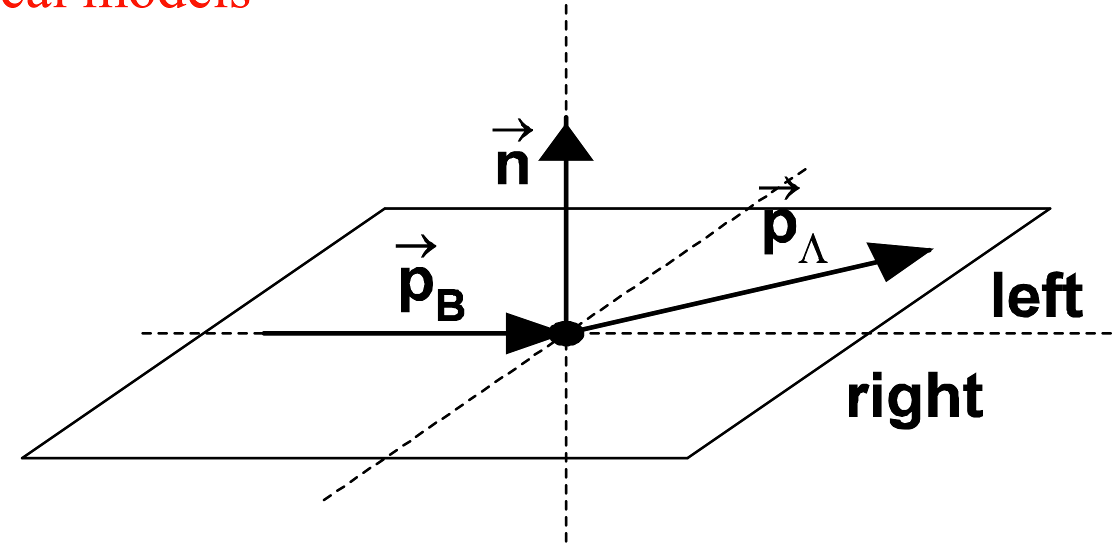
Introduction

Discovery of hyperon polarization in inclusive production at high energies

Left-right asymmetries in single-spin hadron-hadron collisions

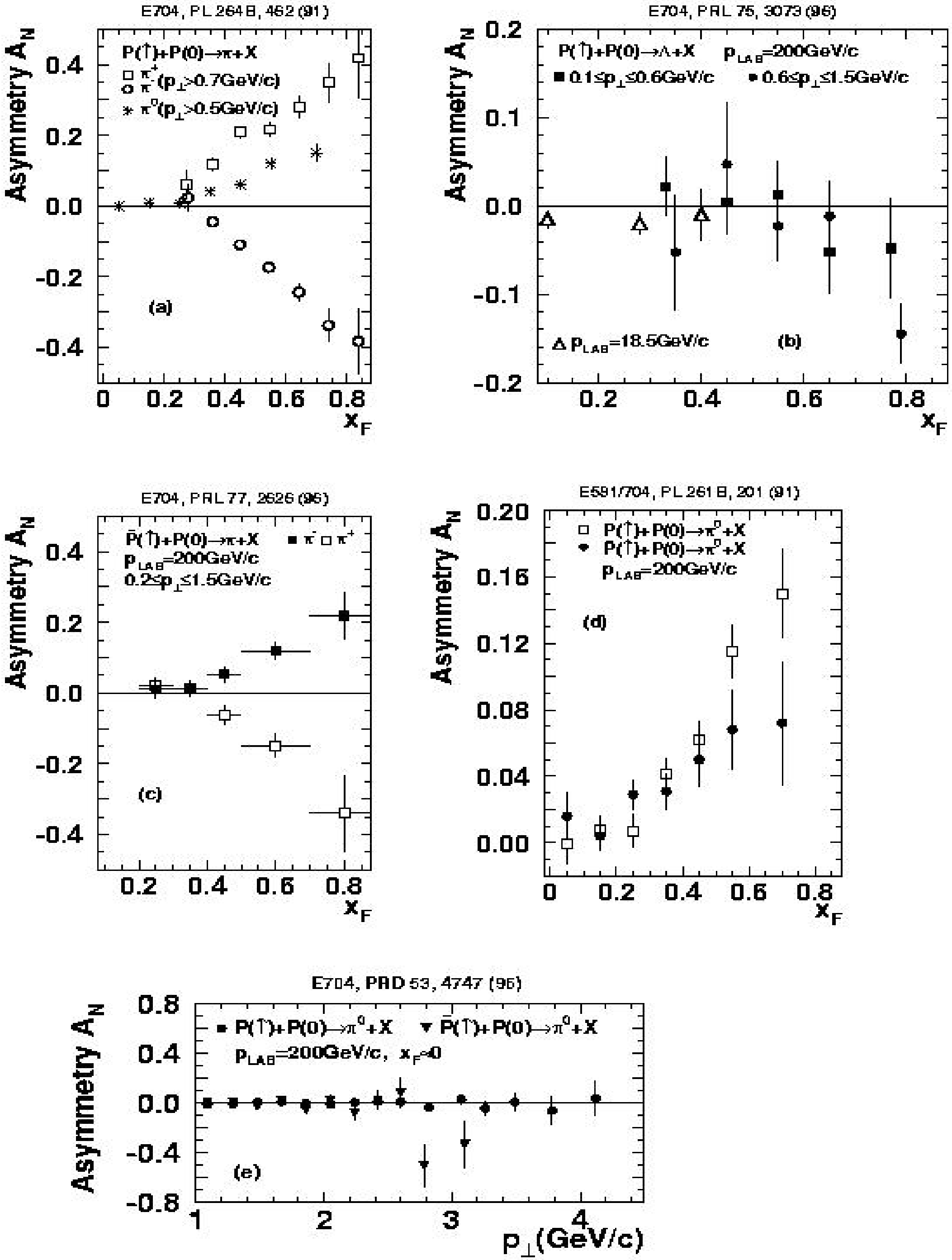
A. Experimental results

B. Theoretical models



$$A_N(x_F, p_T, h|s) \equiv \frac{N_L(x_F, p_T, h|s,\uparrow) - N_L(x_F, p_T, h|s,\downarrow)}{N_L(x_F, p_T, h|s,\uparrow) + N_L(x_F, p_T, h|s,\downarrow)}$$

$$A_N(x_F, p_T, h|s) \equiv \frac{N_L(x_F, p_T, h|s,\uparrow) - N_R(x_F, p_T, h|s,\uparrow)}{N_L(x_F, p_T, h|s,\uparrow) + N_R(x_F, p_T, h|s,\uparrow)}$$



A_N experimental results

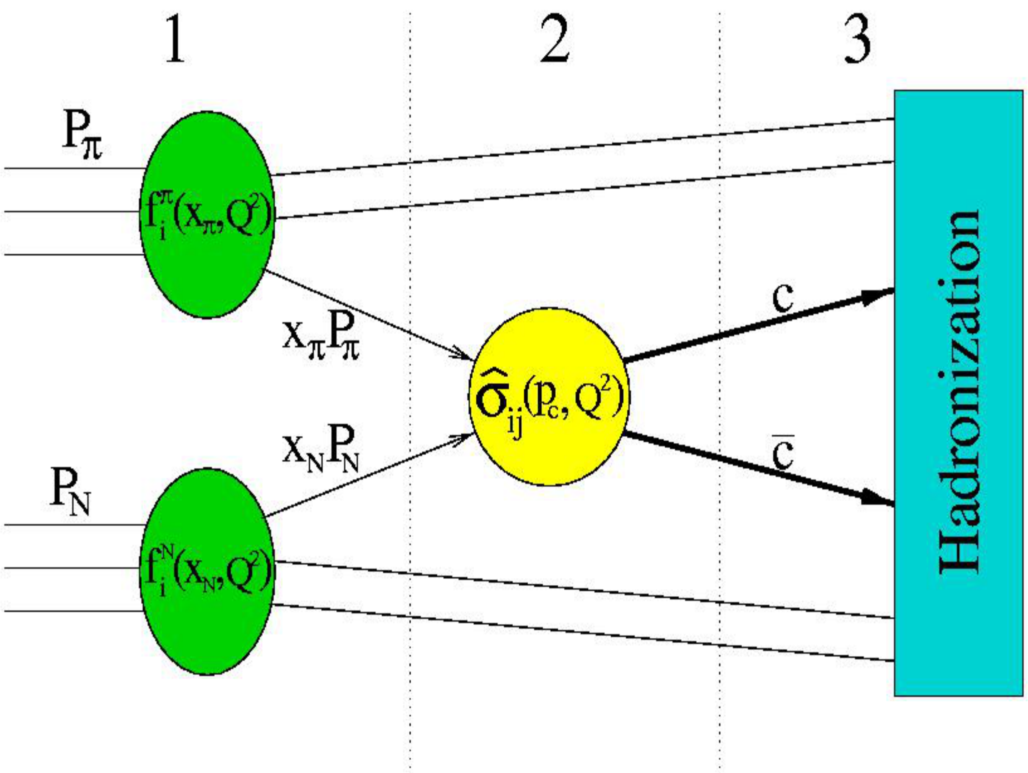
Theoretical Models

A. pQCD based hard scattering models:

1- **Incoming hadron parton distributions:** $f_i^A(x_A, Q^2)$

2- $q\bar{q}$ **production from partons** $\hat{\sigma}_{ij}(p_c, Q^2)$ Calculable? by pQCD

3- $q\bar{q}$ **hadronization (fragmentation) into hadrons:** Incalculable by pQCD



A. pQCD based hard scattering models (cont.):

In order to describe the observed large asymmetries we can make use of one these possibilities:

1- Look for higher order in the elementary processes which may lead to larger asymmetries

2- Introduce asymmetric intrinsic transverse momentum distributions for the transversely polarized quarks in a transversely polarized nucleon

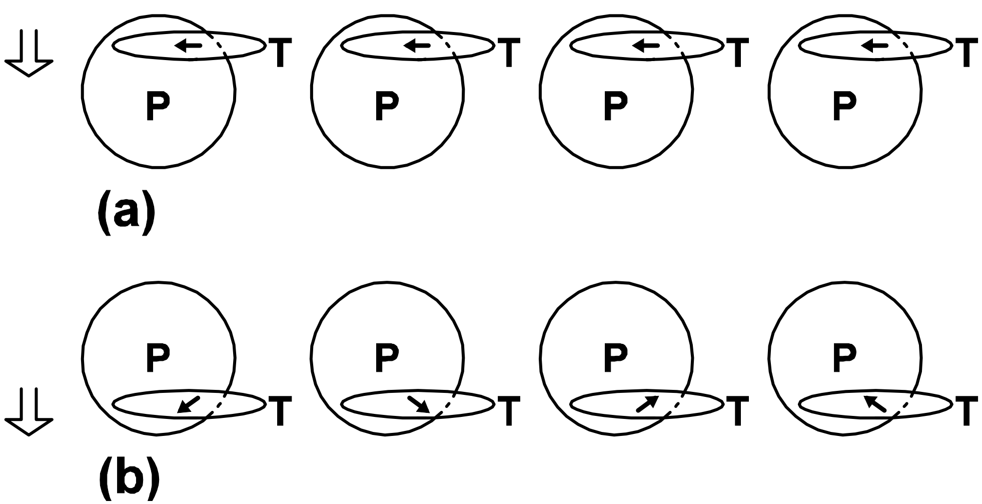
3- Introduce asymmetric transverse momentum distribution in the fragmentation functions for the transversely polarized quarks, which lead to the observed hadrons

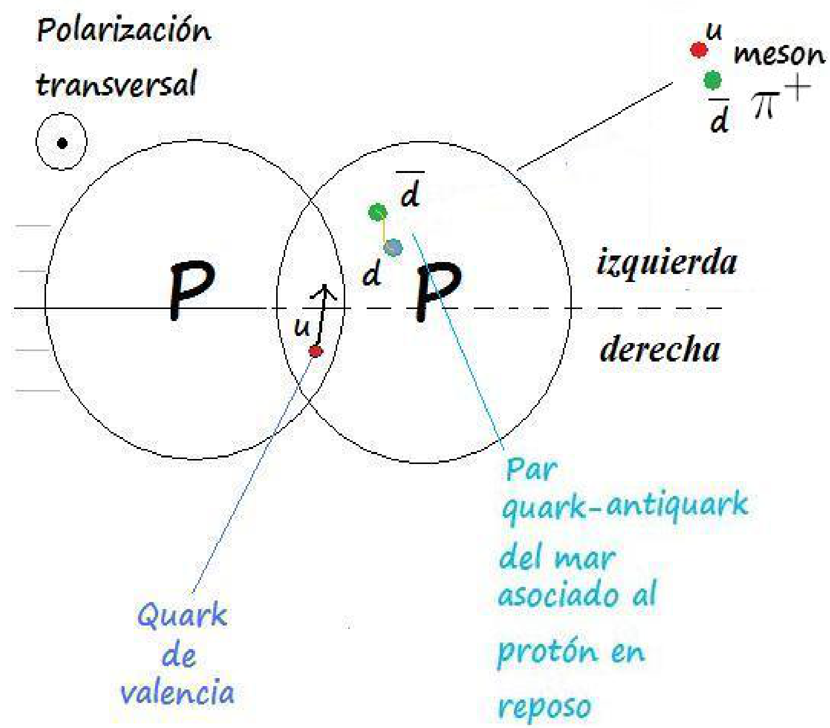
The cross sections of the elementary processes are result of theoretical calculations.

Probabilities 2- and 3- can only be probed experimentally because those asymmetric momentum distributions are introduced by hand.

B. Non-perturbative quark-antiquark fusion models:

- Orbiting Valence Quark Model based in the Static (constituent) Quark Model.
- Basic elementary process is quark-antiquark fusion (incalculable by pQCD). The fusion is of 1(2) valence quark(s) of Projectile with suitable sea quark/antiquark(s) from the Target.
- Existence of orbital motion of the valence quarks in transversely polarized nucleons.
- Existence of *surface effect* in single spin hadron-hadron collisions.





B. Non-perturbative quark-antiquark fusion models (cont.):

The number density of produced h´s is given by

$$N(x_F,p_T,h|s) \equiv N_0(x_F,p_T,h|s) + D(x_F,p_T,h|s)$$

where $N_0(x_F,p_T,h|s)$ is the contribution for non-direct formation and $D(x_F,p_T,h|s)$ the number density of h´s produced through direct formation process $q_v^P + \bar{q}_s^T \rightarrow h$

The left-right asymmetry is dominated by

$$\Delta N(x_F,p_T,h|s,tr) \equiv C \cdot \Delta D(x_F,p_T,h|s,tr)$$

experimentally C ~ 0.6

$$D(x_F,h|s) = \sum_{q_v,\bar{q}_s} \int dx^P dx^T q_v(x^P)\bar{q}_s(x^T) K(x^P,q_v;x^T,\bar{q}_s|x_F,h,s)$$

$$D(x_F,h|s) \approx k_h \cdot q_v(x_F)\bar{q}_s\left(\frac{x_0}{x_F}\right)$$

where $x_0 = \frac{m_h^2}{s}$

In fragmentation region $N(x_F,h|s) \propto D(x_F,h|s) \propto q_v(x_F)$

B. Non-perturbative quark-antiquark fusion models (cont.):

The polarization of the valence quarks inside a polarized nucleon is determined by the wave function of the model (Static (constituent) Quark Model).

This implies that, for proton, 5/3 of the 2 u valence quarks are polarized in the same, and 1/3 in the opposite, direction as the proton. For d, they are 1/3 and 2/3 respectively.

It should be emphasized that $q(x_F, tr) \neq q(x_F, l)$

The simplest ansatz is

$$u_v^+(x_F, tr) = \frac{5}{6} u_v(x_F) \qquad u_v^-(x_F, tr) = \frac{1}{6} u_v(x_F)$$

$$d_v^+(x_F, tr) = \frac{1}{3} d_v(x_F) \qquad d_v^-(x_F, tr) = \frac{2}{3} d_v(x_F)$$

Properties of $\pi^{\pm}$, π^0 or η in $p(\uparrow)+p(0)\rightarrow\pi^{\pm}(\pi^0,\eta)+X$

P(sea)—T(val)					P(val)—T(sea)				
P(sea)	u	$\bar{u}$	d	$\bar{d}$	P(val)	u		d	
p_y	0	0	0	0	p_y	$\leftarrow$	$\rightarrow$	$\leftarrow$	$\rightarrow$
Weight	1	1	1	1	Weight	5/3	1/3	1/3	2/3
T(val)		d		u	T(sea)	$\bar{d}$	d	$\bar{u}$	u
p_y		0		0	p_y	0	0	0	0
Weight		1		2	Weight	1	1	1	1
Product		$d\bar{u}$		$u\bar{d}$	Product	$u\bar{d}$		$d\bar{u}$	
p_y		0		0	p_y	$\leftarrow$	$\rightarrow$	$\leftarrow$	$\rightarrow$
Weight		1		2	Weight	5/3	1/3	1/3	2/3
T(val)		u		d	T(sea)	$\bar{u}$	u	$\bar{d}$	d
p_y		0		0	p_y	0	0	0	0
Weight		2		1	Weight	1	1	1	1
Product		$u\bar{u}$		$d\bar{d}$	Product	$u\bar{u}$		$d\bar{d}$	
p_y		0		0	p_y	$\leftarrow$	$\rightarrow$	$\leftarrow$	$\rightarrow$
Weight		2		1	Weight	5/3	1/3	1/3	2/3

Properties of $\pi^{\pm}$, π^0 or η in $\bar{p}(\uparrow)+p(0)\rightarrow\pi^{\pm}(\pi^0,\eta)+X$

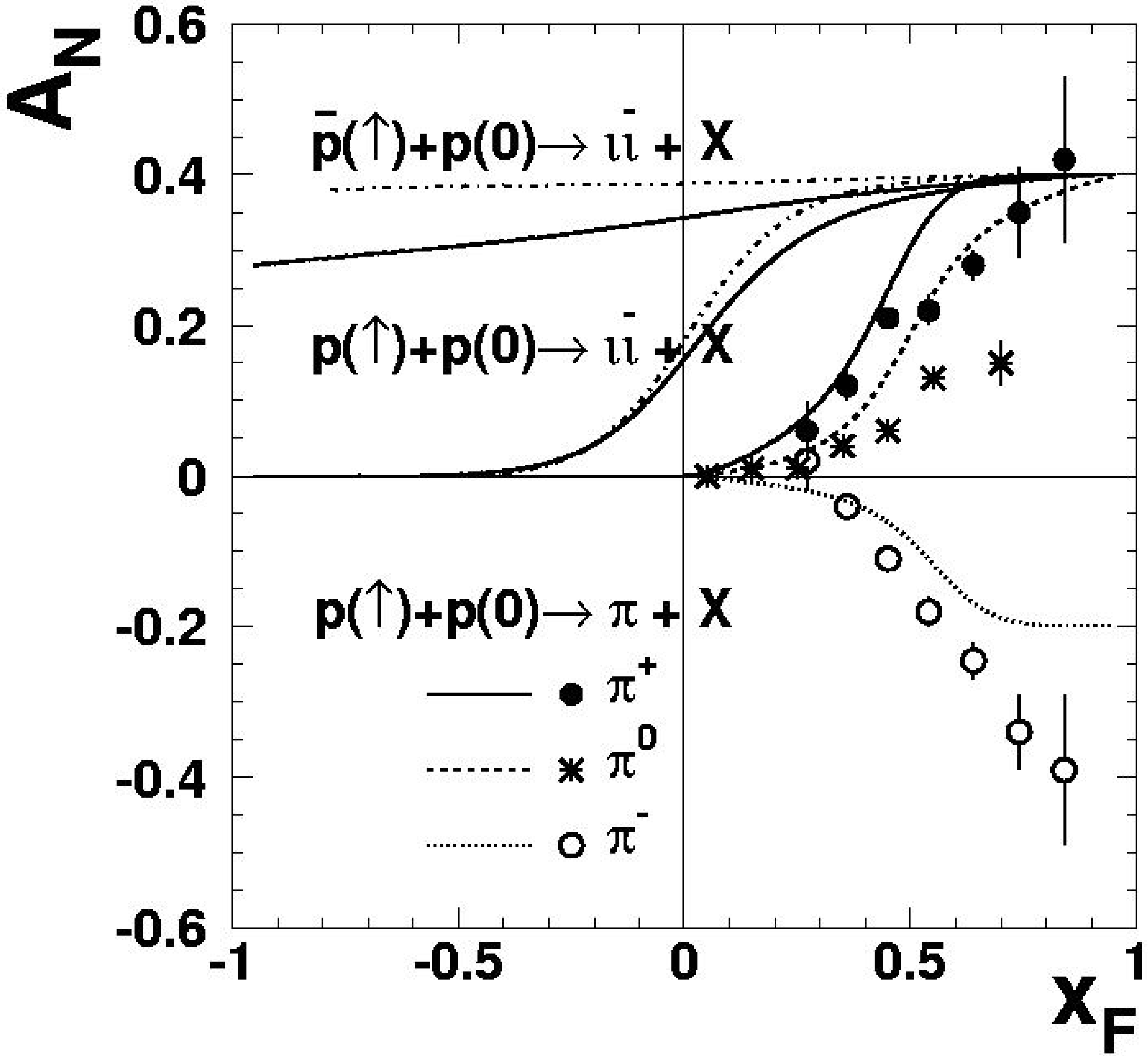
P(sea)—T(val)

P(sea)	u	$\bar{u}$	d	$\bar{d}$
p_y	0	0	0	0
Weight	1	1	1	1
T(val)		d		u
p_y		0		0
Weight		1		2
Product		$d\bar{u}$		$u\bar{d}$
p_y		0		0
Weight		1		2
T(val)		u		d
p_y		0		0
Weight		2		1
Product		$u\bar{u}$		$d\bar{d}$
p_y		0		0
Weight		2		1

P(val)—T(sea)

P(val)		$\bar{u}$				$\bar{d}$		
p_y	$\leftarrow$		$\rightarrow$		$\leftarrow$		$\rightarrow$	
Weight	5/3		1/3		1/3		2/3	
T(sea)		d		$\bar{d}$		u		$\bar{u}$
p_y		0		0		0		0
Weight		1		1		1		1
Product		$d\bar{u}$				u$\bar{d}$		
p_y	$\leftarrow$		$\rightarrow$		$\leftarrow$		$\rightarrow$	
Weight	5/3		1/3		1/3		2/3	
T(sea)		u		$\bar{u}$		d		$\bar{d}$
p_y		0		0		0		0
Weight		1		1		1		1
Product		$u\bar{u}$				$d\bar{d}$		
p_y	$\leftarrow$		$\rightarrow$		$\leftarrow$		$\rightarrow$	
Weight	5/3		1/3		1/3		2/3	

Pion and lepton pair production



Proposed Reactions

A. Left-right asymmetry in $e^- + p(\uparrow) \to e^- + \pi^\pm + X$

We consider the photon from the eeγ - vertex.

The effective interaction is $\gamma + p(\uparrow) \to \pi^\pm + X$

The left-right asymmetry is

$$A_{\gamma p}^{\pi^+}(x_F, Q|s) = \frac{C_\gamma k_\pi [\Delta u_v^p(x^p, Q^2)] \bar{d}^\gamma(x^\gamma, Q^2)}{N_0(x_F|s) + 2 k_\pi u_v^p(x^p, Q^2) \bar{d}^\gamma(x^\gamma, Q^2)}$$

N_0 is significant only for small x_F . Then for $x_F > 0.5$

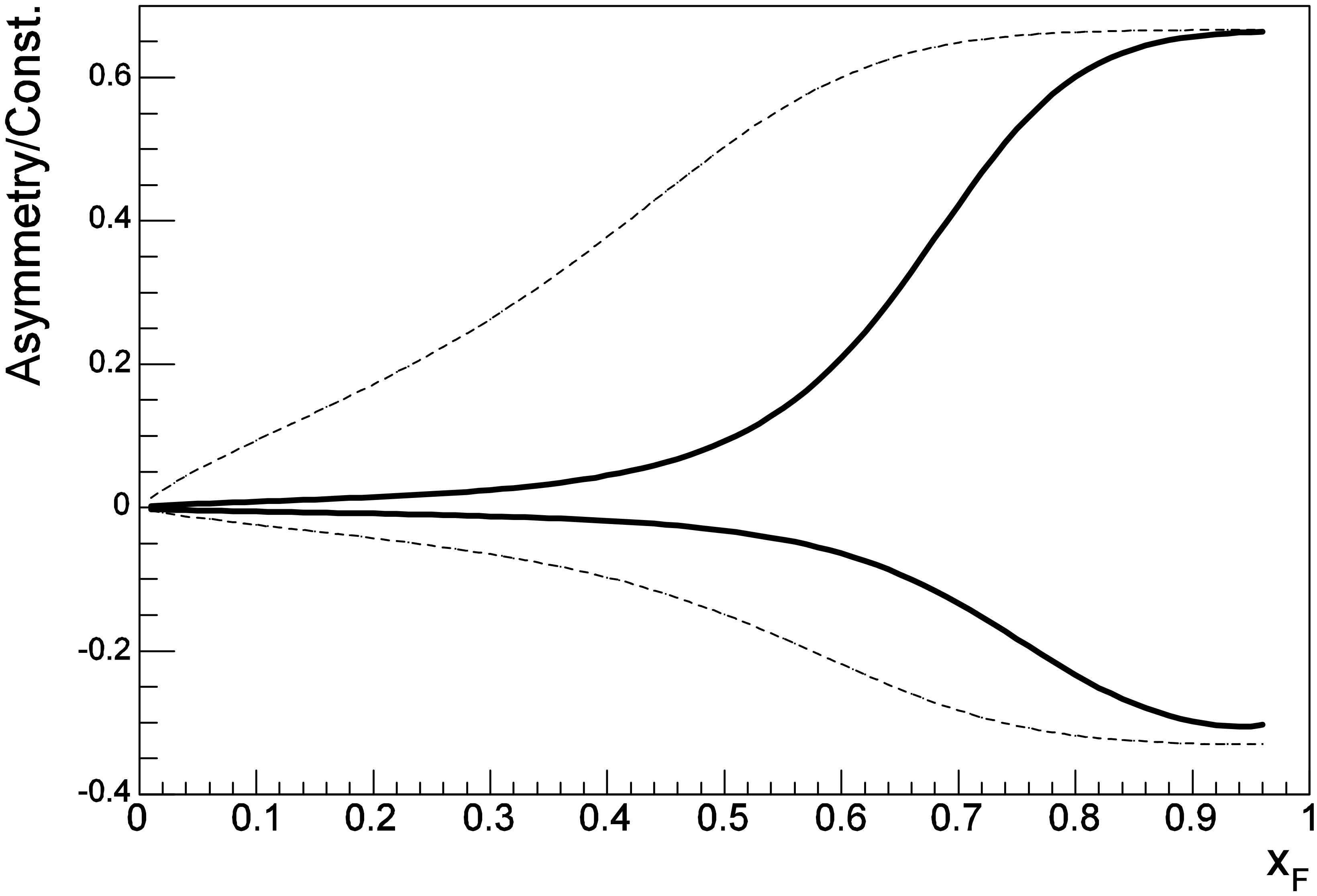
$$A_{\gamma p}^{\pi^+} \simeq C_\gamma \frac{\Delta u_v^p(x^p, Q^2)}{2 u_v^p(x^p, Q^2)} \simeq \frac{2}{3} C_\gamma$$

This predicts $A_{\gamma p}^{\pi^+}$ positive for large x_F and similar to $A_N^{\pi^+}$ seen in $p(\uparrow) + p \to \pi^+ + X$

and $A_{\gamma p}^{\pi^-}$ to be smaller than $A_{\gamma p}^{\pi^+}$ but negative and similar to $A_N^{\pi^-}$

A. Left-right asymmetry in $\gamma + p(\uparrow) \rightarrow \pi^{\pm} + X$ and $p(\uparrow) + p \rightarrow \pi^{\pm} + X$

(using PDFs of CTEQ for proton and GRSV for photon)



B. Transverse polarization of hyperon (H) in

$$e^{-} + p \rightarrow e^{-} + H + X$$

- Here the effective interaction is $\gamma + p \rightarrow H + X$

where p is unpolarized and H = Λ, Σ, Ξ, etc.

- Kinematics is like case A, but here the hyperon tranverse polarization P(H) is measured.

Denote transverse polarization of a valence quark, in the unpolarized proton, by $\uparrow(\downarrow)$

- Assume a quark with upward $(\uparrow)$ (downward $(\downarrow)$) polarization preferentially scatter to the left (right) in the production plane with respect to the beam direction.

- This quark will combine with a two quark state $(qq)_{\gamma}$ from the photon to form hyperon H. It is also possible that two quarks from the proton combine with a quark from the photon to to give the polarized H.

Some examples for transverse polarization of hyperon (H) in

$$e^{-}+p \rightarrow e^{-}+H+X$$

1- When H = Σ^-(dds)

- Only valence d-quark from the proton $\left(d_v^p\right)$ is common with those in Σ^-.

- Let probability of $d_v^p(\uparrow)\left(d_v^p(\downarrow)\right)$ from the proton to move to left (right) be α. Then the probability to move to right (left) will be (1-α)

- The unpolarized proton has equal probability of having $d_v^p(\uparrow)$ or $d_v^p(\downarrow)$

- But the probability of $d_v^{\Sigma}(\uparrow)\left(d_v^{\Sigma}(\downarrow)\right)$ in a $\Sigma^{-}(\uparrow)$ is 5/6 (1/6).

- We expect $N\left(\Sigma^{-}(\uparrow)\right)$, number of $\Sigma^{-}(\uparrow)$ formed by left moving $d_v^p(\uparrow)$ or $d_v^p(\downarrow)$ will be proportional to $\frac{5}{6}\alpha+\frac{1}{6}(1-\alpha)$, while $N\left(\Sigma^{-}(\downarrow)\right)$ to $\frac{1}{6}\alpha+\frac{5}{6}(1-\alpha)$

- Thus, one expects that the polarization

$$P\left(\Sigma^{-}\right)=\frac{N\left(\Sigma^{-}(\uparrow)\right)-N\left(\Sigma^{-}(\downarrow)\right)}{N\left(\Sigma^{-}(\uparrow)\right)+N\left(\Sigma^{-}(\downarrow)\right)}=\frac{2}{3}(2\alpha-1)$$

- As expected, this is zero if α = 1/2. Since, it is assumed α ≥ 1/2, the model predicts

$$0 \leq P\left(\Sigma^{-}\right) \leq \frac{2}{3}$$

Other examples:

2- H = Ξ^-(dss) and Ξ^0(uss)

The u_v^p and d_v^p will contribute to their production by combining with $(ss)_\gamma$ - state from the photon. One expects

$$P(\Xi^-)=P(\Xi^0)=\frac{1}{3}(1-2\alpha)=-\frac{1}{2}P(\Sigma^-)$$

3- H = $\Sigma^\pm$(uus)

There are two formation mechanisms: (1) $u_v^p+(us)_\gamma$ and (2)$(uu)_v^p+(s)_\gamma$. One expects that at low x_F the non-direct formation dominates, at middle x_F (0.4-0.6) the mechanism (1) will dominate (then $P(\Sigma^+)\simeq P(\Sigma^-)$ or smaller), and a large x_F the mechanism (2).

4- H = Σ^0(uds)

There are 3 formation mechanisms: (1) $u_v^p+(ds)_\gamma$, (2) $d_v^p+(us)_\gamma$ and (3) $(ud)_v^p+(s)_\gamma$
If the valence diquark mechanism is negligible one may expect $P(\Sigma^0)\simeq P(\Sigma^-)$

5- H = Λ^0(uds)

Here the polarization comes only from the s-quark. The mechanism suggested is the associated production of $K^+(u_v^p\bar{s}_\gamma)$ or $K^0(d_v^p\bar{s}_\gamma)$. One expects $P(\Lambda^0)=-(2\alpha-1)$

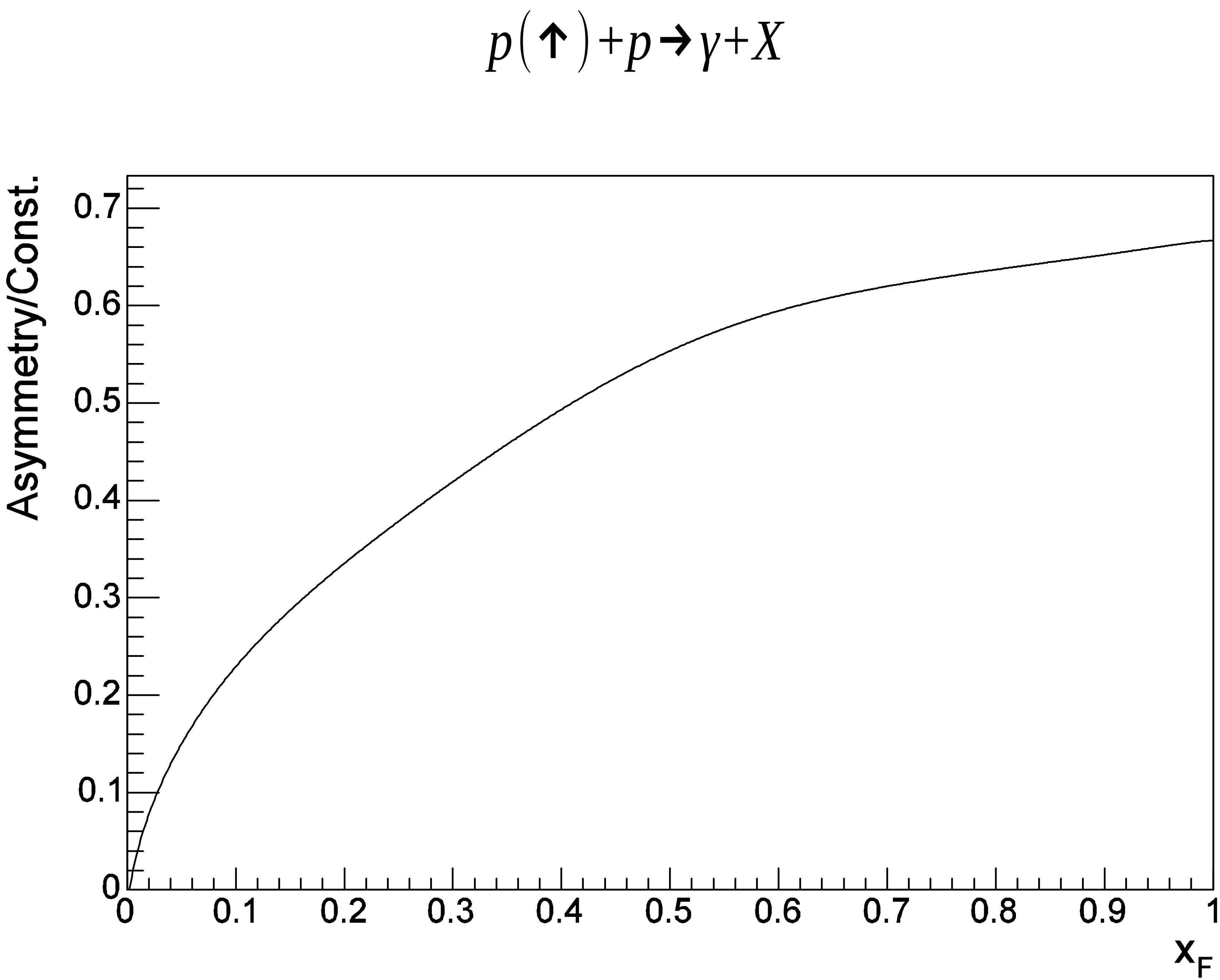
C. Left-right asymmetry in $p(\uparrow)+p \rightarrow \gamma+X$:

- It has a larger cross section than $p(\uparrow)+p \rightarrow l^{+} l^{-}+X$
- In this reaction the projectile proton is polarized, so one expect a A_N^{γ} left-right asymmetry of the emitted photon very small (exper. results compatible with zero).
- The process at the quark level is $q_v^P(tr)+\bar{q}_s^T \rightarrow \gamma+gluon$ where $q_v^P=u,d$ and $\bar{q}_s$ is from the sea of the other proton.
- Formation of γ through $u\bar{u}$ is 4 times larger than through $d\bar{d}$
- The model gives the asymmetry

$$A_N^{\gamma}(x_F^{\gamma})=\frac{C_{\gamma} k_{\gamma}[4\Delta u_v^p(x^p)\bar{u}_s^T(x^T)+\Delta d_v^p(x^p)\bar{d}_s^T(x^T)]}{N_0(x_F^{\gamma})+k_{\gamma}[4u_v^p(x^p)\bar{u}_s^T(x^T)+d_v^p(x^p)\bar{d}_s^T(x^T)]}$$

- For large $x_p^{\gamma}>0.5$ one expects

$$A_N^{\gamma}(x_F^{\gamma})\approx\frac{C_{\gamma}}{3}\frac{8u_v^p(x^p)+d_v^p(x^p)}{4u_v^p(x^p)+d_v^p(x^p)}$$



$p(\uparrow)+p \rightarrow \gamma+X$
Asymmetry/Const.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x_F

D. Effects of Sea Polarization:

- Experimental studies of g_1^p structure function (J.Ashman et.al.) led to the possibility that the sea of the proton is strongly polarized (Goshtasbpour, Ramsey).
- This could lead to a possible observable asymmetry in the target fragmentation region ($x_F < 0$).
- Consider the rection $p(\uparrow)+p\rightarrow\pi^{\pm}+X$ where the projectile is polarized

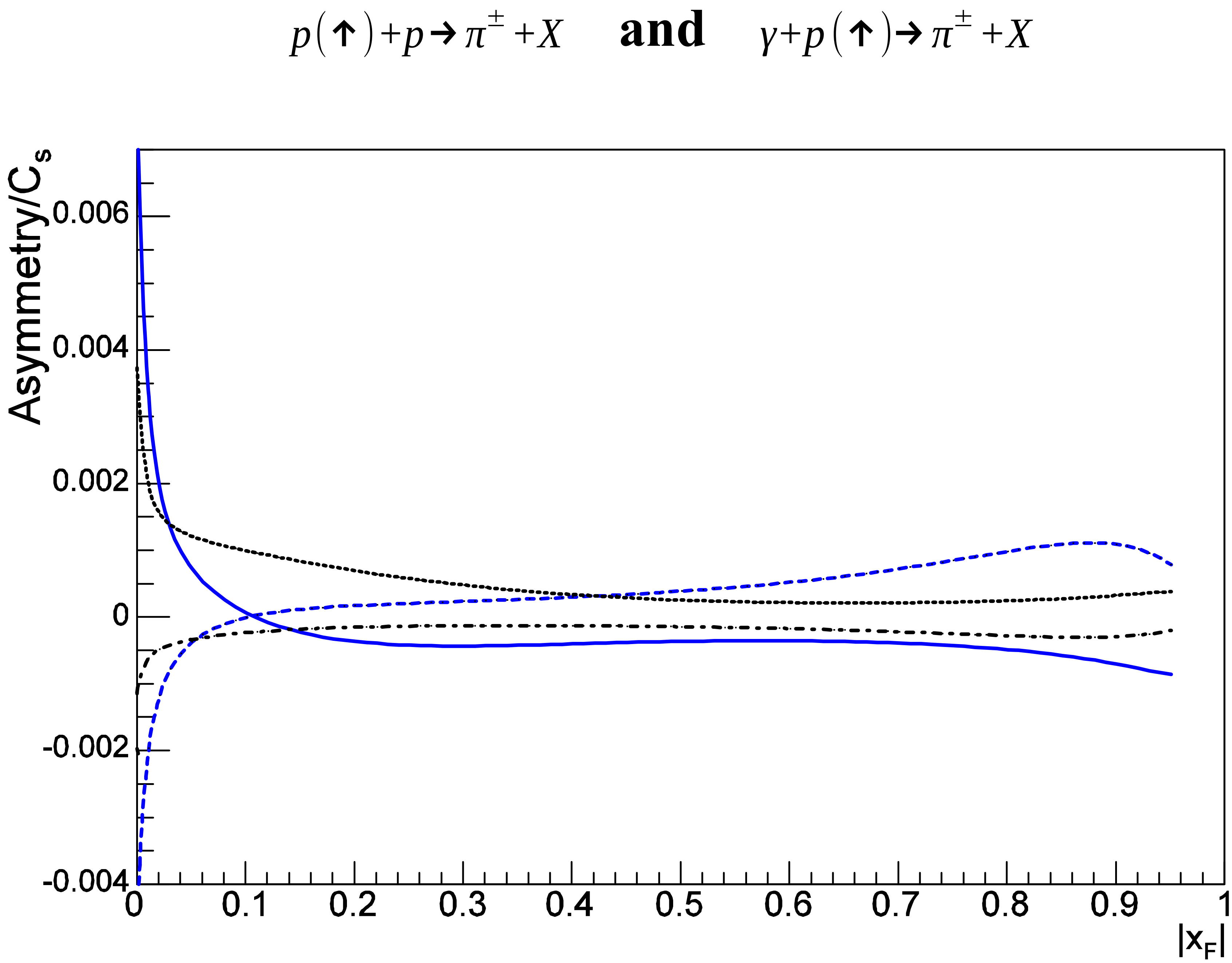
$$A_N^{\pi^+}(-|x_F|,s)=\frac{C_s k_\pi \Delta \bar{d}_s^p(x^p)u_v^T(x^T)}{N_0(-|x_F|)+k_\pi d_s^p(x^p)u_v^T(x^T)}$$

- $A_N^{\pi^-}$ is obtained by $u\leftrightarrow d$. Note that $-x^T+x^P=-|x_F|$ and $|x^P x^T|=m_\pi^2/s$
- One can also prove the sea polarization with reaction $\gamma+p(\uparrow)\rightarrow\pi^{\pm}+X$

$$A_{\gamma p}^{\pi^+}(-|x_F|,s)=\frac{C_s^\gamma k_\pi \Delta \bar{u}_s^p(x^p)d_\gamma(x^\gamma)}{N_0(-|x_F|)+k_\pi u_s^p(x^p)d_\gamma(x^\gamma)}$$

- $A_{\gamma p}^{\pi^+}$ is obtained by $u\leftrightarrow d$
- Estimates of $\Delta\bar{u}_s$ have been extracted (Goshtasbpour-Ramsey) from data giving

$$\Delta\bar{u}_s\approx(-0.1)u_s$$



$p(\uparrow)+p\to\pi^{\pm}+X$ and $\gamma+p(\uparrow)\to\pi^{\pm}+X$
Asymmetry/C_s
0.006
0.004
0.002
0
-0.002
-0.004
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
$|x_F|$

Conclusions

- In this preliminar work, test of a particular phenomenological model are given for some new processes.
- In particular, relations like $P(\Sigma^{-}) = -2P(\Xi^{0})$ for process B and $A_{\gamma p}^{\pi^{+}} \approx \frac{2}{3} C_{\gamma}$ in B, provide new and simple tests of the model.
- The processes which provide these tests would prove small x-region of the proton (C) and photon (A).
- Further, the possibility of a left-right asymmetry in the target fragmentagion due to a polarized sea is suggested.
- We expect that the new generation of experiments (maybe at Jefferson Lab?), will be able to measure the effects discussed above.