EDS

EVANSTON (89)

NEW YORK (87)

ELBA (91)

PROVIDENCE (93)

BLOIS (85)

HAMBURG (07)

BLOIS (95)

CERN (09)

SEOUL (97)

BLOIS (05)

PROTVINO (99)

HELSINKI (03)

PRAGUE (01)

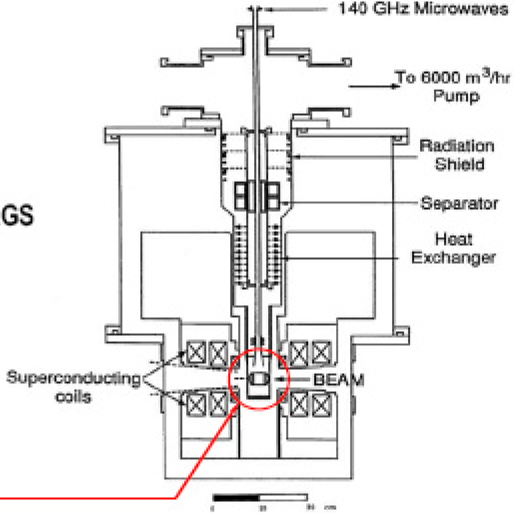
BLOIS CONFERENCES

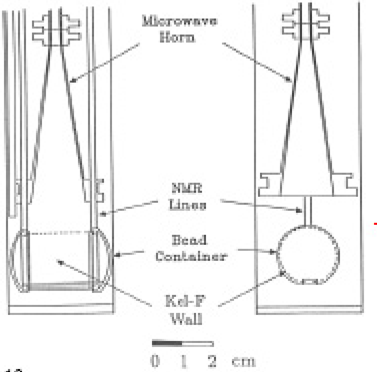
Elastic Scattering Spin Obervablas Confront QCD

d. sivers

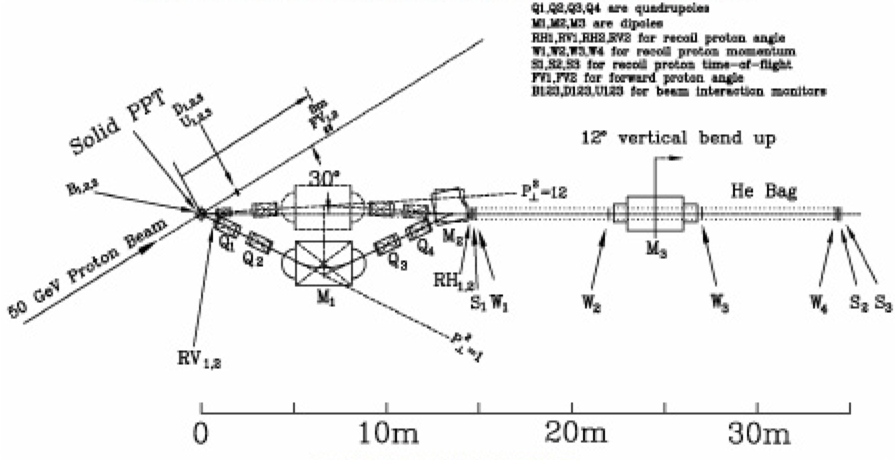
MICHIGAN SOLID POLARIZED PROTON TARGET
NOW at KEK

- Highly uniform 5 T field
- 1 W of cooling power at 1 K
- 140 GHz / 20 W microwaves
- NH_3 in target cavity
- 96% proton polarization in NH_3
- 85% average over 3-month at AGS





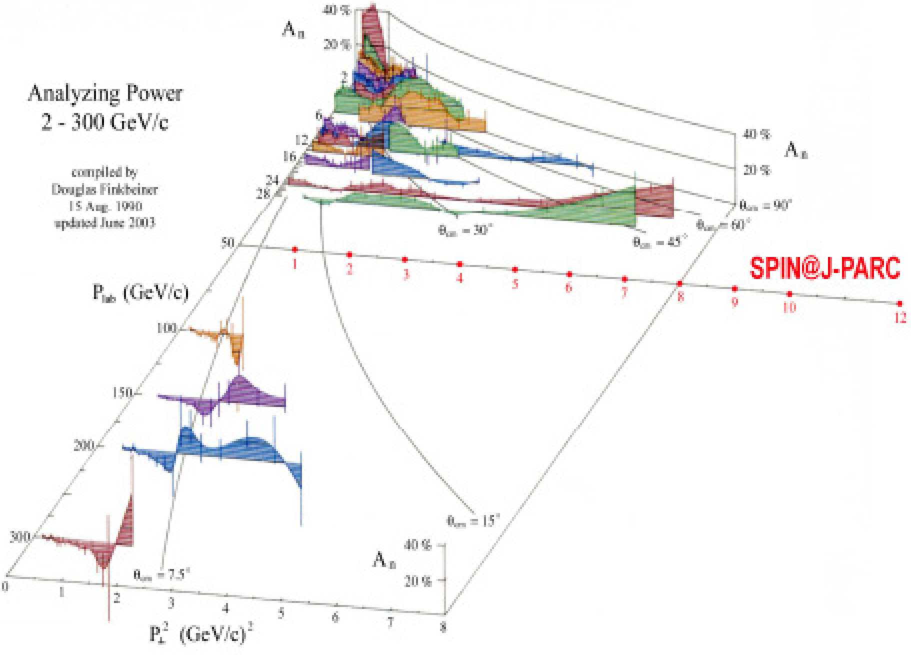
PROPOSED SPIN@J-PARC SPECTROMETER



MAGNET PARAMETERS

MAGNET	LENGTH (m)	DIAMETER OR GAP (cm)	B'_{MAX} (T/m)	B_{MAX} (T)
Q_1, Q_2, Q_3, Q_4	1.00	20	14.8	
Q_1^{SUPER}	0.60	10x16	60.8	
M_1, M_3	3.00	20		1.8
M_2	1.50	20		1.8

ANALYZING POWER for PROTON-PROTON ELASTIC SCATTERING



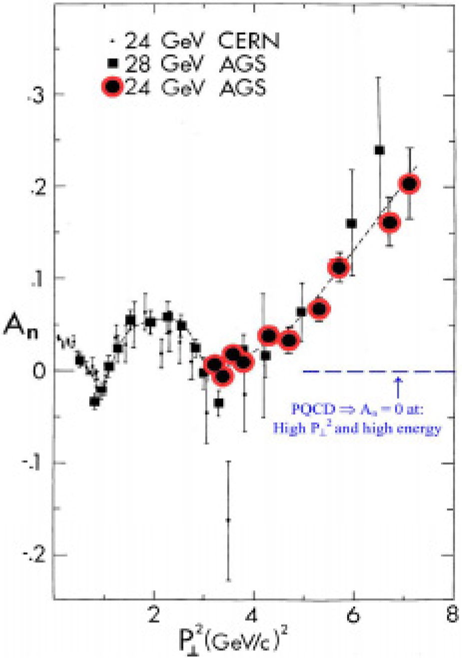
AGS A_n DATA

PERTURBATIVE QCD $\Rightarrow$
$A_n = 0$ at HIGH $P_\perp^2$ and HIGH ENERGY

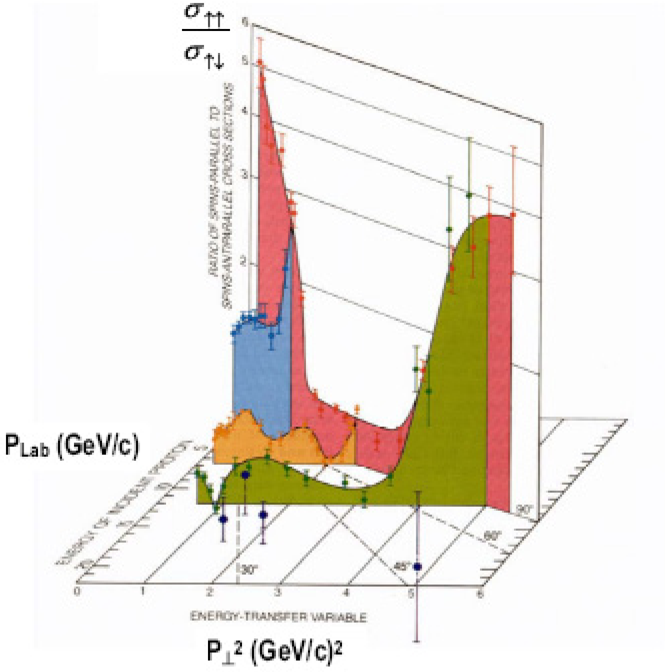
$A_n \neq 0 \Rightarrow$
PROBLEM WITH PQCD?

NO MODEL CAN EXPLAIN ALL
HIGH-$P_\perp^2$ SPIN EFFECTS (A_n & A_{nn})

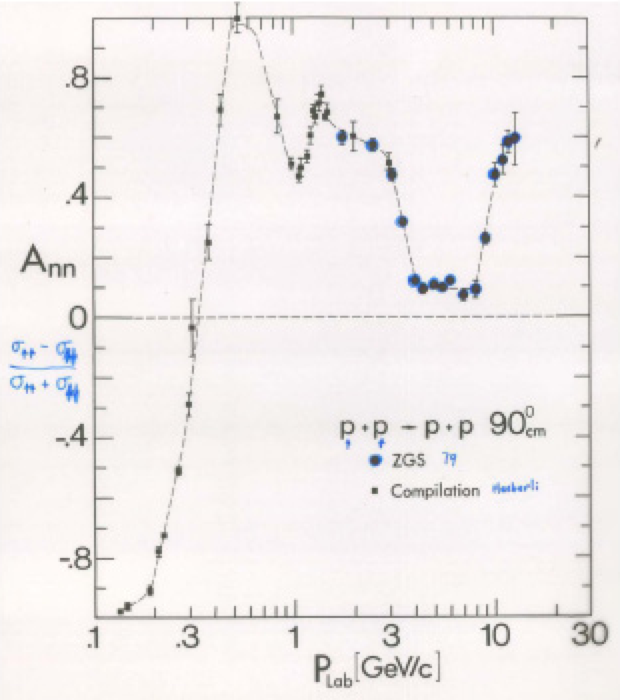
GOAL at J-PARC
MEASURE A_n (and A_{nn})
up to $P_\perp^2 = 12\ (GeV/c)^2$



Ratio Spin-Parallel:Spin-Antiparallel Proton-Proton Elastic Cross-Sections



COMPILATION: Proton-Proton Elastic A_{nn} at 90^{o}_{cm} 10 MeV to 12 GeV



OUTLINE

I. Introduction

II. Effective Field Theories (EFT(s))

EFT(s) beyond the standard model (symmetry breaking, naturalness, landscapes)

EFT(s) in QCD confinement, chiral symmetry

Lattice EFT's, χPT, Massive Quark EFT(s)

III. Light-Quark EFT's

Brodsky-Lepage - Amplitude Methods

IV. pp→pp amplitudes

Helicity-Conserving, Helicity non-conserving

Transversity, ... Spin observables

Effective Field Theories (EFT's)

EFT's have become familiar tools in the presentation of physics beyond the standard model naturalness, landscapes, ...
patterns of symmetry breaking

EFT's of QED → condensed matter physics, molecular physics

Many EFT's based on QCD -
Lattice Regularized EFT's --- enhanced lattice actions
Heavy Quark EFT's -- v, v^2 ---
χPT -- full blown EFT's π, ...
Mixture of Perturbative & Nonperturbative Effects ---

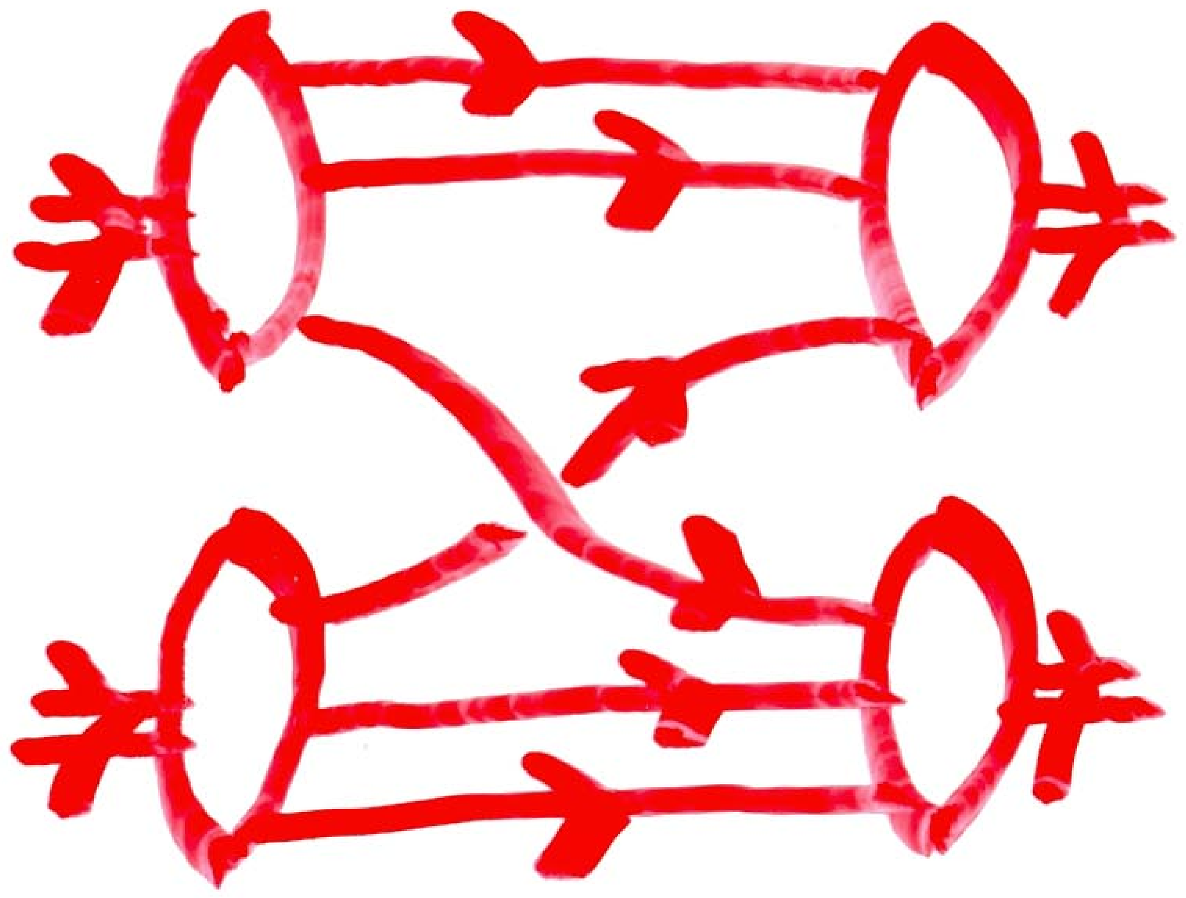
Brodsky-Lepage EFT(s) for exclusive hadronic process (1980,81)

amplitude methods pp→pp [Farrar, Gottlieb, Sivers Thomas - Brodsky, Carlson Lipkin (1979)]

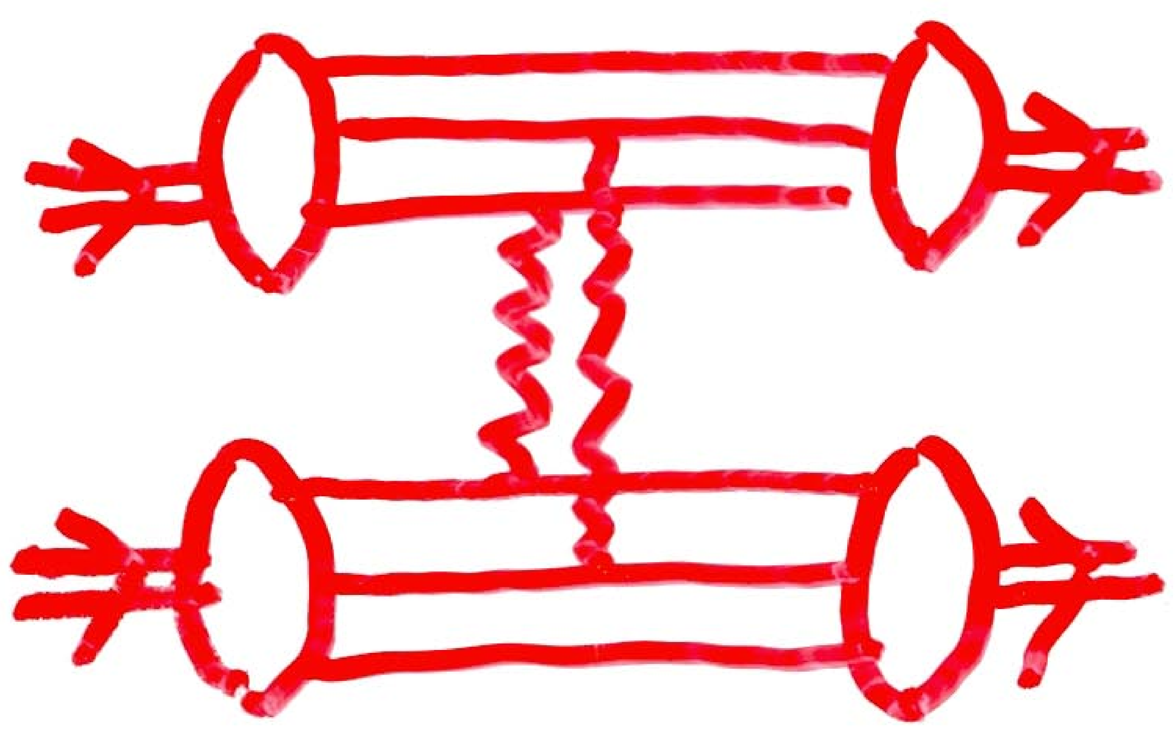
Truncated Fock expansion based on constituent counting (Brodsky Farrar) & helicity conservation for light quarks

organize ≥ 300,000 Feynman Diagrams into amplitude classes ..

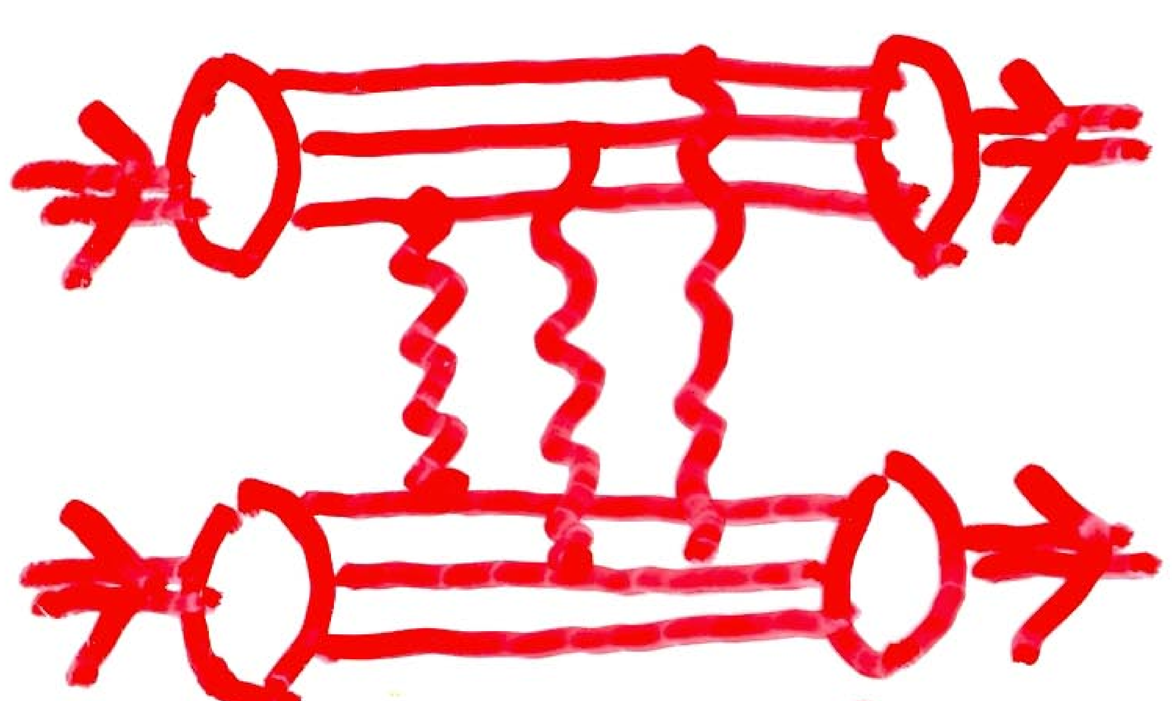
Sample Diagrams



Quark Interchange



connected gluon

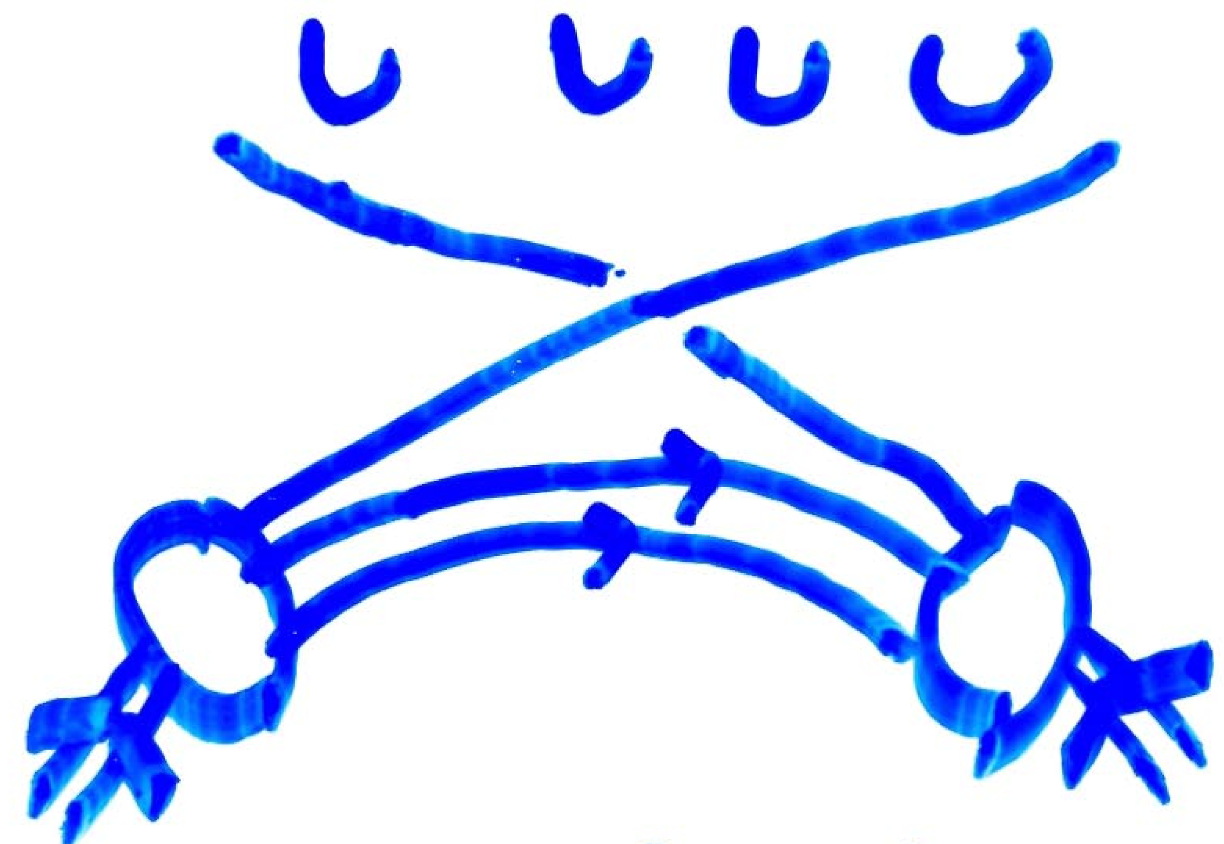


Landshoff process

scaling laws

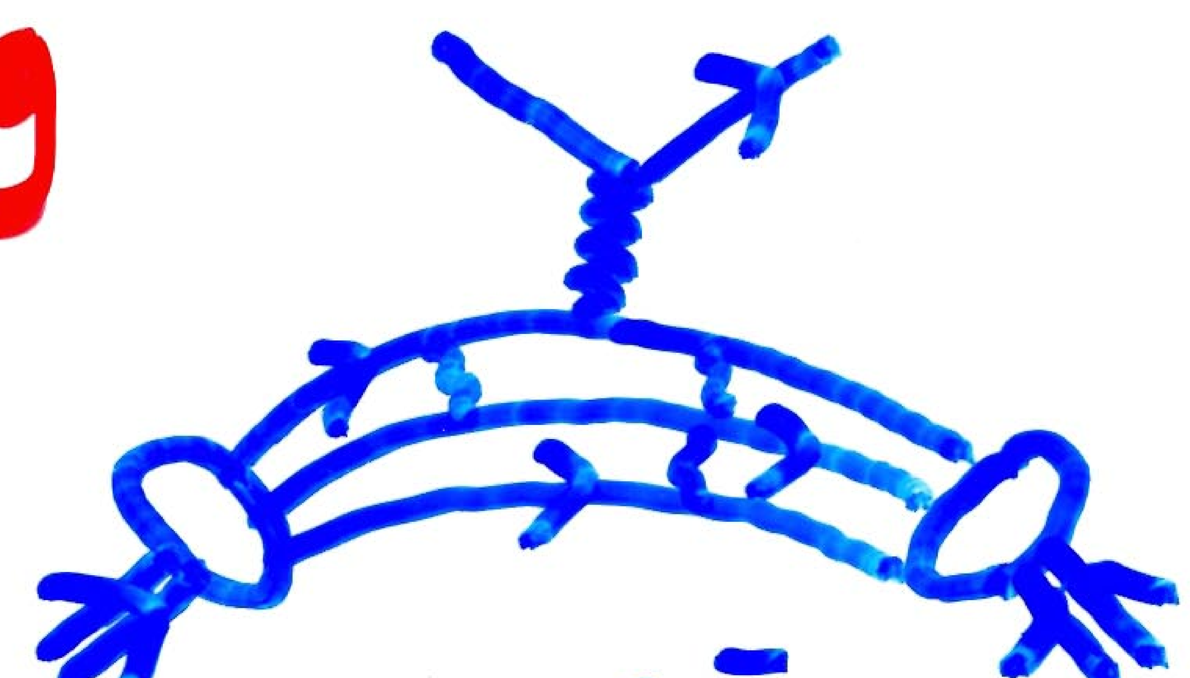
t-channel

($\bar{q}q$ jet)



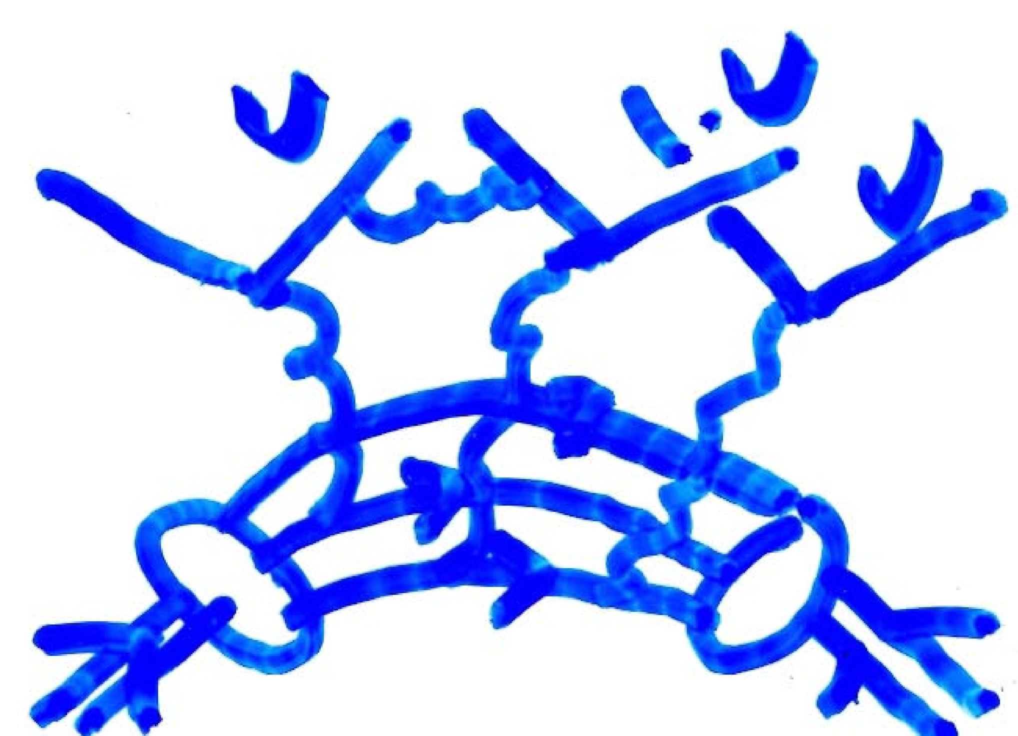
$\bar{p}p \to$ hadrons

(proton form factor)



$\bar{p}p \to l\bar{l}$

(multi-jet)



$\bar{p}p \to$ hadrons

low t

helicity, & transversity amplitudes

$\phi_1 = \langle ++|M|++\rangle$

$\phi_2 = \langle ++|M|--\rangle$

$\phi_3 = \langle +-|M|+-\rangle$

$\phi_4 = \langle +-|M|-+\rangle$

$\phi_5 = \langle ++|M|+-\rangle$

$\Phi_\alpha = \langle \uparrow\uparrow|M|\uparrow\uparrow\rangle$

$\Phi_\beta = \langle \downarrow\downarrow|M|\downarrow\downarrow\rangle$

$\Phi_\gamma = \langle \uparrow\downarrow|M|\uparrow\downarrow\rangle$

$\Phi_\delta = \langle \uparrow\uparrow|M|\downarrow\downarrow\rangle$

$\Phi_\epsilon = \langle \uparrow\downarrow|M|\downarrow\uparrow\rangle$

← <u>obervables</u> →

$$\Sigma = \frac{s-4m^2}{\pi} d\sigma/dt$$

$$= \frac{1}{2}(|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2) = |\phi_\alpha|^2 + |\phi_\beta|^2 + |\phi_\gamma|^2 + |\phi_\delta|^2 + |\phi_\epsilon|^2$$

$$A_N \Sigma = -\text{Im}[\phi_5^*(\phi_1 + \phi_2 + \phi_3 - \phi_4)] = |\phi_\alpha|^2 - |\phi_\beta|^2$$

$$A_{NN} \Sigma = \text{Re}[\phi_1\phi_2^* - \phi_3\phi_4^* + 2|\phi_5|^2] = |\phi_\alpha|^2 + |\phi_\beta|^2 + 2(|\phi_\delta|^2 + |\phi_\gamma|^2 + |\phi_\epsilon|^2)$$

↗ Feynman Diagrams

↗ Spin-Orbit Dynamics

For s-channel helicity-conserving amplitudes

Φ_1, Φ_3, Φ_4 $\quad \Phi_i = \Phi_i^R + \Phi_i^Q + \Phi_i^B + \Phi_i^L$

$$\Phi_i^Q = Q(\alpha_s, s, t) f_i^Q(z) + Q(\alpha_s, s, u) f_i^Q(-z)$$

$$\Phi_i^B = G^B(\alpha_s, s, t) f_i^B(z) + G^B(\alpha_s, s, u) f_i^B(-z)$$

$$\Phi_i^L = G^L(\alpha_s, s, t) f_i^L(z) + G^L(\alpha_s, s, u) f_i^L(-z)$$

$z = \cos\theta$

f_i^Q, f_i^B

f_i^L calculable from diagrams using helicity conservation

truncate to 3q fock state

$$(s/s_0)^4 Q(\alpha_s, s, t) = \left[\frac{\alpha_s^{eff}(t)}{\pi}\right]^5 \hat{Q}_0(s,t)\left[1 + \frac{\alpha_s}{\pi} g_i^Q(\ )\right]$$

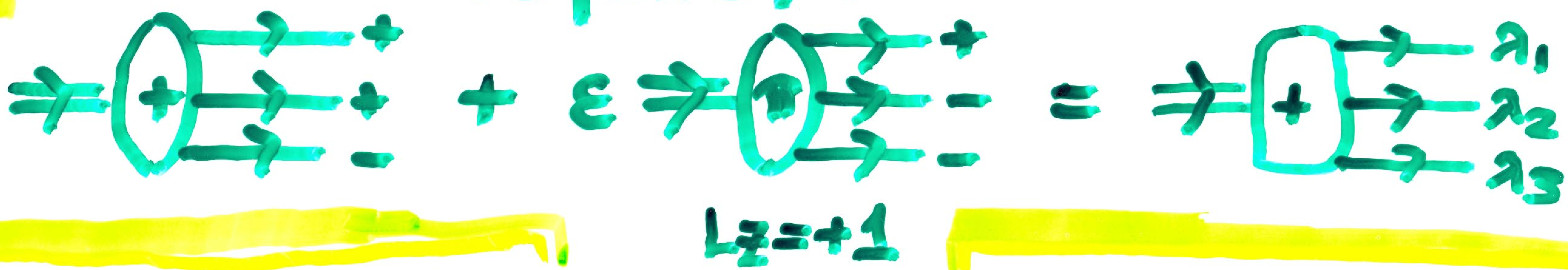
$$(s/s_0)^4 G^B(\alpha_s, s, t) = \left[\frac{\alpha_s^{eff}(t)}{\pi}\right]^5 \hat{G}_0^B(s,t)\, e^{i\delta_B(t)}\left[1 + \frac{\alpha_s}{\pi} g_i^B(\ )\right]$$

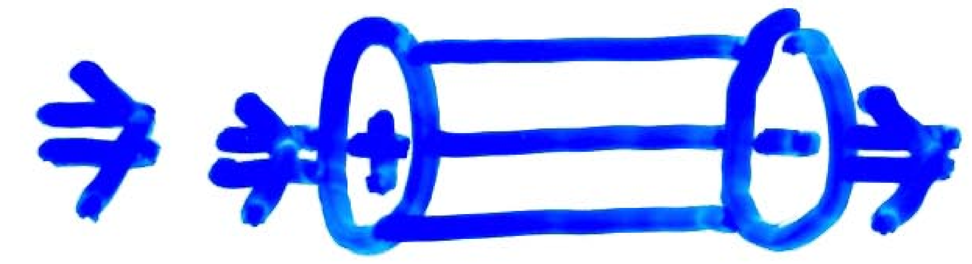
$$(s/s_0)^4 G^L(\alpha_s, s, t) = \left[\frac{\alpha_s^{eff}(t)}{\pi}\right]^3 \hat{G}_0^L(s,t)\left(-\frac{s}{s_0}\right)^{\gamma(t)} e^{i\delta_L(t)}\left[1 + \frac{\alpha_s}{\pi} g_i^L\right]$$

δ_L Berry phase

γ Regge phase

$\alpha^{eff}(t)$ chosen to cancel h.o.s. in proton form factor calculations for Φ_2, Φ_5 orbital angular momentum required !!



$$\varepsilon(t) = \frac{\varepsilon\,(-t)^{1/2}}{t - m_\rho^2}$$ overlap 

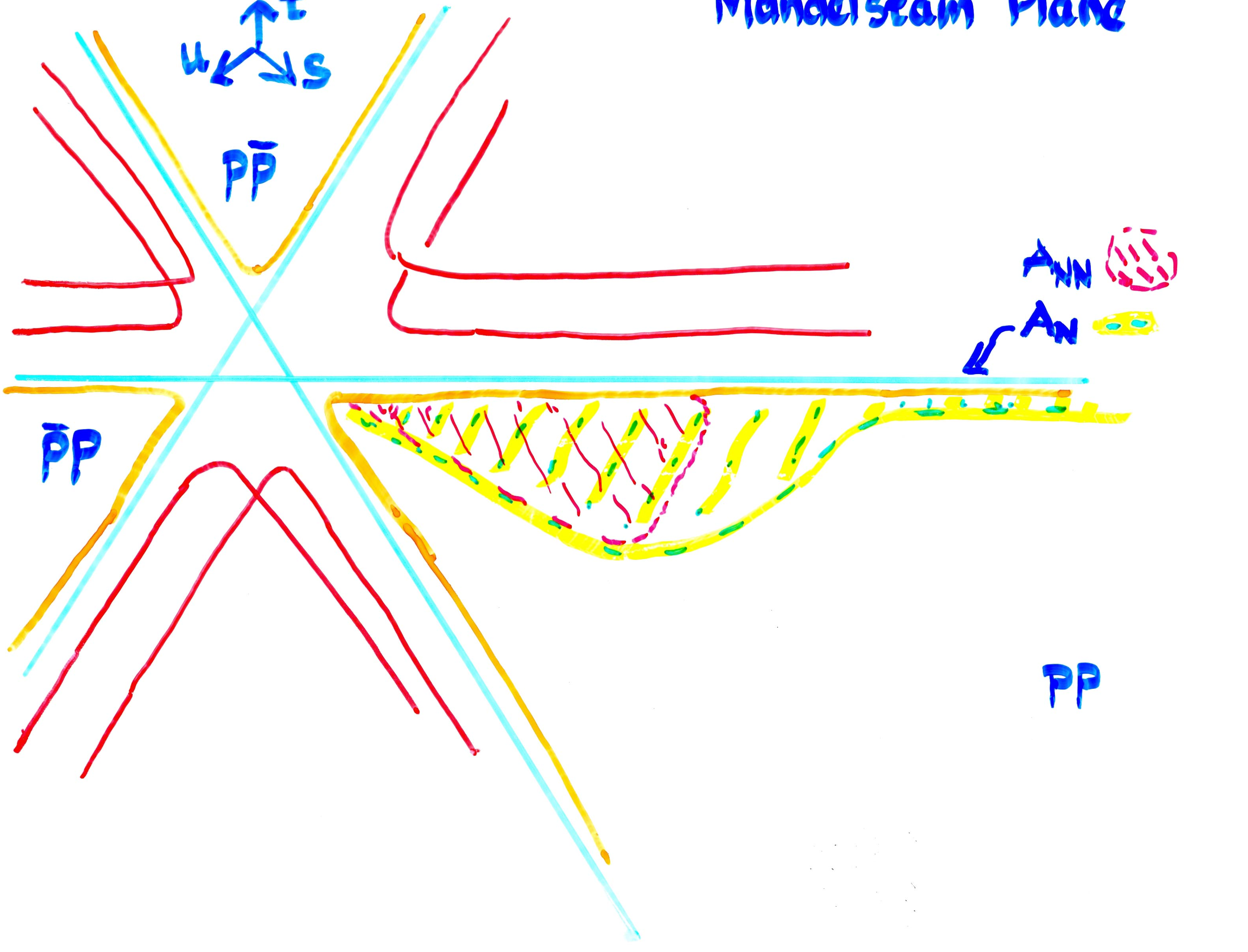
$$\Phi_5 \cong (\varepsilon(t) - \varepsilon(u))\,\Phi_1 + (\varepsilon(t) + \varepsilon(u))\,[\Phi_3 + \Phi_4]$$

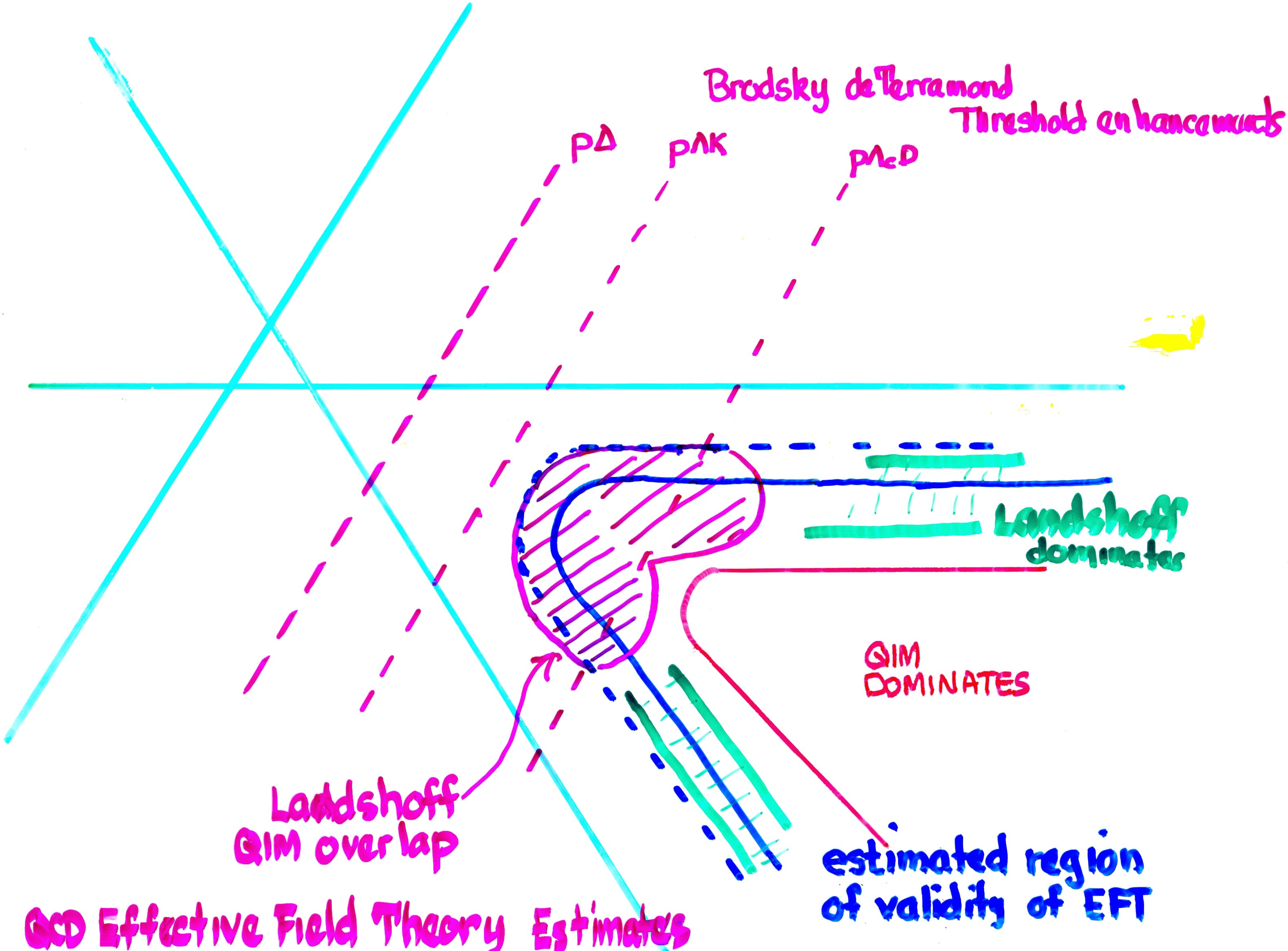
$$\Phi_2 \cong \frac{1}{2}(\varepsilon(t) - \varepsilon(u))\,\Phi_5$$

incorporates $\vec{L}\cdot\hat{\sigma}$ effects when ε small

Small number of parameters G^B/Q, G^L/Q, δ_B, δ_L, γ, ε describe rich data set !!

Mandelstam Plane




Brodsky deTerramond
Threshold enhancements
pΔ
pΛK
pΛcD
Landshoff
dominates
QIM
DOMINATES
Landshoff
QIM overlap
estimated region
of validity of EFT
QCD Effective Field Theory Estimates

Fits to A_{NN}

Brodsky, deTeramond (88) Q + thresh enhancement (intrinsic charm)

Ralston, Pire (86) Q+L

Fits to A_{NN} + A_N

Ramsey-Sivers (92, 93) Q+L + L≠0 ansatze for Φ_5, Φ_2

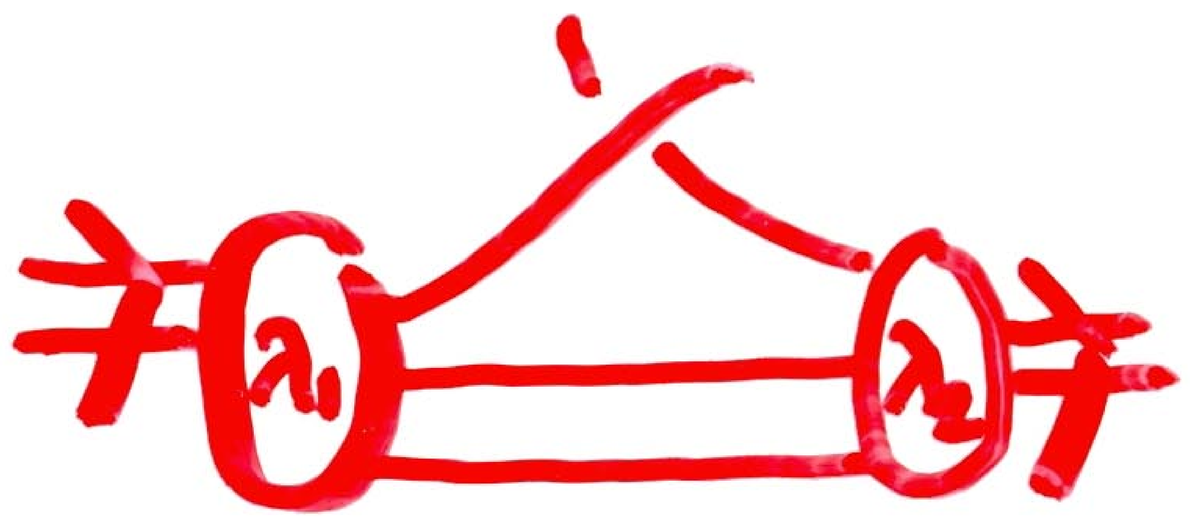
However, B diagrams cannot be neglected -- all approaches do poorly for $r = \frac{d\sigma(pp)}{d\sigma(pn)}$.

need to rethink normalizations!

Constituent Counting (Polchinski, Strassler (2002))
→ "freezing" α_s^{eff} .. not consistent with Sudhakov suppression

are there other effects that need to be inserted by hand??

Mandelstam Plane
t
u
s
Brodsky deTerramond
Threshold enhancements
pΔ
pΛK
pΛcD
p̄p
A_NN
A_N
p̄p
Landshoff dominates
QIM DOMINATES
pp
Landshoff QIM overlap
estimated region of validity of EFT
QCD Effective Field Theory Estimates



proton elastic amplitudes

Generalized Parton Distributions

2 different approaches to same information

More data on hard exclusive hadronic processes has high discovery potential

processes with minimal # diagrams $K^{-}_{0} p \to \pi^{+} \Sigma$

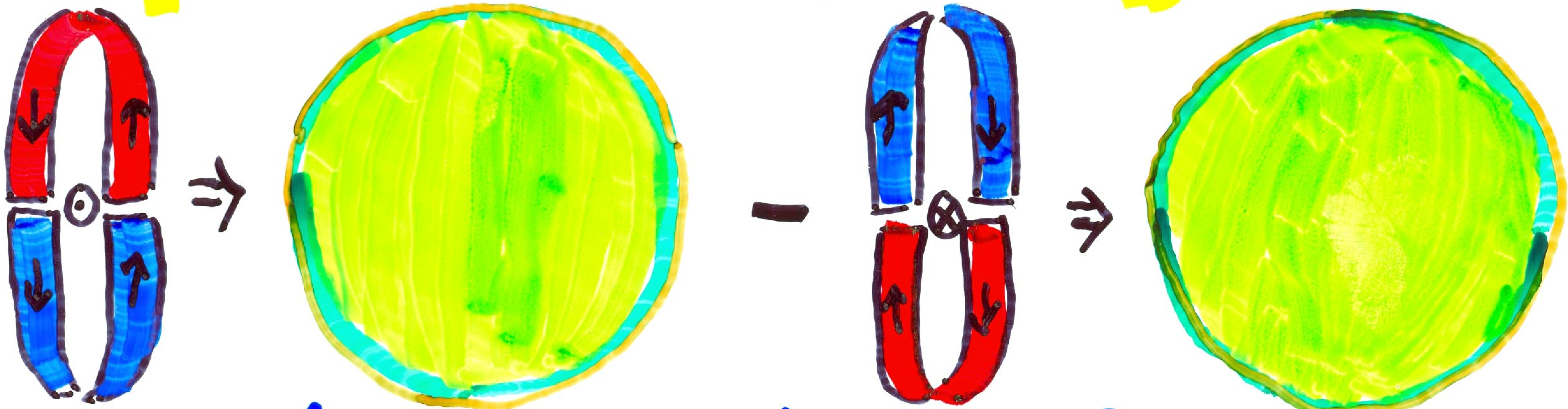
$\pi^{-} p \to K_{0} \Lambda$

transition form factors

$p\bar{p} \to p\bar{p}$ elastic (unpol. + single spin!)

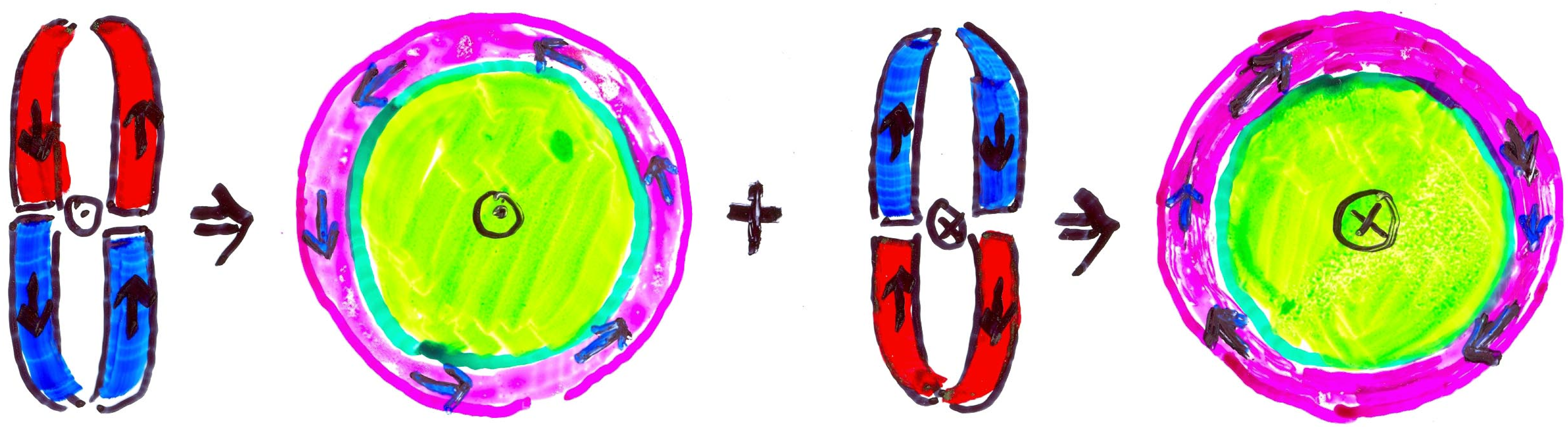
+ More data on A_{NN}, A_{SL}, A_{N} for pp elastic

Transversity Amplitudes



A^N (Spin-Orbit) $\propto (|\phi_\alpha|^2 - |\phi_\beta|^2)$

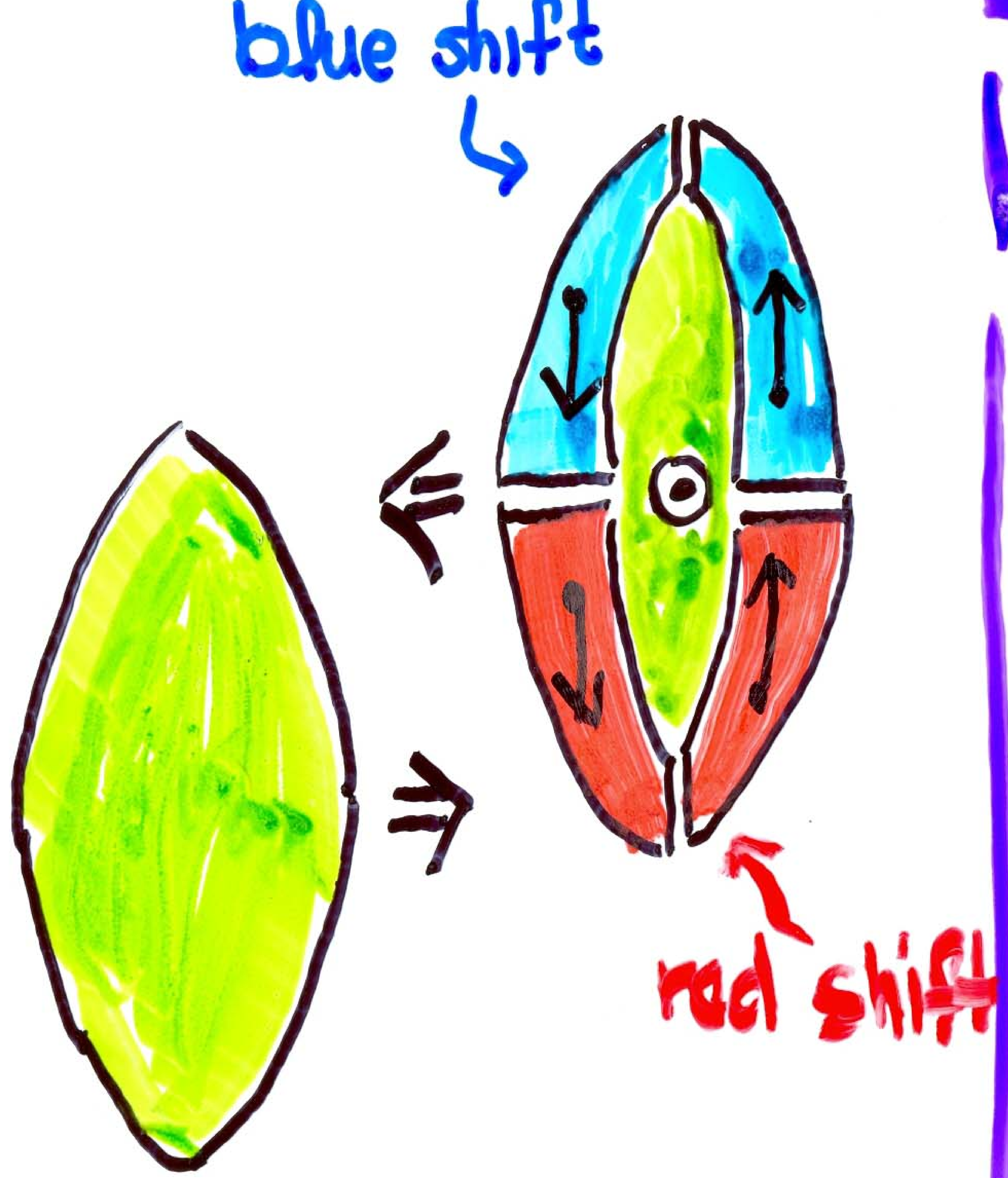
(Chou-Yang, 1978)



+ others

$A^{NN} \propto (|\phi_\alpha|^2 + |\phi_\beta|^2) + 2(-|\phi_\delta|^2 + |\phi_\gamma|^2 - |\phi_\epsilon|^2)$

ORBITAL ANGULAR MOMENTUM & A_N



After Projections

screening

$$d\sigma_{el} = d\sigma_u + \varepsilon[d\sigma_f + \eta\, d\sigma_b]$$

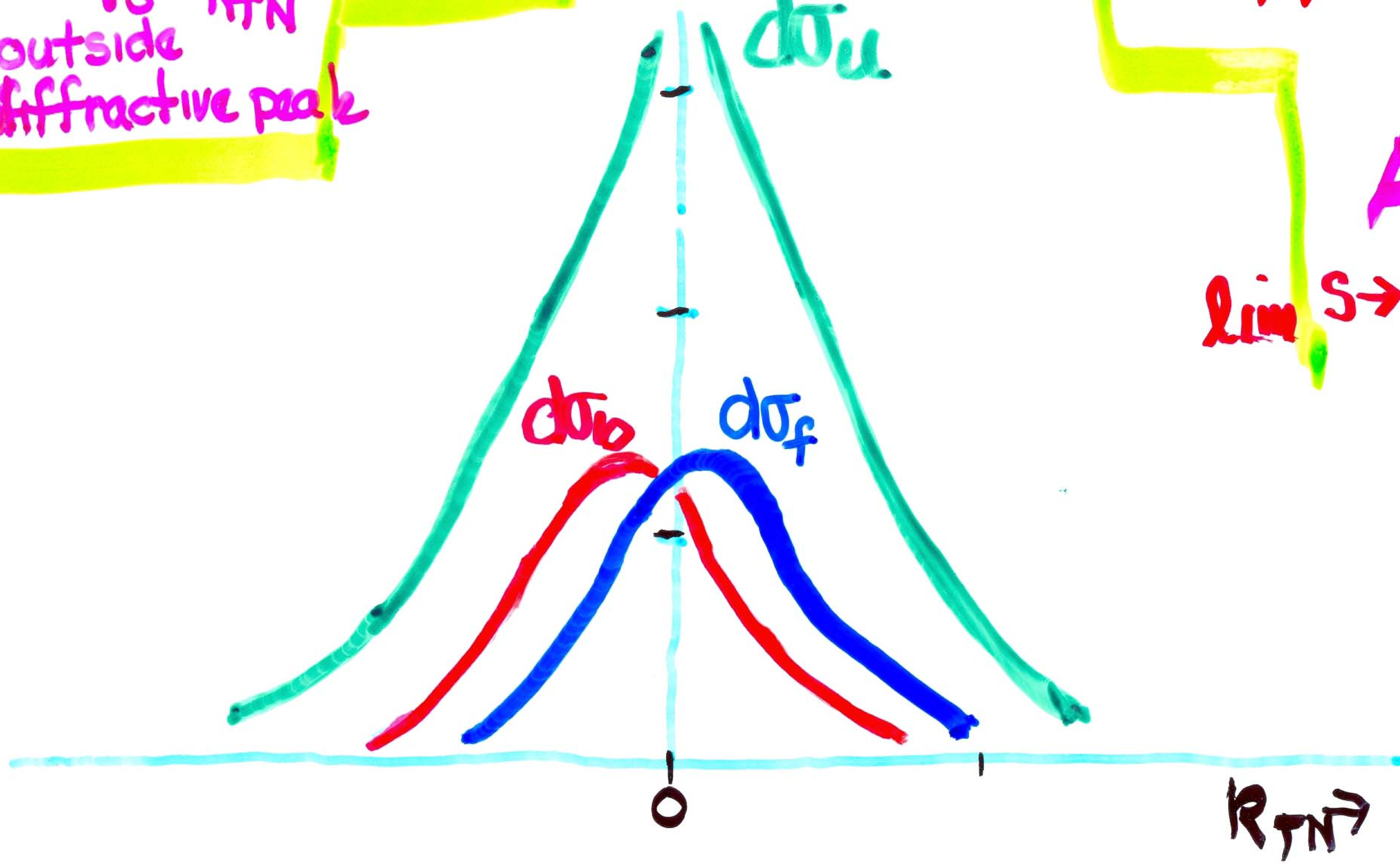
$$d\sigma_f = d\bar{\sigma} + \delta\sigma(k_T)$$

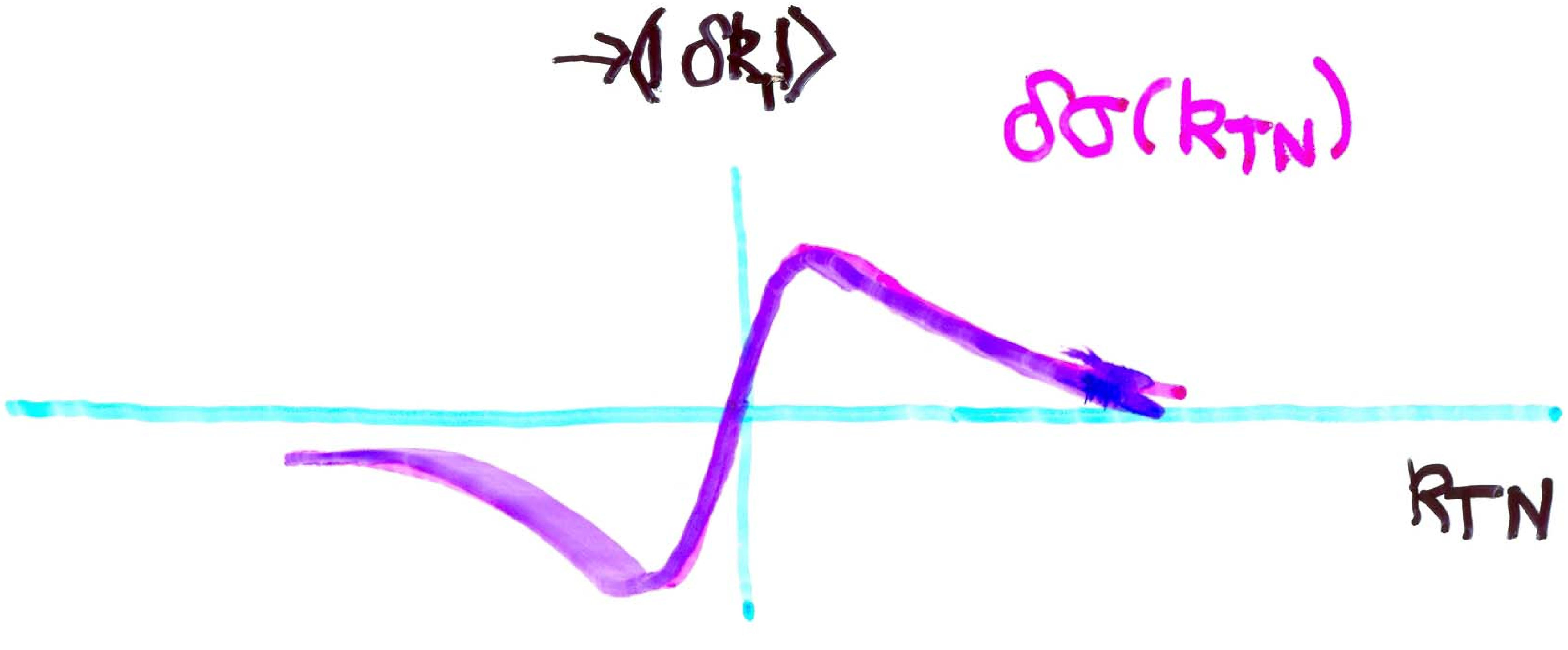
$$d\sigma_b = d\bar{\sigma} - \delta\sigma(k_T)$$

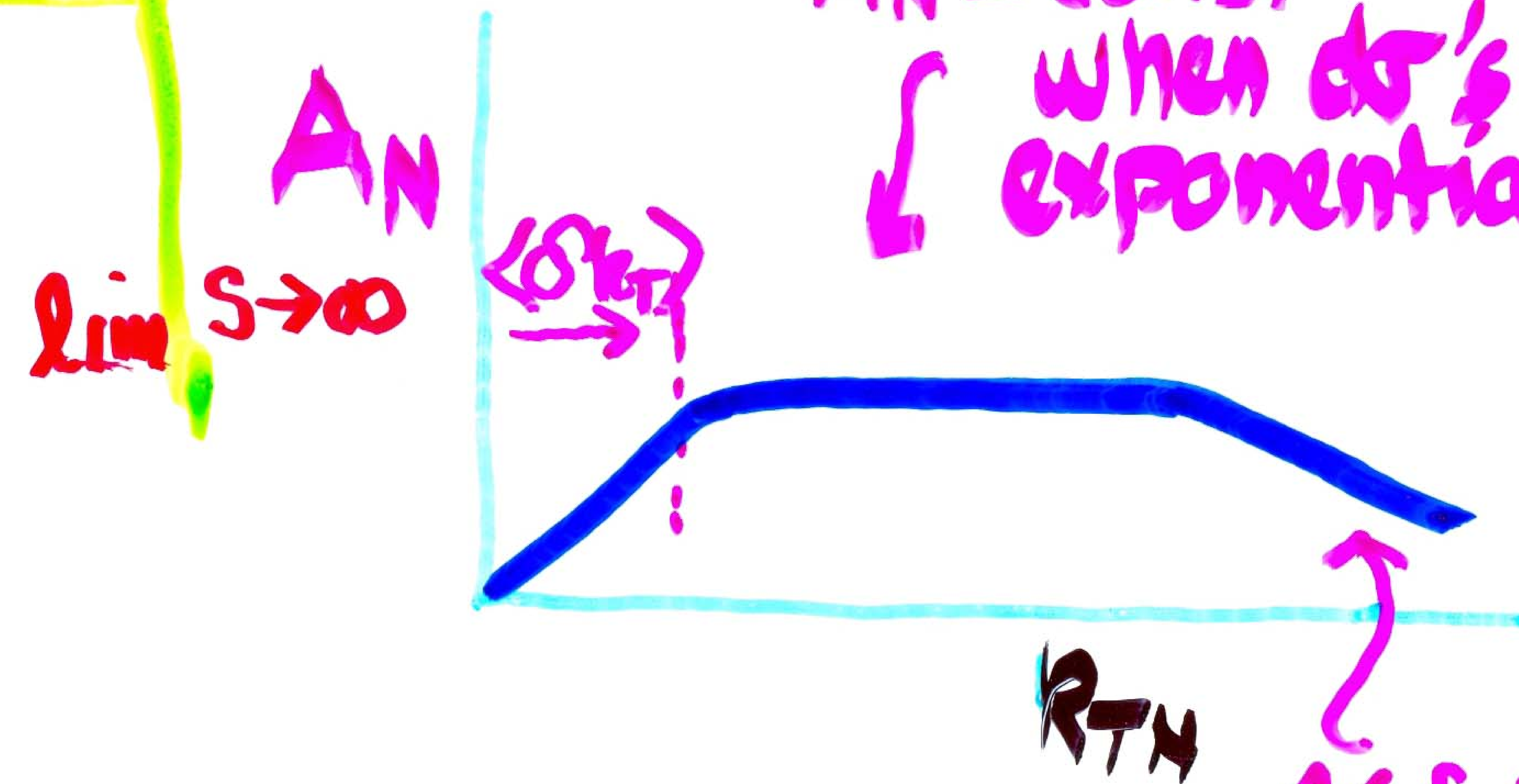
$$A_N = \frac{\varepsilon(1-\eta)\,\delta\sigma(k_T)}{d\sigma_u + \varepsilon(1+\eta)\,d\bar{\sigma}}$$

Systematics of A_N

simplified "Geometrical" CROSS SECTIONS vs R_{TN} outside diffractive peak







$A_N \simeq$ const when $d\sigma$'s exponential

$1/k_T$ falloff in Brodsky-Lepage region!

A_N measure of

$$\langle L\rangle_n = a_1\langle L_q\rangle + a_2\langle L_g\rangle$$