The many Roles of $^3P_0$ $q\bar{q}$ pairs in nonperturbative Quantum Chromodynamics

triplet-pee-zero & $J^{PC}=0^{++}$

the non-Abelian gauge connection and the nonlocality of Gaussian charge

dennis sivers - U. Michigan & Portland Physics Inst.

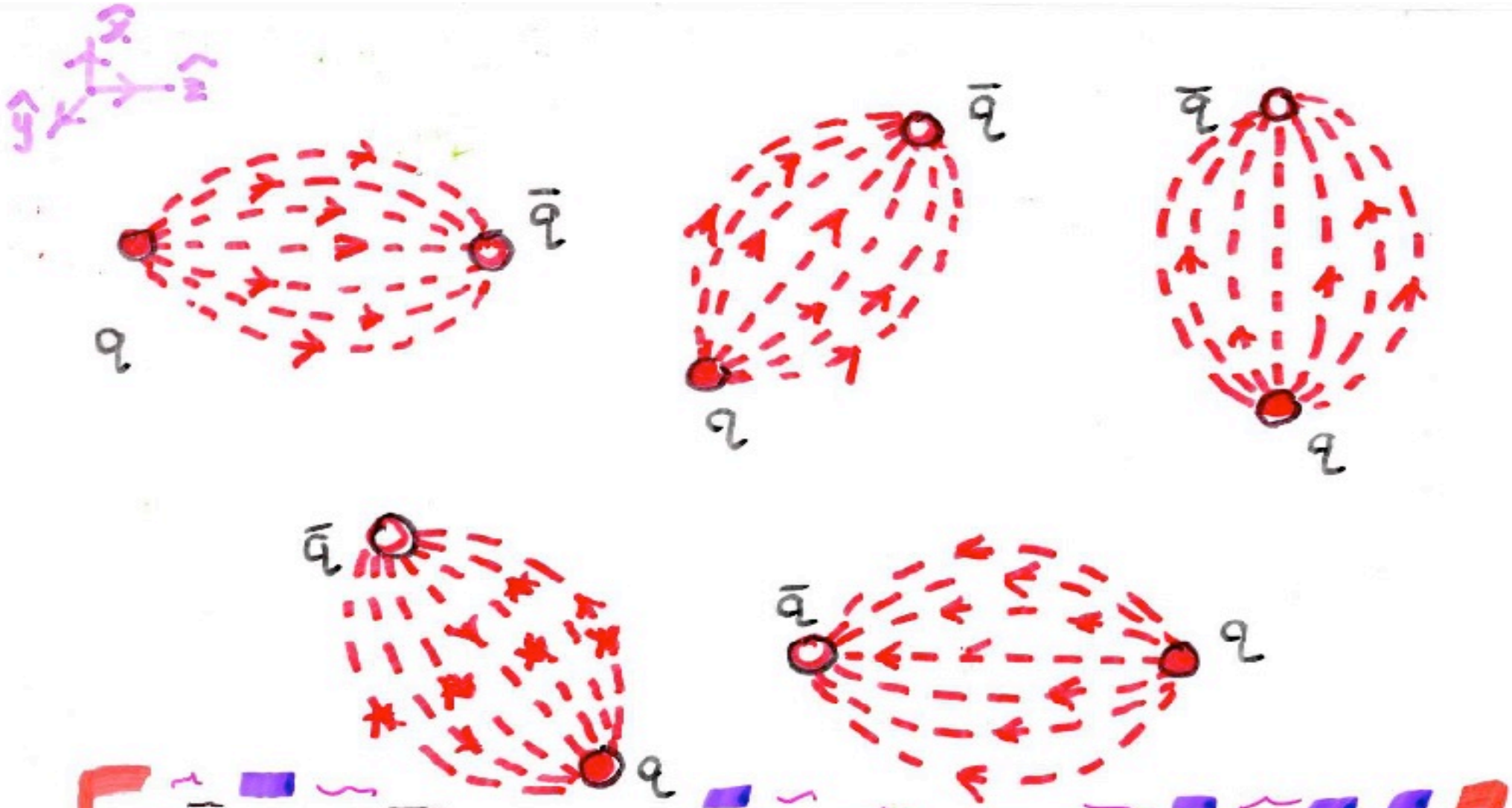
prelude : Spin Physics 2008- Charlottesville

Eliot Leader: The Power of Spin:
a scalpel-like probe of theoretical ideas

Franco Strocchi: An Introduction to
Non-Perturbative Foundations of Quantum Field Theory

SM: Superselection Charges & gaussian charges
or (gauss charges)

prejudice: The Strong Conjecture for color
confinement & topological domain walls


$\hat{z}$
$\hat{x}$
$\hat{y}$
$\bar{q}$
q
$\bar{q}$
q
$\bar{q}$
q
$\bar{q}$
q
$\bar{q}$
q
$^3P_0$ $\bar{q}q$ pair as rotating dipole
in $\hat{x}$-$\hat{z}$ plane

Sample $^2P_{1/2}^3$ Roles

Chiral structure combining gauss charges & super-selection charges

Generation of intrinsic charm & other heavy flavors

Creation of virtual orbital angular momentum in hadrons

Generation of spin-oriented transverse momentum in flux-ruptures

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QCD: non PERTURBATIVE TOOLS

1. Lattice gauge theory simulations
   Wilson α_s large $\Rightarrow$ $V_{q\bar{q}}(r) = \sigma r + \cdots$
   for massive quarks
   necessary but not sufficient for confinement

2. Effective Field Thys. (EFT's)
   Massive Quark EFT, Soft-collinear EFT, chiral EFT
   ...

3. Schwinger-Dyson Eq.'ns
   $\Rightarrow$ analytic properties of quark, gluon dressed propagators

4. Classical non-Abelian Field Eqn's
   topological properties of confined systems

Streater Wightman Axioms

Gauge theories &
Cluster Decomposition

non-Abelian gauge theories accomodate:

(A) area law for Wilson loops

(B) emergent structures such as topological domain walls

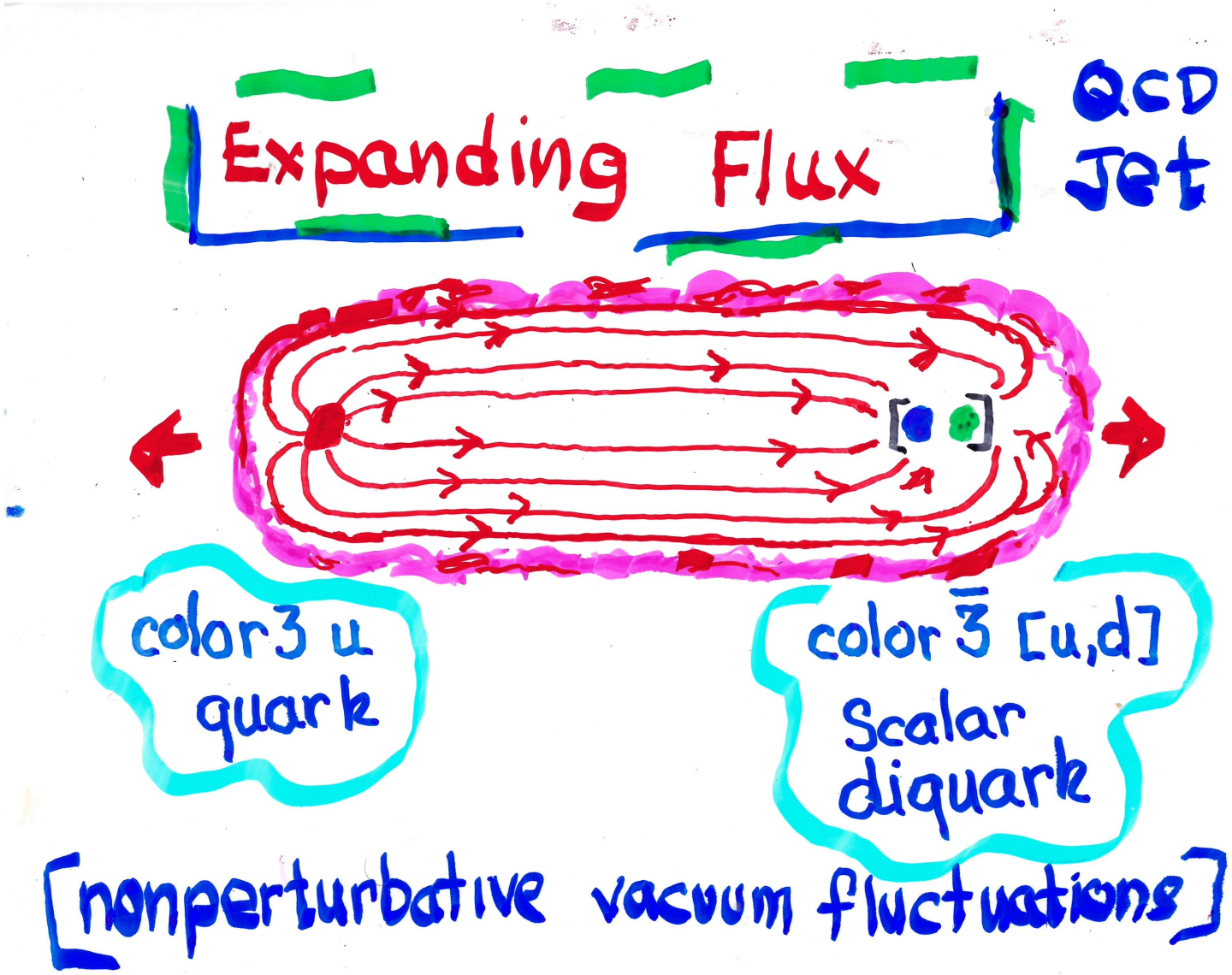
local fields ⇏ non-local correlations

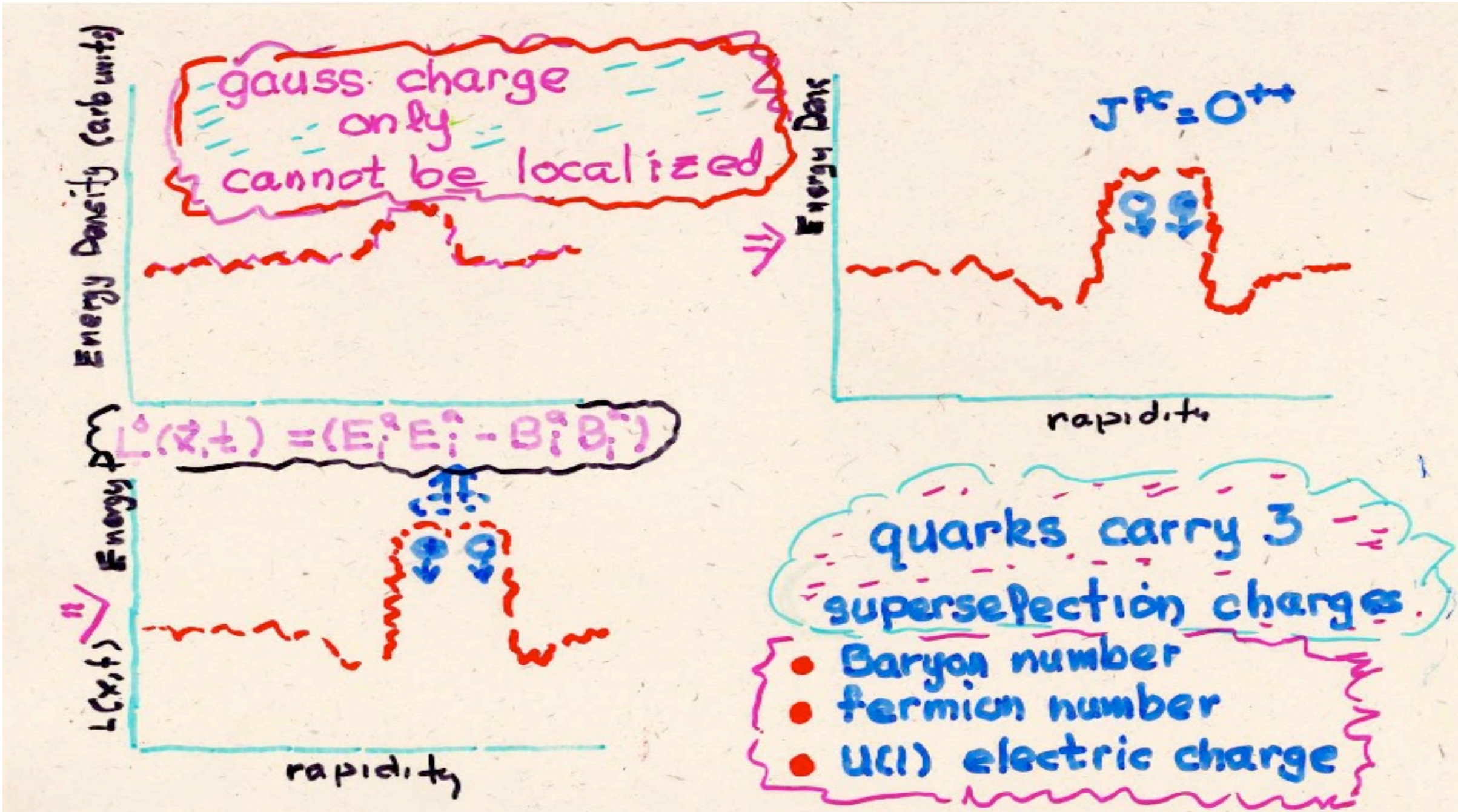
IV. Constructive Field Theory

(a. jaffe)

A topological stable solution to the classical (Yang-Mills Maxwell) eq.'ns provides robust scaffolding

for understanding hadron structure


Expanding Flux
QCD Jet
color 3 u quark
color $\bar{3}$ [u,d] Scalar diquark
[nonperturbative vacuum fluctuations]


gauss charge
only
cannot be localized
Energy Density (arb units)
$J^{PC}=0^{++}$
Energy Dens
rapidity
$L^0(\vec{x},t) = (E_i^a E_i^a - B_i^a B_i^a)$
Energy
$L(x,t)$
rapidity
quarks carry 3
superselection charges.
• Baryon number
• fermion number
• U(1) electric charge

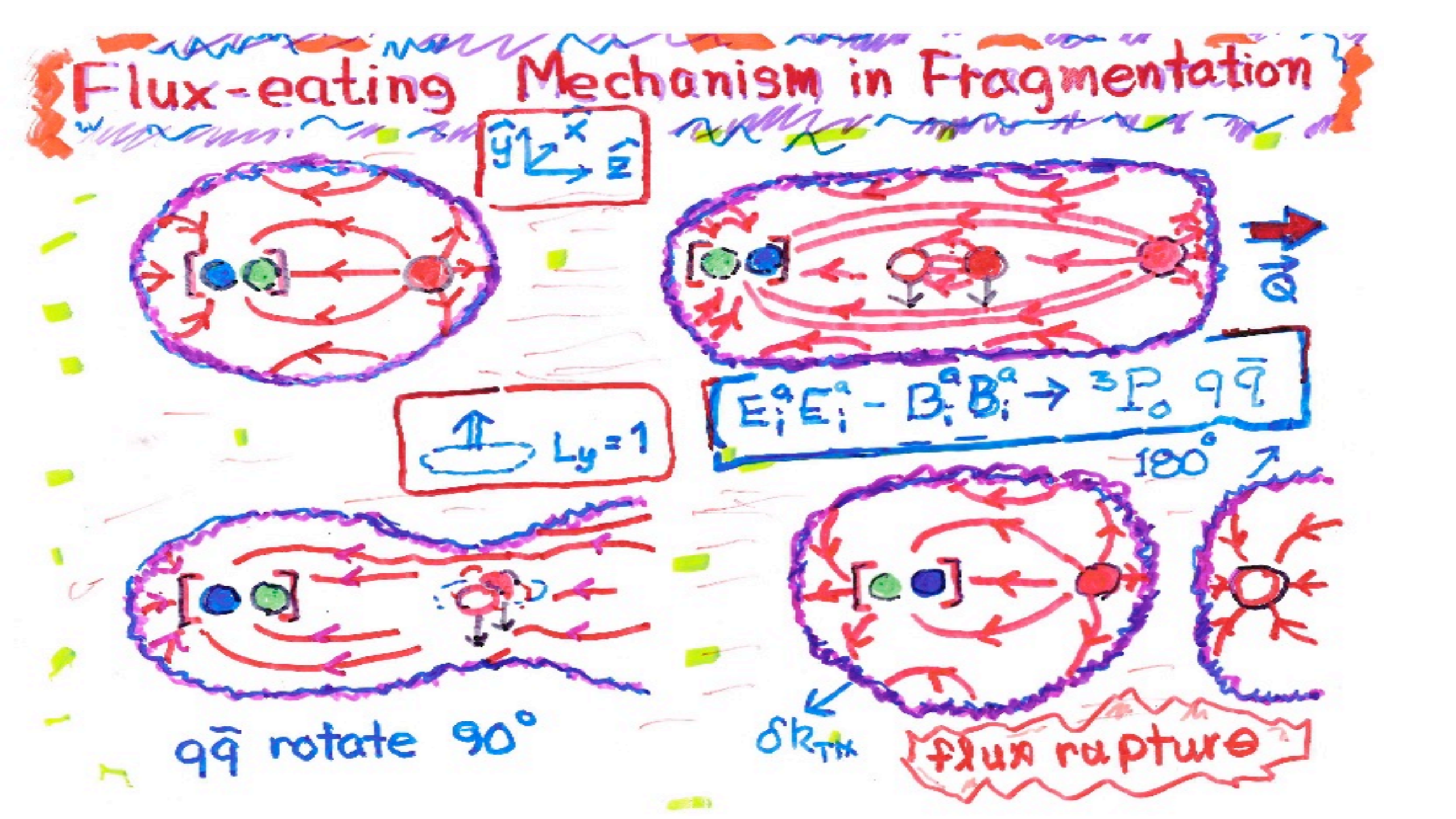
INTRINSIC CHARM

The non-perturbative production of massive quarks (strange, charm, bottom)

Stan Brodsky → Fock-space labels

$$|p\rangle \sim |qqq\rangle + |qqqG\rangle + |qqq Q\bar{Q}\rangle + \cdots$$

Flux-eating Mechanism in Fragmentation



Orbital angular momentum in the proton

virtual $^3P_0$ pairs generate $\langle L \rangle$ in stable hadrons - Georgi-Manohar chiral quark model

U, D constituent quarks u, d current quarks

$L\uparrow \rightleftarrows d\downarrow \pi^+$ $u\downarrow \pi^- \rightleftarrows D\uparrow$ $L = \pm 1$

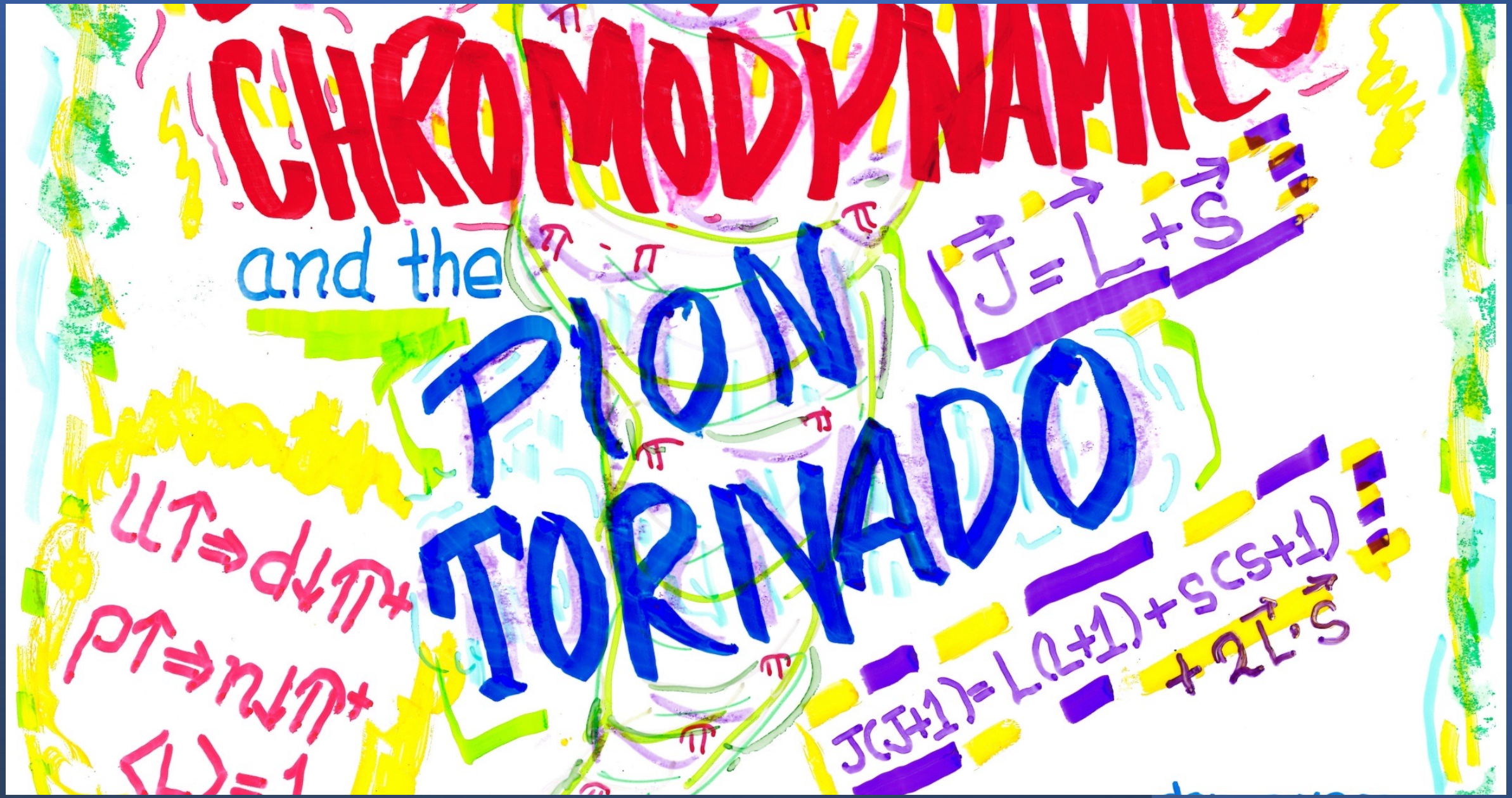
Michael Engelhardt

$$\left\langle \sum_{\text{quarks}} 2\vec{L}\cdot\vec{S} \right\rangle = -0.65 \pm 0.012$$

modifies isospin structure of parton sea

$\bar{d}(x) \neq \bar{u}(x)$

$p\uparrow \rightarrow n\downarrow\pi^+$ $L = 1$


CHROMODYNAMICS
and the
PION
TORNADO
$\vec{J} = \vec{L} + \vec{S}$
$J(J+1) = L(L+1) + S(S+1) + 2\vec{L}\cdot\vec{S}$
$\Sigma^+ \Rightarrow d\bar{d}\pi^+$
$p\uparrow \Rightarrow n\bar{d}\pi^+$
$\langle L \rangle = 1$

The Straw that Stirs the Drink

helicity & transversity dist'ns

+q helicity in + proton | boost to proton rest frame | rotate 90° | boost back to original frame

$\langle L_z^i \rangle = \langle x k_y - y k_x \rangle^i$ preserved under z-boosts

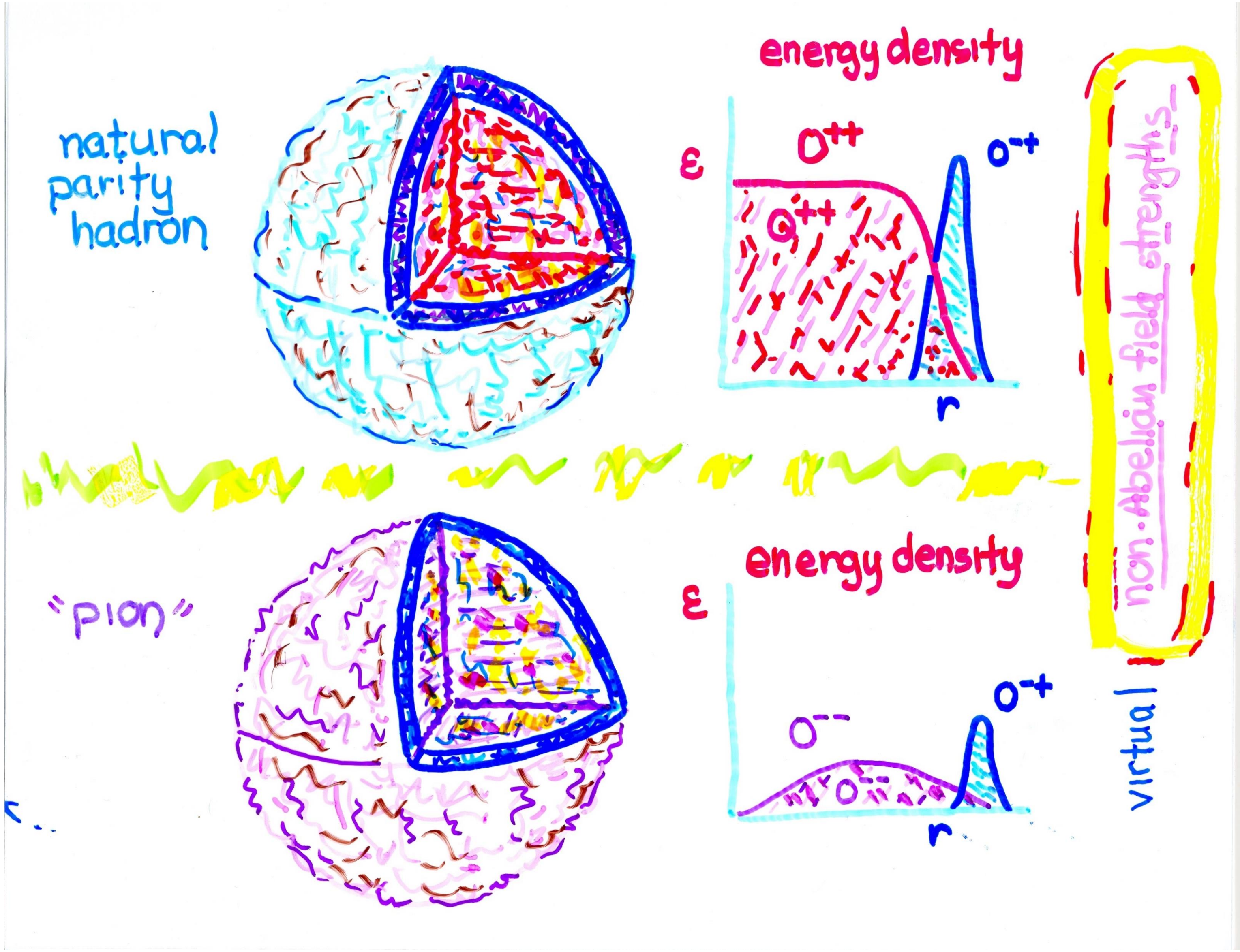
$\Delta^L q_i = \sum_L (|a_L|^2 - |b_L|^2)$ $\quad \Delta\bar{q}_i = \sum_L (|\bar{a}_L|^2 - |\bar{b}_L|^2)$

$\delta^T q_i = (|a_0|^2 - |b_0|^2)$ $\quad \delta^T \bar{q}_i = (|\bar{a}_0|^2 - |\bar{b}_0|^2)$

quarks

$(\Delta^L q_i - \delta^T q_i) = \sum_{L\neq 0} (|a_L|^2 - |b_L|^2)$ $\quad (\Delta^L \bar{q}_i - \delta^T \bar{q}_i) = \sum_{L\neq 0} (|\bar{a}_L|^2 - |\bar{b}_L|^2)$

Differences measure $L \neq 0$ components of proton structure



natural parity hadron
energy density
ε
0++
0-+
0++
r
non-Abelian field strengths
"pion"
energy density
ε
0-+
0--
0--
r
virtual

The Non-Abelian Maxwell's Eq'ns of QCD

with spherical symmetry and confining boundary conditions provide solutions that display the phenomenological content of MIT bag model - Chiral quark soliton & cloudy bag models ... +...

the "dual-Meissner-effect" approact to confinement can be replaced by a "dual topological insulator" picture

Constituent Quark
$J^P = 1/2^+$ not Dirac Fermion
$G \neq 0$ (spin/orbit structure)

Fundamental charge
3, $\bar{3}$

o dirac antifermion (hole)

3 color

$\bar{3}$ color

Scalar diquark
[,] antisymmetric in flavor
$J^P = 0^+$

• dirac fermion

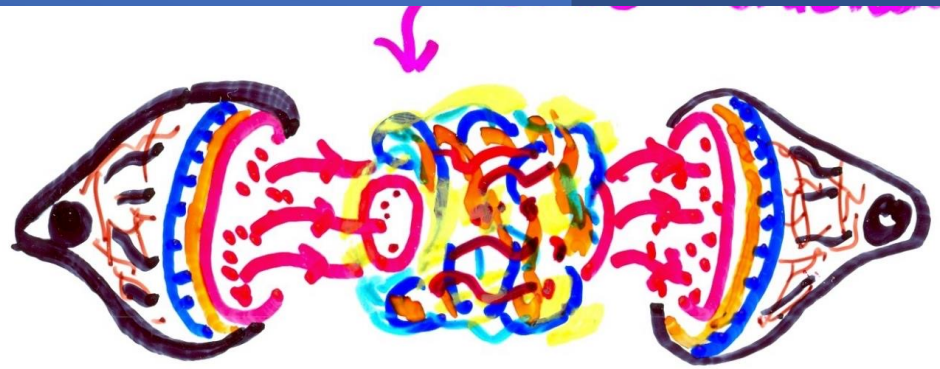
$\bar{3}$ color

axial vector diquark
{,} symmetric in flavor
$J^P = 1^+$ spin-orbit structure

8 color

$d^{abc}(E_i^b E_i^c - B_i^b B_i^c)\ J^{PC} = 0^{++}$

$f^{abc}(E_i^b E_i^c - B_i^b B_i^c)\ J^{PC} = 0^{+-}$



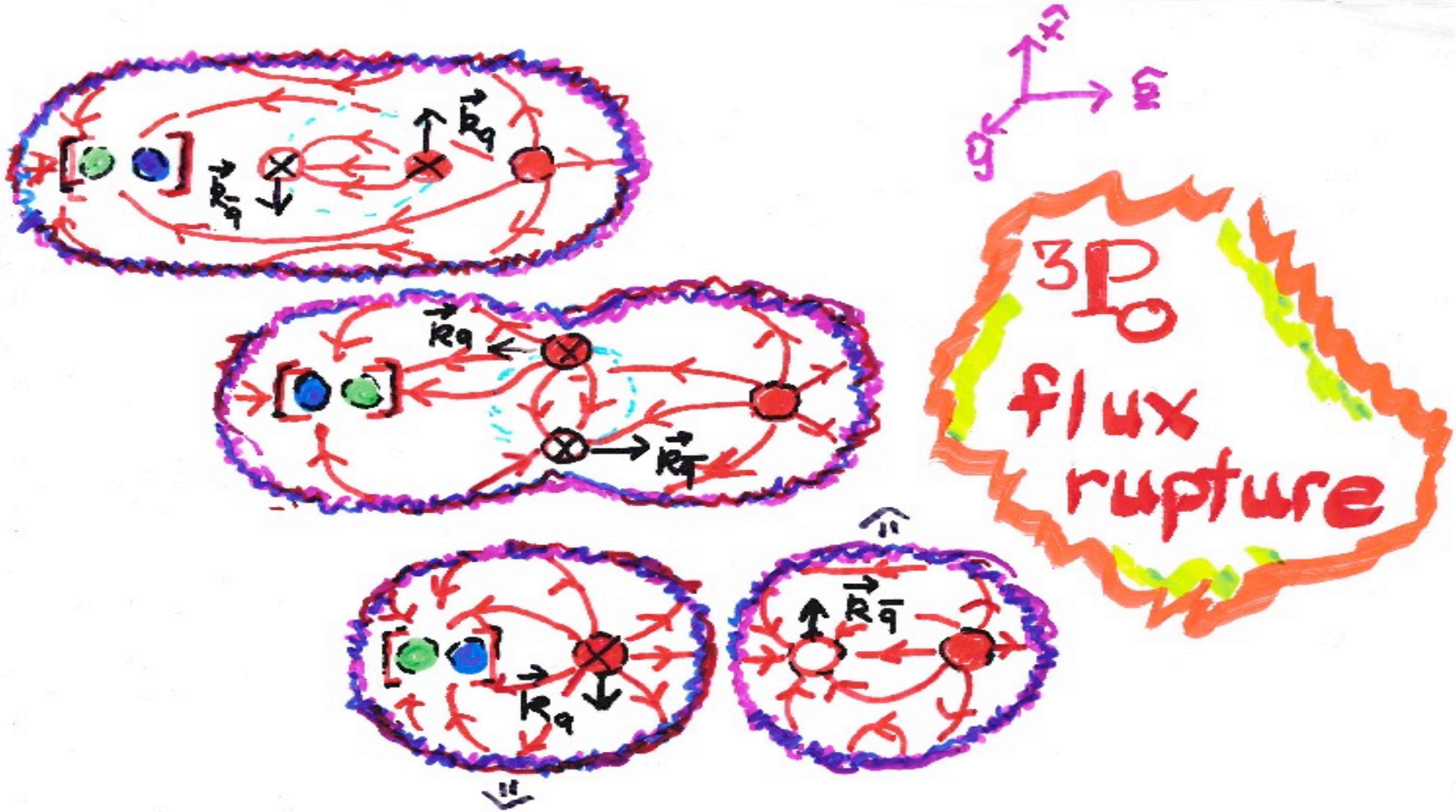
8 color

$d^{abc} E_i^b B_i^c \quad J^{PC} = 0^{-+}$

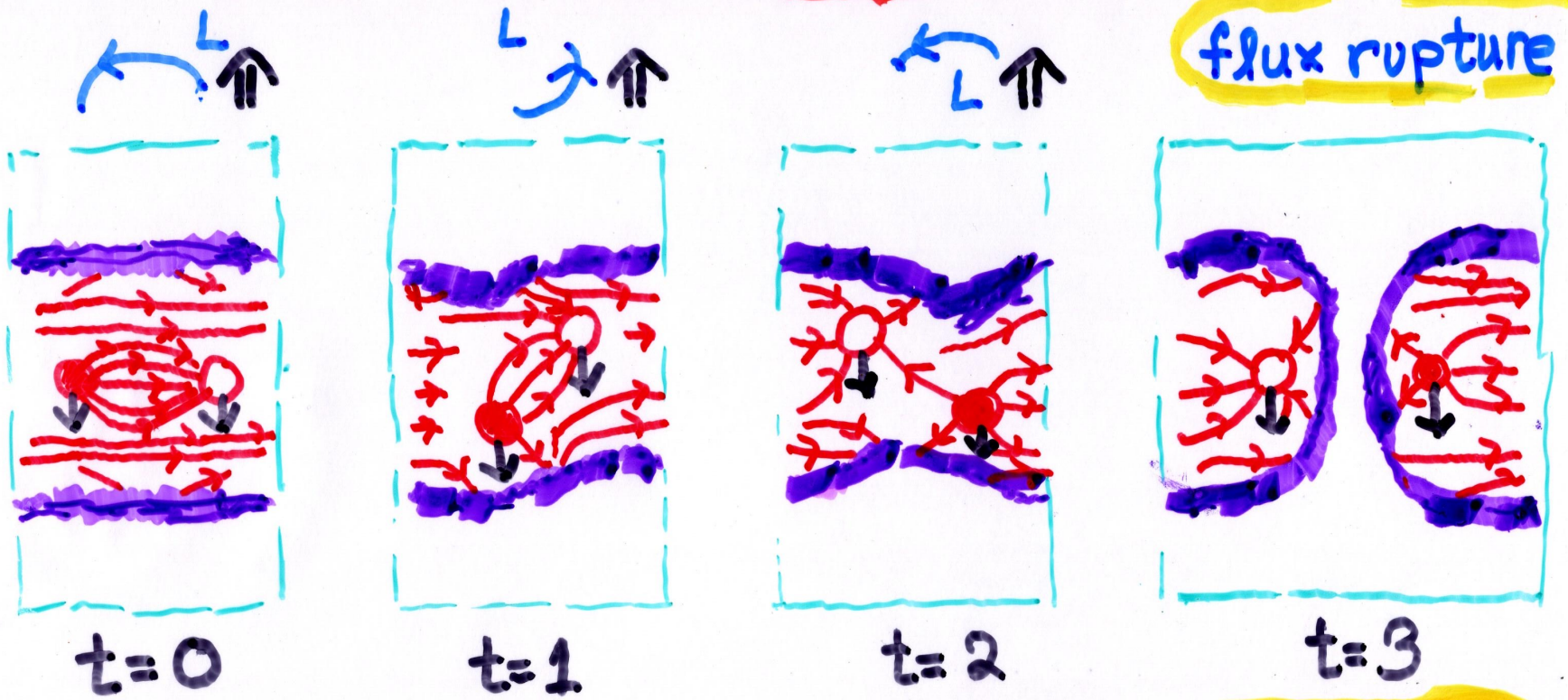
$f^{abc} E_i^b B_i^c \quad J^{PC} = 0^{--}$

How about $J^{PC} = 1^{-+}, 1^{--}; 1^{+-}, 1^{++}$ (Poynting vector)?

These sketches done in maximally Abelian coordinate gauge T_3, T_8 diagonal along $\vec{e}$-axis


$\vec{k}_q$
$\vec{k}_q$
$\vec{k}_q$
$\vec{k}_{\bar{q}}$
$\vec{k}_q$
$\vec{k}_{\bar{q}}$
$^3P_0$
flux
rupture

$^3P^0$ $J^{PC}=0^{++}$ $q\bar{q}$ Pairs



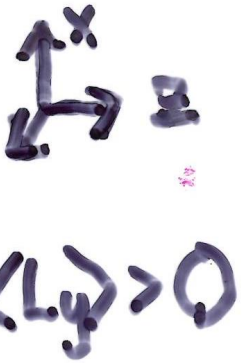
generate flux rupture with spin-oriented momentum transfer δk_{TN}

QUANTUM ENTANGLEMENT in Hard Scattering Processes

$\langle L_y \rangle > 0$

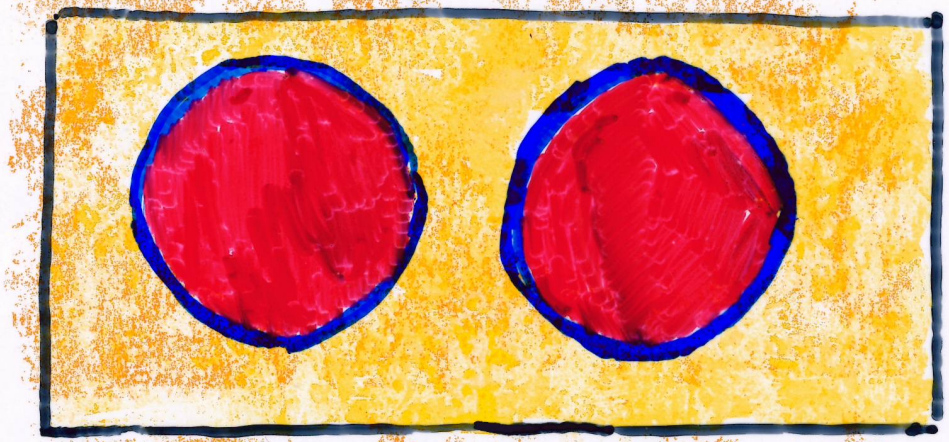
SIDIS beyond quark parton model

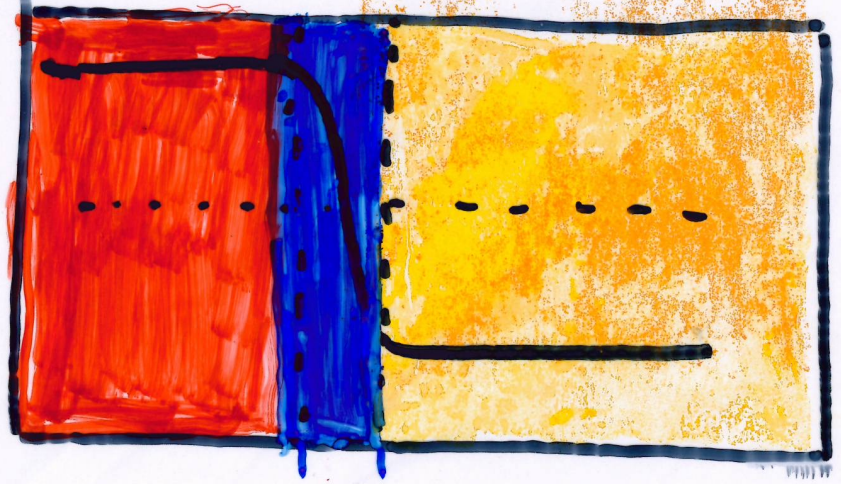
ENTANGLEMENT in Hard Scattering Processes



SIDIS beyond quark parton model

Domain Zones





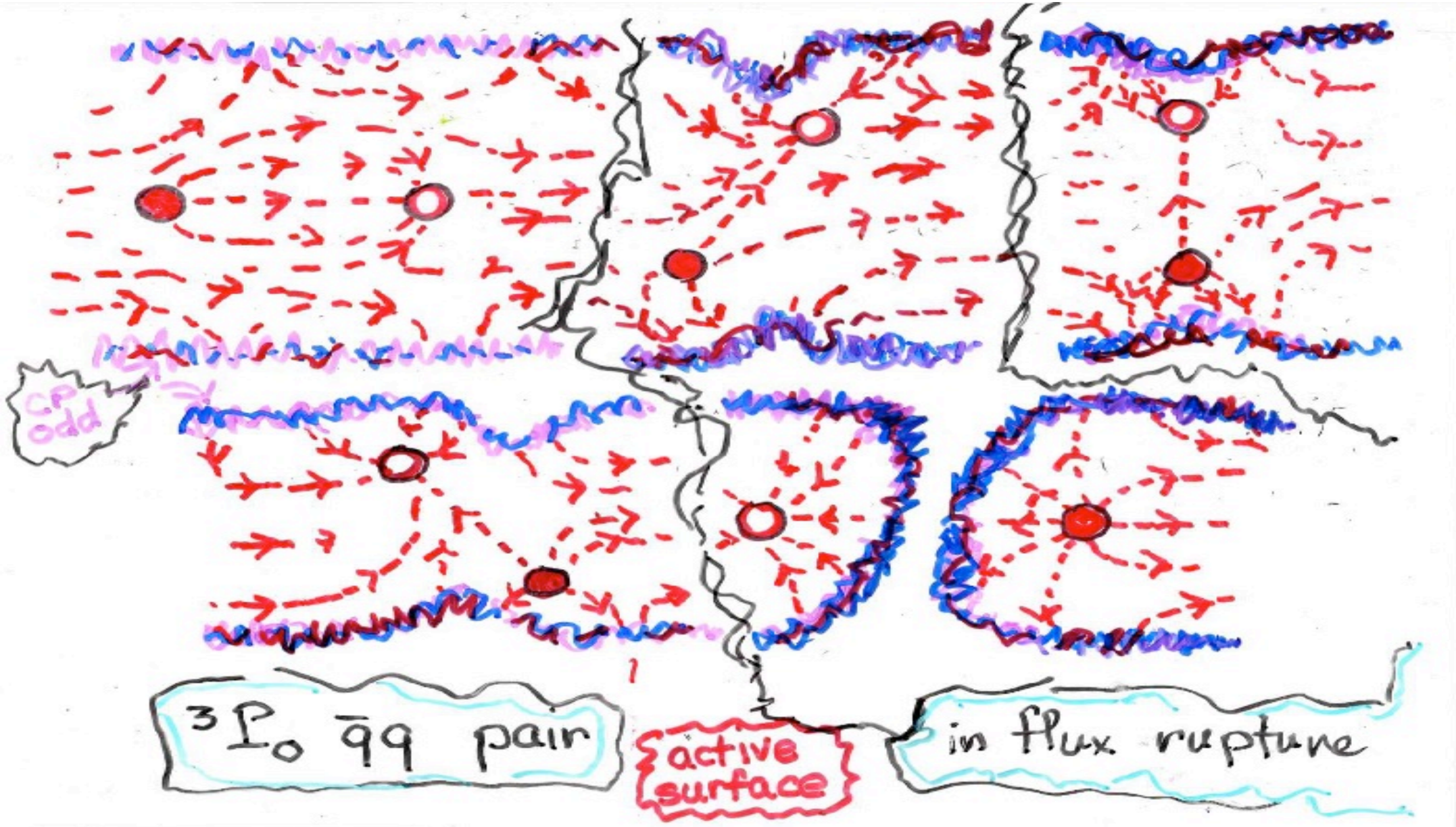
Color-averaged Lorentz-invariant densities

$E_i^a(r) E_i^a(r) - B_i^a(r) B_i^a(r)$ $\quad E_i^a(r) B_i^a(r)$

will not evolve in the adiabatic flow but the radially-directed Longitudinal Poynting vector is a strong signal for topological structure.

What properties are required for this structure ??

How Can you Stop Color flow outward?


CP odd
$^3P_0$ $\bar{q}q$ pair
active surface
in flux rupture

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