Wee Partons in the Pion and in the Pomeron

Abstract

The role of wee partons in carrying infinite momentum vacuum properties is discussed. The Feynman-Gribov parton model is used to illustrate how a universal wee parton distribution is part of the Critical Pomeron description of soft physics. A brief, qualitative, description is given of how, in Color Superconducting QCD, with SU(2) color, the chiral anomaly produces an anomalous wee gluon condensate (associated with a Dirac sea shift) in the pion and in the pomeron. The condensate is responsible for the vacuum properties of confinement and chiral symmetry breaking. It is argued that, as SU(3) color is restored, the condensate becomes dynamical and the Critical Pomeron occurs. Because wee partons carry vacuum properties, the QCD parton model should be maximally valid. Phenomenological consequences, such as soft and gentle confinement, the pomeron as a single reggeized gluon, and the factorization of pomeron jet cross-sections, are briefly mentioned, as are possible caveats.

Wee Partons in the Pion

and in the Pomeron

The general theme of this talk will be the role wee partons can play in carrying infinite momentum vacuum properties. The presentation will be very qualitative, concentrating on essential ideas. More details can be found in my recent papers.

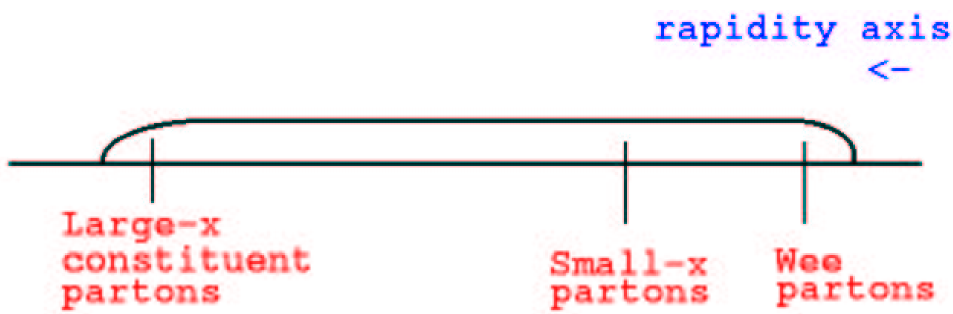
OUTLINE

1. **Wee Partons in the Feynman-Gribov Parton Model**
2. **Can the Feynman-Gribov Parton Model be Valid in QCD ?**
3. **The Chiral Anomaly and Wee Gluons in the Pion**
4. **A Wee Gluon Critical Phenomenon**
5. **Soft and Gentle Confinement**
6. **Pomeron Cross-Sections**
7. **Possible Caveats**

Wee Partons in the

Feynman-Gribov Parton Model

- **"Partons" are hadron constituents, assumed to have infinite momentum wave-functions (no vacuum production).**
- **In the Feynman-Gribov model (based on general features of high-energy soft physics) "partons" have the properties of pions. Interactions are short-range in rapidity and cut-off in transverse momentum ($\rightarrow$ regge pole pomeron).**
- **"Feynman Scaling" occurs when, at infinite momentum, partons are uniformly distributed on the rapidity axis. The long-range rapidity effects involved have to build up from the short-range interactions as a "Critical Phenomenon".**



- **Interactions of "wee" partons, with $x \sim 0$, dominate hadron scattering and produce the "central plateau" in production processes.**
- **Because of their critical phenomenon origin, wee partons appear universally in all hadrons. As a result, they can carry vacuum properties - allowing the "parton model" to be valid even when there is a non-trivial vacuum !**
- **The full critical phenomenon is described in detail by "Critical Pomeron" Reggeon Field Theory (RFT).**

Can the Feynman-Gribov Parton Model be valid in QCD ?

- Confinement should imply that, within QCD, small-x partons can equally well be thought of as pions.
- Can this be consistent with the presence of large-x constituent quarks and medium-x gluons that have long-range rapidity interactions ??
- This is the highly non-trivial requirement of matching confinement with short-distance perturbation theory in QCD.
- In principle, at least, gluon long-range rapidity interactions can be matched if there is a critical phenomenon in terms of pion interactions !!

RFT suggests that, from the supercritical side,

- the Critical Pomeron describes a transition from Color Superconducting QCD with SU(2) color (CSQCD) to pure QCD - with SU(3) color.
- CSQCD contains an SU(2) triplet of massless gluons, two doublets and one singlet of massive gluons.

My goal is to obtain the Critical Pomeron via CSQCD.

- The matching with the Feynman-Gribov model should imply that vacuum properties can be carried by wee partons, and the QCD parton model can be maximally valid.

A priori, we have very little knowledge of the wee partons in QCD hadrons, but

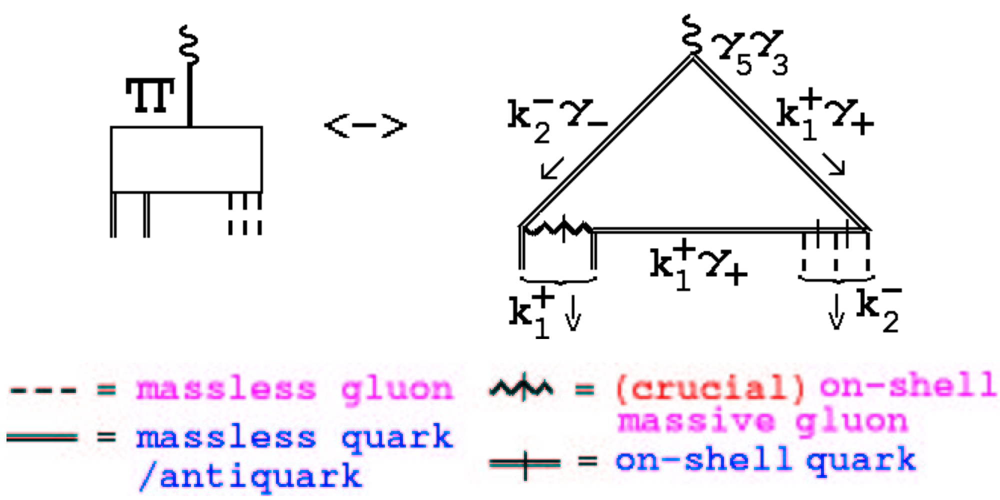
The Chiral Anomaly and

Wee Gluons in the Pion

- in CSQCD, we can show, via the flavor chiral anomaly, that a massless GOLDSTONE BOSON pion with light-cone momentum k_1^+ necessarily has two components.

1. A massless quark-antiquark pair with momentum k_1^+ and vector-like spin.
2. Massless "wee-gluons" with momentum k_2^- $(k_2^- / k_1^+ \rightarrow 0)$

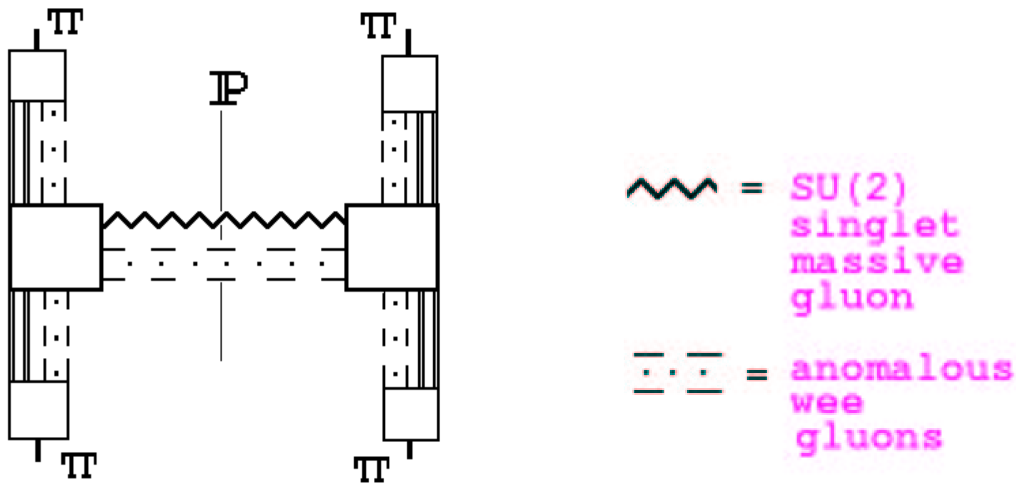
The infra-red anomaly in an axial-current triangle diagram (with "effective vertices") provides the pion pole and coupling - when $k_2^- \rightarrow 0$. The pole is generated[a] by the combination of a light-like quark propagator and a zero momentum propagator that connects quark and antiquark pole couplings.



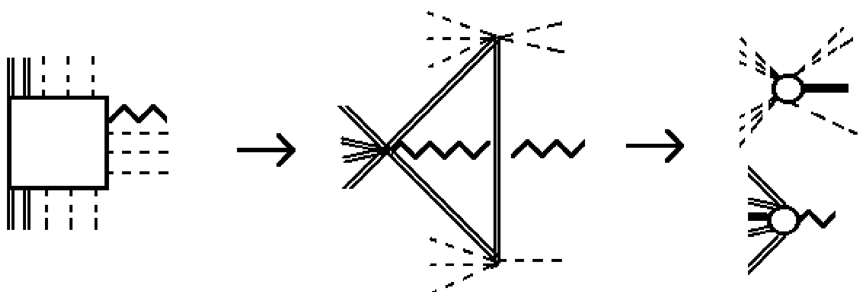
[a] *Effectively, the pion is created by the product of a physical quark field and a zero momentum "unphysical" antiquark field in which the Dirac sea is shifted. The antiquark becomes physical because there is an accompanying gluon field that moves the Dirac sea back to it's perturbative location.*

- Wee gluon infra-red divergences select the diagrams that contribute to the physical $\pi - \pi$ scattering amplitude.
- The exponentiation of reggeon infra-red divergences removes all but the "anomalous" wee gluons, with the quantum numbers of the U(1) anomaly current (i.e. color zero, odd-signature and even color parity.)

- The simplest contributing diagrams have the form

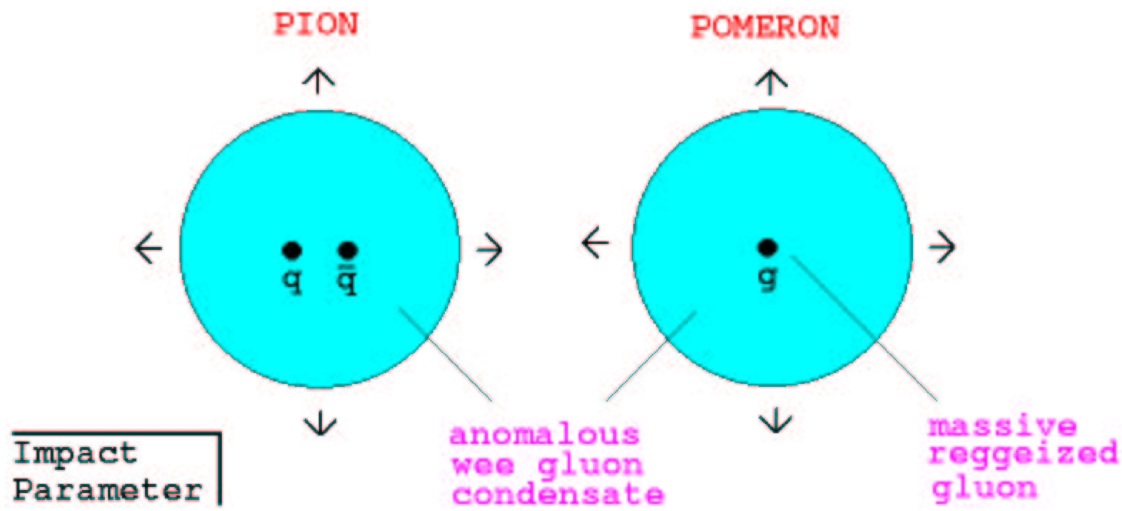


- The wee gluons couple through an infra-red U(1) anomaly in the "$\pi\pi\mathbb{P}$" vertex and produce an overall divergence at zero transverse momentum that can be factorized out.



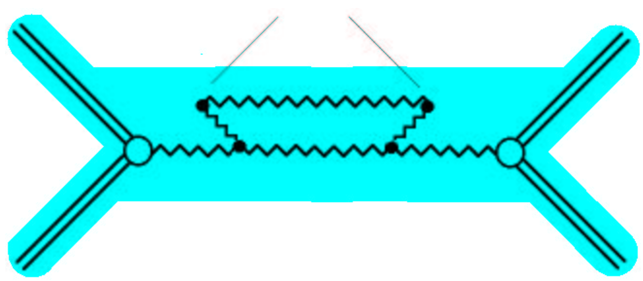
- The physical interpretation is that there is a "wee gluon condensate" in both the pion and the pomeron that originates from the shifted Dirac sea in the pion.
- "Nucleons", i.e. quark/quark (and antiquark/antiquark) Goldstone bosons similarly contain the condensate and have the same scattering amplitudes.

- The wee gluon condensate is, essentially, all that remains of the SU(2) part of the theory.
- Without the massive part of CSQCD, there would be no scattering amplitudes (c.f. the unit S-Matrix in the Schwinger model).
- The condensate can be thought of as occupying a space around a hadron that expands (in the impact parameter plane) as the momentum increases. Schematically -



- Since the condensate is not dynamical, it does not give an increasing cross-section. It does produce additional “pomeron” interactions, e.g.

Condensate production of massive gluon pairs



- Wee partons (gluons) produce both confinement of SU(2) color and chiral symmetry breaking -

the only physical states are color zero Goldstone boson pions and nucleons !!

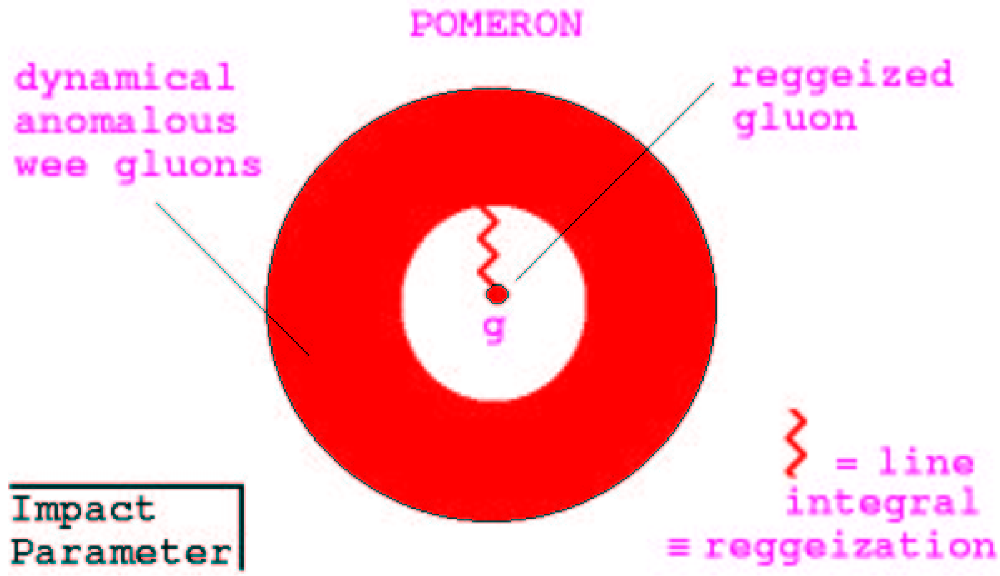
A Wee Gluon Critical Phenomenon

- SU(3) color symmetry will be restored if the condensate disappears and, simultaneously, the massive gluon becomes massless and decouples in physical amplitudes.
- The analagous features are all present in Supercritical RFT as the critical point is approached.
- All indications are that the high-energy behavior of CSQCD is described by Supercritical RFT.
- It has, however, been difficult to find a good starting point from which a full graphical correspondence (beyond lowest order) can clearly be made. (Although, it now seems that starting with the pion coupled to infinite momentum electroweak vector bosons may be the best framework.)

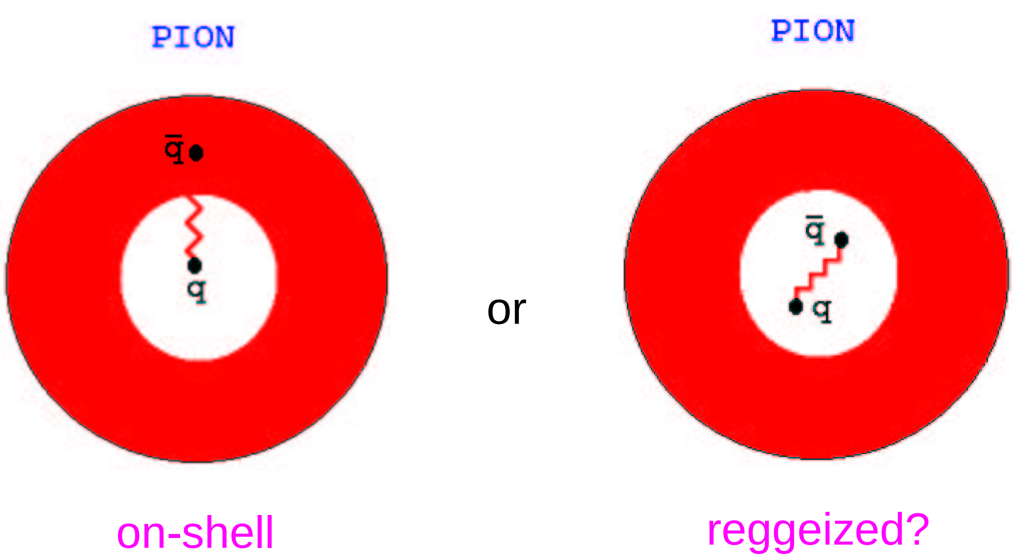
The physical picture that emerges is the following.

- As the condensate component of the wee gluon contribution disappears, a corresponding dynamical contribution appears. This is a common signal of a phase transition and should be the Critical Pomeron transition, seen from the supercritical side.
- Both the massive, reggeized, gluon and the wee gluon condensate are SU(2) singlets and, together, they have a projection on an SU(3) singlet. Therefore, we expect that -

- within QCD, the pomeron will (in first approximation) be a short-distance reggeized gluon combined with the anomalous wee gluon (or shifted Dirac sea) contribution - which is now dynamical.



- A reggeized gluon is gauge invariant, but carries a global SU(3) color. It is this global color that is neutralized by the wee gluon contribution.
- The pion will be similar to the pomeron



Soft and Gentle Confinement

The QCD parton model should be maximally valid in various ways. In particular, confinement will be "semi-perturbative" and will not involve any strong coupling physics.

After a parton interaction a (massless) pion is formed directly via the anomaly (a nucleon is more subtle).

- An outgoing fast quark combines with a soft antiquark that becomes unphysical (and locked inside the pion) via a wee gluon anomaly interaction that produces a Dirac sea shift.
- Infinite momentum confinement of this form matches naturally with the finite momentum confinement, involving a non-perturbative adjustment of the Dirac sea, proposed by Gribov.
- Since no strong force between quarks is involved, Dokshitzer has called this "soft and gentle confinement".
- Significant experimental evidence for this form of confinement is provided by the momentum properties of multi-hadron production (mutiplicity distributions etc.).
- Since there appears to be very little momentum reordering in the transition from quarks to pions, confinement must take place in a soft and gentle manner.

Pomeron Cross-Sections

The matching of short-distance perturbative QCD with pomeron processes should be strikingly simple.

- **Since the short-distance pomeron is a single reggeized gluon, it should have a leading single gluon in deep-inelastic scattering.**
- **Single diffractive jet cross-sections, double-pomeron jet cross-sections etc. should have the same regge factorization properties as the corresponding soft pomeron cross-sections (c.f. CDF results !)**

In general, perturbative cross-sections should smoothly transition into soft regge region cross-sections. There is surely much additional experimental evidence for this that can be looked for.

Possible Caveats

- **Removal of an implicit $k_\perp$ cut-off, and contact with asymptotic freedom, may be possible only in special circumstances.**
- **Perhaps a large number of quarks is needed in the massless theory to prevent the infra-red growth of α_s. To be physically relevant, this could require that electroweak symmetry breaking is due to color sextet quarks.**
- **Perhaps the whole picture is only valid way above the electroweak scale !**

Perhaps not !!!