Shrinkage of diffraction cone:

the case for small-x diffractive DIS at THERA

N. N. Nikolaev

IKP, Forschungszentrum Jülich

&

L. D. Landau Institute, Moscow

THERA Workshop

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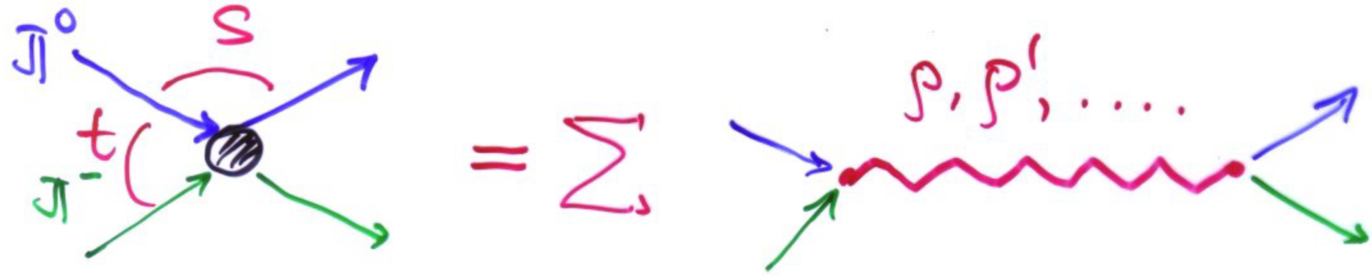
- The t-channel view at high energy scattering for layman
- Chew-Frautshi plot & Regge trajectories
- Gribov's shrinkage of the diffraction cone
- Hadronic scattering archives
- The unitarity view at the shrinkage: Gribov-Feinberg-Chernavski random walk in the impact parameter space
- Small-x BFKL dynamics in QCD corrupted by infrared regularization
- Shrinkage of diffr. cone in QCD: the evidence from ZEUS?
- Decisive proof at THERA

s-channel asymptopia from the t-channel exchanges



$$t > 4\mu_\pi^2 \quad , \quad s < 0$$

$$\cos\Theta_t = 1 + \frac{2s}{t - 4\mu_\pi^2}$$

$$= \sum_n \frac{g_1 \cdot g_2}{t - m_n^2} P_{j_n}(\cos\Theta_t)$$

Try $t < 0 \quad , \quad s \to \infty$

$$|\cos\Theta_t| \to \infty$$

$$P_j(z) \sim z^j$$

Sommerfeld - Watson - Froissart - Gribov analytic continuation:
swap the sum for a contour integral in the j-plane; continuation by deformation of the integration contour

$$T(s,t) = g_1(t) \cdot g_2(t) \cdot \left(\frac{s-u}{s_0}\right)^{\alpha(t)} \cdot \frac{1 + \tau \exp[-i\pi\alpha(t)]}{\sin \pi\alpha(t)}$$

- the Regge trajectory

$$\alpha(m_n^2) = j_n$$

keeps a memory of the t-channel resonances; $T(s,t)$ has a pole at $\alpha(t) = j_n$

- the signature factor $\tau = \pm 1$ labels crossing-even and crossing-odd resonances/exchanges

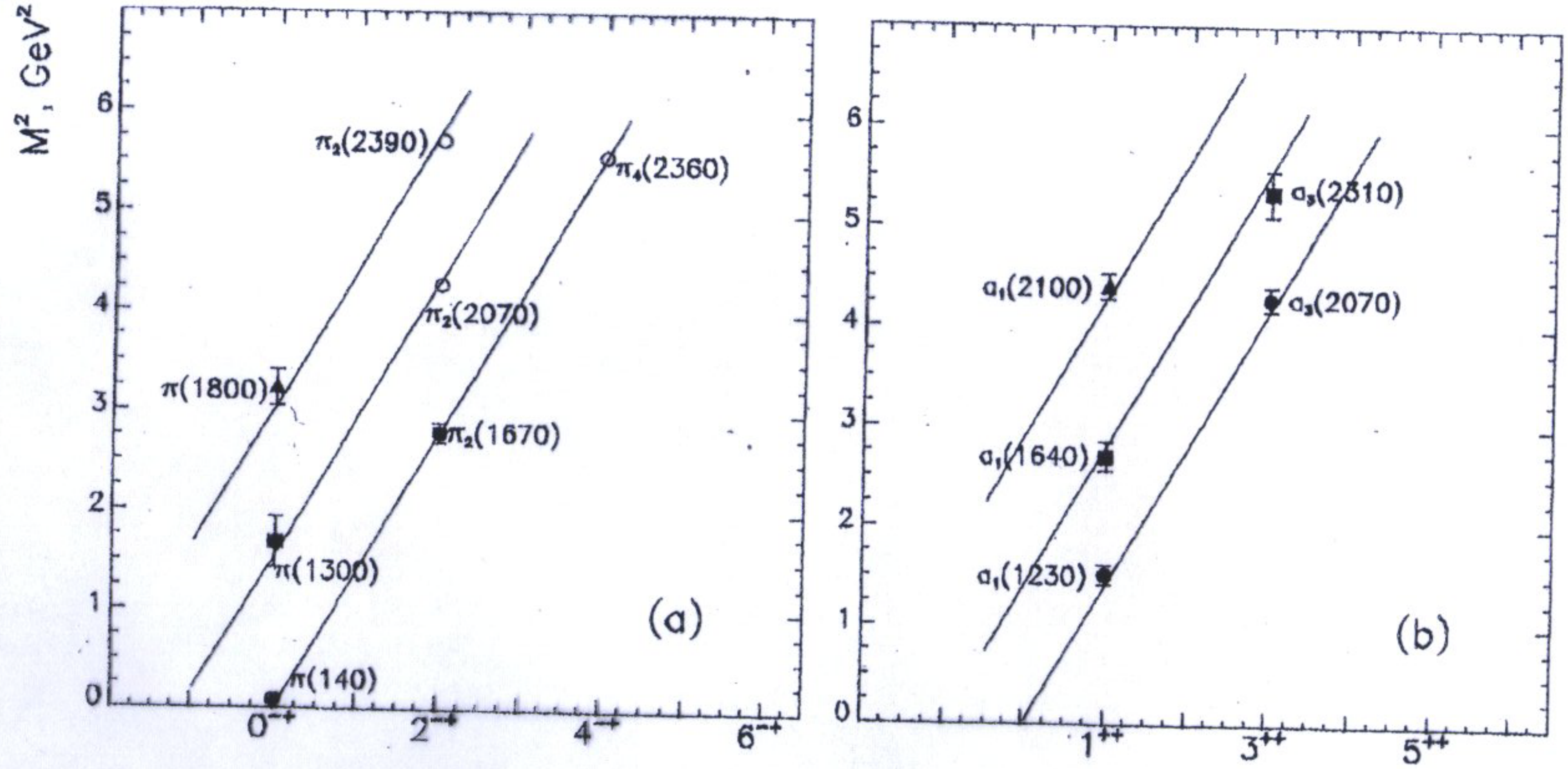
$\pi^0\pi^0$, resonances only at even j

$\pi^+\pi^-$, $I=1$, resonances only at odd j

Chew-Frautschi plots

A. V. ANISOVICH, V. V. ANISOVICH, AND A. V. SARANTSEV

$$\alpha(M^2) = \alpha(0) + \alpha' \cdot M^2$$



$$\alpha_\pi(t) = -0.015 + 0.72 \cdot M^2$$

$$\alpha_{a_1}(t) = 0 + 0.72 \cdot M^2$$

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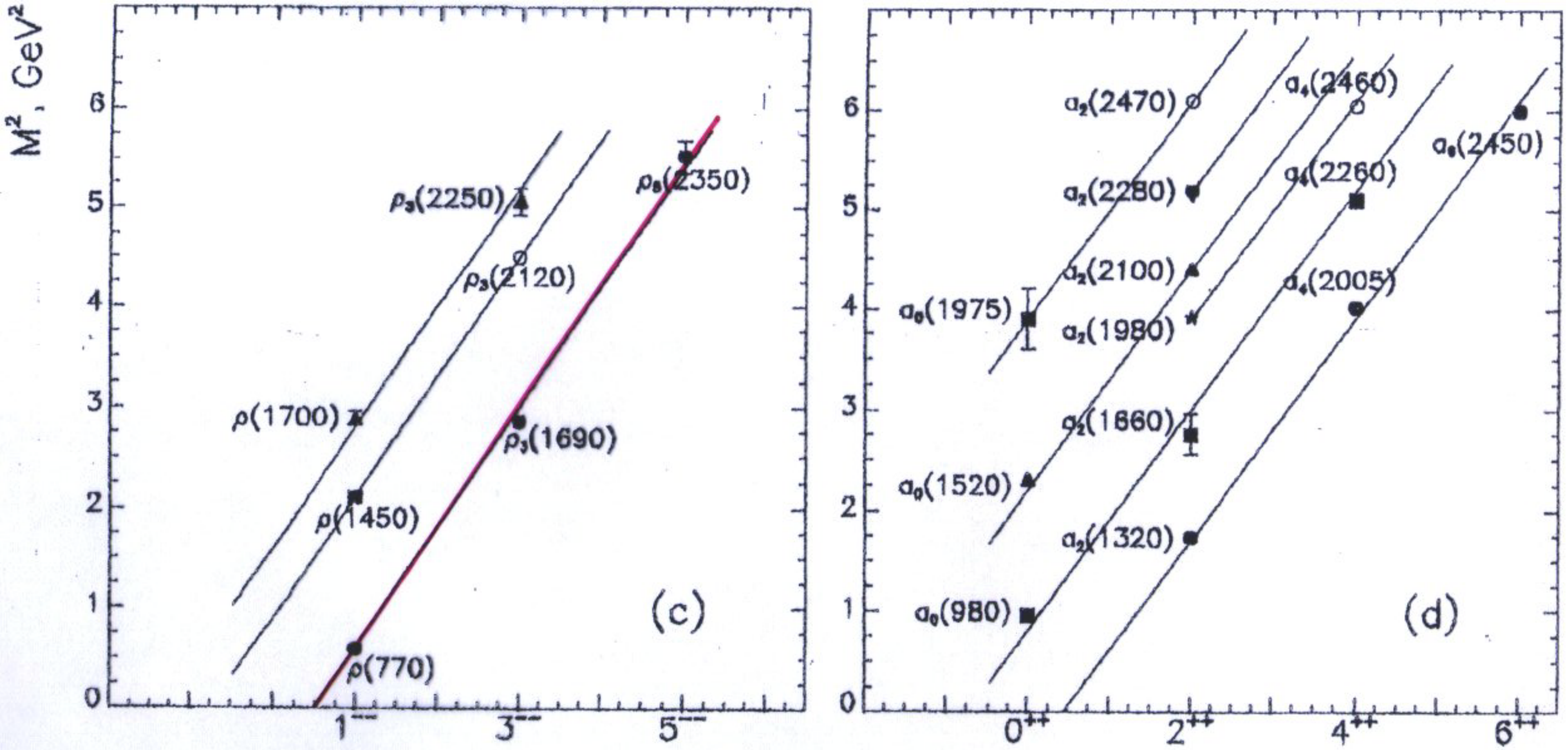
$$\alpha_\rho(t) = 0.5 + 0.83 \cdot M^2$$



$$\alpha_{a_2}(t) = 0.45 + 0.91 \cdot M^2$$

$$\alpha_{\mathbb{P}'}(t) = \alpha_f(t) = 0.71 + 0.83\, M^2$$

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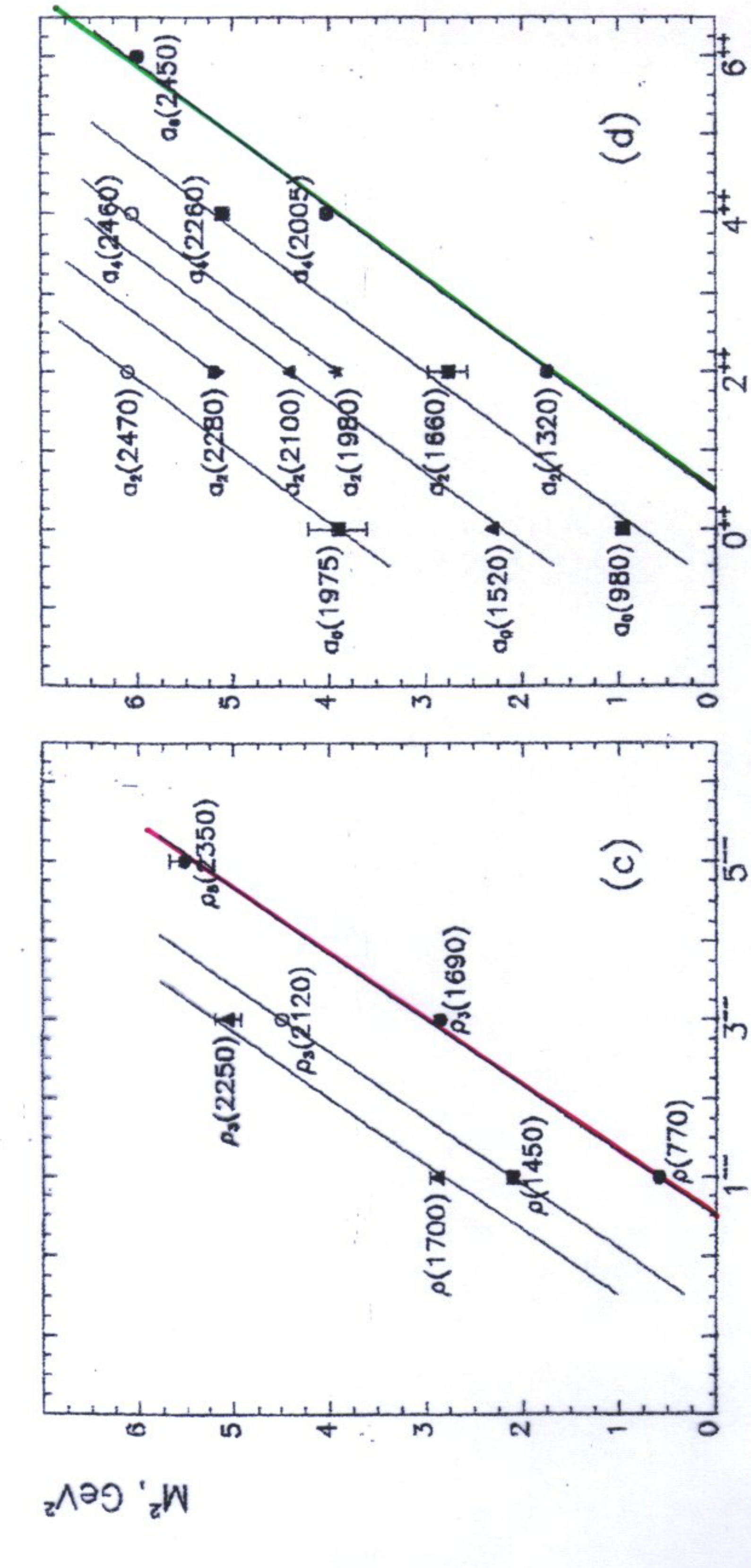
THERA-7.



M², GeV²
(c)
ρ(770)
ρ(1450)
ρ(1700)
ρ₃(1690)
ρ₃(2120)
ρ₃(2250)
ρ₅(2350)
(d)
a₀(980)
a₀(1520)
a₀(1975)
a₂(1320)
a₂(1660)
a₂(1980)
a₂(2100)
a₂(2280)
a₂(2470)
a₄(2005)
a₄(2260)
a₄(2460)
a₆(2450)
1⁻⁻
3⁻⁻
5⁻⁻
0⁺⁺
2⁺⁺
4⁺⁺
6⁺⁺

Regge trajectories from scattering processes vs. ~~Chew~~ Chew-Frautshi extrapolations

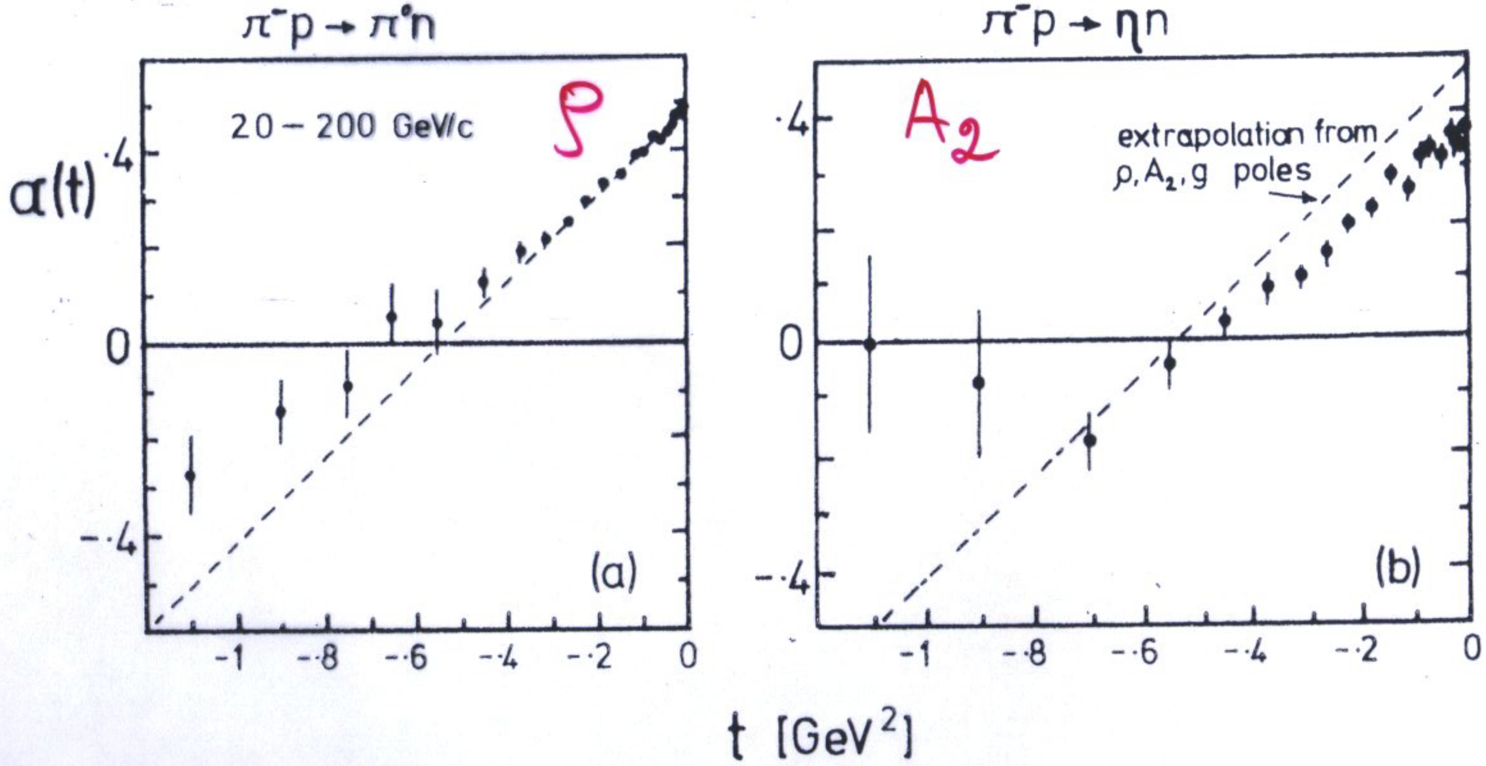


Fig. 2.2. Effective trajectories for (a) $\pi^- p \to \pi^0 n$, (b) $\pi^- p \to \eta n$ in the range 20–200 GeV/c [298, 306].

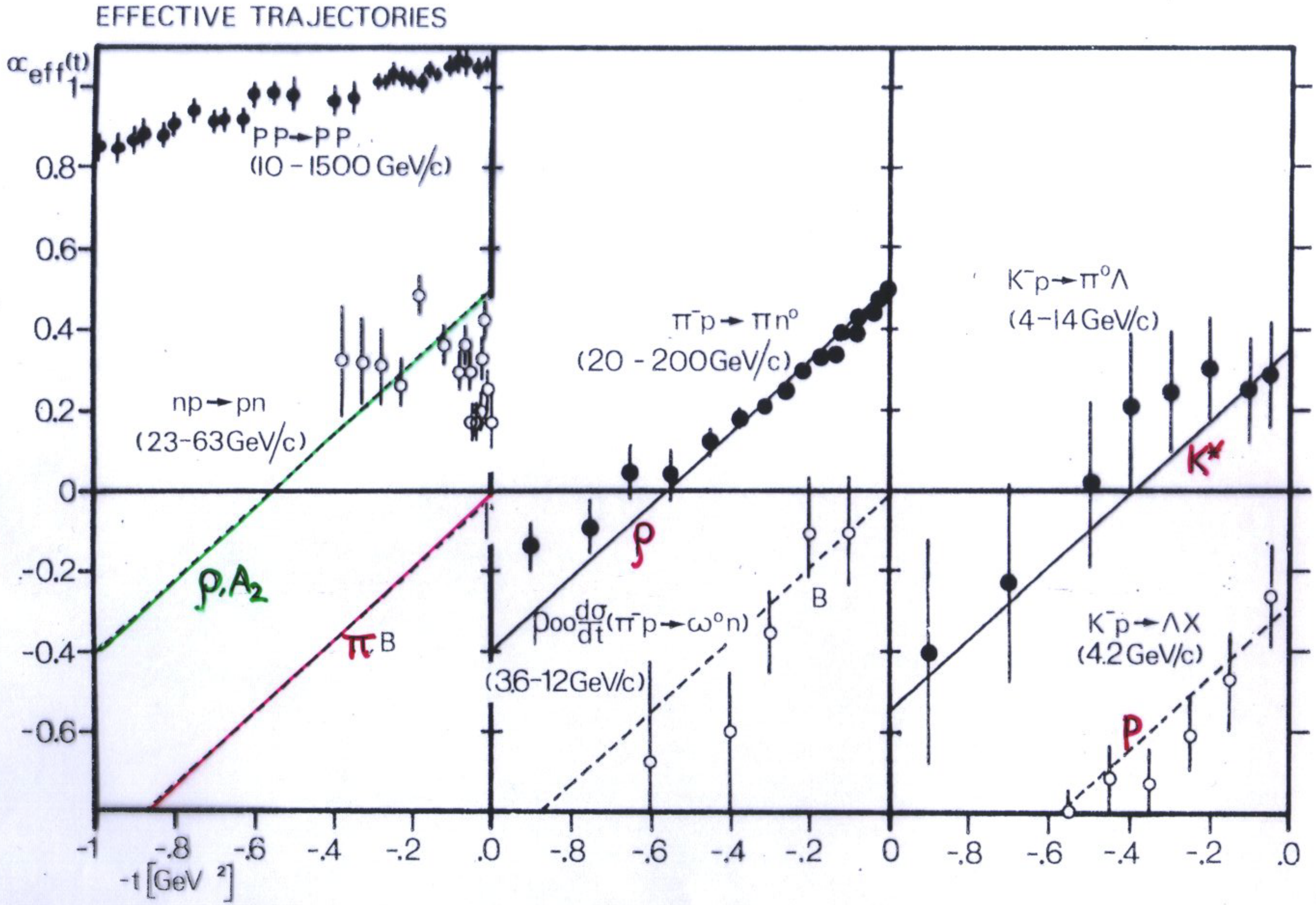


Fig. 2.7. Effective trajectories calculated from the energy dependence of various reactions.

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Gribov's shrinkage of the diffraction cone:

- $\alpha(t) = \alpha(0) + \alpha' \cdot t$

$$s^{\alpha(t)} = s^{\alpha(0)} \cdot s^{\alpha' \cdot t} =$$

$$= s^{\alpha(0)} \cdot \exp[t \cdot \alpha' \cdot \log s]$$

- $T(s,t) = T(s,0) \cdot \exp[\frac{1}{2} B t]$

* $B = B_0 + 2\alpha' \cdot \log \frac{s}{s_0}$

The diffraction cone B rises with energy.

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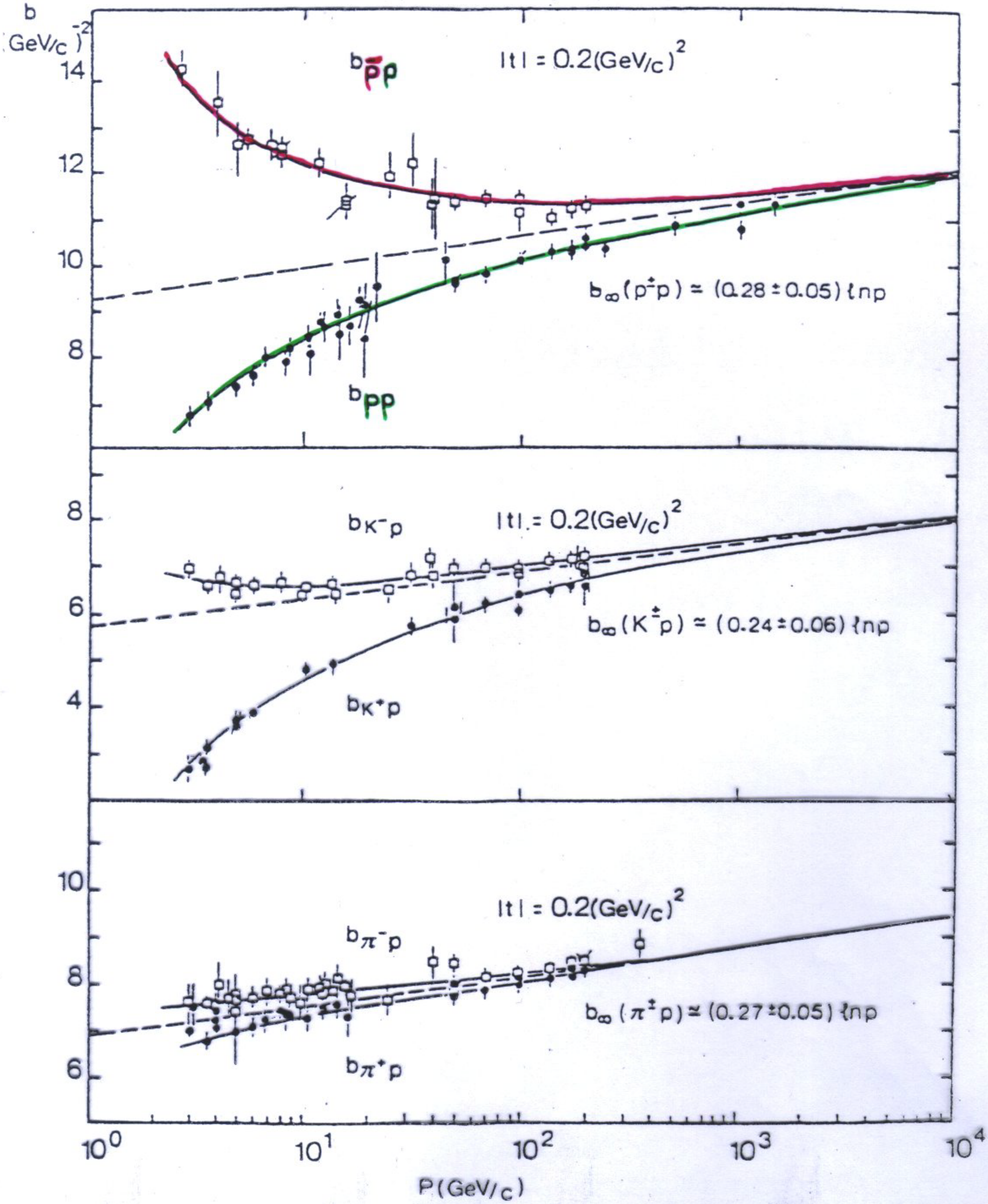
Hadronic archives

K. Goulianos, Diffractive interactions of hadrons at high energies

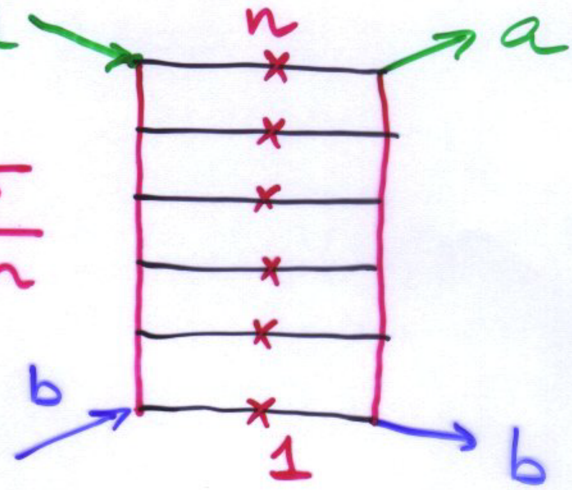


Down to the Earth from the heavy math of the Froissart-Gribov-Sommerfeld-Watson transformation:

S-channel unitarity and Gribov-Feinberg-Chernavski random walk

- Elastic scattering is driven by strong absorption & dominant multiple production:

$$\mathrm{Im}\,T_{el}(s,0) = \sum_n$$



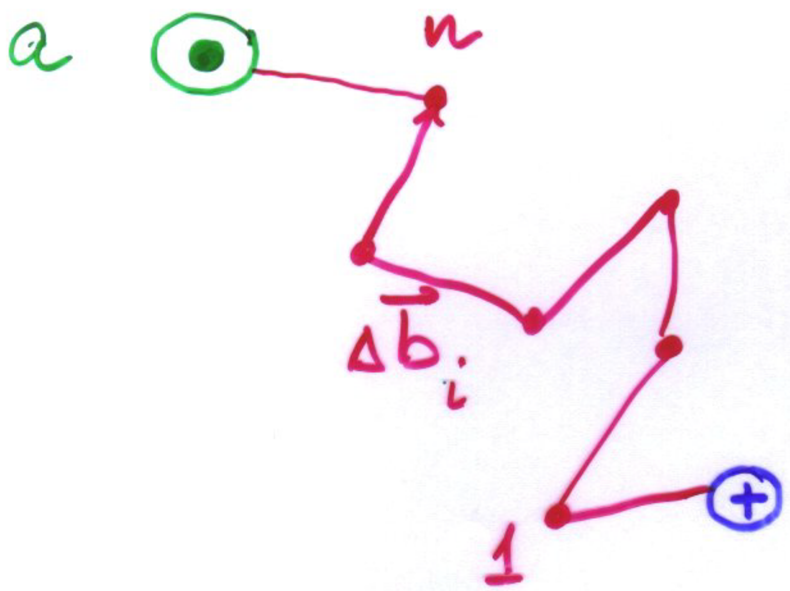
- Approx. uniform rapidity distrbn of secondary hadrons

- $\langle n \rangle \sim \log \frac{s}{s_0}$

- Approx. constant mean $\langle p_\perp \rangle$

- $B = \frac{1}{2}\langle \vec{b}_{ab}^{\,2} \rangle$

- The impact parameter structure of the multiproduction processes:



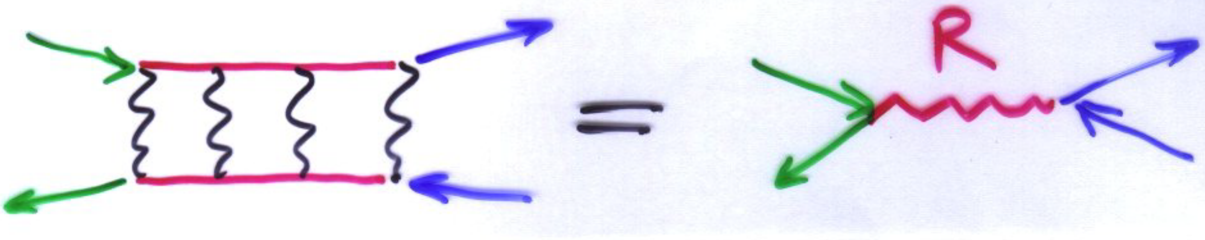
- $\vec{b}_{ab} = \sum_i \Delta\vec{b}_i$

$$\langle \vec{b}_{ab}^{\,2} \rangle \sim \langle n \rangle \cdot \langle \Delta\vec{b}_i^{\,2} \rangle$$

$$\langle \Delta\vec{b}_i^{\,2} \rangle \sim \frac{1}{\langle p_\perp^2 \rangle}$$

- Linkage to resonances:

$b\bar{b} \to R \to \bar{a}a$



A fly in the ointment:

- Very strong absorption, the black disc limit:

$$\sigma_{in} = \pi R^2$$

$$\sigma_{el} = \pi R^2$$

$$\sigma_{tot} = 2\pi R^2$$

$$\frac{1}{2} B = \frac{1}{8} R^2 = \frac{1}{16\pi} \sigma_{tot}$$

- The rise of σ_{tot} entails a shrinkage of the diffraction cone not necessarily related to the Gribov's diffusion

★ A large part of $\alpha'_{eff} \simeq 0.25\,\mathrm{GeV}^{-2}$ seen in pp & $p\bar{p}$ scattering can be attributed to the rise of $\sigma_{tot}(p\bar{p})$, $\sigma_{tot}(pp)$ rather than $\alpha'_{\mathbb{P}}$.

Diffraction cone in QCD

(corrupted by inevitable infrared regularization: α_S freezes? gluons do not propagate beyond $R_c \simeq 0.2-0.3$ f)

- BFKL small-x asymptotics in color dipole representation
  NNN, Zakharov, Zoller 94
  Mueller, Patel 94

- "Hadronic" final states $\equiv$ multiproduction of gluons

- The subject of the BFKL equation is the color dipole cross section $\sigma(x,\vec{r})$

- Perturbative soft gluons in the $q\bar{q}$ dipole give rise to the LL $\frac{1}{x}$ evolution of $\sigma(x,\vec{r})$

- $$\frac{\partial \sigma(x, \vec{r})}{\partial \log \frac{1}{x}} = [K \otimes \sigma](\vec{r})$$

- The ideal case:

  $\alpha_S = \text{const}$

  $R_c = \infty$

$\Longrightarrow$ the scaling kernel K

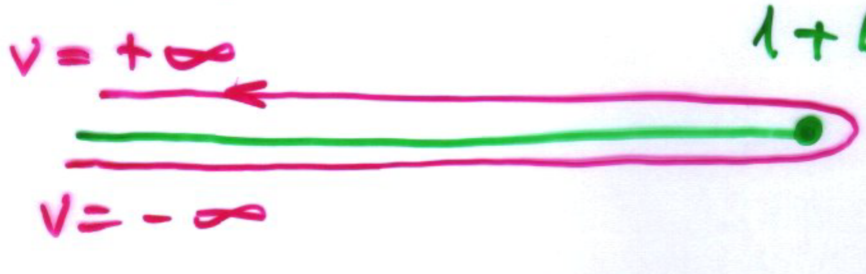
$\Longrightarrow$ the continuous spectrum

$$\frac{1}{r}\sigma(x, r) = \left(\frac{1}{x}\right)^{\Delta(\nu)} \exp[2i\nu \log r]$$

Eigenfunctions are plane waves in the $\log r$ space with very nonlinear relationship between the momentum ν and energy $-\Delta(\nu)$

$\Longrightarrow$ the Regge cut in the j-plane

j



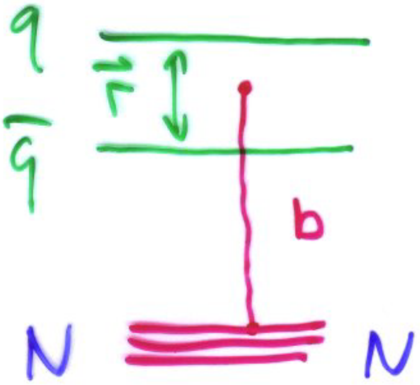
! $\alpha'_{\mathbb{P}} = 0$ because of a lack of any dimensional parameter.

- Asymptotic freedom & finite R_c: the Regge cut $\Longrightarrow$ sequence of Regge poles

  Kuraev, Lipatov, Fadin 76
  Lipatov, JETP 63 (1986) 904

- Explicit breaking of scaling: $\alpha'_{\mathbb{P}} \neq 0$

The technical argument: write the BFKL equation directly for $\langle b^2 \rangle$.



$$B = \frac{1}{3} R_N^2 + \frac{1}{8} r^2 + \Delta B$$

- $\lambda(x,r) = \langle b^2 \rangle \cdot \sigma(x,r)$

in a symbolic form:

- $$\frac{\partial \lambda(x,r)}{\partial \log \frac{1}{x}} = [K \otimes \lambda](r) + \underbrace{\left[K \otimes \frac{1}{8} r^2 \sigma(x,r)\right](r)}$$

$$\downarrow$$

$$\underbrace{\text{const} \times R_c^2 \times \log \frac{1}{x} \times \sigma(x,r)}$$

$$\downarrow$$

$$B = B_0 + \underbrace{\text{const} \cdot R_c^2 \cdot \log \frac{1}{x}}$$

$$\alpha'_{\mathbb{P}} = \text{const} \cdot R_c^2$$

- Gribov's diffusion at work because asymptotic freedom pushes the BFKL evolution to the infrared corner.

$\alpha'_{\mathbb{P}}$ is a non-pQCD quantity.

NNN, Zakharov, Zoller 97

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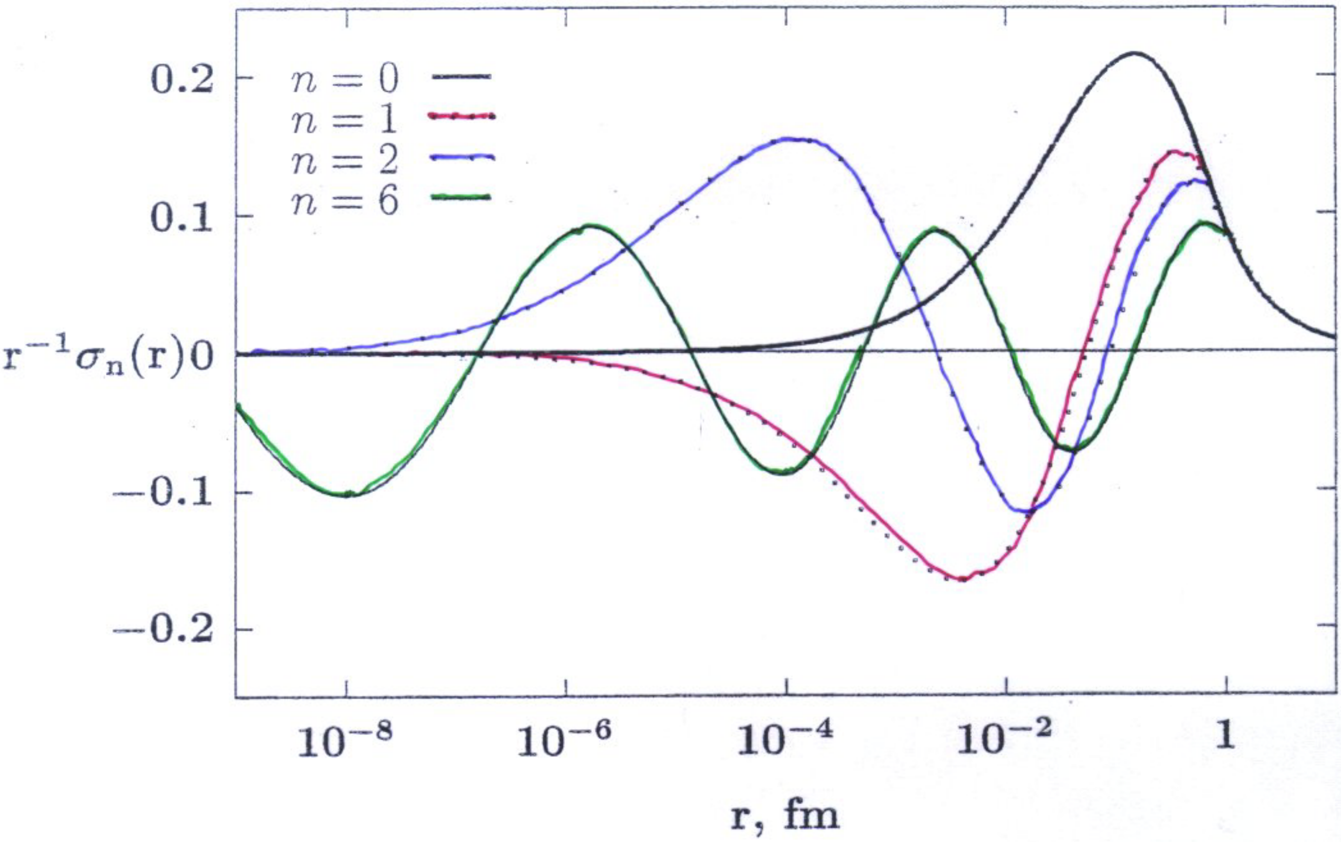
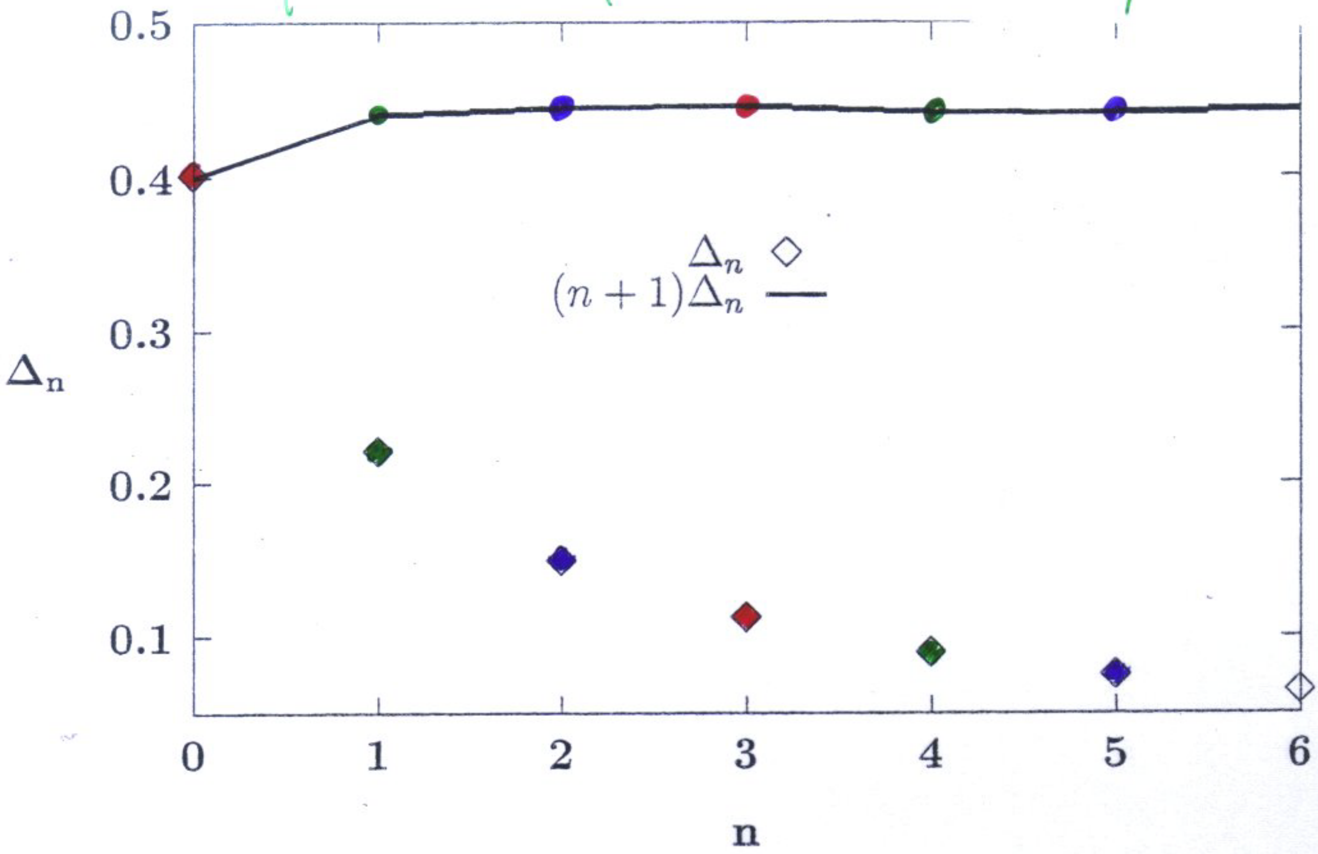


The nodal structure of eigenfunctions of the color dipole BFKL equ.

$R_c = 0.27 f$

The spectrum of the BFKL pomerons



$$\alpha'_n = 0.072, \; n=0$$

$$\downarrow \qquad \downarrow$$

$$0.060, \; n=3$$

The HERA / THERA range of energy:

$$\alpha'_{eff} \simeq 0.1 - 0.12 \ \mathrm{GeV}^{-2}$$

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$$r_S = \frac{6}{\sqrt{Q^2 + m_V^2}}$$

NNN 92

THERA

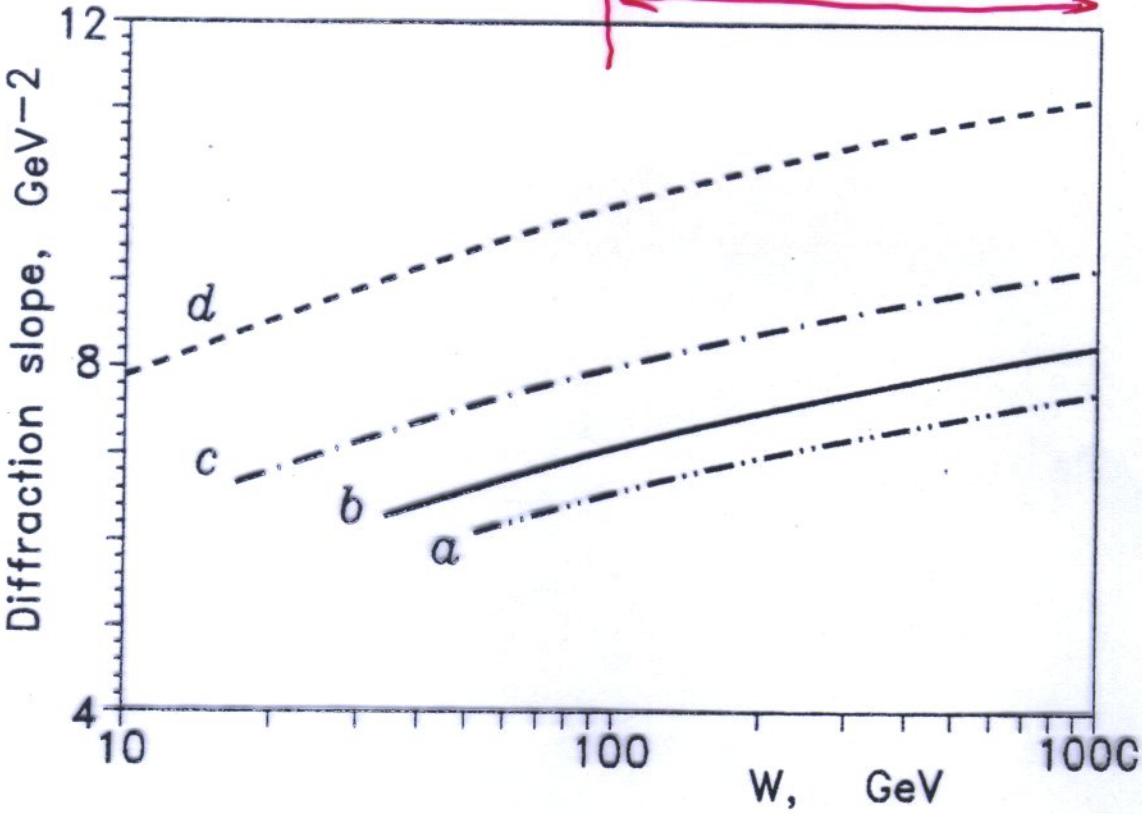

Fig. 4. The c.m.s. energy W dependence of the diffraction slope $B(\xi, r_S)$ at a dipole size (scanning radius) r_S relevant to different diffractive $\gamma^* p \to Vp$ processes: (a) $r_S = 0.12$ fm, $\Upsilon(Q^2 \sim 0)$, (b) $r_S = 0.21$ fm, $J/\Psi(Q^2 \sim 30\,\mathrm{GeV}^2)$, (c) $r_S = 0.4$ fm, $J/\Psi(Q^2 \sim 0)$ and $\rho^0(Q^2 \sim 20\,\mathrm{GeV}^2)$, (d) $r_S = 0.76$ fm, $\rho^0(Q^2 \sim 3.5\,\mathrm{GeV}^2)$.

Subasymptotic effects are large at HERA, die out at THERA.

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The great discovery by ZEUS

Energy Dependence of the t-Slope

- Regge phenomenology: $\frac{d\sigma}{dt} \sim f(t) \cdot W^{2\cdot(2\alpha(t)-2)}$

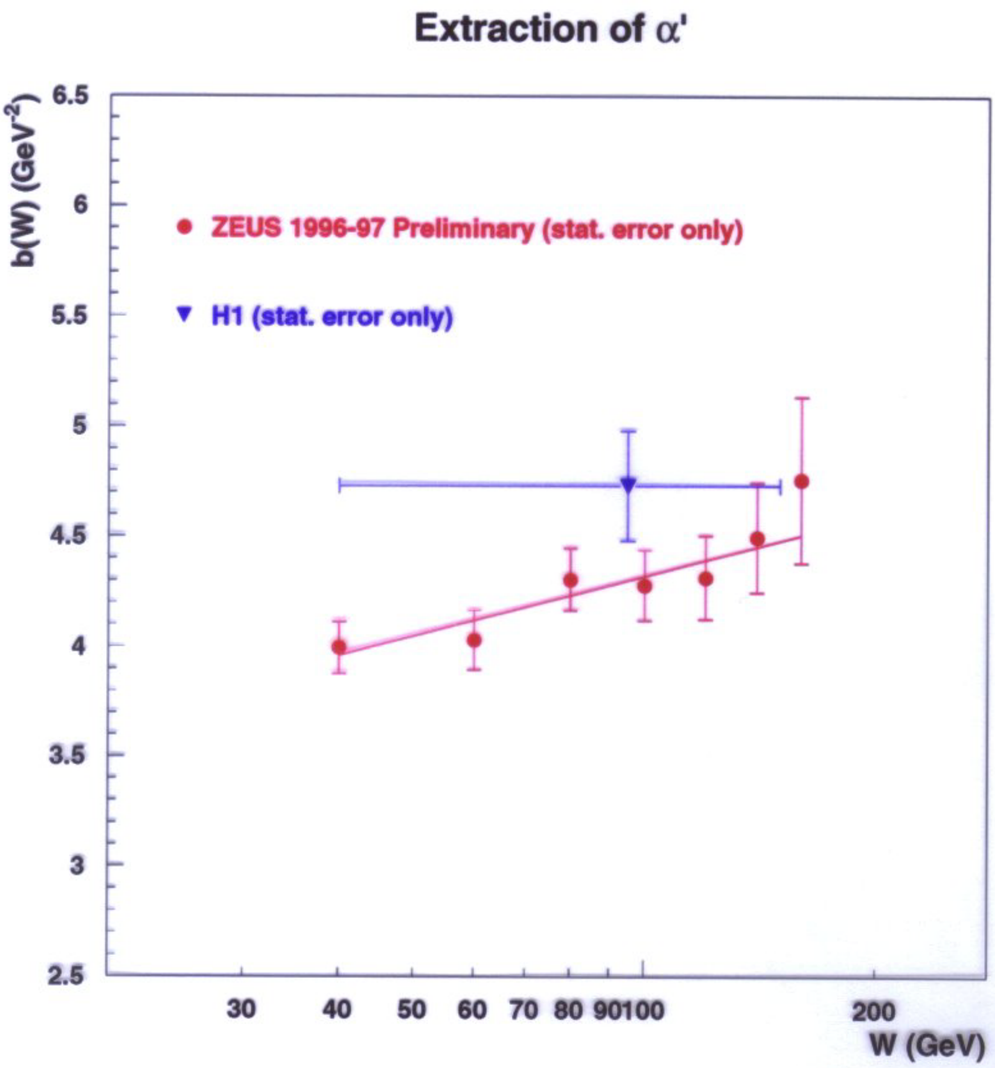
Assuming $f(t) \sim e^{-b|t|}$ and $\alpha(t) = \alpha_0 + \alpha\prime \cdot t$

$$\frac{d\sigma}{dt} \sim e^{-b|t|}, \quad b = b_0 + 2\alpha\prime \cdot \log(\frac{W}{W_0})^2$$

$\alpha(t) = 1.08 + 0.25 \cdot t$ (DL) $\Rightarrow$ shrinkage

- QCD: the t distribution is energy independent

$\Rightarrow$ almost no shrinkage of the forward diffractive peak



- ZEUS: $\alpha'_{\mathbb{P}} = 0.098 \pm 0.035(stat) \pm 0.050(syst)$

THERA – 22[a]

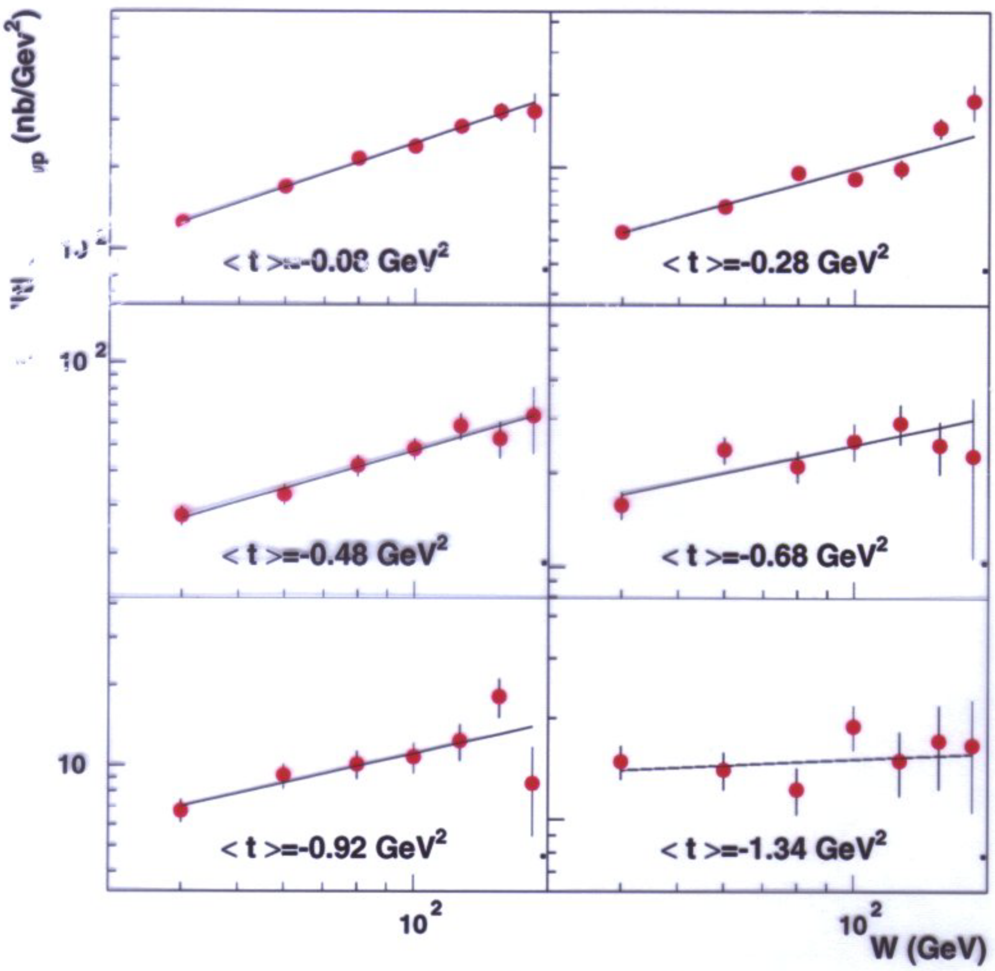
Pomeron Trajectory

Study the $W_{\gamma p}$ dependence of $d\sigma/dt$ at fixed t

$$\frac{d\sigma}{dt} = f(t)(W^2)^{[2\alpha_{\mathbb{P}}(t)-2]}$$

fit a linear trajectory $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} \cdot t$

ZEUS 1996-97 Preliminary



- fit: $\frac{d\sigma}{dt} \sim (W^2)^{[2\alpha_{\mathbb{P}}-2]}$

★ Do we understand the MAGNITUDE of B ?

The Chou-Yang model:

$$T_{pp}(s,t) \propto [G_{em}(t)]^2$$

$$G_{em}(t) = \frac{1}{\left[1 + \frac{t}{\Lambda^2}\right]^2}$$

$$\Lambda^2 \simeq 0.7 \text{ GeV}^2$$

$$B = \frac{8}{\Lambda^2} \sim 11\text{-}12 \text{ GeV}^2$$

! The superb prediction for $E_{lab} \simeq 200$ GeV

But a complete failure at $E_{lab} \sim 10-20$ GeV

The hadronic size of the proton is SUBSTANTIALLY smaller than its electromagnetic size.

CONCLUSIONS

- Shrinkage of diffraction cone is an inevitable consequence of QCD taken together with its nonperturbative facets.

- High lumi of THERA and large lever in $\log \frac{1}{x} = \log W^2$ would allow a crucial test of $\alpha_{\mathbb{P}}' \neq 0$ for HARD diffractive processes:

! $\underline{\gamma p \to \Upsilon p}$

$\gamma^* p \to (\rho, \varphi, J/\psi) \; p$

$$\sigma \sim (x G(x, Q^2))^2 e^{-B|t|}$$

$$B = B_0 + 2\alpha' \ln 1/x$$