XXIX-th International Workshop on High Energy Physics
NEW RESULTS and ACTUAL PROBLEMS
in PARTICLE & ASTROPARTICLE PHYSICS and COSMOLOGY
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High-Energy Collisions in Space-Time Perspective

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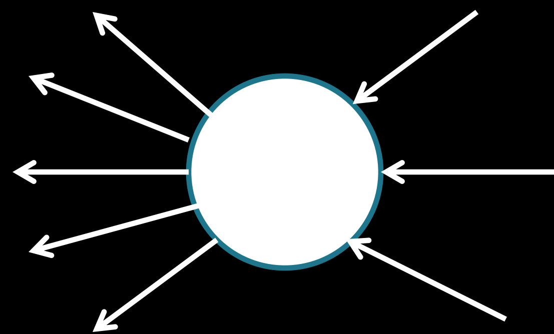
What are observables in particle physics?

- S-matrix (W. Heisenberg, 1943)

$\Psi (x)$

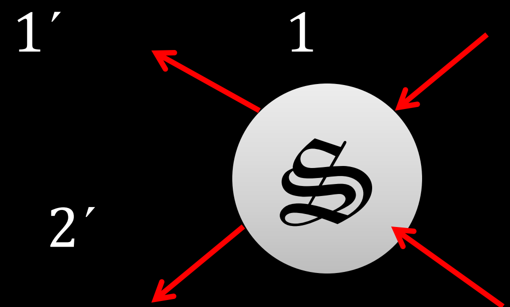


$$S^{+}S = 1$$

- "The Lagrangean Field Theory is dead and should be buried, with all the proper honors of course." (L. Landau, 1960)

"ELASTIC" OBSERVABLES

$t = -p^{*2}(1 - \cos\theta^*)$



$s = (E^*_1 + E^*_2)^2$

$$\sigma_{p+p\to everything} = \sigma_{tot}$$

$$\sigma_{p+p\to p+p} = \sigma_{el}$$

$$d\sigma_{p+p\to p+p}/dt$$

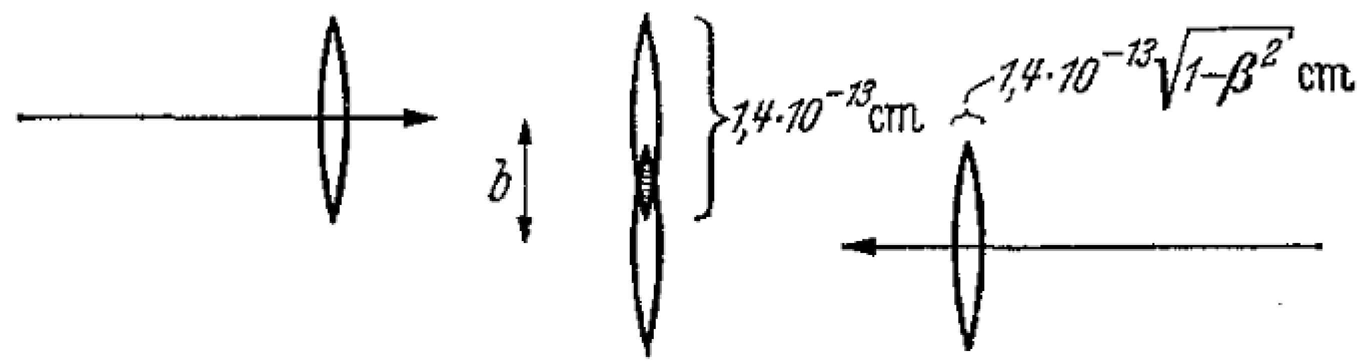
Mesonenerzeugung als Stoßwellenproblem.

Von

W. HEISENBERG.

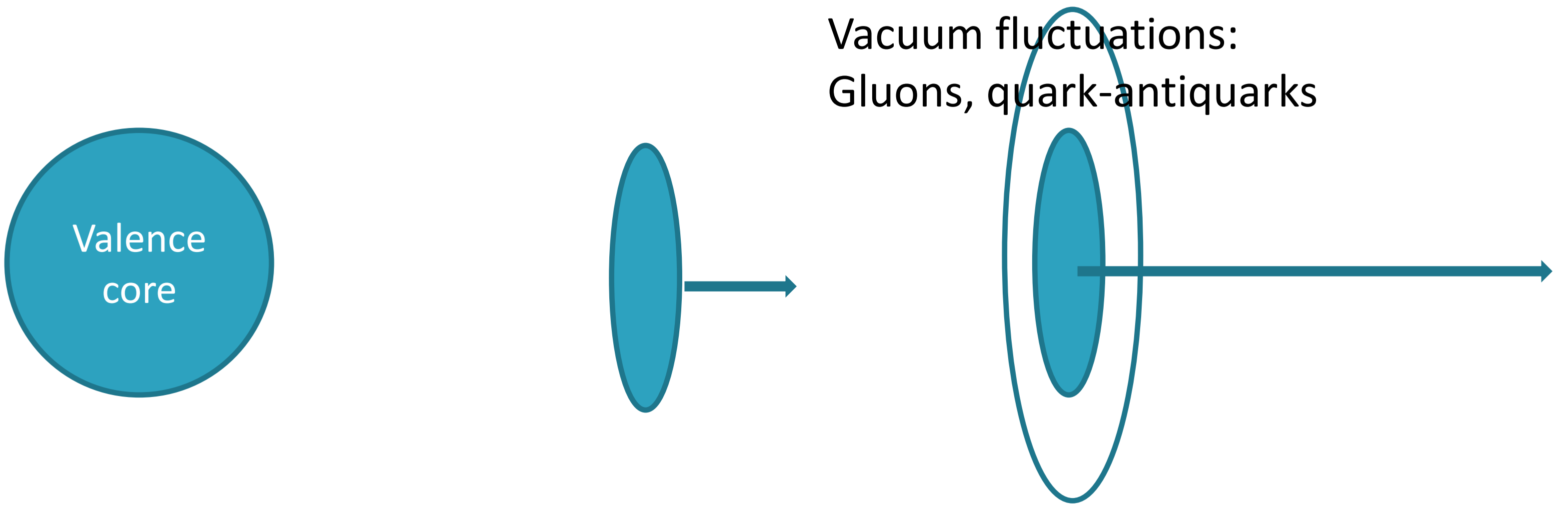
Mit 6 Figuren im Text.

(Eingegangen am 5. Mai 1952.)

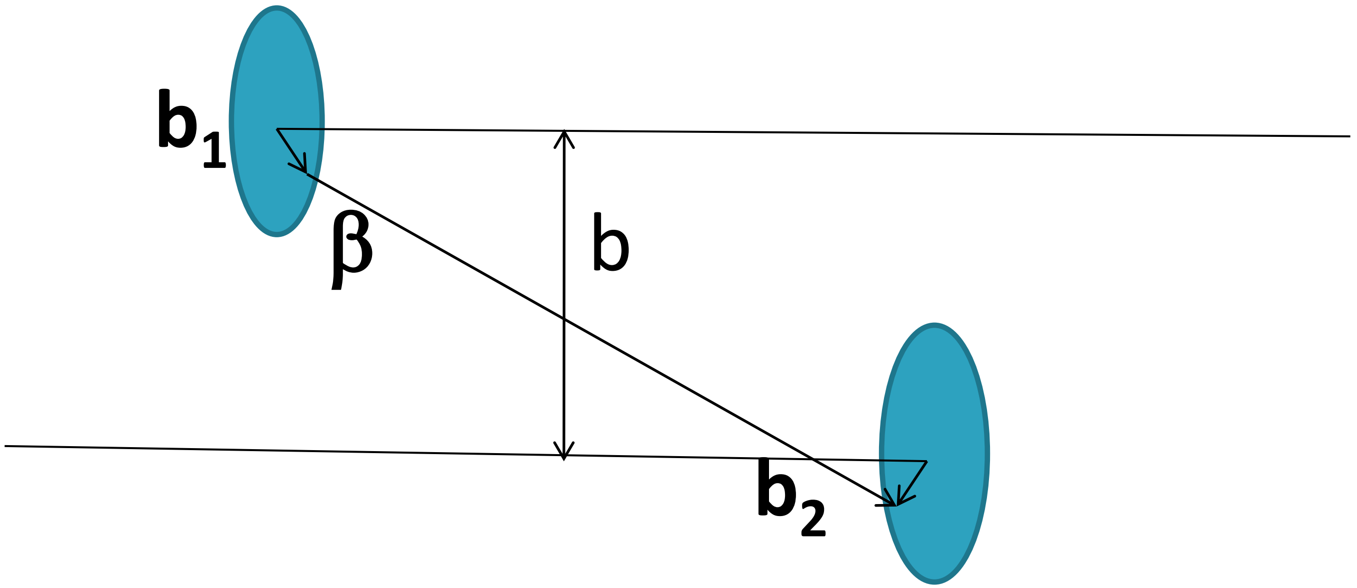


Transverse Space

- **Moving nucleon's spatial structure**



Collision Geometry



$b = \; b_1 + b_2 + \beta \qquad \langle b^2 \rangle = \langle b^2_1 \rangle + \langle b^2_2 \rangle + \langle \beta^2 \rangle$

Nucleon's valence size

- $\langle b^2_1 \rangle = ?$
- Often: $\langle b^2_1 \rangle = 2/3\, r^2_p$
- r_p = "protons charge radius" $\cong$ 0.88 fm

$$r^2_p = -6\, dF(q^2)/dq^2|_{q=0}$$

- r^2_n = "neutron charge radius" $\cong -0.115\ \mathrm{fm}^2$

- Correct option:
- $\langle b^2_1 \rangle = 2/3\,(r^2_p - r^2_n) \cong 0.44\ \mathrm{fm}^2 = 11\ \mathrm{GeV}^{-2}$

Overlaps

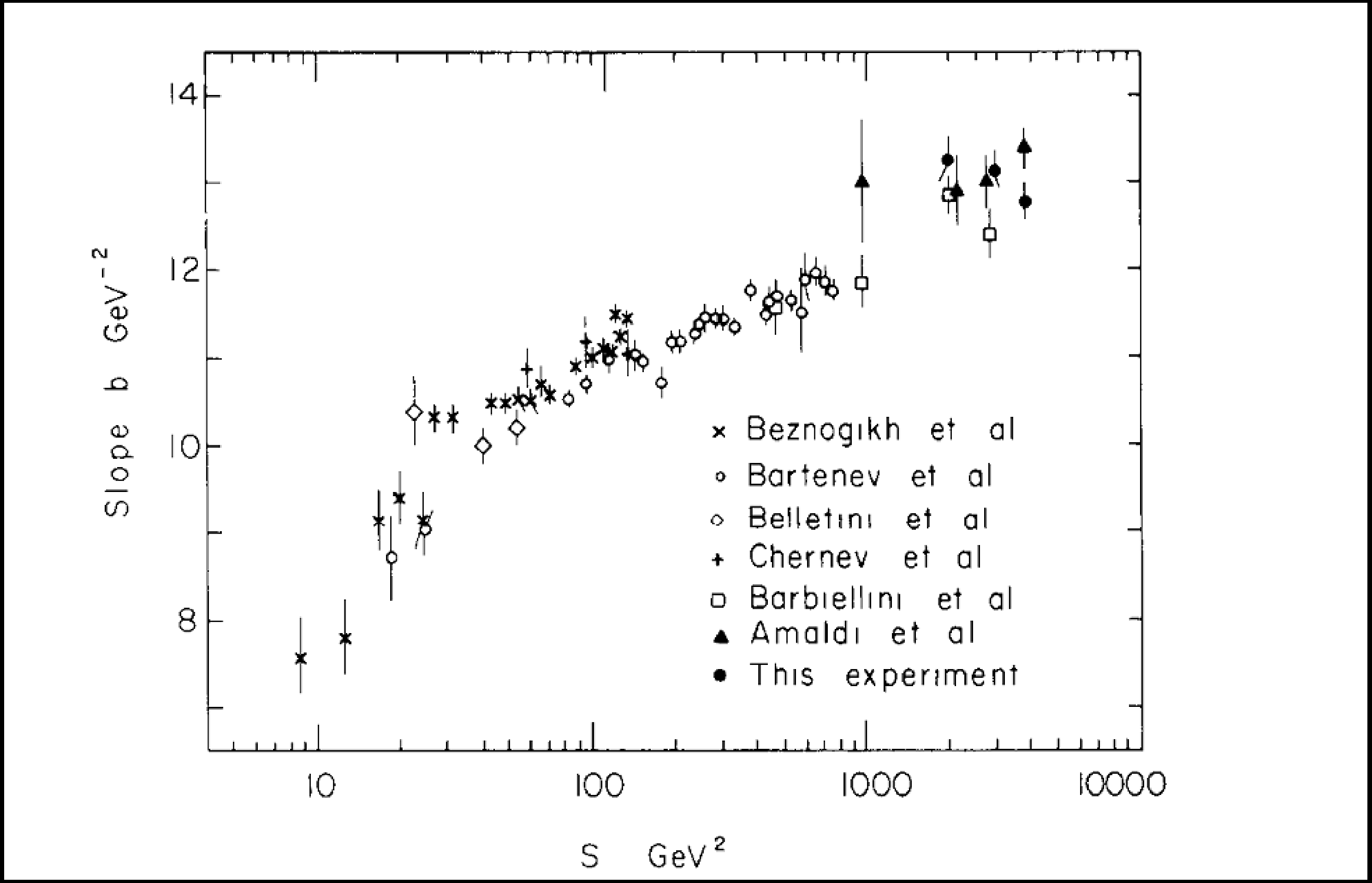
- $<b^2> = <b^2_1> + <b^2_2> + <\beta^2>$
- $<b^2>_{critical} = <b^2_1> + <b^2_2> = 2 \cdot 11\ GeV^{-2}$
- Relation to observables

$$d\sigma/dt \sim e^{Bt}$$

$$2B(s) \approx <b^2>$$

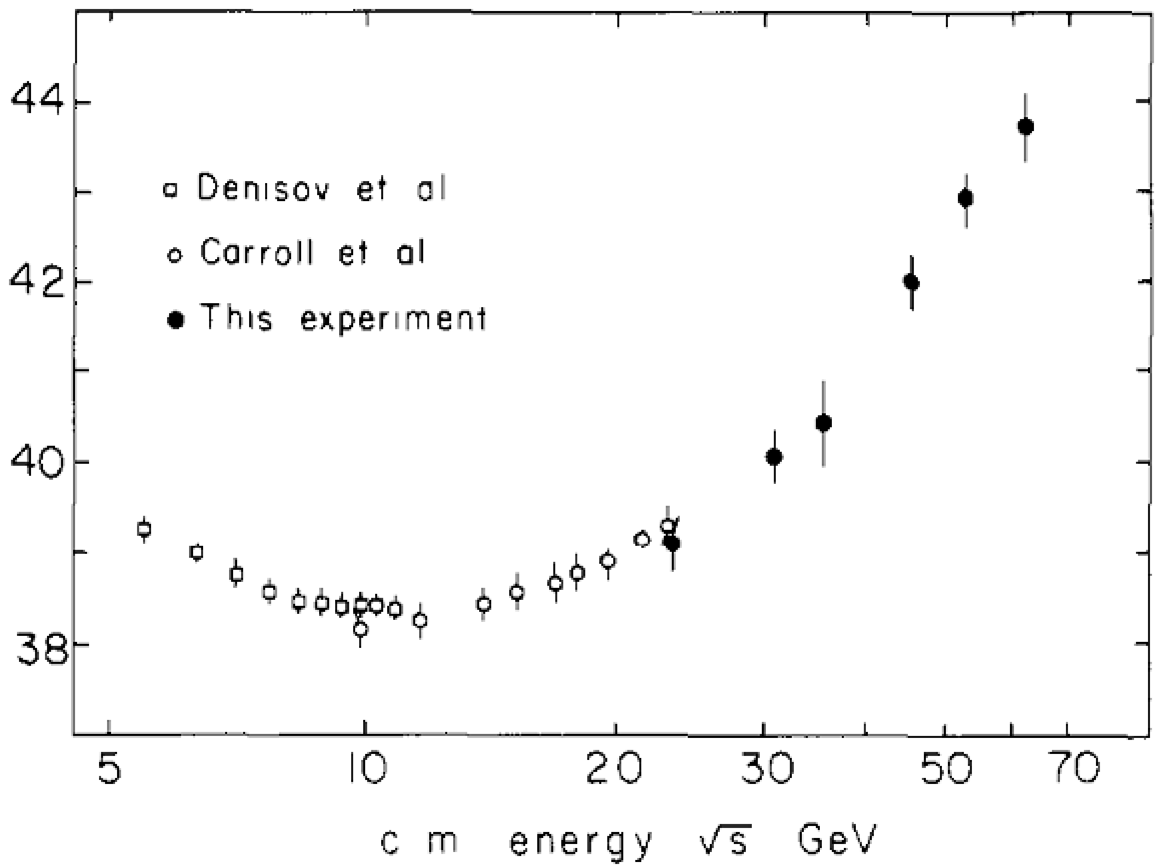
- $B(s)_{critical} \approx 11\ GeV^{-2}$

Experiment



B = b = 11 GeV^{-2} at $s_{critical}$ ≈ 110-120 GeV^2

Proton-proton total cross-section



$\sqrt{S}_{critical}$ = 10.5 ÷11.0 GeV

Hypothesis:

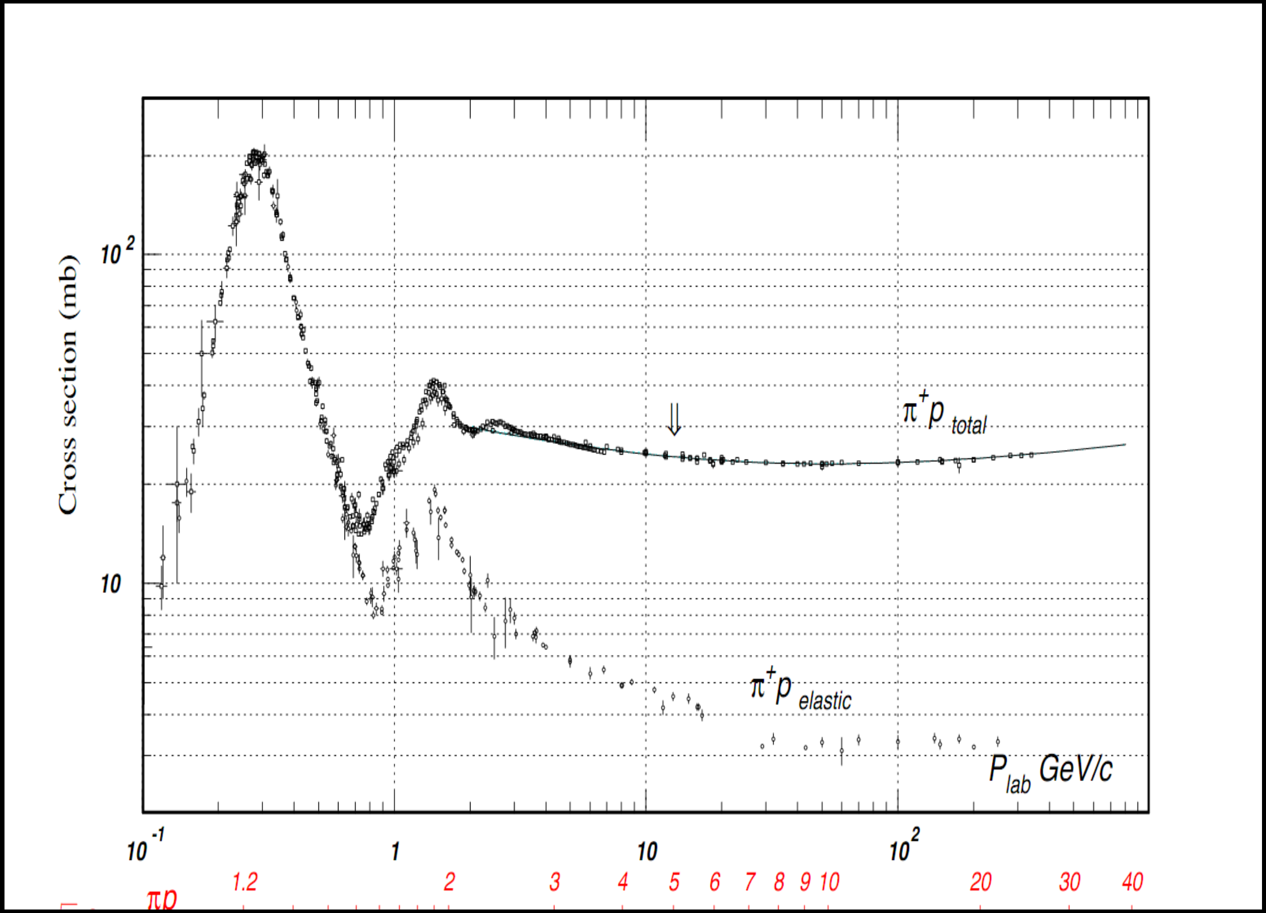
- total cross sections start to grow when valence cores of the colliding hadrons cease to overlap.

Cross-check: πp collisions

$B_{critical} \approx 9.1\ GeV^{-2}$

Happens at $p_{lab} \approx$ 40-50 GeV

Experiment



The growth starts at P_{lab} = 40-45 GeV

Where is "true asymptotics"?

Natural criterium: $B \gg B_{critical}$

LHC (7 TeV) :

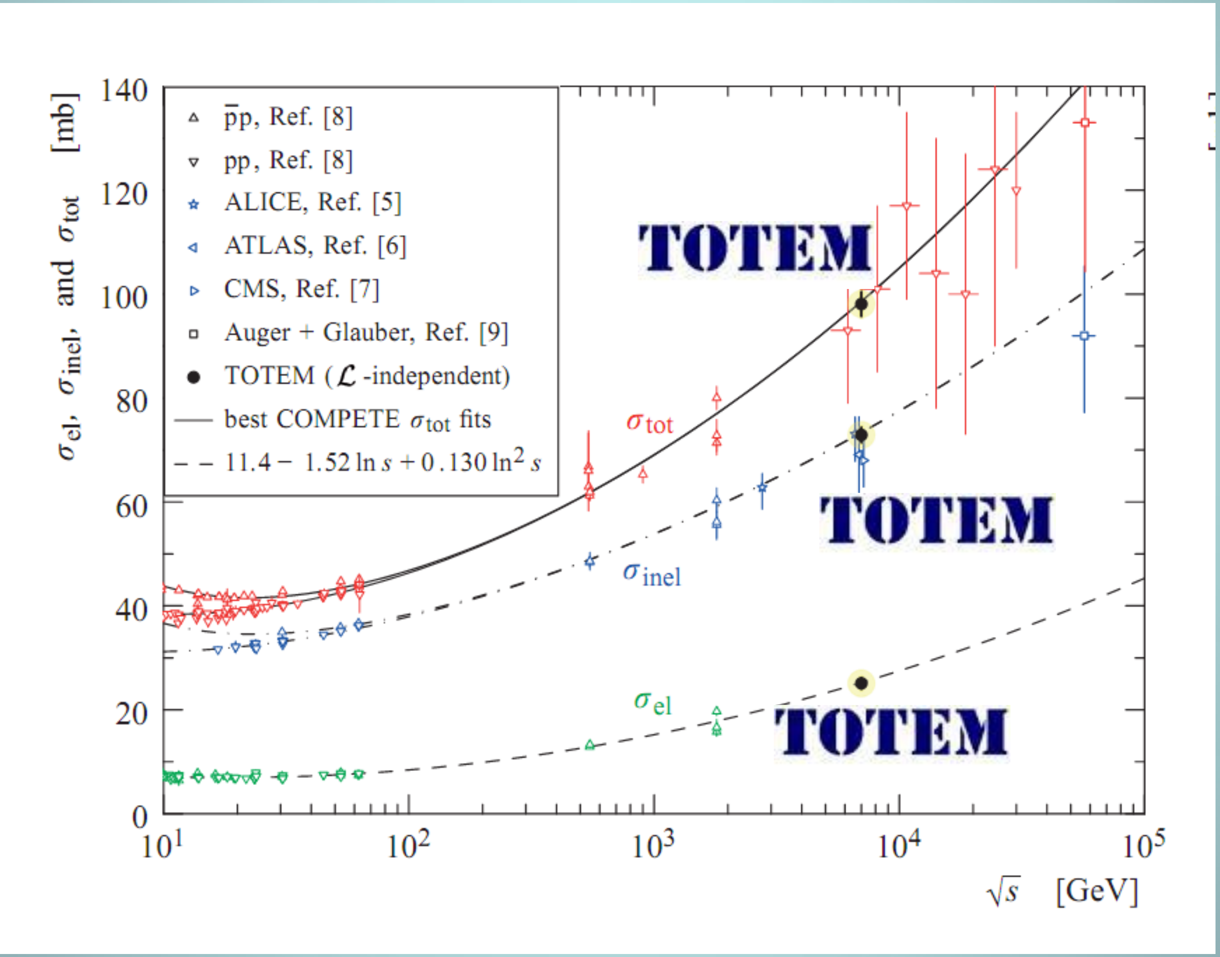
$B = 20\ GeV^{-2} = 1.8\ B_{critical}$

$B = 5\ B_{critical}$

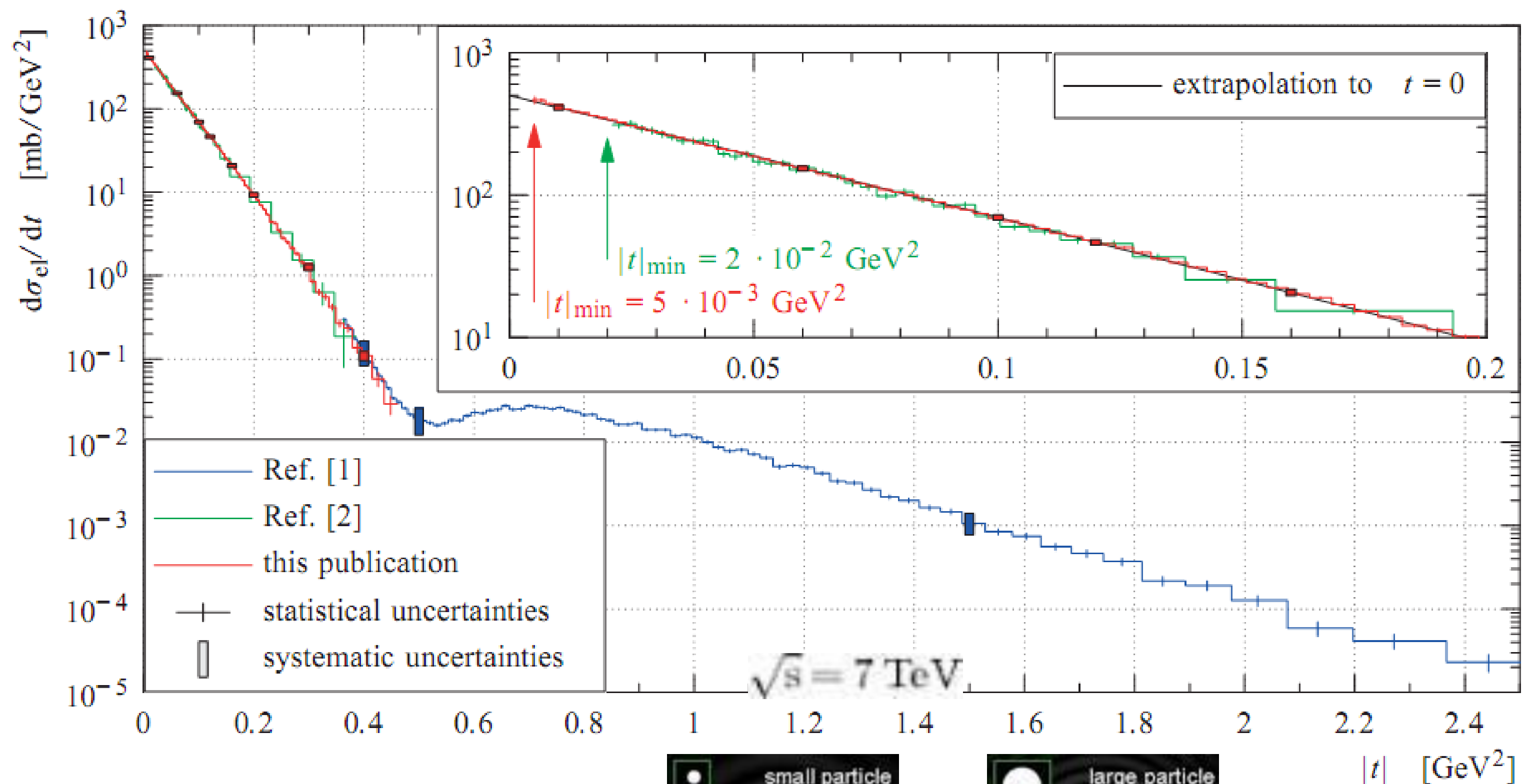
corresponds to the energy

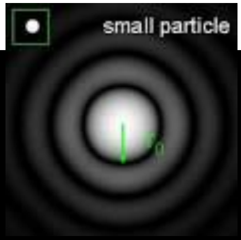
50-100 TeV

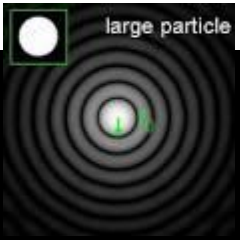
Cross-sections vs Energy



Angular Distribution of Elastically Scattered Protons







Where are other minimae?

- Optical analogy (Fraunhoffer diffraction)

$$\mathbf{d\sigma/dt \sim \{J_1(Rq)/q\}^2}$$

$$\mathbf{q^2 = -t}$$

Minimae are situated at (non-zero)zeroes of the Bessel function $x_{1,2,\ldots}$

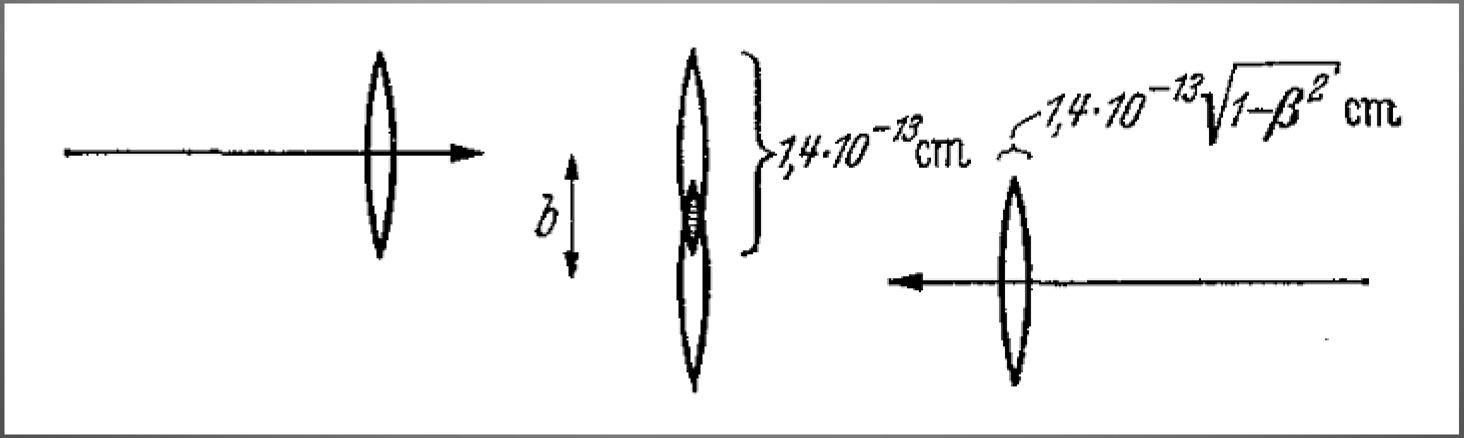
$$\text{LHC: } -t_1 = 0.5\ \text{GeV}^2 = x^2_1/R^2$$

The next minimum should be at

$$-\ t_2 = -t_1\ (x_2/x_1)^2 \approx \mathbf{1.7\ GeV^2}$$

ABSENT!

Longitudinal



Does the interaction region shrinks in the longitudinal direction?

$$\langle x_{||}\rangle = \langle -i\,d/dp_{||}\rangle = 2p^{*}\langle d\varphi/dt\rangle,\; p^{*} \approx \sqrt{s}/2$$

$$T = |T|\exp(i\,\varphi\,(s,t))$$

$$d\sigma/dt \sim |T|^{2}$$

Can be the scattering phase observed?

Regge poles

$$T = (e^{-i\pi/2} s/s_0)^{\alpha(t)}$$

$$\alpha(t) \approx \alpha(0) + \alpha'(0)\, t$$

$$\langle x_{||} \rangle = \pi \sqrt{s/2\, \alpha'(0) \ln(s/s_0)} \approx$$

40-50000 fm at $\sqrt{s} = 7$ TeV

0.5 Angstrem ~ atomic Bohr radius

Is there any relation to observables?

- Fluctuations

$< \Delta x_{||} > = p^* / \sqrt{<t^2> - <t>^2} \approx \sqrt{s}\, B/2$

$= 7000 \cdot 20/2 = 70000\ GeV^{-1} = 14\,000\ fm$

Longitudinal range grows with energy enormously.

Where is QCD?

- Can we calculate Regge trajectories perurbatively ?
- Naïve expectation:

$$\alpha(t) = \Sigma\, g^{2n} \cdot \alpha_n(t)$$

$$\alpha(0) = \Sigma\, g^{2n} \cdot \alpha_n(0)$$

$$\alpha'(0) = \Sigma\, g^{2n} \cdot \alpha'_n(0)$$

Renormalization group:

$\alpha(0)$ does not depend on g^2

$\alpha'(0) \sim \exp(1/\beta_0\, g^2)$

TIME?!

- Interaction time grows with energy proportionally

CONCLUSION

There remains much to be said in C-major

(Arnold Schoenberg)