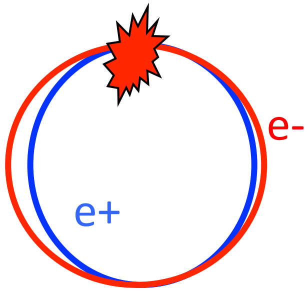
INFN
Istituto Nazionale
di Fisica Nucleare

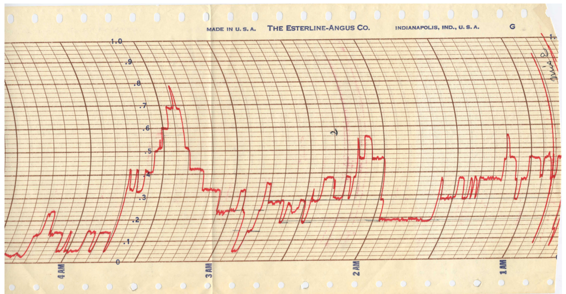


Photoproduction and CR showers:

Post-LHC updates of Photoproduction total cross section at ultra high energies and shower development from cosmic ray photons

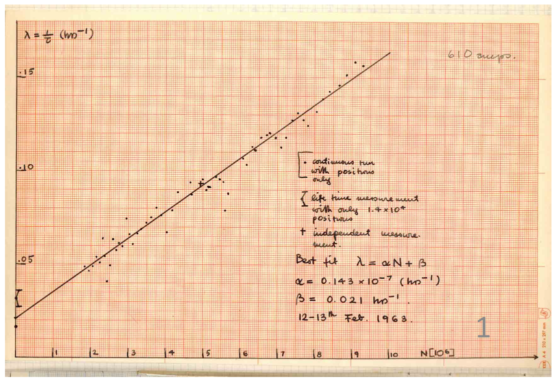
G. PANCHERI with

F. Cornet, C. Garcia-Canal, A. Grau, S. Sciuto



AdA – First charging
21st February 1961

AdA – Positron run
12-13th February 1963



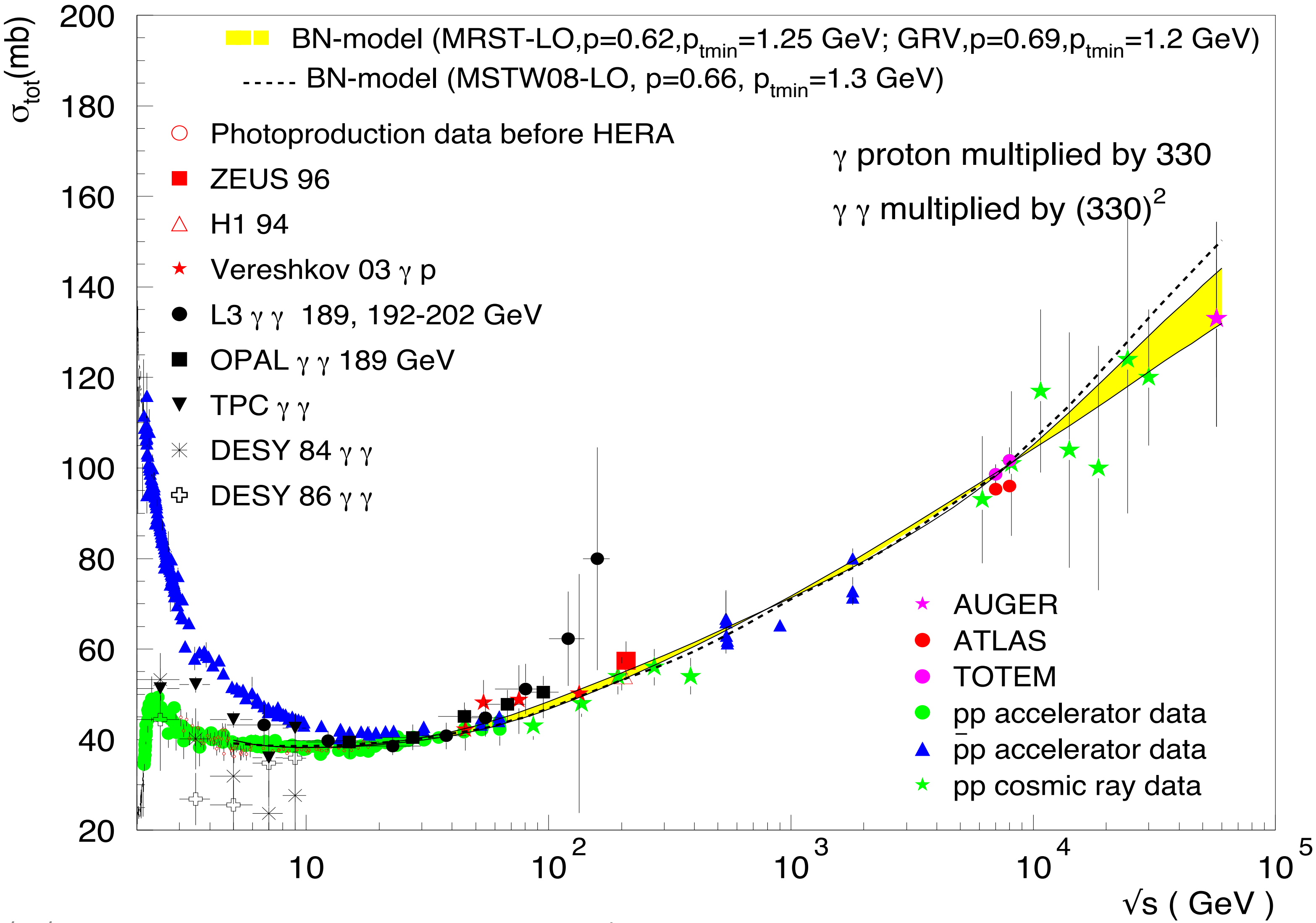
Photons in cosmic rays

- CR Composition not yet well known
- Photon content still unclear
- Showers development can give information

- Input in MC depends on Hadronic Interaction Model
  - i.e. QSGJET-II in AIRES
  - $\gamma p \to X$ → $\gamma - air$

- Data for γp are only up to $\sqrt{s} = 210\ GeV$ (HERA)
  - $E_{lab} \simeq 10^{19} eV$ → 10- 100 TeV yet unexplored in photoproduction
  - Models for $\gamma p \to X$ differ at very high energies

Total hadronic cross-sections



Post-LHC update of Godbole, Grau, GP, Srivastava (GGPS) 2009 figure

Updating

F.Cornet, F. Cornet, C. Garcia-Canal, A. Grau,G.P, S. Sciuto

PHYSICAL REVIEW D 92, 114011 (2015)

- Results of simulations of photon showers with AIRES from
- 2 Models for γp total cross-section at very high energies
  - Block and Halzen (BH) Phys.Rev. D70 (2004) 091901
    → present in AIRES
  - Godbole, Grau, Pancheri, Srivastava (GGPS)
    Eur.Phys.J. C63 (2009) 69-85
    → Bloch-Nordsieck (BN) model implemented in AIRES by Sciuto and Garcia-Canal

A selection of models for γp

- Block and Halzen : 2001

$$\ln^2(E^\gamma/m_p)$$

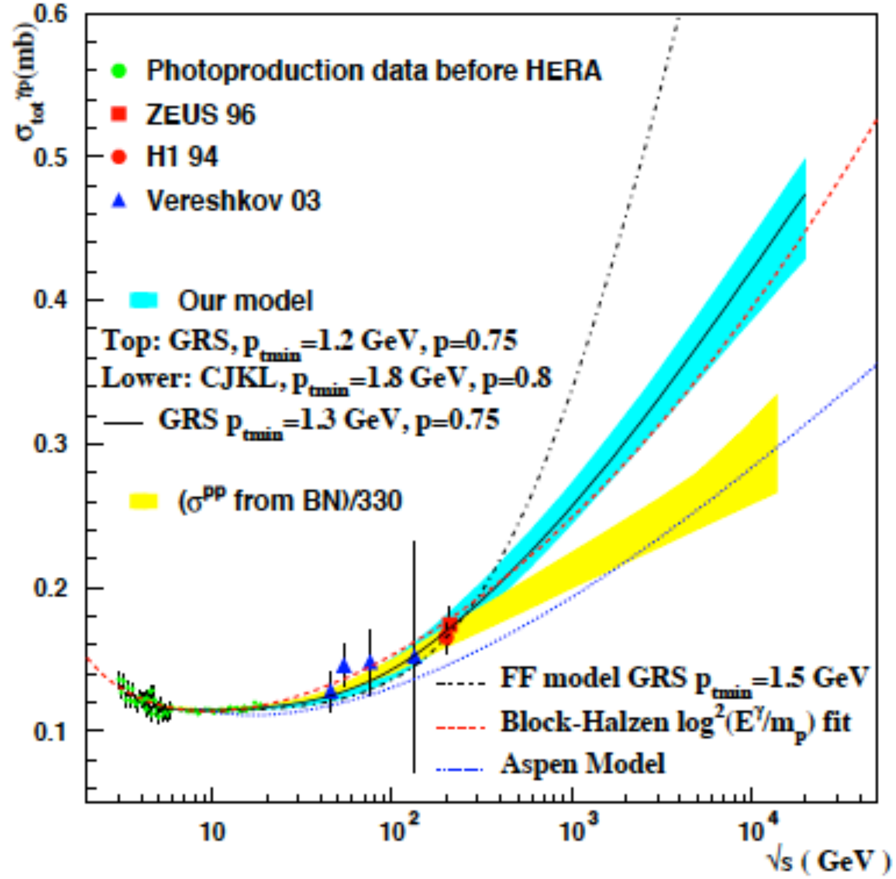
- GGPS for photons 2008
  - Fletcher Gaisser Halzen for

$$\gamma p \to X$$

  - Eikonal minijet driven with Infrared gluons for pp (see slides later)

- Eikonal minijet with form factors

- Aspen model PRD 1999 “QCD inspired” Block, Gregores, Halzen, GP



GGPS Eur.Phys.J. C63 (2009) 69-85

Extension of mini-jet model to photoproduction

GGPS Eur.Phys.J. C63 (2009) 69-85

$$\sigma_{tot}^{\gamma p} = 2P_{had} \int d^2b \left[1 - e^{-n^{\gamma p}(b,s)/2}\right]$$

$$P_{had} = \sum_{V=\rho,\omega,\phi} \frac{4\pi\alpha}{f_V^2}$$

$$n^{\gamma p}(b,s) = n_{soft}^{\gamma p}(b,s) + n_{hard}^{\gamma p}(b,s)$$

Mimics details of photon fluctuation into a hadron

Fletcher, Gaisser, Halzen,Phys.Rev. D45 (1992) 377

$$n_{hard}^{\gamma p}(b,s) = A_{BN}(b,s)\sigma_{jet}^{\gamma p}(s)/P_{had}$$

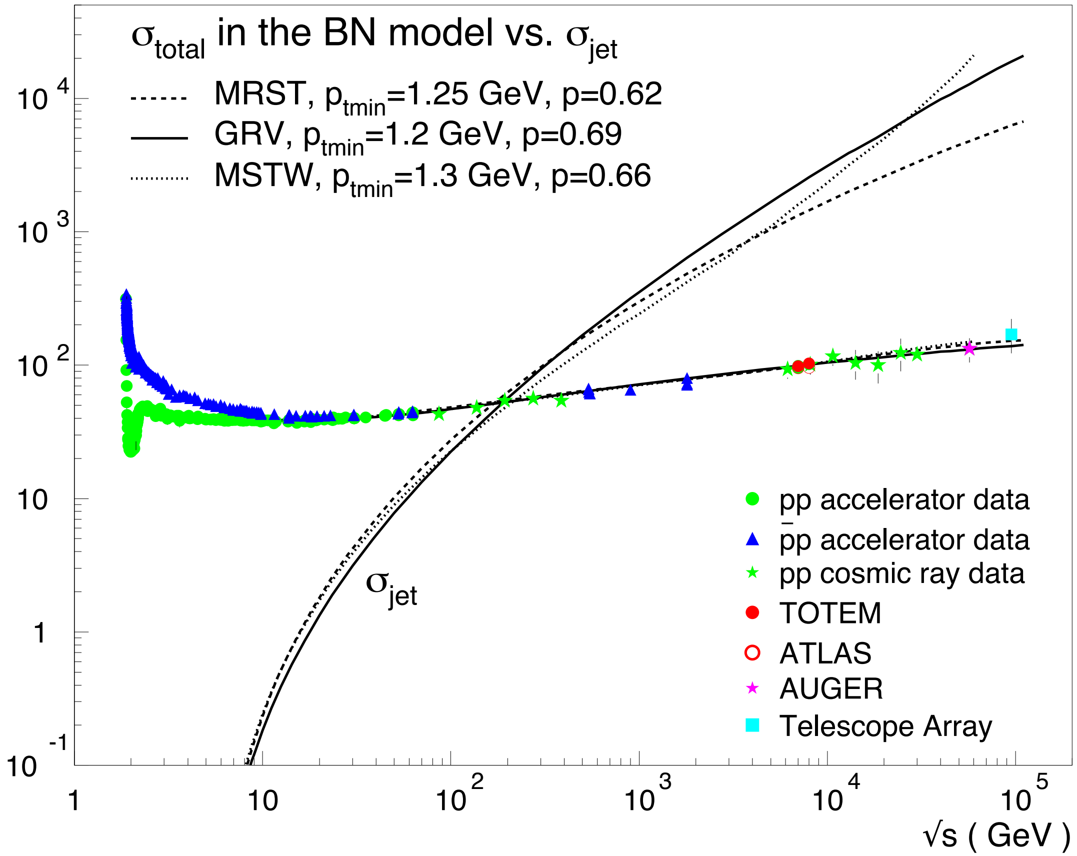
resummation

LO current PDFs

Input from our pp model with infrared gluon resummation for mini-jet

The   model for pp

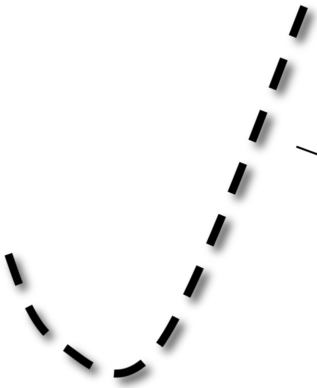
- Mini-jets with pQCD → DGLAP LO PDFs
  Grau,GP,Srivastava PRD1999
  Godbole, Grau,GP, Srivastava PRD2004
- A (democratic) resummation scheme to probe the infrared limit for soft gluons
  Corsetti, Grau,GP,Srivastava 1996
  Grau, GP, Srivastava PRD 1999
- Maximally allowed singularity
  Nakamura, GP, Srivastava PLB 1984



All total cross-sections rise… but not too much (Froissart dixit)

What generates the rise? Low-x parton collisions

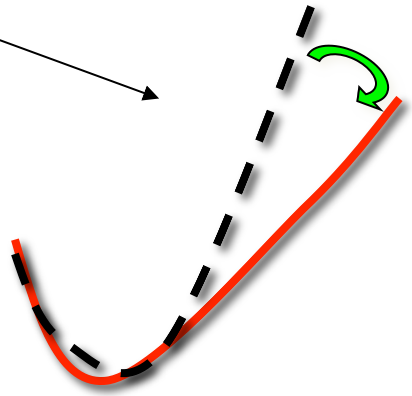
Cline, Halzen &Luthe 1973
Gaisser, Halzen, Stanev 1985
G.P., Y.N. Srivastava 1986
Durand, Pi 1987
Sjostrand, van Zijl 1987
…



s^{ϵ} $\quad \epsilon \sim 0.3$

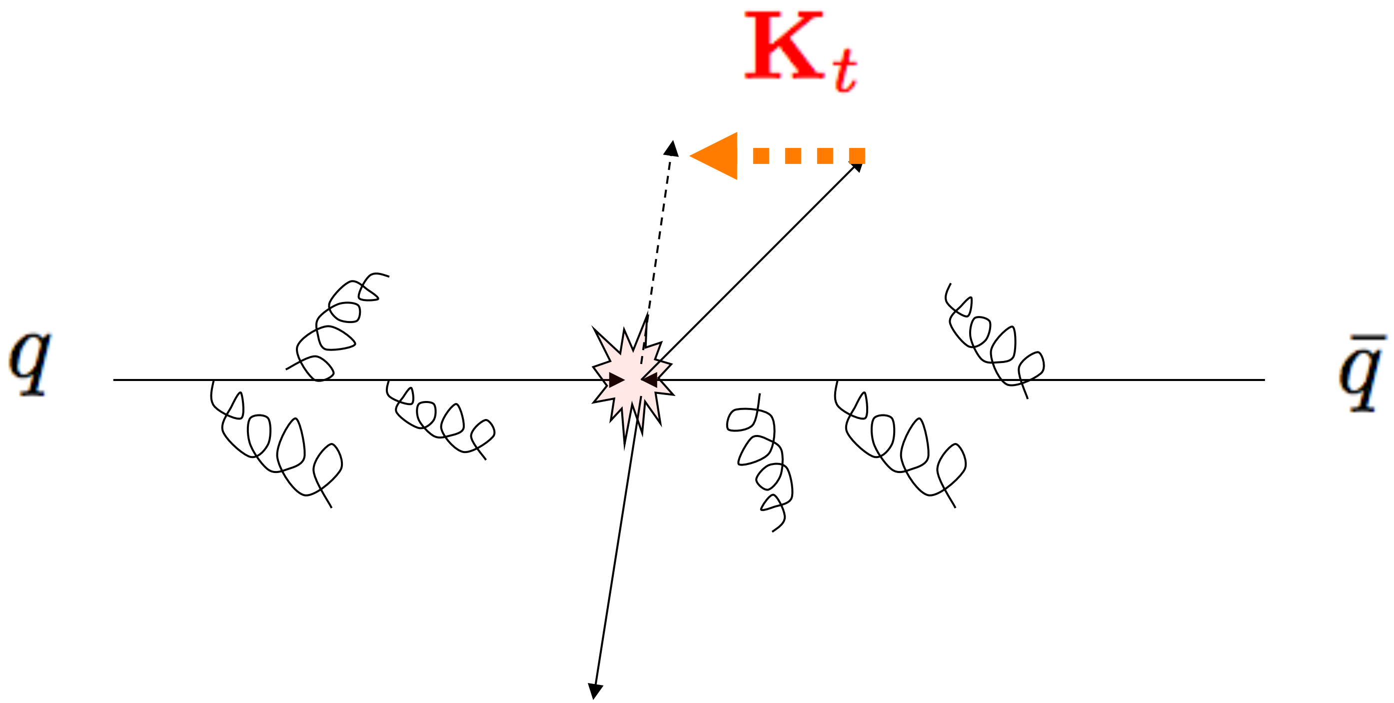
How to go from hard to soft ?

What tames the rise into to a Froissart-like behavior?



A cut off obtained by [embedding into the eikonal] the acollinearity induced by IR kt-emission
[our model, G.P. et al. **Phys.Lett.B382, 1996**]

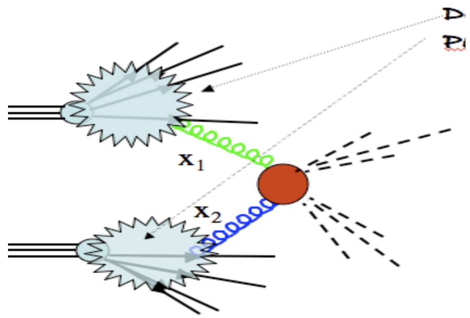
Soft gluon emission introduces acollinearity



Acollinearity reduces the collision cross-section as
partons do not scatter head-on any more, also explained as the gluon cloud
becoming too thick for partons to see each other : gluon saturation

Our model for pp

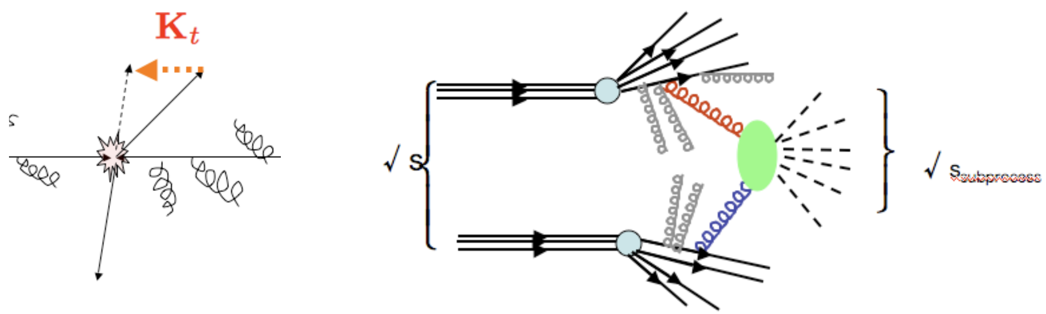
1.



PDFs DGLAP

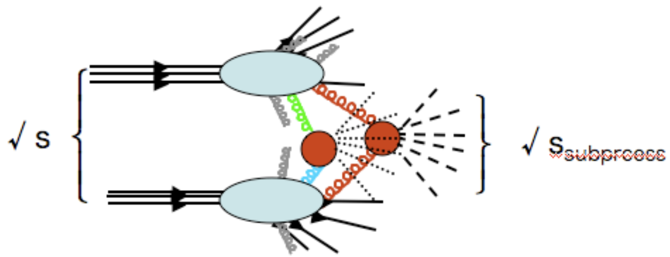
Mini-jet cross-sections
Pt ~ 1 GeV

2.



Dress with Initial State
Infrared Radiation

3.



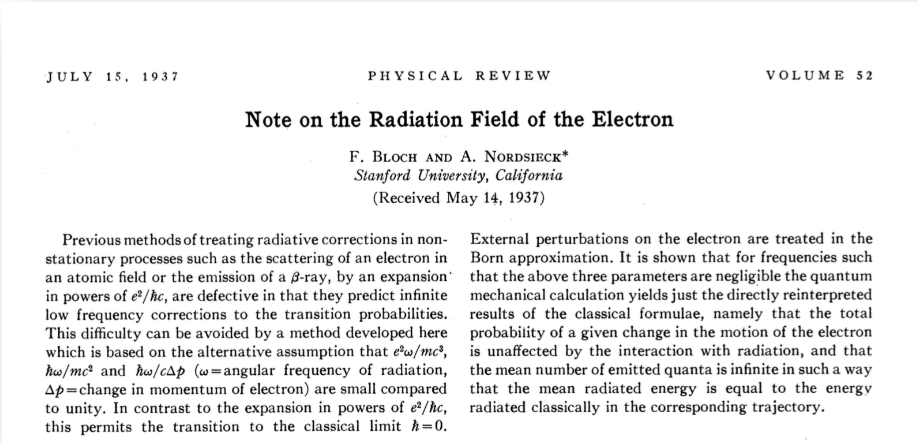
Eikonalize

$$\sigma_{total} = 2 \int d^2\mathbf{b}[1 - e^{-\chi(b,s)}]$$

The infrared region in hadronic collisions → large distance QCD

- To access the infra-red region and tame the rise of total x-sections from minijets contributions, we use a resummation procedure different from the usual LLA or Sudakov

- The Bloch and Nordsieck theorem on infinite "photon" emission + Energy Momentum Conservation



JULY 15, 1937 PHYSICAL REVIEW VOLUME 52

Note on the Radiation Field of the Electron

F. BLOCH AND A. NORDSIECK*
Stanford University, California
(Received May 14, 1937)

Previous methods of treating radiative corrections in non-stationary processes such as the scattering of an electron in an atomic field or the emission of a β-ray, by an expansion in powers of $e^2/\hbar c$, are defective in that they predict infinite low frequency corrections to the transition probabilities. This difficulty can be avoided by a method developed here which is based on the alternative assumption that $e^2\omega/mc^3$, $\hbar\omega/mc^2$ and $\hbar\omega/c\Delta p$ (ω=angular frequency of radiation, Δp=change in momentum of electron) are small compared to unity. In contrast to the expansion in powers of $e^2/\hbar c$, this permits the transition to the classical limit $\hbar=0$. External perturbations on the electron are treated in the Born approximation. It is shown that for frequencies such that the above three parameters are negligible the quantum mechanical calculation yields just the directly reinterpreted results of the classical formulae, namely that the total probability of a given change in the motion of the electron is unaffected by the interaction with radiation, and that the mean number of emitted quanta is infinite in such a way that the mean radiated energy is equal to the energy radiated classically in the corresponding trajectory.

- Maximally allowed divergence of the coupling of soft gluons to quarks

From Bloch Norsdieck (1937) (B-N) theory of emission from a classical source to our proposal for maximally allowed infrared singularity in QCD (1984)

- F. Bloch and A. Nordsieck
  - Neglecting recoil → Poisson distribution of soft photons (gluons) emitted

$$\frac{[\bar{n}_{\mathbf{k}}]^{n_{\mathbf{k}}}}{n_{\mathbf{k}}!} e^{-\bar{n}_{\mathbf{k}}}$$

  - Only emission of infinite number of soft photons (gluons) is finite

- B. Touschek
  - 1952 with W. Thirring : covariant formulation
  - 1968 (with E.Etim+GP) : summation to all orders

$$d^4P(K) = \sum_{\mathbf{k}} P(\{n_{\mathbf{k}}\})\delta^4(\sum_k k n_{\mathbf{k}} - K)d^4K$$

$$\delta^4(\sum_{n_k} n_k k - K) = \int \frac{d^4x}{(2\pi)^4} e^{-iK\cdot x} e^{\sum n_k k\cdot x}$$

  - Exchange Sum (in k) with Product (on n_k)

Semi-classical and democratic (no branching or ordering) summation

→ $$d^4P(K) = \frac{1}{(2\pi)^4}\int d^4x\; e^{-h(x)-iK\cdot x}$$

Soft "photon" spectrum is exponentiated and regularized

$$h(x) = \sum_k (1 - e^{ik\cdot x})\bar{n}_{\mathbf{k}} \to \int d^3\bar{n}_{\mathbf{k}}[1 - e^{ik\cdot x}]$$

→ Integrate over $K_0 \;\; and \;\; K_3$

$$\Pi(K_t, s) = d^2\mathbf{K}_t \int d^2\mathbf{b} e^{-i\mathbf{K}_t\cdot\mathbf{b} - h(b,s)}$$

→ $h(b, s)$?

QED or QCD : integrand can be finite or singular but to be finite → integrable is the basic condition

Applied to K-t resummation in QCD

G.Parisi R.Petronzio 1979 and Dokshitzer, Diakonov, Troian 1978
With Asymptotic Freedom

$$h^{(PP)}(b,s) = \frac{4}{3\pi^2}\int_{M^2}^{Q^2} d^2k_\perp [1 - e^{i\mathbf{k}_\perp \cdot \mathbf{b}}]\alpha_s(k_\perp^2)\frac{\ln(Q^2/k_\perp^2)}{k_\perp^2}$$

Our Proposal (ZPC 1984)

$$M^2 \to 0$$

$$\alpha_{IR}(k_t) \propto [\frac{\Lambda}{k_t}]^{2p}$$

$$p < 1$$

Dropped in DDT, Phys. Lett. B79, 26

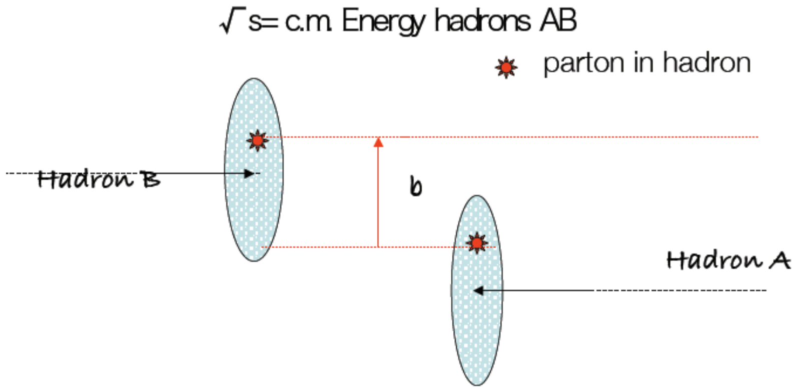
We model the impact parameter distribution as the Fourier-transform of ISR soft k_t distribution and thus obtain a cut-off at large distances : Froissart bound?

$$A_{BN}(b,s) = N \int d^2\mathbf{K}_\perp \; e^{-i\mathbf{K}_\perp \cdot \mathbf{b}} \frac{d^2P(\mathbf{K}_\perp)}{d^2\mathbf{K}_\perp} = \frac{e^{-h(b,q_{max})}}{\int d^2\mathbf{b} \; e^{-h(b,q_{max})}}$$

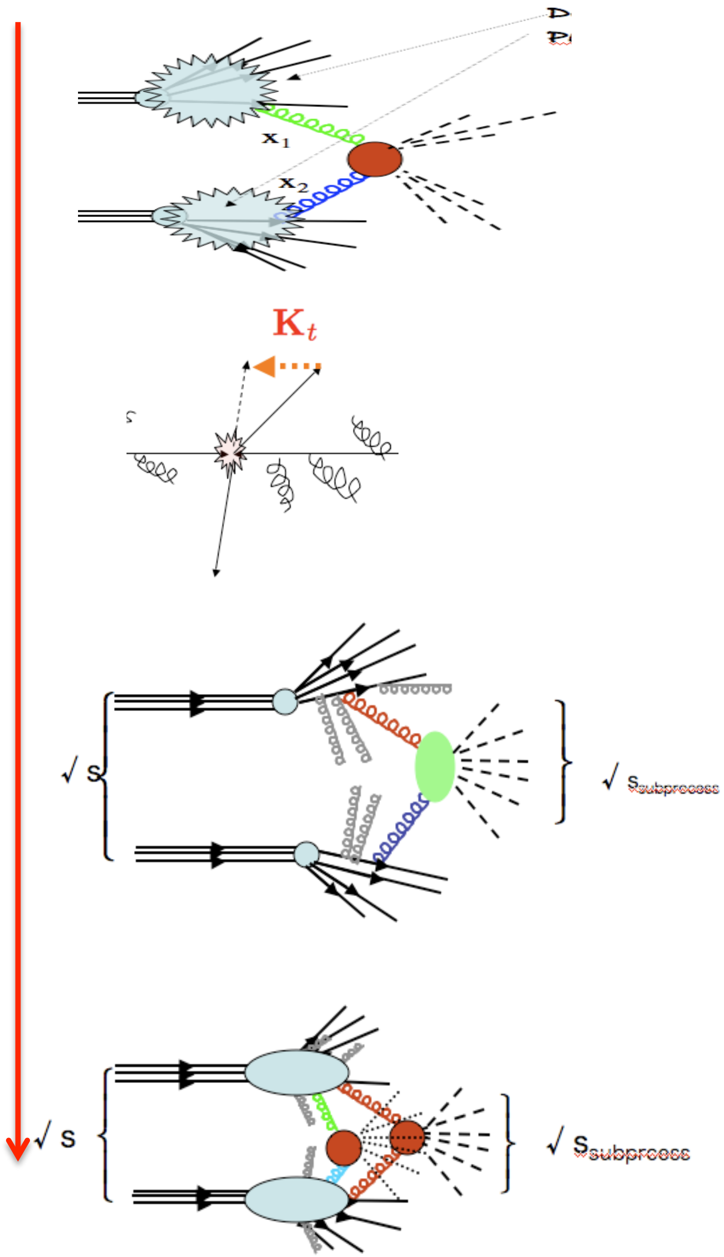
$$h(b,E) = \frac{16}{3\pi} \int_0^{qmax} \frac{dk_t}{k_t} \alpha_{eff}(k_t) \ln\left(\frac{2q_{max}}{k_t}\right)[1 - J_0(bk_t)]$$

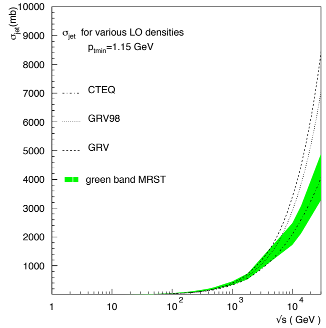
$$\alpha_{eff}(k_t \to 0) \sim k_t^{-2p}$$

$$A_{BN}(b,s) \sim e^{-(b\bar{\Lambda})^{2p}}$$



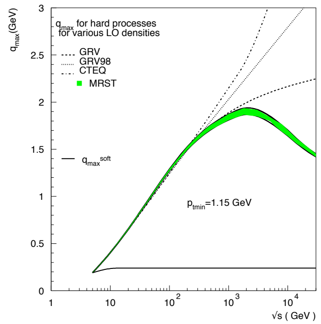
q_{tmax} ? Fixed by single gluon emission kinematics





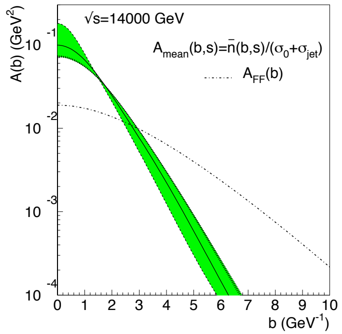
1. Calculate mini-jet cross-section Choosing densities and ptmin

$$\sigma_{mini-jet} \simeq s^{\epsilon}$$
$$\epsilon \simeq 0.3 - 0.4$$



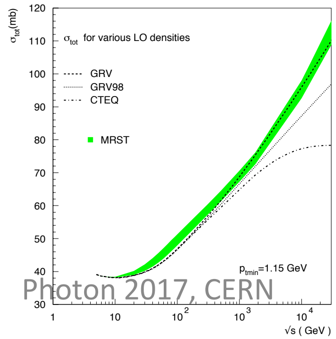
2. Calculate qmax: single soft gluon upper scale, for given PDF, ptmin

$$q_{max} \simeq p_{tmin}$$
$$\lesssim 2 - 3\ GeV$$



3. Calculate impact parameter distribution for given qmax and given infrared parameter p

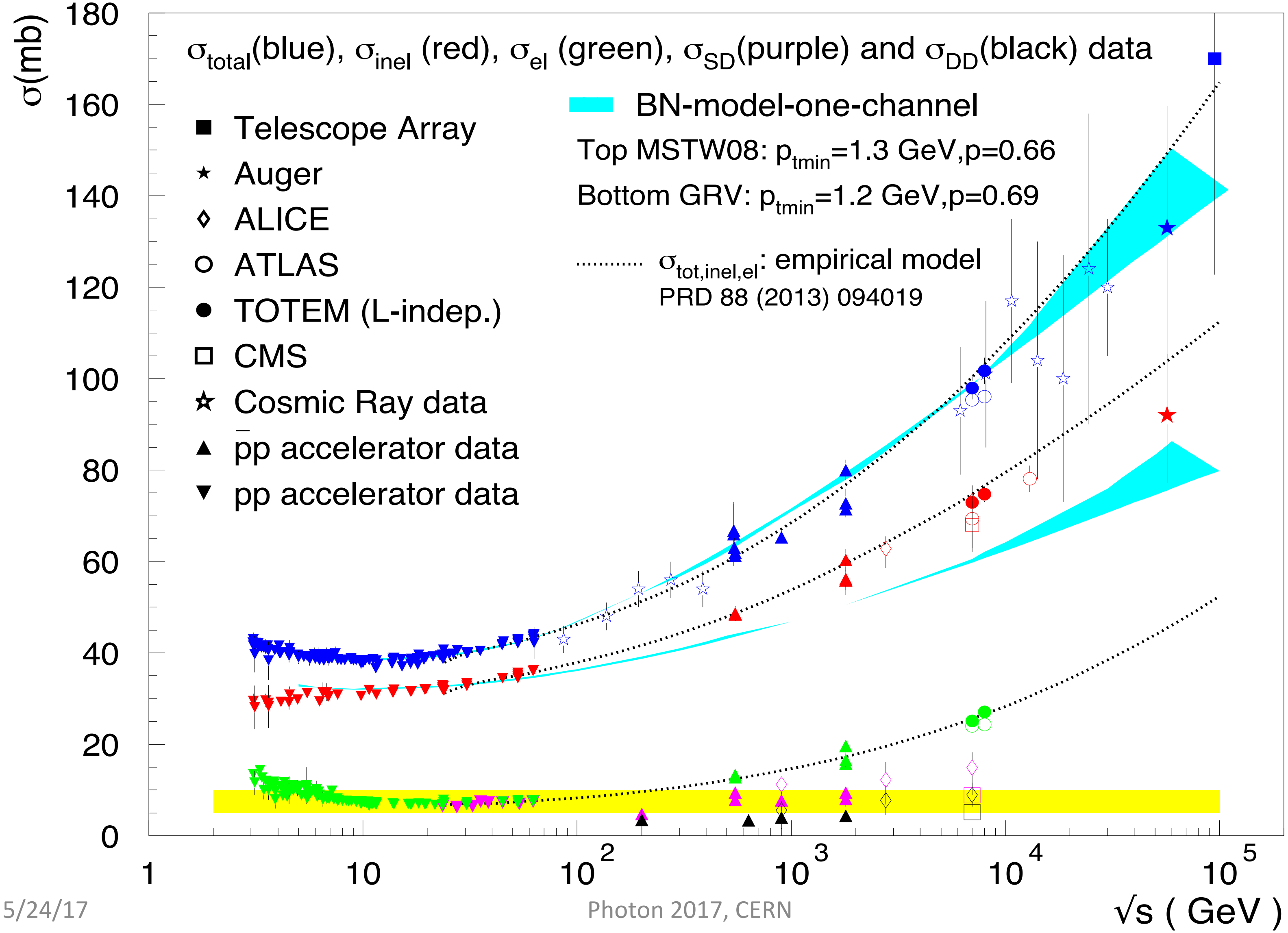
$$\chi(b,s) = \chi_{low\ energy} + $$
$$+ A(b, qmax)\sigma_{jet}$$



4. Eikonalize

$$\sigma_{total} = 2\int d^2\mathbf{b}[1 - e^{-\chi(b,s)}]$$

The total cross-sections in pp



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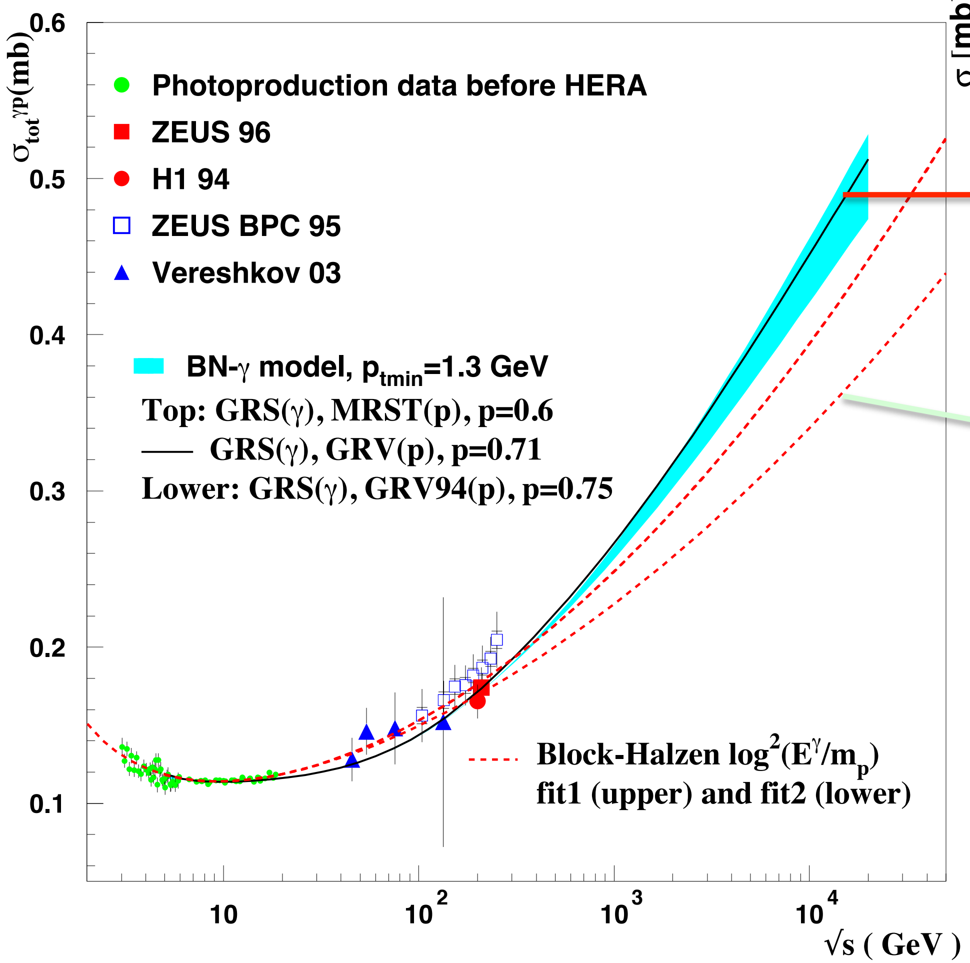
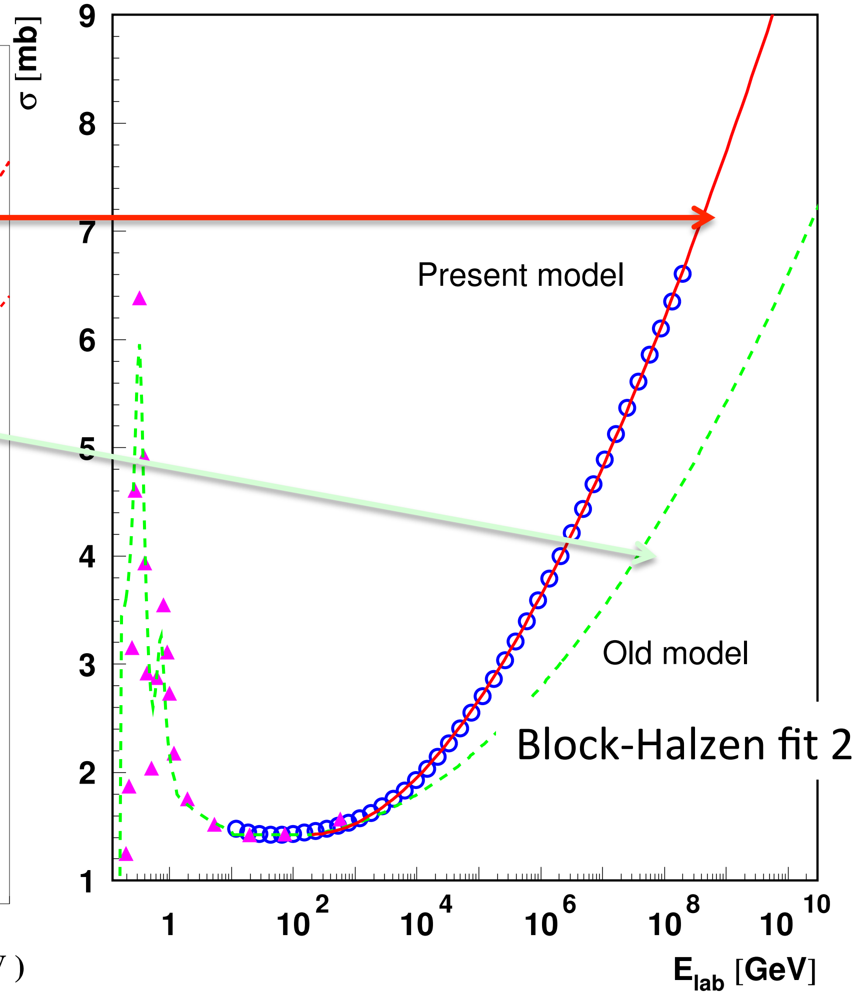
γp

$\gamma - air$



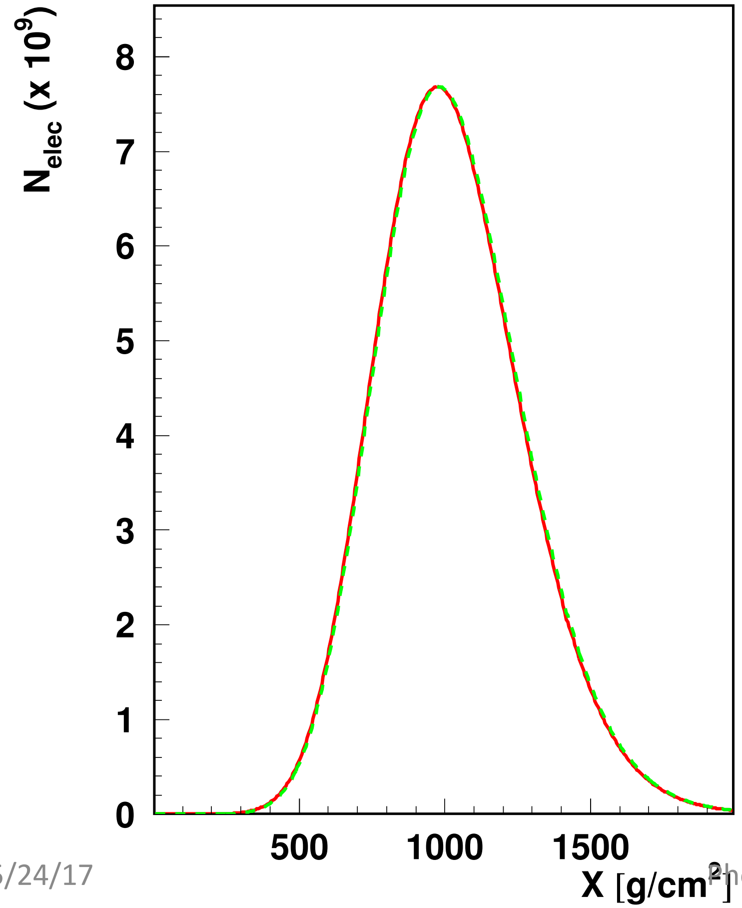


Updated with newer PDFs

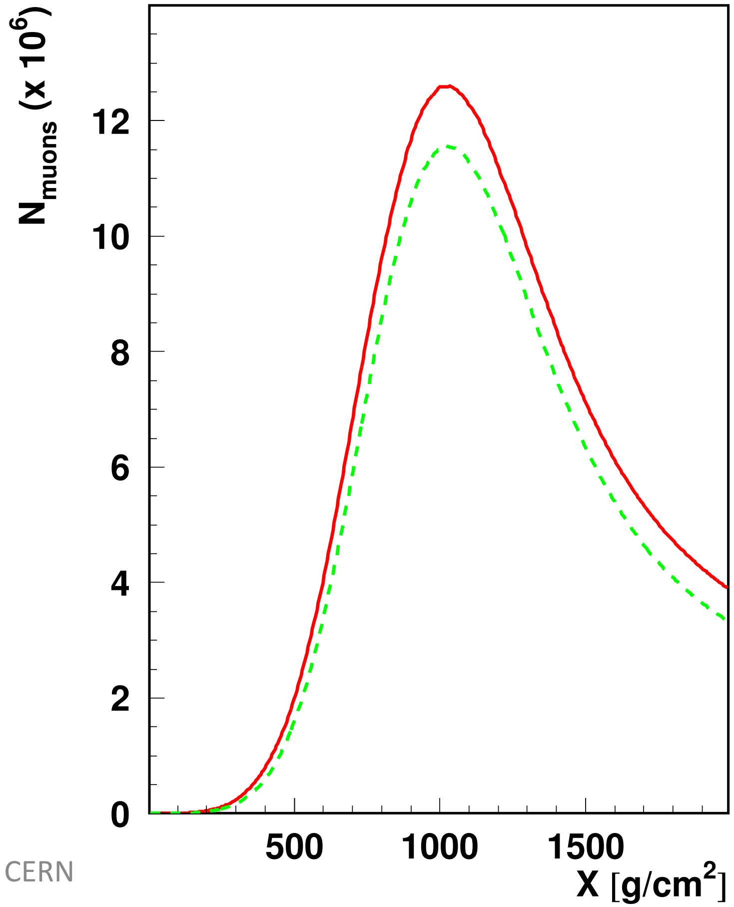
Longitudinal development from 10^{19} eV photon showers

---- standard cross sections implemented in AIRES

Electrons and positrons



muons

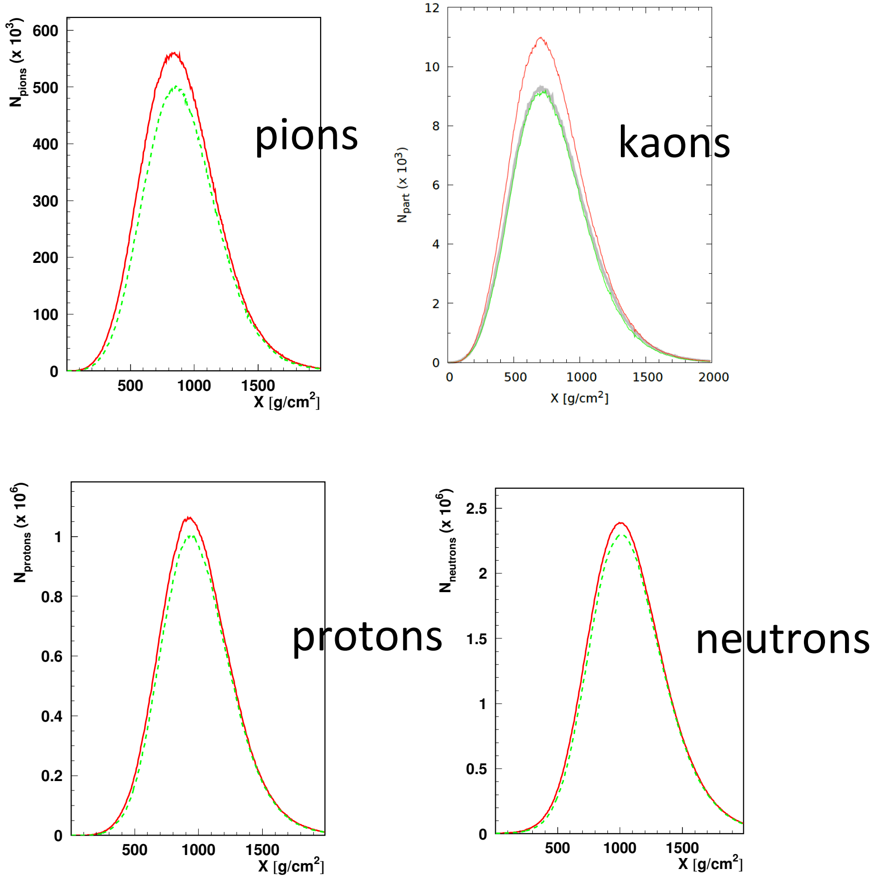


Longitudinal shower development of hadrons from our model input and comparison with Block Halzen fit

RED : Using central curve from our model for proton - γ cross-section into AIRES simulation

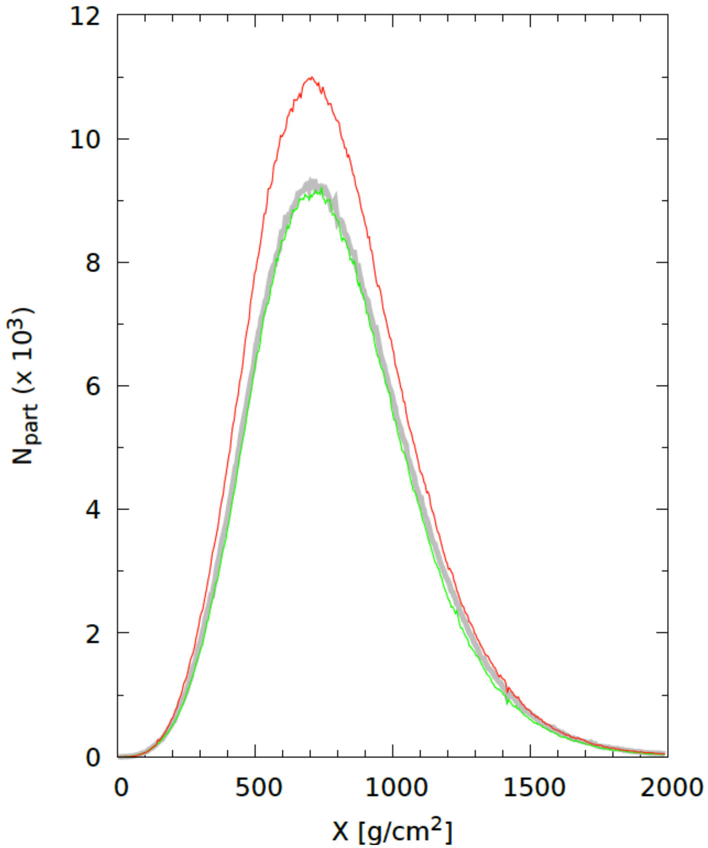
GREEN : BH model lower fit (both fit are consistent with present HERA data)

GREY : pre-LHC QSGJET-II For BN



Green : standard cross sections implemented in AIRES

Kaon longitudinal development, 60 degrees inclined – a difference confirmed by new simulations



Using QGSJET post-LHC.

Work in progress

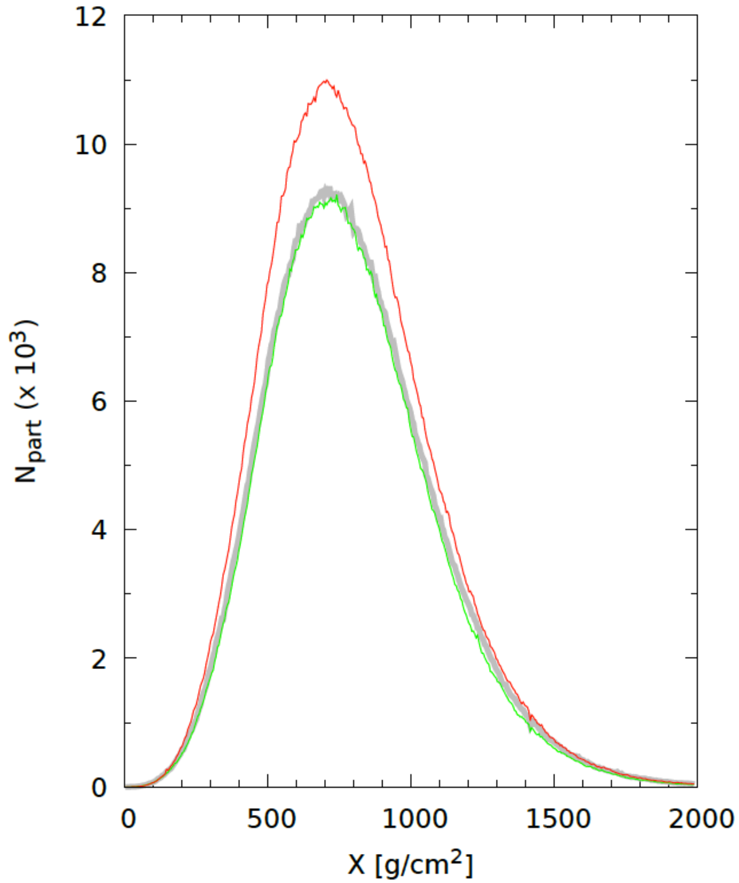
- CR :
  - Update the simulations
  - Inspect transition $\gamma p \rightarrow \gamma - air$

- Model for survival probabilities in pp
- Diffraction?

- Photon-photon → see Rohini's talk

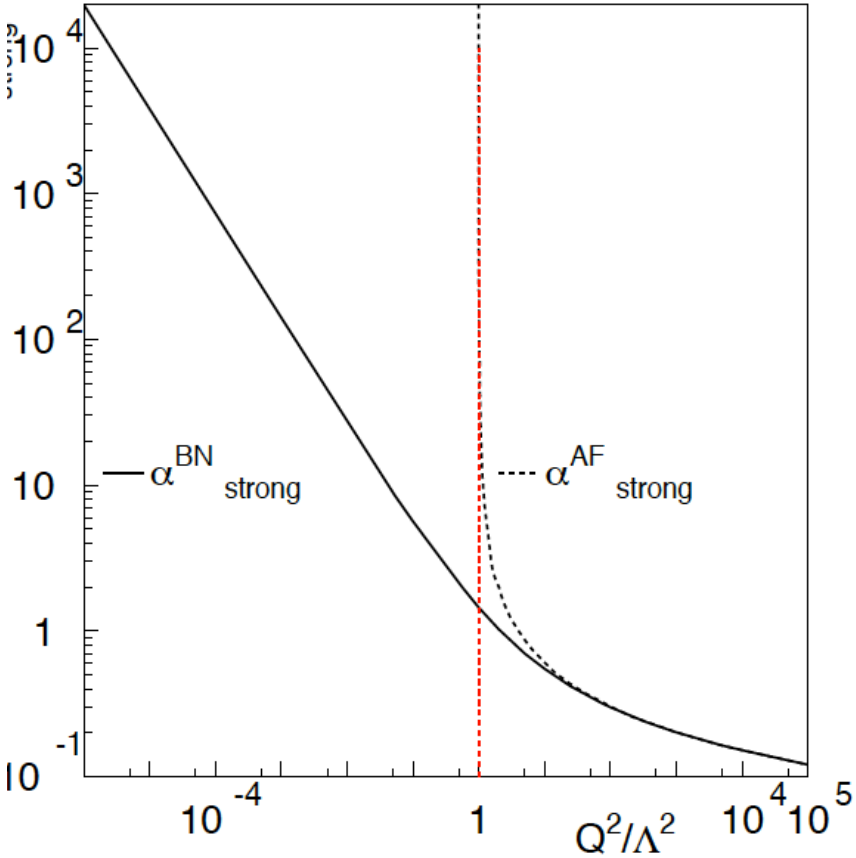
Studying showers with this model and post-LHC Aires

- Kaon Longitudinal development indicates a difference:
- QGSJET pre-LHC : 20% difference between simulations with BH and our model
- QGSJET post-LHC : simulated spectrum still shows difference between using our gamma-p or BH model



A maximally allowed singular expression for coupling of zero momentum gluons

$$\alpha_{strong}(k_t^2) = \frac{1}{\ln[1 + (\frac{k_t^2}{\Lambda^2})^{b_0}]}$$



Photon 2013

arXiv:1403.8050

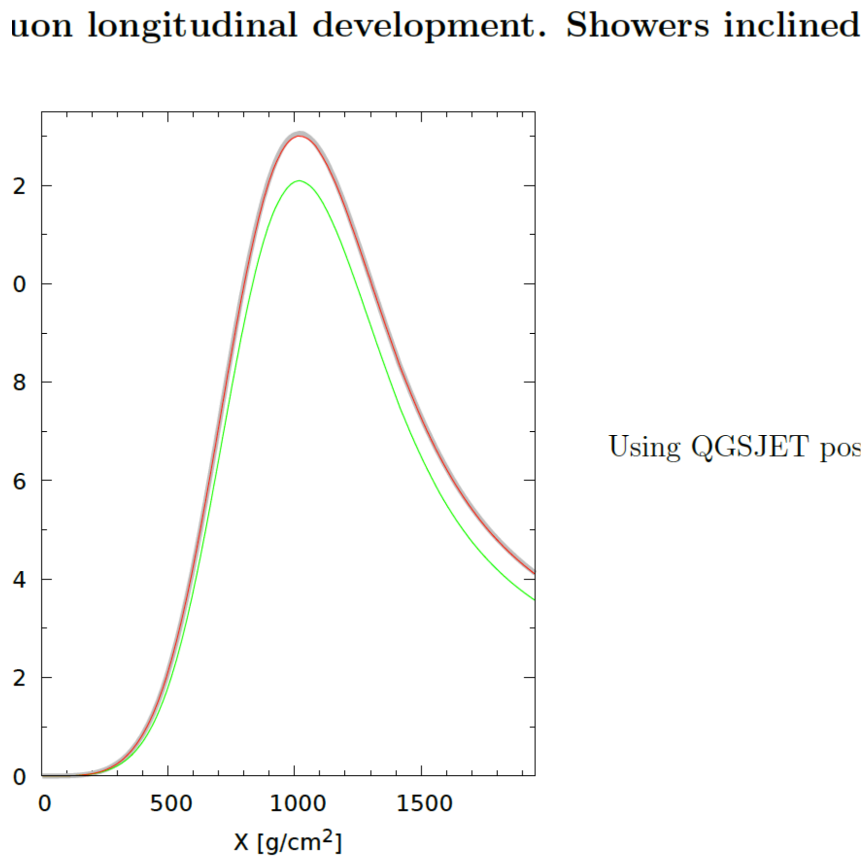
D. Fagundes, A. Grau, GP O.Shekhovtsova and YSrivastava

Muon longitudinal development, 60 and 80 degrees inclination

- Green is BH with post-LHC
- Red is BN with post-LHC QGSJET
- Grey is BN with pre –LHC QGSJET

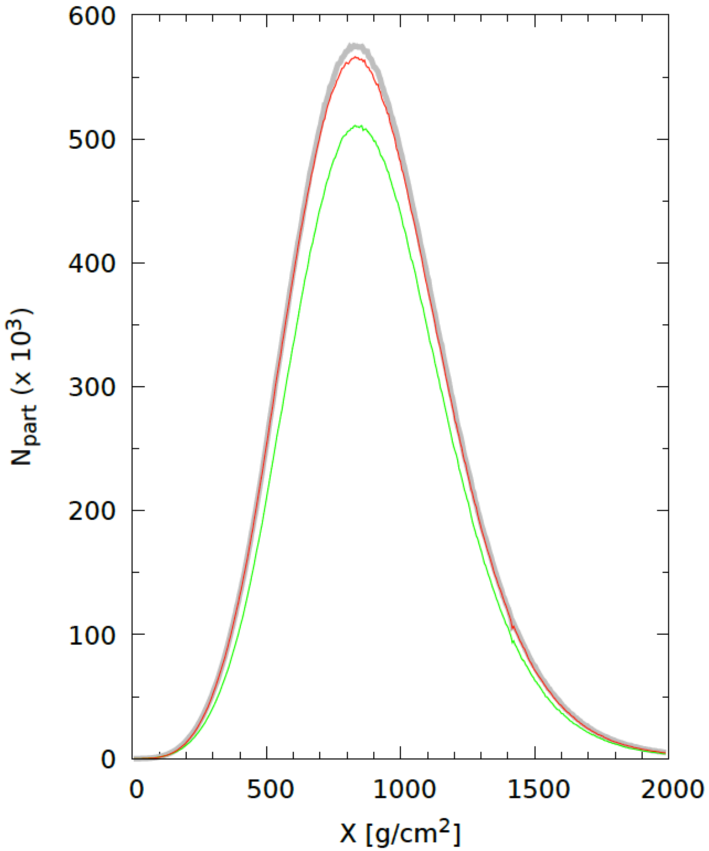
→no change in simulation of longitudinal development for muons for BN

→ BN model gives higher number of particles both pre-LHC and post-LHC



Pion longitudinal developmnt,60 degrees

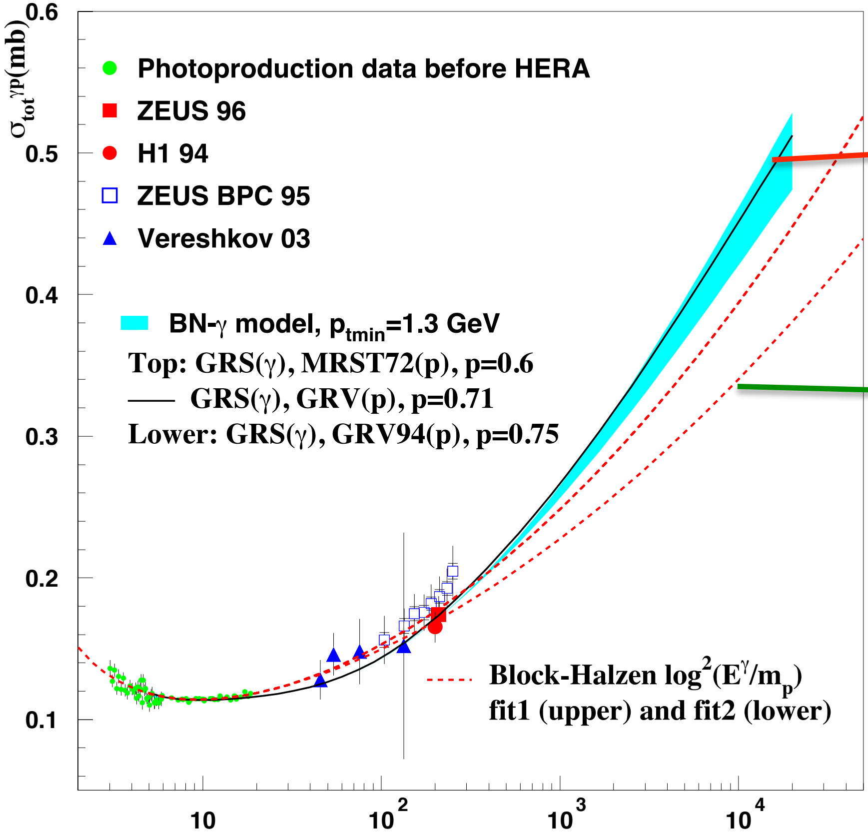
- Green is BH post-LHC
- Red is BN with post-LHC QGSJET
- Grey is BN with pre – LHC QGSJET
- →
- Slightly higher for pre-LHC
- Still BN higher than BH



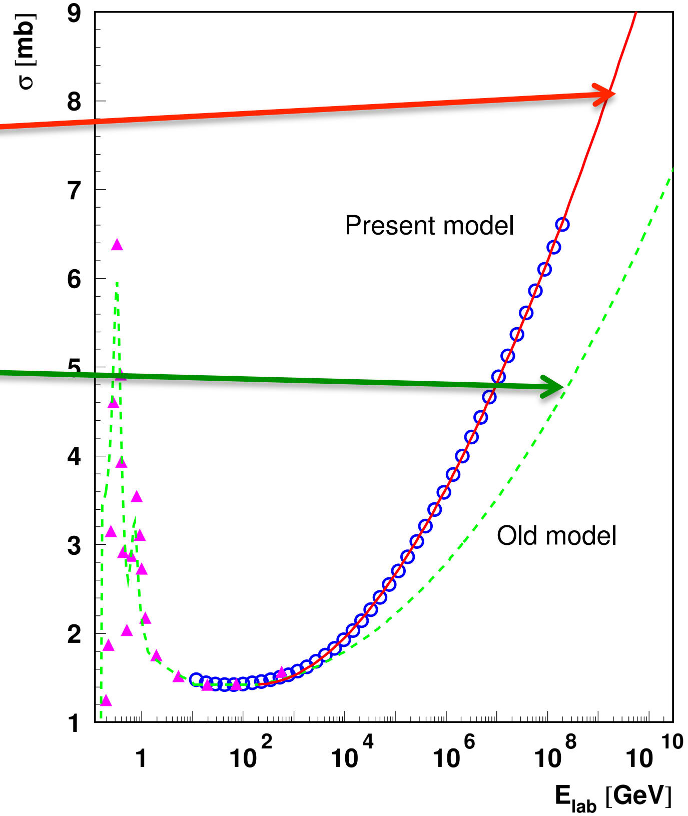
Shapes of shower observables

With F. Cornet, C.A. Garcia Canal , A. Grau and S. Sciutto

Photon-proton

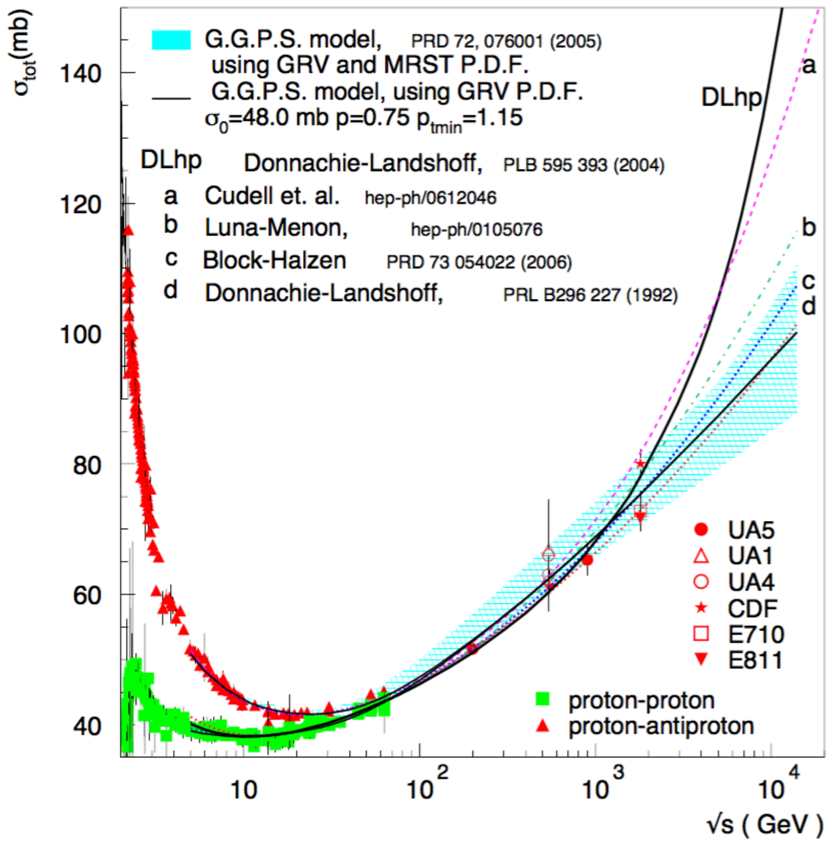


Photon-air



"old"= standard cross sections implemented in AIRES and other SP

How does our (GGPS) pp model for the total cross-section differ from other models?



Pre-LHC
Summary