INFN Istituto Nazionale di Fisica Nucleare

Hadronic total cross-sections

From $\gamma\gamma \rightarrow \pi\pi$ to the ultrahigh TeV regions

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Jefferson Laboratory 23 June 2004

With affections and thanks
to Mike
who guided and
accompanied me
through DAPHNE physics
and beyond

Thanks to Jefferson Laboratory for the invitation and the opportunity to thank Mike for his support through all the years he was with our **DAPHNE** physics group

DAPHNE or DAFNE = Double Accelerator For Nice Experiments

Outline

- The DAPHNE Physics project 1992
- The call to experts and the DAPHNE Physics Handbook
- The European networks
  - EURODAPHNE 1992-95
  - EURODAPHNE II 1998-2002
  - EURIDICE 2002-2006
- Mike's contribution to
  - two photon physics at DAPHNE
  - the formation of young European physicists who were then starting to move across Europe.

•An overview of the TOTAL hadronic scattering from fixed target to Cosmic Rays

The DAPHNE project was approved by INFN in 1991 to perform CP violation tests

- Cabibbo, INFN president at the time, thought that we needed a back-up physics program beyond CP violation tests
- Maiani was put in charge of theoretical program
- Motivated and led by Maiani, a group of Italian theorists prepared a short report and showed that there was physics beyond CP violation
- and charged Frascati to contact scientists who would be knowledgeable about the physics at a phi factory

- So we started looking outside Italy

The DAPHNE Physics project 1992

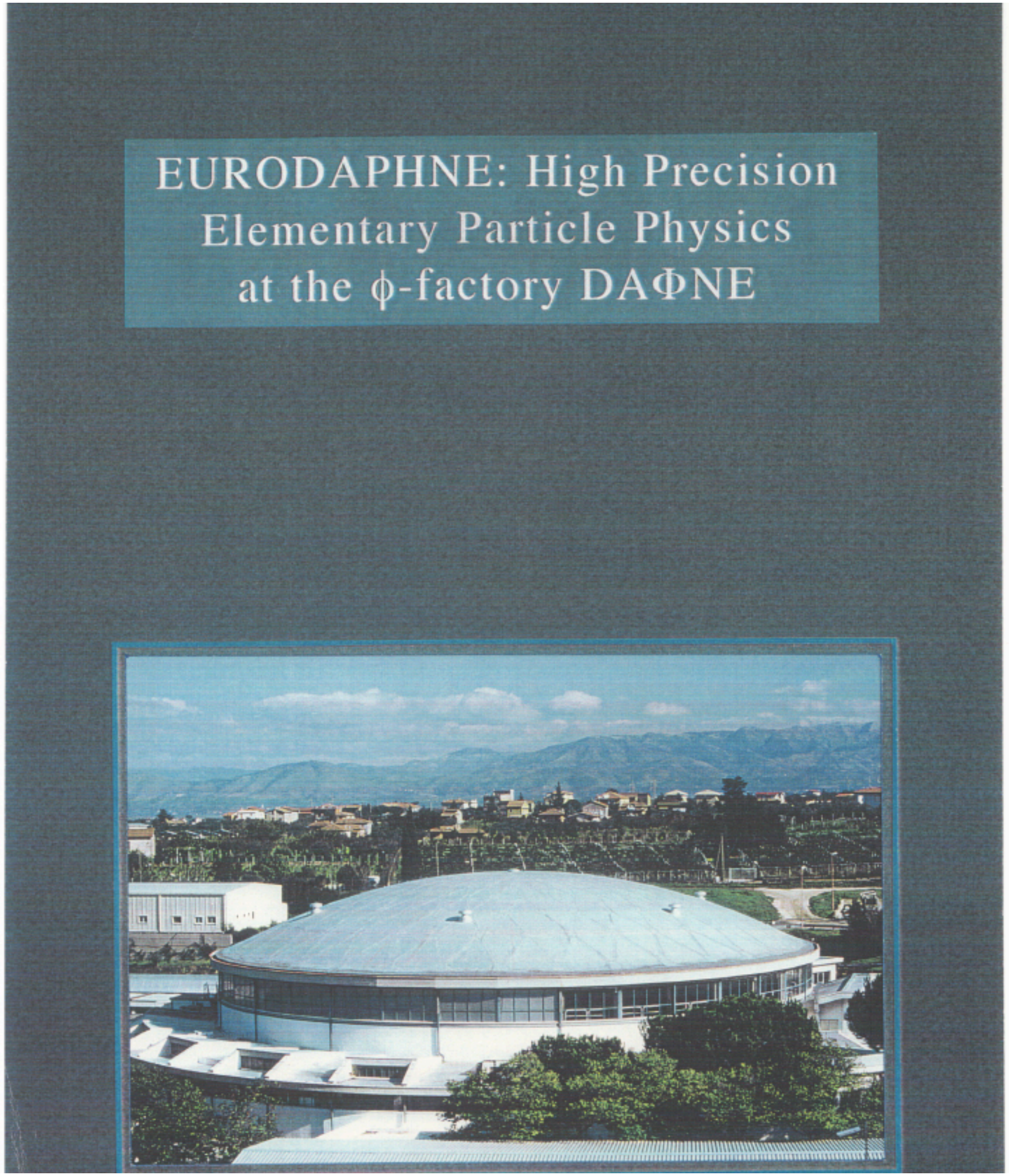
A photo with a story… which I will tell at dinner …

In 1992 we started the first EURODAPHNE Handbook

Experimentalists neeed a handbook (said Luciano Maiani)

- And were told that the EU had programs to fund research groups
- Mike seemed to know everything about it

And we wrote a proposal…



Thus we
built a network across Europe of which the UK was one of the pillars…and got funded for it

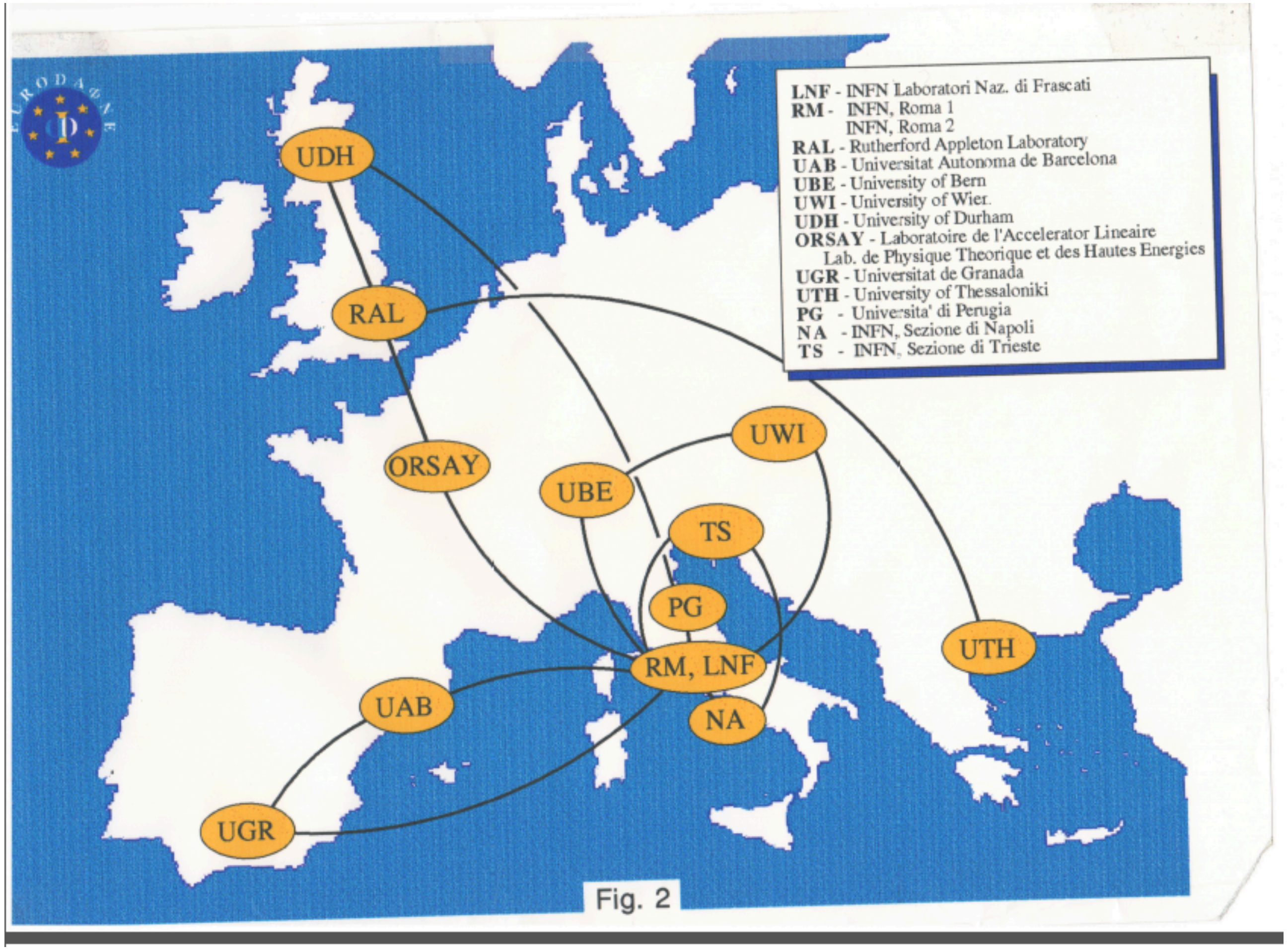


Fig. 2

Early EU days

- Europe was very different in the early ‘90s:
- only 7 member states, Austria was only associated, UK was one of 7… (will it stay?)
- When we finished in 2006 the member states were 25 (now 29 …-1?)
- Starting with a virtual entity called the ECU, we had to distribute funds in 7 different currencies: Italian liras, British pounds (still so…), German marks, French francs, Austrian shillings, Greek dracmas, Swiss francs
  - in the last network (2002-2006) we finally could do the finances in EUROs , but still the UK had the pounds…-
- We changed man-month into person-month … not so nice but we made a point

Mike

II EURODAΦNE Collaboration Meeting
Frascati, 19–22 April, 1994

III EURODAPHNE Collaboration Meeting

- The third meeting took place in Durham

Mike's contribution to a New EUROPE: 1992-2006

•Young researchers?

MOBILITY was a new word and a new imperative for EU funded research:

when the young Italian Southerner woman post-doctorate Fulvia De Fazio went from Bari to Durham, UK, she did not a word of English and it was Mike who mentored her through as he did for other 4 young Europeans of the network through the years

- Mike in Durham (UK) 1994 during III EuroDAPHNE

M.R. Pennington and P. Gensini
in St. John's College, Durham 10–15 December, 1994

III EuroDAPHNE Collaboration Meeting

When we had the III Eurodaphne Collaboration Meeting in Durham: what fun it was!!

For many of us, it was the first travel to the North of England.

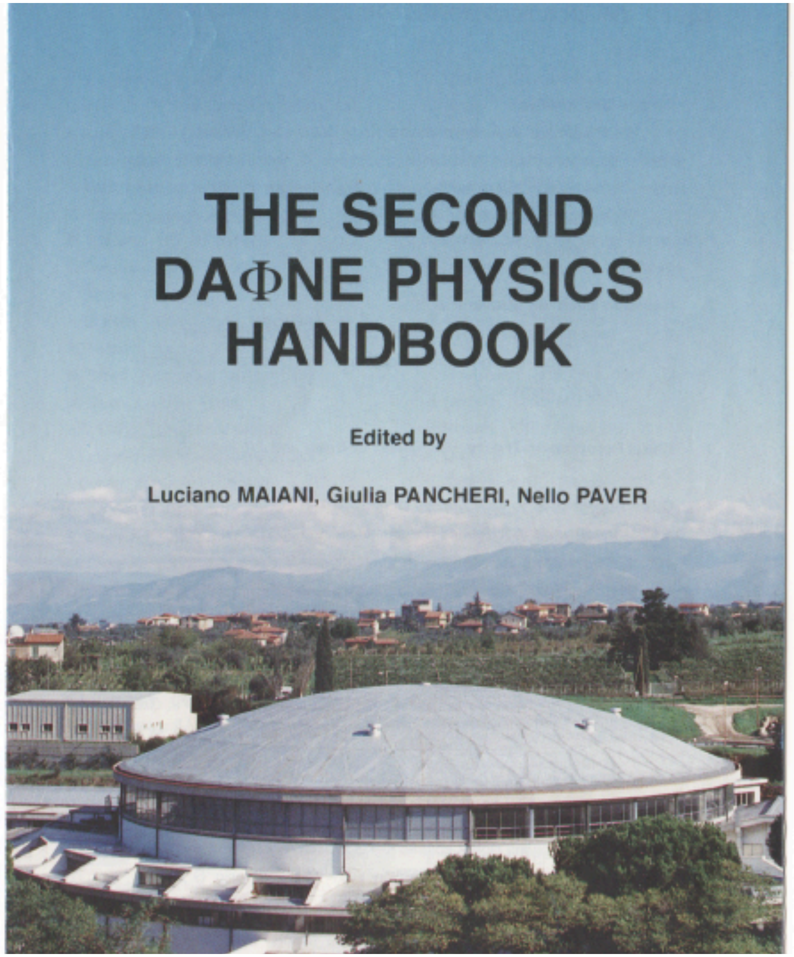
Our french colleague from Orsay was satisfied that the Durham cathedral was not superior, au par…perhaps… to the Chartres cathedral …(unlike what happened when we went to Barcelona and saw the Spanish Art Nouveau cathedral, the Sagrada Familia… that was really VERY different)

Some members of the nework in Durham, UK

G. D'Ambrosio, N. Paver, A. Pugliese, G. Pancheri and P. Gensini during the III EURODAΦNE Collaboration Meeting, in Durham, 10–15 December, 1994

A. Courau, A. Bramon and A. Grau at the Collaboration Meeting in Durh

1995



THE SECOND
DAΦNE PHYSICS
HANDBOOK
Edited by
Luciano MAIANI, Giulia PANCHERI, Nello PAVER

The Second Daphne Physics Handbook

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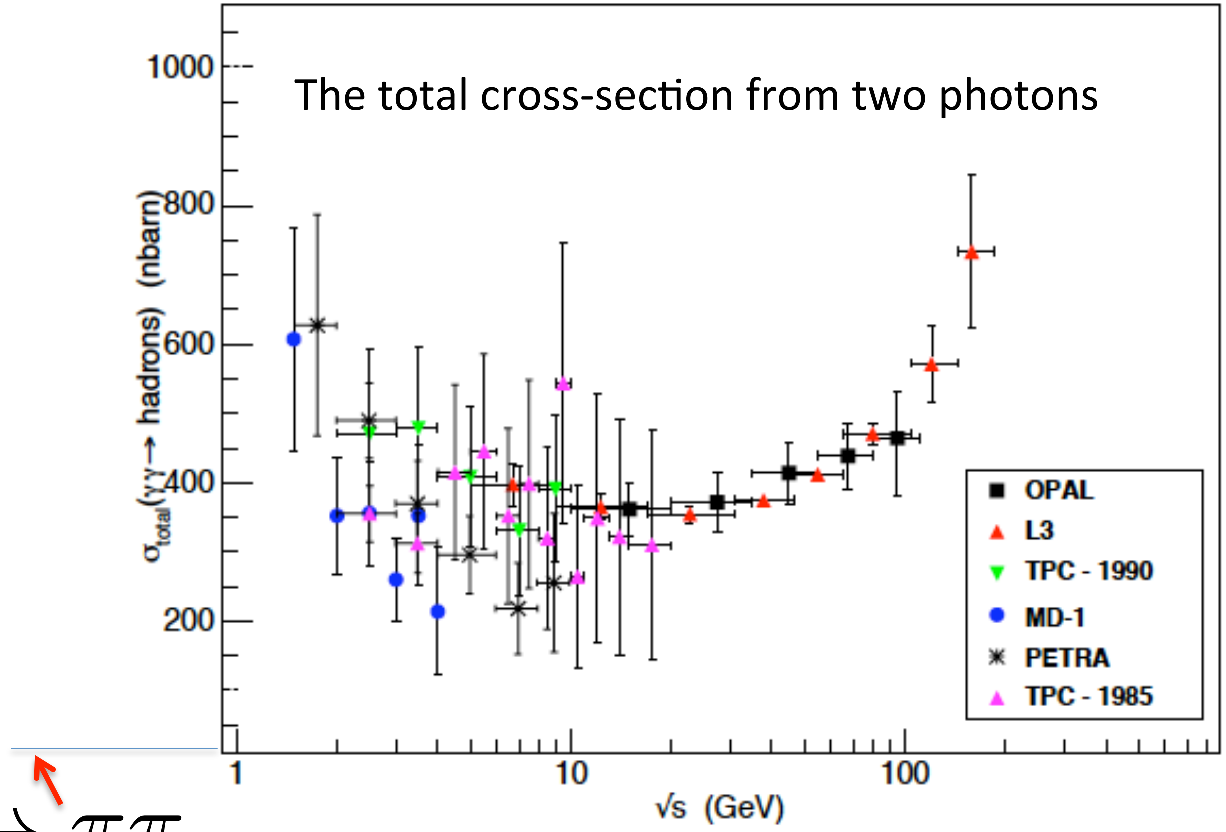
Mike's contribution to the Handbook had been with $\gamma\gamma \to \pi\pi$ at threshold

Where we are now with $\gamma\gamma \to hadrons$

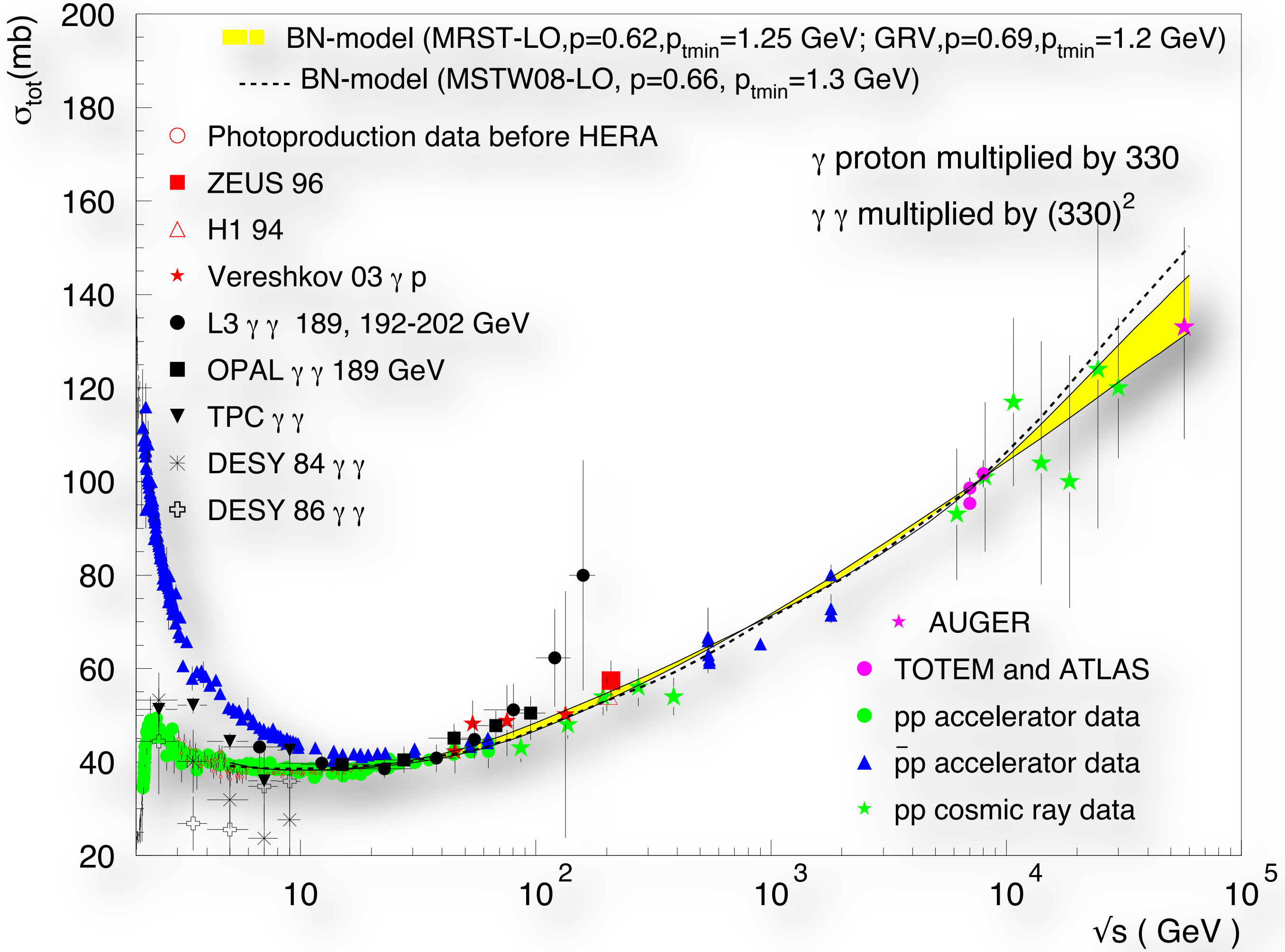


$\gamma\gamma \to \pi\pi$

Hadronic physics now?

- A road to understands QCD
- The total hadronic cross-section is one of them: the ultimate way to see experimentally study hadron confinement

The total hadronic cross-section: a well known figure .. But so very interesting…WHY?



- protons or antiprotons :

an initial descent followed by a dramatic change in curvature

And then

a slow approach to asymptotia

- photons ~ protons : upon normalization at the minimum with ad hoc factor proportional to alpha-QED

The total cross-section: cut-off in b-space ?

- In Heisenberg 1952 shock wave model, a cut off in b-space determined by the extension of the pion cloud leads to

$$\sigma_{total} \simeq \frac{\pi}{m_\pi^2}(\ln \frac{\sqrt{s}}{< E_0 >})^2$$

$$< E_0 > \simeq constant \quad \sigma_{tot} \sim [\ln s]^2$$
$$< E_0 > \simeq \ln s \quad \sigma \simeq constant$$

Confinement ?

A long history of Models

- Heisenberg with pion cloud – 1952 $constant \quad or \quad [\ln s]^2$

Optical theorem + Regge behaviour

- Regge exchanges -> $s^{-\eta}$ $-\eta = \alpha_R(t=0) - 1 < 0$
  decreasing before ISR (1972) $for \quad Regge \ poles$

- Pomeron exchange -> $s^{+\epsilon}$ $\epsilon = \alpha_P(t=0) - 1 \geq 0$
  constant or rising after ISR $for \quad Pomeron$
  (and cosmic rays ~ 1970)

- Regge + Pomeron for everybody - in 1992 $X s^{-\eta} + Y s^{+\epsilon}$

But a power law contraddicts the Froissart bound

If the cross-section rises, it cannot rise too much

WHY?

- Because of the asymptotics of the Froissart bound

i.e.

- Because of confinement….

Basic fact: All total cross-sections rise... but not too much (Froissart dixit in 1961 + Martin 1962+Lukaszuk 1967)

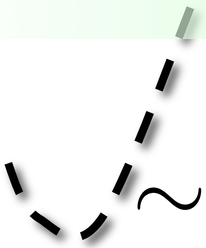
Asymptotically

$$\sigma_{tot} \lesssim \sum_{0,L} \simeq L^2_{max} \longrightarrow \sigma_{total} \lesssim [\log s]^2$$

$$L_{max} = qb_{max} \sim \log s$$

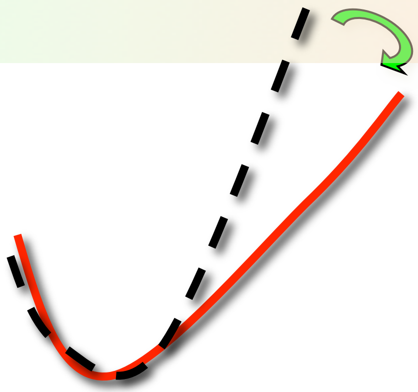
What generates the rise, which is very fast at the start (ISR)?

What tames the rise into a Froissart-like behavior?



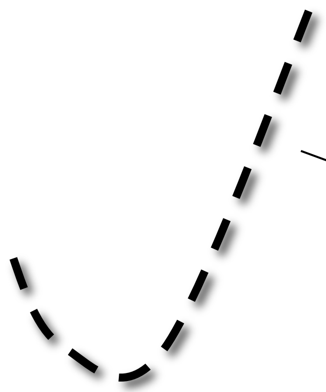
$\sim s^{0.1}$

How to go from a power-law to log s ?



Mini-jet models : All total cross-sections rise… but not too much (Froissart dixit)

What generates the rise? Low-x parton collisions



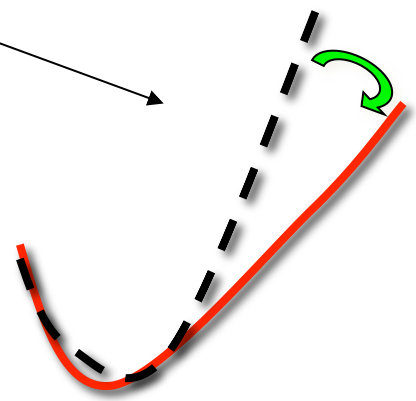
$s^{\epsilon} \qquad \epsilon \sim 0.3$

How to go from hard to soft ?

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

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, PRD1999, PRD2005**]



Minijets and the rise for √s ≈ 20 GeV

pQCD

- asymptotic freedom regime

$$\alpha_s(p_t) \to \alpha_{AF} = \frac{b_0}{\ln[p_t^2/\Lambda^2_{QCD}]}$$

$p_t >> \Lambda_{QCD} \quad p_t \simeq 1\ GeV$

$$p_t \geq p_{tmin}$$

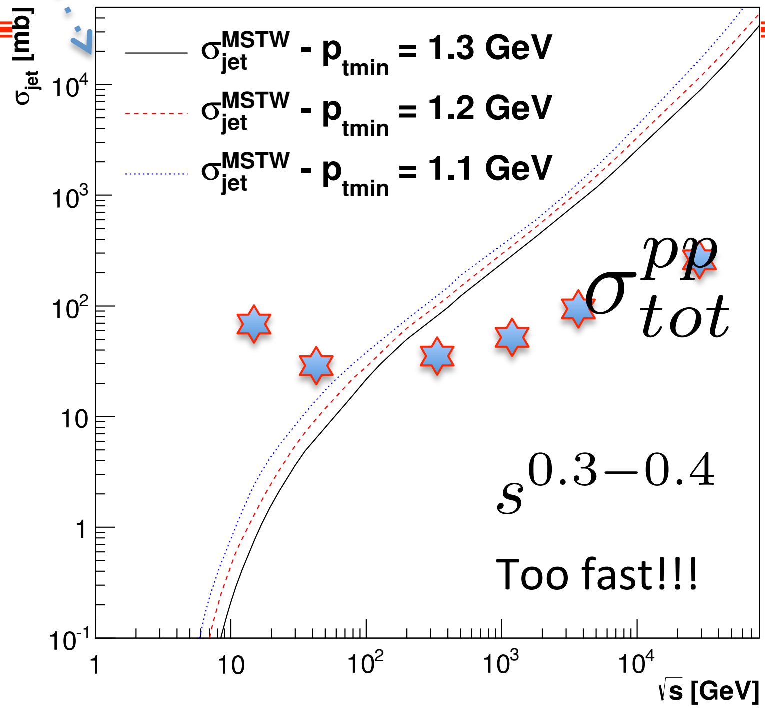
- parton-parton scattering with final parton

$f(x) \sim 1/x \qquad x \geq 2p_{tmin}/\sqrt{s}$

$x \leq 0.1 - 0.2 \quad and \quad \downarrow \quad \sigma_{mini-jet} \uparrow$

$$\sqrt{s} \gtrsim 10 - 20\ GeV$$

$$\sigma^{AB}_{\rm jet} = \int_{ptmin}^{\sqrt{s}/2} dp_t \int_{4p_t^2/s}^{1} dx_1 \int_{4p_t^2/(x_1 s)}^{1} dx_2 \sum_{i,j,k,l} f_{i|A}(x_1, p_t^2) f_{j|B}(x_2, p_t^2) \frac{d\hat{\sigma}^{kl}_{ij}(\hat{s})}{dp_t}$$



GP et al. , 1504.04890, PRD91 (2015)

How to generate a cut-off in b-space, asa confinement?

- Heisenberg 1952 shock wave model, cut off in b-space determined by the extension of the pion cloud

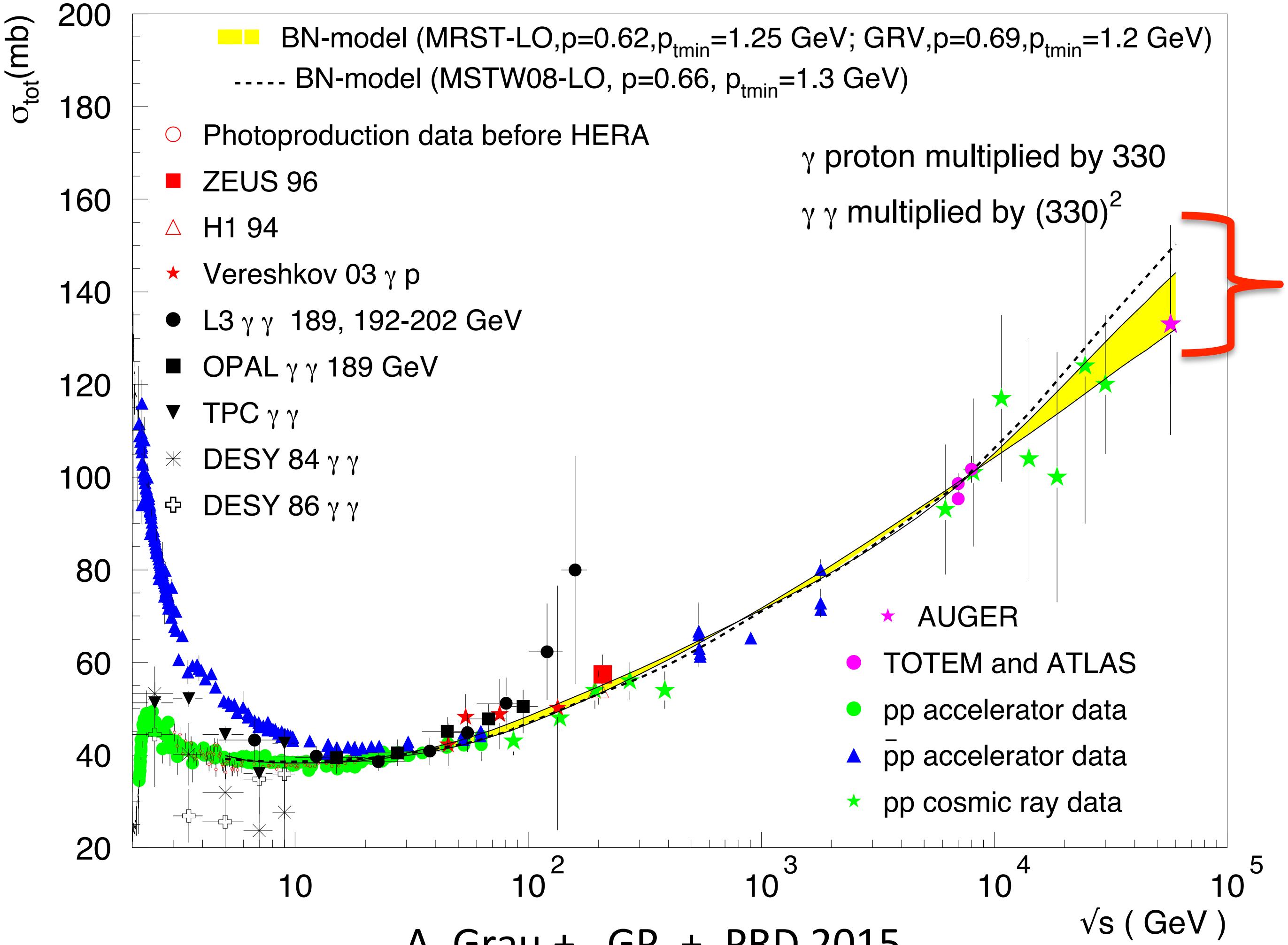
$$\sigma_{total} \simeq \frac{\pi}{m_\pi^2}(\ln \frac{\sqrt{s}}{< E_0 >})^2$$

$$< E_0 > \simeq constant \quad \sigma_{tot} \sim [\ln s]^2$$
$$< E_0 > \simeq \ln s \quad \sigma \simeq constant$$

- Form factors (most commonly used, early mini-jet models 1984-85), soft Pomeron models, etc.

- Resummation with singularity confinement in a eikonalized minijet model (GP et al. model, *Bloch-Nordsieck(BN model*)

A model for soft gluon resummation (RGS) with infrared singularity effects

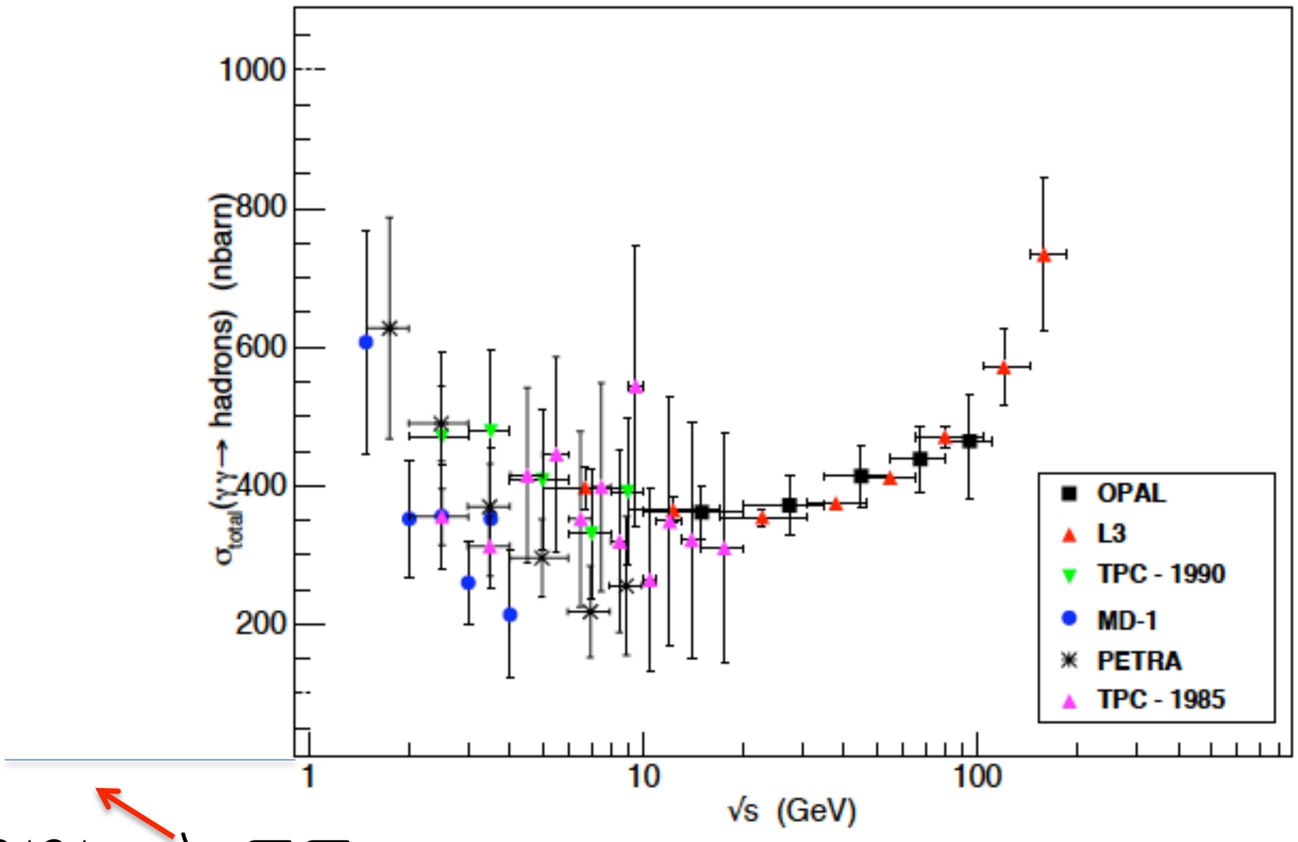


A. Grau,+ , GP, +, PRD 2015

PRD 2005 A.Grau, R.Godbole, GP, Y.Srivastava

- Impact parameter distribution from RGS down to infrared
- Singular integrable $\alpha_{IR}(k_t^2)$
- Minijets lead the rise with asymptotic freedom $\alpha_{AF}(p_t^2)$

Thanks to Mike and to Jefferson Laboratory



$$\gamma\gamma \to \pi\pi$$

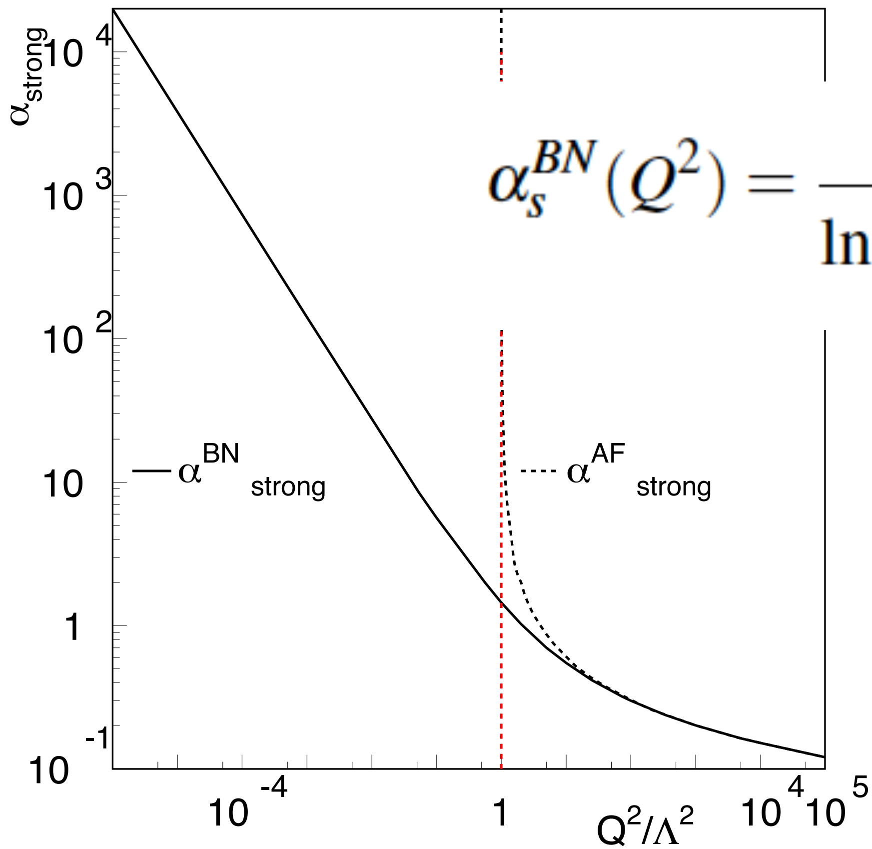
Spares

Our model ansatz for $\alpha_{IR}(k_t^2 \to 0)$

$$\alpha_{IR}(k_t^2 \to 0) = (\frac{\Lambda}{k_t})^{2b_0}$$

$$b_0 = \frac{11N_c - 2N_f}{12\pi}$$

Phenomenological behaviour used in our Bloch-Nordsieck model for total cross-section



$$\alpha_s^{BN}(Q^2) = \frac{1}{\ln[1 + (\frac{Q^2}{\Lambda^2})^{b_0}]}$$

GP +, Photon 2013 Proceedings, PoS

The total hadronic cross-section

At low energy, when $\sqrt{s} \leq$ 4-5 GeV, Regge type exchanges dominate, soft emissions lower the cross-section, no hard scatterig between constituents can be seen

Quarks can have an average energy $\sqrt{s}/6 < 1$ GeV, constituents/partons are not yet emerging fro the non perturbative region

As the $\sqrt{s}$ goes up, there can be hard scattering among constituents and the cross-section increases because more and more low-x partons can participate to the production of particles

- At the same time, soft emission does take place and tames the rise
- At very high energy, a balance between soft emission and hard scattering leads to a quiet rise, logarithmic like or at most midway between a log and the a square log, a la Froissart
- When does the transition take place?

Of notice

- In pp and $p\bar{p}$
  - The shape with an apparent minimum
  - The rise
  - The softening of the rise
- In γp and $\gamma\gamma$
  - Lack of high energy data
  - Apparent stronger rise, especially in gamma gamma

Questions to address:

1. What does one learn from
   – Present models

   vs

   – Accelerator data : most models accommodate new data just by changing the parameters (a little bit…)

   – Cosmic ray data : large uncertainties on pp from data extraction

2. Which machines and experiments can give new information to move ahead with models and get understanding of the underlying dynamics?