Collisions from 40 years ago…

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after Collège de France (Paris 1995-2007), Research Ministery(Paris 2000-2006) and University of Bordeaux (1975-1994) in earliest contact with CORSIKA at Karlsruhe after 1989

Outlook

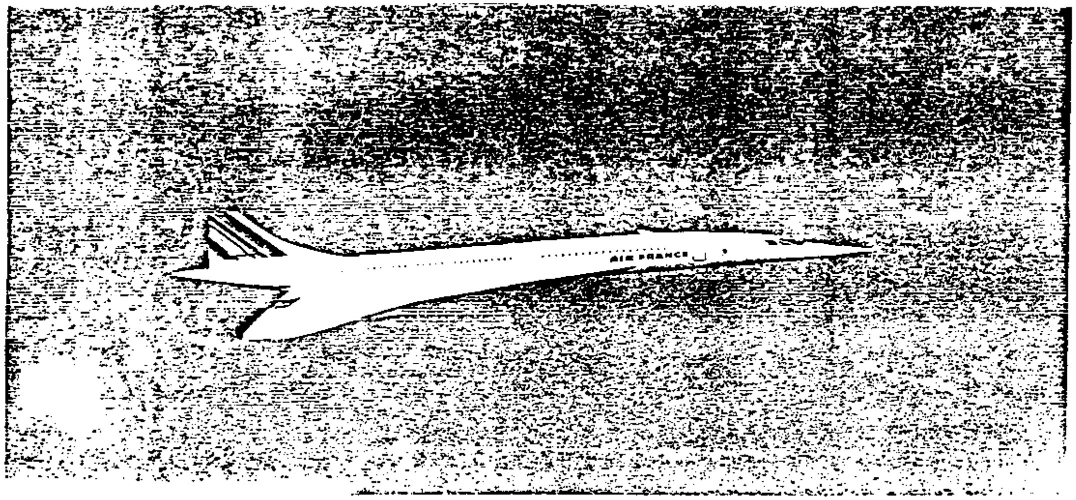
Cosmic Ray Collisions above 1 PeV, flights near 18 km altitude (Paris-Tokyo collab.)

-Near 1000 Concorde flight, Oct. 78-Oct.84. One collision at n 1 PeV(250h , 25cmX20cm) and 10 PeV(500h, 45cmX50cm)

Nuclear Interaction models and accelerator data for Corsika($\sqrt{s}$= 0.2 TeV up to $\sqrt{s}$= 0.9 TeV for Cern, for Tevatron- Fermi-lab near $\sqrt{s}$= 1.8TeV**, near** $\sqrt{s}$= 13TeV in LHC**)**

- HDPM(2 Gaussian)-Corsika, violation of KNO scaling at UA5 energies from 1987, HDPM extended to 4 gaussians or multiple clusters(2014) with GHOST

After 1020eV?**



Concorde — adding to the repertoire of cosmic ray experiments.

(Photo Air France)

CERN Courier
October 1981

- *Experiences ECHOS started in October 1978*
- *0ne collision of 10^6 GeV (high multiplicity, spikes in the distribution of pseudo-rapidité) at first exposure*

High flying physics

Cosmic ray physicists have always had to aim high. In the constant search for interactions produced as close as possible to the immensely high primary particles entering the earth's atmosphere from outer space, they have installed experiments on high mountain peaks and flown detectors aloft in balloons.

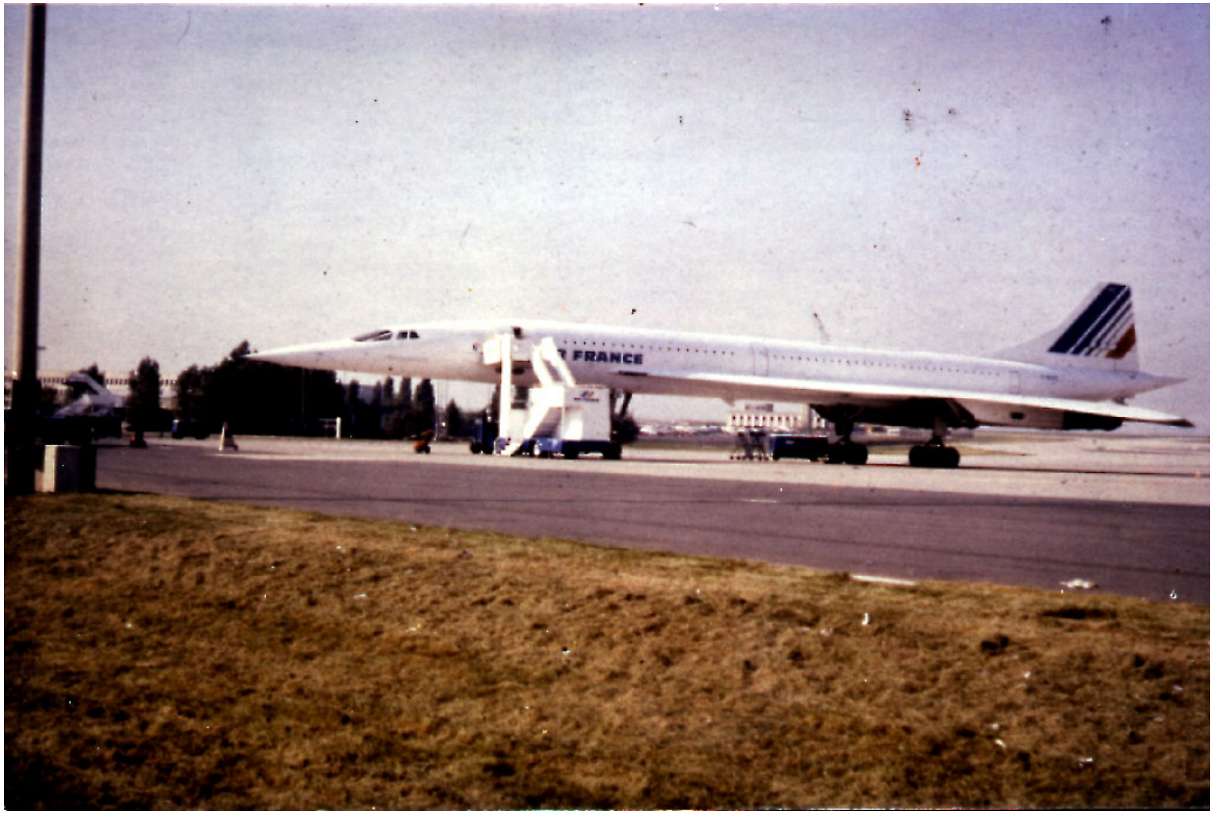
In these studies, there have been periodic sightings of remarkable configurations of secondary particles. These events, many of which bear exotic names like Centauro, Andromeda, Texas Lone Star, etc., frequently defy explanation in terms of conventional physics ideas and give a glimpse of what may lie beyond the behaviour seen so far under laboratory conditions.

The 540 GeV collisions at the CERN proton-antiproton collider (equivalent to a 155 TeV proton beam hitting a stationary target) will for the first time provide man-made energies which approach the region where these exotic events might turn up. This search is perhaps second only on the experimental agenda to the quest for the intermediate weak interaction bosons.

But cosmic ray studies continue to produce interesting results. In 1978, the ECHOS experiment began by a France/Japan collaboration using emulsion chambers mounted in the baggage compartment of an Air France Concorde supersonic airliner. This has too produced its exotic event, tamely referred to as JF1af1.

Two emulsion chambers were packed in the Concorde baggage hold, one being specifically designed for the detailed observation of high energy events. This 35 kg JF1a chamber contained three sections, an upper one with different types of nuclear emulsion plates to enable charge determinations to be made, a central target layer, and an emulsion calorimeter at the bottom. The second Concorde detector was more concerned with measuring particle fluxes.

The exposure was planned to cover 200 hours of level flight some 16 km above sea level, requiring a total of some two months in the aircraft. Because of the high altitude and relatively long exposure, a good crop of high energy interactions was obtained. In particular, the very first flight produced the JF1af1 event, estimated as containing about 150 gamma rays and a total radiated energy of 260 TeV. As well as its large energy and high multiplicity, the event is remarkably well collimated. The presence of a certain level of hadrons implies that the event was due to a nuclear interaction and analysis suggests that it occurred somewhere on or inside the Concorde, rather than in the outer atmosphere. Its closest counterpart so far observed is the Texas Lone Star interaction picked up by balloon-borne emulsion stacks.



R FRANCE

CONCORDE OCT.1978 ROISSY AIRPORT

Inserting one pair of ECHOS CHAMBERS (20 cmX25 cm).

Daily returned Paris-Washington, duration 1H41mn increasing level from 15 km to 17 km.

Chamber 1 received the result of a collision in the top of the cabin wall allowing to measure an event around 1 PeV. (interaction point at 2.27m +/- 0.88m) . Total of cumulated fly 250H.

Next flights were at the bottom of the passenger room (45 cm X 50 cm) and one event with energy exceeding 10 PeV. Total cumulated fly 500H.

1st flight Oct.1978 (down), 2nd Oct.1992(up)

- Oct. 94 (up)

- Oct. 1978

COSMIC RAYS
Concorde hits the fan

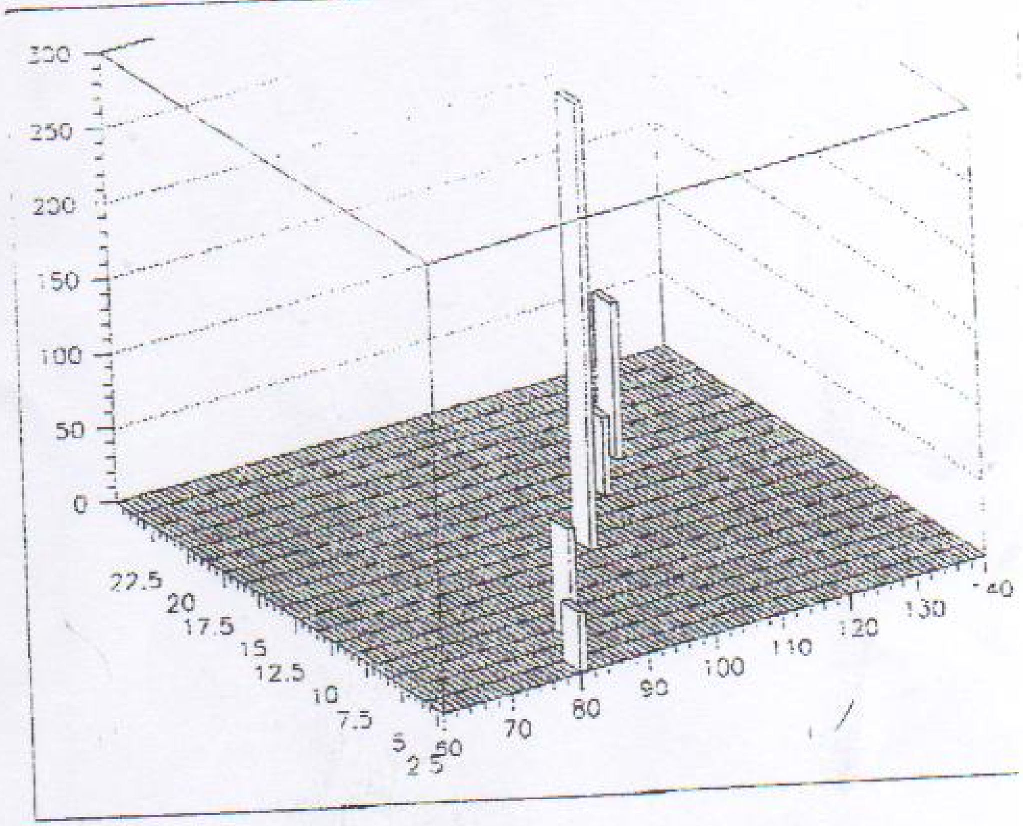
CERN Courier april 97

For the past 15 years, a Paris/Tokyo cosmic ray collaboration has been flying emulsion chambers on Concorde, typically exposing for 200 hours at altitudes of 17 kilometres.

While the event harvest has enabled the researchers to cover a wide range of physics - gamma ray flux, nucleon-nucleus collisions, fragmentation of heavy primaries, hyperstrange baryonic matter,....... one particularly intriguing event, corresponded to a stratospheric gamma ray shower at 10^7 GeV, containing over 200 gammas above 200 GeV (higher energy events, up to 10^{11} GeV, have been seen elsewhere).

At first, this high energy event, dating from 1982, was neglected. Only later did physicists notice the tendency for its gammas to slot together in a plane, or sheet, following suggestions reported from cosmic ray exposures at 4360 m in the Pamir mountains in Central Asia.

Taking another look at the high energy Concorde event last year, Jean-Noël Capdevielle of the Collège de France started to plot the gammas by hand, starting with the most energetic, and was startled to find they were on an almost perfect straight line.



Near 10^7GeV, 211 γ's

Fan-like array of high energy gamma rays (photons) seen in a cosmic ray event recorded by a Paris/Tokyo collaboration flying emulsion chambers on Concorde at altitudes of 17 kilometres. The photon energies (vertical axis) are in TeV, while the horizontal pixels are 1 mm square.

Such sheet-like alignments are also seen in a dozen or so events by the large Pamir chambers (several hundred tonnes), which also see the emergent hadrons but are degraded

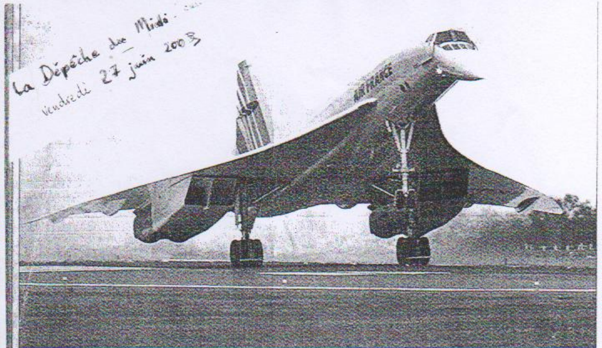
Linear collision course

While attention is focused on CERN's LHC proton collider the next major step for particle physics, the parallel electron-positr collider route is acknowledged as providing a complementary approa to many outstanding physics questions.

With CERN's 27-kilometre LEP electron-positron ring defining a feasibility limit for circular electron machines, research and

27 june 2003 Last Flight

La Dépêche du Midi
vendredi 27 juin 2003



Un dernier atterrissage à 400 km/h avant de retrouver la terre natale dont l'avion s'est envolé il y a presque 30 ans. Photo AFP

RECHERCHE *L'avion transformé en laboratoire volant*

Quand le supersonique traquait les rayons cosmiques

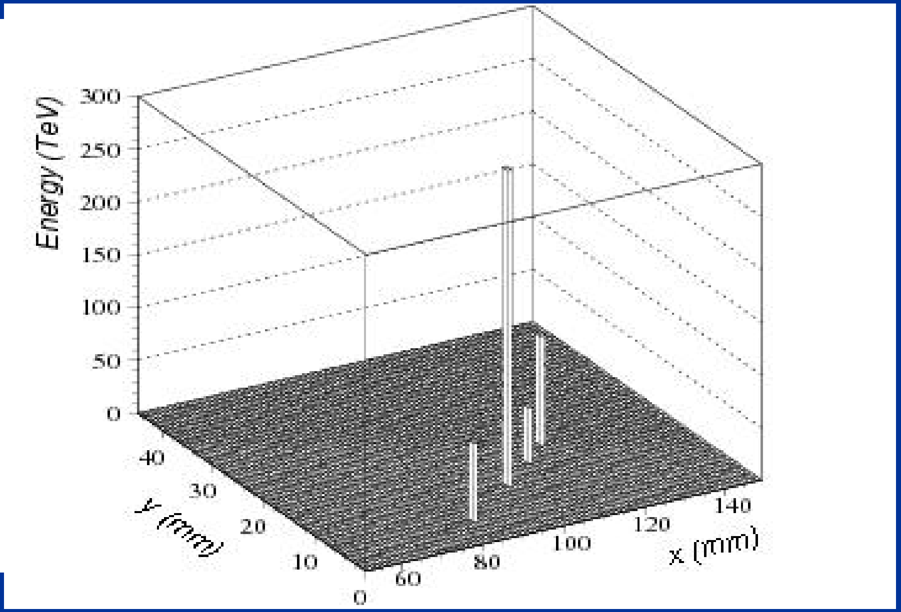
Grâce à Jean-Noël Capdevielle, Concorde a transporté dans ses soutes des films à rayon X pour capter les explosions de particules cosmiques. Photo DDM –

— Qui savait que Concorde avait servi d'outil original pour étudier et observer des phénomènes de matière insoupçonnés ? Qui savait que le prototype 001 avait servi d'observatoire de l'éclipse du 30 juin 1973, avec une seconde expérience menée le 11 août 1999 à bord cette fois de deux Concorde ? Mais les éclipses de soleil n'ont pas été la seule mission scientifique confiée au supersonique qui a également permis de traquer la couche d'ozone, mais aussi les rayons cosmiques.

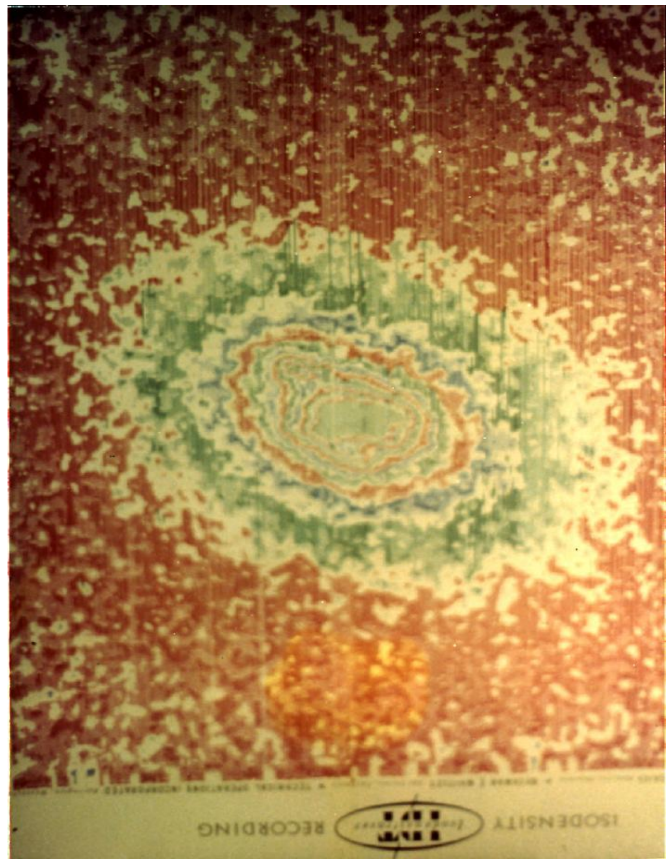
Pour en parler, Jean-Noël Capdevielle, un chercheur qui obtint son diplôme d'ingénieur à Toulouse avant de devenir en 1968 lauréat de la Fondation de la vocation pour ses travaux en physique nucléaire. « concorde disparaît et, franchement, ça me rend triste», confiait hier le scientifique entré au Collège de France en 1994, d'autant plus amoureux du Concorde que, grâce à lui, il a pu explorer des particules de matières issues du ciel profond. Si ces expériences ont pu être conduites, c'est parce que l'avion commercial était le seul capable de voler aussi longtemps à une altitude de 18 km. A l'époque, Jean-Noël Capdevielle avait réussi à convaincre la compagnie Air France d'embarquer dans les soutes de l'avion des chambres à émulsion, c'est-à-dire un empilement de plaques de plomb et de films à rayon X capables de capter les particules de haute énergie. Pourquoi sur Concorde précisément? Parce que, dans la haute atmosphère, les protons contiennent un fort degré d'énergie qu'ils perdent à chaque collision de particules. Tout cela est complexe, mais il faut savoir que ces particules, des milliers de fois plus petites que l'atome, permettent de décrire les secrets de la matière. Chaque seconde, ces rayons cosmiques qui correspondent à des grains de lumière, des noyaux d'atome, viennent frapper notre planète. Et ces rayons parfois chargés d'une formidable énergie restent une source inépuisable de recherches pour les scientifiques du monde entier. Ces études, rappelle le savant, sont indispensables car elles permettront des applications dans le domaine de la navigation spatiale. Les dangers des orages solaires, les risques permanents de collision avec des météorites, les risques d'ionisation des cosmonautes n'ont pas fini de nous interroger. ■ J.-M.D.

JF2af2 (Concorde)

- Xray film under 8 c.u.
- Lego plot with the 4 most energetic Gamma 's



One γ ray of 200 TeV…in the event exceding 10 PeV(52deg)

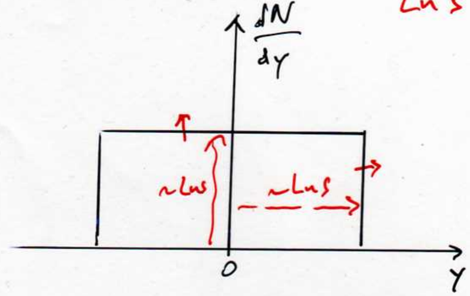


In connection with the CERN

- First attempts for CORSIKA
- after Beijing (1986) , Proc. Int. Symp. On UHE interactions, 7, 23.
- Moscow(ICRC 1987, vol.5 p.135, 160, 182, 263, 430),
- Lodz(5th international symposium on very high energy interactions, p.128 invited papers)

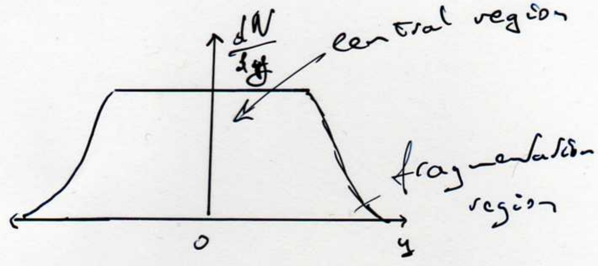
Inclusive data → guidelines versus energy

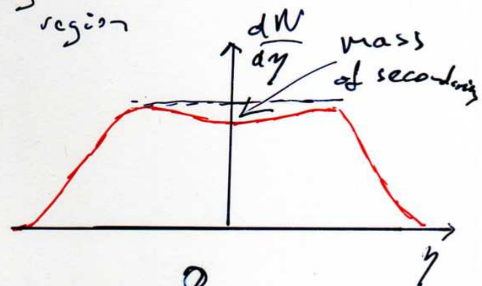
Ln s physics



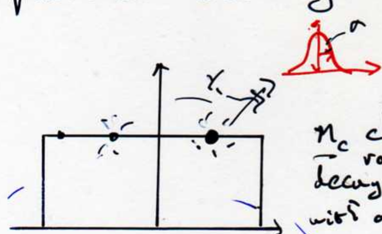
$n_s \sim \ln^2 s$

plateau





How to reproduce a plateau with gaussian wings ?

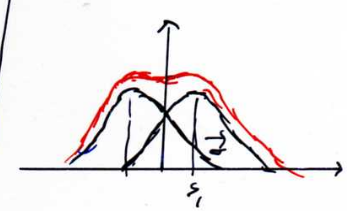


n_c clusters randomly distributed decaying with a gaussian distribution.

m secondaries per cluster

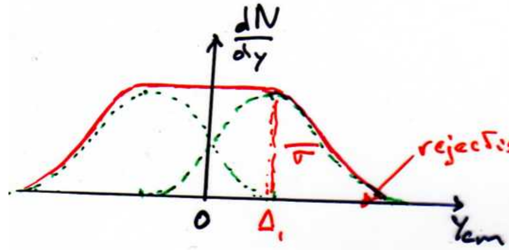
an alternative

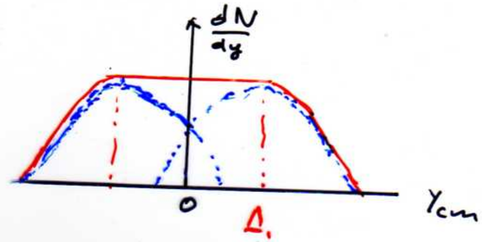
2 gaussians or more



GENCL / UA5.

From Gaussian r. Hyperbolic Generators?





GAUSSIAN

$$\frac{dN_{ch}}{dy} = A\left\{ e^{-\frac{1}{2}\left(\frac{Y-\Delta_1}{\sigma}\right)^2} + e^{-\frac{1}{2}\left(\frac{Y+\Delta_1}{\sigma}\right)^2} \right\}$$

$$Y_i = \pm\Delta_1 \pm \sigma\sqrt{-2\ln\eta_1}\cos 2\pi\eta_2$$

HYPERBOLIC

$$\frac{dN_{ch}}{dy} = A\left\{ \frac{1}{ch^2\alpha(y-\Delta_1)} + \frac{1}{ch^2\alpha(y+\Delta_1)} \right\}$$

$$Y_i = \pm\Delta_1 + \frac{1}{\alpha}\,\mathrm{Arg\,th}\,(2\eta - 1)$$

at collider $A \sim 2.9$
$\alpha \sim 0.35$

Semi-inclusive regularity (S.I.R.)

$$\left(\frac{dN}{dy}\right)_0^2 / \rho_0 = (az+b)^2$$

	a	
$z \leq 1.5$	0.7	0.24
$z \geq 1.5$	0.49	0.55

$$\left(\frac{dN}{dy}\right)_0 = \rho_0 = 0.313\,\ln s + 0.063 \quad \text{(incl.)}$$

$$\langle n_{ch}\rangle = 0.127\ln^2 s + 0.58\ln s + 0.57$$

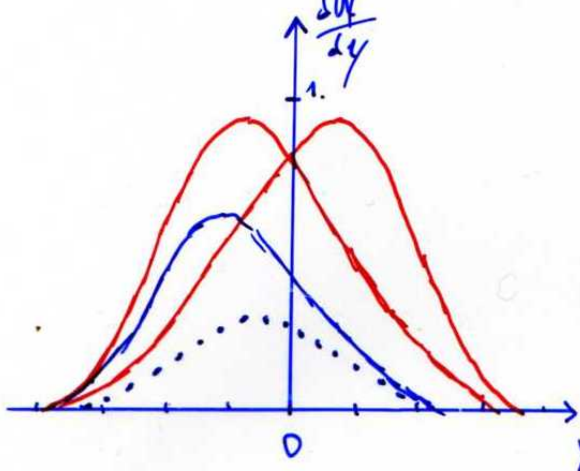
$$\begin{cases} \left[\frac{dN_{ch}}{dy}\right]_{z,0} = (az+b)^2\rho_0 \\ \int_{Y_{min}}^{Y_{max}} \left[\frac{dN_{ch}}{dy}\right]_z dy = z\langle n_{ch}\rangle \end{cases}$$

$$\Delta_1 = \sigma\sqrt{2\ln\left\{\frac{z\langle n_{ch}\rangle}{\sqrt{2\pi}\,\sigma\rho_0(az+b)^2}\right\}}$$

$$\Delta_1 = \frac{1}{\alpha}\,\mathrm{Arg\,ch}\left\{\frac{1}{az+b}\sqrt{\frac{\alpha}{2}\frac{z\langle n_{ch}\rangle}{\rho_0}}\right.$$

P-air collision with 4 components

p+A with 4 components



2 $q\bar{q}_v - q_v$

2 rescattering $\begin{cases} q_s - q\bar{q}_v \\ \bar{q}_s\ \bar{q}_s \end{cases}$

$$\nu = A \frac{\sigma^{p\text{-}p}}{\sigma^{p\text{-}A}}$$

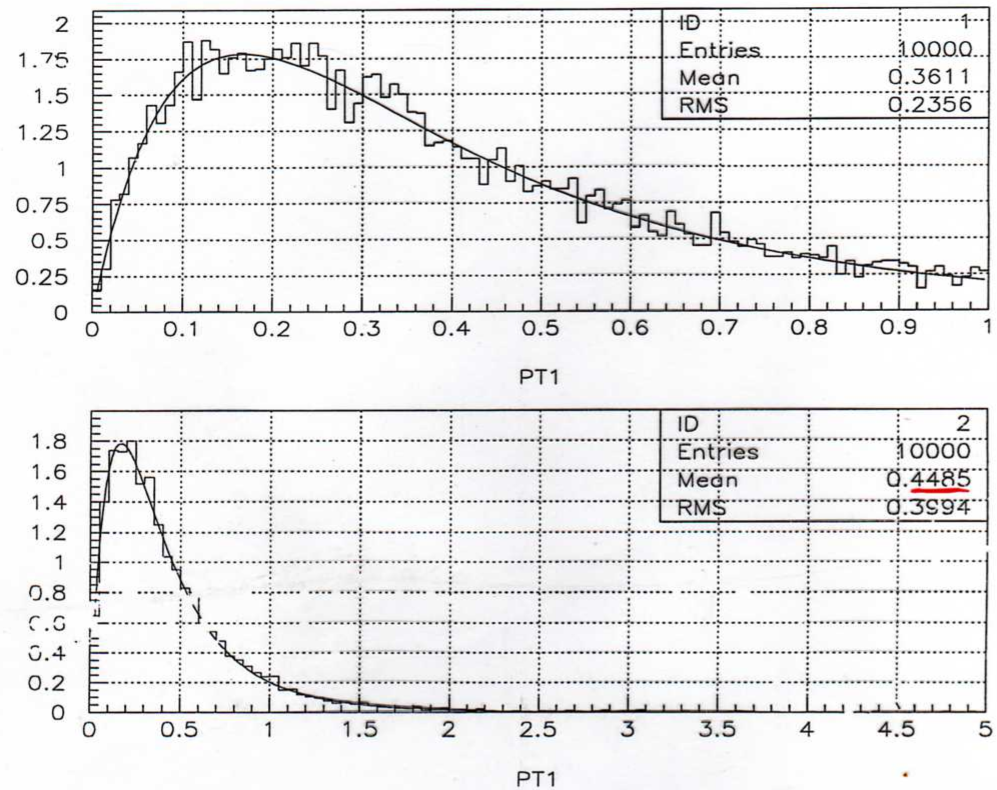
$$n_{p\text{-}A} = n_{p\text{-}p}\left(\frac{\nu}{2} + 1\right)$$

$$D(y,\nu) = \left(\frac{dN}{dy}\right)_{p\text{-}A} - \left(\frac{dN}{dy}\right)_{p\text{-}p}$$

see J.W.C. J. Phys. G., 15, 909 (1989)

P_t generation by "dichotomy", following UA1/mini 96 data.

J.-W.C. 96



$m_{\perp i} = \sqrt{m_i^2 + p_{t_i}^2}$ $\quad E_i = m_{\perp i} \cosh y_i$.

increases $m_\perp$, then $\sum m_{\perp i}$

and inelasticity K_{tot} by 10% for p-p.

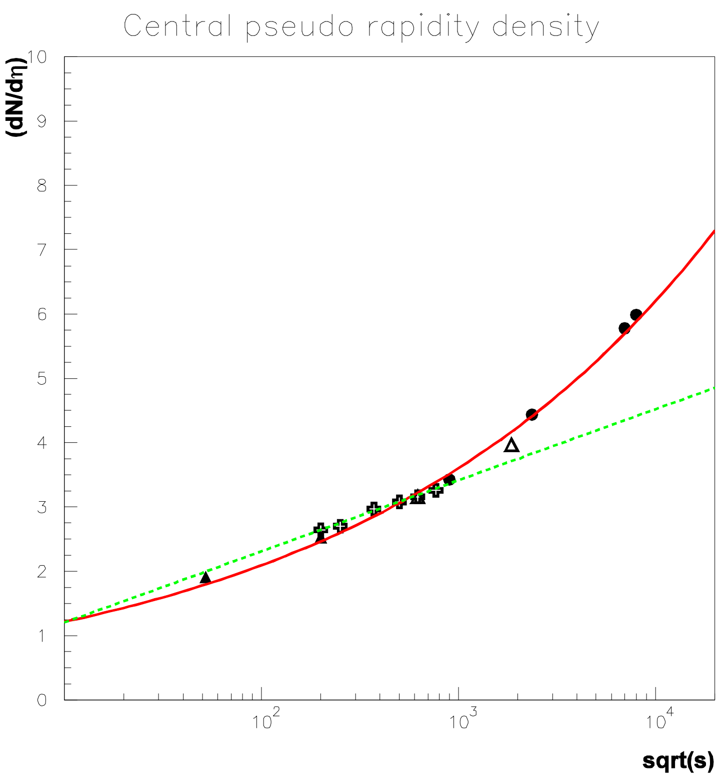
From HDPM to GHOST

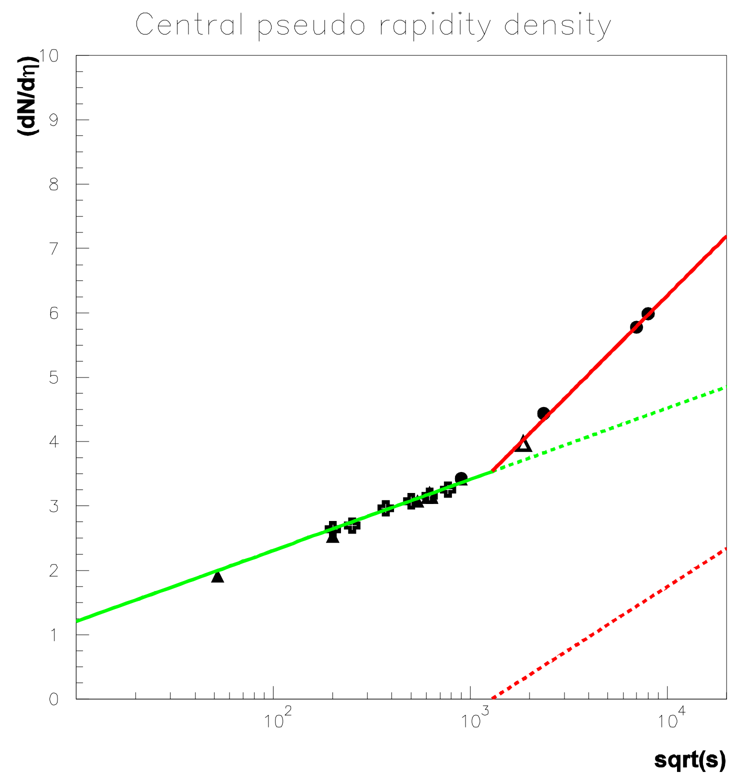
- HDPM (hadron dual parton model) appears more difficult to use than GHOST at energies larger than sqrt(s) = 1500 GeV
- GHOST, with 4 plateau instead of 2, is better adapted at UHE and can follow different »plateau» if necessary with fast calculations;

$$\rho_o = 0.70835\ s^{0.11775}$$

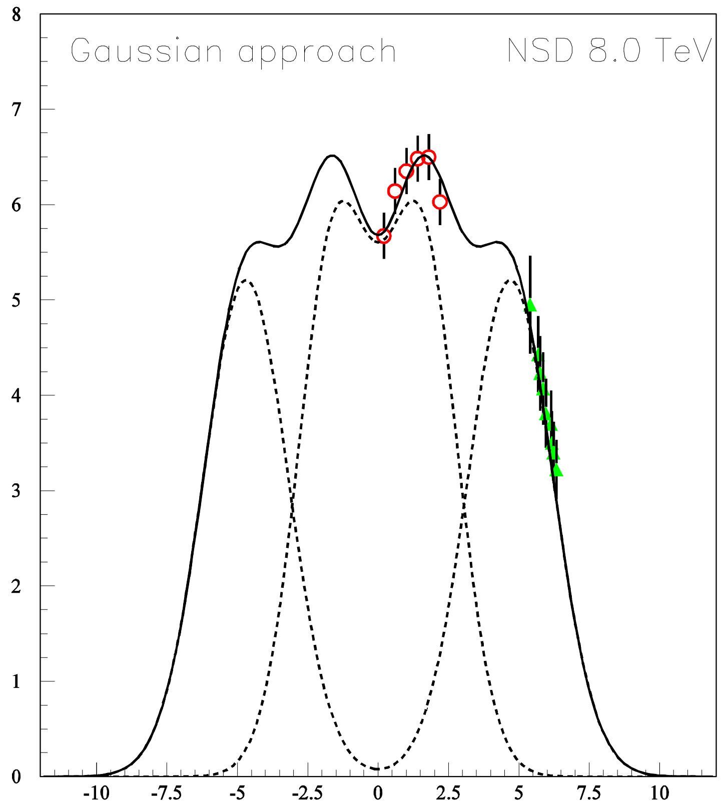
or

0.24Ln(s) +0.1 + 0.426Ln(s)-6.1 ?





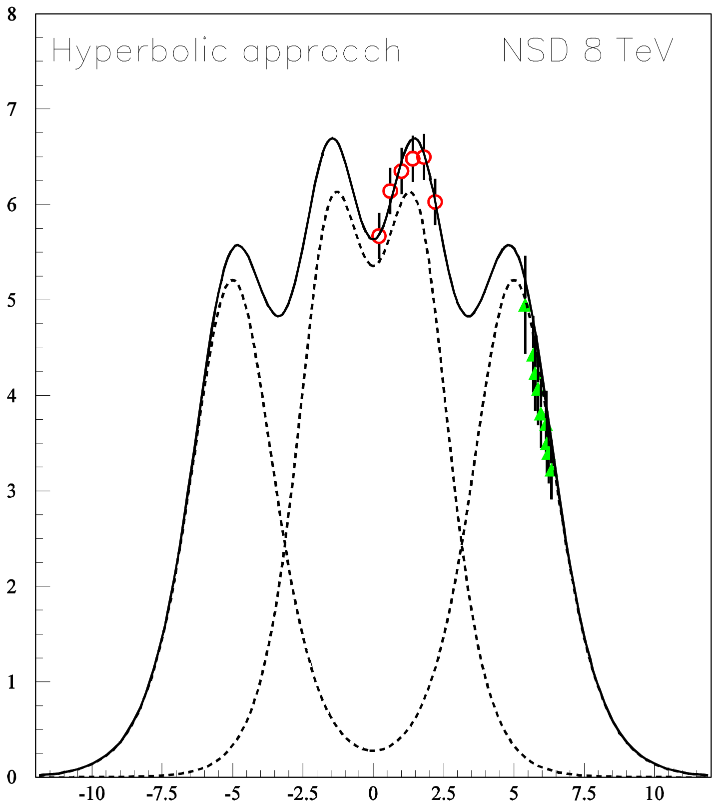
Approach with Gaussian deviates



- 4 gaussian functions
- $A_i\ \{\exp(-0.5u_i\ ) +\ \exp(-0.5v_i)\}$
- $u_i = \{(y-y_i)/\sigma_i\}^2$
- $v_i = \{(y+y_i)/\sigma_i\}^2$

A_i = 5.21, 5.6
Y_i = 4.7, 1.53
σ_I = 1.5, 1.3

Hyperbolic approach



Dependance $1/\cosh^2 y$

$A_i\{1/\cosh^2 u_i + 1/\cosh^2 v_i\}$

- $u_i = \{a_i(y-y_i)\}$

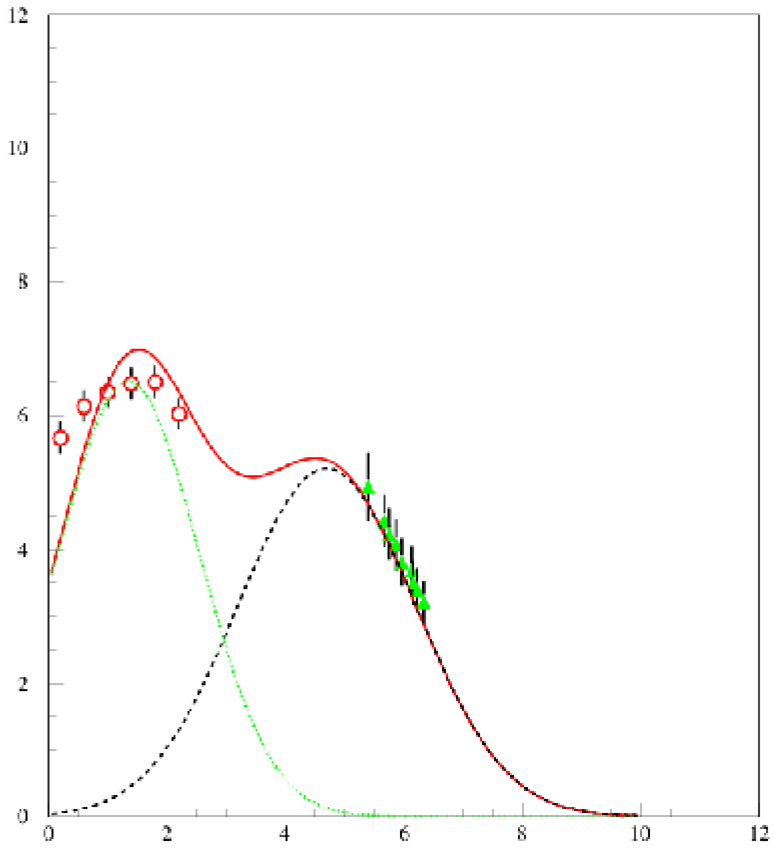
- $v_i = \{a_i(y+y_i)\}$

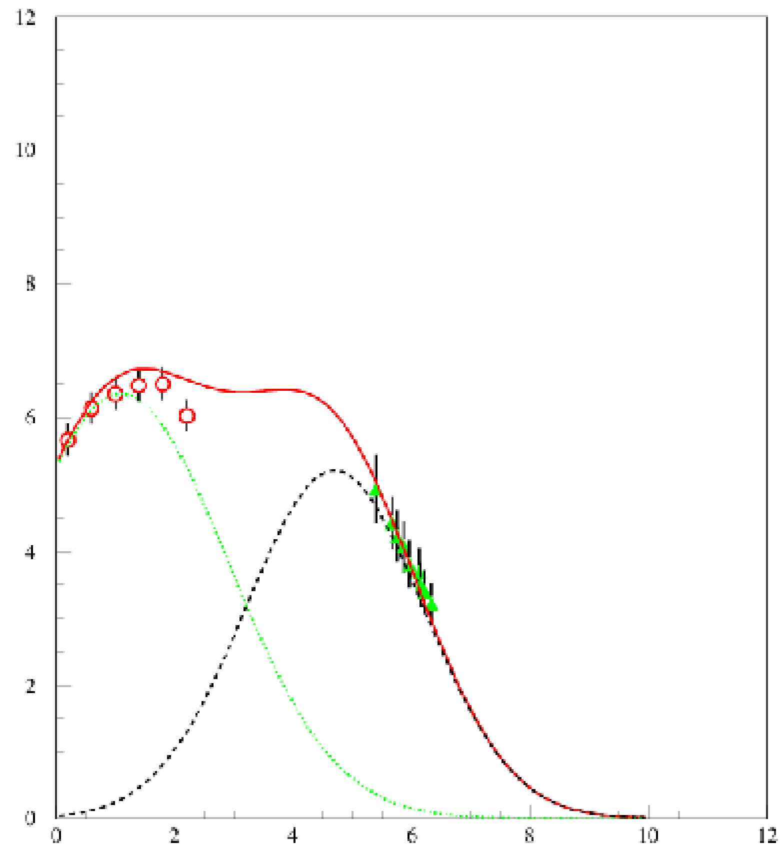
A_i = 5.21, 5.5
Y_i = 5.0, 1.5
a_I = 1.5, 1.3

Gaussian hadronic generation

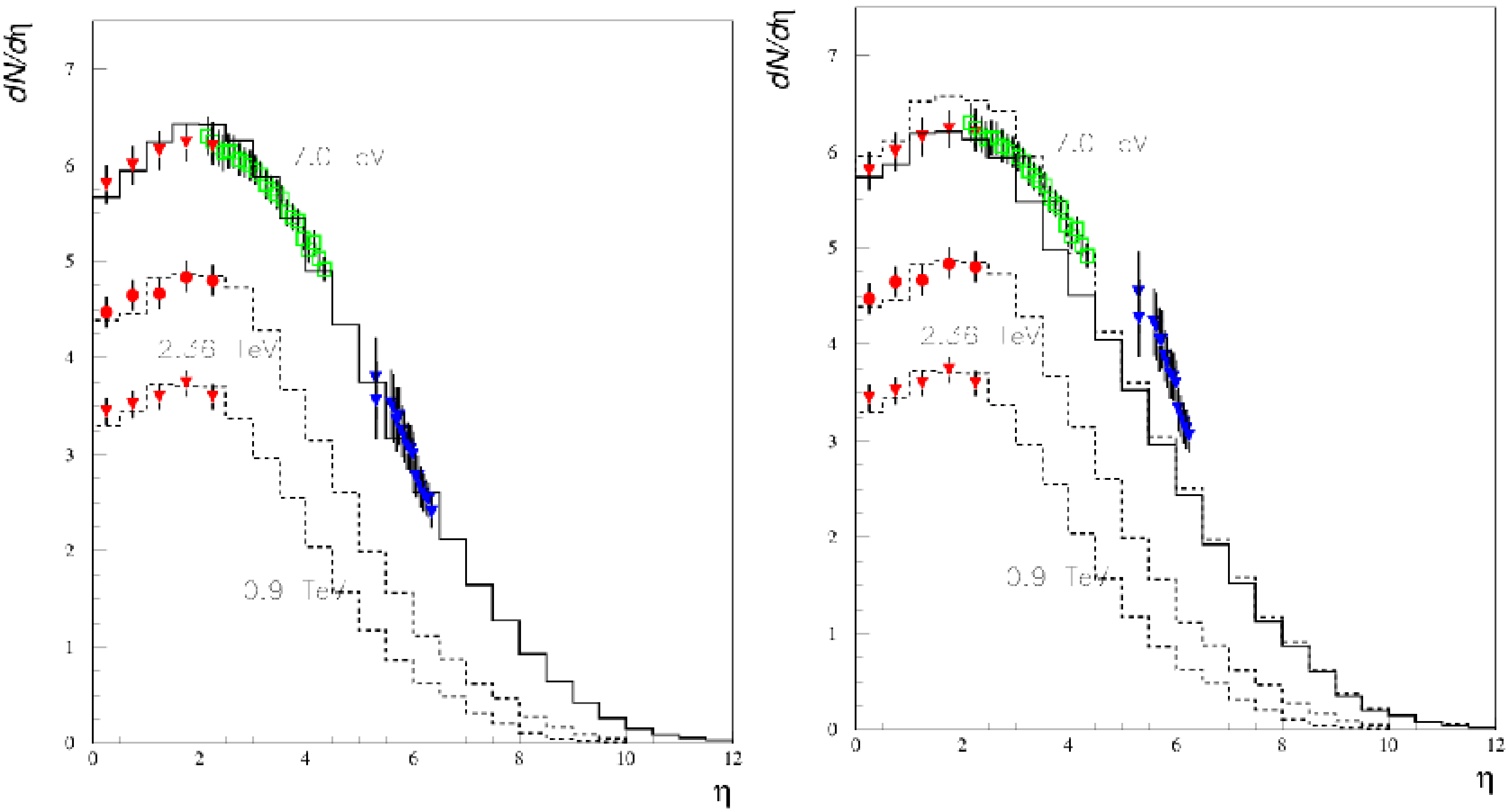
- **Multiplicity N via negative binomial function $\Psi(z)$ with KNO scaling violation (z=N/<N>)**
- **Central regularity vs z, parameters for semi-inclusive data**
- **couples (y_i, $p_{t\ i}$) via gaussian generation of rapidity and p_t**
- **Validity of the set of secondaries for a single collision, conservation laws, rejections…**
- **Treatment of SD and DD**
- **Respective cross sections for SD, DD, NSD and inelastic data**

Approach of the pseudo**rapidity** source (no more plateau of Feynman?)





Pseudo-rapidity distributions (NSD) √s = 7 TeV
left wrong (blue points Totem inelastic others NSD)
right estimated blue points NSD, all NSD



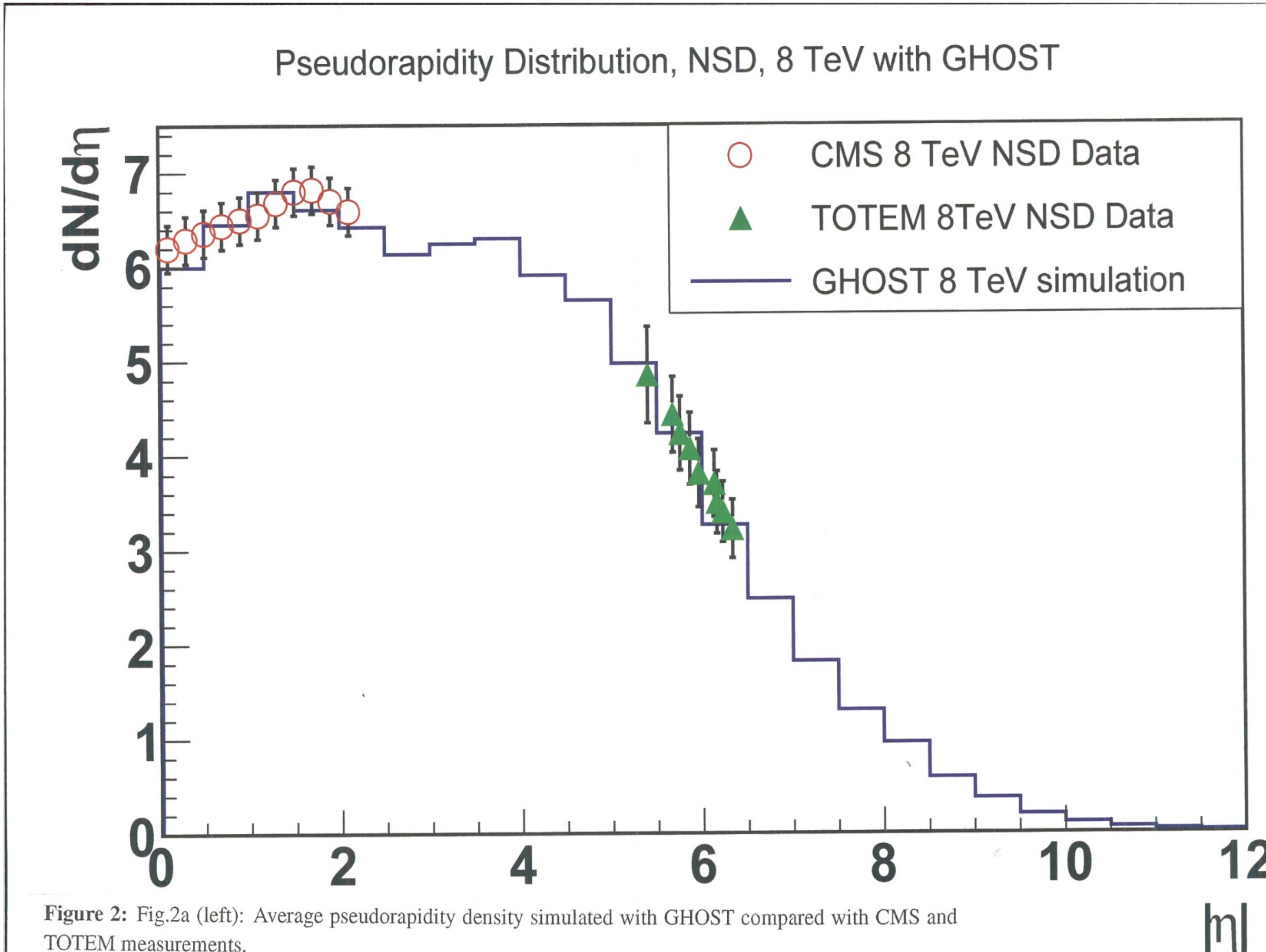
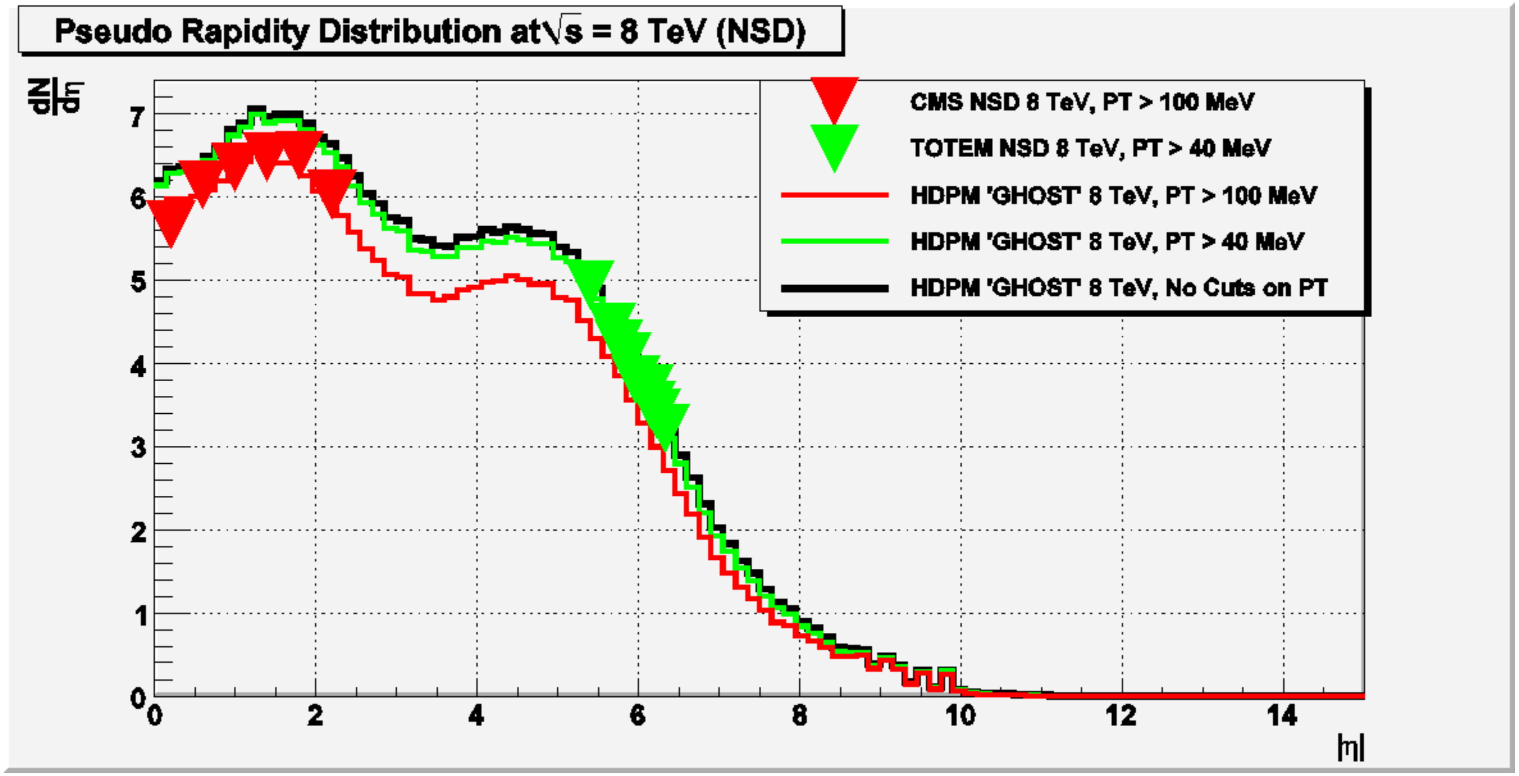


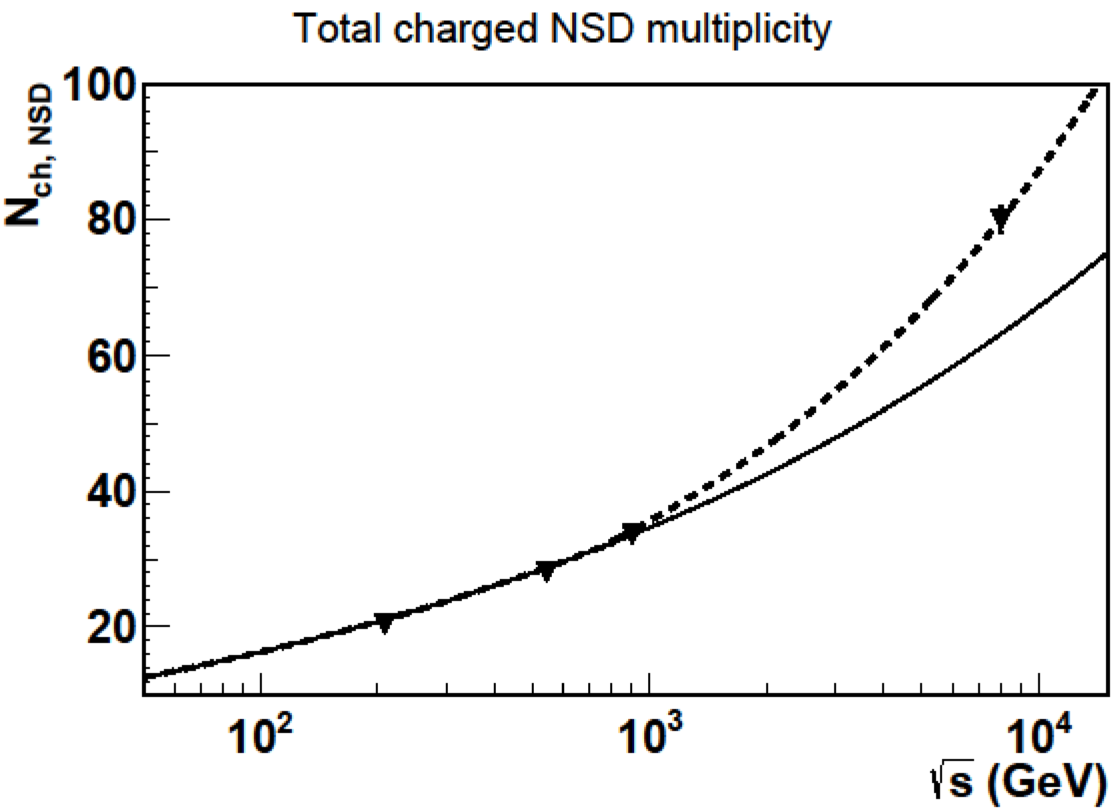
Figure 2: Fig.2a (left): Average pseudorapidity density simulated with GHOST compared with CMS and TOTEM measurements.

INTEST option of CORSIKA

(with Z. Plebaniak and J. Szabelski)



Charged NSD Multiplicity



_ch-ua5>= −7▹0 +7▹2 s^0▹127

<Nch >= −0▹74 +
›59 s^0▹191

ρ_o = 0.708

ɩ775

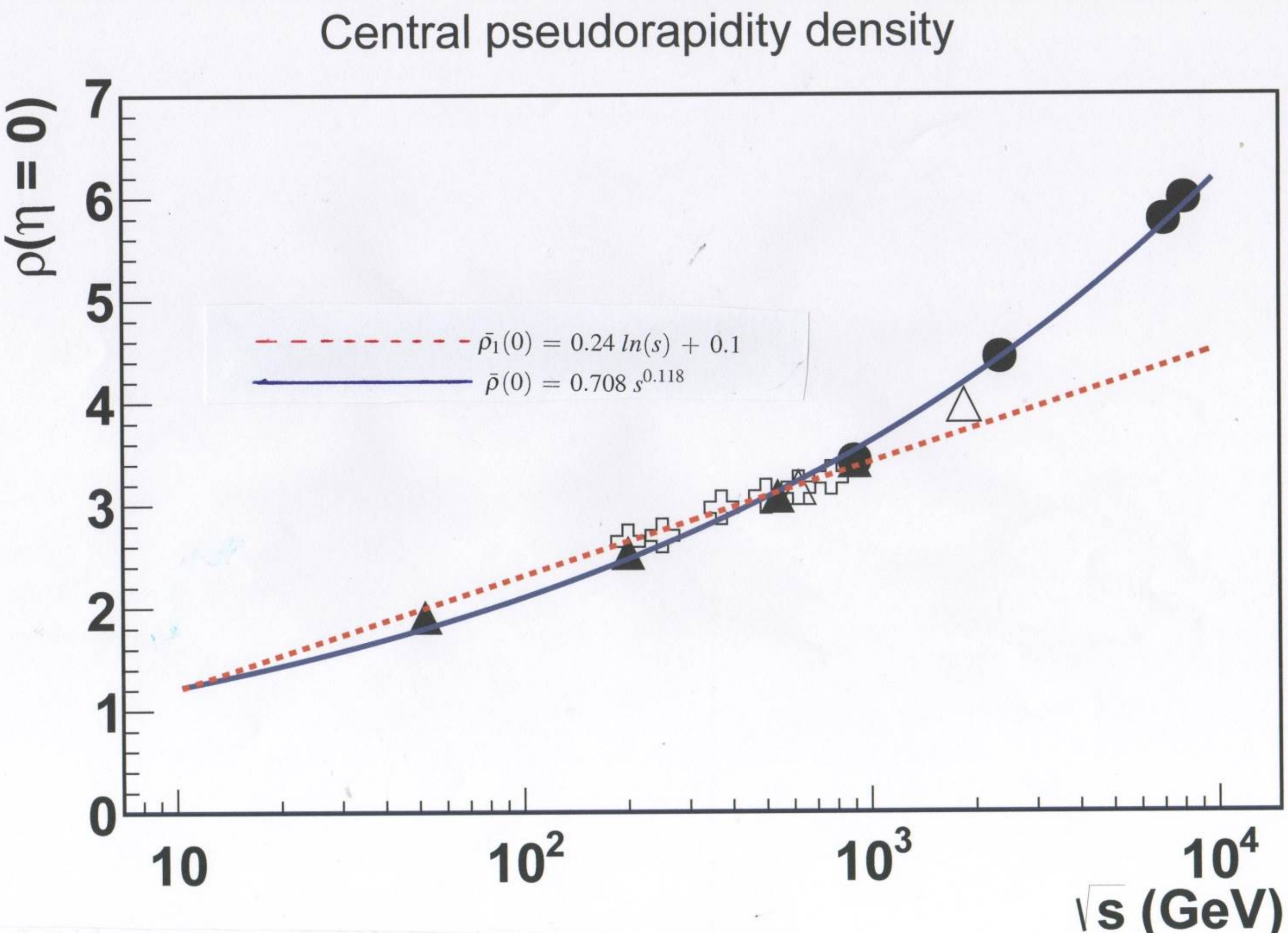


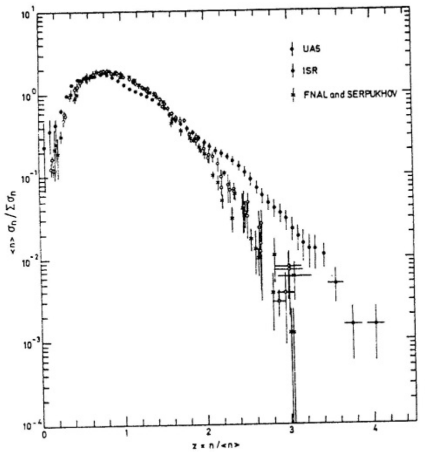
Fig.1b (right): Central pseudorapidity density dependence on s for $E_0 = 10^{13}$-10^{17} eV.

KNO scaling violation

Fluctuations of NSD total multiplicity

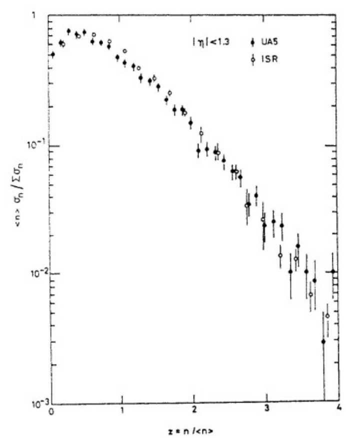
Violation between ISR (√s = 53 GeV)and UA5 (√s = 540 GeV) established in 1983

UA5, Alner et al.,Phys. Lett. B 180 (1986), 415



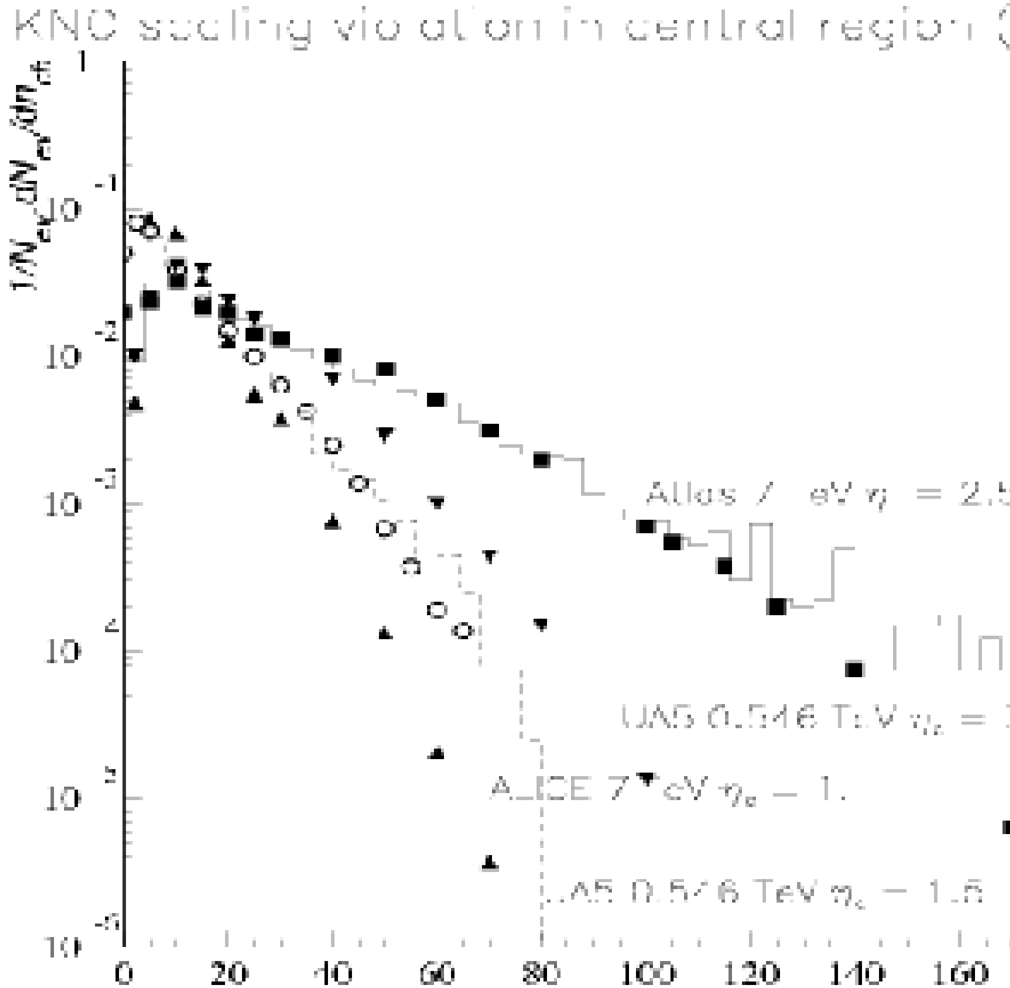
Scaling in central region √s = 53 GeV and √s = 540 GeV ?? for |η| < 1.3

UA5, Alner et al., Phys. Lett. B 138 (1984), 304



Violation of KNO scaling in central region

Comparison of GHOST results (histograms) with Alice and Atlas data at Vs = 8 teV



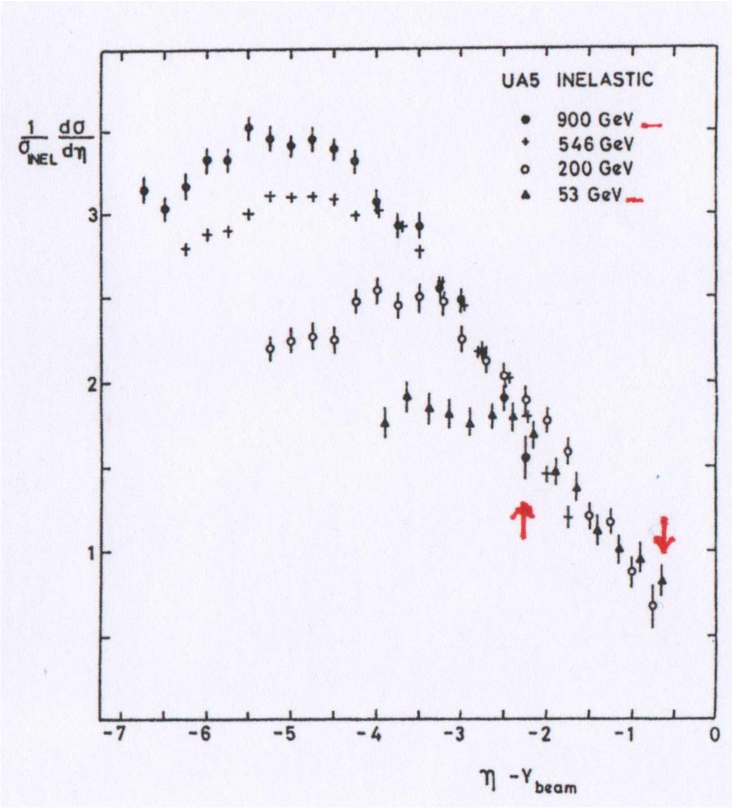
Test of scaling in fragmentation region

UA5 Inelastic pseudorapidty distribution in the beam rest frame for √s=53 (triangle), 200(circle), 546(cross), 900(dark circle) GeV far from fragmentation area

(-2.5 units)

No evidence for scaling

UA5, ZPC 33, 1986, 1



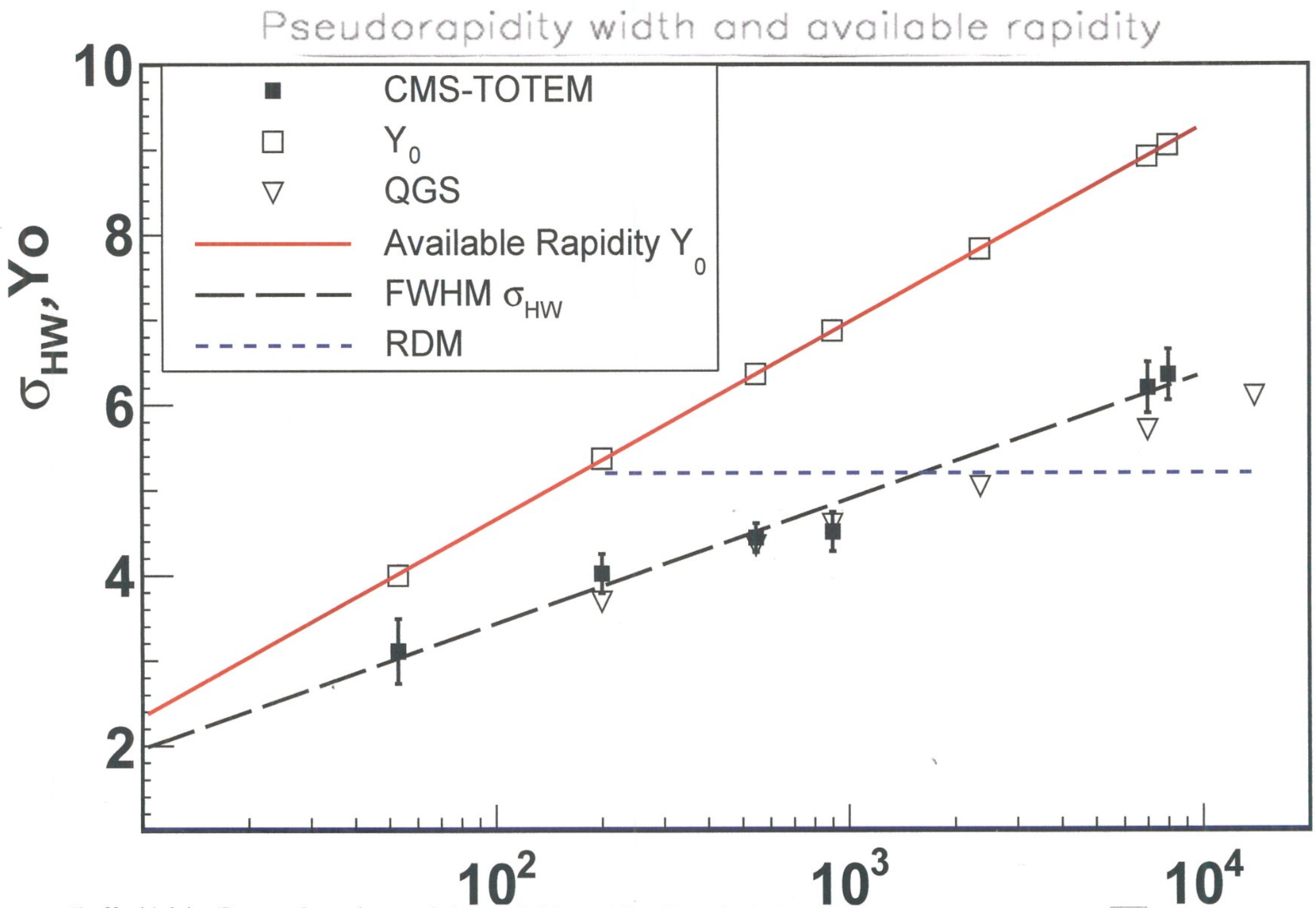


Fig.2b (right): Energy dependence of the available rapidity Y_0 and of the FWHM, σ_{HW}, respectively, open squares, solid line and dashed line from GHOST, dark squares from CMS-TOTEM, triangles from QGSJET01 model, horizontal line from the relativistic diffusion model RDM [7].

Hadron experiment in Tian SHAN

The hadron array

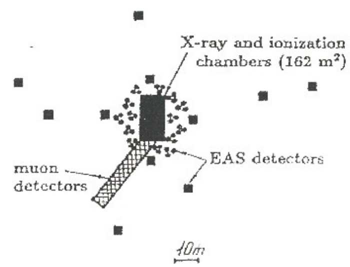


Figure 1. The HADRON array.

Energy spectra of electrons and photons

trons are divided by the number of EAS in which

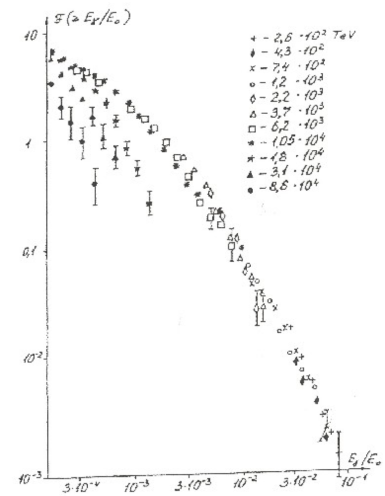
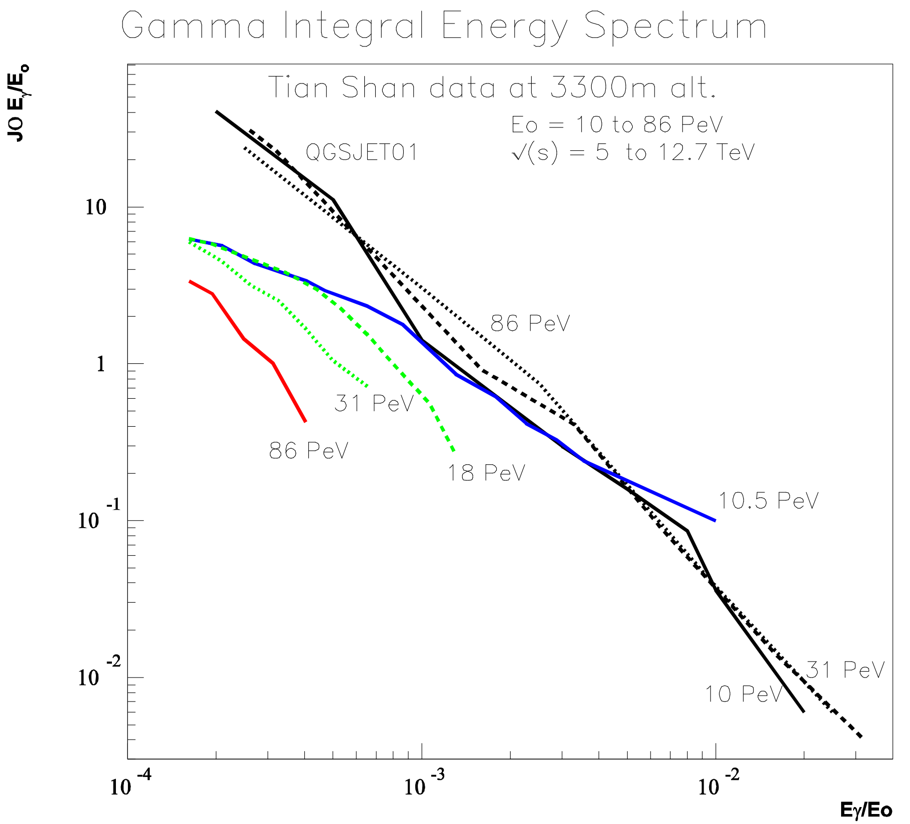
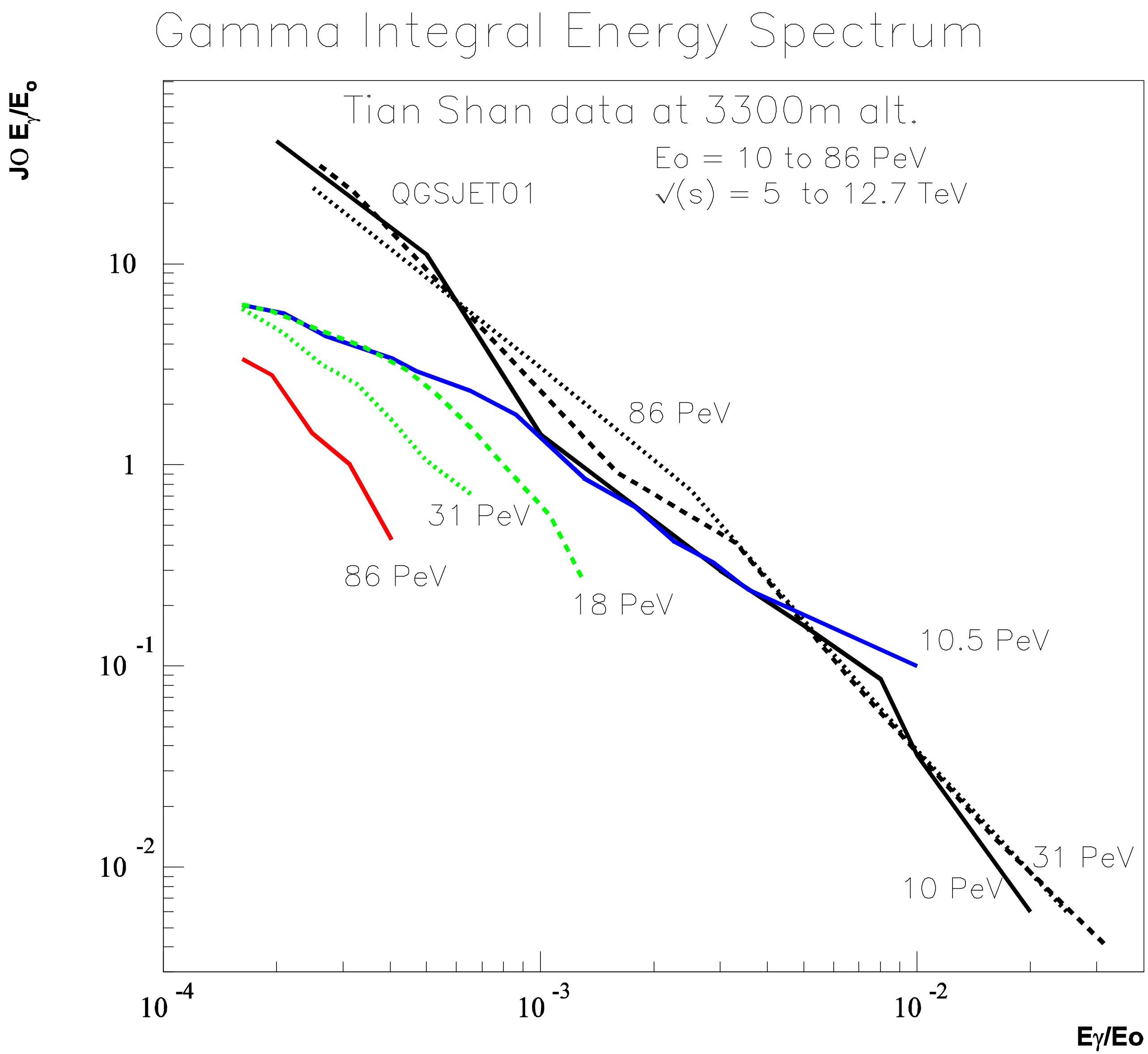


Figure 2. Energy spectra of electrons and γ-quanta in EAS cores for different energies of the primary particles.

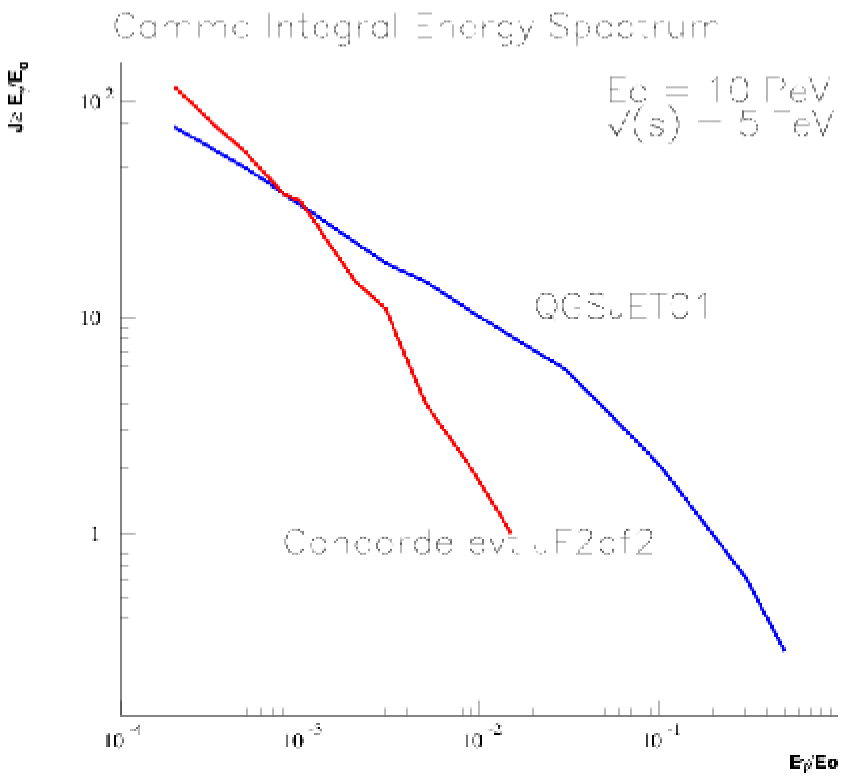
Gamma integral energy spectrum





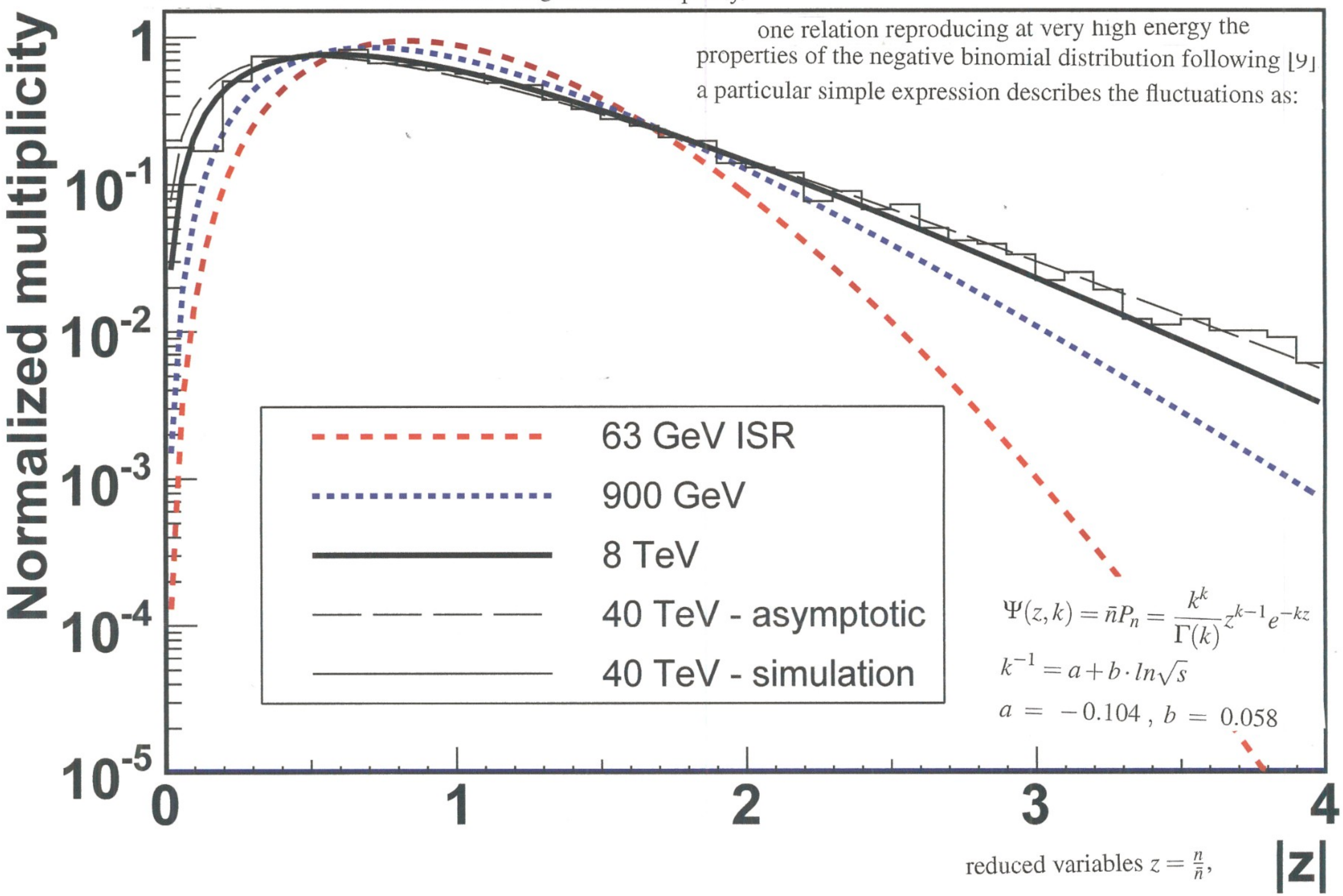
Gamma Integral Energy Spectrum
Tian Shan data at 3300m alt.
Eo = 10 to 86 PeV
√(s) = 5 to 12.7 TeV
QGSJET01
86 PeV
31 PeV
86 PeV
18 PeV
10.5 PeV
31 PeV
10 PeV
JO E$_\gamma$/E$_o$
Eγ/Eo
10
1
10^{-1}
10^{-2}
10^{-4}
10^{-3}
10^{-2}

Gamma ray family at 17 km altitude



(Violation of) KNO scaling

Figure 3: Fig.3a. Fluctuations of total charged NSD multiplicity.



Central regularity

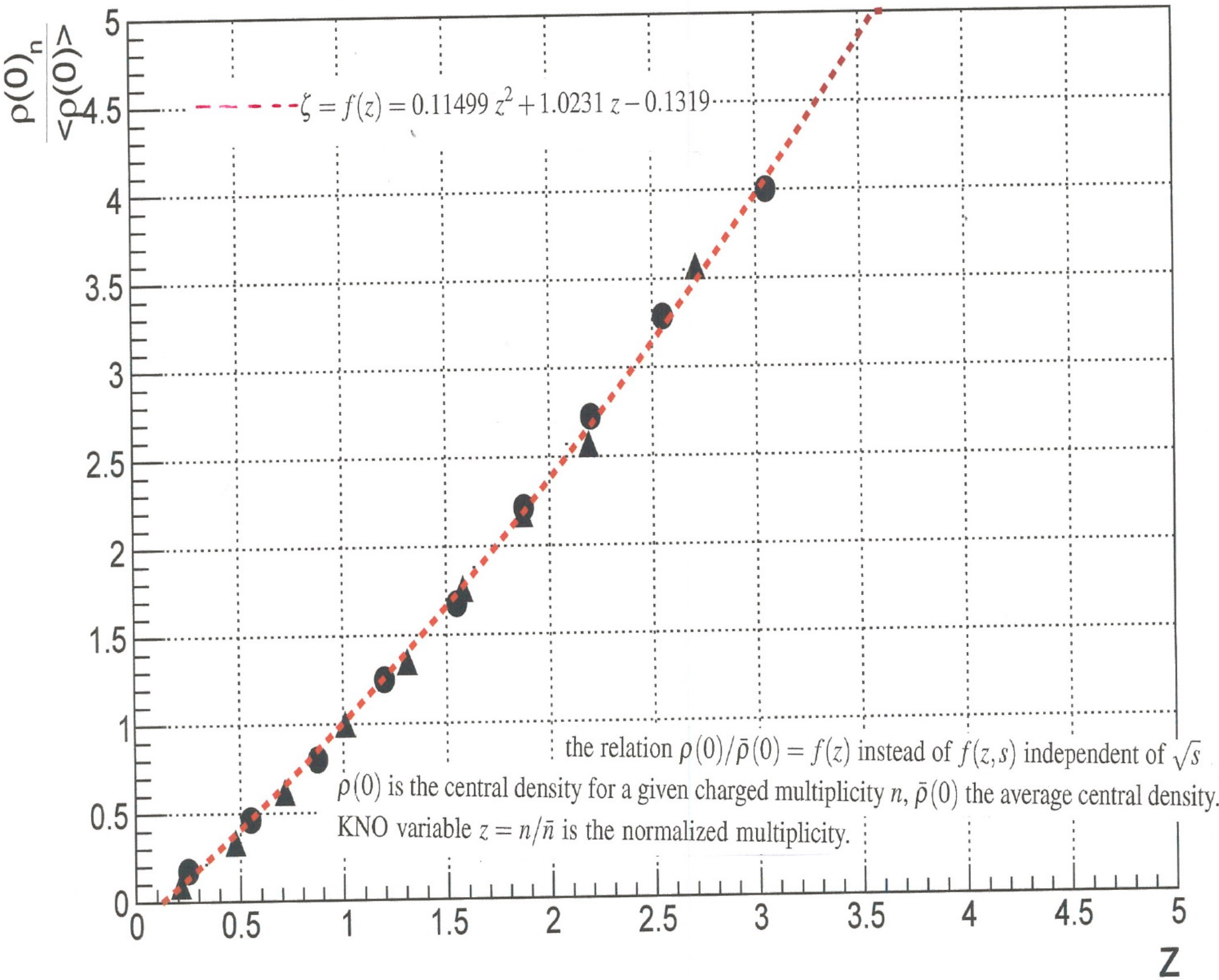


Fig.3b. Empirical scaling function $\zeta = f(z)$ for $\sqrt{s} = 200$, 546 and 900 GeV for NSD collisions.

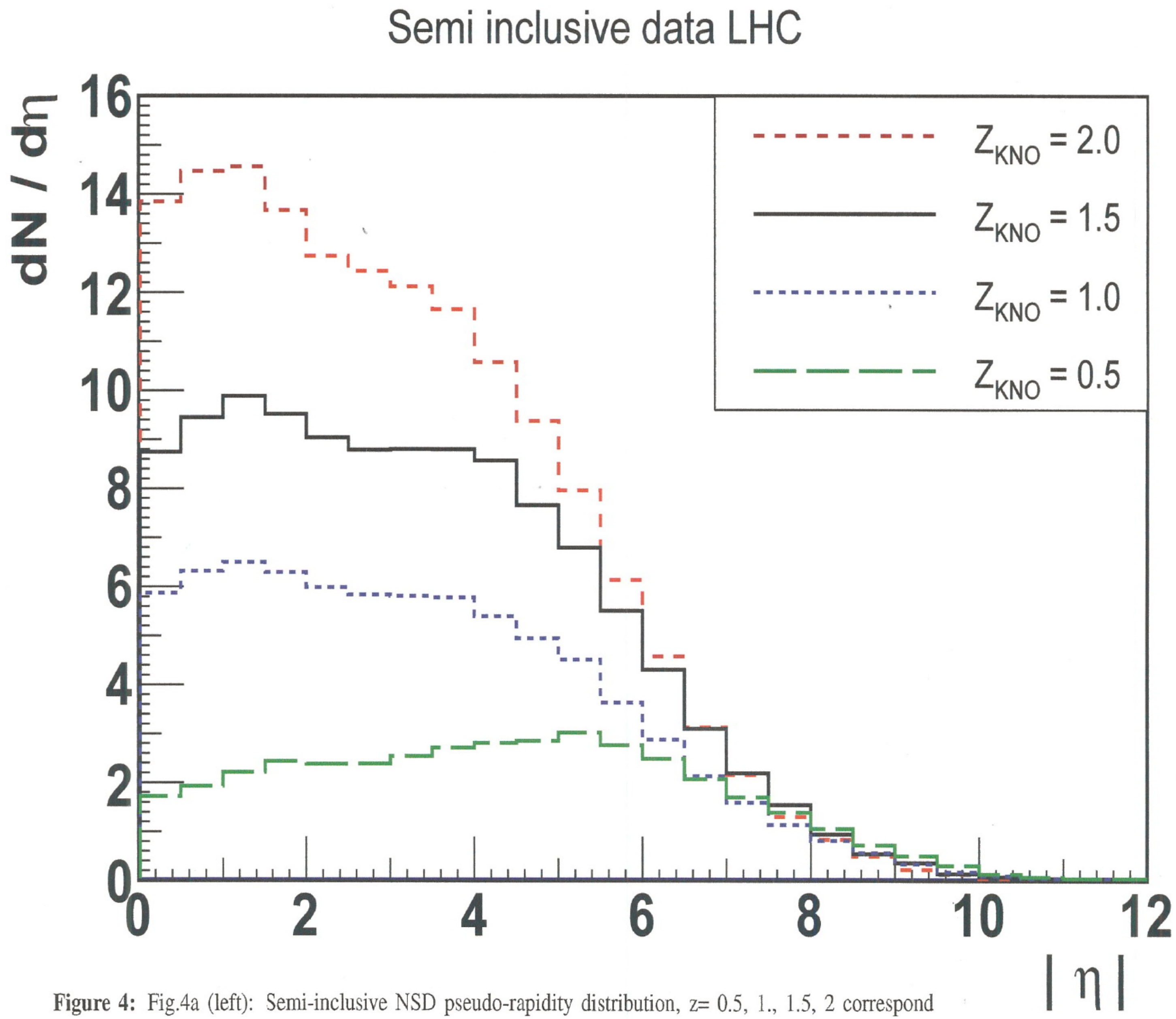


Figure 4: Fig.4a (left): Semi-inclusive NSD pseudo-rapidity distribution, z= 0.5, 1., 1.5, 2 correspond respectively to relative intervals of N_{ch} $[0.25-0.75], [0.75-1.25], [1.25-1.75], [1.75-2.25]$.

3.3 Semi-inclusive data

The semi-inclusive data is governed by the integro-differential system:

$$\frac{dN}{dy}_{y=0} = m_r \frac{dN}{d\eta}_{\eta=0} = m_r \, \zeta \, \bar{\rho}(0) \tag{3.3}$$

$$\int \frac{dN}{dy} dy = z < n > \tag{3.4}$$

m_r is the ratio of central mean rapidity density and mean central pseudo rapidity density derived from the "dip" existing in the centre of the pseudorapidity distribution, resulting from the mass m and the transverse mass m_T of the secondaries as $m_r = \sqrt{1 - \frac{m^2}{m_T^2}}$. In the case of the 4 gaussian generation (one pair of functions in each hemisphere, symmetrics around the center of mass,

$$\frac{dN}{dy} = \sum_{i=1}^{i=2} a_i (e^{-0.5 u_i} + e^{-0.5 v_i}) \tag{3.5}$$

$$u_i = (\frac{(y - y_i)}{\sigma_i})^2, \; v_i = (\frac{(y + y_i)}{\sigma_i})^2$$

it is possible to use the opportunity of the scaling $3-2$ in the relation between the center y_i and the width σ_i of each gaussian function as

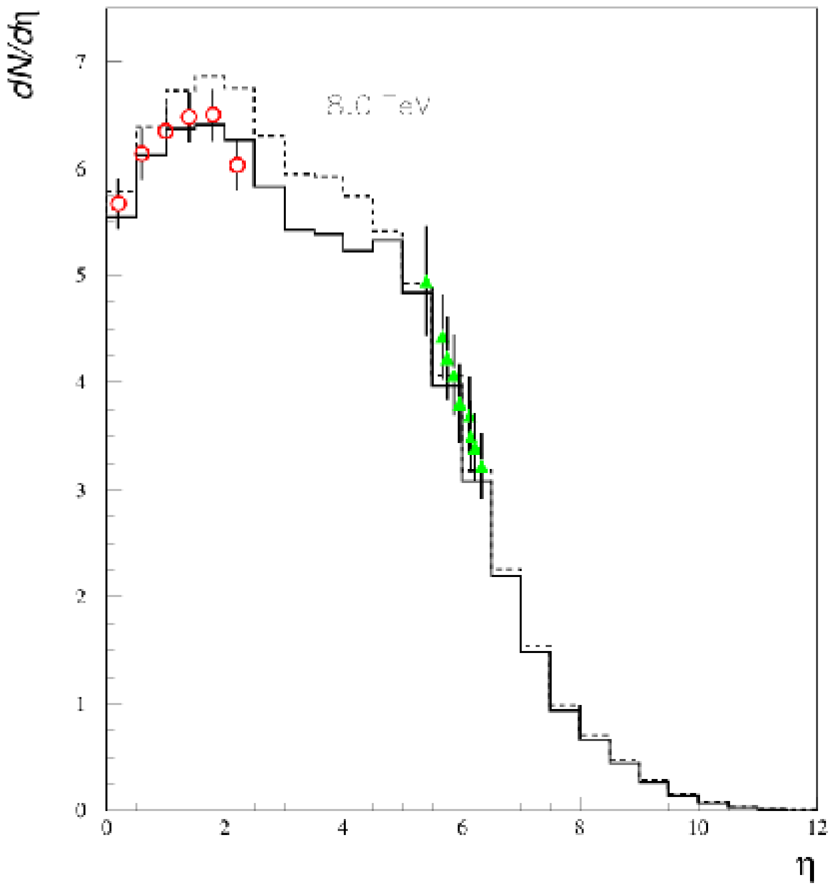
$$y_i = \sigma_i \; (2 ln(\frac{z < n >}{\sqrt{(2\pi)} \; \zeta \; \sigma_i}))^{0.5} \tag{3.6}$$

After introducing one proportion χ of the multiplicity distributed to the pair of gaussian centered in central region and in mid-rapidity region, it is possible to obtain with a minimal Monte Carlo generation of random deviates the total original rapidity distribution source of the distribution of

INELASTIC pseudo-rapidity distribution $\sqrt{s}$ **= 8 TeV**

(… all secondaries, corrected for Pt<100 MeV red CMS Pt<40 MeV TOTEM) balance g1 52% N, g2 48% N

$\mathbf{y_1 = 1.28\ \sigma_1 = 1.22 \quad y_2 = 4.4\ ,\ \sigma_2 = 1.4}$



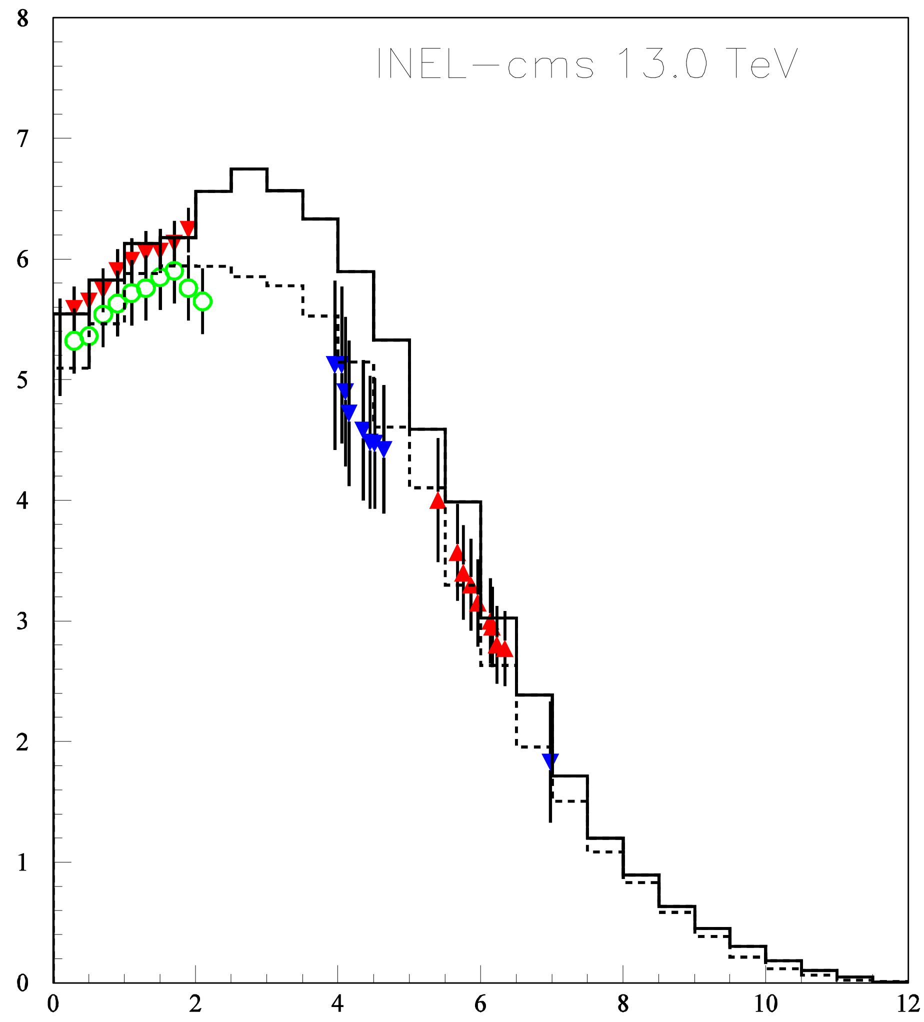
Inelastic pseudorapidity

CMS and Totem data.

Calculation with the generator GHOST

at $\sqrt{s}$ = 8 TeV and

$\sqrt{s}$ = 13 TeV.



Conclusion

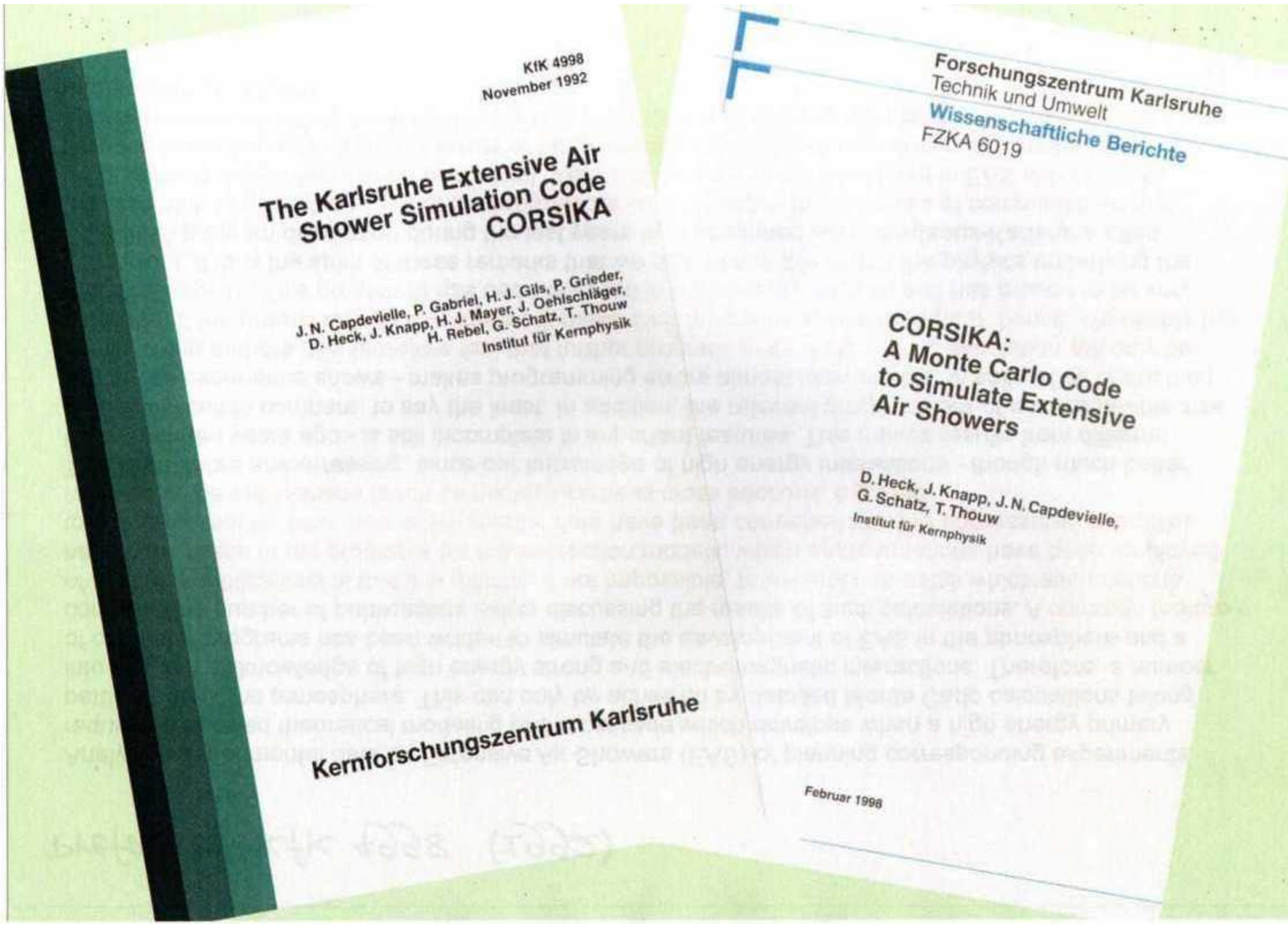
- **The multi-source Generator GHOST (in continuity of HDPM) can reproduce the inclusive data and also the semi-inclusive data with larger control (needed in the case of the semi-inclusive data).**

- **The guidelines derived from LHC data at Vs = 8, 13 TeV allow better simulations and extrapolations up to 100TeV.**

- **Attempts are proceeded to insert GHOST in CORSIKA.**

One interrogation for the future

- Delegate of the Ministery of research on 2000-2006, I had obtained the gift of Brussels, first step of our installation in Argentina with Germany, England, Russia
- An important simulation is in progress now for the AUGER results at energies larger than the earlier GZK consideration.
- Above 10**20 eV with rare events, it is time to use the AUGER area for new works in relation with the gravitationnal waves of U.S.A.(Ligo-Livingston) and Europe(Virgo-Italy,France..)


KfK 4998
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The Karlsruhe Extensive Air Shower Simulation Code CORSIKA
J. N. Capdevielle, P. Gabriel, H. J. Gils, P. Grieder, D. Heck, J. Knapp, H. J. Mayer, J. Oehlschläger, H. Rebel, G. Schatz, T. Thouw
Institut für Kernphysik
Kernforschungszentrum Karlsruhe
Forschungszentrum Karlsruhe
Technik und Umwelt
Wissenschaftliche Berichte
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