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HERA, LHC and Cosmic Rays

Armen Bunyatyan

- Introduction
- Forward particles at HERA and impact for CR interaction models
- LHC and cosmic ray models

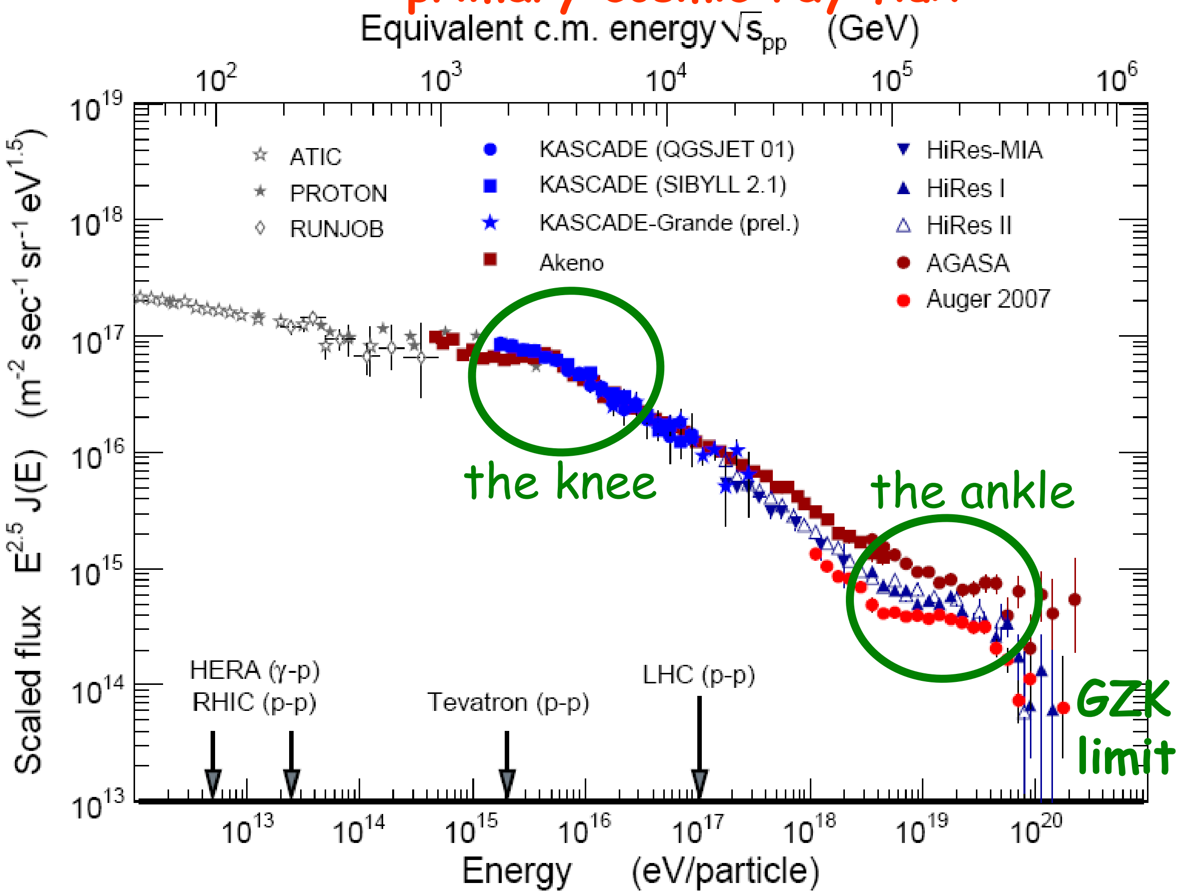
A central questions of astroparticle physics – source and propagation of cosmic rays.
Knowing the cosmic ray composition is the key for understanding the CR puzzles,
(as the Knee and the Ankle)

Above 10^{14} eV, primary cosmic rays particles are detected via air showers- determination of their energy and mass relies on the modeling of hadronic interactions.

Significant differences between the model predictions for particle multiplicities, energy flow etc.

➔ need measurements from accelerator experiments to tune the models !

primary cosmic ray flux



Introduction

Considering the underlying theory entering the models, almost all measurements at colliders are relevant for understanding of very high energy cosmic ray interactions.

- parton densities, low-x dynamics and saturation, jets, transition between hard and soft regimes, heavy flavour production, forward hadron production,… are important for the basic structure of the models

Shower development dominated by forward, soft interactions. Forward measurements are of the greatest importance for shower development

The key measurements are :
-total cross section,
-multiplicity,
-forward particle (baryons, π^0) spectra;
x_L=E/E $_{p\text{-beam}}$ (~ elasticity variable =Emax/Etot used by CR)
-antibaryon production,
-…

Good cooperation of Particle physics and Cosmic Ray physicists !

A session dedicated during HERA-LHC workshop, stimulating discussions, 60 pages contribution to proceedings (DESY-PROC-2009-02) .

Chapter 5

Working Group
Cosmic Rays, HERA and the LHC

Convenors:

C. Diaconu (DESY and CPPM, Marseille),
Ch. Kiesling (MPI Munich)
T. Pierog (FZ Karlsruhe)

Introduction

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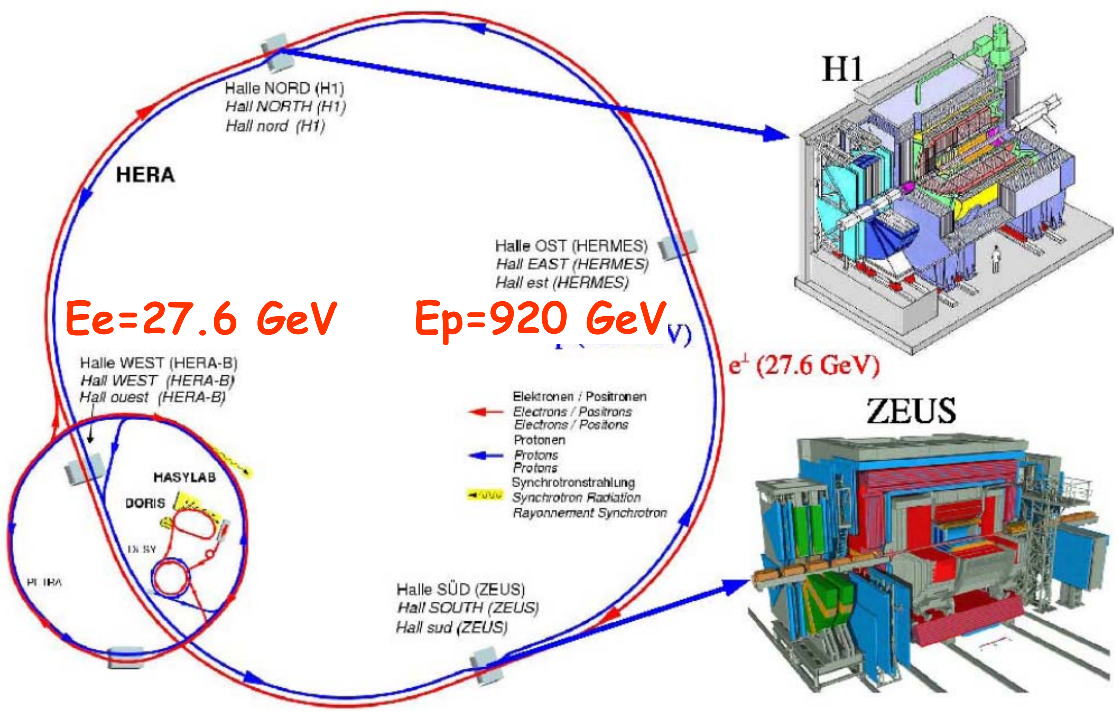
Abstract

When particle physic started, cosmic ray were used as source of new particles. Nowadays particle physic is a fundamental key to understand the nature of the very high energy cosmic rays. Above 10^{14} eV, primary cosmic rays are detected via air showers whose development strongly rely on the physic of the forward region of hadronic interactions as tested in the HERA and LHC experiments. After an introduction on air shower phenomenology, we will review how HERA and LHC can constrain the physic used both in hadronic interaction model, or for photon or neutrino primaries.

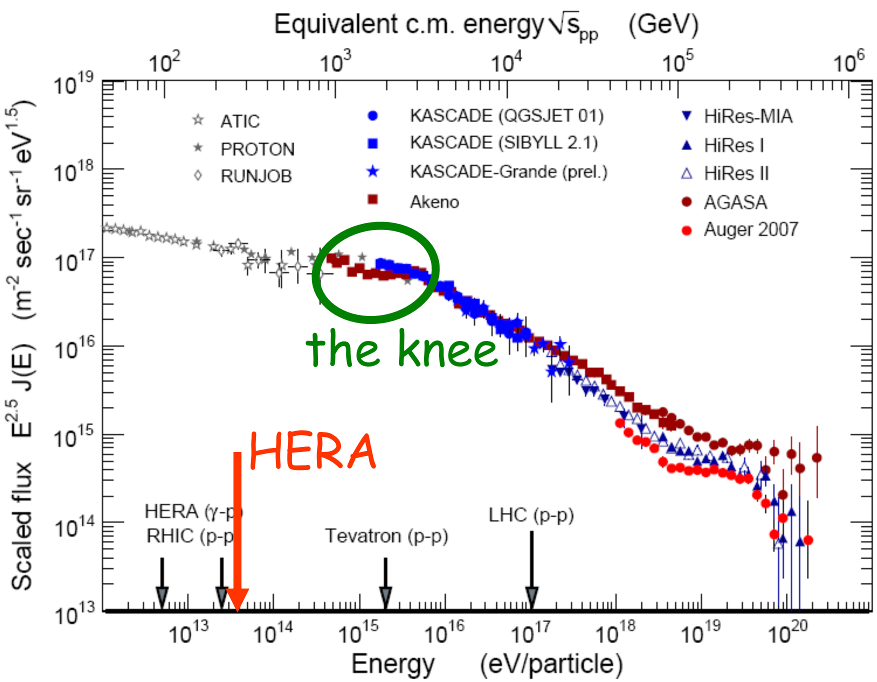
1 Physics questions and problems



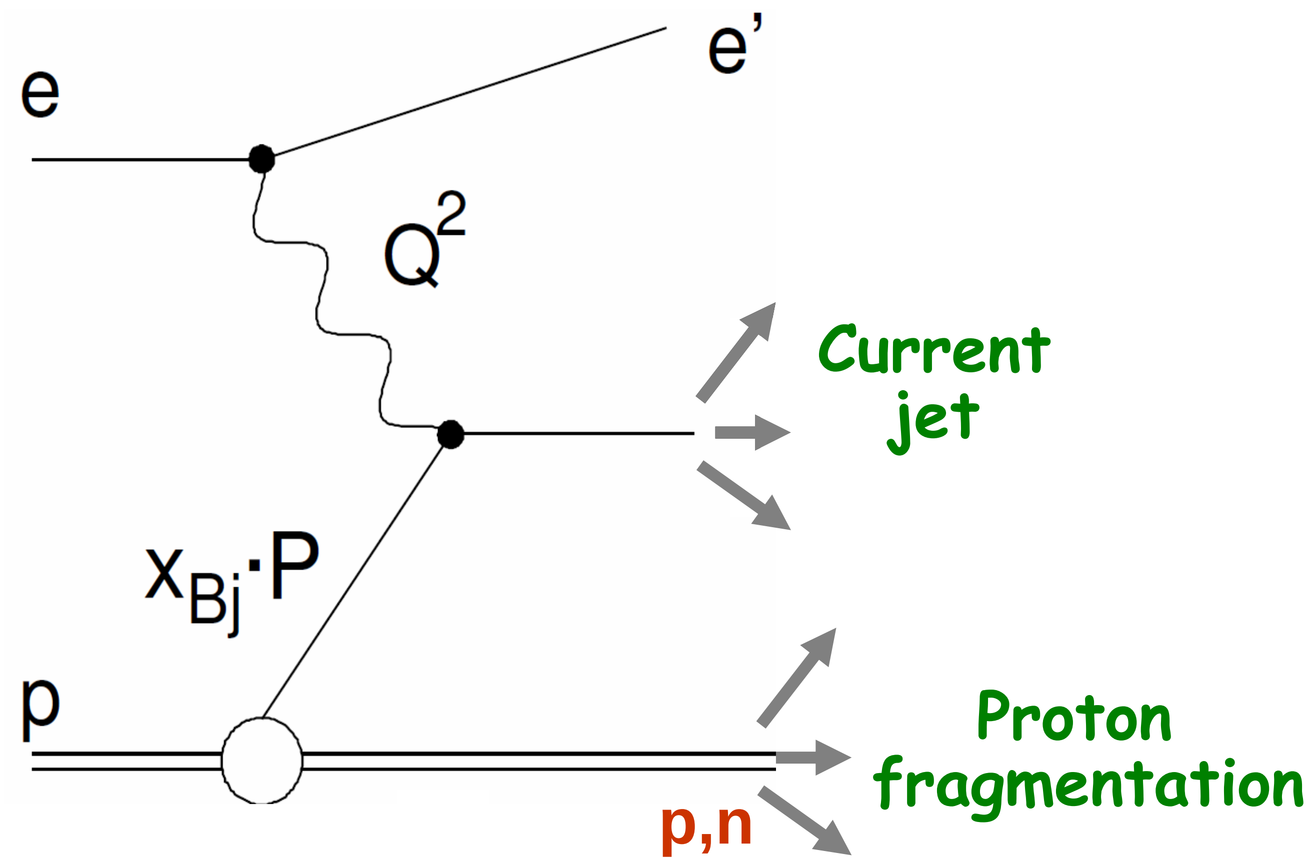
HERA- the QCD machine
(1992-2007)

➔ equivalent to 5·10^{13}ev photon beam on a stationary proton target

H1+ZEUS: extensive and precision studies of different aspects of QCD, Heavy Flavours production, Physics Beyond the Standard Model, Diffraction,...



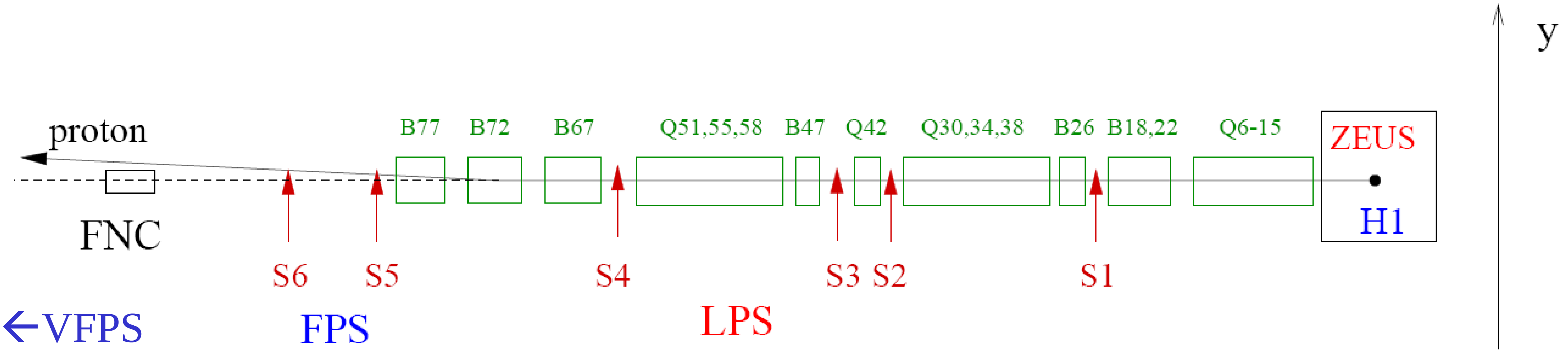
Forward baryons at HERA



ep collisions - a clean environment to study the proton fragmentation

Significant fraction of *ep* scattering events contains in the final state a leading proton or neutron which carry a substantial portion of the energy of the incoming proton: $e+p \rightarrow e'+n+X$ or $e'+p+X$

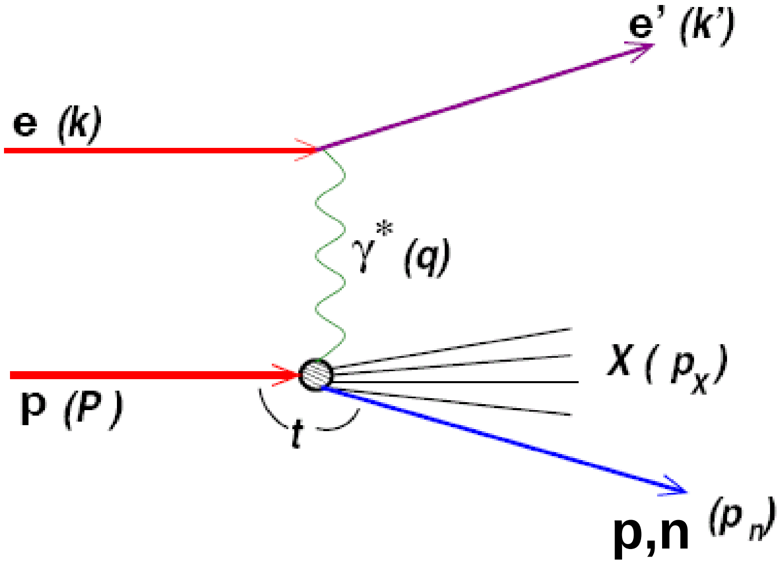
Forward detectors at HERA

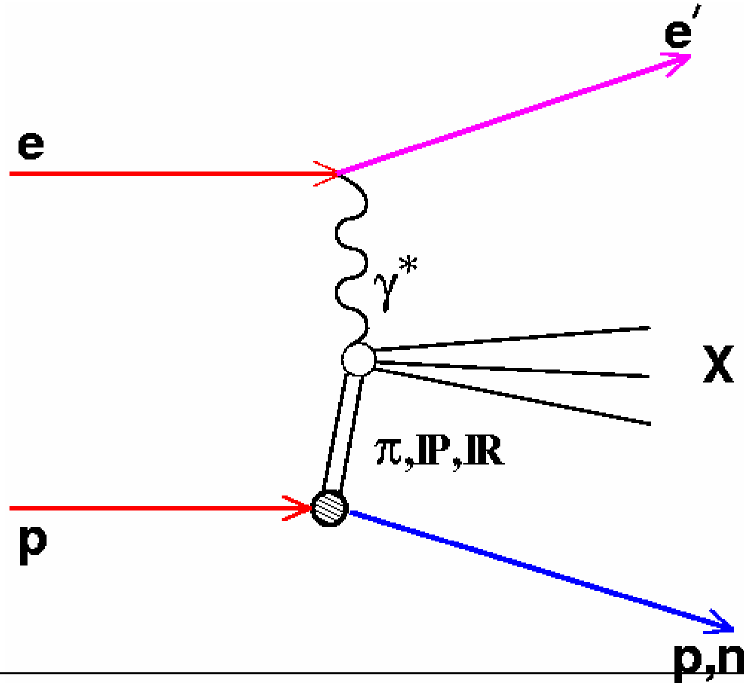


- **FPS/VFPS (H1); LPS (ZEUS) – forward proton spectrometers (Roman Pots) , at z=24…220m from interaction point; measure scattered protons with x_L=E/Ep = ~0.3÷0.9 (vertical pots), ~0.85÷1 (horizontal pots)**

- **FNC – forward neutron calorimeters- 105m from interaction point. Neutral particles (neutrons, photons) scattered at angle <0.8mrad are within the FNC acceptance**

Leading forward particles are produced at a very small angles from the fragmentation of proton remnant or from the exchange mechanism (Pomeron, Reggeon, $\pi+,\pi^0,\rho,\ldots$)





Leading baryon variables:

$x_L = E_{LB}/E_p$

$t = (p - p_{LB})^2$

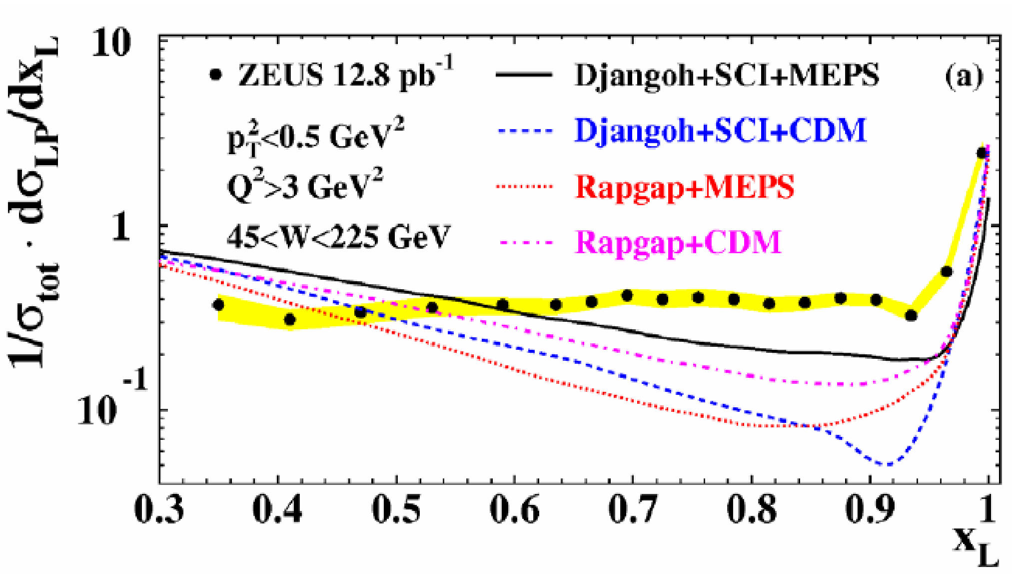
$$\sigma(ep \rightarrow e'NX) = f_{\pi/p}(x_L, t) \times \sigma(e\pi \rightarrow e'X)$$

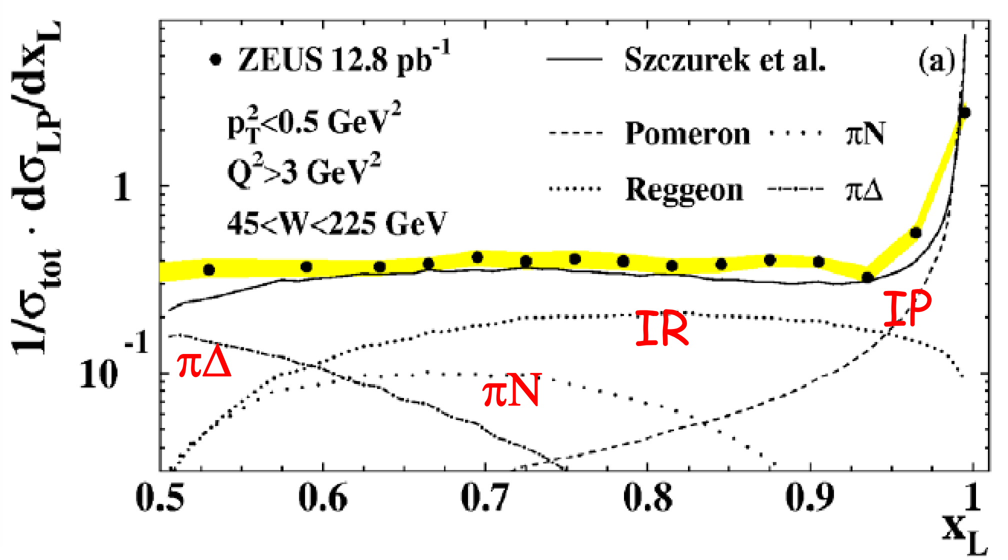
pion flux

cross section of $e\pi$ scattering

Many results are presented by H1 and ZEUS Collaborations on forward neutron and proton production in DIS, photoproduction, events containing jets or charm in the final state.

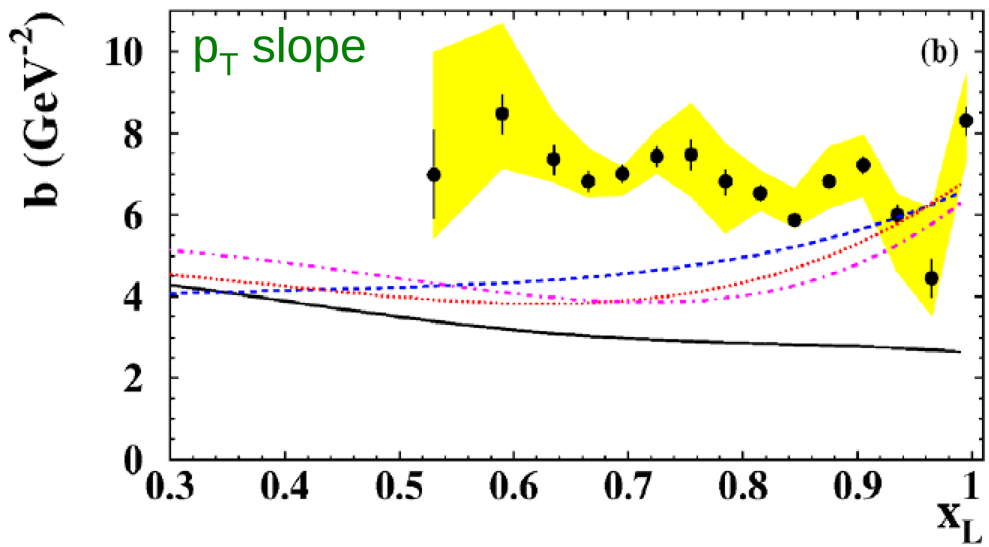
(more details about in my talk at this conference)





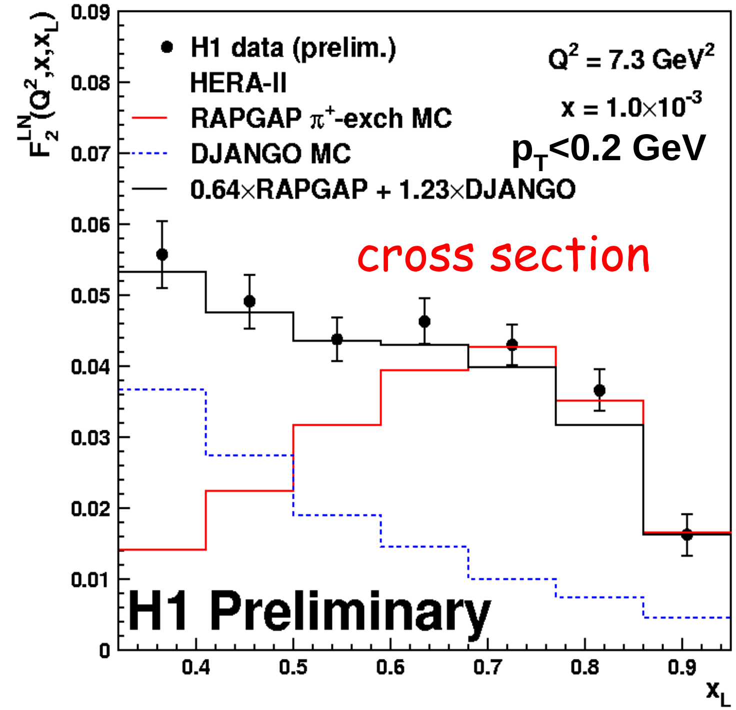
What did we learn from forward baryons at HERA ?

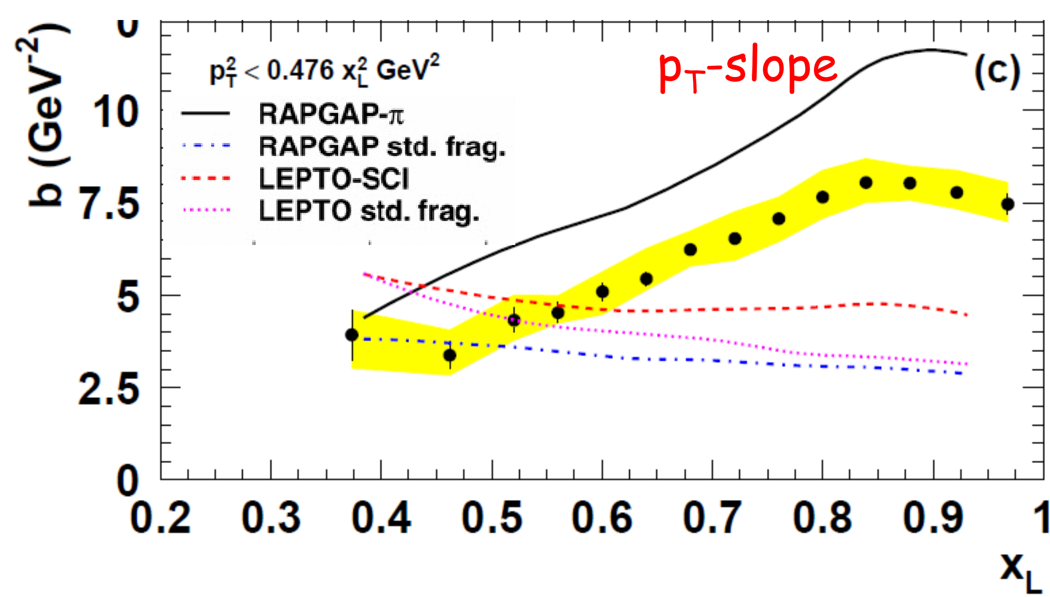
- standard fragmentation MC models don't describe the data out of the diffractive peak
- good description by exchange model



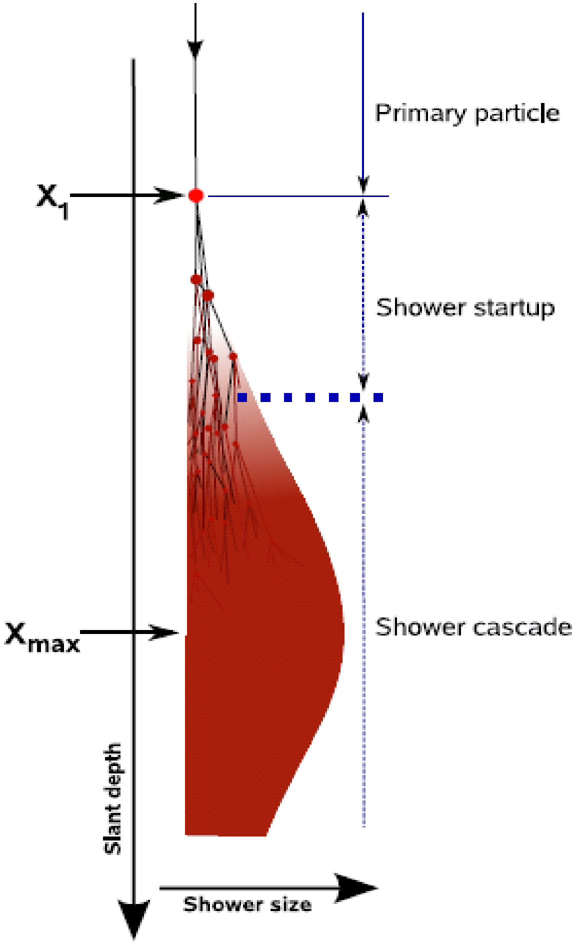
What did we learn from forward baryons at HERA ?

- the standard fragmentation models underestimate the neutron yield at high x_L
- RAPGAP-π-**exchange** describes data well for x_L>0.6, underestimate data at lower x_L
- Mixture of RAPGAP-π-exchange and std. fragmentation (e.g. DJANGO-CDM) gives the best description of the data
- Absorption/rescattering: important ingredient to interpret the results in terms of particle exchange





Hadronic interaction models for Cosmic Rays



The Earth's atmosphere acts as a giant calorimeter for high energy CR particle. Experiments can measure only the products of hadronic shower.

The hadronic interaction models needed to estimate the primary energy of cosmic ray.

In accelerators the incoming particle energy is known.
If the hadron production in the proton fragmentation region is ~independent of the type of interacting particle, e.g. of the photon virtuality Q^2 for ep scattering, then the models can make predictions for the accelerator energies, which can be compared to the measurements.

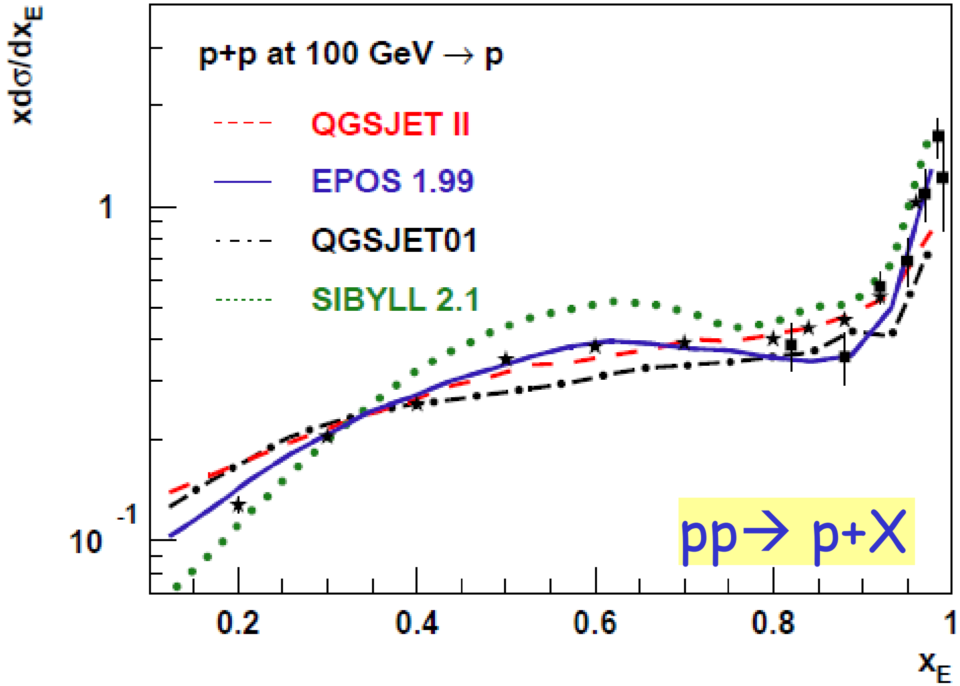
High-energy models: (R.Engel, HERA-LHC workshop)

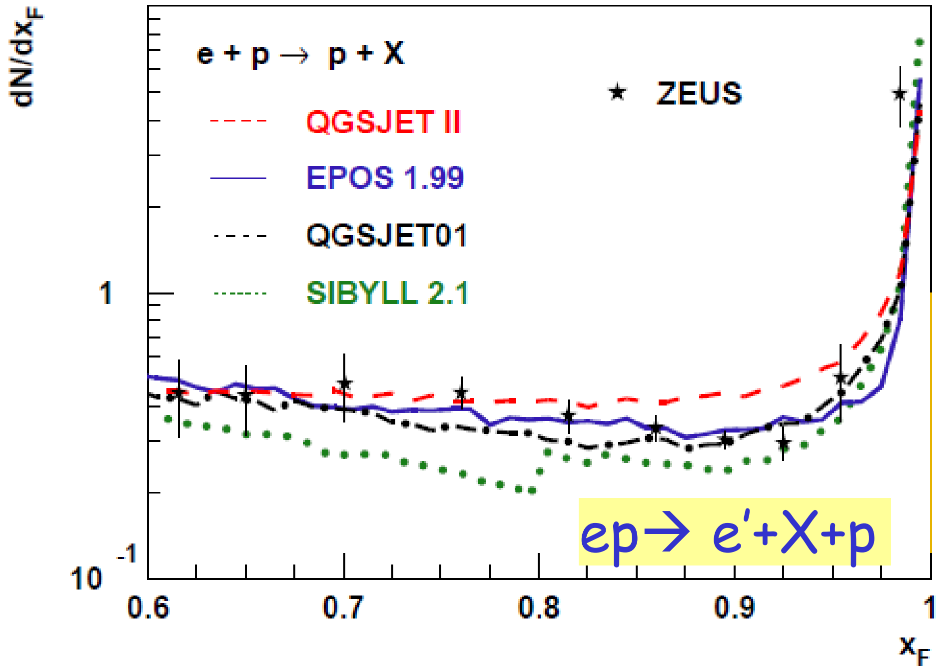
- DPMJET II.5 and III *(Ranft / Roesler, Engel , Ranft)*
- neXus 2 and 3 *(Drescher, Hladik, Ostapchenko, Pierog, Werner)*
- EPOS 1.6, 1.9 *(Pierog, Werner)*
- QGSJET 01 and II (*Kalmykov, Ostapchenko)*
- SIBYLL 2.1 *(Engel, Fletcher, Gaisser, Lipari, Stanev)*

Forward particle spectra vs models for cosmic rays

elasticity distributions:

(T.Pierog,R.Engel)



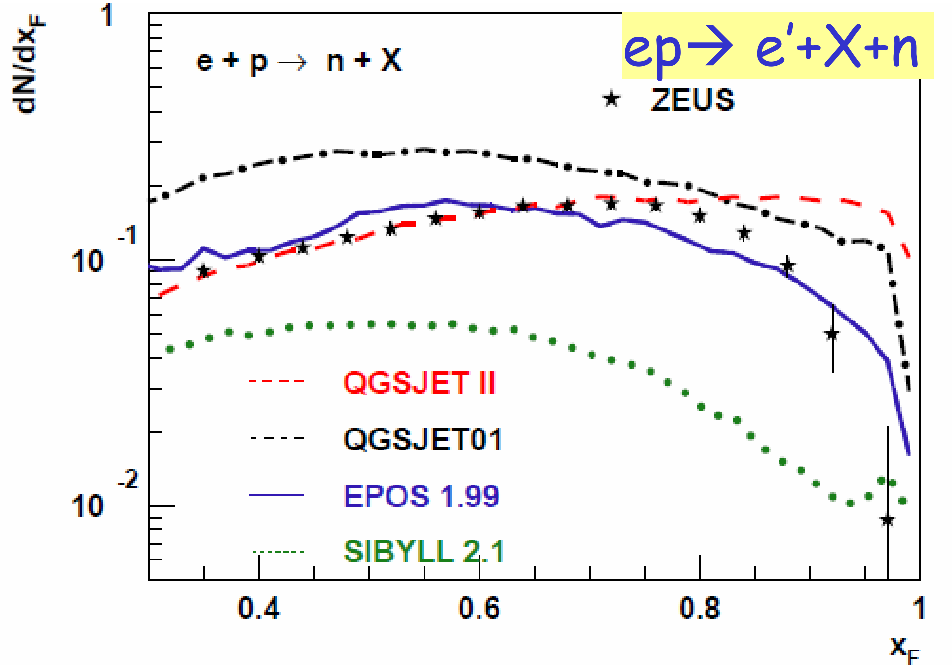


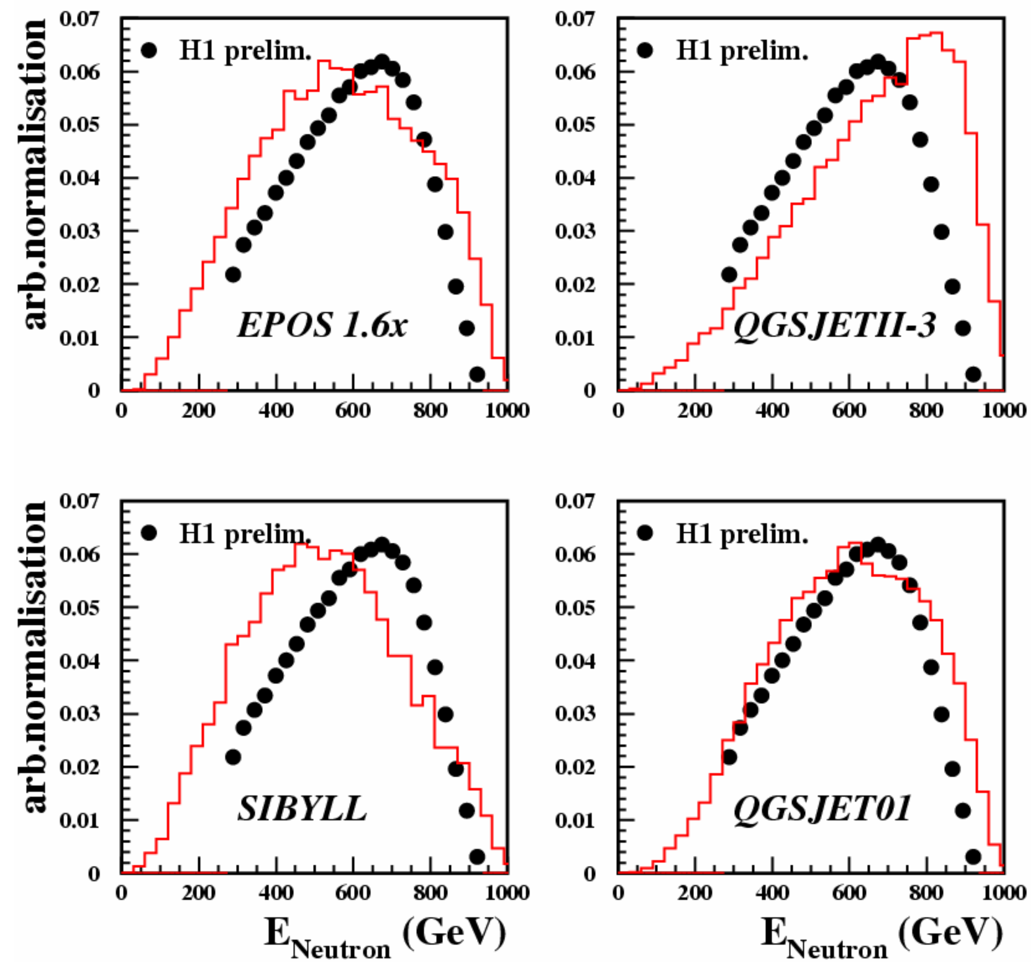
- data at low energy (fixed target experiment)
- extrapolation tested with HERA data

Comparison of HERA data with the MC models used for cosmic ray physics:

- the HERA data discriminate between the models and contribute to the model tuning
- reasonable agreement between the measurements and the models (after tuning to these data !)

Forward particles at HERA and models for cosmic rays





Analysis by A.Bunyatyan

(T.Pierog ISMD08 symposium)

Forward neutron measured energy distribution compared to CR models

→ HERA data sees large difference between the predictions,

→ none of models describe data well (new EPOS 1.99 not bad)

→ room for improvement

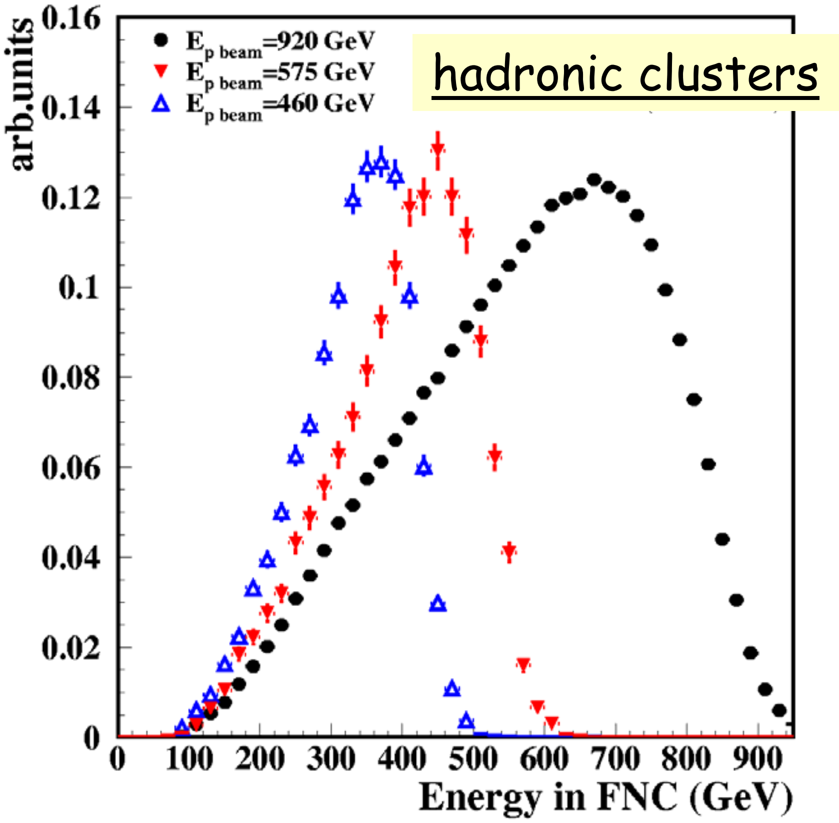
Neutral Particle measurements in the FNC

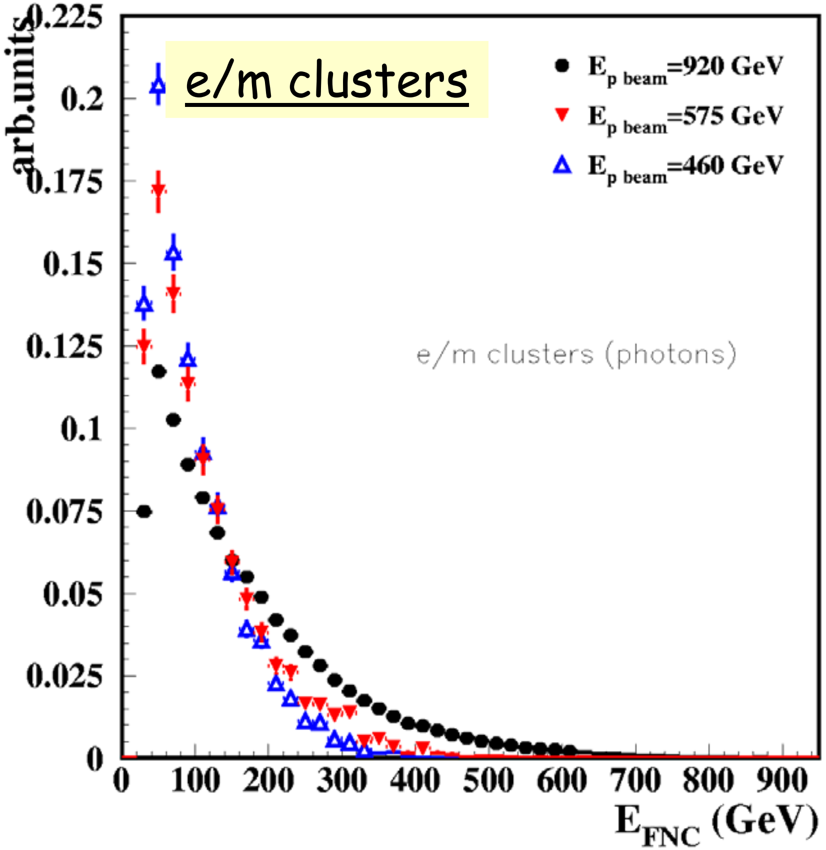
HERA can further contribute to the understanding of high energy cosmic rays

We measure the differential distributions of x_L and p_t for protons, neutrons and photons, in the photoproduction and DIS regimes

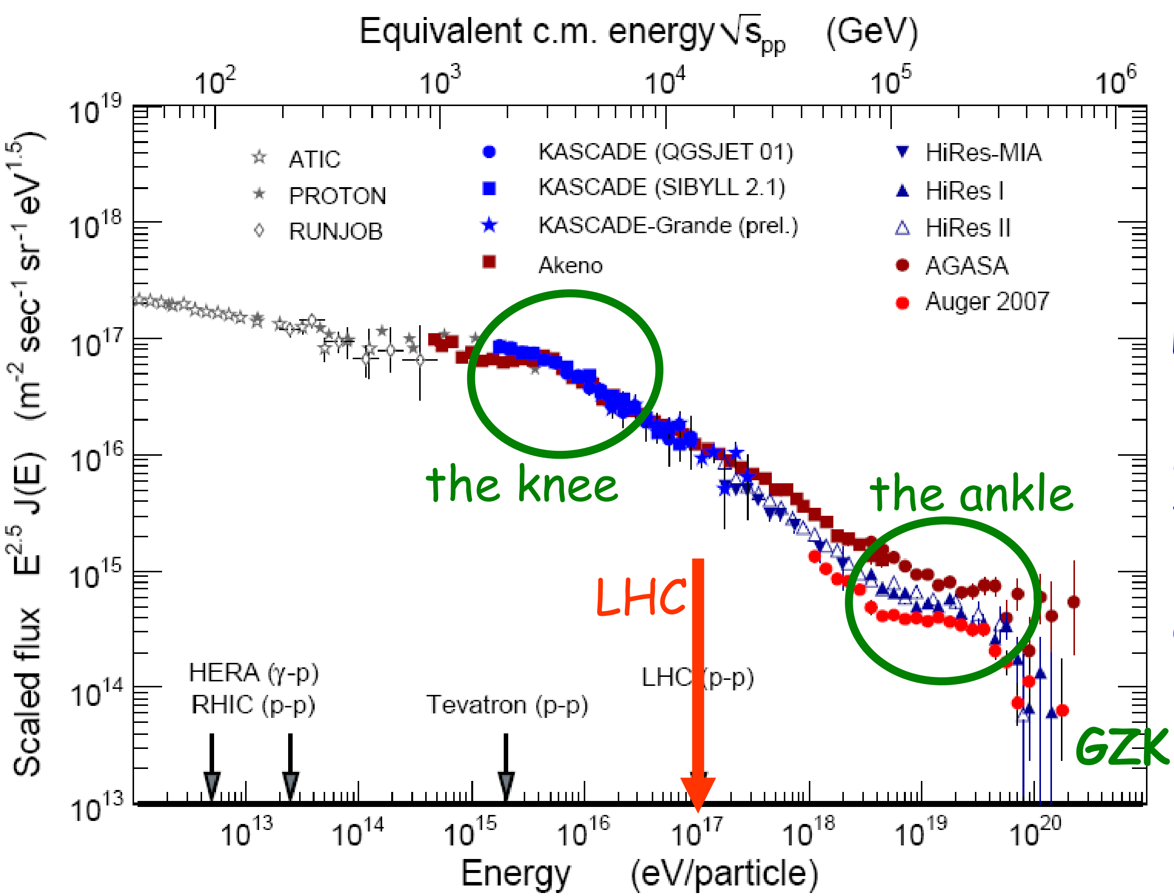
The measurements can be made also as a function of proton beam energy
(The last 3 months HERA was running with 460 GeV and 575 GeV protons.)

Energy distributions of electromagnetic (photons) and hadronic (neutron) clusters in H1-FNC at tree different proton beam energies (920, 575 and 460 GeV).





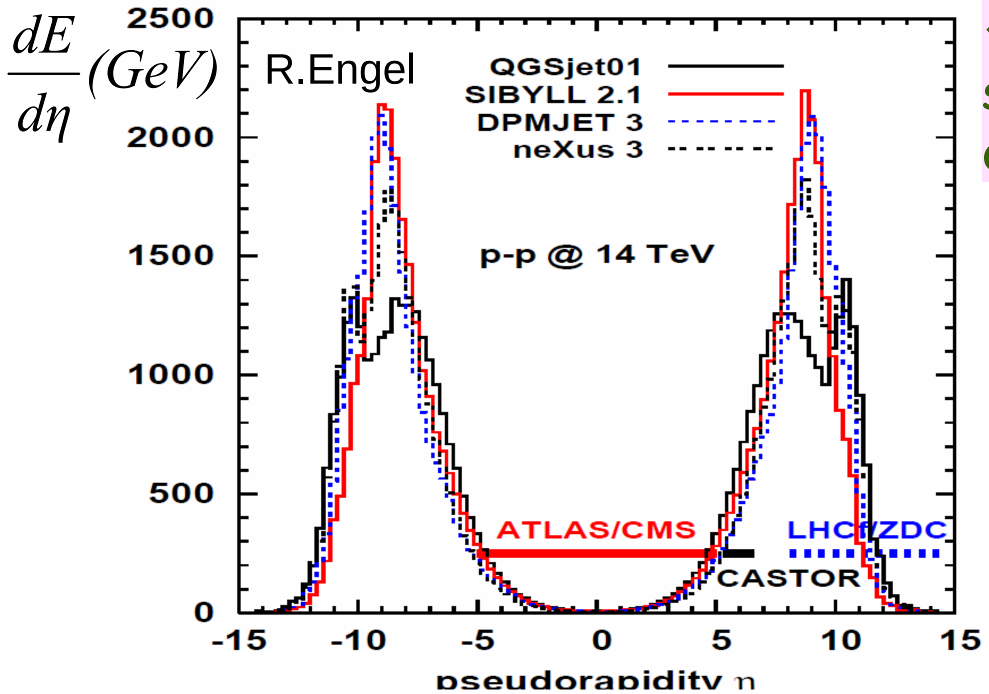
LHC and Cosmic Rays



LHC - **equivalent to E_{lab}=10^{17}eV**

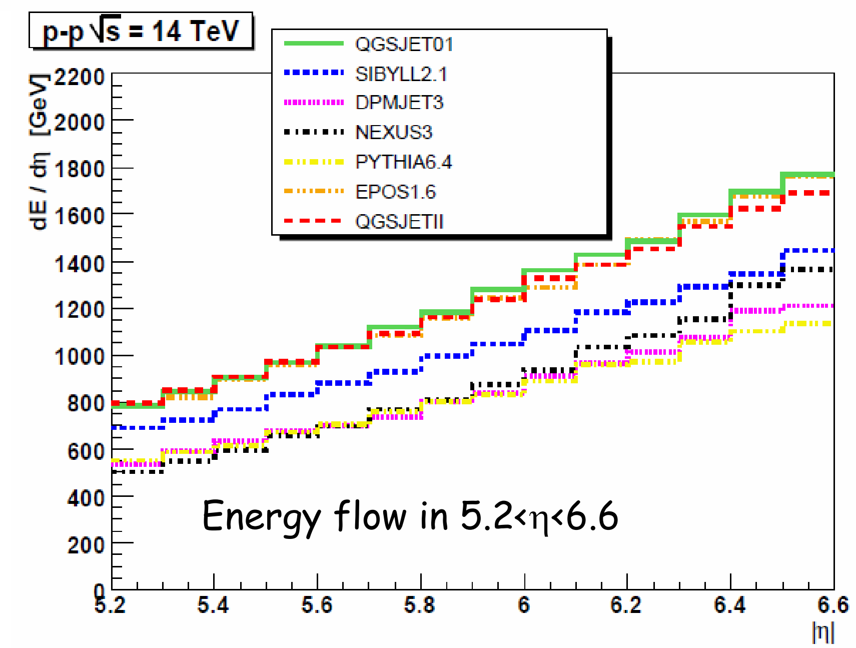
LHC data will reduce uncertainties from extrapolations from SpS, HERA, RHIC, Tevatron to higher energy and the GZK limit

LHC and Cosmic Rays



← energy flow: the LHC opens up a phase space for particle production up to 20 units of rapidity

CR model predictions differ by large factors, in particular in forward region, where the most of energy is going

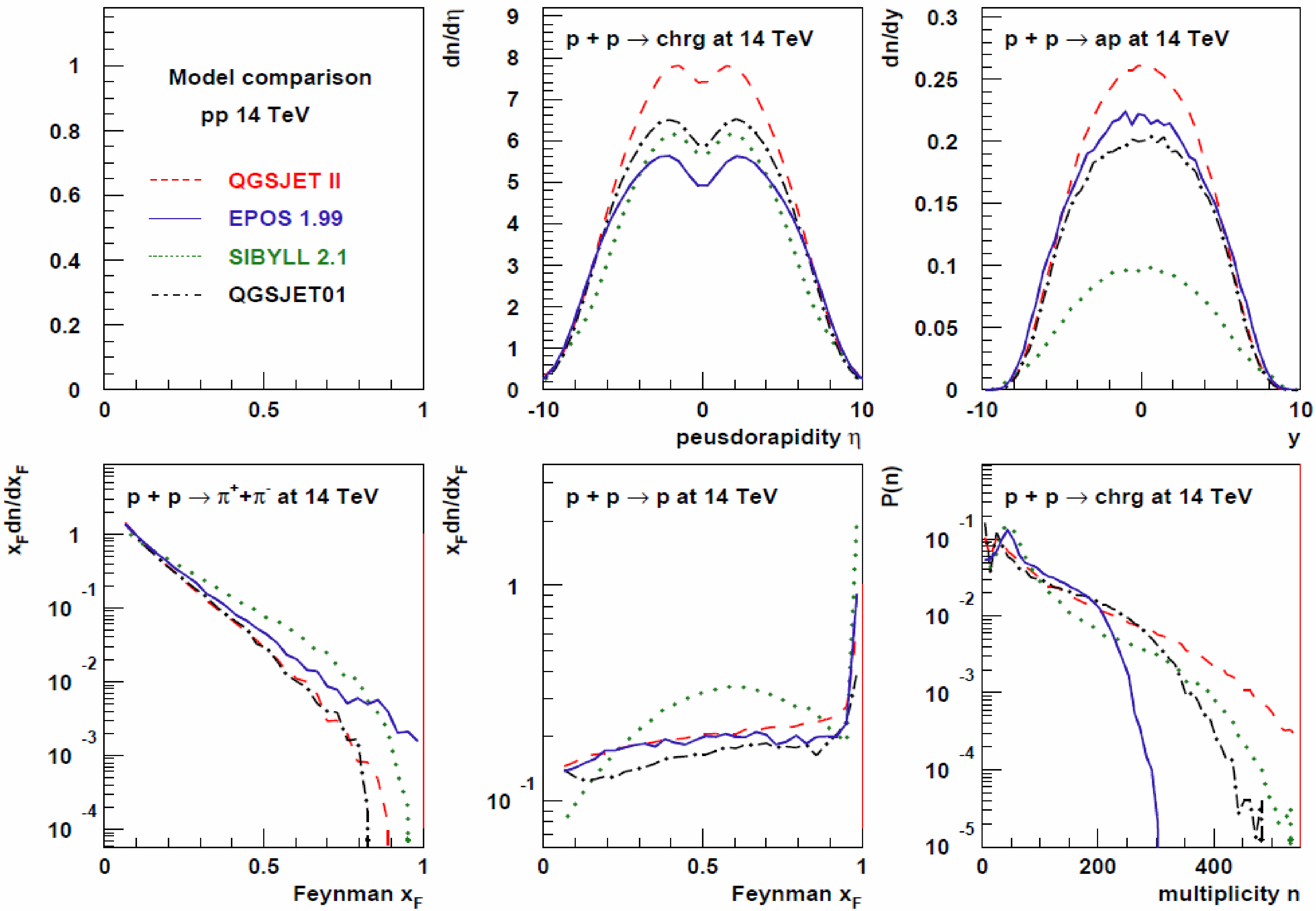


→ strong model constrain from the measurement of leading baryons, neutral mesons and γ (ZDC, LHCf) and particle flow in pp, pA, AA

← Forward detectors (e.g. CASTOR) are very essential

LHC minimum bias measurements: multiplicity distributions

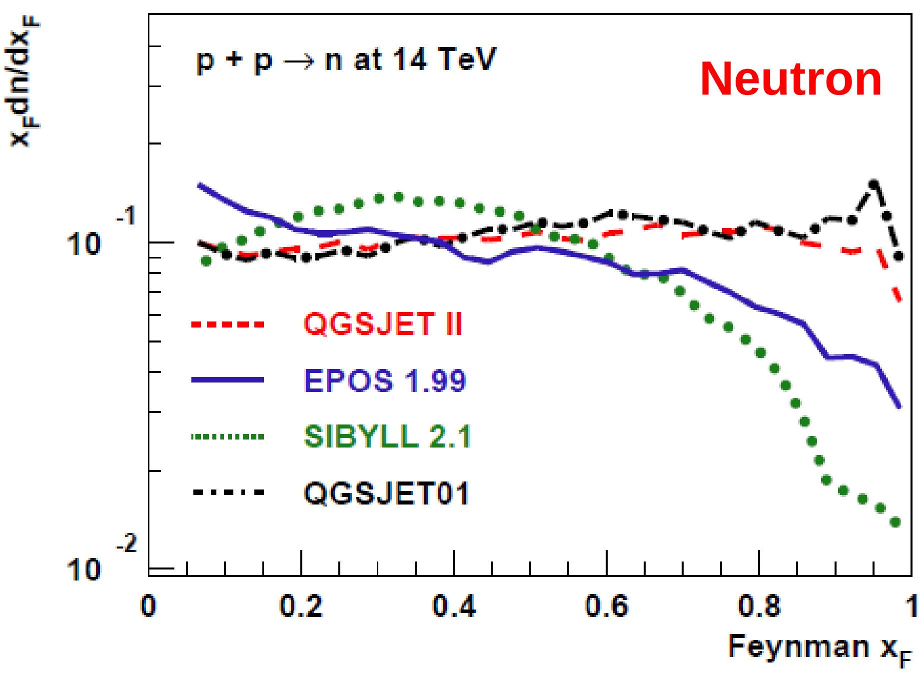
T.Pierog

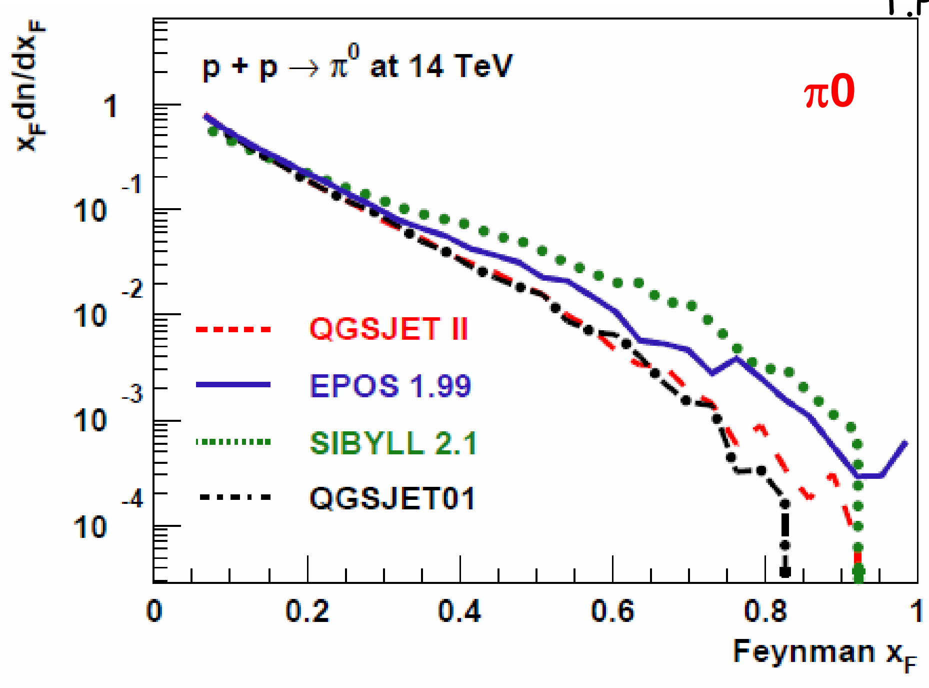


Strong model dependence ! Even simple distributions provide constraints

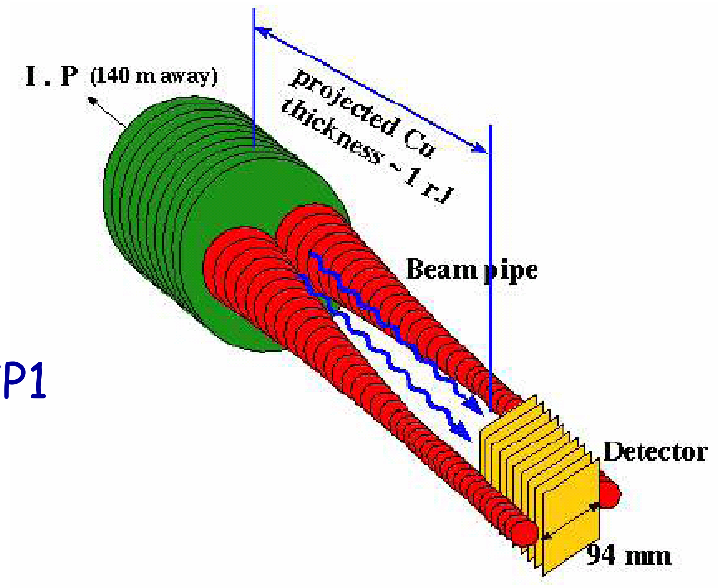
Forward neutral particles at LHCf

T.Pierog





LHCf experiment:
Detection of γ,π^0 (also n,K^0) at 140m from IP1



Summary

Interpretation of Cosmic Ray observation data in 10^{15}-10^{20}eV depends on the interaction model used in the analysis. Precision of elemental composition analyses limited by modeling of hadronic interactions and depends on particle physics measurements

HERA provides an equivalent of a $5 \cdot 10^{13}$ev photon beam on a stationary proton target
→ very useful input for models of CR interactions with matter
→ a wealth of measurements of forward baryon production:
important for an improved theoretical understanding of the proton fragmentation
→ more measurements useful for CR can be provided on forward neutrons and photons (still HERA data has the highest available energy)

LHC is equivalent to 10^{17}eV proton beam
→ LHC data will reduce uncertainties from extrapolations from SpS, HERA, RHIC, Tevatron to the energies beyond 10^{18}ev
→ The forward detectors are crucial to exploit physics potential