DIS 2014

Warzaw
28.04-02.05.2014

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Measurement of Feynman-x Spectra of Photons and Neutrons in the Very Forward Direction in DIS at HERA

(DESY 14-035, arXiv:1404.0201)

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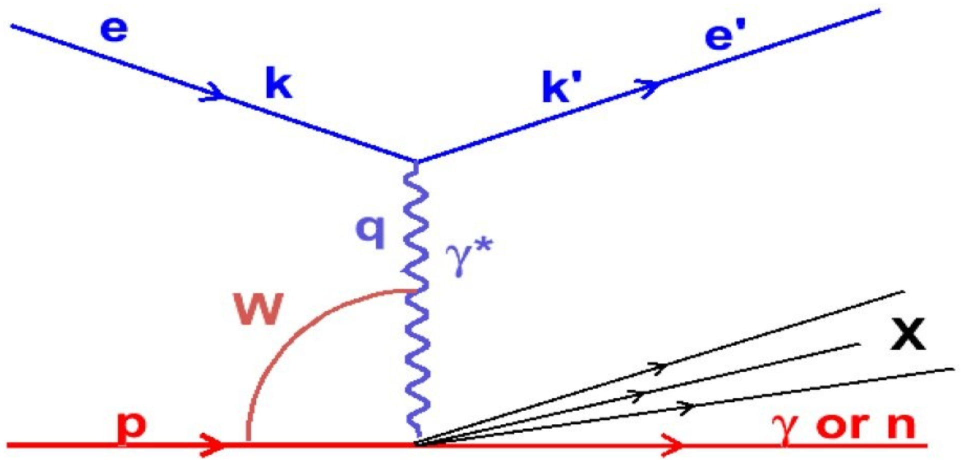
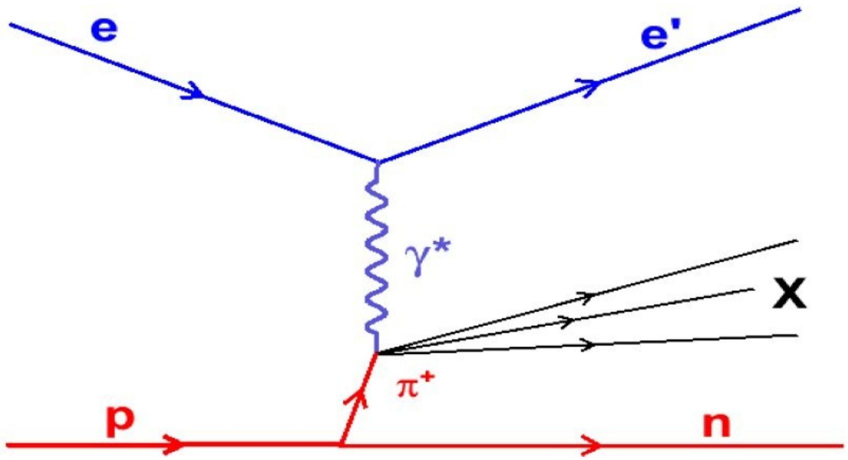
for the H1 Collaboration

Neutron and Photon production in the very forward direction



Proton Fragmentation



Pion Exchange

$$q = k - k'; \quad Q^2 = -q^2$$
$$y = (q \cdot p)/(k \cdot p)$$
$$W^2 = (q + p)^2$$

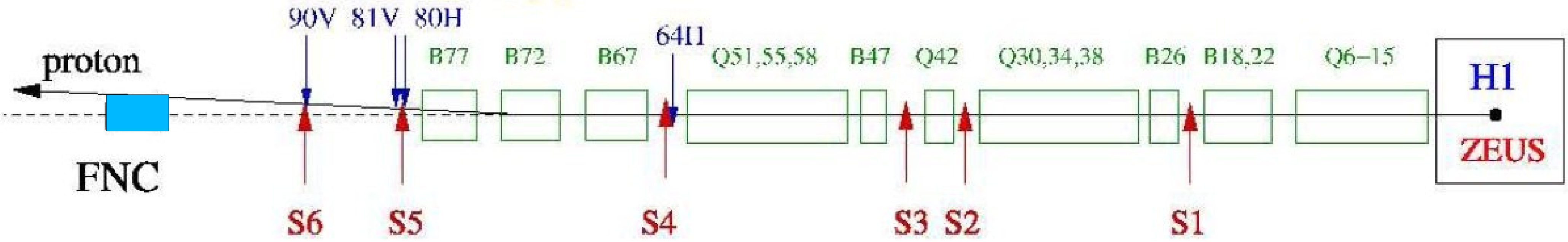
Photons: from Proton Fragmentation (mainly from π^0 decay)

Neutrons: from Proton Fragmentation and, from Pion Exchange

Feynman - x: $$x_F = 2p^*_{||}/W = p^*_{||}/p^*_{||,max}$$

$$x_L = E_{n,\gamma}/E_{beam}$$

H1 Forward Neutron Detector, FNC



Main Calorimeter: 8.9λ

$\sigma(E)/E \approx 63\%/\sqrt{E\,[\mathrm{GeV}]} \oplus 3\%$

$\sigma(x,y) \approx 10\mathrm{cm}/\sqrt{\mathrm{E}\,[\mathrm{GeV}]} \oplus 0.6\,\mathrm{cm}$

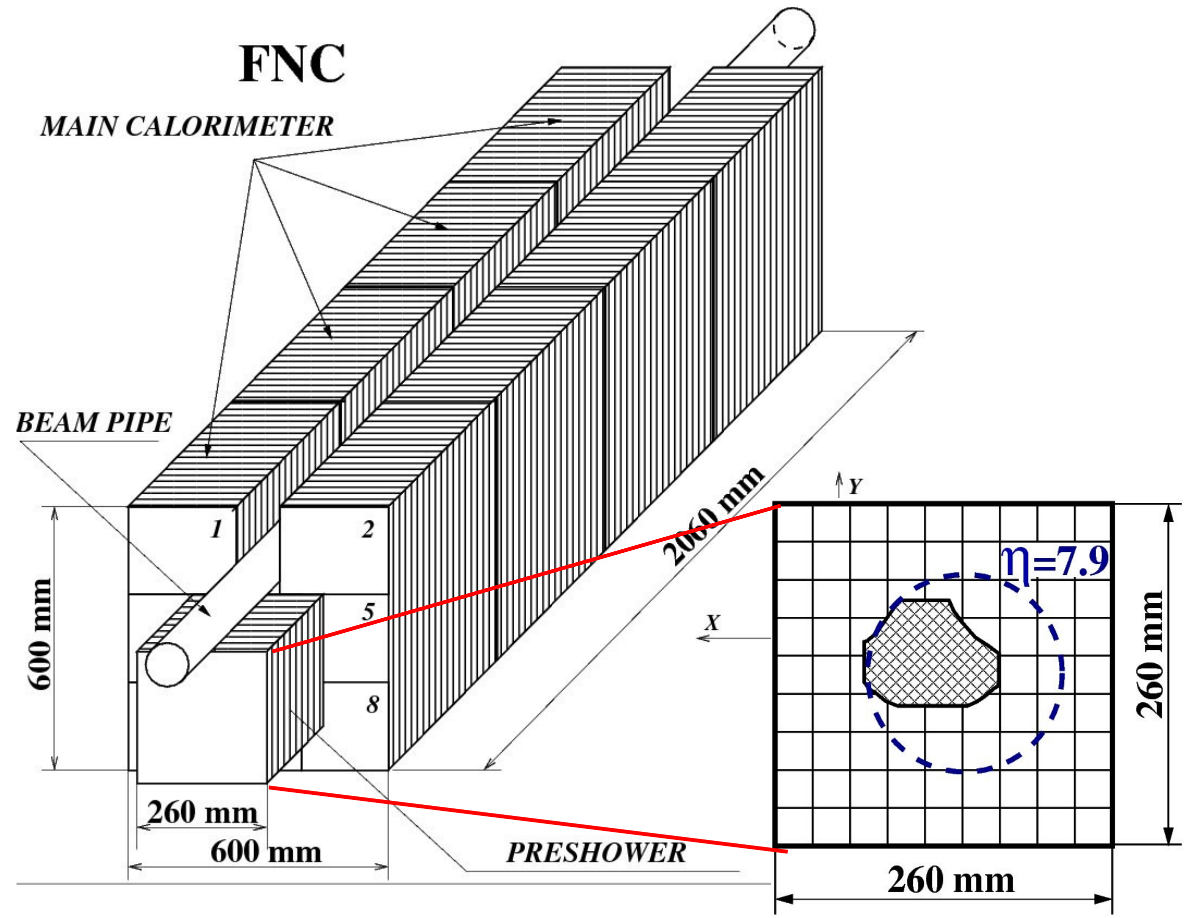
Preshower: 1.6λ $(60X_0)$

$\sigma(E)/E \approx 20\%/\sqrt{E\,[\mathrm{GeV}]} \oplus 2\%$

$\sigma(x,y) \approx 2\mathrm{mm}$

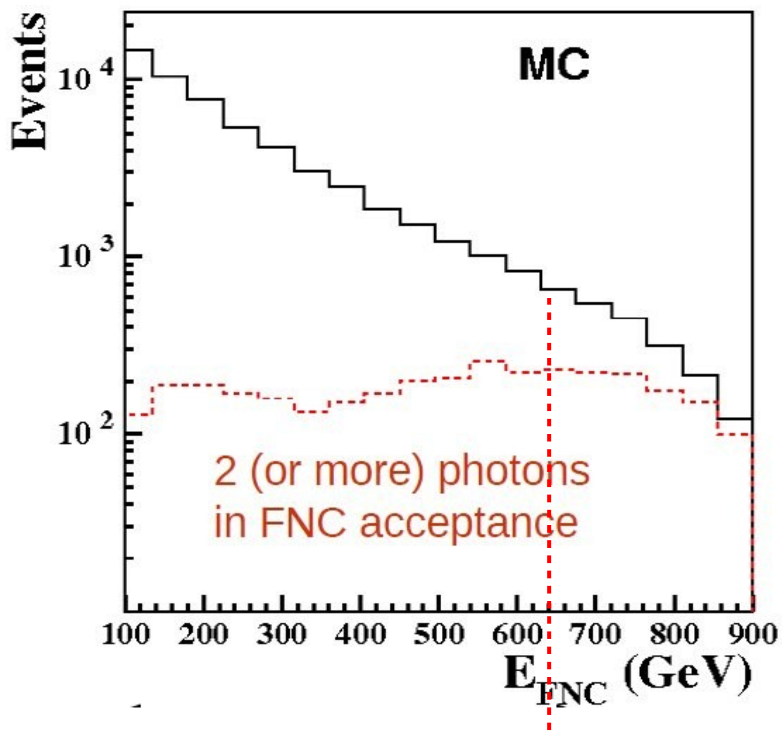
"Very Forward":

$\eta > 7.9 \quad (\theta < 0.75\mathrm{mrad})$



The Phase Space of the Measurement

HERA II period 2006-2007
131 pb^{-1}
230000 Neutron Events
83000 Photon Events



Suppress multi-photon events

NC DIS Selection	
$6 < Q^2 < 100$ GeV^2	
$0.05 < y < 0.6$	
$70 < W < 245$ GeV	
Forward photons	**Forward neutrons**
$\eta > 7.9$	$\eta > 7.9$
$0.1 < x_F < 0.7$	$0.1 < x_F < 0.94$
$0 < p_T^* < 0.4$ GeV	$0 < p_T^* < 0.6$ GeV
W ranges for cross sections $\frac{1}{\sigma_{DIS}} \frac{d\sigma}{dx_F}$	
$70 < W < 130$ GeV	
$130 < W < 190$ GeV	
$190 < W < 245$ GeV	

Cross Sections are normalised to the total DIS cross section σ_{DIS}

Motivation

Confront commonly used ep scattering MC models with data in an extreme corner of phase space

LEPTO

DJANGOH and Leading Log PS for higher orders, with Soft Colour Interactions option for forward Photons

CDM

DJANGOH and ARIADNE with Colour Dipole Model for higher orders

RAPGAP-π

RAPGAP, with virtual photon scattering off the exchanged pion

Two production mechanisms for neutrons:

Already known from earlier FNC data analyses, that neutrons in data can be well described by combinations of Proton Fragmentation and Pion Exchange simulations:

$$0.7 \cdot \mathrm{LEPTO} + 0.6 \cdot \mathrm{RAPGAP}\text{-}\pi$$
$$1.4 \cdot \mathrm{CDM} \quad + 0.6 \cdot \mathrm{RAPGAP}\text{-}\pi$$

Motivation

High Energy Cosmic Ray Physics

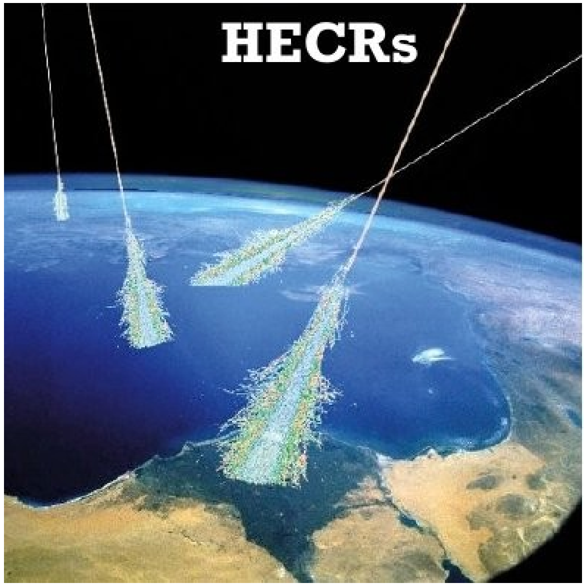
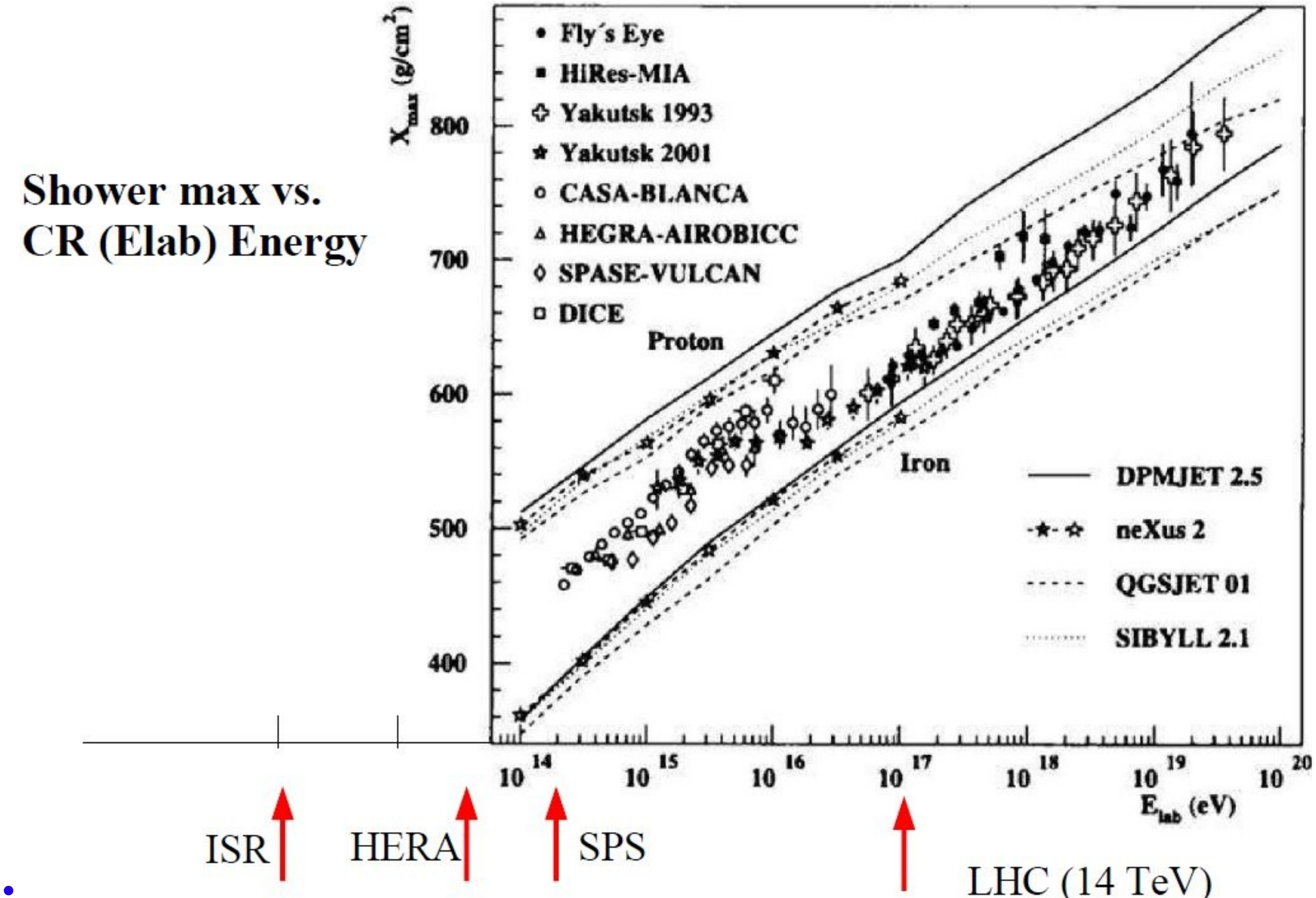


Image Credit: Simon Swordy



Air Shower MC Models
need calibration/tuning
with data from
Forward Particle Production
at High Energy Accelerators

So far, only scarce data on Forward Production at High Energies:
e.g. UA5, UA7 (SPS), LHCf at 900 GeV, 7 TeV a.o.

Air Shower Cosmic Ray Models

SIBYLL 2.1 QGSJET 01 QGSJET II-04 EPOS LHC

- These programs model hadronic interactions (protons, nuclei);
- Adapted to e p -scattering kinematics via interface to PHOJET

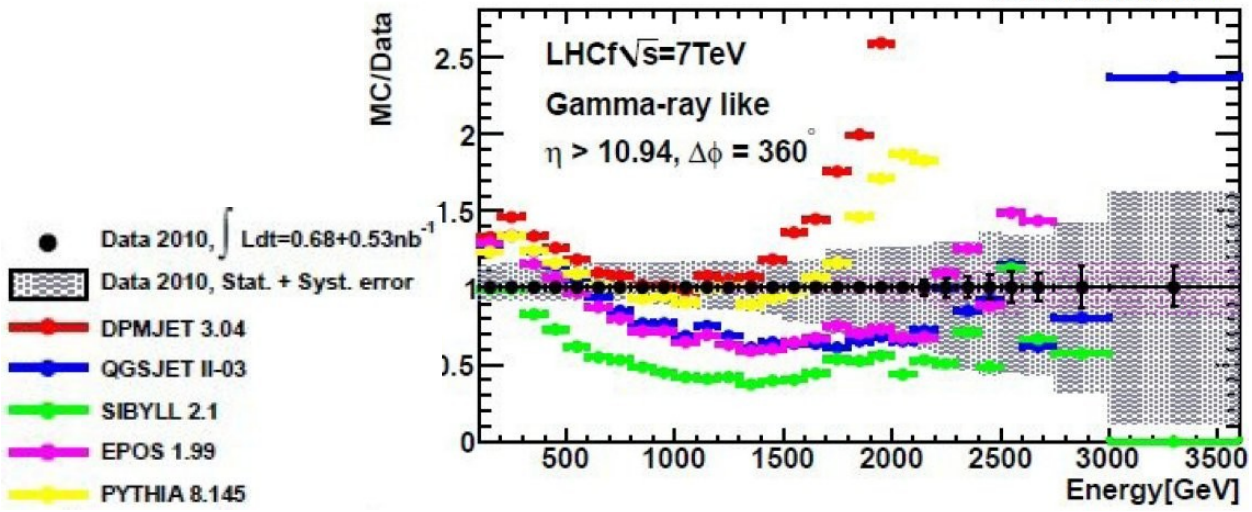
- Based on
  Regge Theory,
  Regge-Gribov approximation,
  pQCD, Unitarisation

- Internal differences in treatment of:
  Mini-jet production,
  Colour strings formation,
  Fragmentation, Saturation,
  Multiparton interactions,
  Hadron remnant treatment

Cosmic Ray MC Simulation Data provided by the authors.
No further tuning of parameters in the comparison to H1 Data

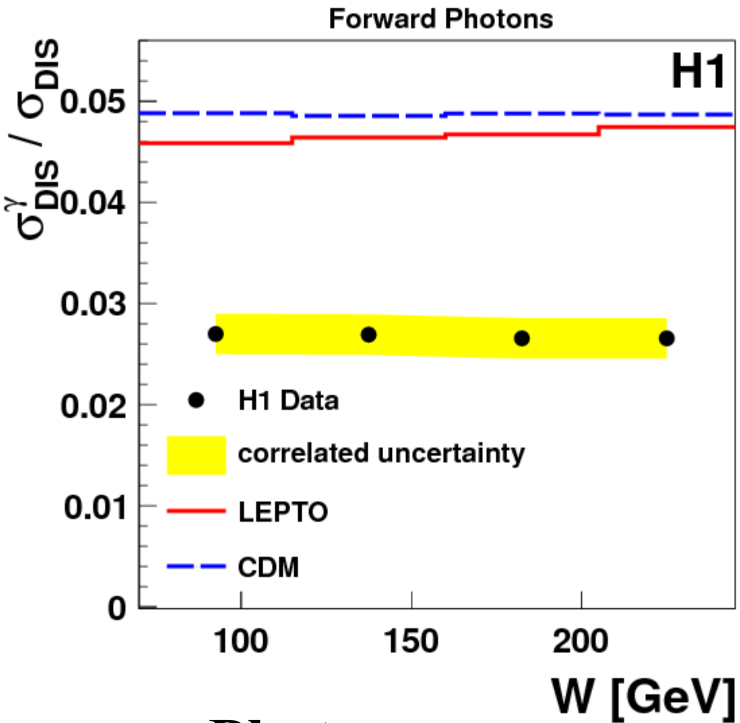
Models in development,
in particular using LHC data:
ATLAS, CMS, LHCb, LHCf ...

arXiv:1104.5294

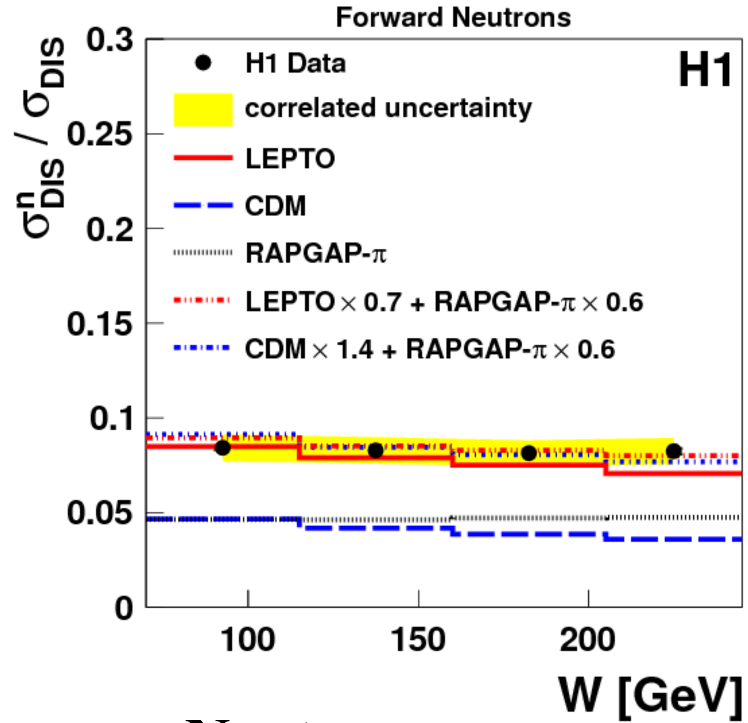


RESULTS

Normalised Cross Sections as a function of W



Photons

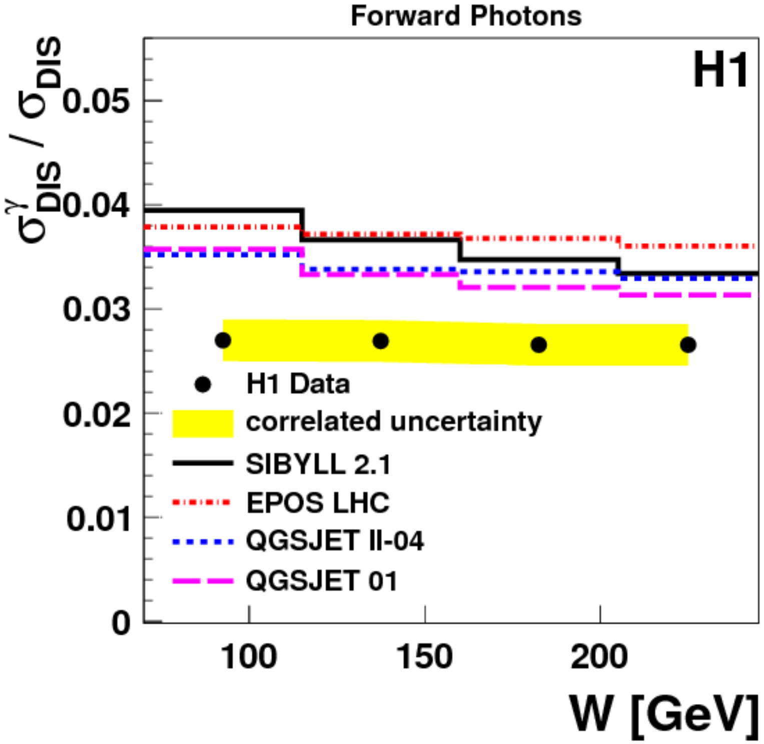


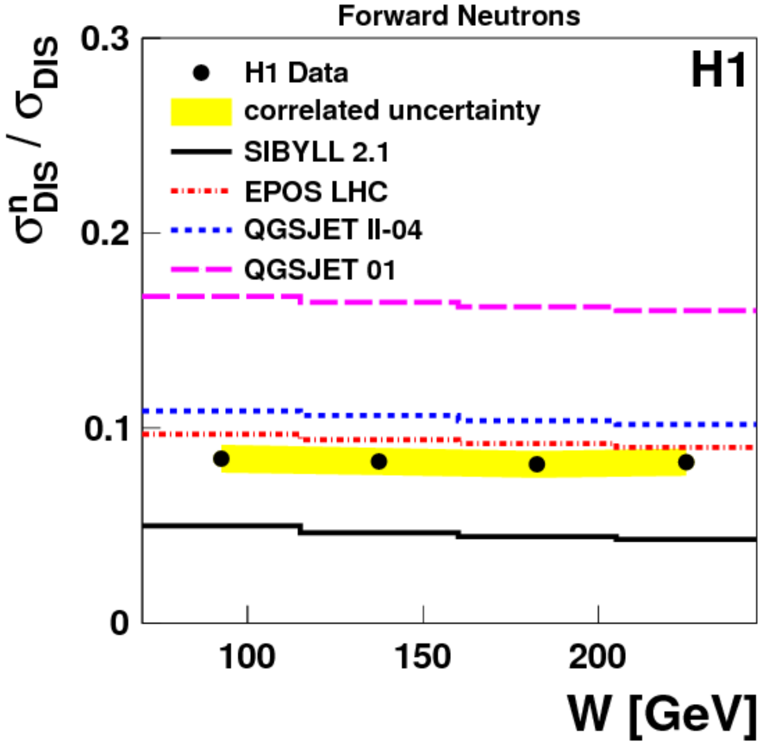
Neutrons

Fraction of forward photons and neutrons in DIS events independent of W (Limiting Fragmentation)

- LEPTO and CDM predict too high rate of photons, by ~70%
- LEPTO predicts the neutron rate rather well, CDM has too low rate
- LEPTO has a slight W-dependence, opposite for photons and neutrons
- CDM has constant W-dependence for photons, slightly falling for neutrons

Normalised Cross Sections as a Function of W



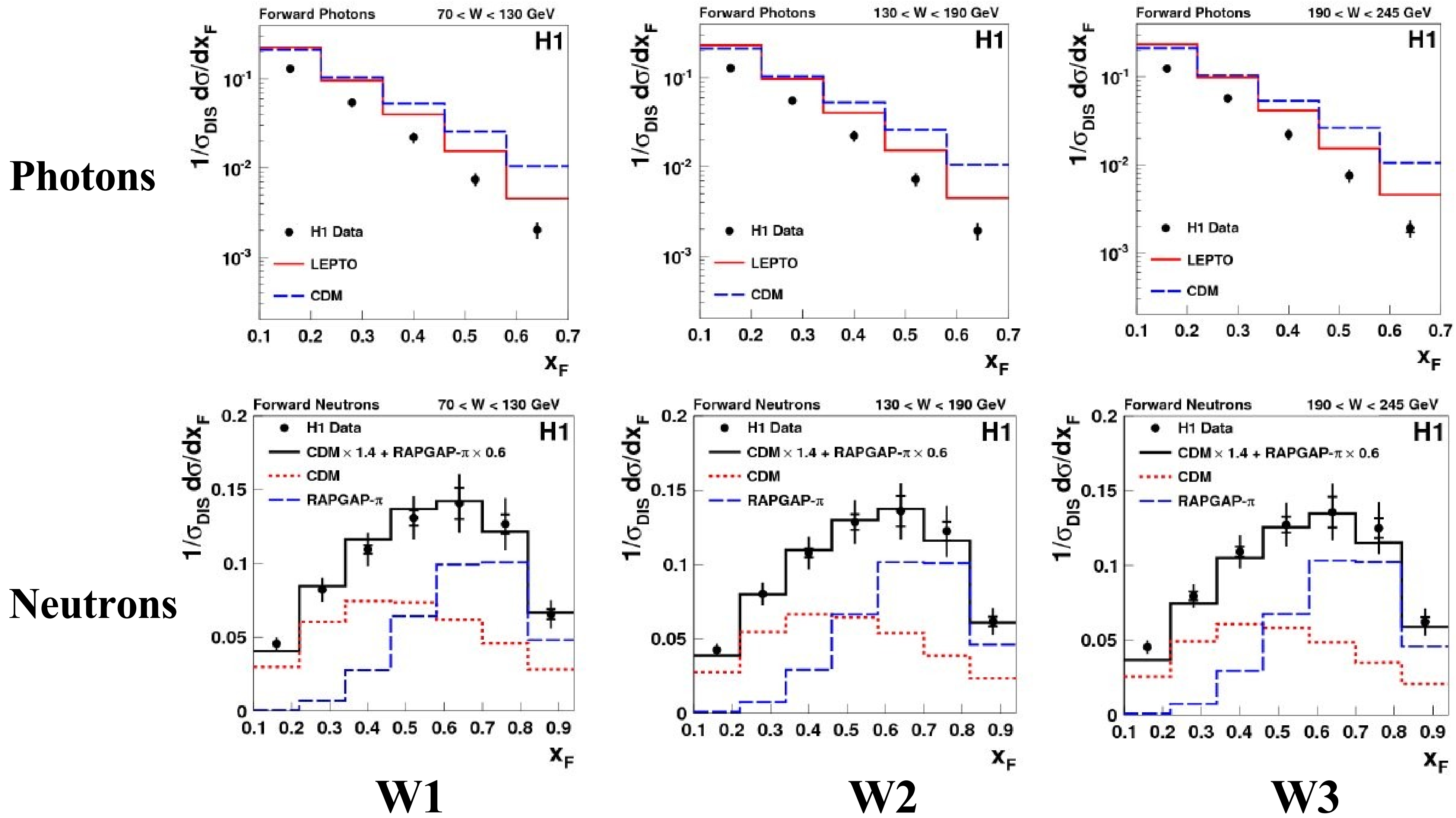


Photons **Neutrons**

- All CR Models predict too high rate of forward photons, by 30-40%
- Large spread in the forward neutron predictions, EPOS LHC closest, but still different

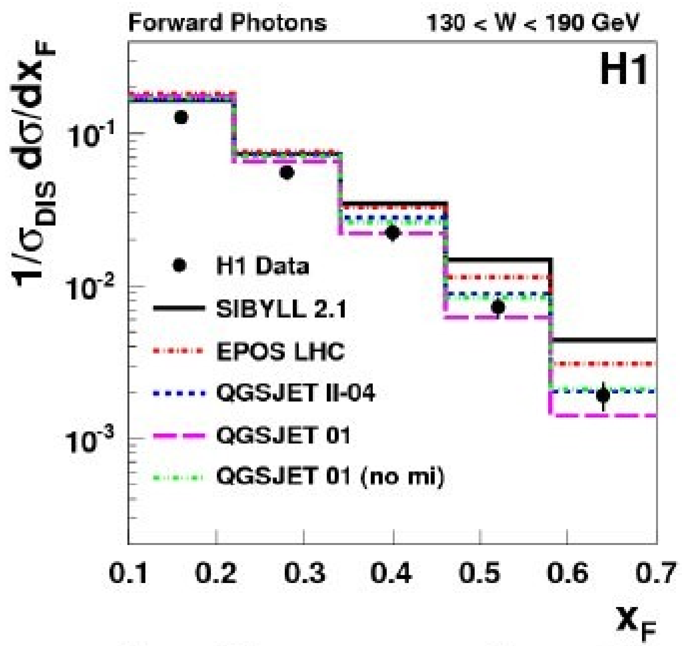
- All CR Models (possibly except EPOS LHC) indicate a W-dependence for photons, but less so for neutrons

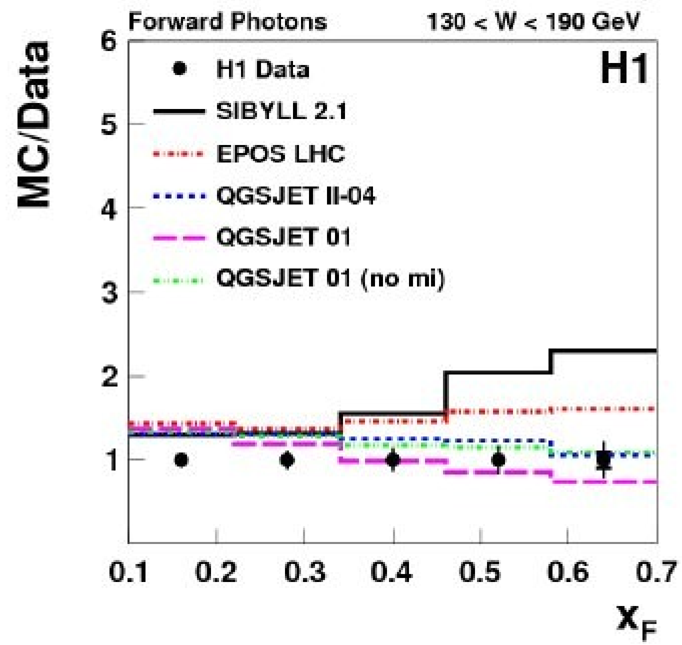
Normalised Cross Sections as a Function of x_F, in 3 W-intervals

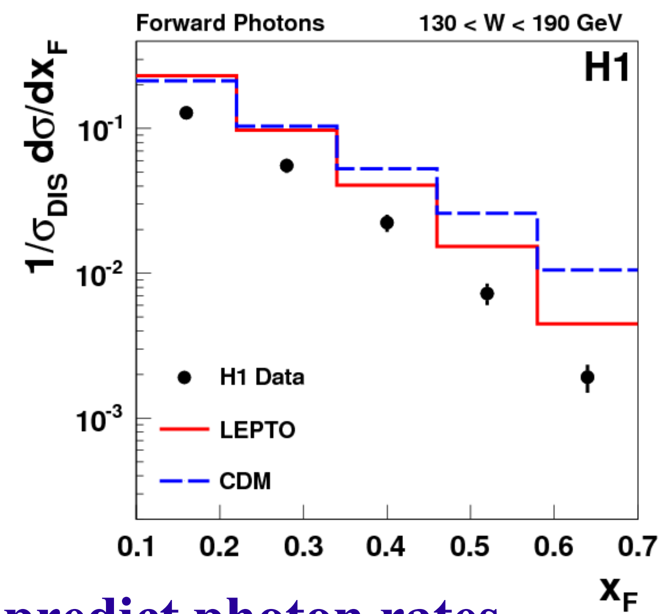


- LEPTO describes the shape of photon x_F spectra well, CDM is too hard
- Neutron x_F spectra well described by Combination of MC Models
- Both LEPTO and CDM overestimate the photon rate significantly

Normalised Cross Sections as a function of x_F; Photons, Interval W2







Photon rates:

- CR Models in general predict photon rates which are closer to data, in comparison to fragmentation models

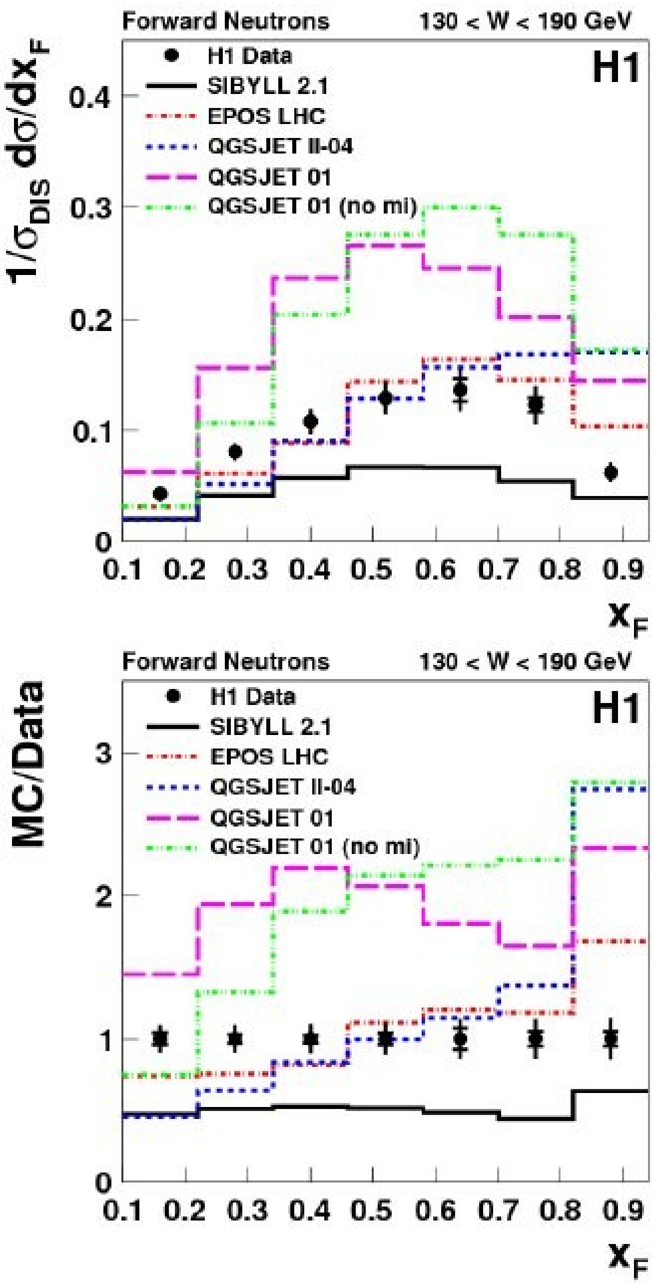
x_F dependence:

- QGSJET models are too soft
- SIBYLL 2.1 is too hard,
- EPOS LHC gives the best description, but is also too hard

Multi-parton Interactions:

- Only small effect in QGSJET 01 (no mi)

Normalised Cross Section as a Function of x_F; Neutrons, Interval W2

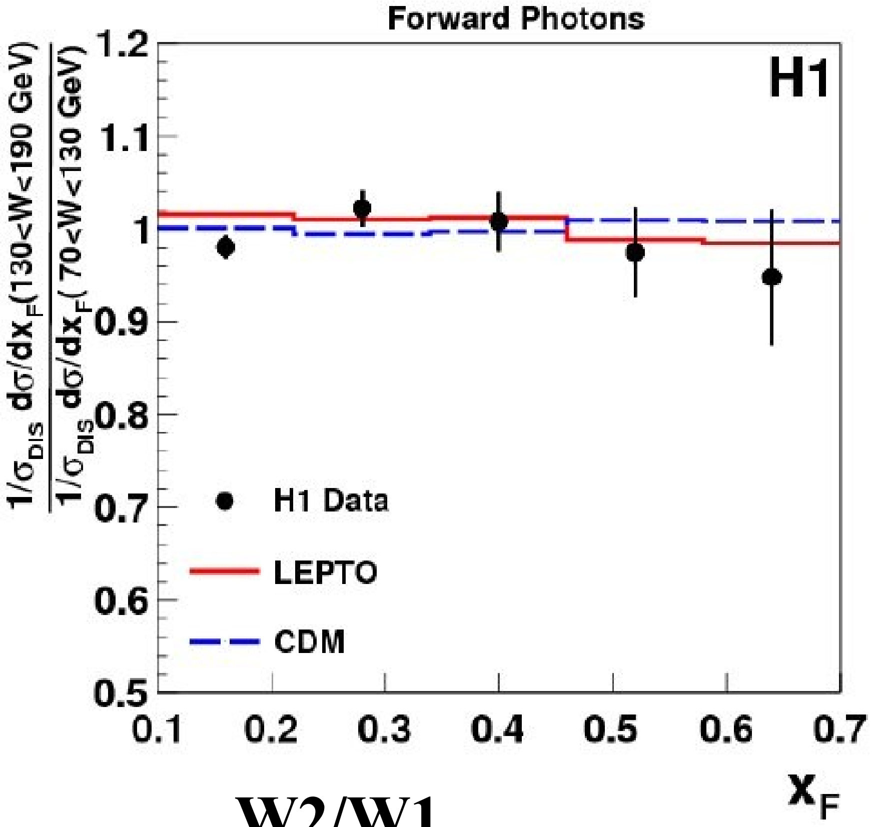


Neutron rates:
- CR Models predict very different neutron rates

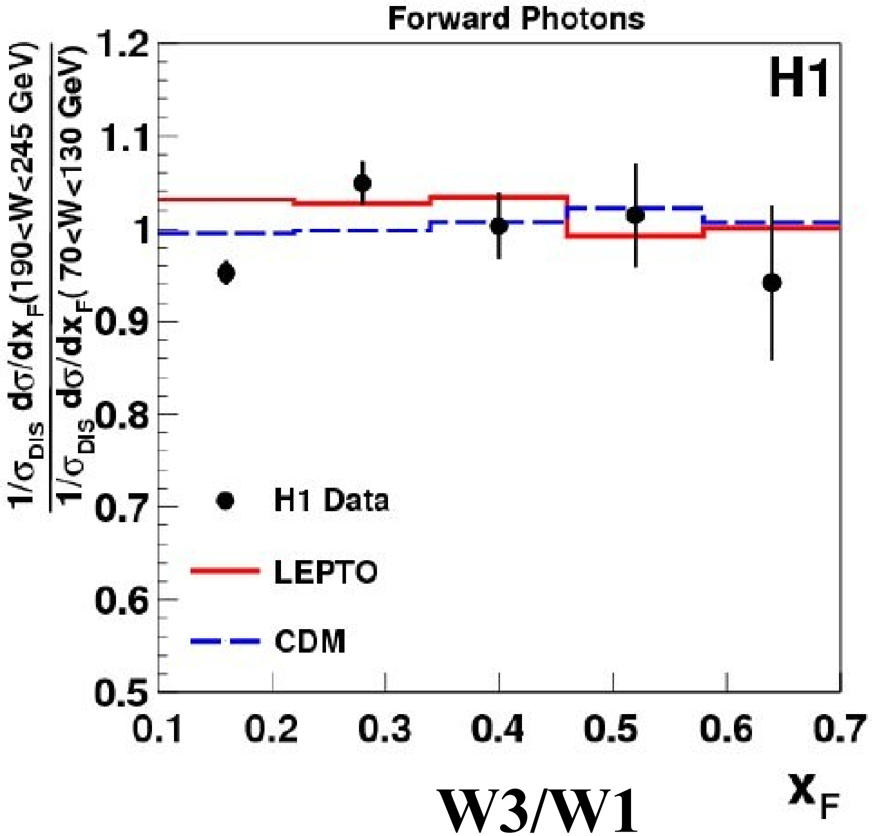
x_F dependence:
- QGSJET models are too hard, and predict too high rates
- SIBYLL 2.1 describes the x_F dependence, but too low rate
- EPOS LHC gives reasonable description, except at highest x_F values

Multi-parton Interactions in QGSJET 01:
- Still harder x_F dependence with “no mi”

Test of Feynman Scaling: Photons



W2/W1



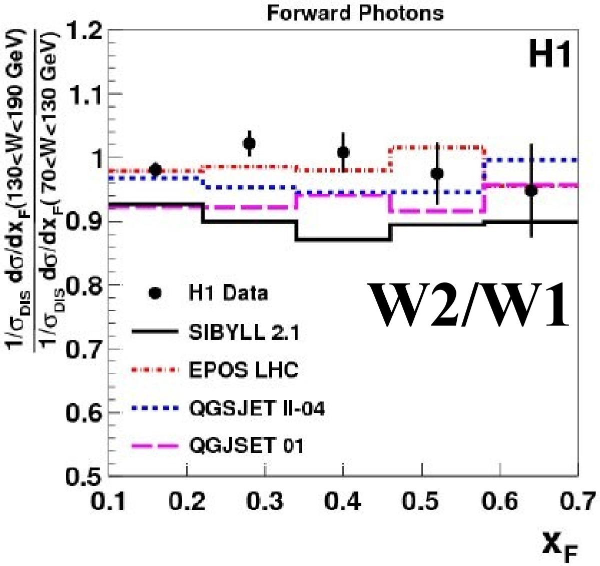
W3/W1

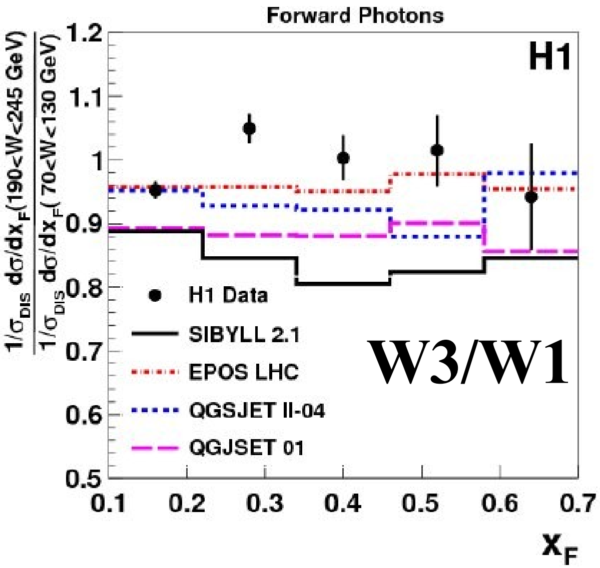
Feynman Scaling:

- Expect Feynman-x distributions to stay unchanged in the high energy limit;
- Compare Feynman-x distributions in 3 W- intervals, by ratios W2/W1, W3/W1

Data and Fragmentation Models are compatible with Feynman Scaling

Test of Feynman Scaling: Photons and Neutrons, CR Models



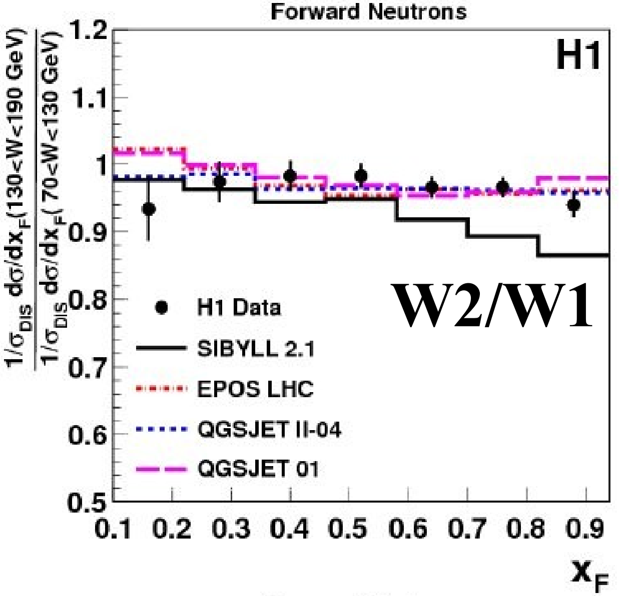


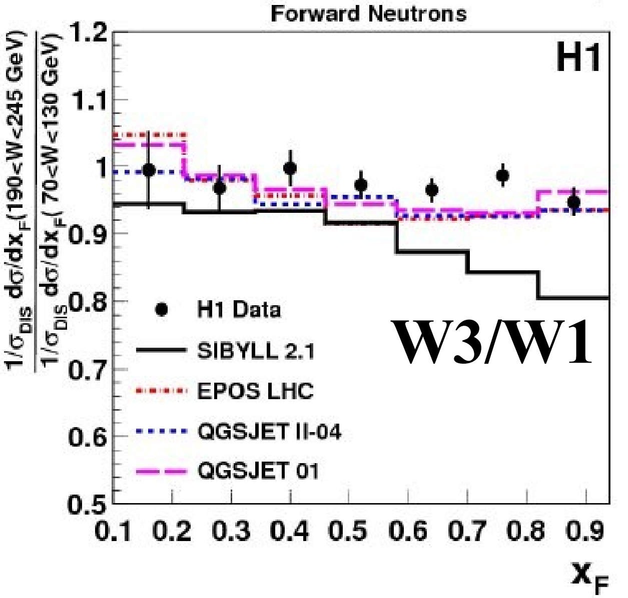
Photons

**Photons and Neutrons:
Data are compatible
with Feynman Scaling**

CR Models, Photons:
- **Feynman Scaling violated**
  - **Lower rates with increasing W**
- **Effect strongest for SIBYLL 2.1 and QGSJET models,**
- **EPOS LHC closer to data**

CR Models, Neutrons:
- **Compatible with Feynman Scaling, except SIBYLL 2.1**





Neutrons

SUMMARY

- Measurements of High Energy Forward Neutrons and Photons, in HERA ep DIS: $6<Q^2<100\ \mathrm{GeV}^2,\ 0.05<y<0.6,\ 70<W<245\ \mathrm{GeV},\ \eta>7.9$
- Normalised cross sections $1/\sigma_{DIS}\ \mathrm{d}\sigma/\mathrm{d}x_F$ in several W intervals
- Data compatible with Feynman Scaling in W range 70-245 GeV

ep DIS MODEL COMPARISONS

- Photon Rate overestimated by LEPTO and CDM, by 70 %
- Shapes of Photon Spectra described by LEPTO, CDM fails at large x_F
- Neutron Spectra well described by
  Combination of Fragmentation and Pion Exchange models

COSMIC RAY MODEL COMPARISONS

- Photon Rate overestimated by all CR models, by 30-40 %
- None of the CR models is able to describe
  photon and neutron data simultaneously well
- EPOS LHC is closest to give a good description, but still different

OUTLOOK

- New information to improve understanding of Proton Fragmentation
- New input to MC Model Simulation of Collider and Cosmic Ray data

BACKUP

The Year is 1969 ... Quark Model proposed, but no Gluons, no pQCD

Limiting Fragmentation

Feynman Scaling

J.Benecke et al. Subm. 8/1969 Publ. 12/1969

PR 188 (1969) 2159

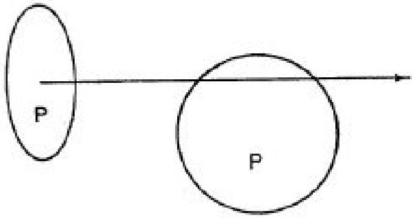


FIG. 4. Passage of Lorentz-contracted projectile through an extended target in the lab system.

R.P.Feynman Subm. 10/1969 Publ. 12/1969

PRL 23 (1969) 1415

Both concepts based on the same fact: the Lorentz Contraction of the Projectile

Both concepts aim at Finding Regularities in Multi-Particle Production

Both Hypotheses predict that cross sections at high enough energy for given particles approach limits, with different limits for different particles.

Thus, both hypotheses predict a Scaling Behaviour:

Cross sections measured at high enough energies allow predictions about cross sections at still higher energies --> CR MC Models

Are Limiting Fragmentation and Feynman Scaling the same thing ?

Yes, in the Fragmentation Region they are identical.

But, Feynman Scaling was proposed to be valid also in the Central Region, at small values of Longitudinal Momenta.

The Year is 1969 ... Quark Model proposed, but no Gluons, no pQCD

Limiting Fragmentation

J.Benecke et al. Subm. 8/1969
Publ. 12/1969

PR 188 (1969) 2159

Feynman Scaling

R.P.Feynman Subm. 10/1969
Publ. 12/1969

PRL 23 (1969) 1415

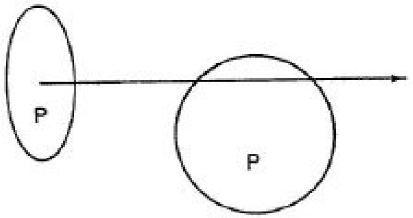


FIG. 4. Passage of Lorentz-contracted projectile through an extended target in the lab system.

Both concepts based on the same fact: the Lorentz Contraction of the Projectile

Both concepts aim at Finding Regularities in Multi-Particle Production

Single particle Momentum Distribution limited by a function

$$f(p_t, y)$$

$$y = \frac{1}{2} ln \frac{(E+p_{||})}{(E-p_{||})}$$

Single particle production at high energy described by a function

$$f(p_t, x_F)$$

$$x_F = 2p^*_{||}/W = p^*_{||}/p^*_{||,max}$$

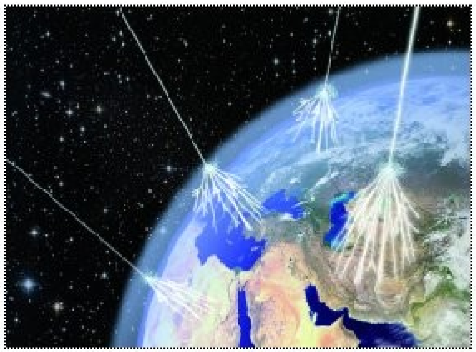
Note: $x_F = 2\mu/W sinh(y), \ \mu = \sqrt{p_t^2 + m^2}$

High Energy Limit:
Distributions are Independent of beam energy (CM Energy)

CERN Bulletin, Apr. 2011 (http://cds.cern.ch/journal/CERNBulletin/2011/18/News Articles/1345733)

LHCF SHEDS NEW LIGHT ON COSMIC RAYS

The energy spectrum of the single photon obtained using data from the LHCf experiment has turned out to be very different from that predicted by the theoretical models used until now to describe the interactions between very high-energy cosmic rays and the earth's atmosphere. The consequences of this discrepancy for cosmic ray studies could be significant.

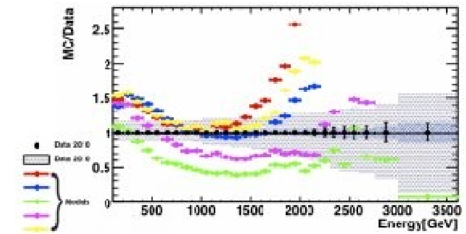


Artistic impression of cosmic rays entering Earth's atmosphere. (Credit: Asimmetrie/Infn).

It took physicists by surprise when analysis of the data collected by the two LHCf calorimeters in 2010 showed that high-energy cosmic rays don't interact with the atmosphere in the manner predicted by theory.

The LHCf detectors, set up 140 metres either side of the ATLAS interaction point, are dedicated to the study of the secondary particles emitted at very small angles during proton-proton collisions in the LHC, with energies comparable to cosmic rays entering the earth's atmosphere at 2.5×10^{16} eV. The aim of the experiment is to refine the models currently used to study very high-energy cosmic radiation. And according to the recent results of the LHCf experiment, these models will indeed require some changes. LHCf Deputy Spokesman Oscar Adriani explains: "We have used the data recorded to measure the energy spectrum of the single photon, which derives from the decay of a neutral pion appearing in the particle shower formed when very high-energy cosmic rays interact with atmospheric gas." The researchers can use studies of the single photon to extrapolate information on the physical processes induced by cosmic radiation.

The results of this work have caused quite a stir because of discrepancies with respect to the results predicted by the most common Monte-Carlo models used for the study of cosmic rays. The discrepancies appeared in the single photon spectrum for energies above 1.5 TeV. Beyond this value, the energy distribution no longer corresponds to that anticipated by the models. "Thanks to the LHC, we've been able to explore a hitherto inaccessible energy region," Oscar Adriani relates.



A comparison between the different Monte-Carlo models and experimental data gathered by LHCf in 2010.

"Given the significant disparities between the theoretical predictions and our experimental data, I believe that physicists specialising in this research field will be obliged to re-visit their results in the light of this new information."

Although the jury is obviously still out, the members of the LHCf collaboration expect this news to cause some upheaval in the field of cosmic rays in the not-too-distant future.

by Anaïs Schaeffer