EPS-HEP2015

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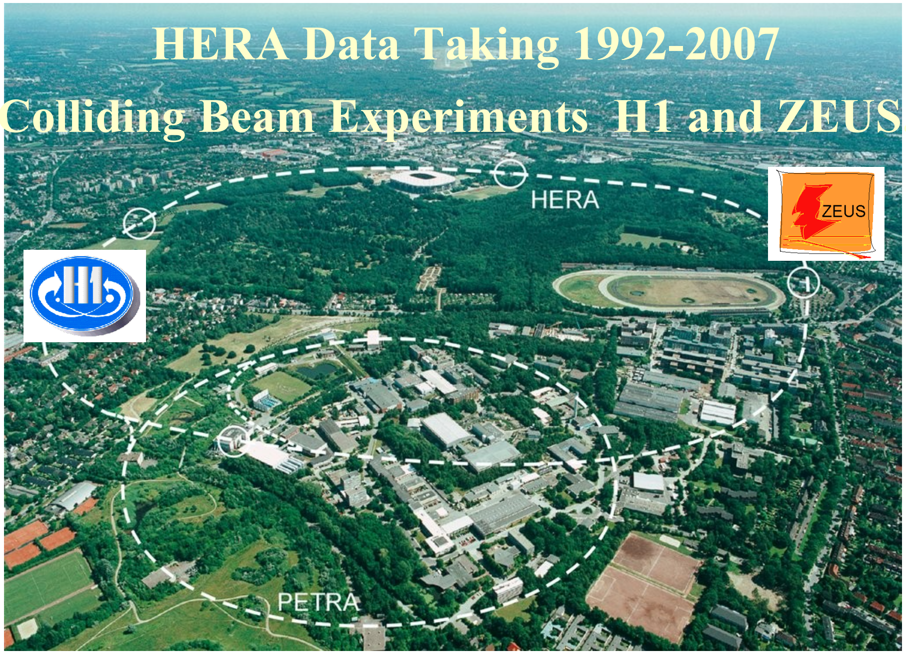
Measurement of Feynman-x Spectra of Photons and Neutrons in the Very Forward Direction in DIS at HERA

DESY 14-035, arXiv:1404.0201 , Eur. Phys. J. C74 (2014) 2915

Jan Olsson, DESY
for the H1 Collaboration

HERA, the World's first and only High Energy ep Collider



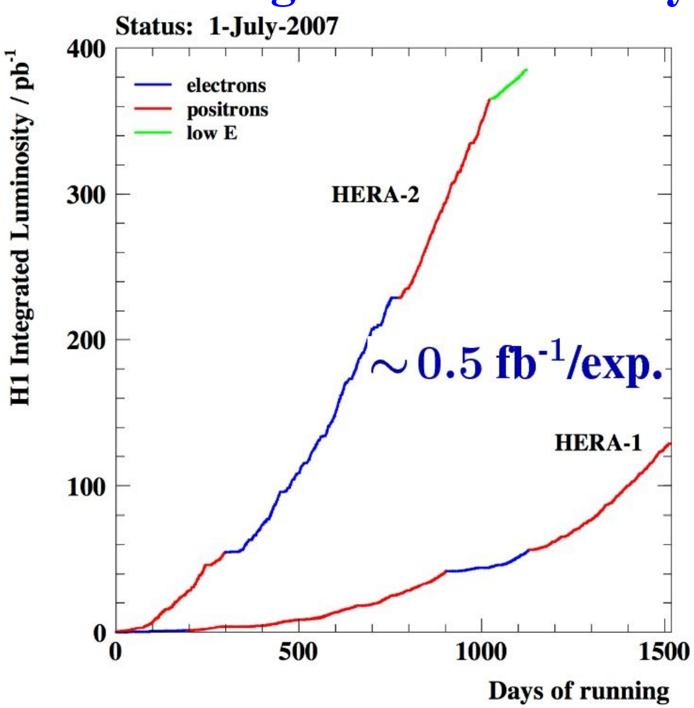
HERA Beams

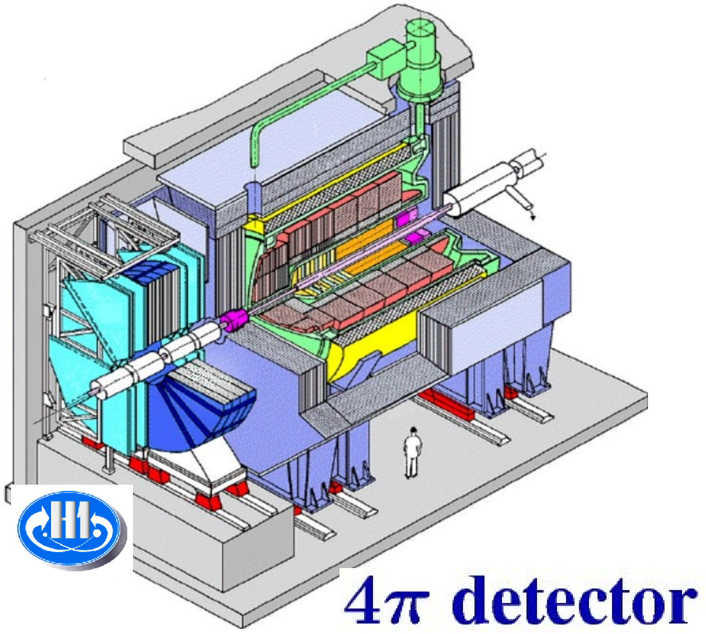
$E_e = 27$ GeV

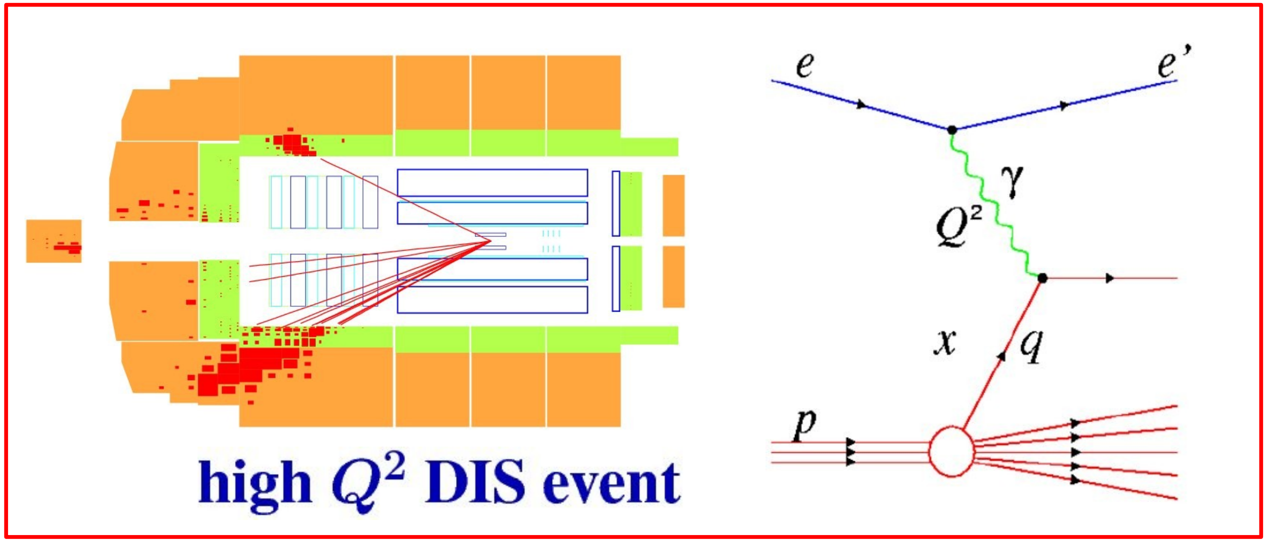
$E_p = 920$ GeV

$\sqrt{s} = 319$ GeV

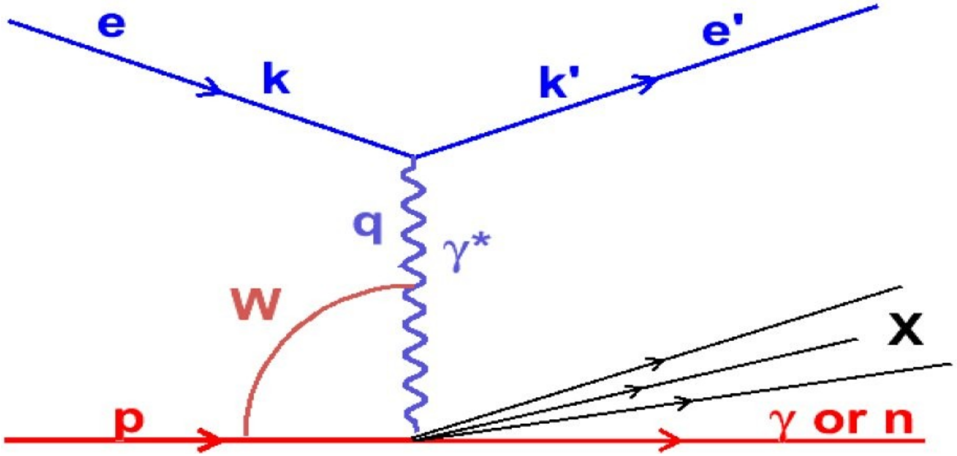
H1 Integrated Luminosity



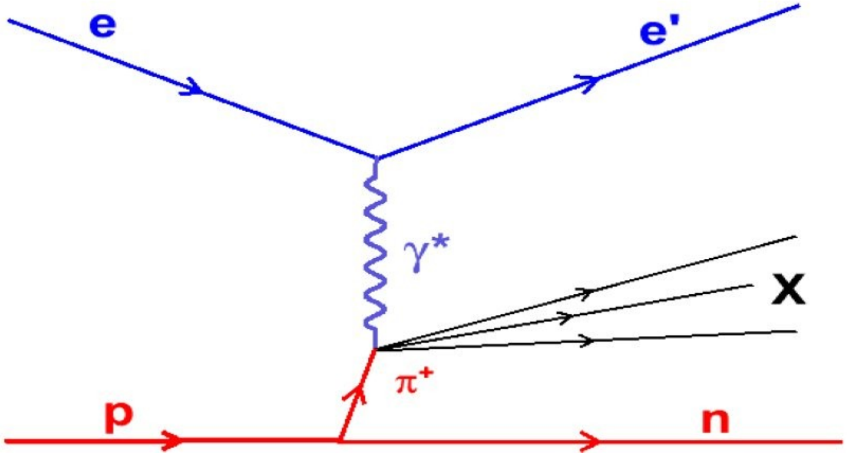




Neutron and Photon Production in the Very Forward Direction



Proton Fragmentation



Pion Exchange

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

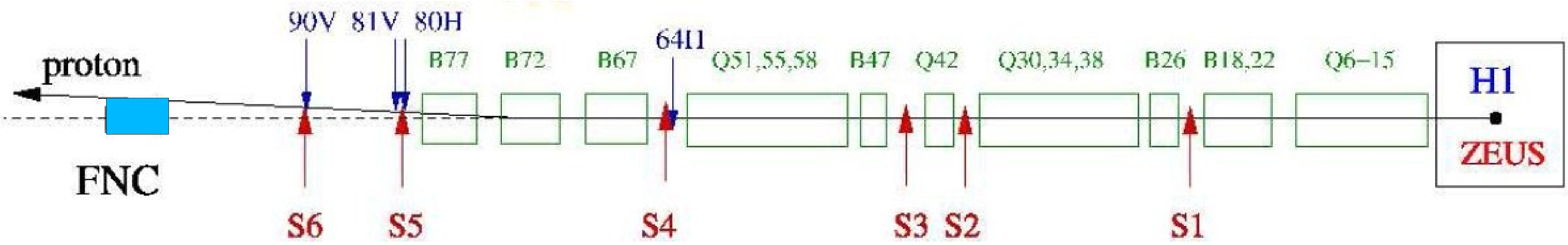
Photons: from Proton Fragmentation (mainly from π^0 decay)

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 $(60X_0)$

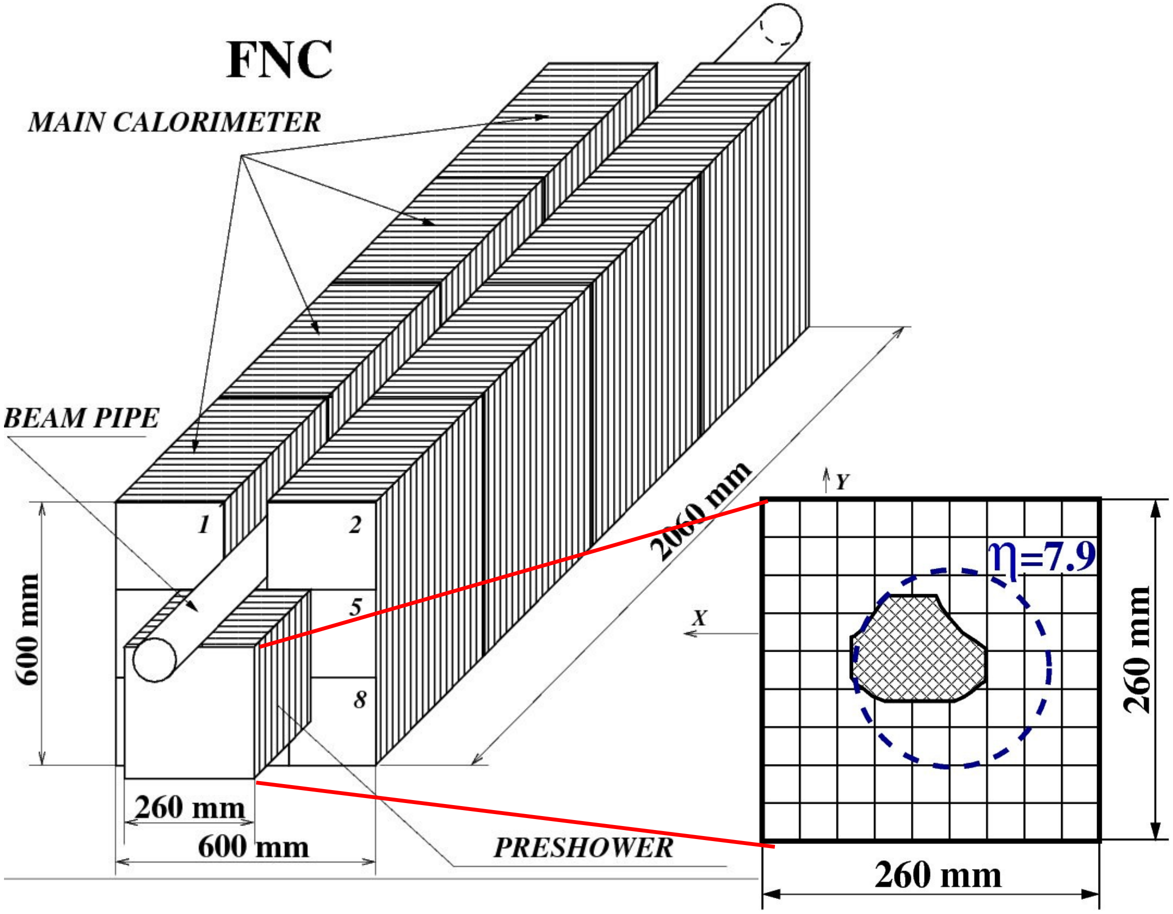
$\sigma(E)/E \approx 20\%/\sqrt{E\,[\mathrm{GeV}]} \oplus 2\%$

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

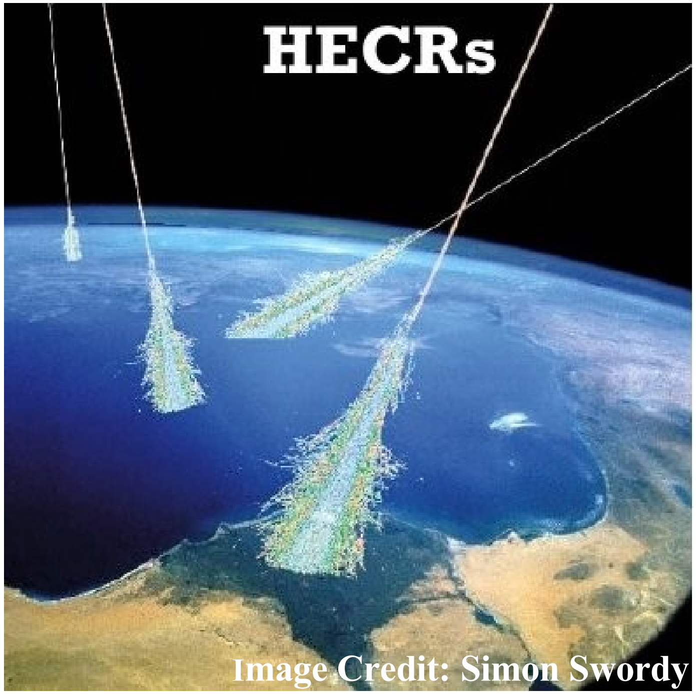
FNC located 106 m from I.P.

"Very Forward":

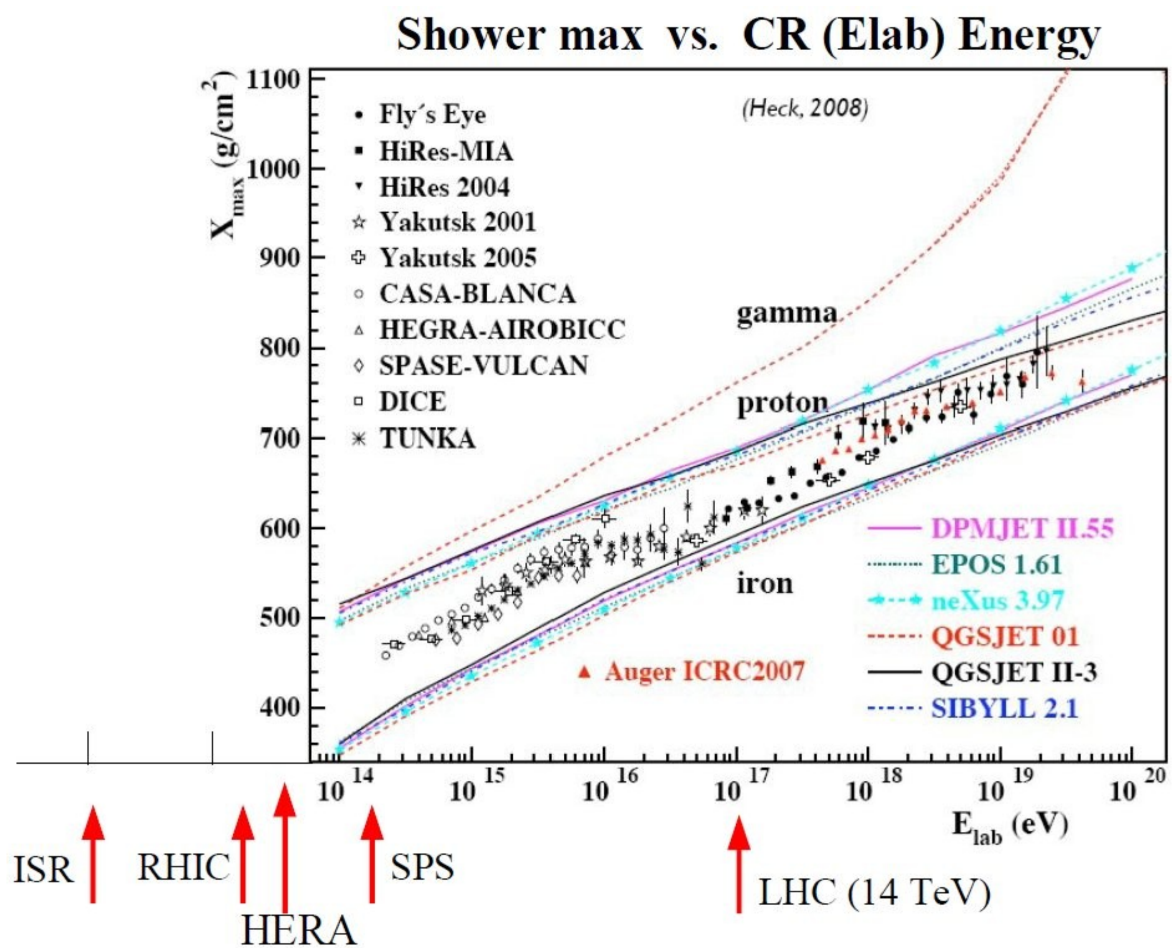
$\eta > 7.9 \quad (\theta < 0.75\mathrm{mrad})$



Motivation



High Energy Cosmic Ray Physics



Air Shower MC Models need Calibration / Tuning with Data from Forward Production at High Energy Accelerators

So far, only scarce data on Very Forward Production at High Energies: ISR, RHIC, SPS and recently LHC (900 GeV, 7 and 8 TeV)

Neutrons, photons: even more rare data: LHCf

Air Shower Cosmic Ray Models

SIBYLL 2.1 QGSJET 01 QGSJET II-04 EPOS LHC

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

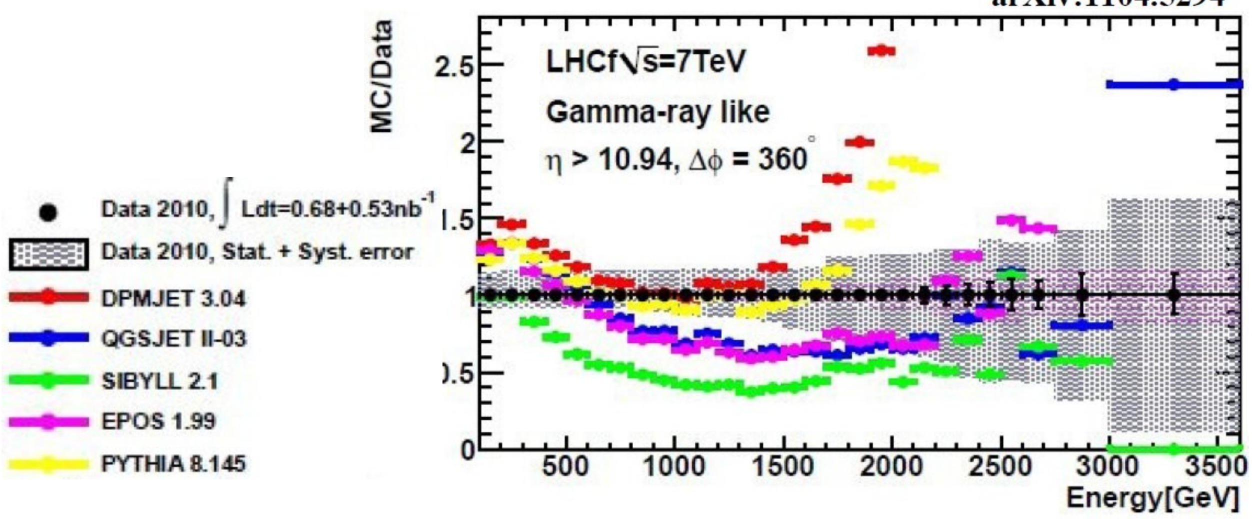
- Based on
  Regge Theory,
  Regge-Gribov approximation,
  pQCD, Unitarisation

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

Cosmic Ray MC Simulation Data provided by the Authors
(Thanks to T.Pierog, R.Engel, S.Ostapchenko !)
No further tuning of parameters in the comparison to H1 Data

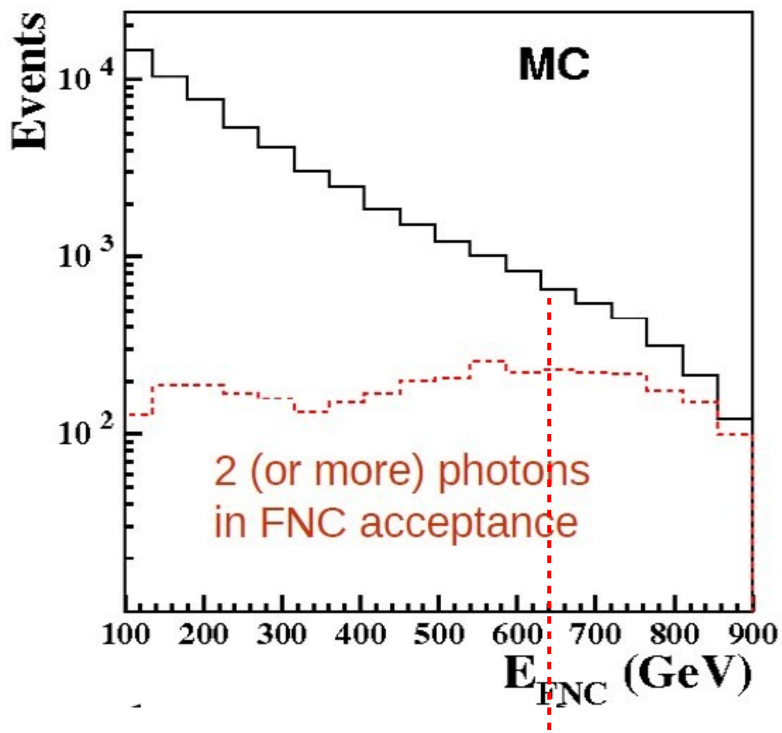
Models in development,
in particular using LHC data:
ATLAS, CMS, LHCb, LHCf ...

arXiv:1104.5294



Data and Phase Space of the H1 Measurement

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



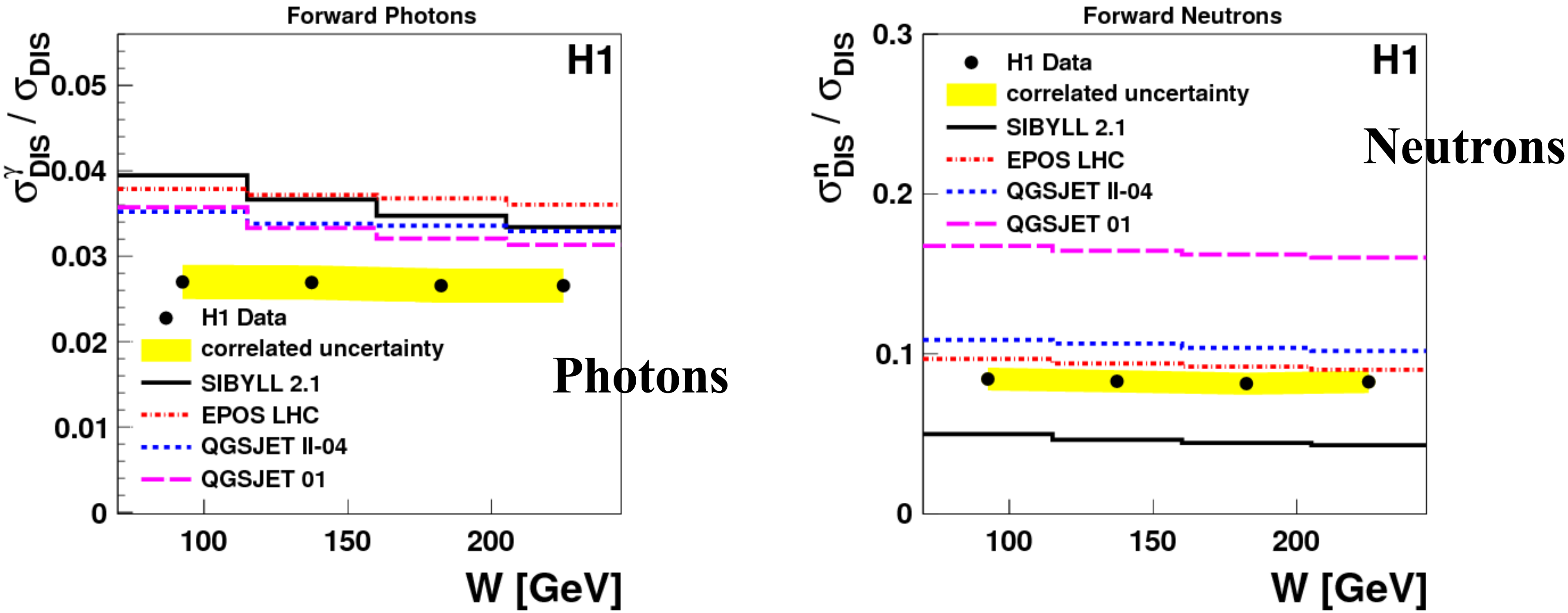
Suppress multi-photon events

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}

RESULTS

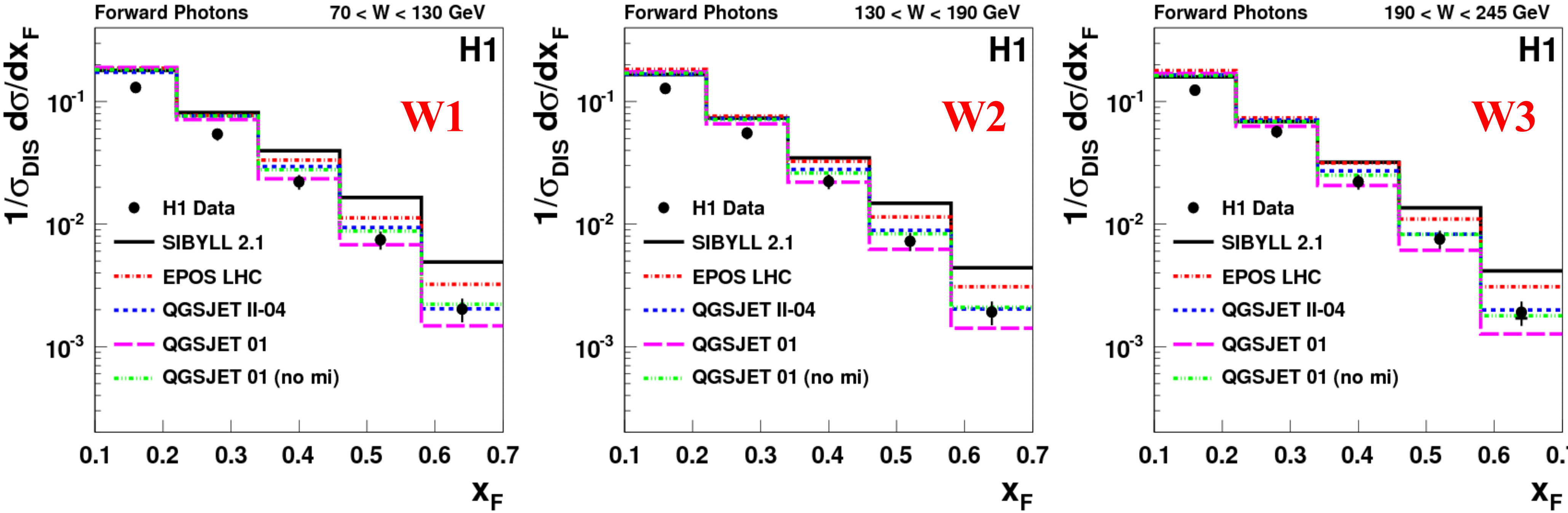
Normalised Cross Sections as a Function of W

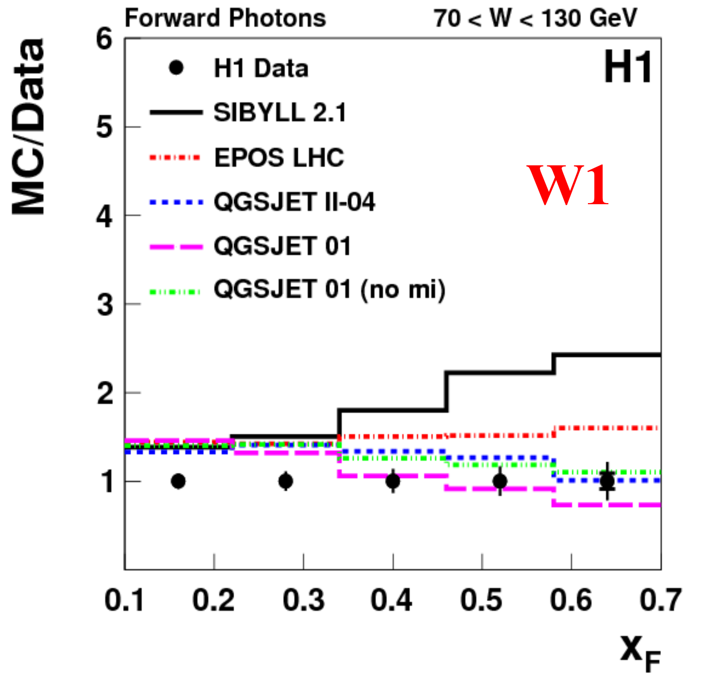


Forward Photons: All CR Models predict too high rate, by 30-40%
Models predict falling W-dependence,
Data independent of W

Forward Neutrons:
Large spread in the Model predictions
EPOS LHC closest to data, but still too high
All Models predict falling W-dependence, Data constant with W

Normalised Cross Sections as a function of x_F: Photons



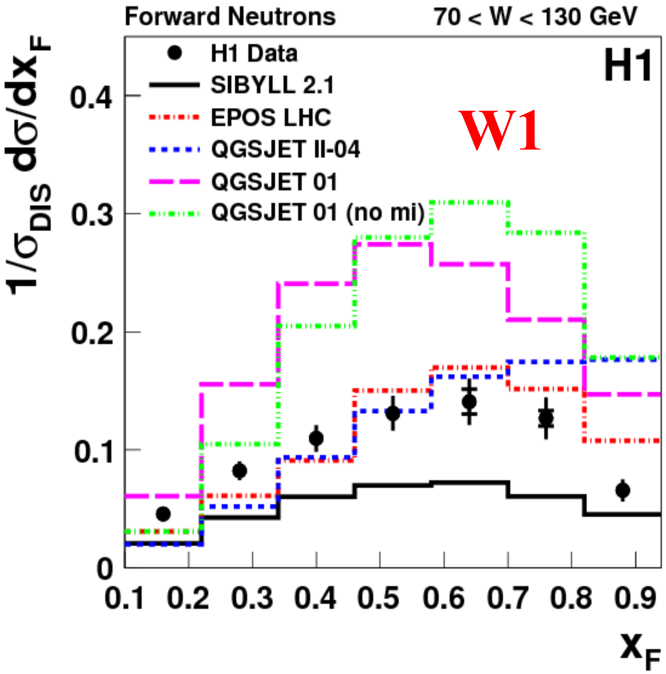


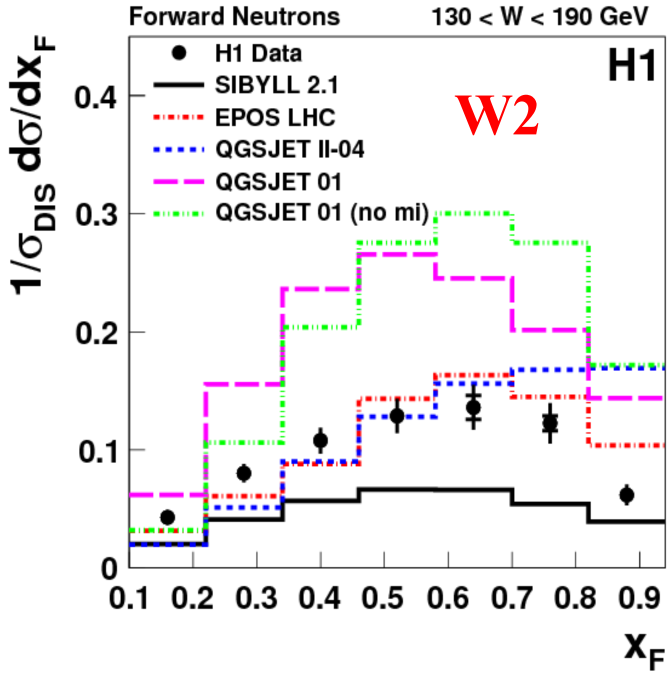
Photon Rates:
- CR Models predict Too High Photon Rates

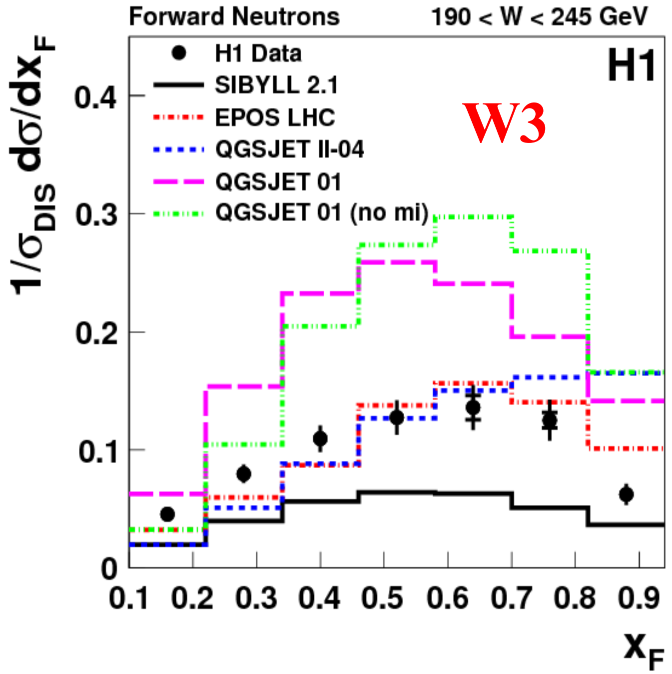
Photon x_F Dependence:
- QGSJET Models are Too Soft
- SIBYLL 2.1: Too Hard,
- EPOS LHC : Best Description, but also Too Hard

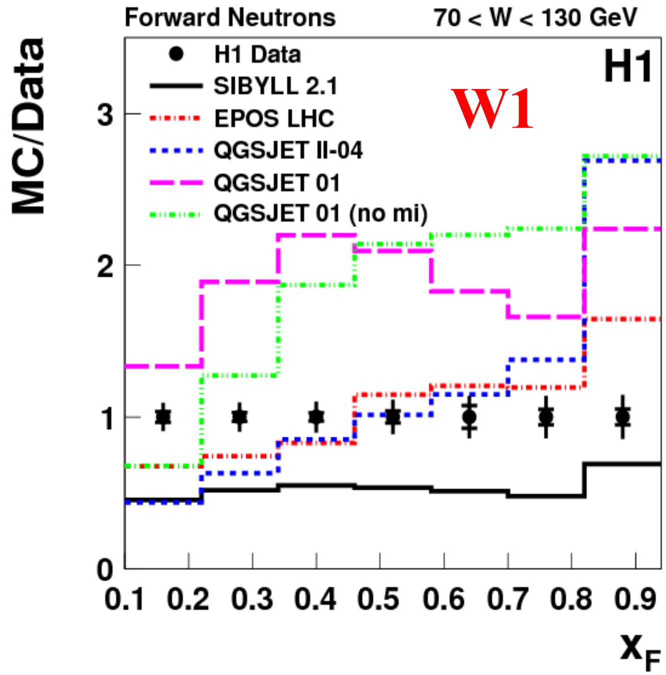
Multi-parton Interactions:
- Only small effect in QGSJET 01 (no mi)

Normalised Cross Sections as a Function of x_F: Neutrons









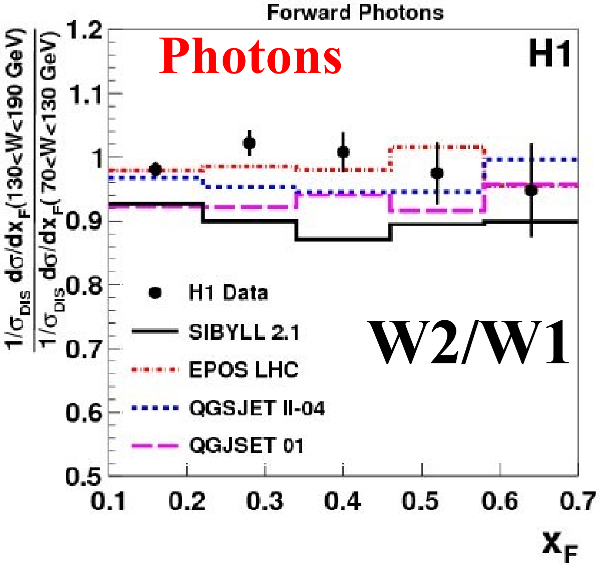
Neutron Rates:
- Very Different Neutron Rates predicted

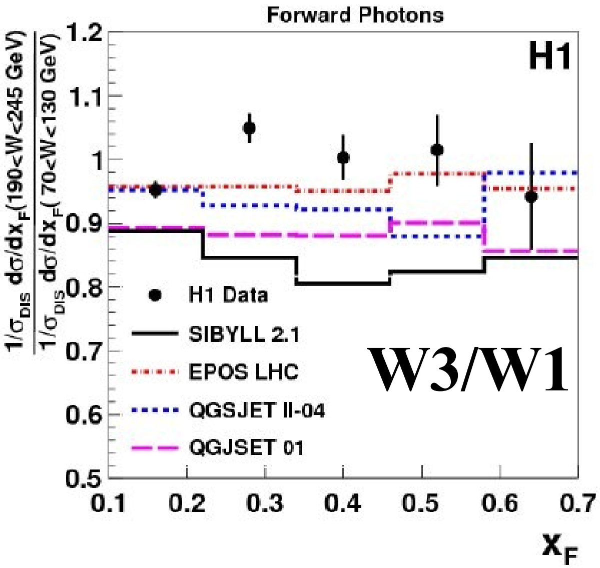
x_F Dependence:
- QGSJET Models Too hard, Too High Rates
- SIBYLL 2.1: describes x_F Dependence, but Too Low Rate
- EPOS LHC: reasonable description, except at highest x_F values

Multi-parton Interactions in QGSJET 01:
- Still Harder x_F Dependence with “no mi”

Test of Feynman Scaling: Photons and Neutrons, Data and CR Models

- 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

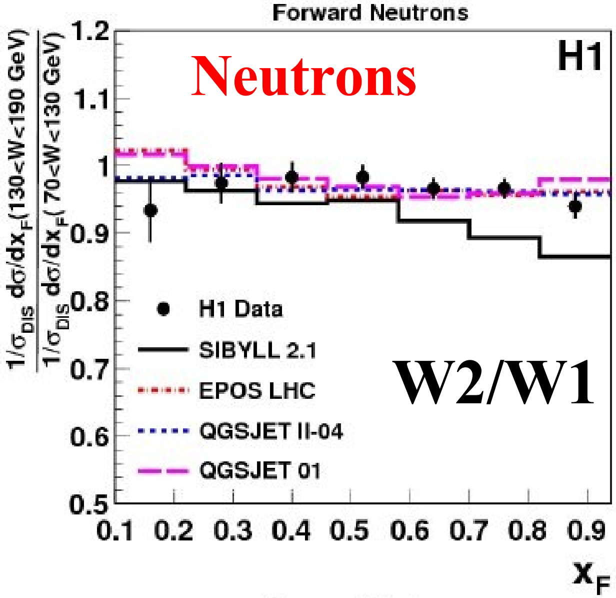


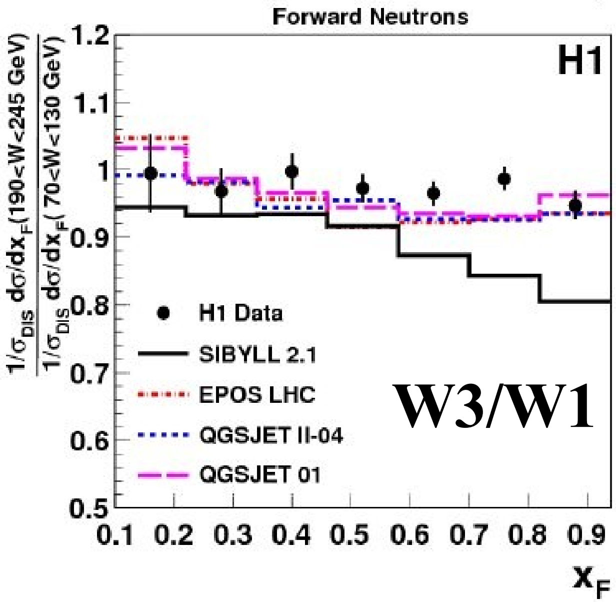


Photons and Neutrons:
Data are Compatible with Feynman Scaling

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





SUMMARY

DATA

- 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 independent of W, in W-range 70 - 245 GeV
- 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

COSMIC RAY MODEL COMPARISONS

- Photon Rate overestimated by all CR models, by 30-40 %
- No CR Model able to describe photon and neutron data simultaneously
- EPOS LHC closest to describing data well, but still differs significantly

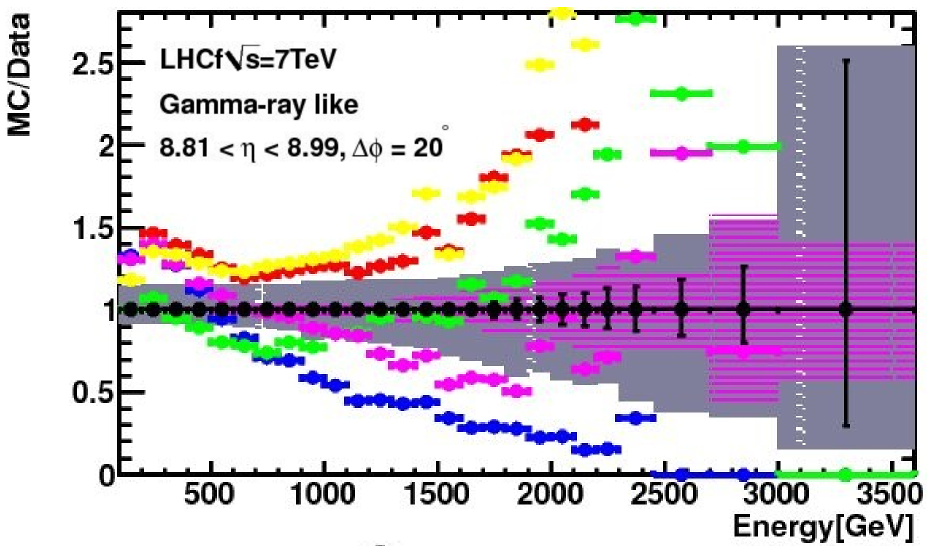
OUTLOOK

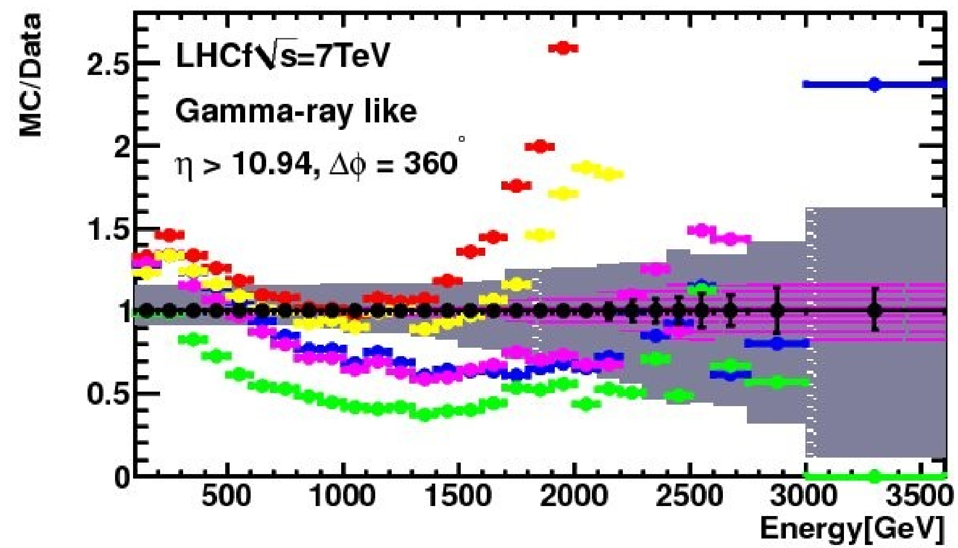
- New information to improve understanding of Proton Fragmentation
- New input to MC Model Simulation of Collider and Cosmic Ray data

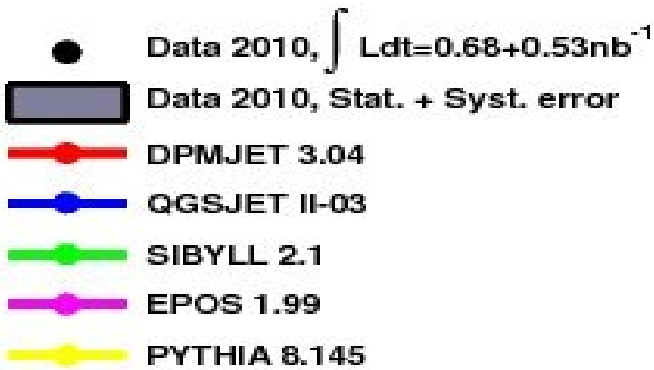
BACKUP

Comparison: LHCf and H1

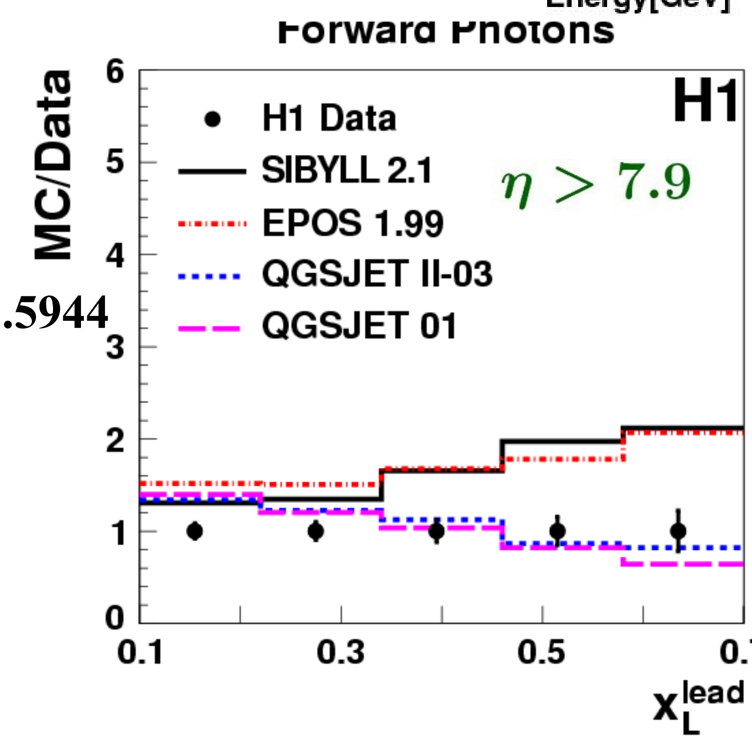
LHCf arXiv:1104.5294







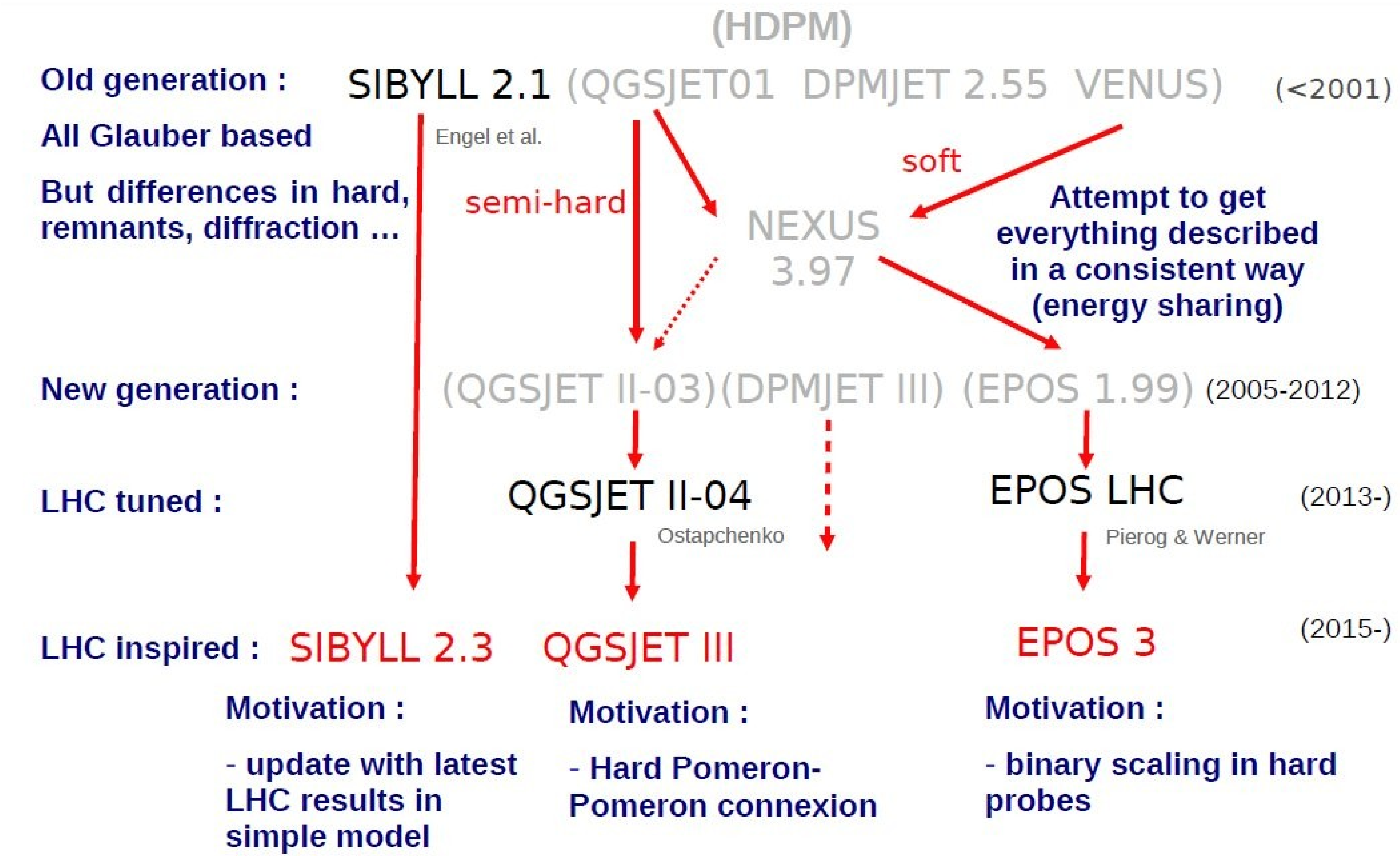
H1 arXiv:1106.5944



Note:
700 GeV: $x_L = 0.1$
3500 GeV: $x_L = 0.5$

CR Models behave differently in LHCf and H1

Overview of CR Model Development



Slide taken from T.Pierog, ISVHECRI 2014

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

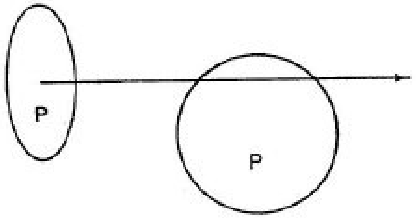


FIG. 4. Passage of Lorentz-contracted projectile through an extended target in the lab system.

Feynman Scaling

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 | **Feynman Scaling**

J.Benecke et al. Subm. 8/1969
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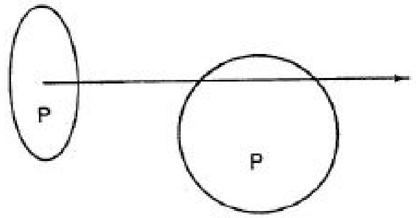

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Both concepts based on the same fact: the Lorentz Contraction of the Projectile

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)

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

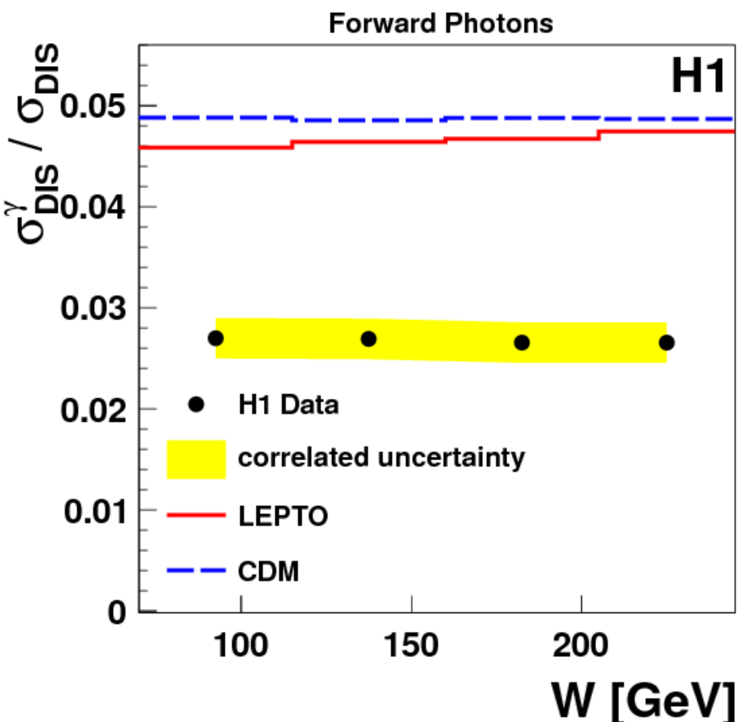
RAPGAP, with virtual photon scattering off the exchanged pion

Two production mechanisms for neutrons:

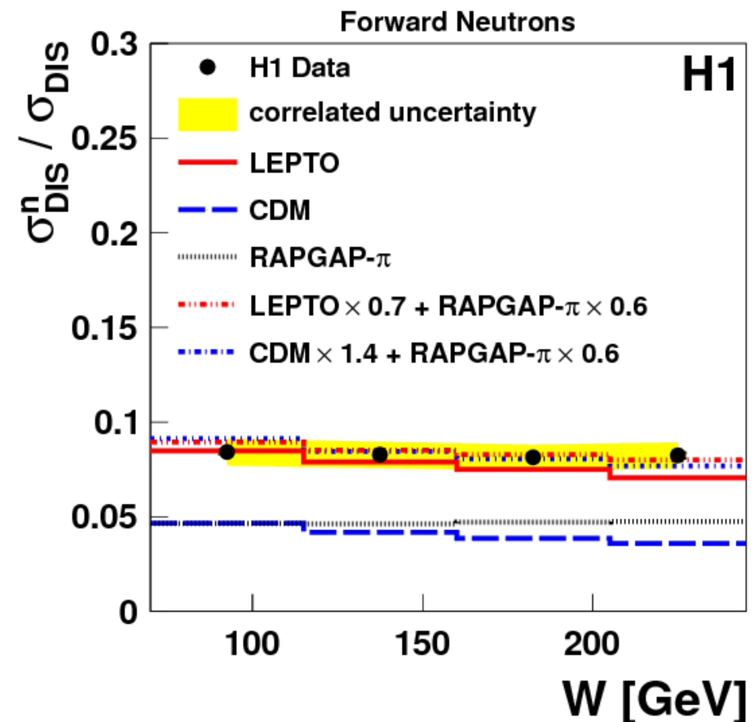
Already known from earlier FNC data analyses, that neutrons in data can be well described by combinations of Proton Fragmentation and Pion Exchange simulations:

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

Normalised Cross Sections as a function of W



Photons



Neutrons

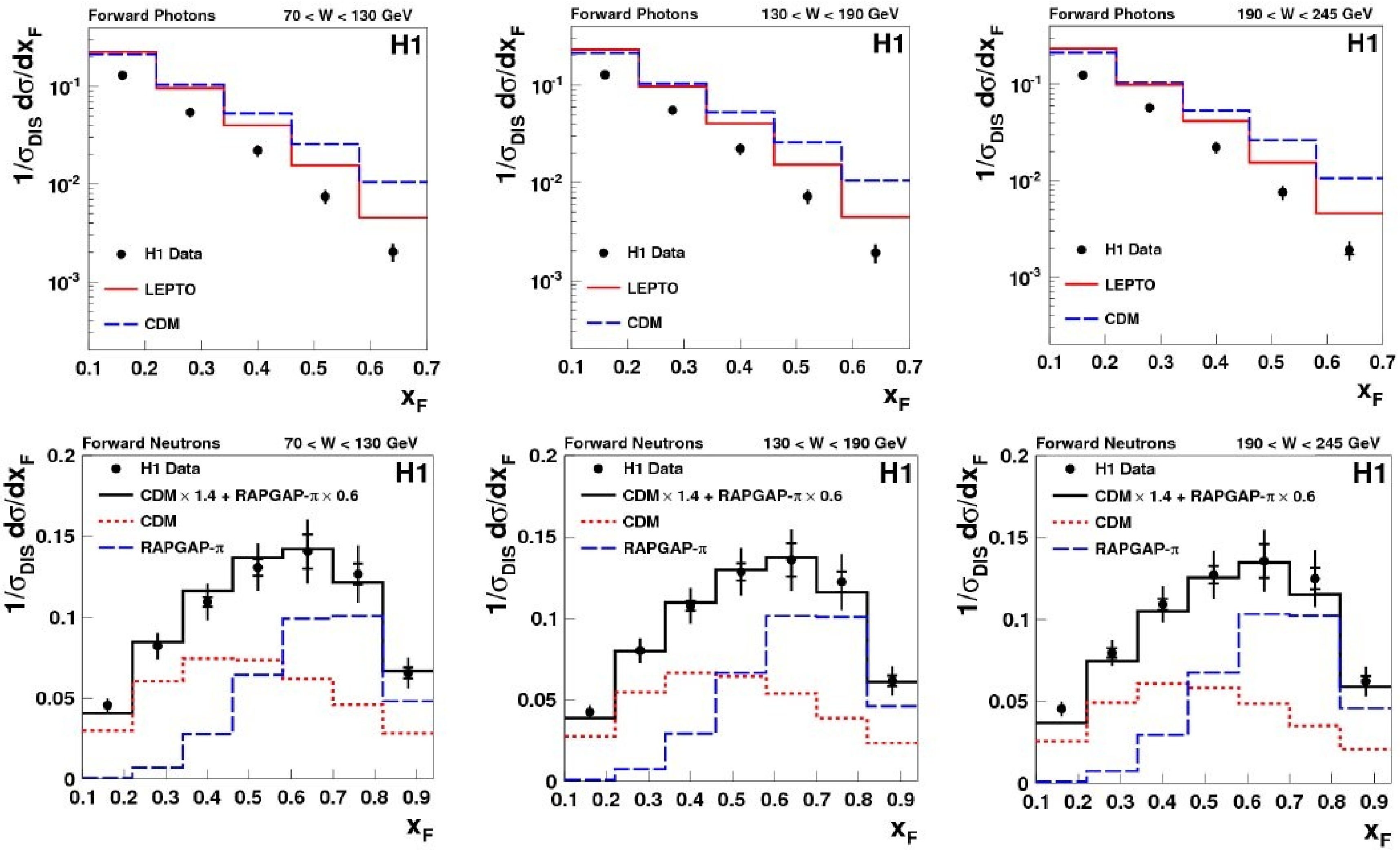
Fraction of Forward Photons and Neutrons in DIS events independent of W (Limiting Fragmentation)

- 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 x_F, in 3 W-intervals

Photons

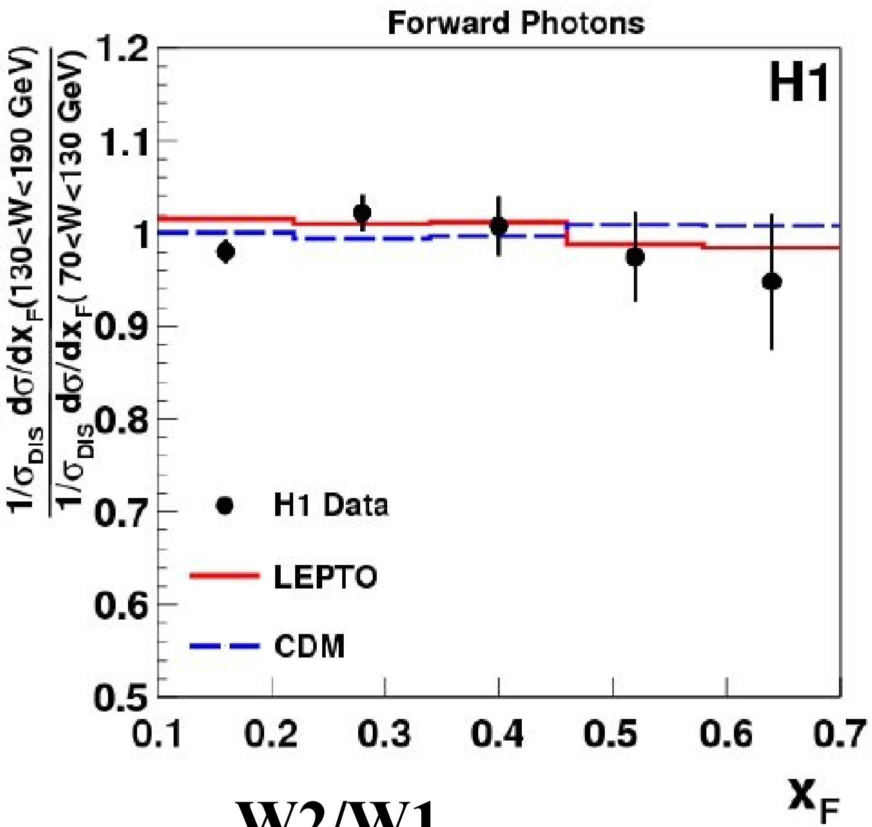
Neutrons



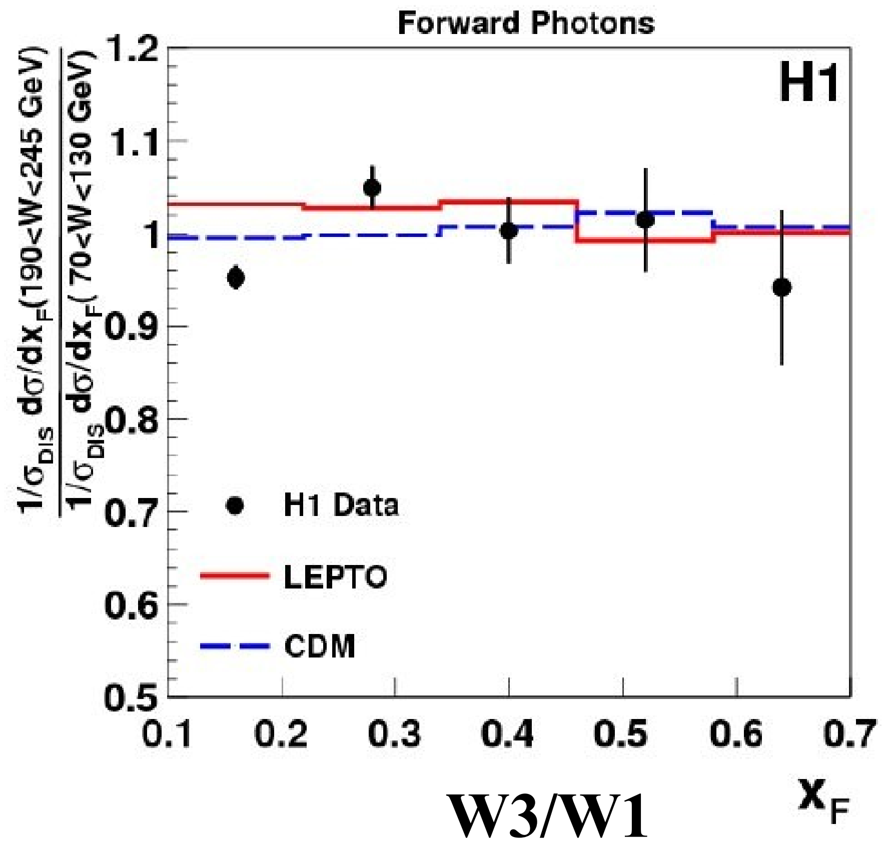
W1 **W2** **W3**

- 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

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