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Deep-Inelastic Scattering and
Related Subjects

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Production of Forward Photons in DIS at HERA

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On behalf of the H1 Collaboration

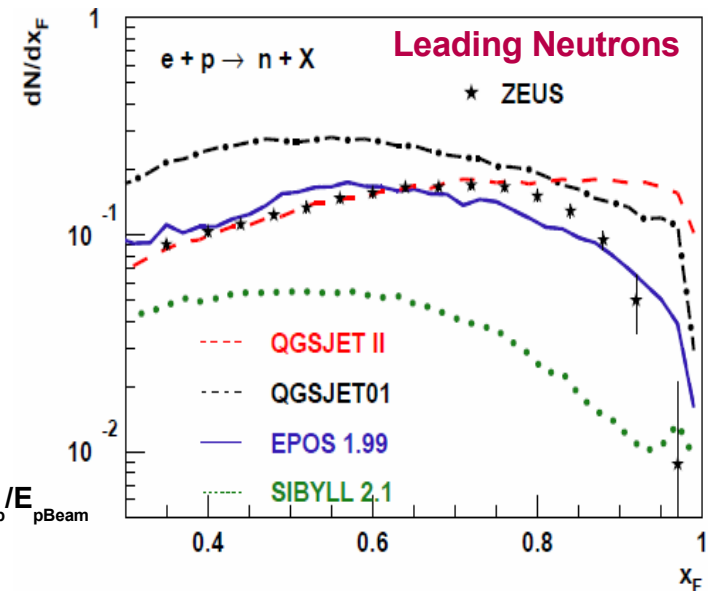
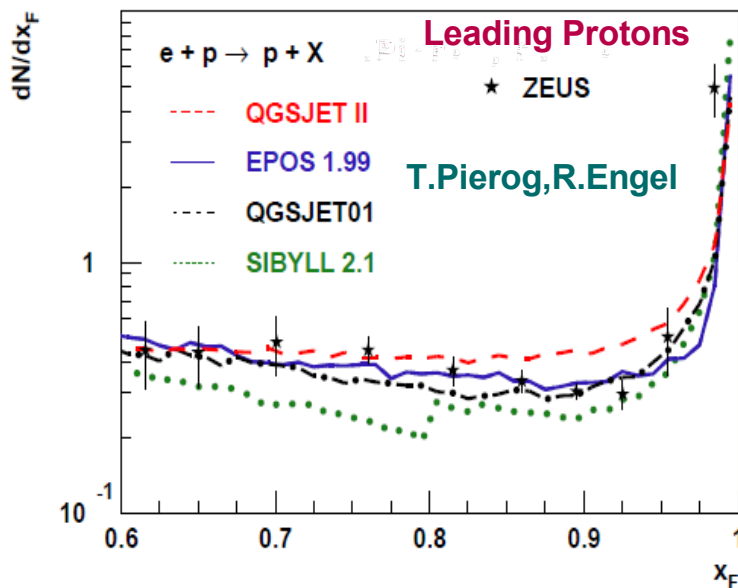
Outline

- ♦ Introduction
- ♦ Data analysis
- ♦ Results
- ♦ Conclusions

Introduction

Measurements of the forward particles (small angles to the proton beam in ep collisions) are important:

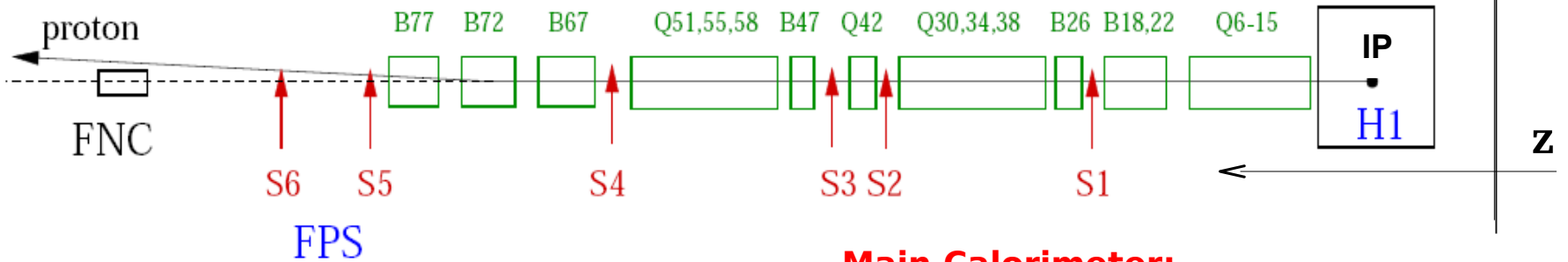
- for understanding the proton fragmentation,
- for models tuning, in particular for hadron interaction Cosmic Ray (CR) models (the shower development in matter is dominated by the soft, forward interactions)
- for testing the hypothesis of limiting fragmentation (production of forward particles is independent from the incident particle energy)



- Reasonable prediction for leading proton data (after model tuning)
- None of models describe leading neutron data well
- **Goal: Measure photon production in DIS and compare to the models**
- Similar measurement reported by LHCf in pp collisions

H1 Forward Neutron Calorimeter (FNC)

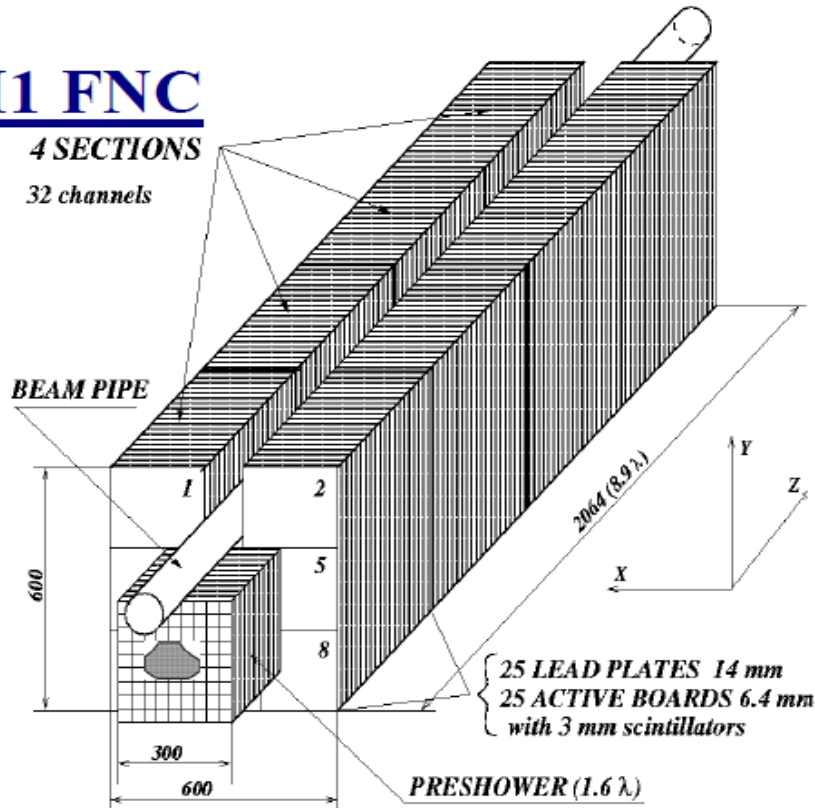
106m from IP



H1 FNC

4 SECTIONS

32 channels



Main Calorimeter:

4 modules $60 \times 60 \times 51 \text{ cm}^3$, 8.9λ

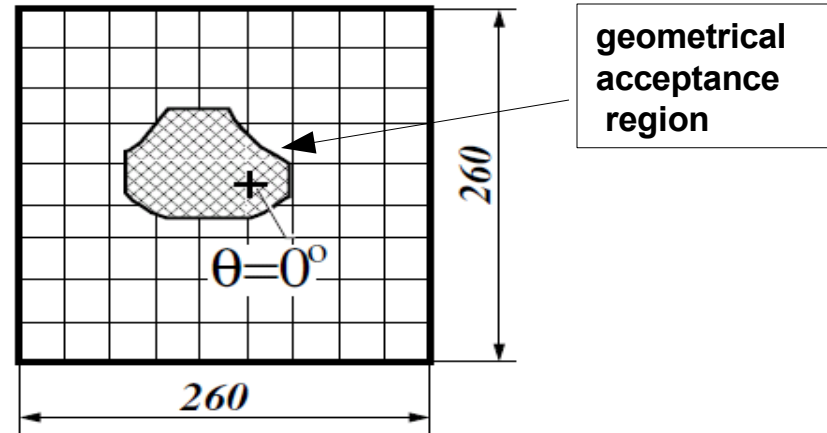
Preshower:

$26 \times 26 \times 40 \text{ cm}^3$, $60X_0$, 1.6λ

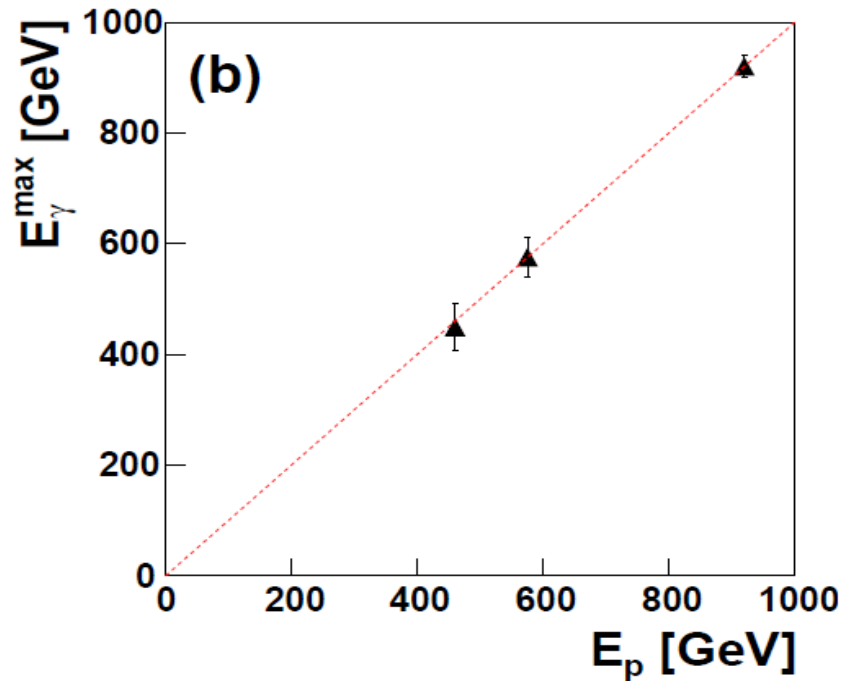
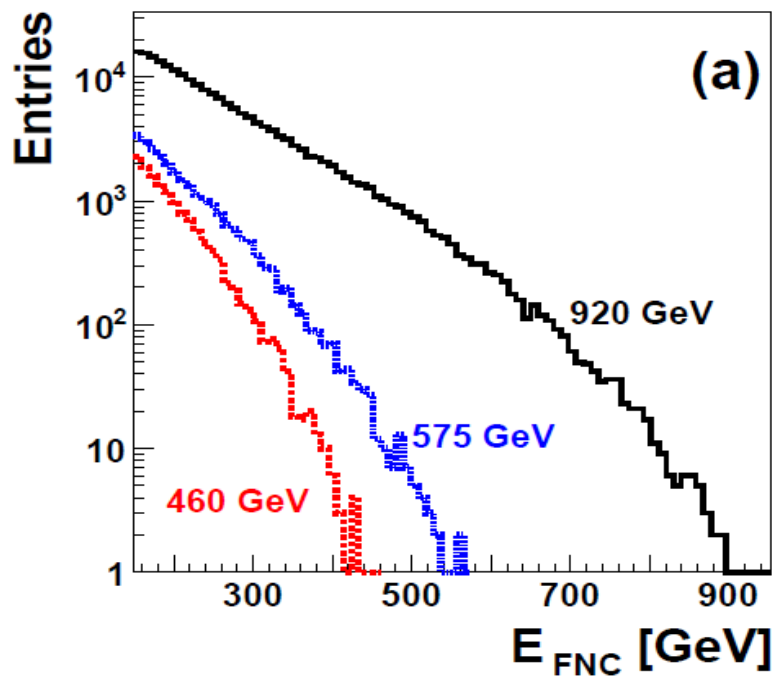
e/m shower contained in Preshower
 \Rightarrow separation photons from neutrons
 9x, 9y strips

Position resolution: 2mm

$\sigma(E)/E \approx 20\%/\sqrt{E[\text{GeV}]} \oplus 2\%$ for e/m shower



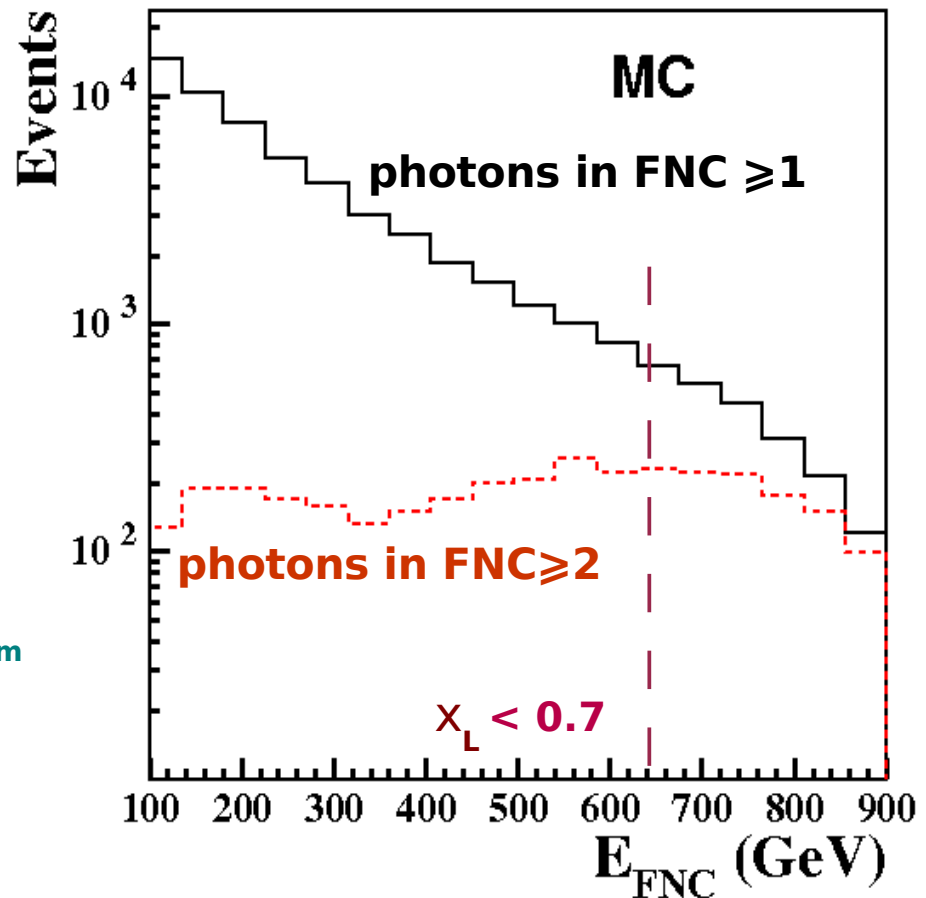
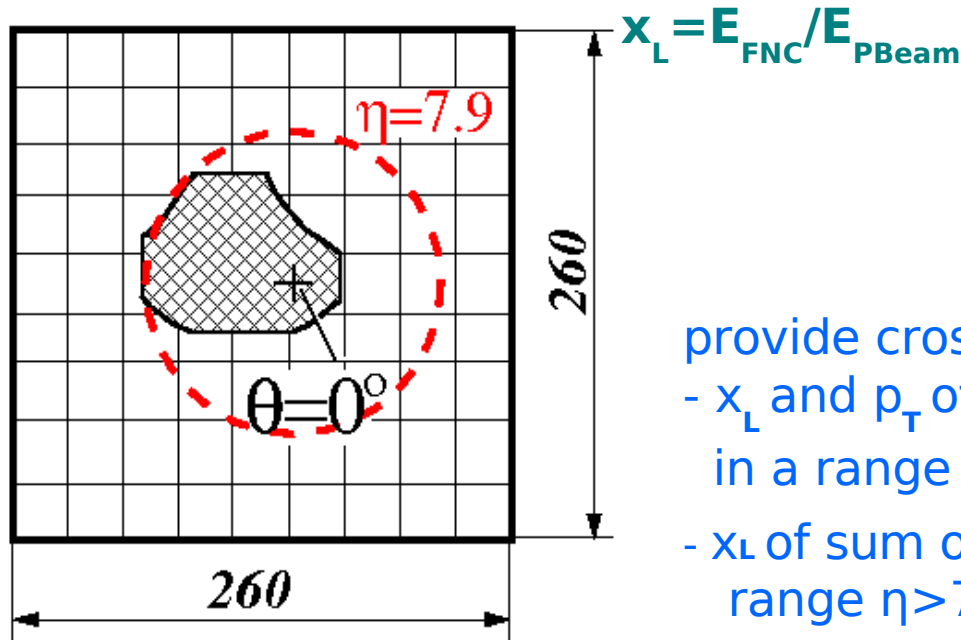
Preshower Calibration



- Refined calibration constants are determined using an iterative procedure assuming that the $E_{\gamma}^{\text{max}} \approx E_{\text{pBeam}}$ in case of unlimited statistics.
- a) The measured photon energy spectra for three proton beam energies.
- b) The correlation between the proton beam energy and E_{γ}^{max}

Photon candidates

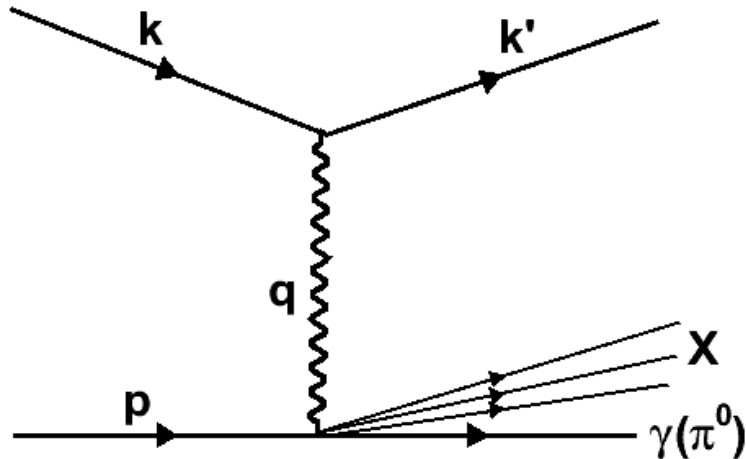
At high x_L , many FNC clusters are from more than one photon!
 So measurement represents the sum of photons inside the angular range defined by the geometrical acceptance $\eta > 7.9$.
 But at lower x_L we can assume that to a good approximation we measure one photon.



provide cross sections:

- x_L and p_T of leading photon in a range $\eta > 7.9$ for $x_L < 0.7$
- x_L of sum of photons in a range $\eta > 7.9$ for $x_L < 0.95$

Kinematics and selection cuts



$$q = k - k'$$
$$y = (qp) / (kp)$$

$$Q^2 = -(k - k')^2$$
$$x_{Bj} = Q^2 / (2pq)$$

2006-2007 data

$E_e = 27.5 \text{ GeV}$ $E_p = 920 \text{ GeV}$ $\sqrt{s} = 319 \text{ GeV}$

Lumi = 126 pb^{-1}

DIS selection:

$E'_e > 11 \text{ GeV}$ $\Theta'_e = (156^\circ - 175^\circ)$ in SpaCal
 $|Z_{vtx}| < 35 \text{ cm}$ $\Sigma(E - pz) = (35 - 70) \text{ GeV}$

$6 < Q^2 < 100 \text{ GeV}^2$ $0.05 < y < 0.6$

Photon selection:

Photon candidate in FNC with

$$\eta_\gamma > 7.9 \text{ (lab frame)}$$

$$x_L = E_\gamma / E_p > 0.1$$

Statistics:

78740 DIS events with forward photons

Monte Carlo models

Data compared to Monte Carlo models:

- inclusive DIS MC **DJANGO14 (H1PDF2009 parametrization)**:
 - LEPTO** - leading log parton shower
 - ARIADNE** - color dipole model (CDM)
- Hadronic interaction Cosmic Rays (CR) models:
 - QGSJET 01 and II-03**: (Kalmykov, Ostapchenko)
 - EPOS 1.9**: (Pierog, Werner)
 - SIBYLL 2.1**: (Engel, Fletcher, Gaisser, Lipari, Stanev)

Based on: Regge theory, Gribov-Regge approximation,
perturbative QCD, unitarisation.

Differences in modeling the mini-jet production, formation of colour strings and fragmentation, treatment of saturation effects, treatment of hadron remnants.

In all these models the main source of forward photons is the decay of π^0 mesons produced from the hadronisation of the proton remnant.

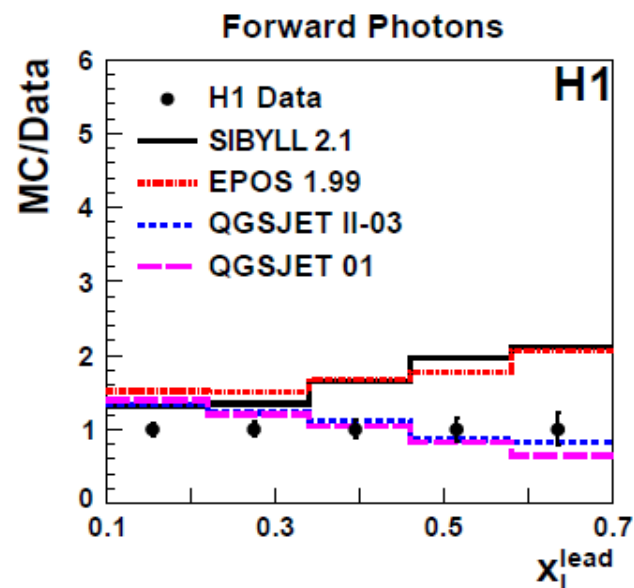
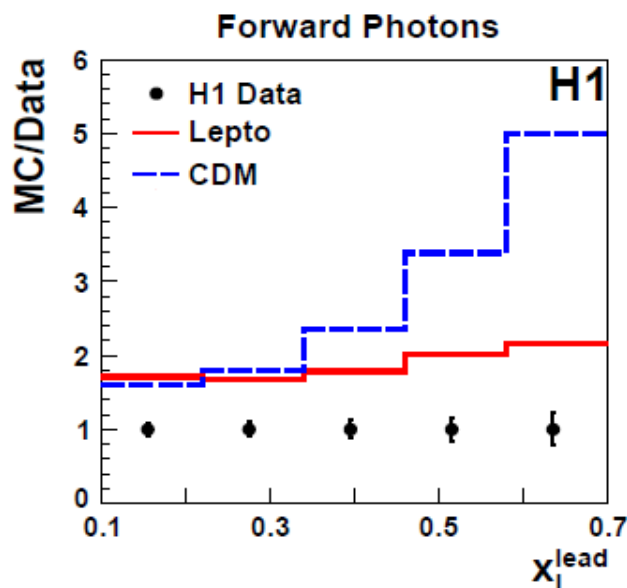
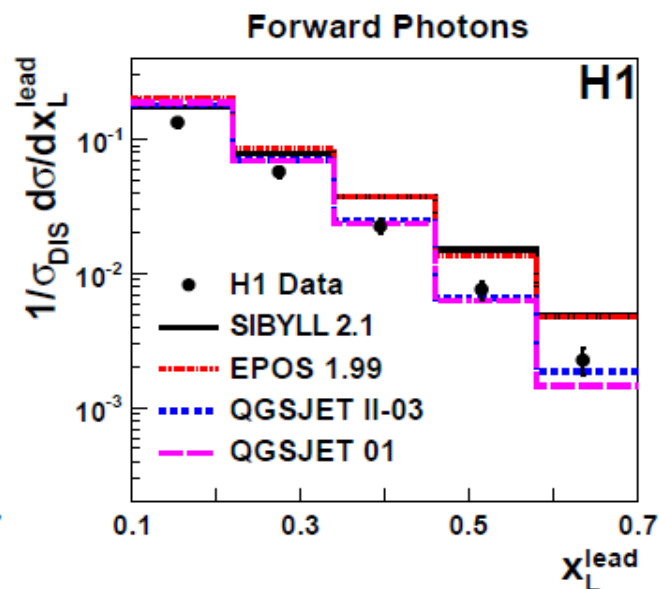
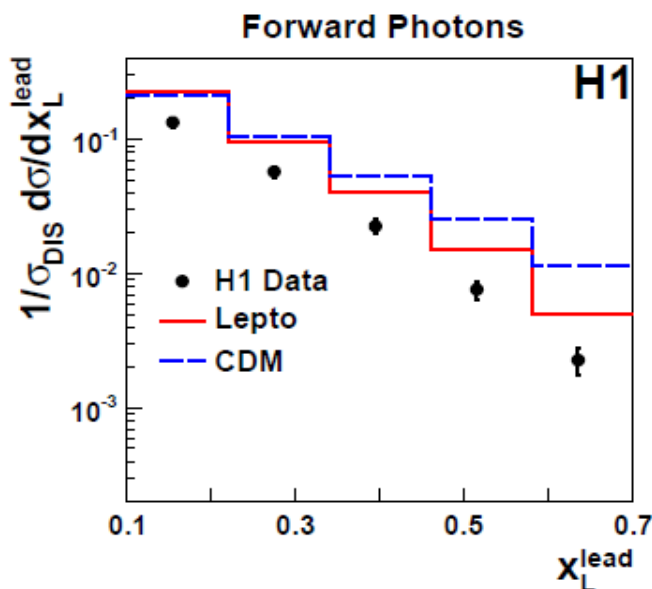
Forward photon cross sections vs x_L^{lead}

Photon rate in all used MC models is significantly higher than in the data. LEPTO, CDM higher by 70% CR models higher by 30-50%.

LEPTO model describe the shape reasonably well.

CDM to data discrepancy larger at higher x_L .

QGSJET models have steeper behavior than the data, close to data in absolute values except at low x_L .



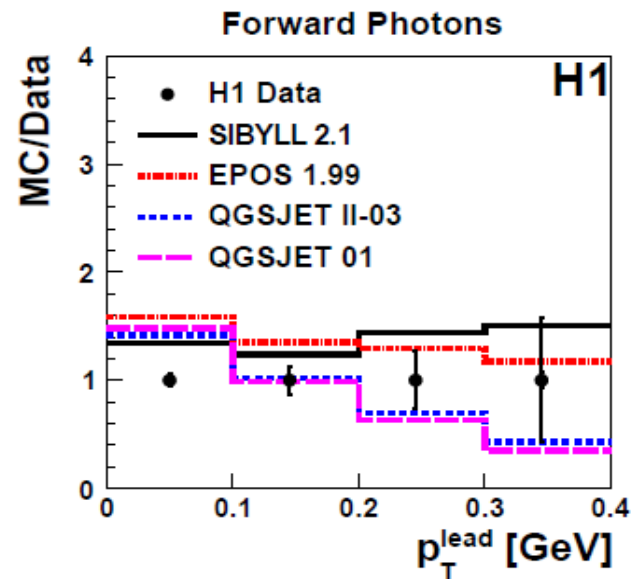
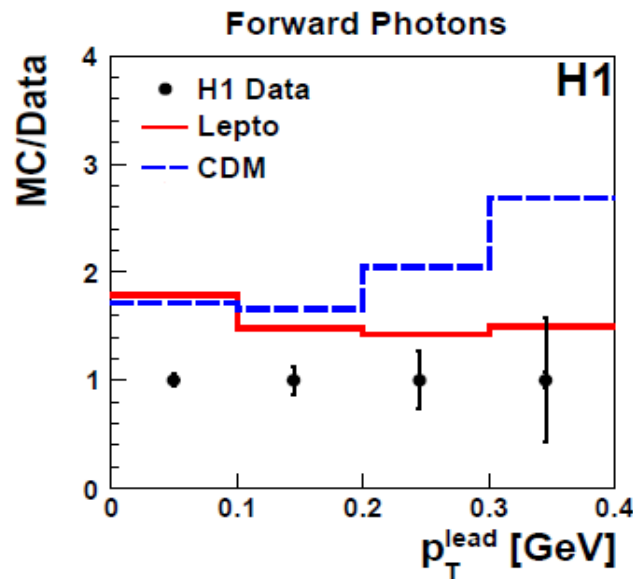
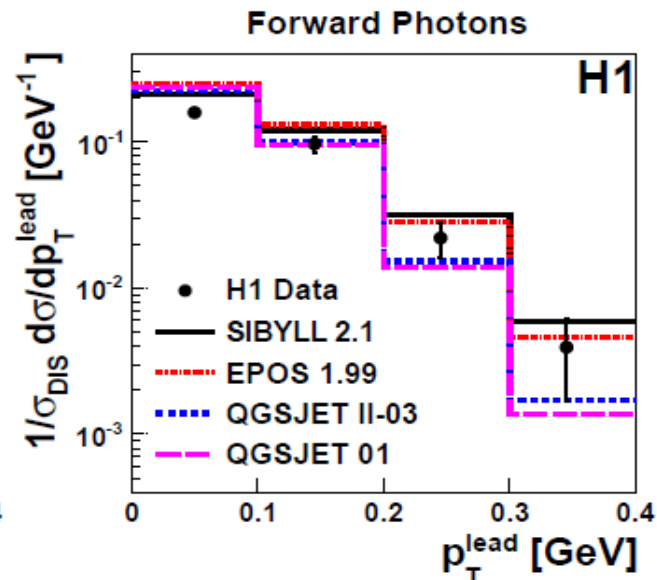
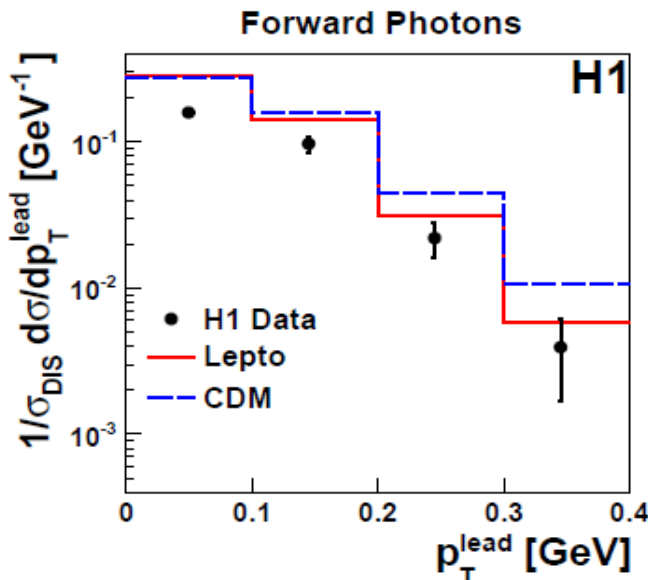
Forward photon cross sections vs p_T^{lead}

Photon rate in all MC the models is significantly higher than in the data.

LEPTO model describe the shape reasonably well.

p_T spectrum shape is well described by SIBYLL and EPOS models.

QGSJET also agree with data within uncertainties (except lowest p_T)



Forward photon cross sections vs x_L^{sum}

$$x_L^{\text{sum}} = \sum E_i / E_{\text{Pbeam}}$$

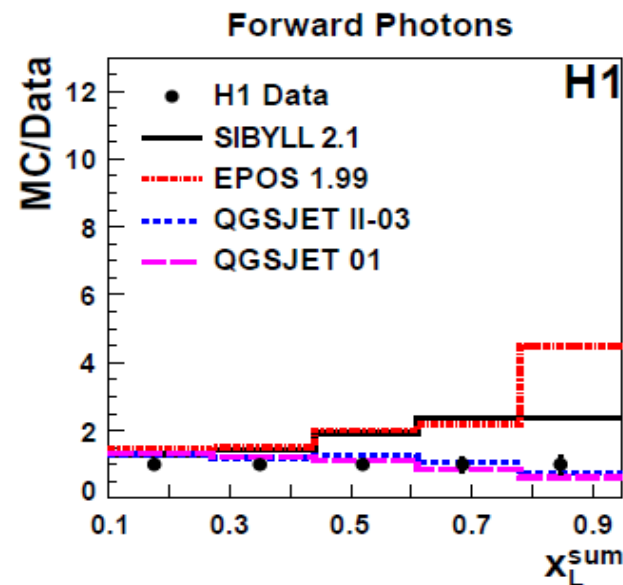
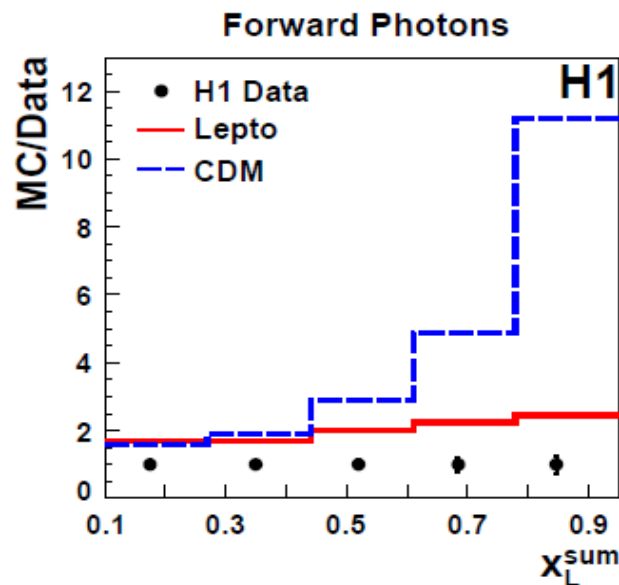
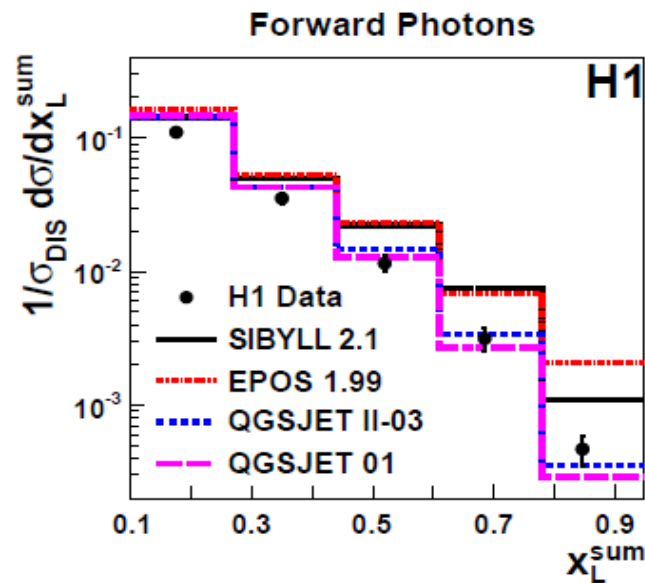
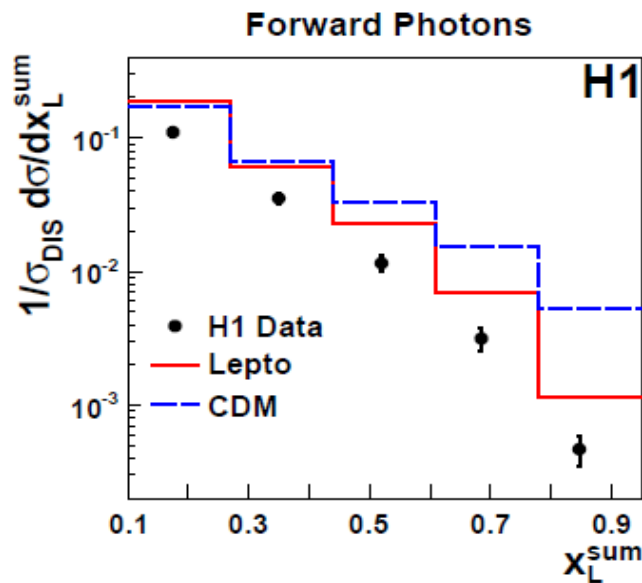
for photons in $\eta > 7.9$

Photon rate in all MC models is significantly higher than in the data.

LEPTO model describe the shape reasonably well.

CDM: large discrepancy at higher x_L .

QGSJET models describe data shape better than SIBYLL and EPOS. Difference is more pronounced for EPOS in highest x_L^{sum} bin.



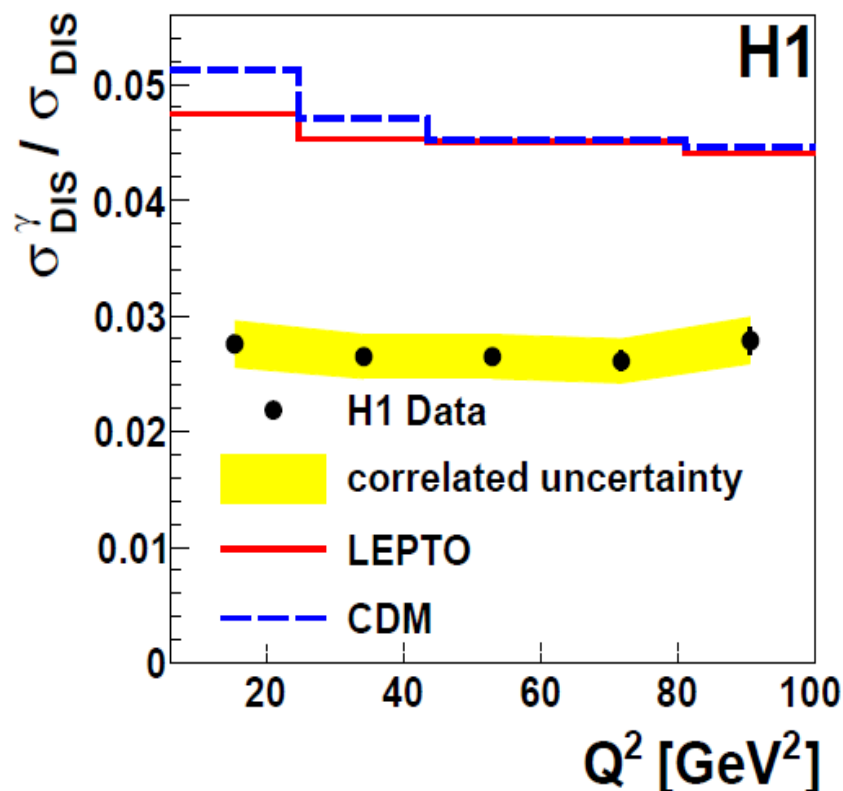
Fraction of DIS events with forward photons

Test of limiting fragmentation hypothesis

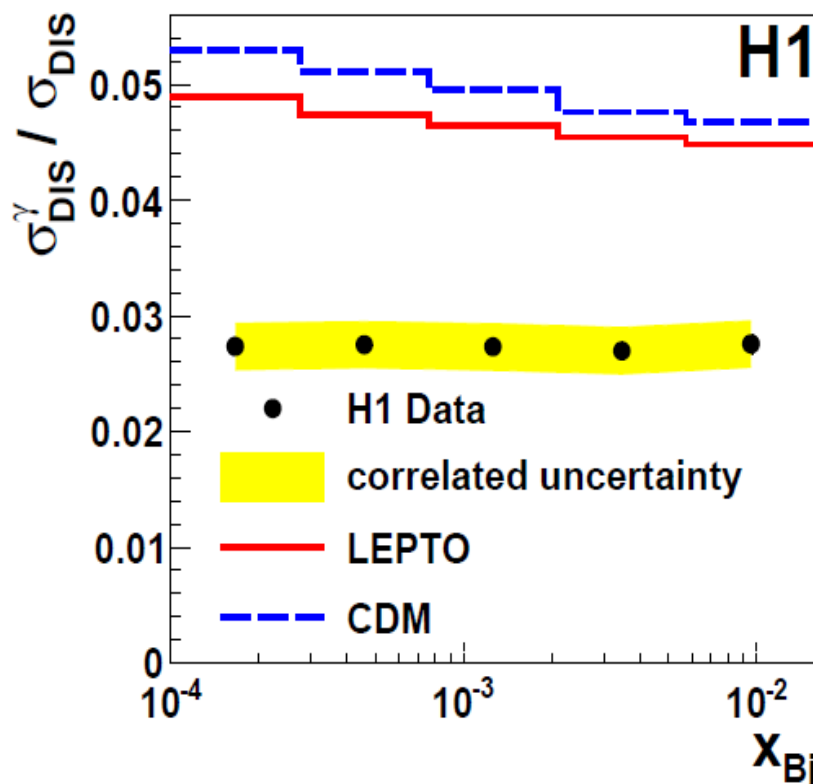
(Forward particle production insensitive to Q^2, x_{Bj}).

DIS events with forward photons $6 < Q^2 < 100 \text{ GeV}^2$, $0.05 < y < 0.6$, $\eta_\gamma > 7.9$, $0.1 < x_L^{\text{sum}} < 0.95$

Forward Photons



Forward Photons



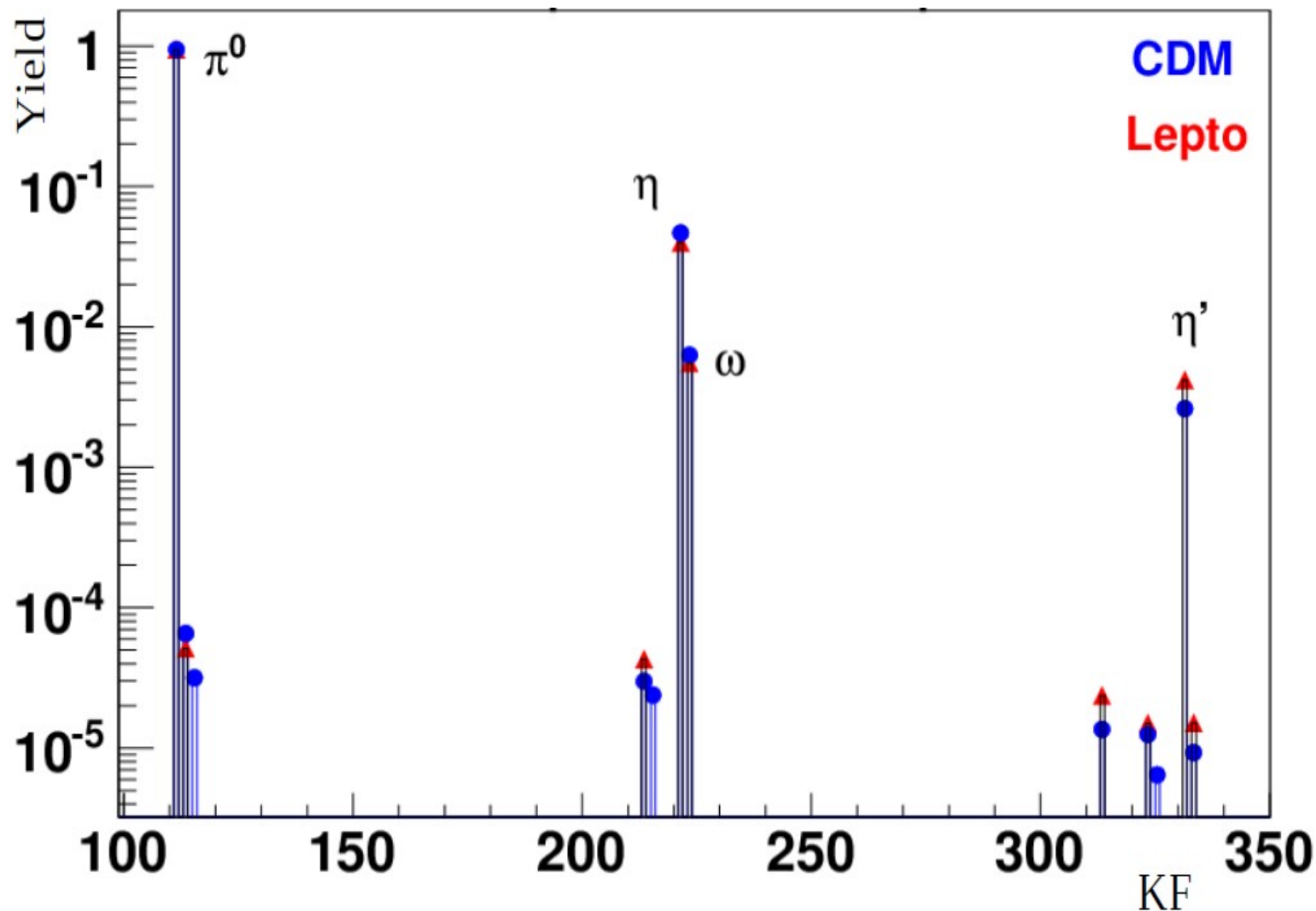
LEPTO and CDM models predict much higher rate of forward photons and show slight Q^2 and x_{Bj} dependence.

Data support the hypothesis of limiting fragmentation.

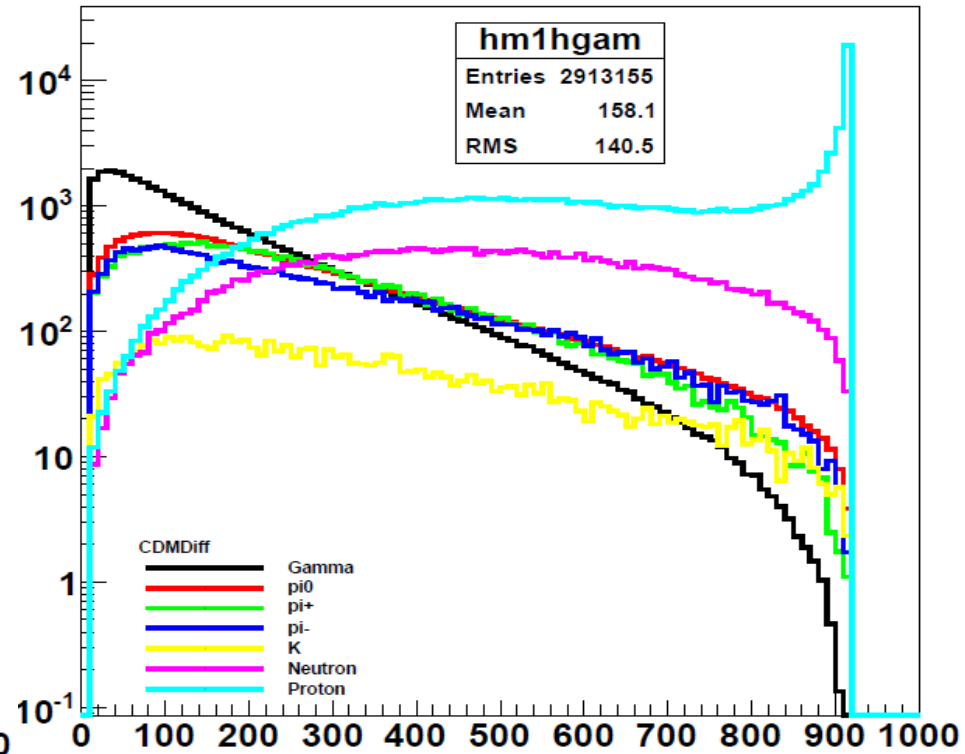
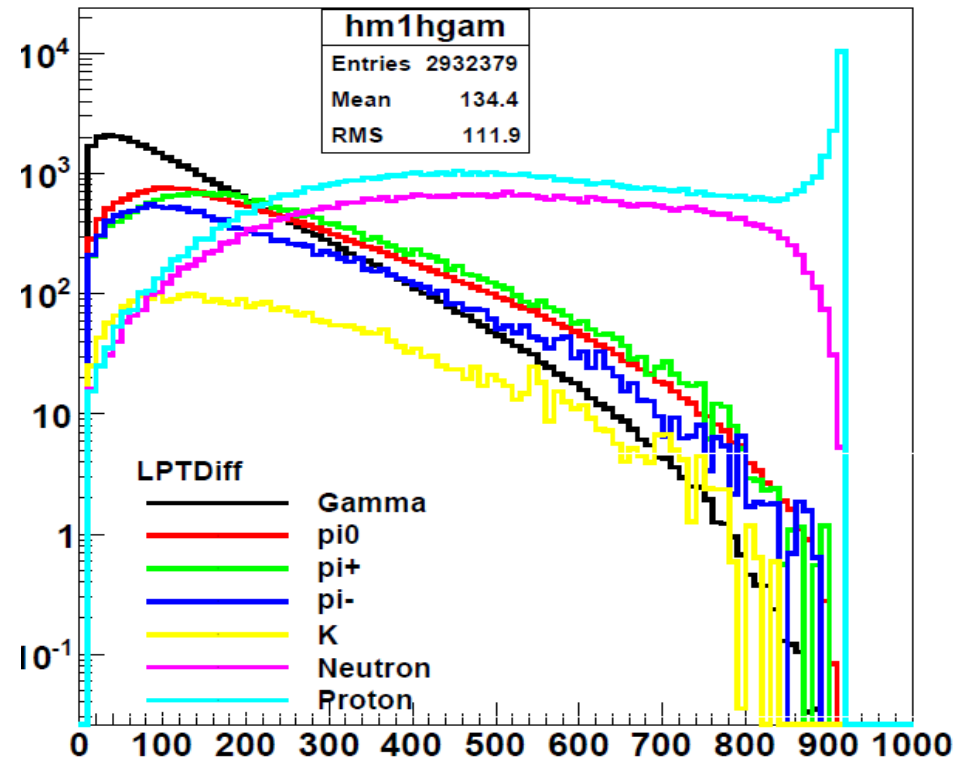
Conclusions

- First measurement of very forward photon production in DIS
- Measurements show sensitivity to proton fragmentation models. Useful input for MC models tuning
- All models predict significantly higher yield of photons than data
- LEPTO describes the shape well
- CDM predicts harder x_L and p_T spectra
- Hadronic interaction CR models overestimate the measurements by 30-50% and predict different x_L and p_T spectra
- Fraction of DIS events with forward photons is independent of Q^2, x_{Bj} , supporting limiting fragmentation hypothesis

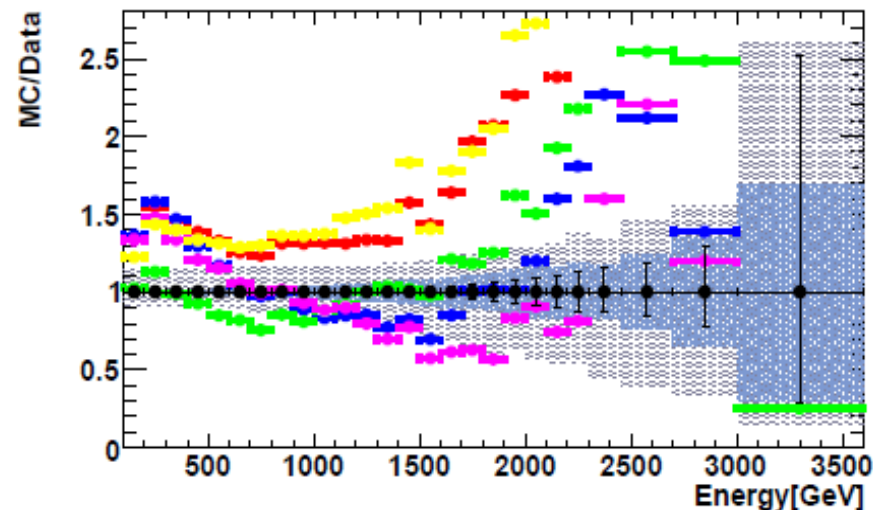
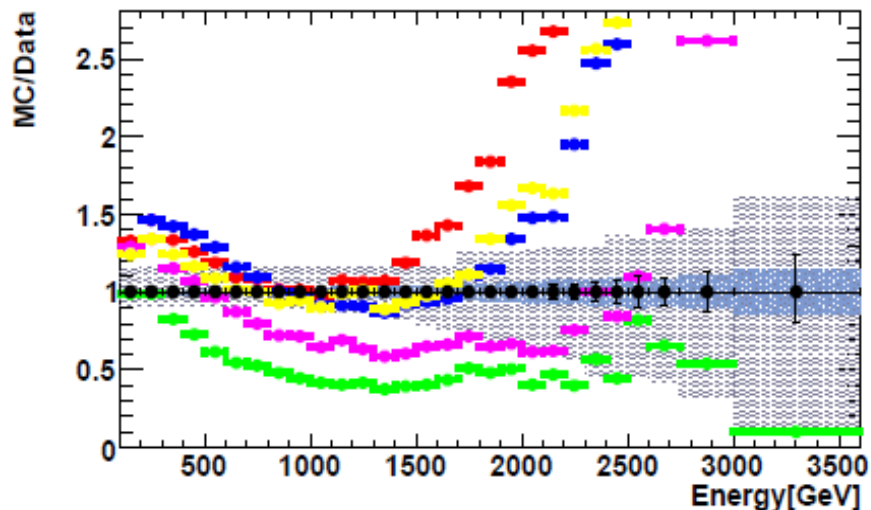
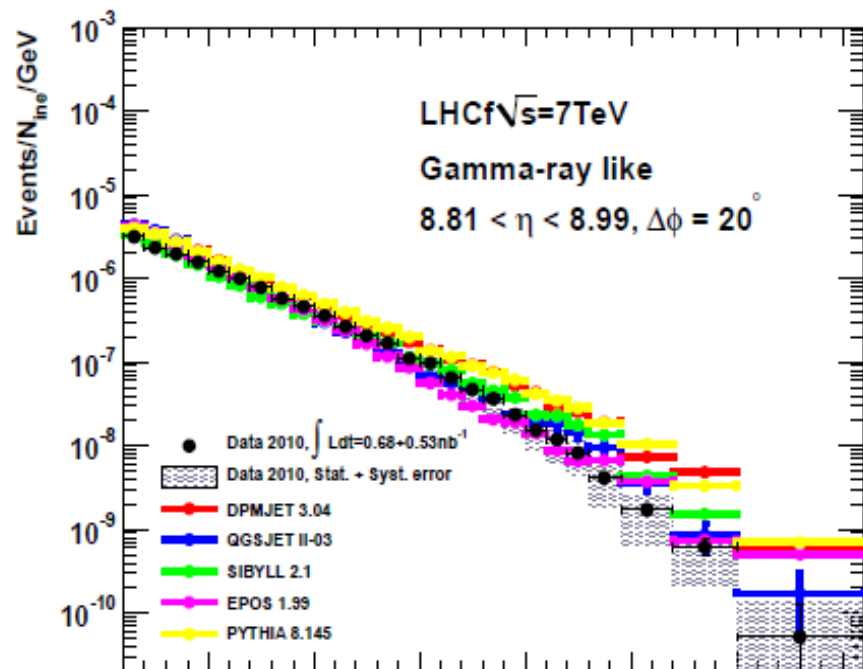
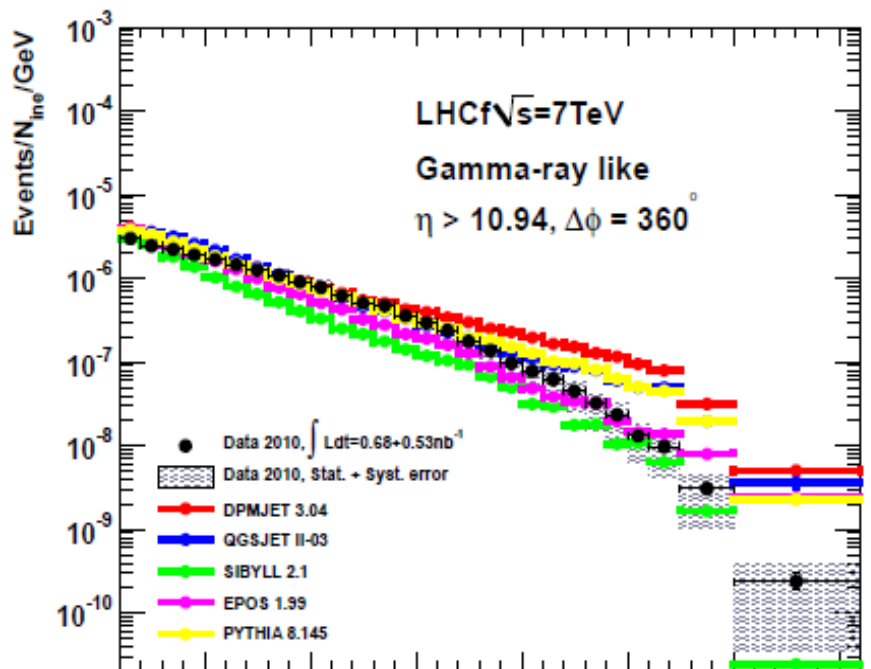
PID of forward photons mother particles



Forward particles from MC



LHCf forward photon measurements and models



Example of event with high energy photon from Lepto

0 e+	beam	-1	-1	-1	-1	-0.0000	-0.0000	-27.6000	27.6000	0.0000
1 proton	beam	-1	-1	-1	-1	-0.0000	-0.0000	919.9995	920.0000	0.9479
2 Z0	doc	0	-1	-1	-1	-1.5038	2.2638	-2.1872	2.0421	-2.8285
3 e+	stable	0	-1	-1	-1	1.5032	-2.2625	-25.3478	25.4929	0.0043
4 gamma	rad gam	0	-1	-1	-1	0.0006	-0.0013	-0.0650	0.0650	-0.0000
5 u	decayed	-1	-1	7	9	-1.8420	2.6292	-0.8964	3.3331	0.0136
6 ud_0	decayed	1	-1	7	9	0.3383	-0.3653	918.7076	918.7079	0.5593
7 u	decayed	5	-1	10	10	-0.9880	2.0348	-0.9832	2.4664	0.0114
8 ud_0	decayed	5	-1	10	10	-0.4697	-0.3783	0.0584	0.8383	0.5793
9 pi0	decayed	5	-1	13	14	-0.0461	0.6073	918.7360	918.7362	-0.1858
10 string	decayed	7	8	11	12	-1.4577	1.6565	-0.9248	3.3047	2.2797
11 Delta0	decayed	10	-1	15	16	-0.9938	1.5687	-0.7063	2.3378	1.2320
12 rho+	decayed	10	-1	17	18	-0.4638	0.0878	-0.2185	0.9670	0.8151
13 gamma	stable	9	-1	0	0	-0.0014	-0.0034	0.8916	0.8916	-0.0003
14 gamma	stable	9	-1	0	0	-0.0447	0.6107	917.8445	917.8446	-0.3884
15 neutron	stable	11	-1	0	0	-0.5484	1.2748	-0.4870	1.7452	0.9396
.....										
20 gamma	stable	16	-1	0	0	-0.0921	0.0370	0.0089	0.0997	0.0000