Leading baryon production in ep and hadron-hadron collisions

Low-x Workshop Meeting @ Kyoto YITP
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Today's subject

- Comparing the leading neutron data from HERA with the new LHCf environment
  - Neutron production in LHCf kinematic range evaluated using HERA parameterisation

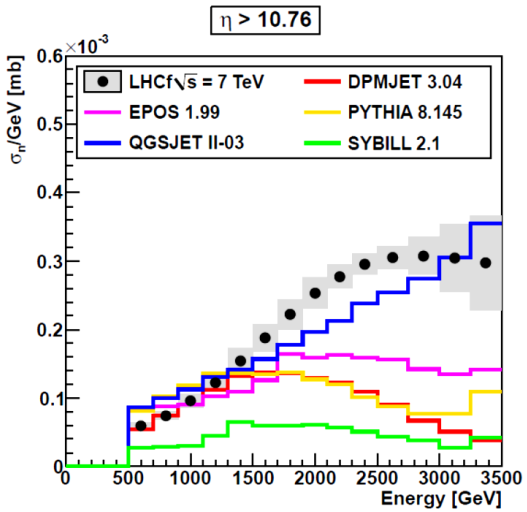
Special thanks to

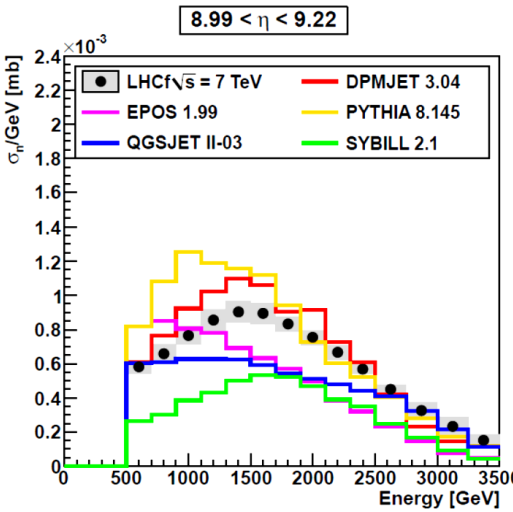
- LHCf group: Prof. Y. Itow, Prof. T. Sako, Dr. K. Kawade
- P. Ostapchenko and T. Pierog – borrowing slides

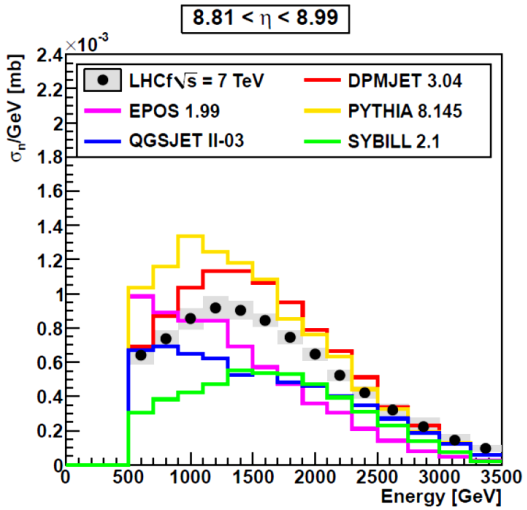
The LHCf measurement

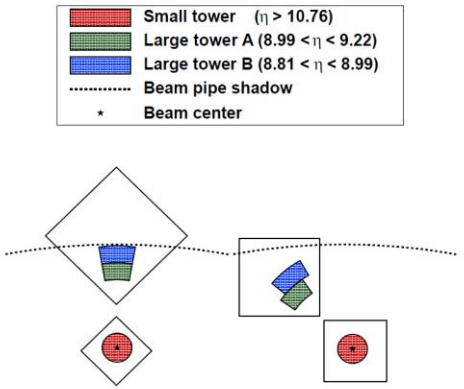
See talk by Takashi Sako

- Self-trigger: inclusive measurement
- Three angular ranges
- Very forward bin: many neutrons at $x_F = 1$
- Many models predict the flat behaviour:
  - QGSJET II-03
  - EPOS 1.99
  - PYTHIA 8.145





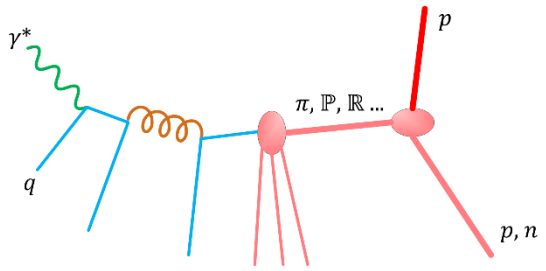




From Doctoral Thesis by K. Kawade

HERA measurements

- DIS events ($Q^2 > 2$ (ZEUS) or 6 (H1) GeV^2)
- Well described by a combination of
  - One-pion exchange (OPE) and
  - Fragmentation
    - as simulated by colour-dipole model etc.
    - … or even a linear function like $\propto (1 - x_F)$



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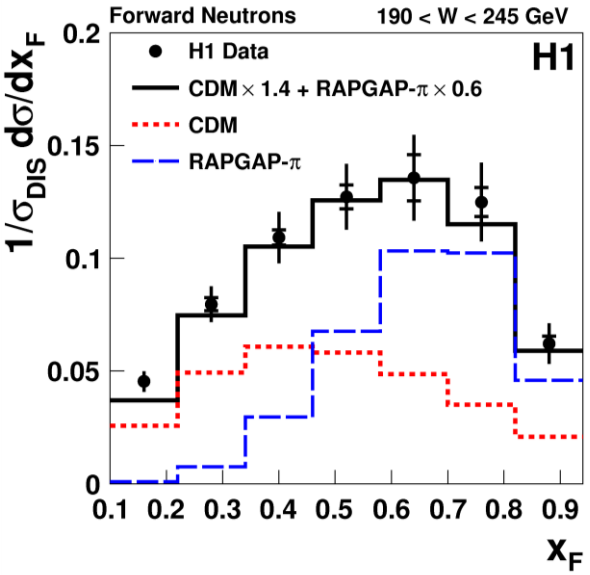
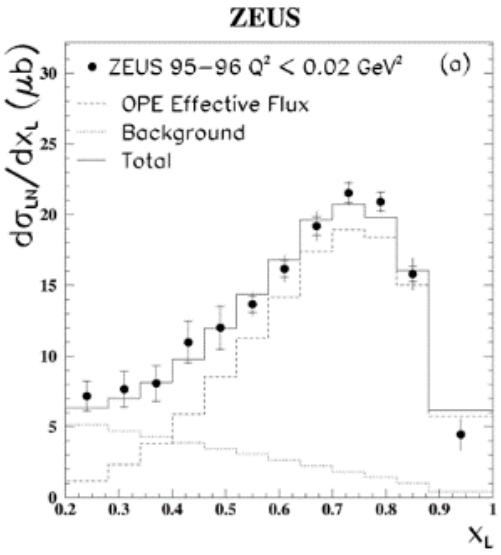


Nucl.Phys.B637(2002)3

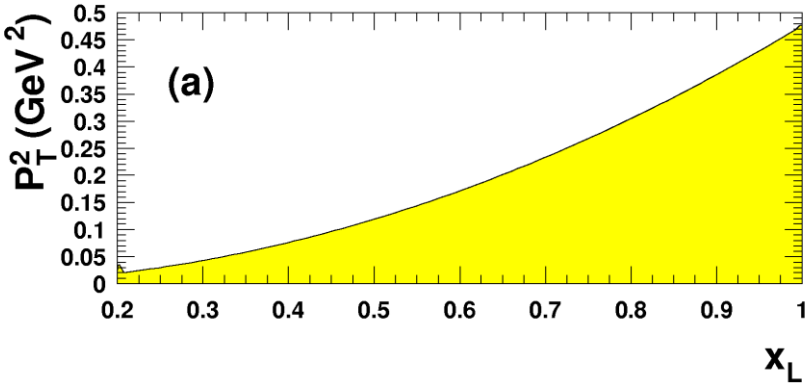


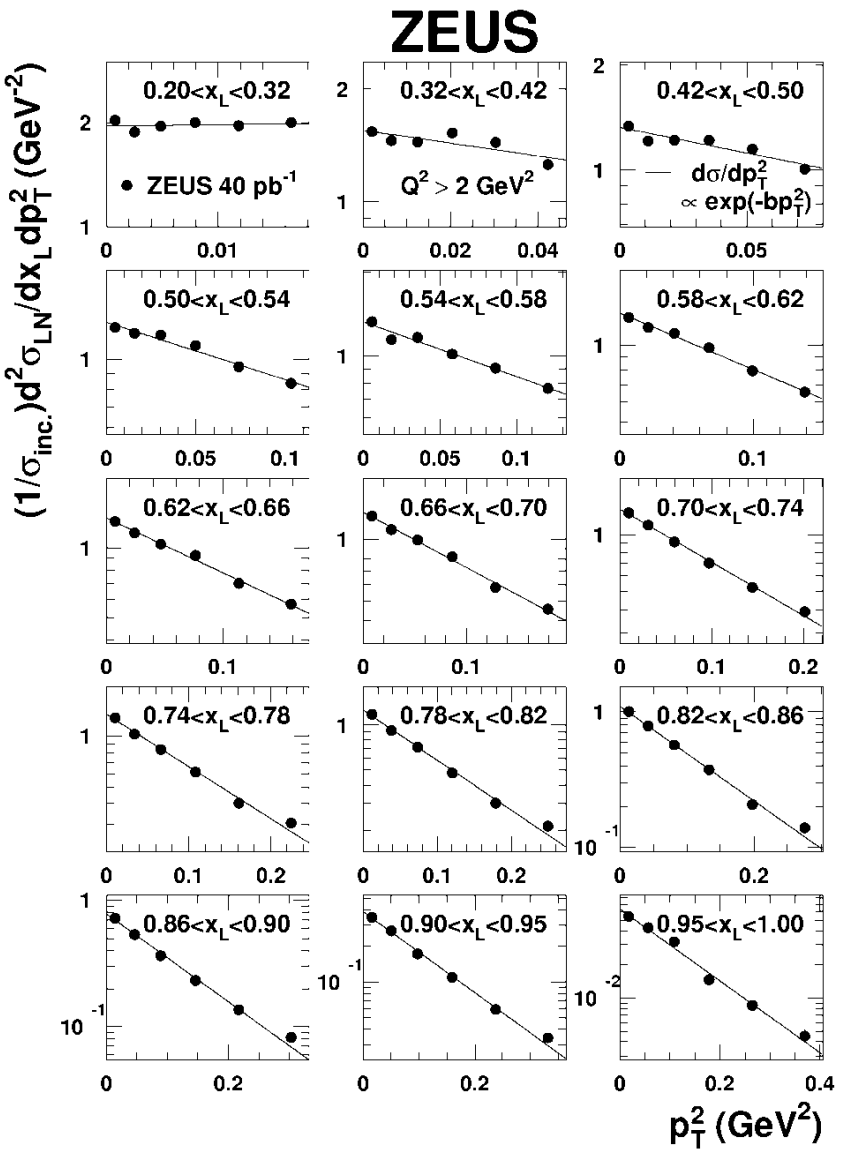
- HERA did not observe the flat behaviour at $x_F = 1$
- Kinematical region different?

p_T distributions vs x_F

Nuclear Physics B 776 (2007) 1-37

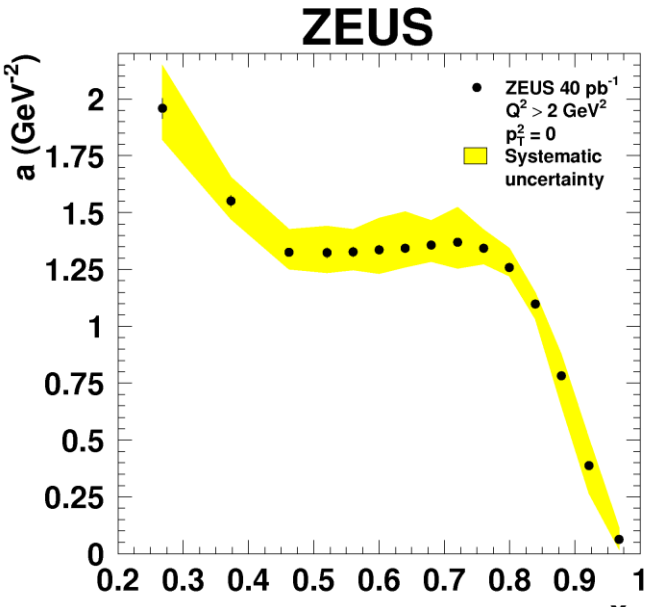
- $x_L = x_F$
- Acceptance:
  $p_T < 0.69 x_F$ GeV
- Well described
  by single exponential
  $\frac{d\sigma}{dp_T^2} = a \exp(-b p_T^2)$

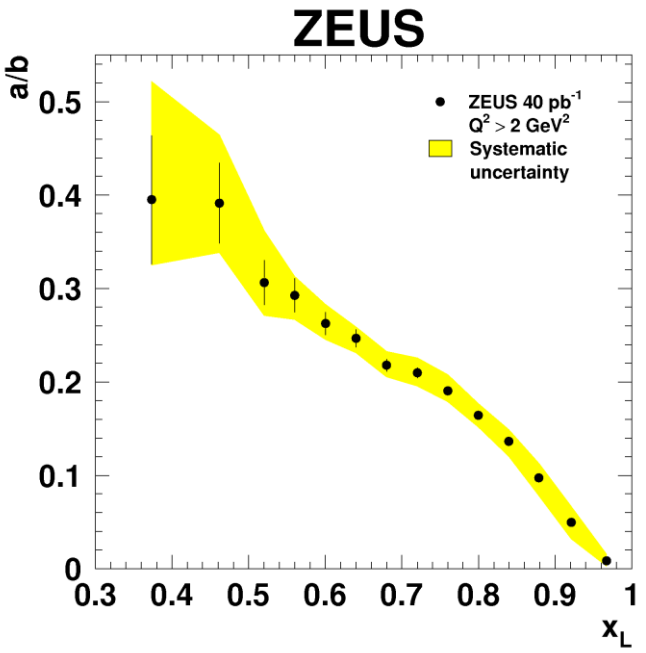


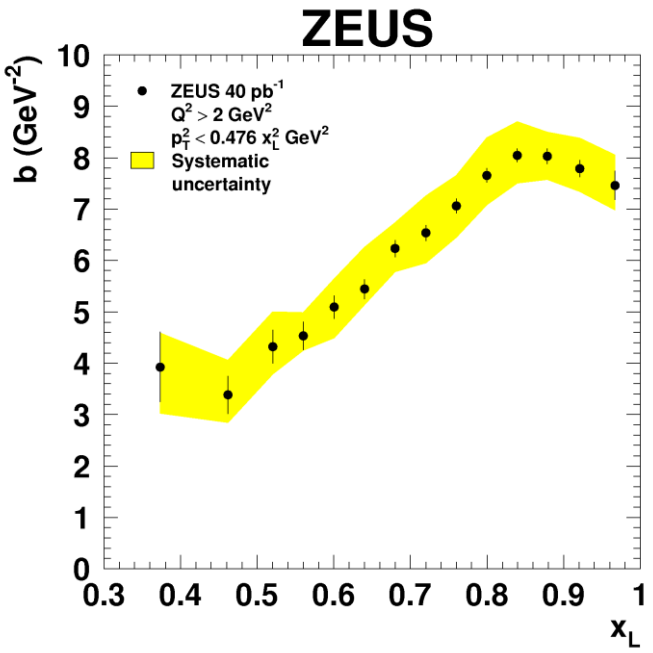


The a and b parameters

- a/b gives "total" $d\sigma/dx_F$
  - assuming the exp. behaviour
- small "peak" at $x_F \sim 0.8$ from OPE
- still no event at $x_F \simeq 1$







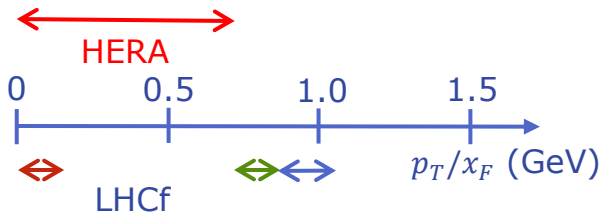
LHCf and HERA kinematic range

- Difference between LHCf and HERA data: maybe from different kinematic coverage?
  - More direct comparison could be made by **assuming** that the cross sections are the same **in** $(\boldsymbol{p_T^2, x_F})$ **space**
    - except that normalisation between pp and $\gamma^* p$ are different

- HERA coverage

  $p_T < 0.69 x_F$ (p_T in GeV)

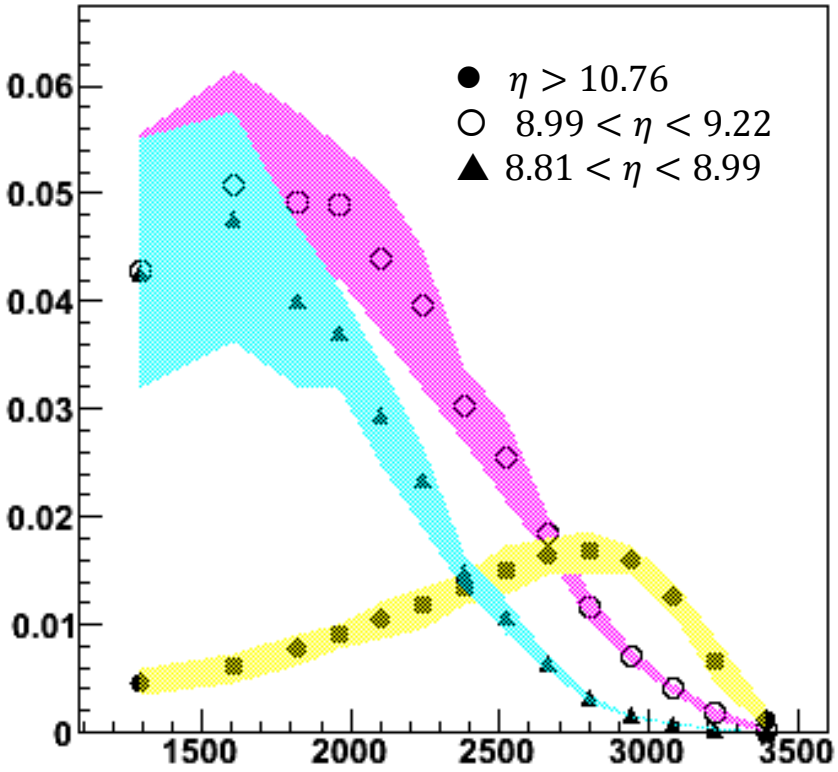
- LHCf coverage



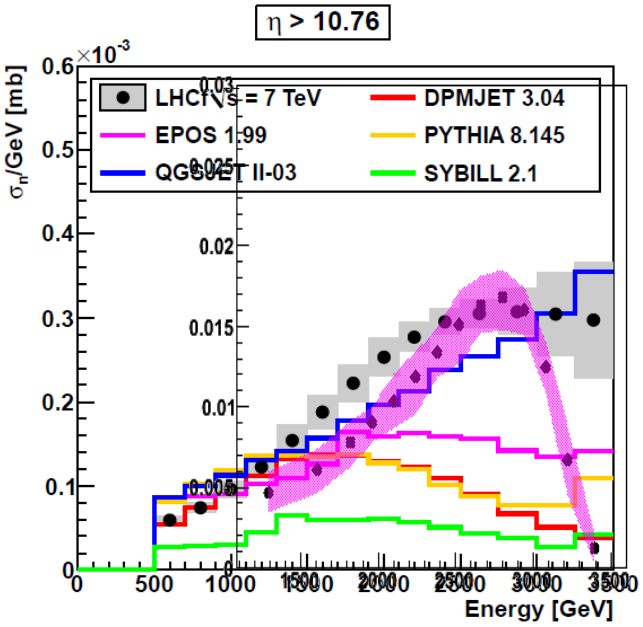
1. $p_T < 0.149 x_F$: covered by HERA
2. $0.693 x_F < p_T < 0.873 x_F$: just outside HERA
3. $0.873 x_F < p_T < 1.045 x_F$: extrapolation assuming exponential behaviour

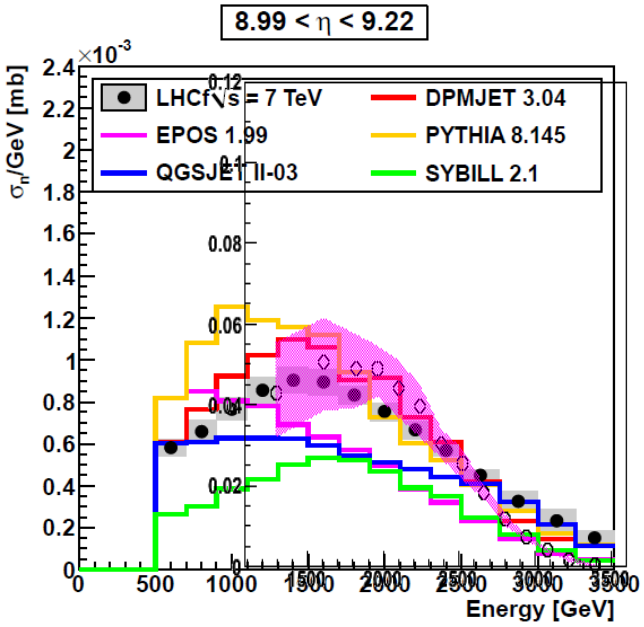
The HERA parameterisation extrapolated to LHCf kinematic range

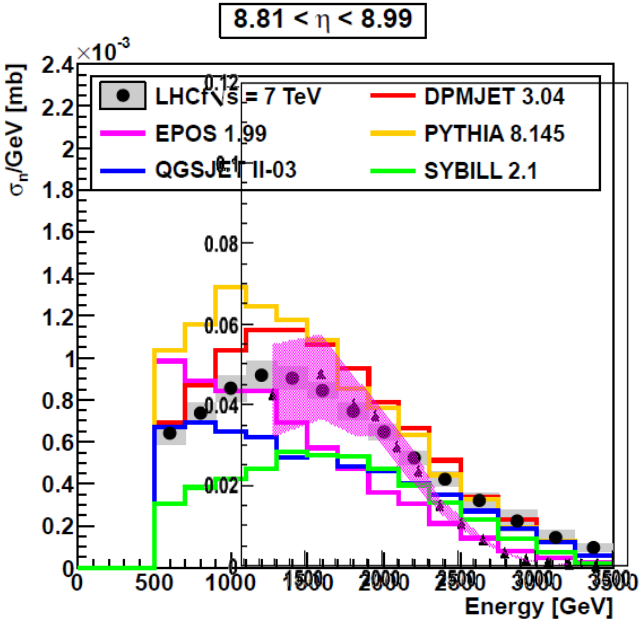
- **assuming** that the behaviour is invariant **in** (p_T^2, x_F) **space**
- Error bars:
  - stat + syst
  - Assuming no correlation between
    - normalisation a and
    - slope b
- Still no flat dependence at high-x_F



- High-p_T bins: extrapolated (outside HERA acceptance)







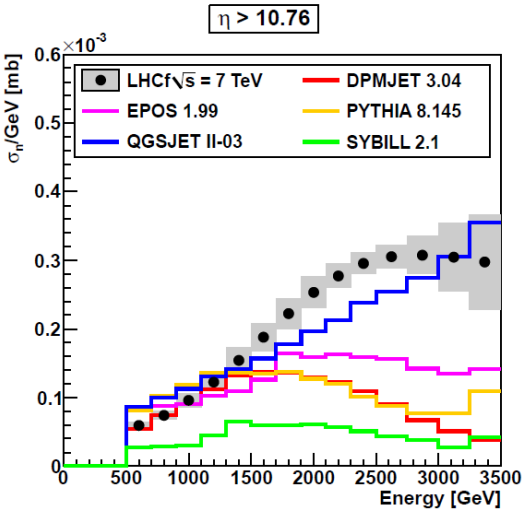
Comparison(2)

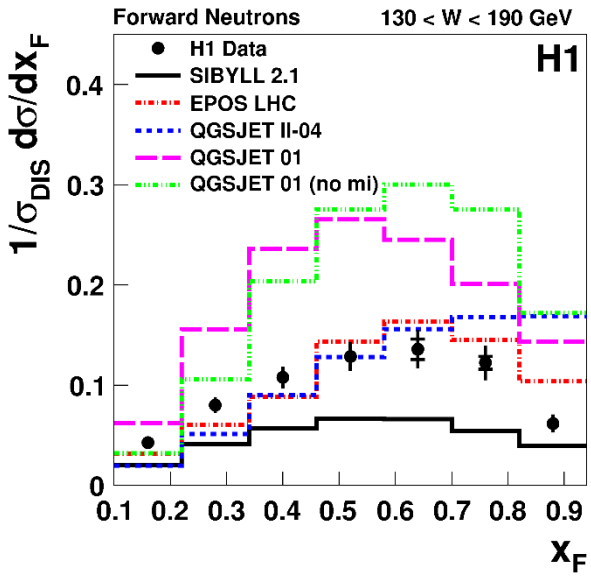
- Medium-x_F behaviour:
  quite well reproduced
  - including the height of peaks,
    if appropriately normalised by a common factor
- Lack of events for E > 2500 GeV
  in the HERA parameterisation
- Low-x_F : slight deficit
  - Note that the exponential parameterisation may not be appropriate when the slope is small

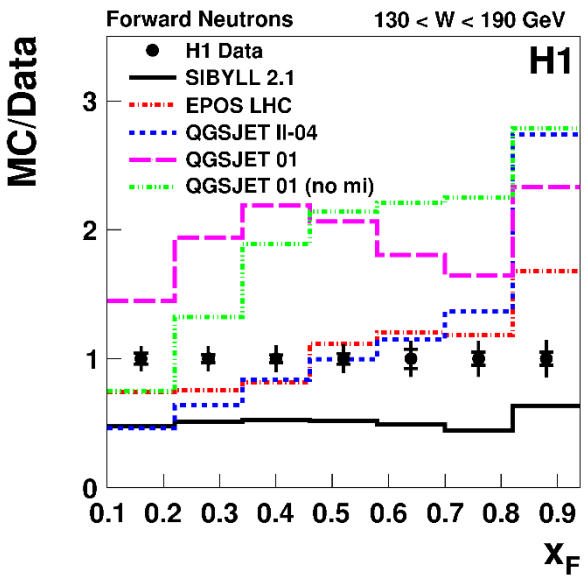
Newest H1 analysis with comparison to models

H1prelim-14-011

spectrum → ratio to data







- LHCf and H1 data show similar tendency at low x_F with respect to model shapes
  - e.g. EPOS shows fair description of shapes at low x_F QGSJET II-04 too hard
- High x_F : models show excess w.r.t. the H1 data
  - e.g. the EPOS model gives excess at high x_F but this describes well the shape of the LHC data

LHCf vs HERA summary

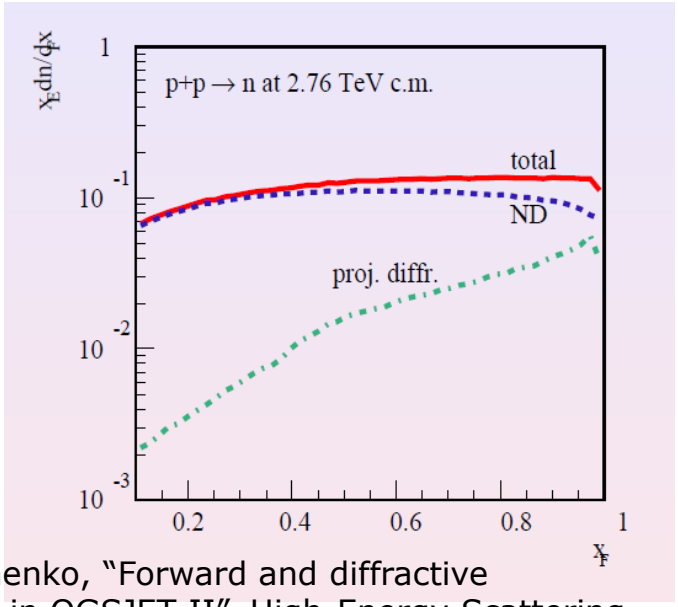
- HERA spectrum is softer at $x_F = 1$ than observed at LHCf
- Low-x_F spectrum looks very similar to HERA parameterisation
  - HERA parameterisation describes the LHCf data possibly better than models at low-x_F

- Models can qualitatively explain the high-x_F behaviour of the LHCf data
- But fails to describe high-x_F behaviour of the HERA data

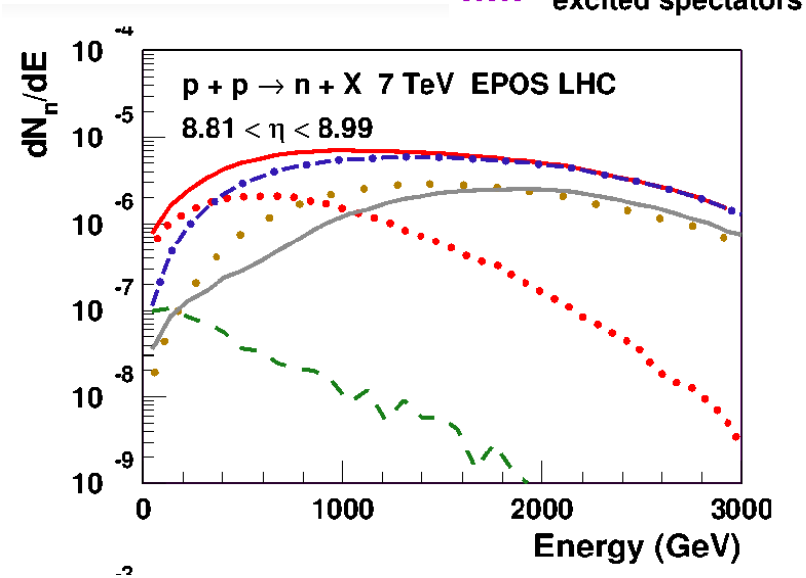
High-x_F description of models

- The flat behaviour of the high-x_L spectrum in the most forward region comes from:
  - the non-diffraction (ND) shape, and
  - the projectile diffraction (diffractive remnants)

    $pp \rightarrow N^* + Y,\ N^* \rightarrow n + (\text{small \# of hadrons})$

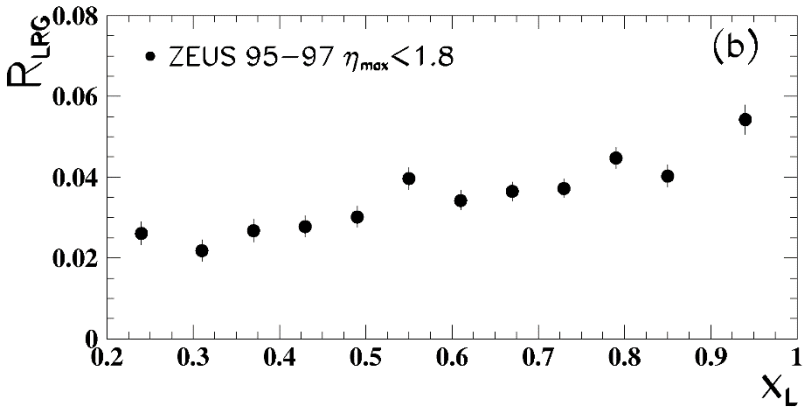


S. Ostapchenko, "Forward and diffractive production in QGSJET-II", High-Energy Scattering at Zero Degrees (HESZ2013), Nagoya Univ., March 2013



T. Pierog, "EPOS and 0 degree particle production", HESZ2013

Diffractive remnant at HERA?



inclusive DIS (7%)

- Fraction of LRG events: 2/3 ~ 1/2 of inclusive DIS
  - No neutron from proton-elastic:
    only proton-dissociative diffraction can contribute
    → we expect the number is small
  - The fraction increases with x_F :
    diffractive production of neutrons at high x_L is certainly there
    BUT: not a dominant mechanism
- Diffractive remnant seems more enhanced at the LHC
  - CMS energy dependence? Re-scattering?

Conclusions

- **High-x_F spectrum:** excess in LHCf against HERA data
- Many of models know about that

$$\text{Models} \simeq \text{LHCf} \gg \text{HERA}$$

  - A large fraction comes from diffractive remnant
  - These models fail to describe the HERA data
    No evidence of diffractive dominance at high-x_L data at HERA

- **Low-x_F spectrum:** LHCf and HERA seems consistent

$$\text{LHCf} \simeq \text{HERA} \neq \text{Models}$$

  - The HERA parameterisation may be good for tuning models