The LHCf experiment: the very forward neutral particle measurements at LHC

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EDS Blois 2017, Prague Czech Republic, 26-30 Jun 2017

Outline

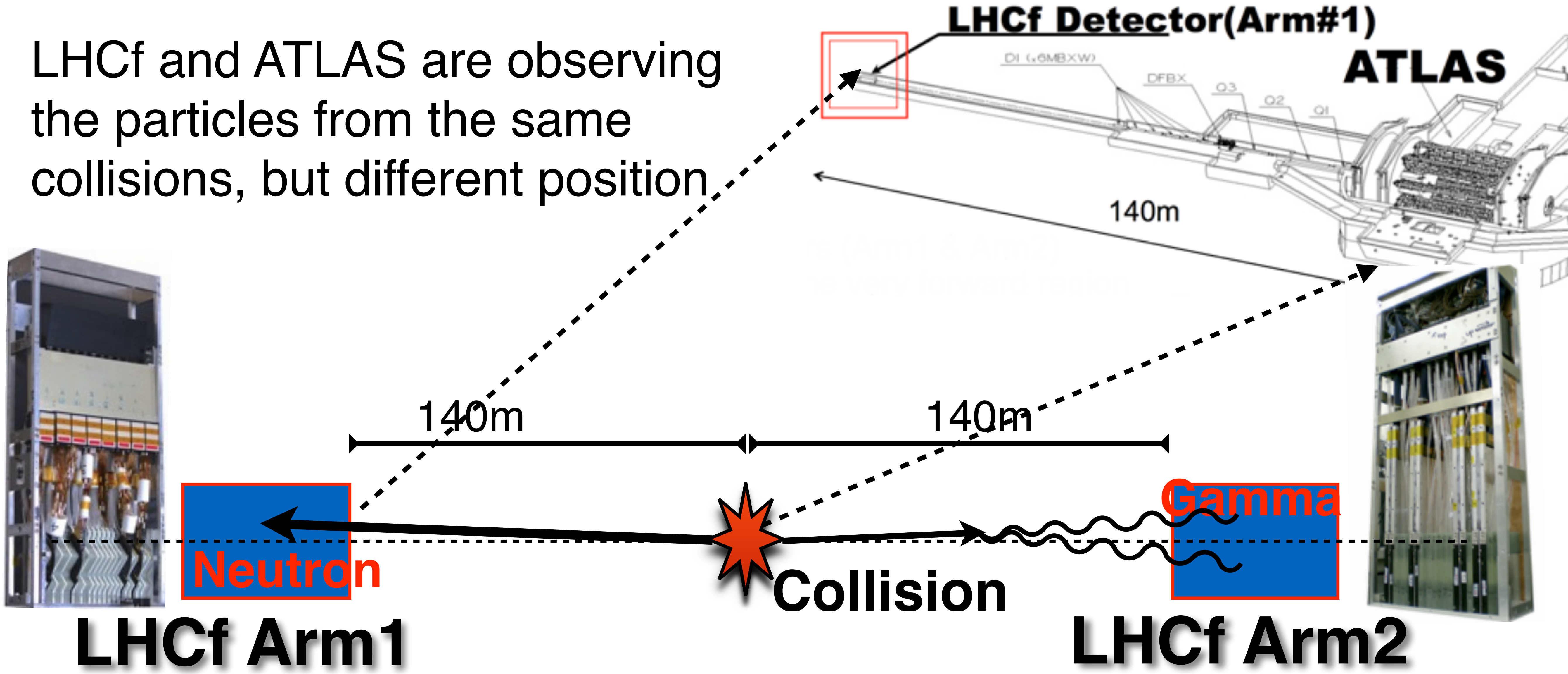
- Introduction
  - LHCf experiment
- The recent LHCf results
  - π^0 (mainly 7 TeV), photon (13 TeV), neutron (7 and 13 TeV)
- MC study about diffractive and non-diffractive interaction contribution to the LHCf spectra.
- ATLAS-LHCf common operation (MC study).
  - Efficiency and purity of diffraction identification by common data
  - Low mass diffraction selection
- Summary

The LHCf experiment

✦Measure hadronic production cross section of <u>neutral particles</u> emitted in the <u>very forward region</u> of LHC.

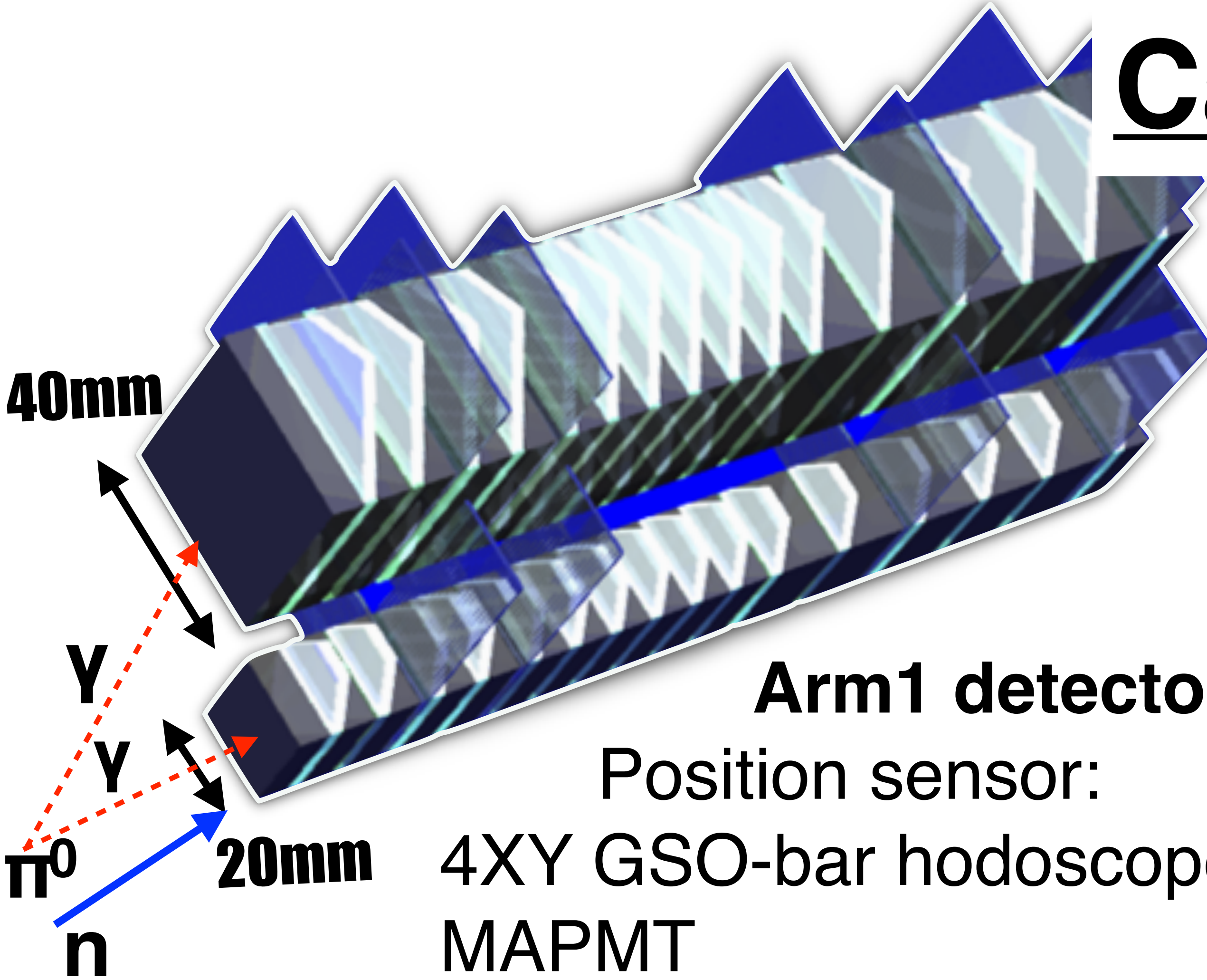
✦To afford the data for <u>verifying</u> and <u>improving</u> the hadronic interaction models.

LHCf and ATLAS are observing the particles from the same collisions, but different position



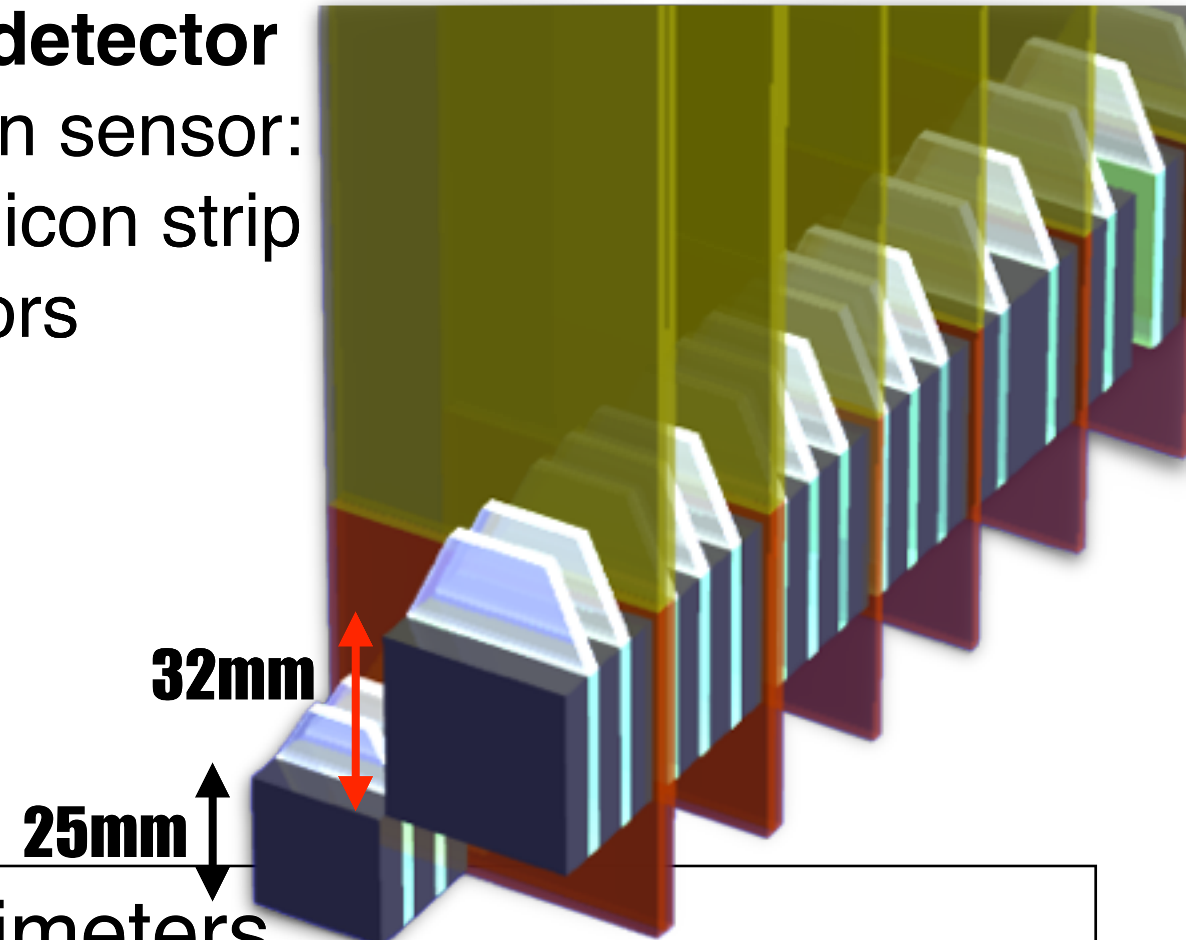
LHCf detectors are sensitive to the ***soft processes***

Calorimeter performance



Arm1 detector
Position sensor:
4XY GSO-bar hodoscope + MAPMT

Arm2 detector
Position sensor:
4XY silicon strip detectors



- Two imaging sampling shower calorimeters
- 44r.l. tungsten, 16 layers of GSO scintillators and 4 position sensitive layers
- The η coverage of the calorimeter: |η|>8.4

Performance

Energy resolution:(>100GeV)
<5% for photons
40% for neutrons

Position resolution:
<200μm for photons
<1mm for neutrons

Operation history at the LHC

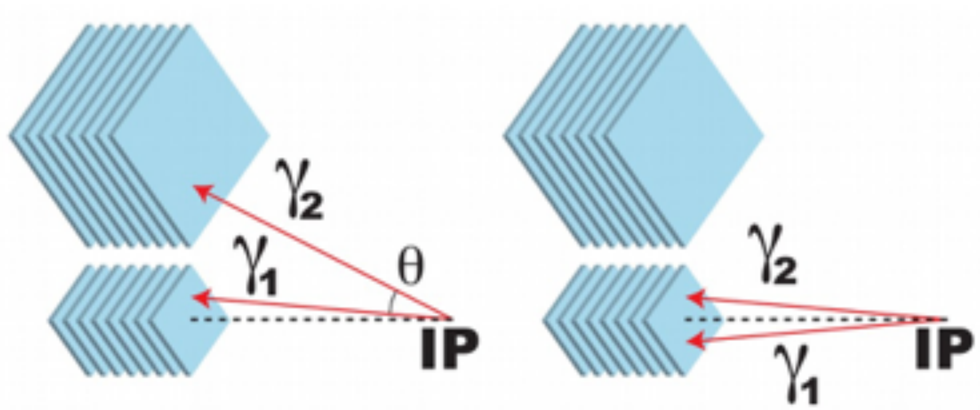
- December 2009 ~ July 2010
  - p+p @ 900GeV
  - p+p @ 7TeV
- January, February~ 2013 (only arm2)
  - p+Pb @ 5.02TeV
  - p+p @ 2.76TeV
- June 2015
  - p+p @ 13TeV
- November of 2016
  - p+Pb @ 8.1TeV (only arm2)

Publication matrix

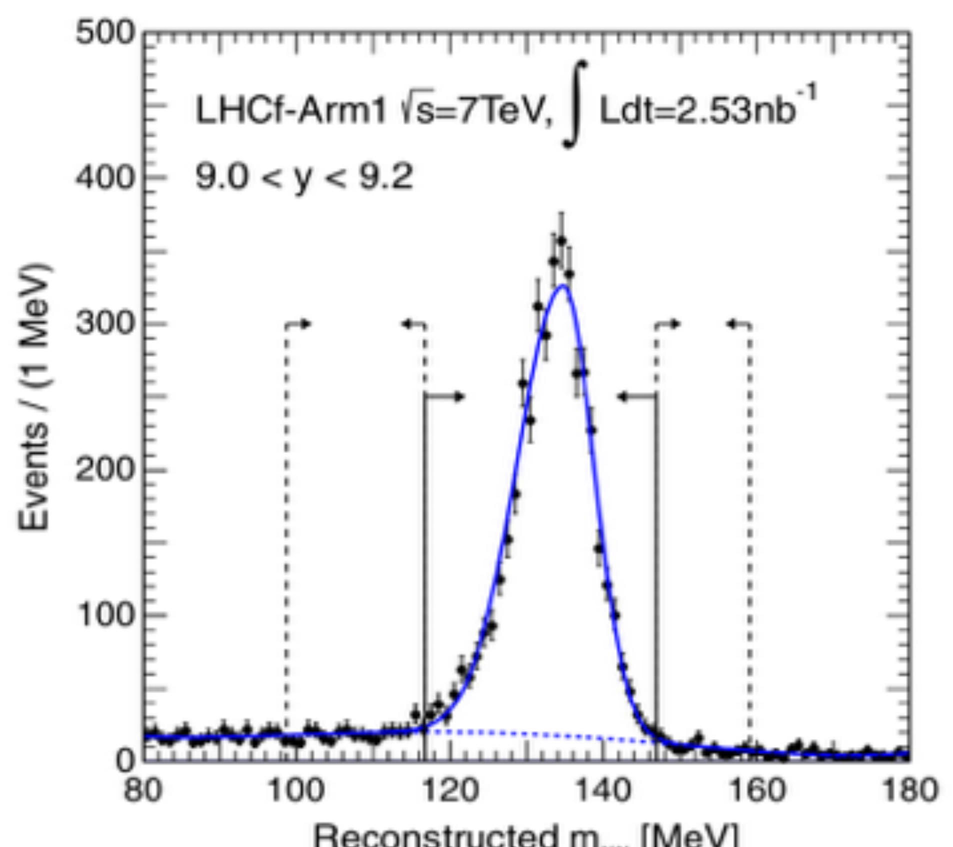
	Photon	Neutron	π^0
p+p 900GeV	Phys. Lett. B 715, (2012)298-303		
p+p 7TeV	Phys. Lett. B 703, (2011)128-134	Phys. Lett. B 750, (2015)360-366	Phys. Lett. D 86, (2012) 092001 + Phys. Rev. D 94 (2016)032007
p+p 2.76TeV			Phys. Rev. C 89, (2014) 065209 + Phys. Rev. D 94 (2016)32007
p+Pb 5.02TeV			
p+p 13TeV	CERN-EP-2017-051 submitted to PLB	Arm2 finished Arm1 On-going	Starting analysis
p+Pb 8.1TeV	Data taking completed on Nov. 2016		

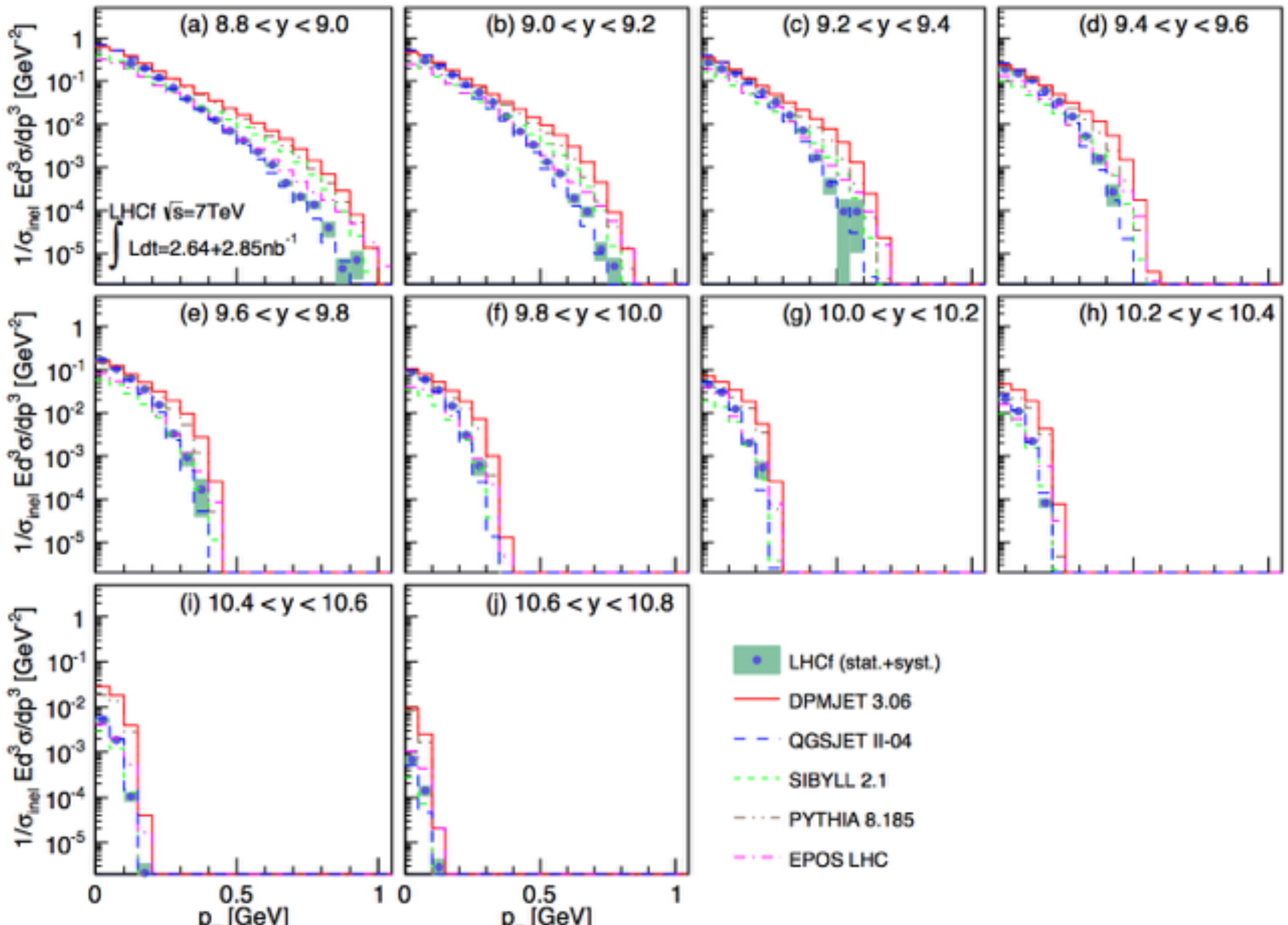
π^0 at $\sqrt{s}$=7TeV, p+p

π^0 was reconstructed from the two decayed γ observed by the LHCf



Type I π^0 Type II π^0



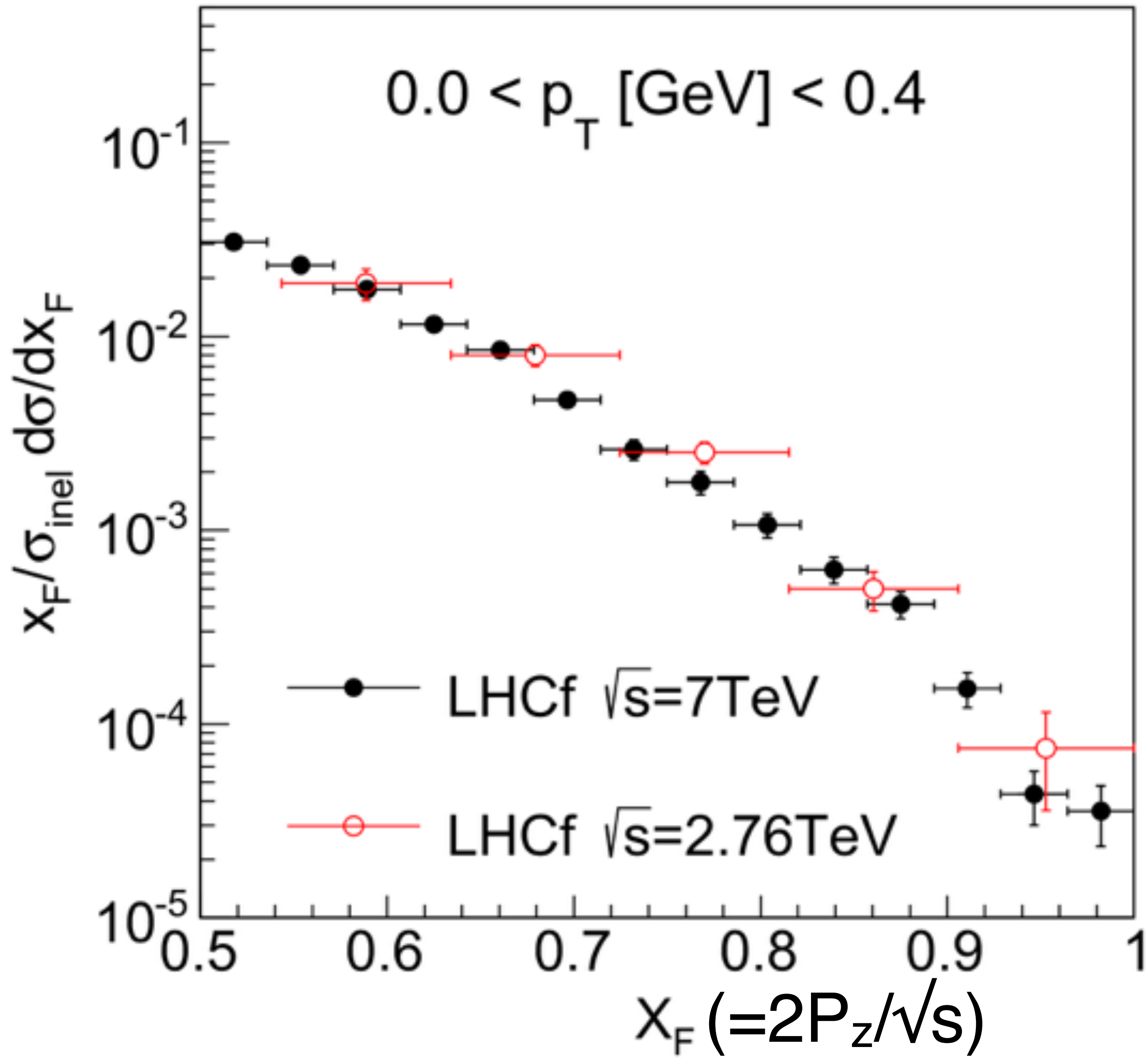


Good agreement with QGSJET-II-04

EPOS-LHC at P_T<0.5 is OK

Test of Feynman scaling

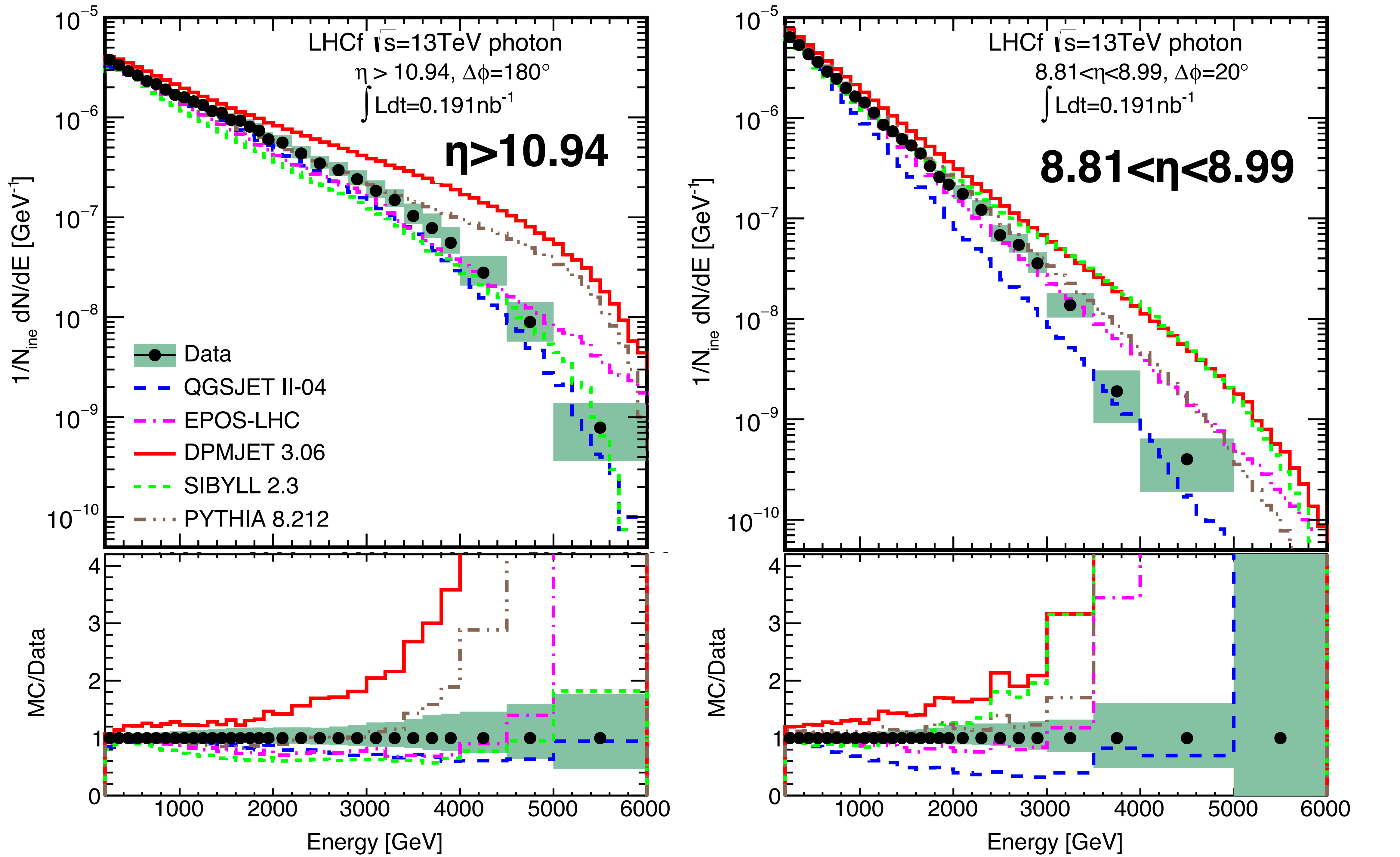
The inclusive cross sections of secondary particles as function of X_F are independent from the incident energy in the forward region (X_F>0.2).



The Feynman scaling for forward π^0 is true at the level of ±20%

The limiting fragmentation is true at the level of ±15%

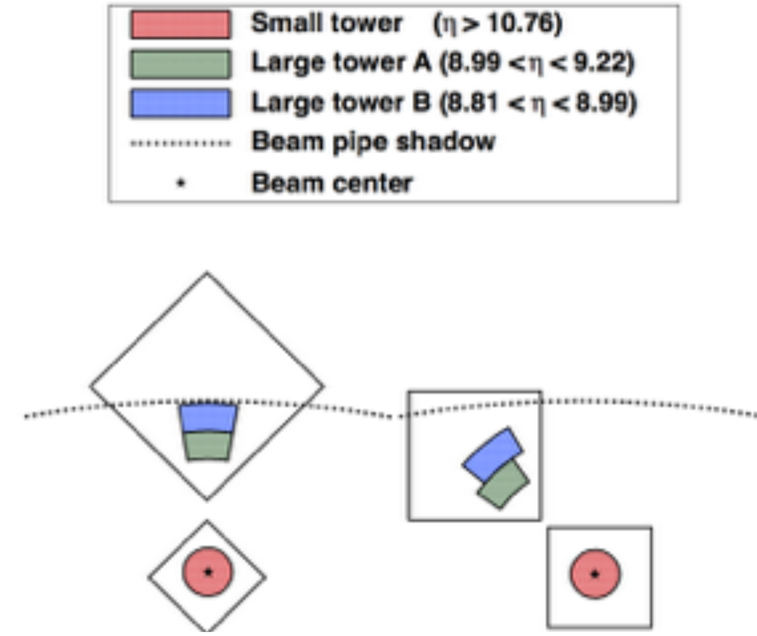
Photon at √s=13TeV, p-p



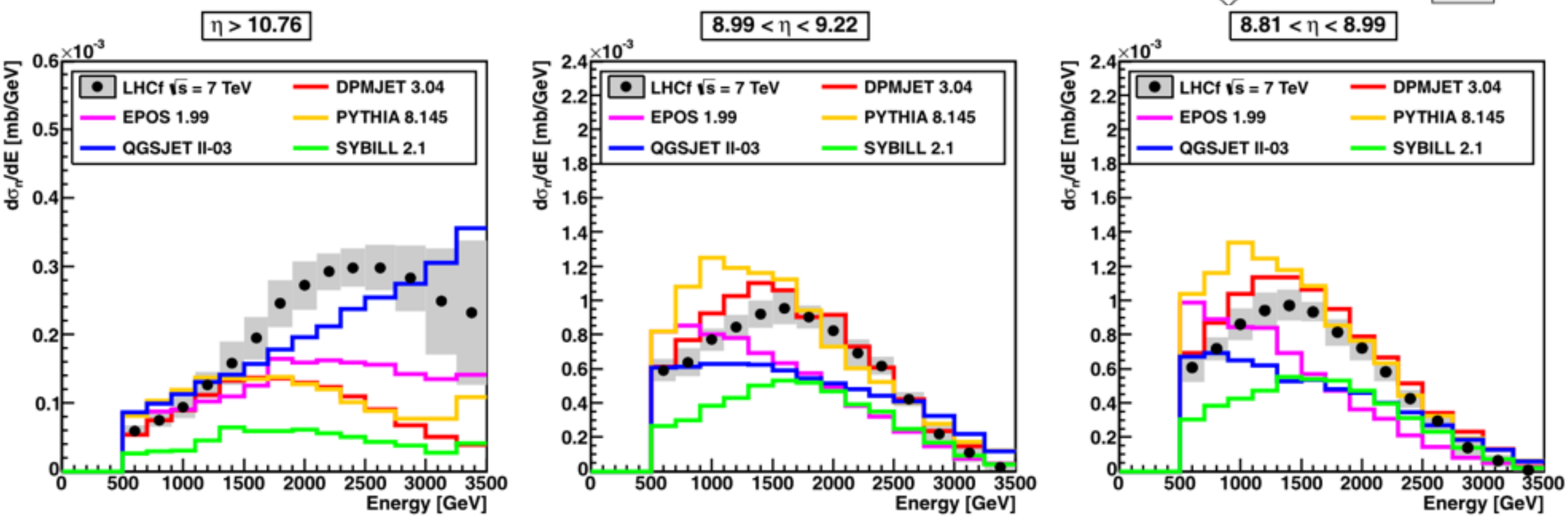
CERN-EP-2017-051

- QGSJET-II-04 is good agreement for η>10.94, softer at 8.81<η<8.99.
- EPOS-LHC is good agreement for E < 3-5TeV, harder at higher energy.
- SIBYLL2.3 give harder prediction for 8.81<η<8.99.

Neutron at $\sqrt{s}$=7TeV, p+p



Forward neutron measurement can give constraint of forward baryon production in the models.

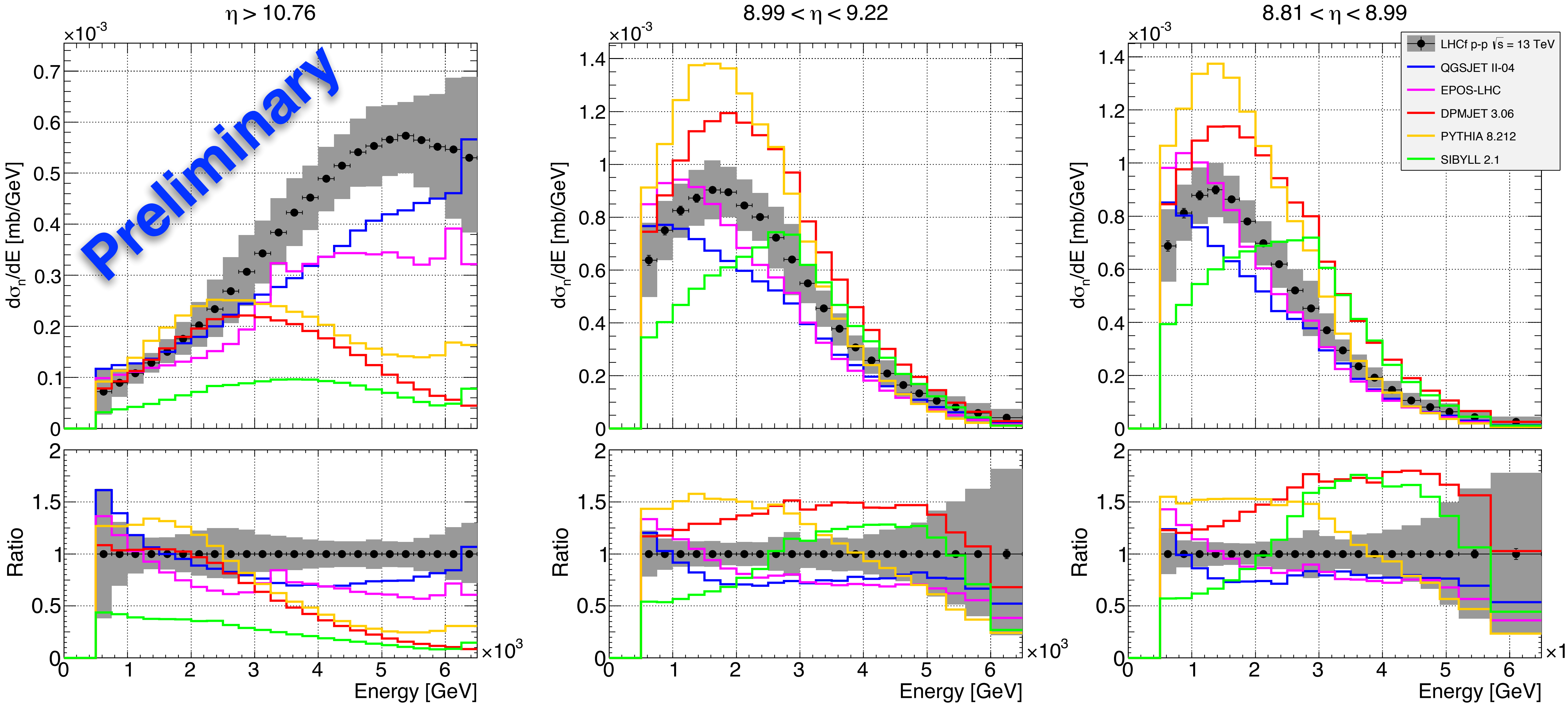


QGSJET-II-03 qualitatively represent the data at η>10.76
DPMJET3 represent the data better than the other models at 8.81<η<9.22

Forward neutron: p+π cross section (pion exchange)

Khoze, V.A. et al. arXiv:1705.03685, 2017; Ryutin, R.A. EPJC, (2017) 77:114

Neutron at √s=13TeV (Arm2), p+p



CERN-THESIS-2017-035

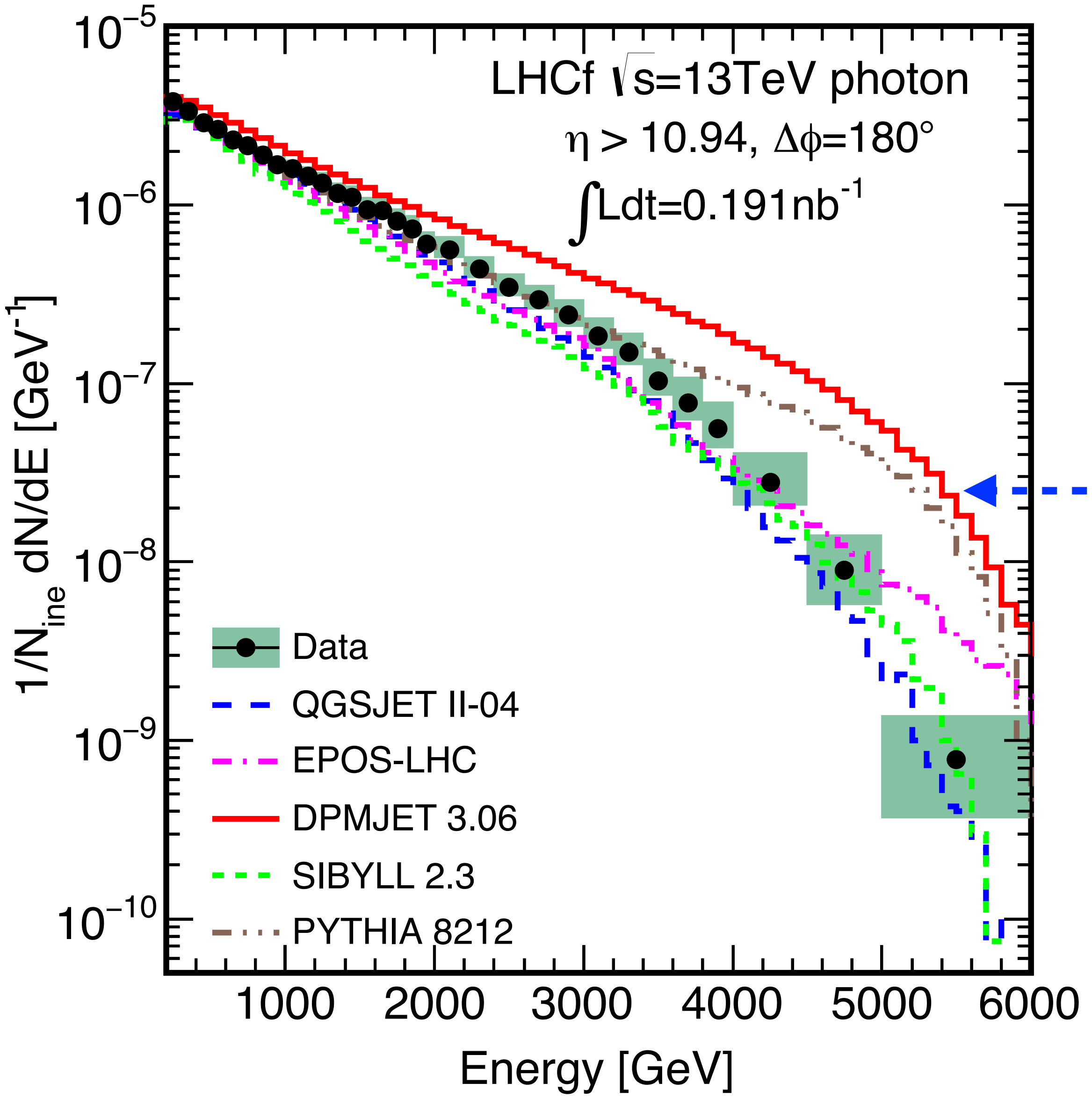
- No model work well in η>10.76, except QGSJET-II-04 (qualitatively)
- EPOS-LHC has better agreement in 8.99<η<9.22 and 8.81<η<8.99.

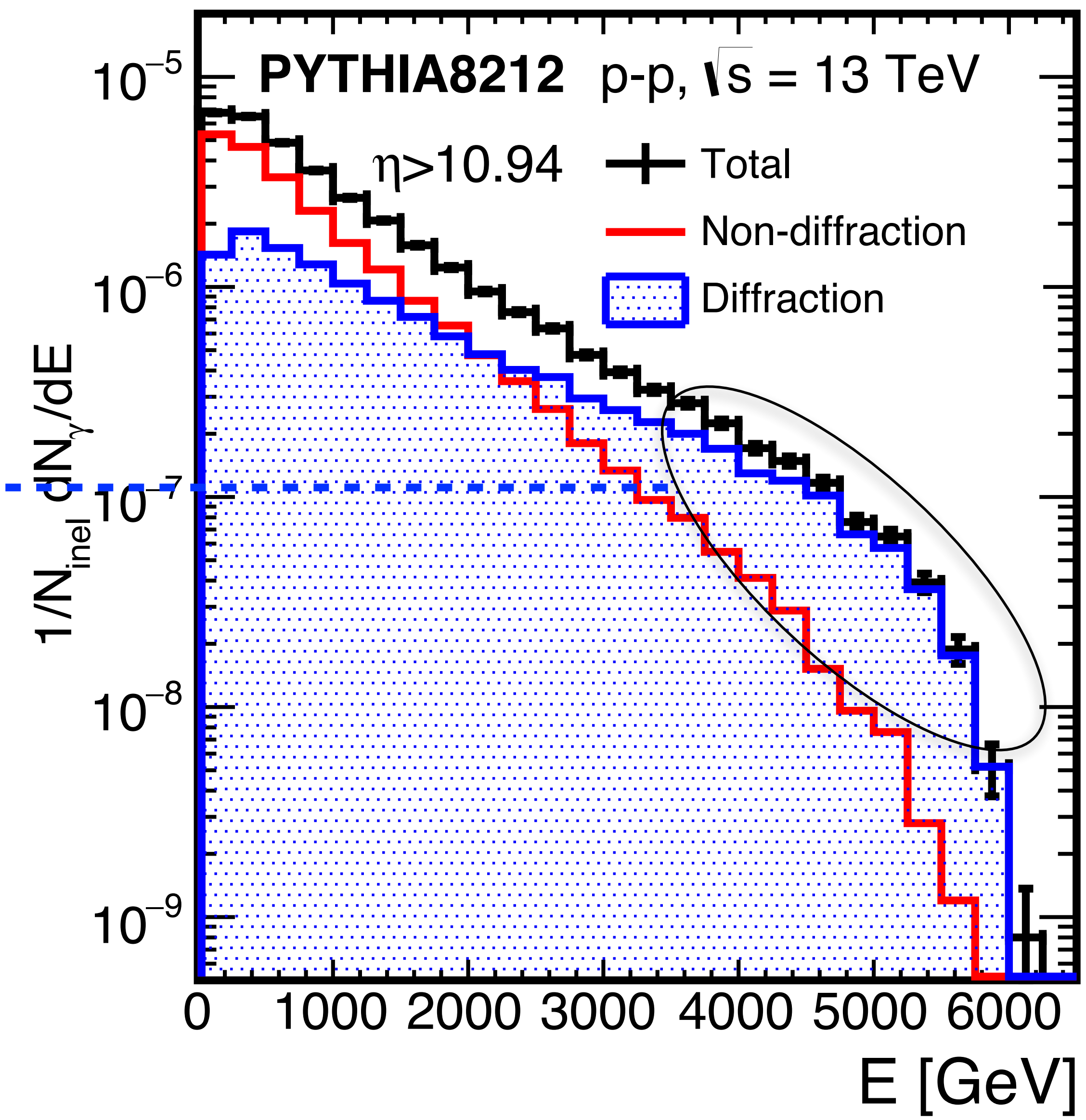
Common analysis with ATLAS is on going

Monte Carlo study about diffractive and non-diffractive interaction contribution to LHCf spectra

Eur. Phys. J. C77:212(2017)

Investigation of photon spectra



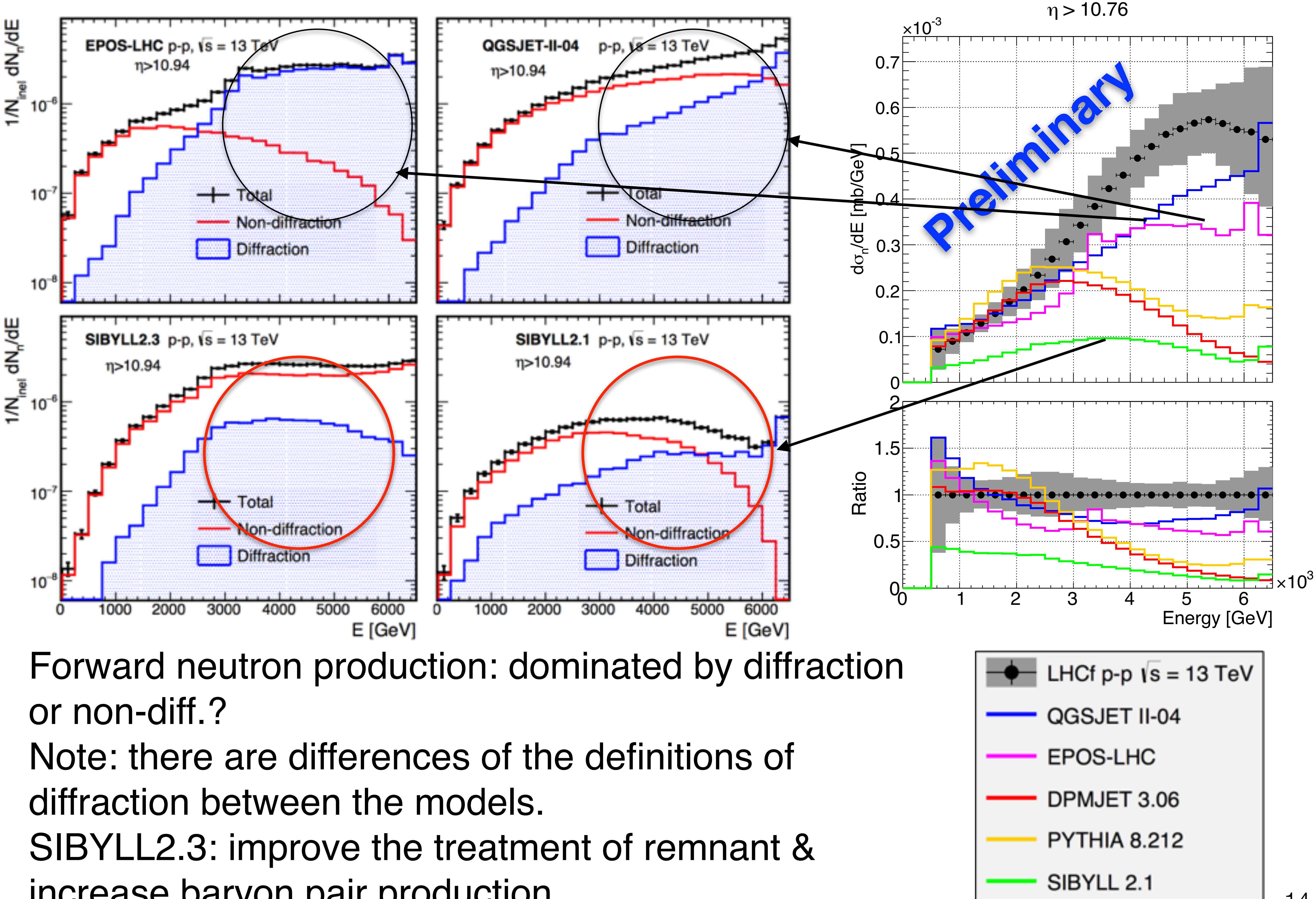


Total inelastic collisions:
diffraction + non-diffraction

Diffraction = SD+DD+CD

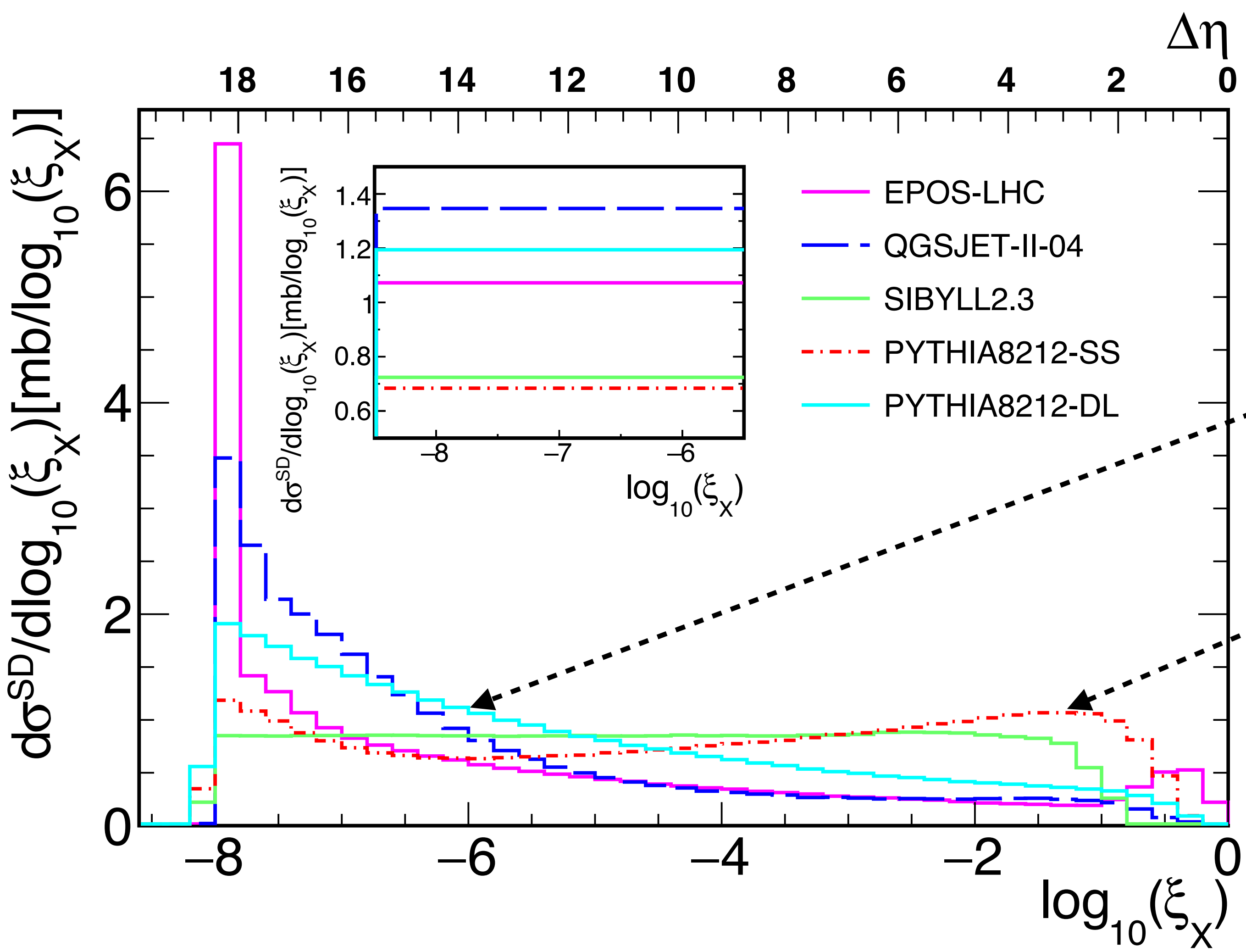
The excess of PYTHIA8 at E>3TeV due to over contribution from diffraction

Investigation of neutron spectra

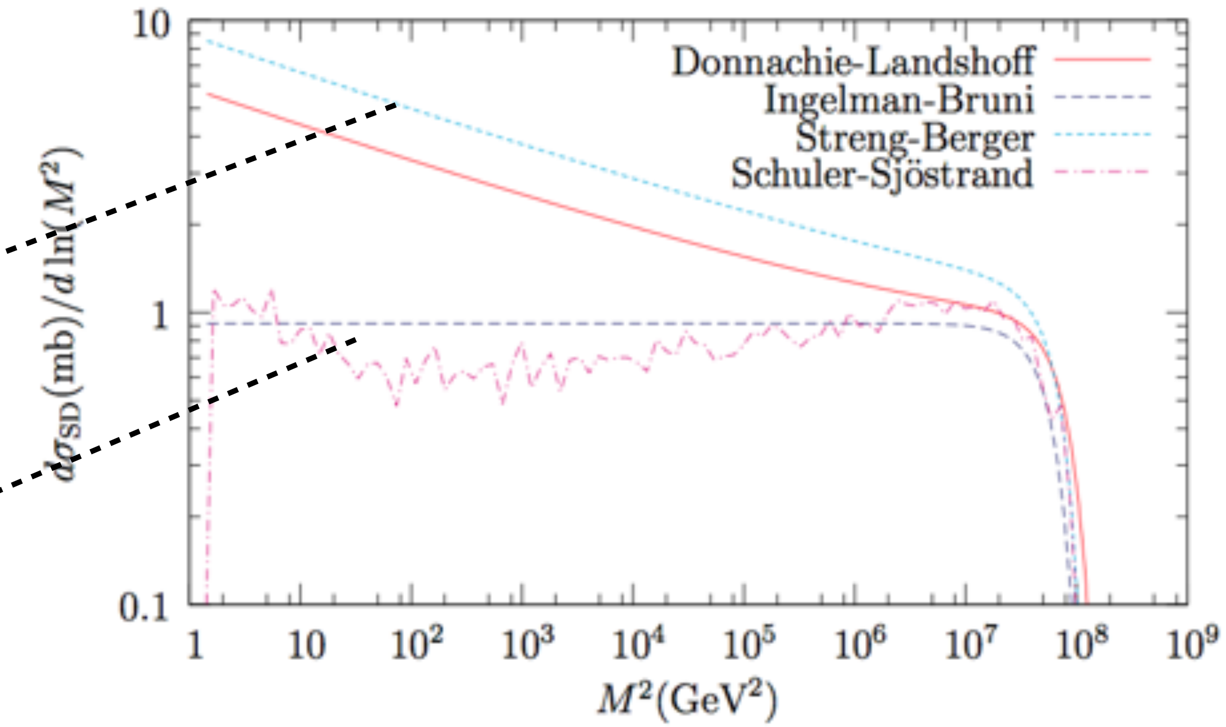


- Forward neutron production: dominated by diffraction or non-diff.?
- Note: there are differences of the definitions of diffraction between the models.
- SIBYLL2.3: improve the treatment of remnant & increase baryon pair production.

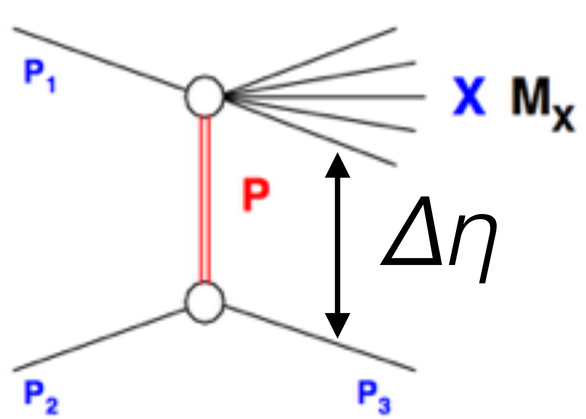
Diffractive mass distribution



Pomeron flux options in PYTHIA



arXiv:1005.3894v1

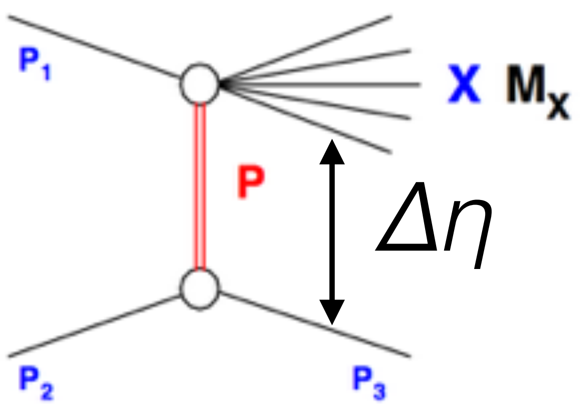


$\xi = (M_{(x)}/\sqrt{s})^2$
$= 1 - X_F$
$\sim e^{-\Delta\eta}$

- Large discrepancy exists between models
- Pomeron flux is an extremely important parameter for modeling diffraction

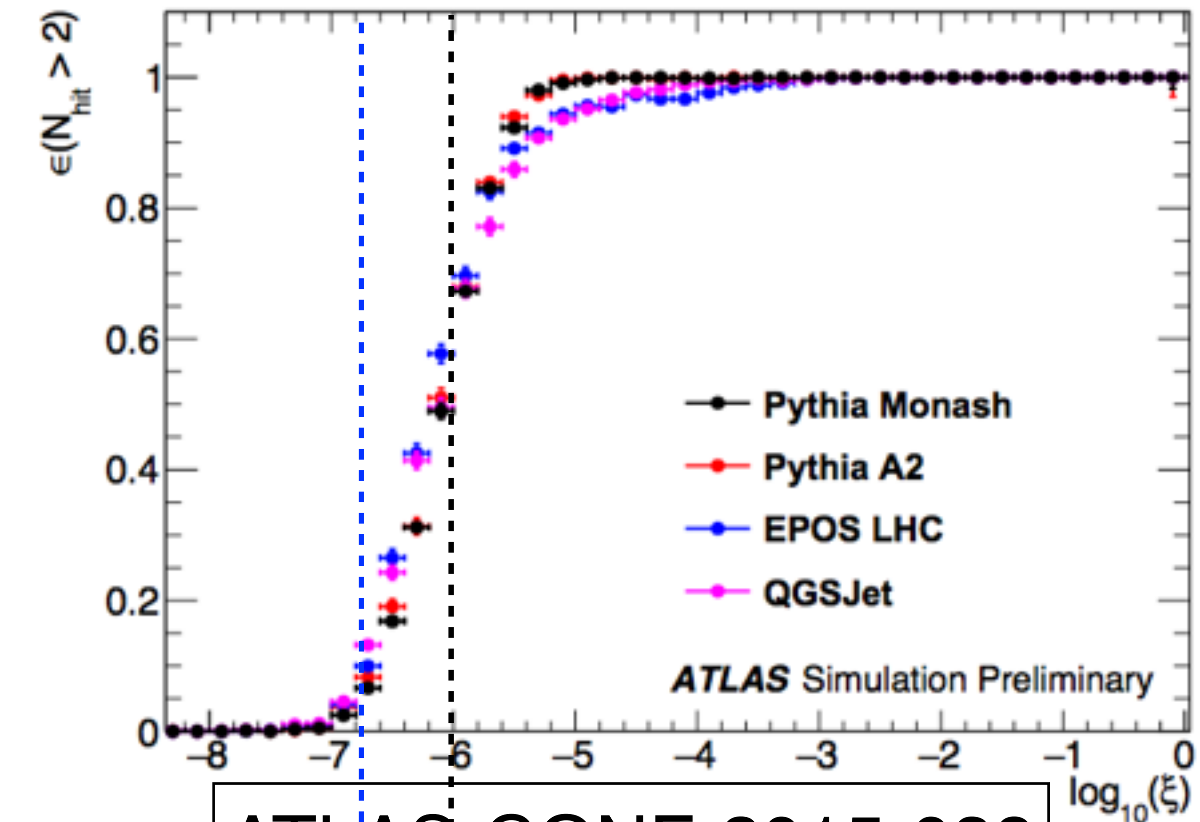
Prospects for ATLAS-LHCf common analysis

Detector acceptance

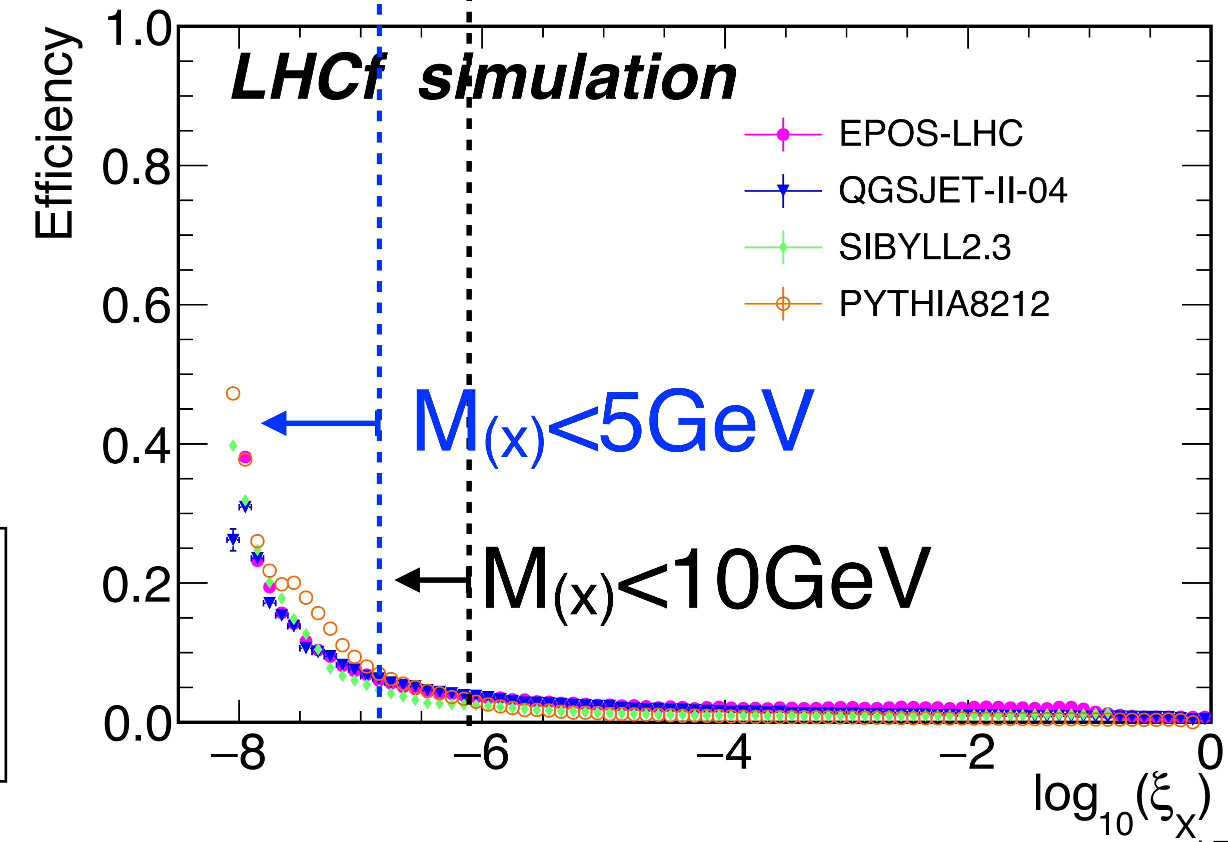


$\xi = (M_{(x)}/\sqrt{s})^2$
$= 1 - X_F$
$\sim e^{-\Delta\eta}$

- Trigger efficiency (only with SD)
- Trigger condition of LHCf
  Photon: $E_\gamma > 200$GeV
  Neutron: $E_n > 500$GeV
- ATLAS
  Pass MBTS hit selection
  $N_{hit} > 2$

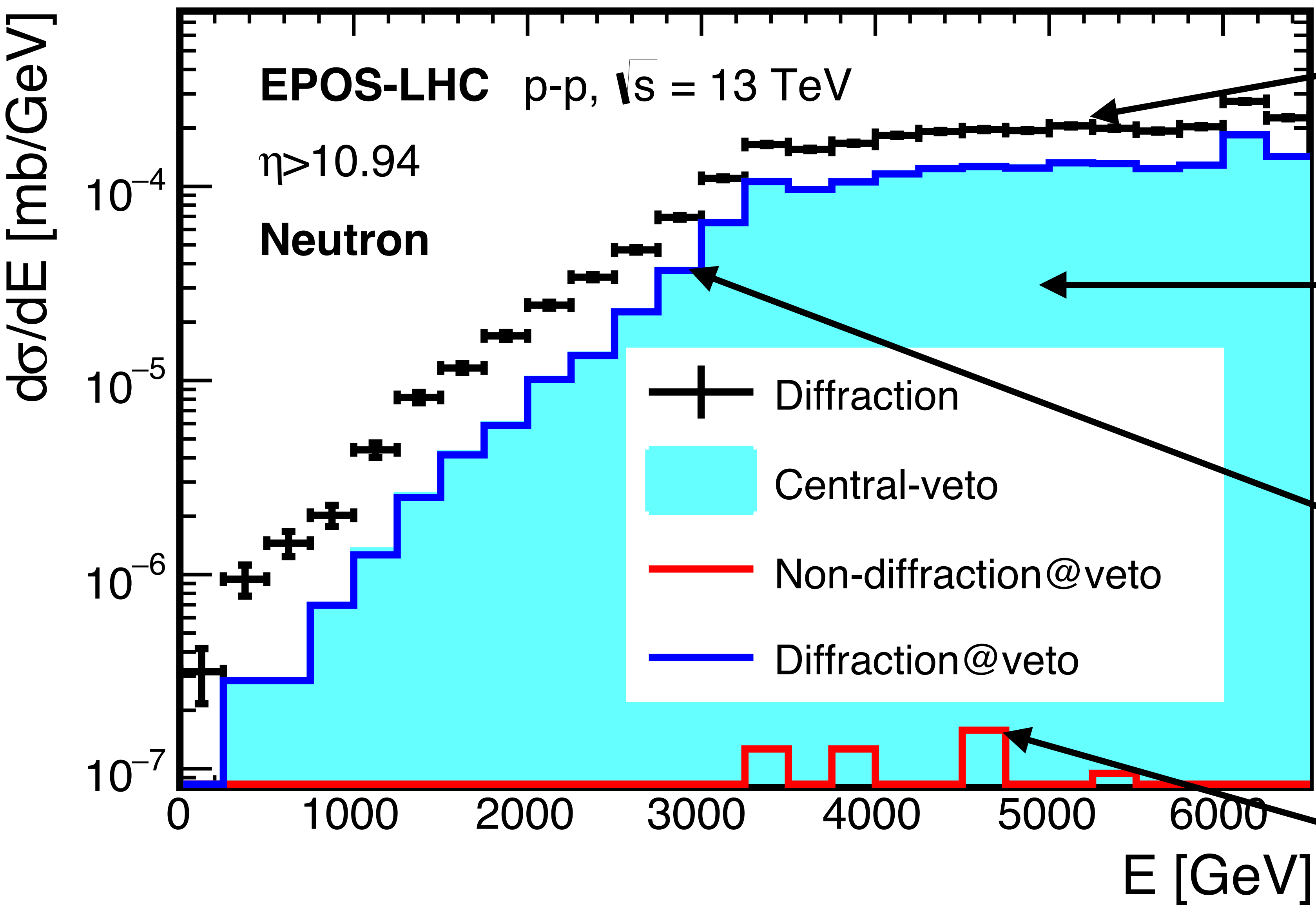


ATLAS-CONF-2015-038



LHCf and ATLAS cover different diffractive mass range

Performance of ATLAS-veto selection



①Diffraction

②Events selected by ATLAS-veto

③Diffractive events identified by ATLAS-veto

② & ③ are mostly consistent

④Non-diff. events mis-identified by ATLAS-veto (②-③)

efficiency = ② / ①

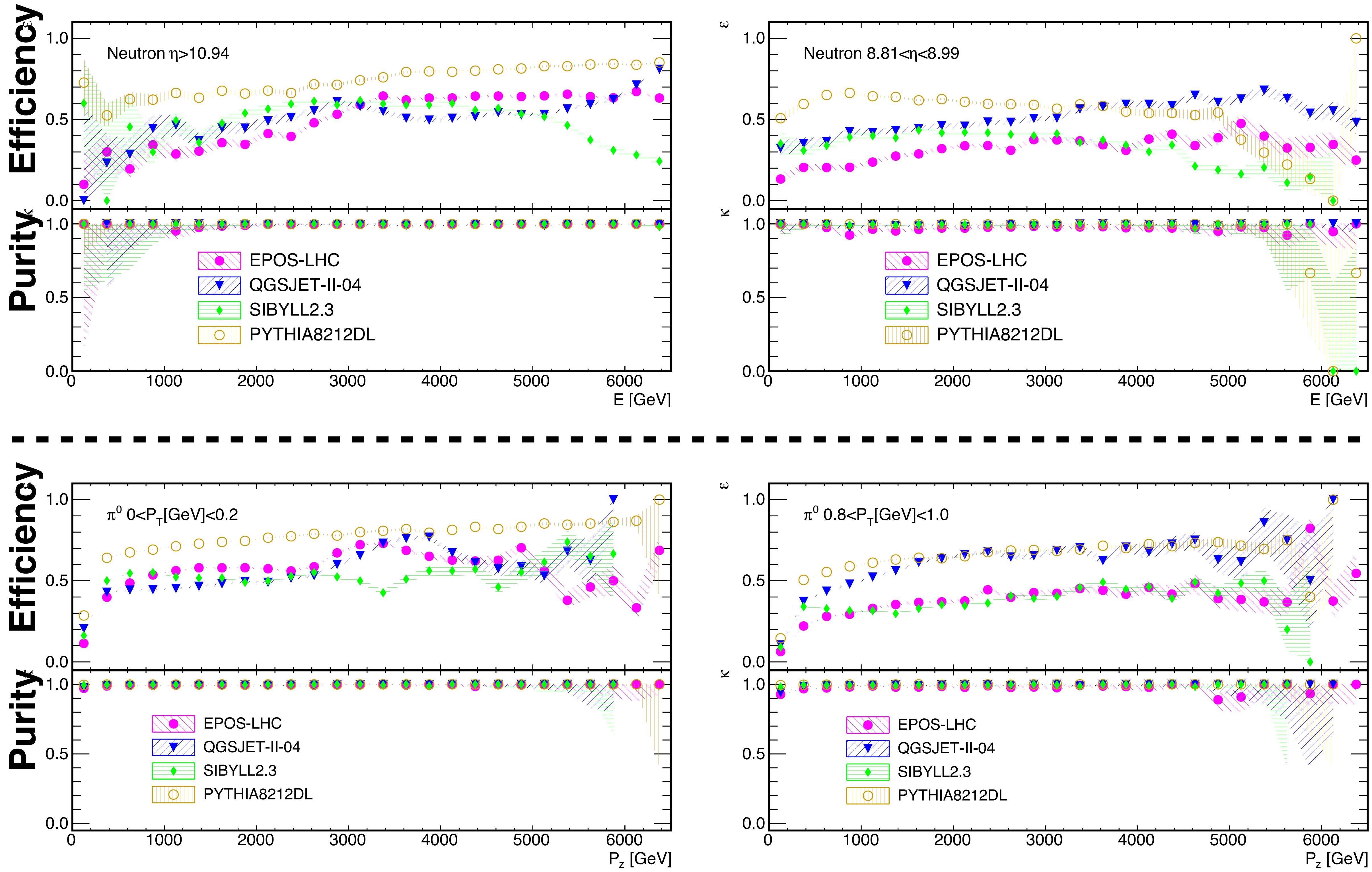
purity = ③ / ②

ATLAS-veto enable diffraction selection with high purity

Performance of ATLAS-veto selection

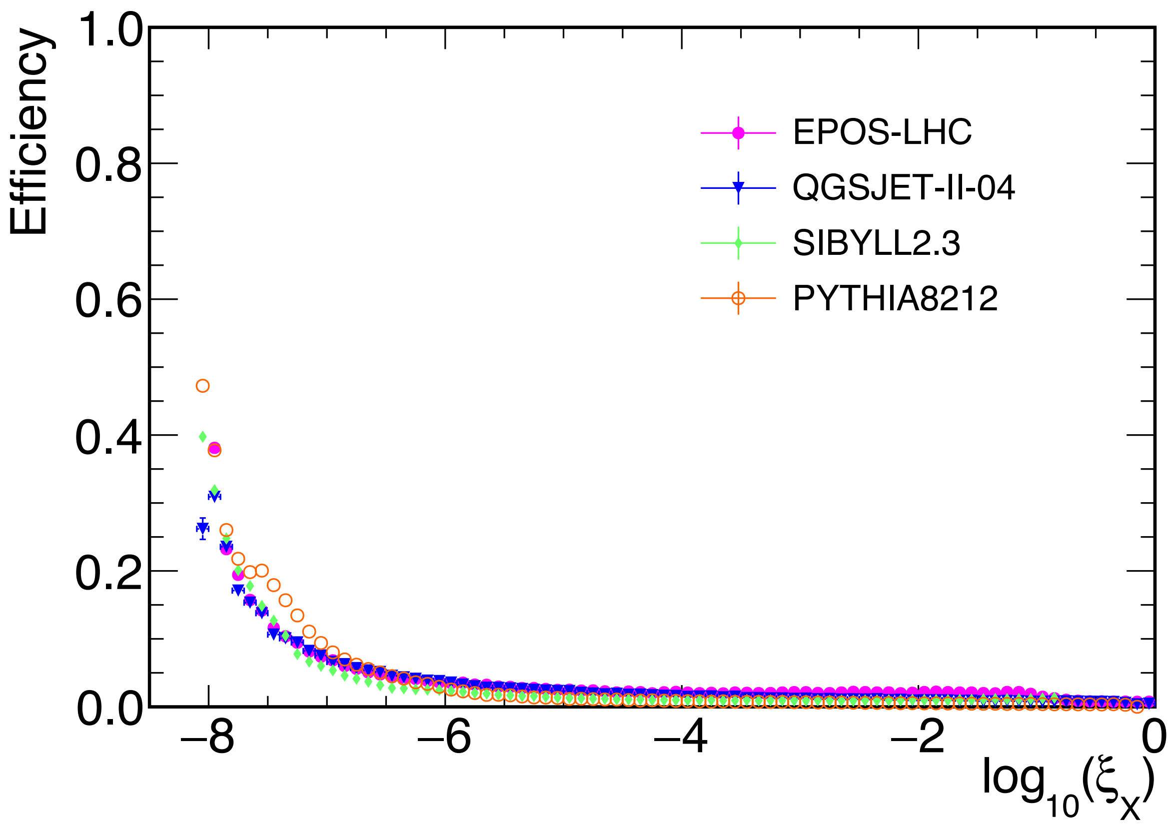
Neutron

π0

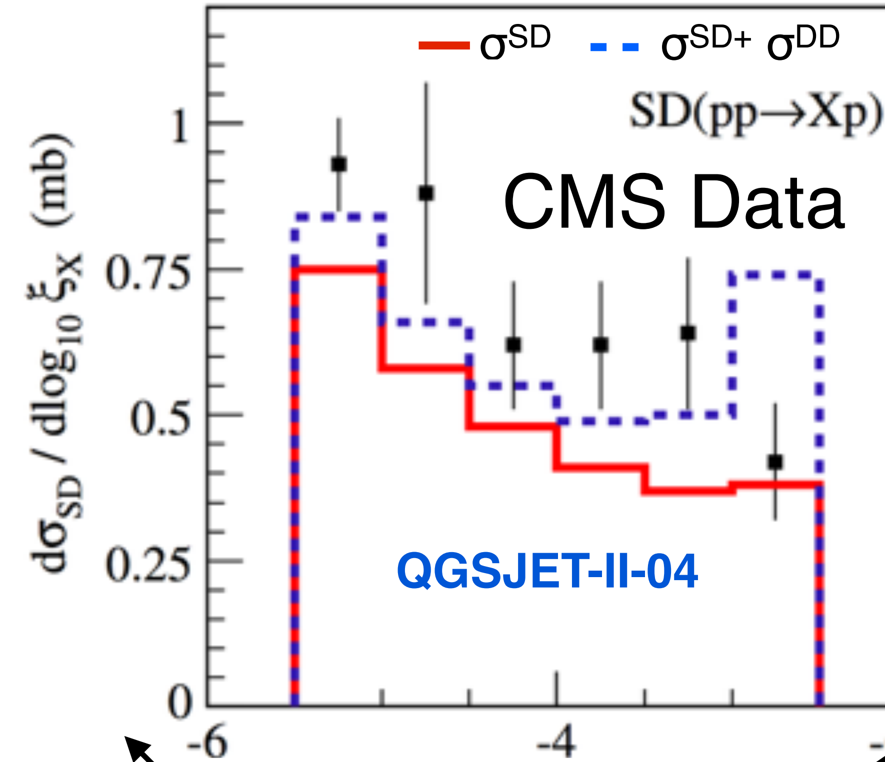


ATLAS-veto enable diffraction selection with high purity

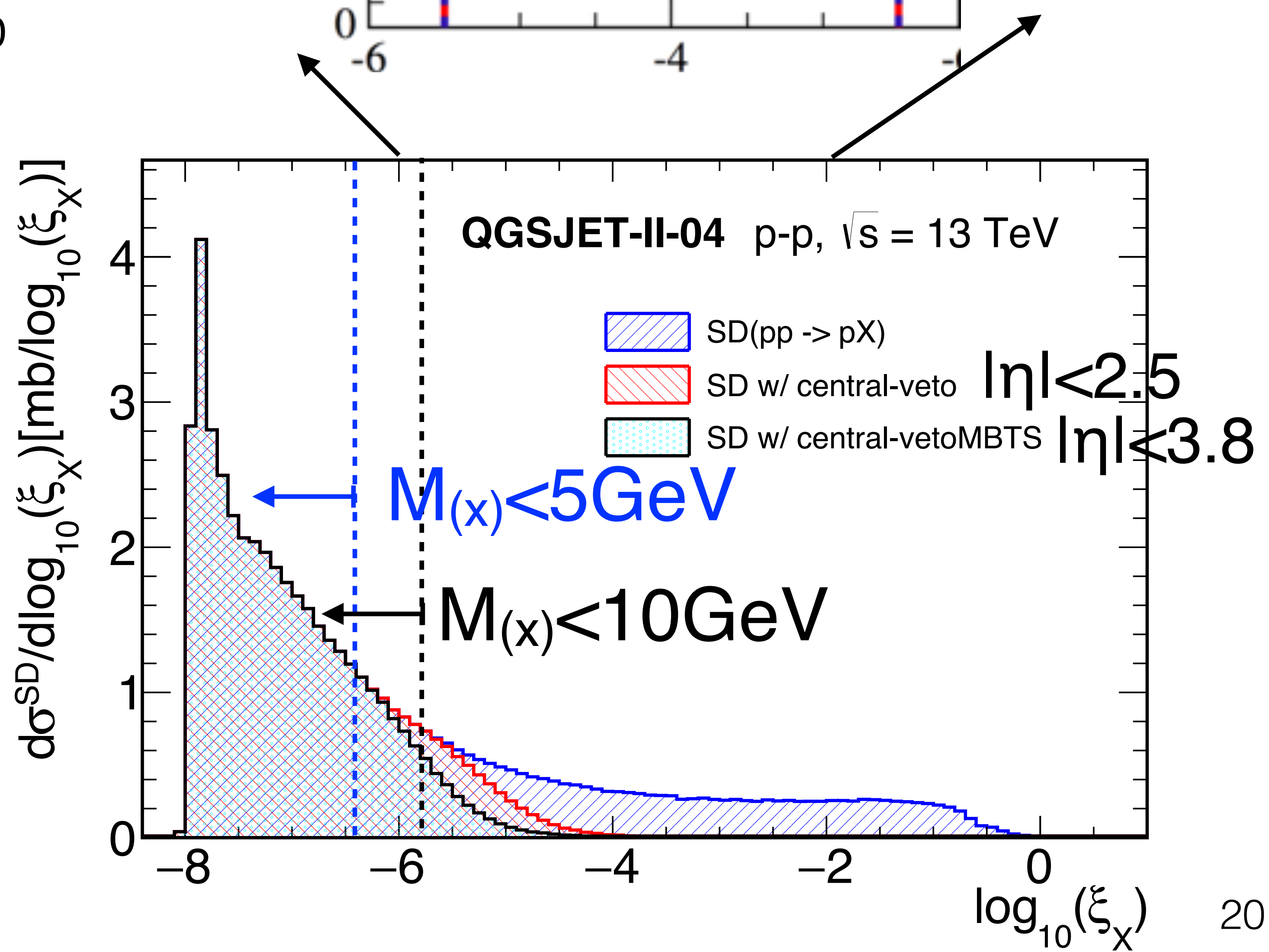
Low mass diffraction



S. Ostapchenko, Phy. Rev. D 89, 074009 (2014)



- The inefficiency parts of ATLAS-veto are high mass diff..
- ATLAS-LHCf can access the low mass single diffraction region, with high efficiency, experimentally.



Summary

✦LHCf has taken data in p-p and p-Pb collisions at different energies, results have been published about photon, neutron and π^0

No models represent the data perfectly

✦Diffraction is one of the poor constraint parts of the hadronic interaction models -> ATLAS-LHCf common operation.

✦The efficiency and purity of diffractive event identification by ATLAS-LHCf common operation were estimated.

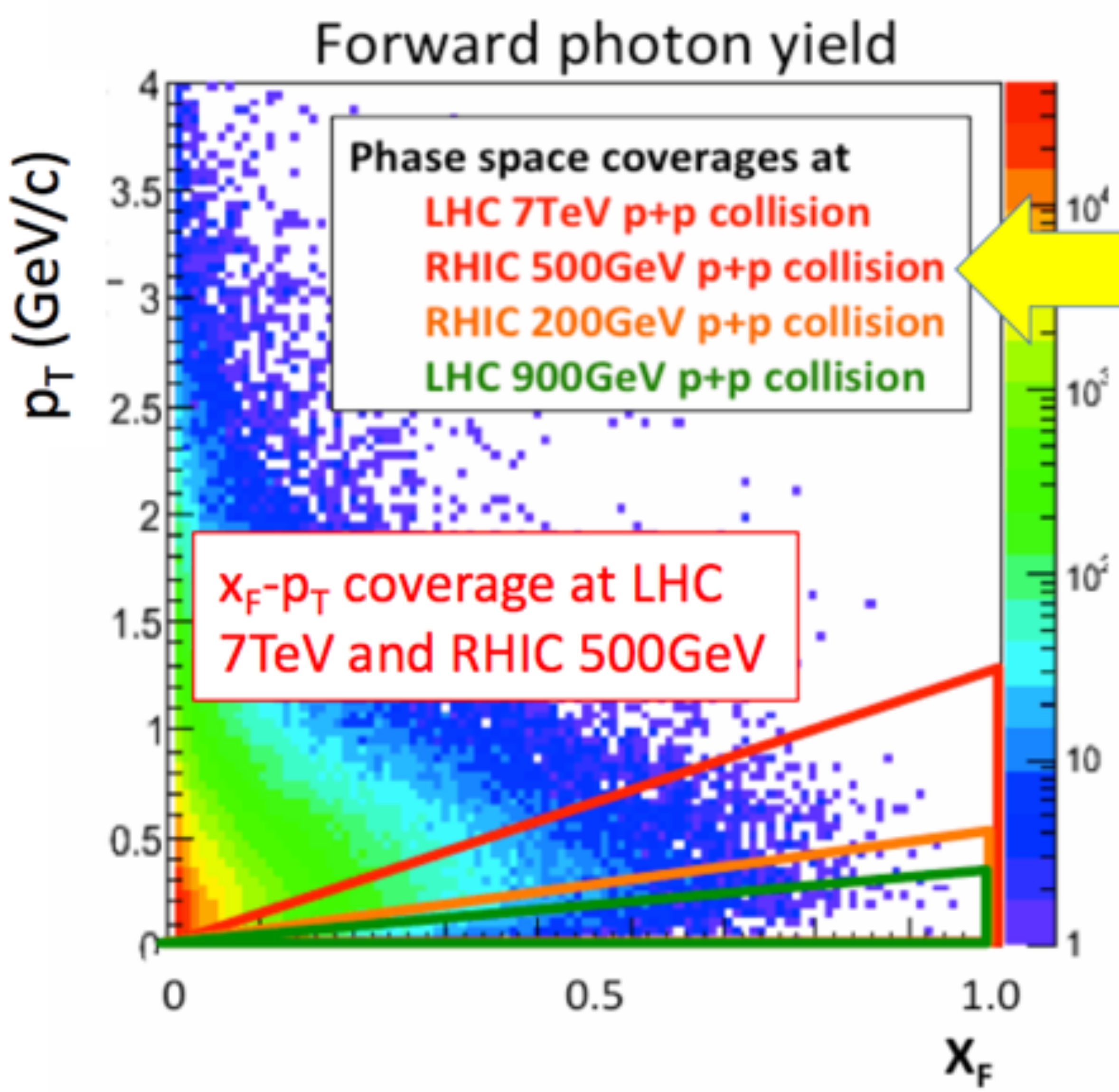
- The efficiency of diffraction identification is approximately 50%, with 99% purity.

✦LHCf detectors have high sensitivity at $\log_{10}(\xi) < -6$

✦Application of ATLAS veto to the LHCf data purifies low mass diffraction event samples

Stay Tuned

RHICf experiment (taking data right now)

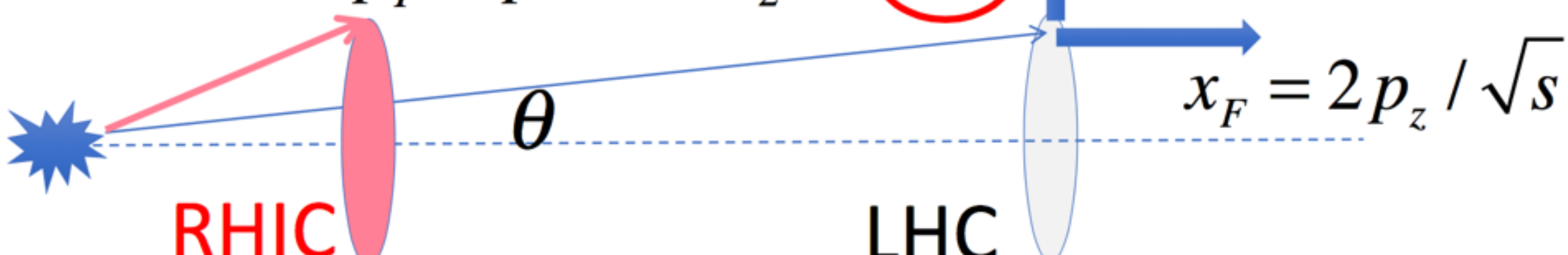


- ✓ Wide x_F-p_T coverage is desired
- ✓ Maximum p_T coverage is proportional to $\theta\sqrt{s}$

⇩

- ✓ RHIC allows larger θ with smaller $\sqrt{s}$
- ✓ x_F-p_T coverage at LHC 7TeV and RHIC 500GeV are almost identical!!

$$p_T = p\sin\theta \leq \tfrac{1}{2}\sqrt{s}\sin\theta$$



Backup

The LHCf Collaboration

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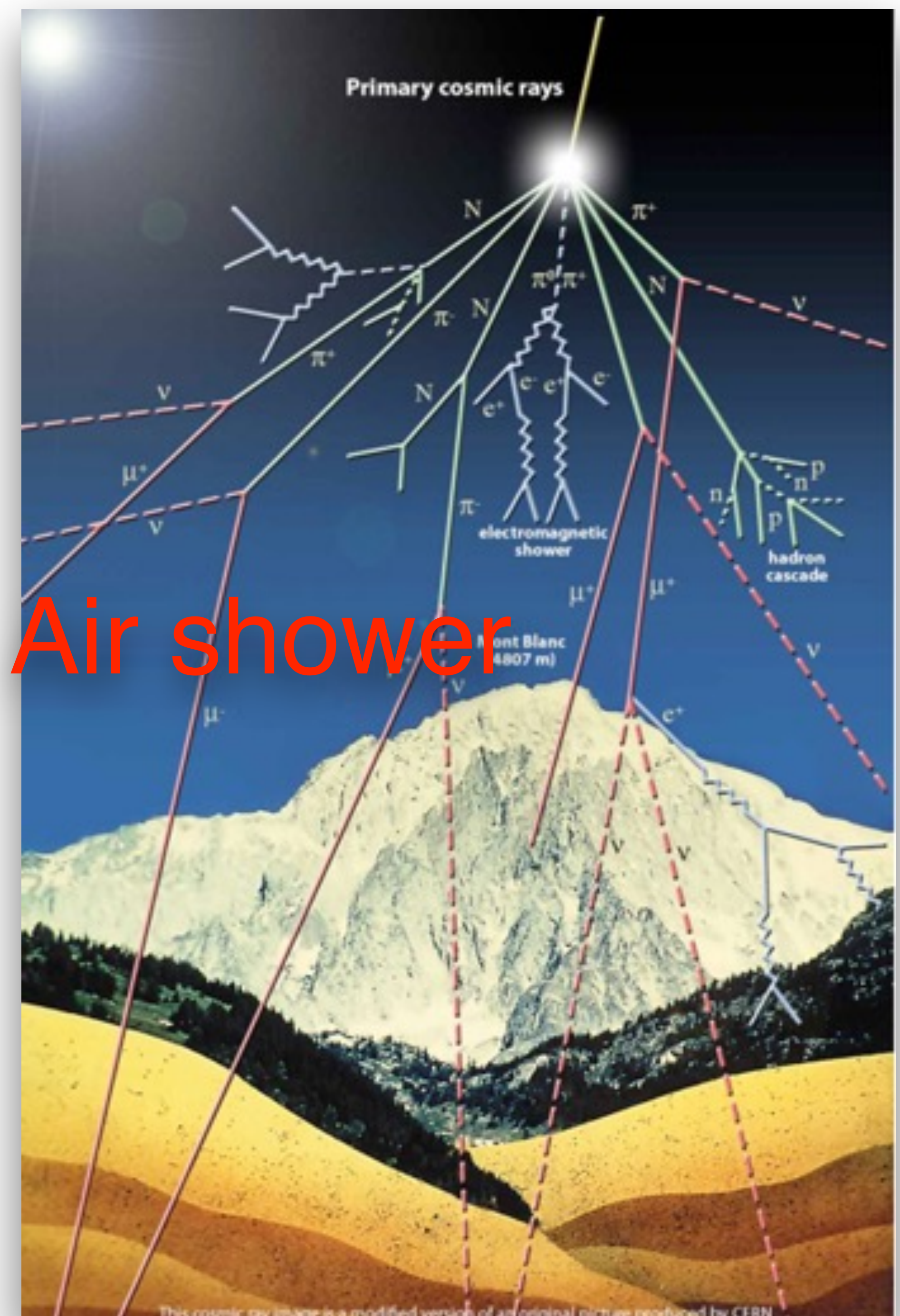
Hadronic interaction models

Puzzles: The origins and the acceleration mechanism of cosmic rays

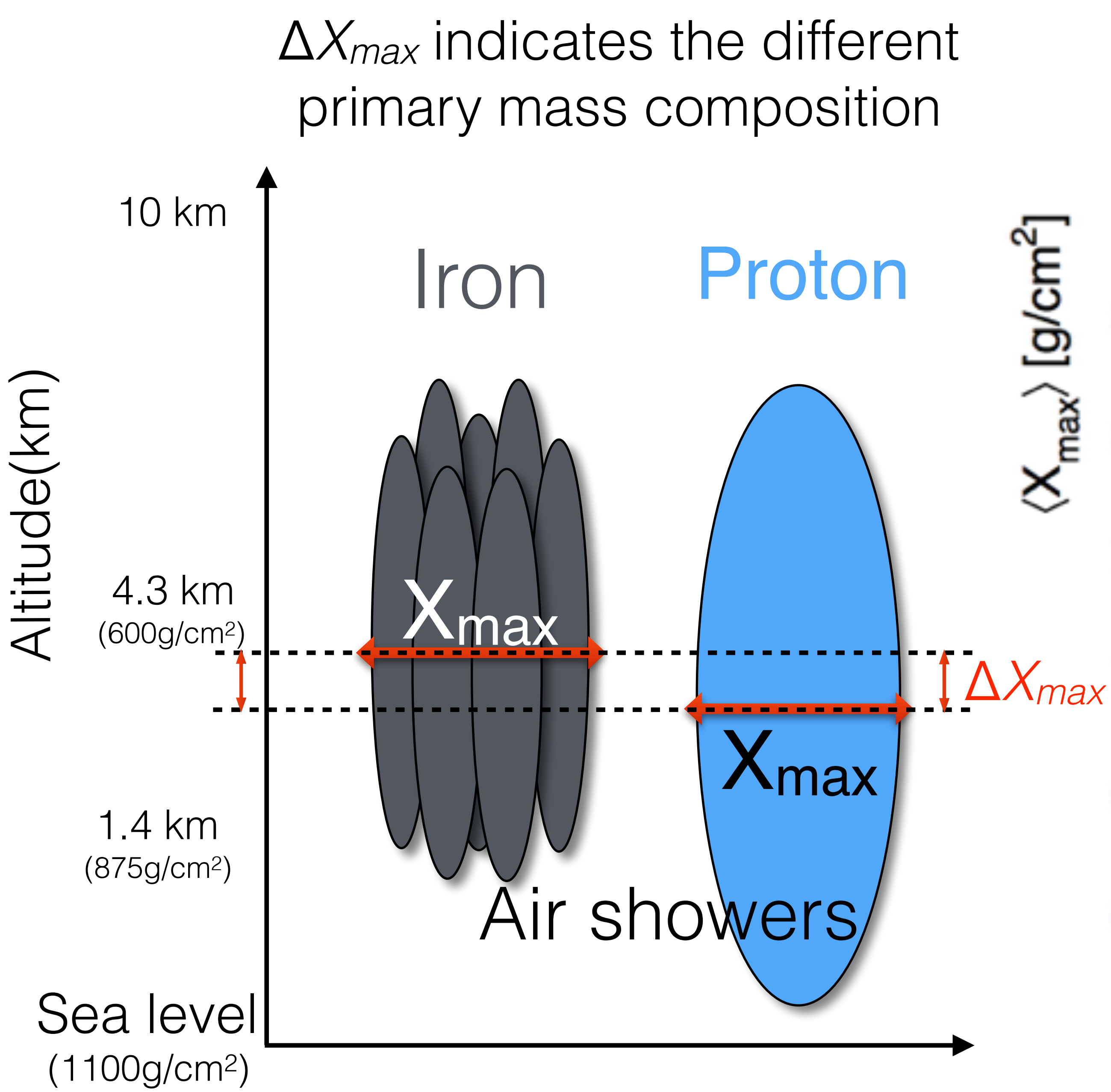
Mass Composition: The key factor for solving these puzzles

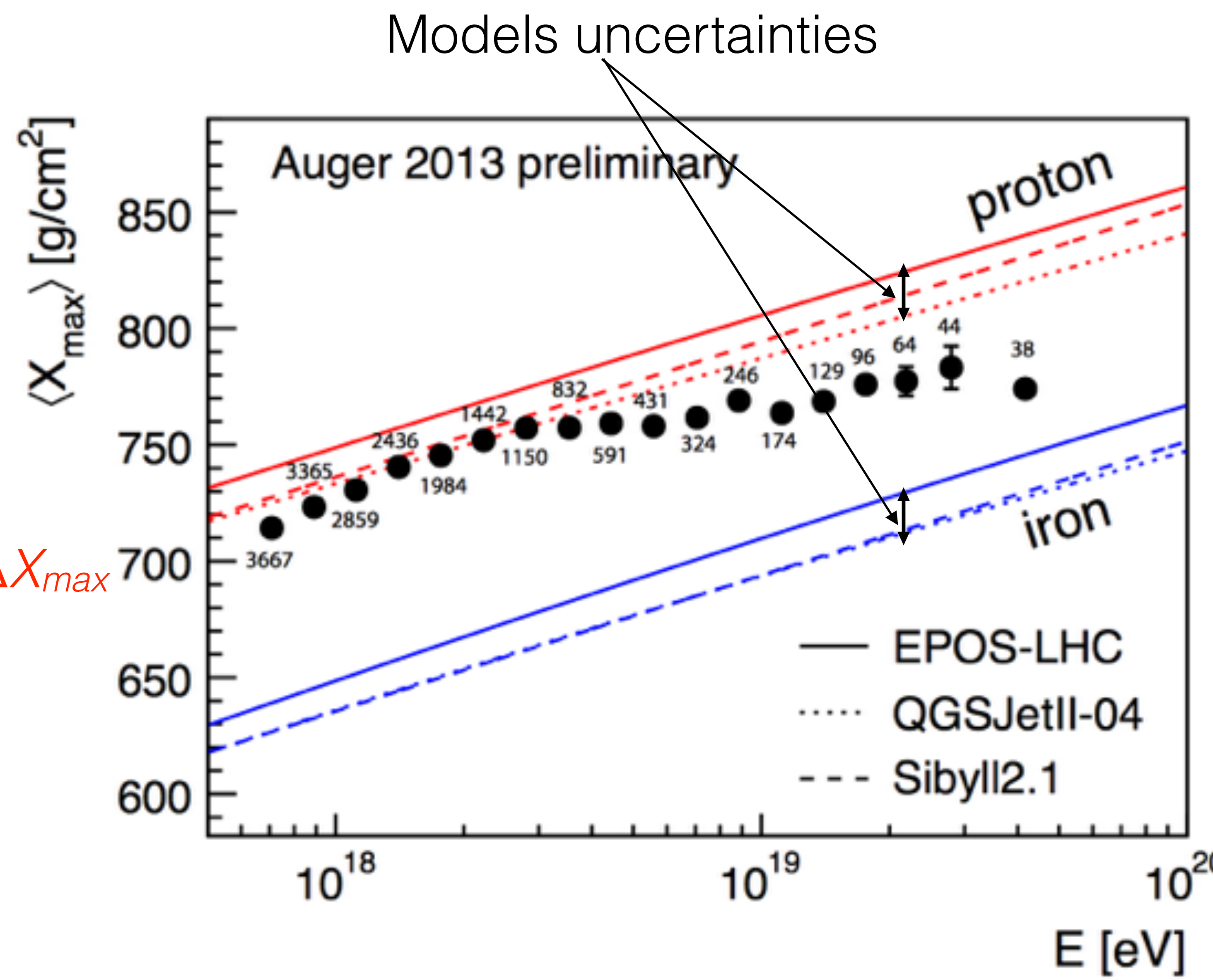
- Determination of composition depends on interpreting the measurement data of air showers
- The interpretation needs to use the hadronic interaction models

The issue to interpret the air shower data:
The limitations in modeling of <u>hadronic interactions</u> cause large model uncertainties.



Hadronic interaction models



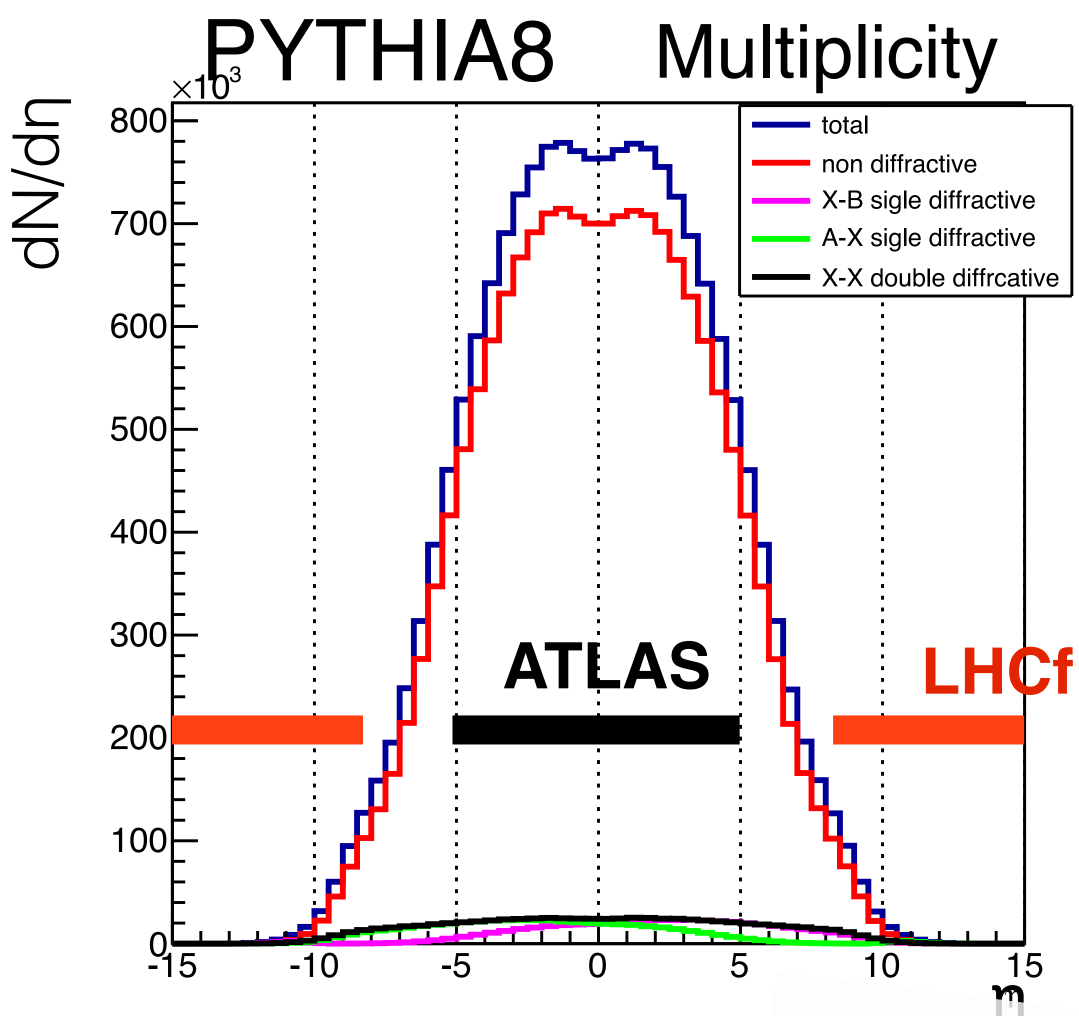


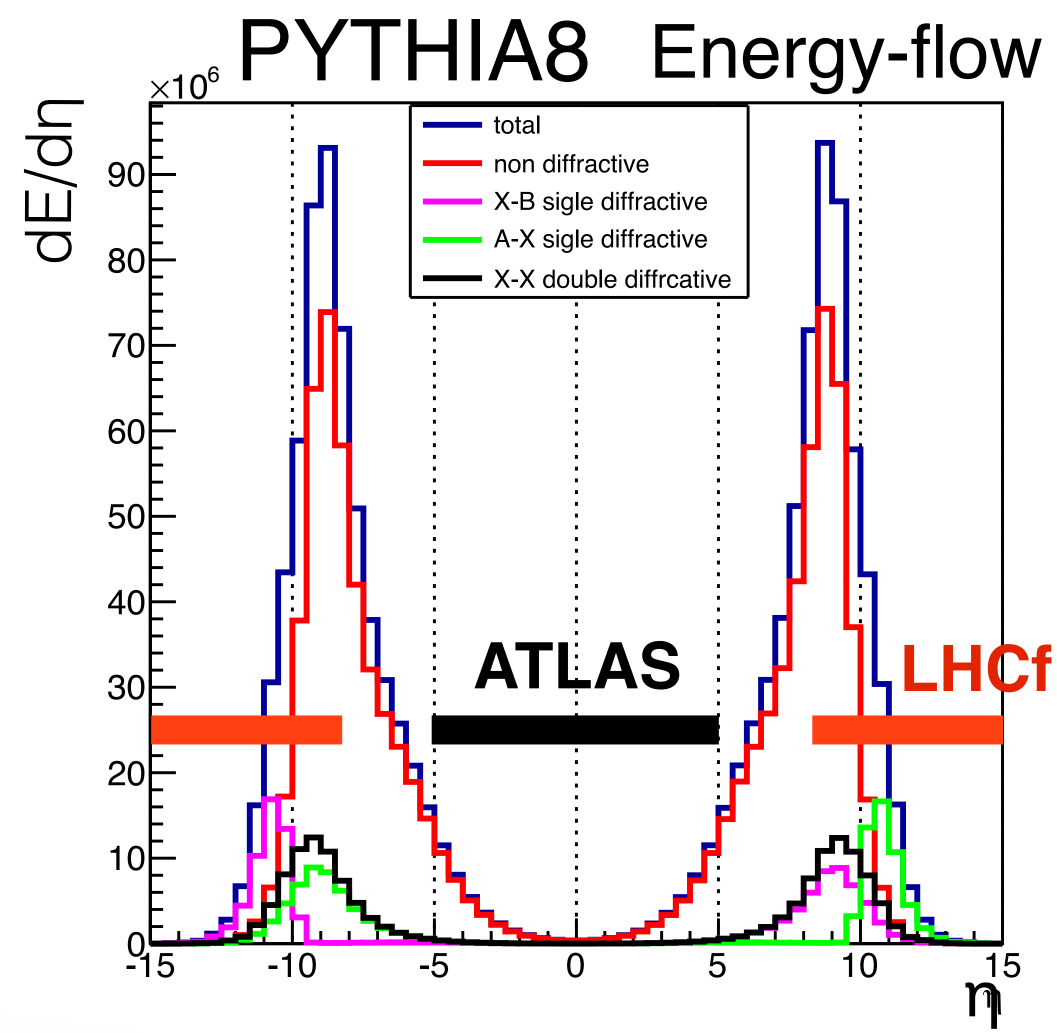
The issue to interpret the air shower data:
The limitations in modeling of hadronic interactions in air shower and largely unknown model uncertainties.

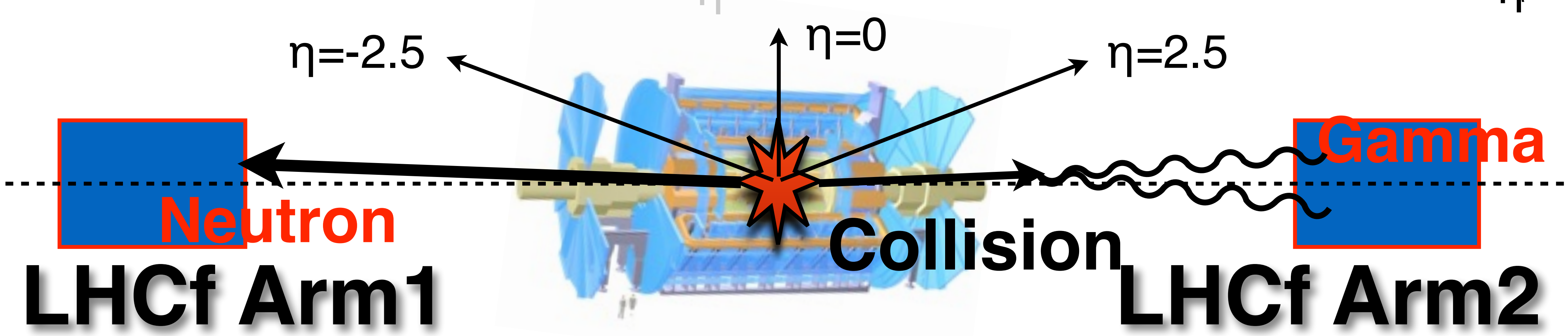
Particle density and energy flow at 13TeV

Most of secondary particles concentrate to the center

The most energetic secondary particles emitted to the very forward region (LHCf sensitive region)

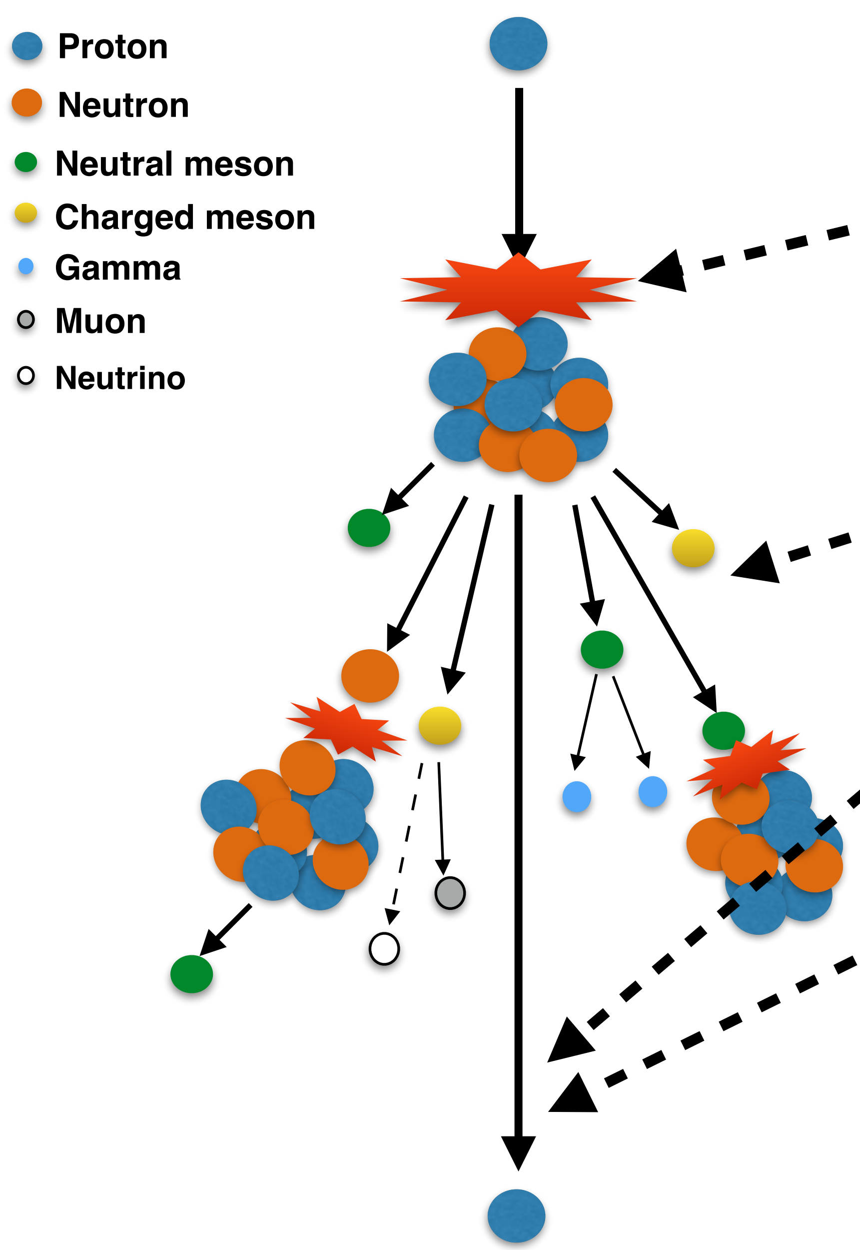






What to be calibrated by accelerators

Interactions between cosmic ray and nucleus:
Hadronic interaction (soft process) ->prediction base on phenomenological models (EPOS, QGSJET, etc.)

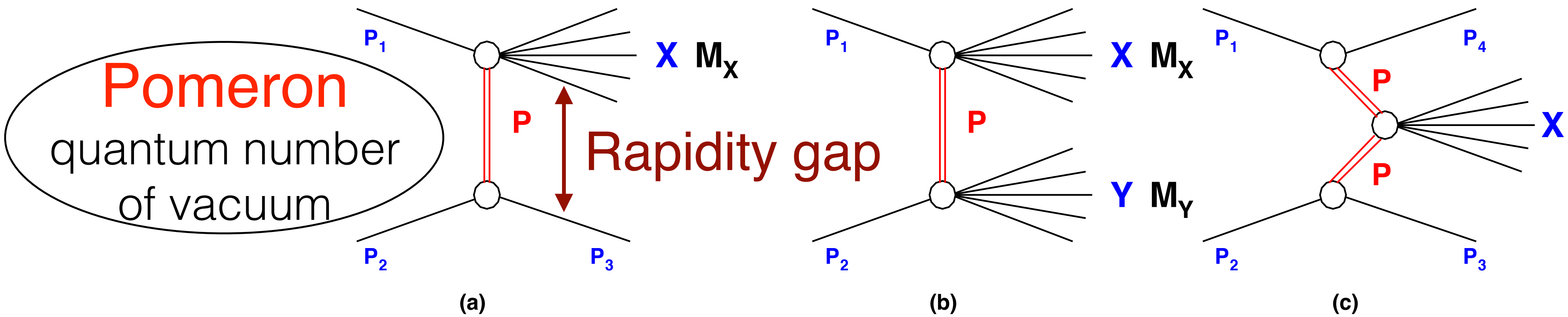


<u>Key parameters</u>

- Inelastic cross section(interaction mean free path)
  TOTEM, ATLAS, CMS etc.
- Multiplicity
  Central detector
- **Inelasticity ($k = 1 - P_{lead}/P_{beam}$)**
  LHCf, ZDC, etc.
- **Forward energy spectrum**
  LHCf, ZDC, etc.
- Nuclear effect
  LHCf, ALICE, etc.

Diffractive dissociation

Diffraction contribute 25%~30% of total cross sections.



Single-diffraction Double-diffraction Central-diffraction

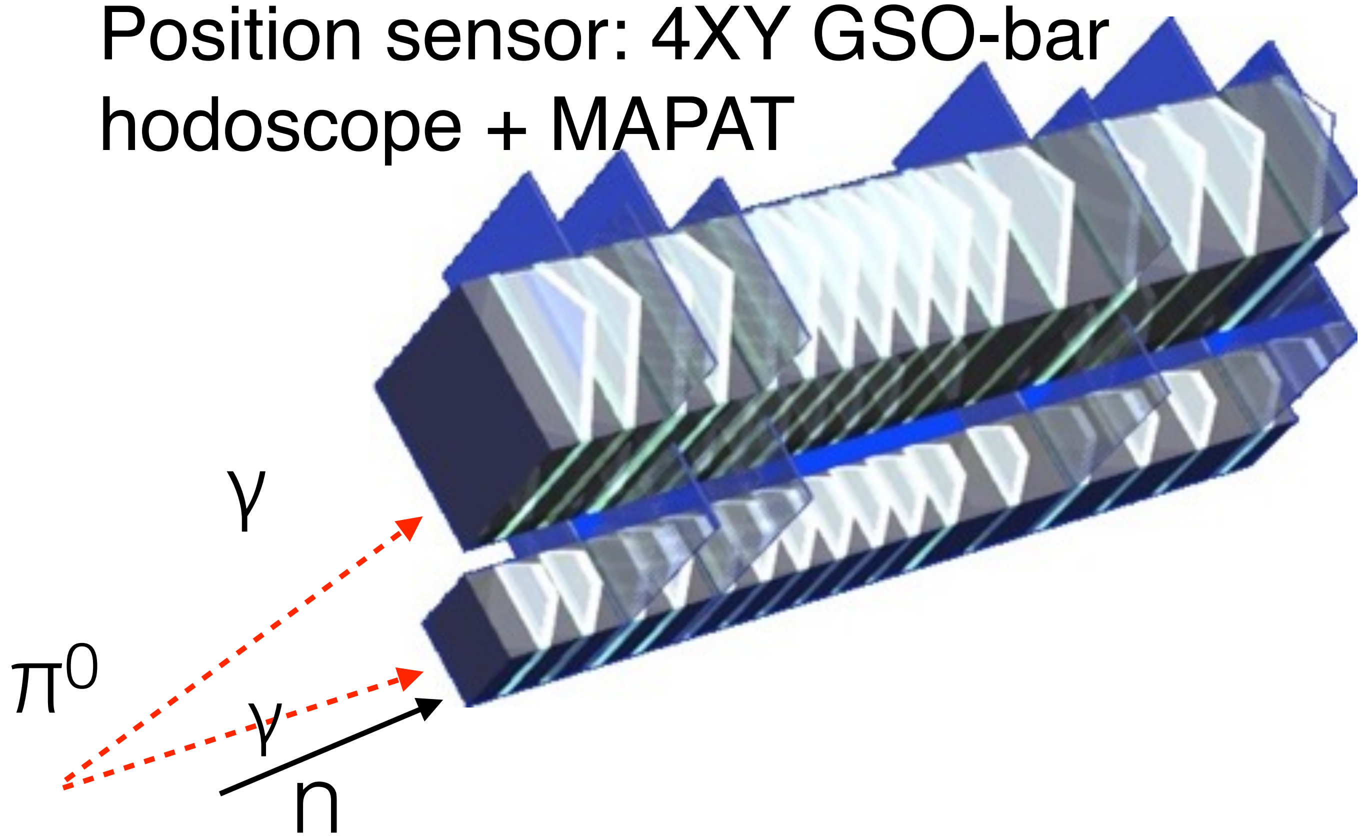
Diffraction was described by pemeron based model, but the technic of calculation in each model is a little different

EPOS-LHC : cut diagrams (pomeron)
QGSJET-II-04: renormalized pomeron flux
SIBYLL2.1 : eikonal picture

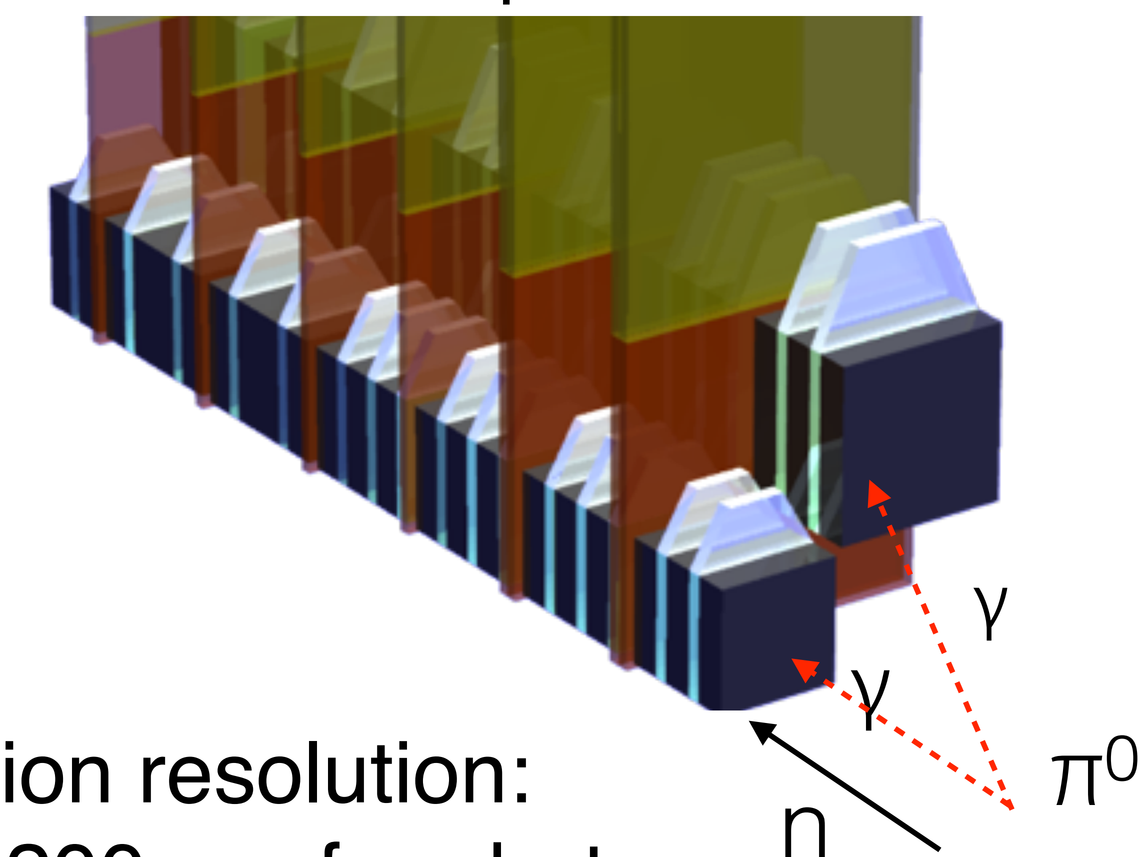
Calorimeters performance

- Two imaging sampling shower calorimeters
- 44r.l. tungsten, 16 layers of GSO scintillators and 4 position sensitive layers
- The η coverage of the calorimeter: |η|>8.4

Arm1 detector
Position sensor: 4XY GSO-bar hodoscope + MAPAT



Arm2 detector
Position sensor:
4XY silicon strip detectors



Energy resolution:(>100GeV)
<5% for photons
40% for neutrons

Position resolution:
<200μm for photons
<1mm for neutrons

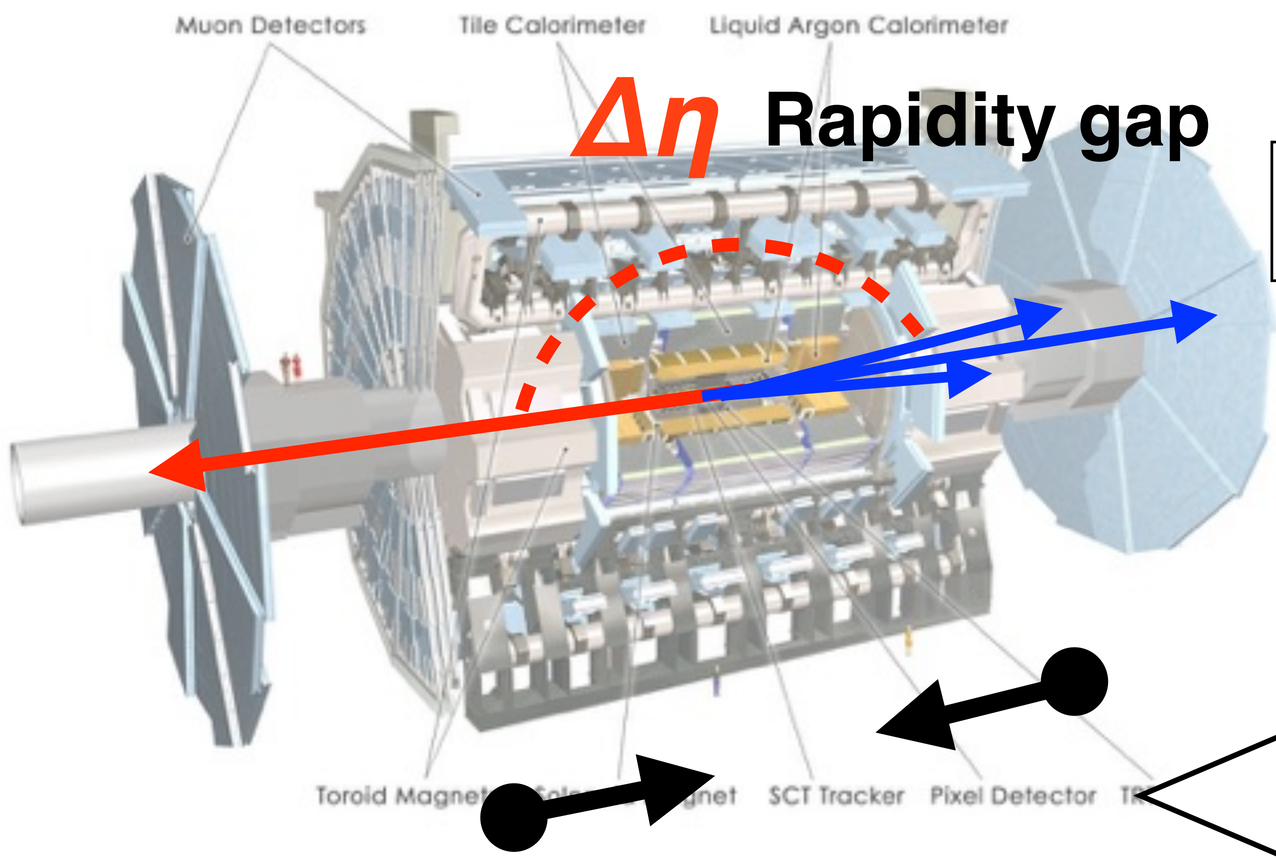
What’s the source of the difference

No MC simulation model can represent LHCf data perfectly

- Hard interactions can be predicted by using perturbative QCD, and well be tested by many experiment data.
- Soft interactions dominate by non-perturbative QCD, phenomenological models base on Gribov-Regge theory proposed
- Diffractive dissociation belong to soft process.

Diffraction measurement is difficult issue for experiment.
especially, low mass diffraction.

Diffraction identification by ATLAS-veto



LHCf triggered events

ATLAS veto:

|η|<2.5&P_T>100MeV
Charged particle number
N_{track}

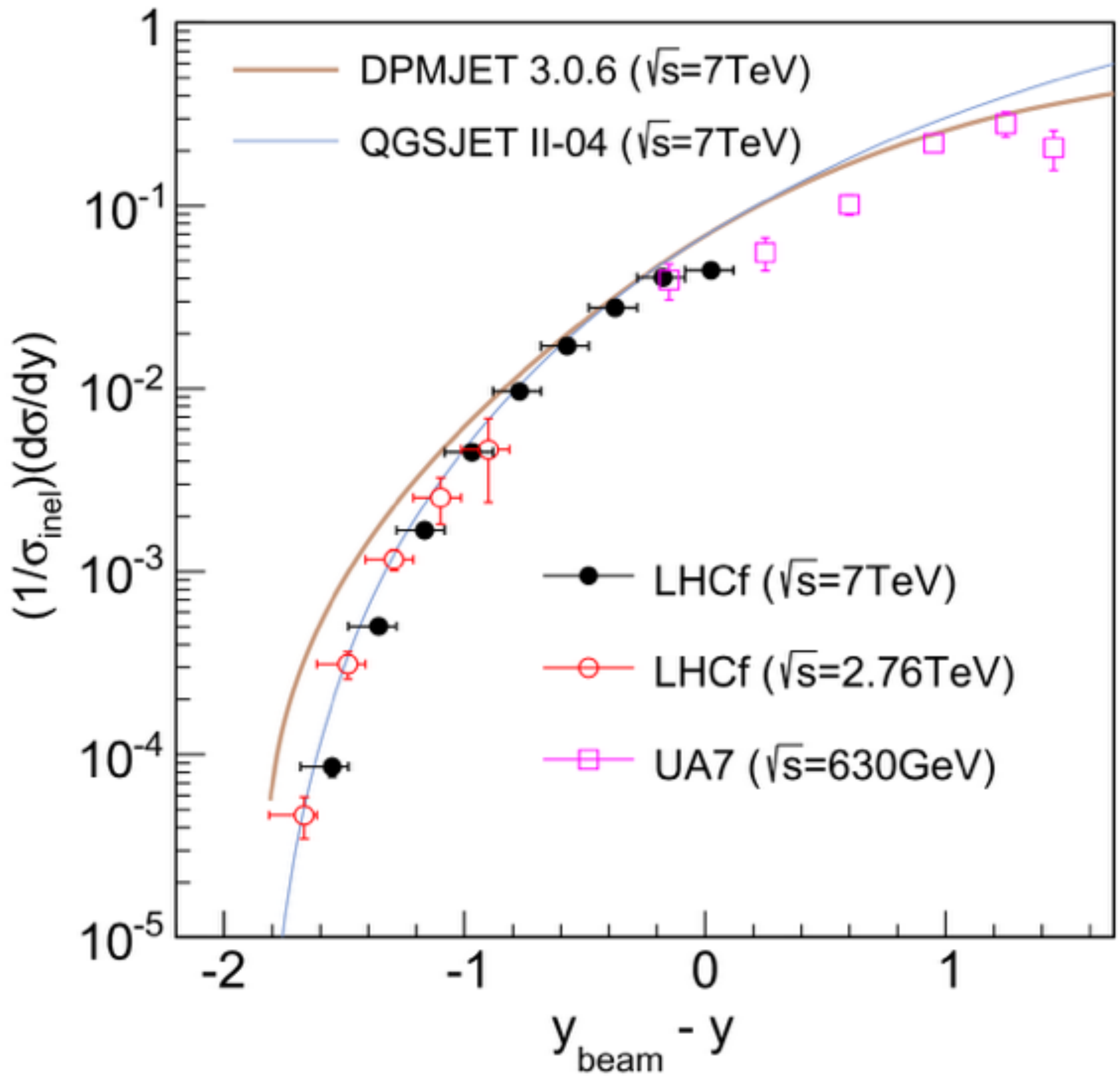
$N_{track} = 0$ → Diffraction-like

$N_{track} \neq 0$ → Non-diff.-like

Limiting fragmentation in forward π^0 production

Hypothesis of limiting fragmentation:

The rapidity distribution of secondary particles in the forward region (target's fragment) would be independent of $\sqrt{s}$.



The scaling for forward π^0 is true at the level of ±15%