Photon analysis status

Alessio

LHCf collaboration meeting

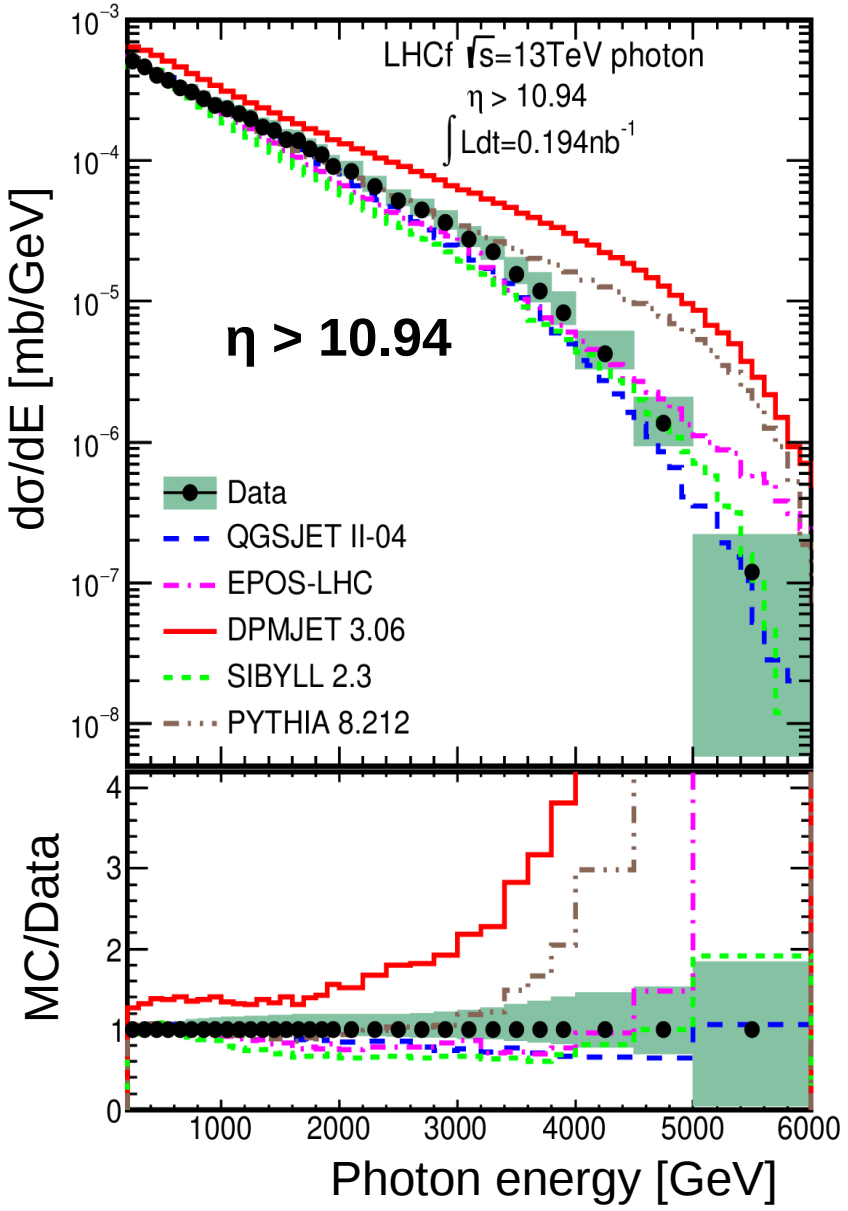
Firenze, 26-27/11/2018

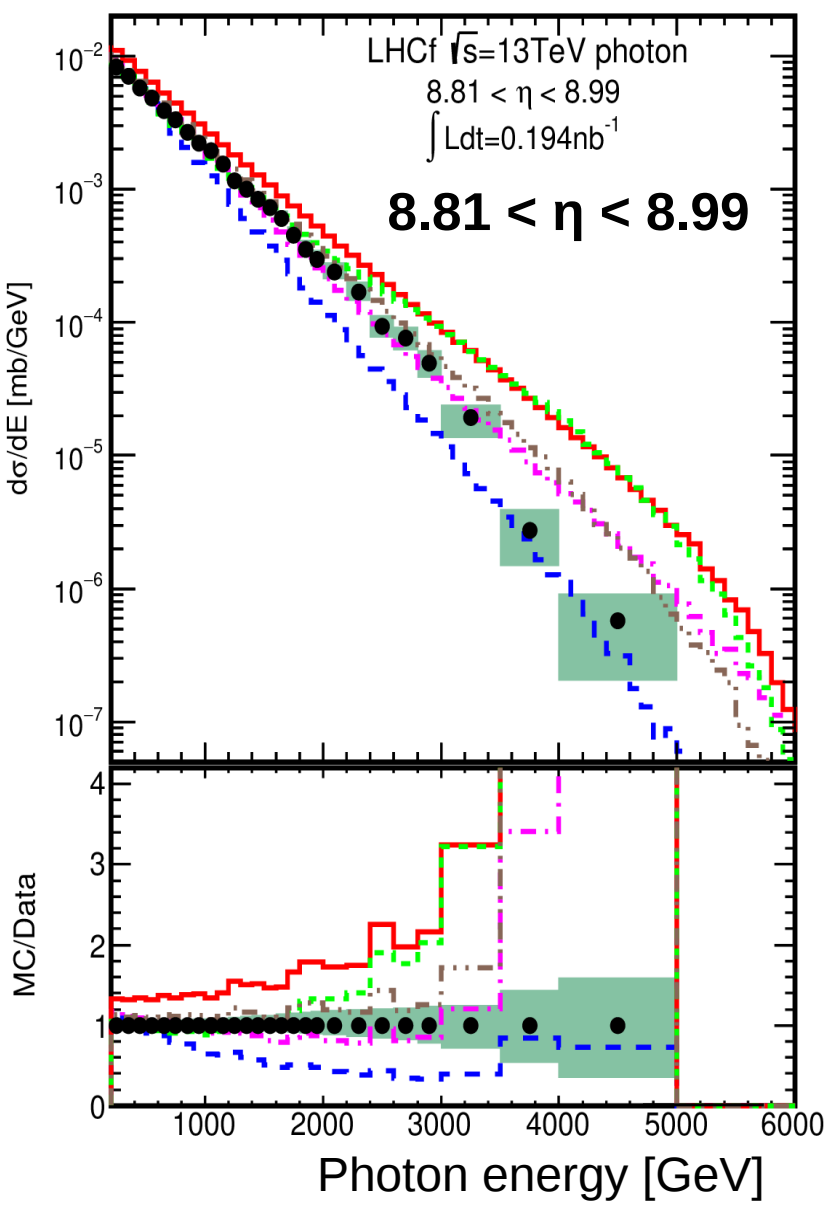
Photon analysis topics

- **p-p at 13 TeV**
  - energy spectrum – Completed
  - η-extension of analysis – Preliminary
  - dE/dη – Preliminary
  - Feynman scaling – Preliminary
  - P_T vs η – To do (?)
- **p-Pb at 8.16 TeV**
  - energy spectrum – Preliminary
  - η-extension, dE/dη, scaling, P_T – To do (?)

Results in p-p at 13 TeV

Photon spectrum in p-p at 13 TeV





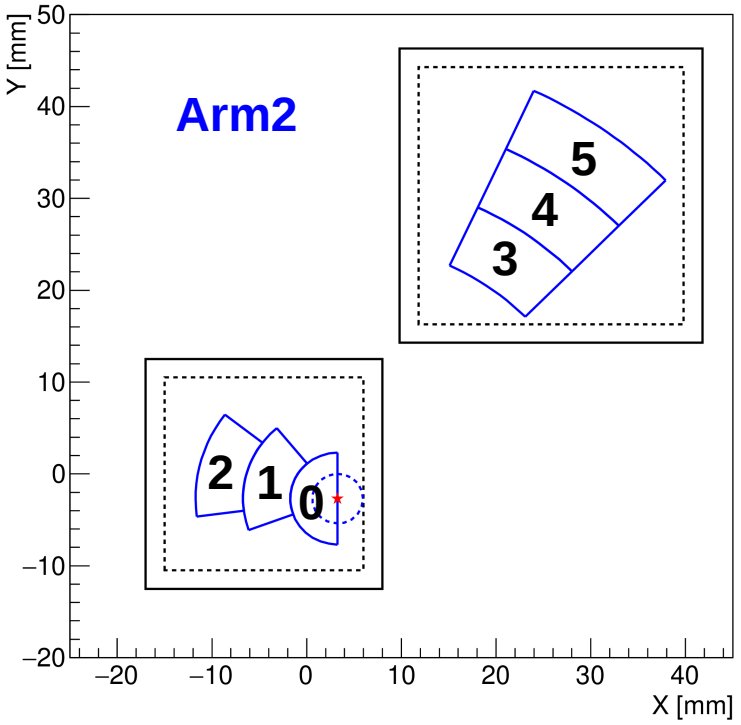
PLB 780 (2018) 233–239

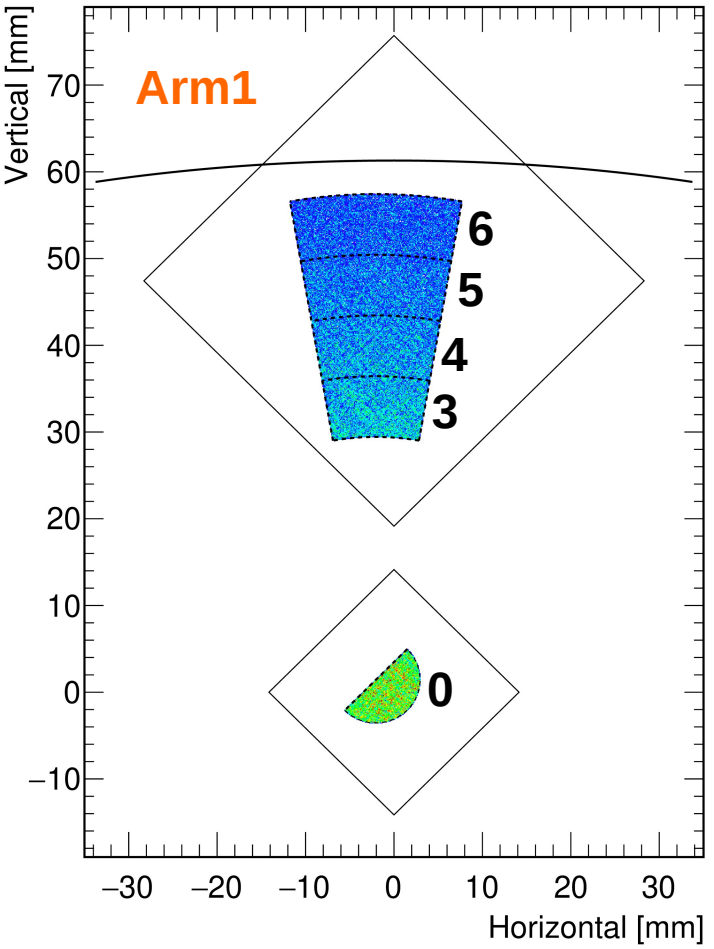
- **EPOS-LHC**: good agreement for E < 3-4 TeV in both pseudorapidity regions
- **QGSJET II-04**: good overall agreement for high-η, softer spectrum in low-η

Pseudorapidity extension

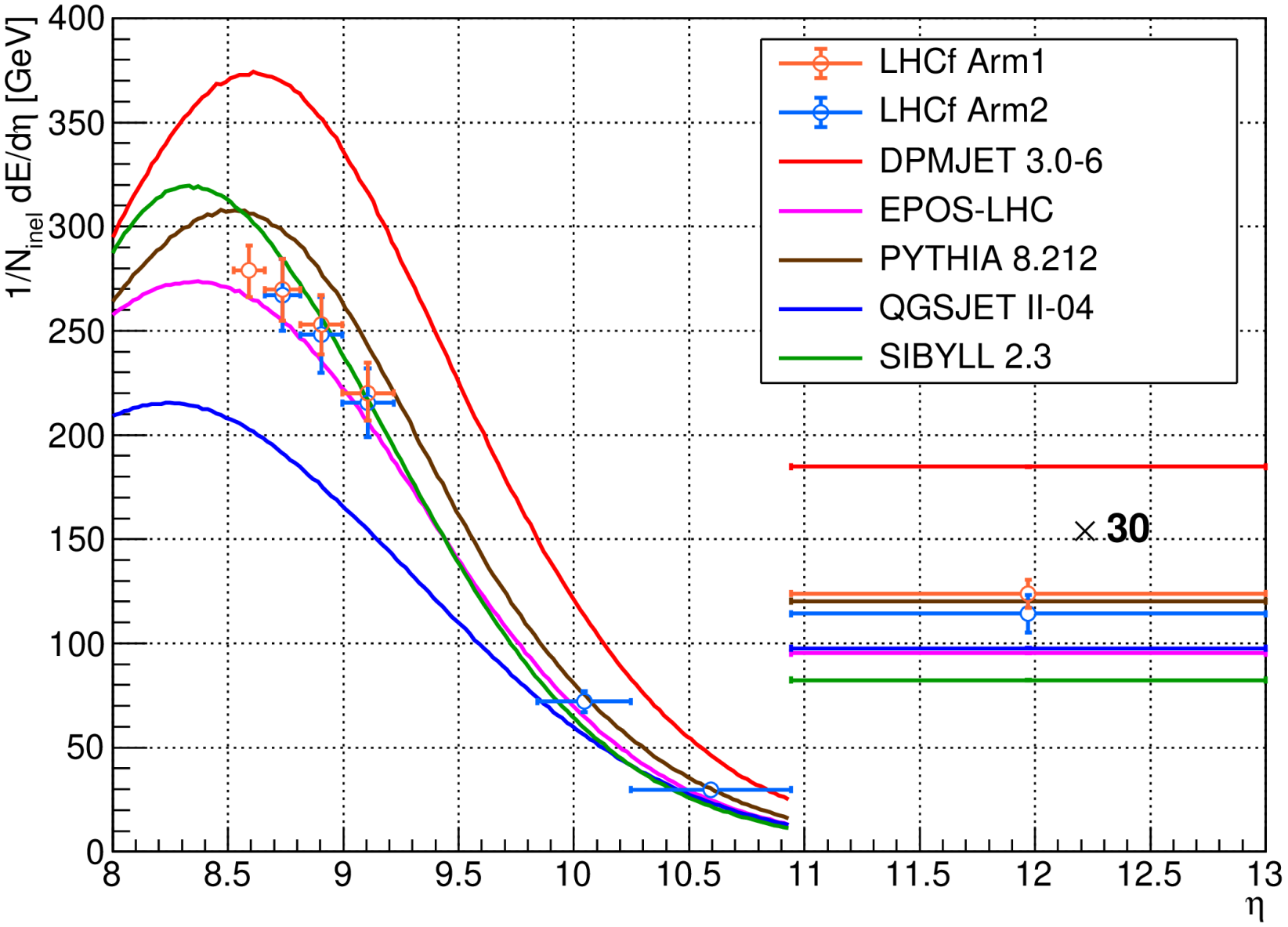
- Regions added:
  - **0) η > 10.94**
  - **1) 10.25 < η < 10.94** (Arm2 only)
  - **2) 9.84 < η < 10.25** (Arm2 only)
  - **3) 8.99 < η < 9.22**
  - **4) 8.81 < η < 8.99**
  - **5) 8.66 < η < 8.81**
  - **6) 8.52 < η < 8.66** (Arm1 only)

- Feynman scaling area (blue dashed): **η > 11.56**, same P_T coverage as 7 TeV analysis





Electromagnetic energy flow (dE/dη)

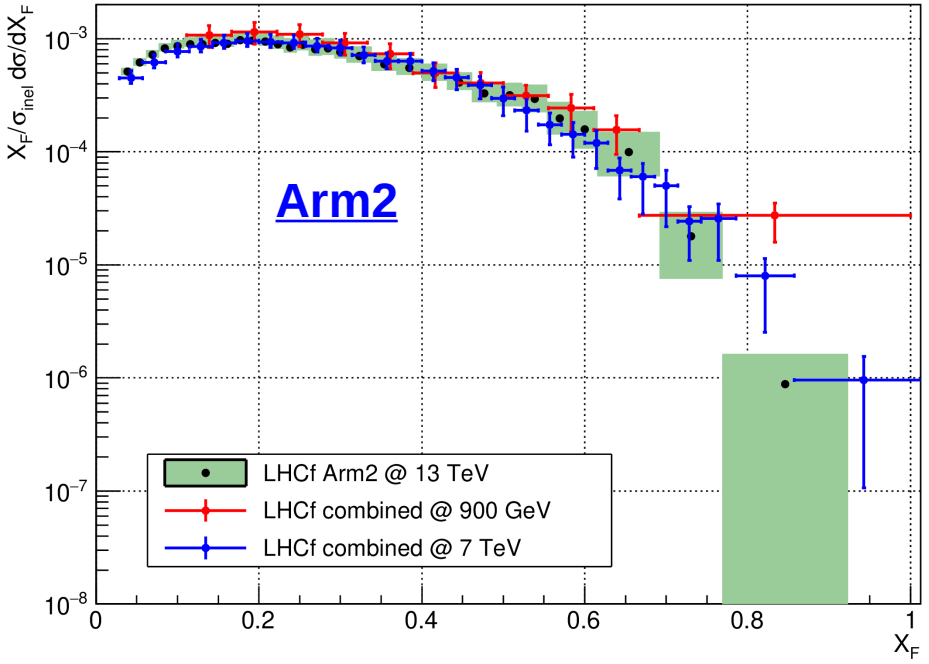


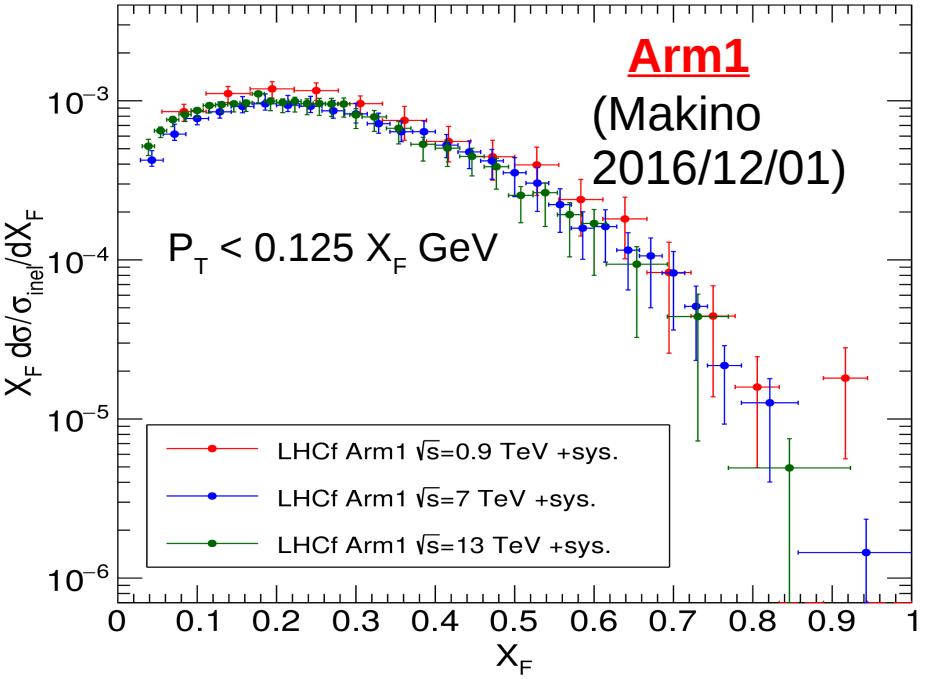
EM energy flow: Arm1 vs Arm2

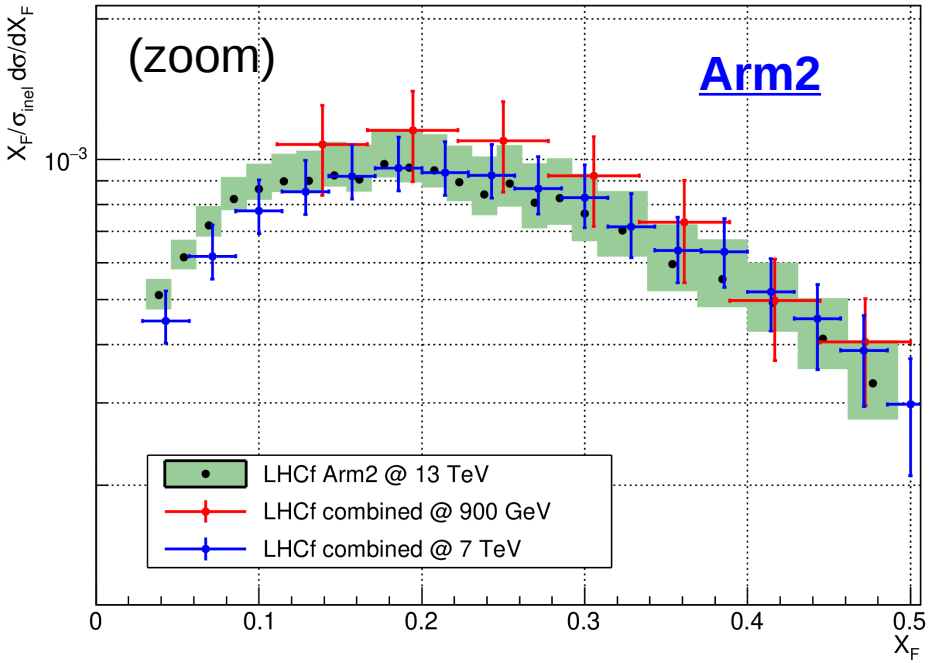
η range	dE/dη (Arm1)	dE/dη (Arm2)
η > 10.94	4.1 (+0.3 -0.3) GeV	3.8 (+0.3 -0.3) GeV
8.99 < η < 9.22	220 (+14 -13) GeV	215 (+16 -16) GeV
8.81 < η < 8.99	253 (+14 -14) GeV	248 (+18 -18) GeV
8.66 < η < 8.81	270 (+13 -13) GeV	267 (+17 -17) GeV

- Correlated errors are removed (unfolding and luminosity)
- Arm1 and Arm2 results are consistent within uncertainties

Feynman scaling



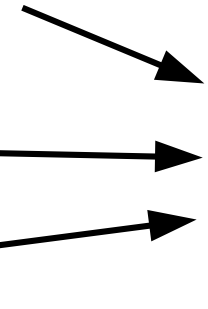




- Errors are statistical+systematic
- Luminosity uncertainty is included (1.9% at 13 TeV, 6.1% at 7 TeV, 21% at 900 GeV)
- Good agreement within errors above X_F~0.1

To do list

- **p-p at 13 TeV**
  - η-extension of analysis
  - dE/dη
  - Feynman scaling



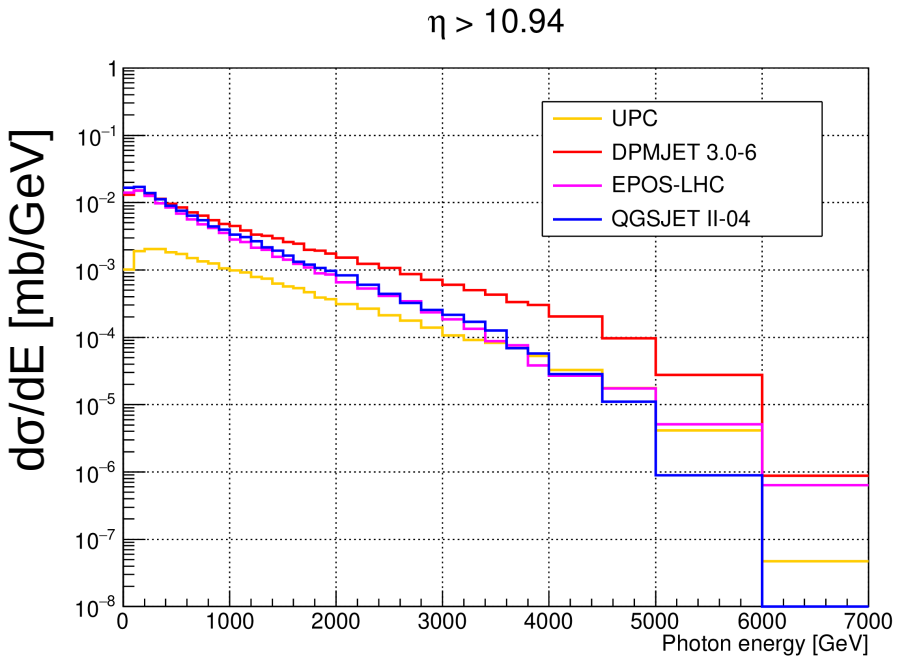
- Better estimate systematic errors
- Combine Arm1 and Arm2

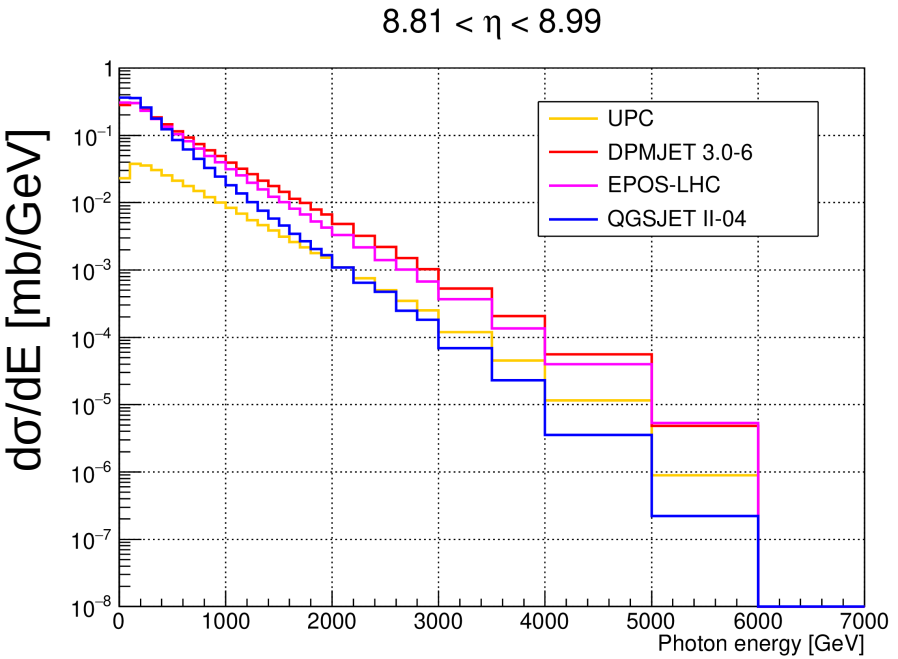
Photon spectrum in p-Pb at 8.16 TeV

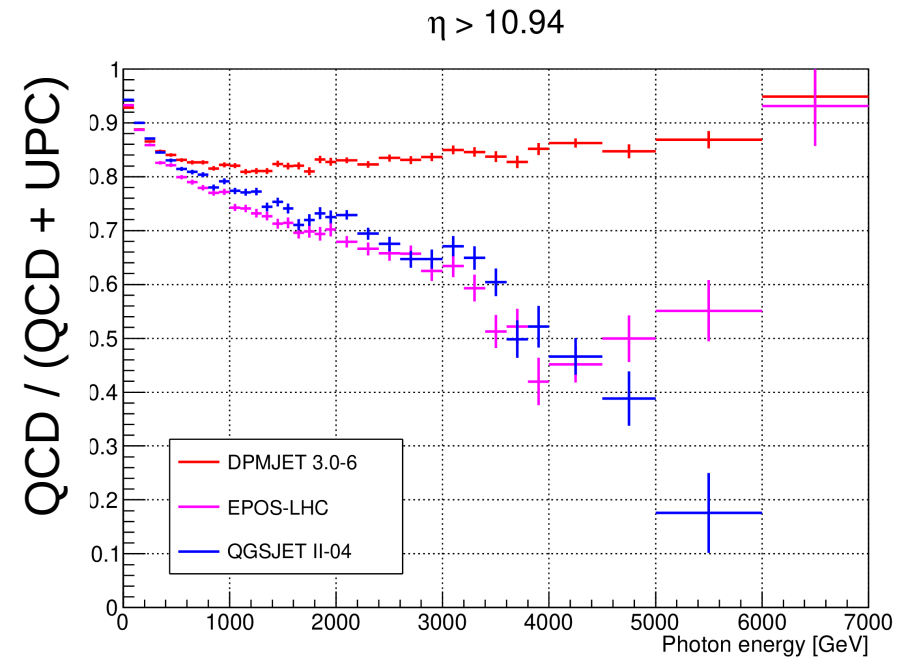
p-Pb analysis

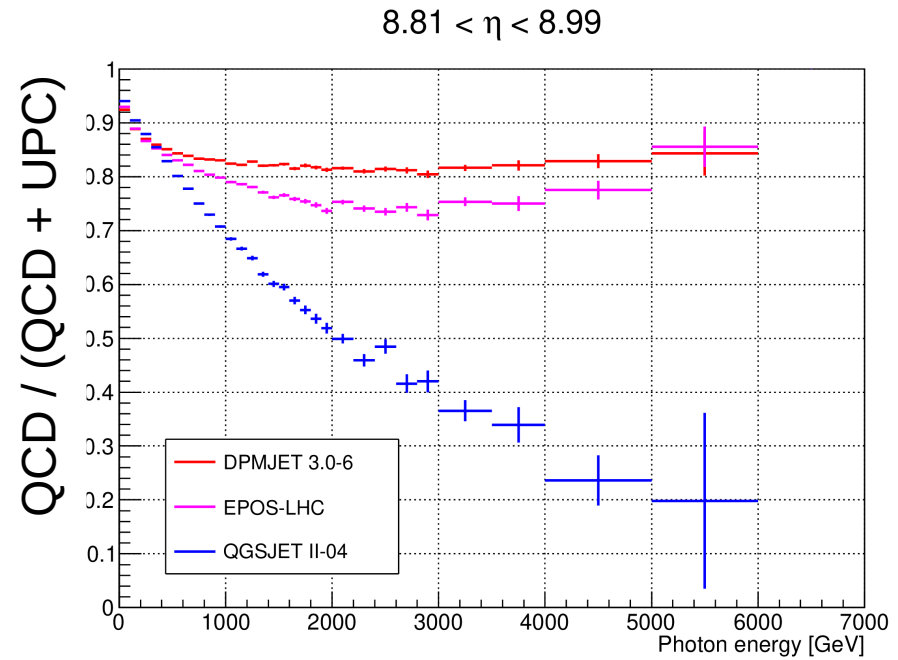
- Same analysis procedure of p-p paper
- MC simulations:
  - CRMC: 10^7 events with DPMJET 3.06, EPOS-LHC and QGSJET II-04 → for final comparison with data
  - CRMC+DoubleArm+End2End: 10^7 events with EPOS-LHC (no beam-pipe interaction, DPMJET 3.04 for the interaction with the detector) → for template fit and unfolding
  - UPC simulations (software from Mitsuka-san): 10^7 events with STARLIGHT+SOPHIA/DPMJET → add UPC contribution to MC
- Integrated luminosity: 8.145 μb^{-1} +-6.2%
  - calculated on runs 61874-61991 of fill 5538 (~2h)

UPC contribution





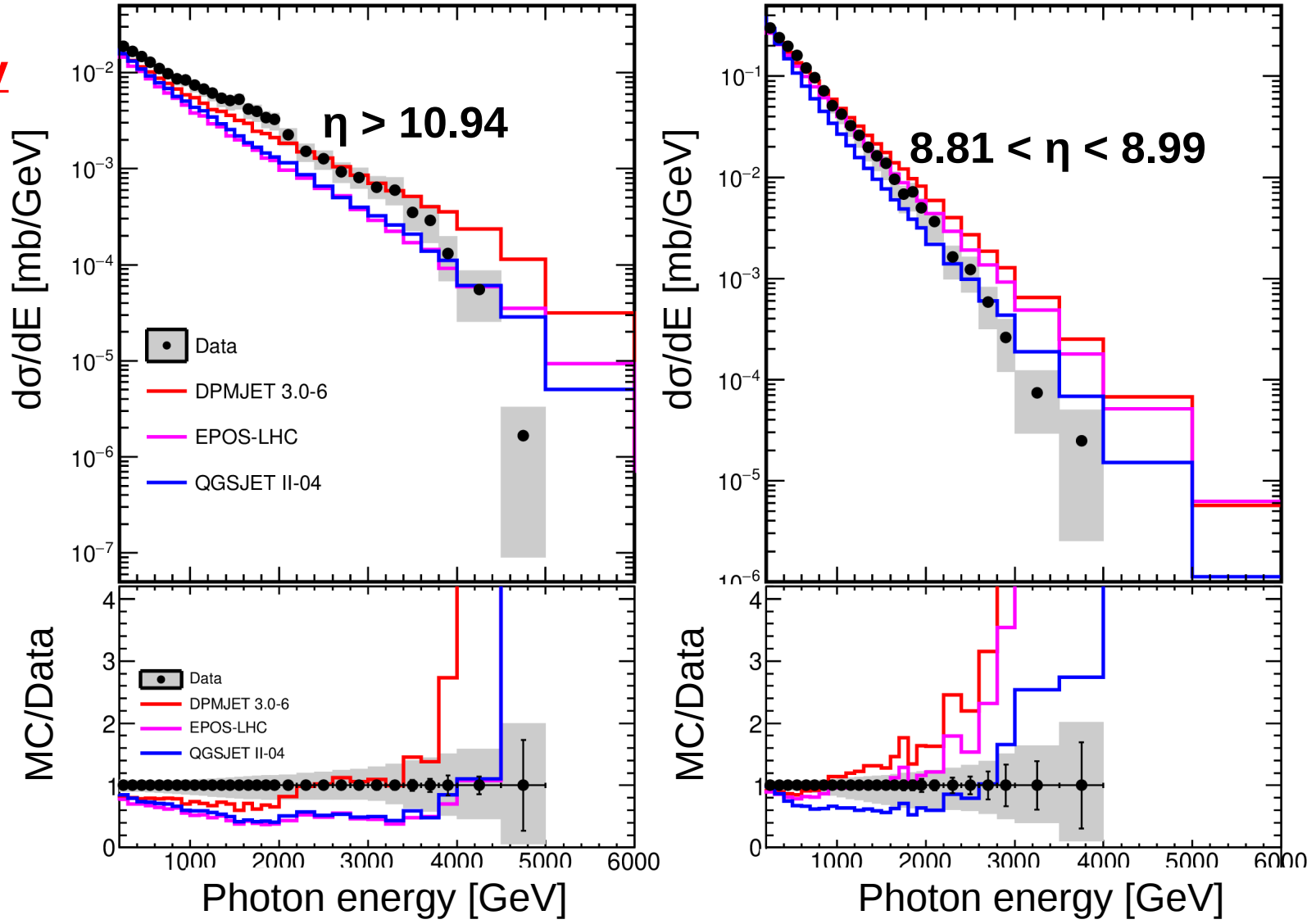




Photon spectrum in p-Pb at 8.16 TeV

LHCf Arm2
Preliminary

UPC added to MC simulations



- η > 10.94: lower yield from all models
- 8.81 < η < 8.99: all models predict an harder spectrum

To do list

- Increase MC statistics for template fit and unfolding
- Include UPC contribution in MC template and unfolding sample (now it is included only in generators)
- Check discrepancy of hadron L90% distribution between data and MC (broader distribution in MC)
- Include UPC model dependence in sys. uncertainty

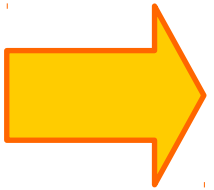
backup

LHCf p-p run at 13 TeV

- Low luminosity dedicated run for LHCf: 9th – 13th of June 2015

LHCf run:

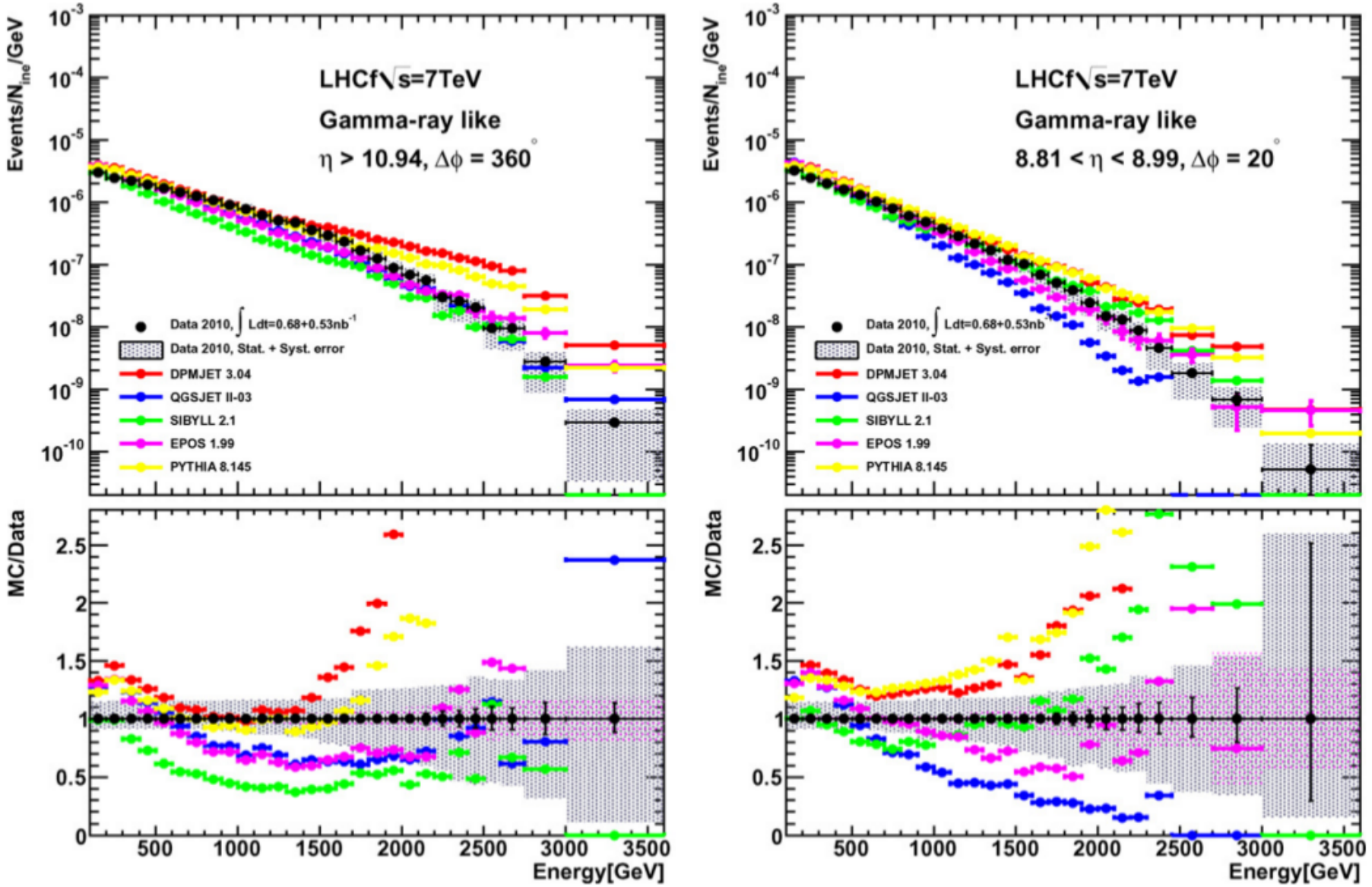
- **√s = 13 TeV**
- ~ 27 hours of operation
- **Luminosity:** $0.3 - 1.6 \cdot 10^{29}$ cm^{-2} s^{-1}
- **Pile-up:** 0.01 - 0.03
- $4 \cdot 10^{7}$ **events**
  $5 \cdot 10^{5}$ **π^0s**
- Trigger exchange with **ATLAS**



Analysis data set:

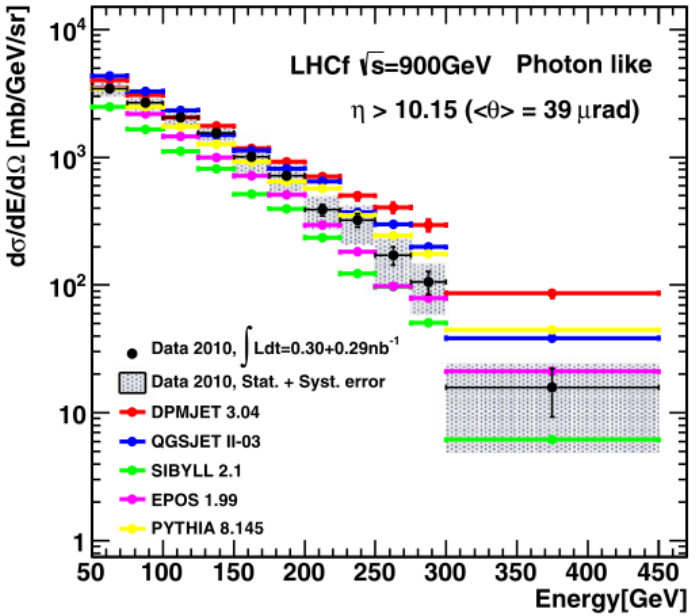
- ~ 3 hours of operation
- **Luminosity:** $0.3 - 0.5 \cdot 10^{29}$ cm^{-2} s^{-1}
- **Pile-up:** 0.007-0.012
- **Integrated luminosity:** 0.194 nb^{-1}
- $4 \cdot 10^{6}$ **events**

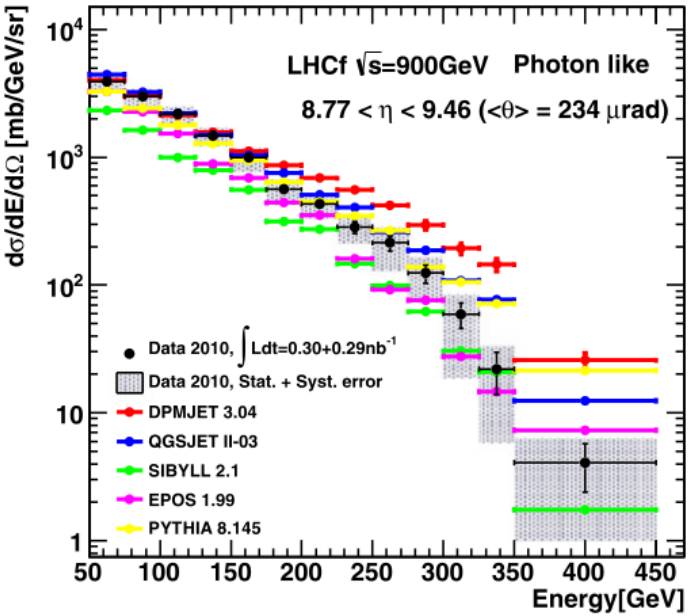
Photons spectrum in p-p at 7 TeV

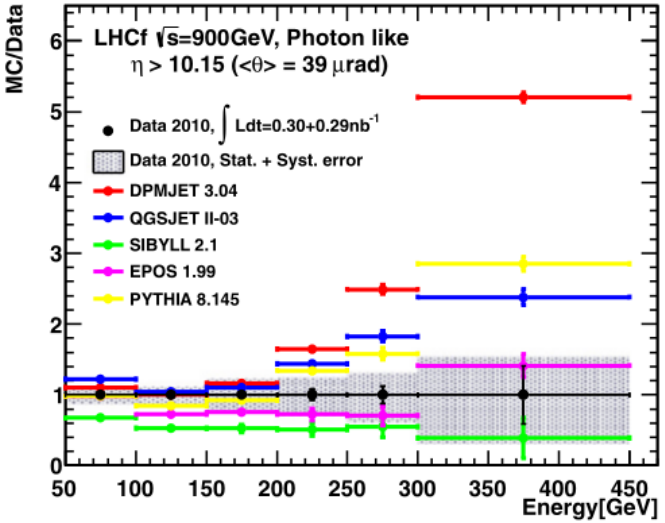


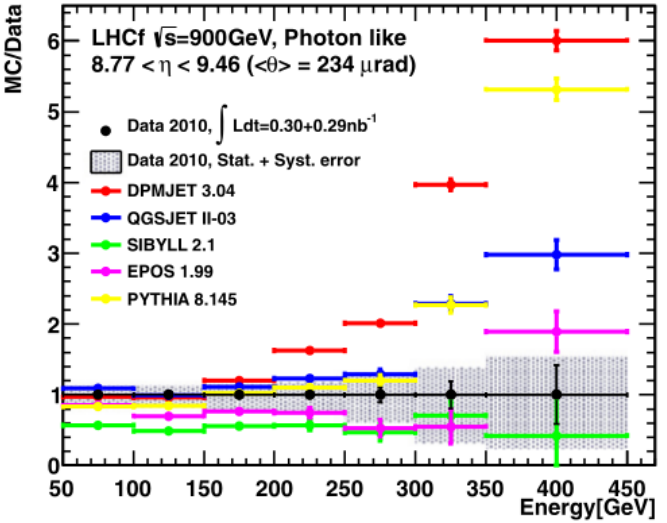
PLB 703 (2011), 128-134

Photons spectrum in p-p at 900 GeV





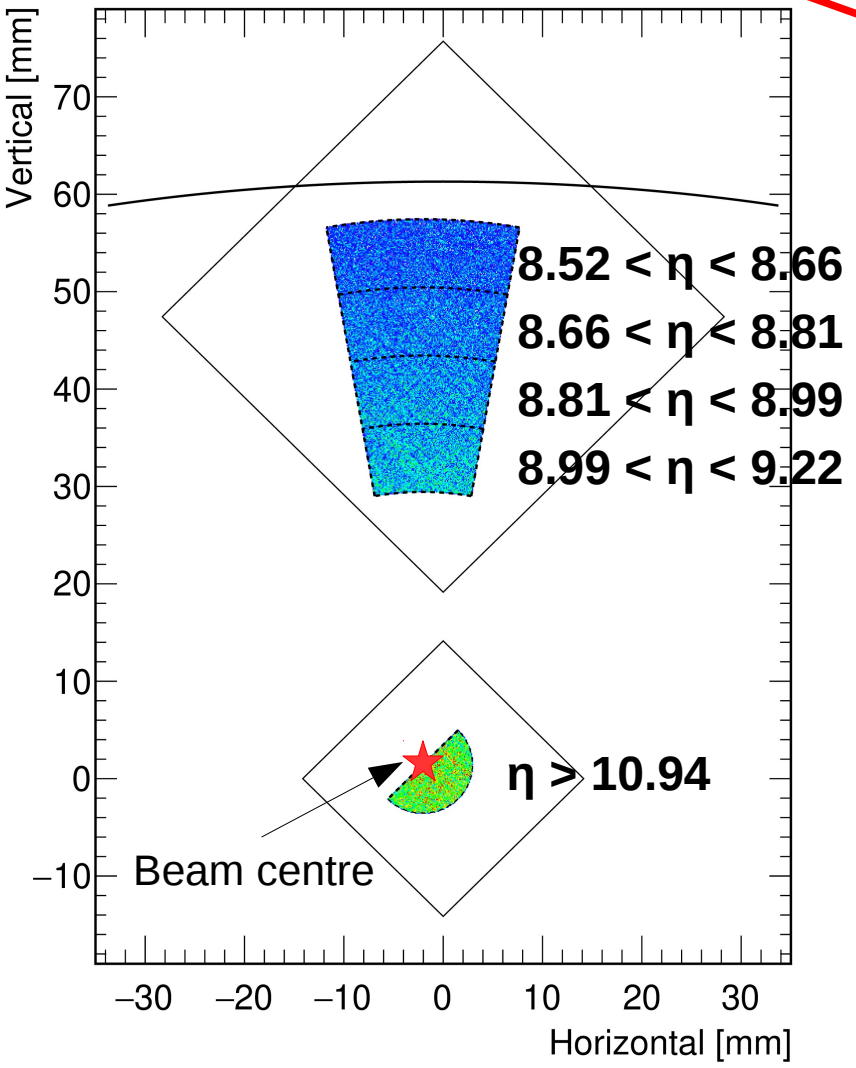


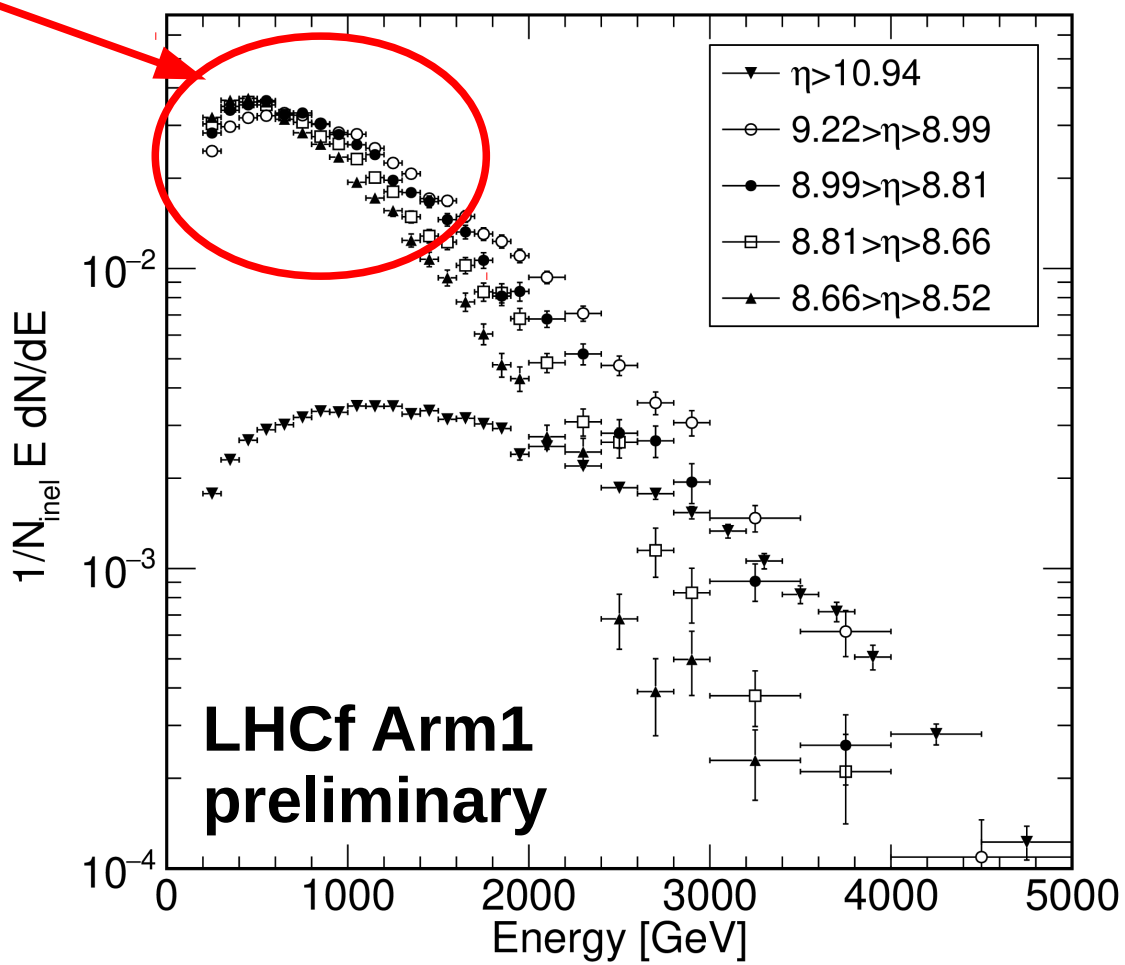


PLB 715 (2012), 298-303

Acceptance extension

- Acceptance region extended to study the η dependence of energy flow
- Low energy region of the spectrum gives the dominant contribution for $8.52 < \eta < 9.22$





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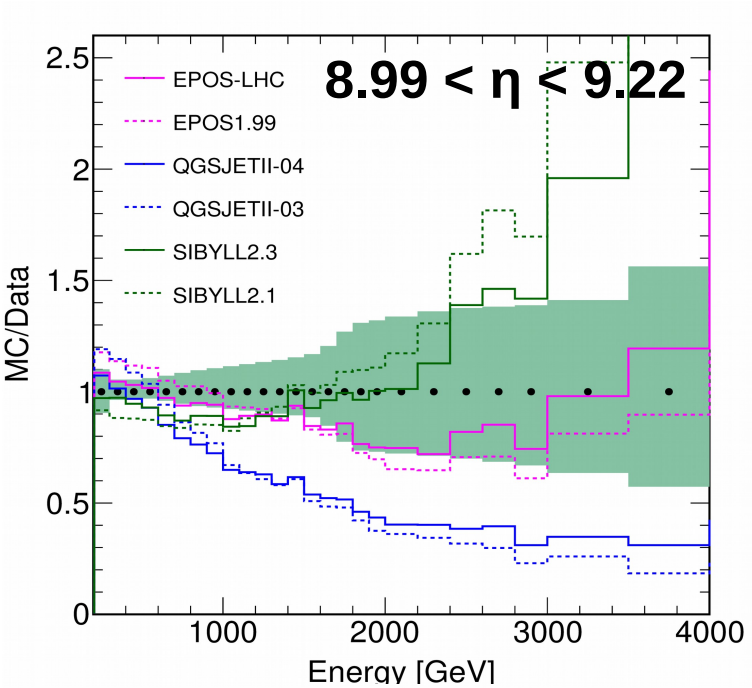
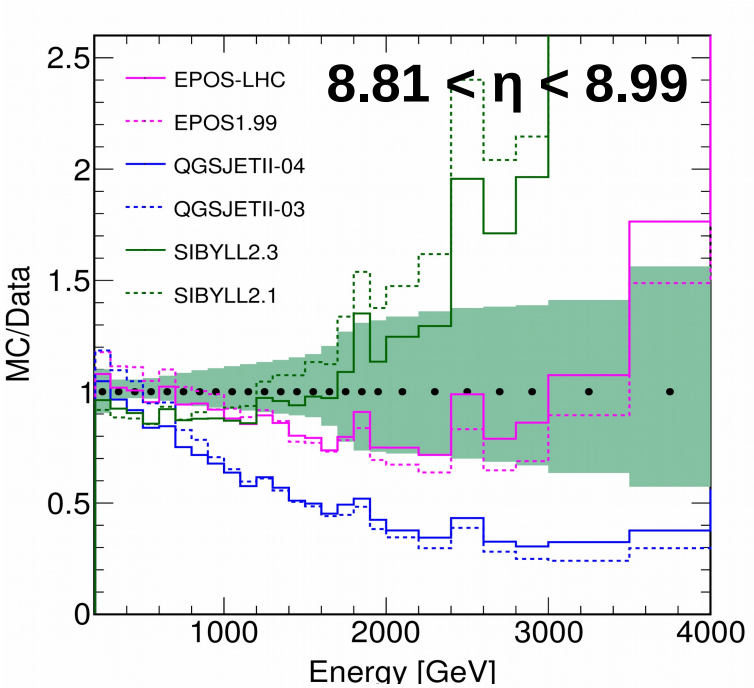
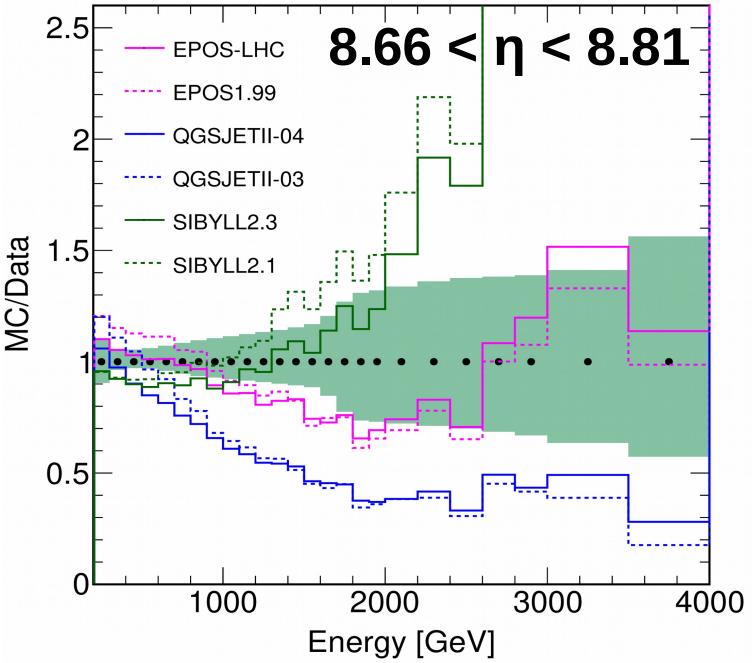
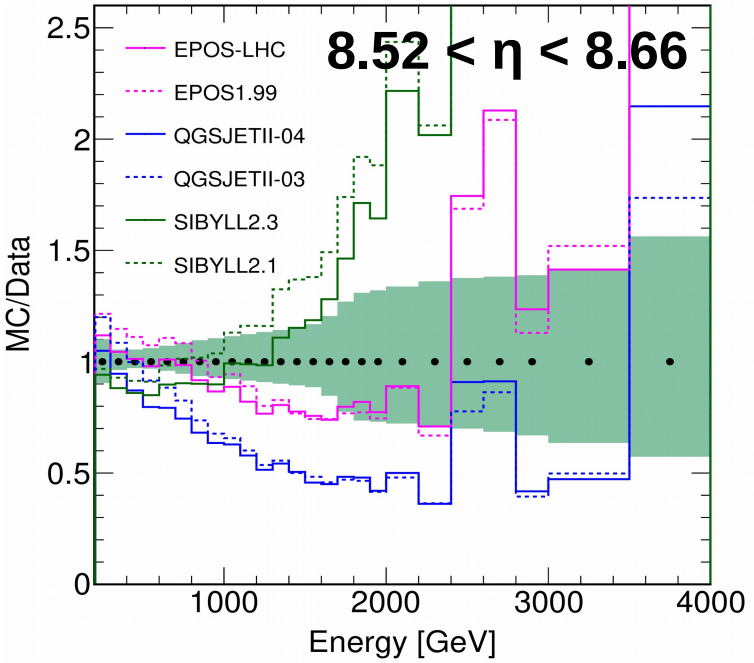
Data vs models: η dependence

LHCf Arm1 preliminary

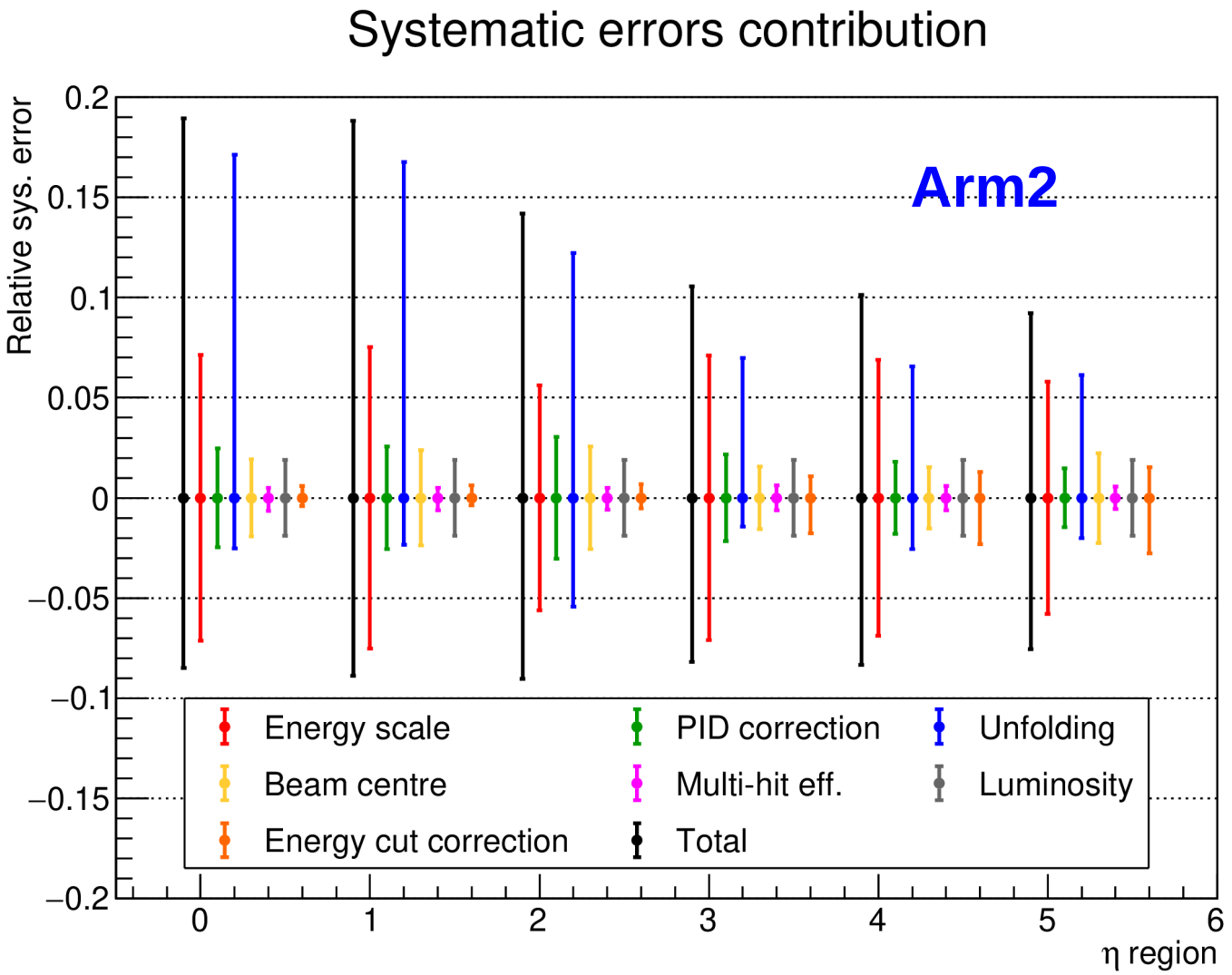








EM energy flow: systematic error



Pseudorapidity regions:

0) $\eta > 10.94$

1) $10.25 < \eta < 10.94$

2) $9.84 < \eta < 10.25$

3) $8.99 < \eta < 9.22$

4) $8.81 < \eta < 8.99$

5) $8.66 < \eta < 8.81$

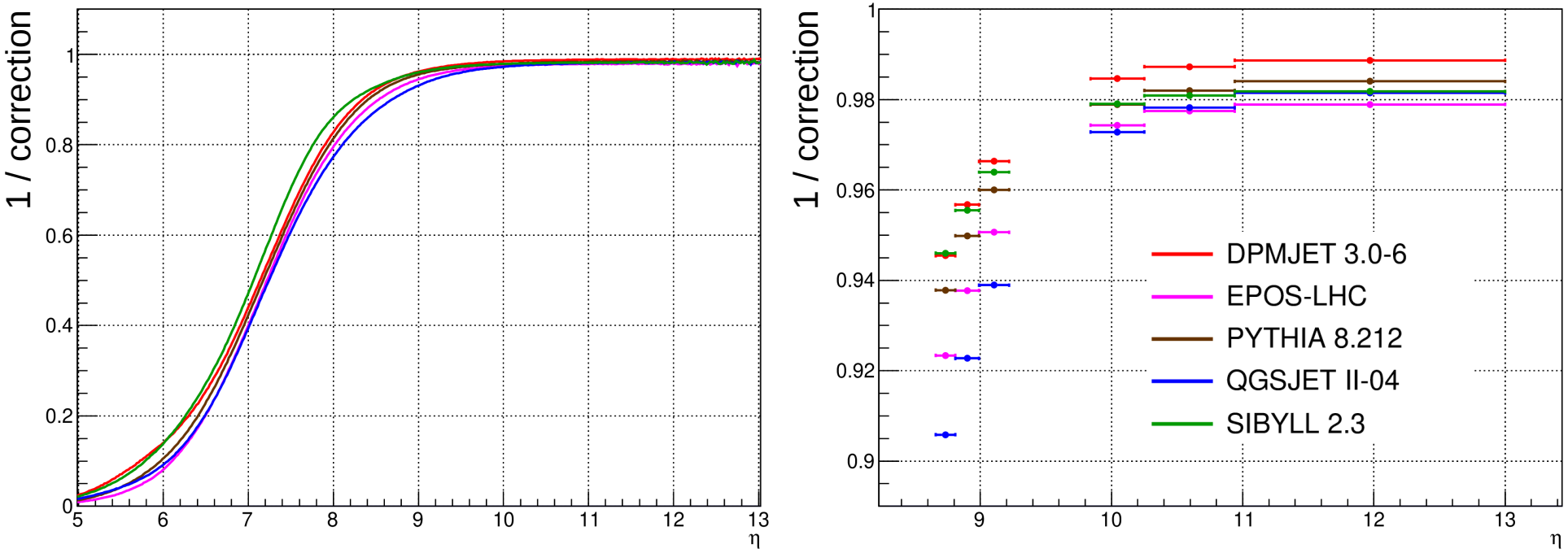
- Energy scale and unfolding give the dominant contribution to the systematic error

EM energy flow: energy cut correction

η range	Correction (error)
η > 10.94	0.983 (+0.006 -0.006)
10.25 < η < 10.94	0.981 (+0.006 -0.006)
9.84 < η < 10.25	0.978 (+0.007 -0.007)
8.99 < η < 9.22	0.956 (+0.018 -0.017)
8.81 < η < 8.99	0.945 (+0.023 -0.021)
8.66 < η < 8.81	0.932 (+0.028 -0.026)

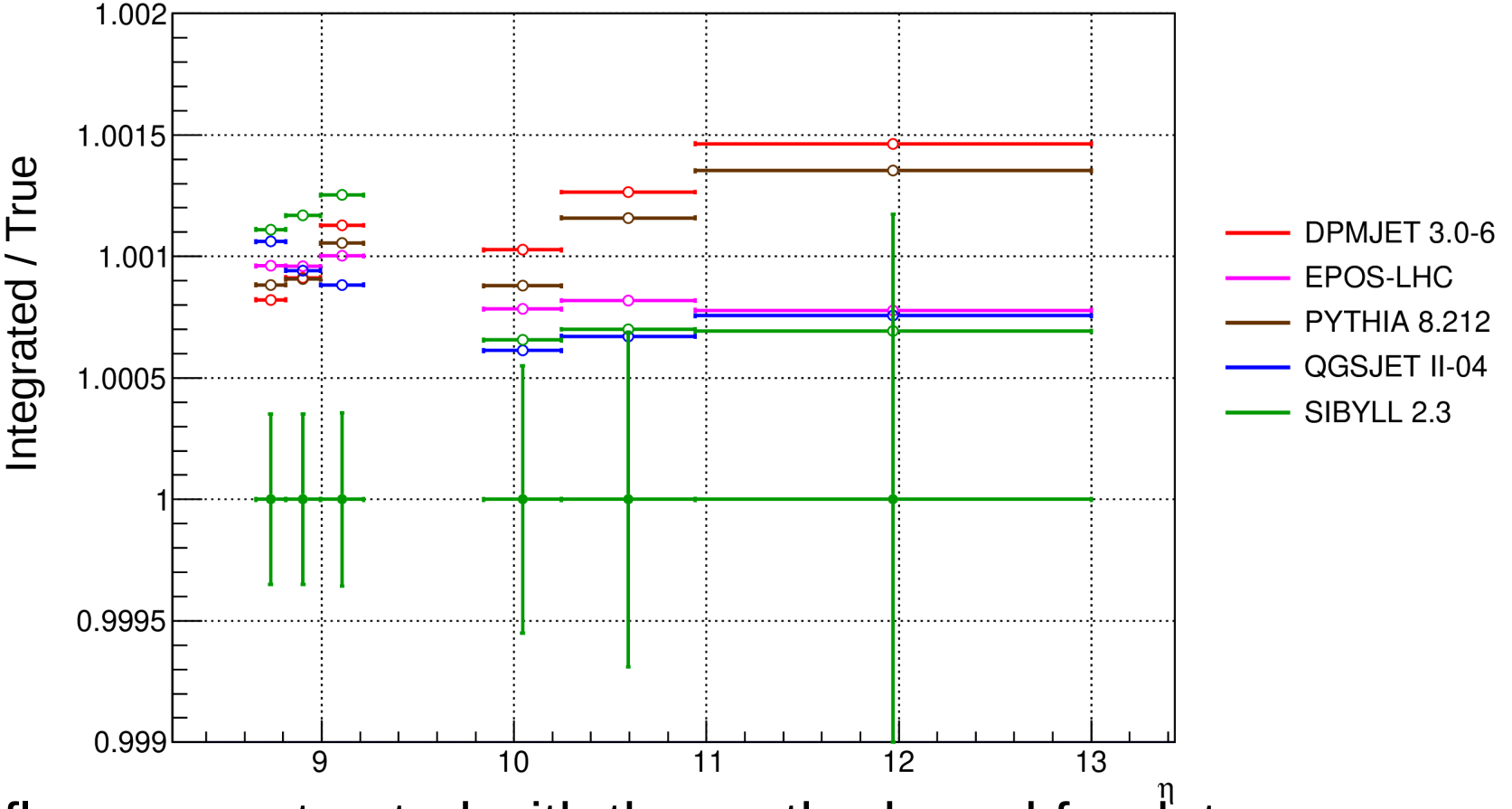
- Systematic uncertainty between predictions of models: 0.6%-3%

EM energy flow: energy cut correction



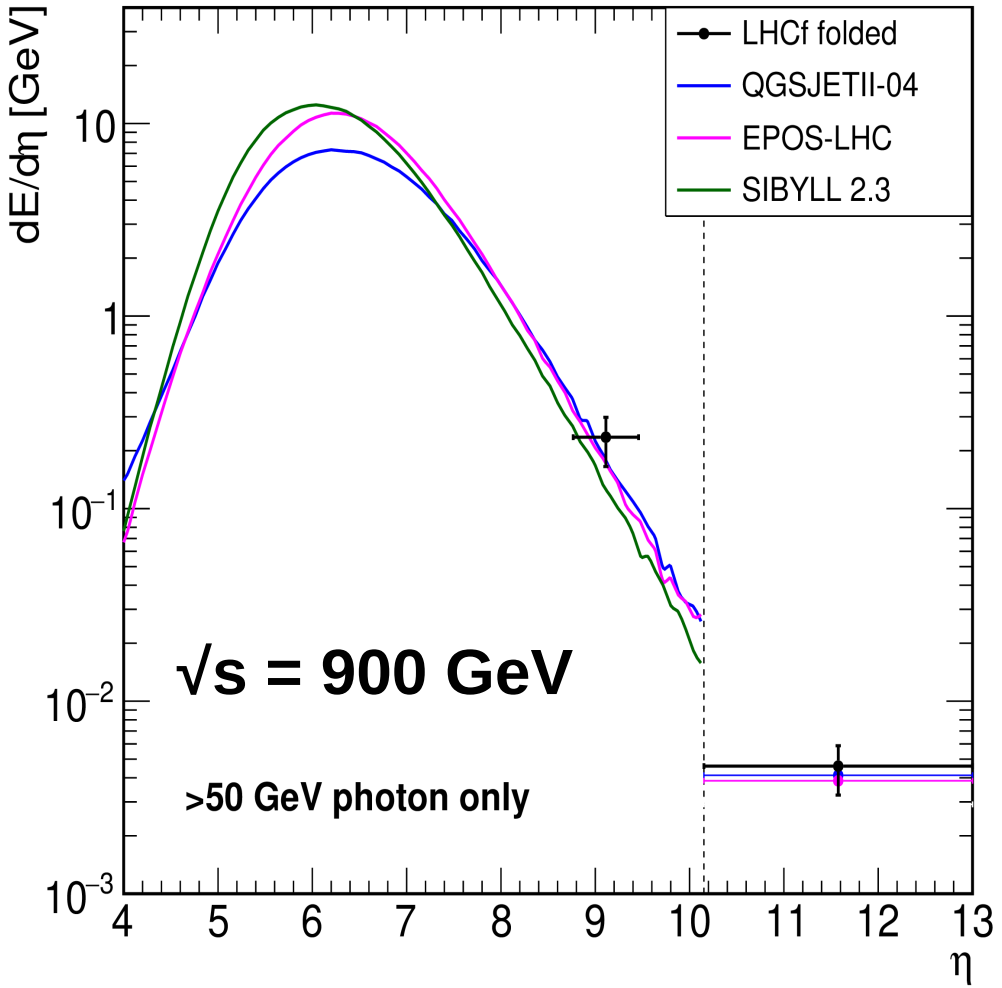
- A correction must be applied for the photon energy cut (e > 200 GeV)
- Correction = flux(all photons) / flux(photons with E > 200 GeV)
- Correction is estimated with CRMC simulations for each model in every η region
- Mean and maximum deviation between all models are used as the correction and its error

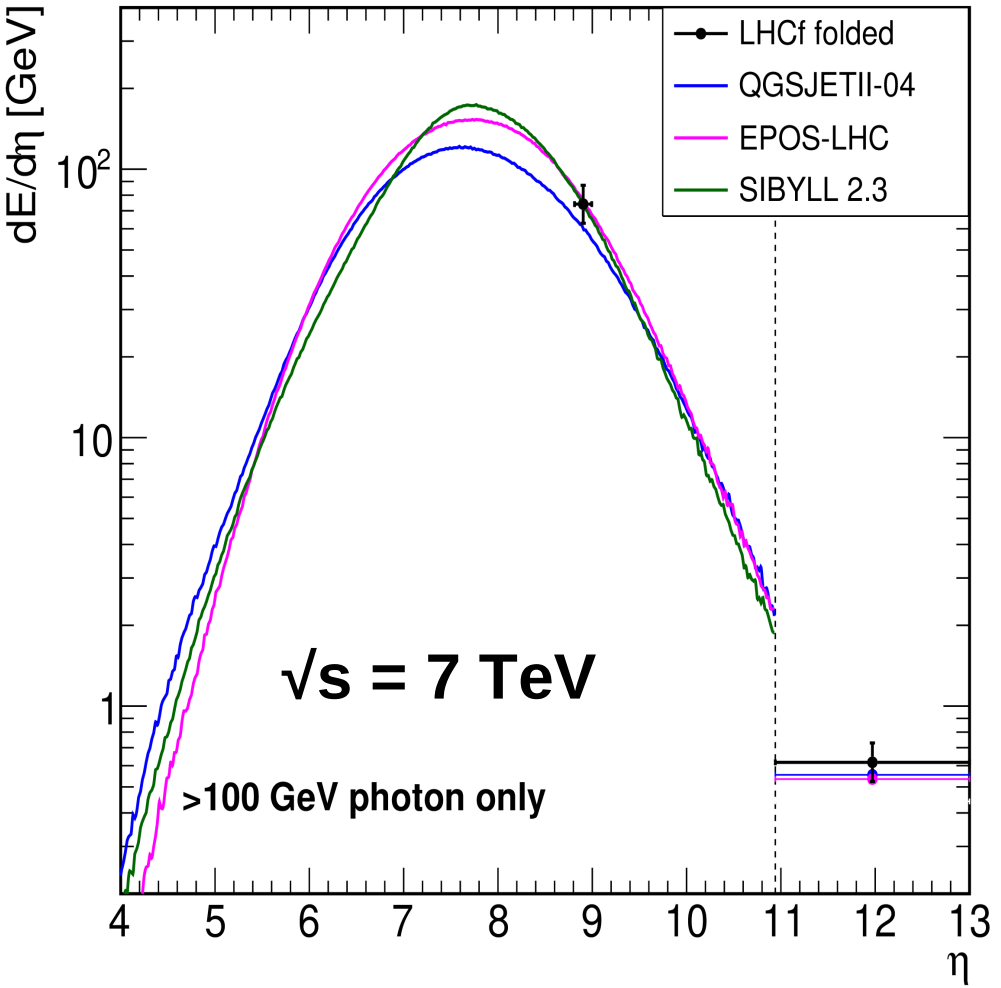
dE/dη: bias in spectrum integration?



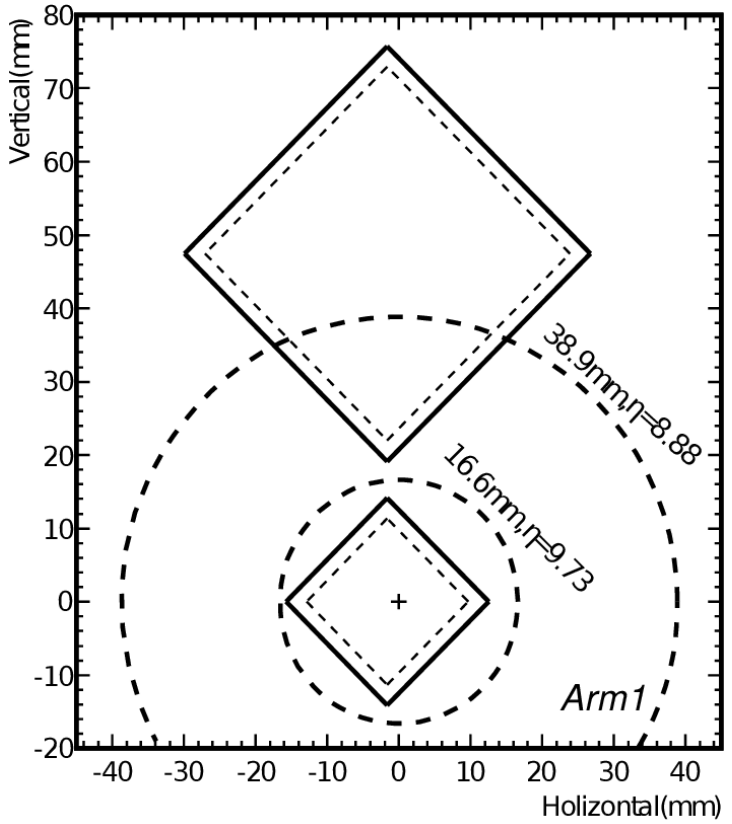
- MC flow reconstructed with the method used for data (=integration of spectrum) vs true energy flow
- Normalised to true flow for each model (only SIBYLL statistical error is shown)
- ~0.1% bias → negligible

Energy flow: results at √s = 0.9, 7 TeV





Feynman scaling: 900 GeV spectrum



- to cover the same X_F-P_T phase space of 7 TeV analysis (r < 5 mm), the region with r < 38.9 mm must be considered
- obviously, it cannot be covered by detectors → extrapolation needed
- assuming a limited η-dependence (ref. Taki's thesis), ST spectrum is extrapolated in r < 16.6 mm region while LT spectrum is extrapolated in 16.6 mm < r < 38.9 mm region, then the two spectra are added

- final spectra in 900 GeV paper are normalised to the solid angle covered (dσ/dE/dΩ [mb/GeV/sr])
- the extrapolation is done multiplying the spectrum by the solid angle covered by each region
- difference with Taki's method: I scaled combined spectra while he directly scaled only Arm1 data (not normalised to dΩ)

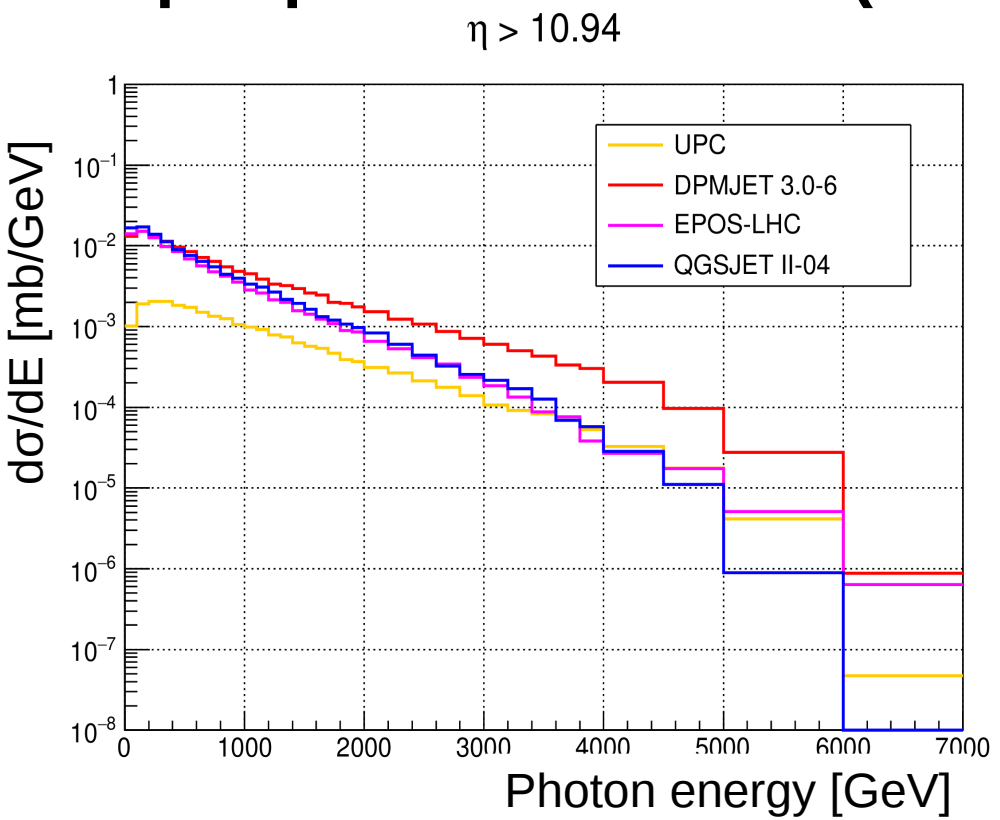
LHCf p-Pb run at 8.16 TeV

- Low luminosity dedicated run for LHCf: 25th of November 2016 (~9 hours)

Analysis data set:

- ~ 2 hours of operation
- **Luminosity:** ~ $0.8 \cdot 10^{28}$ cm^{-2} s^{-1}
- **Pile-up:** 0.01
- $3 \cdot 10^{6}$ **events**
- **Integrated luminosity:** 8.145 μb^{-1}

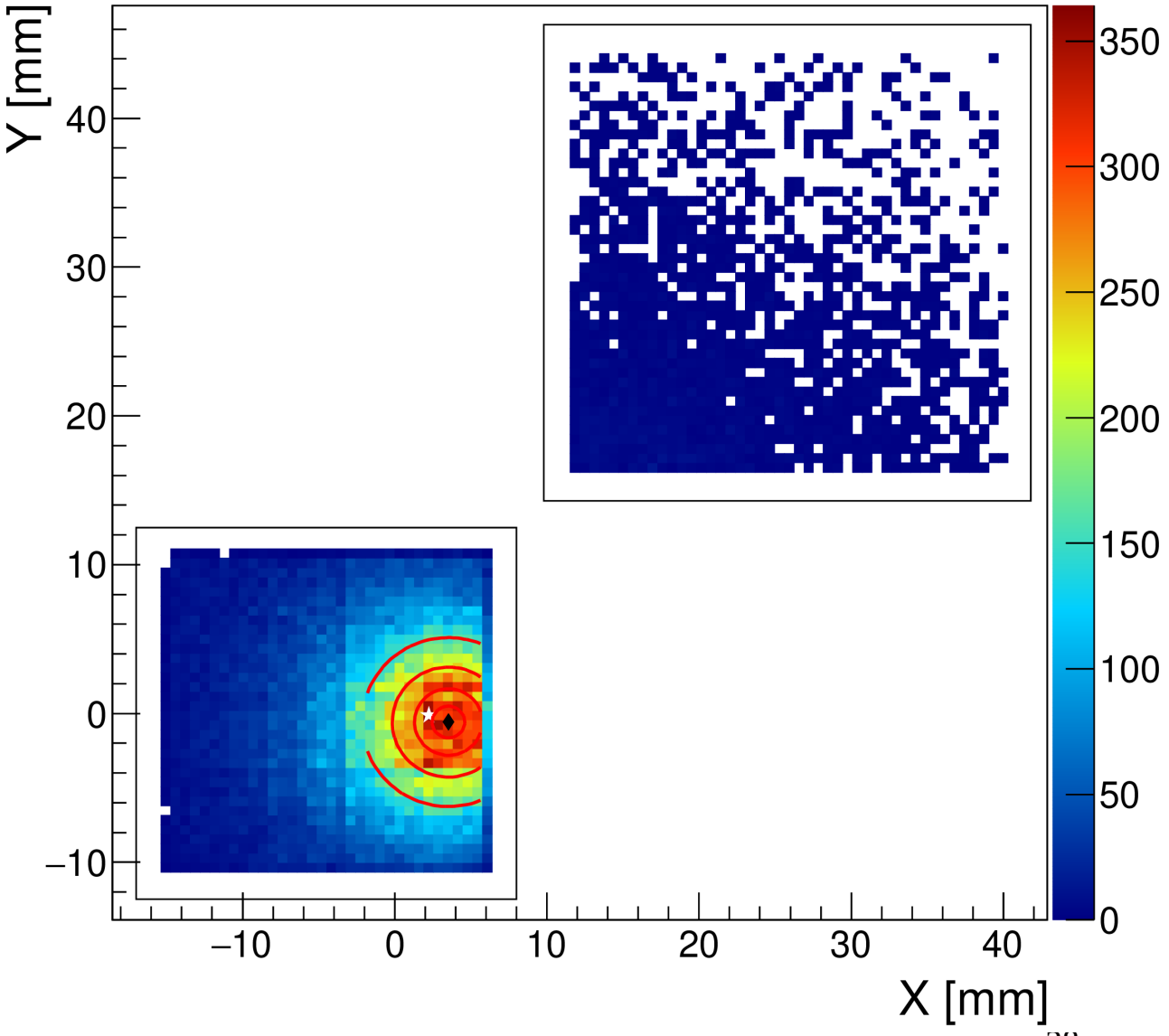
Ultra peripheral collisions (UPC)



UPC simulation → STARLIGHT + SOPHIA/DPMJET

p-Pb: beam centre

- Beam centre fit is needed:
  - select pseudo-rapidity regions
  - artificially include the real value in simulations
- Event selection:
  - E > 1.5 TeV
  - $L_{20\%} < 10\ X_0$
  - $L_{90\%} > 20\ X_0$
  - ~90k events



p-Pb: beam centre

- Fit result:

  X = (3.53 +- 0.05) mm Y = (-0.58 +- 0.03) mm

- Systematic error
  - Comparison with 1D fit:

    X = (3.59 +- 0.09) mm Y = (-0.58 +- 0.03) mm

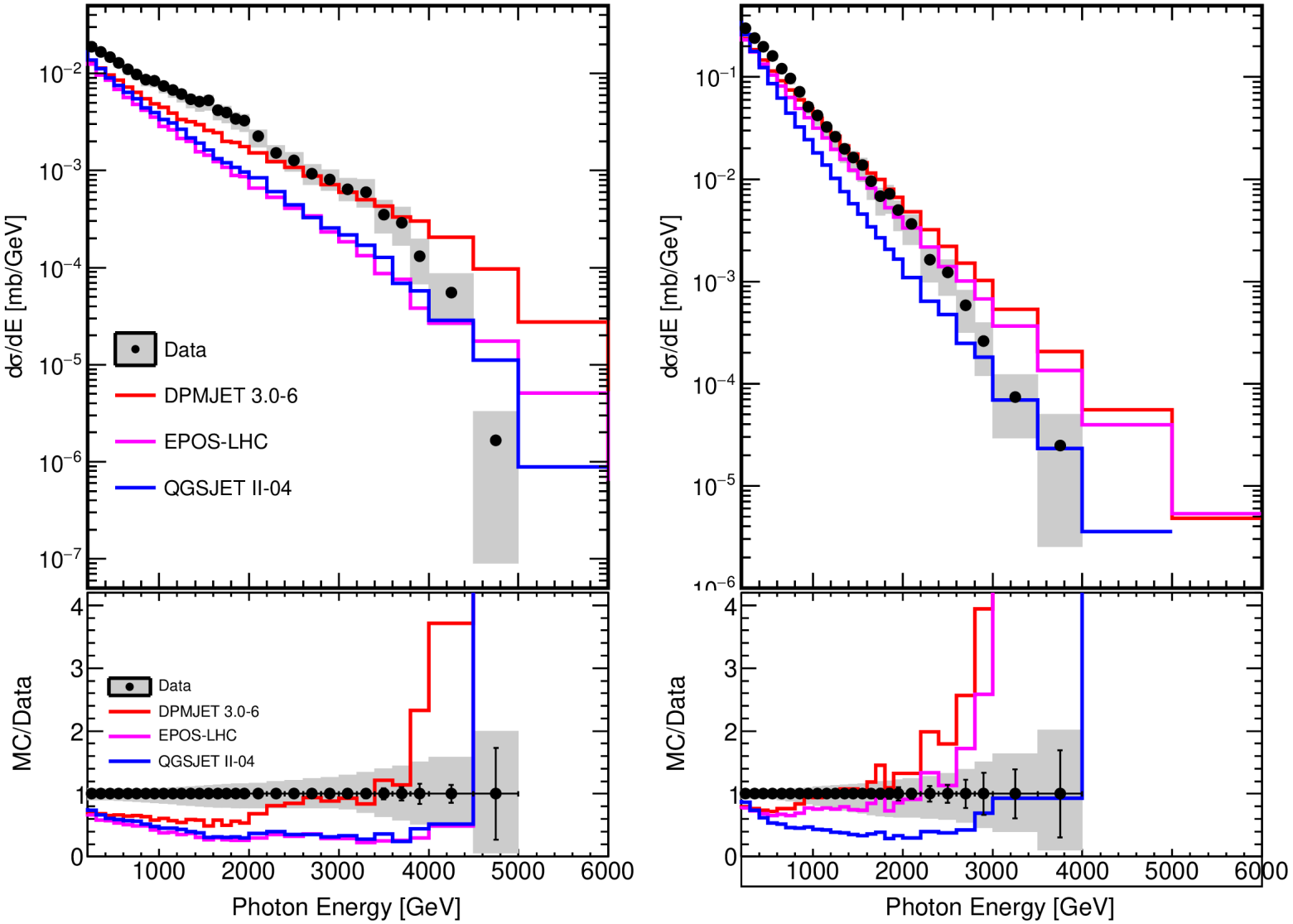
    ΔX = 0.06 mm, ΔY = 0.00 mm (!) → consistent with statistical error
  - Modified energy threshold in event selection:

    X = 3.85...3.01 mm between 0.3 and 3 TeV

    Y = -0.66…-0.40 mm between 0.3 and 3 TeV

    ΔX_{sys} = 0.5 mm, ΔY_{sys} = 0.2 mm ?
  - Need to check time dependence of beam centre

Photon spectra in p-Pb (w/o UPC!)



- η > 10.94: lower yield from all models
- 8.81 < η < 8.99: all models predict an harder spectrum

Combining algorithm

$$\chi^2 = \sum_{i=1}^{N_{bin}} \sum_{a=1}^{N_{arm}} \left(\frac{R_{a,i}^{obs}\left(1+S_{a,i}\right) - R_i^{comb}}{\sigma_{a,i}} \right)^2 + \chi^2_{penalty}$$

$$S_{a,i} \equiv \sum_{j=1}^{N_{sys}} f^{j}_{a,i}\, \epsilon^{j}_{a}$$

$$X^2_{penalty} \equiv \sum_{j=1}^{N_{sys}} \sum_{a=1}^{N_{arm}} \left|\epsilon^{j}_{a}\right|^2$$