Summary of
$\sqrt{s}$=13 TeV photon analysis

Yuya Makino for the photon analysis team

LHCf collaboration meeting @ Nagoya

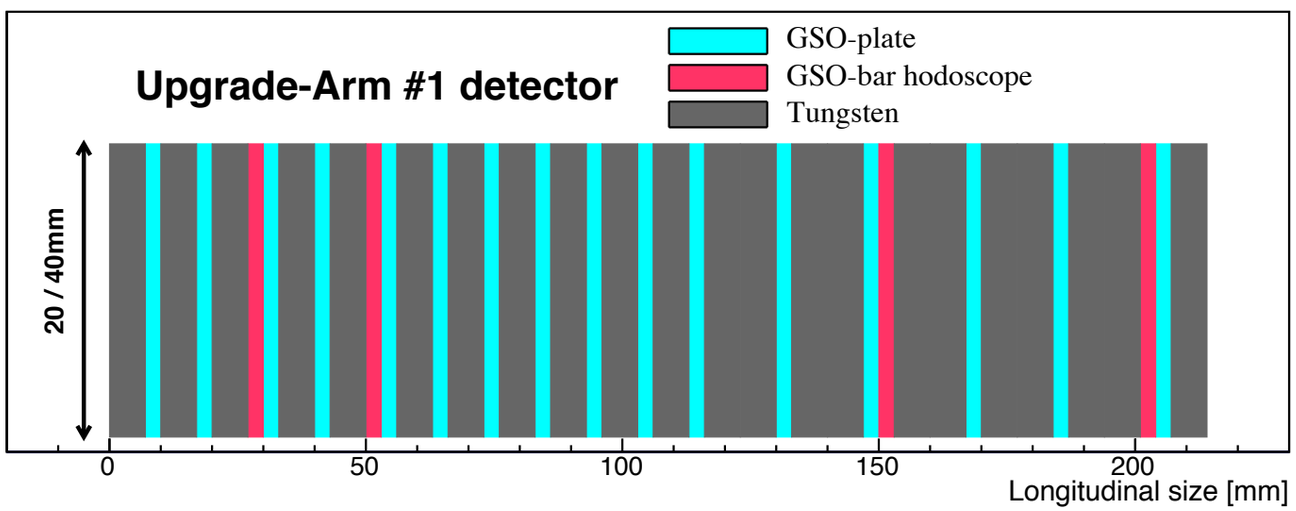
06/04/2017

Contents

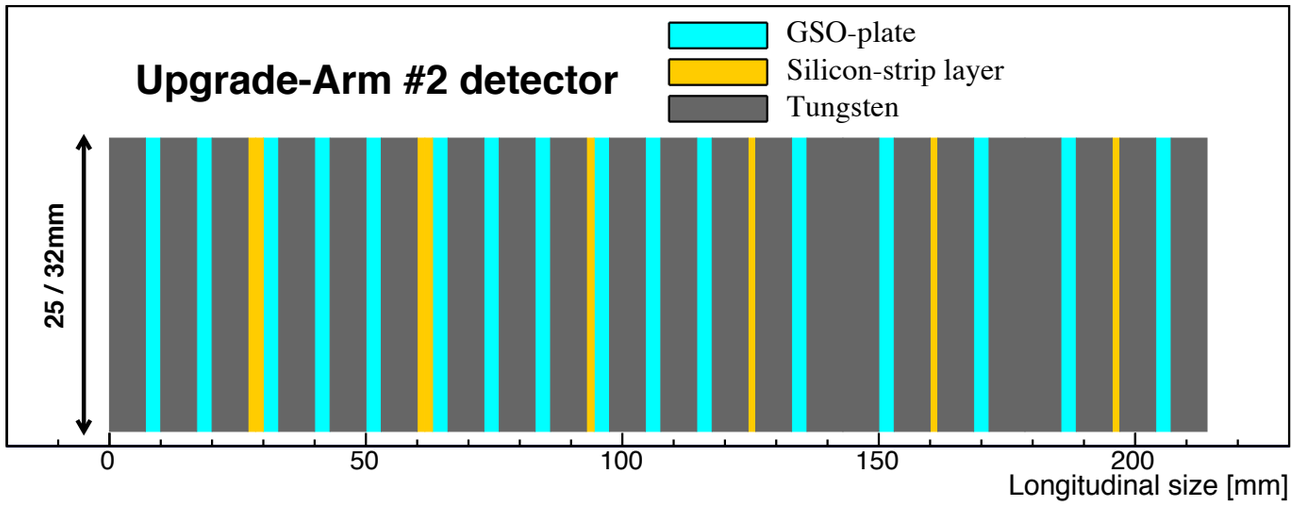
- New LHCf detectors for 13 TeV runs
  - Performance of the new LHCf detectors

- 13 TeV photon analysis
  - $\eta > 10.94$ & $8.99 > \eta > 8.81$ Arm1-Arm2 combined results
  - $8.52 > \eta > 9.22$ with Arm1only

New LHCf detectors for 13 TeV runs



(a) Arm1

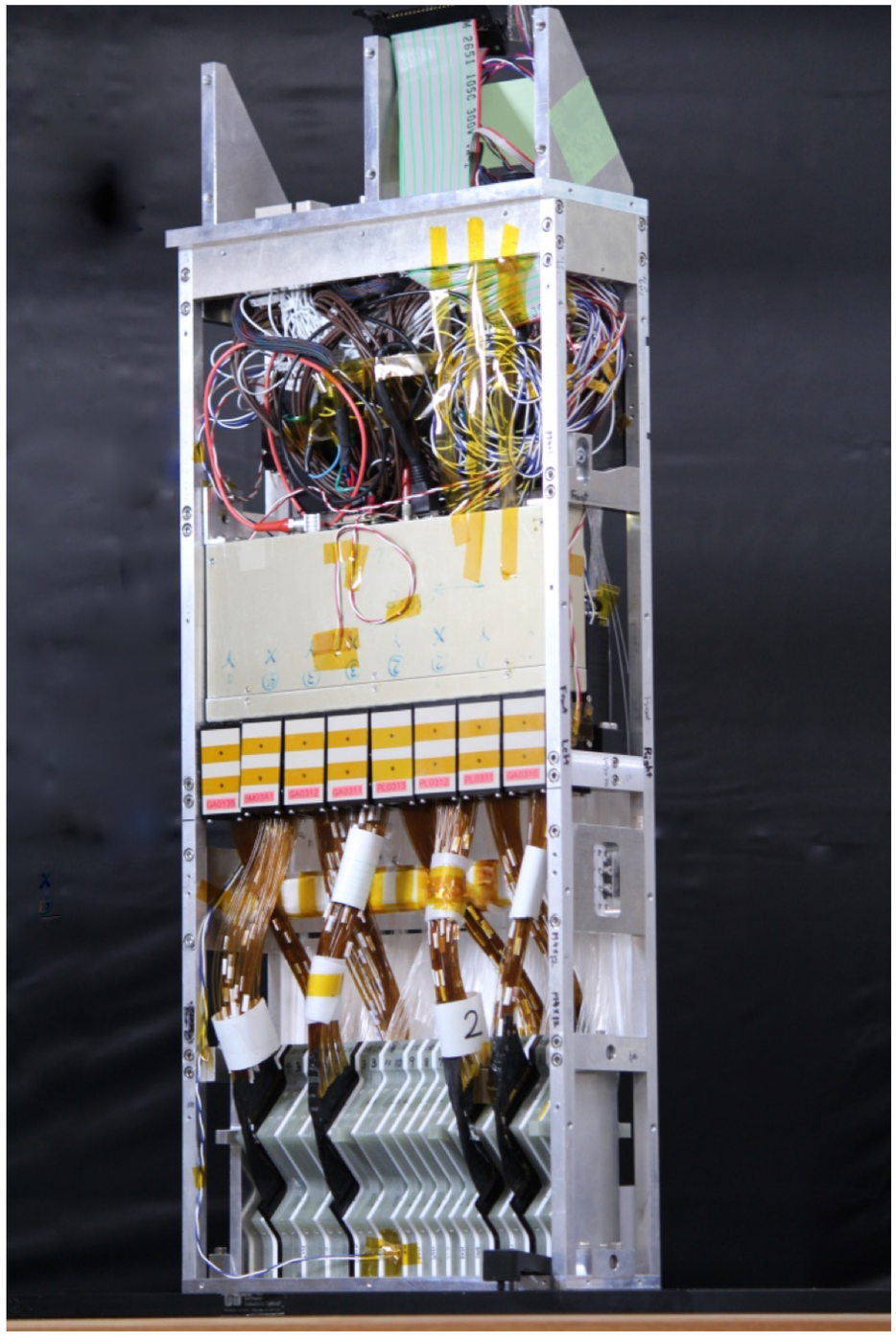


(b) Arm2

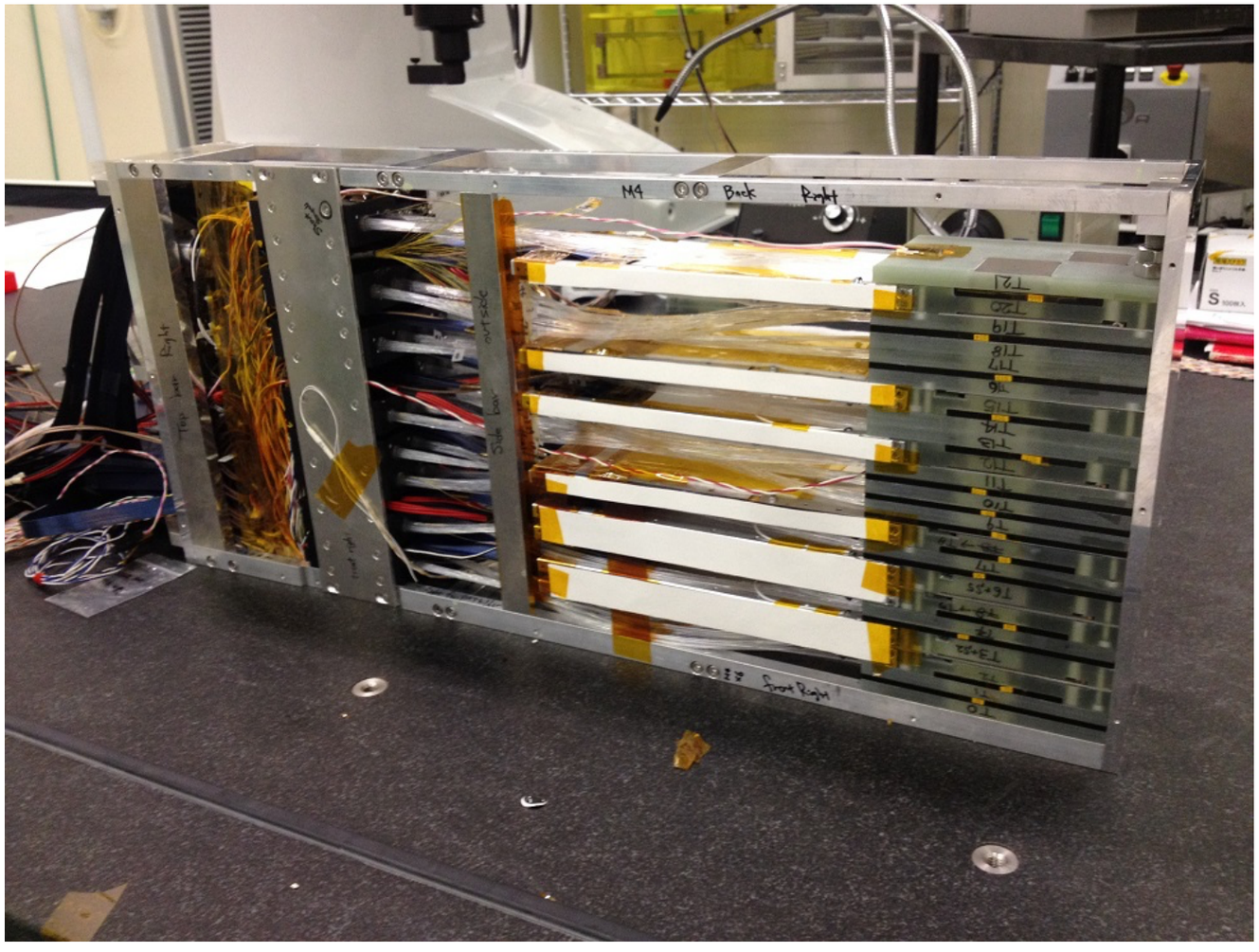
- Sampling layers
  - EJ-260 is replaced with GSO
  - 3mm (EJ-260) -> 1mm (GSO)
- Position sensitive layers
  - Arm1
    - SciFi is replaced with GSO-bar hodoscope
  - Arm2
    - Longitudinal configuration is changed
    - Grounding for not-used strips

New LHCf detectors for 13 TeV runs

Arm1

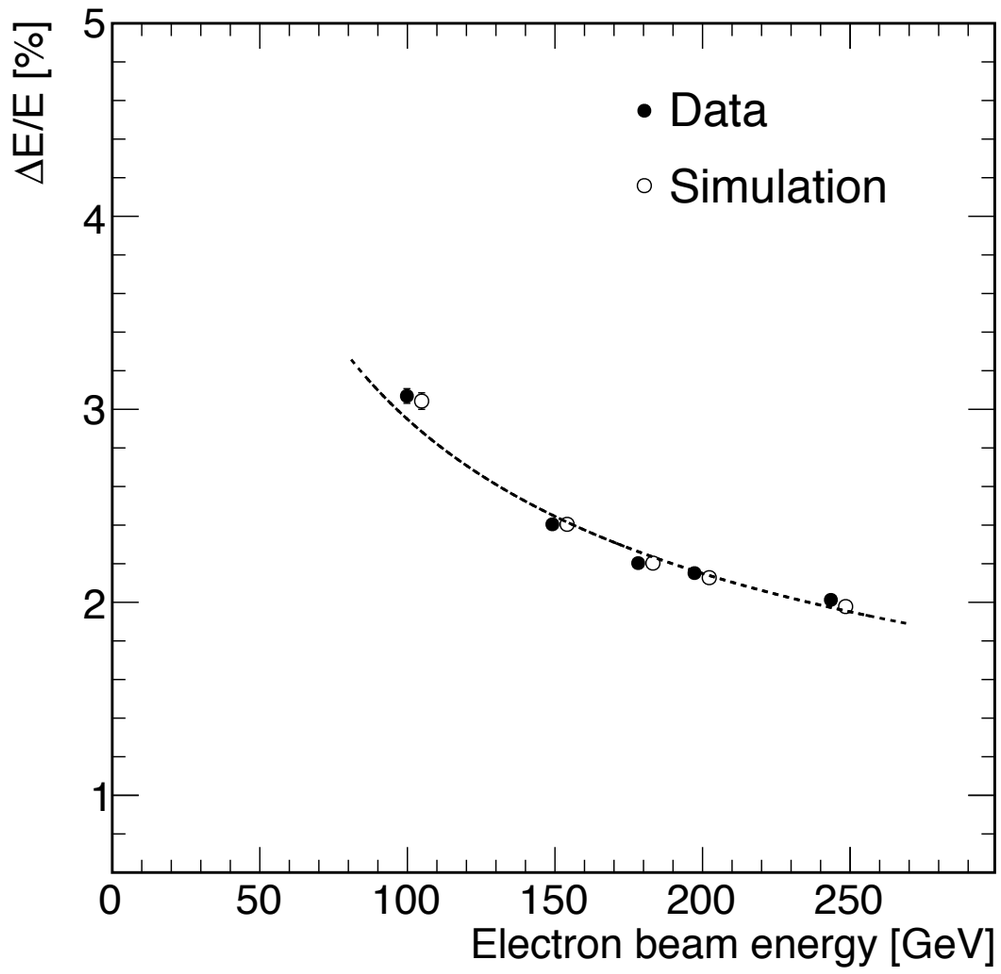


Arm2

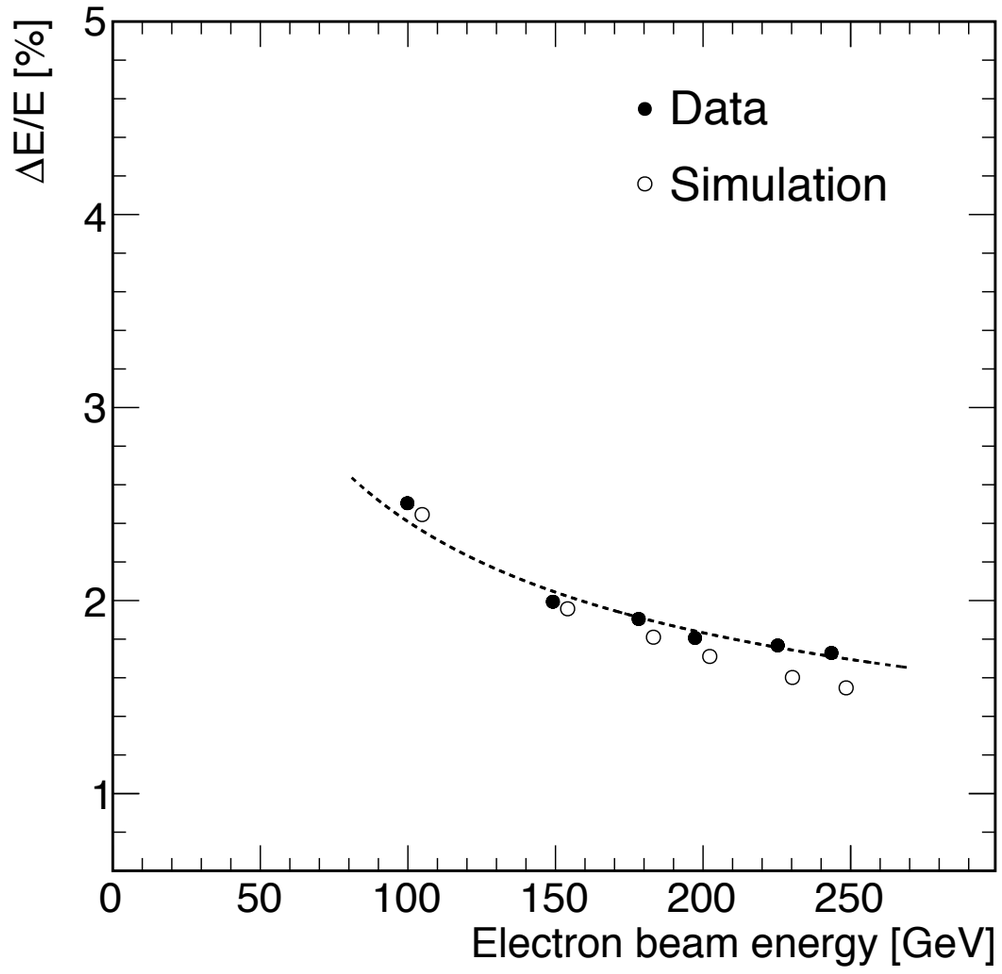


Performances of the new LHCf detectors

Energy resolutions



Arm1 20 mm cal.

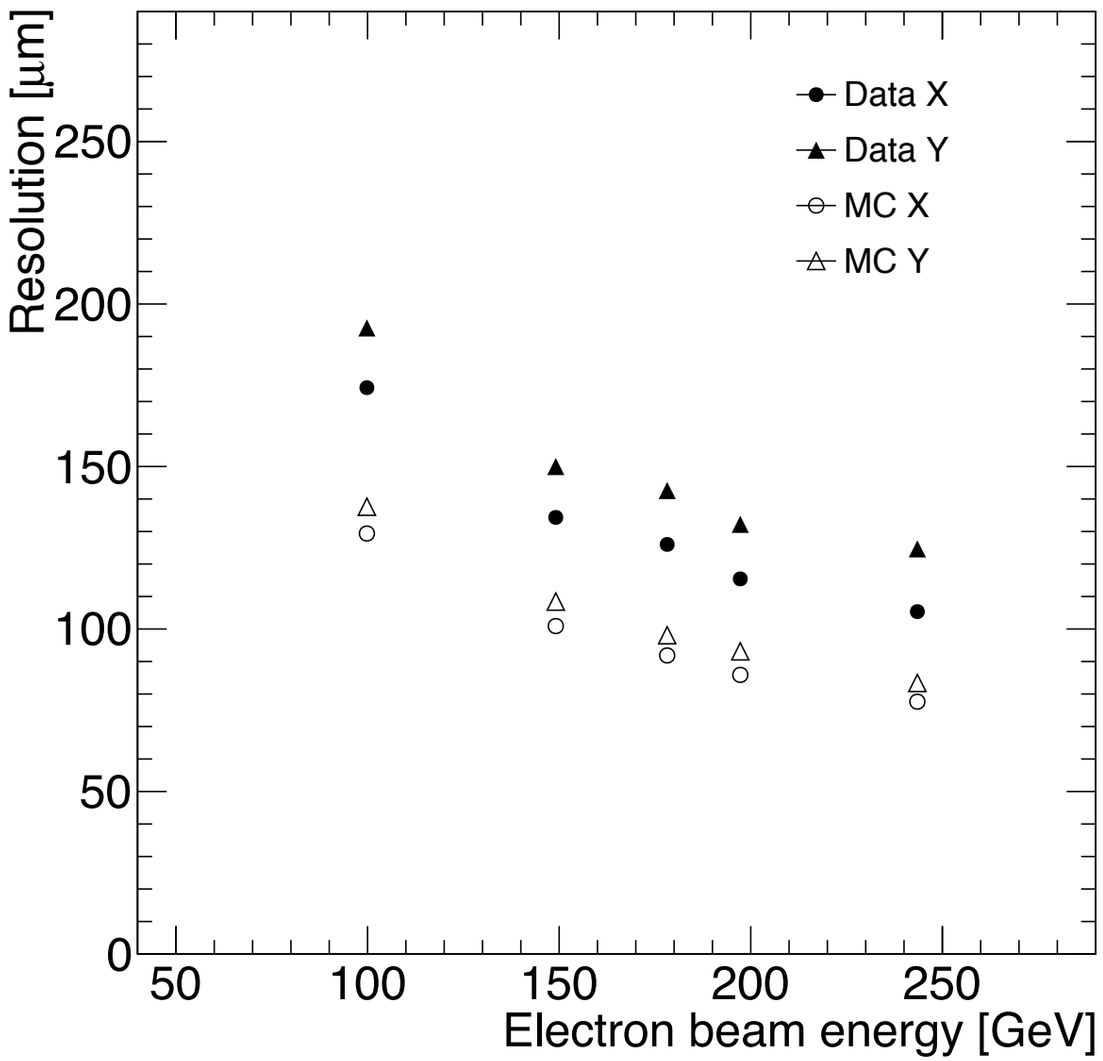


Arm2 25 mm cal.

Energy resolution is 2 % for 200GeV elections (@SPS)
-> ~5 % at LHC

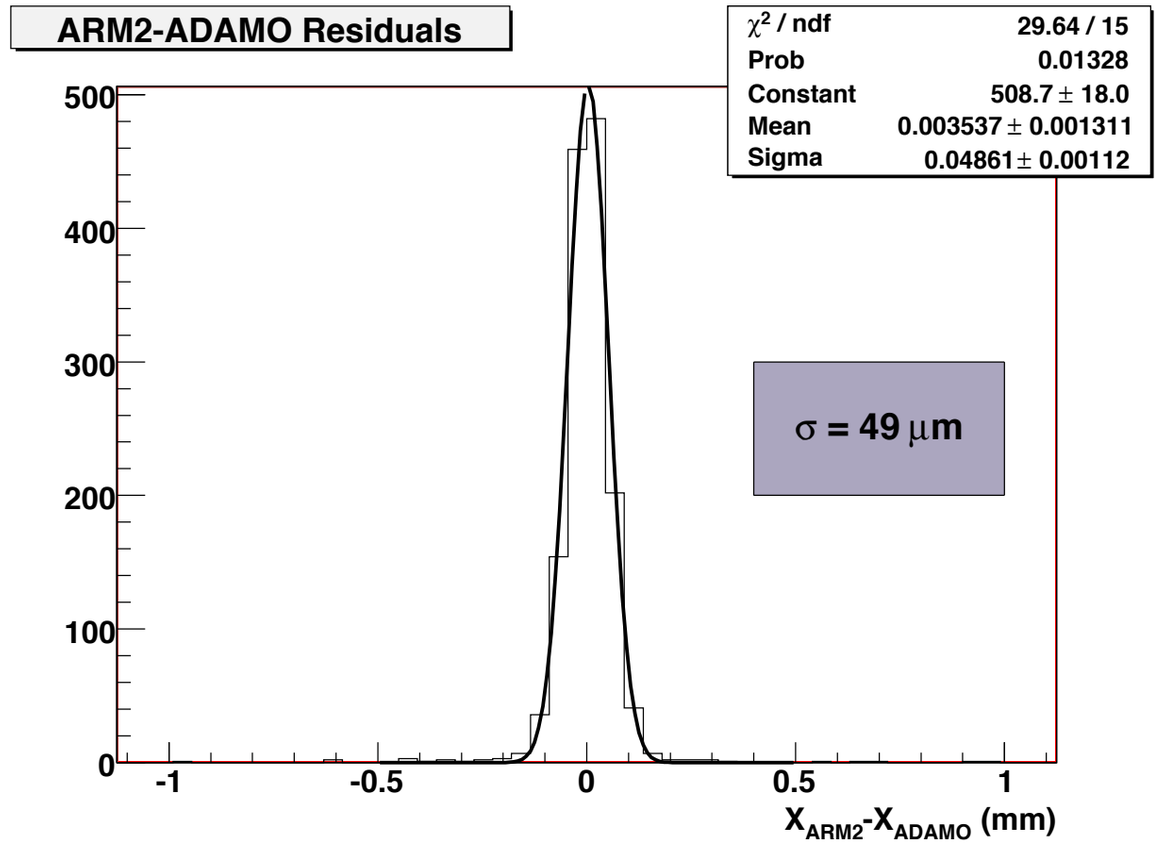
Performances of the new LHCf detectors

Position resolutions



Arm1 40 mm cal. 2nd layer

JINST 3 S08006



Arm2

Position resolutions are <200μm for Arm1 and 50μm for Arm2 (@ SPS).

…then published!

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Performance study for the photon measurements of the upgraded LHCf calorimeters with Gd_2SiO_5 (GSO) scintillators

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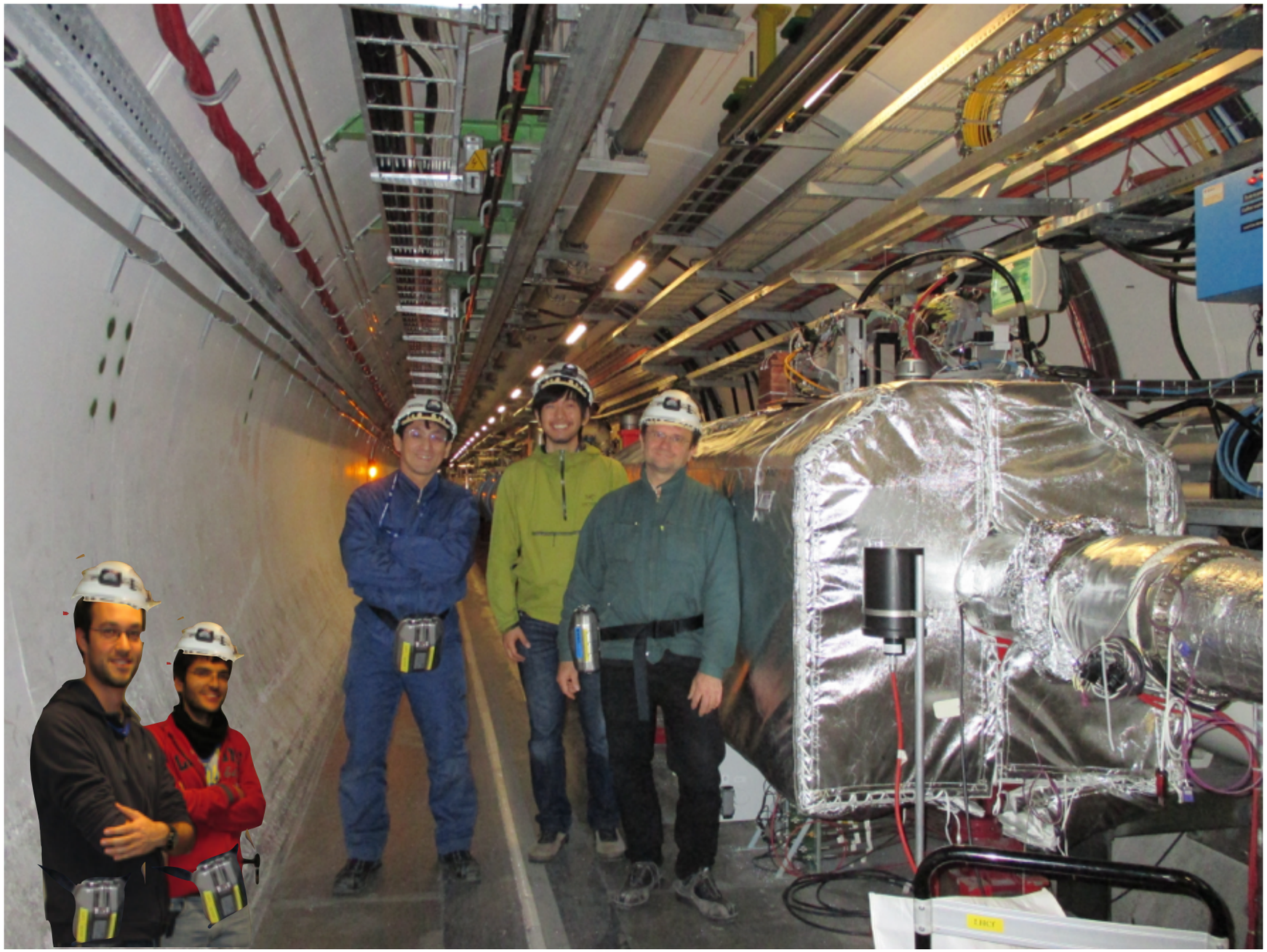
Big efforts from Alessio

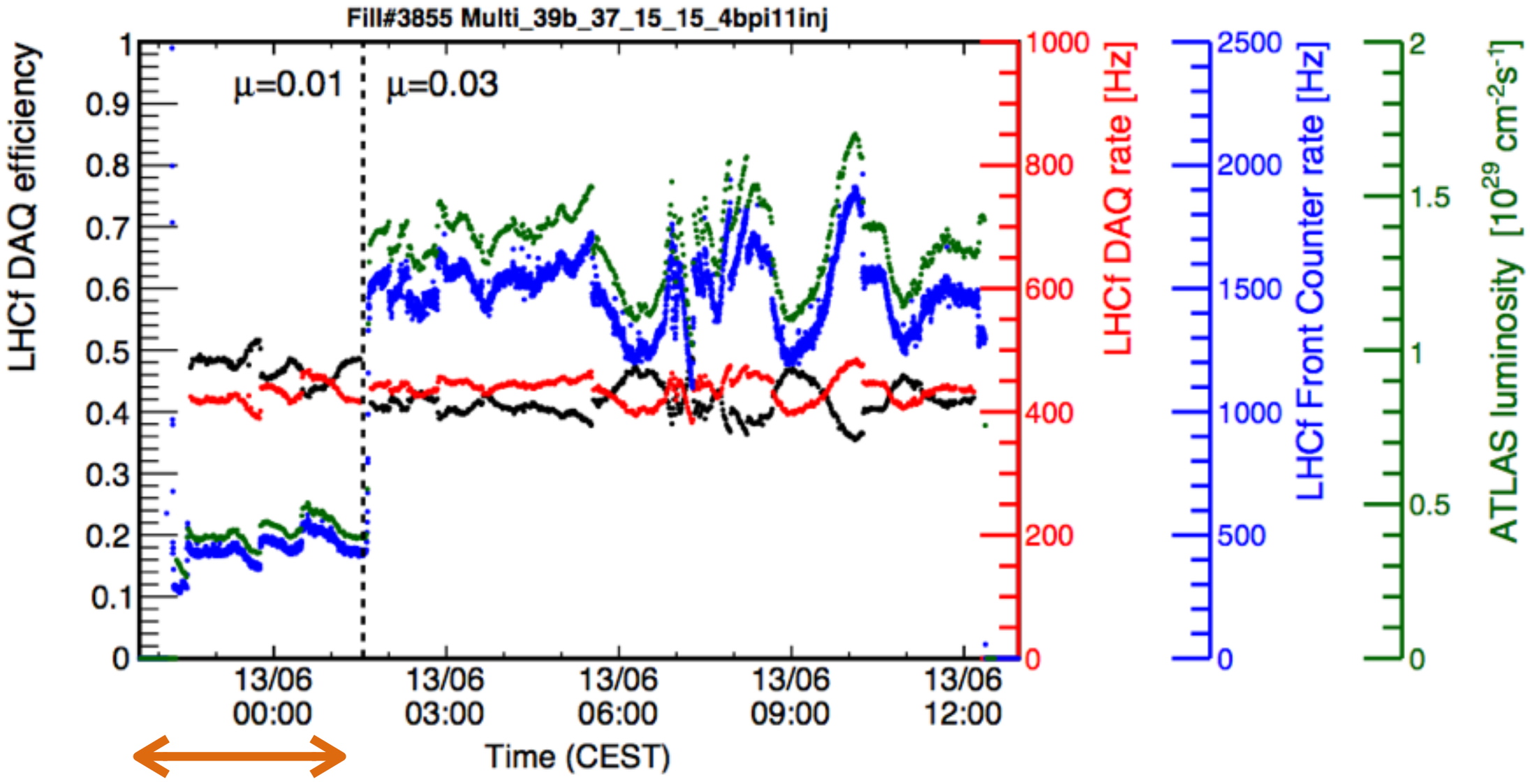
Installation to LHC tunnel

Successful installation to the LHCf tunnel in Nov. 2014



A photo of the LHCf installation team at TAN

LHCf dedicated run in p-p √s=13TeV @ LHC

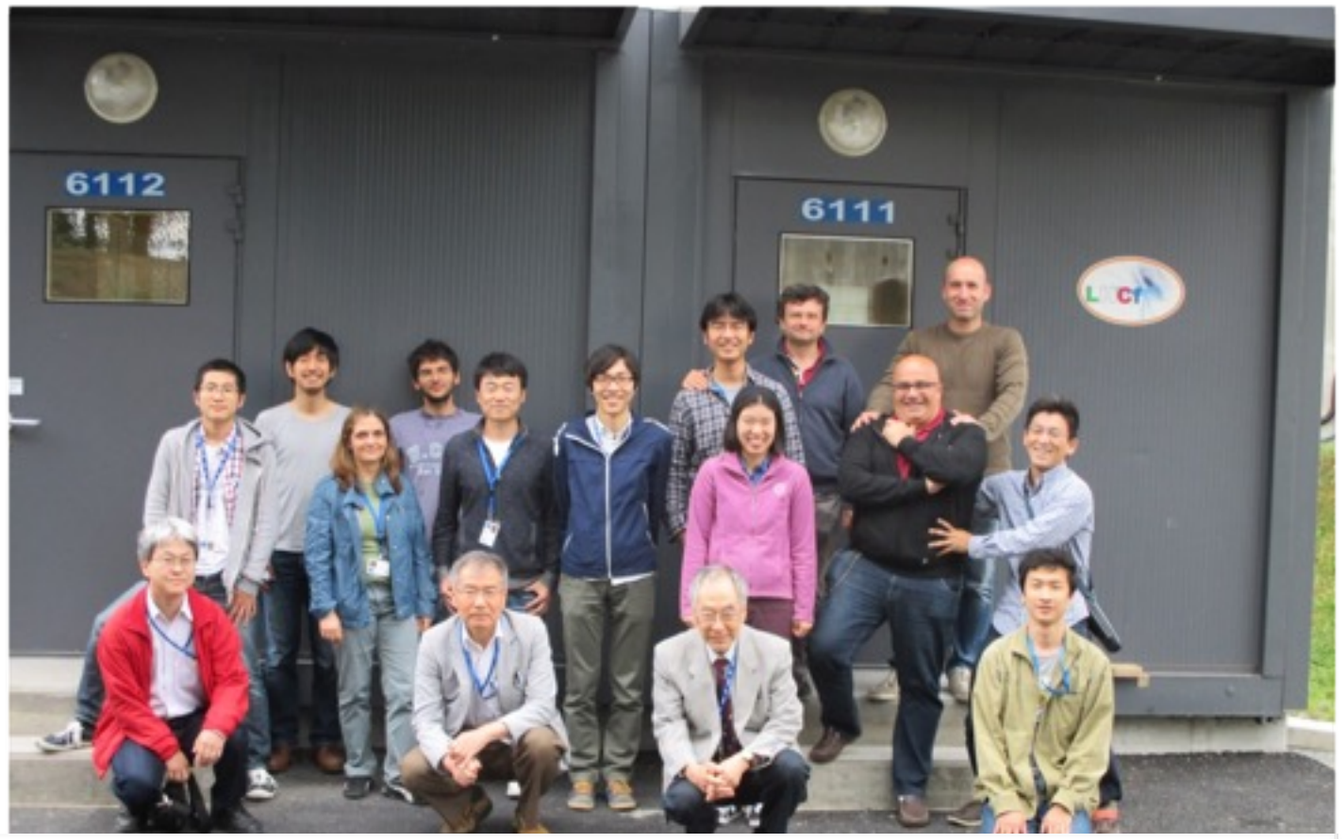


- LHCf run #44299-44472 from LHC Fill #3855
- Only the runs with μ=0.01 are used for the photon analysis
  - Pile-up probability for LHCf is 0.3 %
  - Integrated luminosity is 0.19 nb^{-1}(eq. 1.5×10^7 inelastic collisions)

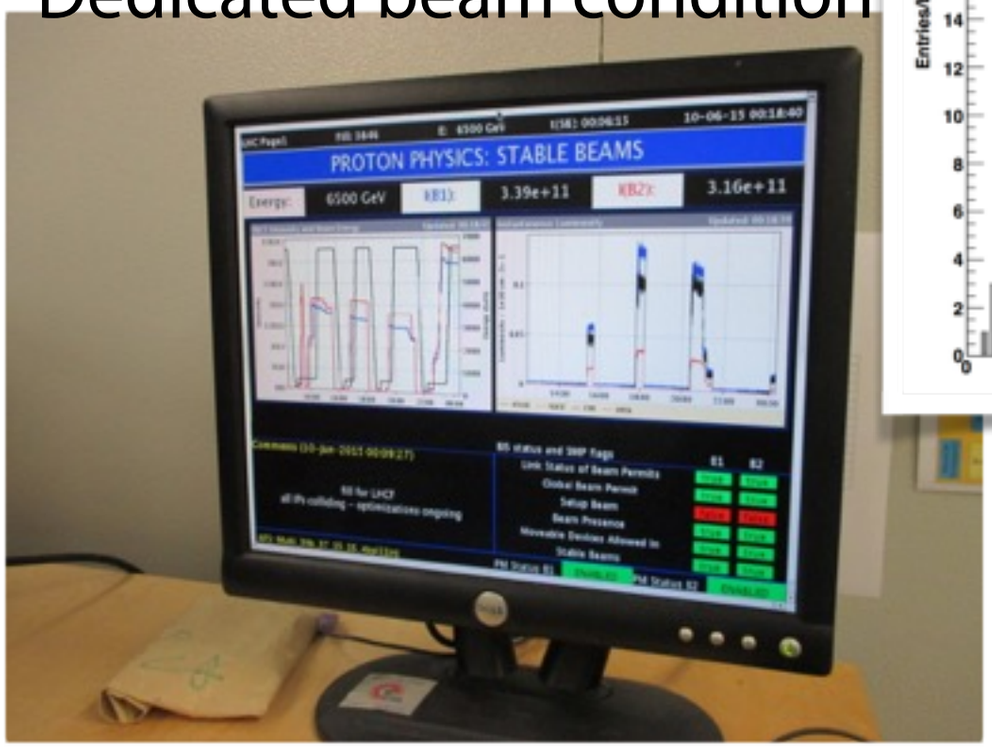
Photos…

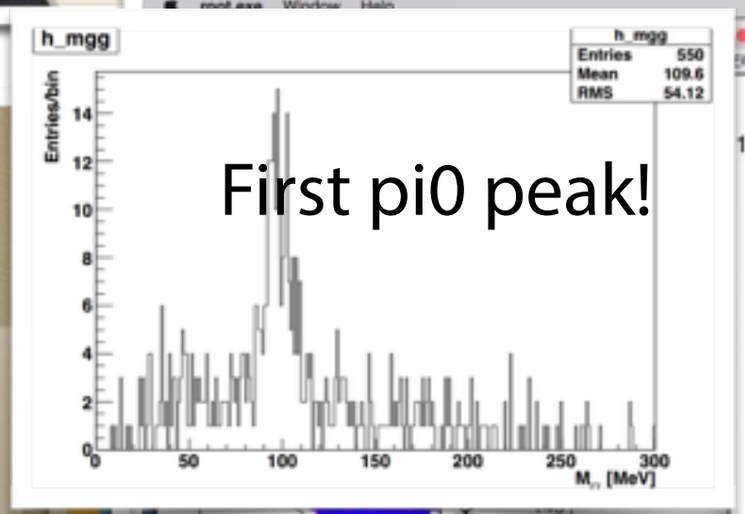
During LHCf runs

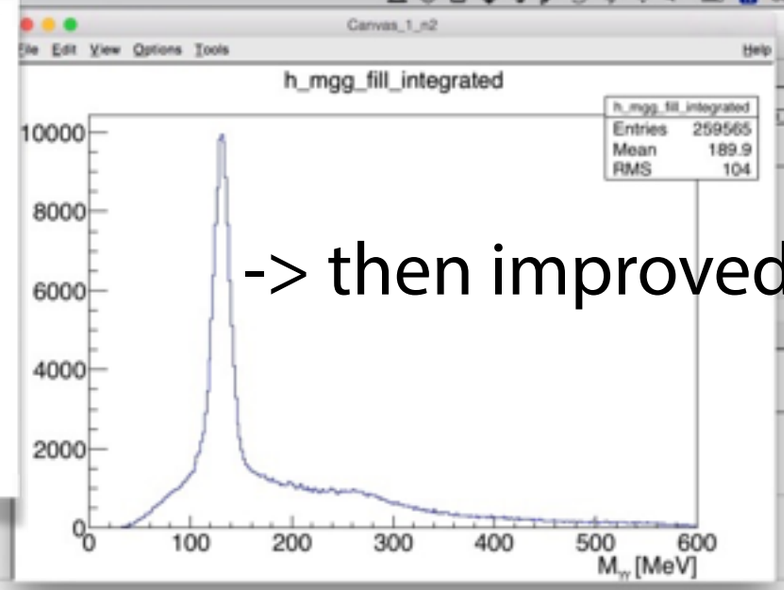
After the runs



Dedicated beam condition







Quick checks

Photon analysis procedure

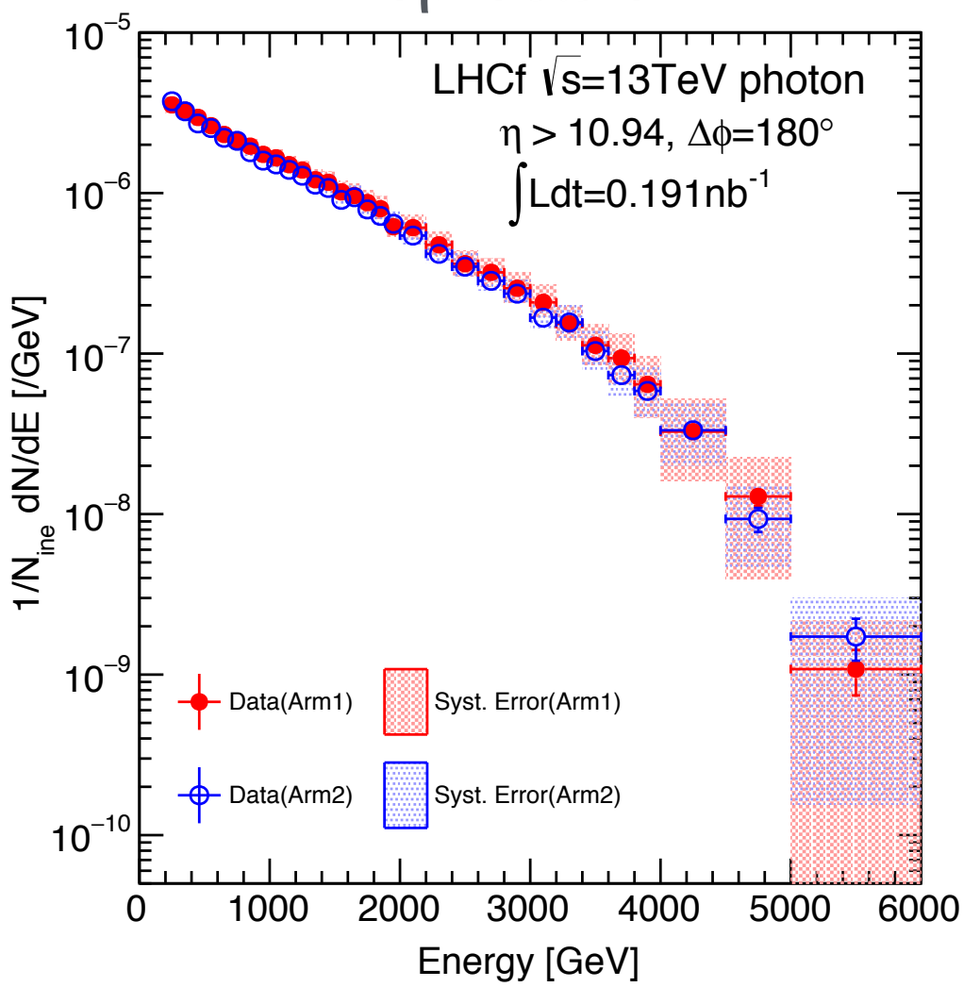
I don't discuss the details of the photon analysis today…

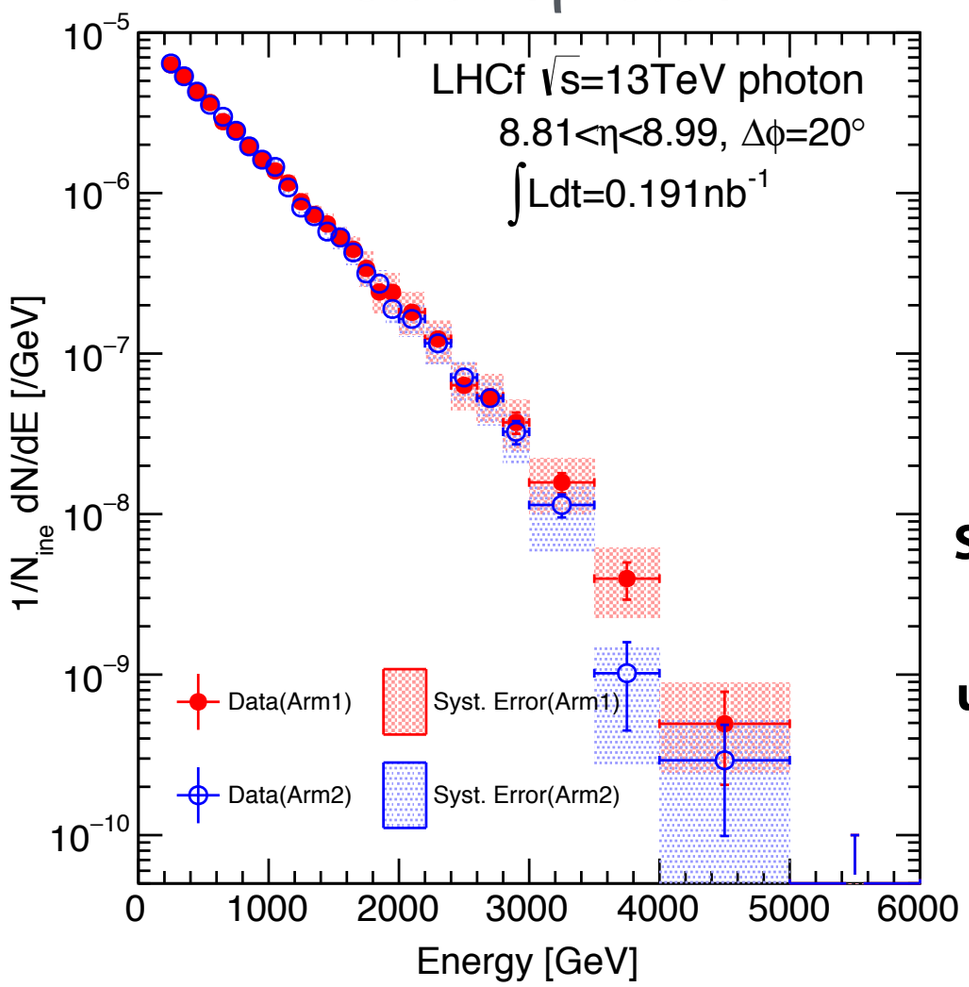
but, what are different from 7 TeV photon analysis?

- Almost same procedure except for **multi-hit** and **unfolding**
- **Unfolding** is newly introduced in photon analysis
  - To avoid full detector simulation for each model
  - Easy to add another model
  - Good for non-LHCf people
- Situation of **multi-hit** (MH) becomes serious (i.e. 4% of TRG events for Arm1 20mm cal.), thus
  - Our new strategy is 1. Identify MH events properly, 2. Cut MH events, 3. Model-dependent correction of MH contribution inside Unfolding
- Luminosity measurement is very precise (1.9%), so added into the uncertainties of the spectrum (not true in 900 GeV and 7 TeV)

Arm1-Arm2 combined inclusive photon spectra in η-ranges : η>10.94 & 8.99>η>8.81

Inclusive photon spectra of Arm1 & Arm2 and spectrum combine





Shown errors are only Arm1-Arm2 uncorrelated

Spectra combine ("pull method" same as 7 TeV pi-zero)

$$\chi^2 = \sum_{i=1}^{n}\sum_{a=1}^{2}\left(\frac{N_{a,i}^{measured}(1+S_{a,i}) - N_i^{combine}}{\sigma_{a,i}}\right)^2 + \chi^2_{penalty}$$

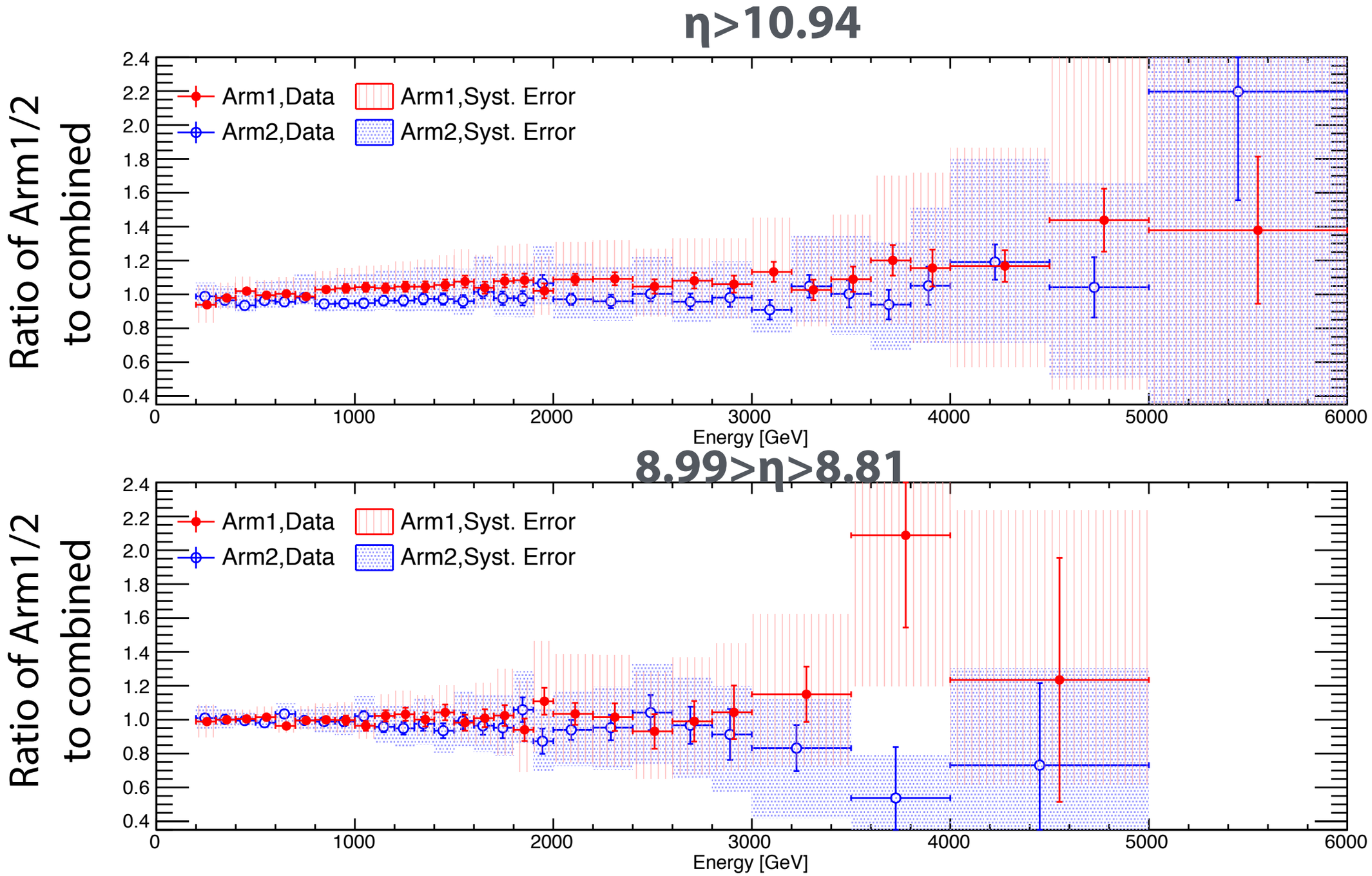
Arm1-Arm2 uncorrelated & bin-by-bin components only

penalty term depending on S

χ²/d.o.f. = **1.6** for η>10.94
χ²/d.o.f. = **1.6** for 8.99>η>8.81

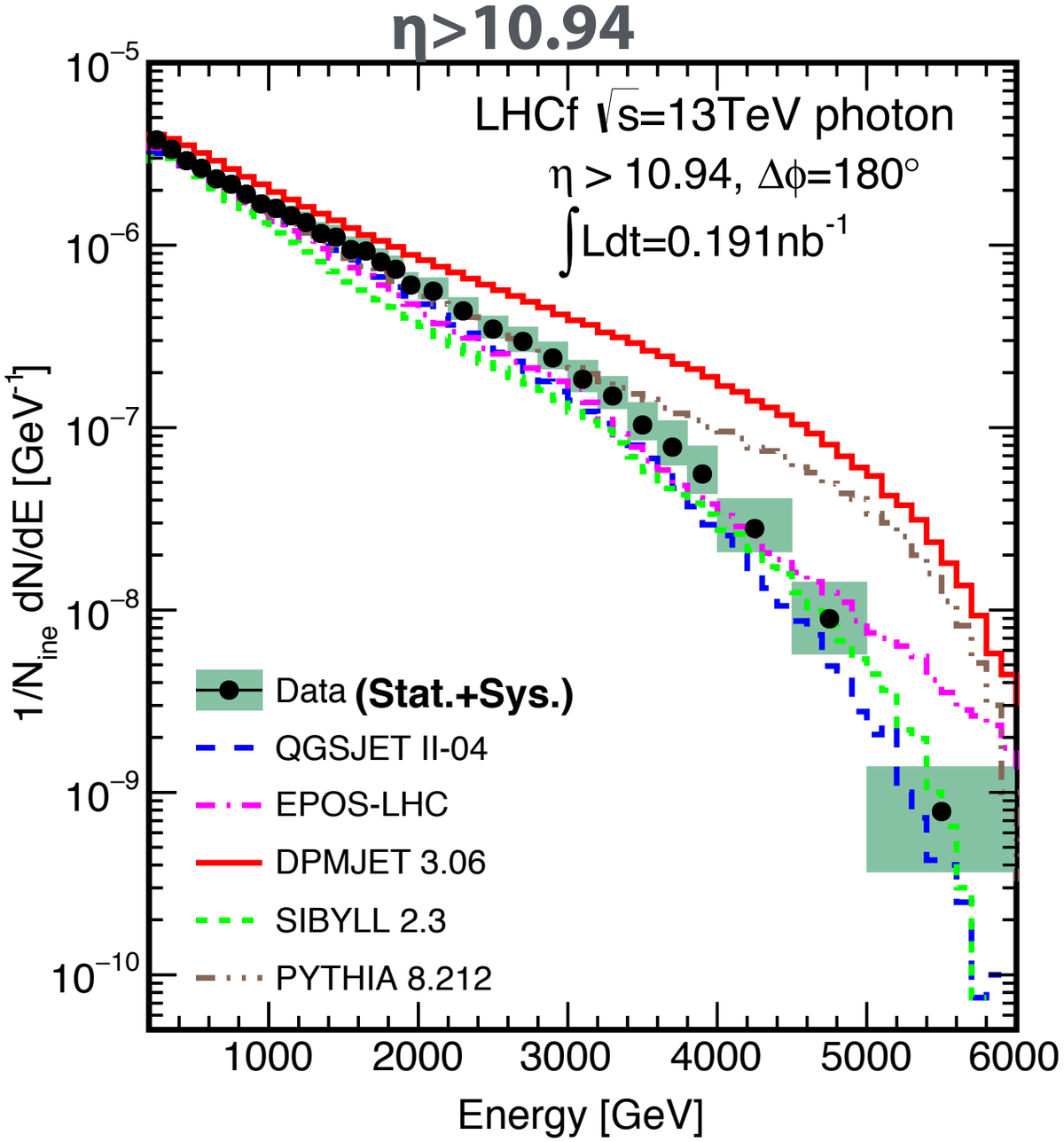
(Energy scale, PID correction, beam center, multi-hit performance)

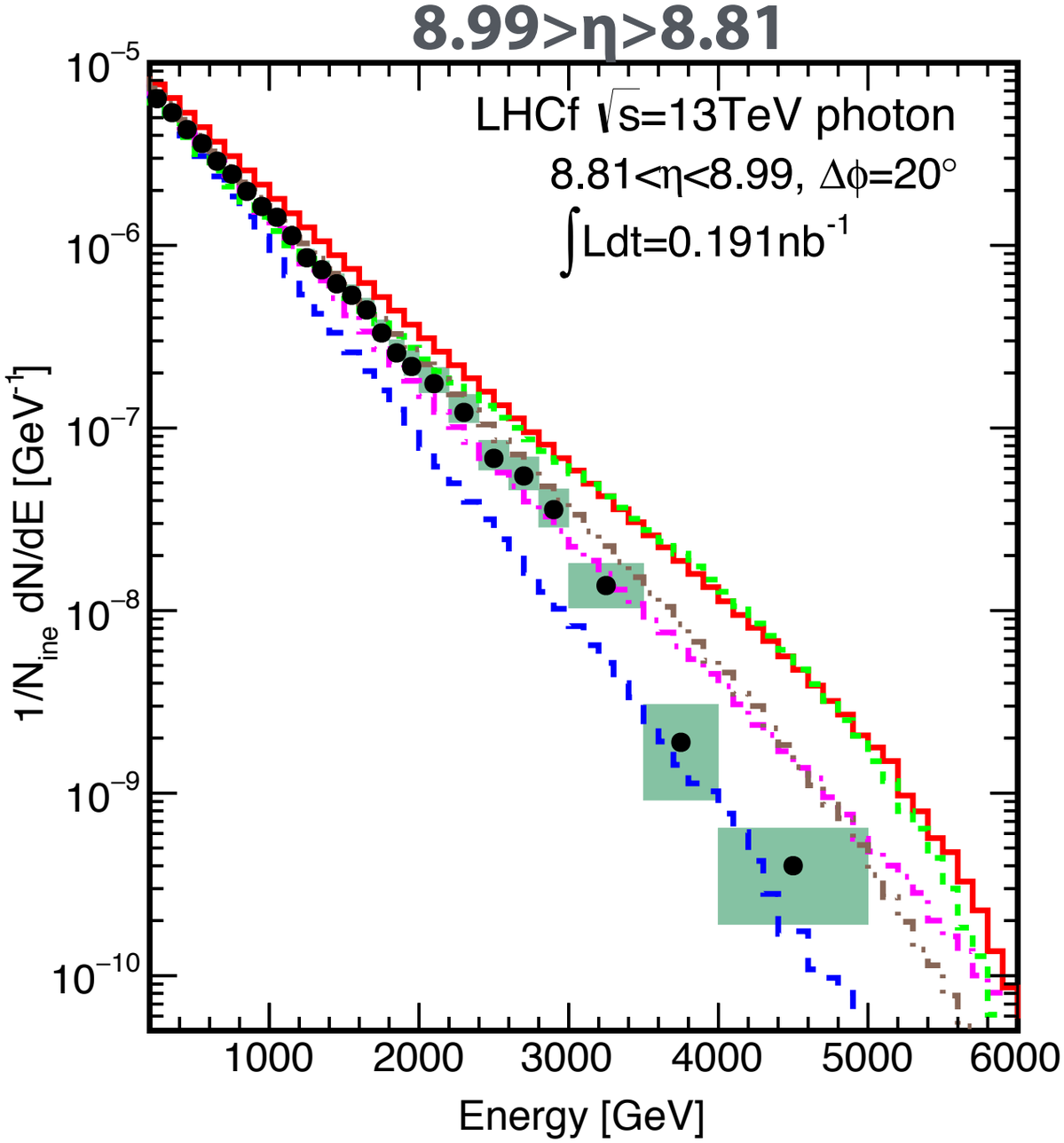
Ratios of Arm1/Arm2 to the combined spectra



- Arm1 and Arm2 are consistent within the uncertainties
- Spectrum combining seems to work correctly

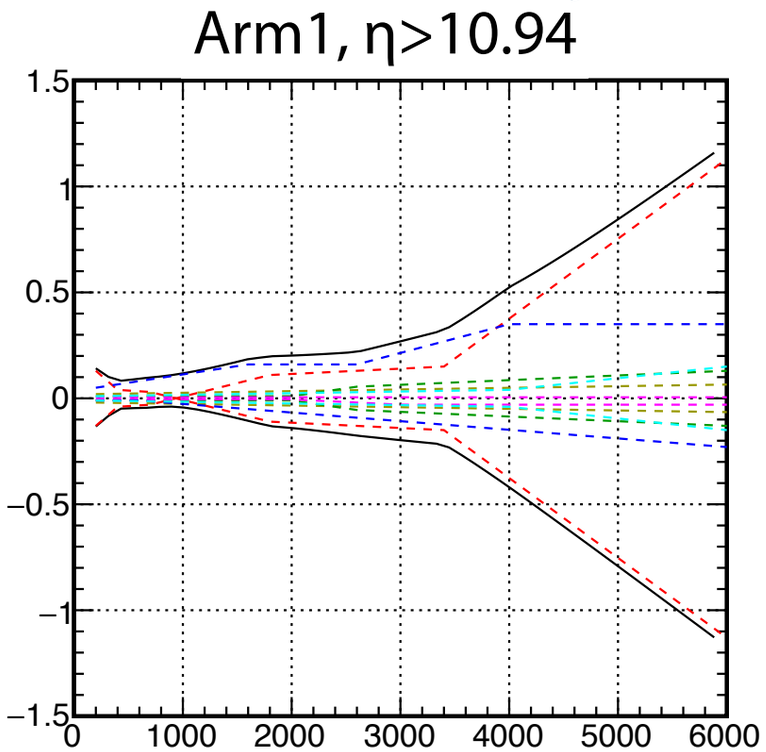
√s=13 TeV LHCf inclusive photon spectra

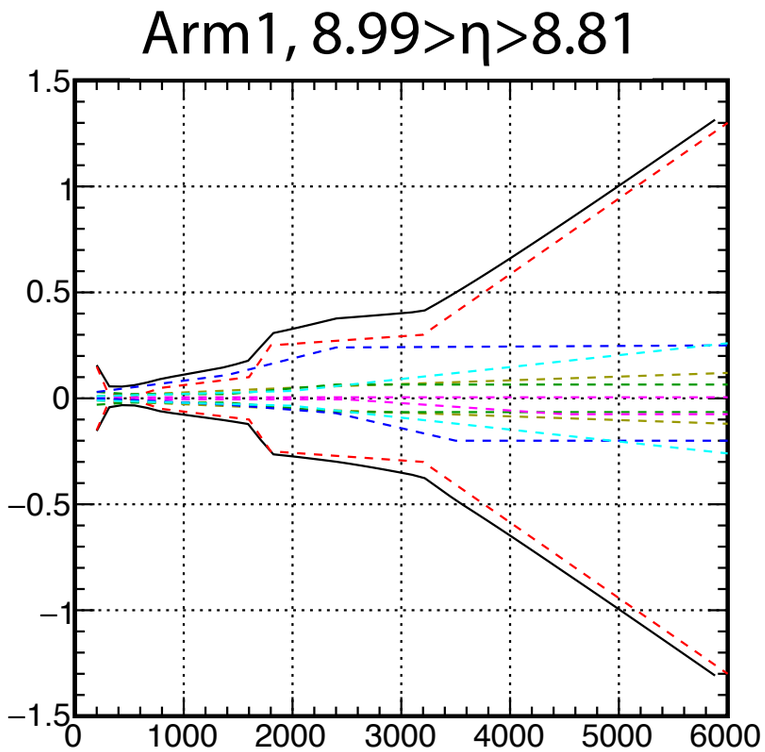


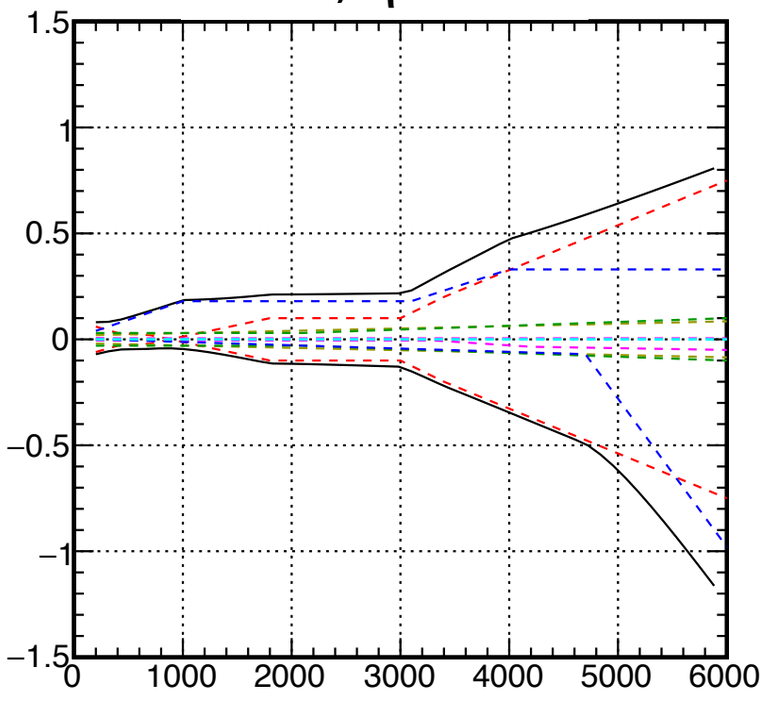


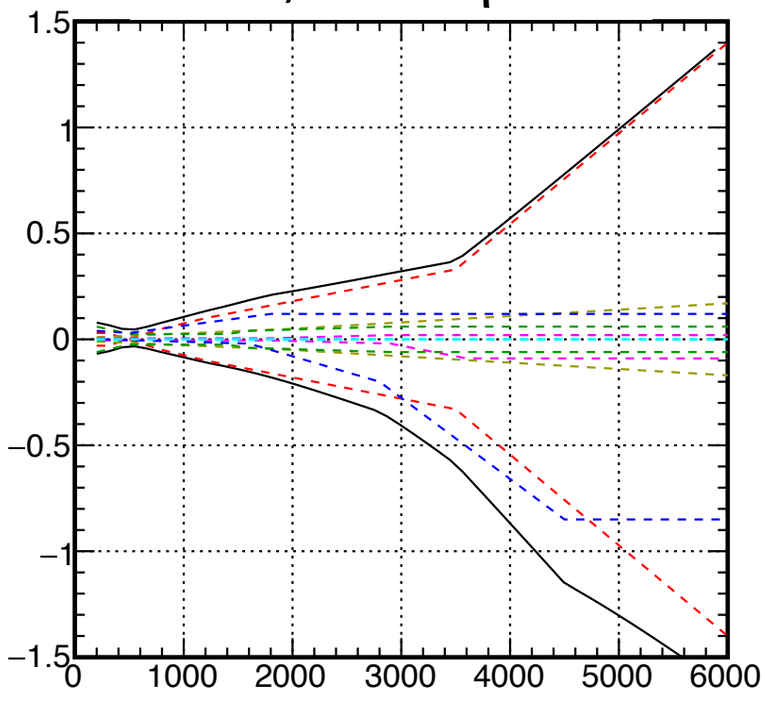
- MC predictions calculated by CRMC (v1.6 / v1.5.xx)
- Background
  - 1%-level-correction of beam gas background (estimated by non-crossing bunches)
  - Beam pipe background is negligible (<1%, estimated by QGSJETII-04 DoubleArm simulations)

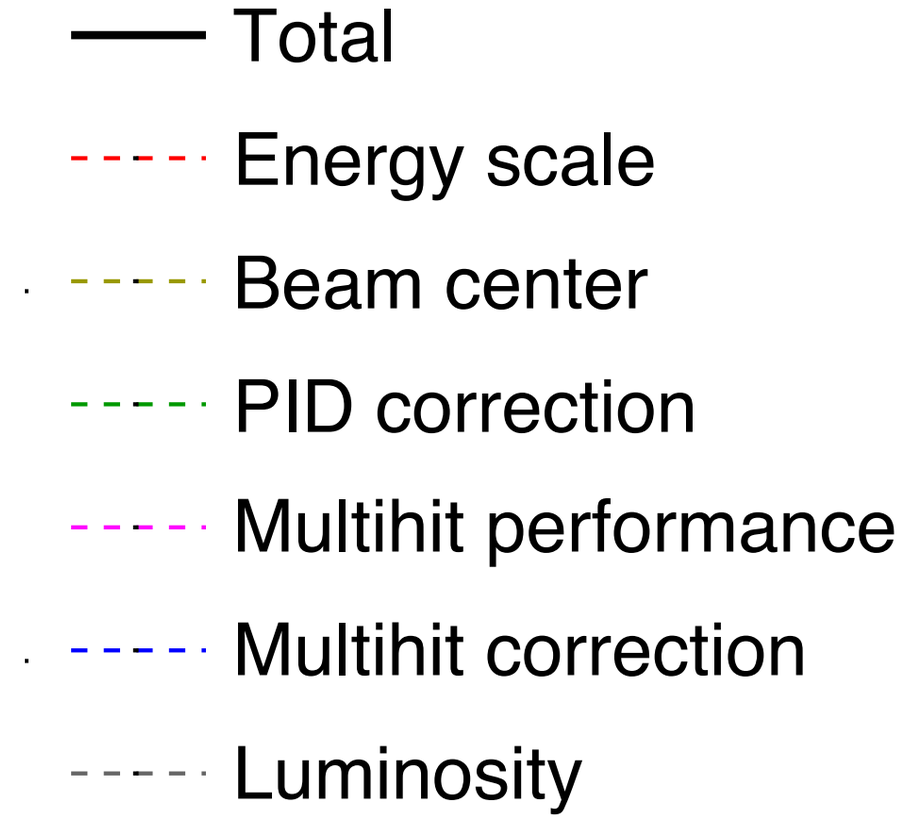
Systematic uncertainties





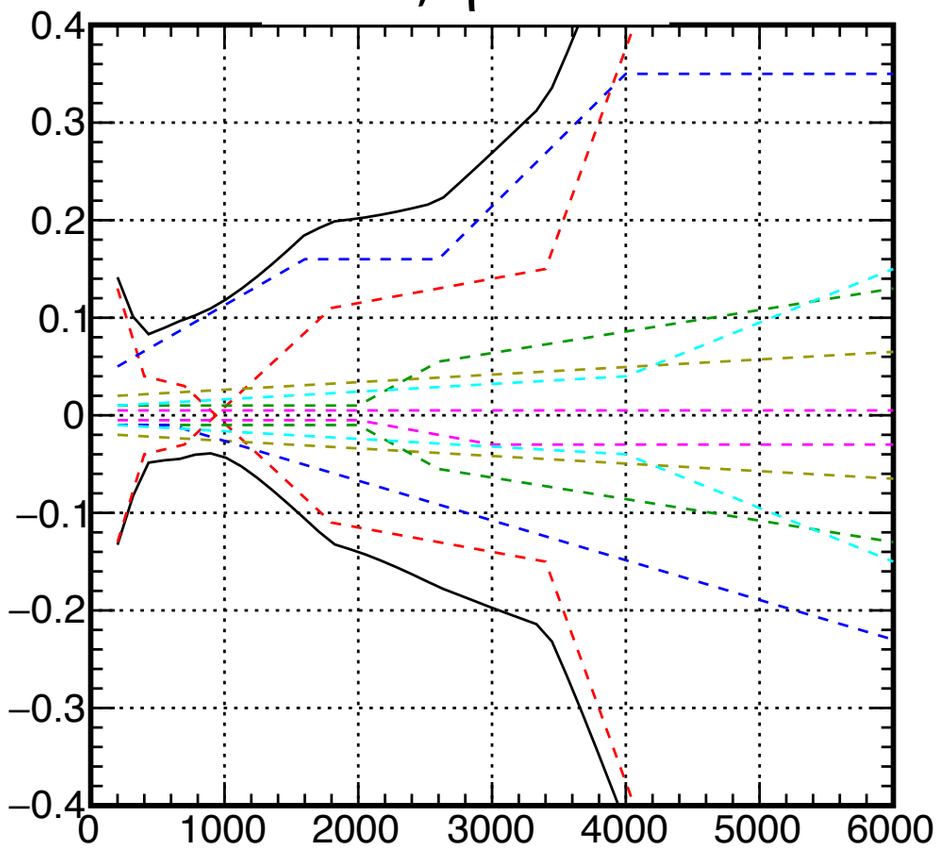




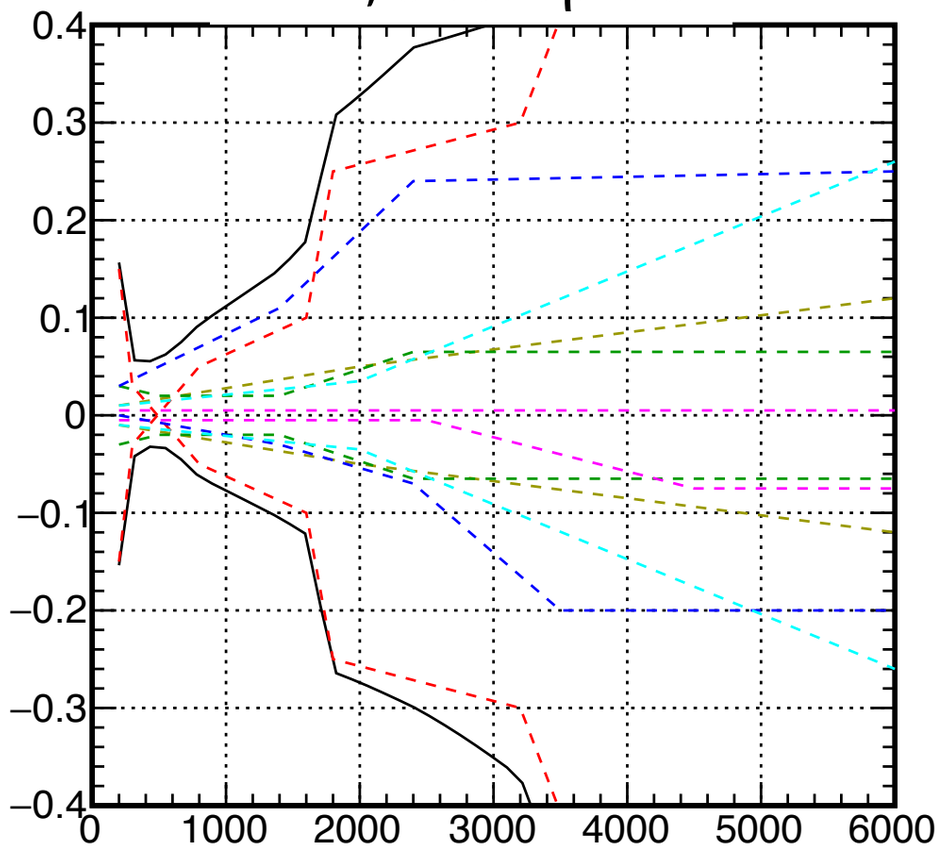


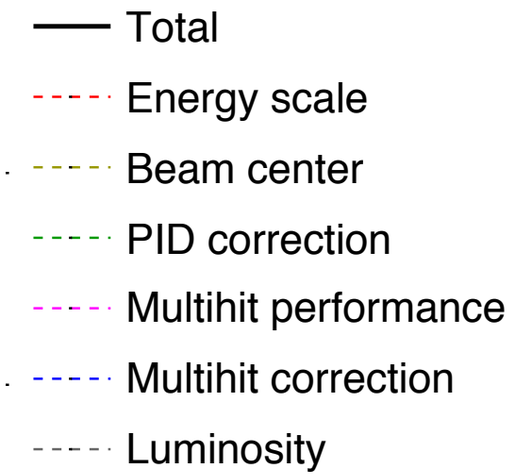
Large contribution from energy scale and unfolding (MH correction)

Arm1, η>10.94

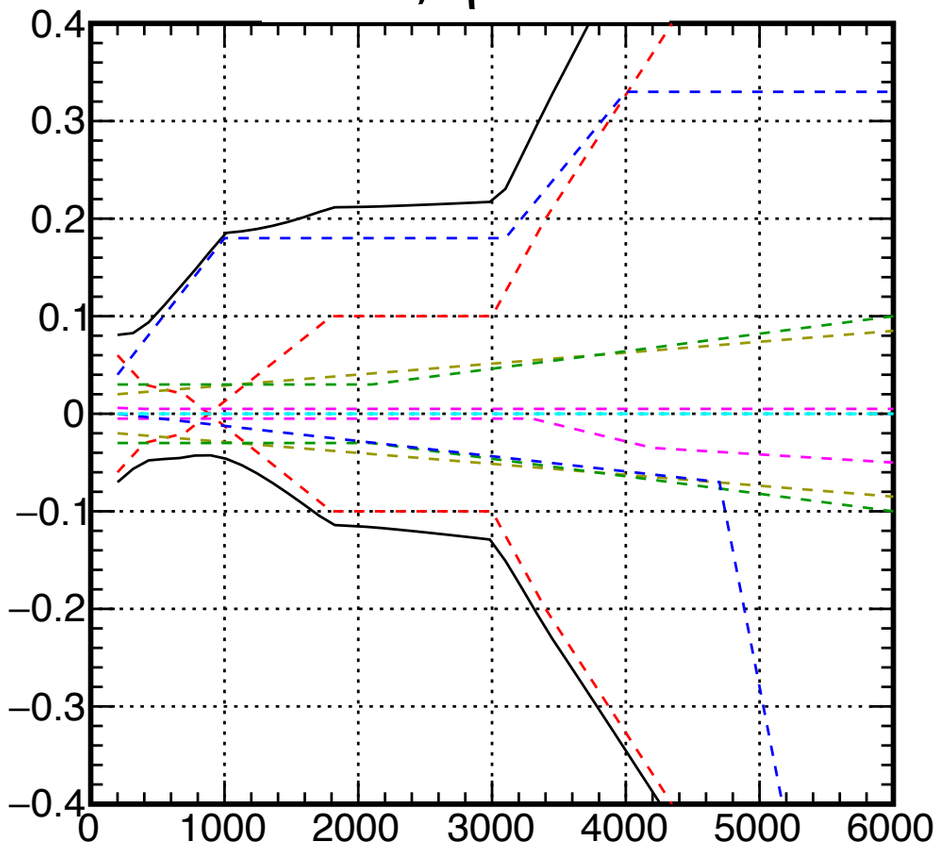


Arm1, 8.99>η>8.81

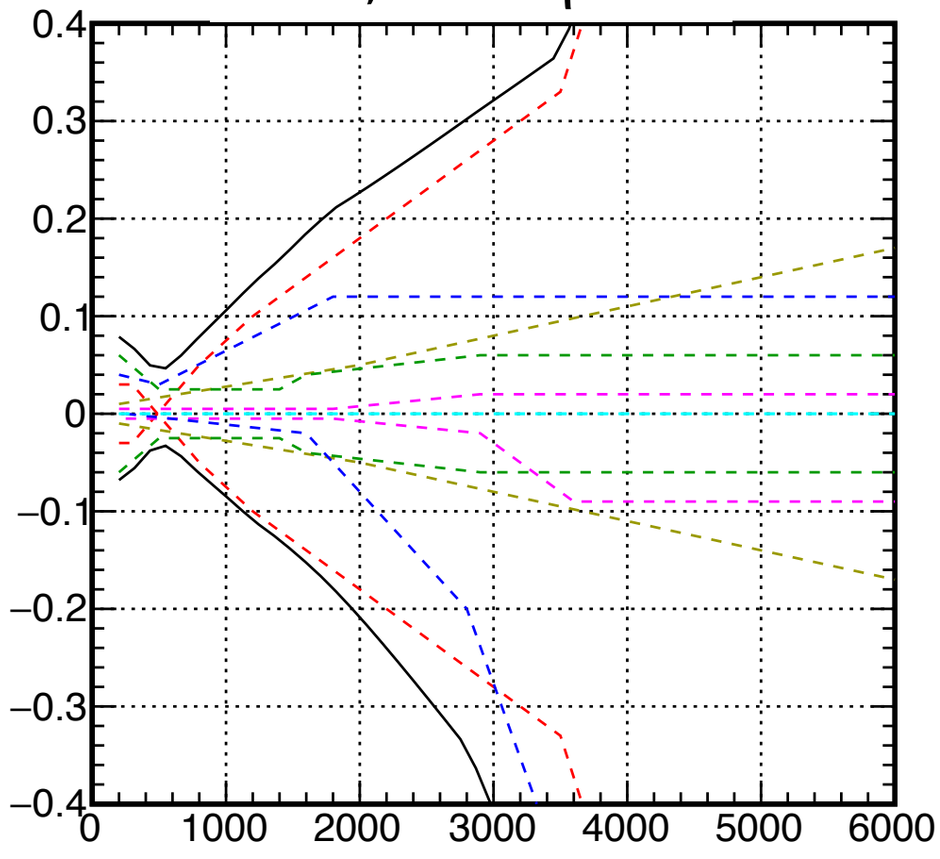




Arm2, η>10.94



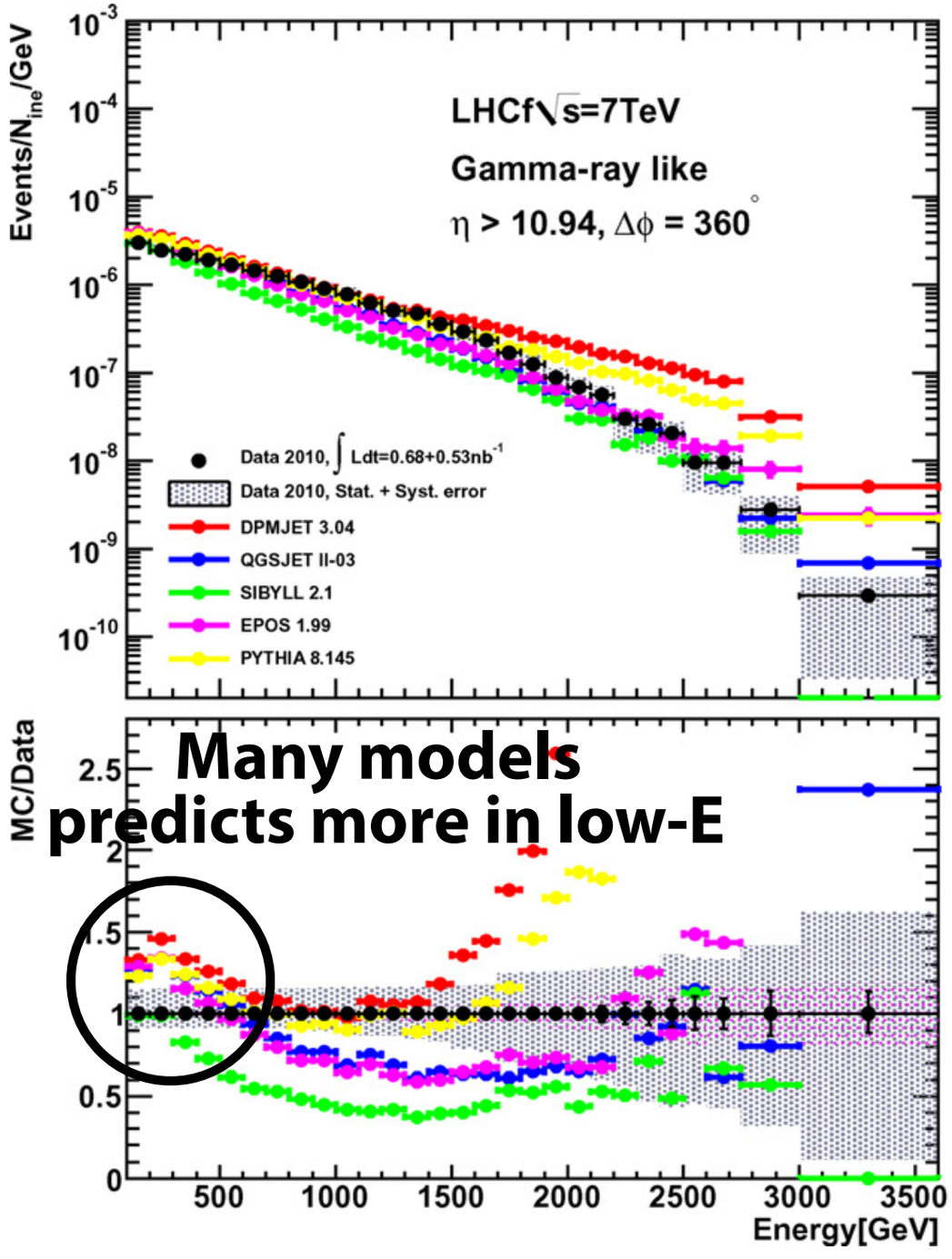
Arm2, 8.99>η>8.81

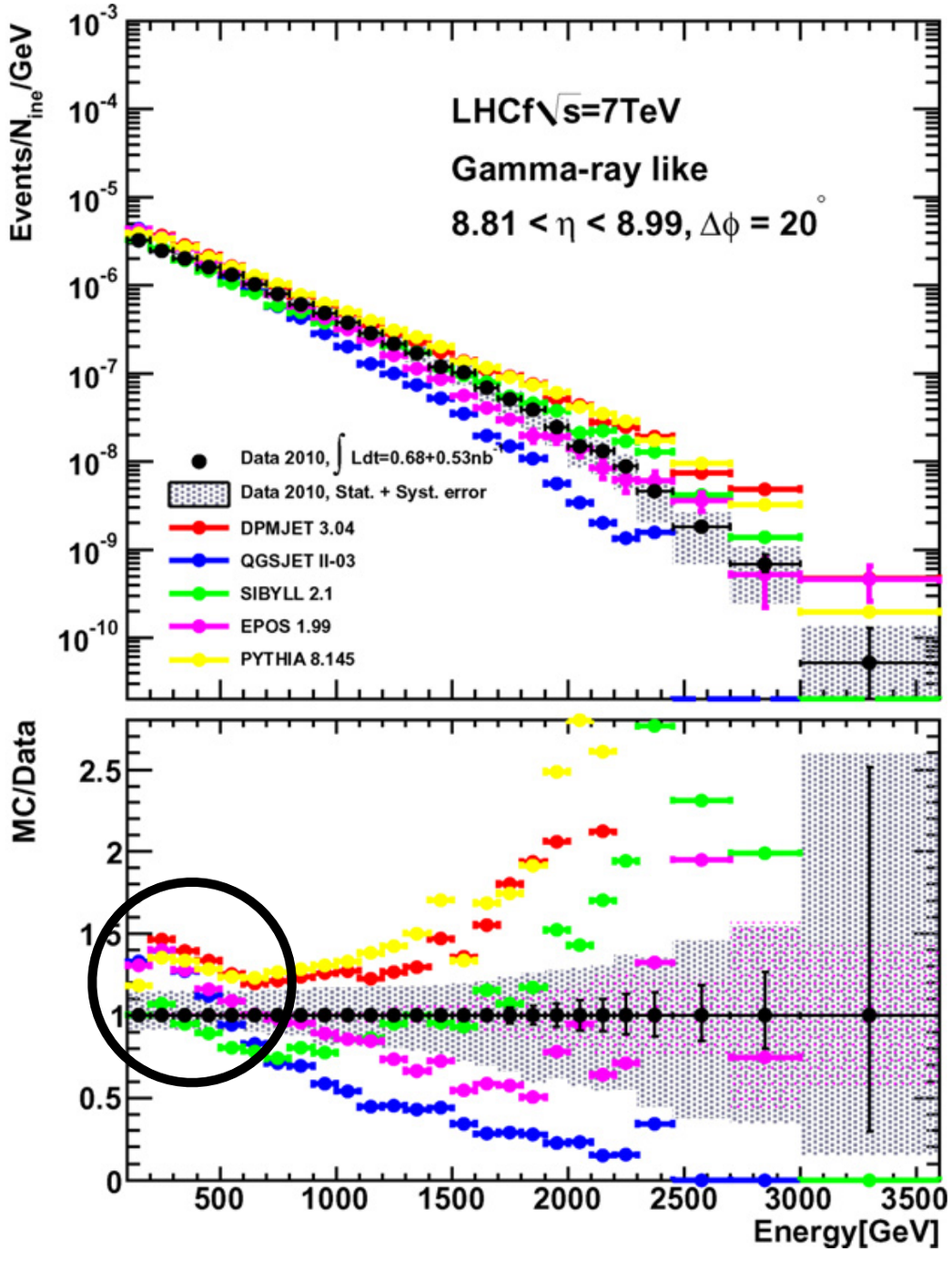


Y-axis enlarged

p-p √s=7 TeV, single photon spectra

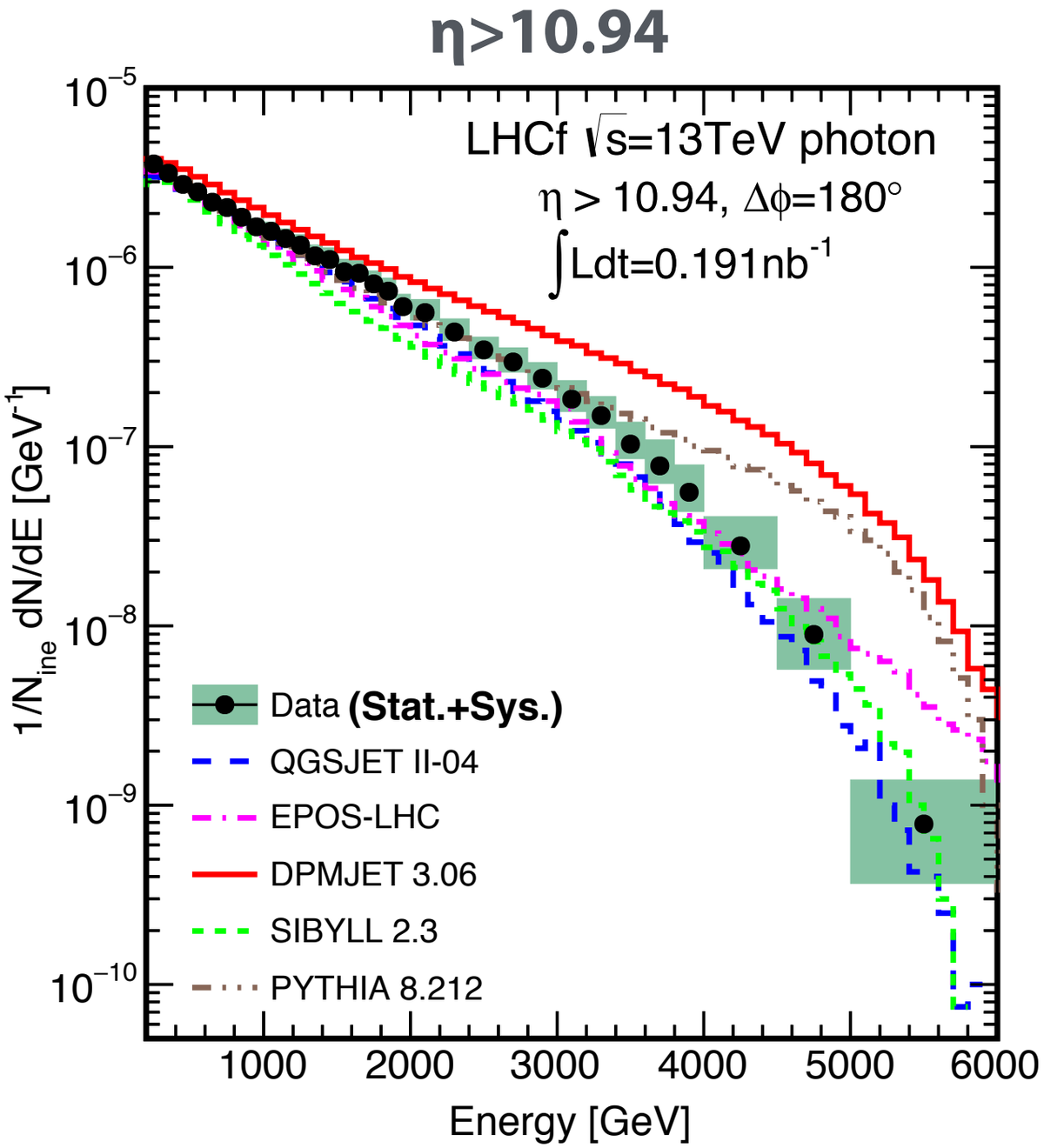
Before going to the detailed comparison with the models, just for remind…

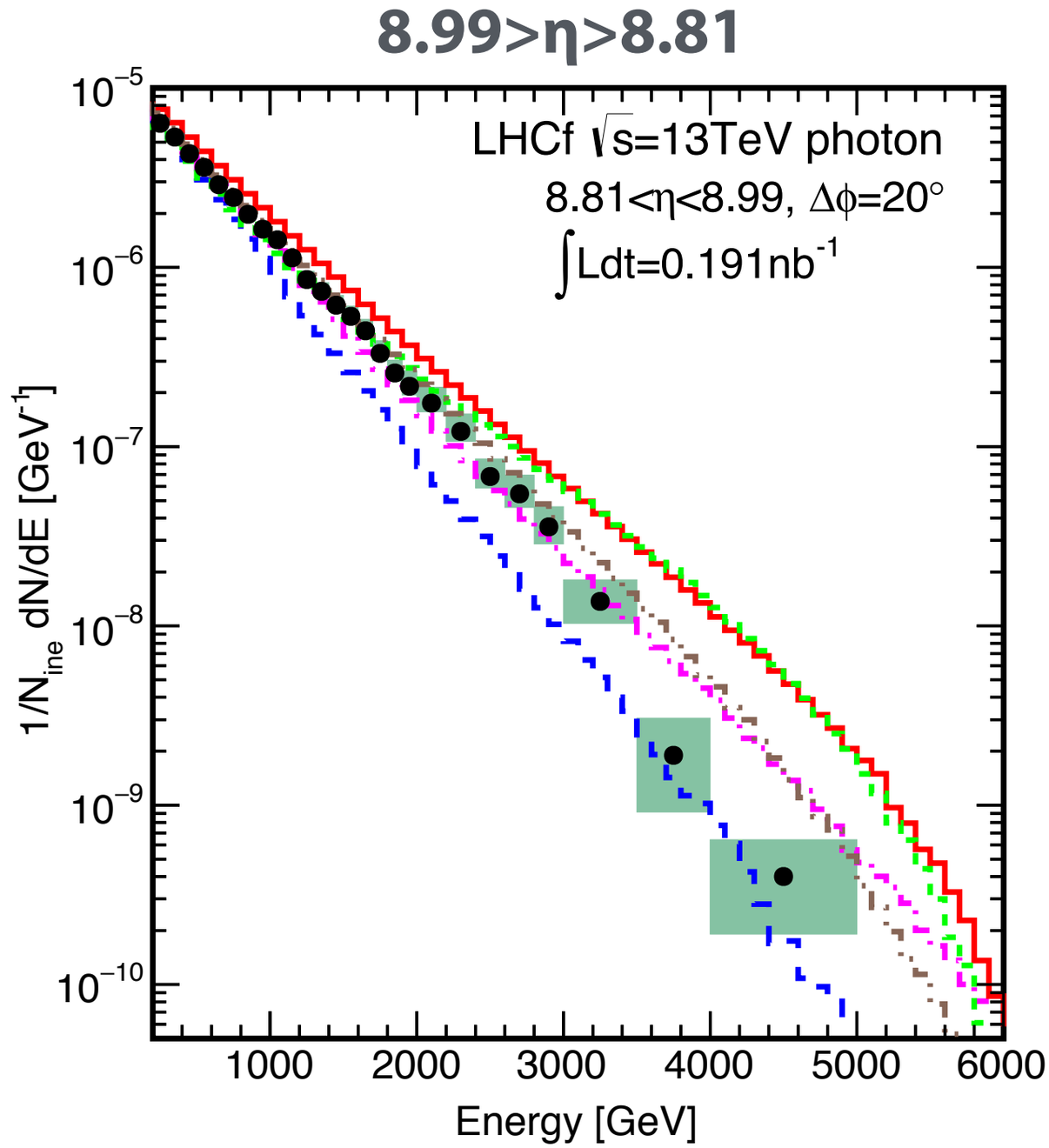




Basically, no models (but only pre-LHC ones) reproduce LHCf results

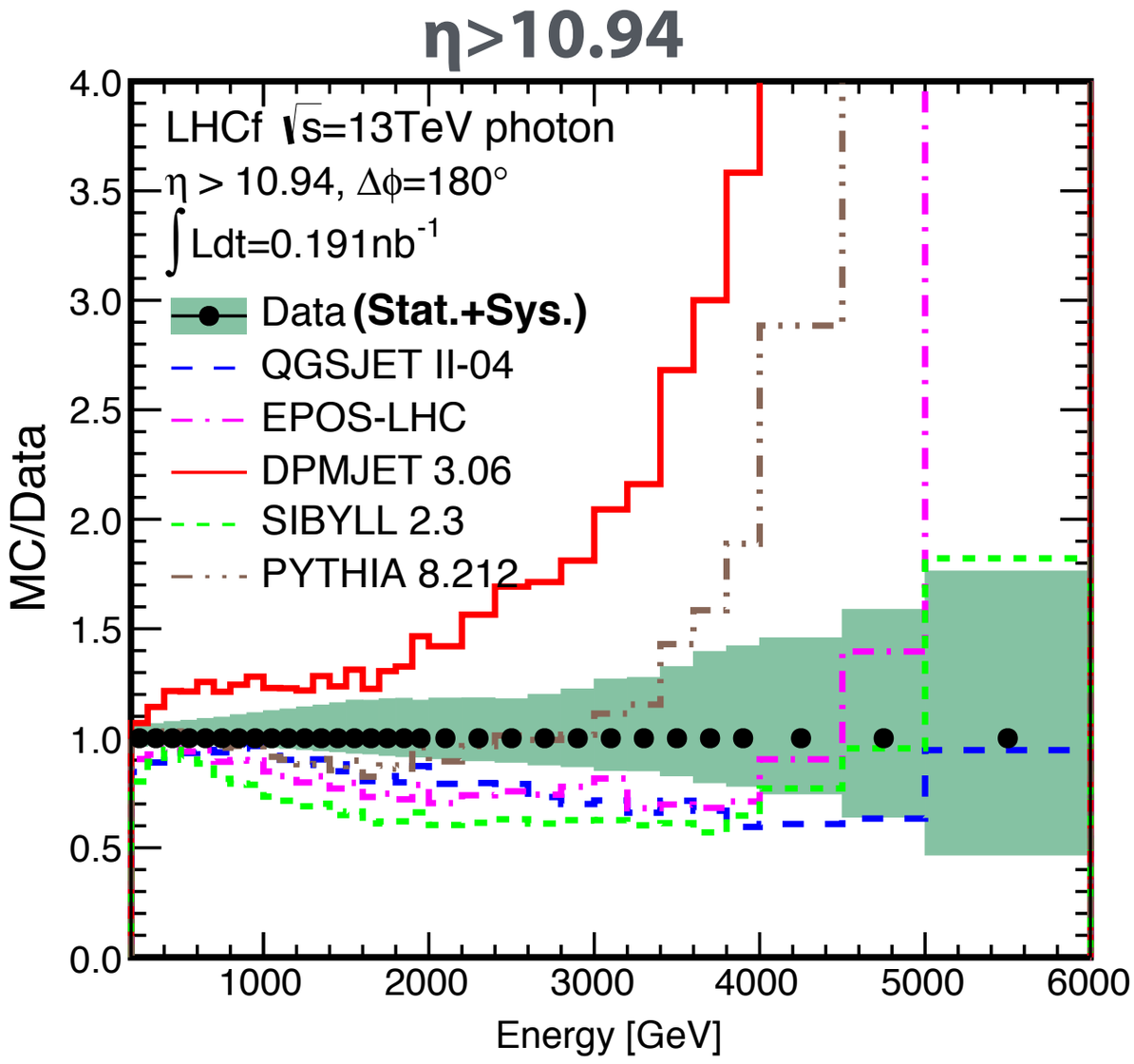
√s=13 TeV LHCf inclusive photon spectra

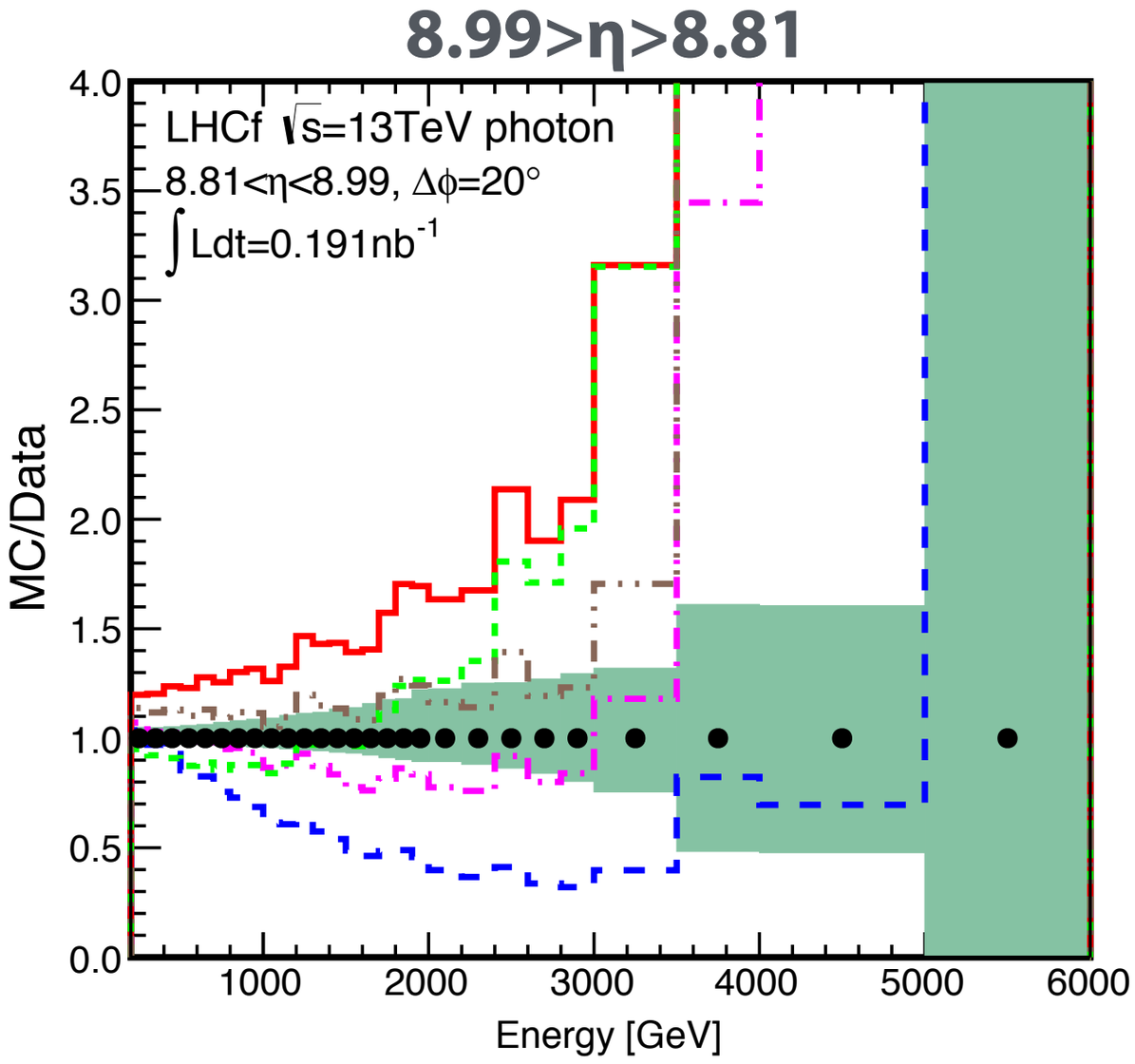




-> Ratio plots in the next slides

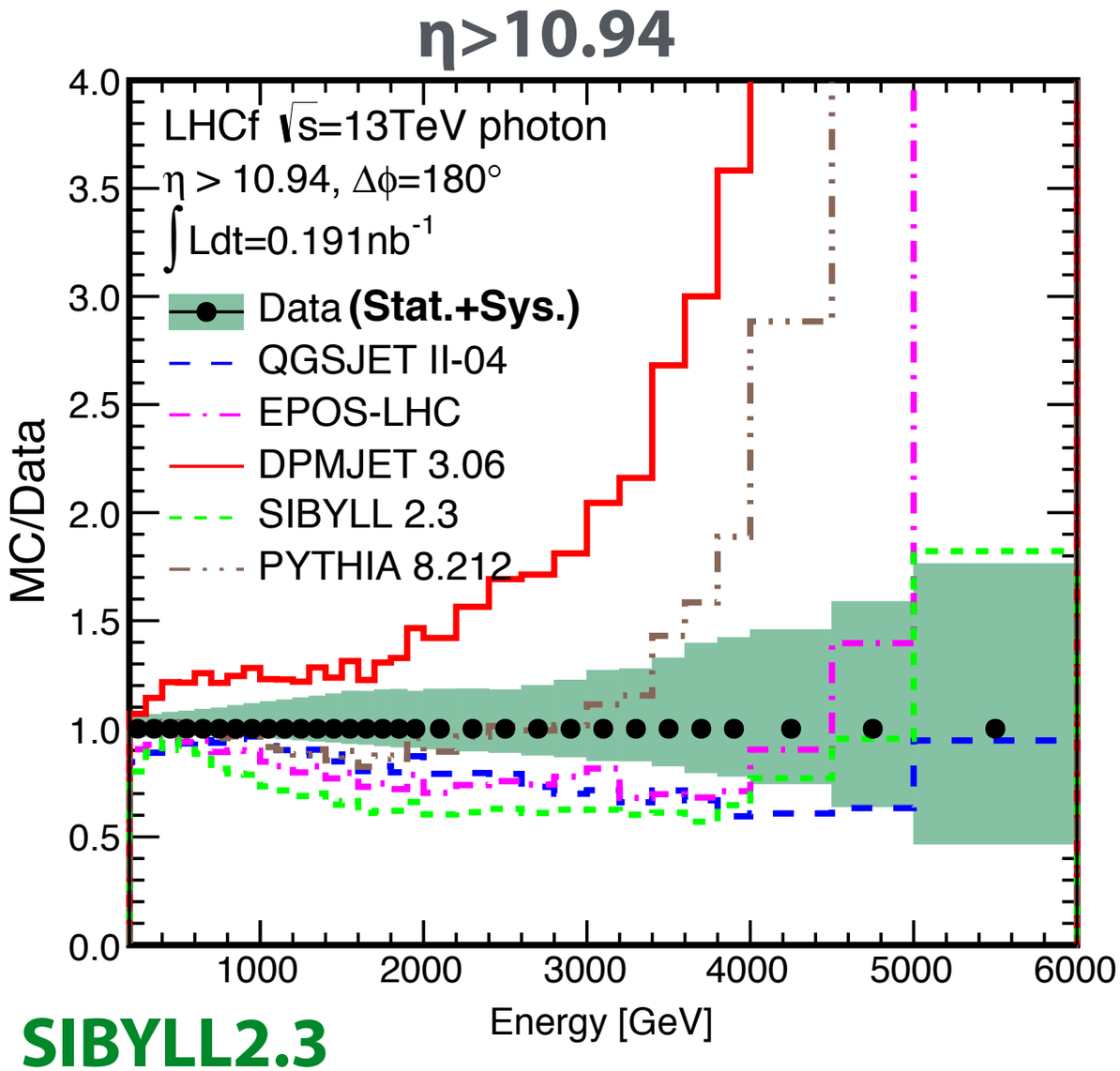
p-p √s=13 TeV, Inclusive photon spectra

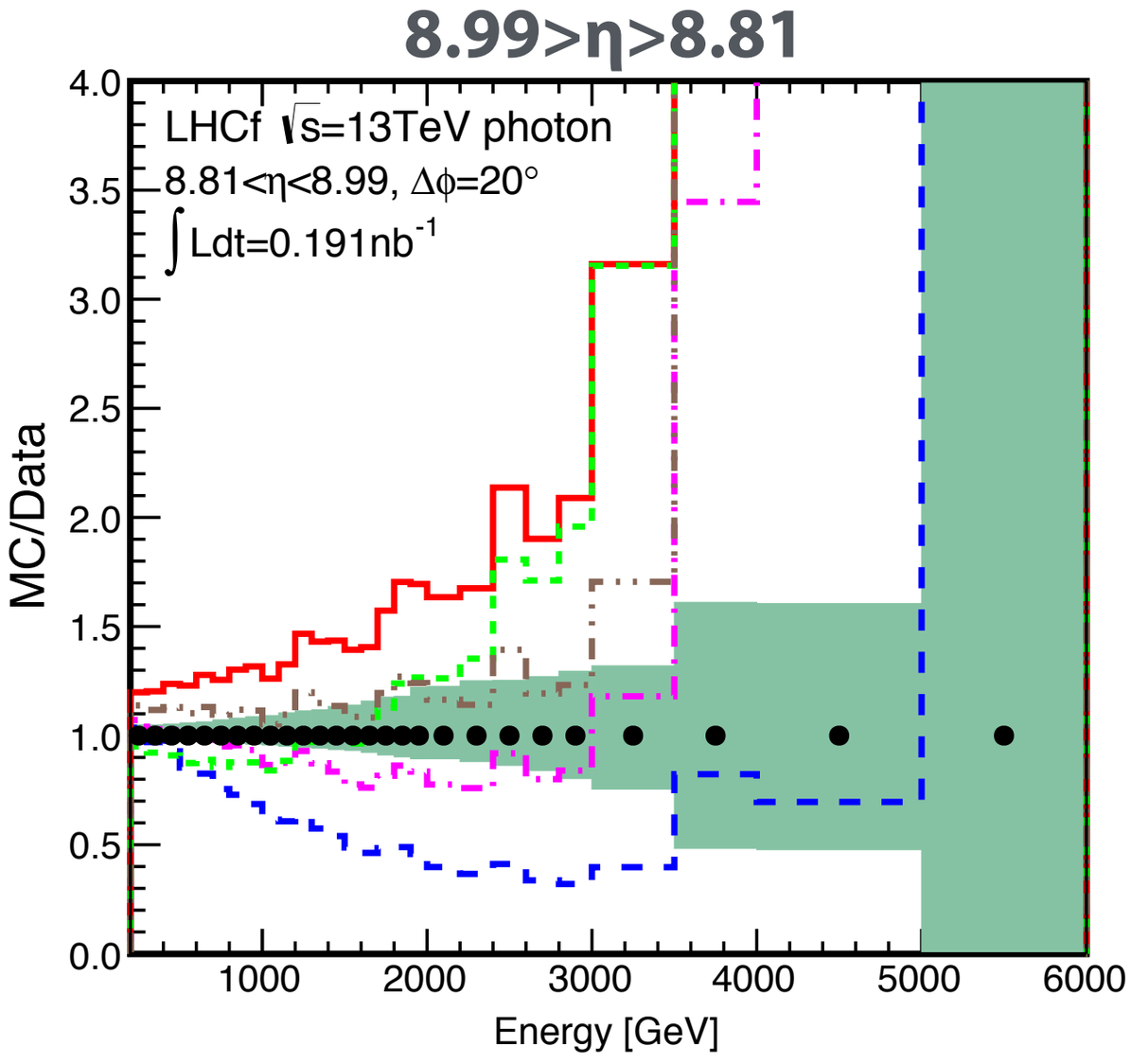




- **PYHTIA8.212**
  - Good agreement with LHCf up to 3000 GeV
  - Harder spectral shape above 3000 GeV (should be connected with diffractive events)
- **DPMJET3.06**
  - Too much, Too hard

p-p √s=13 TeV, Inclusive photon spectra

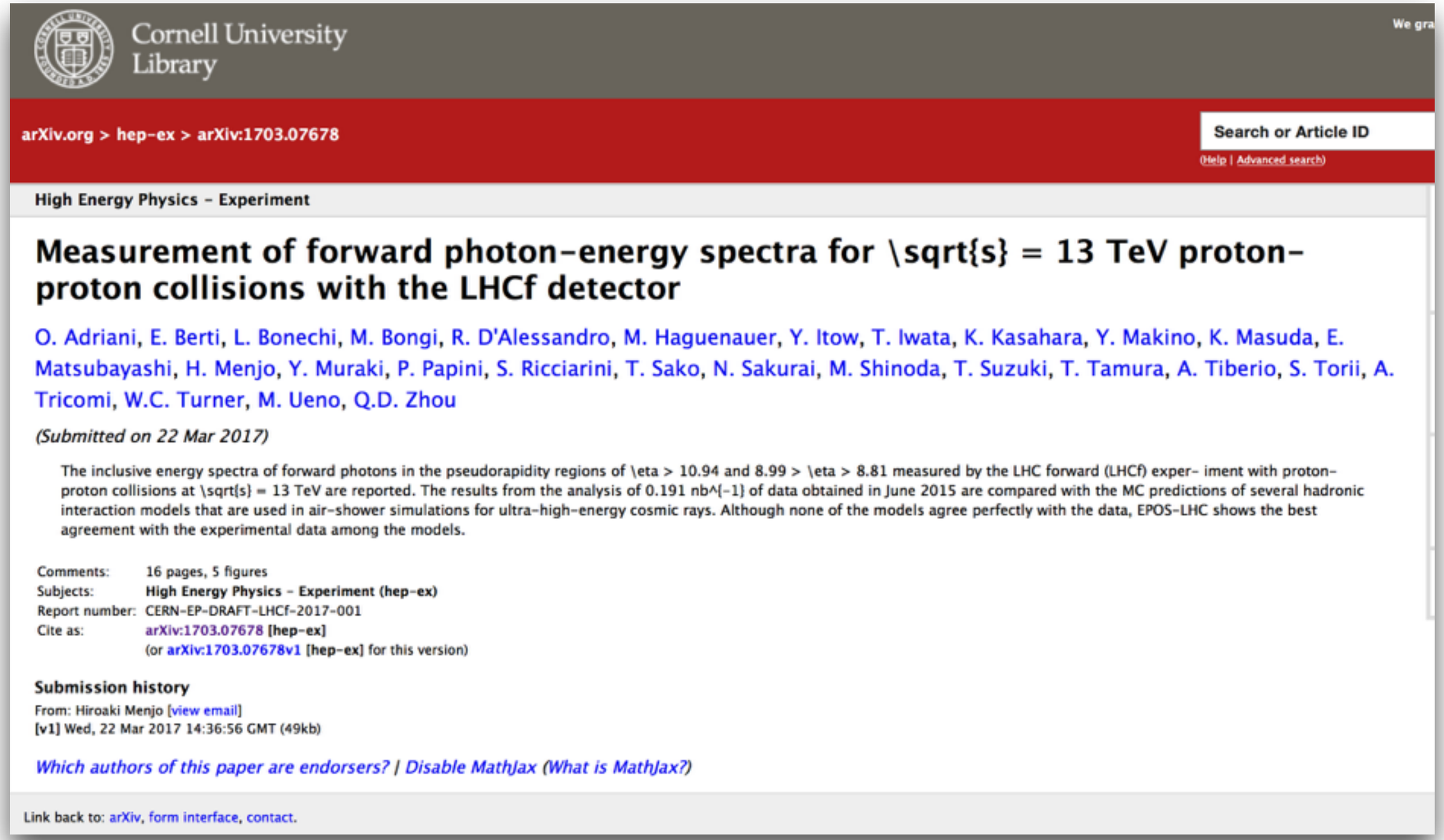




- **SIBYLL2.3**
  - Agree with LHCf only in low energy region of 8.99>η> 8.81
  - Particular η-dependence of the spectral shape
- **QGSJETII-04**
  - The softest spectra among models, and shortage in 8.99>η>8.81
- **EPOS-LHC**
  - Ratio to LHCf is constantly (even in higher energy) good among the models

Even "post-LHC" models are not able to reproduce LHCf

Now available on arXiv



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High Energy Physics - Experiment

Measurement of forward photon-energy spectra for \sqrt{s} = 13 TeV proton-proton collisions with the LHCf detector

O. Adriani, E. Berti, L. Bonechi, M. Bongi, R. D'Alessandro, M. Haguenauer, Y. Itow, T. Iwata, K. Kasahara, Y. Makino, K. Masuda, E. Matsubayashi, H. Menjo, Y. Muraki, P. Papini, S. Ricciarini, T. Sako, N. Sakurai, M. Shinoda, T. Suzuki, T. Tamura, A. Tiberio, S. Torii, A. Tricomi, W.C. Turner, M. Ueno, Q.D. Zhou

(Submitted on 22 Mar 2017)

The inclusive energy spectra of forward photons in the pseudorapidity regions of \eta > 10.94 and 8.99 > \eta > 8.81 measured by the LHC forward (LHCf) exper- iment with proton-proton collisions at \sqrt{s} = 13 TeV are reported. The results from the analysis of 0.191 nb^{-1} of data obtained in June 2015 are compared with the MC predictions of several hadronic interaction models that are used in air-shower simulations for ultra-high-energy cosmic rays. Although none of the models agree perfectly with the data, EPOS-LHC shows the best agreement with the experimental data among the models.

Comments: 16 pages, 5 figures
Subjects: **High Energy Physics - Experiment (hep-ex)**
Report number: CERN-EP-DRAFT-LHCf-2017-001
Cite as: arXiv:1703.07678 **[hep-ex]**
(or **arXiv:1703.07678v1 [hep-ex]** for this version)

Submission history

From: Hiroaki Menjo [view email]
[v1] Wed, 22 Mar 2017 14:36:56 GMT (49kb)

Which authors of this paper are endorsers? | Disable MathJax (What is MathJax?)

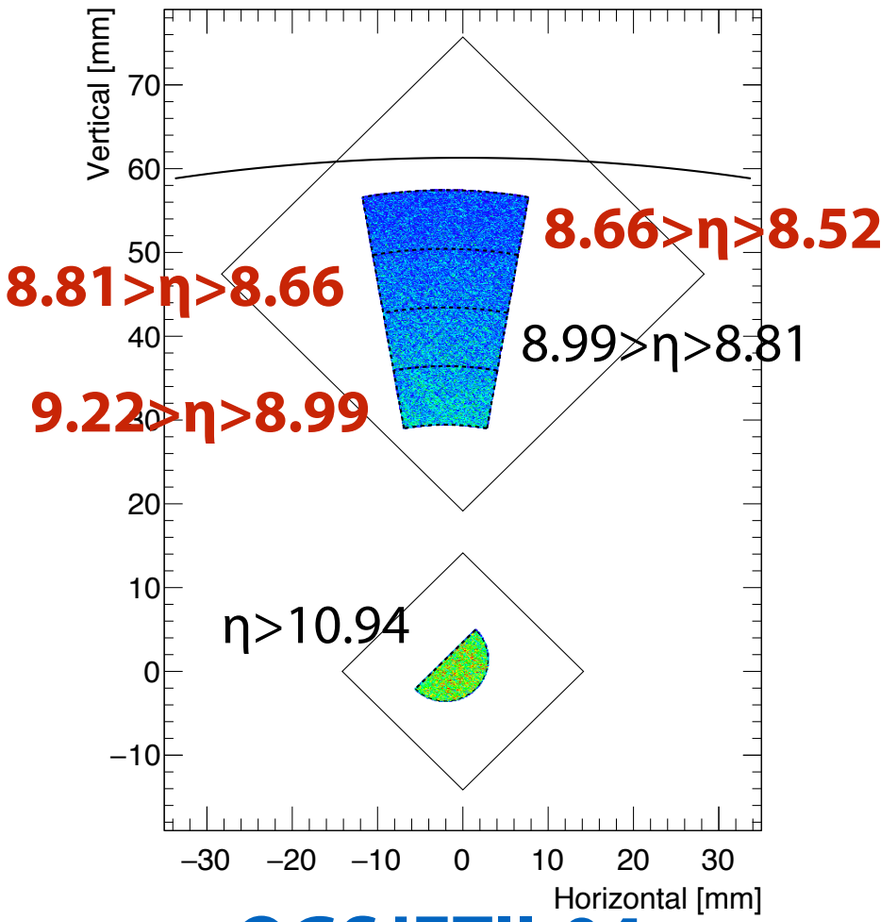
Link back to: arXiv, form interface, contact.

-> PLB submitted

Arm1 photon analysis with large η-acceptance

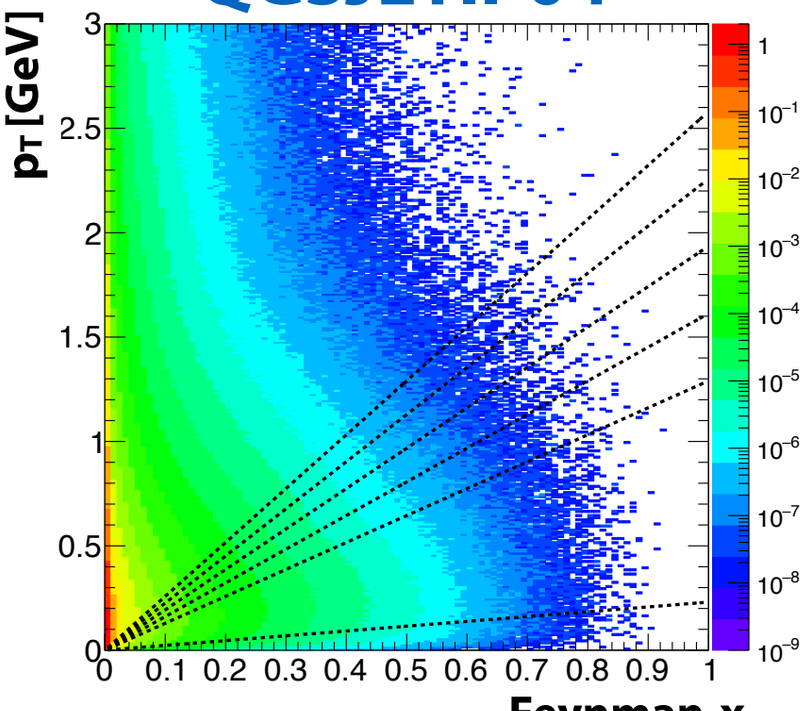
Energy spectrum (dσ/dE)
&
Energy flow (dE/dη)

η-acceptance extension with Arm1

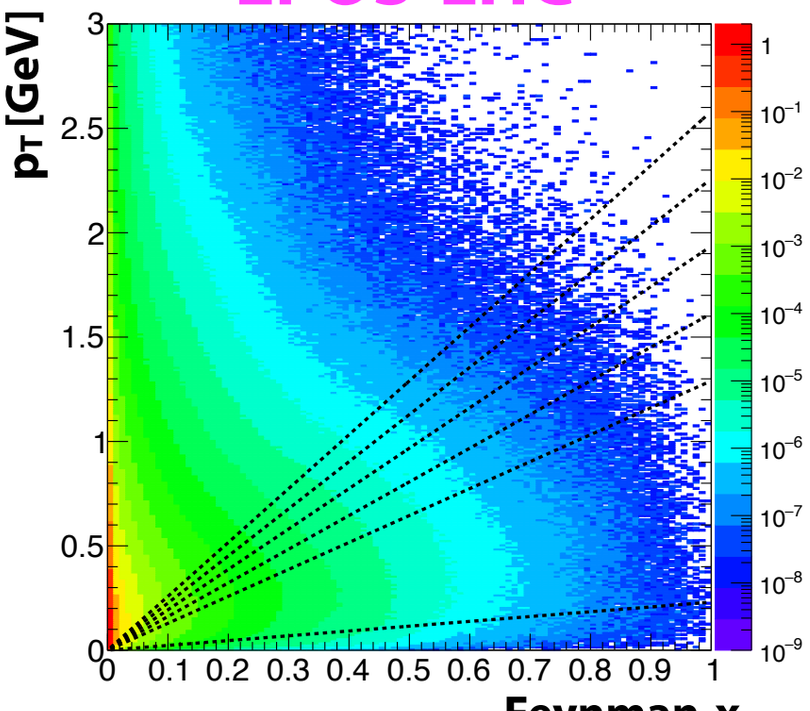


- 9.22>η>8.99, 8.81>η>8.66, 8.66>η>8.52
  - Same procedure as well as in 8.99>η>8.81
  - η dependence of spectral shape / energy flow
- Analysis of lower η region is important from the point view of energy flow
  - Peak of the energy flow distribution locates η=7-8

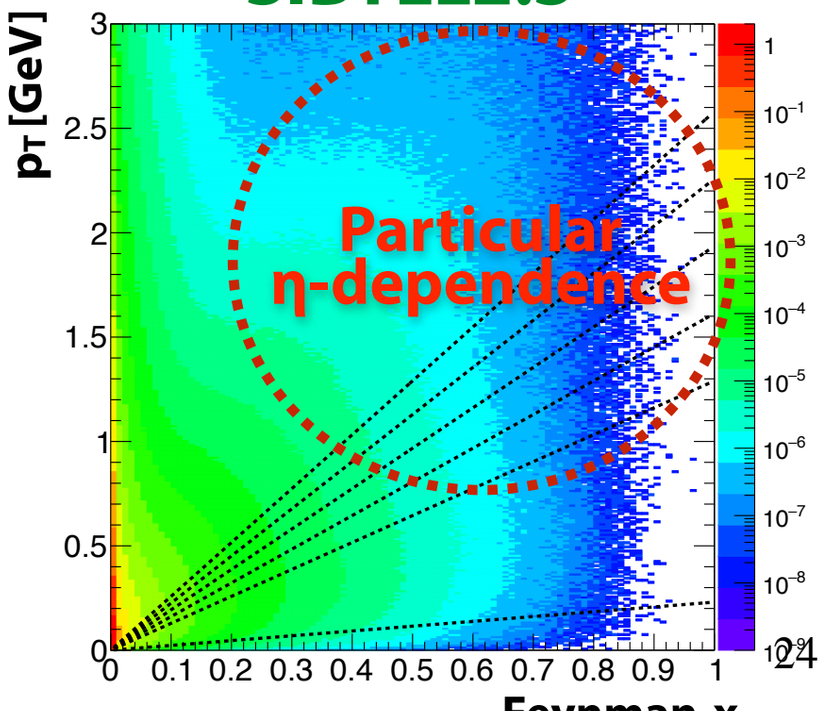
QGSJETII-04



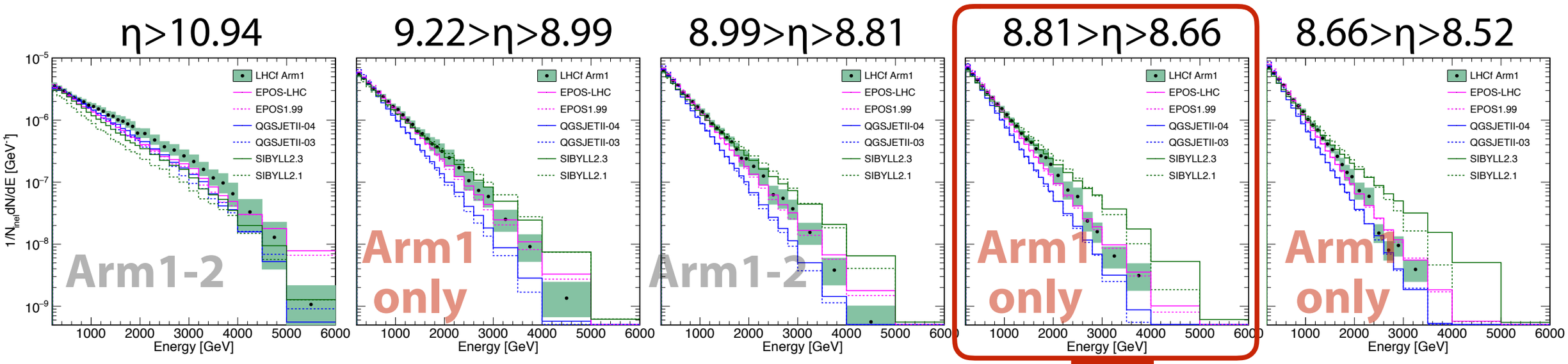
EPOS-LHC



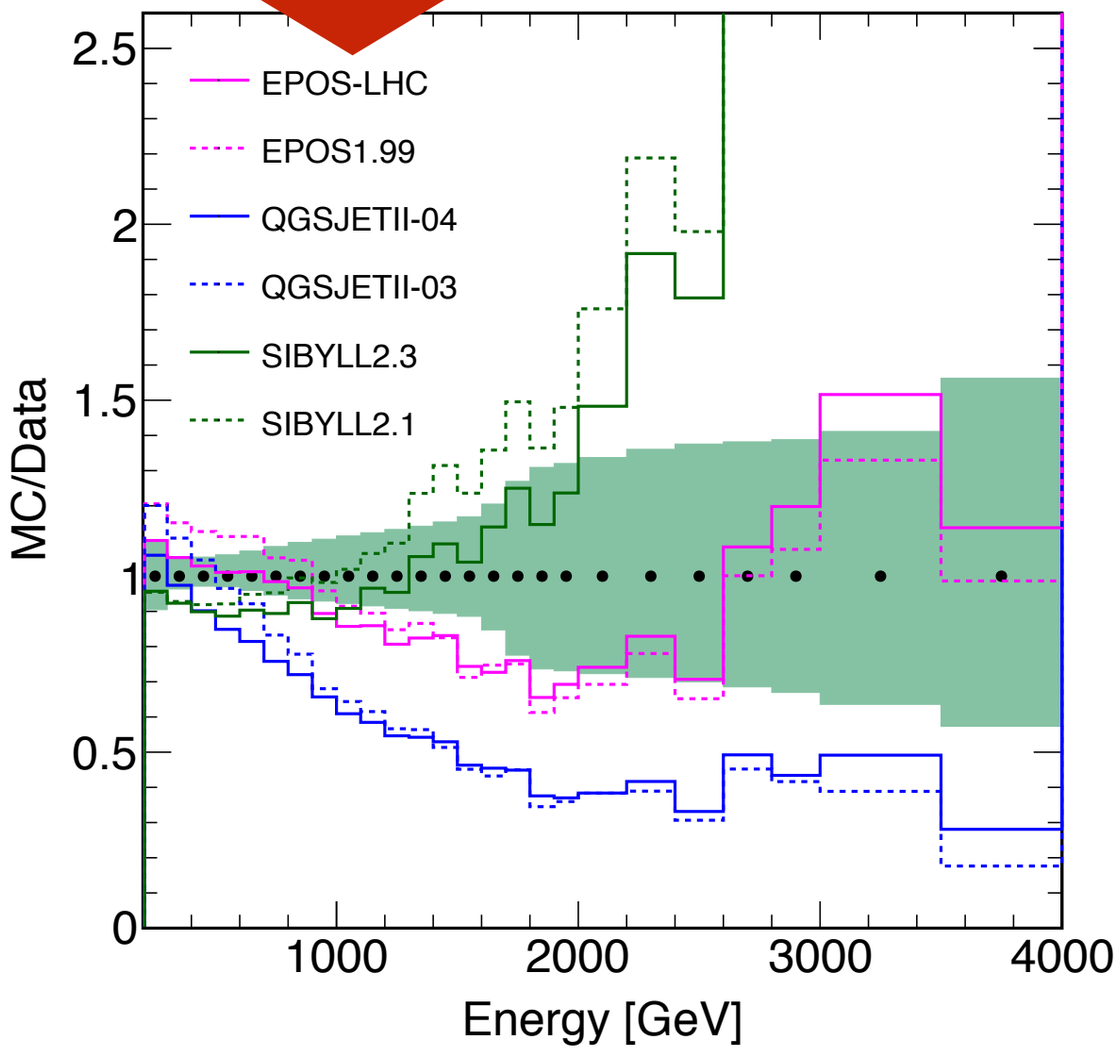
SIBYLL2.3



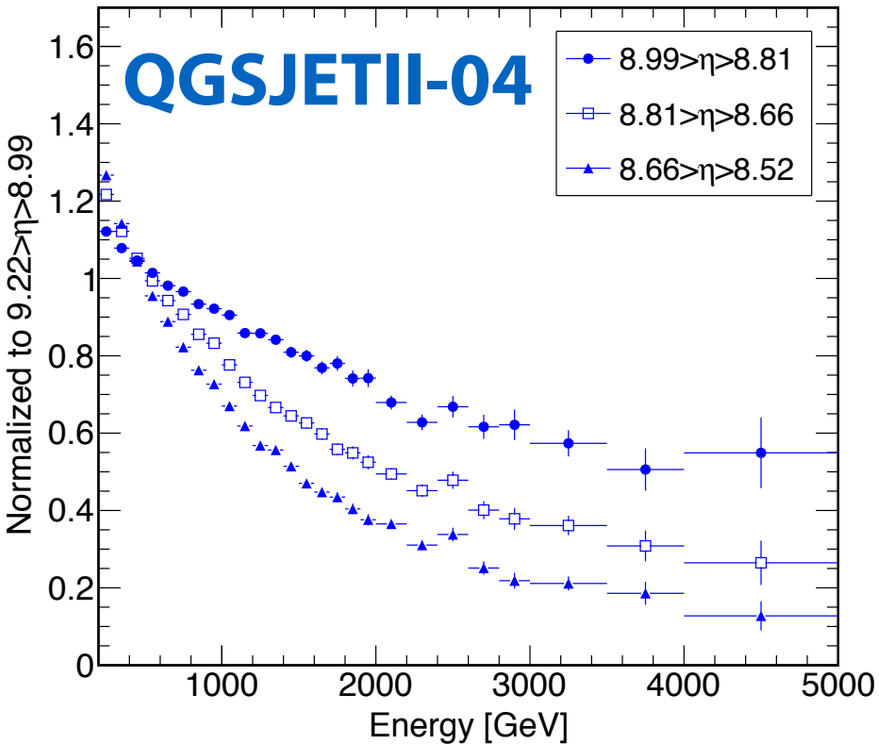
η>8.52, photon energy spectra

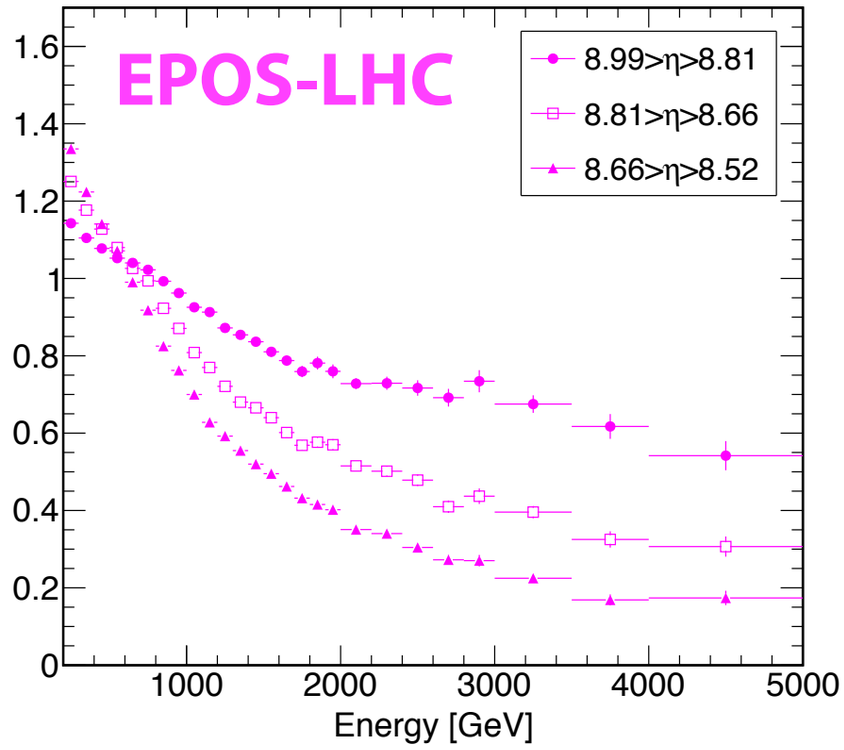


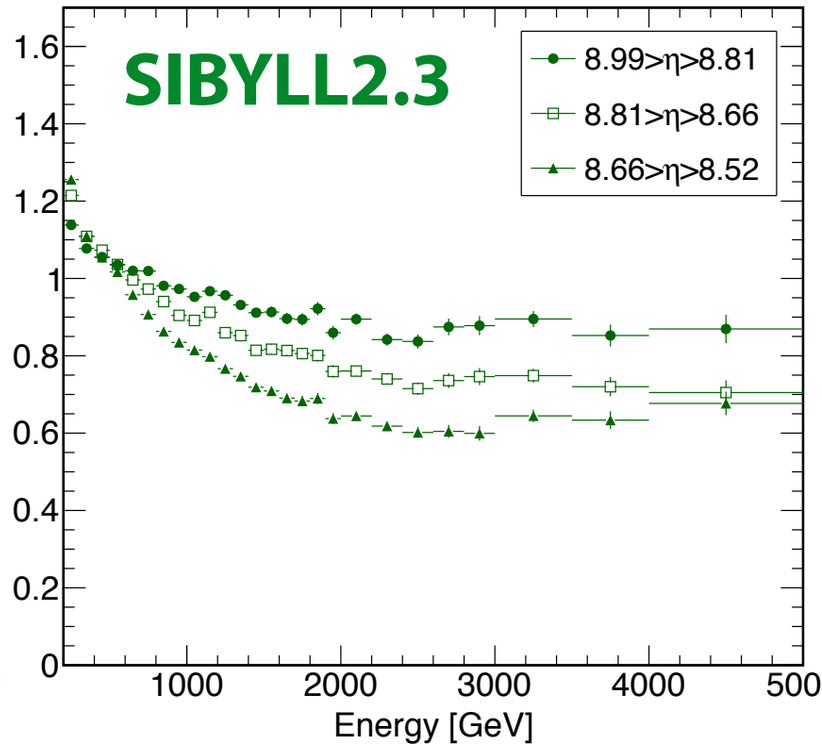
- 8.81>η>8.66 (right figure)
  - **SIBYLL2.3 / QGSJETII-04 are harder / softer**
  - **EPOS-LHC is able to reproduce LHCf almost within the estimated errors**
- Four regions in 9.22>η>8.52
  - How about the η-dependence of the spectra?

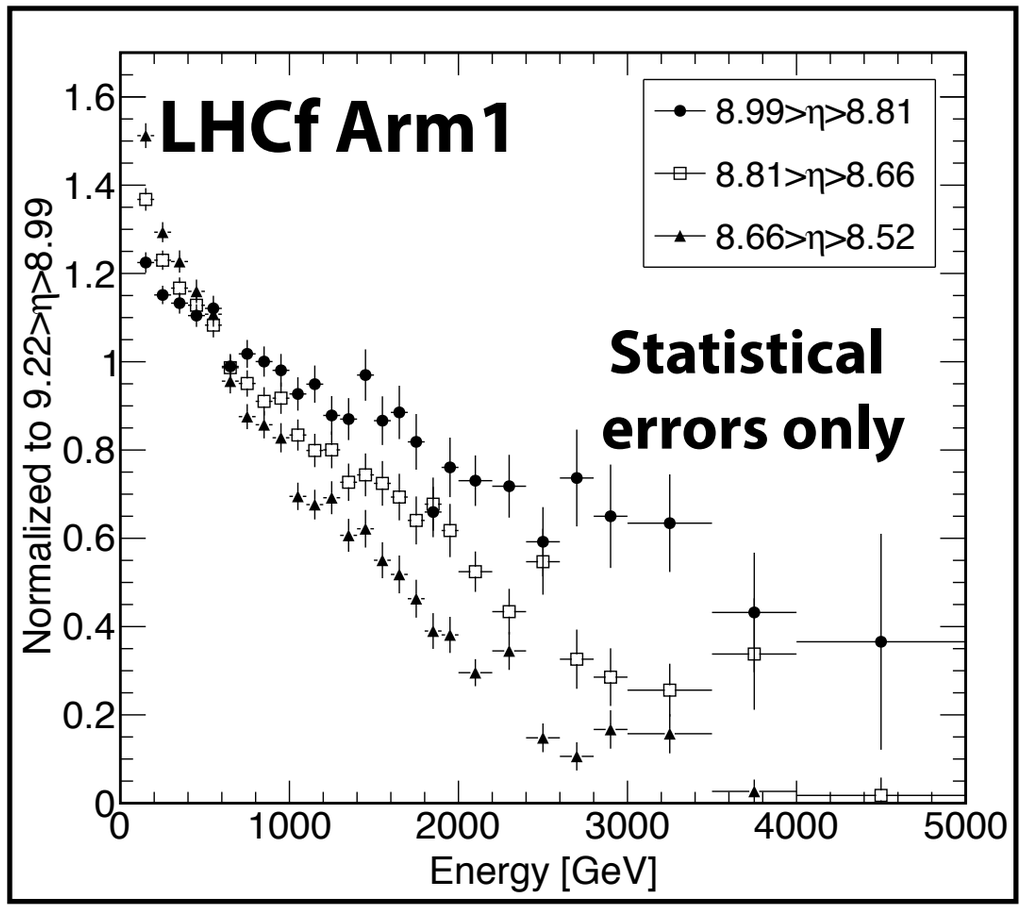


η dependence of the spectral shapes









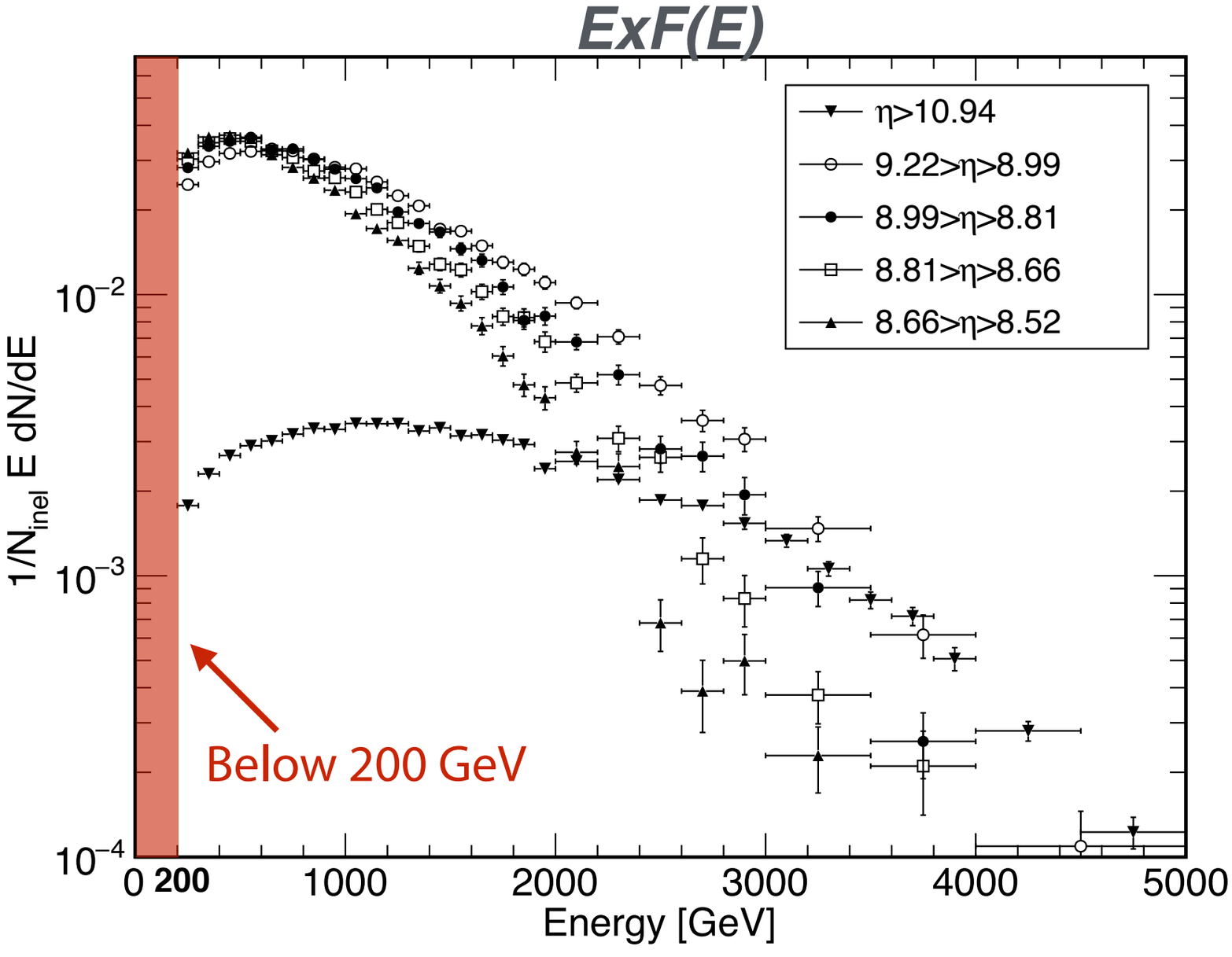
- Observed result shows the largest η dependence
  - MC shows small dependence in higher energy regions
  - Contribution of semi-hard process??
- Particular feature of SIBYLL2.3 is disfavored

Photon energy flow calculation

Energy flow (dE/dη) is calculated by using the obtained inclusive photon spectra,

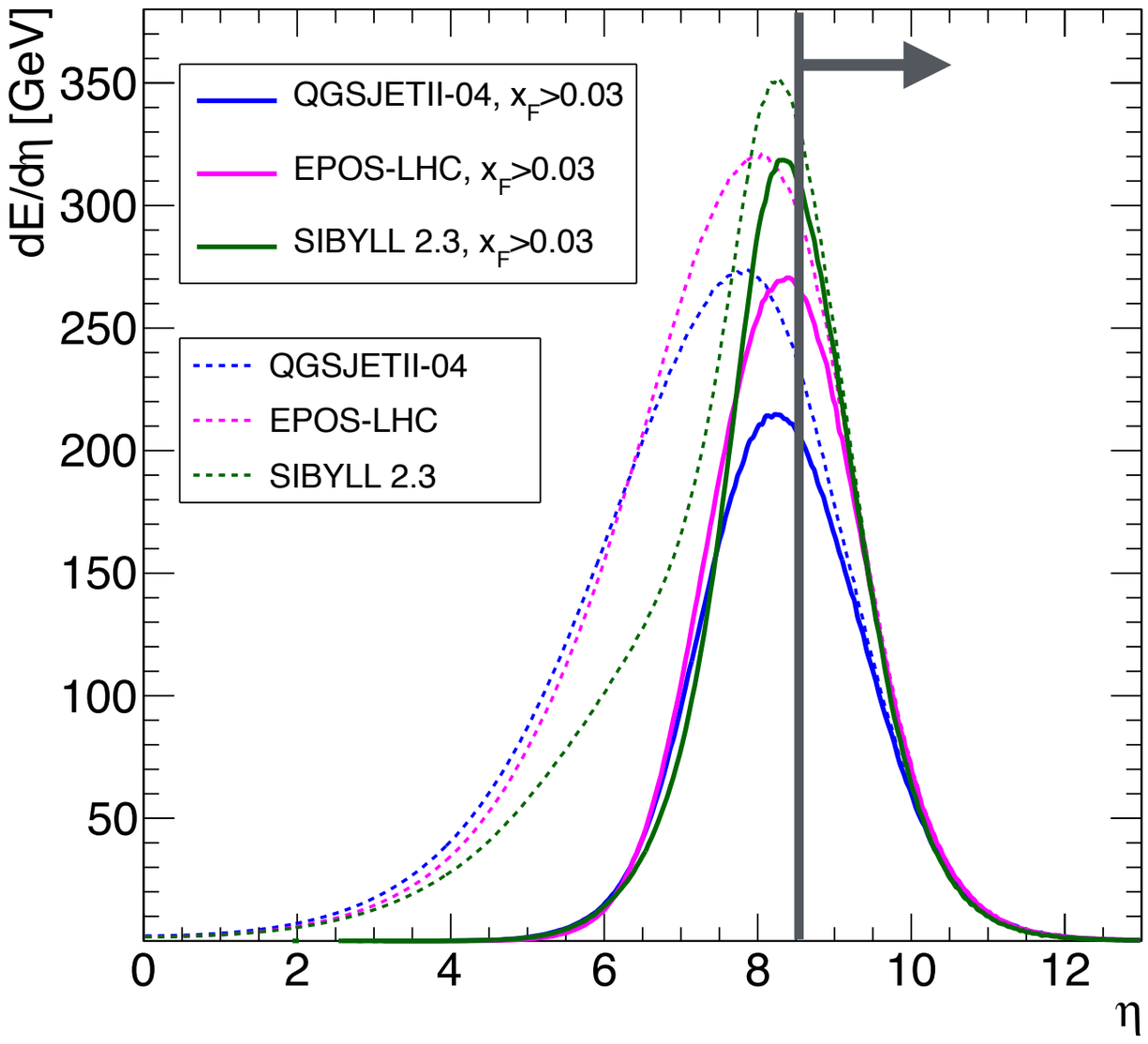
$$Y_i = \frac{1}{\Delta\eta} \sum_j E_j \; F(E_j) \; w_j$$

i : i-th η region, j : bin number, w_j : bin width, $F(E_j)$: ⊿φ acceptance-corrected energy spectrum



- Contribution from low energy is important for energy flow
  - Largest contribution from the energy around 600 GeV in 8.52>η>9.22
  - Spectral shape at higher energy does not effect the flow
- Threshold at 200 GeV

Low energy contribution and correction

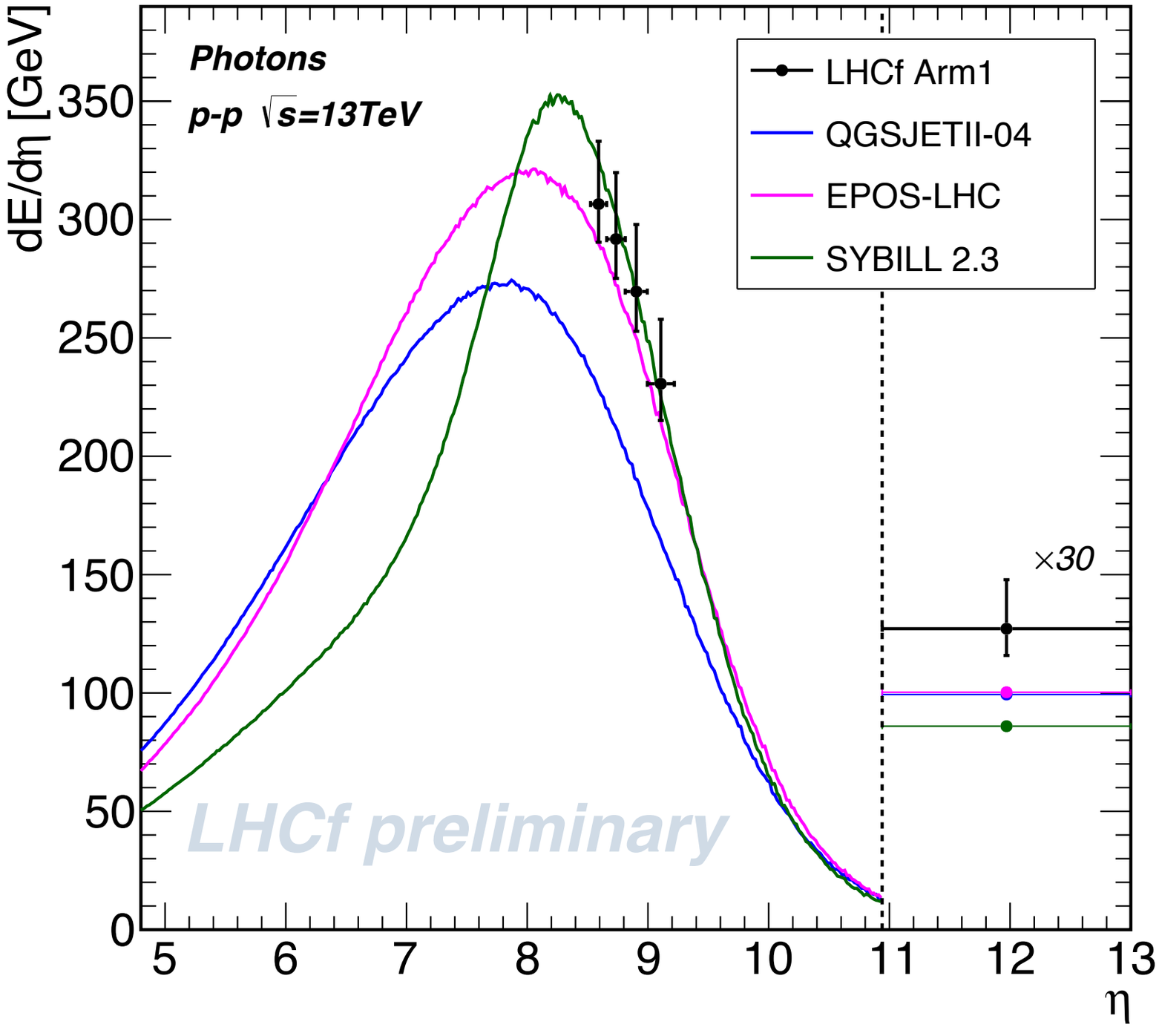


Fractions [%] of energy flow with >200GeV photons to the total

η range	QGSJETII-04	EPOS-LHC	SIBYLL2.3
η >10.94	98.1	98.0	96.4
9.22> η >8.99	93.9	95.0	96.4
8.99> η >8.81	92.2	93.7	95.5
8.81> η >8.66	90.5	92.3	94.6
8.66> η >8.52	88.8	90.7	93.6

- **Basically contribution from <200GeV photons are small**
- **Model-dependent correction**
  - Average values among the models are used as the correction factors
- Bracketed band by the model predictions are used as the uncertainty of the low-energy correction

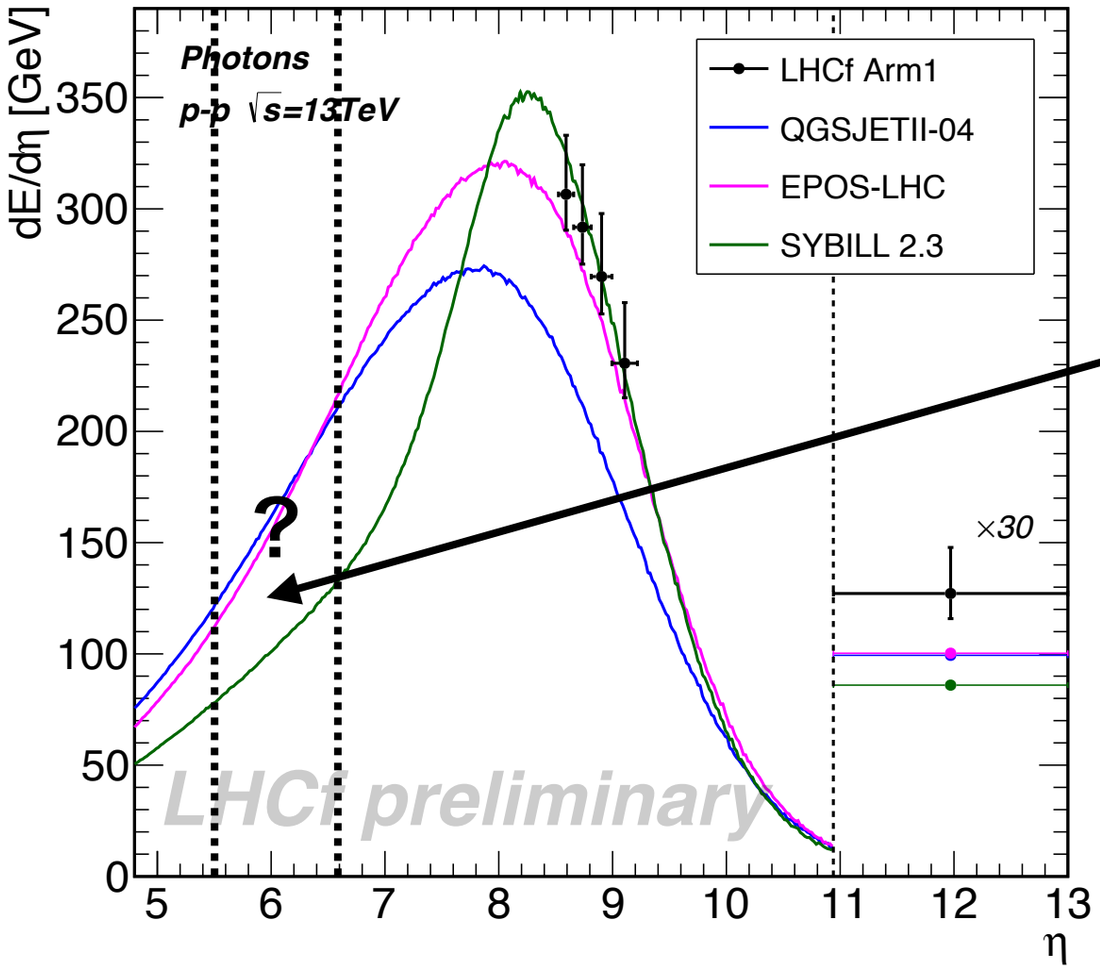
η-dependence of the photon energy flow

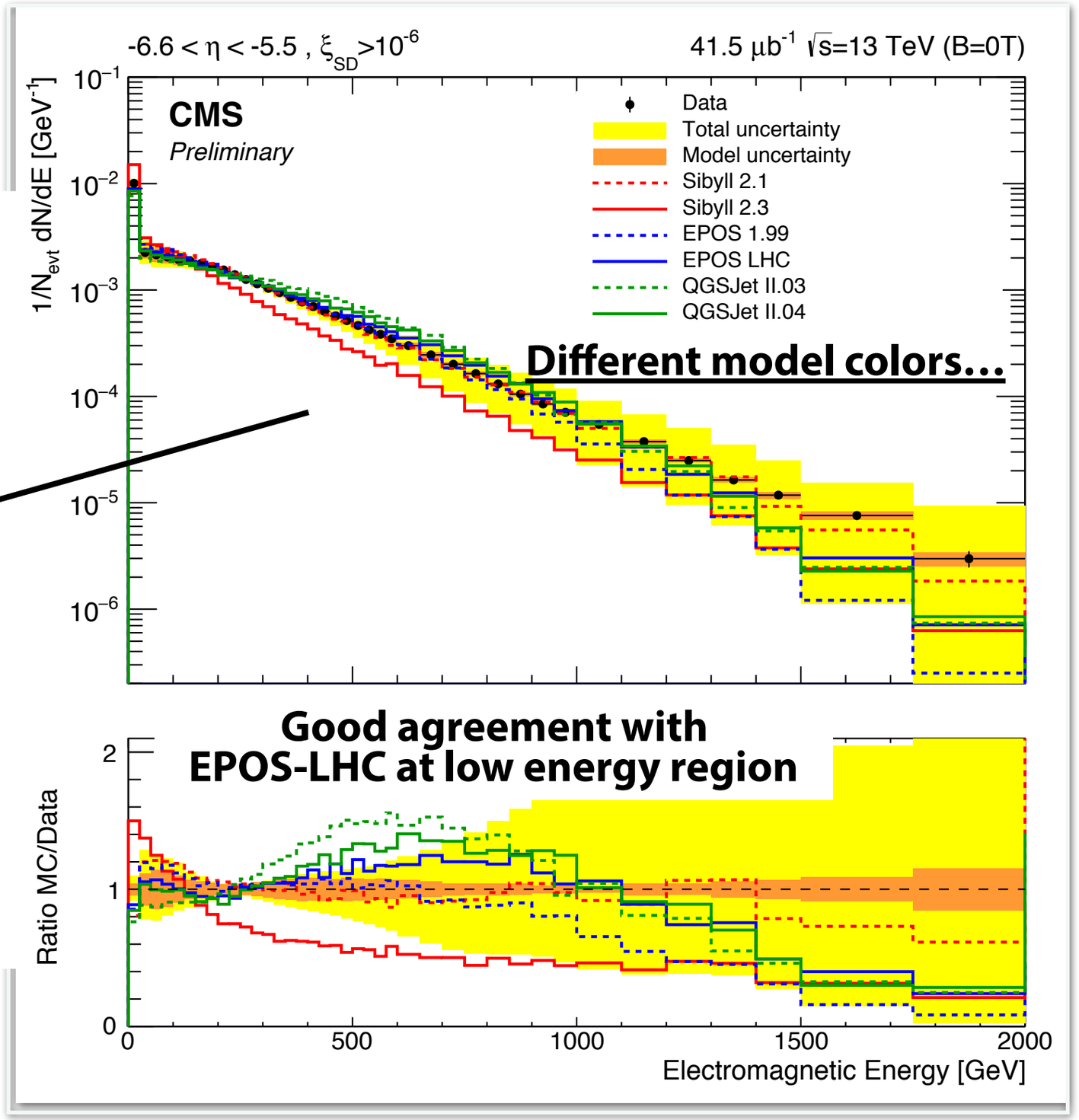


- Around peak, 9.22>η>8.52
  - **EPOS-LHC**, **SIBYLL2.3** agree with LHCf
  - **QGSJETII-04** predicts 30% smaller flow
- Zero-degree, η>10.94
  - No model reproduce LHCf
  - Influence seems small

Electromagnetic energy spectrum by CASTOR

CMS PAS FQS-16-002





Summary 1/2

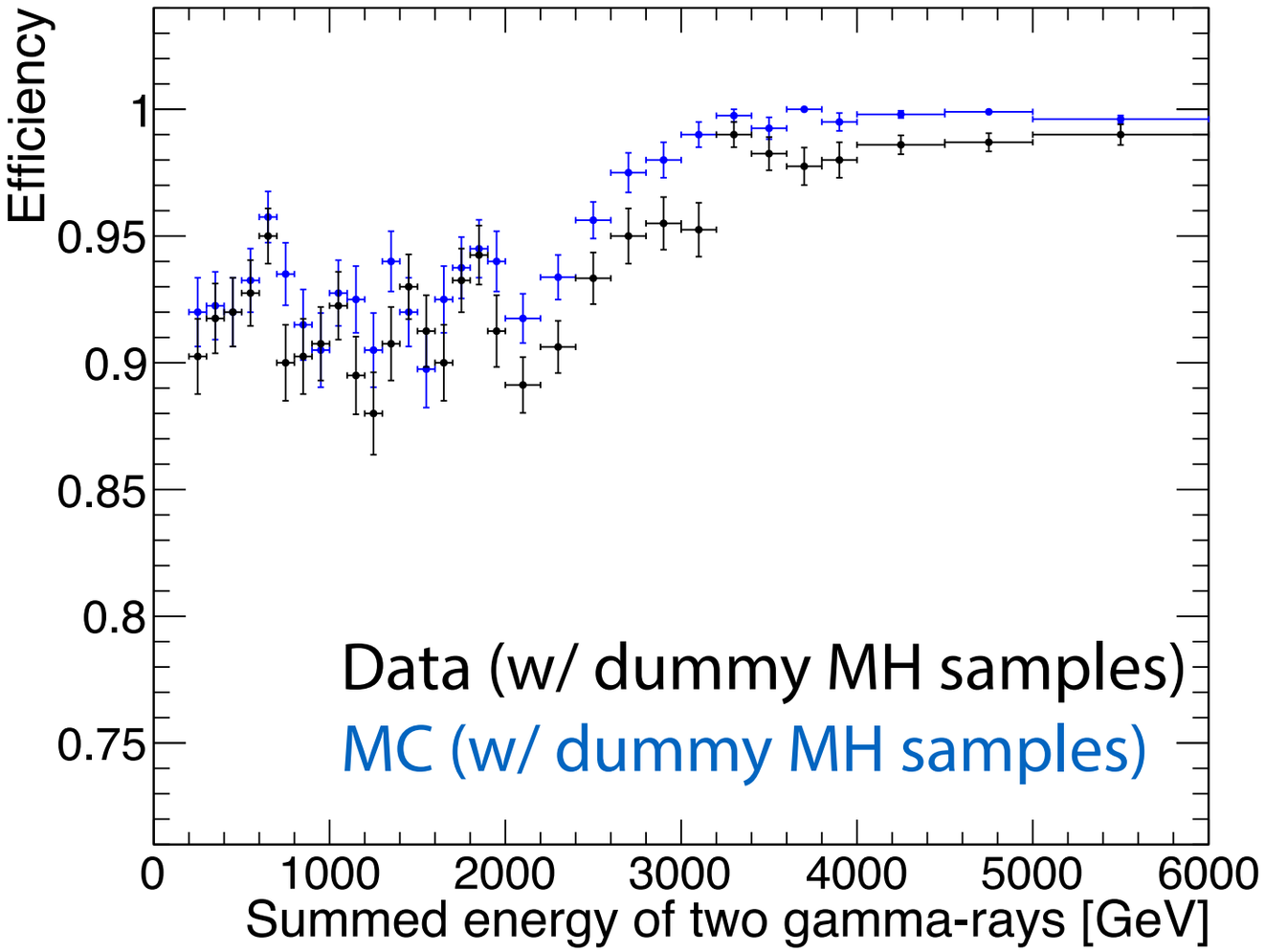
- **Inclusive photon spectra at η>10.94 and 8.99>η>8.81**
  - Our first √s=13 TeV result!!!
  - Unfolded technique is introduced in photon analysis
  - Arm1-Arm2 combined results
  - Systematic uncertainties
    - Energy scale and unfolding dominate the uncertainty
    - Uncertainty arising from luminosity (1.9%) is also taken into account
- Comparison with interaction models including “post-LHC”
  - Even post-LHC models (EPOS-LHC, QGSJETII-04, and SIBYLL2.3) cannot reproduce LHCf results
  - …But, EPOS-LHC seems better among the models
  - Diffractive / non-diffractive separation could be helpful for model improvements
- Submitted to PLB in last month

Summary 2/2

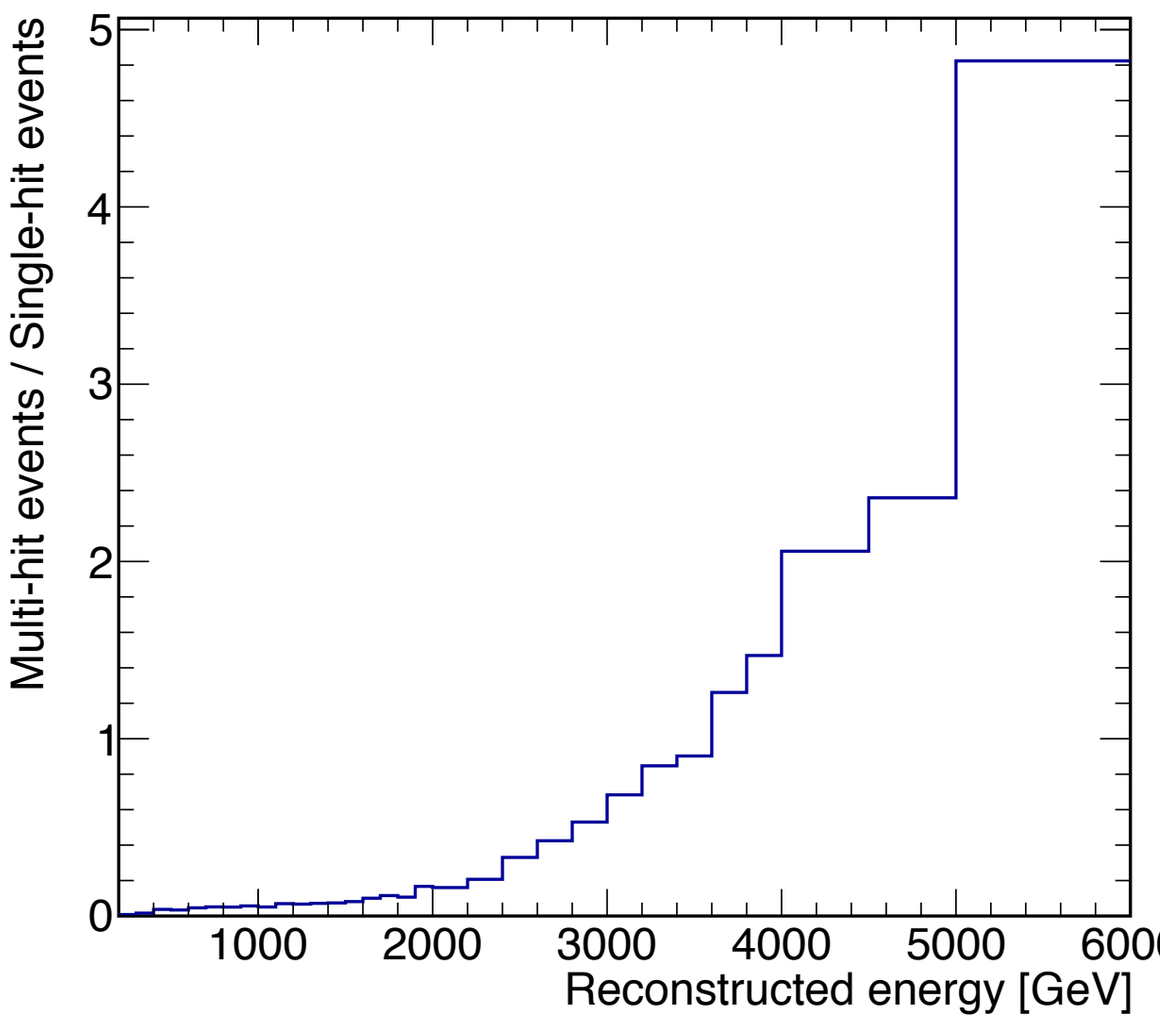
- **Analysis at 9.22>η>8.99, 8.81>η>8.66, and 8.66>η>8.52 with only Arm1**
  - Energy spectrum analysis
    - η-dependence of SIBYLL2.3 is disfavored by our result
  - Energy flow analysis
    - First attempt for photon analysis
    - 30% smaller flow by QGSJETII-04
    - EPOS-LHC and SIBYLL2.3 are good agreement with Arm1
      - (But SIBYLL2.3 is disfavored from the point view of spectral shape)
- **Regarding to the photon production within LHCf acceptance, EPOS-LHC is the best**
- **What are remained for further photon analysis?**
  - Diffraction/non-diffractive energy spectra? => on going
  - Full acceptance photon analysis?
  - or π0 analysis?

Multi-hit detection efficiencies

Data/MCのMulti-hit検出効率

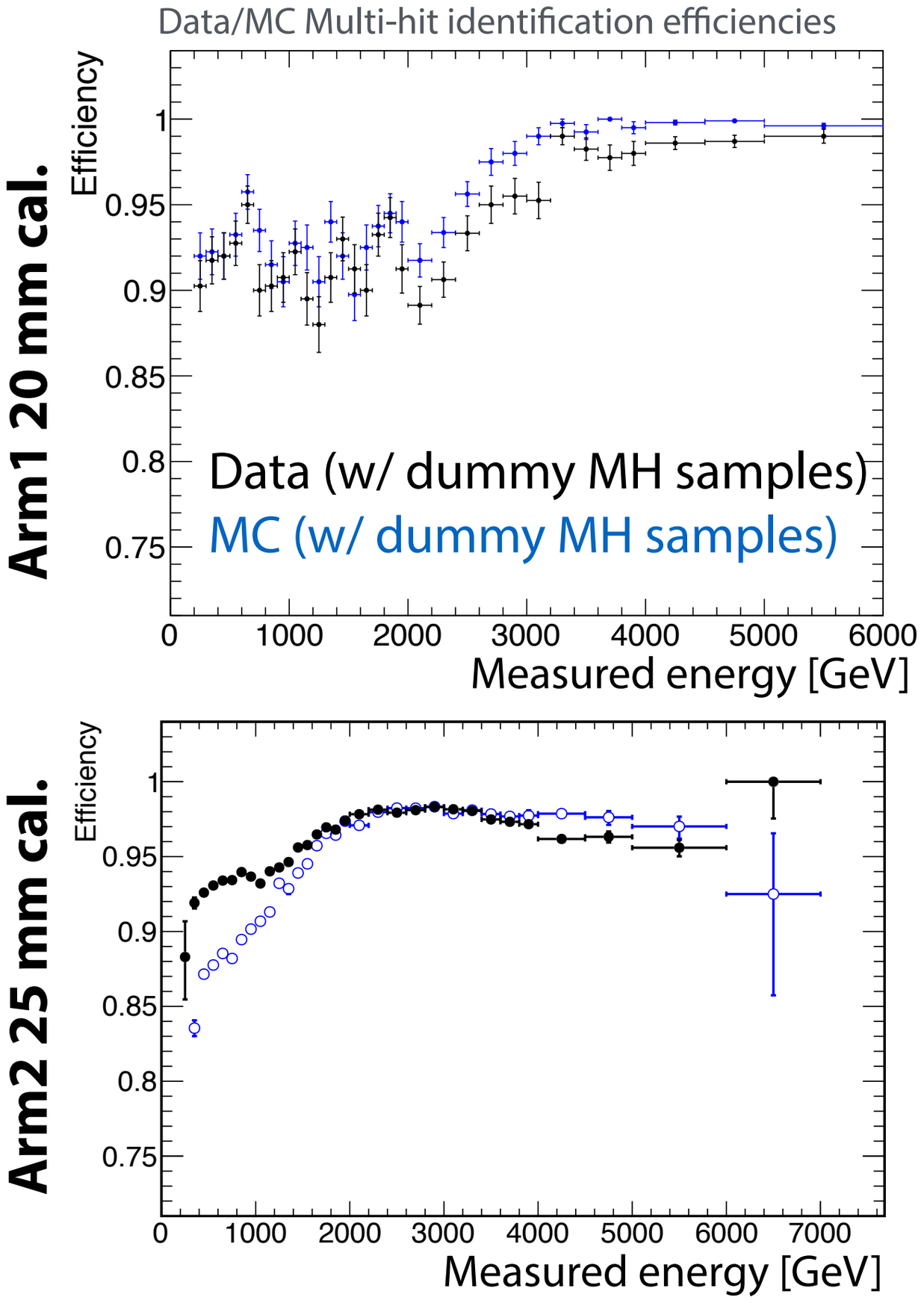


Multi-hit判定/Single-hit判定



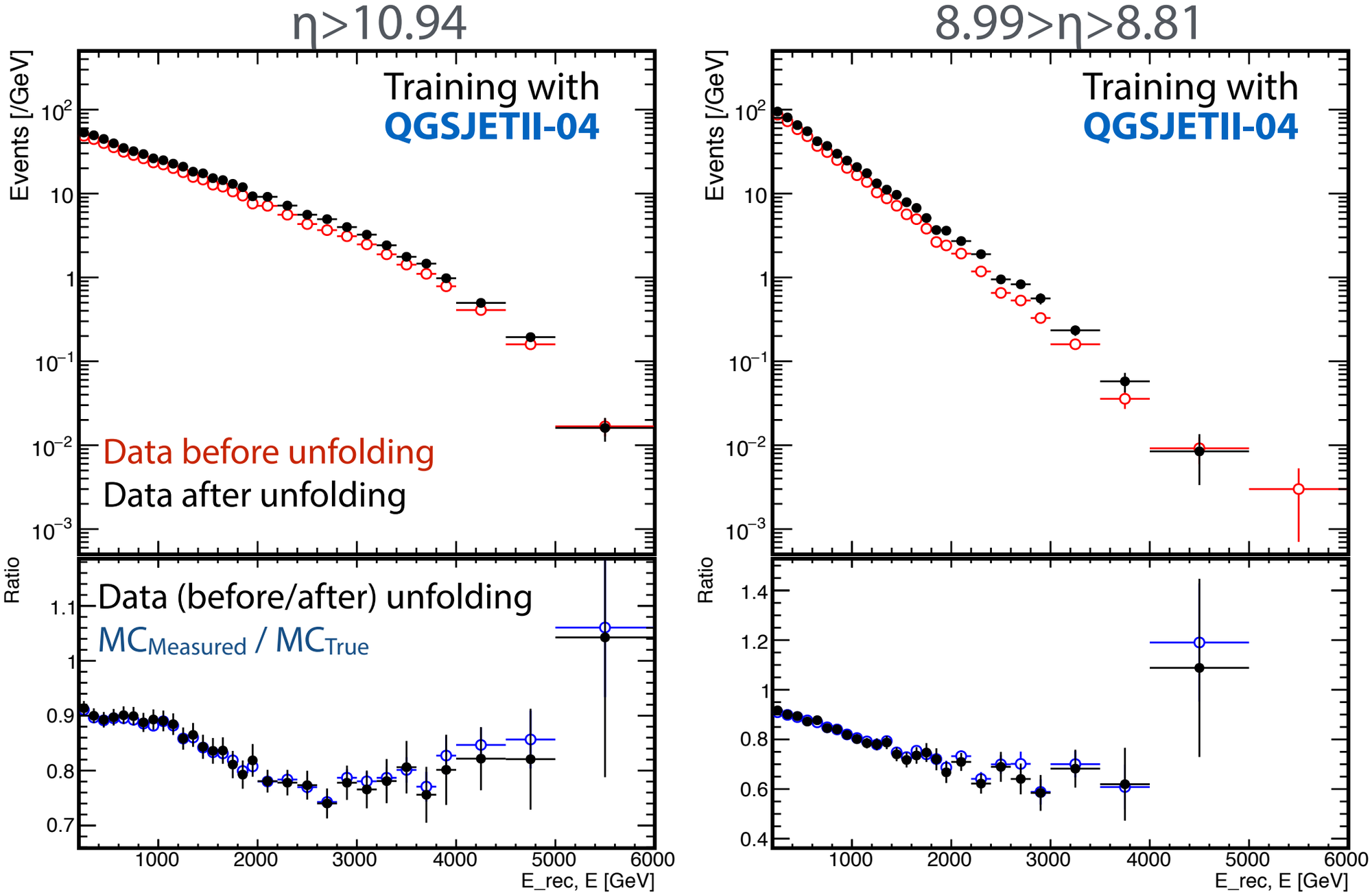
- 85%以上の検出効率を達成
- 高エネルギーになると検出効率が改善 (π^0イベントの割合増加による)
- DataとMCの検出効率は4 %以内で一致
  - Multi-hit選別の系統誤差として考慮
  - スペクトルへの影響は各エネルギーでのMulti-hitの割合も考慮して、およそ2000GeVで<1%, 3% @ 3000GeV

Multi-hit identification



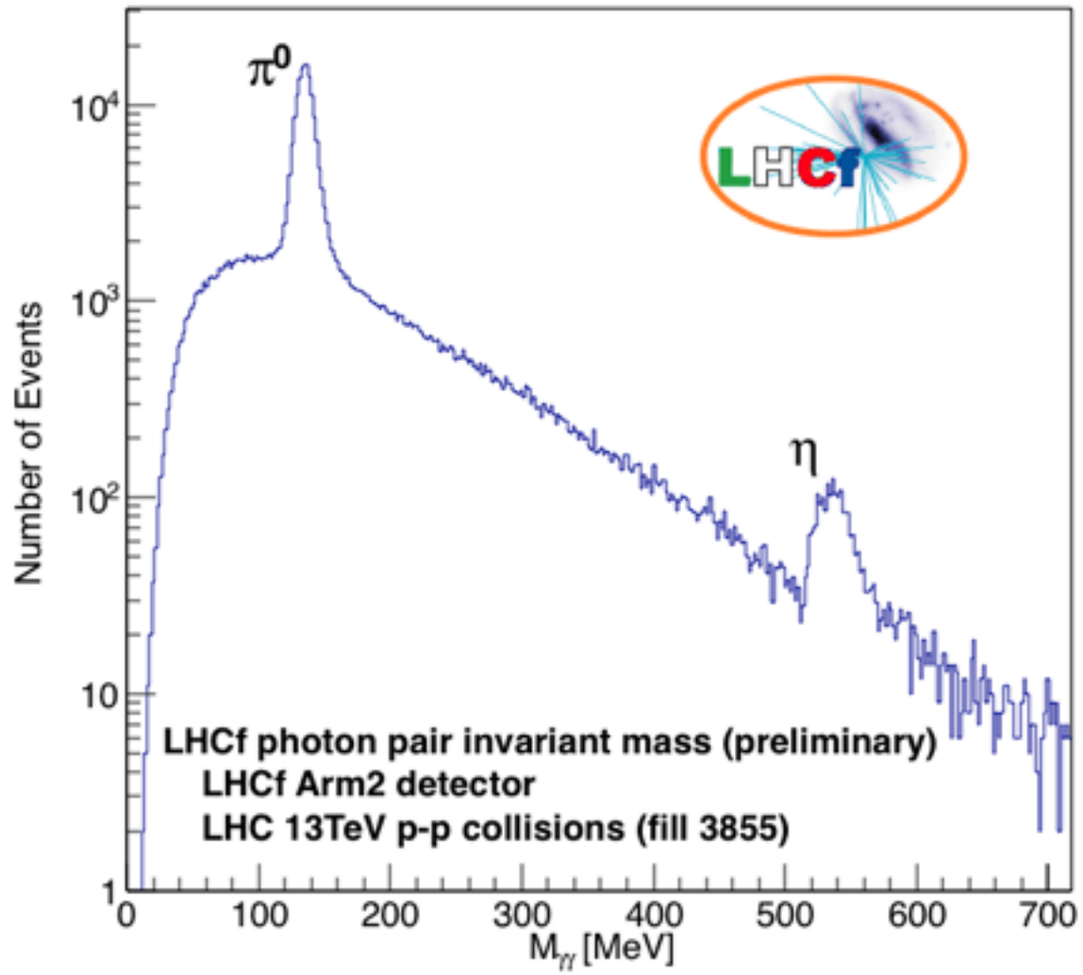
- Multi-hit efficiency above ~85% with "artificial" multi-hit event samples
- Good efficiency in high energy
  - pi0 events dominate the multi-hit events
  - pi0 events (type-II) are easy to be identified due to the opening angle
- Agreement between data and MC within 4 %
  - Considered as systematics of multi-hit selection
  - Systematics are calculated by multiplying observed fraction of MH to the difference of efficiencies
    - Resulting in <1% at 2 TeV, 3 % at 3 TeV

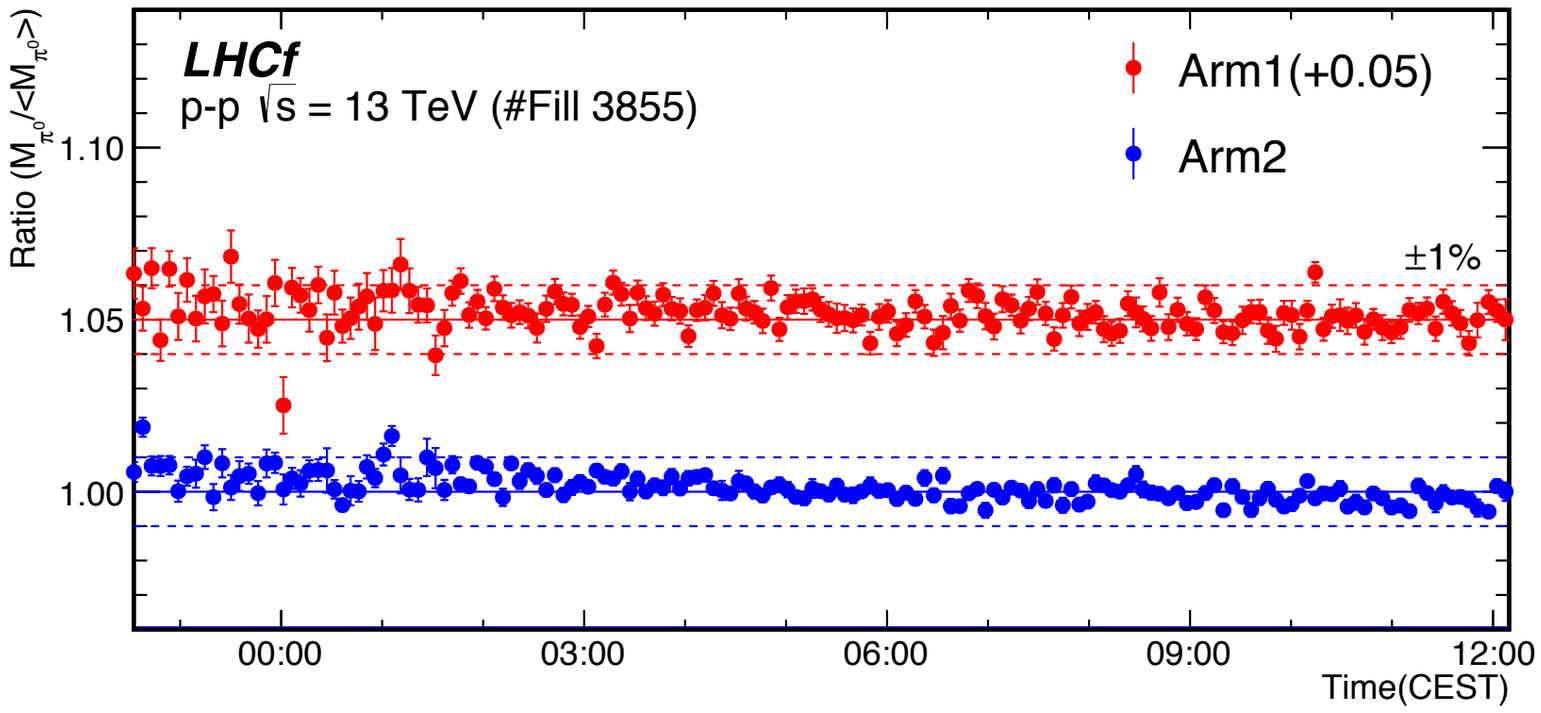
Unfolding


η>10.94
8.99>η>8.81
Training with
QGSJETII-04
Events [/GeV]
Data before unfolding
Data after unfolding
Ratio
Data (before/after) unfolding
MC_Measured / MC_True
E_rec, E [GeV]

Official performance plots from Fill 3855

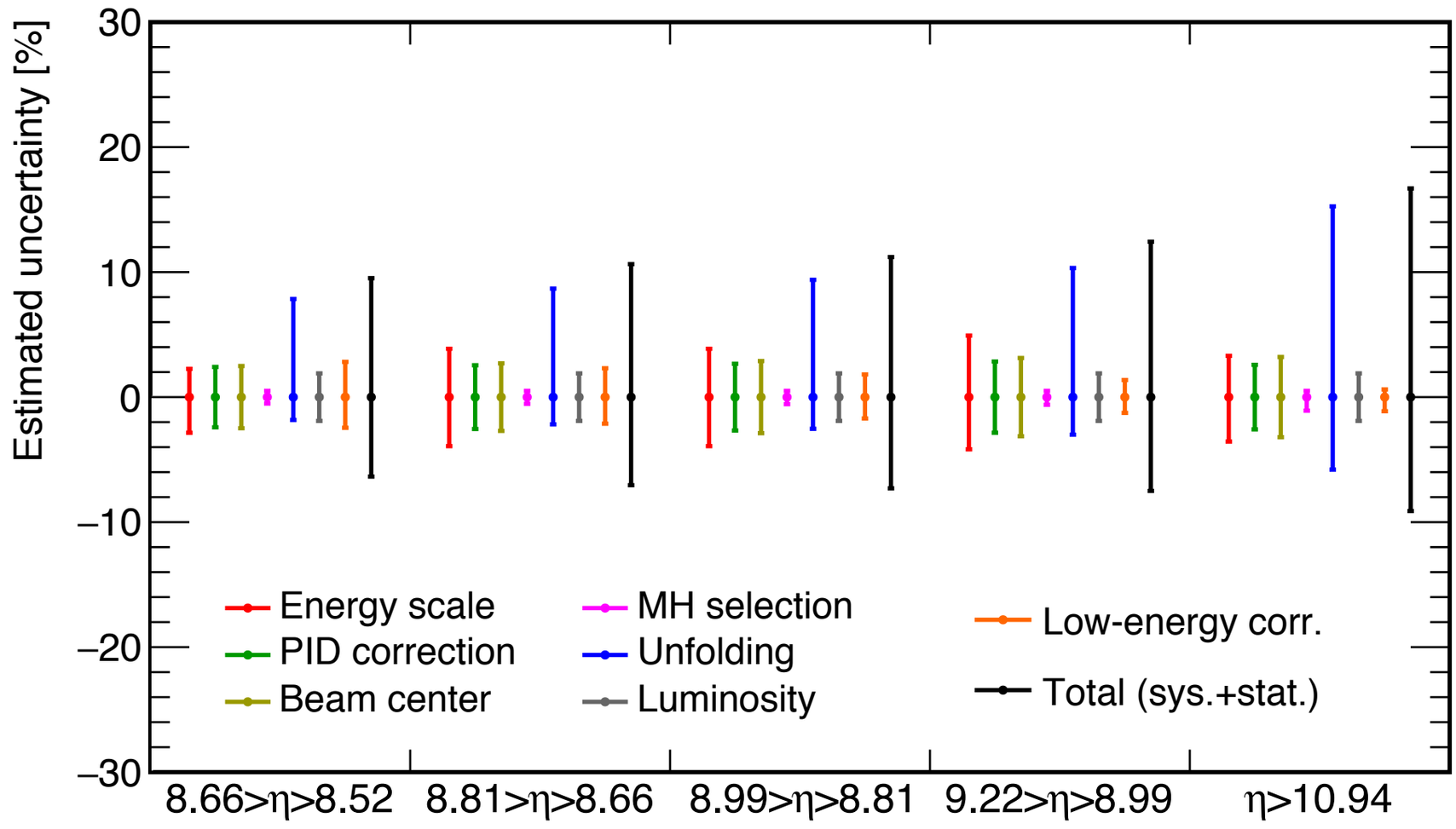
- Clear pi0 peak, and even η in 13 TeV data



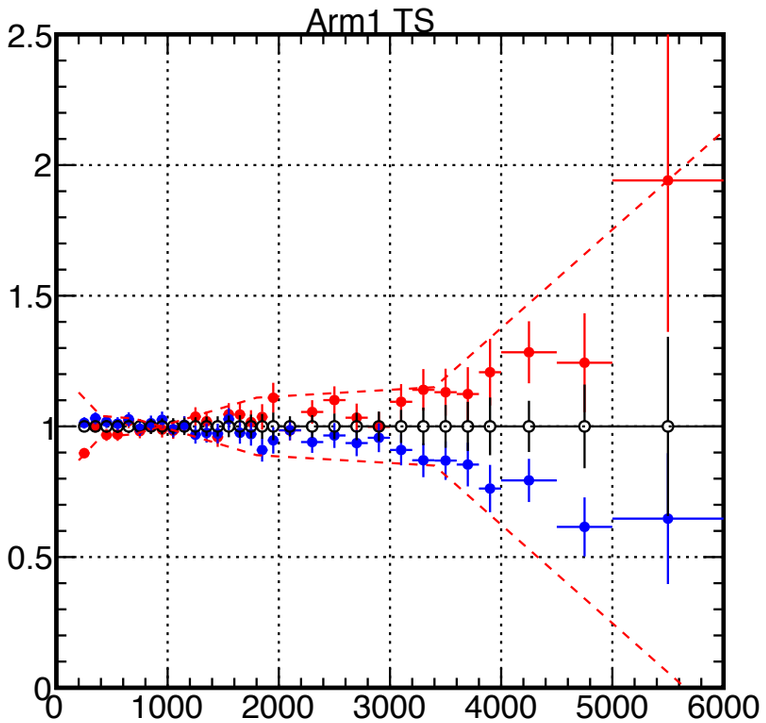


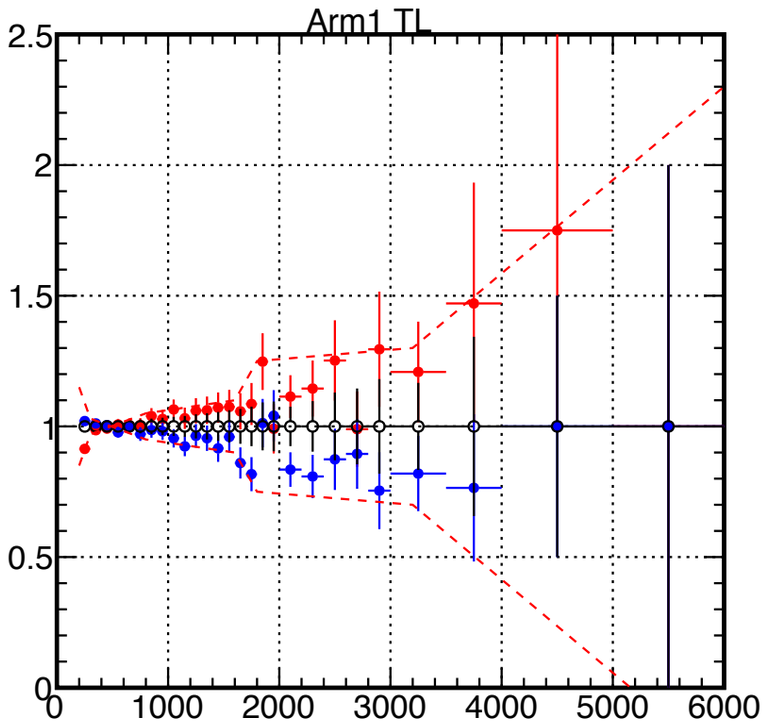
- Variation of pi0 peak
  - Within ±1 % during Fill 3855
  - Our measurement (Arm1/Arm2) was stable for the photon dataset

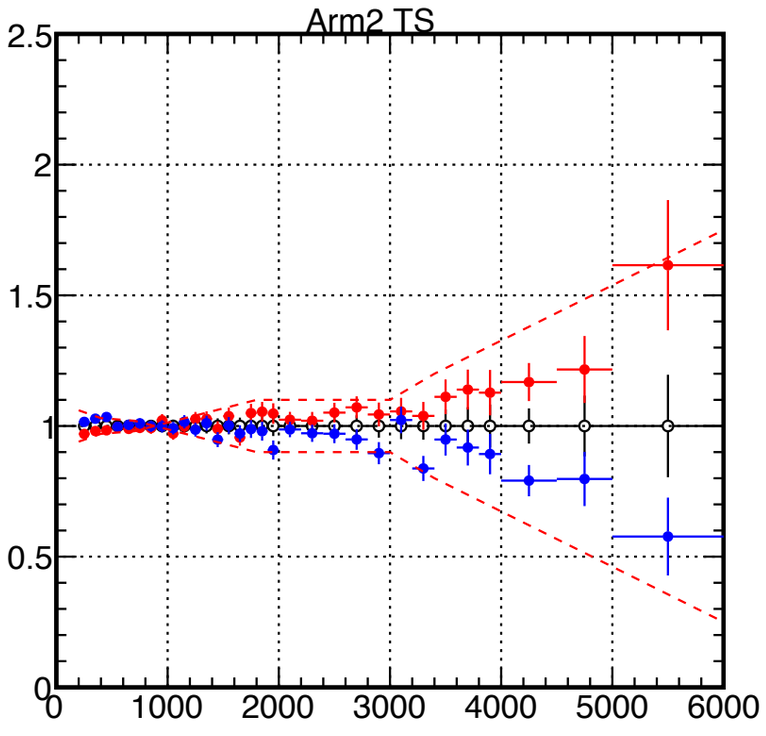
Systematic uncertainties of the energy flow measurement

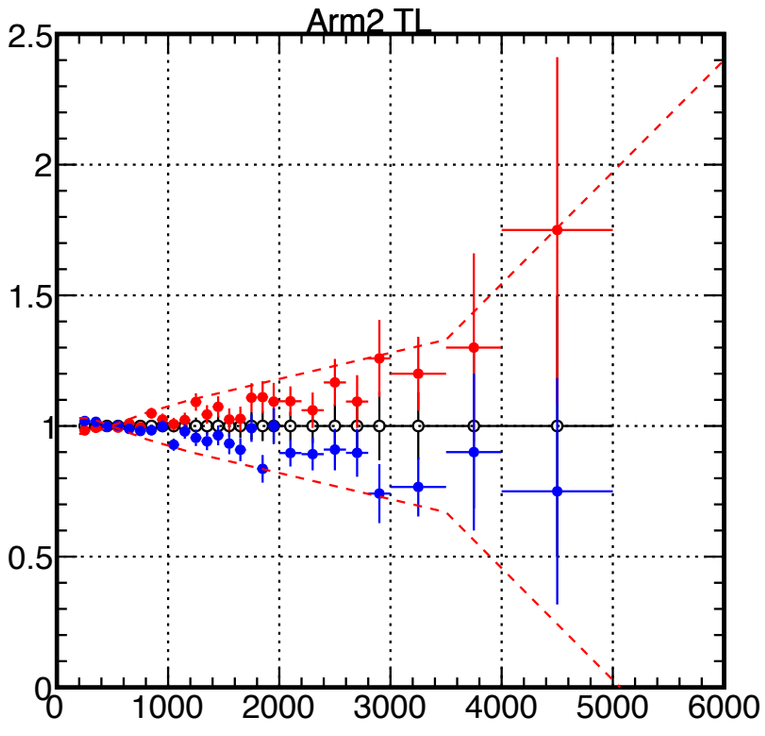


Systematics / Energy scale



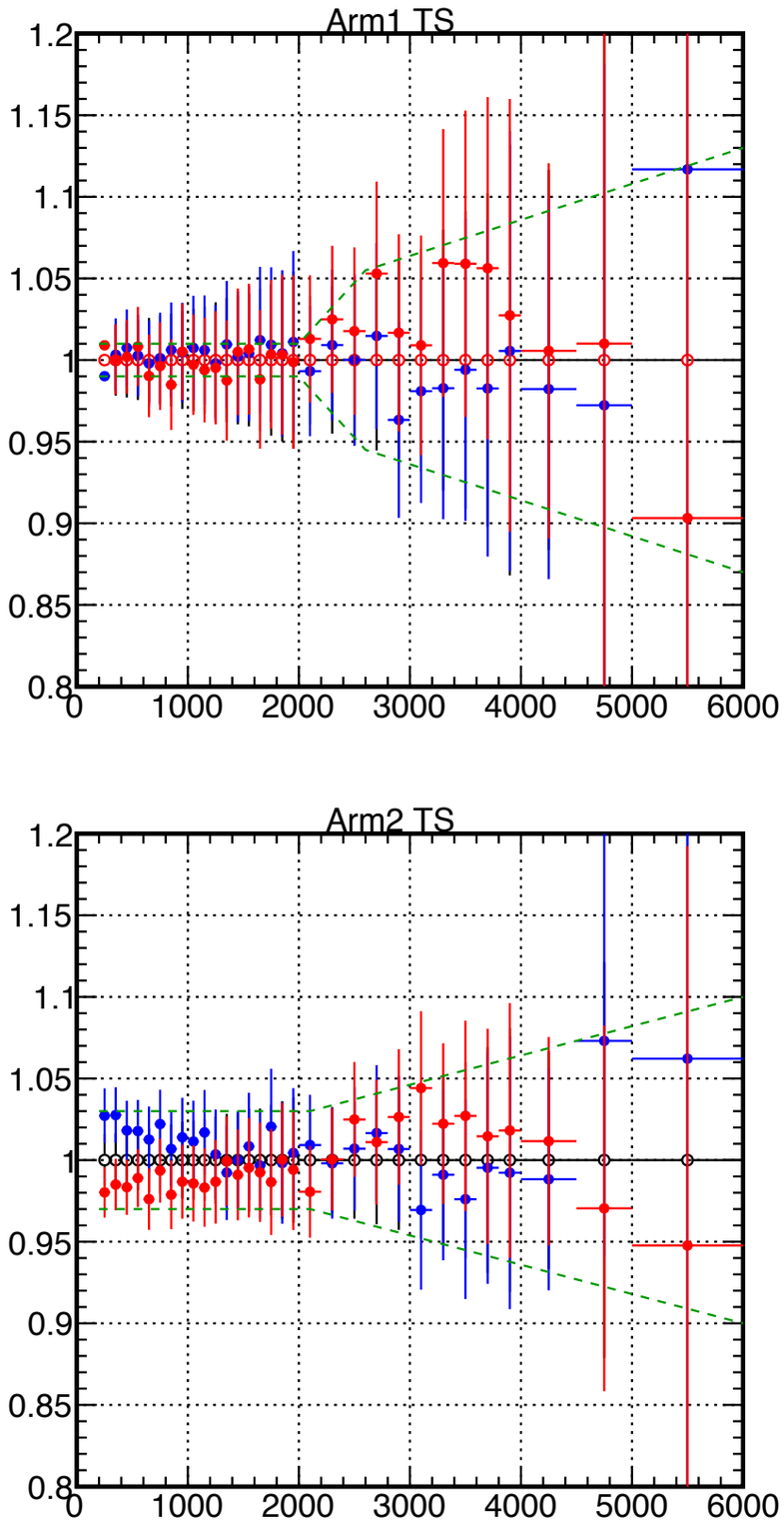






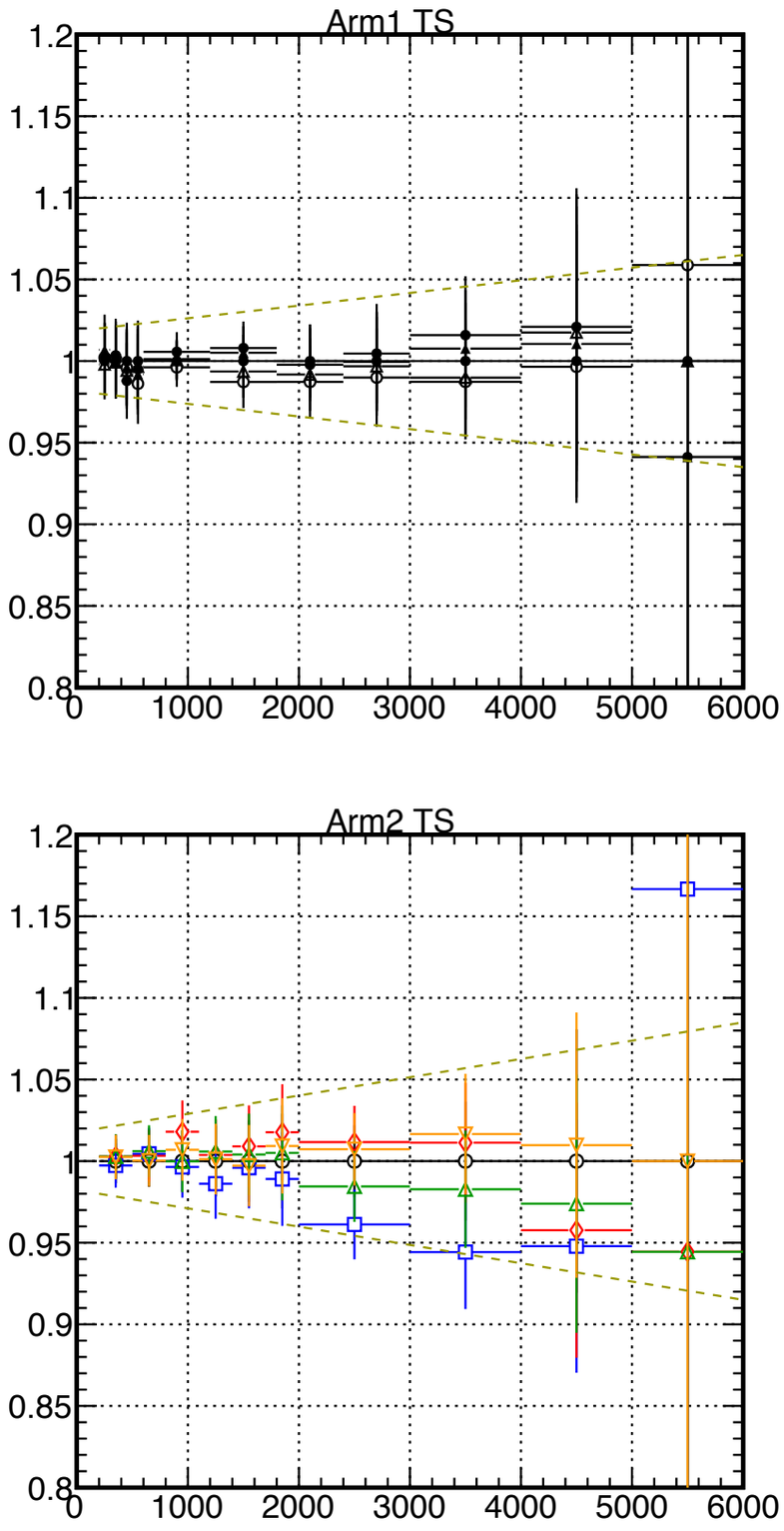
- Estimated by the spectra with ±3.4%-shifted energy scales for Arm1
  - 3.4% is based on the SPS test
  - Consistent with pi0 mass shift seen in the LHC (-3.5% for Arm1 & -1.6% for Arm2)
- One of the largest contribution
- (Lines are crossing at low energy)

Systematics / PID correction



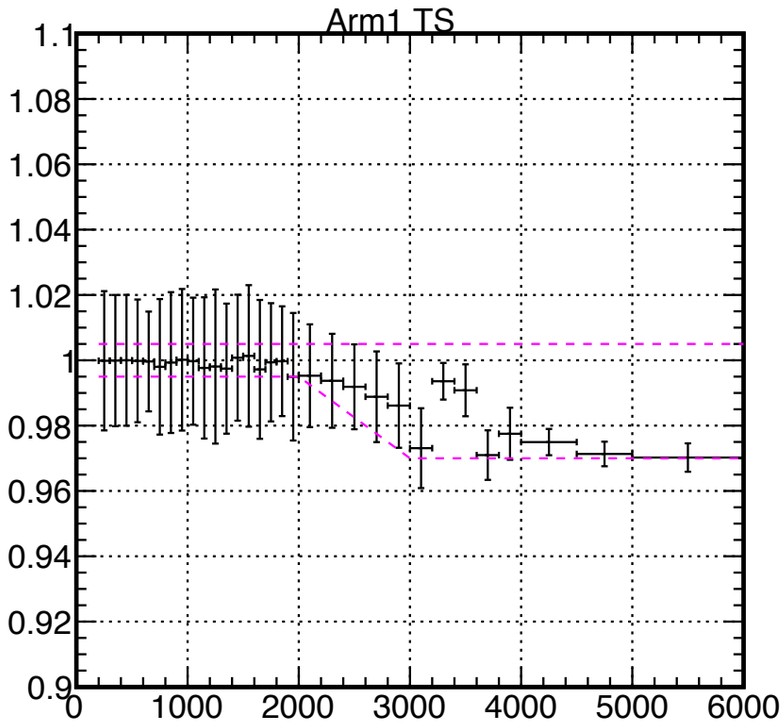
- PID cut and the correction with satisfying efficiencies of 85% and 95% instead of the standard 90%

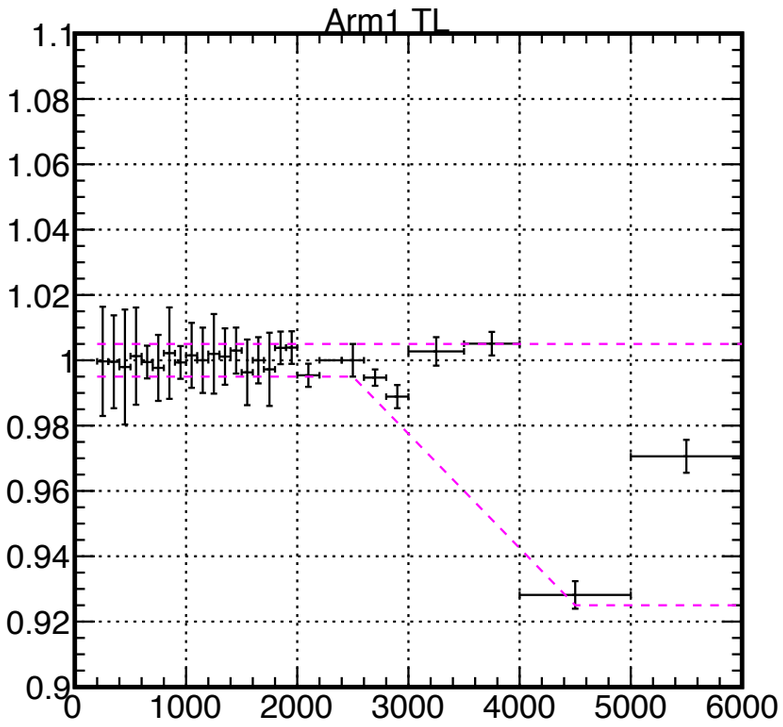
Systematics / Beam position

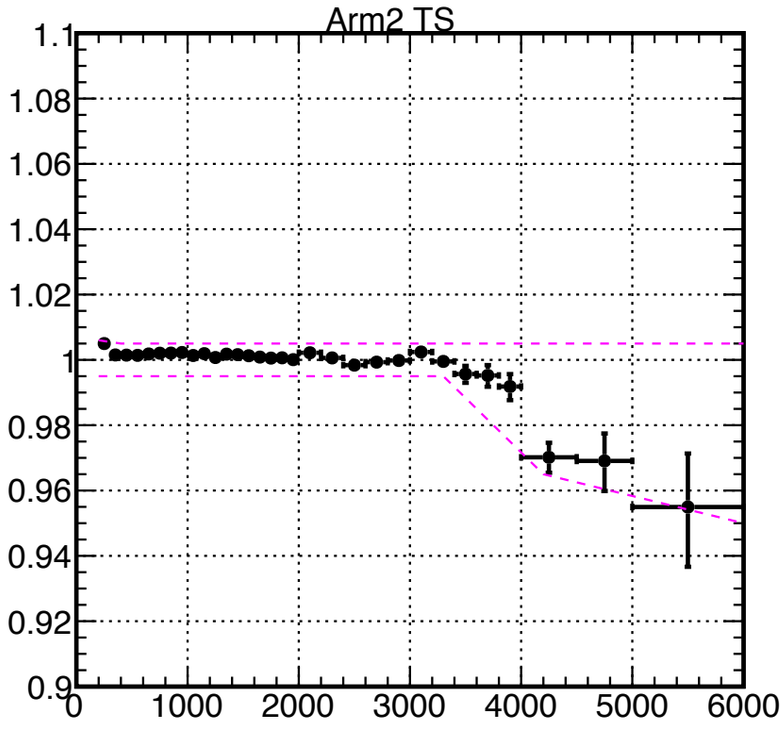


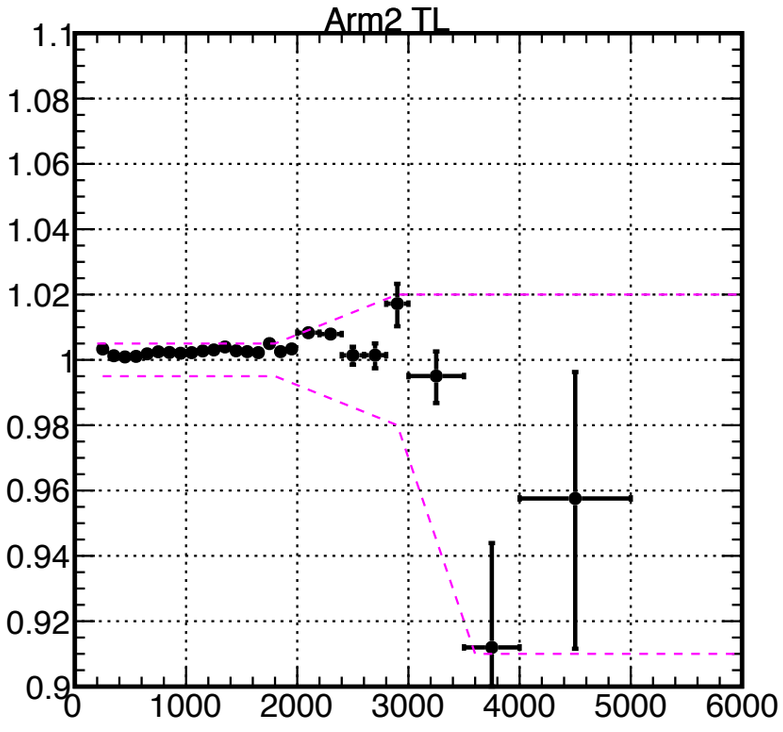
- Calculated by the four spectra having ±0.3mm shifted beam center in x/y

Systematics / MH selection



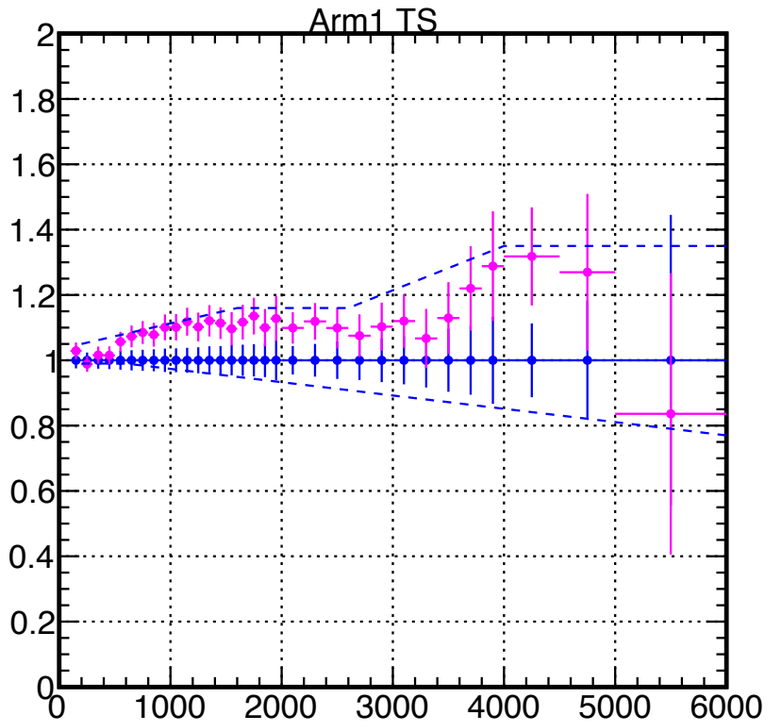


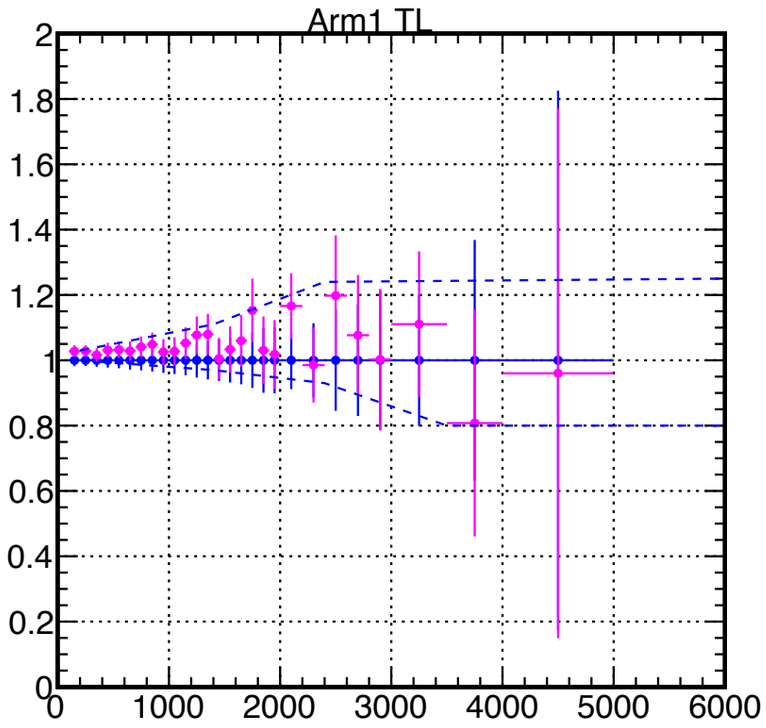


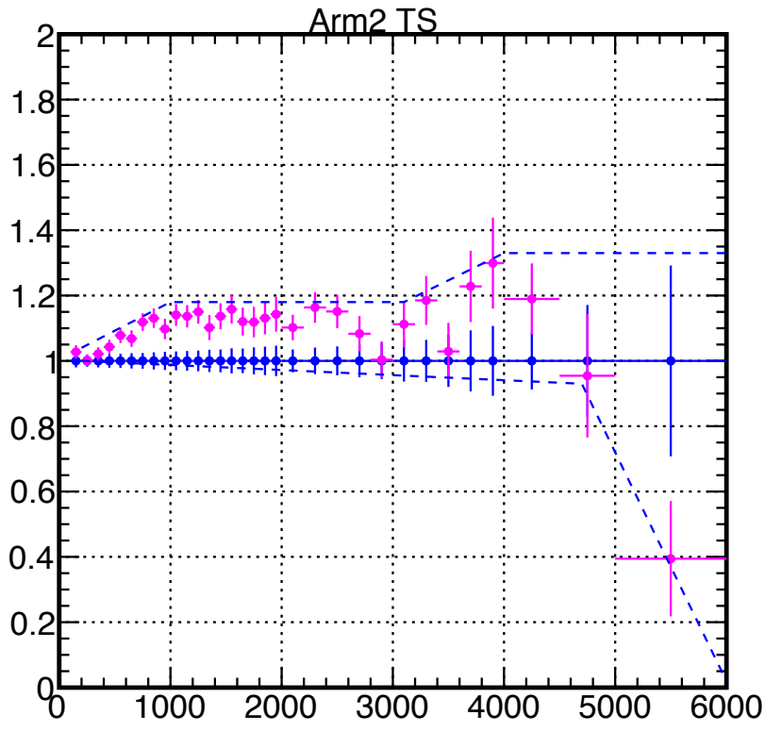


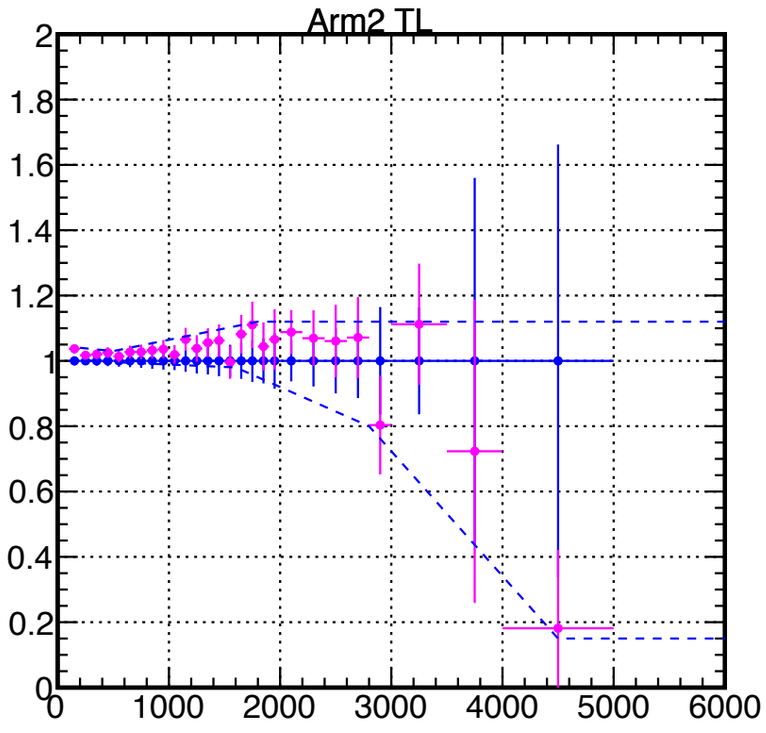
- Calculated from the difference of the multi-hit detection efficiency of data and MC with tanking into account of the fraction of the multi-hit events in each bin
  - MH efficiencies of data and MC with the artificial MH event samples
  - MH fraction derived from the data reconstruction

Systematics / Unfolding (MH correction+Unfolding)





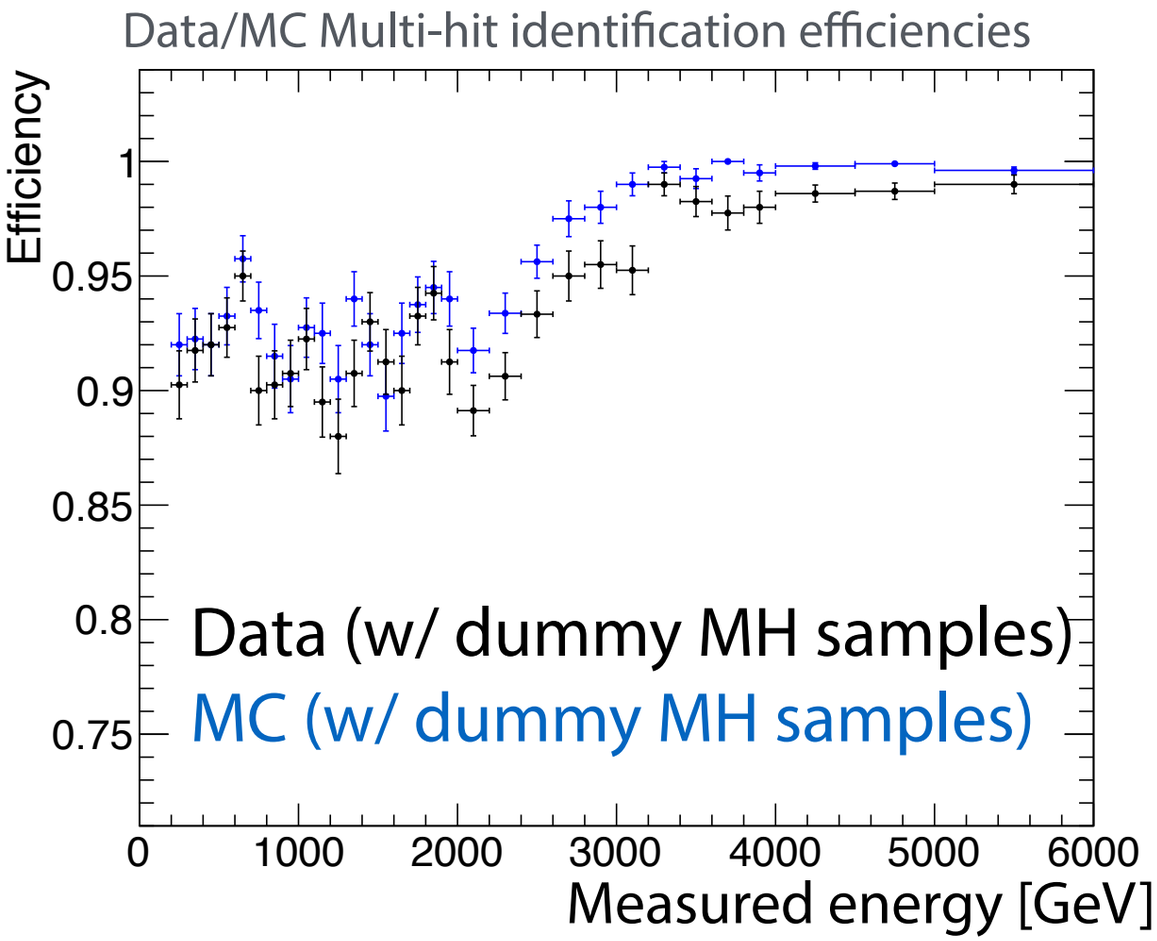


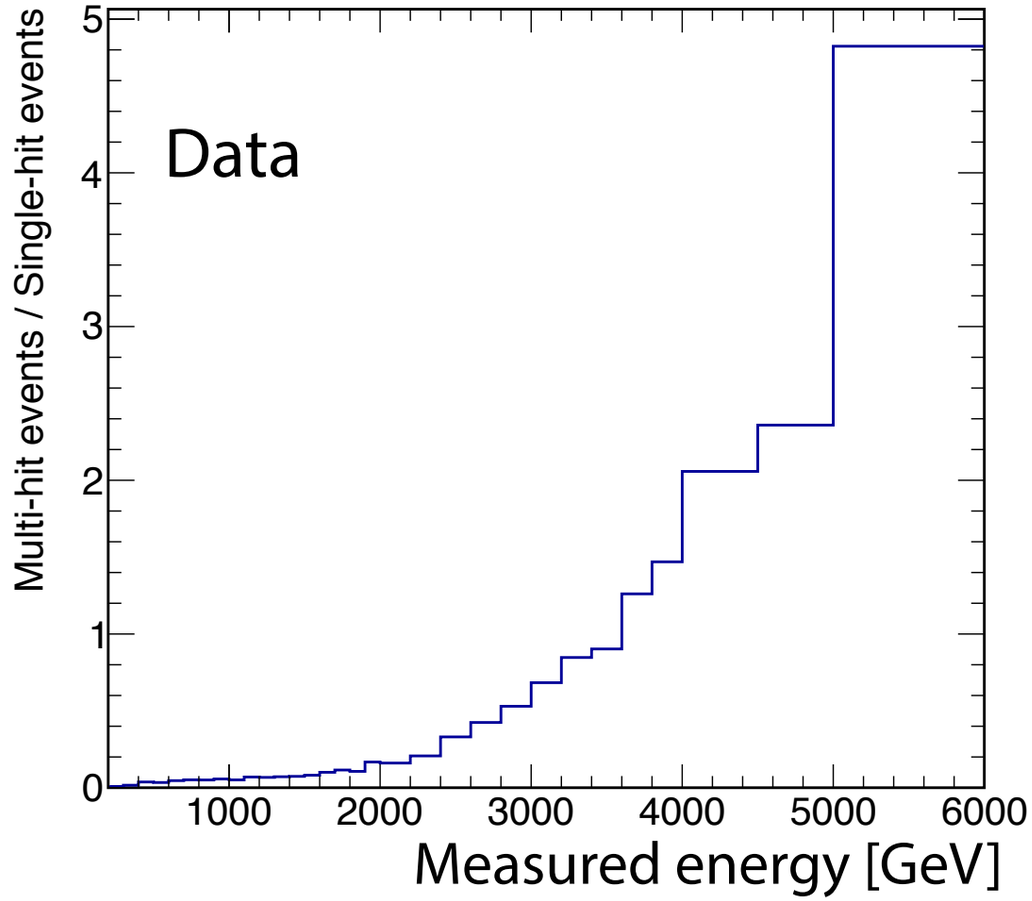


- Estimated from the ratio of the unfolded spectra with EPOS and QGS training
  - This uncertainty includes both unfolding itself and MH correction
- Another large contribution of the uncertainty

Multi-hit identification

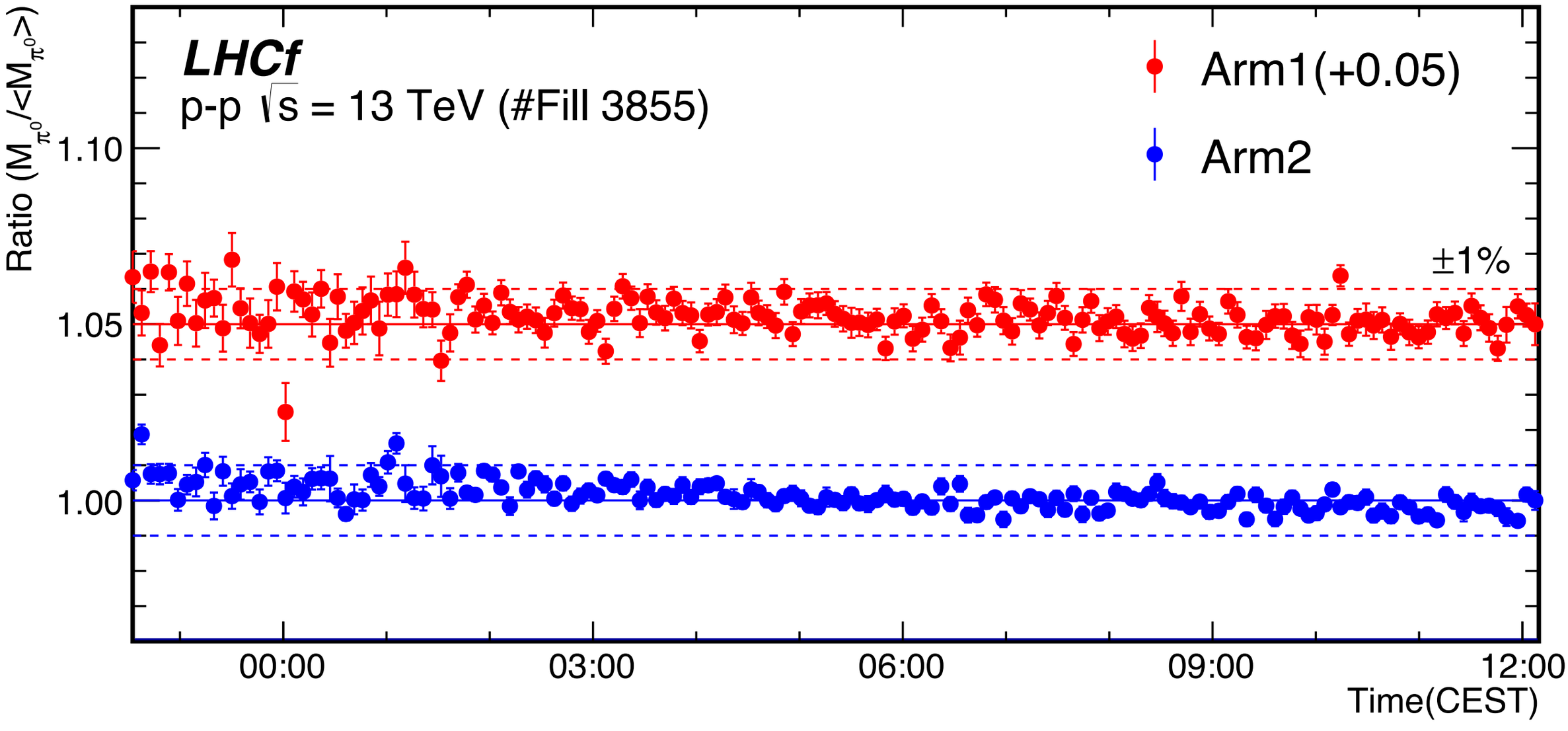
Arm1 20 mm cal.





Arm2 25 mm cal.

Text


LHCf
p-p √s = 13 TeV (#Fill 3855)
Arm1(+0.05)
Arm2
±1%
Ratio (M_π0/<M_π0>)
1.10
1.05
1.00
00:00
03:00
06:00
09:00
12:00
Time(CEST)