Status of
joint analysis with ATLAS

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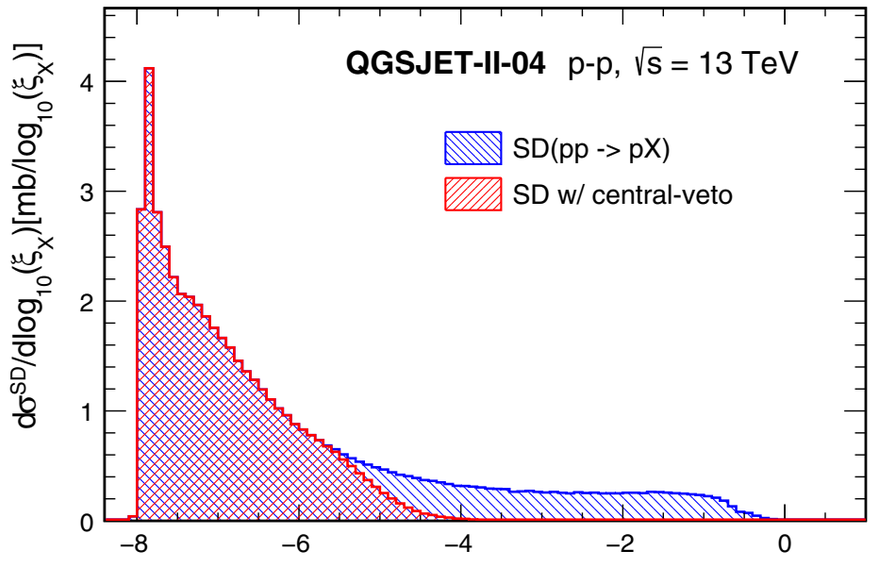
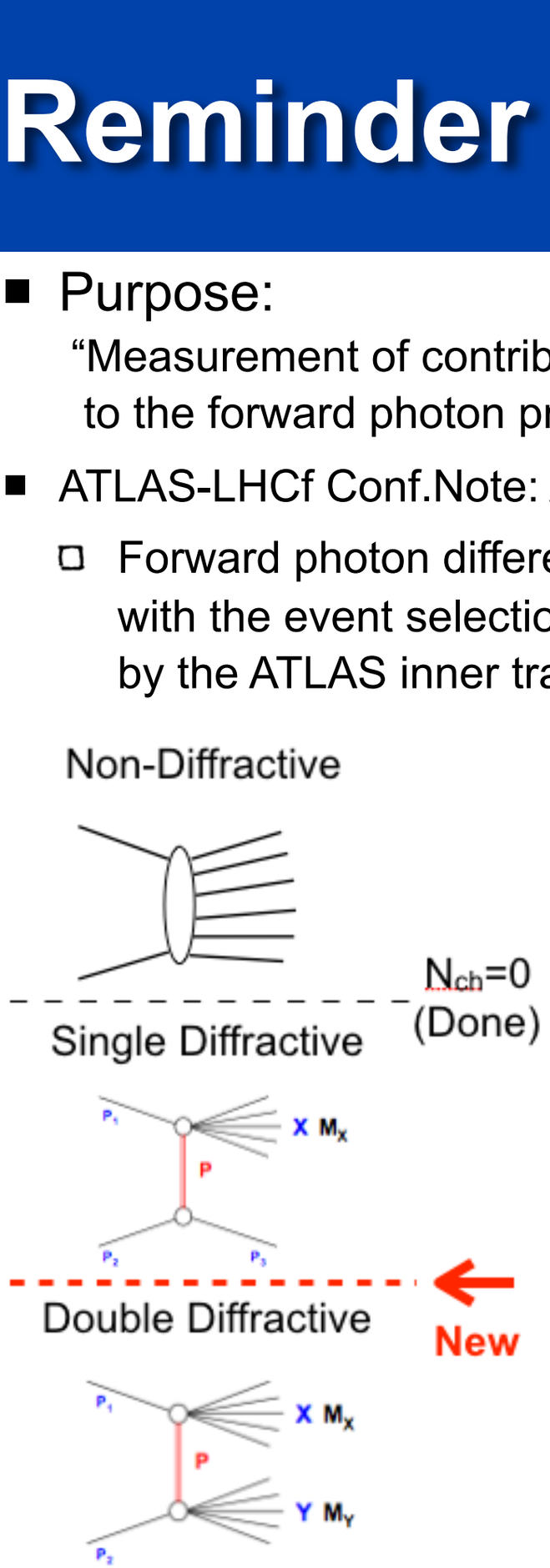
Activities of ATLAS-LHCf joint analysis

- Members of this working group
  - Menjo and Ohashi (LHCf)
  - Leszek Adamczyk (ATLAS)
- Meetings
  - Weekly meeting of the working group (Wed.)
  - Face-to-face meeting at CERN, 25 and 26 Oct.
- Analysis targets
  - Analysis with photon data
    Measurement of diffractive contribution on the very forward photon spectrum
  - Next target is with “neutron data”
    Similar analysis with photon
    + Central track distributions with forward neutron tagging.

Reminder about the photon analysis

- Purpose:
  "Measurement of contributions of diffractive processes to the forward photon production"
- ATLAS-LHCf Conf.Note: ATLAS-CONF-2017-075
  - Forward photon differential cross-section with the event selection by N_{tracks}=0 by the ATLAS inner trackers ($|\eta|<2.5$, $p_T > 100$ MeV)





Two main goals

1. Measurement of forward photon spectra with the N_{ch} = 0 selection (= SD + DD)
   → Mostly achieved in the conf. note
   → Some updates after the note, (C^{CT}, LHCf-Arm2)

2. Measurement of the forward photon production cross-section in low-mass SD(DD) collisions with $\log_{10}\xi < -5.0$
   → Main update after the note.
   → SD(DD) fraction measurement by using MBTS

Current status of the analysis

- Updated the result including the LHCf-Arm2 data.
  - For keeping the consistency with the publish LHCf standalone result for inclusive photon spectra and for increasing the statistics.
- Measurement of the SD(DD) fraction.
  - This measurement done by ATLAS-MBTS data.
  - Changed to the method by using the response function (explain later.). It is only a matter of description.
  - Details will be presented by Ohashi.
- To-do list
  - Additional studies or explanation about MH correction or treatment.
  - Complete the analysis note. It expected around the end of this year.
  - Final checks of the systematic uncertainties, especially, in the SD fraction measurement.
  - Consistency checks with increasing p_T threshold of the charged track detection from 100 MeV to 400 MeV.

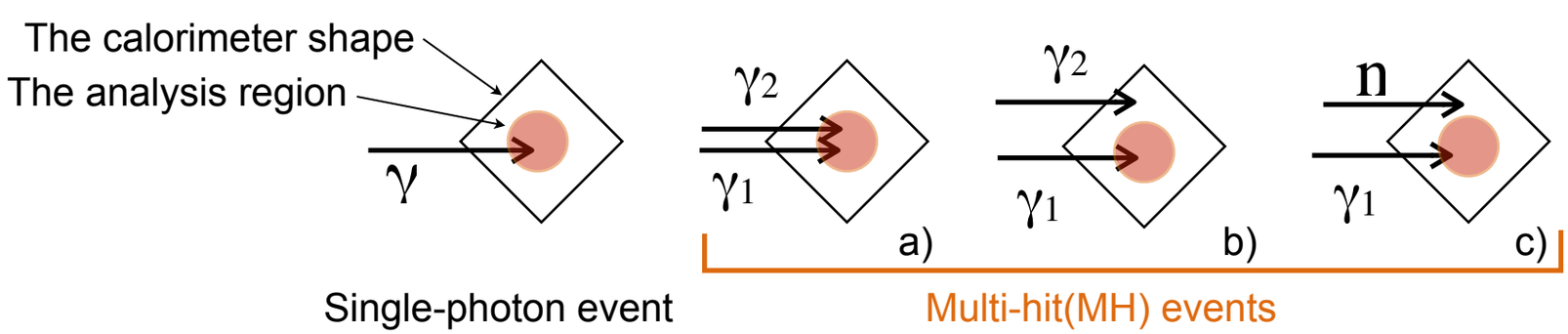
Fiducial region definition and MH issue

- Definition of photon
  - All photons directly produced in the *pp* collisions or from subsequent decays of directly produced particles with $c\tau < 1$ cm (140 m in the conf-note)
- Fiducial region of this measurement
  - Photons with energies of > 200 GeV and produced in $\eta > 10.94$ and $8.81 < \eta < 8.99$ are measured.
  - In cases of multi-photons production per event, all photos produced in the region are counted independently.

In this analysis,

- We select events only with exactly one photon in a “calorimeter” (single hit events).
- The multi-hit (MH) events are rejected because of poor resolution of energy sharing between photons, or between a photon and a neutron.

→ In this measurement, we also count these photons by using MC predictions (corresponding a MC-based correction C^{MH}) because of complex geometrical effect of the LHCf calorimeters.



The contribution of a) γ_1,γ_2, b) and c) γ_1 are estimated by using MC

Method for N_{ch}=0 spectra measurement

Updates from the conference note.

- Include LHCf-Arm2 data. → Combine Arm1 and Arm2 results.
- Additional corrections related to "cτ=1cm" and ϕ selection
- Introducing the unfolding of spectrum to have a consistency with LHCf analysis.

For LHCf-Arm1 or -Arm2

$$N'_{all}(E_i) = C^{MH}_{all}(E_i)\, C^{PID}_{all}(E_i)\, N_{w/o\ sel.}(E_i)\,(1 - R_{bkg,1})$$

replace to

$$U_{all}(E_{i,\mathrm{rec}}, E_{i,\mathrm{true}})$$

$$N'_{N_{ch}\geq 1}(E_i) = C^{Track}(E_i)\, C^{MH}_{N_{tracks}>1}(E_i)\, C^{PID}_{N_{tracks}\geq 1}(E_i)\, N_{N_{tracks}\geq 1}\,(1 - R_{bkg,2})$$

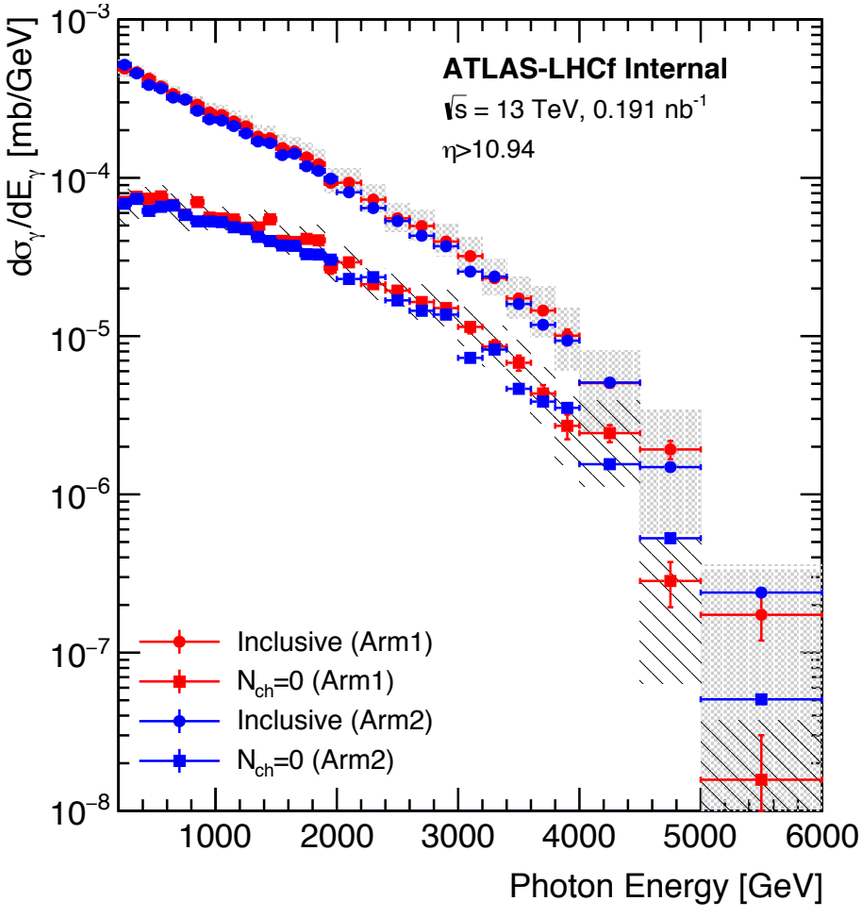
$$U_{N_{tracks}\geq 1}(E_{i,\mathrm{rec}}, E_{i,\mathrm{true}})$$

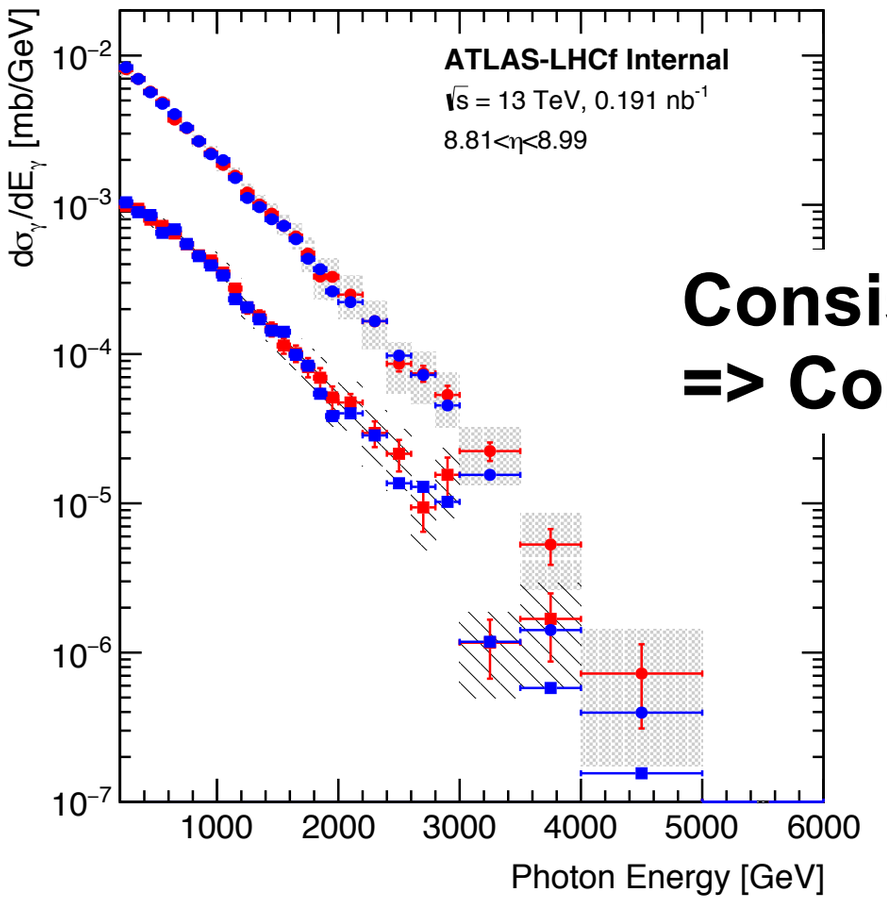
$$N'_{N_{ch}=0}(E_i) = N'_{all}(E_i) - N'_{N_{ch}\geq 1}(E_i)$$

$$\frac{d\sigma_{\gamma}^{\mathrm{N_{ch}}=0}}{dE} = \frac{C^{c\tau}_{N_{ch}=0}(E_i) C^{geometry}}{L} \frac{N'_{N_{ch}=0}(E_i)}{\Delta Ei} \rightarrow N'^{Arm1}_{N_{ch}=0} + N'^{Arm2}_{N_{ch}=0}$$

Combining Arm1 + Arm2

Comparison btw Arm1,2





Consistent within errors
=> Combine the spectra

Combine method:

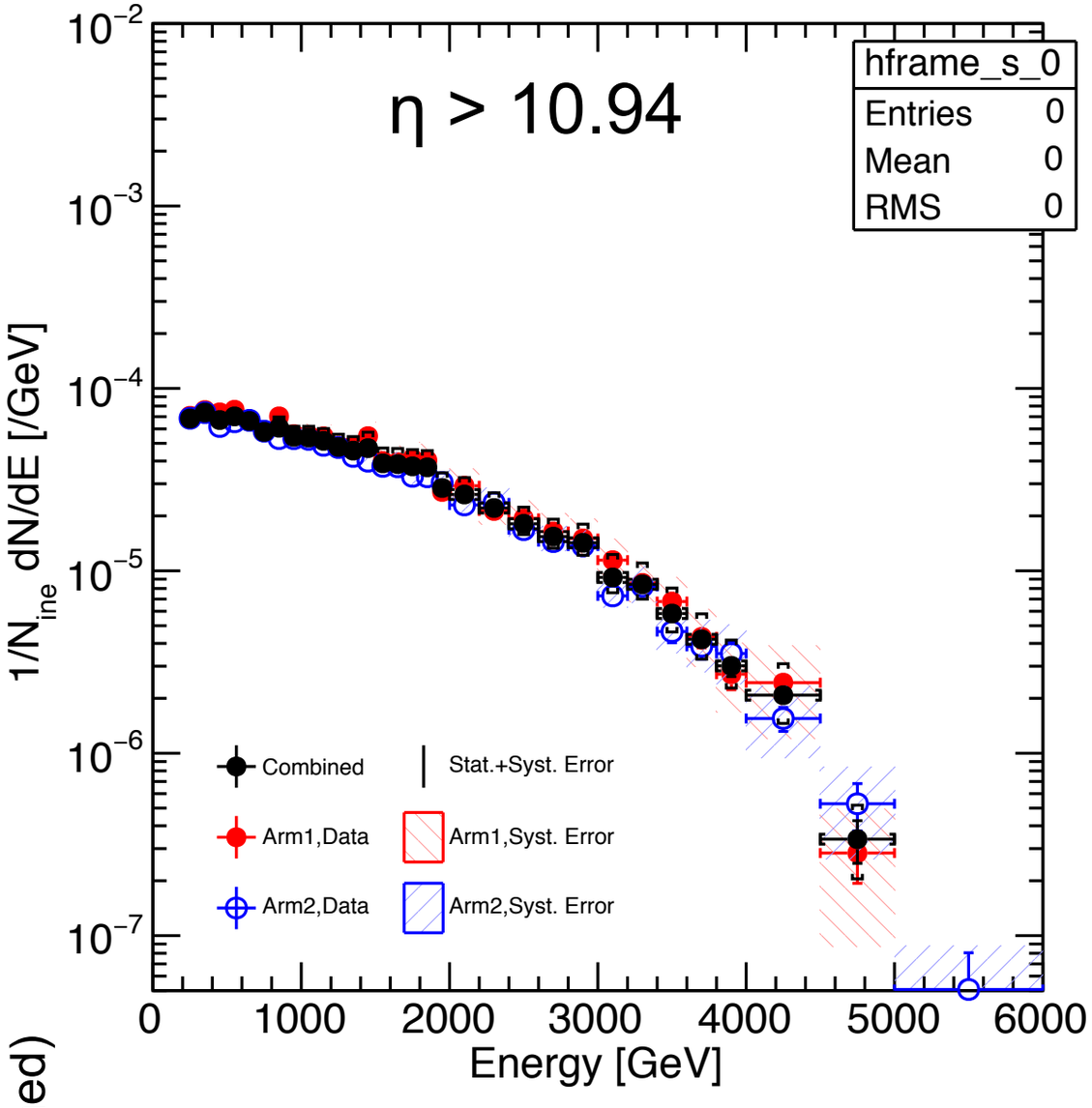
$$\chi^2 = \sum_{i=1}^{n}\sum_{a=1}^{2}\left(\frac{N_{a,i}^{measured}(1+S_{a,i}) - N_i^{combine}}{\sigma_{a,i}}\right)^2 + \chi^2_{penalty}$$

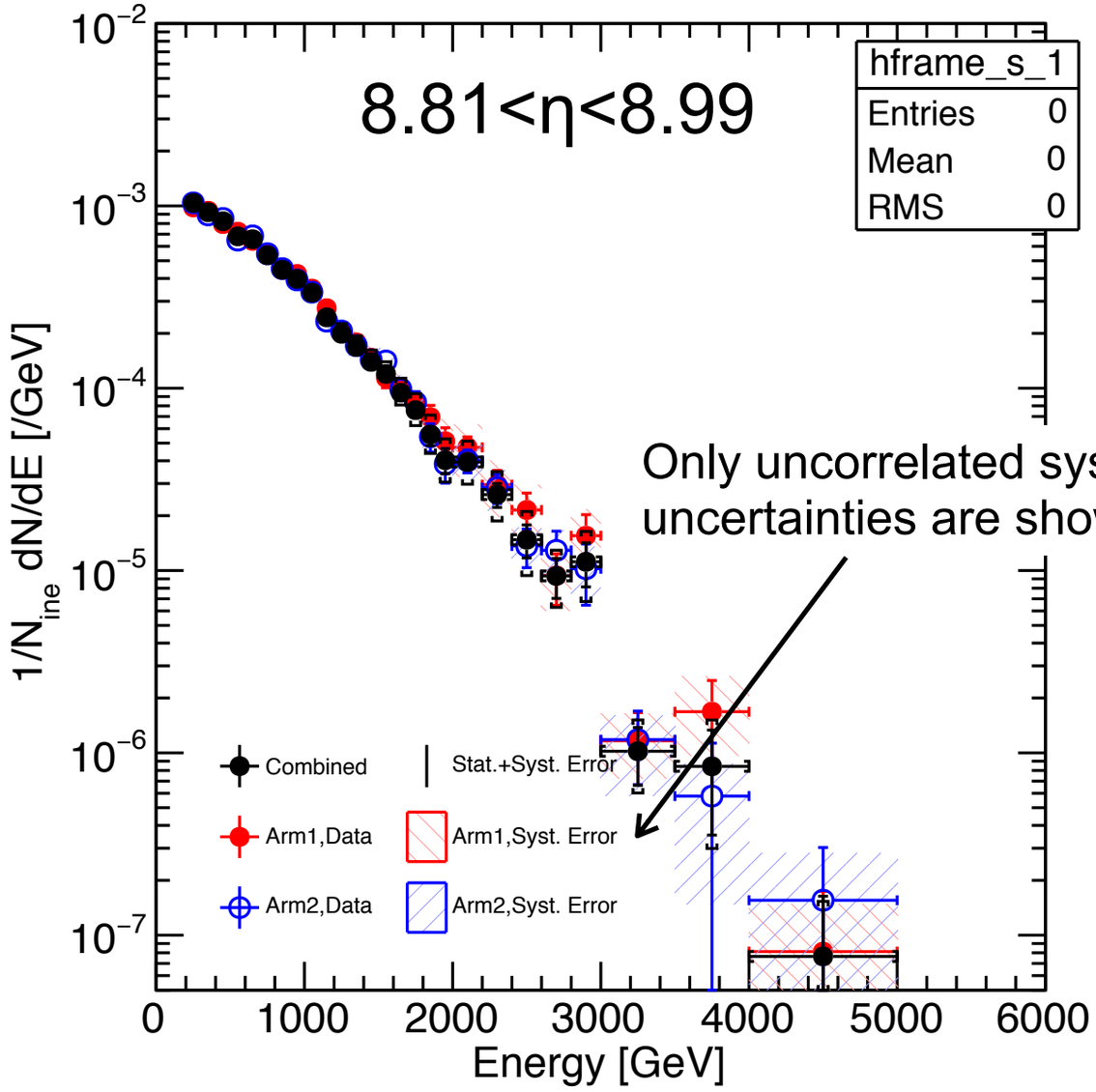
$$S_{a,i} = \sum_{j=1}^{4} f_{a,i}^{j}\epsilon_a^j.$$

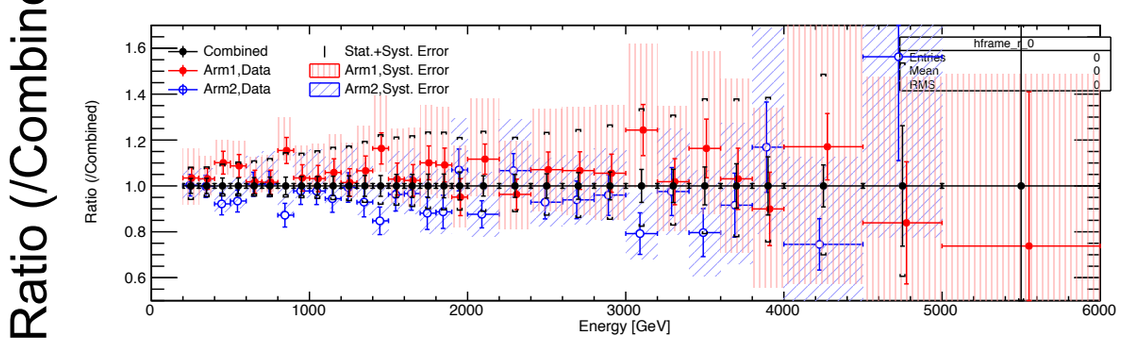
$$\chi^2_{penalty} = \sum_{j=1}^{4}\sum_{a=1}^{2}|\epsilon_a^j|^2$$

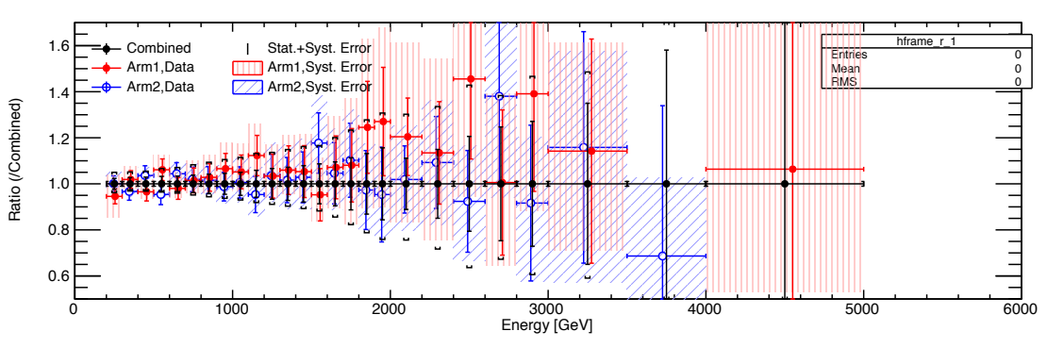
f^j_a: systematic shift (systematic uncertainty)
(Only Arm1-2 uncorrelated uncertainties are considerd.
energy scale, PID, beam center and MH performance)
ϵ^j_a : coefficients for each shift

Combined results (Nch=0 spectra)



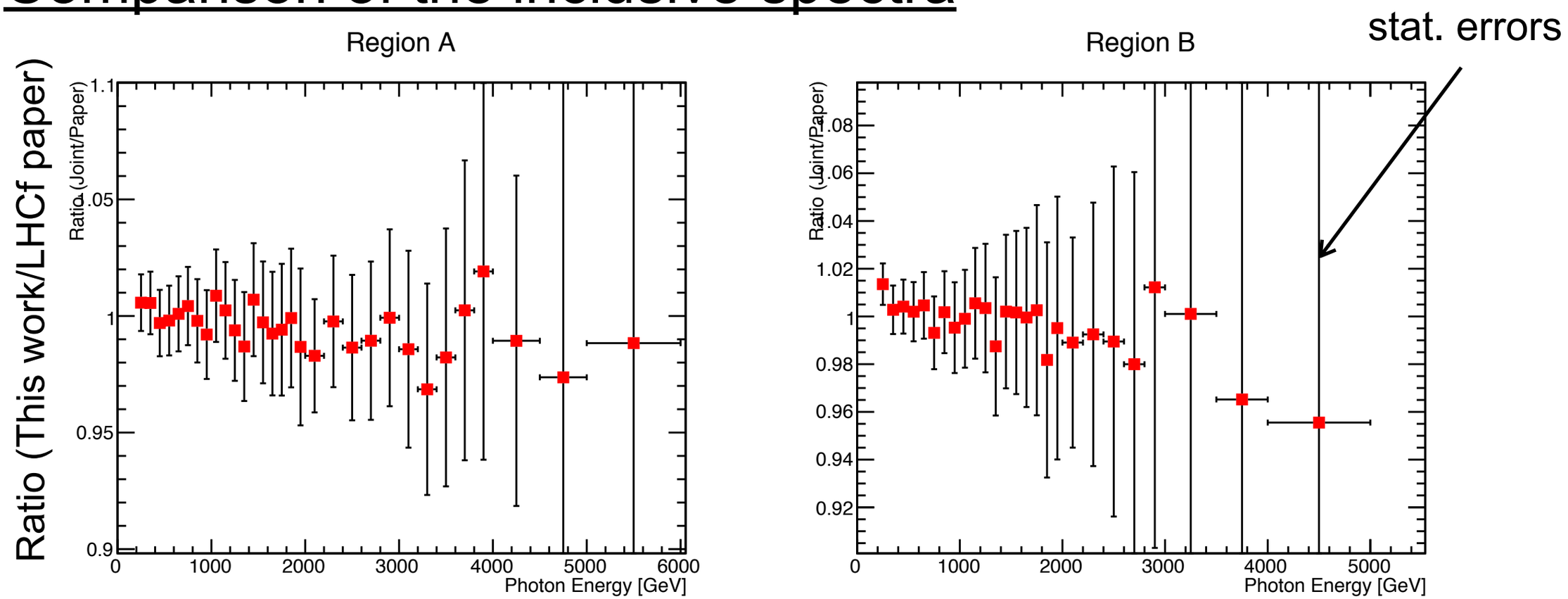






Consistency check with the LHCf paper result.

Comparison of the inclusive spectra



⇒ Good consistency within a few %

Why not perfect ?

- Slightly different data sample (This work ~ 98% of LHCf paper)
- Effect of the unfolding of spectra (iterative Bayesian method).

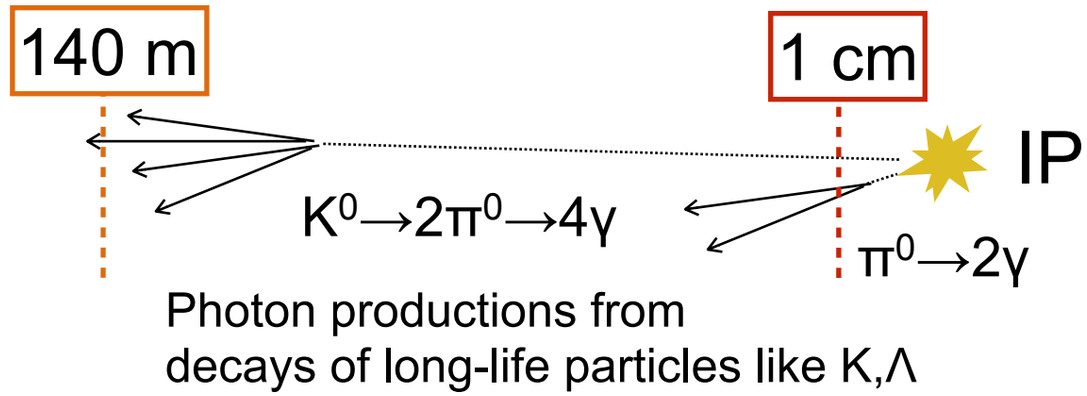
Summary table of correction factors

	Method	Available MC datasets	Comments
$C^{PID}_{all}, C^{PID}_{Ntrack>=1}$	Data driven	-	From template fitting of PID estimator distributions
$C^{MH}_{all}, C^{MH}_{Ntrack>=1}$	MC driven (LHCf full detector MC)	EPOS-LHC,QGSEJETII-04	
C^{Track}	MC driven (Generator MC)	EPOS-LHC, QGSEJETII-04, SIBYLL2.3, PYTHIA 8.212DL	Response function as ATLAS inner tracker efficiency was applied
$R_{bkg,1}$	Data driven	-	Beam-gas collision background estimated from non-colliding bunch events
$R_{bkg,2}$	MC driven (ATLAS full detector MC)	PYTHIA, EPOS-LHC	
L	given	-	Integral luminosity
$C^{Geometry}$	given	-	Related to the fiducial area selection of $\Delta\phi$=180° or 20°
C^{CT}_{all}, $C^{CT}_{Nch=0}$	MC driven (Generator+propagation in the beam pipe)	EPOS-LHC, QGSEJETII-04, SIBYLL2.3, PYTHIA 8.212DL	Estimation of long-life particle contribution like keons. 140 m fly of generated particles.
C^{SD}	Data+MC driven (Modified generator MC by data)	EPOS-LHC, QGSEJETII-04, SIBYLL2.3, PYTHIA 8.212DL	By modified MCs by parameter X.
$C^{log10\xi}$	MC driven (Generator MC)	EPOS-LHC, QGSEJETII-04, SIBYLL2.3, PYTHIA 8.212DL	Nch=0 → $\log_{10}\|\xi\| < -5$

Correction: cτ < 140 m → cτ < 1cm

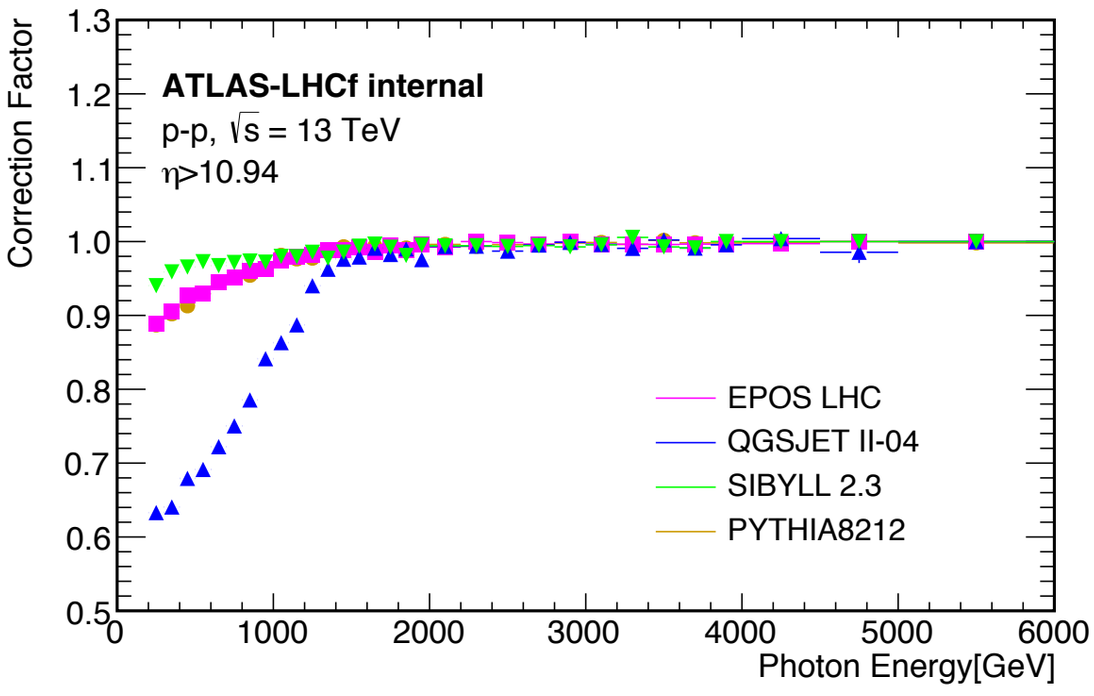
MC simulation was performed with a generator and propagation of particles in the beam pipe.

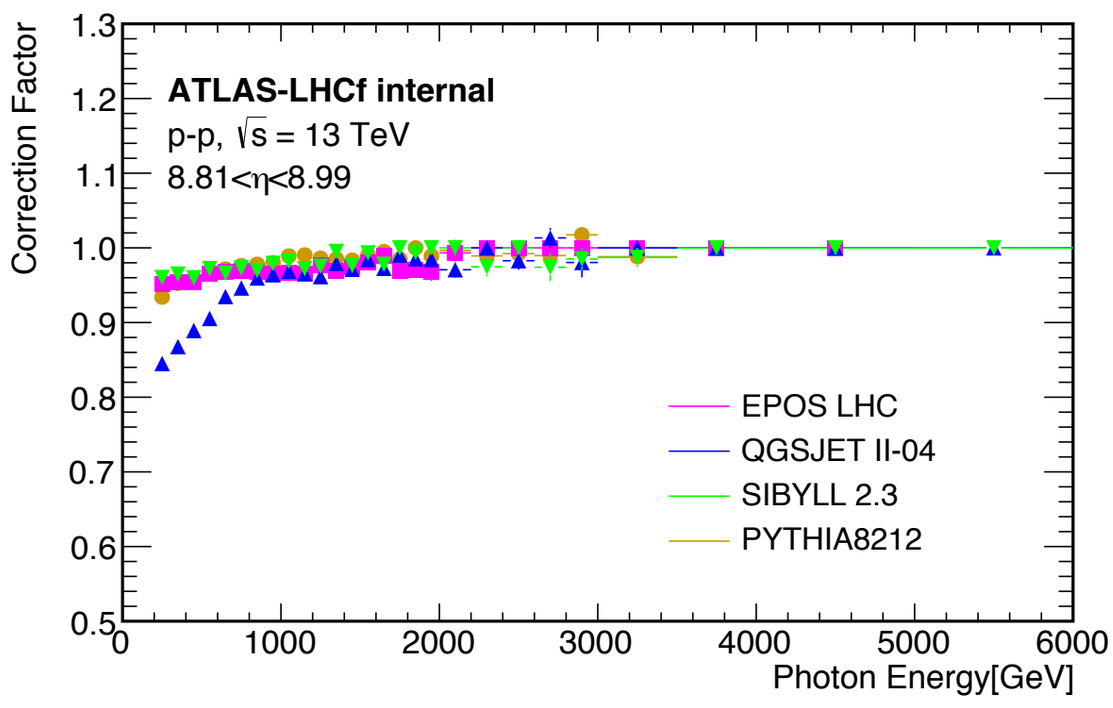
$$C^{c\tau} = \frac{N^{MC}_{@1\mathrm{cm}}}{N^{MC}_{@140\mathrm{m}}}$$



Photon productions from decays of long-life particles like K,Λ

Number of the photon events↗





Correction factor: the average of these four model results
Systematic uncertainty: the discrepancies between the average and each model value (min,max)

Note) In QGSJET II-04, much more Λ^0+K^0 events were found than the other models. They induced a large correction factor in E<1TeV, region A. We are contacting with the developer of QGSJET to understand it.

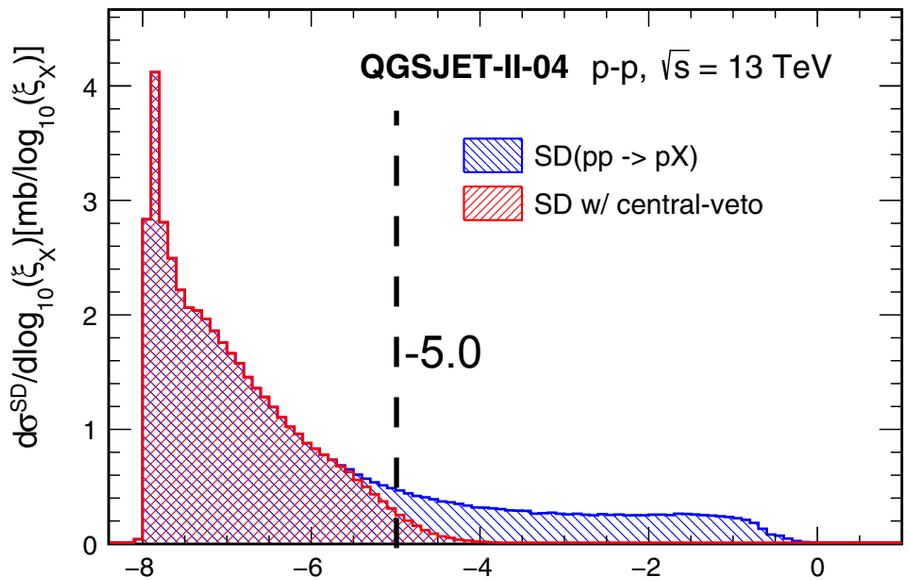
Correction: N_{ch}=0 → $Log_{10}\xi$ < -5.0

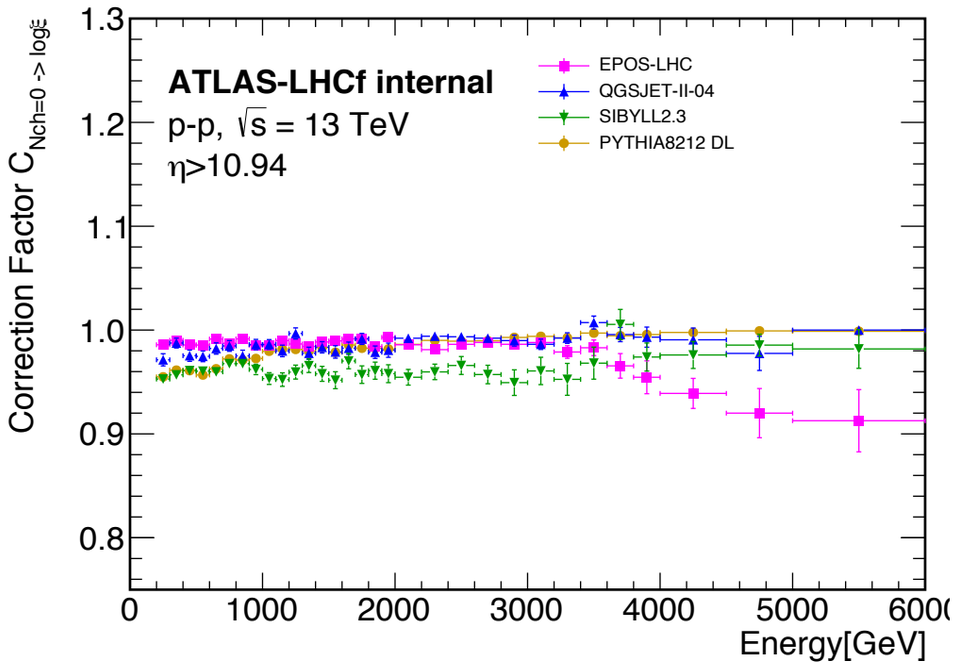
$$C_{N_{ch}=0 \to log_{10}\xi<-5} = \frac{N^{MC}_{log_{10}\xi<-5}}{N^{MC}_{N_{ch}=0}}$$

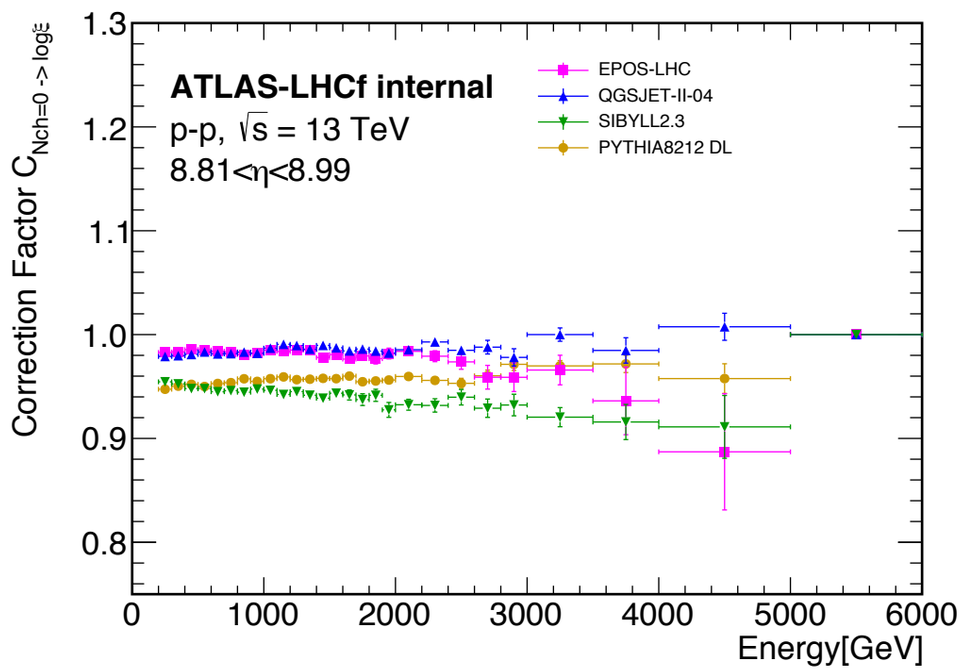
Number of the photon events ⤴

TODO in the previous report in April:

- ✓ Increase the statistics : 10^7 pp collisions → 10^8 pp collisions **Done**
- ✓ Estimation of the systematic uncertainty **Done**







Correction factor: the average of these four model results
Systematic uncertainty: the discrepancies between the average and each model value (min,max)

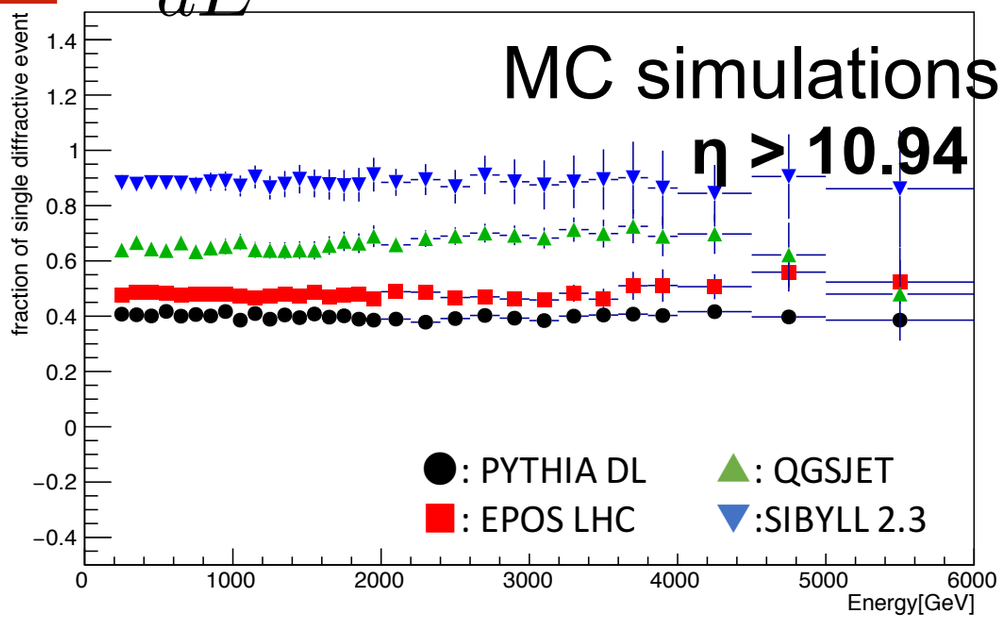
SD fraction measurement

Method of measurement of SD contribution:

$$\frac{d\sigma_{\gamma}^{SD,log_{10}\xi<-5}}{dE} = C^{log_{10}\xi}(E_i)C^{SD}(E_i)\frac{d\sigma_{\gamma}^{\mathrm{N_{ch}}=0}}{dE}$$

Fraction of SD contribution

- Little energy dependency, but
- Large discrepancy among the models (0.4 - 0.9).
  →A data driven method is needed instead of the simple MC driven method.

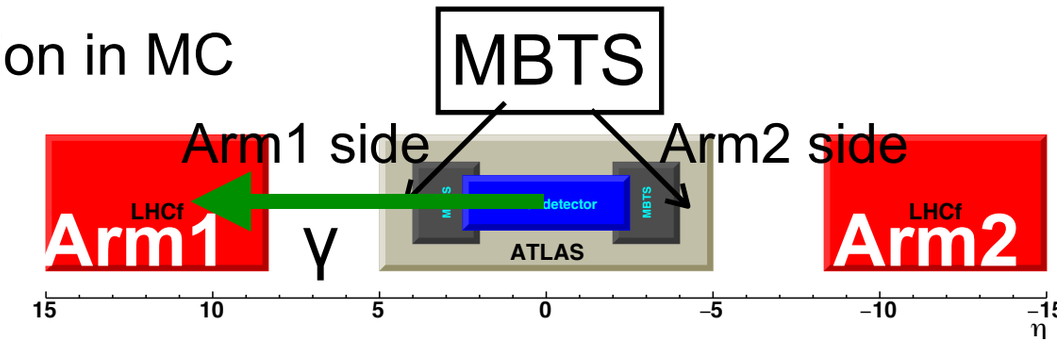


Previous method:

Introducing X,Y parameters to modifying SD(DD) fraction in MC

$$N^{MC} \rightarrow N^{MC'} = X\,N_{SD}^{MC} + Y\,N_{DD}^{MC} + N_{ND}^{MC}$$

X,Y are calculated from samples with MBTS hits



$$\frac{N_{Sample1}^{Data}}{N_{Sample2}^{Data}} = \frac{N'^{MC}_{Sample1}}{N'^{MC}_{Sample2}}$$

Sample 1: Arm1 γ + Nch=0 + $MBTS_{Arm1}$ > 0 + $MBTS_{Arm2}$ =0
→ Single diffractive enriched sample
Sample 2: Arm1 γ + Nch=0 + $MBTS_{Arm2}$ > 0
→ Double diffractive enriched sample.

New method for SD fraction measurement

The basic idea of the new method is same as the previous method.
We modified only the description of the method.
→No difference of the results is expected.

Method: Measure the SD(DD) fractions from the event numbers of sample1,sample2 by applying a response matrix.

$$\begin{pmatrix} N^{Data}_{N_{ch}=0,SD} \\ N^{Data}_{N_{ch}=0,DD} \end{pmatrix} = \mathbf{R}^{-1} \begin{pmatrix} N^{Data}_{Sample1} \\ N^{Data}_{Sample2} \end{pmatrix}$$

Background subtraction (ND contributions)

$$N^{MC}_{BKG,ND}$$

ND contributions (~1%)

$$N^{MC}_{N_{ch}=0,ND}$$

Responce matrix

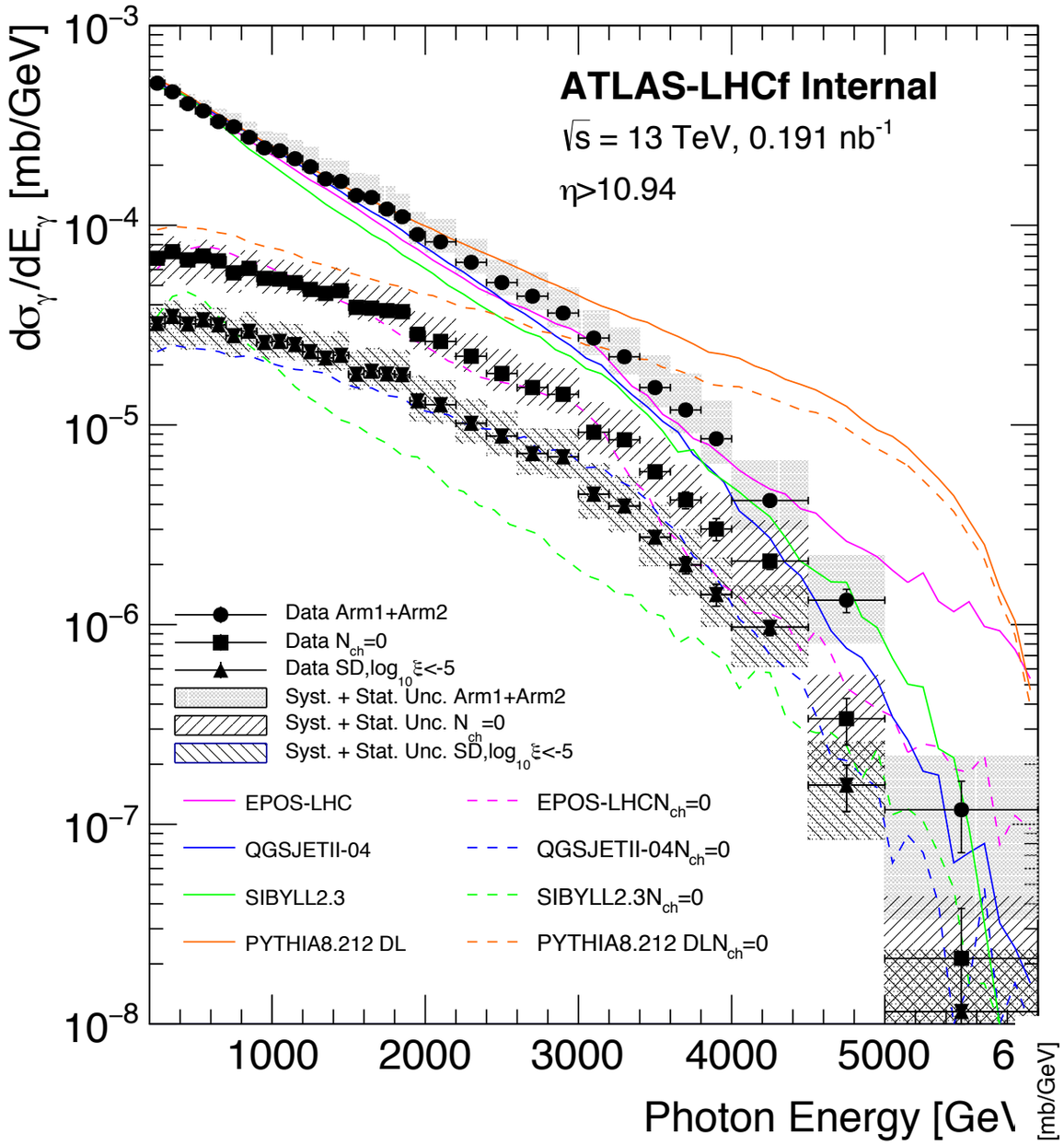
$$\begin{pmatrix} N^{MC}_{Sample1} \\ N^{MC}_{Sample2} \end{pmatrix} = \mathbf{R} \begin{pmatrix} N^{MC}_{N_{ch}=0,SD} \\ N^{MC}_{N_{ch}=0,DD} \end{pmatrix}$$

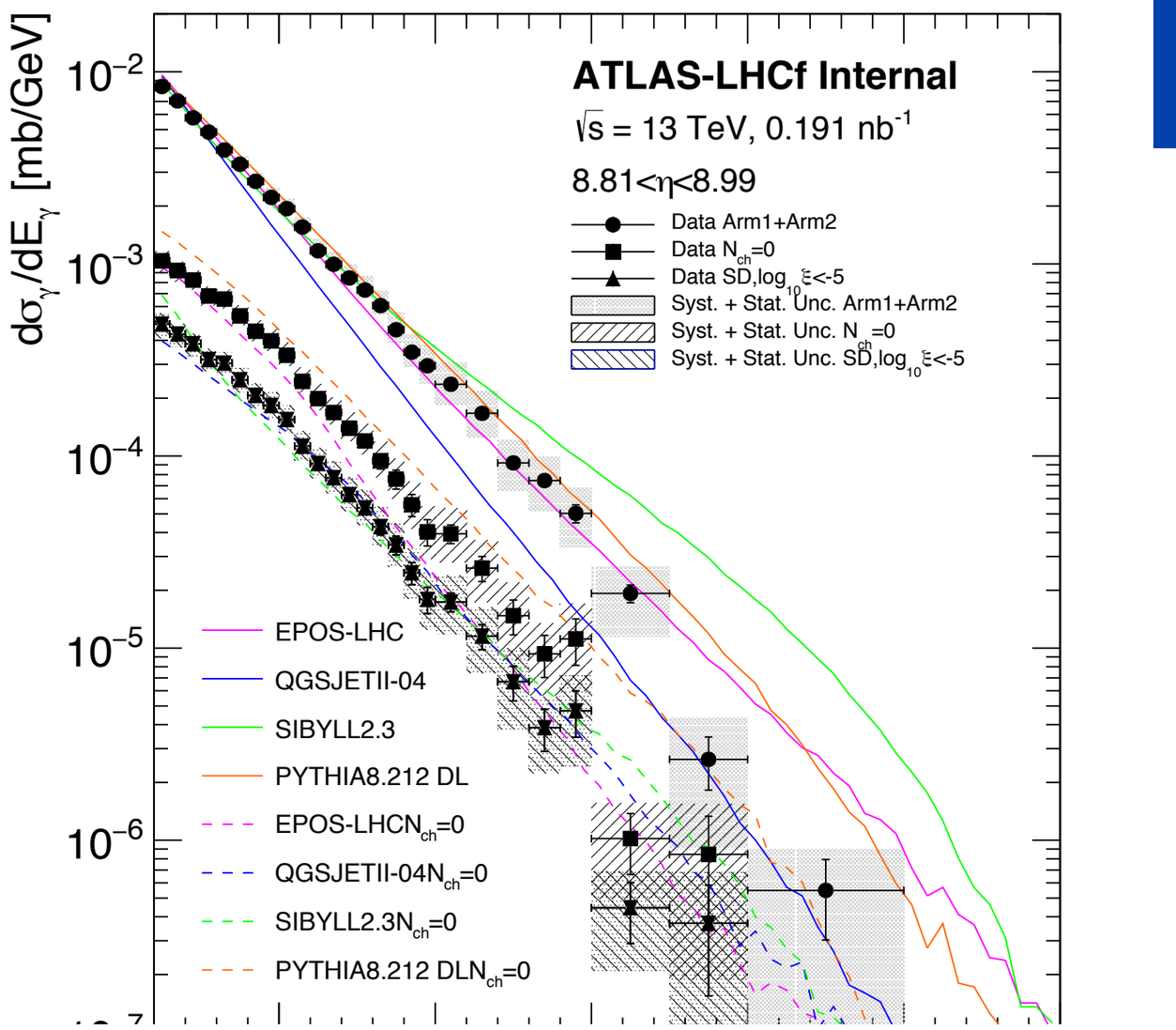
Results: The SD fraction $N^{Data}_{N_{ch}=0,SD}/N^{Data}_{N_{ch}=0,ALL}$

PYTHIA	EPOSLHC	QGSJET	SIBYLL
0.450	0.500	0.531	0.518

← MC model used for response matrix and the ND contribution estimation

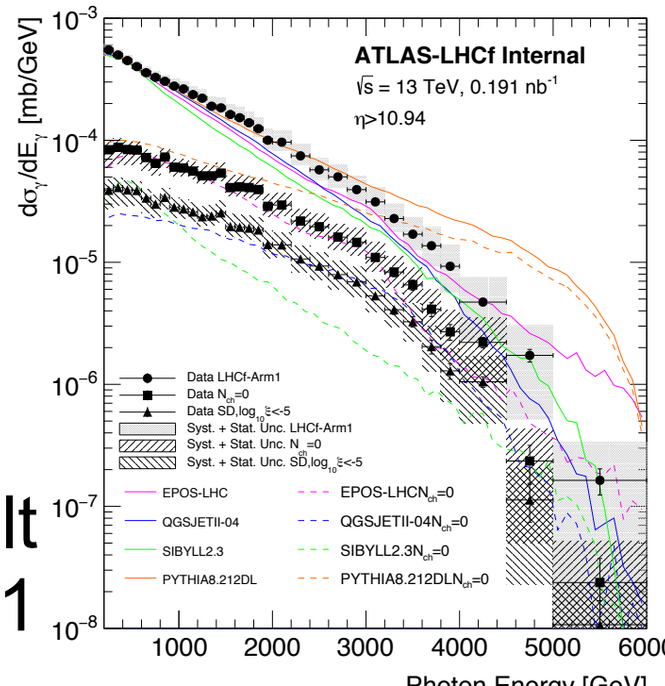
Estimation of systematic uncertainties are on-going
(MBTS efficiency, LHCf detector response, ND contributions.)

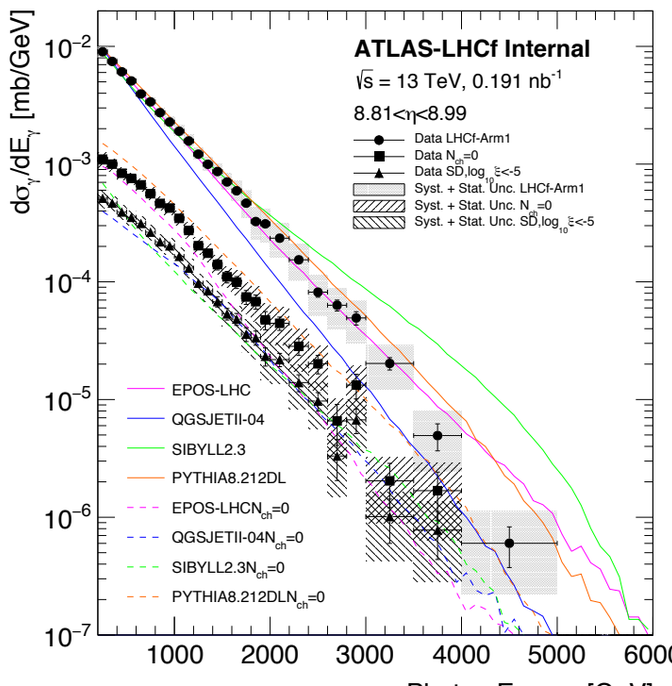




Note) The systematic uncertainties are not finalized yet.

Old result with only Arm1



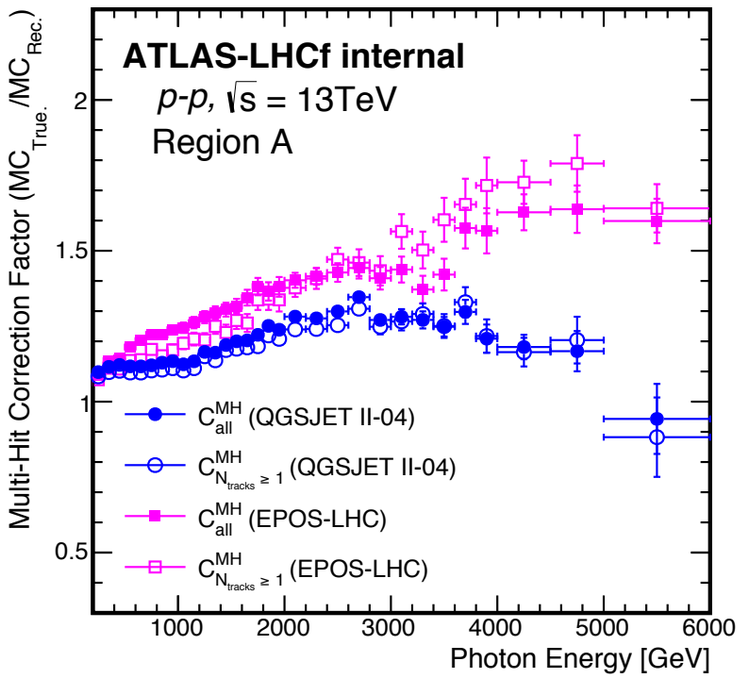


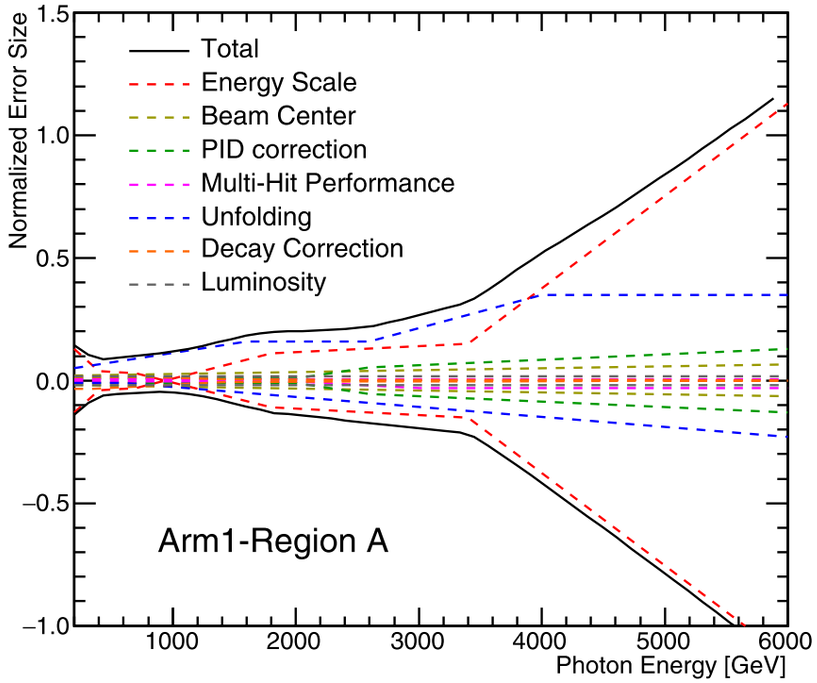
Discussion in the ATLAS softQCD meeting

- We had a presentation in the ATLAS soft-QCD meeting on 13 Nov. and got many comments mainly related to MH issues.
- Comments
  - Treatment of systematic uncertainties in combining spectra of Arm1,2.
    - Correlated and uncorrelated contribution were well separated ? For example, the systematic uncertainties related to the MH detection algorithm. (Different detector but the method is mostly common. How much the contribution ?)
    - How were the systematic uncertainties evaluated ? Especially, that for the MH performance ?
  - Related to Fiducial definition (See the next page)
    - How about the single photon spectrum instead of inclusive spectrum ? (or add such spectrum measurement ?)

Discussion about the fiducial definition

- ATLAS prefers to do “base-ine” measurement:
  no (if possible) interpolation, extrapolation and corrections based on models.
- MH correction is fully model-driven and induces a large systematic uncertainty.





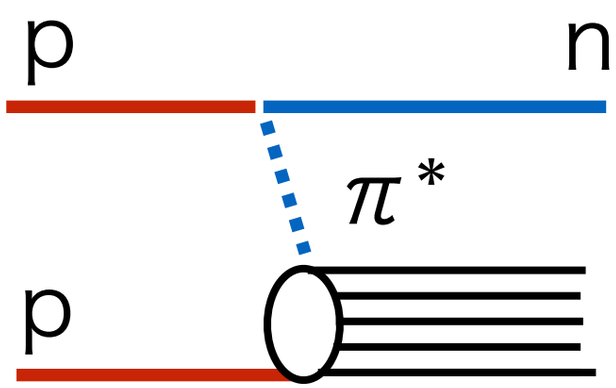
- An example of their proposal is
  “single photon in the region A,B (η cut,φ cut) at 140m”
  without no other particle in the calorimeter geometry
  => This is an experimental biased measurement
  but no MC-based correction is needed (C^{MH}, C^{CT})
- We need to answer about it.
  Accept this proposal or explain about the difficulties of this measurement.

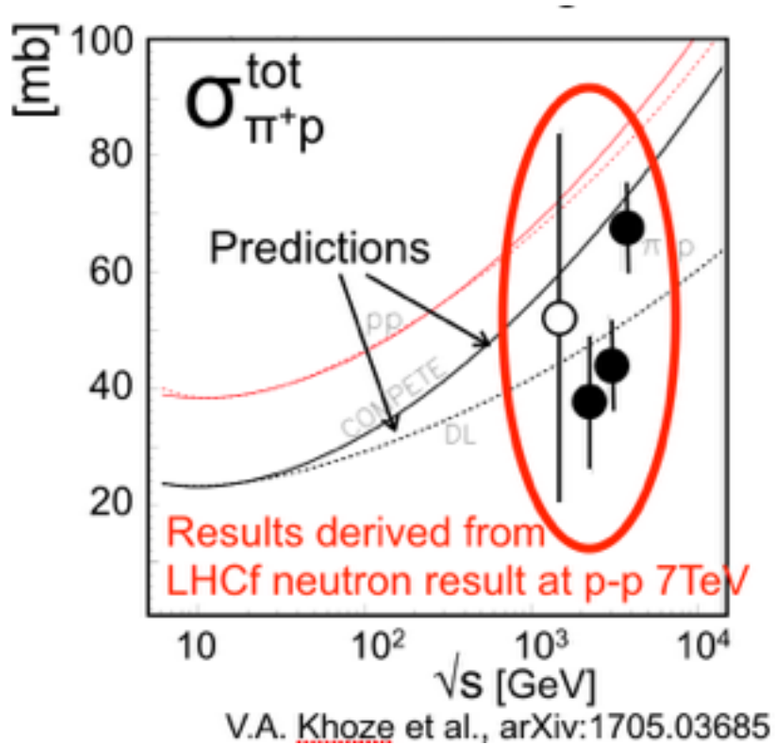
Other to-do

- Update of the analysis note. (End of year)
- Finalize systematic uncertainties (This month)
  - For SD(DD) fraction measurement.
- Evaluation of this analysis
  - Consistency check with changing pT threshold for charged track detection from 0.1 GeV to 0.4 GeV.
  - Comparisons of the multiplicity and pseudorapidity distributions of charged tracks with modified MC's by the measured SD(DD) fractions.

Next target of this joint analysis

- Neutron analysis with ATLAS data.
  - Diffractive contribution on the forward neutron analysis (Repeating the analysis with “neutron”)
  - ATLAS track distribution (central activities) with forward neutron tagging.
    - η distribution, N_{charge} distribution, $\langle p_T \rangle$ distribution
    - ATLAS is going to publish such measurement with proton tagging by Roman-Pots
  - Measurement of p-π^+ cross-section





V.A. Khoze et al., arXiv:1705.03685

Summary

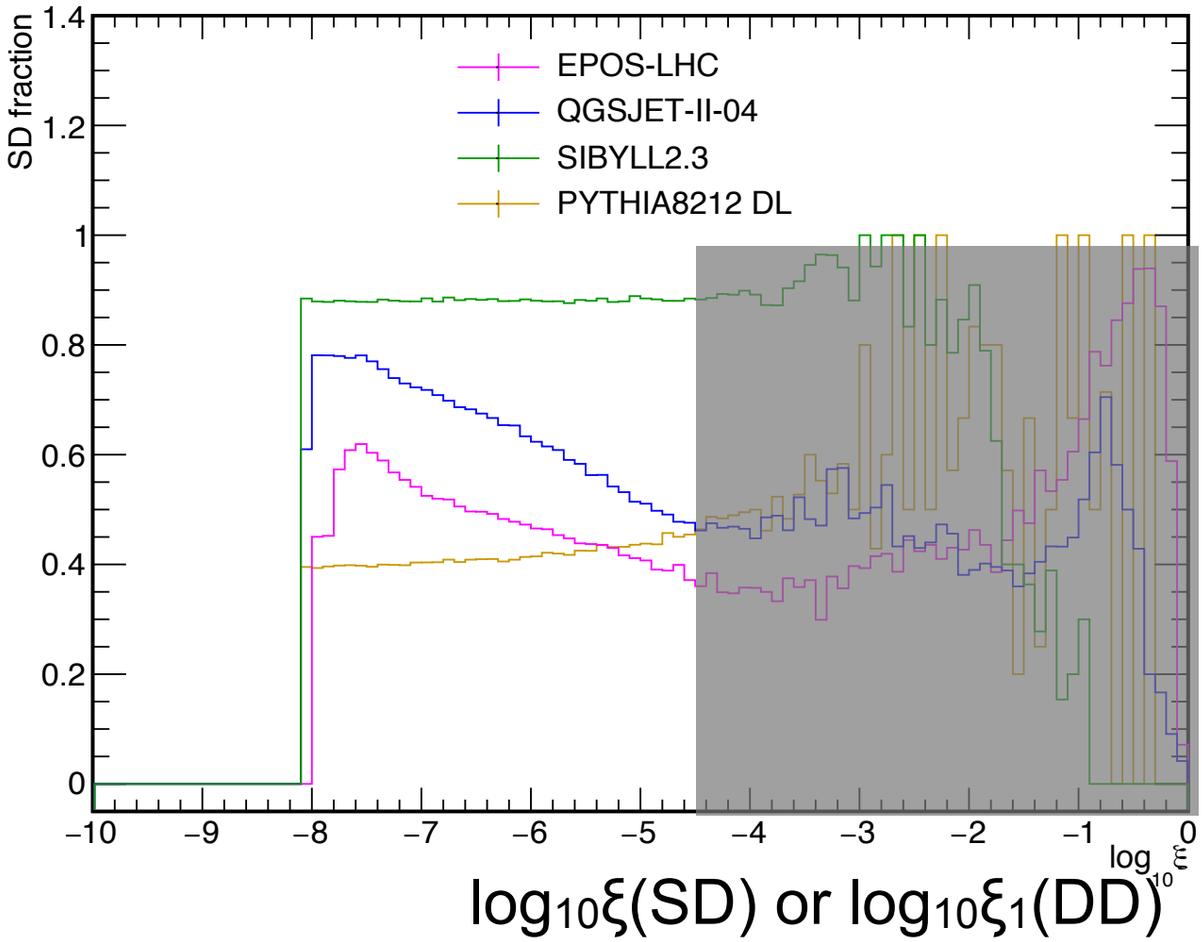
- We added the Arm2 data to this joint-analysis and finalized the Nch=0 spectra. However we need to consider about the fiducial definition of the measurement (MH treatment) again.
- The SD fraction method was updated introducing the response matrix instead of a method with X,Y modification parameters in MC.
- We are updating the analysis note in parallel to the finalization of systematic uncertainties and additional tests for evaluations of this analysis.

Backup

SD fraction in MC

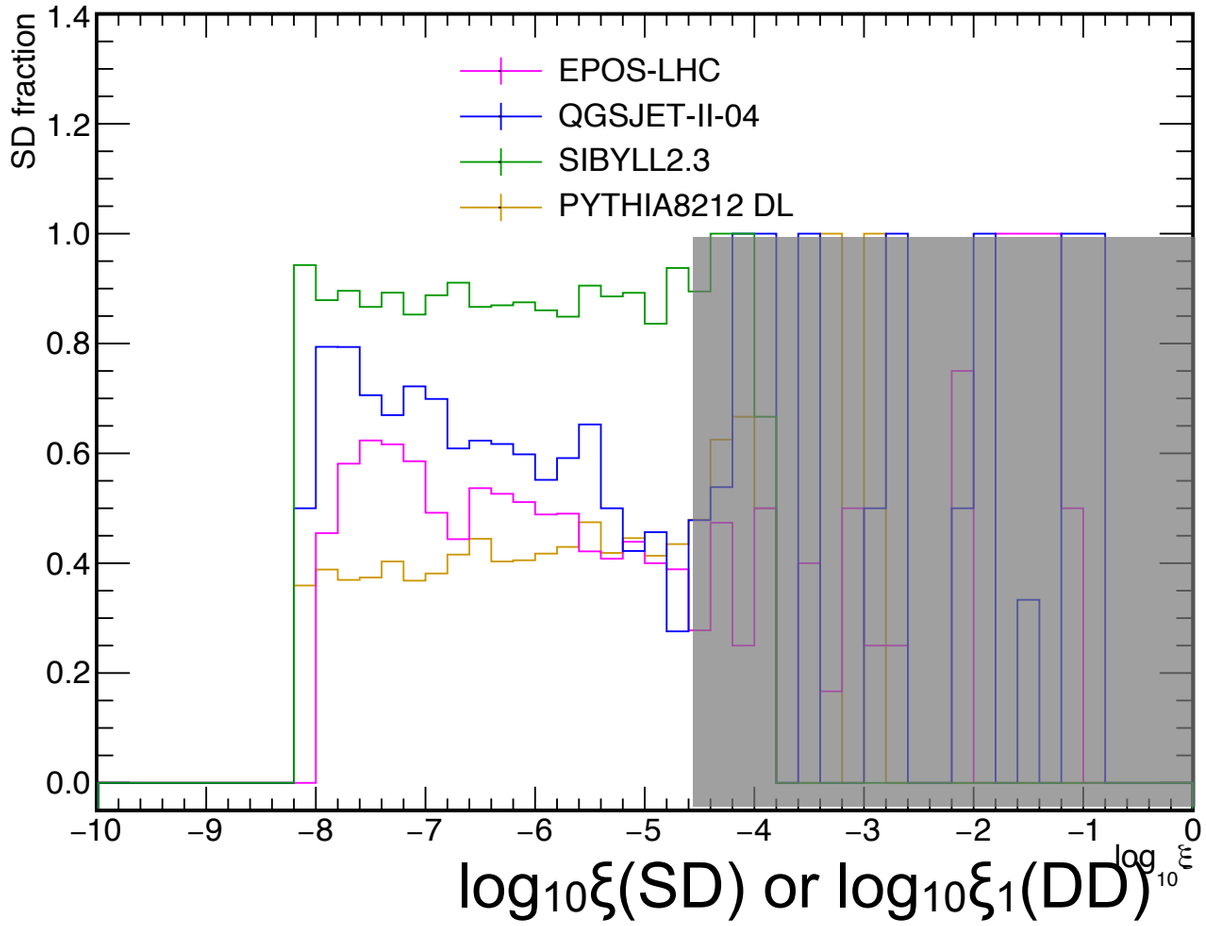
SD(Xp) / (SD(Xp)+DD)

N_{ch}=0 + Without LHCf γ tagging



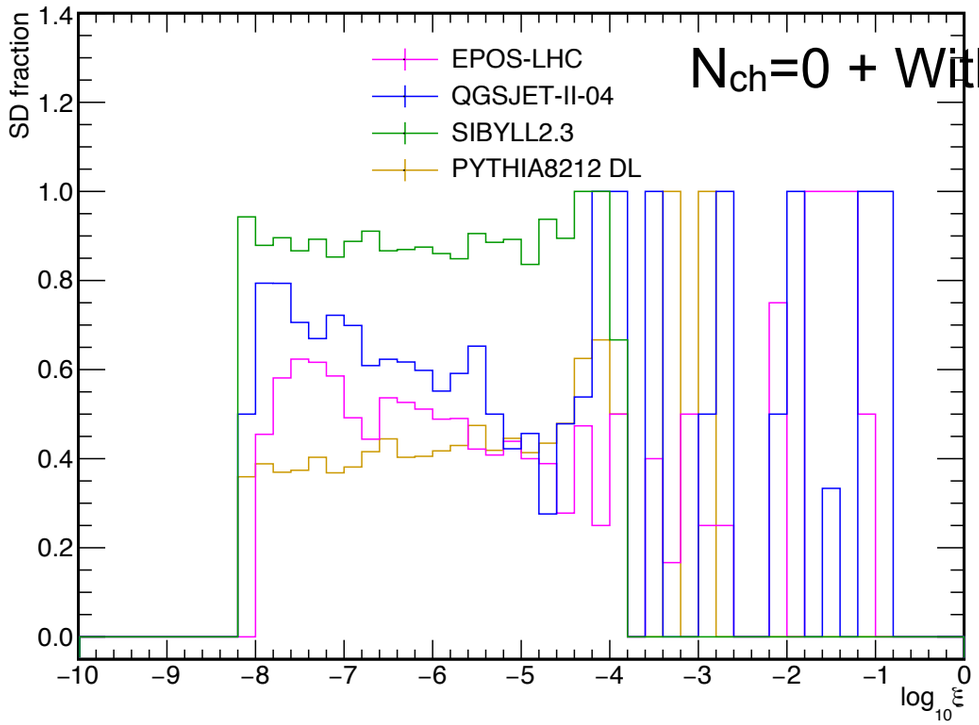
SD(γp) / (SD(γp)+DD(γX))

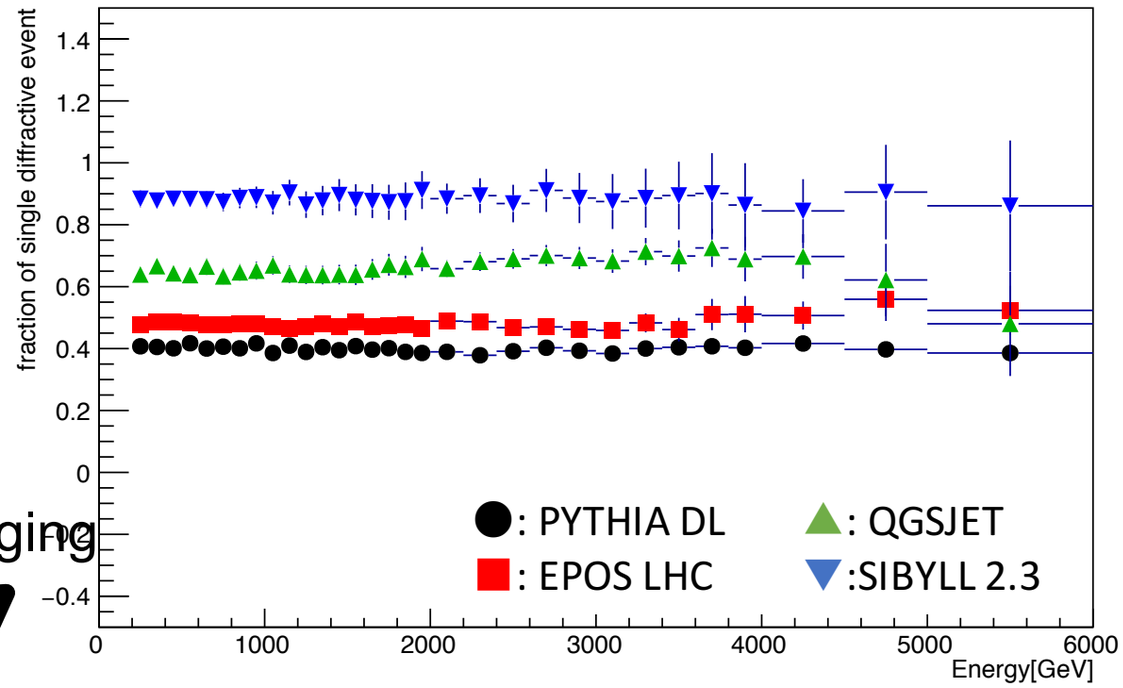
N_{ch}=0 + With LHCf γ tagging



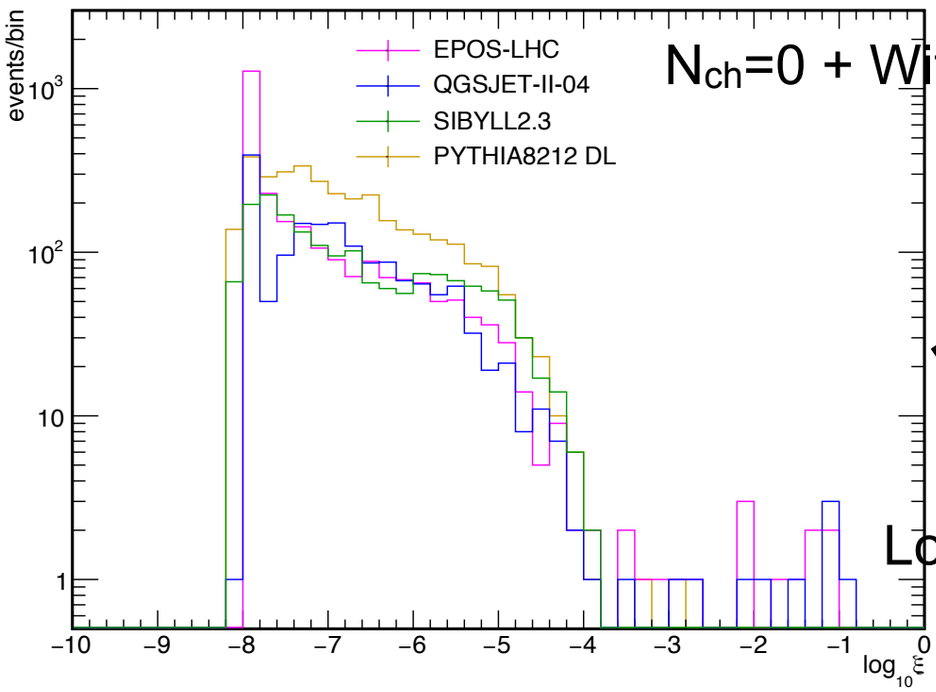
SD fraction in MC

SD(γp) / (SD(γp)+DD(γX))





$\log_{10}\xi$ distribution in SD



Low mass events are dominant.

Analysis method for spectrum

$$
\begin{aligned}
N'_{all}(E_i) &= C^{MH}_{all}(E_i)\, C^{PID}_{all}(E_i)\, N_{w/o\ sel.}(E_i)\,(1 - R_{bkg,1}) \\
N'_{N_{ch}\geq 1}(E_i) &= C^{Track}(E_i)\, C^{MH}_{N_{tracks}\geq 1}(E_i)\, C^{PID}_{N_{tracks}\geq 1}(E_i)\, N_{N_{tracks}\geq 1}\,(1 - R_{bkg,2}) \\
N'_{N_{ch}=0}(E_i) &= N'_{all}(E_i) - N'_{N_{ch}\geq 1}(E_i)
\end{aligned}
$$

↑ Conf-note

$$
\frac{d\sigma_{\gamma}^{\mathrm{inclusive}}}{dE} = \frac{C^{c\tau}_{all}(E_i) C^{geometry}}{L} \frac{N'_{all}(E_i)}{\Delta Ei}
$$

$$
\frac{d\sigma_{\gamma}^{\mathrm{N_{ch}}=0}}{dE} = \frac{C^{c\tau}_{N_{ch}=0}(E_i) C^{geometry}}{L} \frac{N'_{N_{ch}=0}(E_i)}{\Delta Ei}
$$

$$
\frac{d\sigma_{\gamma}^{SD,log_{10}\xi<-5}}{dE} = C^{log_{10}\xi}(E_i) C^{SD}(E_i) \frac{d\sigma_{\gamma}^{\mathrm{N_{ch}}=0}}{dE}
$$

Normalization

L:	Integral luminosity
$C^{geometry}$:	Correction of fiducial area selection with Δφ=180°(region A) or 20°(region B)
$C^{c\tau}$:	Correction of contribution from long-life particles with more than cτ > 1cm
C^{SD}:	Estimated single-diffraction event ratio in Nch=0 events
$C^{log10\xi}$:	Correction of migration in Nch=0 selection to $\log_{10}\xi$<-5 selection.

Photon definition

SD contribution

Correction: SD+DD→ SD (DD)

$$C_{SD(DD)} = \frac{N^{MC,SD(DD)}_{N_{ch}=0}}{N^{MC,SD+DD}_{N_{ch}=0}}$$

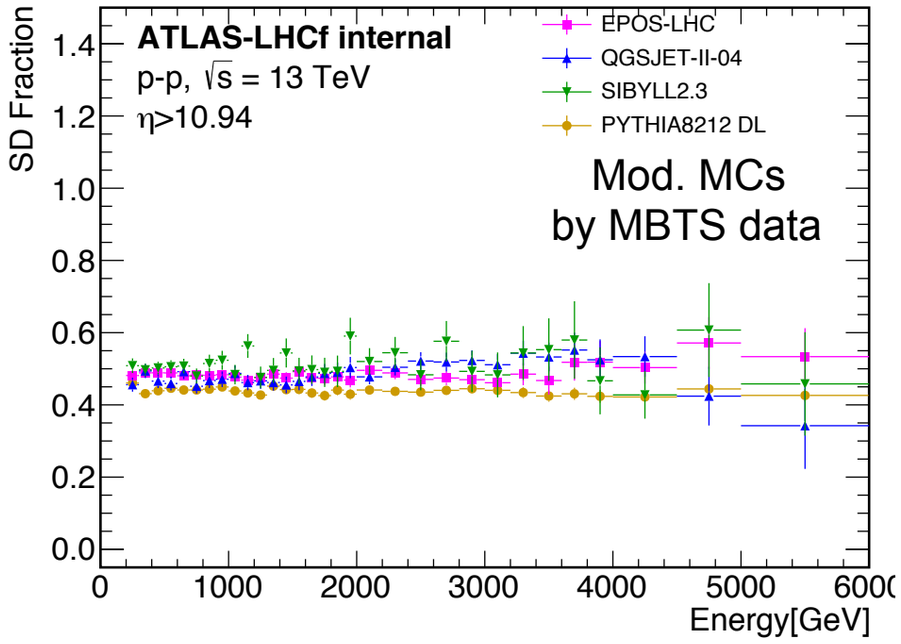
Note) The factor was calculated from modified MC introducing a factor X and Y as $N^{MC} \rightarrow N^{MC'} = X\, N^{MC}_{SD} + Y\, N^{MC}_{DD} + N^{MC}_{non-diff.}$
X and Y were fixed by using the number of photon events with a MBTS-hit selection of data and by conserving the total number of the events. For detail, see the presentation in the last meeting or backup.

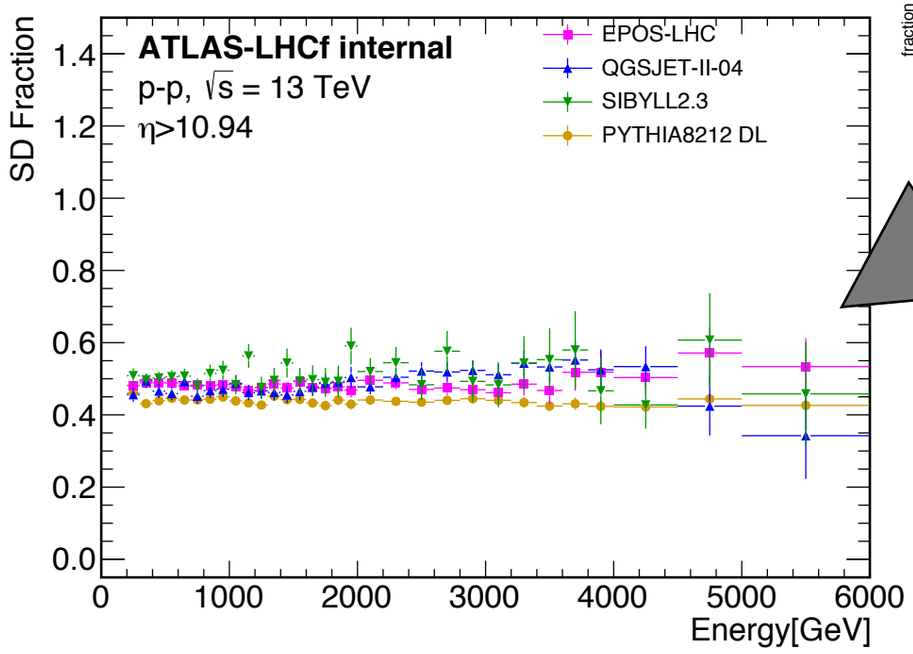
TODO in the previous report in April:

✓ Apply the response function of LHCf detector in the MC tuning. **Done**

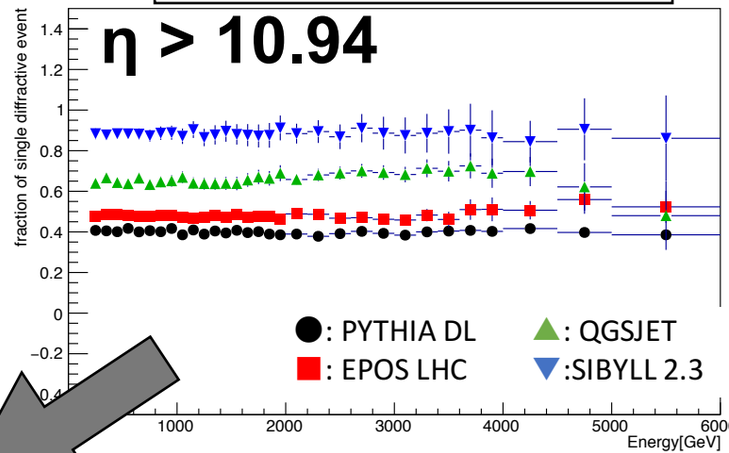
✓ Increase the statistics : 10^7 pp collisions → 10^8 pp collisions **Done**

✓ Estimation of the systematic uncertainty **Done**





Original MC results



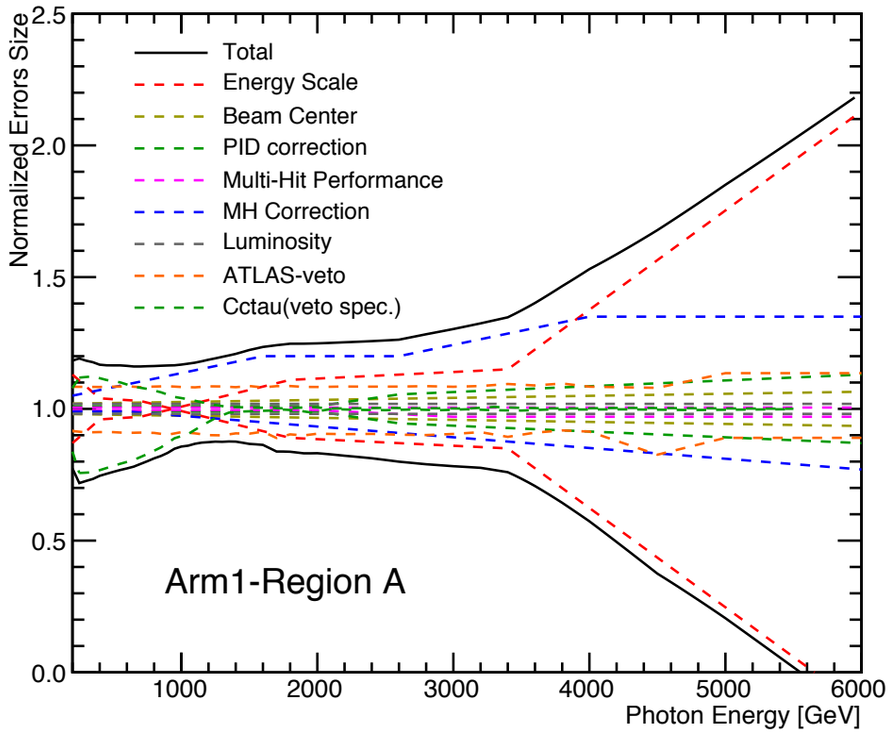
Correction factor: the average of these four model results

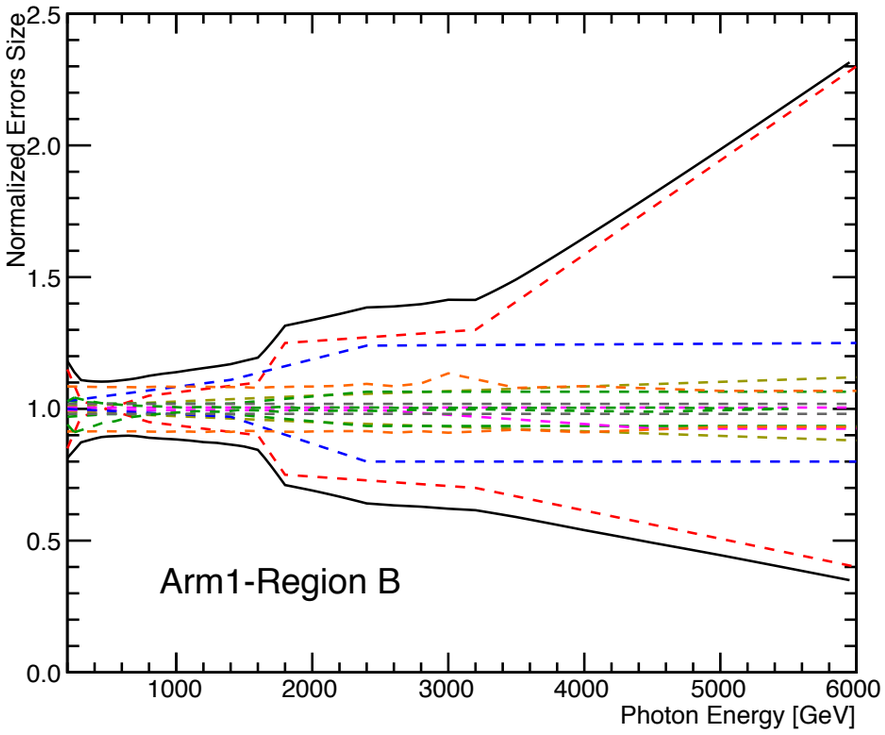
Systematic uncertainty:

- Statistics of data and MC in X,Y determination (~4%)
- Contribution of non-diffractive events (~1.5%)
- LHCf and MBTS response in X,Y determination (~2%)
- the discrepancies (min,max) (5-20%)

Systematic uncertainties (Spectrum)

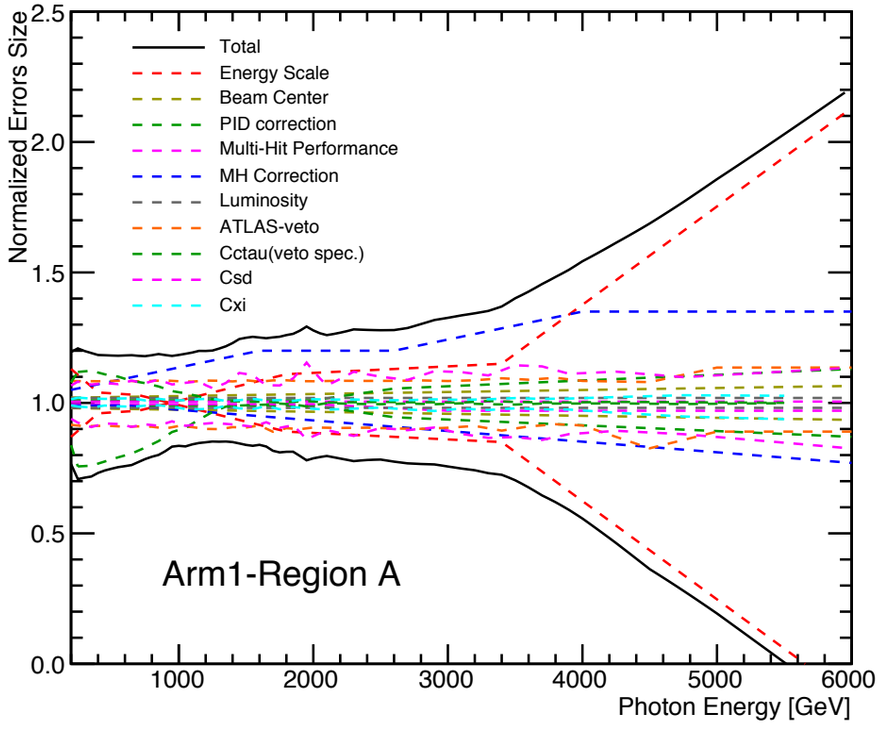
N_{ch}=0 Spectrum

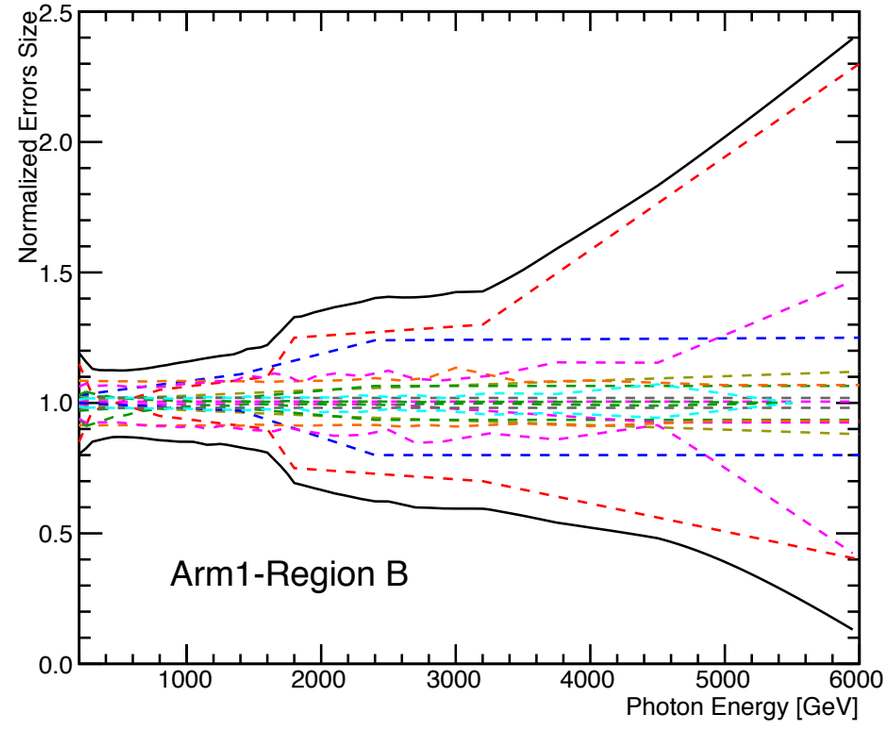




SD Spectrum

Dominant sources:
- Energy scale
- MH correction
- C^{CT}(<1TeV, Region A)

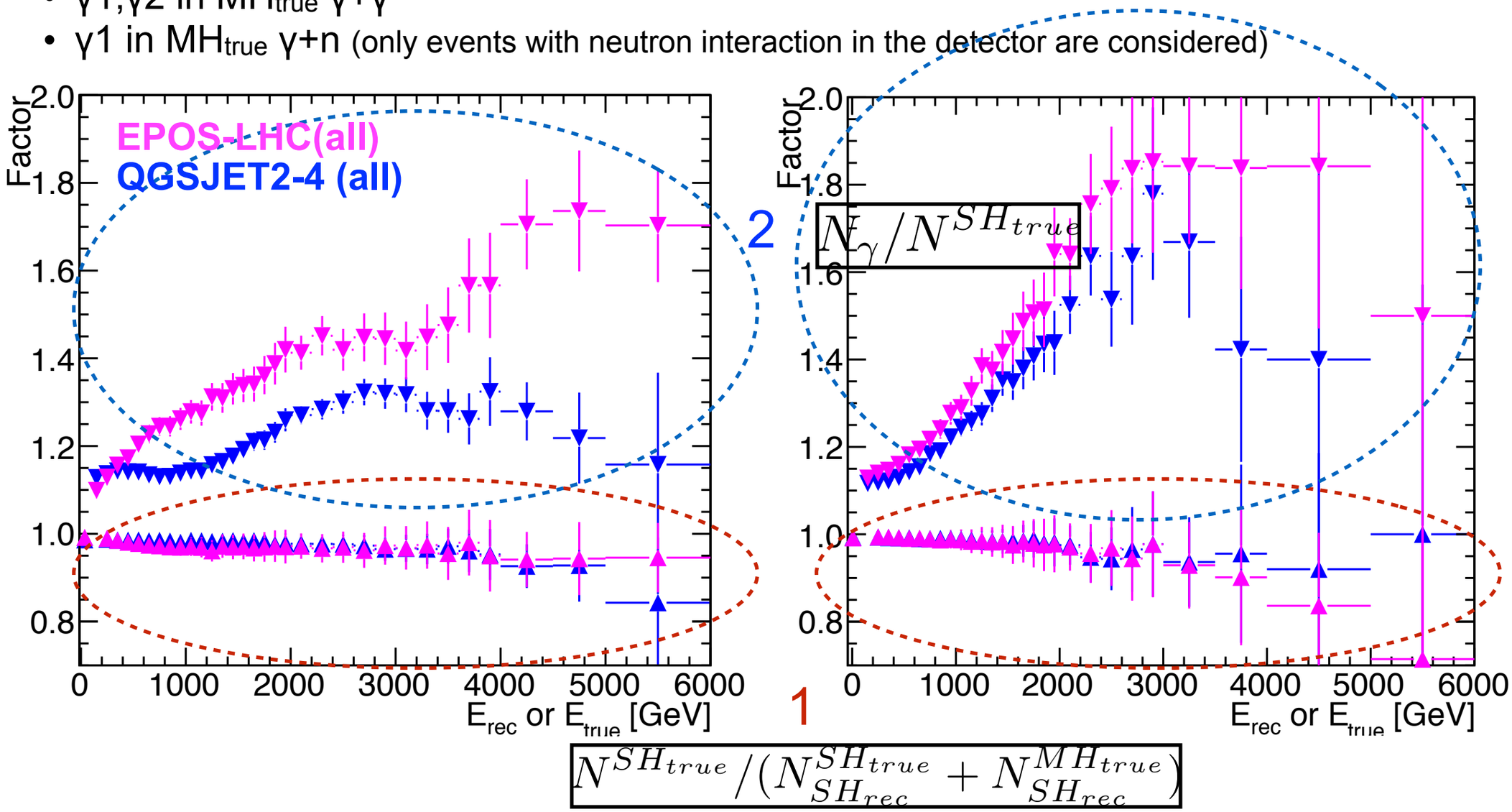




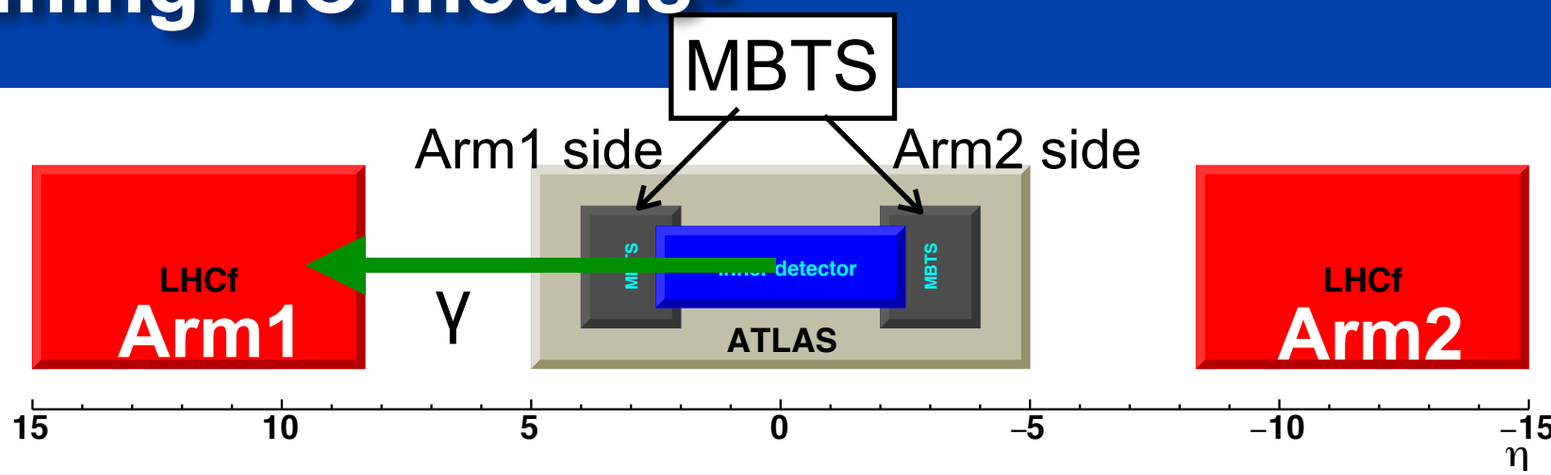
Two components of MH corrections

1 • Mis-reconstruction of events (Detector performance+MH rate)
- SH_{true} photon → MH_{rec} photon (survival efficiency ~99%)
- MH_{true} γ+γ → SH_{rec} photon (identification efficiency ~98% in > 3TeV)
- MH_{true} γ+n → SH_{rec} photon (only events with neutron interaction in the detector are considered)

2 • Contribution of photons in MH_{true} events (MH rate) $N_\gamma/N^{SH_{true}}$
- γ1,γ2 in MH_{true} γ+γ
- γ1 in MH_{true} γ+n (only events with neutron interaction in the detector are considered)



Correction: SD+DD → SD (DD)
-Tuning MC models-



- MBTS Hits

B: Arm1 γ & $N_{MBTS\ Arm1}$>0 & $N_{MBTS\ Arm2}$ =0 ⇒ SD ($\log\xi_{X1}$~-5.0) + DD ($\log\xi_{X1}$~-5.0, $\log\xi_{X2}$<-5.5)

C: Arm1 γ & $N_{MBTS\ Arm1}$=0 & $N_{MBTS\ Arm2}$ >0 ⇒ DD ($\log\xi_{X1}$<-5.5, $\log\xi_{X2}$~-5.0)

D: Arm1 γ & $N_{MBTS\ Arm1}$>0 & $N_{MBTS\ Arm2}$ >0 ⇒ DD ($\log\xi_{X1}$~-5.0, $\log\xi_{X2}$~-5.0)

N_{MBTS}: the number of hit MBTS segments

Then, calculate X from

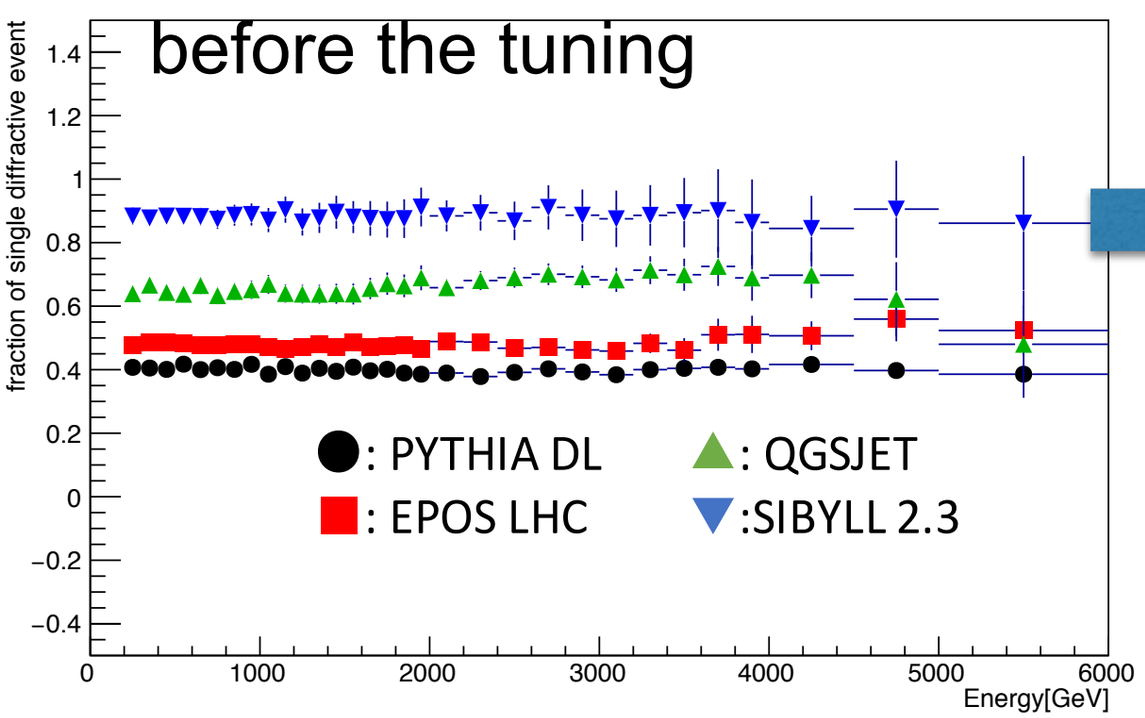
$$\frac{N_B^{Data}}{N_C^{Data}+N_D^{Data}} = \frac{N_B^{MC'}}{N_C^{MC'}+N_D^{MC'}}$$

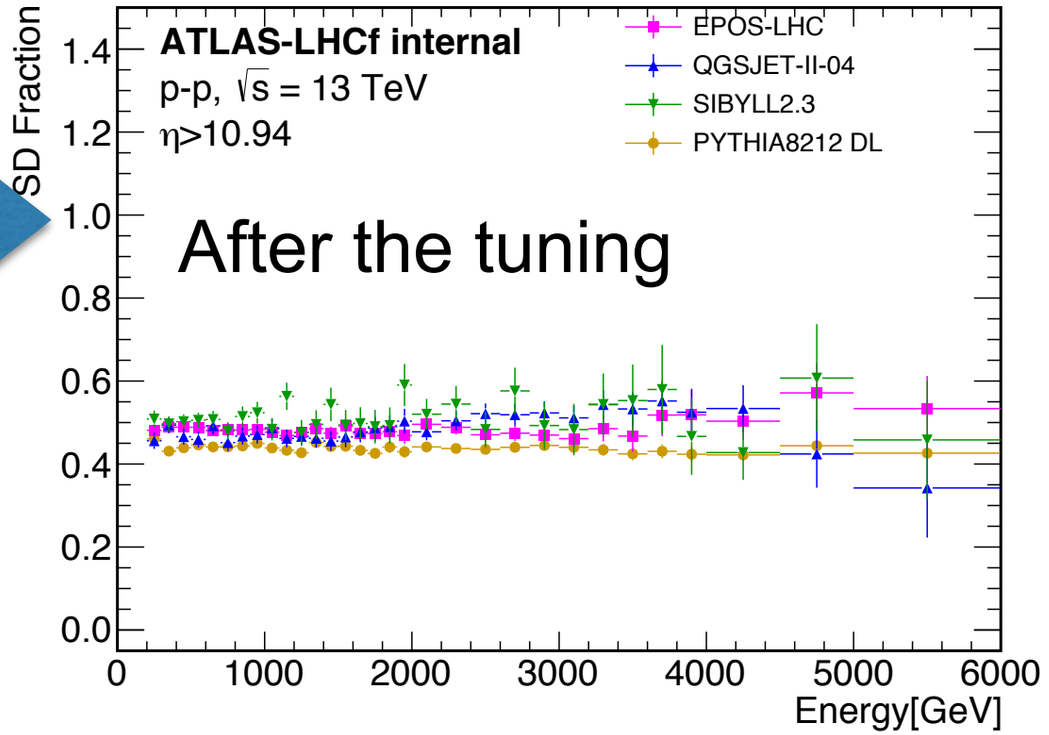
Note)
The MBTS response was emulated as a function of $\log\xi_X$.
The LHCf detector response was considered in MC
N^{Data}: Raw Data
N^{MC}: MC true + MBTS response function + LHCf response

	B	C	D	B/(C+D)
PYTHIA DL	21578 (SD:11252,DD:	20821	5047	0.85
EPOS-LHC	10011(SD:5233,DD:4778)	8639	1816	0.93
QGSJET	6994 (SD:4958,DD:2036)	2401	1781	1.74
SIBYLL 2.3c	7256 (SD:6748,DD508)	1080	392	5.21
Data	1539	802	622	1.08

Correction: SD+DD → SD (DD)
-Results-

$$C_{SD(DD)} = \frac{N^{MC,SD(DD)}_{N_{ch}=0}}{N^{MC,SD+DD}_{N_{ch}=0}}$$





Model discrepancy was suppressed well