ATALS-LHCf joint analysis Single diffractive fraction

11/26 LHCf collaboration meeting

Ken Ohashi

LHCf – ATLAS joint analysis

- Conf. note (Nov. 2017)
  - LHCf photon spectrum with ATLAS inner tracker veto
- Next goal
  - LHCf photon spectrum produced by **single diffractive** with $\log(\xi) < -5$.
  - Correction factor:
    - $C^{\log_{10}\xi}$: Nch=0 → $\log_{10}\xi$ event selection
    - $C^{C\tau}$: c*tau <140 m → c*tau <1cm (+ magnet effect)
    - C^{SD} : **single diffractive fraction in ATLAS veto spectrum**.
  - In this presentation, I report details about C^{SD}

content

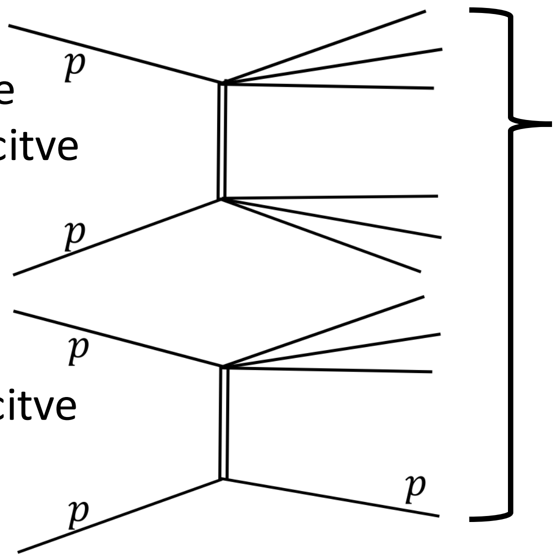
- the effect of diffractive events on the air shower development (using COSMOS 8.035)
- the detail of Single diffractive fraction analysis

diffractive events

<u>In this analysis, we focus on diffractive events</u>

double diffracitve (DD)

single diffracitve (SD)



<u>diffractive events</u>
20-30% of inelastic collisions
diffractive event has large rapidity gap.

Non-diffractive events (ND):
events other than diffractive events

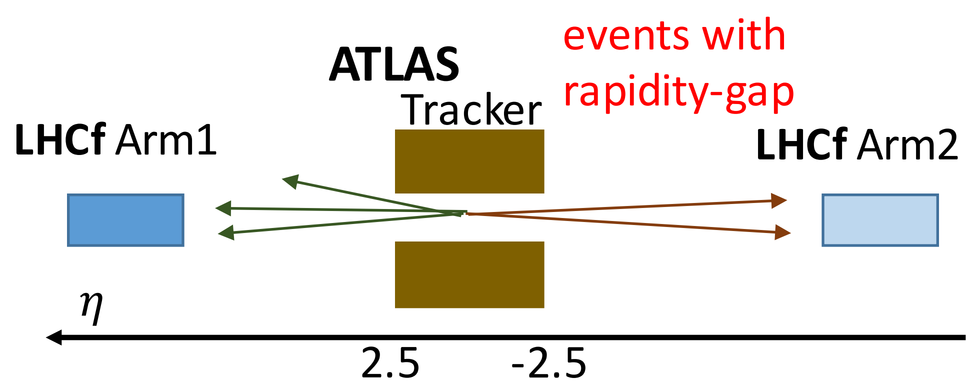
<u>diffractive mass and rapidity gap</u>

$$M_X^2 = \left(\sum_i p_{i,X}\right)^2 \sim s\, e^{-\Delta\eta}$$

Δη **:Rapidity gap,** s=E_{cm}^2

<u>In conf. note of ATLAS-LHCf joint analysis</u>

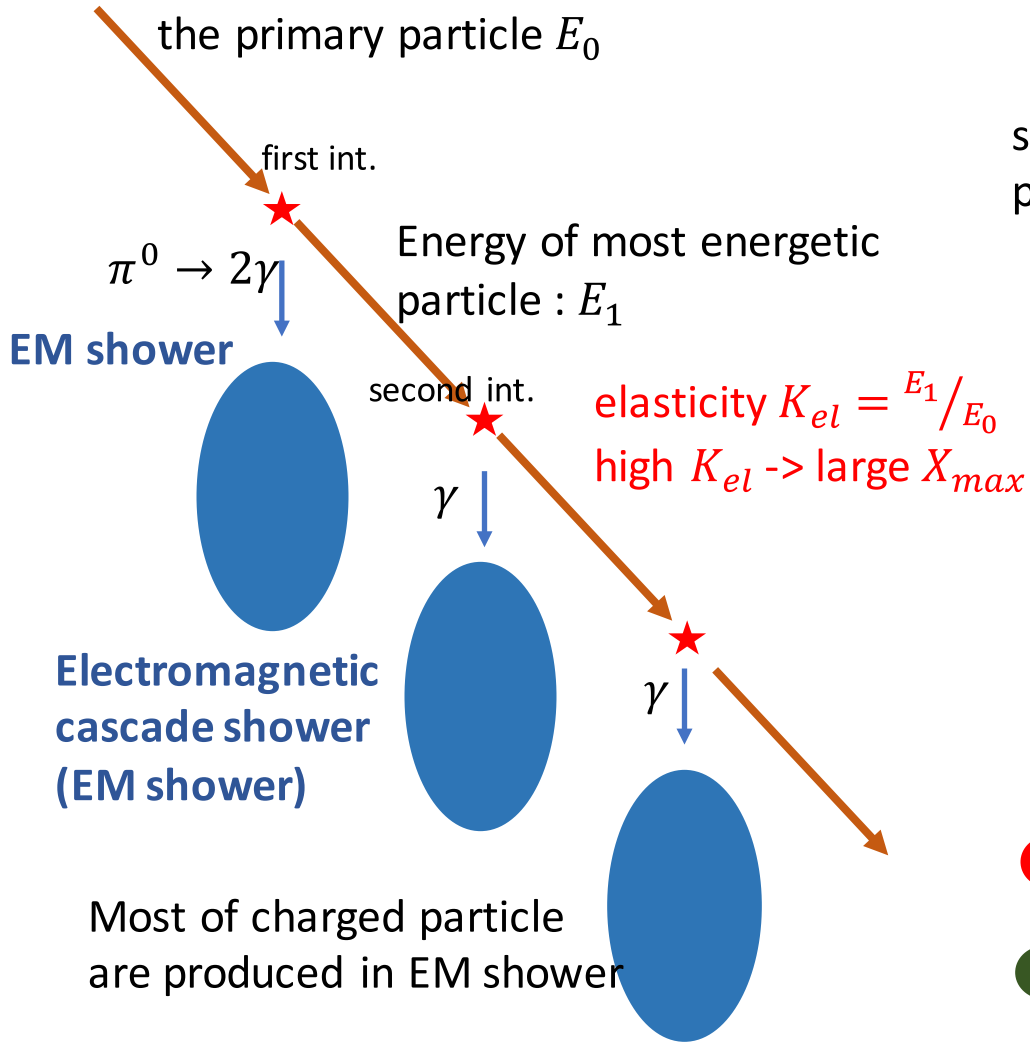
Select diffractive events using ATLAS-Inner tracker which cover $|\eta| < 2.5$.



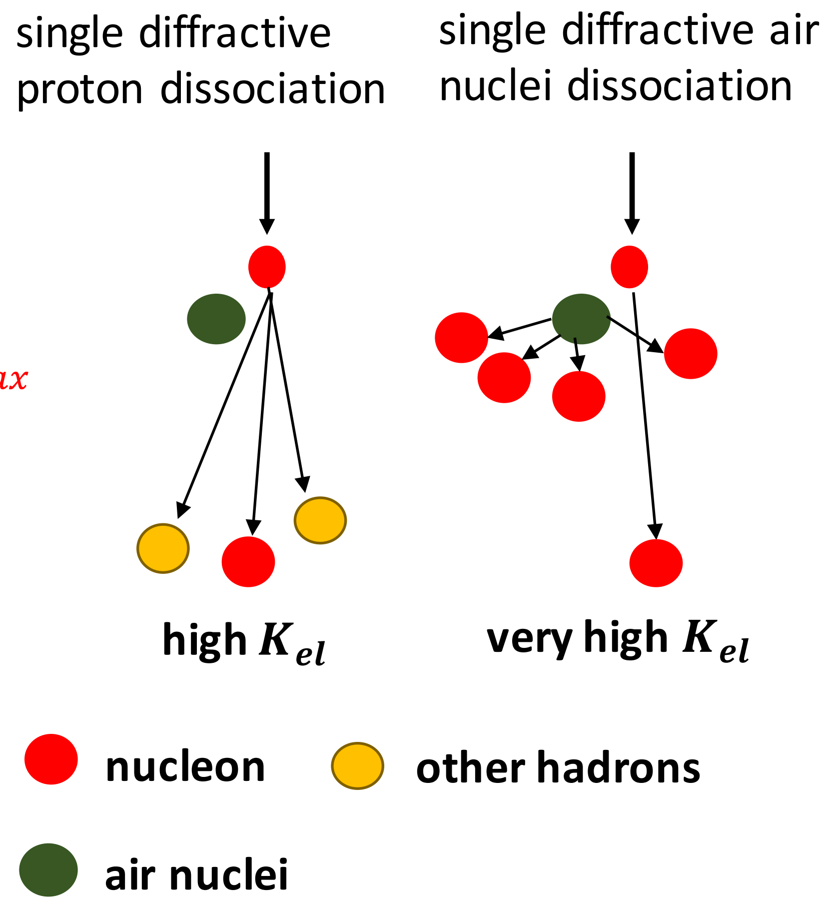
the effect of diffractive events on the air shower development

interactions in air shower

toy model of Air shower



diffractive events : high elasticity



the effect of diffractive events on the shower development

Air shower simulation

- using the air shower simulation package COSMOS
- 50000 events (30000 events for EPOSLHC)
- 10^{15} eV, proton ($\sqrt{s_{NN}} = 1.3$ [TeV])
- diffractive flag from the first interaction
- simulate shower development

From the first interaction information,

1. divide events into 4 or 5 type
   - Non-diff, Single diff. with projectile proton dissociation, Single diff. with target air nucleon dissociation, double diff, central diff. (EPOS only)
2. calculate diffractive mass of SD (proton dissociation)

the effect of diffractive events
1. fraction of single diffraction

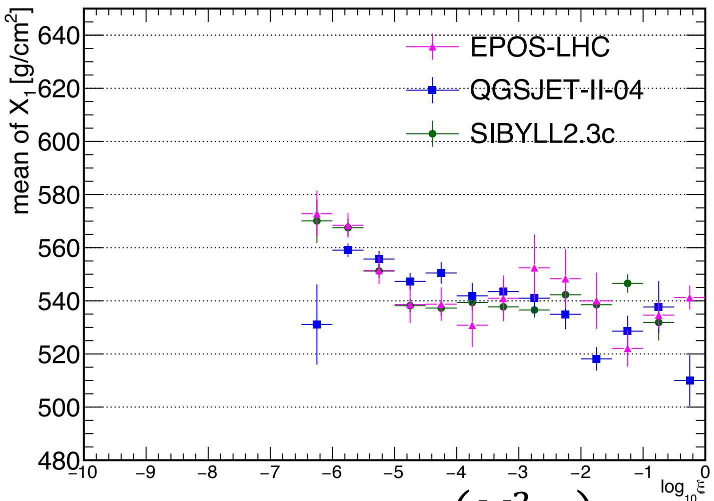
		Non-diffractive	SD, projectile proton dis.	SD, target dis.	DD	CD	**total**
SIBYLL 2.3c	mean X_{max}	577.0	609.9	648.1	605.7		583.8
	fraction [%]	84.2	10.5	4.2	1.1		
QGSJet II-04	mean X_{max}	561.5	612.4	634.8	602.8		569.9
	fraction [%]	84.6	7.2	4.2	4.0		
EPOS LHC	mean X_{max}	565.2	613.8	634.9	605.9	624.1	576.0
	fraction [%]	78.9	4.6	5.0	9.1	2.4	

Unit of mean Xmax : $[g/cm^2]$

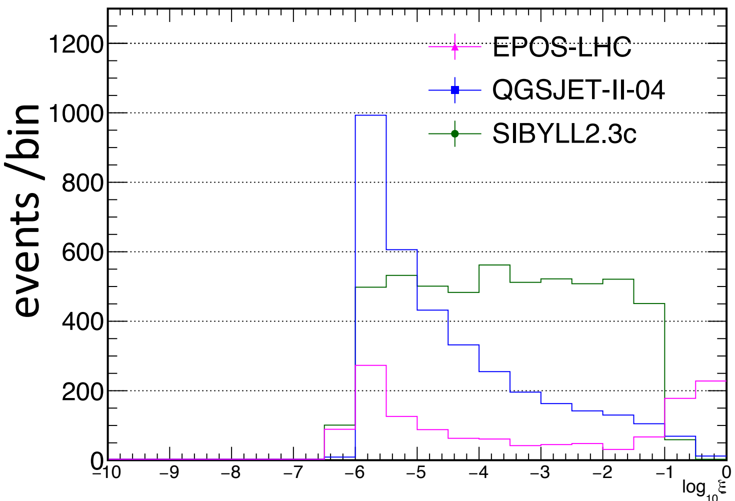
the effect of diffractive events 2. diffractive mass

projectile single diffractive (proton dissociation)

p- Air, $\sqrt{s_{NN}} = 1.3$ [TeV]



$$\log_{10}\xi_X = \log_{10}\left(M_X^2/s\right)$$



$$\log_{10}\xi_X = \log_{10}\left(M_X^2/s\right)$$

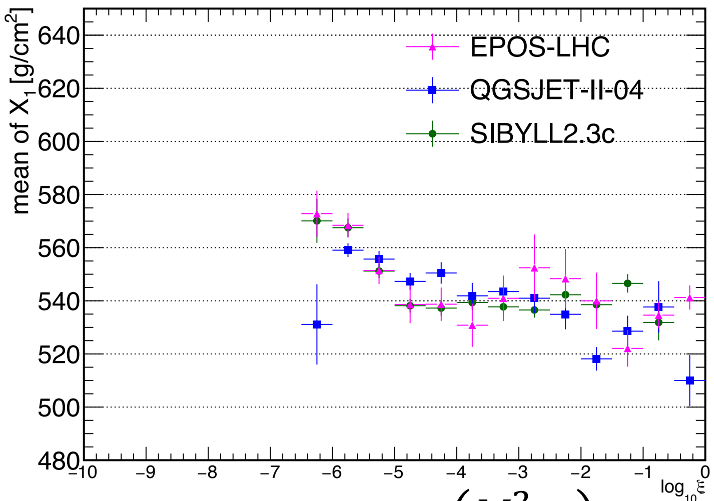
$X_1 = X_{\max} - X_0$,
X_0 : depth of the first interaction

the shower development is deep at low-mass region, where model discrepancy is large.

the effect of diffractive events
2. diffractive mass

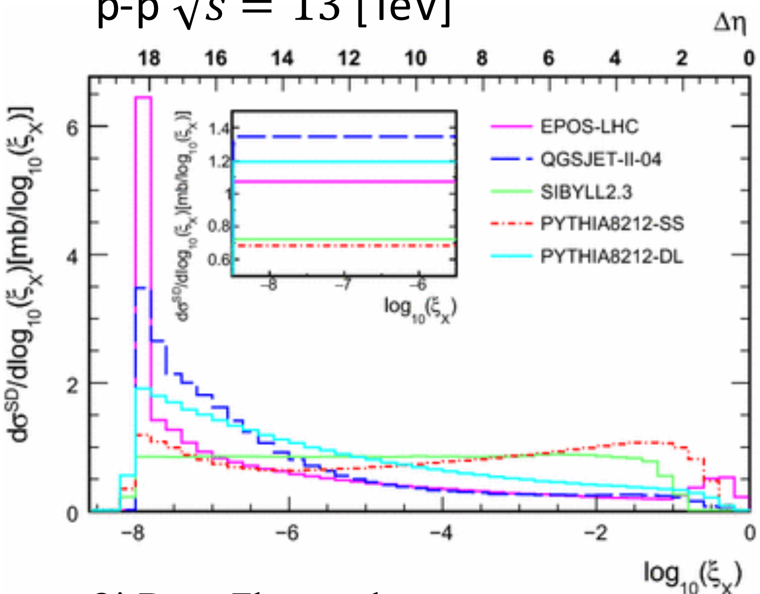
projectile single diffractive (proton dissociation)

p- Air, $\sqrt{s_{NN}} = 1.3$ [TeV]



$$\log_{10} \xi_X = \log_{10} \left(M_X^2 / s \right)$$

p-p $\sqrt{s} = 13$ [TeV]



Qi-Dong Zhou et al.,
Eur. Phys. J. C **77** 212 (2017)

$X_1 = X_{\max} - X_0$,
X_0 : depth of the first interaction

the shower development is deep at low-mass region,
where model discrepancy is large.

Single diffractive fraction

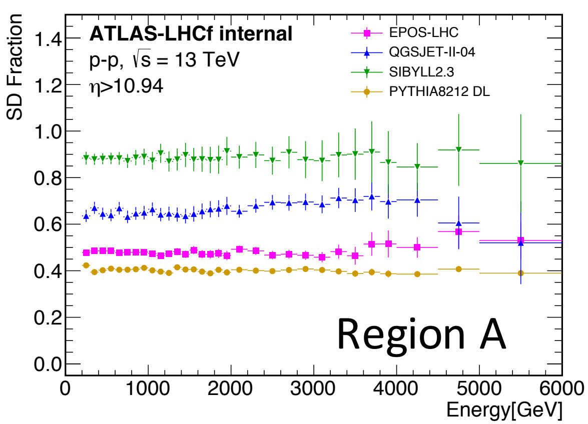
LHCf – ATLAS joint analysis

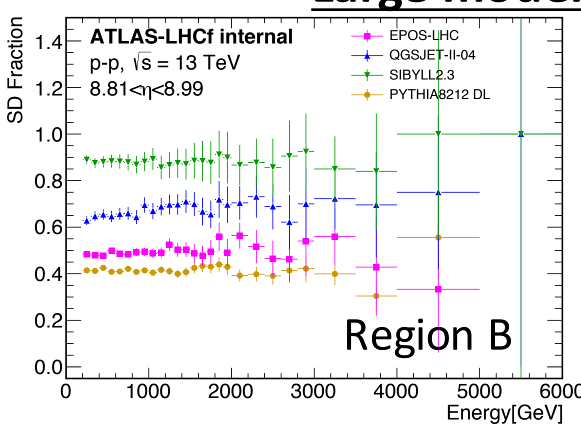
- C^{SD} : single diffractive fraction in ATLAS veto spectrum.
  - MC-based correction factor
    - small statistics of Arm1-Arm2 coincidence events
  - In MC, SD fraction is 0.4 (PYTHIA) or 0.9 (SIBYLL)
  - Energy dependence of SD fraction is small, and SD fraction of Region A is very similar with that of Region B

SD fraction of photon spectrum with ATLAS veto

<u>Large model discrepancy</u>

fraction of single diffractive events





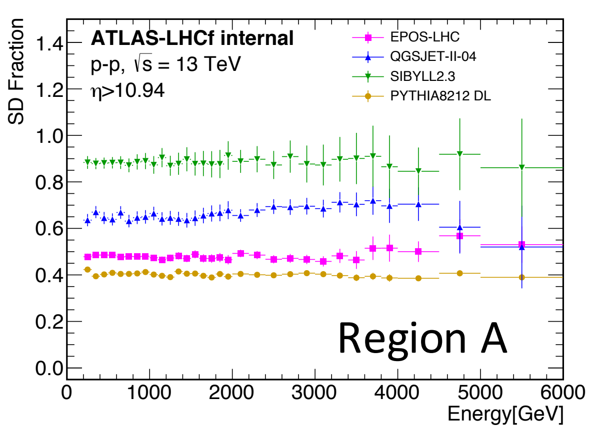
LHCf – ATLAS joint analysis

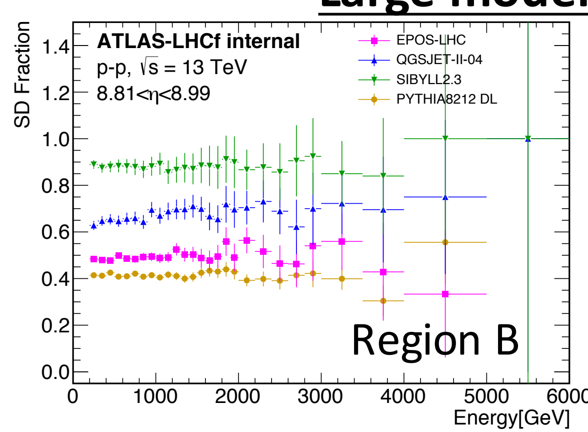
- C^{SD} : single diffractive fraction in ATLAS veto spectrum.
  - Energy dependence of SD fraction is small, and SD fraction of Region A is very similar with that of Region B
  - => ignore energy dependence of SD fraction, and assume that SD fraction is same between Region A and B

SD fraction of photon spectrum with ATLAS veto

Large model discrepancy

fraction of single diffractive events

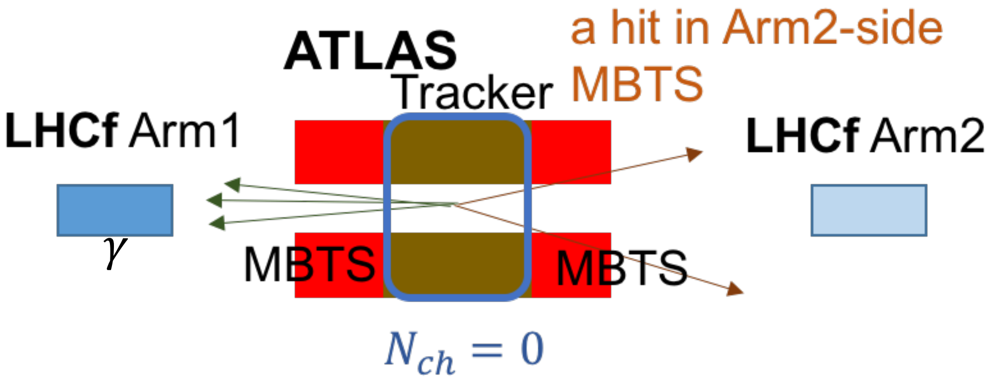




concept

To measure single diffractive fraction, we introduce ATLAS Minimum-bias trigger scintillator (MBTS).

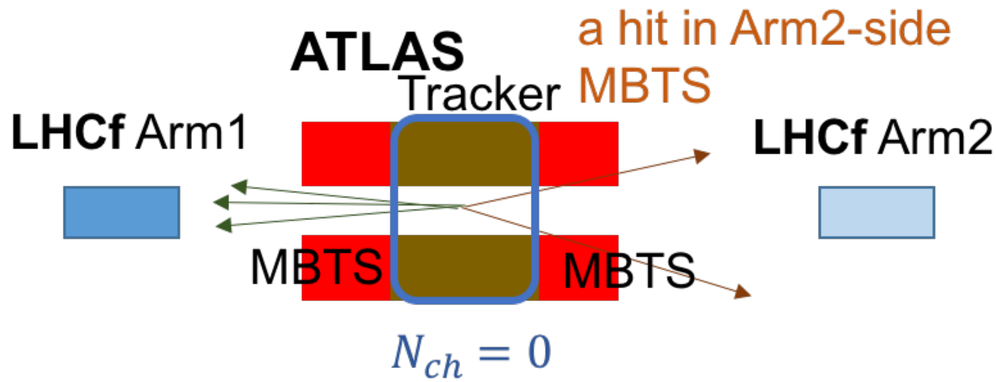
If we measure particles created by dissociation with both side of rapidity-gap, that event is a double diffractive event.



But, MBTSs only cover part of the gap between ATLAS-Inner tracker and LHCf detectors, so we unfold detector effects using MC simulation.

concept

Using MBTS, we can select part of double diffractive events.



Exp. data

Two samples DD-enriched and SD-enriched

=

Response Matrix R^{MBTS}

- MBTS detection efficiency
- photon production
- LHCf detector response

×

without detector effect

true $N_{SD}^{N_{ch}=0}$ and $N_{DD}^{N_{ch}=0}$

Inverse matrix

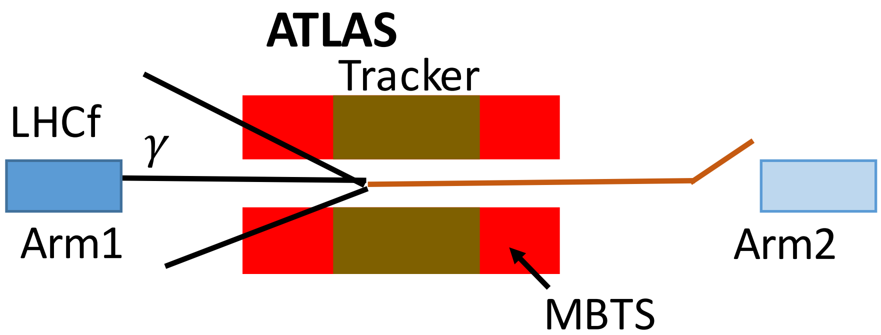
Unfolding

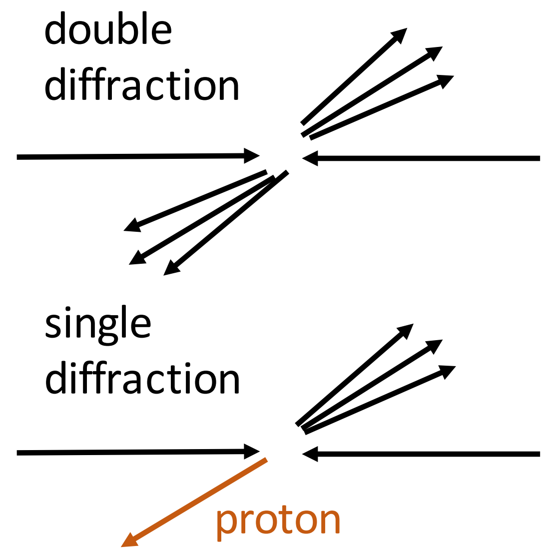
We want to know

SD fraction C^{SD}

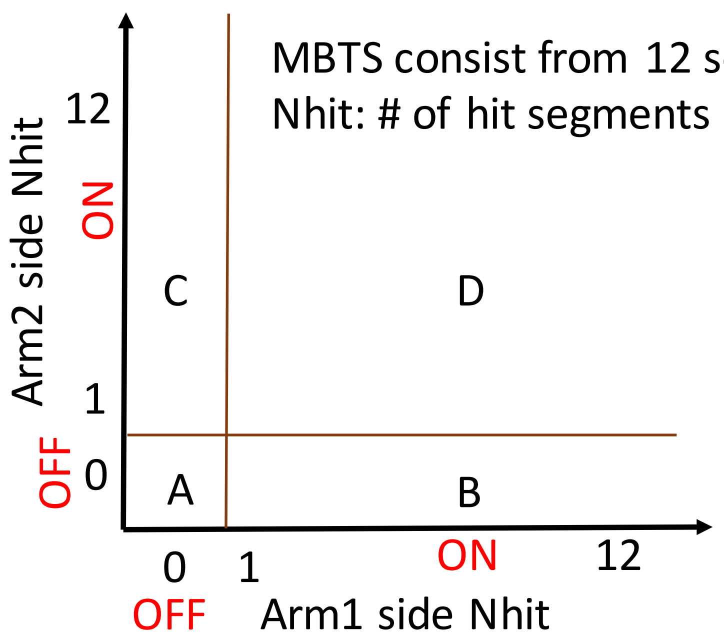
ATLAS MBTS

ATLAS Minimum-bias trigger scintillator(MBTS) is forward detectors which cover $2.08 < |\eta| < 3.86$.





MBTS event selection



MBTS consist from 12 segments.
Nhit: # of hit segments

<u>Two samples</u>
sample I : B (SD-enriched)
sample II: C + D (DD-enriched)

A: Arm1side OFF, Arm2side OFF
(**<u>SD and DD mixed sample</u>**)
B: Arm1side ON, Arm2side OFF
(**<u>SD and DD mixed sample</u>**)
C:Arm1side OFF, Arm2side ON
(**<u>DD sample</u>**)
D:Arm1side ON, Arm2side ON
(**<u>DD sample</u>**)

method

2x2 matrix

generator level

$$\begin{pmatrix} N_{DD}^{N_{ch}=0} \\ N_{SD}^{N_{ch}=0} \end{pmatrix} = (R_{MC}^{MBTS})^{-1} \begin{pmatrix} N_{I}^{MBTS} \\ N_{II}^{MBTS} \end{pmatrix}$$

response

input

unfolding

inverse matrix

with detector response

after unfolding

$N_{SD}^{unfolded}, N_{DD}^{unfolded}$

$$C^{unfold} = \frac{N_{SD}^{unfolded}}{N_{SD}^{unfolded} + N_{DD}^{unfolded}}$$

ND correction

$$C^{SD} = C^{unfold} \times \frac{N_{MC,SD}^{Nch=0} + N_{MC,DD}^{Nch=0}}{N_{MC,SD}^{Nch=0} + N_{MC,DD}^{Nch=0} + N_{MC,ND}^{Nch=0}}$$

for energy dependency

parameter to shift the ratio of SD in MC

Non-diff. subtraction

assumption:

all ND events -> MBTS selection D

Exp. data

$N_{I}^{Data}, N_{II}^{Data}$

I: Nch=0 and MBTS selection B and LHCf Arm1 photon hit (Region A)

II: Nch=0 and MBTS selection C&D and LHCf Arm1 photon hit (Region A)

For energy dependence

In unfolding calculation, we ignore energy dependence.
For energy dependence, we introduce parameter X.

$$C^{SD} = \frac{X \int N_{SD}(E)dE}{\int N_{all}(E)dE}$$

Then, scale true SD fraction using X and get $C_A^{SD}(E)$ for region A.
For region B, assume same parameter X and calculate $C_B^{SD}(E)$ for region B.

test of unfolding

2x2 matrix

$$\begin{pmatrix} N_{DD}^{N_{ch}=0} \\ N_{SD}^{N_{ch}=0} \end{pmatrix} = (R_{MC}^{MBTS})^{-1} \begin{pmatrix} N_{I}^{MBTS} \\ N_{II}^{MBTS} \end{pmatrix}$$

generator level

after unfolding

unfolding

inverse matrix

with detector response

$$C^{SD} = \frac{X \int N_{SD}(E)dE}{\int N_{all}(E)dE}$$

model for response matrix

Non-diff. subtraction

assumption:

all ND events ->

MBTS selection D

result: C_A^{SD}

Input

test of unfolding

Using MC simulation with detector for instead of exp. data, check the performance of this method.

If method is ideal, all results with same input should be same despite of the model for response matrix.

MC simulation (instead of data)

N_I^{Data}, N_{II}^{Data}

I: Nch=0 and MBTS selection B and LHCf Arm1 photon hit (Region A)

II: Nch=0 and MBTS selection C&D and LHCf Arm1 photon hit (Region A)

model for input

test of unfolding

Calculate SD fraction after ND correction using MC simulation as input.
(substitute MC simulation for Exp. data)

The average of SD fraction

model for response

model for input

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL
PYTHIA	0.404	0.444	0.487	0.488

If the method is ideal, results with different model for response matrix should be same, but the results are not same.

test of unfolding

Calculate SD fraction after ND correction using MC simulation as input.
(substitute MC simulation for Exp. data)

The average of SD fraction

model for response

model for input

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL
PYTHIA	0.404	0.444	0.487	0.488
EPOSLHC	0.436	0.484	0.530	0.517
QGSJET	0.591	0.641	0.670	0.649
SIBYLL	0.862	0.891	0.906	0.883

With other inputs, results with different model for response matrix are different. And these difference has clear tendency, the results with pythia response always show smaller results compare to EPOS or QGSJET.
=> This method has some biases due to the model for response matrix.
This bias should be included in systematic uncertainty.

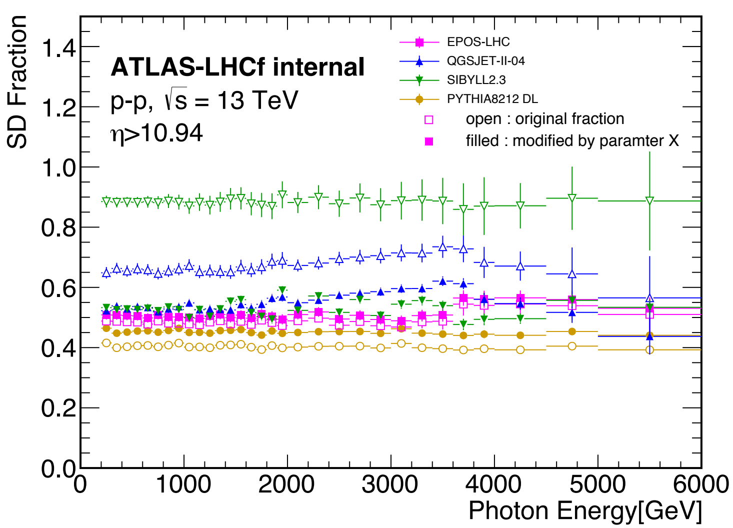
Results

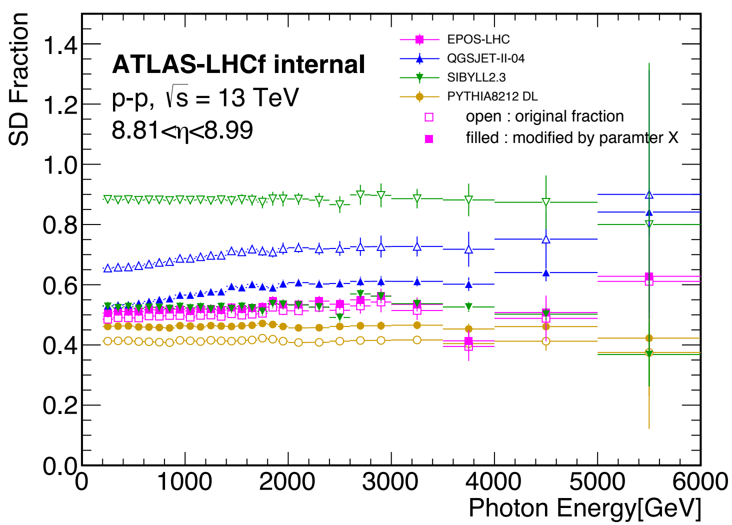
The average of SD fraction
Using exp. data as input of unfolding

model for response

Region A

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL
Data	0.452	0.502	0.546	0.531





Bias of method

Bias of SD fraction

C^{SD}: the fraction of SD in Nch=0 events
(Nch=0 and LHCf photon (**generator level**))

Region A

response

input

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL	TRUE
PYTHIA	0.404	0.444	0.487	0.488	0.404
EPOSLHC	0.436	0.484	0.530	0.517	0.484
QGSJET	0.591	0.641	0.670	0.649	0.670
SIBYLL	0.862	0.891	0.906	0.883	0.883

$$\kappa = \frac{C_{results}^{SD} - C_{true}^{SD}}{C_{true}^{SD}}$$

$C_{results}^{SD}$: calculated results

C_{true}^{SD}: true SD fraction

κ [%]	PYTHIA	EPOSLHC	QGSJET	SIBYLL
PYTHIA	0.0	10.0	20.5	20.8
EPOSLHC	-9.9	0.0	9.5	6.8
QGSJET	-11.7	-4.3	0.0	-3.1
SIBYLL	-2.4	0.8	2.6	0.0

To calculate syst. uncertainty from the bias of method

Region A

response

input

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL	TRUE
PYTHIA	0.404	0.444	0.487	0.488	0.404
EPOSLHC	0.436	0.484	0.530	0.517	0.484
QGSJET	0.591	0.641	0.670	0.649	0.670
SIBYLL	0.862	0.891	0.906	0.883	0.883

Introduce Δ

$$\Delta = \frac{C_{true}^{SD} - C_{results}^{SD}}{C_{results}^{SD}}$$

$C_{results}^{SD}$: calculated results

C_{true}^{SD}: true SD fraction

Δ: Size of difference from $C_{results}^{SD}$

Δ [%]	PYTHIA
PYTHIA	0.0
EPOSLHC	11.0
QGSJET	13.3
SIBYLL	2.5
Bias upper	13.3
Bias lower	0.0

upper one and lower one

To calculate syst. uncertainty from the bias of method

Region A

response

input

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL	TRUE
PYTHIA	0.404	0.444	0.487	0.488	0.404
EPOSLHC	0.436	0.484	0.530	0.517	0.484
QGSJET	0.591	0.641	0.670	0.649	0.670
SIBYLL	0.862	0.891	0.906	0.883	0.883

Introduce Δ

$$\Delta = \frac{C_{true}^{SD} - C_{results}^{SD}}{C_{results}^{SD}}$$

$C_{results}^{SD}$: calculated results

C_{true}^{SD}: true SD fraction

Δ: Size of difference from $C_{results}^{SD}$

Δ [%]	PYTHIA	EPOSLHC	QGSJET	SIBYLL
PYTHIA	0.0	-9.1	-17.0	-17.2
EPOSLHC	11.0	0.0	-8.7	-6.4
QGSJET	13.3	4.4	0.0	3.2
SIBYLL	2.5	-0.8	-2.5	0.0
Bias upper	13.3	4.4	0.0	3.2
Bias lower	0.0	-9.1	-17.0	-17.2

upper one and lower one

To calculate syst. uncertainty from the bias of method

Region A

response model results with exp. data

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL
Data	0.452	0.502	0.546	0.531

Bias

response model

Δ [%]	PYTHIA	EPOSLHC	QGSJET	SIBYLL
Bias Max.	13.3	4.4	0.0	3.2
Bias Min.	0.0	-9.1	-17.0	-17.2
Result +Bias upper	result + 13.3 % 0.512	0.524	0.546	0.548
Result + Bias lower	0.452	0.456	result – 17.0 % 0.453	0.440

syst. uncertainty from the bias of method

Region A

response model

ND subtraction: method 2.

C_A^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL	Method A
Data	0.452	0.502	0.546	0.531	0.508
Result +Bias upper	0.512	0.524	0.546	0.548	Max. of 'Result + Bias upper' 0.548
Result + Bias lower	0.452	0.456	0.453	0.440	Min. of 'Result + Bias lower' 0.440

largest one

lowest one

center value: simple average (just for simplicity)
in real case, weighted average
Bias: Maximum of 'Result + Bias upper'
and Minimum of 'Result + Bias lower'

uncertainties

uncertainty

- uncertainty
  - MBTS response
  - LHCf response function
  - Non-diffractive events
  - model discrepancy + bias of the method
  - statistical error

syst. uncertainty

- MBTS response function
  - MC model for MBTS response function calculation
  - MBTS threshold
- LHCf response function
  - difference between response function and full simulation
- Non-diffractive events
  - Non-diffractive sys. uncertainty is calculated with extreme assumption
  - From ATLAS full simulation, almost 100 % of Non-diff. events make a hit in both MBTS. We assume 100 % and take syst. uncertainty of ND events as 80% of events make a hit in a MBTS.

uncertainties of C_A^{SD} response

	PYTHIA	EPOSLHC	QGSJET	SIBYLL
C_A^{SD}	0.452	0.502	0.546	0.531
statistical (+/-) **[%]**	2.37	2.84	2.00	2.31
MBTS threshold upper **[%]**	2.62	2.72	1.72	1.45
lower**[%]**	-1.84	-1.13	-2.07	-0.99
Model for MBTS response function **[%]**	1.78	2.62		
LHCf response func. upper**[%]**	0.06	0.19	-0.04	0.08
lower**[%]**	-0.21	-0.65	-0.02	-0.40
Non-diffractive **[%]**	-0.67	-1.79	-2.95	-0.91
total upper **[%]**	3.95	4.73	2.64	2.72
total lower**[%]**	3.08	3.60	4.12	2.70

Note: As shown in p.24, C_A^{SD} **average**

Data	0.508	
biases and model discrepancies: upper	0.548	+7.9[%]
biases and model discrepancies: lower	0.440	-13.4[%]

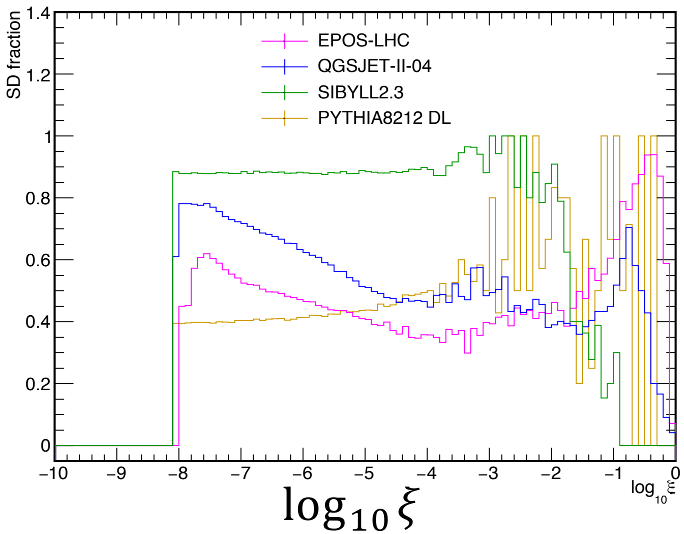
summary

- For final result, we need Single diffractive fraction of ATLAS veto spectrum, but there is large model discrepancy in MC.
- To measure SD fraction, we introduce ATALS Minimum-bias trigger scintillator (MBTS), and unfold detector effects.
- SD fraction is about 0.5.
- the study of uncertainty is on going and still need some update.

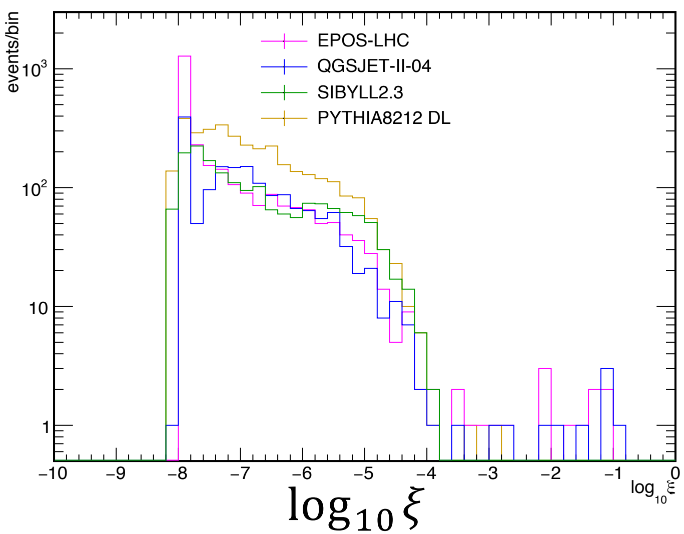
backup

single diffractive fraction

true single diffractive fraction with Nch=0



histogram of single diffractive events with Nch=0 and LHCf Arm1 photon-like hit



The fraction of single diffraction is diffractive-mass dependent.
In our analysis, most of detected events are low-mass events ($\log_{10}\xi < -7$).

detail of unfolding

SD fraction measurement

- Measure SD (DD) fraction based on the data and MC simulation.
- Using ATLAS-MBTS detectors, we divide exp. data into the DD-enriched sample and the SD-enriched sample, and "unfold" SD fraction using response matrixes calculated by MC simulation.
- update from the report at analysis meeting on Jul. 25
    - New method: Unfolding (An Idea and calculation is same as previous, but easier to understand)

Non-diff. subtraction

assumption: all Non-diff. events make a hit in MBTSs (MBTS selection D)

- two method
  - Method 1. $N_{II}^{MBTS} = N_{II}^{Data} \times R$
    - $R = \frac{N_{MC,ND}^{MBTS\,II}}{N_{MC,SD}^{MBTS\,II} + N_{MC,DD}^{MBTS\,II} + N_{MC,ND}^{MBTS\,II}}$
  - Method 2. $N_{II}^{MBTS} = N_{II}^{Data} - N^{ND}$
    - $N^{ND} = N_{Nch=0}^{Data} \times \frac{N_{MC,ND}^{Nch=0}}{N_{MC,SD}^{Nch=0} + N_{MC,DD}^{Nch=0} + N_{MC,ND}^{Nch=0}}$

Input – Response test
To decide Non-diff. subtract method

C^{SD} : the fraction of SD in Nch=0 events
(LHCf Arm1 photon-like)

method 1.

response

input

C^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL
PYTHIA	0.402	0.449	0.483	0.498
EPOSLHC	0.429	0.478	0.509	0.520
QGSJET	0.587	0.639	0.655	0.653
SIBYLL	0.857	0.880	0.879	0.877

method 2.

response

input

C^{SD}	PYTHIA	EPOSLHC	QGSJET	SIBYLL
PYTHIA	0.402	0.441	0.471	0.474
EPOSLHC	0.431	0.478	0.511	0.501
QGSJET	0.589	0.638	0.655	0.637
SIBYLL	0.861	0.888	0.895	0.877

difference $C^{SD} - C^{SD}_{true}$ (% of C^{SD}_{true})

LHCf Arm1 photon-like

method 1.

response (columns) / **input** (rows)

C^{SD}-true	PYTHIA	EPOSLHC	QGSJET	SIBYLL	C^{SD}_{true}
PYTHIA	0.02	11.71	20.17	23.90	0.4019
EPOSLHC	-10.26	-0.01	6.47	8.77	0.4781
QGSJET	-10.34	-2.40	0.04	-0.26	0.6547
SIBYLL	-2.31	0.32	0.20	-0.03	0.8772

method 2.

response (columns) / **input** (rows)

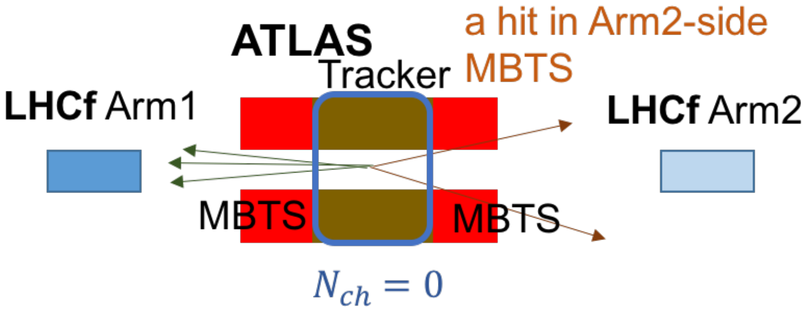
C^{SD}-true	PYTHIA	EPOSLHC	QGSJET	SIBYLL	C^{SD}_{true}
PYTHIA	0.02	9.72	17.19	17.93	0.4019
EPOSLHC	-9.85	-0.01	6.89	4.80	0.4781
QGSJET	-10.04	-2.56	0.04	-2.71	0.6547
SIBYLL	-1.85	1.23	2.03	-0.03	0.8772

=> Method 2 is better than method 1.

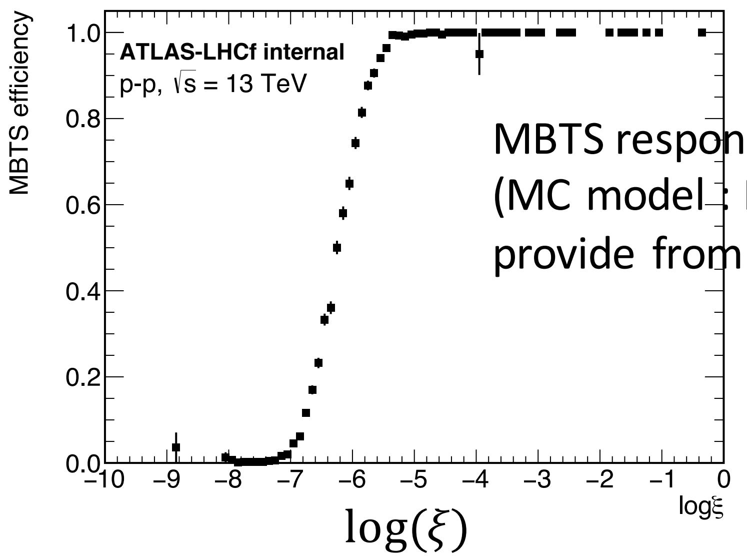
Bias?? Results with the PYTHIA response are smaller than others.

uncertainty

syst. uncertainty



- MBTS response function
  - MC model for MBTS response function
  - MBTS threshold
    - normal and sys up, down
    - 0.15 pC, 0.27pC (up) , 0.07pC (down)



MBTS response
(MC model : PYTHIA)
provide from ATLAS side.

LHCf response sys. uncertainty

difference between LHCf detector response and full simulation is already calculated by zhou-san.

$\kappa = \frac{a-b}{b}$,a: using Response, b: full simulation

Table 4: Parameter κ of each cases

Model	QGSJET-II-04		EPOS-LHC	
Fiducial area	Region A	Region B	Region A	Region B
Single photon	-0.0057	-0.0169	-0.0003	-0.0108
Single neutron	-0.0059	0.3785	0.0478	0.0766
Two photons	-0.0057	0.0231	-0.0057	-0.0175
Photon & hadron	-0.0537	0.0219	0.1964	-0.0376

Δ: ratio of full simulation to response function

$$\Delta = \frac{\mathrm{b}}{\mathrm{a}} = \frac{1}{1+\kappa}$$

EPOS LHC, Region A		
$N_B^{MC,SD}$	Single photon	3028
	Single neutron	94
	Two photon	99
	Photon & hadron	149
	total	4070

shift these number of events by Δ of each type

total number of events shift from 4070 to 4042.94 (EPOSLHC full simulation)

LHCf response sys. uncertainty

difference between Response and full simulation

$\kappa = \frac{a-b}{b}$,a: using Response, b: full simulation

calculated by zhou-san

Table 4: Parameter κ of each cases

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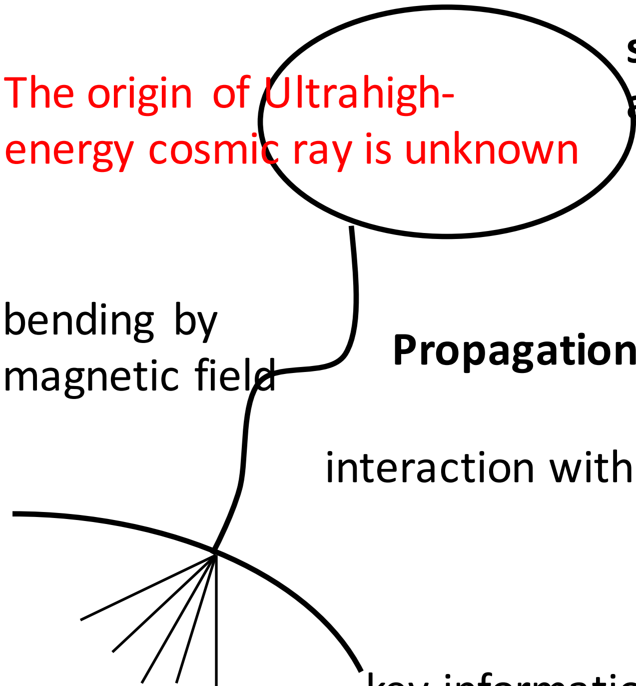
$$\Delta = \frac{b}{a} = \frac{1}{1+\kappa}$$

EPOS LHC Region A	normal	sys. modified (EPOSLHC)	sys. modified (QGSJET II-04)
$N_B^{MC,SD}$	4070	4042.94	4100.95
$N_B^{MC,DD}$	3726	3695.77	3755.9
$N_C^{MC,DD}$	5794	5696.29	5855.27
$N_D^{MC,DD}$	1390	1377.23	1401.55

ultra-high energy cosmic ray and air shower



The origin of Ultrahigh-energy cosmic ray is unknown

source acceleration

bending by magnetic field

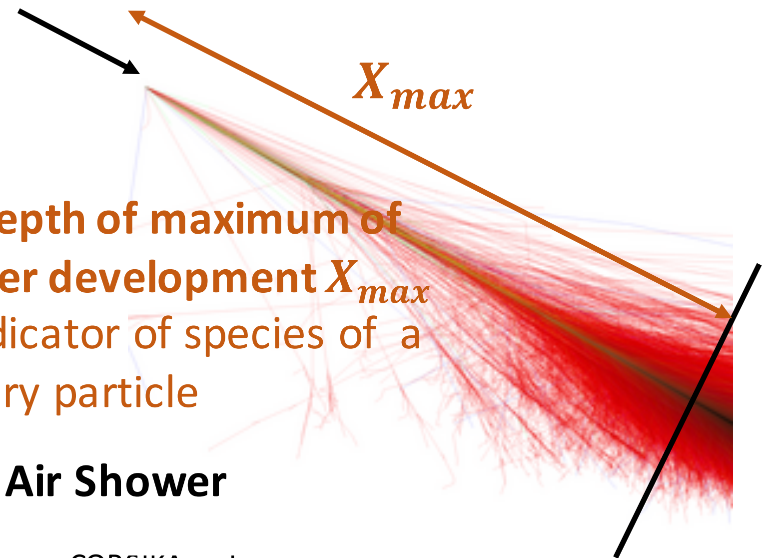
Propagation

interaction with γ_{CMB}

Air shower

key information of cosmic rays
- flux
- species of nuclei
- anisotropy (ultrahigh-energy)

a primary particle
proton or nuclei



X_{max}

the depth of maximum of shower development X_{max}
an indicator of species of a primary particle

Air Shower

CORSIKA web page
https://www-zeuthen.desy.de/~jknapp/fs/proton-showers.html

air shower simulation and data

mean X_{max} RMS of X_{max}

~20 $[\mathrm{g/cm^2}]$

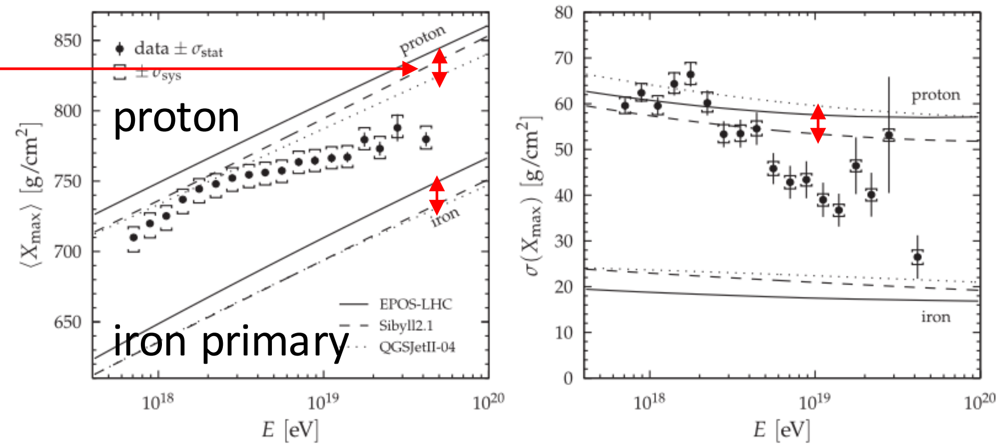


FIG. 13. Energy evolution of the first two central moments of the X_{max} distribution compared to air-shower simulations for proton and iron primaries [80,81,95–98].

A. Aab *et al.* (Pierre Auger Collaboration)
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the simulation of X_{max} has model discrepancy caused by hadronic interaction models,
that make difficult to interpret primary particles.