空気シャワー観測による宇宙線の起源探索勉強会

Introduction of the LHCf experiment

Nagoya University
Qidong ZHOU(周啓東)

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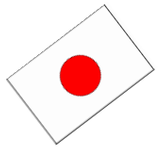
The LHCf Collaboration

*,**Y.Itow, *Y.Makino, *K.Masuda, *Y.Matsubara, *E.Matsubayashi, ***H.Menjo,
*Y.Muraki, *,**T.Sako, *K.Sato, * M.Shinoda, *M.Ueno, *Q.D.Zhou

*Institute for Space-Earth Environmental Research, Nagoya University, Japan
**Kobayashi-Maskawa Institute, Nagoya University, Japan
***Graduate School of Science, Nagoya University, Japan



K.Yoshida *Shibaura Institute of Technology, Japan*

T.Iwata, K.Kasahara, T.Suzuki, S.Torii

Waseda University, Japan

Y.Shimizu, T.Tamura *Kanagawa University, Japan*

N.Sakurai *Tokushima University, Japan*

M.Haguenauer *Ecole Polytechnique, France*

W.C.Turner *LBNL, Berkeley, USA*

O.Adriani, E.Berti, L.Bonechi, M.Bongi, G.Castellini, R.D'Alessandro, P.Papini, S.Ricciarini, A.Tiberio

INFN, Univ. di Firenze, Italy

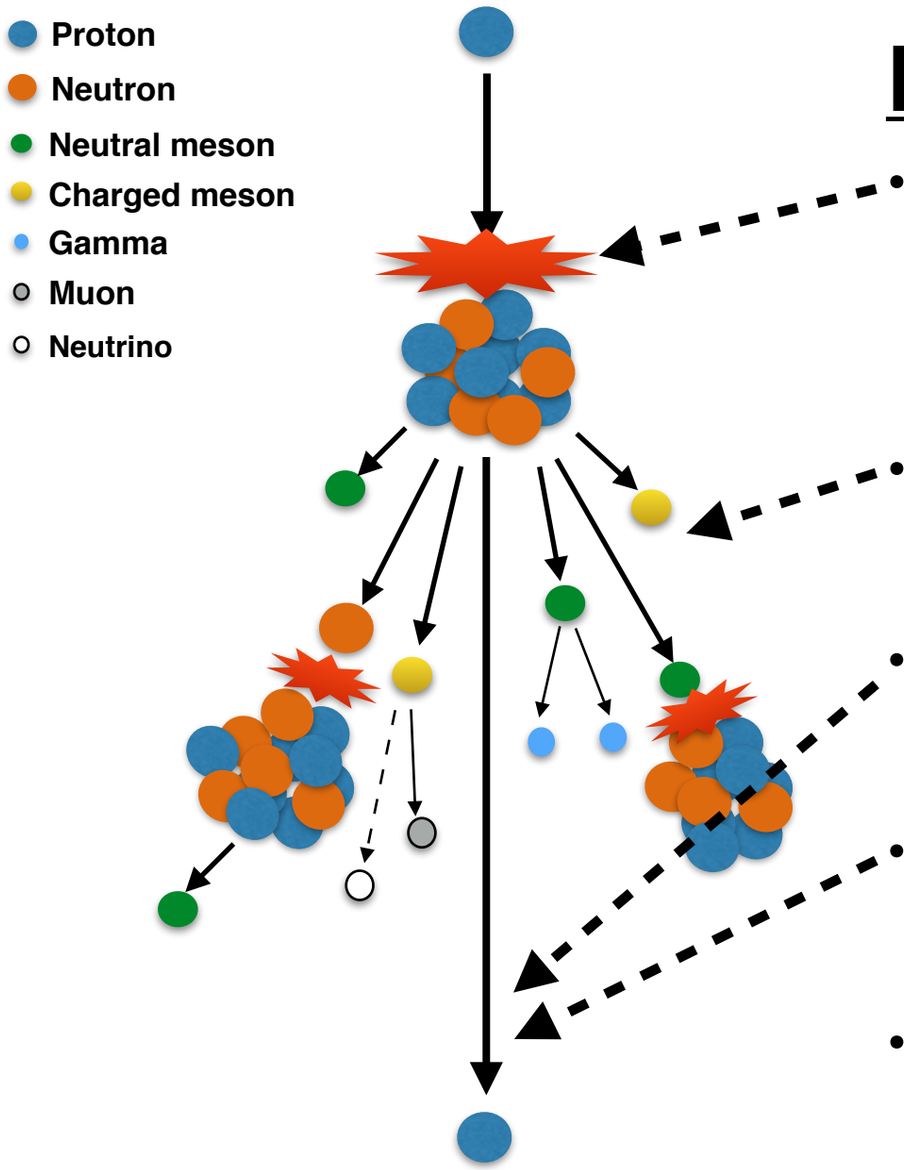
A.Tricomi *INFN, Univ. di Catania, Italy*

Outline

- ✦Introduction
  - ‣Parameters for calibrating hadronic interaction model
  - ‣LHCf experiment
- ✦LHCf detector performance
  - ‣Energy and position resolution
- ✦Analysis procedure
  - ‣PID, position, energy, multihit
- ✦Summary

What to be calibrated by accelerators

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



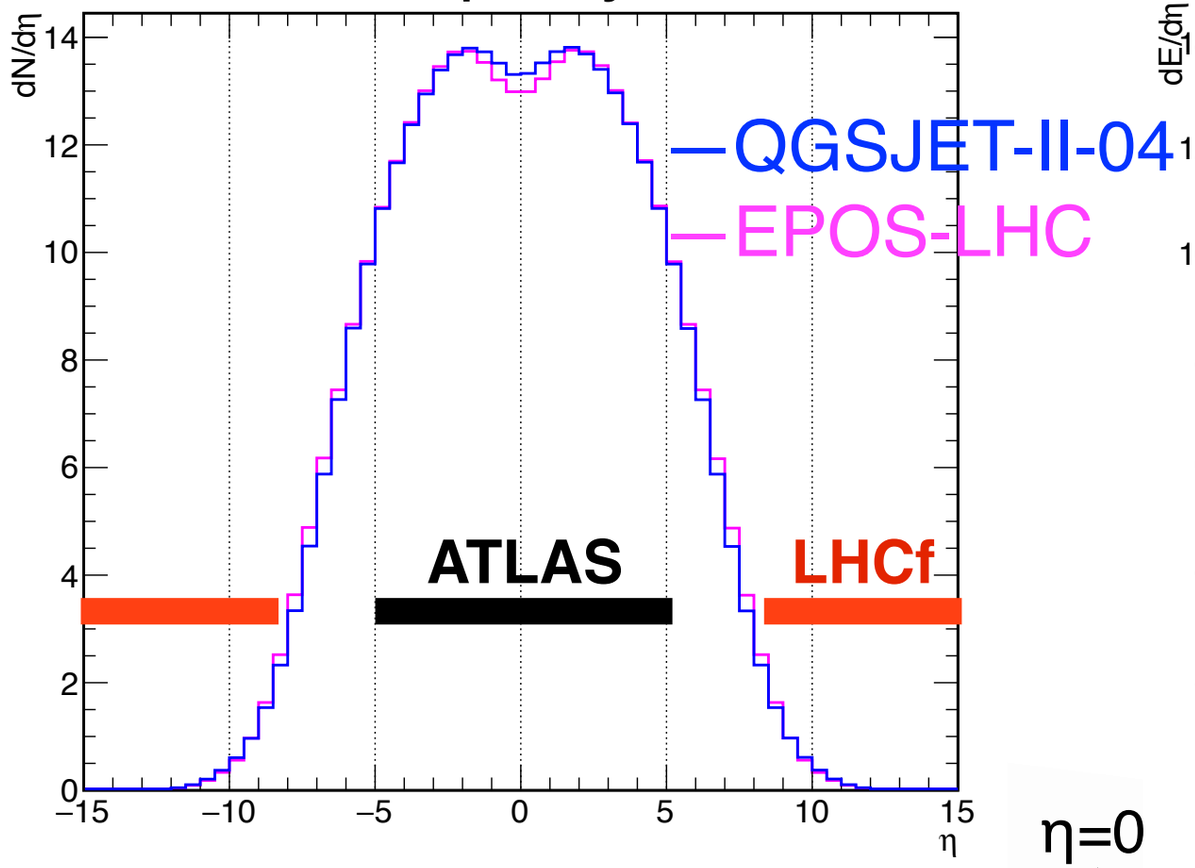
Key parameters

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

Particle density & energy flow for 13TeV p-p

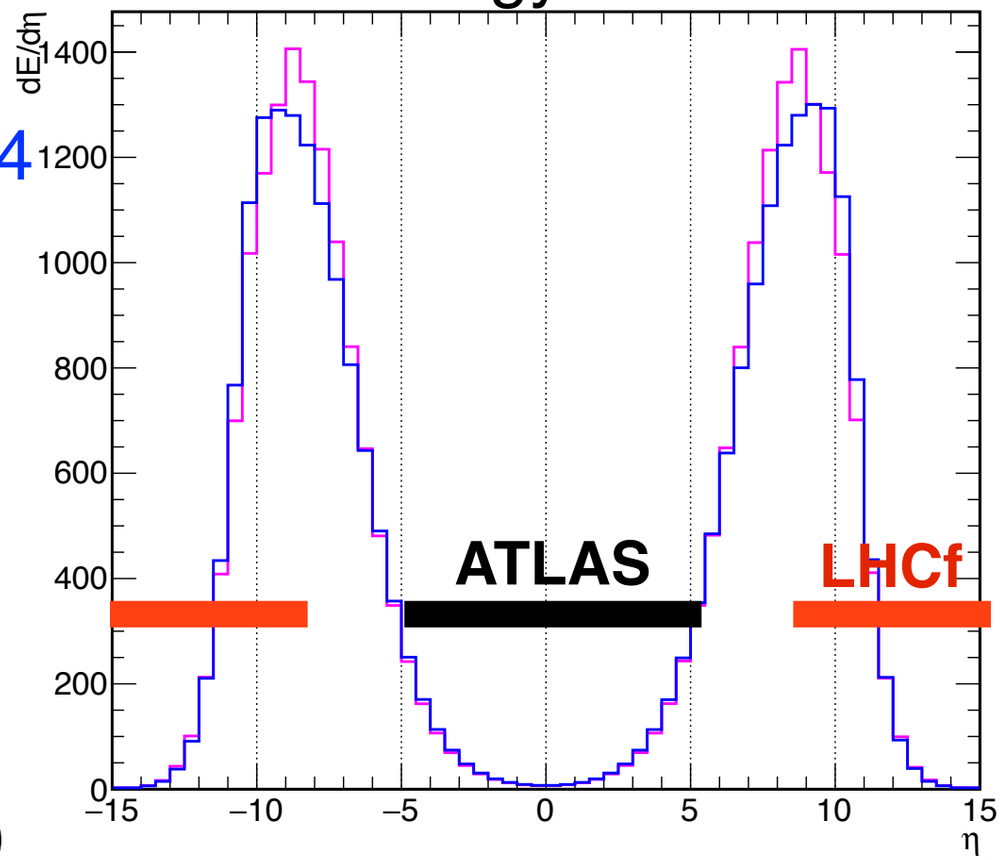
Most of secondary particles concentrate to the center

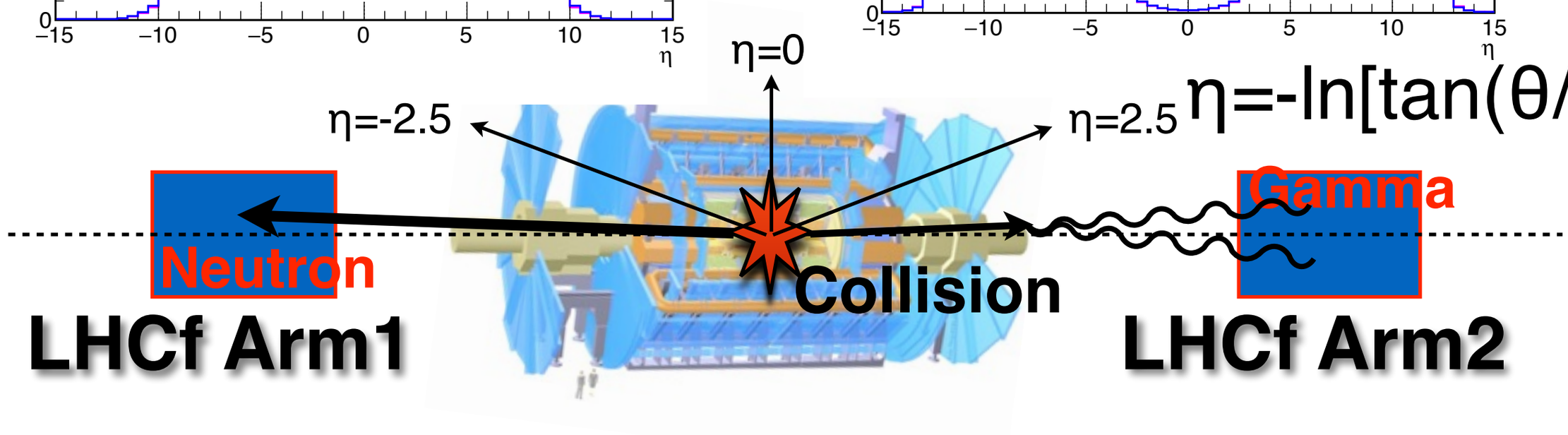
Multiplicity



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

Energy-flow

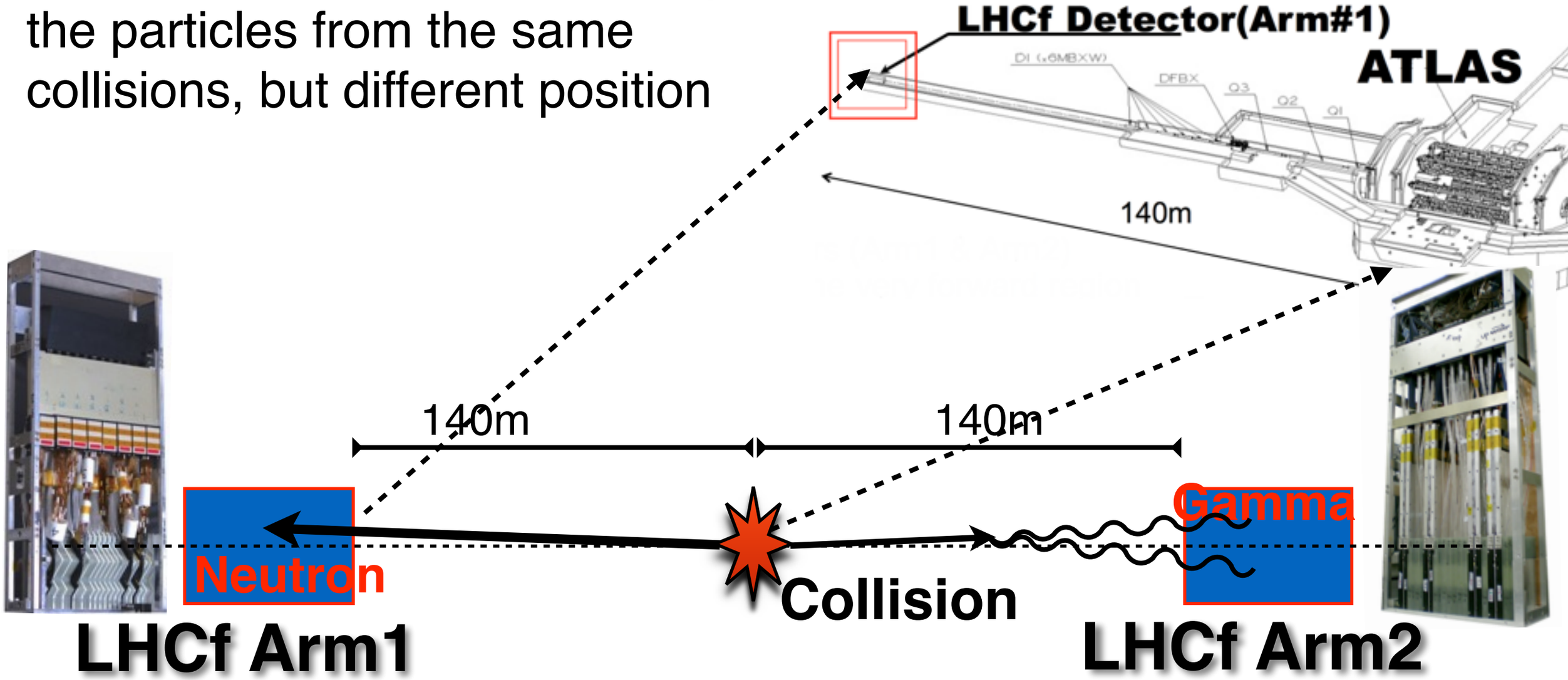




The LHCf experiment

- Measure hadronic production cross section of neutral particles emitted in the very forward region of LHC.
- To afford the data for verifying and improving the hadronic interaction models.

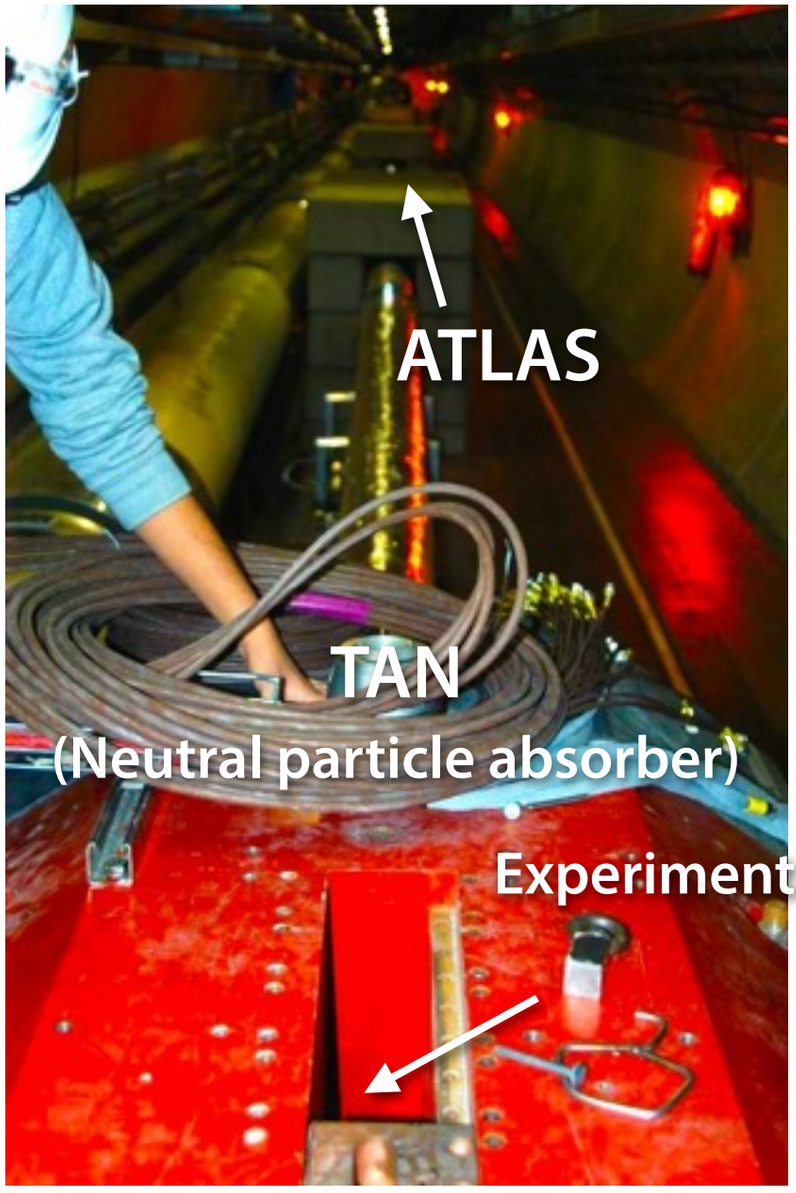
LHCf and ATLAS are observing the particles from the same collisions, but different position



Requirement and constraint to the LHCf detector

Experimental slot @ TAN

- η>8.4 (zero degree)
- slot width: 98mm !
- distance from interaction point:140m
- Neutral particle
- Radiation!



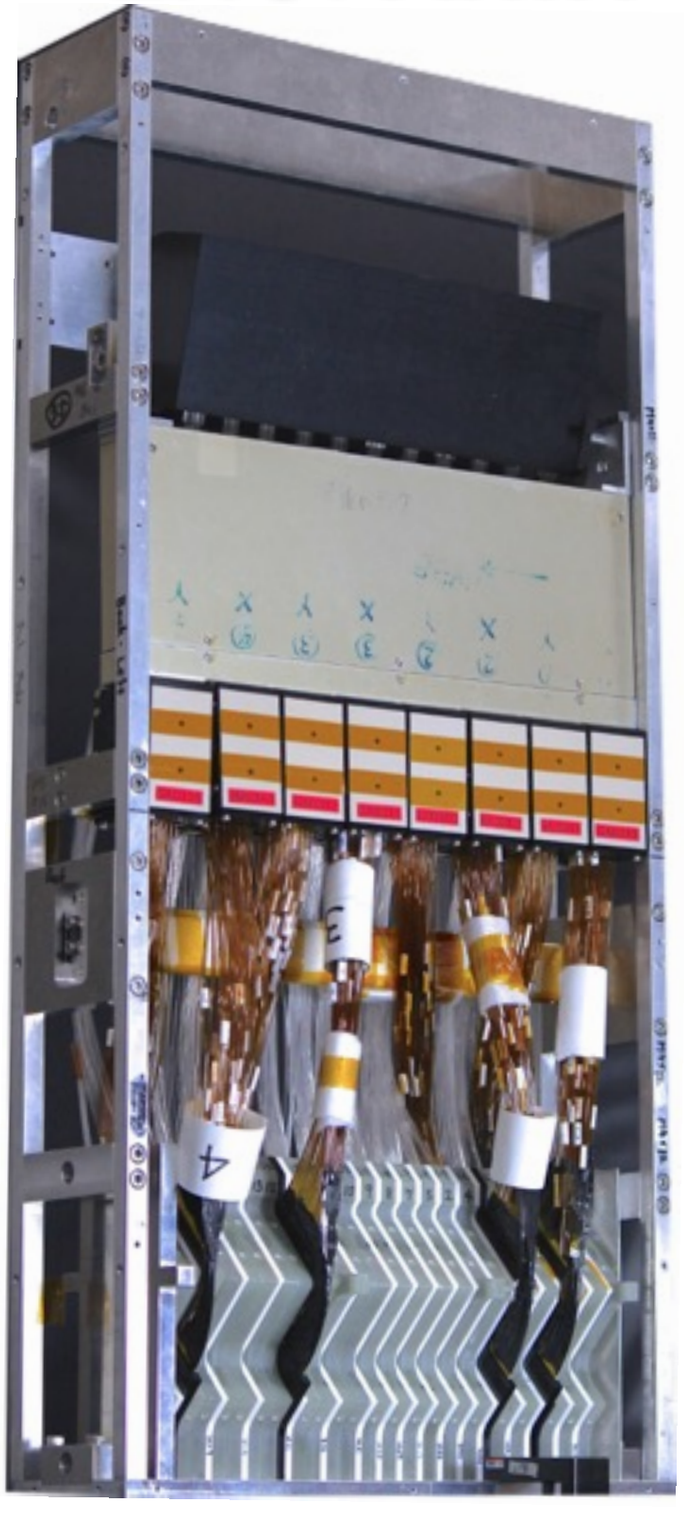
Observables

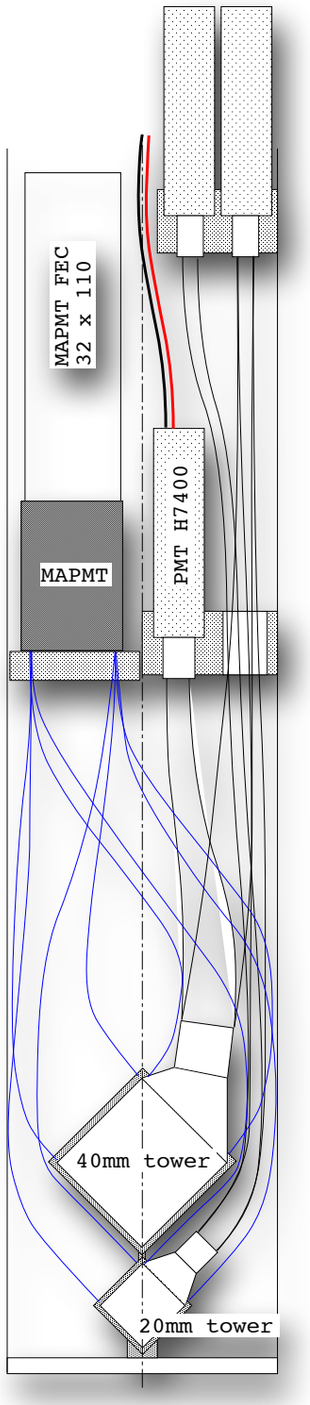
- Targets: photon, π0, neutron
- Spectra
- angular dependence of particle production
- precise measurement up to TeV region

LHCf detector: Small, sampling calorimeter, position determination, radiation-hard

LHCf detectors

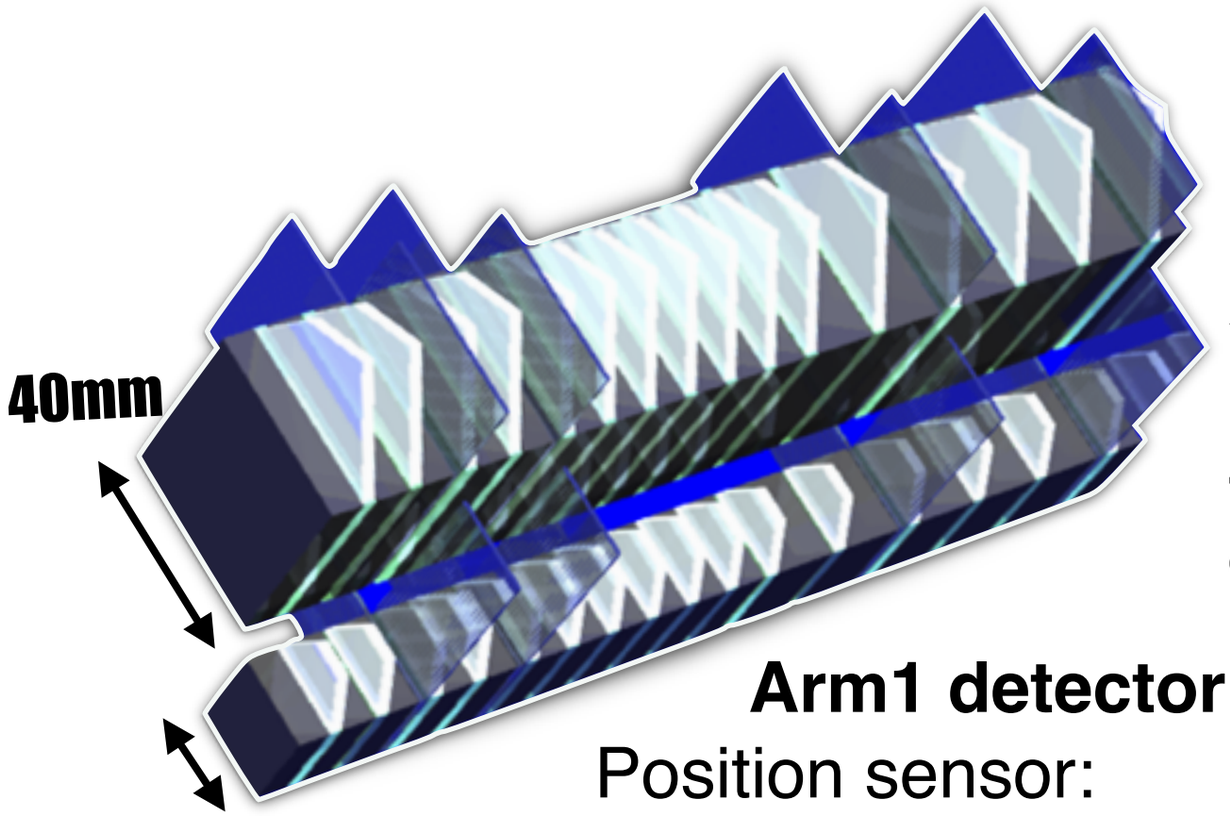
LHCf Arm1





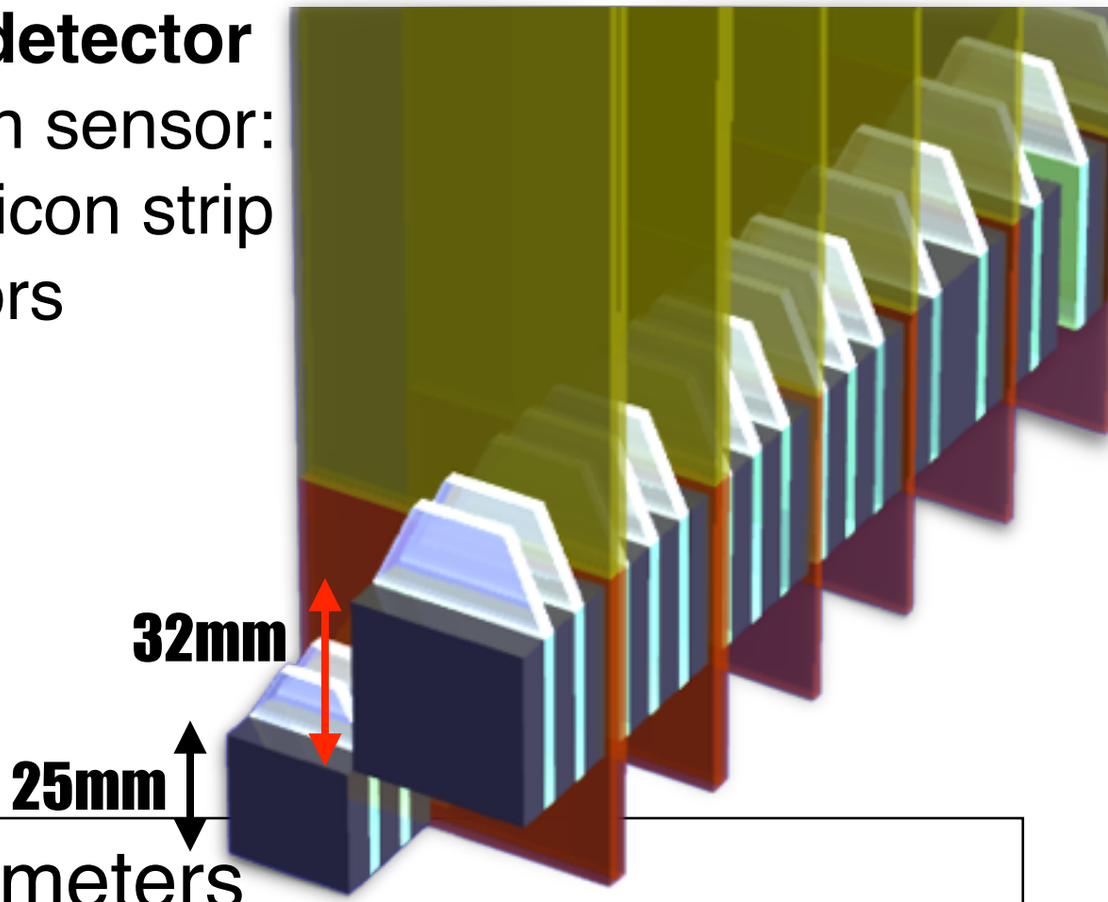
LHCf Arm2

The LHCf calorimeter



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

Arm2 detector
Position sensor:
4XY silicon strip detectors



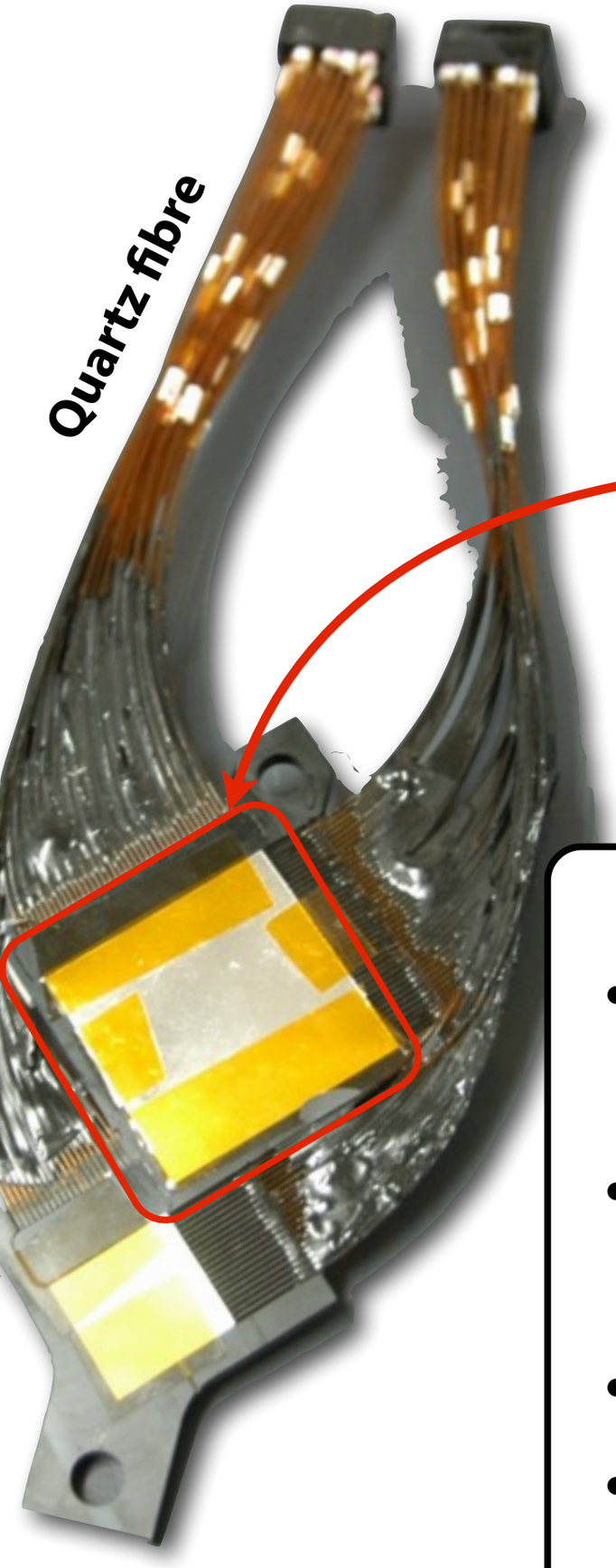
- Two imaging sampling shower calorimeters
- 44r.l. tungsten, 16 layers of GSO scintillators and 4 position sensitive layers
- The η coverage of the calorimeter: $|\eta|>8.4$

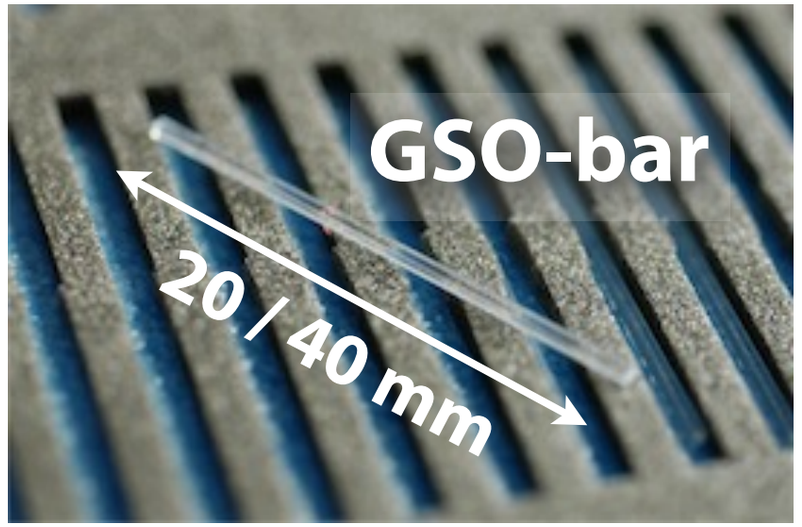
Performance

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

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

GSO-bar hodoscope

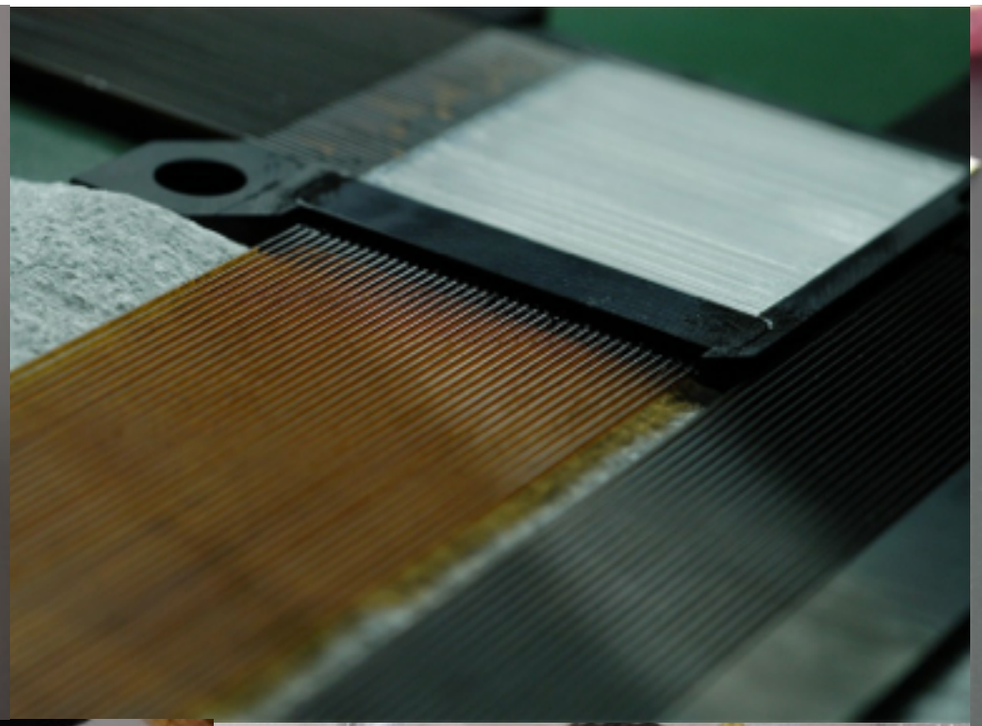


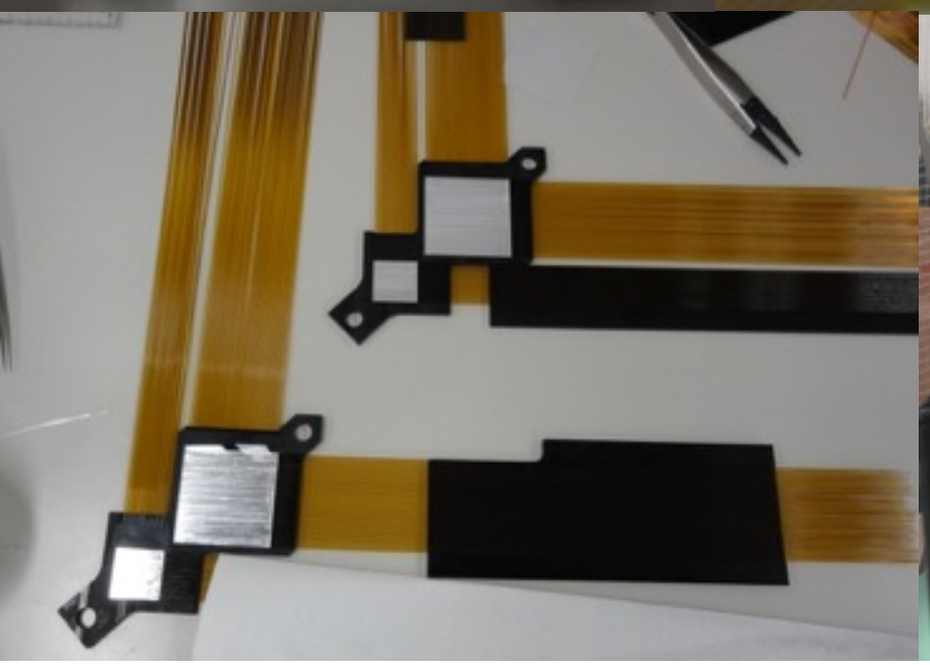


Design

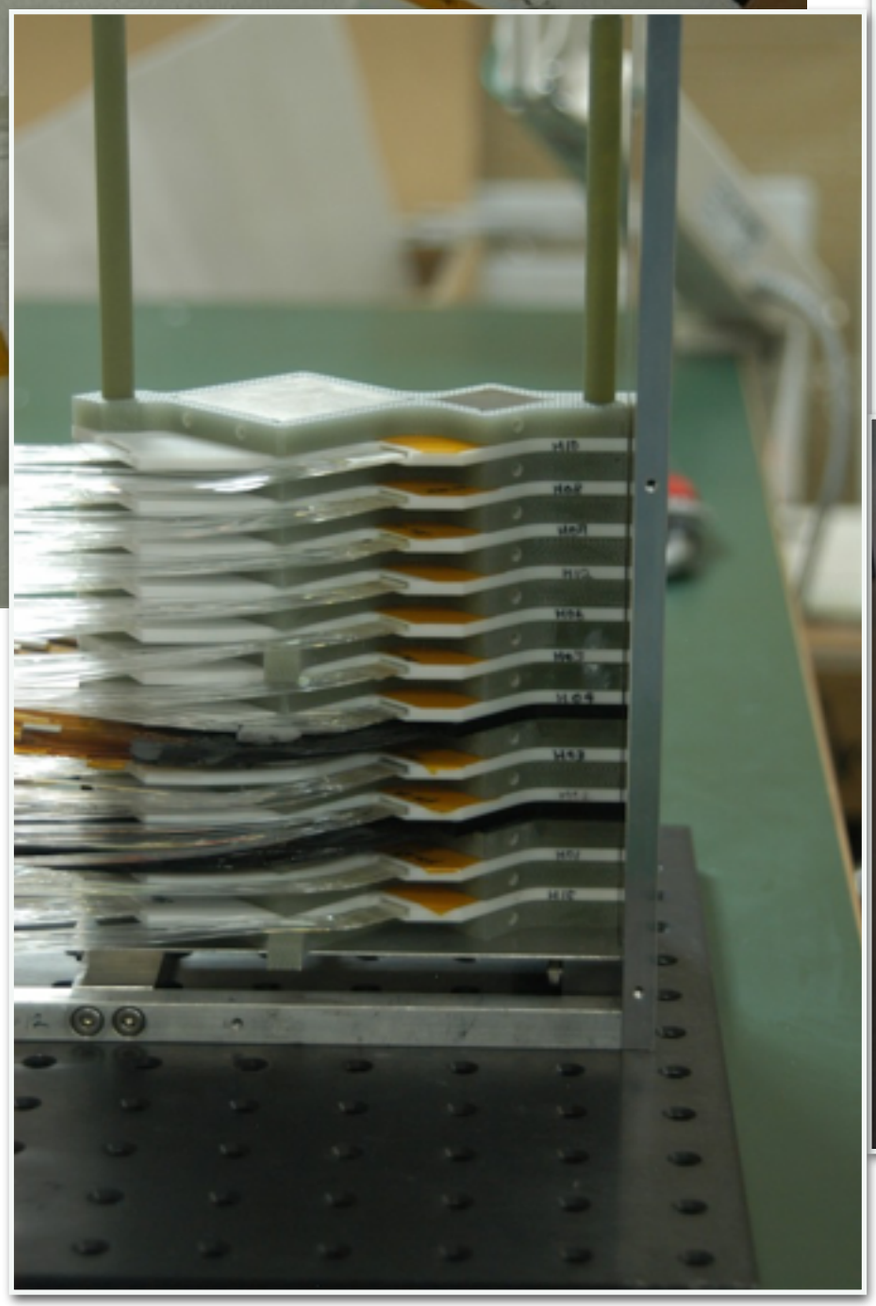
- ”Shower-imaging” layers
  - Pt determination, shower-leakage correction, etc…
- 1mm x 1mm x 20(40) mm long and thin GSO scintillator (**GSO-bar**) --> Radiation-hard
- Without wrapped materials
- Read by MAPMT with 64 anodes (HAMAMATSU H7546)

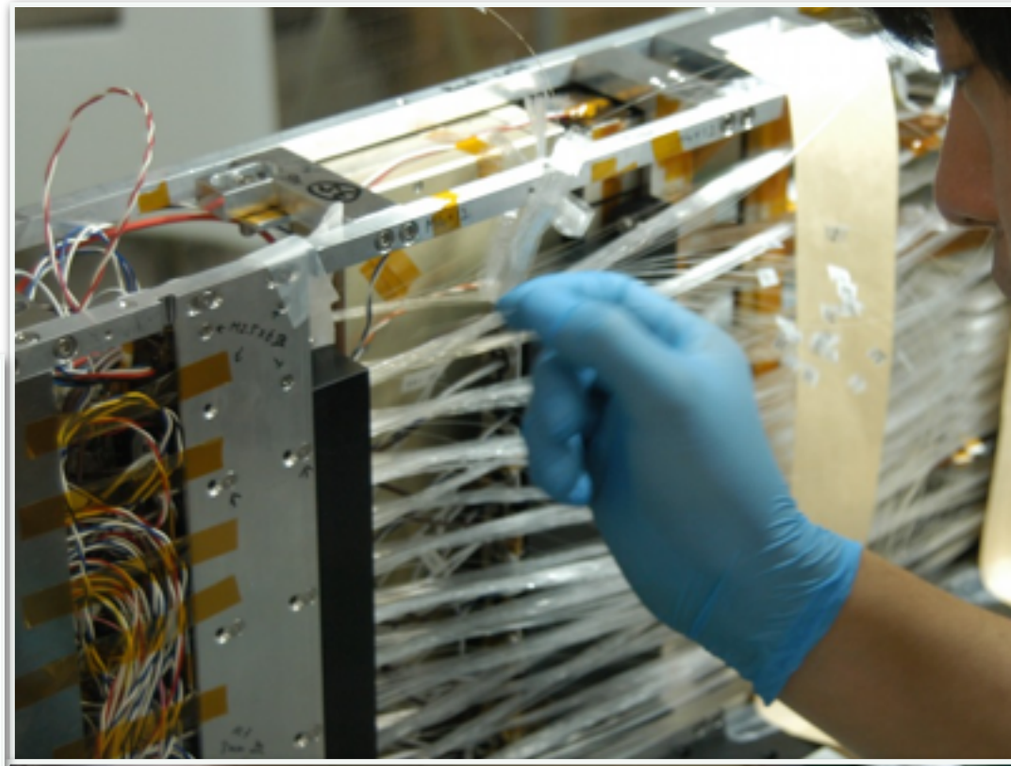
GSO-bar hodoscope



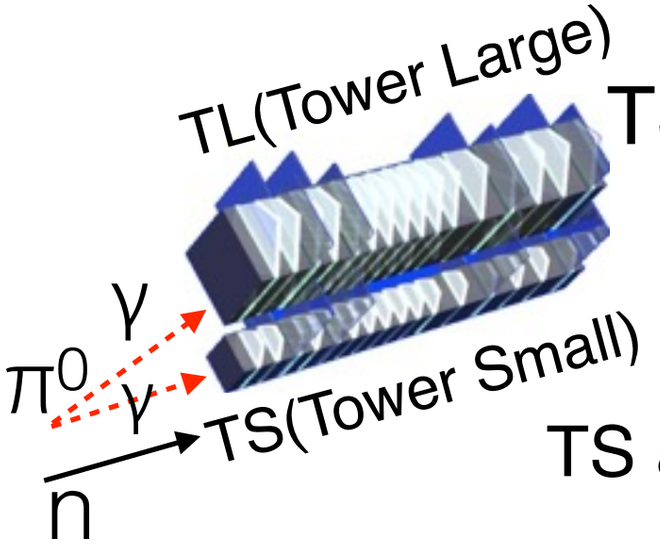


Detector assembling





LHCf Trigger Diagram



TS or TL

3層連続で信号の検出

shower trigger 204Hz

pre-scale

TS and TL

前7層のうちに3層連続で信号の検出

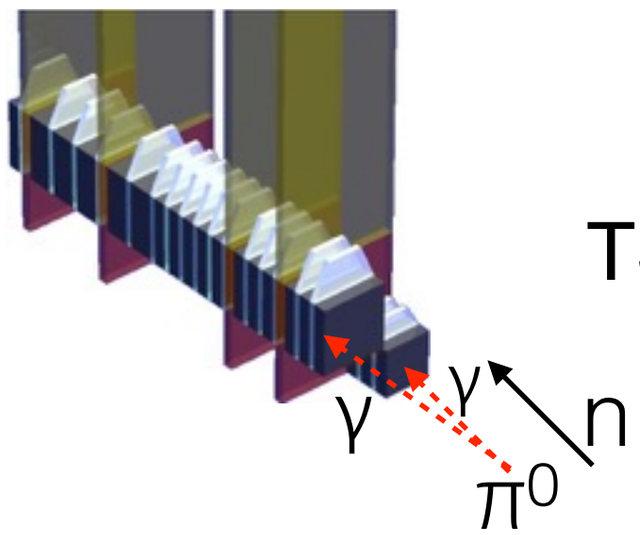
special shower trigger 7Hz

Arm1側

OR

Final Trigger (Trigger to ATLAS)

Arm2側



TS or TL

3層連続で信号の検出

shower trigger 230Hz

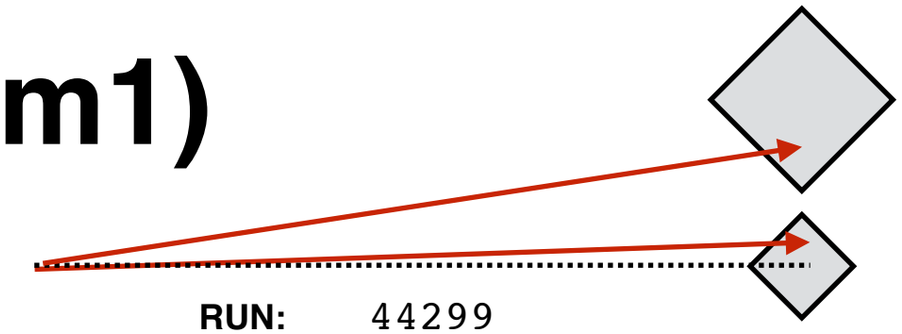
pre-scale

TS and TL

前7層のうちに3層連続で信号の検出

special shower trigger 12Hz

Event view (Arm1)

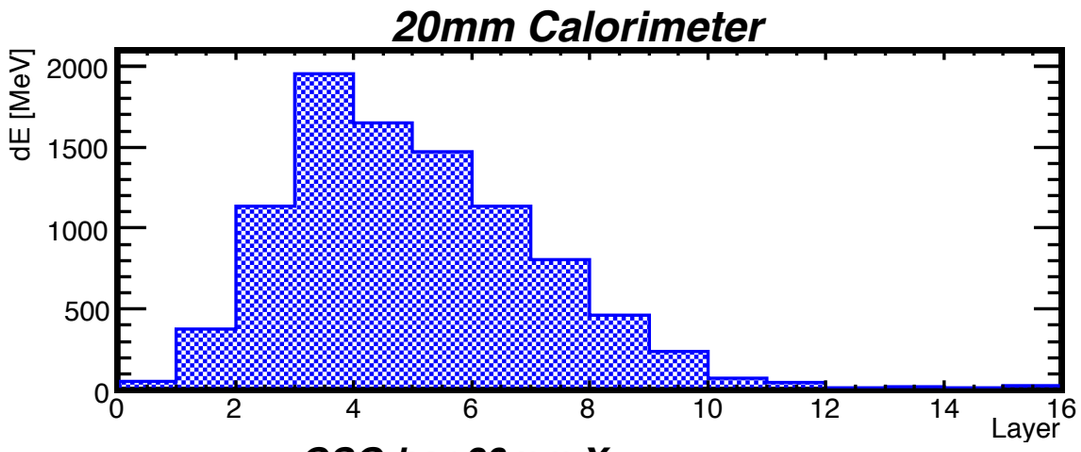


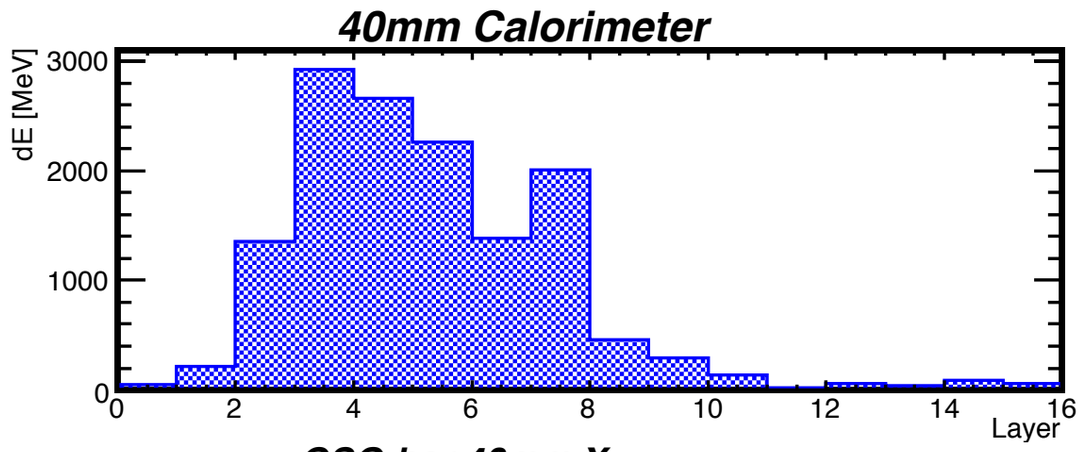
LHCf Arm1 Detector

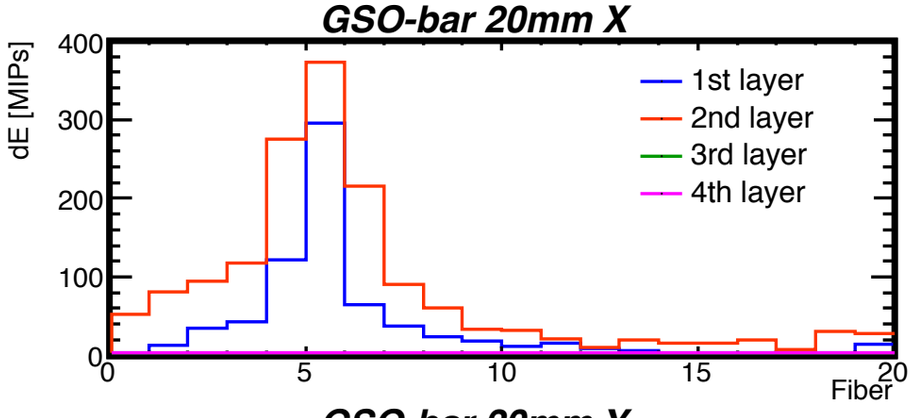
π^0 Candidate Event

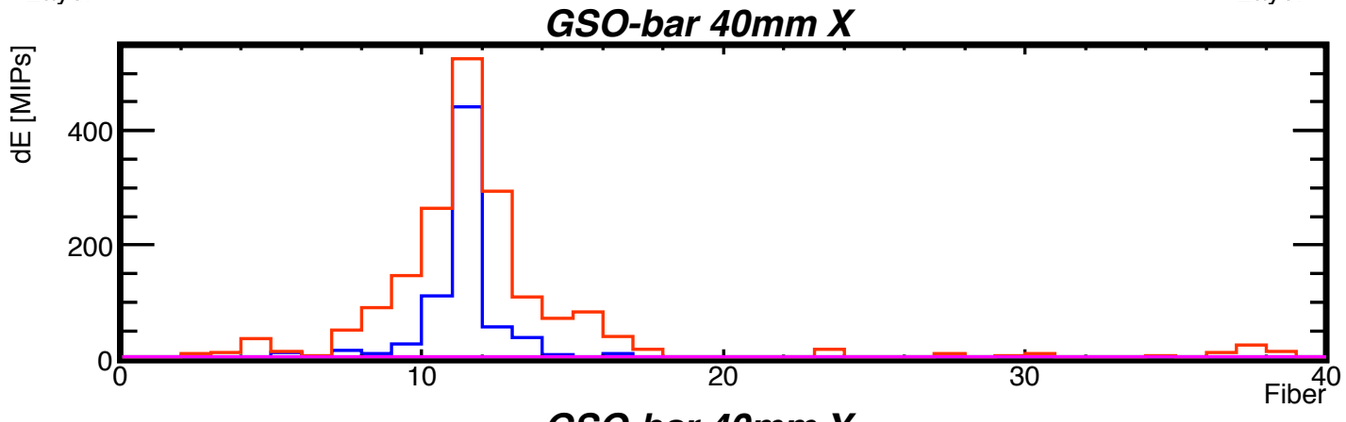
LHC p-p, $\sqrt{s}$ = 13 TeV Collisions

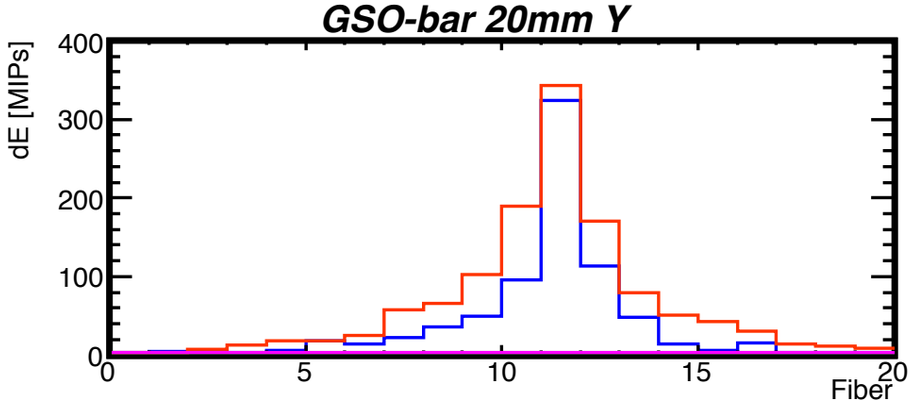
RUN: 44299
NUMBER: 4990
TIME: 1434141164
FILL: 3855
E_{20mm}: 323 GeV
E_{40mm}: 407 GeV
$M_{\gamma\gamma}$: 138 MeV

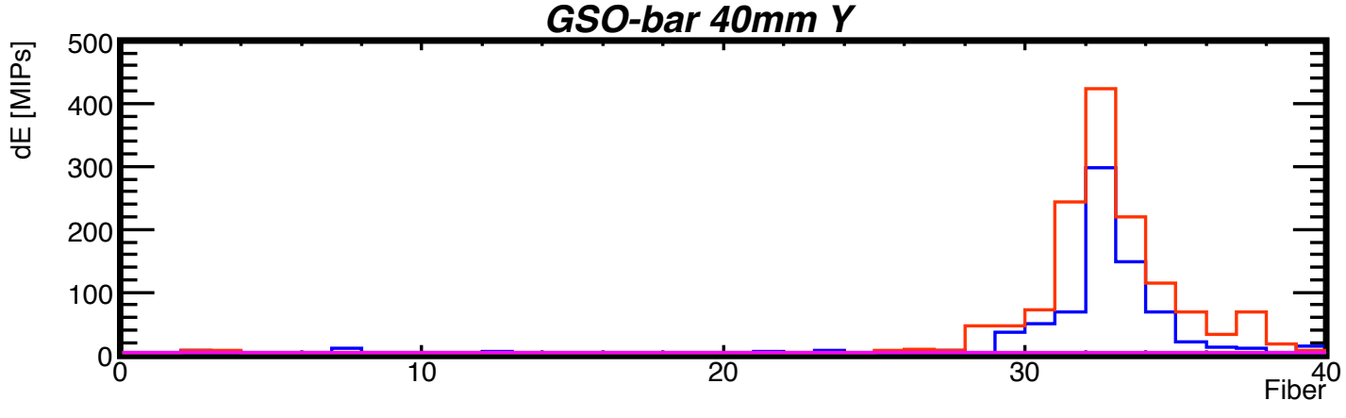












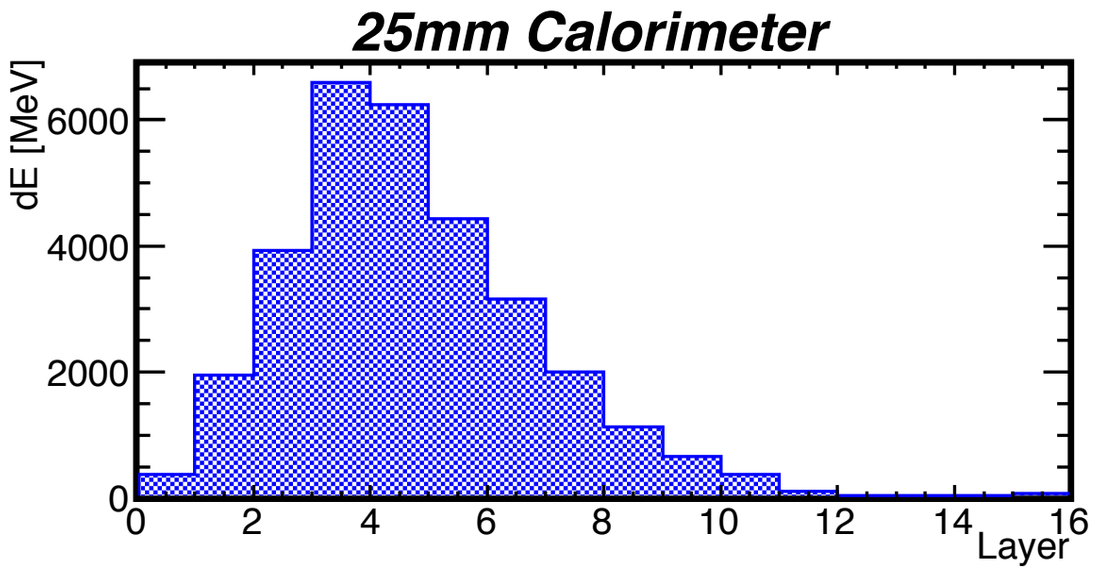
Event view (Arm2)

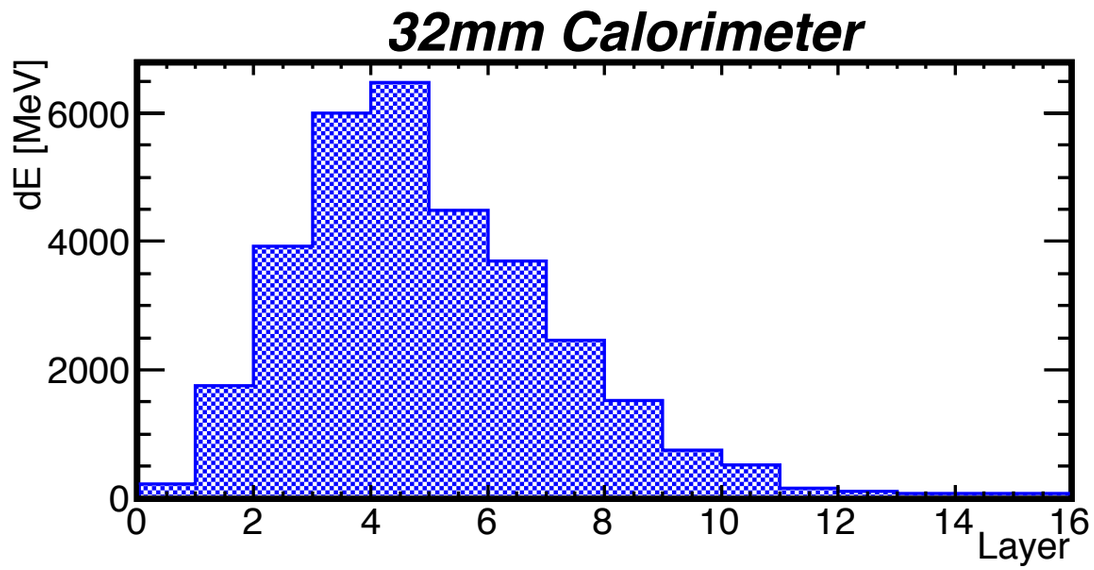
LHCf Arm2 Detector

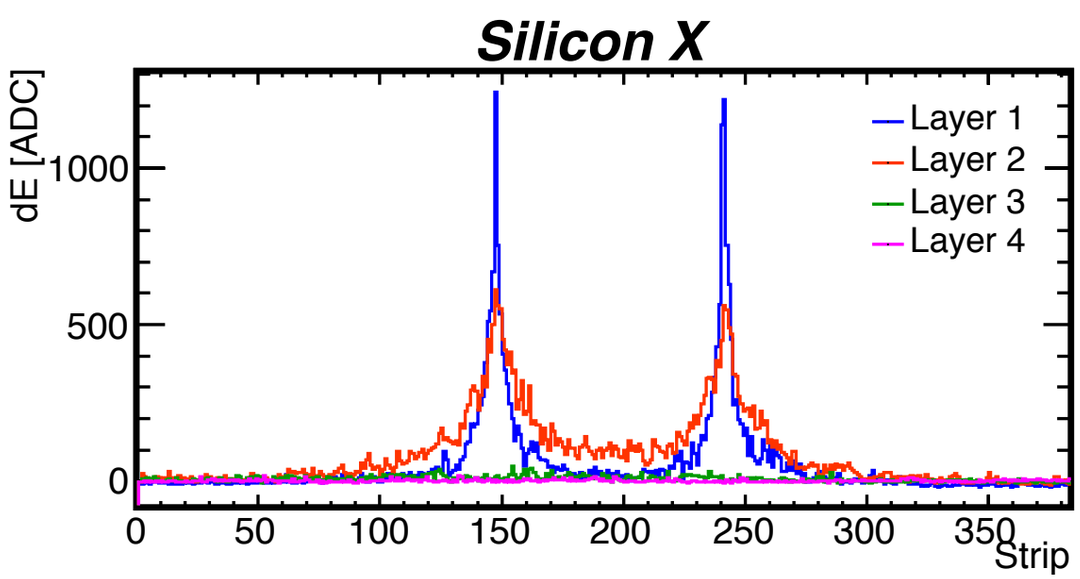
π^0 Candidate Event

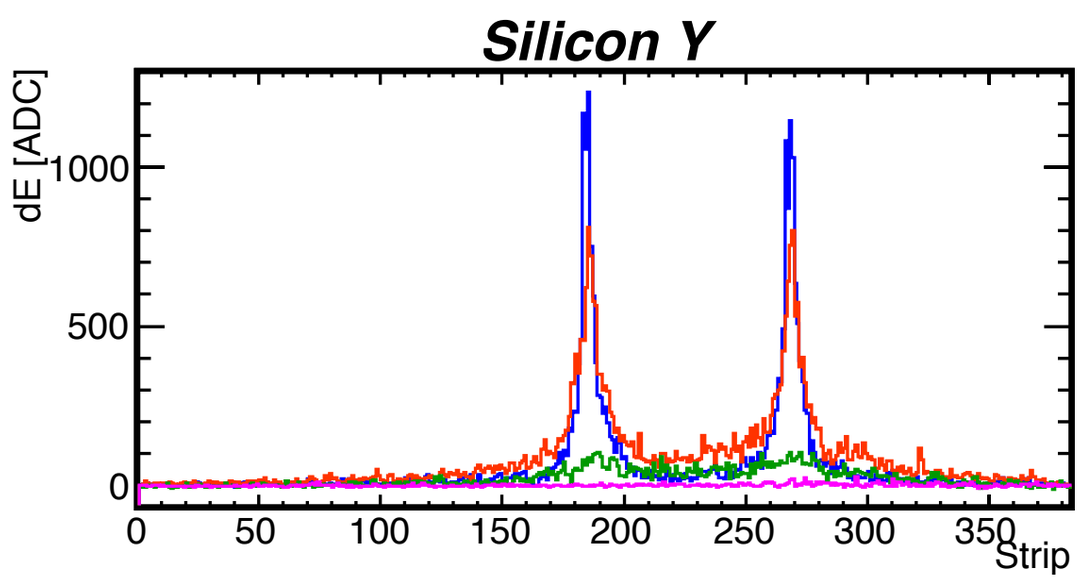
LHC p-p, $\sqrt{s}$ = 13 TeV Collisions

RUN:	44484
NUMBER:	3010
TIME:	1434152507
FILL:	3855
E_{25mm}:	1014 GeV
E_{32mm}:	1021 GeV
$M_{\gamma\gamma}$:	147 MeV



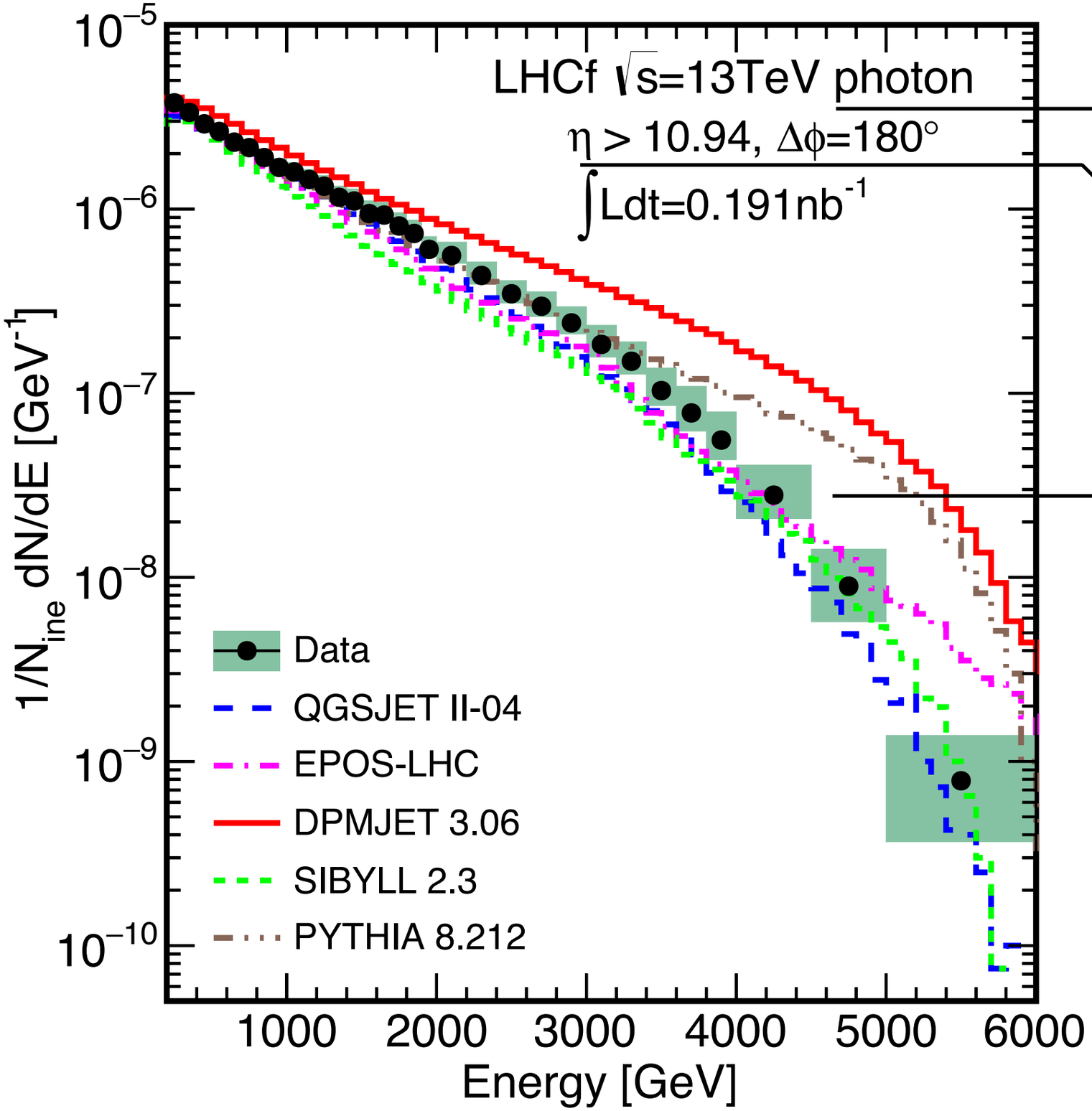






LHCf detector performance & analysis procedure

LHCf photon spectrum



PID

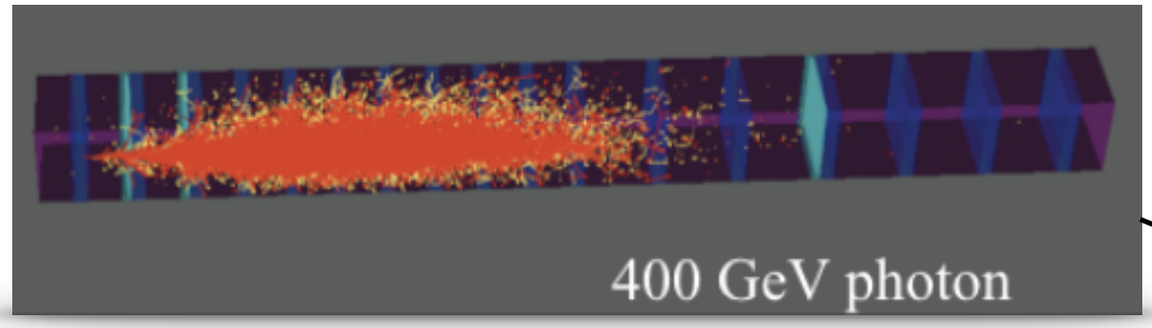
Position

Energy

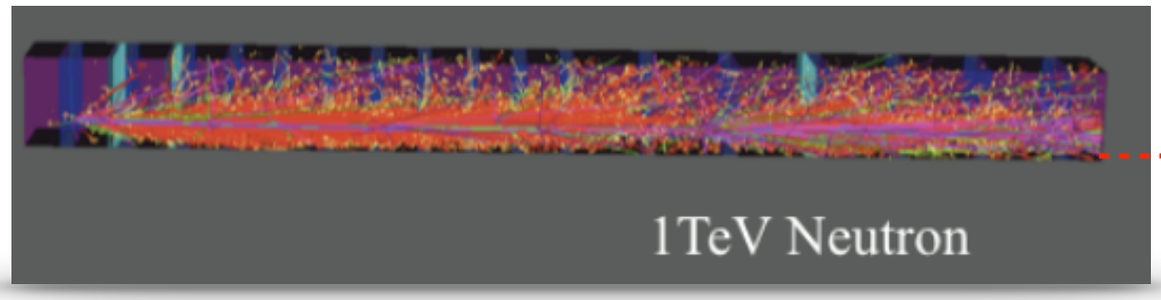
MultiHit

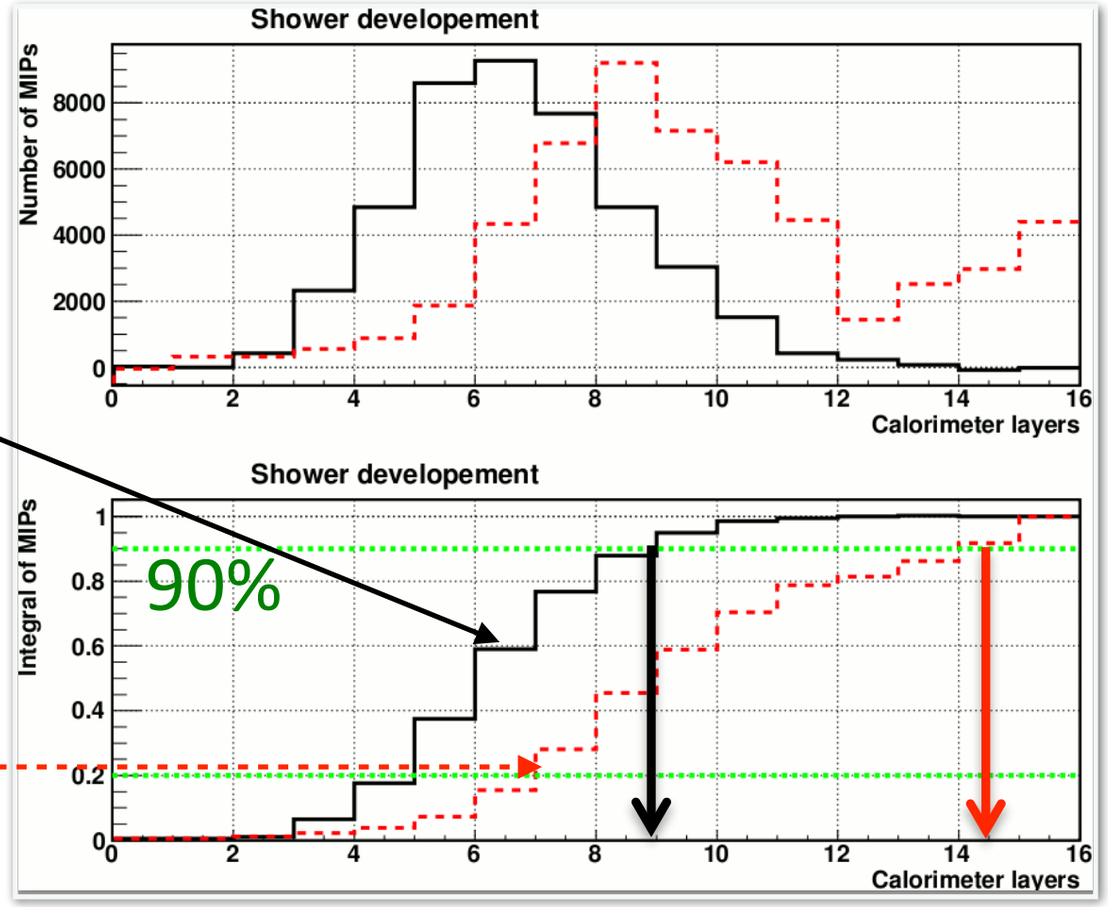
PID

Photon shower development



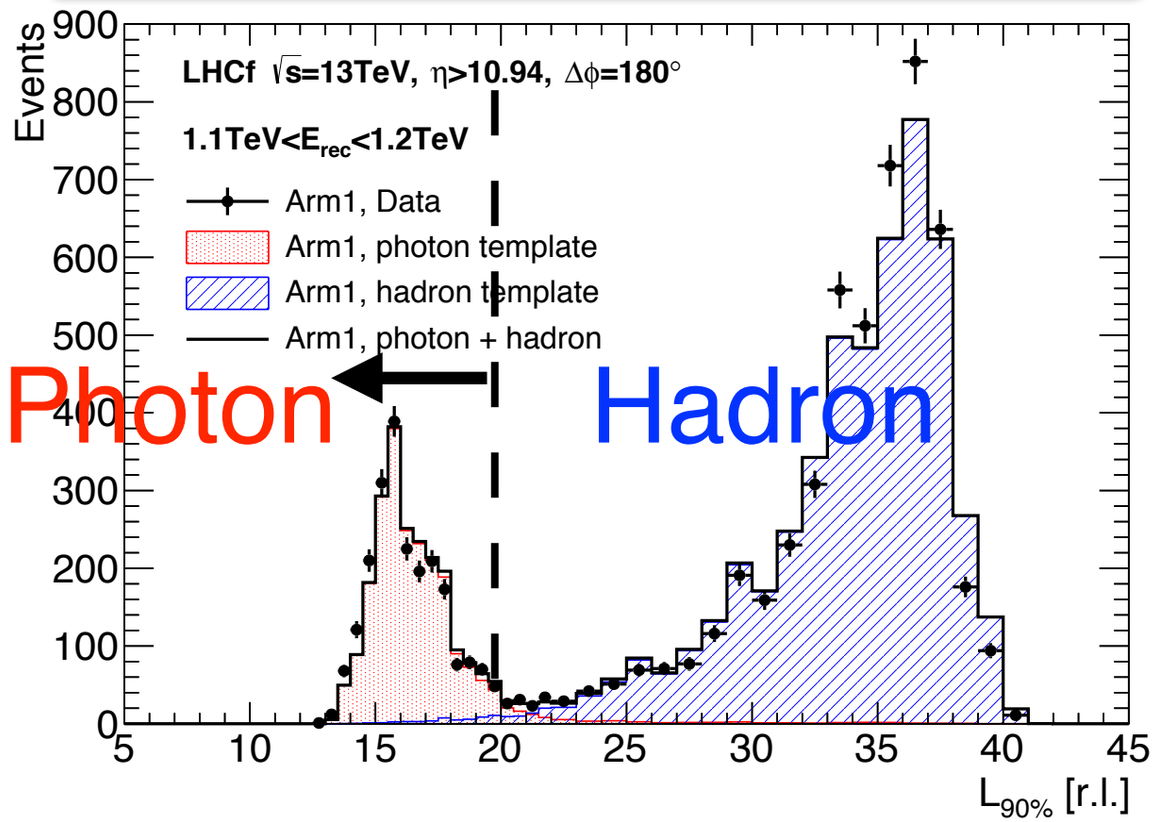
Hadron shower development



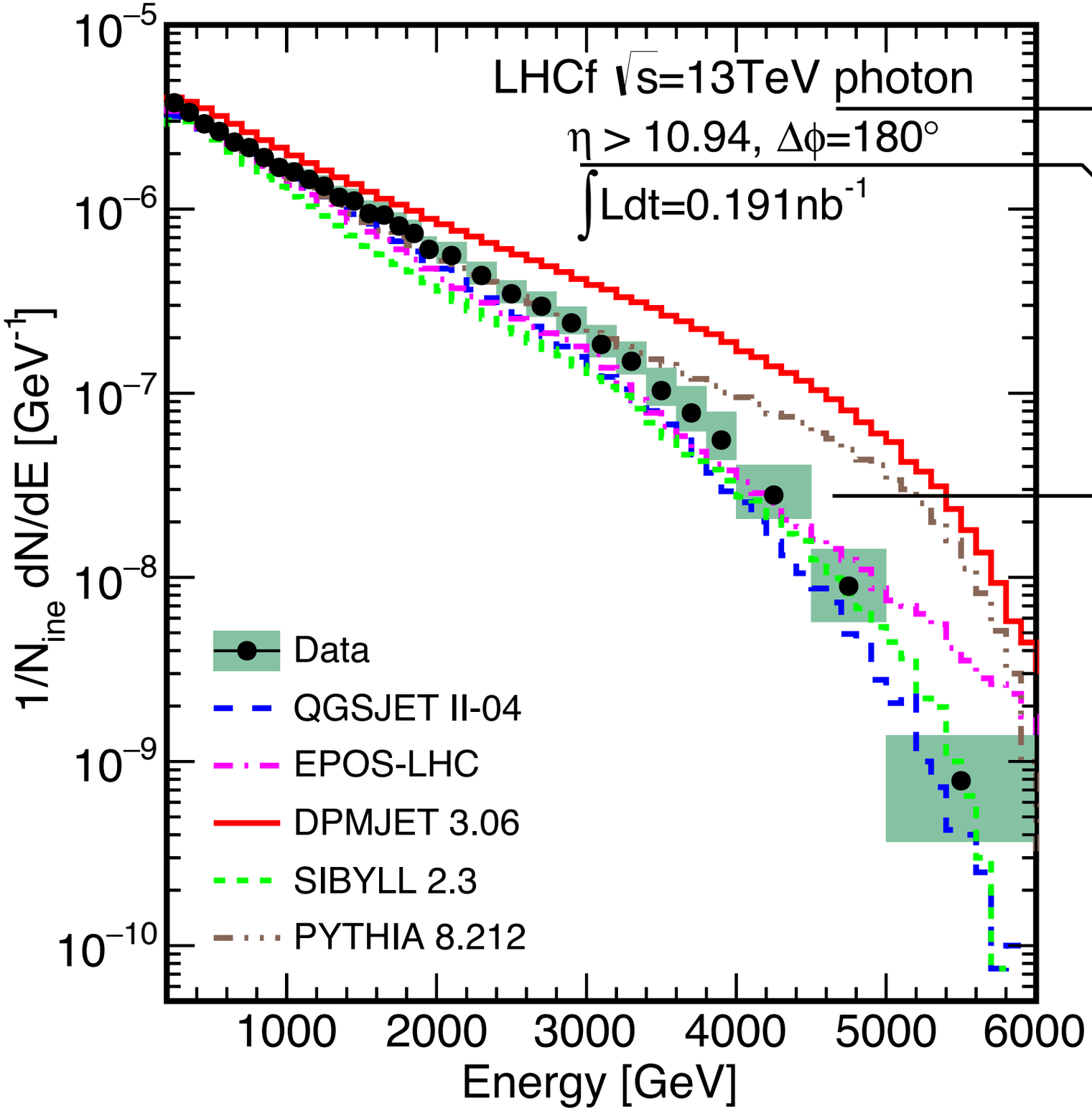


$L_{90\%}$

The 90% depth of cascade shower developed inside LHCf calorimeter



LHCf photon spectrum



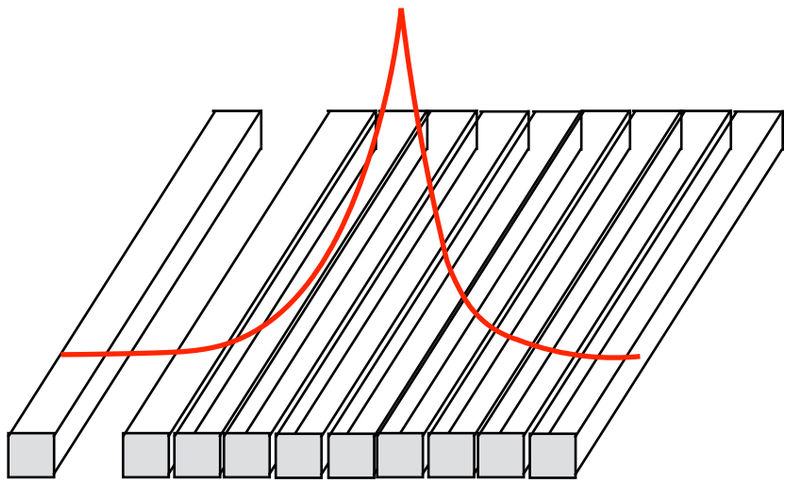
PID

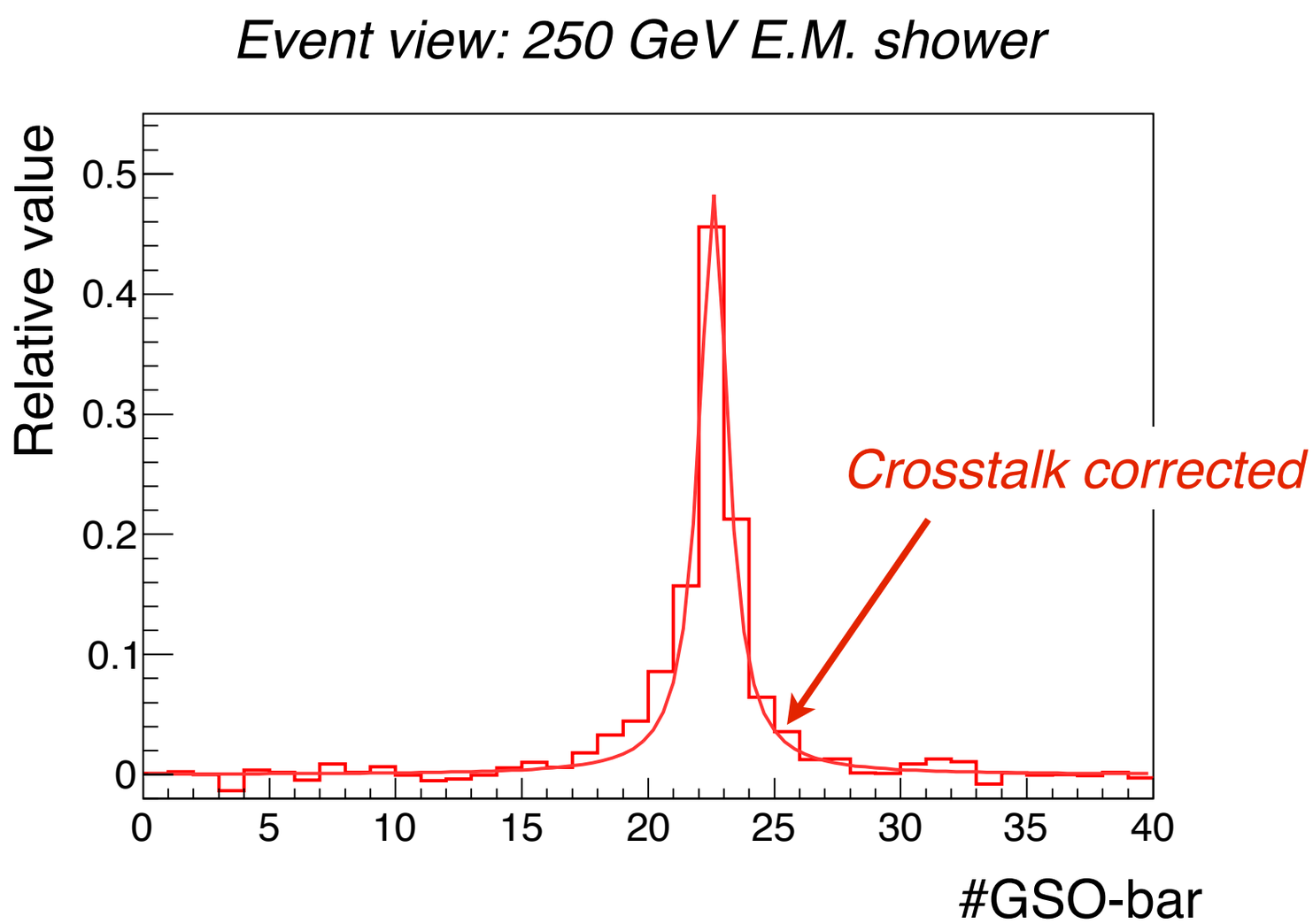
Position

Energy

MultiHit

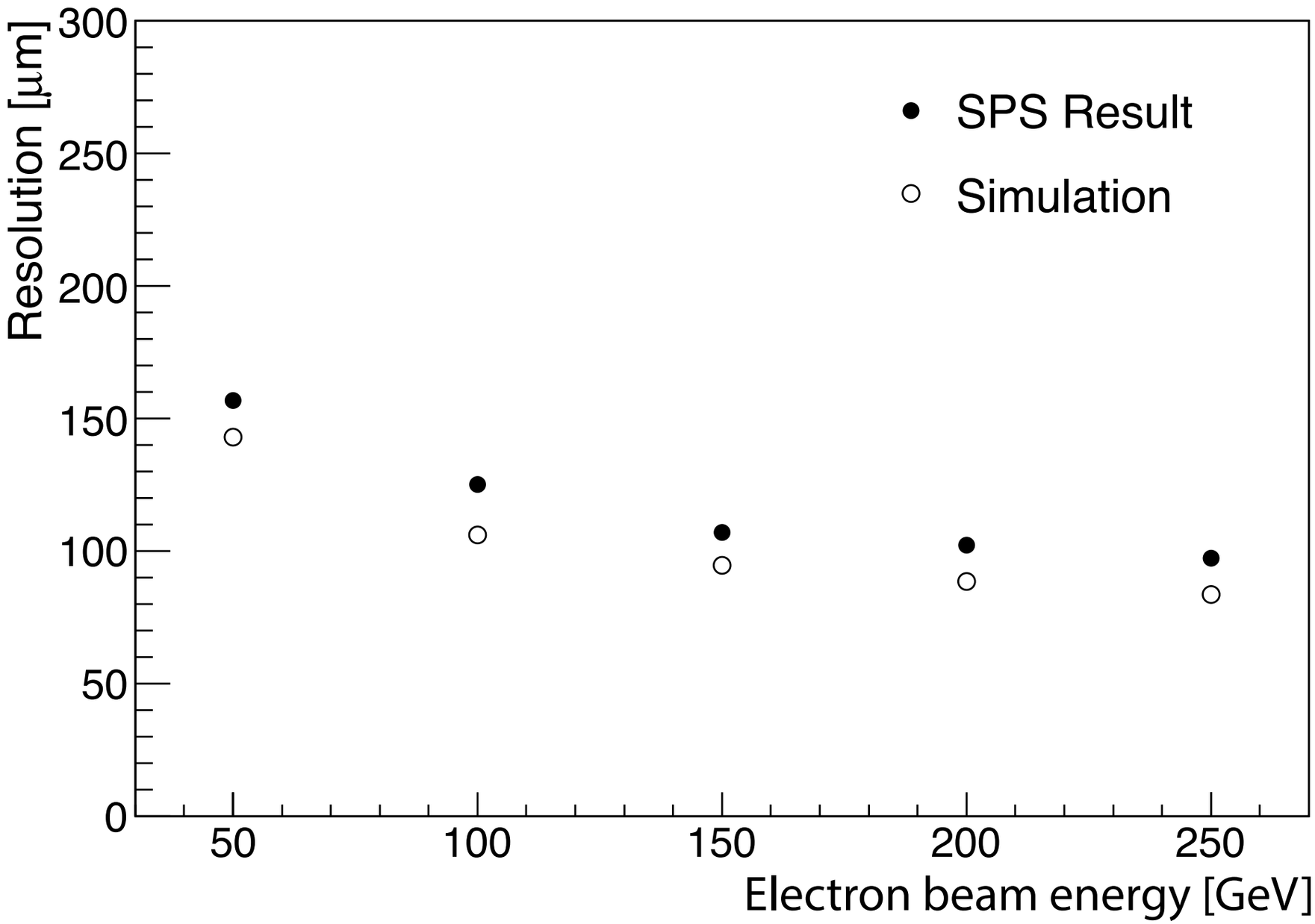
EM shower in GSO-bar hodoscope





- Fit the distribution with the function based on Lorentz function.
- Peak position is the initial position of the particle.

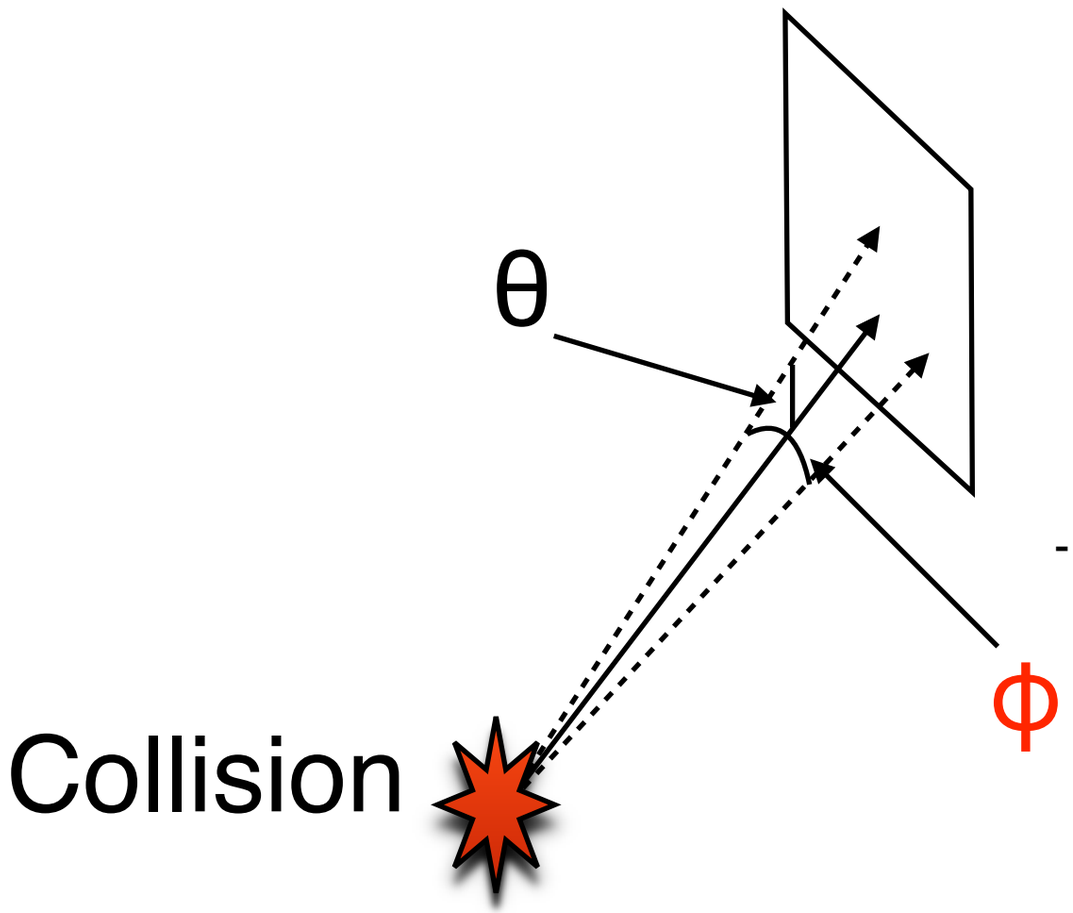
Position resolution

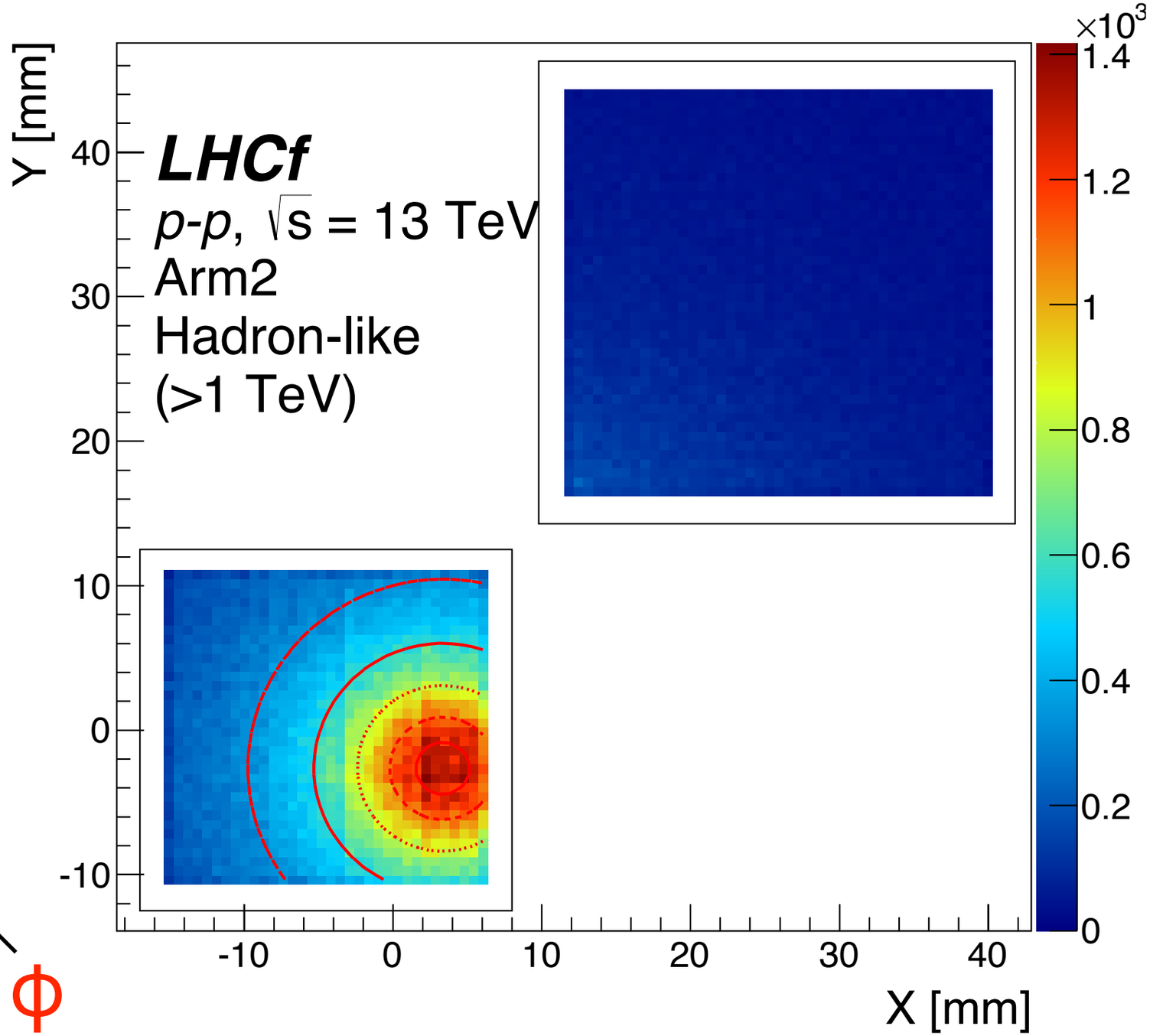


Position resolution investigated by using SPS electron beam, with different energies -> ~1μm

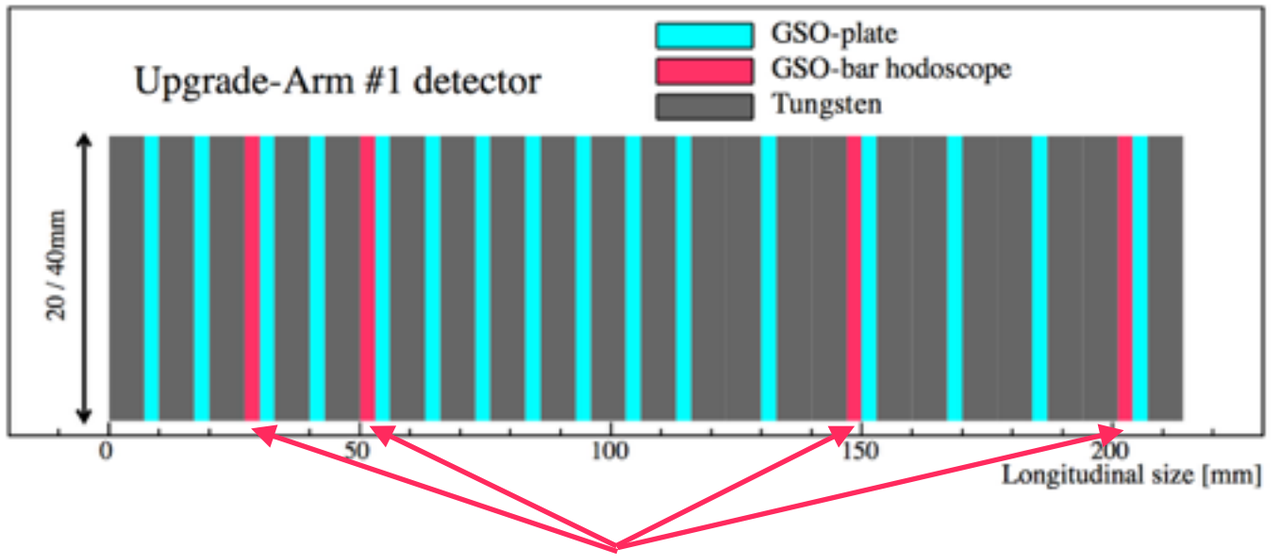
Position

$\eta = -\ln[\tan(\theta/2)]$





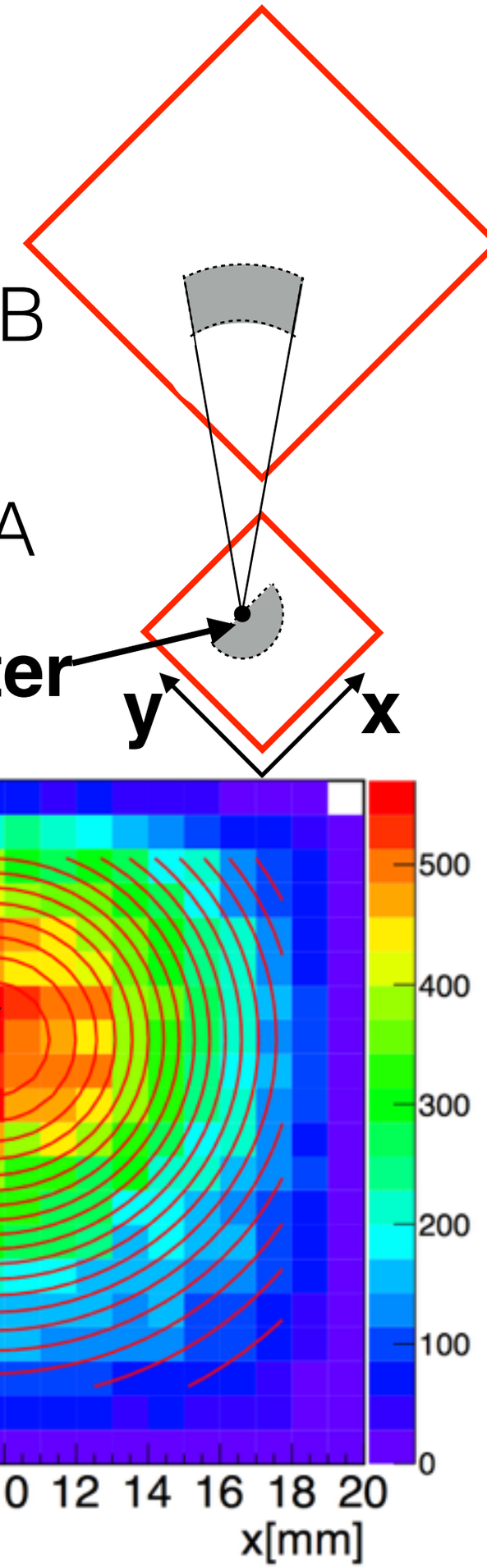
Beam center



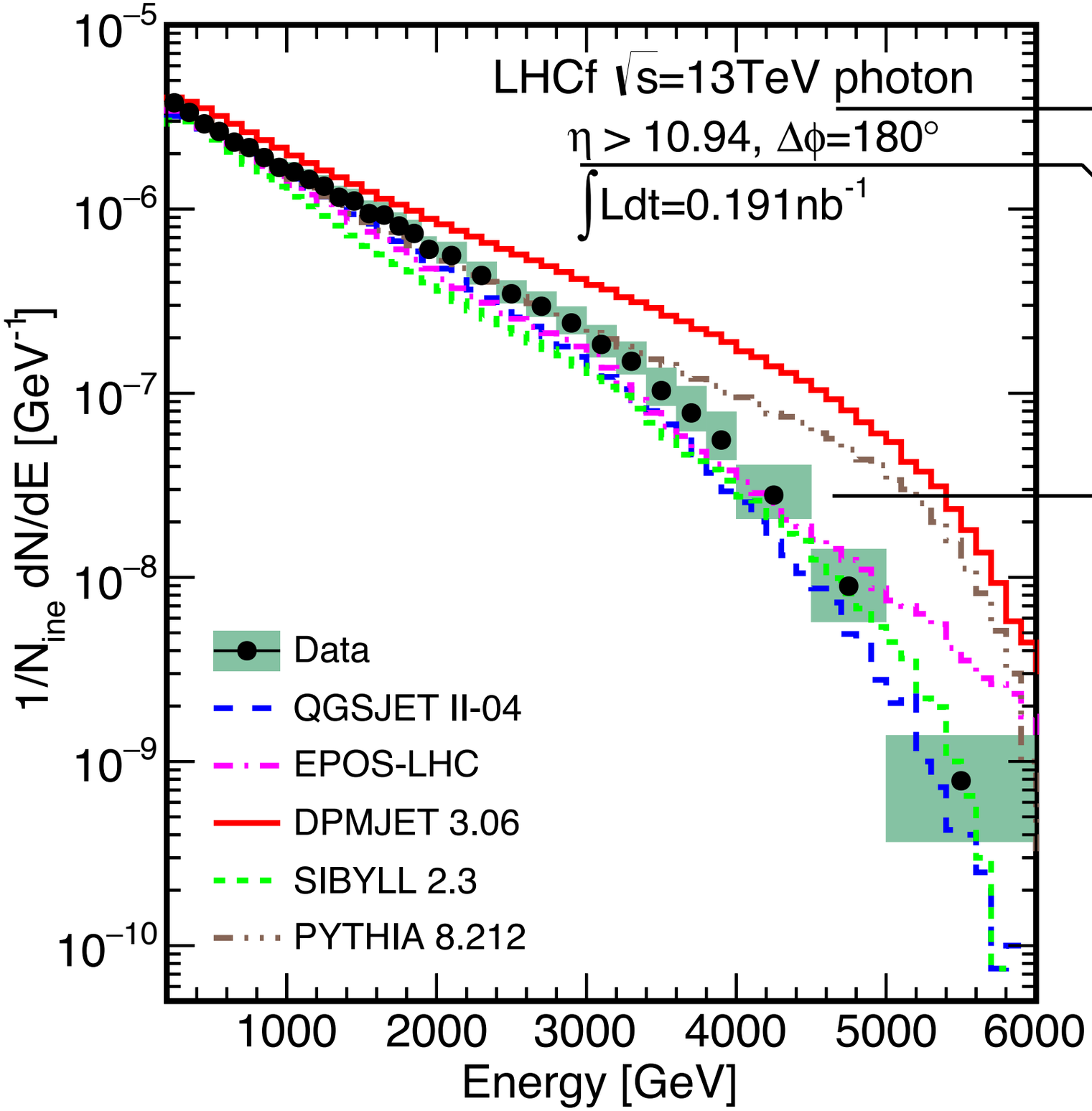
positon detecters

Beam center determination:
fitting the distribution of hit position of high energy neutron (E_{rec}>1.5TeV)

	Value	Error
X [mm]	**9.56**	0.03
Y [mm]	**12.43**	0.03



LHCf photon spectrum



PID

Position

Energy

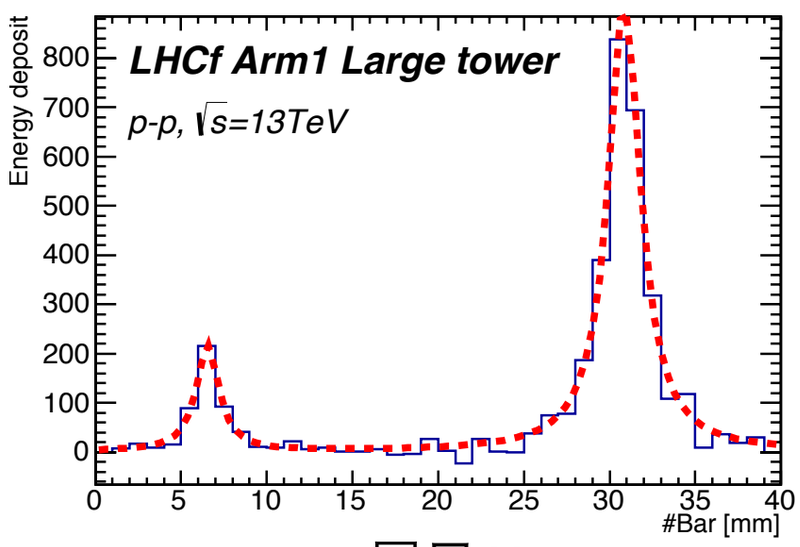
MultiHit

Multihit

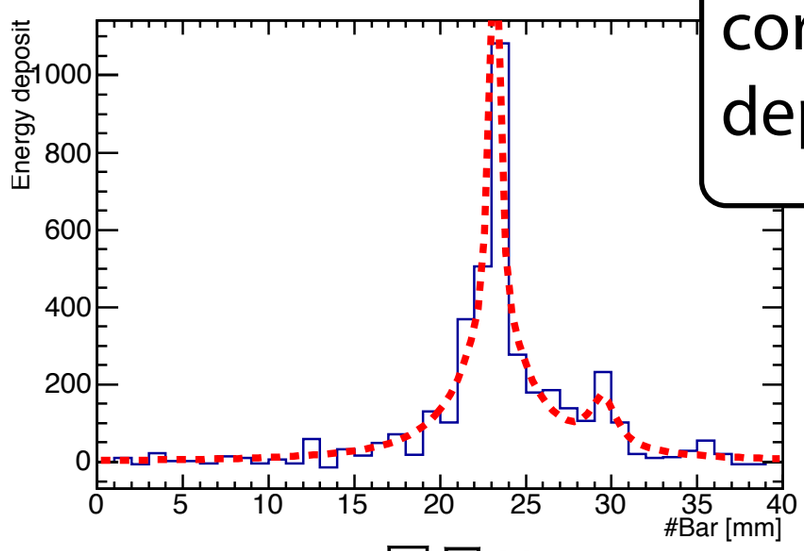
- At √s=13 TeV, the particles will more concentrate to the forward region because of the large boost factor
- Multihit events / triggered events: 4% (QGSJETII-04)

Multihit event

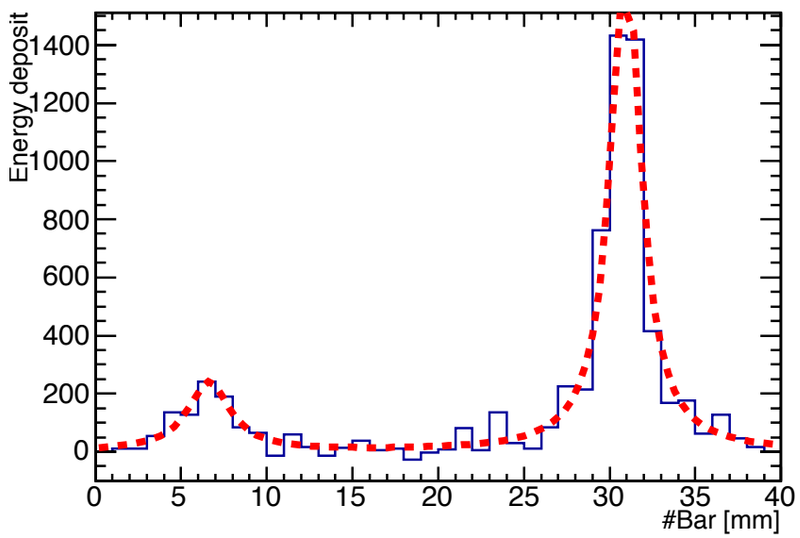
1層目 X



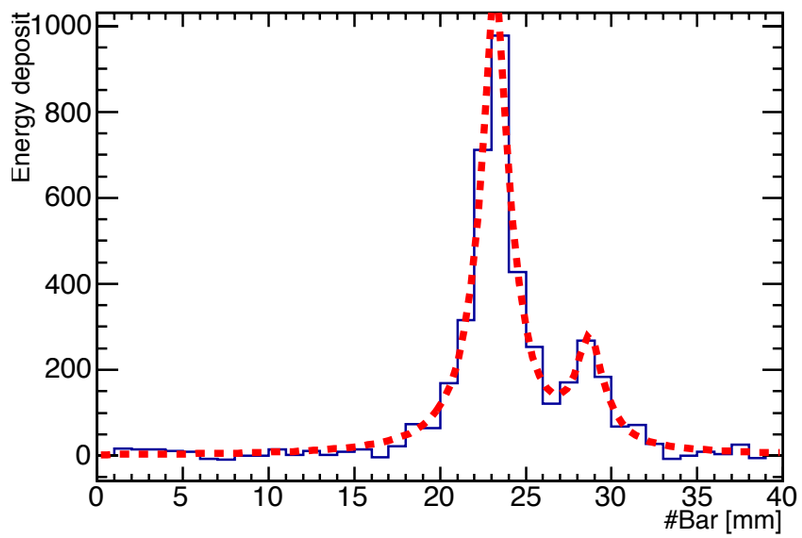
1層目 Y



2層目 X

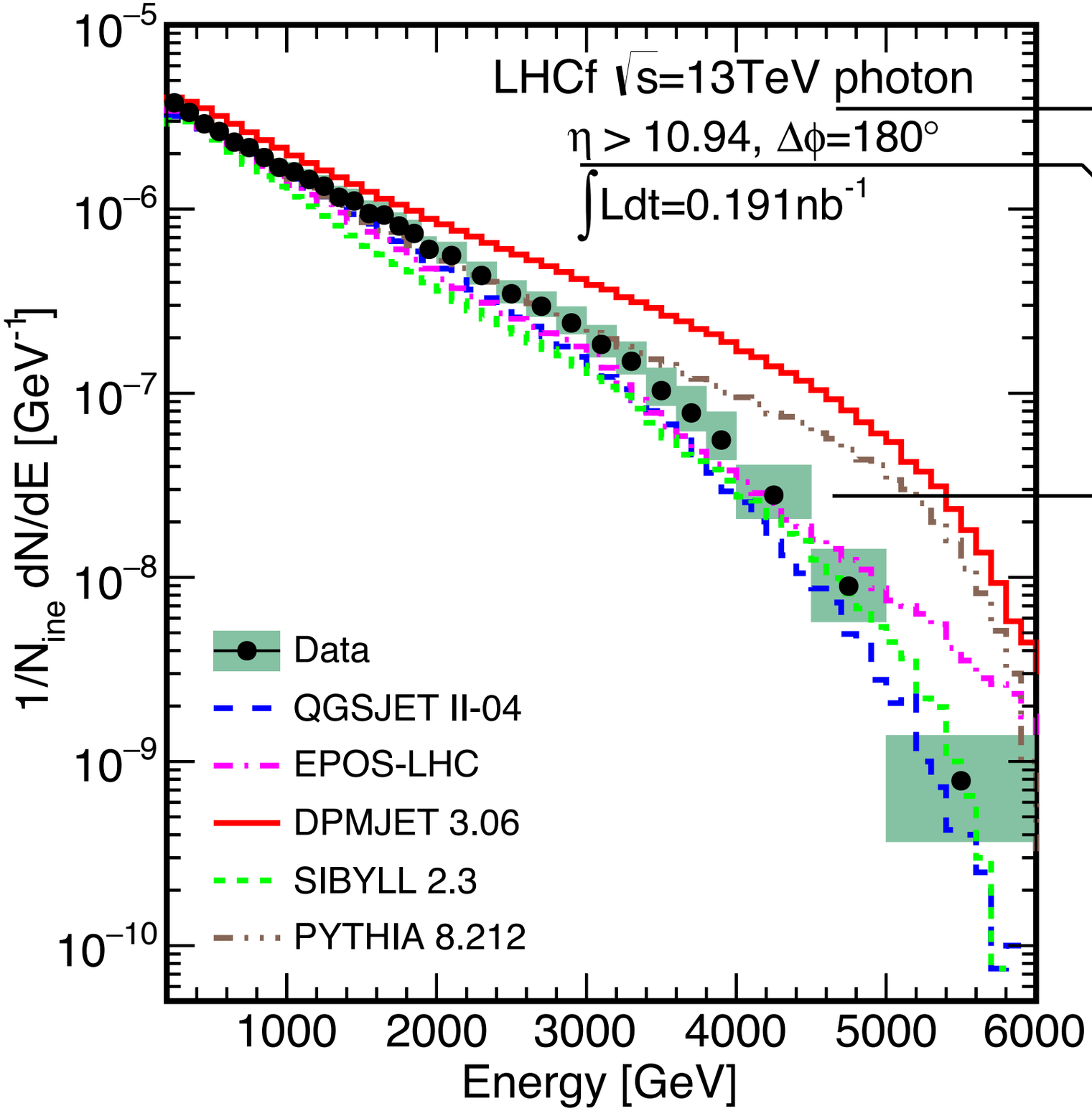


2層目 Y



If the multihit event was not correctly rejected, the energy deposit will over estimate.

LHCf photon spectrum



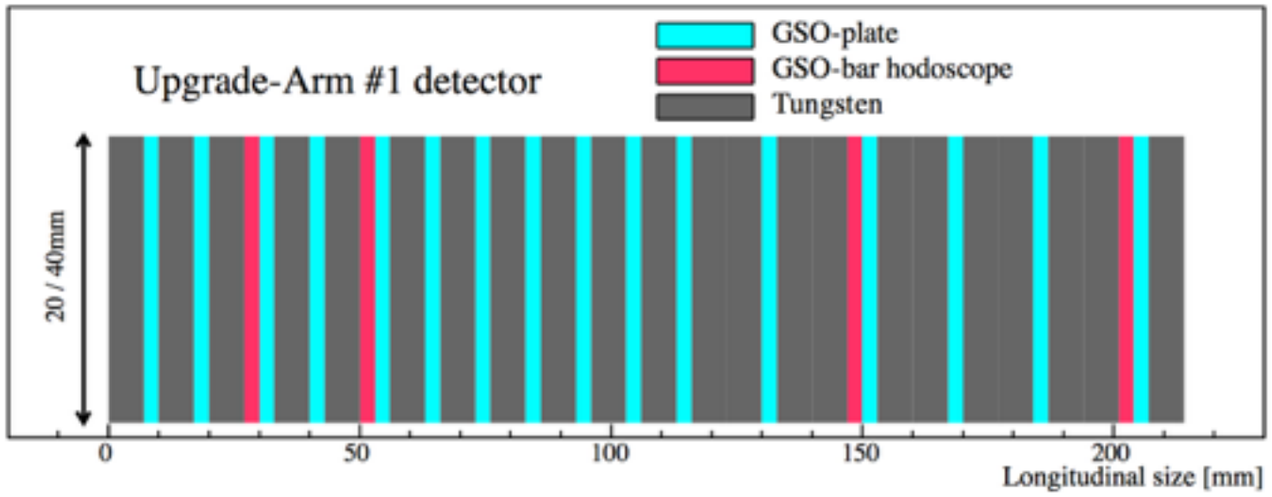
PID

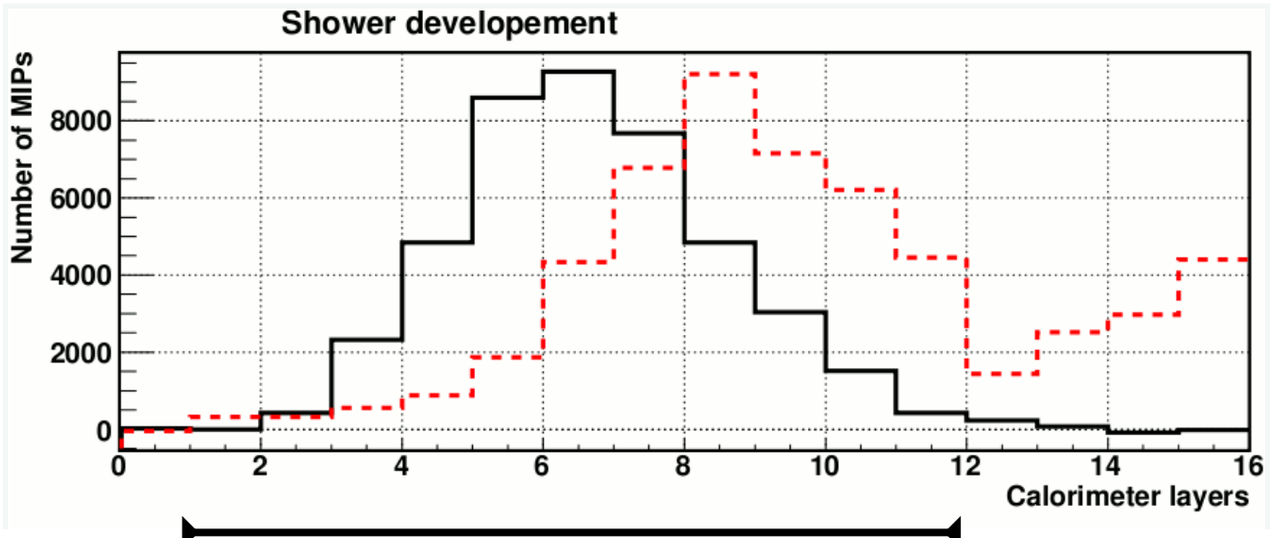
Position

Energy

MultiHit

Energy





Photon: $T_i = 1$

Hadron: $T_i = 1$(1~11layer) +
$T_i = 2$(12~15layer)

How to calculate energy

$S = \Sigma_i dE_i \times F_i$

$F_i = Y_i(x,y)L_i(x,y)T_i$

Y_i: Light yield

L_i: Shower leakage

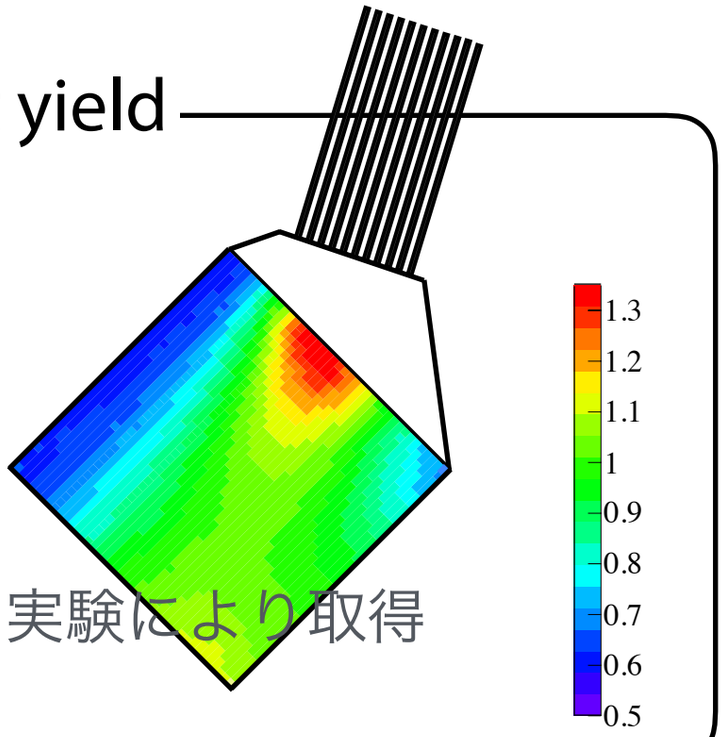
T_i: Thickness factor (1 or 2)

Energy = f(S)

Correction

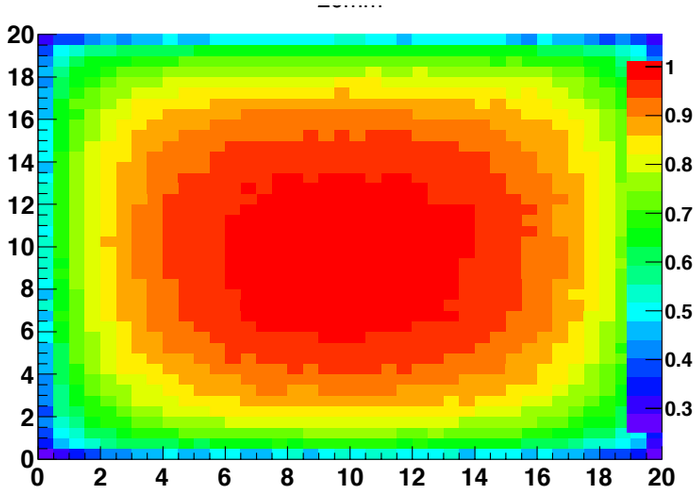
Correction is essential due the small size of calorimeter

Light yield



実験により取得

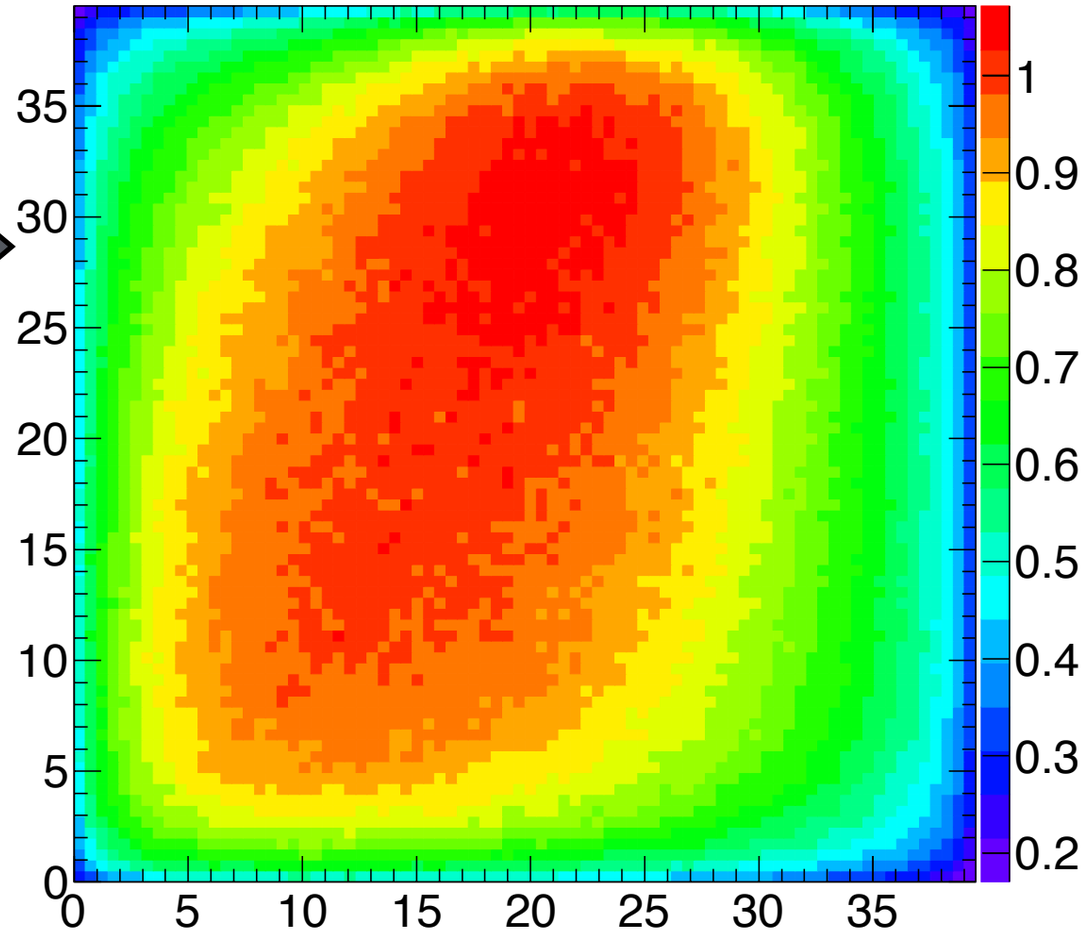
Shower leakage



検出器構造とシャワー拡がりによる

MC

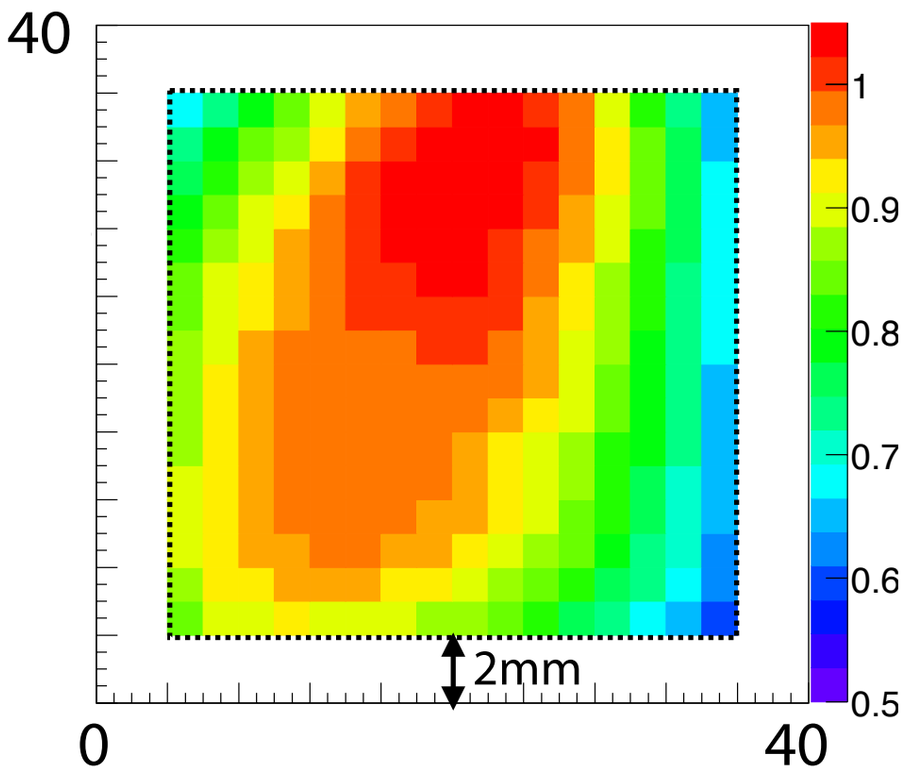
Collection map at each position
light collection efficiency ＋shower leakage



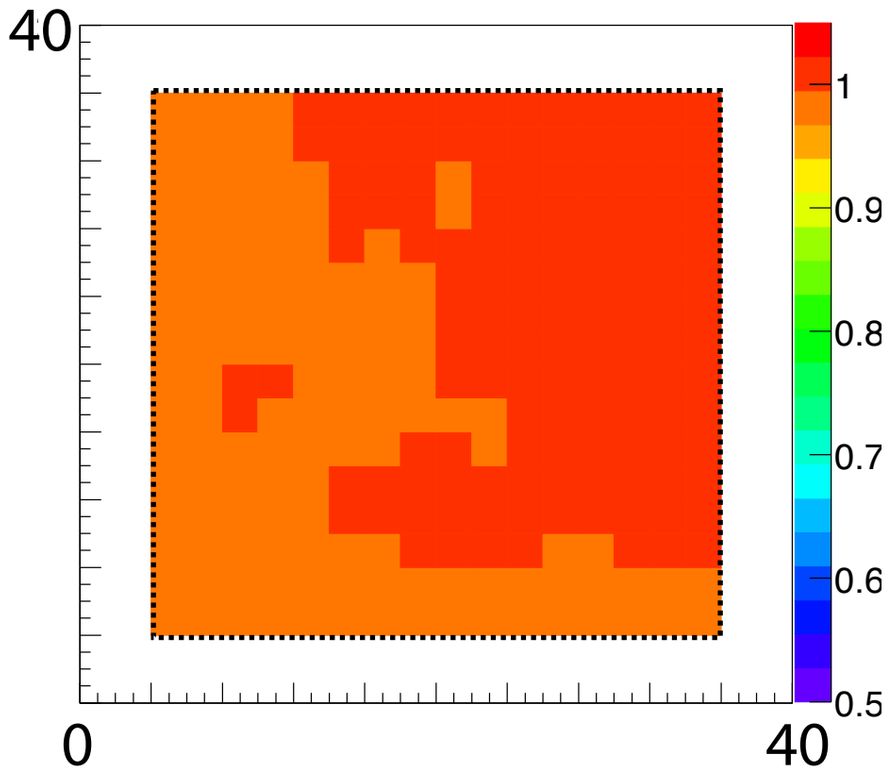
Collection by the map in each layer
according to the position information.

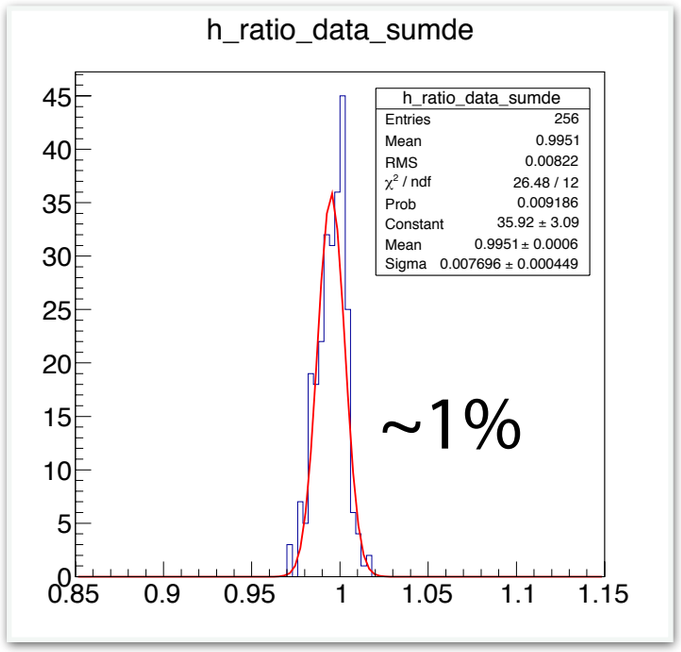
Position dependence of energy deposited

Before correction



After correction



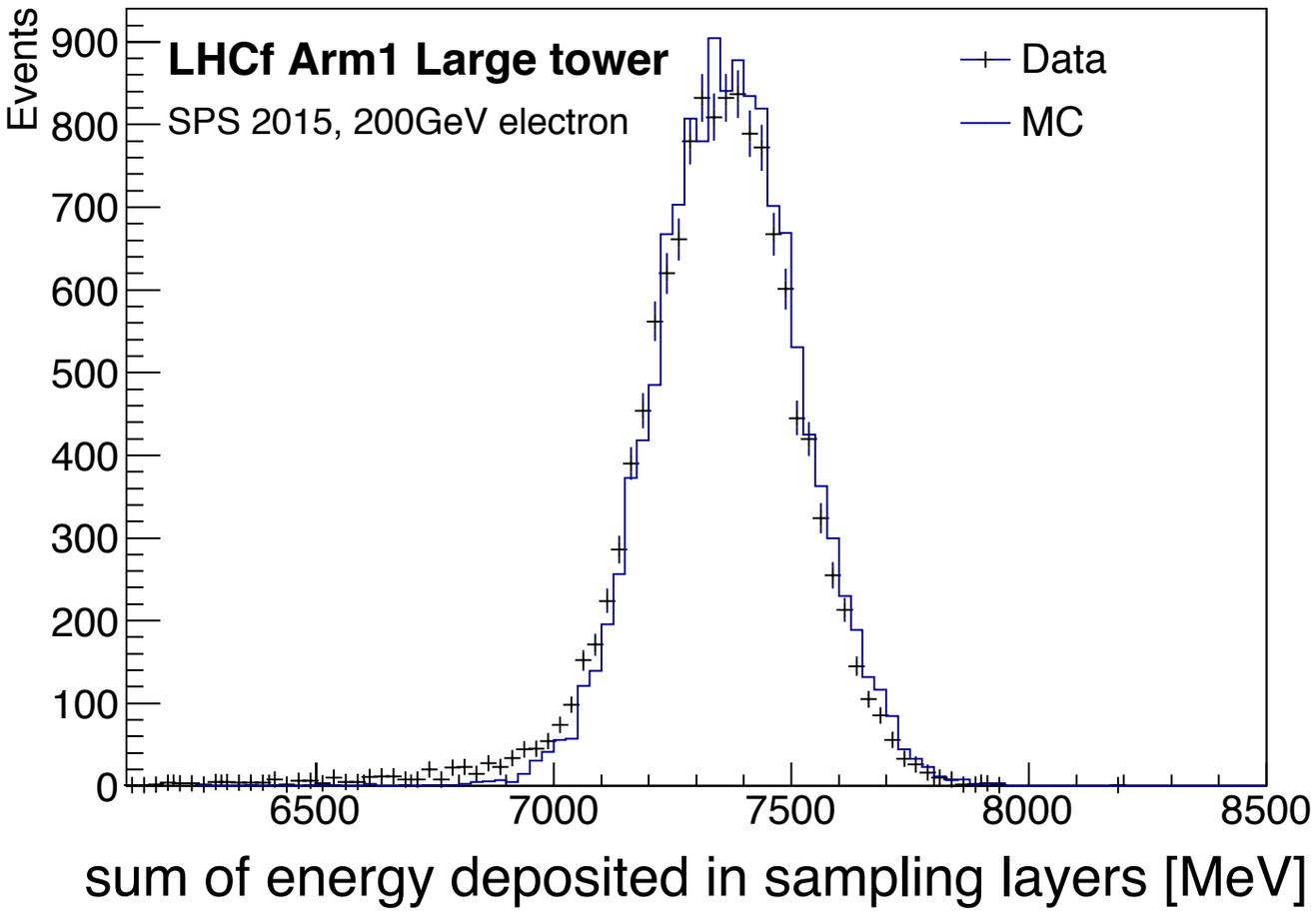


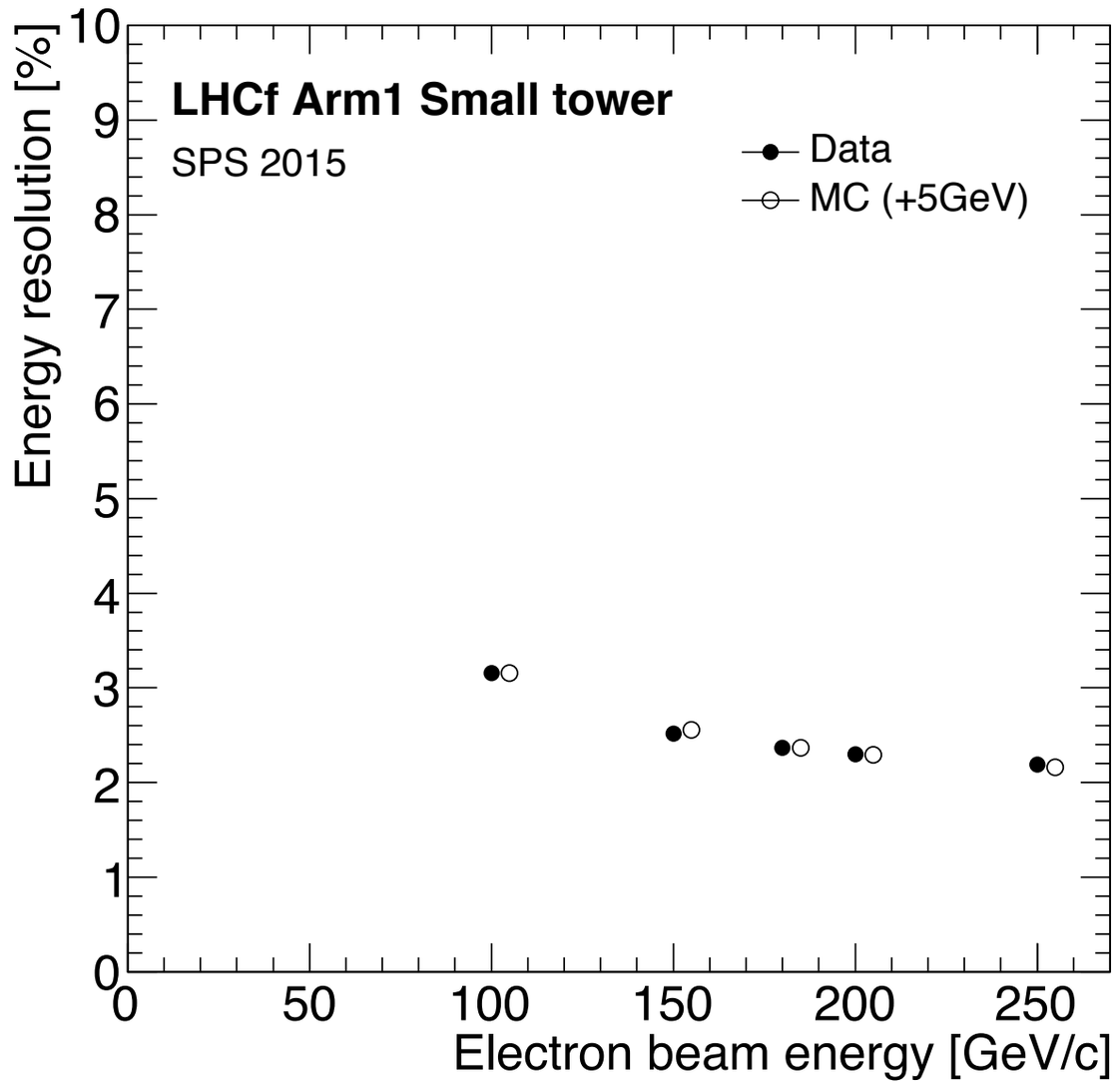
succeed to correct the position dependence with 1%

Energy (Photon)

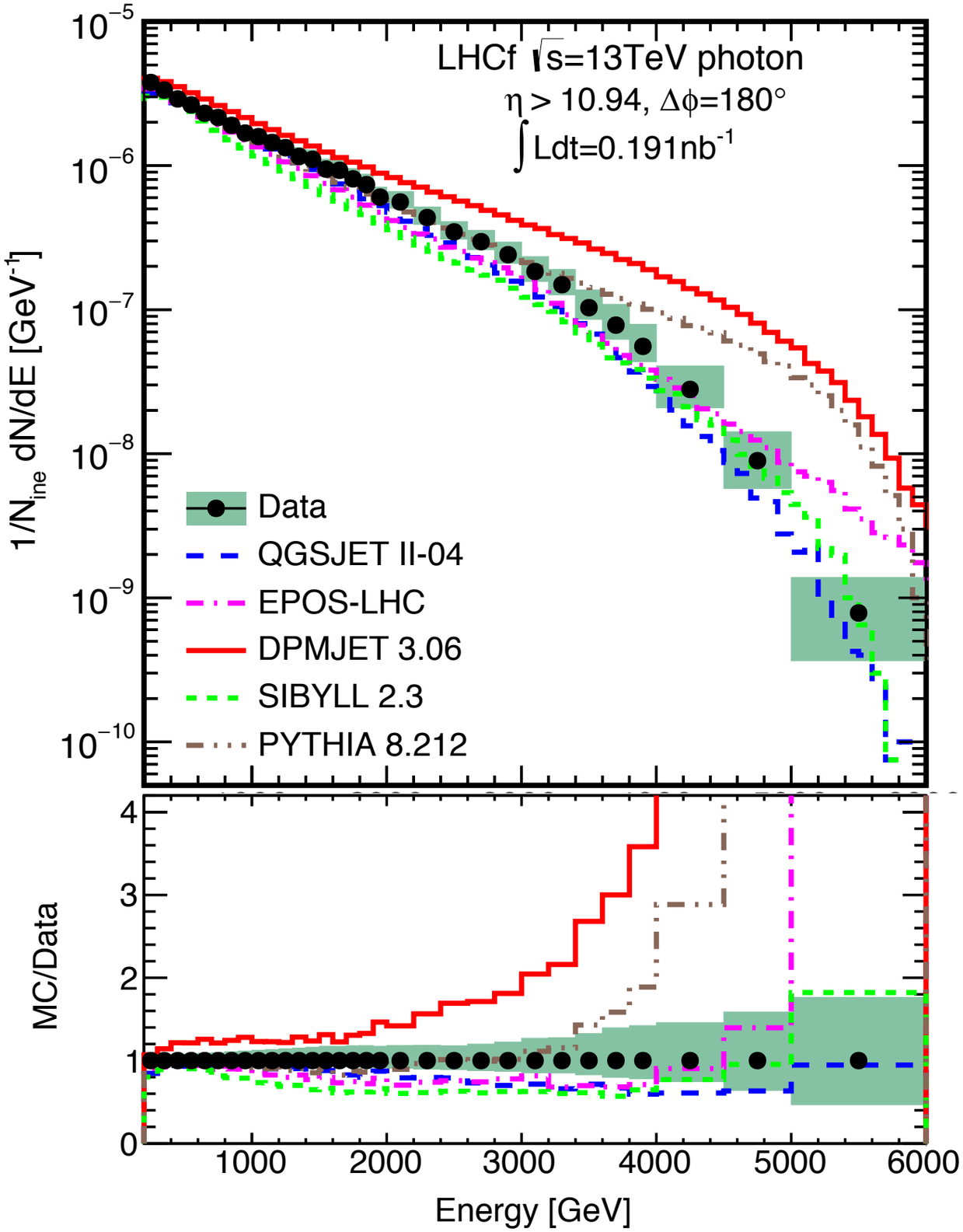
Energy resolution investigated by using SPS election beams

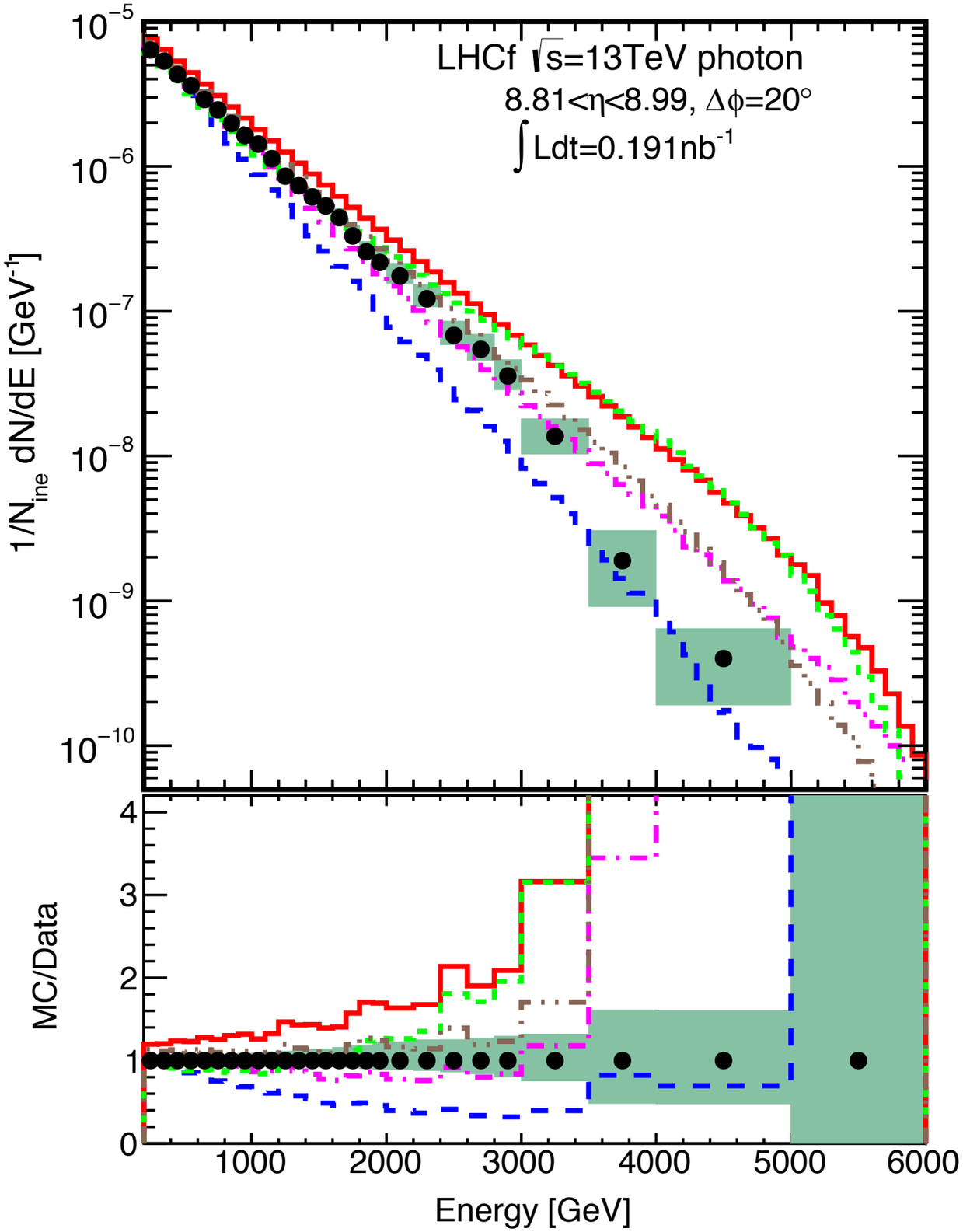
Resolution = σ / mean



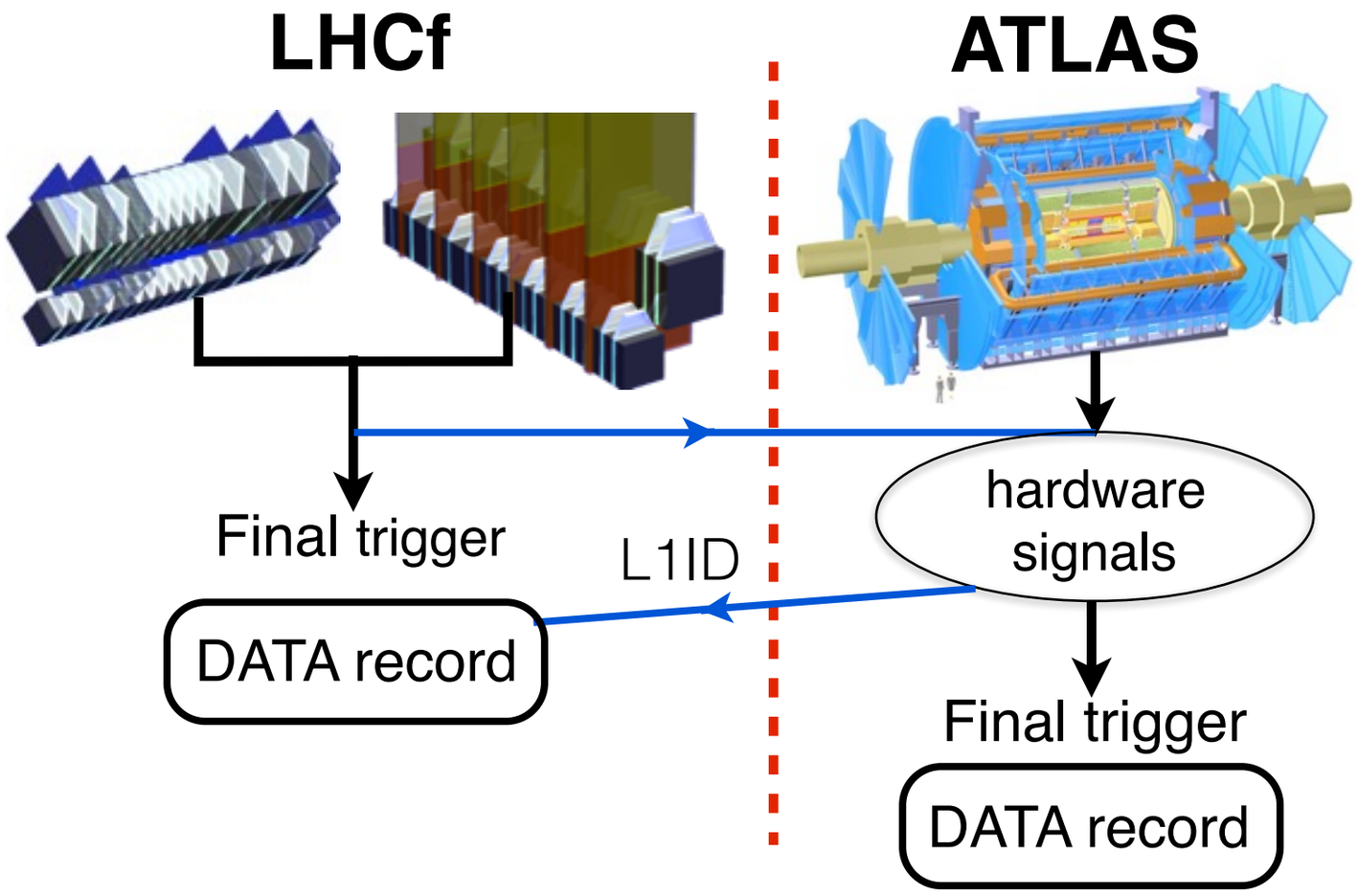


LHCf photon spectra





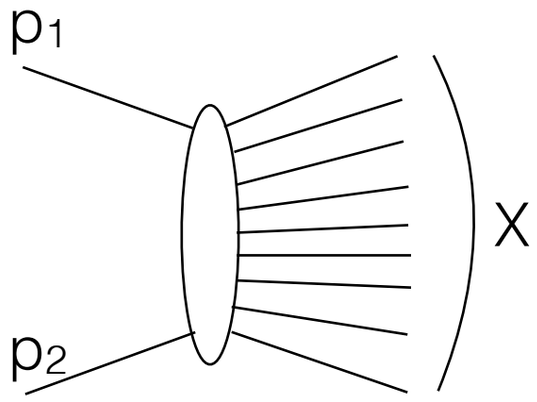
ATLAS-LHCf common operation



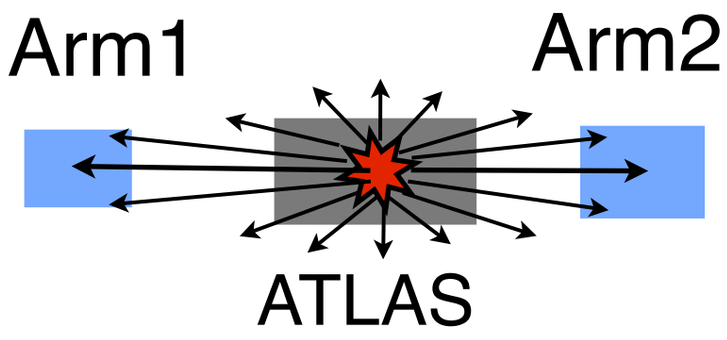
✦LHCf is treated as a part of ATLAS.
✦LHCf triggers ATLAS.

- LHCf has to send the final trigger to ATLAS within a limit time(~**1.6μs)**,
- ATLAS will receive LHCf final trigger to issue the common trigger.

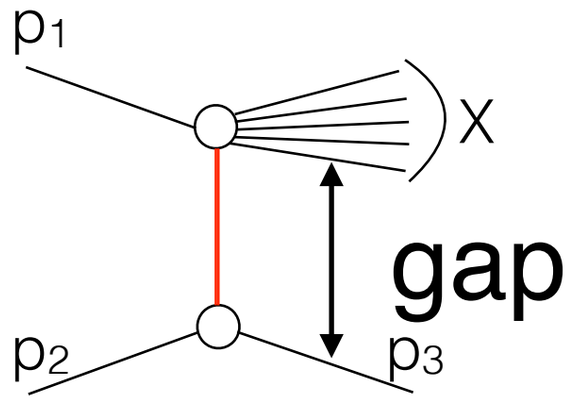
Diffraction collisions



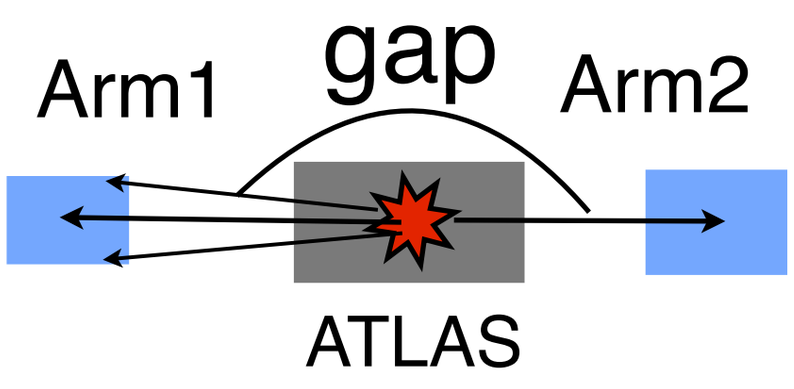
p p—>X



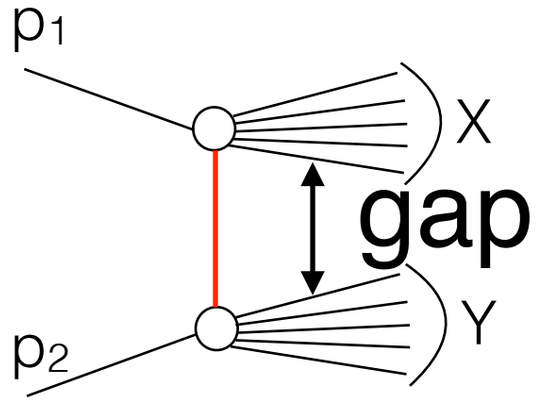
non-diffraction



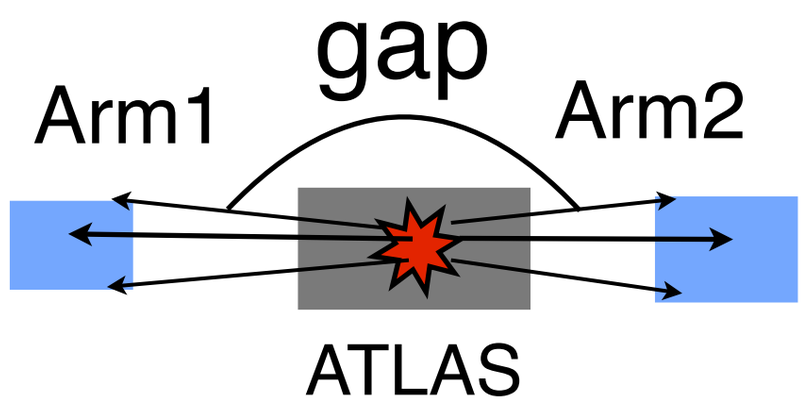
p p—>p X



single diffraction

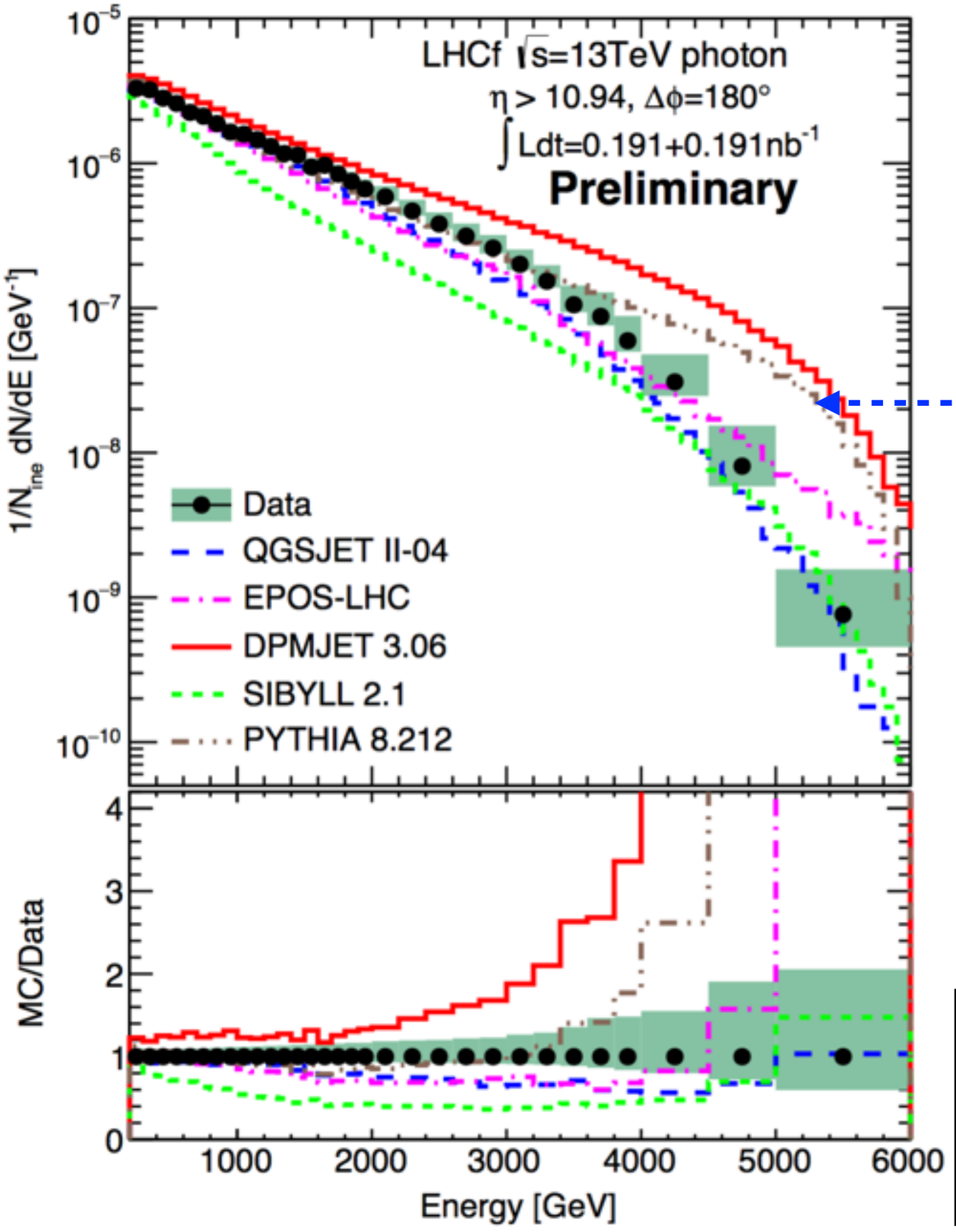


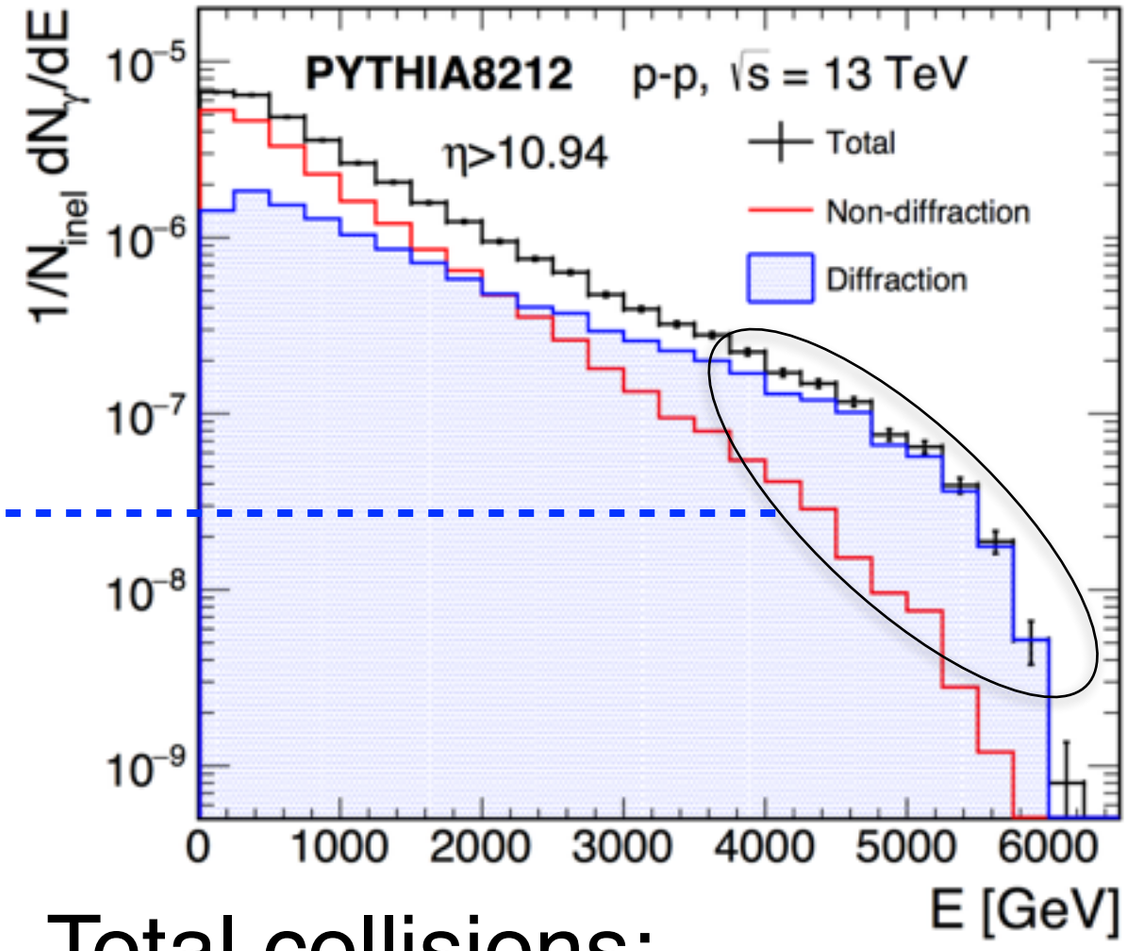
p p—>X Y



double diffraction

Investigation of photon spectrum





Total collisions:
diffraction + non-diffraction

Diffraction = SD+DD+CD

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

Summary

✦LHCf is an experiment dedicated to measure the neutral particles of the LHC, for verifying and improving the hadronic interaction models.

✦LHCf detectors are small sampling calorimeters, with position sensors and radiation-hard.

✦The performance of the detectors:

Energy resolution:(>100GeV)

<5% for photons

40% for neutrons

Position resolution:

<200μm for photons

<1mm for neutrons

✦The analyses of PID, position, energy, multiunit, and relative correction are essential to achieve the final spectra.

✦LHCf and ATLAS had several common operations, the common data analysis is ongoing.

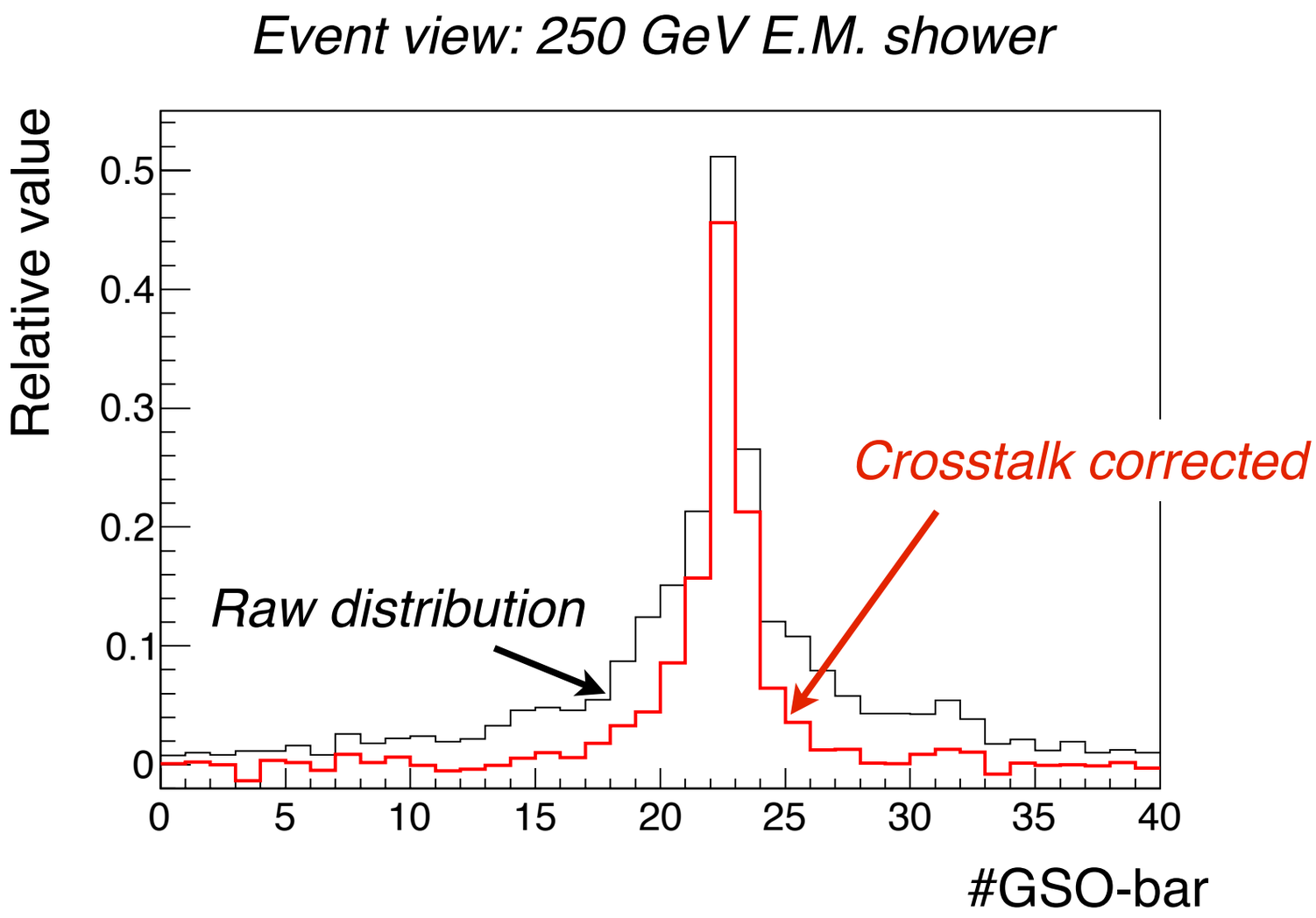
Back up

GSO

表 1　各シンチレータの特性

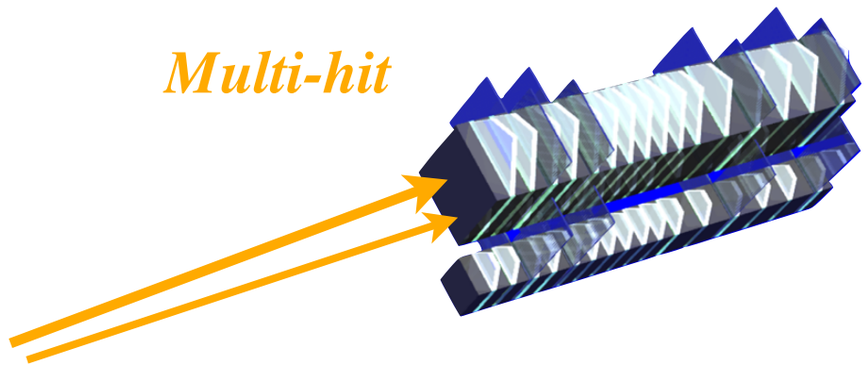
Features	Gd_2SiO_5(GSO):Ce	EJ-260	NaI:Tl	$PbWO_4$ (PWO)
Density [g/cm^3]	6.71	1.023	3.67	8.28
Decay constant [ns]	30-60	9.6	230	6 / 30
Light yield [relative]	20	19.6	100	< 1
Radiation hardness [Gy]	10^6	10^2	10	10^{4-5}
Peak emission [nm]	430	490	415	440 / 530
Radiation length [cm]	1.38	14.2	2.6	0.92
Index of refraction	1.85	1.58	1.85	2.16

GSO-bar hodoscope EMシャワー測定



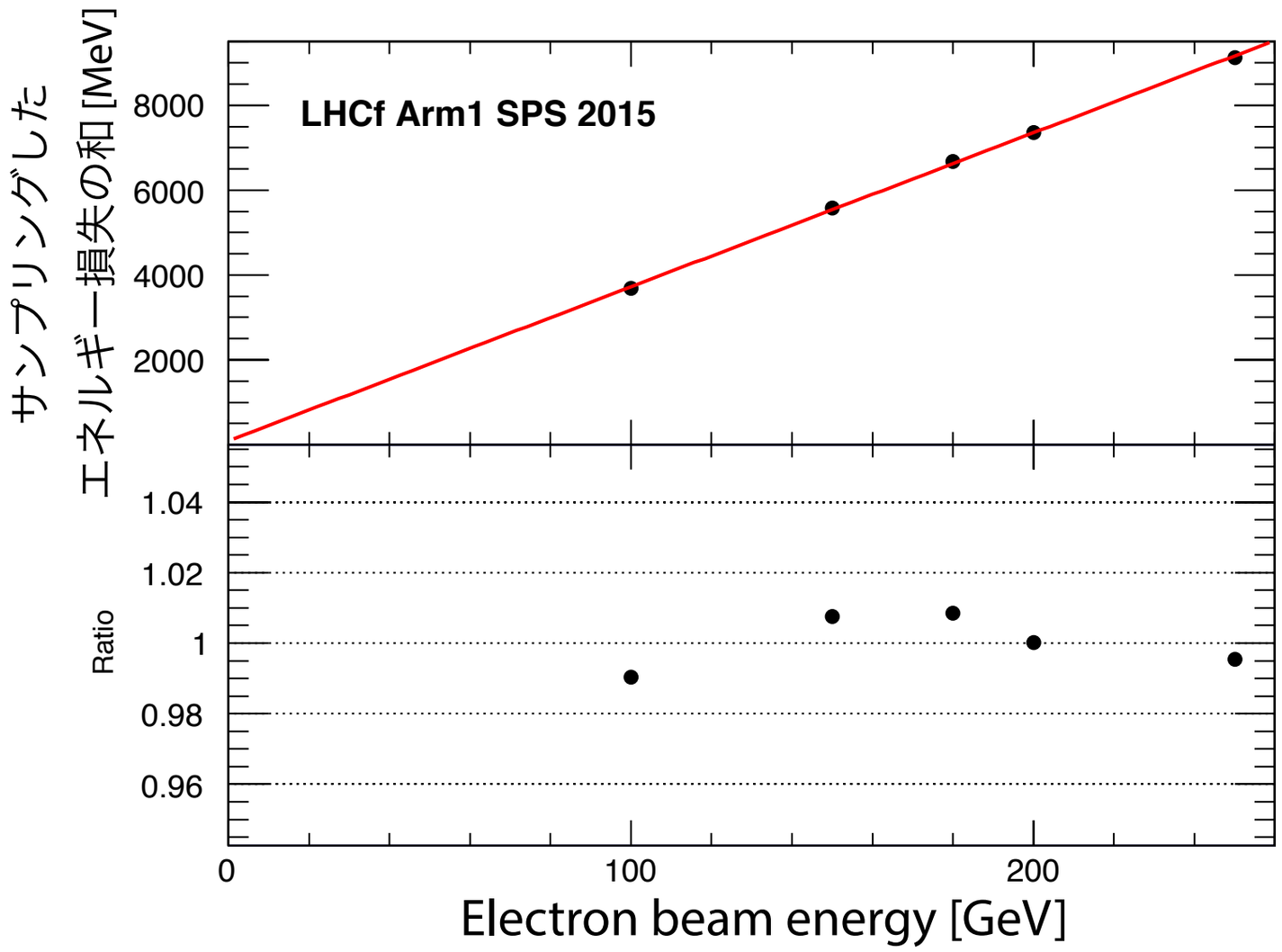
クロストークは位置分解能自体には影響は少ないが、複数粒子の入射時(Multi-hit)の際に問題になる。

→　スペクトルの形を大きく変える。



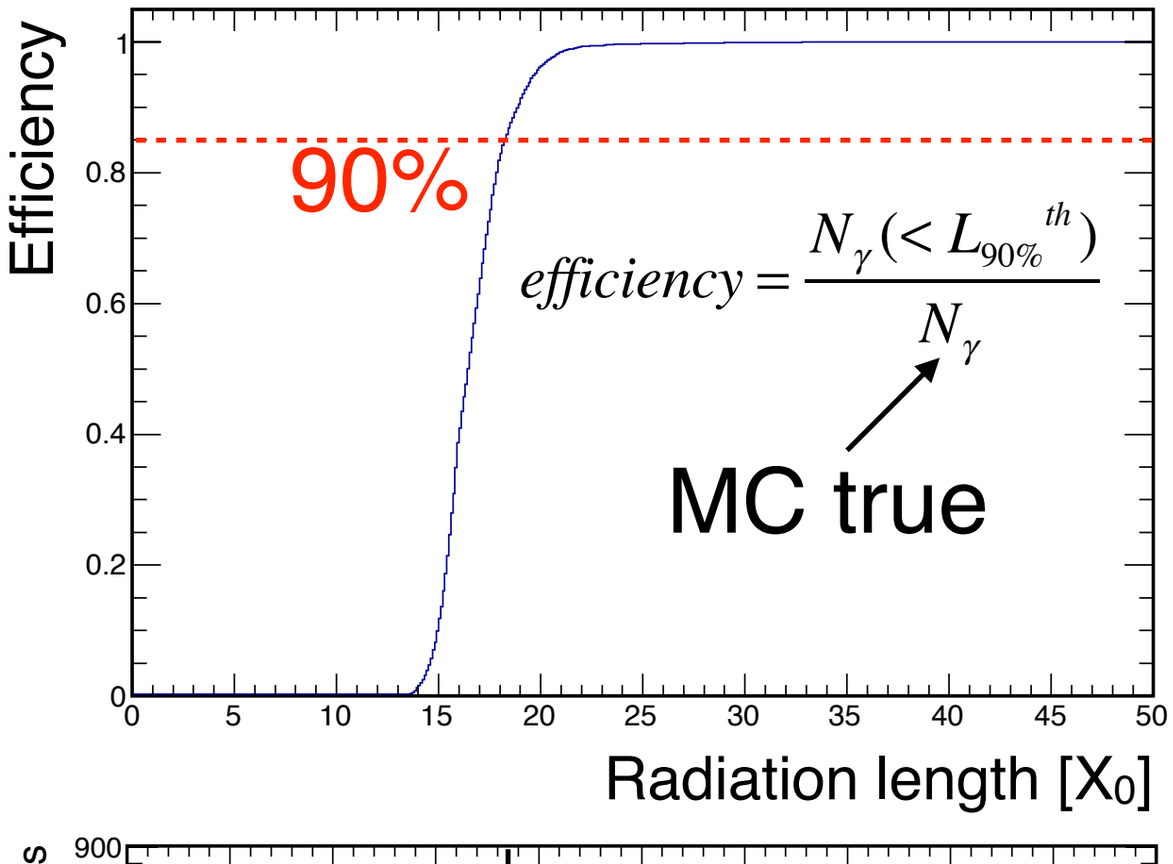
検出器内でのエネルギー損失 vs 入射エネルギー

入射粒子のエネルギーは、カロリメータでのエネルギー損失と既知のエネルギーの入射粒子との対応から推定する。



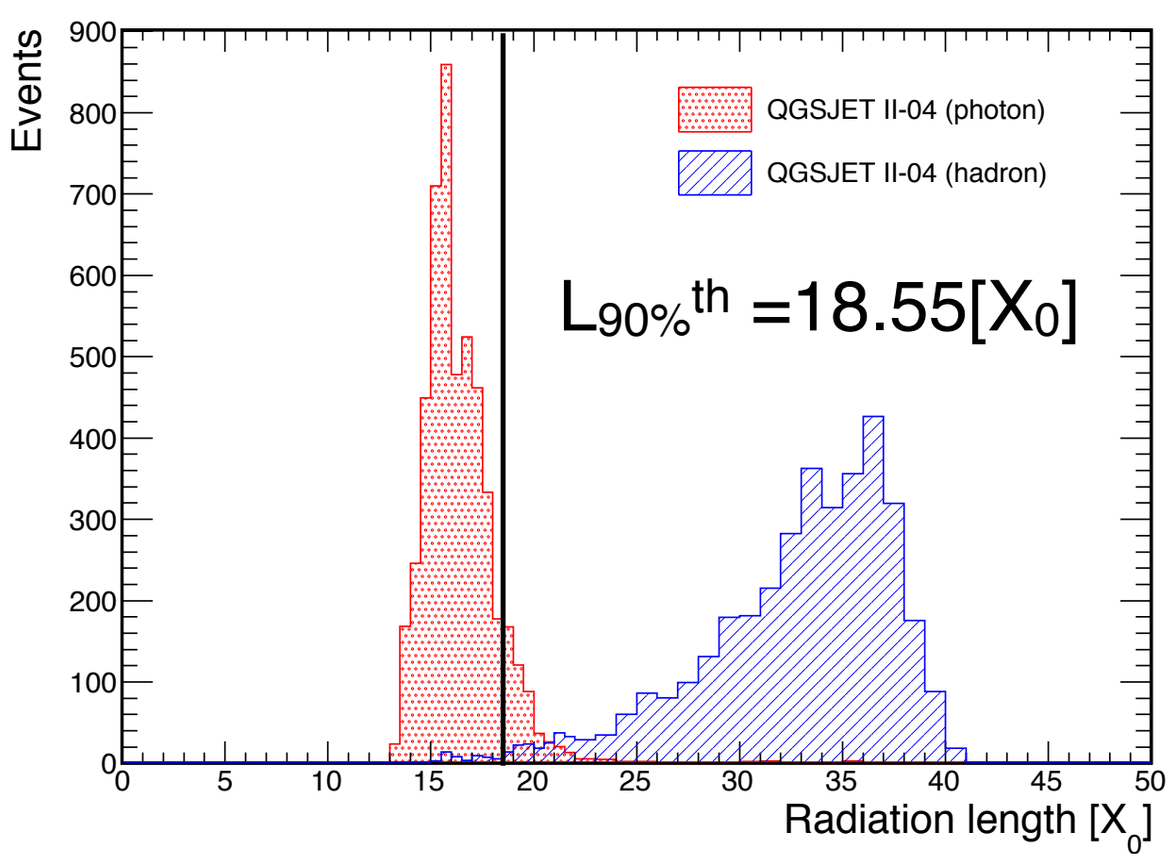
加速器で測定可能な領域でMCとの関係を確認後、高エネルギーへはMCを信頼して外挿を行なう。

$L_{90\%}$ threshold

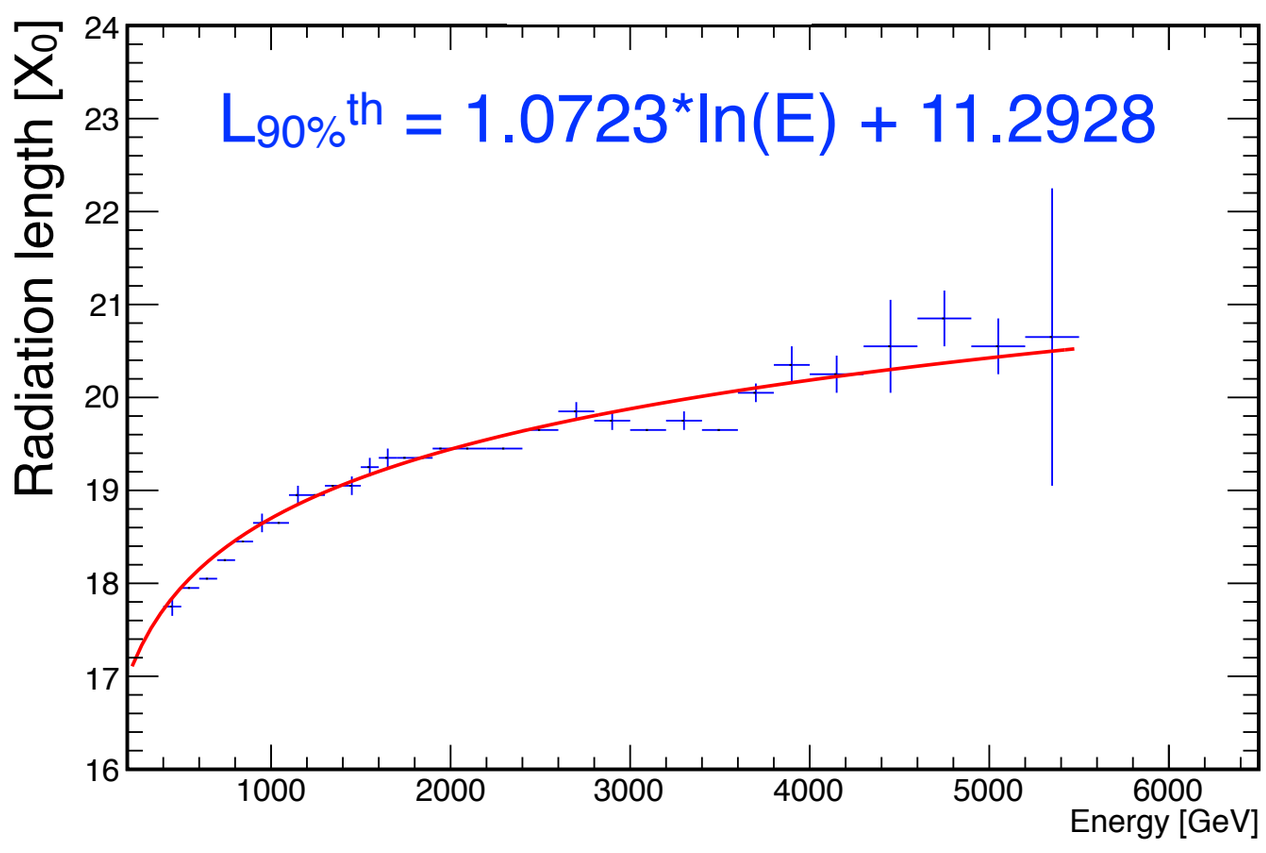


$L_{90\%}$ threshold: efficiency=90%での$L_{90\%}$の値

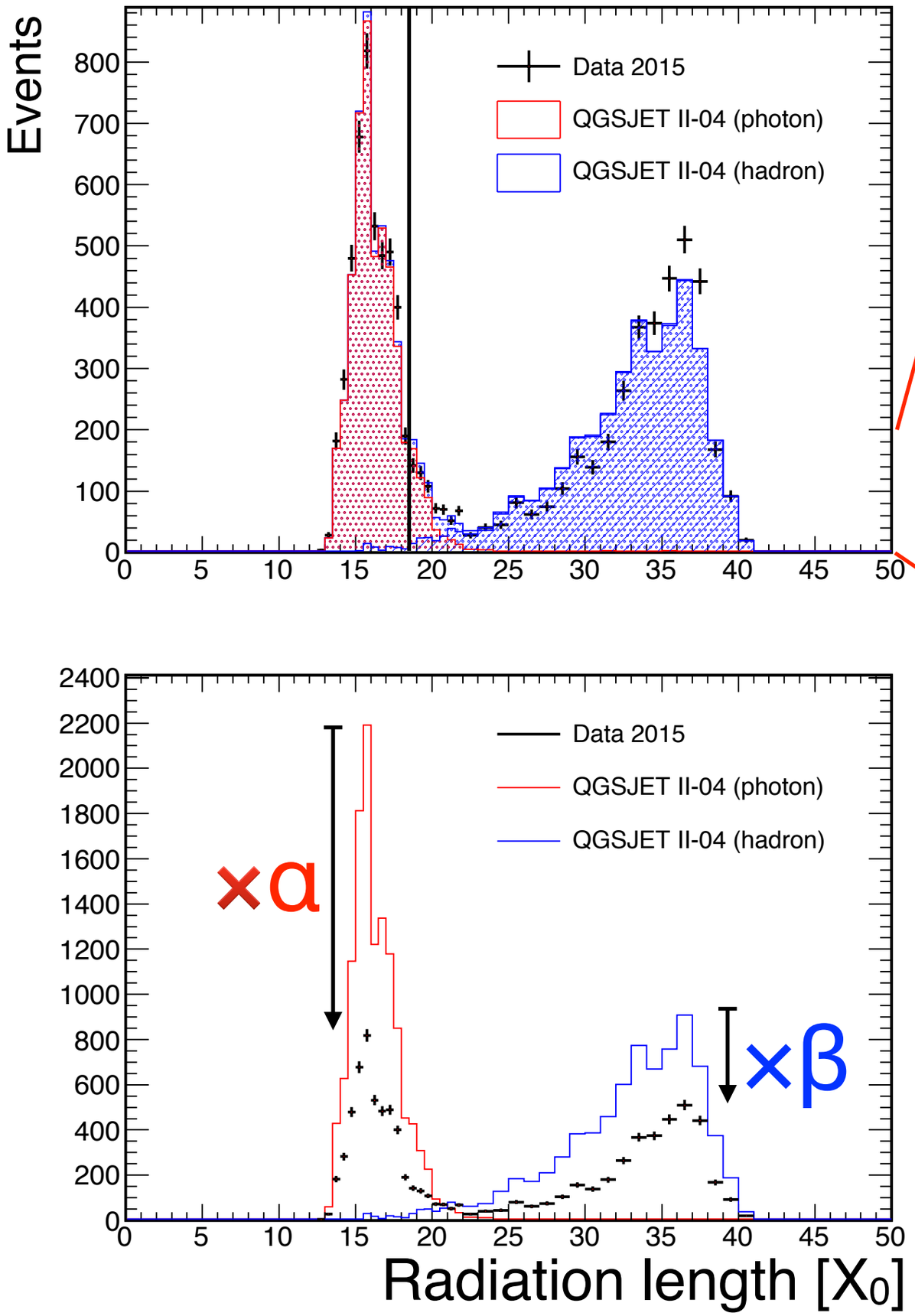
弁別したphoton: $L_{90\%} < L_{90\%}{}^{th}$

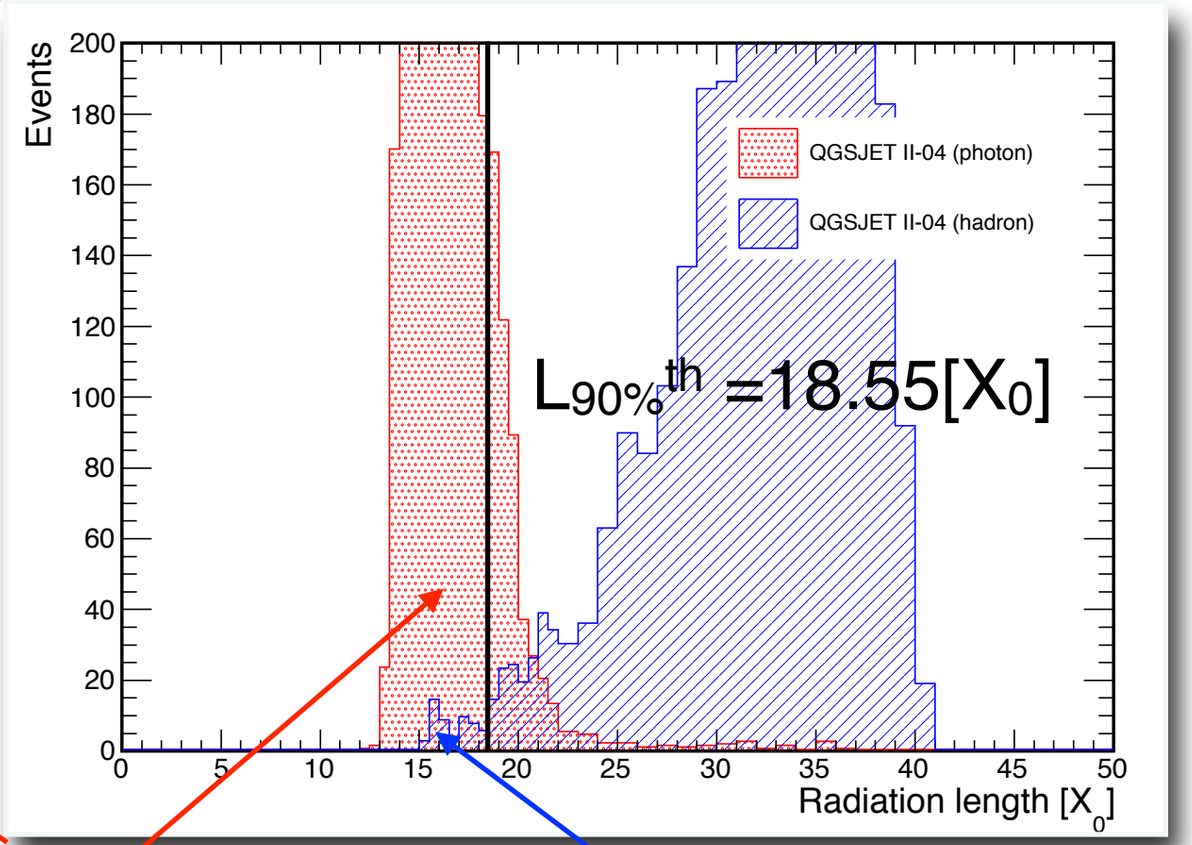


領域A



Templateフィッティング



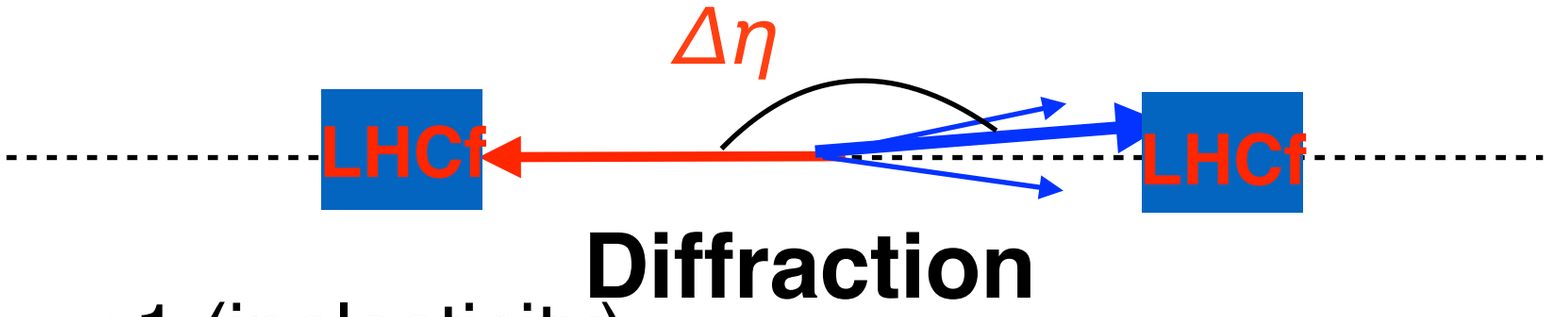


$N_\gamma(<L_{90\%}{}^{th})$ $N_n(<L_{90\%}{}^{th})$

$$efficiency = \frac{N_\gamma(< L_{90\%}{}^{th})}{N_\gamma}$$

$$purity = \frac{\alpha N_\gamma(< L_{90\%}{}^{th})}{\alpha N_\gamma(< L_{90\%}{}^{th}) + \beta N_n(< L_{90\%}{}^{th})}$$

Impact of diffraction collisions to X_{max}



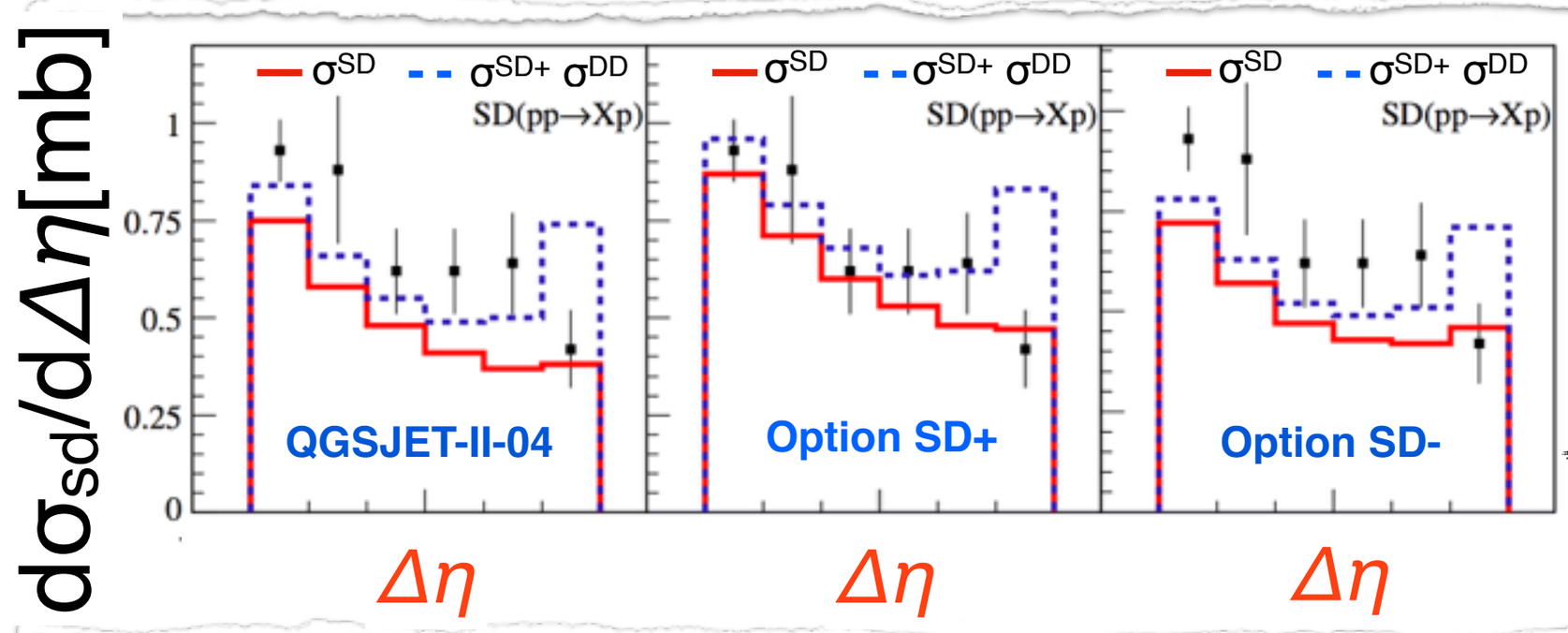
✦K_{inel}= $\Delta E/E_0$ = exp$(-\Delta\eta)$ << 1 (inelasticity)

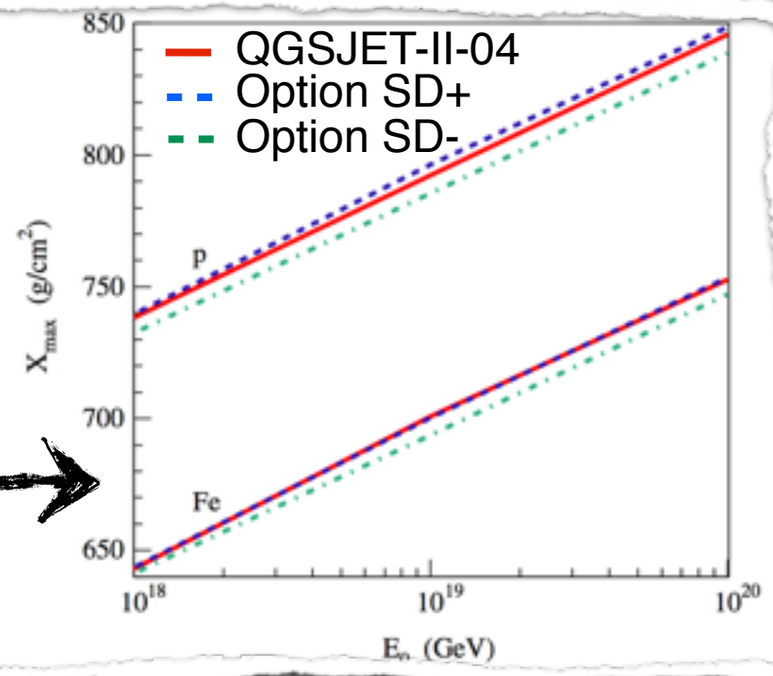
(ΔE: the energy loss of the leading secondary nucleon).

→diffraction collision is relate to the X_{max}

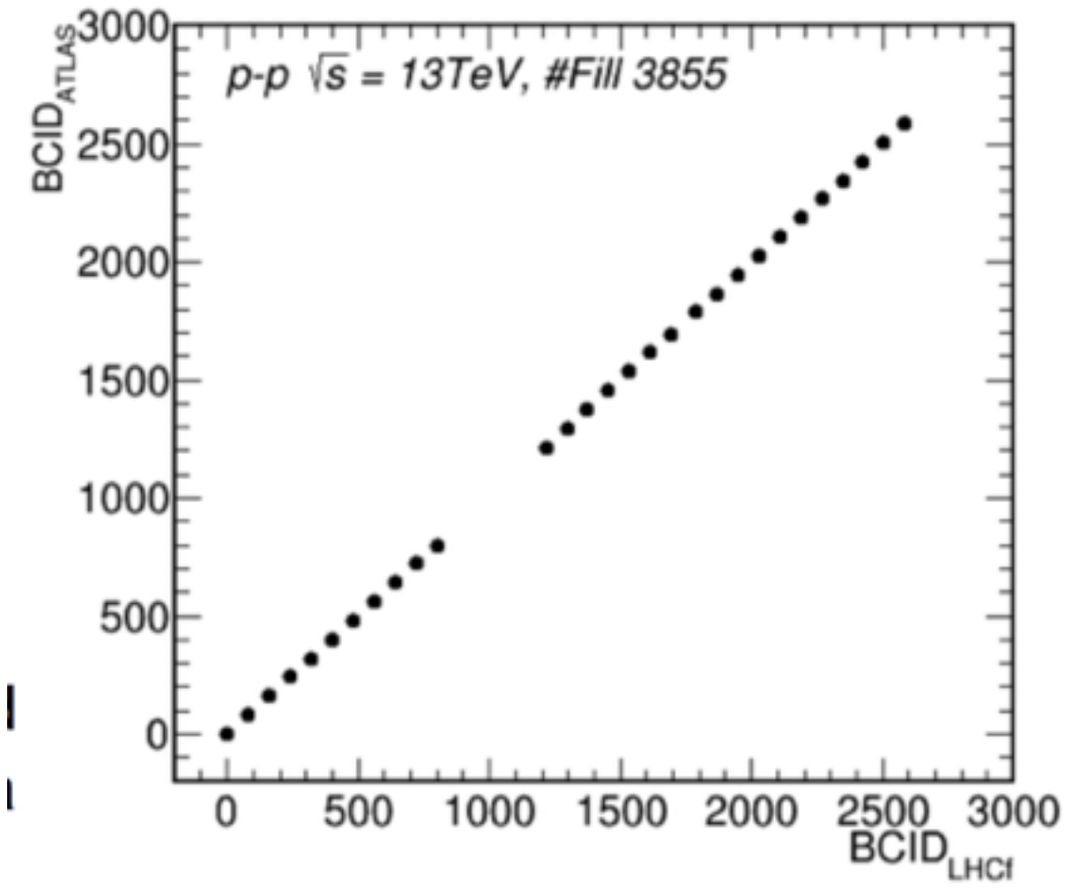
✦ The higher rate of Diffractive collision, the deeper X_{max}

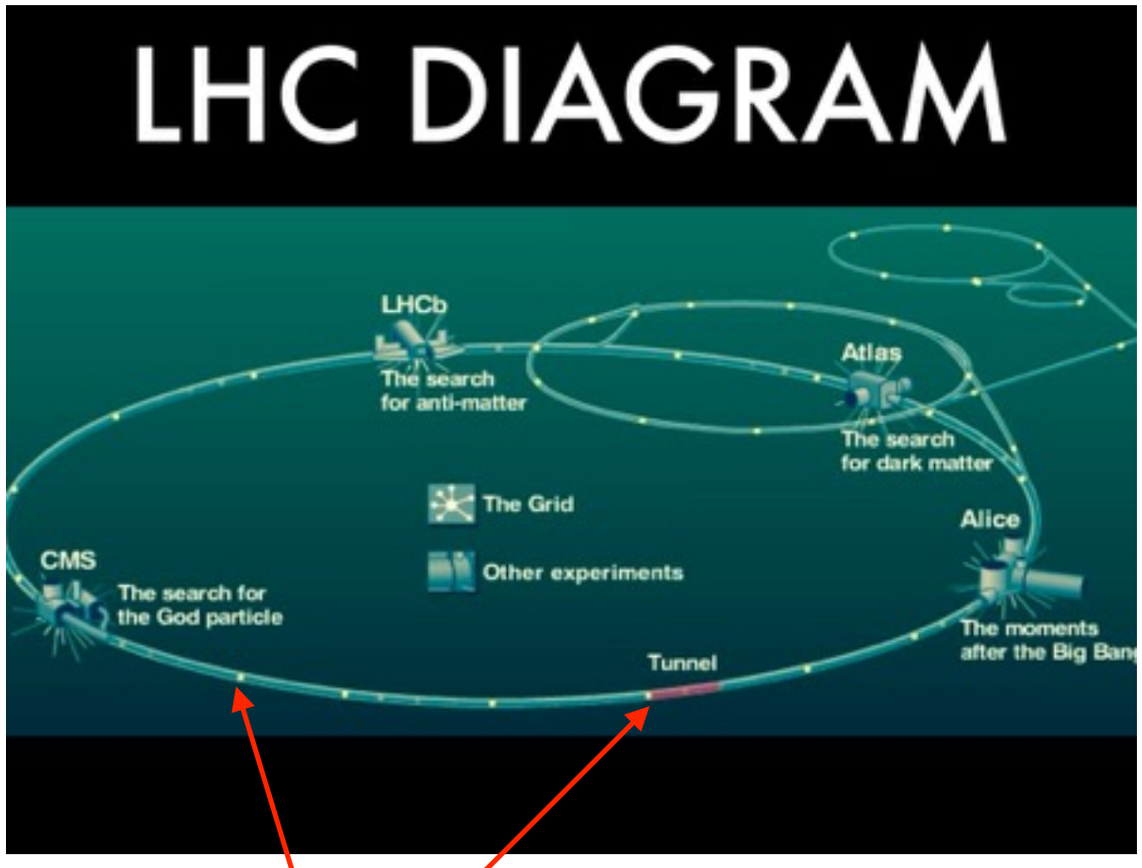
S. Ostapchenko, et al., Phy. Rev. D 89, 074009 (2014)





LHCf-ATLAS Event matching

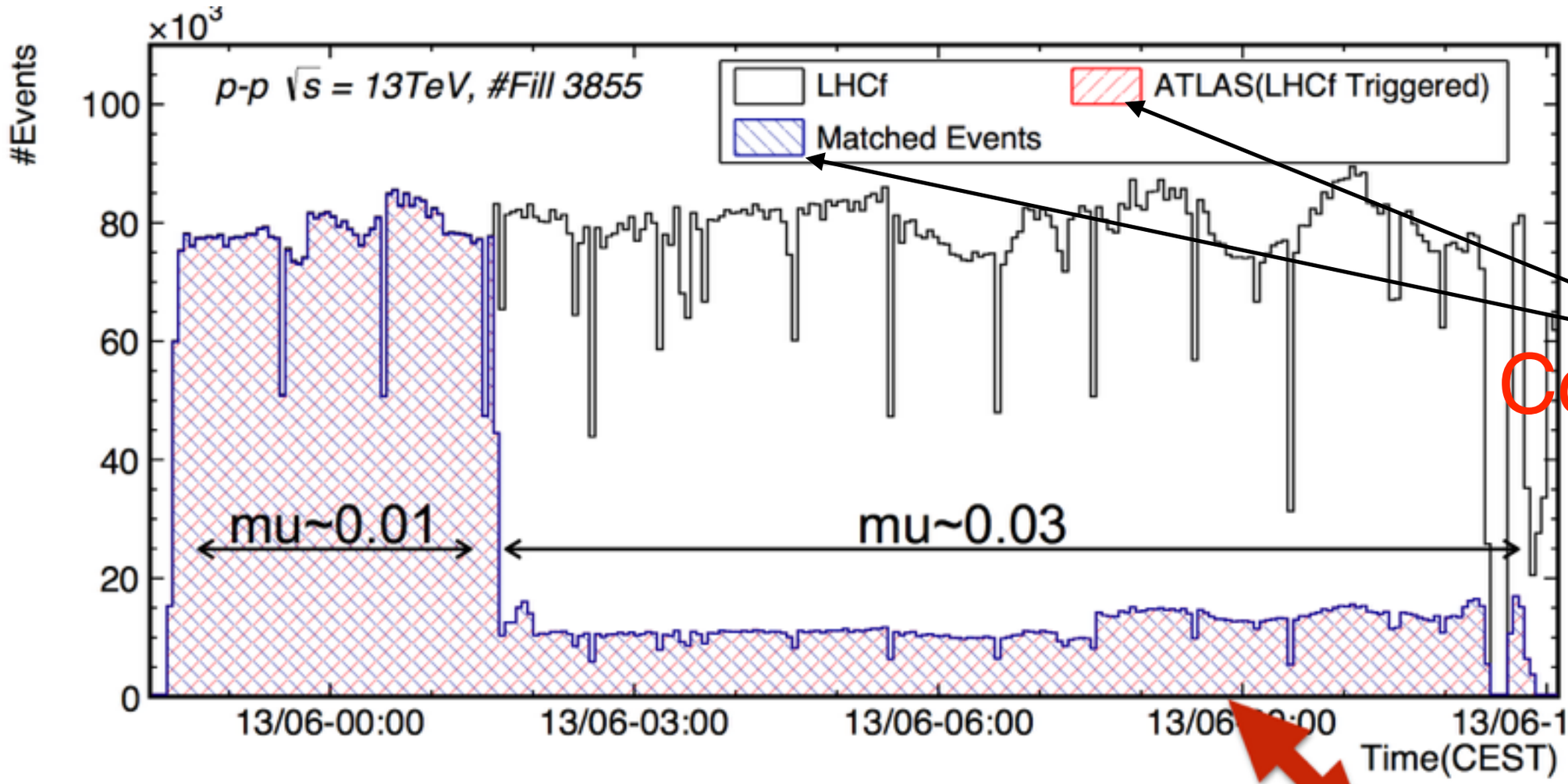




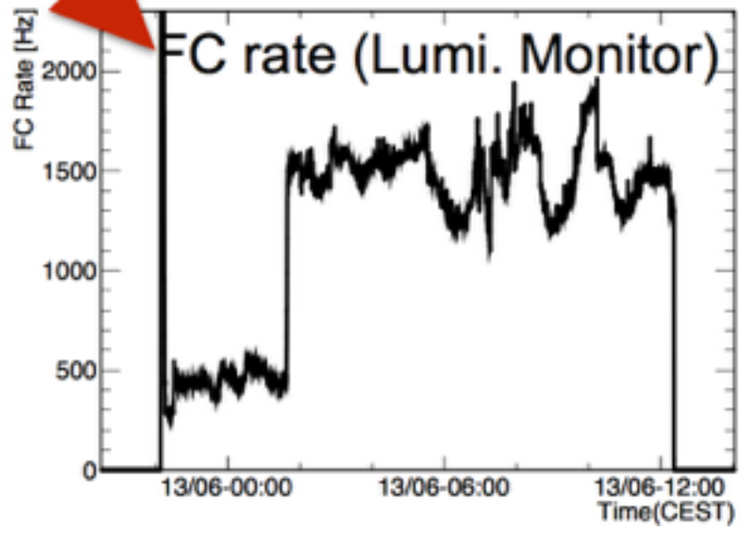
Bunches

- **LHCf-ATLAS common operation has succeeded**
- The event matching was done by using ATLAS L1ID with offline. and confirmed by using BCID(Bunch Crossing ID)

LHCf-ATLAS Event matching

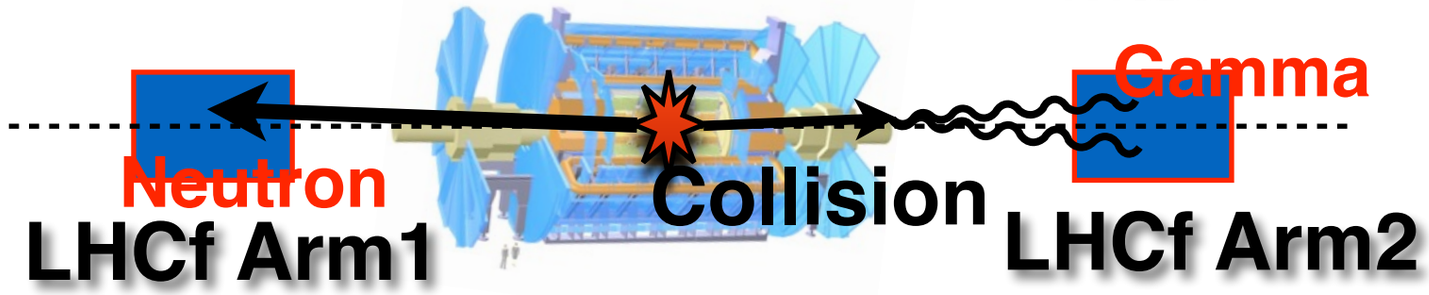


Consistent



	mu=0.01 (run 44299-44472)	mu=0.03 (run44482-45106)
LHCf events	4.168 M	14.194M
Matched events	4.158 M	2.121 M

Impact of diffraction collisions to X^{u}_{max}

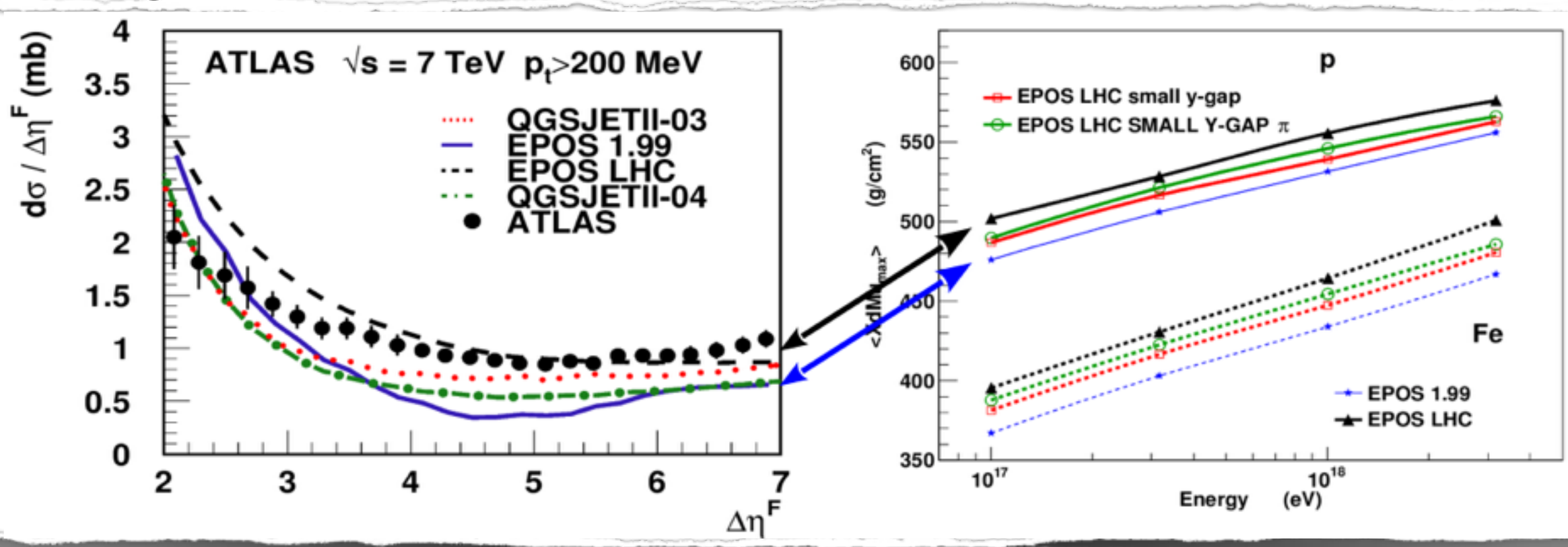


✦Weak influence on EM Xmas

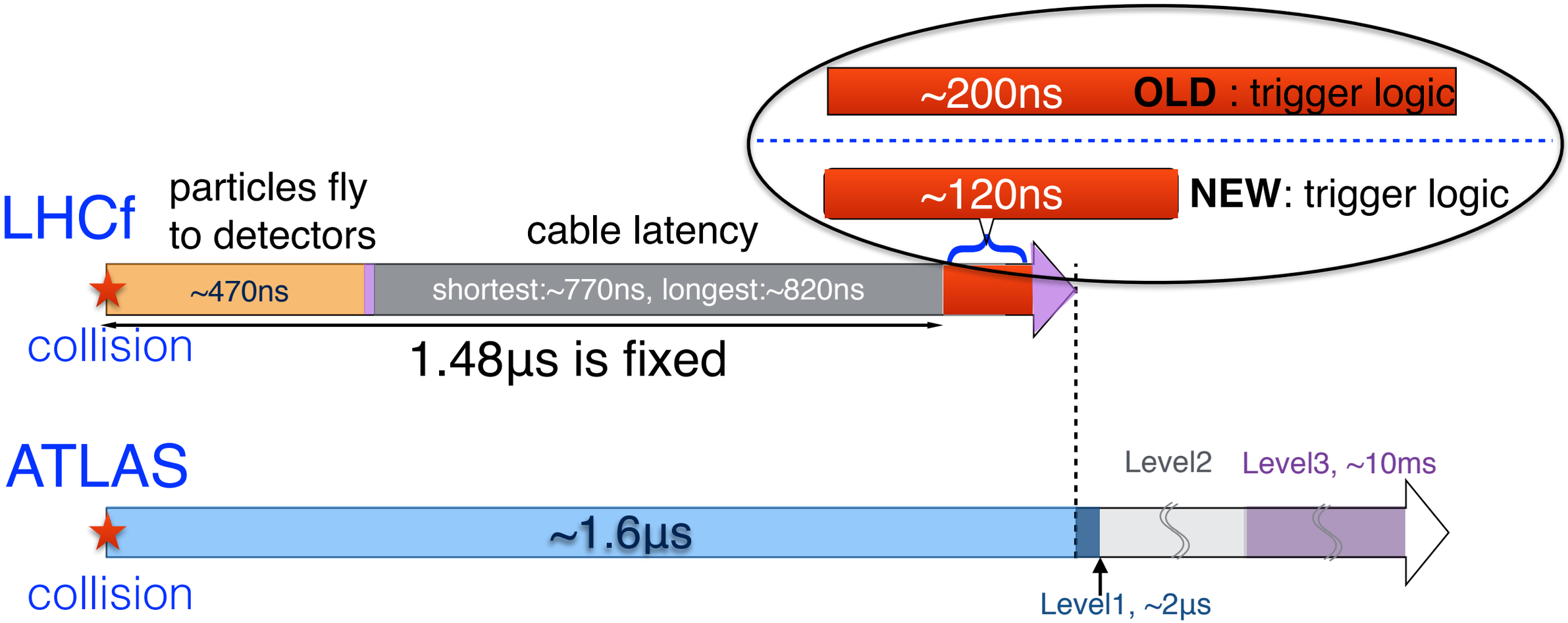
✦Cumulative effect for X^{u}_{max}

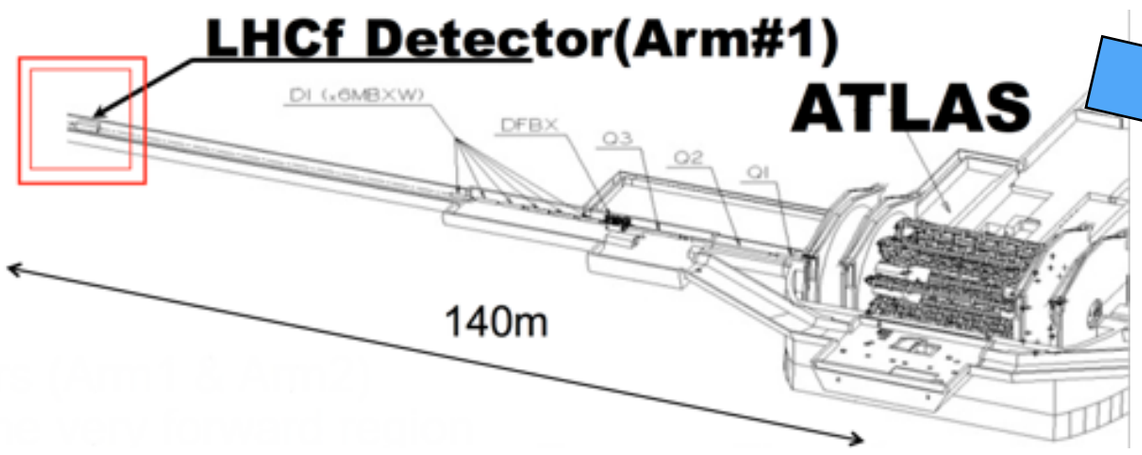
✦ Neutron (baryon) and gamma (pair production from π meson) are detectable for LHCf detectors

T. Pieorg, HESZ 2015



Issues of the new LHCf trigger system





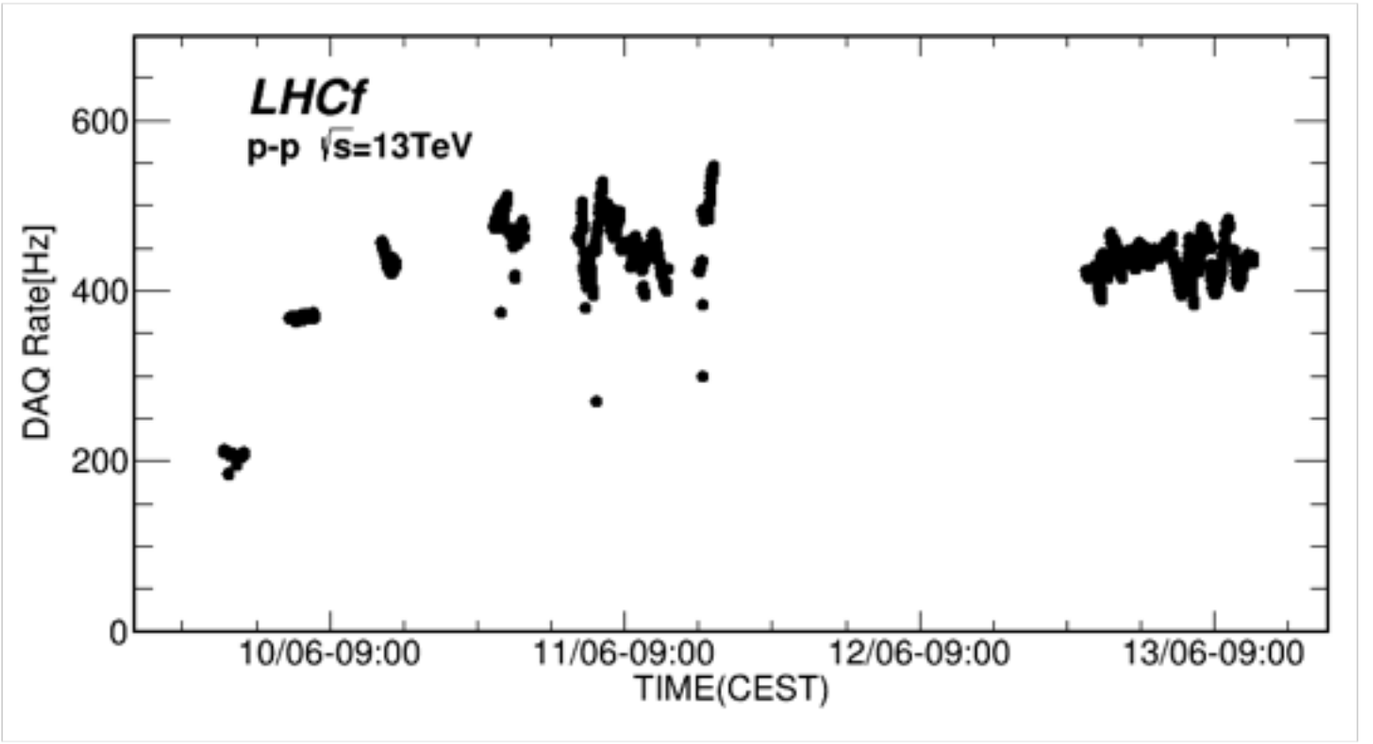
The counting room:
the LHCf trigger logic board placed

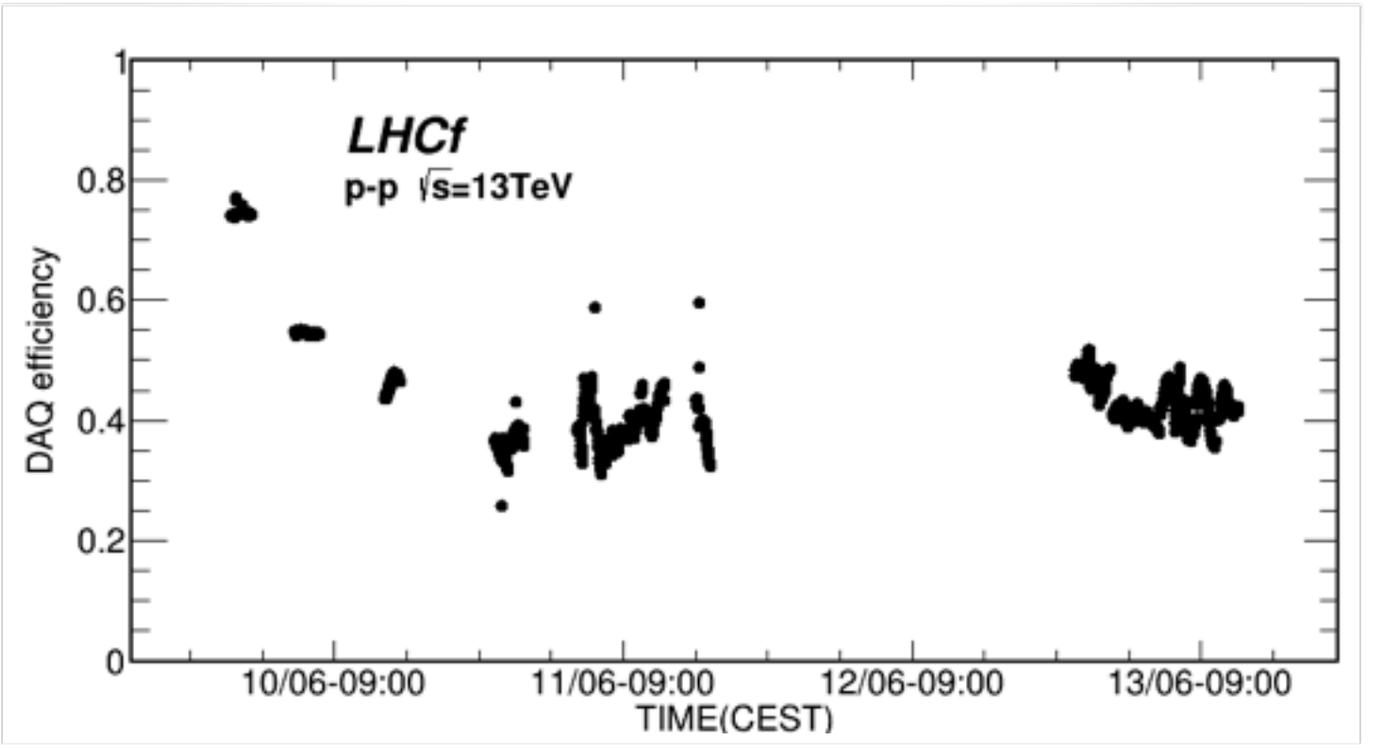
The time limit requirement for the new LHCf trigger logic

< 120ns

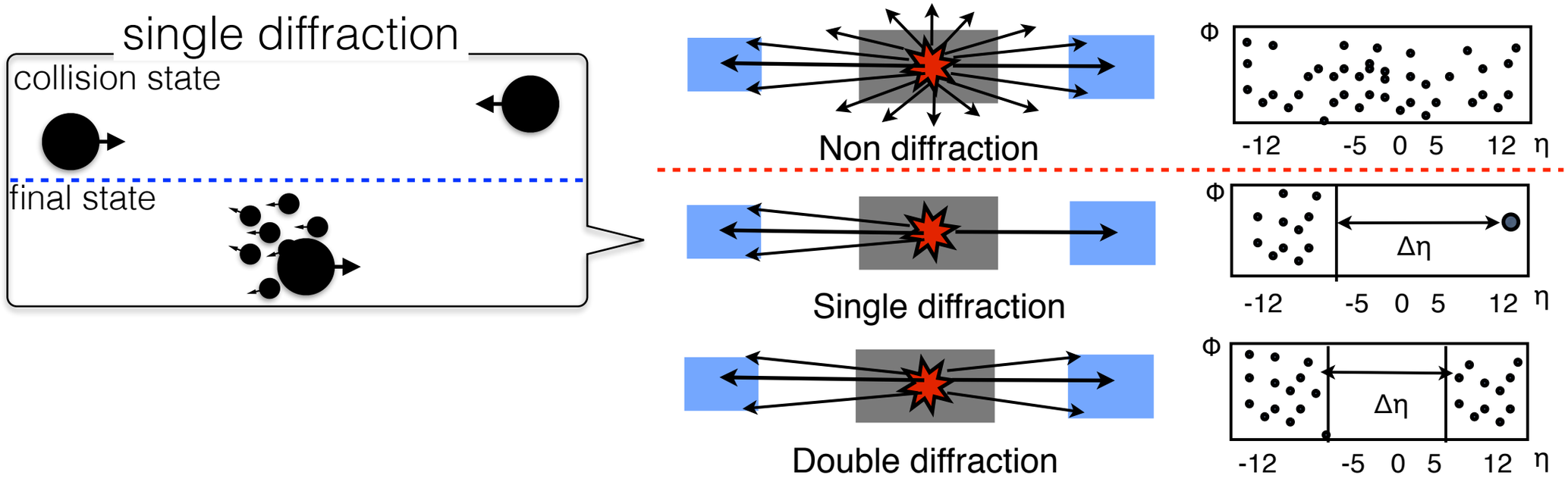
DAQ Rate & DAQ Efficiency

- DAQ rate is limited by the dead time of LHCf DAQ
  The up limit is about 500Hz.





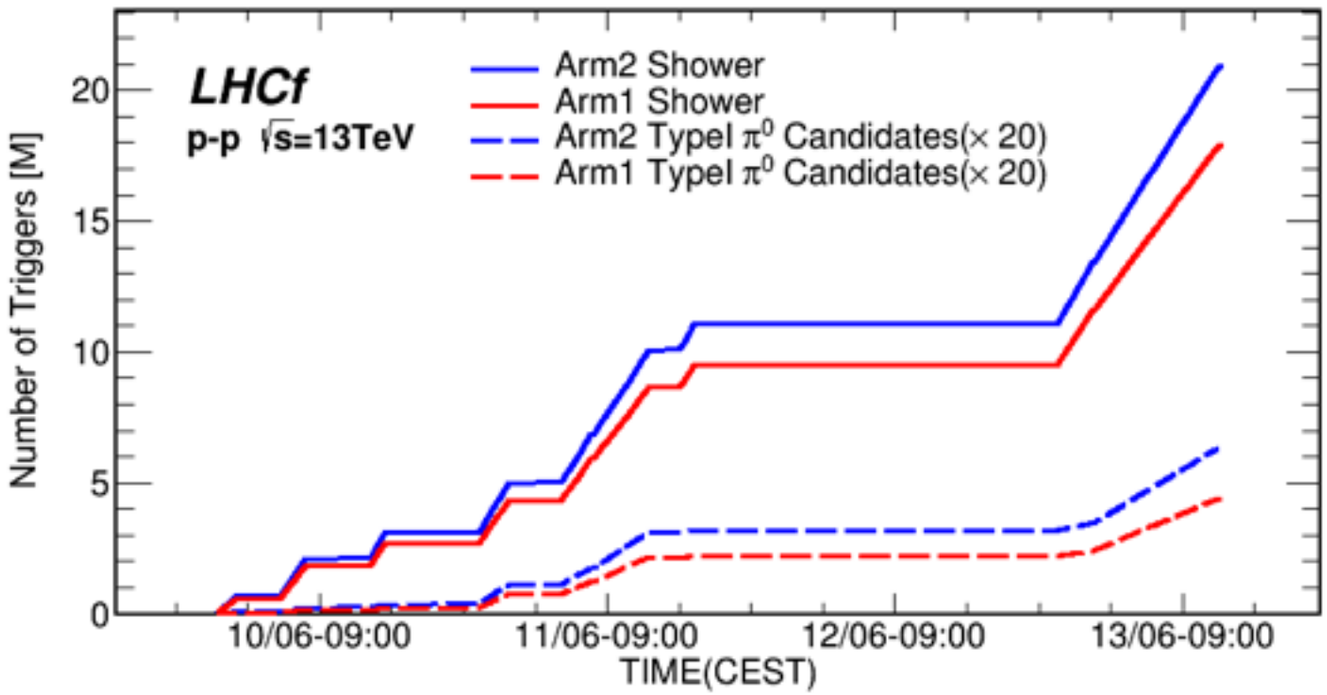
Diffractive event



- ✦The inelastic collisions: classified by diffraction and non-diffraction.
  - The diffraction and non-diffraction are very different mechanisms in hadronic collisions.
  - The diffraction contributes ~28% of the inelastic cross section in proton-proton collisions.
- ✦Diffractive reaction is characterized by a rapidity gap (Δη) in the final state. the rapidity gap is defined as no particle is produced at a rapidity region.
- ✦The measurements of diffractive events require the instruments with large pseudo-rapidity acceptance.

Statistics of 13TeV p-p operation

LHCf detector	Arm1	Arm2
Operation time[h]	26.6	26.6
Collected luminosities[nb^{-1}]	5.15	5.15
Number of recorded shower events[M]	17.94	20.98
Number of typeI Pi0 candidates[M]	0.22	0.31



- In 13TeV operation、Arm1,Arm2 have recorded 17.94M and 20.98M shower events.
  - It's enough compare to the data set in 7TeV analysis with serval M.
  - According to MC PYTHIA study, Arm1,Arm2 can identify 1.97M and 2.31M diffraction-like events, it's enough for LHCf-ATLAS common analyses.