Status of the LHCf experiment

Ken Ohashi (Nagoya Univ.) on behalf of the LHCf experiment

2022 Oct. 5th — 6th International Symposium on Ultra High Energy Cosmic Rays, L'Aquila, Italy — Ken Ohashi

The LHCf collaboration

***,**Y.Itow, Y. Kitagami, *Y.Matsubara, *H.Menjo, *Y.Muraki, *K. Ohashi, *M.Kondo**

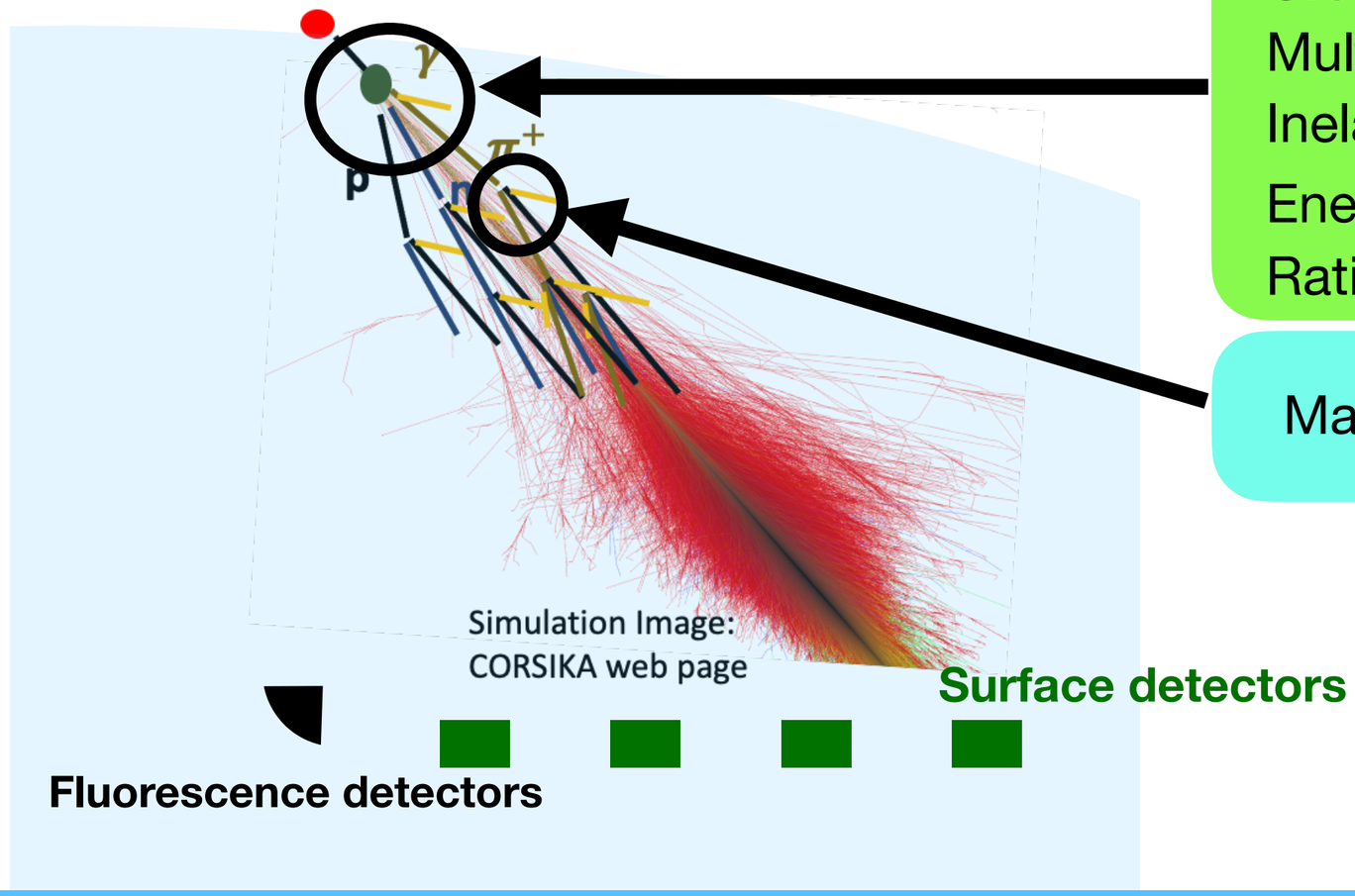
**Institute for Space-Earth Environmental Research, Nagoya University, Japan*
***Kobayashi-Maskawa Institute, Nagoya University, Japan*

T.Sako *ICRR, University of Tokyo, Japan*
K.Kasahara, K.Yoshida *Shibaura Institute of Technology, Japan*
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, P.Betti, L.Bonechi, M.Bongi, R.D'Alessandro, S. Detti, P.Papini, S.Ricciarini, M. Scaringella, A.Tiberio
INFN, Univ. di Firenze, Italy
G.Piparo, A.Tricomi *INFN, Univ. di Catania, Italy*

Air showers and hadronic interactions

For precise predictions of air showers, we need to understand hadronic interactions.



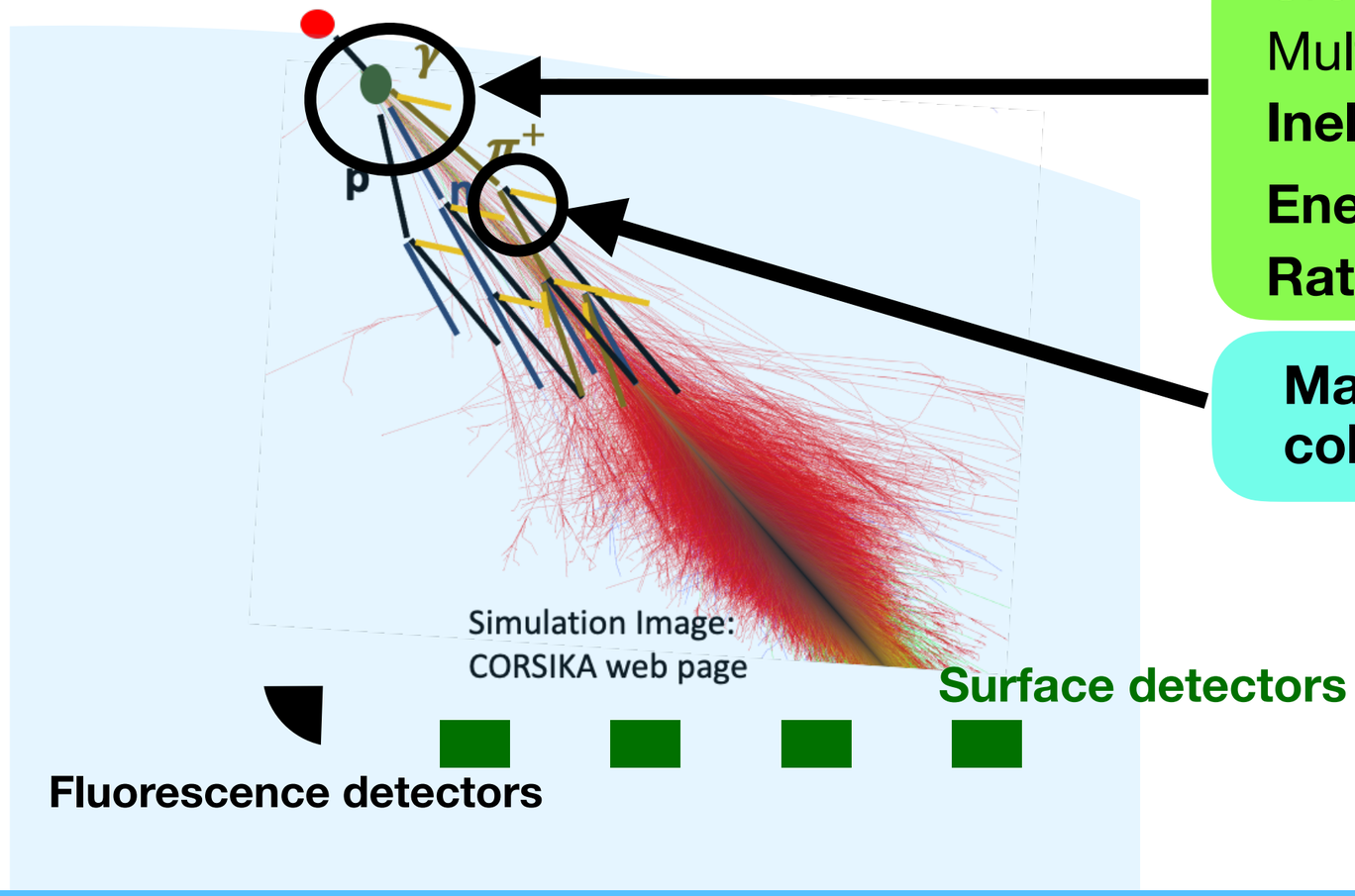
Cross-sections
Multiplicity
Inelasticity
Energy flow of π^0
Ratios of kaons to pions

Many pion-nucleus collisions

They affect predictions of $X_{\max}$ and muons on the ground.

Air showers and hadronic interactions

For precise predictions of air showers, we need to understand hadronic interactions.



Cross-sections
Multiplicity
Inelasticity
Energy flow of π^0
Ratios of kaons to pions

← LHCf experiment

Many pion-nucleus collisions

← ATLAS-LHCf Common analysis

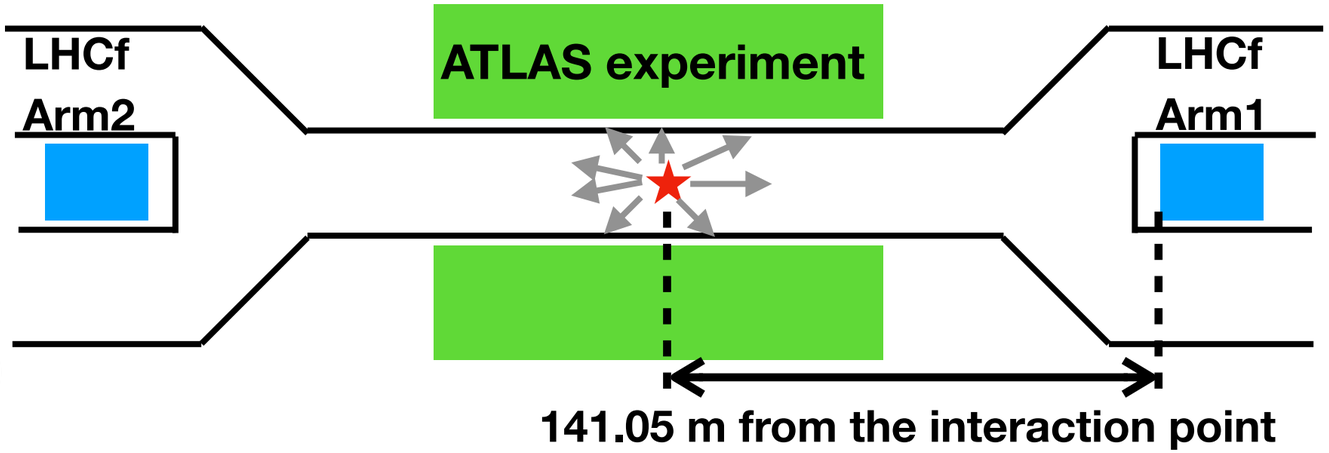
They affect predictions of X_{max} and muons on the ground.

Validation of hadronic interactions by accelerator experiments is necessary.

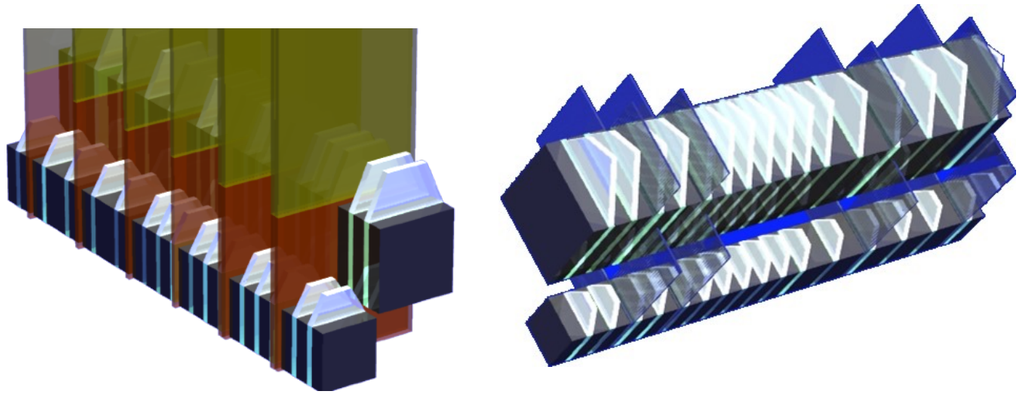
LHC forward experiment

Measuring neutral particles produced in the zero degree

- Two sampling calorimeters with position-sensitive layers.
- Energy resolution
  - < 5% (photons), 40% (hadrons)
- Position resolution
  - <200 μm (photons), 300-100 μm (hadrons)
- Measurements of photons, neutrons, neutral pions, and eta mesons.
- Data-taking
  - Proton-proton collisions
    - $\sqrt{s}$=0.9TeV, 2.76 TeV, 7 TeV, 13TeV, **13.6TeV (2022)**
  - Proton-lead collisions
    - $\sqrt{s_{NN}}$ =5TeV, 8TeV



LHCf-Arm2 detector **LHCf-Arm1 detector**



Recent activity of the LHCf experiment

Analysis of data taken in 2015 (p-p, $\sqrt{s} = 13$ TeV)

Preliminary results of η mesons
ATLAS-LHCf common analysis

Data-taking in 2022 (p-p, $\sqrt{s} = 13.6$ TeV)

Beam test @ SPS in 2021 for joint operation with ATLAS-ZDC detectors
Data-taking of proton-proton collisions in Sept. 2022
Beam test @ SPS in Oct. 2022 for precise calibration of the detector

Measurements of η mesons

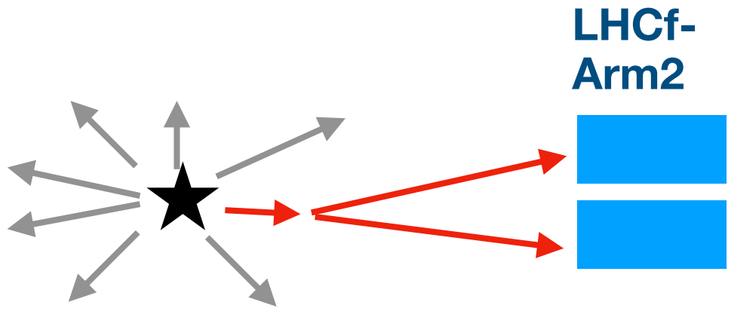
Measurements of mesons with strange at very forward regions

Data set : p-p 13TeV, LHC Fill 3855 (2015)

Integrated luminosity: 0.194 nb^{-1} ($\mu = 0.01$) and 1.9378 nb^{-1} ($\mu = 0.03$)

Event selections

- two photon-like hits
- one hit in each calorimeter tower

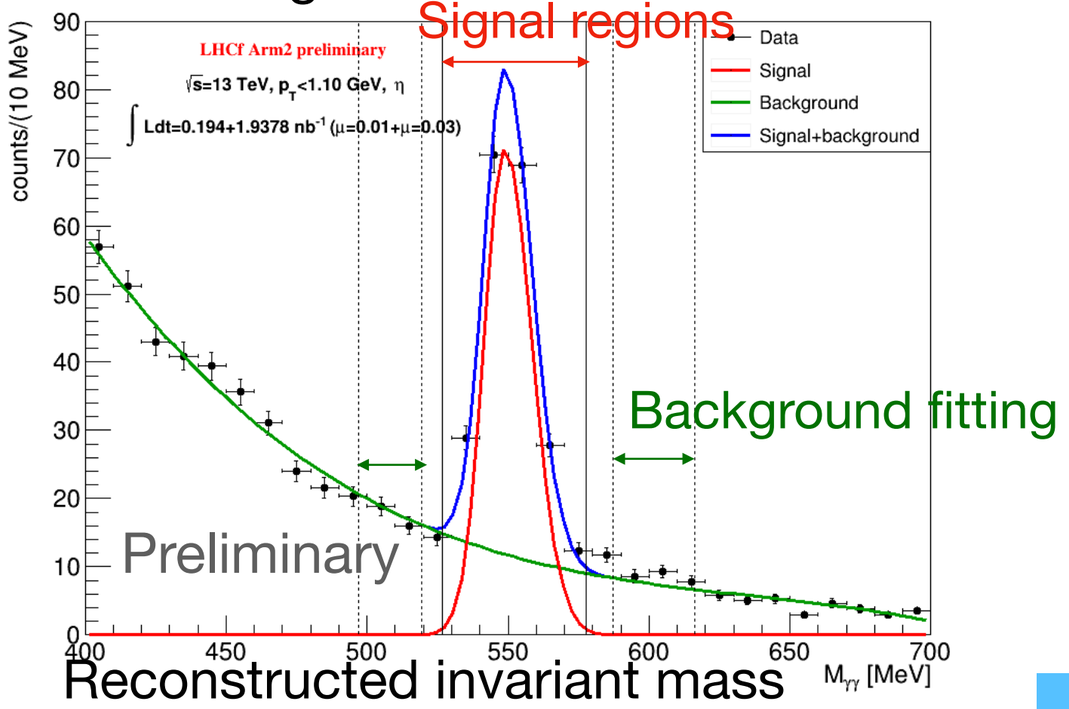


$\eta \rightarrow 2\gamma$

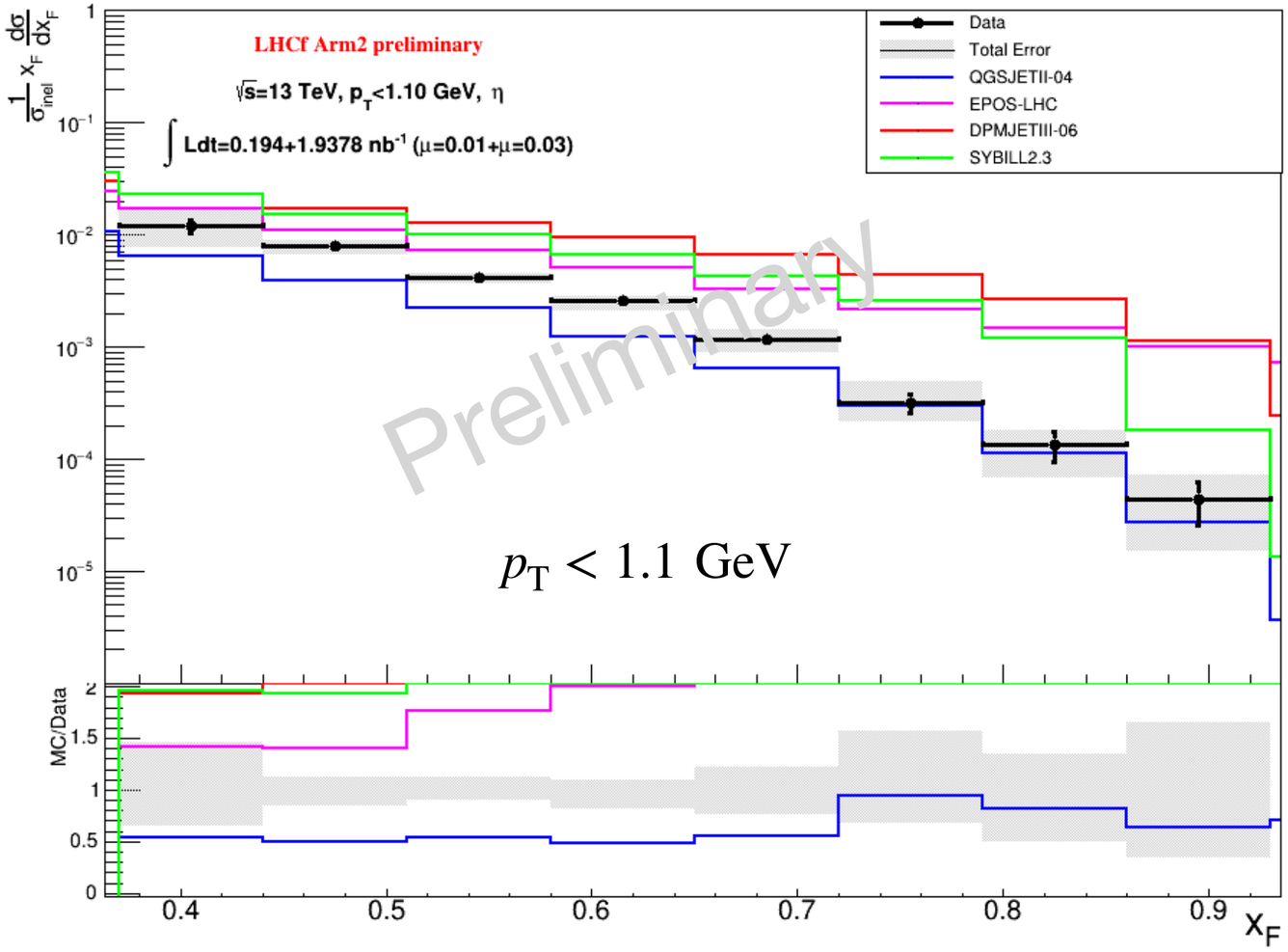
Branching ration : 39.41%

Background subtractions

- From the fitting of invariant mass distributions



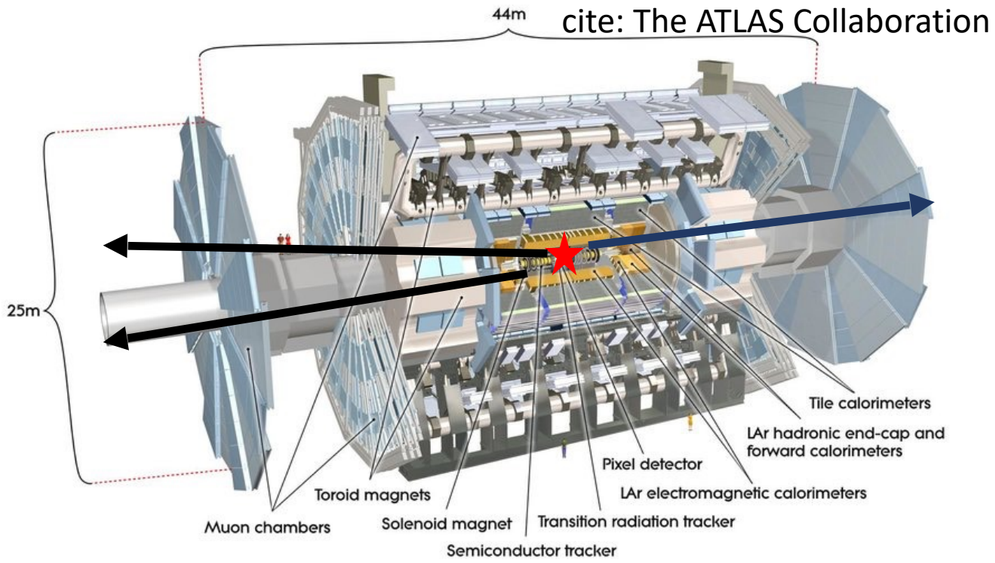
Preliminary results of η mesons



No model can reproduce the data perfectly.

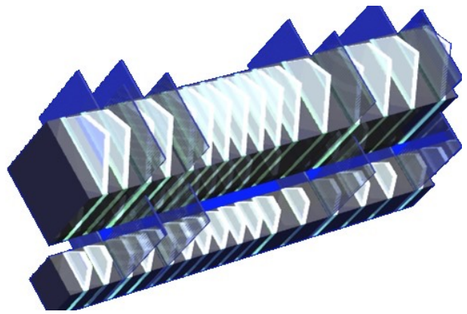
QGSJET II-04 shows a best agreement among the models.

On-going ATLAS-LHCf common analysis



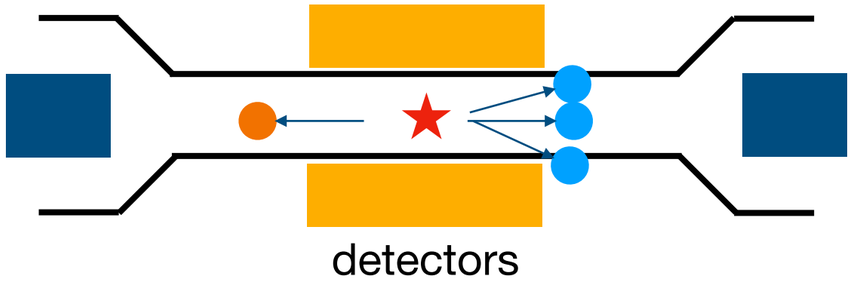
cite: The ATLAS Collaboration

LHCf Arm1 detector



We are finalizing both analyses.

Diffractive collisions



High elasticity & small multiplicity events

Preliminary : ATLAS-CONF-2017-075

Mechanism of multi-parton interactions

Correlation between forward neutrons and the number of charged particles in ATLAS

Number of tracks in ATLAS

-> Number of multi-parton interactions

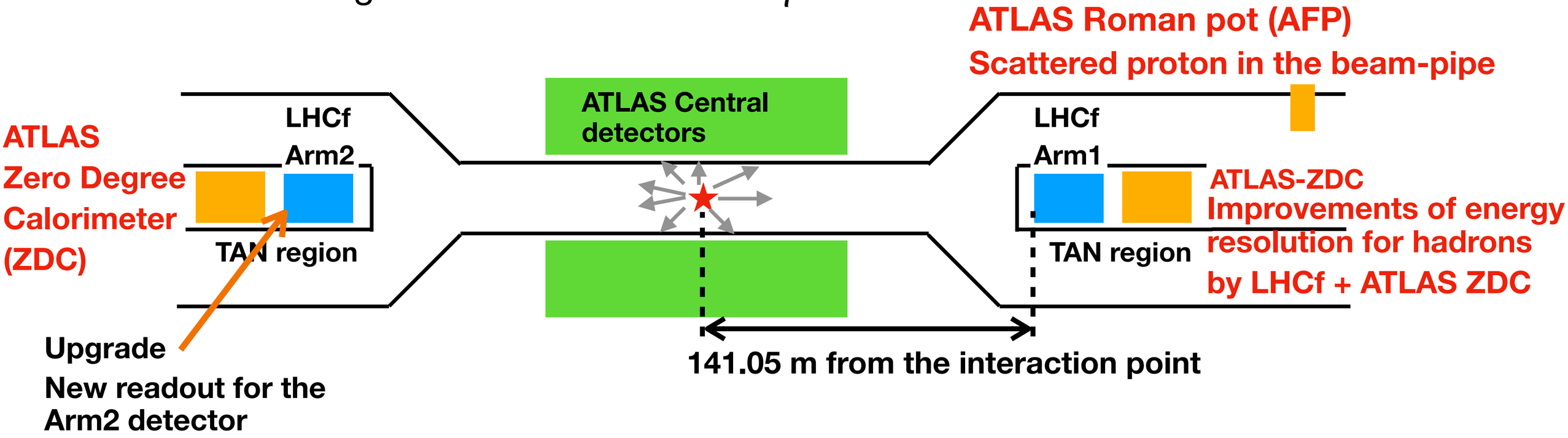
Neutron energy in LHCf

-> energy of the beam remnants

Data-taking in September 2022

Several upgrades from the past operations

- Proton-proton collisions, $\sqrt{s} = 13.6$ TeV (6.8 TeV proton beam)
- Joint data-taking with ATLAS Zero Degree Calorimeter and Roman pots
- Much higher statistics for π^0 and η mesons



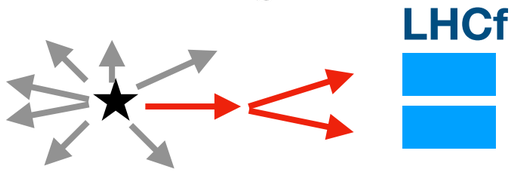
Physics targets

Measurements of π^0, η, and K_S^0

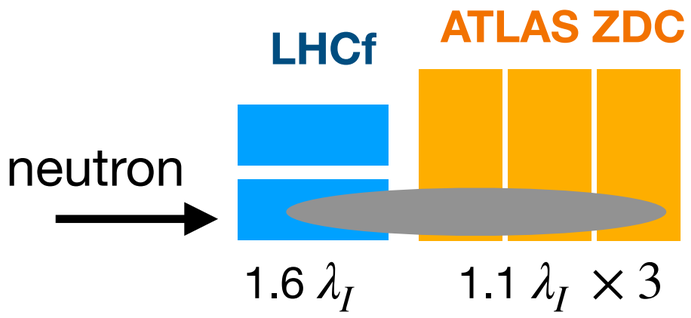
Ten times higher statistics are expected.

Much smaller statistical errors than 2015.

Several hundred K_S^0 candidates are expected.



Improvements of measurements of neutron and elasticity

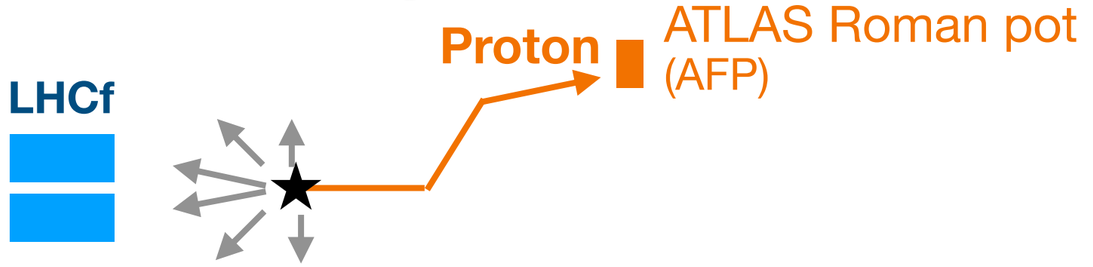


Particles leaked from the LHCf detector are detected by ATLAS-ZDC.

Energy resolution : $40\,\% \rightarrow 20\,\%$

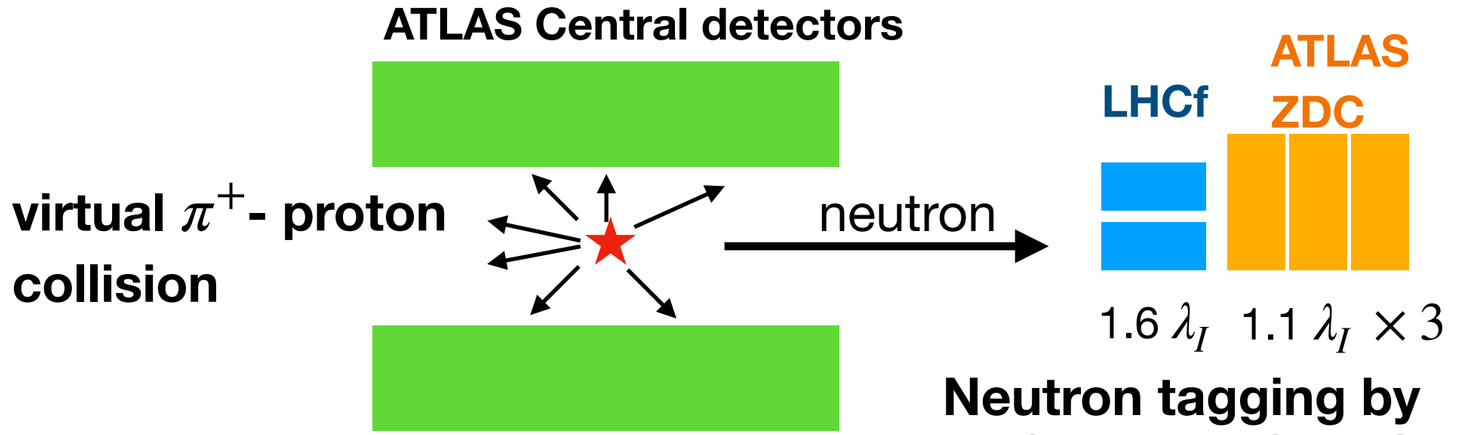
ATLAS-LHCf common data-taking

Single diffraction (high diffractive-mass)



One-pion exchange

To measure high-energy pion-proton collisions

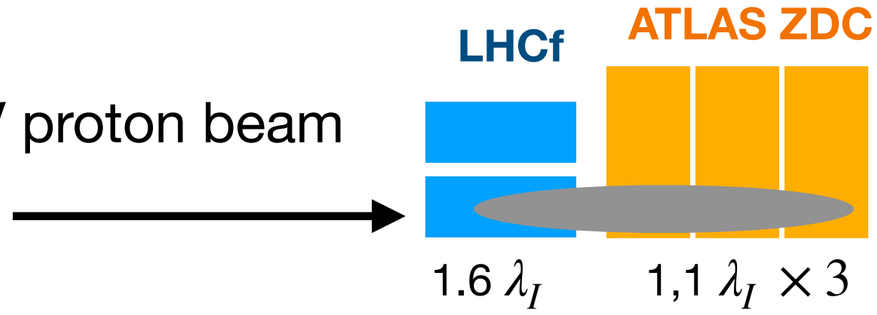


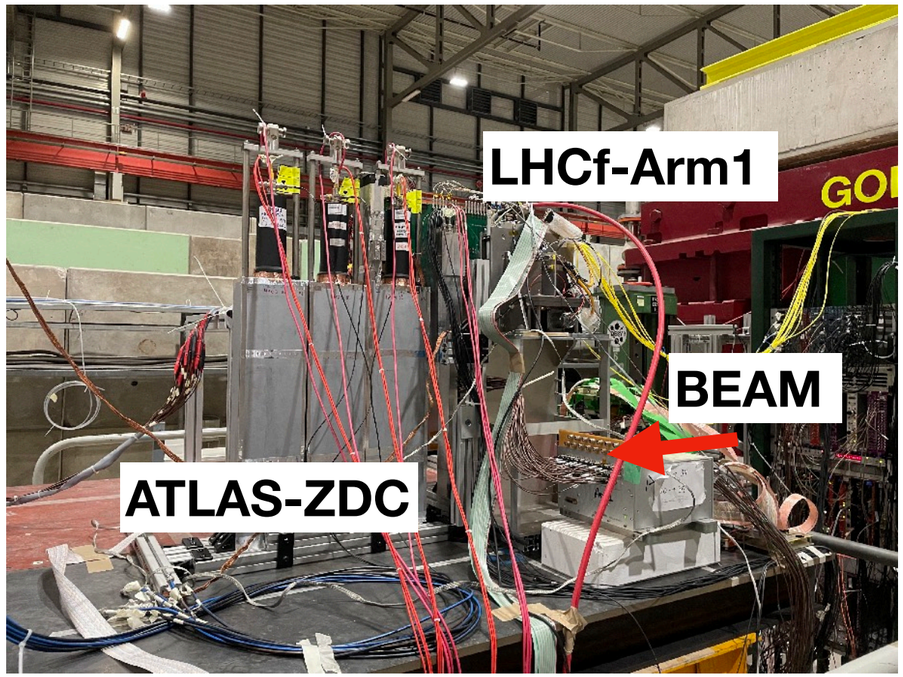
Neutron tagging by LHCf + ATLAS ZDC

SPS beam test in 2021

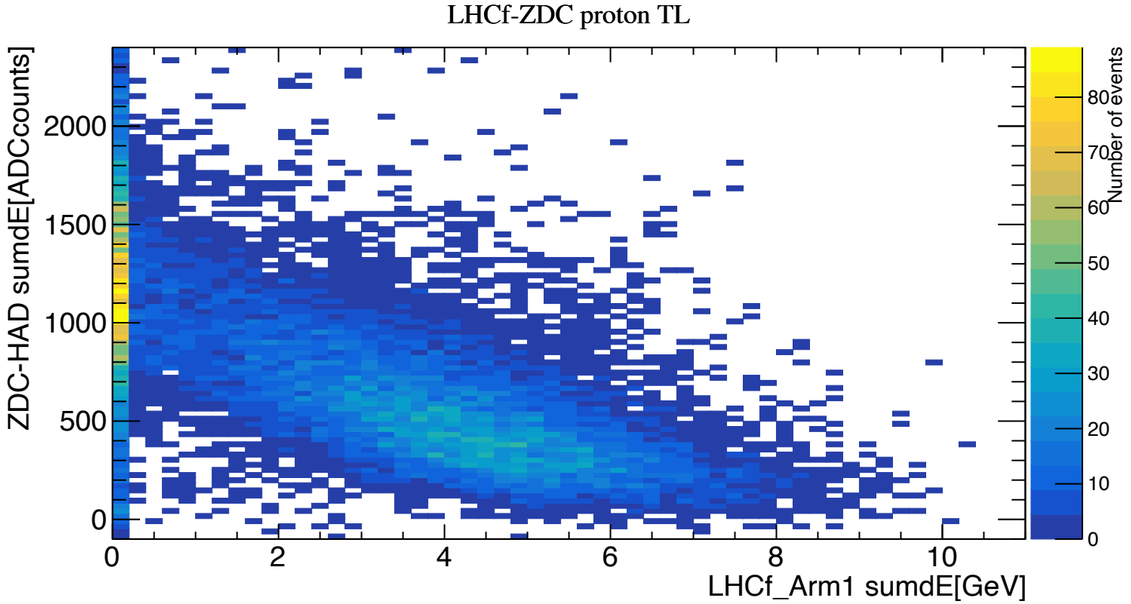
For common operation with ATLAS-ZDC

350 GeV proton beam





Correlations between energy depots in LHCf and in ZDC

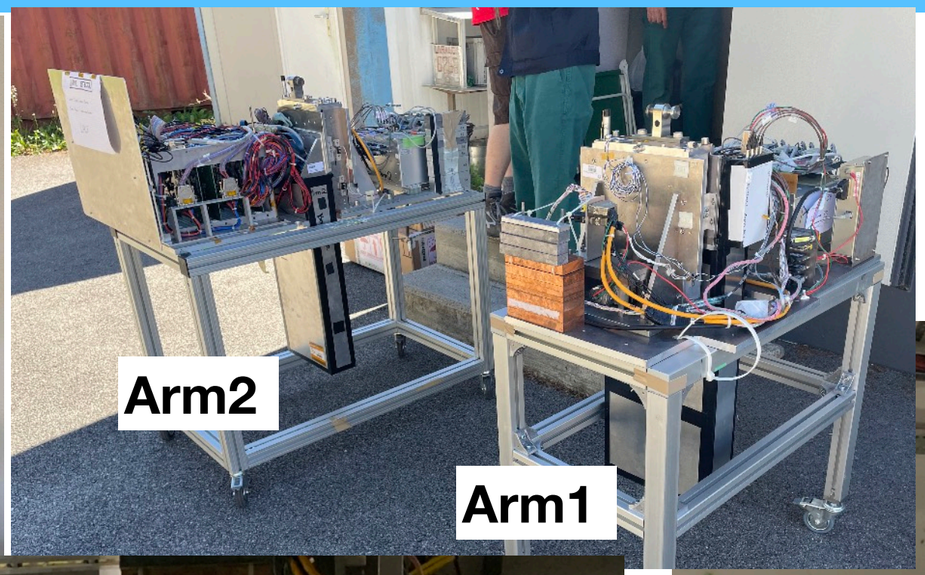


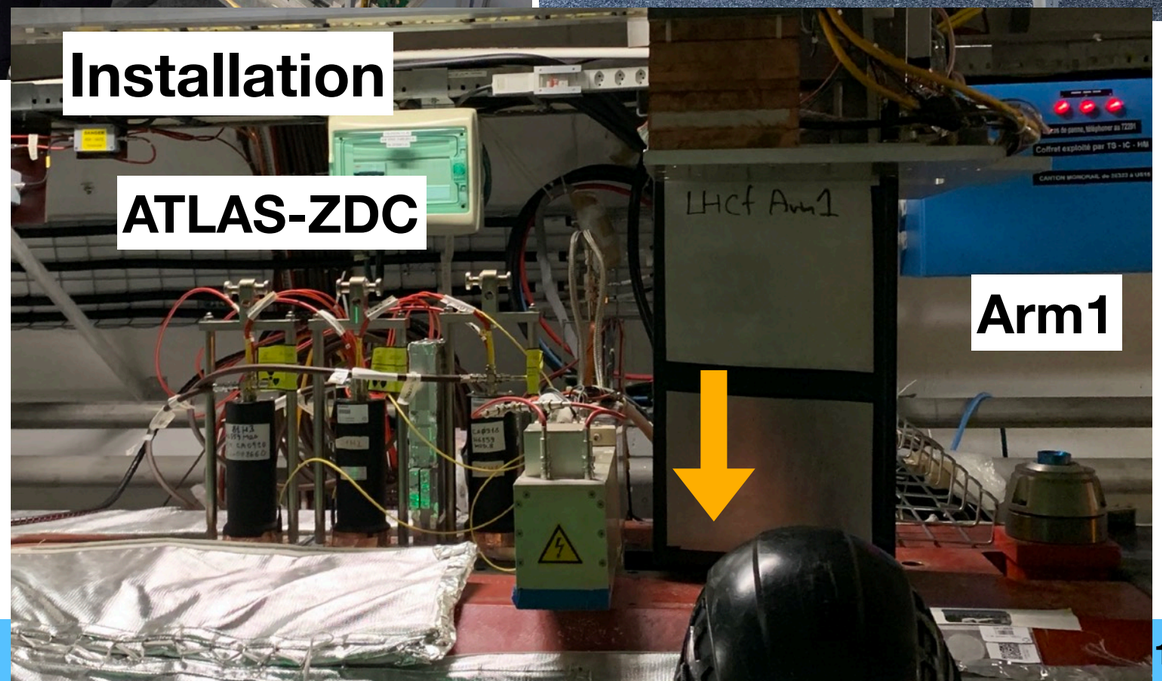
21.2% energy resolution for 350GeV protons.

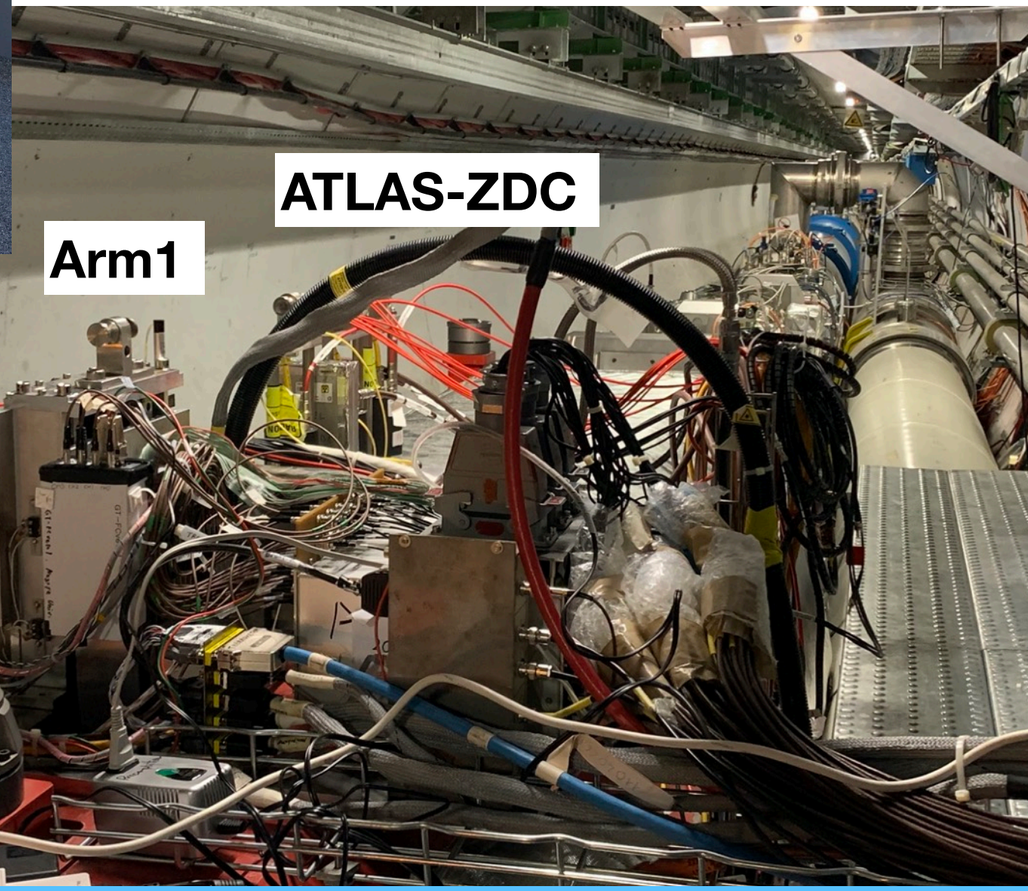
LHCf stand alone: ~40% energy resolution

For more details, see poster by M. Kondo

Preparation and Operation



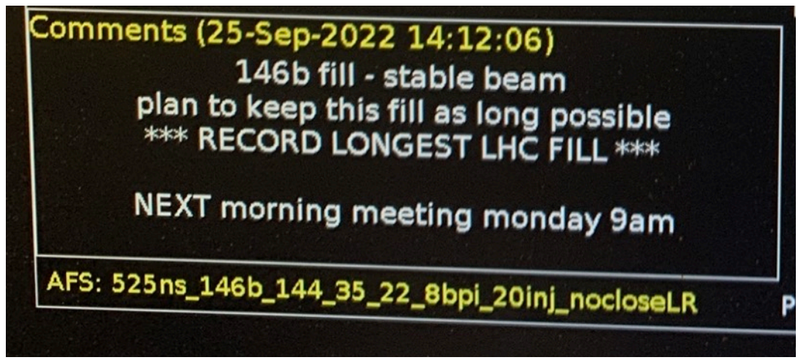




Data-taking

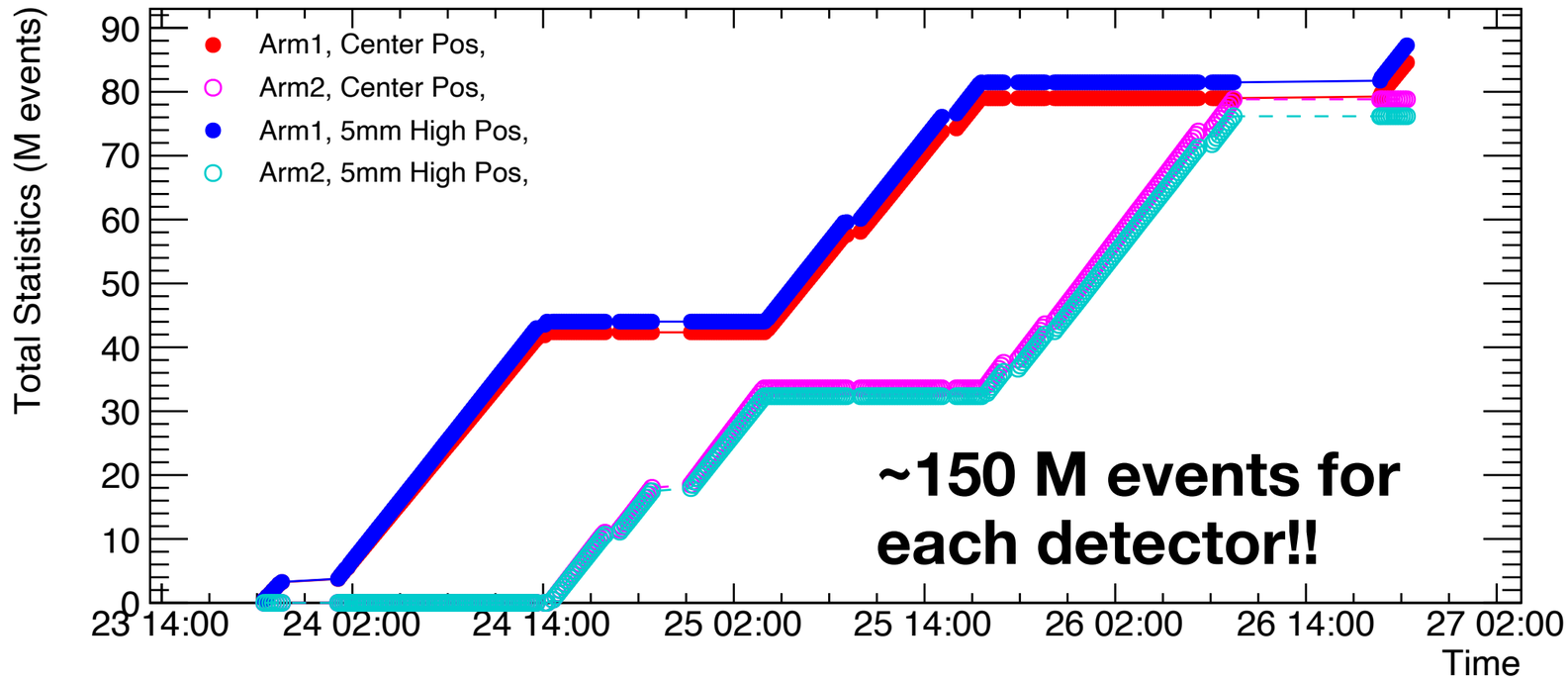
2022 Sept. 23-27

Photo at the control room



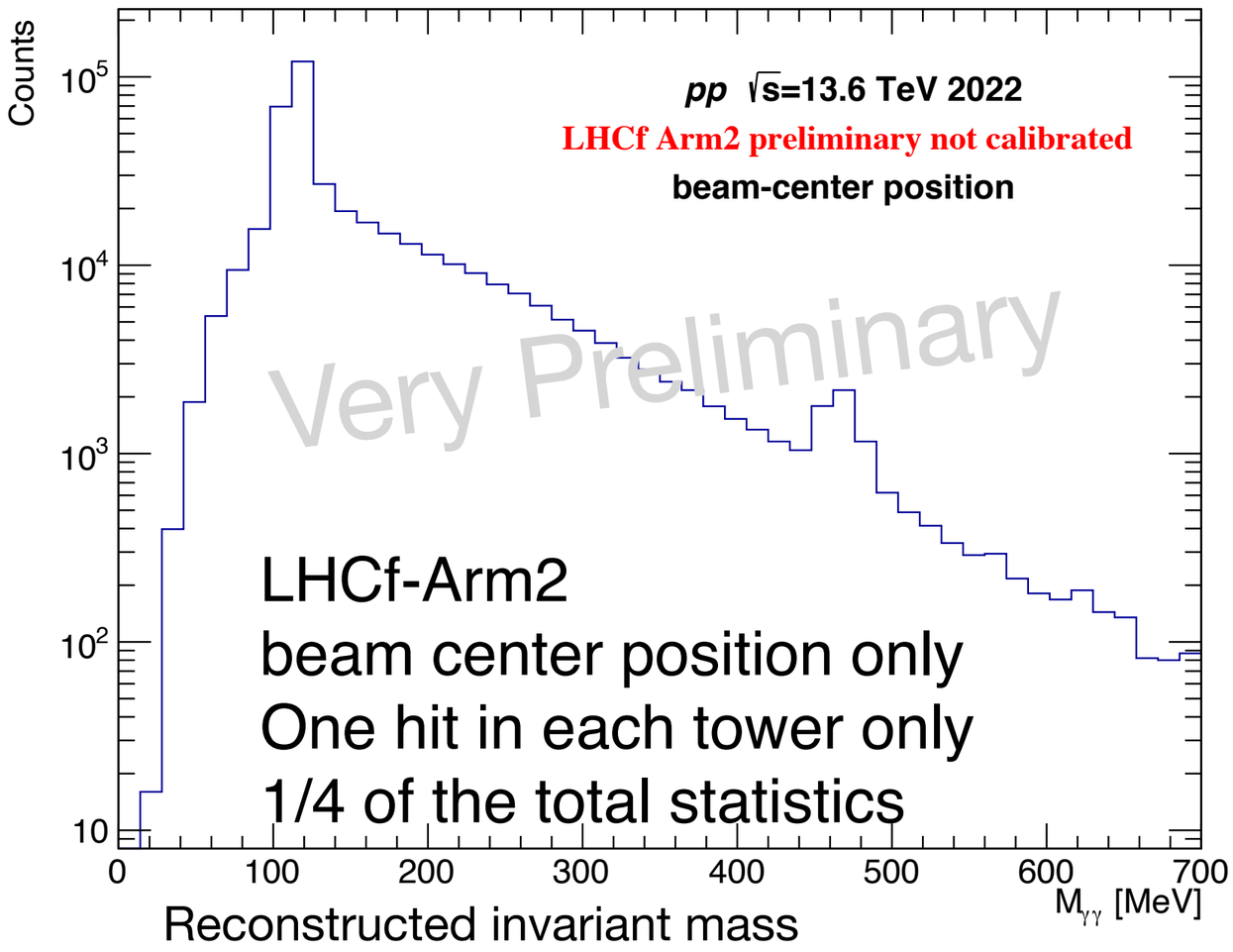
Stable beams for more than 57 hours
(Record the Longest LHC Fill)

LHCf Operation in 2022



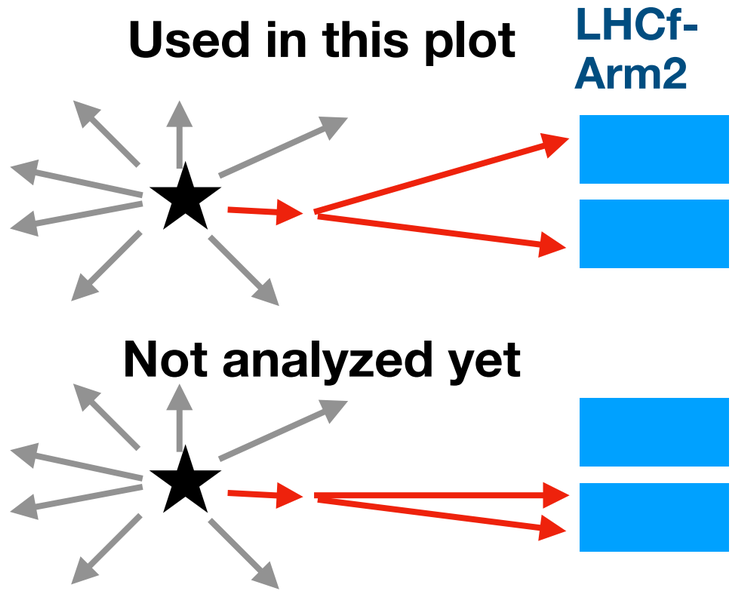
Very preliminary results of invariant mass distributions

Di-photon invariant mass



Reconstructed invariant mass

(**ENERGY SCALE IS NOT CALIBRATED YET**)



We have much more statistics of π^0 and η candidates in our data-set!!

We will have a beam test @SPS this October for precise energy calibration.

Summary and prospects

- The LHCf experiment measures forward neutral particles to validate and improve hadronic interaction models.
- We showed the preliminary result of production cross-sections of forward η mesons.
  - No model can reproduce the data perfectly.
  - QGSJET II-04 shows the best agreement among the models.
- New data-taking was successfully completed this September.
  - Proton-proton collisions, $\sqrt{s} = 13.6$ TeV
  - With ATLAS-ZDC and Roman pots
  - Very large statistics for π^0 and η candidates
- We will have a beam test this October for precise energy calibration.
- We will start analyses of this large data-set, while we continue to finalize analyses for 2015 data-set.

Backup

List of the publications

Run	Photon	Neutron	Pi0	ATLAS-LHCf	eta
p-p $\sqrt{s}$=0.9TeV (2009/2010)	PLB 715, 298 (2012)				
p-p $\sqrt{s}$=2.76TeV (2013)			PRC 86, 065209 (2014) PRD 94, 032007		
p-p $\sqrt{s}$=7TeV (2010)	PLB 703, 128 (2011)	PLB 750 360 (2015)	PRD 86, 092001 (2012)		
p-p $\sqrt{s}$=13TeV (2015)	PLB 780, 233 (2018)	JHEP 2018, 73 (2018) JHEP 2020, 016		Preliminary: ATLAS-CONF-2017-075	Preliminary
p-Pb $\sqrt{s_{NN}}$=5TeV (2013,2016)			PRC 86, 065209 (2014)		

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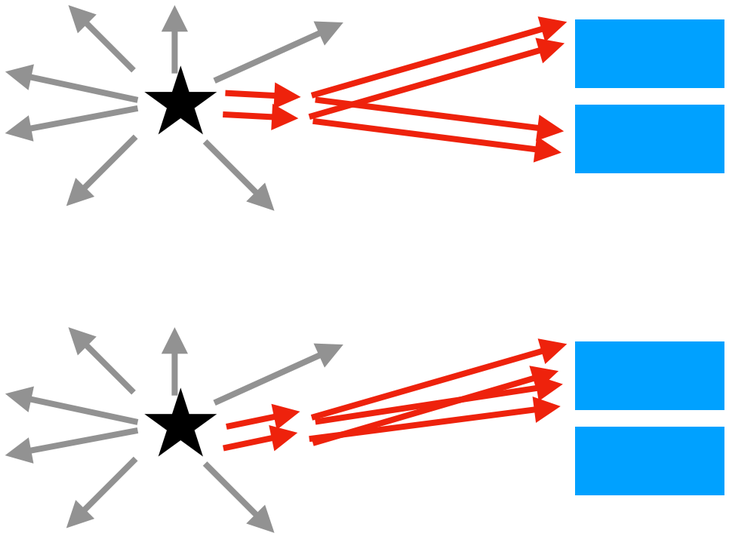
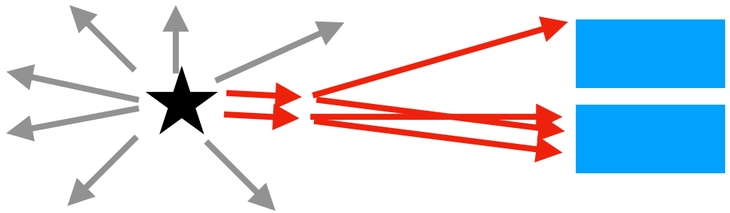
Measurements of K_S^0

$K_S^0 \to 2\pi^0 \to 4\gamma$

Several hundred candidates are expected.





Three or four photons hit in a one calorimeter tower.
We need to develop the reconstruction method for these cases.

Multi-parton interaction

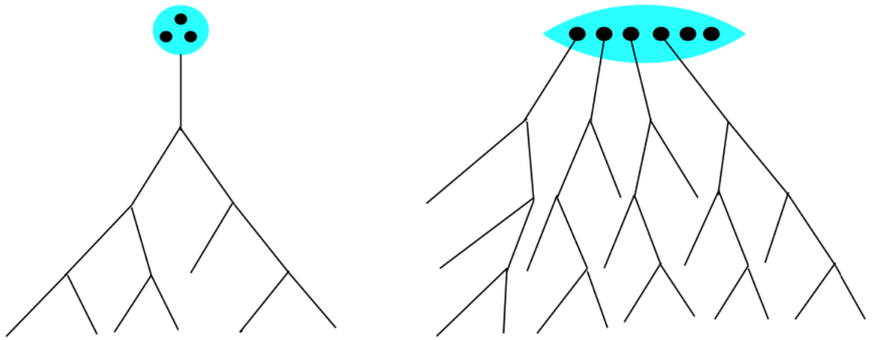
The modeling of multi-parton interaction (MPI) affect central-forward correlation.

Proposed by S. Ostapchenko et al,
Phys. Rev. D 94, 114026

Initial part of Parton cascade are modeled as :

universal state
(PYTHIA and SIBYLL)

superposition of partons
(EPOSLHC and QGSJET II).

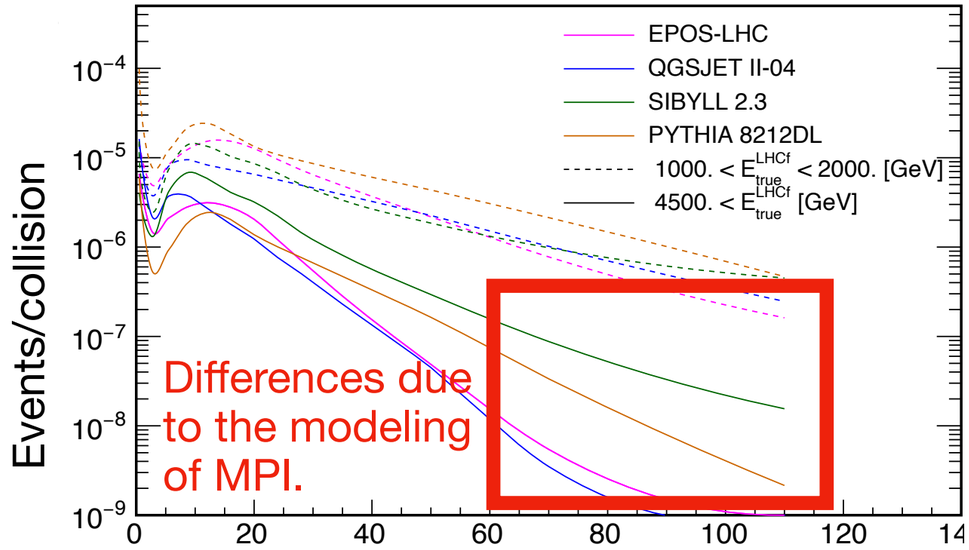


Remnant energy - number of MPI correlation:

Small Large

The number of multi-patron interactions -> N_{ch}

The energy of <u>remnants</u> -> neutrons in LHCf



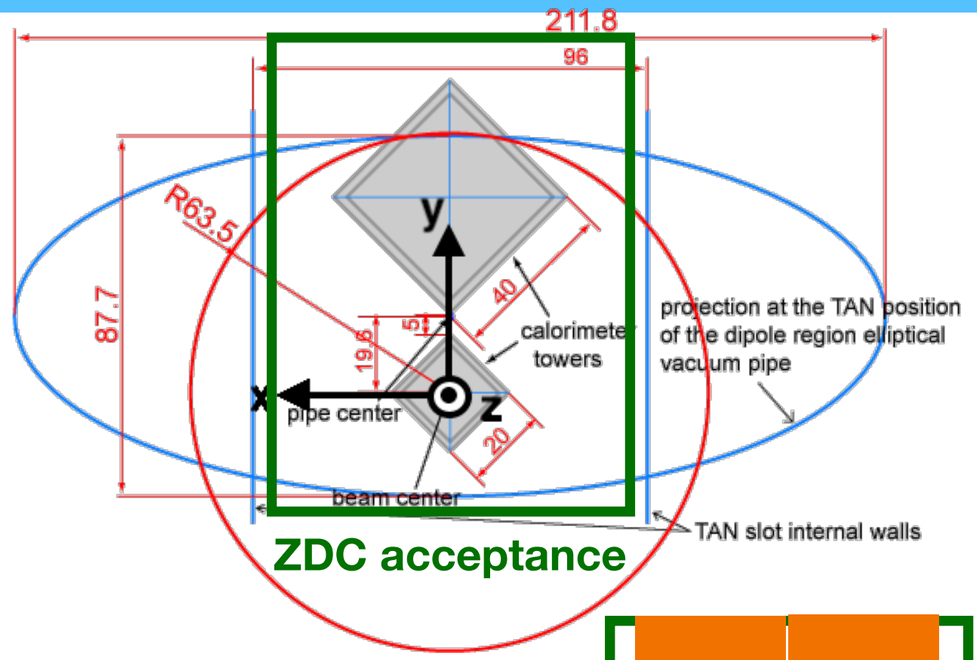
EPOS-LHC and **QGSJET** predict strong central-forward correlation; if high energy neutrons are measured by the LHCf detector, the number of high N_{ch} (high MPI) events is very small.

On the other hand, **SIBYLL 2.3** and **PYTHIA** show weaker central-forward correlation.

New Front Counter for Arm1

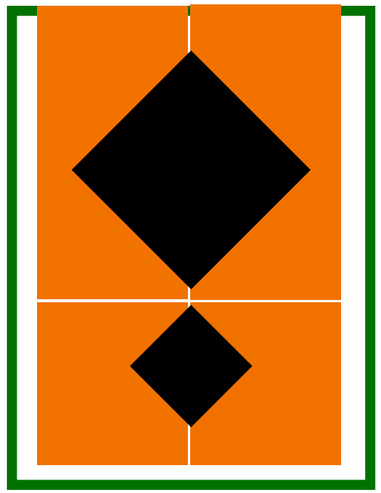
Motivation

- Differences in shape between LHCf detectors and ATLAS-ZDC detectors.
- Some particle without hit in LHCf can make an interaction in ZDC module.
- It is difficult to remove effects of these particles. A MC-driven correction can not be accepted by ATLAS without validation using experimental data.



Concept

- Tagging parts of photons without hit in LHCf but with hit in ZDC.
  - Prepare new front counter with 7mm ($2X_0$) tungsten plate and scintillator.
  - In left plot, orange area is covered by 7mm tungsten + scintillator and black area is covered by plastic plate (NO tungsten)
  - By tungsten plate, parts of high energy photons make an EM shower, and more than 20 MIPs signal is expected.
  - Target of tagging efficiency for photons : ~60% in active area.

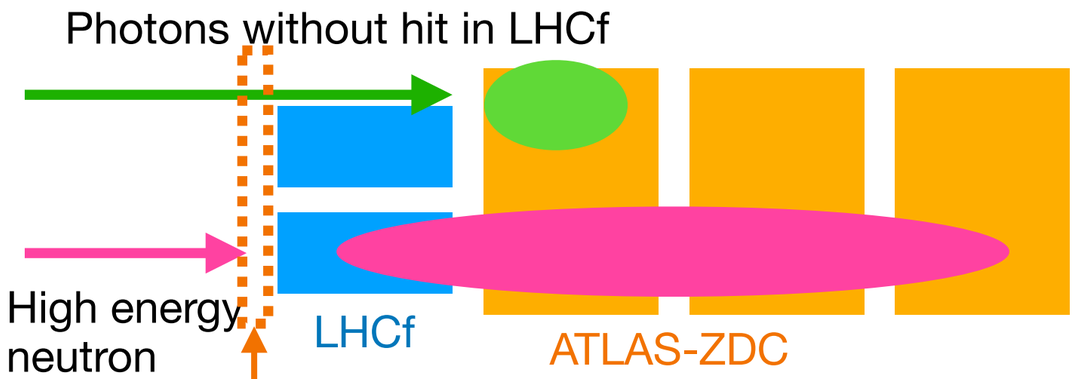


Details of concept

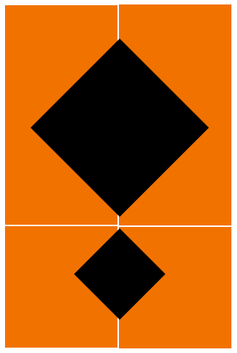
Example: One-pion exchange analysis

(High energy neutron at LHCf-Small tower)

Side view



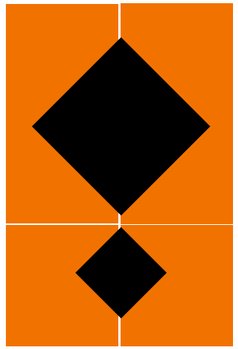
No position sensitive layer in ZDC.



Photon tagging using new front counter.

We can validate MC predictions for these cases.

(Not for veto in analysis, since efficiency is not so high)



Only plastic and 1mm aluminum plat in front of the detector.

No big effects on analysis is expected.

I will confirm this point using full simulation in July.

No scintillator in the black area.

Clearly less performance as collision monitor.