LHCf plan for proton-oxygen collisions at LHC

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on behalf of the LHCf collaboration

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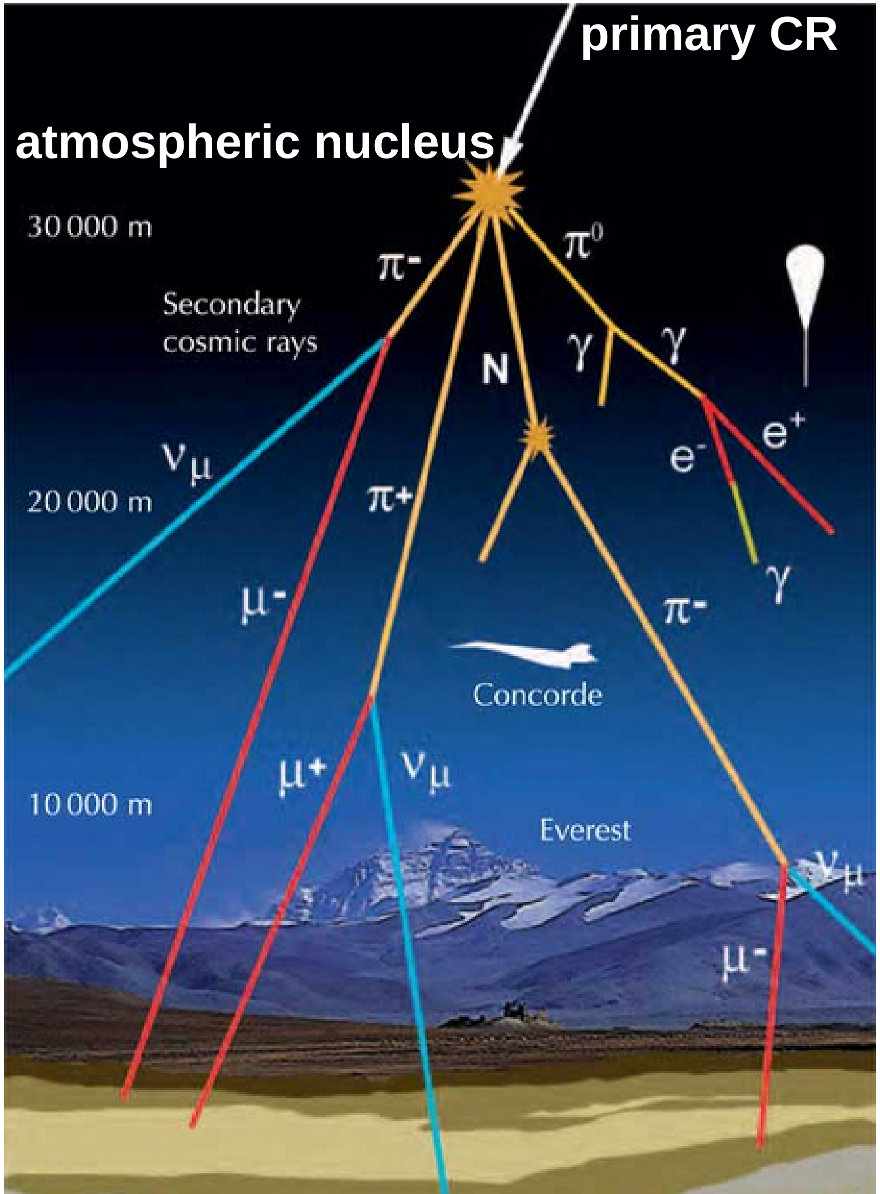
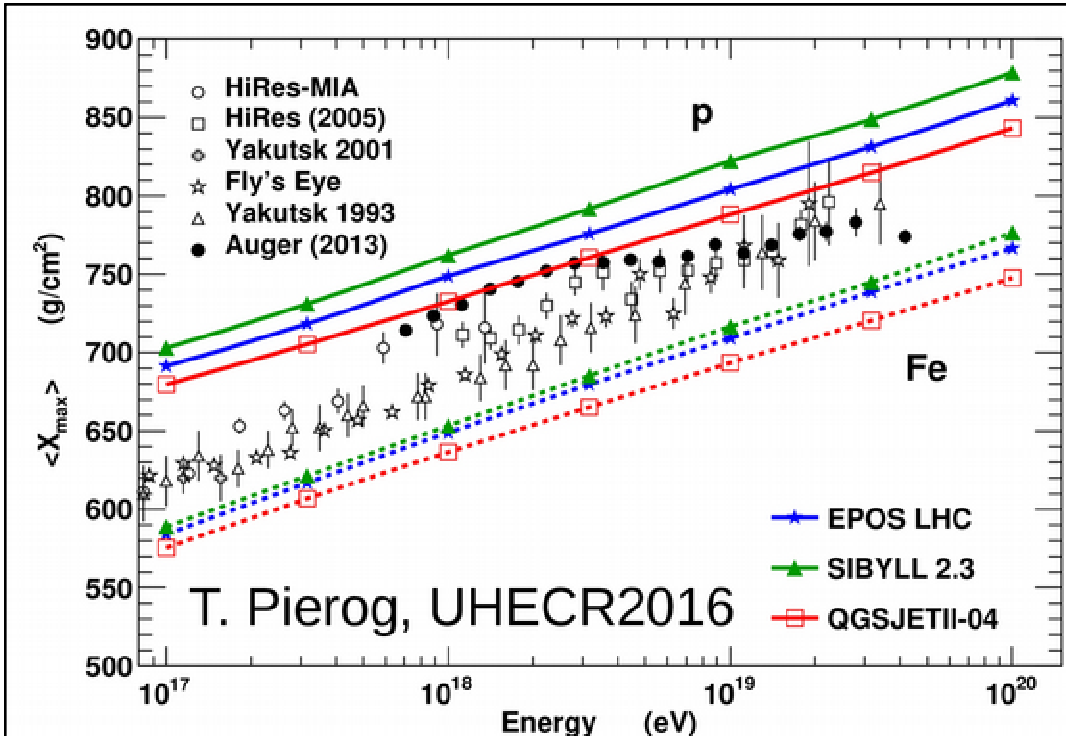
Scientific goal

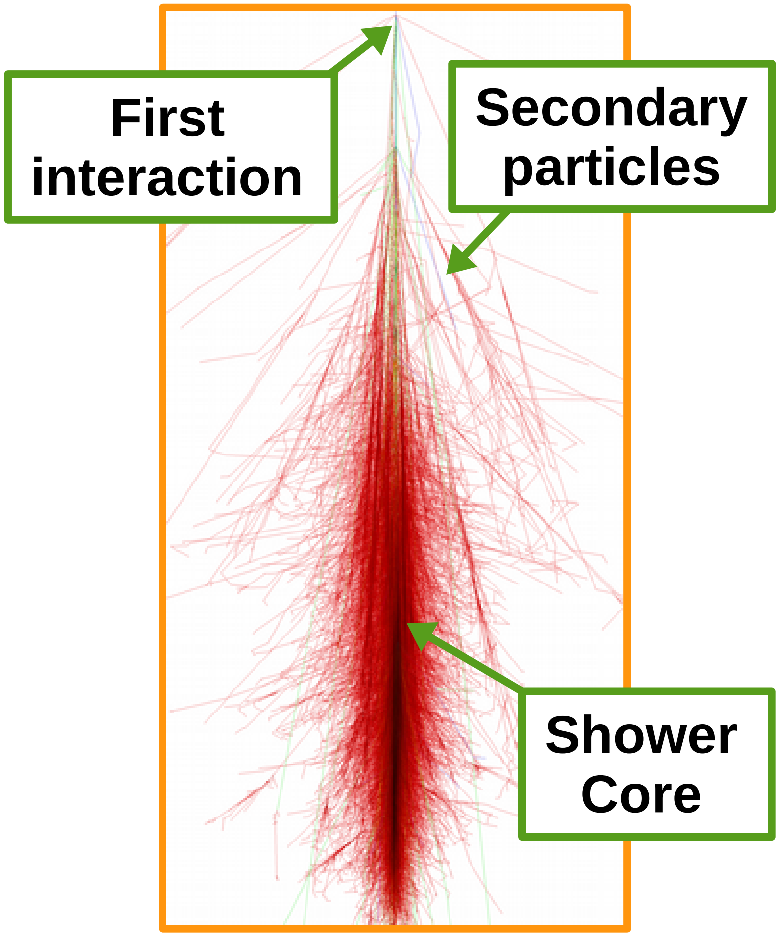


Determination of **mass composition of Ultra High Energy Cosmic Rays** using indirect measurements are limited by the large uncertainty coming from the ability of **hadronic interaction models to simulate the Extensive Air Showers (EASs)**.



EAS input from LHC

In order to tune interaction models we need **high energy calibration data**:
LHC is the best place where to perform these measurements since
p-p at $\sqrt{s}$ = 14 TeV ⇨ $E_{LAB} \sim 10^{17}$ eV



- Inelastic cross section
- Multiplicity

ATLAS, CMS, TOTEM...

- Forward energy spectrum
  - if soft → rapid development
  - if hard → slow development
- Inelasticity $k = 1 - p_{lead} / p_{beam}$
  - if large → rapid development
  - if small → slow development
- Test of scaling laws needed to extrapolate results to E > 10^{17}eV
  - done with p-p at different $\sqrt{s}$
- <u>Test of nuclear modification factor due to target mass number</u>
  - done with p-p, p-ion and ion-ion

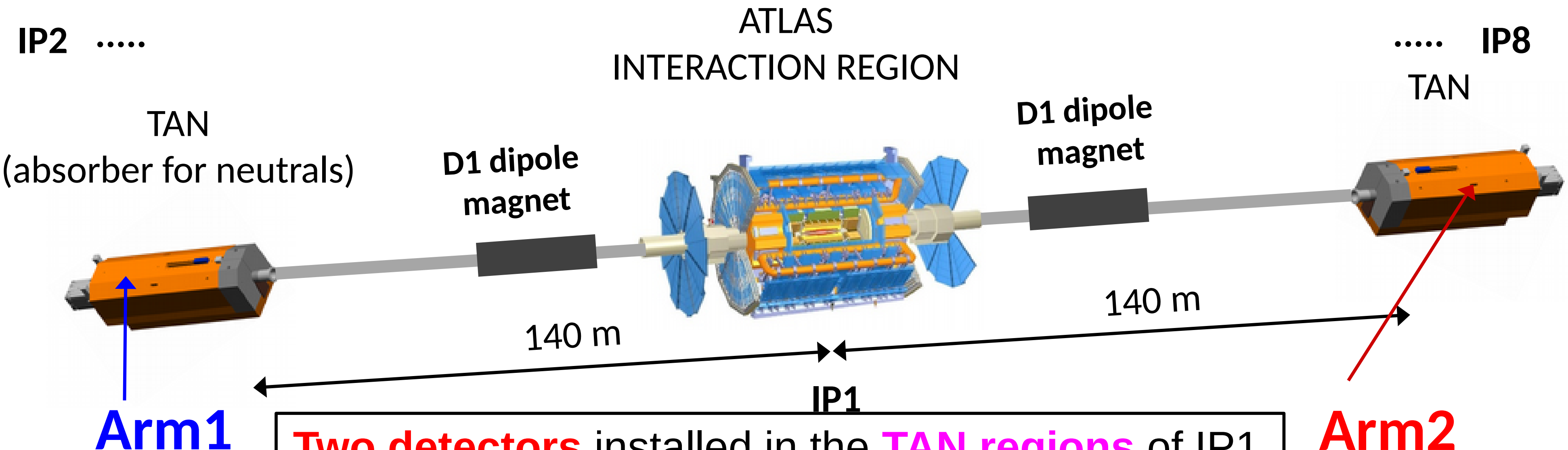
LHCf

The LHCf Experiment

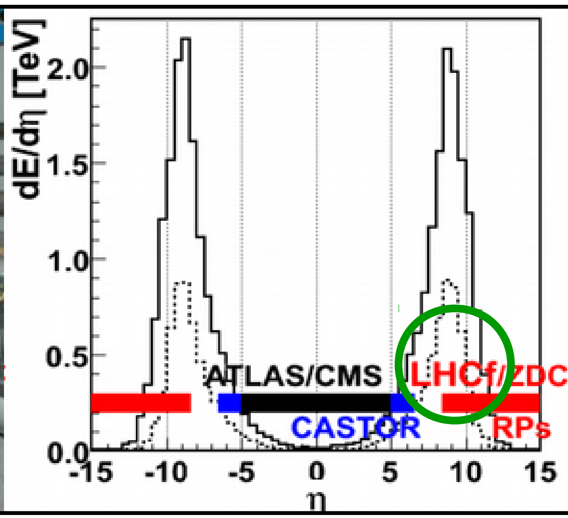
Pseudorapidity

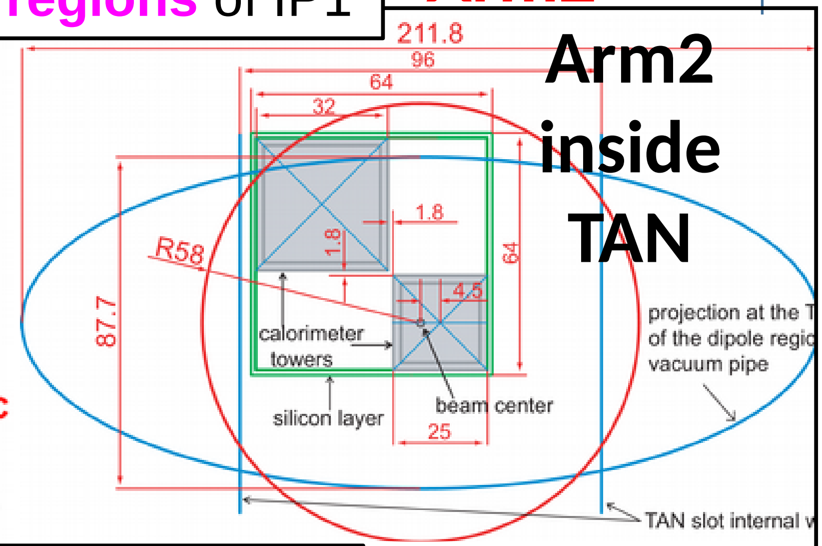
$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

Detection of **neutral particles** (neutrons, γ, π^0) with **pseudorapidity η > 8.4**



Two detectors installed in the **TAN regions** of IP1

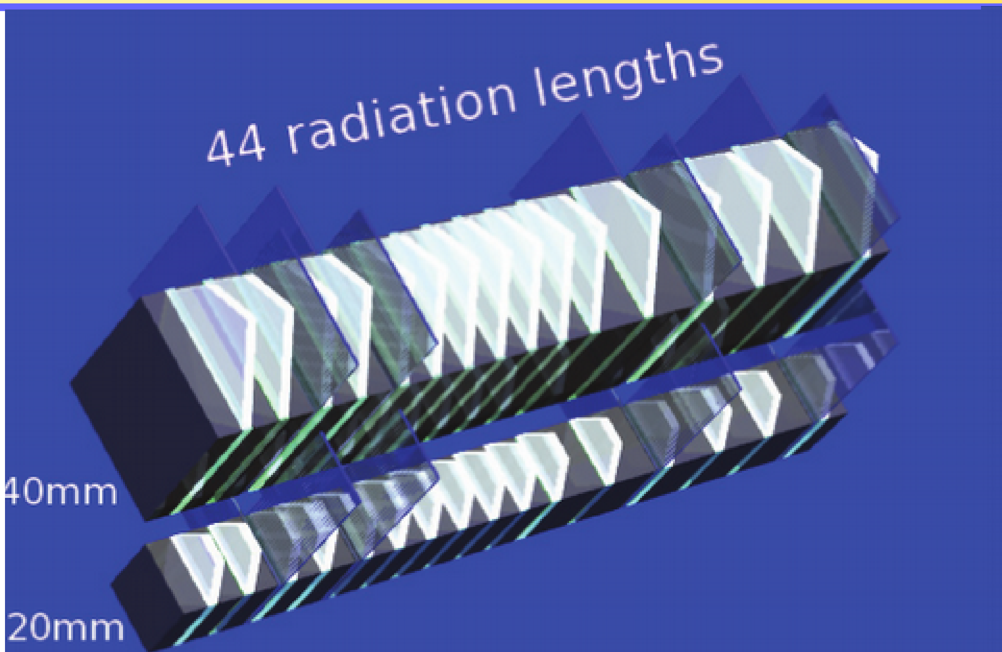


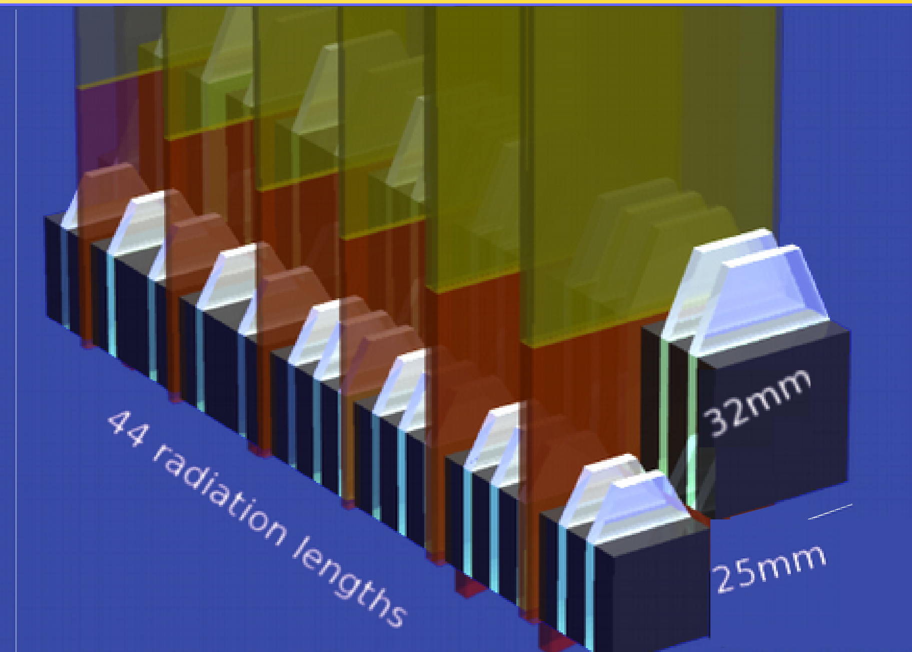


LHCf covers the **energy flow peak** (around η=9)

The LHCf detectors

Arm1 / **Arm2**





Towers Size:
20 x 20 and 40 x 40 mm^2
Imaging layers:
4 x-y 1mm GSO bars
Position resolution:
< 200 μm (photons)
< 1 mm (hadrons)

Two sampling calorimeters
Two towers: 22 tungsten and 16 GSO scintillators layers
Depth: 21 cm, 44 X_0, 1.6 λ_I
Energy resolution:
< 2% (photons)
~ 40% (hadrons)

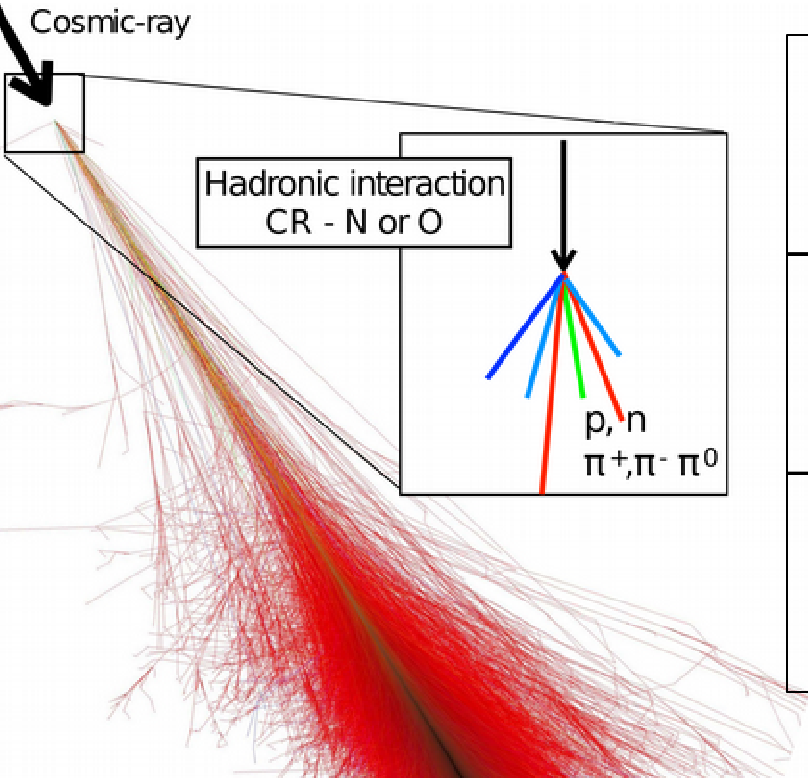
Towers Size:
25 x 25 and 32 x 32 mm^2
Imaging layers:
4 x-y 160μm Si microstrip
Position resolution:
< 40 μm (photons)
< 800 μm (hadrons)

Physics motivation for p-O @ 9.9 TeV

The LHCf experiment acquired data in p-p collisions @ $\sqrt{s}$ = 0.9, 2.76, 7 and 13 TeV and in p-Pb collisions @ $\sqrt{s_{NN}}$ = 5.02 and 8.16 TeV

However, both cases are quite different from the UHECR case, where the first interaction involves a light atmospheric nucleus like N or O

So far, forward production in the realistic EAS case was extracted by interpolating measurement in p-p and p-Pb as a function of A



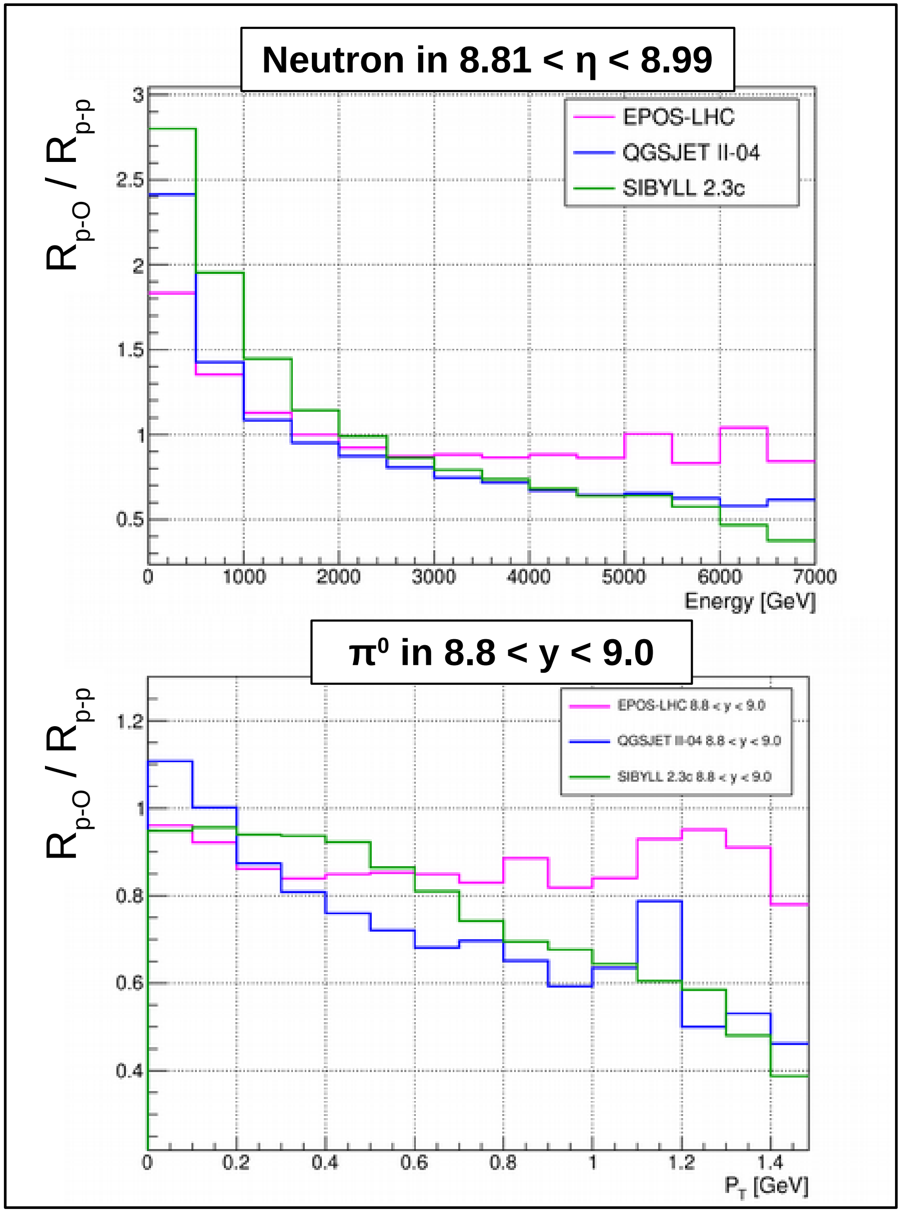
In Run III, LHCf will directly measure forward production in a configuration very similar to the **UHECR-atmospheric light nucleus case**

Due to reshaping of TAN structure after Run III, LHCf cannot operate in Run IV, so this is the **last chance that we have to take this data**

LHCf sent a **support letter** to LHC committee, signed by about 100 researchers working in cosmic rays and accelerator communities

Forward Production in p-O collisions

p-remnant side



When considering forward production in p-ion collisions ($R_{p\text{-}ion}$) and in p-p collisions ($R_{p\text{-}p}$) at the same $\sqrt{s_{NN}}$, we observe that their ratio is not 1.

In particular, if we normalize to the average number of nucleons participating to the collisions we observe that **forward production is suppressed in p-ion respect to p-p**.

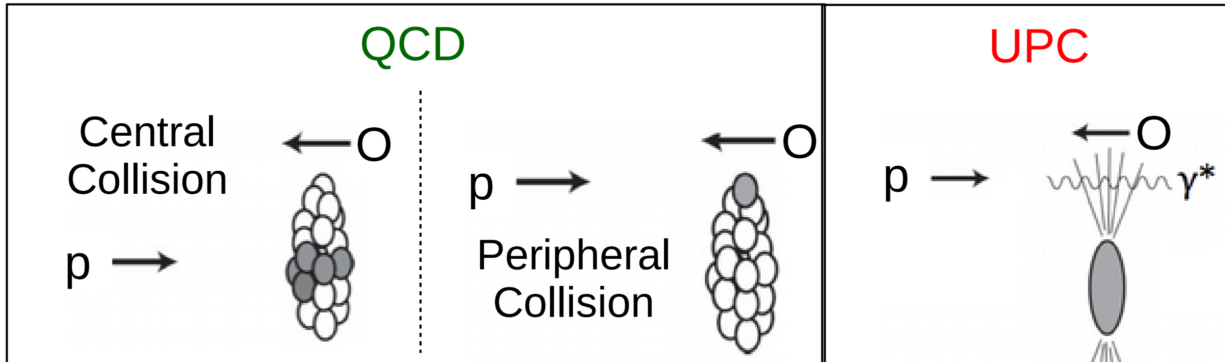
This is due to the fact that parton (gluon) density scale as $\propto A^{1/3}$: respect to p-p, in p-ion, the target is nearer to the **blackbody limit**, where <u>projectile partons cannot move freely inside the target, but suffer large p_T transfers</u>.

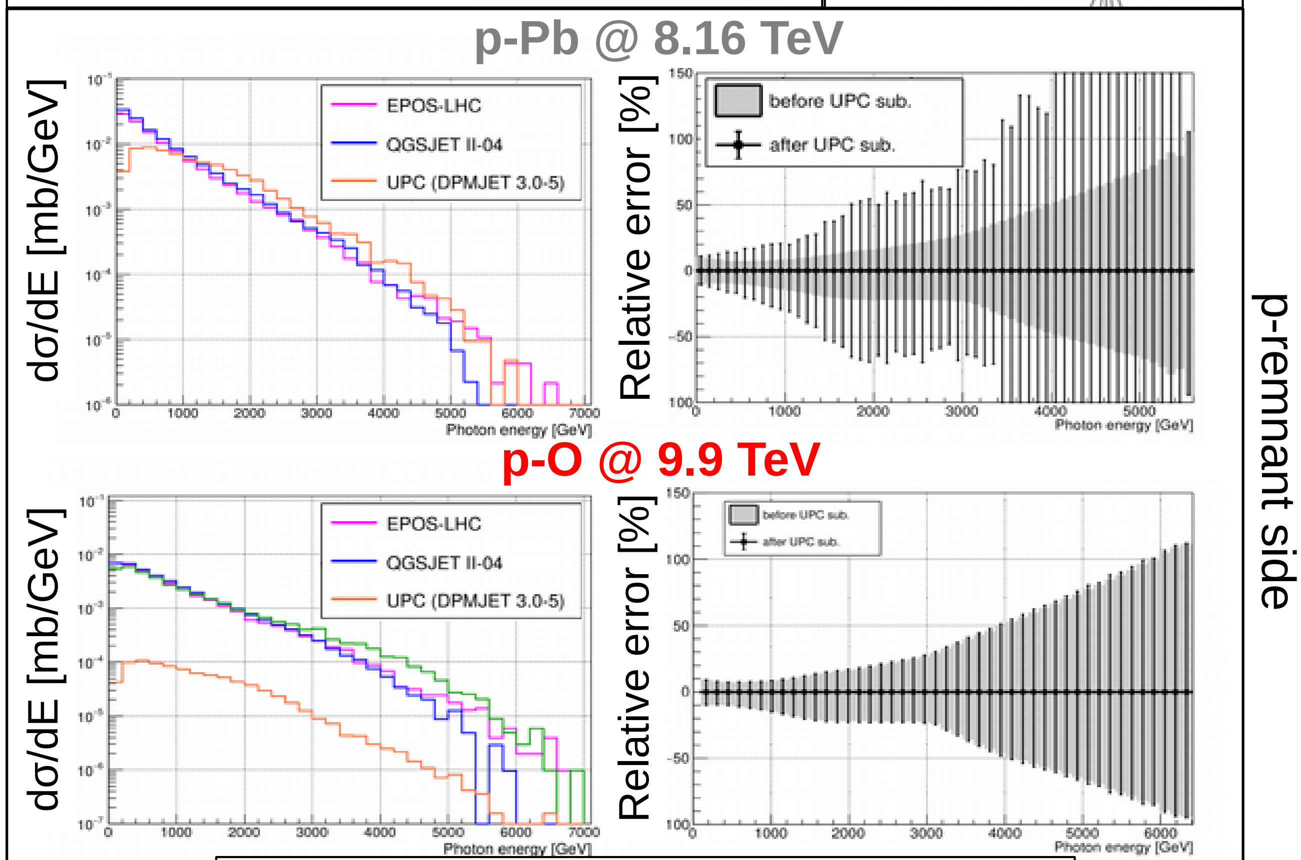
Ultra Peripheral Collision (UPC)

In the case of EAS interaction, forward production is dominated by **soft QCD processes**.

Forward production measured in **p-Pb collisions** was affected by a large contribution from **Ultra Peripheral Collision** (Coulombian interaction) that constitutes a significant source of background for measurements: the uncertainty is dominated by the systematic from the estimation of the UPC contribution (10-50%) to be subtracted from data

In **p-O collisions**, UPC background is negligible and does not contribute to the final error!

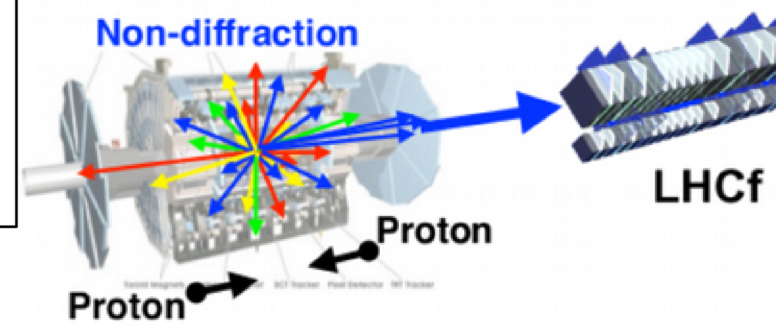


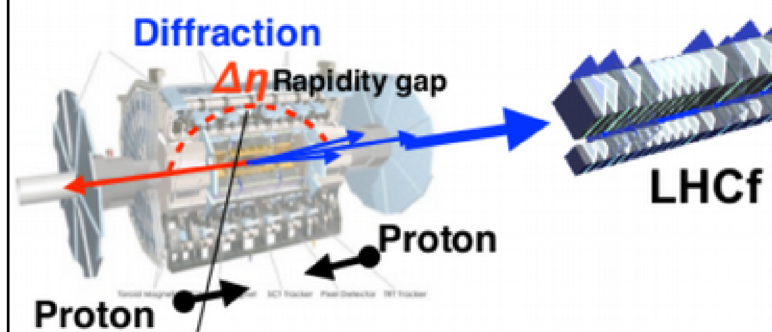


Forward photon production in η > 10.94

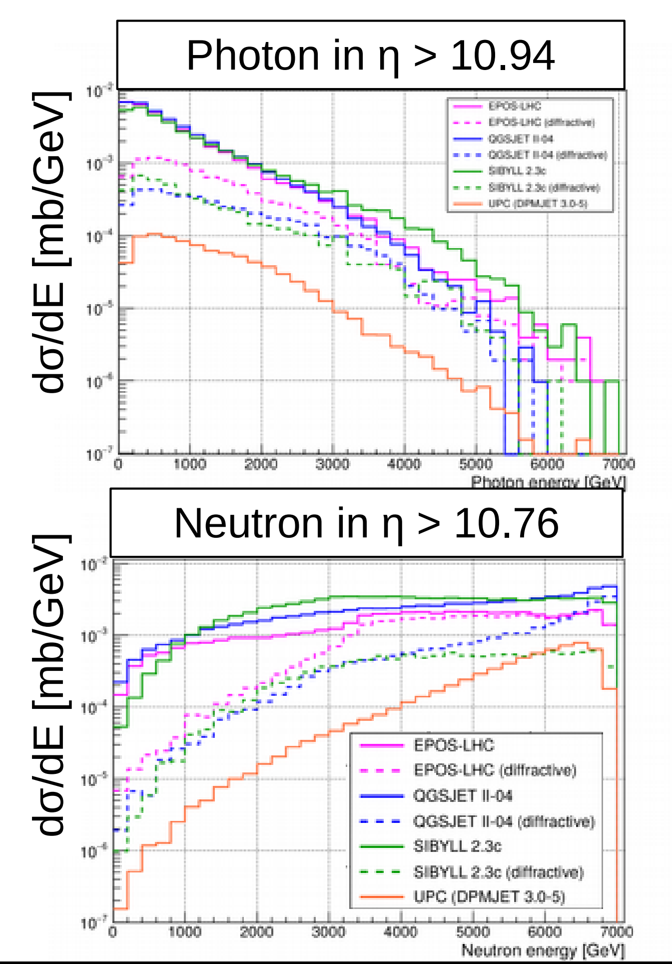
LHCf-ATLAS Joint Analysis

The **LHCf-ATLAS joint analysis** proved to be a very powerful tool to study forward production from different contributions, non-diffractive and diffractive (M_X<50GeV), by looking at the activity in the central region.





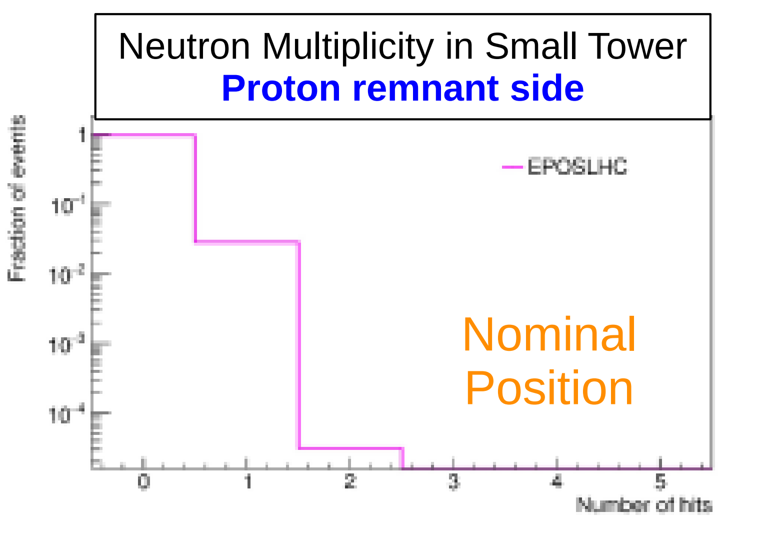
ATLAS-CONF-2017-075



Because of the large UPC contribution, which (having no activity in central region) mimics a diffractive event, the LHCf-ATLAS joint analysis was not effective in **p-Pb collisions**.

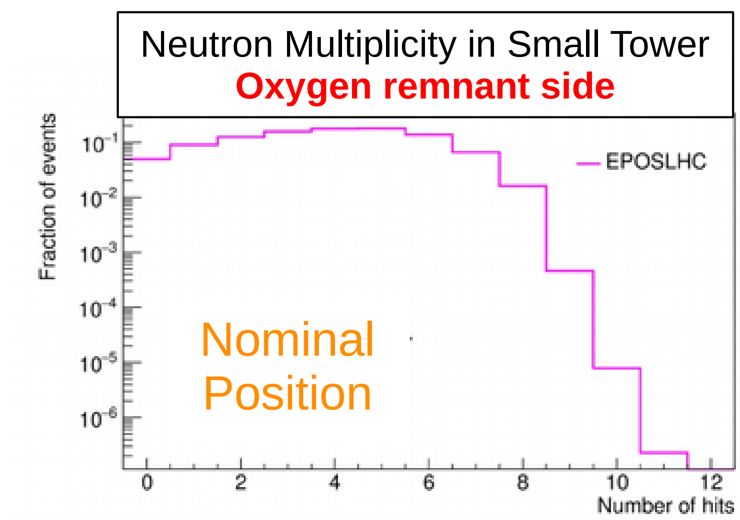
In **p-O collisions**, the UPC contribution is negligible respect to diffraction contribution, so that the LHCf-ATLAS joint analysis can be successfully extended to investigate forward production in p-ion collisions.

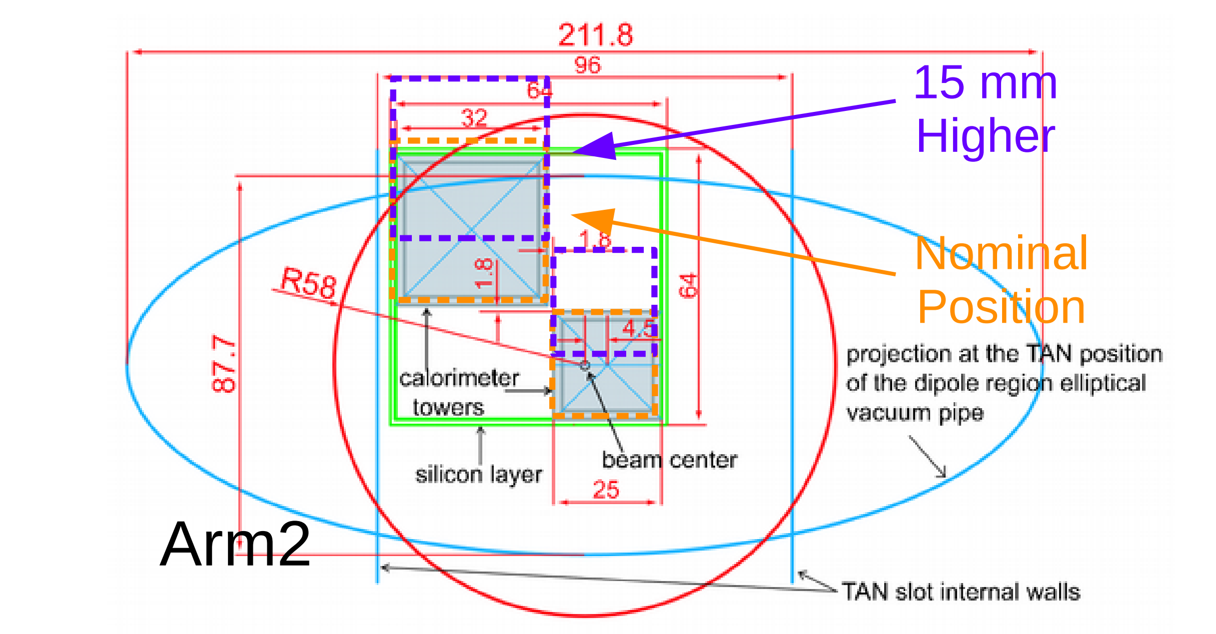
Multiplicity

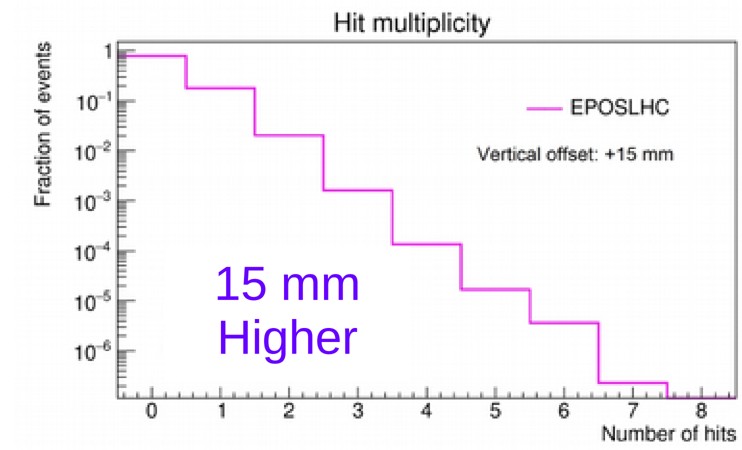


LHCf can safely operate on proton-remnant side since it can separately reconstruct two particles in same tower and less than 10% of events have more than a particle

Due to high multiplicity, LHCf can operate on oxygen remnant side only 15 mm higher ($\eta<11$)







Prospects for Run III

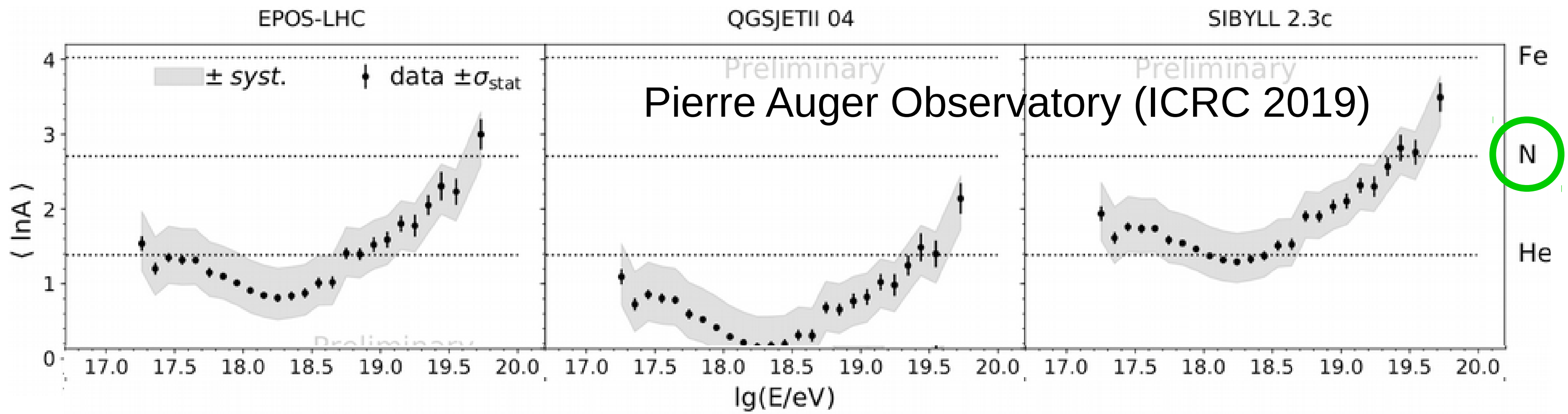
In Run III, **p-O and O-O collisions** are foreseen for about one week in 2023/2024: at the moment, it is not clear how many days will be dedicated to p-O and O-O collisions and which will be the center-of-mass energy.

Why O-O collisions?

Measurements show that the mass composition of UHECRs is compatible with an **admixture of light nuclei**

→

We need **high energy calibration data** in a configuration equivalent to a primary proton or light ion UHECR



Large effort made by the LHCf collaboration to have O-O collisions in Run III, with support letter to LHCC, dedicated session in LHC workshop, discussion at LPC meeting...

...p-O and O-O operations approved by CERN Council in June 2021!

Summary

Due to next reshaping of TAN slot, **Run III will be the last run for LHCf**!

In Run III, the LHCf experiment will have the unique opportunity to measure forward production from **high energy p-O and O-O collisions**.

These measurements are crucial to tune hadronic interaction models used by cosmic-ray experiment at ground, representing a configuration similar to the first interaction of a UHECR with a light atmospheric nucleus.

In addition, in p-O collisions **the UPC background is much smaller** than it was in p-Pb collisions, leading to much more accurate measurements.

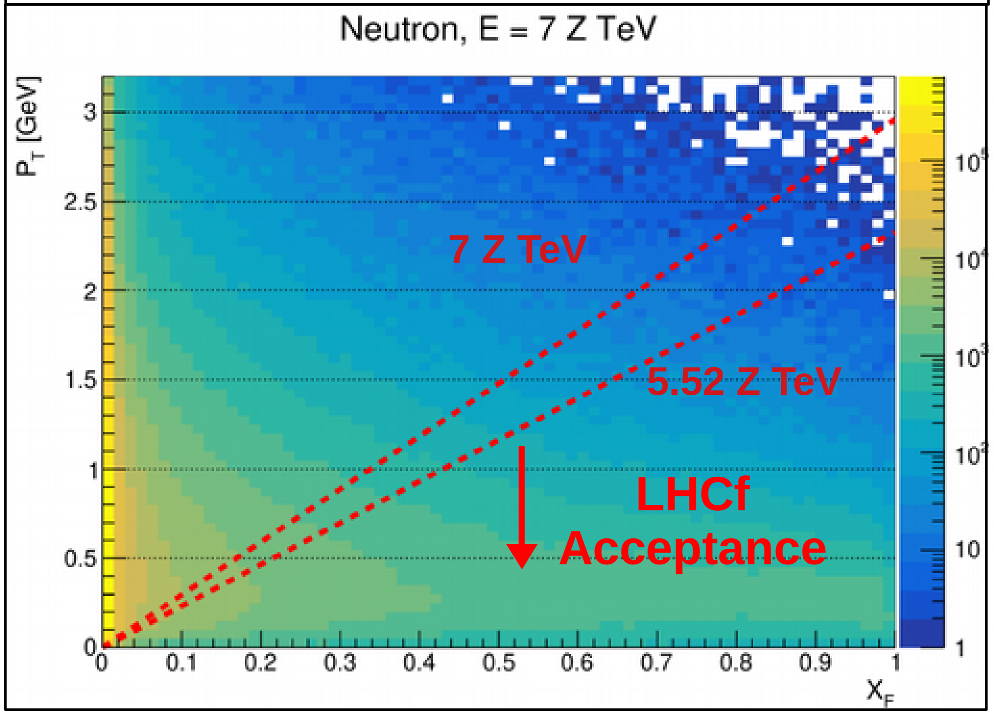
Contribution of diffractive component to forward production can be accurately studied in p-O collisions by the **LHCf-ATLAS joint analysis**.

Operation Schedule

In Run III, **p-O (and O-O) collisions** are foreseen for about one week in 2023/2024: at the moment, it is not clear how many days will be dedicated to p-O and O-O collisions and which will be the center-of-mass energy ($\sqrt{s}$ = 5.52 or 7 Z TeV).

For the LHCf experiment the ideal situation would be to have:

- <u>p-O collisions $\sqrt{s}$ = 7 Z TeV</u>, in order to have the maximum coverage in the p_T-x_F phase space (L_{int} = 0.7 nb^{-1})



- <u>Both p-O and O-O collisions</u>, in order to study the equivalent case where the incoming UHECR is a proton or a light ion