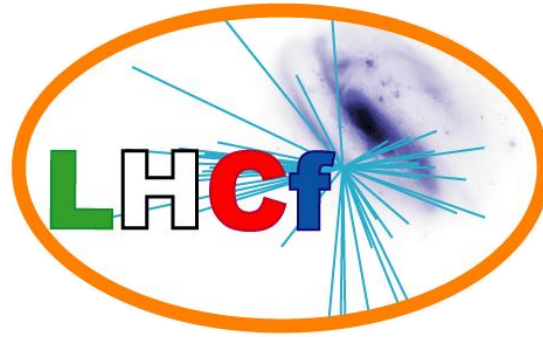


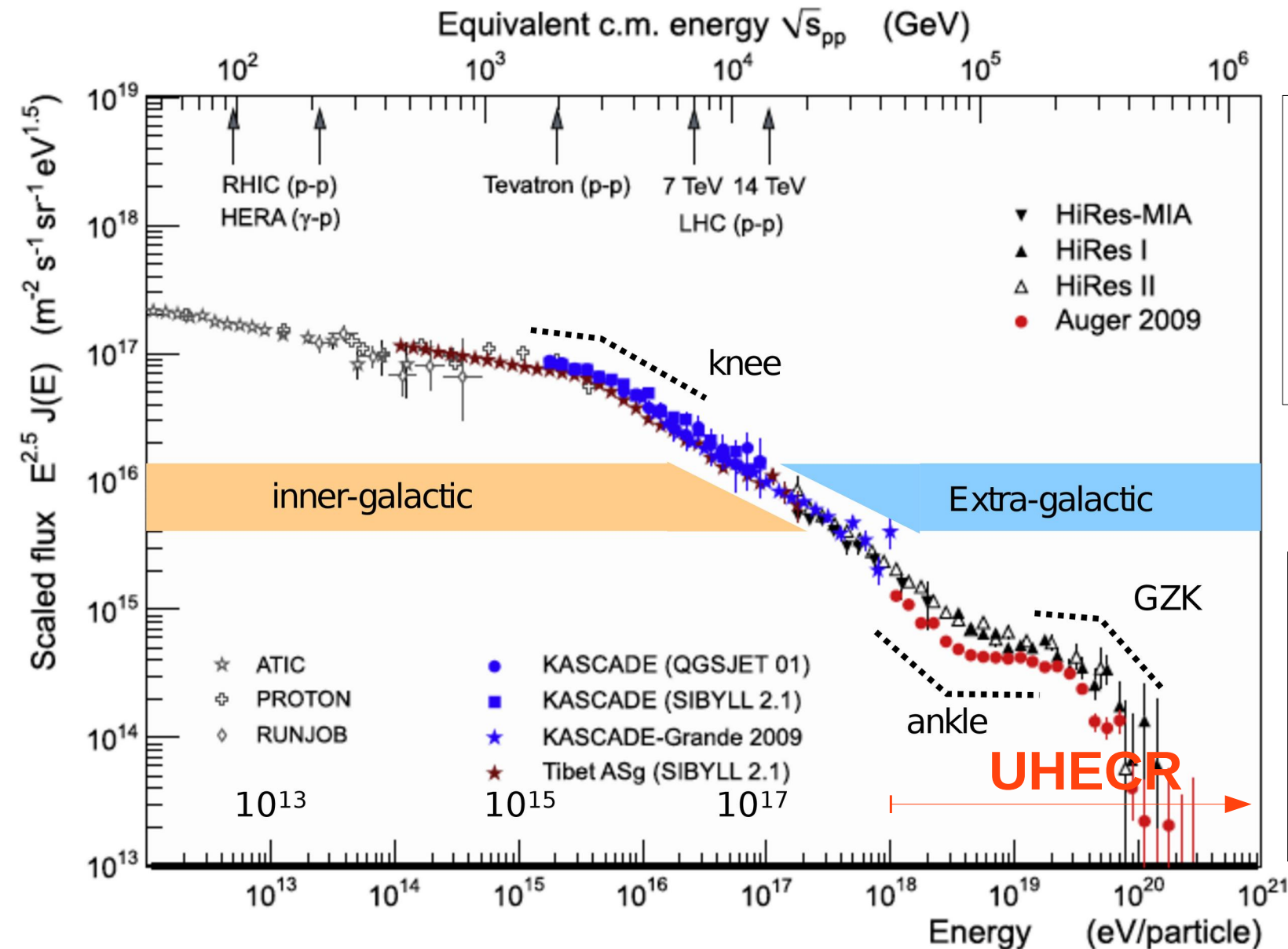
Report from LHCf and cosmic showers

Eugenio Berti, on behalf of the LHCf collaboration
Light Ion Collisions at the LHC - 2025
1-3 December 2025, CERN

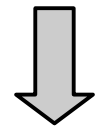


Introduction

Ultra High Energy Cosmic Rays



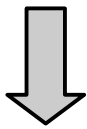
Motivation
 Understand mechanisms responsible for *acceleration* and *propagation*



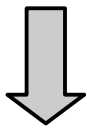
Accurate measurements of UHECR flux and composition as a function of the energy

Extensive Air Showers

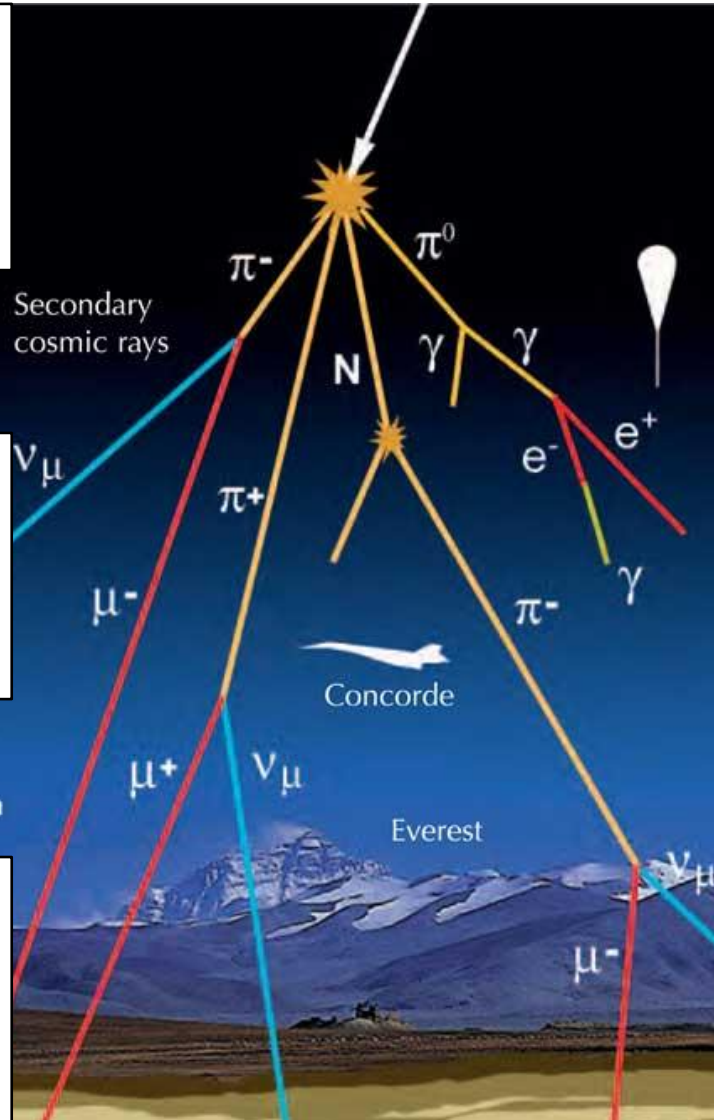
Indirect measurement of UHECR energy flux and average composition by **Extensive Air Showers**



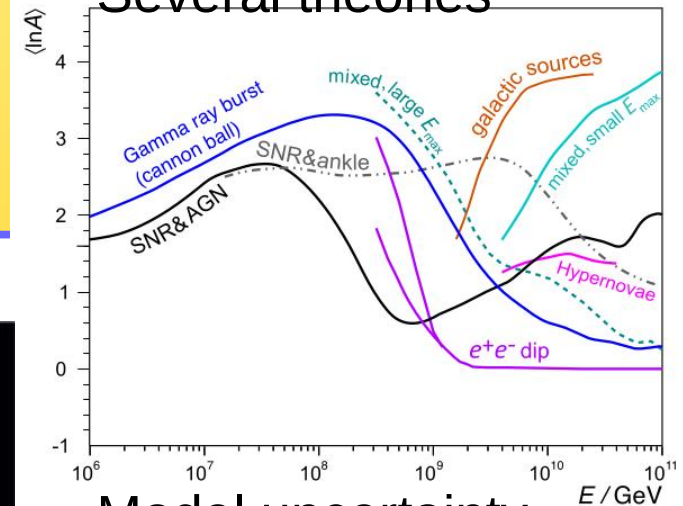
Measurement of average composition strongly relies on hadronic interaction models



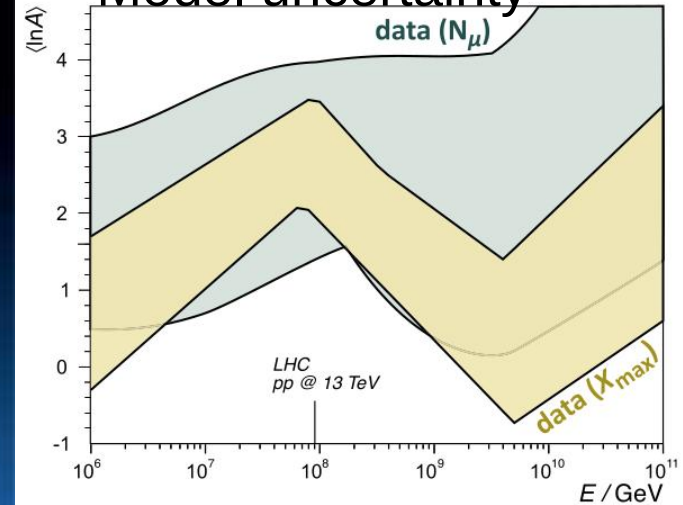
Large uncertainties in interaction models due to the lack of high energy calibration data



Several theories



Model uncertainty

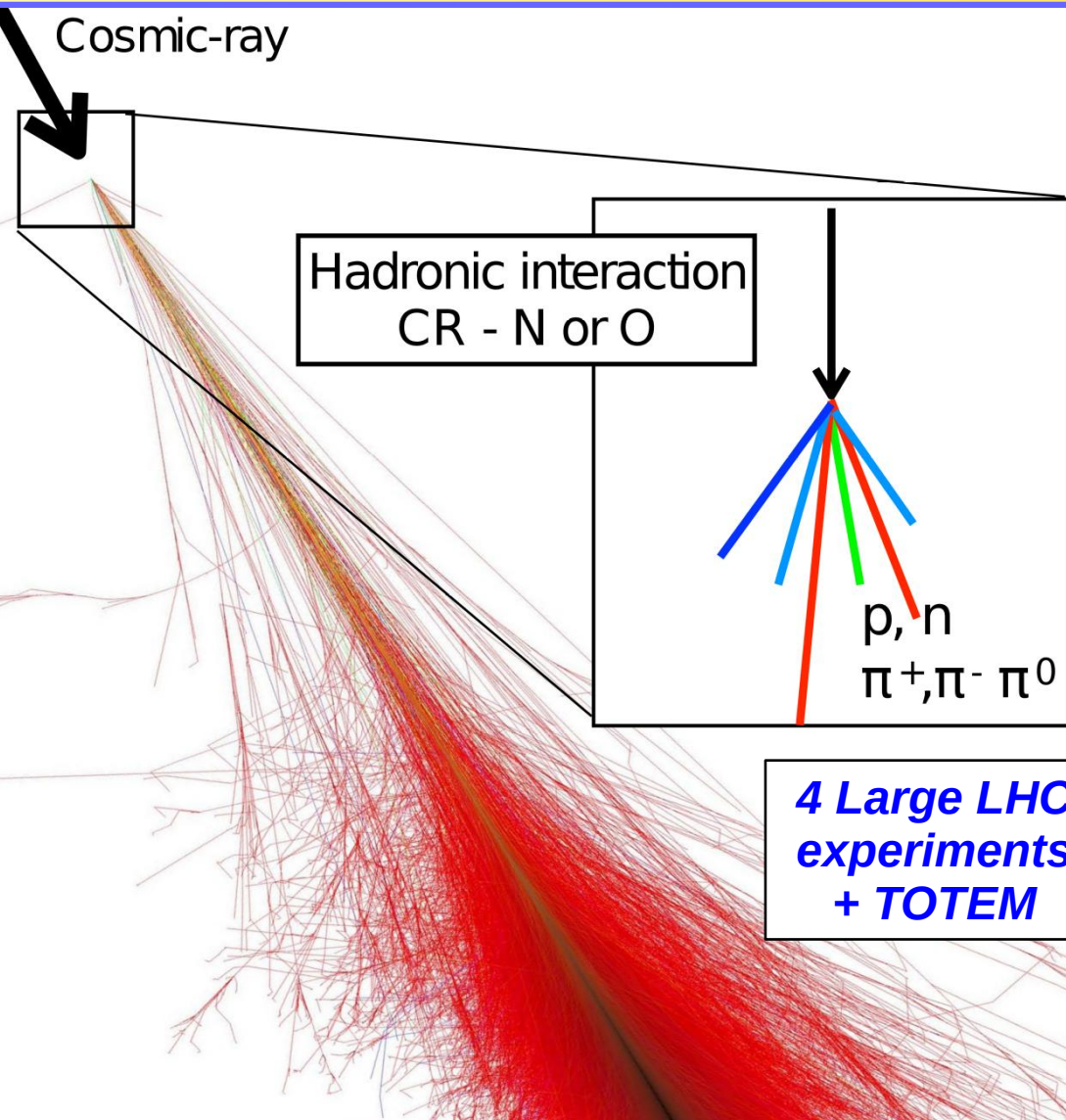


$\langle X_{max} \rangle$: Small uncertainty
 $\langle N_{\mu} \rangle$: Large uncertainty



Muon Puzzle

Hadronic interaction models



High energy calibration data are needed to properly tune hadronic interaction models

LHC is the best place where to study a system that is similar to the first CR-nucleus interaction

4 Large LHC experiments + TOTEM

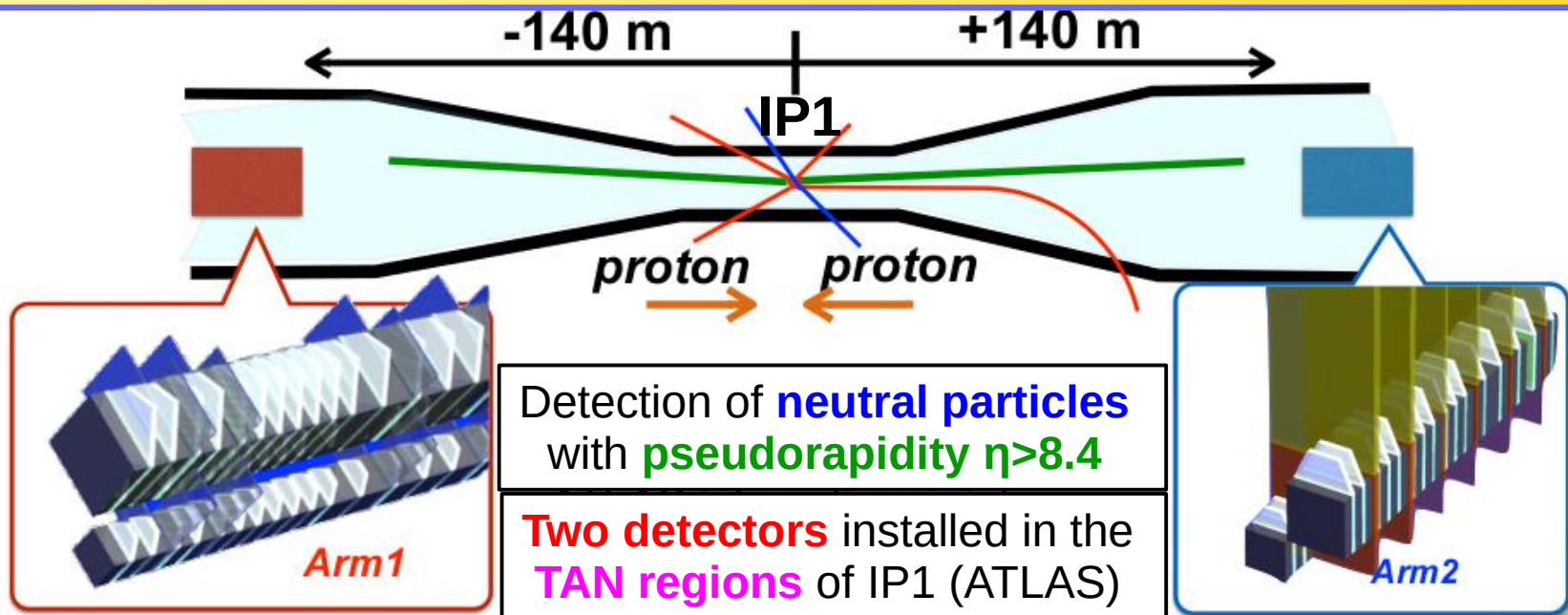
EAS key quantities

- Inelastic cross section
- Particle multiplicity
- E/H Ratio $R = E_y / E_h$ π^0, η, \dots
- Elasticity $k = p_{lead} / p_{beam}$ n
- + *Very forward particle spectra*
 - Extrapolation to $E > 10^{17}$ eV
 - Nuclear effects

LHCf

p-p at $\sqrt{s} = 14$ TeV \rightarrow $E_{LAB} = 10^{17}$ eV

The LHCf Experiment



Tower Size:
 20 x 20 and 40 x 40 mm²

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 X₀, 1.6 λ₁

Energy resolution:
 < 2% (photons)
 ~ 40% (hadrons)

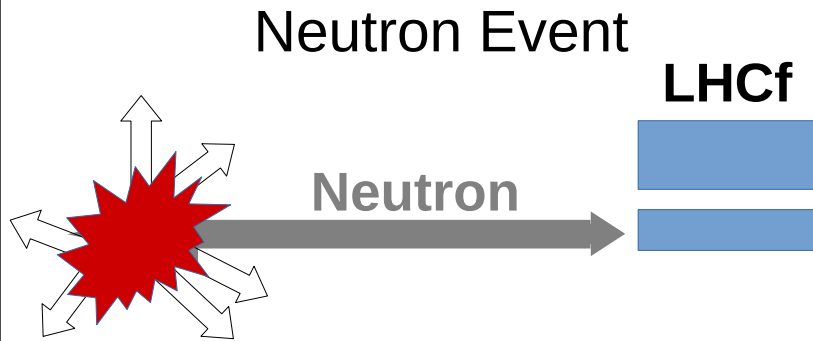
Tower Size:
 25 x 25 and 32 x 32 mm²

Imaging layers:
 4 x-y 160μm Si microstrip

Position resolution:
 < 40 μm (photons)
 < 800 μm (hadrons)

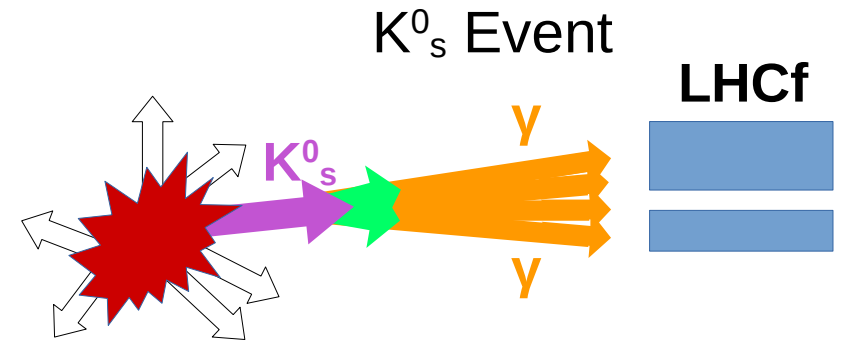
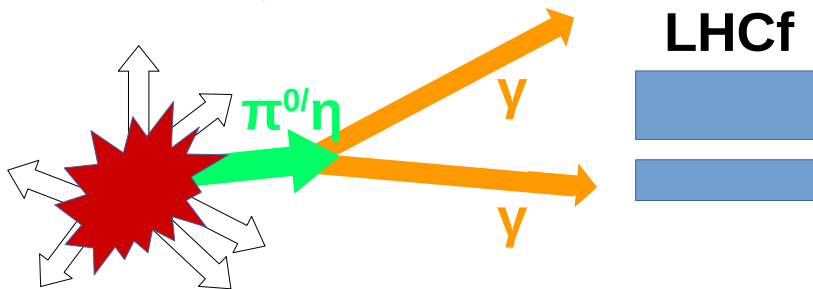
The LHCf acceptance

Information on leading baryon and average inelasticity

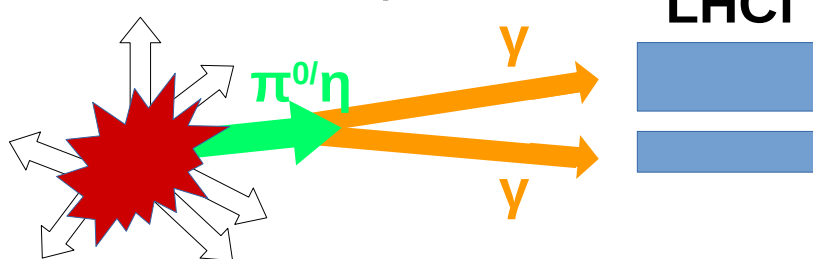


Information on strangeness component (...in progress...)

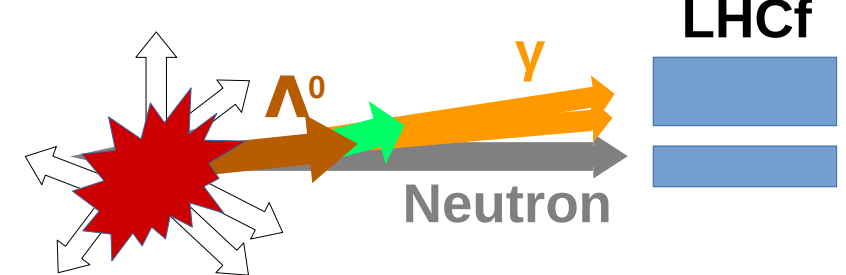
Single Photon Event



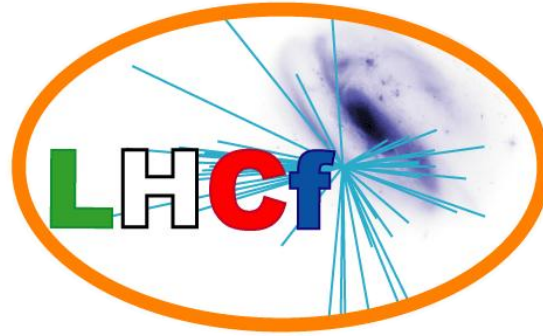
π^0/η Event



Λ^0 Event



Information on electromagnetic component



Main Results

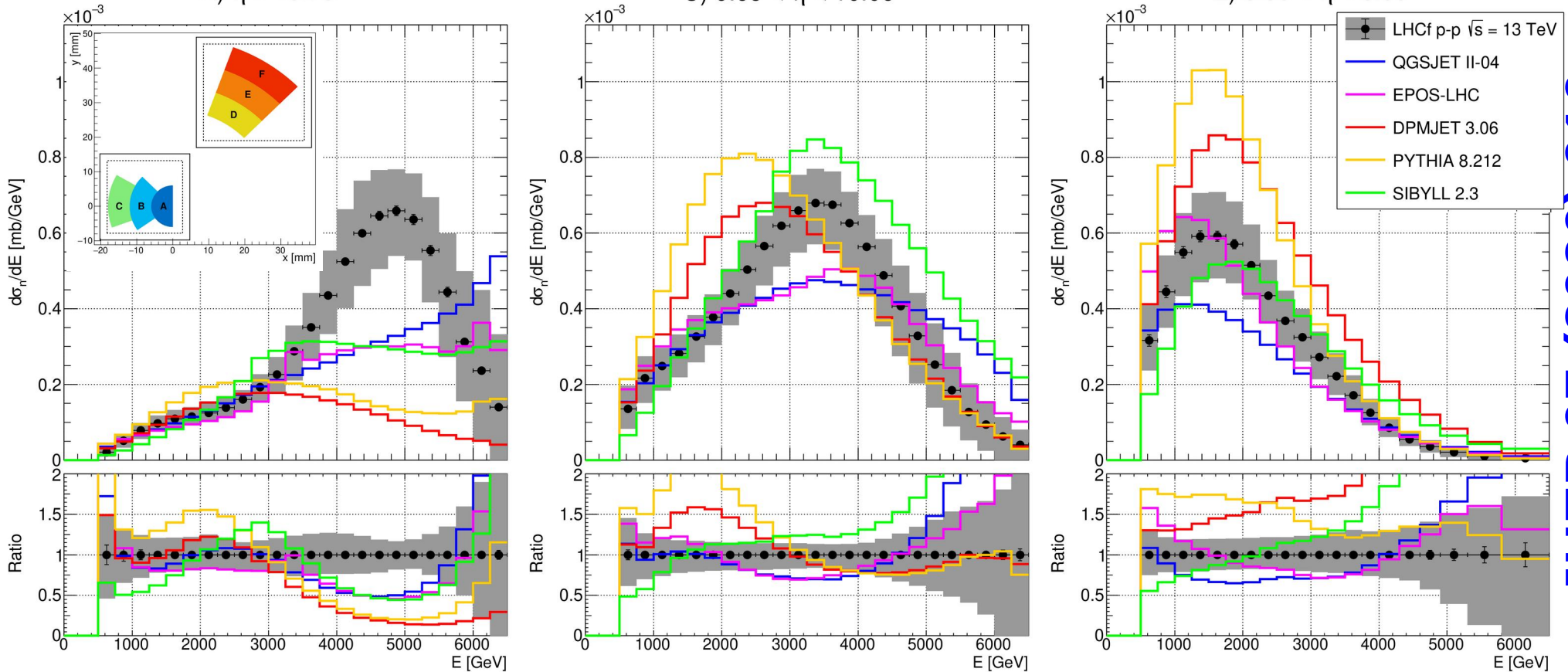
Neutron Production Cross Section

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

A) $\eta > 10.75$

C) $9.65 < \eta < 10.06$

E) $8.80 < \eta < 8.99$

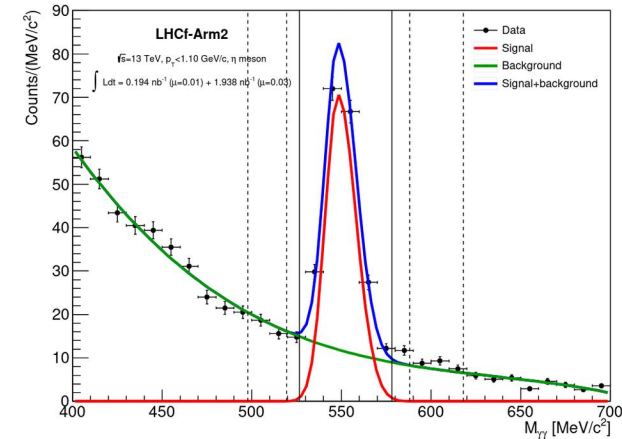
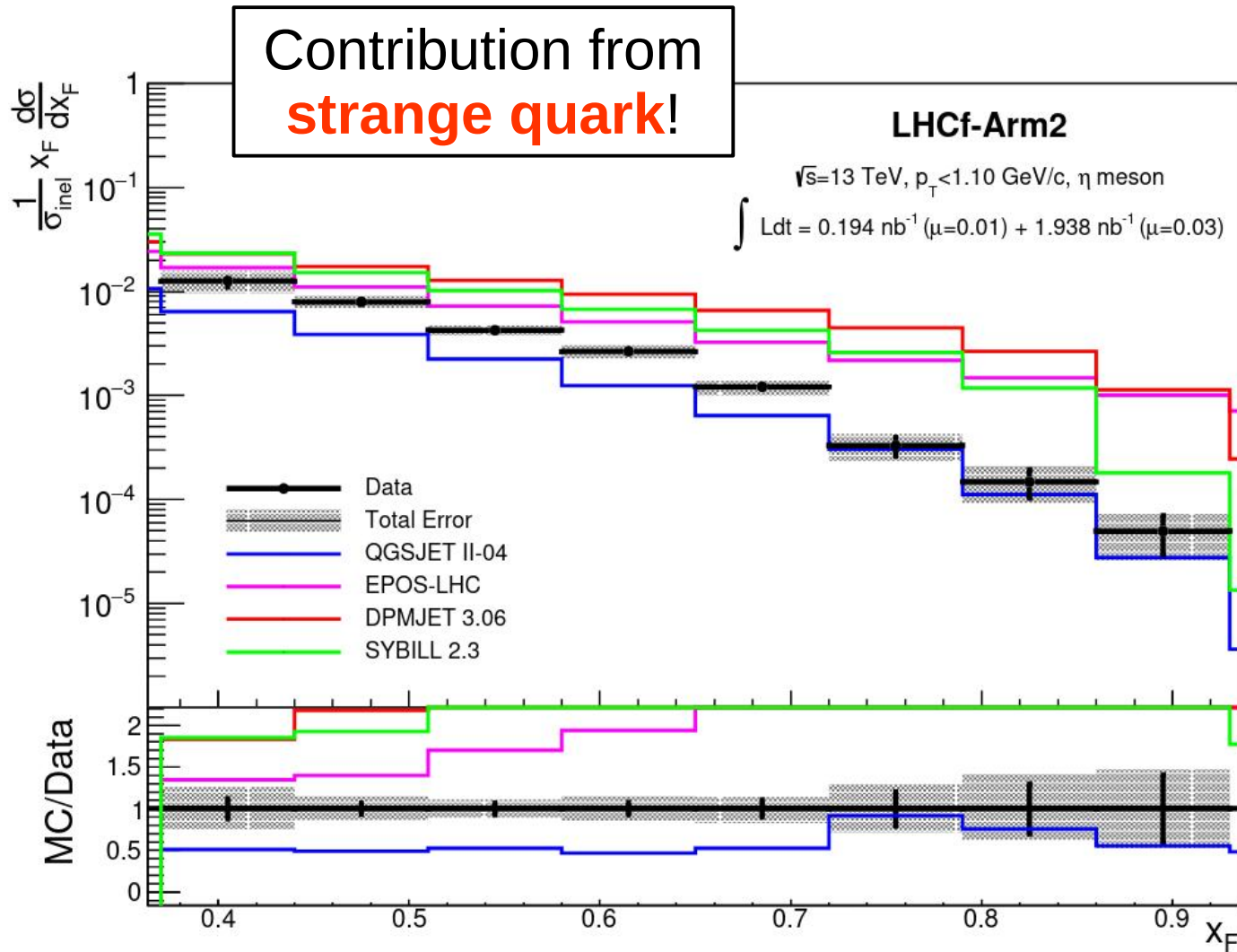


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Models strongly underestimate neutron production in the most forward region and in general have limited agreement with the experimental results

η Production Rate

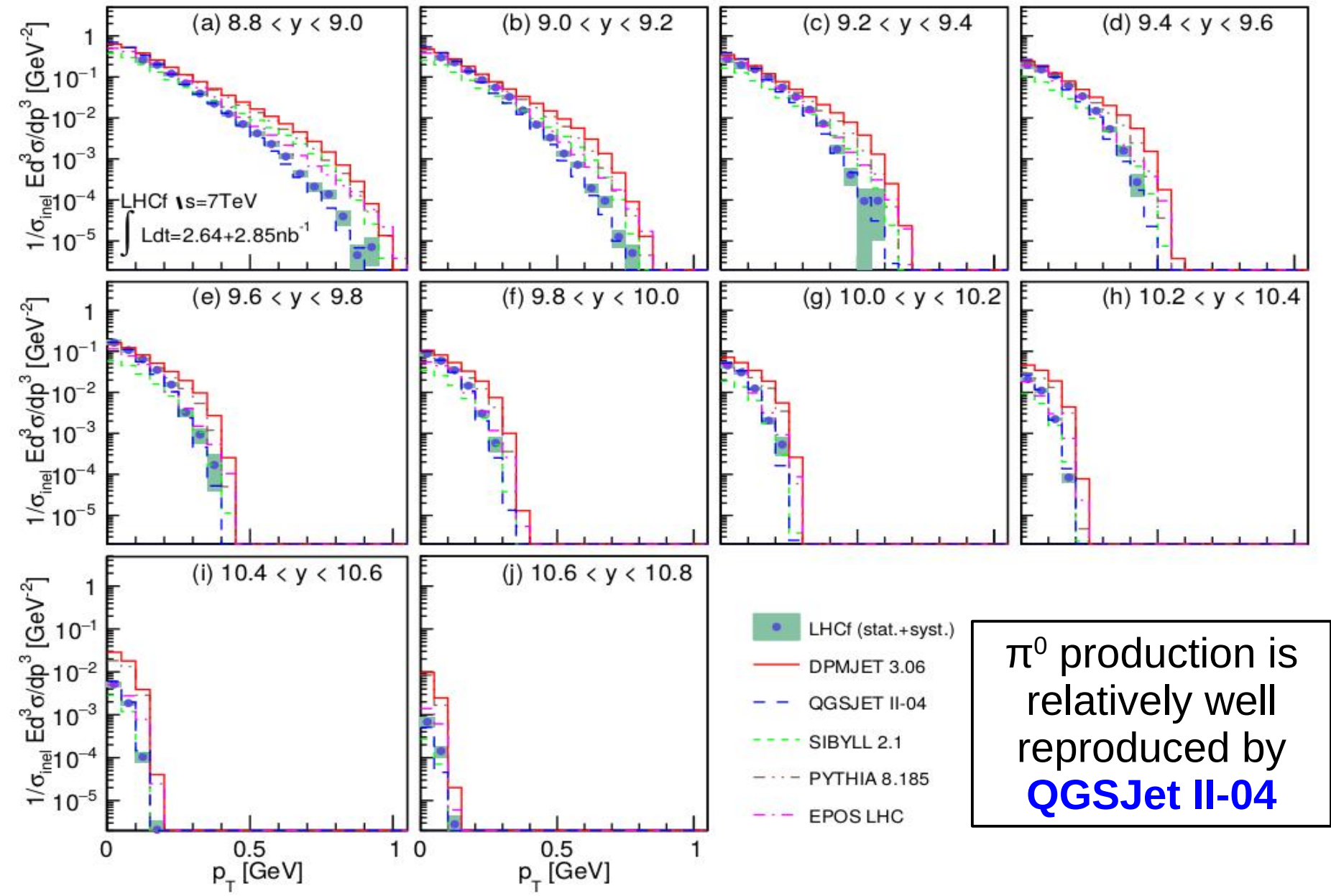
p-p $\sqrt{s} = 13$ TeV



QGSJETII-04 underestimates η production, while other models strongly overestimate it

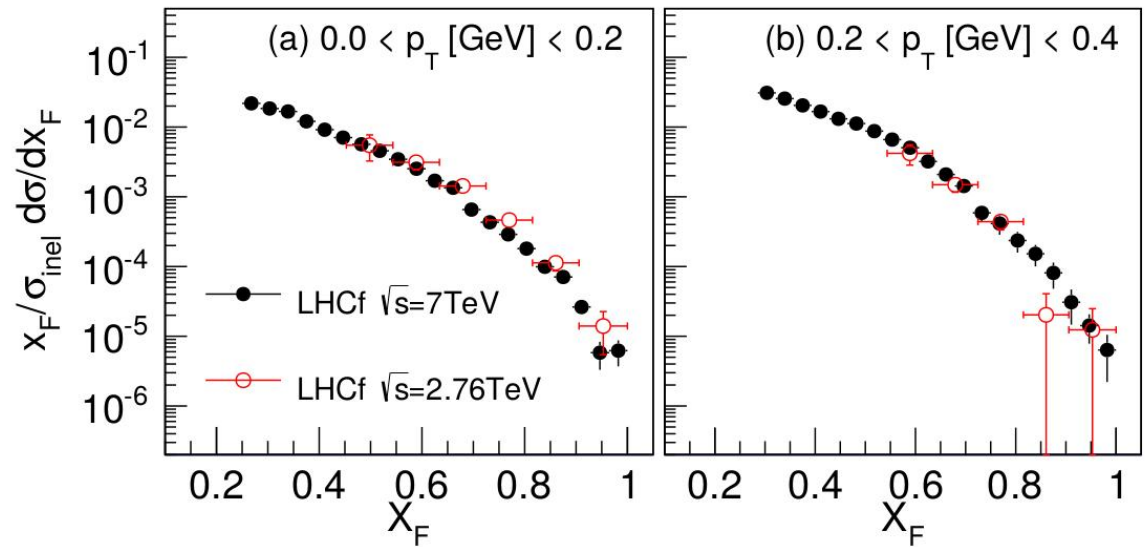
π^0 Production Cross Section

p-p $\sqrt{s} = 7$ TeV



π^0 Production Cross Section

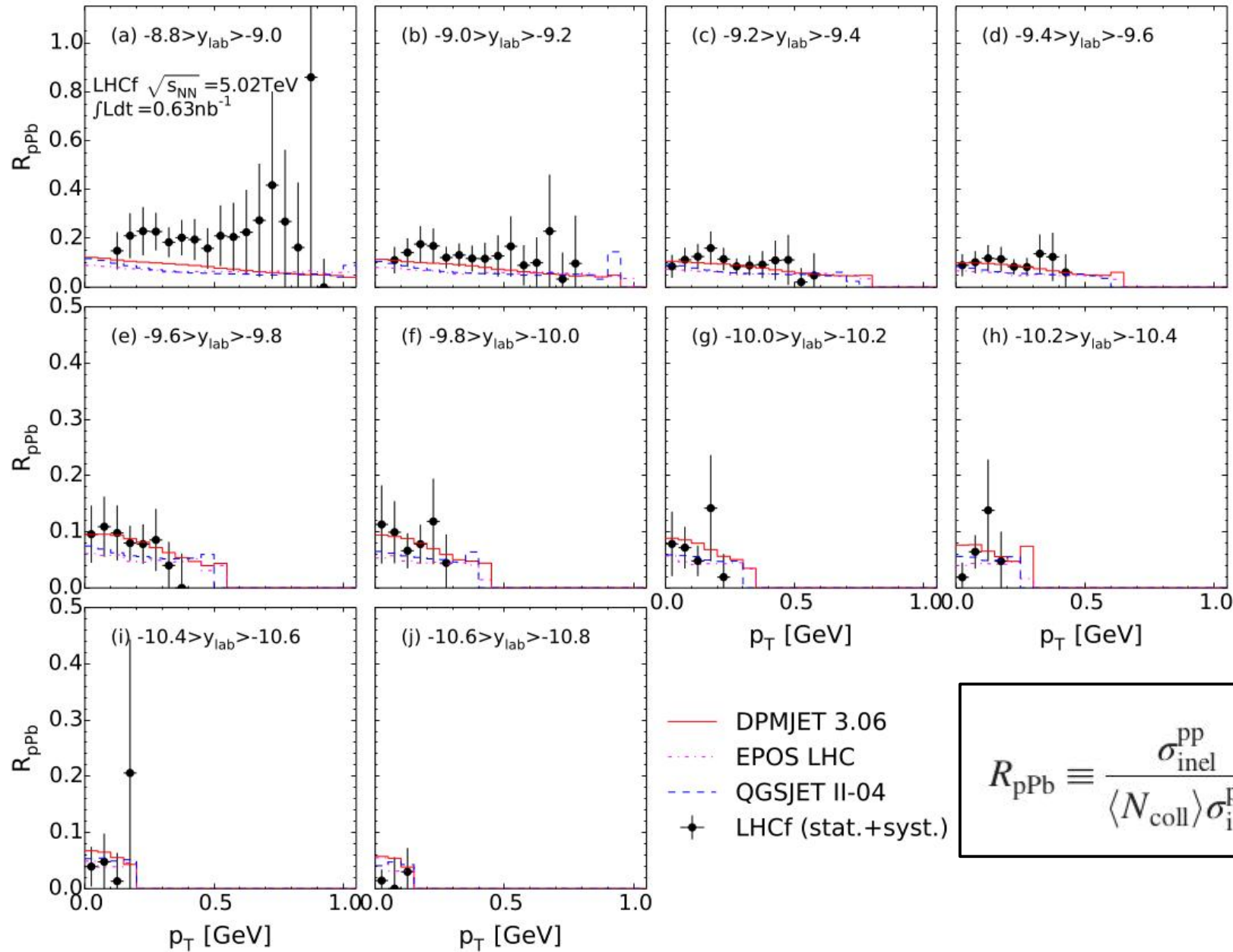
Test of Feynman scaling

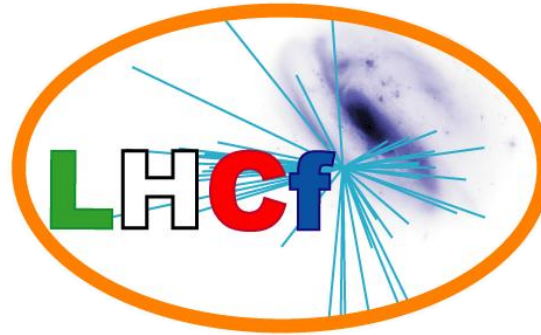


Feynman scaling
holds at $\pm 20\%$ level

π^0 Production Cross Section

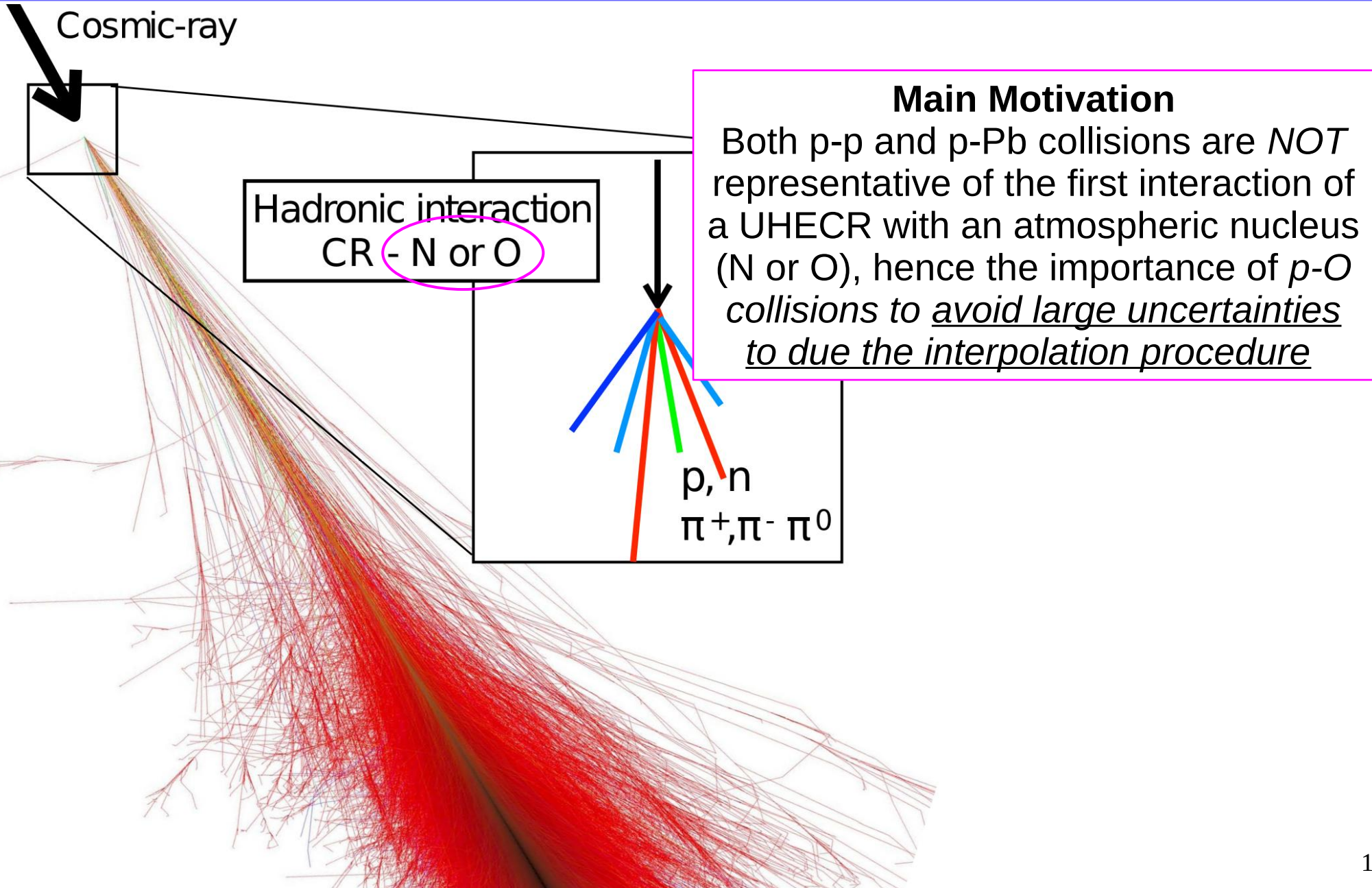
Nuclear modification factor





p-0 Collisions

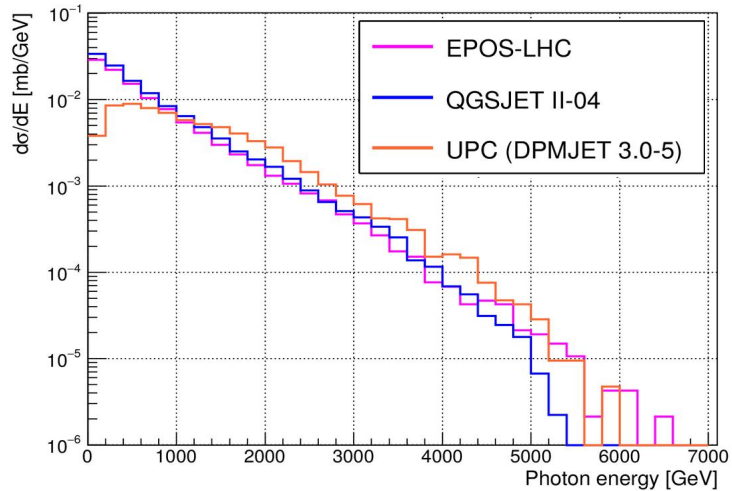
Main Motivation



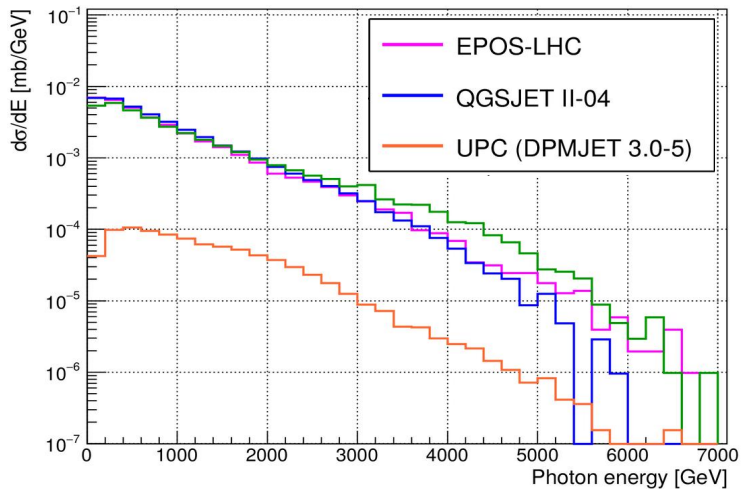
Additional Motivations

Expected forward photon production in $\eta > 10.94$

p-Pb @ 8.16 TeV

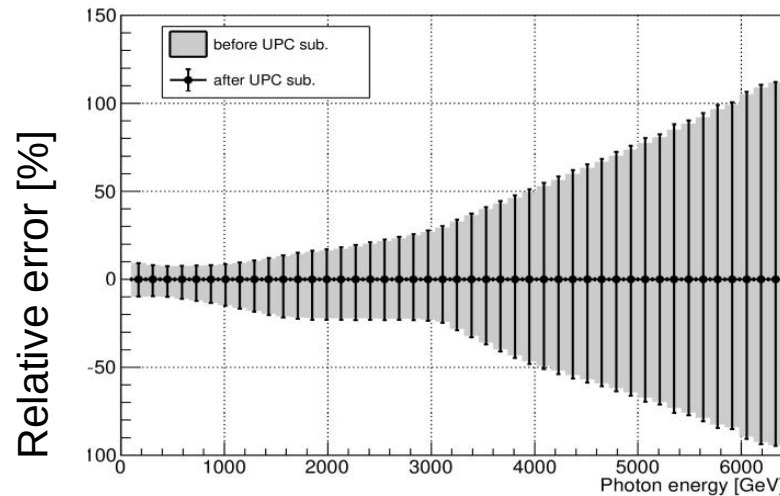
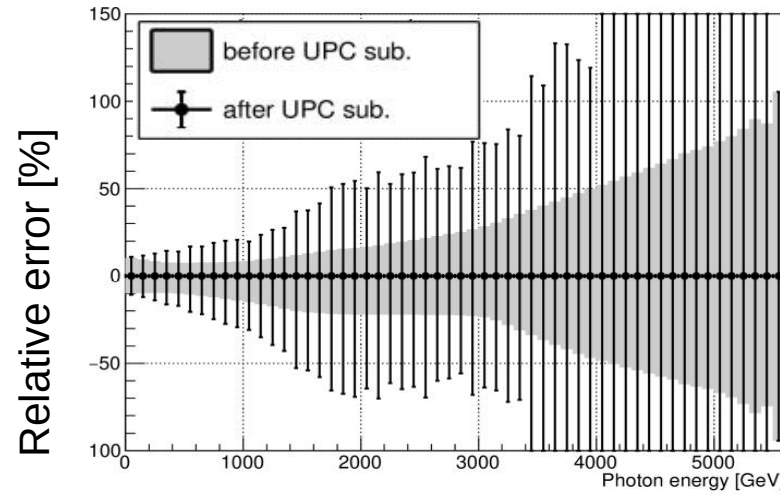


p-O @ 9.6 TeV



Additional motivations wrt p-Pb collisions:

- Ultra Peripheral background negligible
- LHCf-ATLAS analysis possible (no UPC)



p-remnant side

Our history

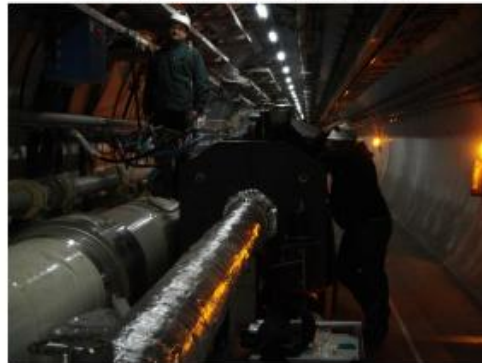
I have joined the experiment here! 😊



2006: SPS (CERN Courier)



2008: 1st installation



2014: test SPS



2015: LHCf team



2016: run p+Pb



2021: test SPS with ZDC



2022: run p+p 13.6 TeV



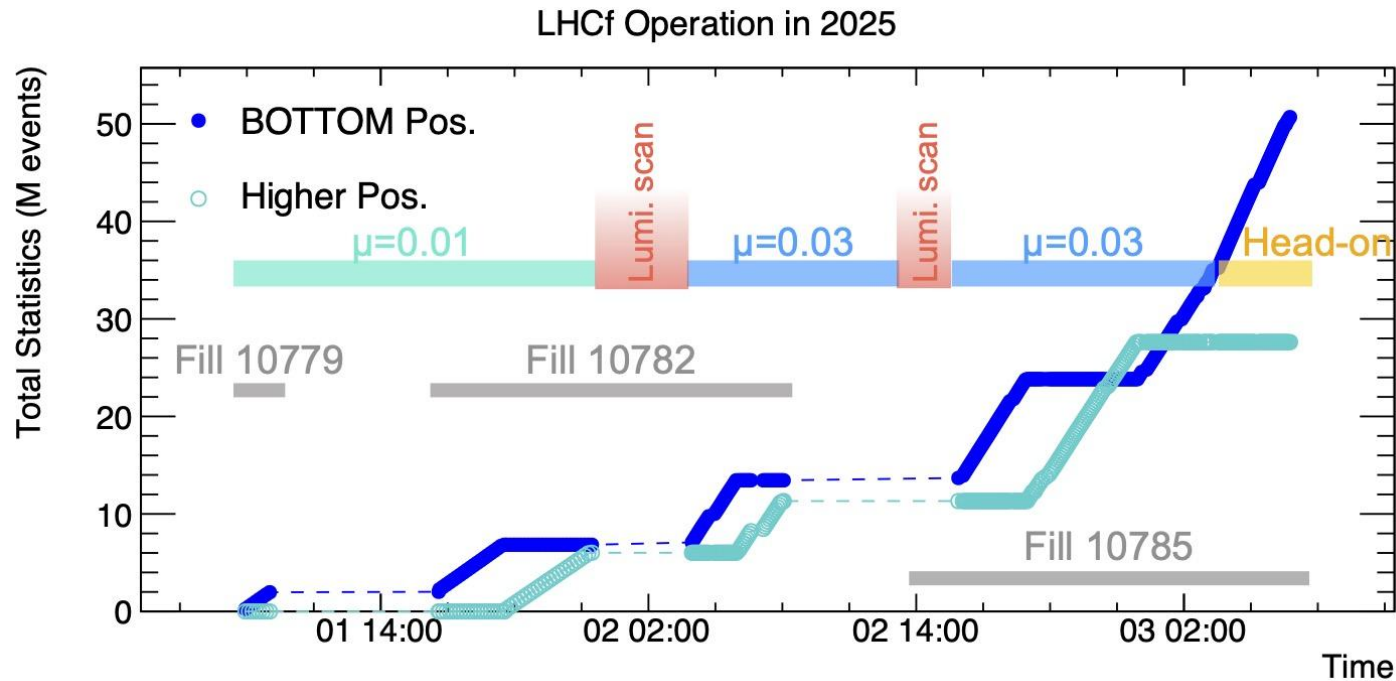
2025 : run p+O



Biggest and last milestone achieved in this July

Data taking

Data taking from 1st to 3rd of July 2025!
Joint operation with ATLAS experiment



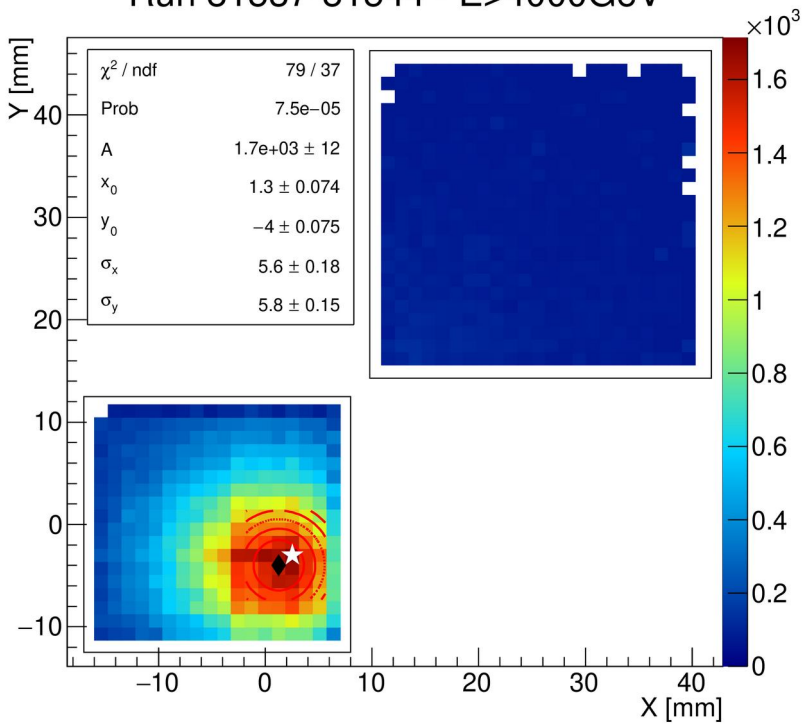
In total we collected about **60M** events with $\mu=0.01$ and 0.03 ,
divided in two detector positions to fully cover the acceptance

Preliminary plots

Hitmap of neutron candidates

Run 81537-81544 - E>4000GeV

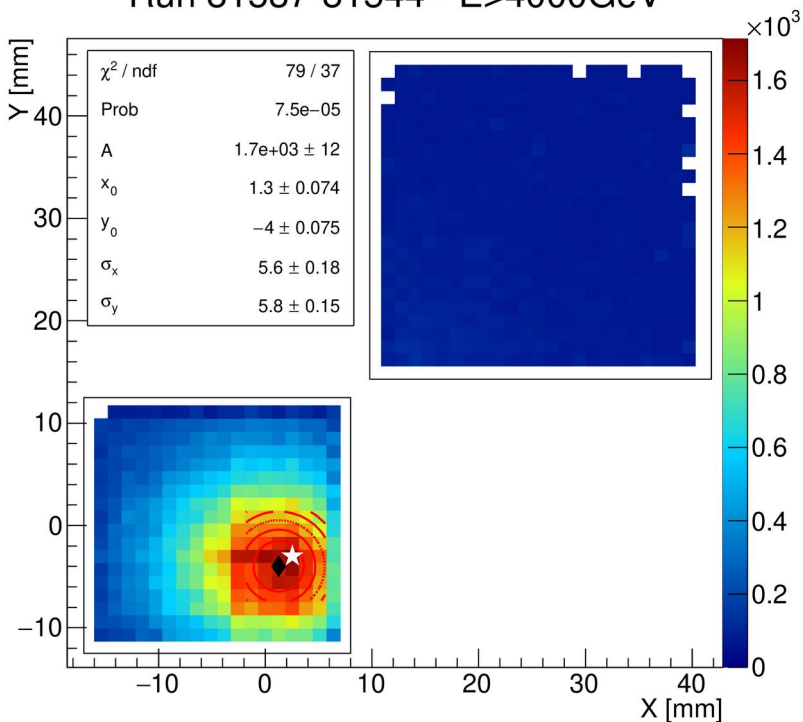
From this distribution we determine the beam axis projection on the detector plane



Preliminary plots

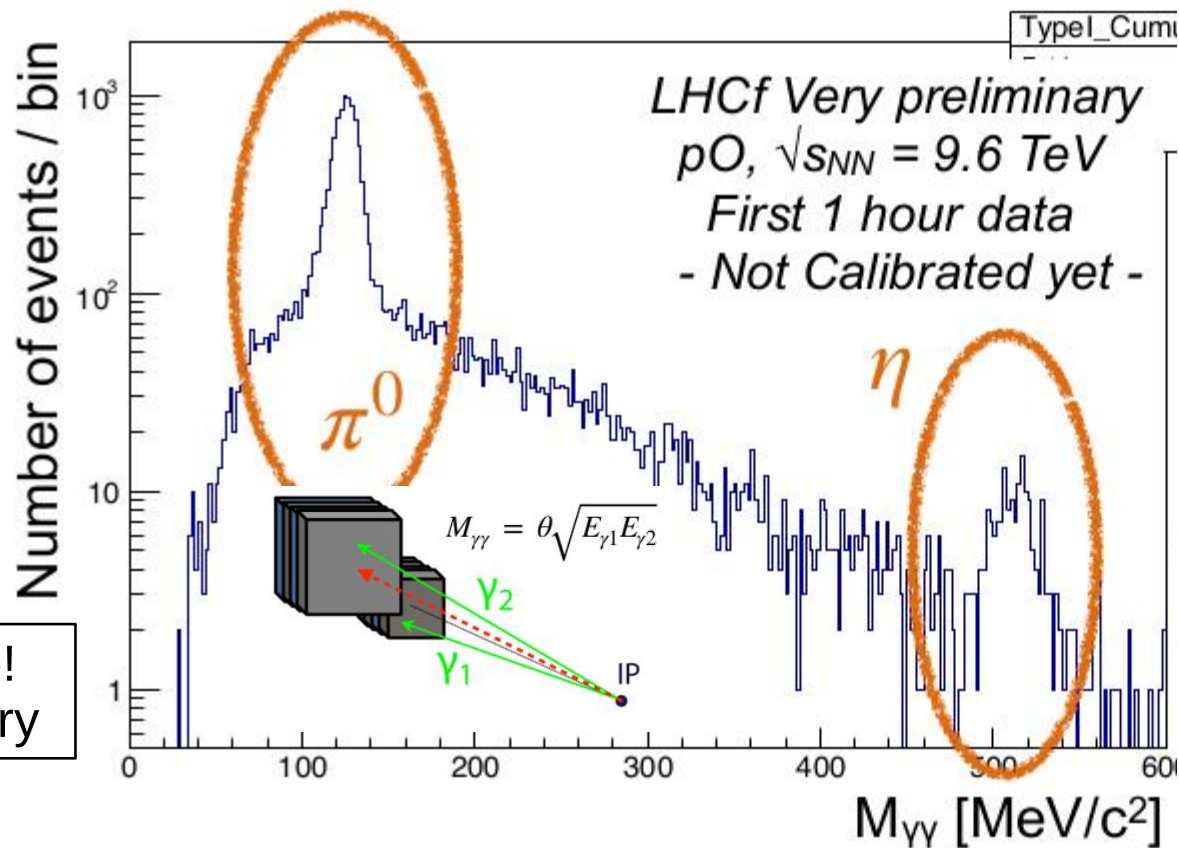
Hitmap of neutron candidates

Run 81537-81544 - E>4000GeV



From this distribution we determine the beam axis projection on the detector plane

Invariant $\gamma\text{-}\gamma$ mass distribution



Despite small sample, π^0 / η are visible!
 Gain calibration with SPS data necessary

Beam test

In October we performed a beam test at SPS in order to calibrate the detector for the analysis of p-O data

AN EPILOGUE?



A new chapter

In October we performed a beam test at *SPS* in order to calibrate the detector for the analysis of p-O data

AN EPILOGUE?



This was the last operation of our experiment, but a lot of results from analysis of *Run III* data is yet to come!



Summary

Data taking with **p-O collisions at $\sqrt{s_{NN}} = 9.6$ TeV** was the final and most important goal of our experiment

The first steps for the analysis of this data set are:

- Gain calibration using SPS Data
- Forward photon production
- Forward π^0 production

We expect to have the first preliminary results of forward production in p-O in about *1 year*

Thank you
for the attention!