η ANALYSIS STATUS

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η MESONS IMPORTANCE IN H.I.M.

- One of the key parameters of hadronic interaction models is the **strangeness production**.
- Differences in strangeness production between the models induce **large discrepancies** in the determination of the production η cross section, larger than those observed for neutral pions.
- In addition, the η/π^0 ratio is useful for model developers to adjust **resonance productions** and ir various mechanisms (e.g. string fragmentation).
- η mesons play also an important role in lepton production in air showers. This have also implications in neutrino experiments.

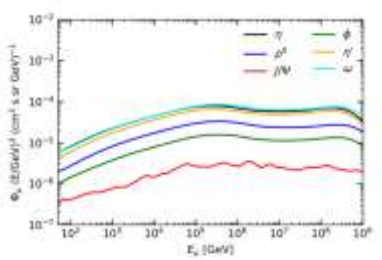

FIG. 6. Breakdown of the unflavored component of the prompt muon flux.

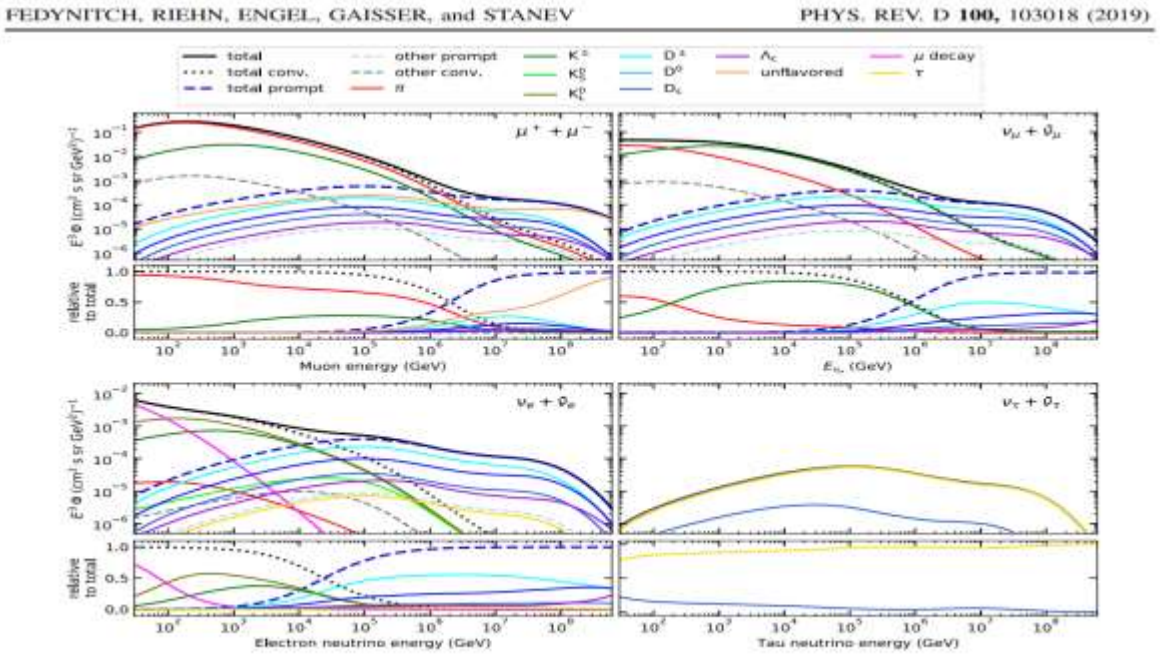

FIG. 5. Contribution from decays of various particles to the atmospheric $\mu^+ + \mu^-$ (top left), $\nu_\mu + \bar{\nu}_\mu$ (top right), $\nu_e + \bar{\nu}_e$ (bottom left) and $\nu_\tau + \bar{\nu}_\tau$ (bottom right) flux in SIBYLL-2.3c and *H3a* primary model at $\theta = 60°$.

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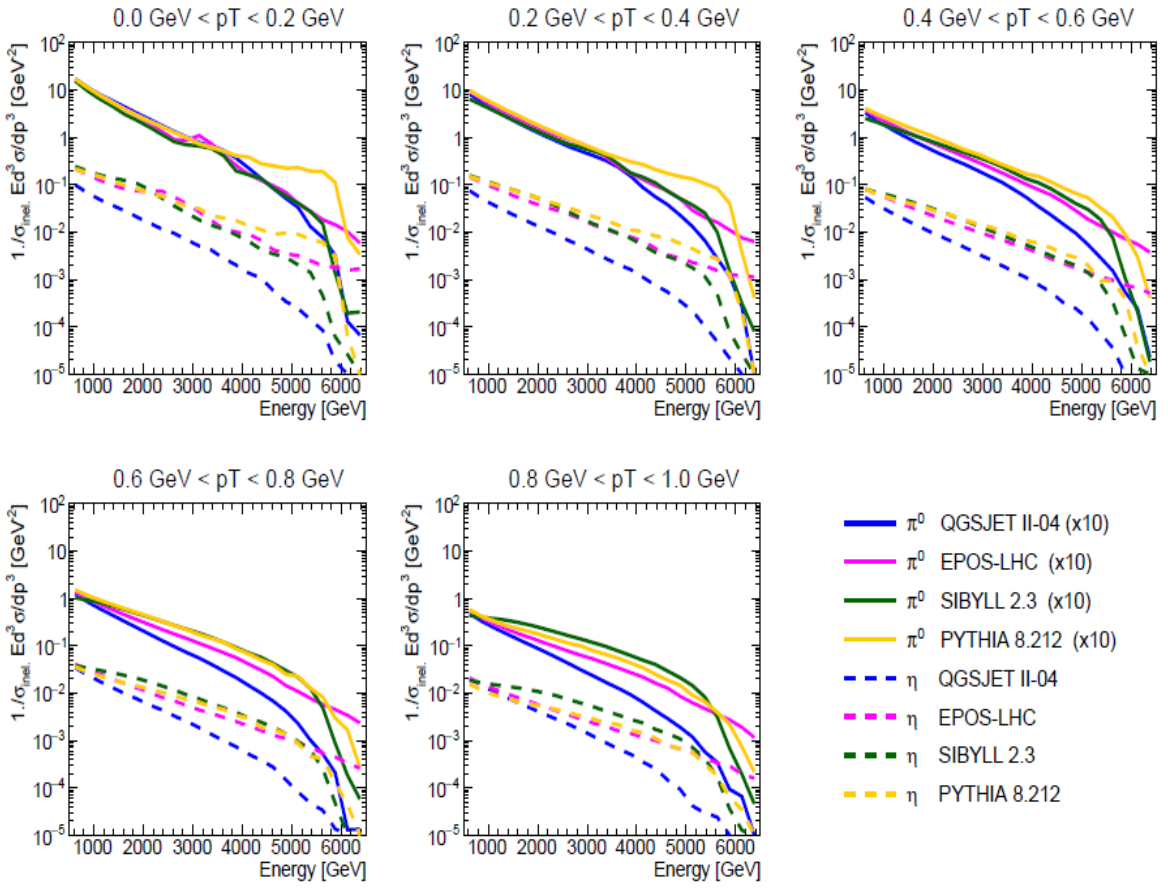


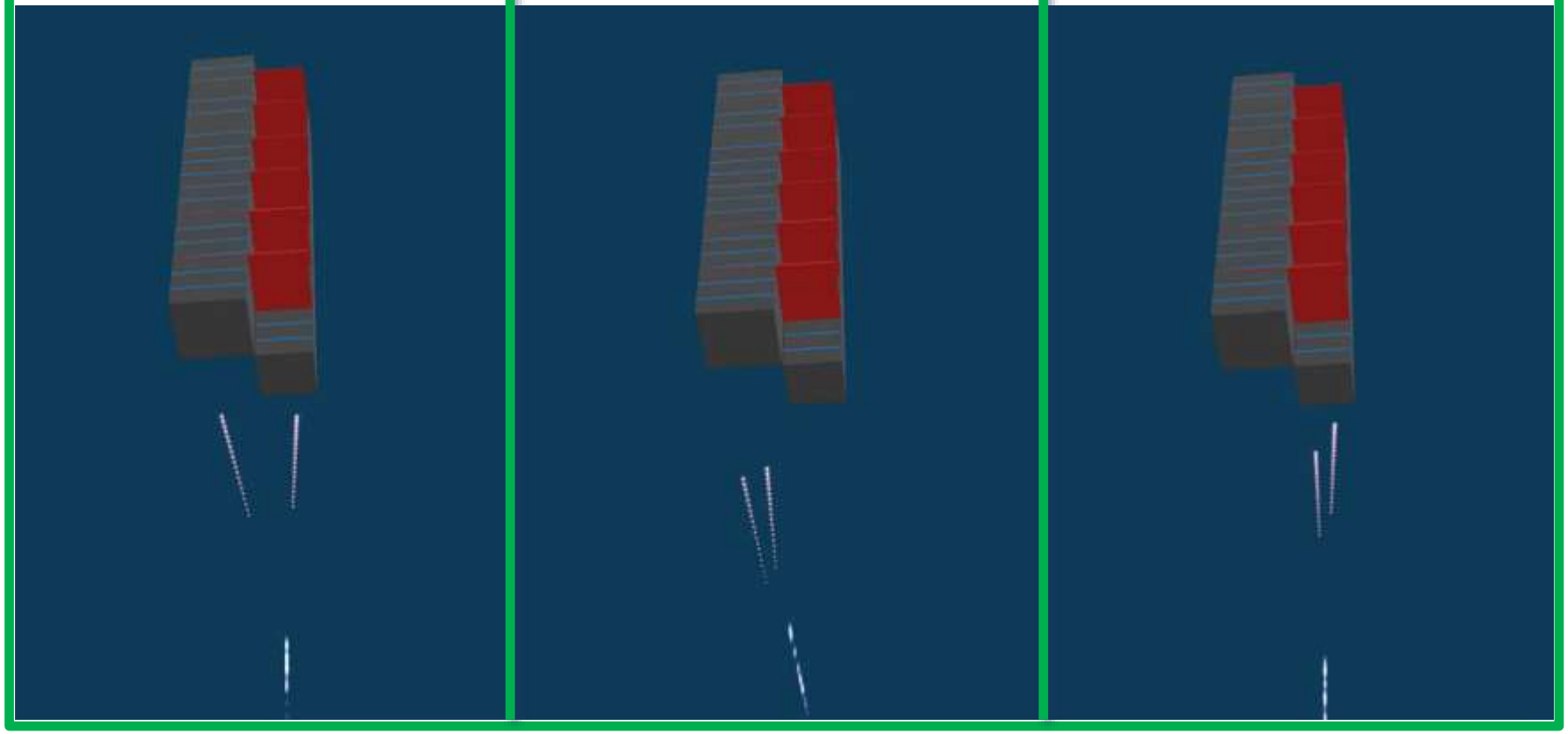
π^0 AND η EVENT RECONSTRUCTION

Scintillator
Tungsten
Silicon

LHCF-ARM2

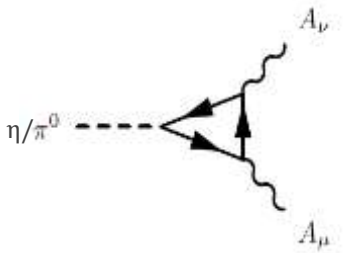
- A double-tower sampling calorimeter.
- **Tungsten** absorbers alternated with 16 **GSO scintillator** layers.
- Tracking system composed of X-Y layers of silicon microstrip detectors.

TYPE I	TYPE II LARGE TOWER	TYPE II SMALL TOWER
One photon for each tower	**Two photons in the large tower**	**Two photons in the small tower**



π^0 AND η DECAY

- Both particles decay mainly into **two photons.**
  $\eta/\pi^0 \rightarrow \gamma\gamma$
- Branching ratio in the case of π^0 is about **98.82%**.
- In the case of η is about **39.36%**.



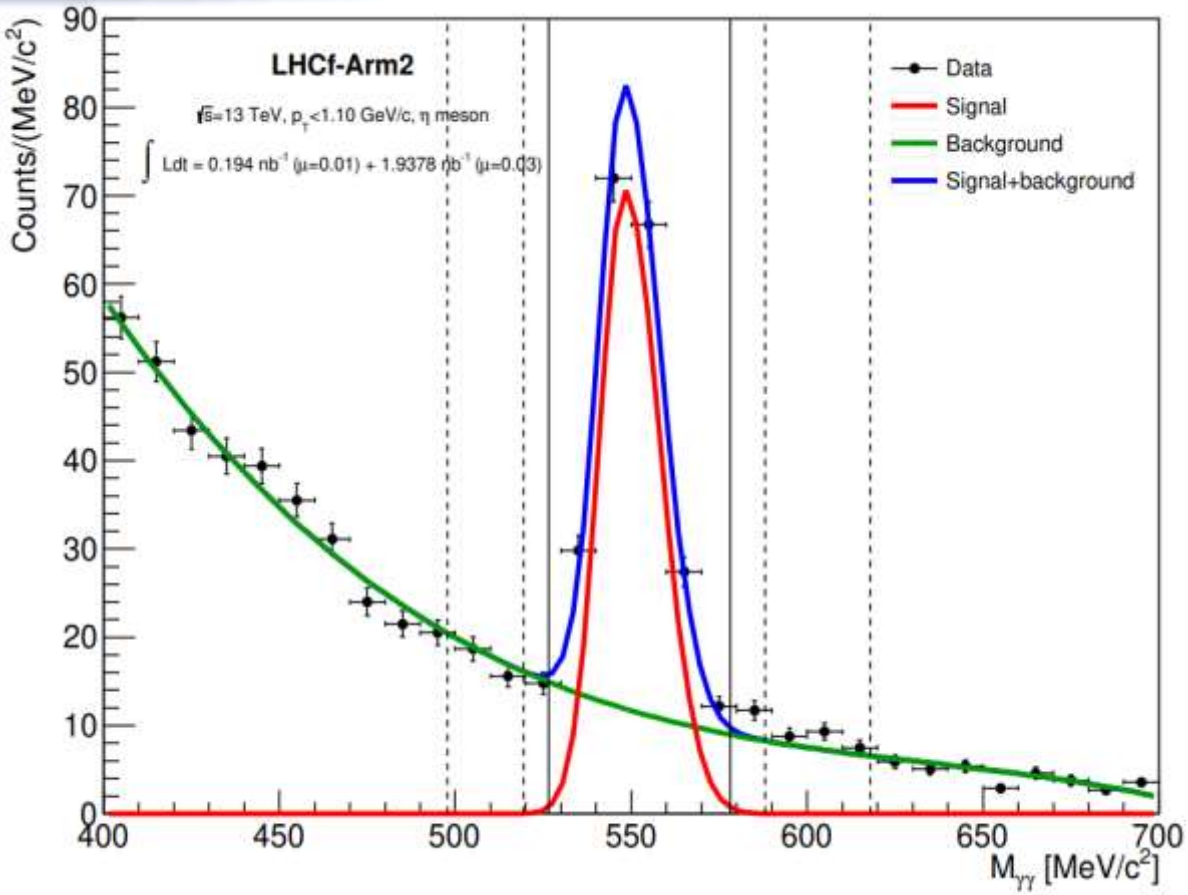
EVENT SELECTION

The event selections of π^0 and η mesons are performed using almost the same criteria:

- **Event Type**: In the case of η mesons only Type I events were considered due to the **low statistics of Type II η** in the analyzed dataset. In the case of π^0 both typologies of events were accounted for.
- **Number of hits:** Events with more background particles in addition to the two photons (**multihit events**) were not considered in the analysis.
- **Energy threshold:** Only photons with energy greater than 200 GeV were selected. This permits to keep the **trigger efficiency** near 100%.
- **Position cut:** In order to avoid unpleasant effects in energy reconstruction due to **lateral leakage**, only events in which photons hit the calorimeter within 2 mm of the edges of the towers were considered.
- **Particle identification:** To discriminate between photons and hadron background **energy-dependent cut functions** on the $L_{90\%}$ variable, defined as the depth within 90% of the energy deposit is contained, were estimated. The cut functions were calculated using MC simulation and imposing **90% selection efficiency for each energy bin**. Two different cut functions were used for π^0 and η, by selecting in each case only photon pairs with an invariant mass similar to the two meson rest masses.

BACKGROUND SUBTRACTION (η MESON)

- The η mesons are reconstructed using the characteristic peak in the **invariant mass** distribution of two photons.
- The events are selected and separated from the background using a **sideband method**.
- **About 1500 η mesons were found with this method.**
- The peak in the original distribution was artificially shifted by increasing the energy of the photons by 2.65%, in order to bring the centroid of the peak around the value of the rest mass of the η mesons (M_η =547.862±0.018 MeV/c^2).



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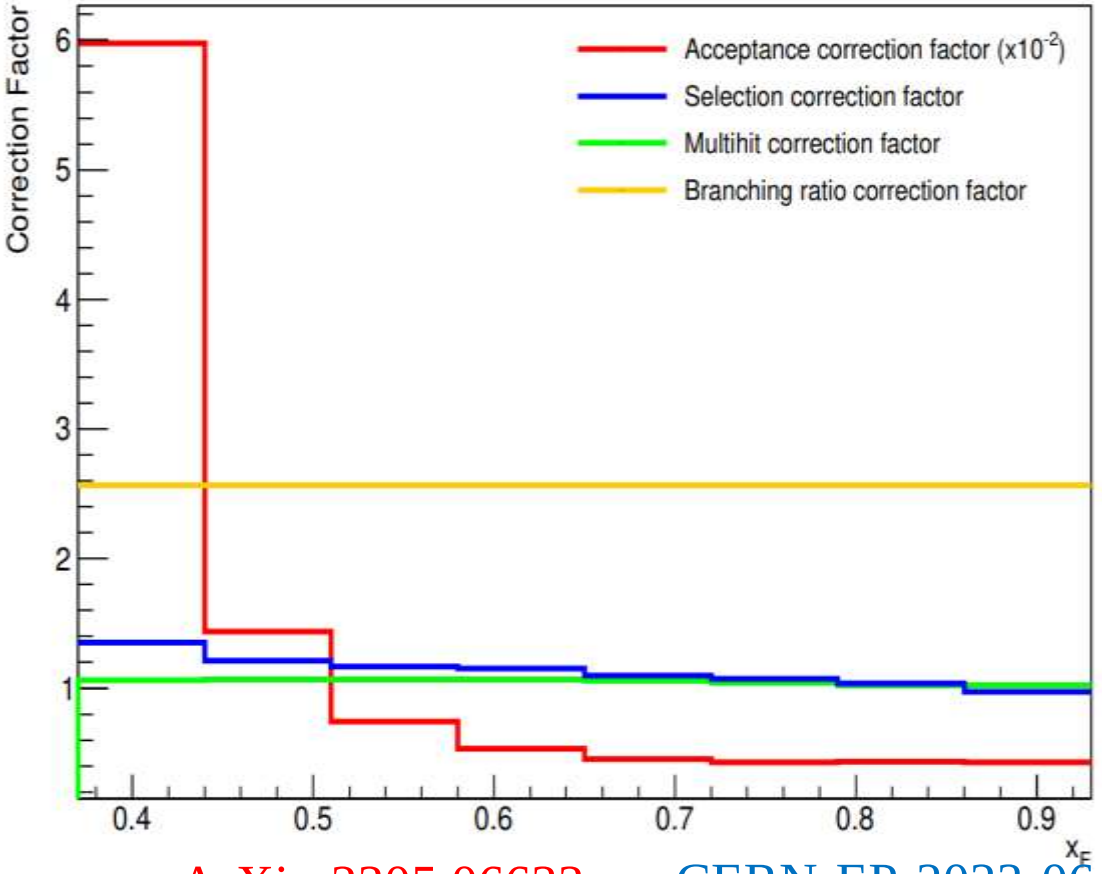
EXPERIMENTAL CORRECTIONS (η MESON)



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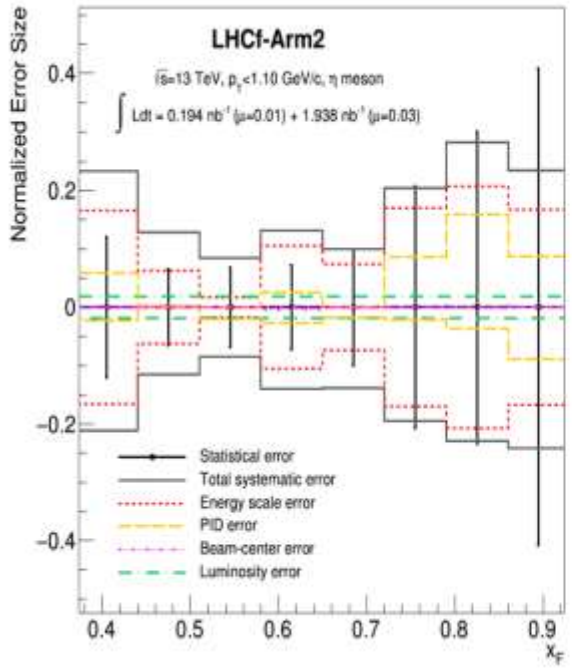
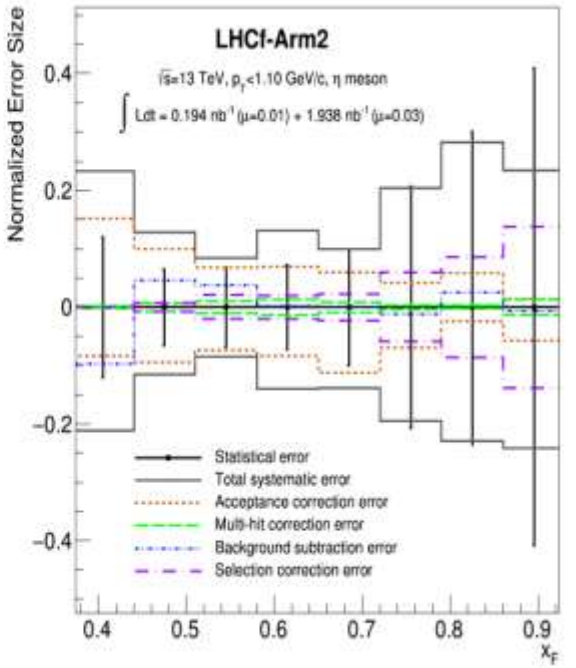
- **Acceptance Correction**: This addresses the signal distribution adjustment for the **limited aperture** of the LHCf-Arm2 detector. It's estimated through a toy MC simulation based on multiple hadronic interaction models.
- **Selection Correction**: This correction is for **selection inefficiency and smearing effects**, using the fully reconstructed simulations of QGSJET II-04 and EPOS-LHC.
- **Multihit Correction**: This correction is for the inefficiencies resulting from **multihit event rejection** at the LHCf-Arm2 detector. It's calculated using QGSJET II-04 and EPOS-LHC simulations.
- **Branching Ratio Correction**: This correction compensates for the inefficiency due to the η **decay branching ratio**. A constant factor is applied to the signal distribution across the whole x_F ($x_F = 2p_z/\sqrt{s}$) range to address this.

SYSTEMATIC UNCERTAINTIES (η MESON)

- **Energy Scale**: Corrections were made for systematic shifts in invariant mass peaks of π^0 and η. Systematic errors were calculated from **scaled photon energies**.
- **Particle Identification (PID)**: Uncertainties were calculated by comparing spectra from **different PID criteria**.
- **Beam-Center Stability**: Systematic error was estimated by **shifting the beam-center position**.
- **Luminosity**: Uncertainty of the integrated luminosity measured by ATLAS is 1.9%.
- **Background Subtraction**: Uncertainty was evaluated using full MC simulations (QGSJETII-04 and EPOS).
- **MC Related Correction**: Systematic errors were calculated to avoid model dependence on corrections for **selection**, **acceptance**, and **multihit**.





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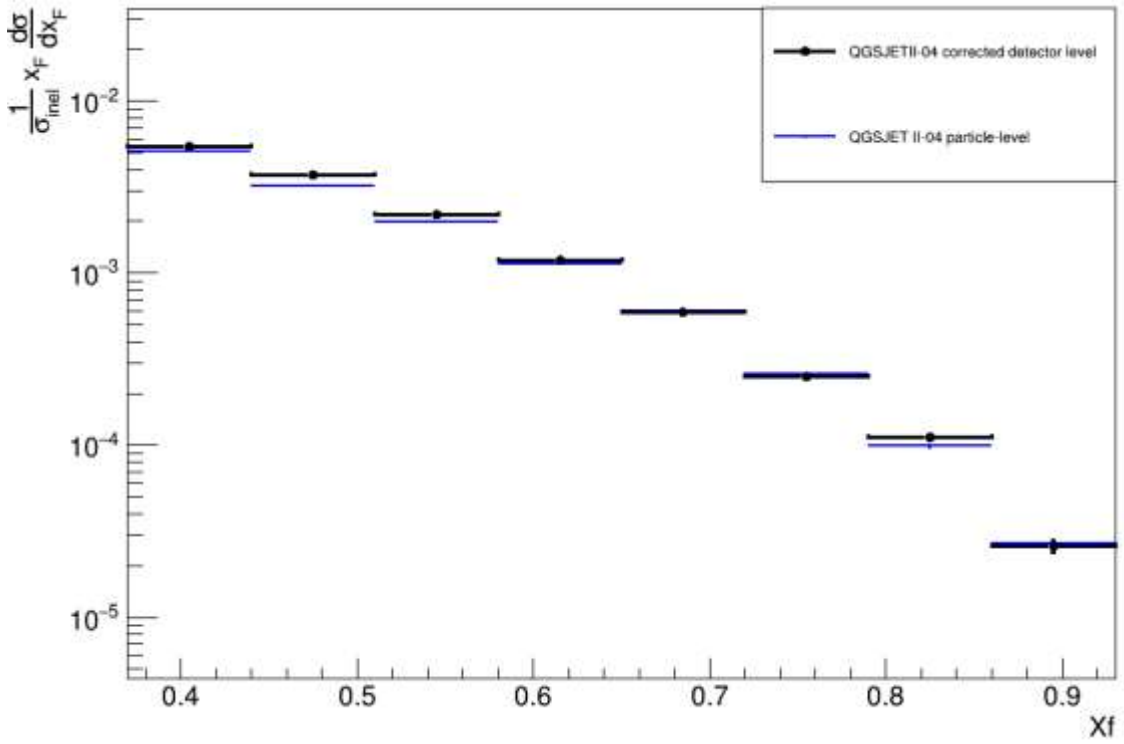
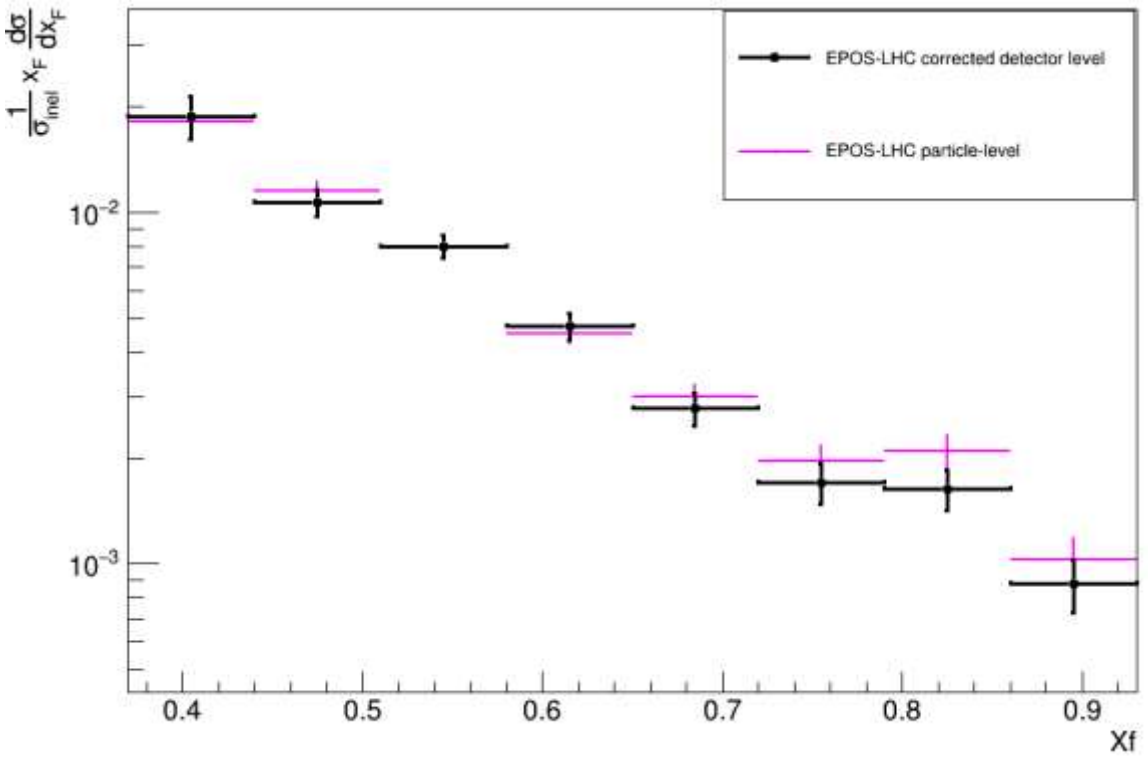
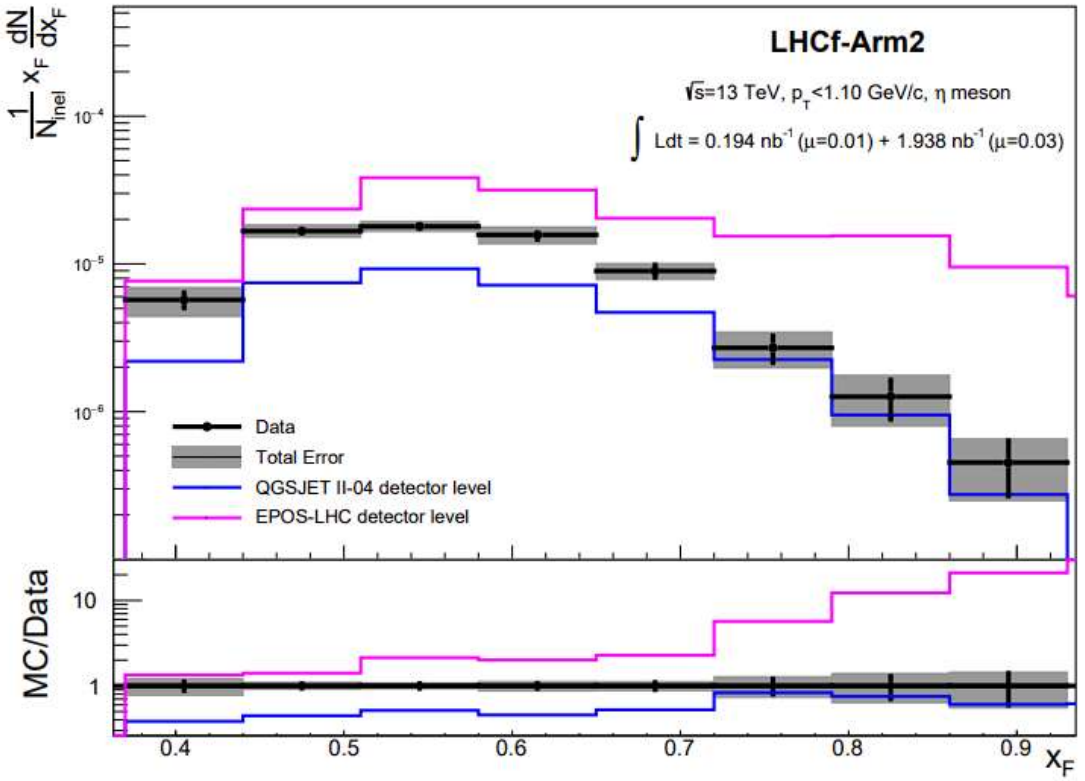
PARTICLE-CORRECTED DETECTOR LEVEL COMPARISON





DETECTOR LEVEL COMPARISON DATA-BASELINE MC



This justifies the use of QGSJET and EPOS for systematic corrections/errors

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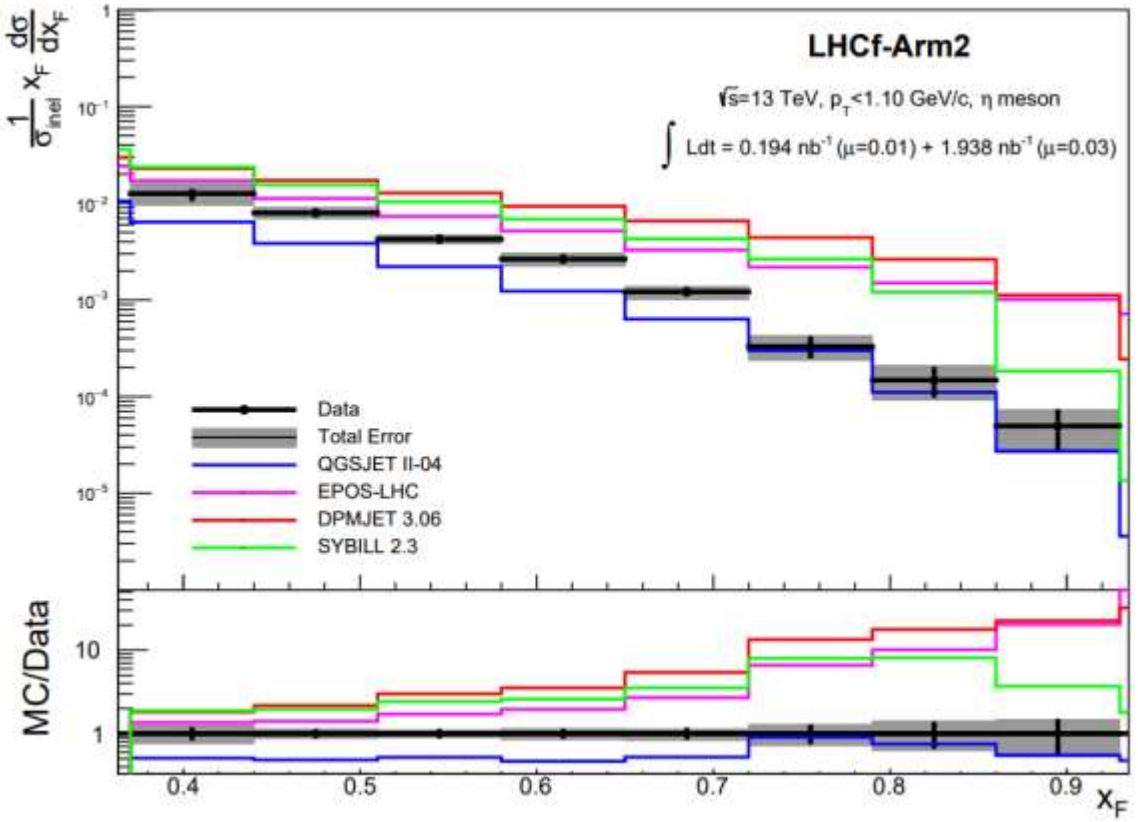
FORWARD η PRODUCTION RATE



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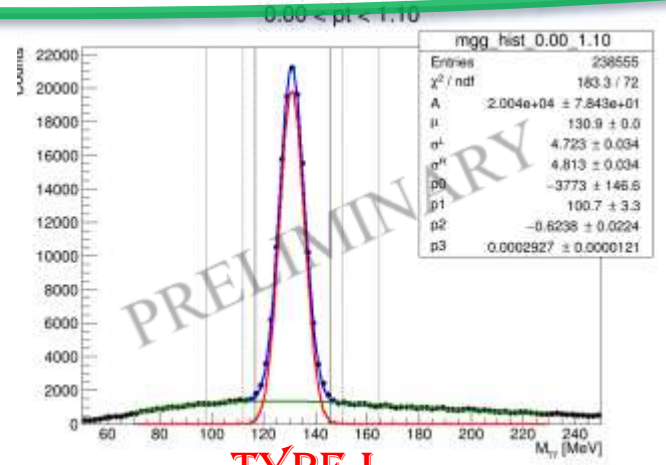
The η meson production rate as a function of x_F, measured with the LHCf-Arm2 detector in p-p collisions at $\sqrt{s}$=13 TeV, was compared with the predictions of four widely used hadronic interaction models:

- QGSJETII-04.
- EPOS-LHC.
- DPMJET 3.06.
- SYBILL 2.3.

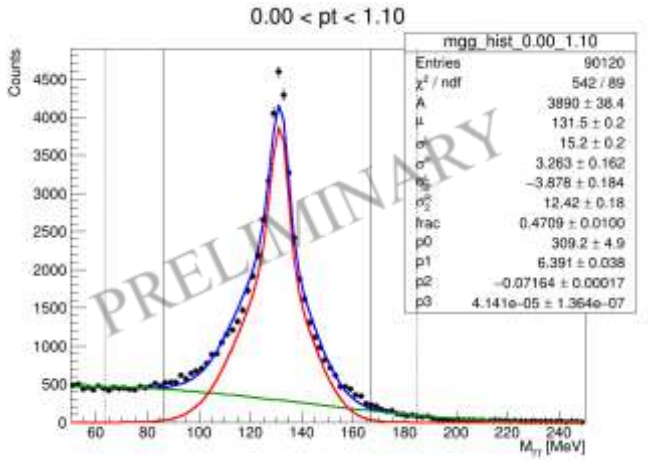
None of the models can correctly reproduce the experimental distribution over the entire x_F range. QGSJETII-04 shows the best agreement, especially at high x_F, but a factor ≈ 2 of differences is visible at low x_F.

FORWARD π^0 INVARIANT MASS

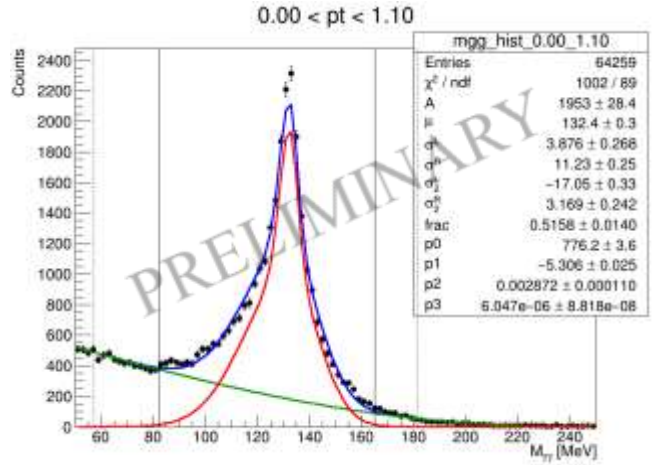
- The inclusive π^0 production rate was calculated using **the same methodology** of η mesons with minor differences.
- The analysis is almost completed, so **final results are still preliminary**.
- The inclusive π^0 production rate is needed to calculate the ratio between η and π^0.
- The analysis of different types of events permits to cover **a larger x_F acceptance region.**



TYPE I



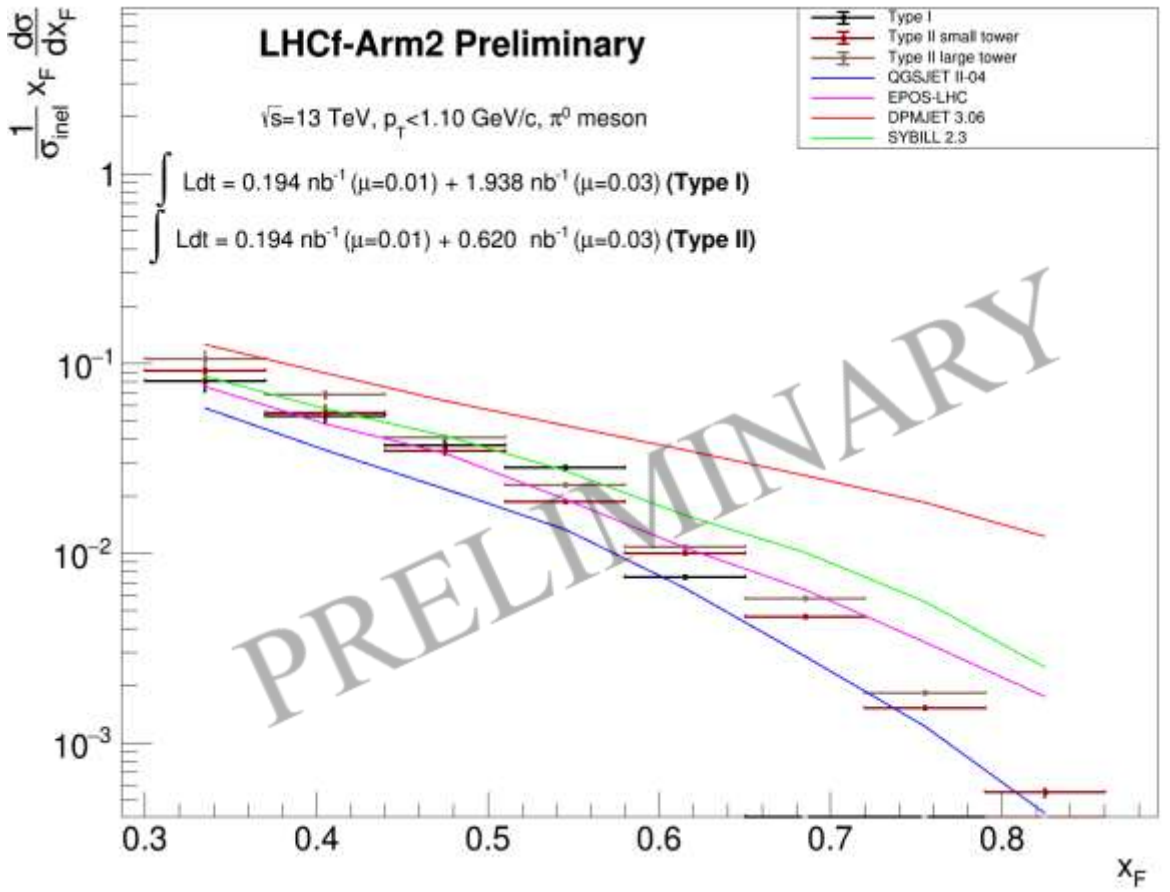
TYPE II SMALL TOWER



TYPE II LARGE TOWER

FORWARD π^0 PRODUCTION RATE

- The inclusive π^0 production rate was calculated using **the same methodology** of η mesons with minor differences.
- The analysis is almost completed, so **final results are still preliminary**.
- The inclusive π^0 production rate is needed to calculate the ratio between η and π^0.
- The analysis of different types of events permits to cover **a larger x_F acceptance region.**
- **Preliminary results indicate that none of the models is able to reproduce the shape of the experimental distribution in the whole x_F range.**



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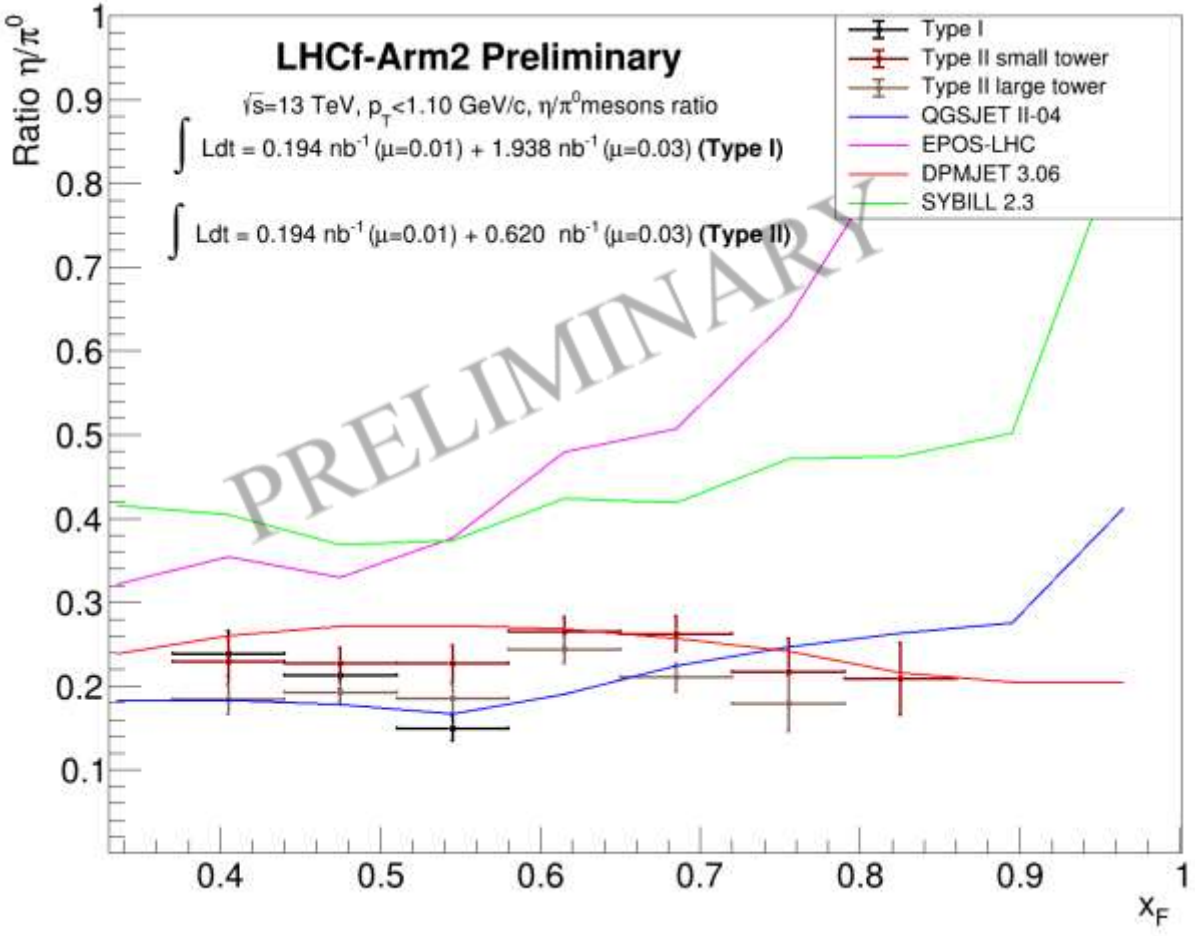
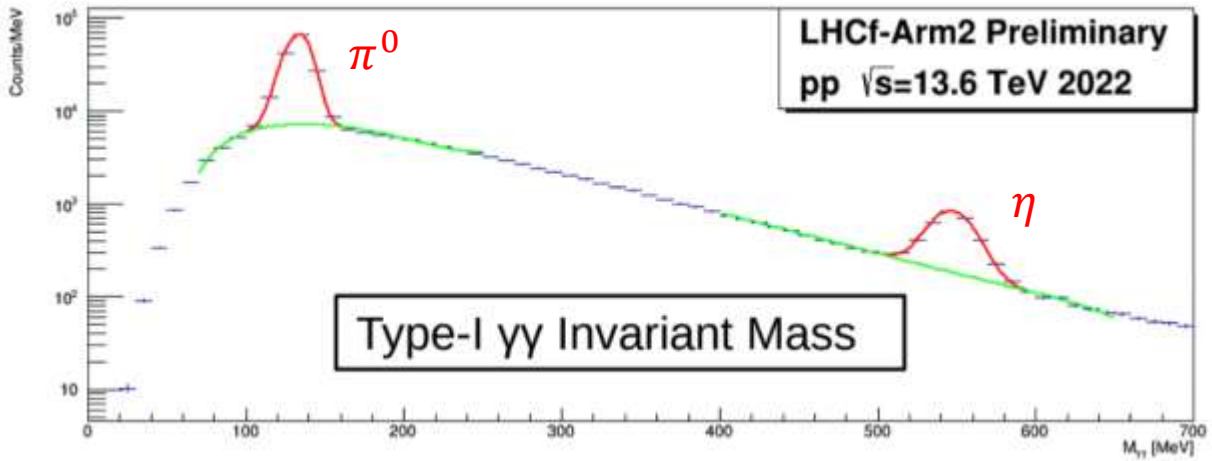
FORWARD η/π^0 PRODUCTION RATIO

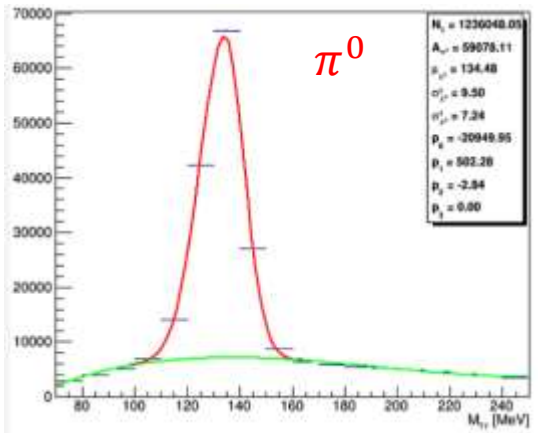


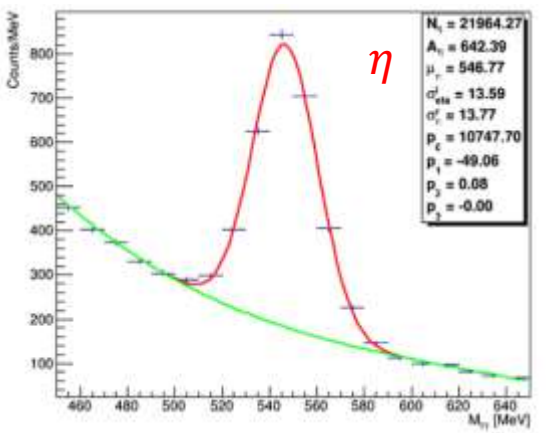
- **The forward η/π^0 production ratio** in p-p collision has been measured by the LHCf experiment.
- **For the first time this measurement is carried out in the forward region of high-energy collisions.**
- The importance of this observation relies on the fact that π^0 and η are **the two main sources of the electromagnetic component of Extended Air Showers** (EASs) so their production and ratio are critical for modelling the EAS development.
- The preliminary results indicate that only **QGSJETII-04** and **DPMJET 3.06** are able to reproduce the shape of the experimental distribution.

FUTURE ANALYSES OF η AND η/π^0 RATIO

- **Previous data taking of LHCf in p-p collisions at 13.6 TeV increased the statistic by about a factor of 10!**
- The results seen in this presentation **can be improved**, and new analyses of interest **are now possible.**
- **The main novelty will be the possibility of extracting η meson and η/π^0 ratio spectra in more $x_F - p_T$bins.**
- It may be possible to carry out these studies by combining with ATLAS data to extract spectra in more central multiplicity bins (2-3 are sufficient).







THANK YOU FOR THE ATTENTION!!

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