FSP ALICE
Erforschung von Universum und Materie

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

Multiplicity dependent and inside-jet measurement of light neutral mesons in pp collisions with ALICE

Stephan Friedrich Stiefelmaier for the ALICE collaboration
Ruprecht-Karls-Universität Heidelberg

ALICE

42nd ICHEP

Prague, July 17-24, 2024

Motivation

Particle production at LHC energies

- **Initial state**:
  - Invariant cross section of identified particles
  - **Multiplicity dependence** of particle p_{T} spectra
- **Fragmentation (parton $\rightarrow$ hadrons)**
  - Particle ratios (η/π^0, ω/π^0, ...)

  $\rightarrow$ Universality of fragmentation function (FF)?
  - **Inside-jet meson** production:

  $\rightarrow$ Direct access to FF
- **Collectivity in small systems**
  - Particle p_{T} spectra in **high-multiplicity** events

Motivation

Neutral meson measurement with ALICE

- Measurable over large p_{T} range

$\rightarrow$ **Precise probe to study particle production** mechanisms (PDF, FF)

- Crucial input for direct photon and dielectron cocktail

Motivation

Neutral meson measurement with ALICE

- Measurable over large p_{T} range

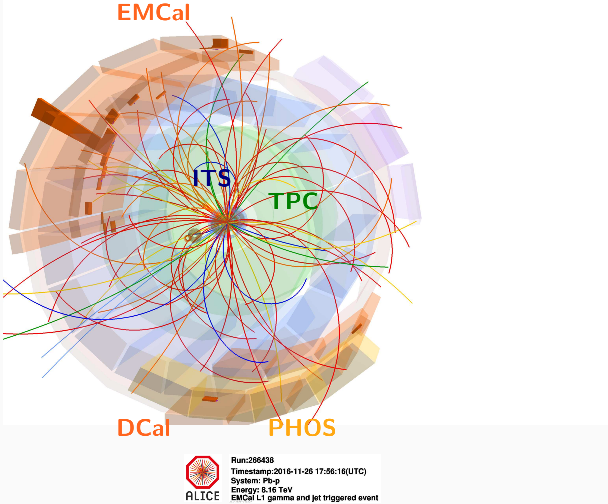
$\rightarrow$ **Precise probe to study particle production** mechanisms (PDF, FF)

- Crucial input for direct photon and dielectron cocktail

In this talk:

- **Inclusive neutral meson cross sections**
- **Multiplicity dependence**
- **In-jet meson production**

Photons and mesons with ALICE in Run 2

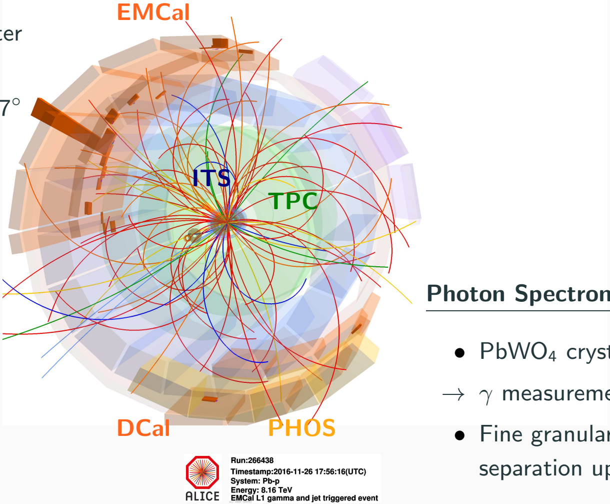


Photons and mesons with ALICE in Run 2

Electromagnetic calorimeter (EMC = EMCal + DCal)

- Lead-scintillator calorimeter
- Large acceptance
  $|\eta| < 0.7, \Delta\phi \approx 107^\circ + 67^\circ$

$\rightarrow$ Photon and neutral jet measurement



Photon Spectrometer (PHOS)

- $PbWO_4$ crystals

$\rightarrow$ γ measurement

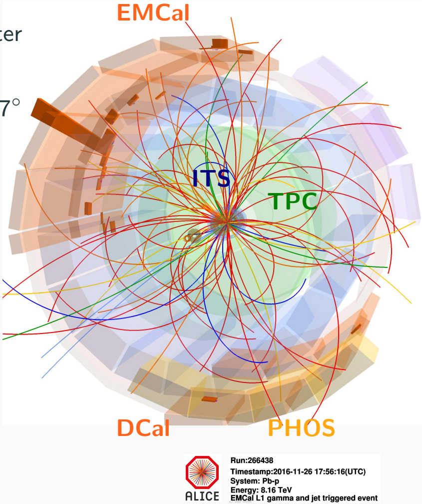
- Fine granularity: π^0 decay γ shower separation up to $p_\mathrm{T} = 50$ GeV/c

Photons and mesons with ALICE in Run 2

Electromagnetic calorimeter (EMC = EMCal + DCal)

- Lead-scintillator calorimeter
- Large acceptance
  $|\eta| < 0.7, \Delta\phi \approx 107^\circ + 67^\circ$

→ Photon and neutral jet measurement



Photon Conversion Method (PCM)

- Utilizing γ conversion probability of $\approx 8\%$

→ Reconstruct γ via $e^{\pm}$ V0-tracks from ITS + TPC

- Excellent energy resolution at low p_{T}: $\sigma(E_\gamma)/E_\gamma \approx 1.5\%$

Photon Spectrometer (PHOS)

- $PbWO_4$ crystals

→ γ measurement

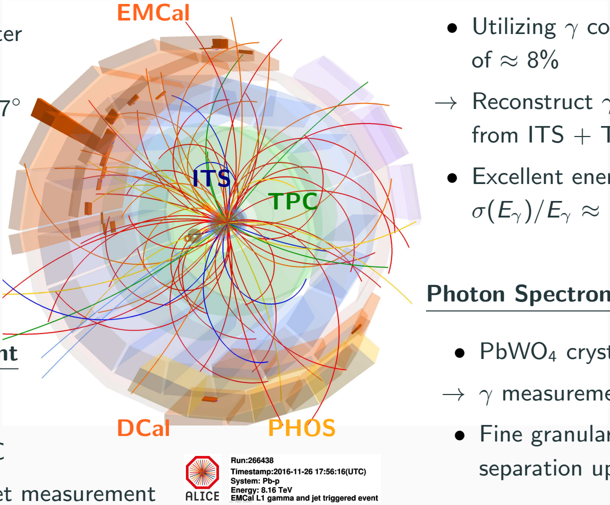
- Fine granularity: π^0 decay γ shower separation up to $p_{\mathrm{T}} = 50$ GeV/c

Photons and mesons with ALICE in Run 2

Electromagnetic calorimeter (EMC = EMCal + DCal)

- Lead-scintillator calorimeter
- Large acceptance $|\eta| < 0.7, \Delta\phi \approx 107^\circ + 67^\circ$

→ Photon and neutral jet measurement



Charged-particle measurement

- ITS+TPC
- PID via dE/dx from TPC
- Rec. tracks for charged jet measurement

Photon Conversion Method (PCM)

- Utilizing γ conversion probability of $\approx 8\%$

→ Reconstruct γ via $e^{\pm}$ V0-tracks from ITS + TPC

- Excellent energy resolution at low p_{T}: $\sigma(E_\gamma)/E_\gamma \approx 1.5\%$

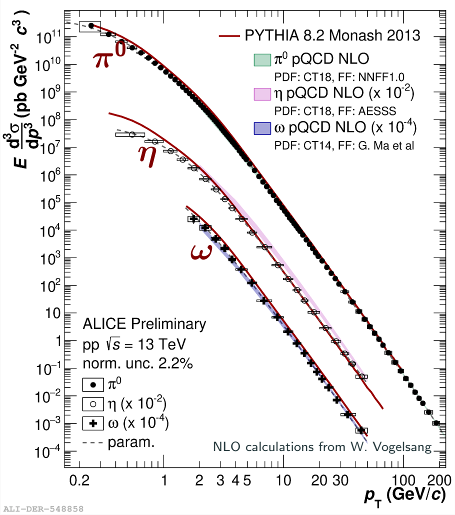
Photon Spectrometer (PHOS)

- $PbWO_4$ crystals

→ γ measurement

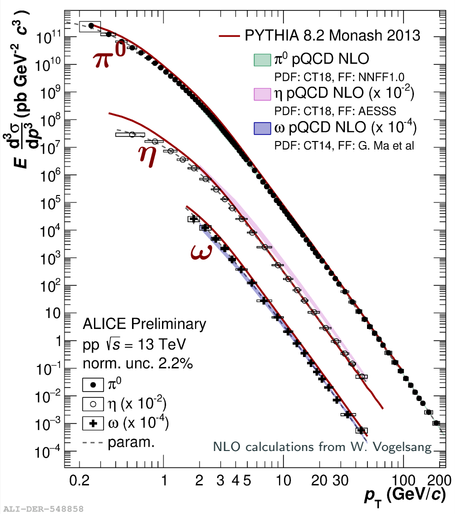
- Fine granularity: π^0 decay γ shower separation up to $p_{\mathrm{T}} = 50$ GeV/c

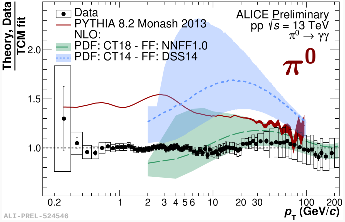
π^0, η and ω in pp at $\sqrt{s} = 13$ TeV

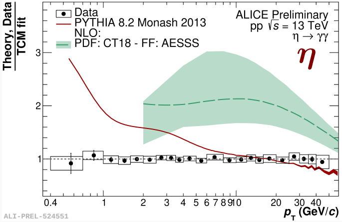


- Combination of various reconstruction methods
- $B = 0.2$ T data used to extract π^0 down to $p_{\mathrm{T}} = 0.2$ GeV/c
- Inv. cross section in pp at $\sqrt{s} = 13$ TeV
  - **π^0: $0.2 < p_{\mathrm{T}} < 200$ GeV/c**
  - **η: $0.4 < p_{\mathrm{T}} < 50$ GeV/c**
  - **ω: $1.5 < p_{\mathrm{T}} < 50$ GeV/c**
- NLO with **NNFF1.0 FF describes π^0 spectrum**
- PYTHIA8 overestimates and does not describe spectral shape

π^0, η and ω in pp at $\sqrt{s} = 13$ TeV

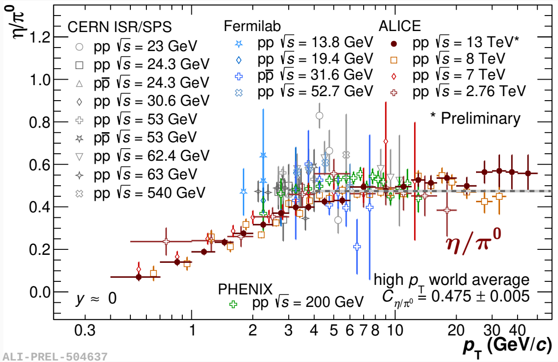


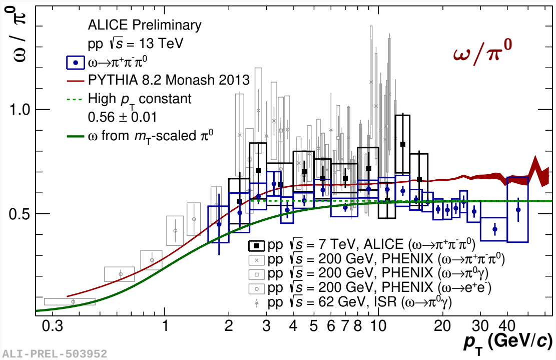




- Combination of various reconstruction methods
- $B = 0.2$ T data used to extract π^0 down to $p_{\mathrm{T}} = 0.2$ GeV/c
- Inv. cross section in pp at $\sqrt{s} = 13$ TeV
  - **π^0: $0.2 < p_{\mathrm{T}} < 200$ GeV/c**
  - **η: $0.4 < p_{\mathrm{T}} < 50$ GeV/c**
  - **ω: $1.5 < p_{\mathrm{T}} < 50$ GeV/c**
- NLO with **NNFF1.0 FF describes π^0 spectrum**
- PYTHIA8 overestimates and does not describe spectral shape

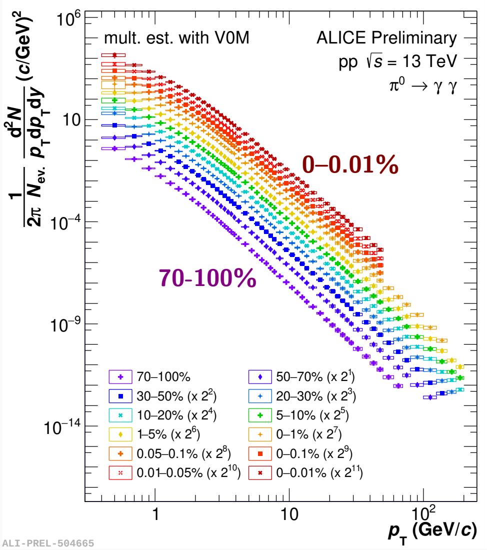
Particle ratios





- Measurements in pp at $\sqrt{s} = 13$ TeV reach **up to $p_T = 50$ GeV/c**
- η/π^0: **No significant dependence on collision energy**
- ω/π^0: Hint of collision energy dependence

Multiplicity dependence — π^0 spectra



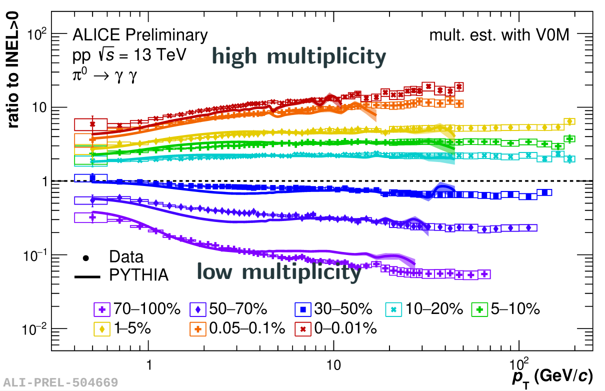
- Highest multiplicities (0–0.01%): $\approx 5.3 \times \langle dN_{ch}/d\eta \rangle_{\mathrm{inel}}$
- π^0 spectra from $p_T = 0.4$ up to 50–200 GeV/c

$\rightarrow$ **Hardening of p_T spectra with rising multiplicity**

Multiplicity dependence — π^0 spectra: ratio to inclusive

- Ratio of π^0 spectra in mult. intervals to inclusive

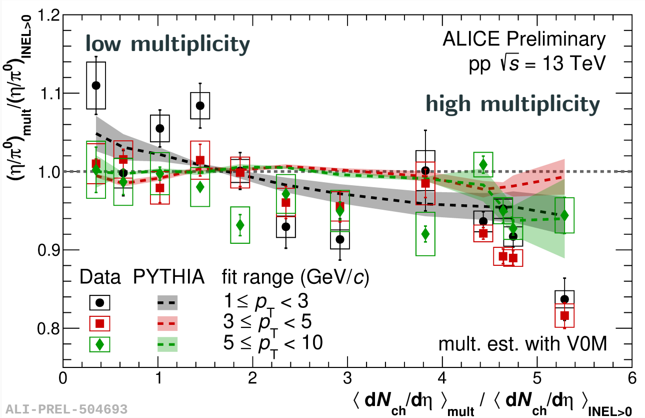
→ **Hardening of p_T spectra with rising multiplicity**



Comparison to PYTHIA

- General ordering and magnitude described by PYTHIA
- Slightly different p_T dependence

Multiplicity dependence of η/π^0



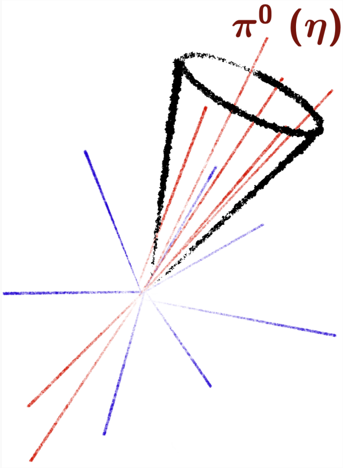
- η/π^0 extracted for all multiplicity intervals
- Hint at multiplicity ordering visible
- **Slight suppression at low p_T** at high multiplicities

→ Larger fraction of π^0 feed-down from heavier particles (η, ω, $\rho^{\pm}$)

→ Described qualitatively by PYTHIA

Neutral mesons inside jets

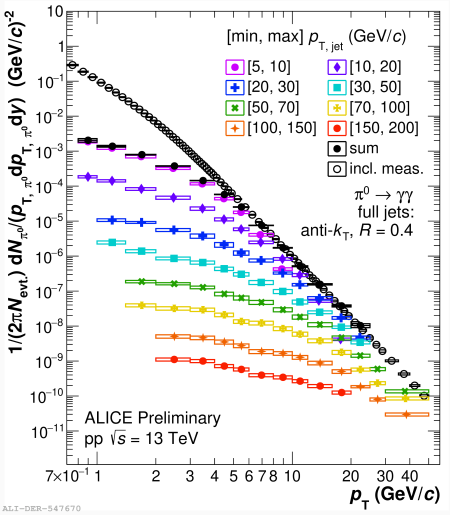
$$E\frac{d^3\sigma^H}{d\vec{p}} = \sum_{a,b,c} \mathrm{PDF}_a \otimes \mathrm{PDF}_b \otimes d\sigma_{ab\to cX} \otimes \mathbf{FF}_c^H(z_c, Q)$$



<u>Observables</u>

- **Full jet** momentum $\to Q$
- Correlation of meson inside jet cone with jet momentum $\to z = \frac{\vec{p}_{\pi^0}\cdot\vec{p}_{jet}}{|\vec{p}_{jet}|^2}$
- Reconstruction of mesons inside jet cone ($R = 0.4$)

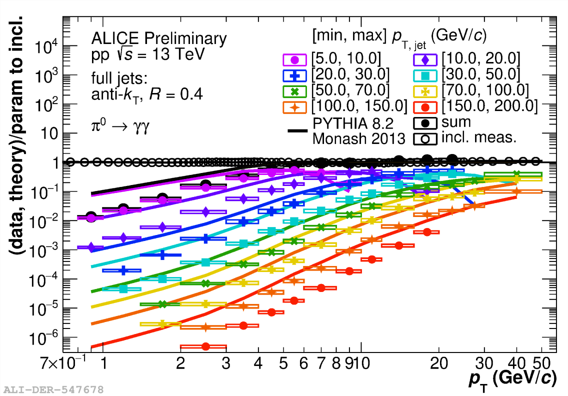
π^0 mesons inside jets



- Reconstruction of mesons inside jet cone ($R = 0.4$)
- Decomposition of π^0 spectra into single $p_{T,\ jet}$ bins

→ **Clear ordering and hardening of meson p_T-spectra with rising $p_{T,\ jet}$**

π^0 mesons inside jets - ratio to incl. param.

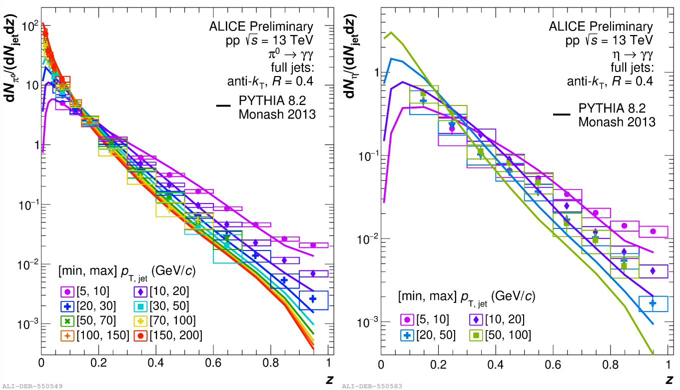


Comparison to PYTHIA

- General ordering and magnitude described
- Contribution to inclusive spectrum peaks at lower p_T

→ **Hint for softer fragmentation in PYTHIA**

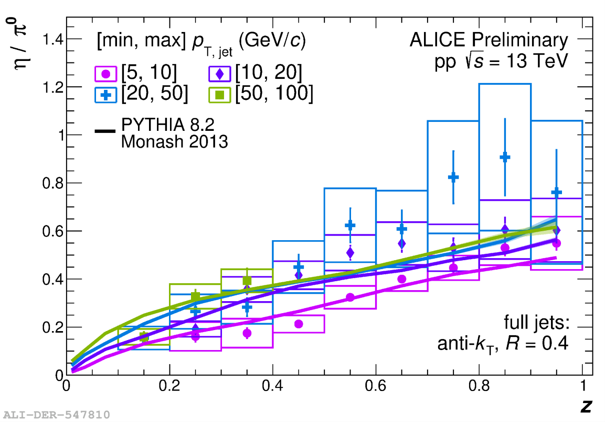
π^0 and η mesons inside jets — Fragmentation



- **First measurement of π^0 and η fragmentation functions at LHC energies**
- For $p_{T,\,jet} > 20$ GeV/c:
  Only small dependence on $p_{T,\,jet}$

π^0 and η mesons inside jets — Fragmentation

$$z = \frac{\vec{p}_{\pi^0} \cdot \vec{p}_{jet}}{|\vec{p}_{jet}|^2}$$



Comparison to PYTHIA

- General ordering and magnitude described, shape slightly different

→ Softer fragmentation predicted by PYTHIA

- $p_{T,\,jet}$ dependence of η/π^0 described

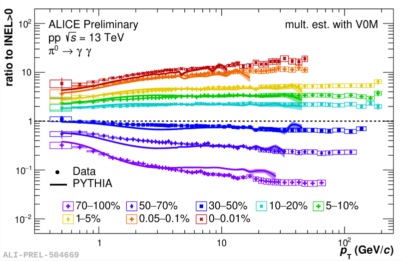
- $\boldsymbol{\eta/\pi^0}$ **ratio similar for** $\boldsymbol{p_{T,\,jet} > 10}$ **GeV/*c*** as function of z

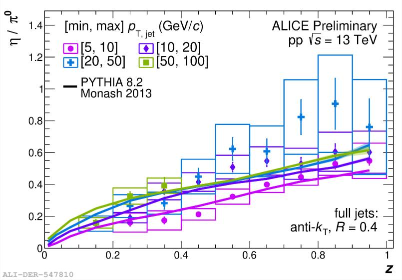
Summary

- **π^0, η and ω mesons in pp at $\sqrt{s} = 13$ TeV**
  - p_T spectra measured over wide p_T range with small uncertainties
  - Hint of collision energy dependence of ω/π^0
- **Multiplicity dependence of π^0 and η production**
  - Precise spectra up to high multiplicities (0–0.01%)
  - Slight multiplicity dependence of η/π^0

  $\rightarrow$ Driven by feed-down into π^0
- **π^0 and η production inside jets**
  - Clear dependence of η/π^0 on $p_{T,\,jet}$

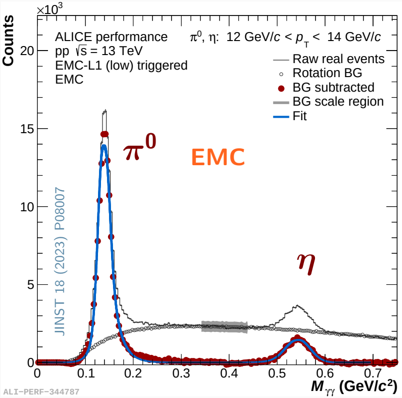
  $\rightarrow$ Driven by feed-down into π^0
  - **First measurement of fragmentation functions**

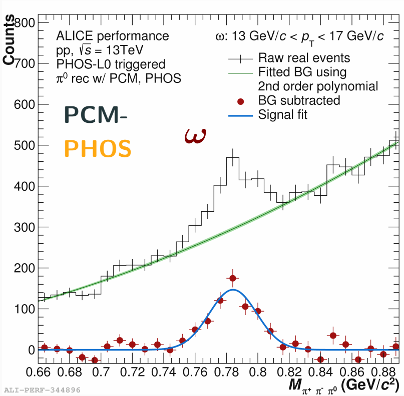




BACKUP

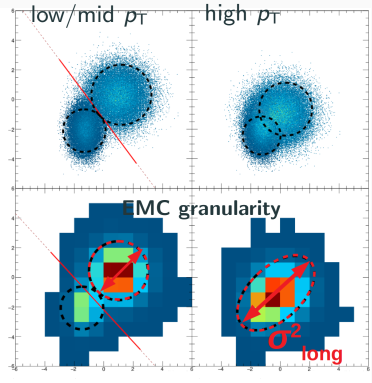
Raw signal extraction — Inv. mass based

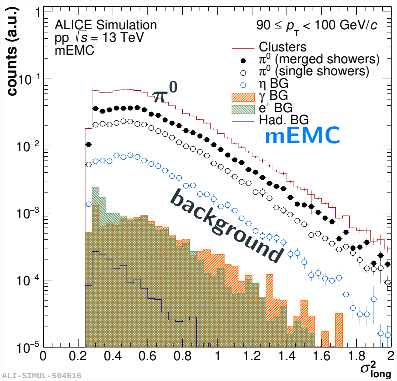




- Reconstructing signal by **combining measured decay particles**
- Background subtraction + integration around mass position
  $\rightarrow$ Raw yield

Raw signal extraction — Purity-based



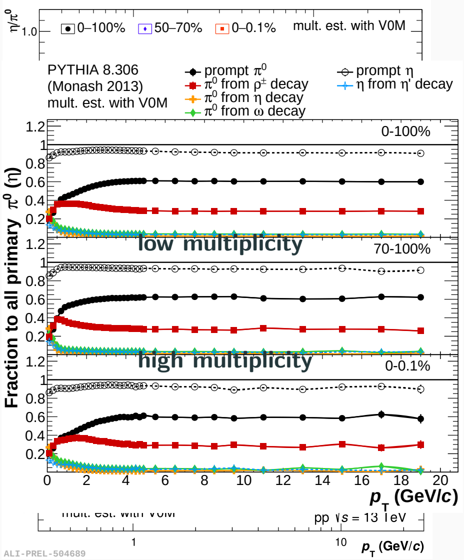


- Using EMCal clusters containing both π^0 decay photons

→ Differentiate between merged π^0 and single γ clusters via long axis of shower ellipse (σ^2_{long})

→ **High π^0 purity (> 70%)**

Multiplicity dependence of η/π^0



- η/π^0 extracted for all multiplicity intervals
- Hint at multiplicity ordering visible
- **Slight suppression at low p_T** at high multiplicities

→ Larger fraction of π^0 feed-down from heavier particles (η, ω, $\rho^{\pm}$)

→ Described qualitatively by PYTHIA