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QCD Challenges from pp to AA

Energy and multiplicity dependence of charged particle production in pp collisions with ALICE at the LHC

Sergio Iga
On behalf of the ALICE collaboration

November 2[th], 2017

Presentation of the analysis and technical details

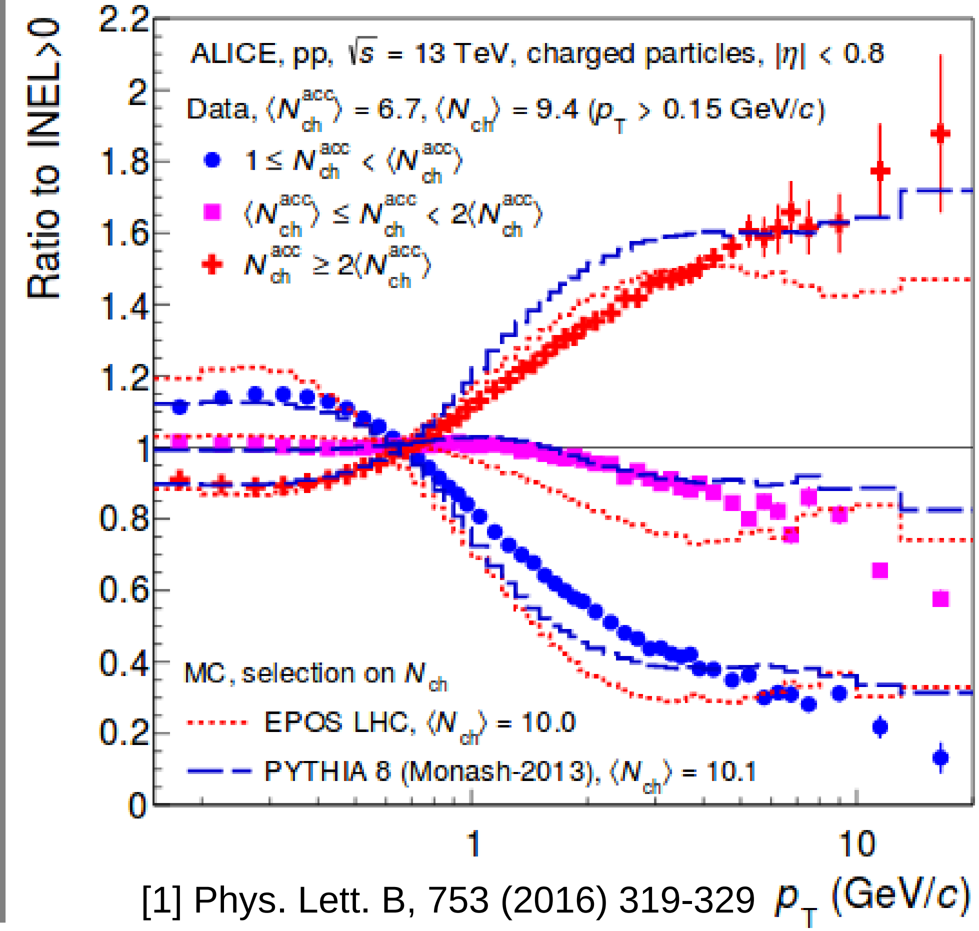
Introduction

- First results on charged hadrons production vs. multiplicity in pp 13 TeV have been presented in [1]

- Now, using **two multiplicity estimators** (in central and forward pseudorapidity) and **adding another energy,** 5.02 TeV, we are able to explore in more detail

- **Ten multiplicity bins** were included **for each estimator**

- Multiplicity dependence analysis helps to **constrain models**



[1] Phys. Lett. B, 753 (2016) 319-329

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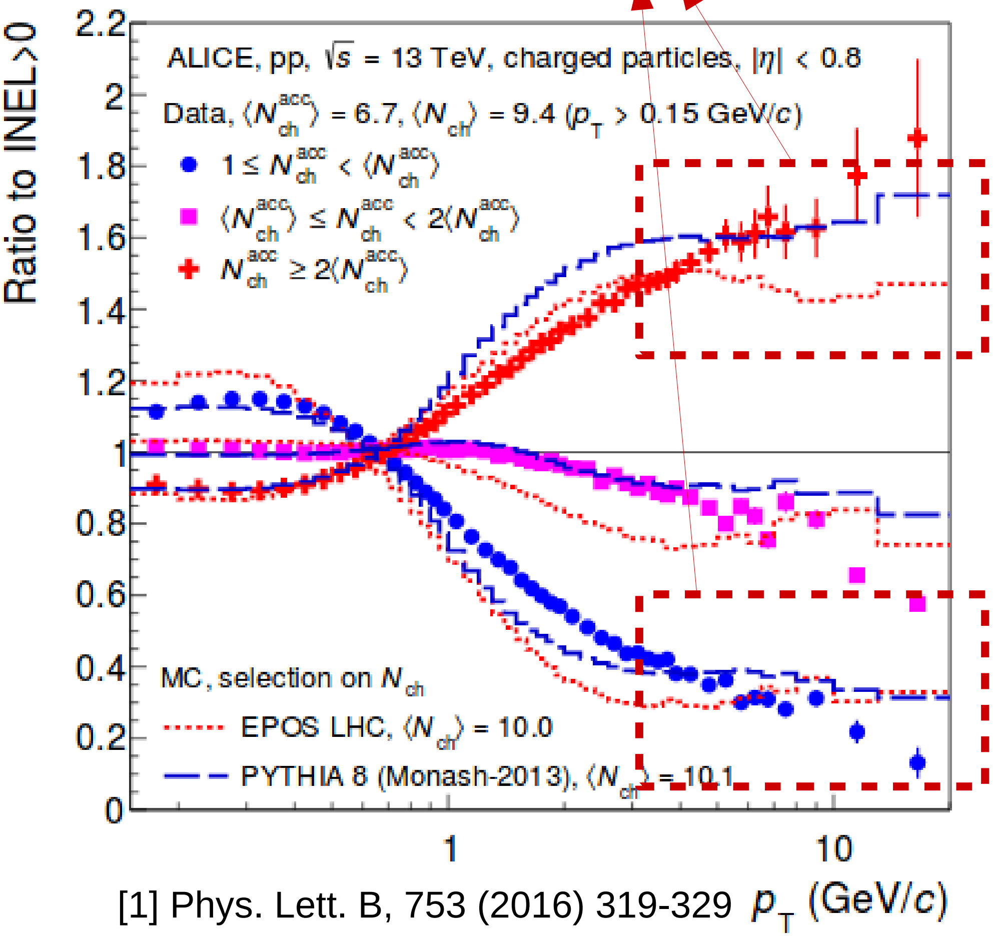
Substantial differences at **high p_T** between EPOS-LHC and Pythia 8



[1] Phys. Lett. B, 753 (2016) 319-329

Try to **factorize the energy and multiplicity dependence**

ALICE

The ALICE apparatus

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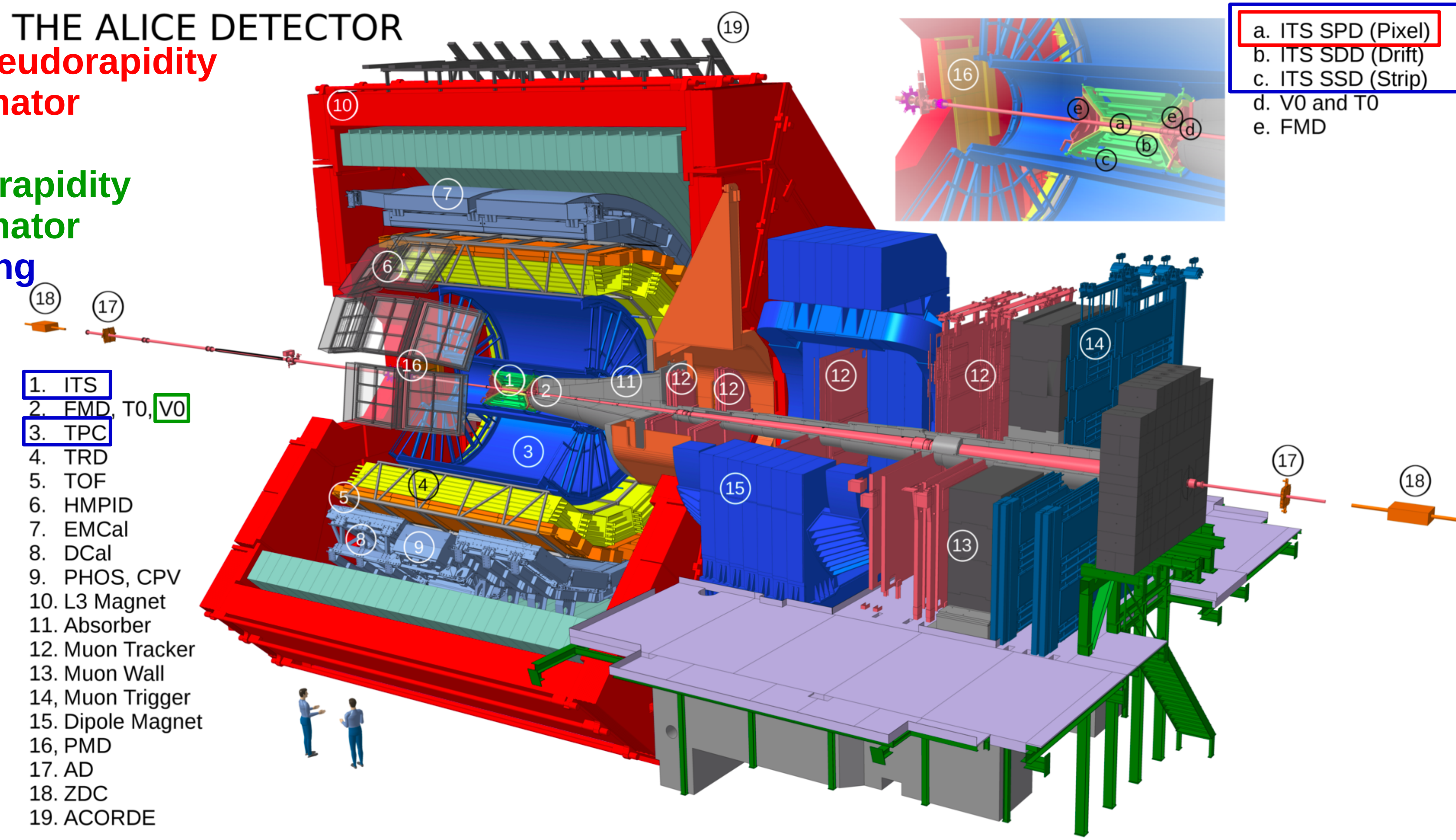
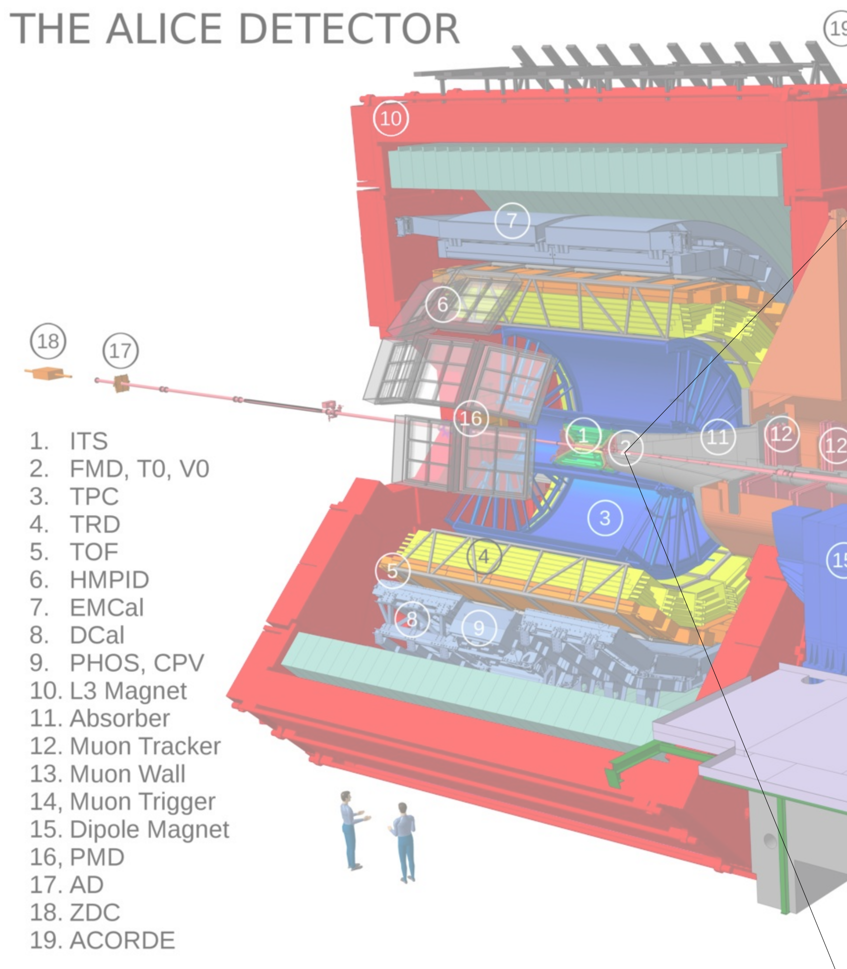
ITS-SPD: Mid-pseudorapidity multiplicity estimator

V0: Trigger and Forward-pseudorapidity multiplicity estimator

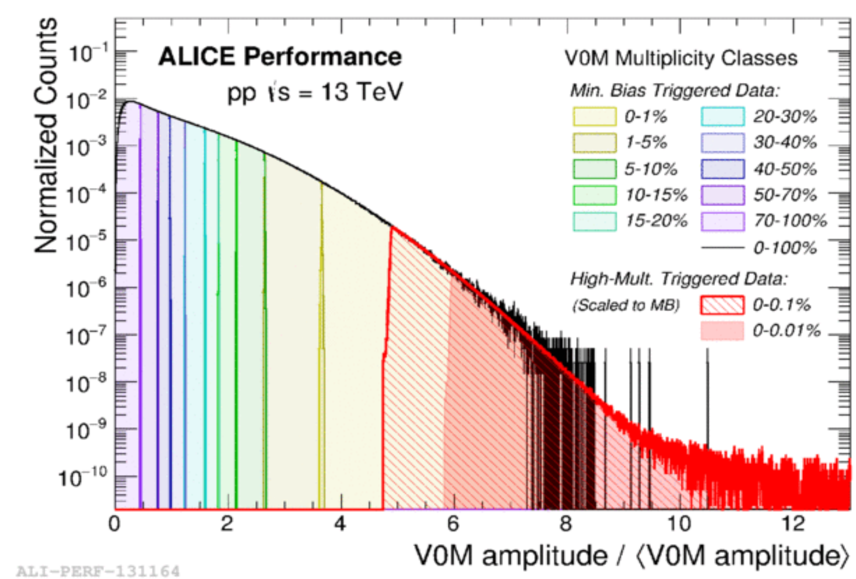
ITS+TPC: Tracking



Multiplicity estimators



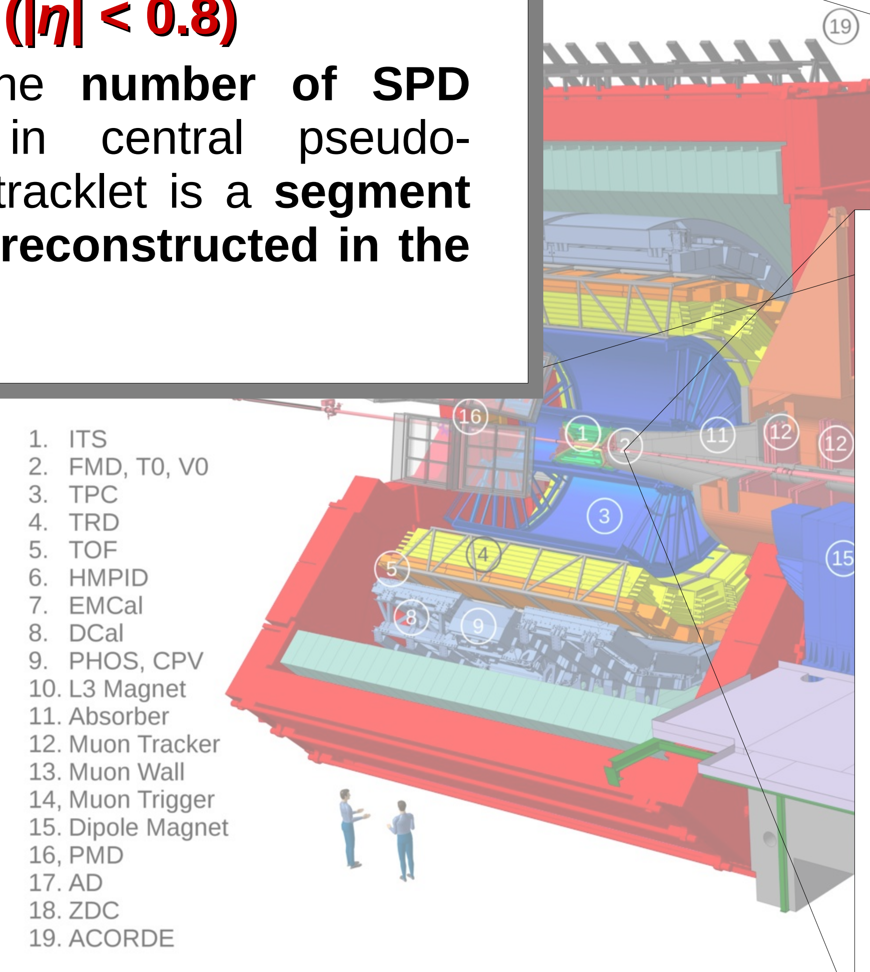
V0M multiplicity estimator
(2.8 < η < 5.1 and -1.7 < η < -3.7)



Multiplicity estimators

Mid-pseudorapidity estimator ($|\eta| < 0.8$)

We use the **number of SPD tracklets** in central pseudo-rapidity. A tracklet is a **segment of a track reconstructed in the SPD**



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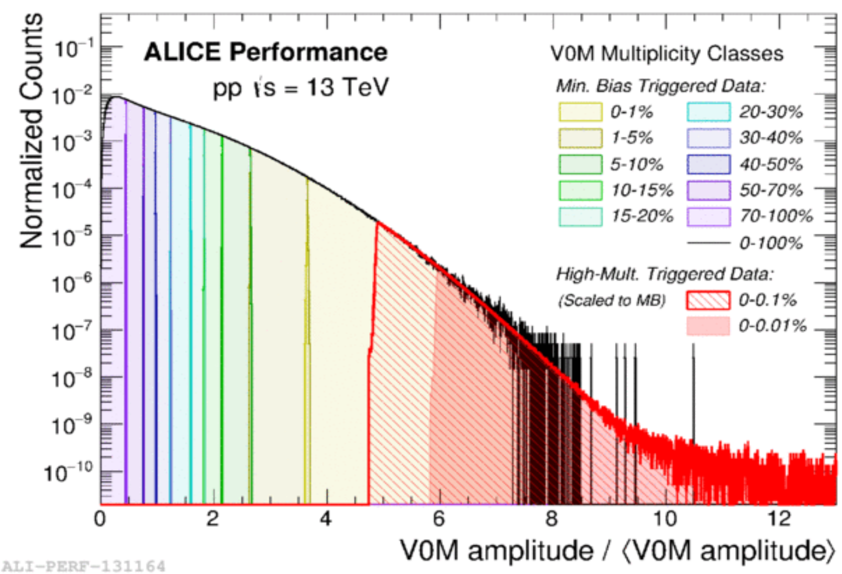
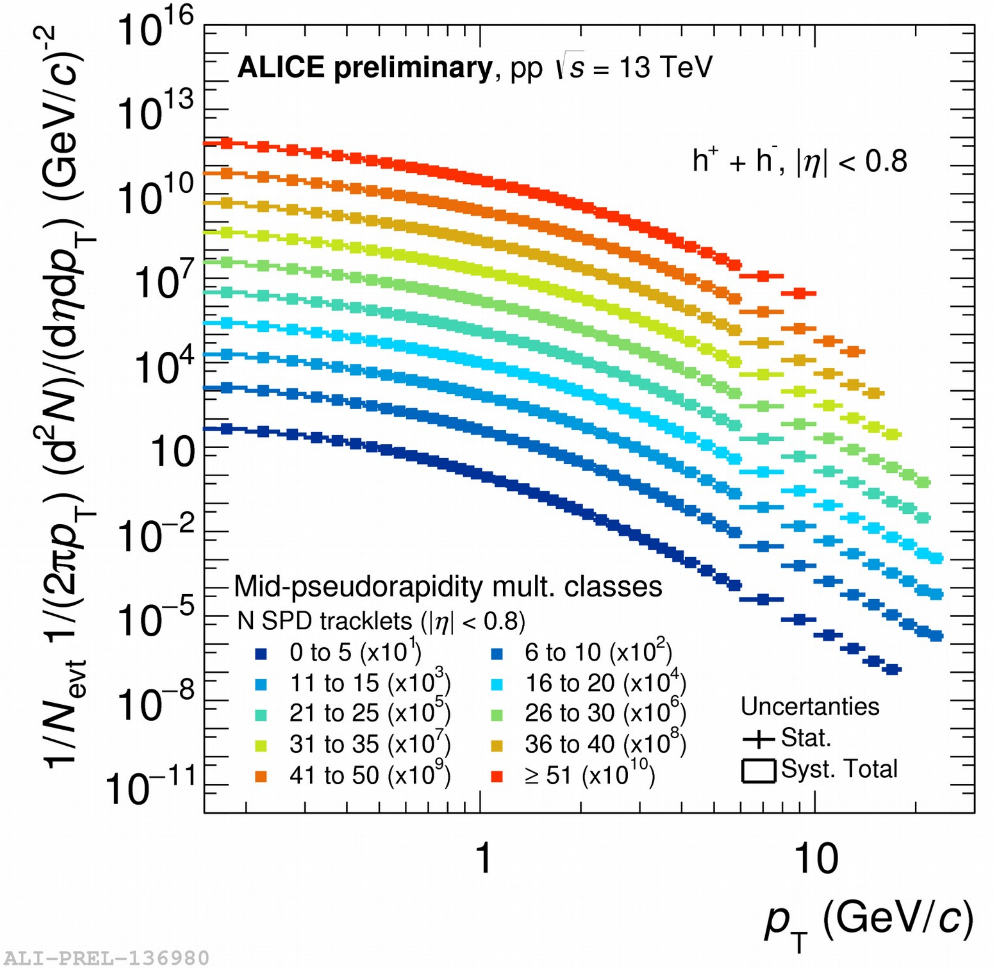
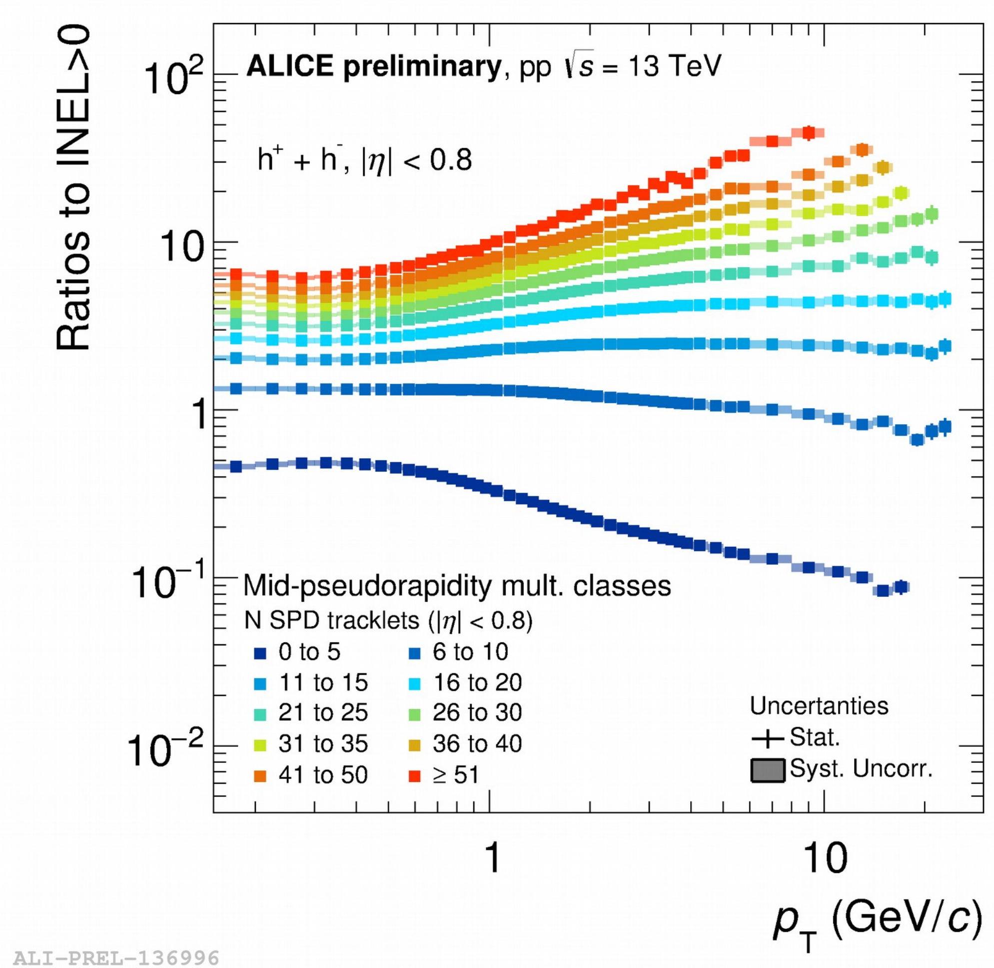


Results

Multiplicity dependence of the transverse momentum distribution

Mid-pseudorapidity estimator ($|\eta| < 0.8$)





Multiplicity dependence of the transverse momentum distribution

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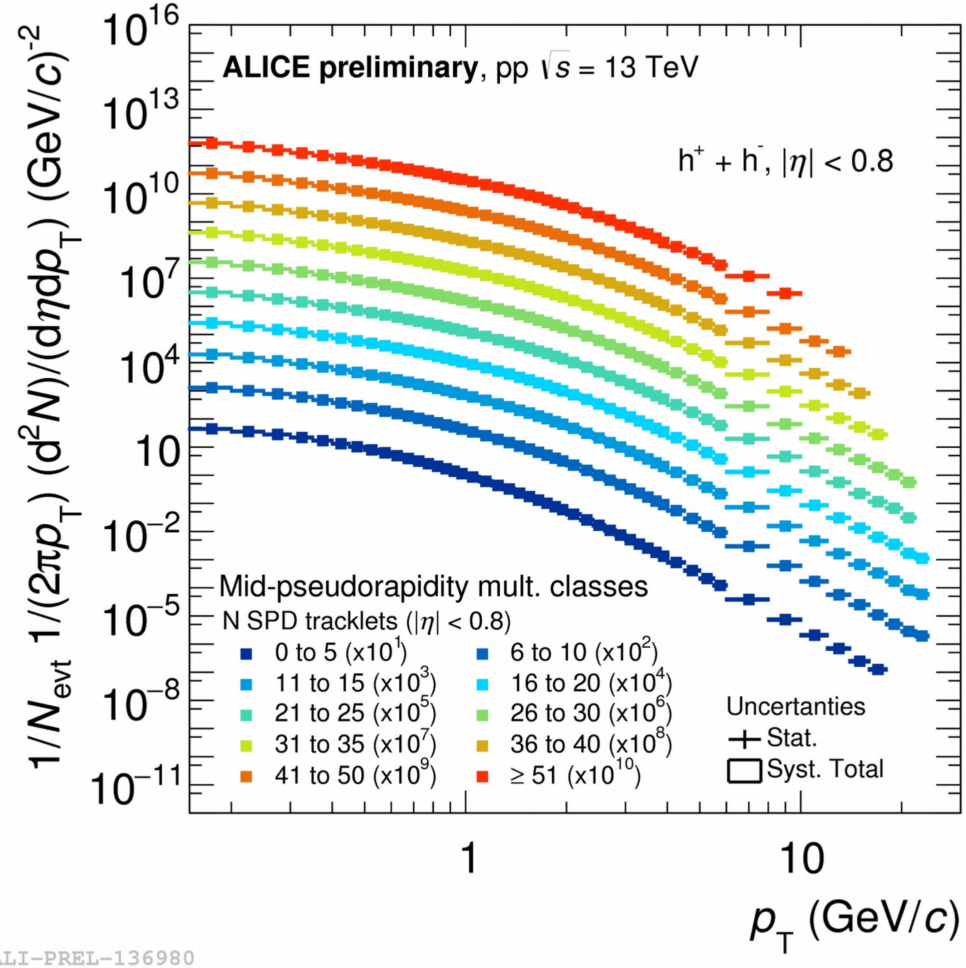
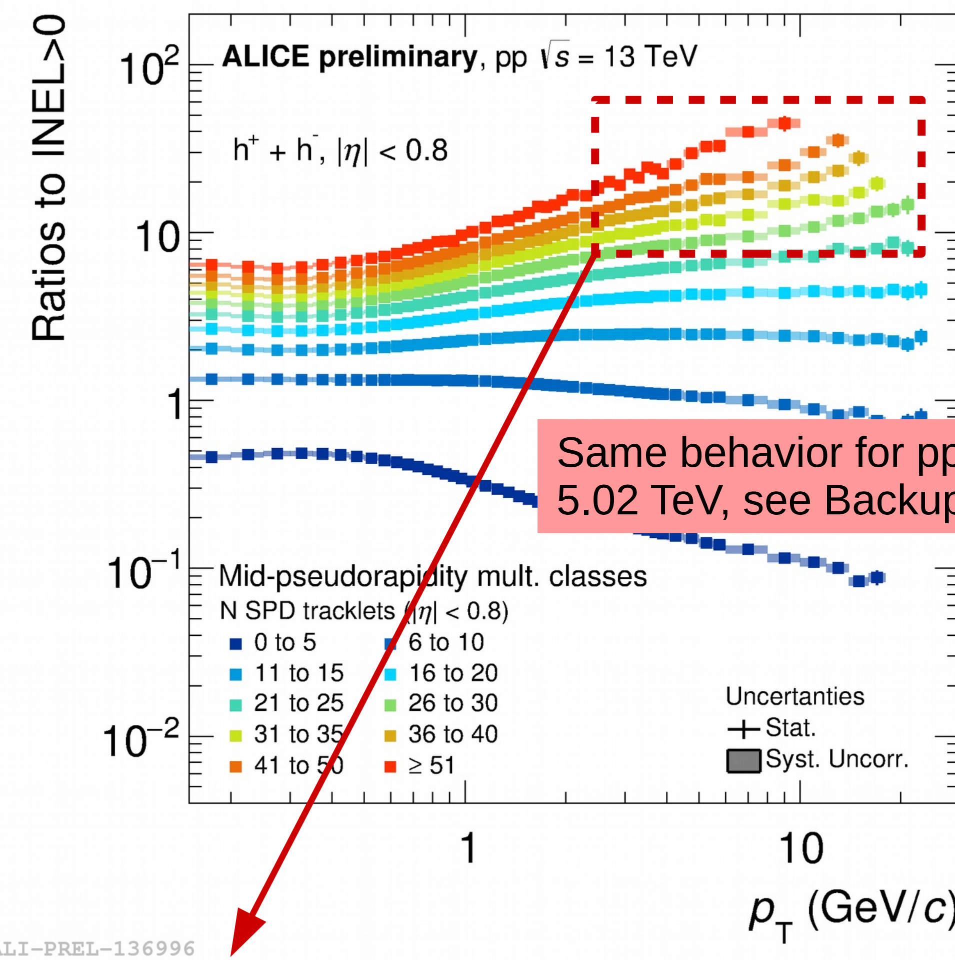




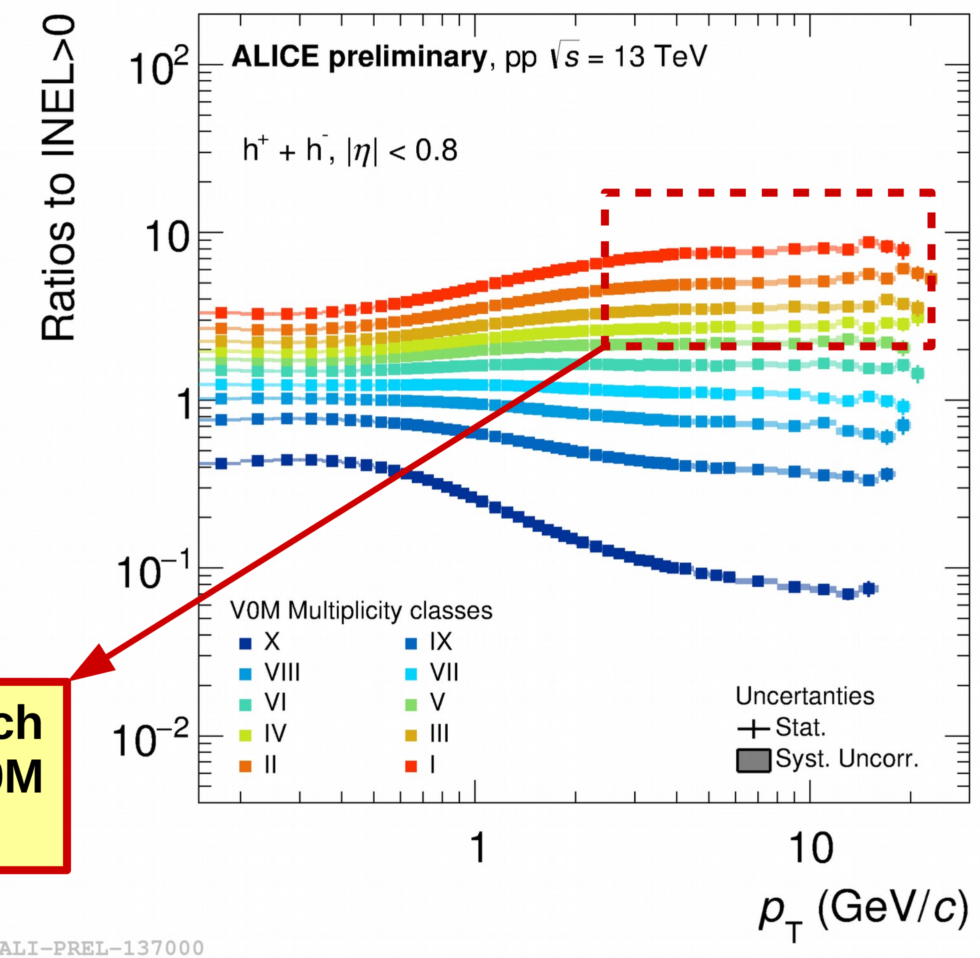
Same behavior for pp at 5.02 TeV, see Backup

An **enhancement is observed** when we move to the higher multiplicity bins using the **mid-pseudorapidity estimator**

Multiplicity dependence of the transverse momentum distribution

V0M multiplicity estimator (2.8 < η < 5.1 and -1.7 < η < -3.7)

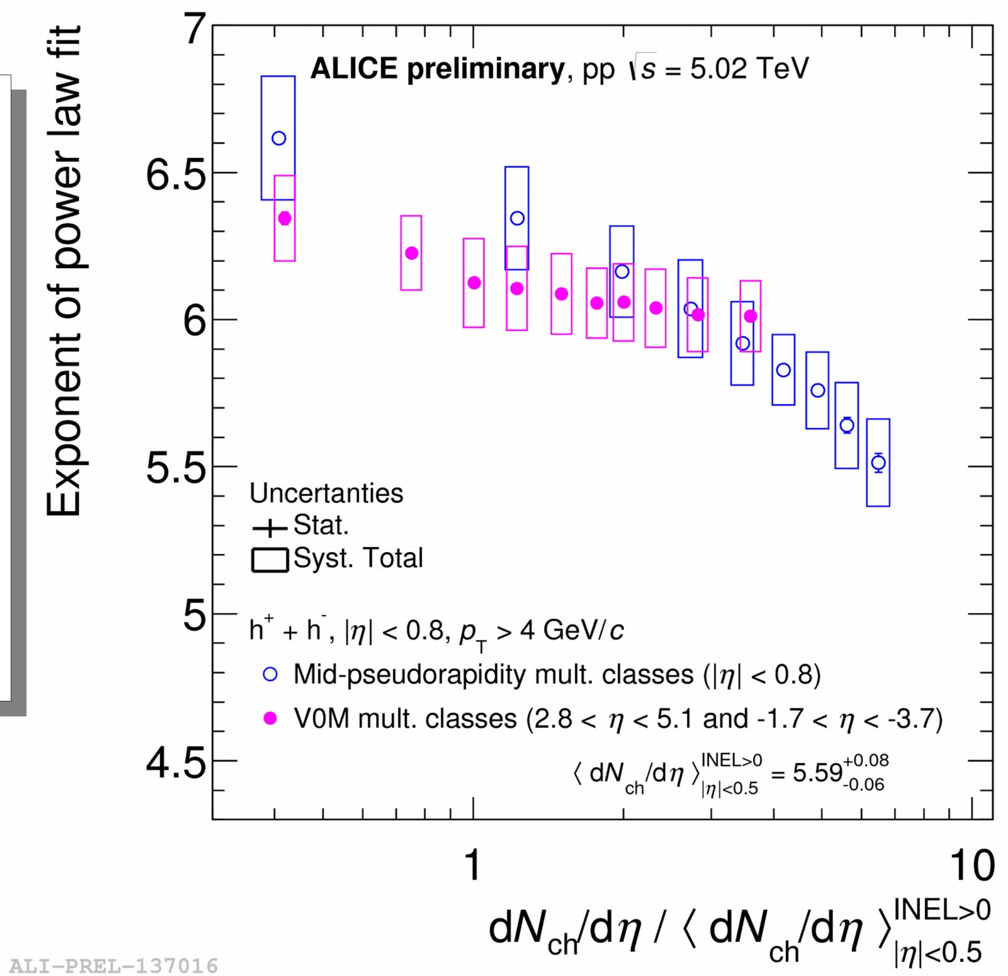
- Similar behavior at low p_T for V0M and mid-pseudorapidity estimators but not for high p_T



Enhancement effect is much weaker when we use the **V0M multiplicity estimator**

High p_T studies: power law fit exponents

- In order to **characterize the high p_T region**, power law functions were fitted to the spectra from 4 GeV/c
- Power law exponents are presented as a function of the **multiplicity normalized by the minimum bias multiplicity**



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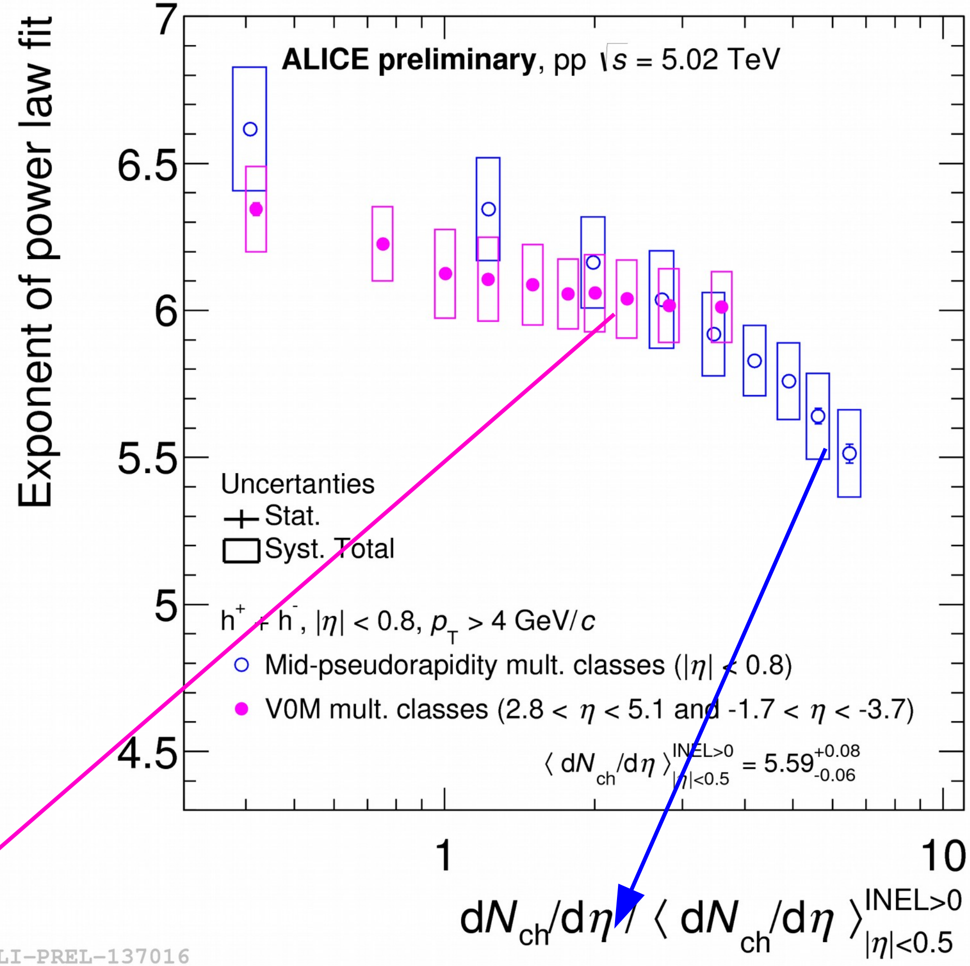
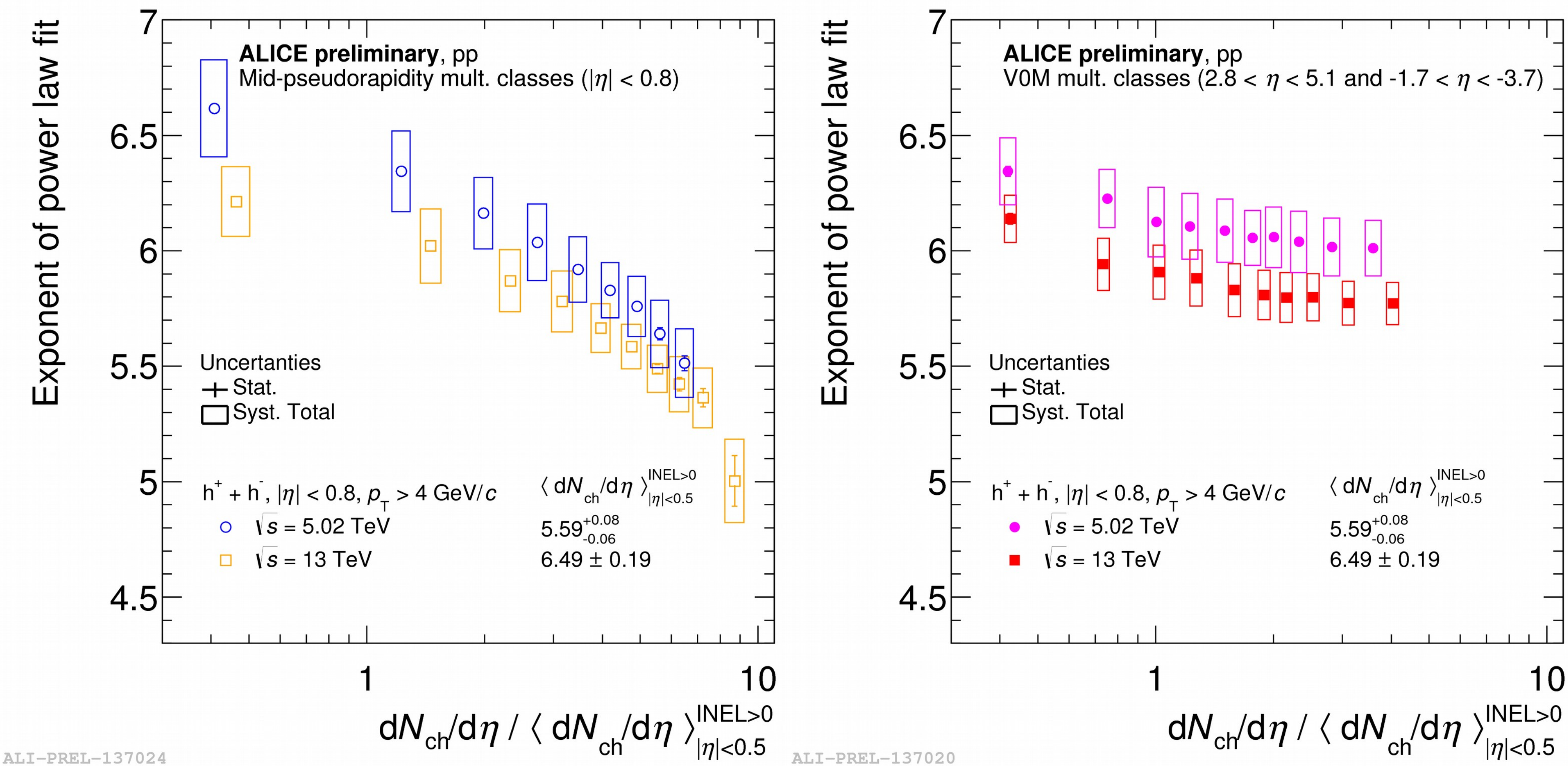


V0M results seem to reach a saturation

Mid-pseudorapidity estimator exponents reach lower values (get harder) as multiplicity increases

Energy dependence of the power law exponent



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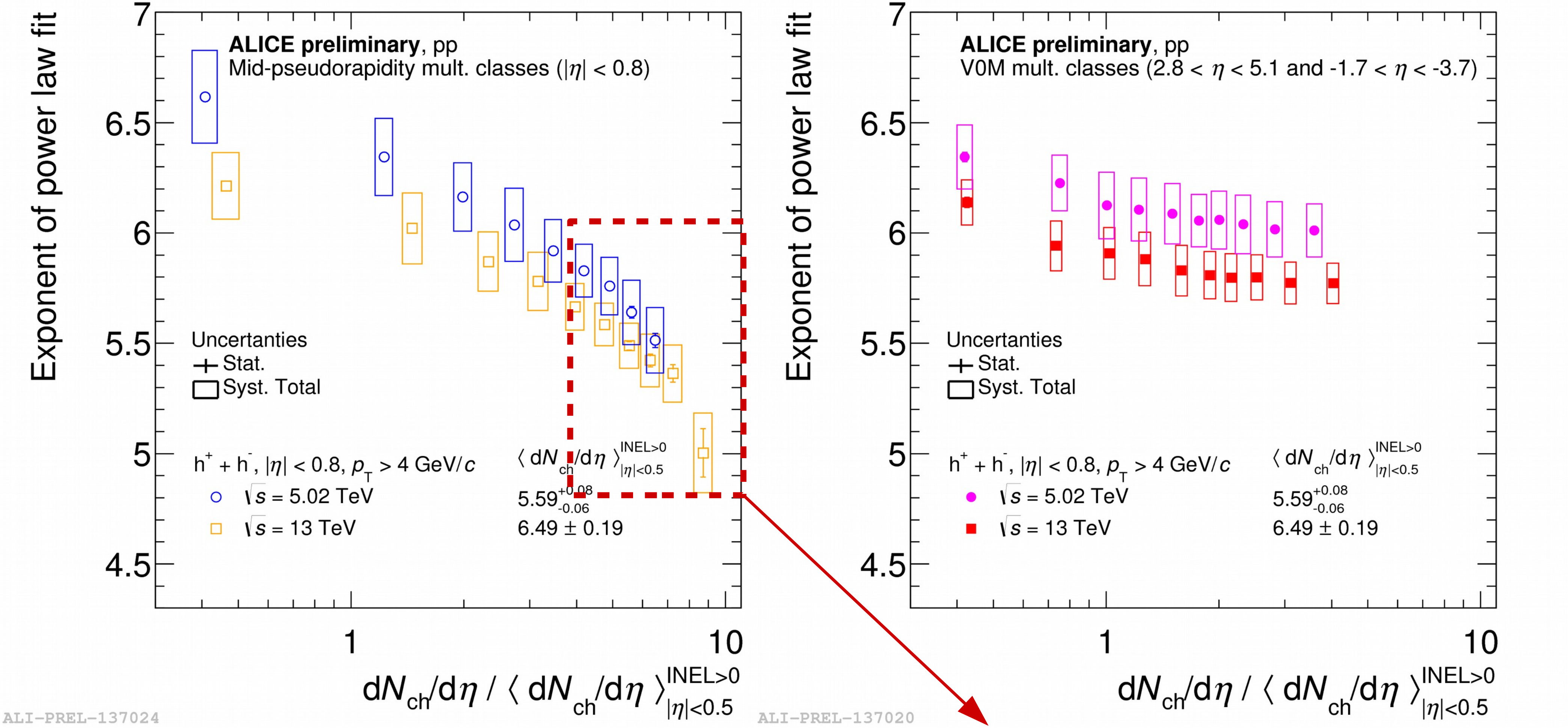

For high multiplicity in the central barrel, both energies tend to have the same value

Energy dependence of the power law exponent

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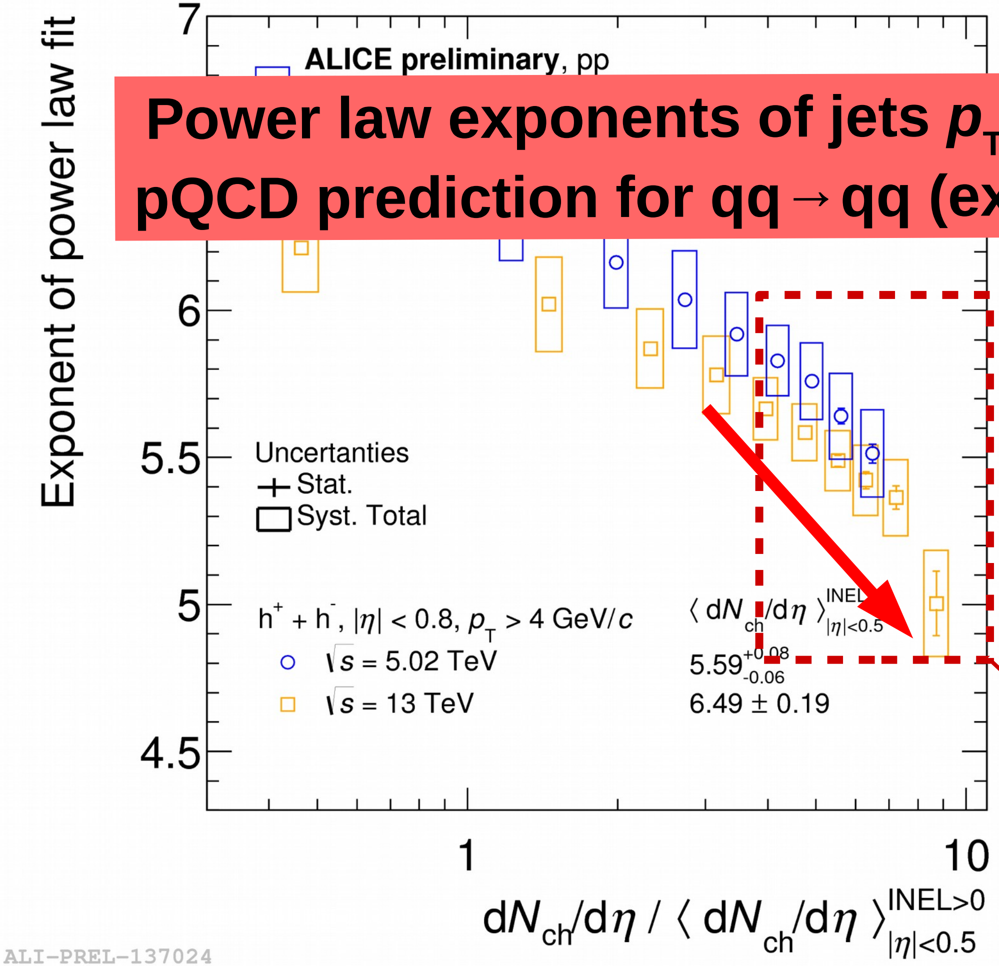
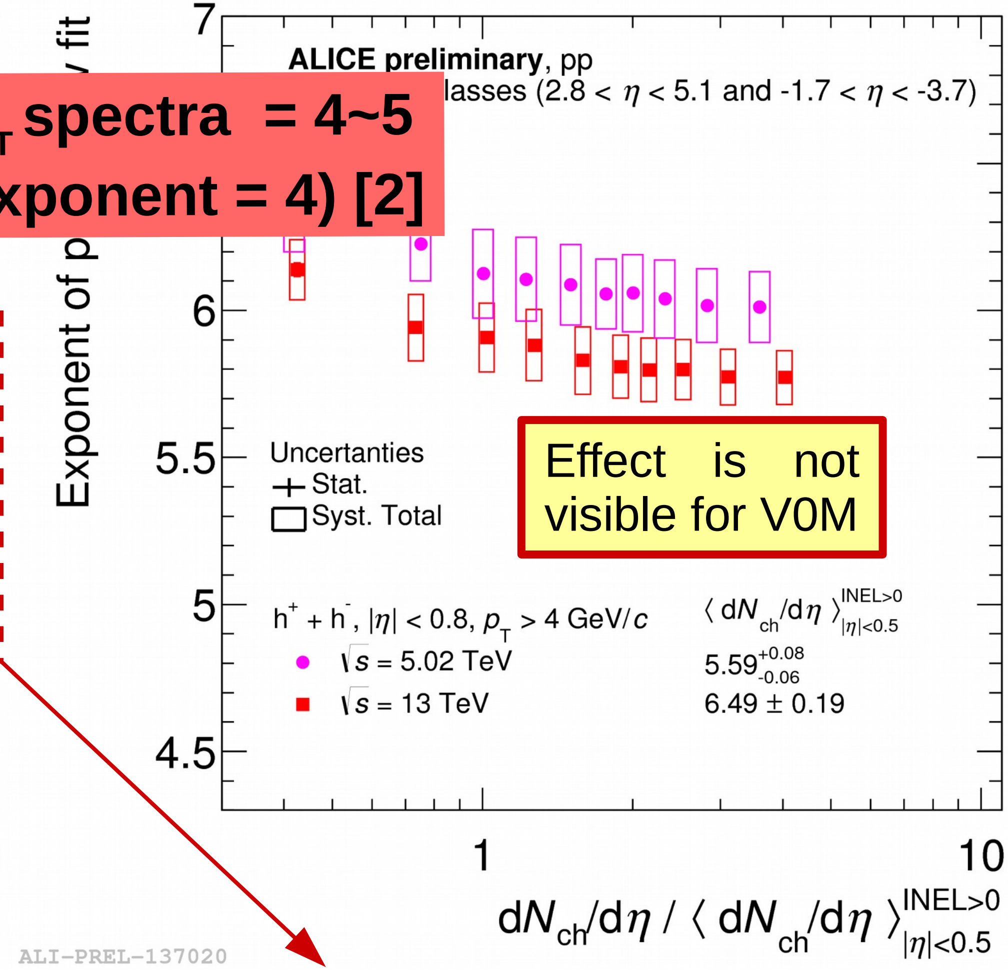
High multiplicity in the central barrel, jetty events [1]

Power law exponents of jets p_T spectra = 4~5
pQCD prediction for qq→qq (exponent = 4) [2]



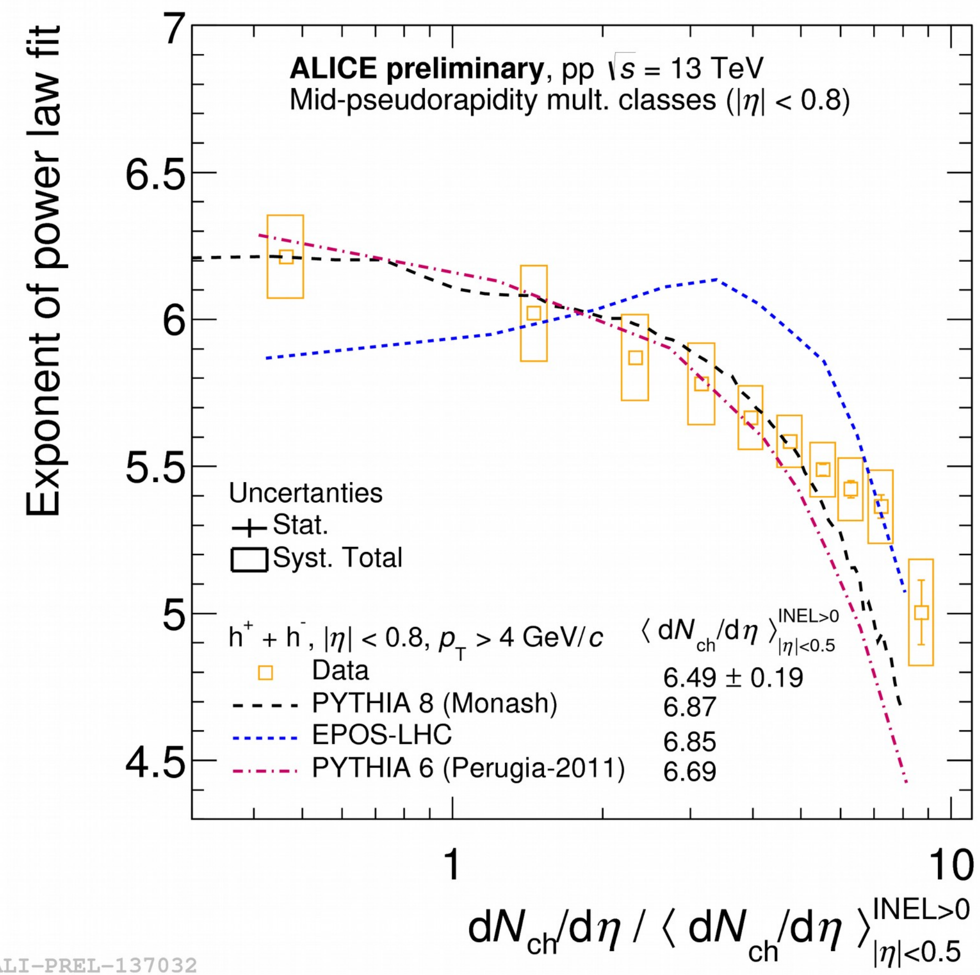


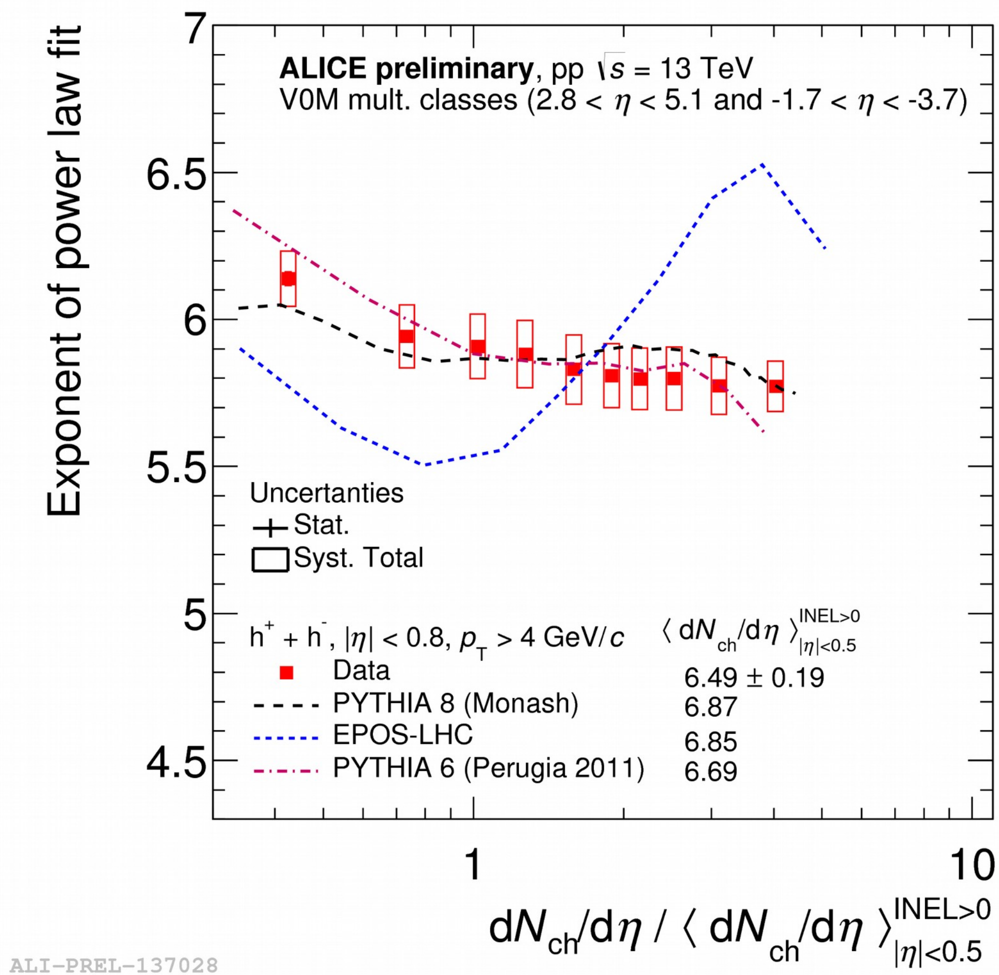
Effect is not visible for V0M

For high multiplicity in the central barrel, both energies tend to have the same value

[1] J. Phys. G: Nucl. Part. Phys. 44 (2017) 065001
[2] Phys. Rev. D 87 (2013) 114007

Power law exponent: Comparison with MC models

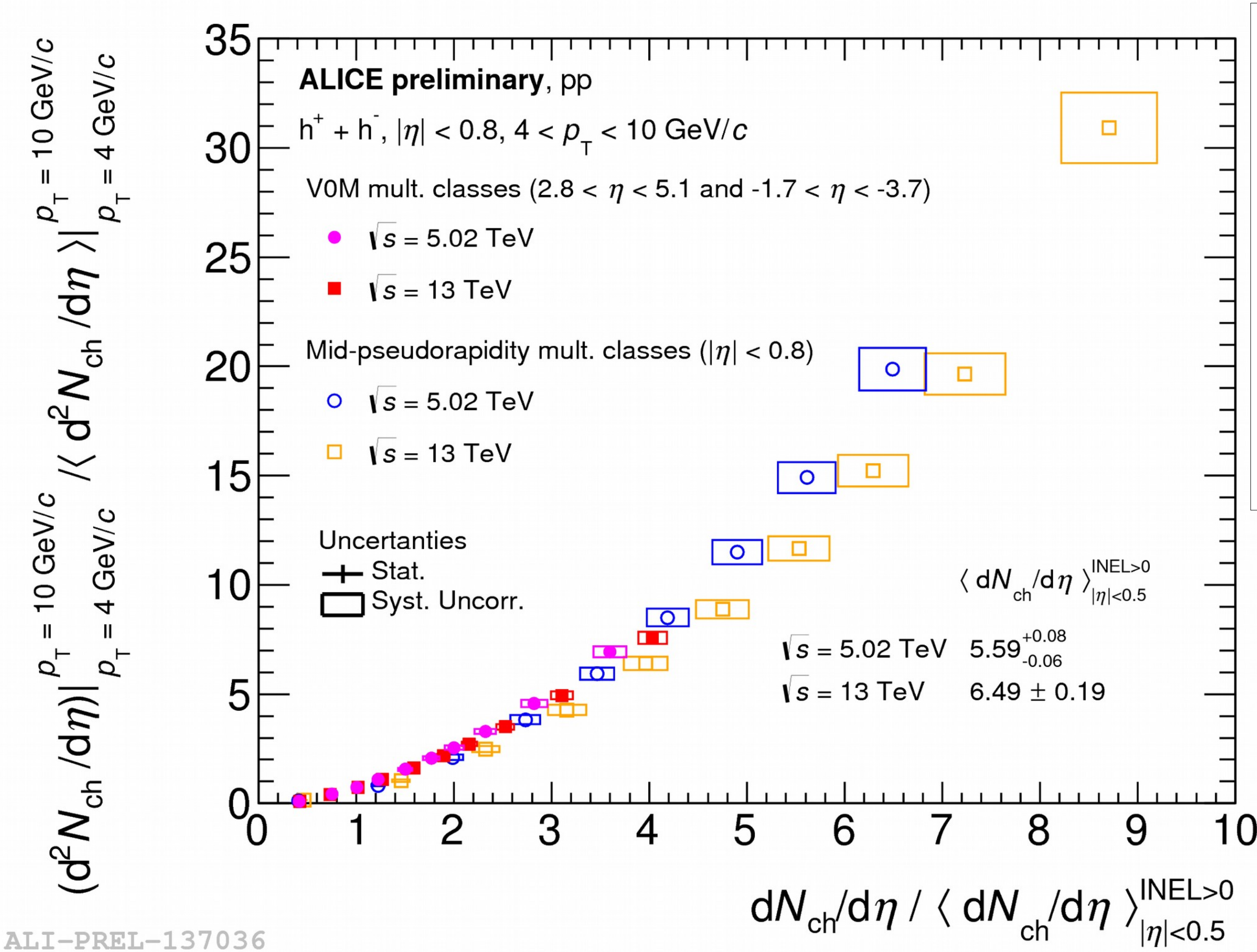




[1] Phys. Rev. C 92 (2015) 034906 (EPOS-LHC)
[2] Phys. Rev. D 82 (2010) 074018 (Pythia 6)
[3] Eur. Phys. J. C 74 (2014) 3024 (Pythia 8)

EPOS-LHC seems not to describe the high p_T region.
Pythia 6 and 8 exhibit good agreement with data

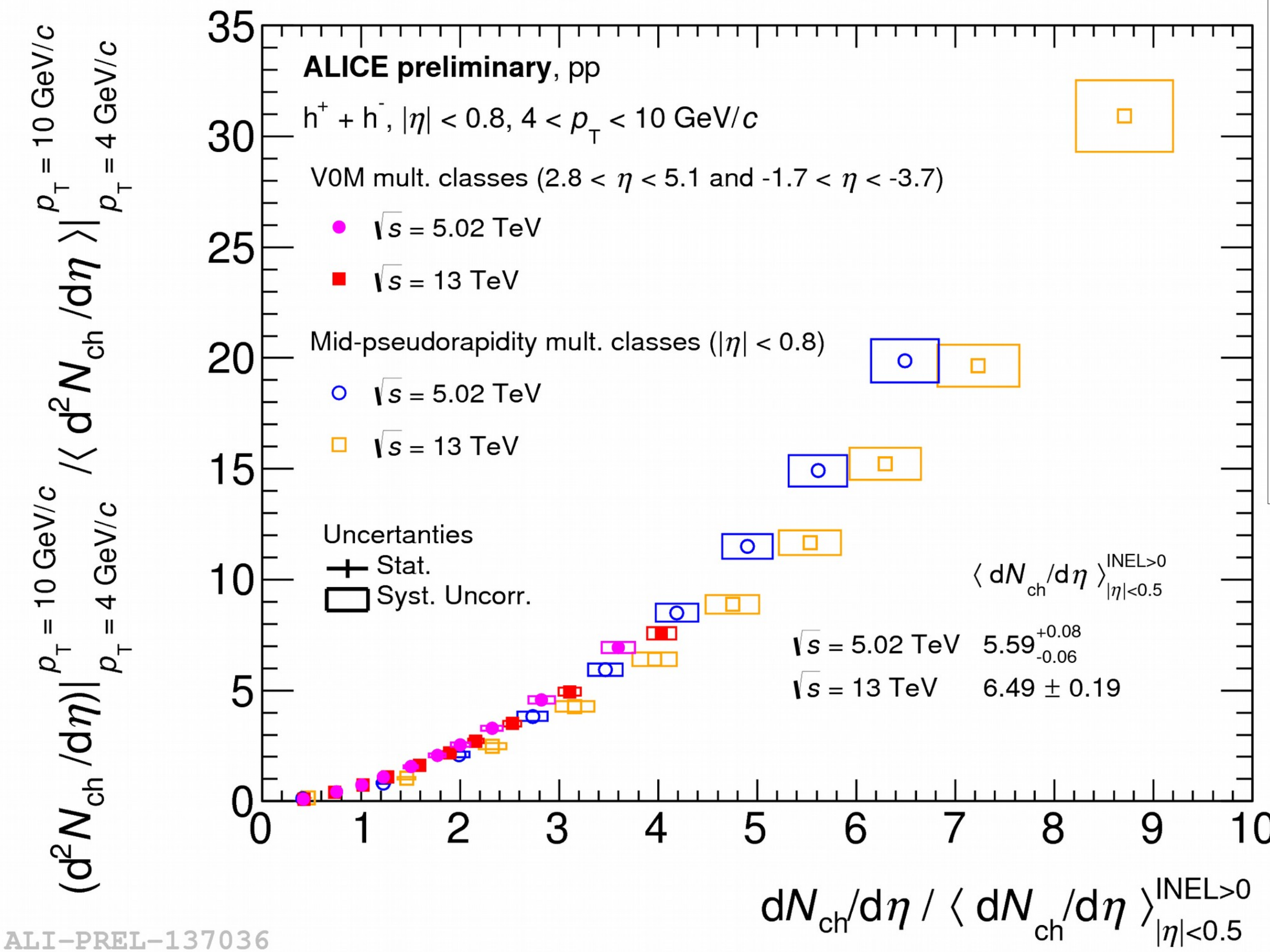
High p_T studies: relative integrated yields



- Integrated yields for high p_T region are another interesting tool to understand the data
- The particle production for a range $4 < p_T < 10$ GeV/c as a function of the event multiplicity was measured

High p_T yields relative to the minimum bias yield increase faster with relative multiplicity at 5.02 TeV with respect to 13 TeV.

High p_T studies: relative integrated yields



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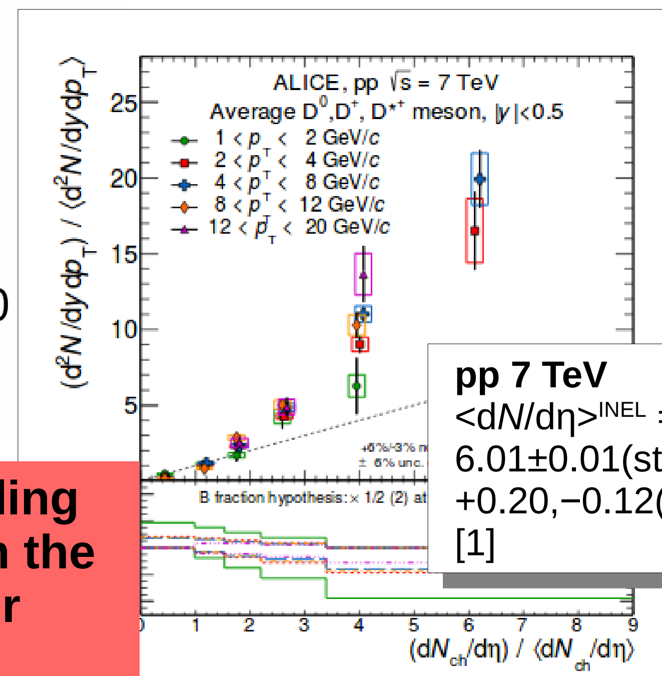

pp 7 TeV
$\langle dN/d\eta \rangle^{INEL}$ = 6.01±0.01(stat.) +0.20,−0.12(syst.) [1]

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Similar scaling observed in the heavy flavor sector[1]

[1]J. High Energy Phys. 09 (2015) 148

High p_T studies: relative integrated yields

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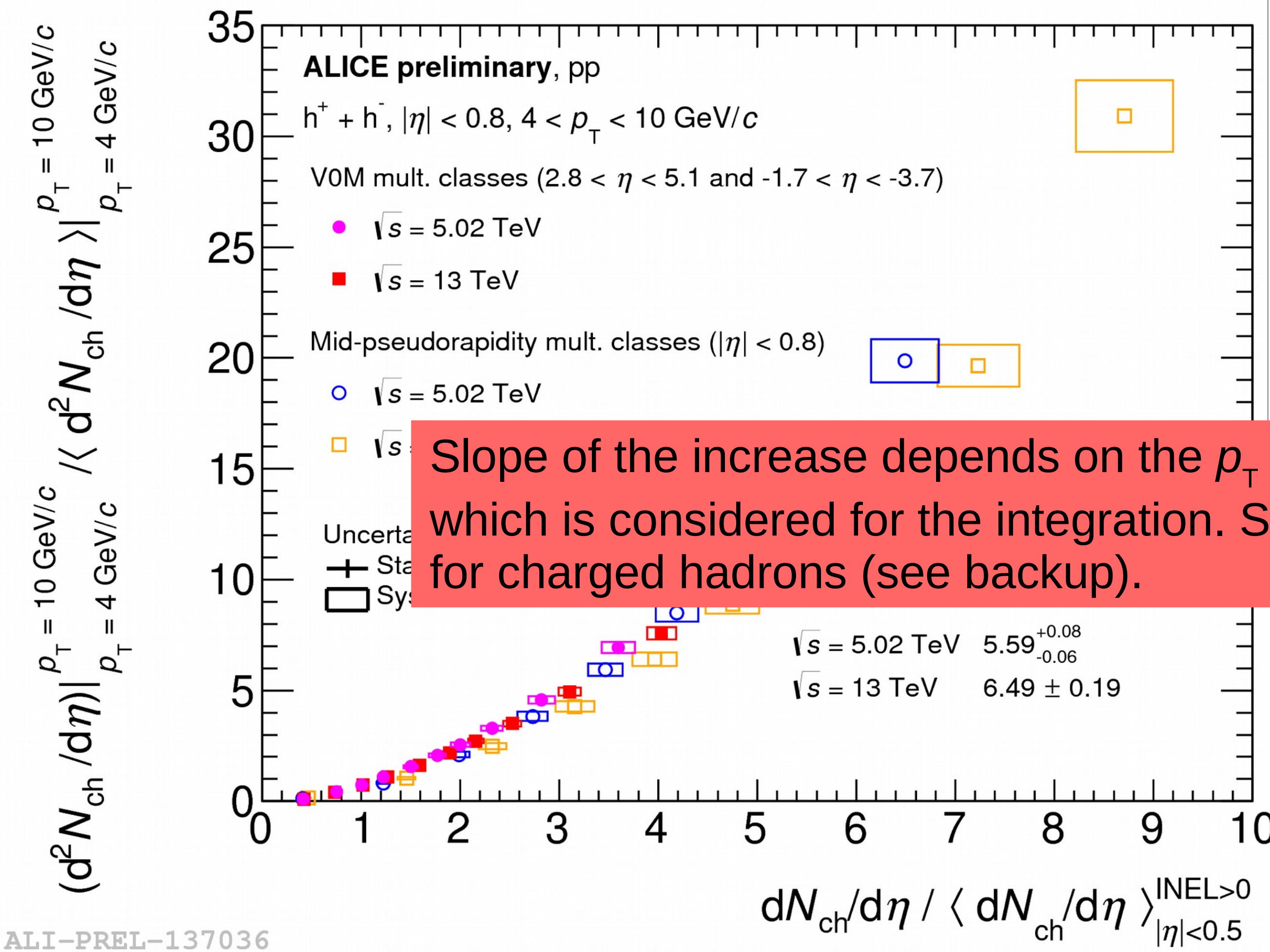

- Integrated yields for high p_T region are another interesting tool to understand the data
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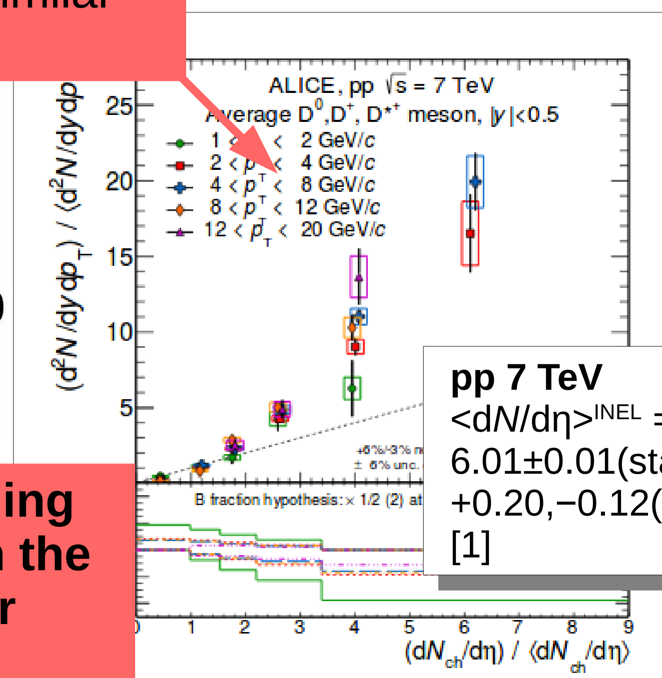
Slope of the increase depends on the p_T range which is considered for the integration. Similar for charged hadrons (see backup).



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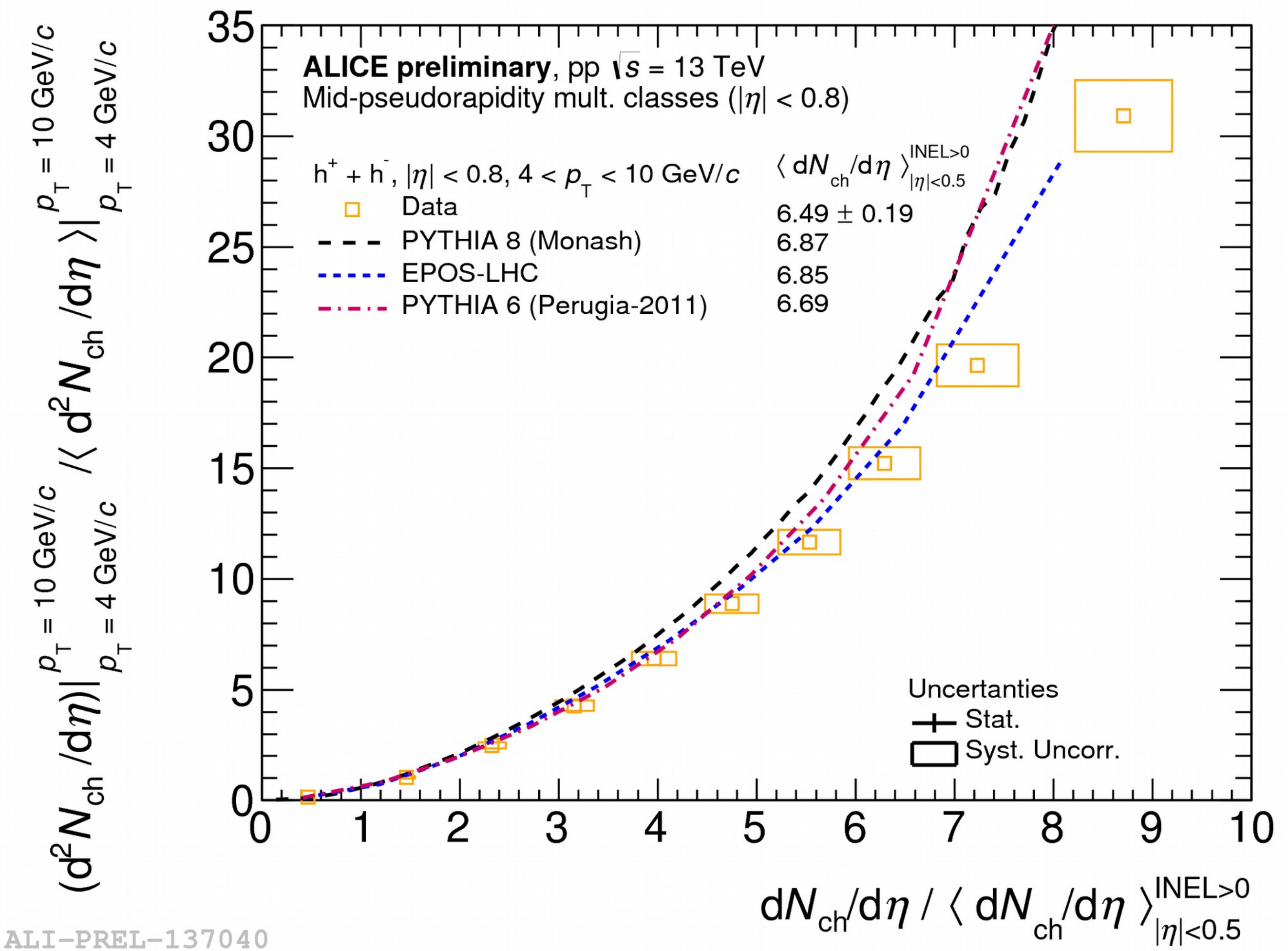


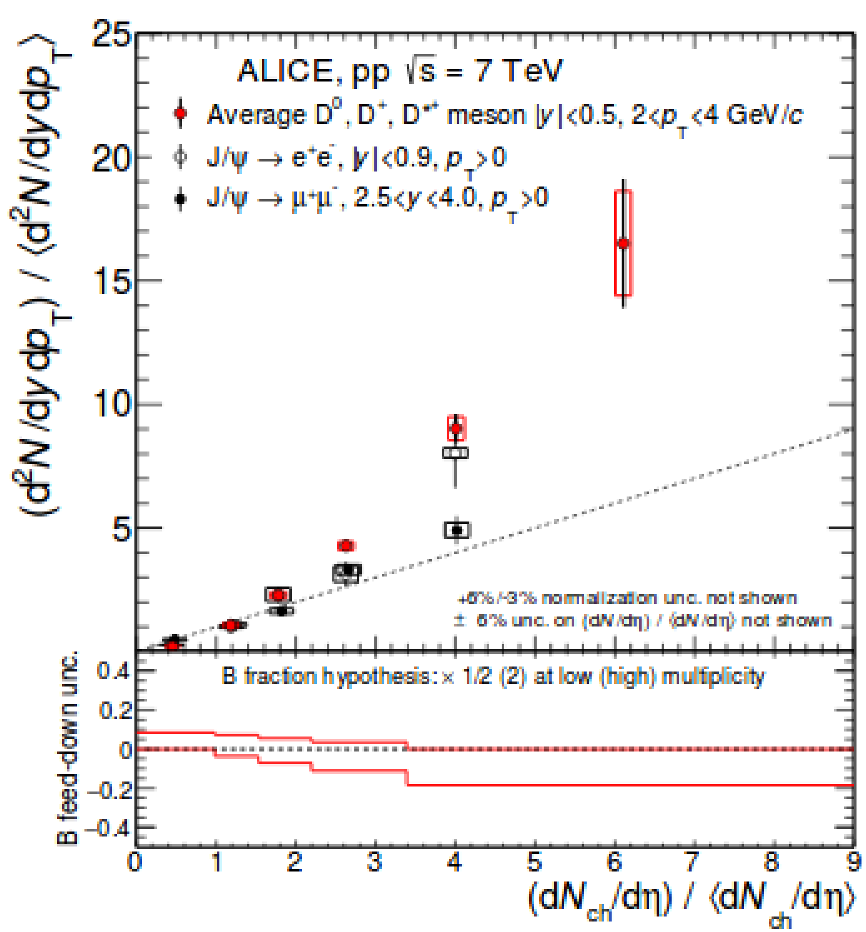
- All the models describe the trend well
- The relative production rate is better reproduced by EPOS-LHC

Conclusions

- The p_T **distributions** measured in $|\eta|<0.8$ as a function of **two multiplicity estimators**, central and forward pseudorapidity, have been measured in **pp collisions at 5.02 and 13 TeV.**
- The slope of the **spectra at high p_T exhibits** a **continuous increase with increasing multiplicity** for the **central estimator** while it stays **rather constant** with the **forward estimator**.
- For the mid-pseudorapidity estimator, the power law exponent exihibits a rapid change with multiplicity with a **tendency to the pQCD predictions and the results for jets.**
  - Comparison with event generators indicates that **Pythia (6 and 8) qualitatively reproduces the data** while this is **not the case for the EPOS-LHC** generator.
  - Production **of inclusive charged hadrons high p_T** exhibits a **stronger than linear increase with multiplicity** similar to the one observed in the **heavy flavor sector** suggesting a common **underlying mechanism.**

Back-Up

Additional motivation



[1]J. High Energy Phys. 09 (2015) 148

- **Charm and beauty** hadrons production, produced in **hard processes**, exhibit an enhancement with the multiplicity faster than linear [1]
- It will be very interesting to verify if **high p_T inclusive charged hadrons**, that come from **hard processes** too, show the same behavior
- **High p_T studies** as a function of the event multiplicity will be presented

Corrections to data

The fully-corrected charged hadron spectra, $\frac{1}{N_{\mathrm{ev}}}\frac{\mathrm{d}^2N}{\mathrm{d}\eta\mathrm{d}p_{\mathrm{T}}}$, were obtained as:

$$\frac{1}{N_{\mathrm{ev}}}\frac{\mathrm{d}N}{\mathrm{d}\eta\mathrm{d}p_{\mathrm{T}}} = \frac{(\epsilon_{\mathrm{trigger}})(\mu)}{N_{\mathrm{raw}}}\frac{\mathrm{d}N_{\mathrm{raw}}}{\mathrm{d}\eta\mathrm{d}p_{\mathrm{T}}}\frac{f_{\mathrm{primary}}}{(\epsilon_{\mathrm{tracking}})(\zeta)}$$

Where

- $\boldsymbol{\varepsilon}_{\mathbf{trigger}}$ → Is the trigger efficiency
- $\boldsymbol{\mu}$ → Is the missing vertex correction
- $\boldsymbol{f}_{\mathbf{primary}}$ → Correction to take into account the secondary particle contamination. Data driven method by fitting the transverse DCA distributions of primary and secondary particles from M.C. to data
- $\boldsymbol{\zeta}$ → Correction by the fraction of signal loss due to the event selection
- $\boldsymbol{\varepsilon}_{\mathbf{tracking}}$ →Tracking efficiency computed with measured particle composition [1]

[1]QM2017, Particle composition correction

Systematic uncertainties

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Different components to the **total systematic errors** were calculated, they were assumed as uncorrelated and added in quadrature.

- Track cuts parameter variations
- Tracking efficiency
  - Multiplicity dependence of tracking efficiency
  - Particle composition variations
- Secondary particles contamination
  - Fitting transverse DCA range varied
  - Multiplicity dependence of primary fractions
- Matching efficiency
- Material budget
- Pile-up
- P_T resolution
- Z vertex position
- Trigger efficiency (Normalization)

Since some of the errors were common for all the multiplicity bins, **multiplicity uncorrelated** fraction of the systematic errors was also computed.

Multiplicity dependence of the transverse momentum distribution

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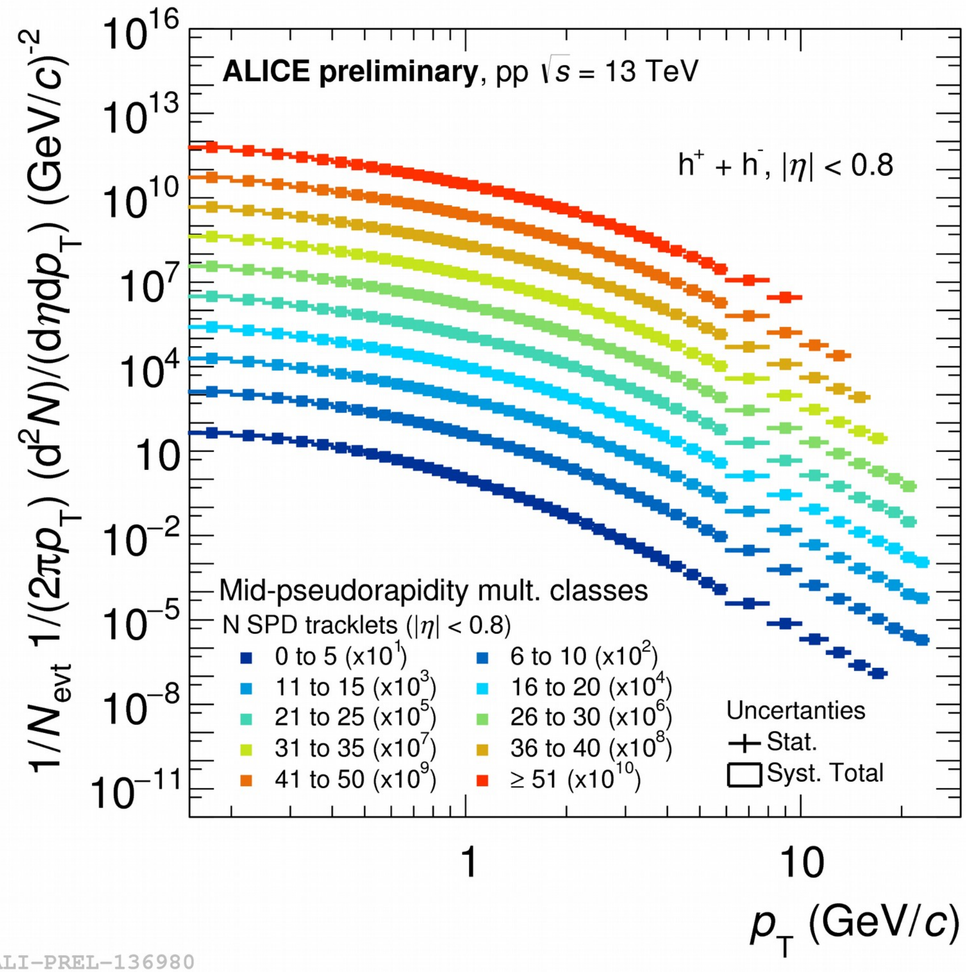
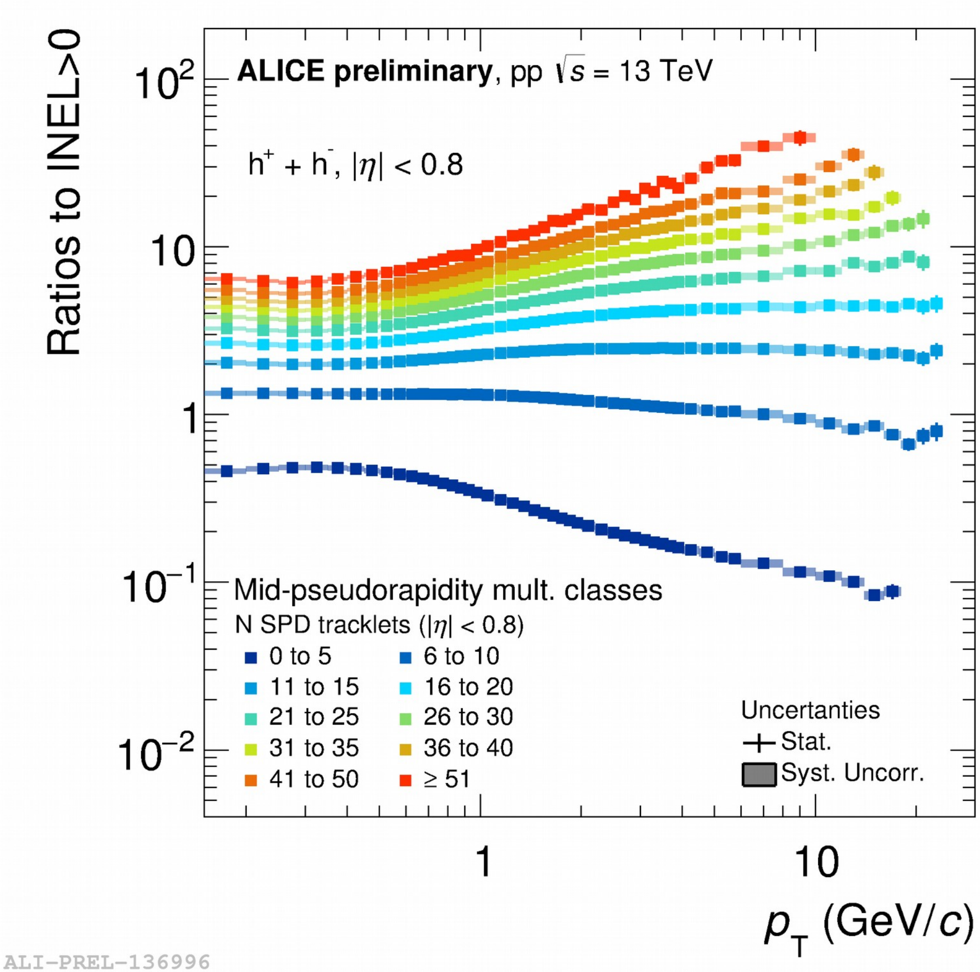
Mid-pseudorapidity estimator (|η| < 0.8)





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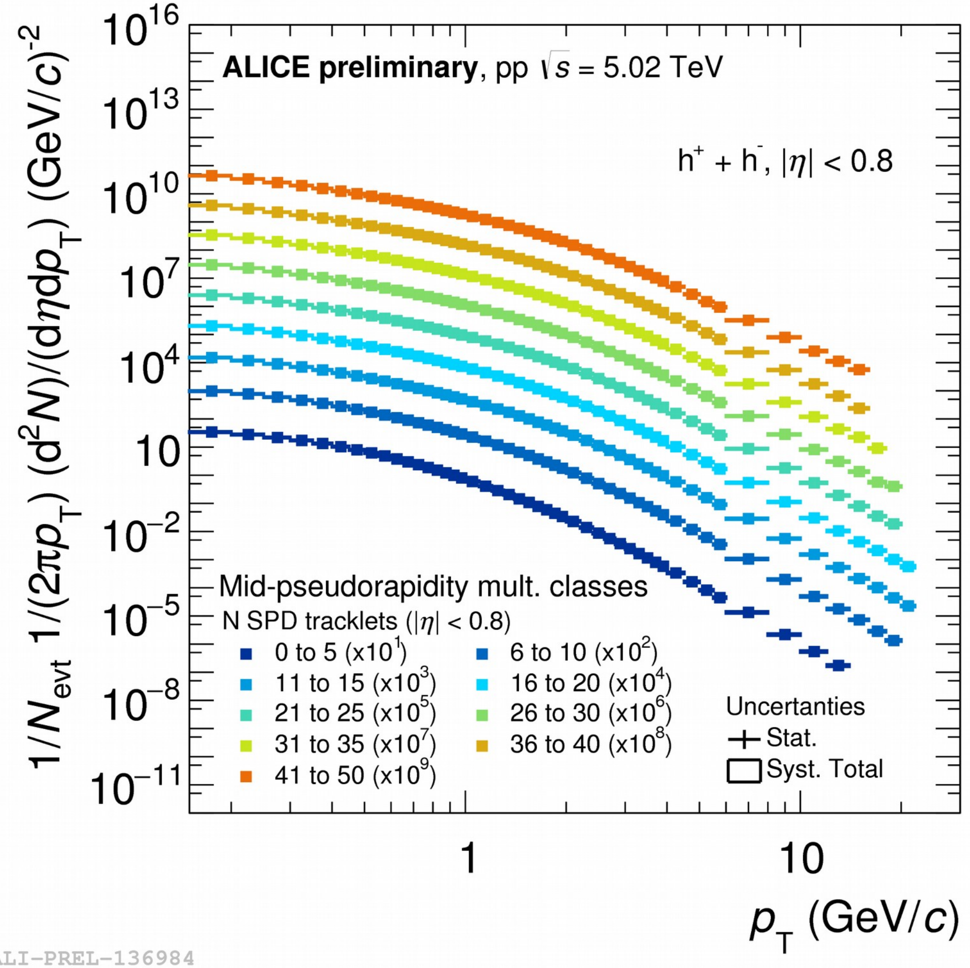

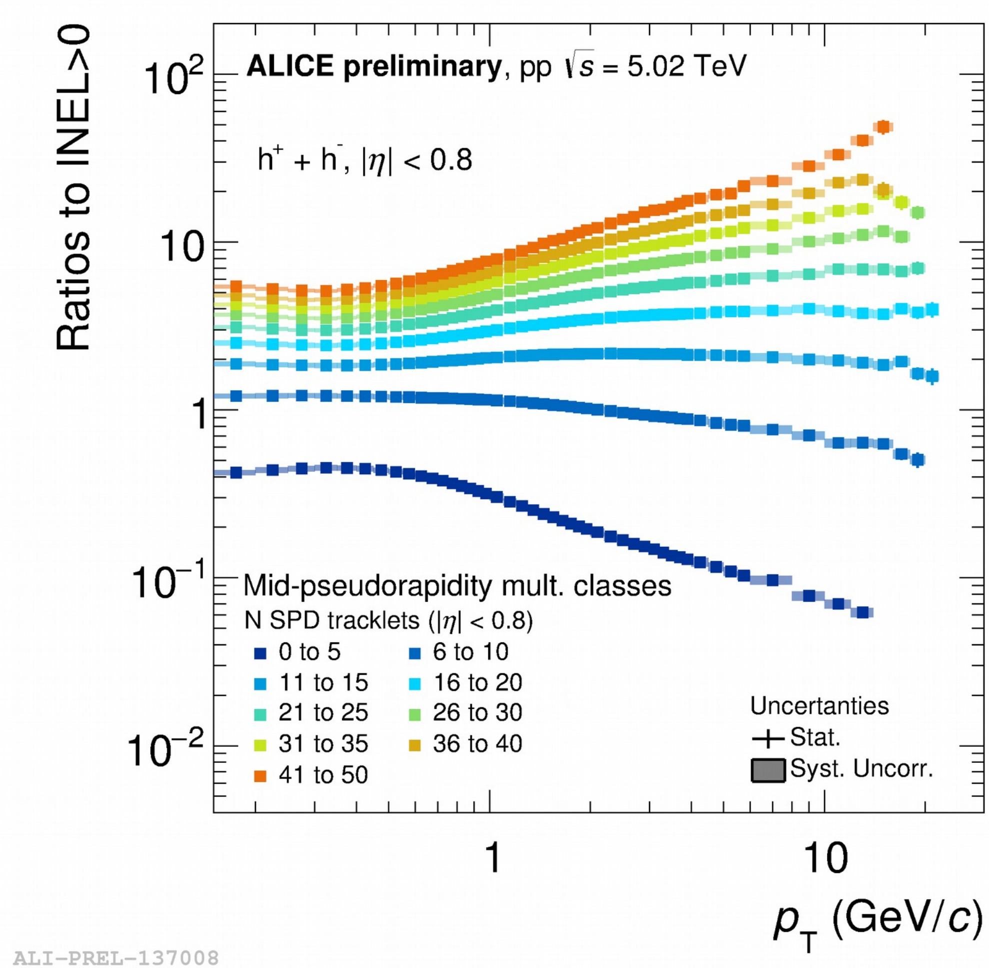

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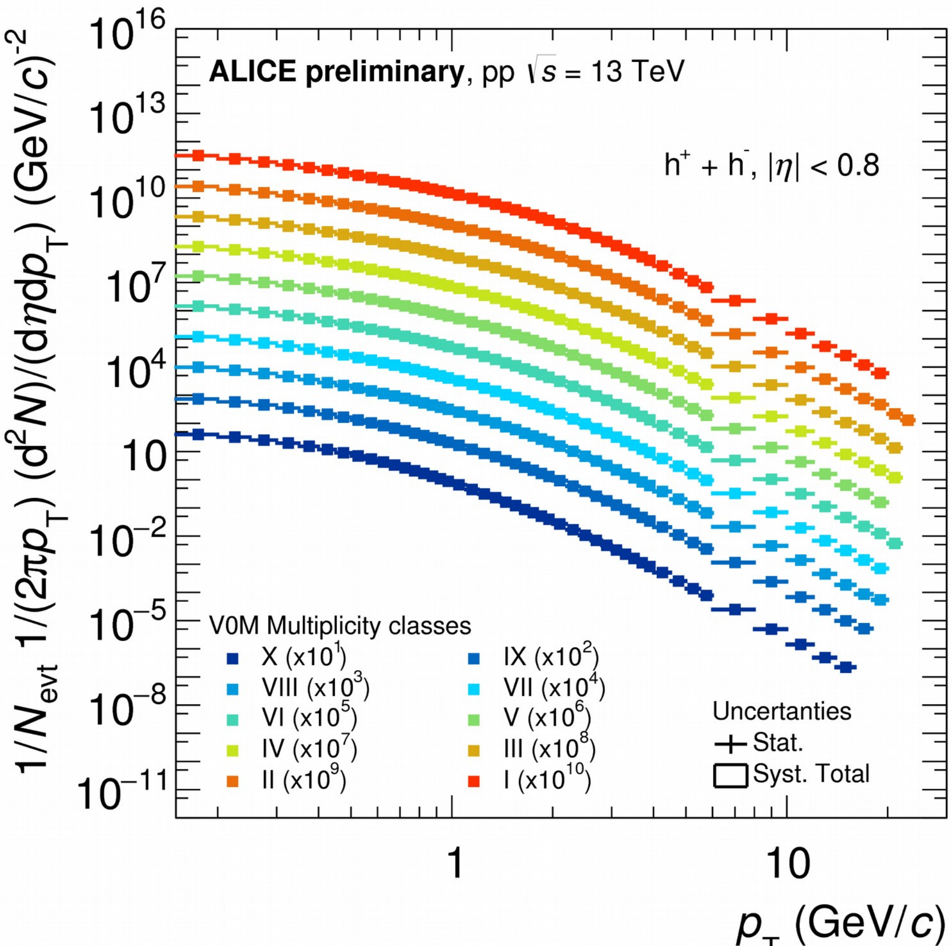

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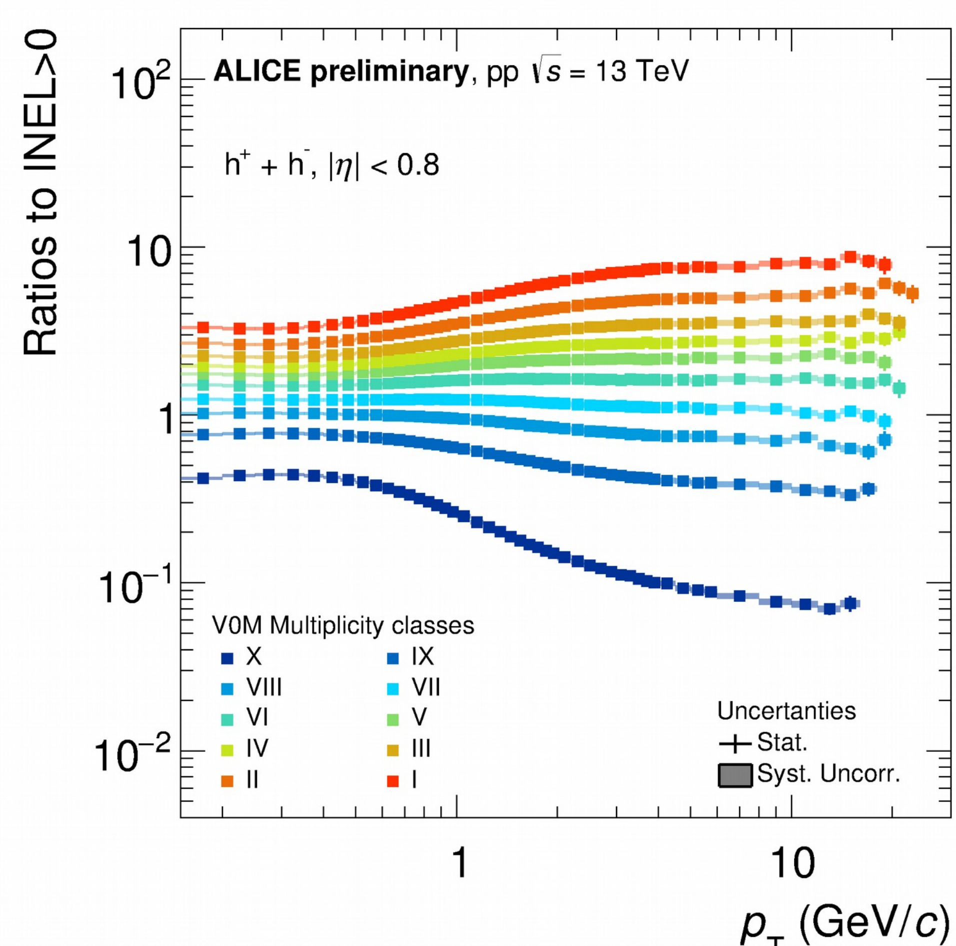

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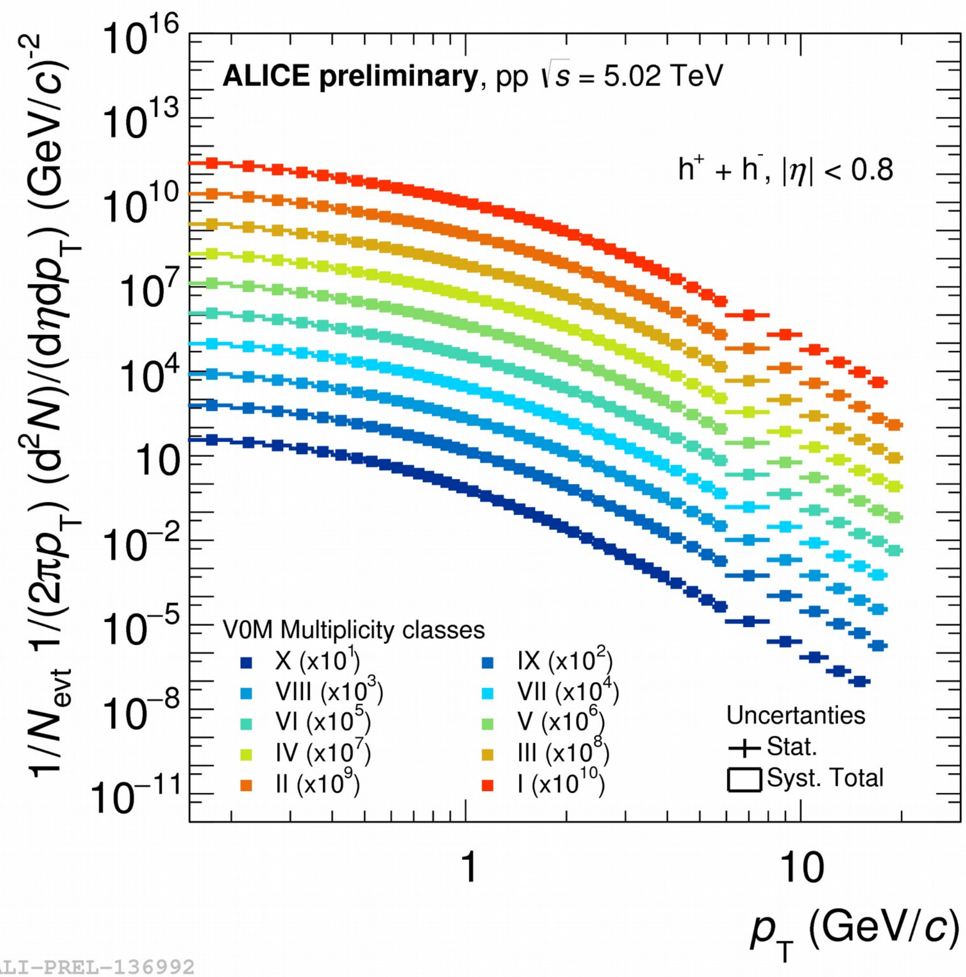
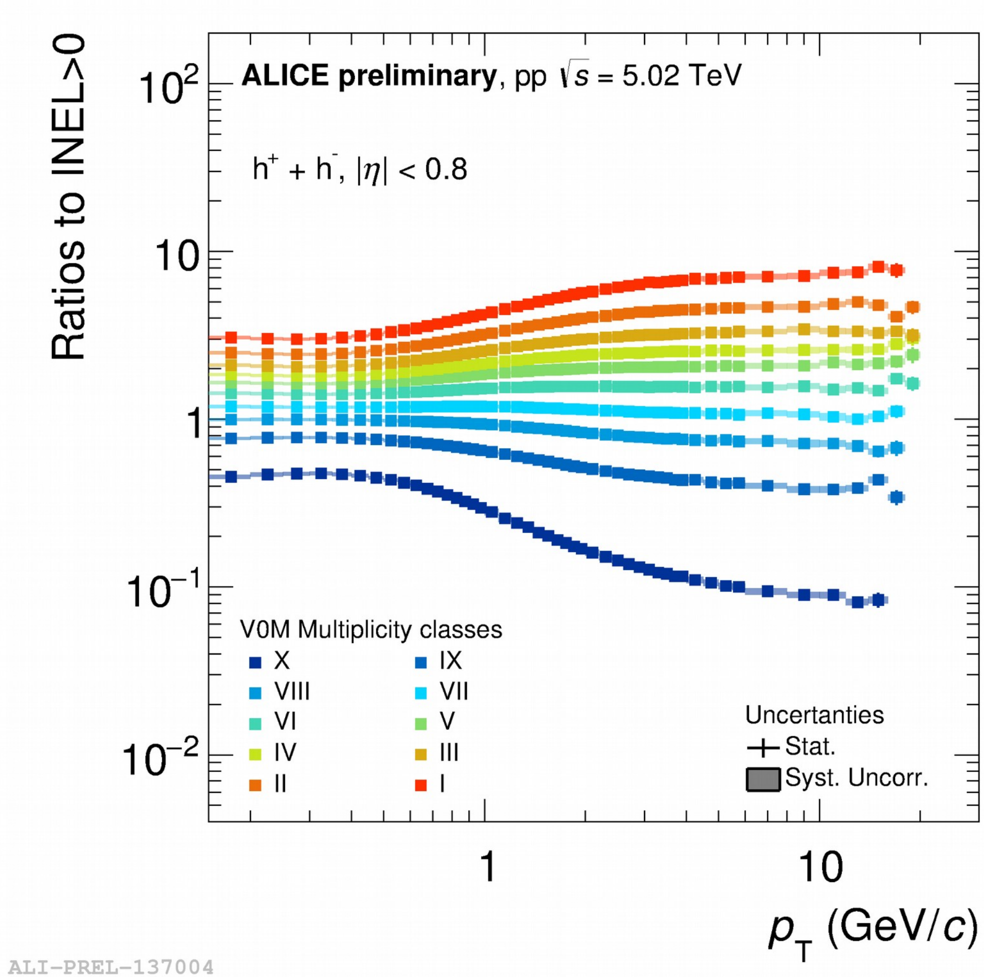
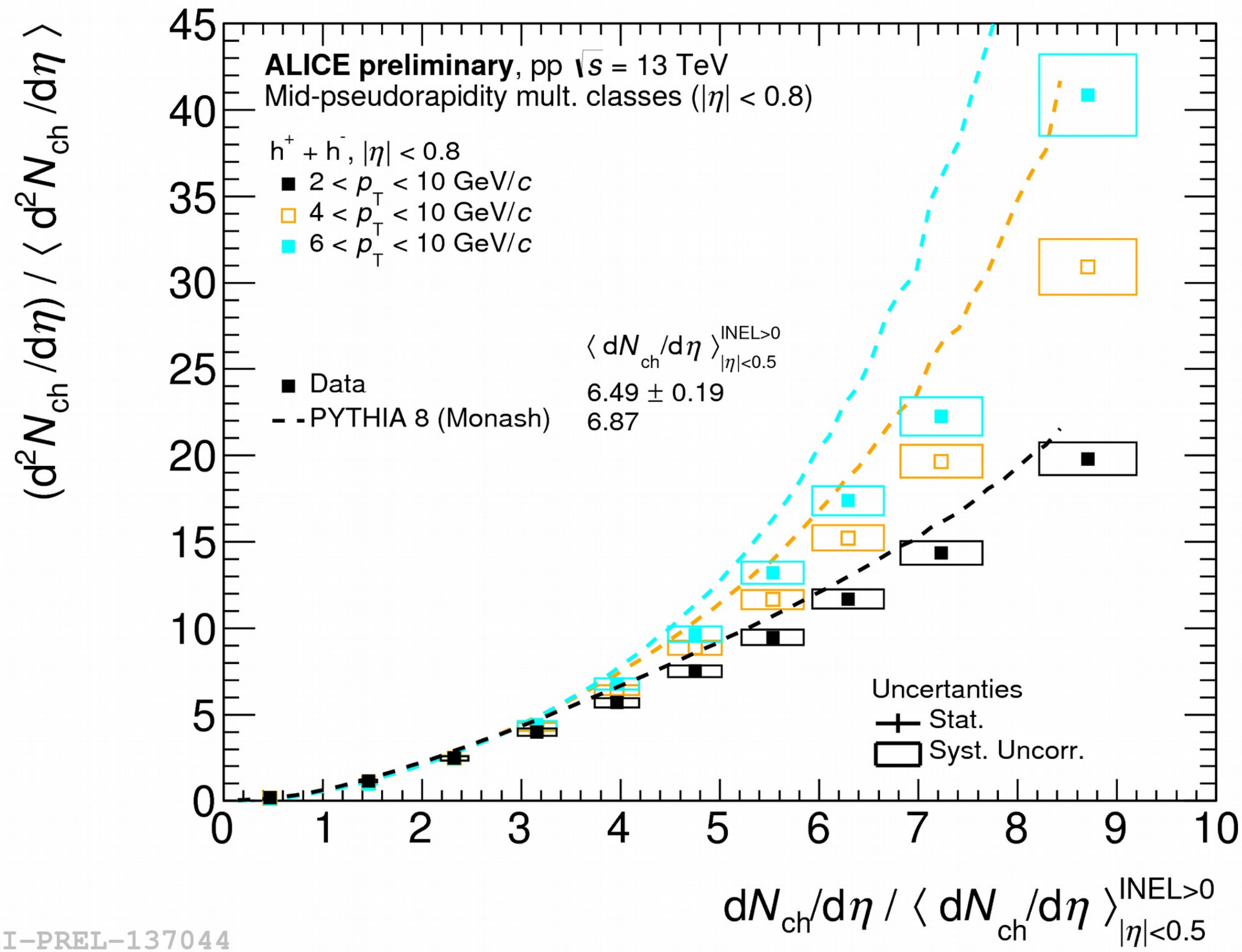




relative integrated yields, p_T cut dependence



- The increase with multiplicity is present for the three ranges shown in the plot. As can be observed, is stronger for higher p_T

Power law exponent vs. multiplicity, pp 13 TeV