Quark Matter 2015 – Kobe

28th September 2015

Charged-Particle Multiplicity Distributions over a Wide Pseudorapidity Range in Proton-Proton Collisions with ALICE

Valentina Zaccolo

Niels Bohr Institute

University of Copenhagen

for the ALICE Collaboration

Motivation and Outline

Data from the Silicon Pixel Detector (SPD) and the Forward Multiplicity Detector (FMD) in ALICE are used to access a uniquely wide pseudorapidity range at the LHC of more than **eight** η units, from $-3.4 < \eta < 5.0$

The results presented here for pp collisions from $\sqrt{s}$ = 0.9 TeV to 8 TeV extend:

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ii. the high-multiplicity reach.

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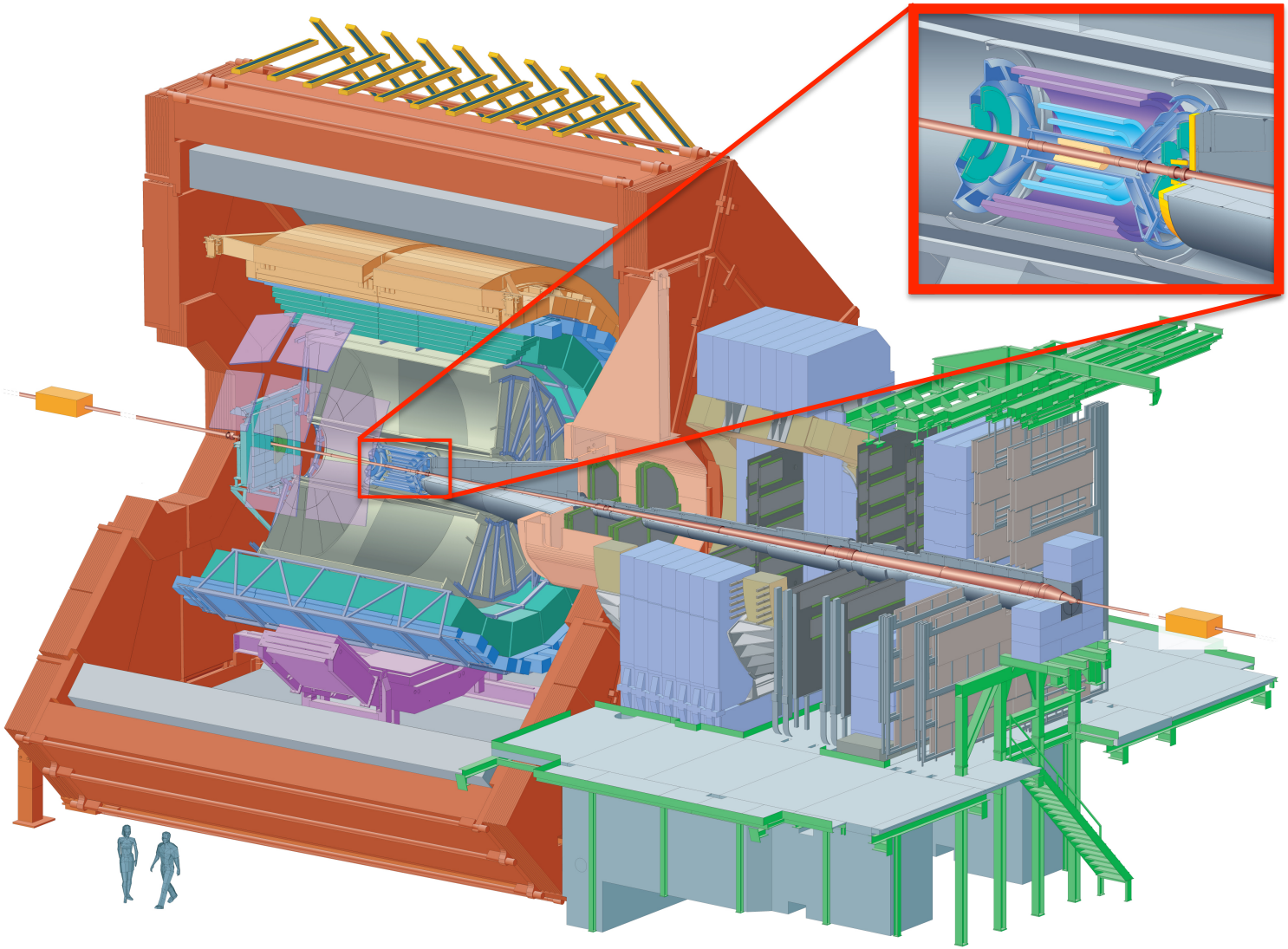
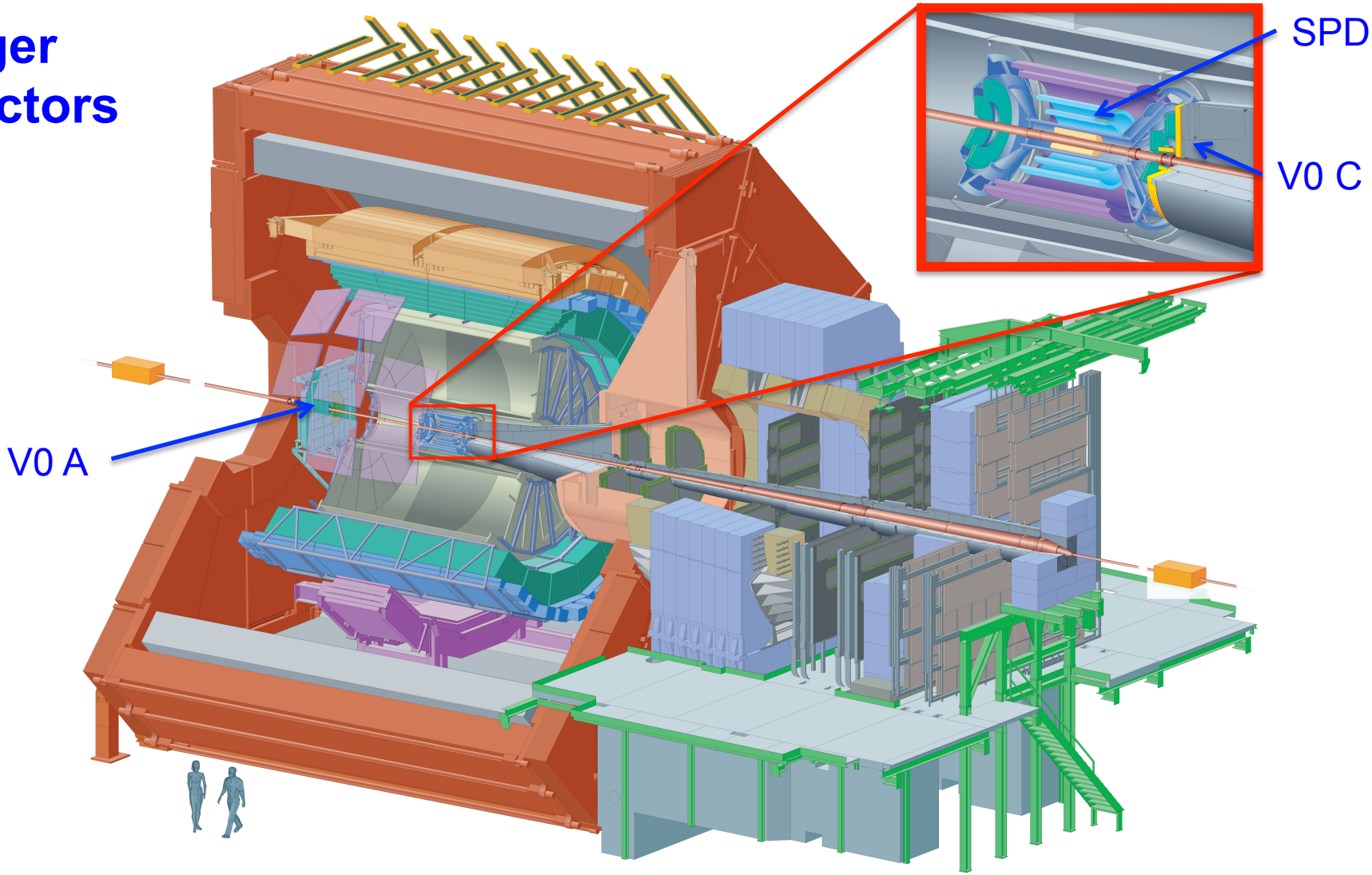
1. ALICE Detector
2. Analysis Procedure
3. Results
4. Summary and Outlook

A Large Ion Collider Experiment



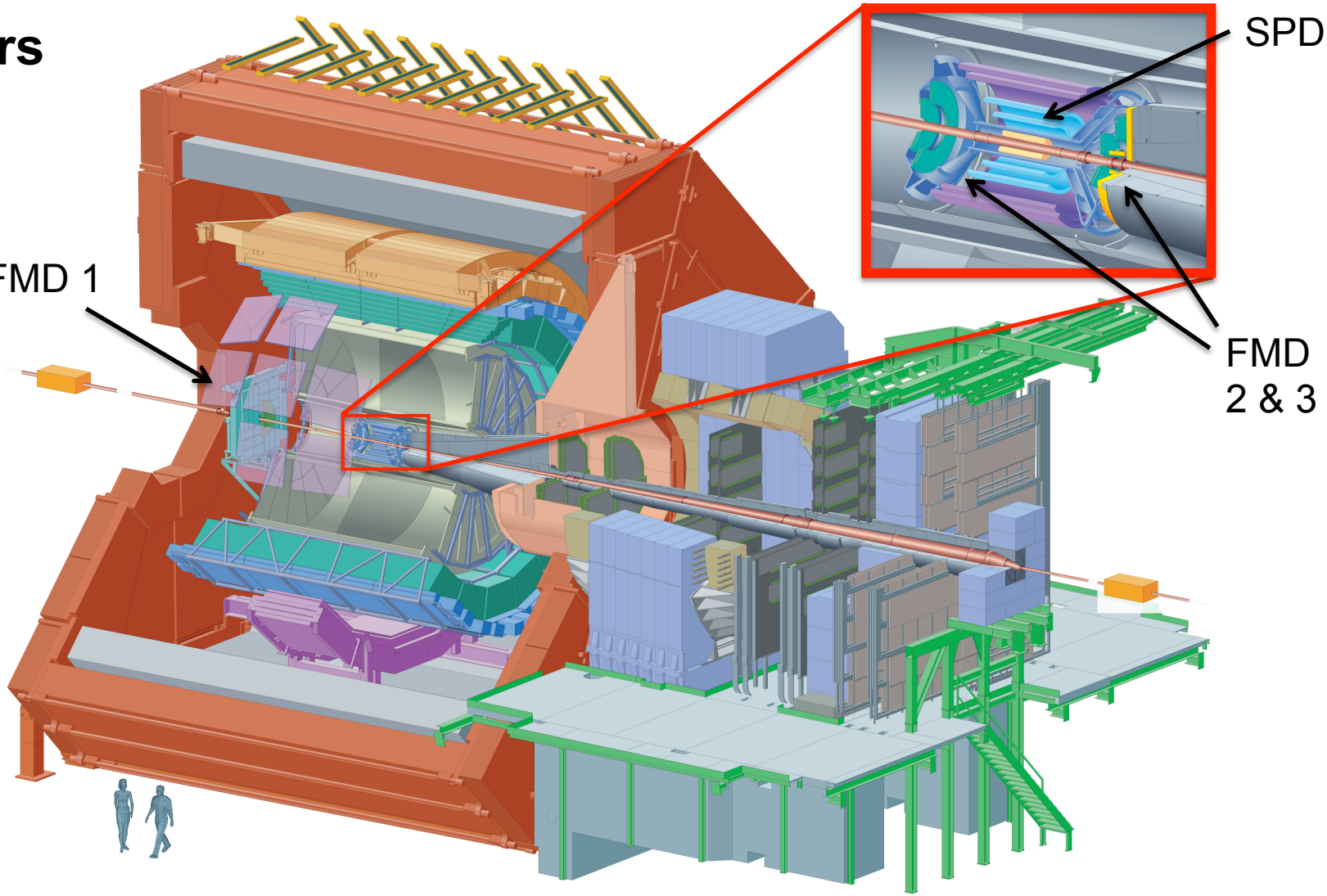
A Large Ion Collider Experiment

Trigger Detectors



A Large Ion Collider Experiment

Detectors Used

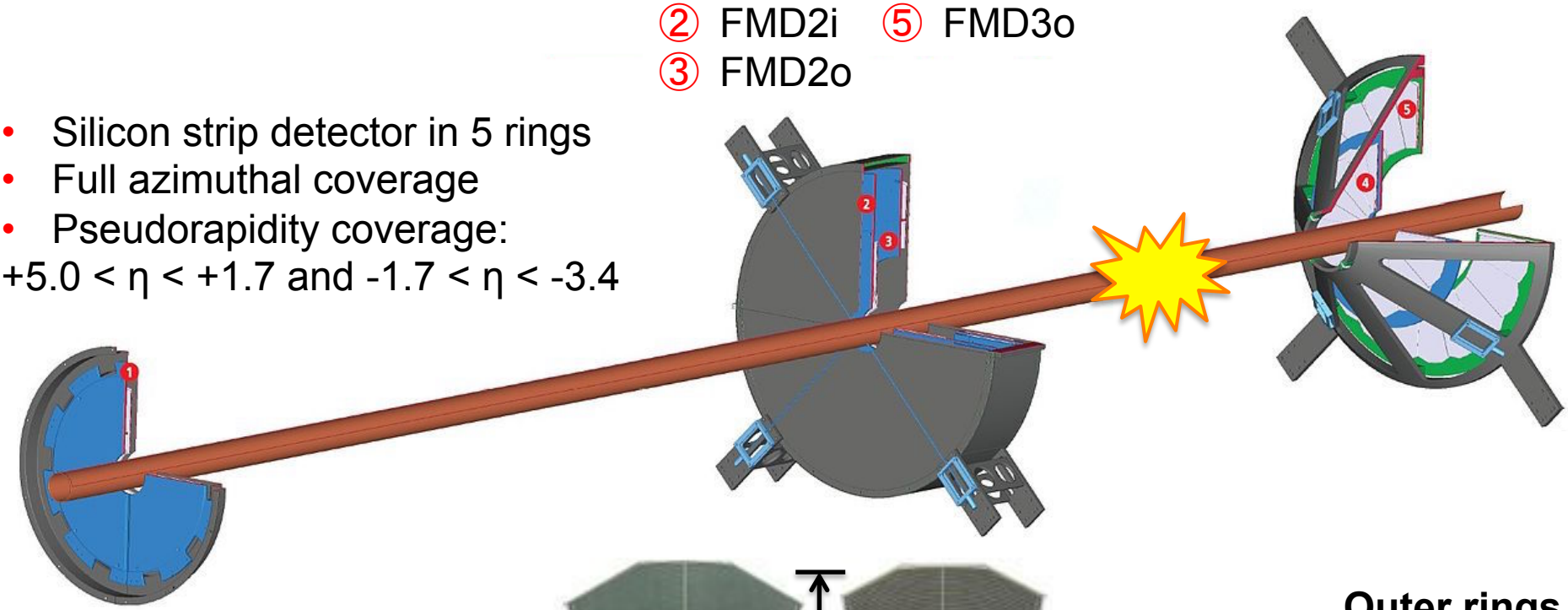


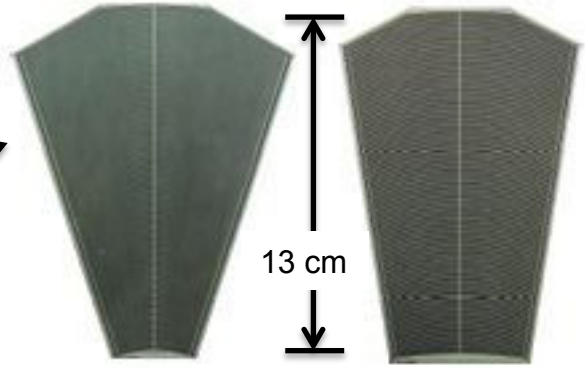
Forward Multiplicity Detector

① FMD1i ④ FMD3i
② FMD2i ⑤ FMD3o
③ FMD2o

- Silicon strip detector in 5 rings
- Full azimuthal coverage
- Pseudorapidity coverage:

$+5.0 < \eta < +1.7$ and $-1.7 < \eta < -3.4$





Inner rings
10 sensors
with 512 silicon strips each

Outer rings
20 sensors
with 256 silicon strips each

Total of 51200 silicon strips

Forward Multiplicity Detector

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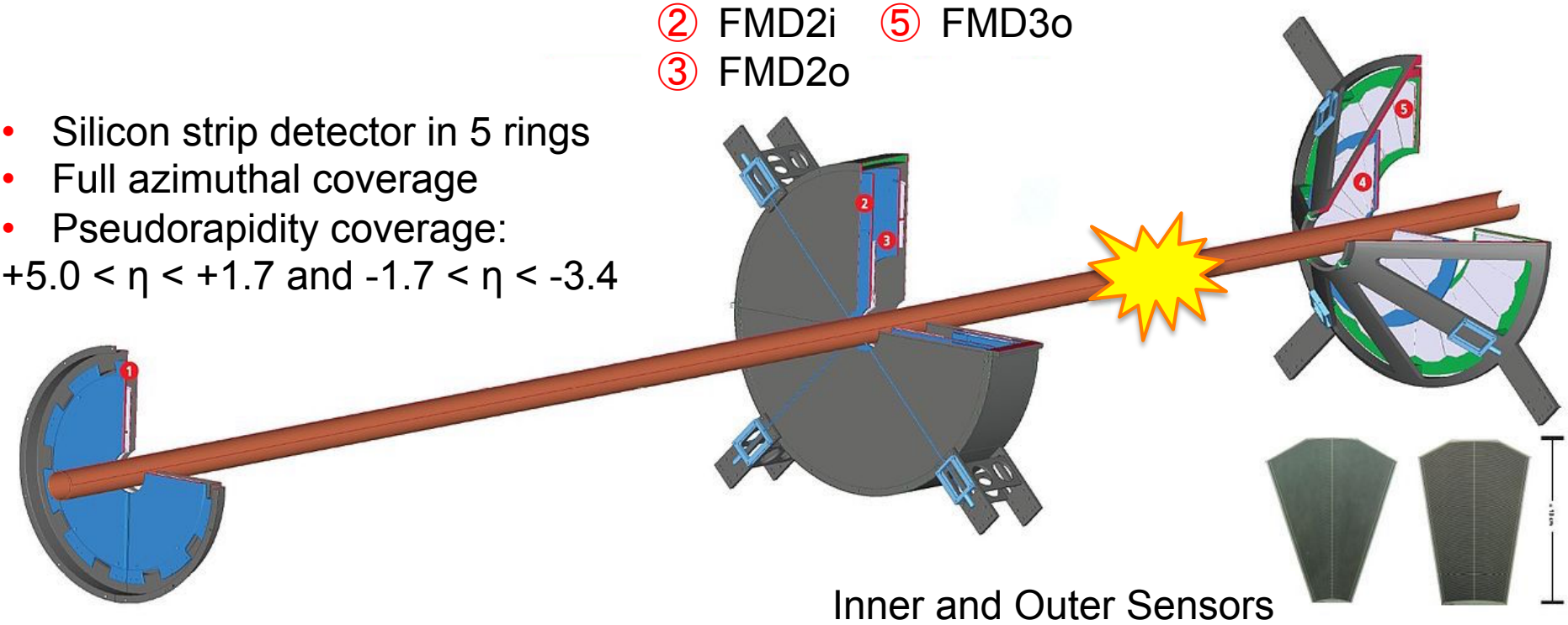


Inner and Outer Sensors

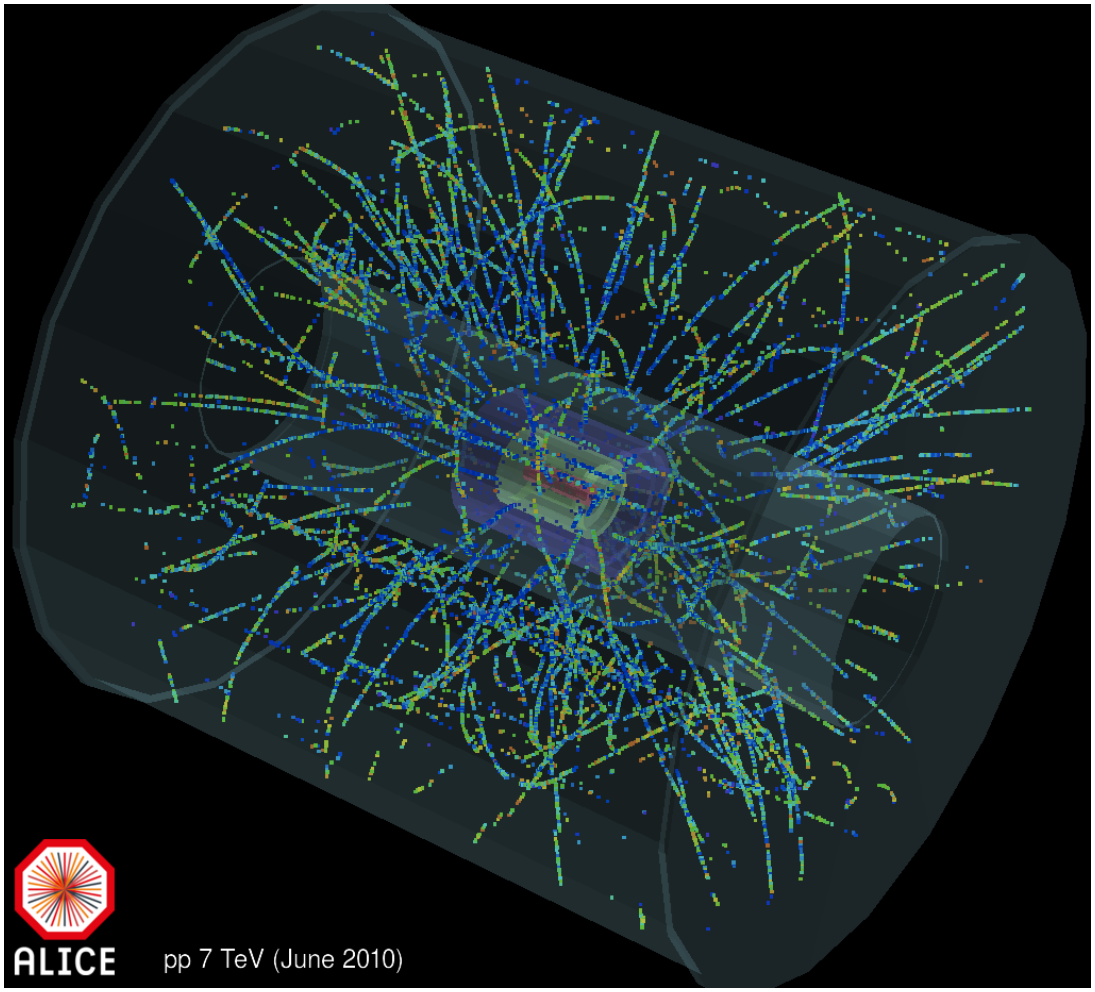
+ Silicon Pixel Detector Inner Layer $-2 < \eta < +2$

Event Display for a pp Collision

Raw Data

↓

Disentangle the Primary Spectrum (*) of Charged Particles



(*) Primary particles are defined in ALICE as particles produced in the collision except decay products from weak decays of light flavour hadrons and muons.

Unfolding

Bayes' theorem [1] $$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

$$\widetilde{R}_{tm} = \frac{R_{mt}P_t}{\sum_{t'} R_{mt'}P_{t'}} \longrightarrow U_t = \sum_m \widetilde{R}_{tm} M_m$$

[1] G. D'Agostini, arXiv:1010.0632 [physics.data-an]

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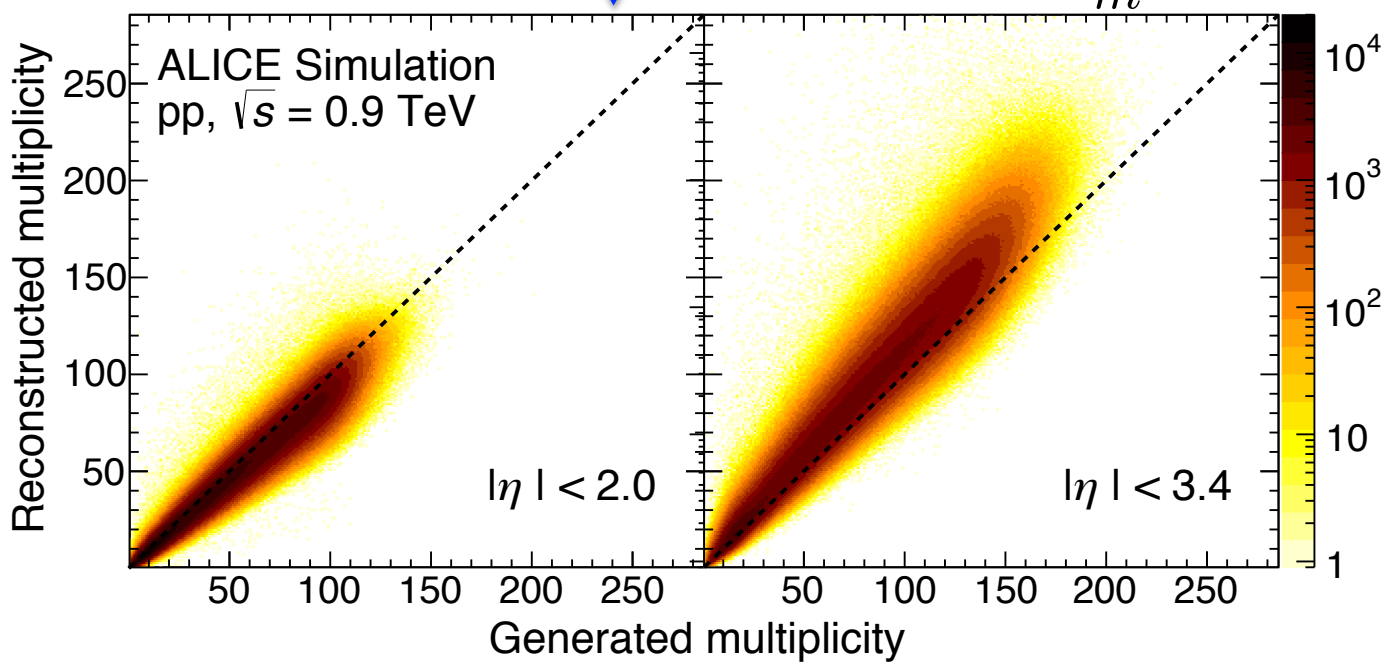

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Trigger and Vertex Efficiency

event class: INEL = Diff + Non-Diff → trigger: MB_{OR} = V0A || SPD || V0C

NSD = (Diff – Single-Diff) + Non-Diff → MB_{AND} = V0A && V0C

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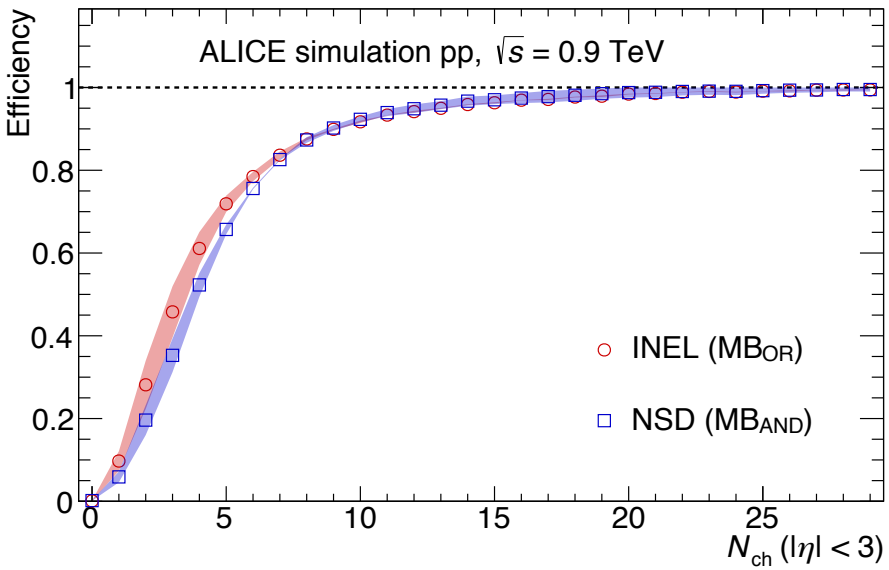
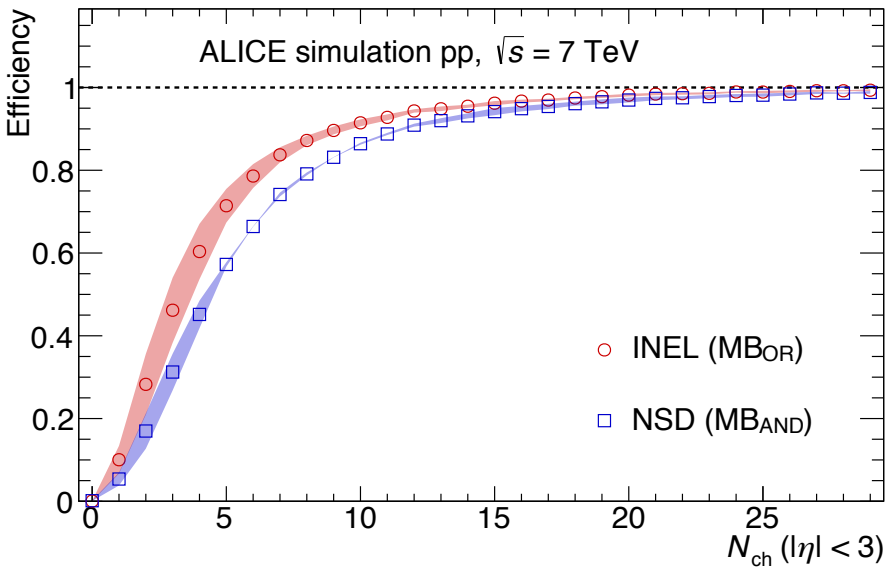
$$\varepsilon_{\mathrm{trig}} = \frac{N_{ch,reco}(\mathrm{trig}\,\&\,|v_{z,reco}| < 4\mathrm{cm})}{N_{ch,gen}(\mathrm{trig}\,\&\,|v_{z,gen}| < 4\mathrm{cm})} \longrightarrow \boxed{U_t = \frac{U_t^*}{\varepsilon_{\mathrm{trig}}}}$$

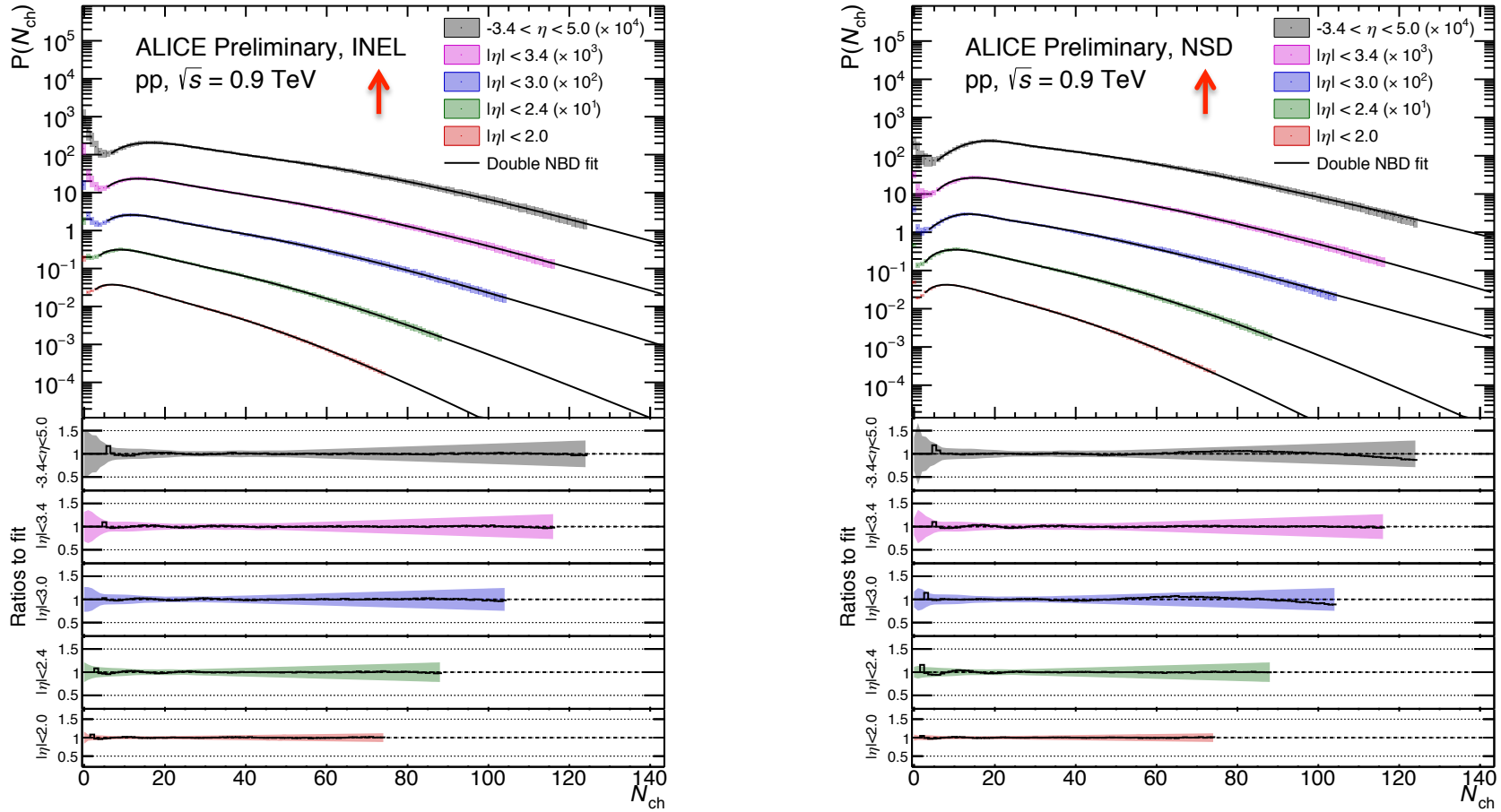




Diffraction tuned [2] generators used: PYTHIA 6 (Perugia 0) and PHOJET.

[2] A. B. Kaidalov and M. G. Poghosyan, arXiv:0909.5156 [hep-ph]

Results for √s = 0.9 TeV



Fit with a **Double Negative Binomial Distribution**:

$$P(n) = \lambda[\alpha P_{NBD}(n, \langle n\rangle_1, k_1) + (1-\alpha)P_{NBD}(n, \langle n\rangle_2, k_2)]$$

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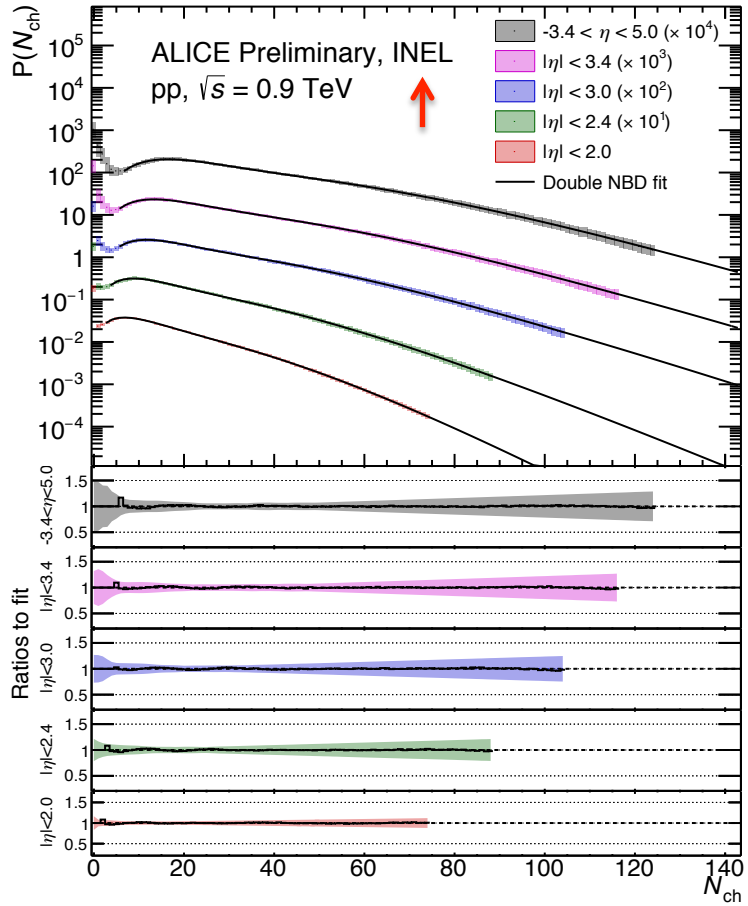

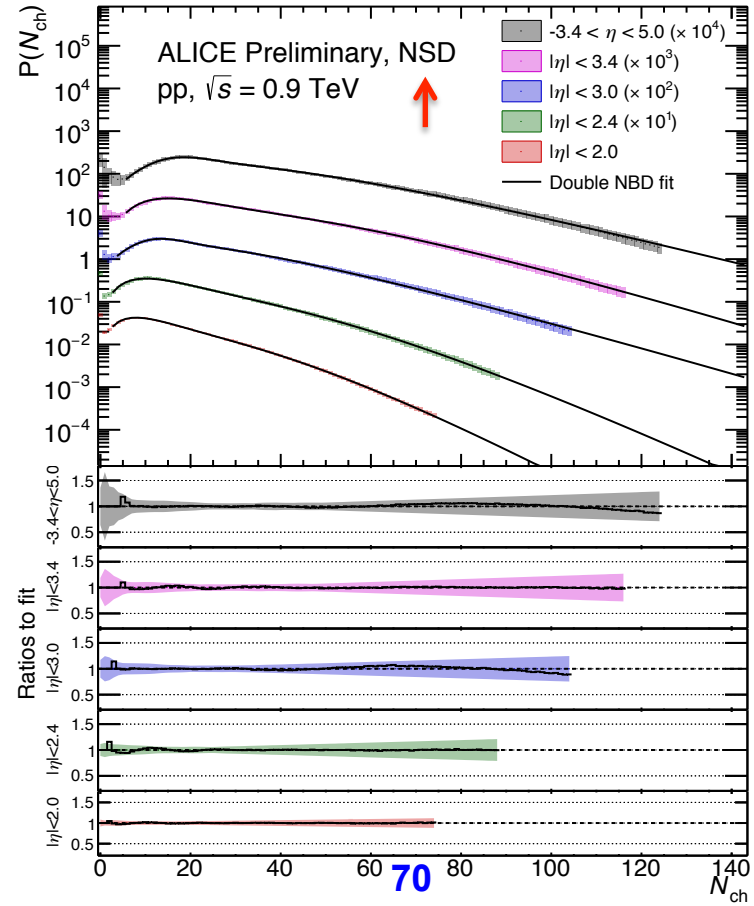

Fit with a **Double Negative Binomial Distribution**: ALICE SPD only: on arXiv today [3]

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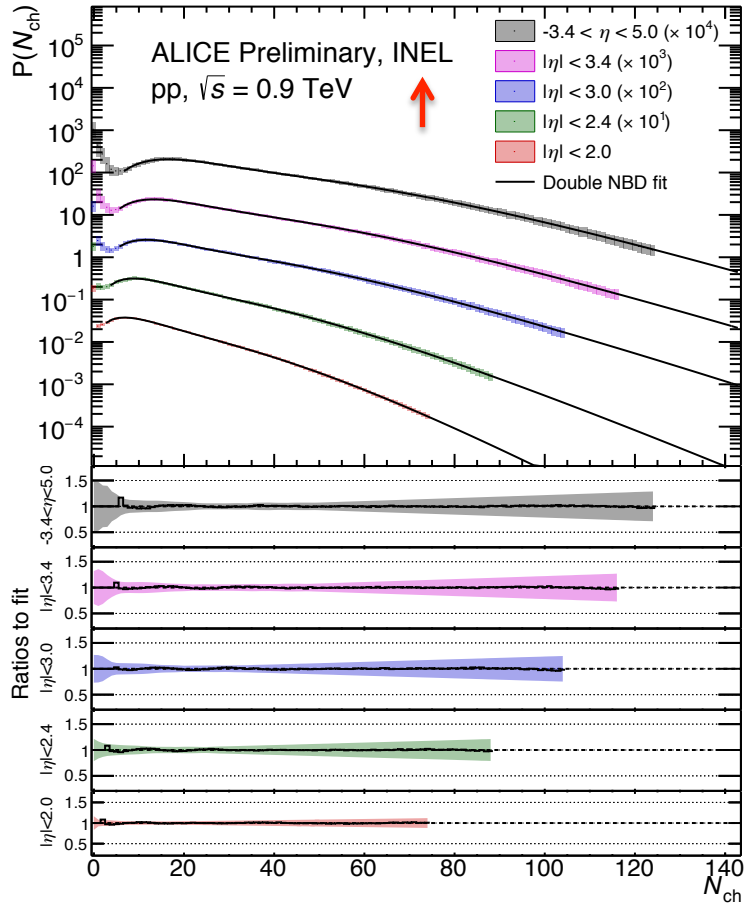

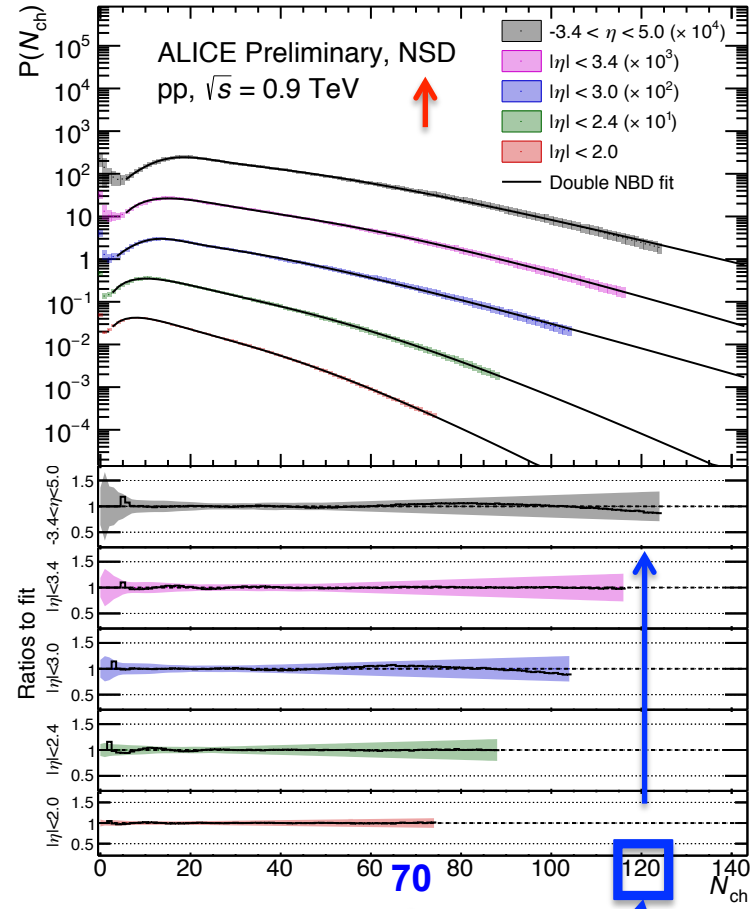

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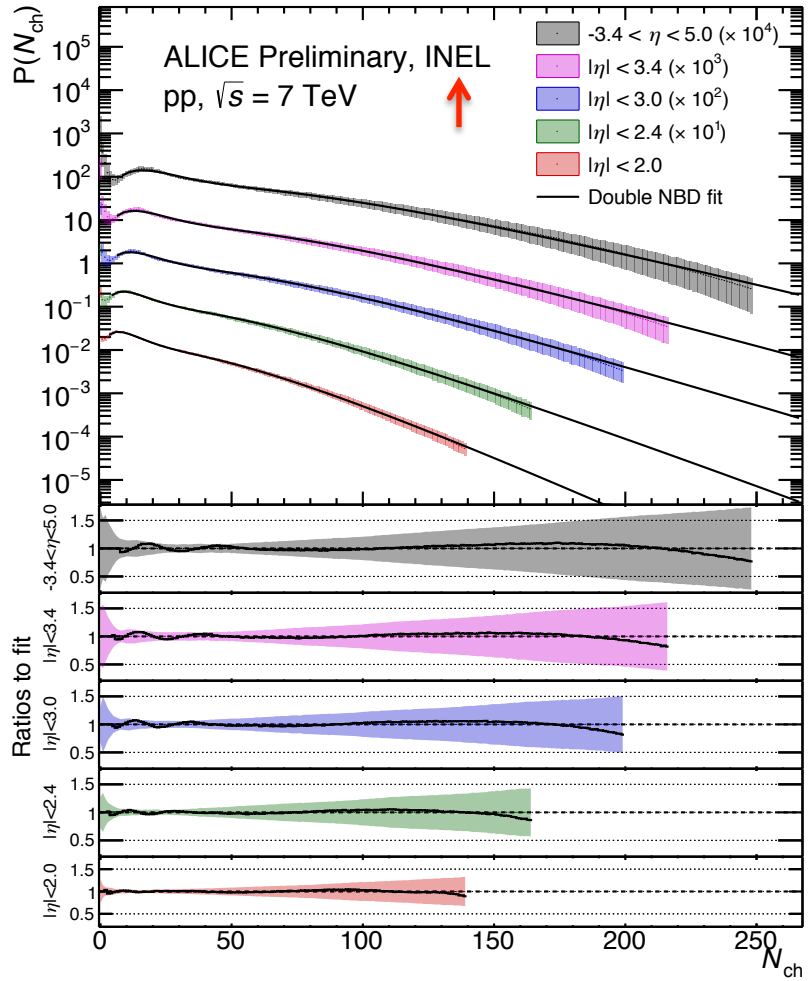
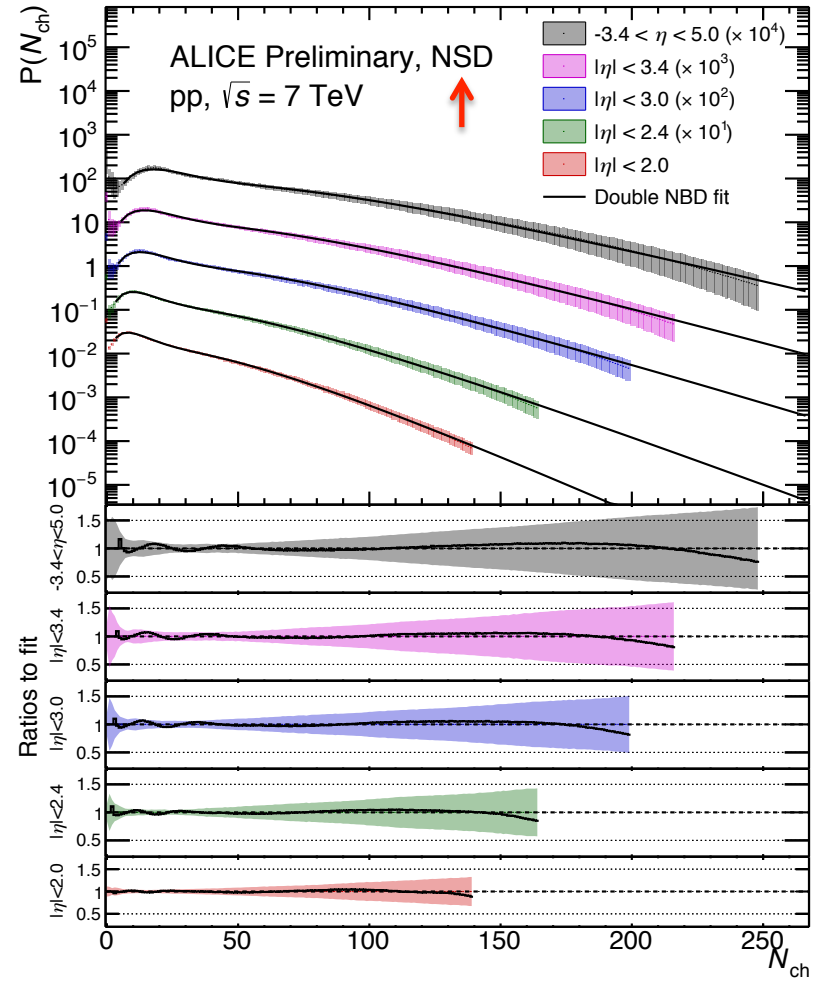
Results for √s = 7 TeV





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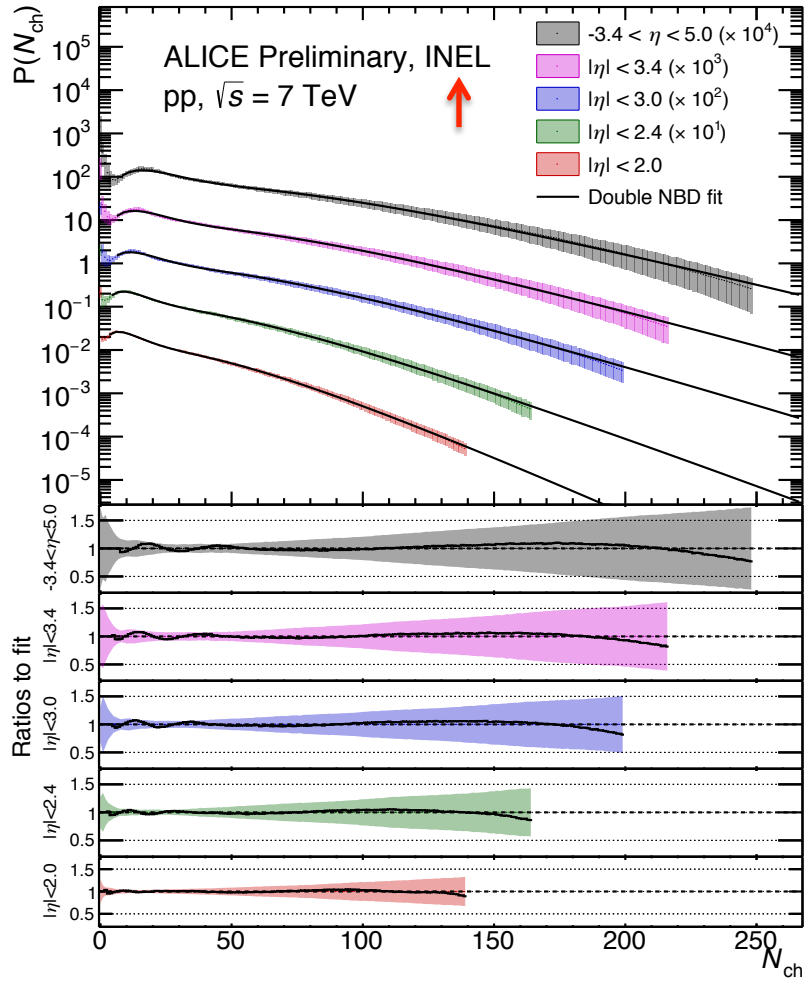

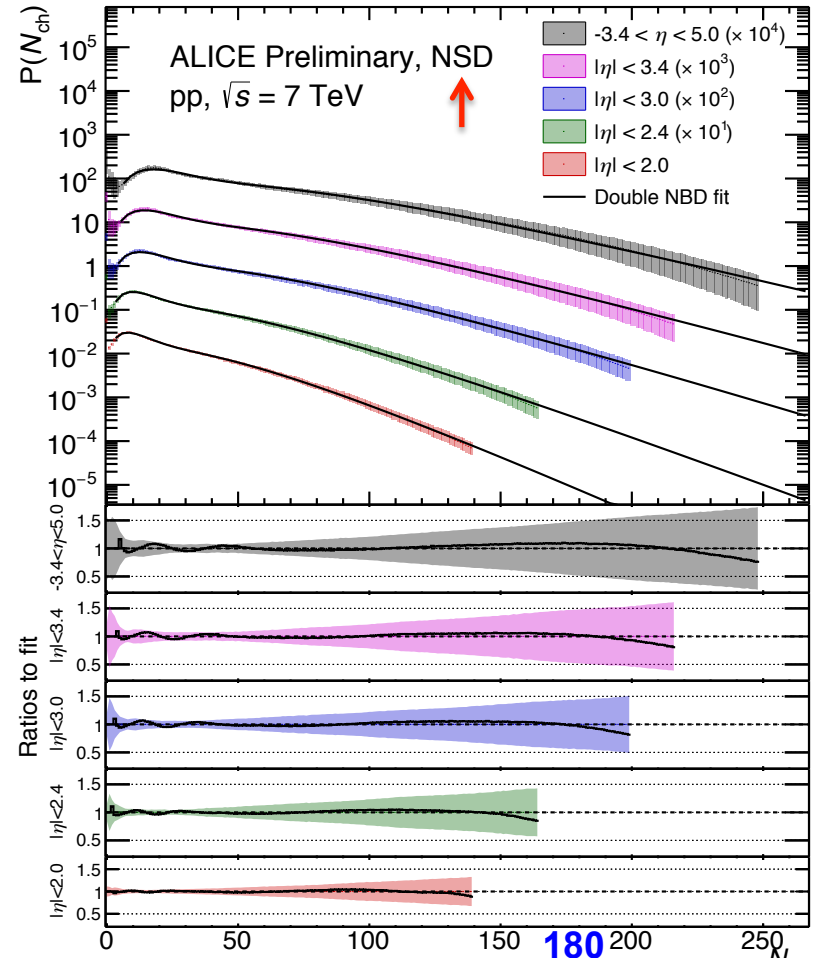

CMS: JHEP 1101,079 [4]

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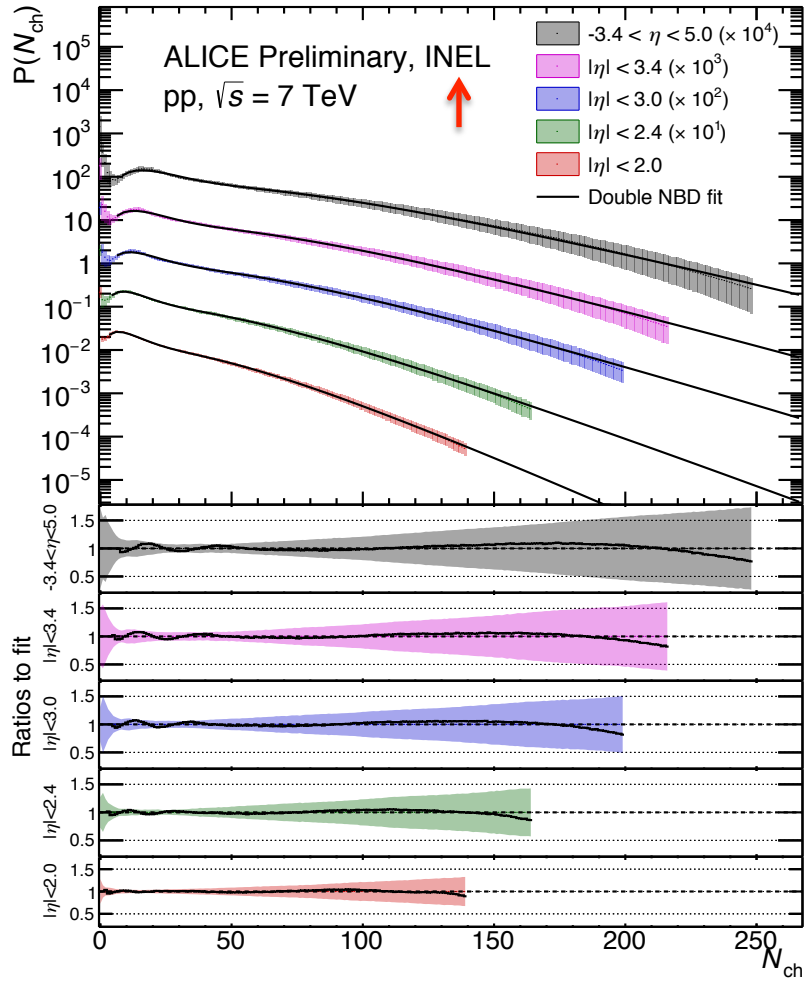

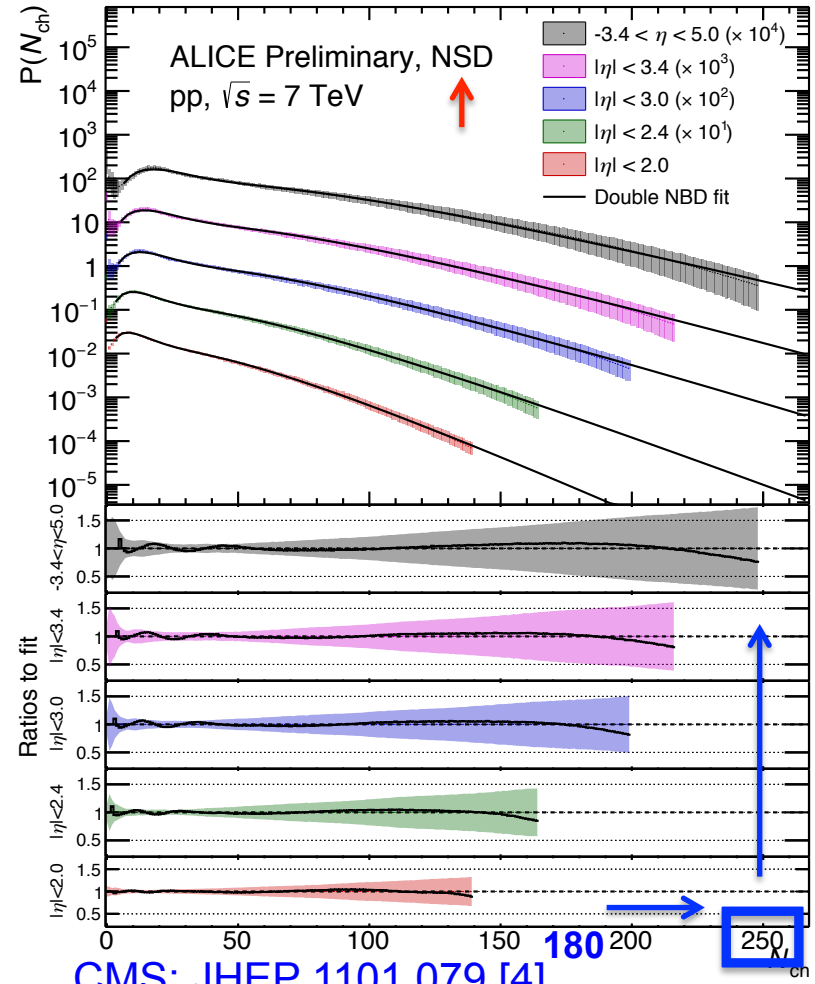

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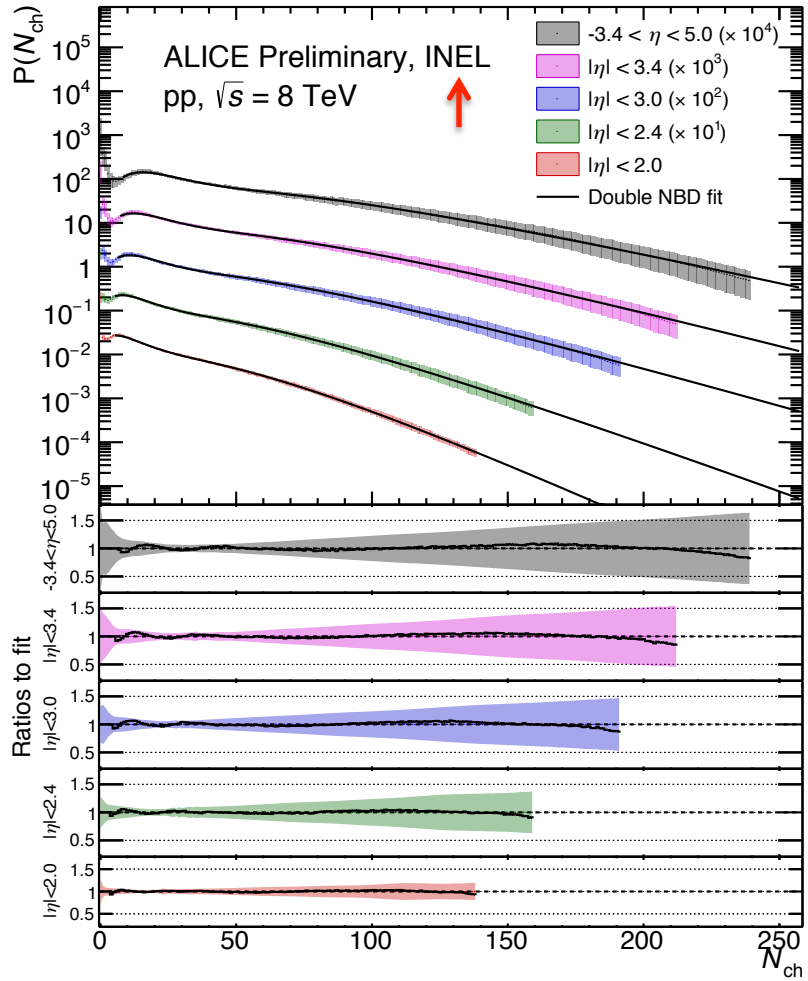
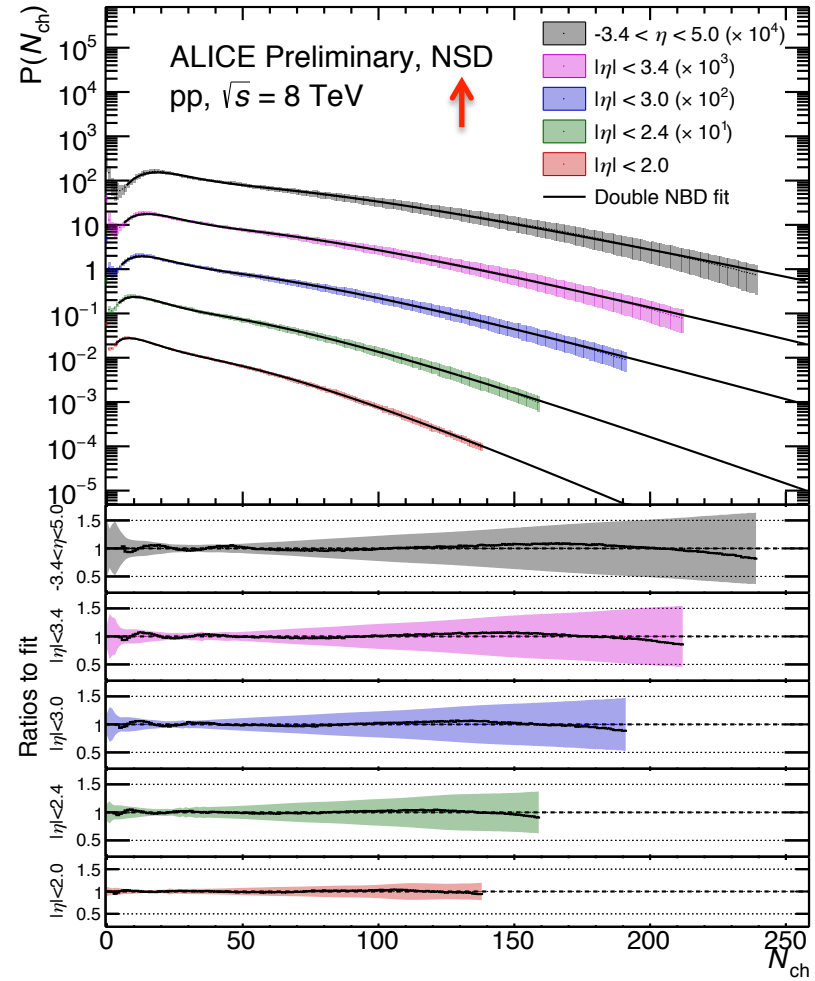
Results for √s = 8 TeV





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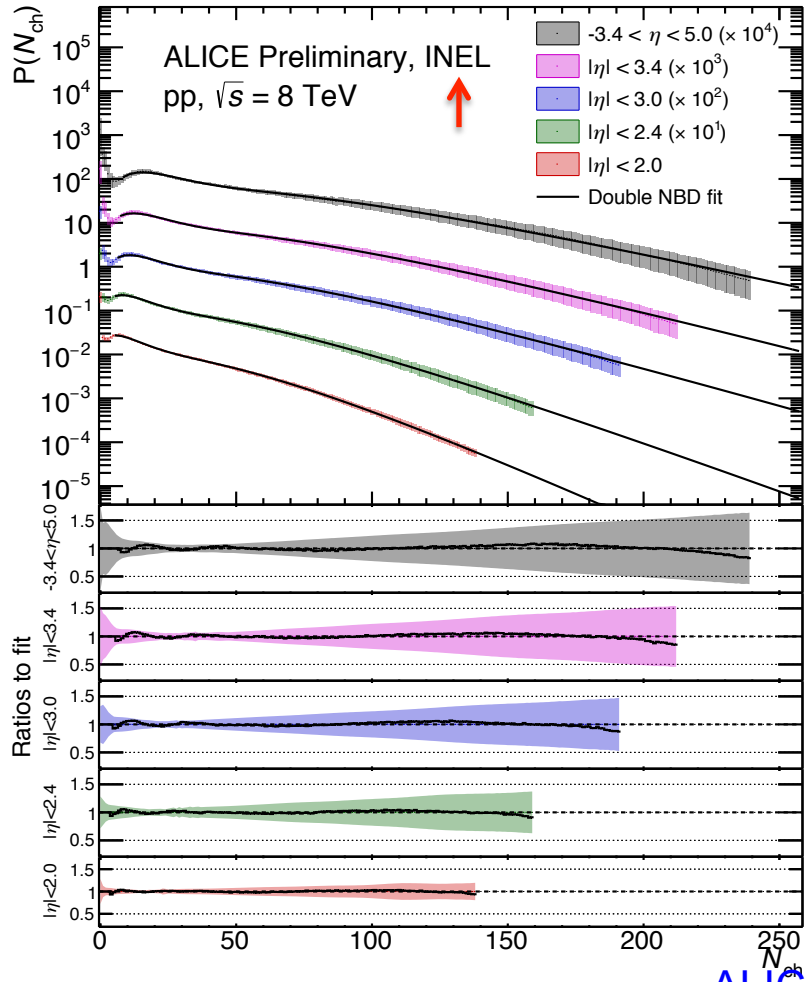

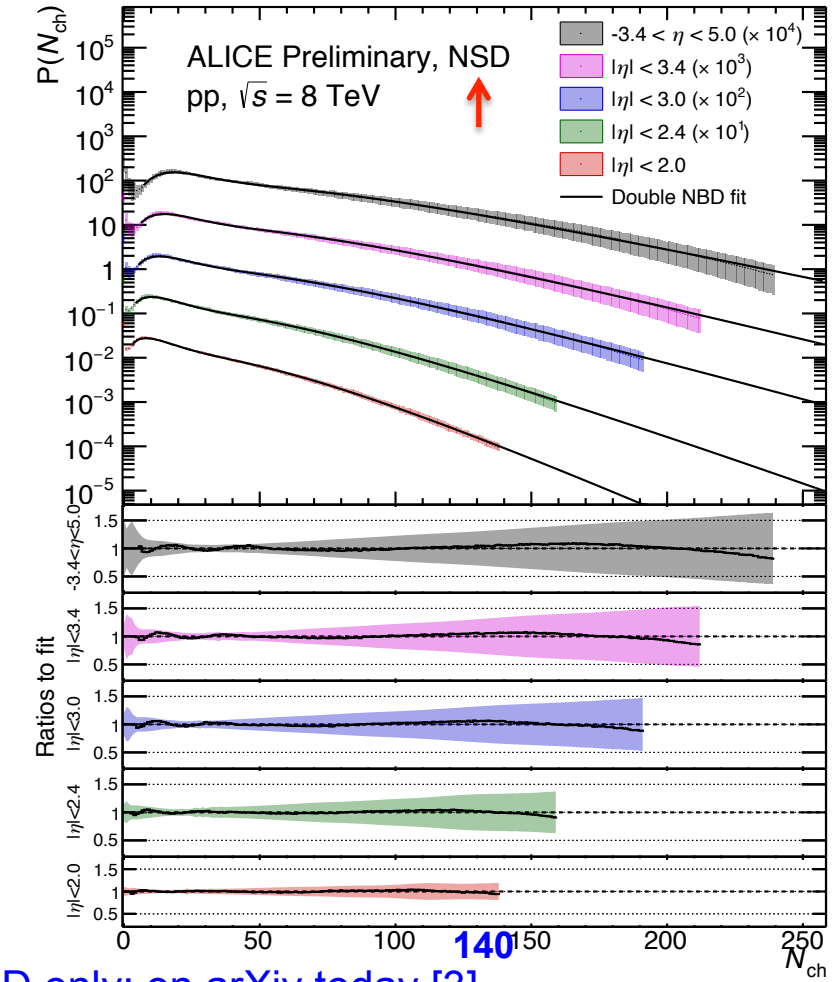

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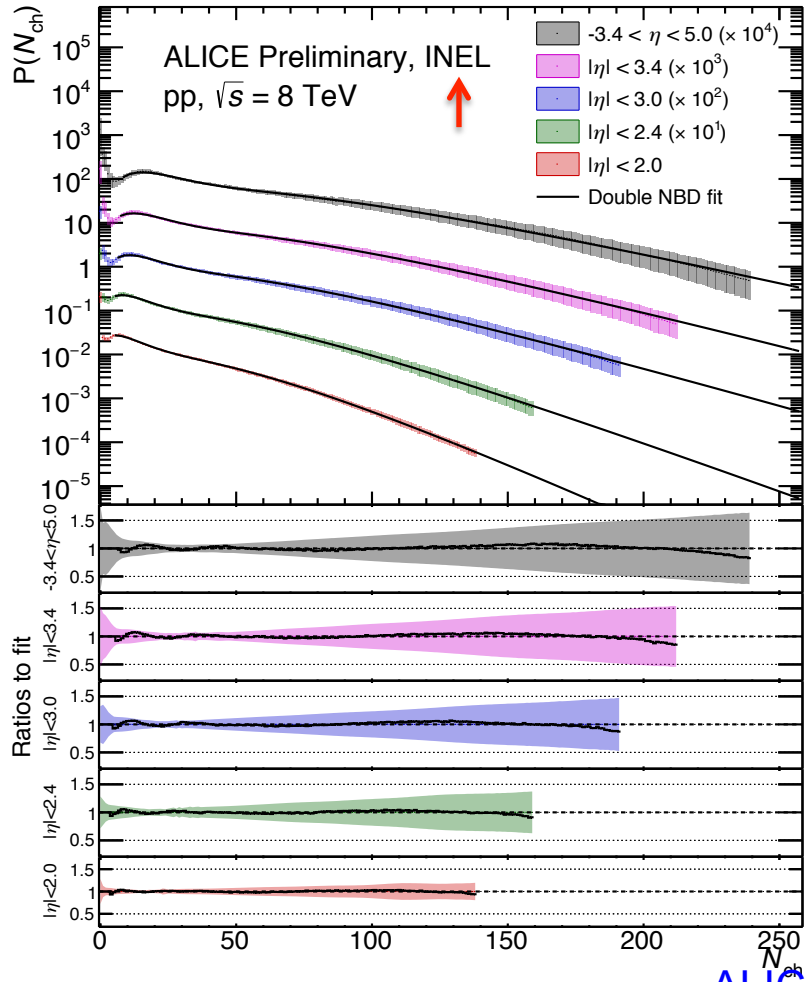

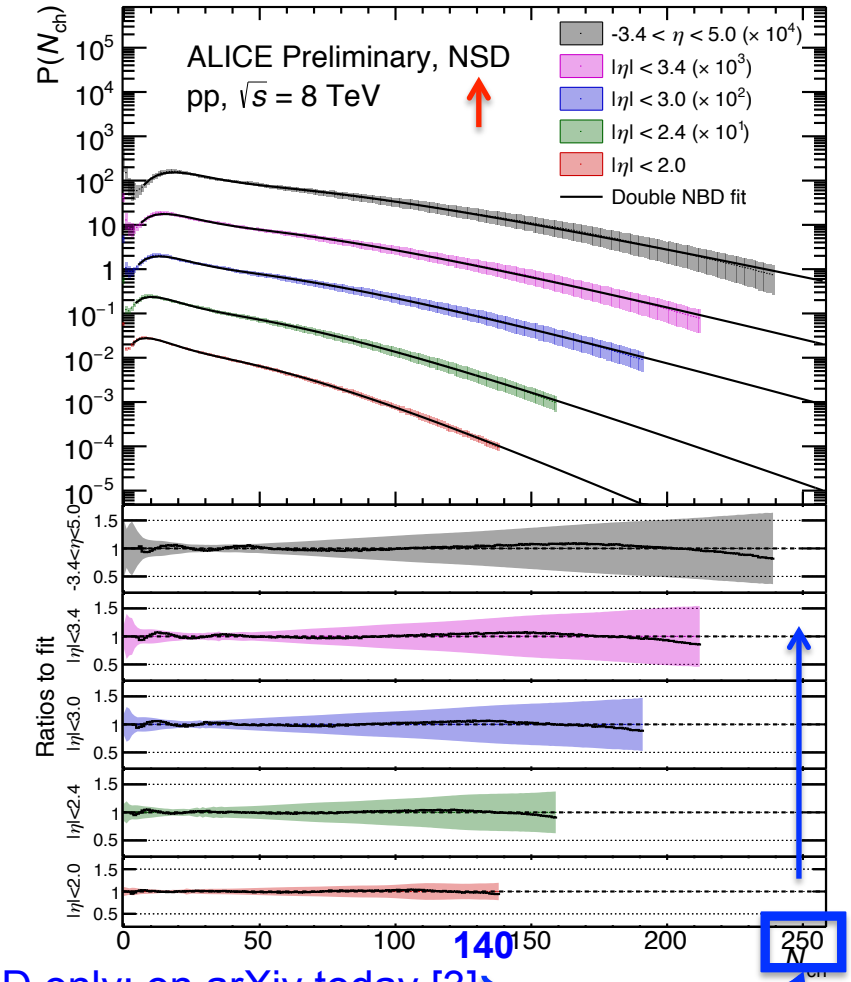

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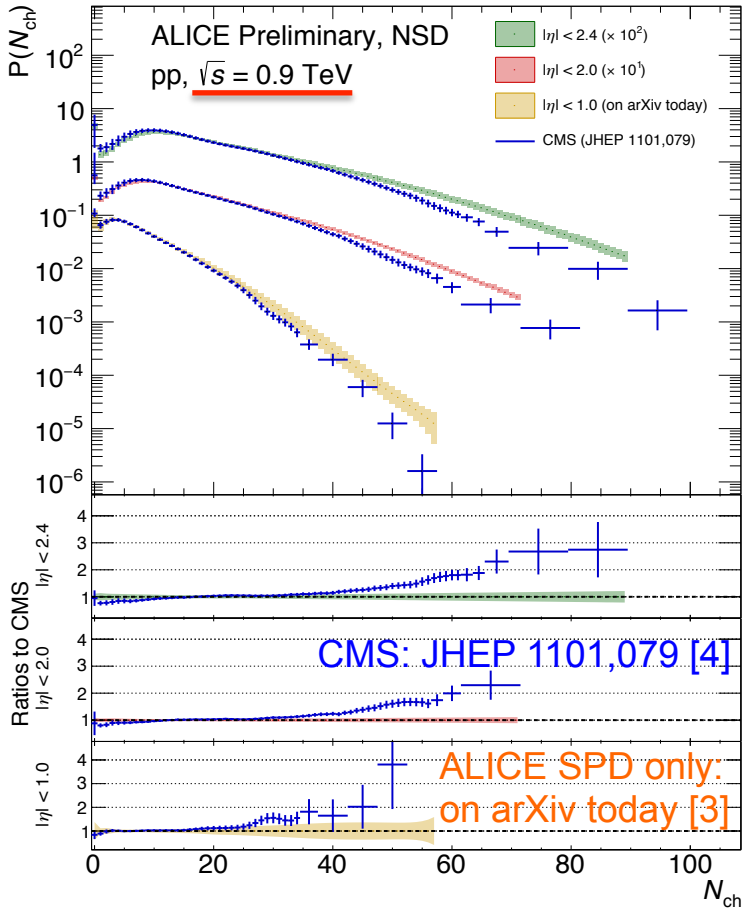
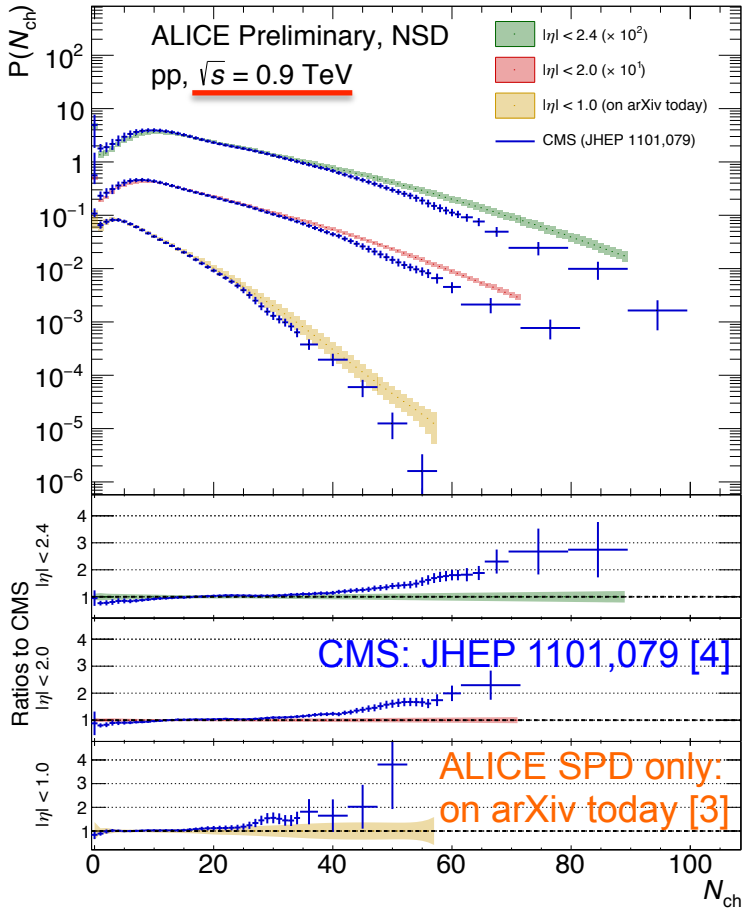
Comparisons with CMS Results

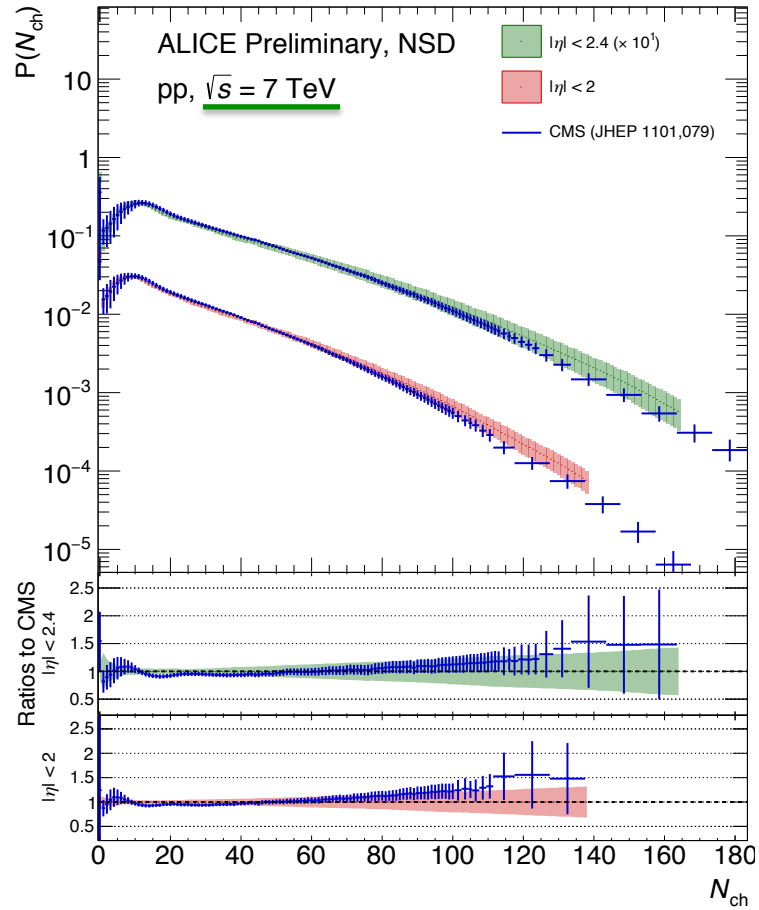


Difference with CMS for **√s = 0.9 TeV**

- no diffraction tuning in CMS
- different cut in diffractive mass

Comparisons with CMS Results





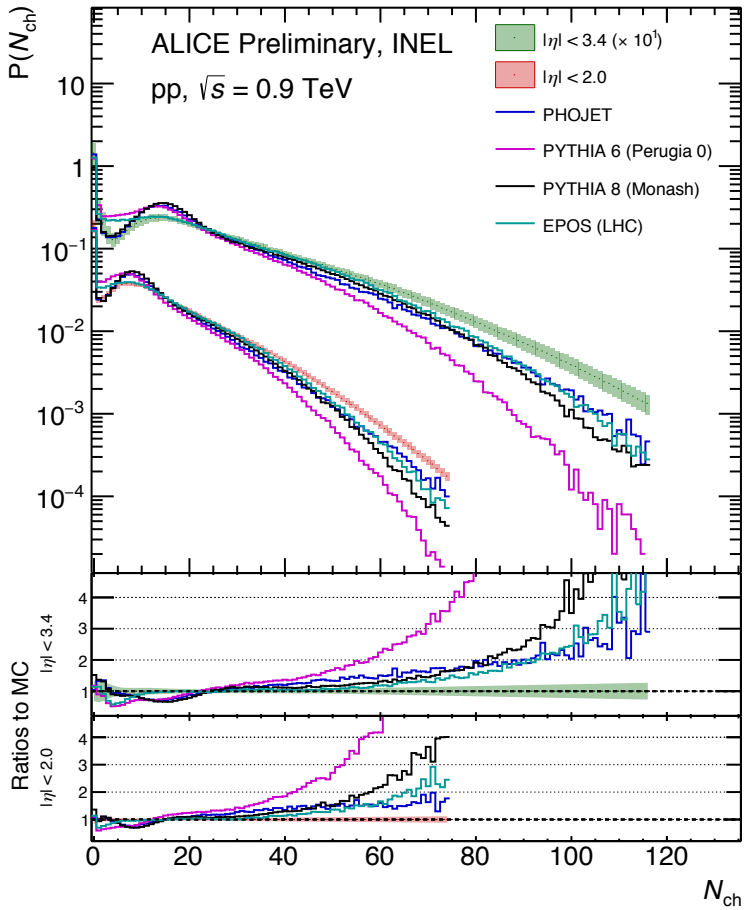
Difference with CMS for **√s = 0.9 TeV**

Good agreement for **√s = 7 TeV**

no diffraction tuning in CMS

different cut in diffractive mass

Comparisons with Monte Carlo



✓ PHOJET tuned to √s = 0.9 TeV

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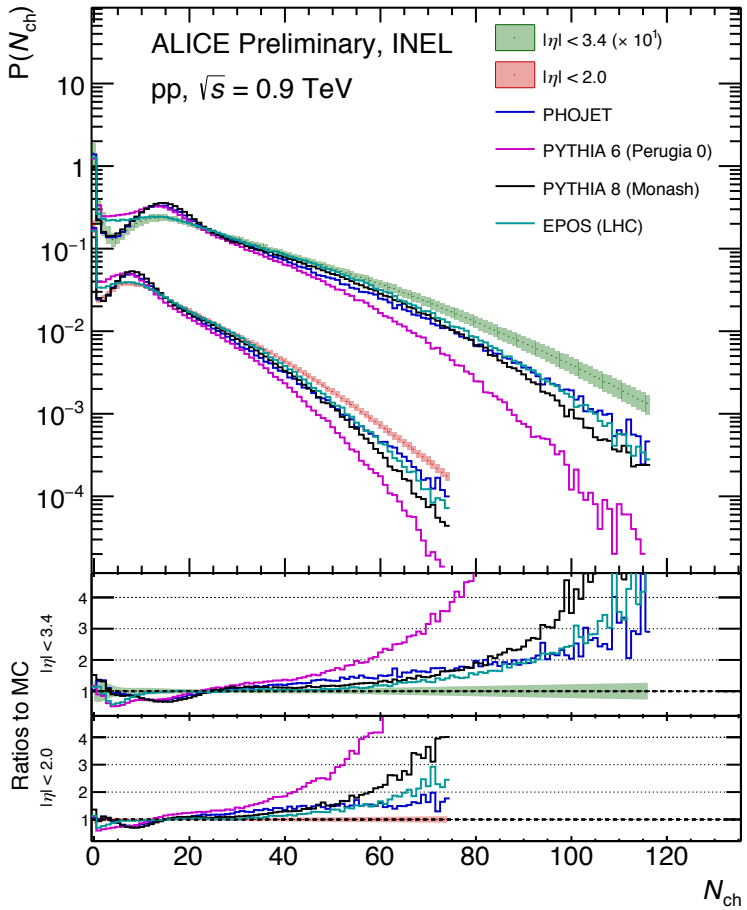
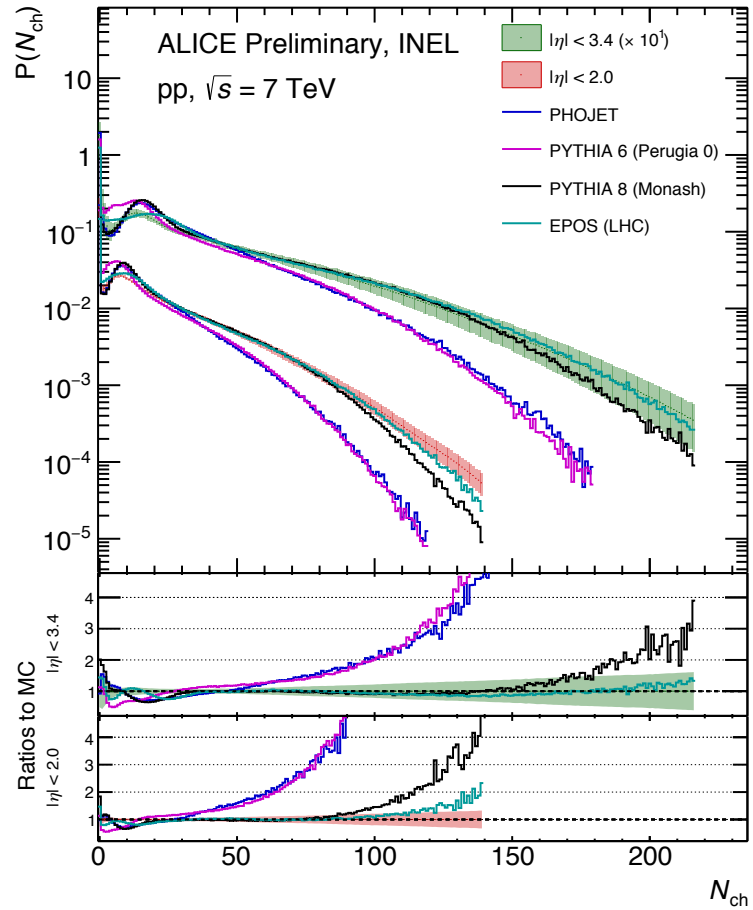




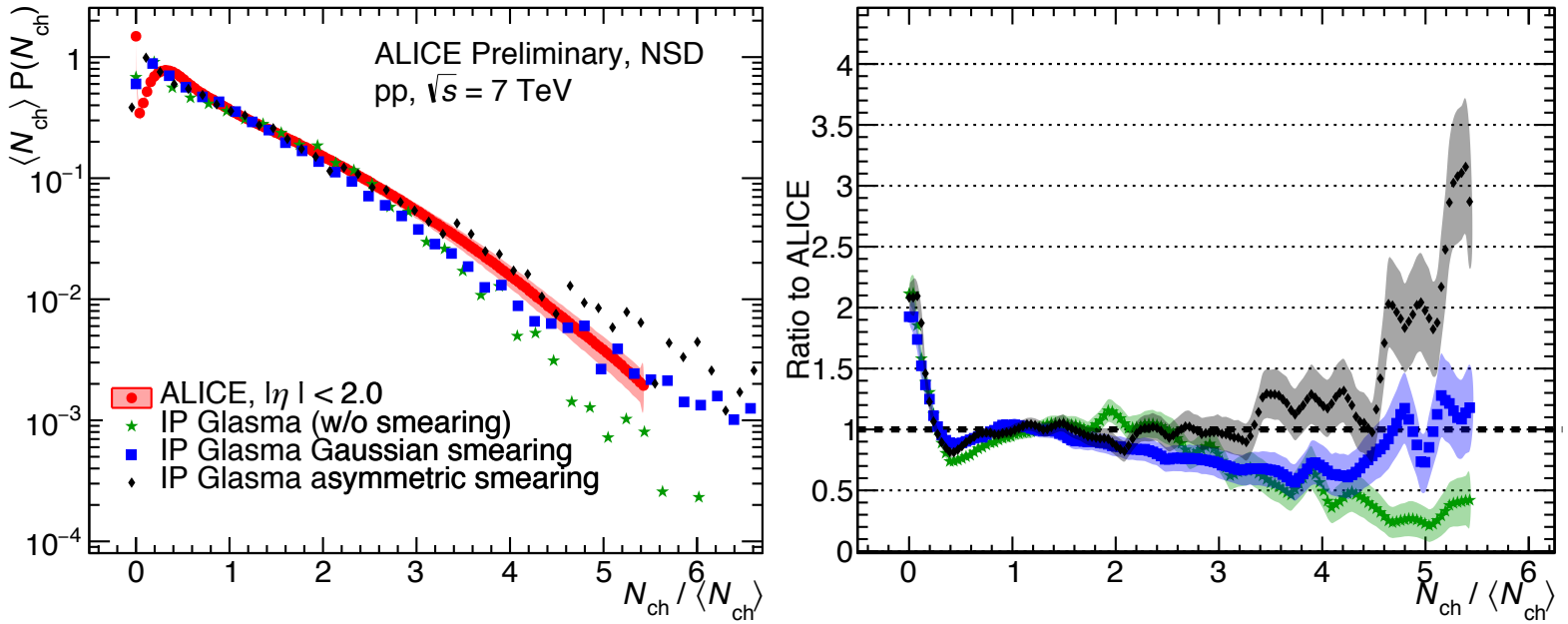
✓ PHOJET tuned to √s = 0.9 TeV

✓ EPOS LHC
✓ PYTHIA 8 Monash

Comparison with IP-Glasma Model

Color Glass Condensate based
1. Color-Charge Fluctuations
2. Glasma fields

green no fluctuations of color charge [5]
blue includes Gaussian fluctuations [5]
black includes asymmetric fluctuations [6]



[5] B. Schenke, P. Tribedy, and R. Venugopalan, Phys.Rev. C89 no. 2, (2014) 024901
[6] L. McLerran and P. Tribedy, arXiv: 1508.03292 [hep-ph]

Summary and Outlook

$P(N_{ch})$ vs N_{ch} from ALICE analyzed:

- **$\sqrt{s}$ = 0.9, 7, and 8 TeV**
- **INEL and NSD**

a **uniquely wide pseudorapidity coverage at the LHC** of more the eight η units, from **$-3.4 < \eta < 5.0$ → extend high-multiplicity reach**

- Multiplicity distributions for **7 TeV** collisions measured for NSD events agree with CMS. For **0.9 TeV**, the results are **systematically higher** in the high multiplicity tails with respect to CMS → different definition of the diffractive mass.

- **Monte Carlo** models and the Color Glass Condensate based **IP–Glasma** model **underestimate** the fraction of high multiplicity events. Exceptions are **EPOS LHC** for 7 TeV and IP-Glasma model with **color-charge fluctuations**, which **model better the tails** of the distributions.

***13 TeV** multiplicity distributions over wide rapidity coming soon!*

Thank you!

References

[1] G. D'Agostini, "Improved iterative Bayesian unfolding," ArXiv e-prints (Oct., 2010) , arXiv: 1010.0632 [physics.data-an].

[2] A. B. Kaidalov and M. G. Poghosyan, "Description of soft diffraction in the framework of reggeon calculus: Predictions for LHC," arXiv:0909.5156 [hep-ph].

[3] **ALICE** Collaboration, A. Jaroslav et al., "Charged-particle multiplicities in proton–proton collisions at √s = 0.9 to 8 TeV," on arXiv today.

[4] **CMS** Collaboration, V. Khachatryan et al., "Charged particle multiplicities in pp interactions at √s = 0.9, 2.36, and 7 TeV," JHEP 1101 (2011) 079, arXiv:1011.5531 [hep-ex].

[5] B. Schenke, P. Tribedy, and R. Venugopalan, "Multiplicity distributions in p+p, p+A and A+A collisions from Yang-Mills dynamics," Phys.Rev. C89 no. 2, (2014) 024901, arXiv:1311.3636 [hep-ph].

[6] L. McLerran and P. Tribedy, Intrinsic Fluctuations of the Proton Saturation Momentum Scale in High Multiplicity p+p Collisions, arXiv: 1508.03292 [hep-ph].

Backup

Systematic Uncertainties Overview

1. **Efficiency Correction**
   - derived from the difference between diffractive tuned PYTHIA 6 and PHOJET
   - influences the first bins of the distributions
2. **Run-to-run Fluctuations**
   - derived analyzing different runs to study the effect of run conditions
3. **Unfolding**
   - covariance matrix obtained from Bayesian Unfolding procedure
4. **Counting Methods**
   - variation of 5% of the cuts used in the FMD for counting the particles and performing the energy loss fits
5. **Material Budget**
   - derived from the missing information of the material in front of the FMD
   - major source of systematics

On average, the systematics are of around:

- 25% in the first bins
- 7% around the mean value
- 40-50% in the last bins.

In general, they increase increasing the pseudorapidity range and the collision energy.

Koba-Nielsen-Olesen Scaling

Nucl.Phys., vol. B40, pp. 317-334, 1972

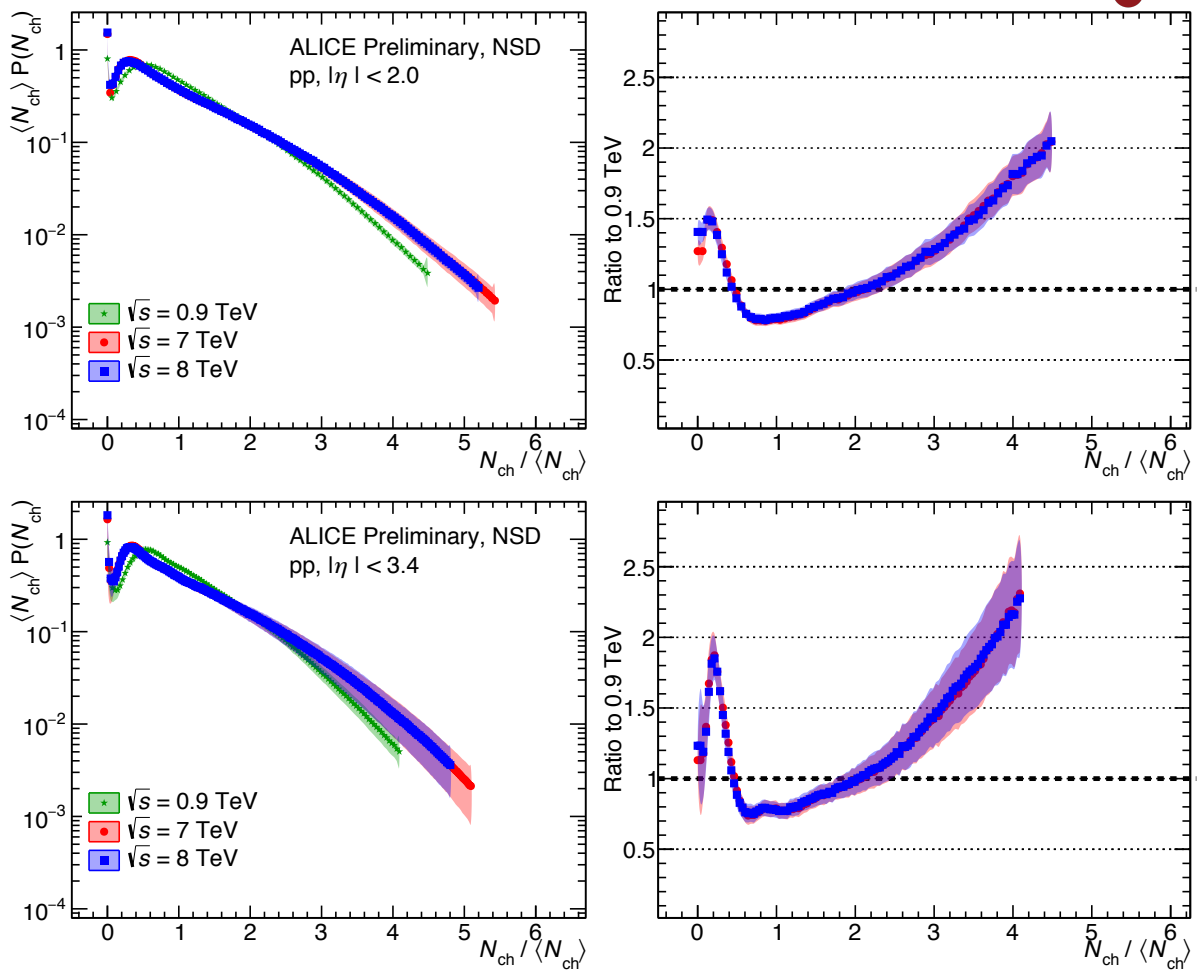
1. Feynman Scaling

$$\langle N \rangle \propto \ln W \propto \ln \sqrt{s}$$

2. Moments define uniquely the distribution

$$c_q = \frac{\langle n^q \rangle}{\langle n \rangle^q}$$

$$P_n(s) = \frac{1}{\langle n \rangle} \psi\left(\frac{n}{\langle n \rangle}\right)$$



KNO scaling is violated

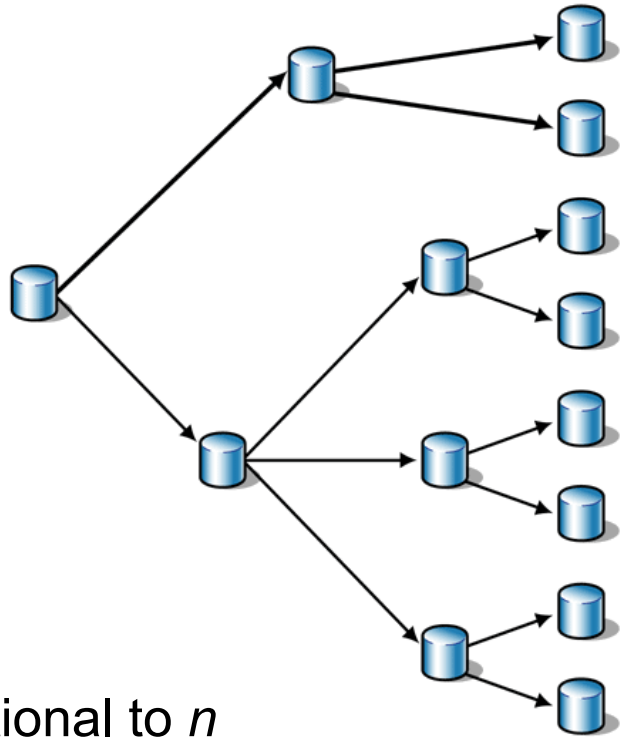
for all the pseudorapidity ranges probed → More violated for wider ranges (spectrum of the events is harder)

Negative Binomial Distributions

Clusters Model Z.Phys., vol. C30, p. 391, 1986

Ancestor + daughters

Cascade Process

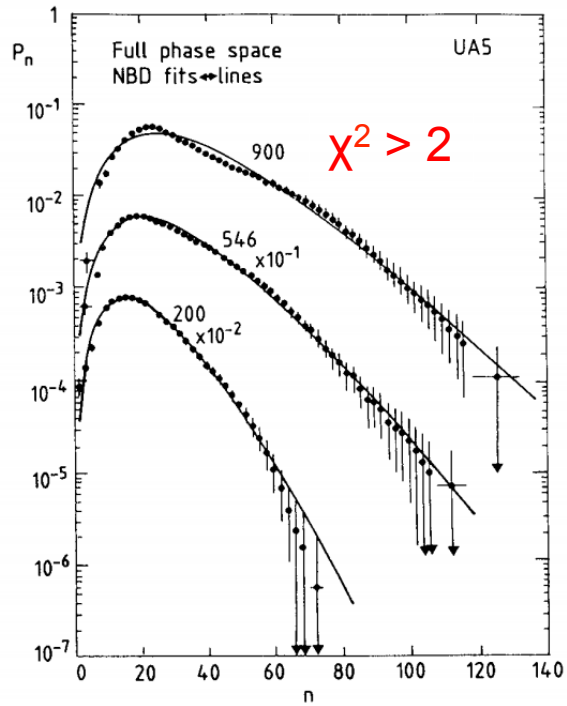


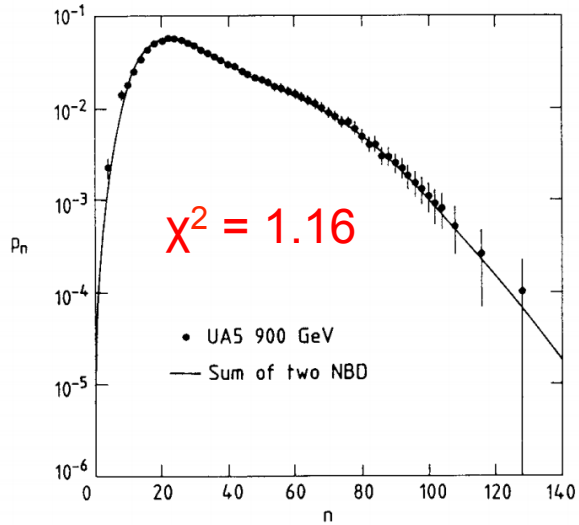
***(n+1)th* particle**

1. ancestor ⟶ constant term
2. emitted by preexisting cluster ⟶ proportional to *n*

$$P(n;\langle n\rangle;k) = \binom{n+k-1}{k-1}\left(\frac{1}{1+\langle n\rangle/k}\right)^k\left(\frac{\langle n\rangle/k}{1+\langle n\rangle/k}\right)^n$$

Double Negative Binomial Distributions





CERN-EP-89-135, C89-03-20.3

1. *w* mini-jets
2. $\langle n_{semi-hard} \rangle \approx 2 \langle n_{soft} \rangle$
3. soft obeys KNO!

$$P_n^{total}(w, \langle n_{soft} \rangle, k_{soft}, \langle n_{semi-hard} \rangle, k_{semi-hard}) =$$
$$= (1-w) P_{NBD}^{soft}(n; \langle n_{soft} \rangle, k_{soft}) + w P_{NBD}^{semi-hard}(n; \langle n_{semi-hard} \rangle, k_{semi-hard})$$