Recent results on hard and rare probes with ALICE

LHCP2020
May 25-30, 2020

Alena Gromada for the ALICE Collaboration

8th Edition of the Large Hadron Collider Physics Conference

25 May 2020

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

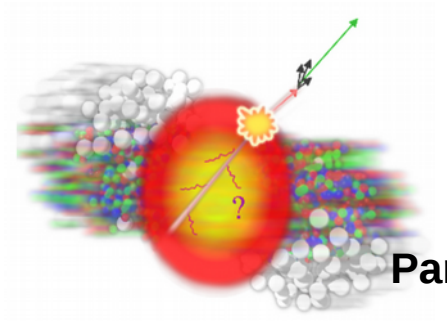
GSI

ALICE

Hard and rare probes in ...

Pb–Pb

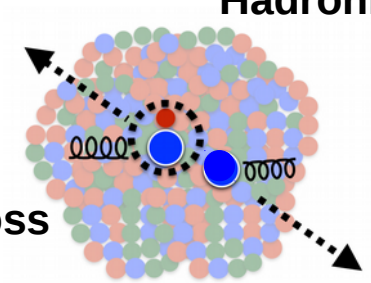
Jets



Parton energy loss

Open heavy flavors

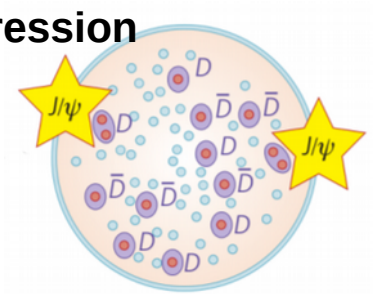
Hadronization



Degree of heavy-flavor thermalization

Quarkonia

(Re)generation and suppression



P. Braun-Munzinger, J. Stachel, *Nature* 448 (2007) 302

Hard and rare probes in ...

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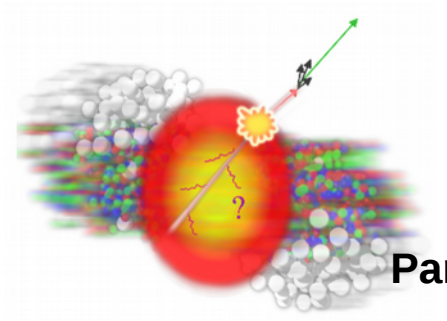

Parton energy loss

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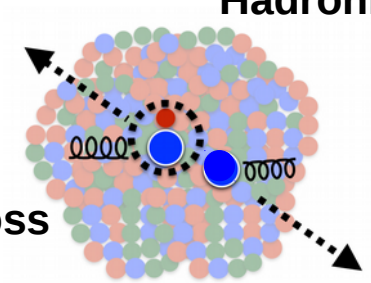
Hadronization



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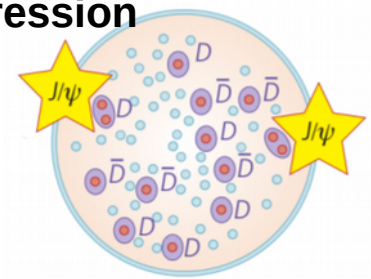
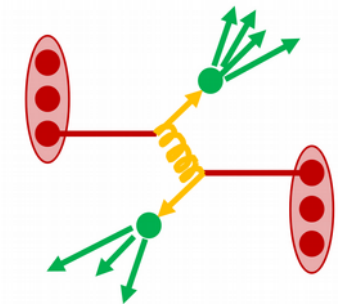
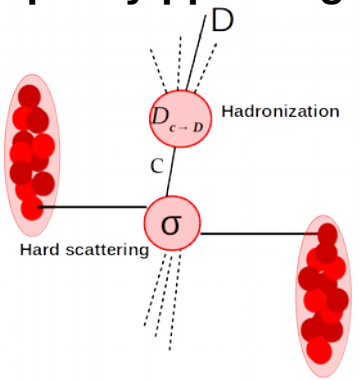


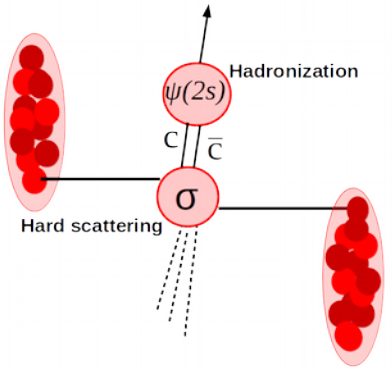
P. Braun-Munzinger, J. Stachel, *Nature* 448 (2007) 302

pp

pp: testing pQCD, investigating hadronization, reference for Pb–Pb
high multiplicity pp: bridging to Pb–Pb



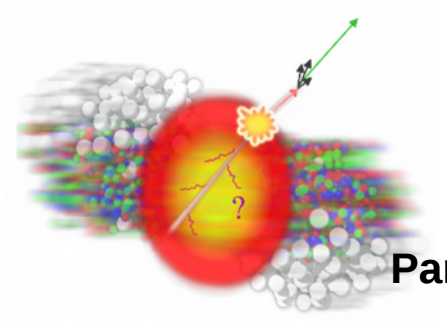




Hard and rare probes in ...

Pb–Pb

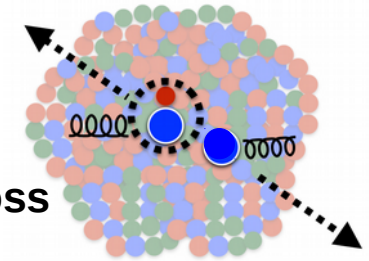
Jets



Parton energy loss

Open heavy flavors

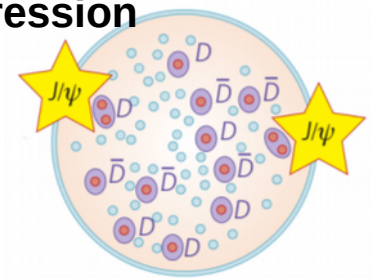
Hadronization



Degree of heavy-flavor thermalization

Quarkonia

(Re)generation and suppression



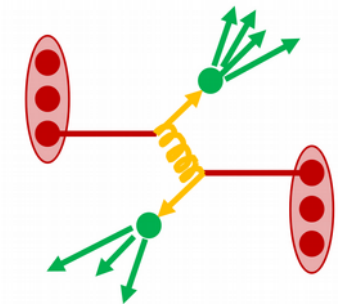
See talk by R. Vertesi
Wednesday 15:03

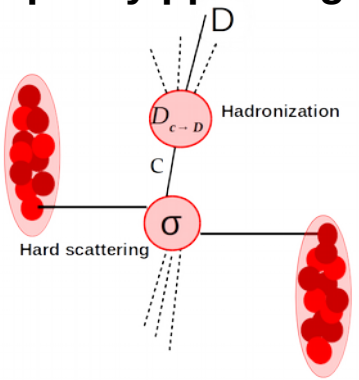
See talk by C. Huang
Wednesday 15:21

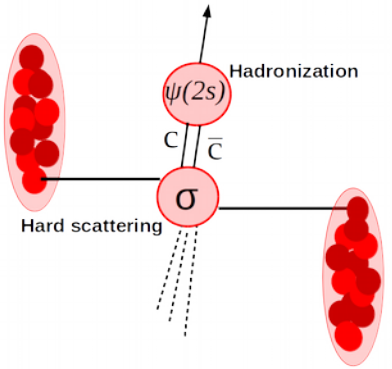
pp

See talk by C. Terrevoli
Friday 14:33

pp: testing pQCD, investigating hadronization, reference for Pb–Pb
high multiplicity pp: bridging to Pb–Pb







P. Braun-Munzinger, J. Stachel, *Nature* 448 (2007) 302

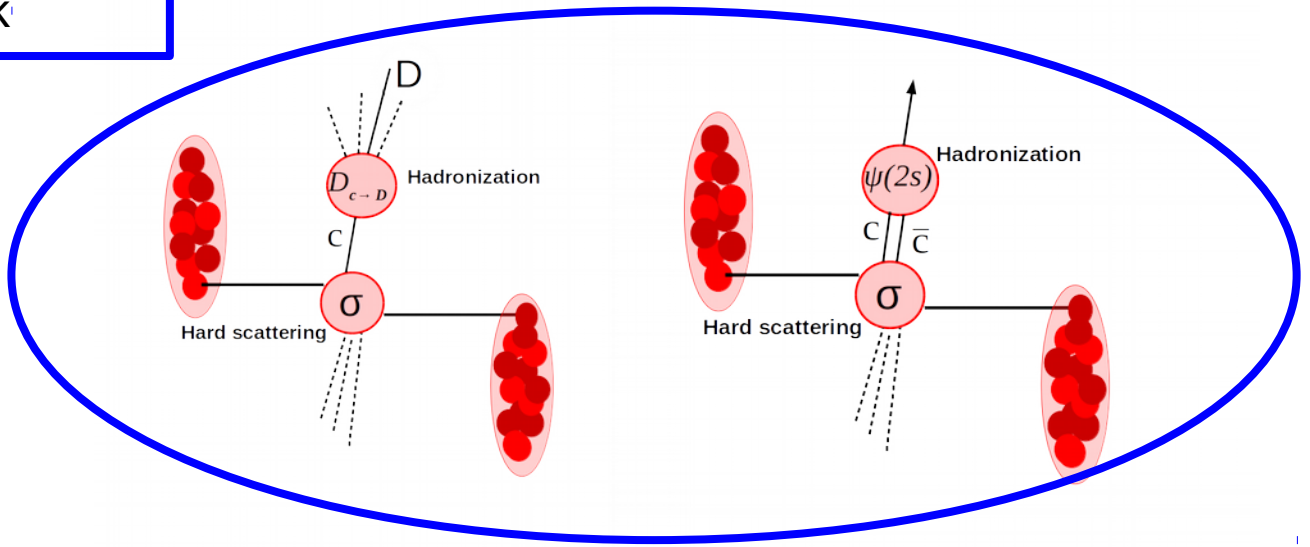
Heavy-flavor in pp collisions

- Charmed baryons in pp collisions at $\sqrt{s}$ = 13 TeV → Highest energy → Highest multiplicity
- Charmonia in pp collisions at $\sqrt{s}$ = 13 TeV
- Dielectron continuum in pp collisions at $\sqrt{s}$ = 5.02 TeV

} Large datasets → differential measurements

See this talk

High-multiplicity pp collisions



ALICE detector

Charmonia leptonic decays
- $J/\psi \rightarrow e^+e^-$ (mid-rapidity)
- $J/\psi \rightarrow \mu^+\mu^-$ (forward rapidity)
- $\psi(2S) \rightarrow \mu^+\mu^-$ (forward rapidity)

e^+e^- continuum

D^0 hadronic decays
- $D^0 \rightarrow \pi^+K^- + c.c.$

Charm baryon hadronic decays
- $\Lambda_c^+ \rightarrow p^+K_s^0$
- $\Lambda_c^+ \rightarrow p^+\pi^+K^-$
- $\Xi_c^0 \rightarrow \pi^+\Xi^-$
- $\Xi_c^+ \rightarrow \pi^+\pi^+\Xi^-$
- $\Sigma_c^0 \rightarrow \Lambda_c^+\pi^-$
- $\Sigma_c^{++} \rightarrow \Lambda_c^+\pi^+$

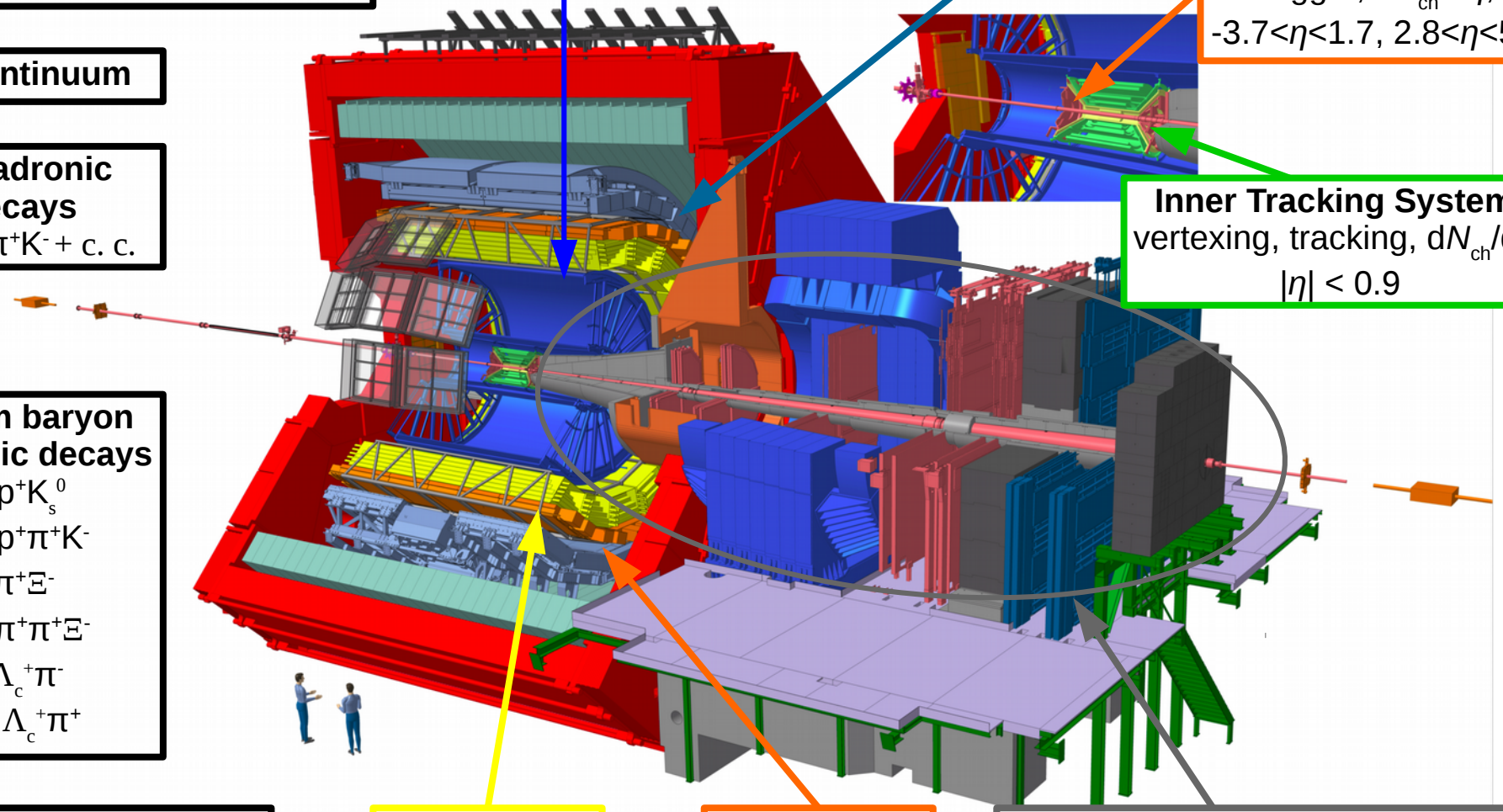
Charm baryon semi-leptonic decay
- $\Xi_c^0 \rightarrow \nu_e e^+\Xi^-$

Time Projection Chamber:
tracking, PID,
$|\eta| < 0.9$

EMCal:
trigger, eID,
$|\eta| < 0.7$

V0 Detector:
trigger, $dN_{ch}/d\eta$,
$-3.7<\eta<1.7$, $2.8<\eta<5.1$

Inner Tracking System:
vertexing, tracking, $dN_{ch}/d\eta$,
$|\eta| < 0.9$



TRD:
trigger, PID,
$|\eta| < 0.9$

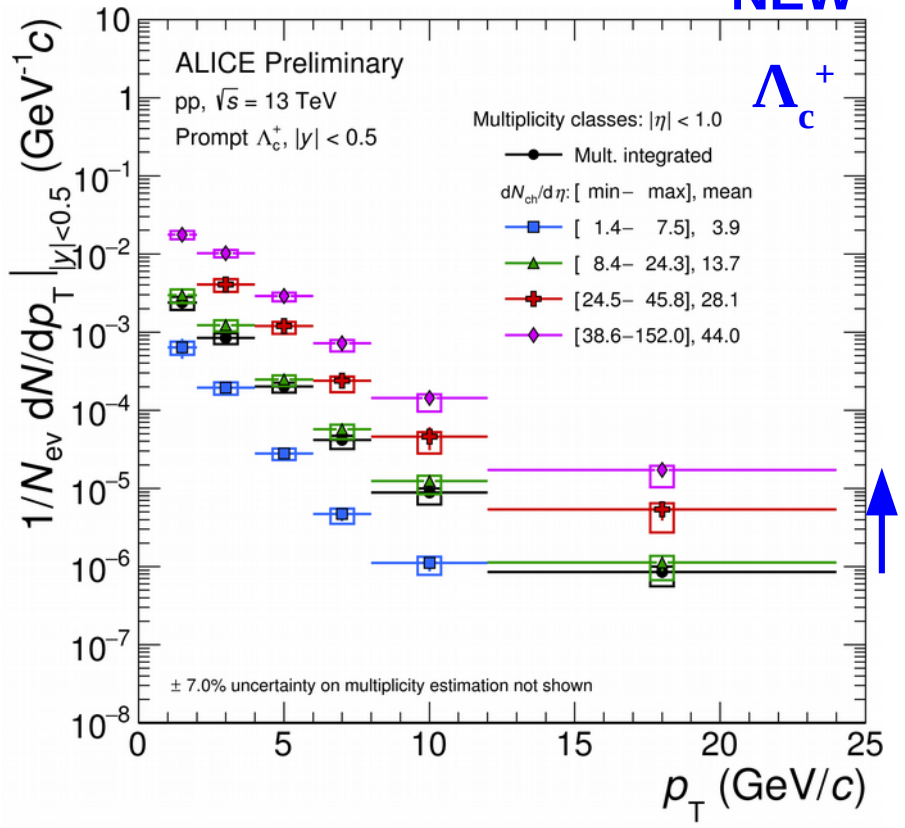
TOF:
PID,
$|\eta| < 0.9$

Dimuon Spectrometer:
triggering and tracking for muons,
$-4.0<\eta<-2.5$

Λ_c^+/D^0 in pp collisions at $\sqrt{s}$ = 13 TeV: multiplicity dependence and model comparison

- Which role does multiplicity play?

NEW



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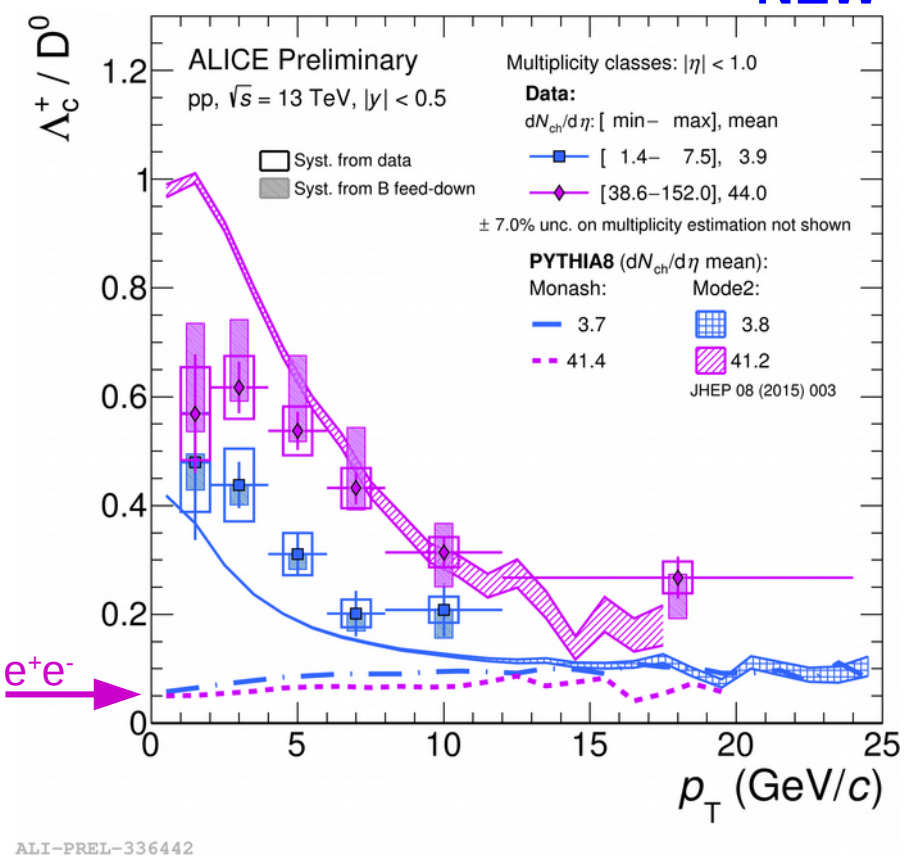
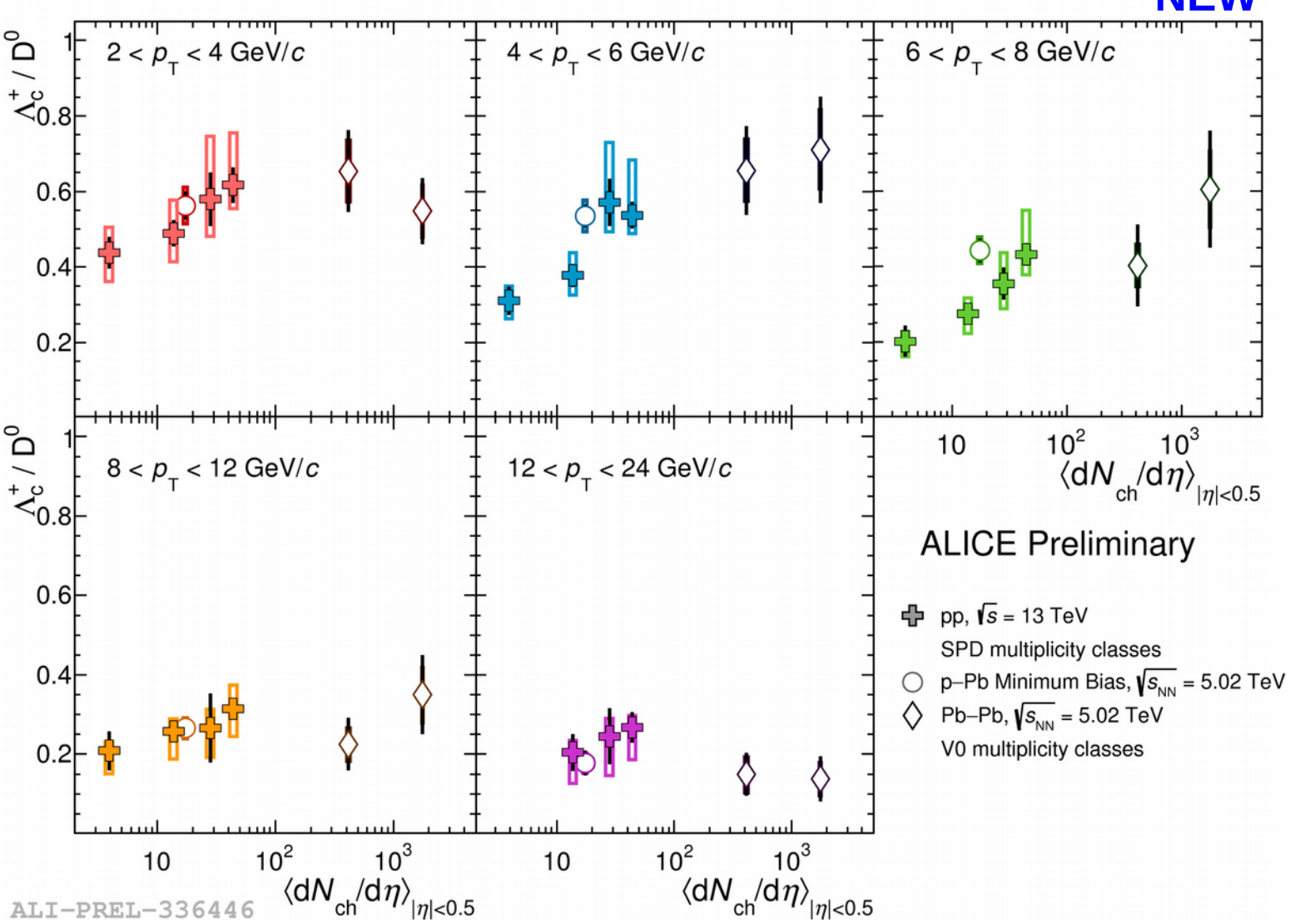


- Λ_c^+ and D^0 production enhanced in higher multiplicity events
- Λ_c^+/D^0 ratio:
  - Ratio increases with multiplicity
    → hints that difference between charm fragmentation to Λ_c^+ and D^0 evolves with multiplicity
  - PYTHIA Monash tuned on e^+e^- underestimates measurement
  - PYTHIA with Color Reconnection (CR) beyond Leading Color (LC) agrees with higher multiplicity class

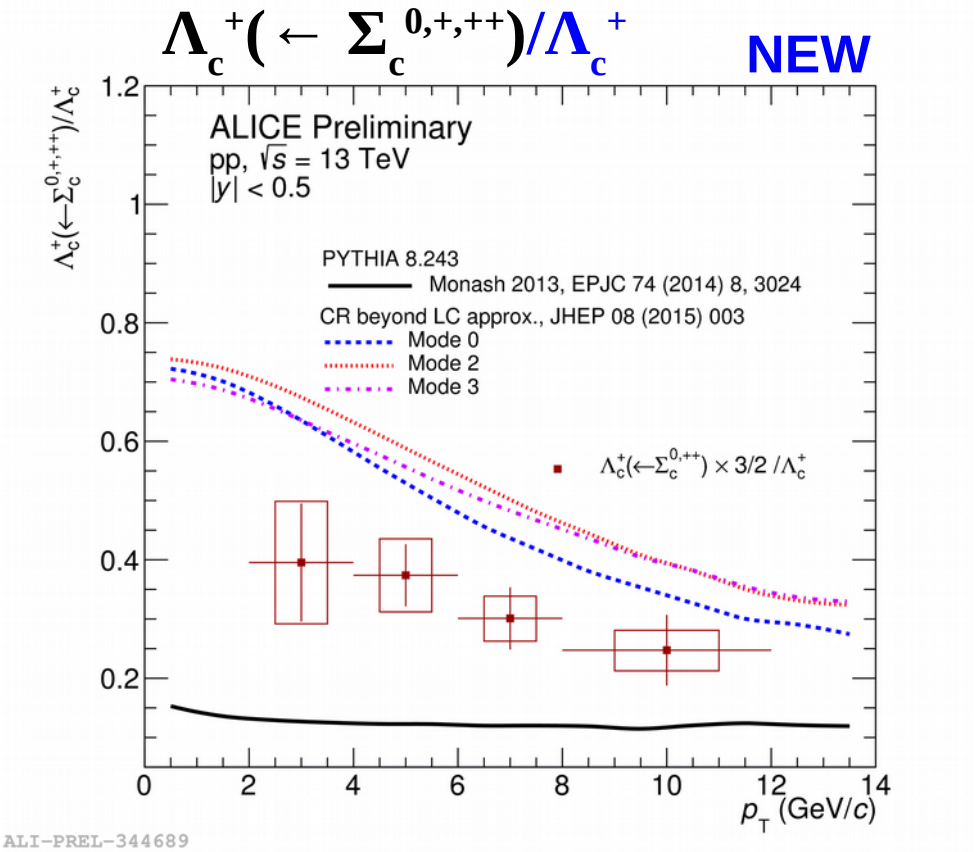
Λ_c^+/D^0 in different colliding systems: multiplicity dependence

NEW



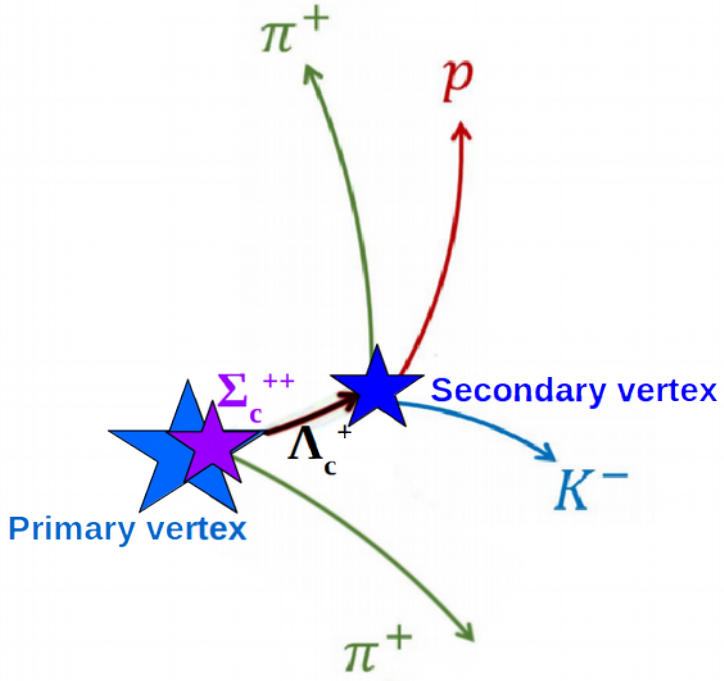
- Λ_c^+/D^0 ratio smoothly evolves as function of multiplicity when including p–Pb and Pb–Pb collisions
  → multiplicity matters

Effect of Σ_c feed-down on Λ_c^+/D^0?



$\Sigma_c^0 \rightarrow \Lambda_c^+(\rightarrow p^+\pi^+K^-)\pi^- + c.c.$

$\Sigma_c^{++} \rightarrow \Lambda_c^+(\rightarrow p^+\pi^+K^-)\pi^+ + c.c.$



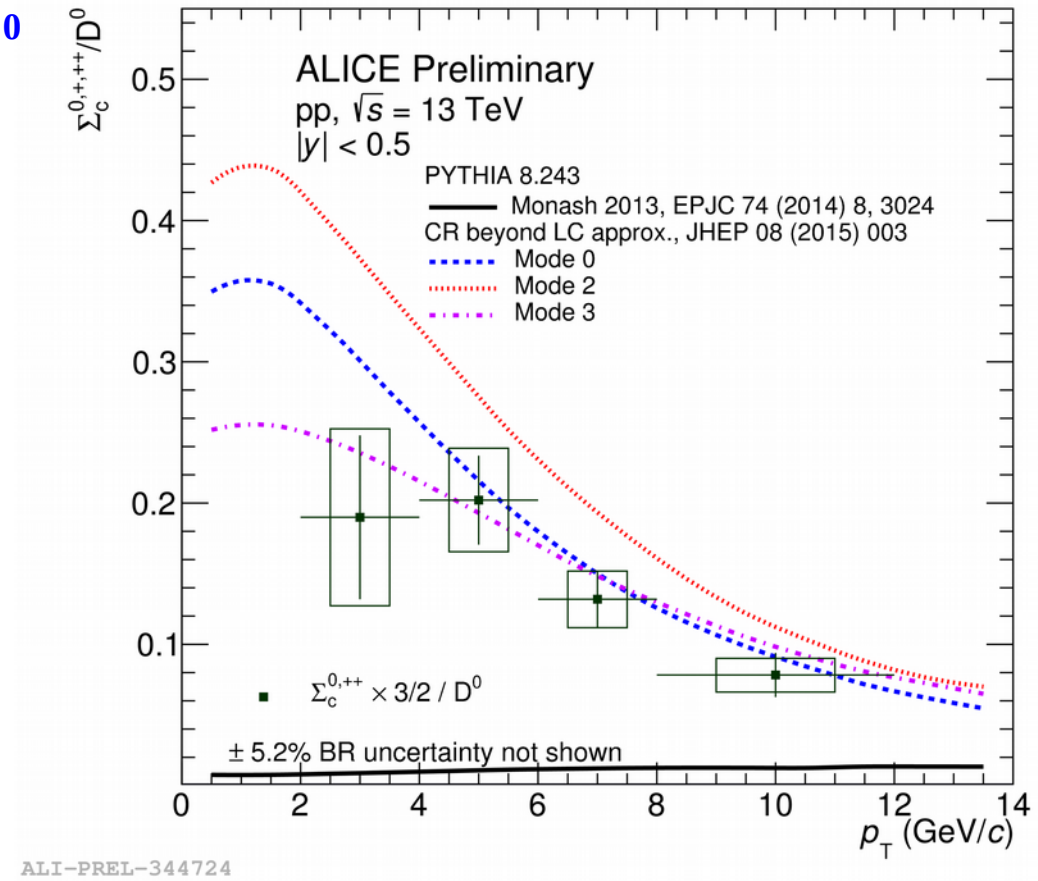
- Models:
  - PYTHIA Monash: tuned on e^+e^-
  - PYTHIA CR beyond LC
    - Mode 0: no time dilation constraints, Mode 2: dipoles involved in CR causally connected, Mode 3: single connection causally connected
  - Models do no not describe the data

- How does feed-down affect Λ_c^+/D^0?
  - Fraction of Λ_c^+ originates from $\Sigma_c^{0,+,++}$ feed-down

$\Sigma_c^{0,+,++}/D^0$ in pp collisions at $\sqrt{s}$ = 13 TeV

NEW

$\Sigma_c^{0,+,++}/D^0$

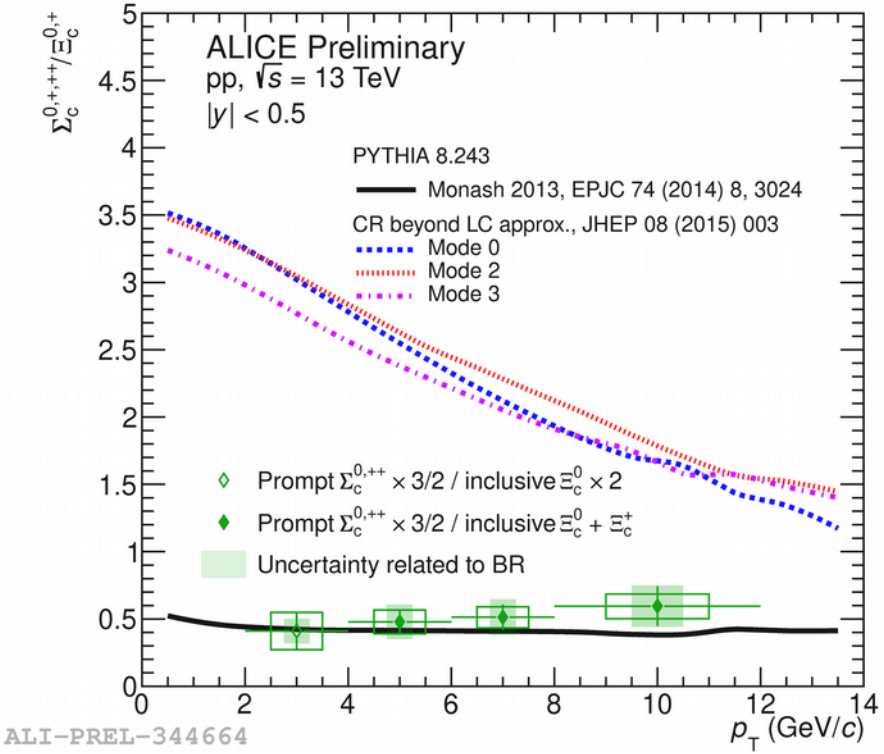


- Fraction of Λ_c^+ originates from $\Sigma_c^{0,+,++}$ feed-down
- $\Sigma_c^{0,+,++}/D^0$ has similar p_T-dependency as Λ_c^+/D^0
  → $\Sigma_c^{0,+,++}$ feed-down could explain part of the Λ_c^+ enhancement in pp collisions
- $\Sigma_c^{0,+,++}/D^0$ in agreement with PYTHIA with CR beyond LC, underestimated by PYTHIA Monash
  → Charm fragmentation not well understood

- **ALICE data can constrain charm fragmentation**

$\Sigma_c^{0,+,++}/\Xi_c^{0,+}$ and $\Xi_c^{0,+}/D^0$ in pp collisions at $\sqrt{s}$ = 13 TeV

NEW



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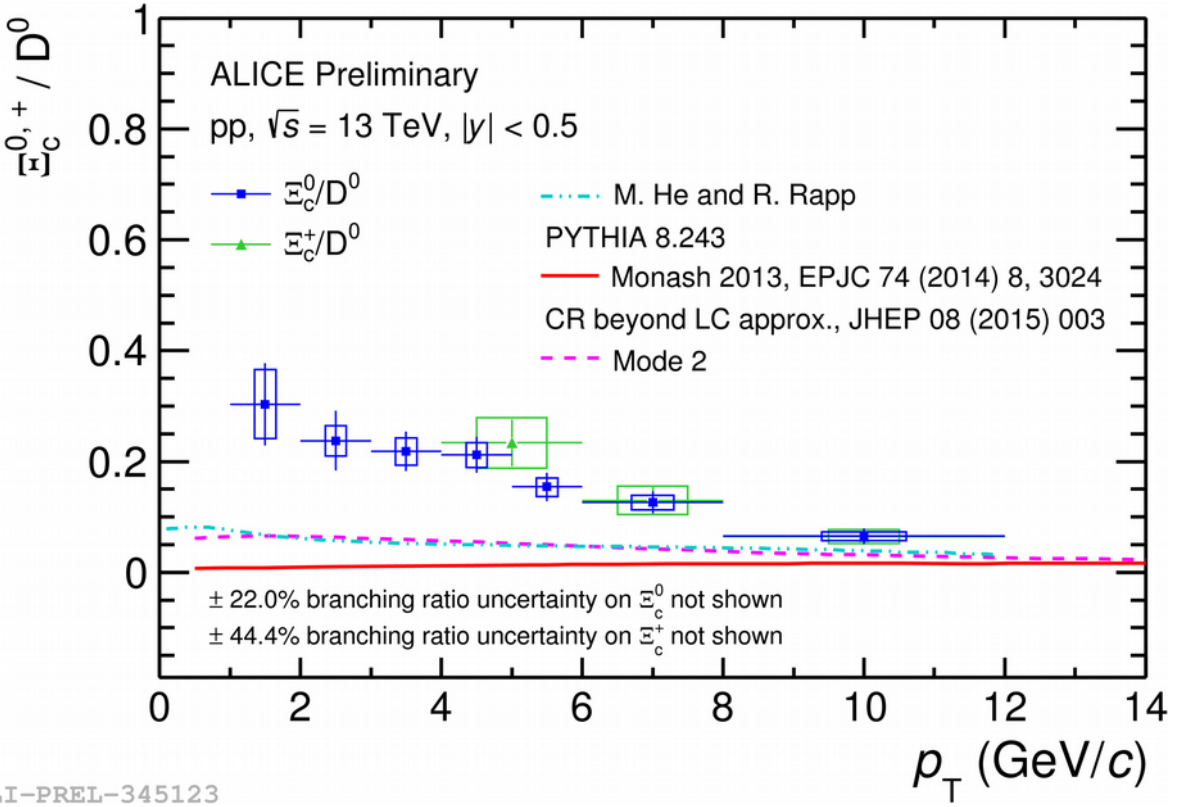


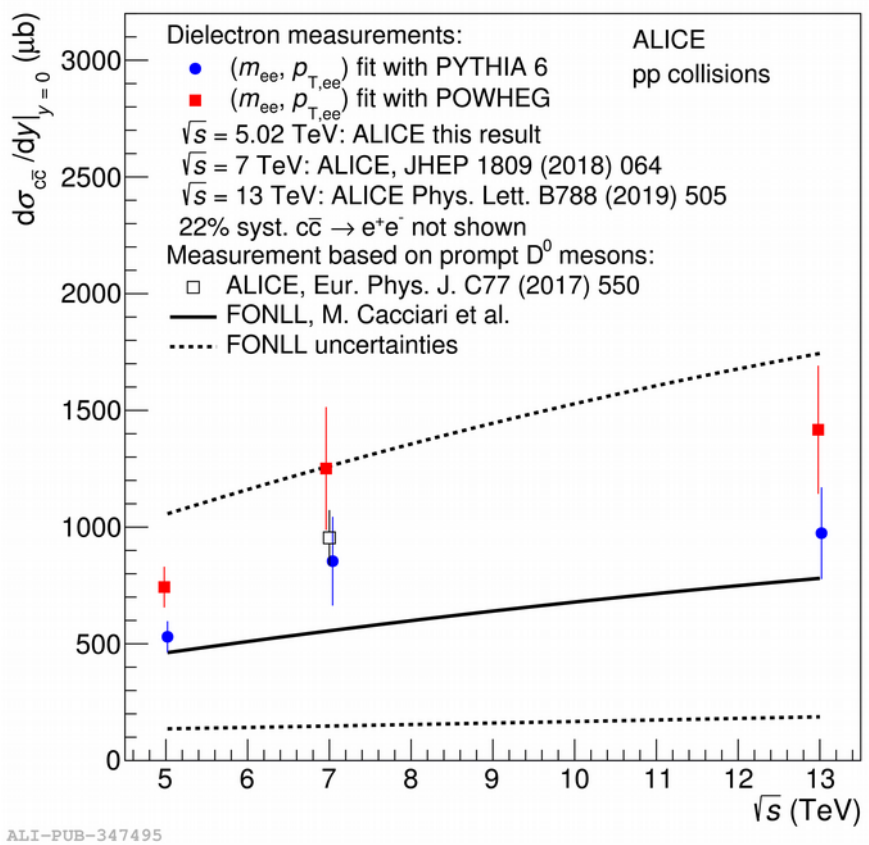
- $\Sigma_c^{0,+,++}/\Xi_c^{0,+}$:
  - Reproduced by PYTHIA Monash
    → Is almost identical mass of $\Sigma_c^{0,+,++}$ and $\Xi_c^{0,+}$ what matters?

- $\Xi_c^{0,+}/D^0$:
  - Similar p_T-dependency as Λ_c^+/D^0
    → Breaking of baryon-fragmentation-function universality?
  - Models underestimate measured ratios
    - Lowest-p_T data point 20-30 times higher than e^+e^-
    - M. He, R. Rapp: Statistical hadronization model with augmented set of charm-baryon states

→ **Crucial to estimate $c\bar{c}$ cross section**

Heavy-flavor cross sections in pp collisions at $\sqrt{s}$ = 5.02 TeV

NEW



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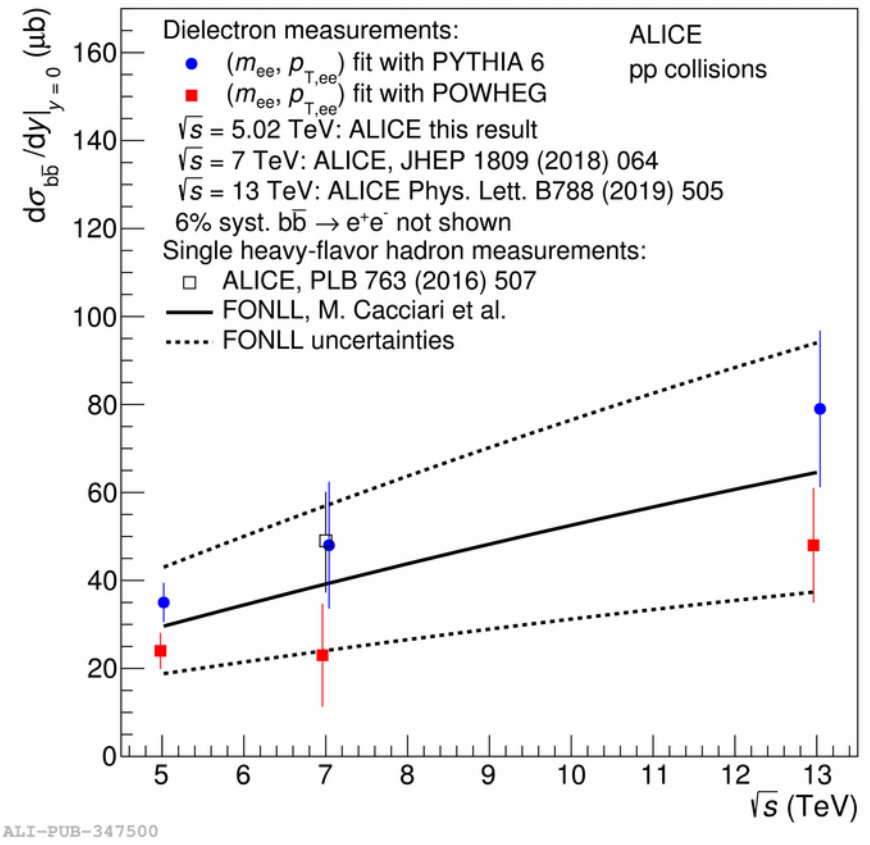
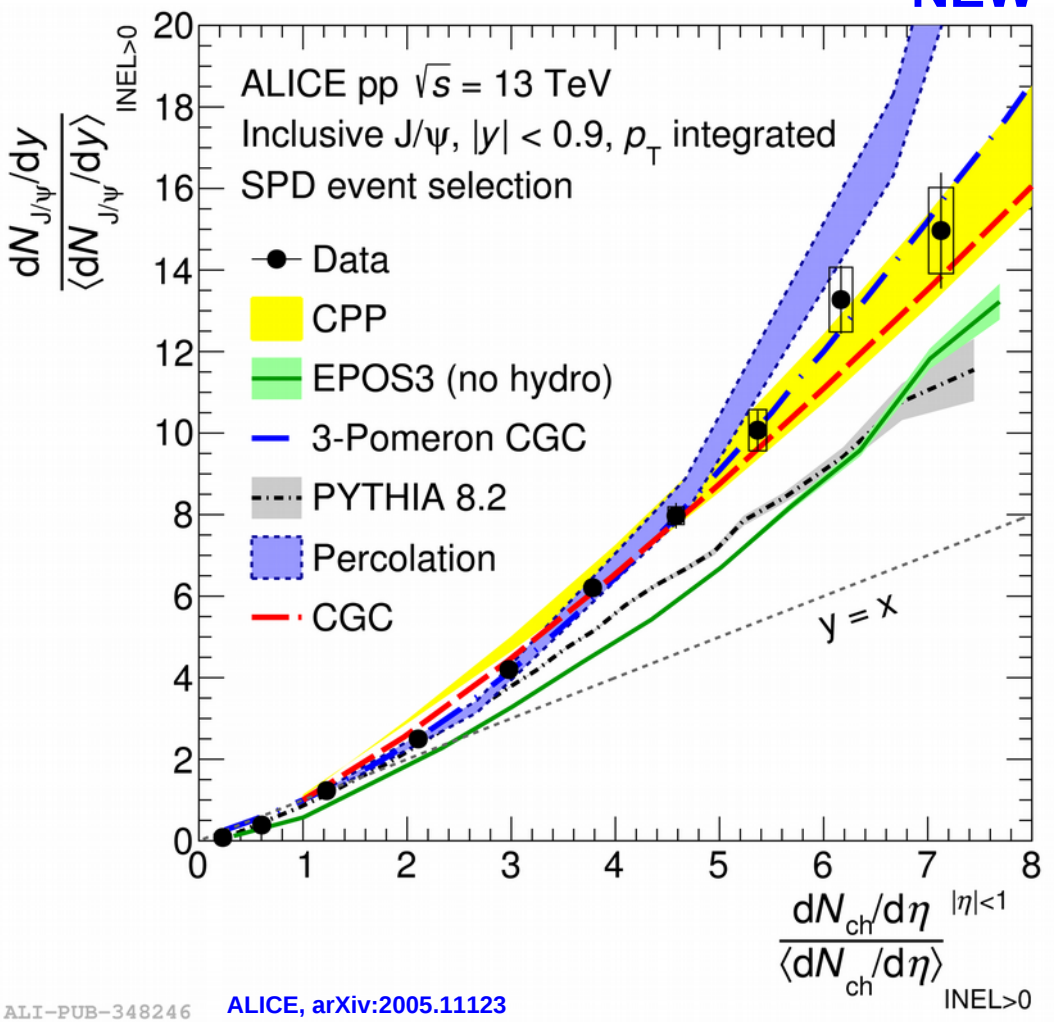


ALICE, arXiv:2005.11995
PYTHIA6: JHEP 05 (2006) 026
POWHEG: JHEP 06 (2010) 043, JHEP 11 (2007) 070, JHEP 09 (2007) 126, JHEP 11 (2004) 040

- Charm and beauty cross sections are obtained by PYTHIA6 and POWHEG double-differential fits to the dielectron continuum
  - $1.1 < m_{ee} < 2.7$ GeV/c^2 and $p_T < 8$ GeV/c
- Results in agreement with measurement based on prompt D^0 mesons
- Sensitive to production mechanisms from Monte Carlo generators
- Slope of the $\sqrt{s}$-dependence is described by FONLL calculation

J/ψ vs. multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV: model comparison

NEW

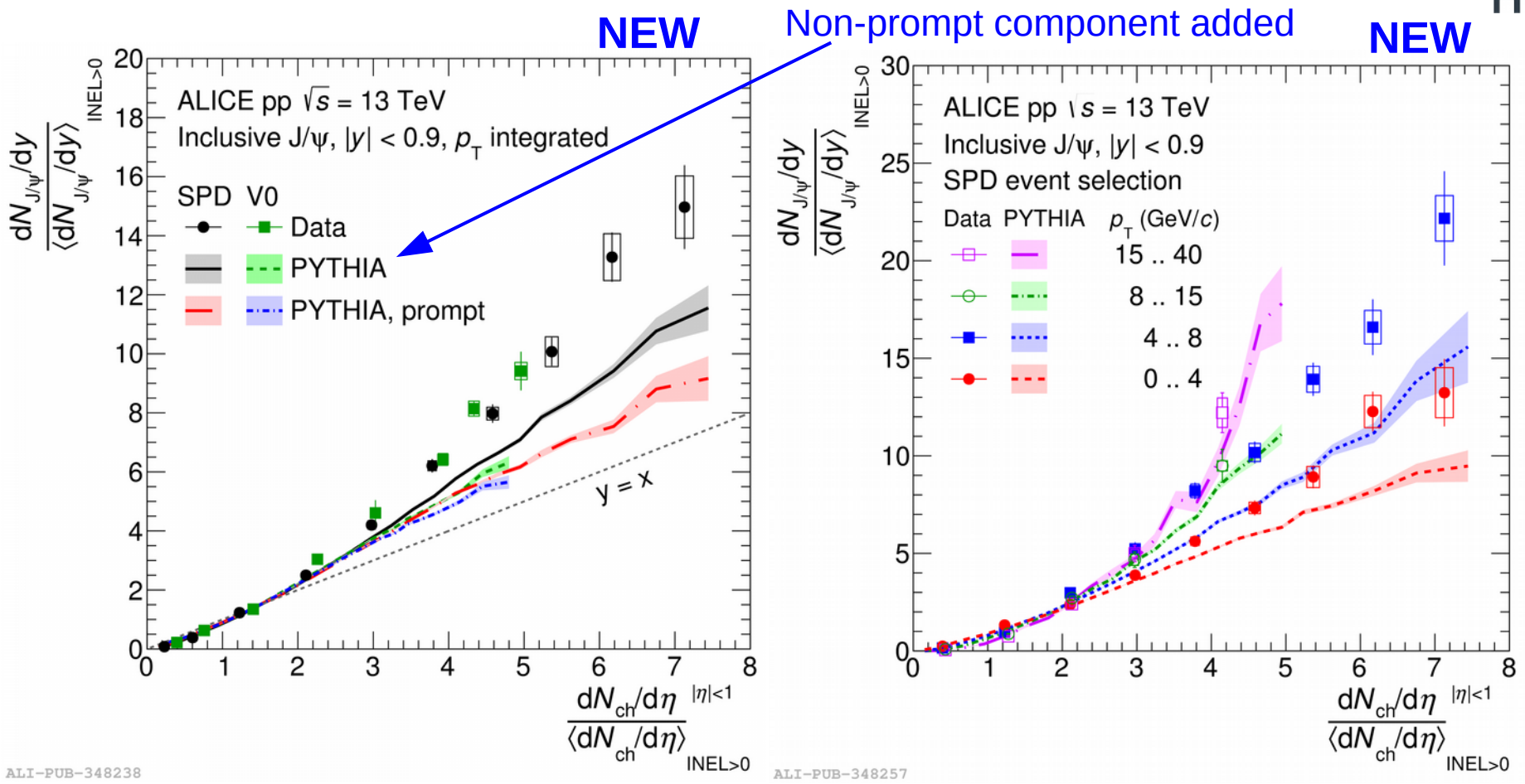


ALI-PUB-348246

- J/ψ yield at mid-rapidity:
  - Increases faster than linear as function of multiplicity
  - Quantitatively described by models with different physics mechanisms
    - Coherent Particle Production (CPP)
    - Color Glass Condensate (CGC)
    - 3-Pomeron CGC
  - Increase of J/ψ yields in models arises from reduction of charged-particle multiplicity
- Models consider only prompt J/ψ contribution

ALICE, arXiv:2005.11123
CPP: Phys. Rev. D88 (2013) 116002
EPOS3: Phys. Rev. C89 (2014) 064903
3-Pomeron CGC: arXiv: 1910.13579
PYTHIA 8.2: Comput. Phys. Commun. 191 (2015) 159-177
Eur. Phys. J. C79 (2019) 36
Percolation: Phys. Rev. C86 (2012) 034903
CGC: Phys. Rev. D98 (2018) 074025

J/ψ vs. multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV: comparison to PYTHIA



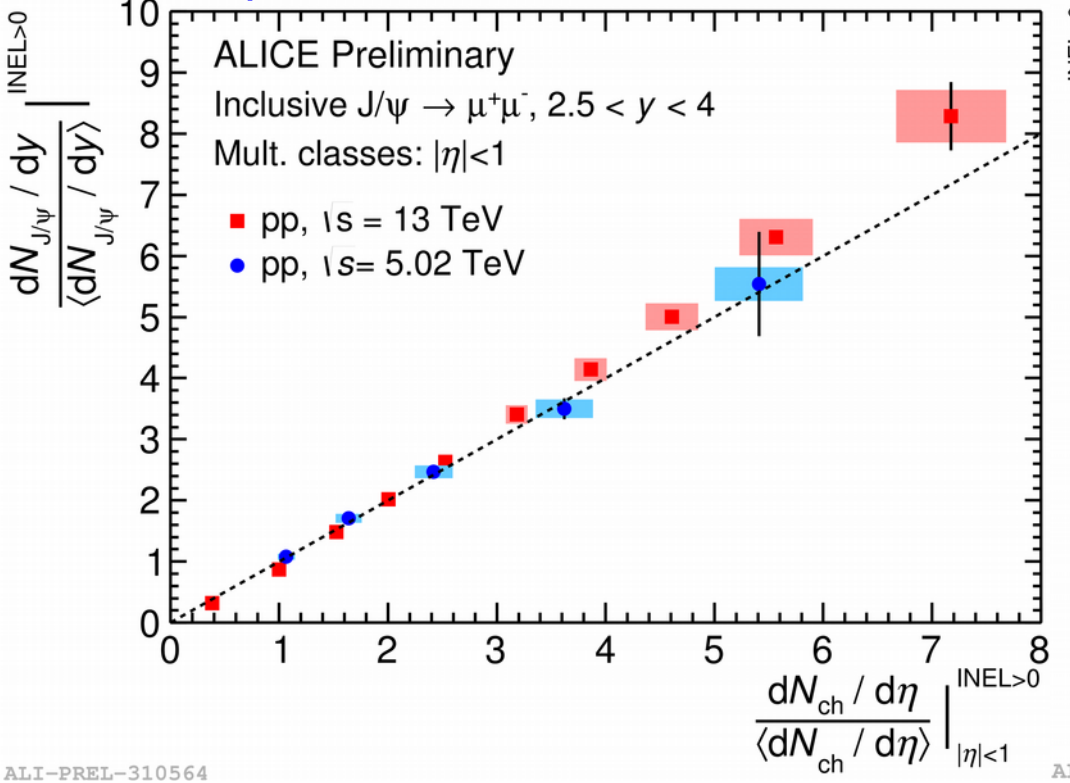
ALICE, arXiv:2005.11123
PYTHIA: Eur. Phys. J. C79 (2019) 36
PYTHIA, prompt: Comput. Phys. Commun. 191 (2015) 159-177

- Predictions of PYTHIA with prompt component only underestimate slope of the trend of p_T-integrated J/ψ yields
  - Closer to J/ψ yields when including feed-down from beauty-hadron decays
- Significant increase between J/ψ p_T-intervals 0-4, 4-8 GeV/*c*
  - Result of auto-correlation mechanisms, like jet or beauty-quark fragmentation?

J/ψ and ψ(2S) vs. multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV

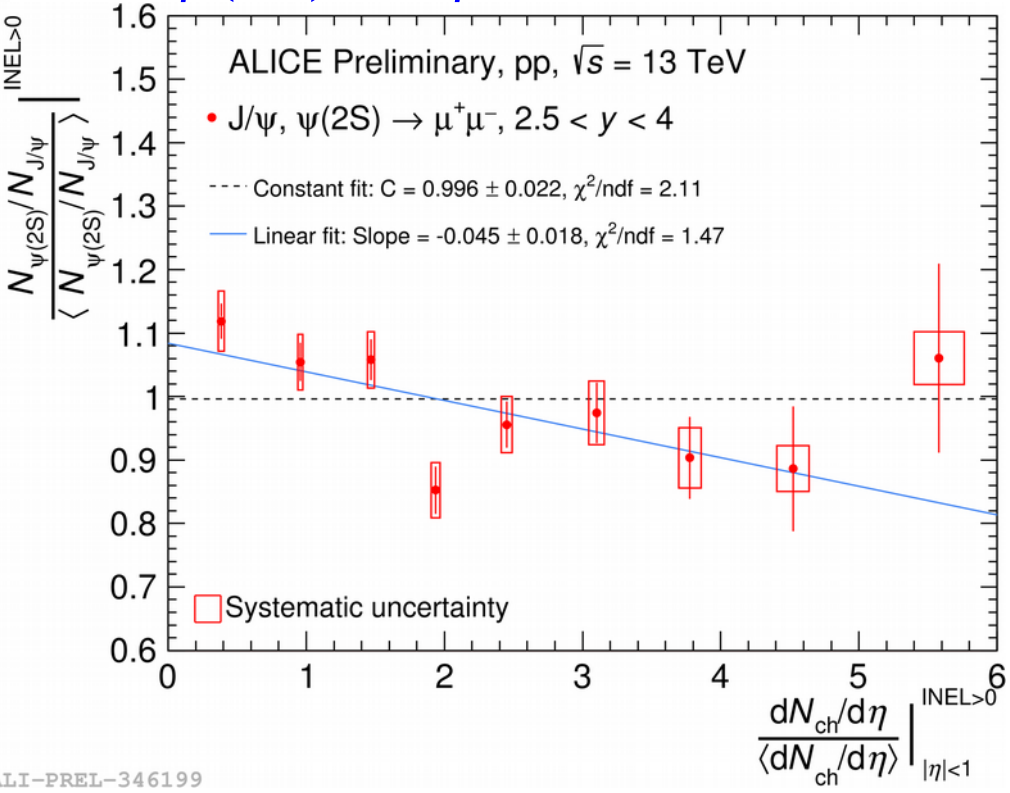
ALICE

J/ψ



ψ(2S) / J/ψ

NEW



- Forward rapidity:
  - J/ψ yield shows slower increase than at mid-rapidity
    → Possible bias due to auto-correlation for J/ψ at multiplicity in same acceptance?
  - Ratio of ψ(2S) to J/ψ yields hints that J/ψ production might increase faster with multiplicity

Conclusions

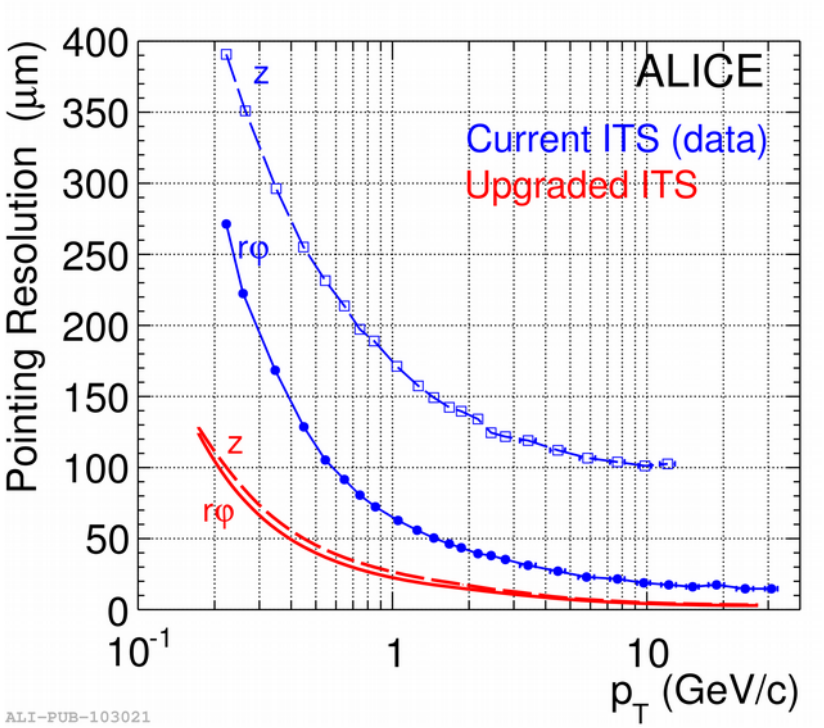
- Comparisons of charmed **baryon/meson** and **baryon/baryon** to the models:
  → Breaking of baryon-fragmentation-function universality
  → Implications on $c\bar{c}$ cross section estimate

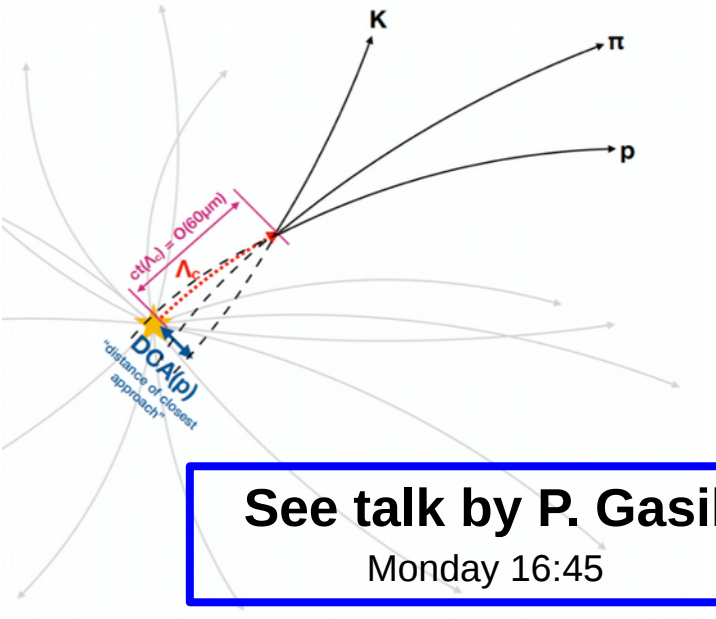
- **Dielectrons:**
  → Constraining beauty and charm cross sections

- **Multiplicity dependent measurements:**
  → Λ_c^+/D^0 in agreement with PYTHIA with CR beyond LC for higher multiplicity class
  → Charmonium multiplicity dependence waiting for clearer physics interpretations (J/ψ at mid-rapidity: Effect of feed-down? Auto-correlation? Reduction of event multiplicity?)

Zoom meeting room: https://cern.zoom.us/j/9713538810?pwd=TEJOMFhuNnMySmhnUVlxSWNnZ3Bldz09

Outlook: Run 3 + Run 4





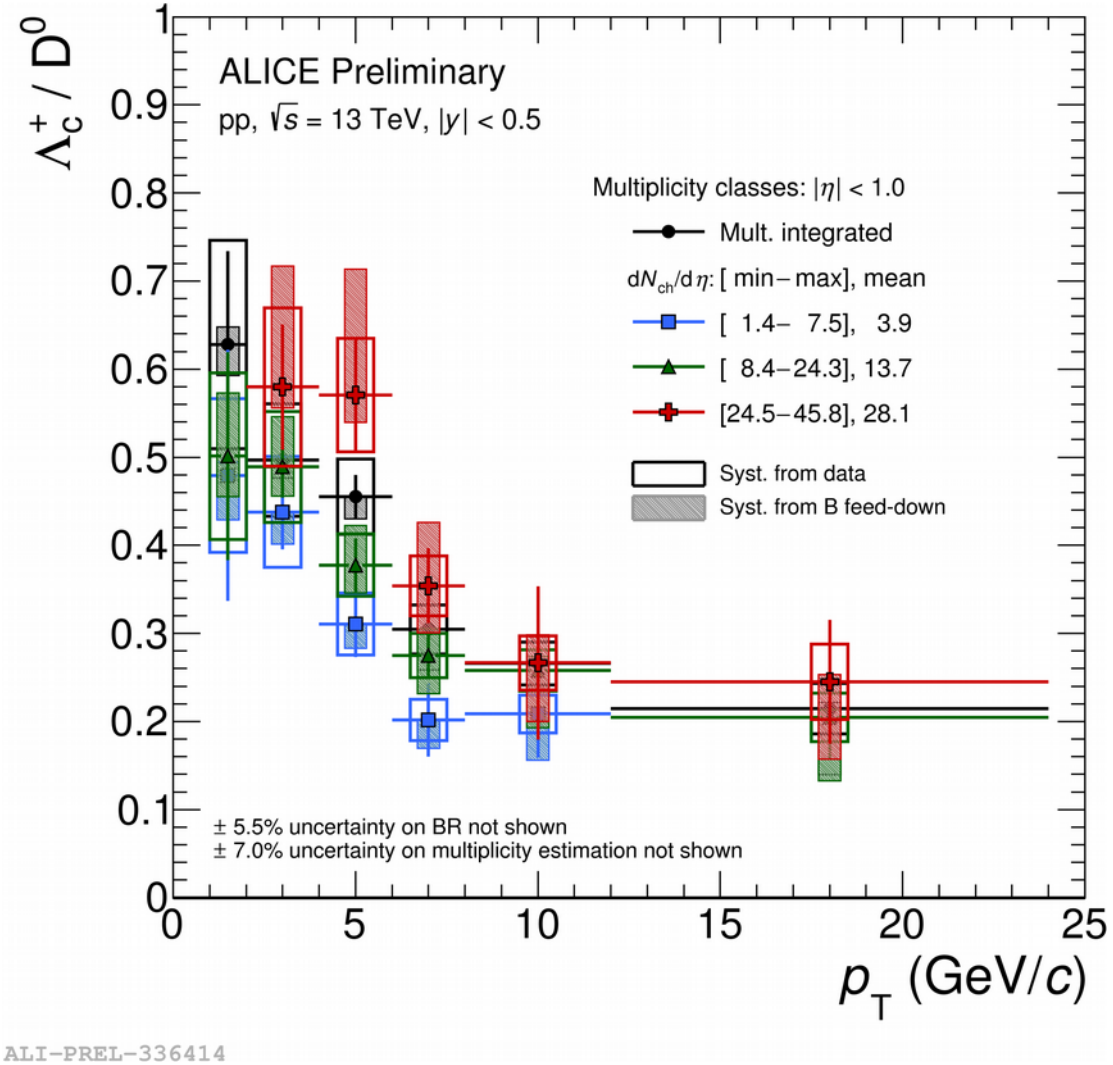
See talk by P. Gasik
Monday 16:45

ALICE helps with answering the questions

- Major upgrades of ALICE apparatus
  - Readout rate increases → Pb–Pb minimum-bias data sample by factor 50-100 larger
  - Mid-rapidity: tracking resolution at low p_T improves by factor of 3
  - Forward-rapidity: newly secondary vertex reconstruction
  - Heavy-flavor production measurements with higher precision down to $p_T = 0$ GeV/c
    - Total charm cross section
    - Multi-differential measurements
    - Better separation of prompt and non-prompt components

Backup

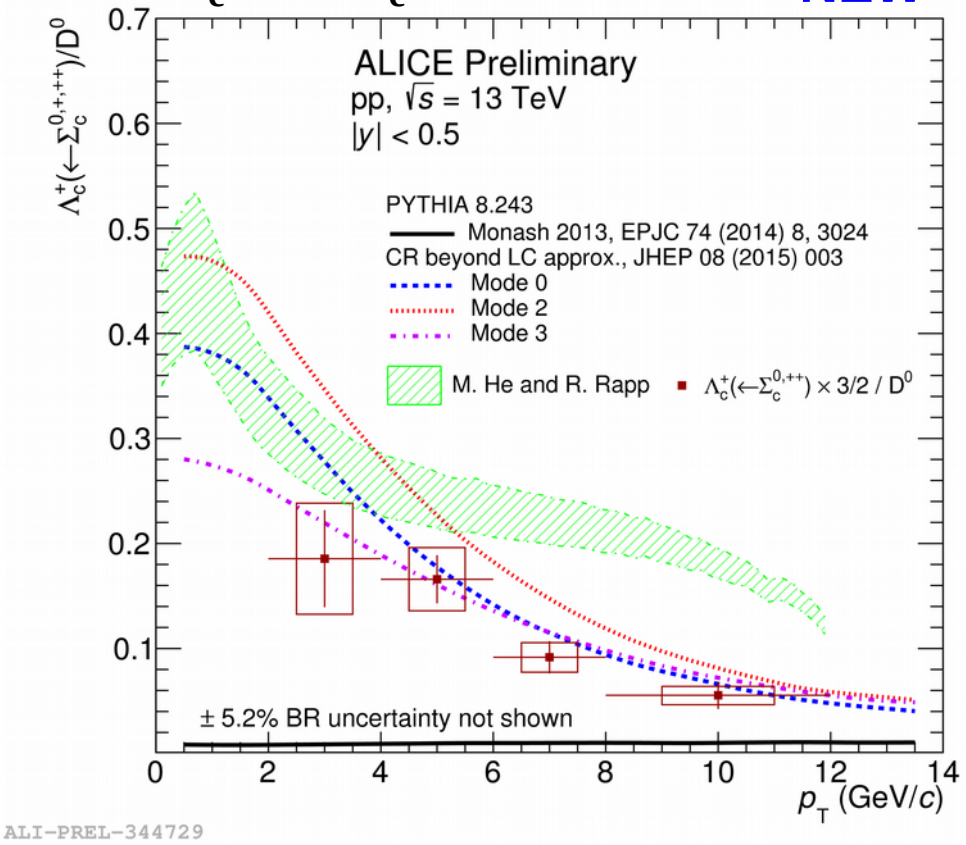
Λ_c^+/D^0 spectra in pp collisions at $\sqrt{s}$ = 13 TeV: multiplicity dependence



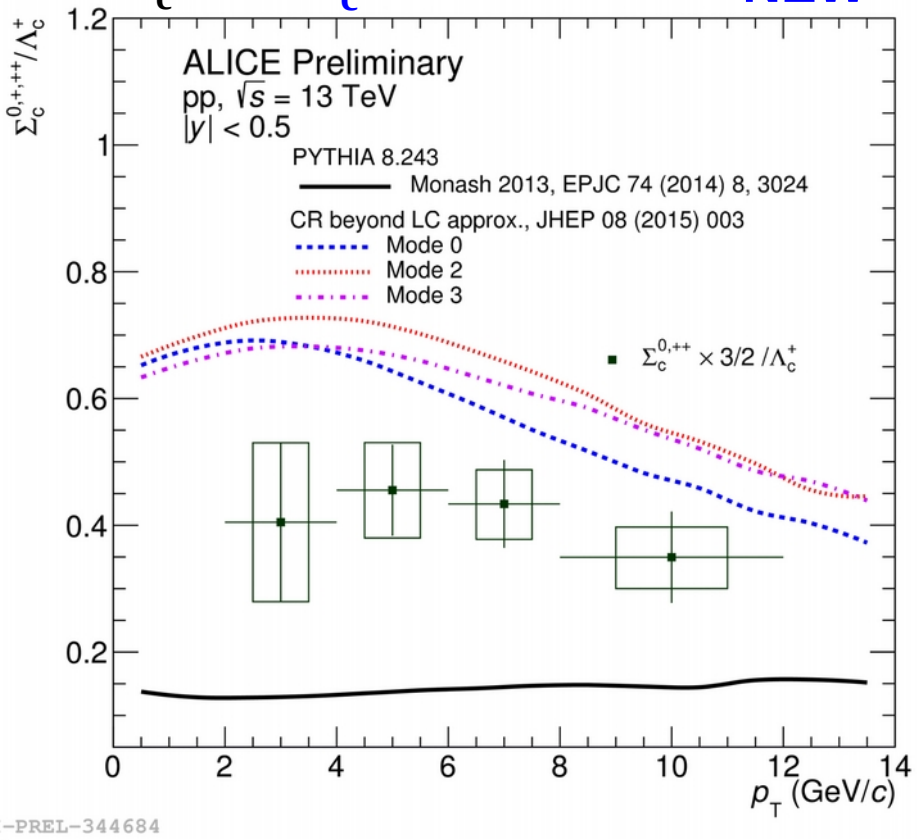
- Λ_c^+/D^0 :
  - Ratio increases with multiplicity

$\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/D^0$ and $\Sigma_c^{0,+,++}/\Lambda_c^+$ in pp collisions at $\sqrt{s}$ = 13 TeV

$\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/D^0$ NEW



$\Sigma_c^{0,+,++}/\Lambda_c^+$ NEW



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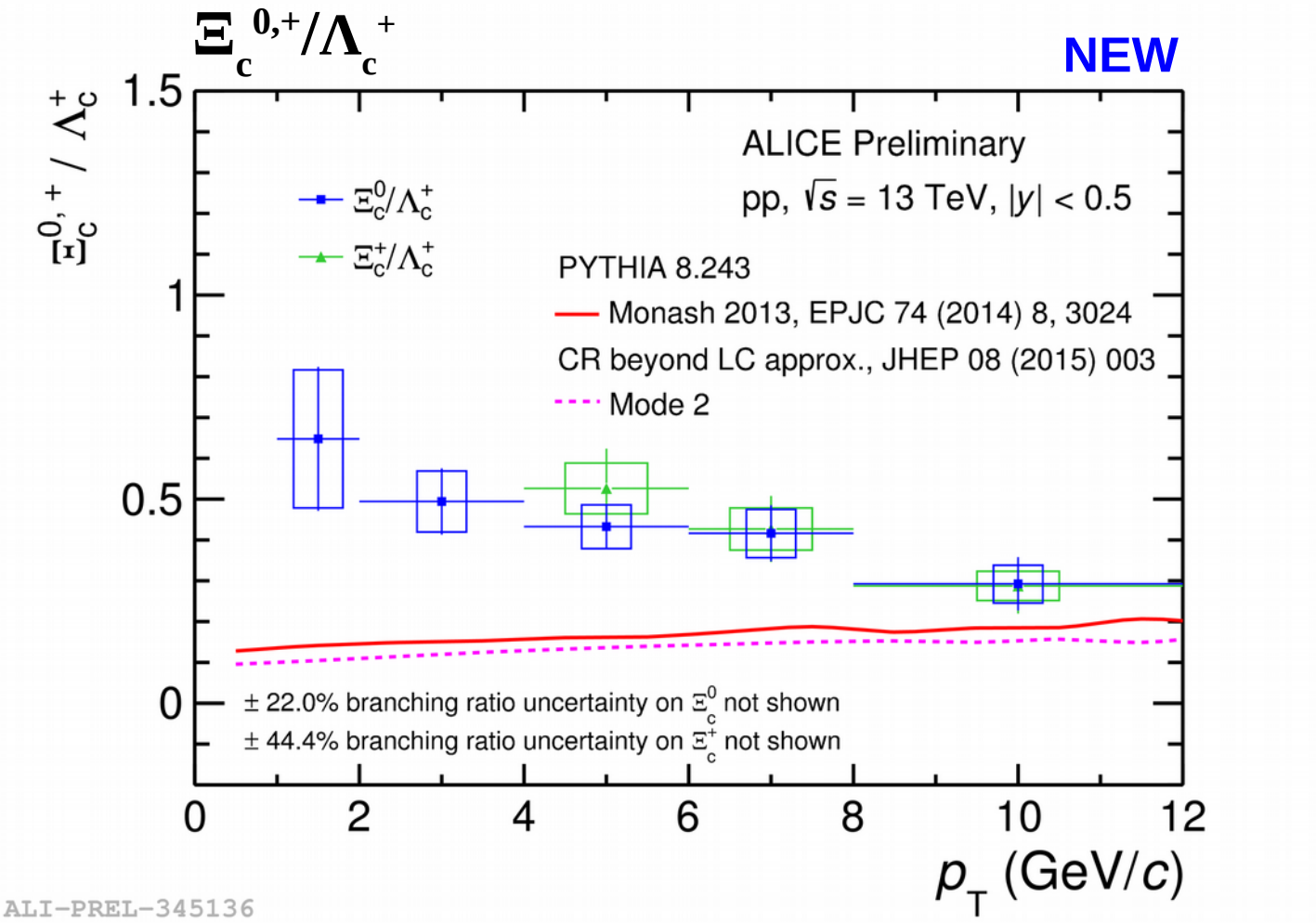
  - M. He, R. Rapp: Statistical hadronization model with augmented set of charm-baryon states

$\Xi_c^{0,+}/\Lambda_c^+$ in pp collisions at $\sqrt{s}$ = 13 TeV



- $\Xi_c^{0,+}/\Lambda_c^+$ underestimated by PYTHIA CR beyond LC approx. and PYTHIA Monash

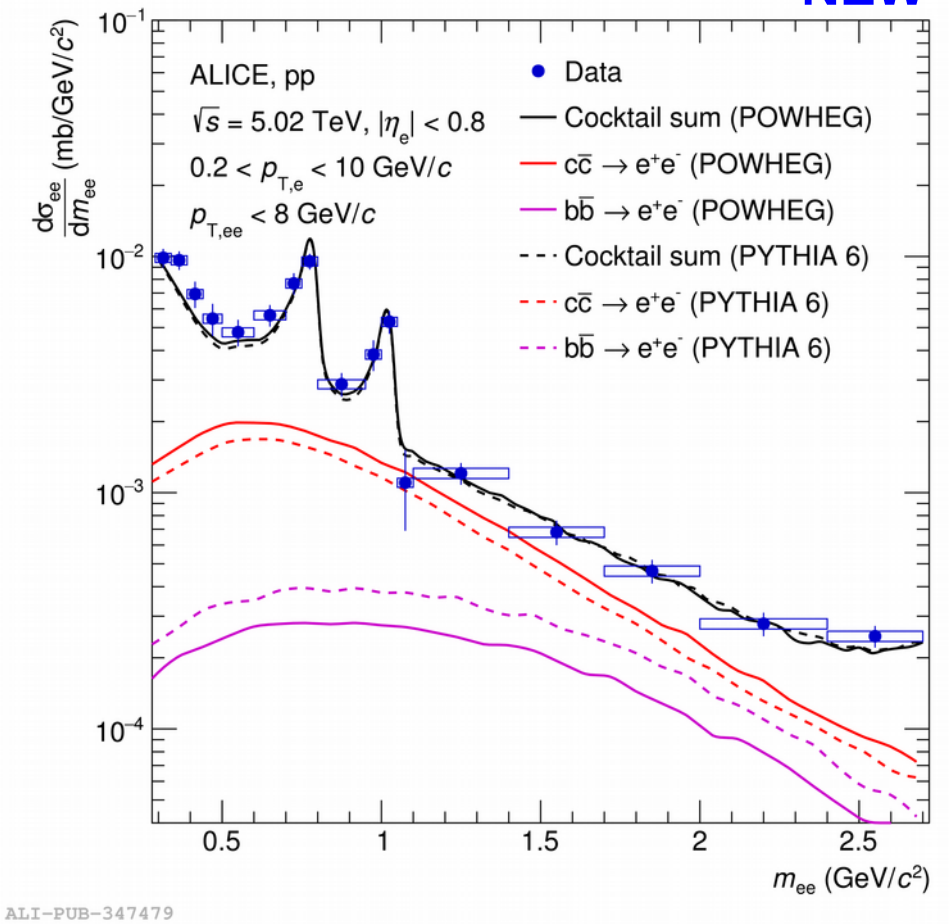
Baryon/meson and baryon/baryon compared to models in pp collisions at $\sqrt{s}$ = 13 TeV

- Baryon/meson and baryon/baryon ratios compared to models:

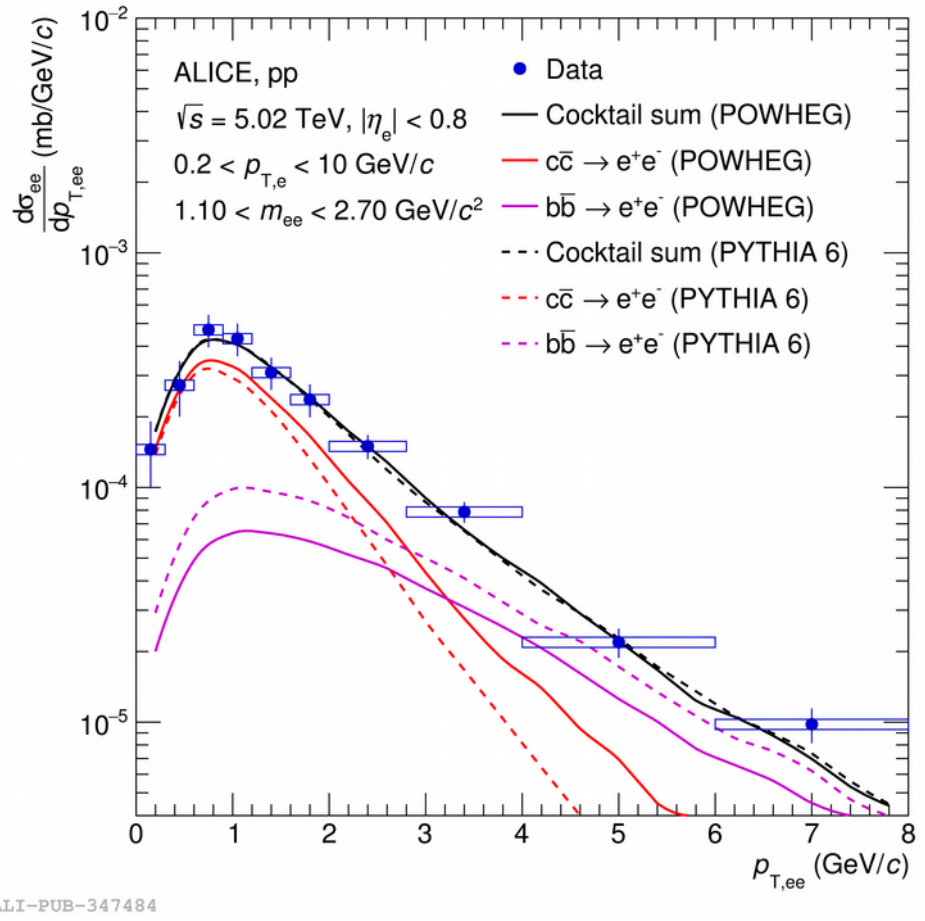
Consistent with:	PYTHIA with CR beyond LC approx.	PYTHIA Monash
Λ_c^+/D^0 in multiplicity interval [34.1-52.5]	Yes	No
Ξ_c^0/D^0	No	No
$\Sigma_c^{0,+,++}/D^0$, $\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/D^0$	Yes	No
$\Sigma_c^{0,+,++}/\Lambda_c^+$, $\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/\Lambda_c^+$	No	No
$\Sigma_c^{0,+,++}/\Xi_c^0$	No	Yes

Heavy-flavor cross sections in pp collisions at $\sqrt{s}$ = 5.02 TeV

NEW



NEW



ALICE, arXiv:2005.11995
PYTHIA6: JHEP 05 (2006) 026
POWHEG: JHEP 06 (2010) 043, JHEP 11 (2007) 070, JHEP 09 (2007) 126, JHEP 11 (2004) 040