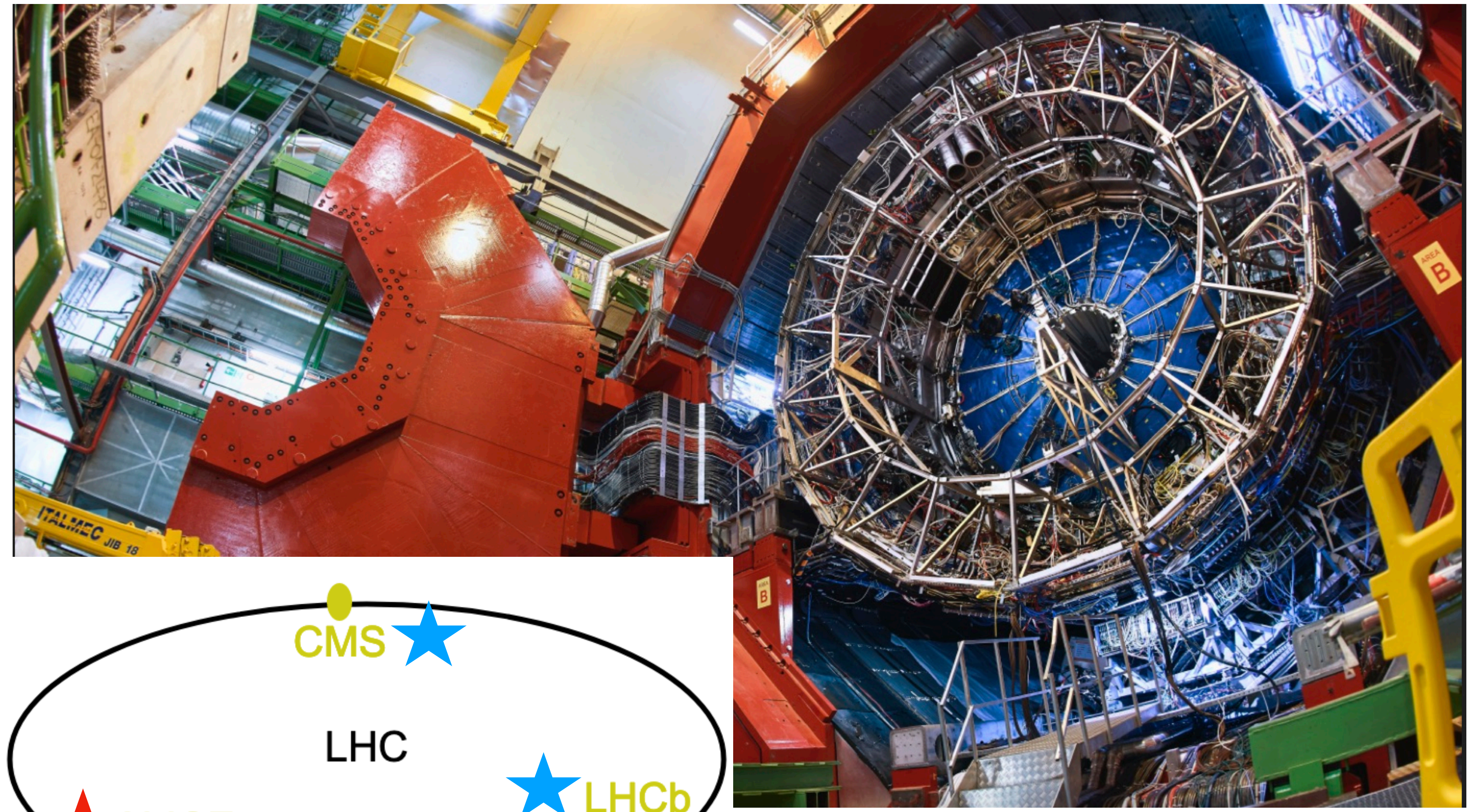
Recent highlights on heavy-flavour measurements: focusing on ALICE results

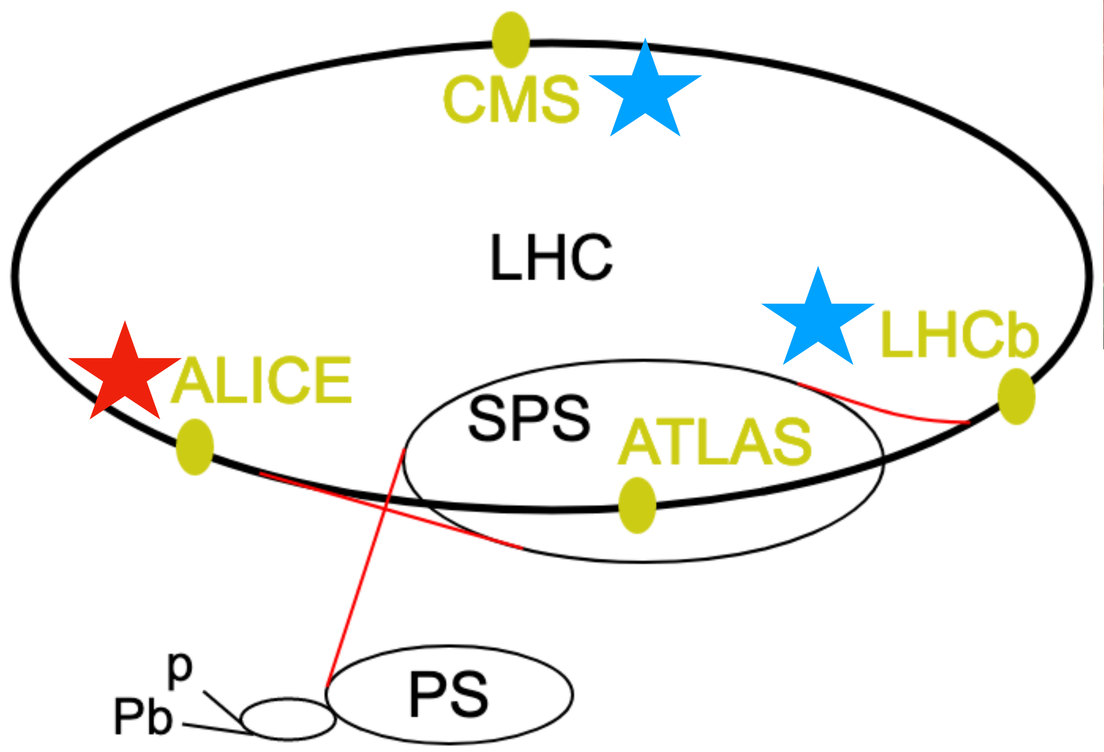
from a personal selection

Cristina Terrevoli, INFN Bari

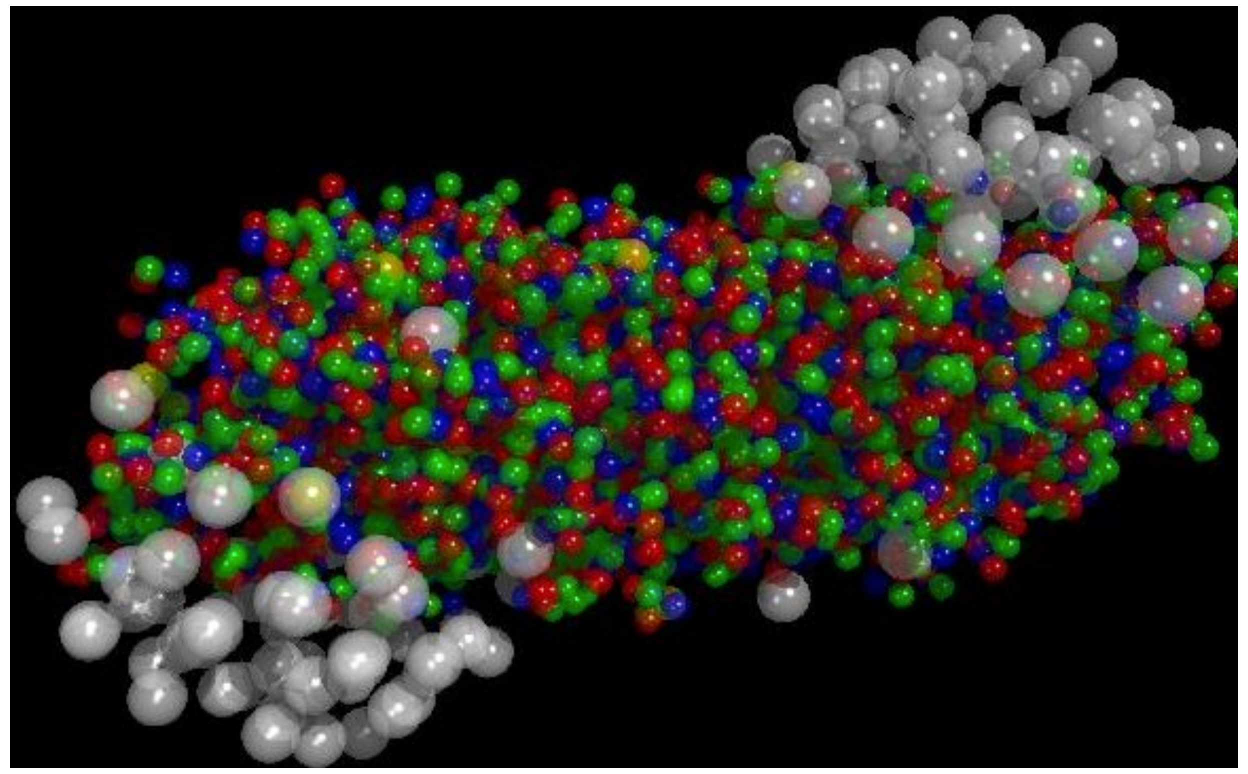
Wuhan, China - 19 - 24 October 2024

Goal of the ALICE experiment at the LHC





Study of the matter created at extreme conditions of temperature and energy density: quark-gluon plasma (QGP)



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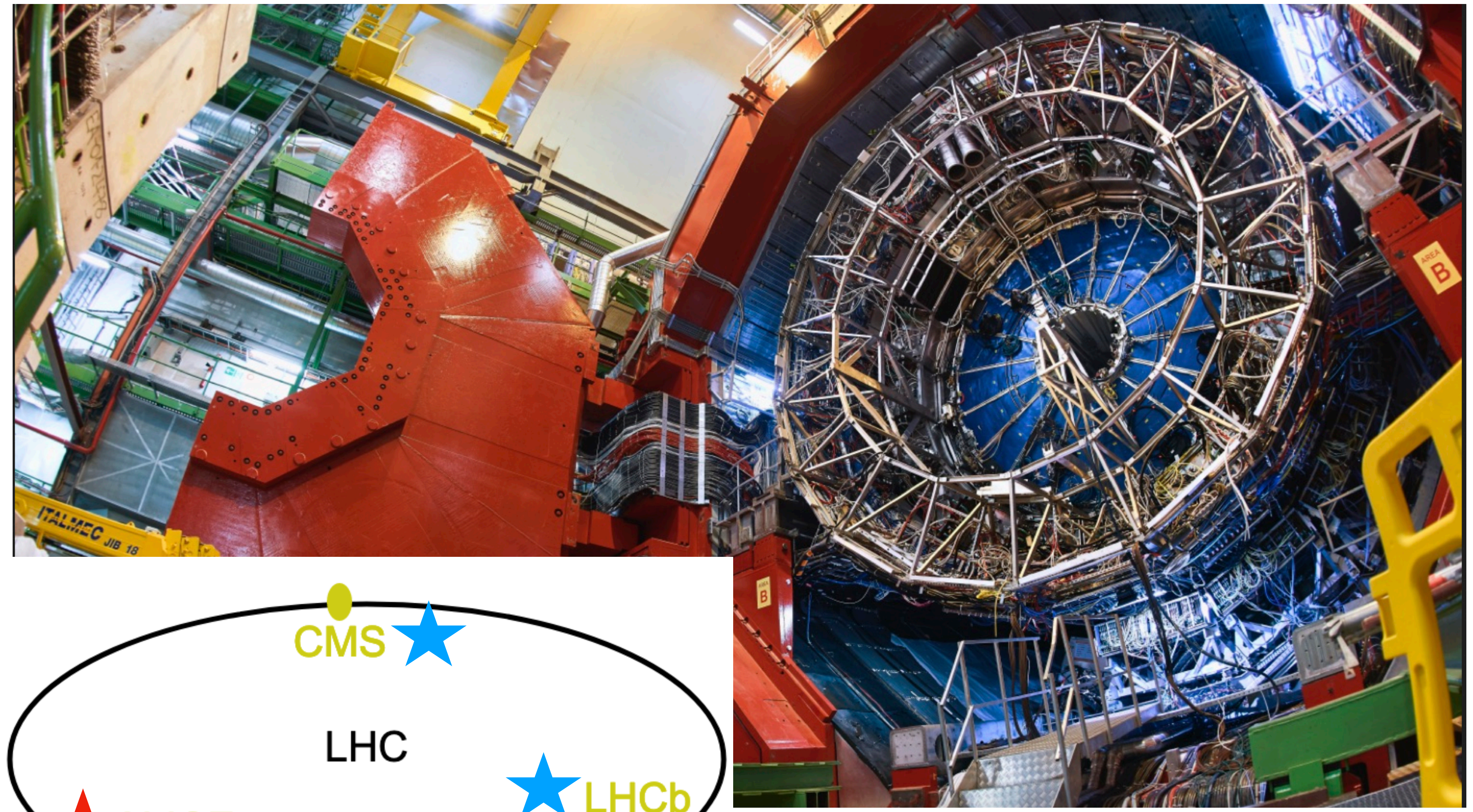

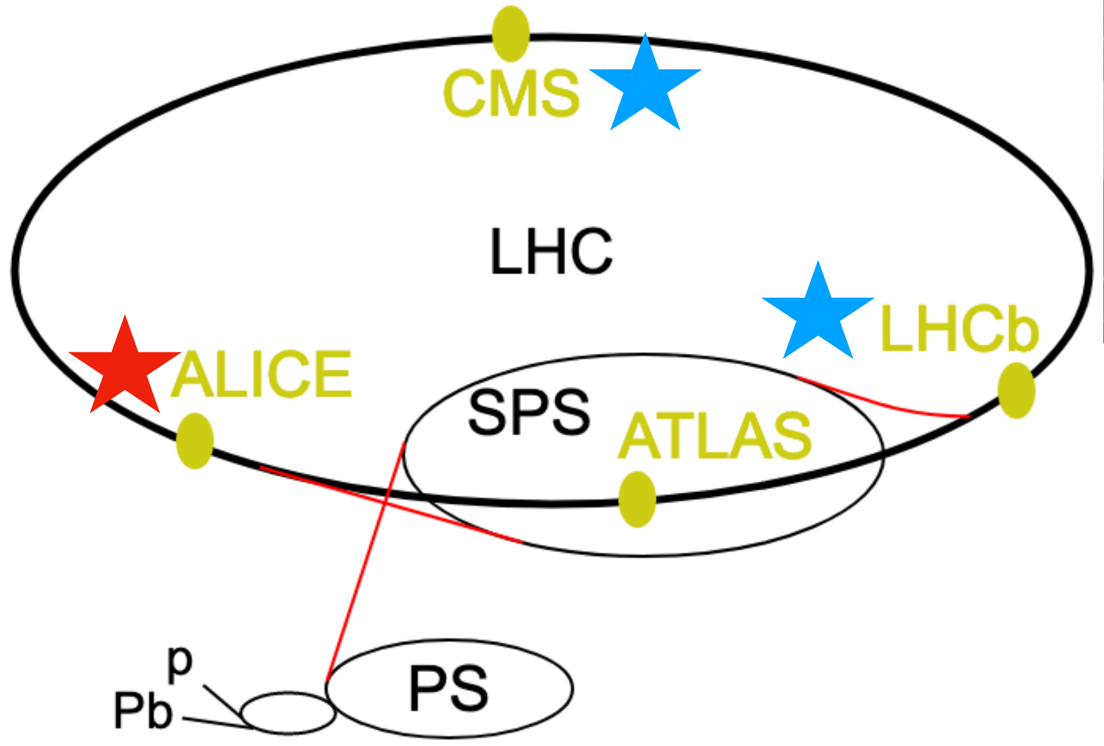

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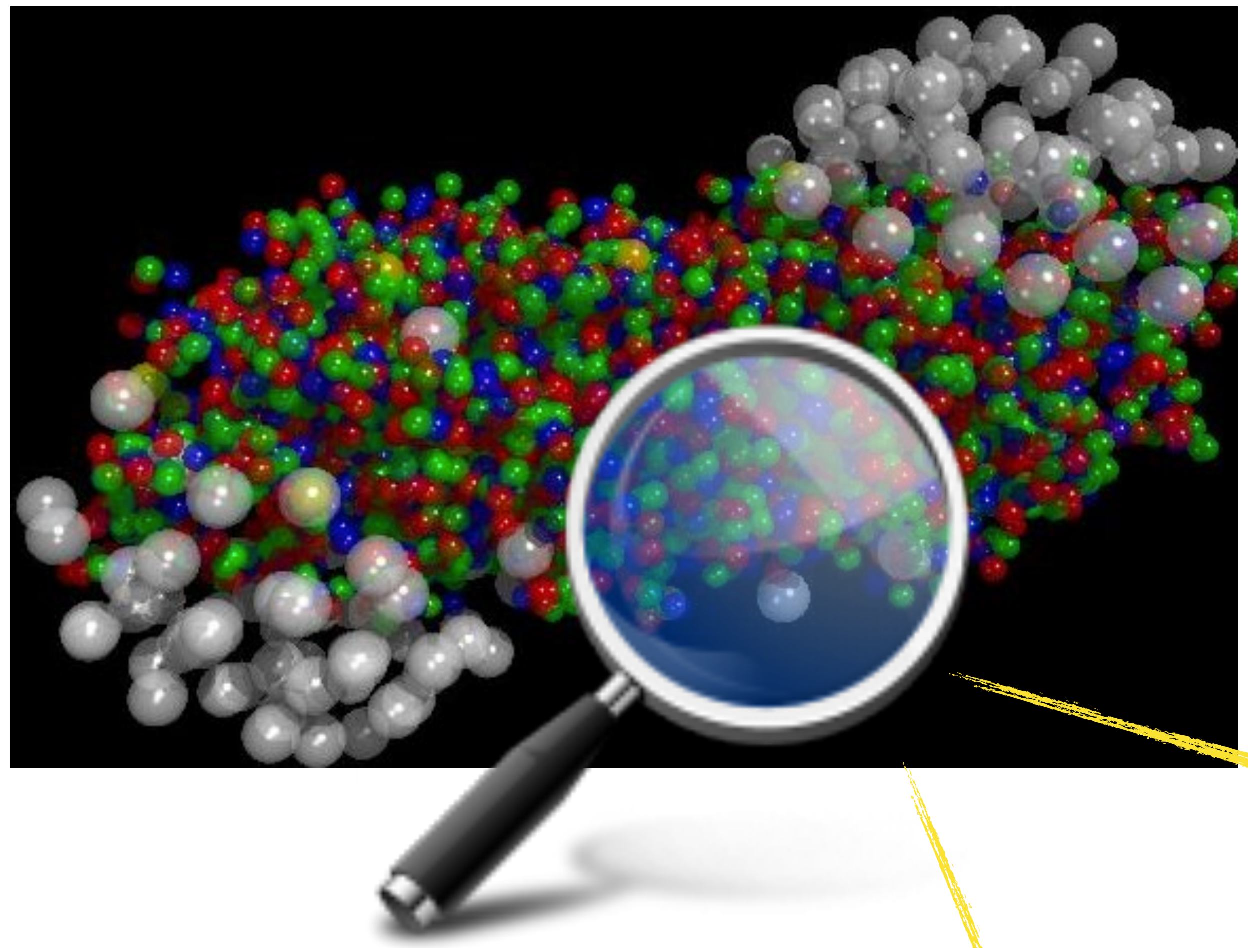
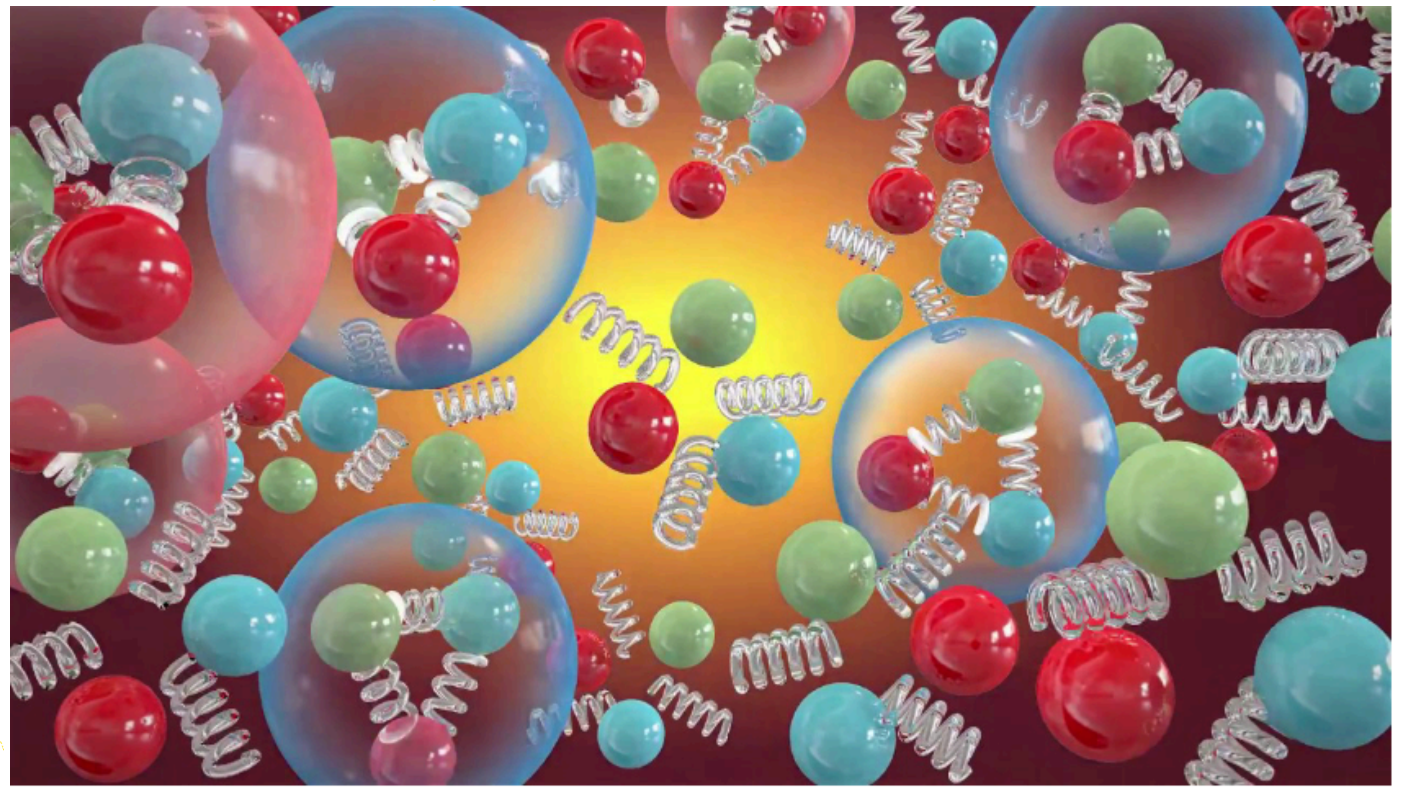




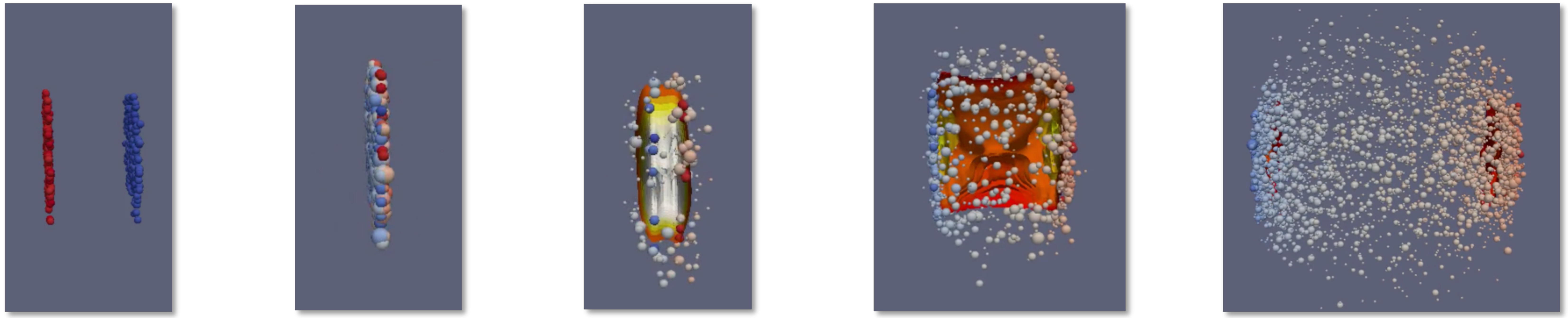
- characterization of the QGP created in heavy-ion collisions, understand QGP-like effects in smaller collision systems
- but also test of pQCD
- and much more…

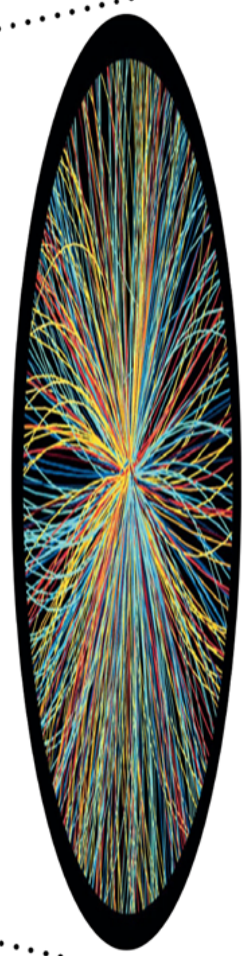
The ALICE experiment: a journey through QCD
Eur. Phys. J. C 84, 813 (2024)

Heavy Flavor (charm and beauty) as probes of the QGP

Initial State | Hard Scattering | QGP formation | Hydrodynamic expansion | Hadronization and freeze out | Detection

brief life of the QGP —> **emerging particles as ‘probes’**





$\tau = 0$ $\tau \sim 1$ fm/c $\tau \sim 10$ fm/c

$\sim 10^{15}$ fm/c

time

temperature

T ~ 200-800 MeV[1]

T ~ 155-100 MeV[2]

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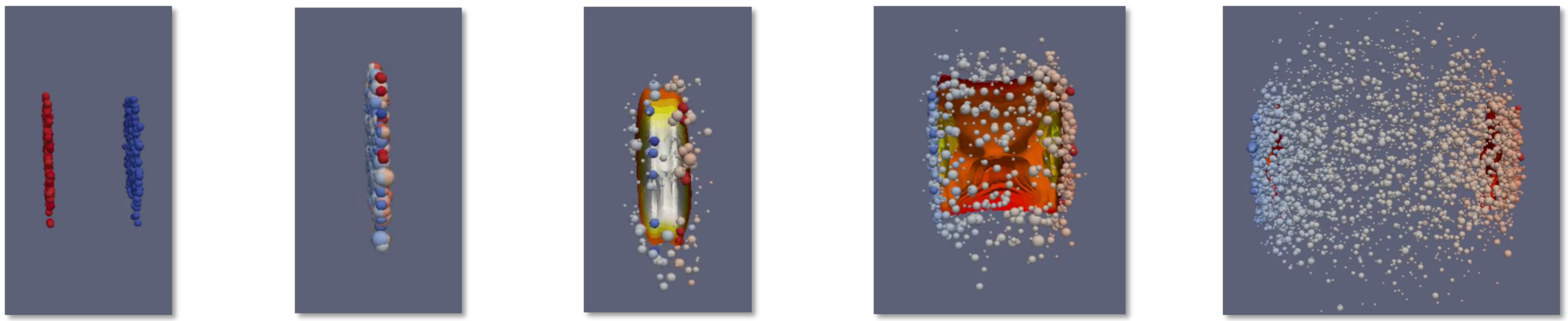

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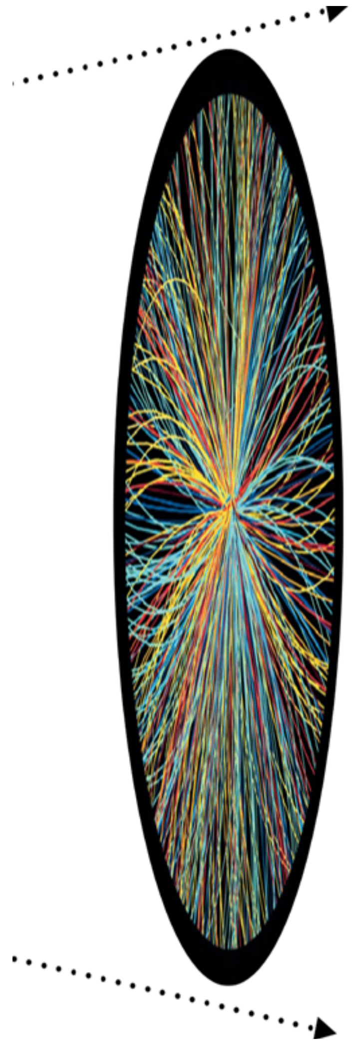

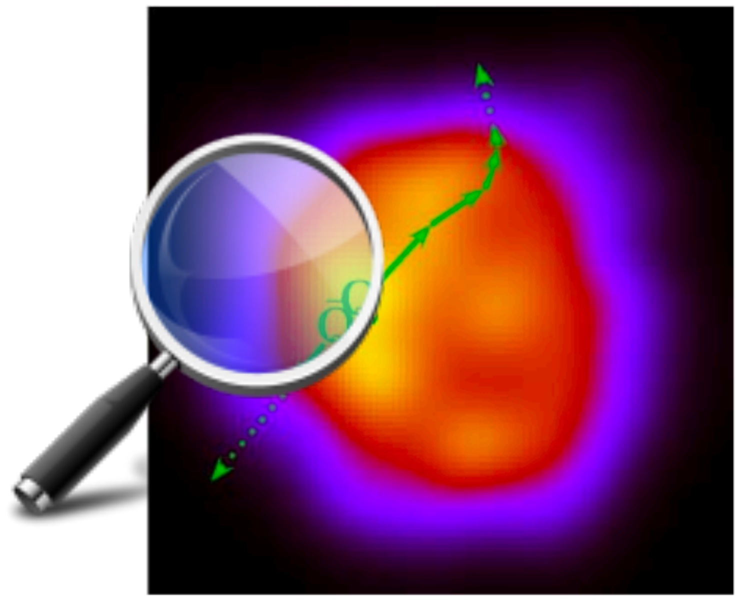

- ***m*Q >> TQGP** ($m_Q \gg T_{QGP}$)
  - formation time ~1/m$_q$: τ_b ~0.12 fm/c < τ_c ~0.39 fm/c < τ_{QGP} ~1.5 fm/c[1][2]
    - production restricted to initial hard scatterings
    - long relaxation time τ_Q, possibly comparable to the fireball lifetime (~ few fm/*c*)
- **$m_Q \gg \Lambda_{QCD}$**
  - their production cross section calculable with pQCD calculations

[1] Ann.Rev.Nucl.Part.Sci. 69 (2019) 417-445
[2] F.M Liu et al., PRC 89, 034906 (2014)

Heavy Flavor (charm and beauty) as probes of the QGP

HQ as tools to provide constraints to pQCD calculations,
investigate onset of QGP formation in smaller systems,
probes of the opacity of QGP, test of the degree of thermalization

For detailed discussions:
A. Rossi: hadronization
F. Grosa: QGP characterization

In this talk: overview of recent results from ALICE, *focusing* on new Run 3 measurements and few points to be addressed with the new data

- ***$m_Q \gg T_{QGP}$***
  - formation time ~1/m_q: τ_b ~0.12 fm/c < τ_c ~0.39 fm/c < τ_{QGP} ~1.5 fm/c[1][2]
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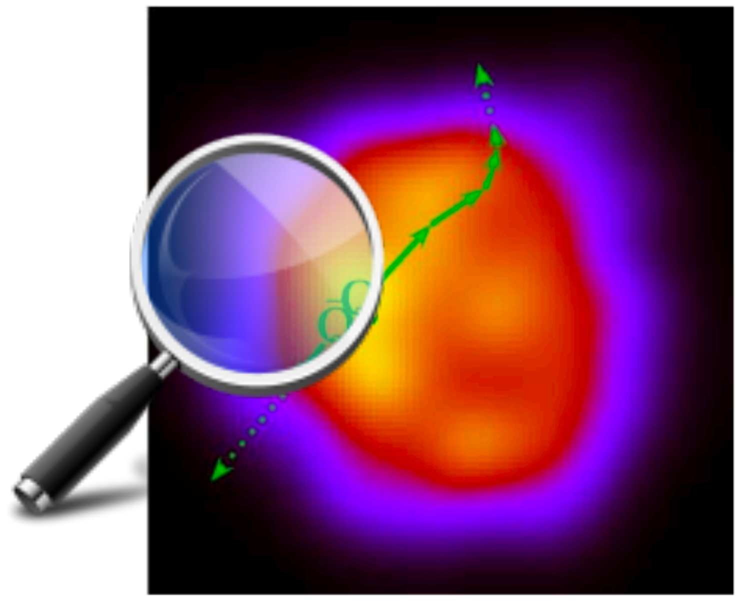

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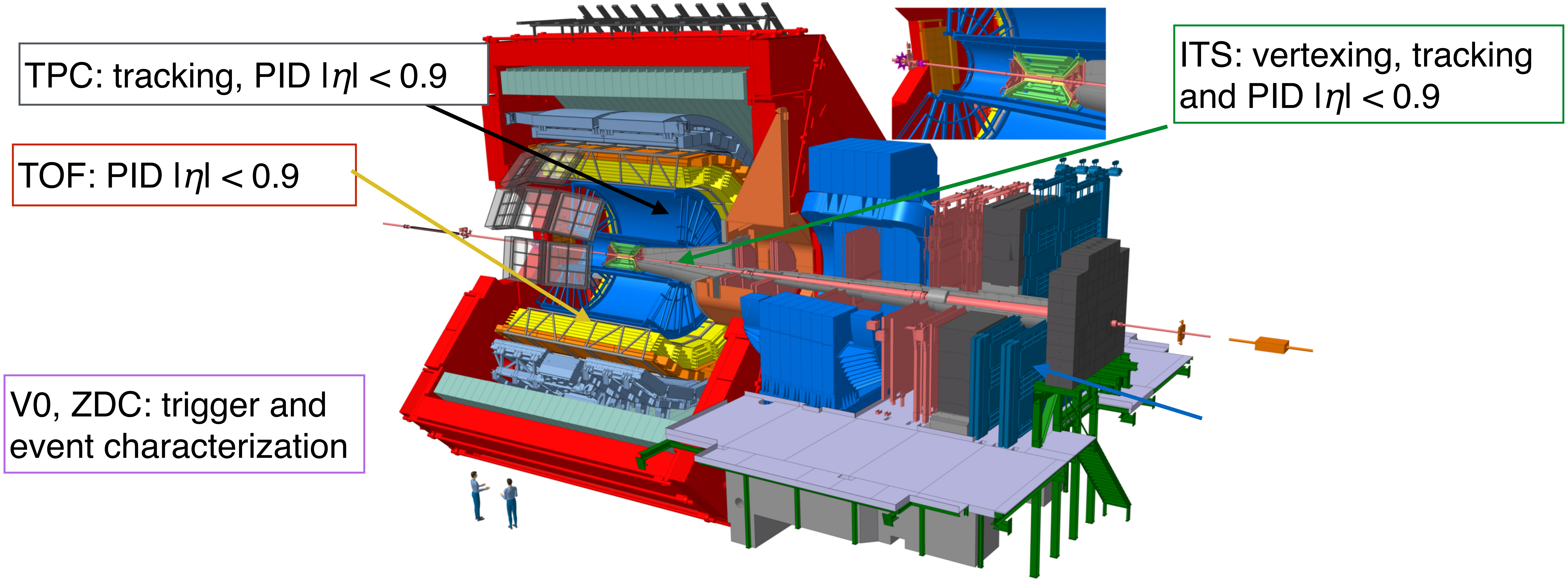
Upgrade of the ALICE detectors during LS2

ALICE Detector in Run 1 and Run 2



Key features for HF measurements:

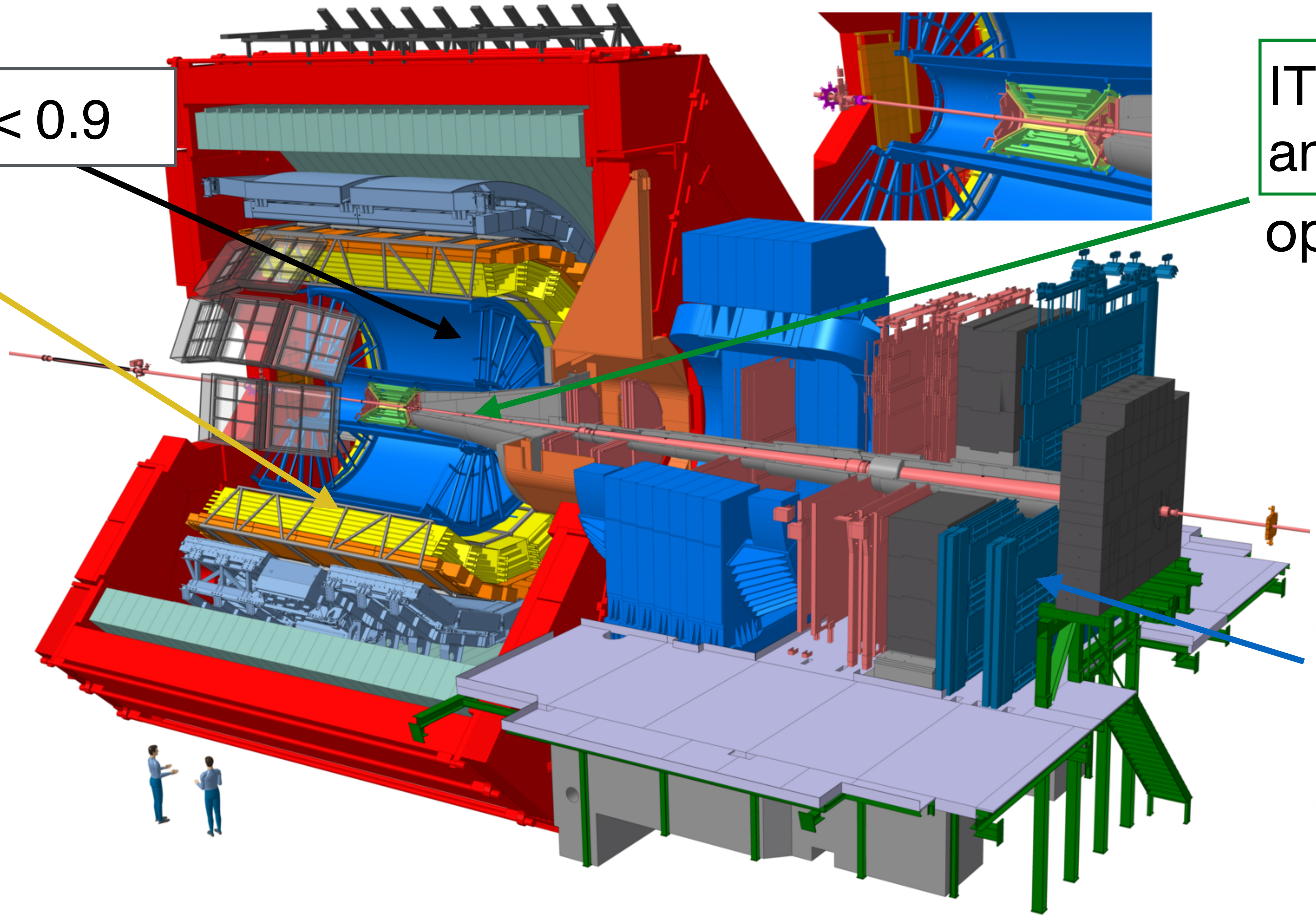
- precise vertex separation, low momentum tracking
- excellent PID

ALICE Detector in Run 1 and Run 2

TPC: tracking, PID $|\eta| < 0.9$

TOF: PID $|\eta| < 0.9$

V0, ZDC: trigger and event characterization



ITS: vertexing, tracking and PID $|\eta| < 0.9$

open HF hadrons reconstructed:

- $D^0 \to K^-\pi^+$ (c, b)
- $D_s^+ \to K^-K^+\pi^+$ (c, b)
- $D^+ \to K^-\pi^+\pi^+$ (c, b)
- $D^{*+} \to D^0\pi^+$
- $D_{s1}^+ \to D^*K_s^0$
- $D_{s2}^{*+} \to D^+K_s^0$

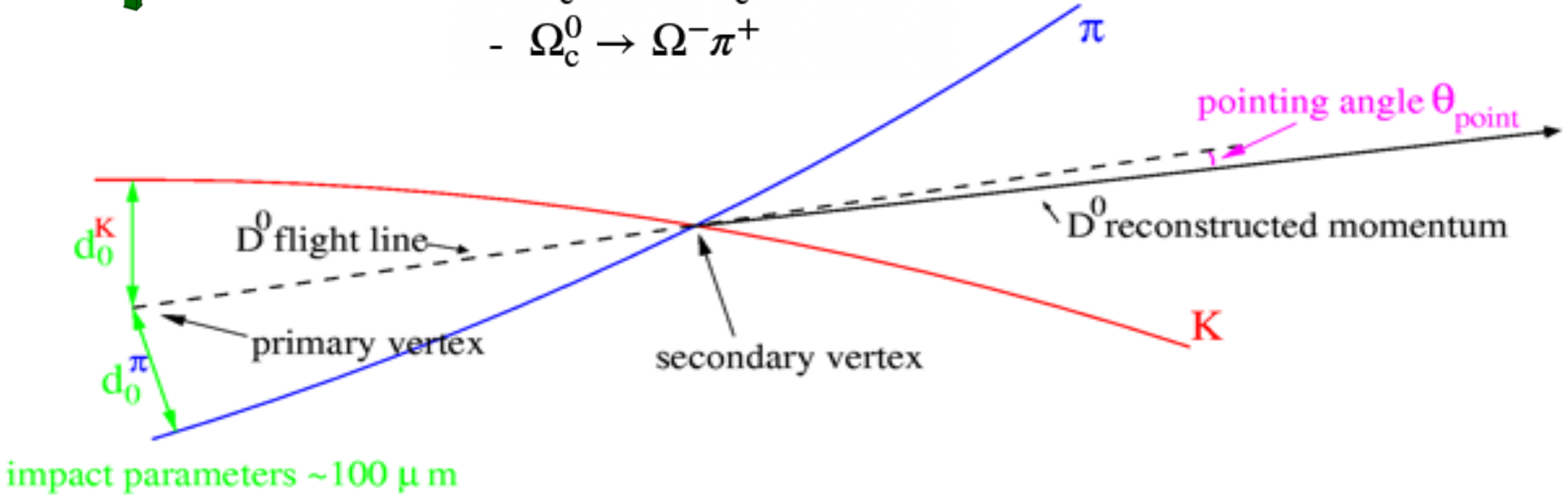
- $\Lambda_c^+ \to pK_s^0$ (c, b)
- $\Lambda_c^+ \to pK^-\pi^+$ (c, b)
- $\Xi_c^0 \to \Xi^-\pi^+$
- $\Xi_c^+ \to \Xi^-\pi^+\pi^+$
- $\Sigma_c^{0,++} \to \Lambda_c^+\pi^{-,+}$
- $\Omega_c^0 \to \Omega^-\pi^+$

*beauty via non-prompt D and Λ_c. +leptons from HF decays

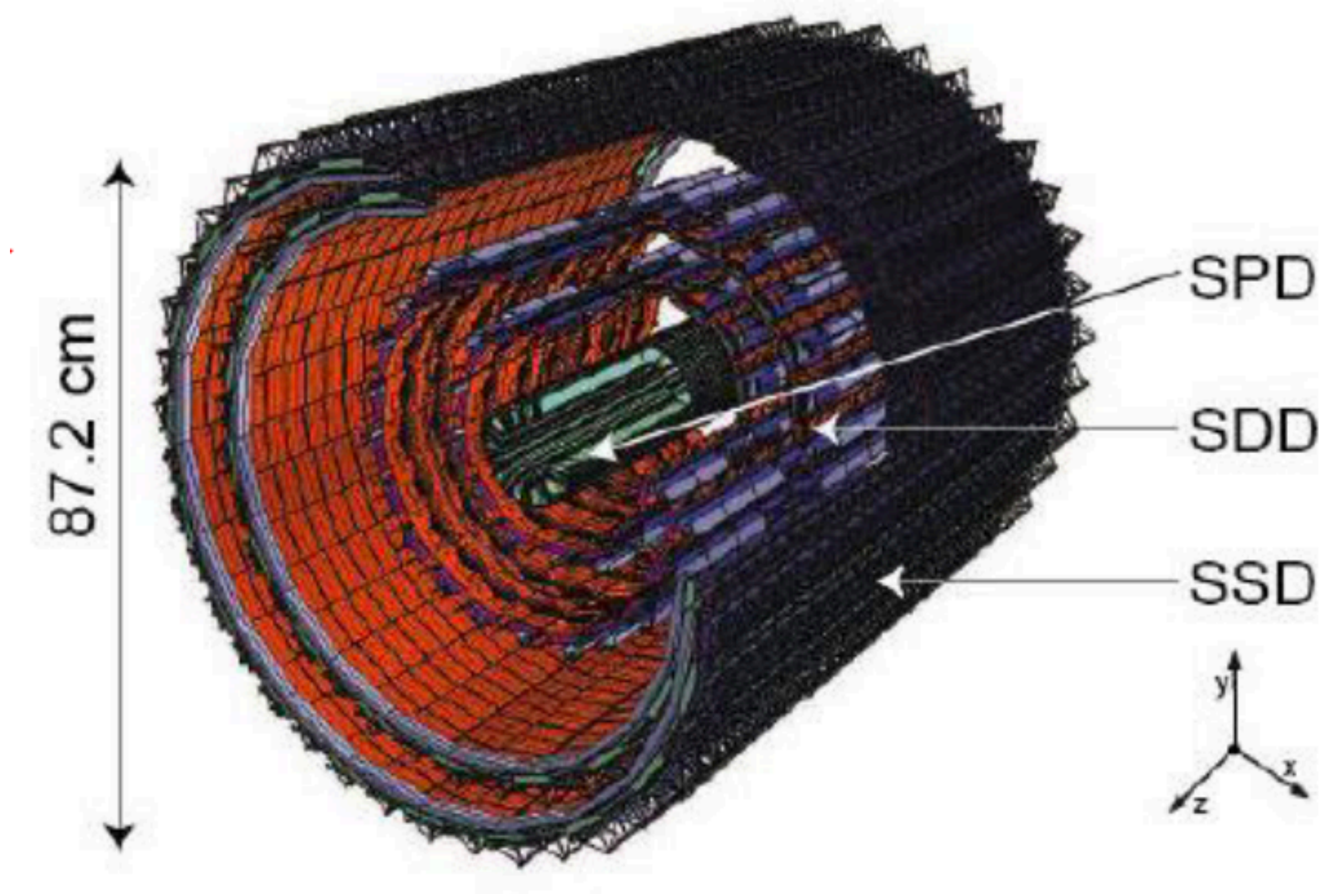
cτ few hundred microns

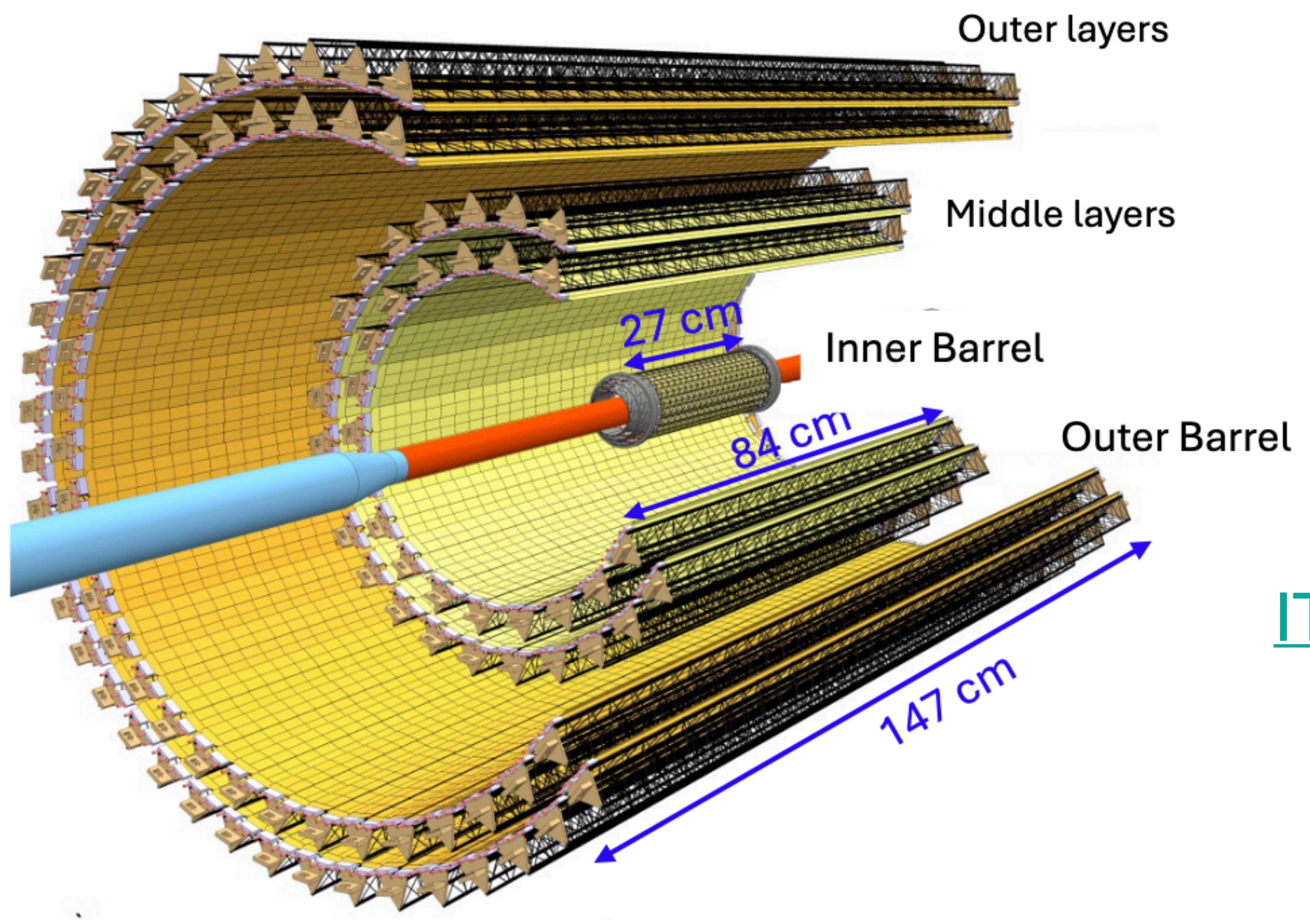
Key features for HF measurements:

- precise vertex separation, low momentum tracking
- excellent PID



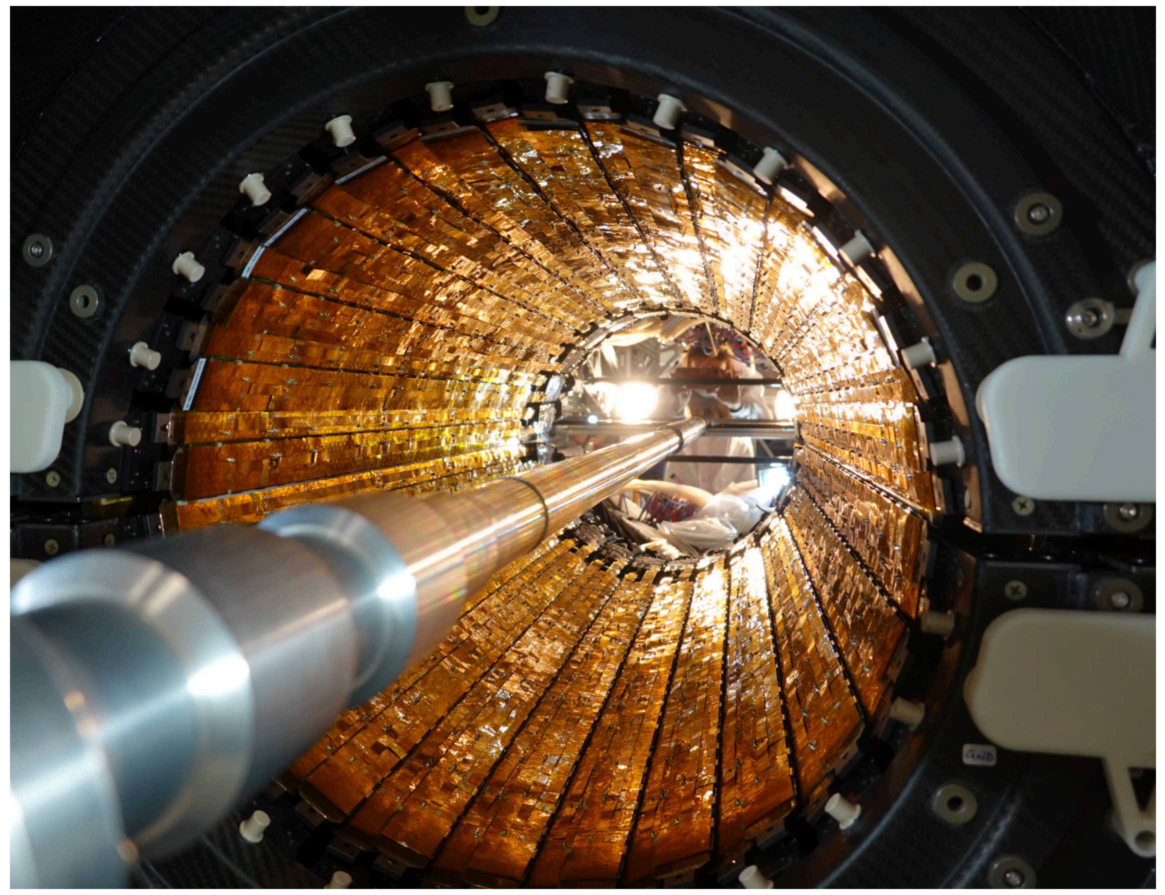
Upgrade of the Inner Tracking System: ITS 2





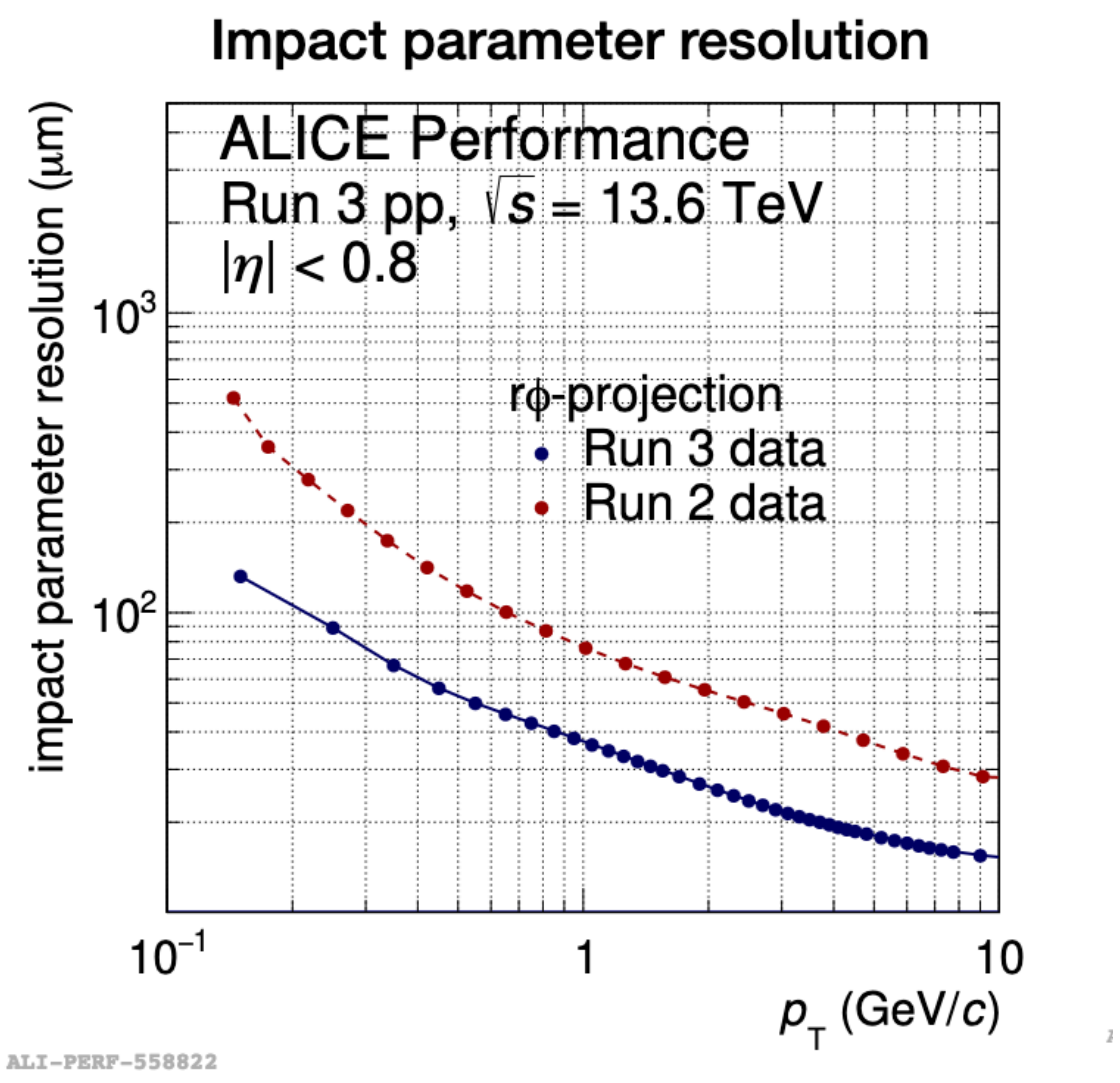
ITS 2

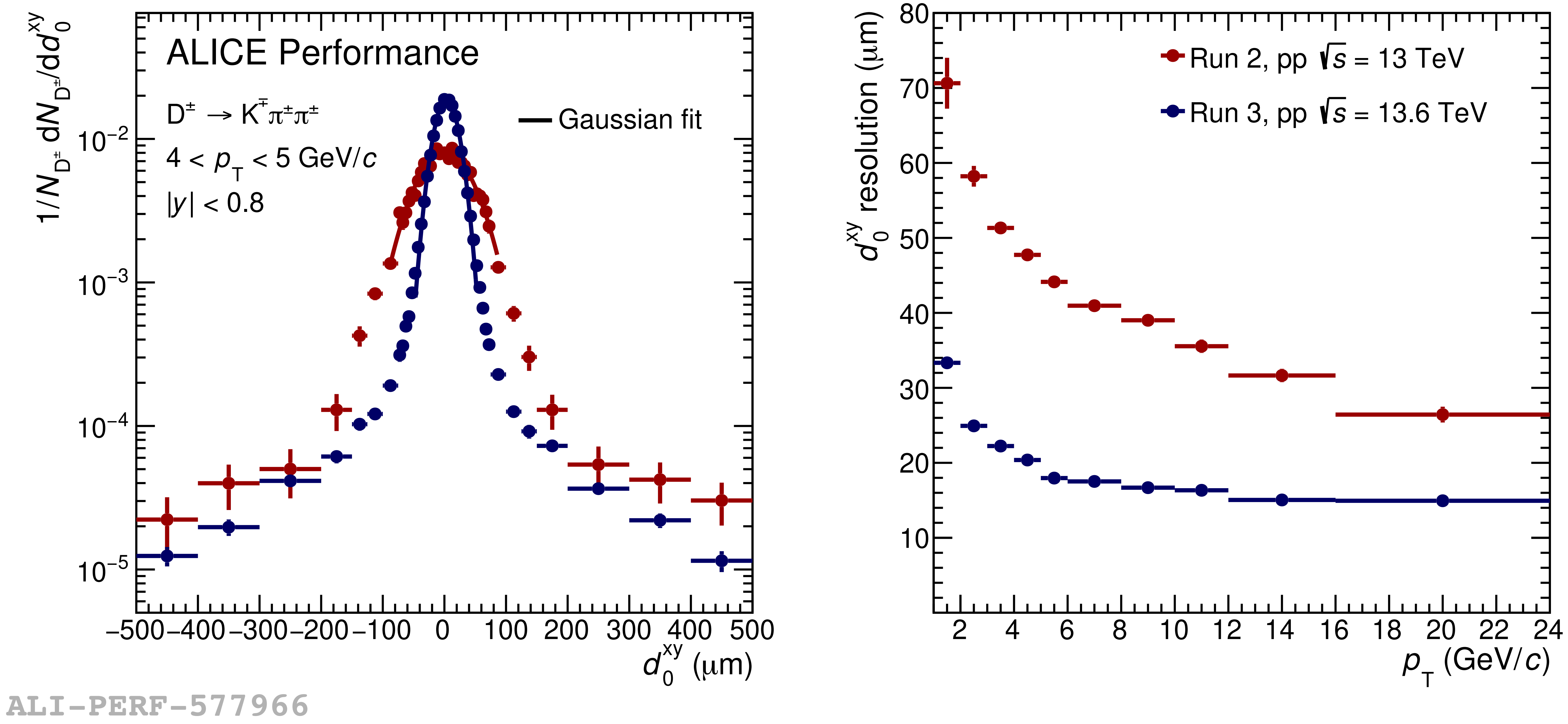
- Main features of the ITS 2 upgrade:
  - first layer closer to the beam-pipe: from 3.9 cm to **2.3 cm**
  - reduced material budget: from 1.14% X_0 to **0.36% X_0** per layer
  - reduced pixel size: from 50x425 μm² to **29x27** μm²
    - reduced multiple scattering, improved spacial resolution and tracking precision
  - additional layer
    - improved efficiency and p_T resolution at low p_T



ITS upgrade: ITS2

Impact parameter resolution in Run 3





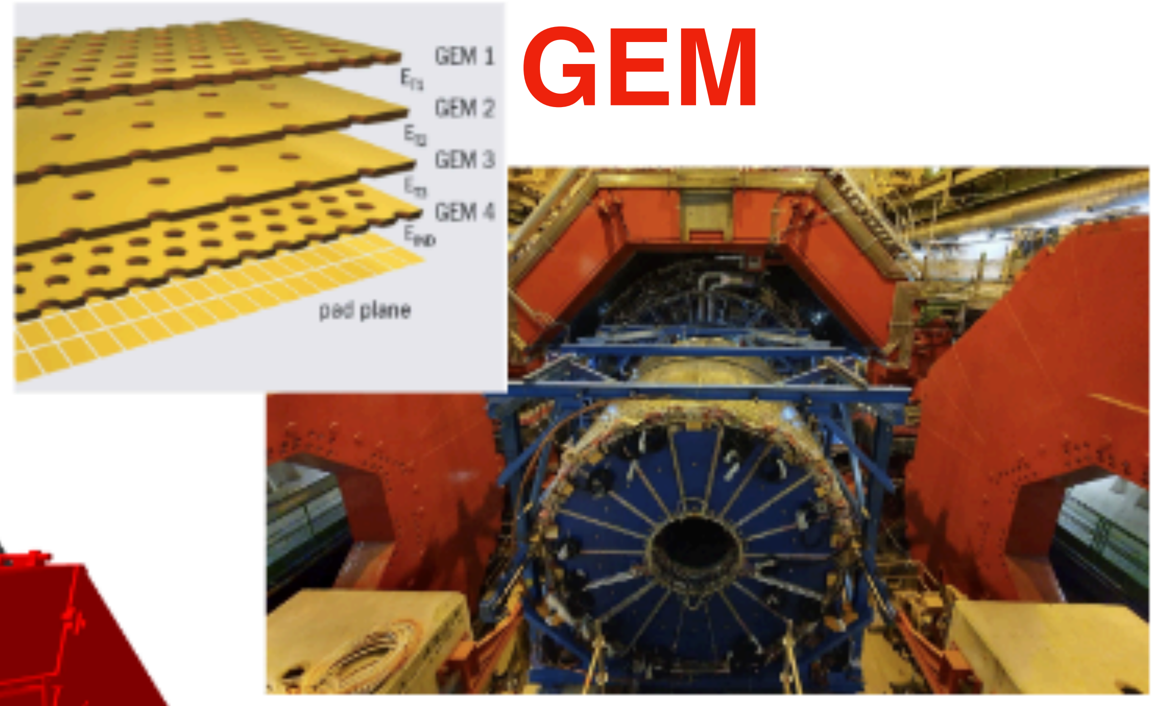
Improved impact parameter resolution: by a factor of ~3 in rϕ, ~5 in z

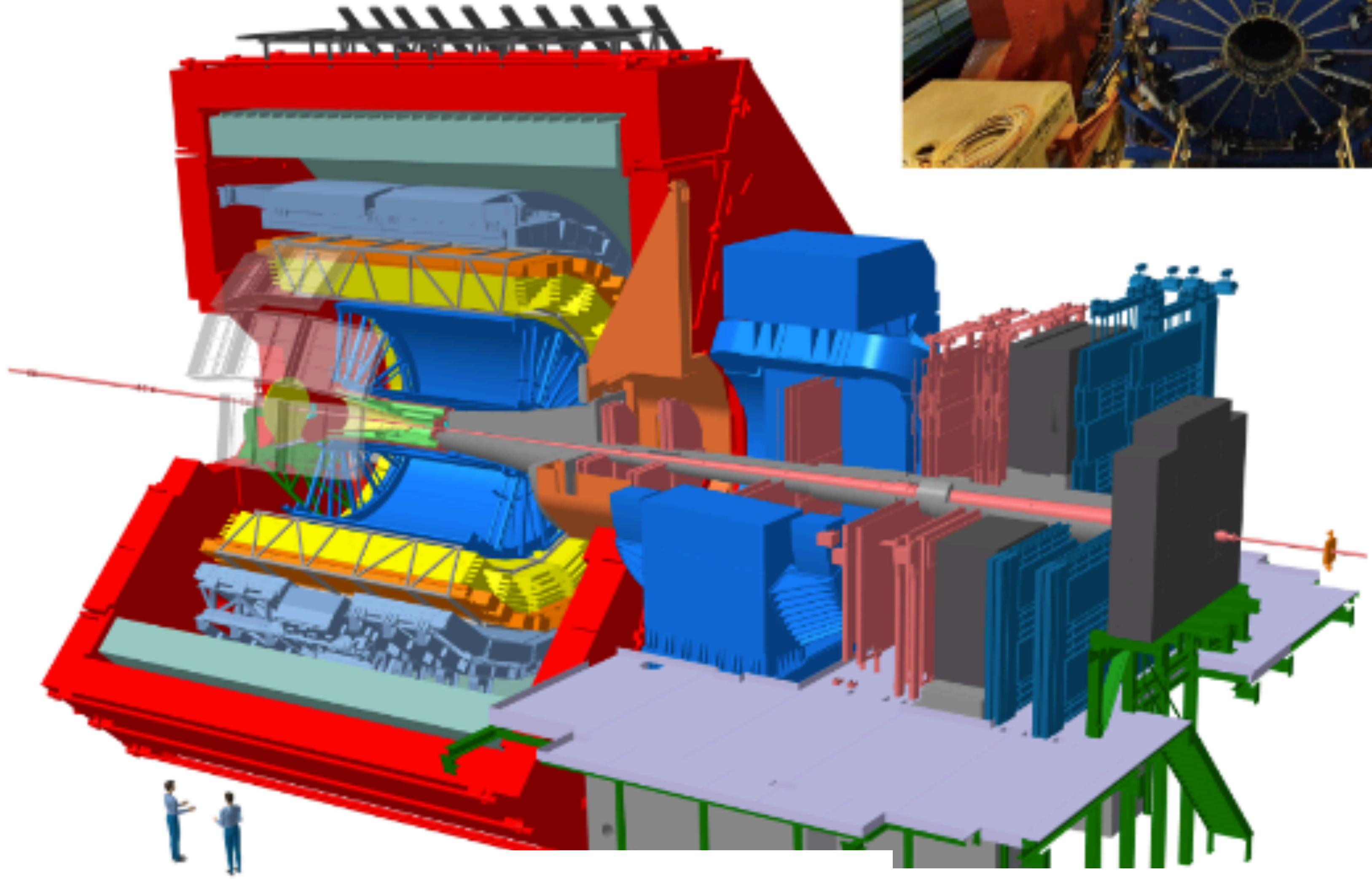
Improved resolution for D meson reconstruction

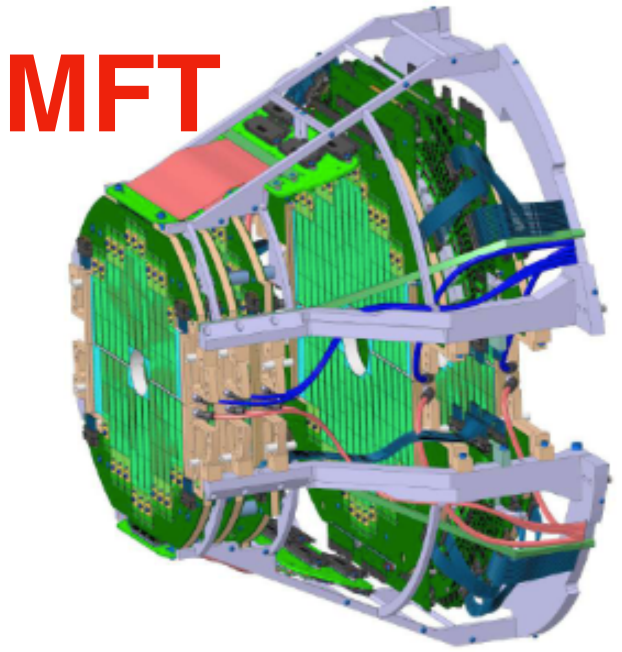
…and upgrade of the readout

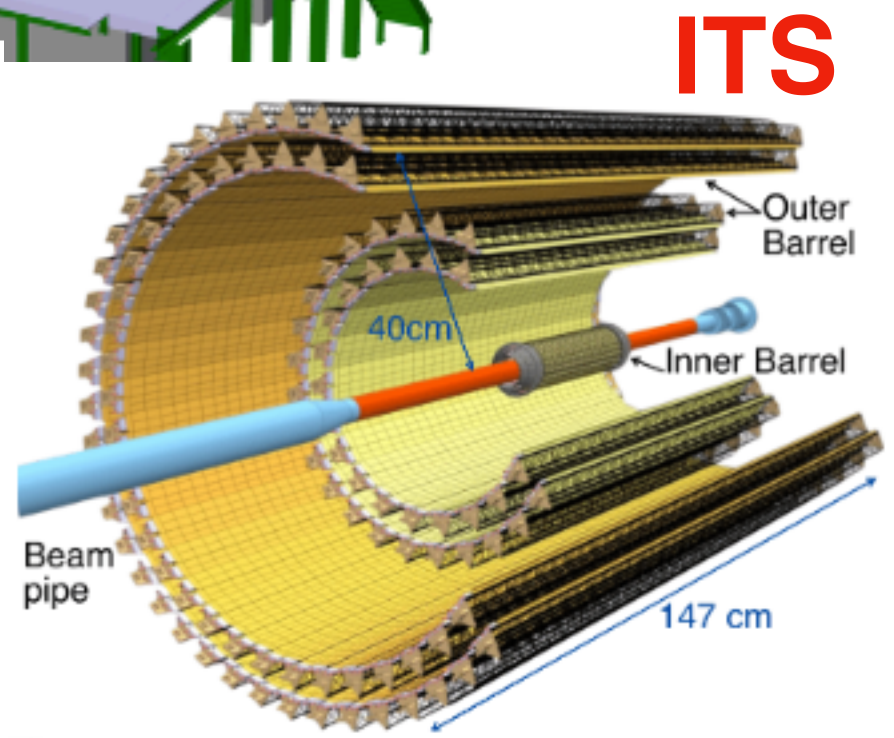
- **fast readout** for the **ITS 2**[1]:
  - rate up to 100 kHz (Pb-Pb, was 1kHz) and 400 kHz for pp
- **GEM readout for the TPC**[2]
- **new** Muon Forward Tracker (**MFT**)[3]
- **new** Forward Interactions Trigger (**FIT**)[4]
- new Event Processing Farm
- upgraded readout for most detectors

continuous readout at high rate: more collected statistics









ALICE upgrade during LS2

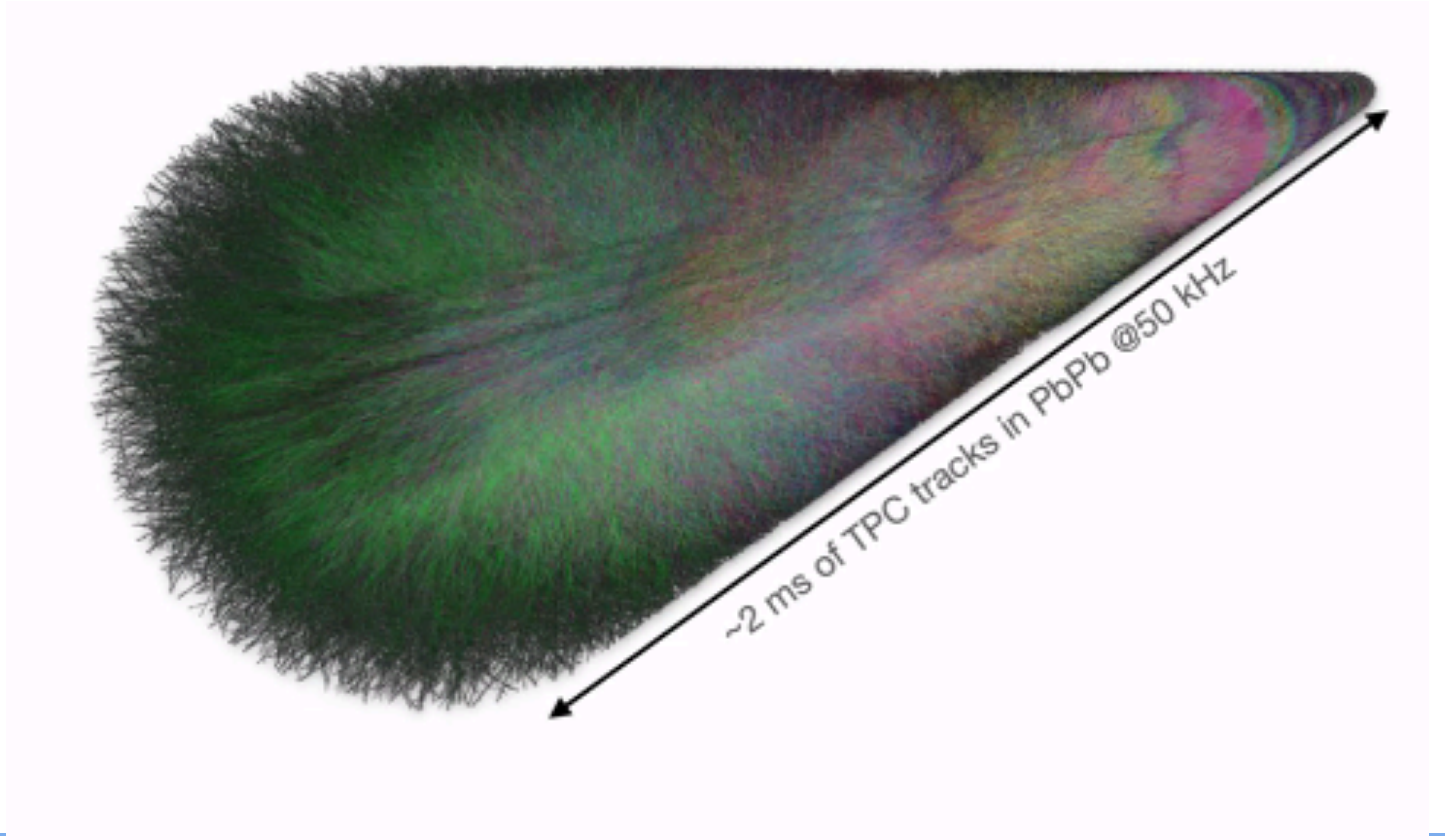
ITS [1]

TPC GEM upgrade [2] MFT [3] FIT[4]

From triggered events to continuous readout

See. F. Ronchetti talk

- All collisions are stored for main detectors:
  - no collision events, but stream of data split in ‘timeframes’
  - in 2023, in Pb-Pb: collected 40x minimum bias, 6x central wrt Run 1 + 2



Software trigger: strategy for HF measurements

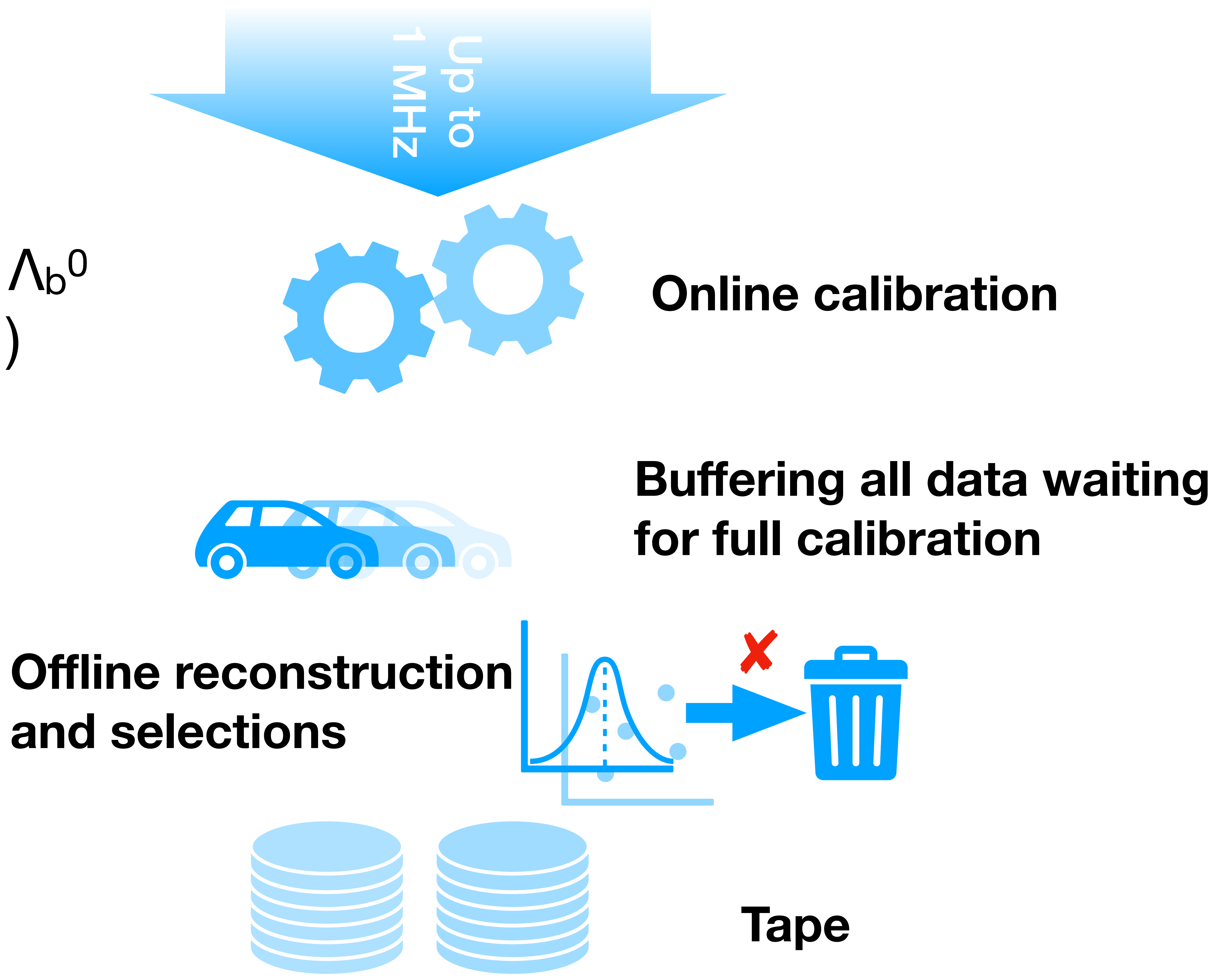
New offline trigger strategy for beauty/rare candidates

Software triggers: flag collisions based on the presence of interesting signals

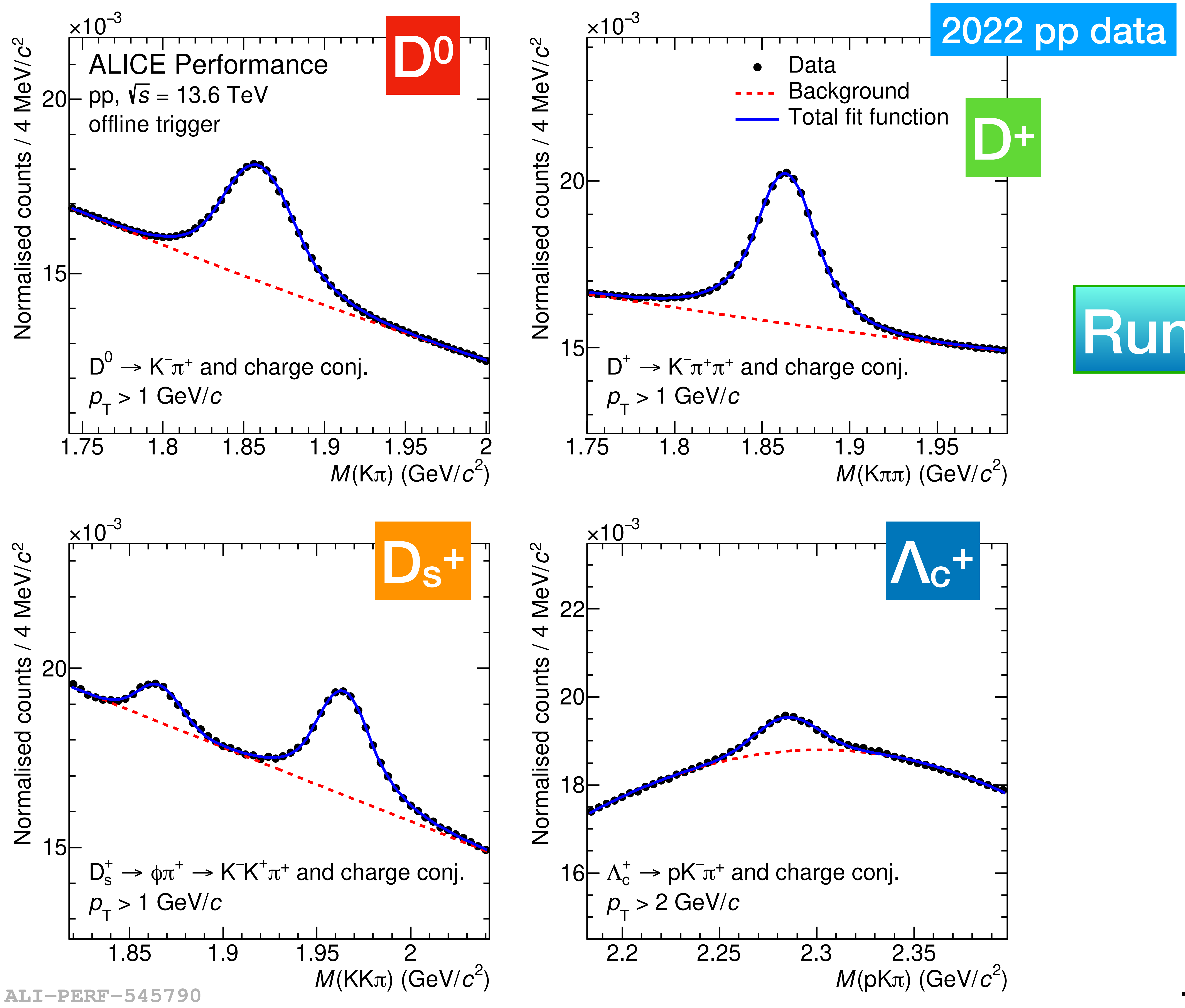
- rare baryons and beauty hadrons: Ω_c^0, $\Xi_c^0 \rightarrow \Xi\pi$, B^+, B^0, B_s^+, Λ_b^0
- and more (p-Λ_c, double charm production, D_s resonances…)

Steps of the software trigger:
Online calibration + offline reconstruction and selection:

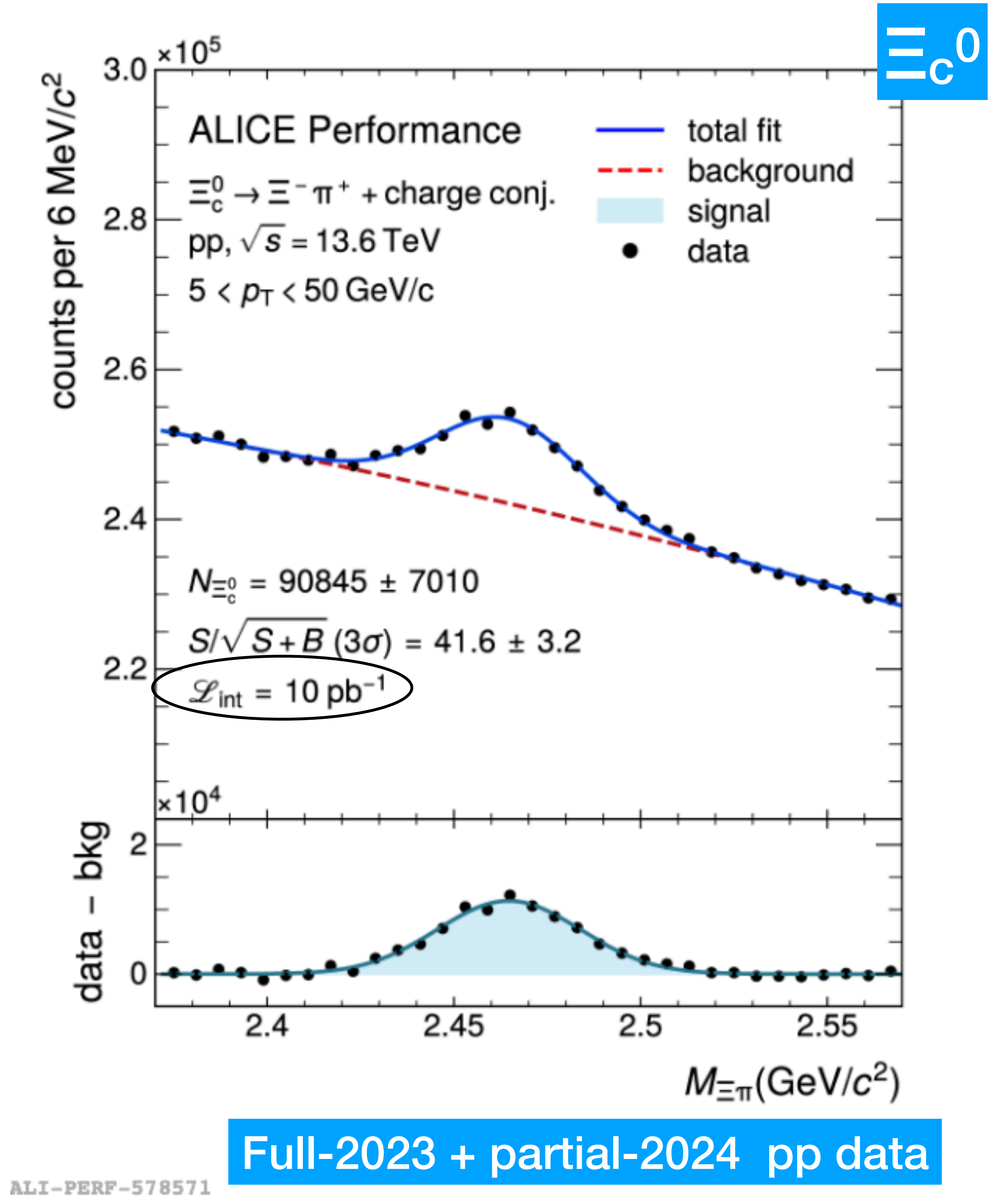
- single track selection
- combinatorics (->reconstruction)
- applying p_T, mass and topological cuts
- Machine Learning tecniques, PID



Performance from triggered data



Run 3

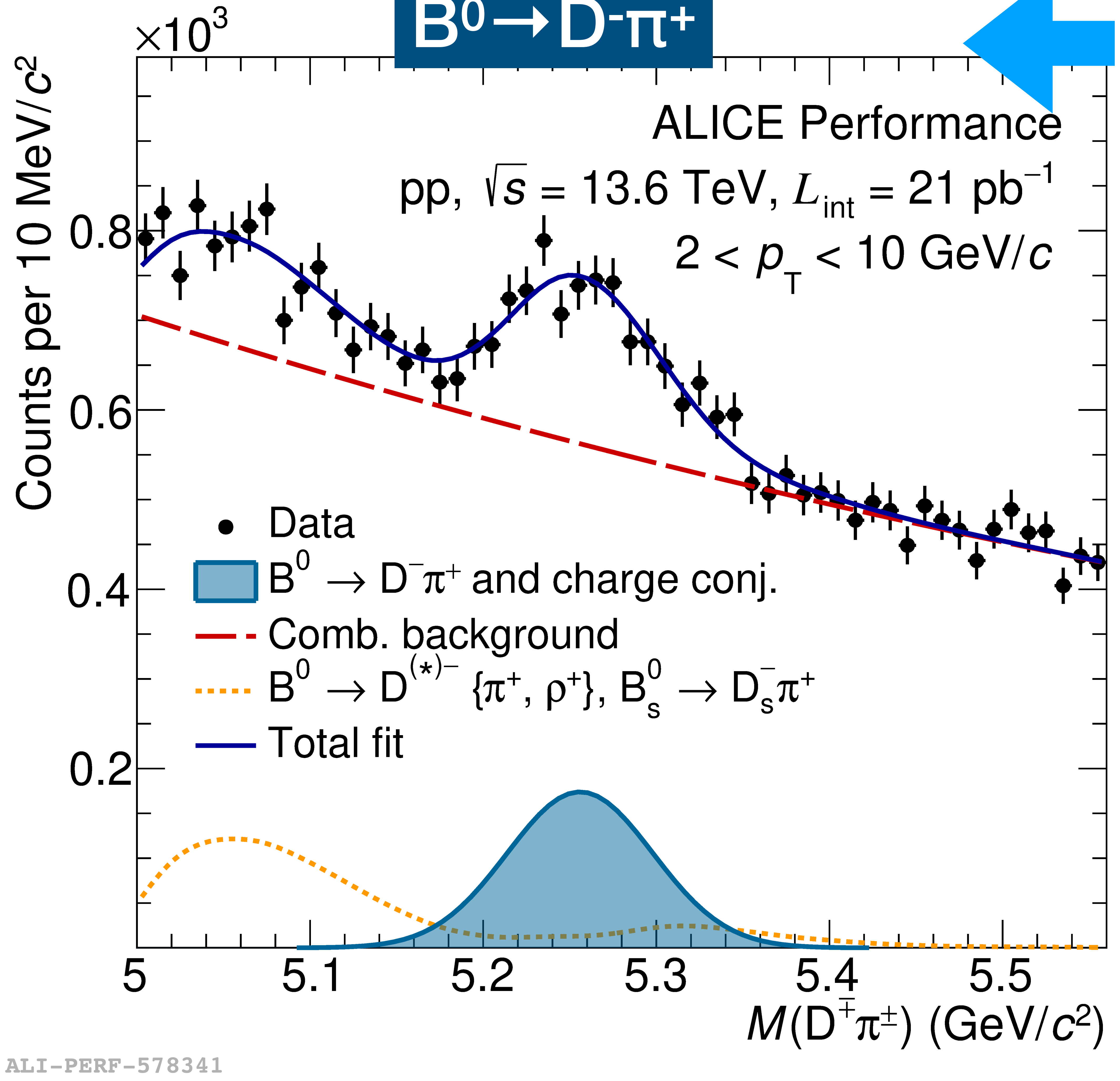


10 pb^{-1}: with dedicated software trigger

First measurement of the exclusive B meson decays in ALICE

Run 3

$B^0 \to D^-\pi^+$

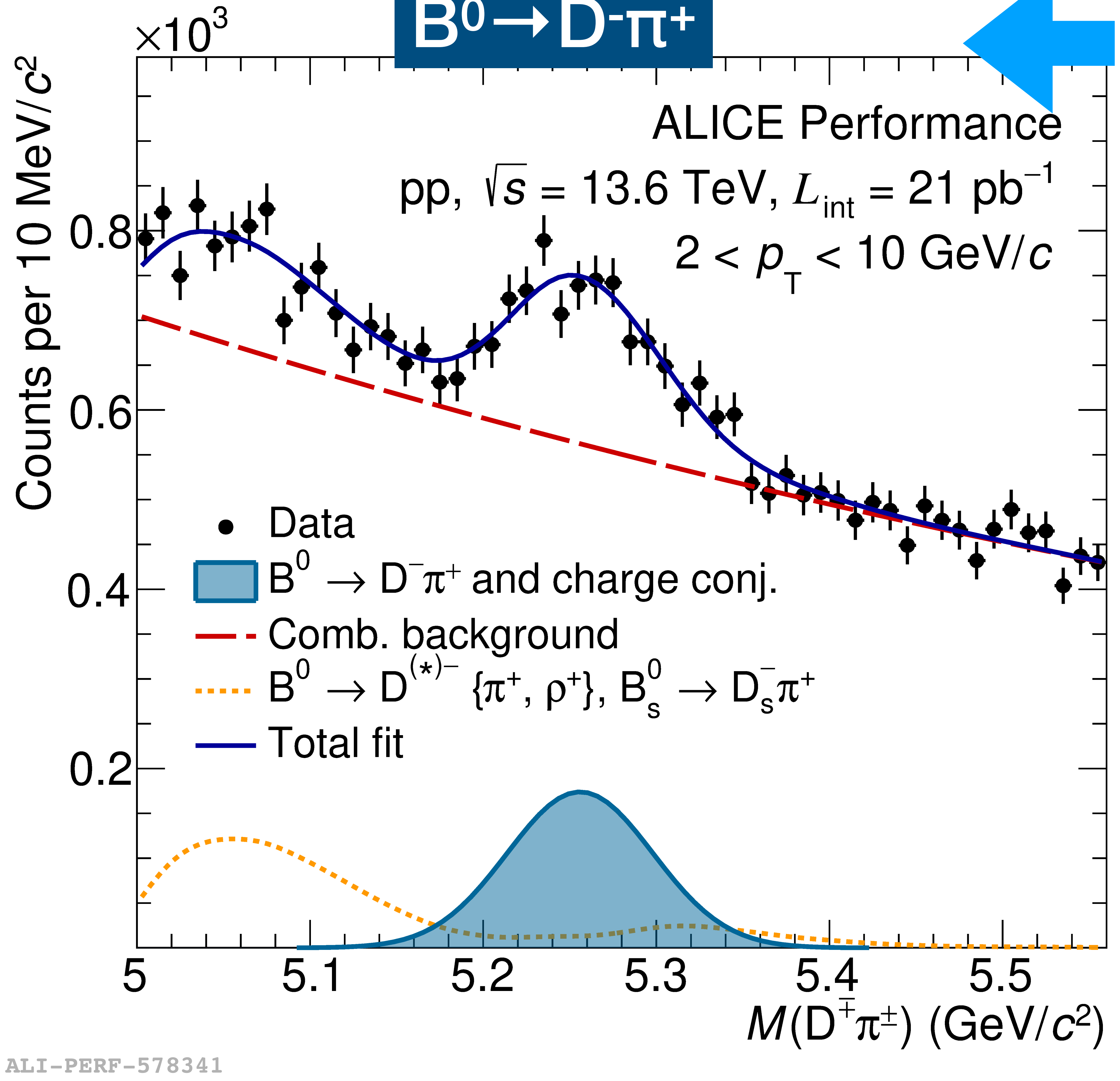


Access to fully reconstructed beauty meson decays at midrapidity, down to very low p_T

First measurement of the exclusive B meson decays in ALICE

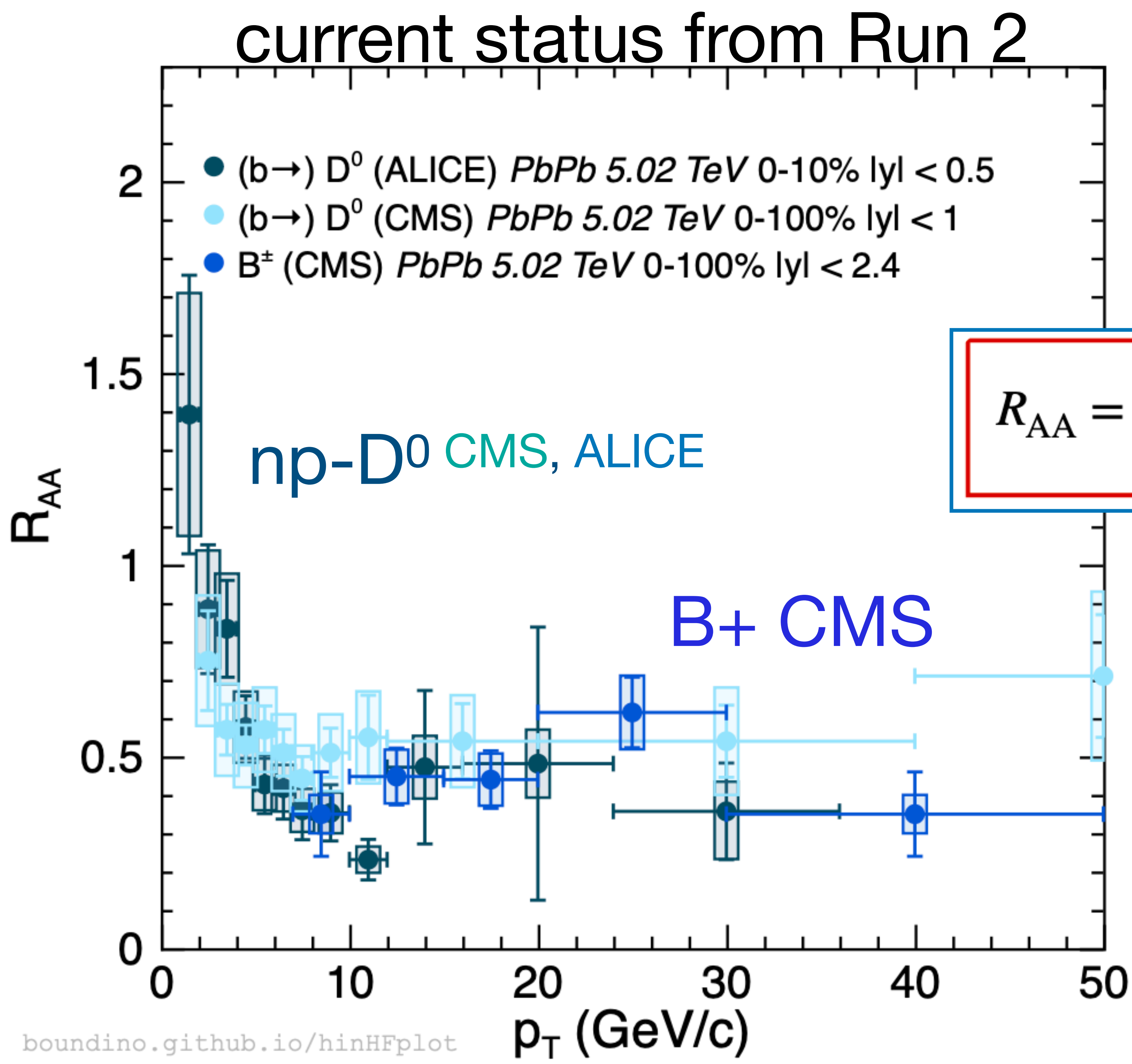
Run 3

$B^0 \rightarrow D^- \pi^+$



Access to fully reconstructed beauty meson decays at midrapidity, down to very low p_T

current status from Run 2

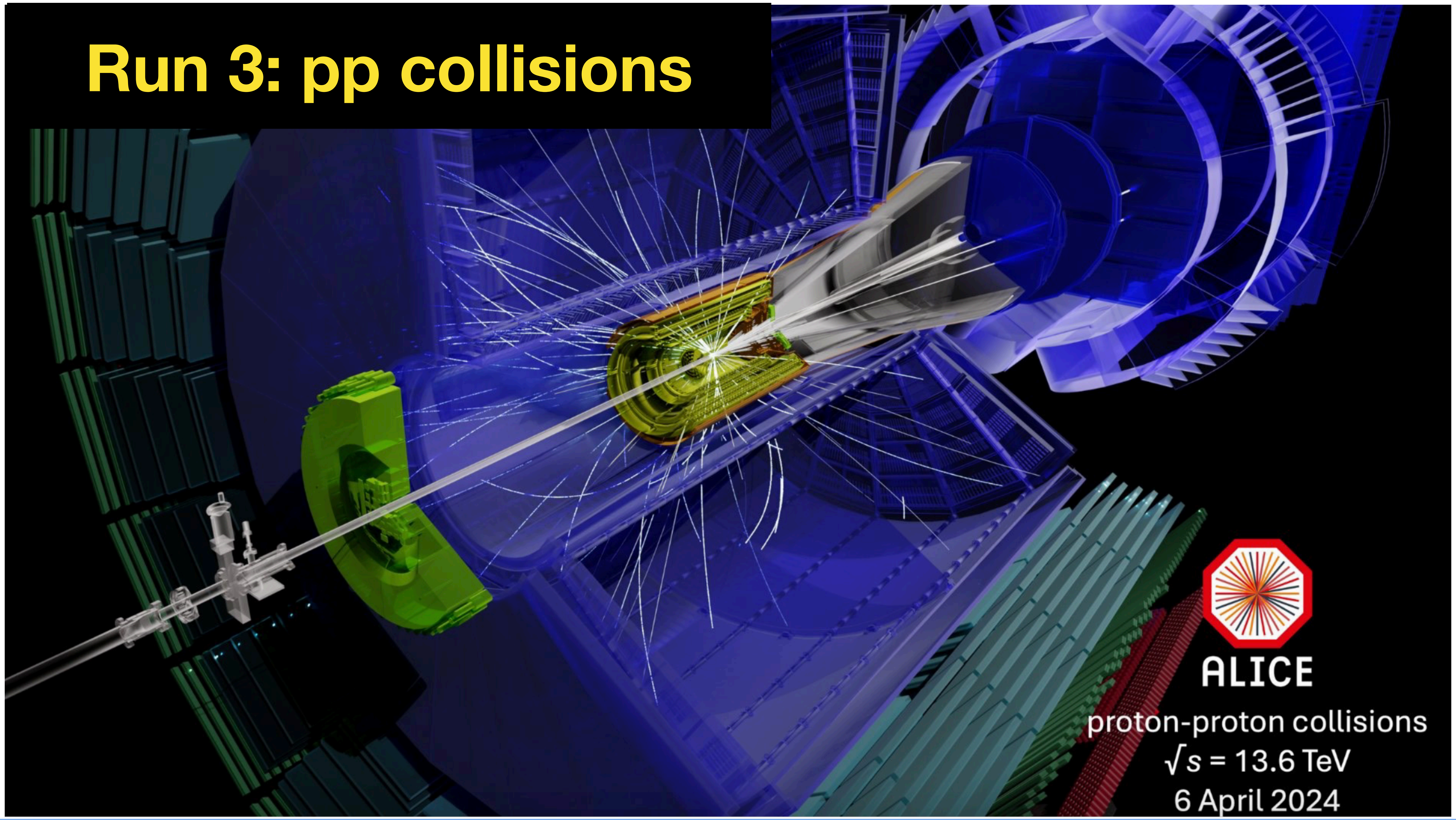


https://boundino.github.io/hinHFplot/

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

→ JHEP 12 (2022) 126 → PRL 123 (2019) 022001
→ PRL 119 (2017) 152301 Phys. Lett. B 771 (2017) 435

overview of recent open-HF measurements



Testing pQCD with heavy quarks

Large masses —> Large squared momentum transfer, Q^2 —> perturbative QCD

Factorization approach

$$\sigma_{AB\to H} = \mathrm{PDF}(x_a, Q^2)\mathrm{PDF}(x_b, Q^2) \otimes \sigma_{ab\to q\bar{q}}(x_a, x_b, Q^2) \otimes D_{q\to H}(z = \mathrm{p_H}/\mathrm{p}_q, Q^2)$$

Parton distribution functions

Hard scattering cross section

Fragmentation function

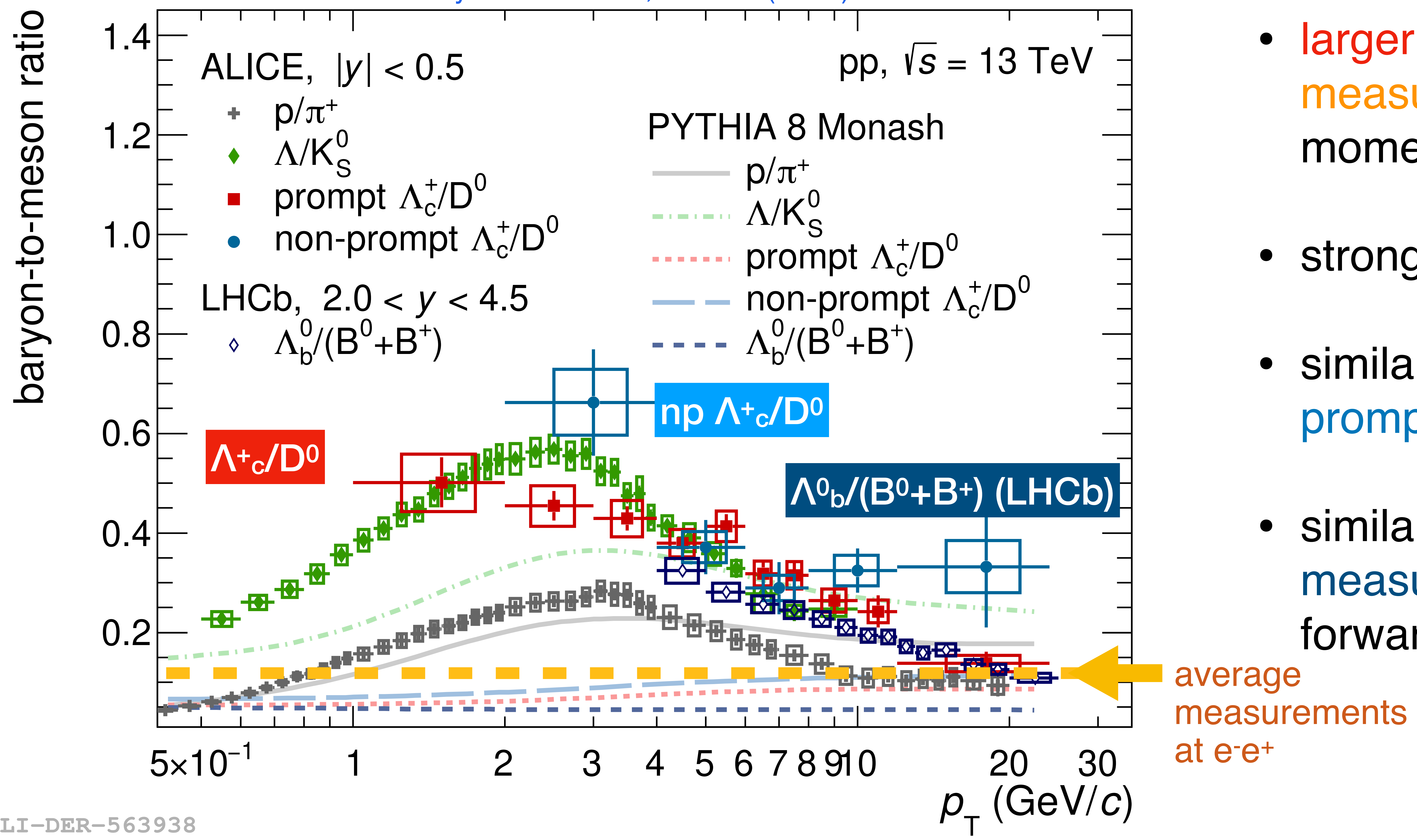
Fragmentation fractions: assumed to be universal across collision systems and extracted from e^-e^+, e^-p measurements

Measurements of **relative abundances of particle species** are **sensitive to hadronisation mechanisms**.

For detailed discussion, see A. Rossi talks

baryon-to-meson ratios: testing pQCD and heavy-quark fragmentation

Phys. Rev. D 108, 112003 (2023)



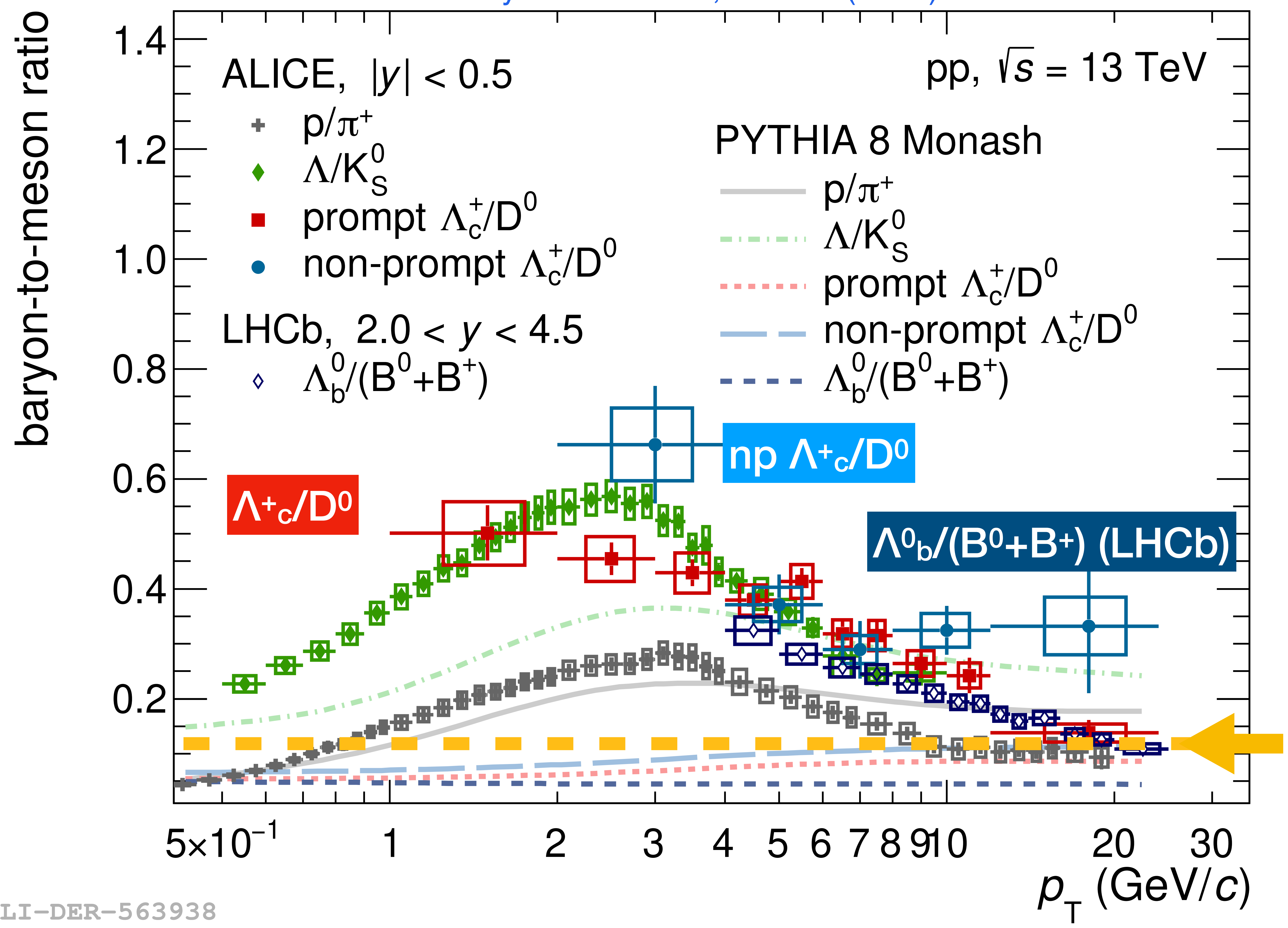
- larger baryon-to-meson ratios wrt to ee measurements at low-intermediate momenta
- strong p_T dependence
- similar trend vs p_T measured for non-prompt Λ^+_c/D^0 at mid-rapidity
- similar trend vs p_T for $\Lambda^0_b/(B^0+B^+)$ measured by LHCb in pp collsions at forward rapidity

PHYS. REV. D 99, 052011 (2019)

Run 2

baryon-to-meson ratios: testing pQCD and heavy-quark fragmentation

Phys. Rev. D 108, 112003 (2023)



average measurements at e-e+

- Models based on standard string Lund fragmentation and with fragmentation functions constrained by ee, ep measurements, fail to describe data (PYTHIA Monash)

Fragmentation of heavy quarks (c,b) is not an universal process among different collision systems:
➡ hadronic environment plays a role!

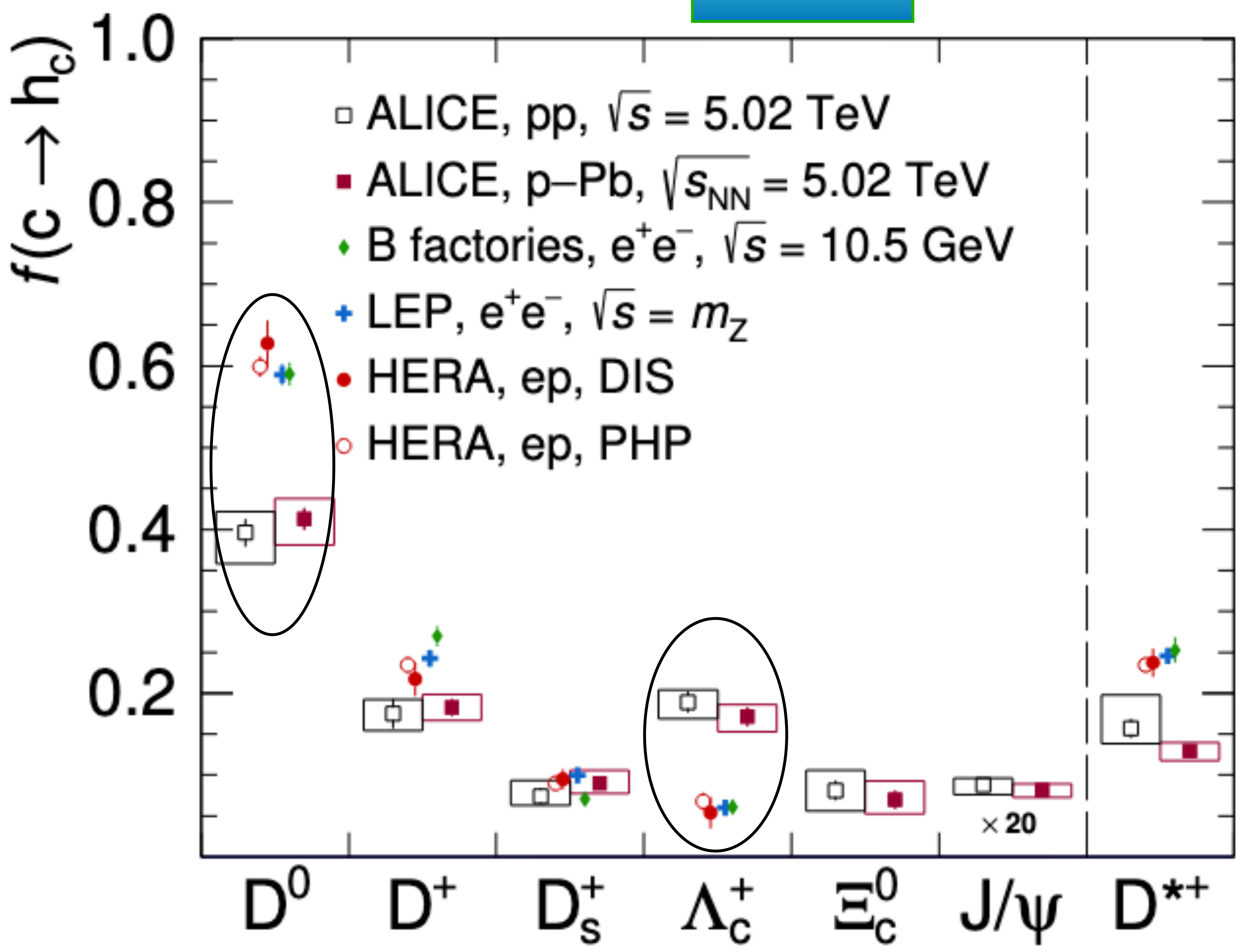
Charm Fragmentation Fractions

Run 2

arXiv:2405.14571

First measurement of charm fragmentation fractions in pp and p-Pb collisions:

- all ground states of charm hadrons measured with high precision
- D^0, D^+, Λ^+_c measured down to p_T=0 in pp collisions



Fragmentation fractions are not universal!

Charm Fragmentation Fractions

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First measurement of charm fragmentation fractions in pp and p-Pb collisions:

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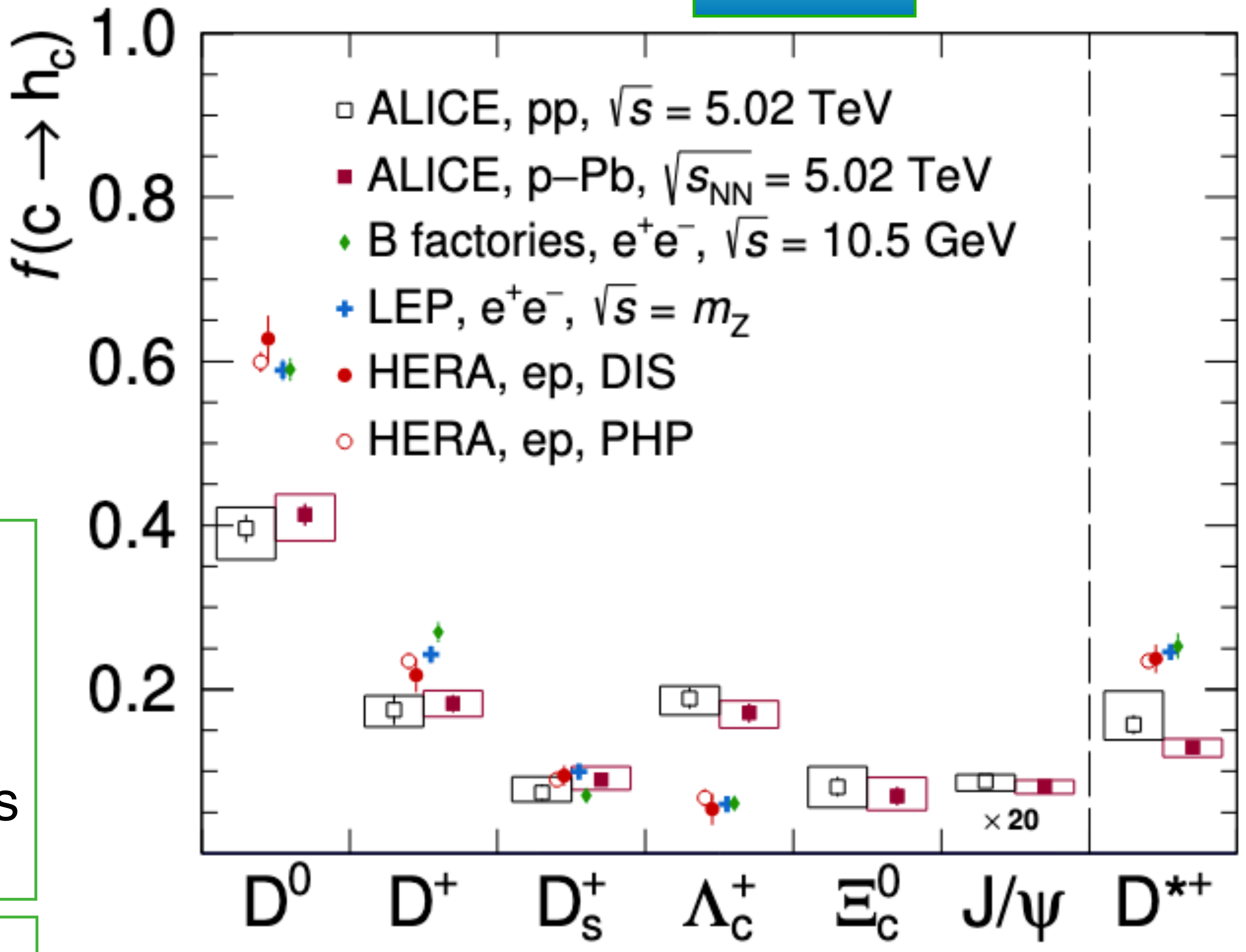
- D^0, D^+, Λ^+_c measured down to p_T=0 in pp collisions

Points to be addressed:

- improve precision of Ξ^0_c (and Ξ^+_c) measurements
- measurements to be done down to p_T=0 for all the species (to be independent on extrapolations based on theoretical models)



Beauty fragmentation at mid-rapidity?

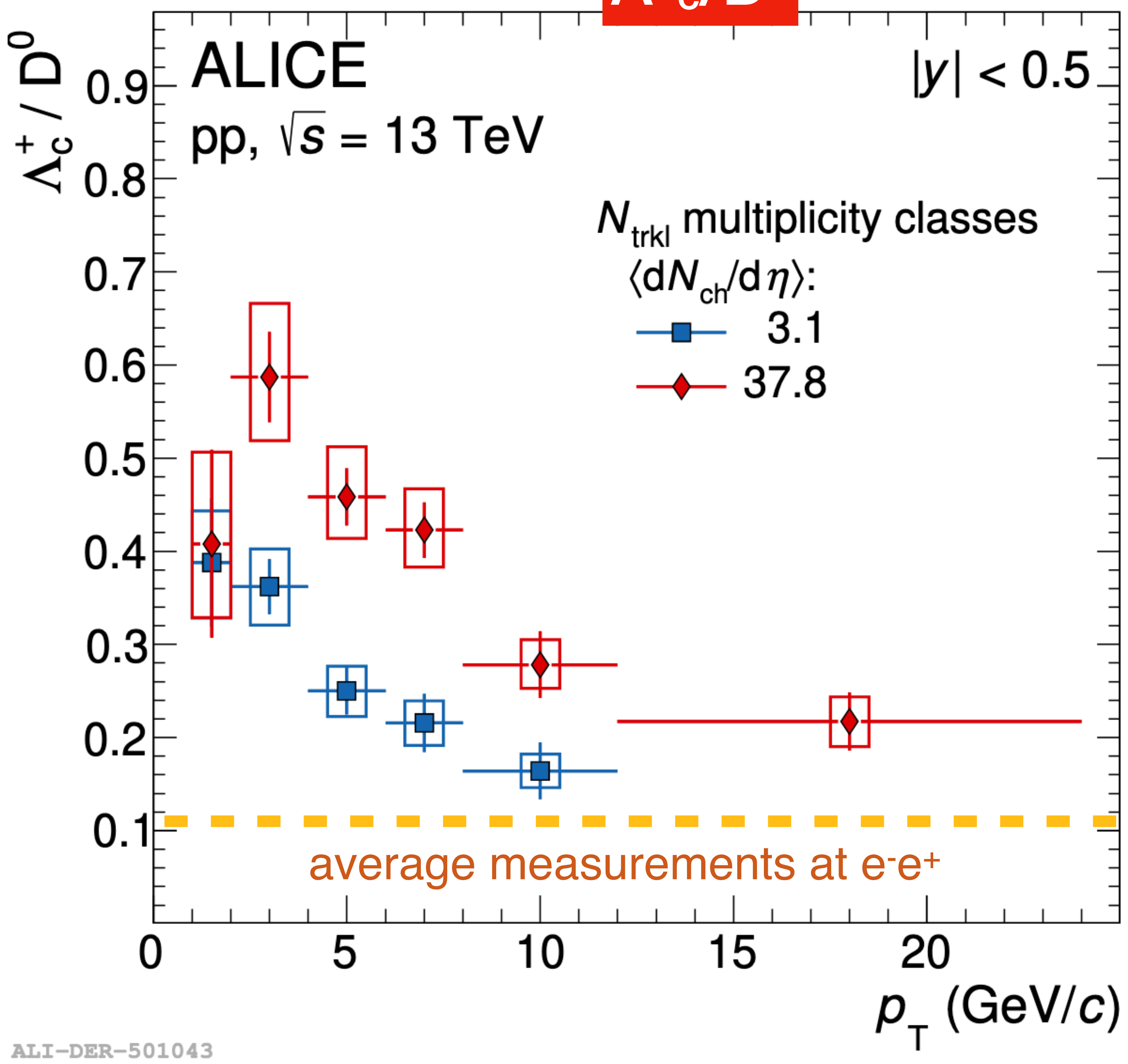
Production cross section of beauty meson decays down to low p_T with Run 3 data: stay tuned!

Hadronization from small to large systems: multiplicity dependence?

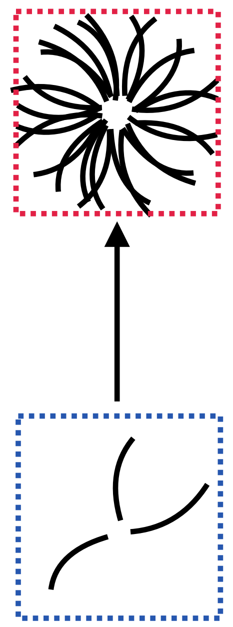
Run 2

Phys.Lett.B 829 (2022) 137065

Λ^+_c/D^0



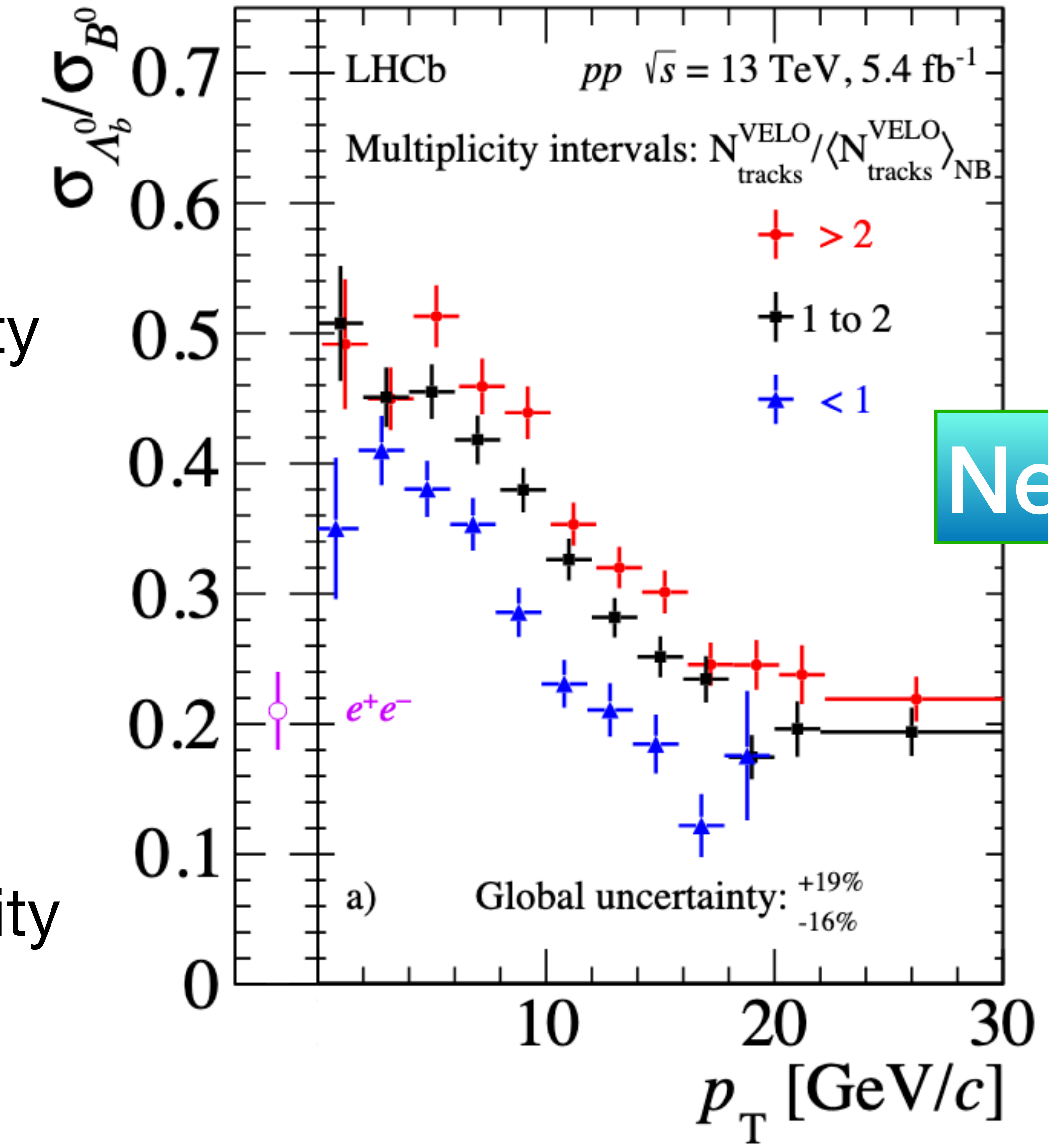
HM: high multiplicity

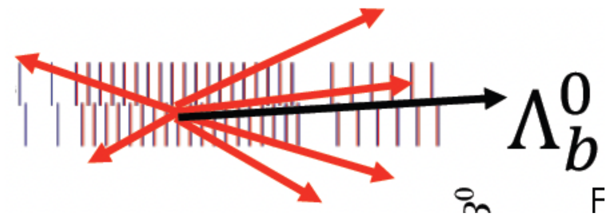


LM: low multiplicity

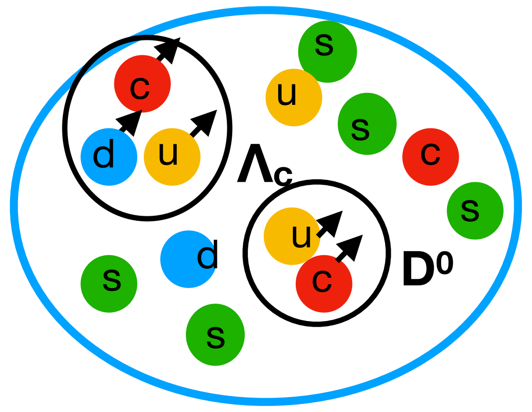
PLB 132 (2024) 081901

$\Lambda^0_b/(B^0+)$





New

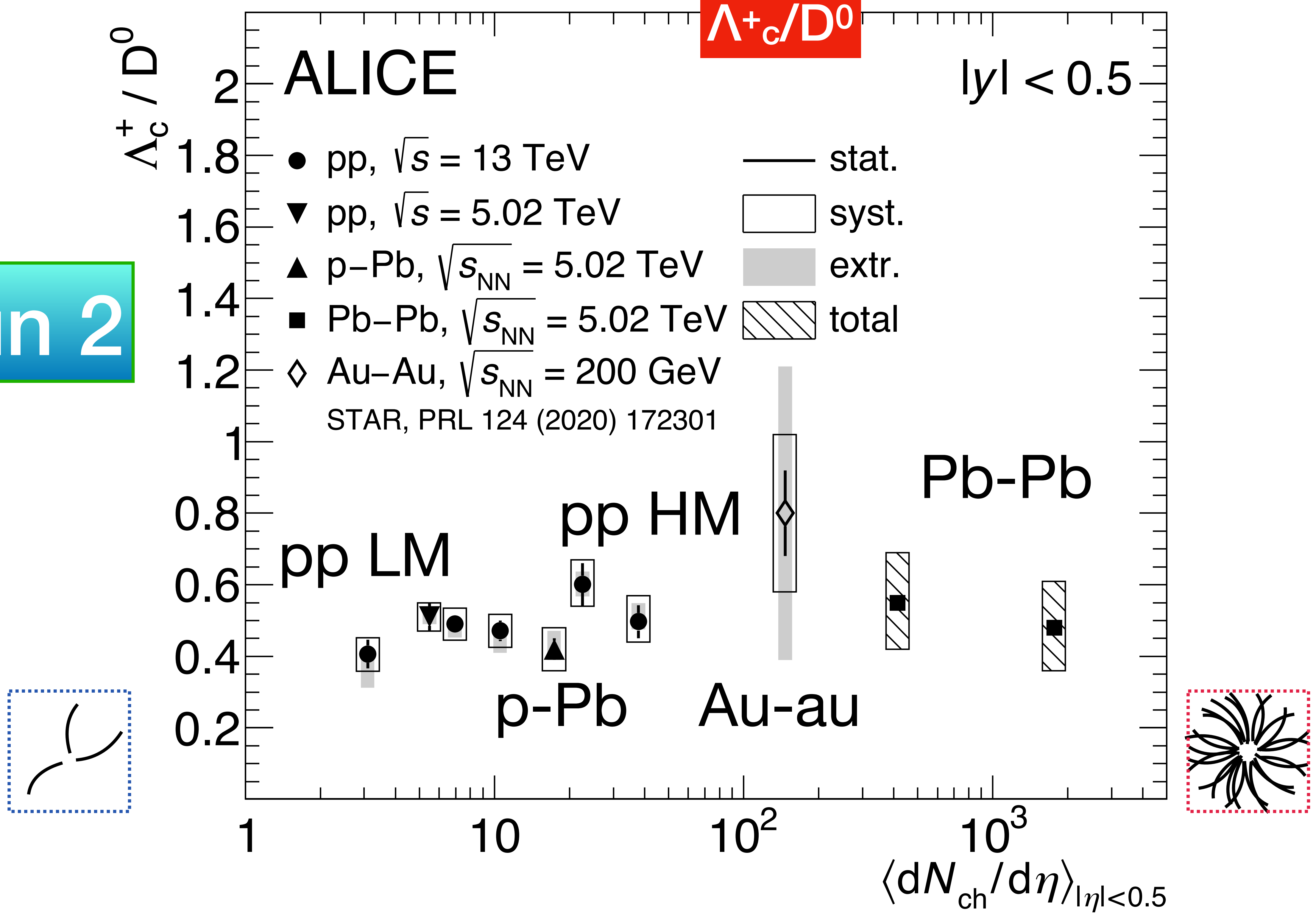


Multiplicity dependence for heavy-flavour baryon/meson ratios at low intermediate momentum, at midrapidity and forward rapidity

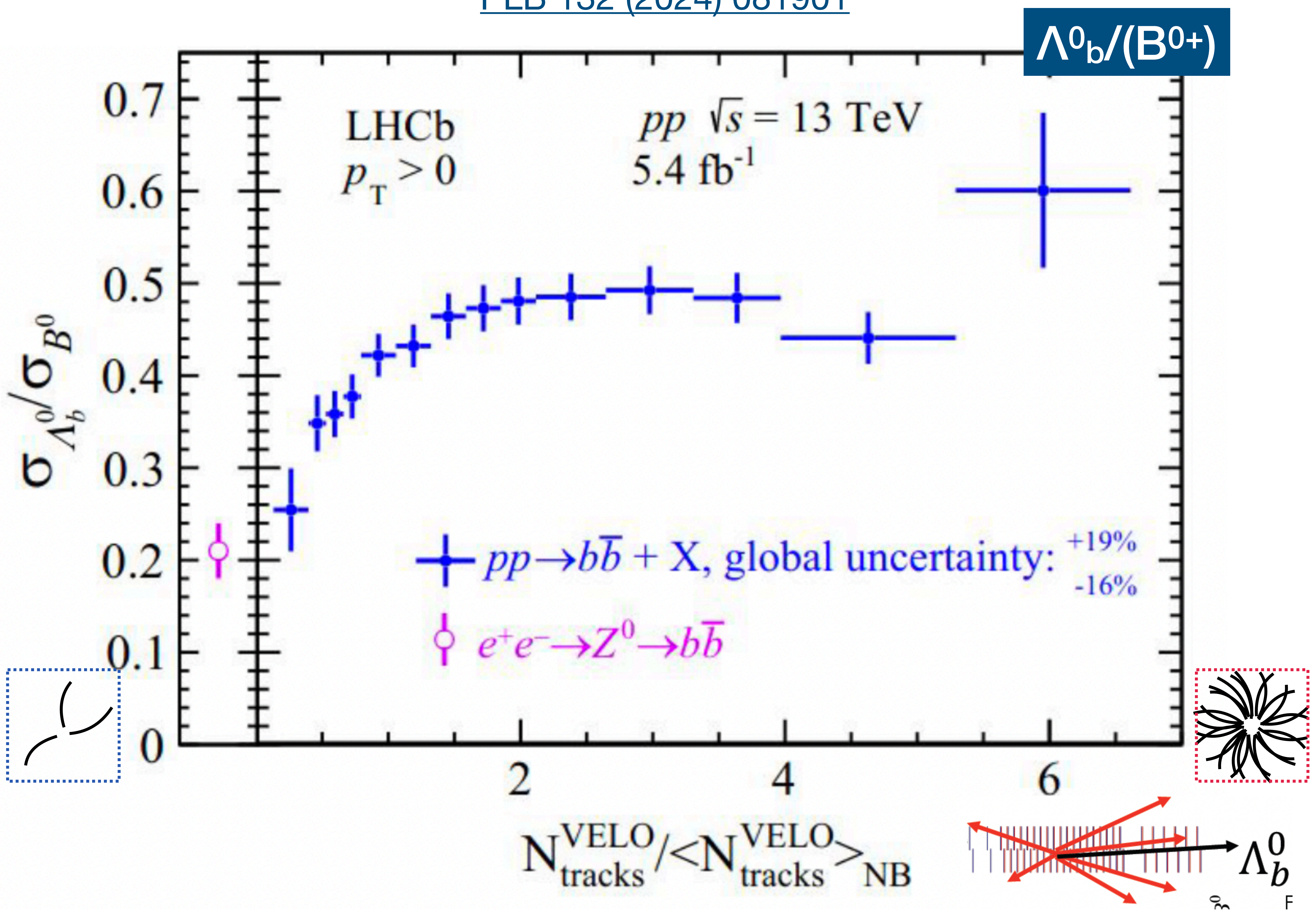
Hadronization from small to large systems: multiplicity dependence?

Run 2

PLB 839 (2023) 137796



PLB 132 (2024) 081901



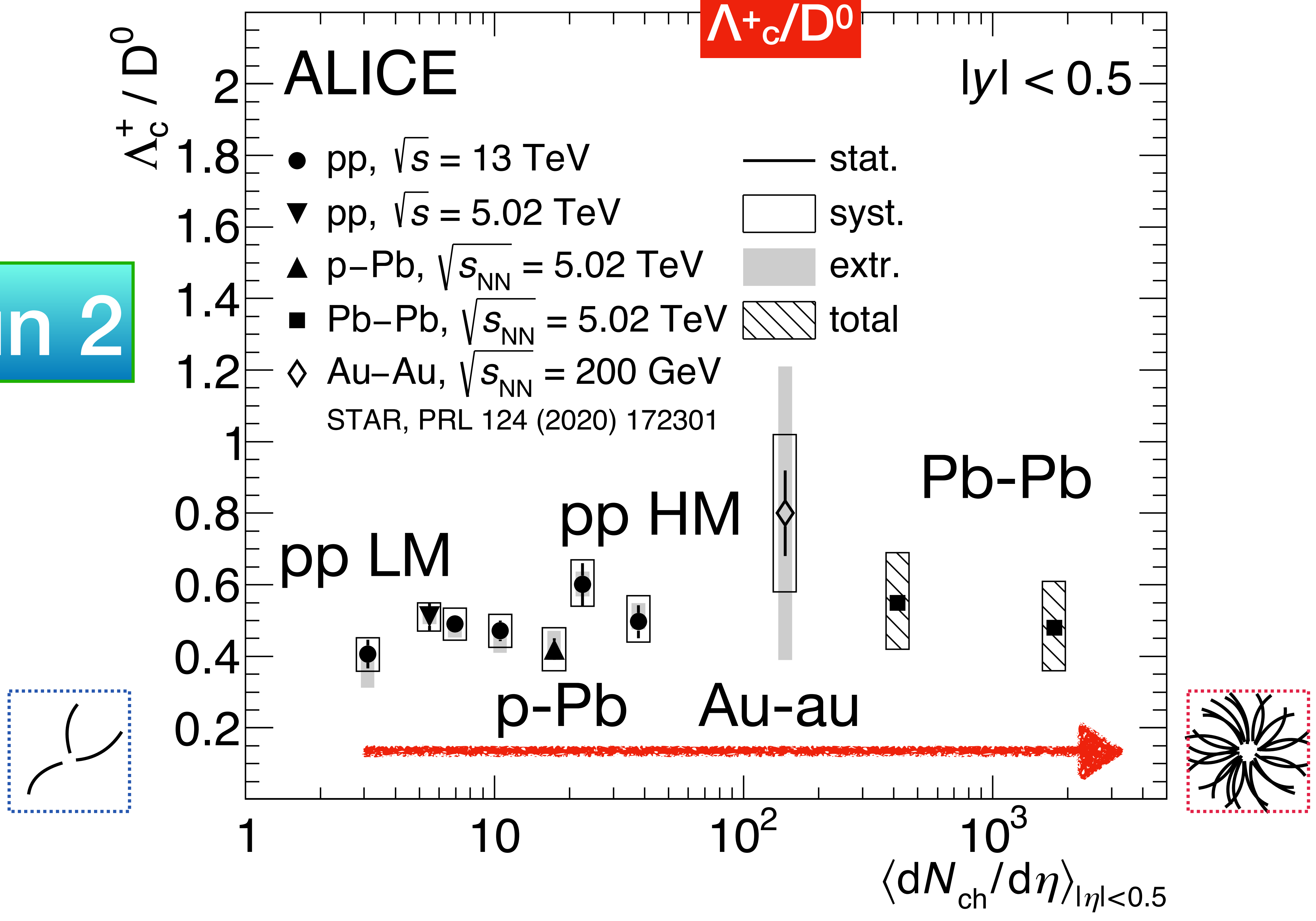
LM: low multiplicity

HM: high multiplicity

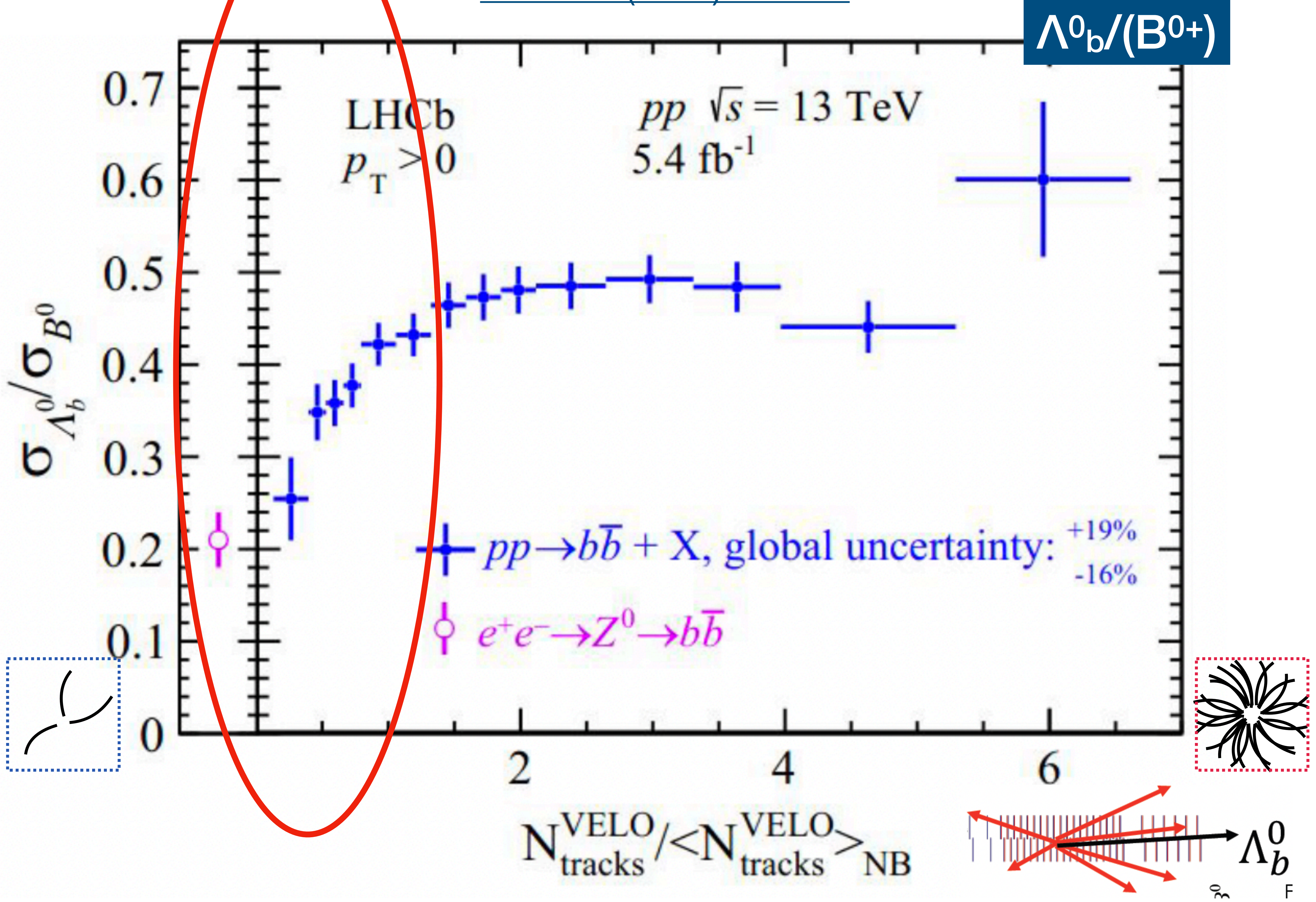
Hadronization from small to large systems: multiplicity dependence?

Run 2

PLB 839 (2023) 137796



PLB 132 (2024) 081901



LM: low multiplicity

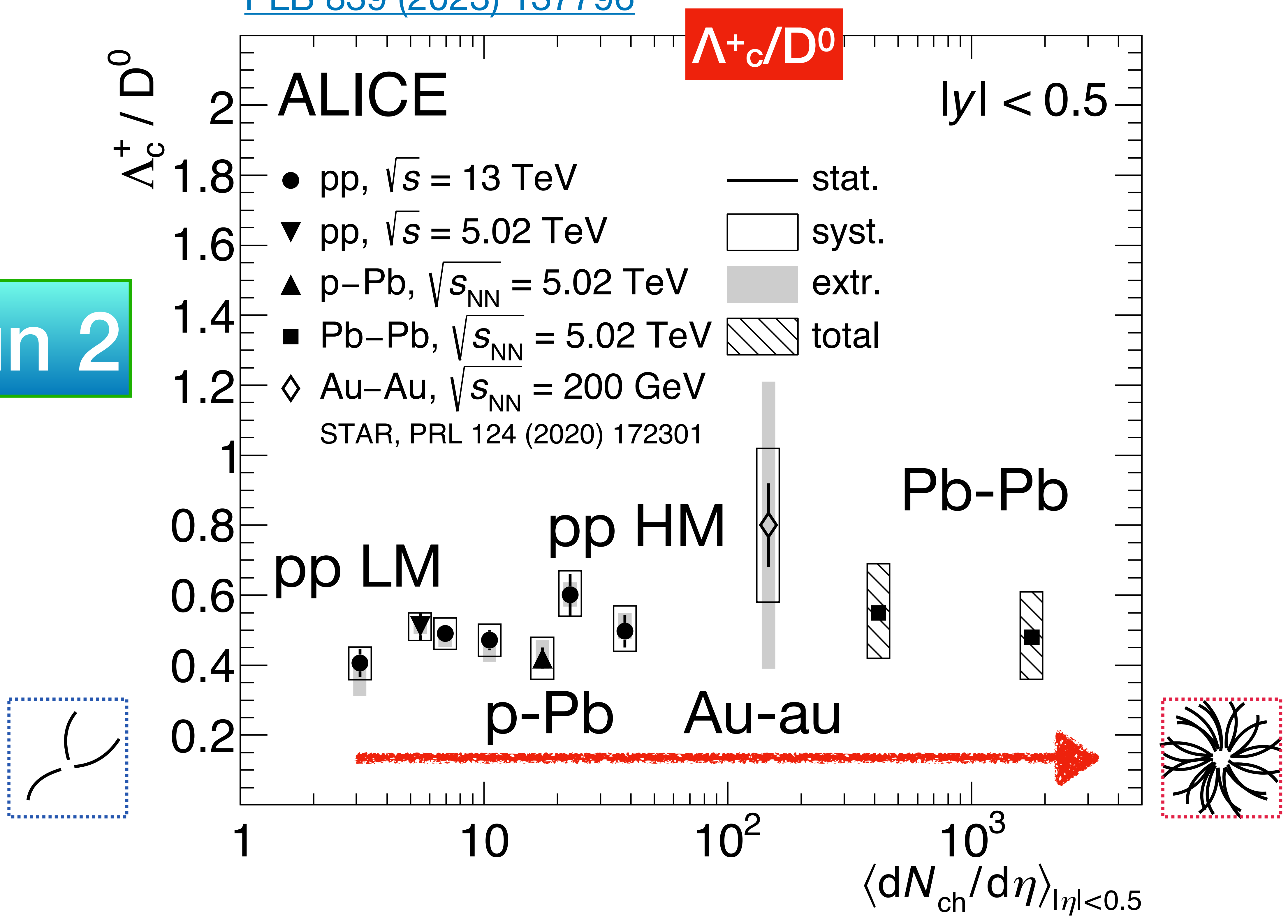
HM: high multiplicity

- p_T-integrated Λ_c/D^0 **independent on multiplicity** from small to large systems
- Λ^0_b/B^0 at **forward rapidity shows an increasing trend** at **very low multiplicity:** baryon enhancement over mesons in pp?

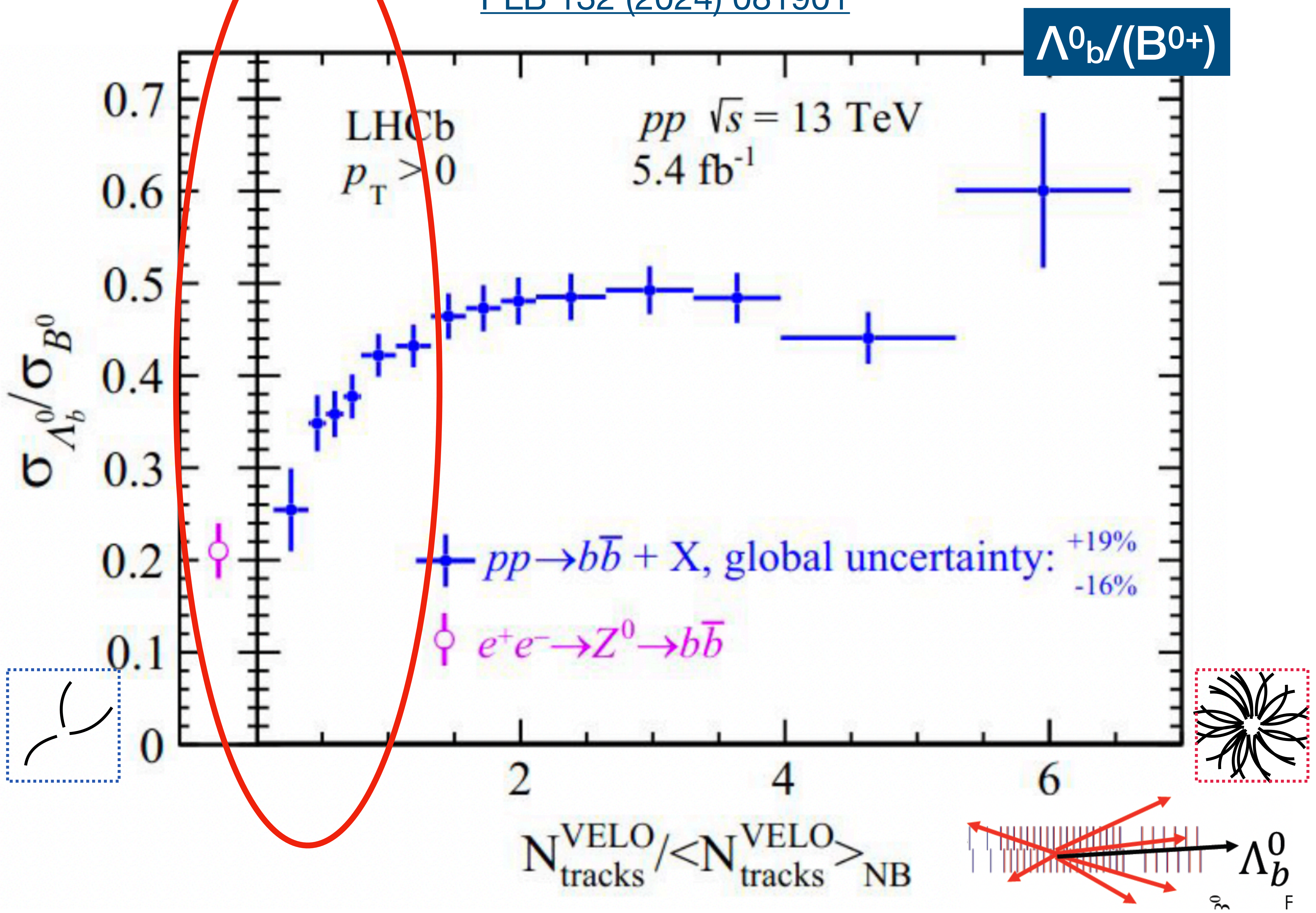
Hadronization from small to large systems: multiplicity dependence?

Run 2

PLB 839 (2023) 137796



PLB 132 (2024) 081901



LM: low multiplicity

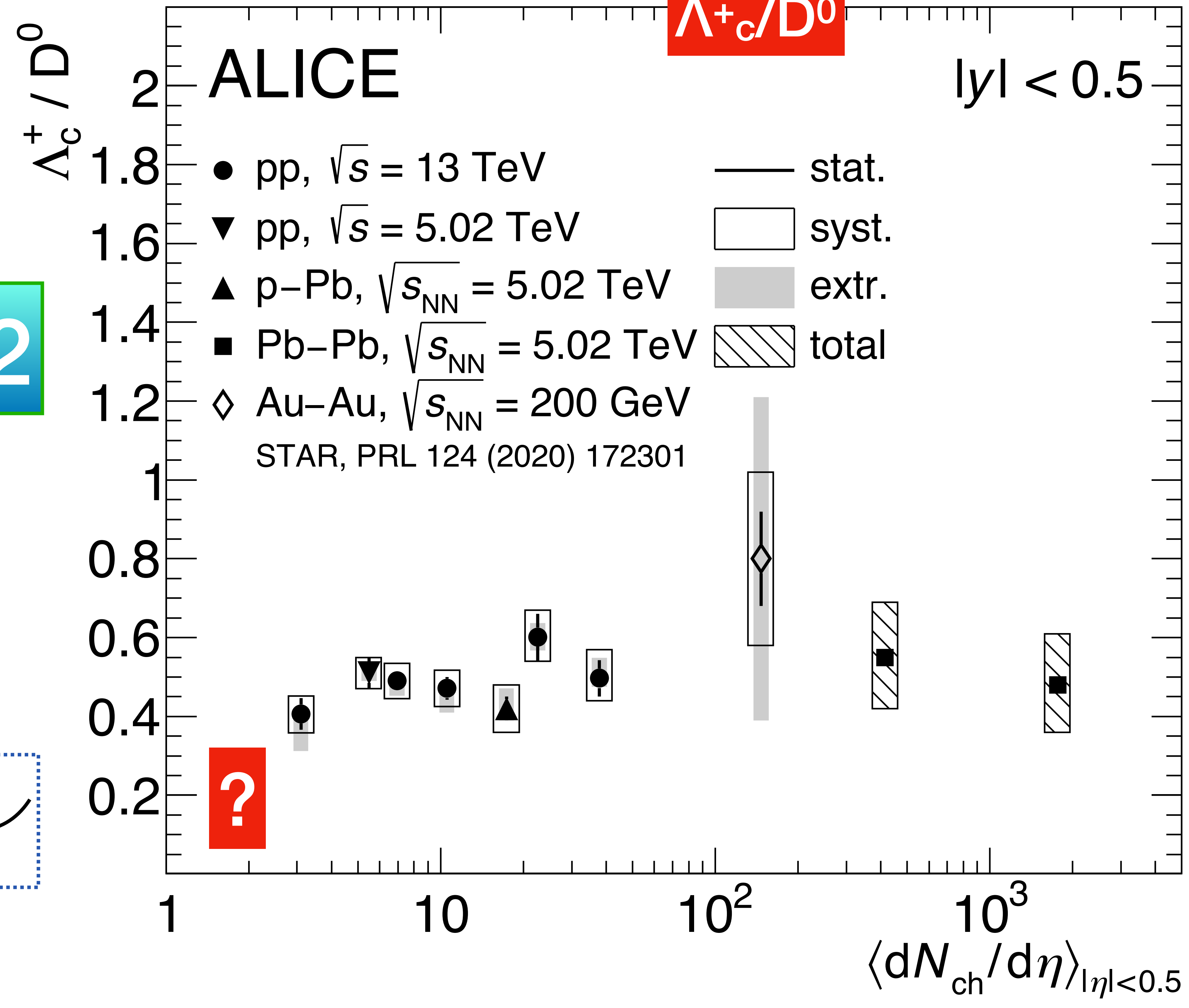
HM: high multiplicity

different hadronisation mechanisms for charm and beauty vs multiplicity and across collision systems?
is there a rapidity dependence of the hadronisation mechanisms?

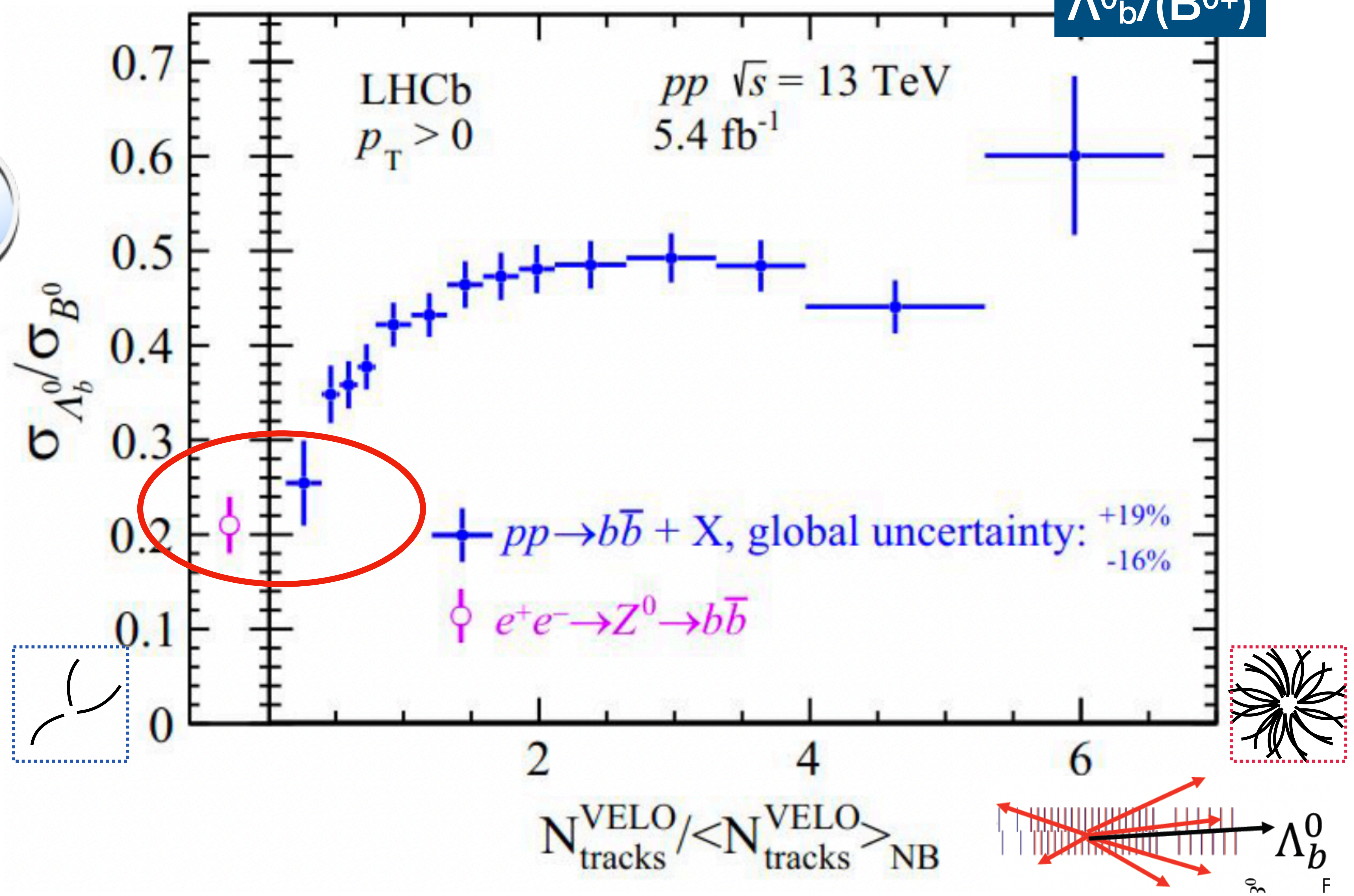
Hadronization from small to large systems: multiplicity dependence?

Run 2

Λ^+_c/D^0



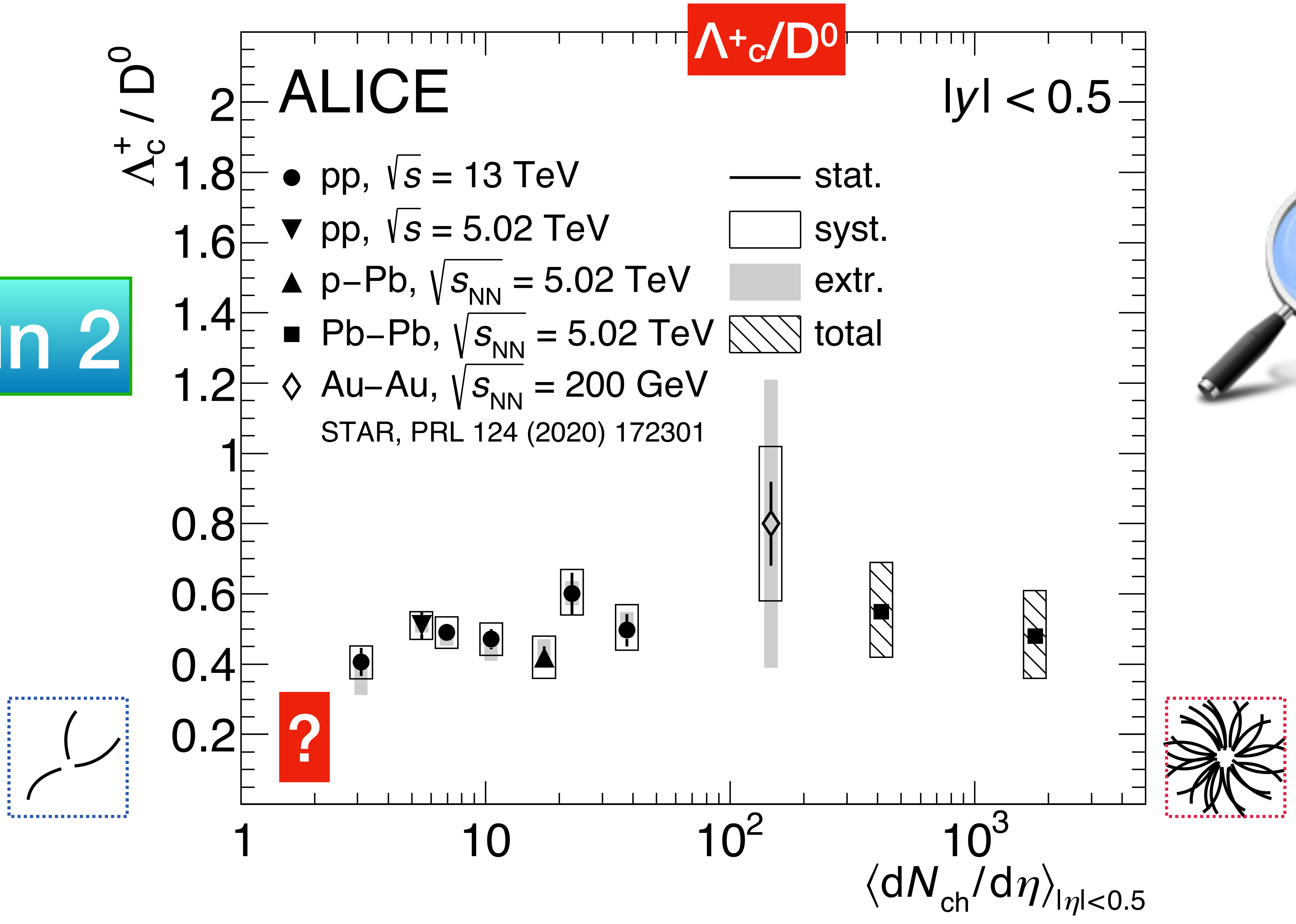
$\Lambda^0_b/(B^{0+})$

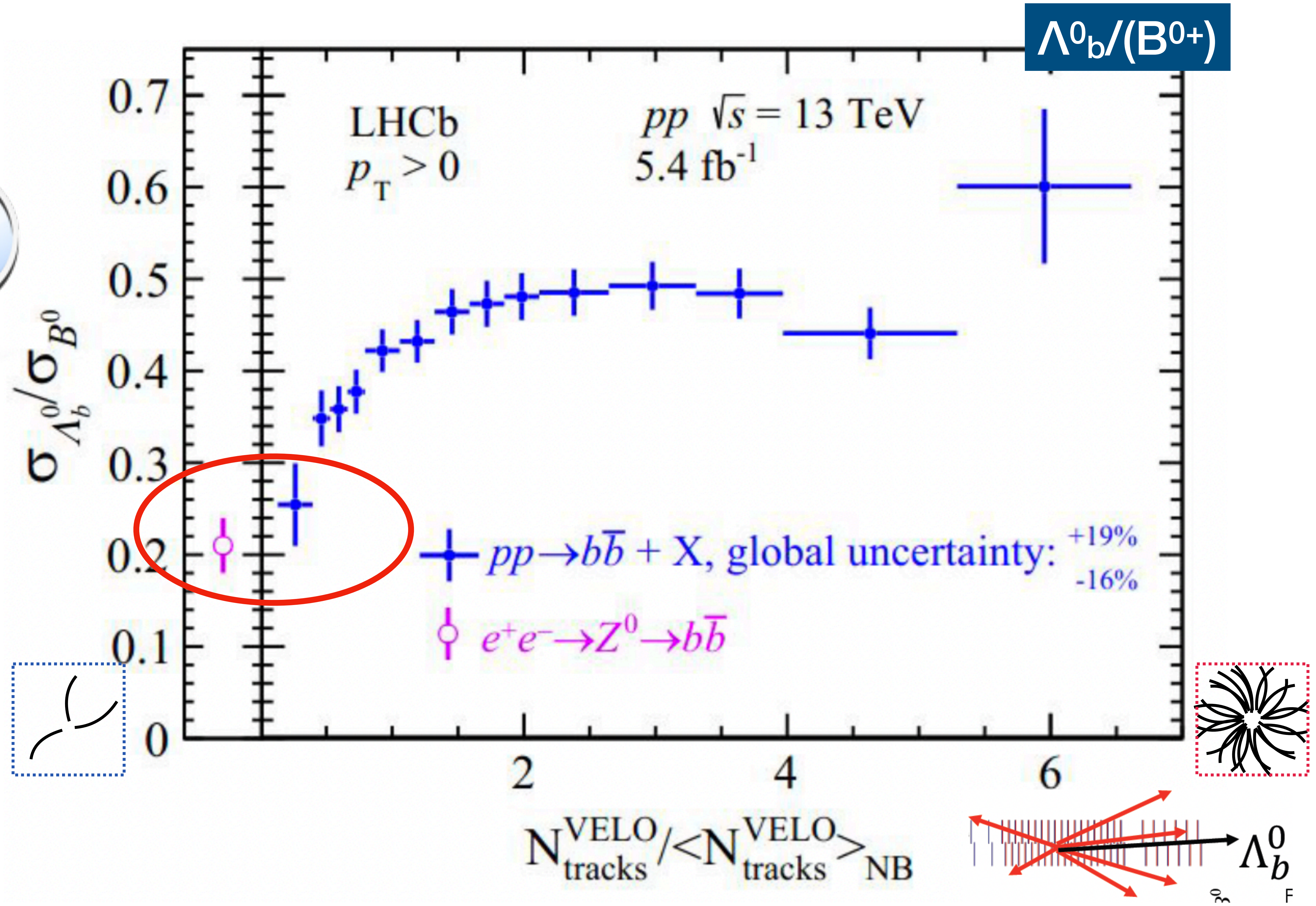


- worth to define **comparable multiplicity estimators** (and same ‘x-axis’ observable to be defined!)
- charm measurements at midrapidity to be **extended to lower multiplicity**
  - investigate multiplicity dependence for more baryon species
- measure beauty vs multiplicity at midrapidity

Hadronization from small to large systems: multiplicity dependence?

Run 2





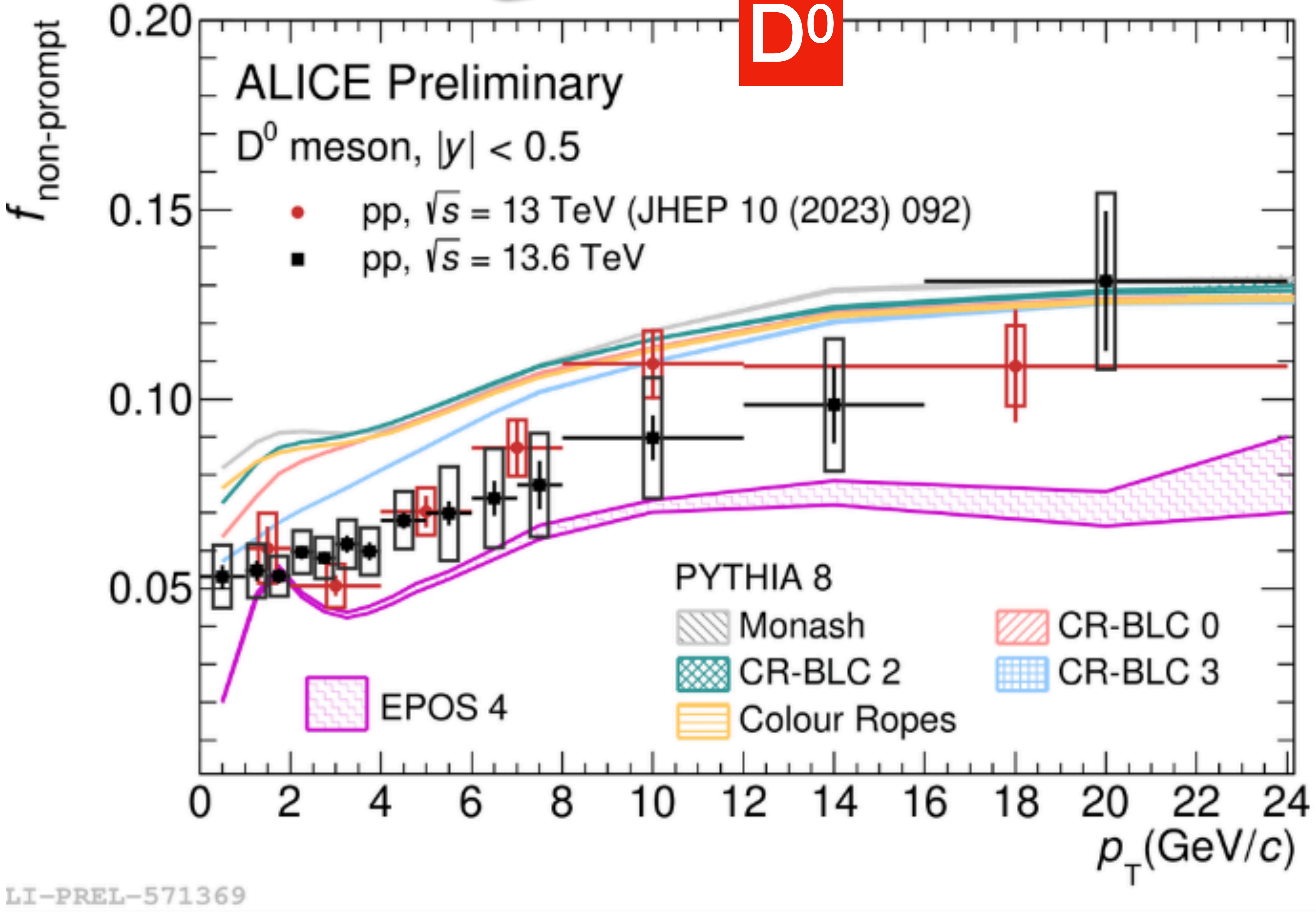
- worth to define **comparable multiplicity estimators** (and same 'x-axis' observable to be defined!)
- charm measurements at midrapidity to be **extended to lower multiplicity**
  - investigate multiplicity dependence for more baryon species
- measure beauty vs multiplicity at midrapidity

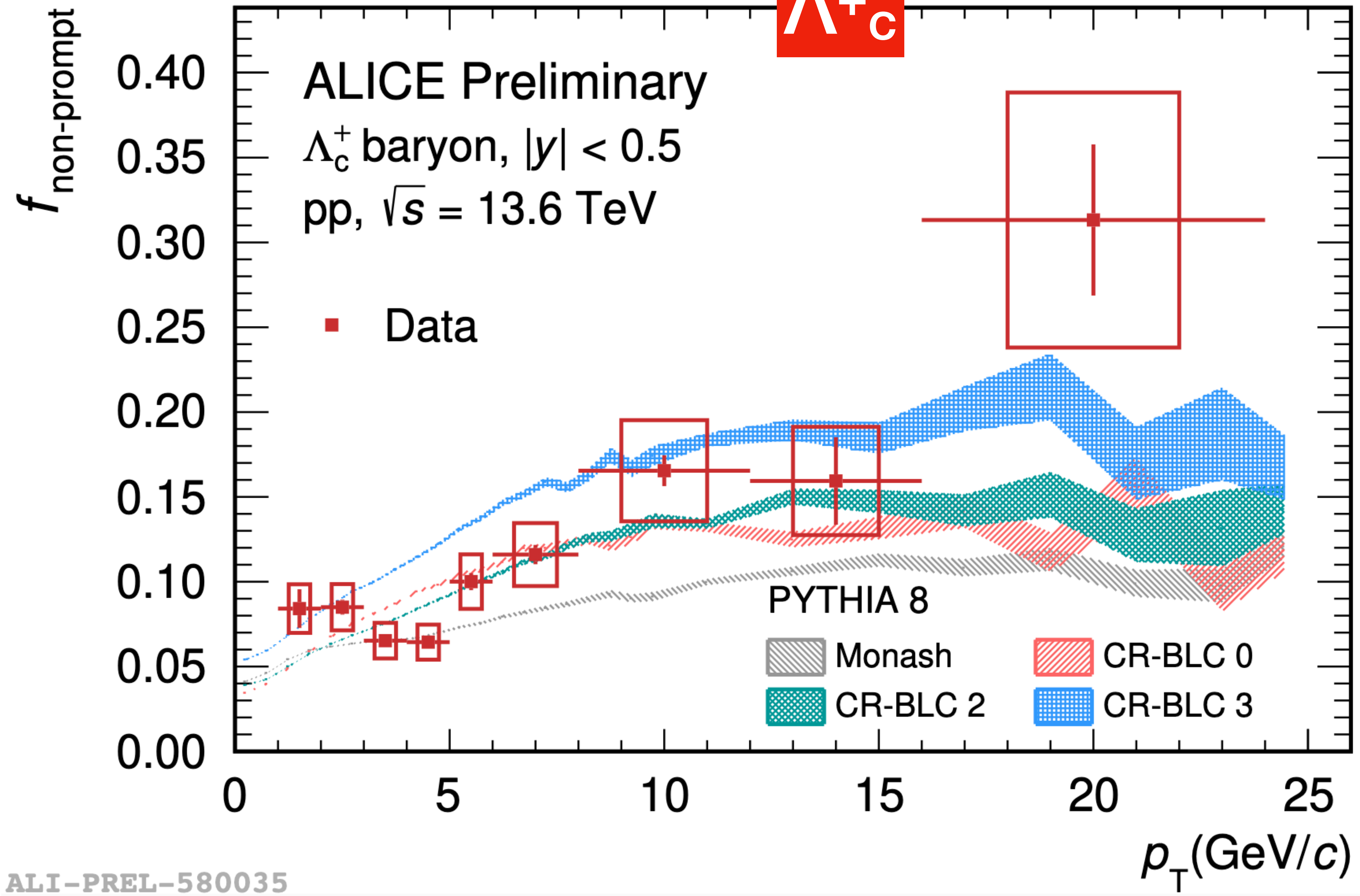
models implementing evolution of hadronisation from small to large systems with multiplicity may help

Measurements of non-prompt fractions for D mesons and Λ_c baryons

Run 3

important inputs for charm hadron cross section measurements



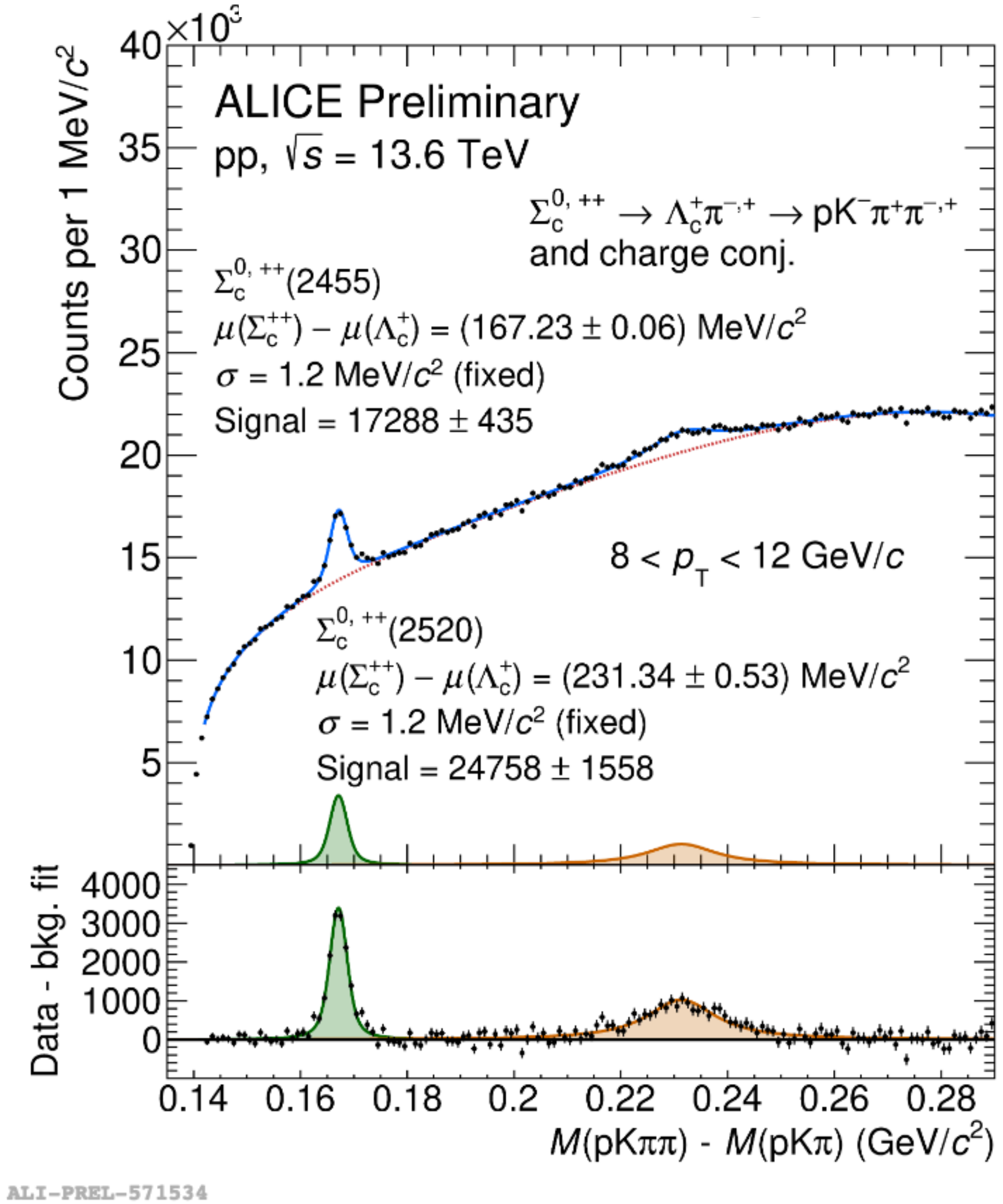


Increased precision wrt Run 2 and more granular results
Provide tighter constraints for hadronisation models

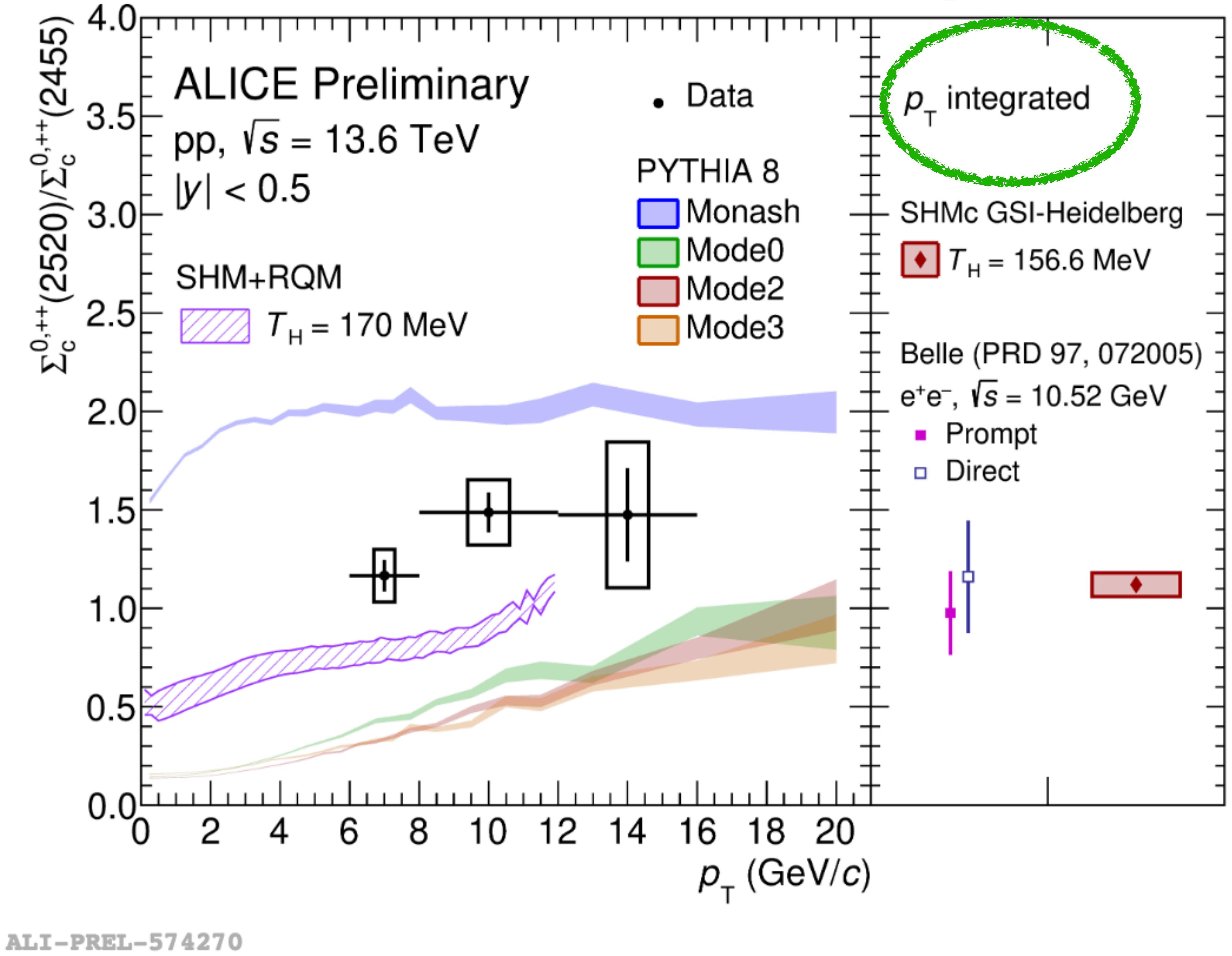
Access to higher mass charm baryon resonances

Run 3

$\Sigma_c^{0,++}(2455)$, $\Sigma_c^{0,++}(2520)$



Yield ratios and model comparison



PYTHIA8:
Monash
Mode012

SHM+RQM

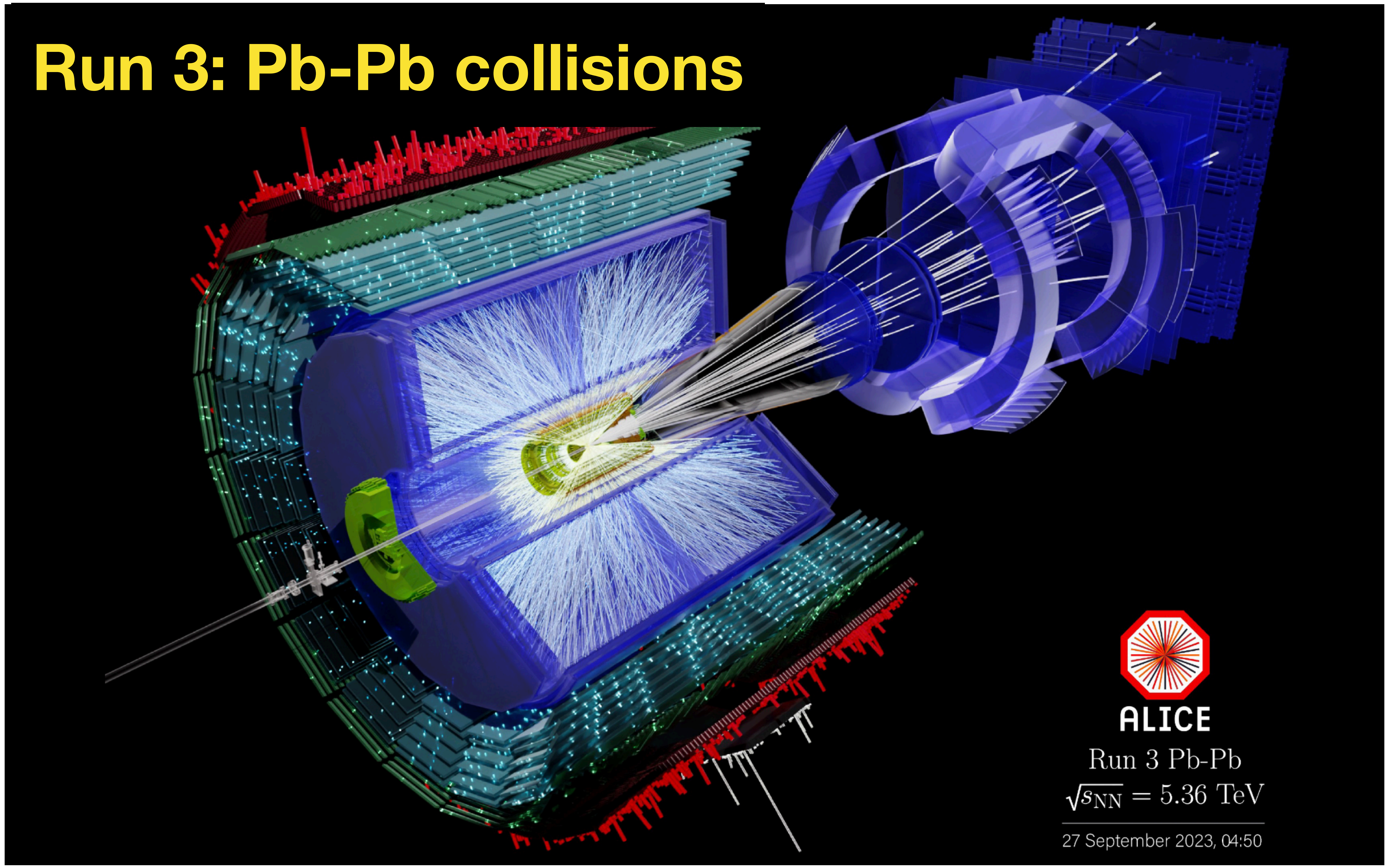
SHMc

Profiting of the large Run 3 statistics in pp: first measurement at LHC of the charm baryon resonances $\Sigma_c^{0,++}$ (2520)

Predictions: **challenge to reproduce** the $\Sigma_c^{0,++}$ state ratio in pp**—> further constraints to pQCD models**

see A. Rossi talks

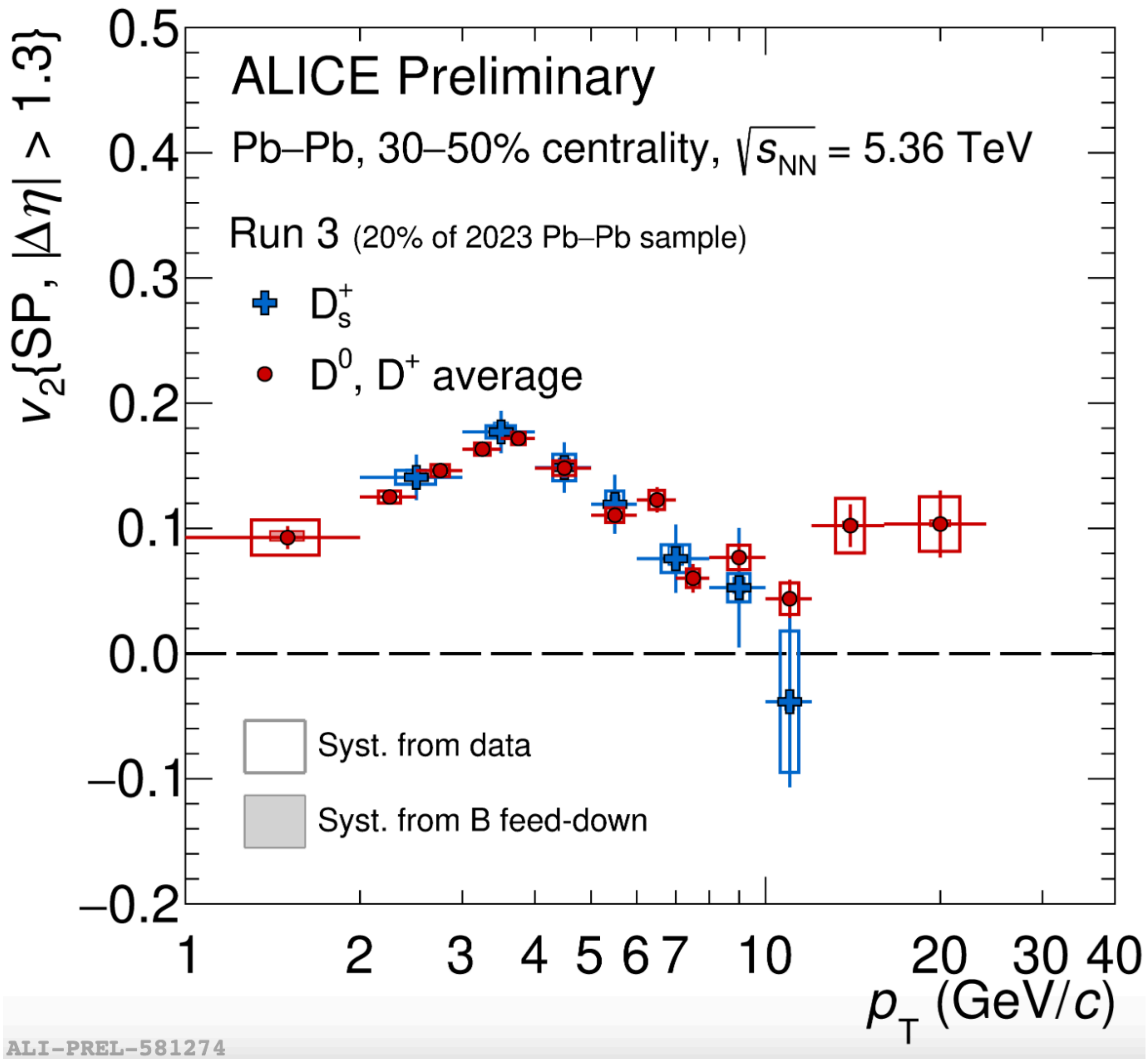
overview of recent open-HF measurements

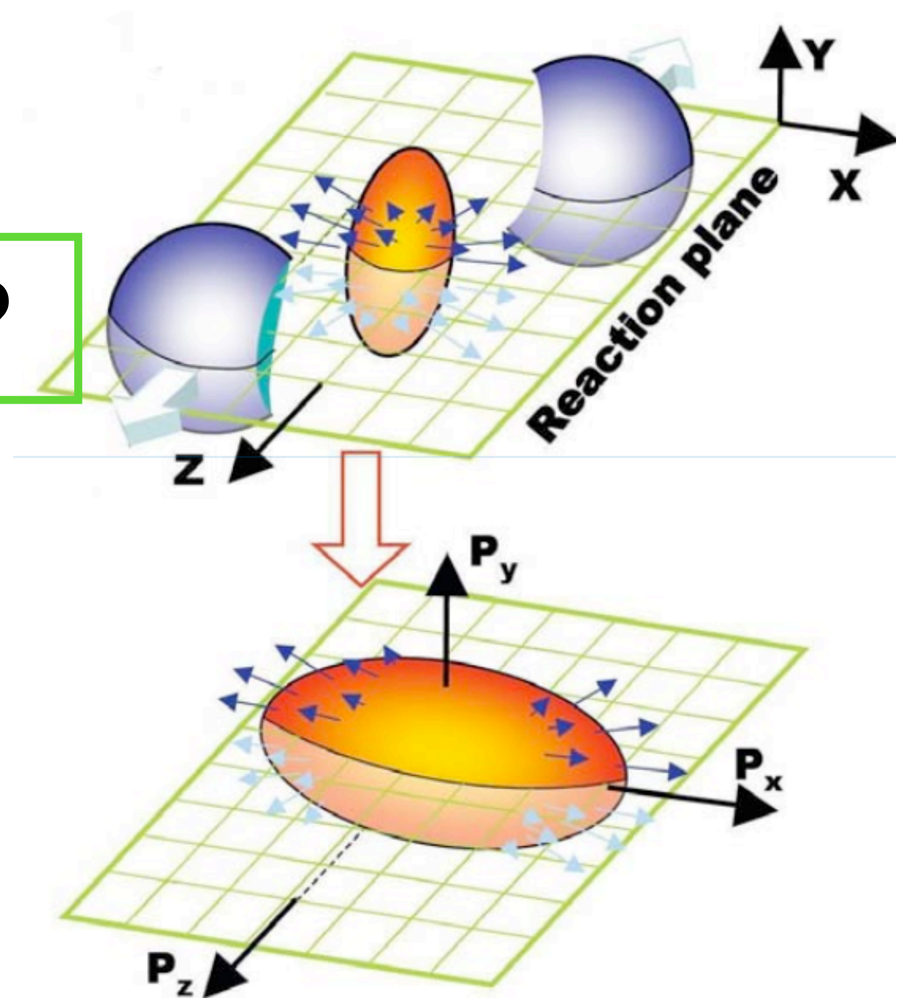


charm v_2

Run 3

Which is the degree of thermalization of HQs in the medium?





$$v_2 = \langle \cos[2(\varphi - \Psi_2)] \rangle$$

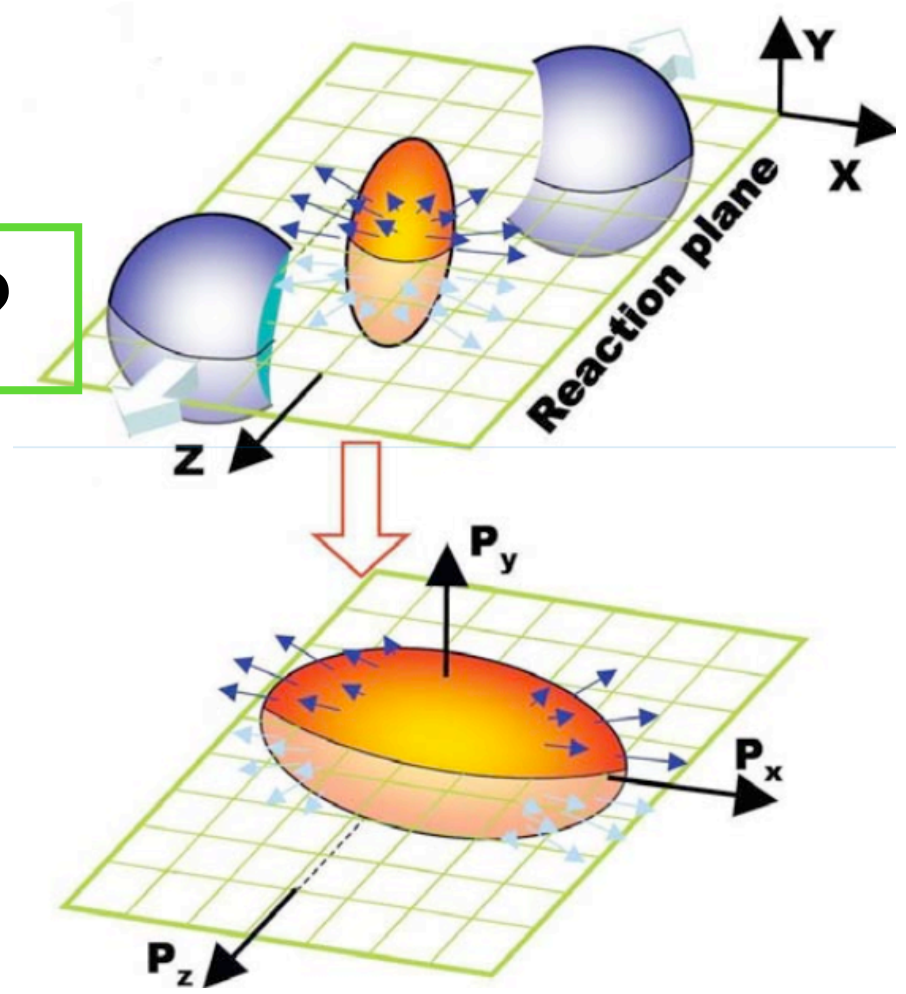
$$E\frac{d^3N}{dp_T} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

- **Strange** and **non-strange D mesons v_2** measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV, compatible within uncertainties
- x4 larger statistics more than Run 2, x5 more statistics will come soon

charm v_2

Run 3

Which is the degree of thermalization of HQs in the medium?



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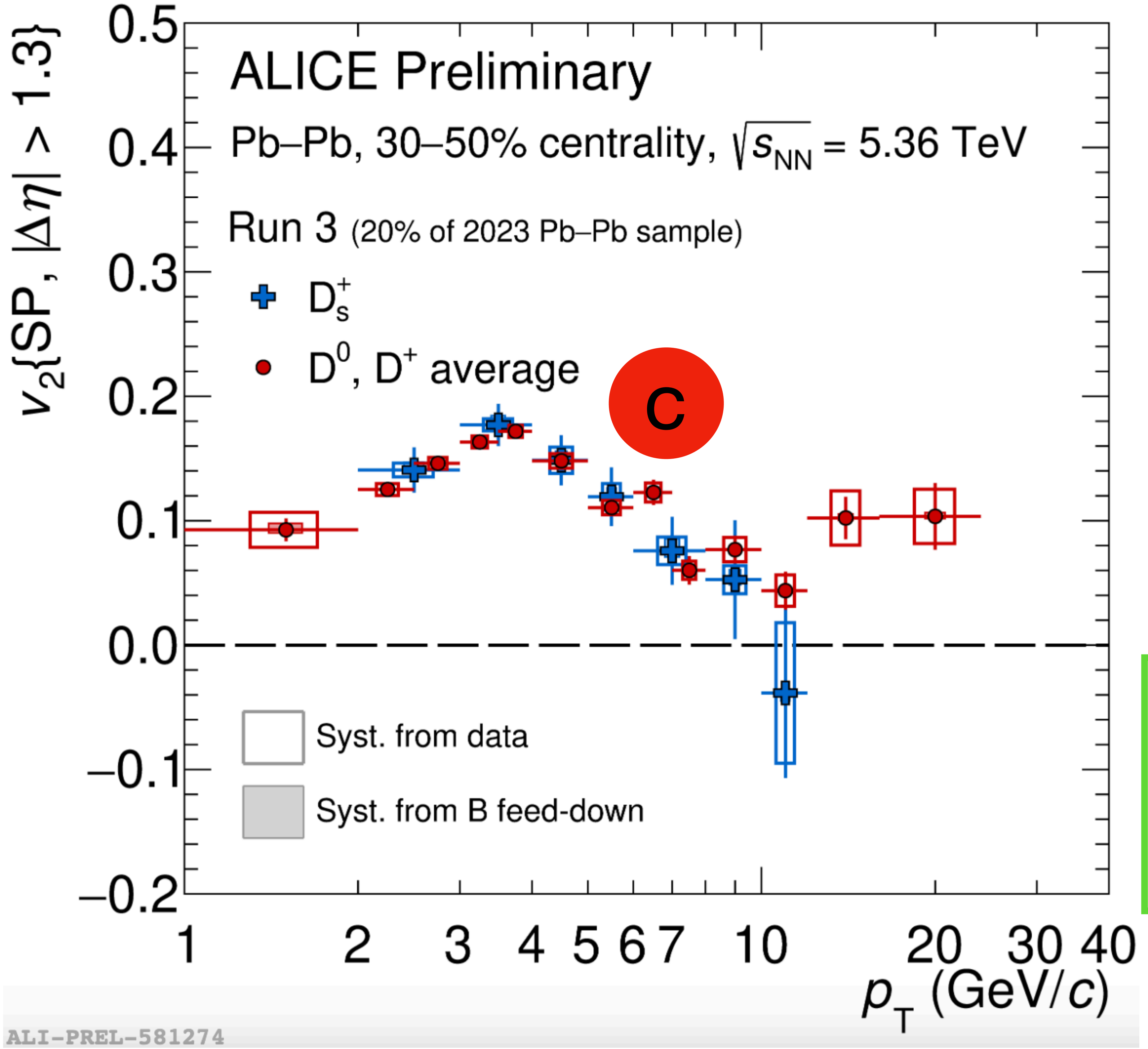


➡Positive v_2 of hadrons with charm:

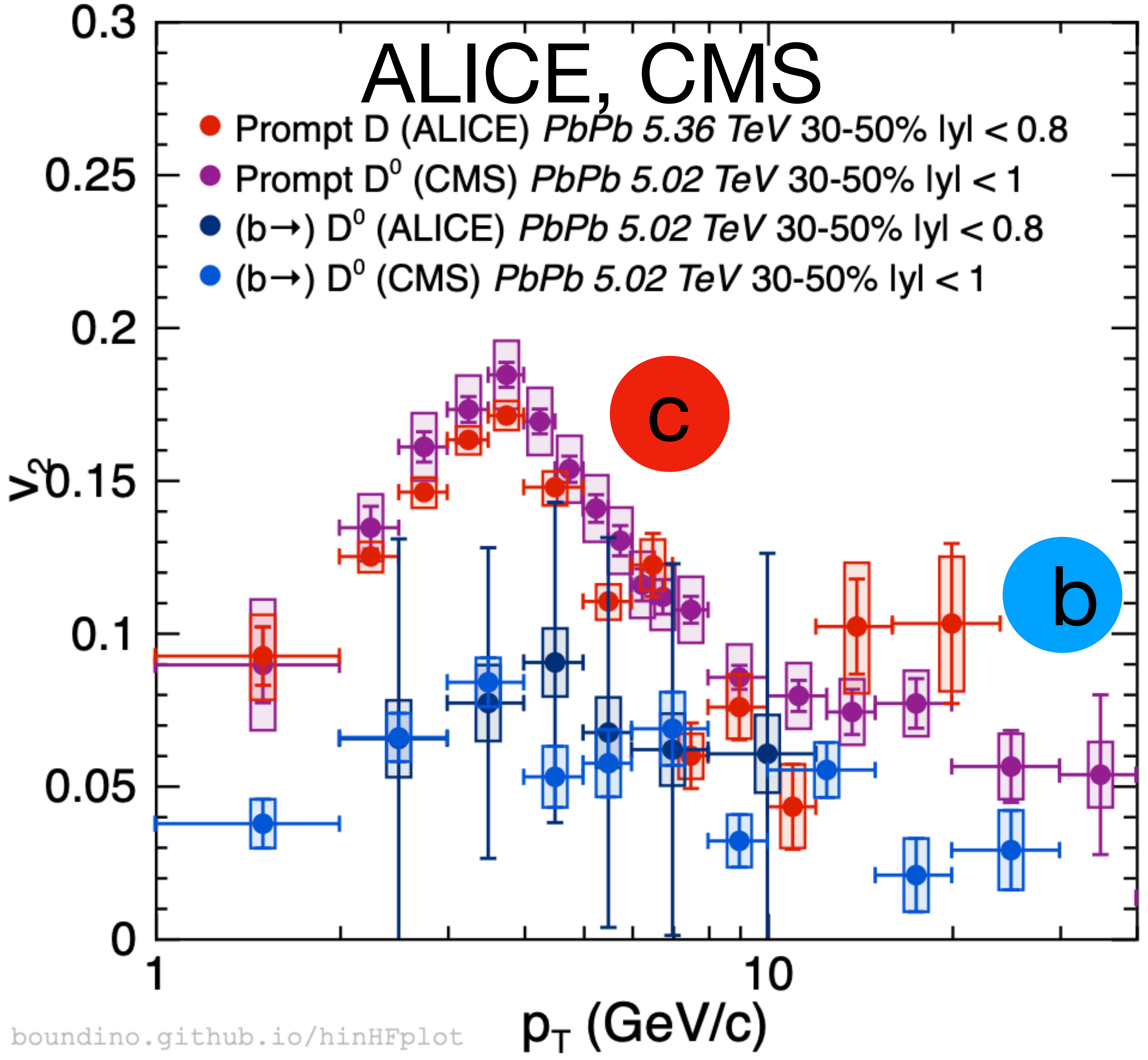
➡ **charm quarks largely thermalize in QGP until hadronization**

see F. Grosa talks

… and beauty v_2 ?

Run 3

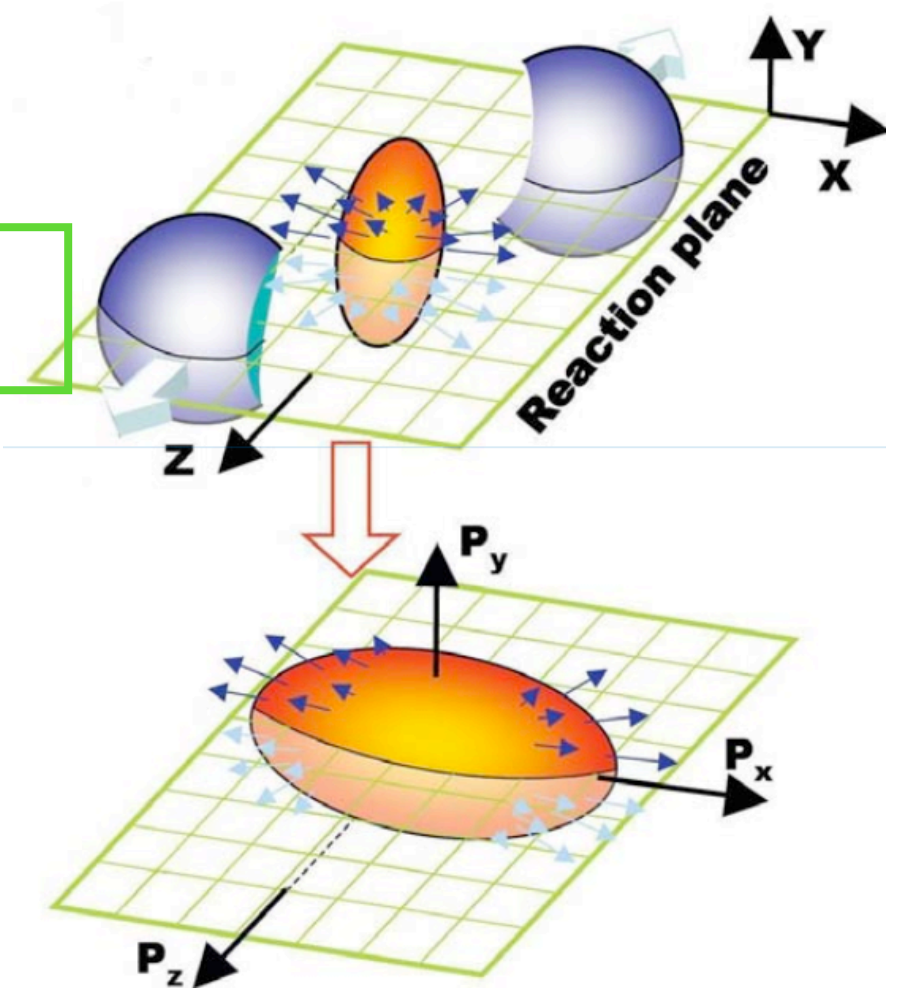
Which is the degree of thermalization of HQs in the medium?



→ PLB 816 (2021) 136253 → ALICE Preliminary
→ EPJC 83 (2023) 1123 → PLB 850 (2024) 138389

$$v_2 = \langle \cos[2(\varphi - \Psi_2)] \rangle$$

$$E\frac{d^3N}{dp_T} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$



➡Positive v_2 of hadrons with charm:
- ➡ **charm quarks largely thermalize in QGP until hadronization**
- **smaller v_2 of open-beauty hadrons**

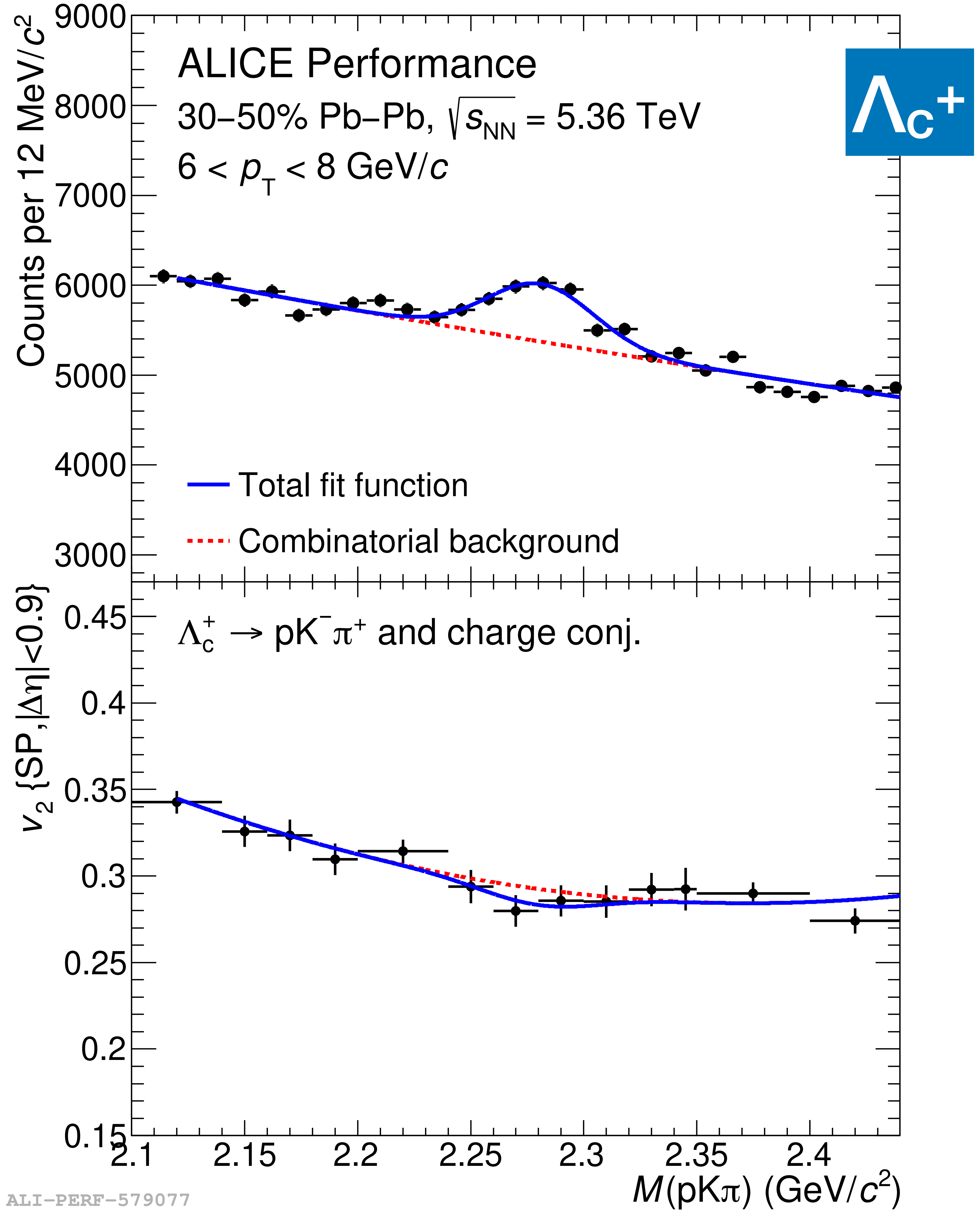
- from recombination with light quarks?
- Does beauty flow?

see F. Grosa talks

… and charm baryon v_2 ?

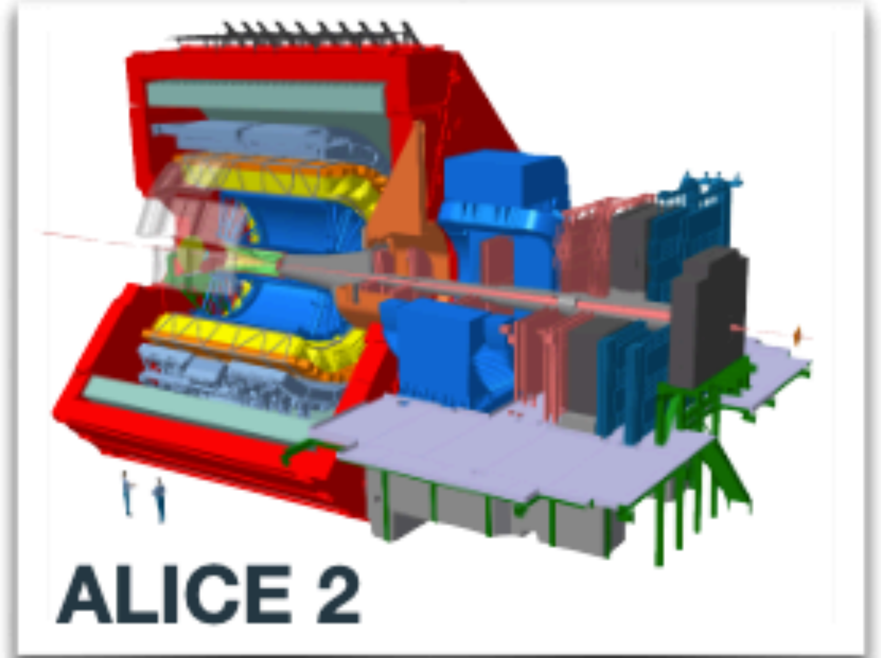
Run 3

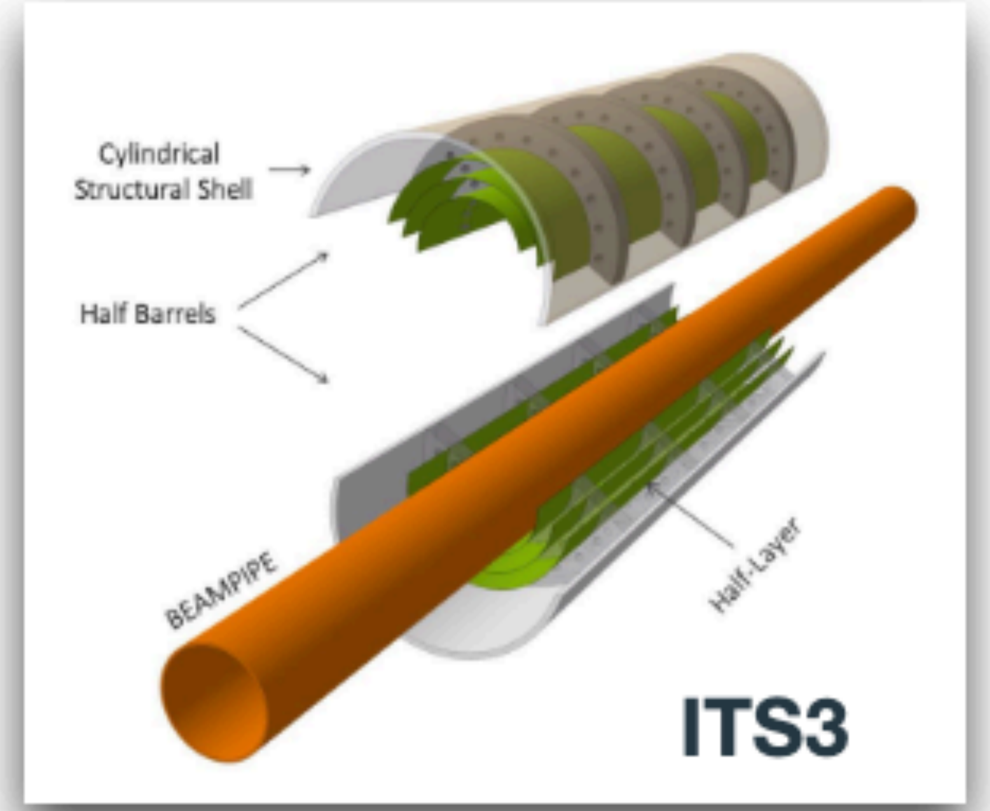
Which is the degree of thermalization of HQs in the medium?

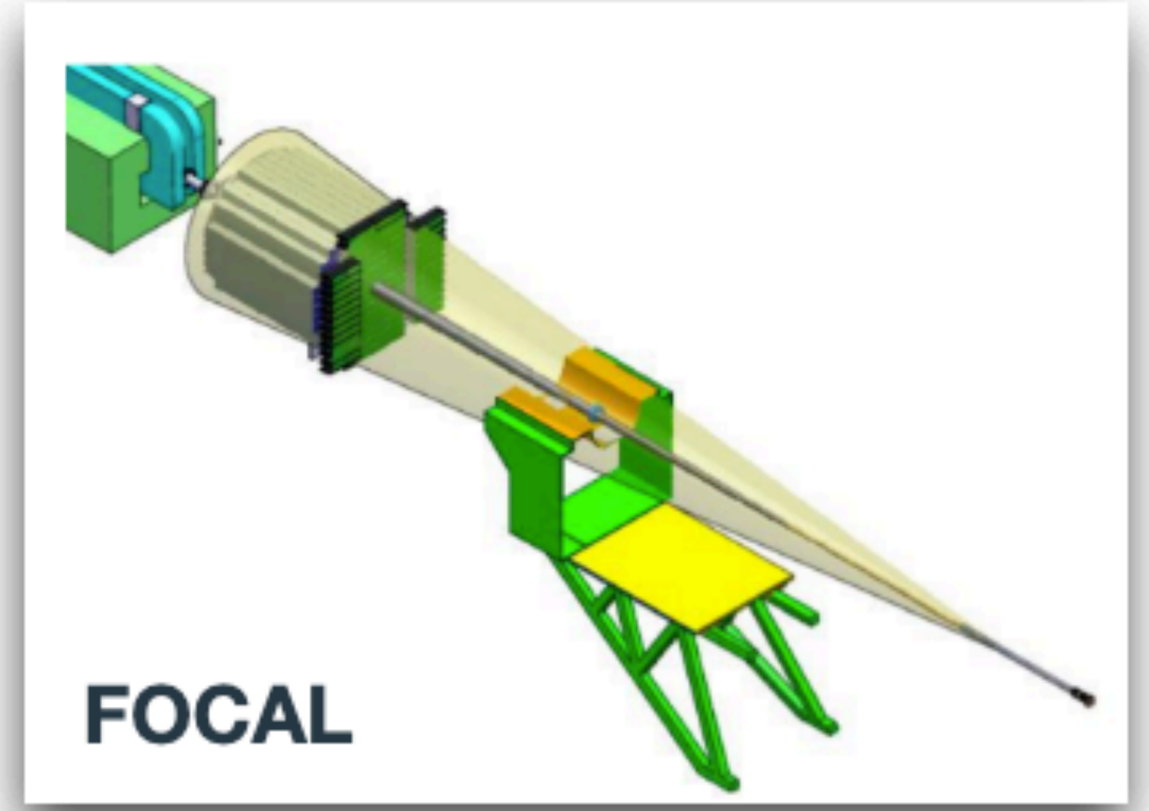


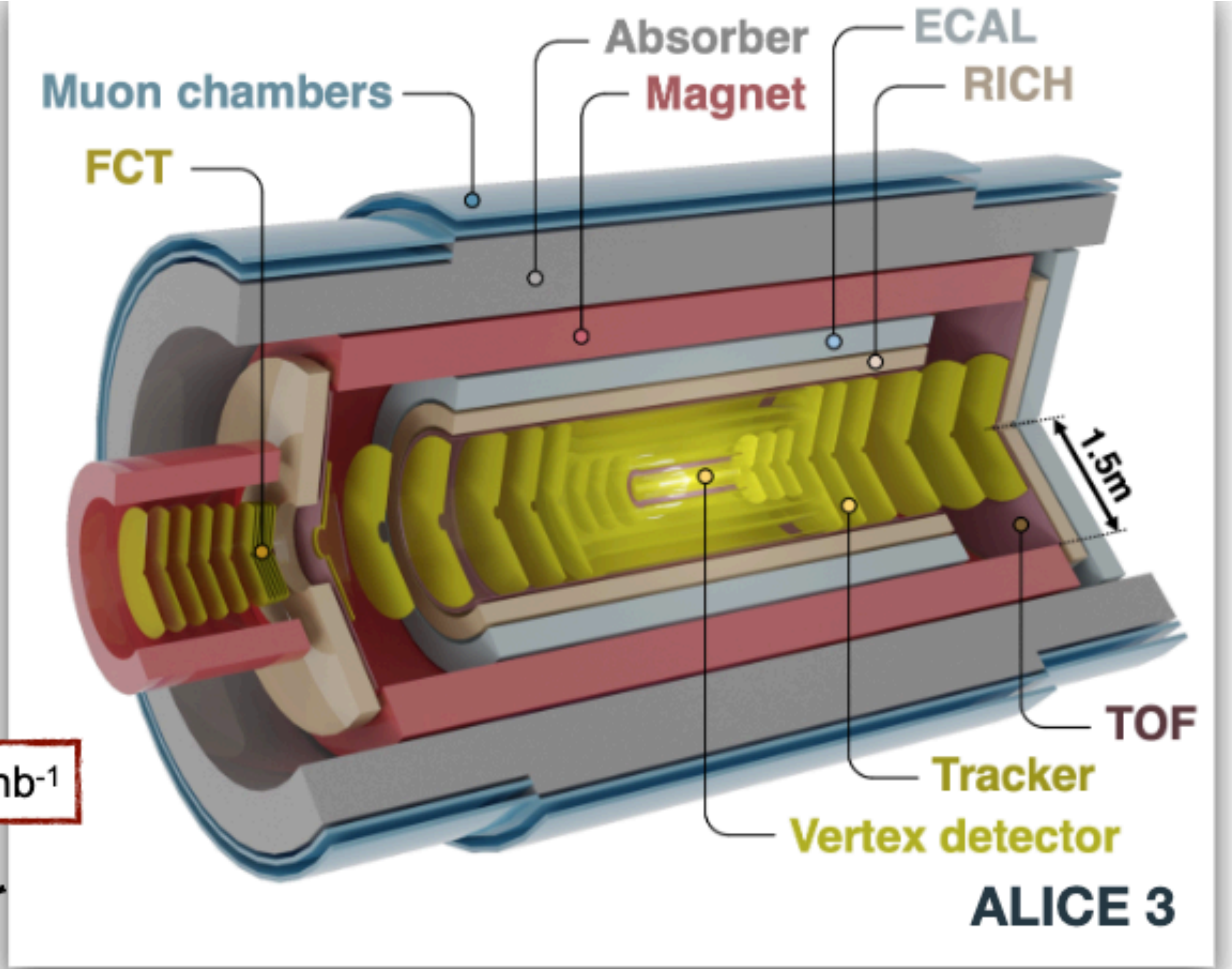
First look at the Λ_c v_2:
HF v_2 measurements extended to the charm baryon sector

What next? ALICE Upgrade roadmap







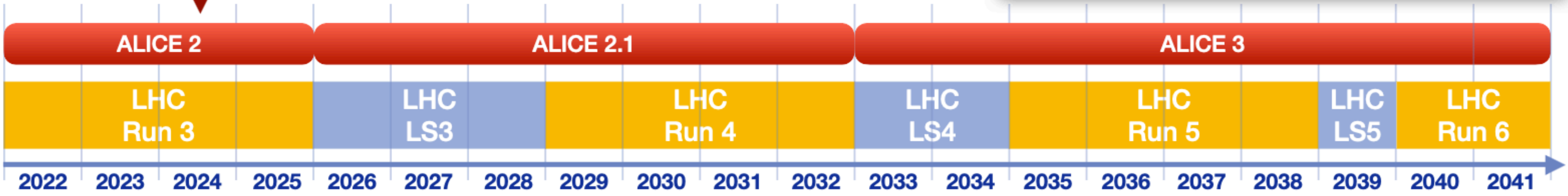


Pb-Pb: 6.2 nb^{-1}
O-O: 500 μb^{-1}

Today

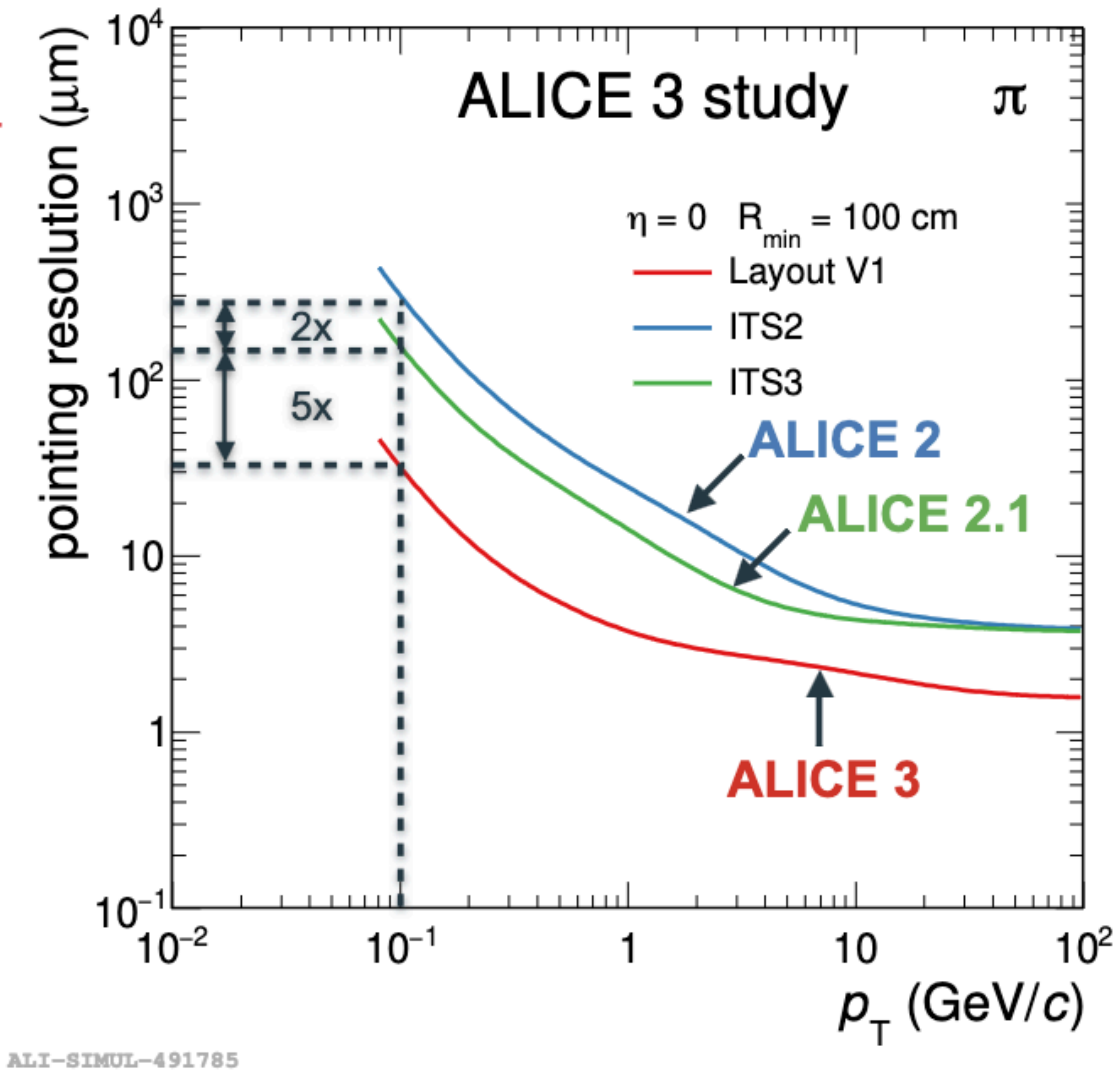
Pb-Pb: 6.8 nb^{-1}
p-Pb: 0.6 pb^{-1}

Pb-Pb: ~ 35 nb^{-1}



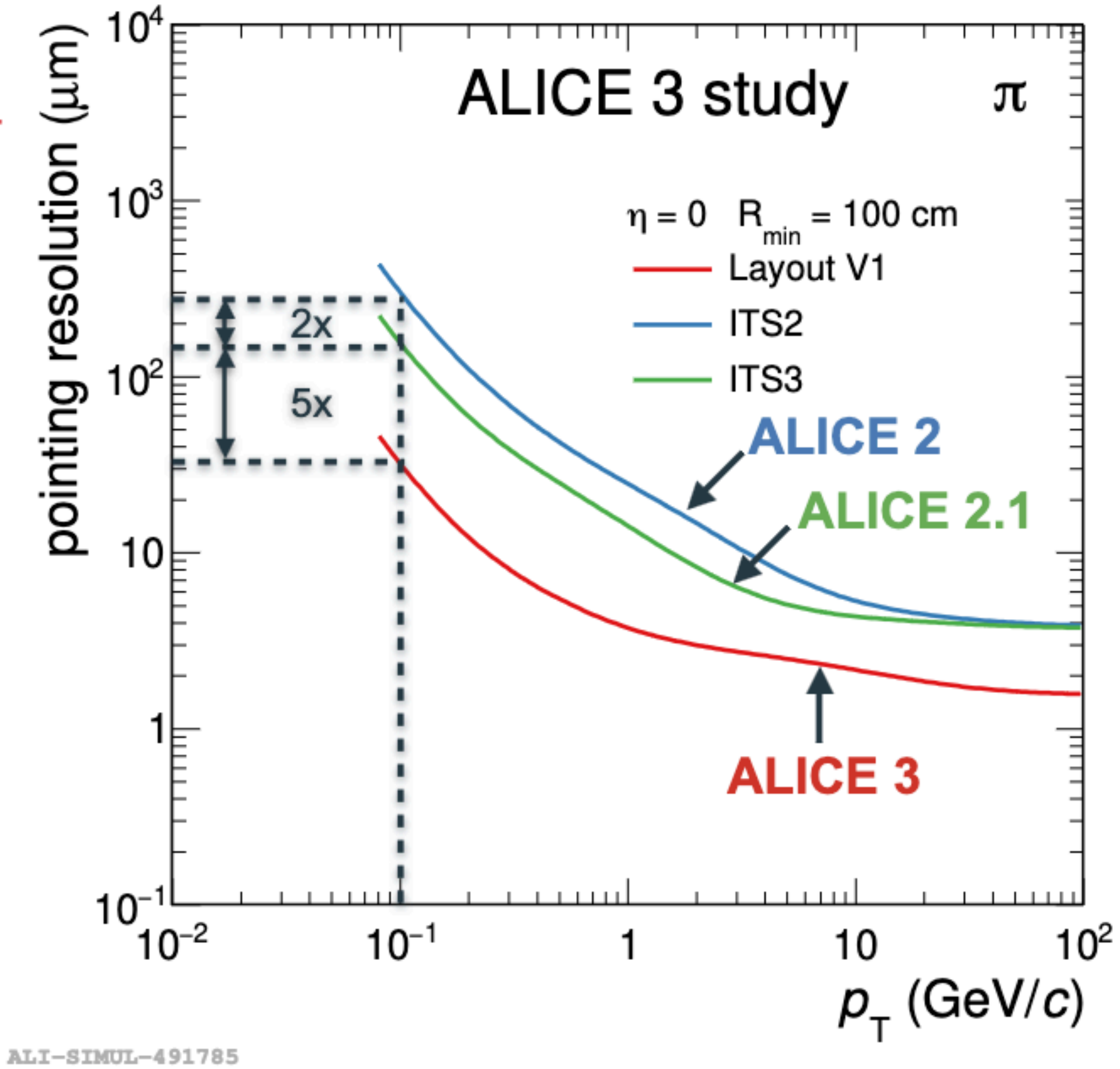
see M. van Leeuwen, A. Maire, A. Fantoni talks

ALICE Upgrade: ITS 3 in Run 4 and ALICE 3 in Run 5-6

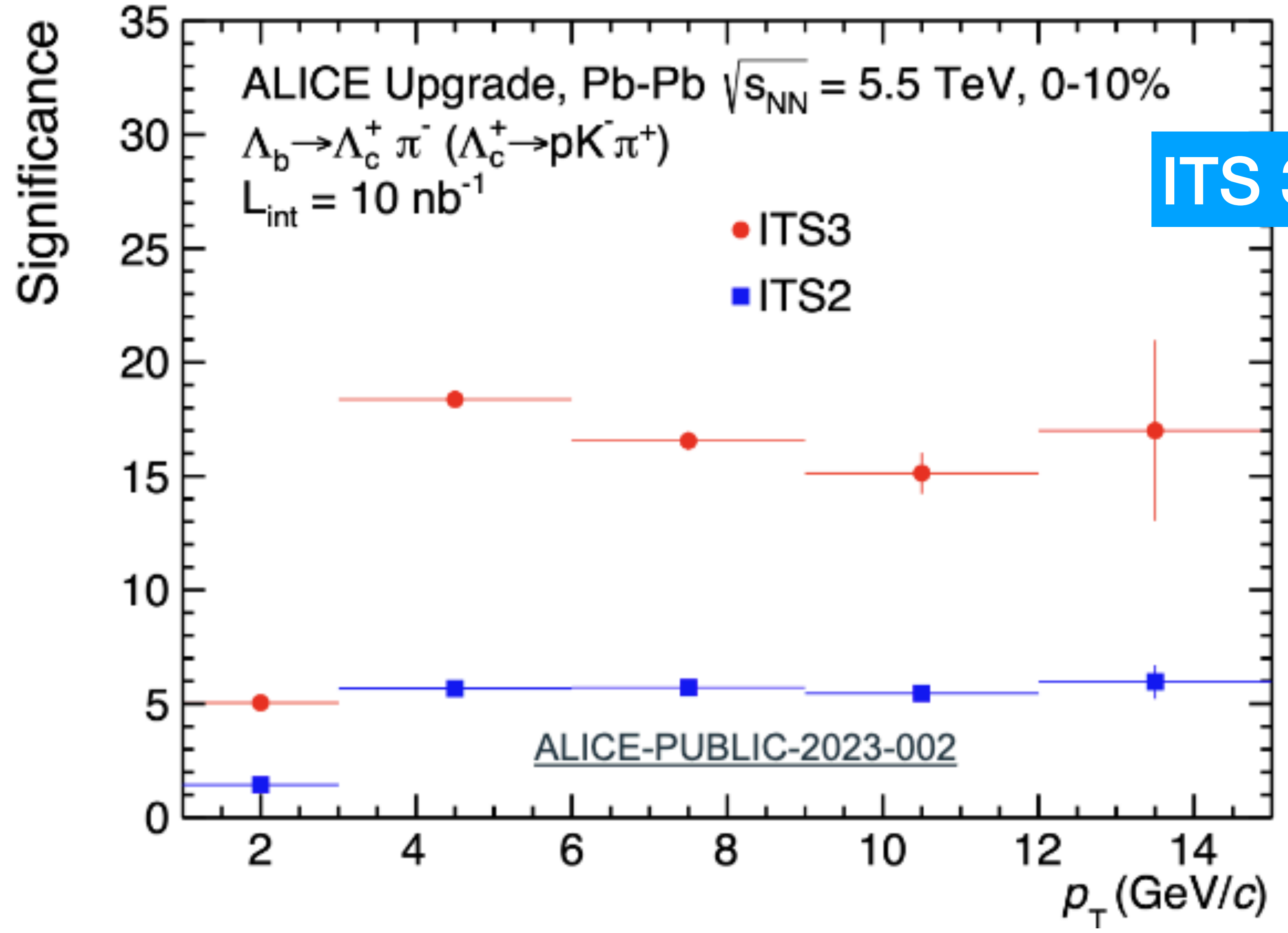


Further improvements of the pointing resolution with ITS3 (ALICE 2.1) and ALICE 3

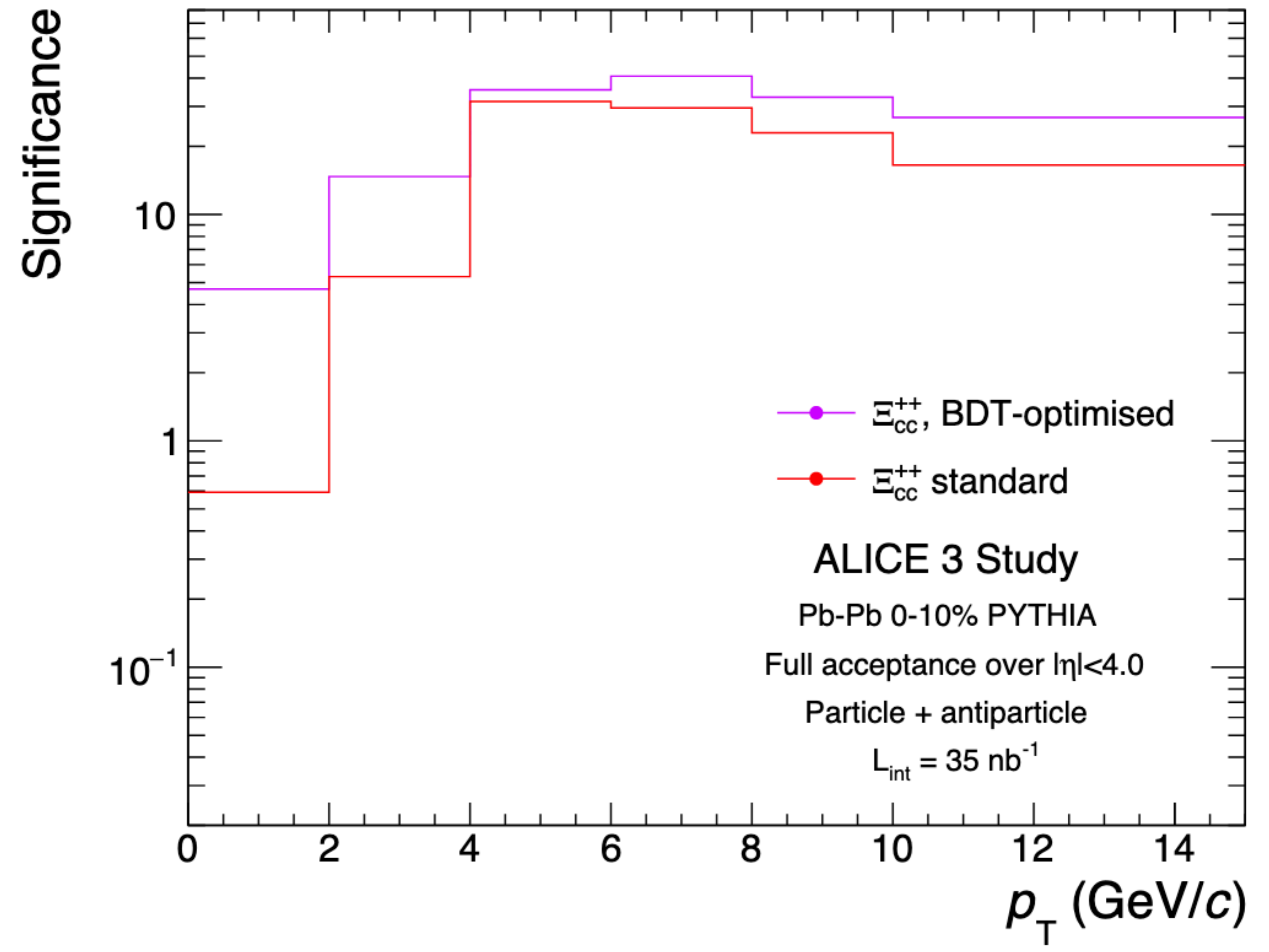
ALICE Upgrade: ITS3 in Run 4 and ALICE 3 in Run 5-6



Λ_b significance in Pb-Pb



ALICE 3



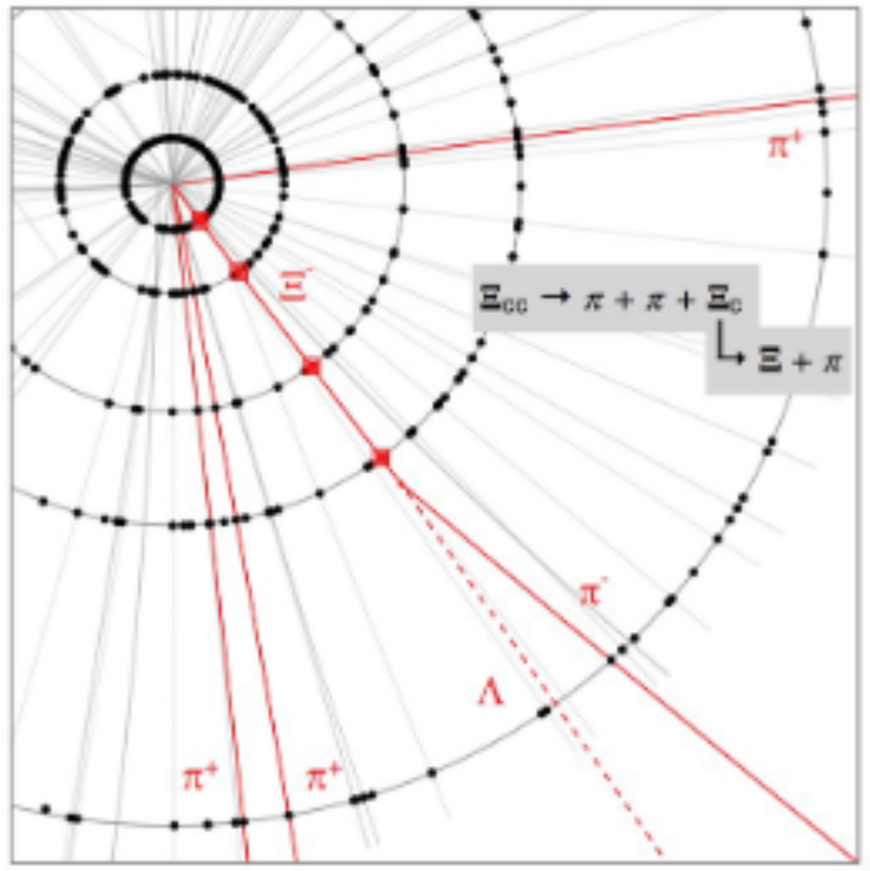
Physics case - selected highlights:

- **investigate quark transport in the QGP**
  - access to B_s, Λ_b hadrons at very low p_T,
  - and more charm baryons measurements in Pb-Pb
- **hadron formation via multi-charm baryons study:**
  - precision measurements and access to unexplored particles in Pb-Pb

CERN-LHCC-2022-009

Strangeness tracking
- Track particles before their (weak) decay
- Exploiting
  - layer granularity
  - multiple decays

$$\Xi_{cc}^{++} \to \Xi_c^{+} + \pi^{+}$$
$$\Xi_c^{+} \to \Xi^{-} + 2\pi^{+}$$



Conclusions

Physics program with HF: investigating multi-body QCD from pp to Pb-Pb collisions

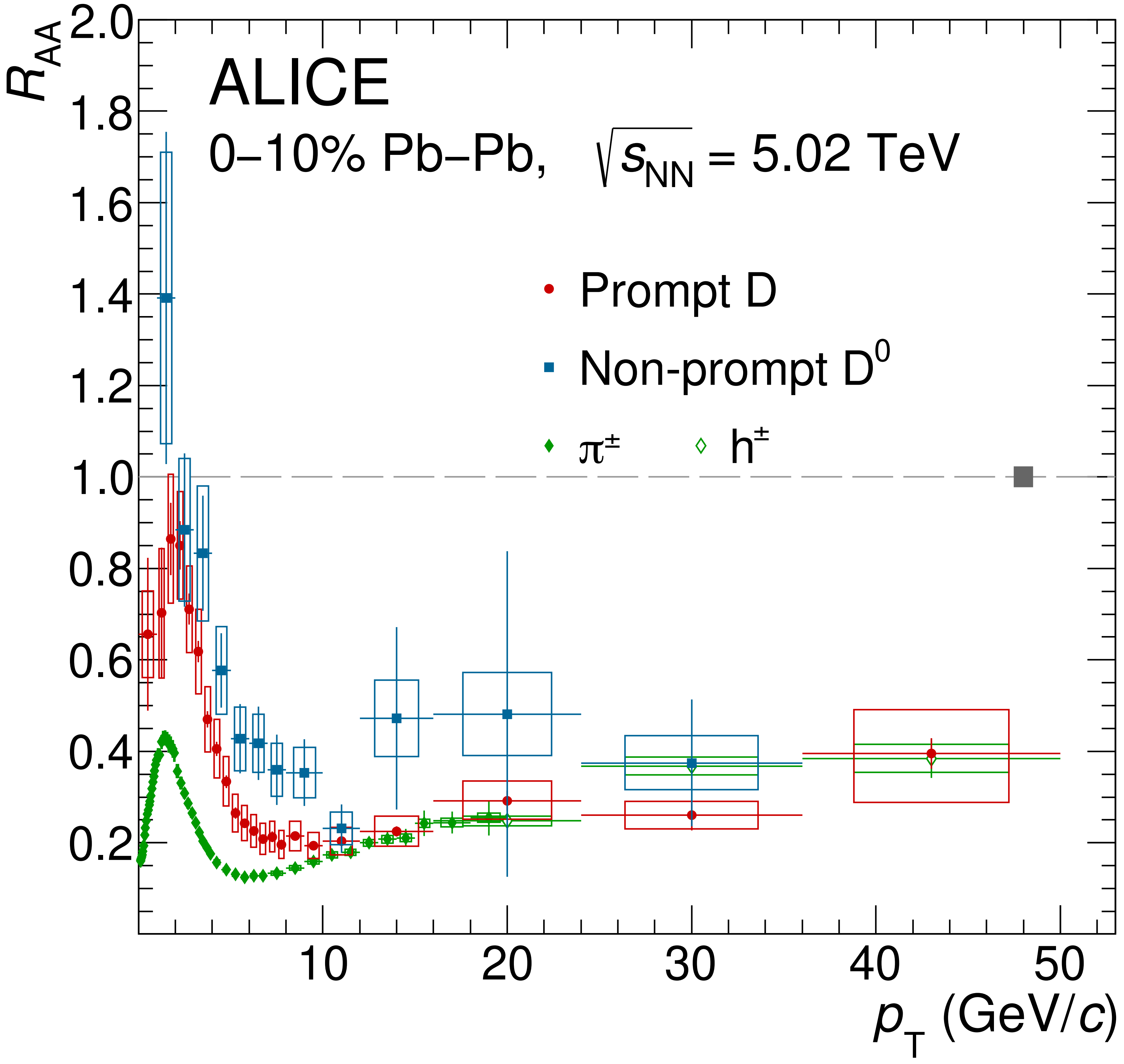
- testing pQCD, characterizing QGP, and its onsets in smaller collision systems
- **LS2 detector upgrades performing very well: good harvest from first Run3 data taking**
  - several measurements profiting of the larger statistics:
    - better precision, more differential measurements, new observables
  - **Important questions to be addressed already in Run3, but also in a near future:**
    - **Ambitious upgrade program, for further understanding of QGP and QCD matters:**
      - Upgrades for Run 4 and Run 5-6 in preparation, progressing well!

Thank you for your attention!

backup

Nuclear modification factors with HF hadrons

Run 2



$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

Colour-charge and mass dependence

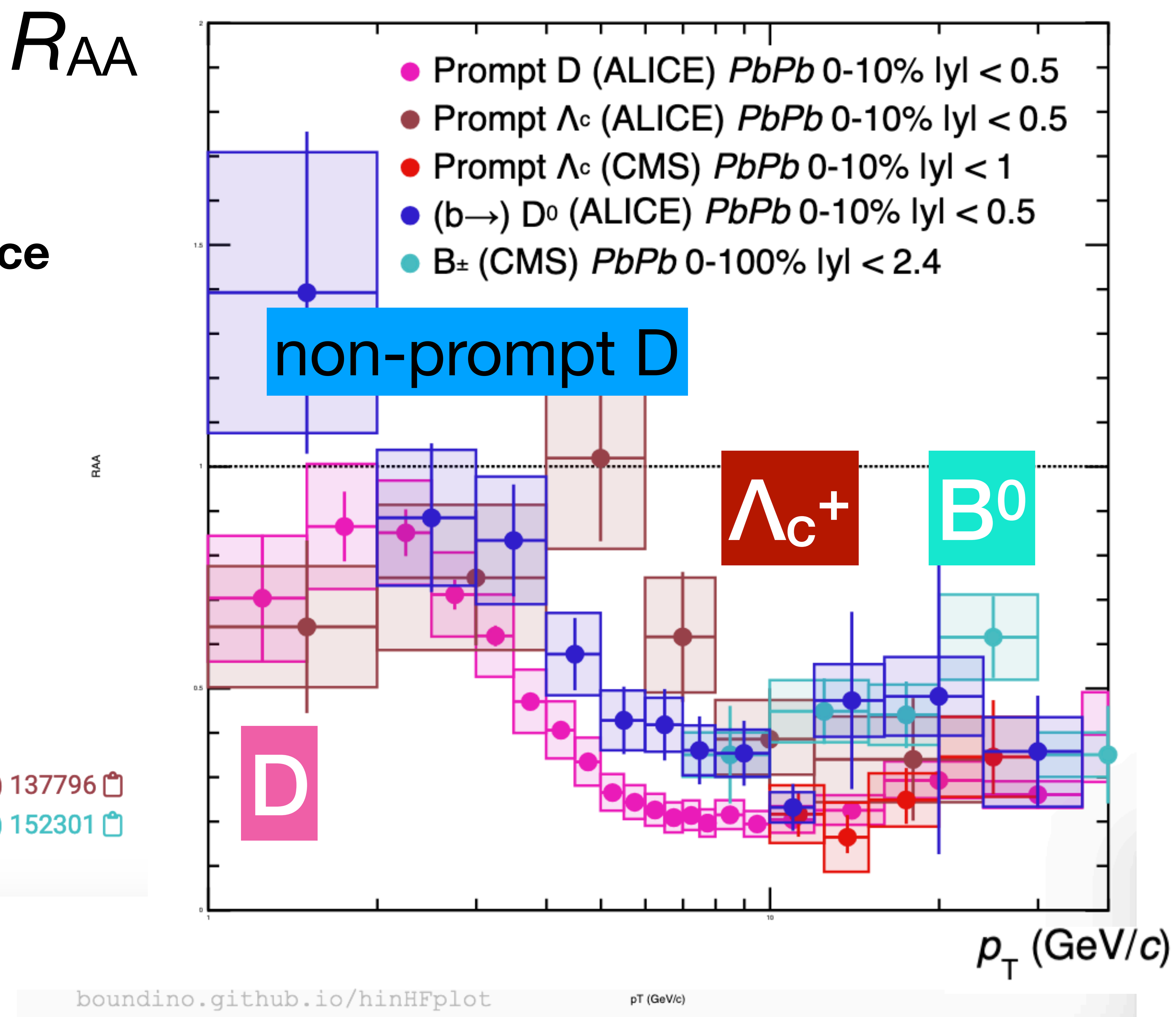
$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

Expected hierarchy

$$R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$$

→ JHEP 01 (2022) 174
→ JHEP 01 (2024) 128
→ JHEP 12 (2022) 126
→ PLB 839 (2023) 137796
→ PRL 119 (2017) 152301

https://boundino.github.io/hinHFplot/

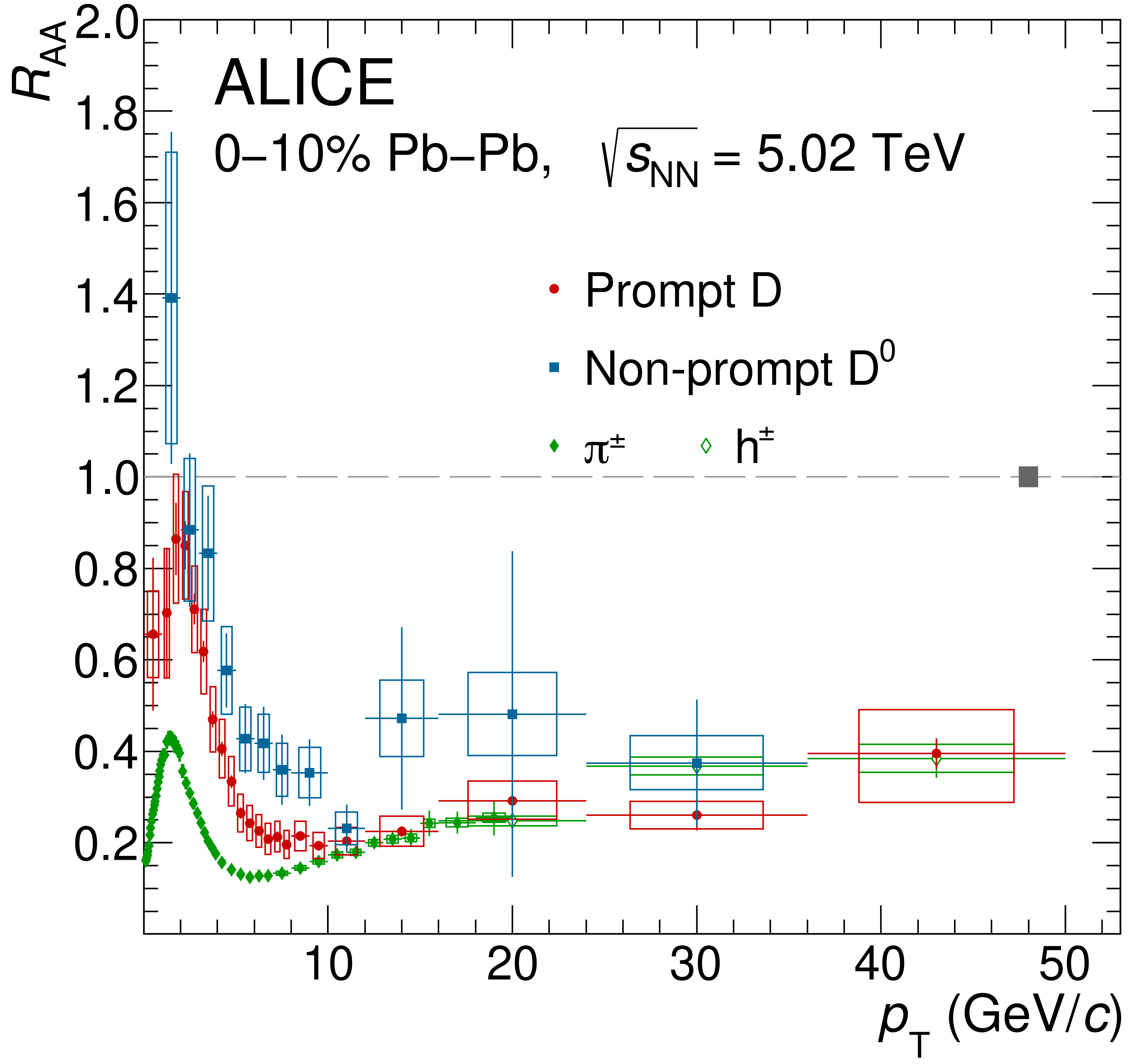


R_{AA} not determined just by 'energy loss'
➡Interplay of energy loss, collective motion and hadronization mechanisms

Better precision expected from Run 3 and access to p_T=0 for more hadrons, including heavy-flavor baryons!

For detailed discussion, see F. Grosa talks

Nuclear modification factors with HF hadrons



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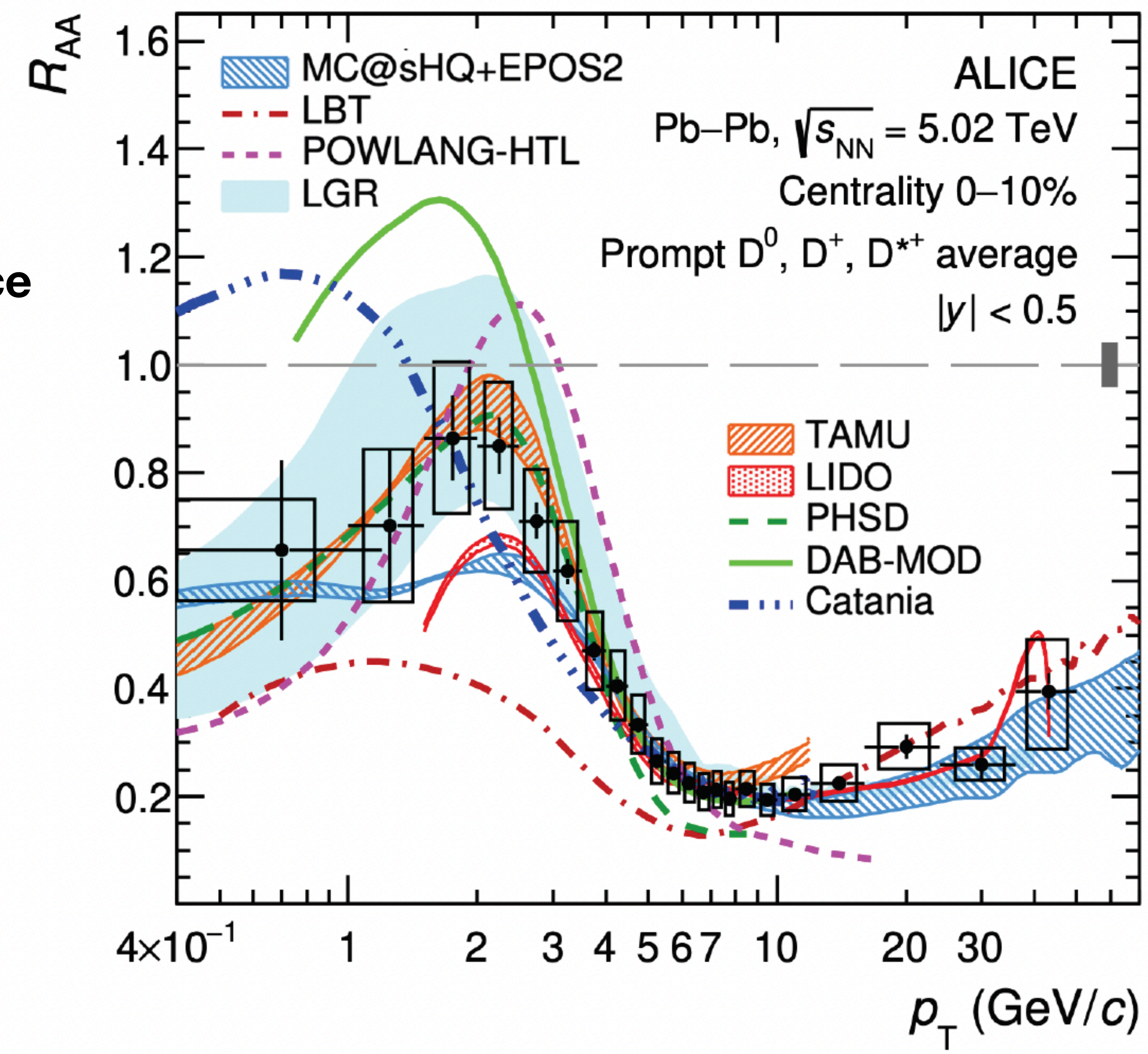


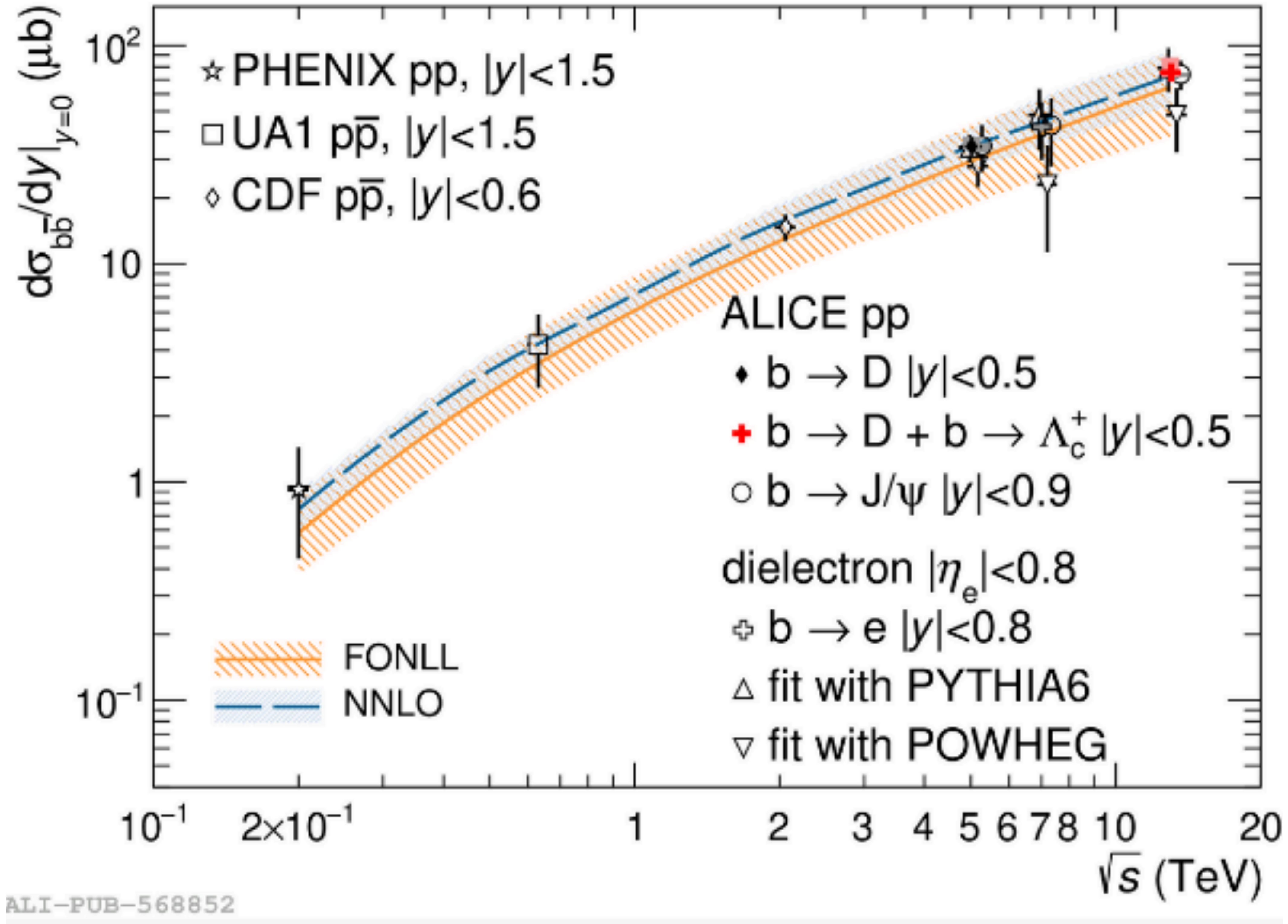
R_{AA} not determined just by 'energy loss'
➡Interplay of energy loss, collective motion and hadronization mechanisms

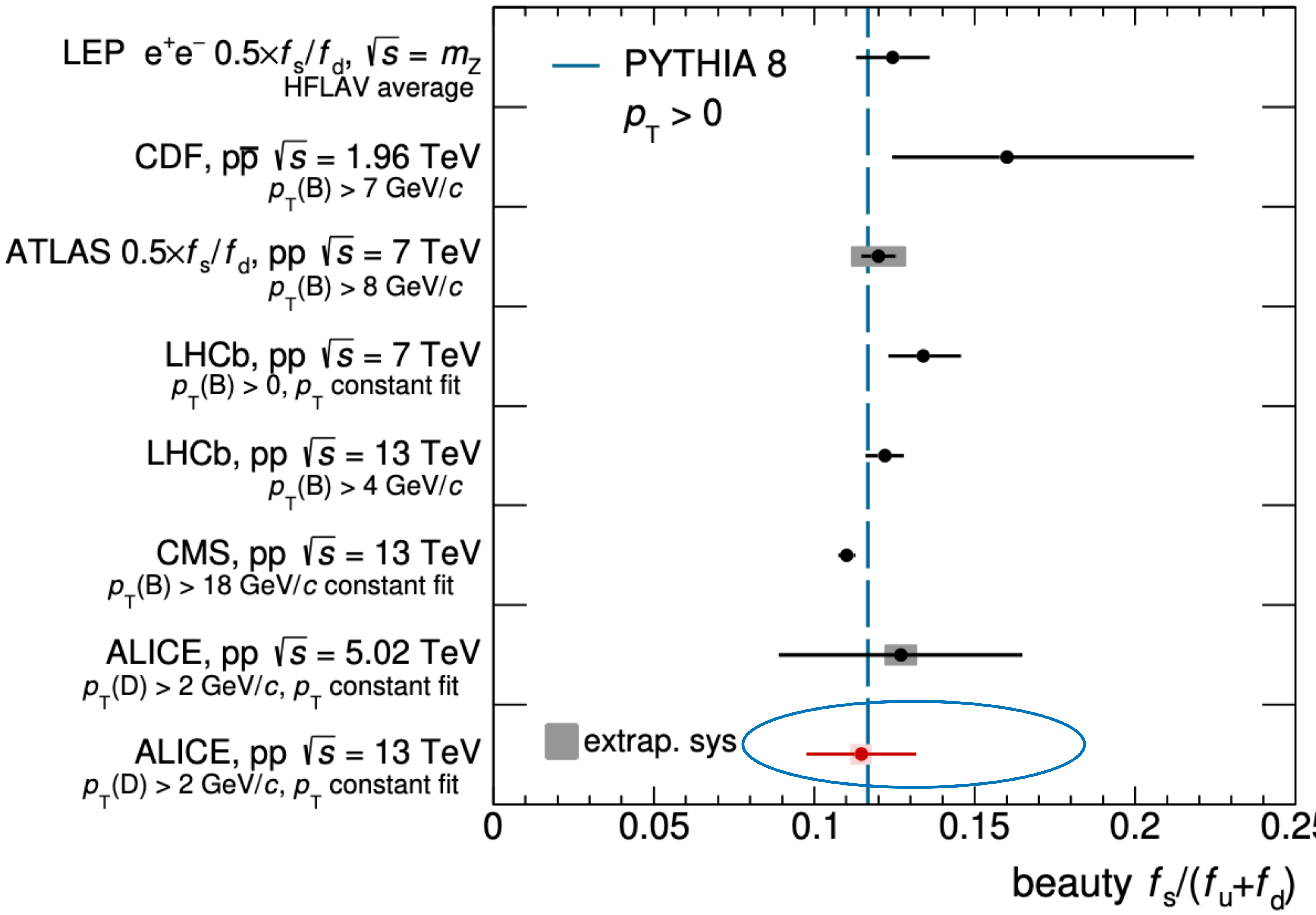
Better precision expected from Run 3 and access to pt=0 for more hadrons, including heavy-flavor baryons!

Testing pQCD in the beauty sector

Total beaty production cross section: lie on upper edge of pQCD, better described by NNLO
Beauty fragmentation fractions (here f_s/f_u+f_d) are compatible with those measured in ee and ep collisions

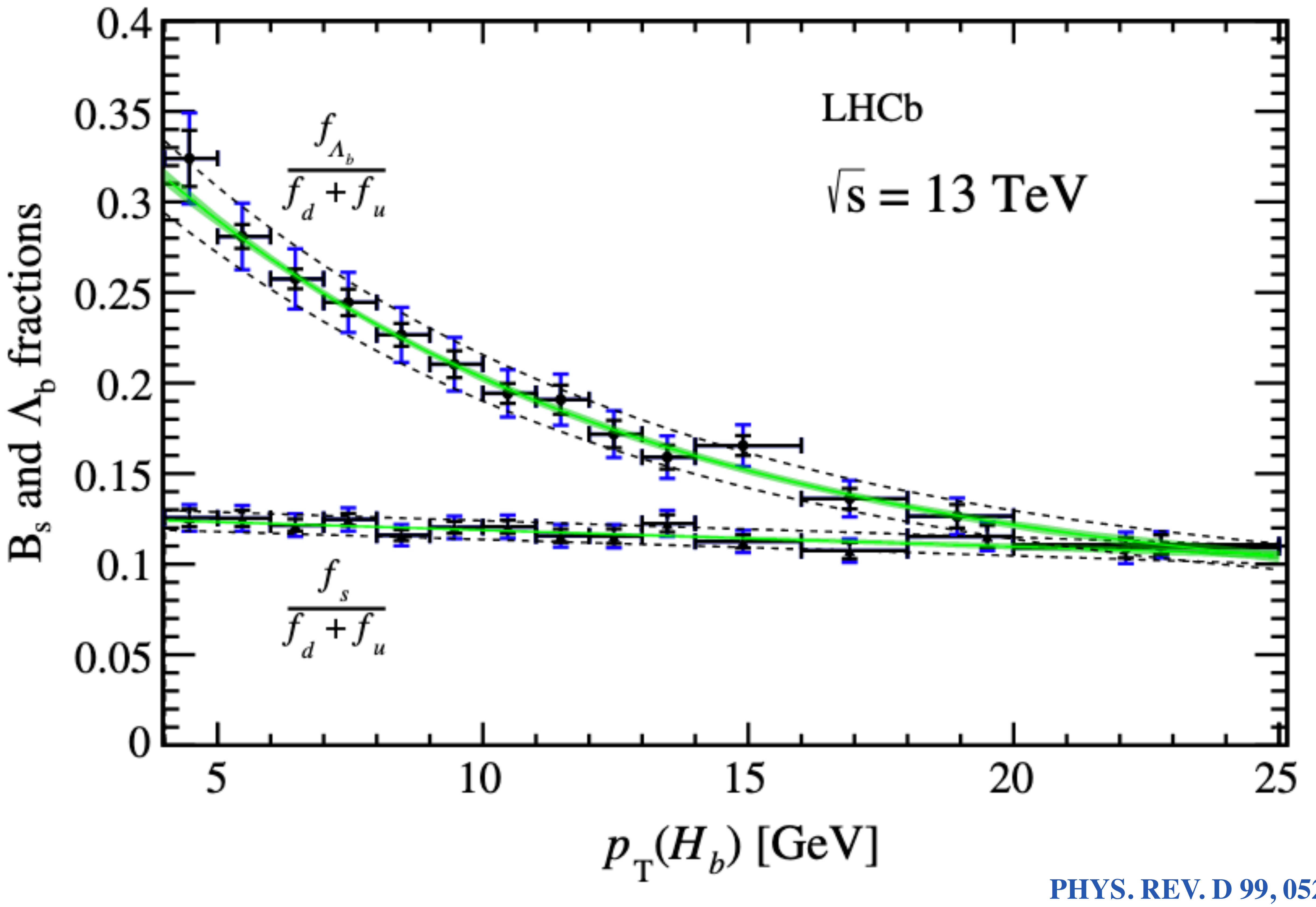
arXiv:2402.16417





pT-integrated measurement at midrapidity based on the production cross section of non-prompt D^0, D^+, Λ_c
access to Beauty measurement avaible with Run 3 data: stay tuned

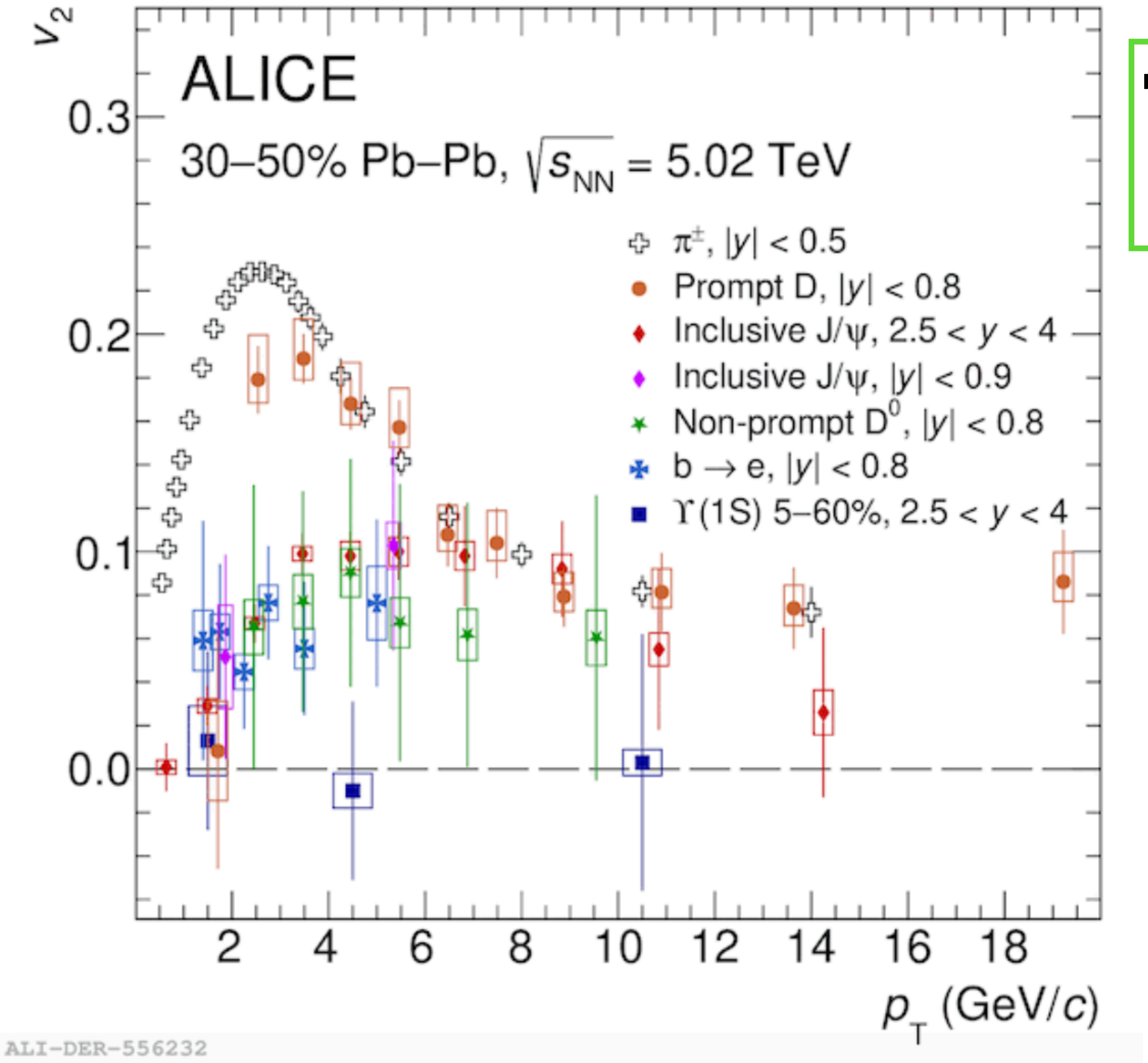
Fragmentation fractions for beauty baryons Λ_b



PHYS. REV. D 99, 052011 (2019)

Studying thermalization: v_2 of heavy-flavour hadrons

Run 2



➡Positive v_2 of hadrons with charm observed

➡ **charm quarks largely thermalize in QGP until hadronization**

- **smaller v_2 of open-beauty hadrons**

- **beauty** v_2 measured via leptons from HF hadron decays and non-prompt D, and quarkonia: Y

$0 \sim \boldsymbol{v_2}^{(\Upsilon(1S))} < v_2^{(b\rightarrow e)} \sim \boldsymbol{v_2}^{(incl\ J/\Psi)} < v_2^{(D)} < \boldsymbol{v_2}^{h}$ at low p_T

- **Open beauty-hadrons $v_2 > 0$: for** from recombination with light quarks?
- **Bottomonia: $v_2^{(\Upsilon(1S))} = 0$:** negligible recombination. Does beauty flow?

access to v_2 of beauty and charm baryons in Run 3

ITS 3: ultra-light fully cylindrical tracking layers

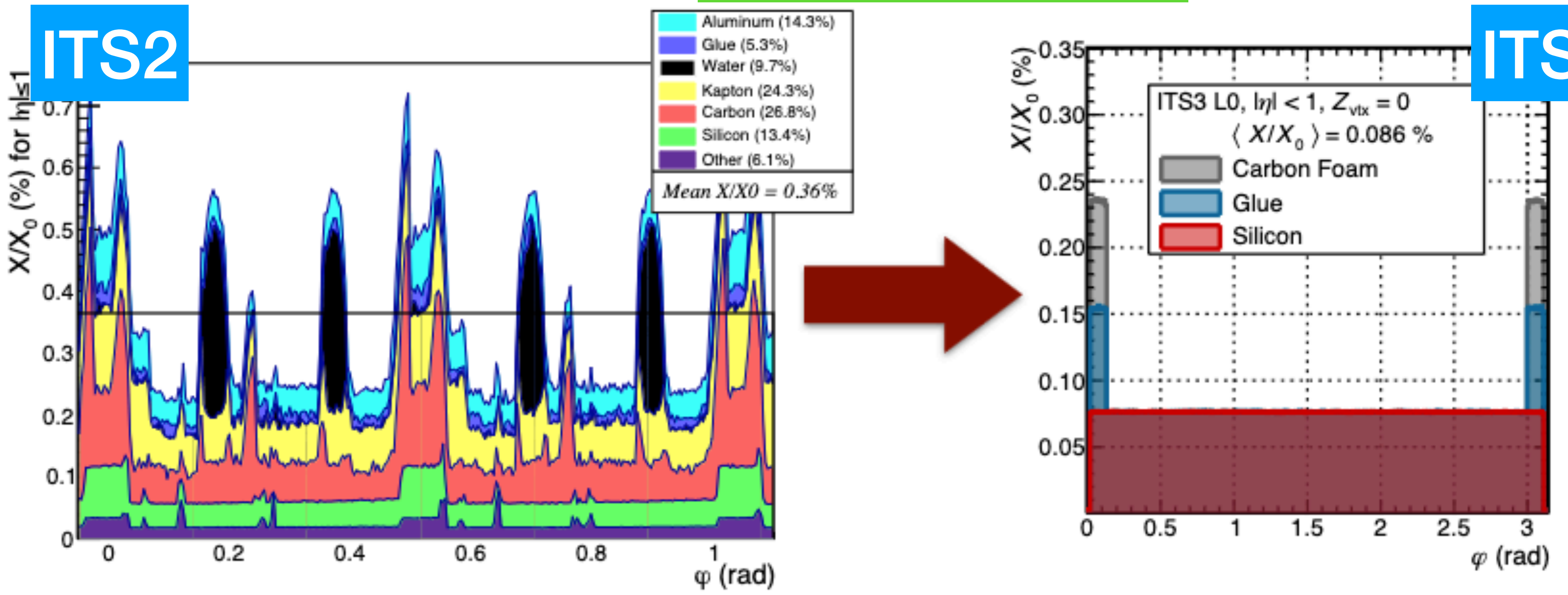
Requirements

Replacement of **ITS 2** Inner Barrel with 3 layers of **curved 50 µm thick wafer-scale MAPS**

- Air cooling and ultra-light mechanical supports
- **Reduced material** budget of 0.09% X_0 instead of 0.36% X_0 per layer
- **Smaller radius** of the innermost layer: 19 mm instead of 23 mm

Material budget

ITS2

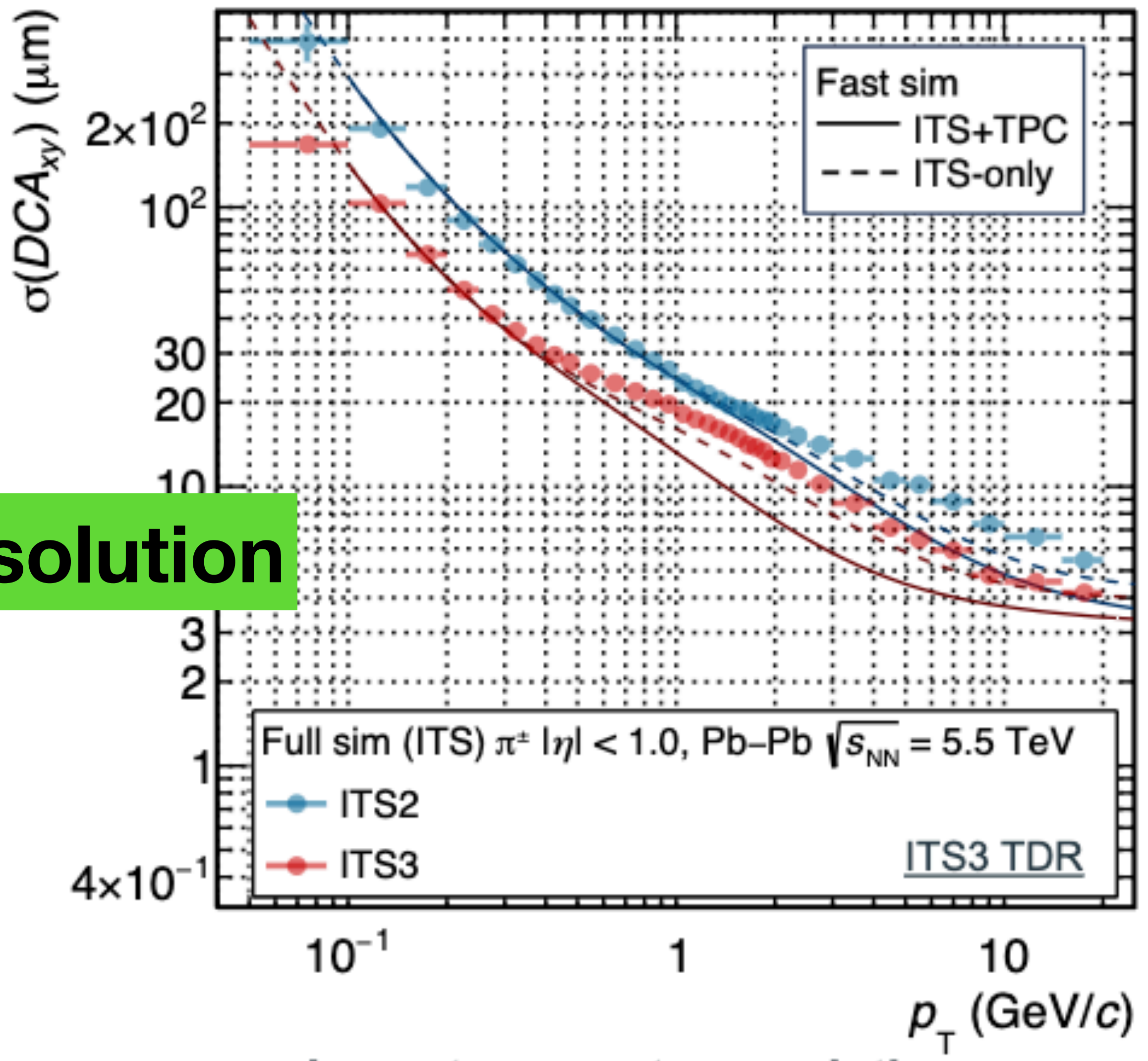


ITS3

ITS2 Layer 0

ITS3 Layer 0

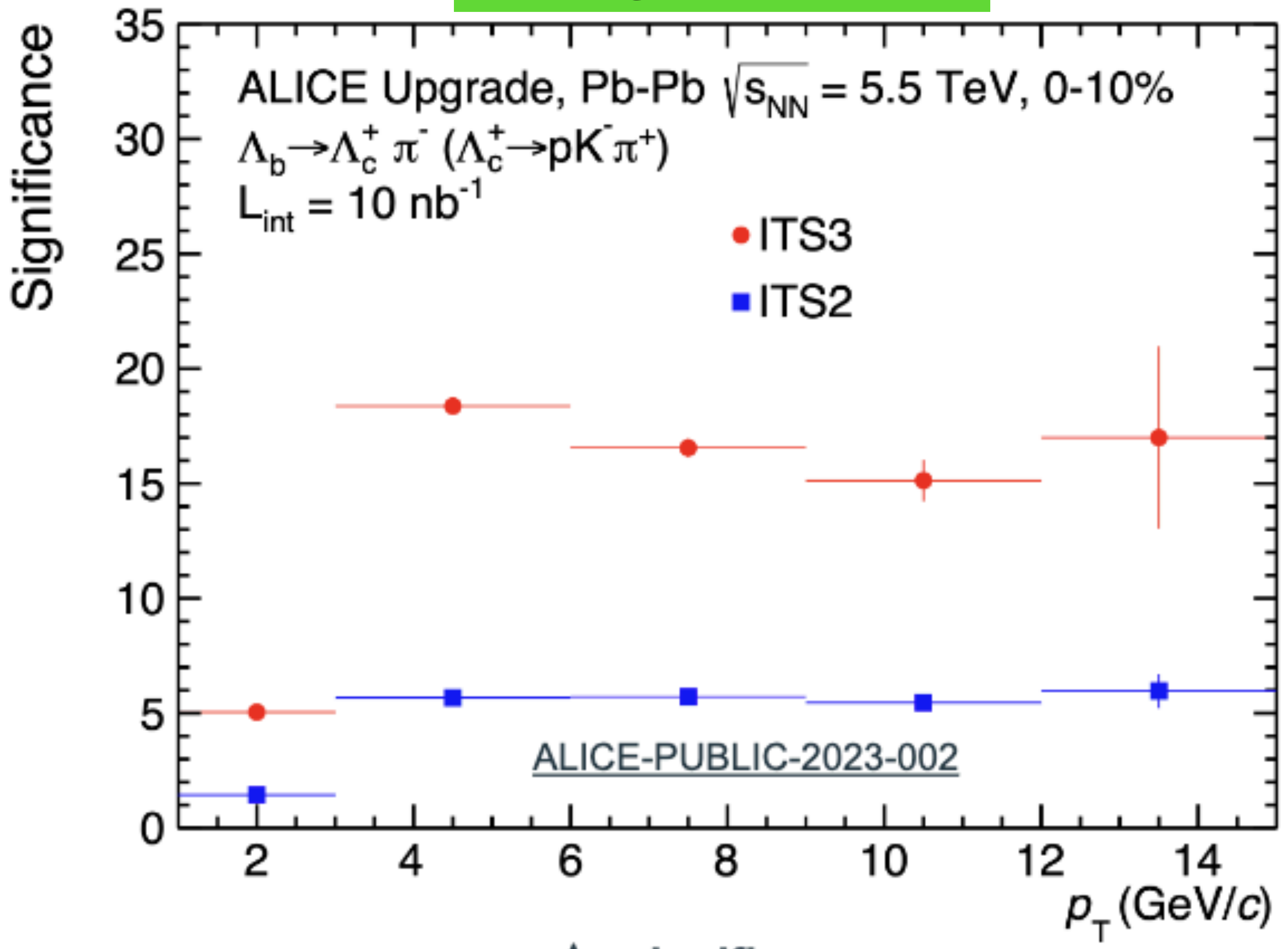
Physics performance



DCA resolution

Impact parameter resolution

Λ_b significance



Λ_b significance

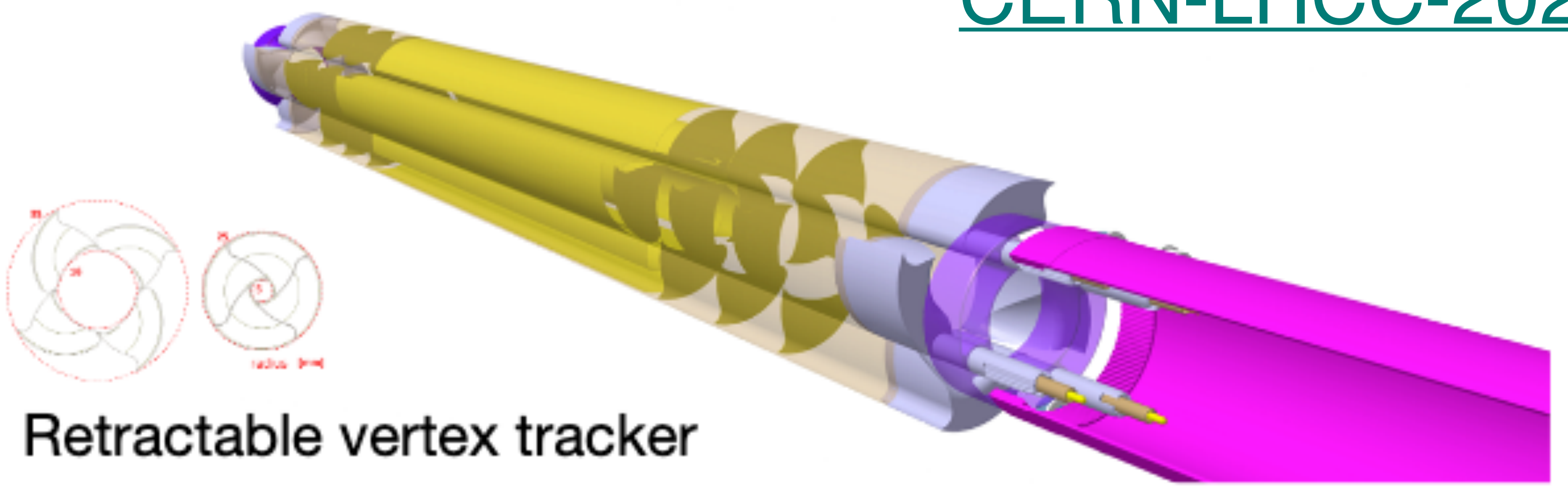
ITS 3 TDR - CERN-LHCC-2024-003

ITS3 physics perfomance studies: ALICE-PUBLIC-2023-002

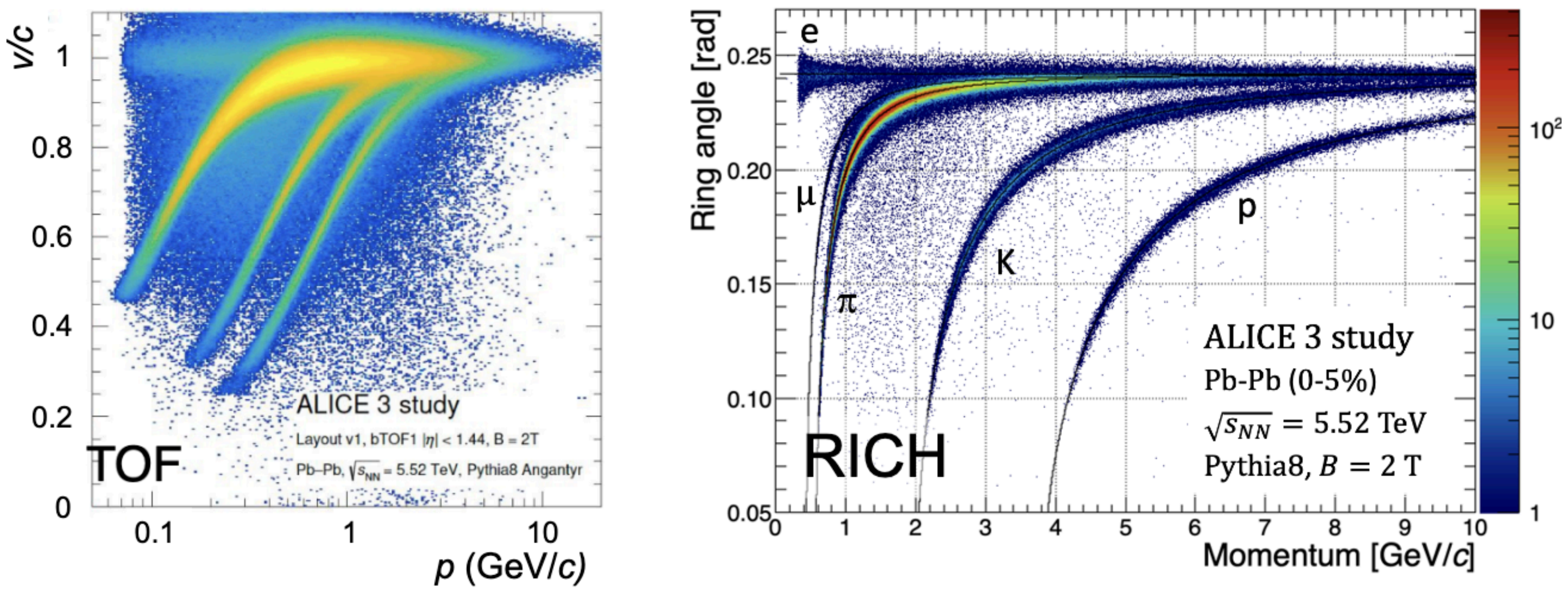
ALICE 3 in Run 5 and Run 6

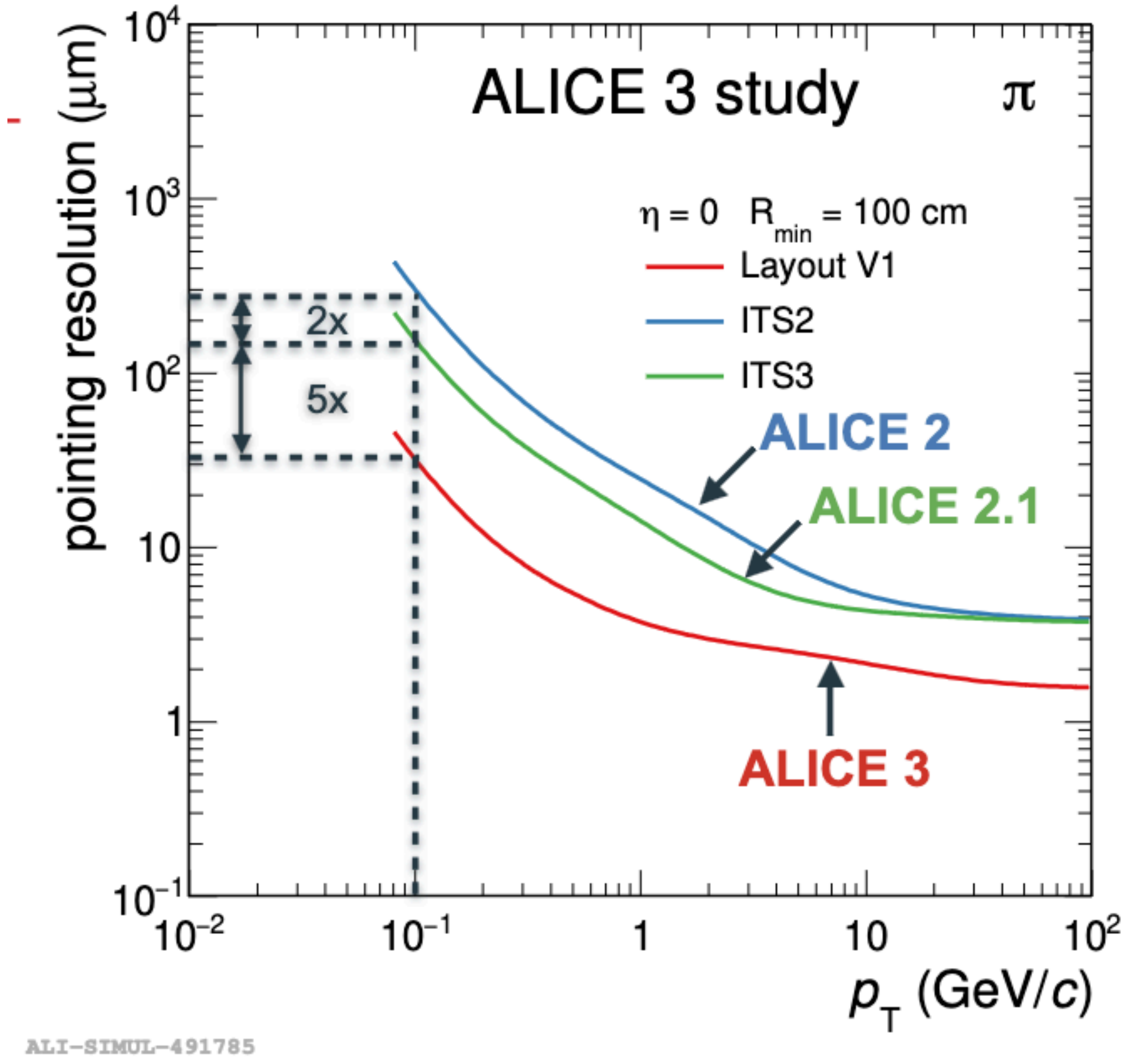
CERN-LHCC-2022-009

- **Compact**, with **low-mass all-silicon tracker**
  - Retractable vertex detector
    - 0.1% X_0/layer, 2.5 µm spatial resolution
- **Excellent vertex reconstruction and PID** capabilities over **large acceptance** (-4 < η < 4)
  - TOF: time resolution 20 ps, low material budget 1-3% X_0/layer
  - RICH: extending PID to higher p_T
  - MID: muon and photon ID
- **Continuous read-out and online processing**



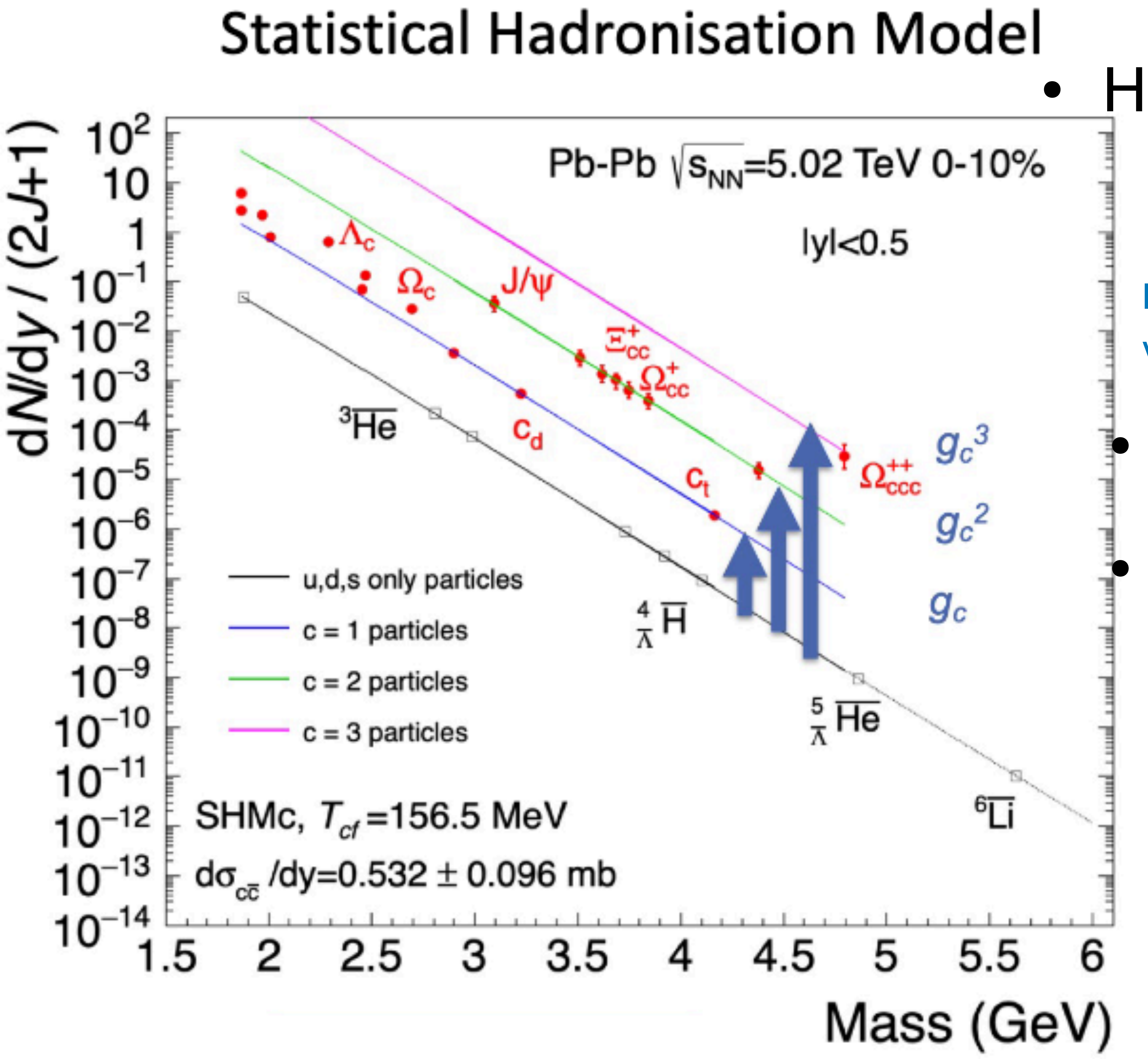
R ≈ 5 mm at top energy, R ≈ 15 mm at injection energy





ALICE 3 in Run 5 and Run 6

CERN-LHCC-2022-009



A Andronic et al.: JHEP 07 (2021) 035

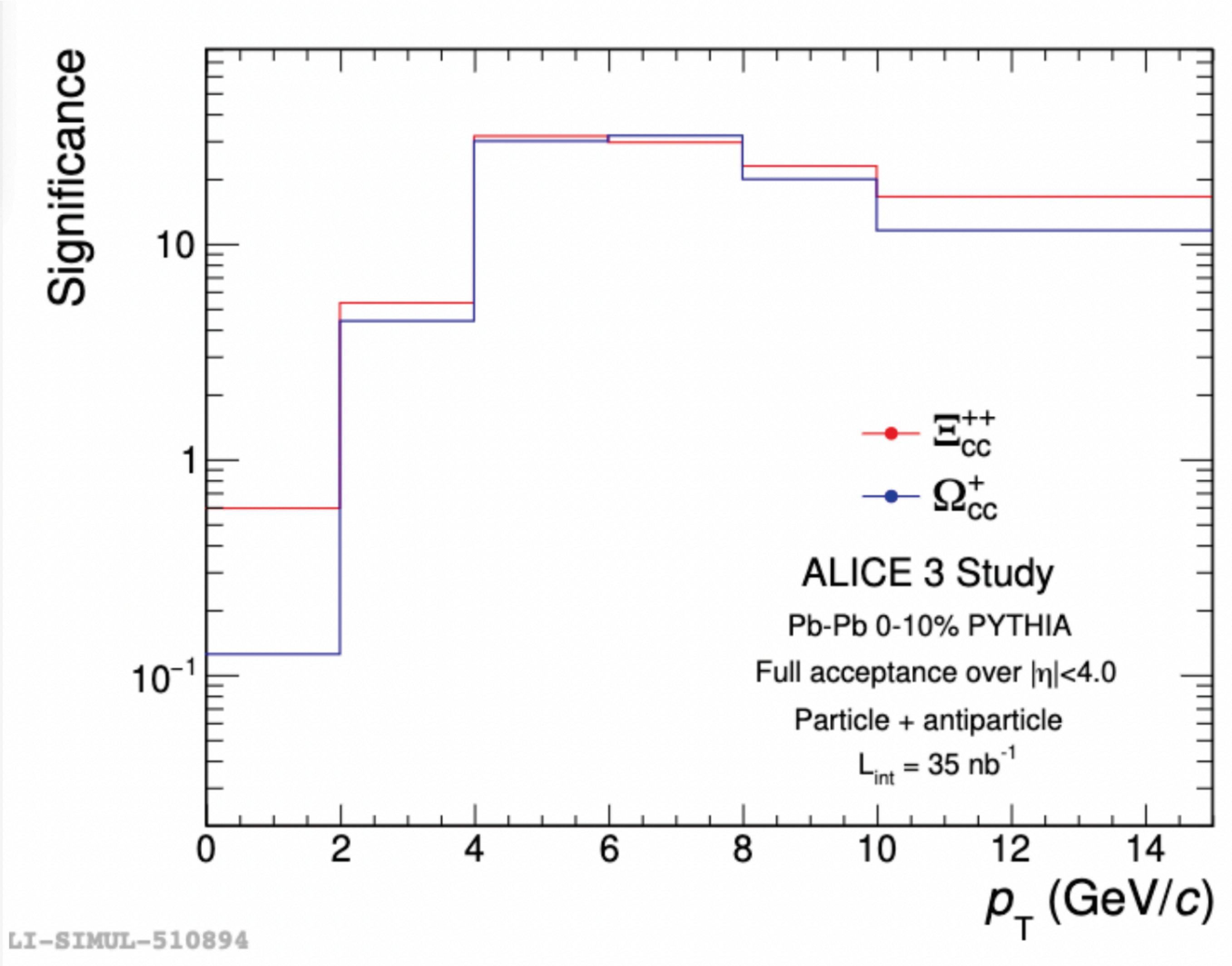
- Huge enhancements predicted: up to 10^3 wrt pQCD for the Ω_{ccc}

F Becattini: Phys.Rev.Lett. 95 (2005) 022301

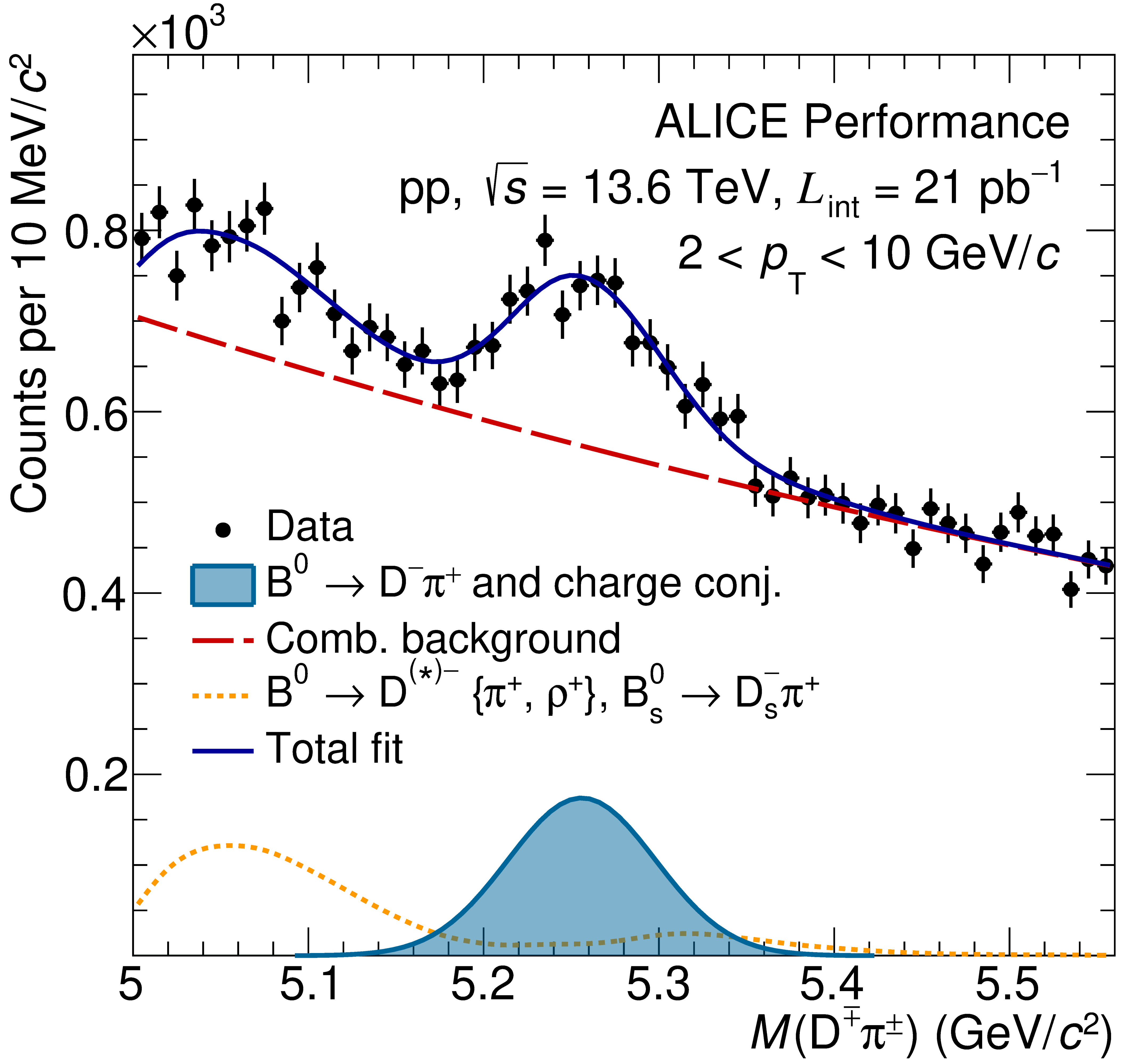
V Minissale et al.: arXiv:2305.03687

- negligible production in Single-Parton Scattering
- ultimate sensitivity to degree of c thermalisation

$$\Omega_{ccc}^{++} \rightarrow \Omega_{cc}^{+} + \pi^{+}$$
$$\Omega_{cc}^{+} \rightarrow \Omega_{c}^{0} + \pi^{+}$$
$$\Omega_{c}^{0} \rightarrow \Omega^{-} + \pi^{+}$$



Beauty hadron reconstruction



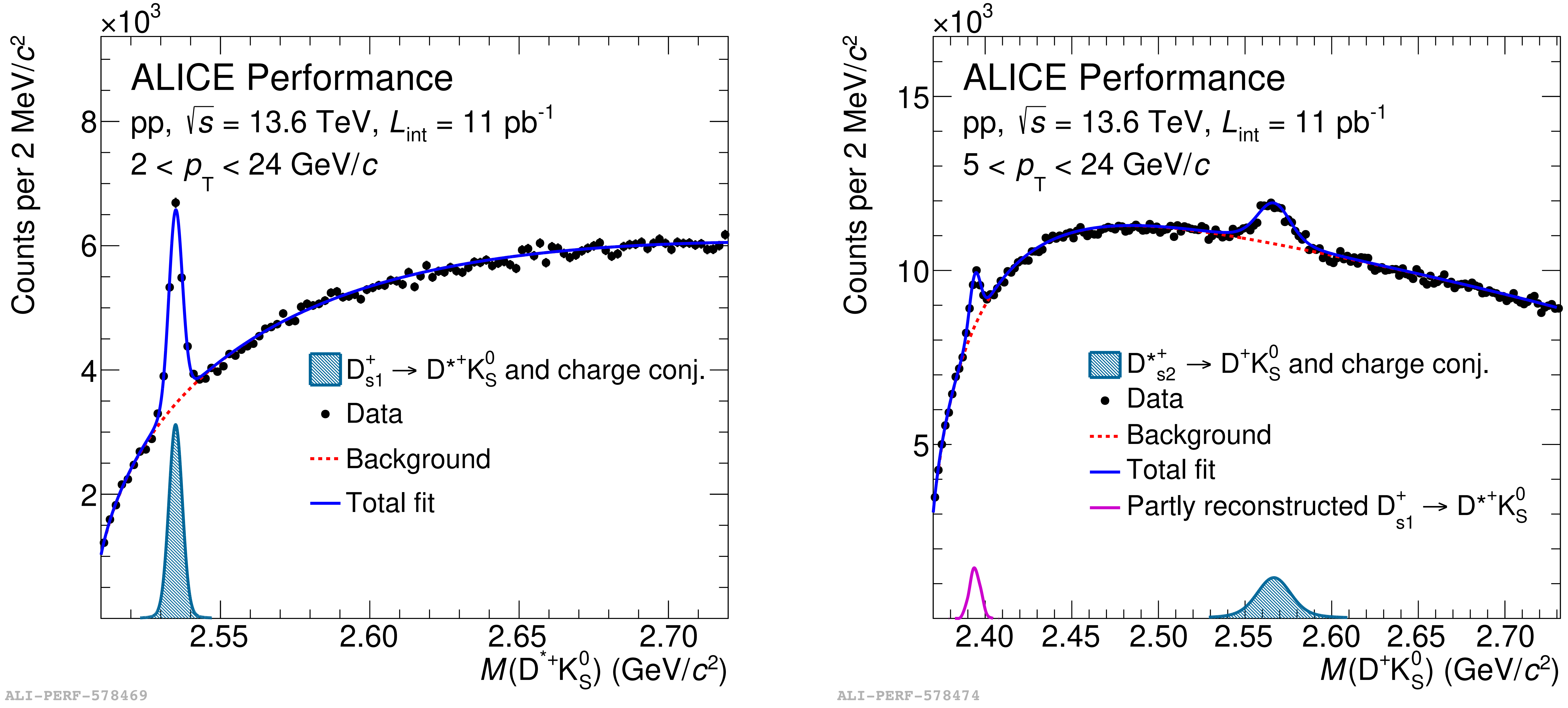
ALI-PERF-578341

- Unbinned log-likelihood fit
- Fit functions:
  - Signal: Gaussian
  - Combinatorial background: exponential
  - Correlated backgrounds: template from MC parameterised with Kernel Density Estimation

    Main contributions:

    i. $B^0 \to D^{*-}\pi^+ \to D^-\pi^+\pi^0$
    ii. $B^0 \to D^{*-}\pi^+ \to D^-\pi^+\gamma$
    iii. $B^0 \to D^-(\to K^+K^-\pi^-)\pi^+$

Dedicated triggers for D_s resonances



$D_{s1}^{\ +} \rightarrow D^* K^0{}_s$ and $D_{s2}^{\ *+} \rightarrow D^+ K_0{}^s$

Λ_b/B vs multiplicity at forward rapidity

PRL 132 (2024) 8, 081901

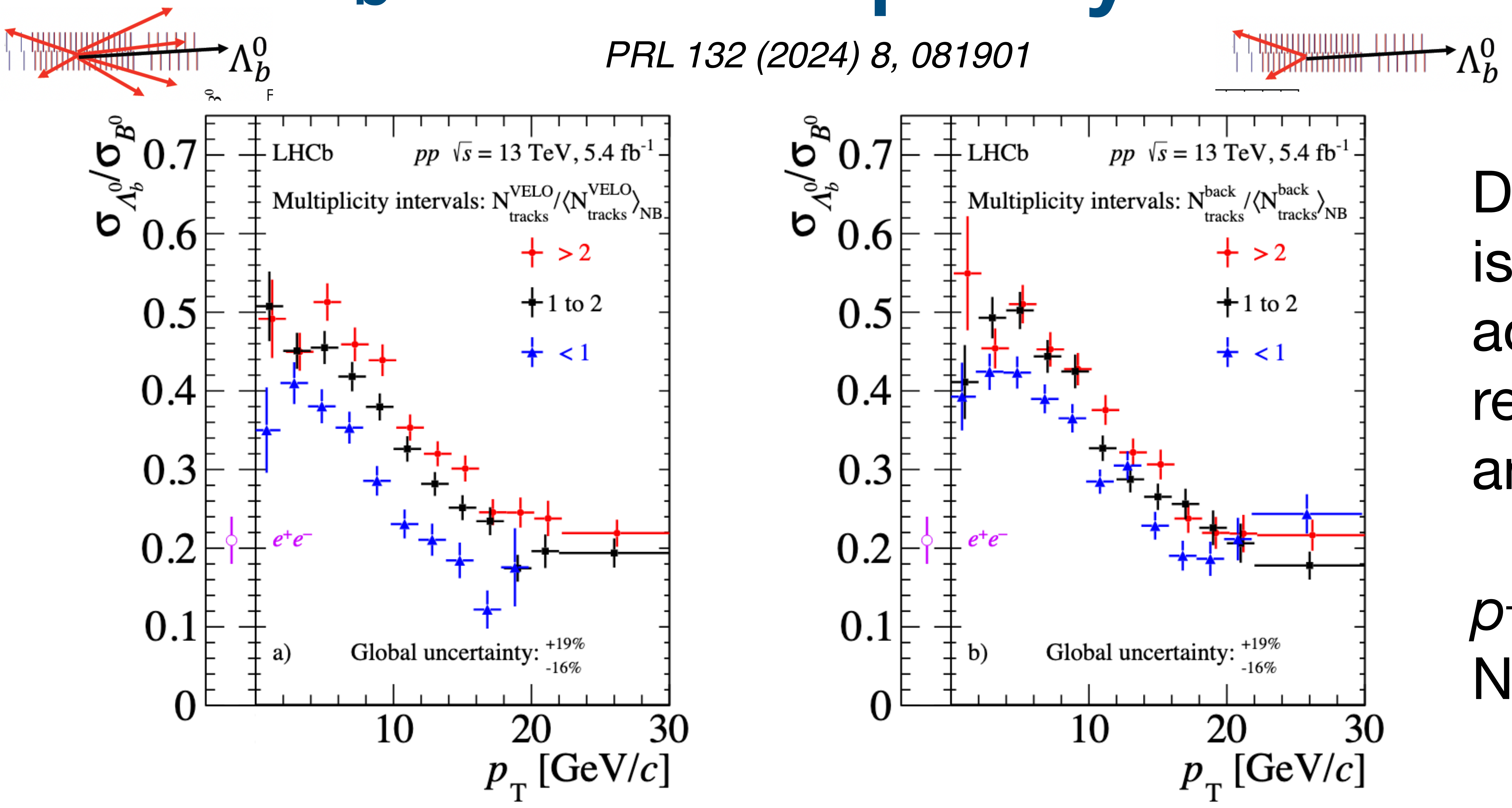
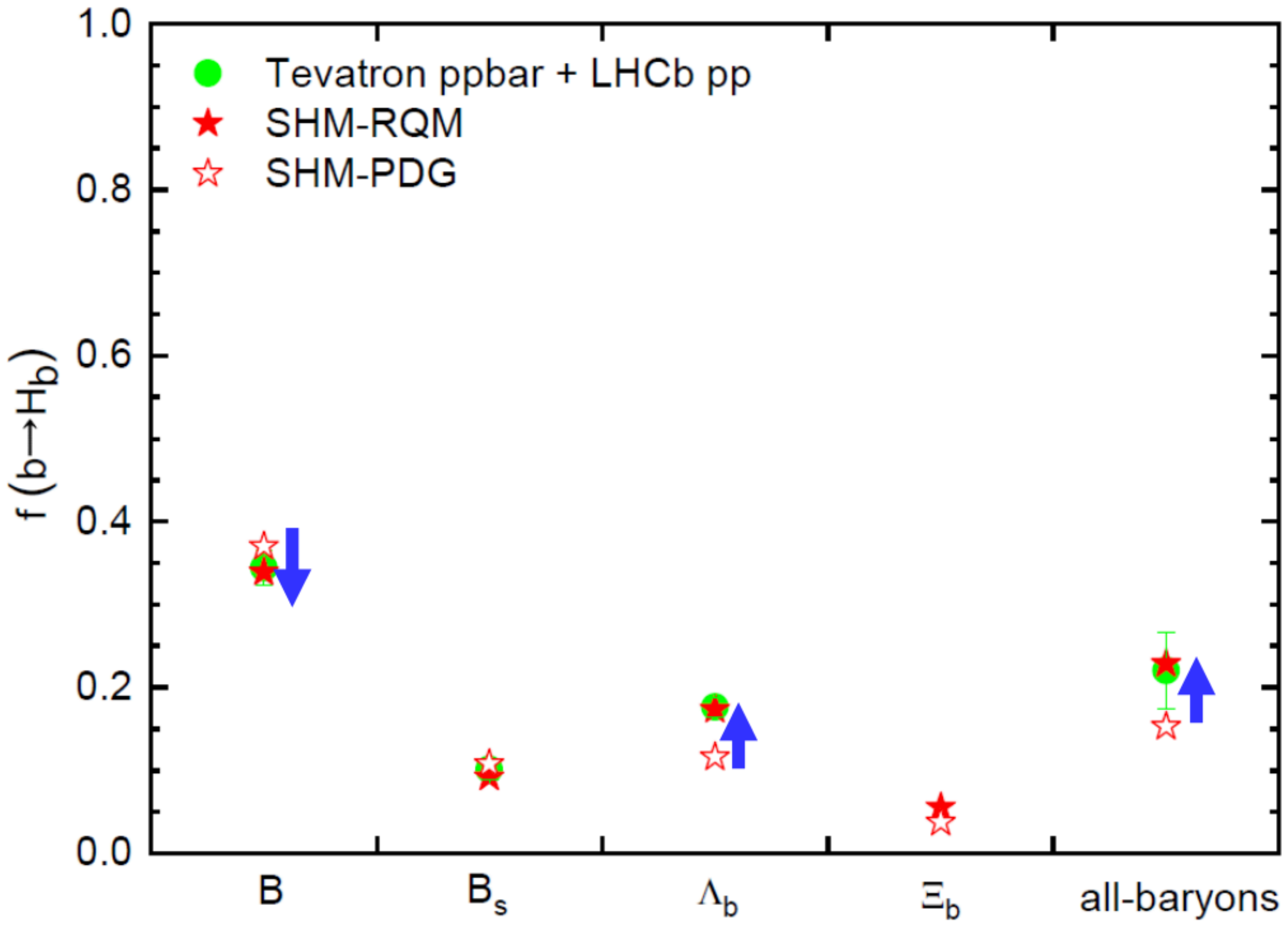


Figure 4: Ratio of Λ_b^0 to B^0 cross-sections as a function of p_{T}, in bins of a) the total multiplicity measured in the VELO detector and b) the backwards track multiplicity. The purple point shows the value measured in $e^+e^- \to Z^0 \to b\bar{b}$ reactions at LEP [61].

Dependency with multiplicity is still there if a eta-gap is added between reconstructed candidates and multiplicity evaluation.

p_{T}-integrated ratios with $N^{\mathrm{back}}_{\mathrm{tracks}}$?

beauty Fragmentation Fraction



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