

# 科技部国家重点研发计划项目

## ALICE实验夸克物质性质的硬探针研究 进展报告

报 告 人：张晓明（代表项目课题组）

牵头承担单位：华中师范大学

国内合作单位：中国科学技术大学

国外合作单位：欧洲核子研究中心（CERN）

中国ALICE实验学术研讨会，2021年7月31 – 8月1日

# 汇报提纲

- 研究内容
- 研究进展
- 执行情况
- 研究计划

# 主要研究内容

- 重夸克能量损失和集体关联的实验研究
- 重夸克强子及多重味重子态的产生的实验研究
- 单举喷注、喷注结构的实验研究
- 强子、光子-喷注，重夸克喷注的实验研究

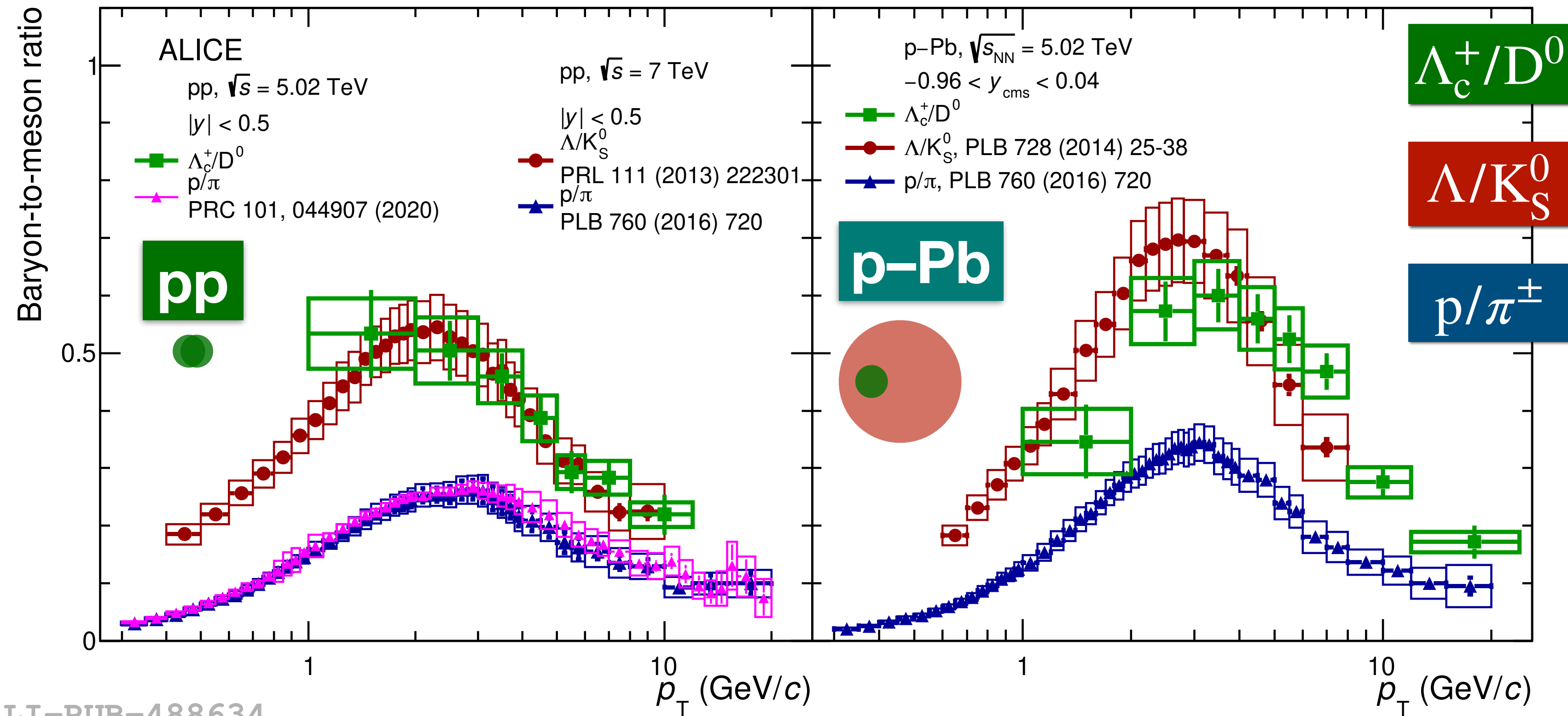
# 项目进展 — 文章发表

文章发表指标 发表ALICE合作组SCI论文10-12篇

- 截止今年1月
  - ➔ 已发表文章4篇
  - ➔ 已投稿文章2篇
  - ➔ 已获批文章10篇
- 当前执行情况
  - ➔ 已发表文章7篇
  - ➔ 已投稿文章6篇
  - ➔ 已接收文章1篇
  - ➔ 已获批文章7篇

1月份进展汇报: <https://indico.ihep.ac.cn/event/13639/session/3/contribution/16>

# $\Lambda_c^+/D^0$ ratio in pp and p-Pb



ALI-PUB-488634

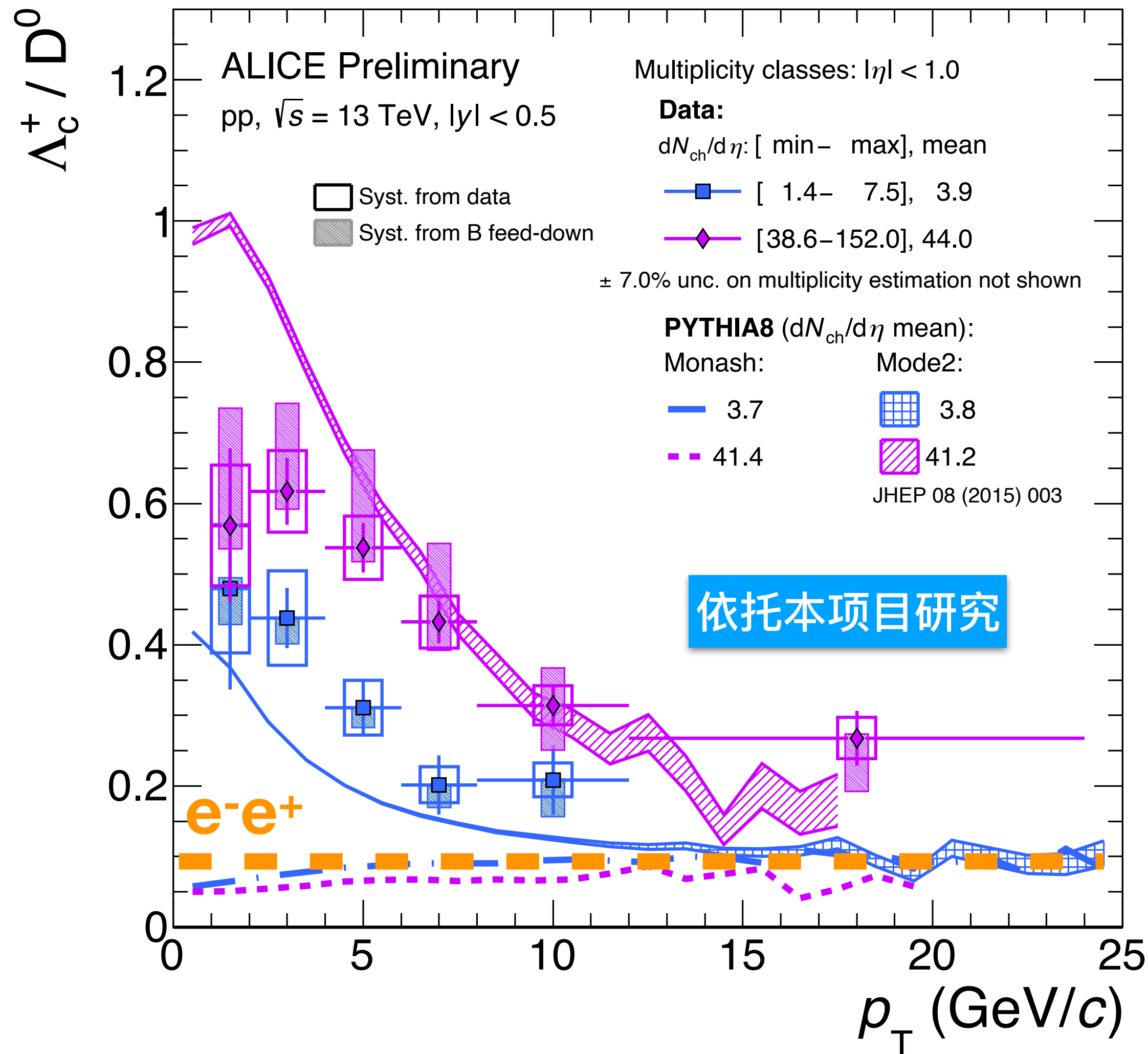
- Baryon-to-meson ratio enhancement is observed in p-Pb and pp collisions at high multiplicities in **charm sector**

➔ Similar as that in strange sector

ALICE arXiv:2011.06079

arXiv:2011.06078

# $\Lambda_c^+ / D^0$ ratio vs. $p_T$ in pp



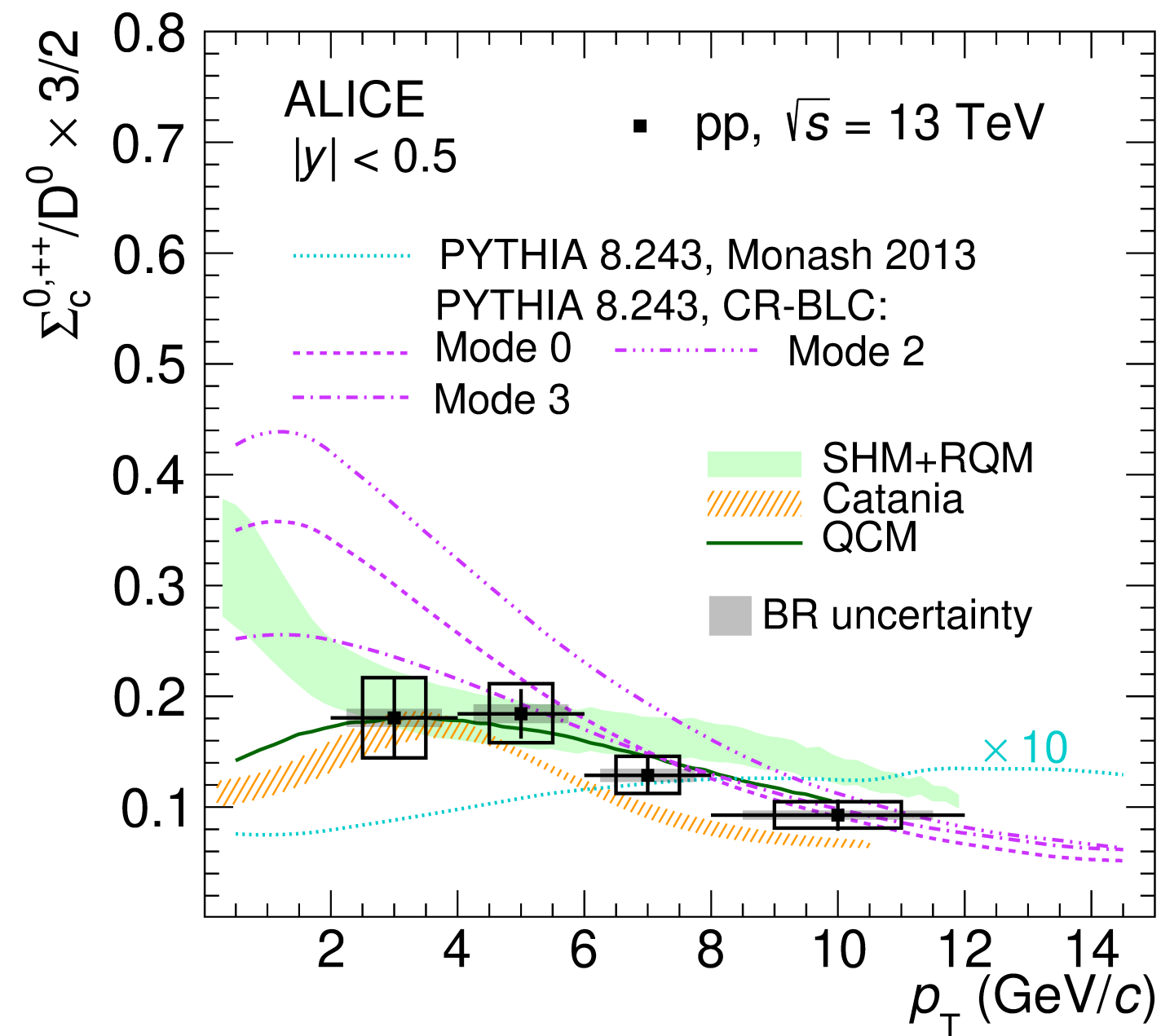
- $\Lambda_c / D^0$  ratio shows a more substantial increase for increasing multiplicity
- Largely underestimated when comparing to the default PYTHIA tune (Monash)
- Good agreement including color-reconnection processes (eg “junctions”) between partons created in different MPIs



# $\Sigma_c$ , $\Xi_c$ and $\Omega_c$ production in pp

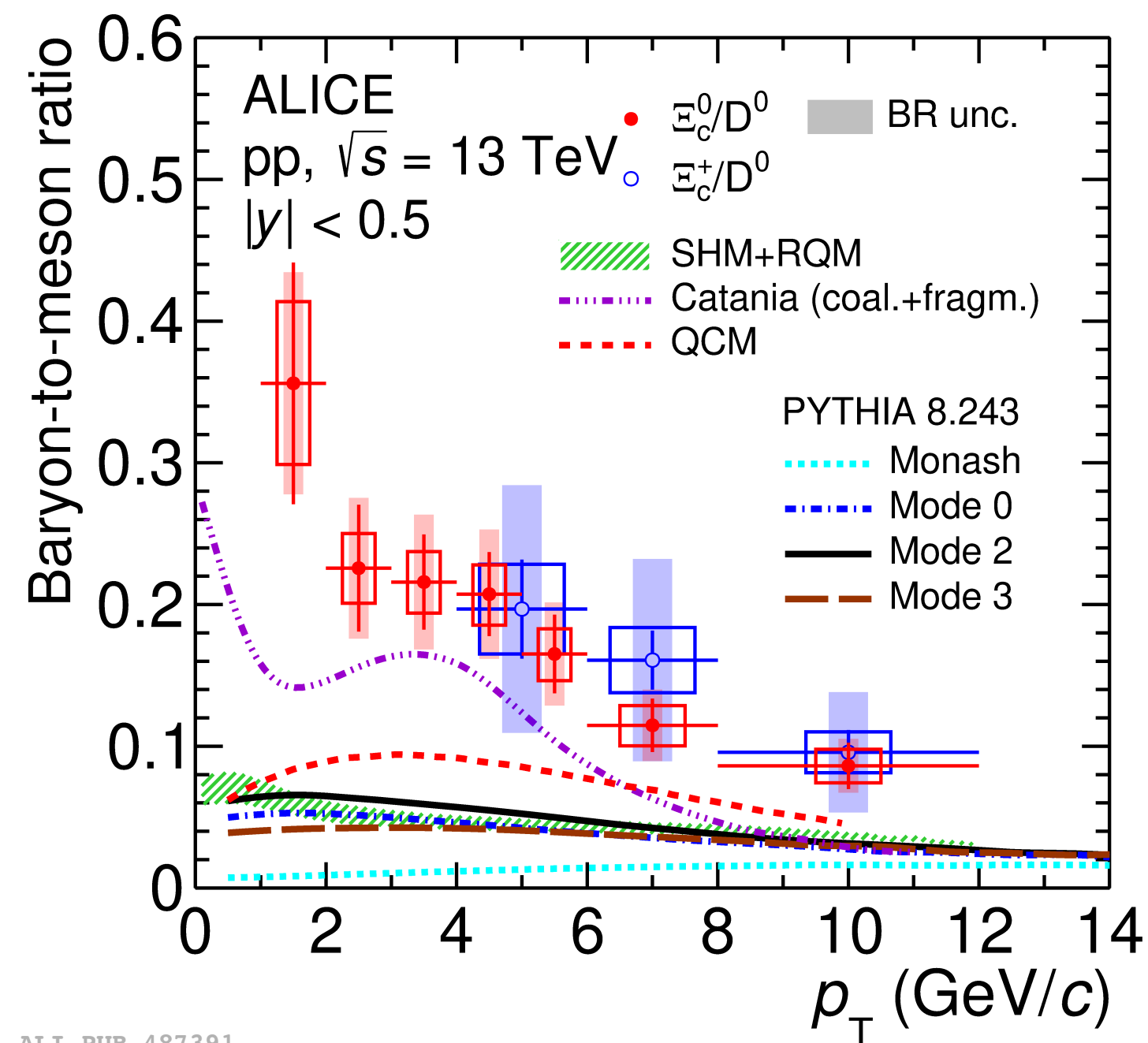


$\Sigma_c^{0,++}/D^0$



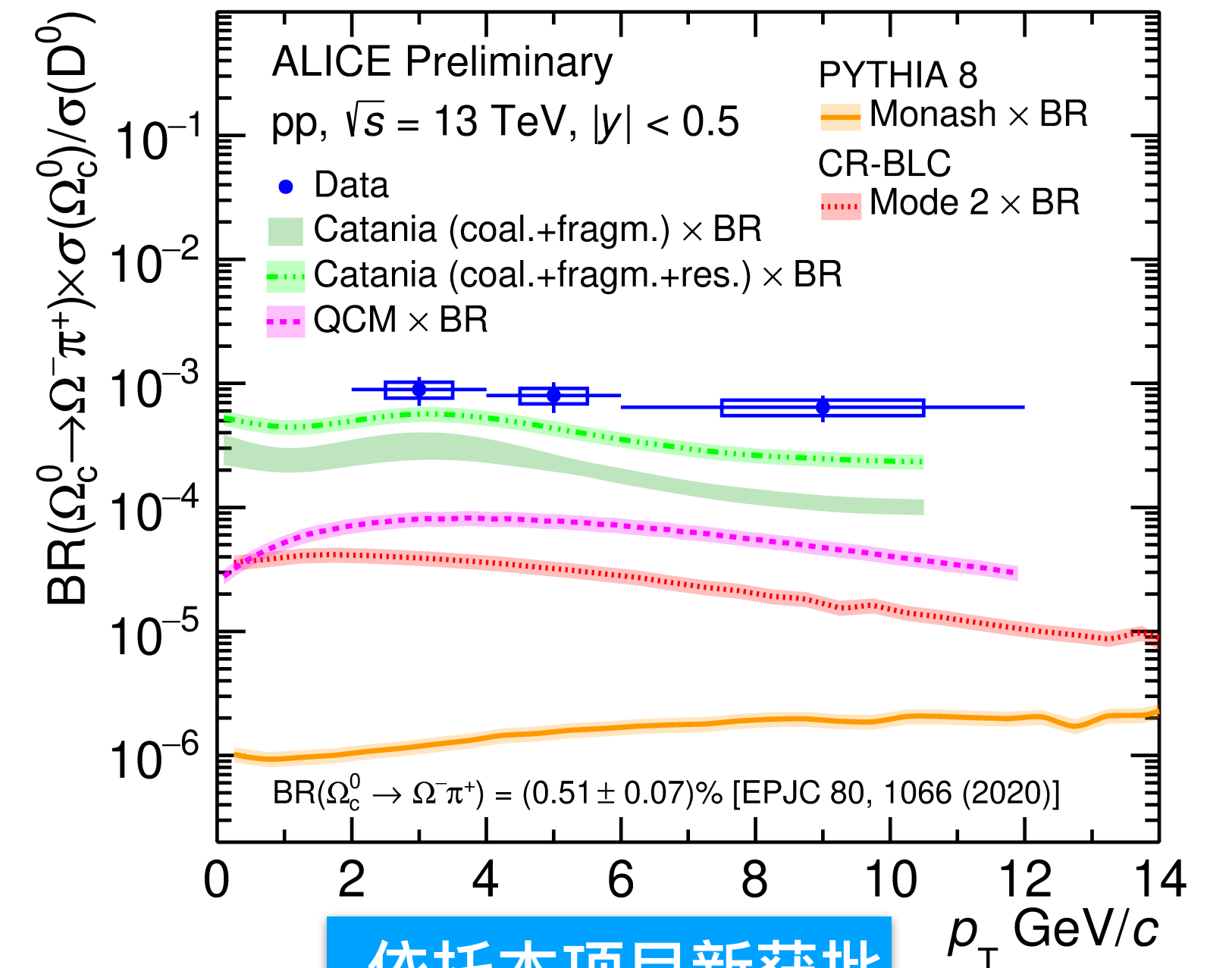
ALI-DER-493901

$\Xi_c^0/D^0$   $\Xi_c^+/D^0$



ALI-PUB-487391

$\Omega_c^0/D^0$



ALI-PREL-486632

依托本项目新获批  
preliminary results

- PYTHIA with color-reconnection underestimates data
- Catania model gets closer to data in all cases
- ➔ Coalescence also in pp collisions (?)

ALICE arXiv:2106.08278  
 arXiv:2105.05178  
 arXiv:2105.05616  
 arXiv:2011.06078

# 重夸克碎裂函数研究

## The assumption that charm-to-hadron fragmentation is universal is not valid



The large data samples collected during Run 2 of the LHC at  $\sqrt{s} = 5.02$  TeV allowed the ALICE collaboration measure the vast majority of charm quarks produced in the pp collisions by reconstructing the decays of the ground-state charm hadrons, measuring all the charm-meson species and the most abundant charm baryons ( $\Lambda_c^+$ , and  $\Xi_c^{0,+}$ ) down to very low transverse momenta. The result was presented [today](#) at the European Physical Society conference on high-energy physics (EPS-HEP 2021).

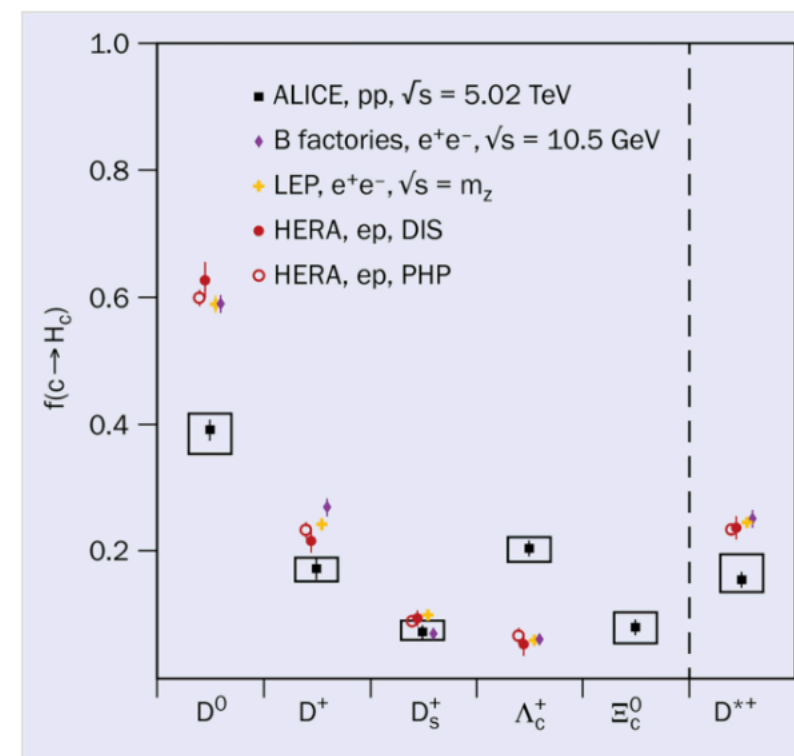


Fig. 1. Charm-quark fragmentation fractions into charm hadrons measured in pp collisions at  $\sqrt{s} = 5.02$  TeV (black squares), in  $e^+e^-$  collisions (purple and yellow markers) and in ep collisions (closed and open red circles). The  $D^*$  meson is depicted separately since its contribution is also included in the ground-state charm mesons.

Charm fragmentation fractions,  $f(c \rightarrow H_c)$ , represent the probability for a charm quark to hadronise into a given charm hadron. These have now been measured for the first time at the LHC in pp collisions at midrapidity, and, in the case of the  $\Xi_c^0$ , for the first time in any collision system (figure 1). The measured  $f(c \rightarrow H_c)$  are observed to be different from those measured in  $e^+e^-$  and ep collisions – evidence that the assumption that charm-to-hadron fragmentation is universal is not valid.

Charm quarks were found to hadronise into baryons almost 40% of the time – four times more often than at colliders with

CERN高能前沿通讯

arXiv:2105.05616 submitted to JHEP  
arXiv:2105.06335 submitted to PRL  
arXiv:2105.05187 submitted to PRL



# 质子-质子碰撞中底夸克的产生

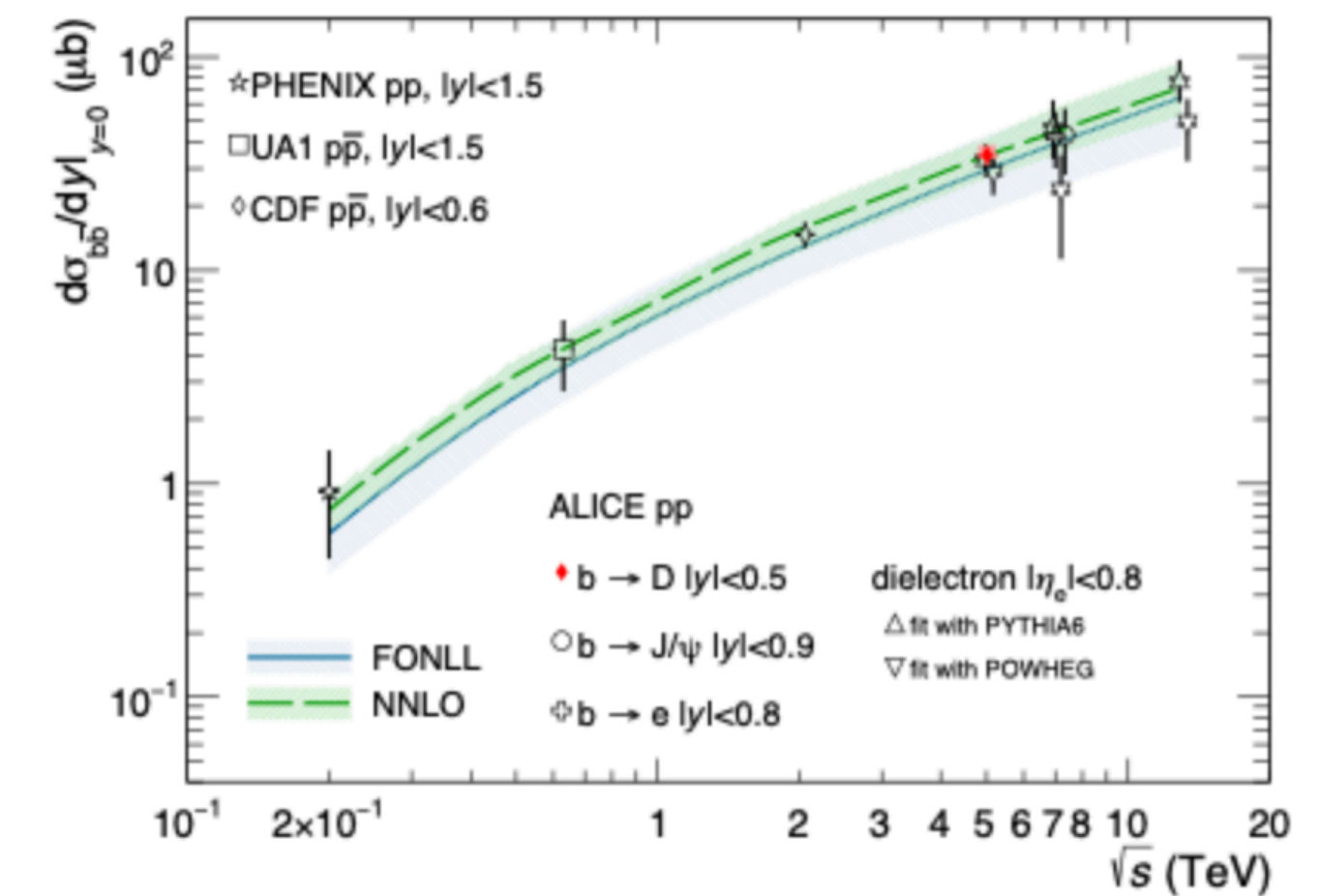
## Beauty frontier in pp: machine learning vs NNLO

Measurements of the production of hadrons containing charm or beauty quarks in proton-proton collisions provide an important test of Quantum Chromodynamics (QCD) calculations. They also set the reference for the respective measurements in heavy-ion collisions.

The excellent track and decay-vertex reconstruction capabilities of the ALICE experiment, together with machine-learning techniques for multi-class classification, were exploited to single out the signal of non-prompt D mesons (produced in beauty-hadron decays) from that of prompt D mesons (produced in the charm-quark fragmentation) and the combinatorial background. The production of non-prompt  $D^0$ ,  $D^+$ , and  $D_s^+$  mesons has been measured, as a function of the transverse momentum, at midrapidity in proton-proton collisions at  $\sqrt{s} = 5.02$  TeV. The estimated  $b\bar{b}$  production cross section per unit of rapidity is in good agreement with both calculations at next-to-leading-order with next-to-leading logarithm resummation (FONLL) and recent and more precise calculations including next-to-next-to-leading-order (NNLO) QCD radiative corrections.

### Further reading

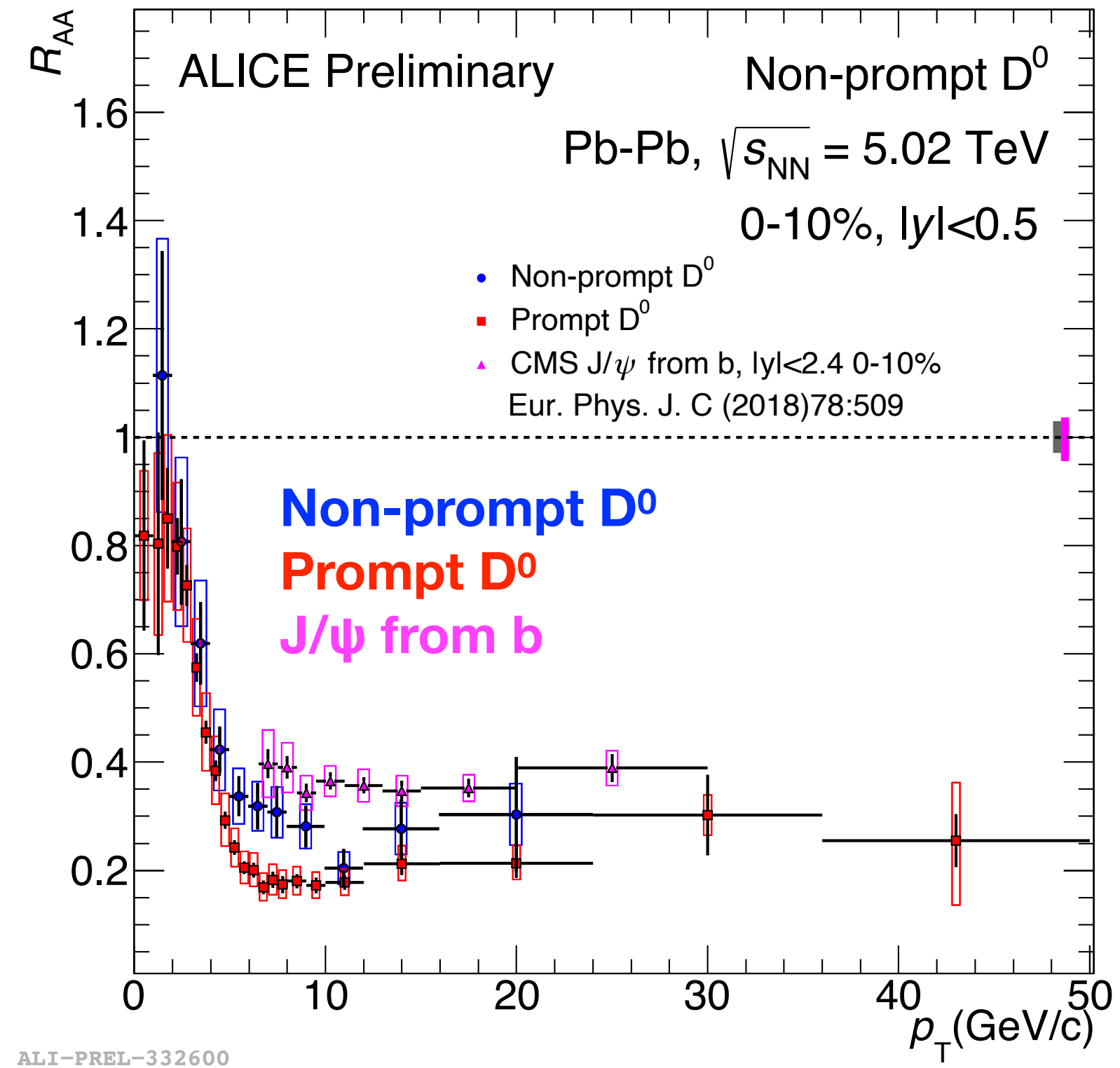
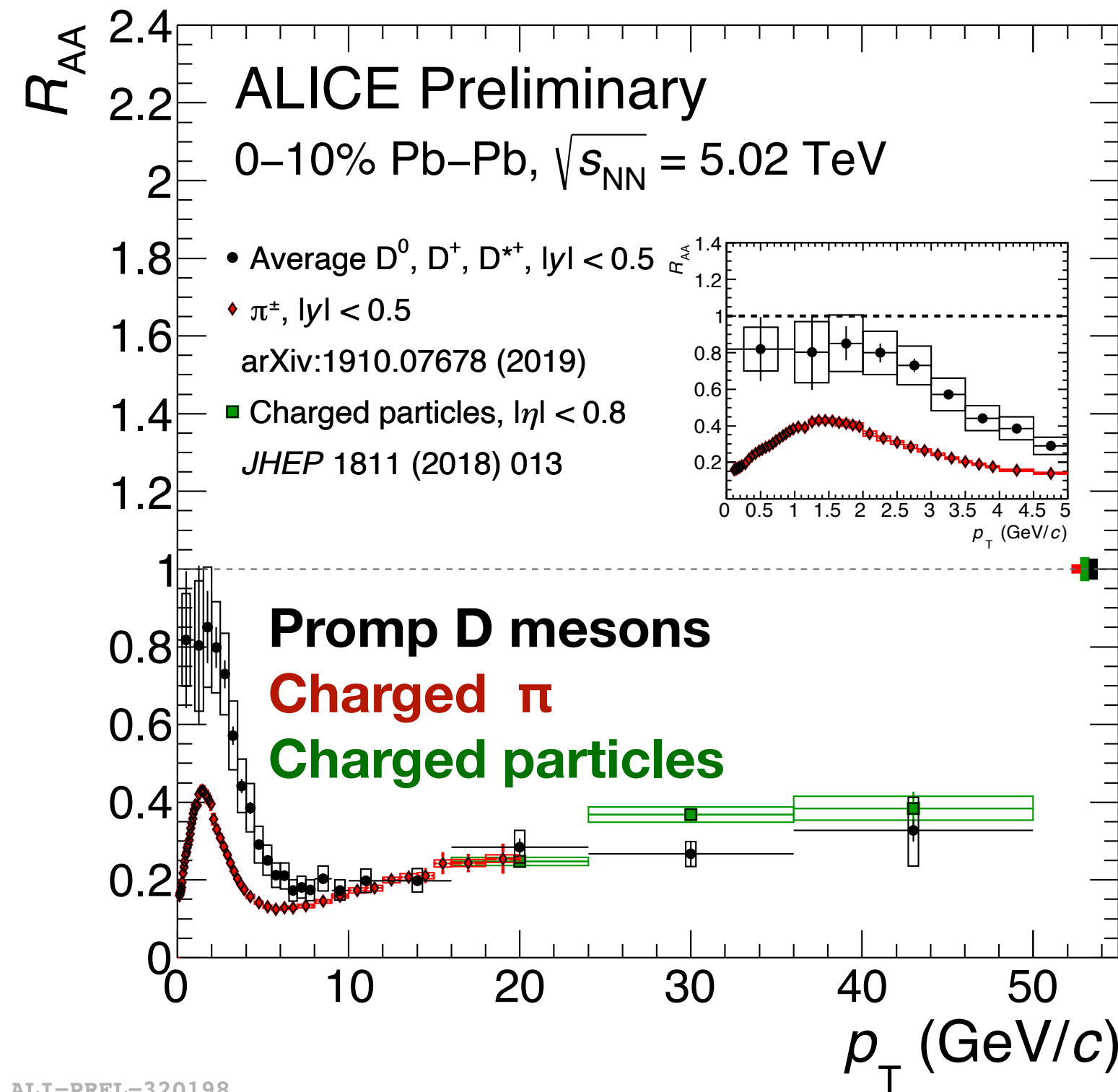
ALICE Collaboration 2021 <https://arxiv.org/abs/2102.13601>



ALICE首页亮点成果 质子-质子碰撞中的底夸克前沿

JHEP 2105 (2021) 220

# Color charge and mass dependence



- Low- and/or intermediate- $p_T$ : hint of  $R_{AA}$  hierarchy

$$R_{AA}(h^\pm) \approx R_{AA}(\pi^\pm) < R_{AA}(\text{prompt } D) < R_{AA}(\text{non-prompt } D) \approx R_{AA}(J/\psi \leftarrow b)$$

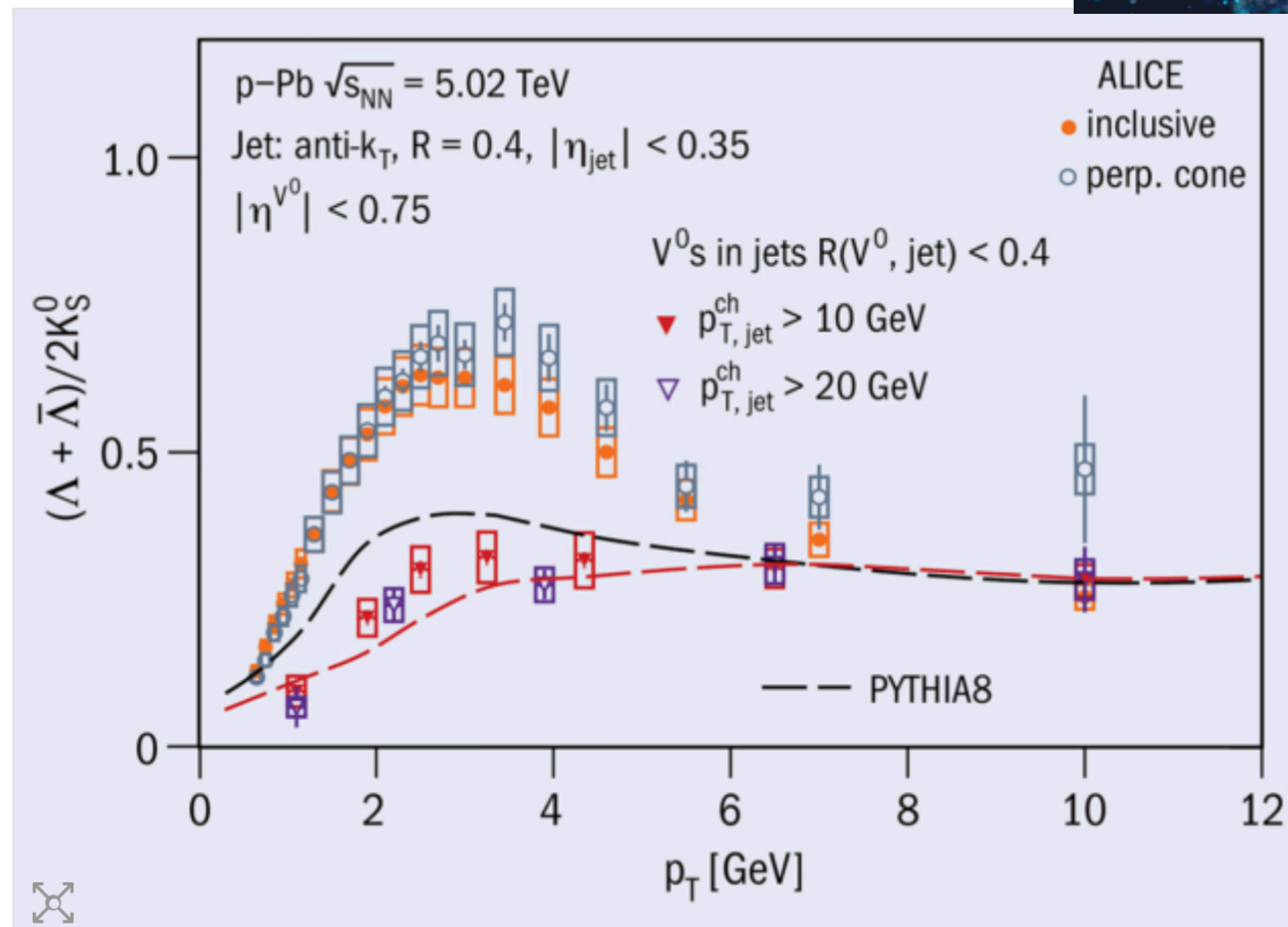
➔ Expected for color charge and mass dependence of energy loss

# 喷注内奇异强子的产生

STRONG INTERACTIONS | NEWS

## Hadron formation differs outside of jets

1 July 2021



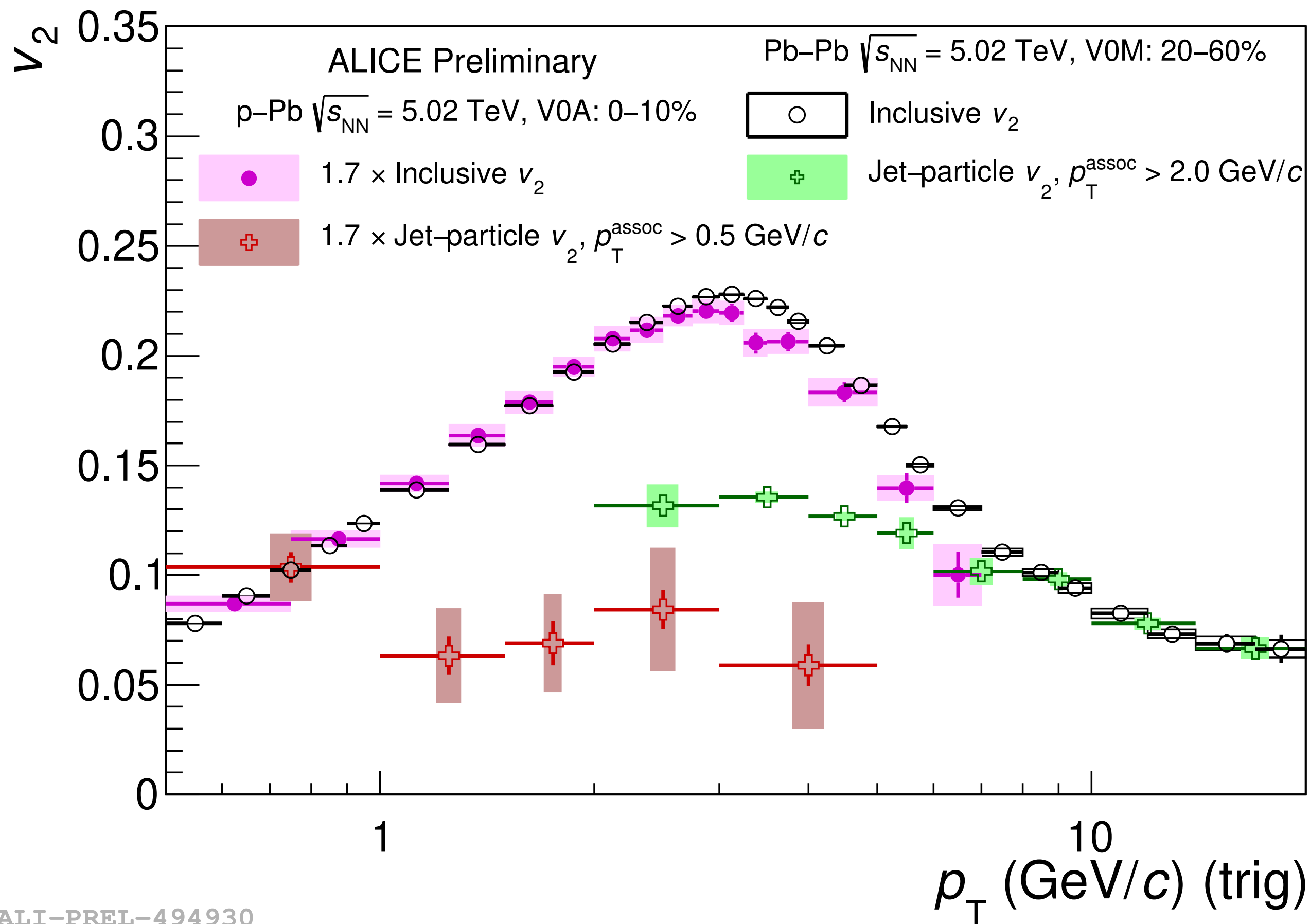
CERN高能前沿通讯

arXiv:2105.40890  
submitted to PLB

**Fig. 1.** The enhancement in the production of  $\Lambda$  baryons with respect to  $K_s^0$  mesons at intermediate transverse momenta (orange circles) is largely due to  $V^0$ -particle decays found outside charged-particle jets (open circles), and is not seen for the  $V^0$ -particle decays found inside them (red and open triangles). The dashed curves represent PYTHIA 8 simulations of pp collisions outside (black) and inside jets (red). Credit: CERN



# 喷注内强子的集体关联



- LHC能区对喷注内强子集体关联的首次测量
- 核-核碰撞与小系统碰撞中，喷注内强子均存在显著的集体关联
  - ➔ 小系统碰撞中是否存在喷注“淬火”？
  - ➔ 如何理解喷注内强子集体关联性的标度破坏？

Paper proposal approved in May 2021  
Target journal: Phys. Rev. Lett.

# 重夸克输运性质研究

STRONG INTERACTIONS | NEWS

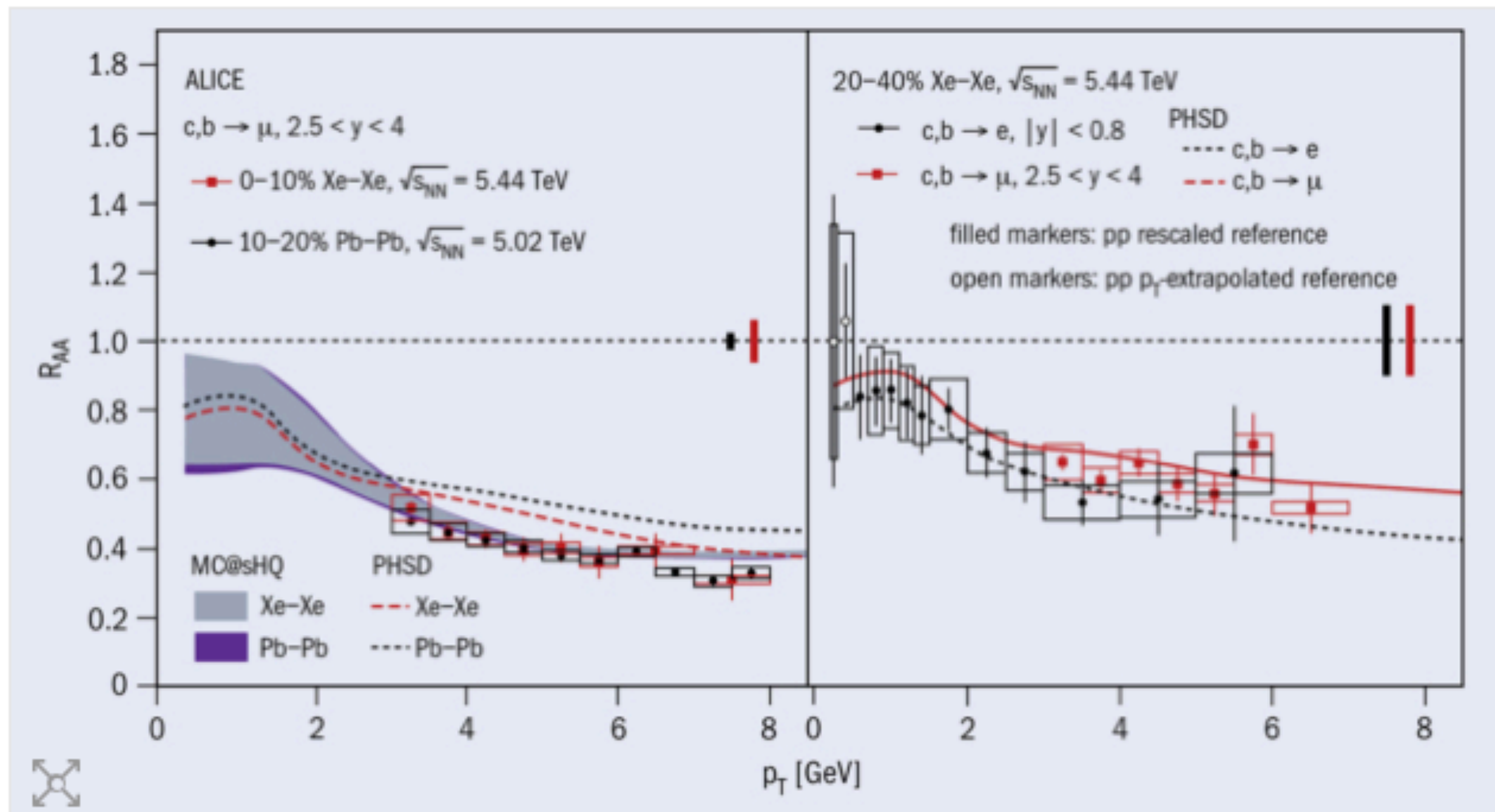
## Heavy flavours probe QGP geometry

22 January 2021



CERN高能前沿通讯

Phys. Lett. B819 (2021) 136637

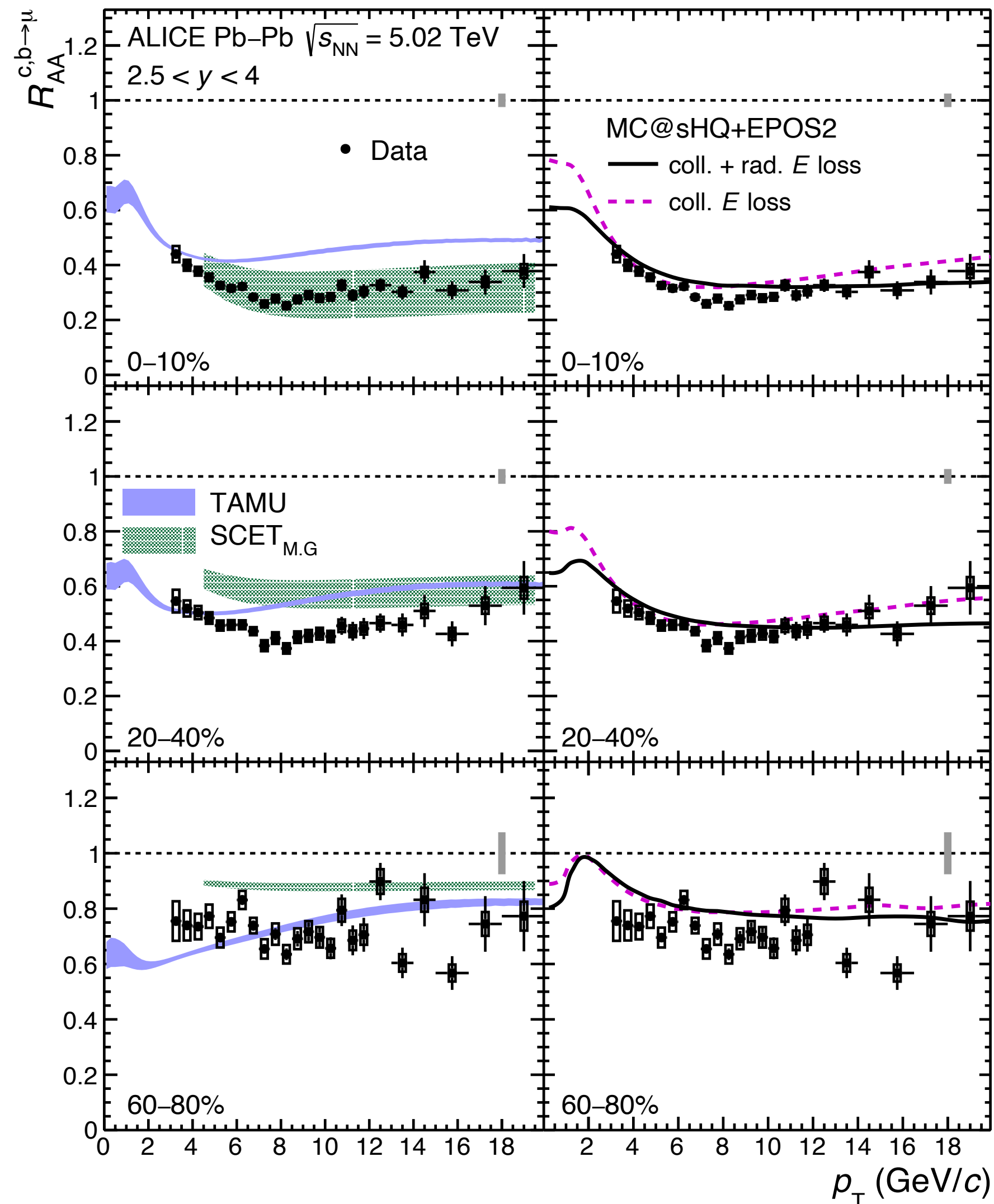


**Fig. 1.** Left: the  $p_T$ -differential  $R_{AA}$  of muons from heavy-flavour hadron decays at forward rapidity in Xe-Xe (centrality class 0-10%) and Pb-Pb (centrality class 10-20%) collisions. Right: the  $p_T$ -differential  $R_{AA}$  of muons and electrons from heavy-flavour hadron decays in semi-central (20-40%) Xe-Xe collisions. Comparisons with transport-model calculations are displayed. Credit: CERN

对重夸克能量损失量子  
“记忆”性的首次直接观测



# 前向快速重夸克能量损失



- ALICE LHC第二期运行中对前向快速区重夸克衰变渺子核压低的**首次观测**
- $p_T > 6 \text{ GeV}/c$  — 主要源于底夸克的贡献
- LHC能区对**底夸克在前向快速区能量损失的最精确实验观测之一**
- 对重夸克能量损失机制的重要实验限定

arXiv:2011.05718  
Accepted by *Phys. Lett. B*

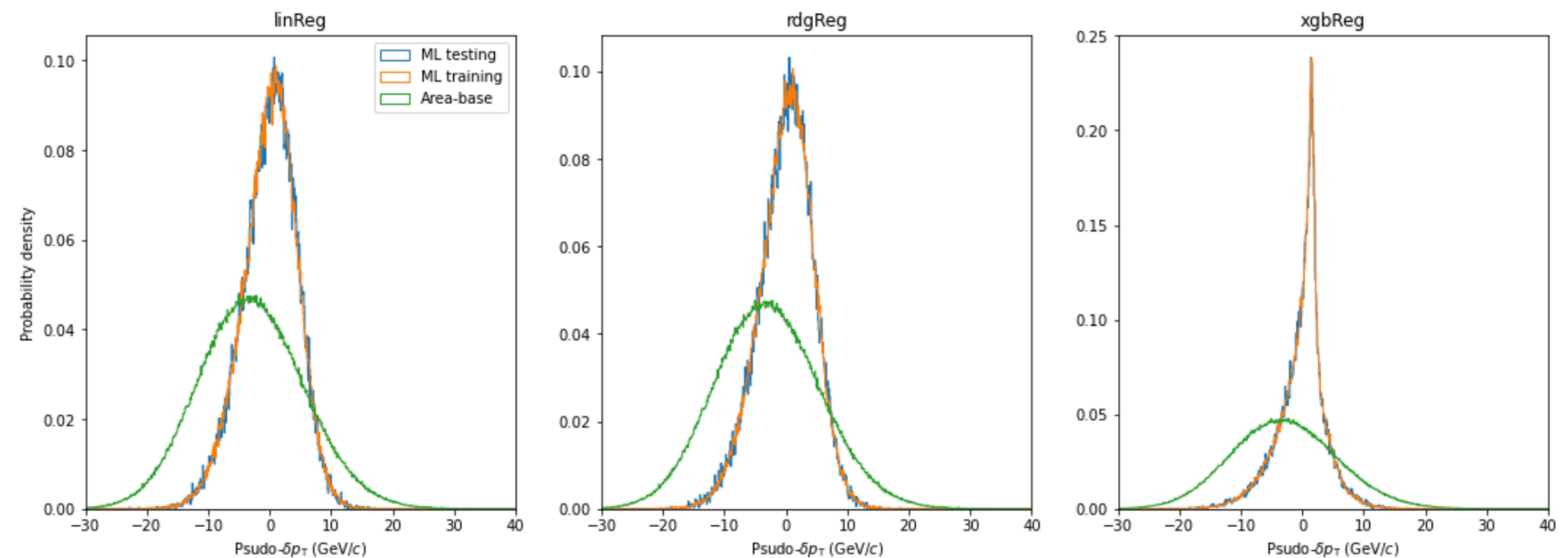
# 经费使用情况

## 经费投入

- 项目总经费：888万元（直接经费753.24万元）
- 已到位经费：709万元（直接经费601万元）
- 已支出经费：102.8万元
- 今年支出预算：约100万元

# 近期研究计划

- 参与ALICE LHC run 3 O<sup>2</sup>分析框架开发，参与今年（2021年）10月900 GeV 质子-质子碰撞数据获取及首次物理分析（预期投入3-4人）
- 开展明年（2022年）所获取的14 TeV质子-质子碰撞及5.5 TeV铅核-铅核碰撞数据中非瞬时D介子、非瞬时 $\Lambda_c$ 的产生研究，非瞬时D介子集体流研究；前向快度重味 $\mu$ 子的产生研究；拓展机器学习方法开展喷注结构、化学组份的精细研究



# 成果转化

- 拓展运用机器学习方法，在重离子碰撞的高本底条件下，实现稀有探针信号的高精度提取
- 推广运用Kalman-Filter实现对强衰变顶点的约束，及其对应稀有重夸克信号的有效重建
- 参与构建ALICE LHC run 3 O<sup>2</sup>高性能数据处理与分析平台
- 参与ALICE 3探测器优化仿真，以及物理分析可行性研究