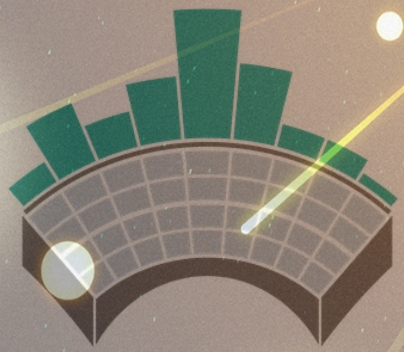
Recent Probes of *b*-quark Hadronization at LHCb

Julie Berkey, *jlnelson@lanl.gov*
on Behalf of the LHCb Collaboration



HP2024
NAGASAKI

September 23-27, 2024

Los Alamos NATIONAL LABORATORY

LHCb

NNSA

Heavy Quark Production

- Valence quarks of colliding beams don’t contain heavy quarks
- Production is dominated by hard parton-parton interactions during initial stages of the collision
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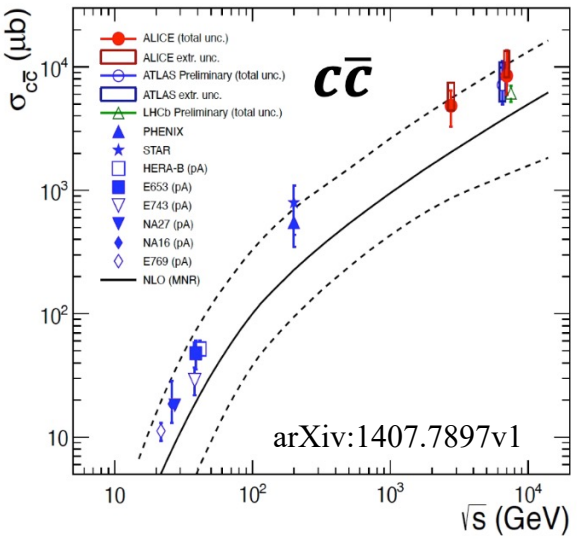

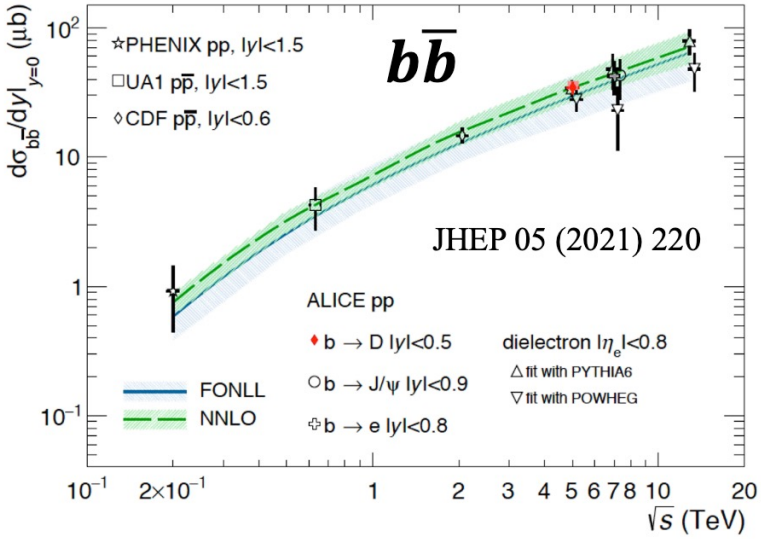

Parton-parton cross-sections – calculable by pQCD

The link between QCD and observable particles

- The defining feature of QCD is **confinement** :
  - Prohibits partons from being observed as free particles
  - Partons only found as constituents of color-neutral hadrons

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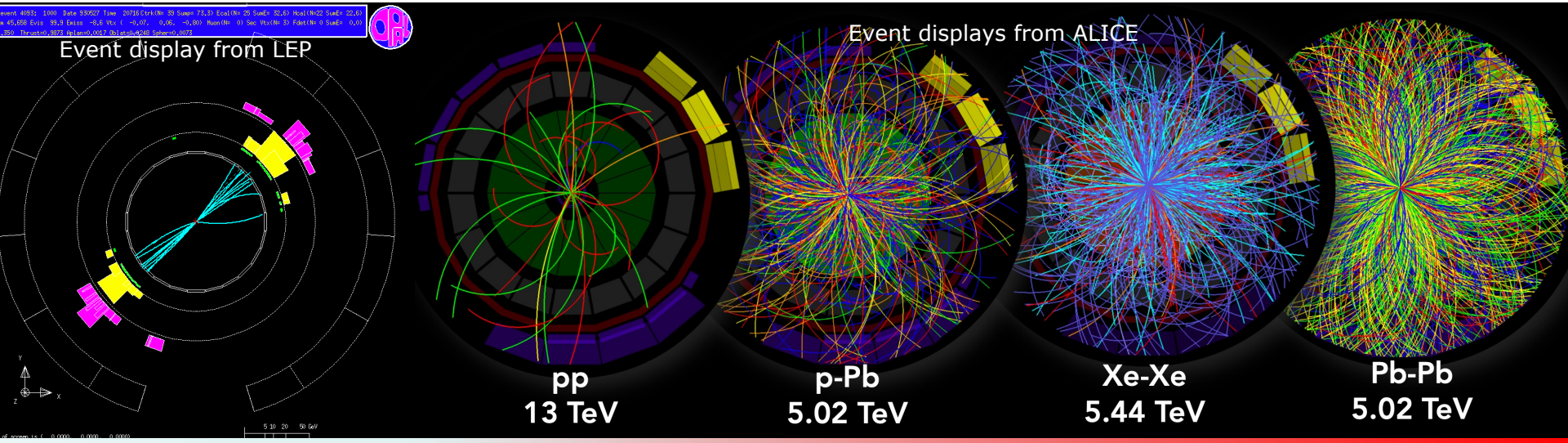

Vacuum (e^+e^-) Diffuse medium (*pp*,*p*A) → Dense medium (*p*A, AA)

Increasing T, $N_{charged}$

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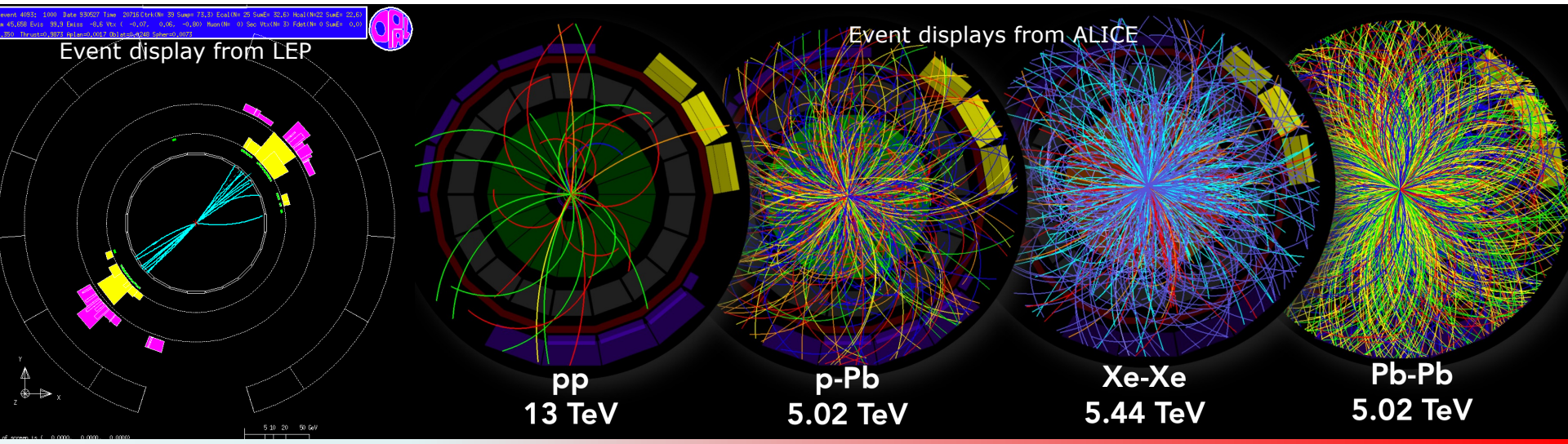

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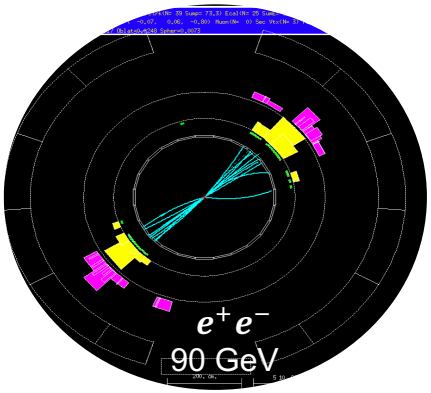
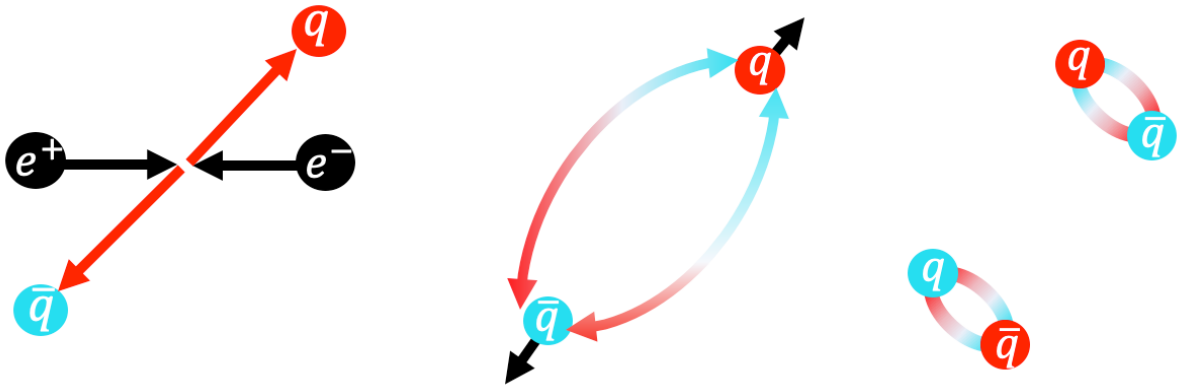
Increasing T, $N_{charged}$

Recent data challenges the notion that hadronization is universal across different collision systems

Hadronization Mechanisms - Fragmentation



Event display from LEP



$$V_0^{(c\bar{c})}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br$$

- Potential between quarks increases until it becomes more energetically favorable to produce quarks in vacuum to maintain color confinement
- Models tuned precisely to data from e^+e^- collisions

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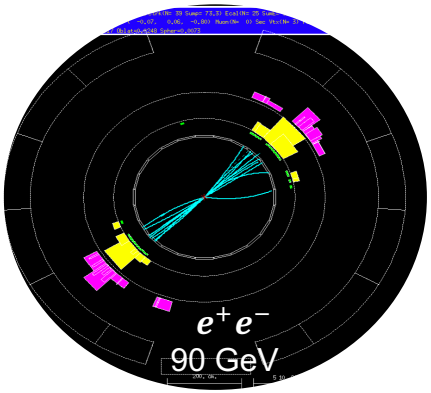

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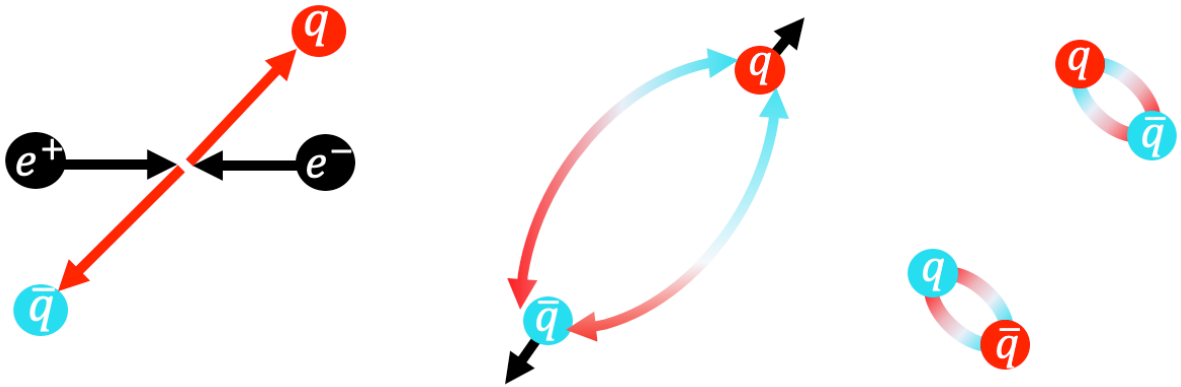

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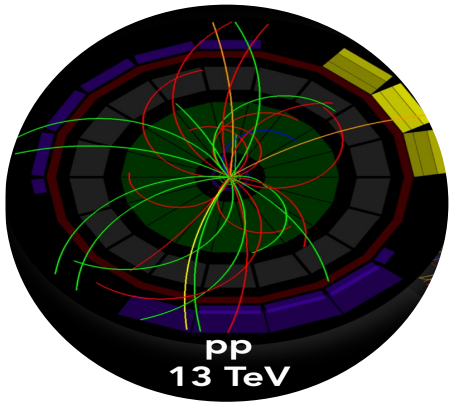
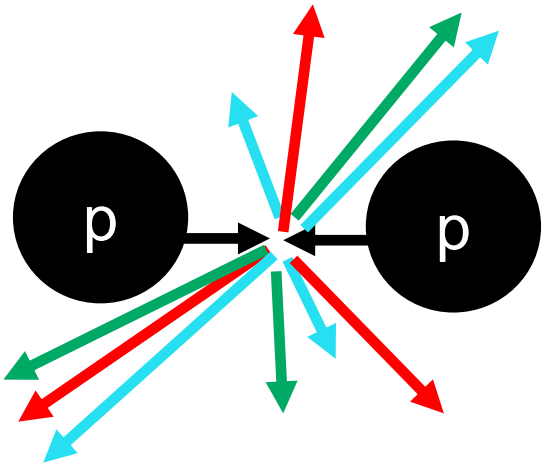
Models **FAIL** to describe particle production in *pp*, *p*A, and AA collisions

Hadronization Mechanisms – Quark Coalescence

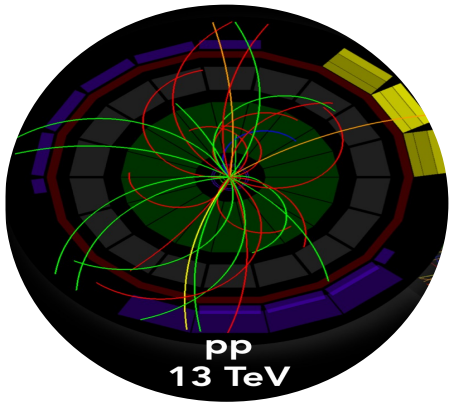


Event display from ALICE



- Quarks overlap in position/velocity space and form color neutral hadrons
- Expected to occur in particle-dense environments and at relatively low p_T

Hadronization Mechanisms – Quark Coalescence



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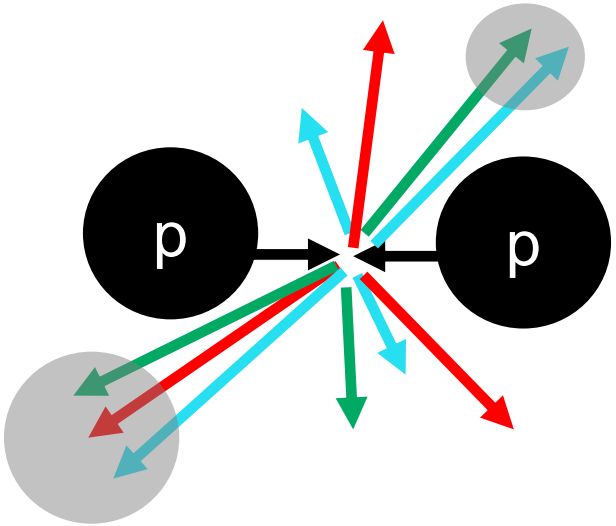

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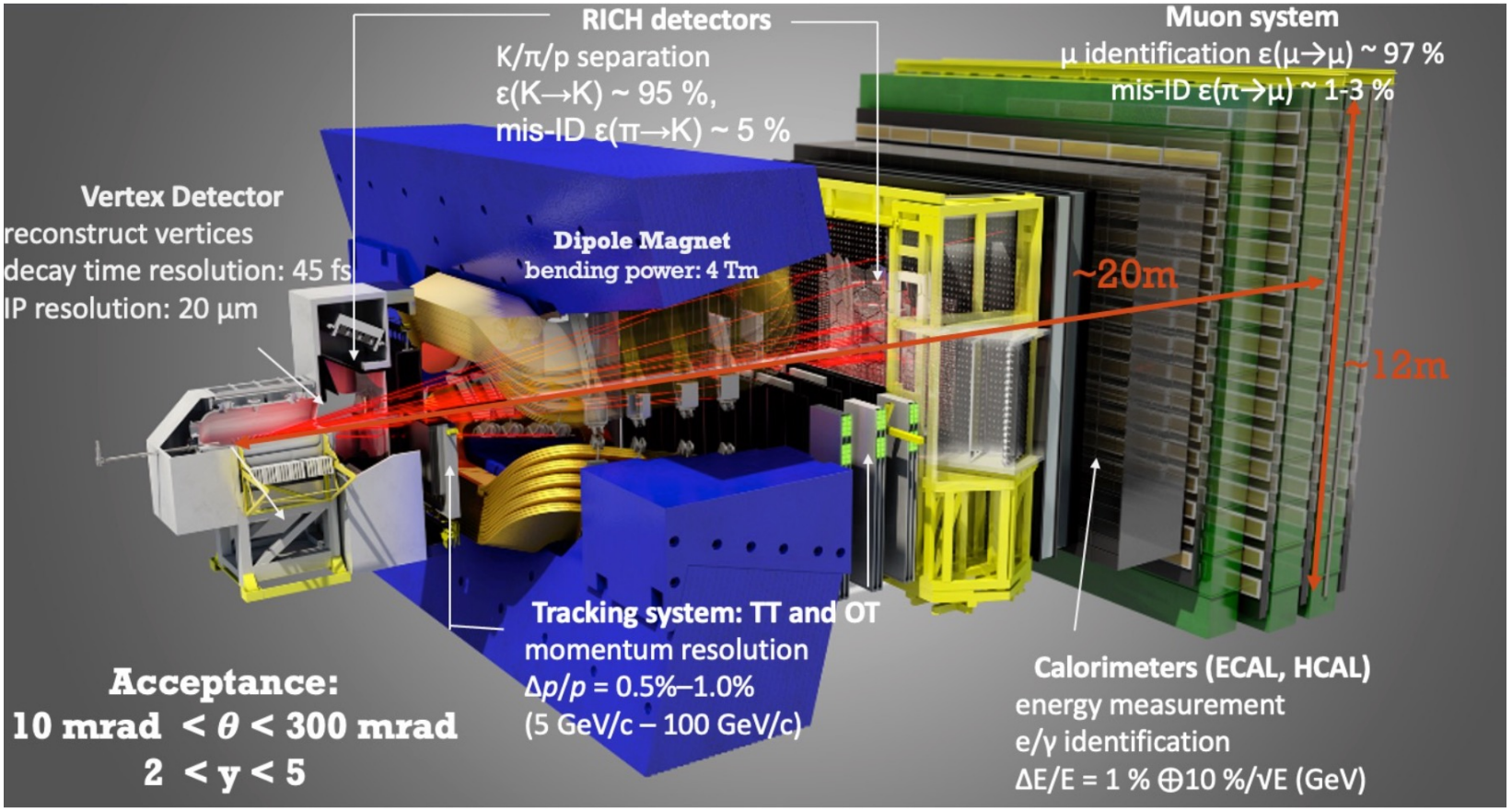
Enhanced production of hadrons with strange quarks and 3-quark baryons

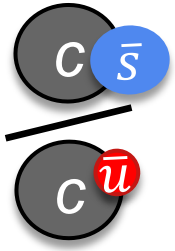
The Large Hadron Collider beauty (LHCb)

The LHCb Detector: Forward rapidity coverage, full tracking, particle identification, electromagnetic calorimetry, and muon ID

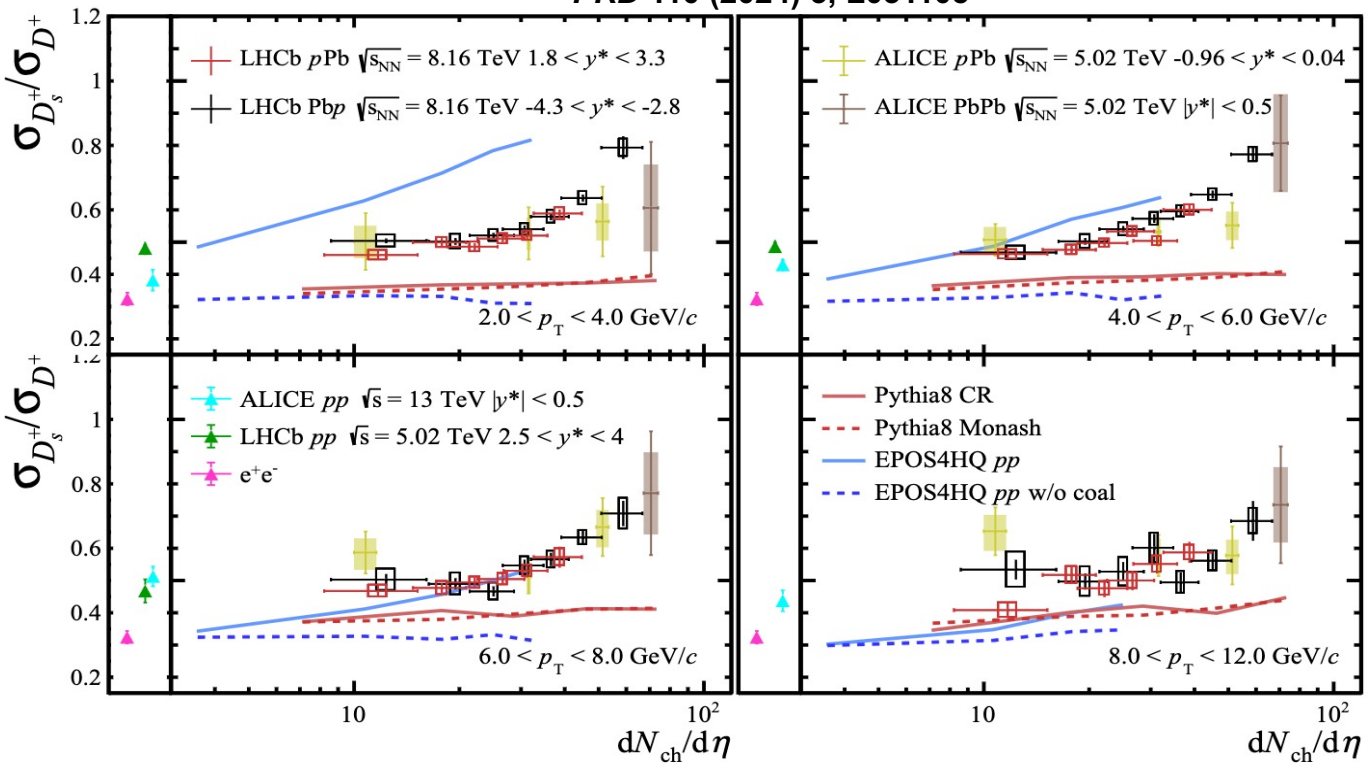


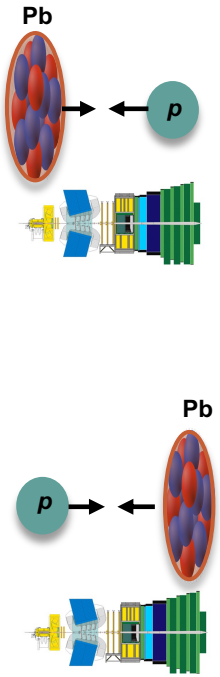
JINST 3 (2008) S08005
Int. J. Mod. Phys. A 30, 1530022 (2015)

Strangeness Probes into Hadronization

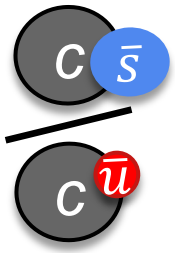


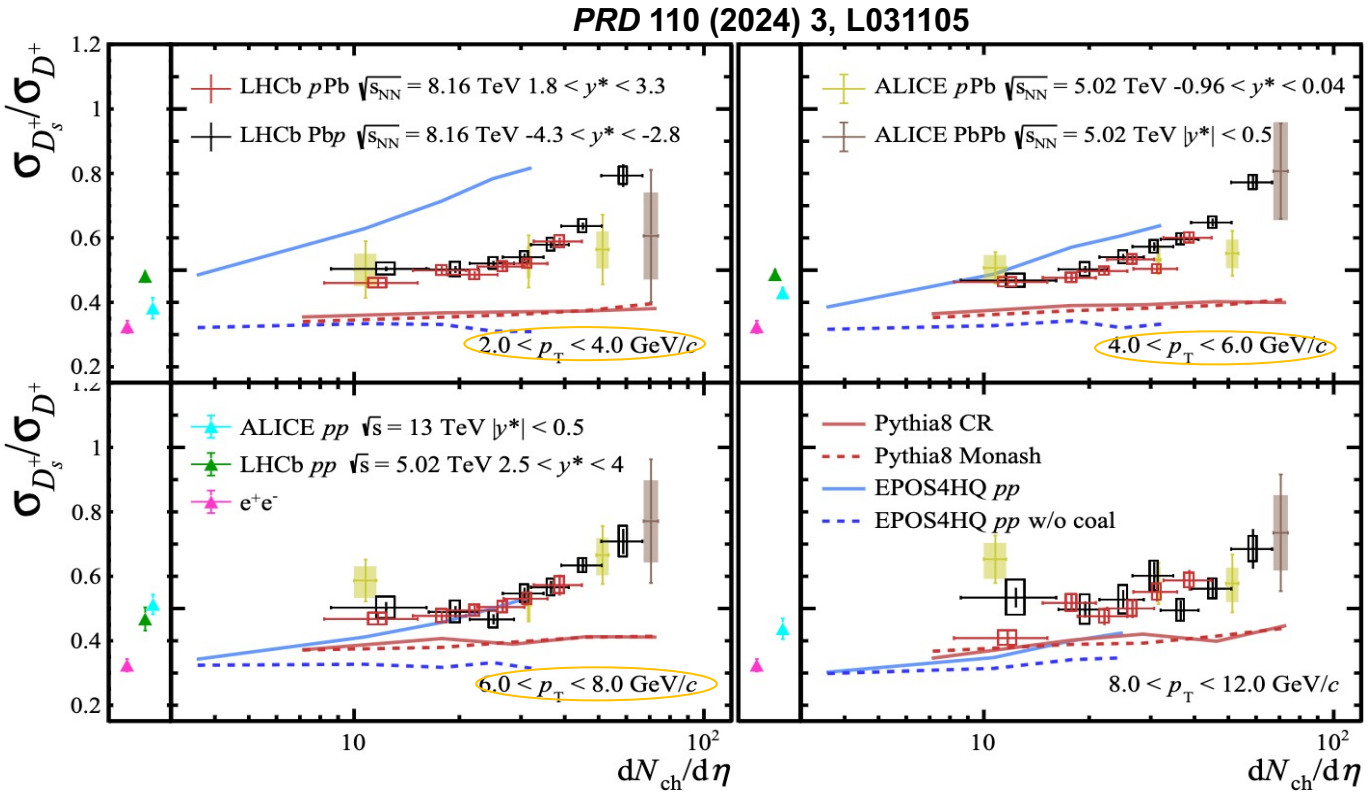
PRD 110 (2024) 3, L031105

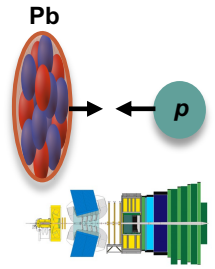


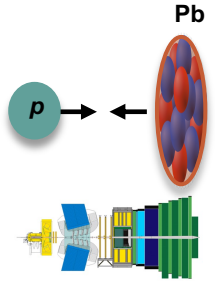


Strangeness Enhancement – Open Charm









- Enhanced D_s^+ yields at lower p_T as charged particle multiplicity increases

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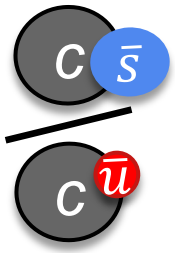
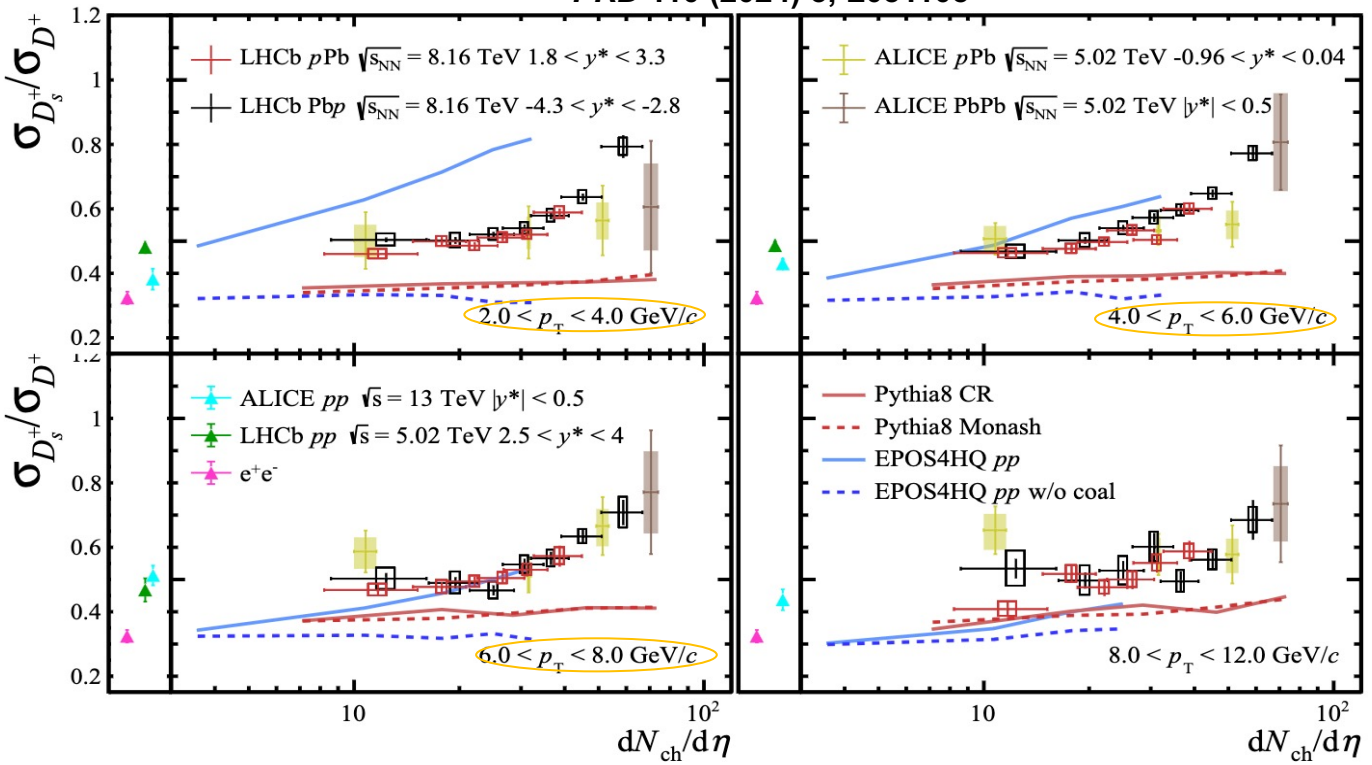
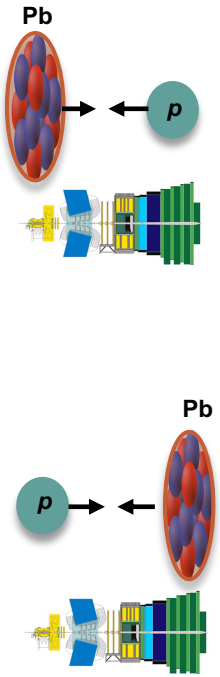


PRD 110 (2024) 3, L031105





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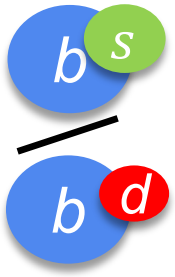
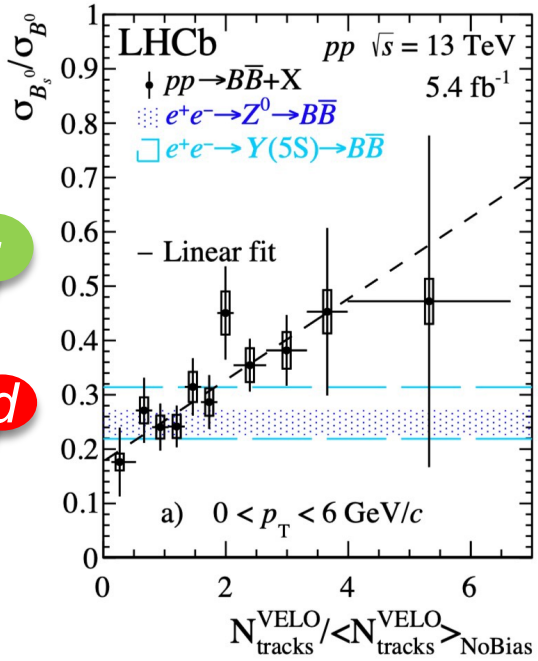
- Enhancement dominated by final state effects

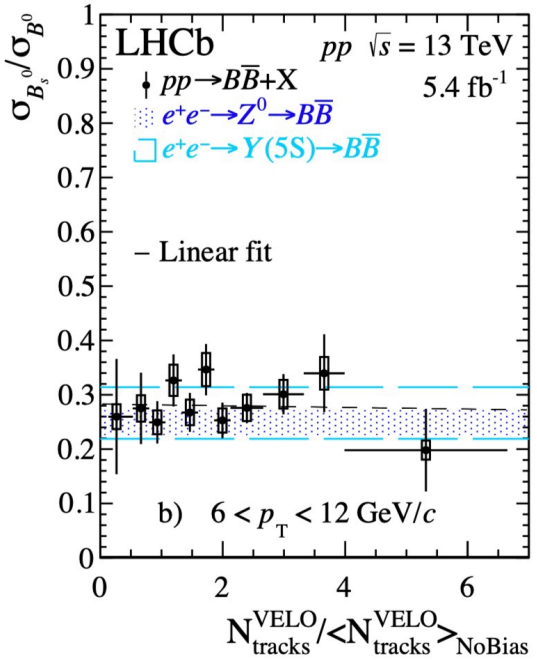
Yiheng Luo & Jianqiao Wang Posters

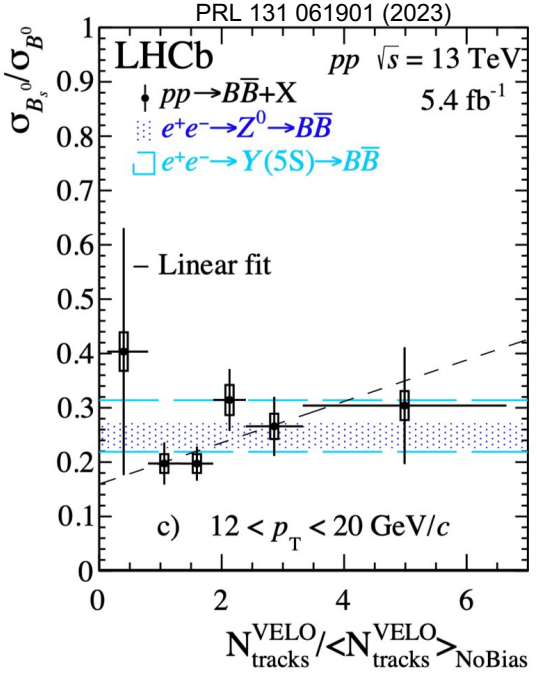
Strangeness Enhancement – Open bottom



PRL 131 061901 (2023)







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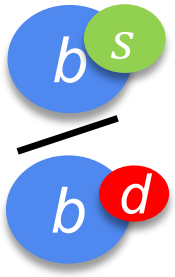

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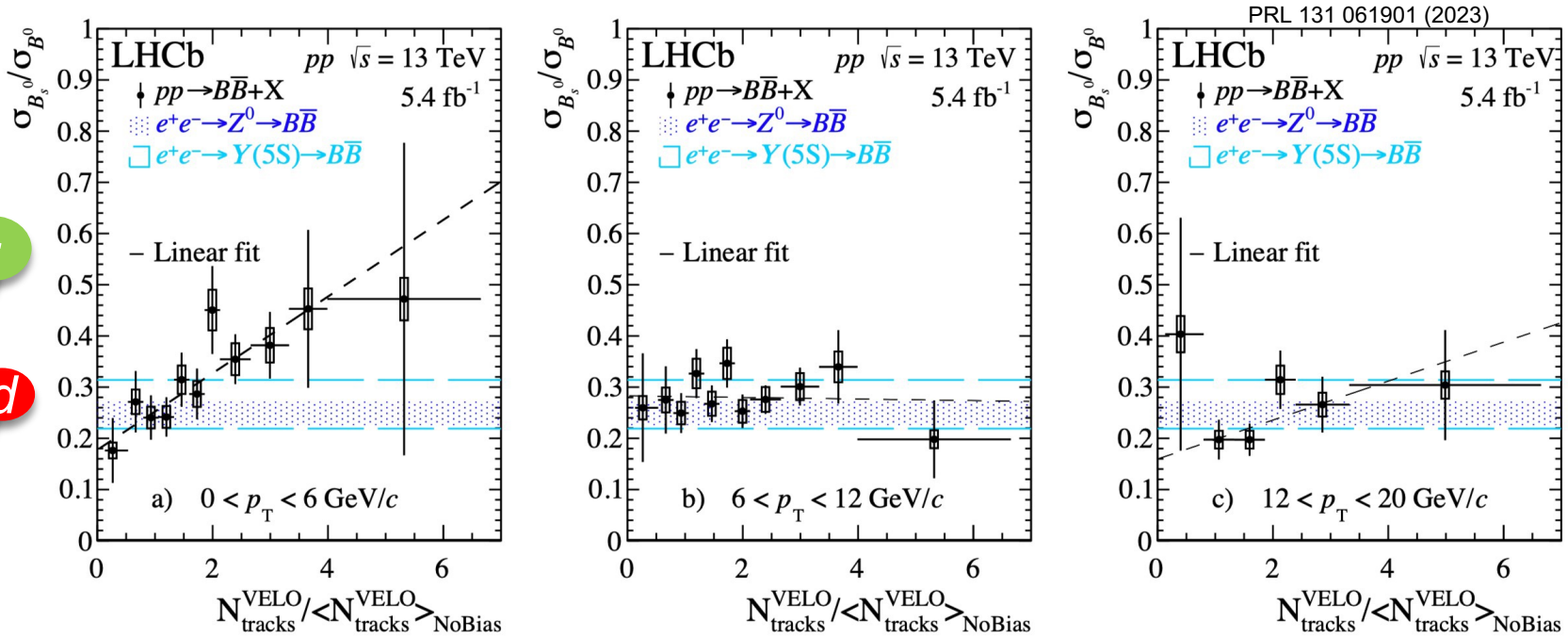

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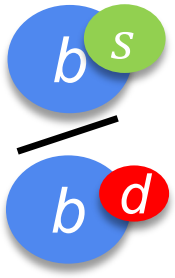

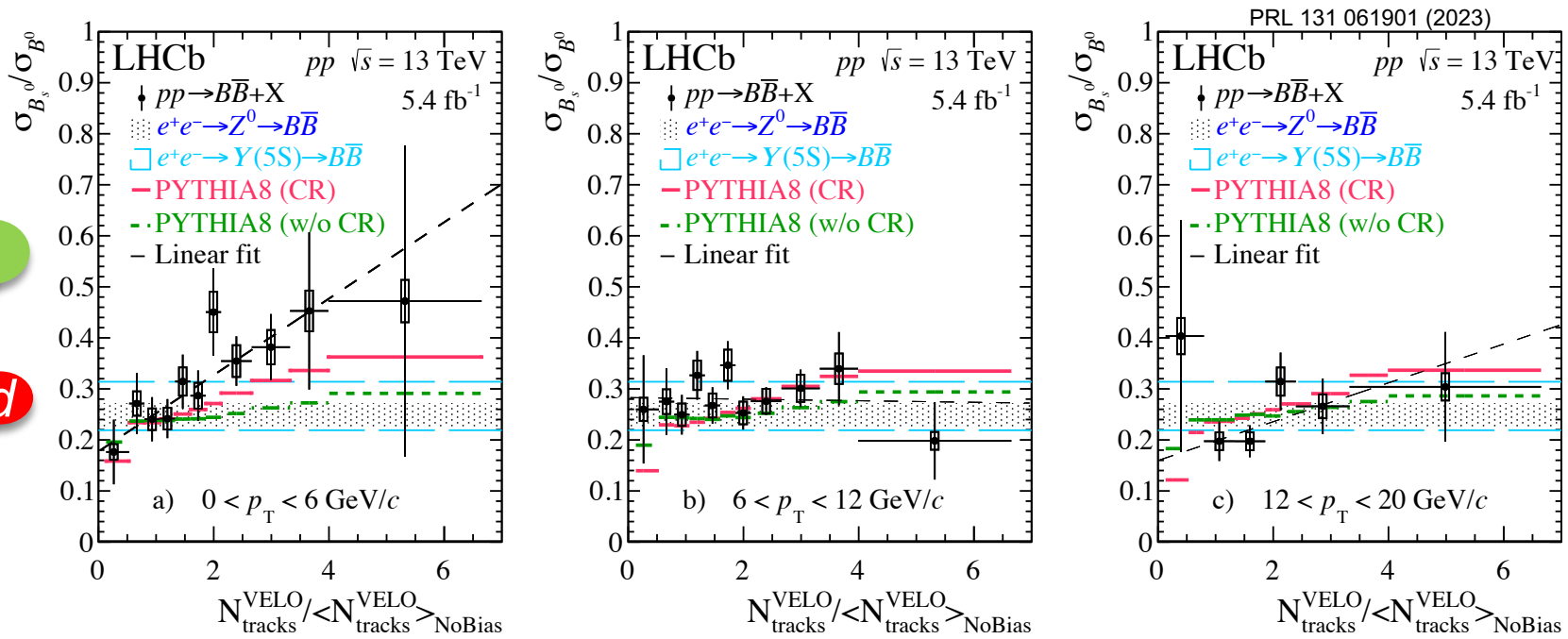

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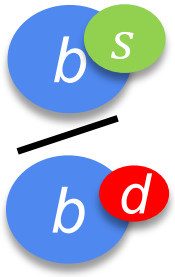

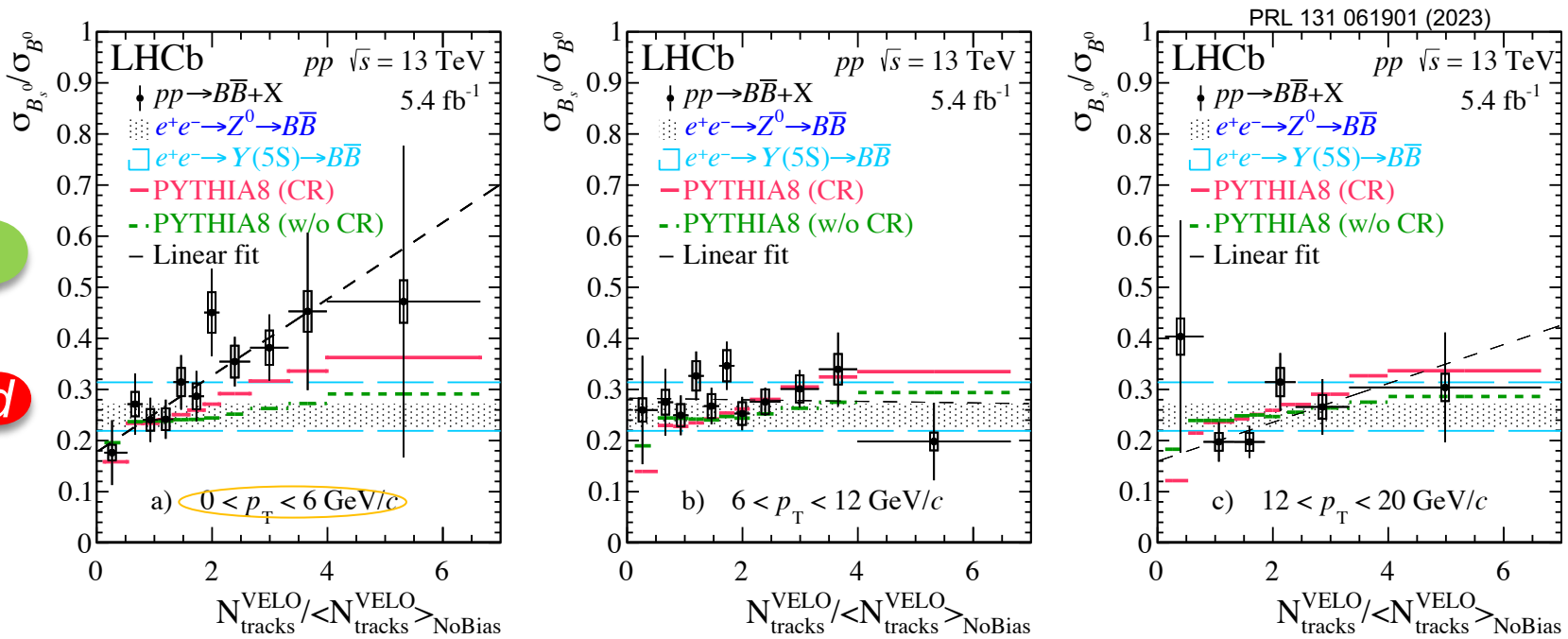

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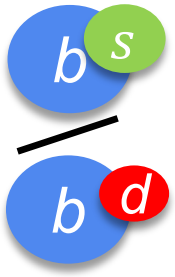
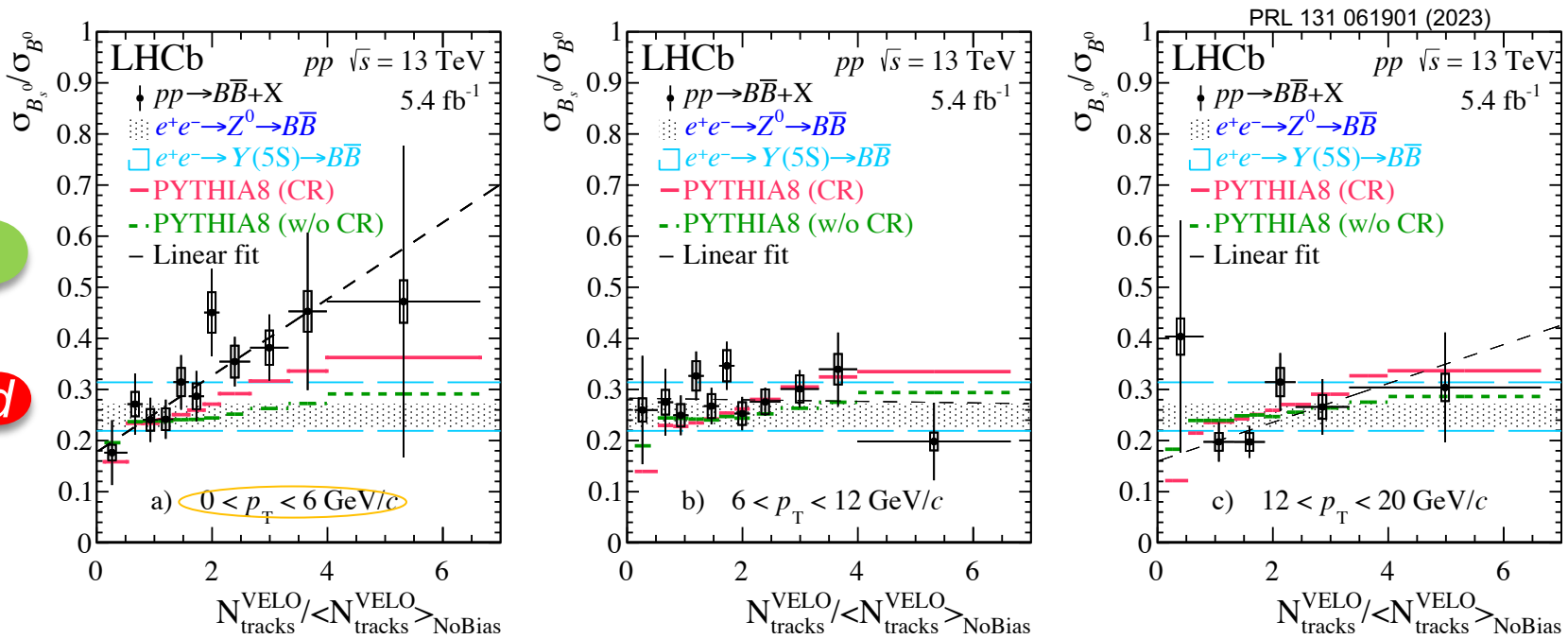
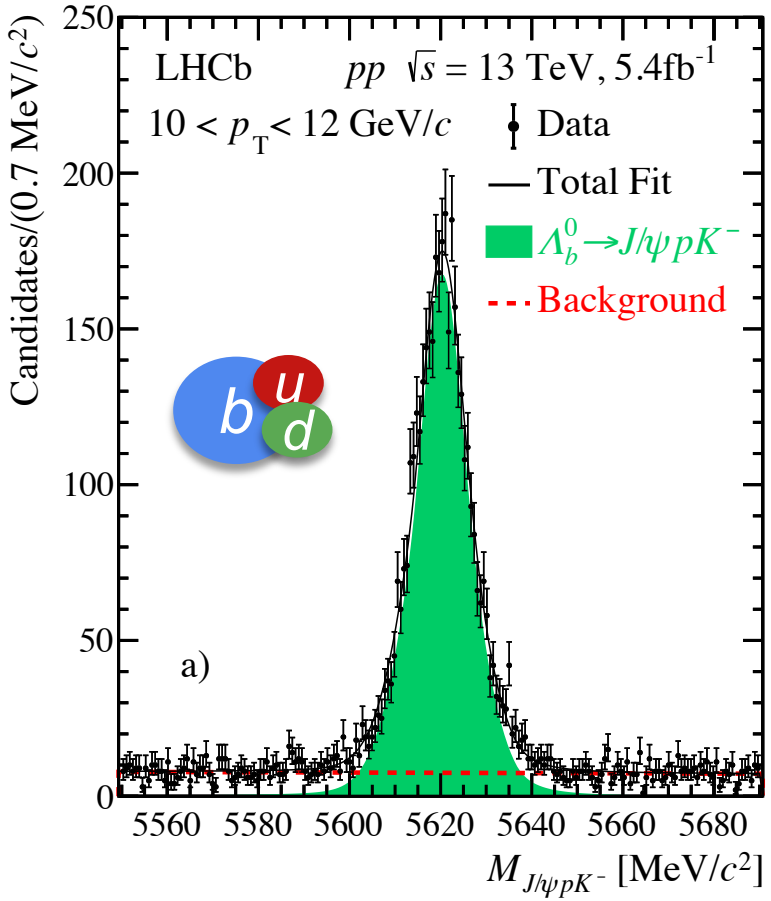


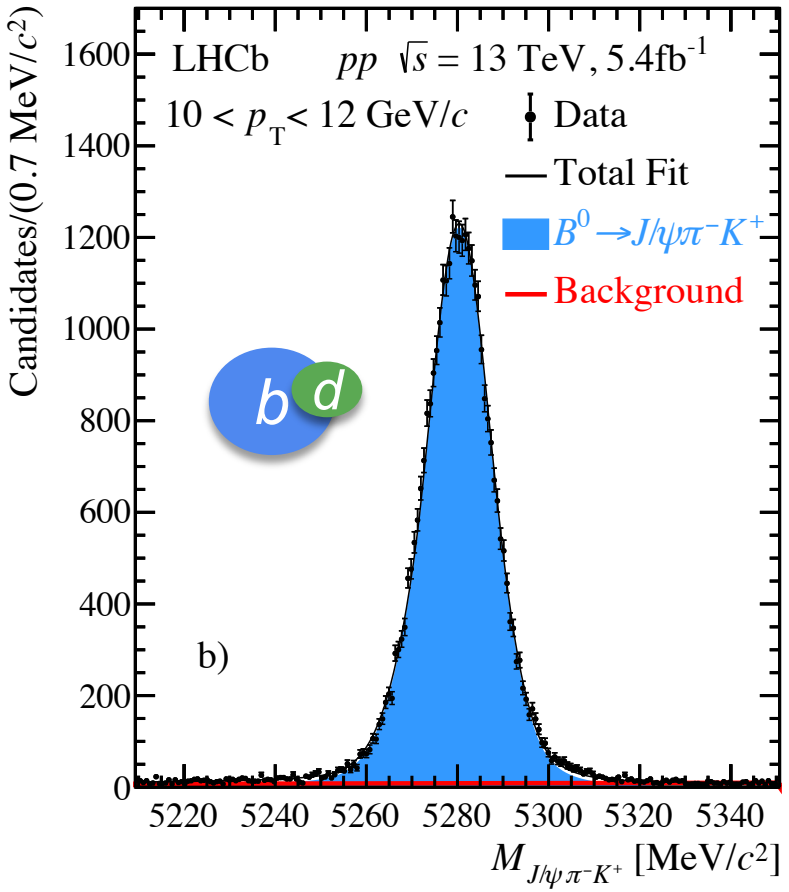


- Low multiplicity yields consistent with fragmentation values measured in e^+e^- collisions
- At low p_T there is evidence of enhanced B_s^0/B^0 yields
- Higher p_T B mesons show no enhancement

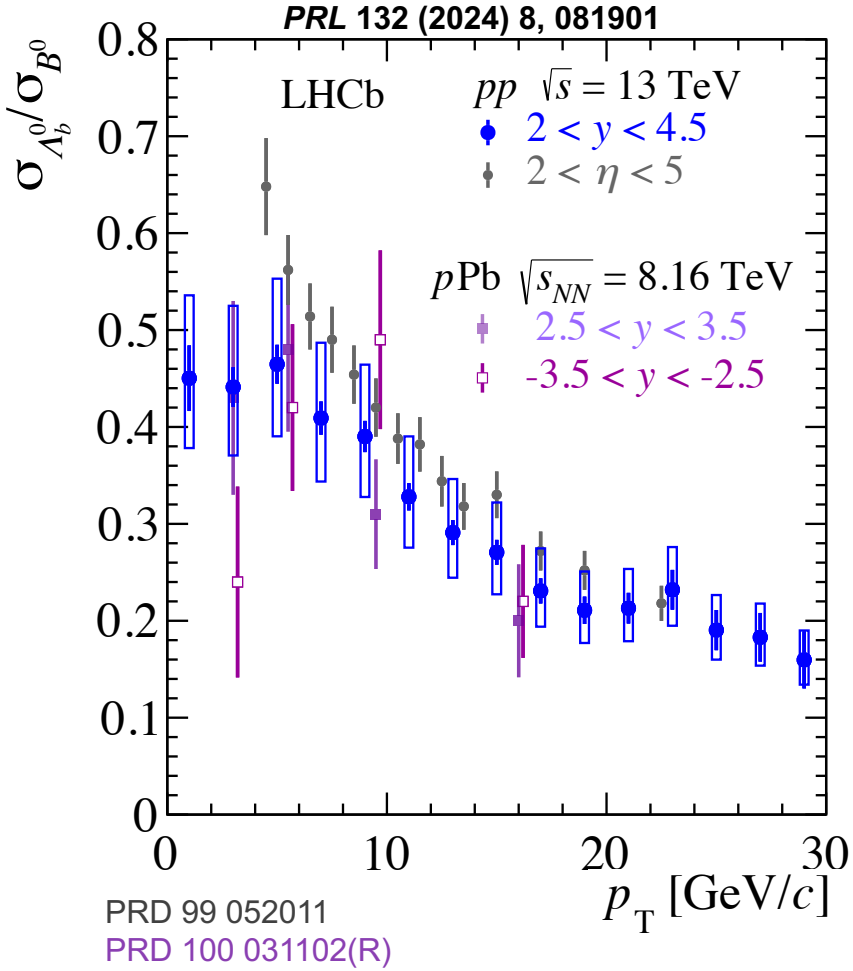
B-baryon Probes into Hadronization

***PRL* 132 (2024) 8, 081901**





B-baryon Enhancement vs pT



PRD 99 052011
PRD 100 031102(R)

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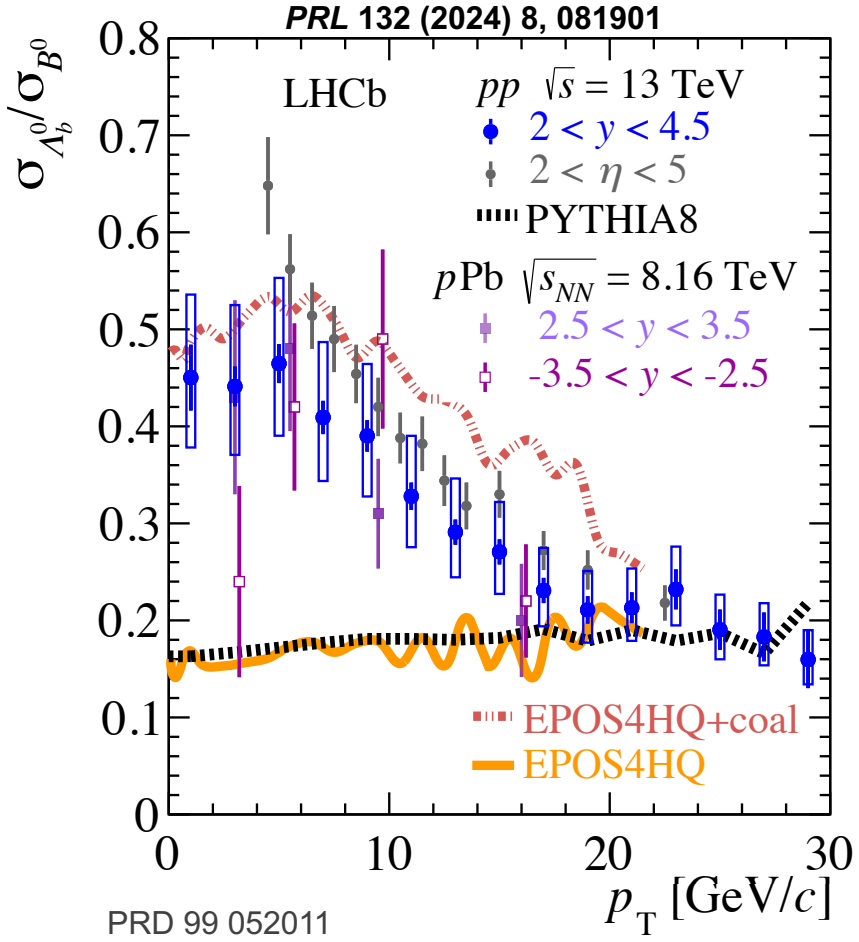

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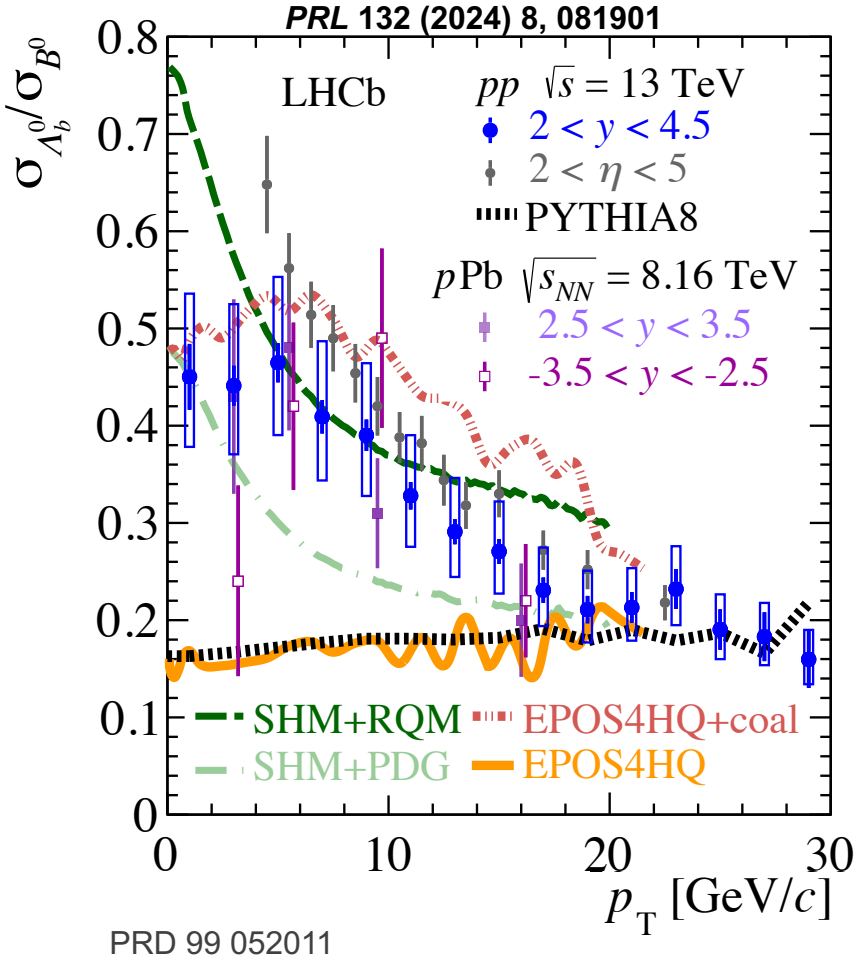

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- Compare to Statistical Hadronization Model that uses two sets of baryons as input:
  - Expanded set of baryons predicted by the Relativistic Quark Model
  - Known baryons from PDG

PRD 99 052011
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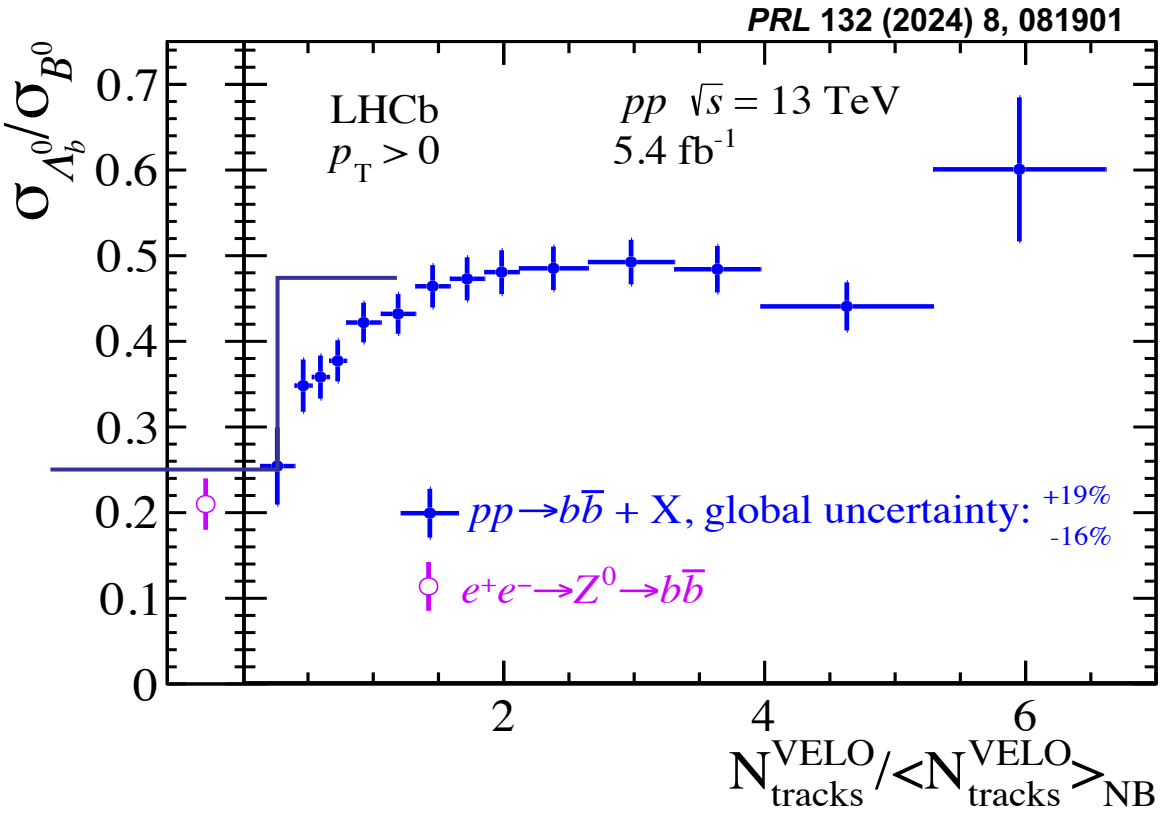
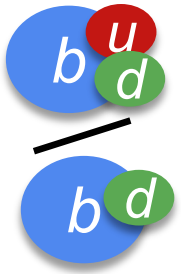
B-baryon Enhancement vs multiplicity

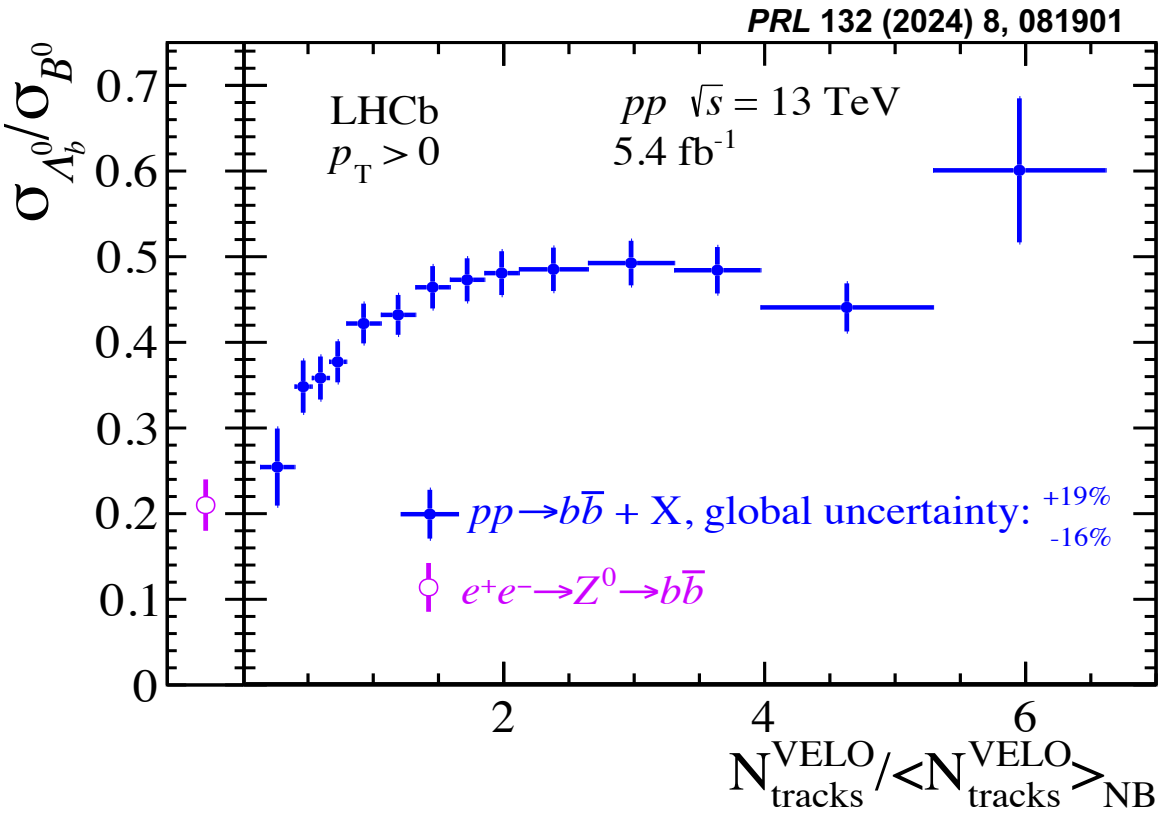
Increase by factor of ~2

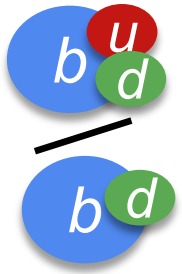




- Baryon/meson ratio shows multiplicity dependence

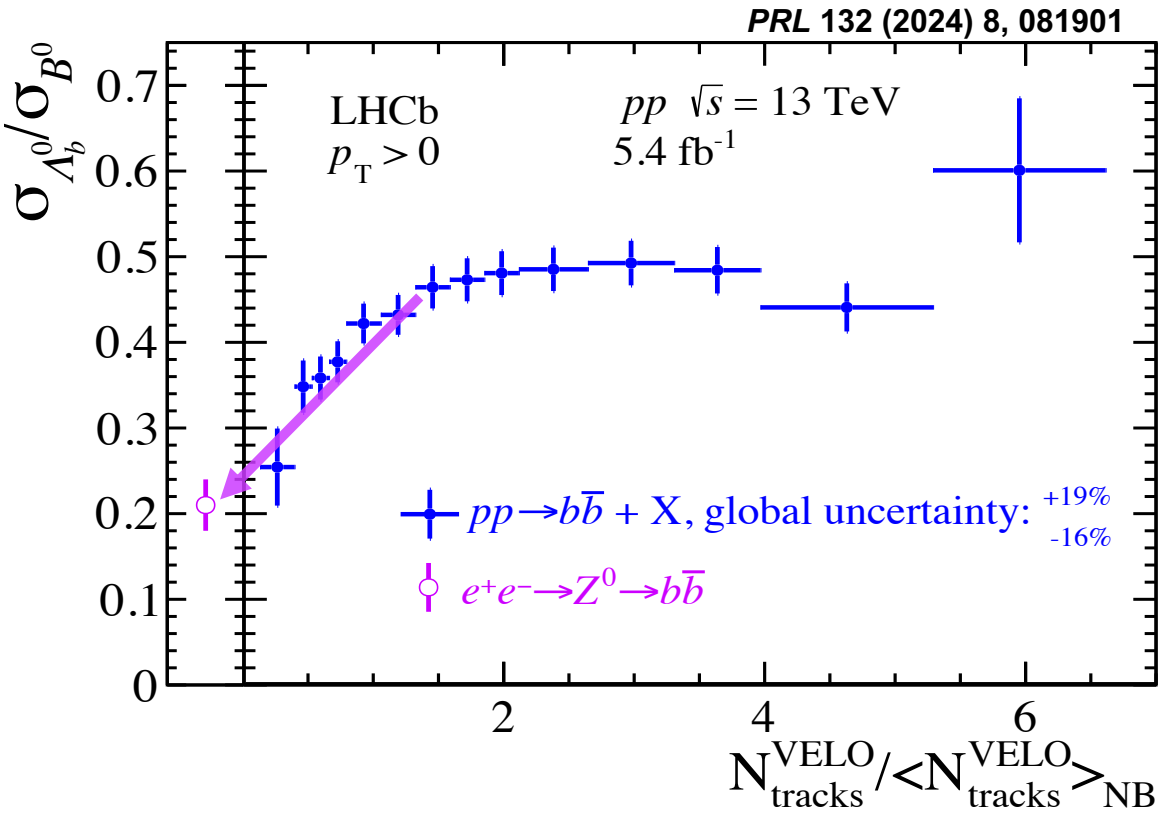
b-baryon Enhancement vs multiplicity

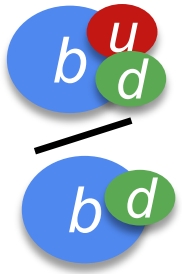




- Baryon/meson ratio shows multiplicity dependence
- Expected in scenario where b quarks coalesce with light quarks to form baryons

b-baryon Enhancement vs multiplicity

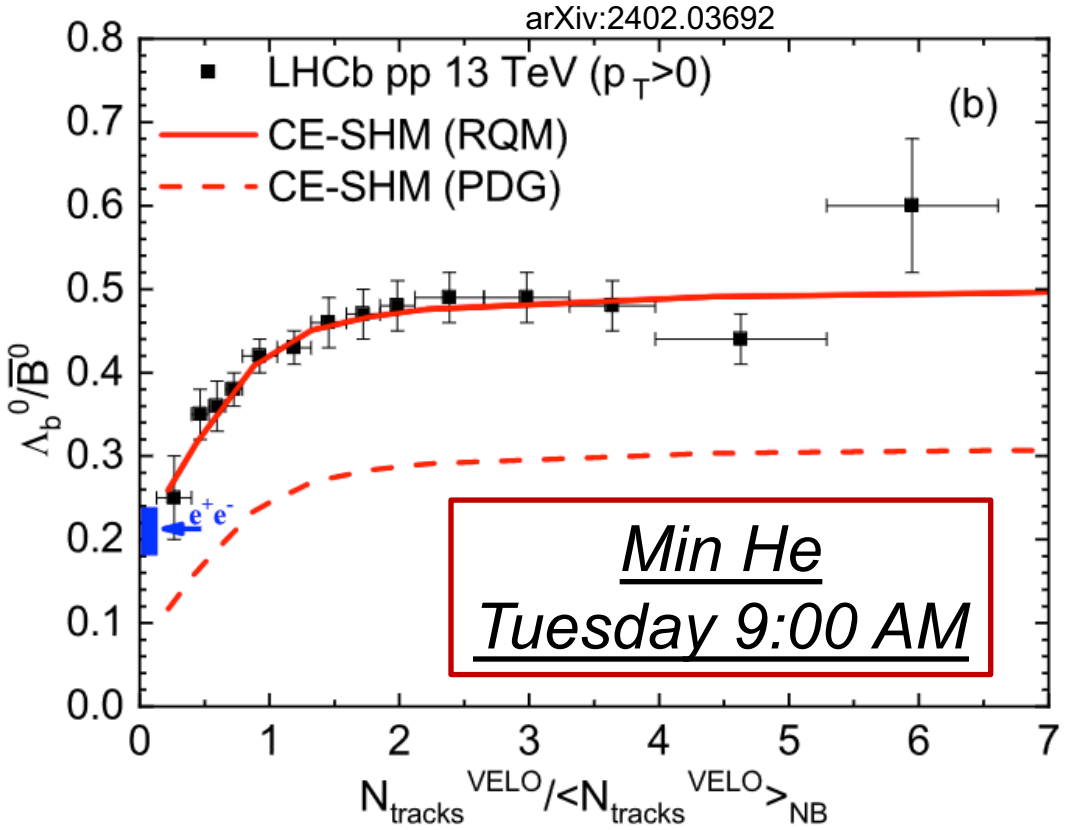




- Reproduce e^+e^- result as multiplicity approaches zero
- b quarks in low multiplicity environments have nothing to coalesce with - fragment in vacuum

b-baryon Enhancement vs multiplicity

- SHM reproduces plateauing trend
- All possible baryon states are populated at high multiplicity



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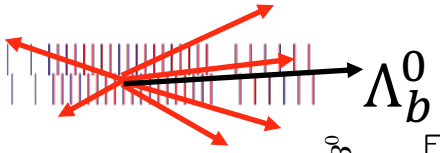
- b quarks in low multiplicity environments have nothing to coalesce with - fragment in vacuum

B-baryon Enhancement via Coalescence



N_{tracks}^{VELO}

Dominated by forward tracks

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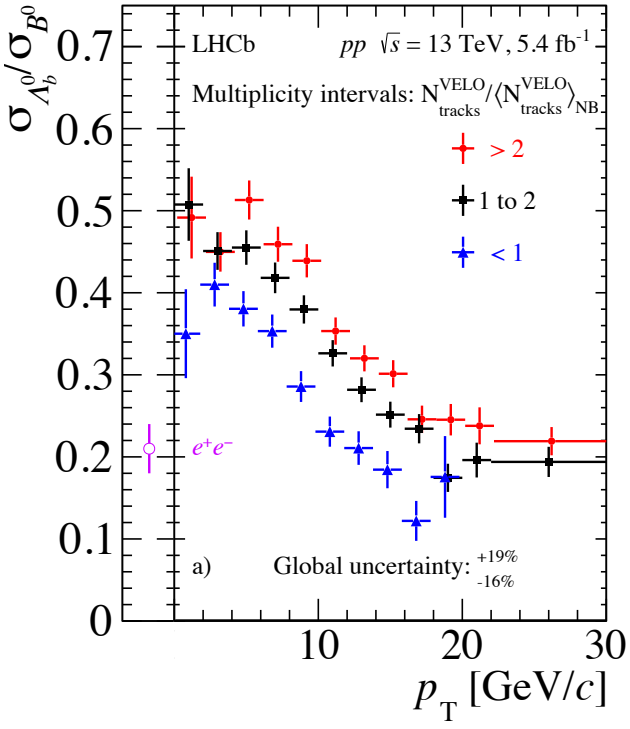
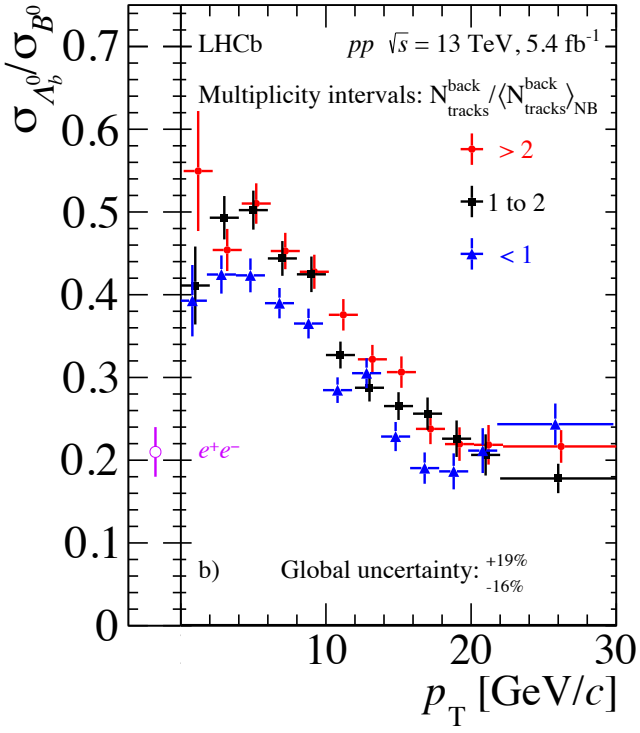
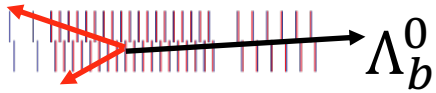
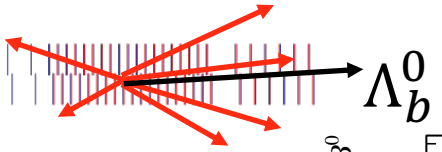






N_{tracks}^{back}

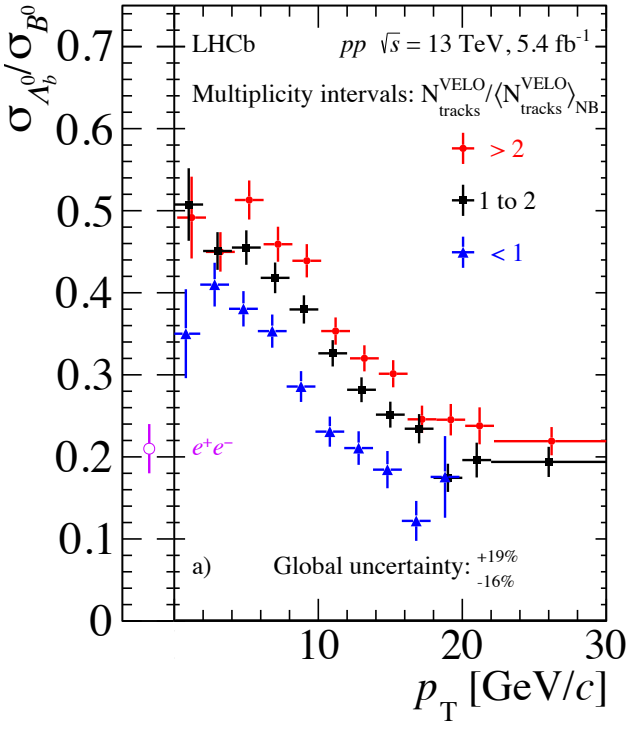
B-baryon Enhancement via Coalescence

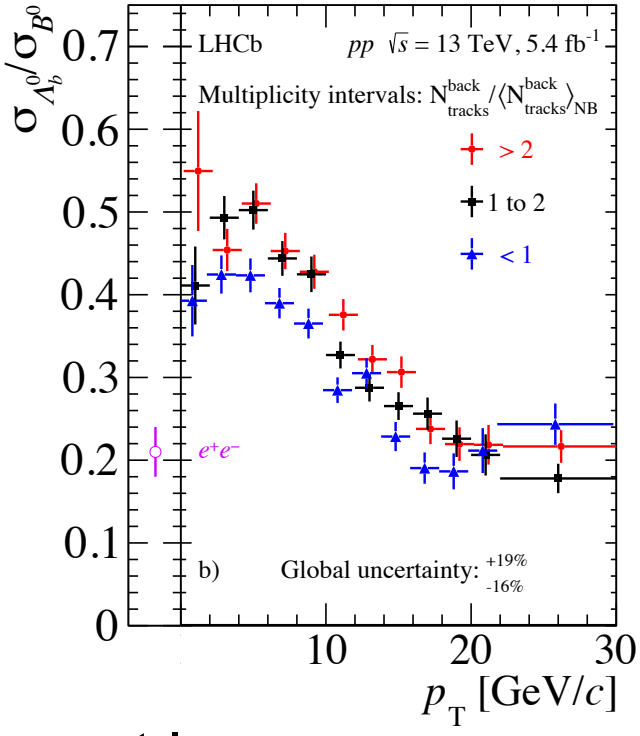


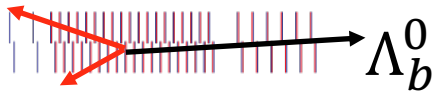
N_{tracks}^{VELO}

Dominated by forward tracks

PRL 132 (2024) 8, 081901



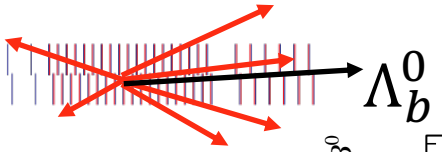




N_{tracks}^{back}

- Clear multiplicity dependence at low p_T

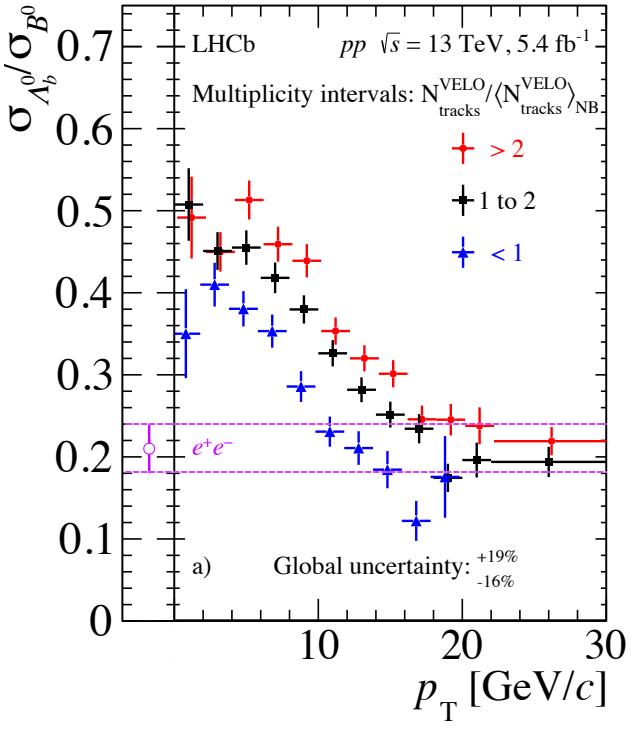
B-baryon Enhancement via Coalescence

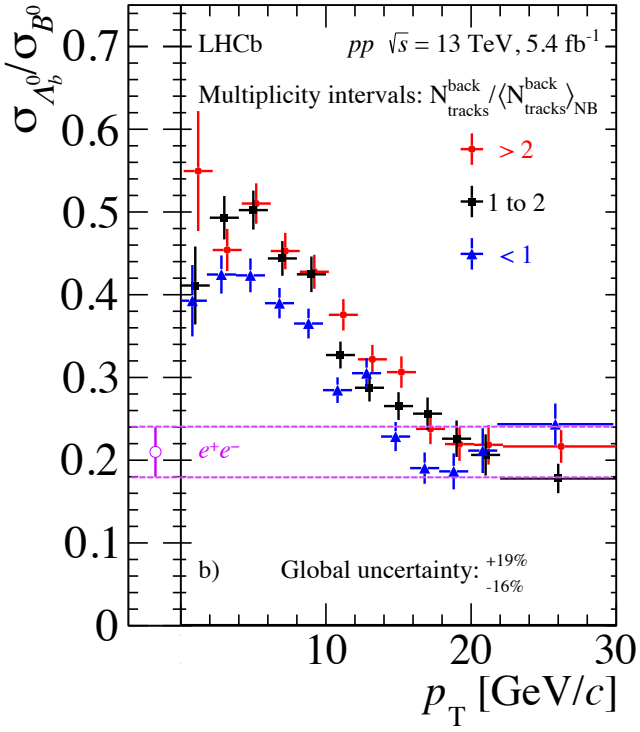


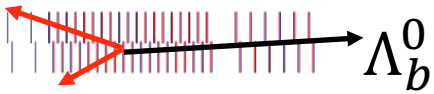
N_{tracks}^{VELO}

Dominated by forward tracks

PRL 132 (2024) 8, 081901







N_{tracks}^{back}

- Clear multiplicity dependence at low p_T
- Reproduce e^+e^- result at high p_T where b quarks don't interact with the bulk and fragment instead

Coalescence in Exotic Measurements

- Ratio mostly cancels out initial state effects
- Enhanced X(3872) as hadronic environment becomes more dense
- Potential coalescence for tetraquarks?

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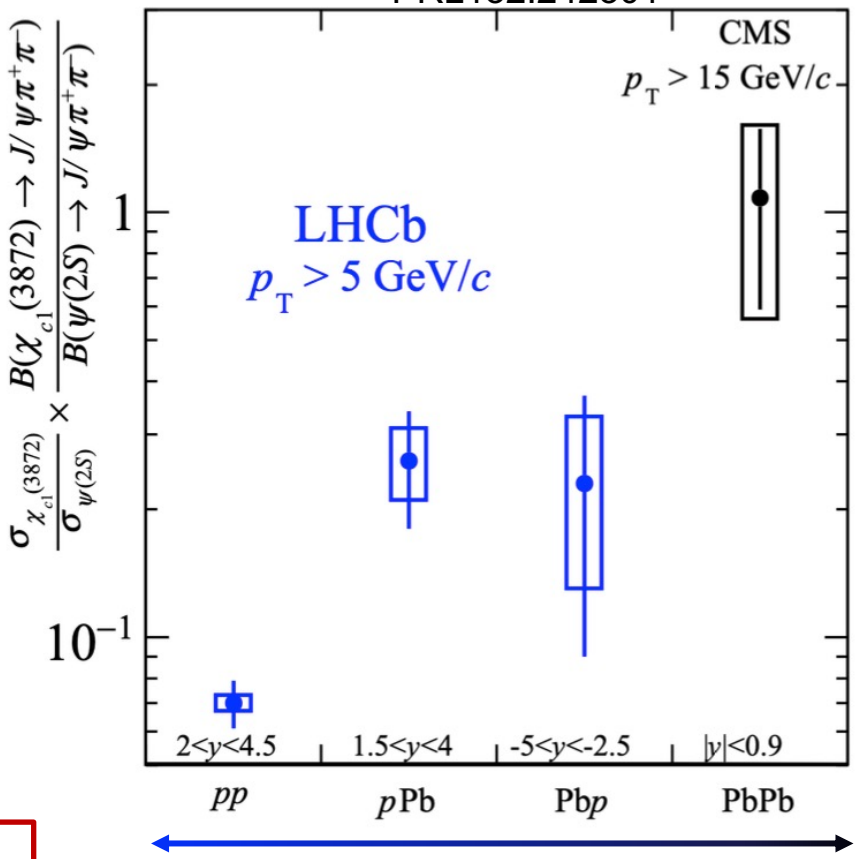


Matt Durham
Tuesday @ 3:00 PM

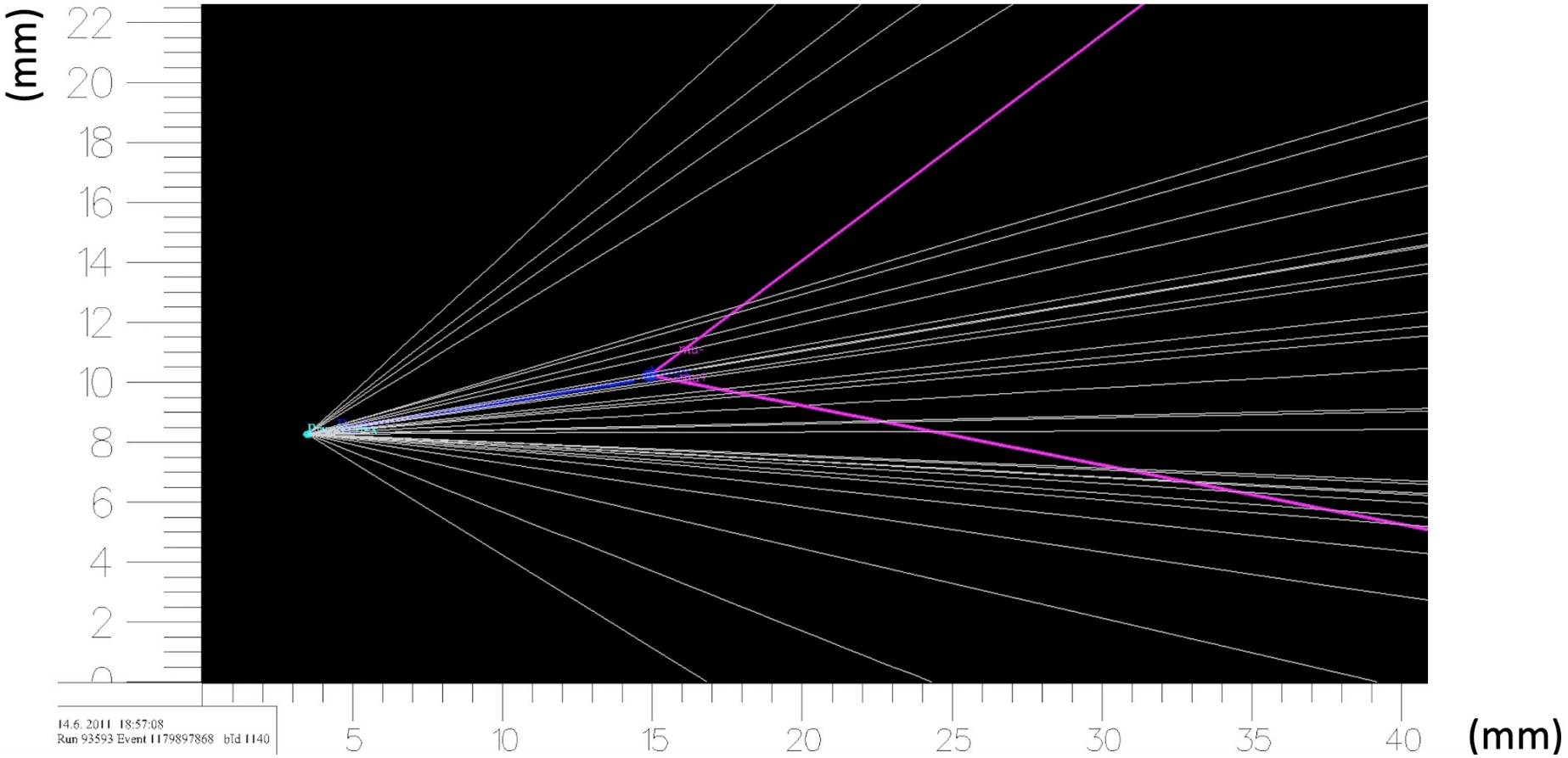
Summary

- LHCb is well suited to study hadronization.
- Heavy quarks are an extremely useful tool for studying hadronization.
- The universality of hadronization fails across different collision systems.
- Clear indication that the QCD medium affects the hadronization process.

Los Alamos is supported by the US Dept. of Energy/Office of Science/Office of Nuclear Physics and DOE Early Career Awards program

The Large Hadron Collider beauty (LHCb)

Event display of $B_s \rightarrow \mu^+\mu^+$ candidate



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