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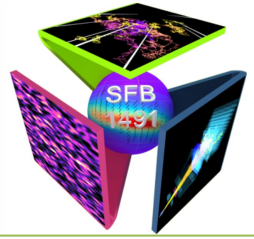


Fakultät Physik /
AG Albrecht

Hadron composition in p-ion collisions measured in LHCb fixed-target mode

Lars Kolk, Johannes Albrecht, Hans Dembinski

Overview

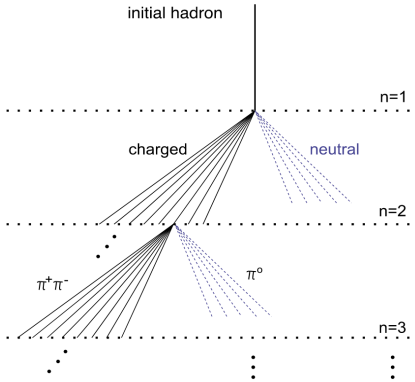
- Muon Puzzle: Muon deficit in air shower simulation
- Multiplicity-dependent strangeness enhancement: Potential key ingredient to solving muon puzzle
  - Discovered by ALICE in pp, pPb, and PbPb at mid-rapidity
  - **New** evidence from LHCb at forward rapidity in B_S^0 / B^0 ratio
  - My thesis: study of p-(He, Ne, O) collisions using LHCb's fixed-target mode

The Muon Puzzle

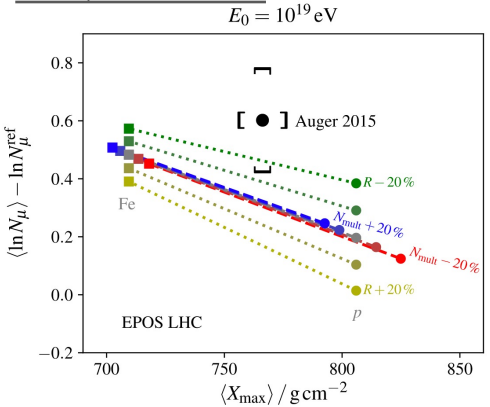
- Air showers: Cosmic-ray induced hadronic showers in Earth's atmosphere
- Muon puzzle: 8σ discrepancy in the number of observed shower muons

- Potential solution within Soft-QCD
  - Reduce $\mathrm{R} = \frac{\mathrm{E}_{\pi^0}}{\mathrm{E}_{\text{other hadrons}}}$ by **10-20%** at LHC energy scale
  - More strangeness → less π^0 → more muons in air showers
  - Cannot change R within QCD factorization framework
    Collins et al., Adv.Ser.Direct.High Energy Phys. 5 (1989) 1-91
  - Evidence for alternative hadronization mechanism discovered at LHC
  - Alternative mechanism reduce R up to **10-20%**

J. Matthews, Astropart. Phys. 22 (2005) 387-397



S. Baur, H. Dembinski, M. Perlin, T. Pierog, R. Ulrich, K. Werner, arXiv:1902.09265



Strangeness Enhancement

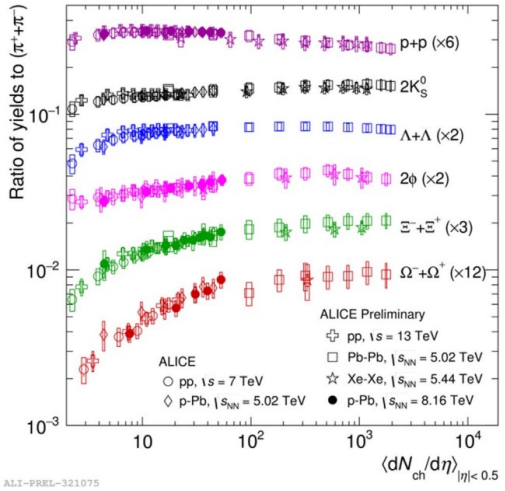
- ALICE discovered universal enhancement of strangeness production in pp, pPb, PbPb
  ALICE, Nature Phys. 13 (2017) 535

- Enhancement seems to depend only on density of charged particles produced in the event → predictive power for air showers **if universal**
  - Extrapolation of density of charged particles safe
  - Hadron composition predicted by charged particle density

- Open questions
  - Does it extend forward to $\eta \gg 1$?
  - **Universality broken** at lower energies?

- My thesis: Study hadronization in p-ion collisions with LHCb fixed-target mode to check universality

M. Vasileiou for ALICE, Phys. Scr. 95 (2020) 064007



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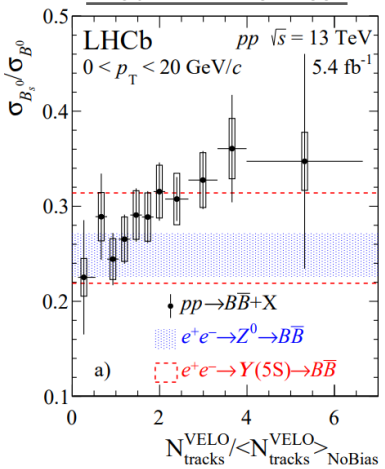
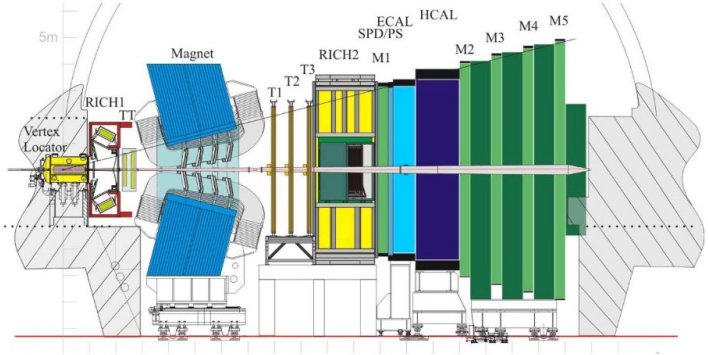
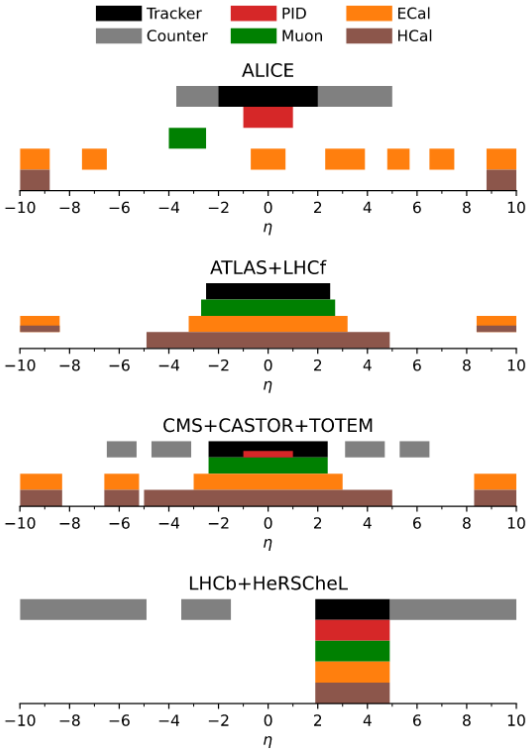


LHCb Experiment

JINST 3 (2008) S08005 IJMPA 30 (2015) 1530022





General purpose single-arm forward spectrometer

- Acceptance
  - $2 < \eta < 5$ with particle identification (PID)
  - $0.1 < p_T / \text{GeVc}^{-1} < 10$
- Very good momentum and vertex resolution
- Accurate luminosity (world record for p-p 7 TeV)
- PID optimal for π, K, p, μ
- Flexible software trigger

- **Unique fixed-target mode**: p,Pb+(He, Ne, Ar)gas

The SMOG System

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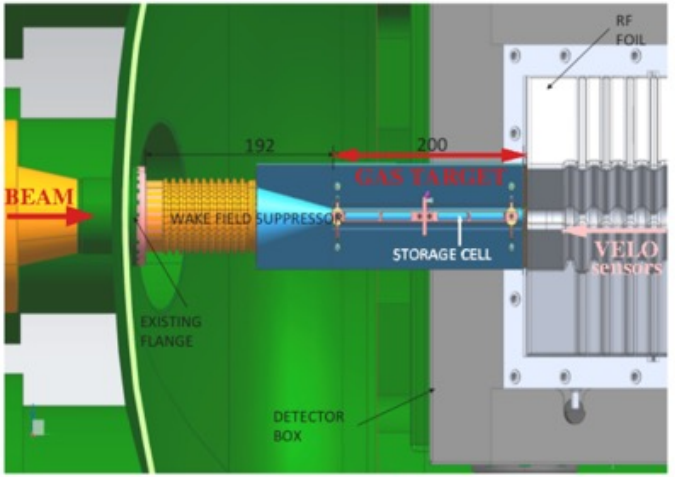
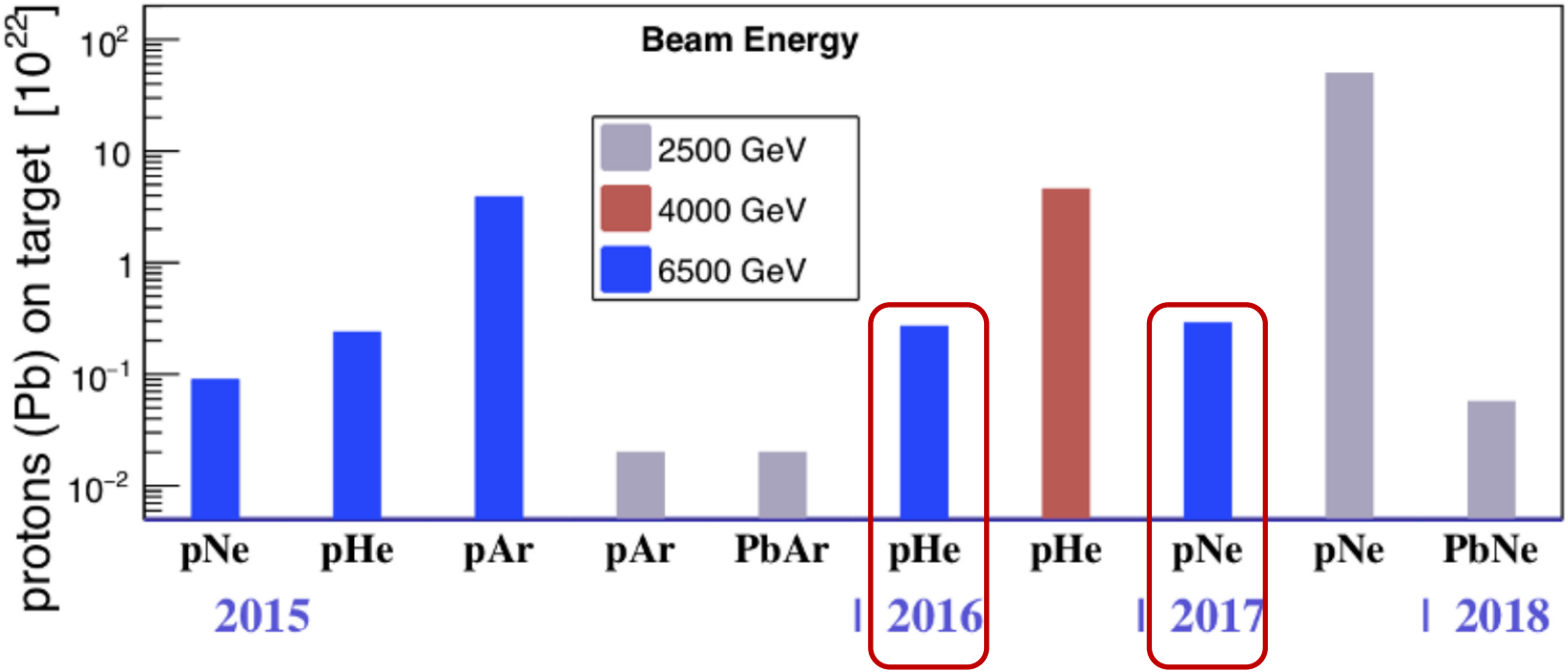


- Fixed target mode vs. beam mode
  - 110 GeV vs. 13 TeV
  - Mid-rapidity vs. forward rapidity
  - Fixed target: study nuclear effects in multiple targets
- SMOG1
  - Designed for beam-gas imaging to improve luminosity measurements
  - Injection of Ne, He, or Ar into the VELO
  - Limitations: Only noble gas, low gas pressure, no precise knowledge of gas pressure
- SMOG2 Upgrade for Run 3
  - Well-controlled gas density and 100x higher
  - Non-noble gases possible: oxygen, nitrogen!

SMOG Datasets



LHCB-TDR-020

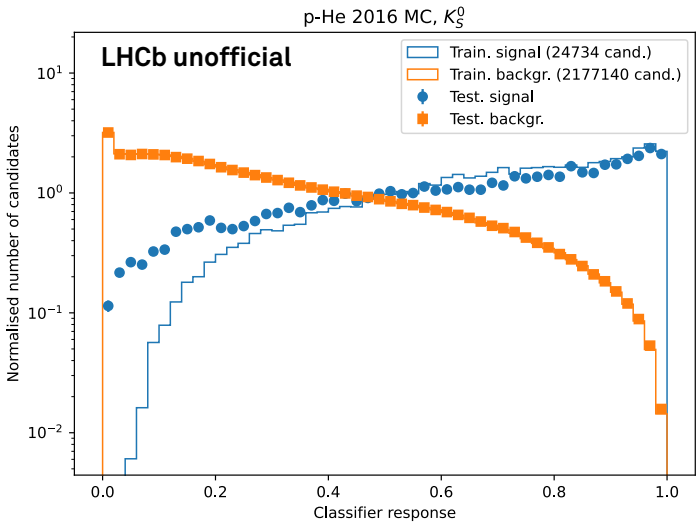
Topic of my Thesis

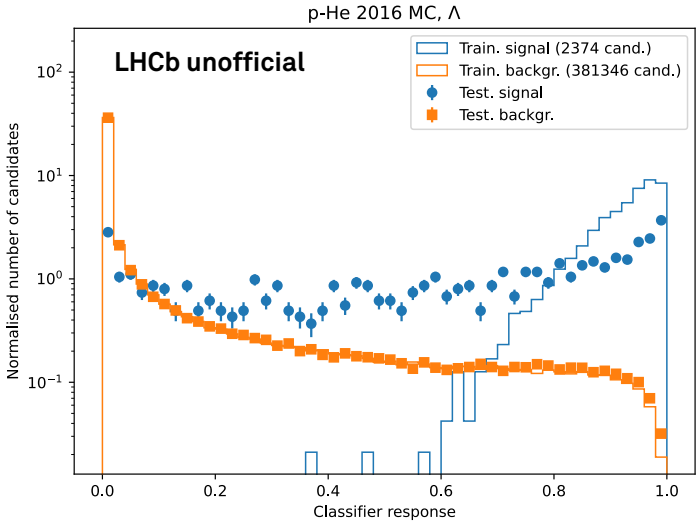
- Topic
  - Multiplicity-dependent strangeness production in SMOG data
  - Study p-He and p-Ne in Run 2, later p-(O,N) in Run 3
  - Study ratios of particles with **ΔS > 0**, e.g. K/π, K^0/π, Λ/π and Ω/π

- Current study of p-He 2016 dataset
  - $K_S^0 \rightarrow \pi^+\pi^-$
  - $\Lambda \rightarrow p\pi^- + \text{c.c.}$
  - Interest in $\Xi^{+/-}$ (double-strange) and Ω^- (triple-strange), feasibility unclear
    - $\Xi^- \rightarrow \Lambda\pi^- \rightarrow (p\pi^-)\,\pi^-$
    - $\Omega^- \rightarrow \Lambda K^- \rightarrow (p\pi^-)\,K^-$

Analysis of K_S^0 and Λ

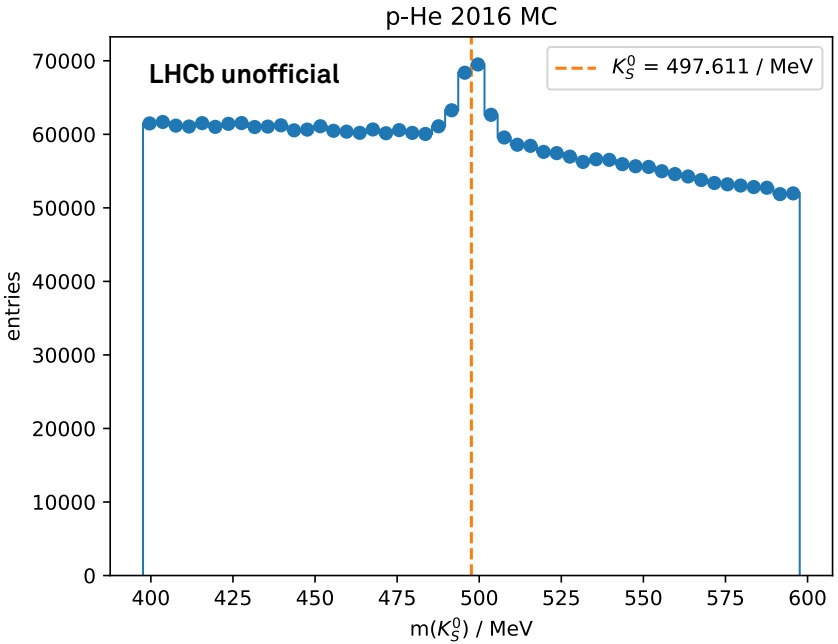
- For K_S^0, Λ and $\overline{\Lambda}$
  - Select tracks based on kinematic and geometrical requirements
  - Train BDT on calculated geometric properties



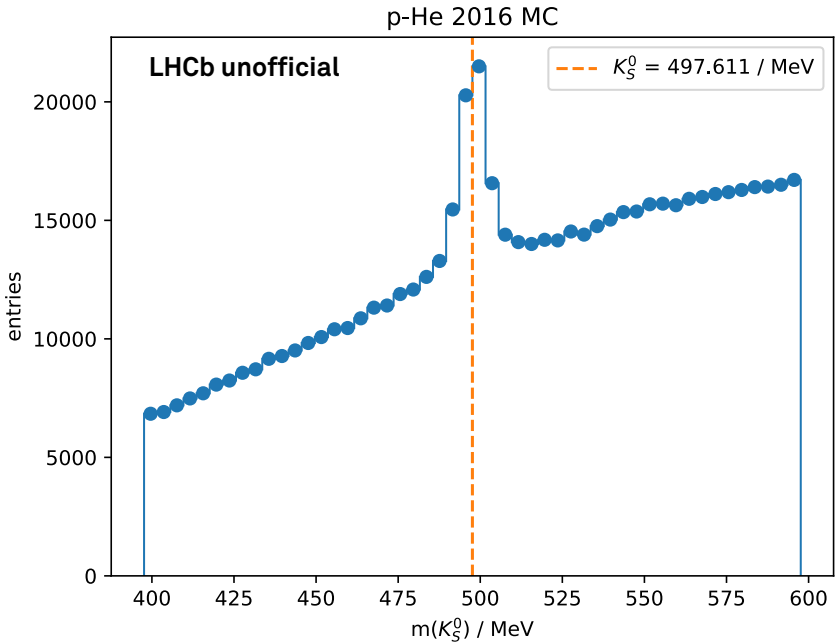


First applied BDT

Before BDT selection



After BDT selection (prediction > 0.5)



Summary and Outlook

- Muon Puzzle in air showers: significant deficit in air shower simulations

- Strangeness enhancement might solve Muon Puzzle
- Multiplicity-dependent enhancement measured by ALICE and LHCb
  - ALICE: Discovery at mid-rapidity in pp, pPb, PbPb
  - LHCb: New evidence for enhancement in forward region in B_S^0/B^0 ratio
  - LHC data cannot be explained within QCD fragmentation framework
  - Alternative hadronization mechanism required

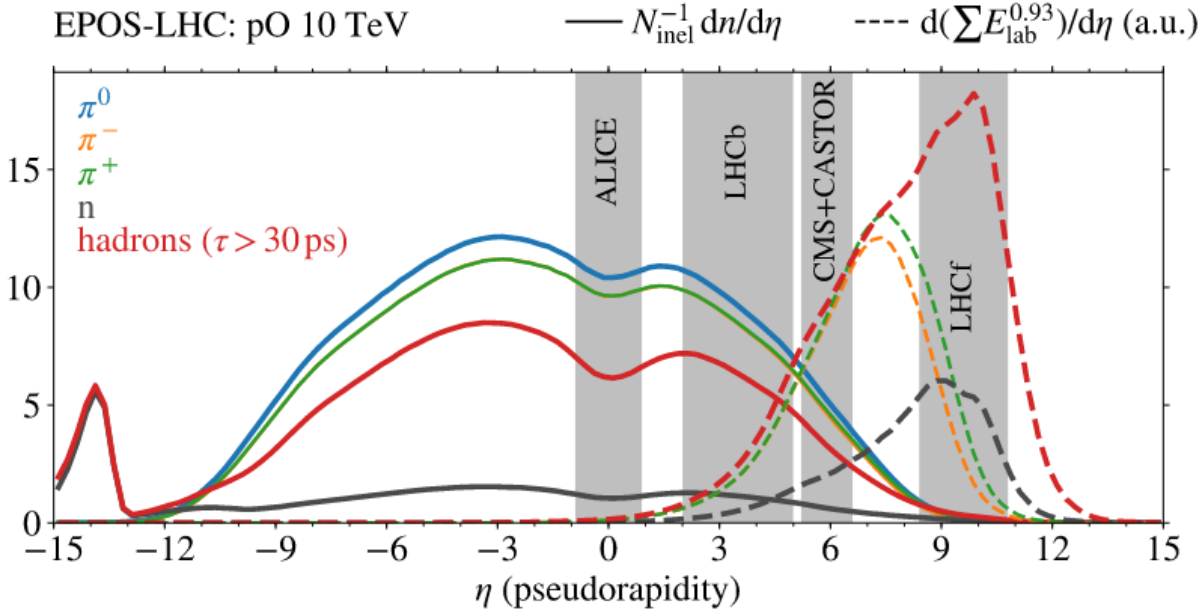
- Need to characterize new hadronization mechanism to include effect in generators
- My thesis: Study multiplicity-dependent strangeness enhancement in LHCb fixed-target mode
  - Run 2: p-He and p-Ne, bracket p-O
  - Run 3: study p-(O,N) directly
  - Currently analysing p-He collisions at 110 GeV

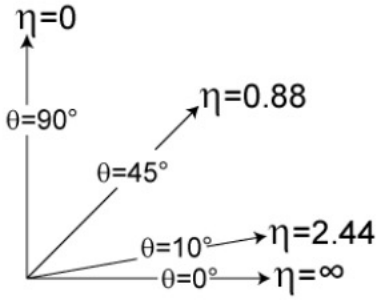
BACKUP

Importance of forward acceptance

arXiv:2105.06148

„Muon production weight“
how many muon would be produced in shower
by secondaries in this collision





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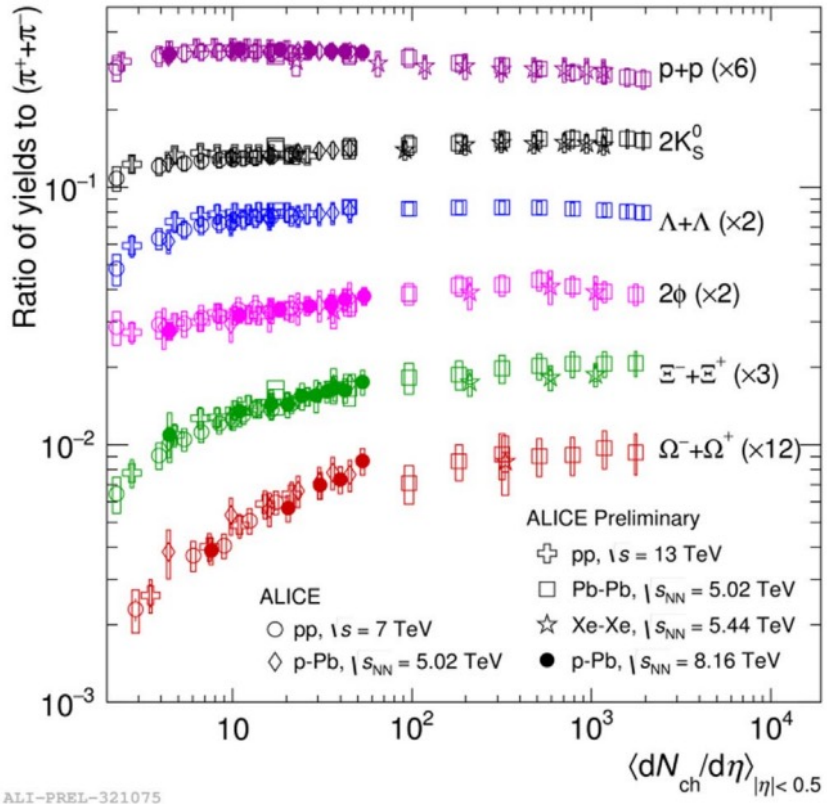
Strangeness Enhancement in ALICE

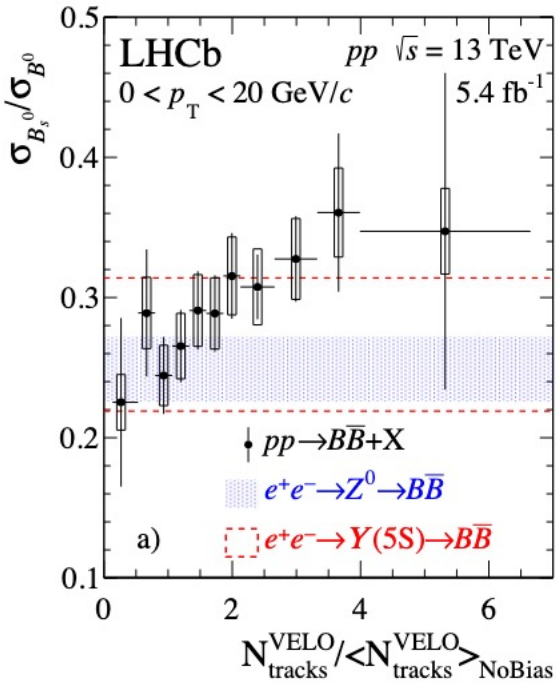
M. Vasileiou for ALICE, Phys. Scr. 95 (2020) 064007



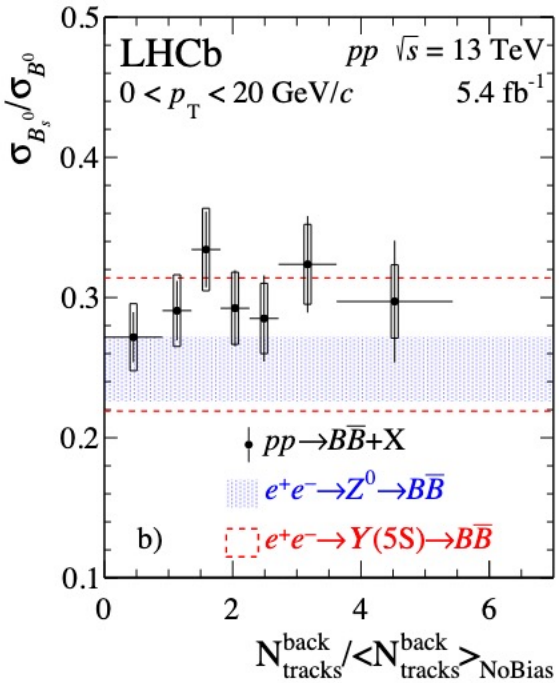
$\sigma(B_S^0)/\sigma(B^0)$

arXiv:2204.13042

all tracks



backwards tracks



$\sigma(B_S^0)/\sigma(B^0)$

arXiv:2204.13042