Reconstruction of jets tagged by heavy-flavor hadrons in sPHENIX

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Outlook

- Early measurements
  - Advantages and limitations
- Development of a new method
  - Dealing with issues head-on
- The sPHENIX experiment
  - What’s new for HF- tagged jets?
- sPHENIX heavy-flavor program

Early measurements

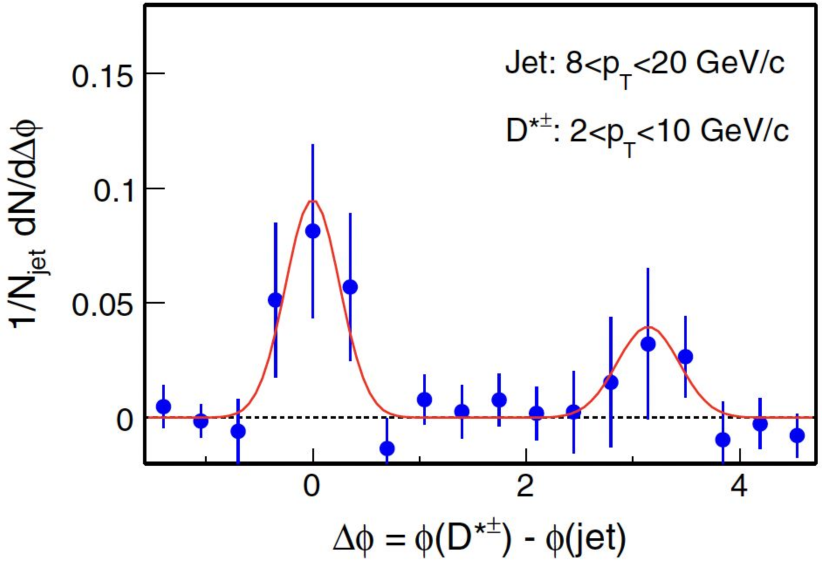
- In 2009, STAR published the first measurement of jets tagged with D mesons

- Measurement done with 180 reconstructed D* mesons

- D* mesons and jets are correlated by angular criterion

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} \leq R_0$$

Phys. Rev. D 79, 112006

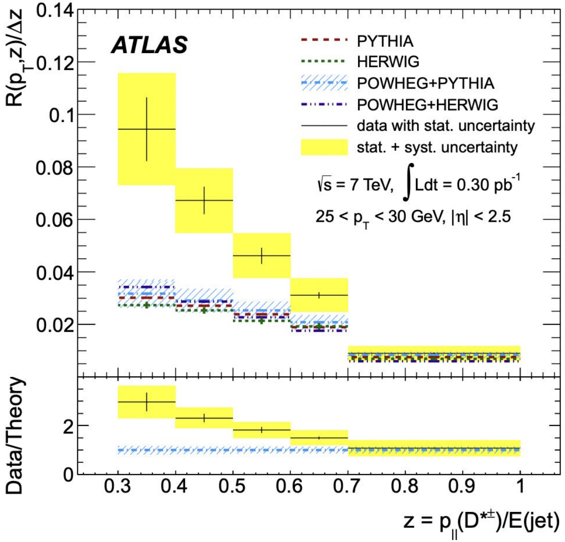


Jet R = 0.4

Early measurements

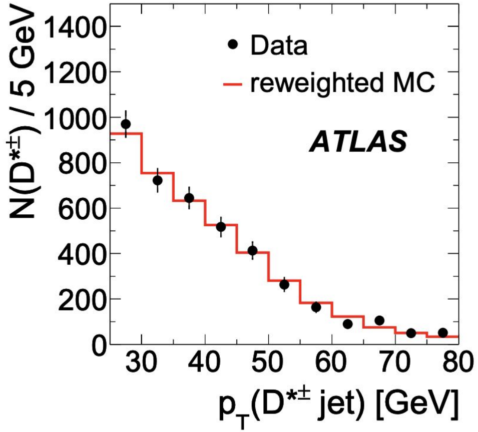
- ATLAS published results on jets tagged with D* mesons in 2012
- D* p_T > 7.5 GeV/c. Jets are in the range 25 < $p_{T,jet}$ < 70 GeV/c
- D*-jet production rate showed a large discrepancy with event generators
- D* mesons and jets are correlated with angular criterion

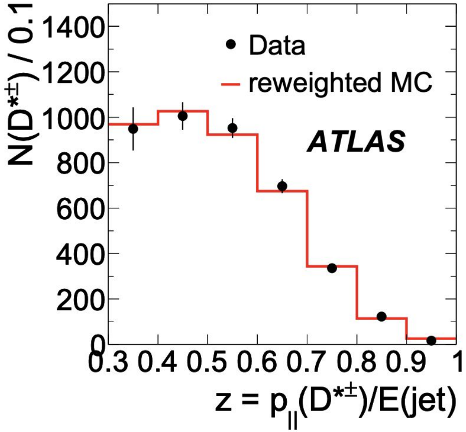
$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} \leq R_0$$



Phys. Rev. D85 (2012) 052005

Jet R = 0.6



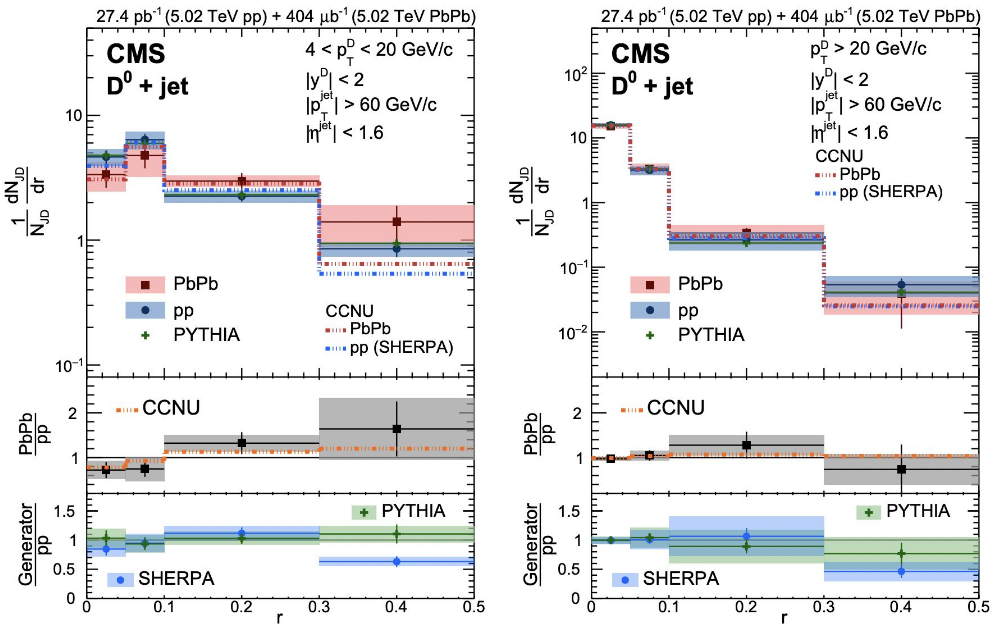


(Not so) Early measurement

- In 2020, CMS published results on heavy-quark diffusion inside jets
- D^0 p_T > 4 GeV/c. Jets p_T > 60 GeV/c
- D^0 mesons and jets are correlated with angular criterion

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} \leq R_0$$

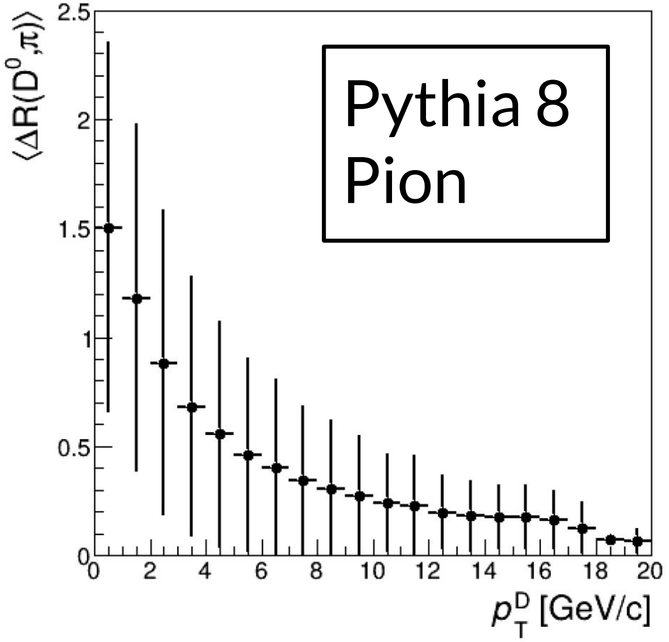
Phys. Rev. Lett. 125, 102001 (2020)

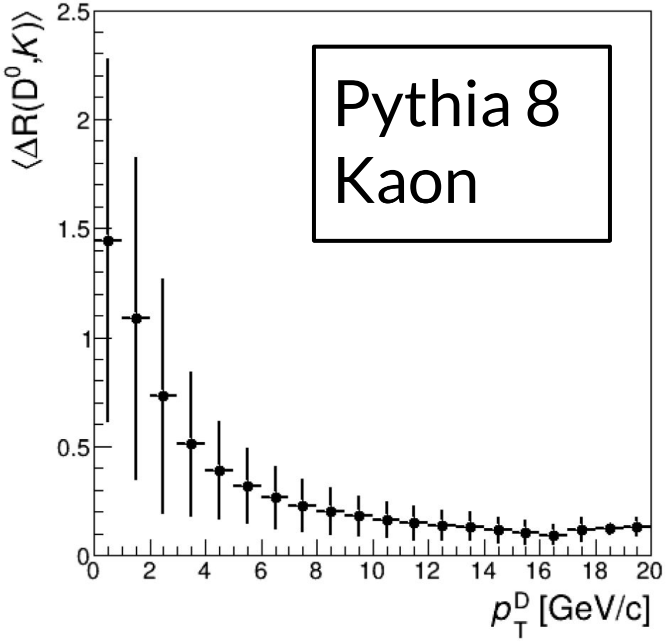


Jet R = 0.3

Characteristics of the $D^0 \rightarrow K\pi$ decay

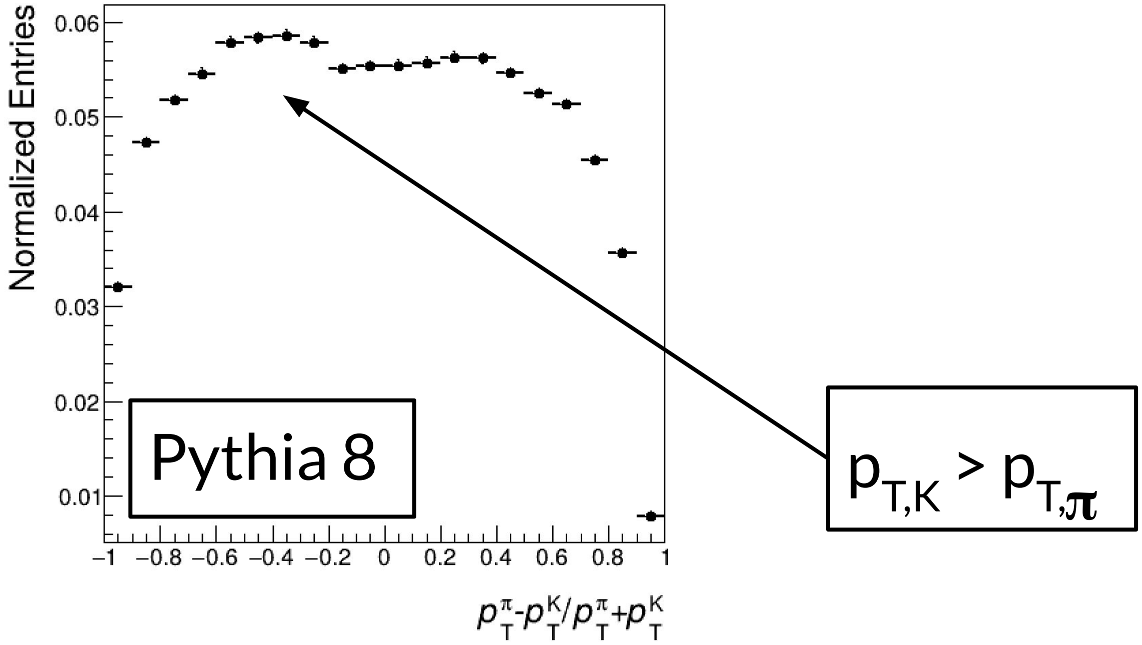
- Decay angle is significantly large at low D^0 transverse momentum
  - Significant probability of one (or even both) decay daughter to be out of the jet cone





Characteristics of the $D^0 \to K\pi$ decay

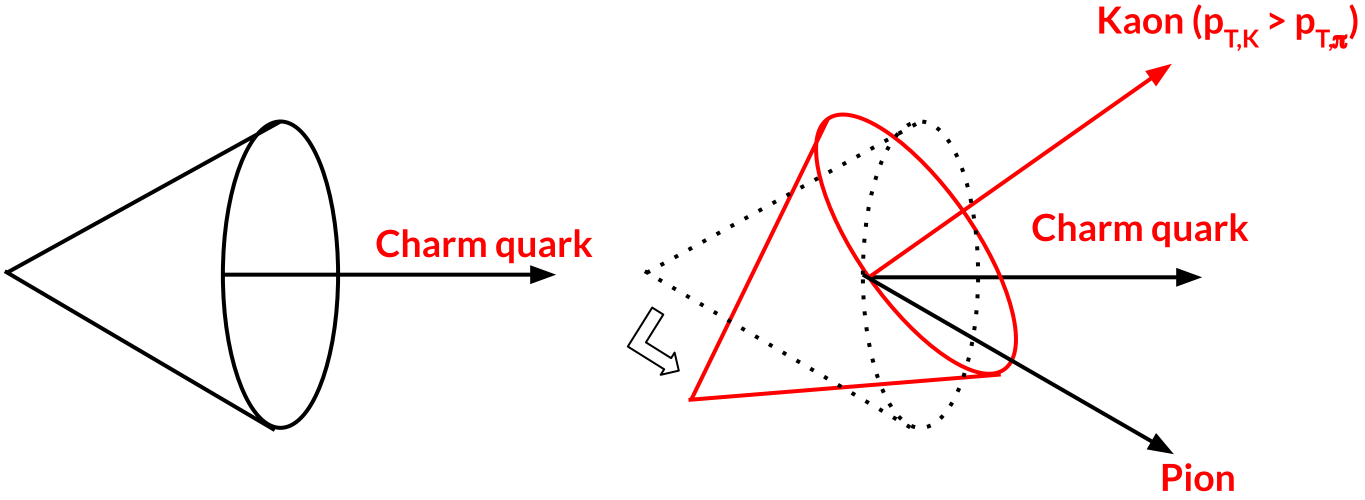
- Momentum imbalance
  - When finding jets with anti-kt algorithm, the kinematics of the jet is calculated from p_T-weighted constituents kinematics



Characteristics of the $D^0 \rightarrow K\pi$ decay

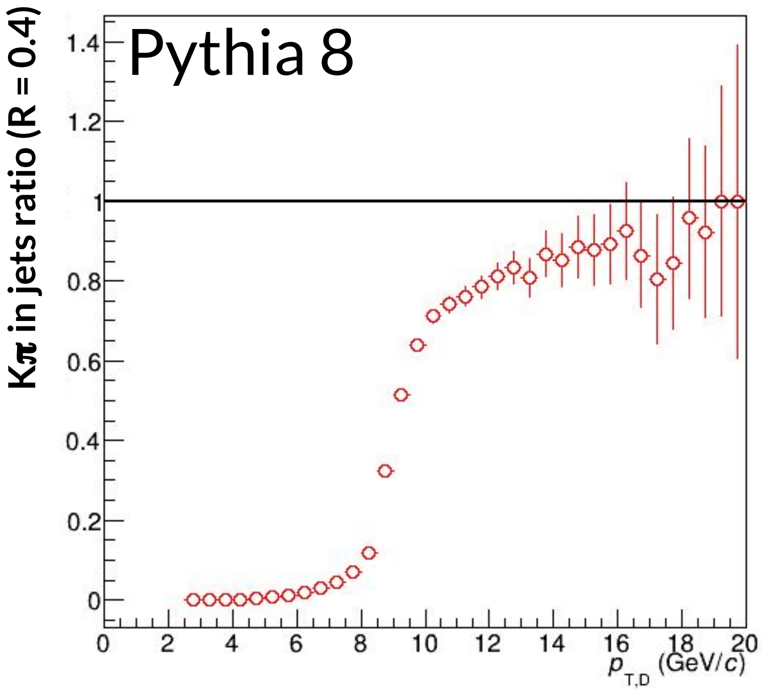
sPHENIX

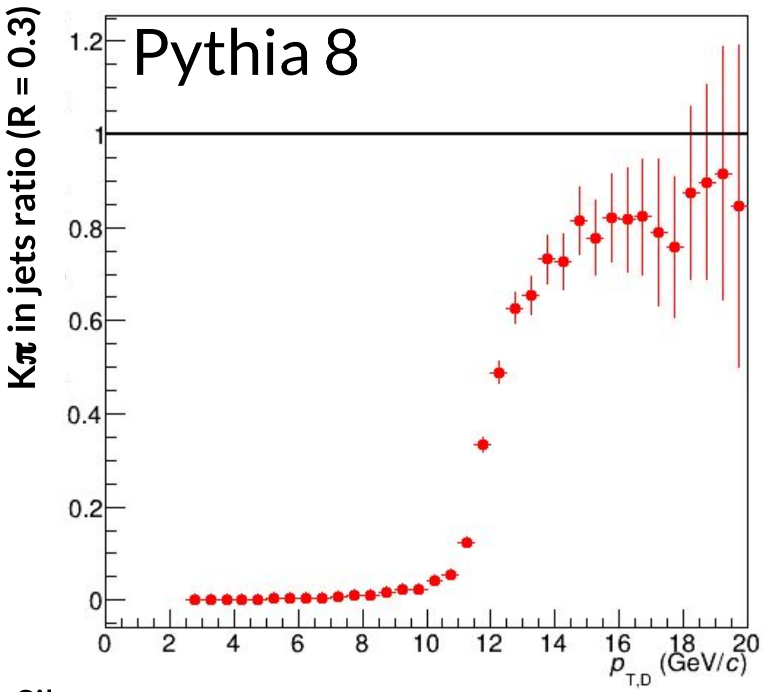
- Large decay angle + momentum imbalance
  - Heavy quarks have a relatively hard fragmentation (large z)
  - A large decay angle and the momentum imbalance could change jet kinematics with respect to quark direction



Characteristics of the $D^0 \to K\pi$ decay

- Fraction of both D^0 decay daughters as constituents of the same jet
  - Huge hit to low and intermediate D^0 p_T
  - Worse for smaller jet resolution parameters (R)





Angular correlation

- Simple method. Heavy-flavor particles and jets are reconstructed independently

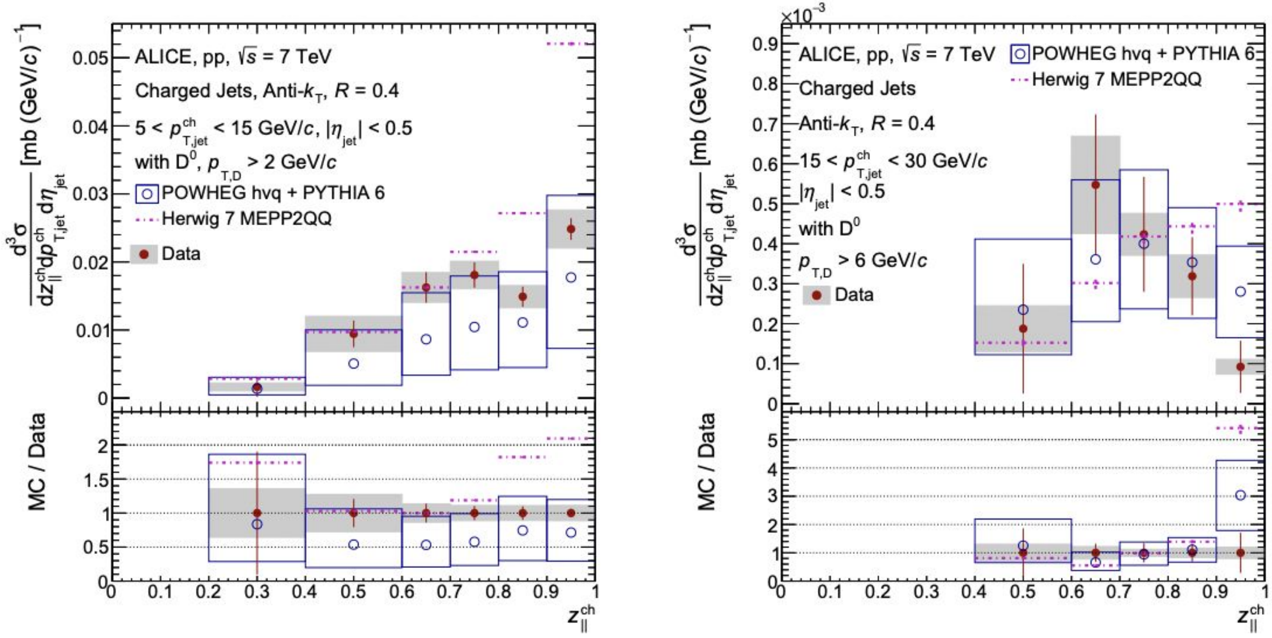
- Having only one of the decay daughters in the jet:
  - Could move the jet centroid to the direction of the daughter
  - Deal with cases where the D meson momentum is larger than jet momentum ($z > 1$)

- Requiring all decay daughters to be part of the jet constituents is a big hit in statistics below $p_{T,D} < 10$ GeV/c

- Probably safe at high D meson and jet p_T

D meson as jet constituent

- In 2019, ALICE published results on D^0 tagged jet production and momentum fraction
- The method used has the D^0 as <u>one of the jet constituents</u>



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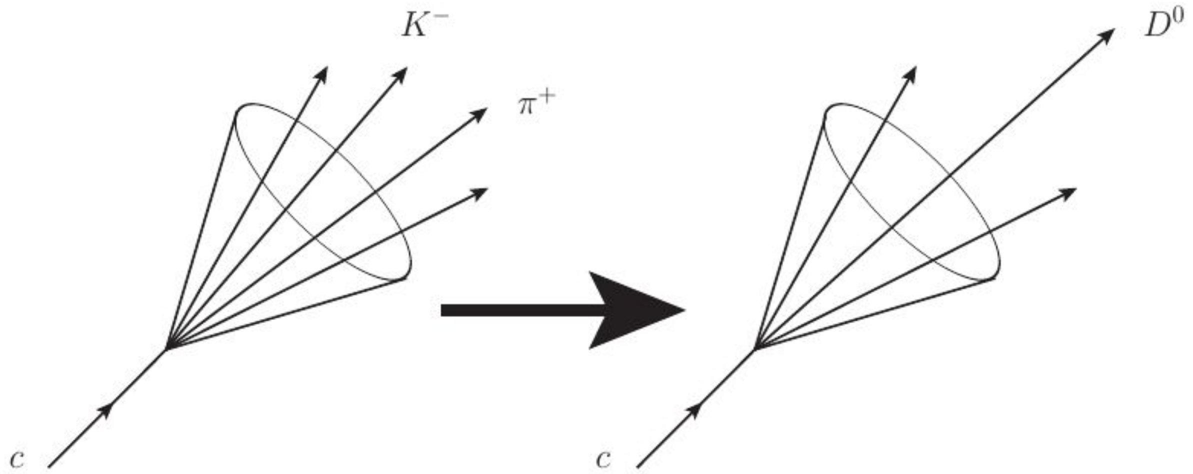
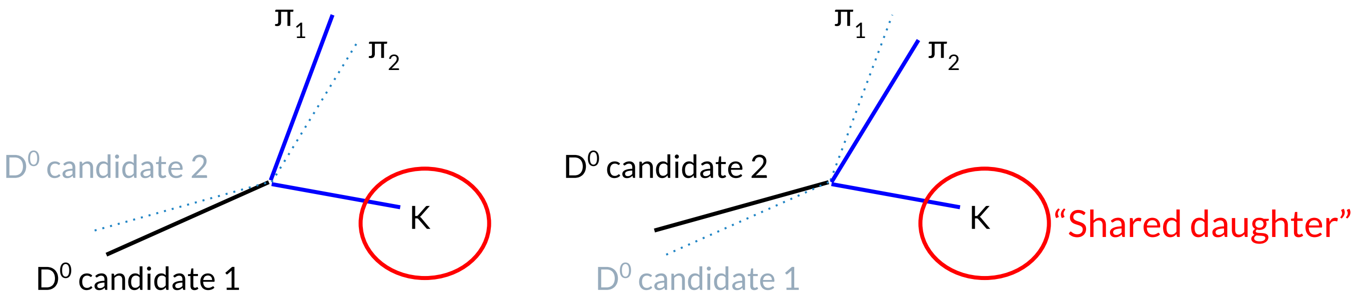
JHEP 1908 (2019) 133

D meson as jet constituent

1. D mesons are reconstructed
2. The D meson decay daughters are replaced by the D meson 4-momentum vector
3. This new set of particles is used to find jets. Typically with FastJet using anti-kt algorithm



D meson as jet constituent



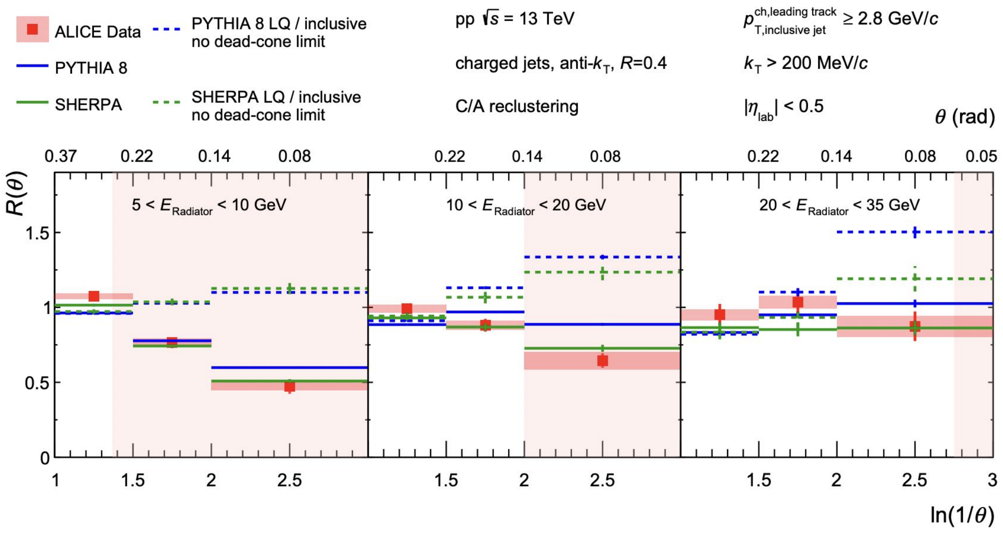
- D-meson tagged jets are reconstructed considering only one D-meson candidate at a time
  - Only one candidate will have their daughters replaced by D-meson candidate
- Jets have to be reconstructed N times per event, where N is the number of D-meson candidates

D meson as jet constituent

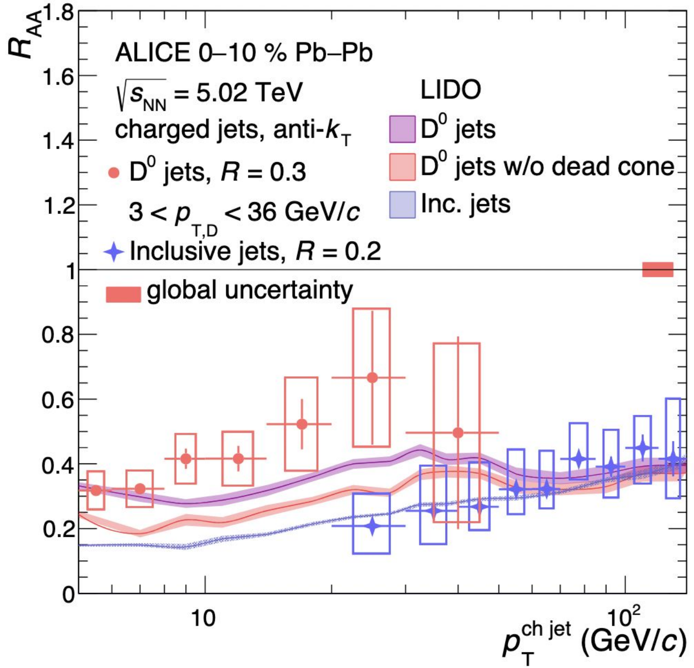
- This method solves issues related to the large decay angle and momentum imbalance
- The momentum fraction of the D meson with respect to the jet doesn't suffer from inconsistent cases ($z > 1$)
- There are additional steps and pitfalls when using this method in comparison with angular correlation
- The consistency provided by the method allowed ALICE to deliver many interesting results

D meson as jet constituent

- ALICE has been using this method in all heavy-flavor tagged jet measurements with great success

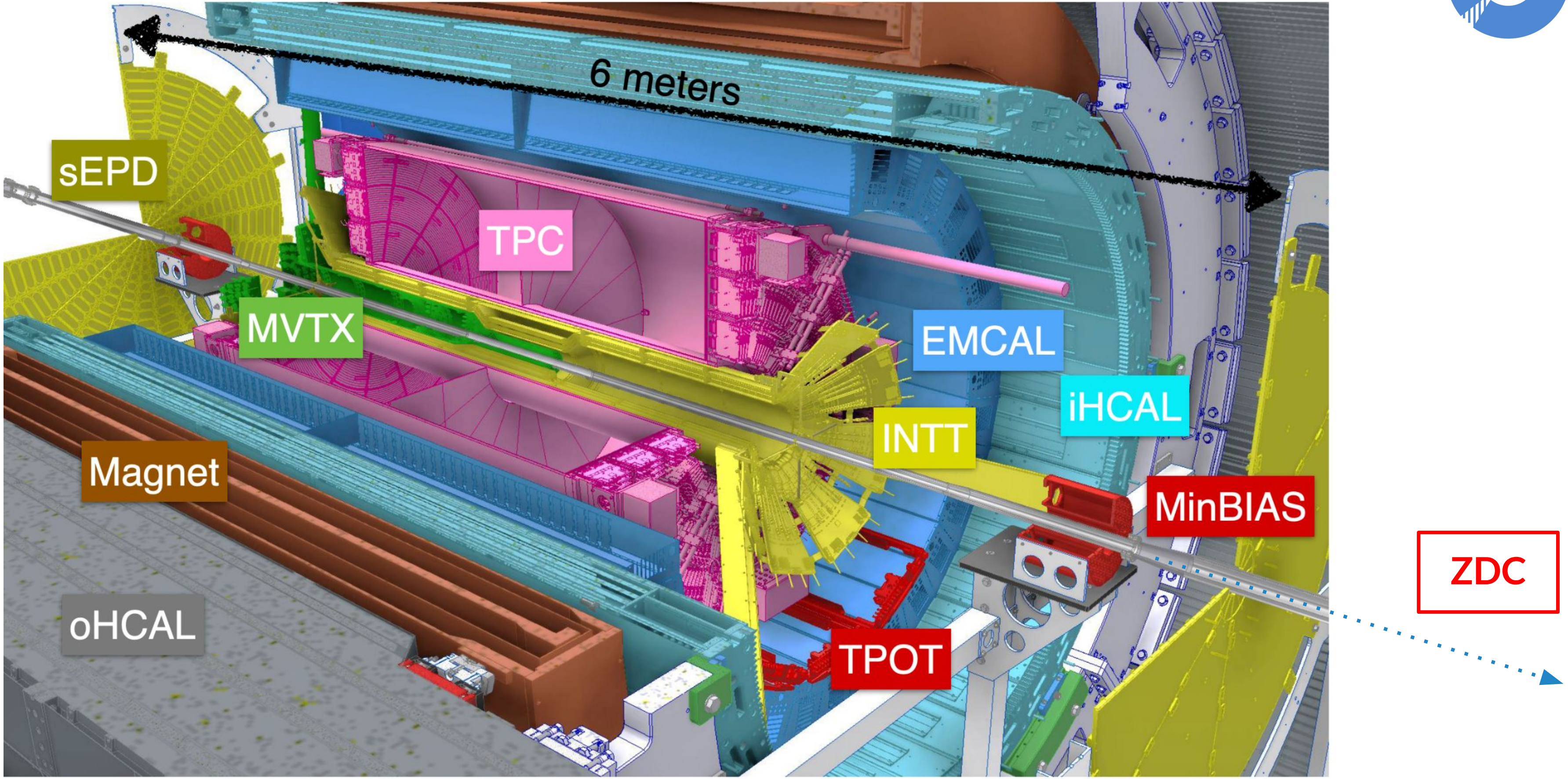


Nature 605 (2022) 440-446



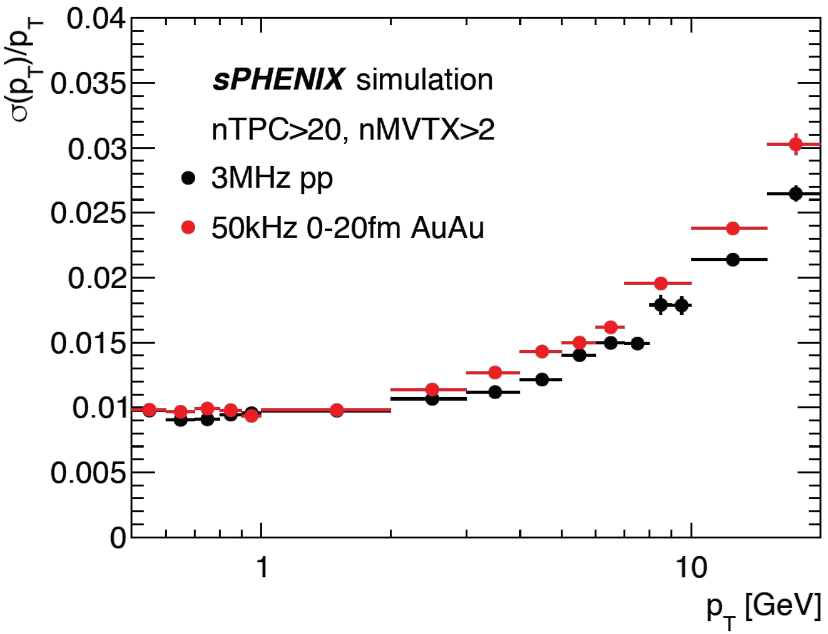
arXiv:2409.11939

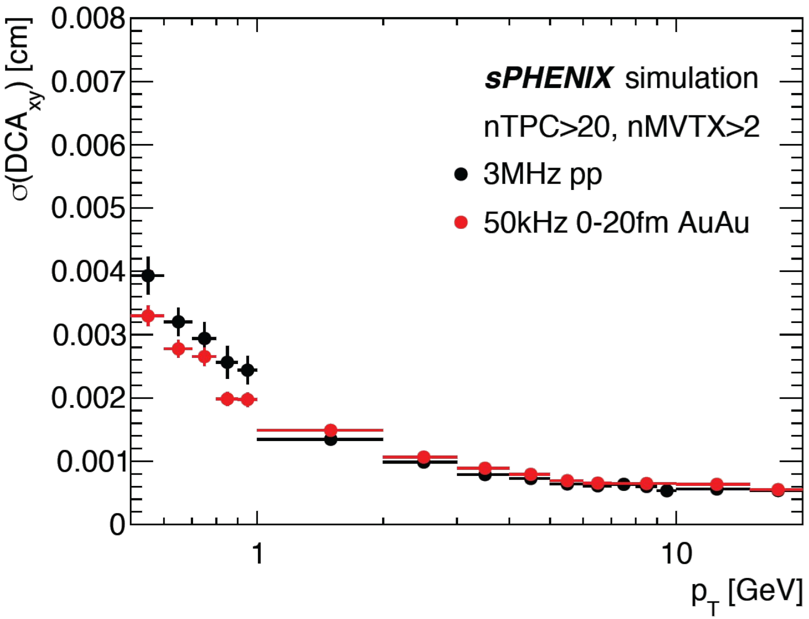
The sPHENIX detector



HF-tagged jets in sPHENIX

- sPHENIX is the first new detector at any hadron collider in over a decade!
- High-quality tracking system allows for precise reconstruction of heavy flavor hadrons



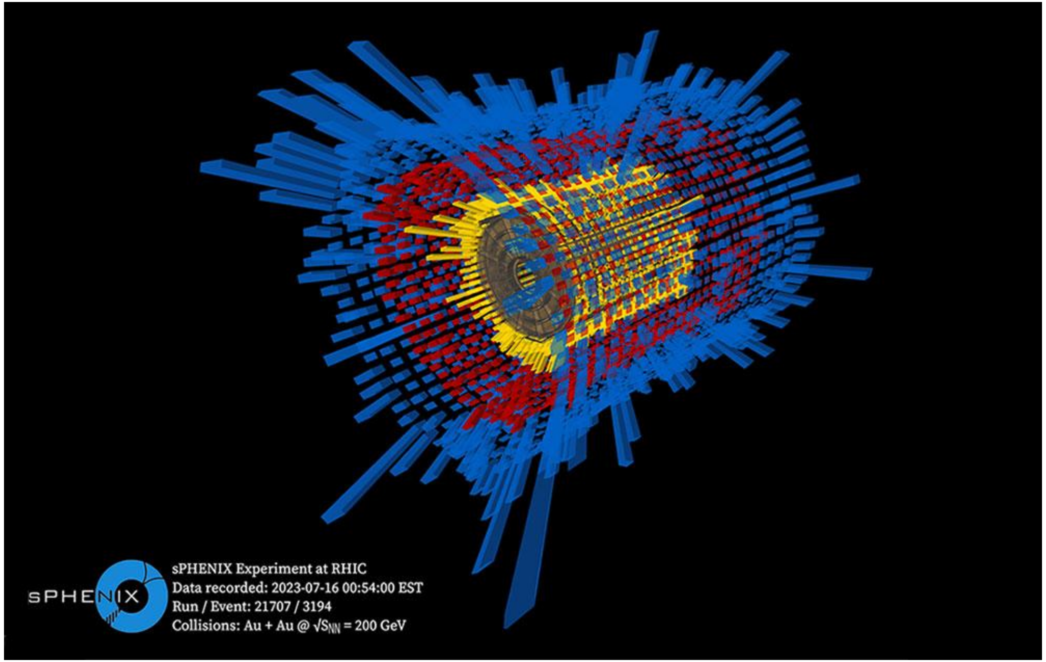


HF-tagged jets in sPHENIX

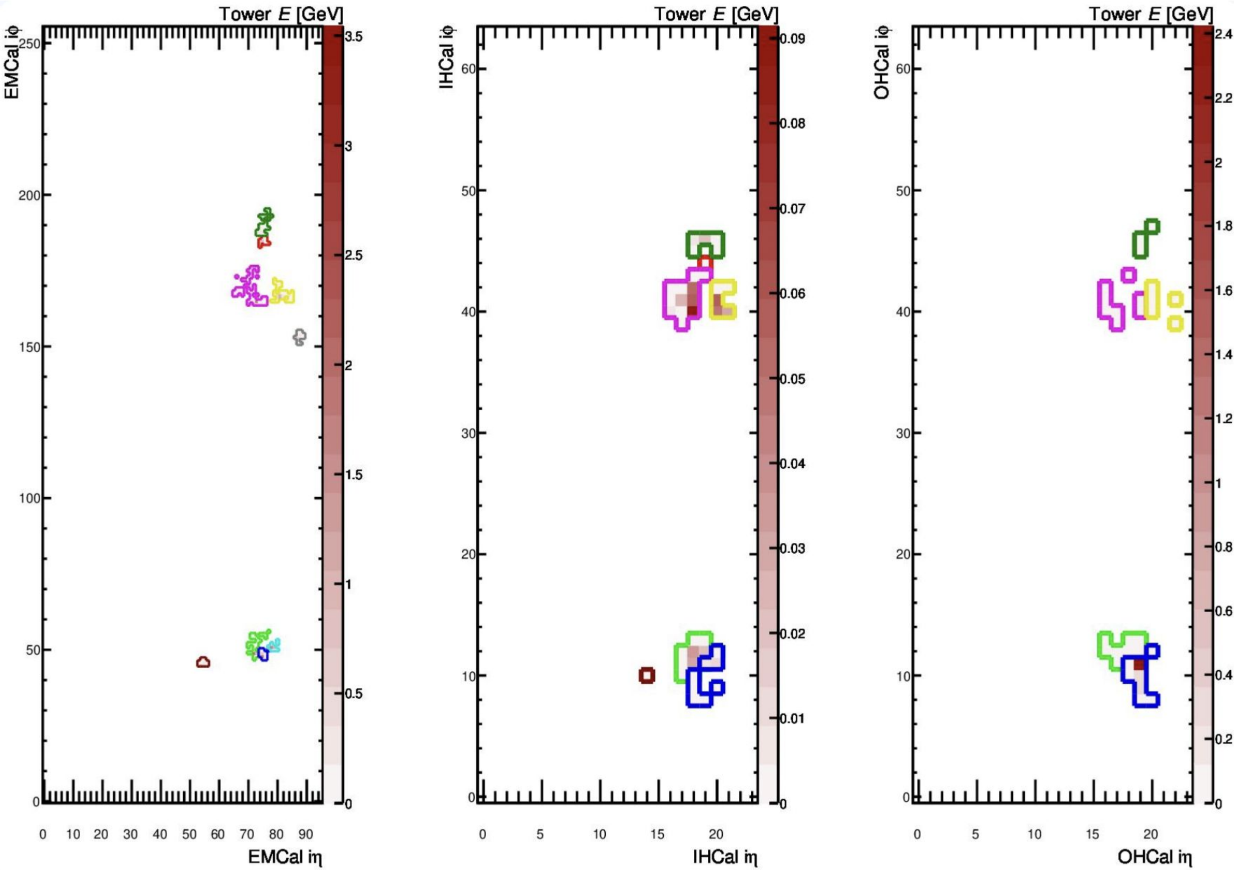
- EMCal and HCal provides full azimuthal coverage

- For jet reconstruction, tracks are combined with calorimeter information using an implementation of particle flow

- Fully reconstructed jets
  - Jets can be measured with the neutral component taken into account



Topo clusters



Topological clusterization

- Towers are grouped in η, ϕ, and R (calorimeter layer)
- For D-tagged jets, the topo clusters are reconstructed in two groups: EMCal and HCal clusters

HF-tagged jets in sPHENIX

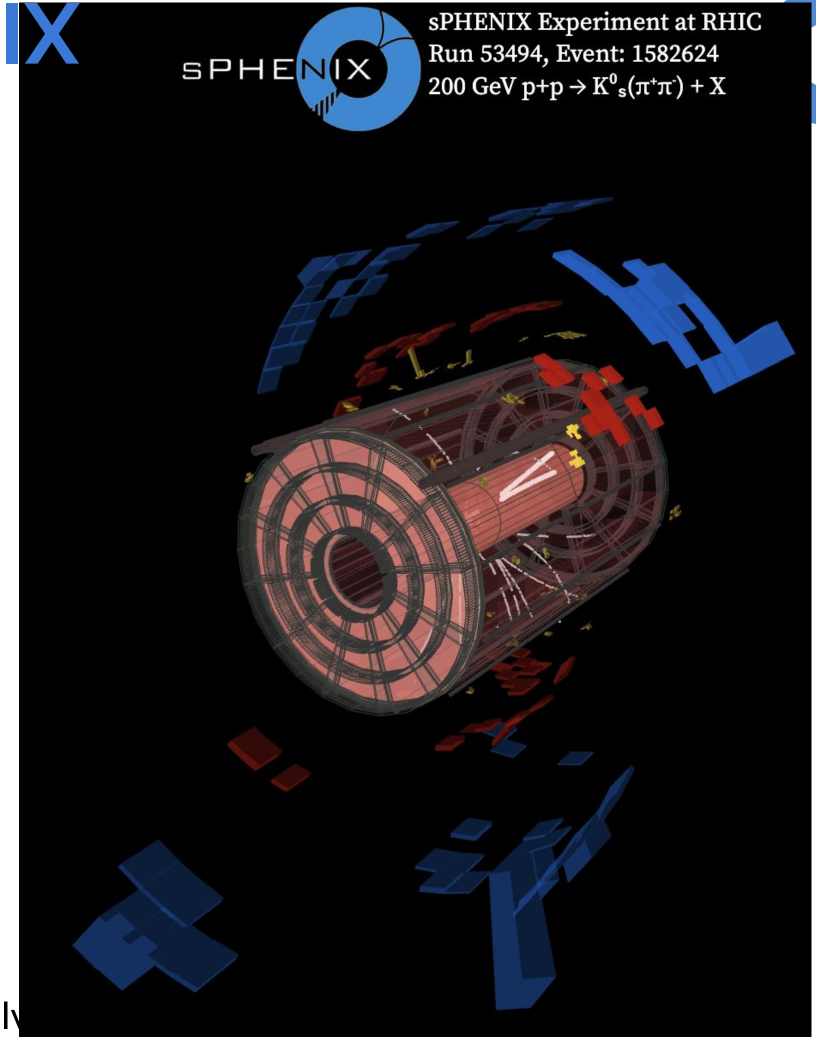
Particle flow combines the tracking information with the topo-clusters

- When using the method of replacing the D-meson decay daughters by the D-meson 4-momentum vector, the whole particle flow element has to be removed

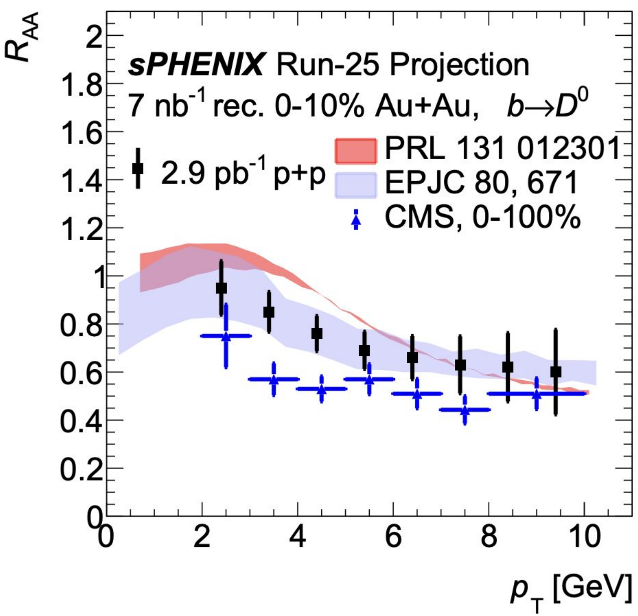
Decay daughter track

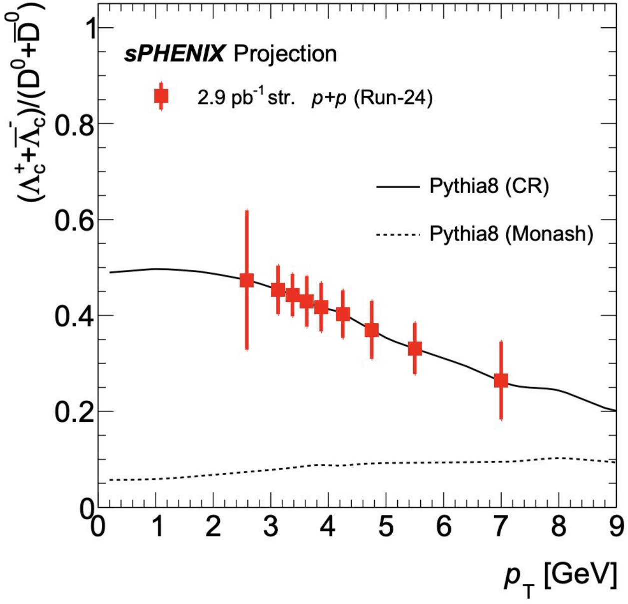
↓

Particle flow
Track + EMCal cluster + HCal cluster



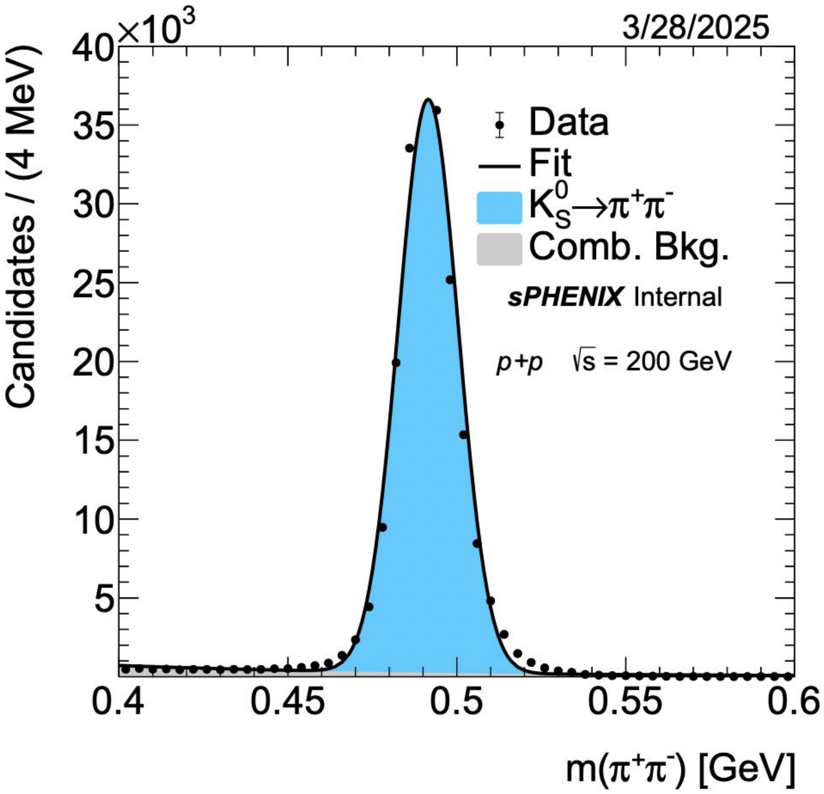
Open heavy flavour in sPHENIX





- Projection using the current recorded pp luminosity. Reach enabled by streaming readout
  - Non prompt D^0 R_{AA}. Unique at RHIC
  - Λ^+_c / D^0 with the current recorded pp luminosity
- Projections indicate that good statistics for D^0-tagged jets is available by using the sPHENIX jet trigger

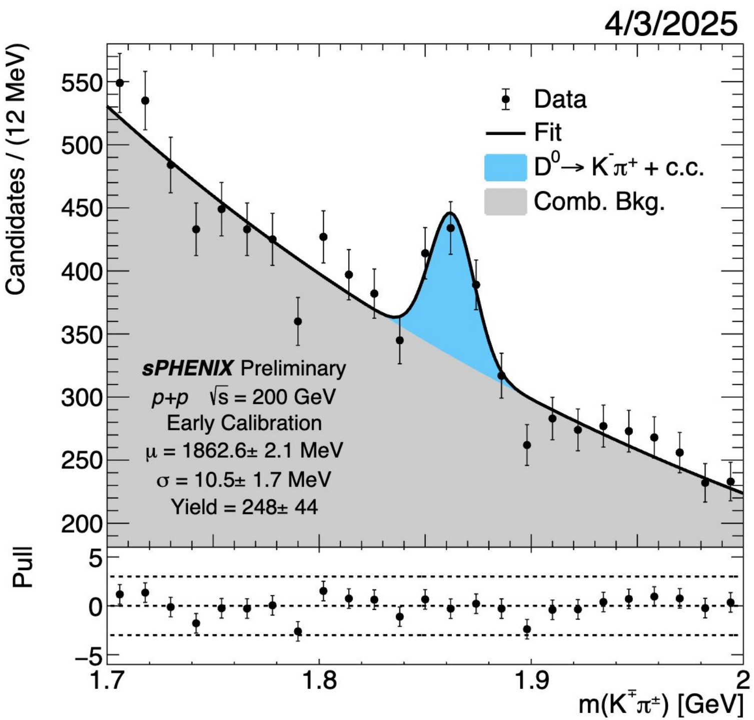
Road to heavy-flavor reconstruction



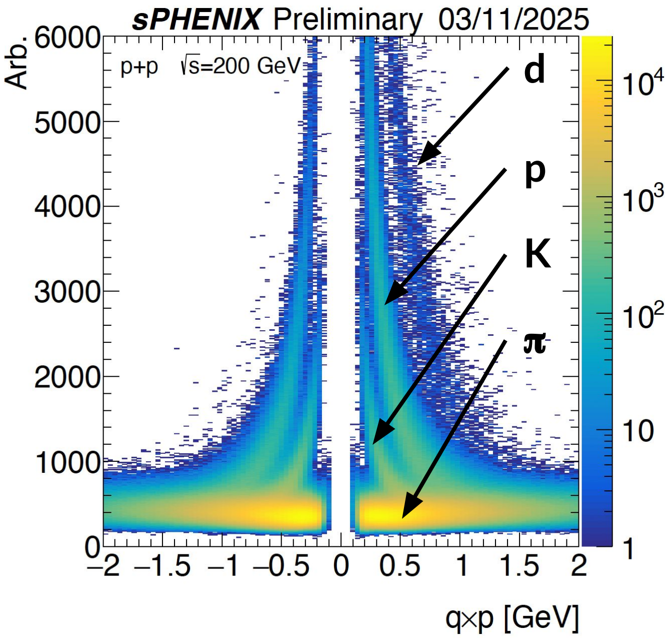
- Early calibration of the tracking system allows us to obtain a clear peak at the expected $K^0{}_s$ mass
- Important first steps before measuring more reconstruction-challenge particles like heavy flavor
- Current ongoing
  - Alignment for field-on data
  - Distortion corrections
  - Selection optimization

Road to heavy-flavor reconstruction

- With early calibrations of the tracking and tight cuts, we can observe the D^0 mass peak using data equivalent to ~1 hour of data taking



Although the sPHENIX heavy-flavor program was planned without it, particle identification provides a significant improvement in background rejection



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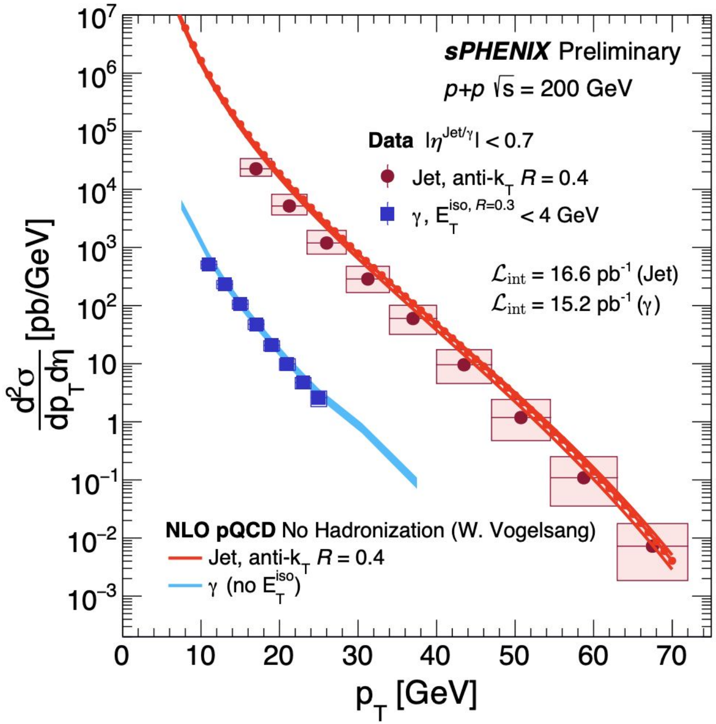
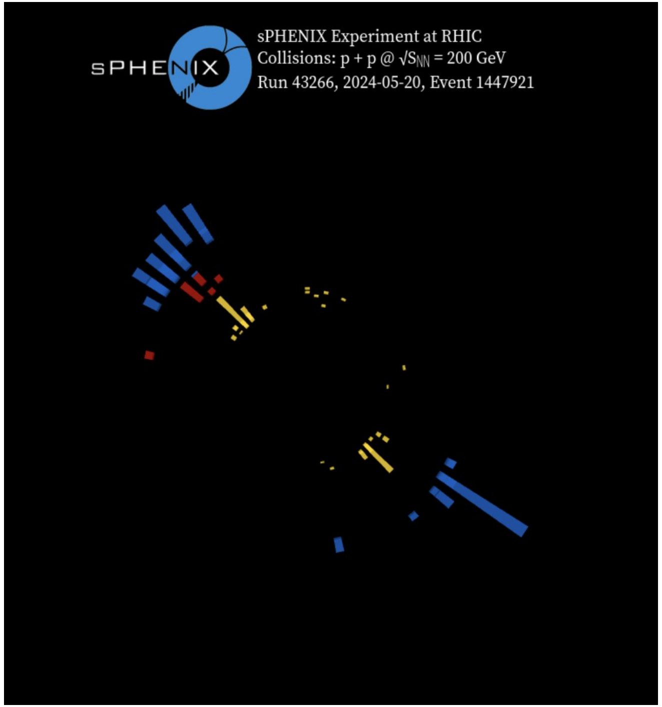
Road to jet reconstruction

- First measurement of jets in p+p collisions at sPHENIX corresponding to a subset of the data collected in sPHENIX run 2024 demonstrate good statistical reach for future photon + jet measurements
- Public results: **https://www.sphenix.bnl.gov/PublicResults**





Summary

- The technique of tagging jets with heavy-flavor hadrons has been improving in the last 15 years

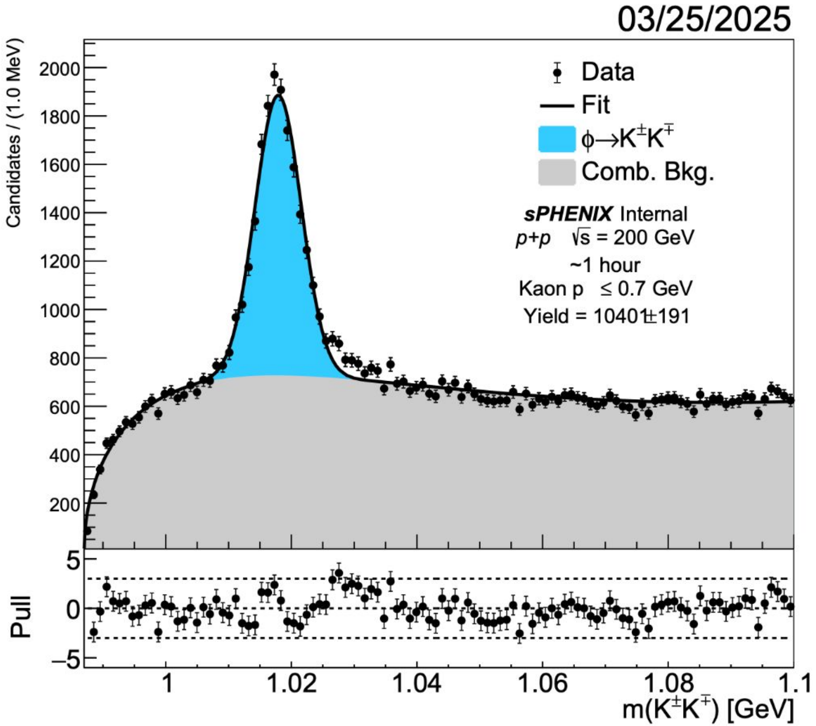
- Reconstructing jets containing the heavy-flavor hadron as one of its constituents solves inconsistencies caused by the decay daughters falling out of the jet cone

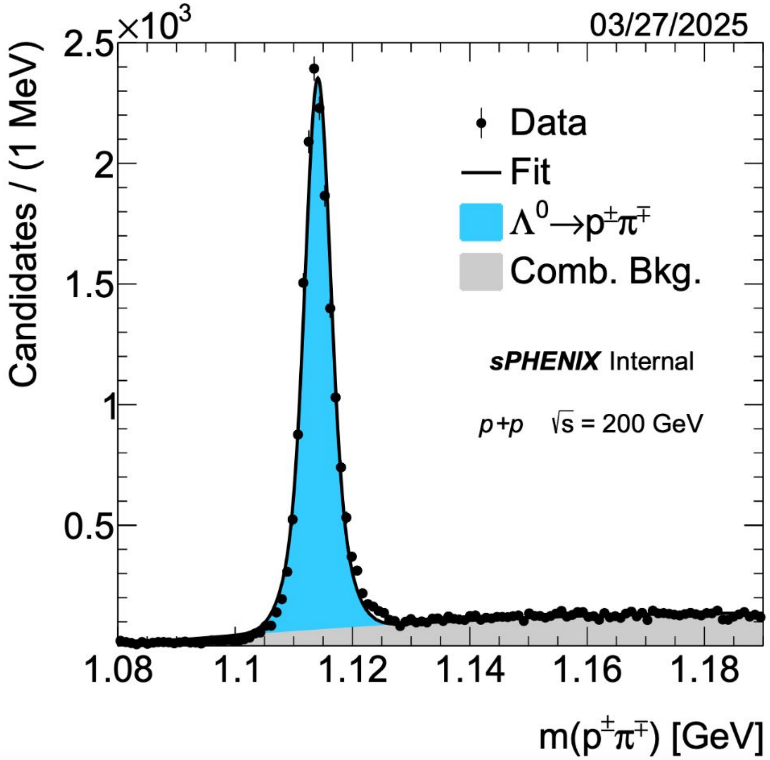
- sPHENIX had a unique capability of measuring heavy-flavor tagged jets
  - High precision tracking system + electromagnetic and hadronic calorimeters at pseudorapidity $|\eta| < 1.1$

- Huge effort in understanding and calibrating the sPHENIX tracking system
  - K^0_s, Λ^0 and ϕ particles successfully reconstructed

Backup

Backup


03/25/2025
Data
Fit
ϕ→K±K∓
Comb. Bkg.
sPHENIX Internal
p+p √s = 200 GeV
~1 hour
Kaon p ≤ 0.7 GeV
Yield = 10401±191
Candidates / (1.0 MeV)
Pull
m(K±K∓) [GeV]


03/27/2025
×10³
Data
Fit
Λ⁰→p±π∓
Comb. Bkg.
sPHENIX Internal
p+p √s = 200 GeV
Candidates / (1 MeV)
m(p±π∓) [GeV]