Heavy Flavor Physics Simulation For Hadronization at EicC

Senjie Zhu(朱森杰), Xiao Huang(黄逍)

University of Science and Technology of China

State Key Laboratory of Particle Detection and Electronics

September 8, 2023

The 5th EicC CDR workshop, Huizhou

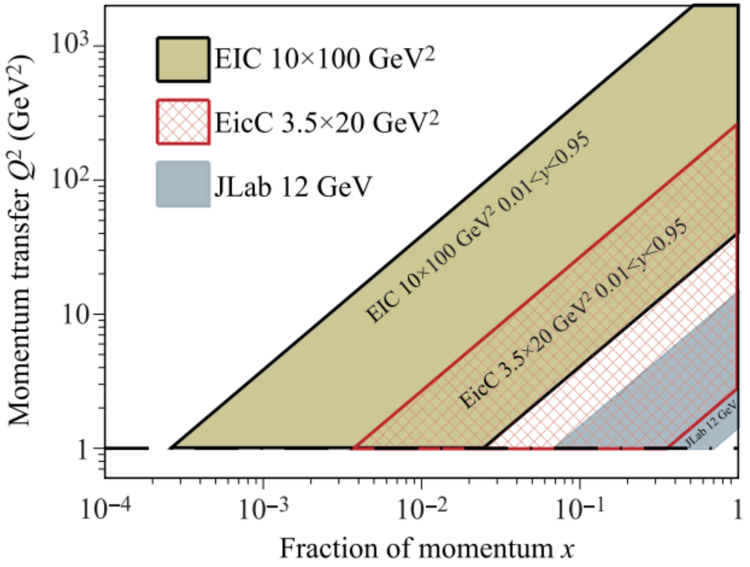
Outline

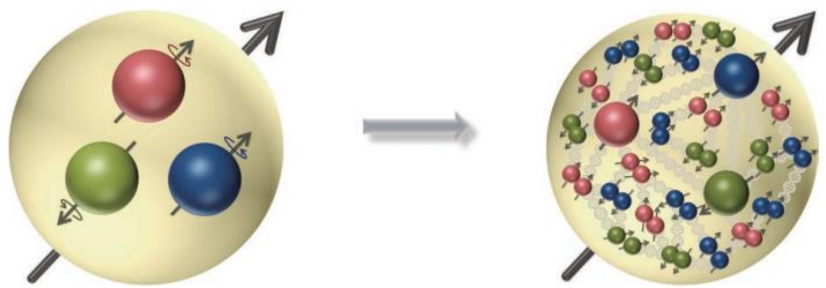
- Introduction
- Simulation Setup
- Reconstruction
- Physics Projections
- Conclusions

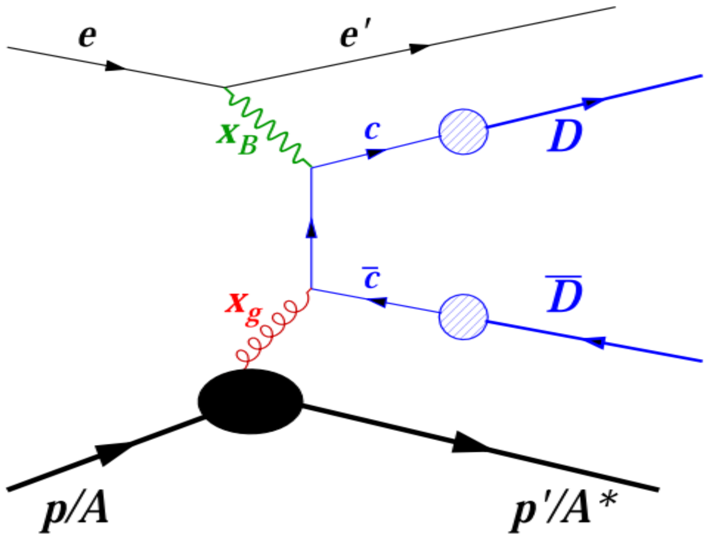
Outline

- Introduction
- Simulation Setup
- Reconstruction
- Physics Projections
- Conclusions

Introduction

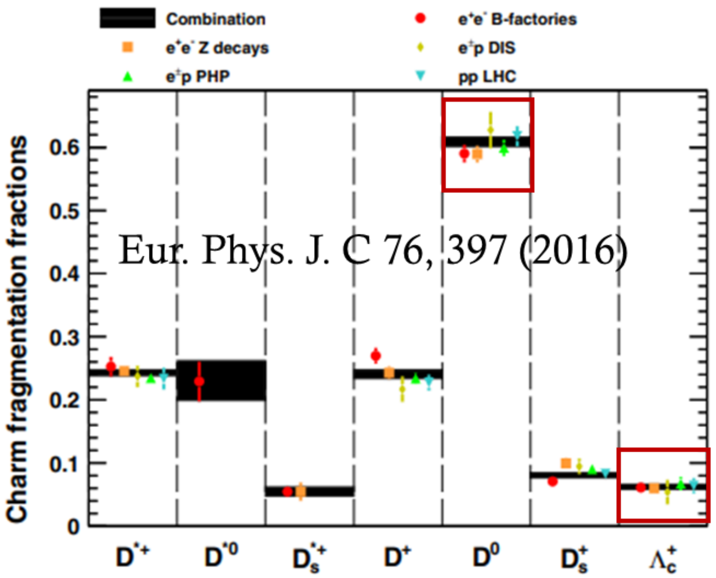


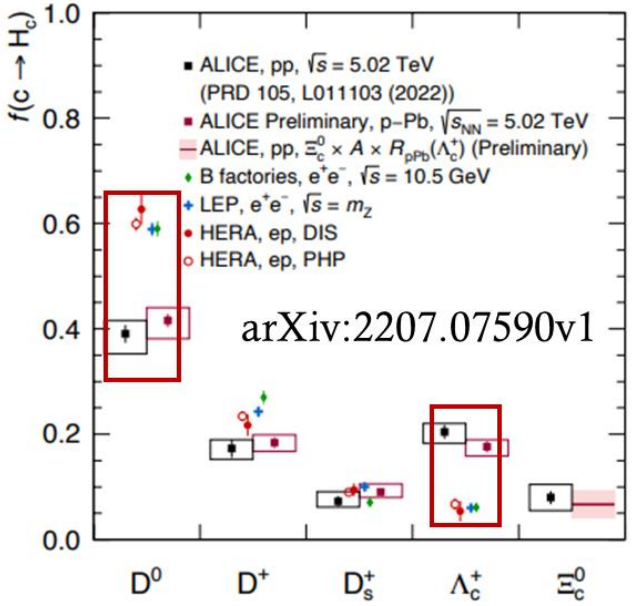


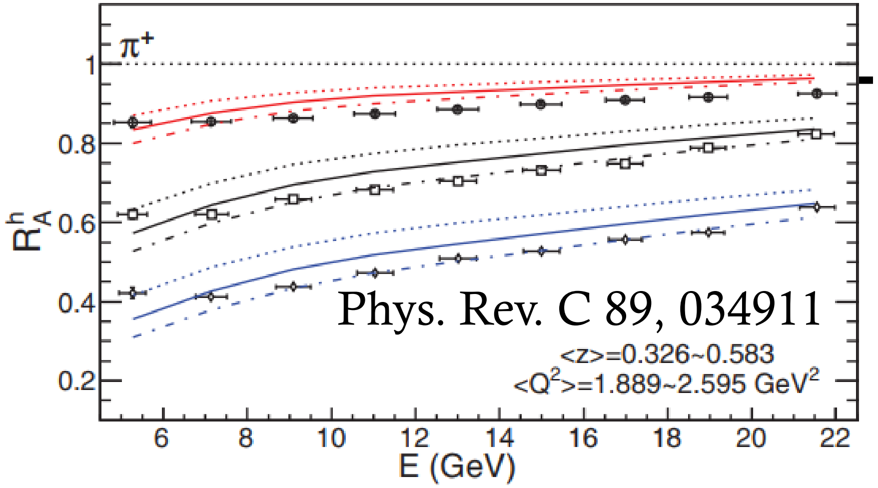


- Why Eic?
  - Electro-magnetic probe for nuclear structure
  - Cleaner DIS background than HI collision
- Why EicC?
  - High luminosity and unique kinematic coverage
- Why heavy flavor?
  - $\gamma g \to c\bar{c}$: Sensitive to gluon distribution

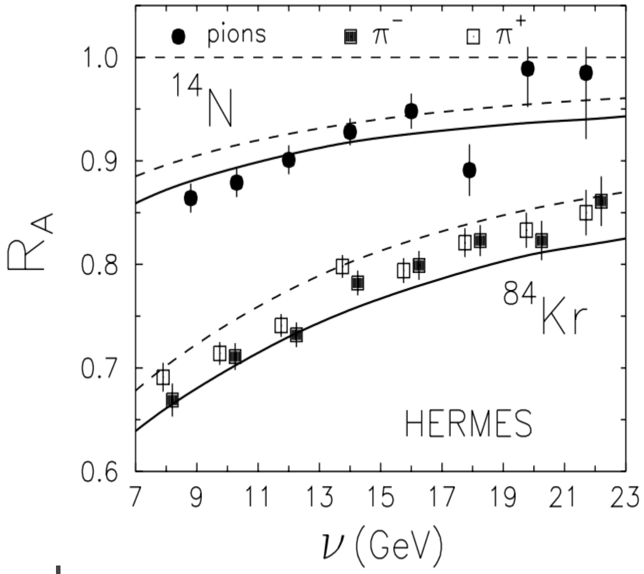
Introduction



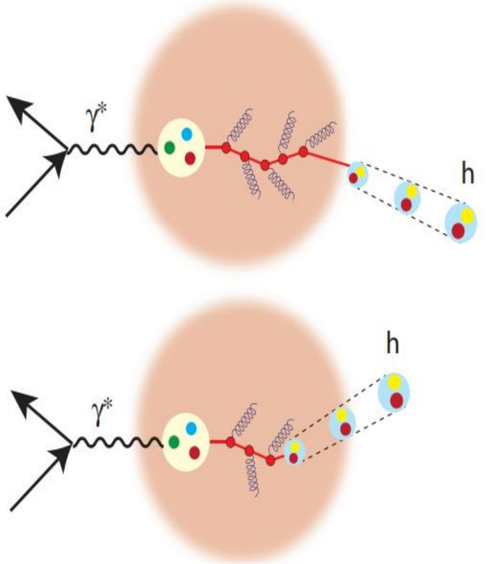




Nuclear Physics A 740 (2004) 211–245



- Both hadronization in vacuum and nucleus medium is complex and poorly understood.
  - In the recent ALICE results, the baryon-to-meson ratio deviated from the results of pp, e^+e^- and ep in the past.
  - Both parton energy loss and the hadron absorption model, two theories with different scales, can well describe the suppression of light hadrons.
- Our poor understanding of hadronization can be improved with precise measurement of heavy flavor production at Electron-ion collider in China (EicC).



Introduction

Available particles and their corresponding energy, polarization, luminosity and integrated luminosity at EicC

Particle	Momentum (GeV/c/u)	CM energy (GeV/u)	Average polarization	Luminosity at the nucleon level ($cm^{-2}\cdot s^{-1}$)	Integrated luminosity (fb^{-1})
e	3.5		80%		
p	20	16.76	70%	2.00×10^{33}	50.5
d	12.90	13.48	Yes	8.48×10^{32}	21.4
$^{3}He^{++}$	17.21	15.55	Yes	6.29×10^{32}	15.9
$^{7}Li^{3+}$	11.05	12.48	No	9.75×10^{32}	24.6
$^{12}C^{6+}$	12.90	13.48	No	8.35×10^{32}	21.1
$^{40}Ca^{20+}$	12.90	13.48	No	8.35×10^{32}	21.1
$^{197}Au^{79+}$	10.35	12.09	No	9.37×10^{32}	23.6
$^{208}Pb^{82+}$	10.17	11.98	No	9.22×10^{32}	23.3
$^{238}U^{92+}$	9.98	11.87	No	8.92×10^{32}	22.5

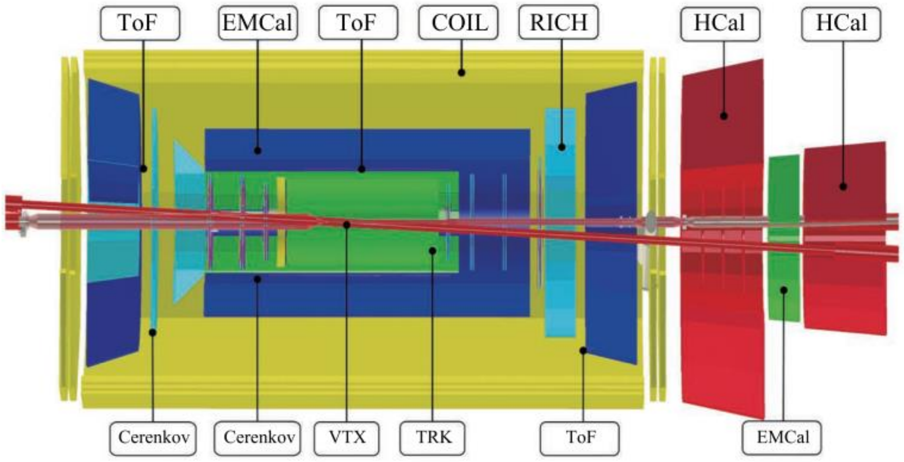
Outline

- Introduction
- Simulation Setup
- Reconstruction
- Physics Projections
- Conclusions

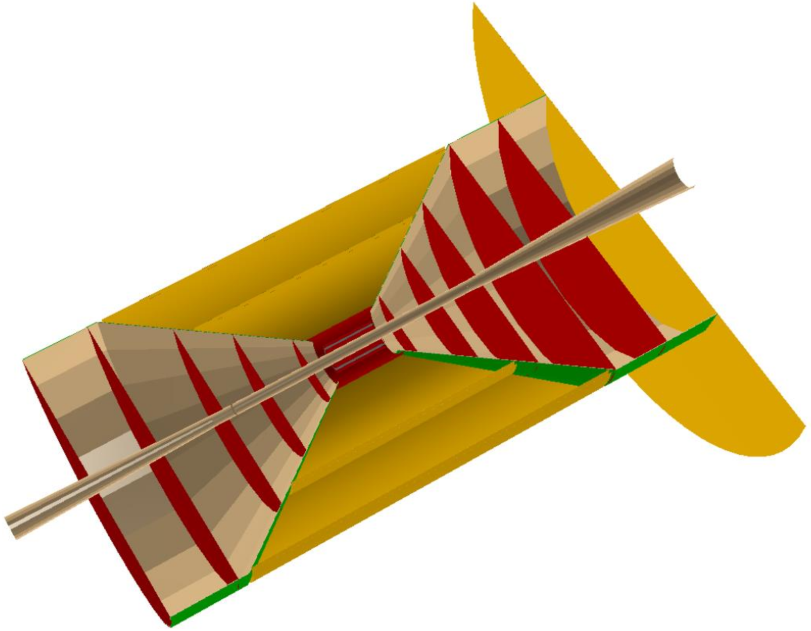
Detectors

	p-going	Barrel	e-going
Silicon	5	5	5
MPGD	1	4	0

ITS3, pixel size 10 μm
$|\eta| < 3$



Front. Phys. **16**, 64701 (2021)



Barrel:

R(cm)	Length(cm)	Pitch Size(μm)
3.30	28	10
4.35	28	10
5.40	28	10
8.00	28	10
15.00	38.70	10
47.72	127.47	150(rp)x150(z)
49.57	127.47	150(rp)x150(z)
75.61	201.98	150(rp)x150(z)
77.46	201.98	150(rp)x150(z)

End cap e going:

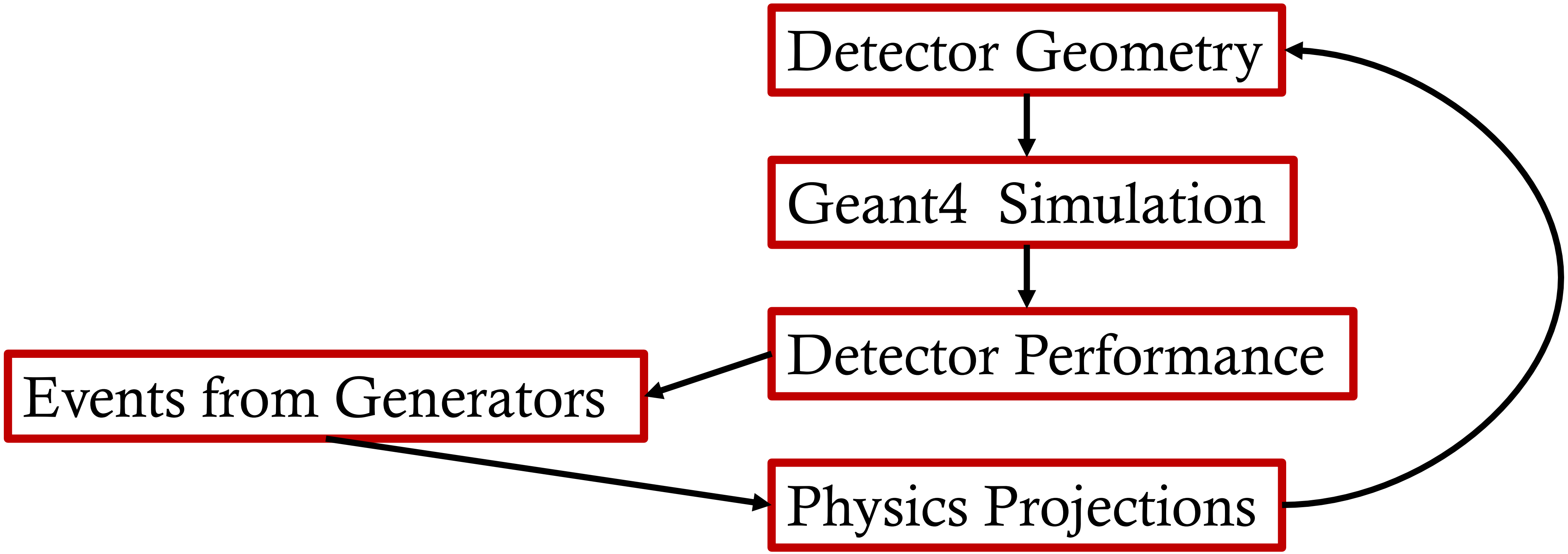
In R(cm)	Out R(cm)	Z(cm)
3.18	18.62	-25
3.18	36.50	-49
3.18	54.66	-73
3.95	77.46	-109.0
5.26	77.46	-145.0

End cap p going:

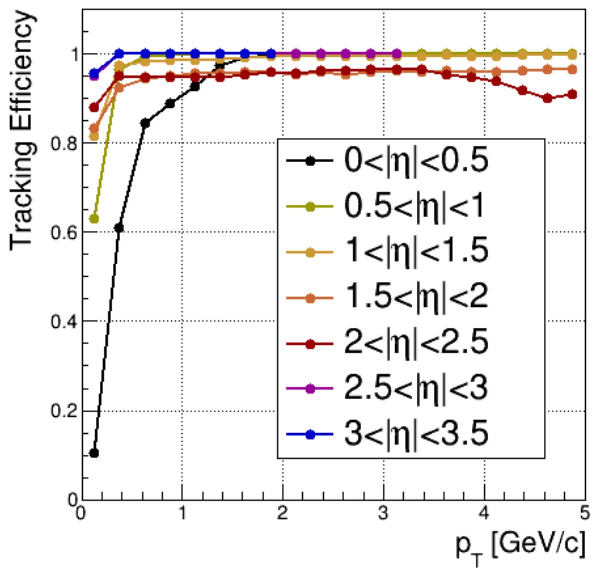
In R(cm)	Out R(cm)	Z(cm)
3.18	18.62	25
3.18	36.50	49
3.47	54.66	73
5.08	77.46	103.65
6.58	77.46	134.33
8.16	150.00	165.00

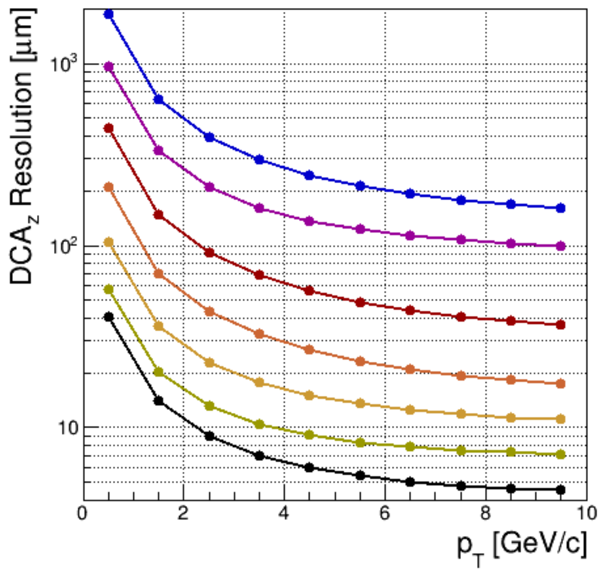
https://gitee.com/aiqiang-guo/EicC_Mvd_DP

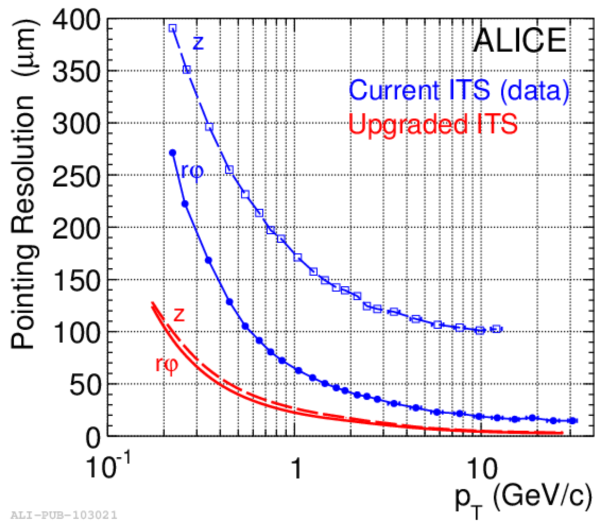
Simulation Setup

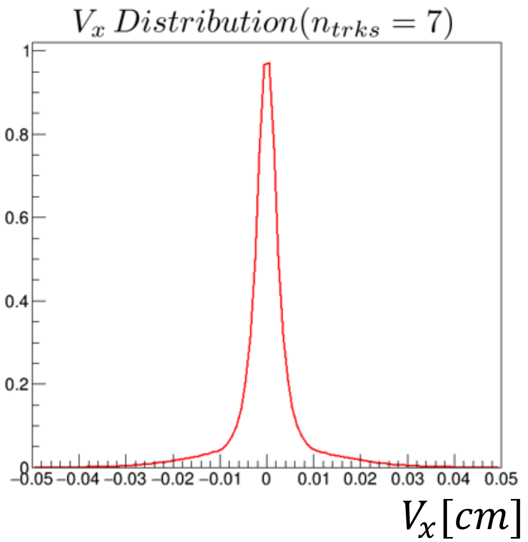


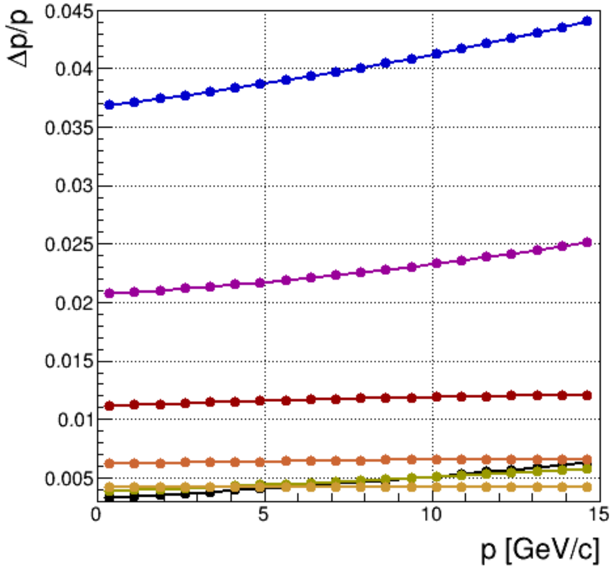
Detector Parameters

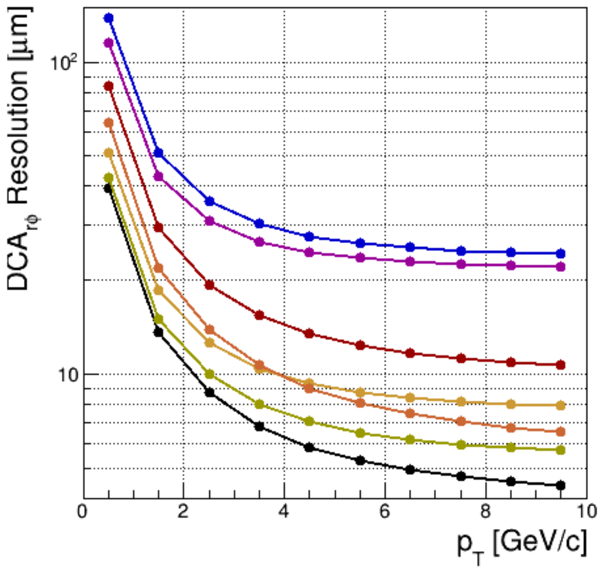












- Tracking Detectors & Vertex Detectors
  - Latest resolutions applied:
    https://gitee.com/aiqiang-guo/EicC_Mvd_DP
- eID Acceptance(3 σ *separation*)
  - $p_e > 0.35GeV/c, p_e < 20GeV/c$
- PID Acceptance (π\K\p) (3 σ *separation*)

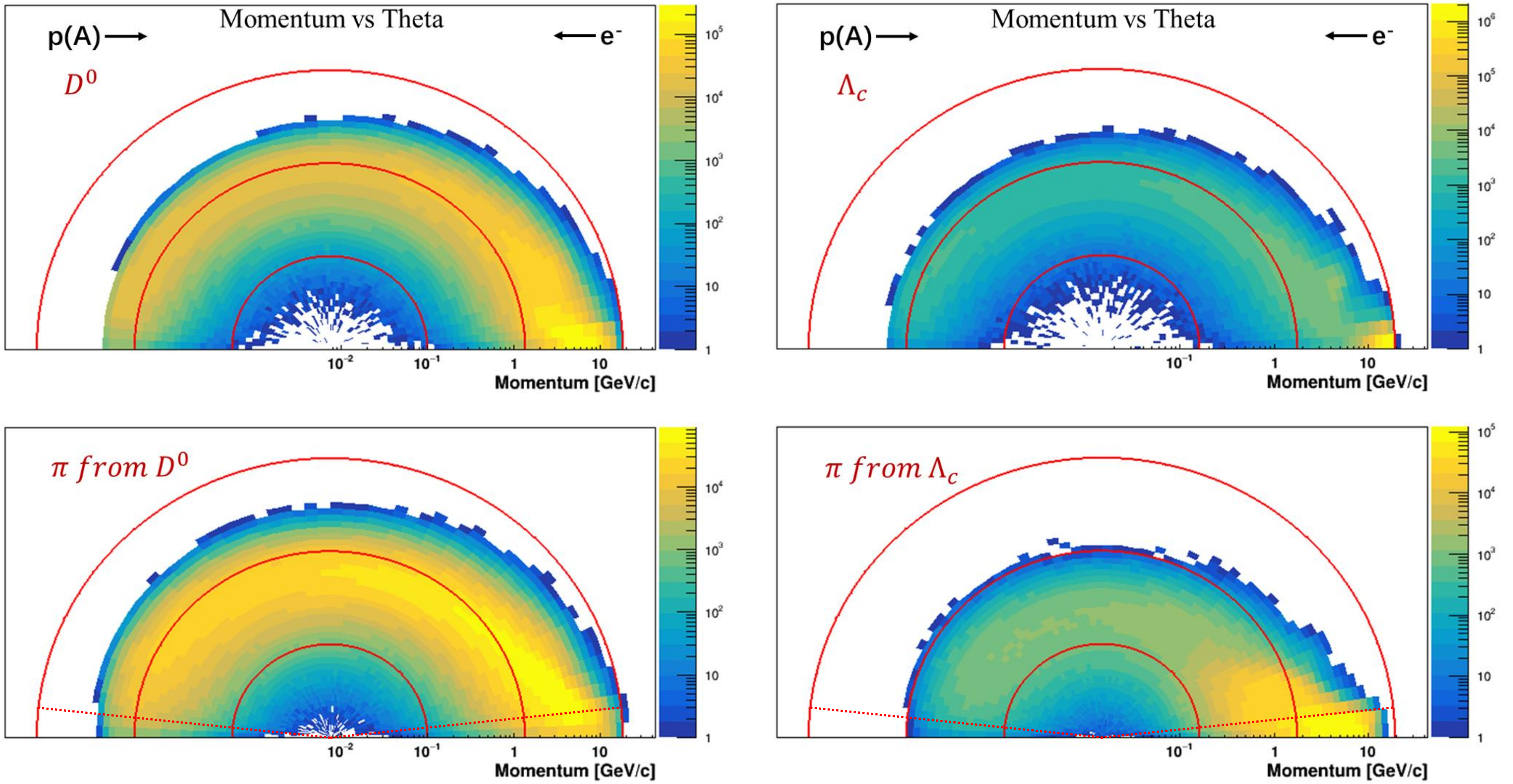
η	$[-3.5,1]$	$(-1,1]$	$(1,3.5]$
p_{max}	$4\ GeV$	$6\ GeV$	$15\ GeV$

$p_{hadron} > 0.3GeV/c$

Outline

- Introduction
- Simulation Setup
- Reconstruction
- Physics Projections
- Conclusions

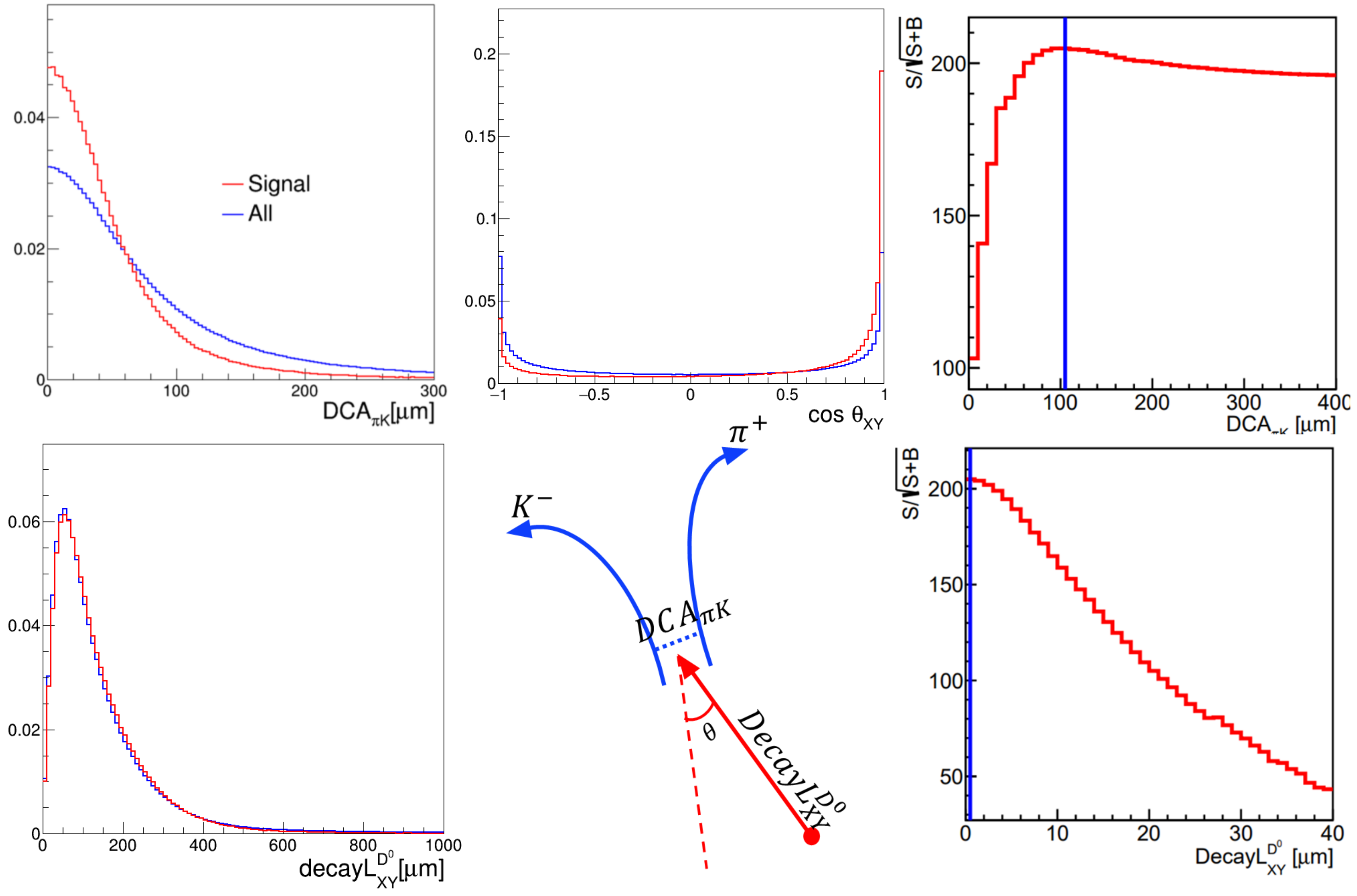
Generator and Reconstruction



- Event Generator
  - $e(3.5\ GeV)p(20\ GeV)$
  - $1\ GeV^2 < Q^2 < 200\ GeV^2$
- Pythiae6.428 $L_{int} = 8.06\ fb^{-1}$

  EicC run for 16 month

$D^0/\overline{D^0}$ Reconstruction



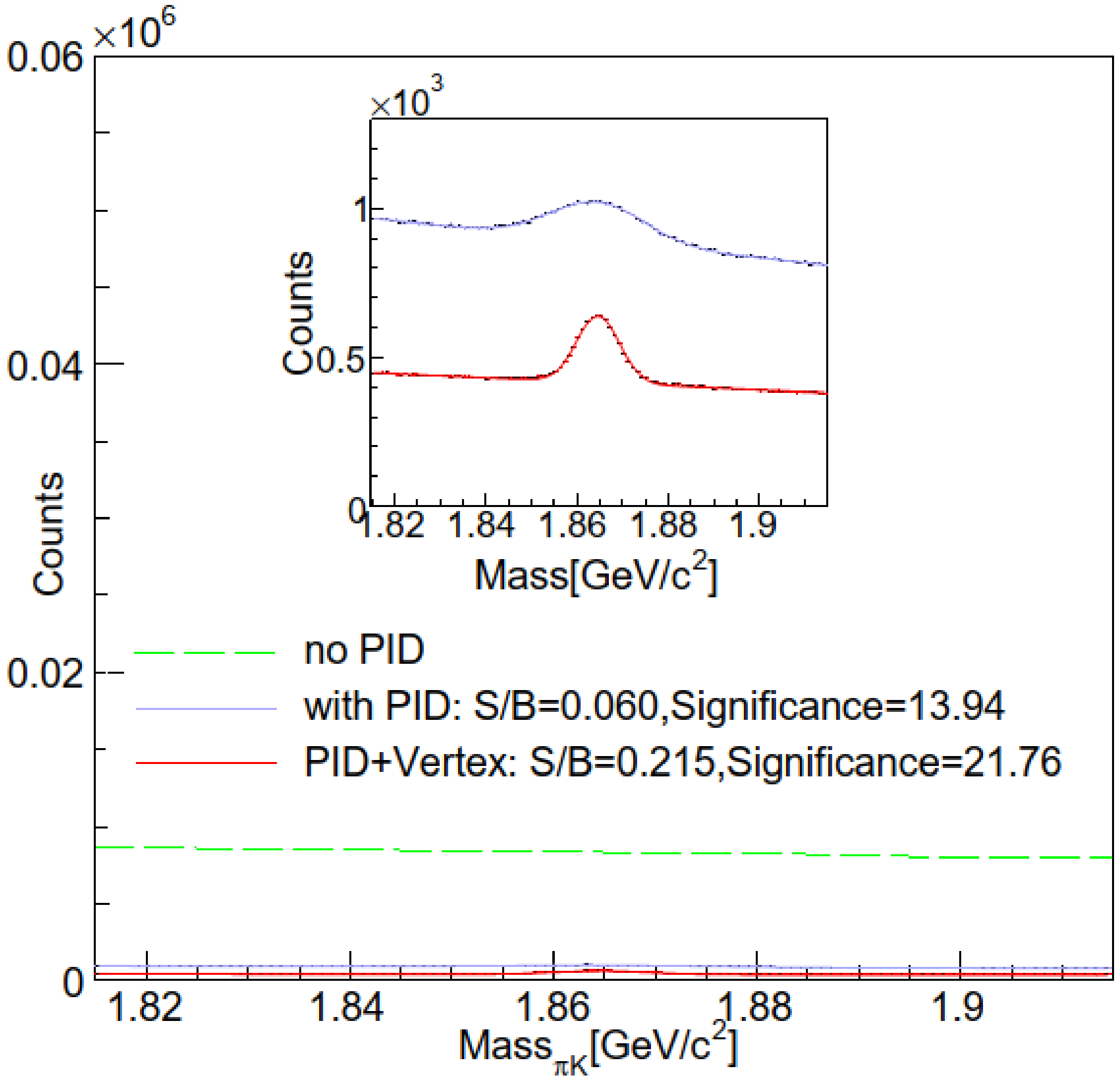
Cuts have been scanned recursively from left to right.

- $DecayL_{XY}^{D^0}$ is noneffective because p_T of most D^0 are lower than 1 GeV/c.

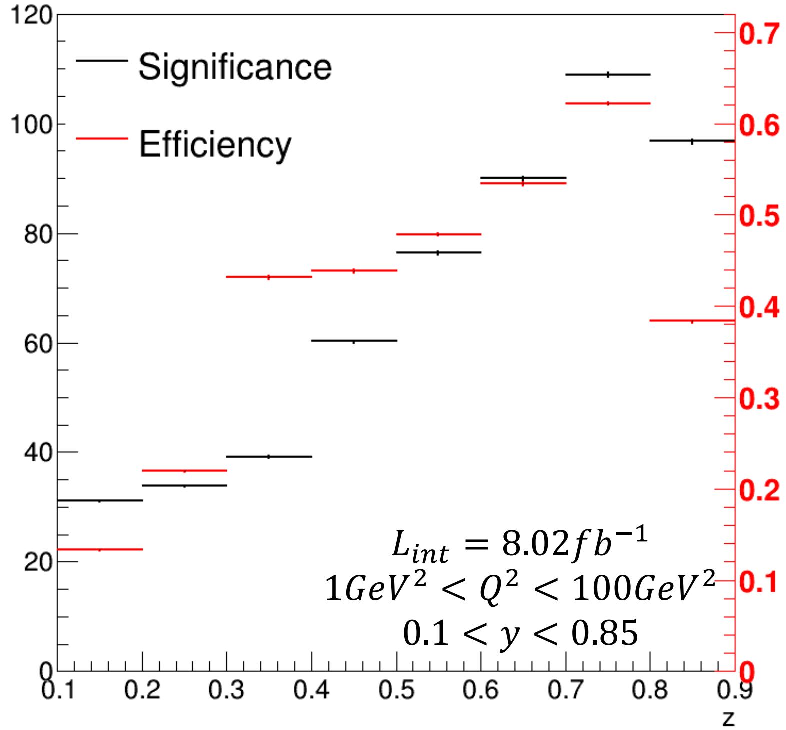
Applied Cut:

- $DCA_{\pi K} < 110\ \mu m$
- $cos\theta_{XY} > -0.75$

$D^0/\overline{D^0}$ Reconstruction

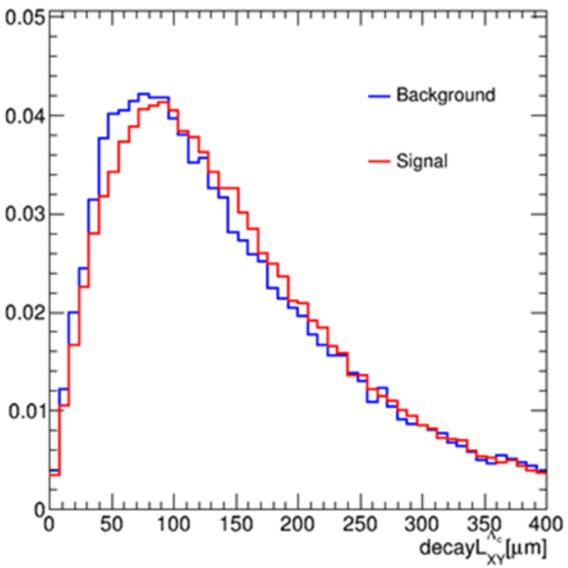


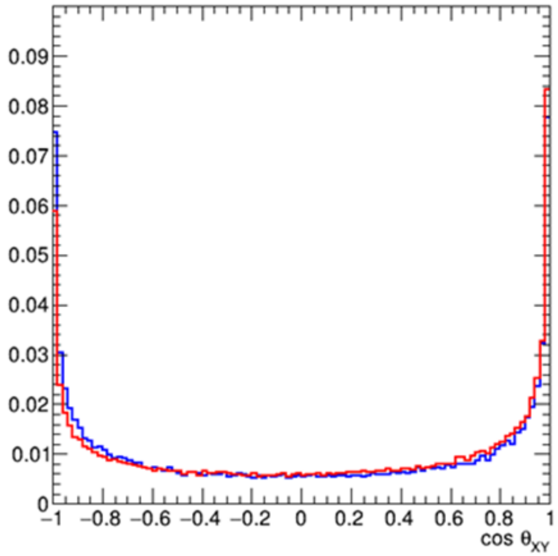
"no PID" and "with PID": Det_v0
"PID+Vertex": Det_v3

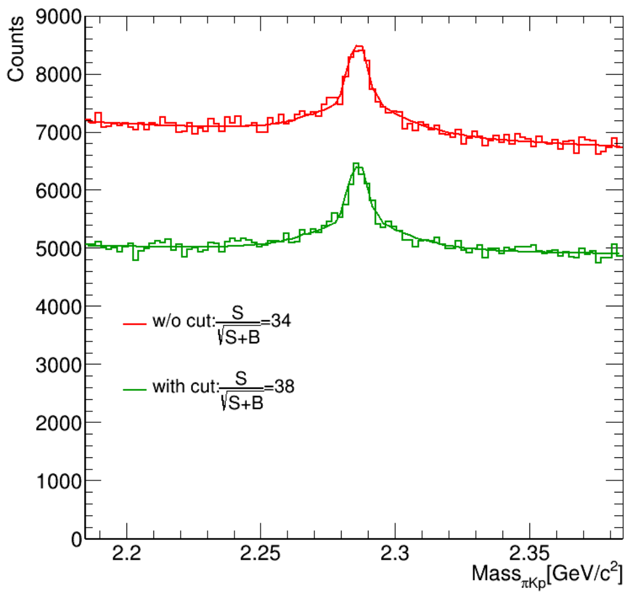


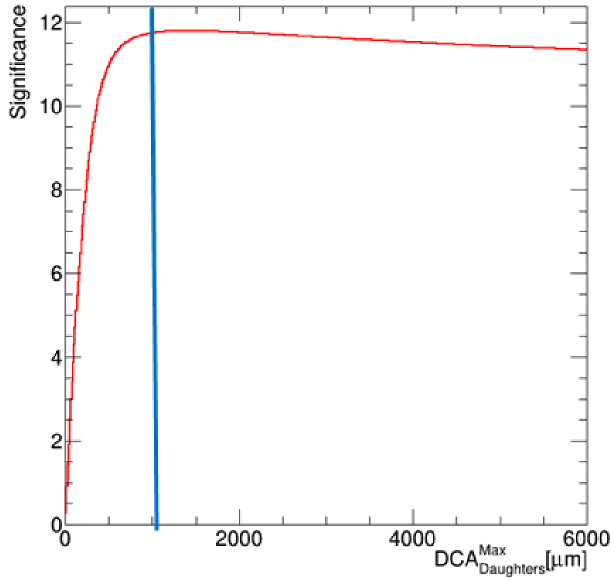
- no PID: all combination between opposite charge particles
- with PID: perfect PID at acceptance and abandoned if out of acceptance
- Vertex: topological cut applied to suppress background

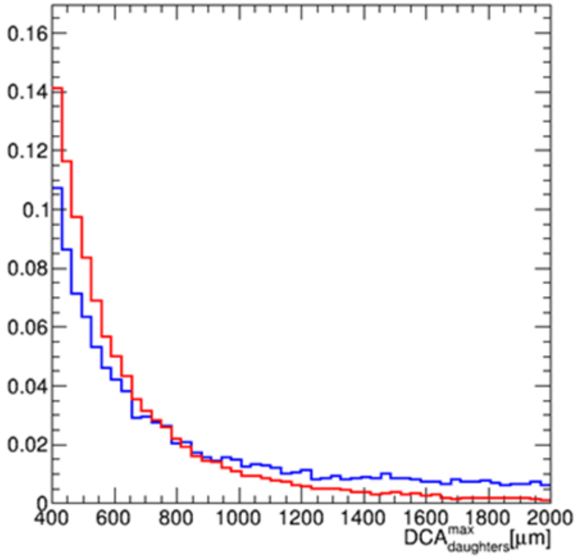
$\Lambda_c^{+/-}$ Reconstruction

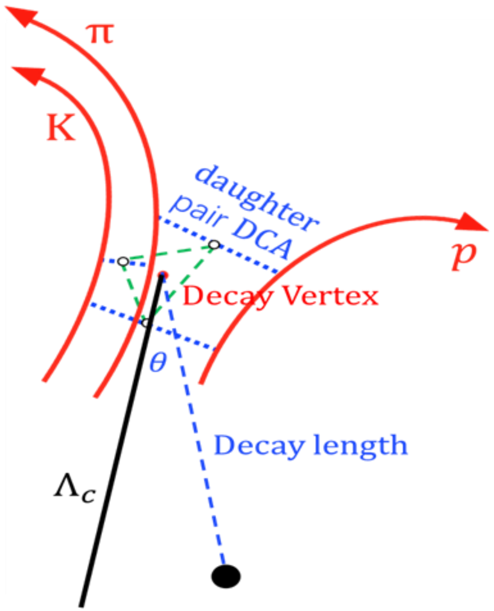










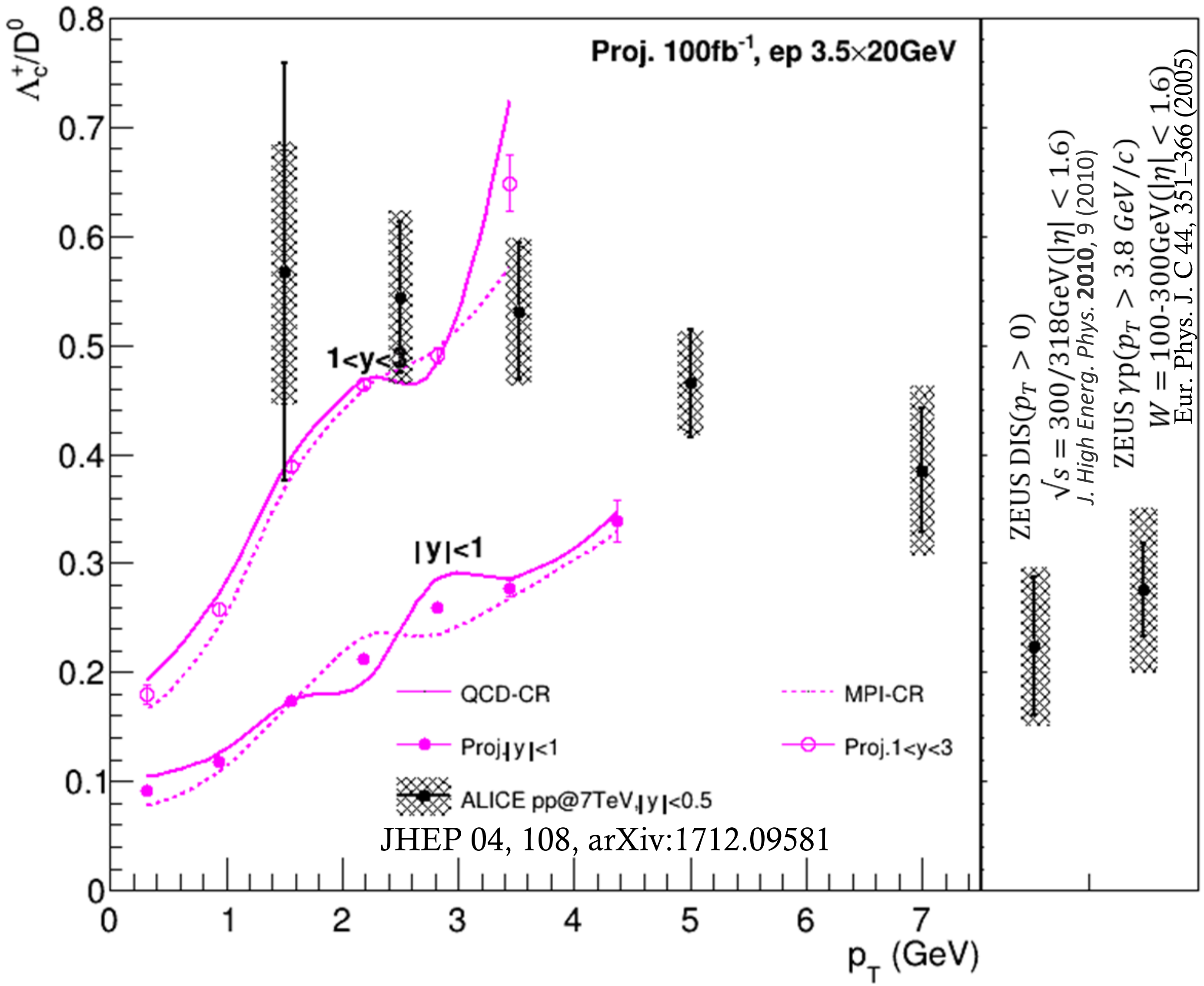


- The peak of Λ_c mass spectrum is broader than that of D^0 and non-gaussian.
- Histogram fit is applied.

Outline

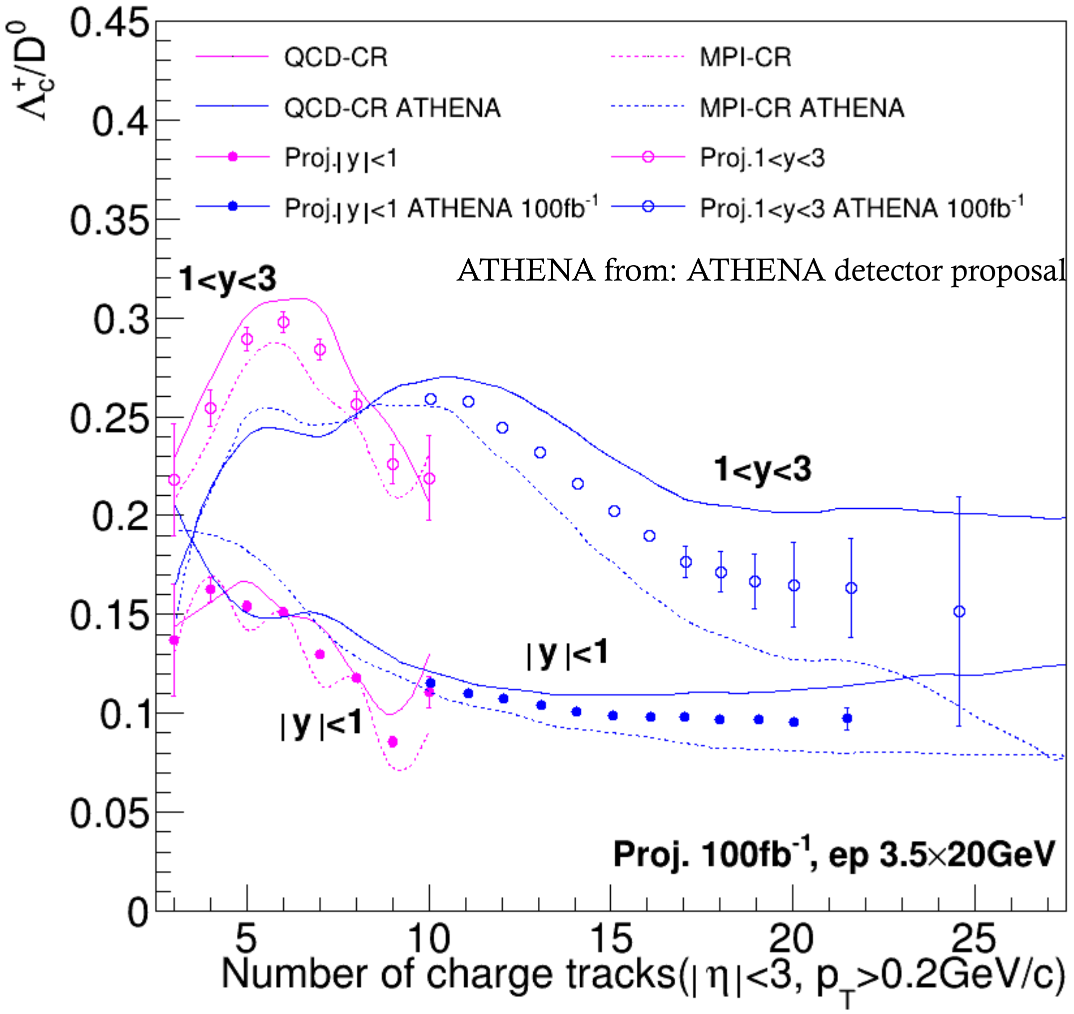
- Introduction
- Simulation Setup
- Reconstruction
- Physics Projections
- Conclusions

Baryon-to-meson Ratio vs p_T



- Fragmentation functions are thought to be universal.
- An enhancement of Λ_c^+/D^0 in pp system are found by ALICE in p+p at $\sqrt{s} = 5\ TeV$ and $\sqrt{s} = 7\ TeV$.
- Fragmentation can be well studied at wide kinematics region, especially at mid-rapidity, because of the high luminosity.

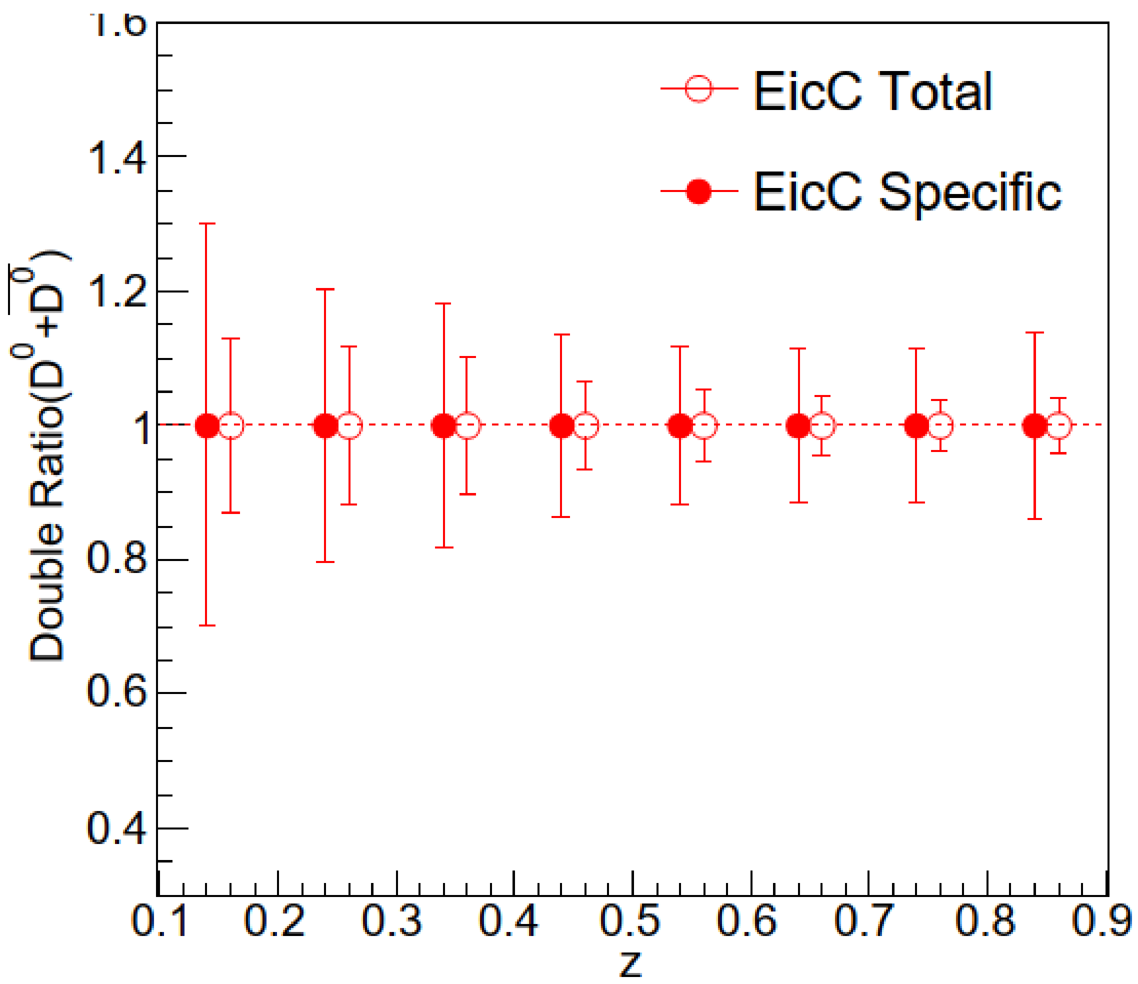
Baryon-to-meson Ratio vs multiplicity



- Track multiplicity are in truth level(efficiency~1 applied).
- Particles from Λ_c^+ and D^0 candidates are removed from multiplicity counting.

- EicC can provide measurement at low multiplicity, a complementary to EIC-US high multiplicity measurements.
- Fragmentation can be well studied, especially at mid-rapidity, because of the high luminosity.

Double Ratio of D^0



- Double Ratio

$$R_A^h = \frac{N_{eA}^h(z,x,Q^2)/N_{eA}^{e_{DIS}}(x,Q^2)}{N_{ep}^h(z,x,Q^2)/N_{ep}^{e_{DIS}}(x,Q^2)}$$

- Number of DIS electron divided to cancel the initial state effects

- Measurements at low ν and Q^2 regions
- Study nuclear matter effects at wider kinematic region.

z: *hadron energy fraction of virtual photon at the target rest frame*

z

New Configuration From Yuming

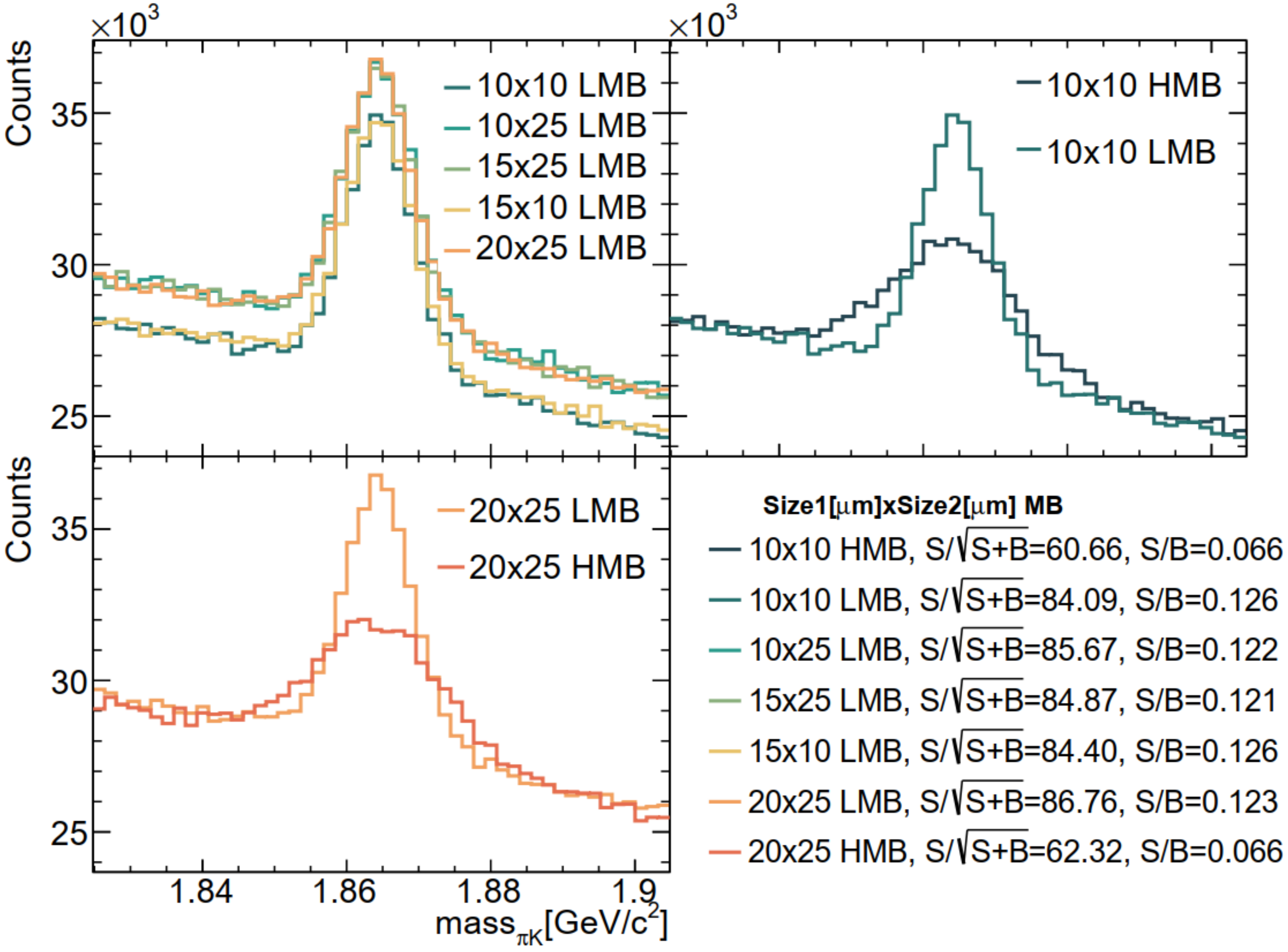
Det_v3_10_10_HMB	Det_v3_10_10_MMB	Det_v3_10_10_LMB
Det_v3_10_25_HMB	Det_v3_10_25_MMB	Det_v3_10_25_LMB
Det_v3_15_10_HMB	Det_v3_15_10_MMB	Det_v3_15_10_LMB
Det_v3_15_25_HMB	Det_v3_15_25_MMB	Det_v3_15_25_LMB
Det_v3_20_10_HMB	Det_v3_20_10_MMB	Det_v3_20_10_LMB
Det_v3_20_25_HMB	Det_v3_20_25_MMB	Det_v3_20_25_LMB

Pitch Size

Low/Middle/High Materiel Budget

In Green Box: To be studied

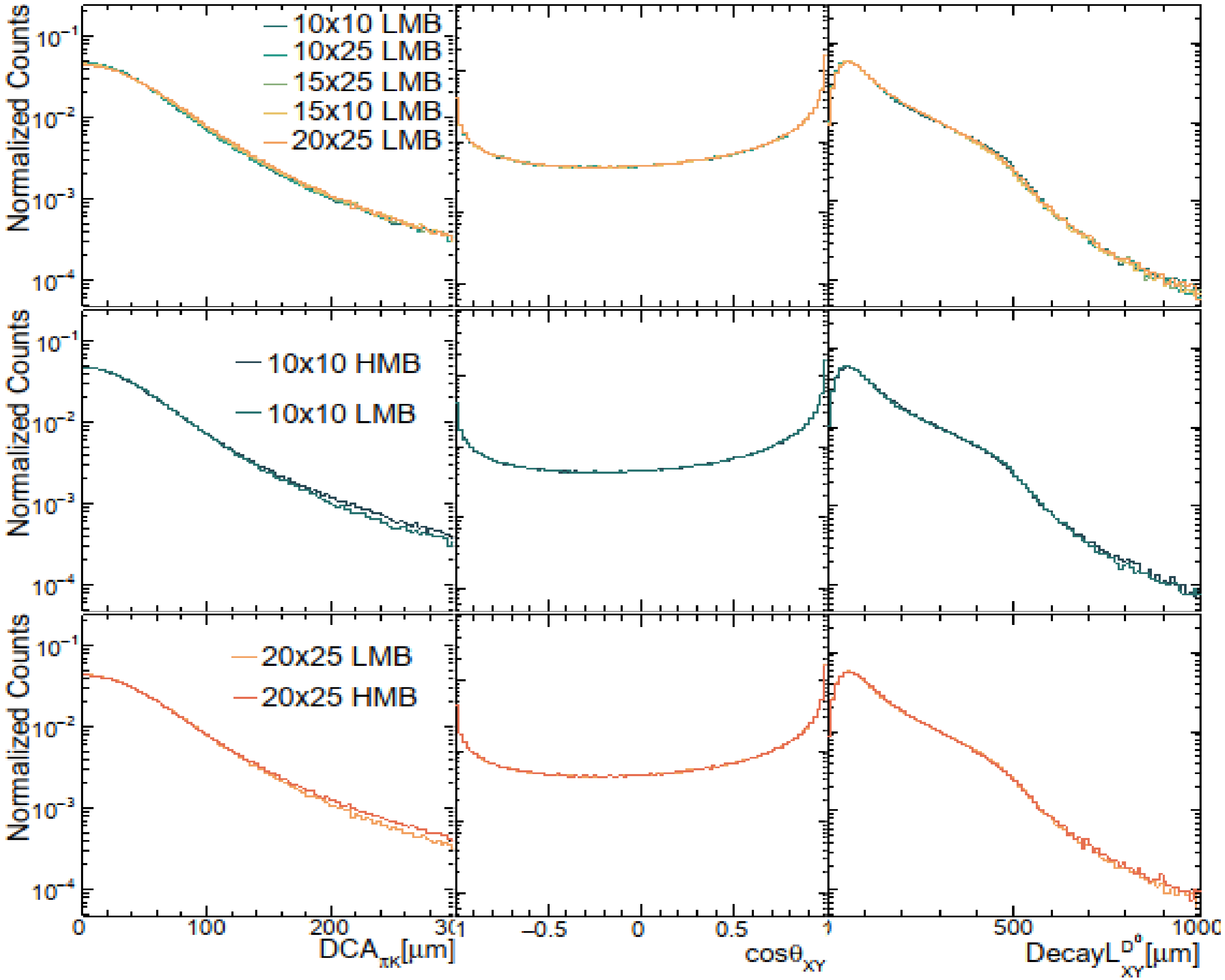
Results Without Any Cut



Without Any Cut

- Size2 is more important to the shape than Size1.
- The material budget will compromise the momentum resolution.
- When the material budget is low, the resolution of signal is almost equal to 48.5 MeV/c^2.
- Significance isn't sensitive to pitch size. Actually, it becomes a little smaller as the pitch size decreases.

Topological Cut Comparison(Signal)



- Pitch sizes and material budget seem to have little effect to the topological distribution.

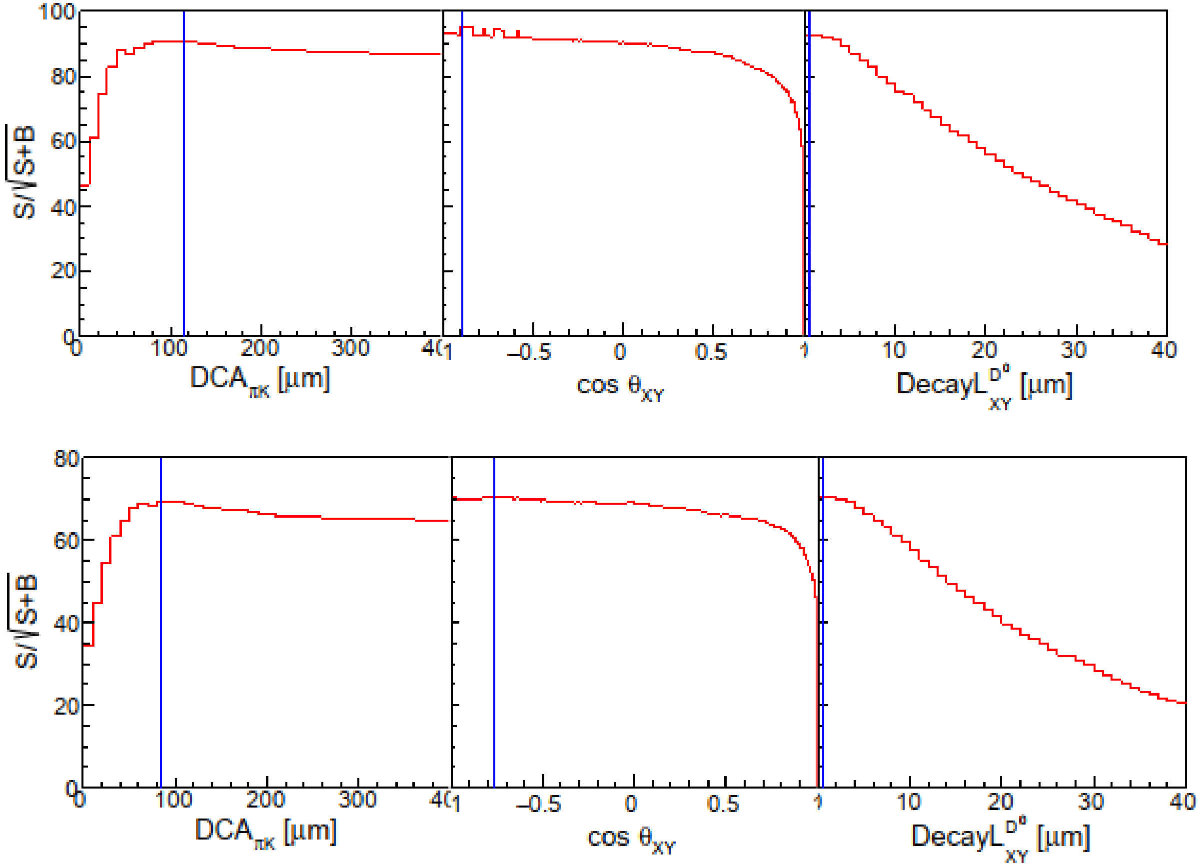
TMVA

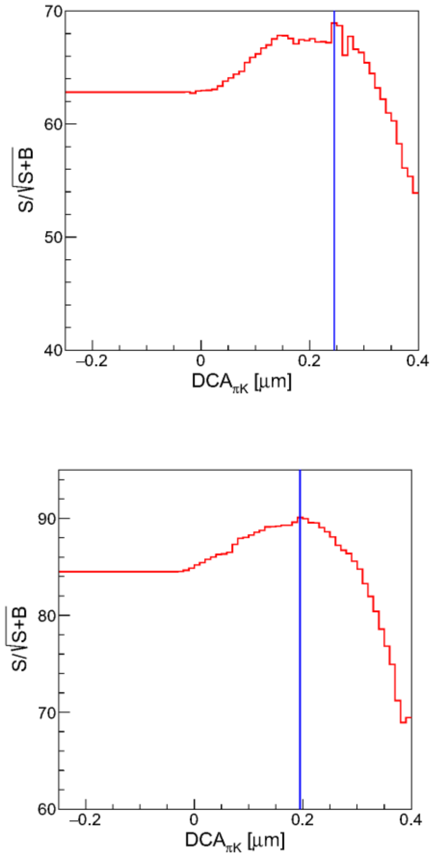
Cut Scan

TMVA

10x10 LMB

10x10 HMB





TMVA can’t improve the performance. It may be caused by poor training.

	10x10 LMB	10x10 HMB
Cut Scan	$s/\sqrt{s+b} = 92.5$	$s/\sqrt{s+b} = 70.6$
TMVA	$s/\sqrt{s+b} = 90.5$	$s/\sqrt{s+b} = 68$

Conclusion

- Heavy flavor physics with the latest detector performance parameters is simulated for EicC.
- Several Projections are done including:
    - Baryon-to-meson Ratio: Hadronization in vacuum at different collision system
    - D^0 double ratio vs. z: a complementary to EIC-US, wider kinematic region to study the nuclear medium of nuclear effect on hadronization
- EicC can provide precise measurements on open heavy flavor production and deepen our understanding of hadronization both in e+p system and in nuclear medium.

Thank you for attention!

BACKUP

pythiaeRHIC tune

```
MSEL=2                  PARP(13)=1                MSTJ(12)=1
MSTP(13)=1              PARP(18)=0.17 ! hermes P/ MSTJ(45)=5
MSTP(14)=30             PARP(81)=1.9              MSTU(16)=2
MSTP(15)=0              PARP(89)=1800             MSTU(112)=5
MSTP(16)=1              PARP(90)=0.16             MSTU(113)=5
MSTP(17)=6 ! MSTP 17=( PARP(91)=0.40 ! rms kt D: MSTU(114)=5
MSTP(18)=3              PARP(93)=5.               ! ----------- Now all
MSTP(19)=1 ! Hermes M! PARP(97)=6.0  ! D=1.0, tı CKIN(1)=1.
MSTP(20)=4 ! Hermes M! PARP(99)=0.40              CKIN(2)=-1.
MSTP(32)=8              PARP(100)=5               CKIN(3)=0.
MSTP(38)=4              PARP(102)=0.28            CKIN(4)=-1.
MSTP(51)=10042 ! if pı PARP(103)=1.0             CKIN(5)=1.00
!MSTP(51)=7             PARP(104)=0.8             CKIN(6)=1.00
MSTP(52)=2   ! ---> pı PARP(111)=2.0             CKIN(7)=-10.
MSTP(53)=3              PARP(161)=3.00            CKIN(8)=10.
MSTP(54)=1              PARP(162)=24.6            CKIN(9)=-40.
MSTP(55)=5              PARP(163)=18.8            CKIN(10)=40.
MSTP(56)=1              PARP(164)=11.5            CKIN(11)=-40.
MSTP(57)=1              PARP(165)=0.47679         CKIN(12)=40.
MSTP(58)=5              PARP(166)=0.67597 ! PARP: CKIN(13)=-40.
MSTP(59)=1              ! PARP(166)=0.5           CKIN(14)=40.
MSTP(60)=7              ! ----------- Now come a' CKIN(15)=-40.
MSTP(61)=2              PARJ(1)=0.100             CKIN(16)=40.
MSTP(71)=1              PARJ(2)=0.300             CKIN(17)=-1.
MSTP(81)=0              PARJ(3)=0.4               CKIN(18)=1.
MSTP(82)=1              PARJ(11)=0.5              CKIN(19)=-1.
MSTP(91)=1              PARJ(12)=0.6              CKIN(20)=1.
MSTP(92)=3     ! herı PARJ(21)=0.40 ! fragpt w: CKIN(21)=0.
MSTP(93)=1              PARJ(32)=1.0              CKIN(22)=1.
MSTP(94)=2     ! D=3  PARJ(33)=0.80              CKIN(23)=0.
MSTP(101)=1             PARJ(41)=0.30             CKIN(24)=1.
MSTP(102)=1             PARJ(42)=0.58             CKIN(25)=-1.
MSTP(111)=1             PARJ(45)=0.5              CKIN(26)=1.
MSTP(121)=0             PARJ(170)=0.20 !pt for rı CKIN(27)=-1.
! ----------- Now all !------------------------ CKIN(28)=1.
PARP(2)=5. !min CMS eı MSTJ(1)=1                  CKIN(31)=2.
PARP(13)=1              MSTJ(12)=1                CKIN(32)=-1.
PARP(18)=0.17 ! herme: MSTJ(45)=5                 CKIN(35)=0.
```

```
CKIN(32)=-1.
CKIN(35)=0.
CKIN(36)=-1
CKIN(37)=0.
CKIN(38)=-1.
CKIN(39)=4.
CKIN(40)=-1.
CKIN(65)=1.e-09          ! M
CKIN(66)=-1.         ! Max f
CKIN(67)=0.
CKIN(68)=-1.
CKIN(77)=2.0
CKIN(78)=-1.
~
```

Color Reconnection

the decay $B^+ = u\bar{b} \rightarrow u\bar{c}W^+ \rightarrow (u\bar{c})(c\bar{s}) \rightarrow (u\bar{s})(c\bar{c}) \rightarrow K^+ J/\psi \rightarrow K^+\mu^+\mu^-$ [4], where we have used brackets in intermediate states to delineate separate color singlet identities.

s10052-015-3674-4 (springer.com)

The MPI-based scheme

PYTHIA 8 online manual

In this scheme partons are classified by which MPI system they belong to. The colour flow of two such systems can be fused, and if so the partons of the lower-pT system are added to the strings defined by the higher-pT system in such a way as to give the smallest total string length. The bulk of these lower-pT partons are gluons, and this is what the scheme is optimized to handle.

The newer scheme

QCD-CR

The newer CR scheme builds on the minimization of the string length as well as the colour rules from QCD. A main feature of the new model is the introduction of junction structures. These are possible outcomes of the reconnection in addition to the more common string-string reconnections. The model works by constructing all pair of dipoles that are allowed to reconnect by QCD colour rules and switching if the new pair has a lower string length. Junctions are also allowed to be directly produced from three, and in some special cases, four dipoles. This is done iteratively until no further allowed reconnection lowers the total string length.

Color Reconnection for Beam Remnants

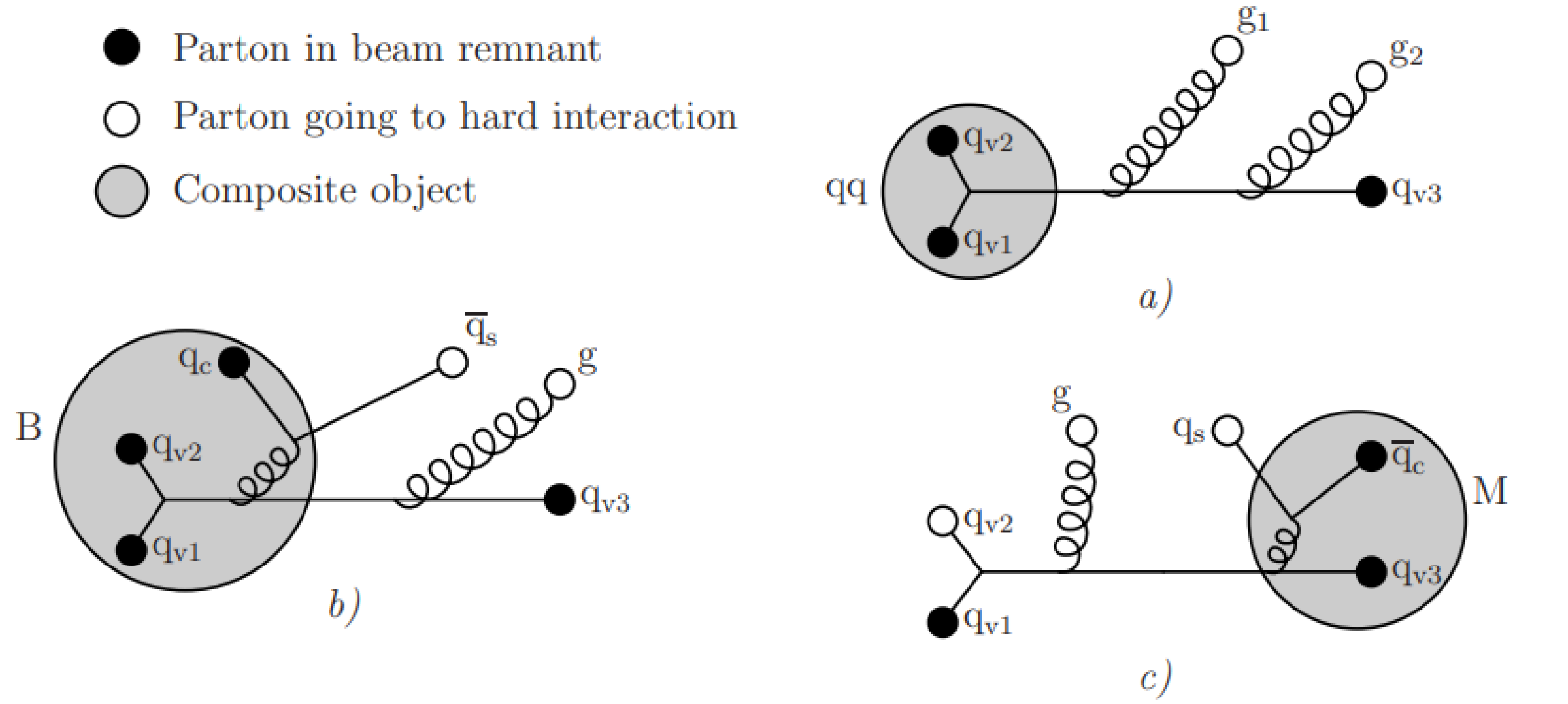


Figure 10: Examples of the formation of composite objects in a baryon beam remnant: (*a*) diquark, (*b*) baryon and (*c*) meson.