Primary Vertex Resolution Studies and Impacts on Charm Reconstruction

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Introduction

Collision position important for reconstructing heavy-flavor (HF) decays

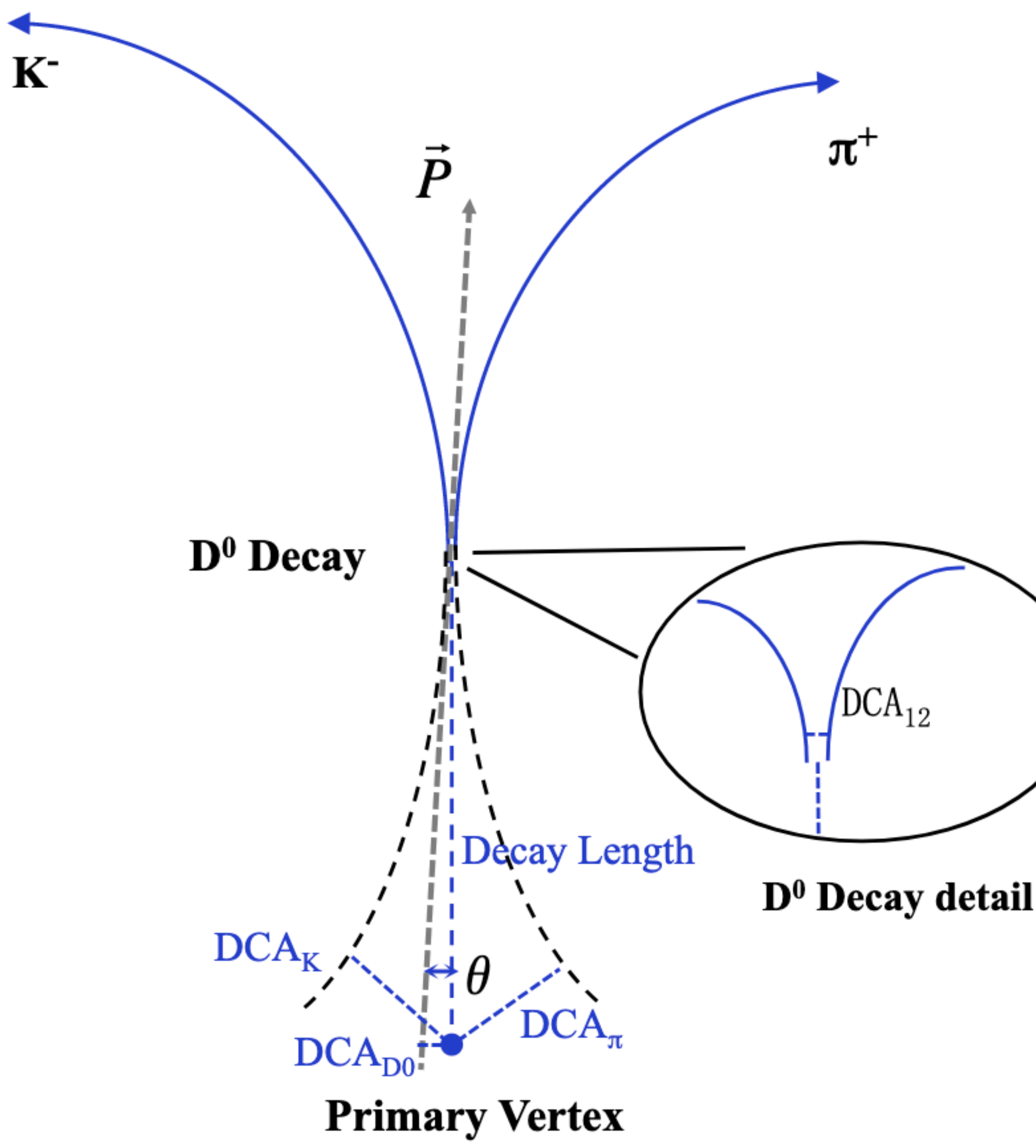
- S/B greatly improved with reconstructing secondary HF decay vertices
- Hadronization studies via $\Lambda_c(\rightarrow pK\pi)$ ($c\tau$ ~60 μm) production in e-A collisions
- Enabling of bottom reconstruction with displaced $D^{0/+}$, e, and J/ψ
- HF jet tagging

Current estimate of transverse and longitudinal beam constraints not "optimal" for heavy-flavor reconstruction

- O(cm) in z and ~60 μm x 10 μm in y-x

Primary vertex (PV) resolution driven by track multiplicity (eff.) and pointing resolution

- e-$p(A)$ collisions expected to have lower multiplicity w.r.t. $p(A)$-$p(A)$
- All-silicon tracker poised for better PV resolution (See Rey's nice ongoing studies)



Basic Outline of PV Studies

Simulated e-p collisions with PYTHIA6.4
Consider all charged π,K, and p with $|\eta|<1,3$
Assume 100% tracking eff.

Track momentum and position smeared using detector matrix
https://physdiv.jlab.org/DetectorMatrix/

PV fit

PYTHIA 6.4 Setup

EIC tune provided by BNL group
(https://wiki.bnl.gov/eic/index.php/PYTHIA)

Minimum $Q^2 = 1$ (GeV²)

No radiative corrections

Simulated beam energies (in GeV):

- $18\ e + 275\ p$
- $10\ e + 100\ p$
- $5\ e + 100\ p$
- $5\ e + 41\ p$
- $18\ e + 110\ p$
- $10\ e + 110\ p$

e-p program (first four); e-A program (last three, from $5\ e + 41\ p$)

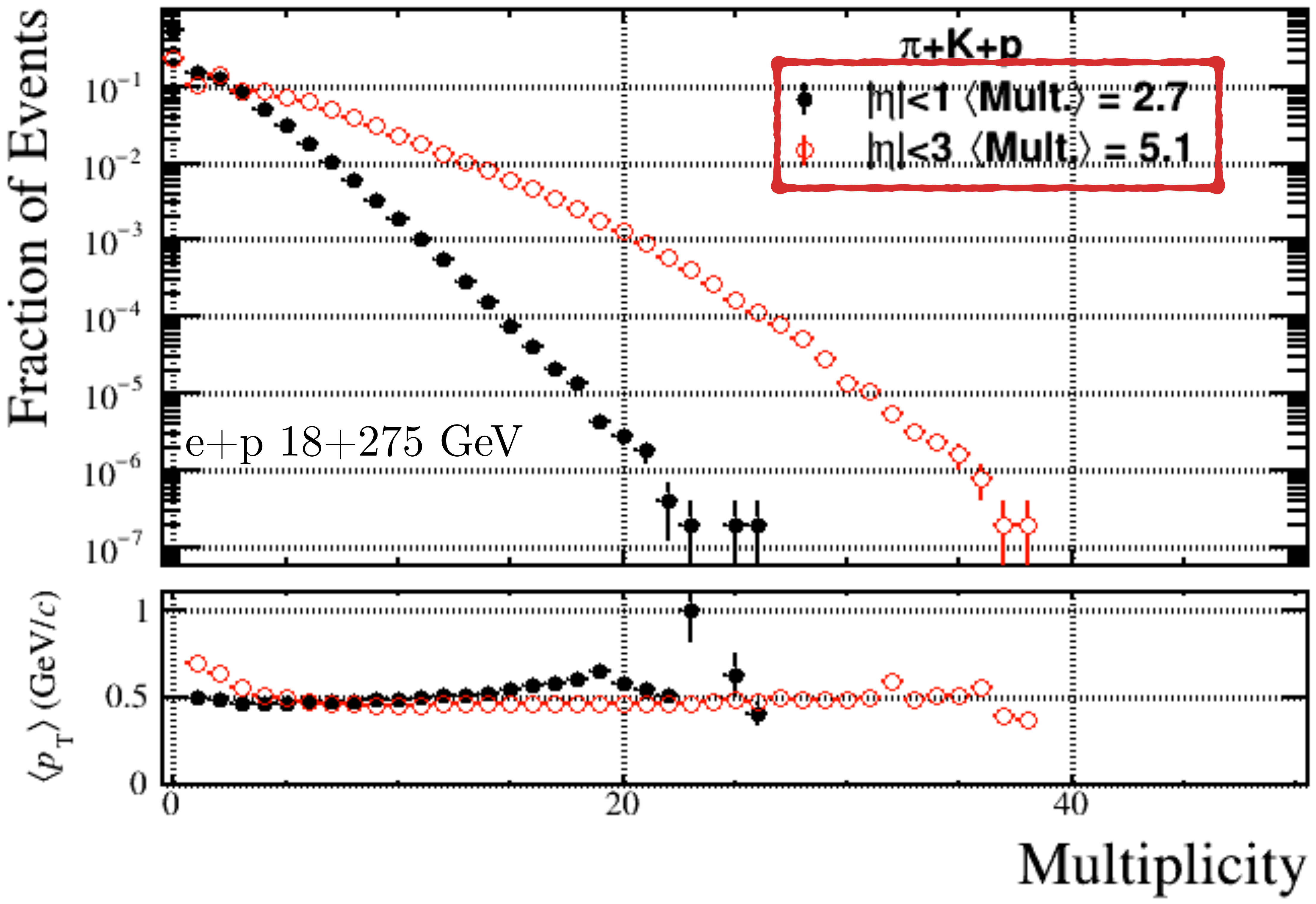
18 GeV e + 275 GeV p mostly highlighted here for PV resolution studies

Subprocesses included

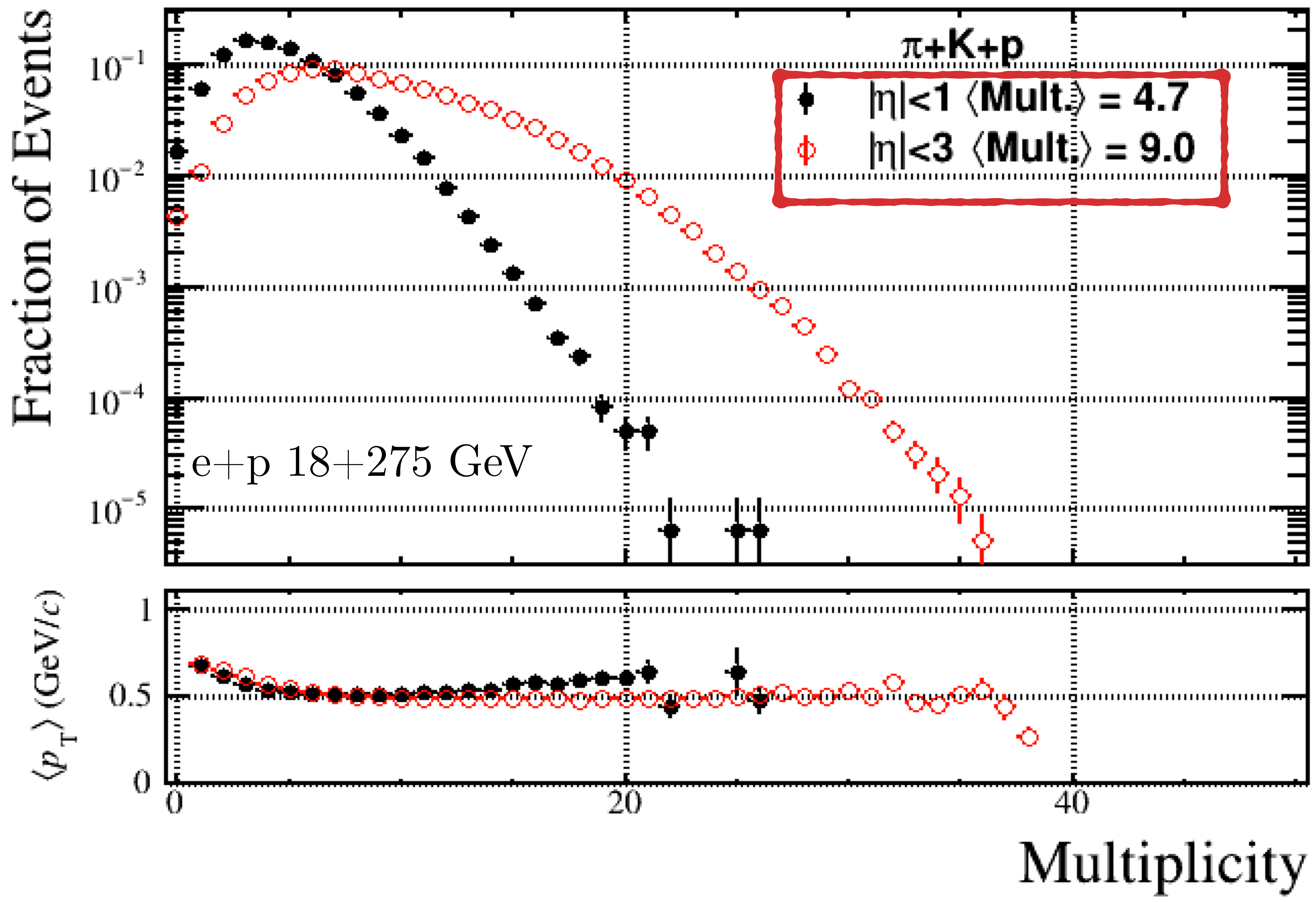
Subprocess	#	Description
soft VMD		
V N → V N	91	elastic VMD
V N → X N	92	single-diffractive VMD
V N → V X	93	single-diffractive VMD
V N → X X	94	double-diffractive VMD
V N → X	95	soft non-diffractive VMD low-pT
QCD 2→2		
	96	semihard QCD 2→2
RESOLVED (hard VMD and anomalous)		
qq → qq	11	QCD 2 → 2(q)
q qbar → q qbar	12	
q qbar → gg	13	
gq → gq	28	
qg → qg	28	QCD 2 → 2(g)
gg → q qbar	53	
gg → gg	68	
DIRECT		
γ*q → q	99	LO DIS
γ*T q → qg	131	(transverse) QCDC
γ*L q → qg	132	(longitudinal) QCDC
γ*T g → q qbar	135	(transverse) PGF
γ*L g → q qbar	136	(longitudinal) PGF

Particle Multiplicity

All DIS Events



HF-Tagged Events



Multiplicity higher in heavy-flavor tagged events (note not removing HF daughters)

Good pointing resolution beyond $|\eta|>1$ would help significantly in average multiplicity

PV Fitting Routine

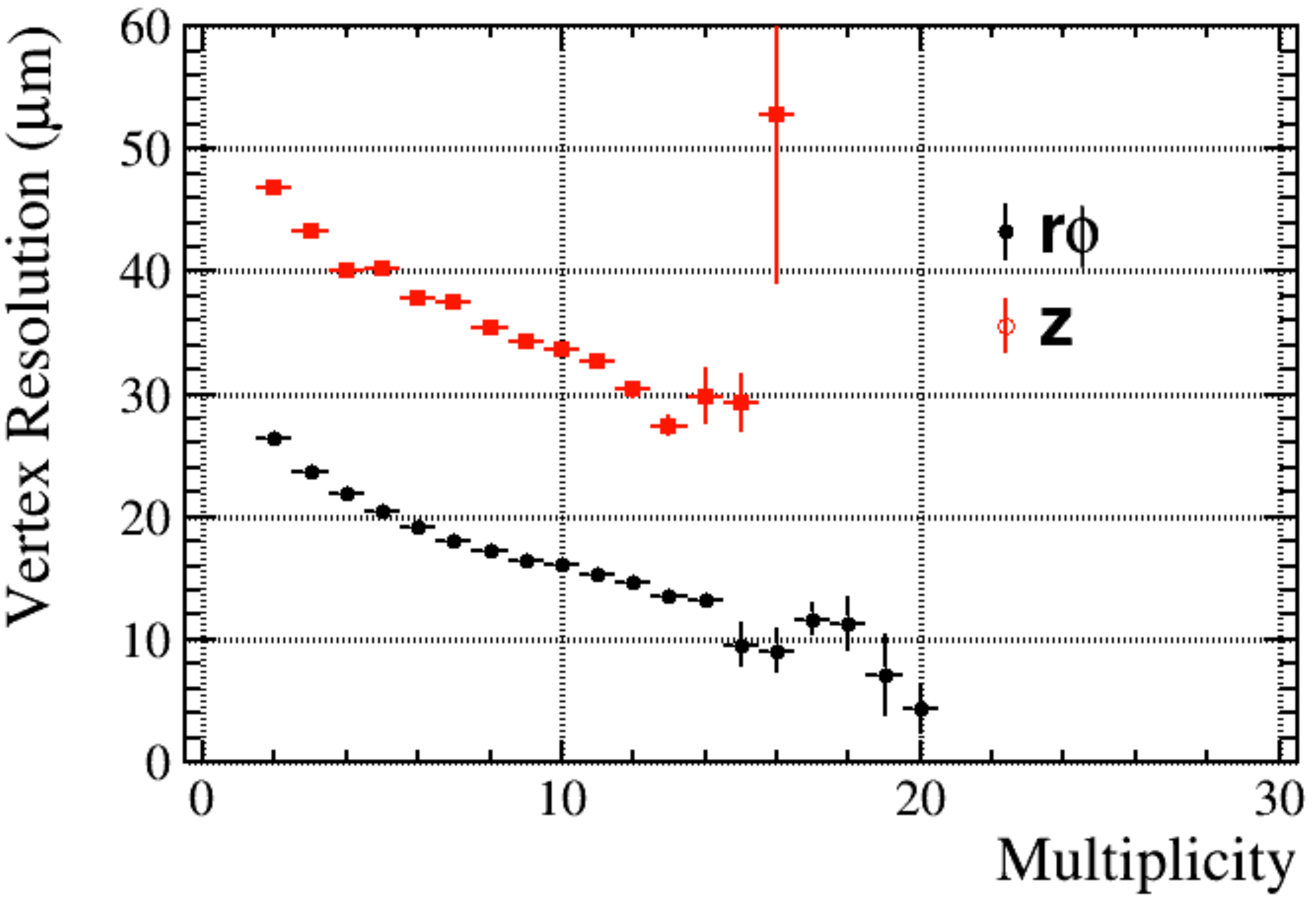
1. **Charged π, K, and p within $|\eta|<1$**
2. **Project particle along trajectories to x=y=0 seed**
3. **Least squares fit to vertex x-y positions using all particle DCA_T**
4. **Project particle along trajectories to new DCA_T w.r.t. fitted vertex x-y**
5. **Least squares fit to vertex z position using all particle DCA_z**

PV Resolution

Longitudinal resolution worse due to fitting routine, can be improved (i.e., compounding rφ errors to z dimension)

Average rφ resolution

- $|\eta|<1$ $\langle \text{mult.} \rangle \sim 5 \rightarrow 20$ μm
- $|\eta|<3$ $\langle \text{mult.} \rangle \sim 9 \rightarrow 16$ μm



D^0 Reconstruction (w/o PV Reco.)

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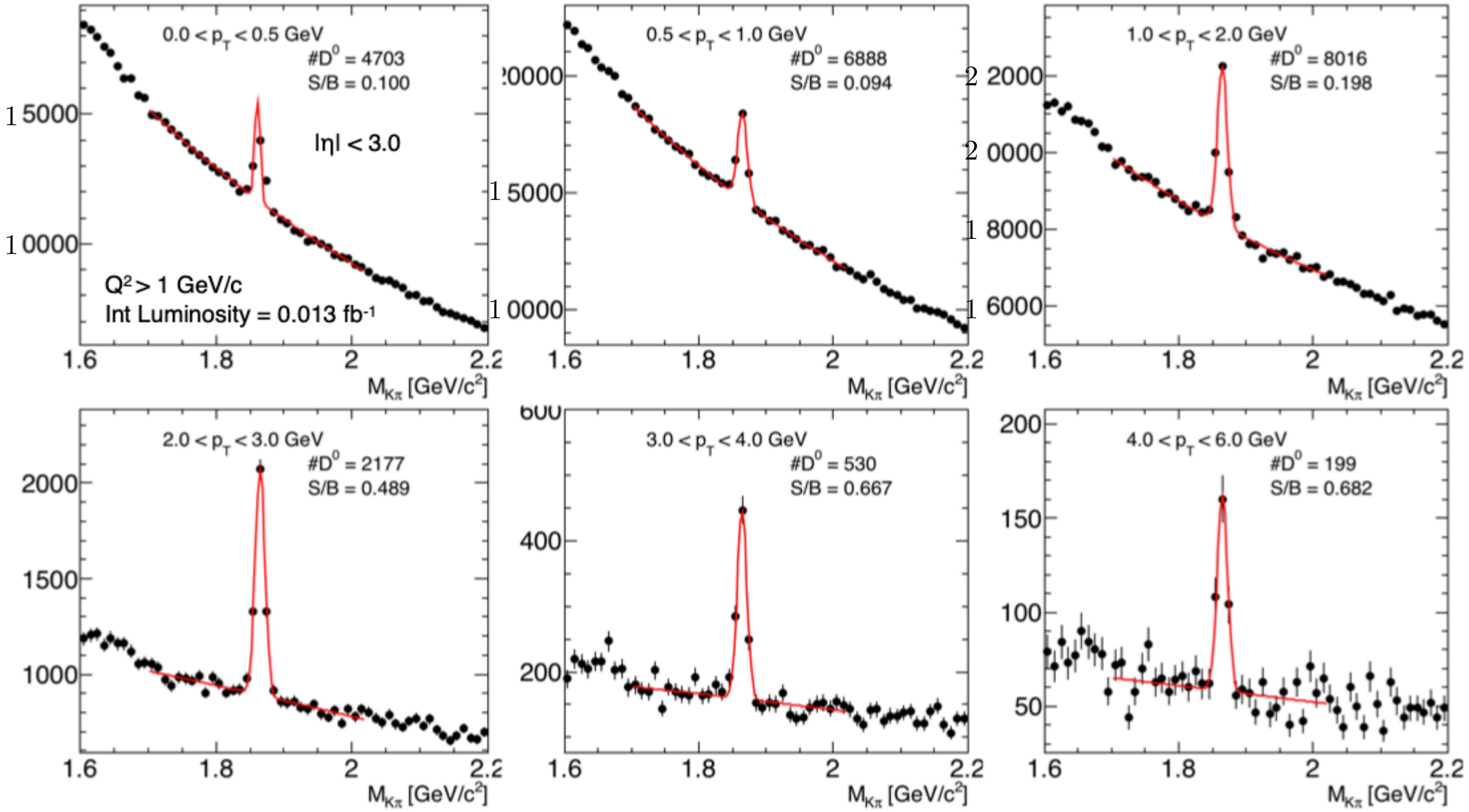
$D^0 \to K\pi$

- All $K\pi$ combinations taken from smeared PYTHIA output
- Backgrounds purely combinatorial and partially reconstructed charm decays

S/B fairly good compared to:

- p+p: 1/100 @ $\sqrt{s}$= 200 GeV
- A+A: 1/10000 @ $\sqrt{s_{NN}}$= 200 GeV



Note: e(20 GeV)+p(100GeV)
$|\eta|<3$

D^0 Topological Variables

Only transverse impact parameters (d_0) looked at

Possibility to add longitudinal dimension for additional improvement

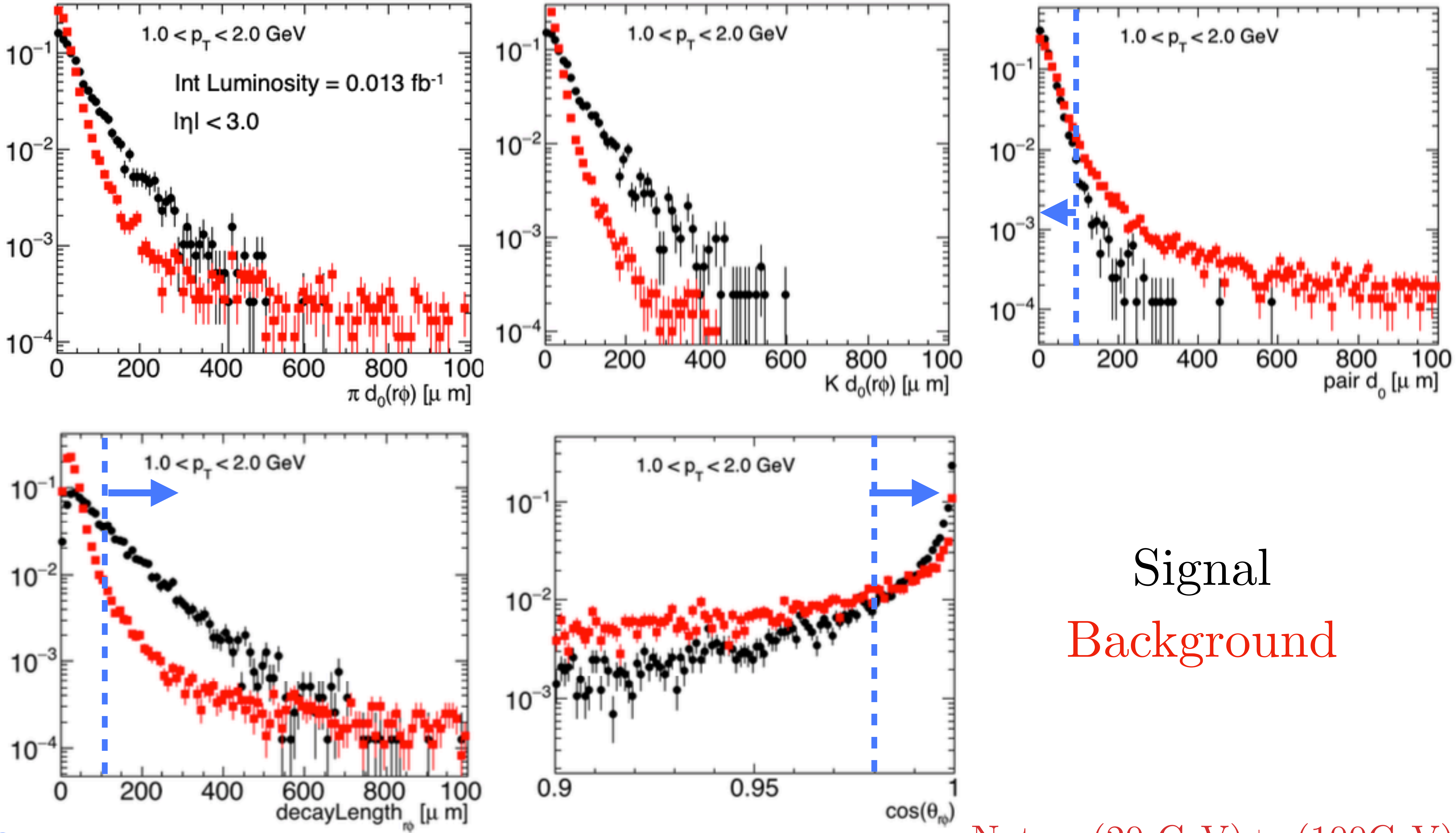
Using a rφ vertex resolution of 20 μm

"By-eye" cuts chosen:

- $\cos(\vartheta_{r\varphi}) > 0.98$
- $dL > 40$ μm
- pair $d0 < 150$ μm

No optimization or p_T dependence

D^0 p_T range of 1-2 GeV/c for example

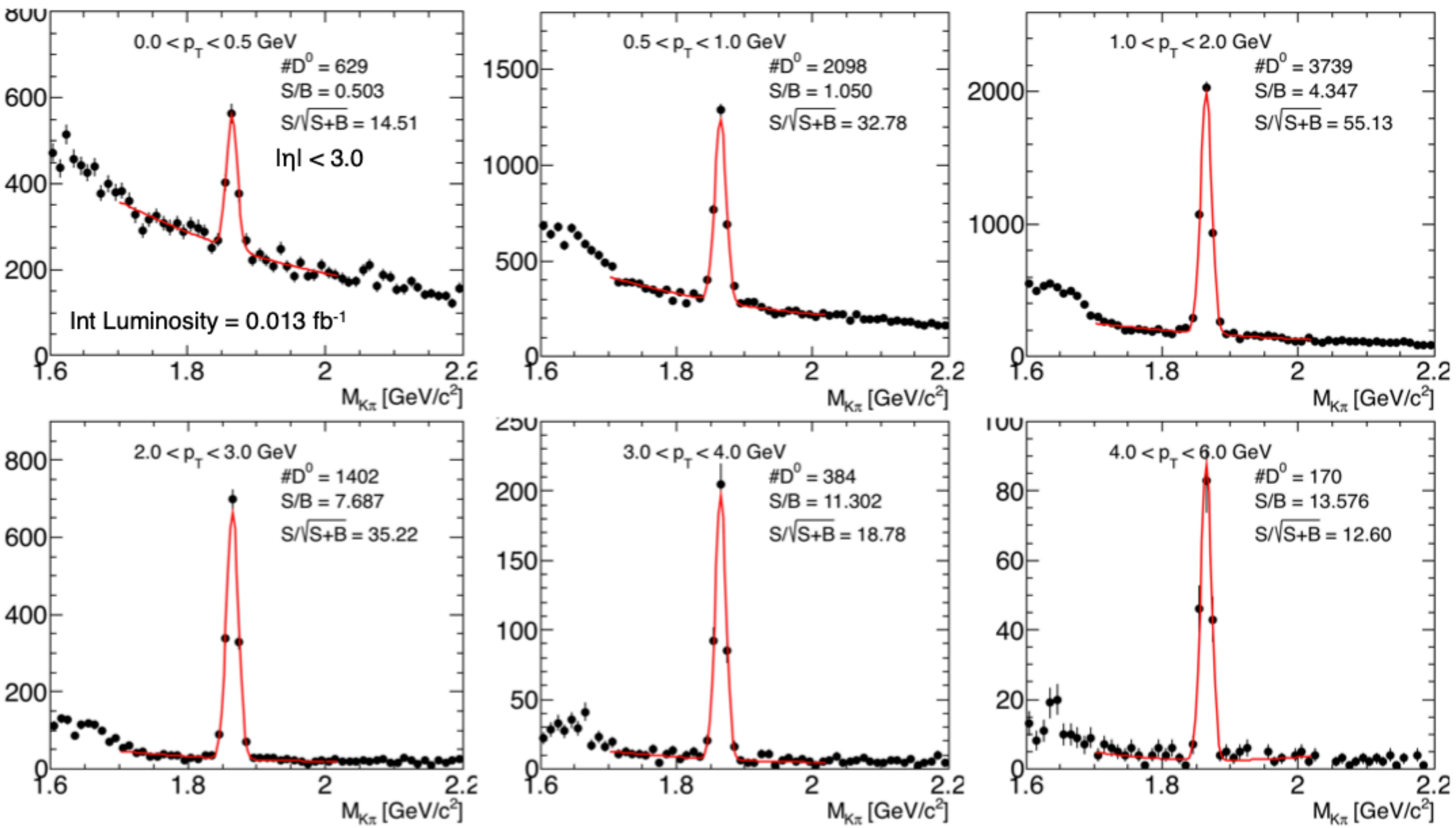


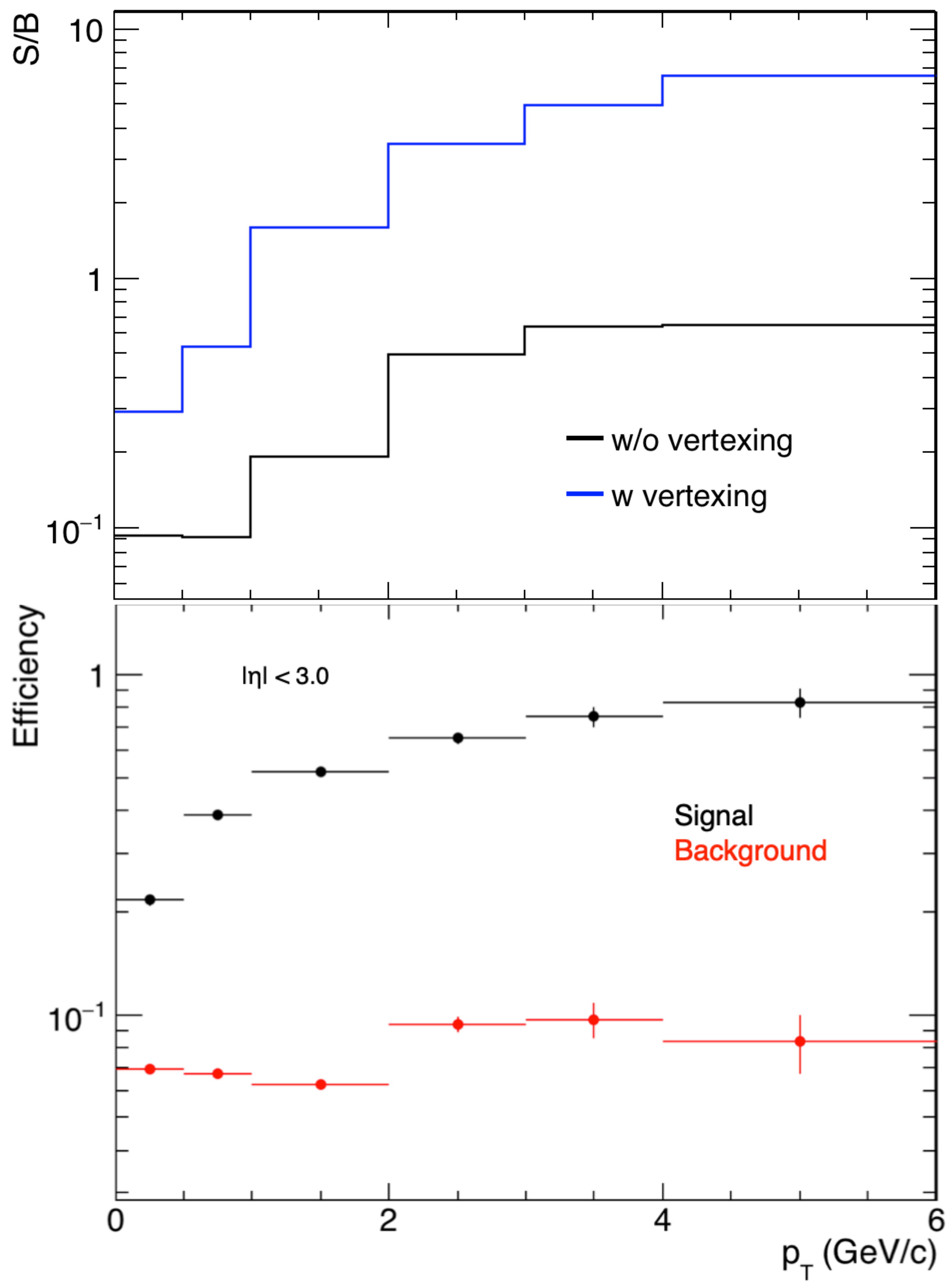
Signal

Background

Note: e(20 GeV)+p(100GeV)

D^0 Reconstruction w/ Vertexing





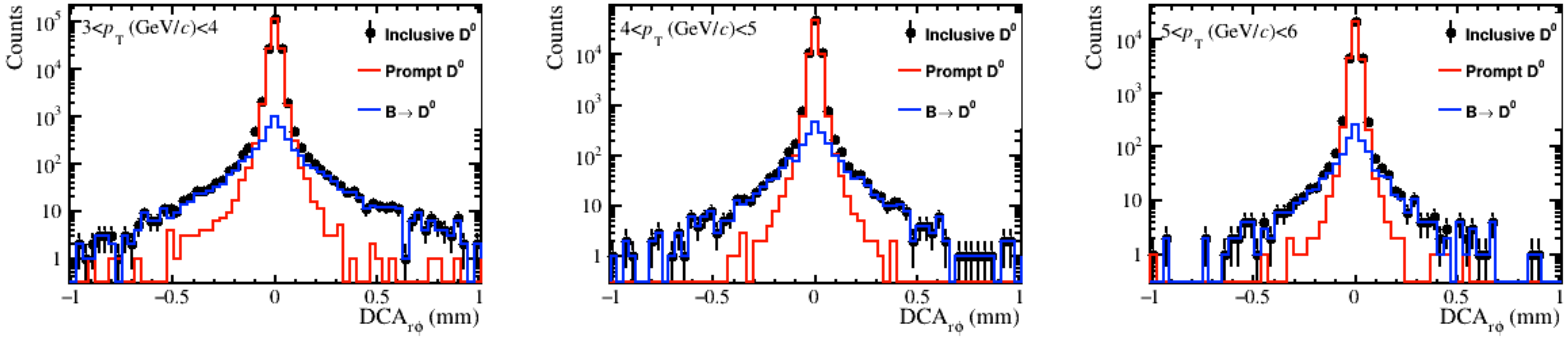
Simple topological cuts chosen "by-eye"

Nice improvement of D^0 S/B with vertexing

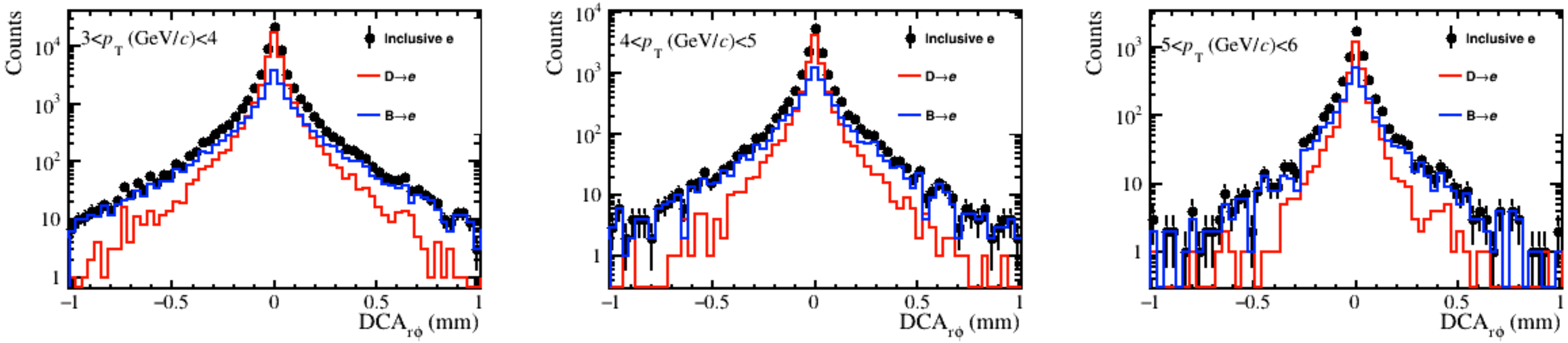
Modest signal efficiency with "by-eye" cuts

$B \to D^0/e$ Reconstruction

$B \to D^0$



$B \to e$



e+p (18+275 GeV)
5.5 fb^{-1}
$|\eta|<1$

Bottom reconstruction enabled using distance-of-closest approach of D^0/e candidates w.r.t. PV

Good separation of prompt and $B \to D^0/e$

Summary

Expected collision distribution not confined enough to use to constrain PV location for HF reconstruction

Can achieve a PV $r\varphi$ position resolution O(20 μm) using a rudimentary PV fitter

Decent longitudinal resolution can probably be achieved with some iterative fitting routine

Using vertexing in charm reconstruction can significant improve S/B and enable studies of bottom hadrons

To-do: Perform PV resolution studies with full detector simulation

Backup slides follow