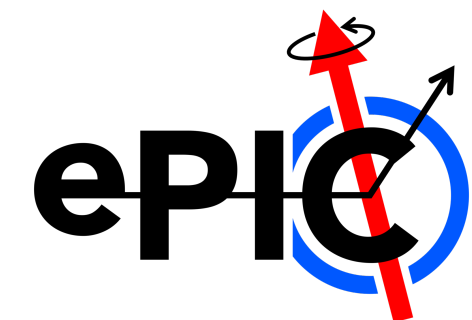


D_S reconstruction in ep and eAu

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University of Illinois Chicago

October 6, 2026



D_s samples

D_s ep samples

1) Ds filtered sample: PYTHIA ep @ 9X275 GeV, $Q^2 > 1$

epic:/RECO/26.07.1/epic_craterlake/SIDIS/Ds_ABCONV/HFsim-PYTHIA/pythia8.316-1.1/ep/9x275/q2_1

2) DIS sample: PYTHIA ep @ 9X275 GeV, $Q^2 > 1$

epic:/RECO/26.07.1/epic_craterlake/DIS/pythia8.316-1.0/NC/noRad/ep/9x275/q2_1to10

epic:/RECO/26.07.1/epic_craterlake/try2/DIS/pythia8.316-1.0/NC/noRad/ep/9x275/q2_1to10

epic:/RECO/26.07.1/epic_craterlake/DIS/pythia8.316-1.0/NC/noRad/ep/9x275/q2_10to100

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epic:/RECO/26.07.1/epic_craterlake/try2/DIS/pythia8.316-1.0/NC/noRad/ep/9x275/q2_100to1000

epic:/RECO/26.07.1/epic_craterlake/DIS/pythia8.316-1.0/NC/noRad/ep/9x275/q2_1000toINF

D_s eAu samples

1) Ds filtered sample: BeAGLE eAu @ 9X100 GeV, $Q^2 > 1$

epic:/RECO/26.07.1/epic_craterlake/SIDIS/Ds_ABCONV/HFsim-BeAGLE/BeAGLE1.03.02-1.0/eAu/9x100/q2_1

2) DIS sample: BeAGLE eAu @ 9X100 GeV, $Q^2 > 1$

epic:/RECO/26.07.1/epic_craterlake/DIS/BeAGLE1.03.02-3.1/eAu/9x100/q2_1to10

epic:/RECO/26.07.1/epic_craterlake/DIS/BeAGLE1.03.02-3.1/eAu/9x100/q2_10to100

epic:/RECO/26.07.1/epic_craterlake/DIS/BeAGLE1.03.02-3.1/eAu/9x100/q2_100to10000

D_s decay channel

$$D_s^\pm \rightarrow \phi + \pi^\pm, \phi \rightarrow K^+ + K^-$$

Branching fraction $(2.25 \pm 0.05) \%$

$D_s^\pm$ rest mass = 1.968 GeV

ϕ rest mass = 1.019 GeV

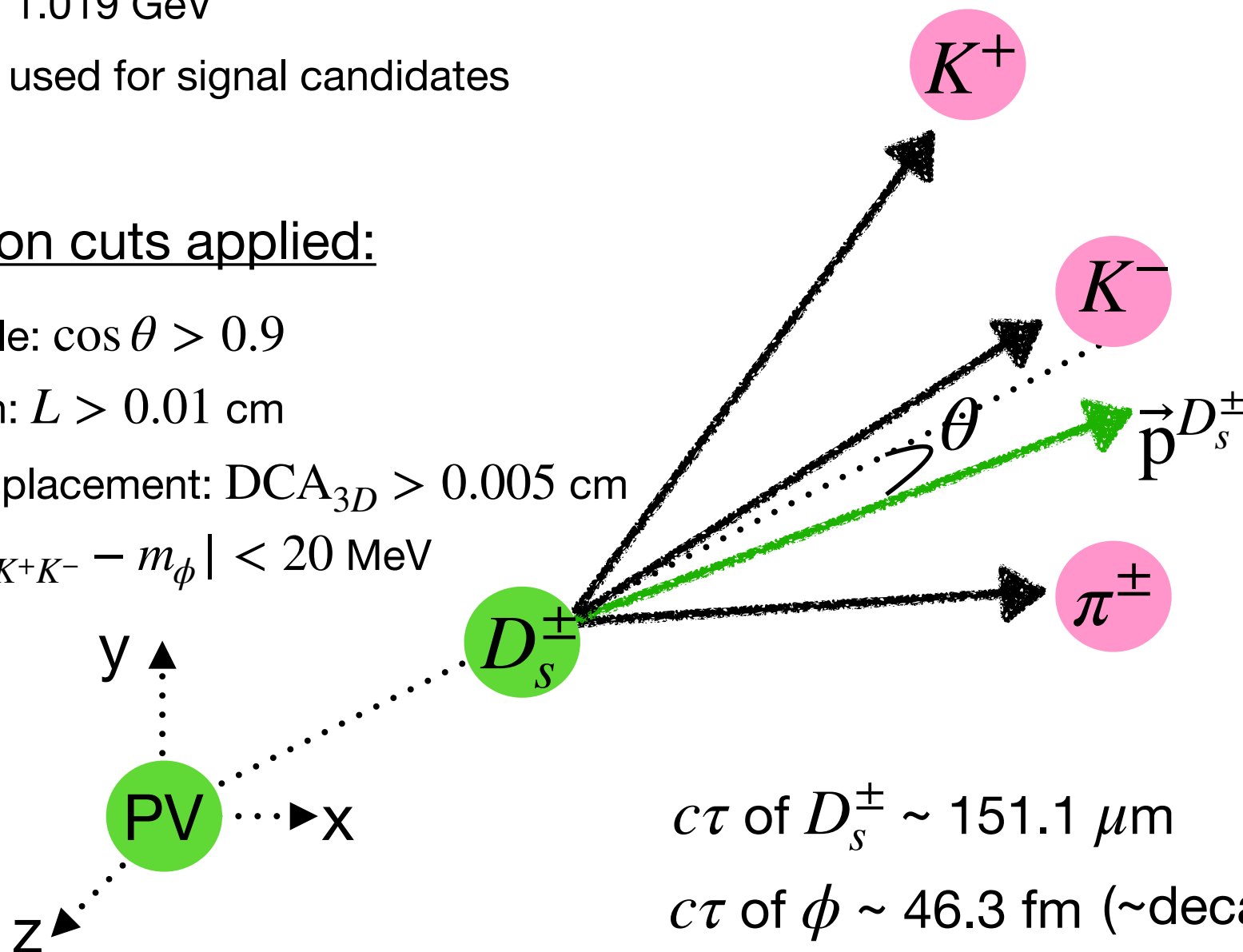
“Realistic PID” used for signal candidates

Reconstruction is done using 3 decay tracks pointing to a single SV

(Thanks to Shyam's Λ_c reconstruction code!)

Basic selection cuts applied:

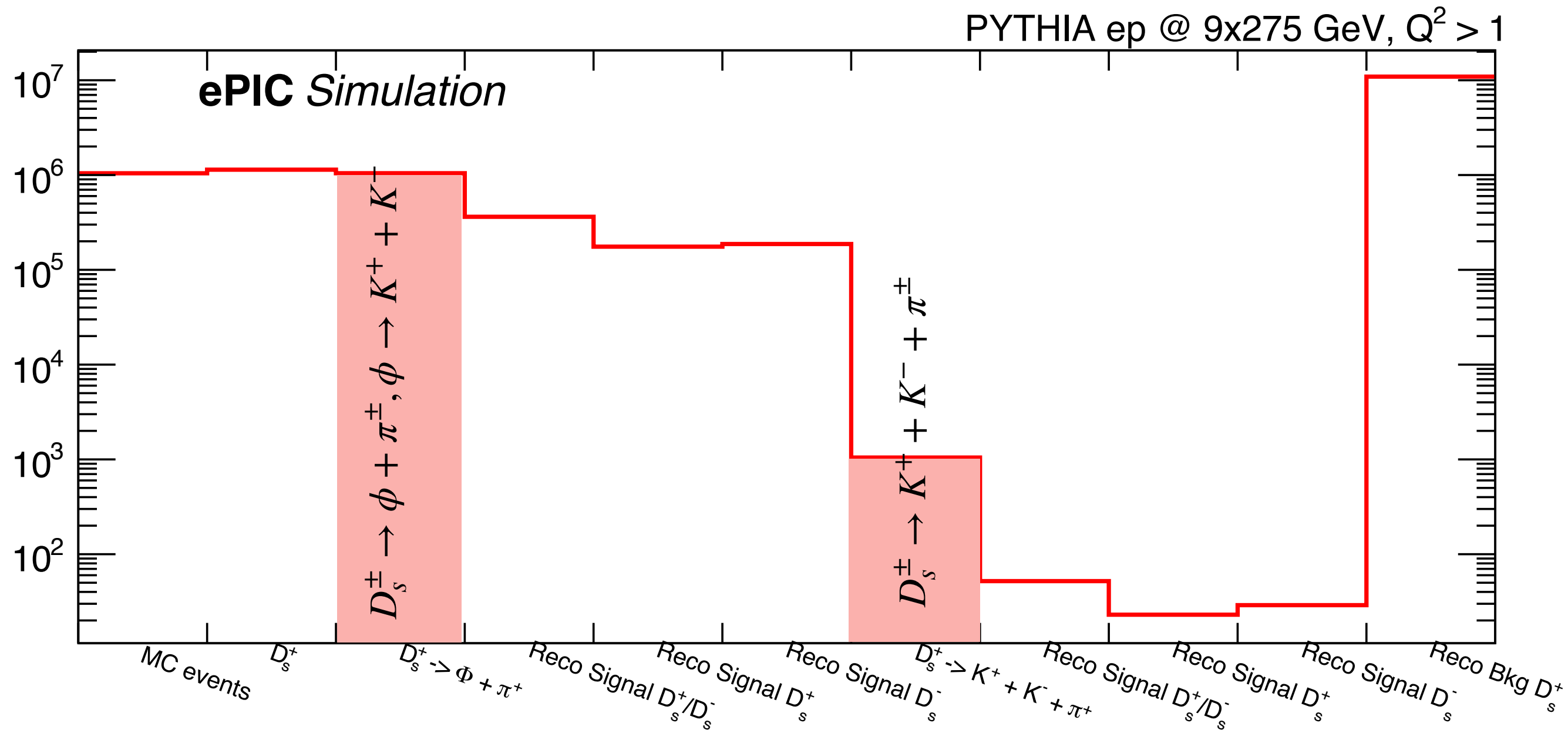
- Pointing angle: $\cos \theta > 0.9$
- Decay length: $L > 0.01$ cm
- Daughter displacement: $\text{DCA}_{3D} > 0.005$ cm
- ϕ mass: $|m_{K^+K^-} - m_\phi| < 20$ MeV



$c\tau$ of $D_s^\pm \sim 151.1 \mu\text{m}$

$c\tau$ of $\phi \sim 46.3$ fm ($\sim$ decays extremely quickly)

D_s event statistics



Negligible contribution of non-resonant decay channel in D_s filtered sample
 Confirmed that the sample is produced by filtering on ϕ decay channel

(see backup for all samples)

Scaling signal to target luminosity

Species	Beam energy (GeV)	Integrated luminosity	Electron-beam polarization	Hadron-beam polarization
$e+\text{Ag}$	9×115	1.0 fb^{-1}	NO	N/A
$e+\text{D}$	9×130	1.5 fb^{-1}	LONG	NO
$e+p$	9×130	1.0 fb^{-1}	LONG	TRANS and/or LONG
$e+p$	9×275	2.5 fb^{-1}	LONG	TRANS and/or LONG
$e+\text{Au}$	9×100	1.0 fb^{-1}	LONG	N/A
$e+{}^3\text{He}$	9×166	1.5 fb^{-1}	LONG	TRANS and/or LONG

. The e+A luminosity is per nucleon

Event generator and process	Decay channel	# of HF events	Sampled DIS events, x-sec and lumi
PYTHIA 8.316 ep, NC, 9×275 $Q^2 > 1$	$D_s \rightarrow \phi + \pi \rightarrow K + K + \pi$ Decay daughters within $ \eta < 3.5$	$N \sim 1\text{M}$	$N = 12\text{B}$ $\sigma = 6.555\text{e}5 \text{ pb}$ $L \sim 18.3 \text{ fb}^{-1}$
BeAGLE v1.03.02 eAu, 9×100 $Q^2 > 1$ $0.01 < y < 0.95$	$D_s \rightarrow \phi + \pi \rightarrow K + K + \pi$ Decay daughters within $ \eta < 3.5$	$N \sim 650\text{k}$	$N = 3\text{B}$ $\sigma = 0.284 \text{ ub}$ $L \sim 10.6 \text{ fb}^{-1}$

Scale MC Signal (S) to target luminosity:

$$w \text{ for ep} = 2.5/18.3 = 0.137$$

$$w \text{ for eAu} = 1.0/10.6 = 0.094$$

Scaling background to target luminosity

D_s ep samples

Scale Background (B) from DIS to target luminosity:

$$w_i = \frac{\sigma_i L_{target}}{N_{i,events}} \qquad L_{target} = 2.5 \text{ fb}^{-1}$$

e+p @ 9x275	$1 < Q^2 < 10$	$10 < Q^2 < 100$	$100 < Q^2 < 1000$	$1000 < Q^2 < \text{INF}$
σ_i	6.025e5 pb	5.178e4 pb	2.292e3 pb	3.697e1 pb
$N_{i,events}$	4.99379E+06	4.98995E+06	4.99043E+06	996801.0
$\sigma_i/N_{i,events}$	0.12064985	0.010376857	0.00045927906	3.7088647E-05
w_i	301.62	25.94	1.148	0.093

Please see Shyam’s email for the procedure to merge different Q^2 bins in the biased DIS sample
- Sent on Oct 4, 2026 to the Jets/HF group

Scaling background to target luminosity

D_s eAu samples

Scale Background (B) from DIS to target luminosity:

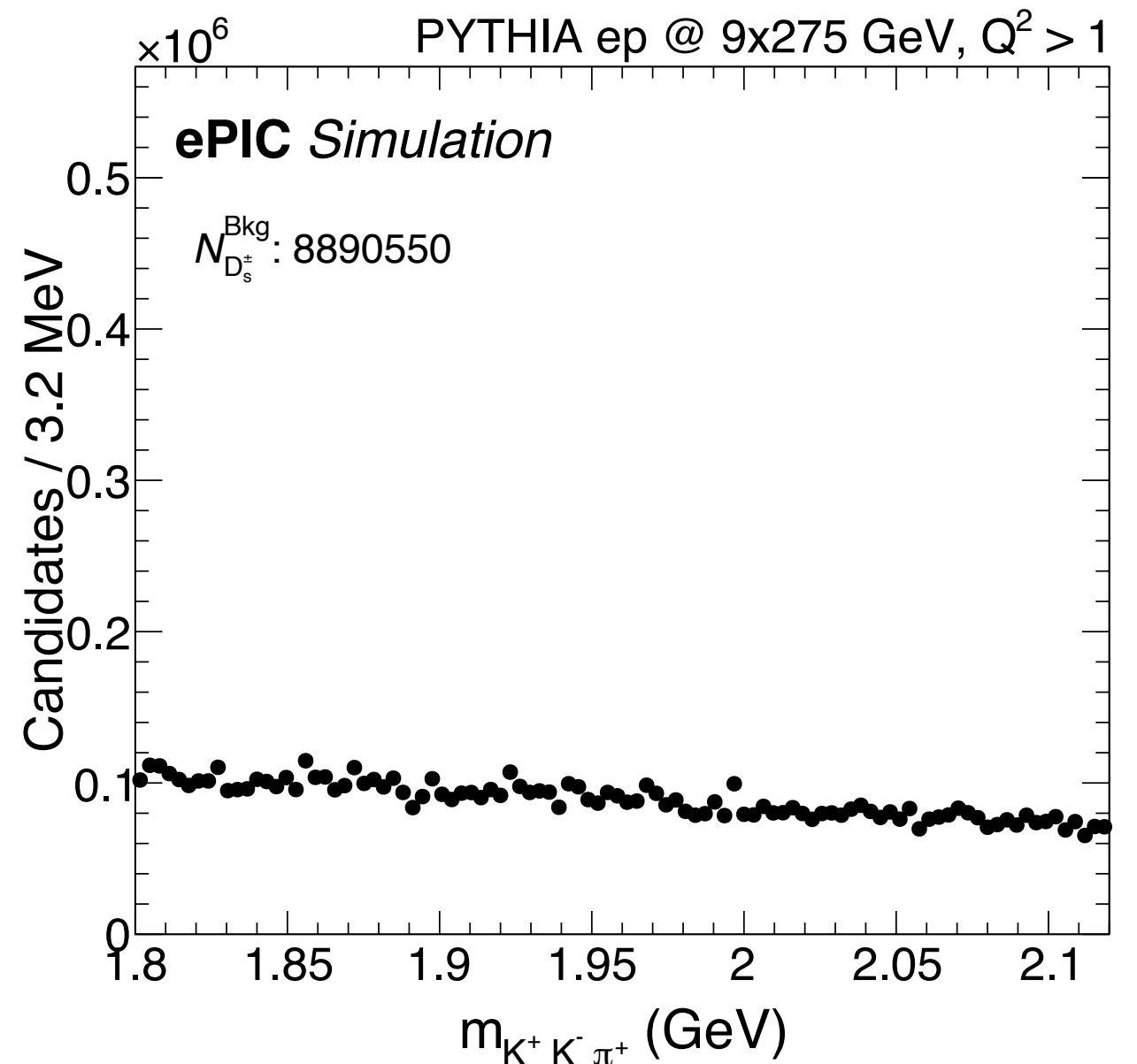
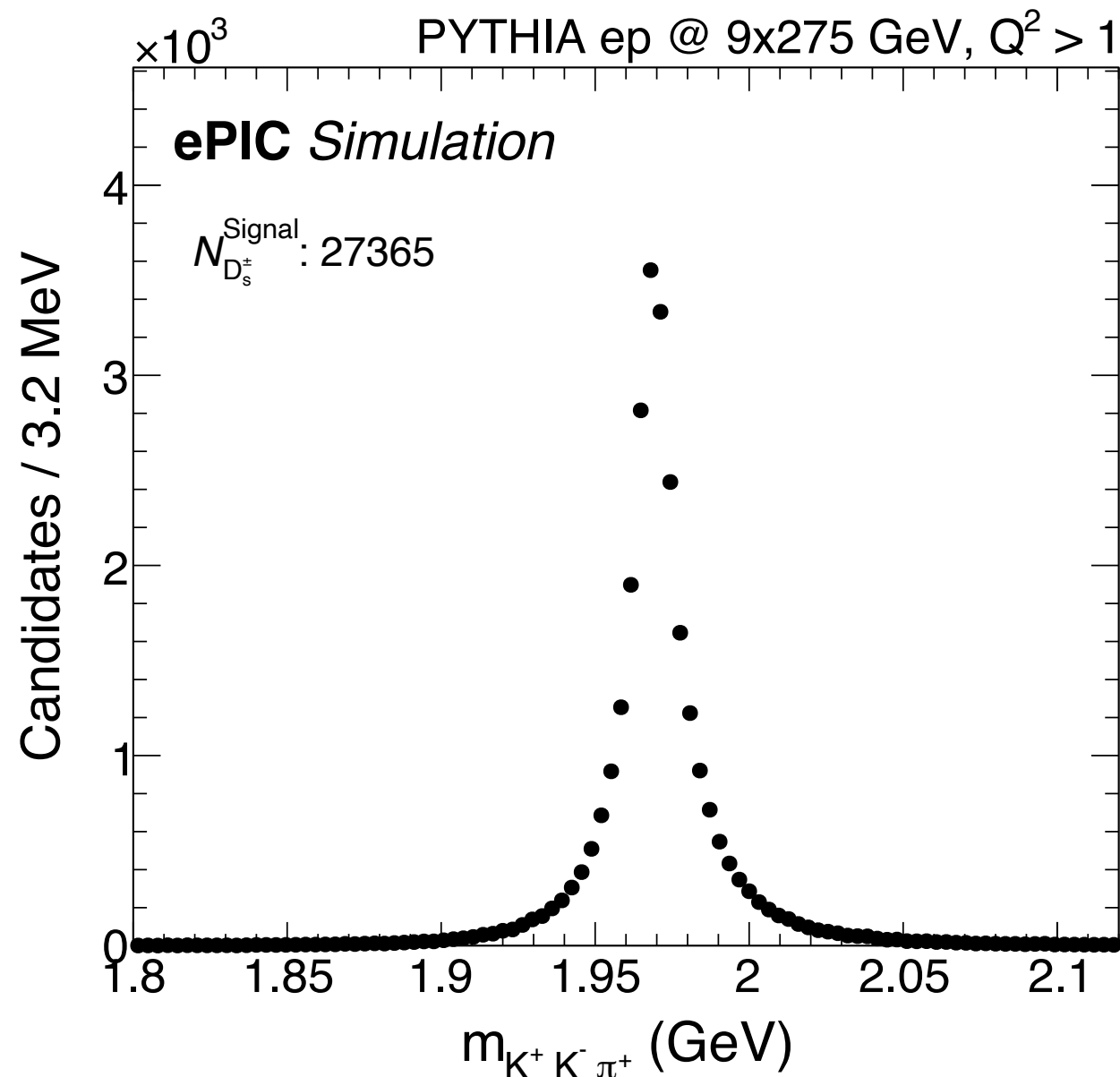
$$w_i = \frac{\sigma_i L_{target}}{N_{i,events}} \quad L_{target} = 1.0 \text{ fb}^{-1}$$

e+Au @ 9x100	$1 < Q^2 < 10$	$10 < Q^2 < 100$	$100 < Q^2 < 10000$
σ_i	3.385e5 pb	3.34e4 pb	9.867e2 pb
$N_{i,events}$	1.61816E+06	1.53051E+06	1.48895E+06
$\sigma_i/N_{i,events}$	0.20918821	0.021822791	0.00066268176
w_i	209.18821	21.822791	0.66268176

Please see Shyam's email for the procedure to merge different Q^2 bins in the biased DIS sample
 - Sent on Oct 4, 2026 to the Jets/HF group

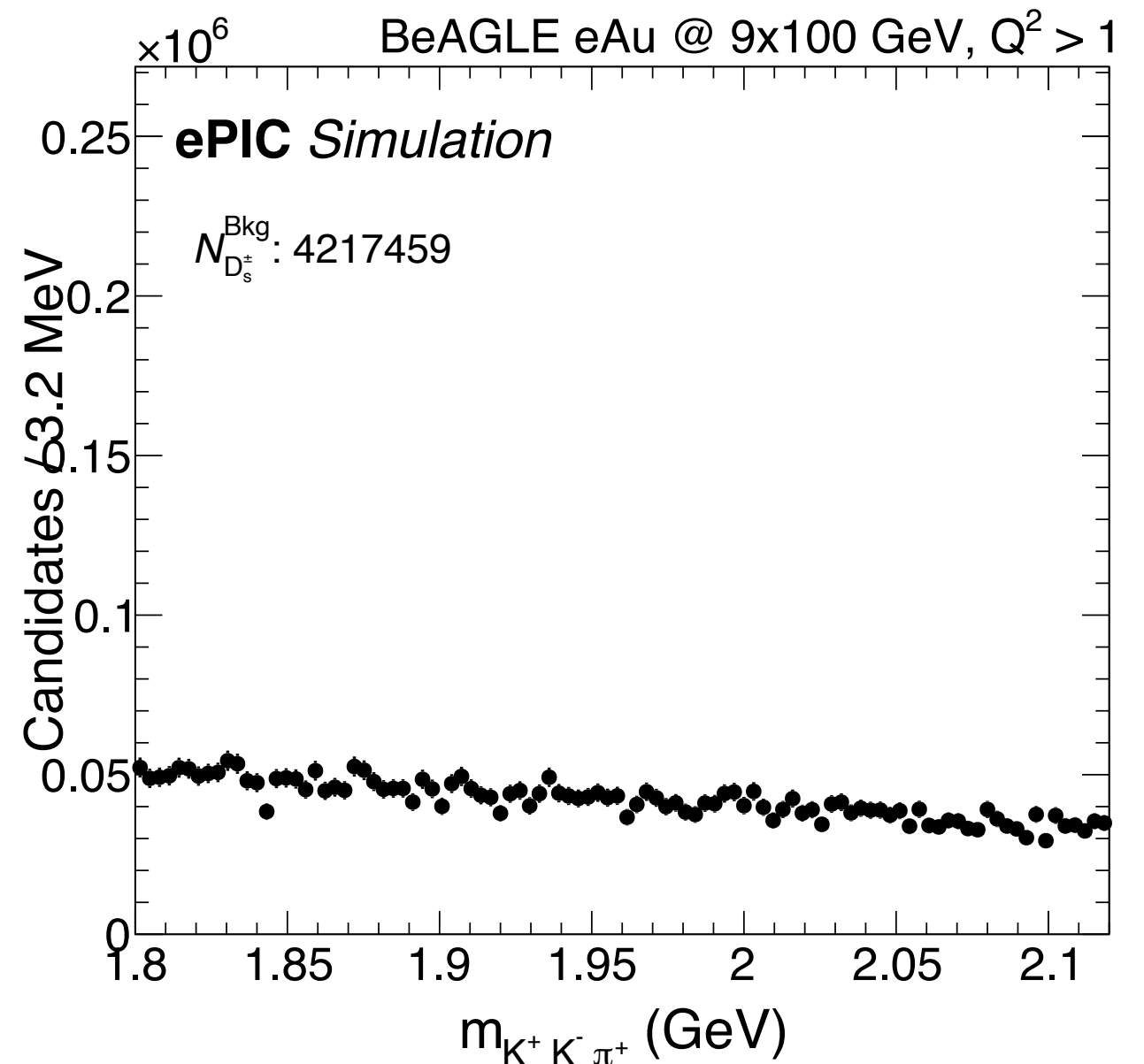
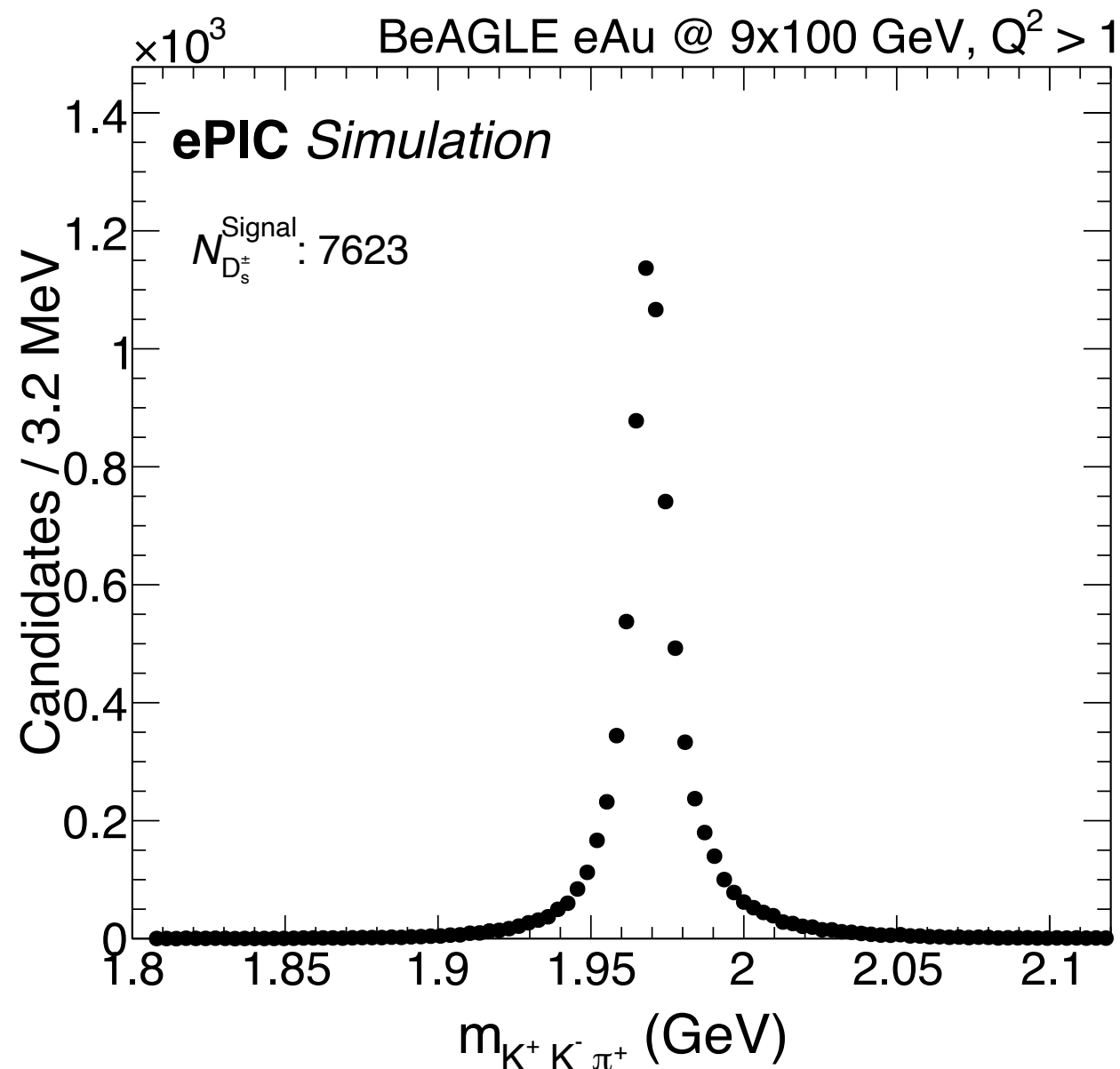
Basic selection cuts applied:

- Pointing angle: $\cos \theta > 0.9$
- Daughter displacement: $\text{DCA}_{3D} > 0.005$ cm
- Decay length: $L > 0.01$ cm



Basic selection cuts applied:

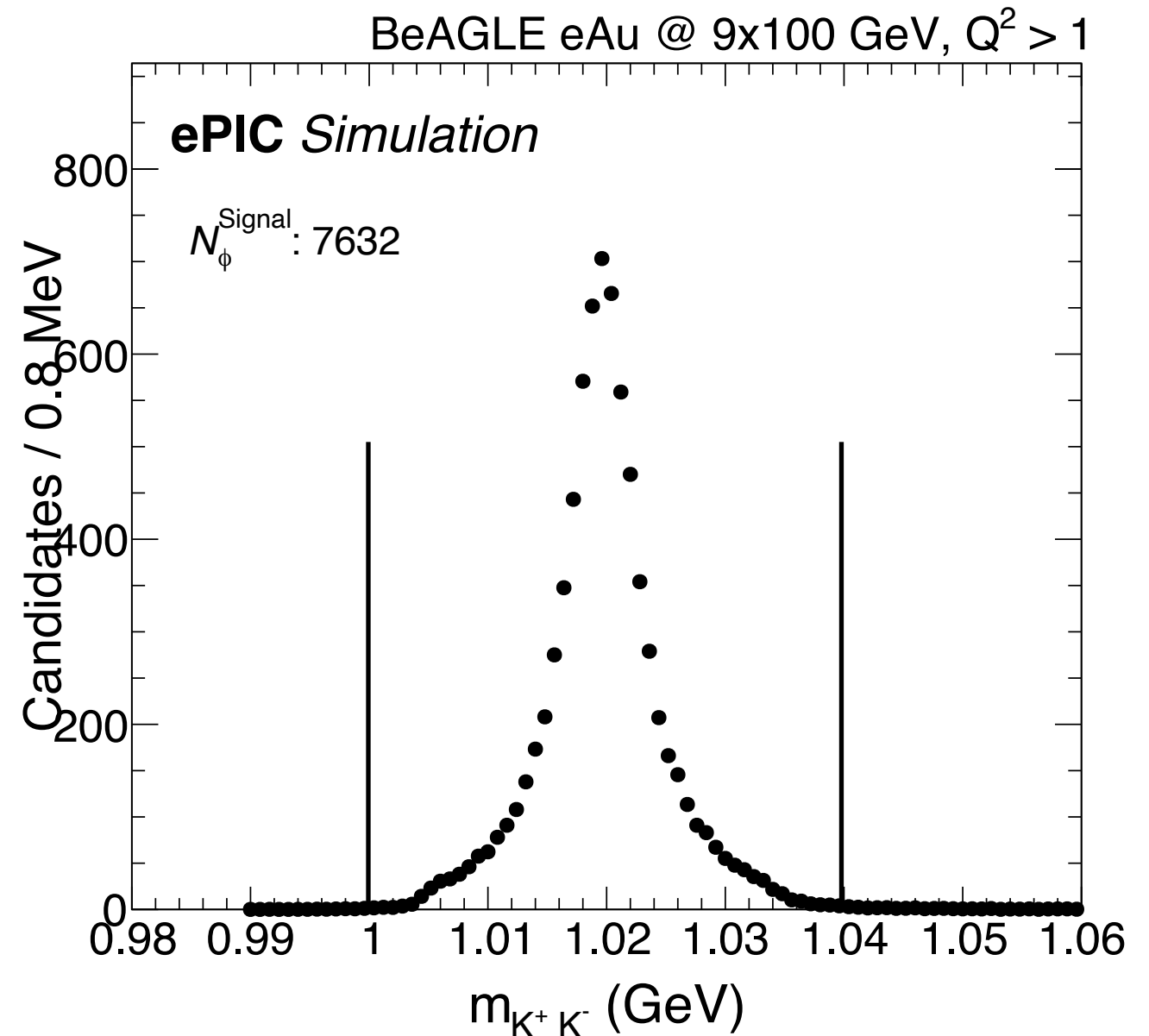
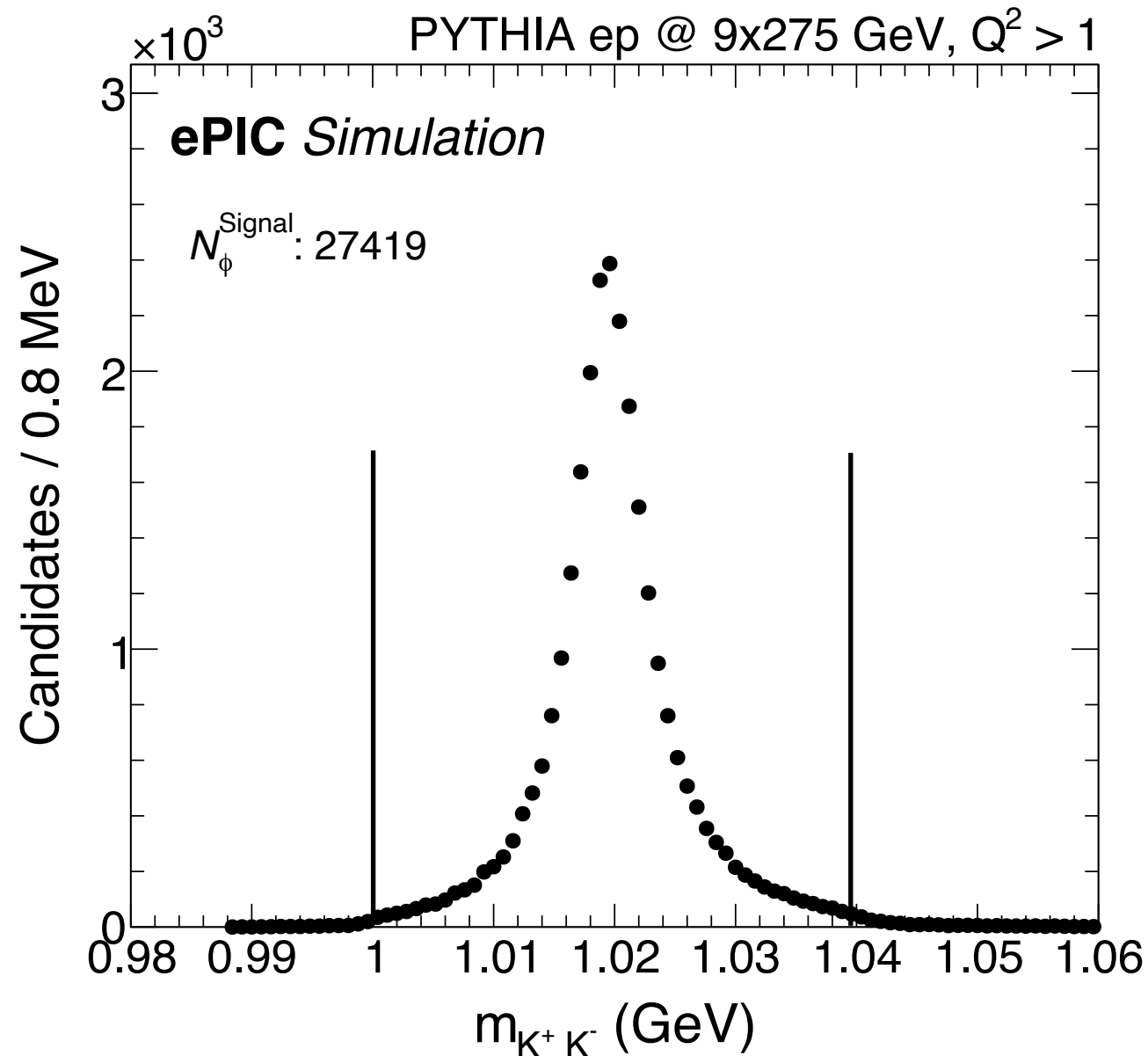
- Pointing angle: $\cos \theta > 0.9$
- Daughter displacement: $\text{DCA}_{3D} > 0.005$ cm
- Decay length: $L > 0.01$ cm



ϕ mass peaks

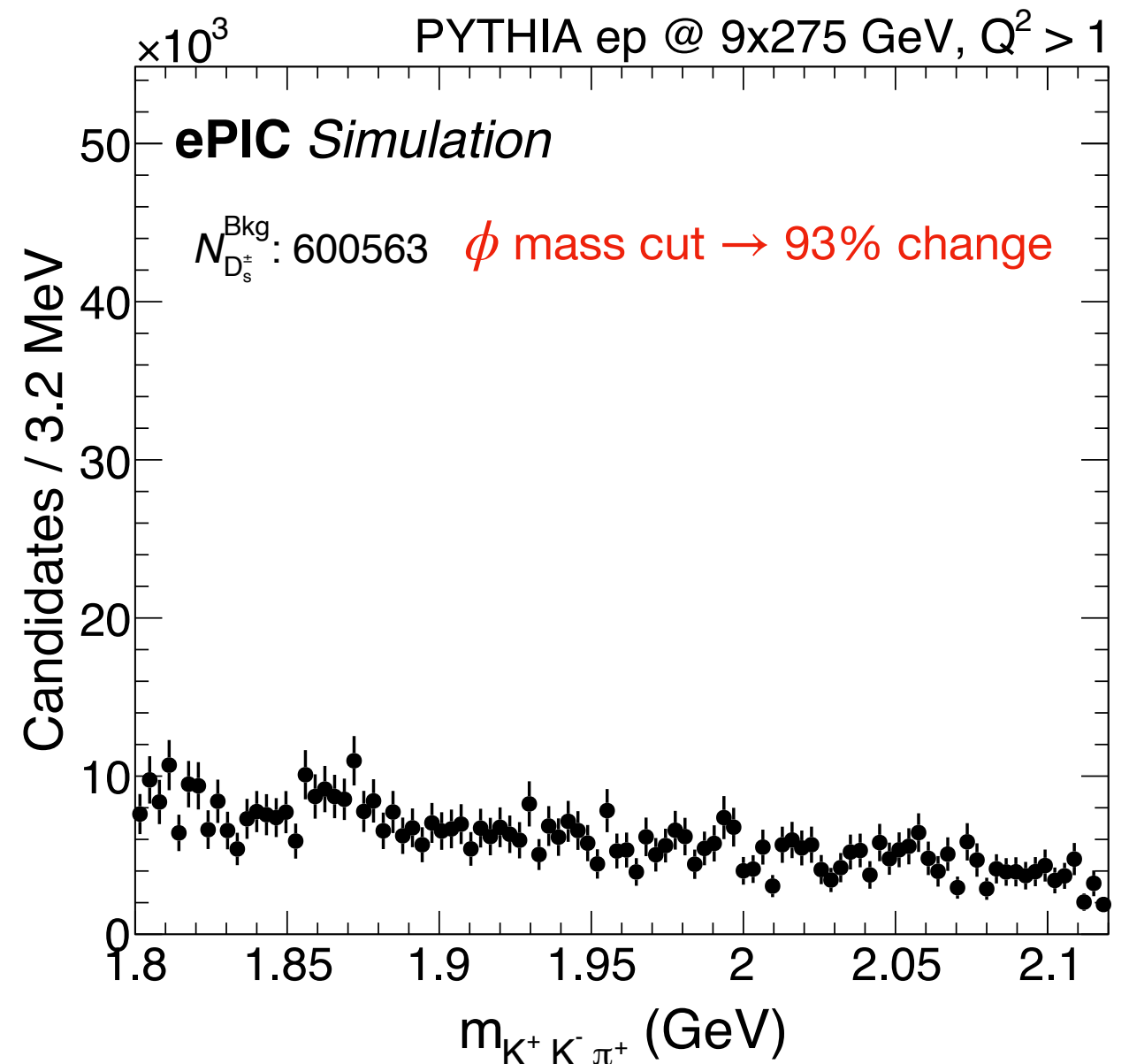
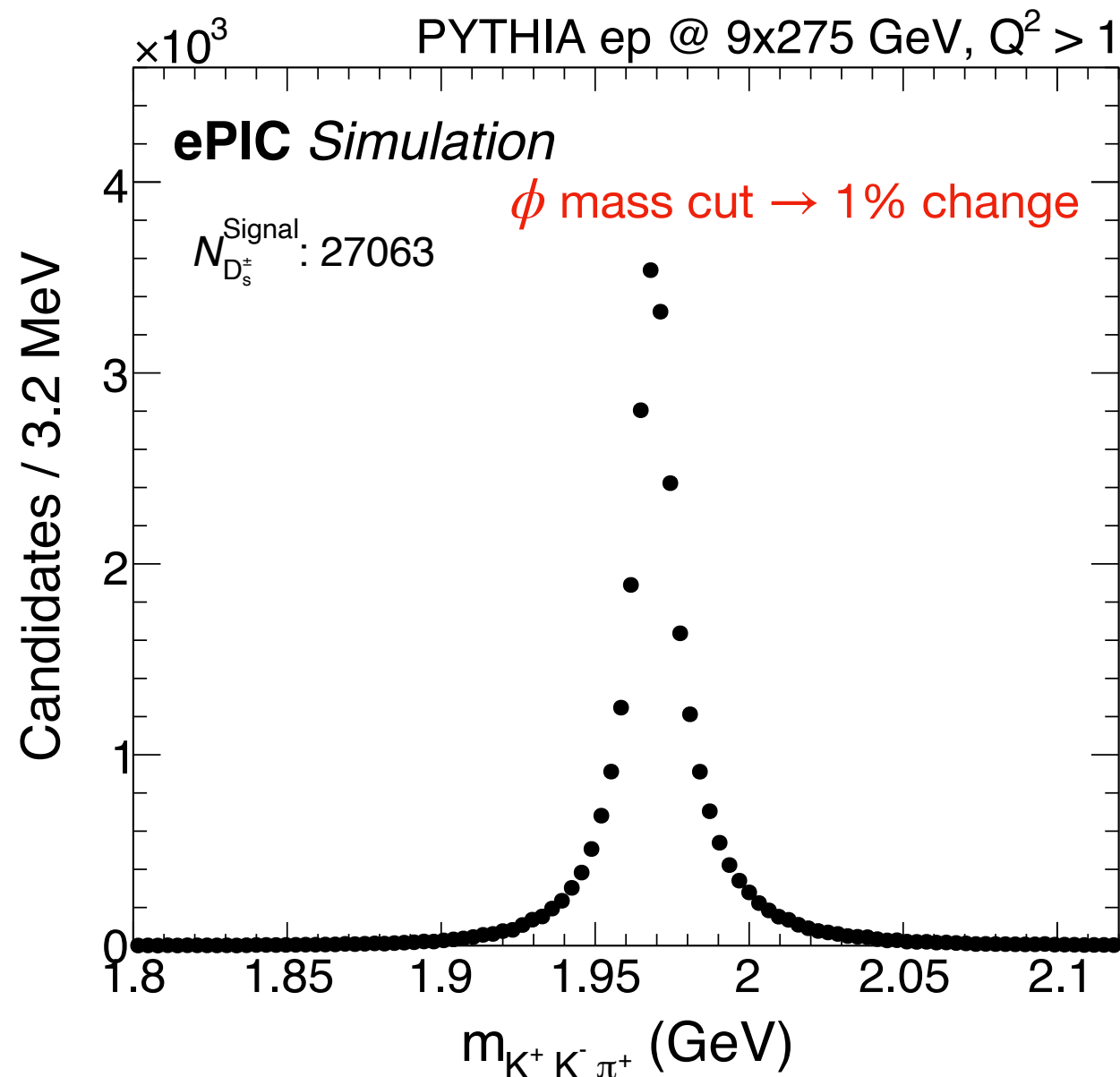
Cuts to be applied to D_s reconstruction

- ϕ mass: $|m_{K^+K^-} - m_\phi| < 20 \text{ MeV}$



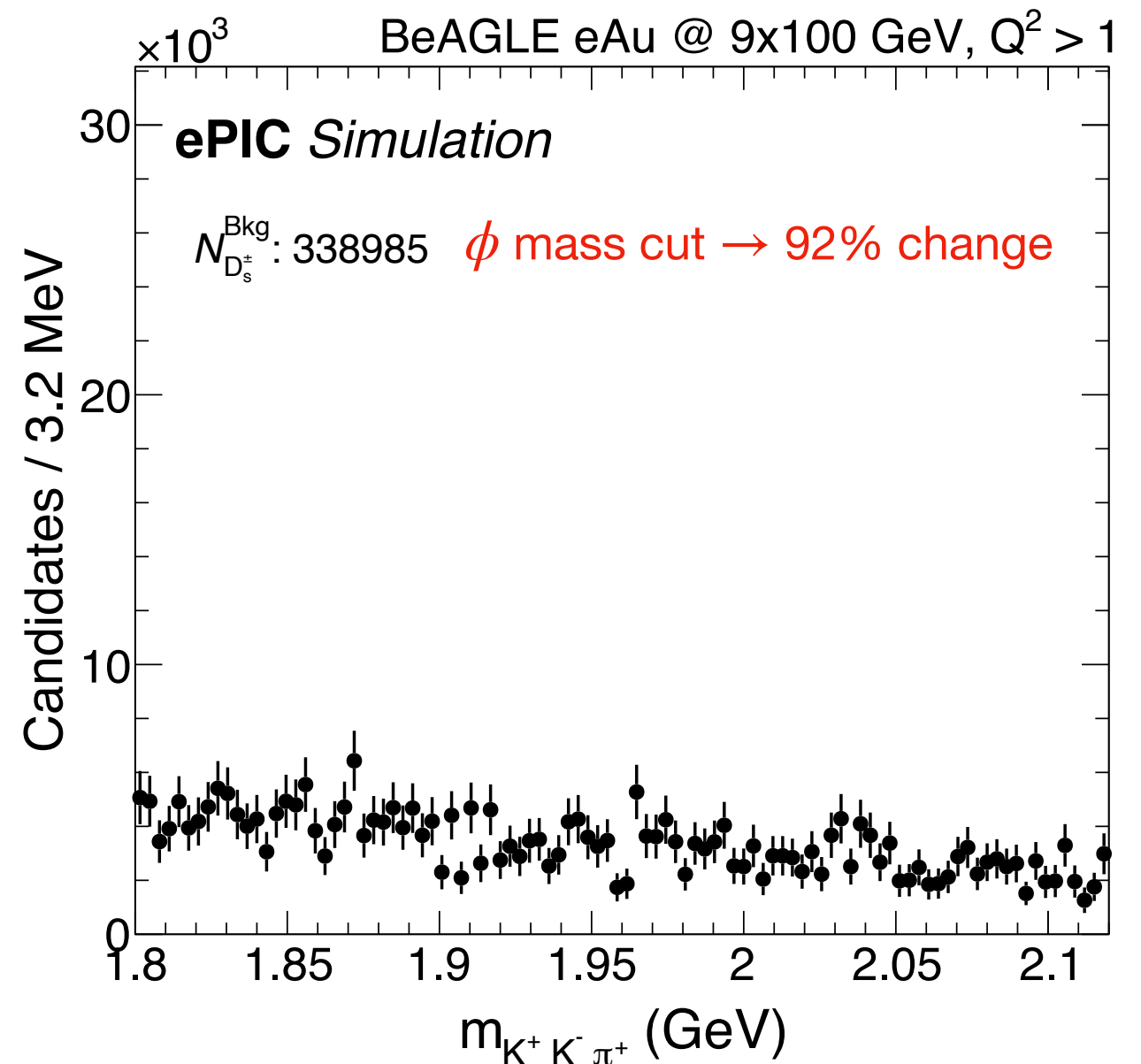
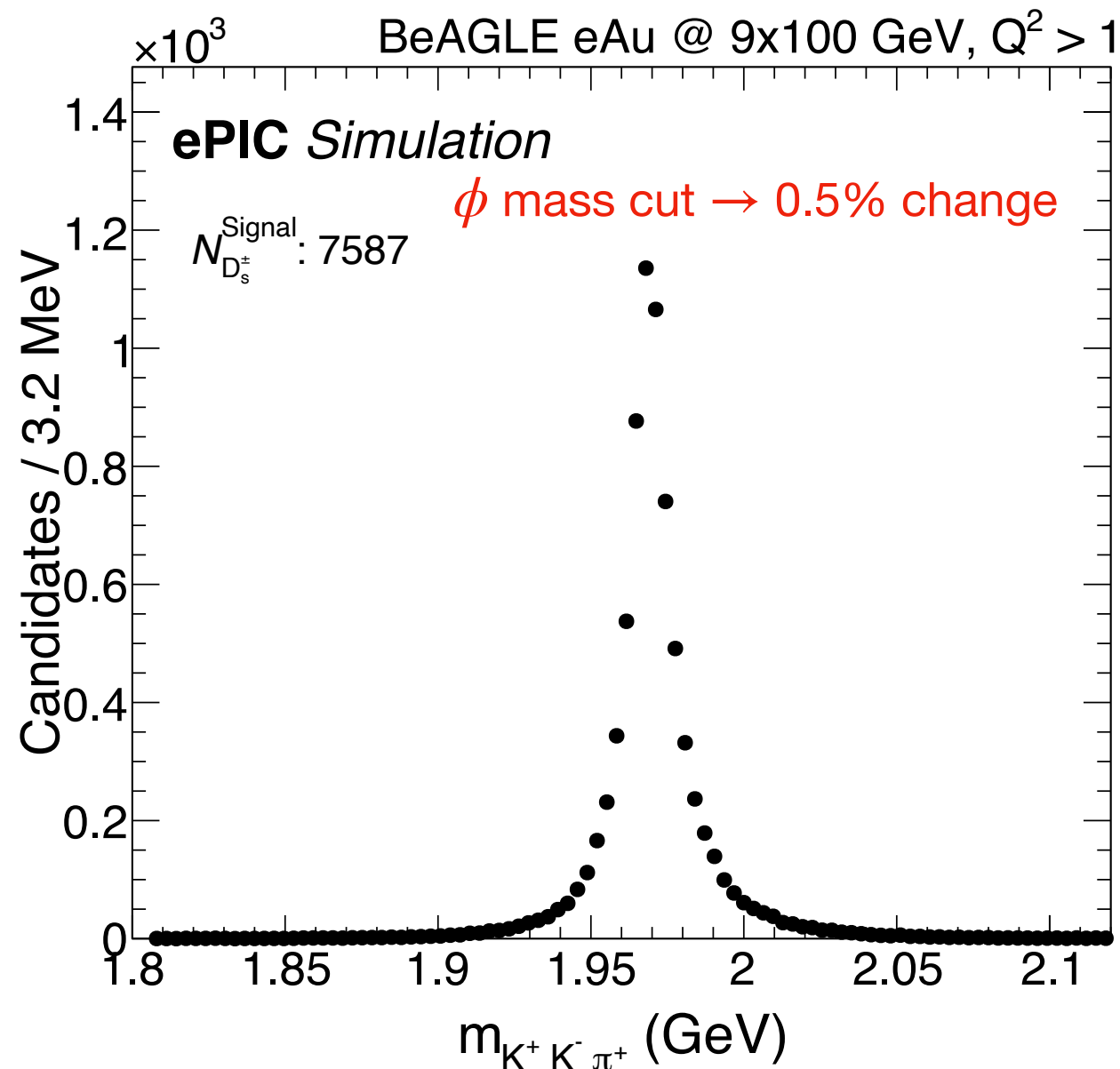
Basic selection cuts applied:

- Pointing angle: $\cos \theta > 0.9$
- Decay length: $L > 0.01$ cm
- Daughter displacement: $\text{DCA}_{3D} > 0.005$ cm
- ϕ mass: $|m_{K^+K^-} - m_\phi| < 20$ MeV



Basic selection cuts applied:

- Pointing angle: $\cos \theta > 0.9$
- Decay length: $L > 0.01$ cm
- Daughter displacement: $\text{DCA}_{3D} > 0.005$ cm
- ϕ mass: $|m_{K^+K^-} - m_\phi| < 20$ MeV



Projected Statistical Uncertainty

For a Poisson distribution, $\sigma_N = \sqrt{N} = \sqrt{S + B}$

Assuming perfectly known background,

$$\sigma_s \sim \sqrt{S + B}$$

$$\frac{\sigma_s}{S} \sim \frac{\sqrt{S + B}}{S}$$

Signal estimation from D_S filtered sample, background estimation from DIS sample

Projected statistical uncertainties on the inclusive counts:

For ep: $\frac{\sigma_s}{S} = 2.9\%$

For eAu: $\frac{\sigma_s}{S} = 7.8\%$

Note: ϕ mass cut has the dominant effect

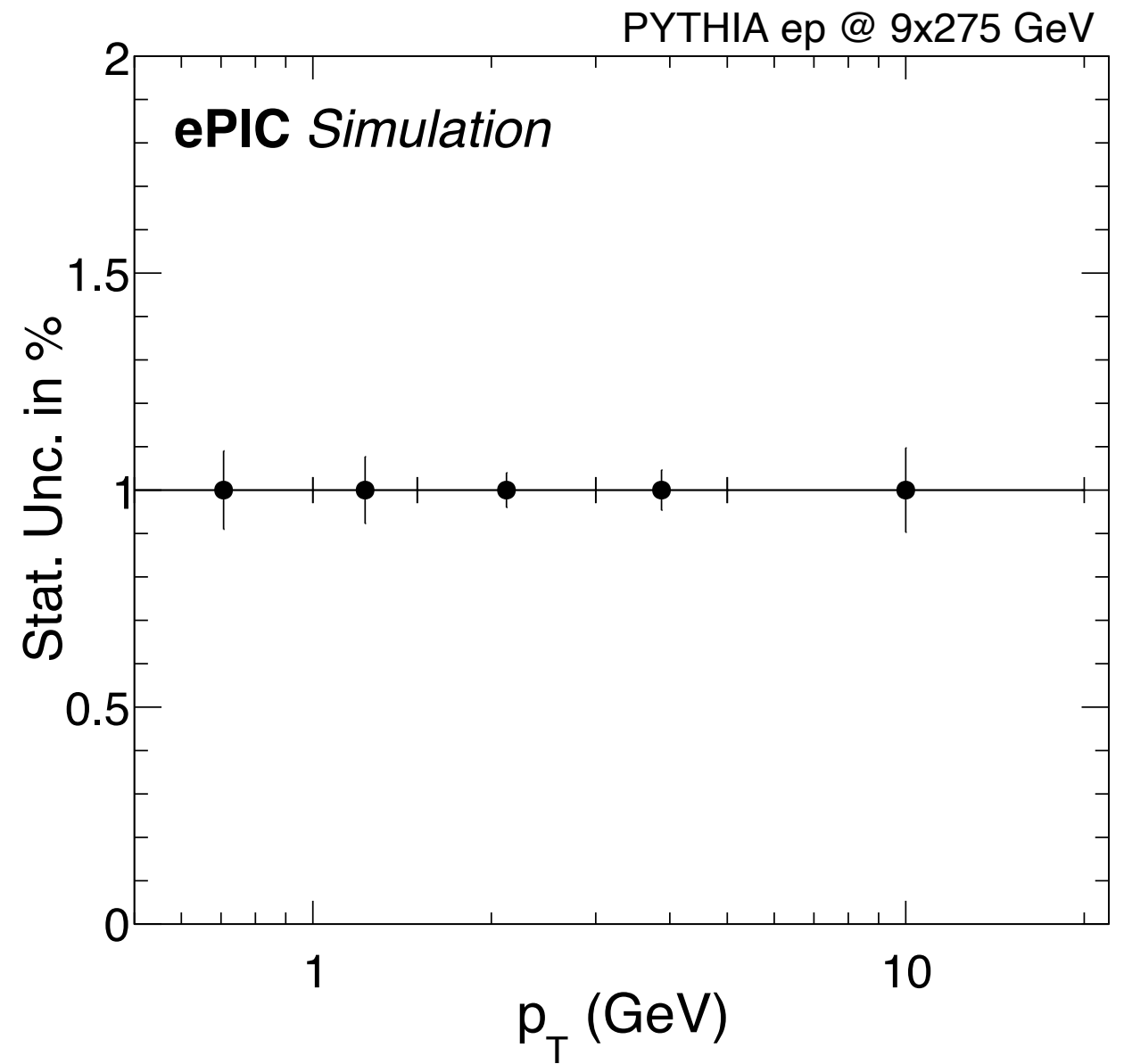
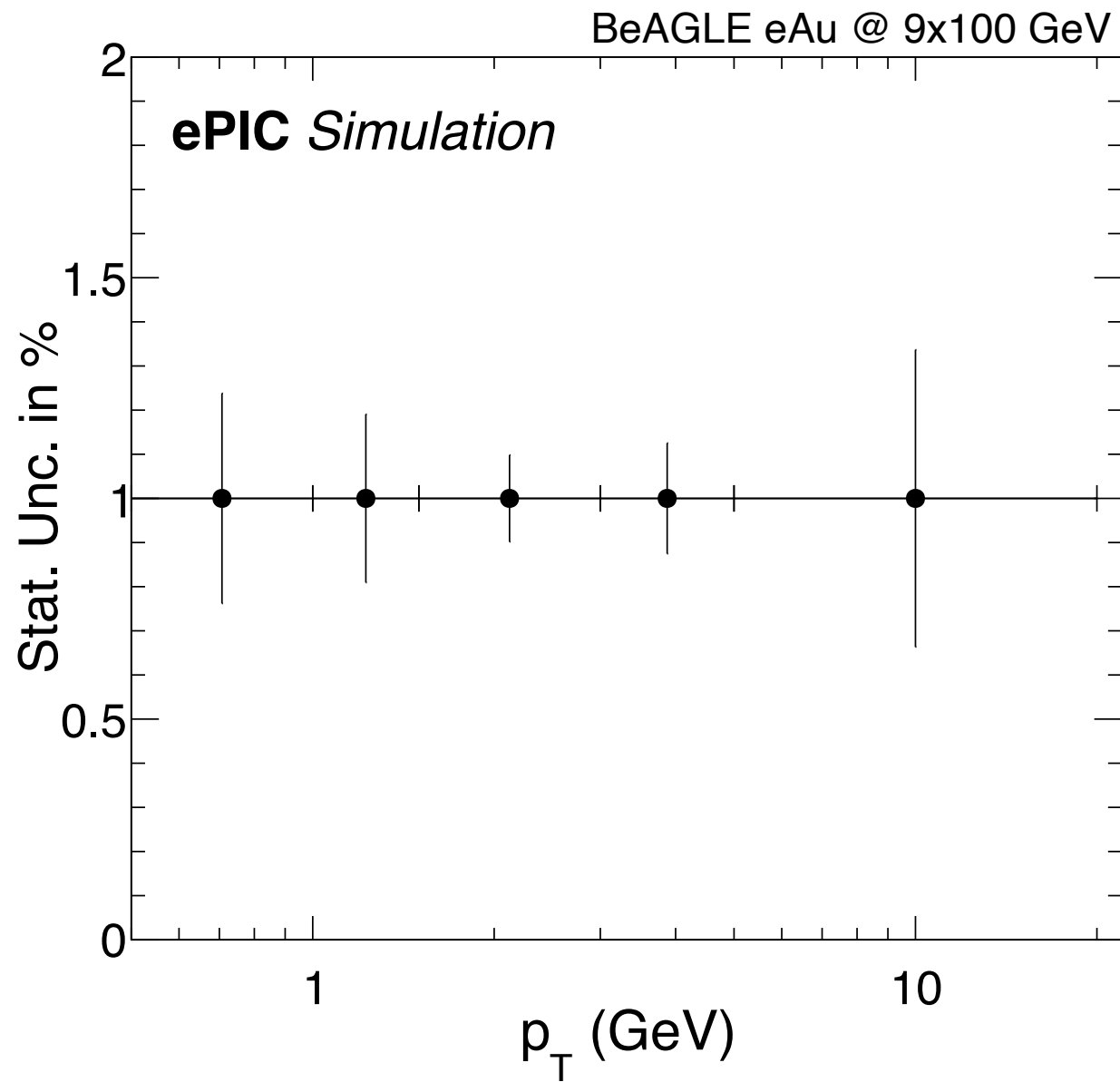
Brings down ep from 11% to 3%

Brings down eAu from 25% to 8%

Projected Statistical Uncertainty; p_T dependence

$$\frac{\sigma_s}{S} \sim \frac{\sqrt{S+B}}{S}$$

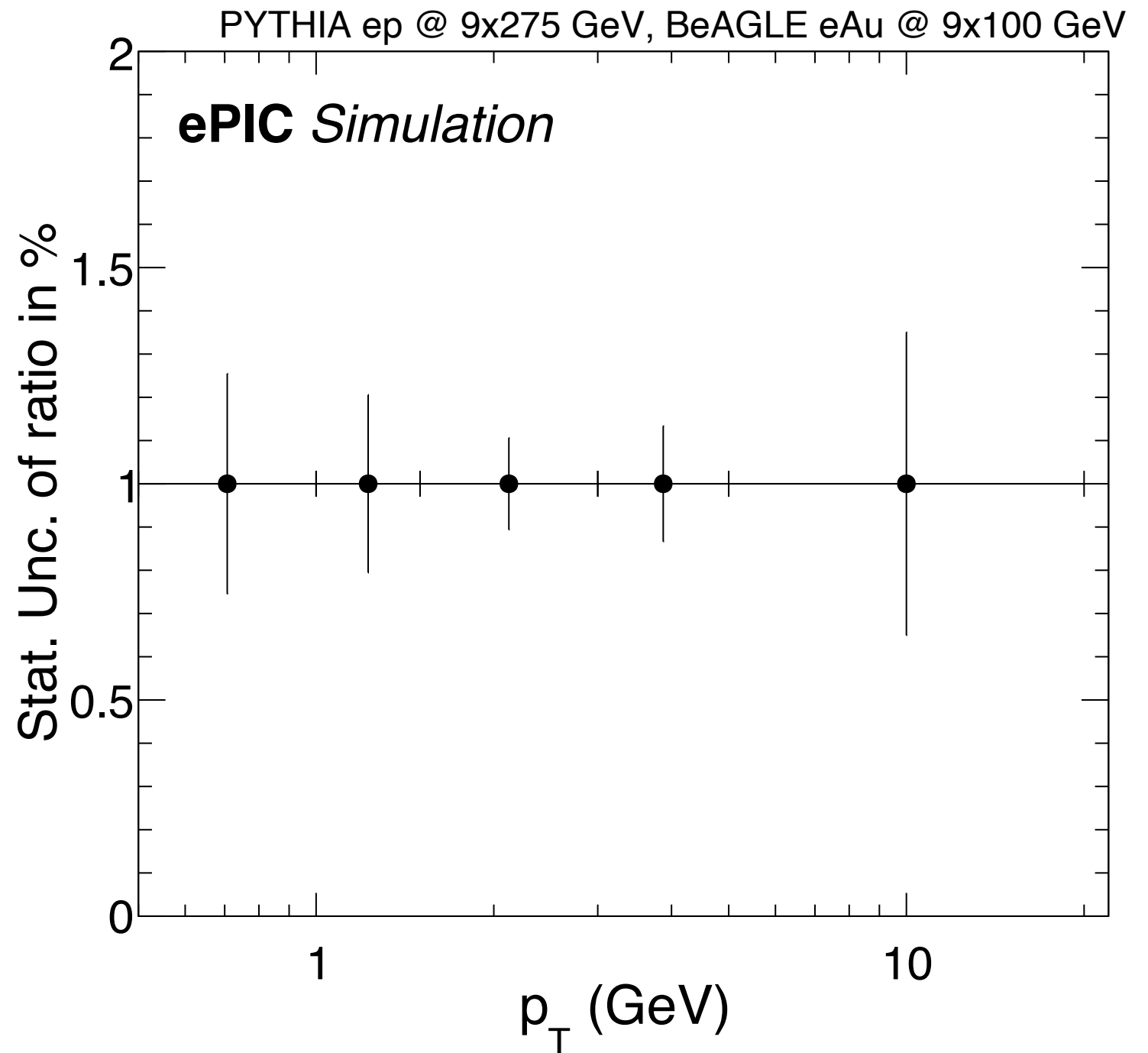
eAu @ 9 x 100 GeV ep @ 9 x 275 GeV



Projected Statistical Uncertainty of D_s ratio

Projected statistical uncertainty on the $D_s(\text{eAu}) / D_s(\text{ep})$ ratio

$$\frac{\delta R}{R} = \sqrt{\left(\frac{\delta N_{e\text{Au}}}{N_{e\text{Au}}}\right)^2 + \left(\frac{\delta N_{ep}}{N_{ep}}\right)^2}$$



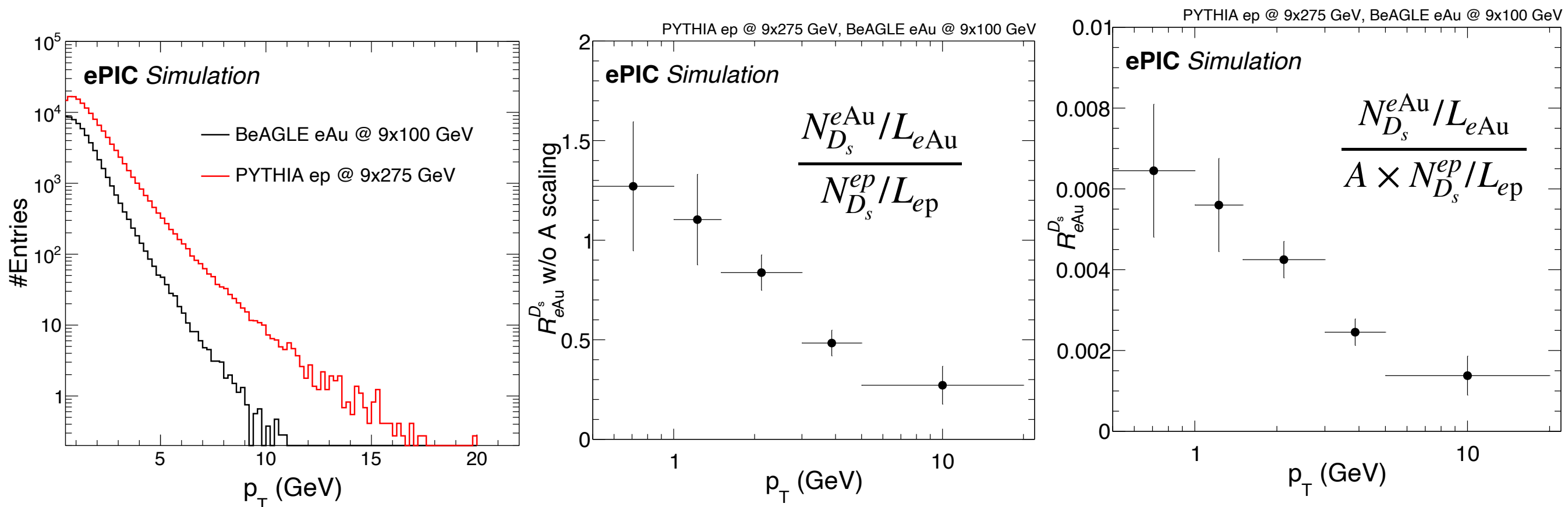
Interested Observables

1) Nuclear modification factor of D_s

$$R_{eAu}(D_s) = \frac{N_{D_s}^{eAu}/L_{eAu}}{A \times N_{D_s}^{ep}/L_{ep}}$$

$A = 197$ for Au
 $L_{eAu} = 2.5 \text{ fb}^{-1}$
 $L_{ep} = 1.0 \text{ fb}^{-1}$

Note: eAu and ep samples are at **different collision energies** → needs careful interpretation
 $N_{D_s}^{eAu}$, $N_{D_s}^{ep}$ is taken as gen-level counts



$R_{eAu}(D_s)$ values look very small, likely due to the energy difference between eAu and ep samples

Interested Observables

2) D_s/D^0 ratio

$$\left(\frac{D_s}{D^0}\right)_{e\text{Au}} = \frac{N_{D_s}^{e\text{Au}}}{N_{D^0}^{e\text{Au}}}, \quad \left(\frac{D_s}{D^0}\right)_{ep} = \frac{N_{D_s}^{ep}}{N_{D^0}^{ep}}$$

This is currently what is proposed in NIM-A overleaf document.

D^0 tree may be obtained from Shyam, or we can run the reconstruction ourselves.

But one thing to note, D^0 and D_s files are produced at different energies for ep

D^0 filtered: ep @ 9 x 130 GeV, eAu @ 9 x 100 GeV

D_s filtered: ep @ 9 x 275 GeV, eAu @ 9 x 100 GeV

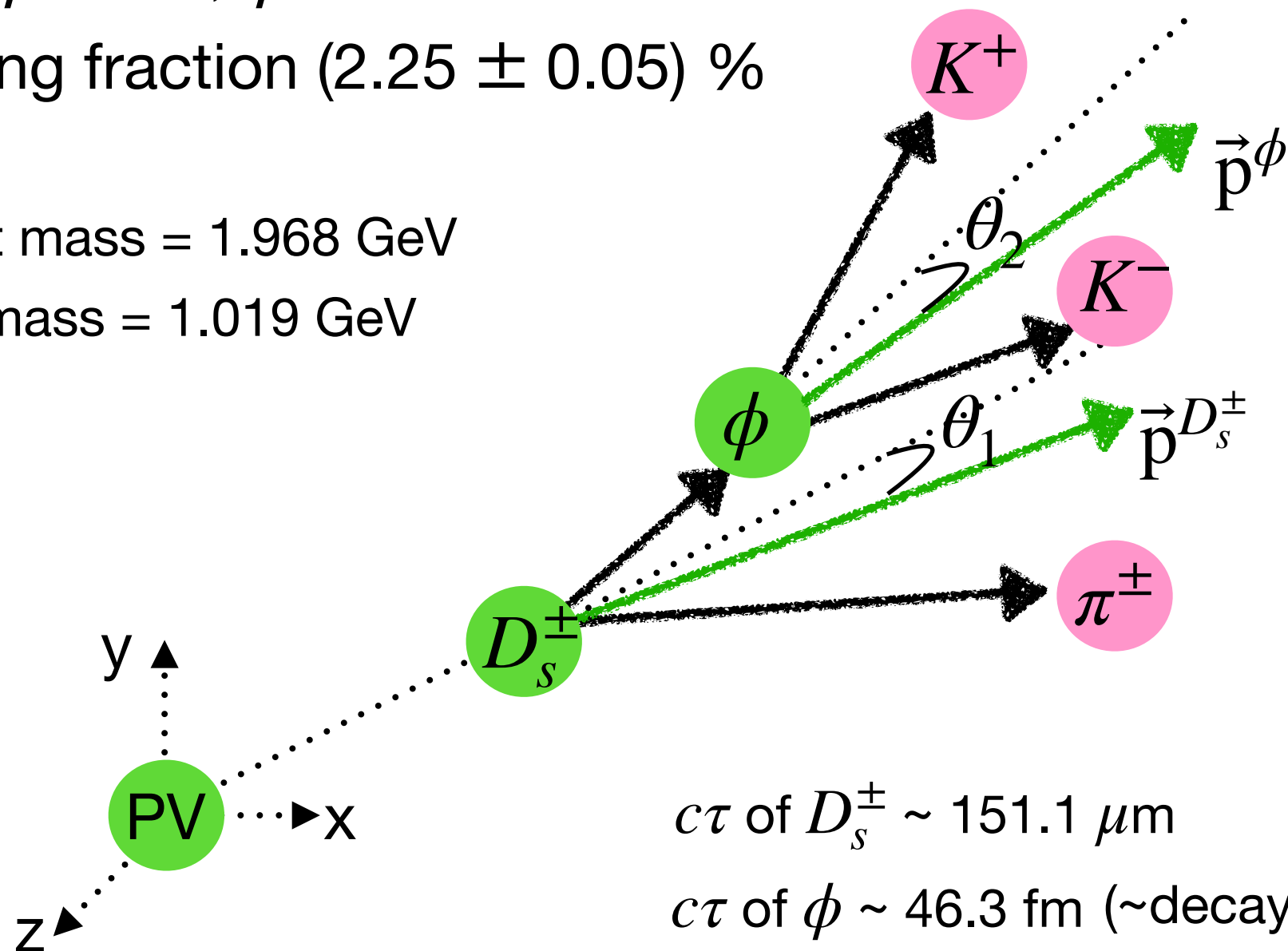
Back up

D_s decay channel

Decay channel of interest

- $D_s^\pm \rightarrow \phi + \pi^\pm, \phi \rightarrow K^+ + K^-$
branching fraction $(2.25 \pm 0.05) \%$

$D_s^\pm$ rest mass = 1.968 GeV
 ϕ rest mass = 1.019 GeV

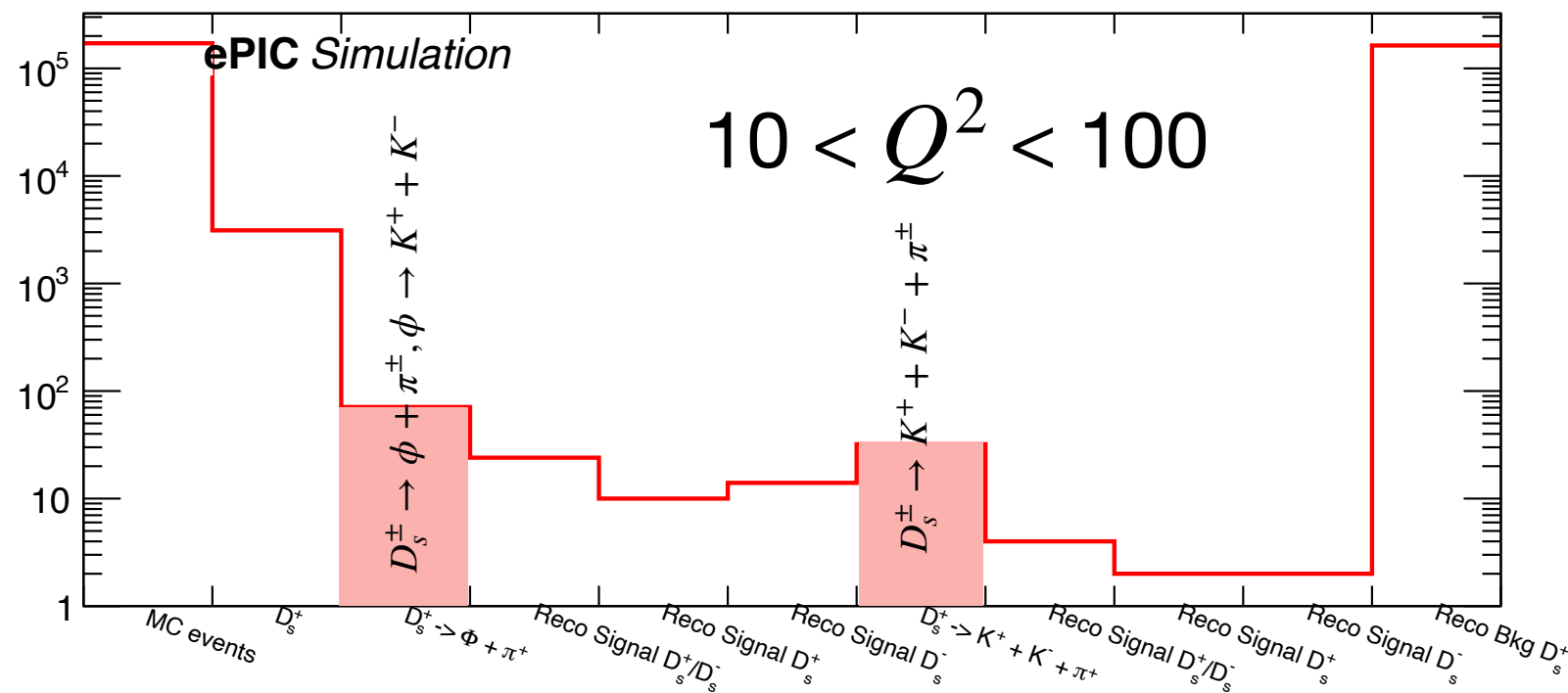
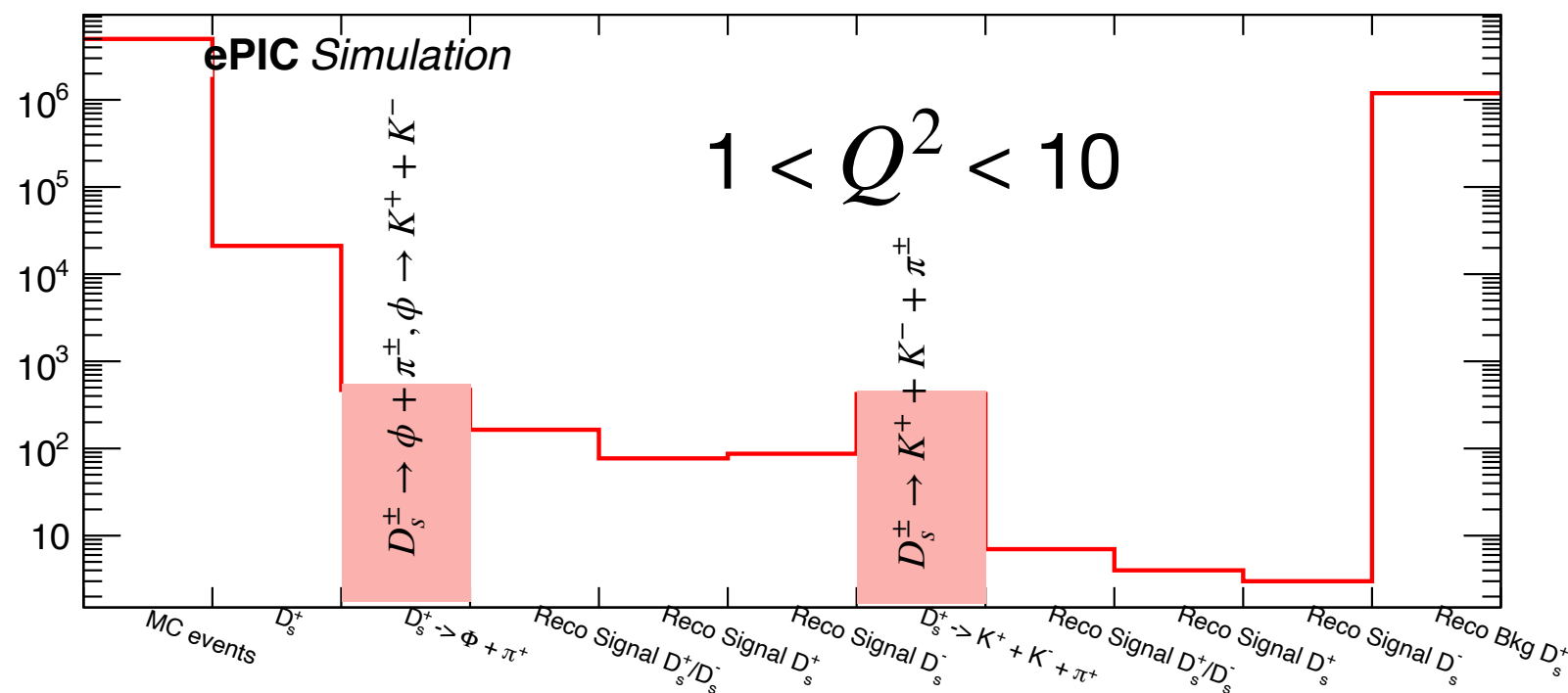


$c\tau$ of $D_s^\pm \sim 151.1 \mu\text{m}$

$c\tau$ of $\phi \sim 46.3 \text{ fm}$ (~decays extremely quickly)

D_s event statistics in DIS sample

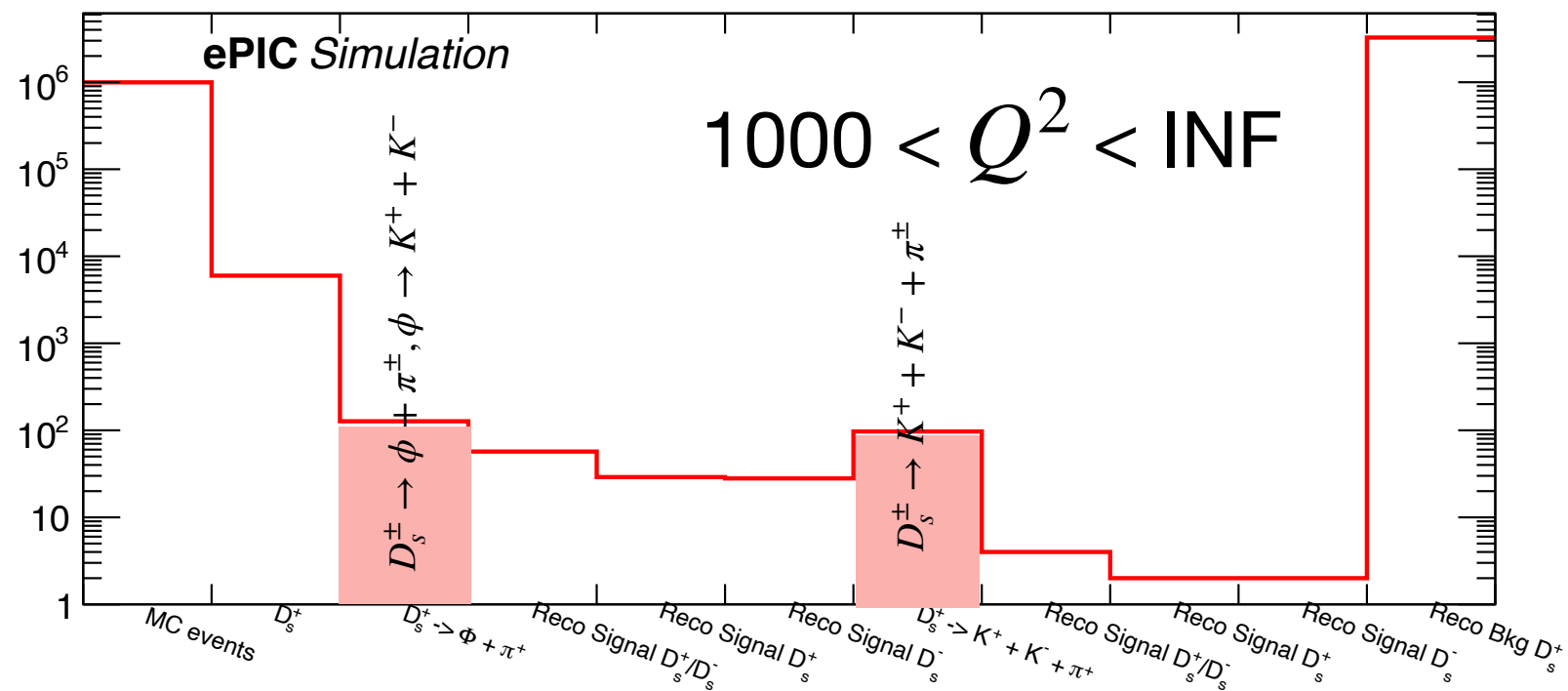
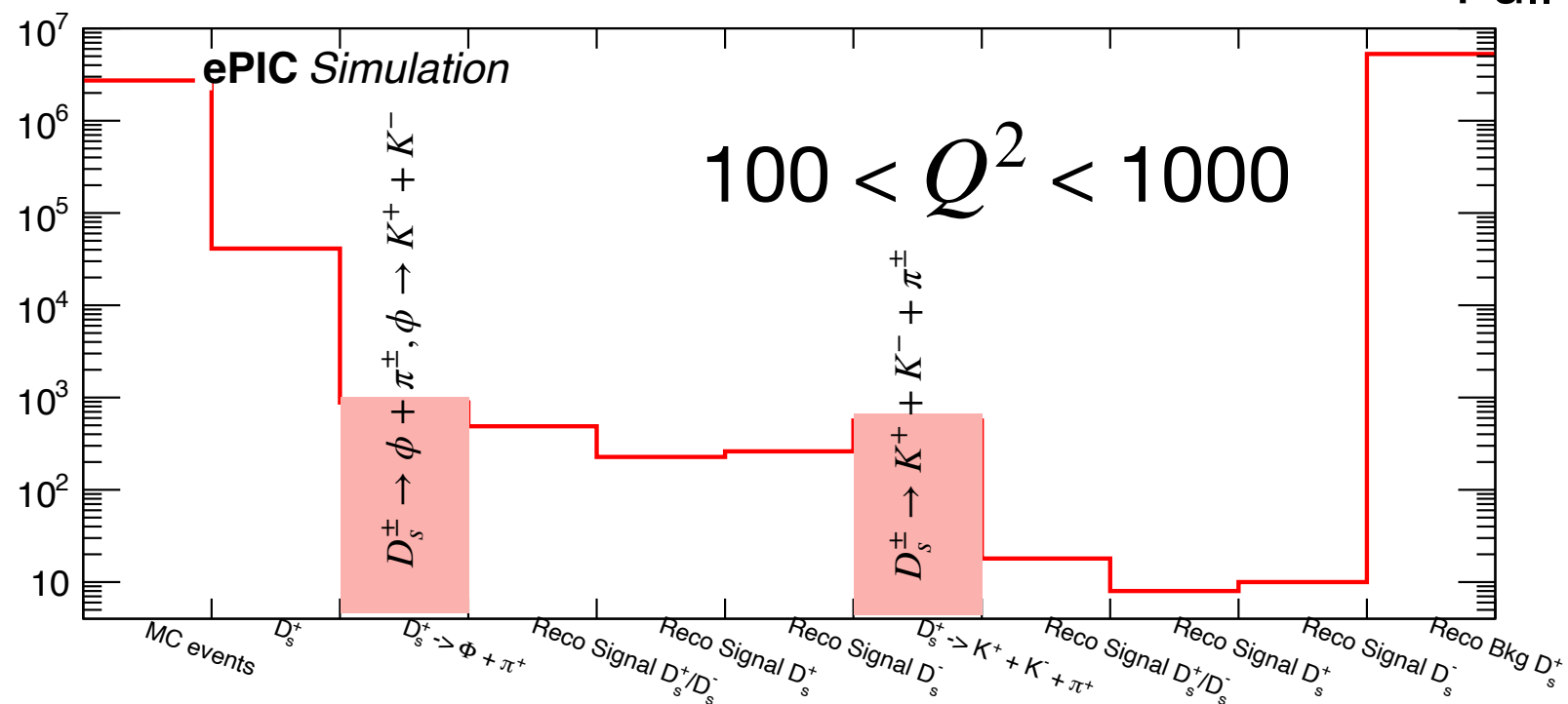
Full sample processed



Roughly similar contribution of resonant and non-resonant decay channel in DIS sample

D_s event statistics in DIS sample

Full sample processed



Roughly similar contribution of resonant and non-resonant decay channel in DIS sample

Basic selection cuts applied:

- Pointing angle: $\cos \theta > 0.9$
- Daughter displacement: $\text{DCA}_{3D} > 0.005$ cm
- Decay length: $L > 0.01$ cm

