Status report on the initial setup campaign

Feasibility study of the rare decay $D^0 \to \gamma\gamma$ & $D^0 \to \mu^+\mu^-$

full & fast MC simulation at PANDA

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Motivation

- In Standard Model (SM), Flavor Changing Neutral Currents (FCNC) are forbidden

  - FCNC decay : $D^0 \rightarrow \gamma\gamma$ / $D^0 \rightarrow \mu^+\mu^-$

  - FCNC could be enhanced by new physics

$BR_{SM}(D^0 \rightarrow \gamma\gamma) \sim 10^{-11}$ $BR_{MSSM}(D^0 \rightarrow \gamma\gamma) \sim 10^{-6}$	$BR_{SM}(D^0 \rightarrow \mu^+\mu^-) \sim 10^{-13}$ $BR_{Theory}(D^0 \rightarrow \mu^+\mu^-) \sim 10^{-6} - 10^{-10}$

  - Experimental results (upper limit CL=90%)

BABAR :	$BR < 2.2 \times 10^{-6}$	PDG(2012) :	$BR < 1.3 \times 10^{-6}$
BESIII :	$BR < 4.6 \times 10^{-6}$	CDF,HERA-B :	$BR < 2.5 \times 10^{-6}$
CLEOc :	$BR < 8.63 \times 10^{-6}$	WA92,E771 :	$BR < 4.1 \times 10^{-6}$

- Search for rare decay as a sign of beyond SM

Sensitivity accessible @ PANDA?

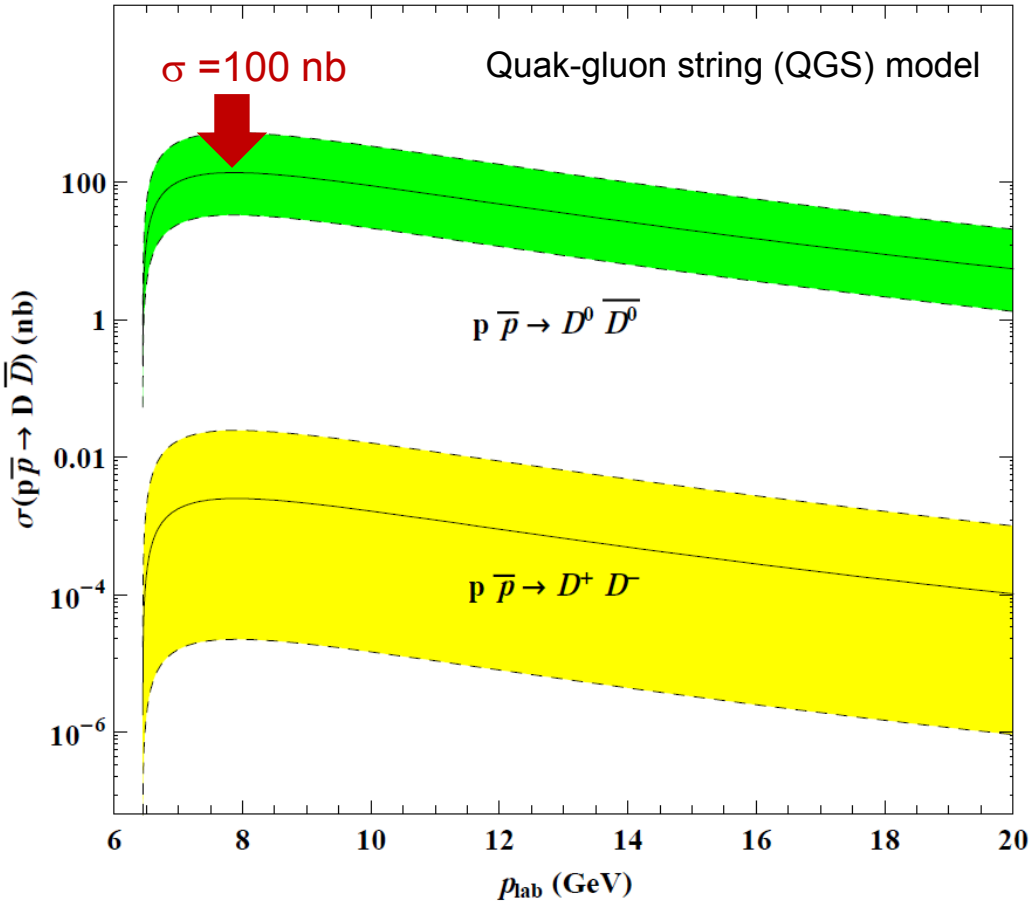
Expected number

High Luminosity : $L = 2\times10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}, t = 120\,\mathrm{days(year)}$

Expected N : $N_B = L_{\mathrm{int}} \times \sigma \times \varepsilon$

$$N_{D\to\gamma\gamma} = 2\,\mathrm{fb}^{-1}\times 100\,\mathrm{nb}\times\varepsilon\times Br$$
$$= 404\times\varepsilon$$
$$\text{with } Br(D^0\to\gamma\gamma) < 2.2\times10^{-6}$$

$$N_B = 2\,fb^{-1}\times 50\mathrm{mb}\times\varepsilon$$
$$= 10^{14}\times\varepsilon$$

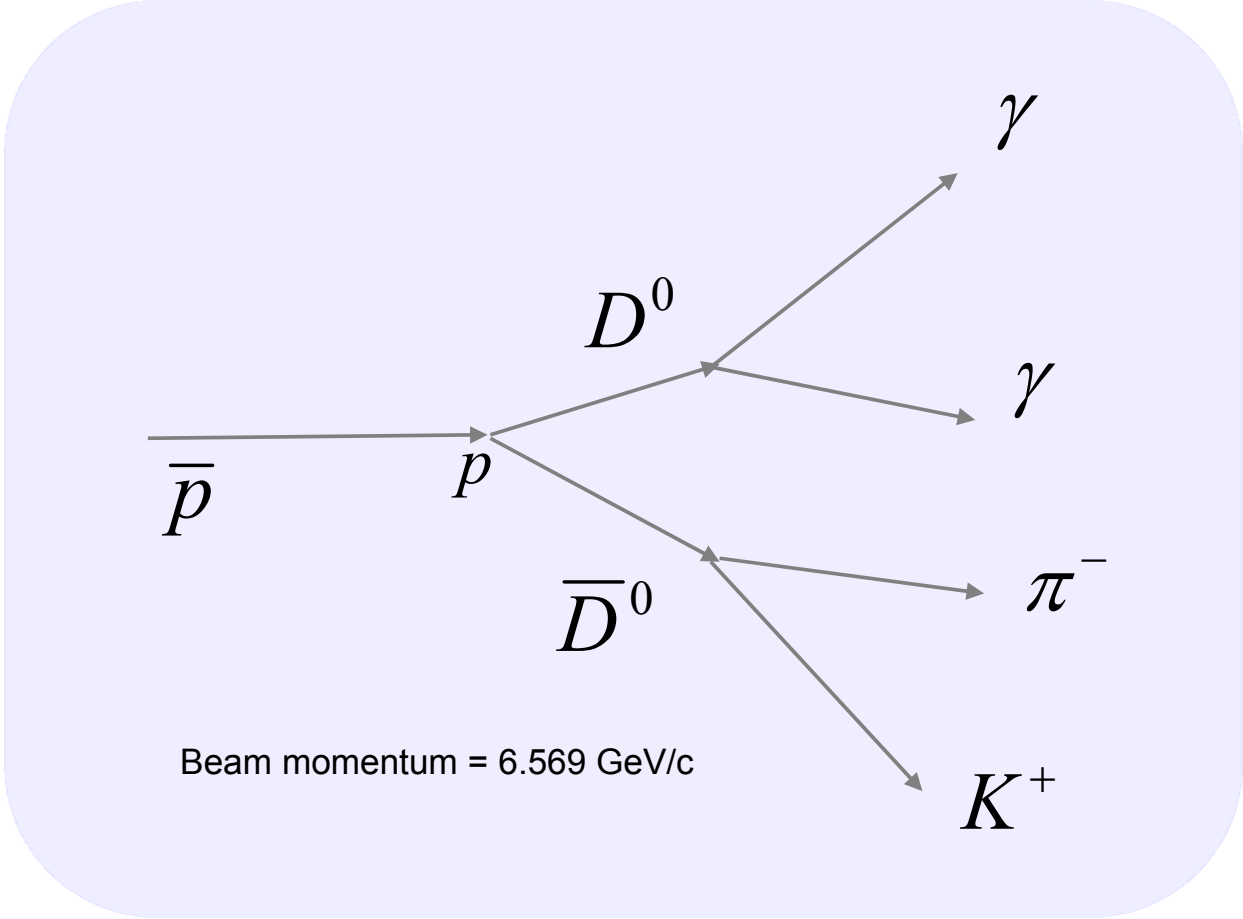


$$\frac{S}{B} = 0.01\sim 1 \to \text{Background reduction} = 10^{-9}\sim 10^{-11}$$

$$D^0 \to \mu^+ \mu^-$$

Event reconstruction

Physics channel : $\bar{p}p \to D^0\bar{D}^0 \to \gamma\gamma\, K^+\pi^-$



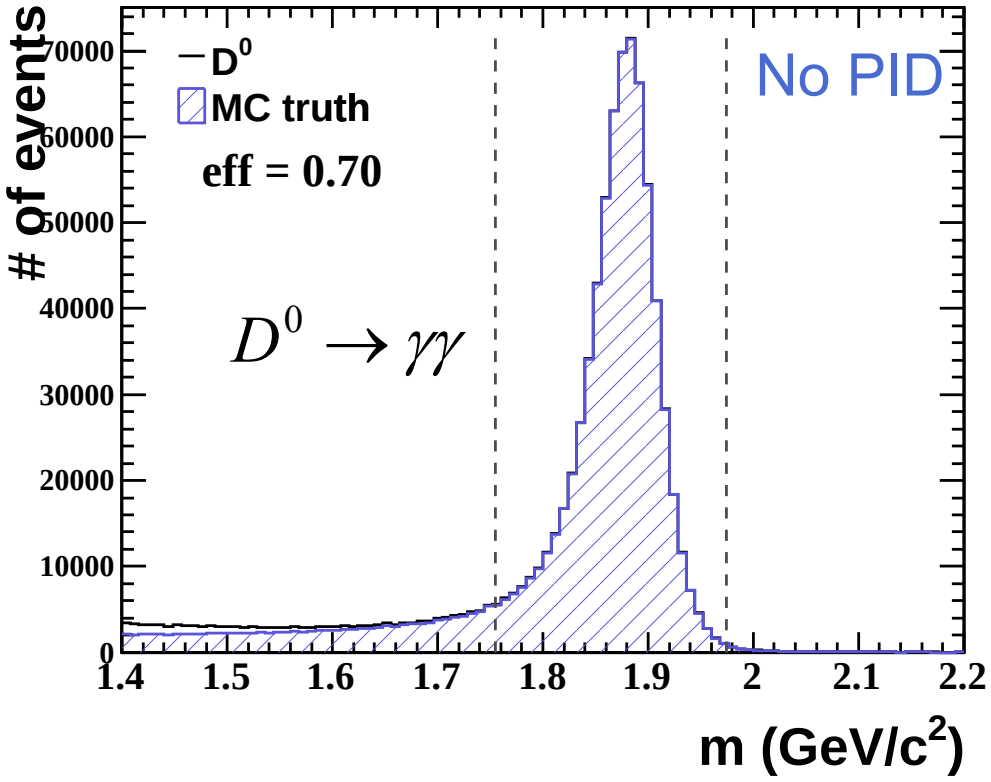
$\bar{p}p \to \psi(3770) \to D^0\bar{D}^0 \to \mu^+\mu^-\, K^+\pi^-$: quantum number fixed $J^{PC} = 1^{--}$

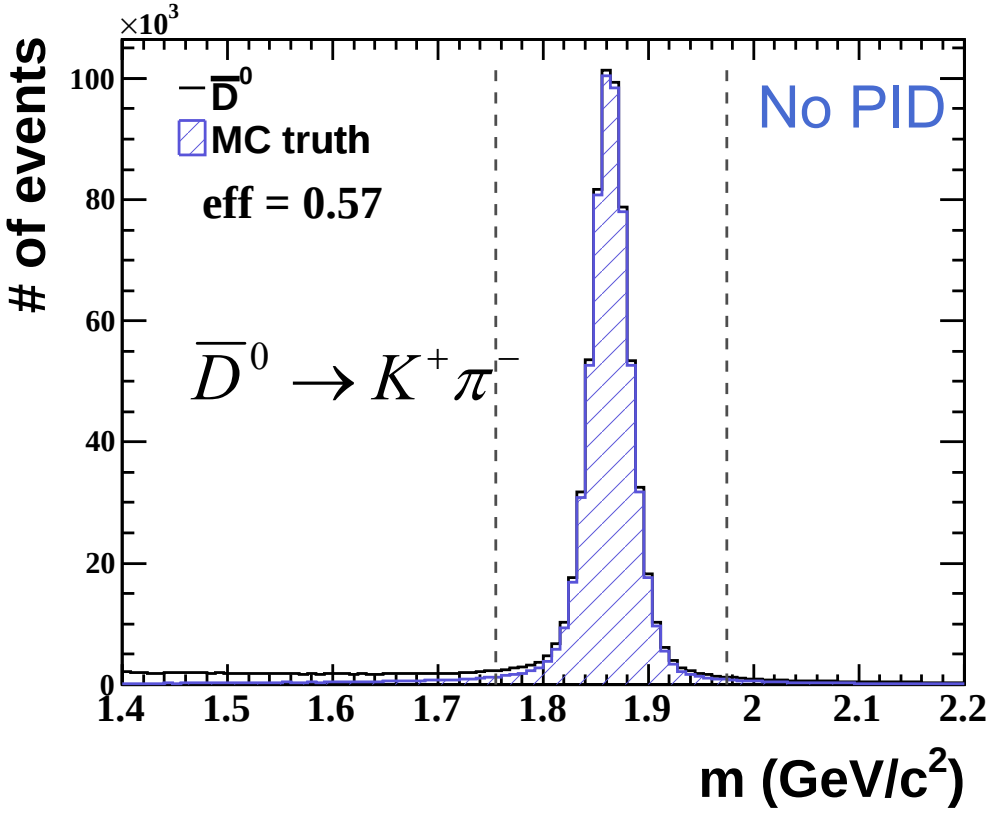
$\bar{p}p \to D^0\bar{D}^0 \to \mu^+\mu^-\, K^+\pi^-$: all possible quantum number (6 states) corresponds σ =100 nb

Full simulation

$$\bar{p}p \to D^0\bar{D}^0 \to \gamma\gamma\, K^+\pi^-$$

$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}} \text{ in the mass window}$$



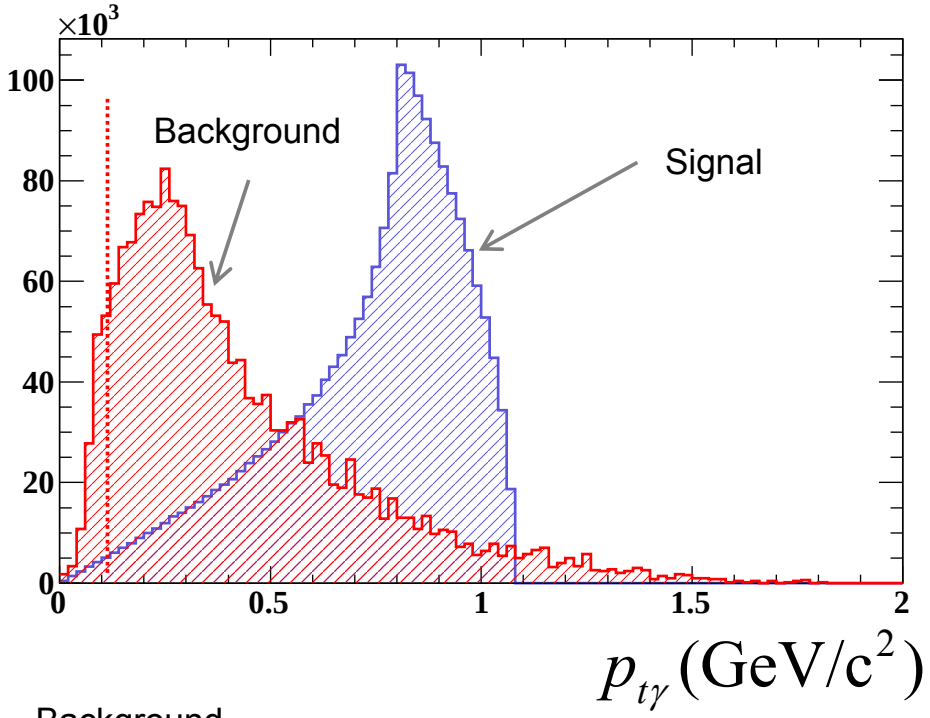


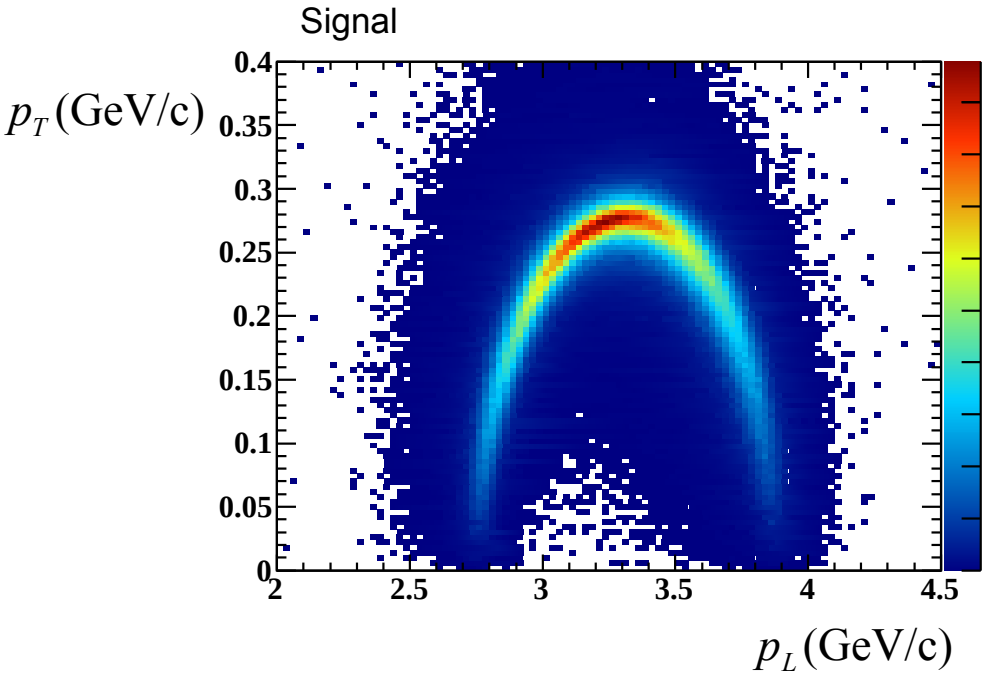
Neutral track : E > 50 MeV
Charged track : p > 100 MeV/c

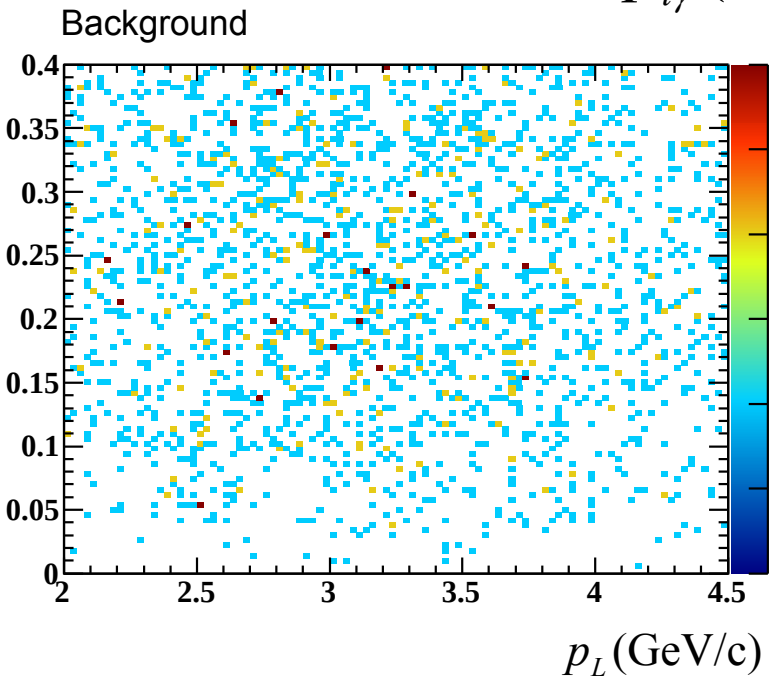
Background rejection

- $p_T > 0.1(\mathrm{GeV/c})$ for γ
- $p_T < p_T^{\max} + 0.2(\mathrm{GeV/c})$ for D^0

$$p_T^{\max}(\sqrt{s};m) = \frac{\sqrt{s^2 - 4 \cdot s \cdot m^2}}{2\sqrt{s}}$$



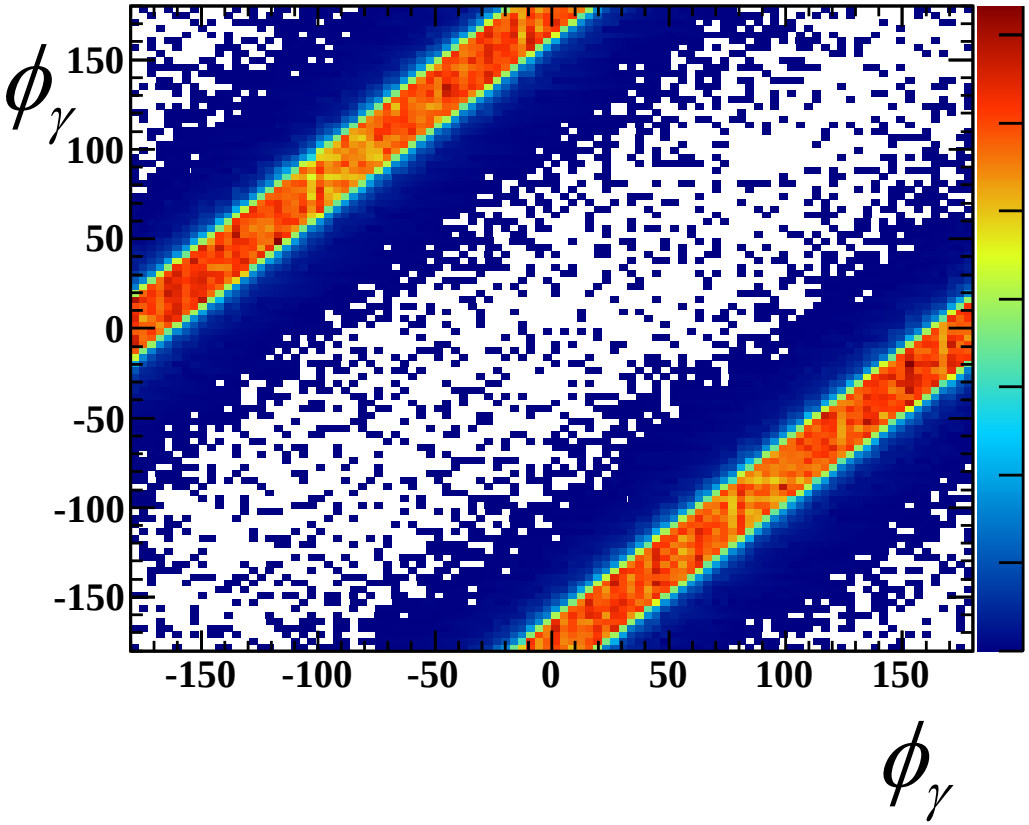




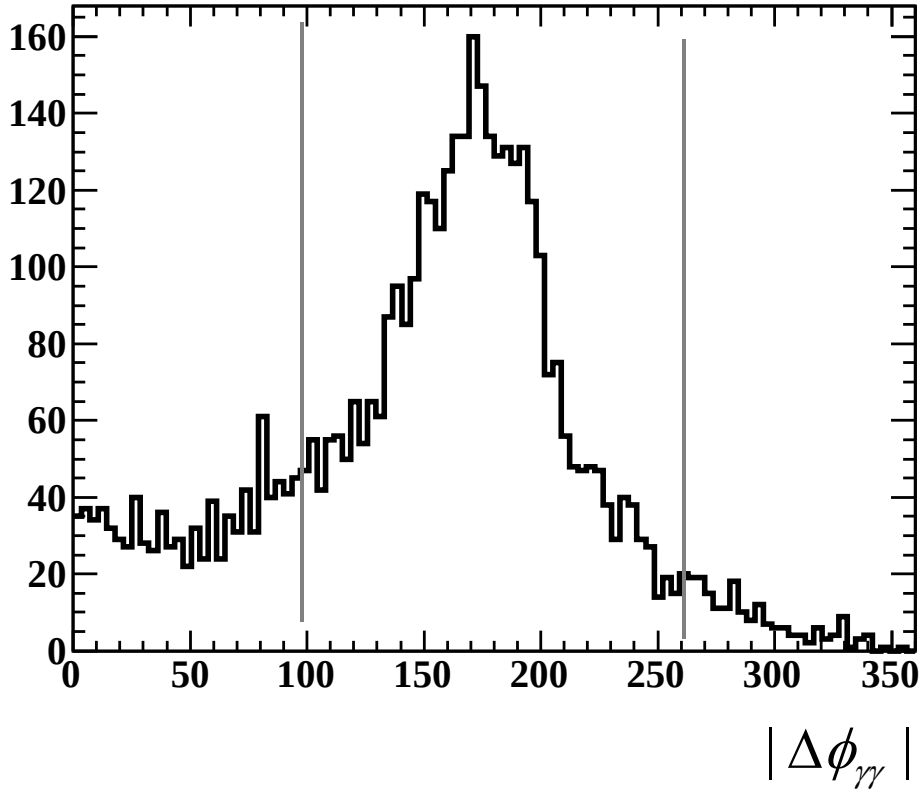
Background rejection

$$100^\circ < |\Delta\phi_{\gamma\gamma}| < 260^\circ$$

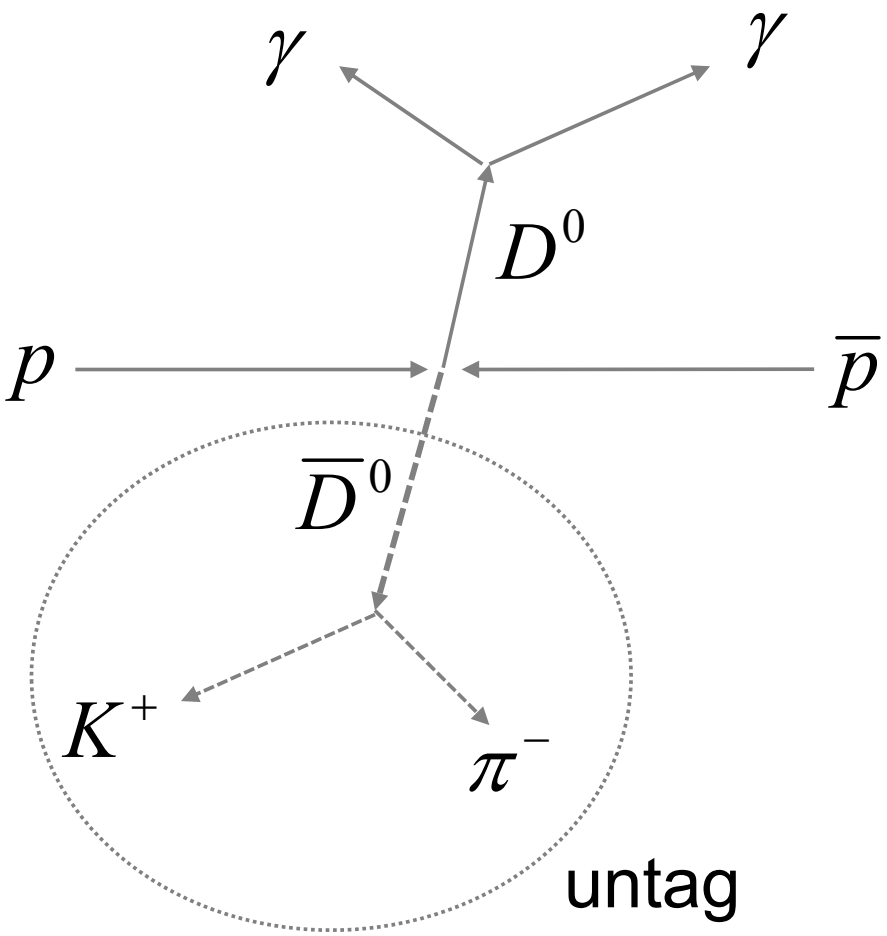
Signal MC generated



Background MC reconstructed

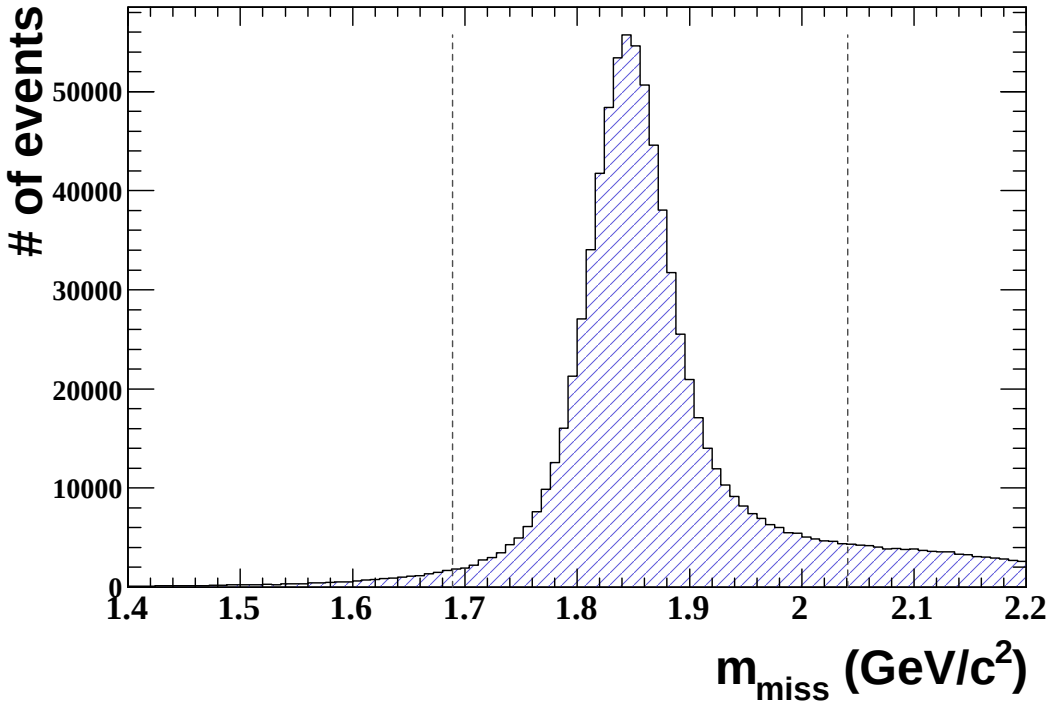


Background rejection



Missing mass of D^0 partner

$$M_{miss} = \sqrt{(E_{CM} - E_{D(\gamma\gamma)})^2 + (\vec{p}_{CM} - \vec{p}_{D(\gamma\gamma)})^2}$$



Tag-mode will be suffered by additional factor

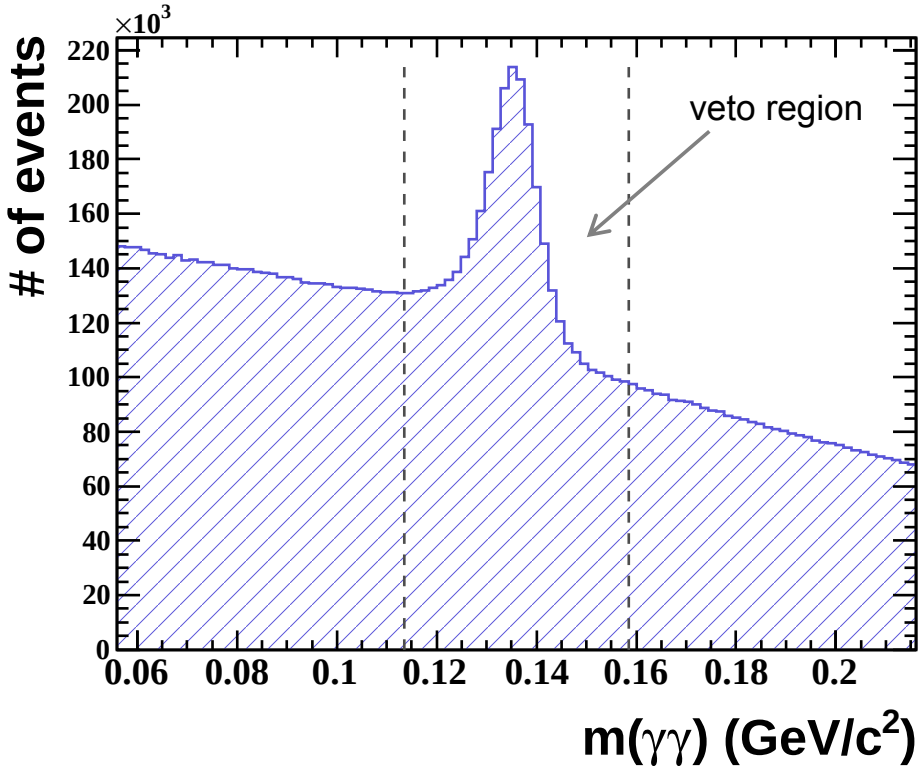
$$Br(\overline{D}^0 \rightarrow K^+\pi^-) = (3.89 \pm 0.05)\%$$

Background rejection

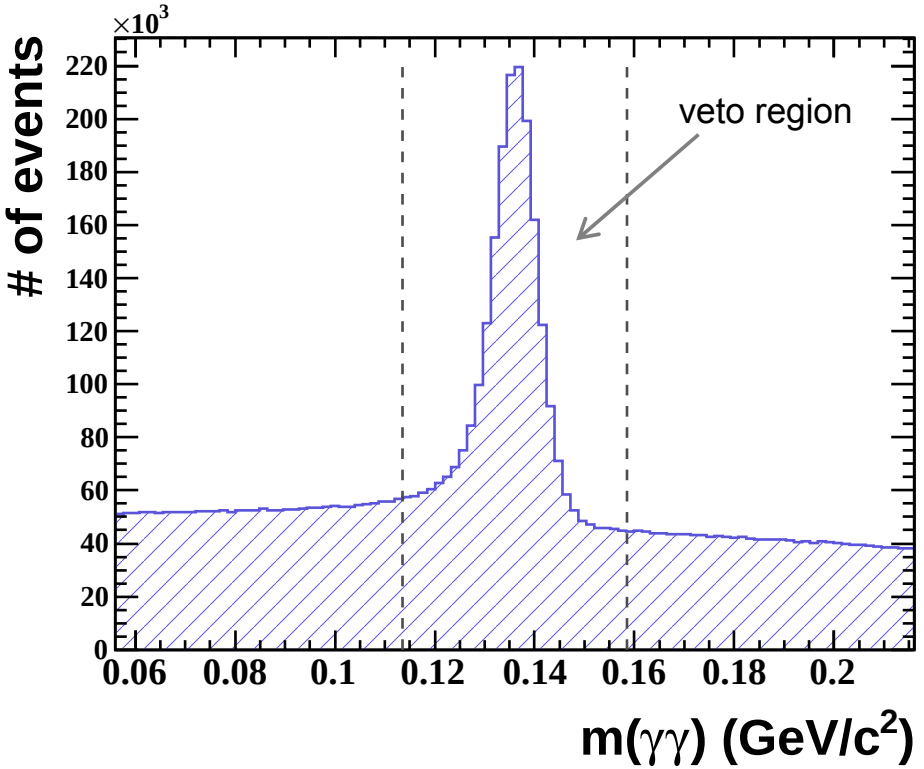
π^0 veto : reject events in which one of the photons can be combined with any other photon candidate in the event to form a π^0

Lower threshold (E= 50 MeV) is more efficient than higher value for pion veto

DPM background



$D^0\overline{D}^0 \to \pi^0\pi^0K^+\pi^-$

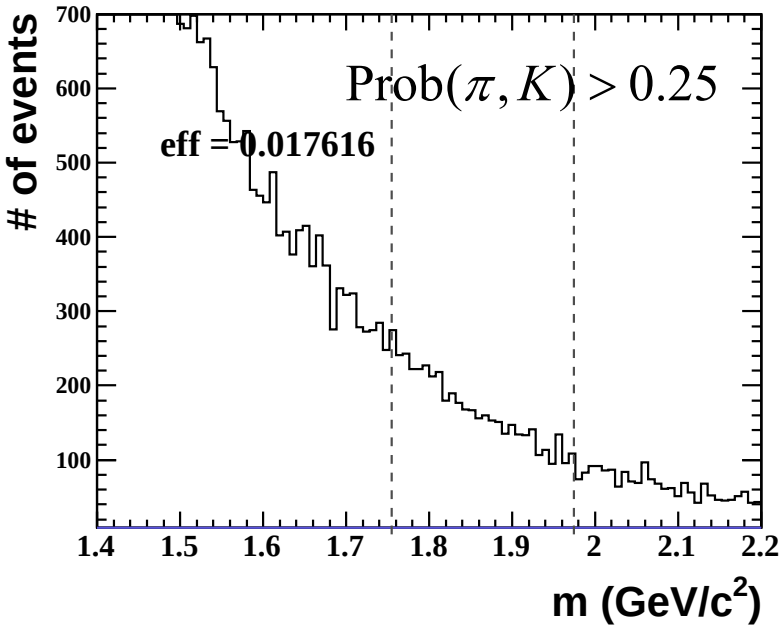


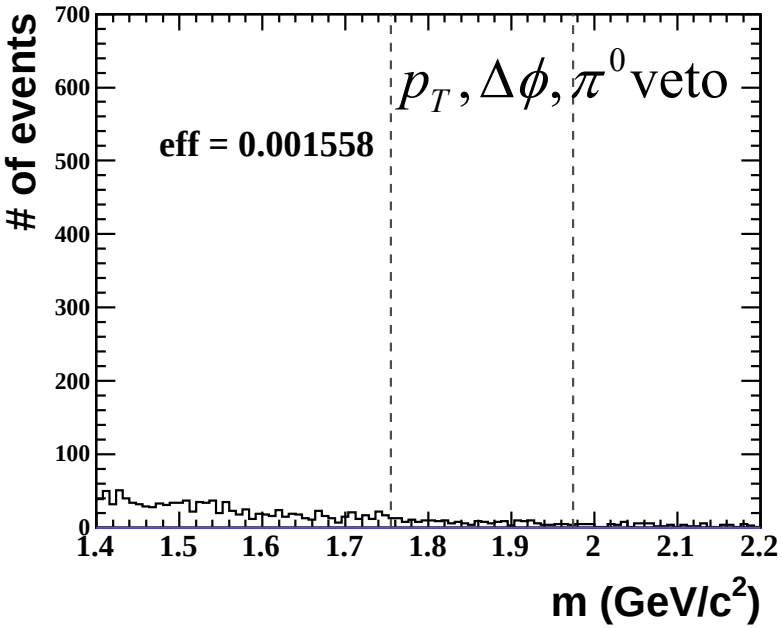
Background rejection

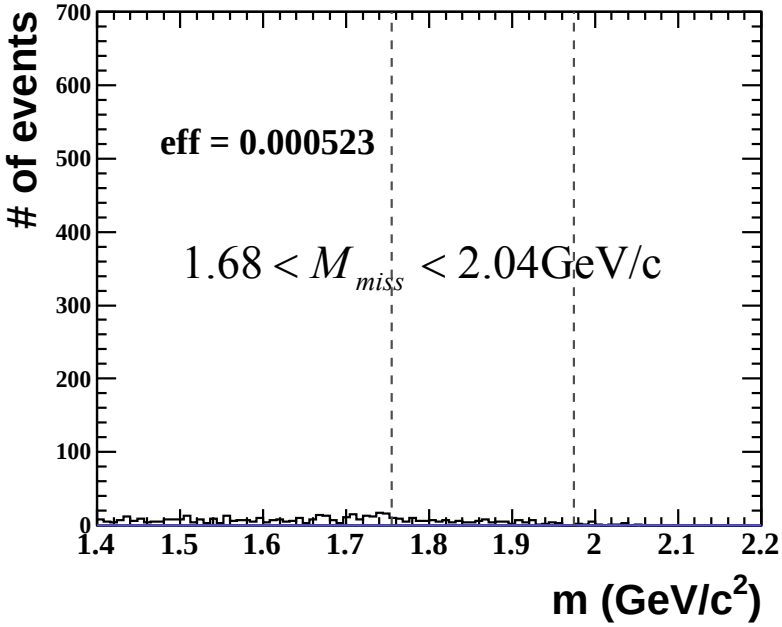
DPM background

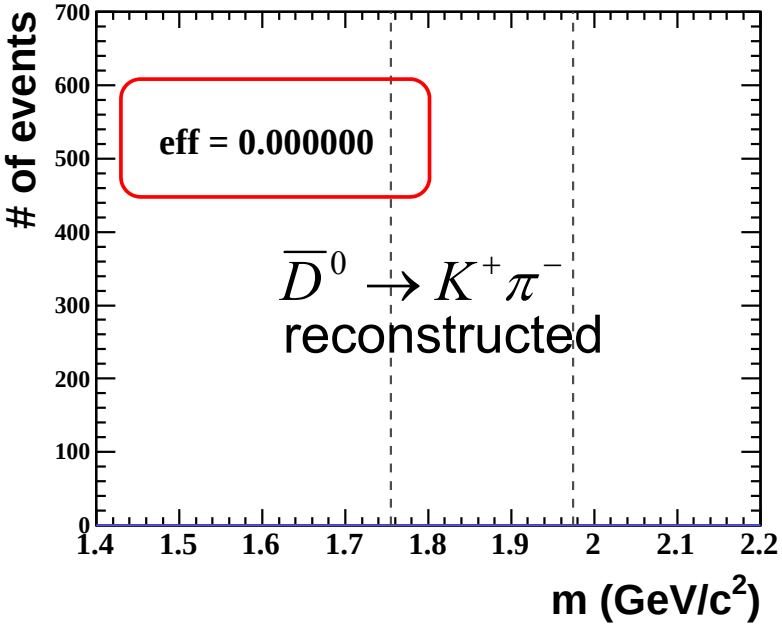
$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}}$$

in the histogram









Backg. Reduciton

$\varepsilon_{back} < 10^{-6}$

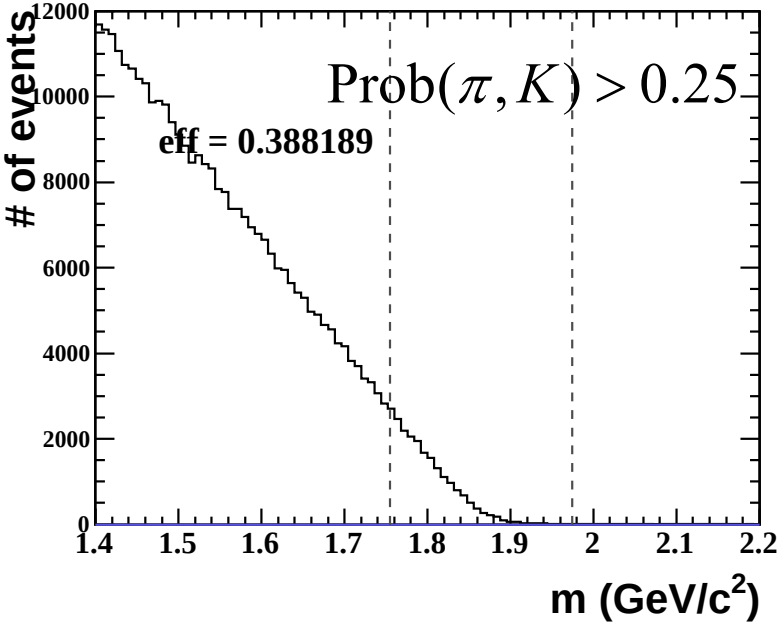
based on the DPM
1M events

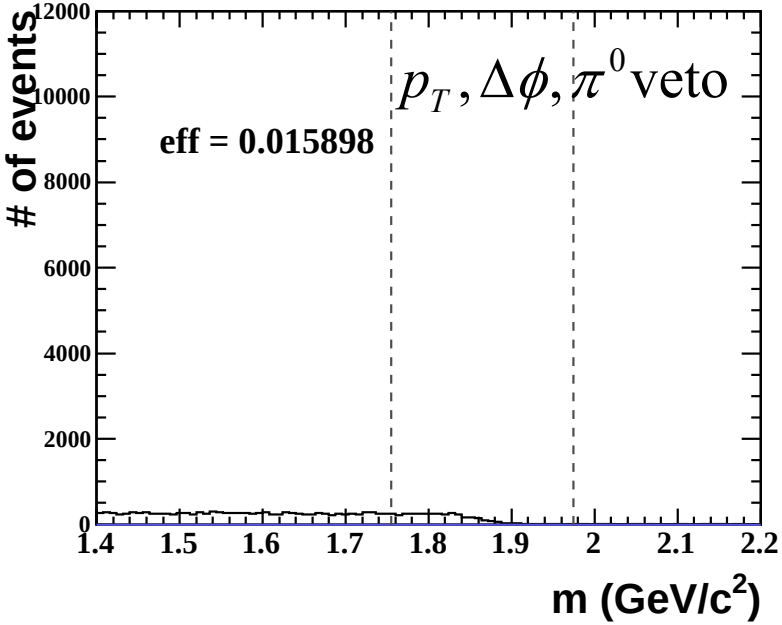
Background rejection

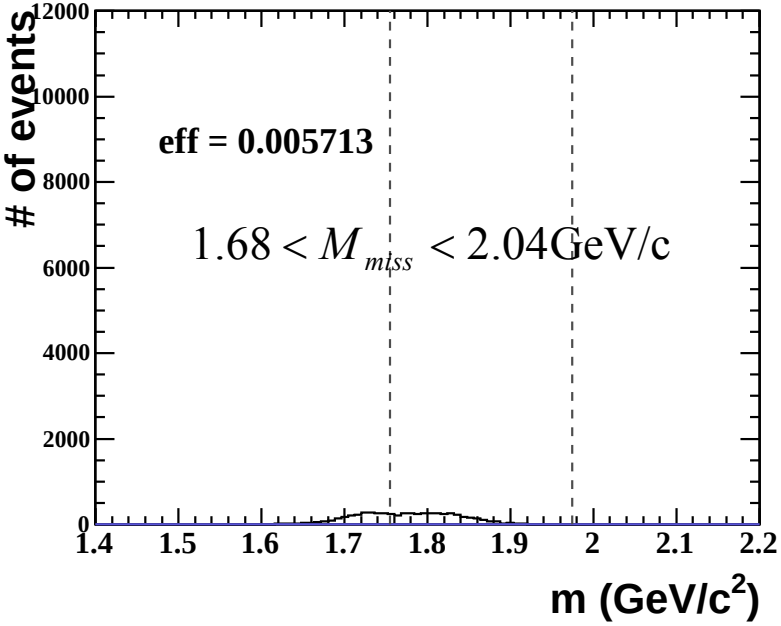
$D^0\overline{D}^0 \to \pi^0\pi^0 K^+\pi^-$ background

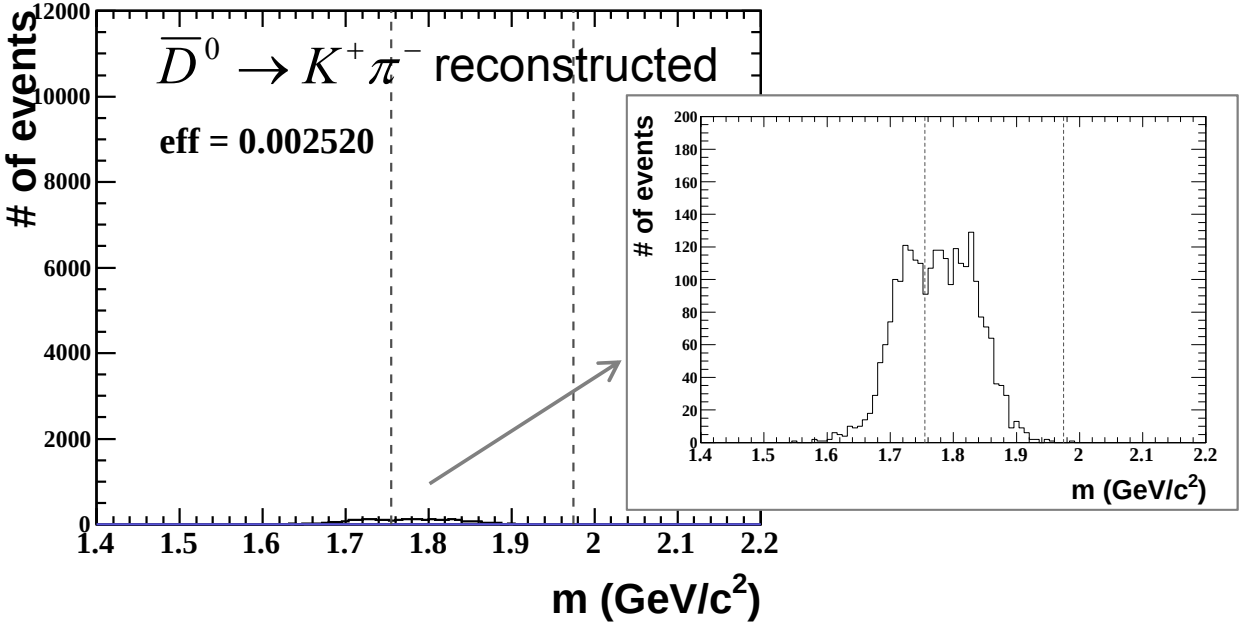
$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}}$$

in the histogram







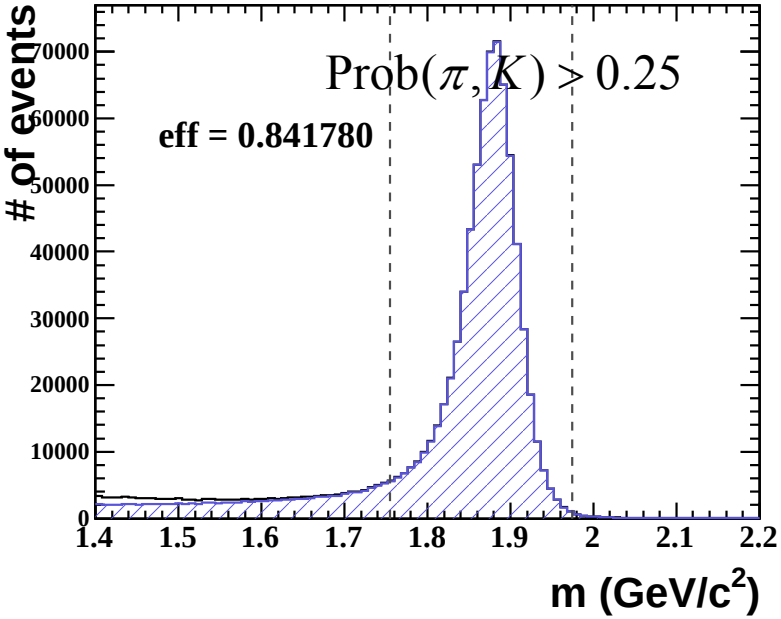


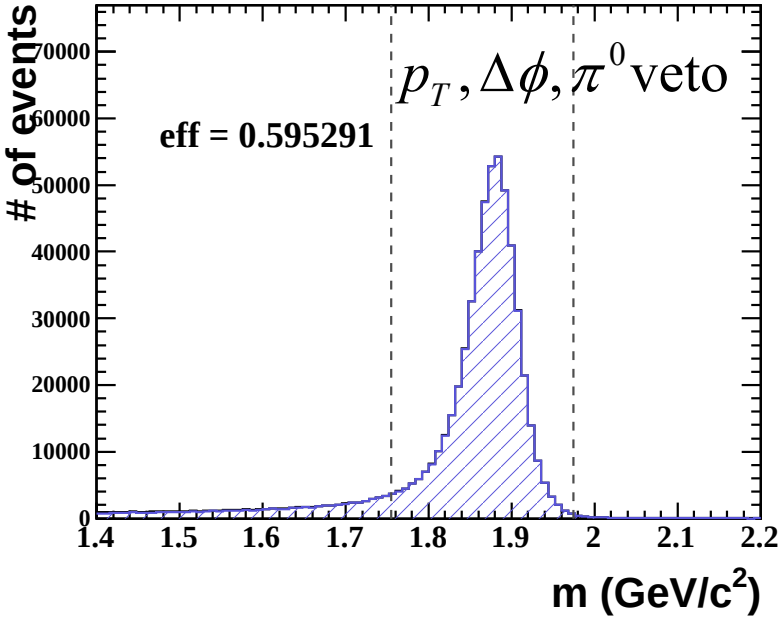
Efficiency

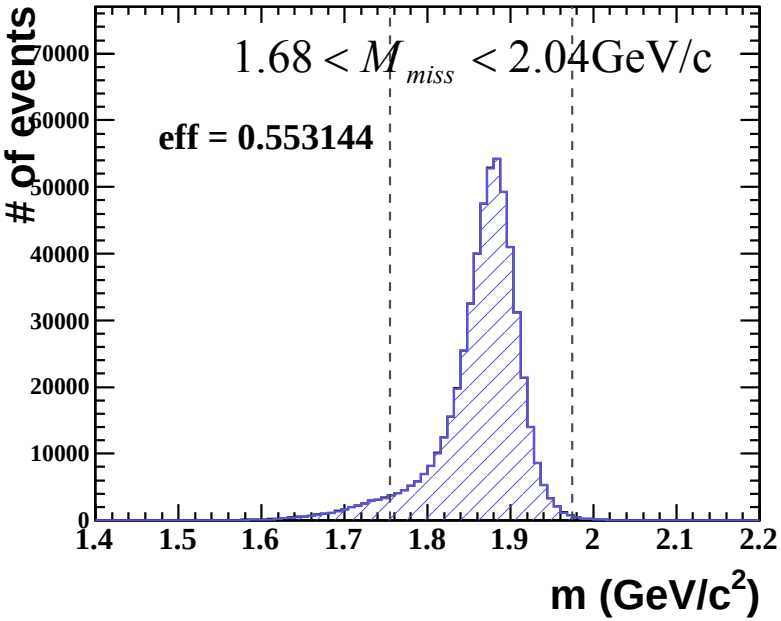
$\bar{p}p \to D^0\bar{D}^0 \to \gamma\gamma\, K^+\pi^-$ data

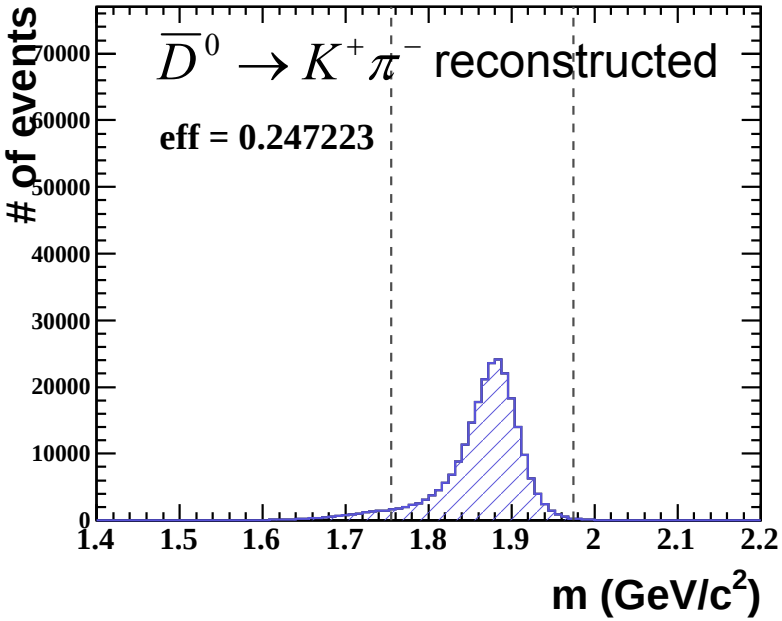
$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}}$$

in the histogram









Signal efficiency

$\varepsilon_{tag} = 0.247$

for double tag

Expected number @ PANDA

$D^0 \to \gamma\gamma$ signal data

$$N_{D\to\gamma\gamma} = 2\,\text{fb}^{-1} \times 100\,\text{nb} \times \Sigma(Br_i) \times \varepsilon_{tag} \times 2$$
$$= 8\,\text{events}$$

$$Br(D^0 \to \gamma\gamma) < 2.2 \times 10^{-6}$$
$$Br(\overline{D}^0 \to K^+\pi^-) = 0.0389$$
$$\varepsilon_{tag} = \varepsilon_{D^0\to\gamma\gamma\,\&\,\overline{D}^0\to K^+\pi^-} = 0.247$$

$D^0 \to \pi^0\pi^0$ background data

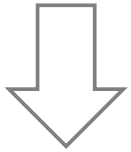
$$N_{D\to\pi^0\pi^0} = 2\,\text{fb}^{-1} \times 100\,\text{nb} \times \Sigma(Br_i) \times \varepsilon_{tag} \times 2$$
$$= 27\,\text{event}$$

$$Br(D^0 \to \pi^0\pi^0) = 8.4 \times 10^{-4}\,[\text{BABAR(2012)}]$$
$$Br(\overline{D}^0 \to K^+\pi^-) = 0.0389$$
$$\varepsilon_{tag} = \varepsilon_{D^0\to\pi^0\pi^0\,\&\,\overline{D}^0\to K^+\pi^-} = 0.0025$$

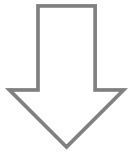
- DPM background can be manageable up to 10^6
- We are sitting in the edge of potential achievement
- Other models for D^0D^0 cross section? Could be larger than σ_{DD} >100 nb?

Test of background reduction

10^9 statistics for DPM events available?



Possible only with fast simulation



Is the fast simulation describe the property correctly in terms of efficiency and resolution?

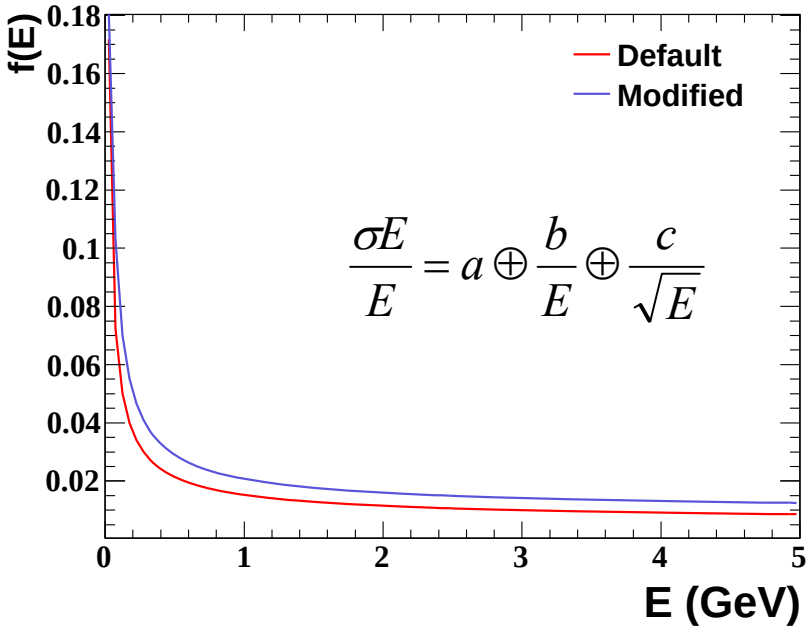
Fast simulation

Tuning of detector parameters @ fast simulation

- Tracking efficiency in barrel part, STT,MVD,GEM
  $\varepsilon=0.85 \rightarrow \varepsilon=0.8$
  Use parameterized efficiency at $P < 0.6$ GeV/c

- PID efficiency in each PID detector : $\varepsilon=1.0 \rightarrow \varepsilon=0.7$
  MDT barrel mis-PID level : $Prob_m=0.01 \rightarrow Prob_m=0.05$

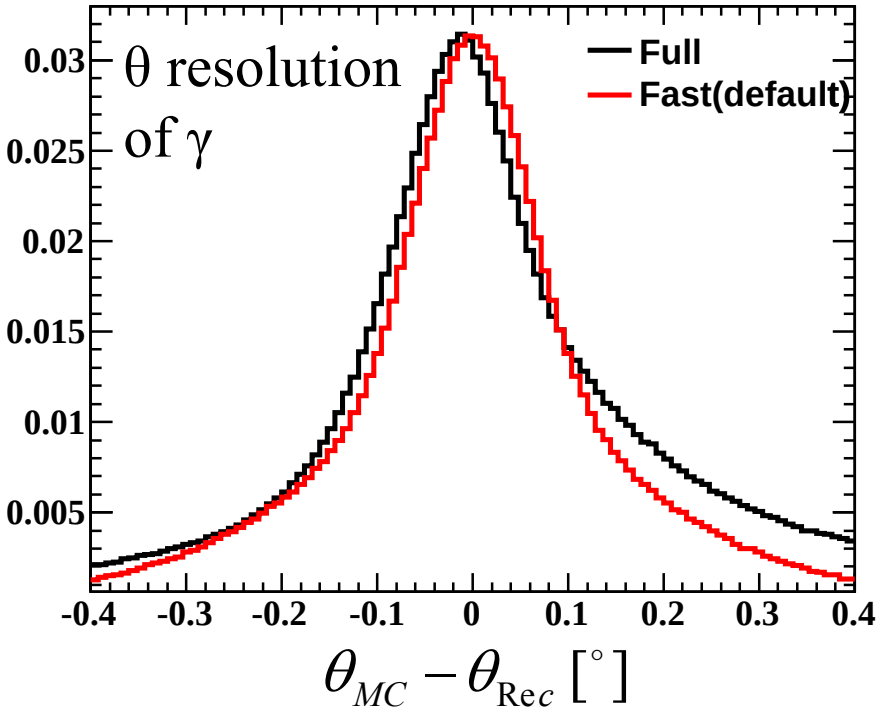
- EMC barrel,endcap,forward efficiency : $\varepsilon=1.0 \rightarrow \varepsilon=0.9$
  Energy resolution for EMC has been tuned

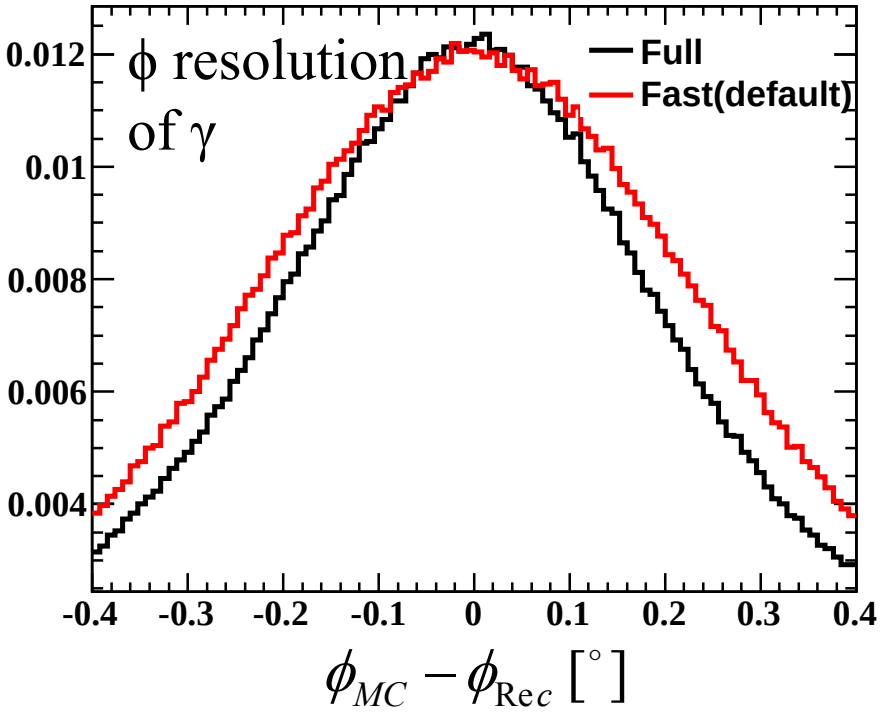


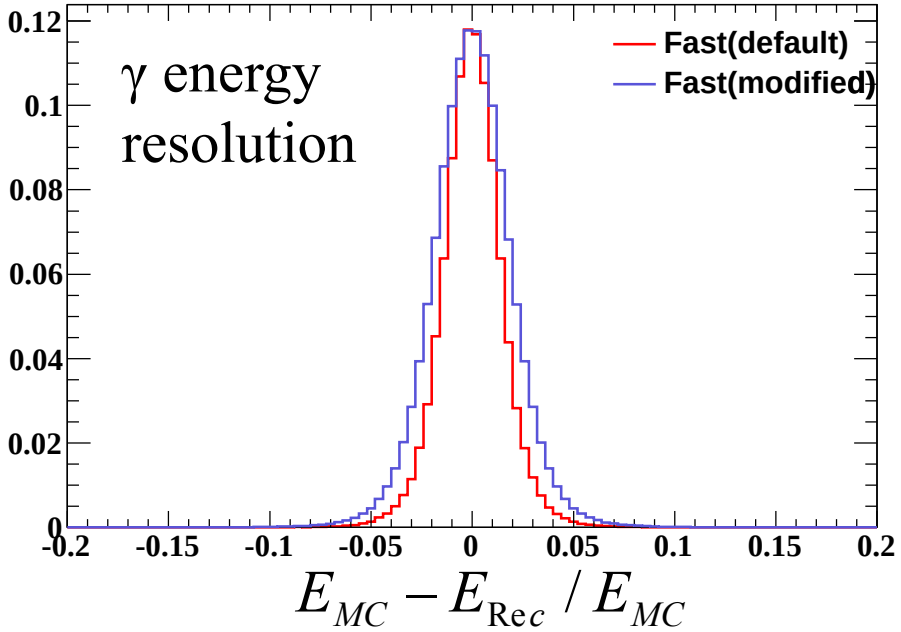
Default	Modified
a= 4.52 × 10^{-3}	a= 8.0 × 10^{-3}
b= 2.95 × 10^{-3}	b= 5.0 × 10^{-3}
c= 7.75 × 10^{-3}	c= 7.75 × 10^{-3}

- shower leakage(a), electric noise(b)

Fast simulation







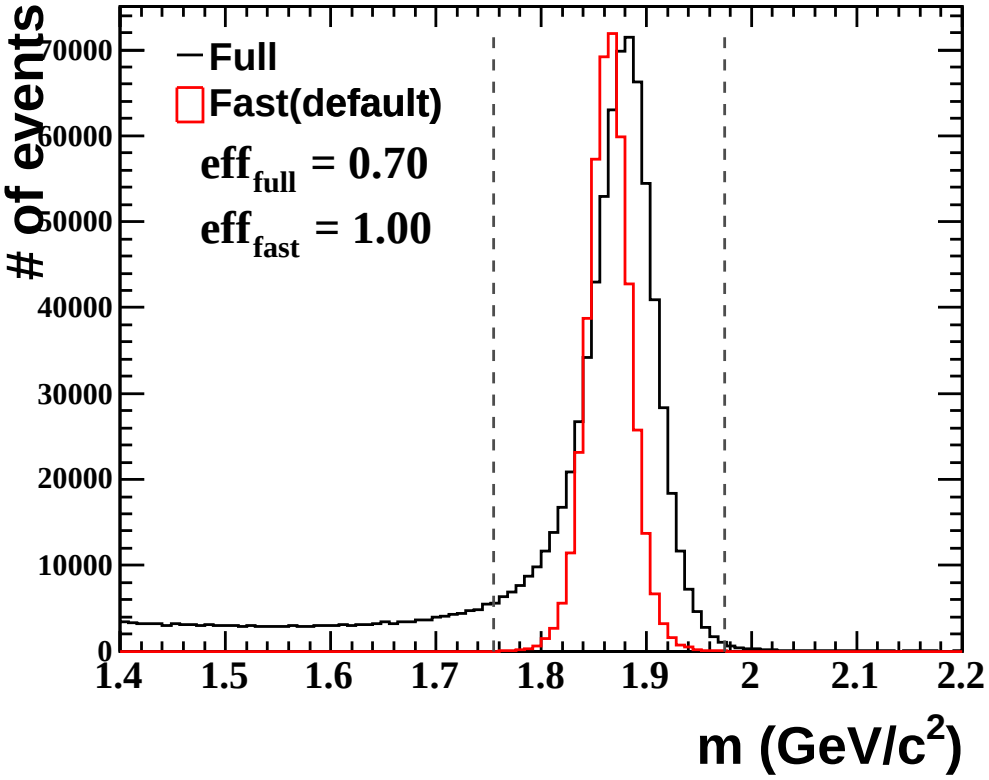
Angular distribution ϕ and θ looks similar between full and fast sim.

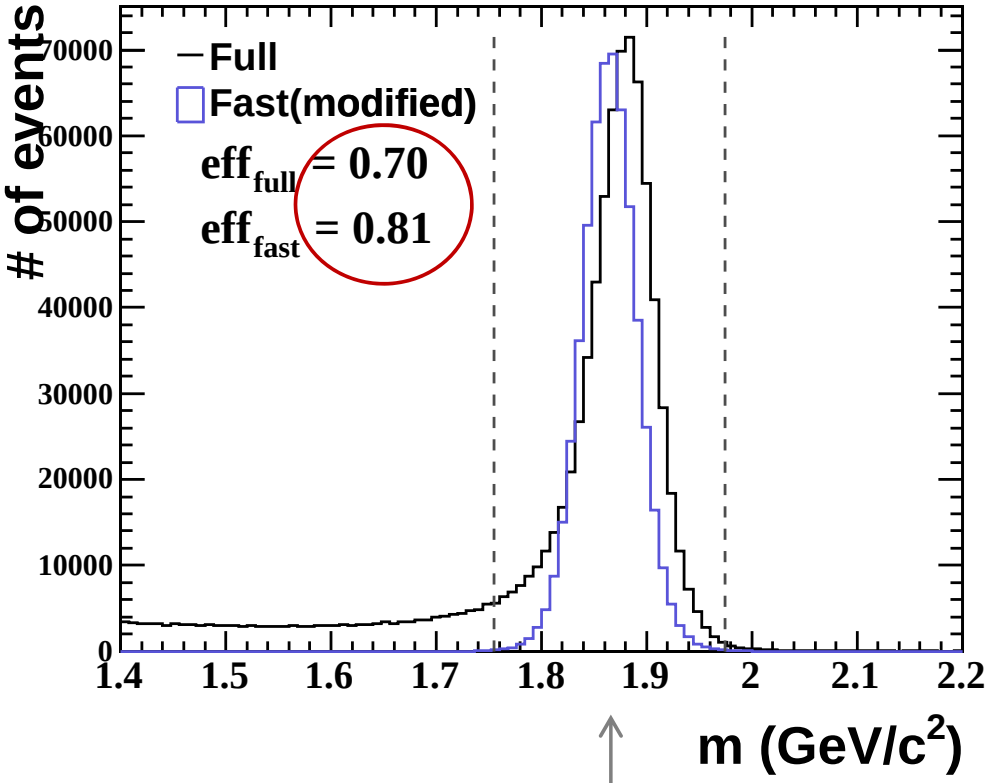
Find tuning parameter for energy based on the γ from the data sample

$\pi^0 \to \gamma\gamma$ & $D^0 \to \gamma\gamma$

Fast simulation

$$D^0 \to \gamma\gamma$$





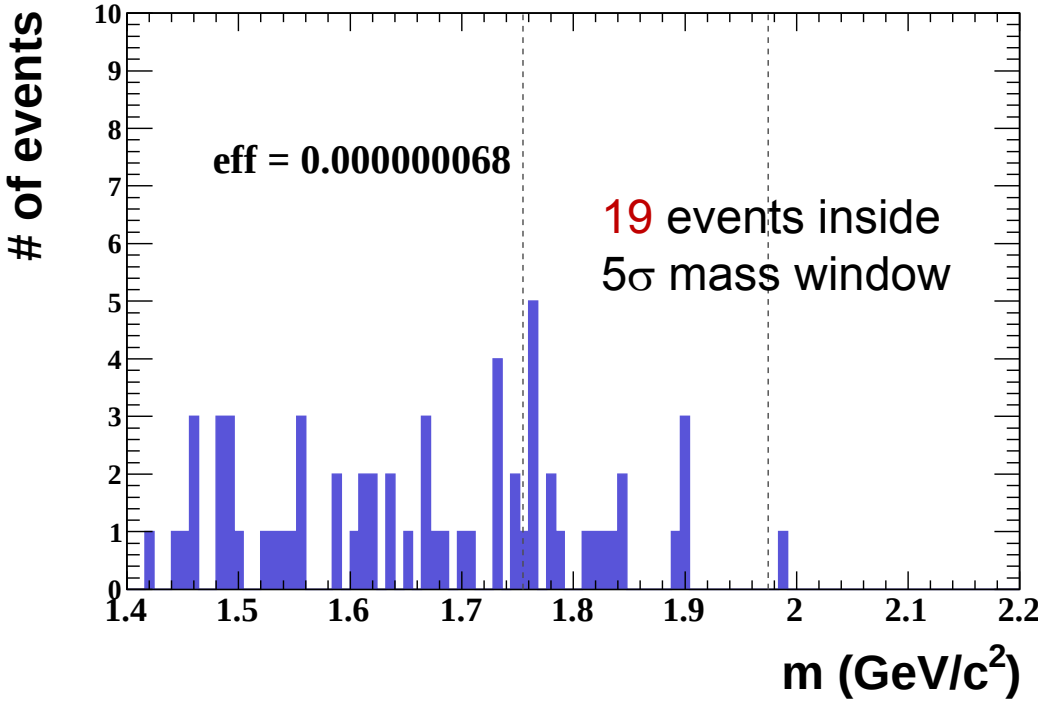
much better balanced distribution for the efficiency and resolution

For $\pi^0 \to \gamma\gamma$ mass spectrum show also better agreement with modified parameter

Test of background reduction

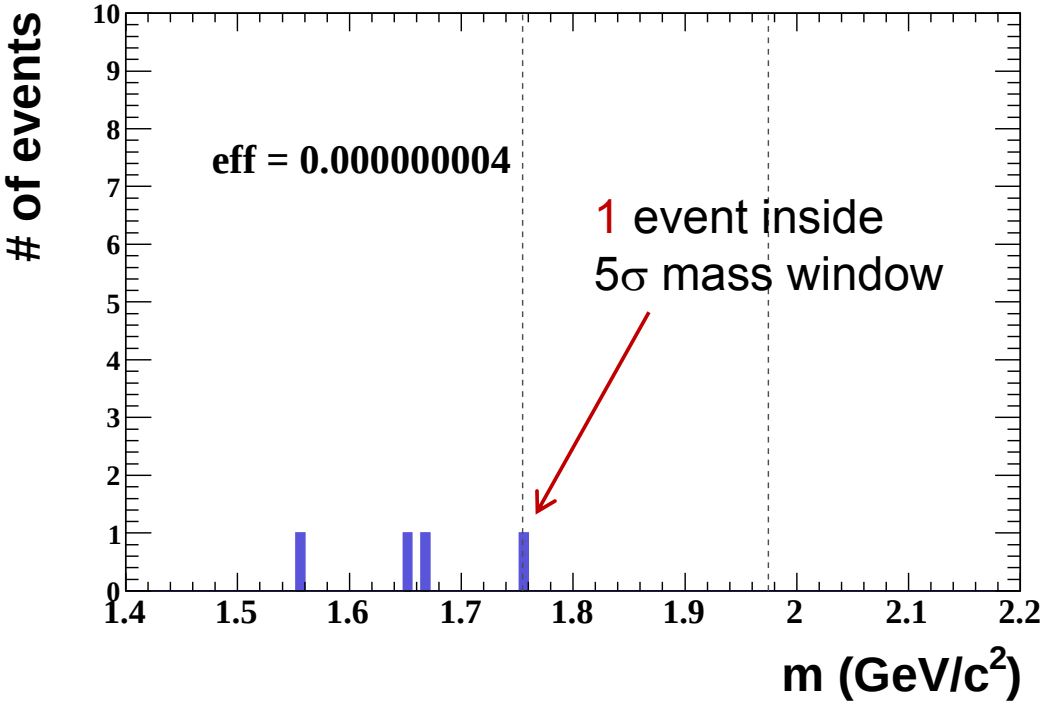
10^9 DPM events with fast simulation

$\mathrm{Prob}(\pi, K) > 0.25 + \text{all cuts}$



Signal efficiency : $\varepsilon_{tag} = 0.3865$

$\mathrm{Prob}(\pi, K) > 0.75 + \text{all cuts}$

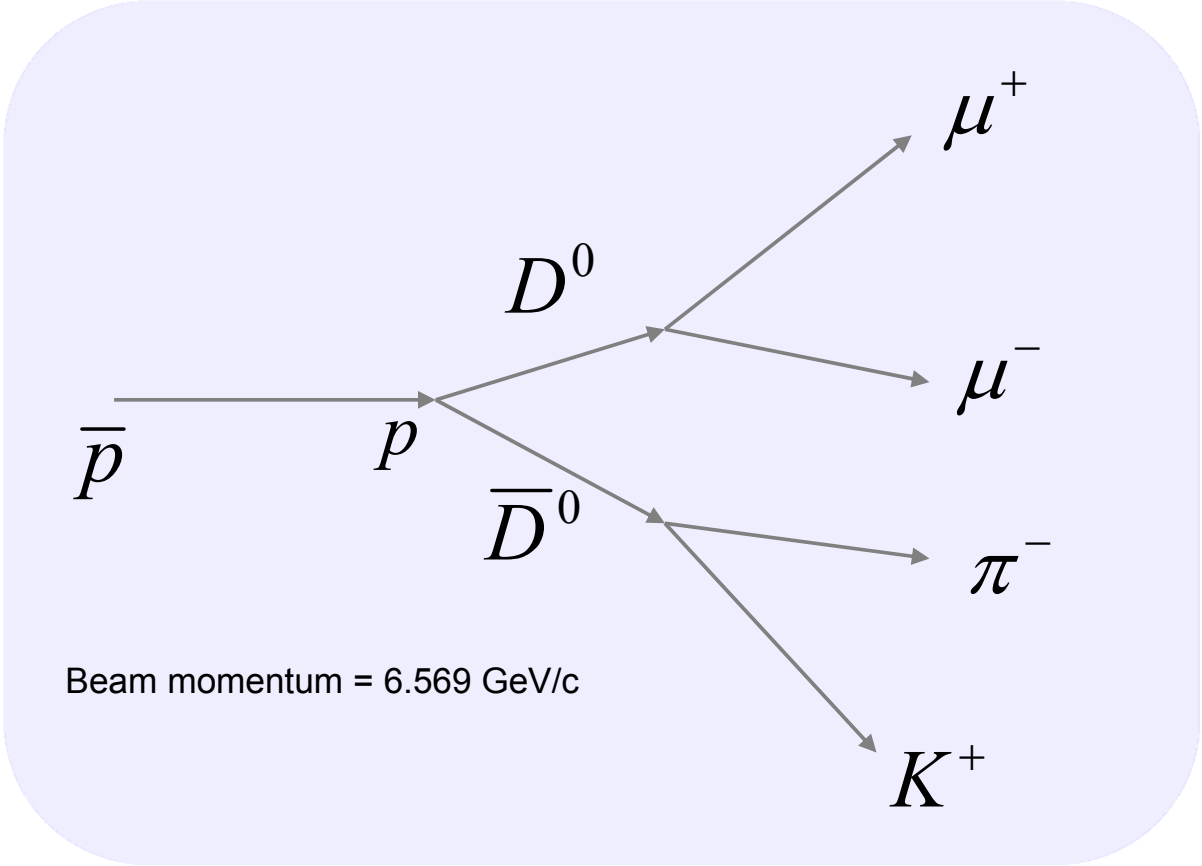


Signal efficiency : $\varepsilon_{tag} = 0.1888$

$$D^0 \to \mu^+ \mu^-$$

Event reconstruction

Physics channel : $\bar{p}p \to D^0\bar{D}^0 \to \mu^+\mu^- K^+\pi^-$



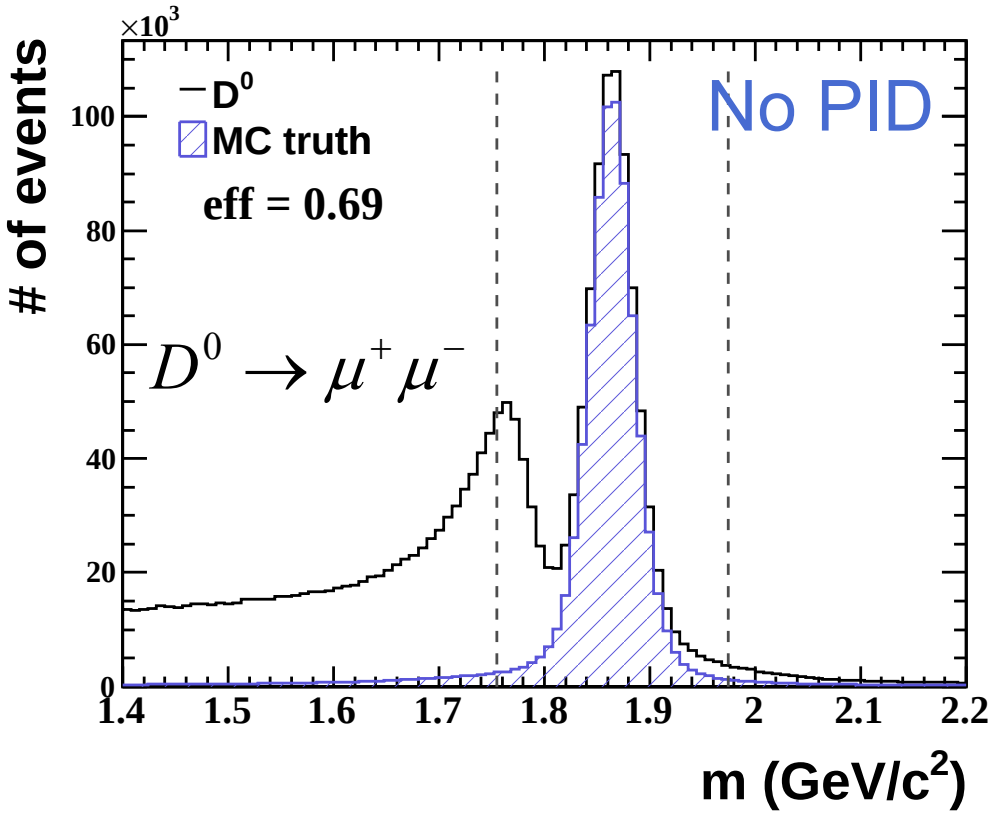
Systematic should be larger than D→γγ due to the cross combination e.g. πμ, μK

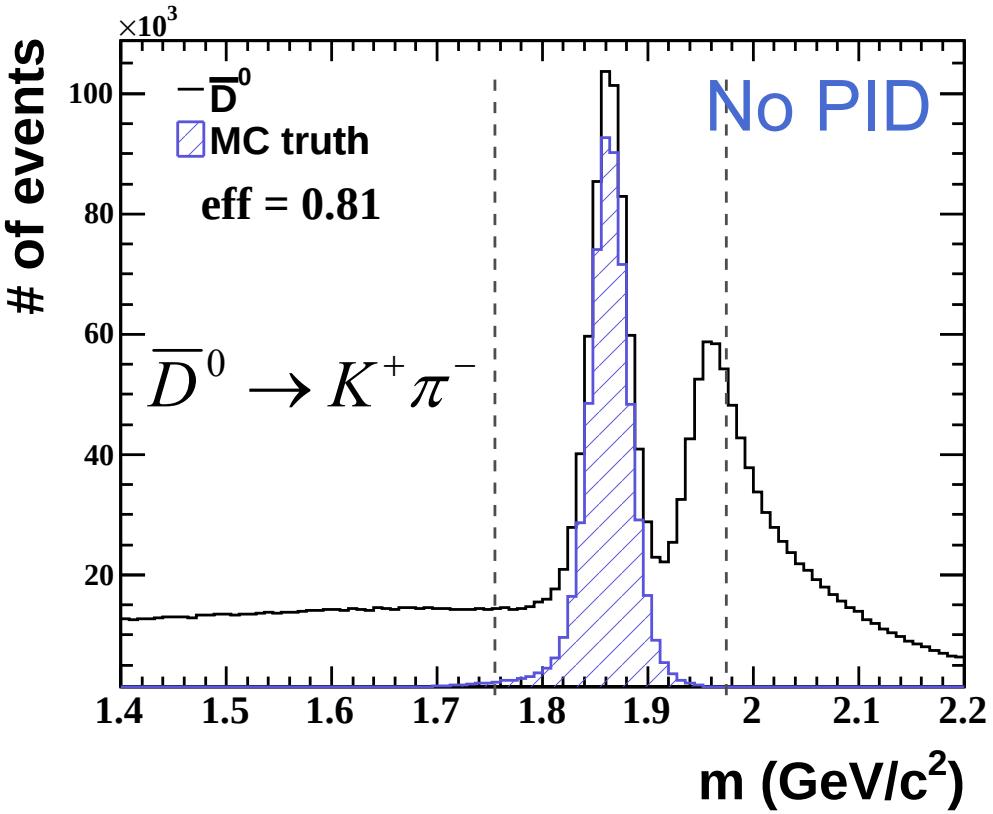
$$\varepsilon_{D^0\to\pi^0\pi^0\&\bar{D}^0\to K^+\pi^-} \neq \varepsilon_{D^0\to\pi^0\pi^0}\varepsilon_{\bar{D}^0\to K^+\pi^-}$$

Full simulation

$$\bar{p}p \to D^0\bar{D}^0 \to \mu^+\mu^- \; K^+\pi^-$$

$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}} \text{ in the mass window}$$



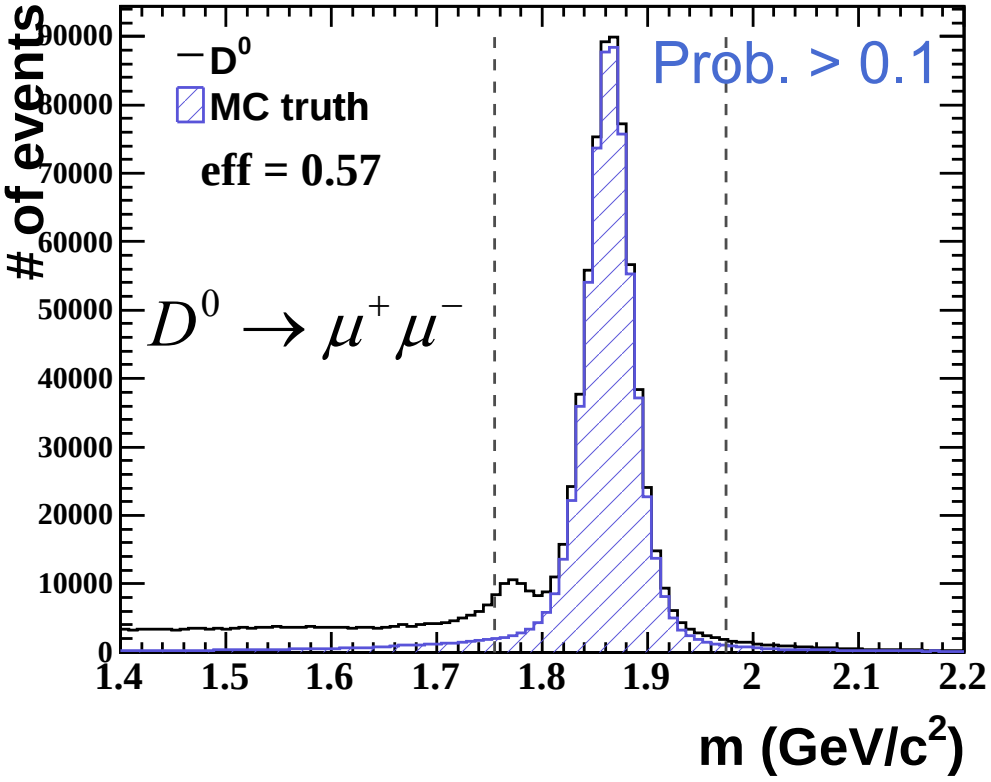


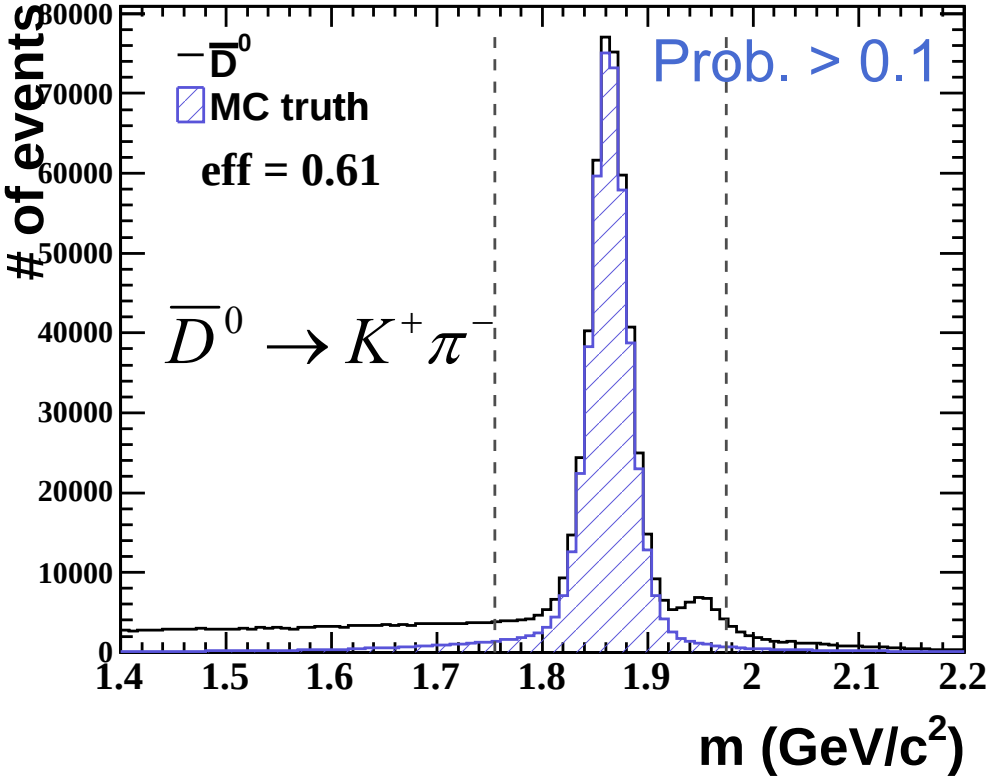
Neutral track : E > 50 MeV
Charged track : p > 100 MeV/c

Full simulation

$$\bar{p}p \to D^0\bar{D}^0 \to \mu^+\mu^- \; K^+\pi^-$$

$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}} \text{ in the mass window}$$





Neutral track : E > 50 MeV
Charged track : p > 100 MeV/c

Background rejection

Selection cuts for $D^0\overline{D}^0 \to \mu^+\mu^- K^+\pi^-$

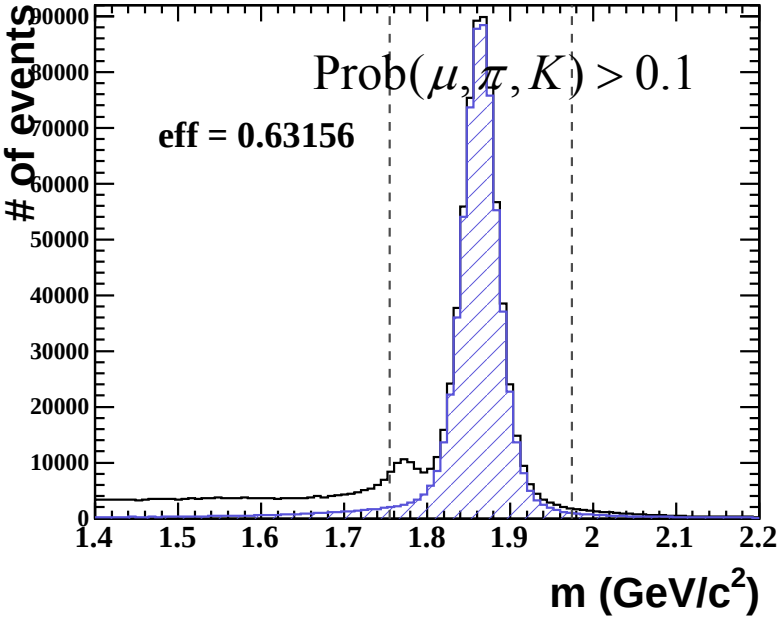
- $\text{Prob} > 0.1$ for charged particle
- $p_T > 0.1(\text{GeV/c})$ for $\mu^{\pm}$
- $p_T < p_T^{\max} + 0.2(\text{GeV/c})$ for D^0
- $-100^\circ < |\Delta\phi_{\gamma\gamma}| < 260^\circ$
- $M_{miss}^{\overline{D}^0} = \sqrt{(E_{CM} - E_{D(\mu\mu)})^2 + (\vec{p}_{CM} - \vec{p}_{D(\mu\mu)})^2}$
- More that 1 hit in the MDT layer only for full simulation
  no hit information at fast simulation, alternatively $\text{Prob}(\mu) > 0.95$
- Require double tag both D^0 & $\overline{D}^0$

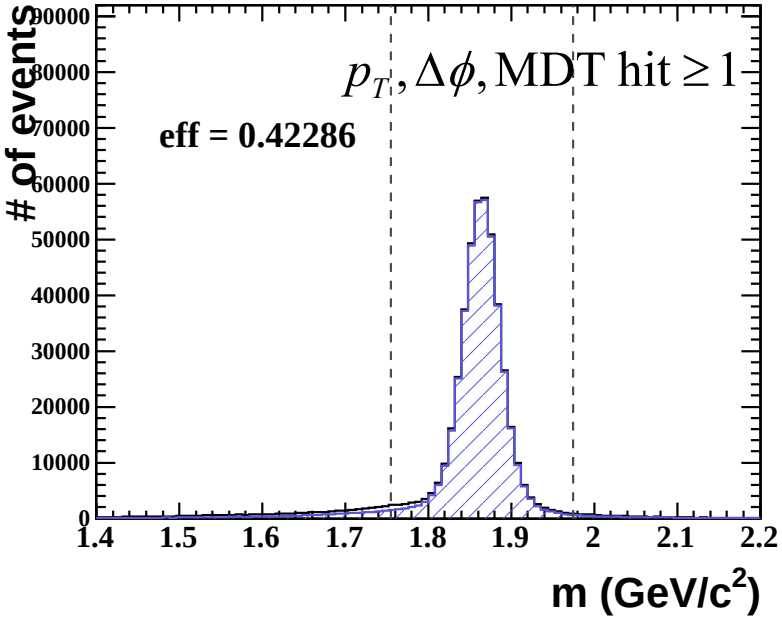
Background rejection

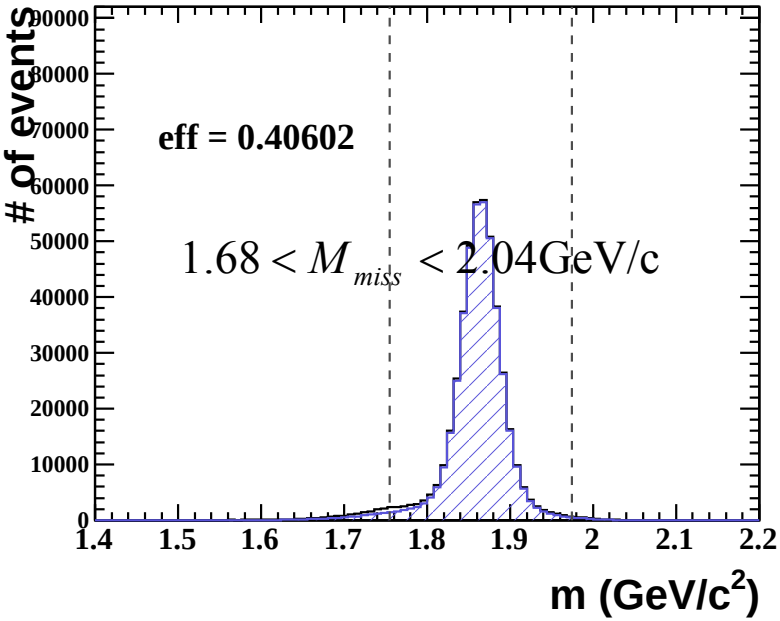
$\bar{p}p \to D^0\bar{D}^0 \to \mu^+\mu^- K^+\pi^-$ data

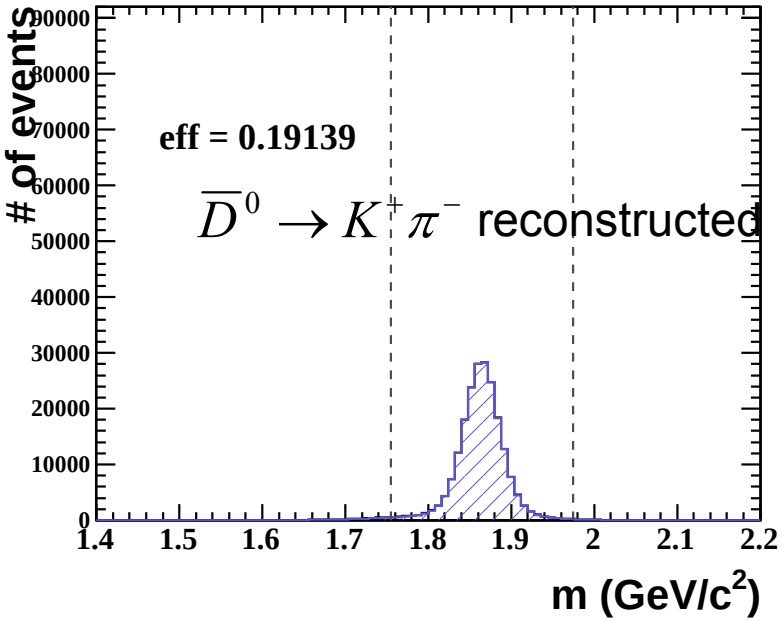
$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}}$$

in the histogram









Signal efficiency

$\varepsilon_{tag} = 0.191$

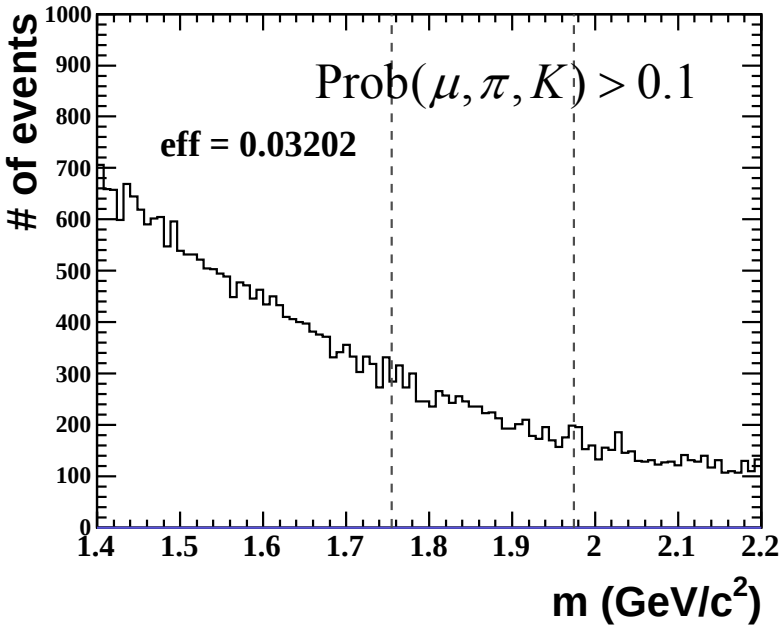
for double tag

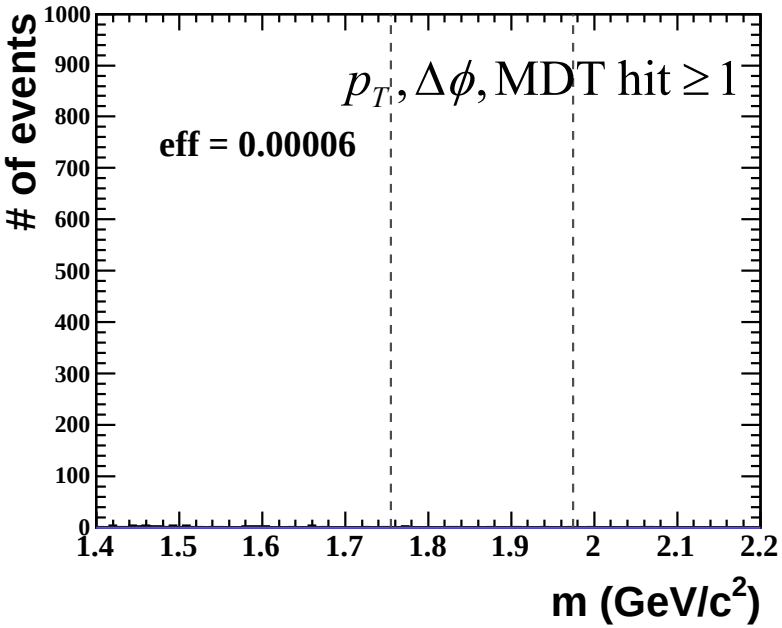
Background rejection

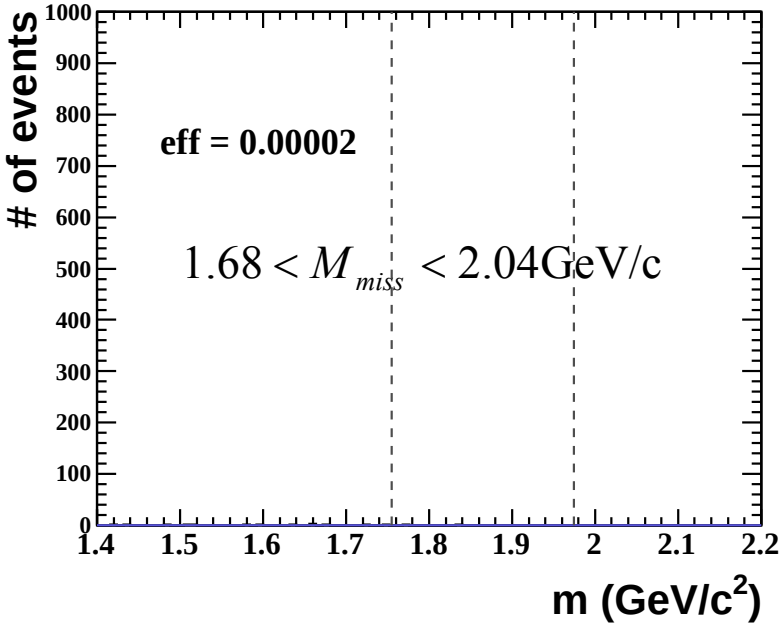
DPM background

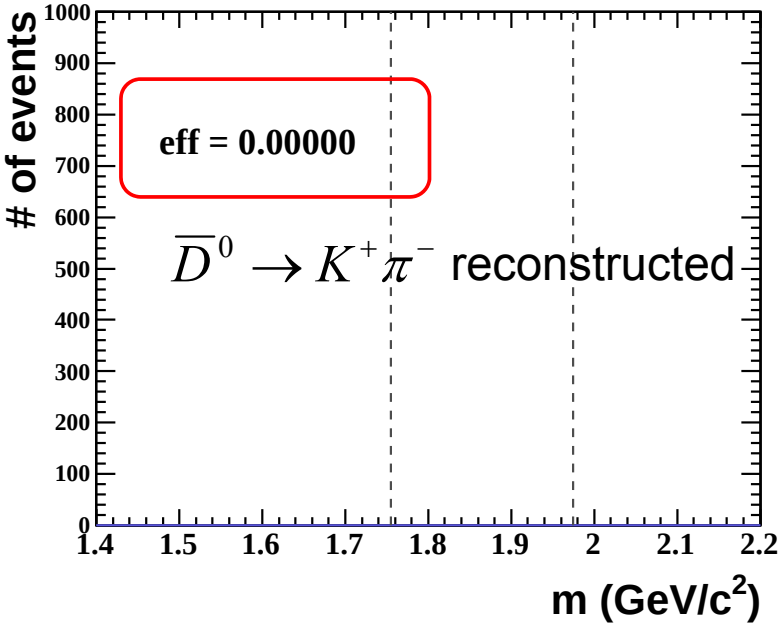
$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}}$$

in the histogram









Backg. Reduciton

$\varepsilon_{back} < 10^{-6}$

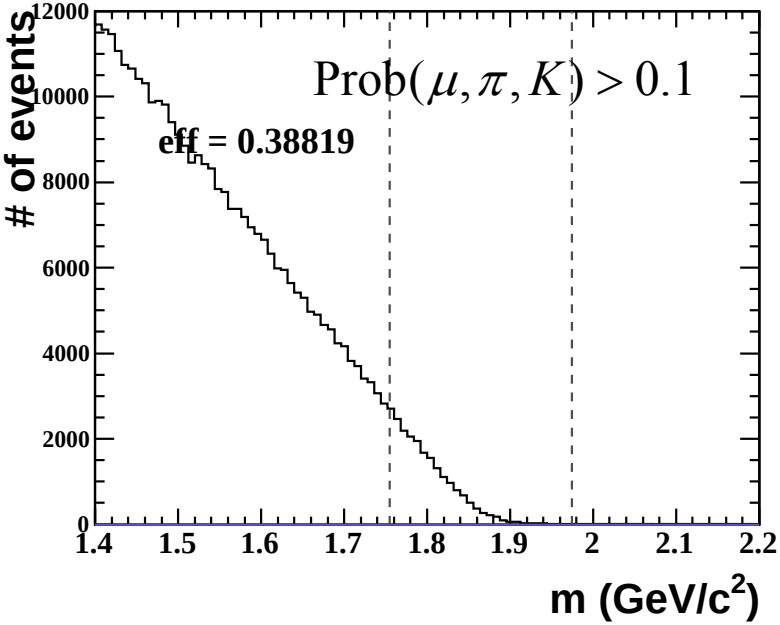
based on the DPM 1M events

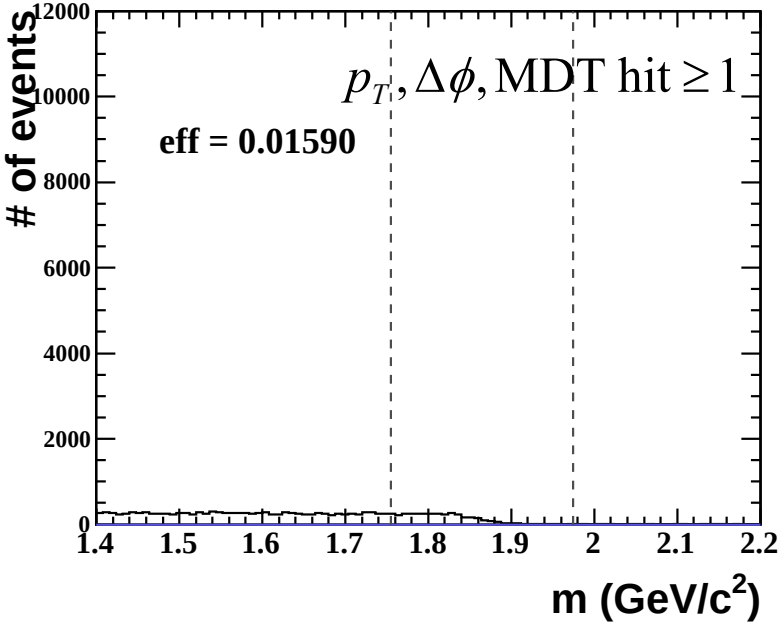
Background rejection

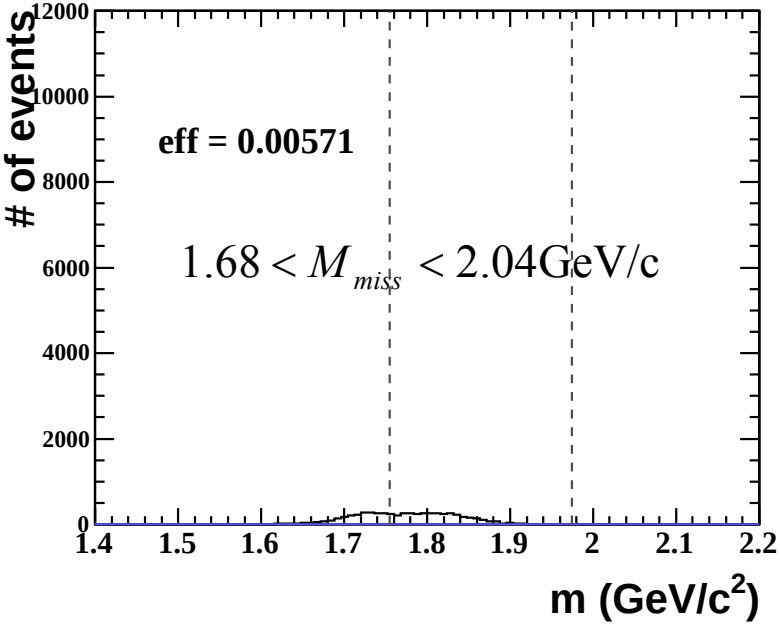
$\bar{p}p \to D^0\bar{D}^0 \to \pi^+\pi^- K^+\pi^-$ background

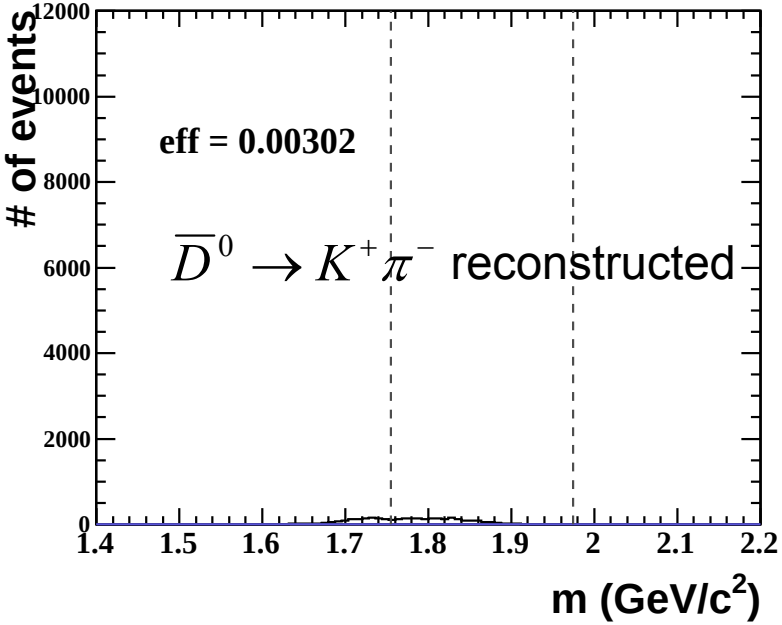
$$\varepsilon = \frac{N_{rec.event,MC}}{N_{gen.event,MC}}$$

in the histogram









Expected number @ PANDA

$D^0 \to \mu^+\mu^-$ signal data

$$N_{D\to\mu\mu} = 2\ \text{fb}^{-1} \times 100\ \text{nb} \times \Sigma(Br_i) \times \varepsilon_{tag} \times 2$$
$$= 4\ \text{events}$$

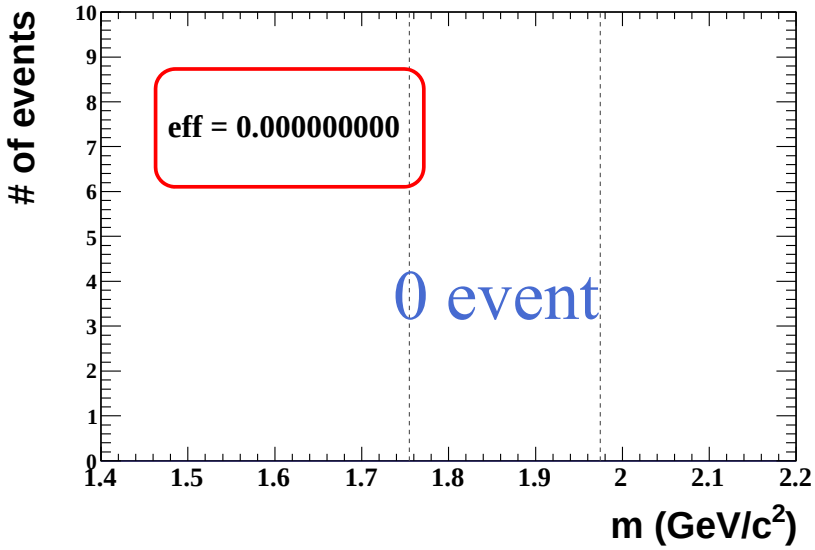
$$Br(D^0 \to \mu^+\mu^-) < 1.3\times10^{-6}\ \text{[PDG(2012)]}$$
$$Br(\overline{D}^0 \to K^+\pi^-) = 0.0389$$
$$\varepsilon_{tag} = \varepsilon_{D^0\to\mu\mu\&\overline{D}^0\to K^+\pi^-} = 0.1914$$

$D^0 \to \pi^+\pi^-$ background data

$$N_{D\to\pi^+\pi^-} = 2\ \text{fb}^{-1} \times 100\ \text{nb} \times \Sigma(Br_i) \times \varepsilon_{tag} \times 2$$
$$= 65\ \text{event}$$

$$Br(D^0 \to \pi^+\pi^=) = 1.397\times10^{-3}\ \text{[PDG(2012)]}$$
$$Br(\overline{D}^0 \to K^+\pi^-) = 0.0389$$
$$\varepsilon_{tag} = \varepsilon_{D^0\to\pi^+\pi^-\&\overline{D}^0\to K^+\pi^-} = 0.00302$$

- No event with 10^9 DPM in fast simulation with Prob (μ) > 0.95 & Prob (π,K) > 0.1
- Signal efficiency ε_{tag}= 0.1492 @ fast
- will find best probability cut to get the optimal signal and background ratio



Outlook

- Rejection power 10^{-8} seems to be OK @ fast simulation
  Starting from 10^{-9} we should meet with resistance

- Test other cut optimization (no big chance at fast sim)

- Single tag mode is not suitable for rare decay
  π^0 veto should not work for the single tag($\gamma\gamma$) case

- Add other decay modes :$\overline{D}^0 \to K^+\pi^-\pi^0 (Br = 13.9\%)$

- Upper limit of branching ratio by Feldmann-Cousin

Open Discussion

Concerning fast simulation campaign

- few other senarios are NOT essential for rare decay
  very difficult with low luminosity and w/o completeness of EMC
  most likely >2 years data taking is required

- data available to test variation of efficiency with
  5 EMC setup for $\gamma\gamma$ and 5 standard setup for $\mu\mu$, do it?

- what is common parameters in other analysis?
  necessary further tuning of parameters? or not need to do?