CP violation searches in $D \to hh\pi^0$ decays @ CEPC

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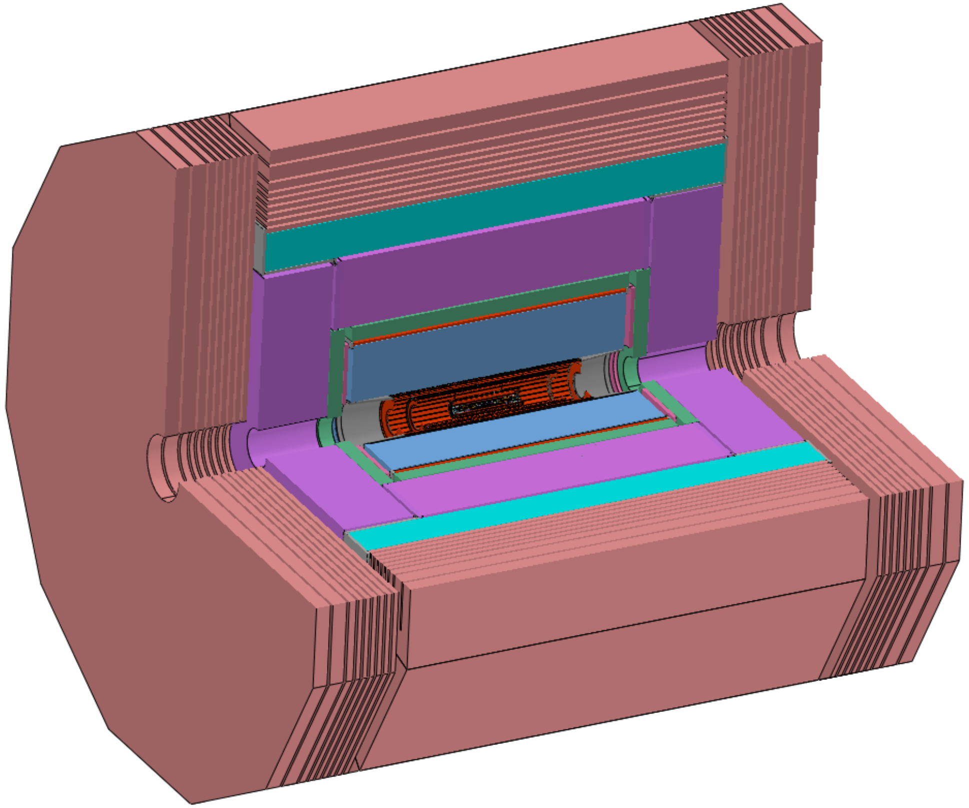


CEPC Tera-Z mode

- CEPC operation modes
  - 50 MW scenario
  - Z decay modes:

$c\bar{c}$ (12.03 ±0.21) %
$b\bar{b}$ (15.12 ±0.05) %

Operation mode	Z factory	WW threshold	Higgs factory	$t\bar{t}$
$\sqrt{s}$ (GeV)	91.2	160	240	360
Run time (year)	2	1	10	5
Instantaneous luminosity ($10^{34}\text{cm}^{-2}\text{s}^{-1}$, per IP)	191.7	26.7	8.3	0.83
Integrated luminosity (ab^{-1}, 2 IPs)	100	6.9	21.6	1
Event yields	4.1×10^{12}	2.1×10^{8}	4.3×10^{6}	0.6×10^{6}

- Heavy flavour particle yields
  - One of the largest heavy flavour samples from e^+e^- collider

Particle	BESIII	Belle II (50 ab^{-1} on $\Upsilon(4S)$)	LHCb (300 fb^{-1})	CEPC (4×Tera-Z)
B^0, $\bar{B}^0$	-	5.4×10^{10}	3×10^{13}	4.8×10^{11}
$B^\pm$	-	5.7×10^{10}	3×10^{13}	4.8×10^{11}
B_s^0, $\bar{B}_s^0$	-	6.0×10^{8} (5 ab^{-1} on $\Upsilon(5S)$)	1×10^{13}	1.2×10^{11}
$B_c^\pm$	-	-	1×10^{11}	7.2×10^{8}
Λ_b^0, $\bar{\Lambda}_b^0$	-	-	2×10^{13}	1×10^{11}
D^0, $\bar{D}^0$	1.2×10^{8}	4.8×10^{10}	1.4×10^{15}	8.3×10^{11}
$D^\pm$	1.2×10^{8}	4.8×10^{10}	6×10^{14}	4.9×10^{11}
$D_s^\pm$	1×10^{7}	1.6×10^{10}	2×10^{14}	1.8×10^{11}
$\Lambda_c^\pm$	0.3×10^{7}	1.6×10^{10}	2×10^{14}	6.2×10^{10}
$\tau^+\tau^-$	3.6×10^{8}	4.5×10^{10}		1.2×10^{11}

CP violation in Charm sector

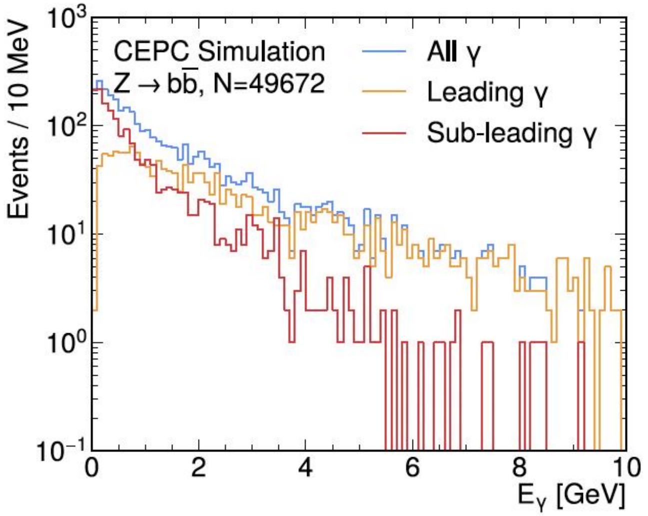
- CP violation in charm sector expected: 10^{-2} to 10^{-3}, much smaller than in b sector
  - Statistics matters in the searches of CP violation
- The only experimental observation of charm CP violation is from LHCb
  - $\Delta A_{CP} = (-1.54 \pm 0.29) \times 10^{-3}$, from two-body decays
- Multi-body decays can help to understand the source of CP violation
  - CP violation originates from interferences of at least two decay amplitudes, decay phase space can identify the interfering resonances
  - Some multi-body decays, i.e. $D \to hh\pi^0$ has larger branching fraction than two-body decays
- PID, p, E, … of final state particles, Decay vertices, π^0 reconstruction

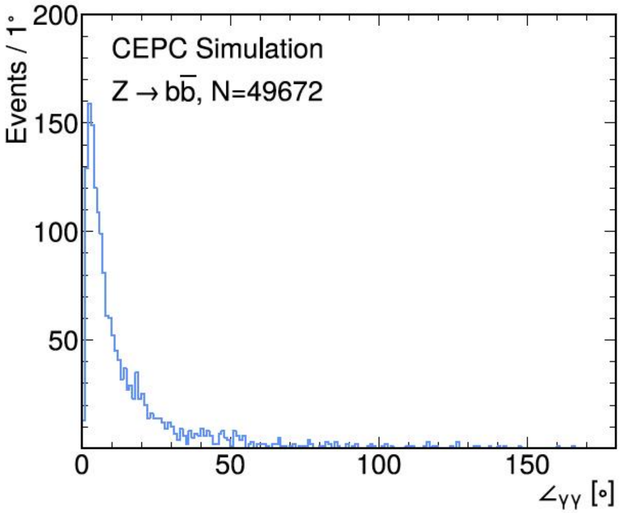
Reconstruct $D \rightarrow hh\pi^0$ decays at CEPC detector

- MC sample produced from $e^+e^- \rightarrow Z \rightarrow b\bar{b}$ at $\sqrt{s} = 91.2$ GeV
  - /cefs/higgs/zhangkl/Production/25036/E91.2_eebb/Reco/rec_E91.2_eebb_*.root
  - The version of CEPCSW is tdr.25.3.2
- Test with 160k collisions
  - Number of truth D^0: 211231
  - Number of truth $D^0 \rightarrow K^-\pi^+\pi^0$: 23842
  - Number of truth $D^0 \rightarrow \pi^-\pi^+\pi^0$: 3215

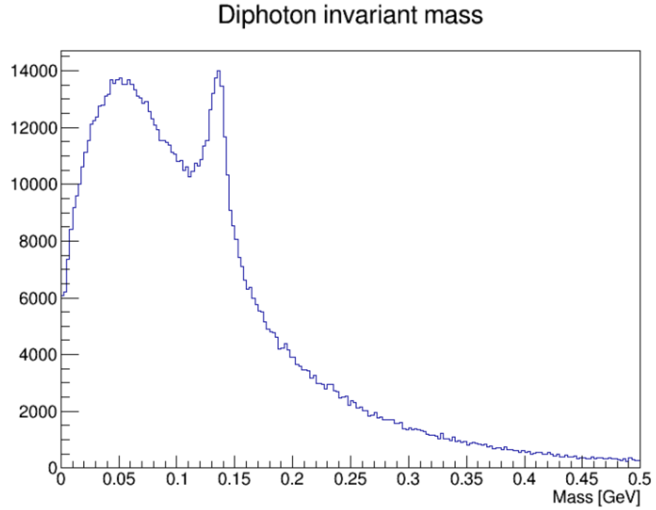
Step 1: π^0 reconstruction

- Truth distribution of γ energy and open angle between 2 γ's



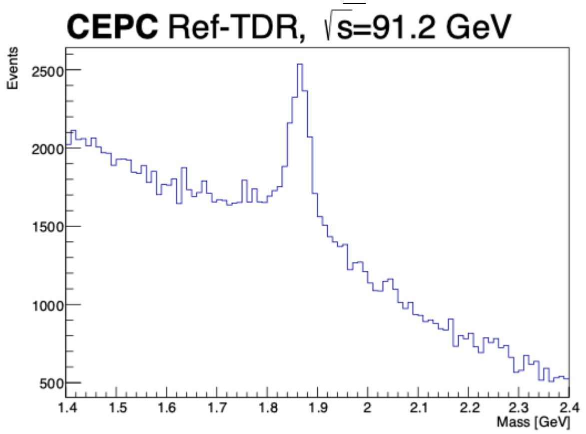


- Select one γ in PFOs with E > 0.5 GeV, then combine a second γ within 10 degrees of open angle
  - Select diphoton between 0.12 and 0.15 GeV as π^0s

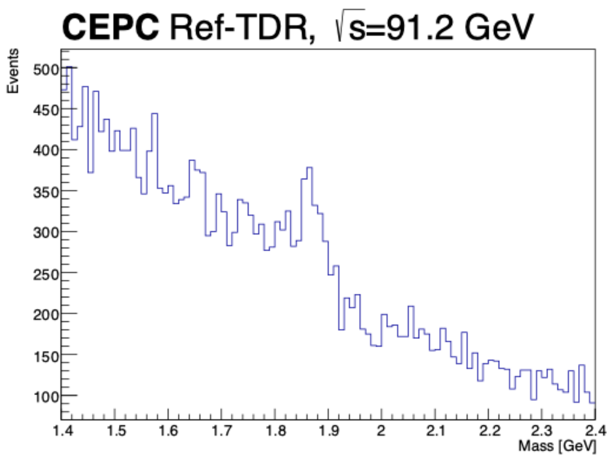


Step 2: combining π^0 with two other tracks

- Two tracks:
  - Select one K(pi) track and one pi track from PFOs using PID information
  - Combine them with π^0 candidates
- Constrain PFO objects with
  - Truth D0 vertex
  - Truth track direction & angle
  - Truth track momentum distributions
- Future optimizations:
  - MVA analysis
  - "DecayTreeFitter"



Kpipi0



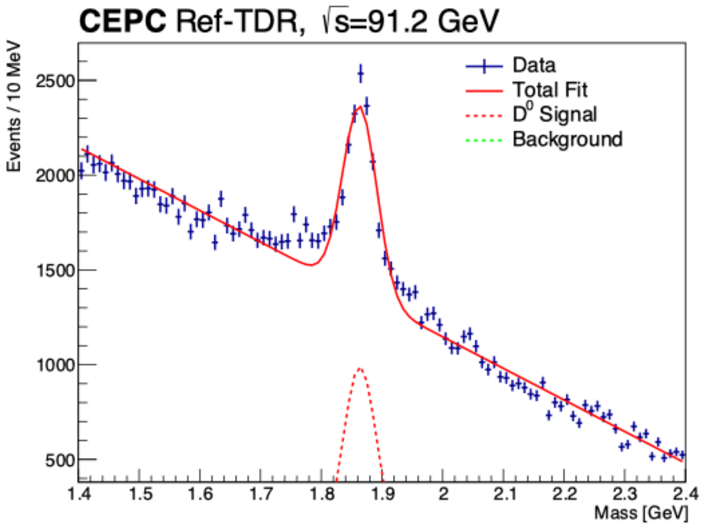
pipipi0

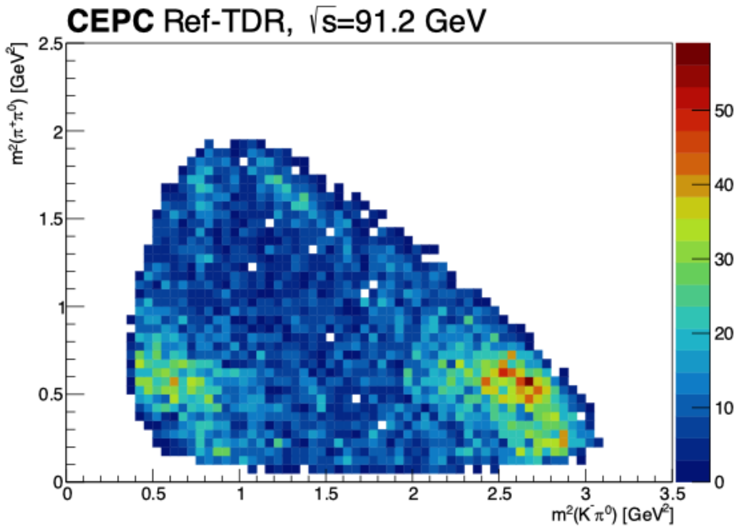
Step 3: fits and Dalitz plot

- Clear D0 peak
  - Purity ~ 20%, eff ~20%
- Clear K* and rho resonance structures in Dalitz plot

- Nuisance asymmetries not considered, systematics not considered

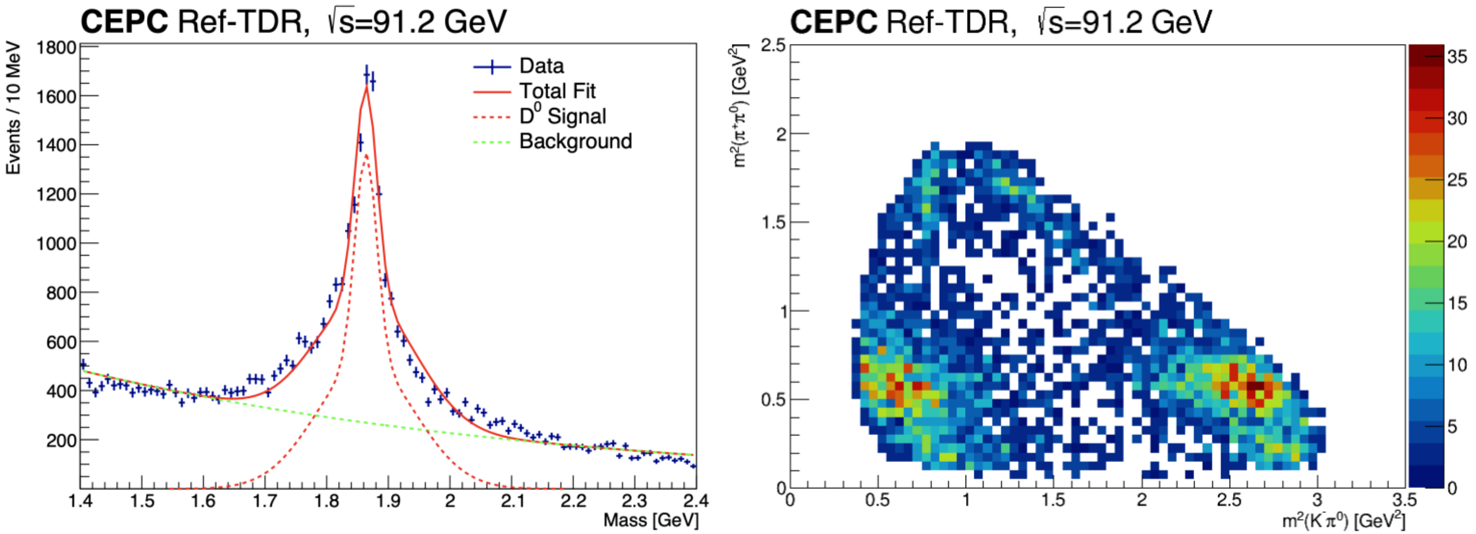
- Future step:
  - Fits to Dalitz plane,
  - Identify resonance fractions





A check: look at events with truth information

- Check Truth $D \to hh\pi^0$ tracks, only reconstruct PFO objects has similar momenta as Truth tracks
  - Ideally this purity should be achievable if we select cleverly
  - Purity ~ 70%, eff ~15%



CP violation prospects at CEPC

- CEPC generally do not have advantages in statistics for charm hadrons compare to LHCb
- However, CEPC can have much higher efficiency with π^0s

Decays	LHCb (6 fb^{-1})	LHCb (300 fb^{-1})	CEPC (4 Tera Z)
D^{*+}	4.7×10^{12}	2.4×10^{14}	4.6×10^{11}
D^0 from D^{*+}	3.2×10^{12}	1.6×10^{14}	3.1×10^{11}
$D^{*+} \to (D^0 \to K^-K^+)\pi^+$	1.6×10^{10}	6.5×10^{11}	1.3×10^{9}
$D^{*+} \to (D^0 \to \pi^-\pi^+)\pi^+$	4.6×10^{9}	2.3×10^{11}	4.5×10^{8}
$D^{*+} \to (D^0 \to K^-\pi^+)\pi^+$	1.6×10^{11}	6.3×10^{12}	1.2×10^{10}
$D^{*+} \to (D^0 \to \pi^-\pi^+\pi^0)\pi^+$	4.8×10^{10}	2.4×10^{12}	4.6×10^{9}
$D^{*+} \to (D^0 \to K^-\pi^+\pi^0)\pi^+$	4.6×10^{11}	2.3×10^{13}	4.4×10^{10}
Reco. & Sel. $D^0 \to K^-K^+$	5.8×10^{7} [147]	2.9×10^{9}	1.3×10^{8}
Reco. & Sel. $D^0 \to \pi^-\pi^+$	1.8×10^{7} [147]	9×10^{8}	4.5×10^{7}
Reco. & Sel. $D^0 \to K^-\pi^+$	5.2×10^{8} [147]	2.6×10^{10}	1.2×10^{9}
Reco. & Sel. $D^0 \to \pi^-\pi^+\pi^0$	2.5×10^{6} [148]	1.2×10^{8}	4.6×10^{8}
Reco. & Sel. $D^0 \to K^-\pi^+\pi^0$	1.9×10^{7} [148]	9.6×10^{8}	4.4×10^{9}