Reconstruction of K_S^0 and Λ at CEPC Baseline Detector

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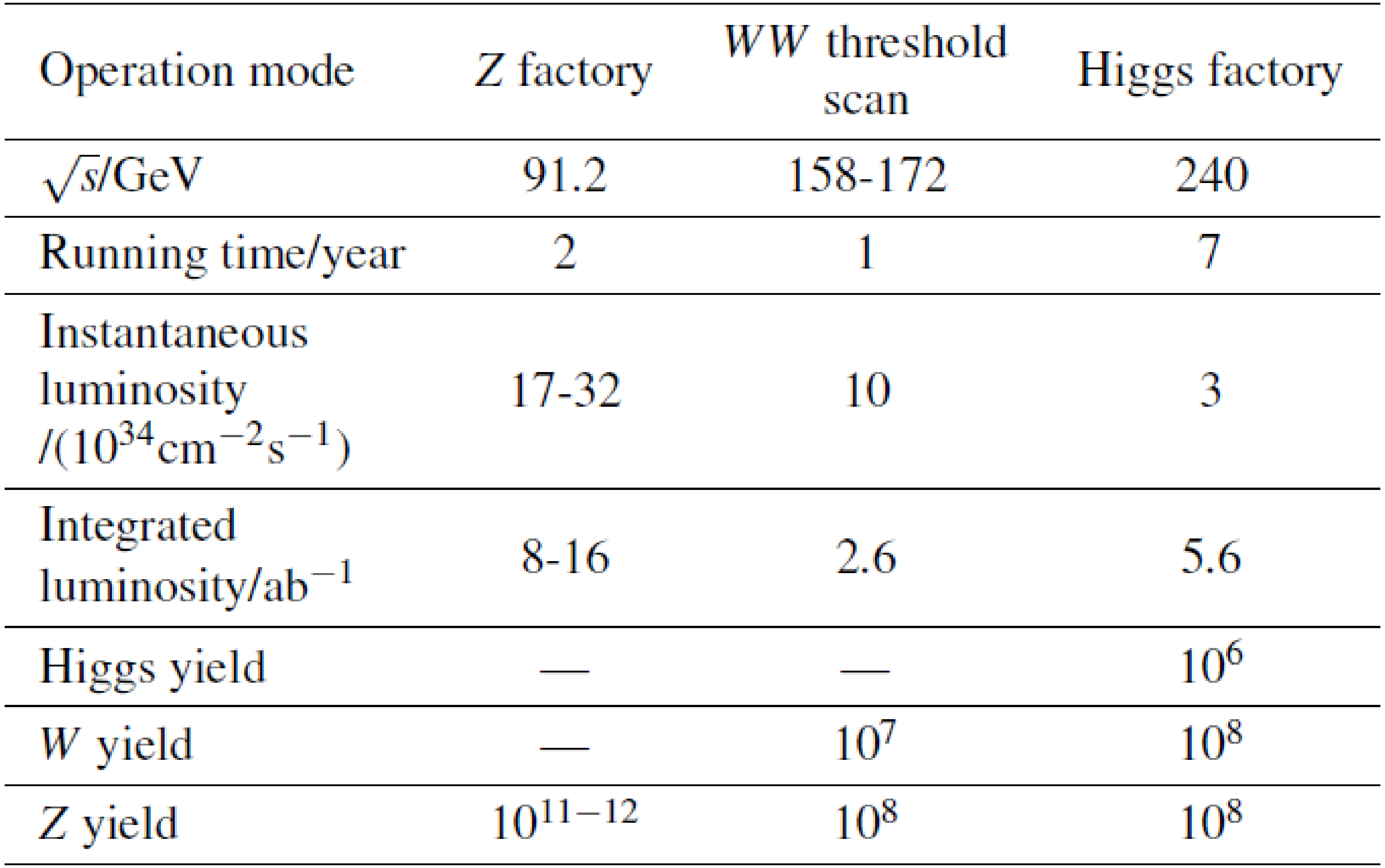
Introduction

Expected boson yields at CEPC



Operation mode	Z factory	WW threshold scan	Higgs factory
$\sqrt{s}$/GeV	91.2	158-172	240
Running time/year	2	1	7
Instantaneous luminosity /(10^{34}cm^{-2}s^{-1})	17-32	10	3
Integrated luminosity/ab^{-1}	8-16	2.6	5.6
Higgs yield	—	—	10^6
W yield	—	10^7	10^8
Z yield	10^{11-12}	10^8	10^8

Introduction

Importance of Z (and W)

- Precise measurements are critical to test SM
- Many BSM models predict their couplings to other elementary particles
- CEPC will operate in Z pole for at least two years and will produce up to 10^{12} Z bosons
- Etc…

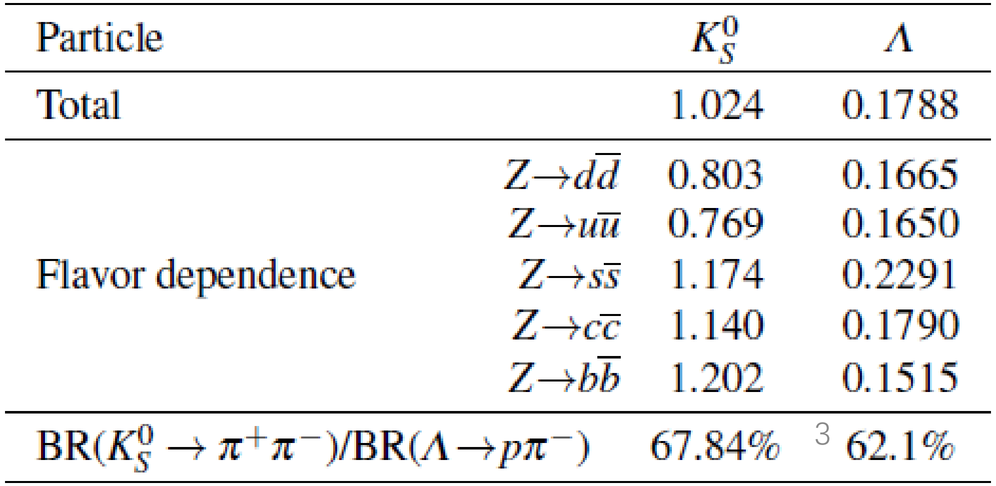
The K_S^0 and Λ:

- are abundant in $Z \to qq$ events. On average, there are 1.0 K_S^0 and 0.18 Λ per event.
- have more than 60% of chance to decay into a pair of charged particles ($K_S^0 \to \pi^+\pi^-, \Lambda \to p\pi^-$).
- have relatively long life time ($c\tau > 2$ cm), and require secondary vertex reconstruction.

Their reconstruction is useful for:

- Calibrate and monitor the tracking system and the PID performance operation.
- Important physics signatures in many flavor physics measurements, such as CP violation in $\tau \to \pi^- K_S^0 \nu_\tau$, the search for $K_S^0 \to \mu^+\mu^-$.

The simulation sample contains 2.5×10^6 $Z \to qq$ events. The table shows the basic statistics in number of particles per event.



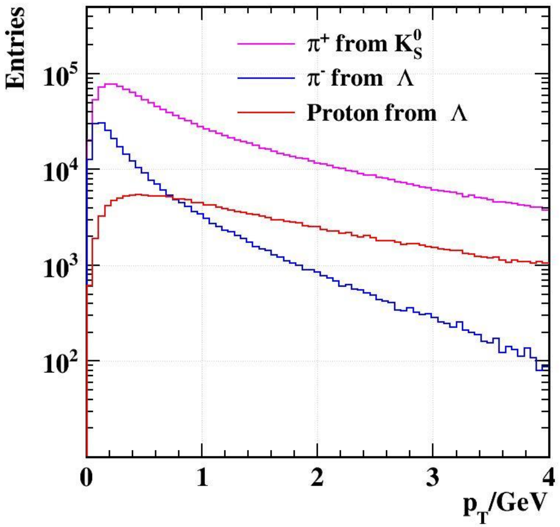
Particle		K_S^0	Λ
Total		1.024	0.1788
Flavor dependence	$Z \to d\bar{d}$	0.803	0.1665
	$Z \to u\bar{u}$	0.769	0.1650
	$Z \to s\bar{s}$	1.174	0.2291
	$Z \to c\bar{c}$	1.140	0.1790
	$Z \to b\bar{b}$	1.202	0.1515
$\mathrm{BR}(K_S^0 \to \pi^+\pi^-)/\mathrm{BR}(\Lambda \to p\pi^-)$		67.84%	62.1%

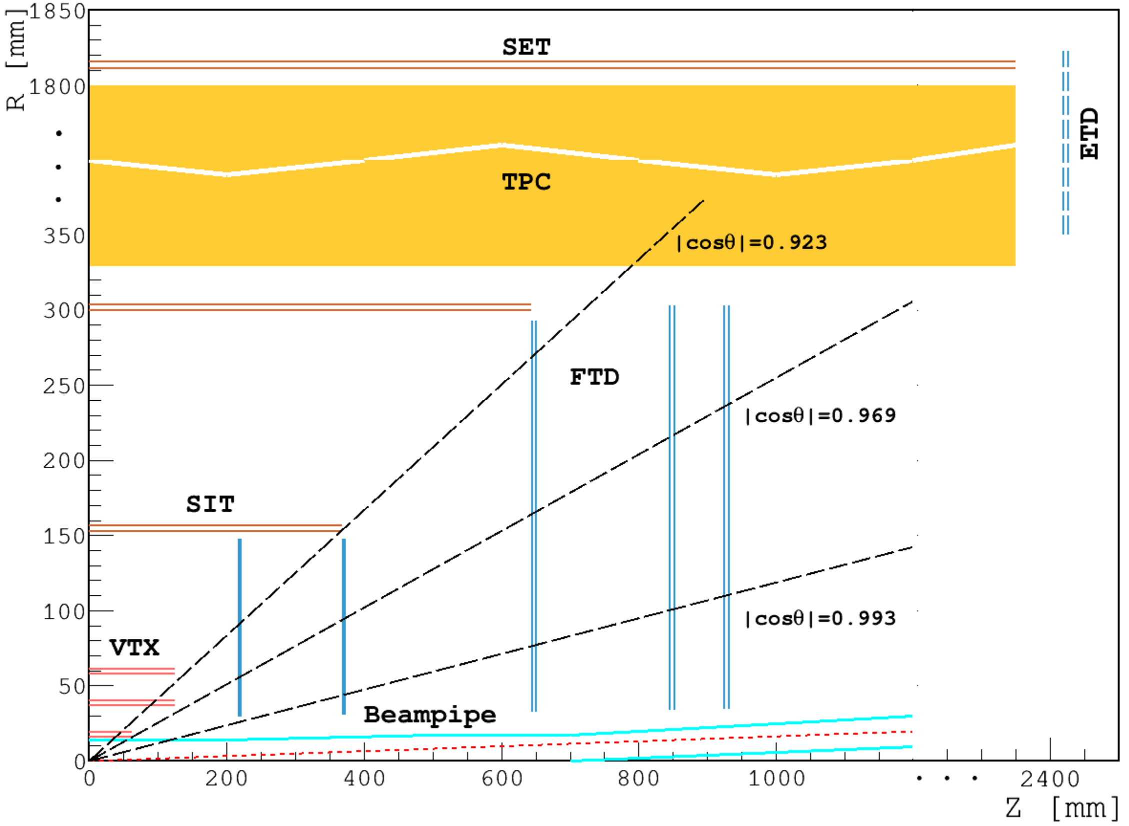
Track Reconstruction Efficiency

The tracker is in a 3 T magnetic field. Therefore, if:

- $p_T < 0.15$ GeV, the particle will not able to reach TPC and leave a handful amount hits on the inner silicon detectors.
- $0.15 < p_T < 0.8$ GeV, the particle will make circles inside the tracker.
- $p_T > 0.8$ GeV, the particle will penetrate from the barrel side and leave around 230 tracker hits.

Most of the π^+s generate enough tracker hits (> 3) to be reconstructed as a charged track in principle.





CEPC tracker layout

Track Reconstruction Efficiency

The track reconstruction efficiency is defined as (for π^+ from K_S^0):

$$\epsilon_{Trk} = \frac{Number\ of\ reconstructed\ \pi^+\ tracks}{Number\ of\ K_S^0 \to \pi^+\pi^-\ events}$$

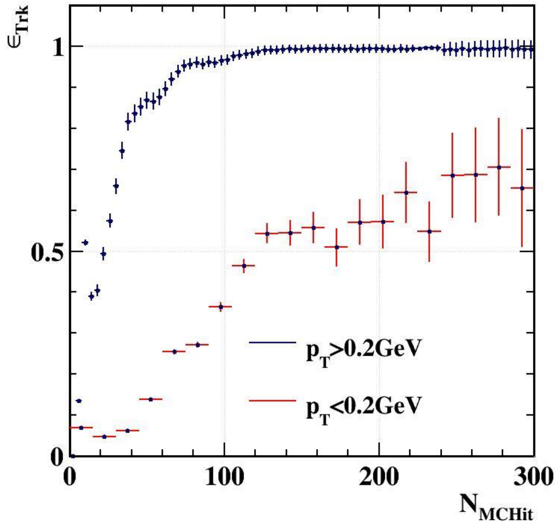
The ϵ_{Trk} for π^+ from K_S^0 is 86.5%. Factors for efficiency loss:

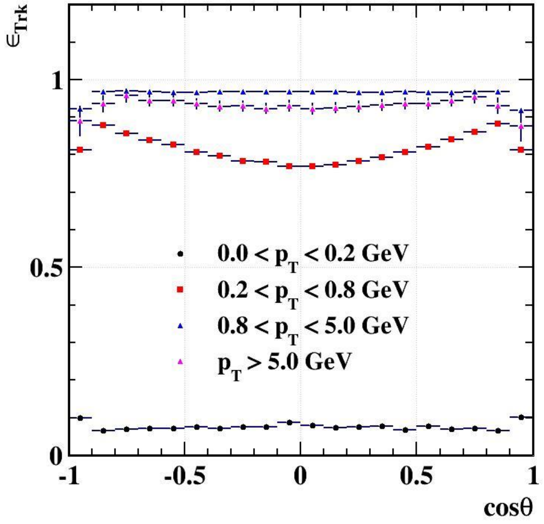
- Low efficiency for π^+s with $p_T < 0.2$ GeV → primary.
- Dependence on the polar angle and the transverse displacement of the secondary vertex → secondary.

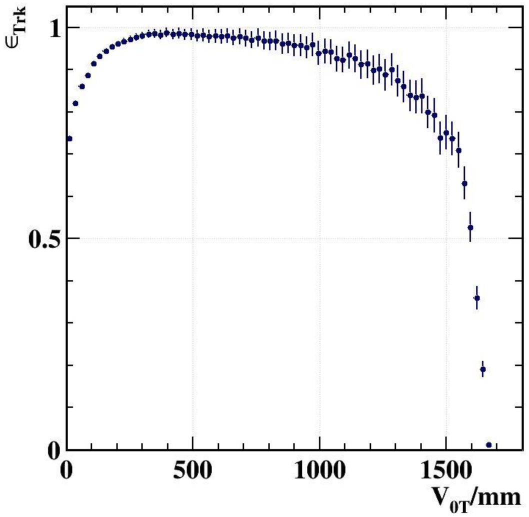
The ϵ_{Trk} will reach ~ 100% if:

1. p_T > 0.2 GeV.
2. The particle has more than 100 tracker hits.
3. The particle is generated within 1 meter from IP.

In total, 73.64% of $K_S^0 \to \pi^+\pi^-$ events and 62.9% of $\Lambda \to p\pi^-$ events have both daughter tracks reconstructed.







Definitions of Efficiency and Purity for $\boldsymbol{K_S^0}$ and Λ

First define the reconstruction efficiency:

$$\epsilon_R = \frac{Number\ of\ correctly\ tagged\ track\ pairs}{Number\ of\ K_S^0\ /\ \Lambda\ daughter\ track\ pairs}$$

Define purity as:

$$P = \frac{Number\ of\ correctly\ tagged\ track\ pairs}{Number\ of\ tagged\ track\ pairs}$$

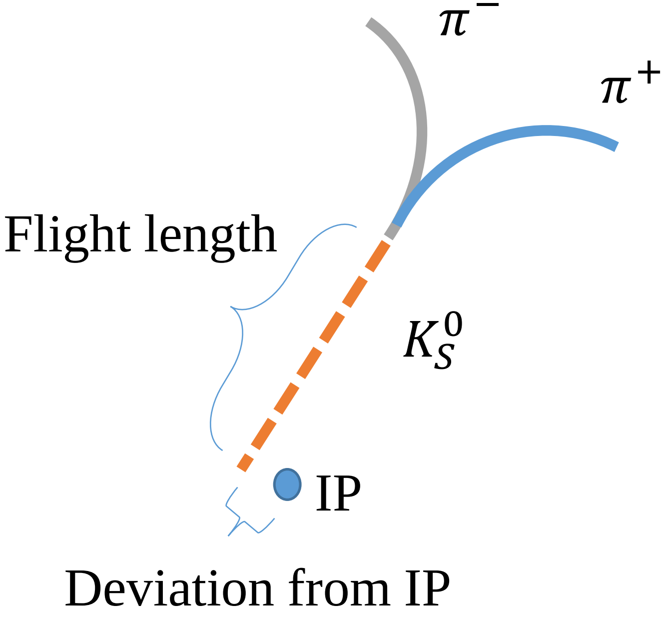
The inclusive efficiency $\epsilon_T = \epsilon_R \times \epsilon(Both\ tracks\ reconstructed) \times BR\left(K_S^0 \to \pi^+\pi^-\right) = \epsilon_R \times 0.4996$ for K_S^0. For Λ, we have $\epsilon_T = \epsilon_R \times 0.391$.

Reconstruction Method

The method to reconstruct K_S^0 (Λ) is as following:

1. Assume all of the tracks belong to either π^+ or π^- (p or π^-).
2. The minimum track separation is smaller than 5 mm (3 mm). Assume the secondary vertex is on the track with larger p_T at that point.
3. Reconstruct the 4-momentum of K_S^0 (Λ) and the invariant mass deviates less than 10 MeV (3 MeV) from the input value.
4. The K_S^0 (Λ) flight path's deviation from IP is less than 0.02 (0.01) of its flight length.
5. The transverse displacement of the secondary vertex is larger than 6 mm (10 mm).

The parameters are tuned to maximize $\epsilon_R \cdot P$.



Reconstruction Method

Use the purity distribution on the Armenteros plot to demonstrate the performance:

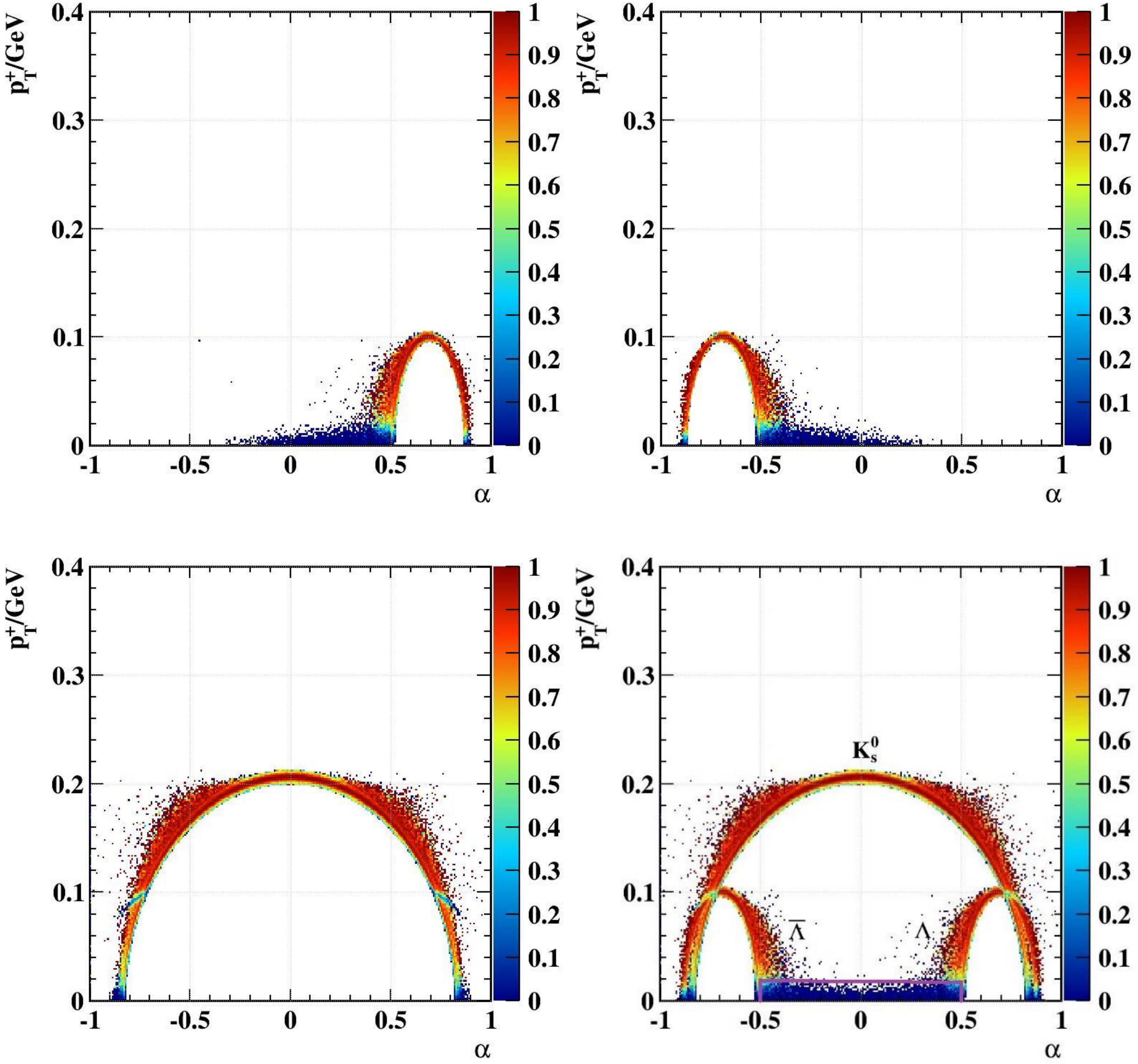
y axis: positive daughter’s transverse momentum p_T^+.
x axis: longitudinal momentum asymmetry, defined as:

$$\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$$

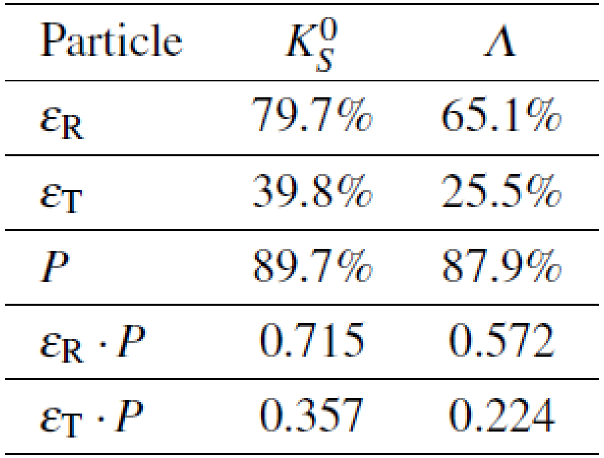
, all in respect to the parent’s momentum.

The three arcs represent $K_S^0/\Lambda/\overline{\Lambda}$ respectively. The low purity tails of $\Lambda/\overline{\Lambda}$ are mostly $\gamma \rightarrow ee$.

We cut off the region where $p_T^+ < 0.02$ GeV and $|\alpha| < 0.5$.



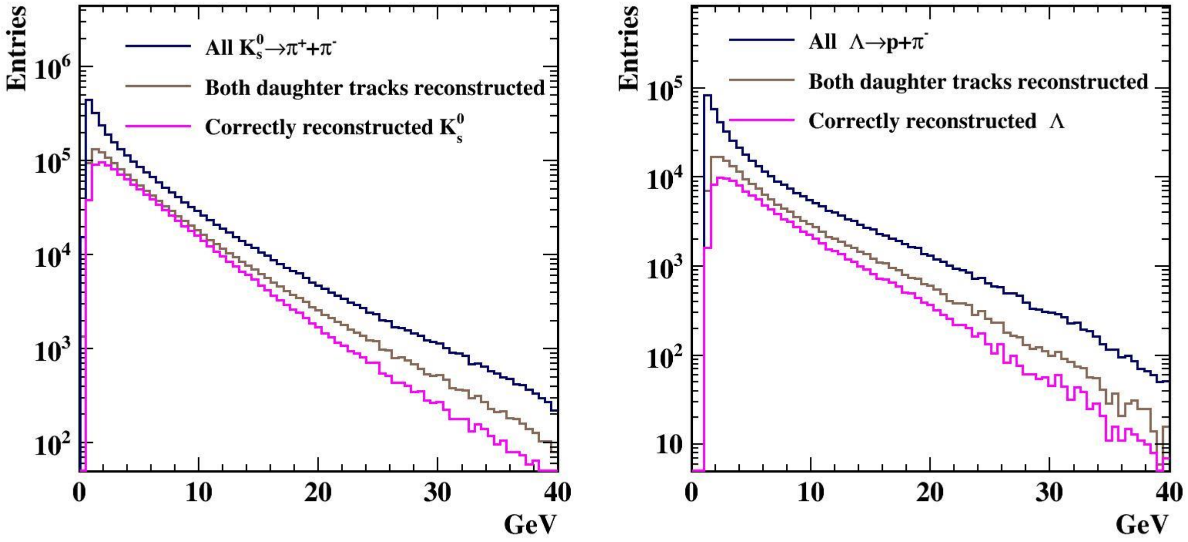
Results



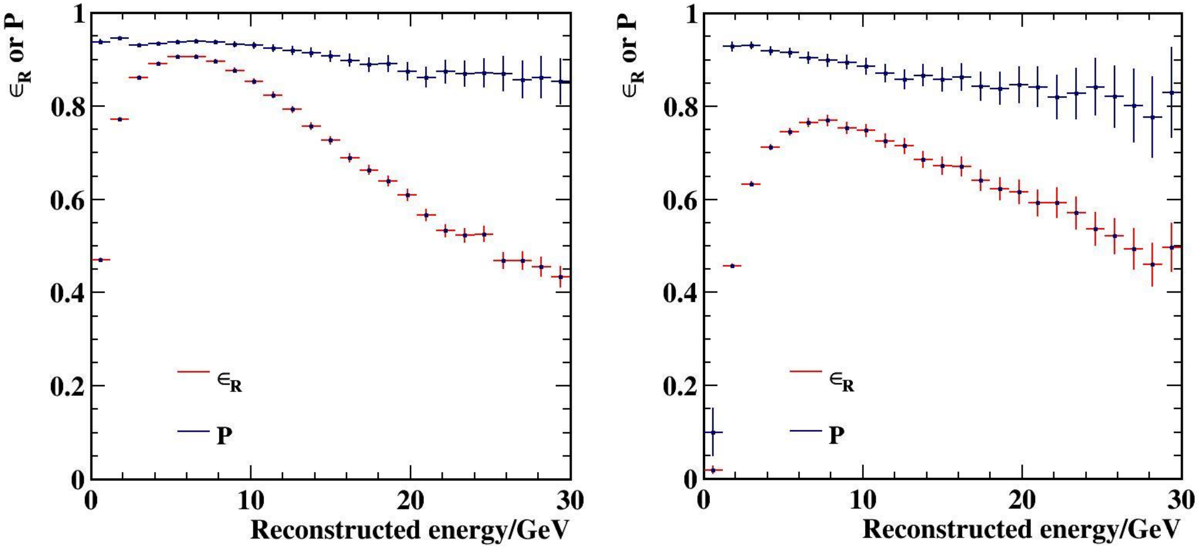
Particle	K_S^0	Λ
ε_R	79.7%	65.1%
ε_T	39.8%	25.5%
P	89.7%	87.9%
$\varepsilon_R \cdot P$	0.715	0.572
$\varepsilon_T \cdot P$	0.357	0.224

Reconstruction performance

Energy distribution

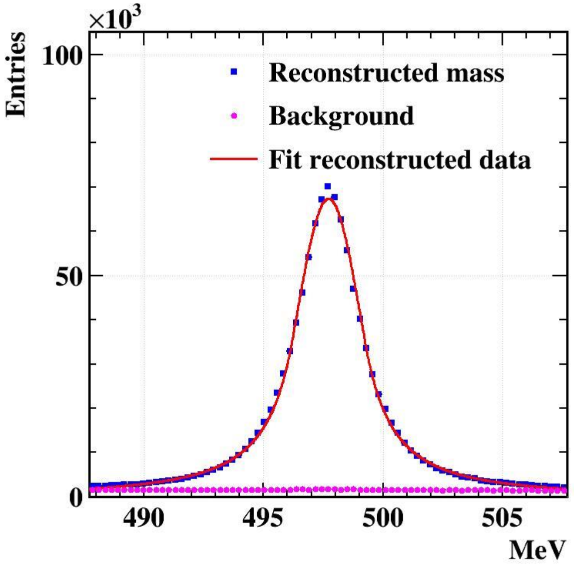


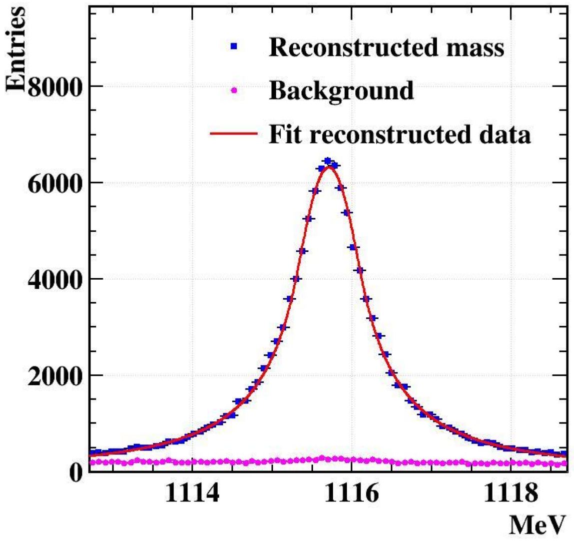
ϵ_R and P versus reconstructed energy



Mass and Life Time Measurements

The value of mass:





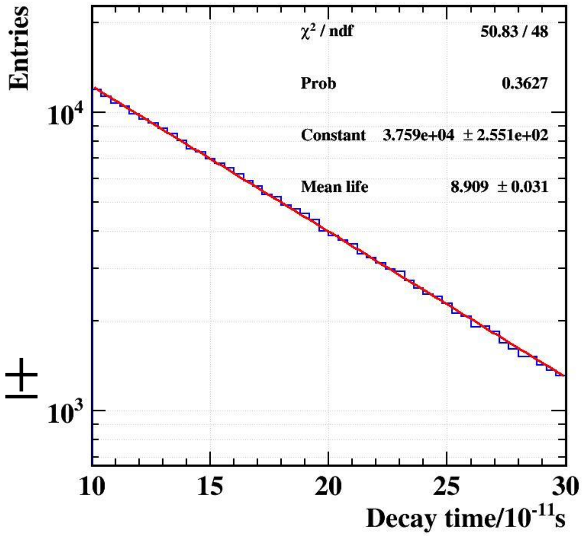
Particle	K_S^0			Λ	
Experiment	CEPC	KLOE [11]	NA48 [10]	CEPC	AGS [12]
Mass/MeV	497.719	497.583	497.625	1115.708	1115.678
Statistical error/MeV	0.002	0.005	0.001	0.003	0.006
Systematical error/MeV	—	0.020	0.031	—	0.006

Mass resolution: Add two more conditions.

1. Both of K_S^0 daughter tracks have more than 200 tracker hits. The Λ's daughter tracks have more than 200/100 tracker hits for its positive/negative daughters.
2. The angle between the to momenta at minimum track separation is grater than 20° for K_S^0 and 10° for Λ.

The resolutions are 1.05 ± 0.02 / 0.32 ± 0.02 MeV for K_S^0 and Λ.

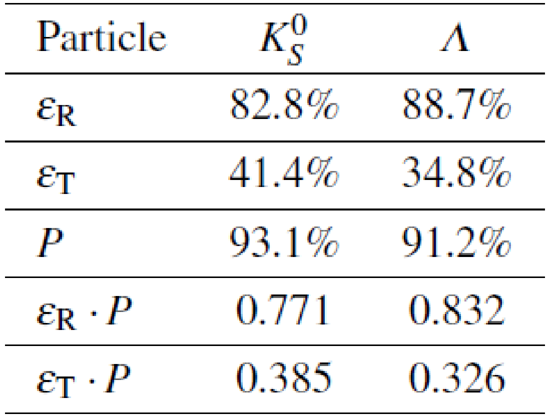
Life time: fit the decay time with an exponential, the measured value is $8.909 \pm 0.031_{stat} \times 10^{-11}$s. The input value is 8.954×10^{-11}s.



Estimations for Future Improvements

1. A proper PID algorithm. Especially the proton identification will reduce K_S^0 backgrounds and increase Λ efficiency. Assuming a perfect PID, we have

2. Ideal track reconstruction performance for $p_T > 0.2$ GeV, $p_T > 0.1$ GeV, and (to test the limit) all charged particles.



Particle	K_S^0	Λ
ε_R	82.8%	88.7%
ε_T	41.4%	34.8%
P	93.1%	91.2%
$\varepsilon_\mathrm{R} \cdot P$	0.771	0.832
$\varepsilon_\mathrm{T} \cdot P$	0.385	0.326

Particle		K_S^0			Λ	
p_T threshold/GeV	0.2	0.1	—	0.2	0.1	—
ε_T	41%	46%	48%	36%	37%	39%
P	89%	89%	88%	87%	87%	86%
$\varepsilon_\mathrm{T} \cdot P$	0.37	0.41	0.42	0.28	0.32	0.34

Application on the Detector Material and Alignment Studies

Material studies:

- K_S^0 has high statistics, which could ensure it is populated inside the detector with fine granularity, and the detector material modeling could be done precisely at the small structure, even for the large decay radii and very forward region.
- K_S^0 has a large decay length ($c\tau \approx$ 2.7 cm), which allows studying the detector material as a function of the radial position of the decaying vertex.

Alignment:

Some detector global distortions preserve the helicoidal trajectory of the tracks. Hence the track-based alignment algorithms have a low sensitivity to those distortions and it is difficult to correct them. We can tackle the problem using the invariant mass constraint of track pairs. This method limited by the maximum opening angle between decaying product, so the low mass of the K_S^0 makes it particularly suitable.