# Tracker Configuration optimization at the CEPC

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# Outline

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  - Jet energy resolution modeling
- Optimization  of tracker R/L for the track/jets
- Budget rather than the baseline
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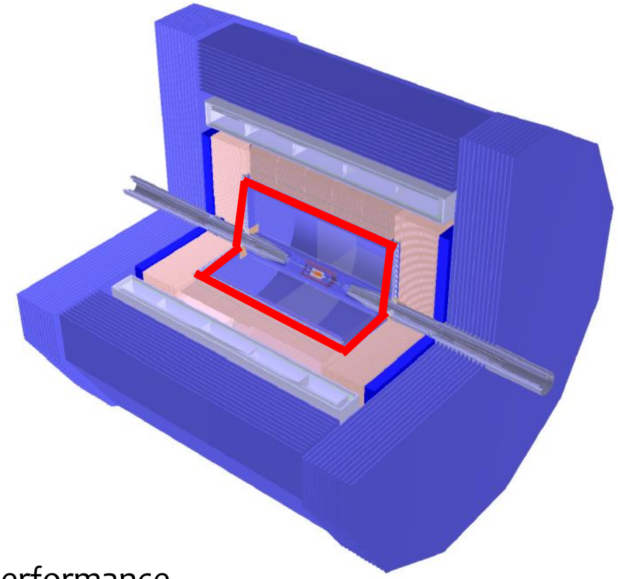
# Introduction



- Tracking system of the CEPC
  - Cylindrical configuration
  - Characterized by its radius ($R$) and length ($L$)
- Why is there an optimal $R$ & $L$?
  - The average performance depends on the $R$ & $L$
  - Construction cost also depends on $R$ & $L$
  - With constraint of cost, optimal $R$ & $L$ exists to achieve best average performance
- CEPC runs:
  - Baseline scheme:
    - One Tera $Z$ boson at CME of 91.2 GeV
    - One million Higgs bosons at CME of 240 GeV
  - Considering:
    - CME of 360 GeV for $t$ quark/W boson fusion etc.
- Key physics objects:
  - Tracks
  - Jets
- Benchmark channels:
  - $Z \rightarrow \mu\mu/qq$ @ 91.2GeV
  - $Z + H \rightarrow \nu\nu + \mu\mu/qq$ @ 240GeV
  - $WW$ fusion, $H \rightarrow \mu\mu/qq$ @ 360GeV ($\mu\mu$ for complement)
  - $tt \rightarrow bb\mu\nu_\mu ud$ @360GeV, $\mu$ and $bb/ud$ for tracks and jets optimization, respectively

# Methodology

- 1. modeling of the resolutions
  - $\mathrm{Res}(\Lambda; R, L)$

    $(p_T, \theta)$ for tracks
    $(E, \theta)$ for jets

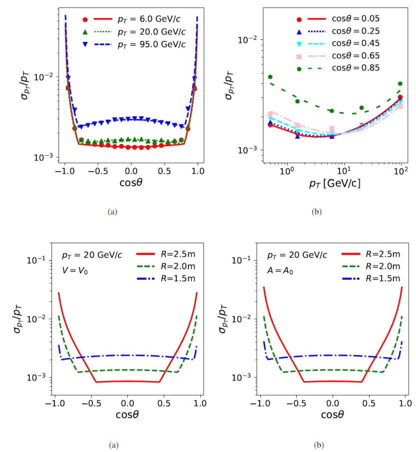
- 2. obtain $R$ vs. $L$ with the constraint of cost
  - $\mathrm{Res}(\Lambda; R)$

- 3. calculate the average resolution employing the x-section of benchmark channels as weights:

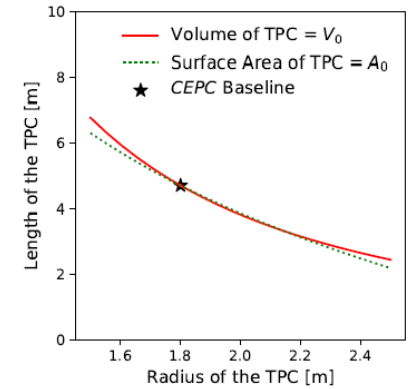
$$\overline{\mathrm{Res(R)}} = \frac{1}{\sigma}\int \mathrm{Res}(\Lambda; R)\frac{\mathrm{d}\sigma}{\mathrm{d}\Lambda}\mathrm{d}\Lambda$$

- 4. obtain the optimal $R\&L$

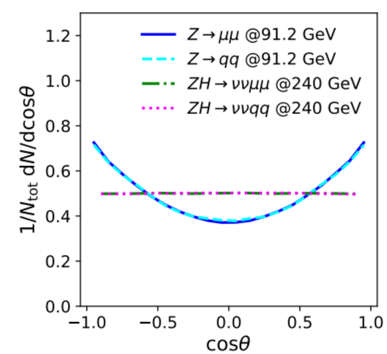
Modeling



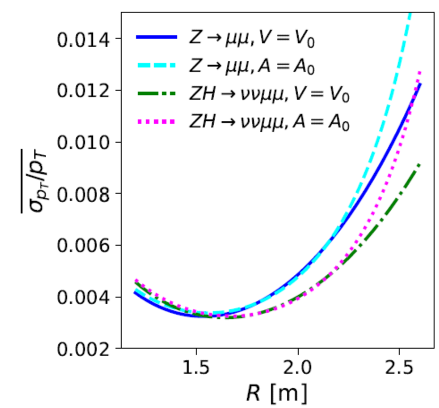

$R$ vs. $L$




X-section




average resolution



# Track $p_T$ resolution modeling

- The effective radius $(r)$ is important to determine $p_T$

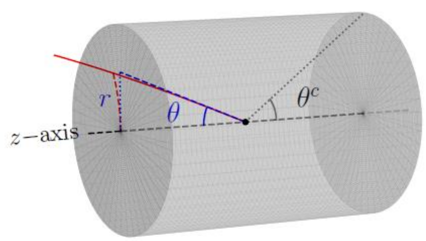



**Figure 2**: Skeleton diagram of a sideview of the TPC and a trajectory of one particle (marked by the solid red line) hitting its endcap, which has a $p_T$ of 1.8 GeV/$c$ and a $\theta$ of 21°.

  - = $R$ for barrel, $\frac{L}{2}\tan\theta$ for endcaps
- bending radius of the track $(\rho)$
  - = $1.1E\ \sin\theta$ for a B-field of 3T (E in GeV/c, $\rho$ in meter)
- With the case of $r \ll \rho$
  - $\sigma_{p_T} \propto r^{-2}$

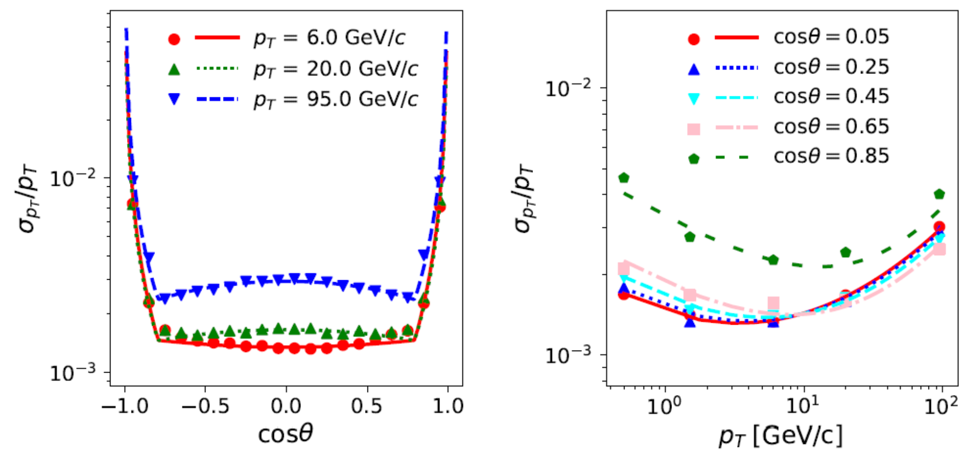
# Track $p_T$ resolution modeling

- Taking account of the dependency on the $p_T$ and the remaining dependency on the polar angle
- Parameters determined from the full simulation data at baseline detector (Mingrui Zhao, et al.)

$$\sigma_{p_T}/p_T = \frac{r^{-2}}{R_0^{-2}}(c_0 + c_1 \cos^2\theta),$$

$$\ln c_0 = a_0 + b_0 \ln p_T + d_0 \ln^2 p_T,$$

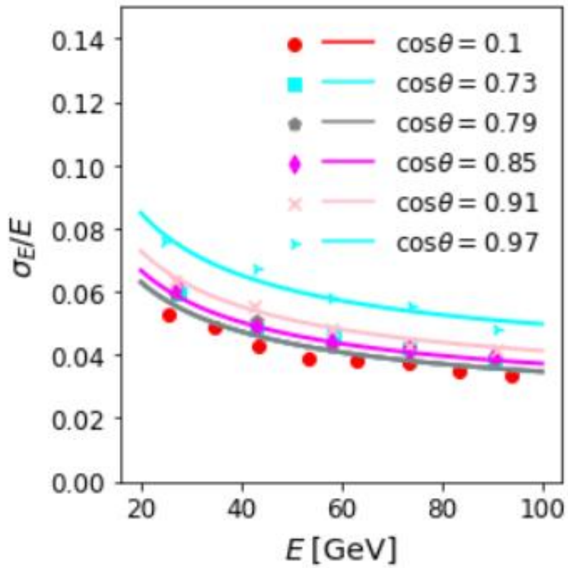
$$c_1 = a_1 + b_1 \ln p_T + d_1 \ln^2 p_T.$$



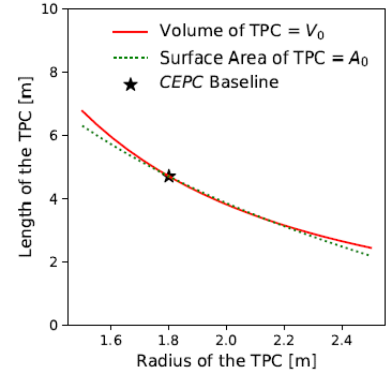

(a) (b)

# Jet energy resolution modeling

- Similar parameterization strategy adopt to jet
- $r$ can effect:
  - The tracks $p_T$ resolution in jets
  - particles separation in particle flow
  - $\mathrm{JER} = \sqrt{b_1(E) + \frac{b_2(E)}{r+b_3}}$
    - $b_i(E) = c + \frac{d_i}{E}, i = 1,2$
      - Fall back to normal formula for particular $\theta$
- Parameters in the formula extracted from full simulation data at baseline (Peizhu Lai, et al.)



# Optimal tracker R/L




- Cost estimation:
  - The volume or the surface area to the tracker
- Adopt constraint of the cost

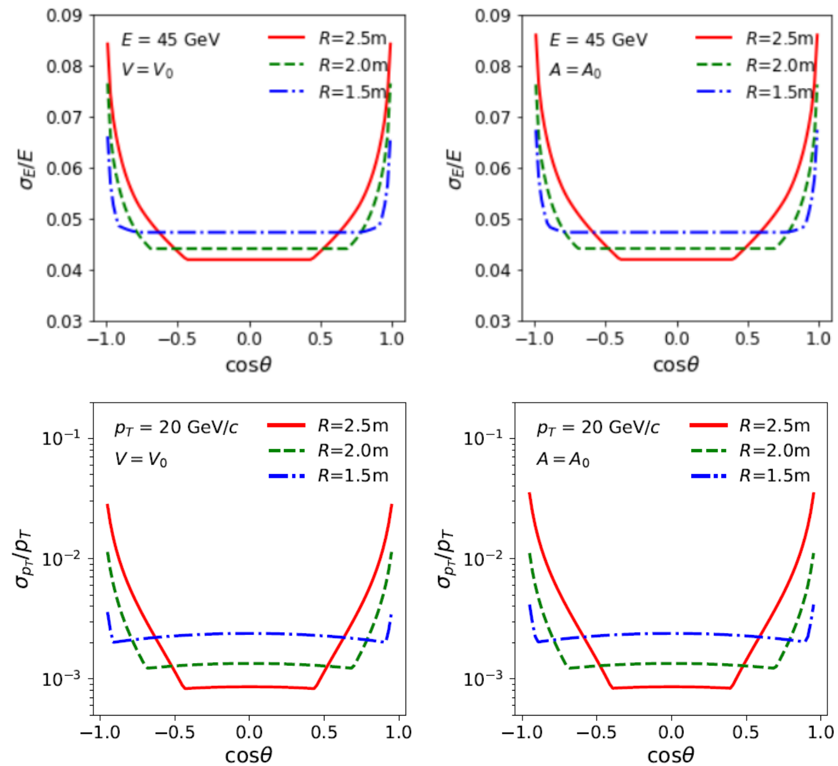
Larger R, Smaller L

better performance for the barrel, worse performance for the endcaps

cost = volume | cost = surface area

jets

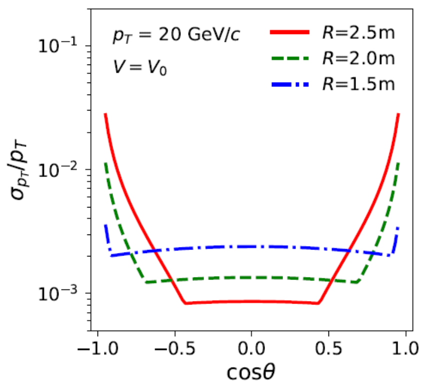
tracks

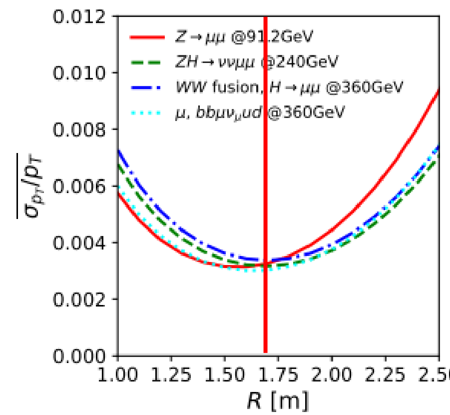


# Optimal tracker R/L

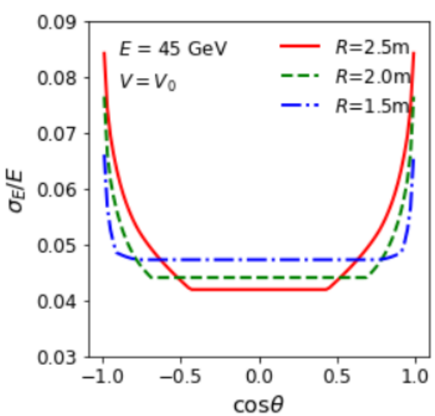
The tracks favor longer tracker than the jets

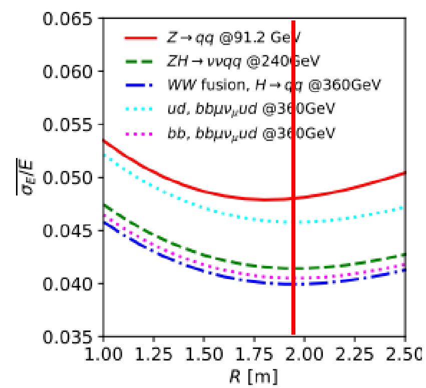
- Optimal R range from 1.6 – 1.73 m for the tracks and 1.8 – 2.0 m for the jets
- Reason: bad performance of the tracks in the endcaps demands longer tracker



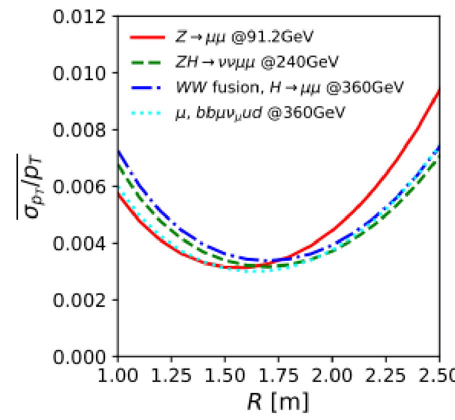

Degradation about 2 for the jets at the polar,
More than ten for the tracks



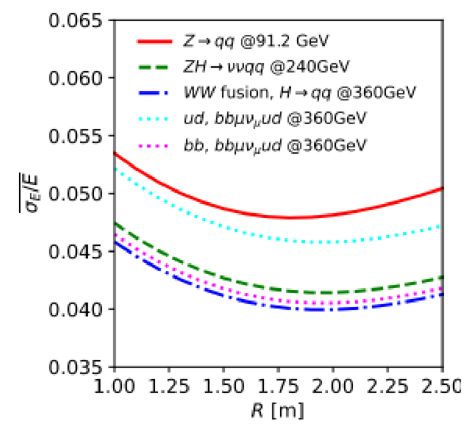



# Optimal tracker R/L

- Optimal Tracks performance
  - Mainly dependent on the polar distribution & energy
  - The more energic and forward distributed tracks have the worse performance
  - Tracks from Z, less energic but forward distributed, have comparable performance to the $ZH$
- Optimal jets performance
  - mainly dependent on the energy
  - The more energic jets have the better performance




tracks

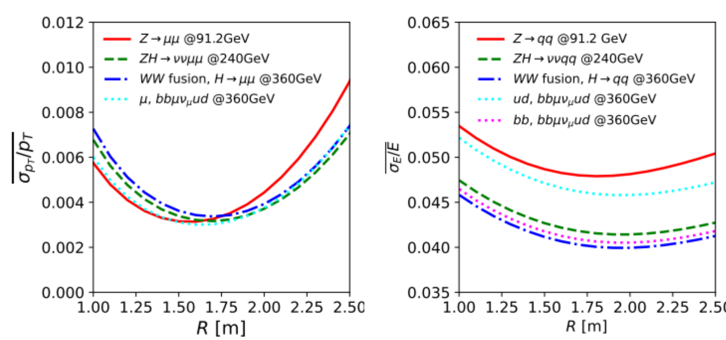



jets

# Optimal tracker R/L

- Tracks are more sensitive to the tracker configuration
- Degradations at baseline
  - Sub-percentage level for jets
  - About ten percent for jets

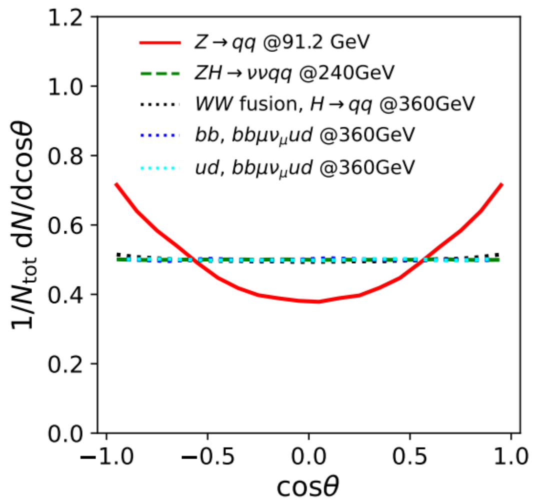
| Benchmark | Cost estimator | Degradations (%) vs. radii (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 |
| $Z \to \mu\mu$ $\sqrt{s} = 91.2$ GeV | volume | 0.8 | 0.3 | 4.2 | 12.4 | 24.9 | 41.8 | 63.3 | 89.6 |
| | surface area | 1.4 | 0.0 | 2.3 | 8.5 | 19.0 | 34.6 | 56.3 | 86.1 |
| $Z \to qq$ $\sqrt{s} = 91.2$ GeV | volume | 1.6 | 0.7 | 0.2 | 0.0 | 0.1 | 0.5 | 1.1 | 1.9 |
| | surface area | 2.0 | 1.0 | 0.4 | 0.0 | 0.0 | 0.4 | 1.1 | 2.1 |
| $ZH \to \nu\nu\mu\mu$ $\sqrt{s} = 240$ GeV | volume | 6.9 | 1.6 | 0.0 | 2.2 | 7.9 | 17.3 | 30.4 | 47.4 |
| | surface area | 8.5 | 2.5 | 0.1 | 1.1 | 5.7 | 14.4 | 28.0 | 47.9 |
| $ZH \to \nu\nu qq$ $\sqrt{s} = 240$ GeV | volume | 3.1 | 1.8 | 0.9 | 0.3 | 0.0 | 0.0 | 0.3 | 0.7 |
| | surface area | 3.4 | 2.1 | 1.1 | 0.4 | 0.1 | 0.0 | 0.3 | 1.0 |
| $W$ fusion, $H \to \mu\mu$ $\sqrt{s} = 360$ GeV | volume | 7.4 | 1.8 | 0.0 | 1.9 | 7.3 | 16.4 | 29.2 | 45.7 |
| | surface area | 9.0 | 2.9 | 0.1 | 0.9 | 5.2 | 13.6 | 27.0 | 46.4 |
| $W$ fusion, $H \to qq$ $\sqrt{s} = 360$ GeV | volume | 3.1 | 1.8 | 0.9 | 0.3 | 0.0 | 0.0 | 0.3 | 0.8 |
| | surface area | 3.4 | 2.1 | 1.1 | 0.4 | 0.1 | 0.0 | 0.3 | 1.0 |
| $\mu$, $bb\mu\nu_\mu ud$ $\sqrt{s} = 360$ GeV | volume | 3.7 | 0.3 | 0.8 | 5.1 | 13.2 | 25.2 | 41.1 | 61.2 |
| | surface area | 5.0 | 0.8 | 0.2 | 3.1 | 9.8 | 20.9 | 37.3 | 60.5 |
| $ud$, $bb\mu\nu_\mu ud$ $\sqrt{s} = 360$ GeV | volume | 2.9 | 1.7 | 0.9 | 0.3 | 0.0 | 0.0 | 0.3 | 0.7 |
| | surface area | 3.2 | 2.0 | 1.1 | 0.4 | 0.1 | 0.0 | 0.3 | 0.9 |
| $bb$, $bb\mu\nu_\mu ud$ $\sqrt{s} = 360$ GeV | volume | 3.1 | 1.9 | 0.9 | 0.3 | 0.0 | 0.0 | 0.3 | 0.7 |
| | surface area | 3.4 | 2.1 | 1.1 | 0.4 | 0.1 | 0.0 | 0.3 | 1.0 |



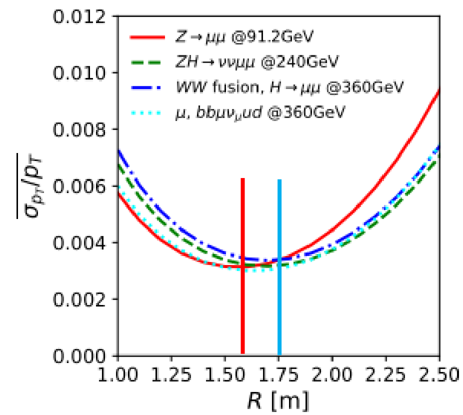

Optimal performance for tracks(left) and jets(rights) vs R, cost estimated, e.g., as volume

# Optimal tracker R/L

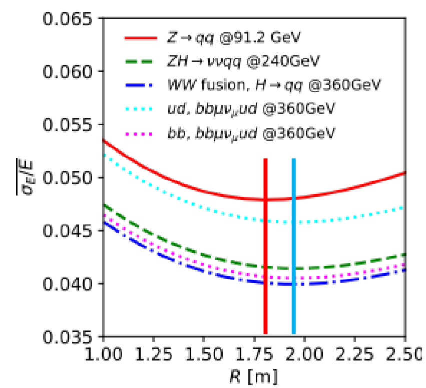
- $Z$ @91.2 favor a longer tracker than the other processes
  - For both the tracks and the jets
  - Physics objects in the former process: forward distribution




Tracks have similar distributions to the jets
Generated with WHIZARD



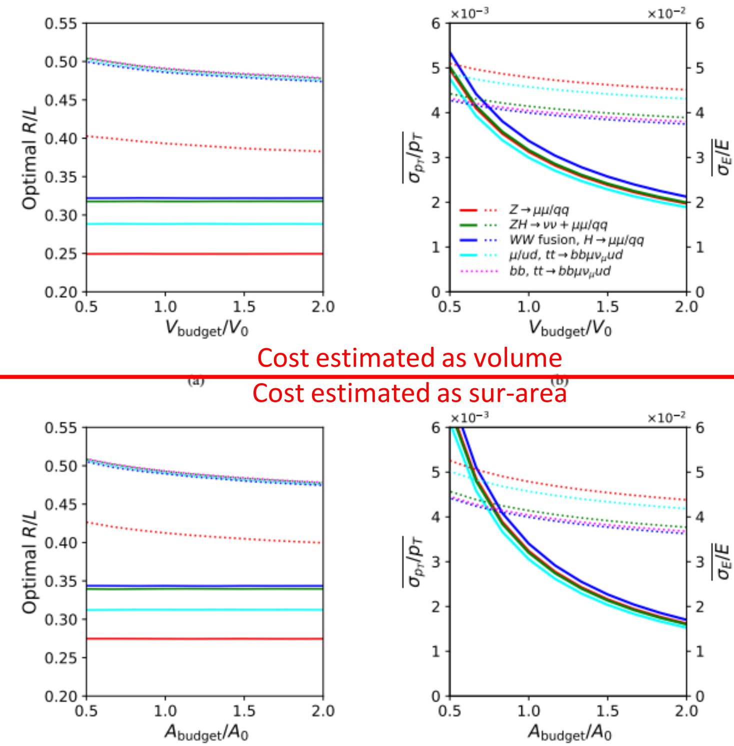

tracks




jets

# Budget rather than the baseline

- Larger budget, better performance
- Tracks:
  - $R/L$ is independent to the budget due to the simplicity of the modeling
  - Performance ~ $\text{scale}^{-2}$
- Jets:
  - $R/L$ : weak dependency on the budget.
  - Deeper valley for jets as R increases, to achieve good average performance, put more resource on the tracker length.




Cost estimated as volume

Cost estimated as sur-area

Solid lines for the tracks

Dotted lines for the jets

# Summary

- Optimal R/L obtained for the baseline
  - Jets & tracks compared
    - Tracks favor longer tracker than the jets
    - Polar angular distribution of tracks affect the optimization more than the jets
    - Tracks are more sensitive to the track configuration
  - Z, ZH, W boson fusion, and tt processes compared
    - Z process favor longer tracker due to the forward polar distribution of physics objects
- Optimal R/L vs. construction cost
  - Weak dependency of R/L on construction cost for tracks/jets
  - The larger budget leads to the longer tracker for the jets