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SJTU

Vertex detector optimization at the CEPC

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10/24/2026

The 2026 International Workshop on the High Energy Circular Electron Positron Collider

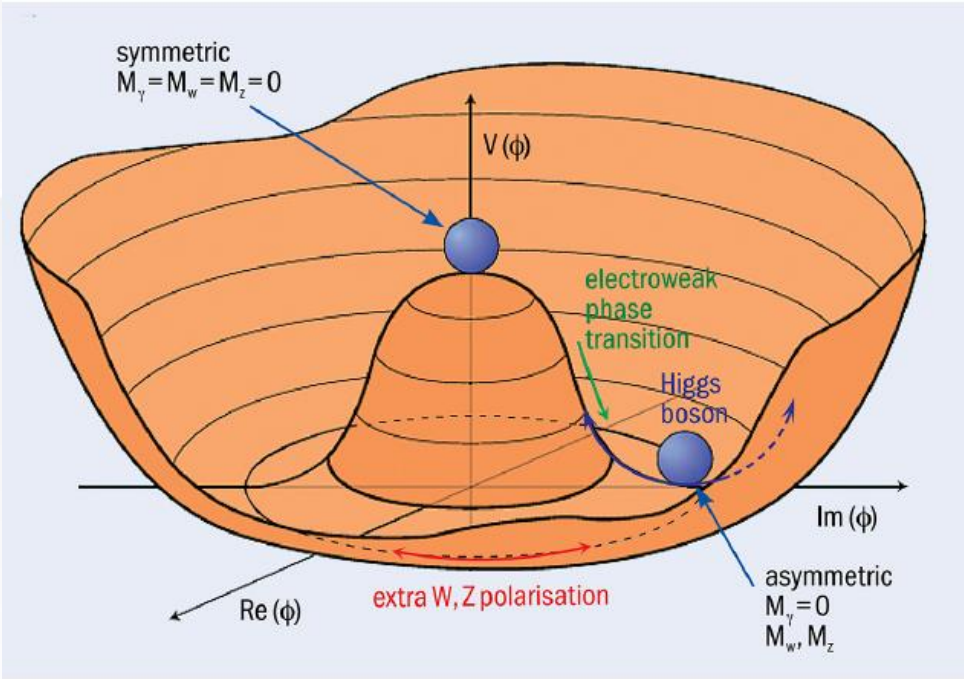
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Higgs Mechanism and Yukawa Couplings

Why Yukawa?

Yukawa interactions

- Yukawa coupling: $y_f = \sqrt{2} \cdot m_f / v$
- SM expectation: coupling ∝ fermion mass



Status at LHC:

- 3rd generation measured t: precision ~ 10%
- 2nd generation quarks (c, s): Upper limit on κ_c: 3.5 x SM at 95% CL from CMS
- Motivation: precision test of Higgs-fermion sector

Second-Generation Yukawa coupling @ CEPC

Challenges at LHC

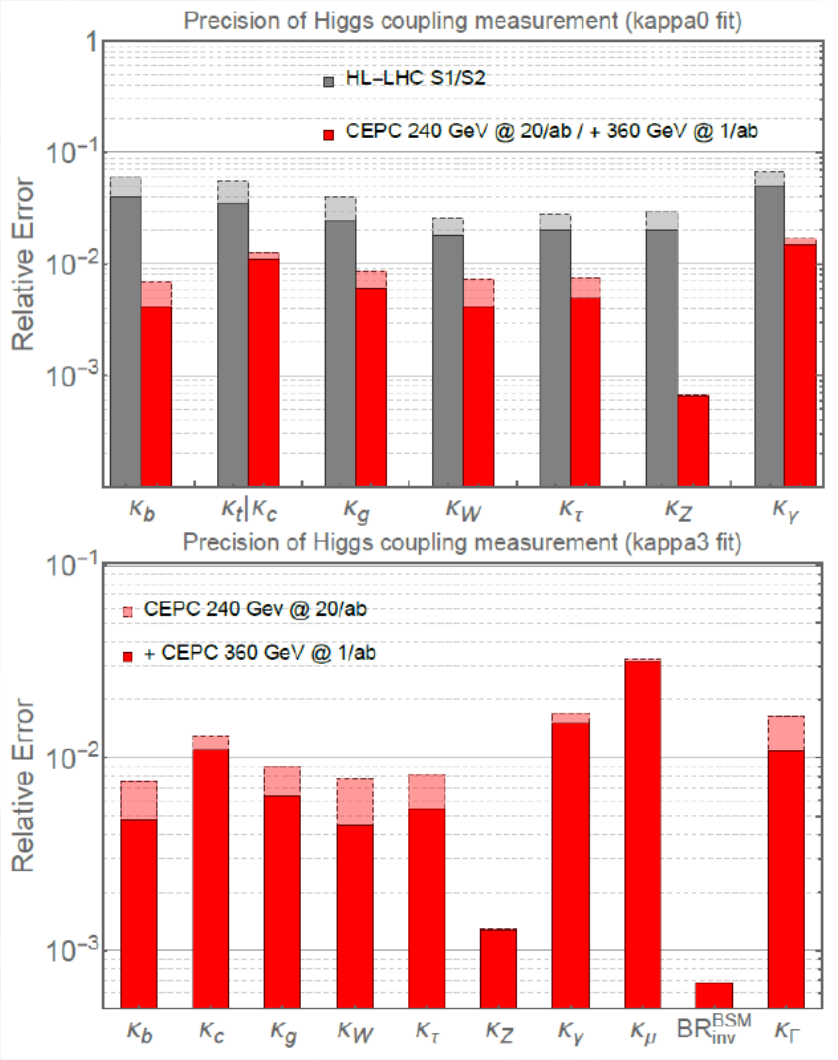
- Rare branching ratio: $H \to c\bar{c}$ and $H \to s\bar{s}$ buried under QCD and heavy-flavor backgrounds.
- Limited jet tagging performance and systematics.

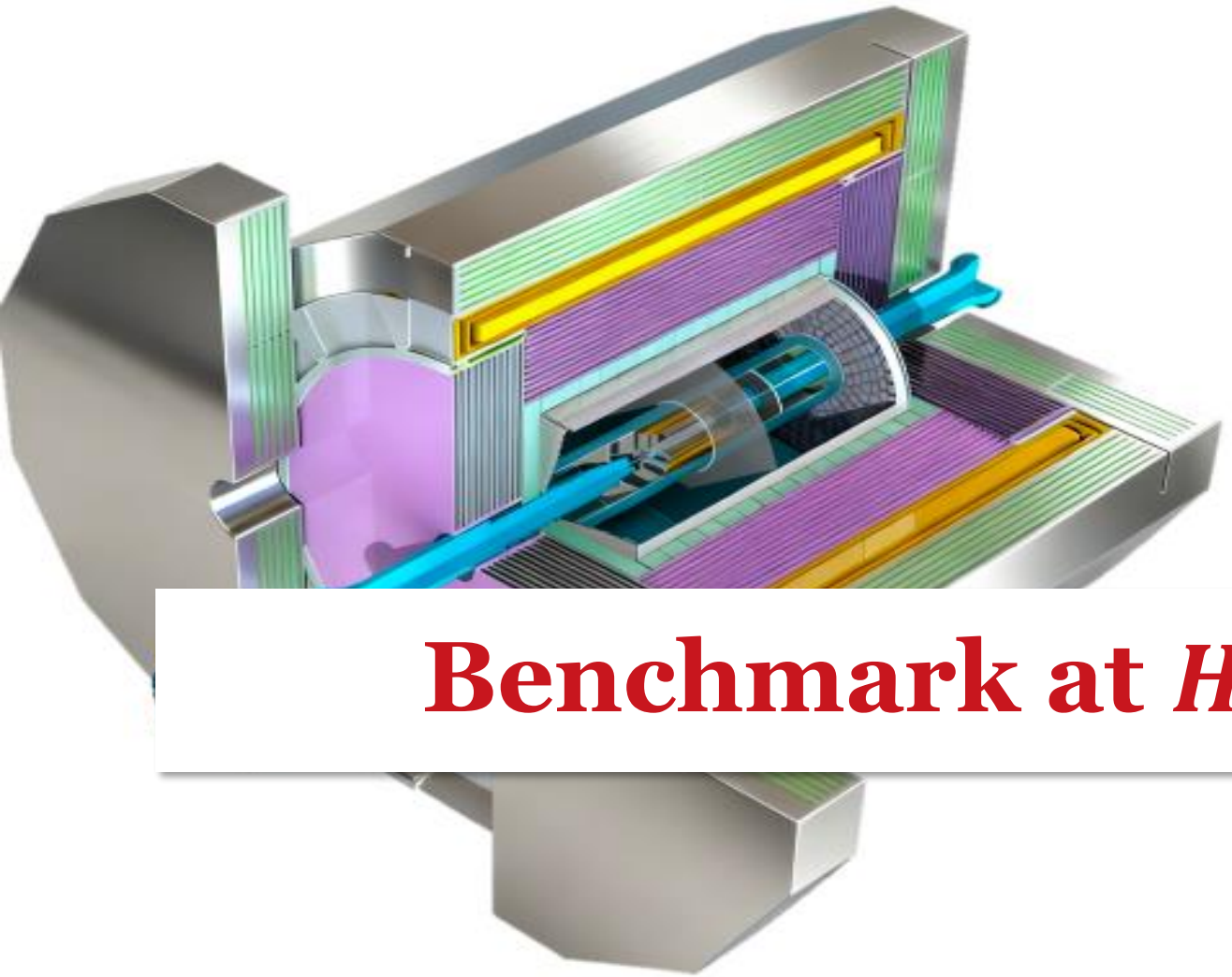
CEPC as a Higgs factory

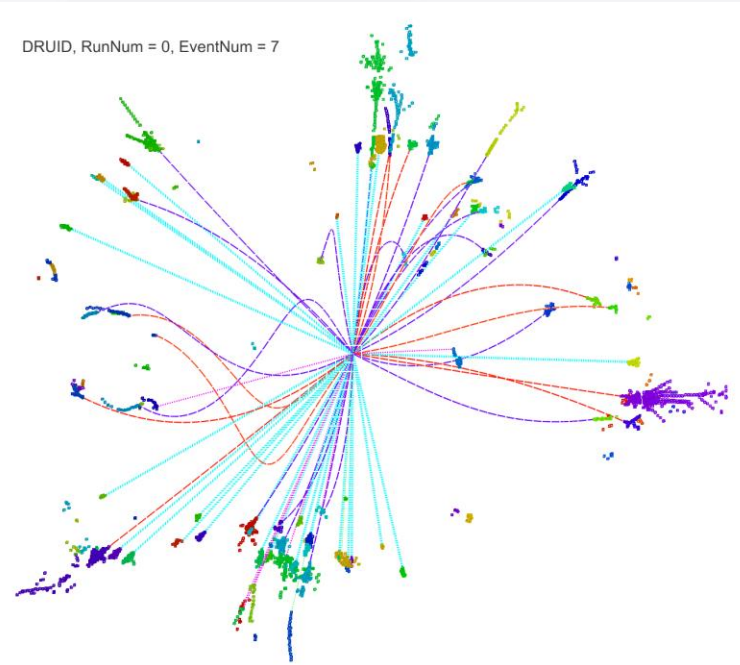
- Clean initial state (e^+e^-).
- Huge Higgs sample ($4*10^6$) at 240 GeV.

Opportunities

- Precision measurements of $H \to c\bar{c}$.
- First observation and measurement of $H \to s\bar{s}$.





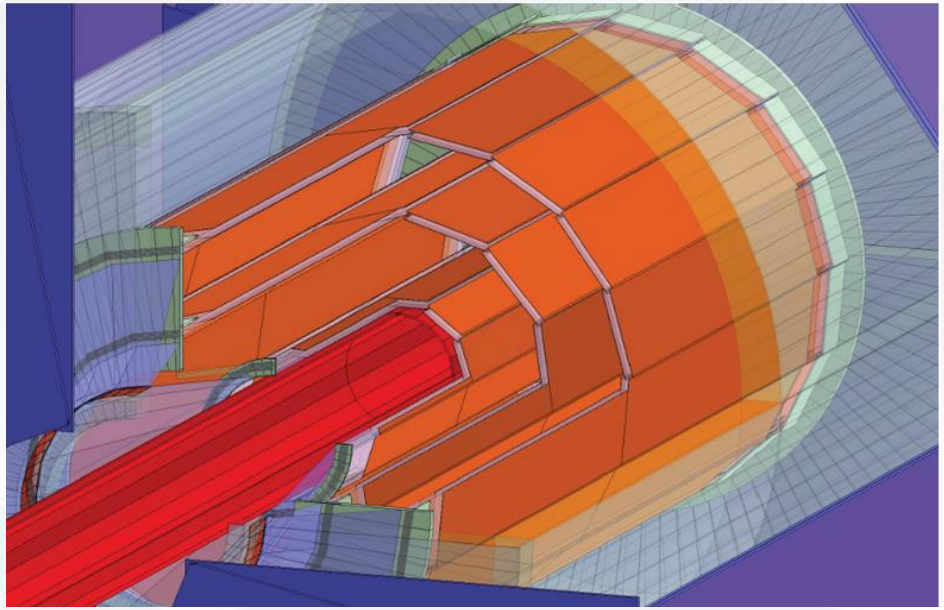


Benchmark at $H \to c\bar{c}$ and $H \to s\bar{s}$

JHEP03(2026)141

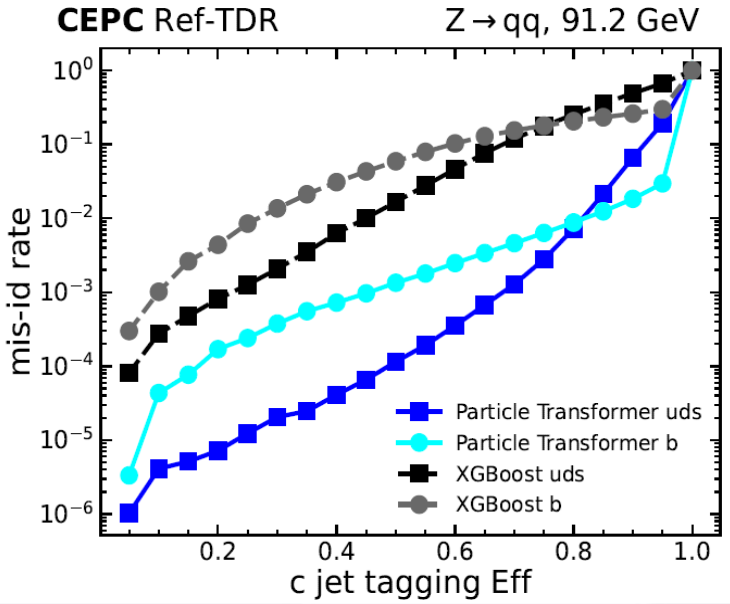
Motivation

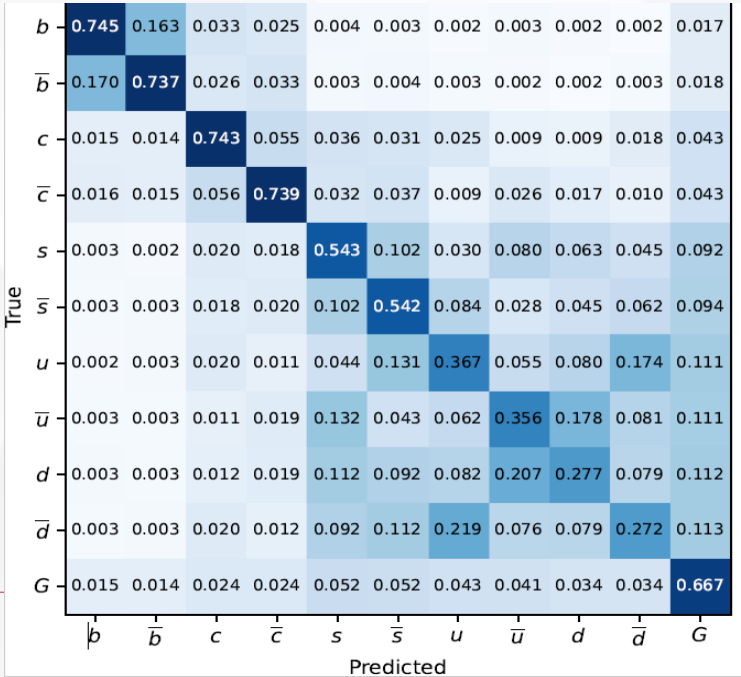
- Limitations of LHC
  - Direct measurement of $H \to c\bar{c}$ and $H \to s\bar{s}$ extremely challenging.
- CEPC as Higgs factory
  - $e^+e^- \to ZH$ at 240 GeV, large Higgs statistics (4M).
  - Clean environment and precise initial state.
- Aim of this study
  - Quantify impact of vertex detector design (inner radius, spatial resolution) on jet flavor tagging.
  - Evaluate sensitivity to $H \to c\bar{c}$ and $H \to s\bar{s}$ using advanced **Jet Origin Identification (JOI)** framework



Jet Origin Identification (JOI) alogrithm

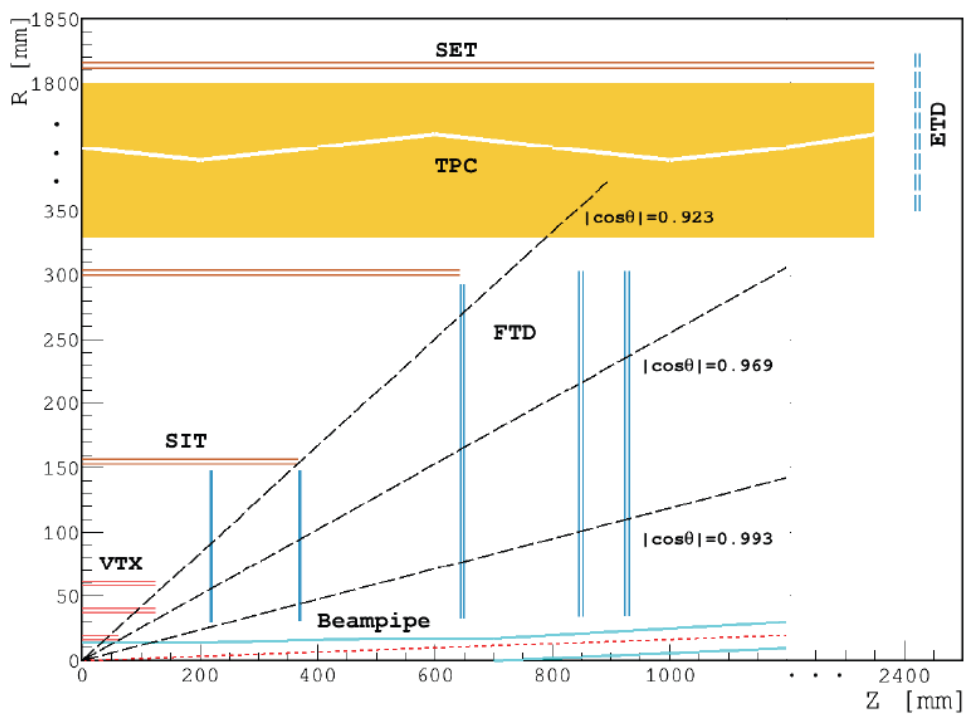
- JOI framework
  - Advanced AI alogrithm to classify jets by partonic origin: b, c, s, u, d and gluon.
- Performance metrics
  - **Confusion matrices** summarizing classification probabilities.
  - **Trace** of confusion matrix as global performance indicator.
- Geometric dependence
  - JOI performance evaluated for each vertex detector configuration





Vertex detector and simulation

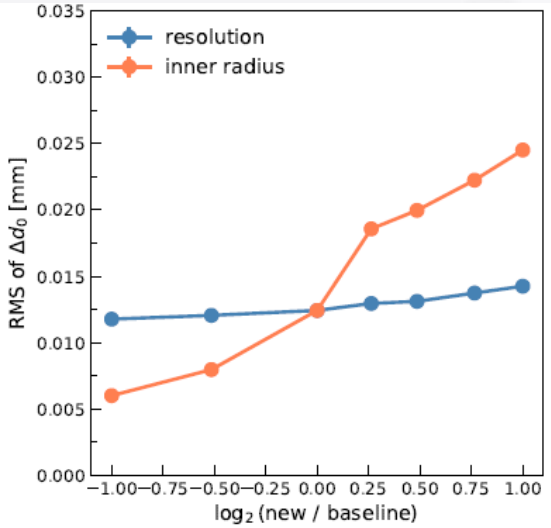
- Vertex detector (VTX): Six-layer pixel detector around IP.
  - Design parameters: Innermost layer radius, single-hit spatial resolution, material budget, etc.
- Benchmark configurations: **Baseline** (@CDR) vs **[0.5 - 2]** varied **radius** and **resolution** scenarios.
- Simulate about 0.9M Higgs events in the $\boldsymbol{\nu\bar{\nu}H}$ final state using **fast** simulation with Delphes.

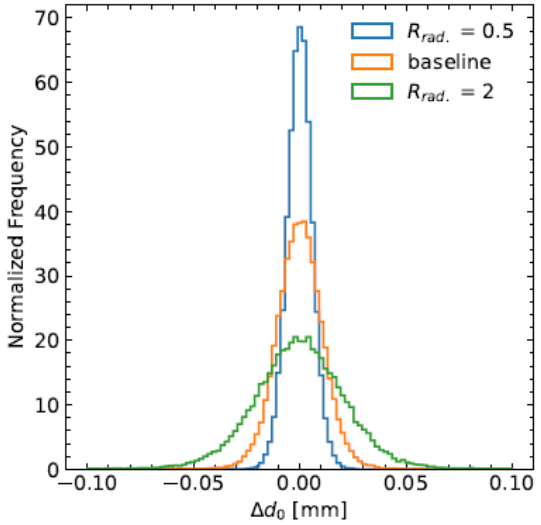


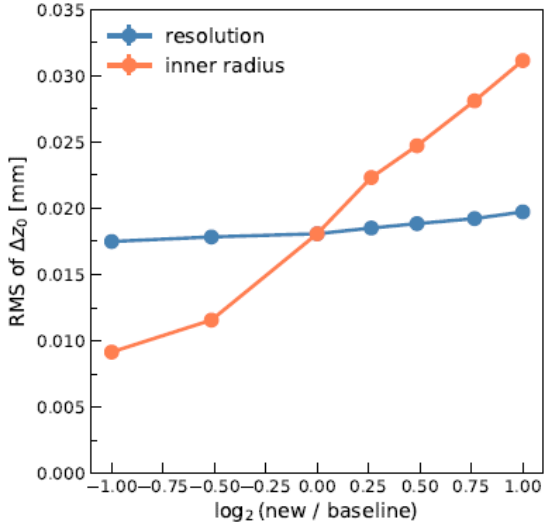
	R (mm)	$\lvert z\rvert$ (mm)	$\lvert\cos\theta\rvert$	σ (μm)
Layer 1	16	62.5	0.97	2.8
Layer 2	18	62.5	0.96	6
Layer 3	37	125.0	0.96	4
Layer 4	39	125.0	0.95	4
Layer 5	58	125.0	0.91	4
Layer 6	60	125.0	0.90	4

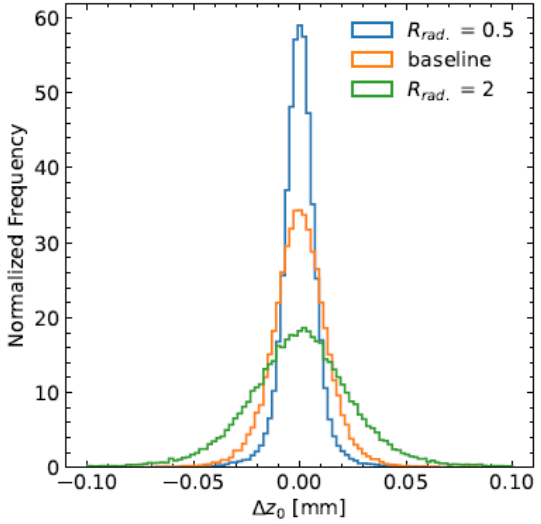
Impact parameter resolution vs. Geometry

- Both do and zo resolutions increase **linearly** with smaller inner radius and worse spatial resolution.
- **Inner radius** has a much stronger impact than resolution.
- Distributions show narrower peaks for smaller $R_{rad.}$(right panel), confirming improved tracking precision.









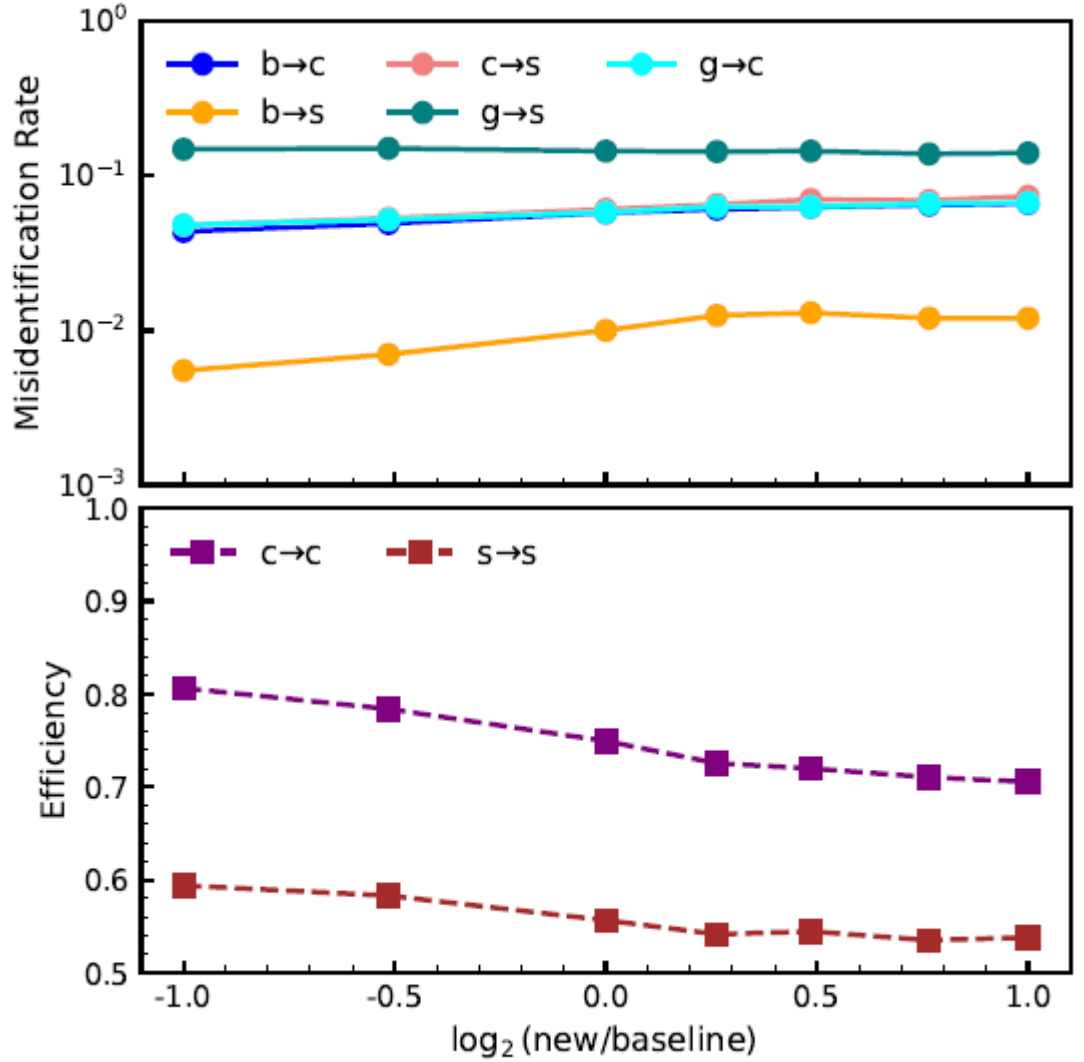
Flavor tagging performance

Tagging efficiencies

- *c*-jet and *s*-jet tagging efficiencies decrease as inner radius increases.

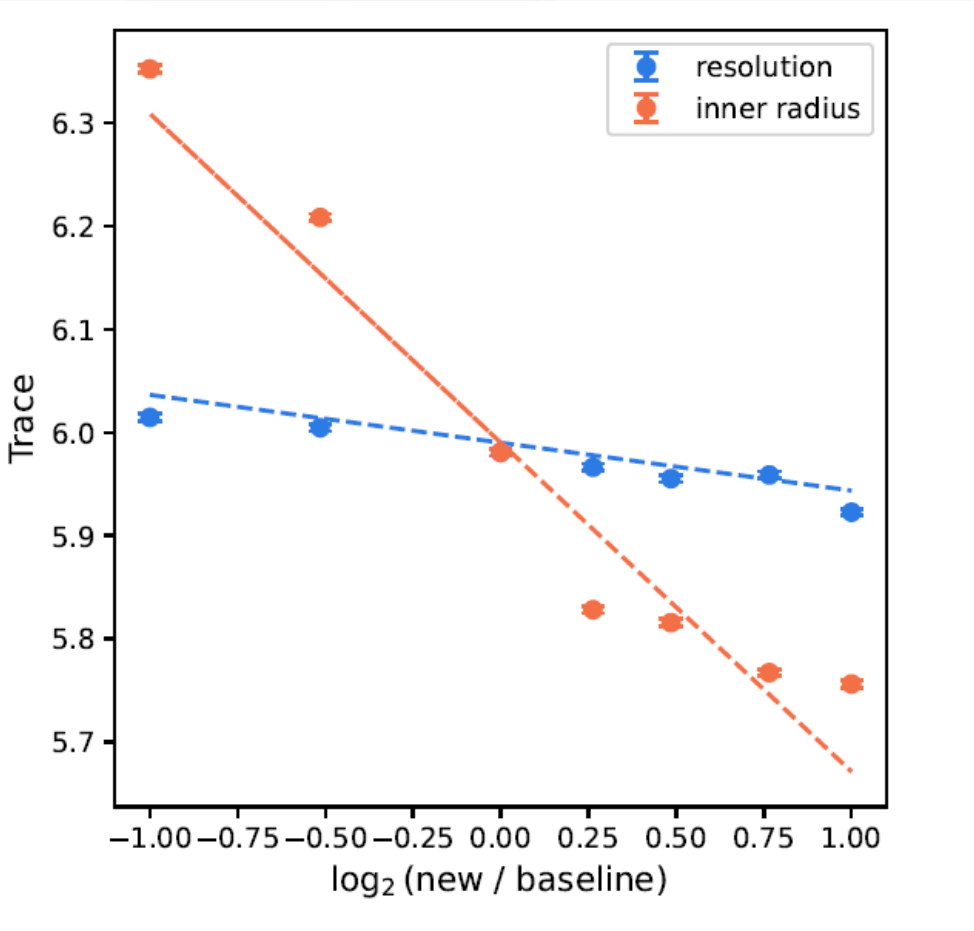
Misidentification rates

- b→s mis-tag rate increases with larger radius.
- Gluon→s mis-tag rate relatively stable (gluons from primary vertex).

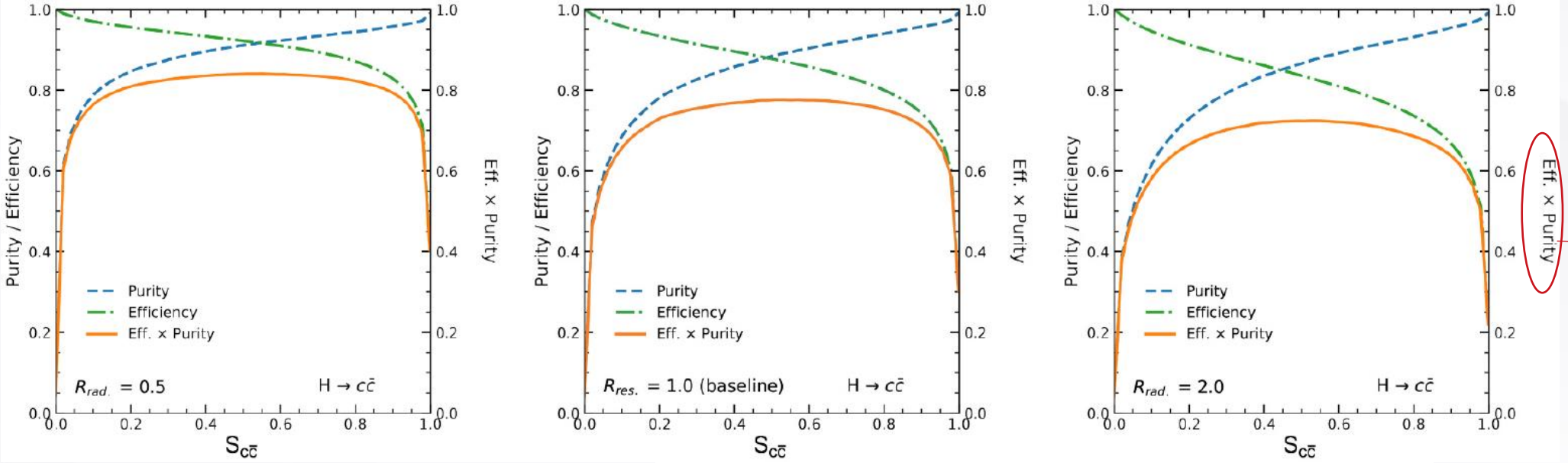


Trace of JOI vs. Geometry

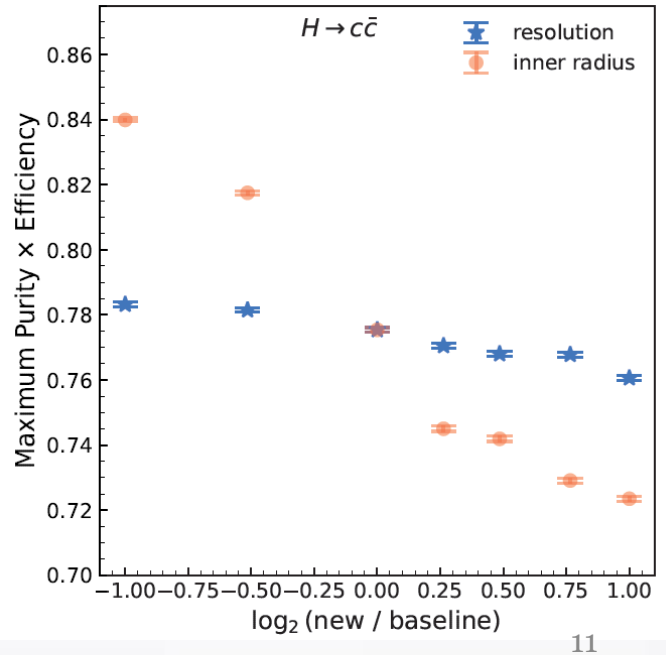
- Vertex resolution scan
  - 5.98 -0.05 * log2($\frac{new}{baseline}$)
- Inner-radius scan
  - 5.98 -0.27 * log2($\frac{new}{baseline}$)
- Sensitivity to $R_{rad.}$ is about **five times larger** than to $R_{res.}$, demonstrating that the JOI performance is dominantly controlled by the vertex *inner radius*.



Measurement of H-> $c\bar{c}$

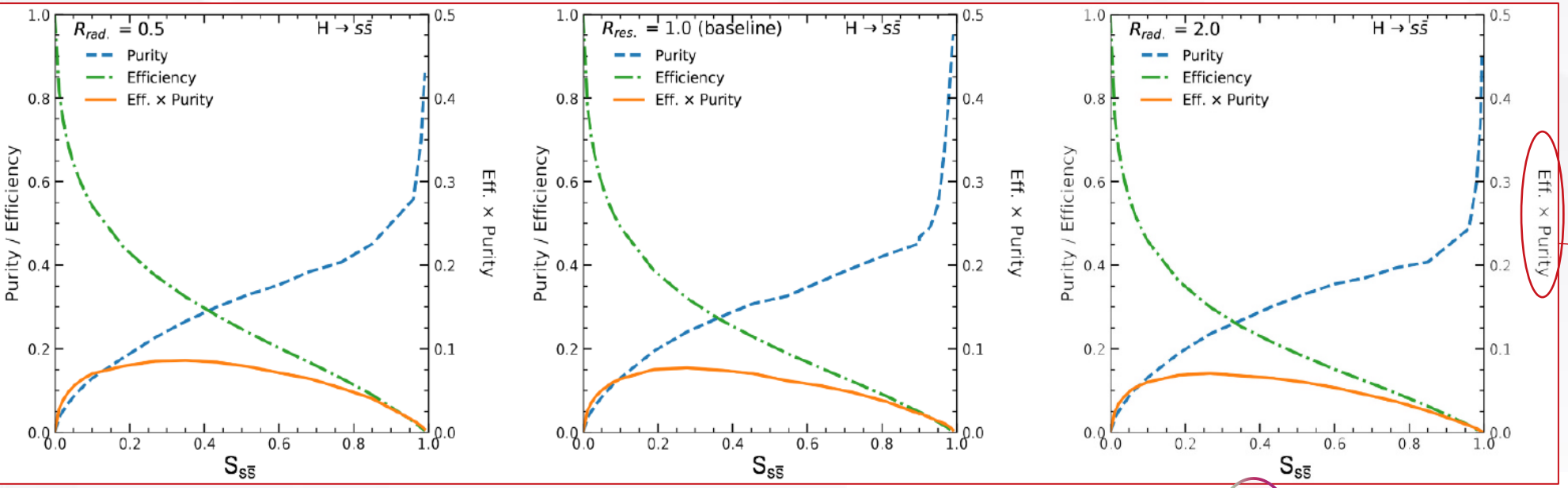


Configuration	$c\bar{c}\,(10^3)$	$b\bar{b}\,(10^3)$	$s\bar{s}$	$gg\,(10^3)$	Uncertainty(10^{-3})
baseline	24.4	1.26	11.0	1.92	6.81
$R_{\text{res}} = 0.5$	24.5	1.21	8.95	1.85	6.78
$R_{\text{res}} = 2$	24.0	1.21	12.9	1.99	6.88
$R_{\text{rad}} = 0.5$	25.6	0.75	5.54	1.75	6.55
$R_{\text{rad}} = 2$	23.2	1.54	1.61	2.04	7.05

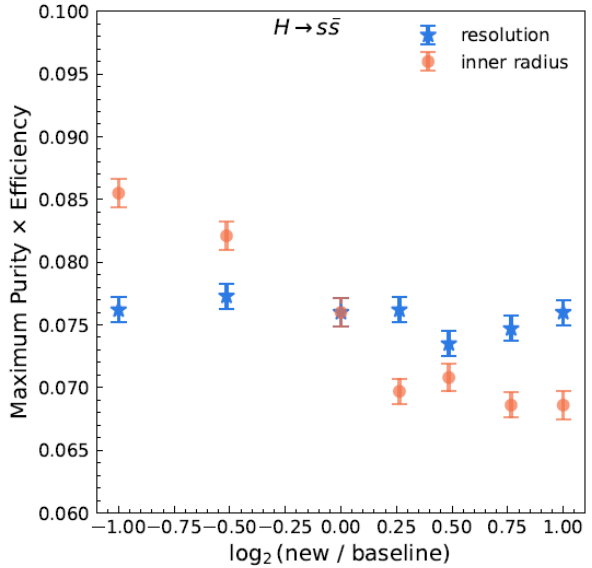


- Inner radius has a greater impact than spatial resolution.
- The best configuration improves the branching ratio uncertainty by **~3.8%**, while the worst worsens it by **~3.5%** compared to baseline.

Measurement of H-> $s\bar{s}$



Configuration	$s\bar{s}$	$b\bar{b}$	$c\bar{c}$	gg	Significance
baseline	70.9	0	10.0	224.6	$4.42\,\sigma$
$R_{\text{res}} = 0.5$	64.1	0	7.6	179.4	$4.45\,\sigma$
$R_{\text{res}} = 2$	64.4	0	10.3	181.4	$4.41\,\sigma$
$R_{\text{rad}} = 0.5$	70.2	0	6.2	189.4	$4.76\,\sigma$
$R_{\text{rad}} = 2$	64.8	0	11.5	203.2	$4.23\,\sigma$



- Backgrounds (especially gg) dominate
- Significance reaches 4.76σ with $R_{\text{rad.}}$=0.5
- The best configuration enhances the significance by **~7.7%**, while the worst reduces it by **~4.3%** relative to baseline.

VTX optimization conclusion

- Vertex detector parameters, especially inner radius, play a critical role in flavor tagging performance.
- For H→ $c\bar{c}$: Best setup improves branching ratio uncertainty by ~3.8%; Worst case worsens it by ~3.5%, compared to baseline.
- For H→ $s\bar{s}$: Best configuration yields ~7.7% gain in significance,Worst case results in ~4.3% loss.
- **4.76σ** for H→ $s\bar{s}$ brings CEPC closer to discovering this rare Higgs decay mode.

Summary & outlook

CEPC and Higgs flavour physics

- For a future CEPC Higgs factory we build a **JOI** framework that connects vertex-detector geometry to flavour-tagging performance and to the precision on $H \to c\bar{c}$ and $H \to s\bar{s}$.
- Optimised layouts, driven by a **small inner radius**, enable **percent-level** $H \to c\bar{c}$ and **evidence-level** $H \to s\bar{s}$,directly probing second-generation Yukawa couplings.

Future lepton colliders

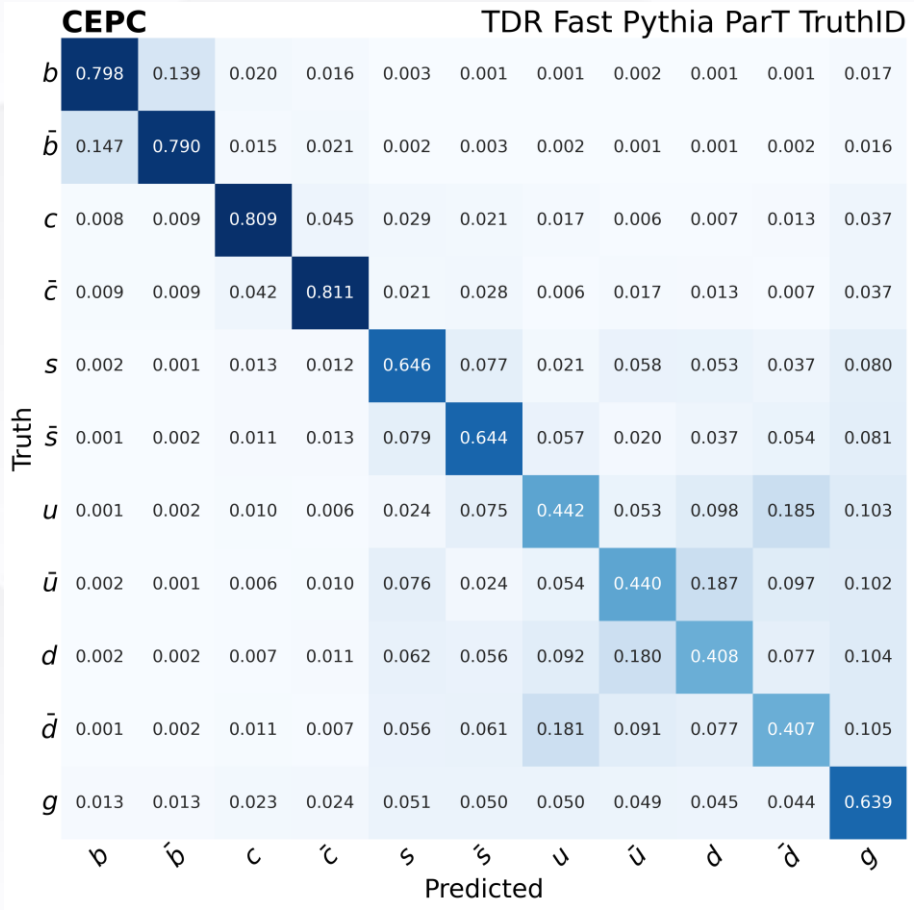
- Use clean e^+e^- Higgs factories with optimized vertex detectors and advanced analysis tools
- Reach percent-level precision on $H \to c\bar{c}$
- Push $H \to s\bar{s}$ close to observation
- Move toward a more complete picture of the Yukawa sector

Thanks for your listening!

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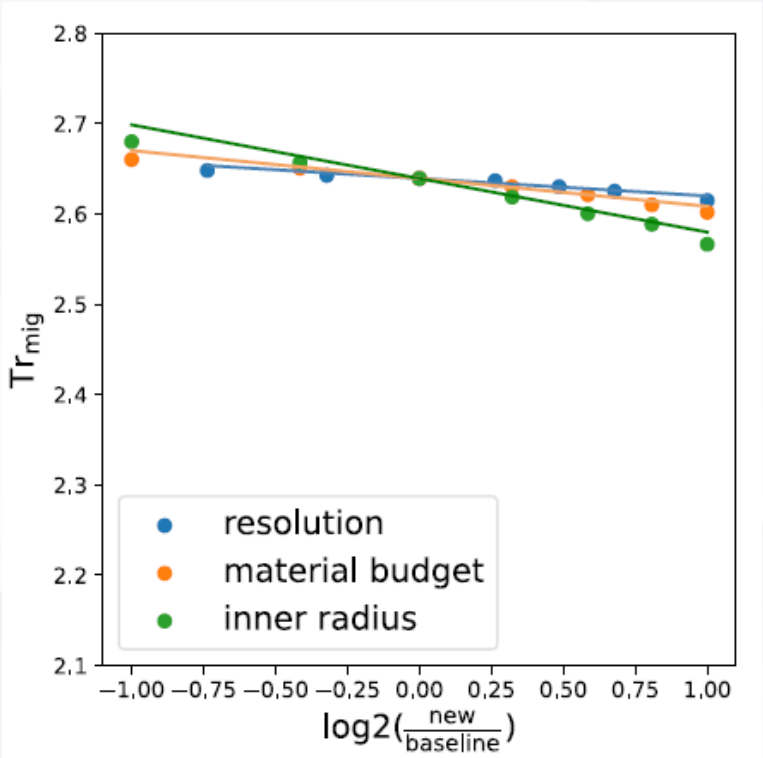
Best simu result

- Setup: TDR+Fast+P8+ParT
- Trace is 6.834
- 14% improvement vs. my baseline and 7% vs. my best result(0.5ir)



3*3 Full simu

$$\mathrm{Tr}_{mig} = 2.64 + 0.03 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{material}}}{\mathrm{R}_{\mathrm{material}}} + 0.02 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{resolution}}}{\mathrm{R}_{\mathrm{resolution}}} + 0.06 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{radius}}}{\mathrm{R}_{\mathrm{radius}}}$$



Simulation validation (Delphes vs. Geant4)

- **Impact-parameter resolution**

  Delphes tuned to Geant4 σ(d0) within ≲10% for $|\cos\theta| < 0.9$.

- **JOI performance (Geant4 vs. Delphes)**

  Similar confusion matrices and trace (≈6.8) → Fast and full simulation results are in good agreement.

