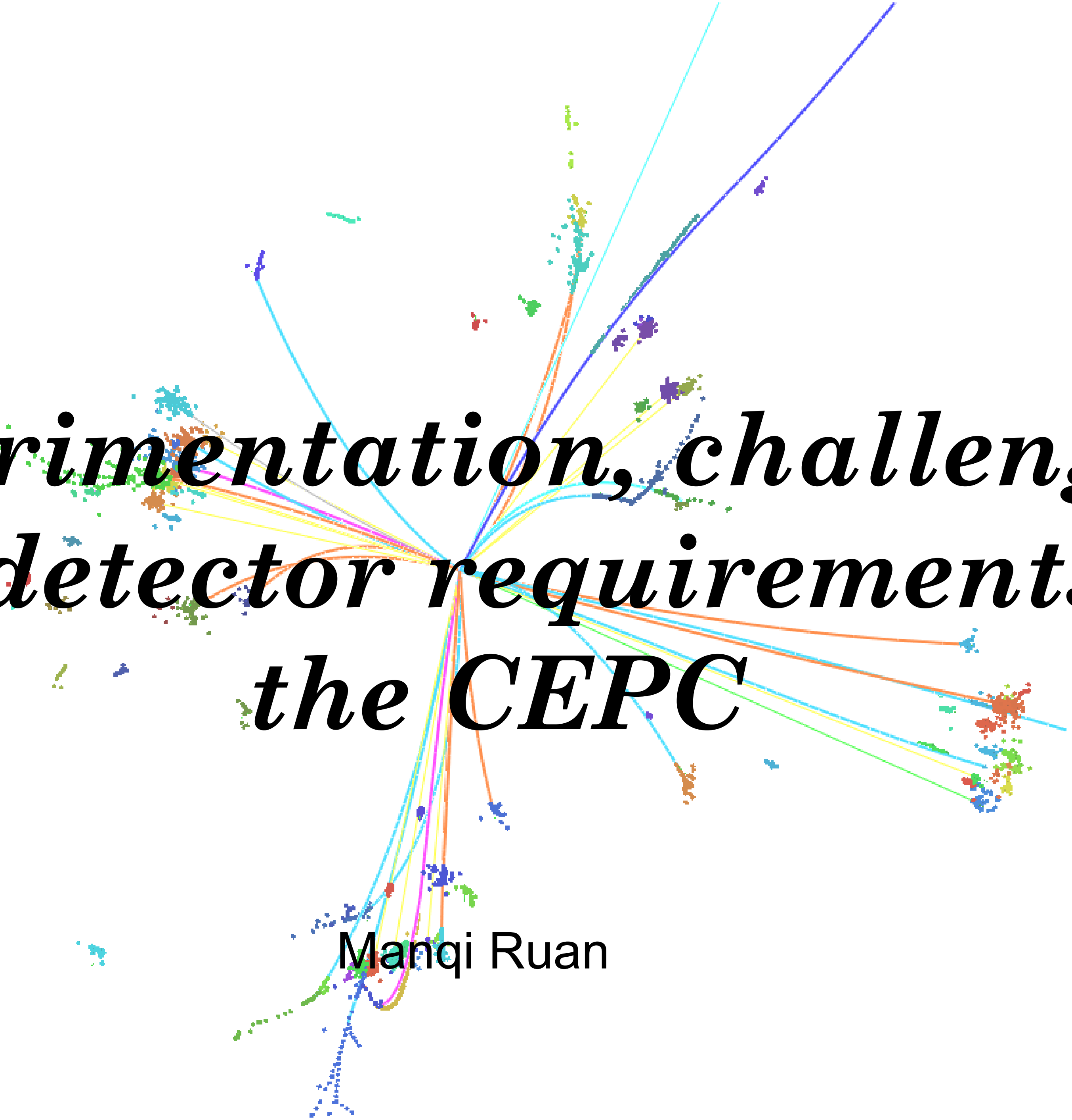
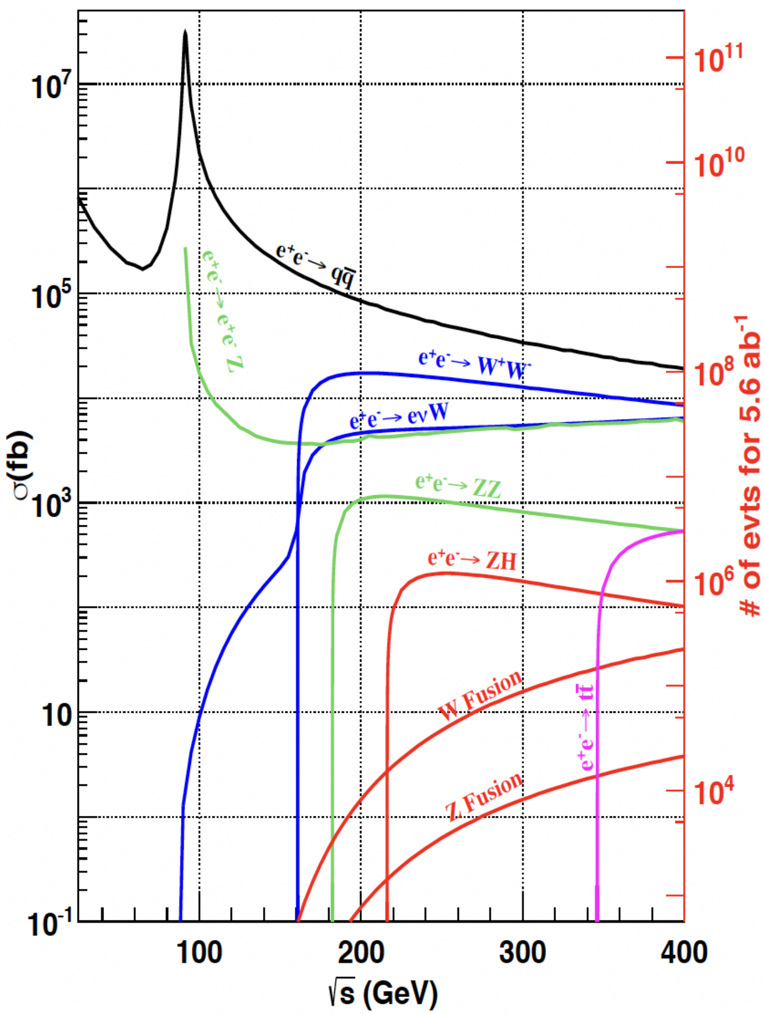
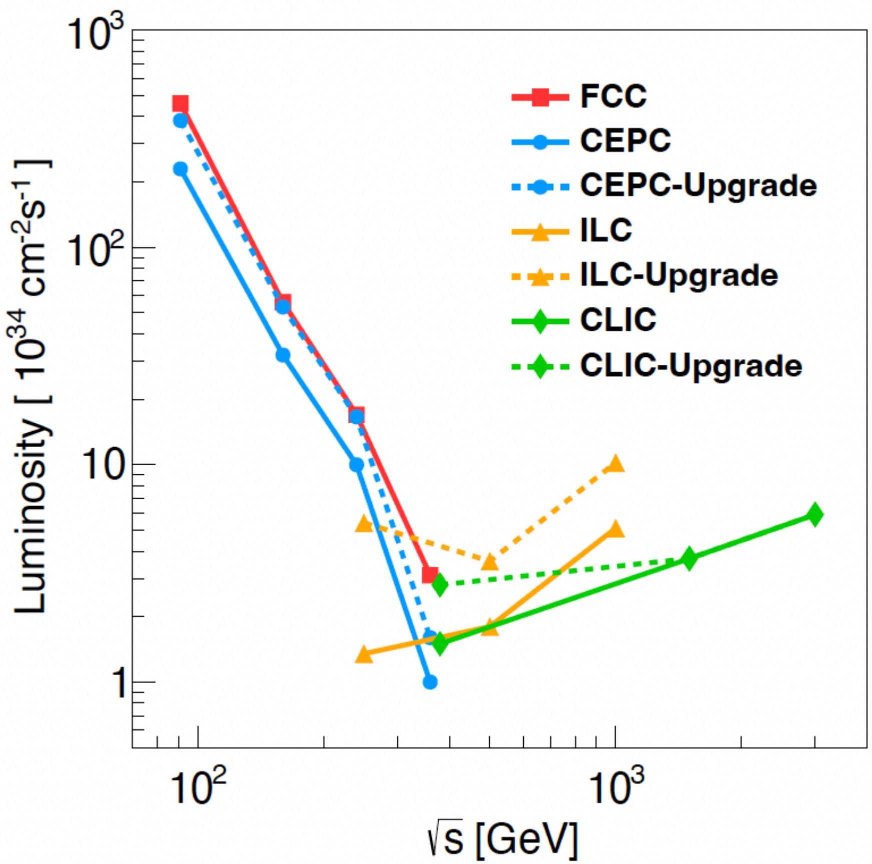


Experimentation, challenges, and detector requirements at the CEPC

Manqi Ruan

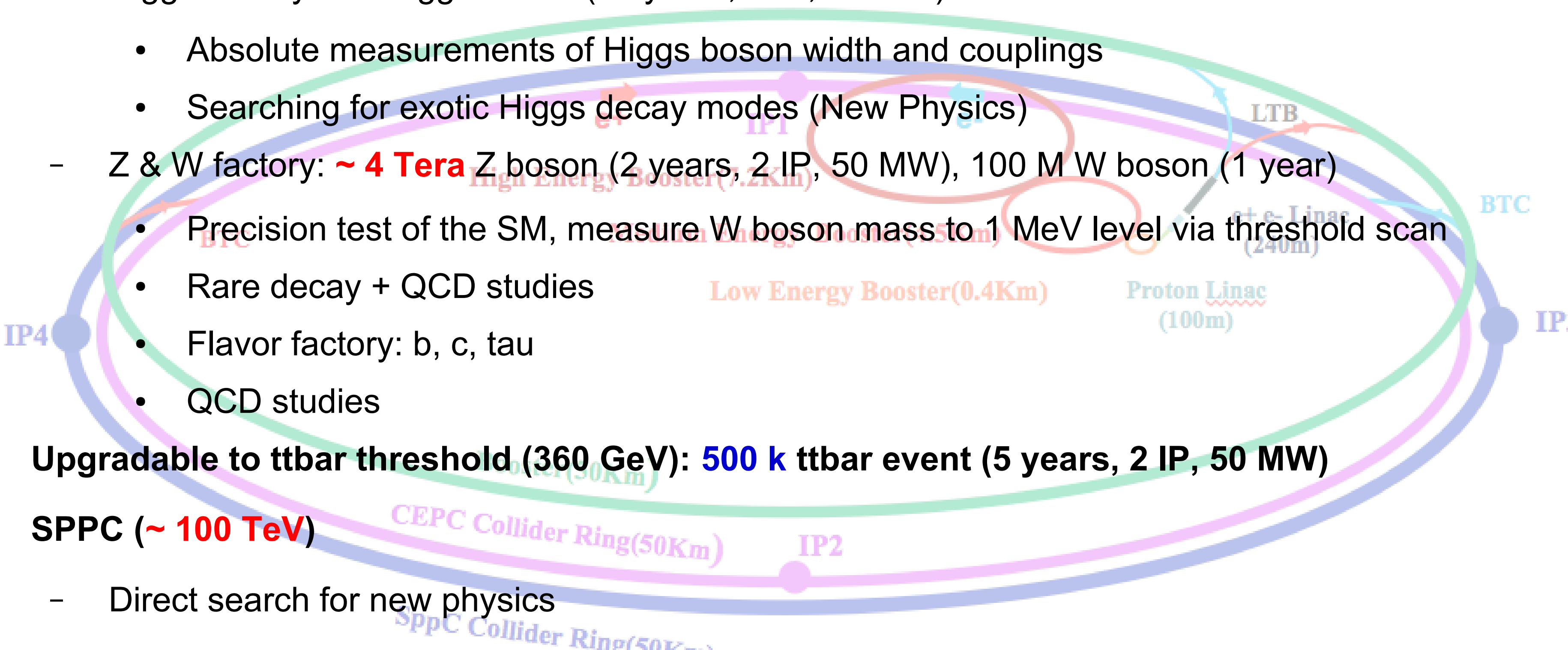
X sections & Luminosities





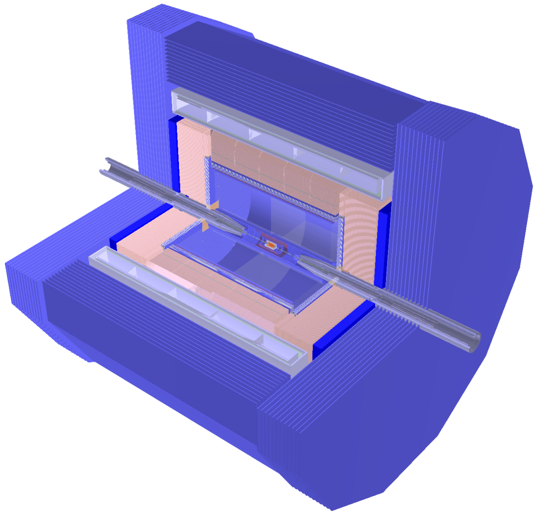
Yields of the CEPC

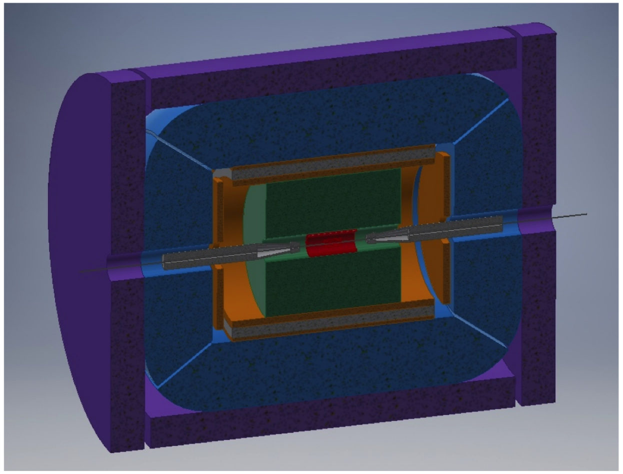
- **Tunnel ~ 100 km，** baseline SR Power/beam **30 MW**, upgradable to **50 MW**
- **CEPC (90 – 240 GeV)**
  - Higgs factory: **4M** Higgs boson (10 years, 2 IP, 50 MW)
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 4 Tera** Z boson (2 years, 2 IP, 50 MW), 100 M W boson (1 year)
    - Precision test of the SM, measure W boson mass to 1 MeV level via threshold scan
    - Rare decay + QCD studies
    - Flavor factory: b, c, tau
    - QCD studies
- **Upgradable to ttbar threshold (360 GeV): 500 k ttbar event (5 years, 2 IP, 50 MW)**
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

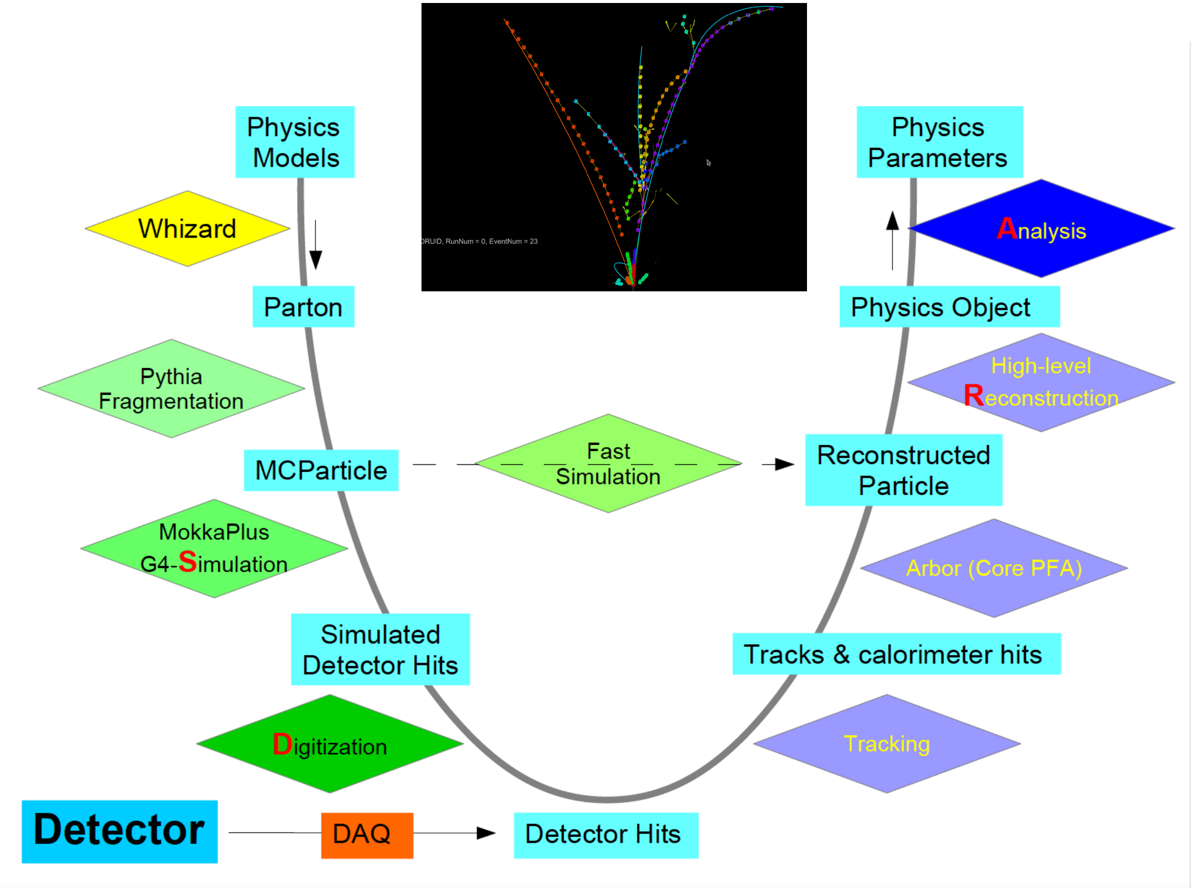


See also: 2205.08553

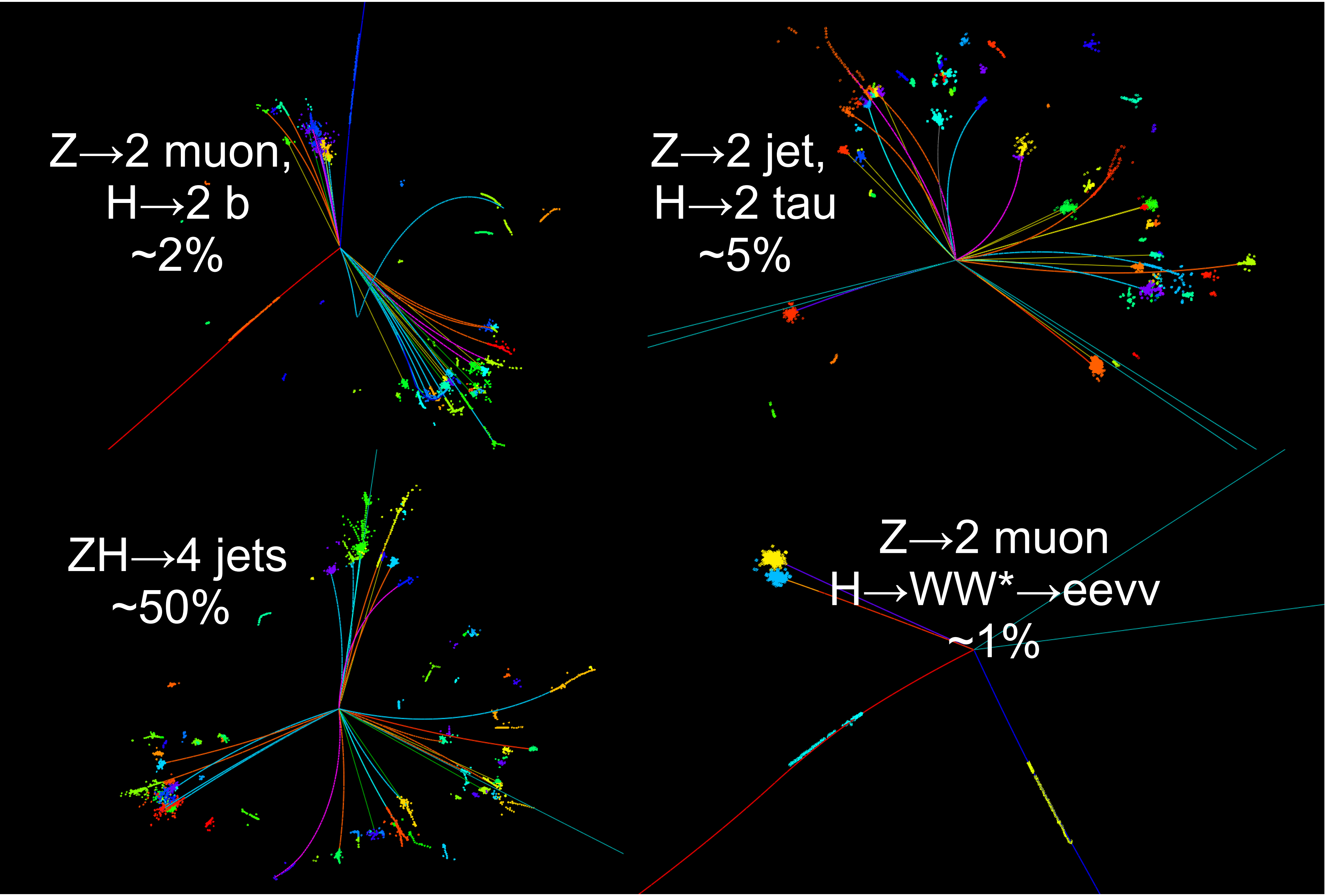
Detector & Software



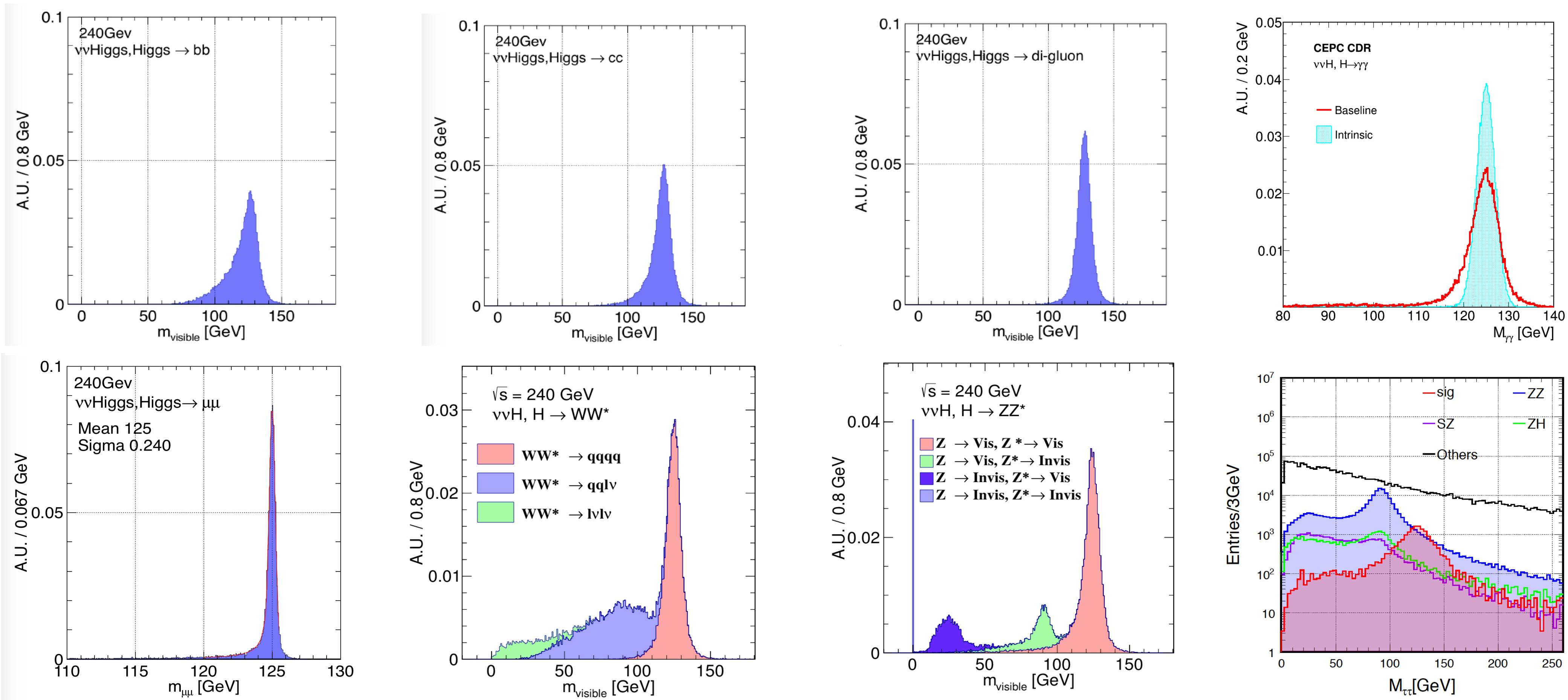




Full simulation reconstruction Chain with Arbor, iterating/validation with hardware studies


Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

Reconstructed Higgs Signatures



Clear Higgs Signature in all SM decay modes

Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

Right corner: di-tau mass distribution at qqH events using collinear approximation

Challenge: Collision/Event Rate

- Z→qq event rate higher than 100 k Hz.
- Collision rate: can be comparable to that of LHC.
  - 2.6 ms for ttbar operation
  - 385/154 ns for Higgs/WW scan
  - 15 ns for Z pole
- Compatibility of the sub-detectors: especially
  - Feasibility of the TPC:
    - Track distortion & correction induced by even the primary ionization
  - Power pulsing is difficult... more efficient cooling + optimization?
  - DAQ: Trigger-less mode, or at least software trigger (as LHCb upgrade)

Challenge: Beam condition

- Beam energy calibration
  - ~ 0.1 MeV at Z pole
  - ~ sub MeV at W threshold
  - ~ MeV at Higgs operation
  - ...with nature beam energy spread of ~ o(1E-3)

- Beam polarization monitoring
  - Transverse... (essential for the Resonance depolarization Method) and even longitudinal...

- Beam Luminosity Spectrum Monitoring, especially at top

Challenge: Forward region & MDI

- CEPC has very compact & difficult forward region design
  - Luminosity measurement requirement
    - At least 1E-4 for Z pole,
    - 1E-3 for W threshold scan, Higgs operation, and top runs
    - Micrometer level position stability & accuracy for Luminometer, et.al.
  - Very short L* (varies from 1.4 – 2 meter), but seems to be definitely installed inside the tracker volume
  - The beam background condition at the CEPC is yet to be quantified. While better flavor tagging performance strongly prefers small inner radius of the vertex system.

- Low material VTX system, with R_in as small as 20 mm, radiation hard...

Challenge: Solenoid

- To reach high luminosity at the Z pole operation, the B-Field of the main Solenoid shall not be higher than 2 Tesla
  - The beam X-angle (2*16.5 mrad) at the collision point induces correlations between the vertical & horizontal emittance..
  - Compared to 3 Tesla B-Field, 2 Tesla B-Field doubles the maximal Z pole luminosity

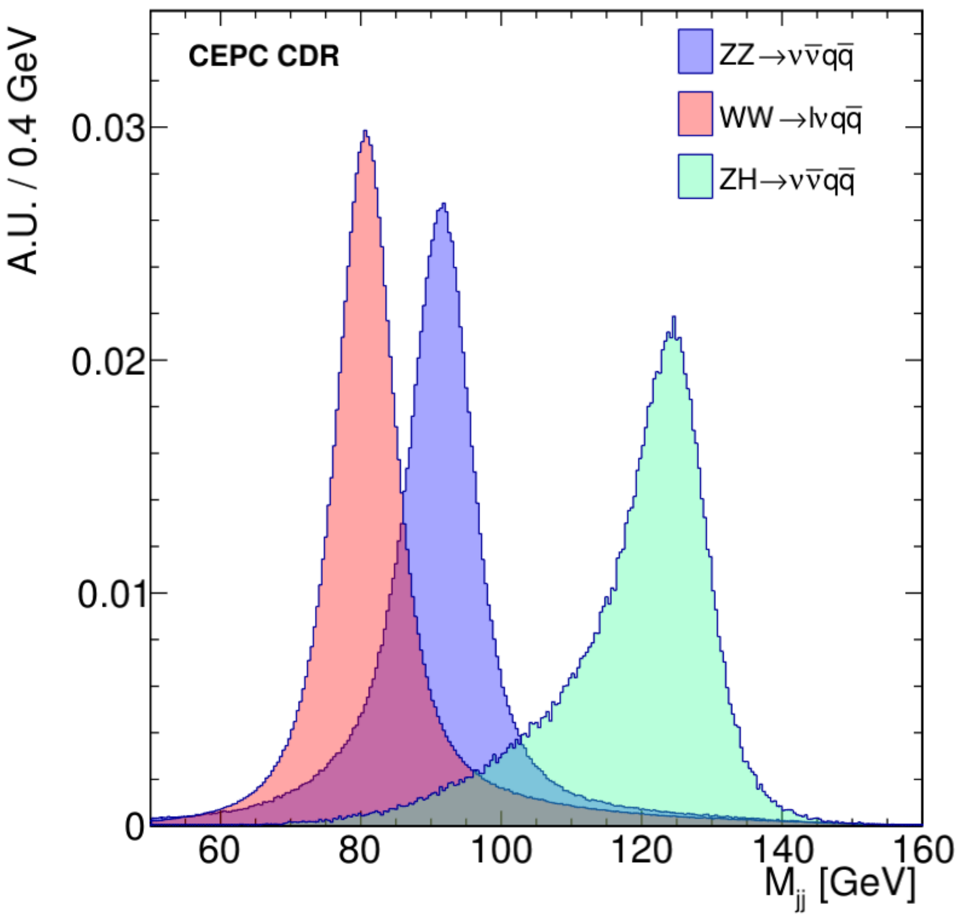
- However, a larger B-Field is strongly favored for Higher Energies.
  - Provide better momentum resolution, especially for the benchmark of Higgs to di-muon.
  - Constrains the beam background.

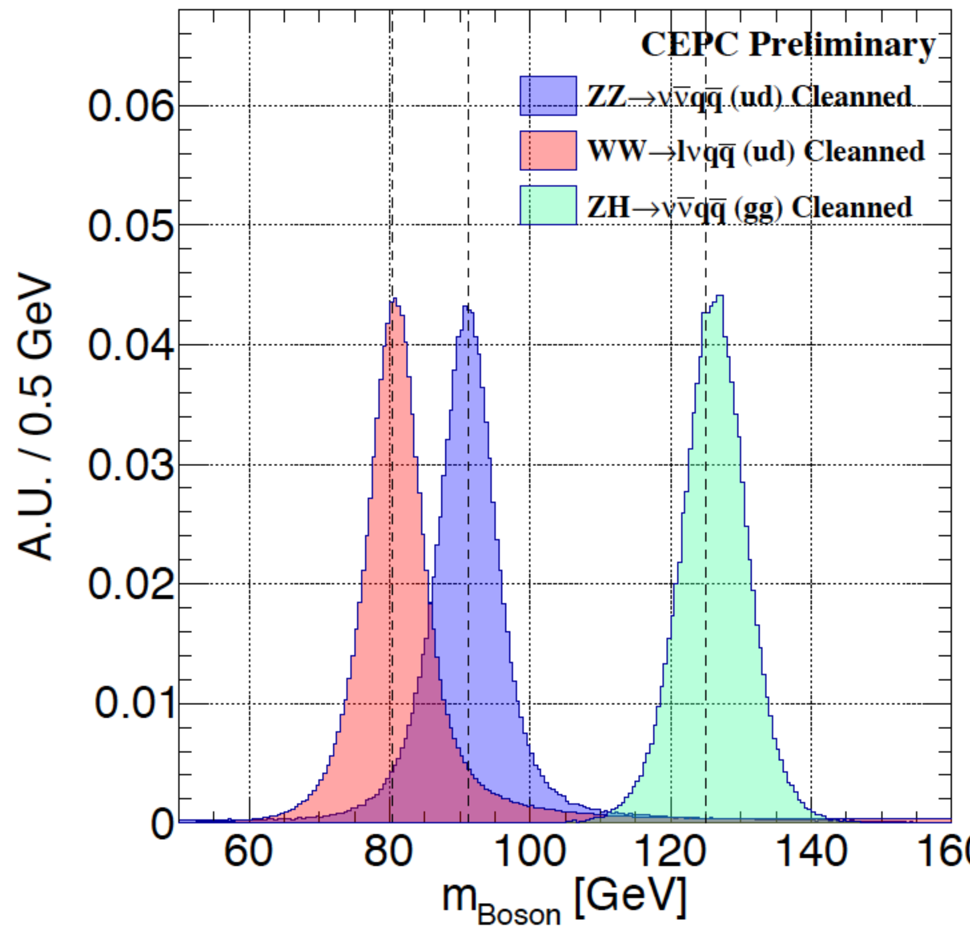
- Thus, a tunable Solenoid (2 to 3, or even higher) system, whose B-Field map can be monitored to a relative precision of 1E-4, and stable enough...

Performance requirements

- A clear separation of the final state particles: Identification of Physics Objects, and Improving the E/P resolution for composited objects, especially jets
  - Leptons, especially these inside jets
  - Composited objects:
    - Two/three body objects: Pi-0, K-short, Lambda, Phi, Tau, D meson...
    - More bodies: Tau & Jets
  - PFA: pursuing 1-1 correspondence...
- BMR (Boson Mass Resolution): mass resolution of Hadronic decayed Higgs/Z/W
  - < 4% for Higgs measurements
  - Much demanding for Flavor Physics/New Physics Hunting
- Pid: Pion & Kaon separation > 3 σ (eff*purity of Kaon at Key processes > 60%...)
- Jet: Flavor Tagging & Charge Reconstruction, Color Singlet identification...
- Intrinsic accuracies: momentum, energy, VTX positions...

Massive Boson Separation





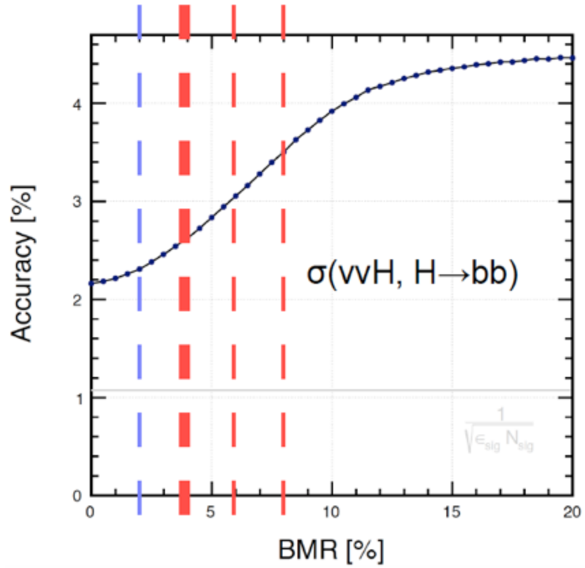
Peizhu Lai & CEPC CDR

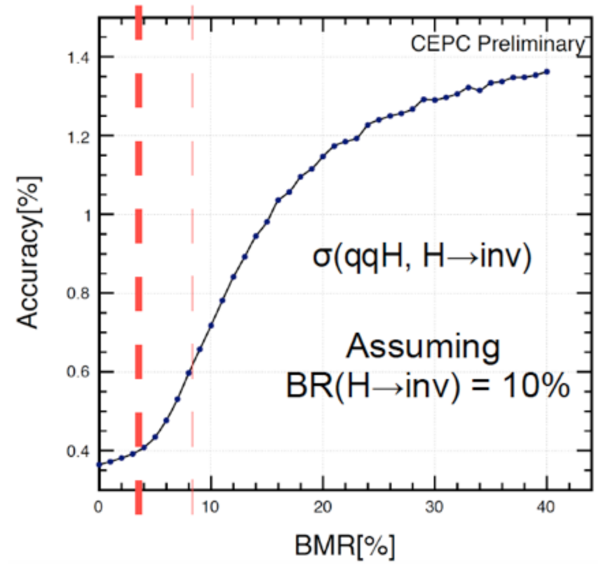
WW sample: using μvqq sample,
Plot: the visible mass without the muon

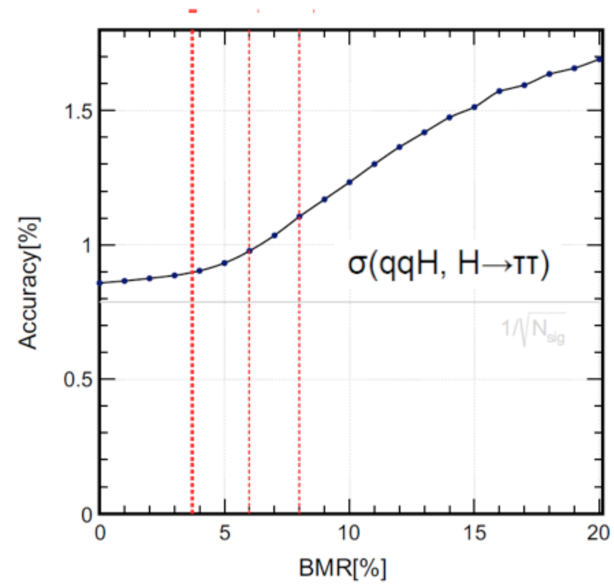
CEPC-RECO-2017-002 (DocDB id-164),
CEPC-RECO-2018-002 (DocDB id-171),

Eur. Phys. J. C (2018) 78: 426

BMR V.S. benchmark accuracy

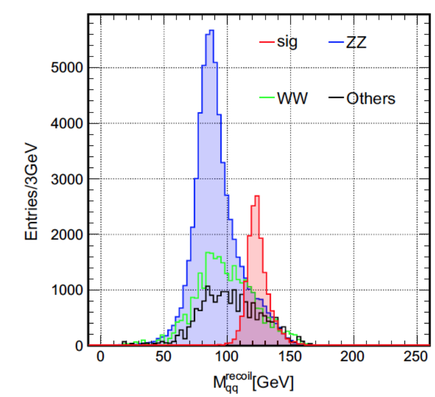




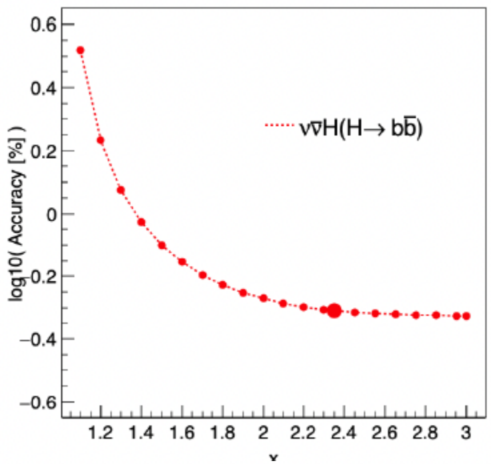


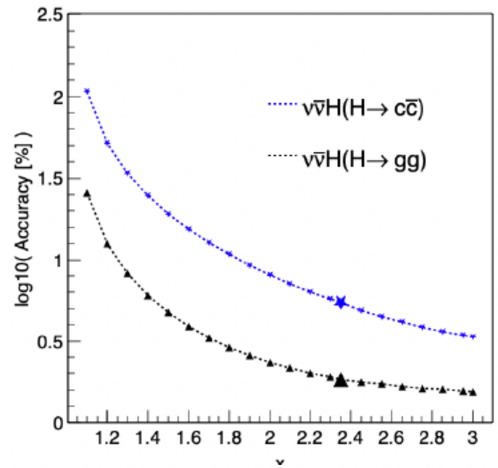
- Boson Mass Resolution: relative mass resolution of vvH, H→gg events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

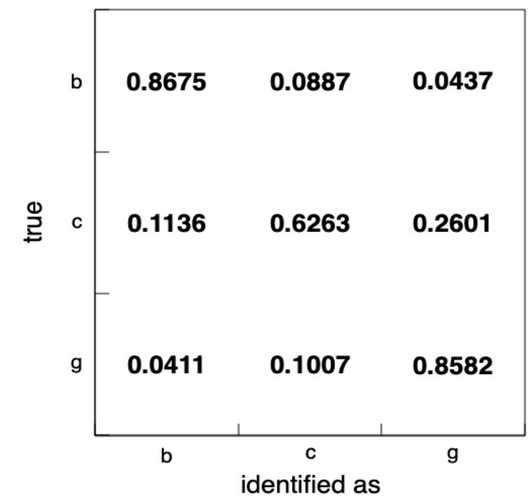
	BMR = 2%	4%	6%	8%
σ(vvH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(vvH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

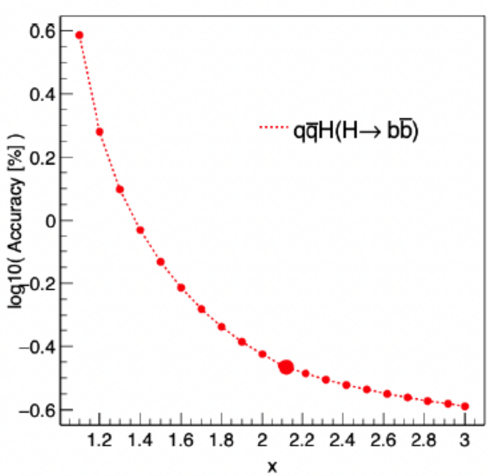


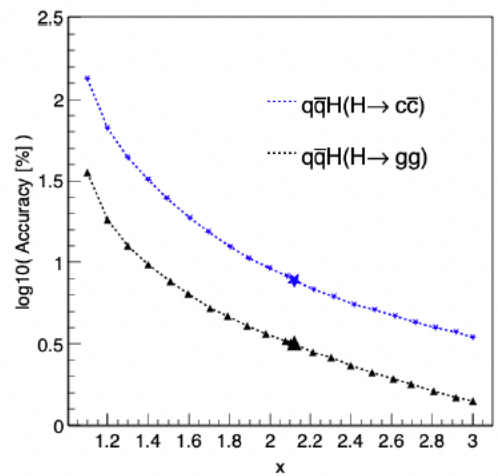
Jet Flavor Tagging for Higgs measurement

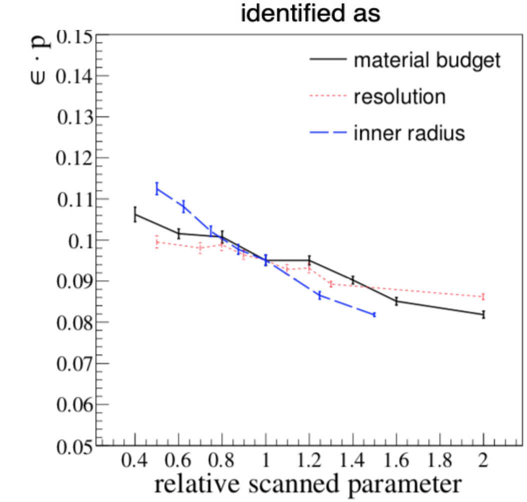








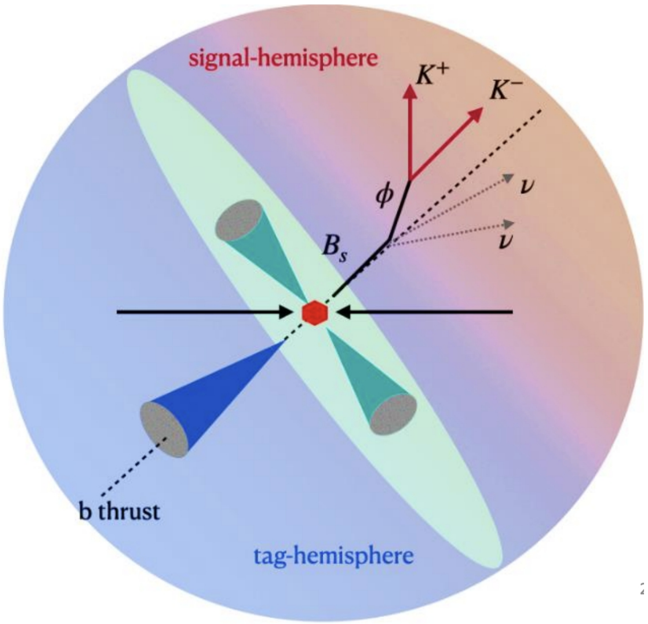


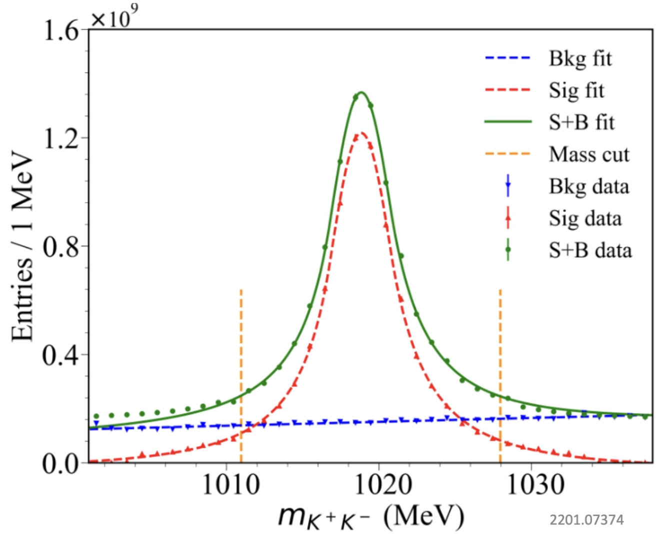


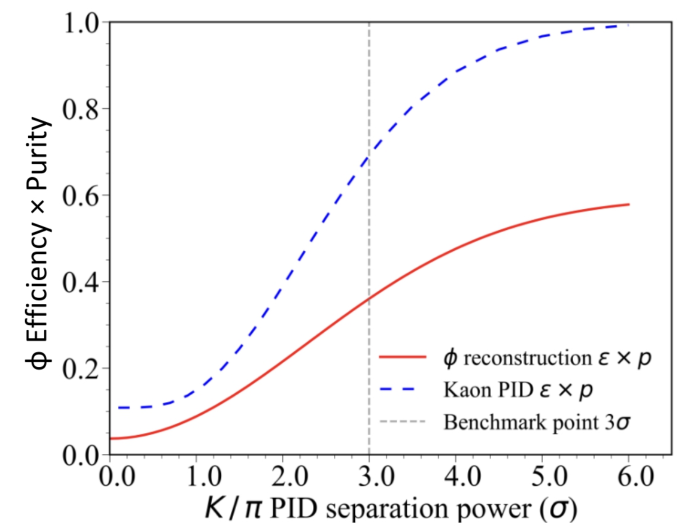
Compared to Baseline, Ideal Flavor Tagging improve the H→bb, cc, gg Measurements significantly, especially at qqH channel (up to 2 times).

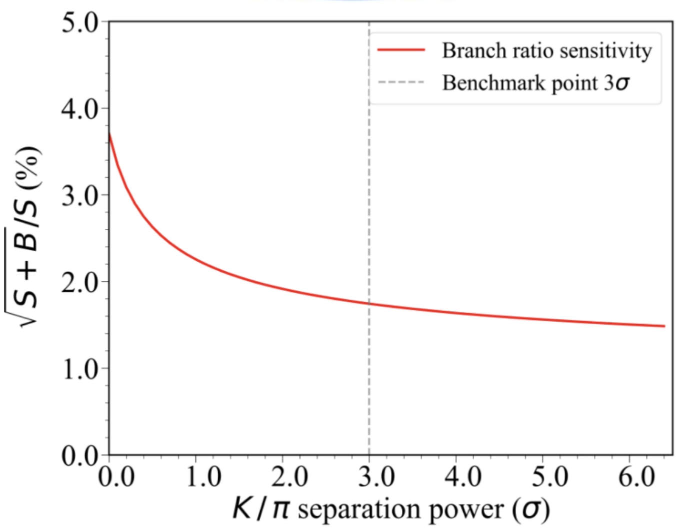
Flavor Tagging can be improved by VTX optimization (i.e., reduce VTX inner radius) & better algorithms...

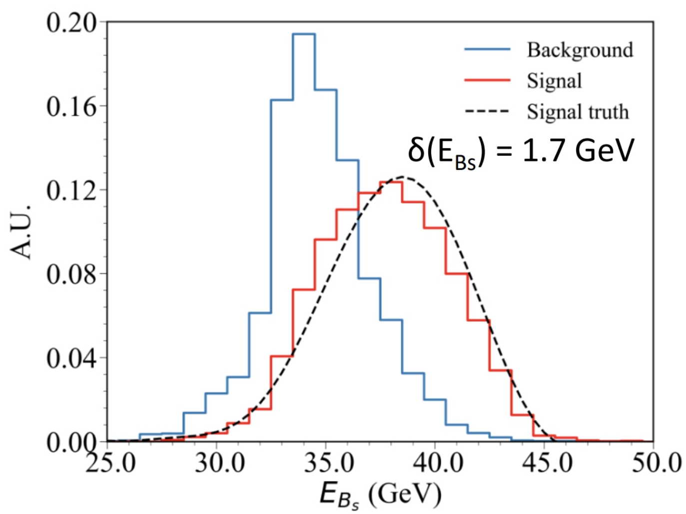
Bs→Phi vv

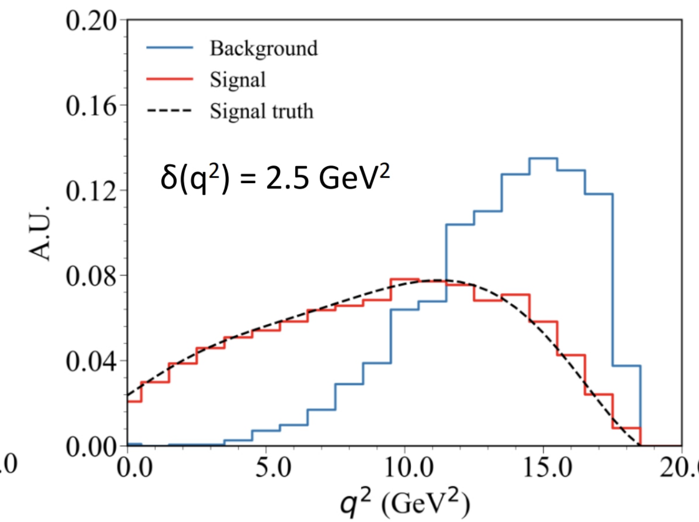






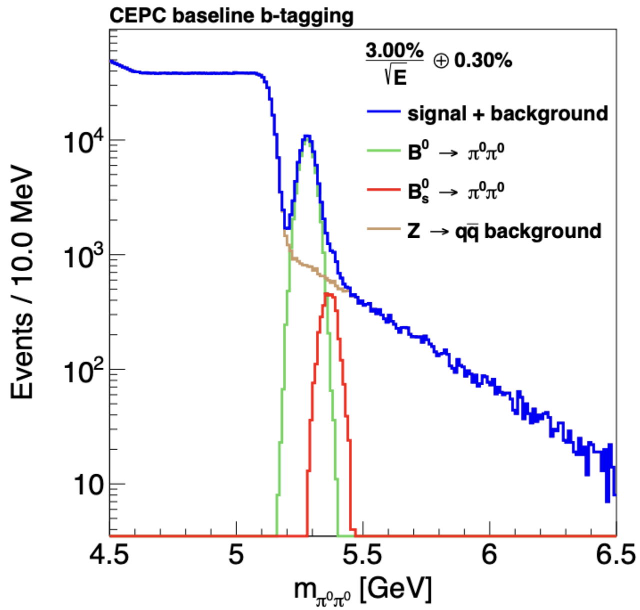


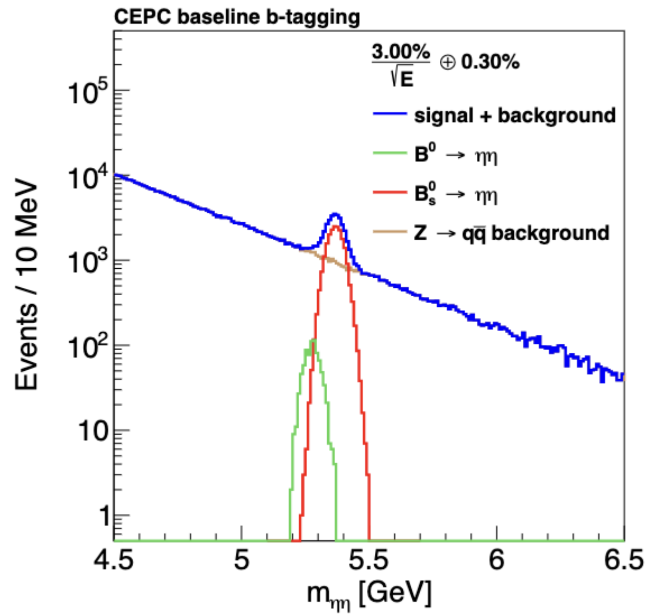


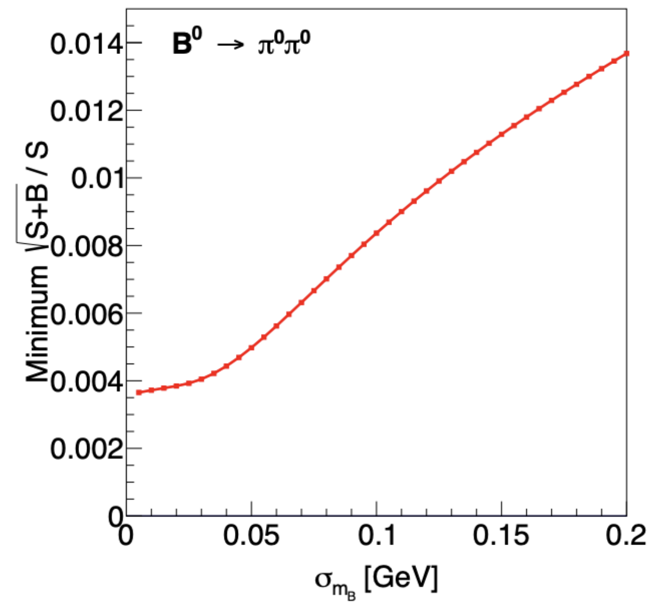


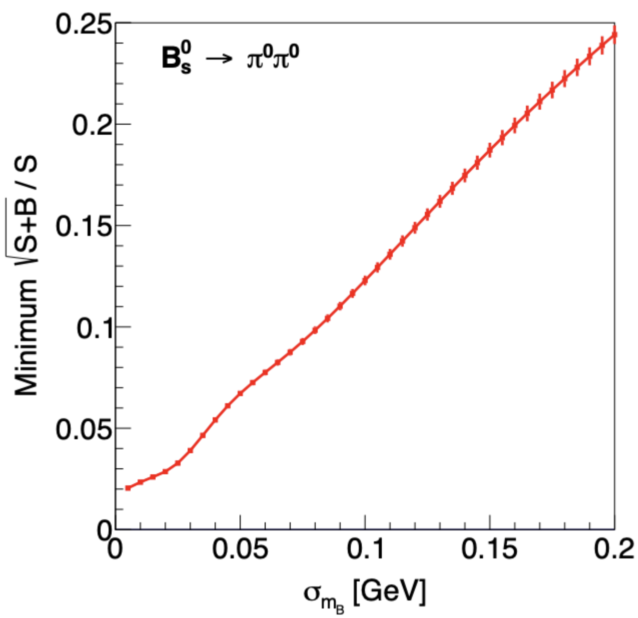
2201.07374

B0/Bs→2 π^0/η









ECAL energy resolution	Channel	σ_{m_B} (MeV)	Signal	$q\bar{q}$ background	Background with false $\pi^0(\eta)$	$\sqrt{S+B}/S$ (%)
$\frac{3\%}{\sqrt{E}} \oplus 0.3\%$	$B^0 \to \pi^0\pi^0$	30.25	75859	15767	7.52%	0.40 ± 0.01
	$B_s^0 \to \pi^0\pi^0$	30.21	2545	5145	14.73%	4.03 ± 0.55
	$B^0 \to \eta\eta$	33.30	693	11034	52.86%	17 ± 2
	$B_s^0 \to \eta\eta$	33.26	19208	10586	65.25%	0.90 ± 0.05
$\frac{17\%}{\sqrt{E}} \oplus 1\%$	$B^0 \to \pi^0\pi^0$	166	57746	381331	4.04%	1.15 ± 0.03
	$B_s^0 \to \pi^0\pi^0$	165	2243	142716	5.74%	19.3 ± 0.6
	$B^0 \to \eta\eta$	170	324	68243	88.27%	85 ± 6
	$B_s^0 \to \eta\eta$	174	8300	49248	86.30%	2.90 ± 0.20

- Combining other relevant measurements at CEPC, the alpha angle can be determined to ~ 0.5 degree (Preliminary)

Summary

- CEPC, a precision & upgradable Higgs/W/Z factory, and a Discover machine!
  - 4 M Higgs, 100 Million – 1 Billion W, 1 Million Top, and 3 Tera Z.
  - For Higgs precision measurements, secures the precisions ~ 1 order of magnitude better compared to HL-LHC
  - Boost the precision on EW, etc, by at 1-2 orders of magnitudes.
  - Lots of opportunities for flavor physics & significant comparative advantages.
  - Strong physics cases for BSM & QCD

    ...
- Lots of challenges
  - High Rate (collision/event)
  - Difficult MDI & Integration
  - Solenoid with changeable B-Fields
  - Beam monitoring/calibration: Energy, Luminosity Spectrum, Polarization
  - ...

Summary

- On the performance side
  - Separation capability is critical, Especially for the flavor measurement at Z pole, where critical physics objects need to be identified inside jets.
  - BMR shall be at least 4%!
  - Improving the Jet Flavor Tagging has a significant impact on critical Higgs measurements.
  - Jet Charge measurement is a strong comparative advantages of Tera-Z
  - Good Pid is mandatory: pion-kaon separation shall be larger than 3-sigma
  - Better ECAL, Better tracking is always appreciated... especially for flavor measurements
  - ...
- Lots of R&D activities, including design of new detector concept, is on going.

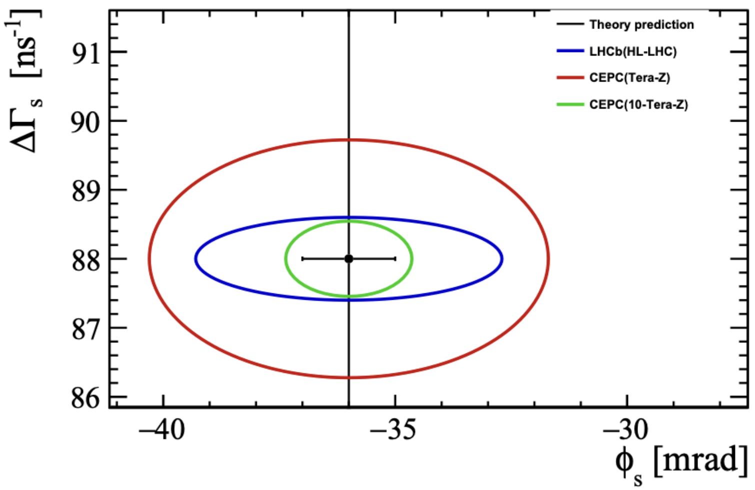
Back up

CP measurement with Bs→J/psi Phi

$\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H, \phi_s = -2\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$

SM: small CPV phase ϕ_s

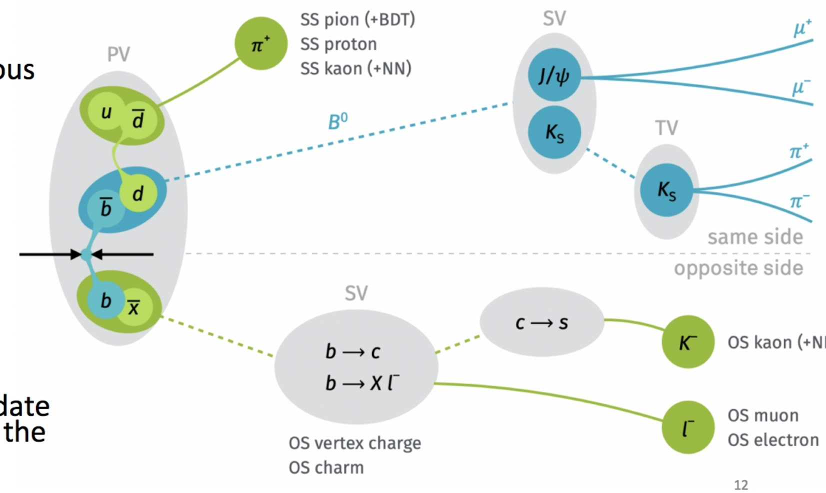
Contributions from physics beyond the SM could lead to much larger values of ϕ_s.

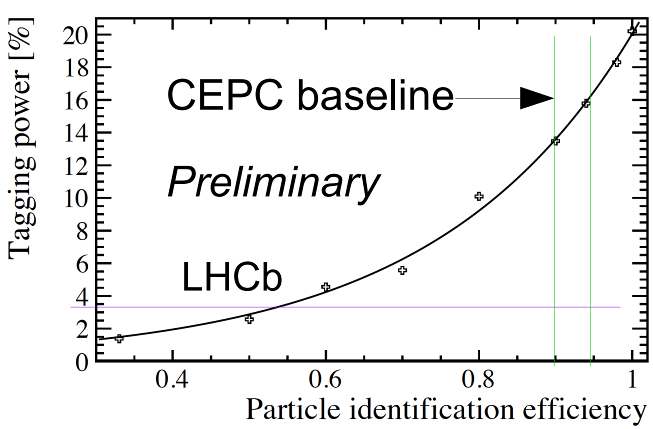


Flavour tagging power

- LHCb: 3~4%
- CEPC: 15% (Previous estimation)
- B factory: ~30%

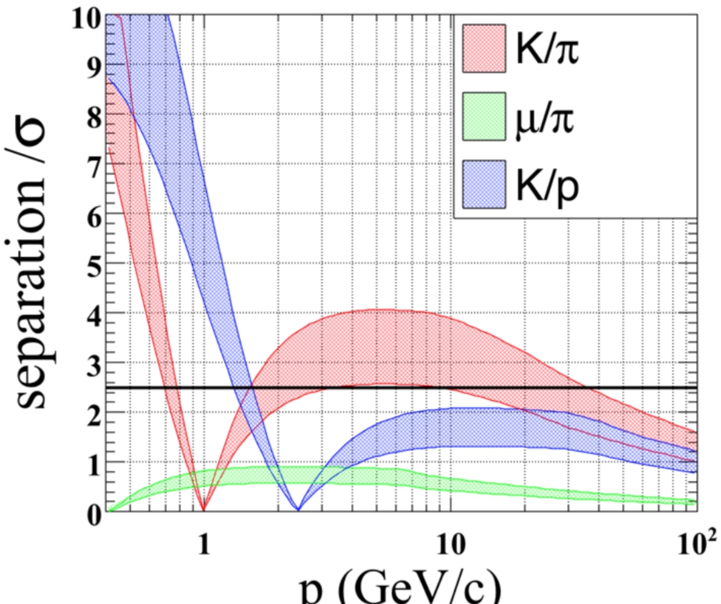
- For Bs:
  - OS lepton
  - OS kaon
  - SS kaon
- A naïve algorithm developed to validate the robustness of the estimation

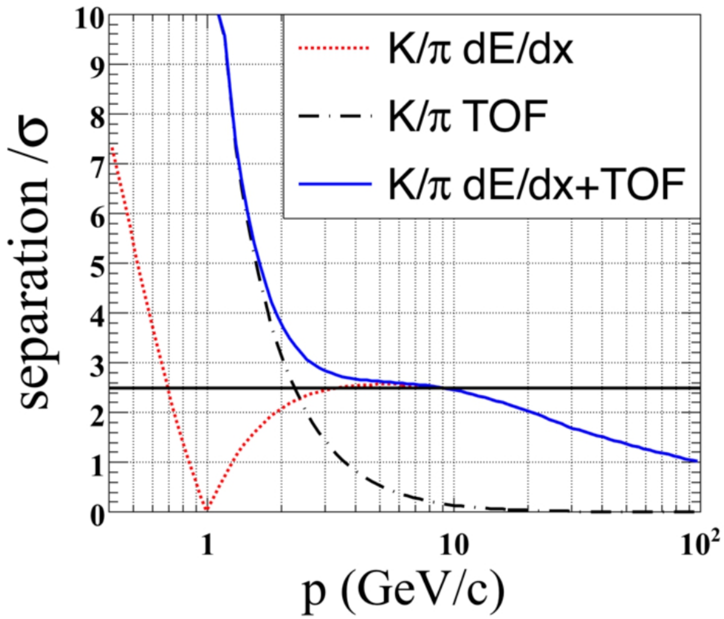


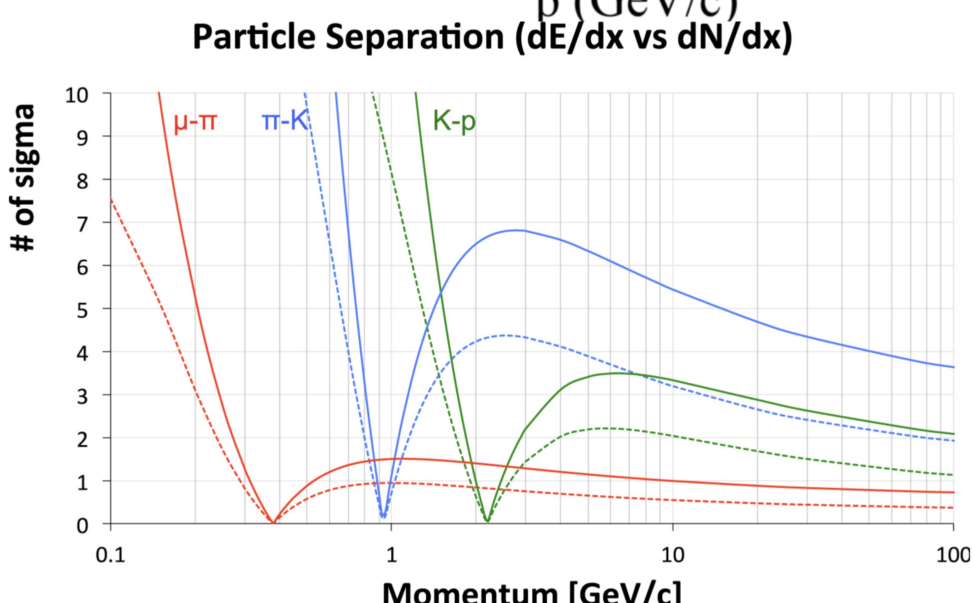


- With a decent Pid, the effective tagging power on jet Charge can be 5-6 times better than LHCb, which can compensate the statistic difference between LHCb & CEPC.
- Strong motivation to higher Luminosity at Z pole

Kaon identification: dE/dx or dN/dx + ToF







	factor	1.	1.2	1.5	2.
dE/dx	ε_K (%)	95.95	94.09	91.08	86.86
	$purity_K$ (%)	81.76	78.17	71.64	60.92
dE/dx & TOF	ε_K (%)	98.42	97.41	95.48	92.14
	$purity_K$ (%)	97.88	96.31	93.18	87.19

CEPC-DocDB-id: 172
https://arxiv.org/abs/1803.05134
Eur. Phys. J. C (2018) 78:464