# Discussion of PID for Full Silicon Tracker Option

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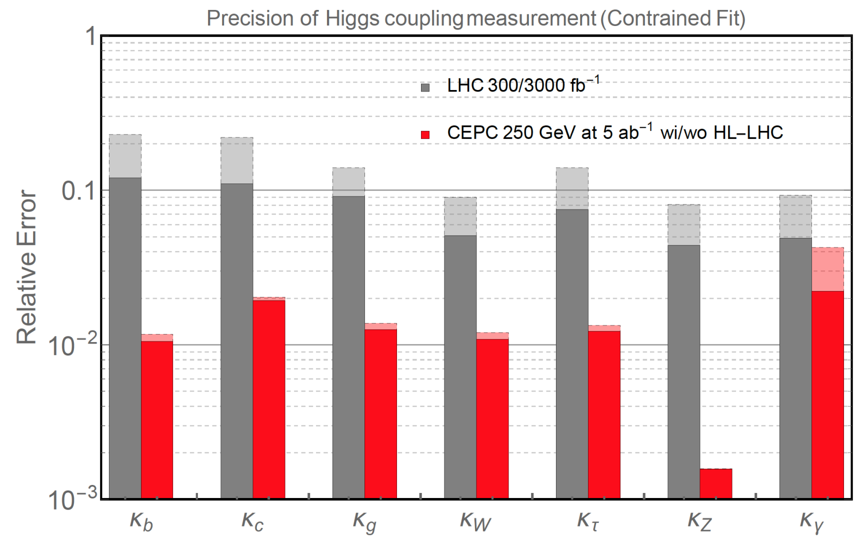
**Mini-workshop on Tracking, Jan 17, 2019**

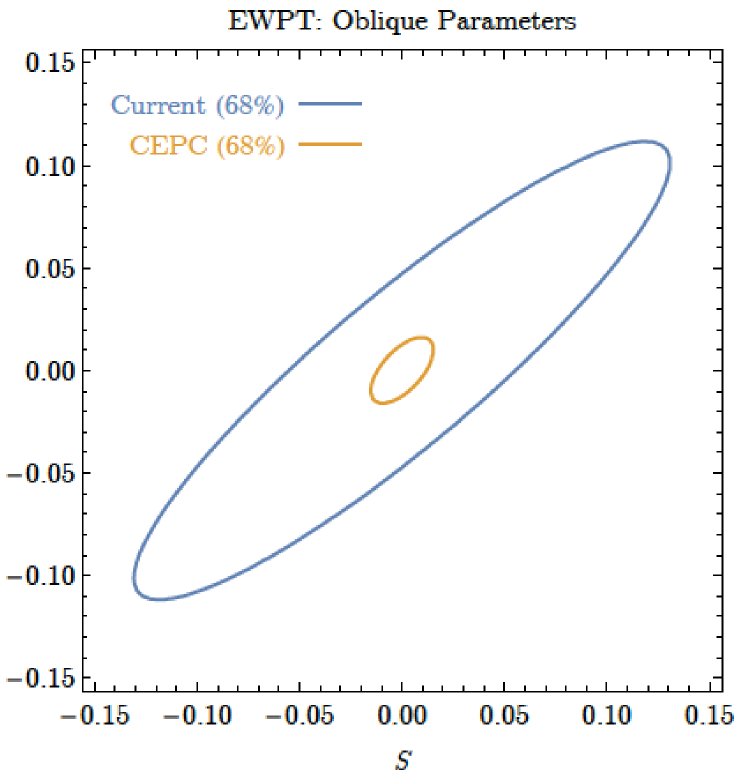
# Outline

- Introduction
- Case studies for PID at future circular e+e- colliders
- PID options
  - Fast timing silicon LGAD
  - RICH
- Conclusion

# Physics Cases

- Measuring Higgs coupling expected at or below 1% level via HZ.
- Constraining BSM physics with precision EW data and heavy flavor physics.

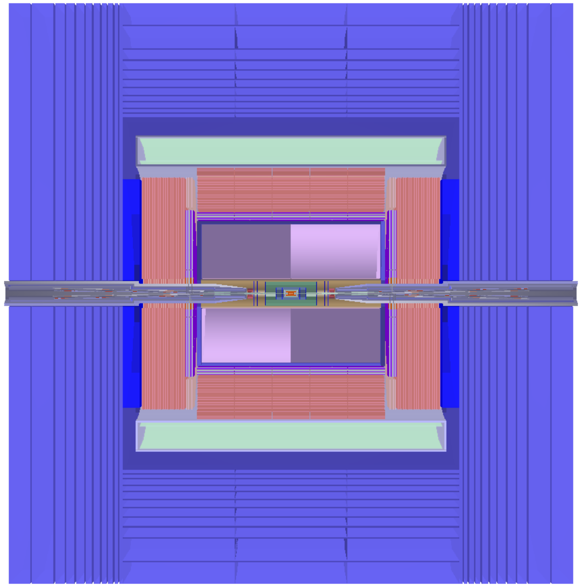


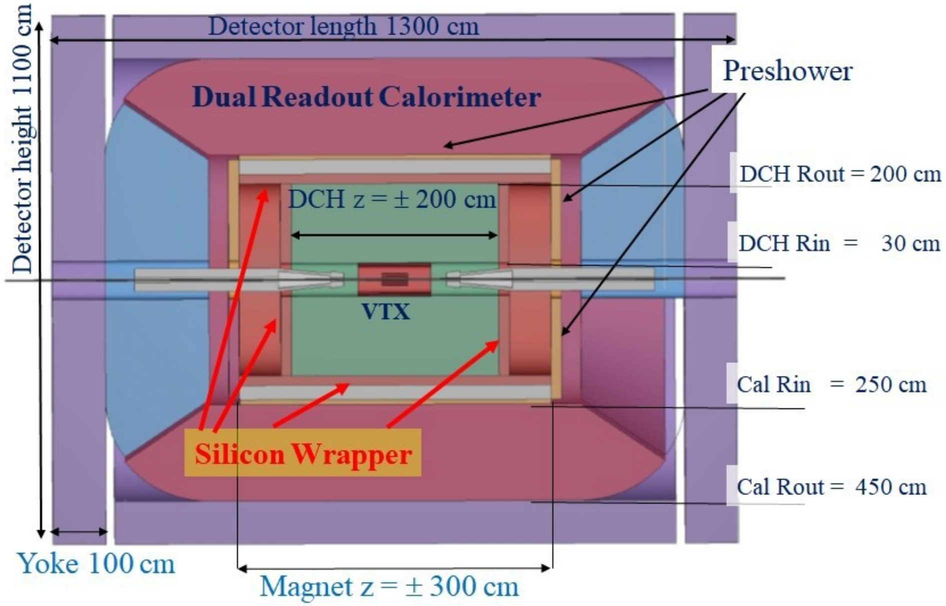



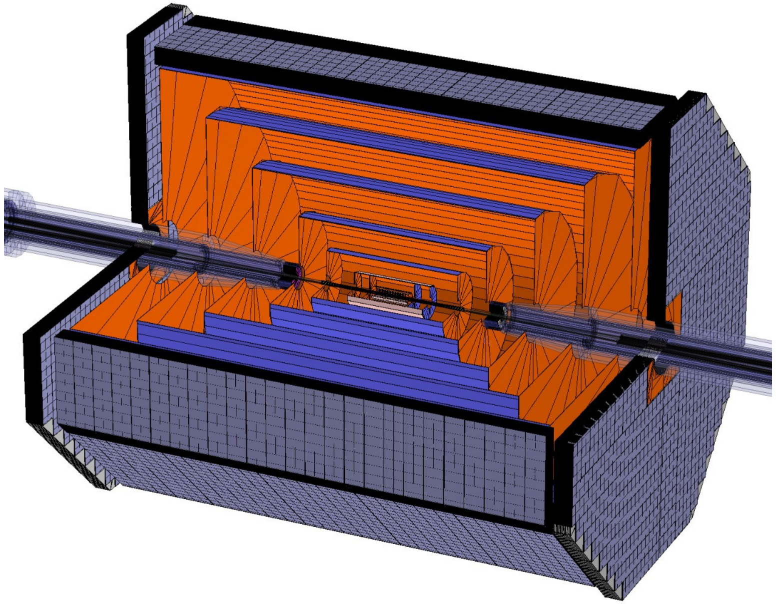

| Observable | Current sensitivity | Future sensitivity | Tera-$Z$ sensitivity |
|---|---|---|---|
| $\mathrm{BR}(B_s \to ee)$ | $2.8 \times 10^{-7}$ (CDF) [438] | $\sim 7 \times 10^{-10}$ (LHCb) [435] | $\sim$ few $\times 10^{-10}$ |
| $\mathrm{BR}(B_s \to \mu\mu)$ | $0.7 \times 10^{-9}$ (LHCb) [437] | $\sim 1.6 \times 10^{-10}$ (LHCb) [435] | $\sim$ few $\times 10^{-10}$ |
| $\mathrm{BR}(B_s \to \tau\tau)$ | $5.2 \times 10^{-3}$ (LHCb) [441] | $\sim 5 \times 10^{-4}$ (LHCb) [435] | $\sim 10^{-5}$ |
| $R_K, R_{K^*}$ | $\sim 10\%$ (LHCb) [443, 444] | $\sim$few% (LHCb/Belle II) [435, 442] | $\sim$few % |
| $\mathrm{BR}(B \to K^*\tau\tau)$ | – | $\sim 10^{-5}$ (Belle II) [442] | $\sim 10^{-8}$ |
| $\mathrm{BR}(B \to K^*\nu\nu)$ | $4.0 \times 10^{-5}$ (Belle) [449] | $\sim 10^{-6}$ (Belle II) [442] | $\sim 10^{-6}$ |
| $\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$ | $1.0 \times 10^{-3}$ (LEP) [452] | – | $\sim 10^{-6}$ |
| $\mathrm{BR}(\Lambda_b \to \Lambda\nu\bar{\nu})$ | – | – | $\sim 10^{-6}$ |
| $\mathrm{BR}(\tau \to \mu\gamma)$ | $4.4 \times 10^{-8}$ (BaBar) [475] | $\sim 10^{-9}$ (Belle II) [442] | $\sim 10^{-9}$ |
| $\mathrm{BR}(\tau \to 3\mu)$ | $2.1 \times 10^{-8}$ (Belle) [476] | $\sim$ few $\times 10^{-10}$ (Belle II) [442] | $\sim$ few $\times 10^{-10}$ |
| $\frac{\mathrm{BR}(\tau\to\mu\nu\bar{\nu})}{\mathrm{BR}(\tau\to e\nu\bar{\nu})}$ | $3.9 \times 10^{-3}$ (BaBar) [464] | $\sim 10^{-3}$ (Belle II) [442] | $\sim 10^{-4}$ |
| $\mathrm{BR}(Z \to \mu e)$ | $7.5 \times 10^{-7}$ (ATLAS) [471] | $\sim 10^{-8}$ (ATLAS/CMS) | $\sim 10^{-9} - 10^{-11}$ |
| $\mathrm{BR}(Z \to \tau e)$ | $9.8 \times 10^{-6}$ (LEP) [469] | $\sim 10^{-6}$ (ATLAS/CMS) | $\sim 10^{-8} - 10^{-11}$ |
| $\mathrm{BR}(Z \to \tau\mu)$ | $1.2 \times 10^{-5}$ (LEP) [470] | $\sim 10^{-6}$ (ATLAS/CMS) | $\sim 10^{-8} - 10^{-10}$ |

# Three Detector Concepts (CDR)

- Baseline: Silicon + TPC
- FST: all-silicon tracker
- IDEA: Silicon+Drift chamber(DCH)





# Detector requirements

- Each detector concept are driven by Higgs physics requirements.
- Additional requirements at WW and Z-pole are not fully explored yet:
  - Particle identification and jet-flavor tagging using kaon.

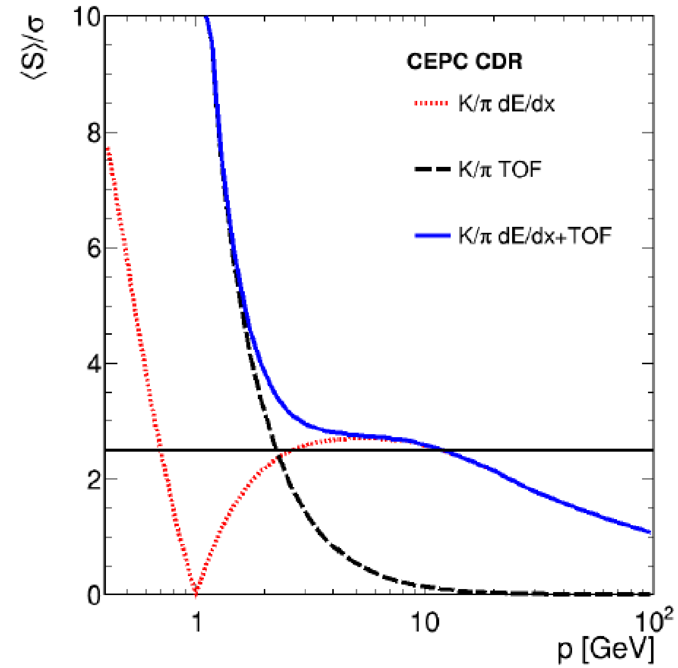
| Physics process | Measurands | Detector subsystem | Performance requirement |
|---|---|---|---|
| $ZH, Z \to e^+e^-, \mu^+\mu^-$<br>$H \to \mu^+\mu^-$ | $m_H, \sigma(ZH)$<br>$\mathrm{BR}(H \to \mu^+\mu^-)$ | Tracker | $\Delta(1/p_T) =$<br>$2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$ |
| $H \to b\bar{b}/c\bar{c}/gg$ | $\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$ | Vertex | $\sigma_{r\phi} =$<br>$5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$ |
| $H \to q\bar{q}, WW^*, ZZ^*$ | $\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$ | ECAL<br>HCAL | $\sigma_E^{\mathrm{jet}}/E =$<br>$3 \sim 4\%$ at 100 GeV |
| $H \to \gamma\gamma$ | $\mathrm{BR}(H \to \gamma\gamma)$ | ECAL | $\Delta E/E =$<br>$\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$ |

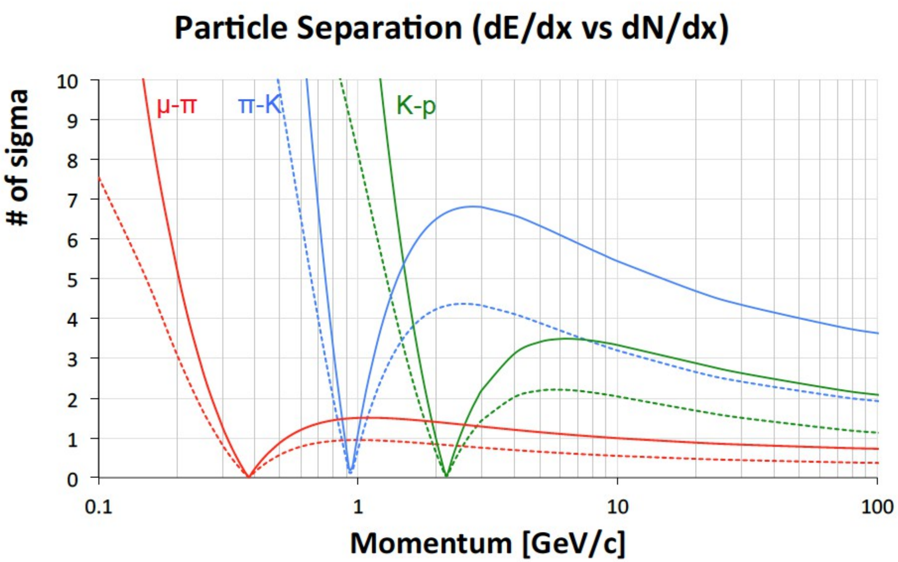
# Particle Identification (PID)

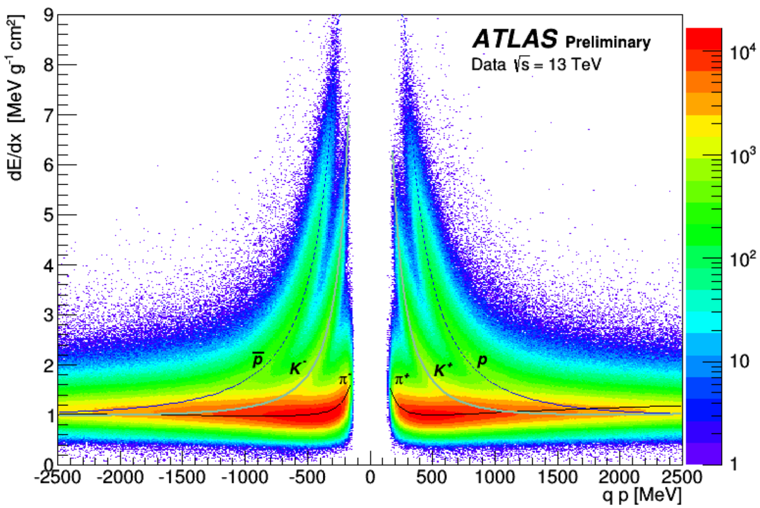
- Particle identification plays a key role in Heavy Flavour physics, but its impact on the Higgs physics is not fully explored yet.
- Detectors must work at three different energies to minimize downtime:
  - at Z-pole (91 GeV)
  - at WW (160 GeV)
  - at Higgs factory (240 GeV)
- FST with limited dE/dx seems a concern for running at Z-pole, which can be mitigated by including fast timing LGAD pixelate and RICH detectors:
  - Pors: PID will help jet-charge and flavor tagging.
  - Cons: Additional materia budget to degradate the detector performance. And technologies challenges that requires significant R&D efforts.
- Building better and robust detector will ensure the success of CEPC program.

# Particle ID

- TPC, DCH both have:
  - dE/dx ~4% + Ecal timing
  - K/π 3σ up to 10 GeV
- Full silicon tracker(FST):
  - Limited dE/dx, similar to ATLAS/CMS
  - Ecal timing
  - K/π 3 σ up to 3 GeV.

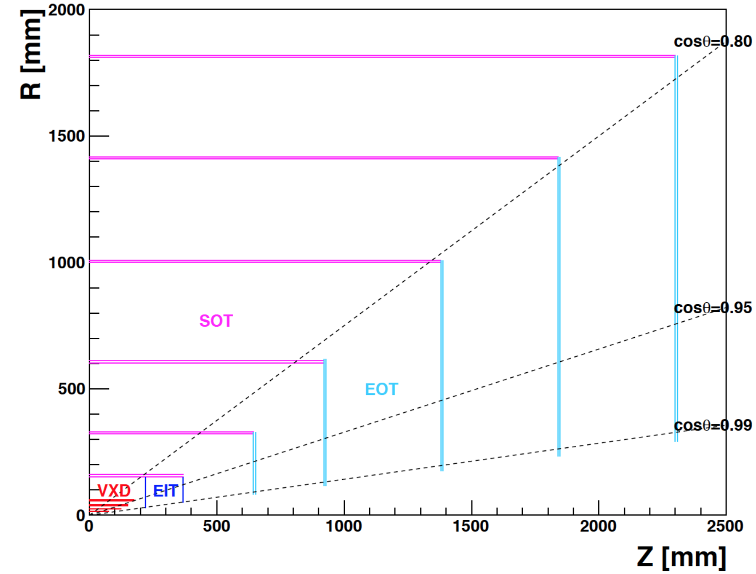


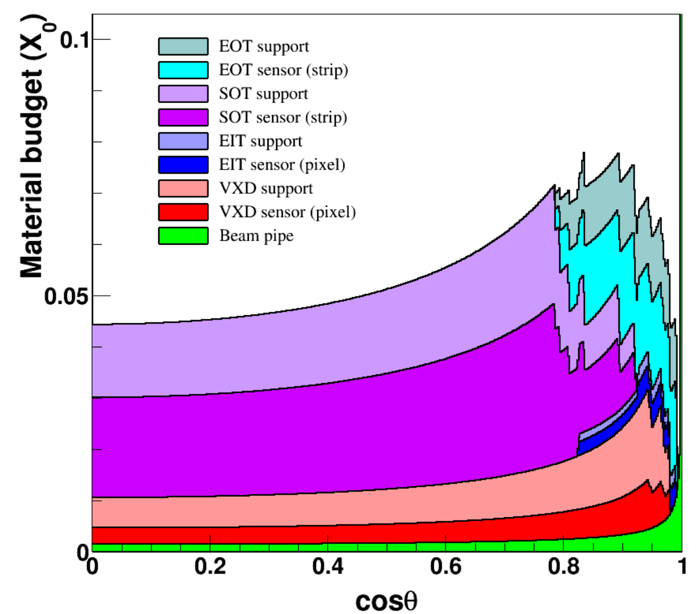



# PID detector options for FST

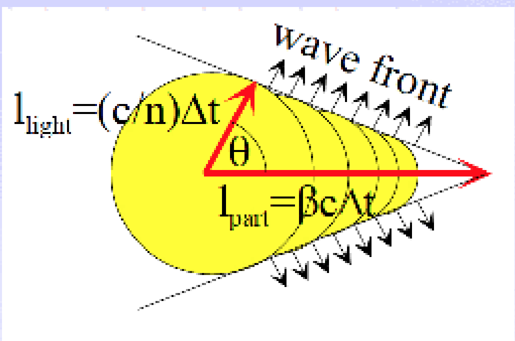
- FST in CDR has few concerns:
  - Limited dE/dx
  - Double sided strip layers with higher material budget
- TOF with LGAD pixelate with 10 ps timing:
  - Replacing outer strip layers  with LGAD layer to reduce material budget.
  - Providing timing for PID up to 10 GeV.
- RICH for PID up to 50 GeV:
  - Minimizing material budget
  - Cherenkov light detection:
    - MWPC, SiPM, HPDs...
    - LGAD pixelate detector for tracking and photon.



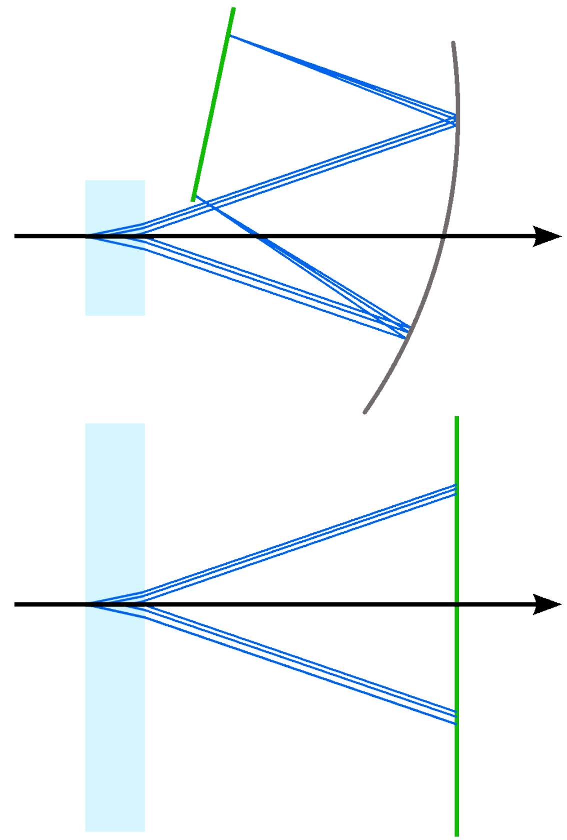



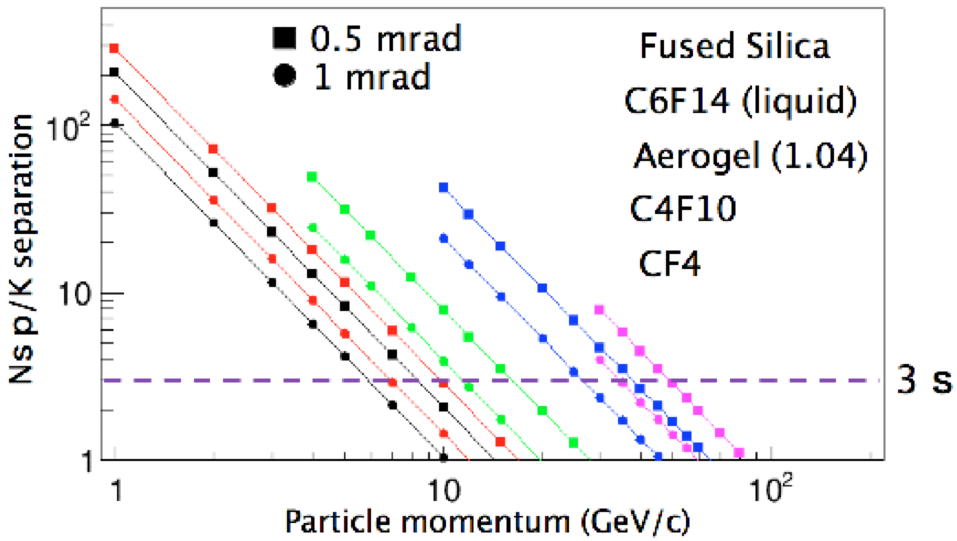
# RICH detector for PID

- Ring Image CHerenkov (RICH) seems only optionfor PID for very high momenta particles up tp $\sim 50$ GeV/c.
- Multiple RICH detectors required to cover full momentum ranges.




$$\cos\theta_C = \frac{1}{n\beta}$$
with $n = n(\lambda) \geq 1$





# RICH detector option for FST