Flavours requirements for detector design

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Outline

1. Vertexing from FCNC *b*-hadron EW penguins

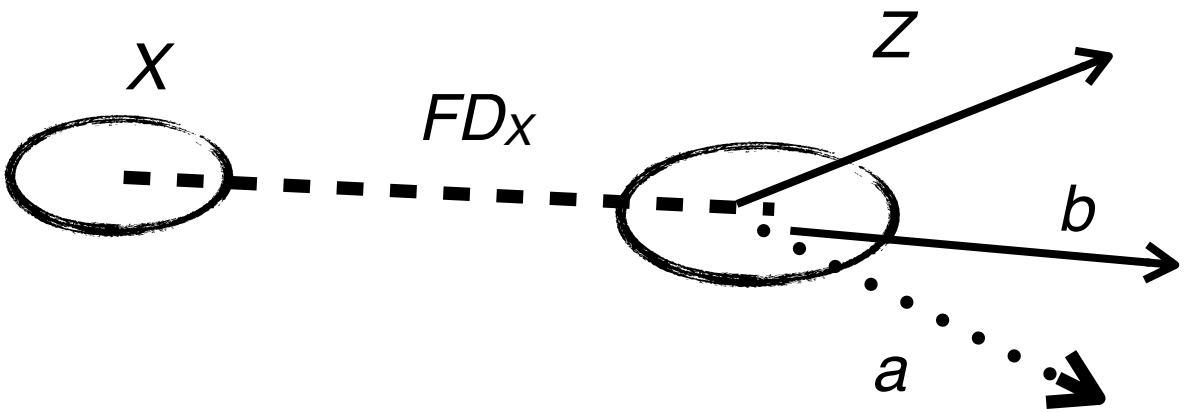
2. Momentum resolution from LFV *Z* decays

3. Charged particle identification p / K / π

1) Vertexing

- One of the most demanding requirement for vertex detectors comes from the missing momentum reconstruction inferred from the decay flight distances.

- Example: $X \rightarrow Y\,(\,Y \rightarrow [a]b\,)\,Z$ with a not reconstructed.

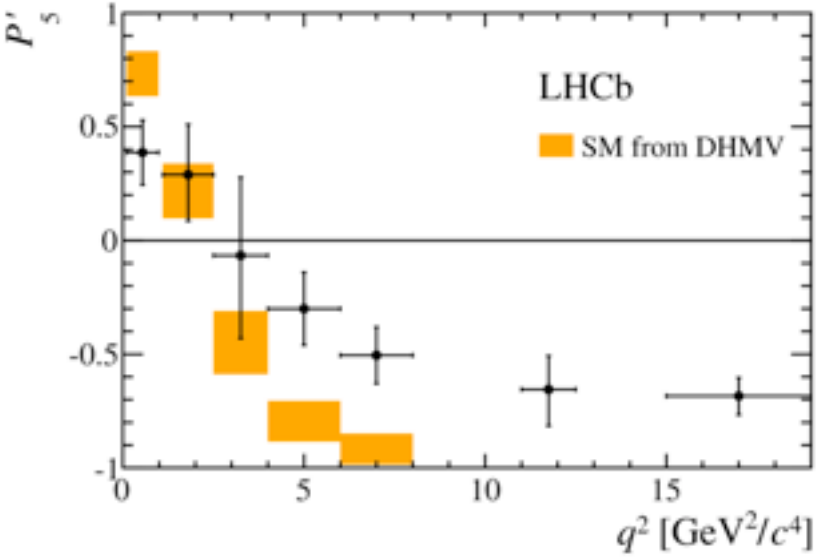


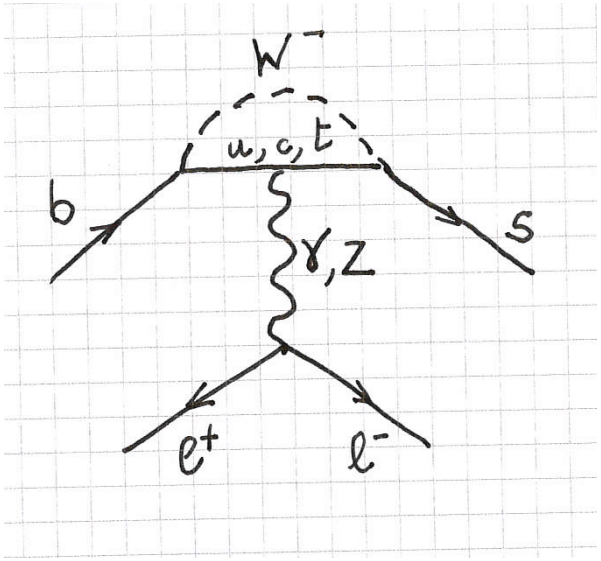
- Three momentum components to be searched for:
  - The measurement of X momentum direction fixes 2 d.o.f.
  - An additional constraint closes the system: m_Y or a tertiary vertex.
  - Usually, quadratic form of the constraints: solution up to an ambiguity.

1) Vertexing. Physics motivations in one slide.

- There are persistent departures of the measurements of the FCNC decays $b \to s\ \ell^+\ell^-$ w.r.t. the SM / QCD predictions. They are consistent among experiments (Belle and LHCb). The mode which is measured is $B^0 \to K^{*0}\ \mu^+\mu^-$.

JHEP 02 (2016) 104





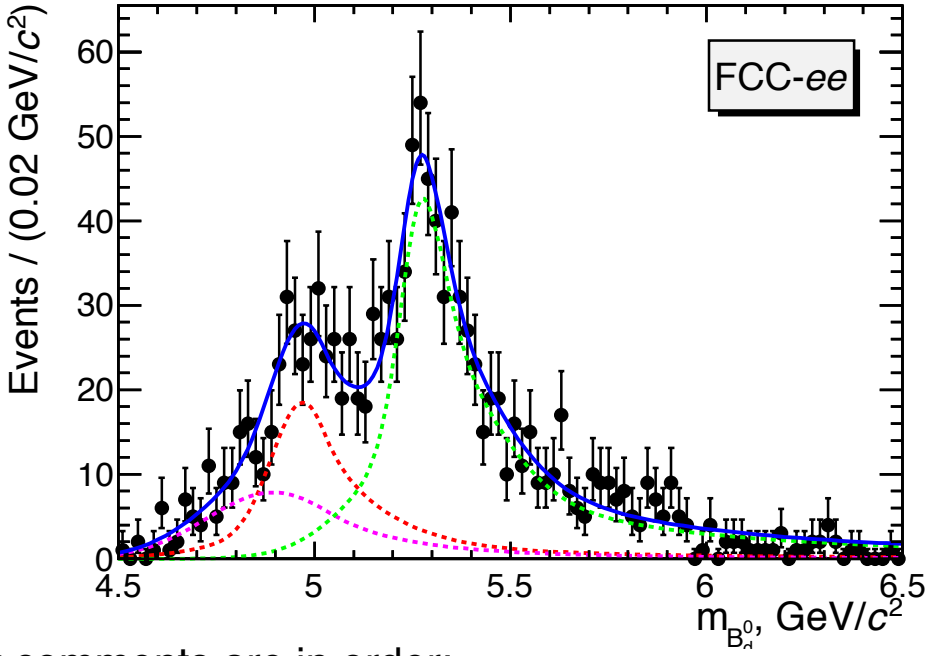
- The companion decay modes $B^0 \to K^{*0}\ e^+e^-$ and mostly $B^0 \to K^{*0}\ \tau^+\tau^-$ necessary to interpret the discrepancy (if real): unique at FCC-*ee*. The latter requires partial reconstruction.

1) Vertexing. Reconstruction.

- Backgrounds:

  (pink) $\bar{B}^0 \to D_s^+ \bar{K}^{*0} \tau^- \bar{\nu}_\tau$
  (red) $\bar{B}_s \to D_s^- D_s^+ K^{*0}$
  (signal in green).

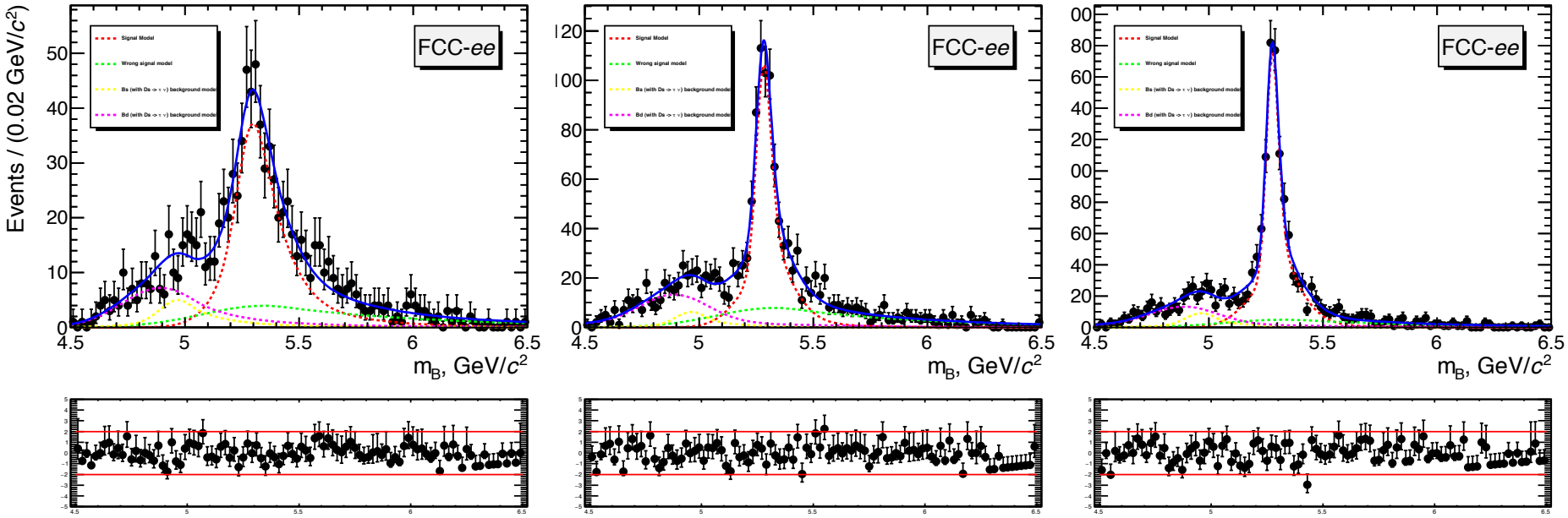
- Conditions: baseline luminosity, SM calculations of signal and background BF, vertexing and tracking performance as ILD detector. **Momentum** → 10 MeV, **Primary vertex** → 3 um, **SV** → 7 um, **TV** → 5 um



Few comments are in order:

- At baseline luminosity, 10^3 events of reconstructed signal. Angular analysis possible.
- With an ALEPH-like vertex detector performance, the signal peak can't be resolved.
- Another interesting and more challenging mode is $B_s \to \tau^+\tau^-$ (Marseille - tuples with the same parametric detector have been produced).

1) Vertexing. Performance of reconstruction (BF)



Performance / Conditions	ILD-like	ILD /2	ILD / 4
Efficiency of the identification of the correct solution (%)	42.3	52.6	62.0
Invariant mass resolution (core) [MeV/c^2]	42(1)	36(1)	27(1)

1) Vertexing. Outlook.

- The Physics perspectives are the sensitivity on the measurements of the branching fraction (differential in q^2) and the angular analysis of the decay.
- BF meas. sensitivity to be estimated w.r.t. vertex performance. Likely yet to vary mildly since wrong solutions of signal events can still be counted.
- As soon as we go to angular observables, the angular resolution will provide additional constraints.
- We are on our way to it (experimental and phenomenology-wise).

2) Momentum resolution from cLFV *Z* decays

- Lepton Flavour-Violating *Z* decays in the SM with lepton mixing are typically

$$\mathcal{B}(Z \to e^{\pm}\mu^{\mp}) \sim \mathcal{B}(Z \to e^{\pm}\tau^{\mp}) \sim 10^{-54} \text{ and } \mathcal{B}(Z \to \mu^{\pm}\tau^{\mp}) \sim 4.10^{-60}$$

- Any observation of such a decay would be an indisputable evidence for New Physics.

- Current limits at the level of ~10^{-6} (from LEP and recently Atlas, *e.g.* [DELPHI, Z. Phys. C73 (1997) 243] [ATLAS, CERN-PH-EP-2014-195 (2014)])

- The FCC-*ee* high luminosity *Z* factory would allow to gain up to six orders of magnitude ... Complementary to the direct search for steriles.

- Explored with FCC-*ee* in mind in [De Romeri et al. JHEP 1504 (2015) 051]. It happens that the final states with taus are the most appealing.

2) Momentum resolution from cLFV Z decays

- There are actually three processes competing in the ball park we can address with a final state with a tau and a beam energy light lepton
  - The lepton Flavour-Violating Z decays
  - The SM $Z \to \tau^+\tau^-$
  - The SM $Z \to l^+l^-$ ($l \to W^*\nu$ and $W^* \to \tau\ \nu$)

- Following Mogens Dam's study reported here :

The SM process $Z \to \tau^+\tau^-$ provides a limit on LFV process which goes linearly with the momentum resolution. Which is asymptotically limited in turn by the beam energy spread (~ 30 MeV at 45 GeV, ~20 MeV at 90°). This makes the former limit pretty fundamental.

The latter process in the list [Durieux et al. arXiv:1512.03071]. is interesting per se (NP enhancements) and can be distinguished from the two others by its kinematical properties: a partial reconstruction technique would make the job.

3) Particle identification: p / K / π separation

Benchmark mode: *CP* violation studies with $B_s \to D_s K$

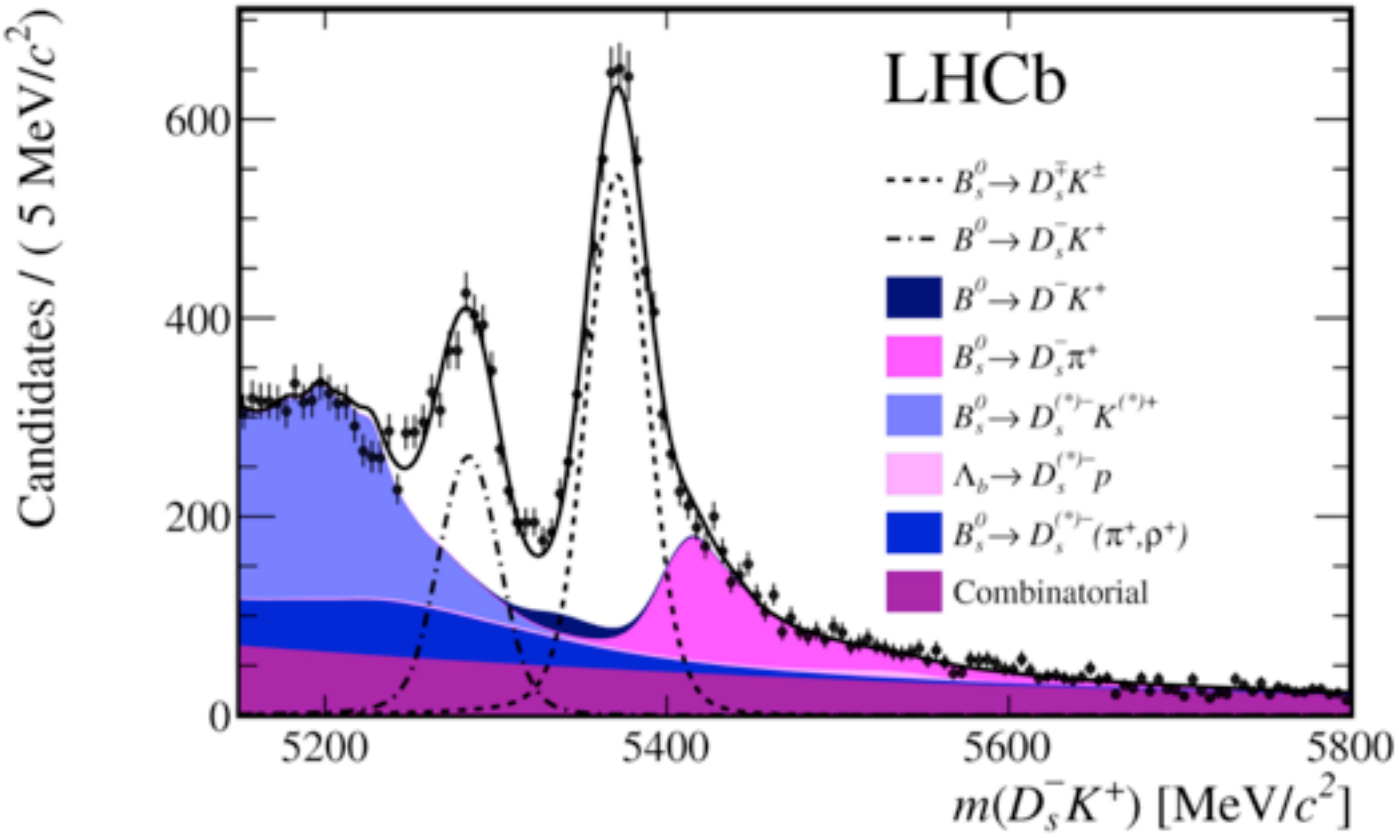
- for Physics: measure simultaneously the phases γ (decay) and ϕ_s (mixing,B_s). No theoretical uncertainty plaguing the interpretation.

- for detectors: understand the needs of p / K / π separation. There is a competition of up-feeding and down-feeding contribution through mis-identification: $B_s \to D_s\pi$ and $\Lambda_b \to D_s\, p$. Serves also the purpose of quark flavour tagging.

3) Particle identification: p / K / π separation

CP violation studies: $B_s \rightarrow D_s K$:

LHCb-PAPER-2014-064
ArXiv:1412.7654

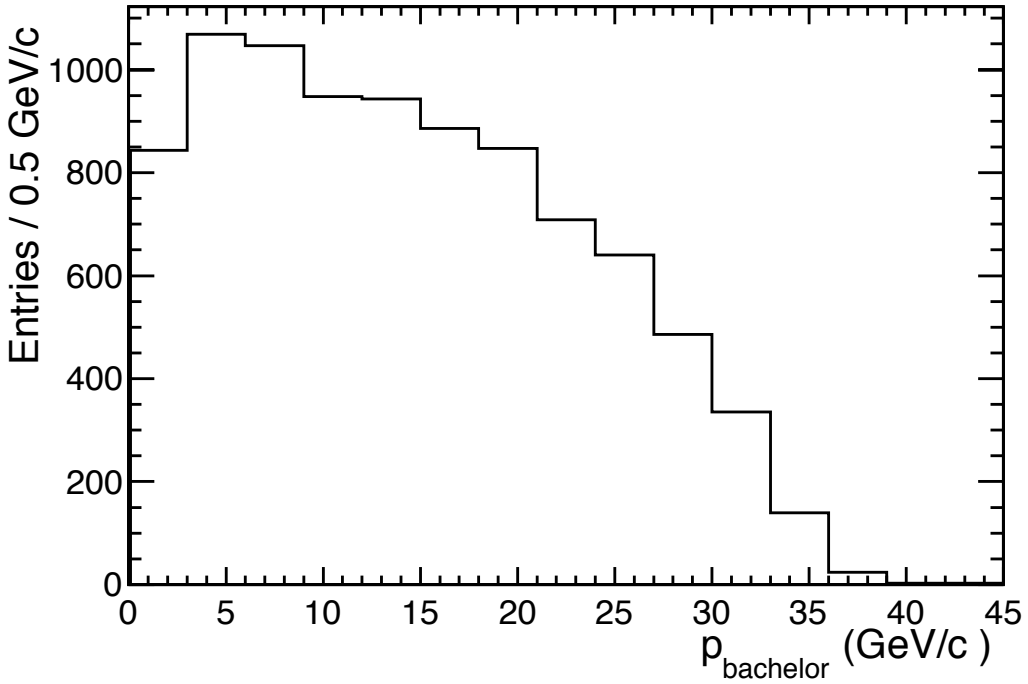


Note: this plot is obtained after PID cuts are applied ...

3) Particle identification: p / K / π separation

- The discrimination acts on the bachelor particle h in $X_b \rightarrow D_s h$, h being p / K / π .

- Momentum of the K bachelor particle from 10 k $B_s \rightarrow D_s K$ simulated events (Pythia + EvtGen).

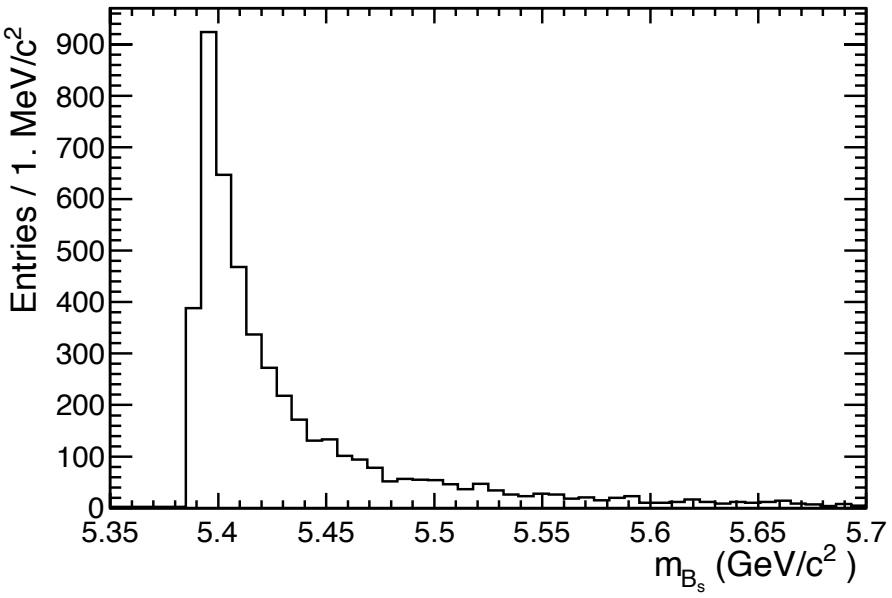


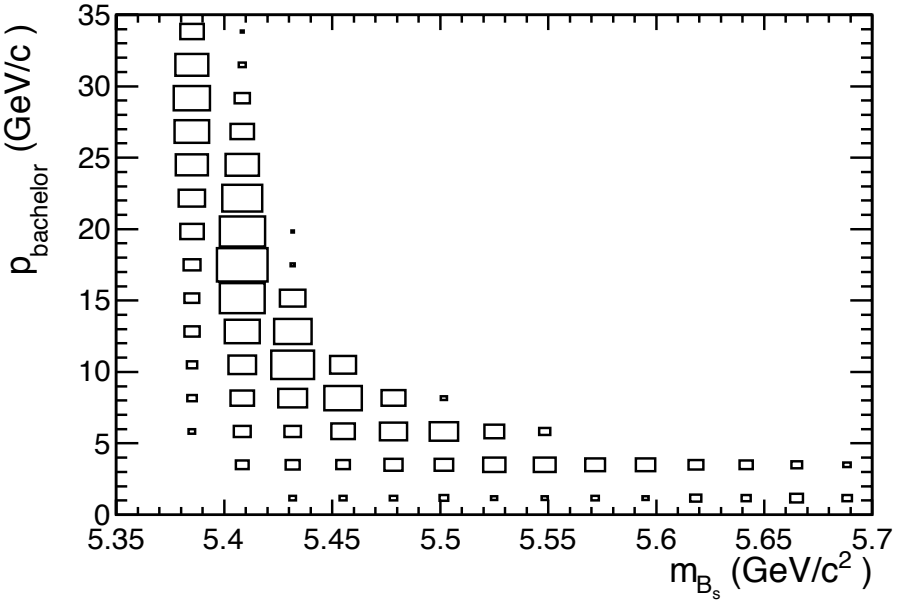
- Since it is a Q2-body decay, one finds a hard spectrum of the bachelor particle (generally not representative of b-hadron decays).

3) Particle identification: p / K / π separation

- The discrimination acts on the bachelor particle h in $X_b \rightarrow D_s h$, h being p / K / π . 10 k of $B_s \rightarrow D_s\pi$ were generated to

- reconstruct $B_s \rightarrow D_s\pi$ as $B_s \rightarrow D_s K$. Correlate the invariant mass with the Bachelor particle momentum.





- The harder is the momentum, the higher is the cross-feeding probability.

3) Particle identification: p / K / π separation

- Reconstruct 10k events of $B_s \rightarrow D_sK$ *and* $B_s \rightarrow D_s\pi$ both under the hypothesis of D_sK final state.

- The momentum resolution was emulated following ILD performance:

$$\frac{\sigma p_\perp}{p_\perp^2} = 2 \times 10^{-5} + \frac{10^-3}{p_\perp \sin\theta}.$$

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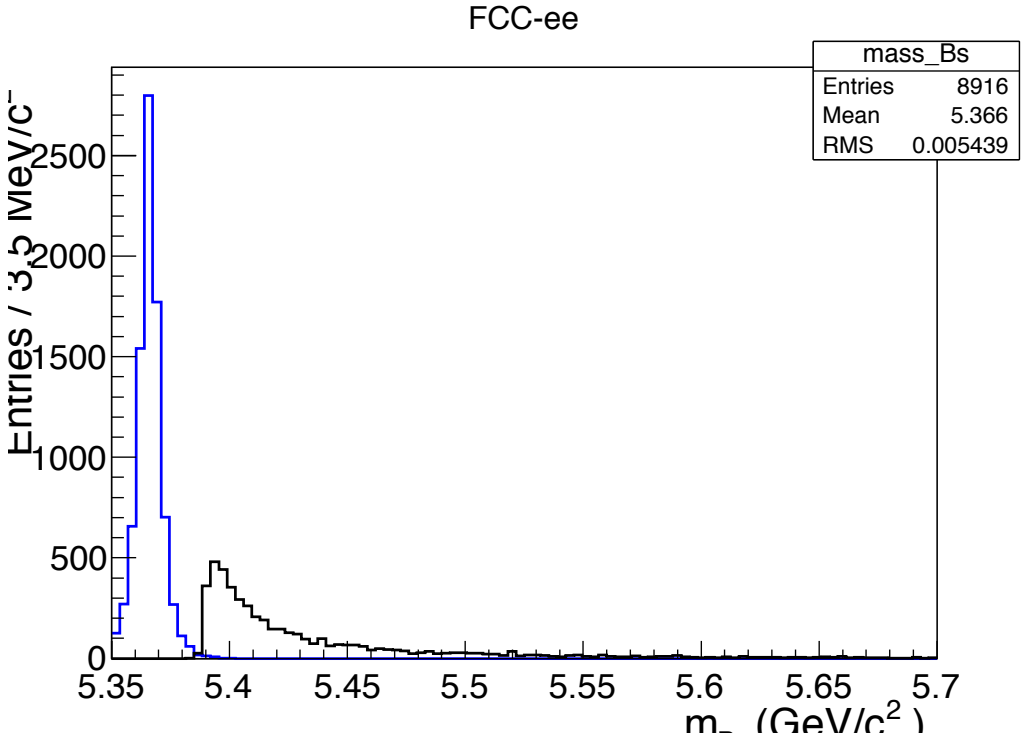
- Given this separation performance, I guess the chosen mode is of modest relevance to qualify the need of a dedicated PID detector.

- This is preliminary and needs to be confirmed.



1. Vertexing from FCNC *b*-hadron EW penguins

One demanding mode (unique to FCC-*ee*): the EW penguin transition $B^0 \to K^{*0}\ \tau^+\tau^-$. Experimental studies driven by branching fraction measurement are setting assessments on vertex detector performance. Angular analysis will provide more (on the way).

2. Momentum resolution from LFV *Z* decays

The limit scales linearly with the momentum resolution (Mogen's result). Aiming at hitting the beam energy spread @ 45 GeV.

3. Charged particle identification *p* / *K* / *π*

My current understanding is that the chosen benchmark mode does not require a dedicated hadron PID detector. To be confirmed and next, examine *b*-hadron flavour tagging performance.