EWPOs: from beauty to strange + photon-energy resolution from and for flavours

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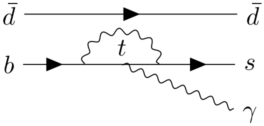
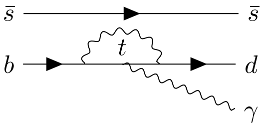
ECAL photon-resolution

This is an academic excercise to emphasize the importance of ECAL resolution for flavours

- Rare, radiative FCNC $b \to s\gamma$ transitions probe NP in loop-diagrams + sensitivity to photon dipole operator C_7

- Distinction between B_d and B_s modes crucial also for angular analysis of $B_s \to K^*\gamma$





→ $B_{d,s}$ differentiation depends of photon-energy resolution

- $B_s \to K^*\gamma$ not yet observed, therefore estimate event yields via

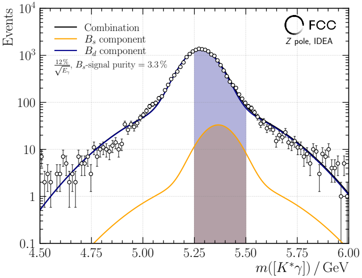
$$\frac{N_{B_d}}{N_{B_s}} \sim \frac{f_{b\to B_d}}{f_{b\to B_s}} \cdot \left|\frac{V_{ts}}{V_{td}}\right|^2 \approx 92$$

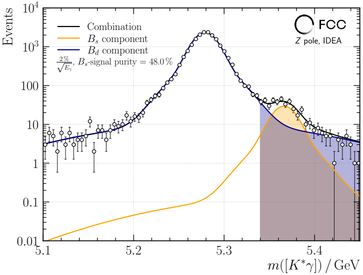
→ Suppressed B_s signal in presence of overwhelming B_d background

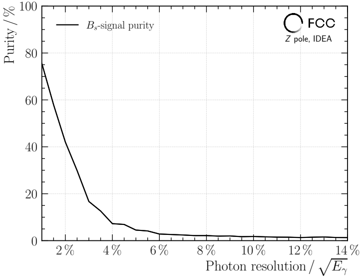
ECAL photon-resolution

This is an academic excercise to emphasize the importance of ECAL resolution for flavours

- From full-stat winter-2023: reconstructed K^*, simplified emulation (stochastic term) of photon-energy resolution from MC γ
- Validated, that $\frac{12\,\%}{\sqrt{E_\gamma}}$ roughly corresponds to IDEA baseline ✓
- High-energy resolution from crystals $\mathcal{O}\left(\frac{2\,\%}{\sqrt{E_\gamma}}\right)$, e. g. [2312.07365]







- Signal purity evaluated 1σ around B_s mass-peak

Overview – exclusive taggers

- Exclusive taggers for EWPOs $R_{b,c,s}$ and $A_{\mathrm{FB}}^{b,(c,s)}$ overcome systematic limitations of LEP-like taggers
- Concept proven for R_b and A_{FB}^{b} ✓

What we have:

- **Beauty tagger** for R_b and A_{FB}^{b} with $\mathcal{O}(200)$ decay modes
  $\rightarrow \sigma_{\mathrm{stat.}}(R_b) = \sigma_{\mathrm{syst.}}(R_b) = 2 \cdot 10^{-5}$ for $\sigma(\Delta C_b)/\Delta C_b = 10\,\%$
  $\rightarrow \sigma_{\mathrm{stat.}}(A_{\mathrm{FB}}^{b}) = \sigma_{\mathrm{syst.}}(A_{\mathrm{FB}}^{b}) = 6 \cdot 10^{-5} (2 \cdot 10^{-5})$ for $\sigma(C_{\mathrm{QCD}})/C_{\mathrm{QCD}} = 5(1)\,\%$
- **Charm tagger** for R_c with $\mathcal{O}(20)$ decay modes
  $\rightarrow \sigma_{\mathrm{stat.}}(R_c) = 1 \cdot 10^{-5}$ from only $\bar{D}^0 \rightarrow K^+\pi^-$
  $\rightarrow A_{\mathrm{FB}}^{c}$ straightforward (D^+, D_s^+, Λ_c)
- **Strange tagger**
  - For R_s with $\phi(1020) \rightarrow K^+K^- \rightarrow \sigma_{\mathrm{stat.}}(R_s) = 1.3 \cdot 10^{-5}$
  - For A_{FB}^{s} with $\Xi^- \rightarrow [p\pi^-]_\Lambda \pi^- \rightarrow \sigma_{\mathrm{stat.}}(A_{\mathrm{FB}}^{s}) = 1.6 \cdot 10^{-4}$

Charm tagger for R_c

- Based on double-tag method to simulatanoesly determine R_c and ε_c^c:

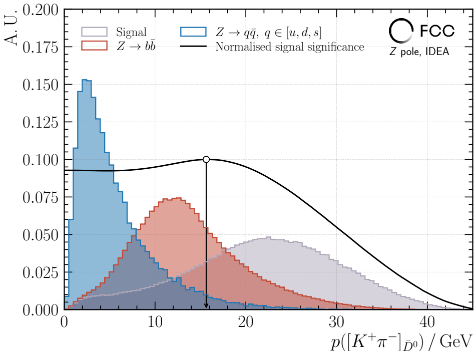
$$N_c = 2N_Z \cdot (R_c \varepsilon_c^c + R_b \varepsilon_b^c + (1 - R_b - R_c)\varepsilon_{uds}^c)$$
$$N_{c\bar{c}} = N_Z \cdot (R_c (\varepsilon_c^c)^2 C_c + R_b (\varepsilon_b^c)^2 C_b + (1 - R_b - R_c)(\varepsilon_{uds}^c)^2 C_{uds})$$

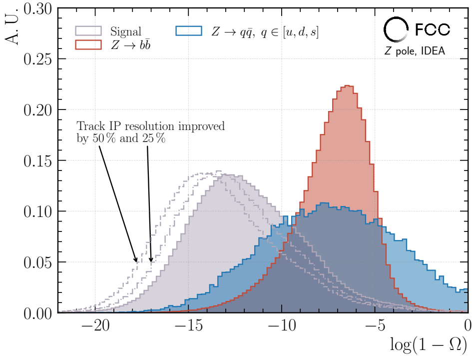
- Assume hemisphere correlations C_i to be unity with track selection outside luminous region
- Leading syst. uncertainties from mistag eff. ε_b^c and ε_{uds}^c $\rightarrow$ the smaller the better
- Exclusive b-hadron decays provide a way to measure ε_b^c
- Starting point: $\bar{D}^0 \rightarrow K^+\pi^-$ reconstruction from $\approx 4 \cdot 10^7$ $Z \rightarrow q\bar{q}$ winter-2023 samples (IDEA)

Charm tagger for R_c

Target: $\sigma_{stat.} = 1.1 \cdot 10^{-5}$ *(full FCC-ee stat.), main background:* $\bar{D}^0 \to K^+\pi^-$ *from* $Z \to b\bar{b}$

- $Z \to uds$ negligible ($\varepsilon^c_{uds} \approx 0$) after momentum cut of $p_{\bar{D}^0} > 16$ GeV
- Define the pointing angle $\Omega = \frac{\vec{p}_{\bar{D}^0} \cdot \vec{d}}{|\vec{p}_{\bar{D}^0}| \cdot |\vec{d}|}$ and $\vec{d} = \mathrm{PV} - \mathrm{SV}$ as discriminative variable
- Train BDT to further purify selection → 97 %, **but:** more decay modes → higher momentum cut → higher purity
- Limiting factor: Knowledge of background efficiency, requirements for track resolution?

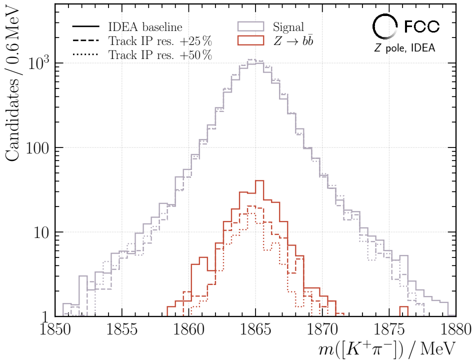


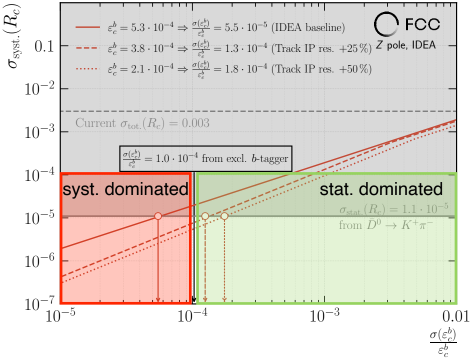


Charm tagger for R_c

Target: $\sigma_{stat.} = 1.1 \cdot 10^{-5}$, *main background:* $\bar{D}^0 \to K^+\pi^-$ *from* $Z \to b\bar{b}$

- Knowledge of background efficiency depends on separation power $\to$ vertex and track resolution crucial
- Improved d_0 and z_0 resolution by 25 % and 50 %



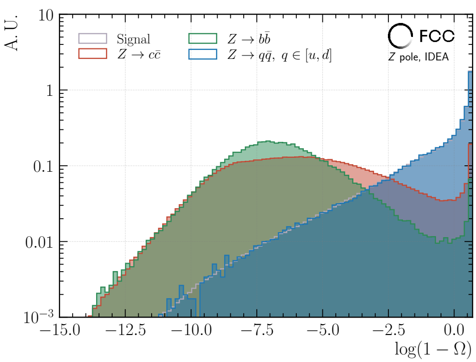


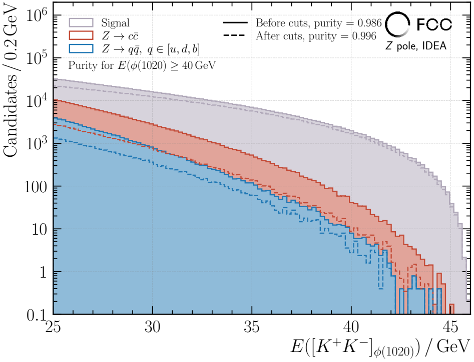
- With 25 % improvement: precision of ε_c^b from excl. b-tagger sufficient to reach $\sigma_{syst.}(R_c) \approx \sigma_{stat.}(R_c)$

Strange tagger for R_s

Disclaimer: All results obtained with PYTHIA*'s* $s \to \phi(1020)$ *hadronisation fraction of* $\mathcal{O}(1\,\%)$*,*
Target: $\sigma_{stat.} = 1 \cdot 10^{-5}$*, main background:* $\phi(1020) \to K^+K^-$ *from* $Z \to c\bar{c}$

- Measurement of R_s examined with $\phi(1020) \to K^+K^-$ ($50\,\%$ branching ratio)
- Reconstruction MC-seeded, but no showstoppers identified for ΔC_i when track selection outside luminous region
- Here: Ω impact higher since less decay modes available, however with $E > 40$ GeV: purity above $99\,\%$





Strange tagger for A_{FB}^s

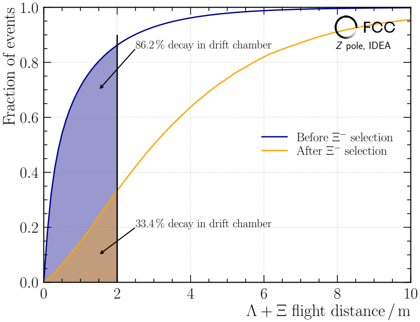
Disclaimer: All results obtained with `PYTHIA`*'s* $s \to \Xi^-$ *hadronisation fraction of* $\mathcal{O}(4\,\%)$,
Target: $\sigma_{stat.} = 1.6 \cdot 10^{-4}$, *main background:* $\Xi^- \to \Lambda\pi^-$ *from* $Z \to c\bar{c}$

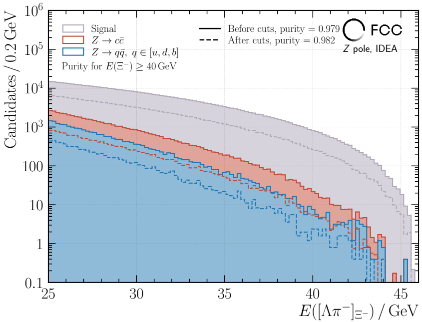
- Outlined on MC-truth level, since Ξ^- reconstruction challenging: $\mathcal{O}(\bar{\tau}_{\Xi^-}) = 10^{-10}\,$s, $\langle L_{\Xi^-}\rangle = 1.2\,$m

→ Started to investigate Ξ^- track reconstruction, however: significant eff. loss due to Ξ^- decay length

- High-energetic Ξ^- tracking for PID (vtx and drift chamber), π^- kink (drift chamber) + late V^0-reconstruction of Λ (drift chamber)

- $E_{\Xi^-} > 40\,$GeV sufficient to reach purity $> 98.2\,\%$





Strange tagger for A_{FB}^{s}

Disclaimer: All results obtained with `PYTHIA`*'s $s \to \Xi^-$ hadronisation fraction of $\mathcal{O}(4\,\%)$,*
Target: $\sigma_{stat.} = 1.6 \cdot 10^{-4}$, main background: $\Xi^- \to \Lambda\pi^-$ from $Z \to c\bar{c}$

- A_{FB}^{s} measurement becomes charge-unambiguous and almost background-free
- Precision depends on hadronisation fraction (tbd from FCC) and selection efficiency for high-E candidates (WIP)