Top-quark reconstruction at FCC-ee

Top LHC France 2024 — Paris

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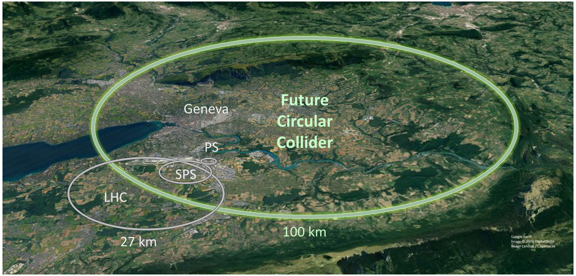
The FCC project at CERN

- Absence of BSM physics at LHC in TeV range: require a new, broad & powerful tool of exploration
- European Strategy for Particle Physics & Snowmass '21: highest priority on e^+e^- Higgs factory
- Europe's longer-term ambitions: *pp* collider at highest achievable energy (sensitive to energy scales $> 10 \cdot \mathcal{O}(E_{\text{LHC}})$)
- Motivated by LEP/LHC success: FCC matches sensitivity, precision (and energy scale) landscape

  16 years: FCC-ee: e^+e^- operation from Z-pole to $t\bar{t}$ threshold

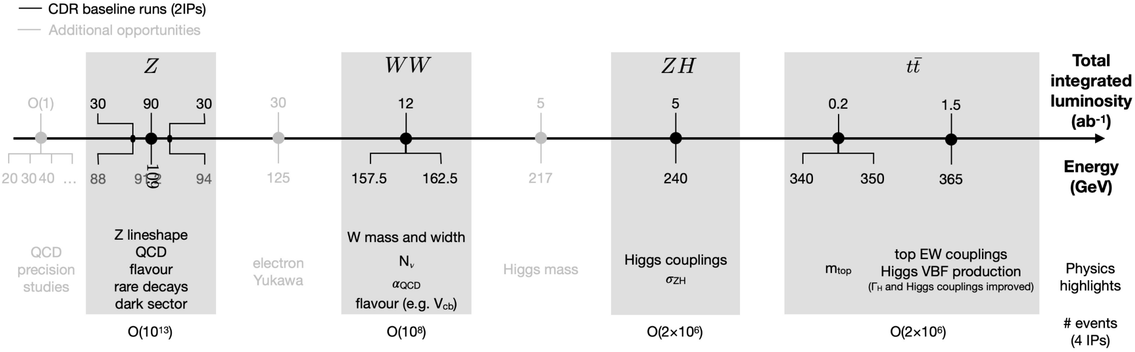
  10 years: Shutdown to prepare *pp* collisions

  25 years: FCC-hh: *pp* collisions up to $\sqrt{s} = 100$ TeV



FCC-ee: defining the physics case

- We don't know the new physics energy scale → go back to precisely measure what we know
- FCC-ee even a discovery machine: statistics allow to identify tiny deviations from SM
- Run plan offers broad opportunities for discoveries

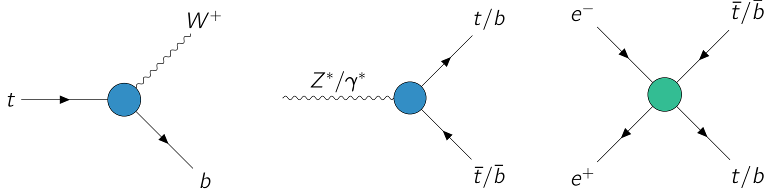


Starting point: EFT approach

- Dimension-6 extensions of the SM Lagrangian

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \mathcal{O}(O^{(5)}) + \frac{1}{\Lambda^2} \sum_i C_i^{(6)} O_i^{(6)}$$

- Affects production + decay processes of heavy quarks



Idea: How much can FCC-ee tighten the limits on C_i?

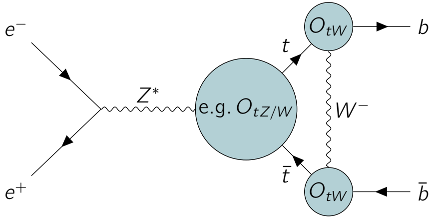
Needs:

1. High precisision measurements at the Z-pole (from b-quark observables like A_{FB}^b)
2. Variety of observables at the top-threshold

Synergies in heavy-quark measurements: the idea

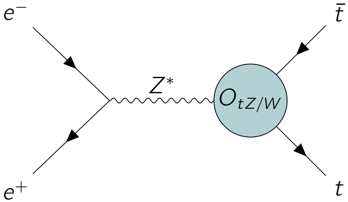
- Global access to SM deviations over different energy scales ($m_Z \to 2m_t$)
  $\to$ Probe beyond-SM interactions with common set of dimension-6 operators

$\mathcal{O}(m_Z) \sim 90$ GeV



$\Rightarrow$ Vertex corrections $\approx 1\,\%$ in the SM...

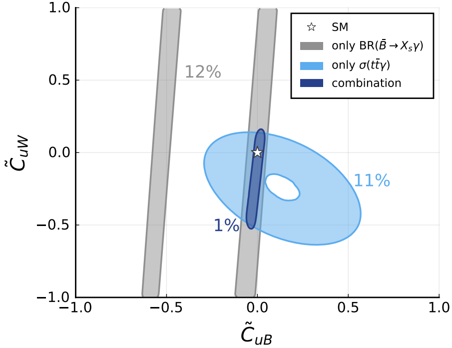
$\mathcal{O}(2m_t) \sim 350$ GeV to 365 GeV



...may reflect in t-quark observables

Synergies in heavy-quark measurements: a proven concept

- Combining t- and b-observables: improves constraints on Wilson coefficients [1]
- Especially constraints on four-fermion interactions can be tighten up to $\mathcal{O}(10^{-4})$



- Start from EFT-fit in top-quark sector + extend to b-quark observables at FCC-ee
- Today: **top-quark reconstruction and observables**

Ingredients

- Find observables, that are sensitive to dimension-6 operators
  $\rightarrow$ Interpolate to extract observable behaviour as function of C_i
- Estimate expected uncertainty
- Combine observables for EFT-fit in top-quark sector: `EFTfitter.jl`

Sensitive observables

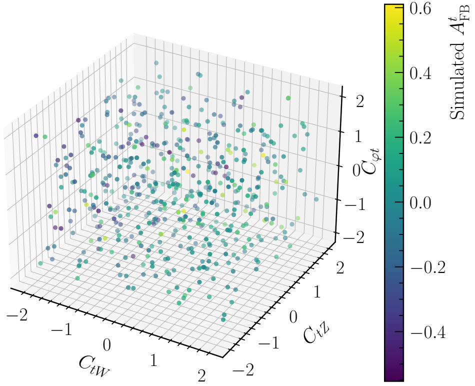
- Study outlined solely on parton-level with `MadGraph` and `dim6_top_LO`
- Simulate semi- and dileptonic observables x

$$x_{\mathrm{MG}}(\{C_i\}) \approx x_0 + \sum_i C_i x_i + \sum_{i \leq j} C_i C_j x_{ij}$$

Observables:

- Semileptonic:
  $\rightarrow$ Top-quark forward-backward asymmetry:
  $A_{\mathrm{FB}}^t(\{O_{tW}, O_{tZ}, O_{\varphi t}, O_{\varphi Q}^{(-)}, O_{te}^{(1)}, O_{tl}^{(1)}, O_{Qe}^{(1)}\})$

  $\rightarrow$ W-helicity fractions:
  $F_{\mathrm{L}}(\{O_{tW}, O_{bW}\}), F_0(\{O_{tW}, O_{bW}\})$



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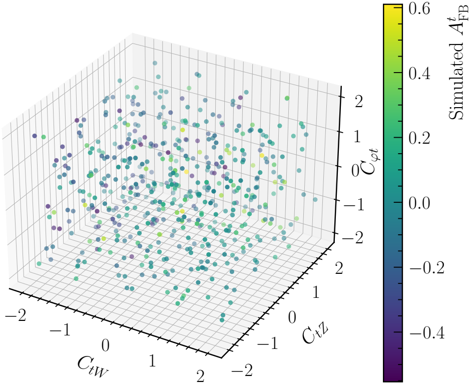
  → W-helicity fractions:
  $F_{\mathrm{L}}(\{O_{tW}, O_{bW}\}), F_0(\{O_{tW}, O_{bW}\})$

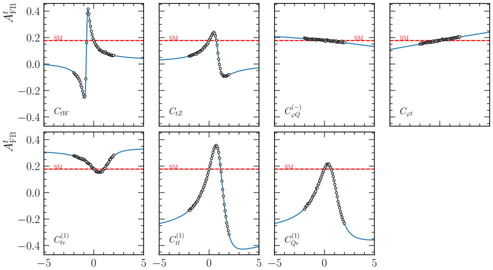
- Dileptonic:
  → Top-quark spin correlations:
  $C_{ij}(\{O_{tW}, O_{tZ}, O^{(-1)}_{Ql}, O^{(1)}_{te}, O^{(1)}_{tl}, O^{(1)}_{Qe}\})$

  → Angle between the two leptons:
  $\cos(\theta_{\ell\ell})(\{O_{tW}, O_{tZ}, O^{(-1)}_{Ql}, O^{(1)}_{te}, O^{(1)}_{tl}, O^{(1)}_{Qe}\})$

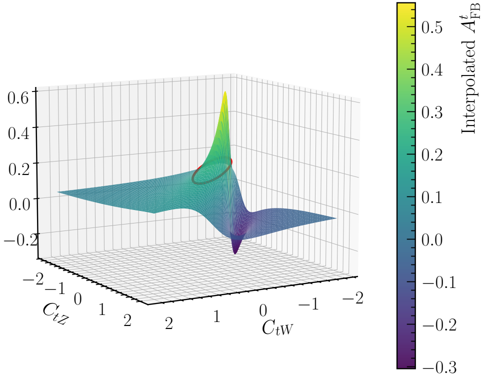


Observable interpolations: A_{FB}^{t}

- Interpolate $x_{\mathtt{MG}}(\{C_i\}) \approx x_0 + \sum_i C_i x_i + \sum_{i\leq j} C_i C_j x_{ij}$ to extract parameters x_0, x_i, x_{ij}
- Fit of 869 sampling points in 7 (C_i-)dimensions
- Reminder: $A_{\mathrm{FB}}^{t} = \frac{N_{\mathrm{F}}-N_{\mathrm{B}}}{N_{\mathrm{F}}+N_{\mathrm{B}}}$ with $N_i = p_0 + p_1 \cdot C_{tW} + p_2 \cdot C_{tW}^2 \rightarrow 72$ parameters
- Fit verification: vary one operator at a time and slice fit function



1D slicing



2D slicing

Ingredients

- Find observables, that are sensitive to dimension-6 operators ✓
- Estimate expected uncertainty
  $\rightarrow$ Top-quark ingredients. . . in a lepton collider environment
- Combine observables for EFT-fit in top-quark sector: `EFTfitter.jl`

Top-quarks in FCC-ee environment

- So far: all on parton-level without showering, detector, . . .
- Let the messy stuff begin. . . or not?

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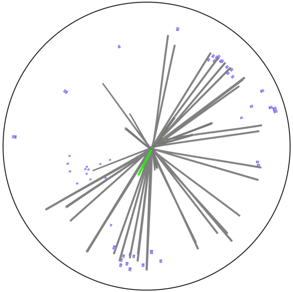
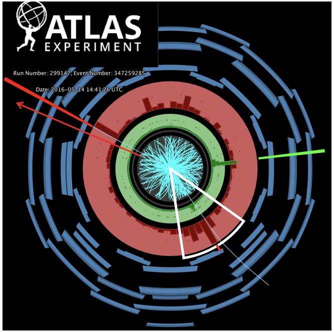


$e^+e^- \to t\bar{t} \to \ell\nu b_1\, j_1 j_2 b_2$ at $\sqrt{s} = 365$ GeV

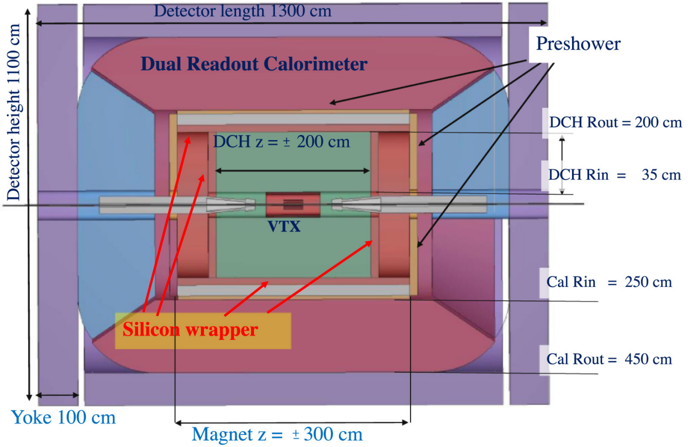


$pp \to t\bar{t}$ candidate

- What is needed: prompt leptons, jets, neutrinos
- Since experimental environments differ a lot, let's take a look at objects
- Disclaimer: only signal events considered here!

Excursion: samples and detector concept

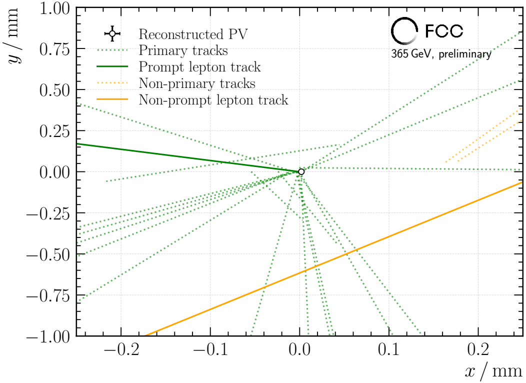
- Samples generated with `whizard_v3` + showered with `pythia` + fast detector simulation with `delphes`
- Processed through **I**nnovative **D**etector for an **E**lectron-positron **A**ccelerator (IDEA) detector concept
- Driven by Higgs-sector requirements on hadr. resolution, tracking, vertexing
  + excellent PID from flavour physics

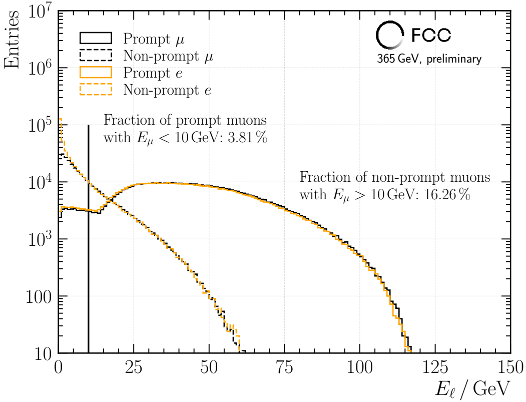


- Silicon vertex detector
- Drift chamber for tracking and PID
- 2 T solenoid
- Dual-readout calorimeter

Prompt leptons

- Beneficial: *one* primary vertex (PV) per event
- From first principles: prompt lepton expected to originate from region around PV + higher energy



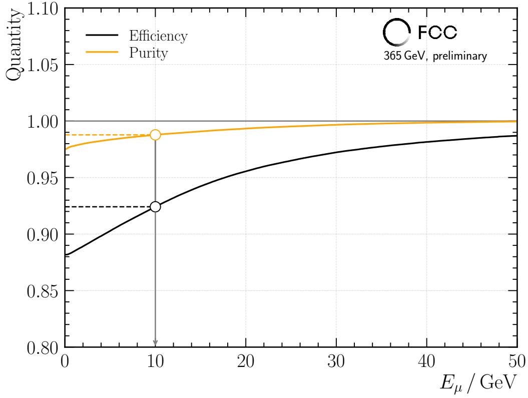


Prompt leptons

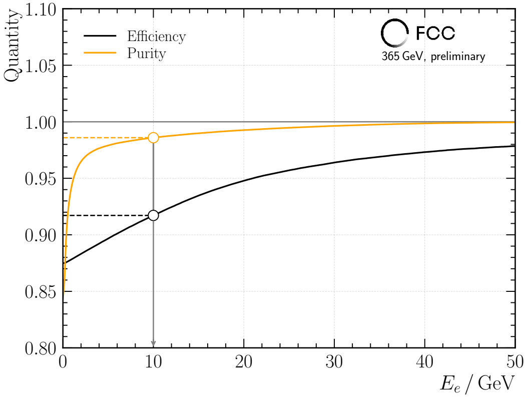
$\text{Purity} = \frac{\text{True positive}}{\text{True positive+False positive}}$

$\text{Efficiency} = \frac{\text{True positive}}{\text{True positive+False negative}}$

- Beneficial: *one* primary vertex (PV) per event
- From first principles: prompt lepton expected to originate from region around PV + higher energy
- Combination of PV fit + $E_\ell > 10$ GeV: high purity and high identification efficiency!



Muon energy.



Electron energy.

Jet clustering

- Remove prompt leptons from the list of reconstructed particles
- Jet reconstruction differs for pp and e^+e^- environment
  $\rightarrow$ Distance measure takes full phase-space information into account (known z-component from $\sqrt{s}$)

Hadron collider

- Anti-k_t algorithm
- Distance based on p_T

$$d_{ij} = \min\left(p_{\mathrm{T},i}^{-2}, p_{\mathrm{T},j}^{-2}\right) \frac{\Delta R_{ij}^2}{R}$$

Lepton collider

- k_t-algorithm for e^+e^- collider (Durham)
- Distance based on energy and polar angle

$$d_{ij} = 2\min\left(E_i^2, E_j^2\right)\left(1 - \cos(\theta_{ij})\right)$$

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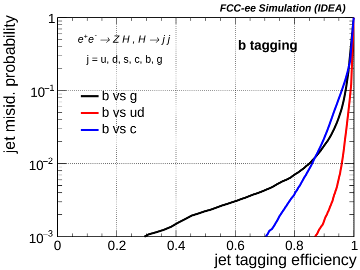


- Exclusively cluster to $n = 2$ or 4 jets

Jet-flavor tagging

Promising results from `ParticleNetIdea` tagger (on $H \rightarrow jj$ sample so far) [link]

- For simplicity: 80 % uniform b-tagging efficiency

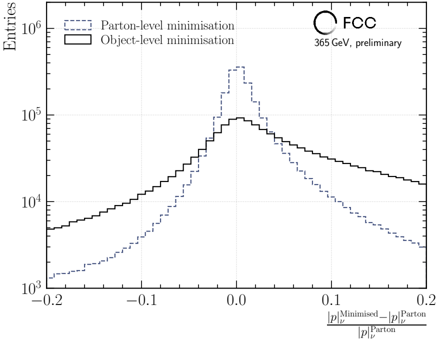
Neutrino reconstruction

Known up to (10 – 20) MeV

- Leptons ✓, jets ✓, neutrinos?
- Different in semi- and dileptonic channel
  - 1ℓ Remaining missing energy as neutrino (complete $\vec{p}$ known)
  - 2ℓ Perform minimisation ([2003.12320]) wrt. W-boson mass from

$$p_{j_1} + p_{j_2} + p_{\ell_1} + p_{\ell_2} + p_\nu + p_{\bar{\nu}} = (0, 0, \sqrt{s})^\top$$

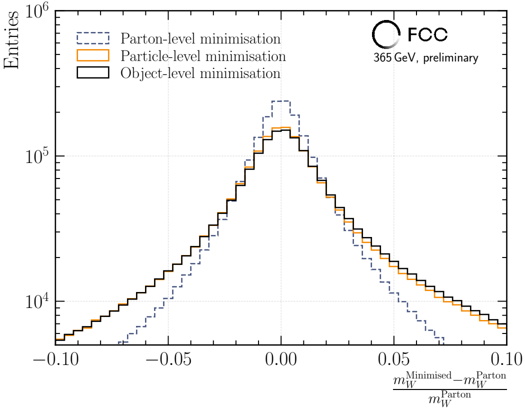
→ Parton-level minimisation: reconstruct ν-four-momenta with error $< 2\,\%$ in $60\,\%$ of the cases

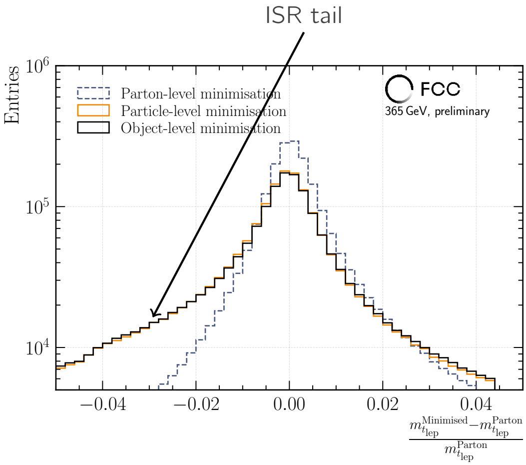


2ℓ channel: neutrino momentum resolution.

Neutrino reconstruction

- Complete $t\bar{t}$ event resolvable
- Higher-level objects (W and t) resolutions look good





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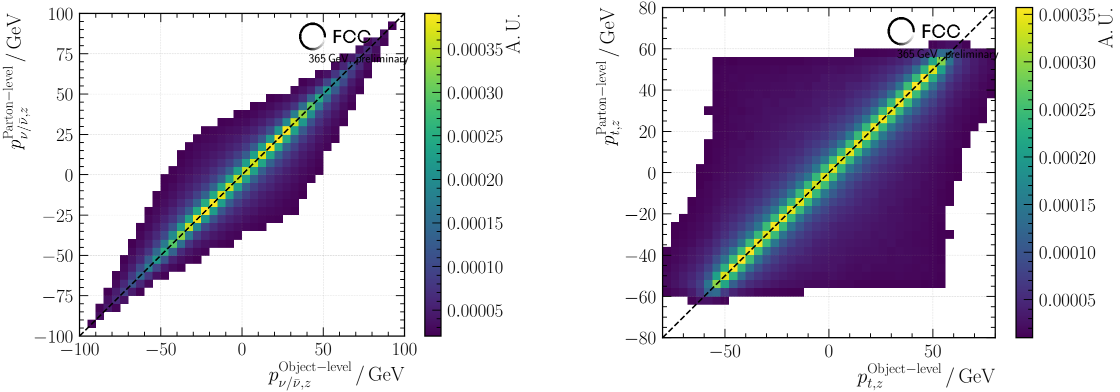
- Two-dimensional correlations lead to comparable results presented in [2003.12320]



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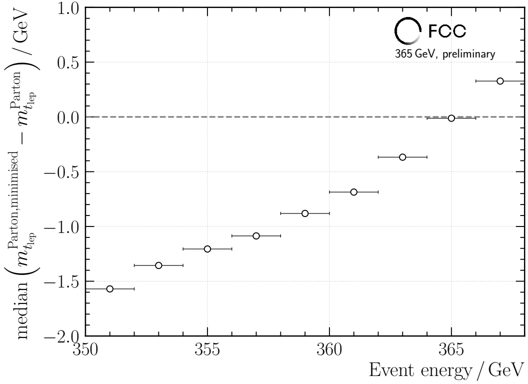


BUT:

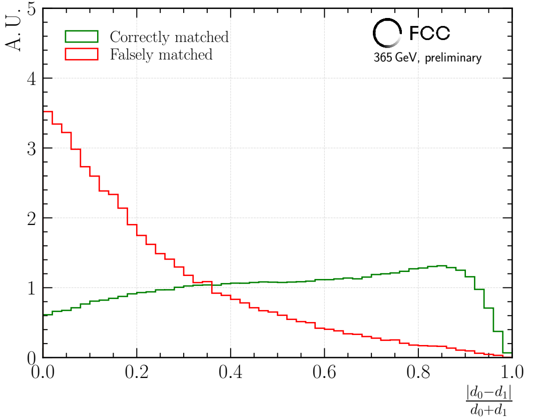
- $\sqrt{s}$ is input for minimisation
- If ISR & FSR lower $\sqrt{s} \rightarrow$ minimisation gets worse!

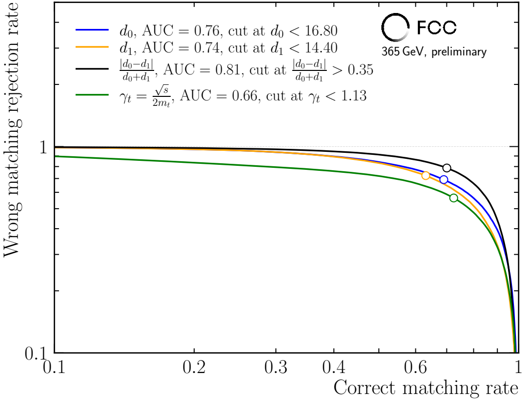
How to match a *b*-jet

- Utilise a χ^2-measure to match a *b*-jet to a *W*-boson:

$$d_i = \sqrt{\left(\frac{(m_{W_{\text{had}}} + m_{b_i}) - 173.1}{\sigma_{m_t}}\right)^2 + \left(\frac{(E_{W_{\text{had}}} + E_{b_i}) - 182.45}{\sigma_{E_t}}\right)^2 + (W_{\text{lep}} + b_j)}$$

- Besides $d_{[0,1]}$: kinematic quantites like m_t, $\frac{|d_0 - d_1|}{d_0 + d_1}$, ...



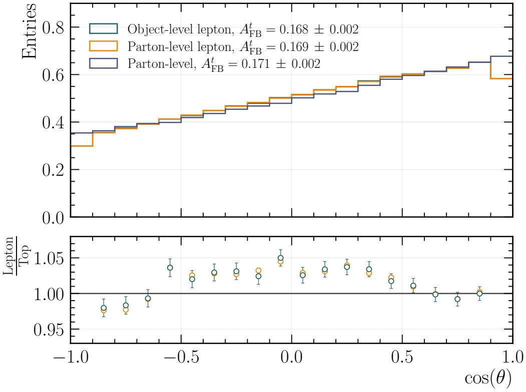


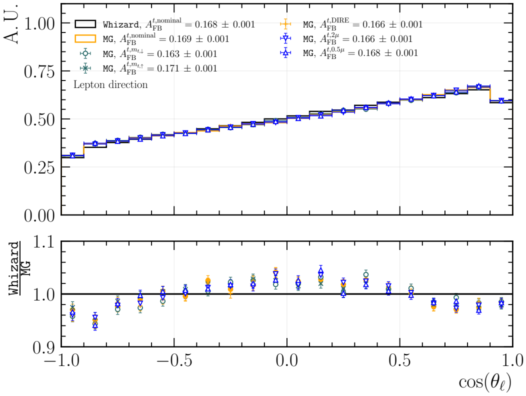
Ingredients

- Find observables, that are sensitive to dimension-6 operators ✓
- Estimate expected uncertainty
  → Top-quark ingredients… in a lepton collider environment ✓
  → How much room to move for the C_i's: extract uncertainties
- Combine observables for EFT-fit in top-quark sector: `EFTfitter.jl`

Uncertainty estimates: A_{FB}^{t} (1ℓ channel)

- First attempt: A_{FB}^{t} from fully reconstructed top-quarks
- Second attempt: A_{FB}^{t} from prompt lepton as direction estimator
- Studies of varying simulation inputs WIP (renormalisation scale, m_t, parton shower, ...)





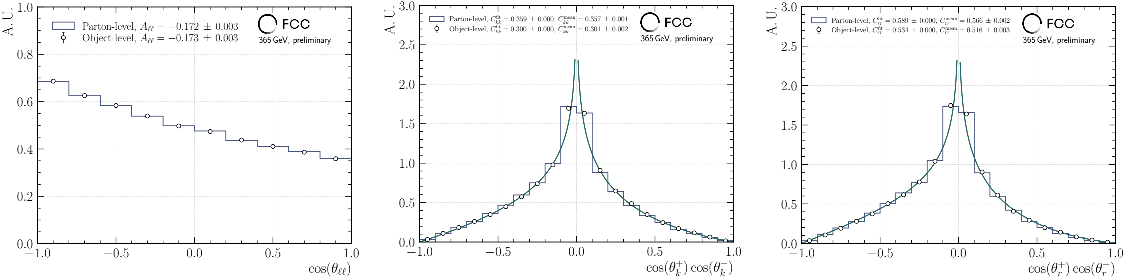
$\rightarrow A_{\mathrm{FB}}^{t} = 0.168 \pm 0.001(\mathrm{stat.}) \pm \mathcal{O}(\sigma_{\mathrm{stat.}})$

Uncertainty estimates: $\cos(\theta_{\ell\ell})$ and C_{ij} (2ℓ channel)

- In the 2ℓ-channel, $\cos(\theta_{\ell\ell})$ and the spin density matrix R are of particular interest
- Top-quark transfers spin information to angular distribution of decay products

$$R \propto A\mathbb{1} \otimes \mathbb{1} + B_i^+ \sigma^i \otimes \mathbb{1} + B_i^- \mathbb{1} \otimes \sigma^i + C_{ij} \sigma^i \otimes \sigma^j$$

- Matrix C characterises the correlation between t and $\bar{t}$ spins



- $\mathcal{O}(\sigma_{\mathrm{stat}}) = 2 \cdot 10^{-3}$, systematic uncertainty studies may be beyond the scope of this work

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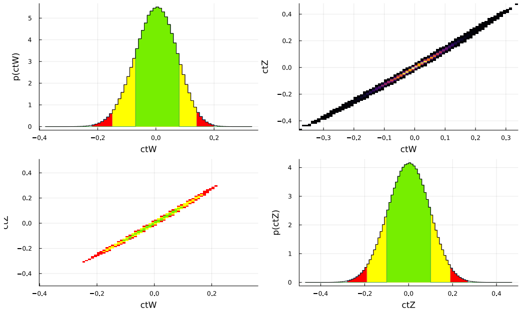
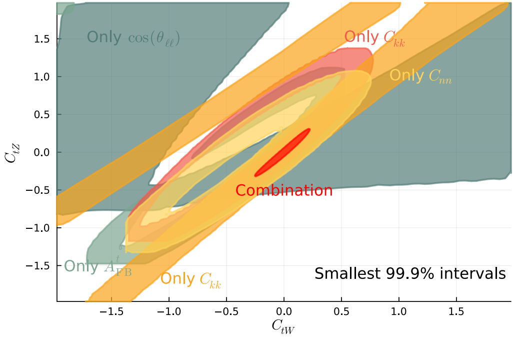
EFT fit (preliminary)

- `EFTfitter.jl`: tool for constraining parameters of physics models using Bayesian inference in `julia`
- First attempt: EFT fit with nominal values of the interpolations at $C_i = 0$ + uncertainties from observables
- Start with (O_{tW}, O_{tZ}) turned on and turn all other operators off



One- and two dimensional representations.

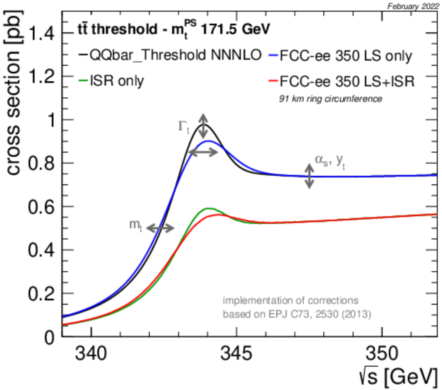


Contribution from different measurements.

- Inclusion of more operators and observables WIP

Conclusion

- Besides broad Z- and H-programme: e^+e^- environment opens new possibilities in top-quark physics
- Additional $t\bar{t}$-threshold scan from $(345 - 350)$ GeV: determine top-mass and width up to $\mathcal{O}(50)$ MeV
- Here: connect flavour observables to access BSM physics consistently in SMEFT
  $\rightarrow$ Start with first results from semi- and dileptonic $t\bar{t}$ observables
- Extension to EWPO (R_b and A^b_{FB}) at a later stage
- Reminder: no backgrounds included yet, first studies here



$t\bar{t}$ threshold scan.

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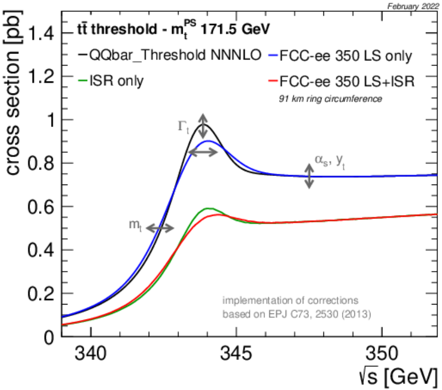


$t\bar{t}$ threshold scan.

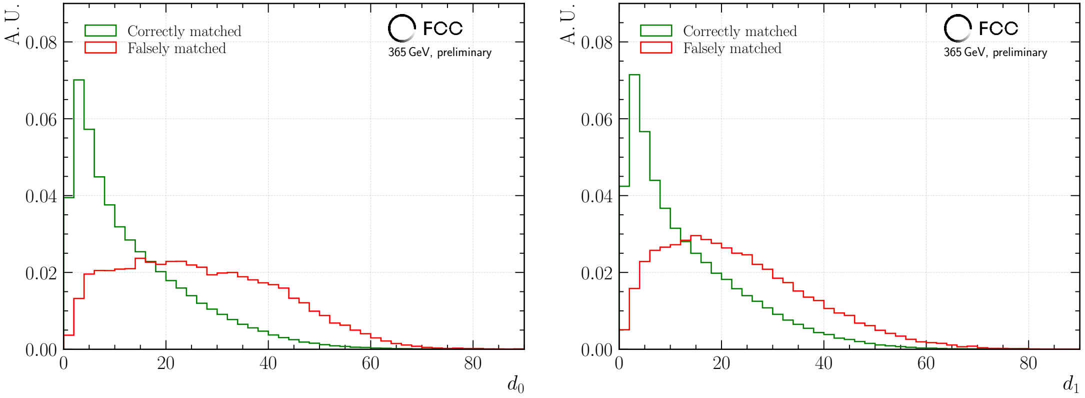
Thank you for your attention!

b-jet matching

- How to match a b-jet to a W-boson? $\rightarrow \chi^2$-measure:

$$d_i = \sqrt{\left(\frac{(m_{W_{\text{had}}} + m_{b_i}) - 173.1}{\sigma_{m_t}}\right)^2 + \left(\frac{(E_{W_{\text{had}}} + E_{b_i}) - 182.45}{\sigma_{E_t}}\right)^2 + (W_{\text{lep}} + b_j)}$$

- Besides $d_{[0,1]}$: kinematic quantites like m_t, $\gamma_t = \frac{\sqrt{s}}{2m_t}$, or $\frac{|d_0 - d_1|}{d_0 + d_1}$, ...



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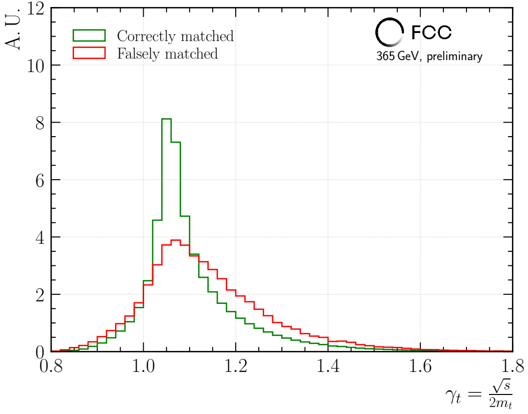

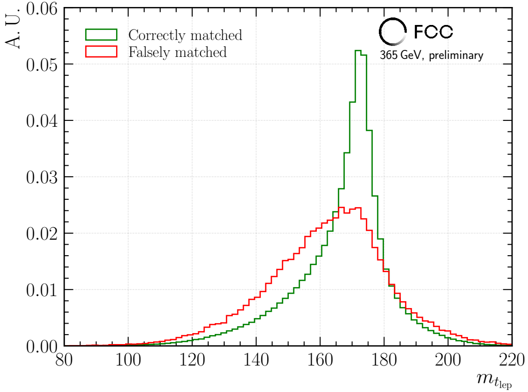

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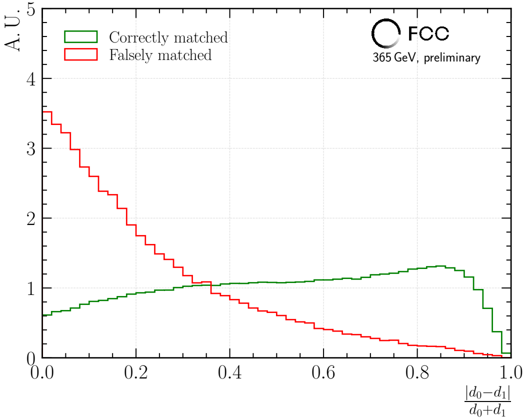
$$d_i = \sqrt{\left(\frac{(m_{W_{\text{had}}} + m_{b_i}) - 173.1}{\sigma_{m_t}}\right)^2 + \left(\frac{(E_{W_{\text{had}}} + E_{b_i}) - 182.45}{\sigma_{E_t}}\right)^2 + (W_{\text{lep}} + b_j)}$$

- Besides $d_{[0,1]}$: kinematic quantites like m_t, $\gamma_t = \frac{\sqrt{s}}{2m_t}$, or $\frac{|d_0 - d_1|}{d_0 + d_1}$, ...



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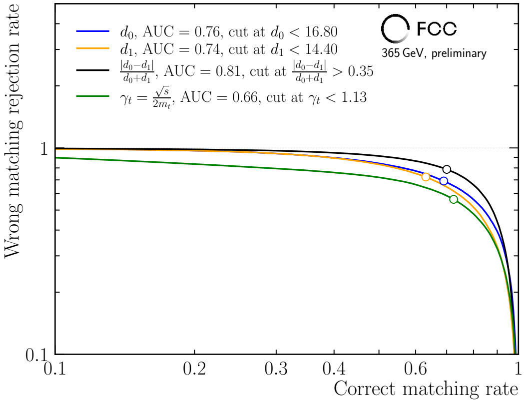
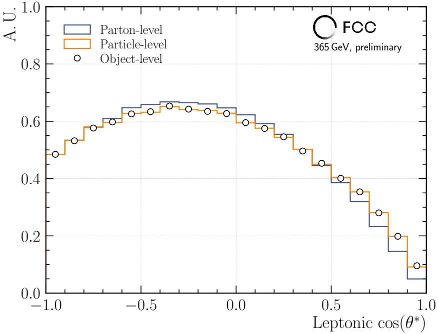


$\rightarrow$ use $\frac{|d_0 - d_1|}{d_0 + d_1} > 0.35$ in the following

W-helicity fractions (preliminary)

- W-helicity fractions sensitive to Wtb structure
  $\rightarrow$ Partial decay rate for given helicity state (left-, right-handed + longitudinal): $F_{\mathrm{L,R,0}} = \frac{\Gamma_{\mathrm{L,R,0}}}{\Gamma}$
- Experimentally: helicity angle $\cos(\theta^*)$ as angle between (ℓ, t) in W rest frame

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos(\theta^*)} = \frac{3}{8}(1-\cos(\theta^*))^2 F_{\mathrm{L}} + \frac{3}{4}\sin(\theta^*)^2 F_0 + \frac{3}{8}(1+\cos(\theta^*))^2 F_{\mathrm{R}}$$



- Since W-spin not directly accessible from simulated samples, calibration procedure installed

W-helicity fractions – continued (preliminary)

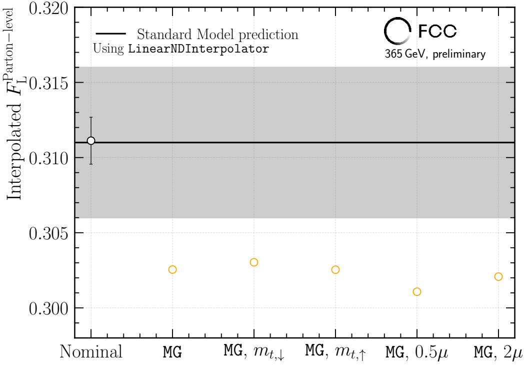
- Reweight parton-level $\cos(\theta^*)$ via

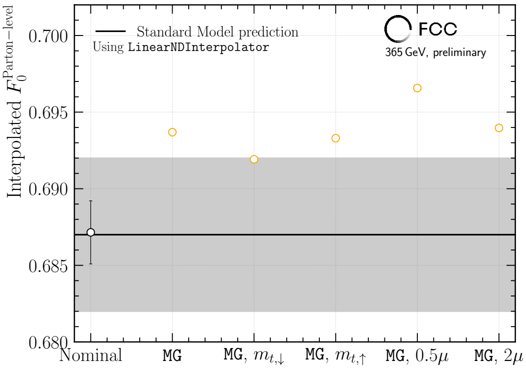
$$w = \frac{\frac{3}{8}(1-\cos(\theta^*_{\text{gen}}))^2 F_{\text{L}} + \frac{3}{4}\sin(\theta^*_{\text{gen}})^2 F_0 + \frac{3}{8}(1+\cos(\theta^*_{\text{gen}}))^2 F_{\text{R}}}{\frac{3}{8}(1-\cos(\theta^*_{\text{gen}}))^2 F_{\text{L}}^{\text{SM}} + \frac{3}{4}\sin(\theta^*_{\text{gen}})^2 F_0^{\text{SM}} + \frac{3}{8}(1+\cos(\theta^*_{\text{gen}}))^2 F_{\text{R}}^{\text{SM}}}$$

- Fit the reweighted object-level distribution and check impact on the observables
- With `LinearNDInterpolator`: $(F_{\text{L}}^{\text{Object-level}}, F_0^{\text{Object-level}}) \to (F_{\text{L}}^{\text{Parton-level}}, F_0^{\text{Parton-level}})$, $\mathbb{R}^2 \to \mathbb{R}^2$

W-helicity fractions – continued (preliminary)

- Also use different generator to get first handle on systematic uncertainties (`MadGraph5` at `LO`)
- Reweight alternative sample on parton-level to the nominal one
- Apply the interpolation from the nominal sample to check impact on the measurement

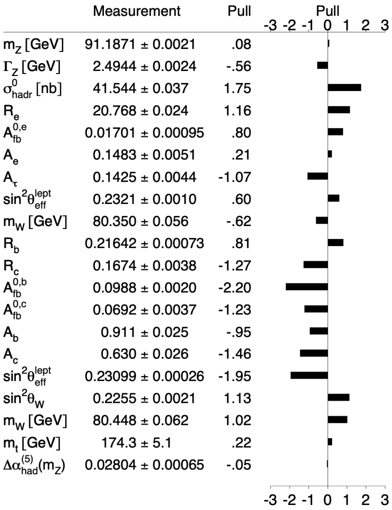




- Statistical precision of $\mathcal{O}(2 \cdot 10^{-3})$, systematic of $\mathcal{O}(10^{-2})$ (due to LO vs. NLO kinematic differences)

Heavy-quark measurements at the Z-pole

- Best suited at FCC-ee for rich heavy-quark programme? $\rightarrow Z$-pole with $N_Z = 5 \cdot 10^{12}$
- Coupling of the Z to b-quark probes fundamental SM parameters



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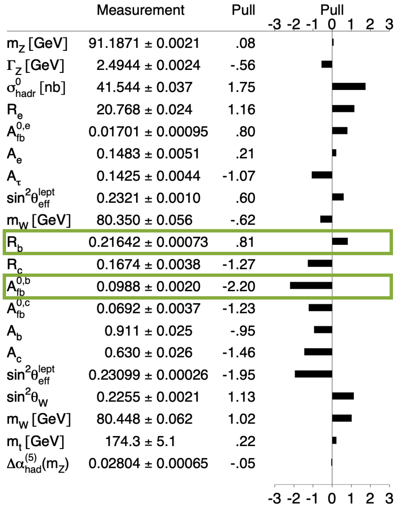
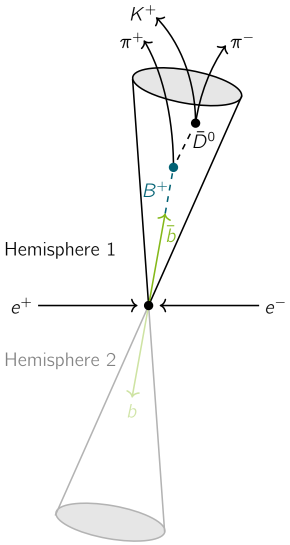
- Best suited at FCC-ee for rich heavy-quark programme?
  $\rightarrow$ Z-pole with $N_Z = 5 \cdot 10^{12}$
- Coupling of the Z to b-quark probes fundamental SM parameters
- Statistics allow for new ways: combining flavour and EWPO
  $\rightarrow$ Ultra pure beauty-flavour tagging

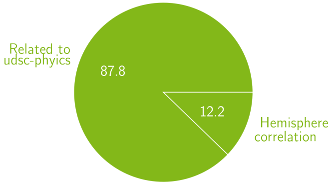


Principle of the measurement

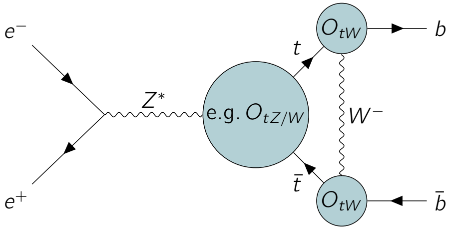
- Produce $Z \to q\bar{q}$ events at $\sqrt{s} = 91\,\mathrm{GeV}$
- Event topology: two back-to-back particle sprays (hemispheres)
- With $N_{Z\to q\bar{q}} = 5 \cdot 10^{12}$ events: measurements limited by $\sigma_{\text{syst.}}$
- Need to reduce $\sigma_{\text{syst.}}$ to $\mathcal{O}(\sigma_{\text{stat.}})$



Principle of the measurement: R_b



- Sensitive to **vertex corrections:** $R_b = \frac{\Gamma_{Z\to b\bar{b}}}{\Gamma_{Z\to q\bar{q}}}$



- **Single tag:** $N_1 = 2N_Z \cdot (R_b\,\varepsilon_b + R_c\,\varepsilon_c + R_{uds}\,\varepsilon_{uds})$
- **Double tag:** $N_2 = N_Z \cdot (R_b\,\varepsilon_b^2\,C_b + R_c\,\varepsilon_c^2\,C_c + R_{uds}\,\varepsilon_{uds}^2\,C_{uds})$
- N_1, N_2, N_Z counted, all other unknown: measure R_b and ε_b simultaneously
- Standard LEP tools (vertex charge, lepton tag): $\sigma_{\text{syst.}}$ dominated by *udsc*-misidentification

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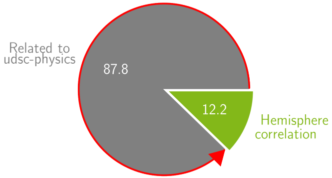
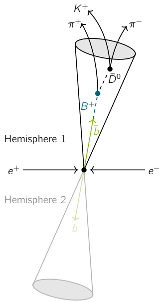


Proposal: b-hemisphere tagger

Hemisphere **flavour**- and **charge** tagging by exclusively reconstructing *b*-hadrons

- Potential purity of 100 %
- Efficiency of 1 %



$\rightarrow$ Expected $\sigma^{\text{stat.}}(R_b) = 2.2 \cdot 10^{-5}$

Setting the stage

- Exclusive b-tagger can play **central role** to reduce $\sigma^{\text{syst.}}$

	R_b
b-hadrons	$B^+, B_d^0, B_s^0, \Lambda_b^0$
Requirements	Flavour
Advantages	Remove *udsc*-physics contribution
Remaining $\sigma_{\text{syst.}}$	Hemisphere correlation C_b

- $\varepsilon_b \geq 1.11\,\%$ with > 200 b-hadron decay modes ✓
- Validate purity on $4 \cdot 10^7$ $Z \to q\bar{q}$ (`winter2023`) on 6/200 **representative modes** (varying $N_{\text{trk.}}$, N_{π^0})
  1. Fully charged, two tracks — $B^+ \to \bar{D}^0\pi^+ \to [K^+\pi^-]_{\bar{D}^0}\,\pi^+$
  2. Fully charged, three tracks — $B^+ \to \bar{D}^0 D_s^+ \to [K^+\pi^-]_{\bar{D}^0}\,[K^+K^-\pi^+]_{D_s^+}$
  3. Fully charged, four tracks — $B^+ \to \bar{D}^0\pi^+ \to [K^+2\pi^-\pi^+]_{\bar{D}^0}\,\pi^+$
  4. One π^0, two tracks — $B^+ \to \bar{D}^0\pi^+ \to [K^+\pi^-\pi^0]_{\bar{D}^0}\,\pi^+$
  5. Two π^0, two tracks — $B^+ \to \bar{D}^0\pi^+ \to [K^+\pi^-2\pi^0]_{\bar{D}^0}\,\pi^+$
  6. Two leptons — $B^+ \to J/\psi\,K^+ \to [\ell^+\ell^-]_{J/\psi}\,K^+$

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Reconstruct exemplarily →

1. Fully charged, two tracks $B^+ \to \bar{D}^0\pi^+ \to [K^+\pi^-]_{\bar{D}^0}\,\pi^+$
2. Fully charged, three tracks $B^+ \to \bar{D}^0 D_s^+ \to [K^+\pi^-]_{\bar{D}^0}\,[K^+K^-\pi^+]_{D_s^+}$
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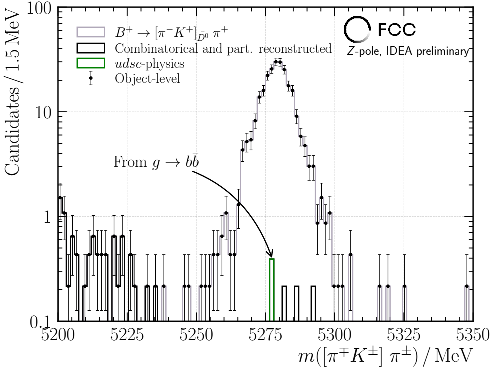
Exclusive b-hadron reconstruction

Fast Simulation (IDEA)

- Combine K and π (100 % particle-ID) tracks to D^0 candidates (emulate 50 μm vertex resolution)
- D^0 candidates + π track to B^+ candidate: cut on B^+ **flight distance** of 300 μm (boost of ~ 6)
- Observable to quantify **purity**: invariant b-hadron mass spectrum with $E_B > 20$ GeV



- First: focus on **mass-peak region** to get control on $\sigma^{\text{syst.}}$
  $\to$ Purity of 99.8 %, contamination in signal region from $q \to q + [b\bar{b}]_g$

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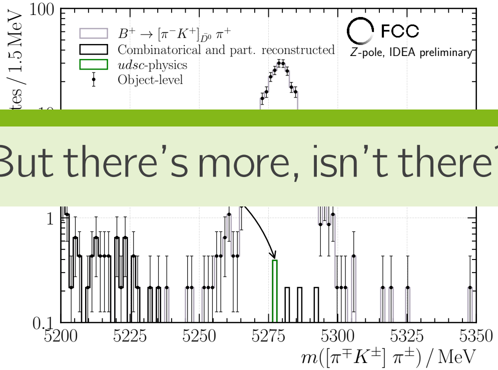

But there's more, isn't there?

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Exclusive b-hadron reconstruction

Fast Simulation (IDEA)

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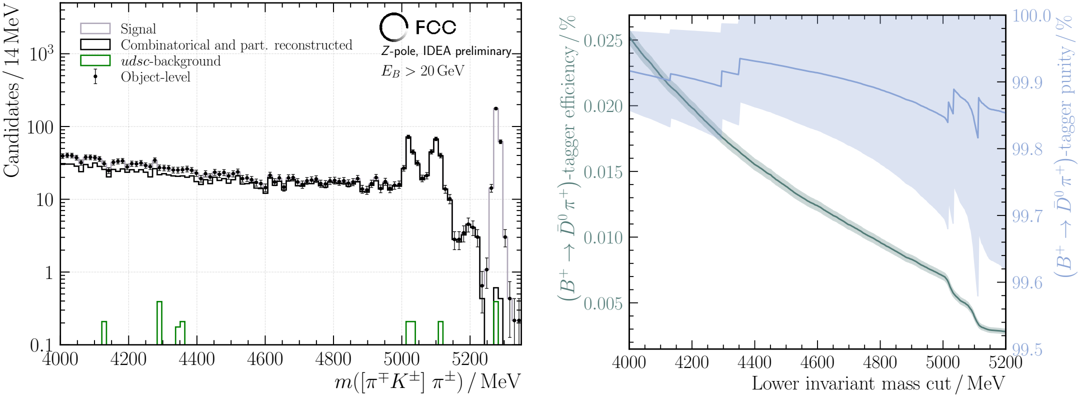
- D^0 candidates + … oost of ~ 6)

But there's more, isn't there? Yes!

- Observable to quantify **purity**: invariant b-hadron mass spectrum with $E_B > 20$ GeV

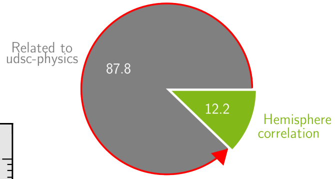


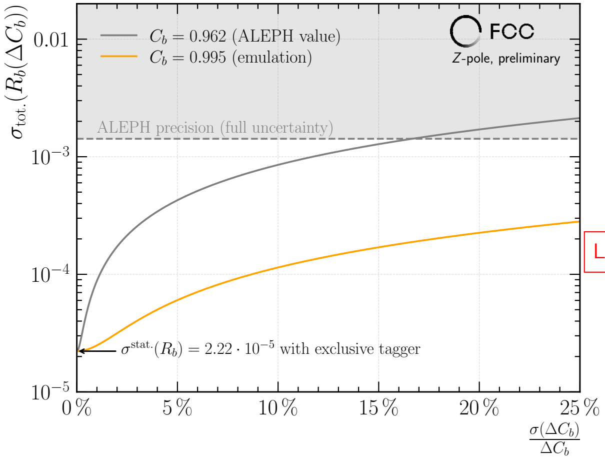
- Part. reconstructed are no background! $\rightarrow$ **efficiency gain** by enlarging mass window to no loss in purity!
- **But for now:** Examine B^+ candidates in mass-peak region

Systematic uncertainty: importance of C_b

$$N_1 = 2\, R_b\, \varepsilon_b\, N_Z$$
$$N_2 = R_b\, \varepsilon_b^2\, C_b\, N_Z$$

- Ultra-pure: hemisphere correlation dominating systematic uncertainty
  → Quantifies dependence of **tagging efficiencies in the two hemispheres**:
  → $C_b = \frac{\varepsilon_{b\bar{b}}}{\varepsilon_b \cdot \varepsilon_{\bar{b}}}$
- Control over $\Delta C_b = 1 - C_b$ crucial for R_b measurement!



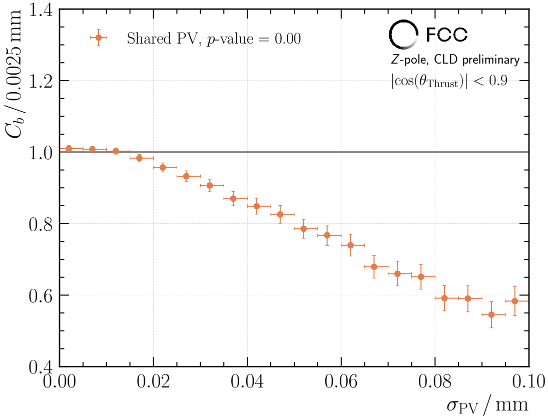


LEP+SLD $\mathcal{O}(\sigma_{\text{tot.}}(R_b)) = 10^{-4}$

Hemisphere correlation: PV measurement uncertainty

Full Simulation (CLD)

- LEP found: C_b mainly departed from 1 because of **primary-vertex measurement uncertainty** σ_{PV}



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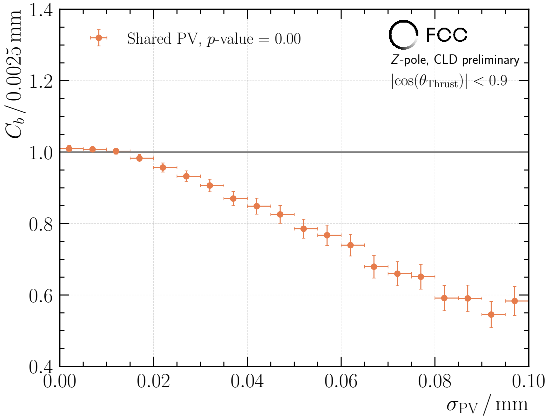
- Sample: 10^6 FullSim CLD events of $B^+ \to [K^+\pi^-]_{\bar{D}^0}\pi^+$ (forcing both legs with `EvtGen`)



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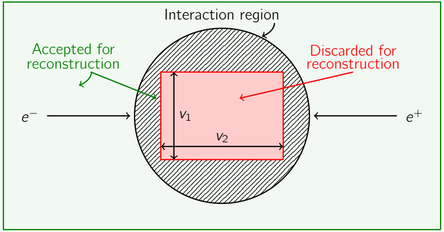
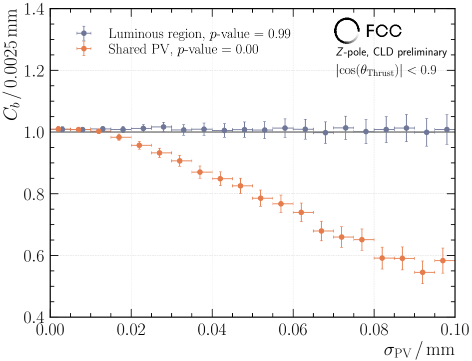
- Here: select tracks for reconstruction by using optimised cuts (v_1 and v_2) in **luminous region**





- $C_b^{\text{PV}} = 0.978 \pm 0.003$ vs. $C_b^{\text{Luminous region}} = 1.009 \pm 0.003$

Results: R_b uncertainty budget

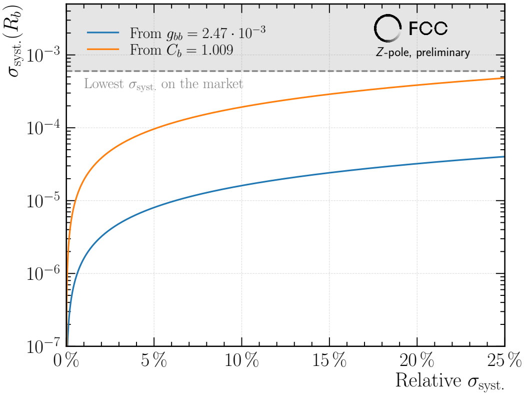
Full Simulation (CLD)

- So far: systematic uncertainty considered
  - Hemisphere correlation: $C_b = 1.009 \pm 0.003 \Rightarrow \frac{\sigma(\Delta C_b)}{\Delta C_b} \approx 33\,\%$

Results: R_b uncertainty budget

Full Simulation (CLD)

- So far: systematic uncertainty considered
  - Hemisphere correlation: $C_b = 1.009 \pm 0.003 \Rightarrow \frac{\sigma(\Delta C_b)}{\Delta C_b} \approx 33\,\%$
  - Signal region contamination from gluon splitting: $g_{b\bar{b}} = (2.47 \pm 0.56) \cdot 10^{-3} \Rightarrow \frac{\sigma(g_{b\bar{b}})}{g_{b\bar{b}}} \approx 23\,\%$
- **Target:** $\sigma^{\text{stat.}}(R_b) = 2.2 \cdot 10^{-5}$ with exclusive tagger and $\varepsilon_b = 1\,\%$



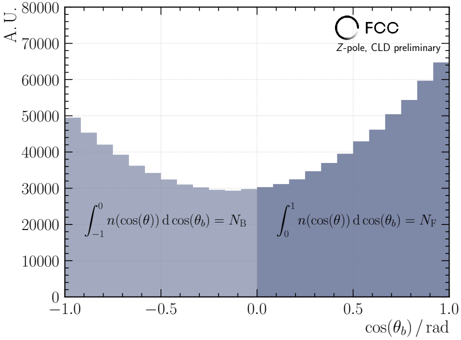
	Luminous region
Current syst. precision	$\sigma^{\text{tot.}}(R_b) = 6.4 \cdot 10^{-4}$
1 % syst. precision	$\sigma^{\text{tot.}}(R_b) = 2.9 \cdot 10^{-5}$

→ C_b dominating uncertainty

Extension for the measurement of A_{FB}^{b}

- We have an **ultra pure tagger** at hand: what else?
- As seen: exclusive b-tagger can play central role to reduce $\sigma^{\mathrm{syst.}}$
- Especially interesting for $A_{\mathrm{FB}}^{b} = \frac{N_{\mathrm{F}}-N_{\mathrm{B}}}{N_{\mathrm{F}}+N_{\mathrm{B}}}$

  → Expected $\sigma_{\mathrm{stat.}}(A_{\mathrm{FB}}^{b}) = 1.05 \cdot 10^{-5}$ (current: $\sigma_{\mathrm{tot.}}(A_{\mathrm{FB}}^{b}) = 1.6 \cdot 10^{-3}$)

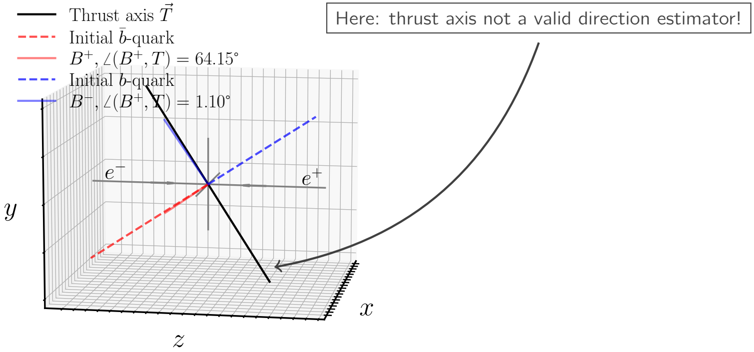


	R_b	A_{FB}^{b}
b-hadrons Requirements	$B^{+}, B_d^0, B_s^0, \Lambda_b^0$ Flavour	B^{+}, Λ_b Flavour, $\vec{p}$ & Q
Advantages	Remove $udsc$-physics contribution	Remove $udsc$-physics contribution **Overcome mixing dilutions** and possibly reduce hemisphere confusion
Remaining $\sigma_{\mathrm{syst.}}$	Hemisphere correlation C_b	QCD corrections

Full Simulation (CLD)

Systematic uncertainty of A_{FB}^b

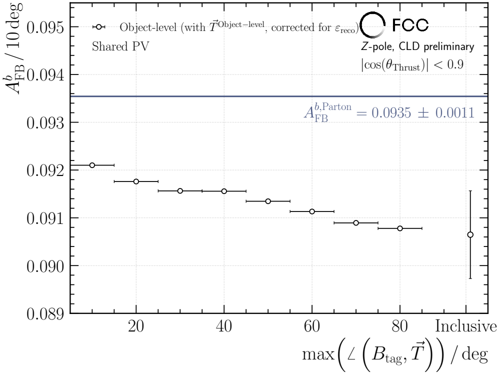
- Dominant systematic uncertainty: (hard) **gluon radiation** from *b*-quark (up to hemisphere confusion)
- Since *b*-quark direction not directly accessible: use **thrust** $\vec{T}$
- Direction of reconstructed *b*-hadron: **estimator for gluon emission quantity**
- The smaller the angle $\angle(\vec{B}_{\text{tag}}, \vec{T})$, the softer is the gluon radiation



Full Simulation (CLD)

Gluon radiation estimator: $\angle(\vec{B}_{\text{tag}}, \vec{T})$

- Quantify the amount of gluon radiation by $\angle(\vec{B}, \vec{T})$
- Cut on maximally allowed angle reduces QCD-related effects by 50 %



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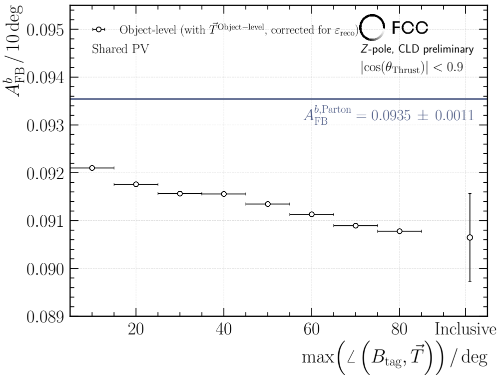
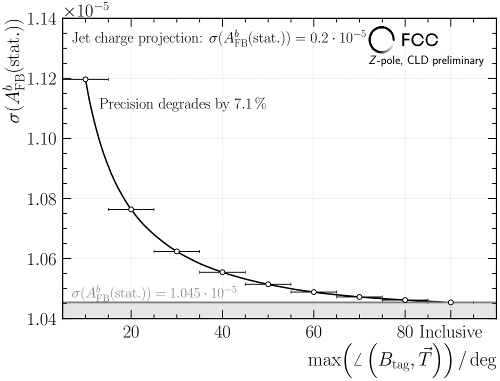
- Cut on maximally allowed angle reduces QCD-related effects by 50 %
- Slight degradation of statistical precision ($\sim 7\,\%$) to $\boxed{\sigma_{\text{stat.}} = 1.12 \cdot 10^{-5}}$ (Z-pole extrapolation)





→ $\sigma_{\text{syst.}}$ WIP by varying b-fragmentation fraction, renormalisation scale & parton shower model