Impact of Advances in Detector Techniques on Higgs Measurements at Future Higgs Factories

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CLUSTER OF EXCELLENCE
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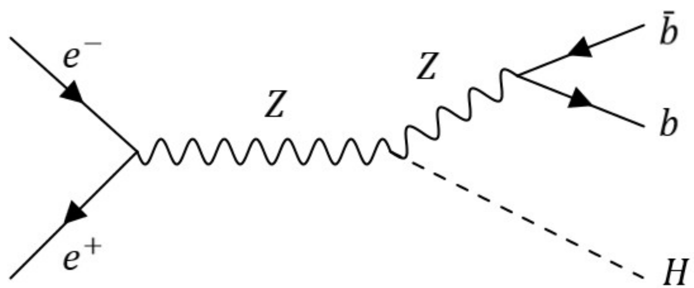
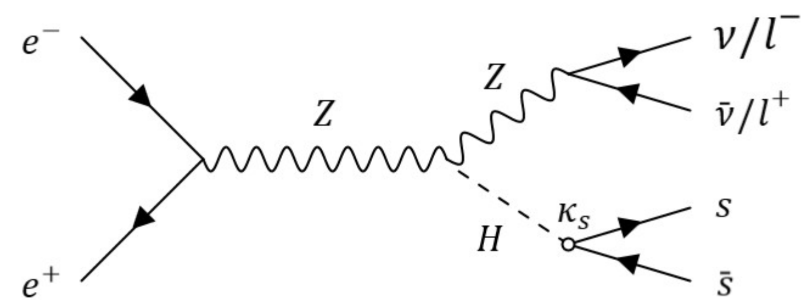
HELMHOLTZ

DESY.

Motivation

- Most of the low-hanging fruit in Higgs analyses have been picked, focus on more challenging channels → b, c, s jets
- Develop new methods and algorithms to utilise each Higgs event as well as possible!
- Inform detector development and requirements

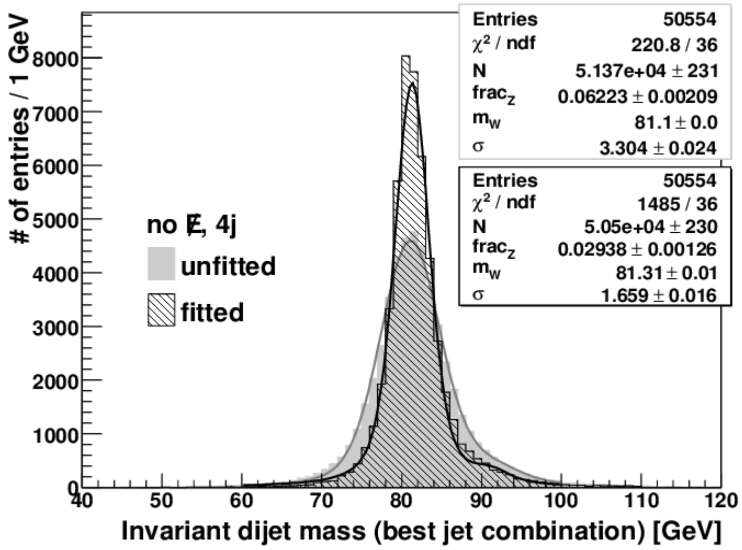




Kinematic Fitting

- Re-assess each event (and e.g. reco inv. mass) by using
- 1. uncertainties on each individual outoing object, e.g. jet or isolated lepton
- 2. constraints unique to e+e- colliders:
  - $\sum_{i=1}^{4} E_i = 500 \text{ GeV}$
  - $\sum_{i=1}^{4} p_{x,i} = 0 \text{ GeV}, \sum_{i=1}^{4} p_{y,i} = 0 \text{ GeV}, \sum_{i=1}^{4} p_{z,i} = 0 \text{ GeV}$ *
- 3. constraints given by the specific analysis, e.g.:
  - $M(j_1, j_2) = M(j_3, j_4)$

$e^+e^- \rightarrow u\bar{d}d\bar{u}$
full ILD reco at E_{cm} = 500 GeV

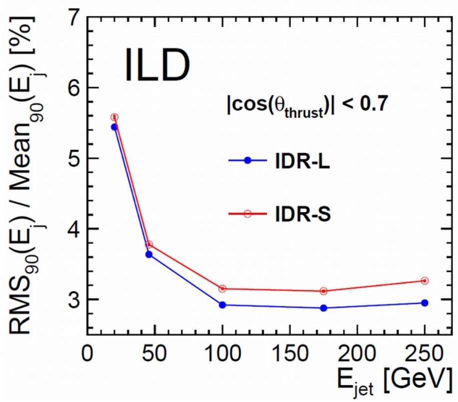


[LC-TOOL-2009-001
https://bib-pubdb1.desy.de/record/88030]

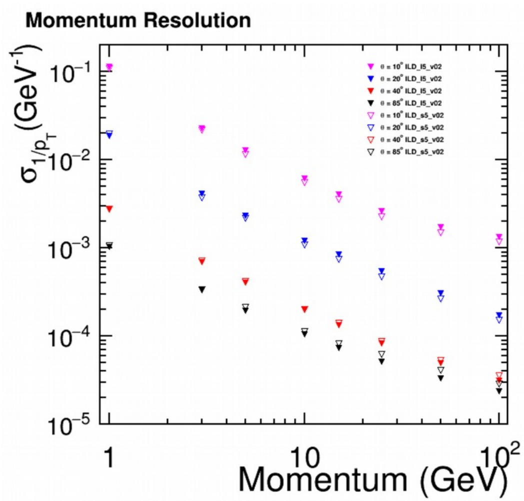
* modulo small opening angle of colliding beams

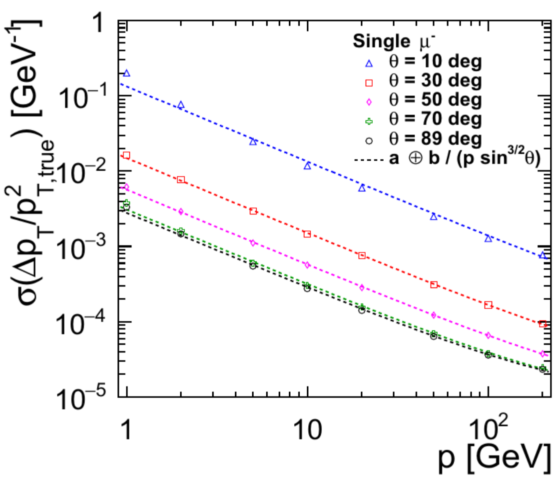
Kinematic Fitting: Detector Requirements

- Need excellent jet energy resolution with full uncertainties
  - → Particle Flow detector
    - → low material budget tracker
    - → high granularity calorimeter
- Need very good single particle res. in both tracker and calorimeter



Side note: this applies also at relatively low momenta, where the relative momentum resolution is dominated by multiple scattering!



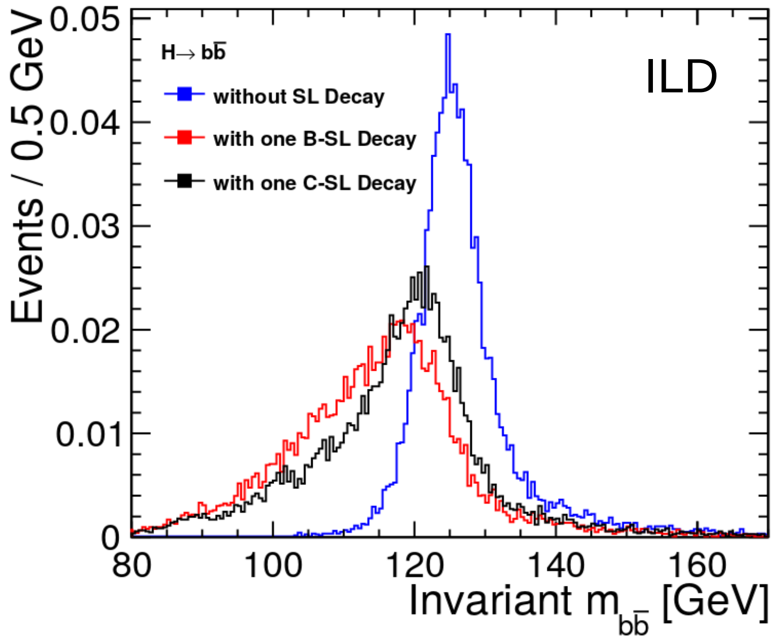


[left, top: ILD IDR 2020
https://arxiv.org/abs/2003.01116]

[right: CLD, FCC-ee CDR 2019
https://doi.org/10.1140/epjst/e2019-900045-4]

Neutrino Correction in Semi-Leptonic Decays

- In $H \rightarrow b\bar{b}$, but also $ZH \rightarrow b\bar{b} + X$
- B- and D-mesons can decay semileptonically (SLD) including a neutrino
  2/3 of $b\bar{b}$-systems have at least 1 SLD
- Significantly worsens reconstructed invariant mass
- Find b- (or c-) jet
- Reconstruct 4-momentum of neutrino by
  - finding its brother lepton (e/μ)
  - finding its mother (= B/D decay) vertex



[https://arxiv.org/abs/2105.08480]

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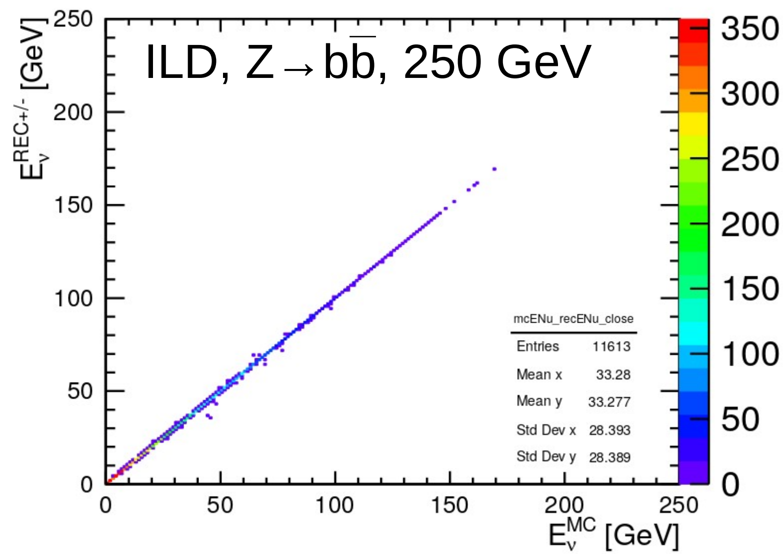
- Works alone up to sign ambiguity, here the better of the two solutions is shown



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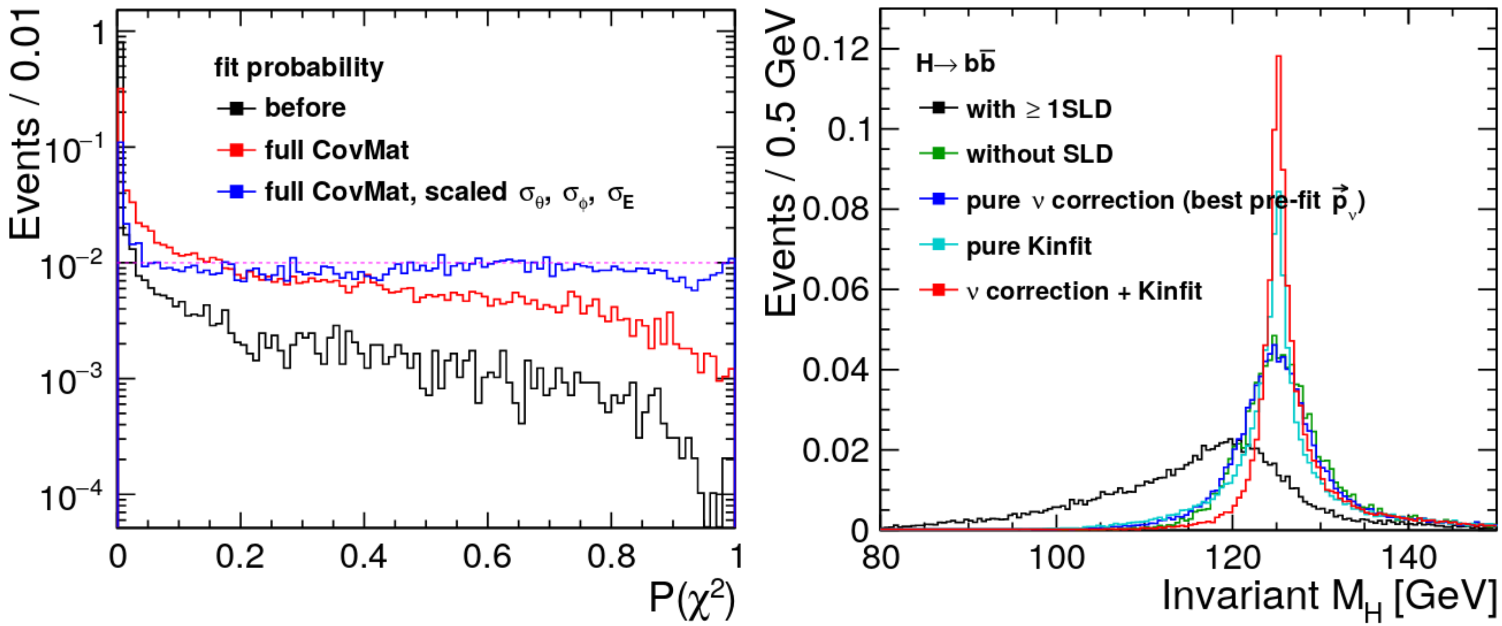
Kinematic Fit + Neutrino Correction

- Implementing full covariance matrix of measurement uncertainties drastically improves fit probability, allows to scale individual contributions to match flat distribution
- Neutrinos correction negates effect of SLD
- Together with kinematic fit allows for much narrower reconstructed Higgs mass



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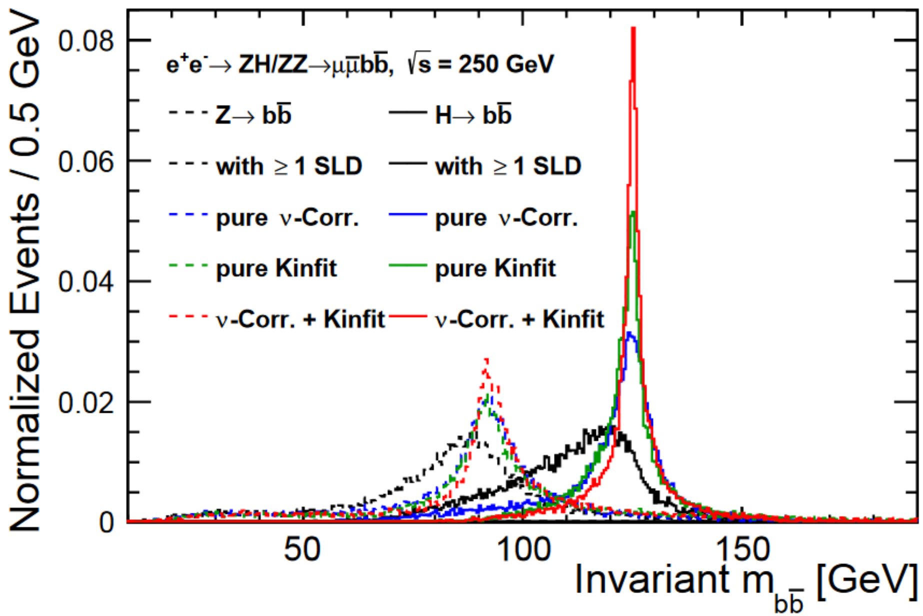
Kinematic Fit + Neutrino Correction

- Implementing full covariance matrix of measurement uncertainties drastically improves fit probability, allows to scale individual contributions to match flat distribution
- Neutrinos correction negates effect of SLD
- Together with kinematic fit allows for much narrower reconstructed Higgs mass and separation from background from Z



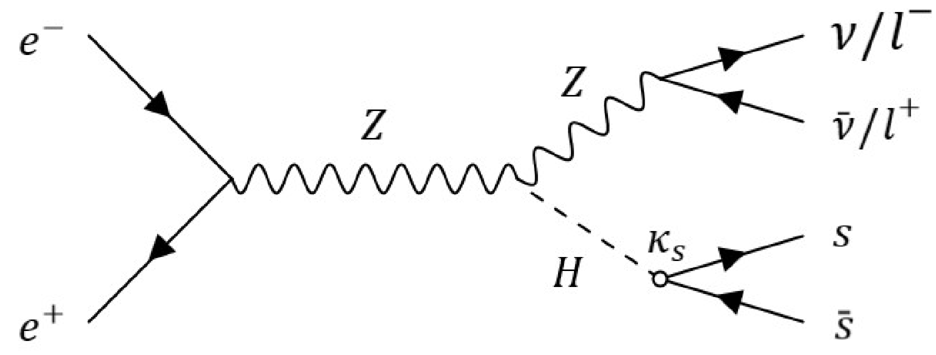
[https://arxiv.org/abs/2110.13731]

Neutrinos Correction: Detector Requirements

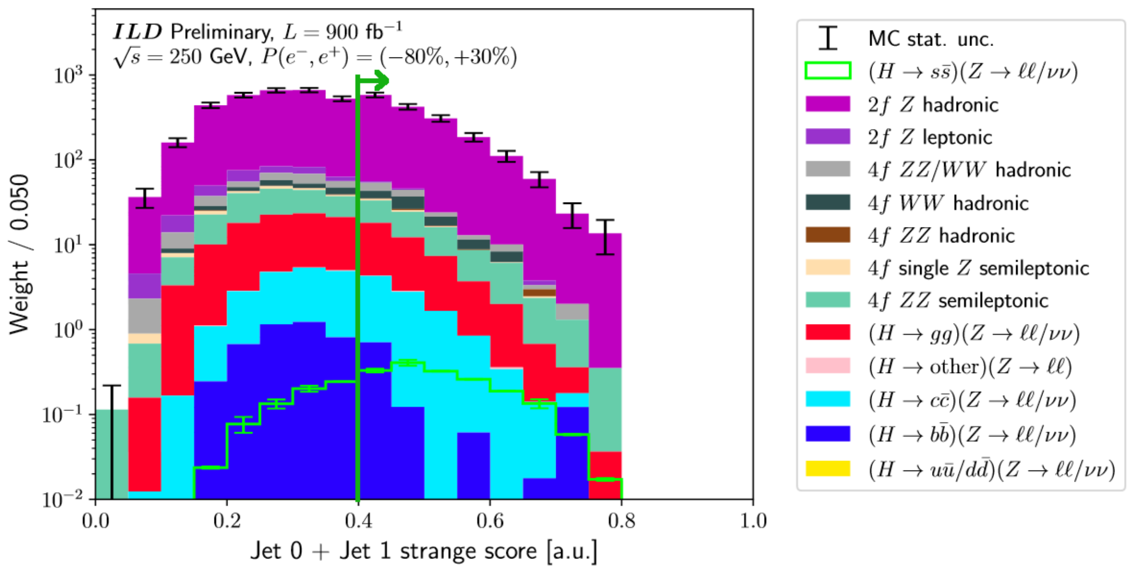
- Find all visible energy: ~ 4π hermeticity, high tracking efficiency at low momenta
- Flavour tagging and B/D-vertex reconstruction:
  - excellent vertex detector
  - hadron PID → high momentum kaons indicate
- Find electrons and muons: e,μ-ID
  - both already very good with low material tracker and dedicated ECal and muon chamber
  - additional PID for electrons via dedicated PID systems pushes efficiency
  - e-ID via bremsstrahlung reconstruction

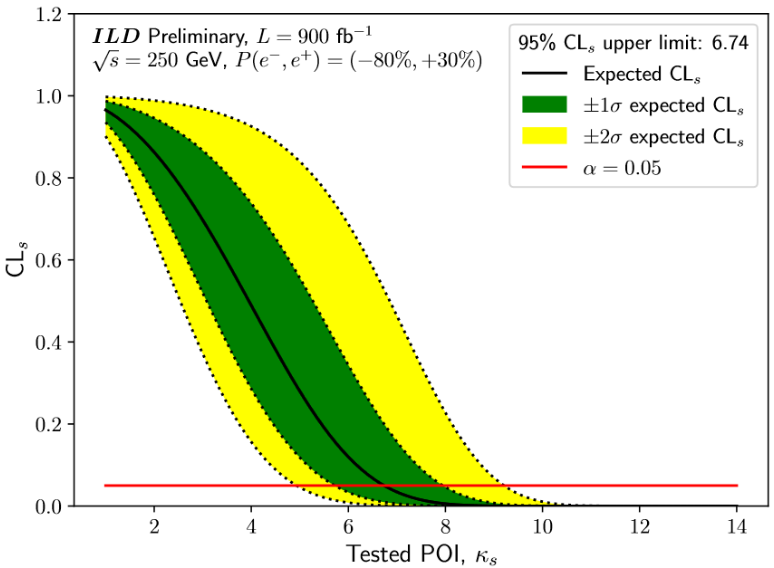
Higgs to strange

- Measure Higgs to strange coupling
- Utilize new strange tagger using $K^{\pm}$, K^0_S, Λ^0
  → allows to cut background by factor 3
- Results in upper limit on $\kappa_s < 6.7$



[https://arxiv.org/abs/2203.07535]





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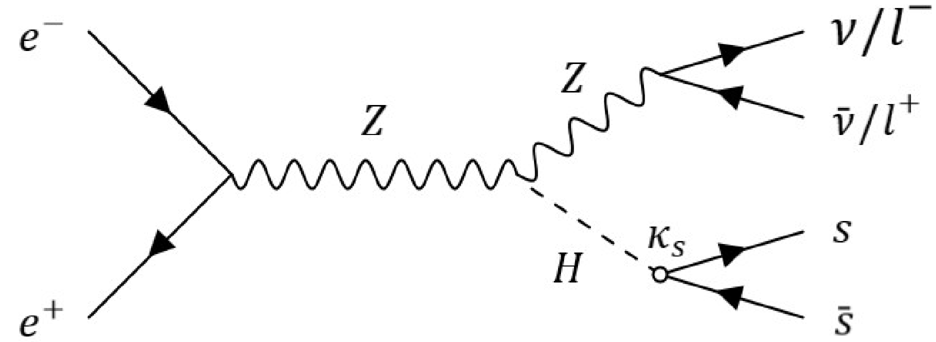

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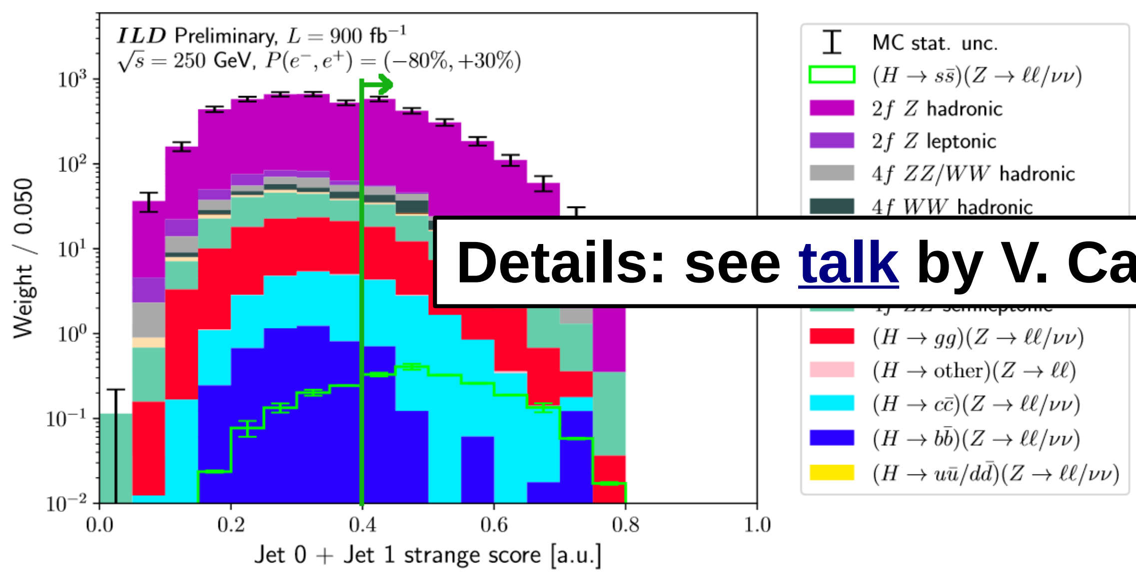
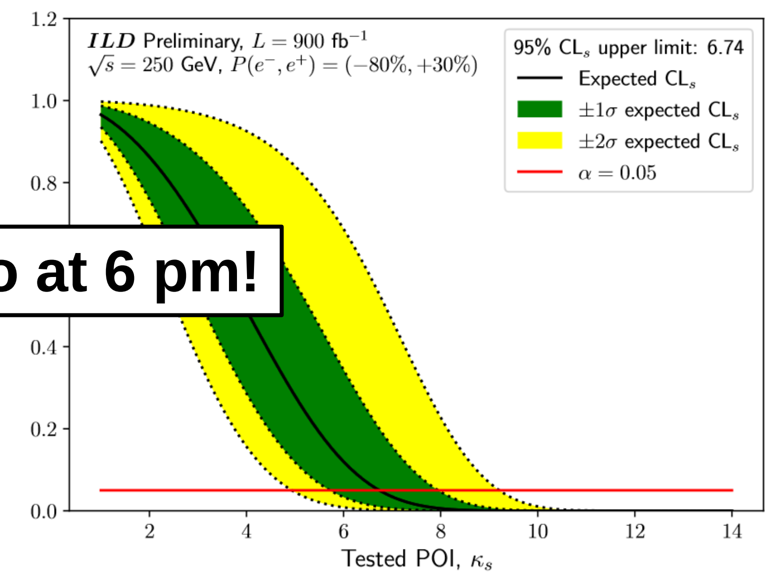


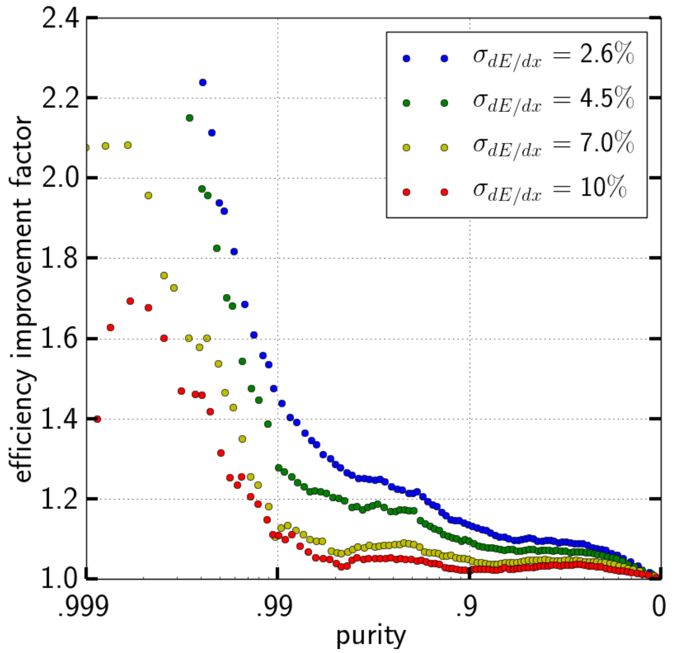
Details: see talk by V. Cairo at 6 pm!



Hadronic W and Z decays

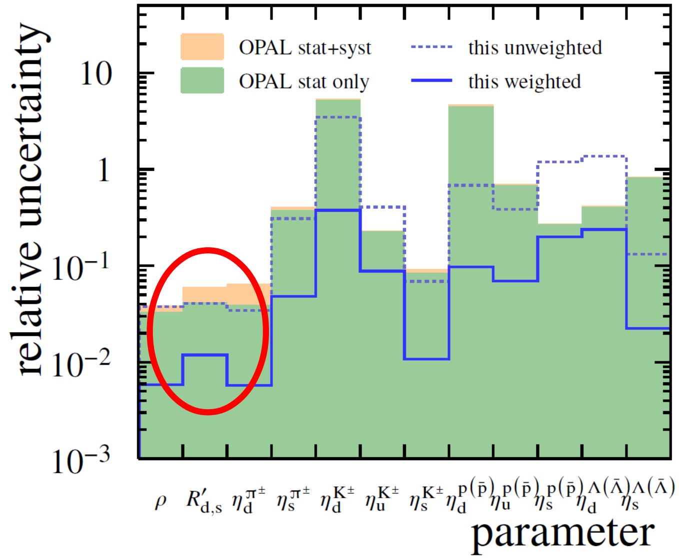
- Side note: strange tagging can also be used to tag hadronic decays of W and Z in order to measure their coupling to quarks → test SM, bread & butter at LEP

W → c+s vs. u+d separation via BDT improves with better dE/dx resolution



Measurement of Z → d/s via simultaneous fit of hadronisation fractions

[https://ediss.sub.uni-hamburg.de/handle/ediss/9634]

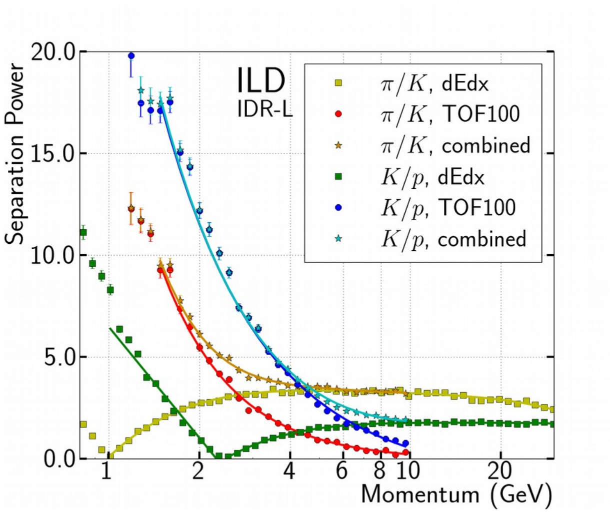


- Excellent vertexing for b/c veto
- Identify $K^{\pm}$, K^0_S, Λ^0

  → kaon / charged hadron PID

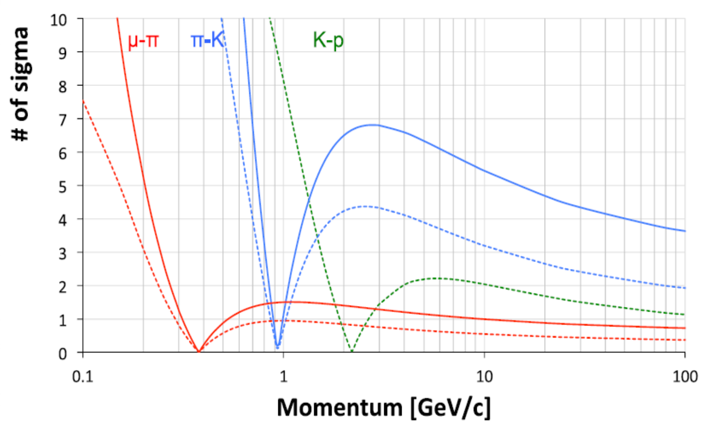
  → V0 finding → benefits from continuous tracker

TPC: dE/dx (dN/dx?)
ECal: TOF



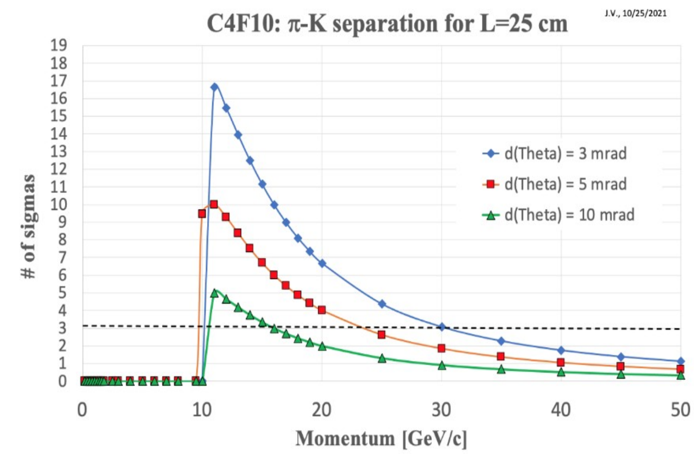
[ILD IDR 2020 https://arxiv.org/abs/2003.01116]

DC: dE/dx or dN/dx



[IDEA, FCC-ee CDR 2019 https://doi.org/10.1140/epjst/e2019-900045-4]

RICH



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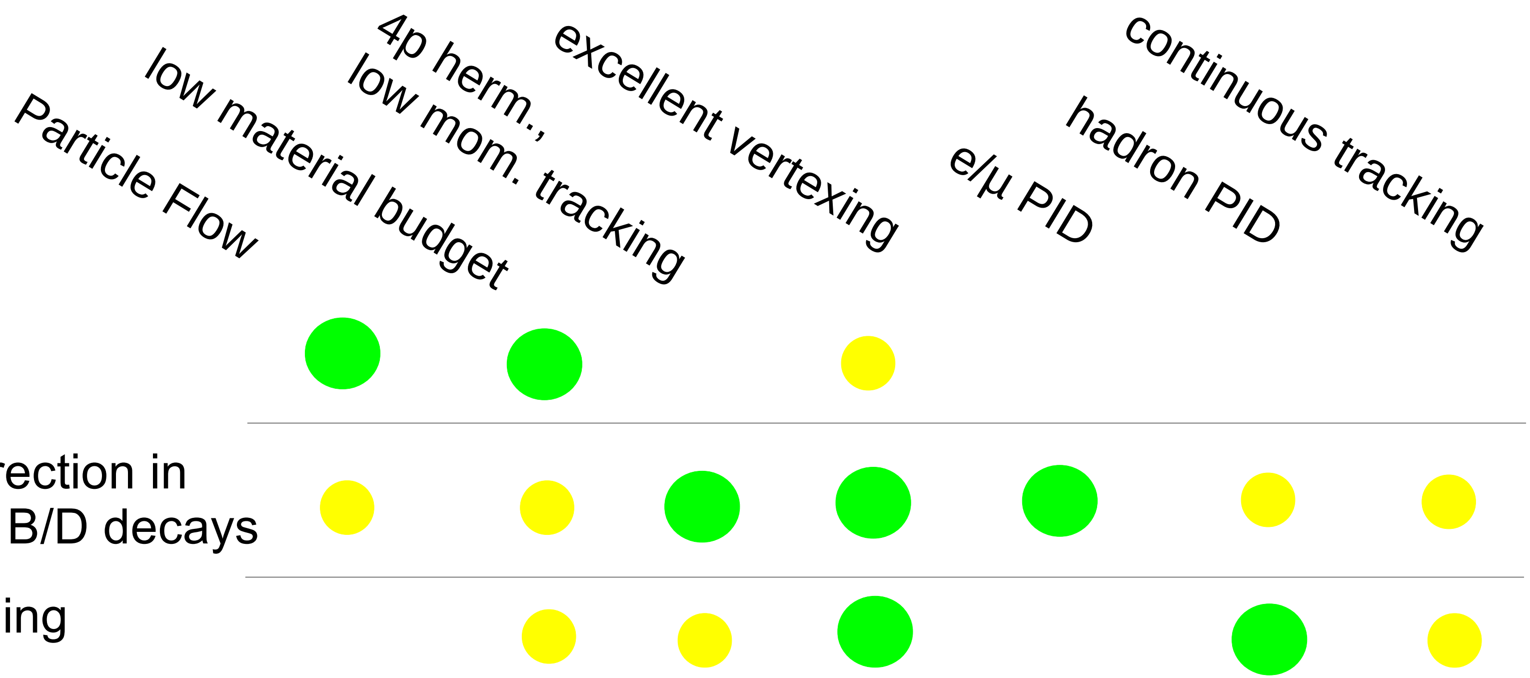
Summary

- In order to utilise precious collisions and precise detectors, new methds and algorithms have been and are being developed and inform detector requirements



- Kinematic fit
- Neutrino correction in semileptonic B/D decays
- Strange tagging