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

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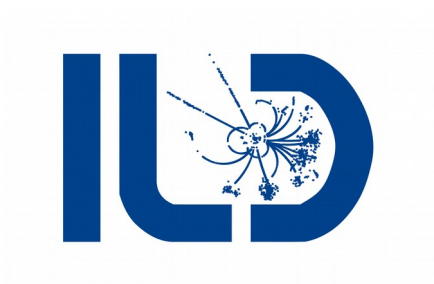
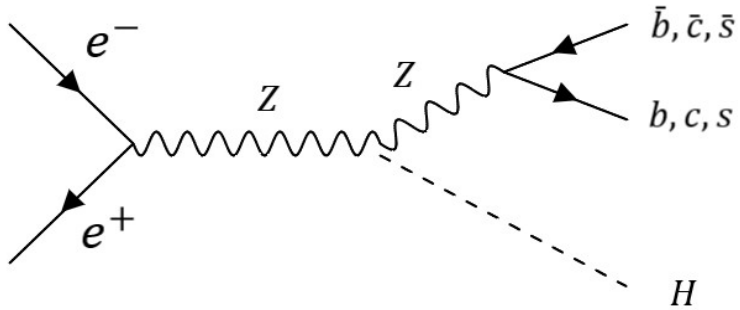


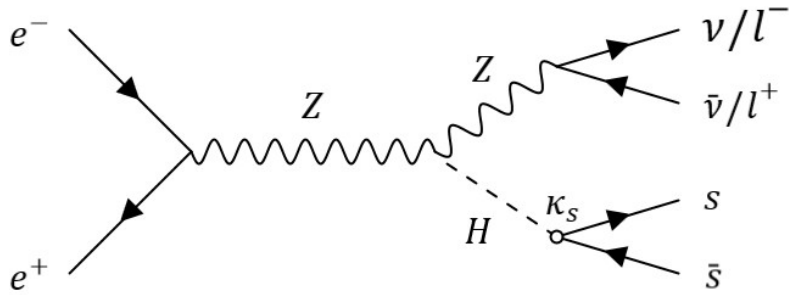
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

HELMHOLTZ

Motivation

- 3 new algorithms developed to utilise the clean and precise detector data at e^+e^- FHF
  → ILC, CLIC, FCC-ee, CEPC, etc.
  - ErrorFlow
  - Neutrino Correction
  - Strange Tagging
- They apply (mostly) to b, c and s-jets → Higgs decay modes or background (Z)
- New algorithms inform detector development and requirements





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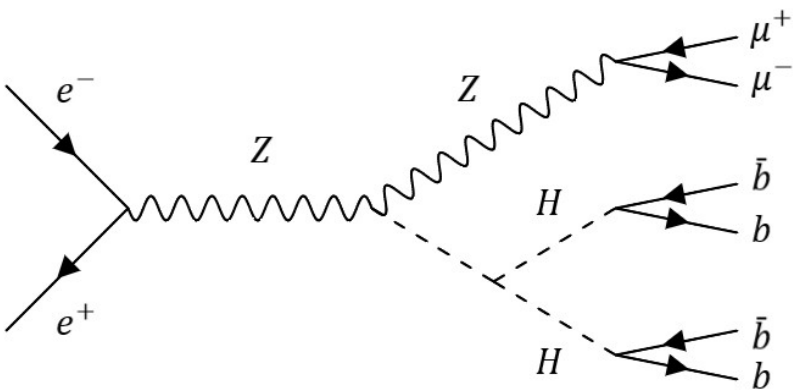
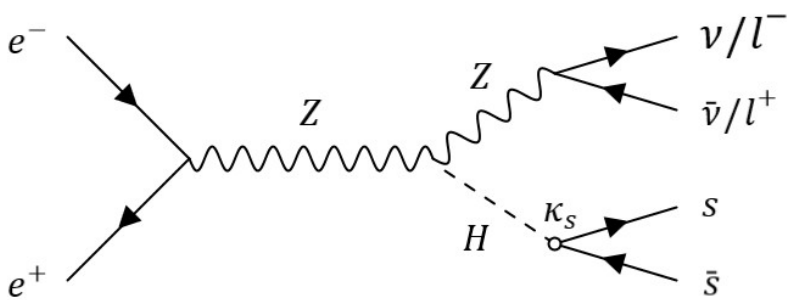
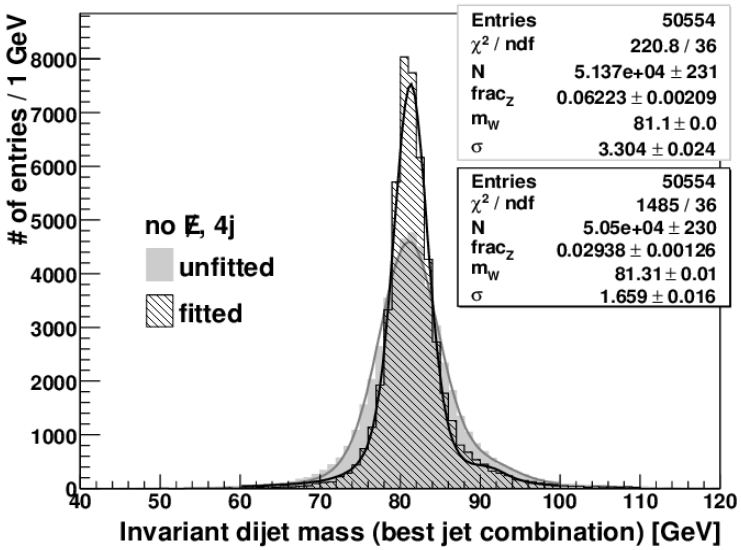




Kinematic Fitting & ErrorFlow

- 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

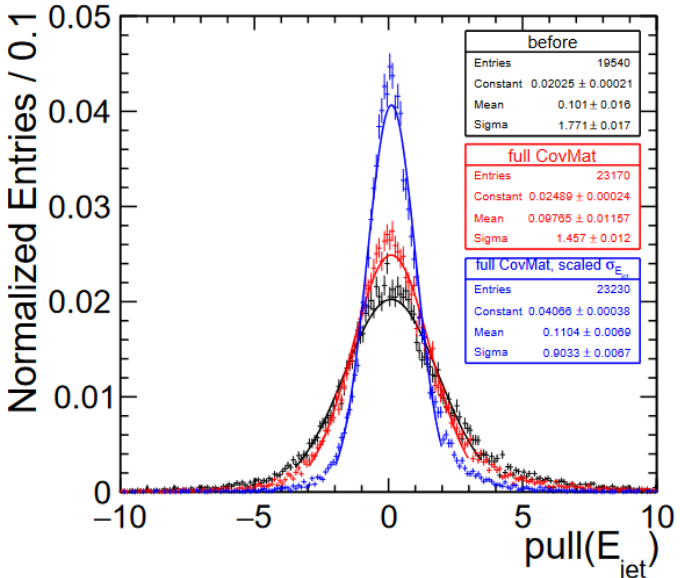


[LC-TOOL-2009-001
https://bib-pubdb1.desy.de/record/88030]

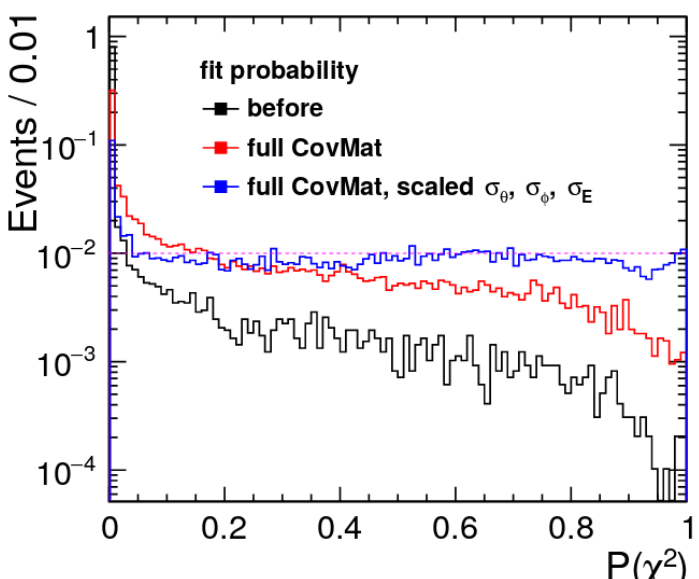
* modulo small opening angle of colliding beams

ErrorFlow

- Instead of using generic jet energy resolution: calculate energy uncertainty for each indiviual jet using error propagation from individual particles via covariance matrix
- Key: well-known uncertainties, particularly wrt. each other
- Different contributions (charged vs. neutral component) and coordinates (p_x, p_y, p_z, E) can be scaled individually to Gaussian pulls



$$pull(x) = \frac{x_{fitted} - x_{measured}}{\sqrt{\sigma^2_{fitted} - \sigma^2_{measured}}}$$



[https://agenda.linearcollider.org/event/9140/]

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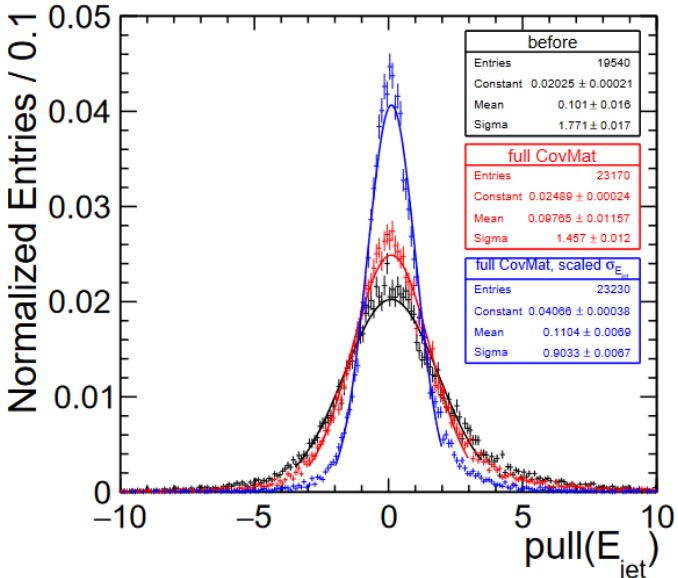

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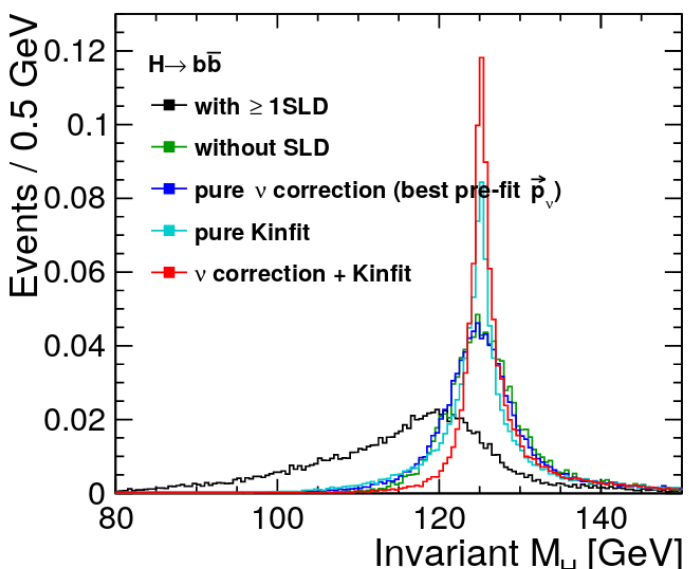

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ErrorFlow: Detector Requirements

- Need excellent jet energy resolution with full uncertainties of each particle

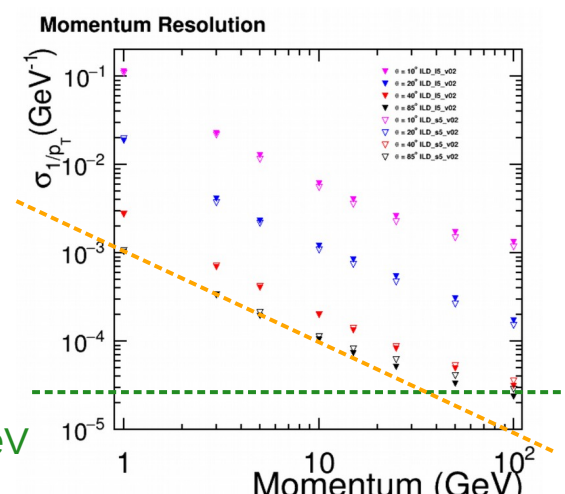
  → Particle Flow detector: low material budget tracker, high granularity calorimeter

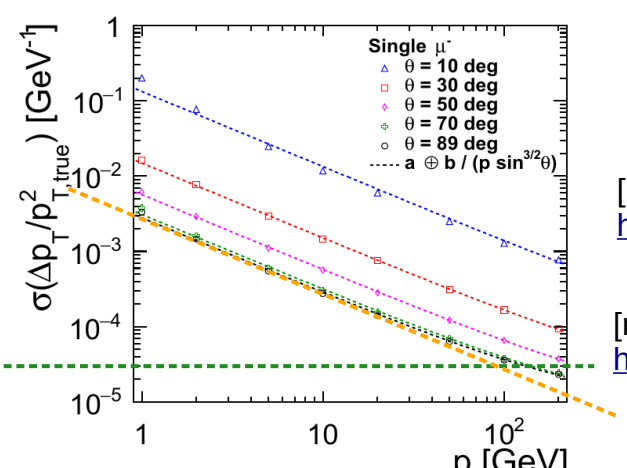
- Need very good single particle res. in both tracker and calorimeter

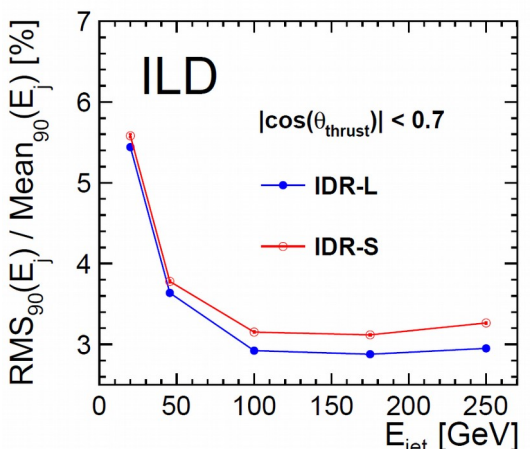
  Side note: this applies also at relatively low momenta, where the relative momentum resolution is dominated by multiple scattering!

multiple scattering mom. res. $O(10^{-3})$

asymptotic mom. res. $O(10^{-5})$ /GeV





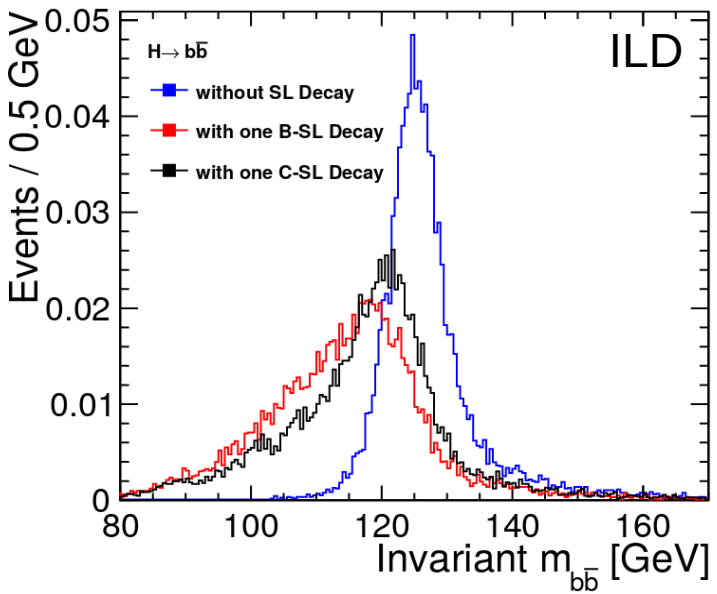


[left, top: ILD IDR 2020 https://arxiv.org/abs/2003.01116]

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

Neutrino Correction in Semi-Leptonic Decays

- B- and D-mesons can decay semileptonically (SLD) including a neutrino, 2/3 of $b\bar{b}$-systems have at least 1 SLD
- Invisible energy 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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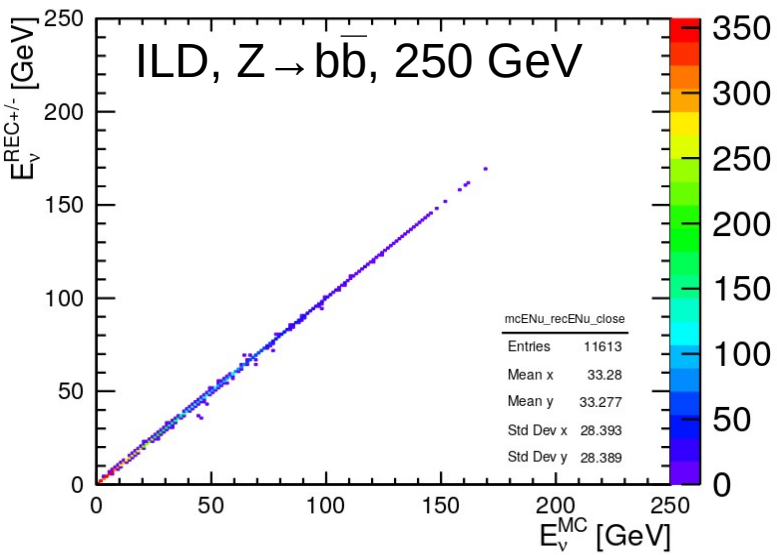
- Works alone up to sign ambiguity, here the better of the two solutions is shown



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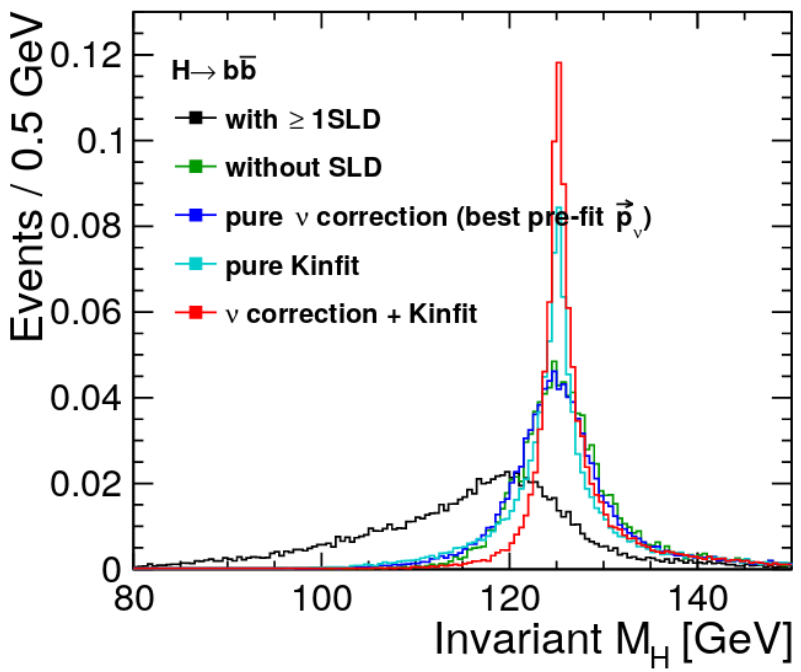
Kinematic Fit + Neutrino Correction

- Neutrinos correction mitigates effect of SLD
- Together with kinematic fit allows for much narrower reconstructed Higgs peak



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Kinematic Fit + Neutrino Correction

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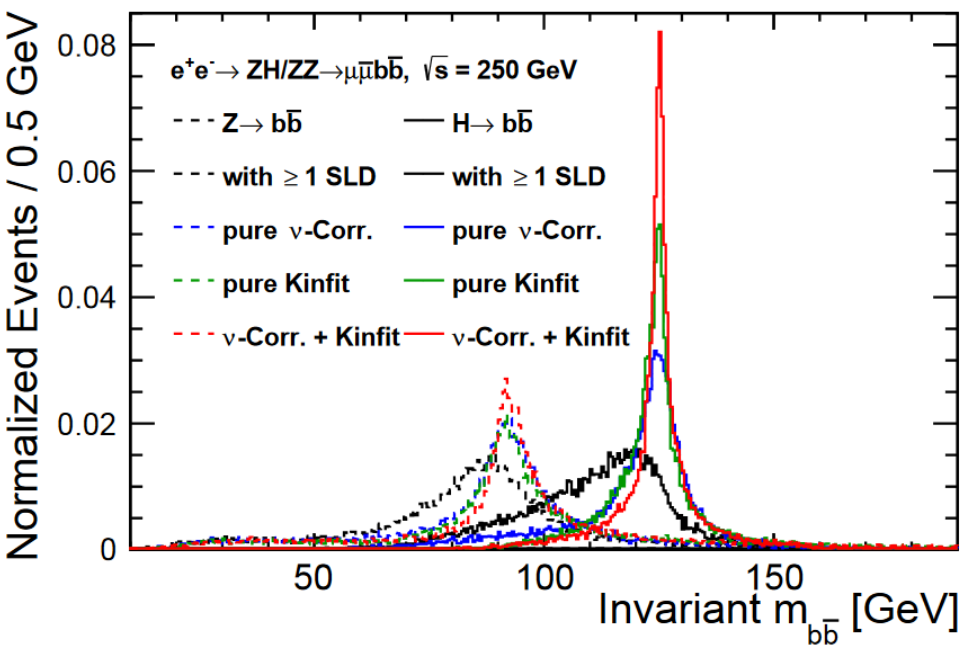
- Together with kinematic fit allows for much narrower reconstructed Higgs peak and separation from background from Z



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

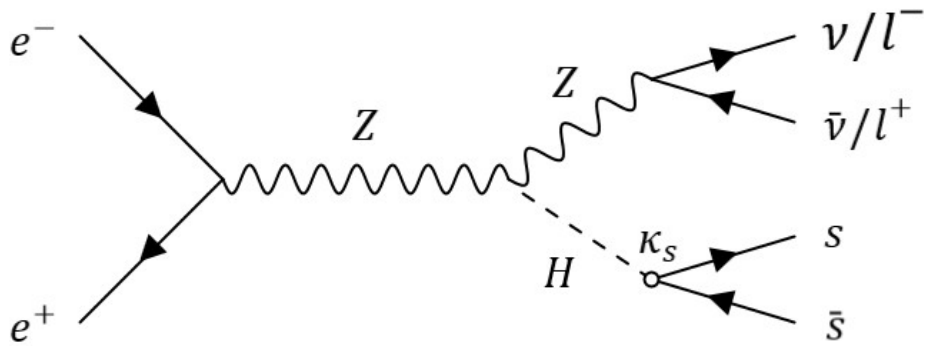
Neutrinos Correction: Detector Requirements

- 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

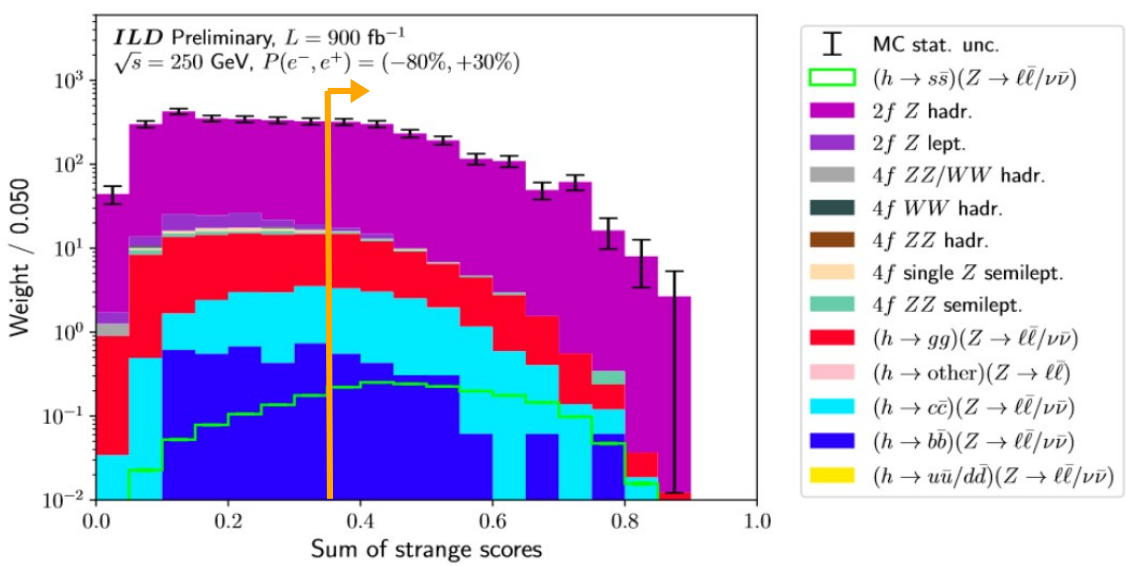
Strange Tagging

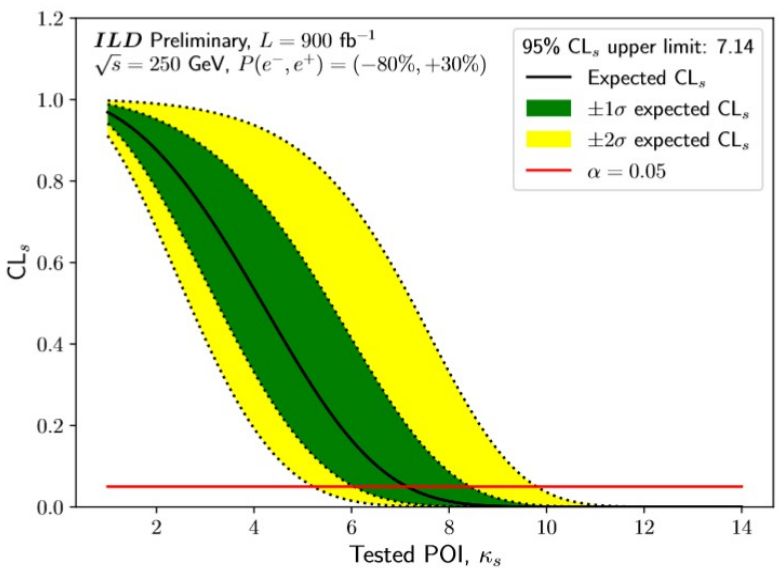
- Measure Higgs to strange coupling
- Utilize new strange tagger using $K^{\pm}$, K^0_S, Λ^0

  → allows to cut background by factor 3
- Results in upper limit on $\kappa_s < 7.1$



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





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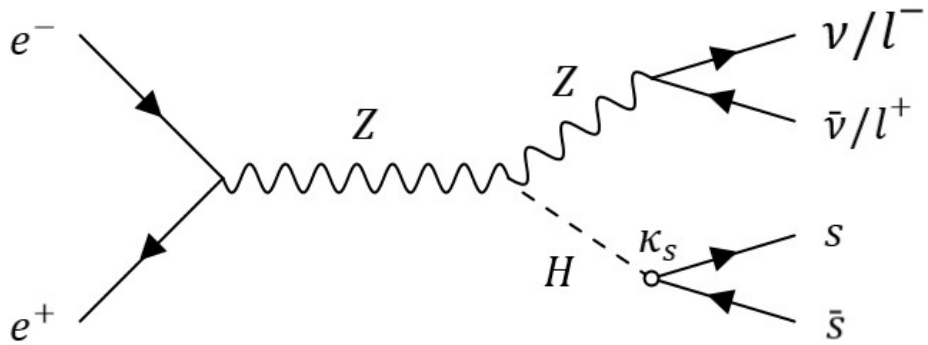

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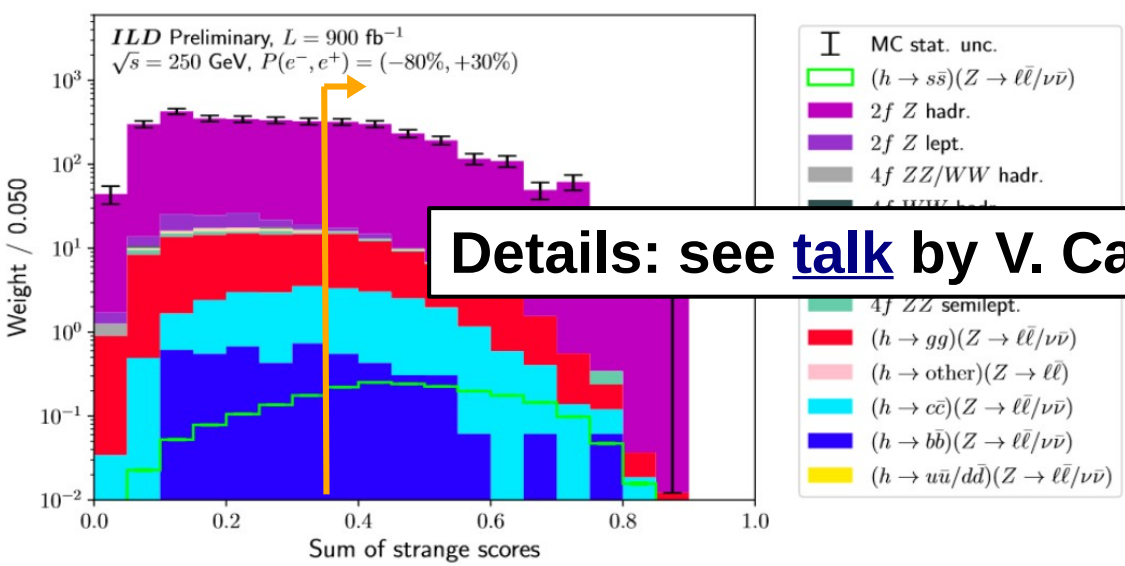
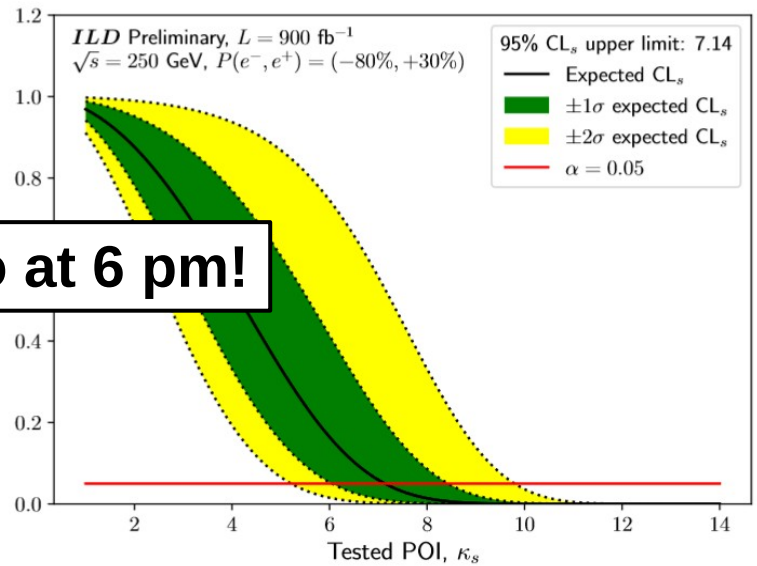


Details: see talk by V. Cairo at 6 pm!

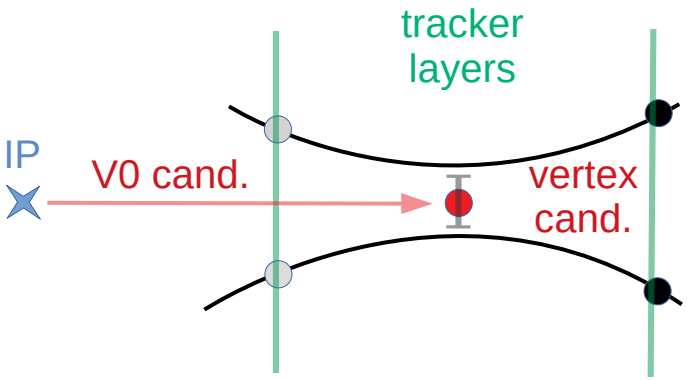


Strange Tagging: Detector Requirements

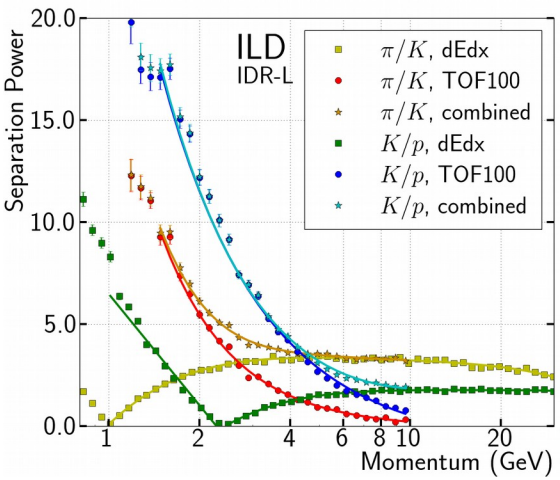
- Excellent vertexing for b/c veto
- Identify $K^{\pm}$, K^0_S, Λ^0

  → kaon / charged hadron PID

  → V0 finding → benefits from continuous tracker

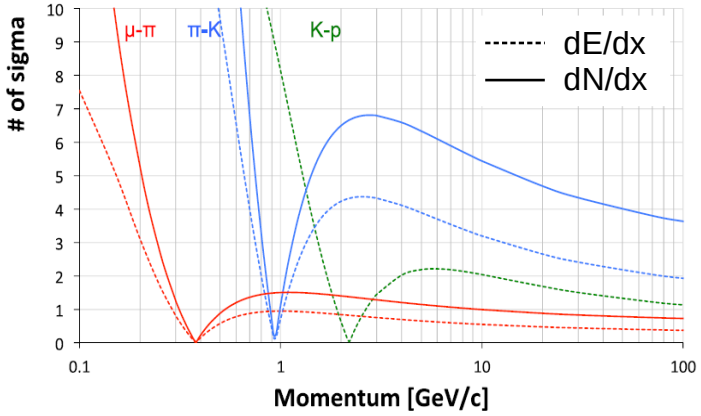


TPC: dE/dx (dN/dx?)
ECal: TOF



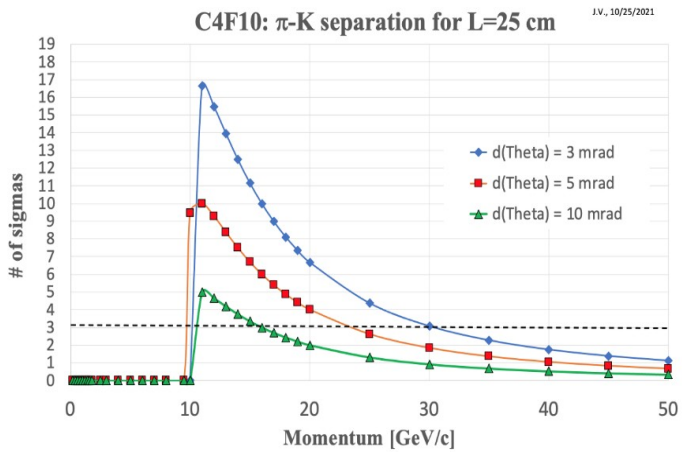
[ILD IDR 2020
https://arxiv.org/abs/2003.01116]

DC: dE/dx or dN/dx



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

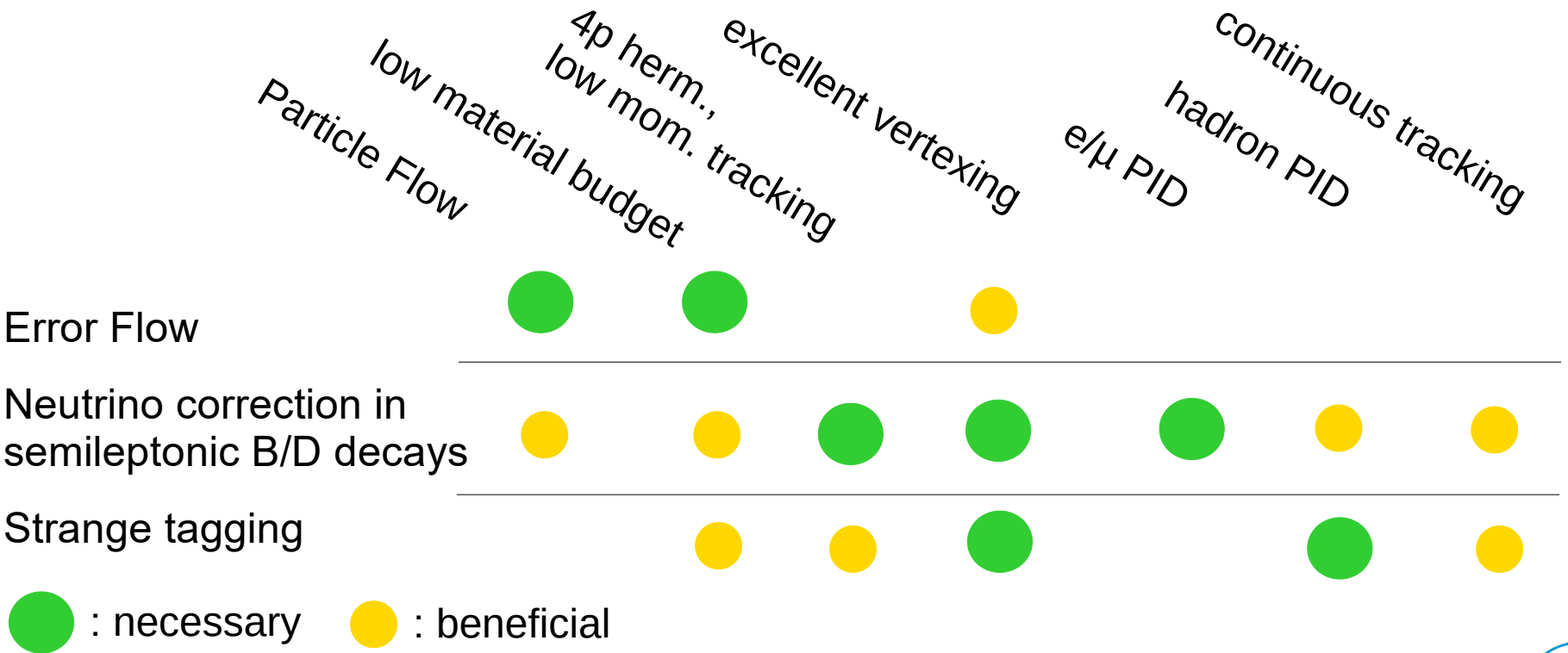
RICH



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

Summary

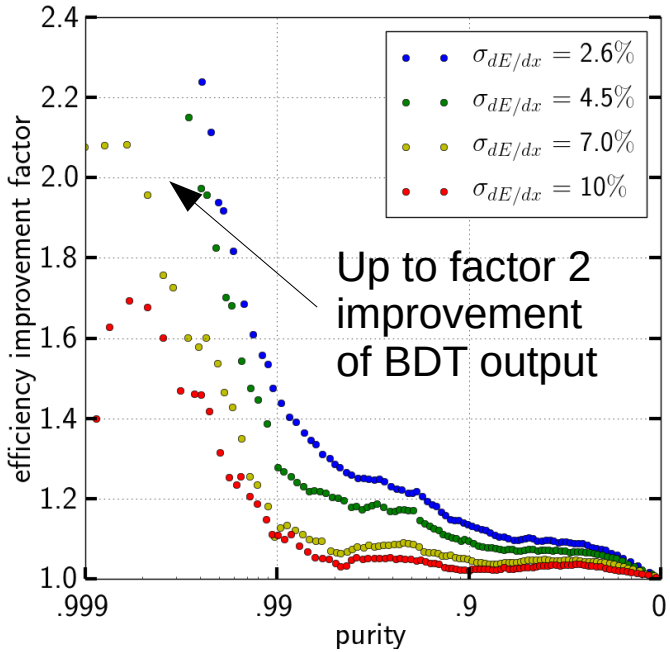
- In order to utilise precious collisions and precise detectors, new methds and algorithms have been and are being developed and inform detector requirements



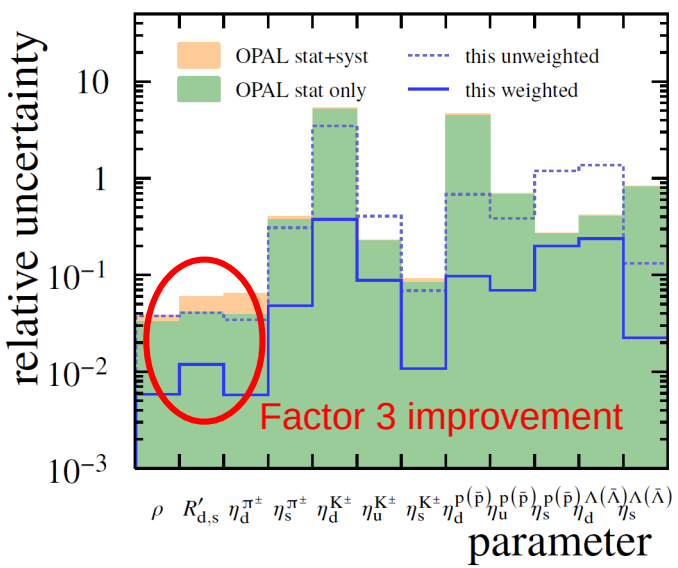
Hadronic W and Z decays

- 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

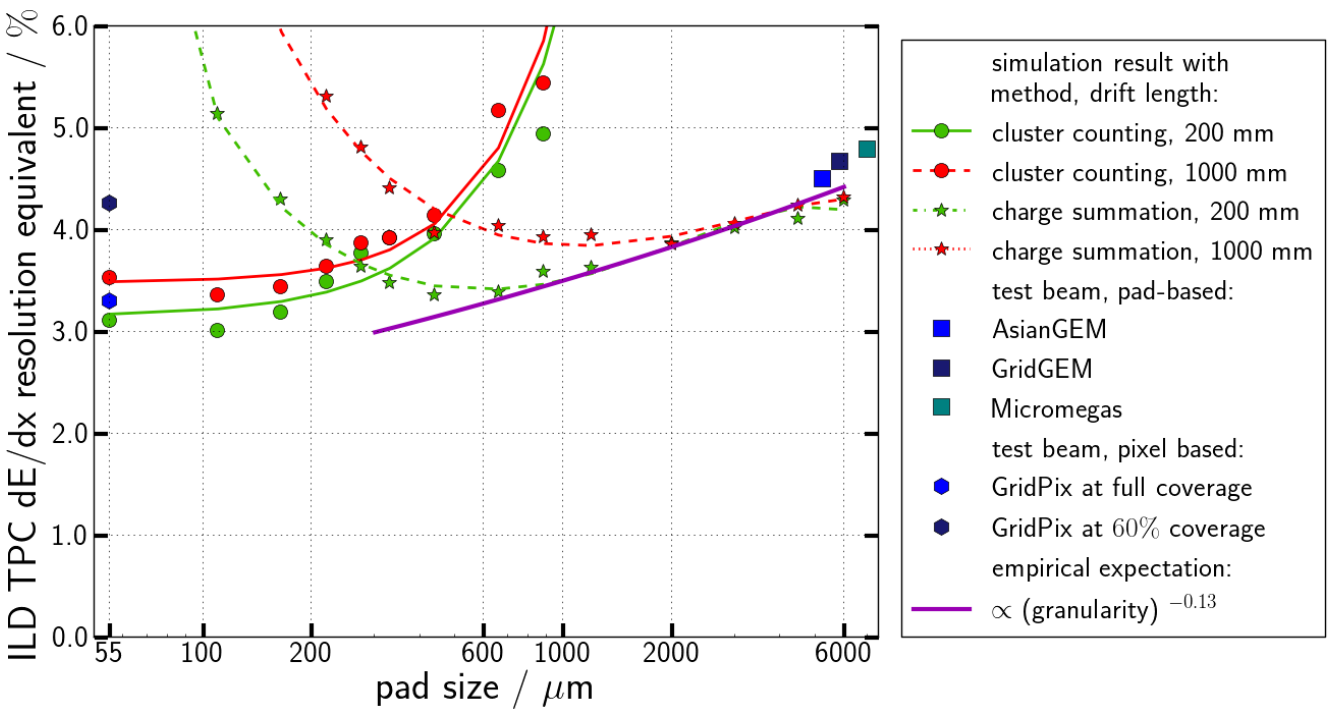


Measurement of Z → d/s via simultaneous fit of hadronisation fractions [https://ediss.sub.uni-hamburg.de/handle/ediss/9634]



TPC dE/dx: Benefits of High Granularity

- Increasing current pad-based granularity by 1 order gives ca. 15% better PID
- Increasing by 2 orders enables cluster counting and gives 30% better PID



[https://arxiv.org/abs/2205.12160]