Detector Optimization and simulation/reco

Loukas Gouskos (Brown University)

US Higgs Factory Planning, Dec 2024 SLAC

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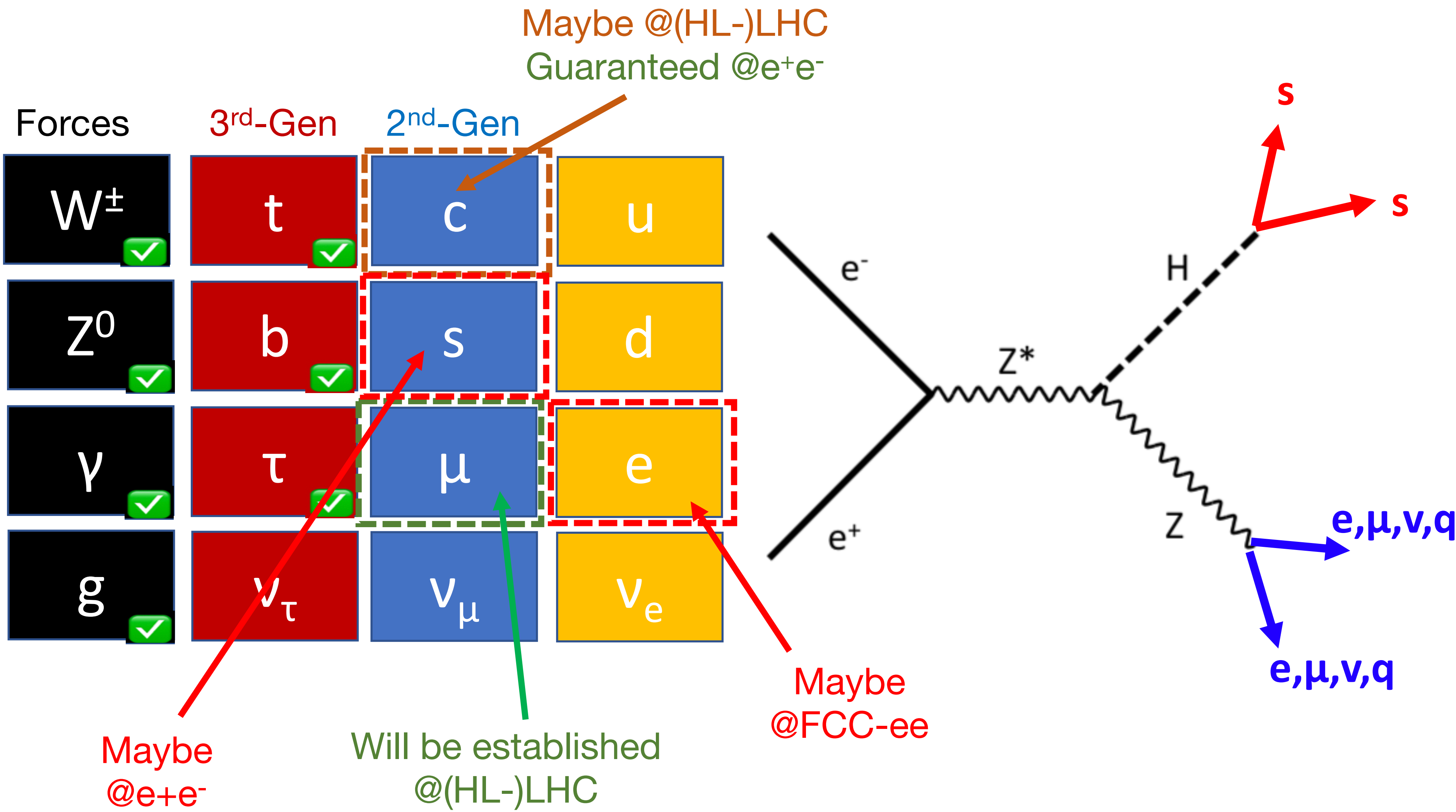
Today's talk:

→ Current status, on-going work, next steps [algorithmic/SW side]
→ Where US is making/can make impact
→ Synergies between US L2/L3 groups

Disclaimer:

→ 10min-talk: High-level (avoid technicalities); Focus on key points/challenges
→ Small "bias" towards FCCee/IDEA [just because I'm directly involved]

Example physics case: H→ss

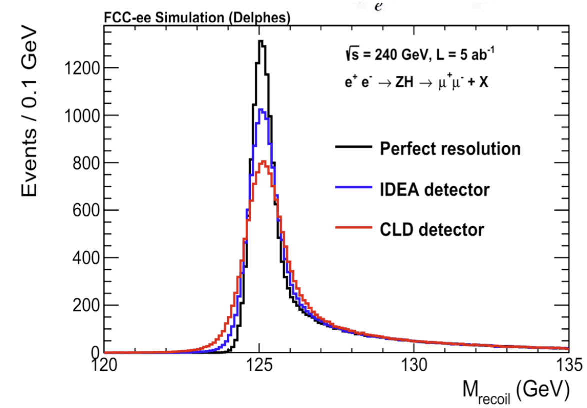


Example physics case: H→ss

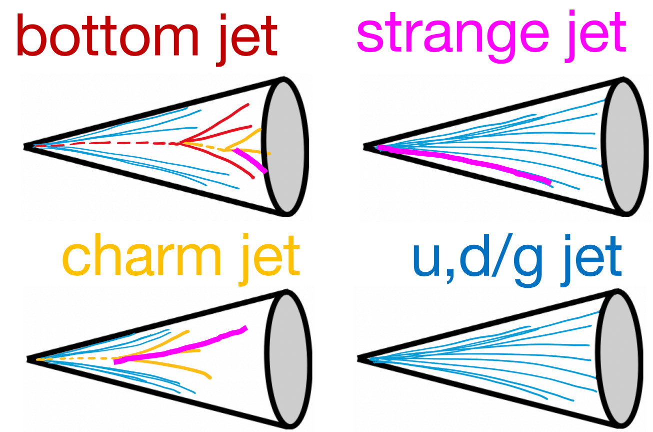
BR(H→had.) ~80%

BR(Z→had.) ~70%

- **Higgs-vs-W,Z,continuum:** σ_{mass}~O(MeV)
  - **Tracking:** $\sigma_{pT}/pT \sim 10^{-3}$ @ ~50GeV
  - **Calorimeter:** 30%/sqrt(E)



- **Bottom/charm vs. strange** quark
  - **SIG:** BR(**H→ss**)~10^{-4}
  - **Higgs BKGs:** BR(**H→bb**)~6×10^{-1} BR(**H→cc**)~3×10^{-2}
  - Light **Pixel** ; 1st layer close to IP



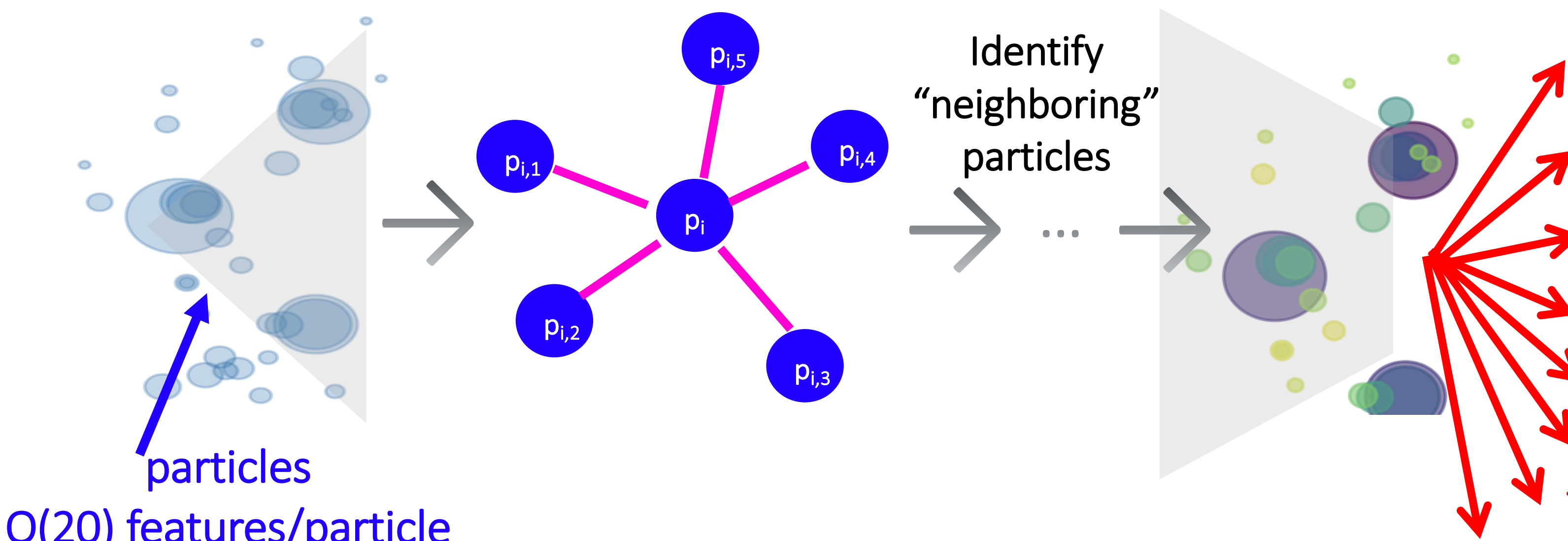
- **u/d/g vs. strange** quark: π-vs-K
  - **PID** detectors
    - dN/dX, TOF, RICH? combination?

Broad set of requirements/challenges

Algorithm front: Jet tagging

- Powerful detectors: only part of the story
- In parallel: Algorithms able to exploit the true potential of these detectors
- Current state-of-the-art: GNN/Transformer-based algorithms
  - very similar across all experiments/detector concepts

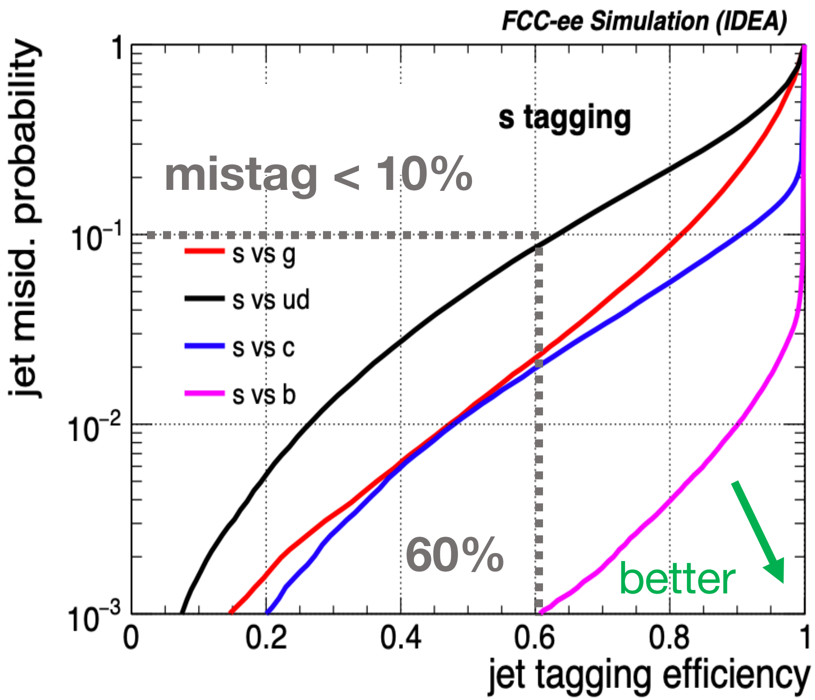
PRD 101 056019 (2020)
EPJ C 82 646 (2022)



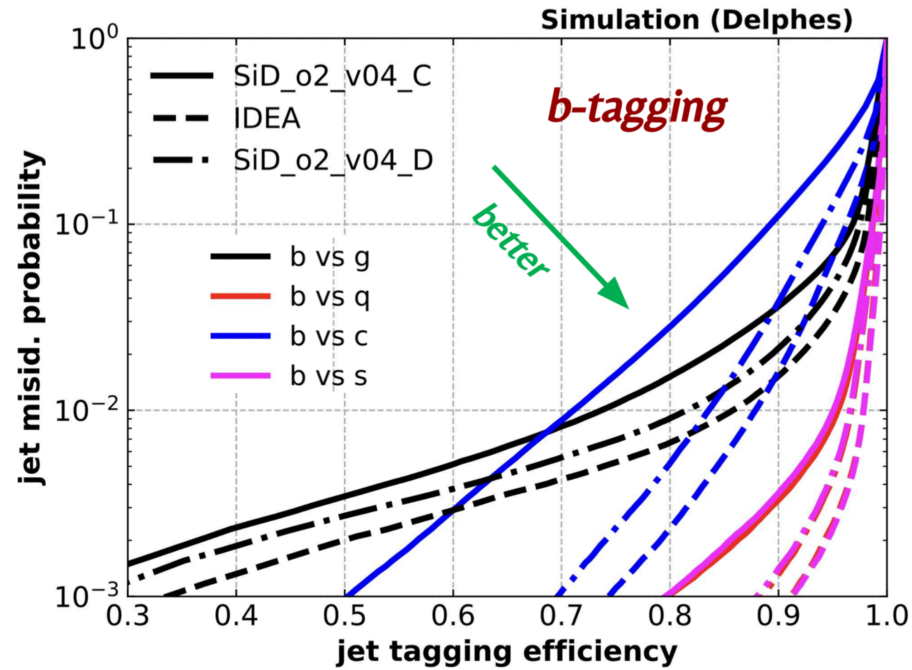
Performance: Detector concepts

D. Ntounis ECFA'24

Started for FCC/IDEA
e.g., s-tagging



More recently: SiD
e.g., b-tagging

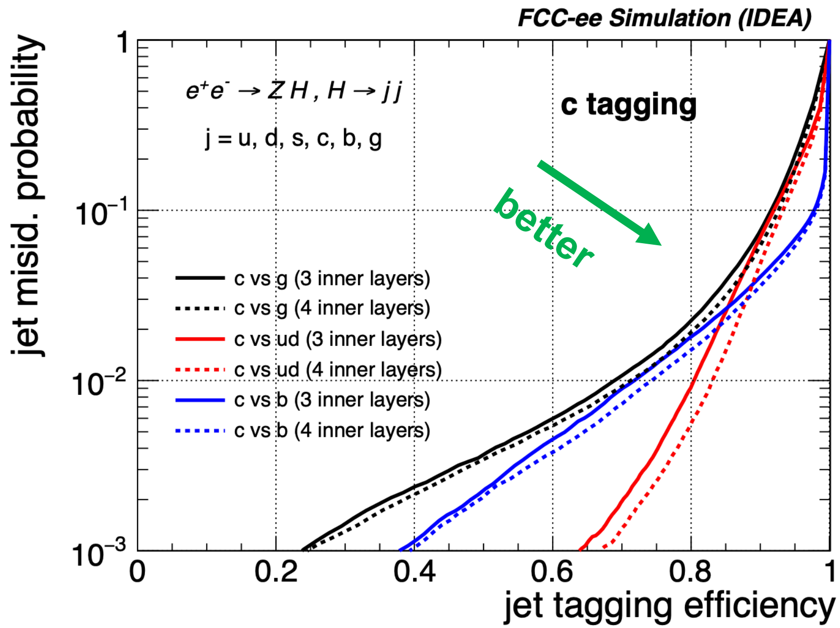


→ Systematic comparison b/w detector concepts (e.g., IDEA vs. SiD)

→ NB: Results based on FastSim (i.e., Delphes)

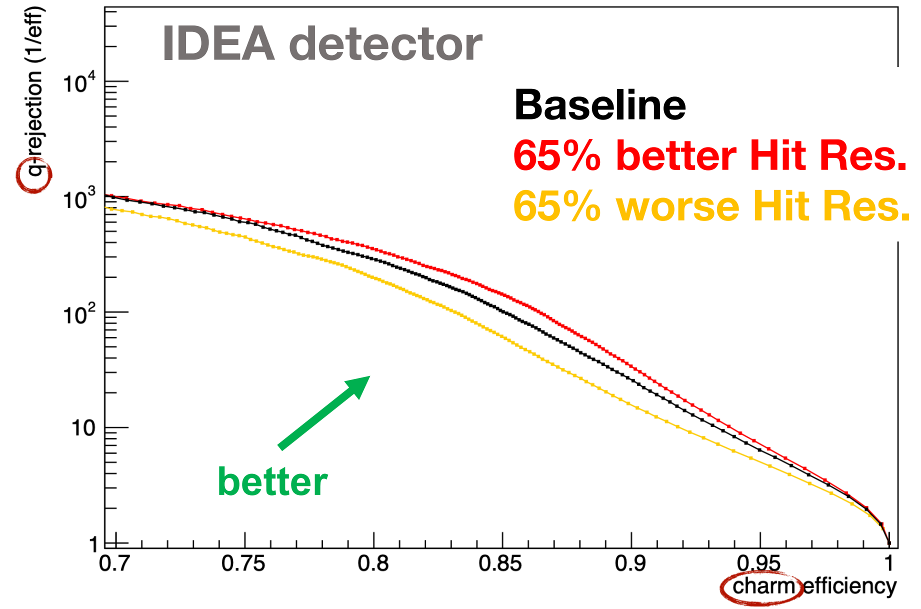
(Sub)Detector optimization: PIXEL

PIX Layers: 3 vs. 4



Single-point resolution

A. Sciandra ECFA'24



Additional PIX layer:
→ c-tag: 2x improved BKG rej.
→ b-tag: Marginal improvement

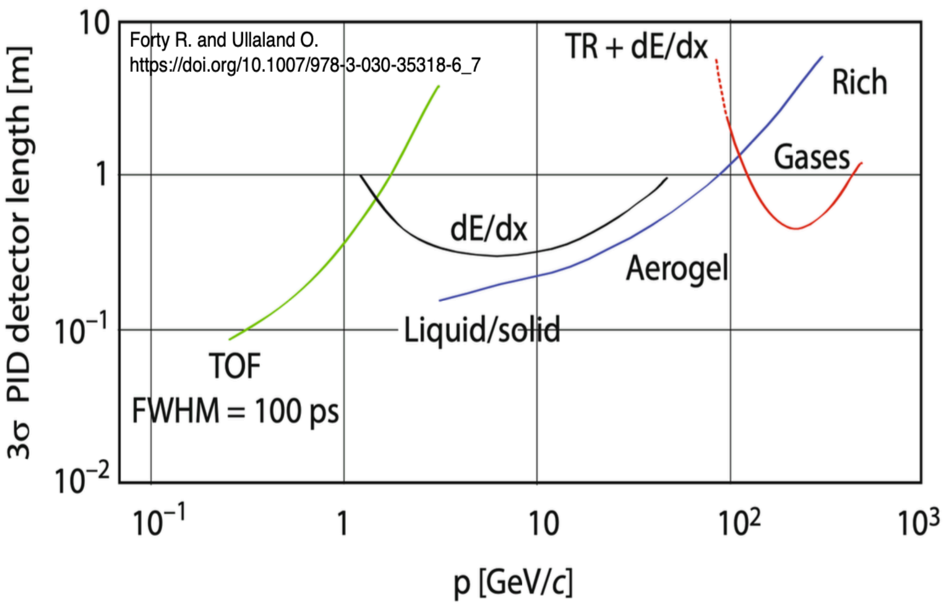
Baseline: 3μm, 25x25μm^2
→ Visible effects for all jet flavours
→ c-tag: up ~50% loss in gluon rej.

Detector Optimization: PID

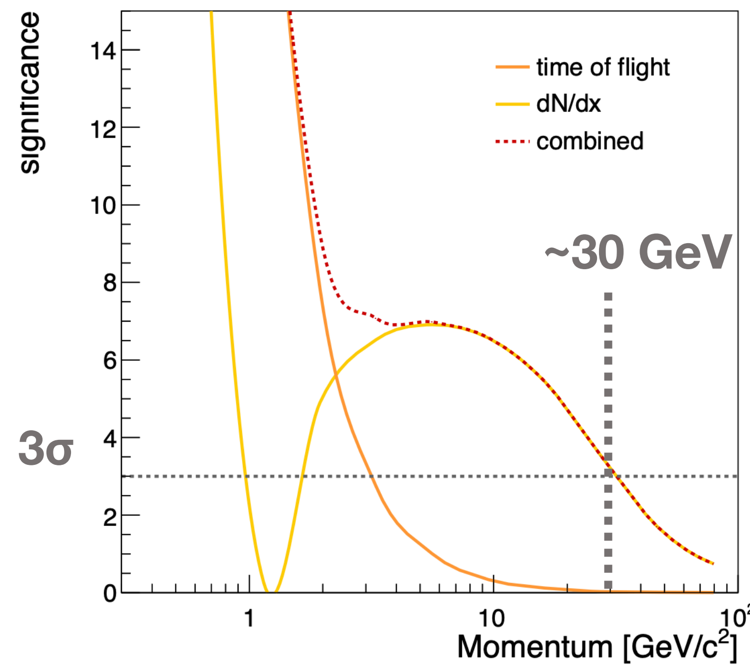
Add refs

- Need PID over a very broad p_T range
  - H→ss: very relevant benchmark

PID solutions vs. p (particle)

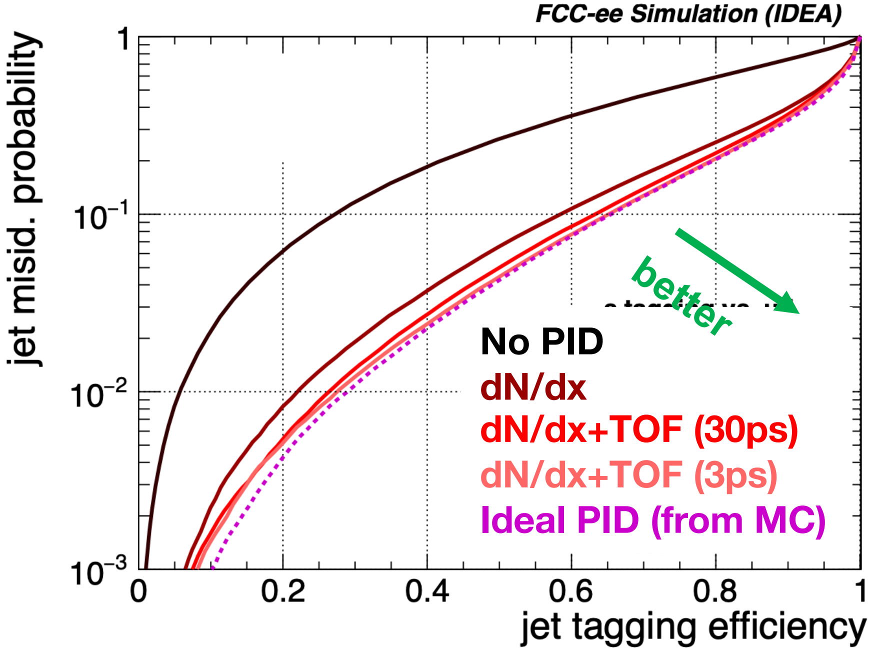


Example of complementarity



Detector Optimization: PID

Strange tagging



(At the ZH)

→ **dN/dx:** most of the gain

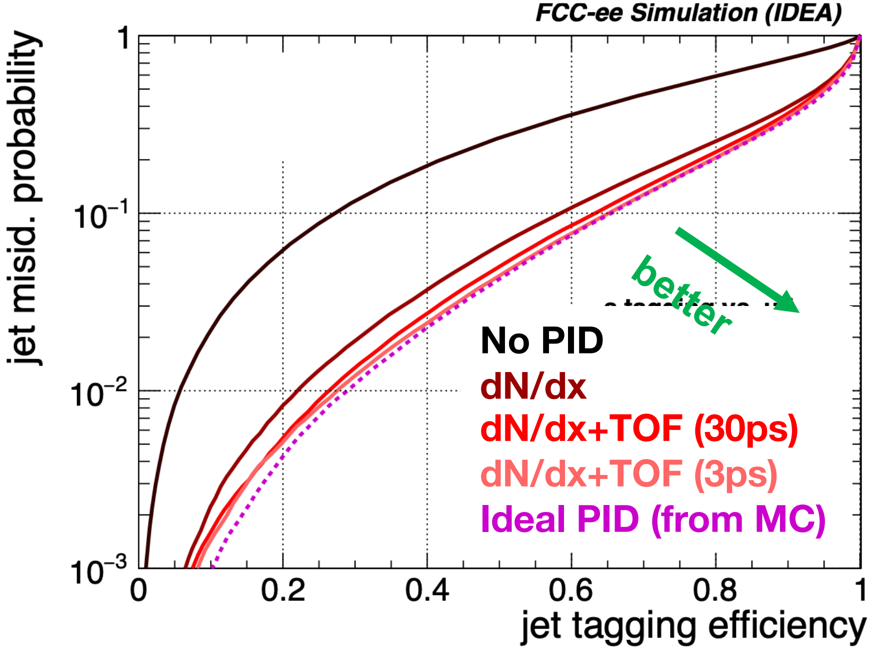
→ additional gain w/ **TOF (30ps)**

→**TOF (3ps)**: marginal gain

→ Still room for improvement (**Ideal**)

Detector Optimization: PID

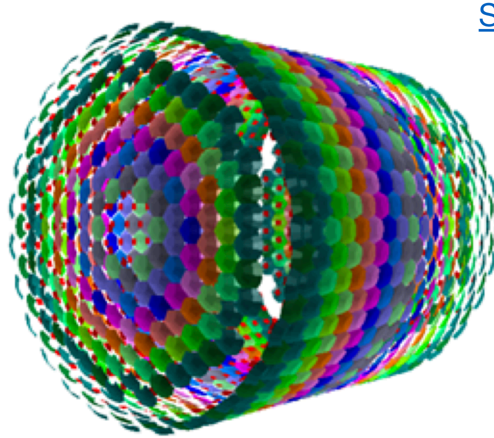
Strange tagging



(At the ZH)
→ **dN/dx:** most of the gain
→ additional gain w/ **TOF (30ps)**
→**TOF (3ps)**: marginal gain
→ Still room for improvement (**Ideal**)

Effort to further improve PID e.g., RICH (ARC)

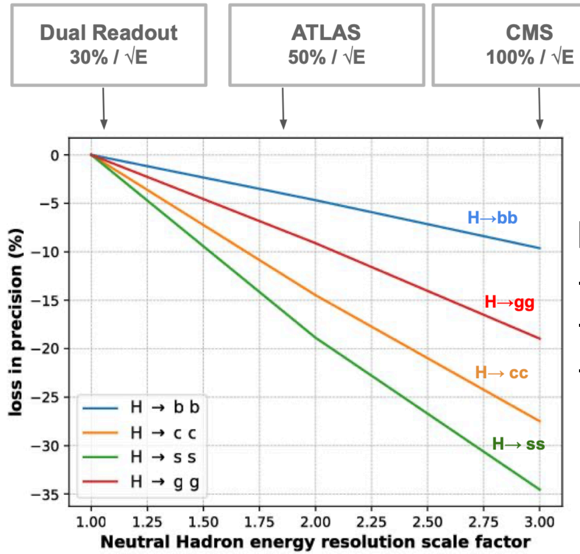
S. Pezzulo ECFA 2024



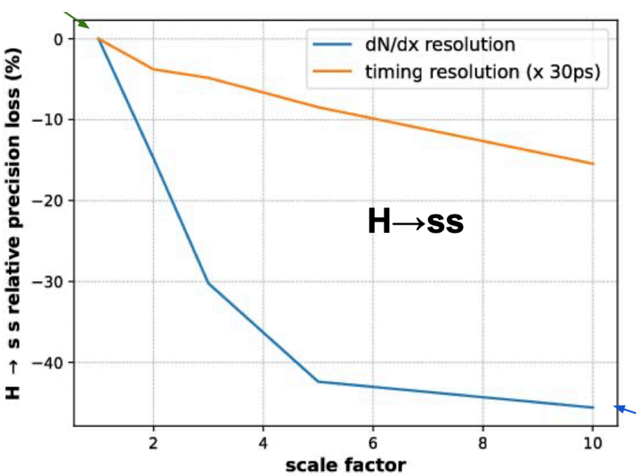
Compact:
→ Radius: 2.1m
→ Length: 4.4 m

→ Integrated for the CLD detector
→ 3σ π-vs-K up to ~45 GeV [studies in FullSim]
→ But: 10% reduction of TRK volume; Important?

Impact on physics outcome (e.g., H→ss)

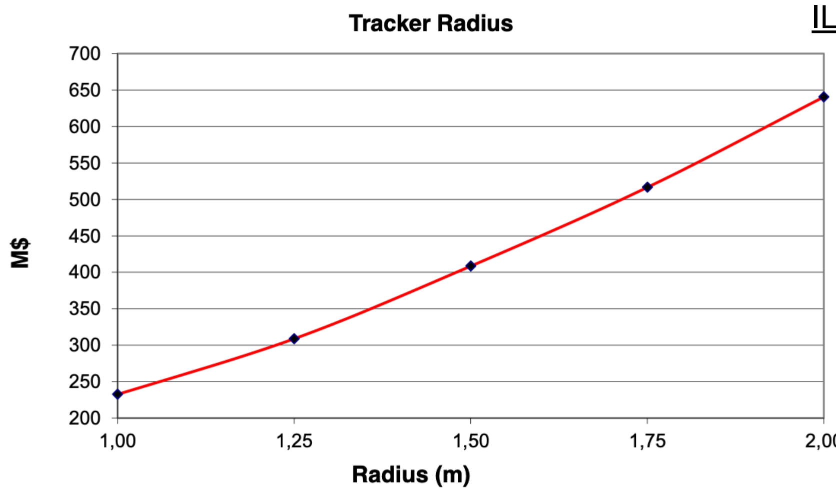


Many open Qs:
- Granularity?
- Realistic PF?
- …



Cost vs. physics outcome ?

ILC TDR



→ Need to carefully access the impact of (sub-)detector proposals to representative Physics benchmarks

→ We are at the very beginning; US active on this front

→ Strengthen cross-talk b/w detector and analysis communities

The Z-pole @ FCC-ee (Circular Colliders)

Observable	Present value ± error	FCC-ee stat.	FCC-ee syst.	Comment and leading exp. error
m_Z (keV)	91186700 ± 2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{eff}(\times 10^6)$	231480 ± 160	**2**	2.4	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952 ± 14	**3**	Small	From $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767 ± 25	**0.06**	0.2–1	Ratio of hadrons to leptons Acceptance for leptons
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196 ± 30	**0.1**	0.4–1.6	From R_ℓ^Z above
σ_{had}^0 $(\times 10^3)$ (nb)	41541 ± 37	**0.1**	4	Peak hadronic cross section Luminosity measurement
$N_\nu(\times 10^3)$	2996 ± 7	**0.005**	1	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216290 ± 660	**0.3**	< 60	Ratio of $b\bar{b}$ to hadrons Stat. extrapol. from SLD
A_{FB}^b, 0 $(\times 10^4)$	992 ± 16	**0.02**	1–3	b-quark asymmetry at Z pole From jet charge

stat

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$A_{FB}^{pol,\tau}$ $(\times 10^4)$	1498 ± 49	**0.15**	<2	τ polarization asymmetry τ decay physics
τ lifetime (fs)	290.3 ± 0.5	**0.001**	0.04	Radial alignment
τ mass (MeV)	1776.86 ±0.12	**0.004**	0.04	Momentum scale
τ leptonic $(\mu\nu_\mu\nu_\tau)$ B.R. (%)	17.38 ±0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350 ± 15	**0.25**	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085 ± 42	**1.2**	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1170 ± 420	**3**	Small	from R_ℓ^W
$N_\nu(\times 10^3)$	2920 ± 50	**0.8**	Small	Ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	**17**	Small	From $t\bar{t}$ threshold scan QCD errors dominate
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$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	**0.10**	Small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	**0.5–1.5%**	Small	From $\sqrt{s}$ = 365 GeV run

- Huge potential [δ(stat)]

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stat syst

- Huge potential [δ(stat)] …but big challenges [δ(syst)]
  - Beam-related syst: Accelerator front
  - All other syst: us (EXP or TH communities)

The Z-pole @ FCC-ee (Circular Colliders)

- Stress test: 10^{12} Z bosons (i.e., LEP x 10^6)
- Challenges:
  - Large event rates O(100kHz)
    - Fast detector response → trigger-less readout (can we?)
  - Beam BKGs, Bhabha scattering,..
    - High occupancy in 1st layer/fwd region
    - Precise modeling crucial
  - Precise acceptance determination: 10^{-4}-10^{-6}
    - e.g., need to model detector transition regions O(15)μm
  - Excellent track momentum $\delta(1/p) \sim 10^{-4}$-10^{-5} & angular resolution
  - tagging efficiencies, etc…

How we address them?
→ Are current detector concepts sufficient ?
→ SW/analysis side: Detailed simulation and understanding needed

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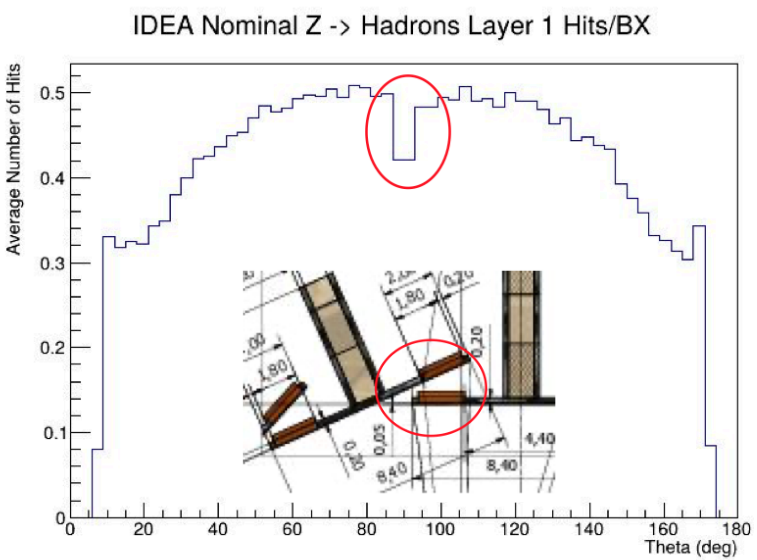
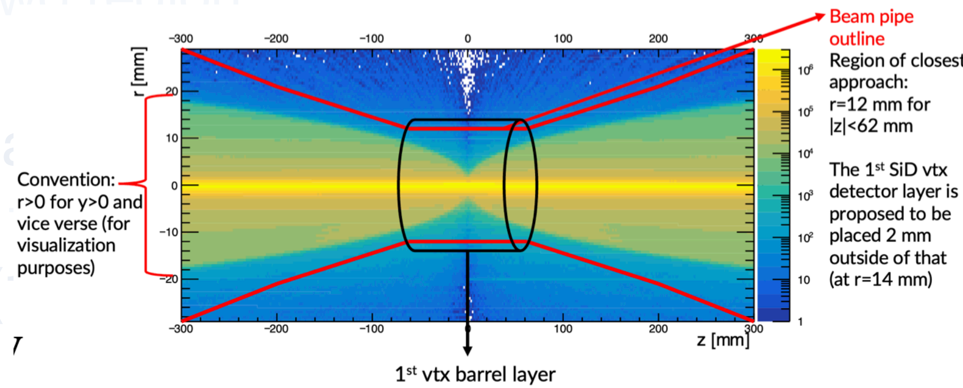
N. Martinez FCC FullSim Mtg



D. Ntounis ILC WG



Gap in detector's half?

Detector's occupancy → impact detector design

→ Are current detector concepts sufficient ?

→ SW/analysis side: Detailed simulation and understanding needed

Simulation and Reconstruction: status

- The majority of all these studies carried out in FastSim
  - great for fast turn around, but:
- We need the Full chain DIGI → SIM → RECO → Analysis
  - Currently only for CLD: 2 analyses: m_H and tau polarization
- IDEA and Allegro:
  - Some parts are FullSIM
  - Much less for RECO
    - e.g., tracking for Drift Chamber → very preliminary
  - IDEA, Allegro FullSim: Effectively not usable for analysis

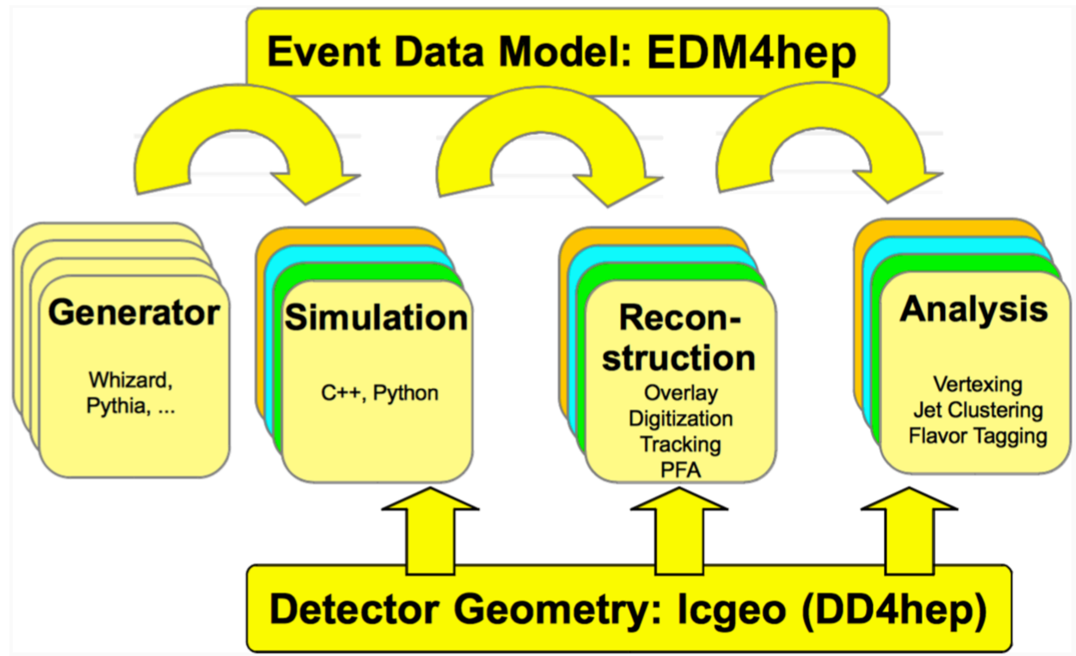
Simulation and Reconstruction: next steps

- Those are areas that US has definitely expertise
  - We are involved but we can make even more impact
- IMHO: No need to start from scratch

Key4HEP

→ Ecosystem where various components "talk" to each other

→ Consistence across detectors/machines



Talk at S&C parallel session by J. Carceller

Executive summary /discussion

- Lot's of work ahead
  - Define relevant physics benchmarks (Higgs, Flavour, LLPs,..)
    - go beyond Physics Object metrics
  - FastSim and FullSim of the (sub-)detectors
    - Versatile framework, fast turn around from detector concept to impact on physics outcome
      - Is FastSim good enough?
  - Reconstruction (Traditional, ML-based)
    - Far from done
  - Simulation of BKGs, understanding rates → inform detector design
  - ....
- Key for success: multi-way communication between groups
  - Detector, SW, Integration