

Muon Collider Physics & Detector effort at CERN

**Maurizio Pierini
CERN EP**

With inputs from P. Roloff, A. Sailer, M. Selvaggi, A. Wulzer, M. Zanetti

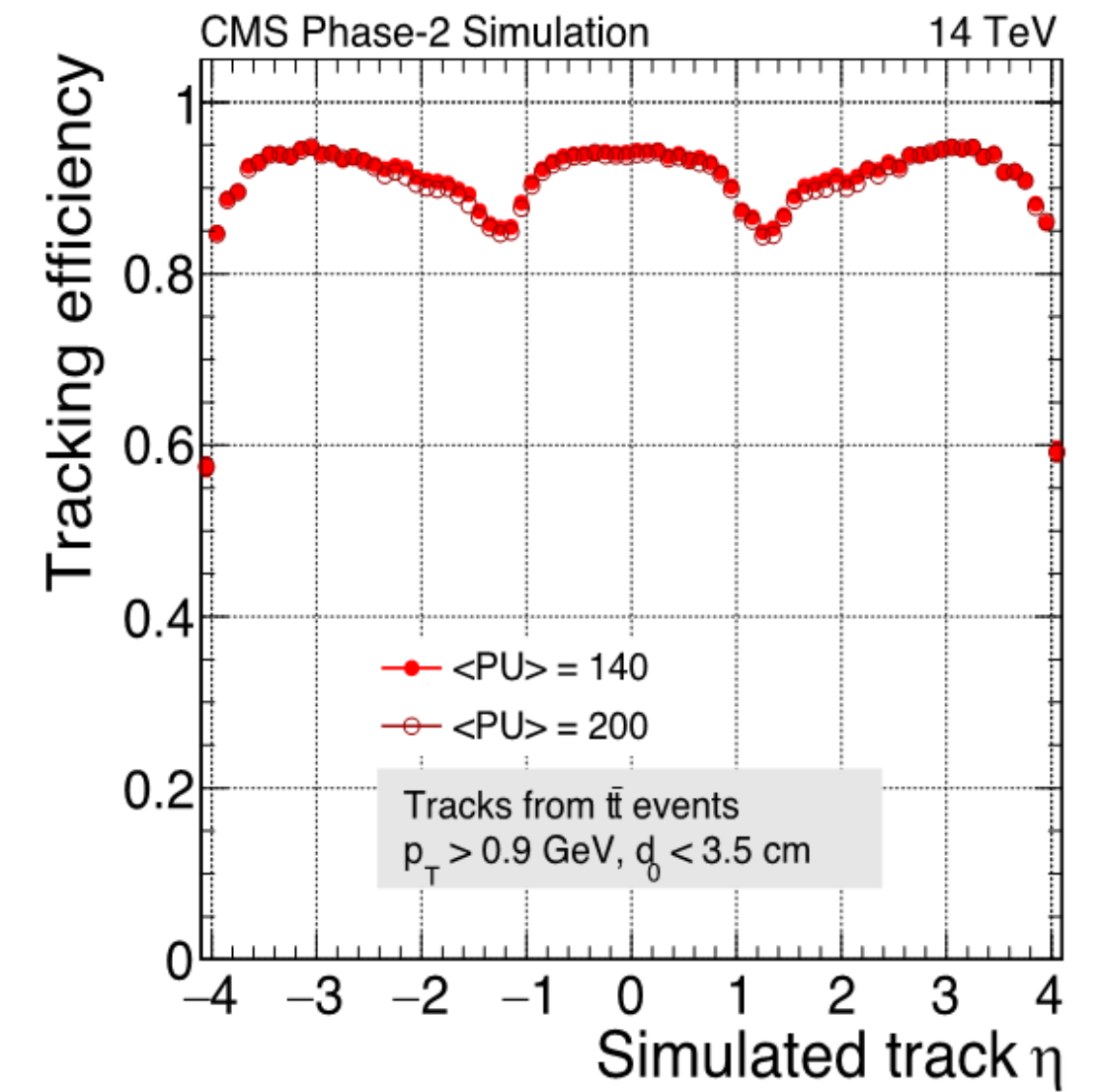
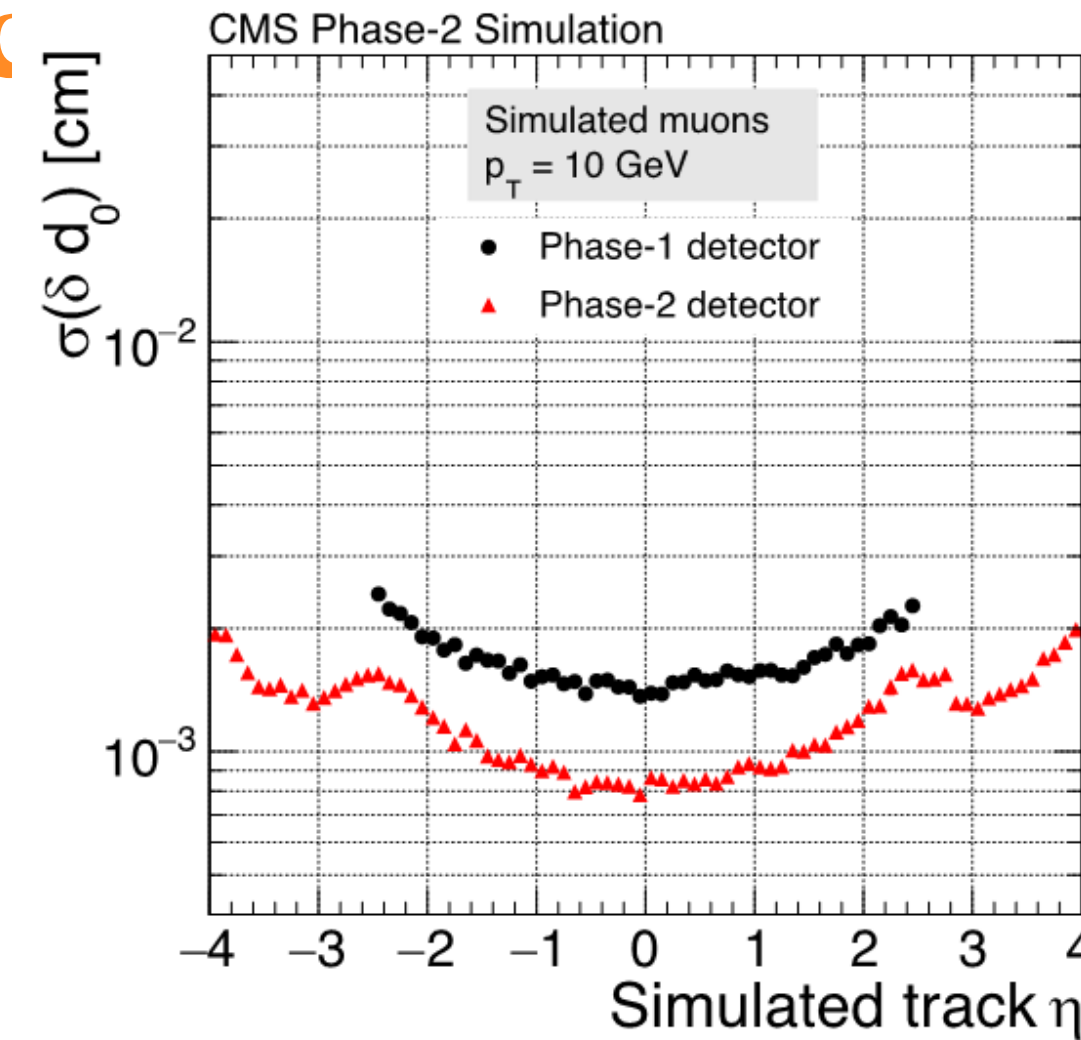
Lesson from FCC effort start

- We are going through starting phase similar to what the FCC ee & hh efforts went through a few years ago
- As them, we start as a no-budget effort on Detector & Physics (the initial effort from CERN perspective is focused on machine, as it should be)
- A few lessons
 - Produce best-case-scenario results to start with
 - Then care about how to get there (they still don't have an end-to-end full simulation)
 - Capitalise on the large community of people at CERN to build a community through regular informal & unstructured meetings
 - My suggestion would be bi-weekly alternated & “factorized” meetings
 - Fastsim studies on best-case-scenario reach for PHYSICS CHANNELS
 - Fullsim studies finalised to OBJECT RECONSTRUCTION

Inhering Factorization Scheme for Future Colliders

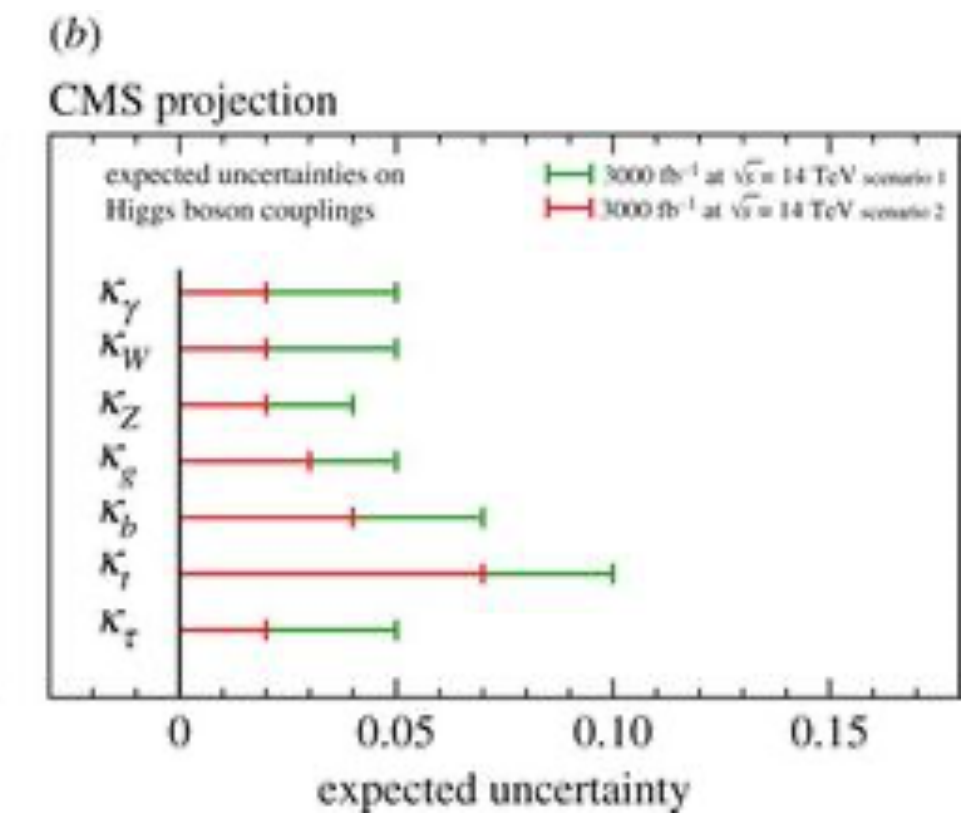
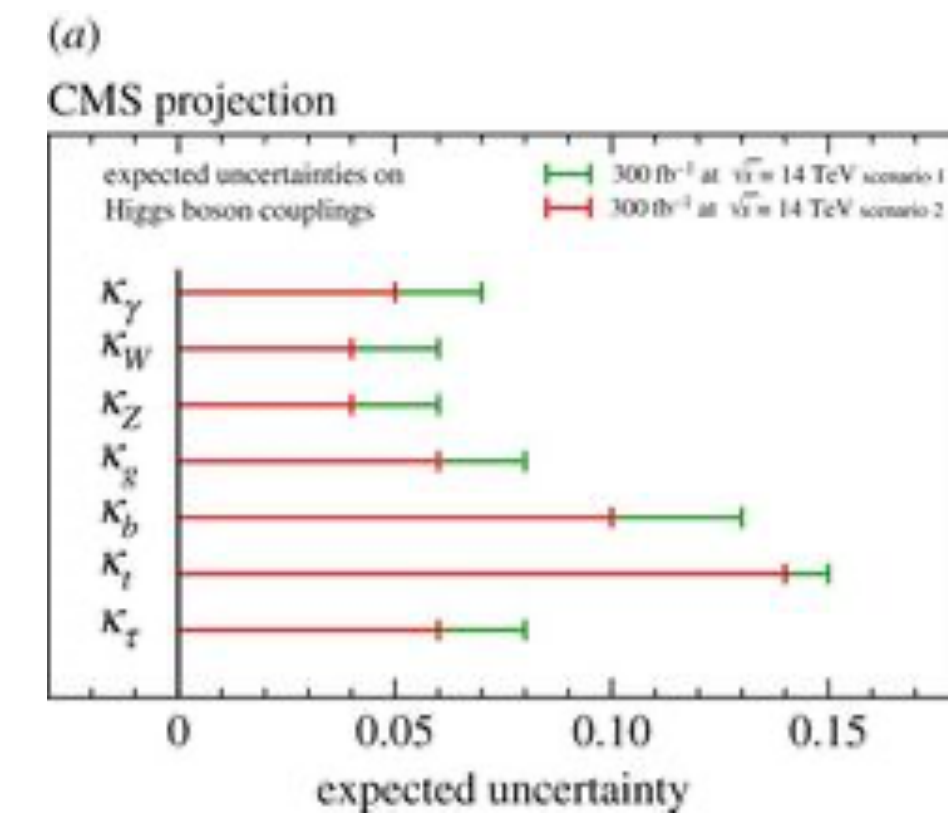
- **Local Reco \rightarrow Parameterized Performance**

- Running in Fullsim
- Delivers performance plots
 - energy/angular resolution
 - efficiency vs $p_{(T)}$
 - ...



- **Parameterized Performance \rightarrow Physics Reach**

- Use Fastsim based on performance plots (Delphes)
- Allows analysis on high-level objects
- Can be used to assess final physics goals



Overview of (personal) contributions from CERN-EP people

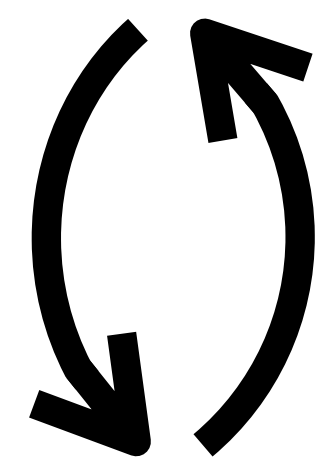
- Fastsim effort with Delphes **Michele Selvaggi (EP-CMG)**
- Local reco at Fullsim with CLIC framework **André Sailer (EP-SFT) & Philipp Roloff (EP-LBD)**
- Generation chain from FCC studies (gridpack+event generation & bookkeeping+ROOT Data Framework) **Clement Helsens (EP-ADE-TK)**
- Key4Hep development **Many people in EP-SFT ++**
- Graph4Reco within mPP **Maurizio Pierini & Mary Touranakou(EP-CMG)**
- **In the future:** Establish Doctoral Student opportunities for MDI studies

Fast Simulation for Physics reach

- Present and Future experiments rely on Delphes to perform fast-simulation studies

- FCCee & FCChh reach
- CMS upgrade
- ...
- These studies allow for best-case-scenario reach assessment
 - One cannot emulate all aspects (e.g., beam background for tracking)
 - But one can emulate some relevant one (e.g., in-time pileup at LHC)

- **Factorization approach**



- Assumes that beam-related issues are sorted out in local reconstruction
- Parameterise resulting resolution in FastSim
- Meanwhile, work on local reconstruction with Fullsim to assess & improve local reconstruction

- Michele Selvaggi (EP-CMG) will assist us with assembling and updating a Muon Collider Delphes card

- [start with CLIC and evolve that](#)

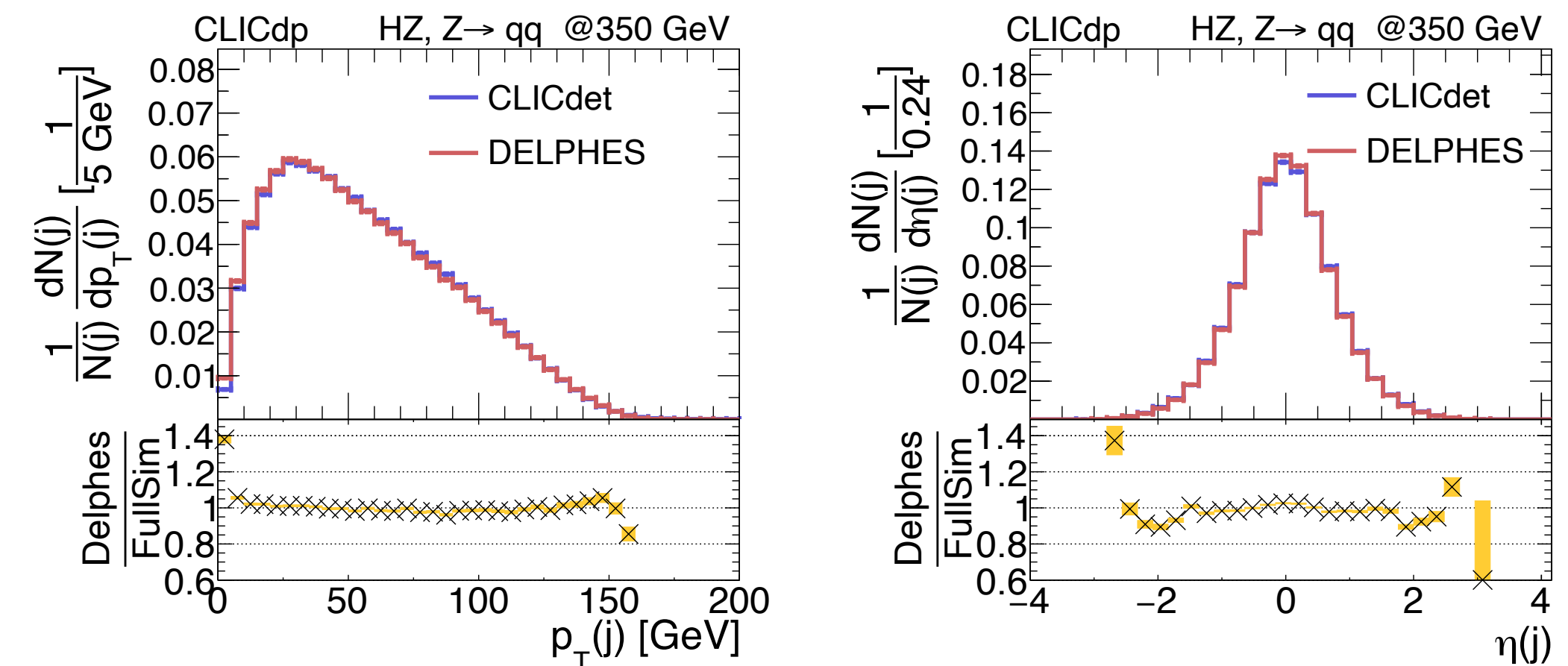
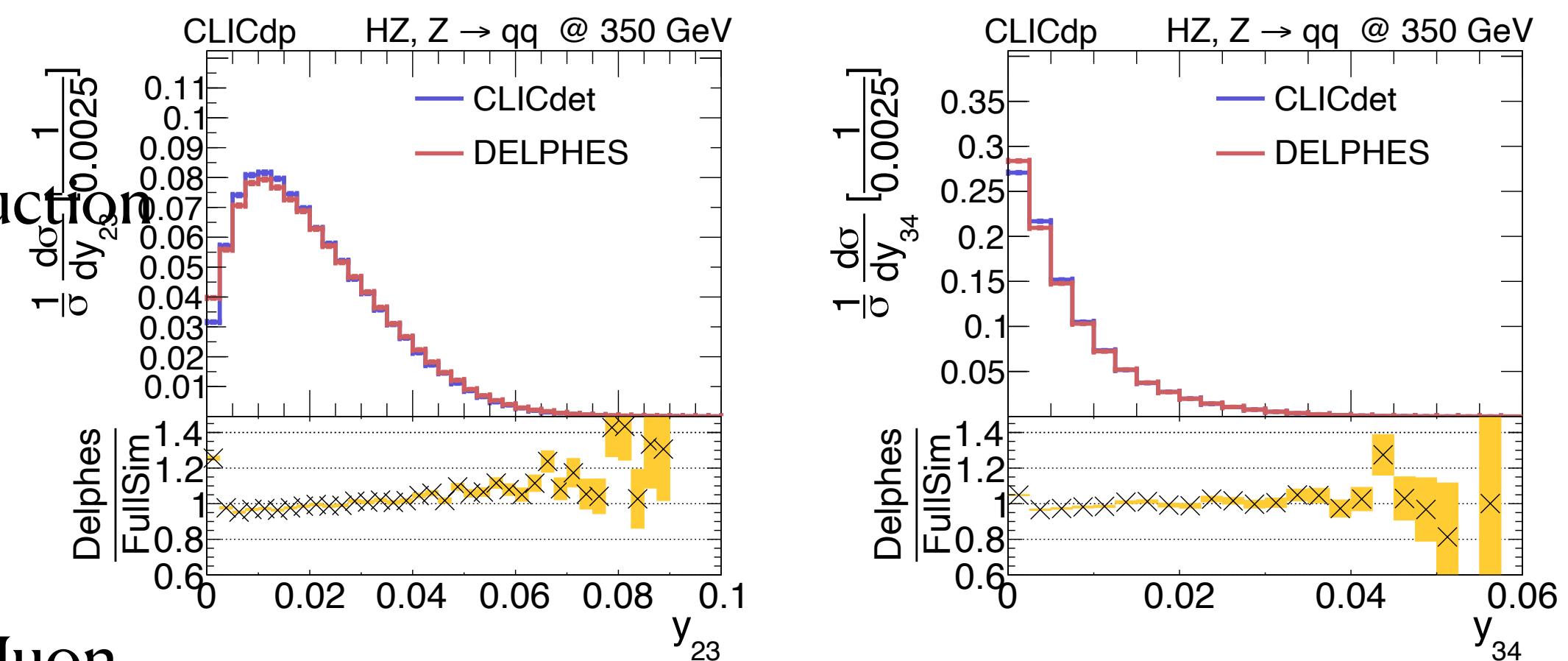


Figure 1: Comparison of jet transverse momentum (left) and pseudorapidity (right) in Higgsstrahlung events with hadronic Z decay for full simulation of CLICdet (blue) and DELPHES (red).



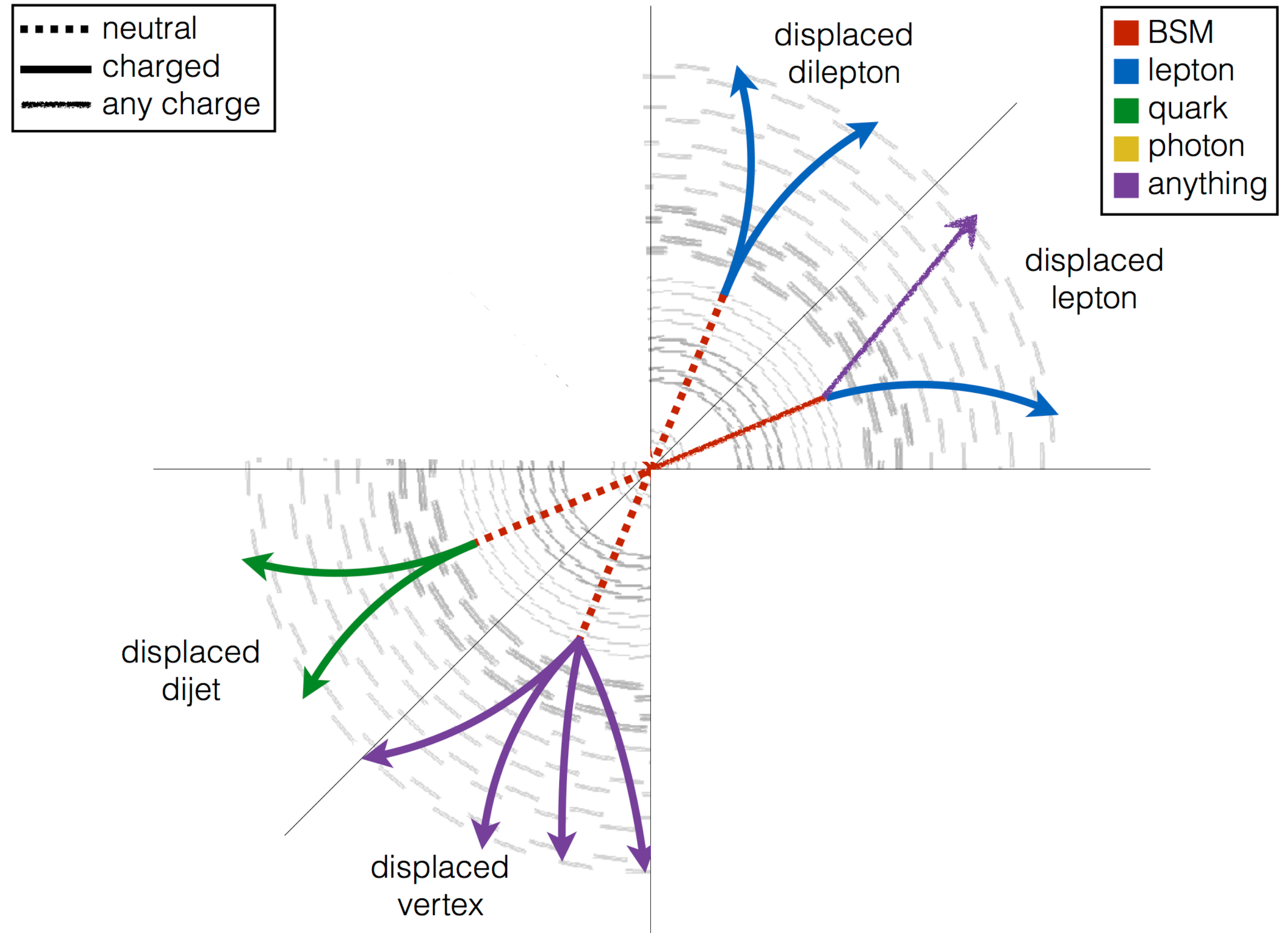
Full Simulation for Local Reconstruction

- Future collider studies investing on Key4Hep
 - Long term, the common framework for all CERN future experiments
 - EP department investing on it (as part of the EP Software R&D program)
 - Same context of other projects (GEANT, ROOT, etc.) supporting community
 - We cannot plan Muon Collider effort @CERN without Key4Hep as long-term solution
 - But this might take a few years
- Meanwhile, can rely on full simulation framework by CLIC
 - Studies advanced in this direction (Padua Group)
 - CLIC group will support framework while transitioning to Key4Hep
- **The effort is not starting NOW:** this is the direction investigated by Donatella et al. since months and first results are there

Assessing Beam Background impact

Interested to investigate BB effect on:

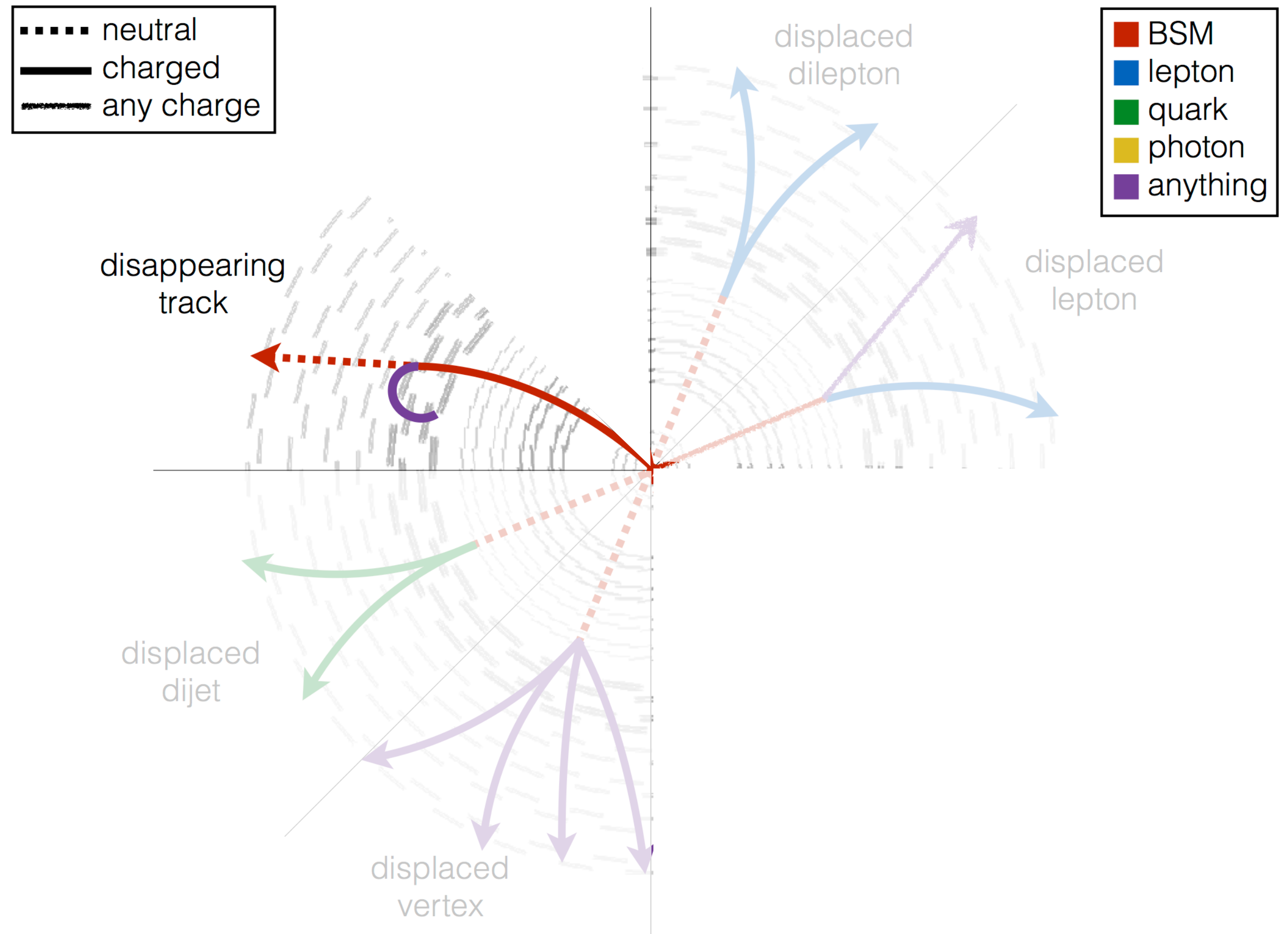
- inner-detector local reconstruction
- displaced vertices resolution



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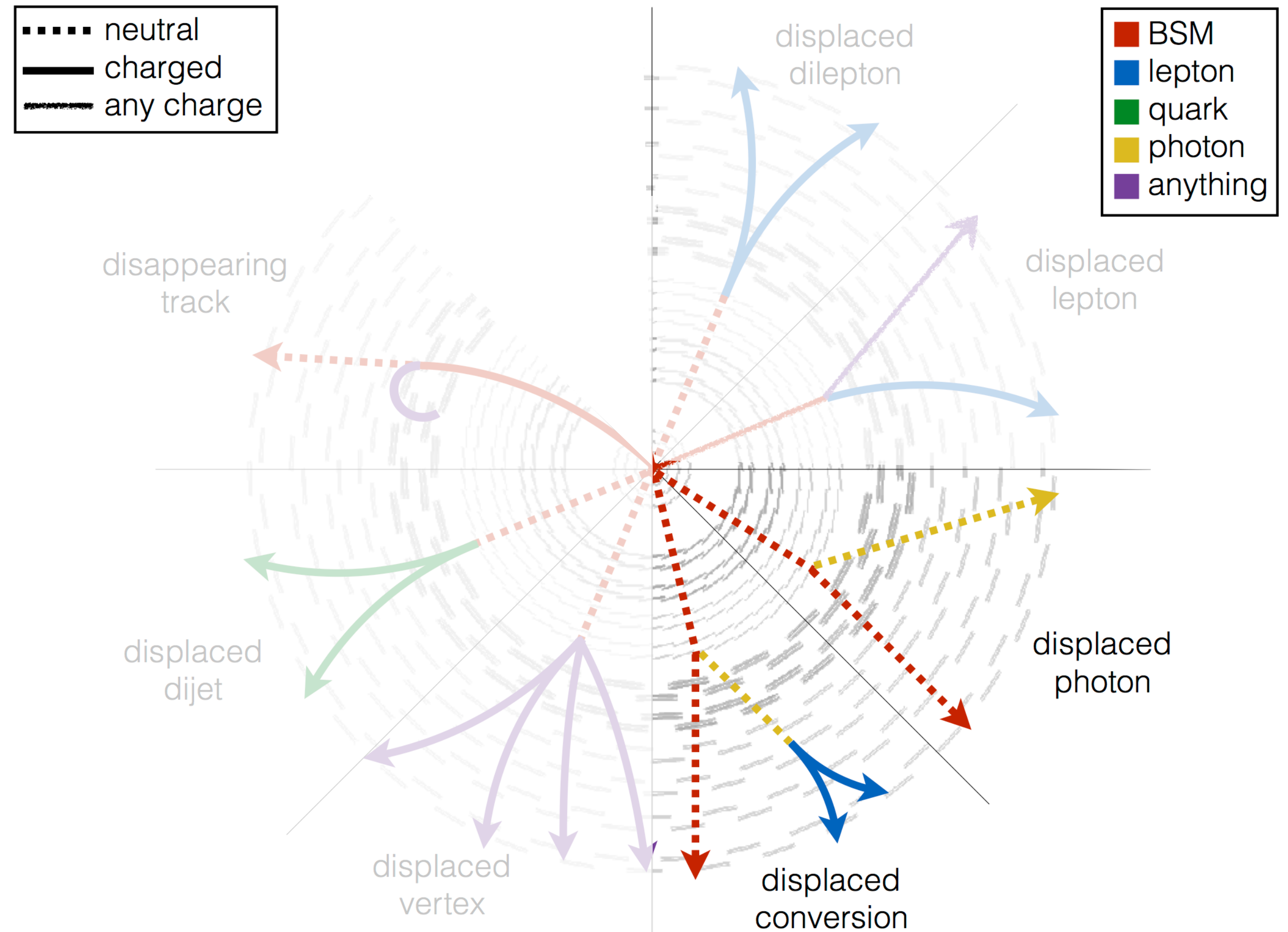
- inner-detector local reconstruction
- displaced vertices resolution
- stub reconstruction



Assessing Beam Background impact

Interested to investigate BB effect on:

- inner-detector local reconstruction
- displaced vertices resolution
- stub reconstruction
- calorimetry
- non-pointing photons



Assessing Beam Background impact

Interested to investigate BB effect on:

- inner-detector local reconstruction
- displaced vertices resolution
- stub reconstruction
- calorimetry
- non-pointing photons
- generic photon/electron reconstruction performance

Calorimetry with Deep Learning: Particle Simulation and Reconstruction for Collider Physics

Dawit Belayneh¹, Federico Carminati², Amir Farbin³, Benjamin Hooberman⁴, Gulrukh Khattak^{2,5}, Miaoyuan Liu⁶, Junze Liu⁴, Dominick Olivito⁷, Vitória Barin Pacela⁸, Maurizio Pierini², Alexander Schwing⁴, Maria Spiropulu⁹, Sofia Vallecorsa², Jean-Roch Vlimant⁹, Wei Wei⁴, and Matt Zhang^{a4}

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⁹ California Institute of Technology

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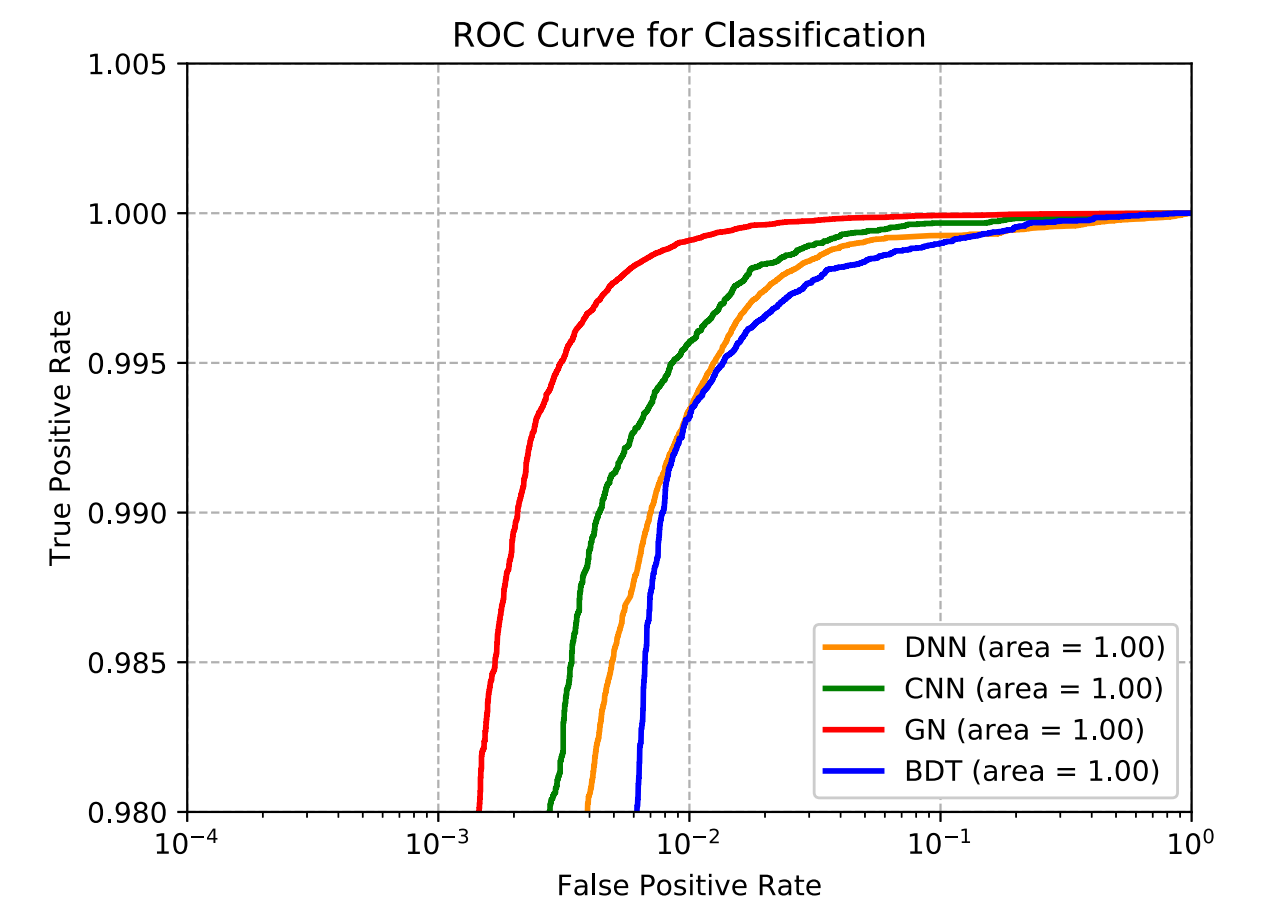
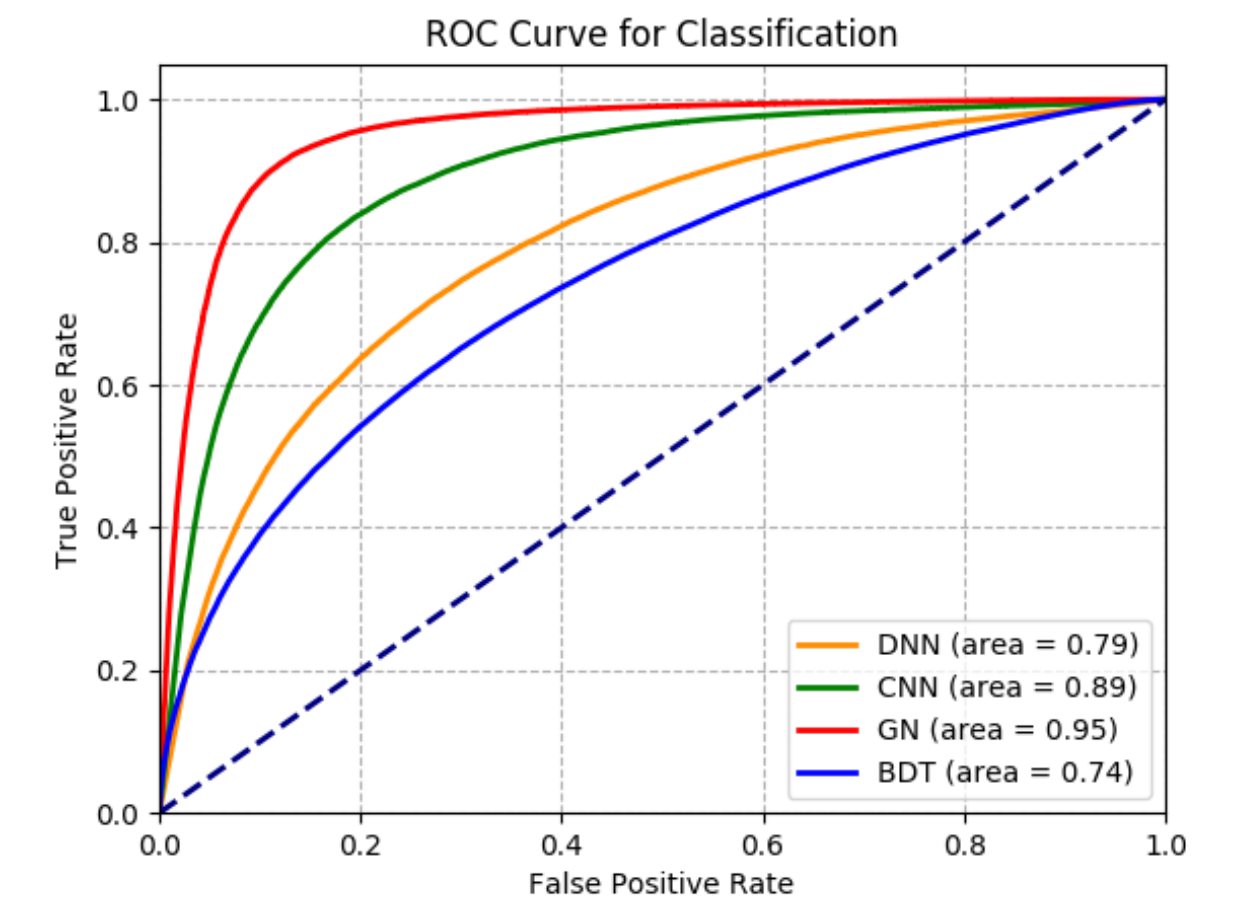
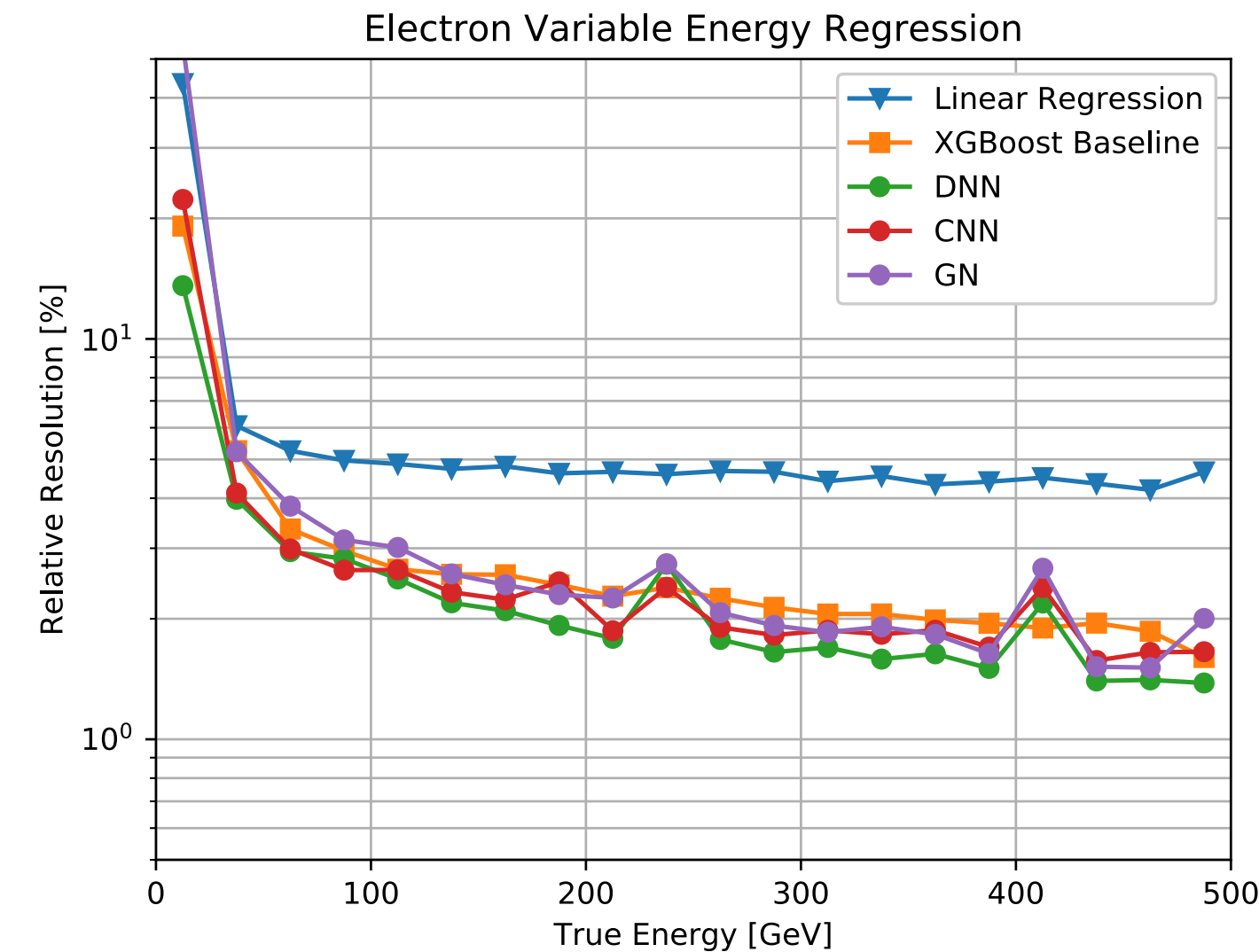
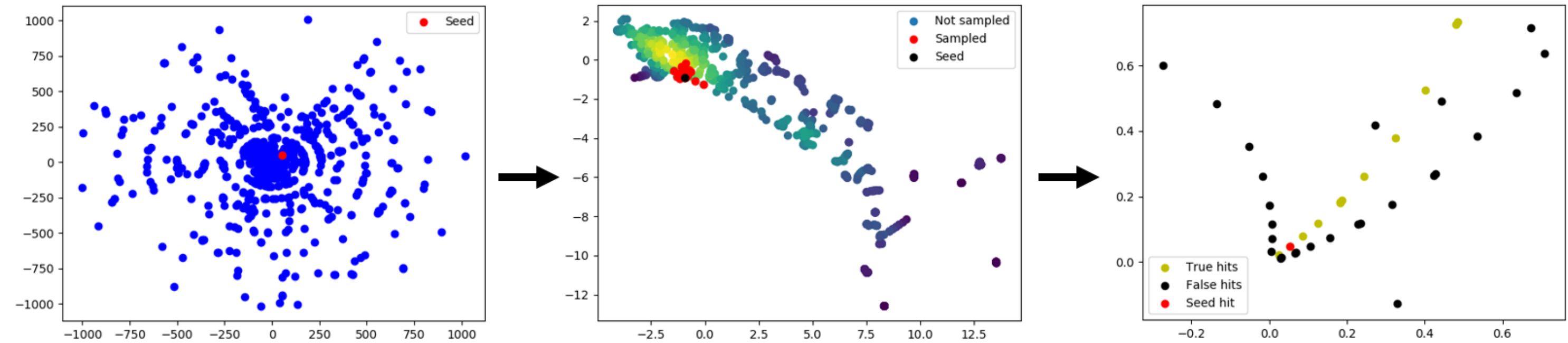


Fig. 13. ROC curve comparisons for γ vs. π^0 (top) and e vs. π^\pm (bottom) classification using different neural network architectures. Samples include particle energies from 10 to 510 GeV, and an inclusive η range.

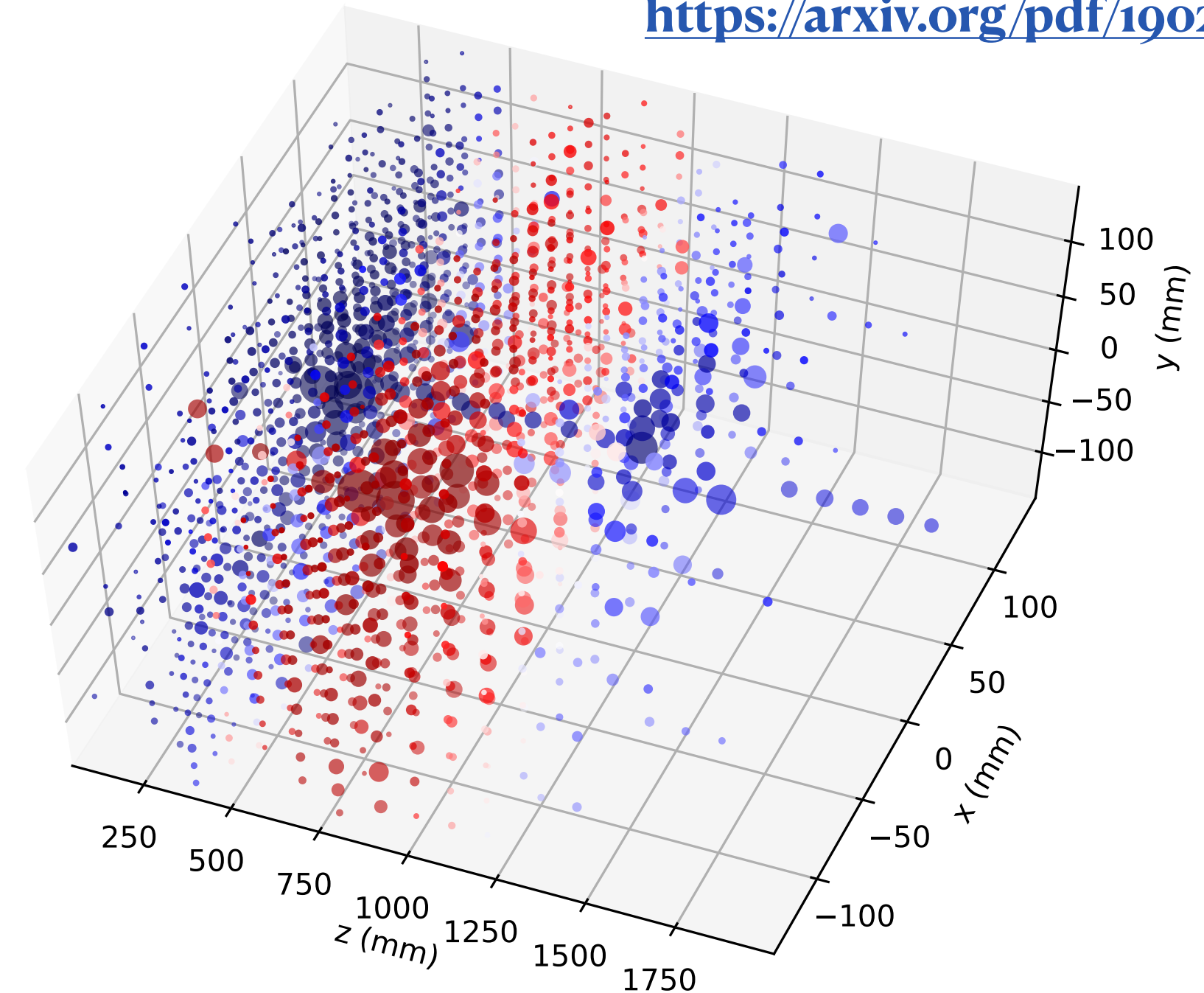
GraphReco for Muon Collider

- Interested to pursue Graph NNs for local reconstruction
 - Tracking
 - Calorimetry
 - Denoising with Autoencoders
- The final goal is to define the input ingredients to PandoraPF
- Longer term, interested to exploit PF linking with Graphs
 - Goal is to have same performance as PandoraPF
 - Advantage: would run on GPUs: faster & better integrated to HPC evolution scheme

<https://arxiv.org/pdf/2007.00149.pdf>

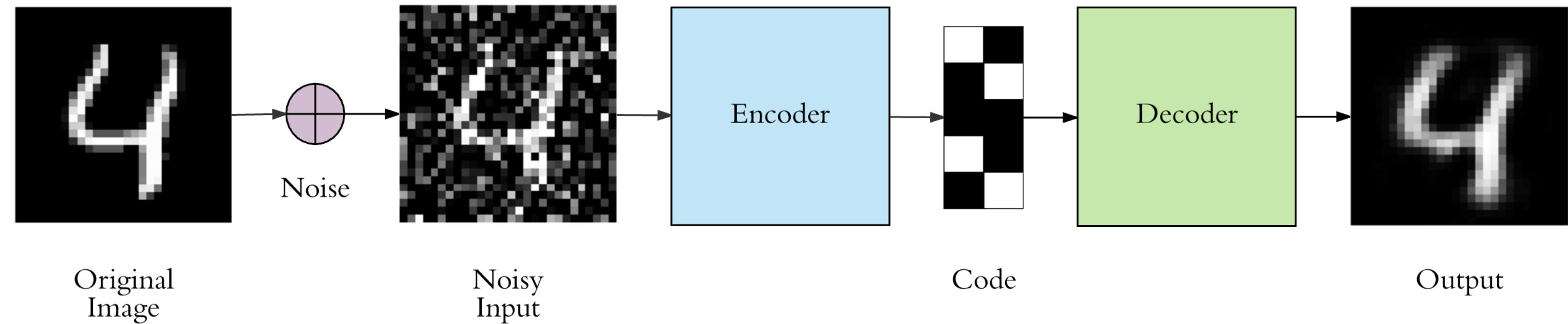


<https://arxiv.org/pdf/1902.07987.pdf>

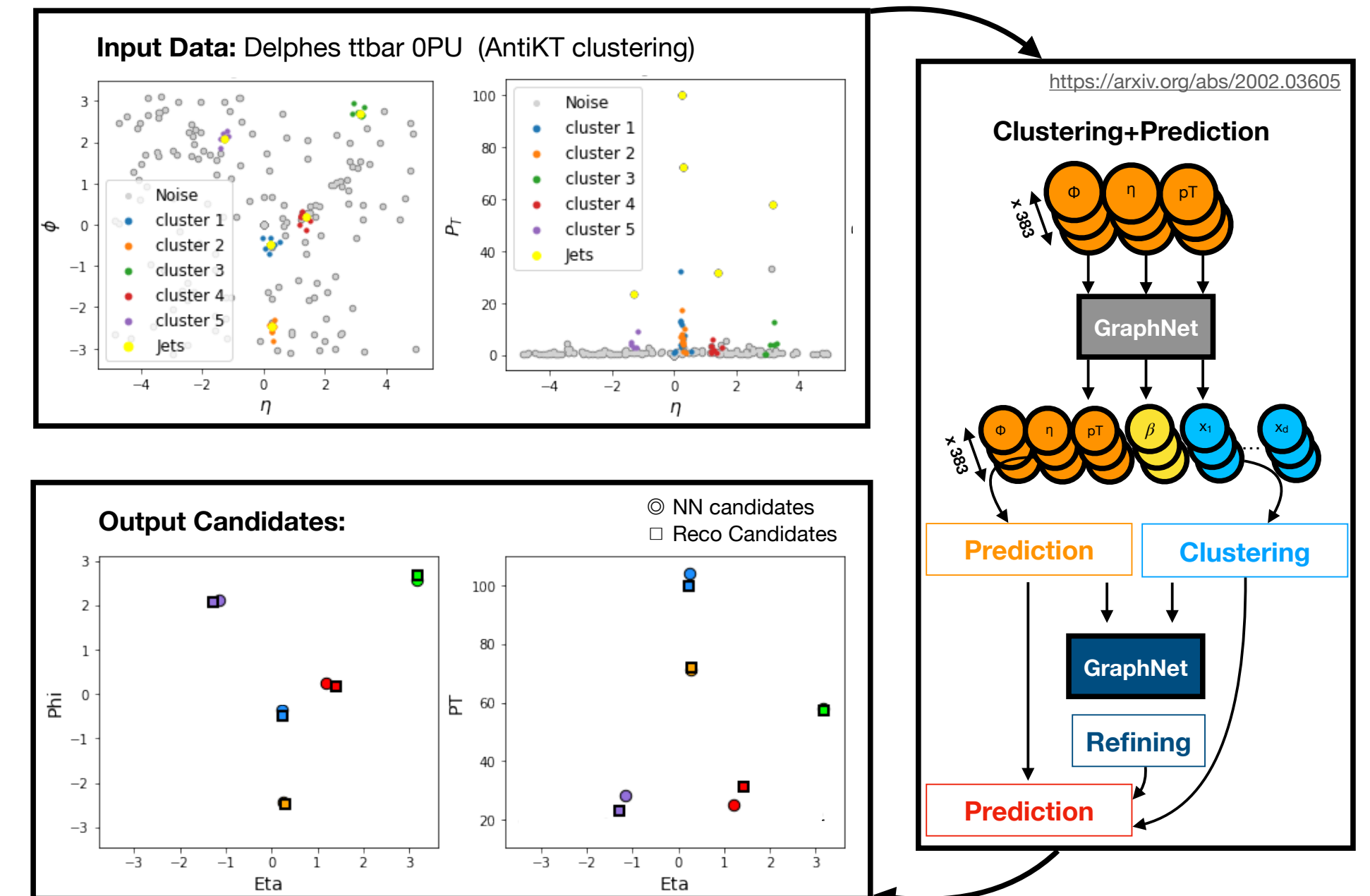


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 - Advantage: would run on GPUs: faster & better integrated to HPC evolution scheme
- Advantage of GraphNN: generalise 3D \rightarrow 5D is conceptually straight forward



G. Grosso et al., in preparation



Person Power Needs & Opportunities

- Currently relying on mPP Consolidation Grant ERC (2018-2023)
 - MP + one student to work on track-related issues with GraphNetworks
 - Recruiting fellow 2021-2023 to (partially) work on Calorimetry
- No help expected from EP
 - Focus on FCCee as main goal of ES implementation
 - Already invested resources on future collider common software infrastructure (ke4hep)
- We should consider creating Doctoral student position(s) to assess common beam/detector issues
 - MDI->Beam Background simulation chain -> local reconstruction is the only task relevant for this audience
 - Candidate from institutions working on Muon Collider, paid by CERN to stay 3 years at CERN during PhD studies