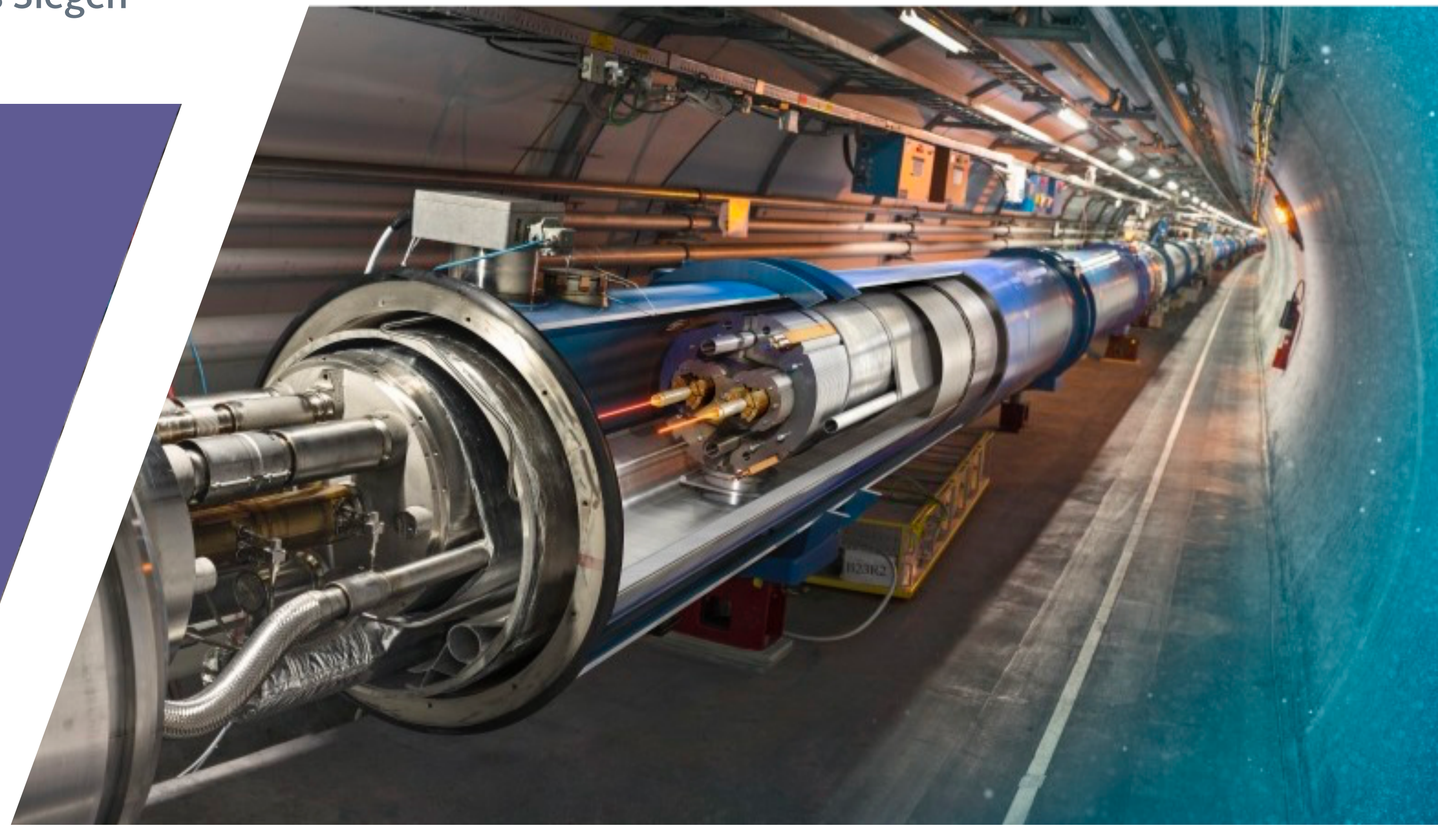
Universität Siegen

HEP Experimental High Energy Physics

CPPS Center for Particle Physics Siegen

Vertex reconstruction using particle tracks in a dense environment



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Current Siegen team

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Diptaparna Biswas

Markus Cristinziani

Vadim Kostyukhin

Particle physics environment

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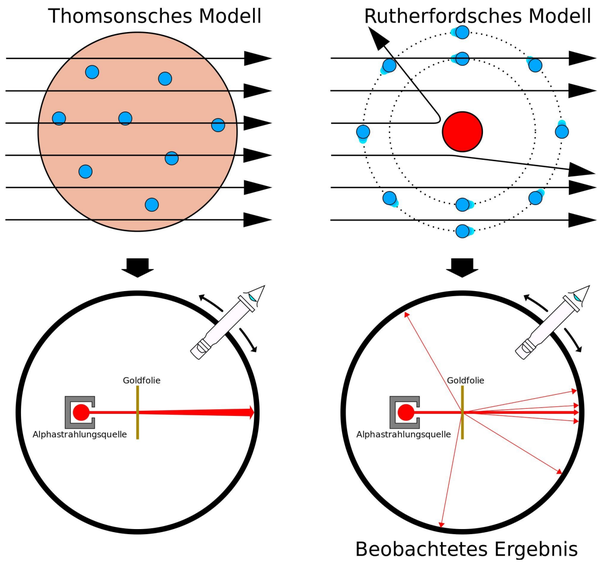
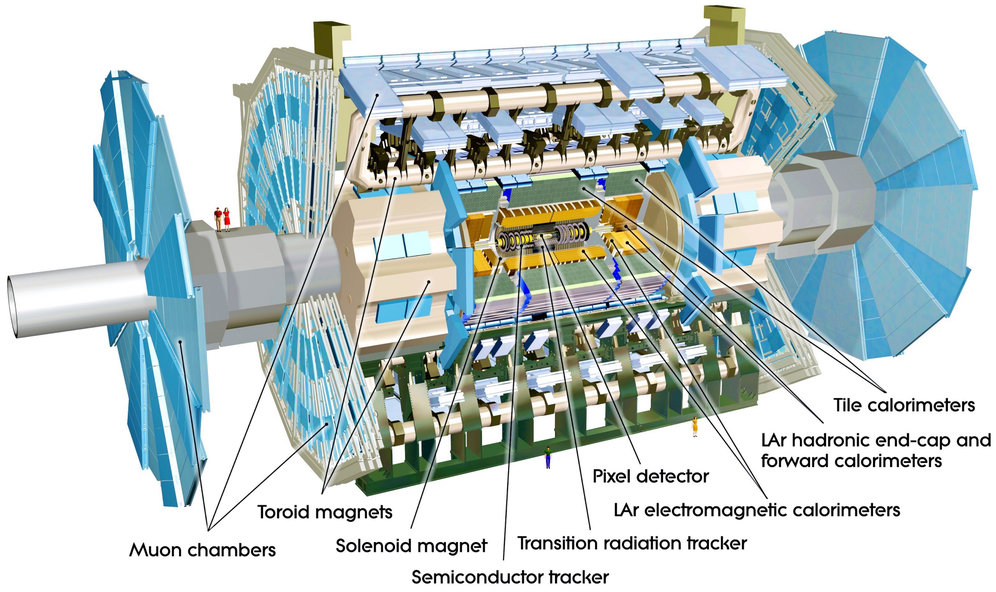
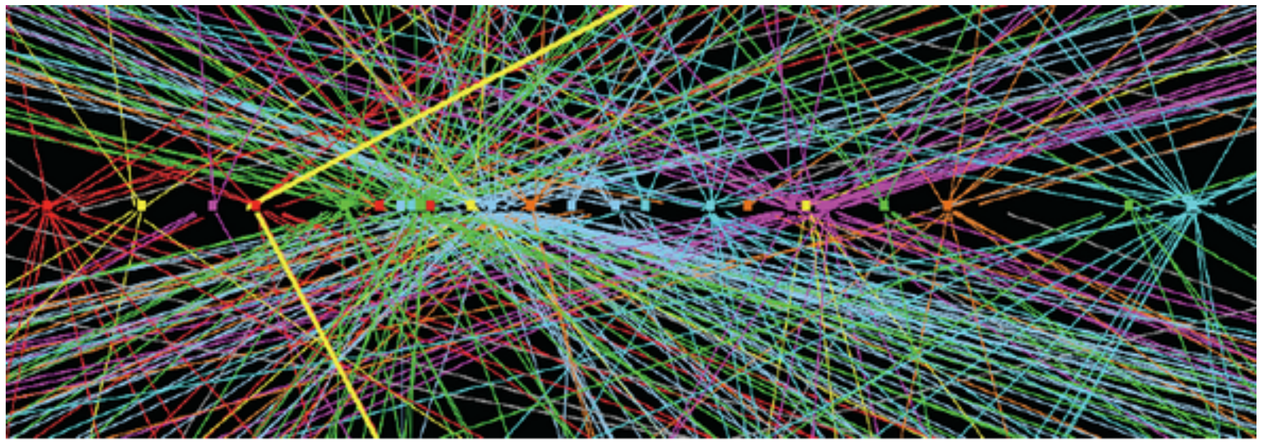
- Goal: understand fundamental structure of matter
- Tool: highest energy collisions (14.000.000.000.000 V) of protons at LHC
- Microscope: ATLAS detector



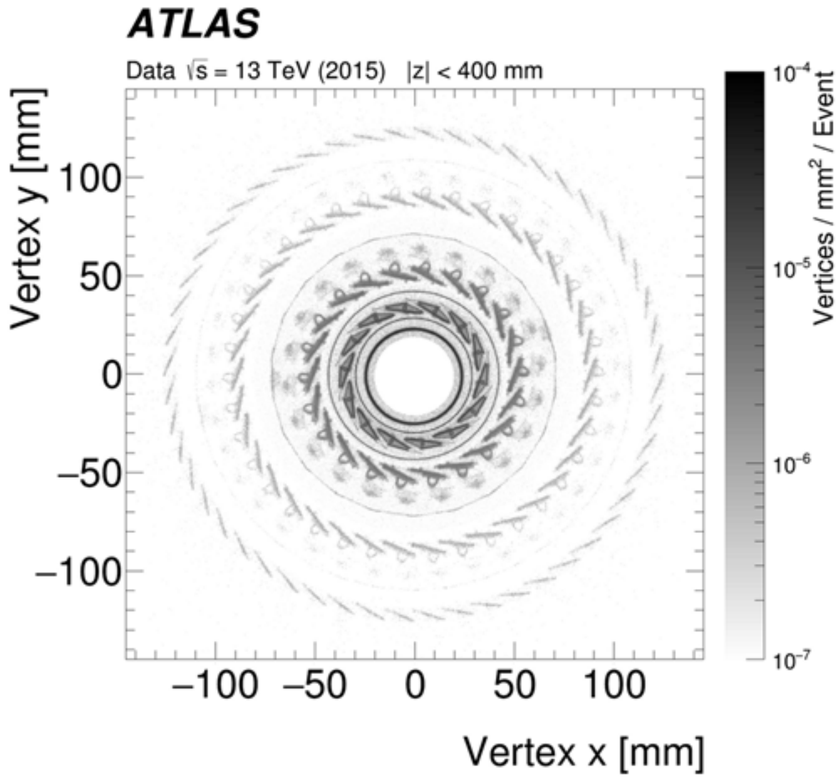


Definitions

- **Track**
  - electronic detector → trajectory of charged particle
- **Vertex reconstruction**:
  - given a set of tracks, estimate where interaction or decay happens



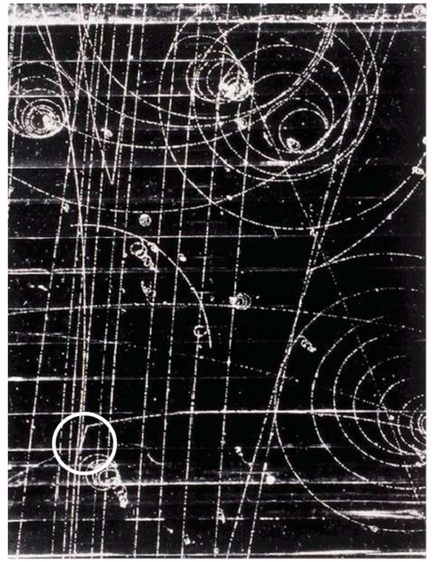
Pileup: Multiple proton-proton collisions at the Large Hadron Collider (up to 200) along the beam line → Primary Vertex

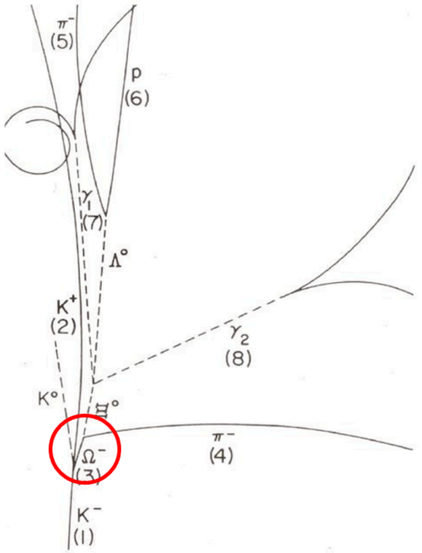


Inner detector “radiography” by reconstructing interaction vertex in detector material

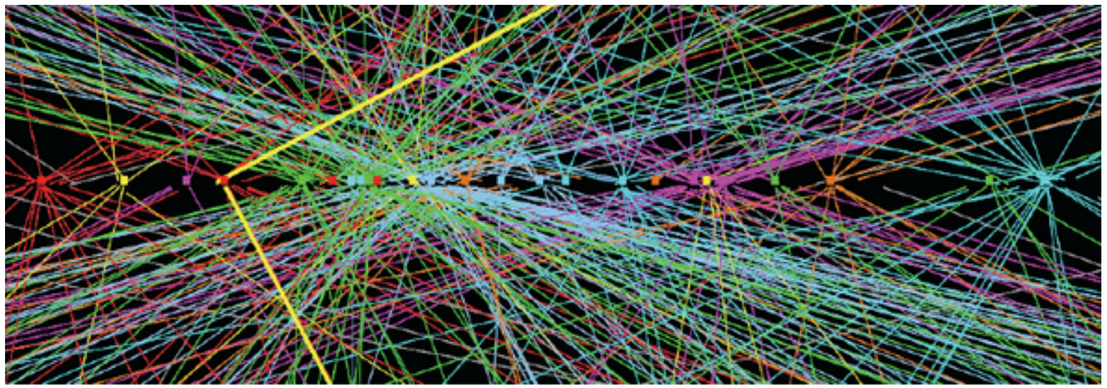
Typical problems

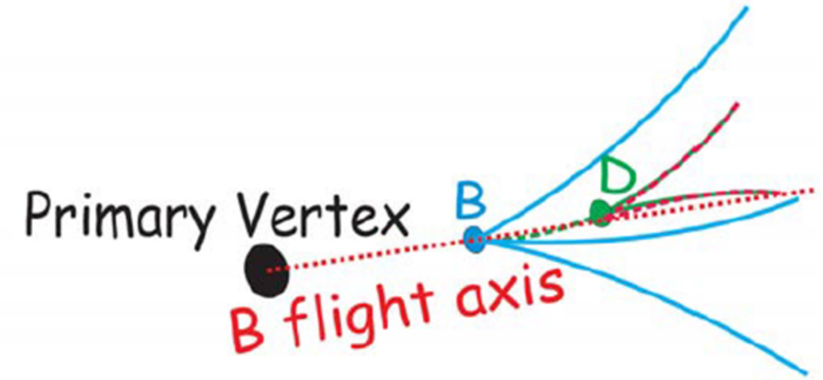
- Vertex reconstruction well known problem
  - e.g. discovery of “strange” Ω^- Hyperon 1964





- Typical current problems
  - Primary vertex reconstruction (collisions)
  - Secondary vertex reconstruction (decay)





Challenges in vertex fitting

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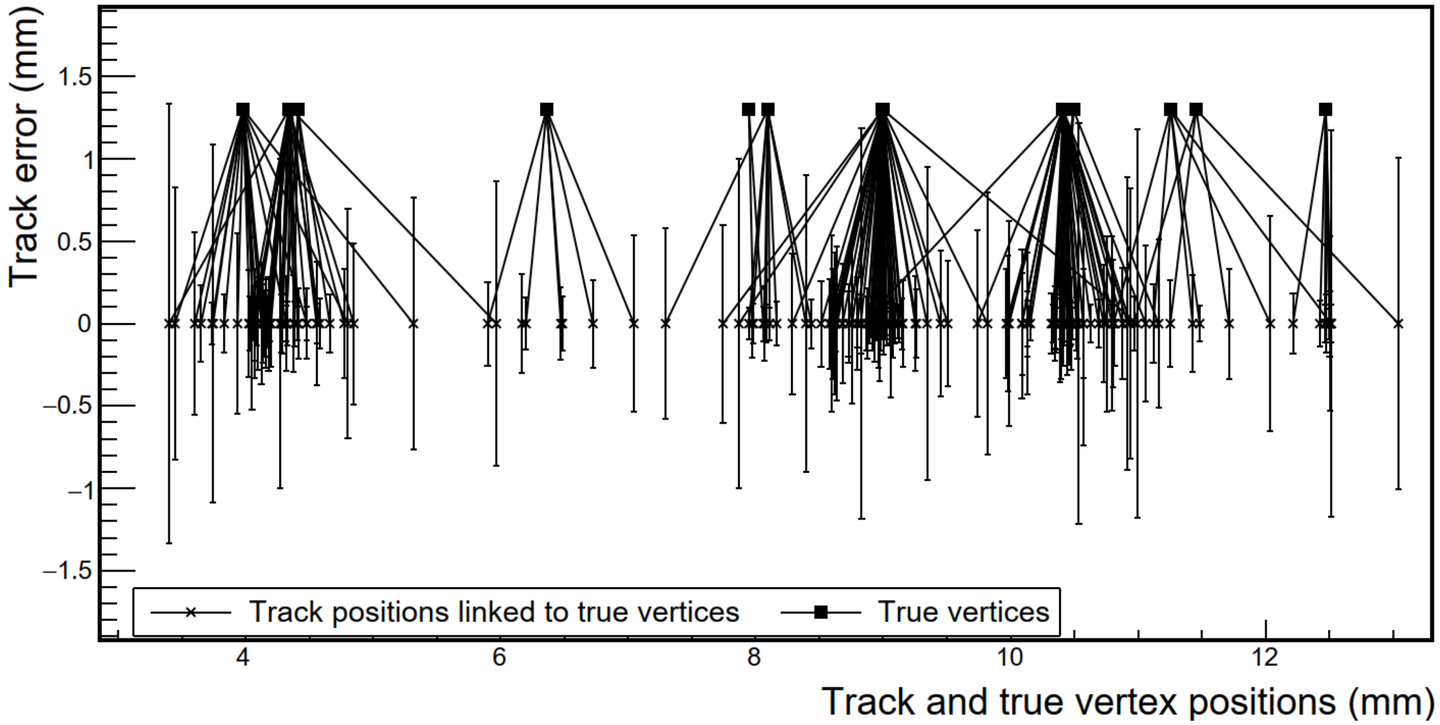
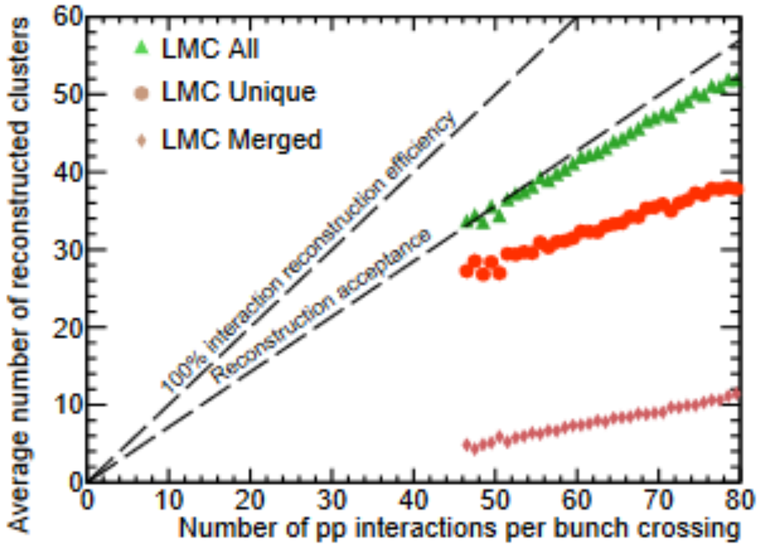
- Detector resolution and large track density
  - often vertex-to-vertex distance smaller than track resolution
  - few-track vertex difficult to detect near a many-track vertex
  - limited resolution → fake vertex candidates

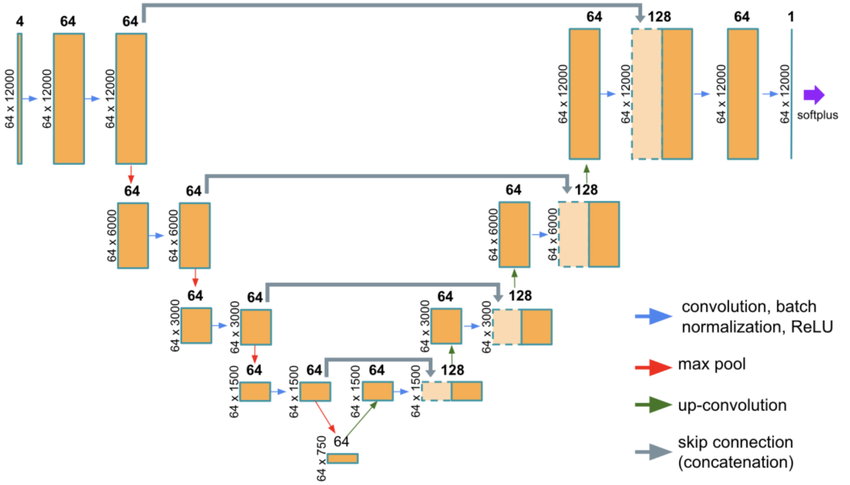


Track from different vertices can overlap

Selected previous work

- Primary vertex (PV) reconstruction with pileup
  - VK, M.Keuper, … MC, “Improving primary-vertex reconstruction with a minimum-cost lifted multicut graph partitioning algorithm”, JINST 18 (2023) P07013 using the Minimum Cost Lifted Multicut algorithm
  - ATLAS Collaboration, “Primary Vertex identification using deep learning in ATLAS”, ATL-PHYS-PUB-2023-011 using UNet, CNN for biomedical image segmentation





Vertices-in-jet reconstruction

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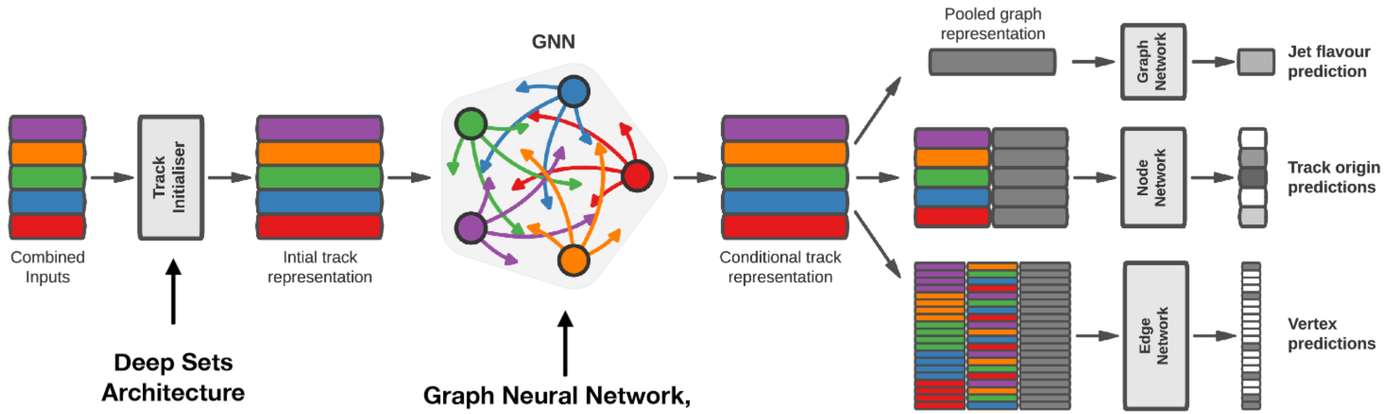
- Great advancements in recent years
  - J. Shlomi et al., “Secondary Vertex Finding in Jets with Neural Networks”, Eur.Phys.J. C 81 (2021) 540 using H. Serviansky et al., “Set2Graph: Learning Graphs from sets”, arXiv:2002.08772
  - … to learning track compatibility matrix with transformer-like attention, S. Van Stroud, CERN Data Science Seminar, March 2023



  - R.E.C. Smith et al., “Differentiable vertex fitting for jet flavour tagging”, arXiv:2310.12804

Datasets available

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- About 100 million fully simulated proton-proton → $t\bar{t}$ events
  - each event has two b-jets (i.e. secondary vertices)
  - owned by the ATLAS Collaboration
  - can be used for first studies (~ 1 year) but not for publication

- Private simulation using open source detector simulation and/or open data
  - available in ~1 year, free to be used in publications

Possible directions

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- Improving reconstruction of vertices (all-in-one approach)
  - simultaneously reconstruct primary, secondary, in/out-of-jet, material interactions …
  - in dense or very dense environments (future collider FCC, planned for ~2050), with 1000 primary vertices, 50 secondary vertices, 10.000 tracks
- Employ Graph Neural Nets
  - possibly processing with attention mechanism for better clustering
- Implement constraints from physics knowledge
- Compare performance with dedicated algorithms