Vertices

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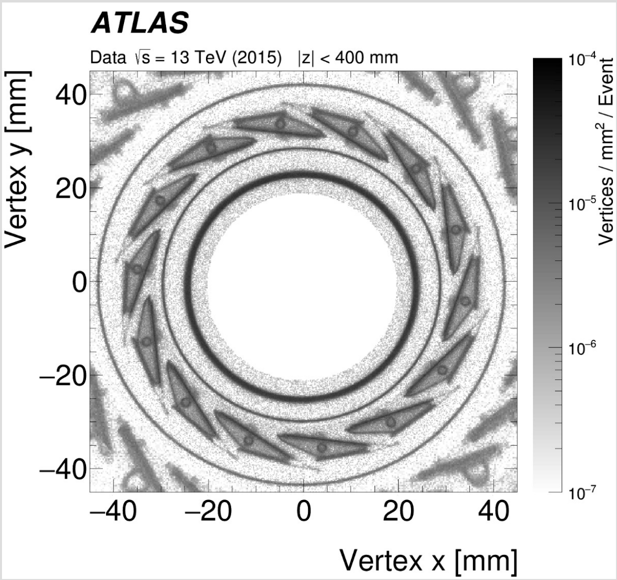
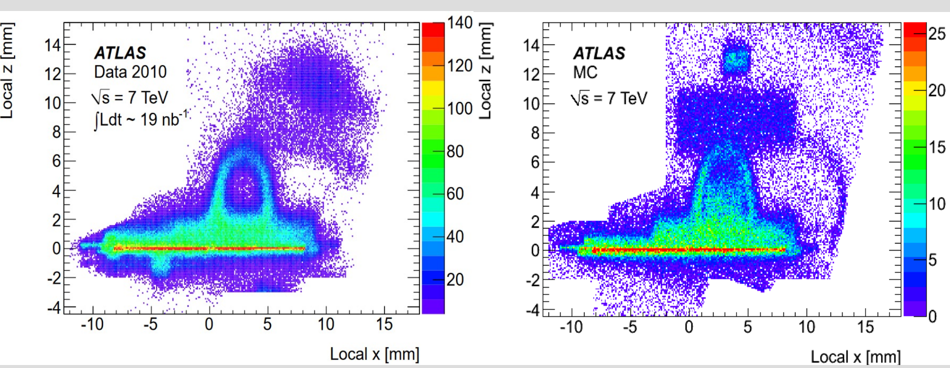
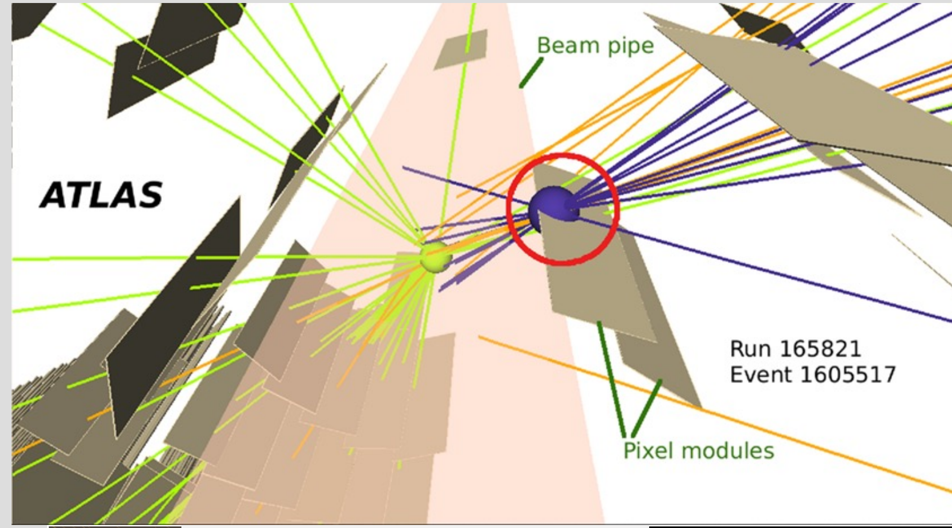
Real data (ATLAS) examples

ATLAS ID material study with hadronic interactions using VSI. Good space resolution.

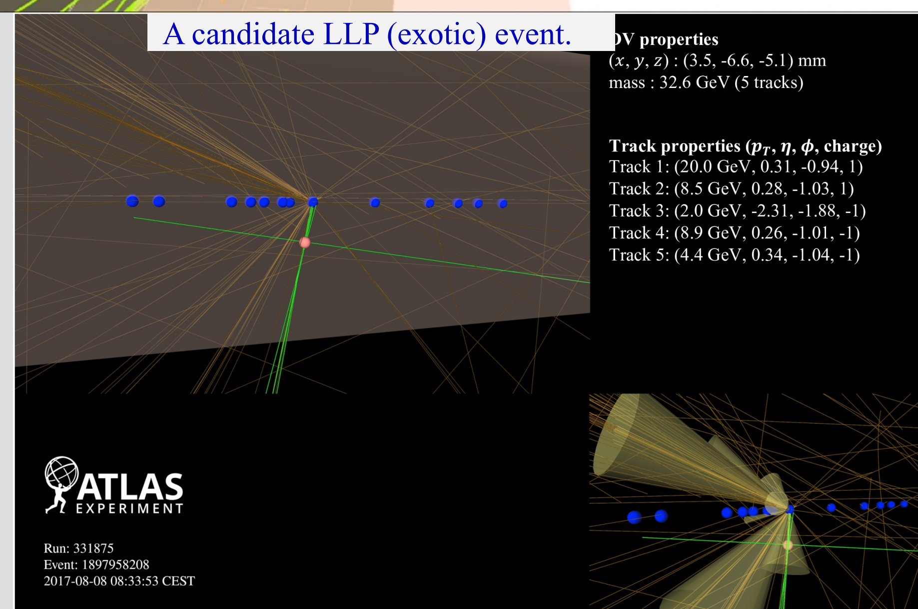




An event from a jet-trigger data sample, where a high-mass vertex (circled) is the result of an apparently random, large-angle intersection between a track and alow-mass hadronic-interaction vertex produced in a pixel module. Tracks originating from this vertex are shown in blue, those from the primary vertex are green, and other tracks are orrange. The beampipe and pixel modules with track hits are shown.

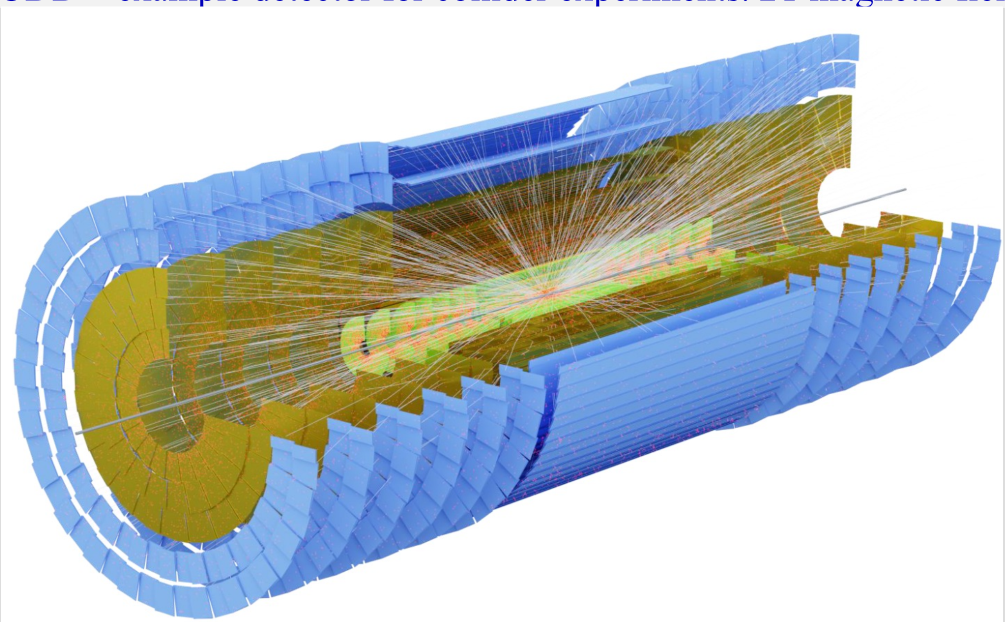


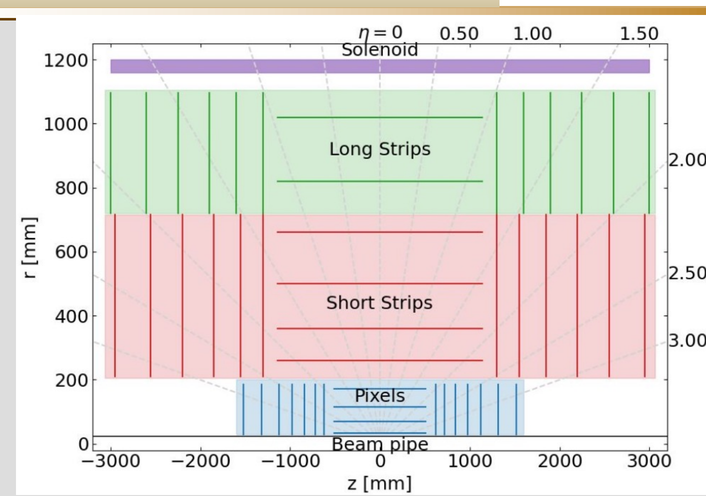
A candidate LLP (exotic) event.

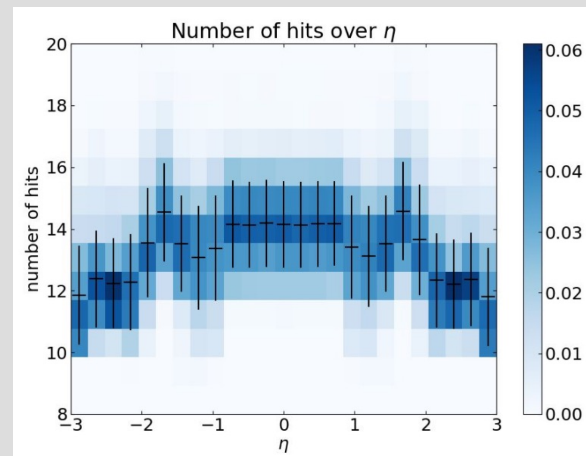


Open Data Detector simulation

ODD – example detector for collider experiments. 2T magnetic field







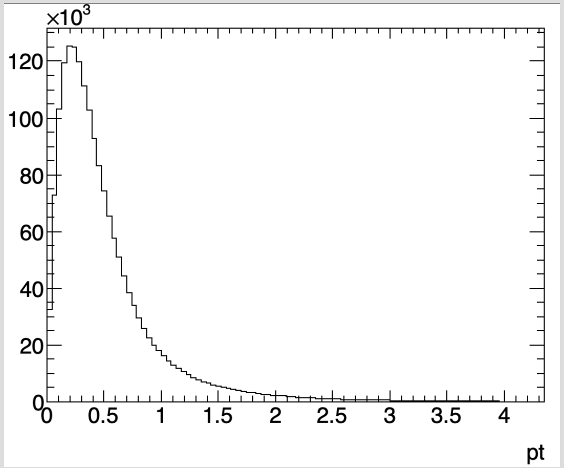
Particle detector provides a collection of HITS(!) – traces left by particles in different detector parts.

Usually tracks (particle traces) are reconstructed from the hits first, then they are used to reconstruct vertices

Why track reconstruction first?

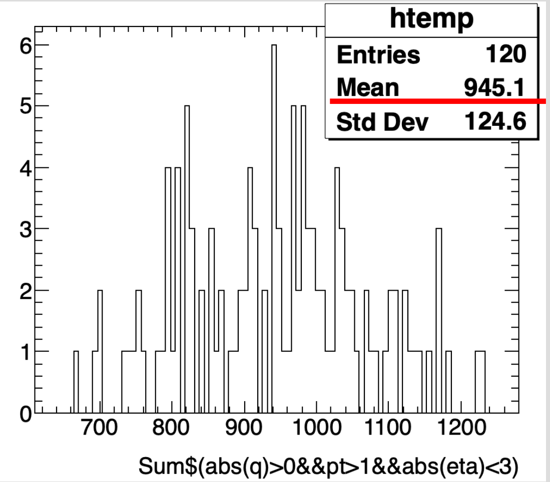
Universität Siegen

Simulated ttbar events with μ=200 pileup.
Charged particle Pt spectrum:

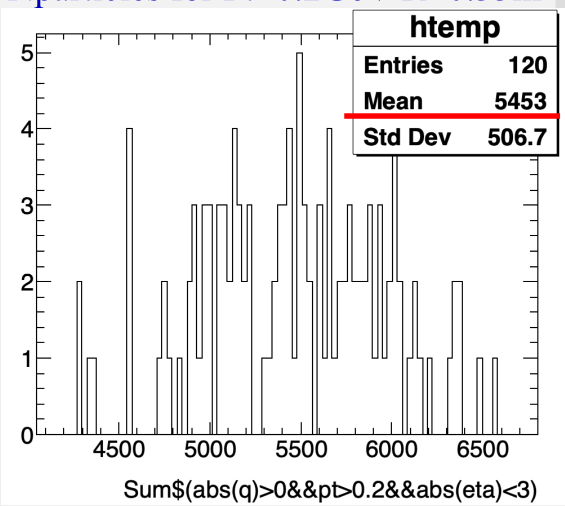


R=pt/(0.3·B) – radius in uniform magnetic field.
All these particles produce hits

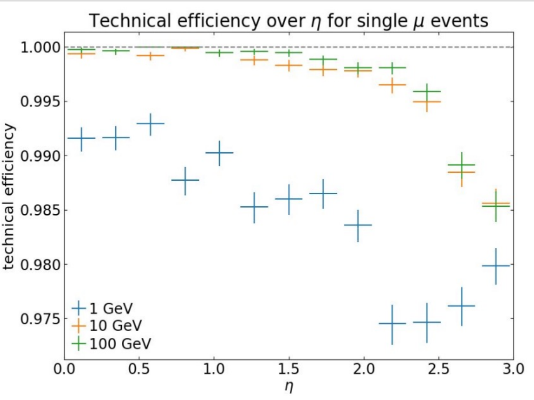
Nparticles for Pt>1GeV R=1.67m

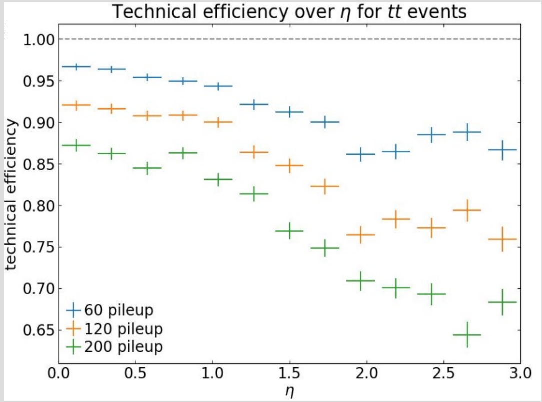


Nparticles for Pt>0.2GeV R=0.33m



Geant4 simulation, ACTS track reconstruction. Efficiency:

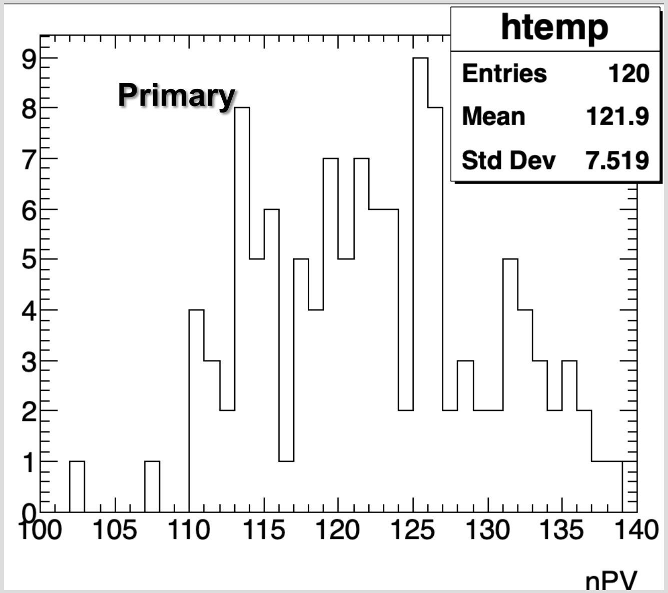


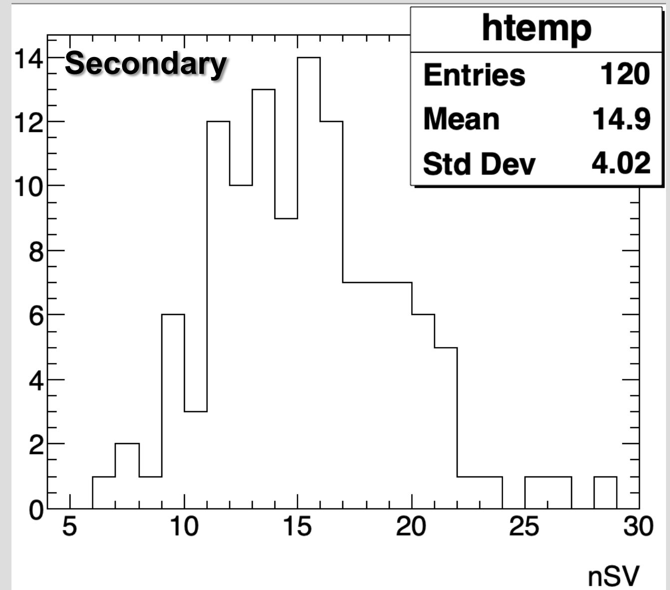


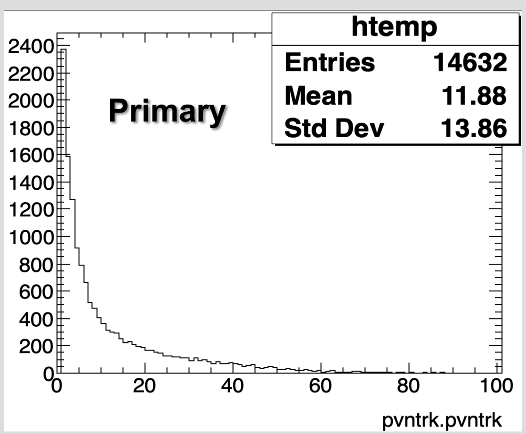
~10÷15% of all detector hits is used for the track reconstruction

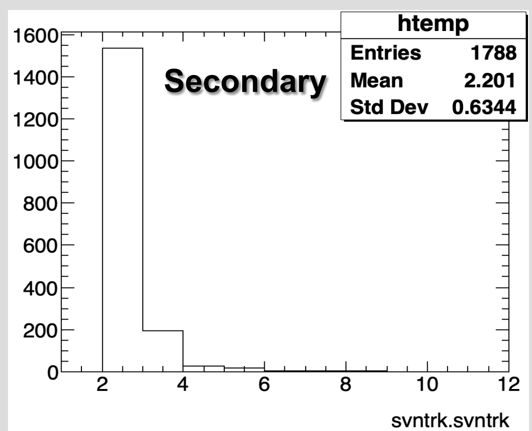
Vertices

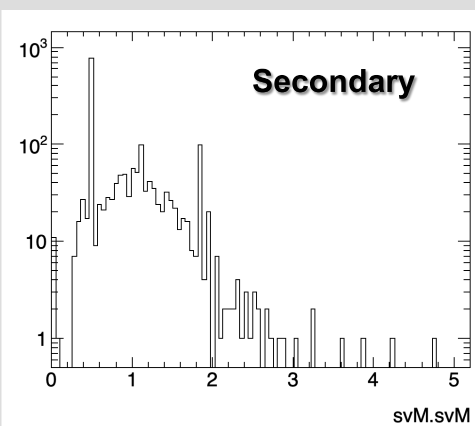
Simulated ttbar events with μ=200 pileup. Vertices <-> crossing points of at least 2 charged tracks with Pt>1GeV.





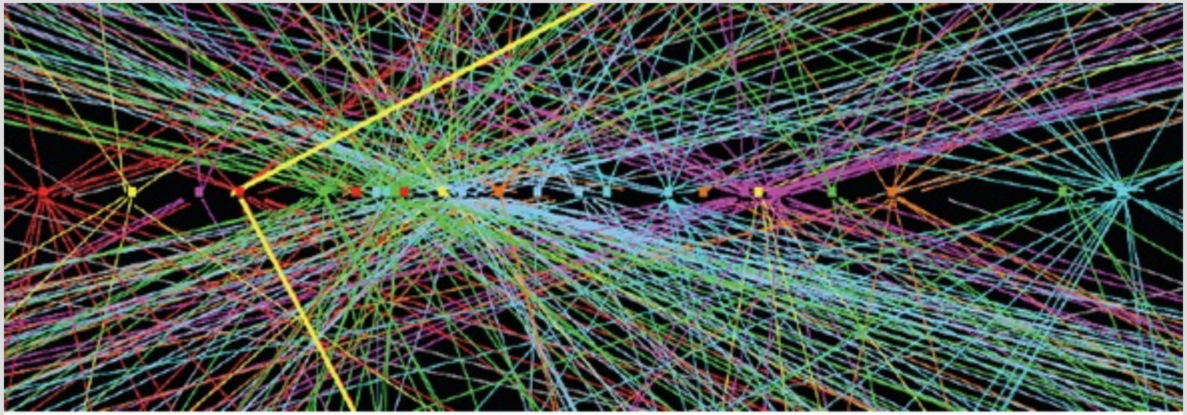


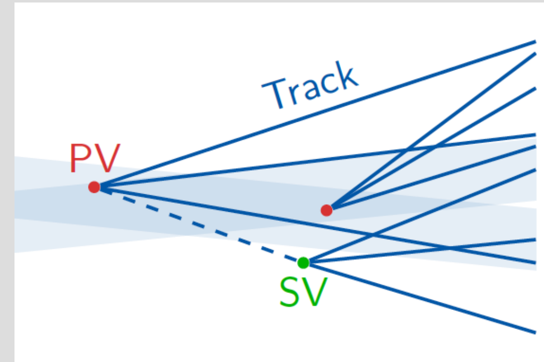




PV vs SV

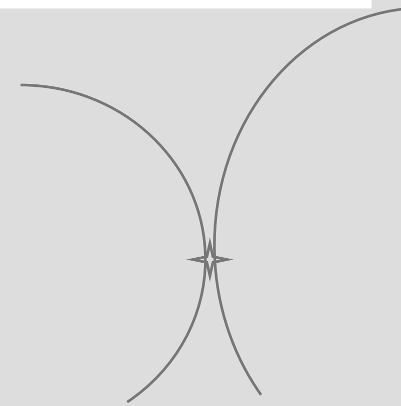
Primary Vertices(PV) – all beam-beam interaction points. 1D problem, doesn't require a curved particle trajectory calculation.



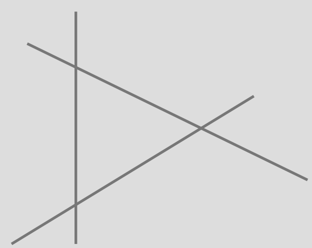


Secondary Vertices(SV) – interaction/decay points in 3D detector volume away from the beam line.
Can be detected by finding a crossing point (in fact a point of the closest approach due to resolution errors) of the curved particle trajectories in 3D space.

In general case the curved trajectory may be very complex due to non-uniform magnetic field.



PV reconstruction – clustering of points
SV reconstruction – clustering of trajectories



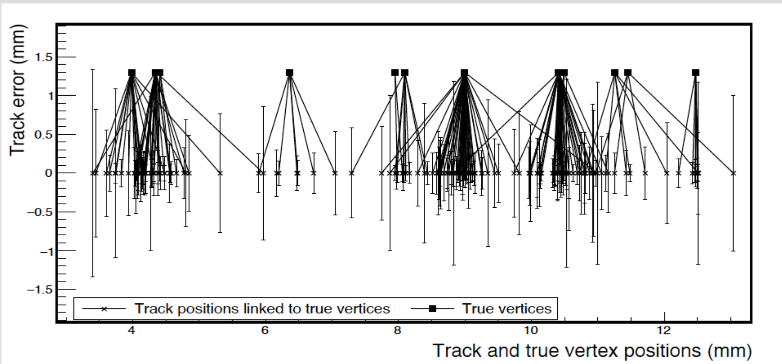
This is not a 3-track SV!

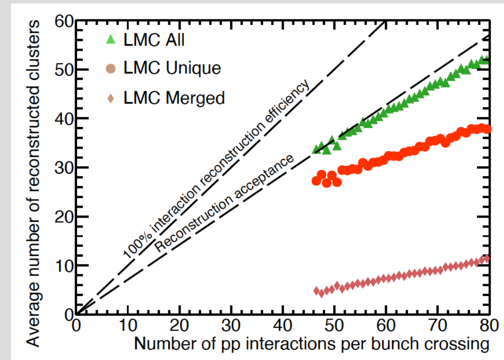
PV reconstruction (1D case)

Many "classical" algorithms in the market (ATLAS,CMS,LHCb,etc. have their own)

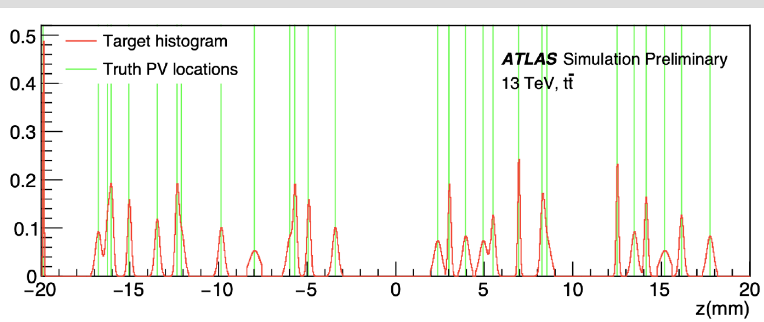
ML – based approaches:

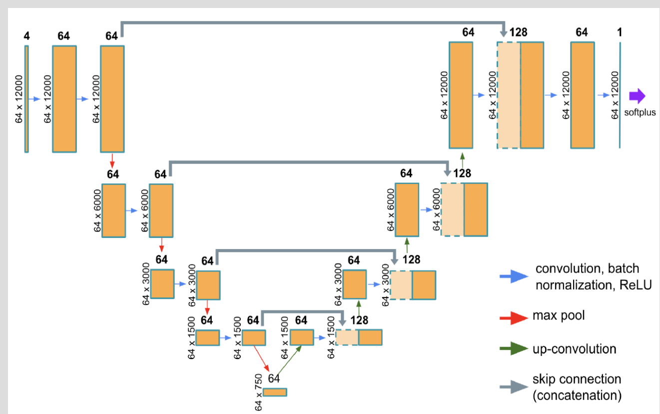
V. Kostyukhin, M.Keuper, M. Cristinziani *et al* 2023 *JINST* 18 P07013:
Point compatibility graph partitioning using Lifted Multi-Cut algorithm

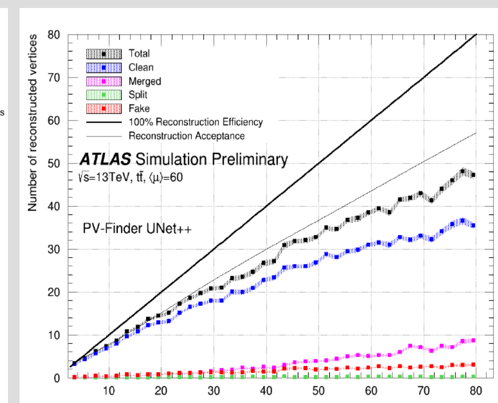




ATL-PHYS-PUB-2023-011. "Primary Vertex identification using deep learning in ATLAS"
Kernel based PDF histogram partitioned (clustered) via UNet network (image segmentation). Proposed/used by LHCb

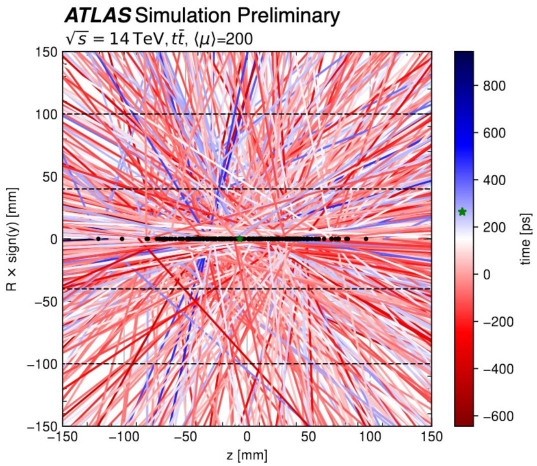


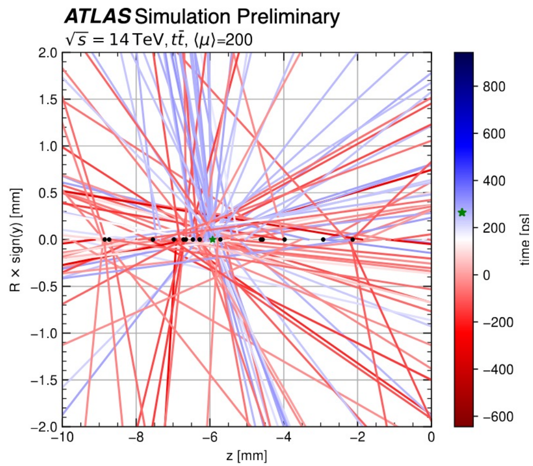


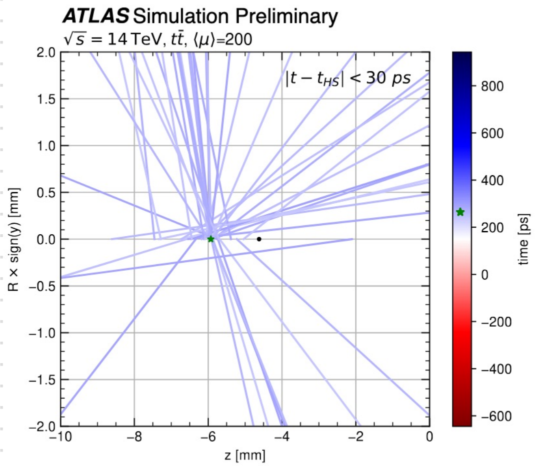


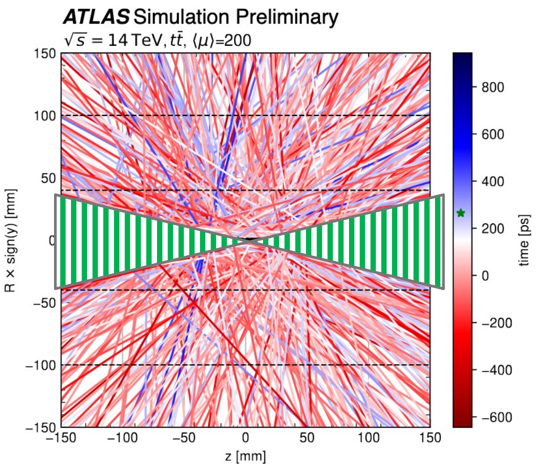
Time info - 4D vertexing

Propaganda plots from ATLAS – complete track set is clustered based on time, vertex search in time cluster only.







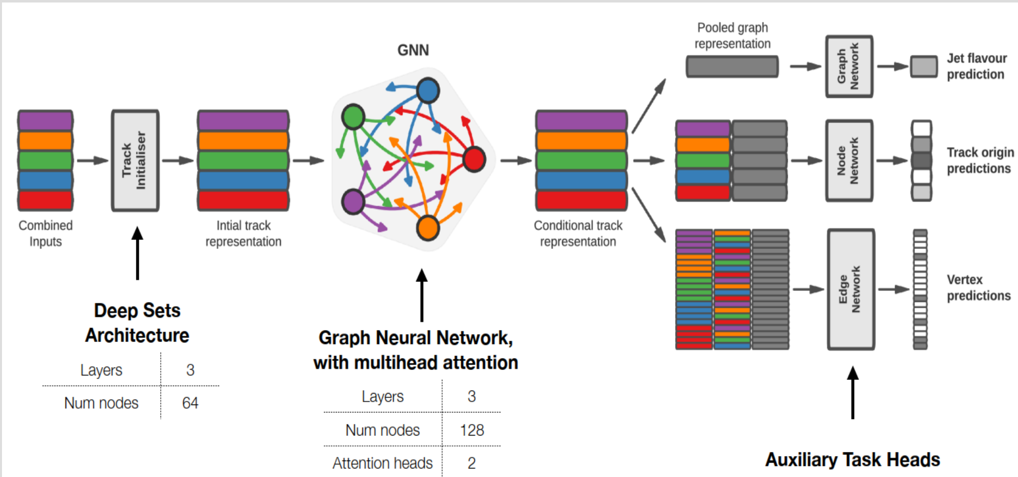


Reality: timing info will be available at |η|>2.4 only.
Most precise and useful tracks at |η|<2.4 won't have time

Design might be different at FCC!

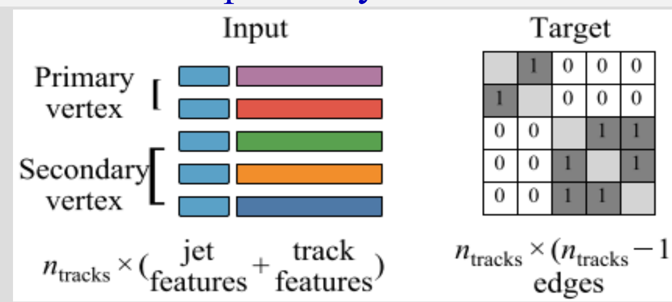
ML SV reconstruction (in jets)

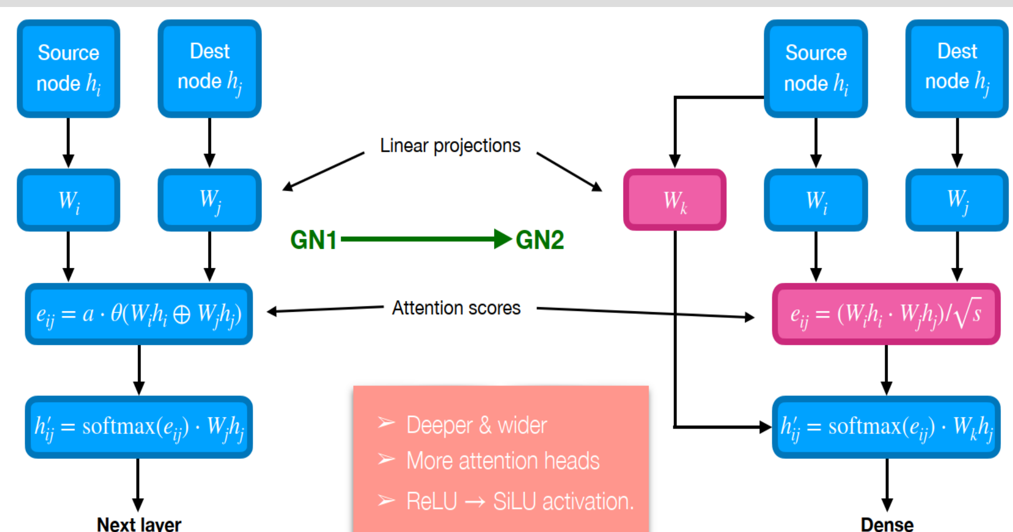
ATL-PHYS-PUB-2022-027 “Graph Neural Network Jet Flavour Tagging with the ATLAS Detector”



Origin papers:
arXiv:2002.08772 “Set2Graph: Learning Graphs From Sets”
arXiv:2008.02831 “Secondary Vertex Finding in Jets with Neural Networks”

In short:
Set of track parameters
→ track compatibility matrix



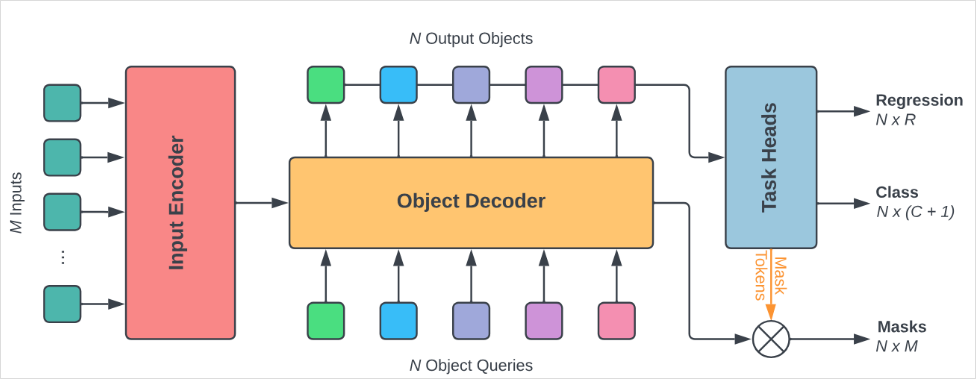


GNx software by itself returns just the track compatibility graph edge weights. The GNx algorithm uses a simple “union find” algorithm for the real graph/matrix partitioning.

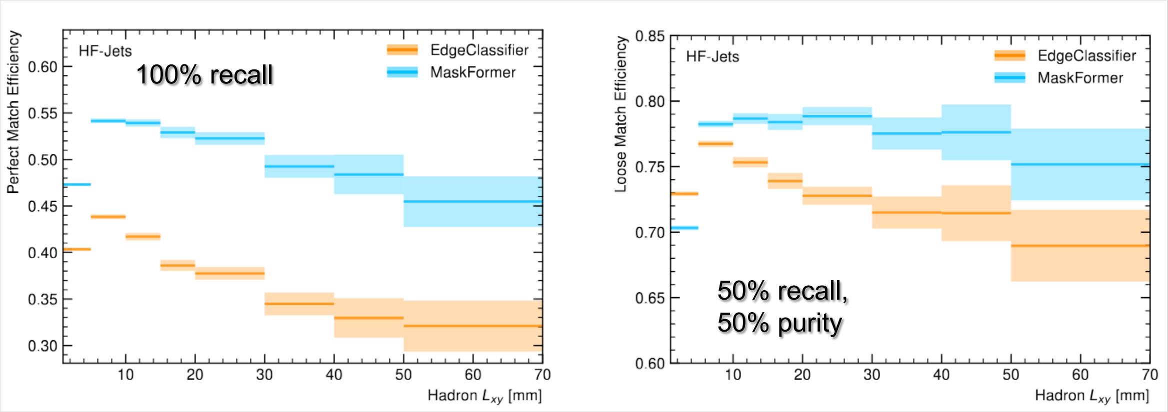
No real vertexing, no vertex quality check. From note:
“A vertex is considered matched if it contains at least 65% of the tracks in the corresponding truth vertex and has a purity of at least 50%. “

SV reconstruction (in jets)

arXiv:2312.12272 “Secondary Vertex Reconstruction with MaskFormers”



1. Vertex features reconstruction via regression
2. Track to vertex assignment via Masks (explicit partitioning)



“Edge classifier” is the algorithm from the previous page

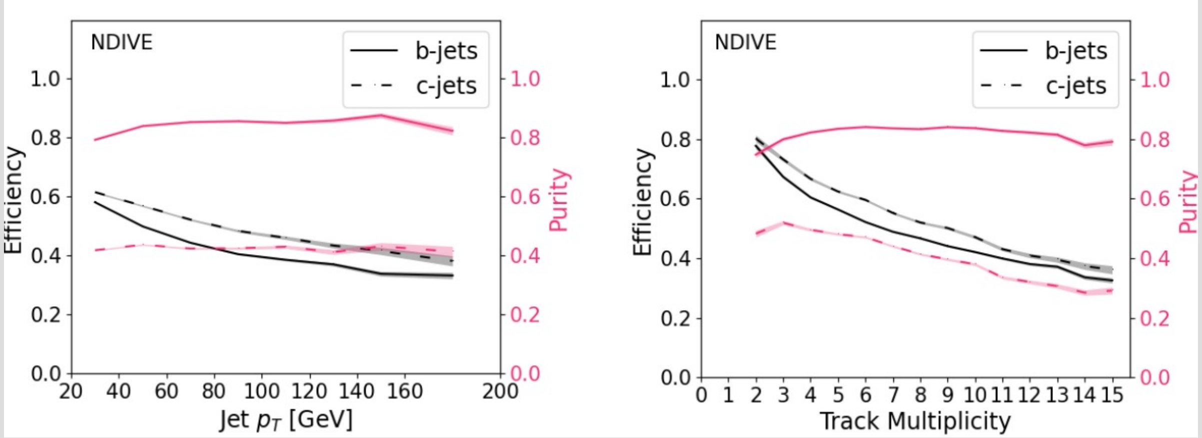
1. No universality – NN is trained on B/C vertices. No extension to many other SV types, especially for exotic vertices with unknown properties
2. Efficiency/purity is far from ideal.

Current state

- A setup (Geant4 ODD+ACTS) for generation of data for ML development is being prepared.
- Initial(!) set of data features is identified (not frozen)
- Data format is not yet defined (needs agreement)

Backup: Track extrapolation in NN

- A step forward is made in arXiv:2310.12804 "Differentiable Vertex Fitting for Jet Flavour Tagging" where a single vertex fit and track extrapolation are explicitly implemented as NN layers.
- Though not a practical recipe for b-tagging:
  - ✓ Vertex fit is based on simple clustering → non-pure and non-efficient vertices.
  - ✓ Single vertex fit only, no accounting for 1-prong vertices



As the authors said: "These methodological developments are generic, applicable to other vertex fitting algorithms and other schemes for integrating vertex information into neural networks."

Backup: Real event in the ATLAS detector