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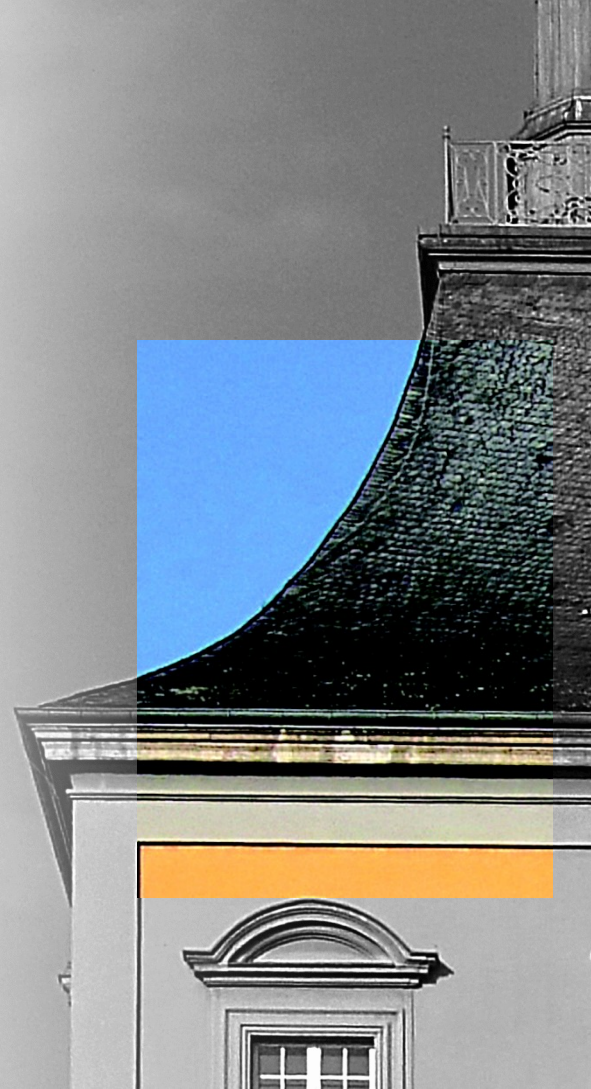
VXDHOUGHTRACKING FOR LOW PT TRACKING

09.11.2021



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VXDHOUGHTRACKING

- Based on the idea to use the Hough Trafo for track finding on DATCON, I implemented a new VXDHoughTracking as a regular tracking module
- Despite its name, currently only works with SVDSpacePoints, but can easily be adapted to also use PXDSpacePoints
- Works as a general purpose track finder
  - Limited to tracks originating close to the IP
  - Inherit problem of the conformal transformation used to map circled tracks into straight lines
  - Can be adapted to search for low pT particles in particular
- More info in talks on June 18th and June 25th

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STRUCTURE OF VXDHOUGHTRACKING

- Load SVDSpacePoints and create internal hit representation
- Perform Hough transformation and QuadTree search of the Hough Space
  - Cluster active cells (= hits from ≥ 3 SVD layers) and collect all hits into a track candidate
- Clean the track candidates by creating relations, applying a cellular automaton, and only using the best track candidates after each step
  - Similar to CKF, without the KF part, only track fits from the VXDTF2 package are used
- Resolve overlaps applying the OverlapResolver from the VXDTF2
- Store final selection of track candidates as RecoTracks
- Perform ROI finding directly within the module (optional)

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OPTIMISATION

- Performed optimisation of the free parameters based on 10000 $\Upsilon(4S)$ events with preRelease-06 background and default SVD reconstruction settings in terms of
  - Tracking efficiency, fake rate, clone rate (using the Python tracking validation framework)
  - Execution time
  - Memory consumption

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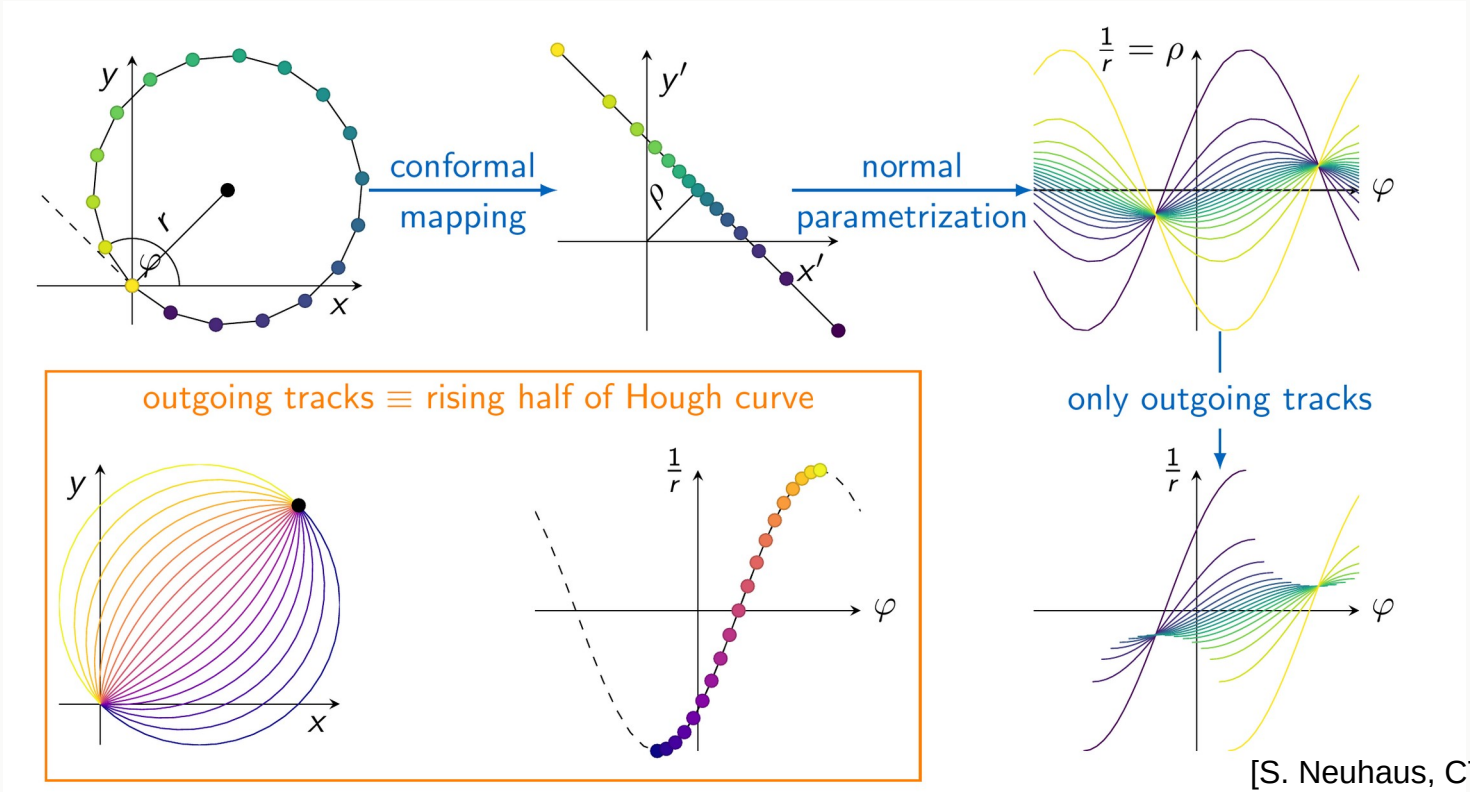
Reminder: Hough Transformation

HOUGH TRANSFORMATION



[S. Neuhaus, CTD/WIT 2017]

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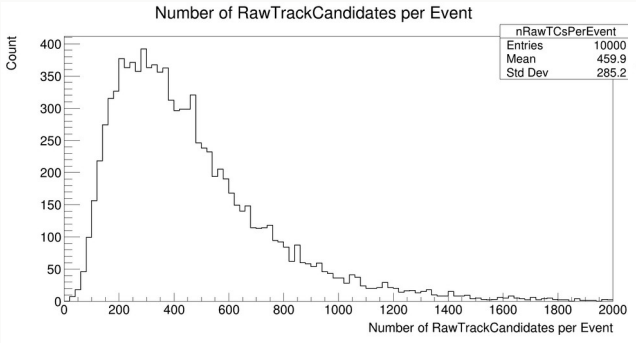
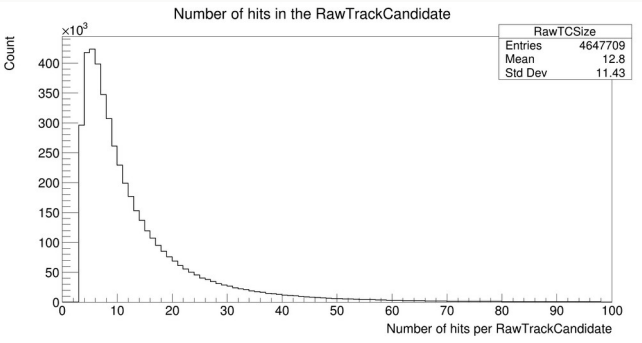
Combinatorics during track finding

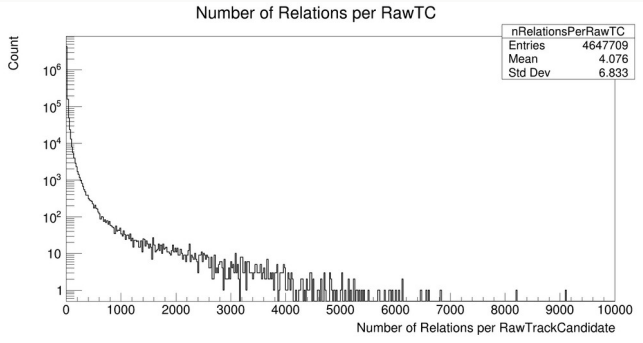
using SVDSpacePoints only

COMBINATORICS

- From Hough Trafo lots of clusters (RawTrackCandidate, RTC) in the Hough Space (left)
- Many of them contain a lot of hits (>= 10 hits, center)
- And the number of relations between the hits in a RTCs can be very large, too (directly related to number of hits in RTC, right)

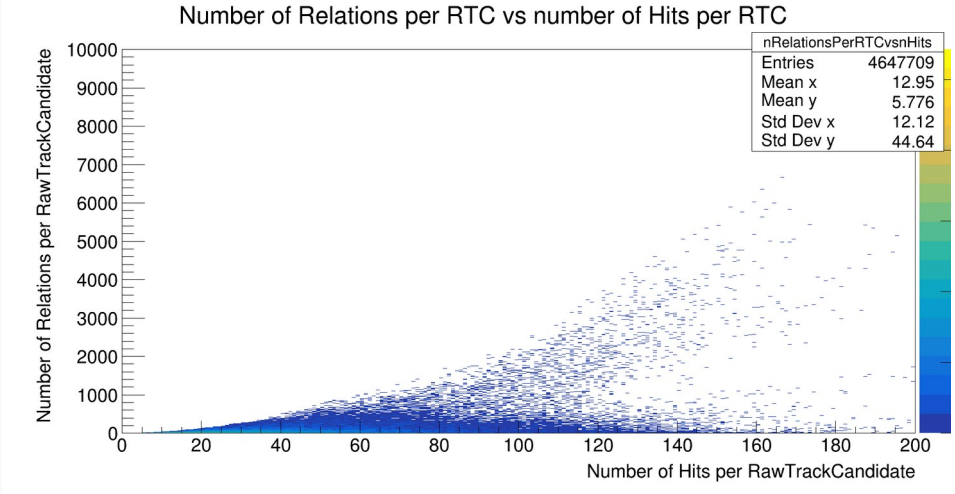


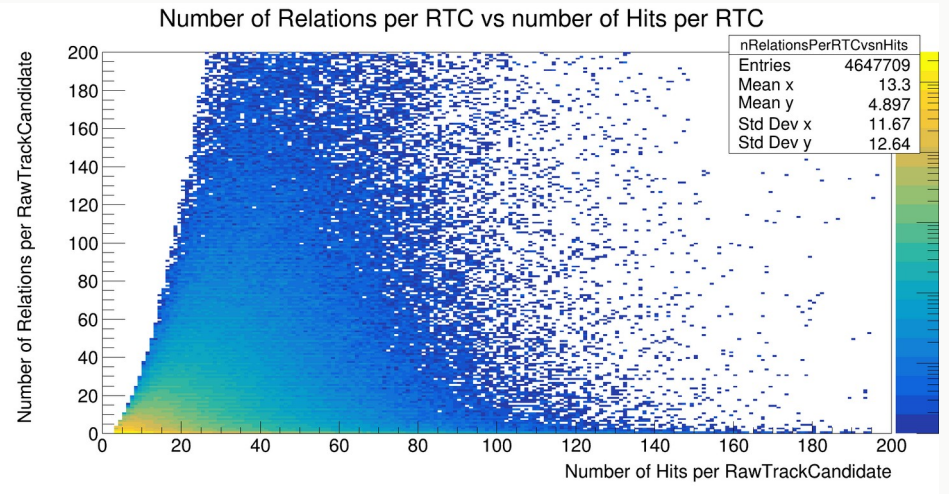




COMBINATORICS

- Number of relations between the hits in a RTCs can be very large
- But not in all cases correlated





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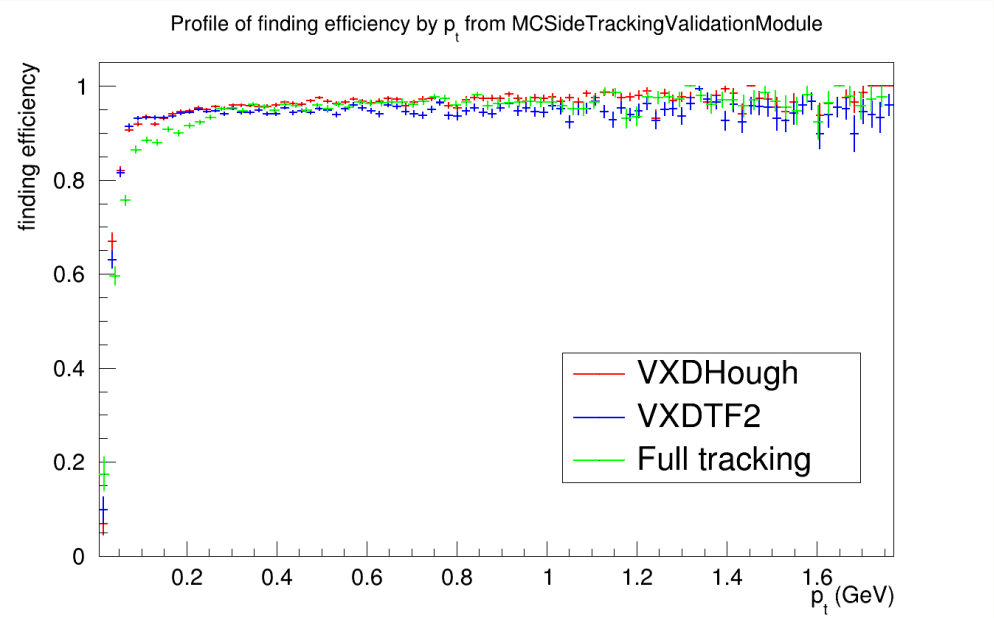
VXDHoughTracking

VXDTF2 tracking

Default full tracking

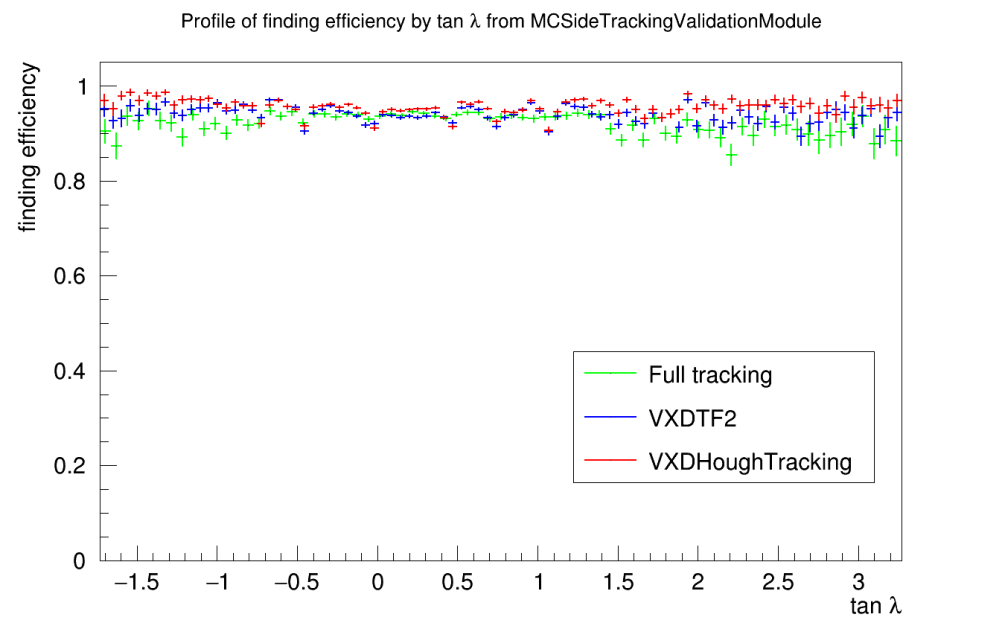
TRACK FINDING EFFICIENCY VS PT

- Low pT: VXDHough / VXTF2 superior to full tracking
- Could be a hint to start with SVD tracking and extrapolate into CDC to have highest low pT tracking efficiency



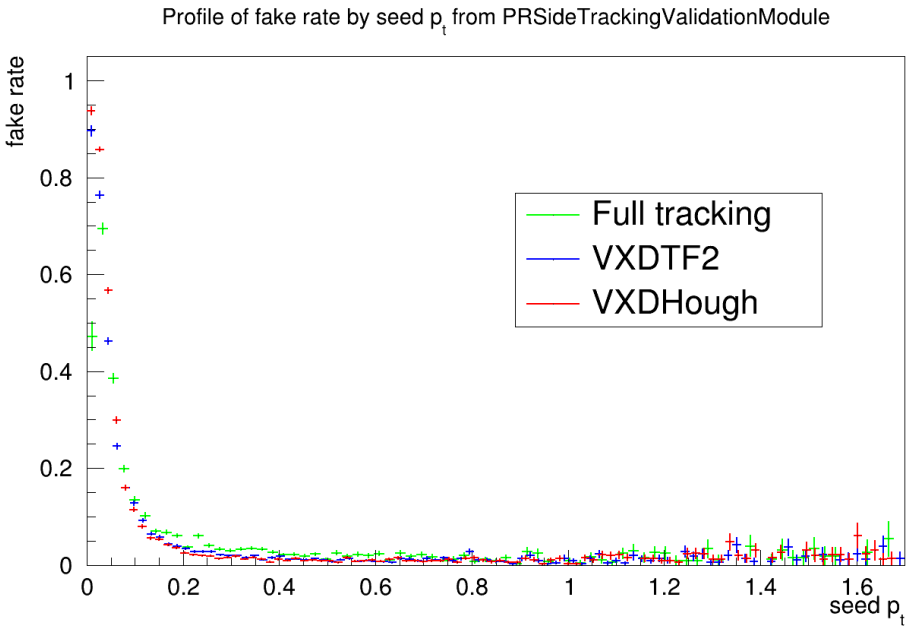
TRACKING EFFICIENCY VS TAN LAMBDA

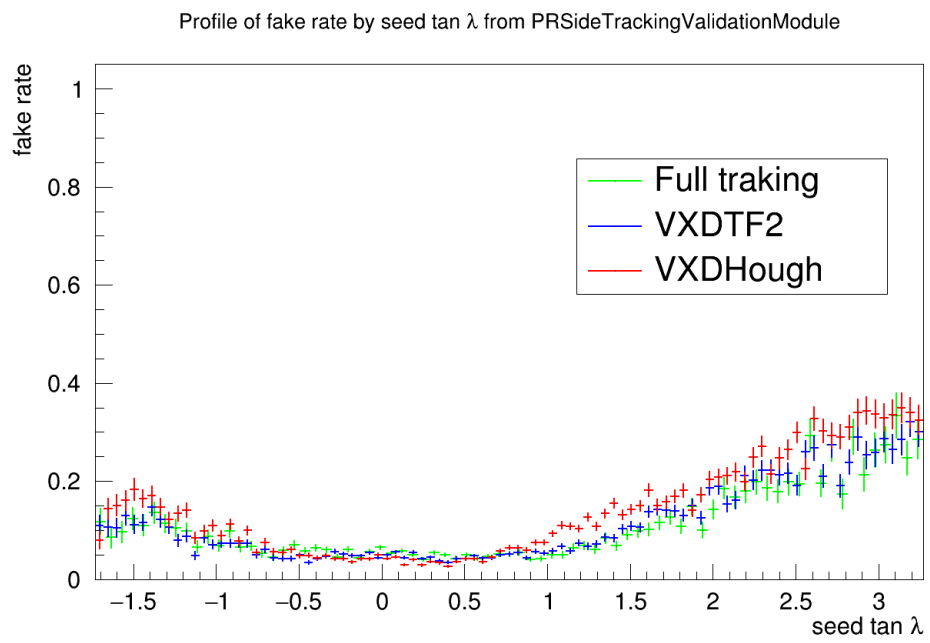
- Central region: similar performance
- Forward / backward: both SVD standalone trackings perform better



FAKE RATE

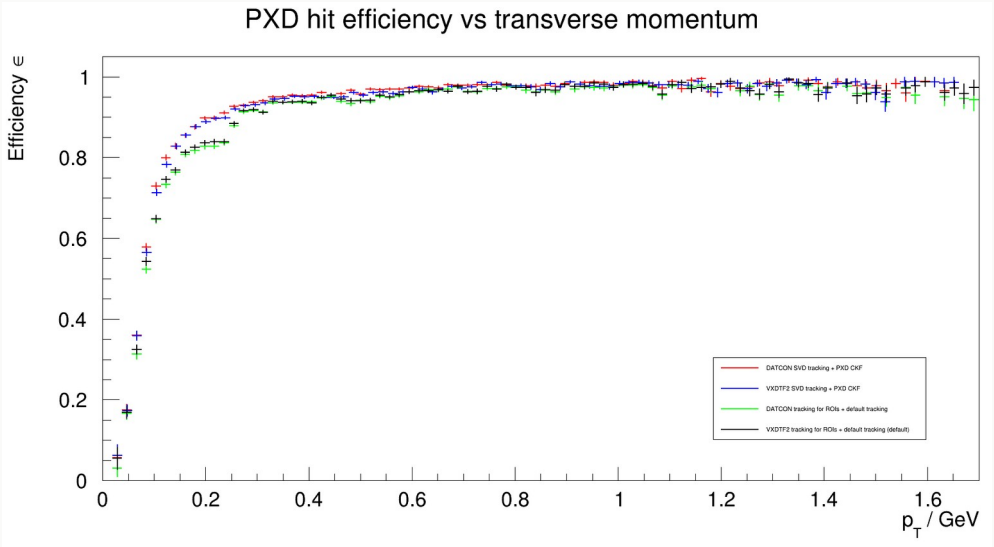
- High fake rate at low pt and in forward and backward





PXD HIT EFFICIENCY VS PT

- Using VXDHoughTracking or VXDTF2 tracking for ROI finding and use the tracks as input to PXDCKF, the PXD hit efficiency is significantly higher in the low pT region compared to full tracking (independent of the tracking for ROI finding)
  - We are missing PXD hits with the current tracking



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Possible options for low pT tracking

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LOW PT TRACKING OPTIONS

- Hough trafo with conformal trafo is “minimum bias” algorithm with few limitations
  - IP position must be known rather precisely
  - Can only find tracks from very close to the IP
  - Best performance for circular tracks, suffers from multiple scattering
- So far, HS y-range of -1/r … +1/r is used, with 1/r = 0.45/pT

  → Use limited range to find tracks below e.g. 200 MeV in pT, like $|1/r| > 0.02\ cm^{-1}$, corresponding to r < 50 cm or pT < 225 MeV
  - Thus the pT range with most of the tracks can be cut out, reducing combinatorics

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LOW PT TRACKING OPTIONS

- In addition, use physics knowledge of the low pT tracks
- Energy loss is statistical process, represented by the Landau distribution
- But low pT particles often are low p / low E, thus they should be on the rising left arm of the Bethe-Bloch formula
- I think this can be exploited:
  - In SVD, the low p particles should leave higher energy clusters
  - This is easier to find compared to PXD due to thicker sensors
  - If a track can be found based on 4 high energy hits, it‘s likely it‘s a low pT particle

    → Search for these tracks, and try to add PXD hits to them

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LOW PT TRACKING OPTIONS

- VXDHoughTracking can be easily adapted to do this, maybe also VXDTF2
- Try to identify very high energy SVD clusters first
- Maybe use only high energy PXD clusters, but this needs to be studied
  - Likely difficult, as the PXD sensors are thin which makes it difficult to perform PID with PXD hits
- Optimise VXDHoughTracking / VXDTF2 hit selection for low pT tracks using MV classifiers
- Currently Hough Space (HS) parameters are optimised to find circles
  - Low pT particles can deviate from circle shape a lot due to multiple scattering and energy loss, which needs to be considered e.g. by adapting the HS parameters

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LOW PT TRACKING OPTIONS

- Already now with SVD hits only, combinatorics can be a problem depending on the occupancy
  - This might be even more concerning with large number of PXD hits if we use everything without any preselection
  - Do we want to require 2 / 3 / 4 SVD hits in addition to 2 PXD hits?
- Which other physics features can be exploited?
- Wanted to start studying the full VXD Hough tracking with high enery SVD hits for my thesis, but no time :(

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LOW PT TRACKING OPTIONS

- Everything presented is rather high level
- What I didn‘t show: DATCON in its current form is incapable of helping
  - DATCON will basically try to work with **all** of the RawTrackCandidates, as it can‘t reduce the number
  - And it will have a similar number of RawTrackCandidates in two HoughSpaces, one in r-phi, one in r-s = theta
  - With 100 “tracks” per HS, there are easily O(10k) ROI in total
  - Reduction of number of tracks required, but currently not possible
    - I don‘t really know what is possible on FPGAs and what is not

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SUMMARY

- Both SVD standalone trackings are advantageous compared to full tracking at low pT
  - In general high fake rate at very low pT
  - Likely actual beam BG tracks
  - Need to be discriminated from slow pions
- VXDHoughTracking can easily be extended to further exploit low pT range
  - Hough Trafo is nearly unbiased except for the IP constraint
  - We need to define physics features of low pT tracks that we want to exploit for finding the tracks
- Rearranging the tracking chain, starting with SVD tracking, likely helps in recovering tracking efficiency at lower pT values

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Belle II

THANK YOU FOR YOUR ATTENTION!

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Following slides were presented in the tracking meeting on

June 18th or 25th

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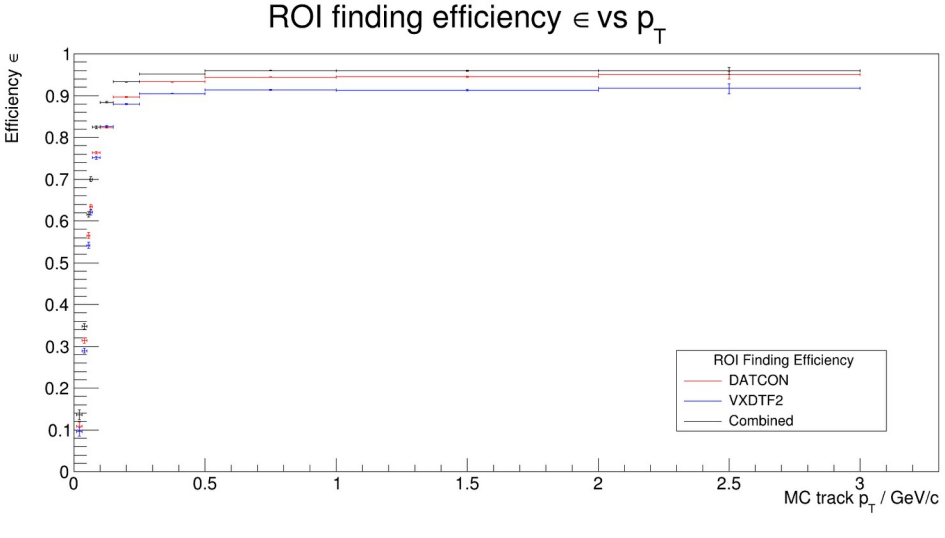
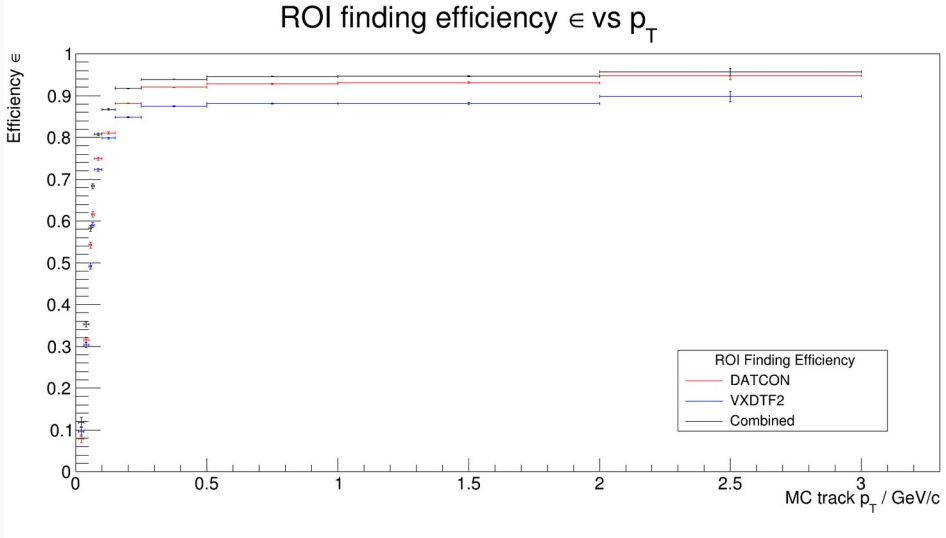
ROI finding performance

ROI FINDING EFFICIENCY VS PT

- Compared DATCON ROI finding, VXDTF2 ROI finding, and combining both
- DATCON performs better than VXDTF2, but combining both seems best

BG18 - BG19





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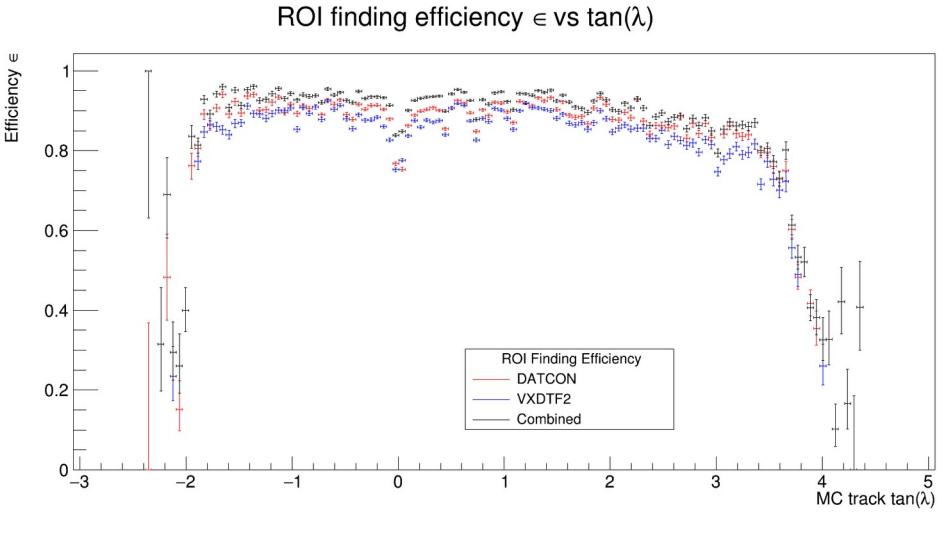

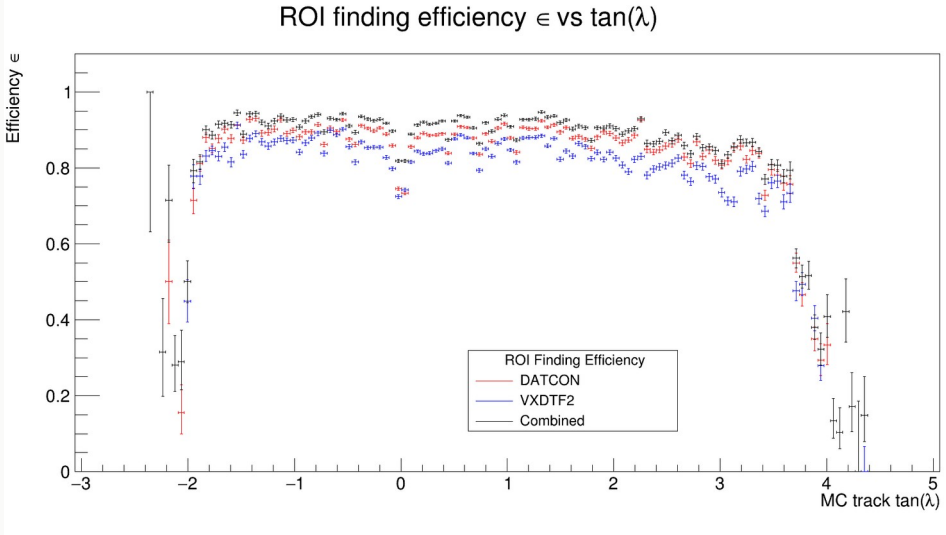

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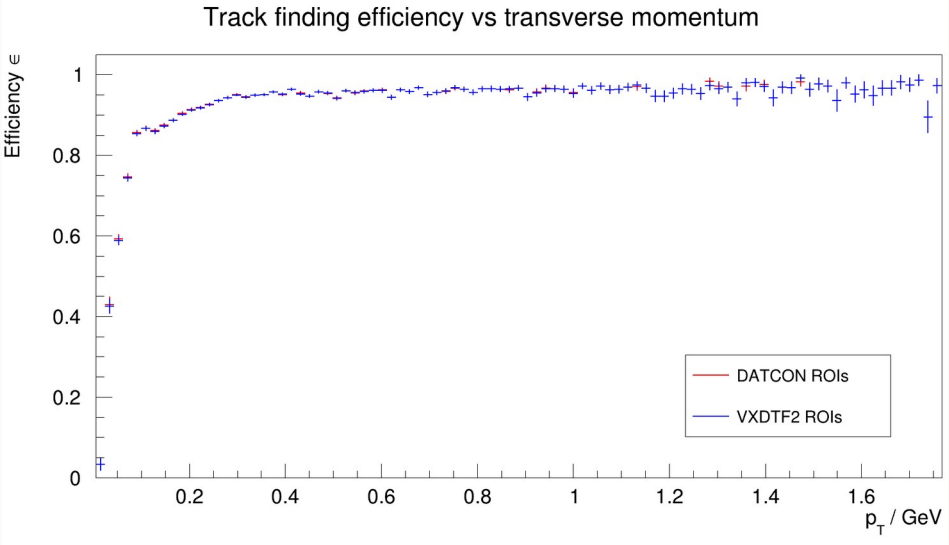
Track finding performance

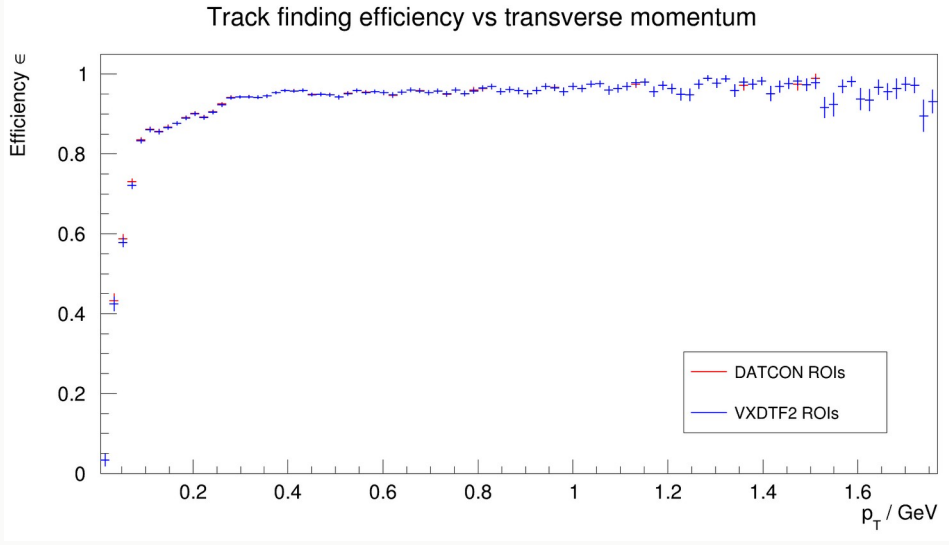
using DATCON or VXDTF2 for ROI finding and the full tracking afterwards

TRACK FINDING EFFICIENCY VS PT

- No difference in full tracking between both ROI finding methods
  - Expectex, as tracking efficiency is domininated by SVD and CDC track finding which are the same

BG18 - BG19

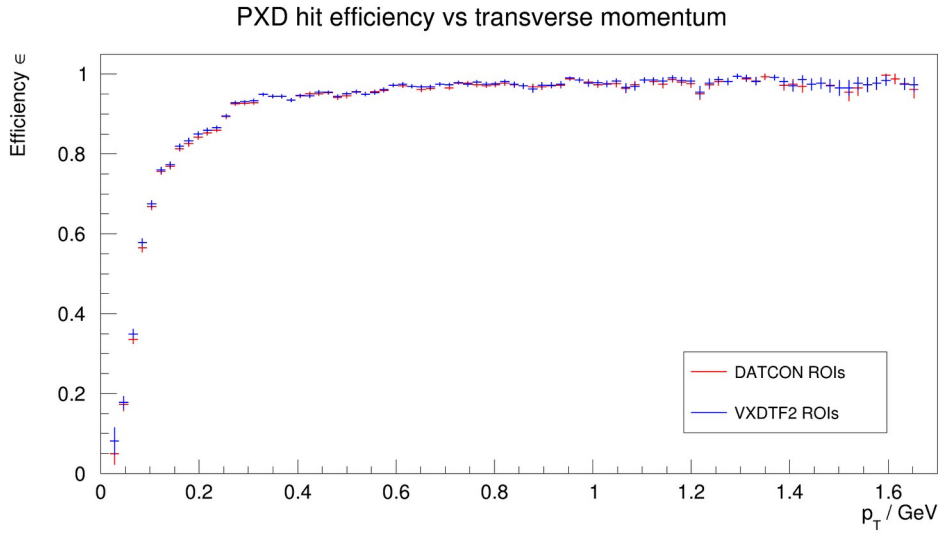


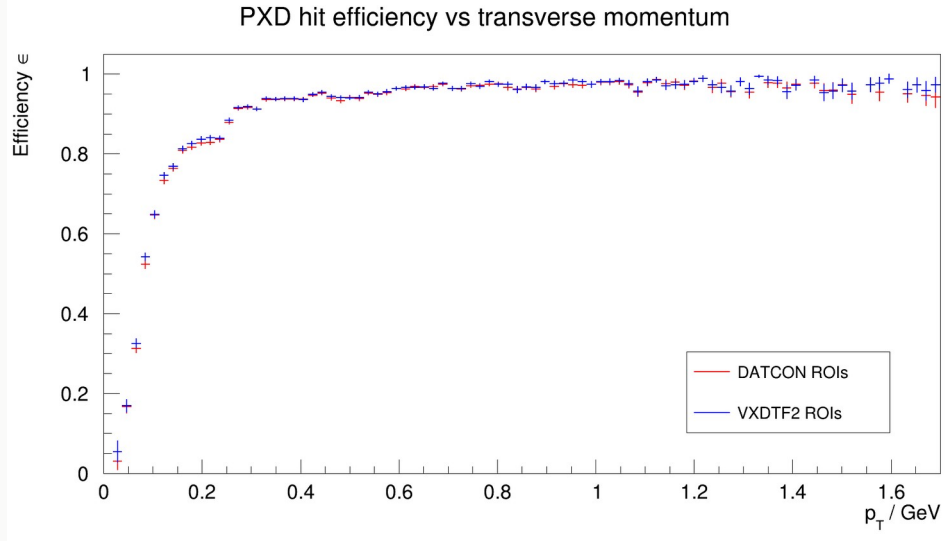


PXD HIT EFFICIENCY VS PT

- No difference in full tracking between both ROI finding methods
- But clear degradation for BG19

BG18 - BG19

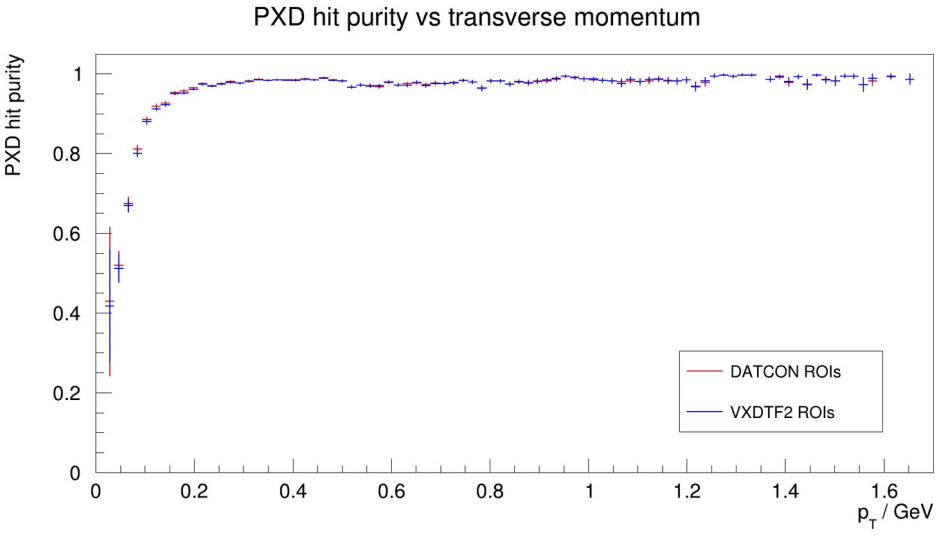


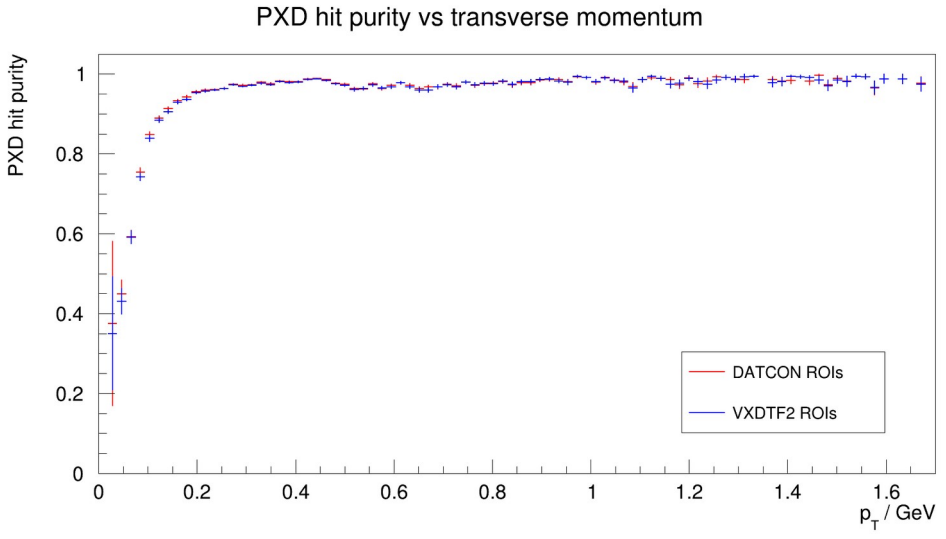


PXD HIT PURITY VS PT

- No difference in full tracking between both ROI finding methods
- But clear degradation for BG19

BG18 - BG19





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Missing PXDDigits

MISSING PXDDIGITS VS TRACK LAMBDA

- PXDDigits not found often seem to be from MCParticles that pass the SVD sensor gaps
- Additionally mostly hits in the very forward region are missing

BG18 - BG19