Status of Hough Transform TPC Tracker

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Outline

- Introduction
- Hough Transform (HT) approach:
  - Description of the algorithm
  - Practical implementation for fast filling of the Hough space
  - Hough space variables
- Recent improvements
- Results:
  - Efficiency, fakes
  - Resolution
  - Time consumption (!)
- Conclusions & Plans

Introduction

- It has been already shown that the presented HT method:
  - Overcomes the common problems in high multiplicity PbPb events
  - Provides reasonably **high tracking efficiency and low fake tracks rate**
  - Can work not only as a seeding for consecutive cluster finder/fitter, but also as a **stand-alone tracking algorithm**
  - **Extremely fast**

- The recent developments were oriented towards:
  - Further **speeding up** $\Rightarrow$ To be able to track central PbPb events **online**, by means of purely software version of HT
  - Adding **dEdx** reconstruction $\Rightarrow$ **online PID**
  - Studies of the sources of inefficiencies and fakes

Hough Transform method

- Hough Transform method:
  - Transformation of TPC Digit coordinates into curve in the track parameter space (Hough space). The curve corresponds to all possible tracks the digit can belong to
  - The transformation is done in η bins
  - Assume that the tracks are coming from the primary vertex
  - Neglect multiply scattering and energy losses
- Each space bin represents a track candidate
  $\Rightarrow$ one can define a certain "road" within a given TPC sector
- The approach consists simply in counting of the number of TPC rows without a digit inside the track "road" - #gaps

Hough Transform method

- After the HT is finished, a simple peak finder runs over the Hough space in order to extract the track candidates
- The peak finder looks for neighbor bins with #gaps<N and identifies the peaks (track candidates)
- Track parameters are extracted by averaging the peak edge points

  $\Rightarrow$ track is guided by the cluster borders

Hough Transform method

- Assuming ordered TPC digits (in time bins, pads, padrows)

  ⇒ the algorithm offers big space for speeding up!
- HT is monotonic along the padrows

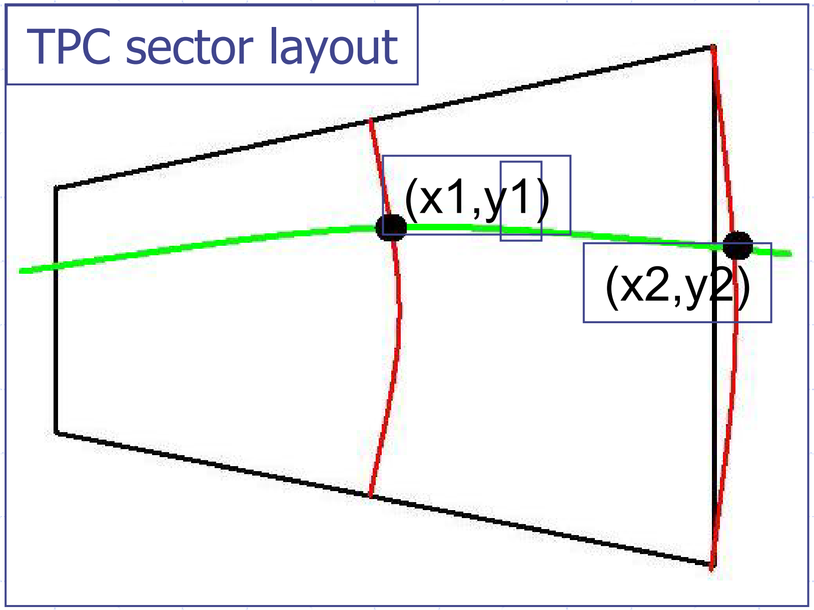
  ⇒ do it only for the first and last (in pad index direction) digits which belong to a cluster and fill at once the corresponding ribbon in the HT space
- Stopping rule using already accumulated #gaps

Hough Space variables

- Initially Hough space defined by track curvature k(=1/R) and emission angle Ψ
- Two main problems:
  - The variables are strongly correlated ⇒ "Butterfly"-like shape of the peaks
    - complex peak finder
    - relatively high fake peak rate
  - Non-linear functions in the filling of HT space
    - Need in LUTs inside HT filling loop
    - "Time consuming" FP operations inside HT filling loop
- Better solution was found

Hough Space variables

- **Conformal Map transformation variables were chosen:**
  - **Variables connected to the physical setup of the TPC**
  - **Variables which lead to linear HT**



- Lets define two curves inside a TPC sector by

  x/R^2 = constant = $\beta 1(\beta 2)$
- Each primary track is represented by two points on these curves
- One can parameterize the track using:

  $\alpha 1 = y1/R1^2$ and $\alpha 2 = y2/R2^2$

- Conformal map coordinates of each space-point along the track trajectory are connected by linear expression

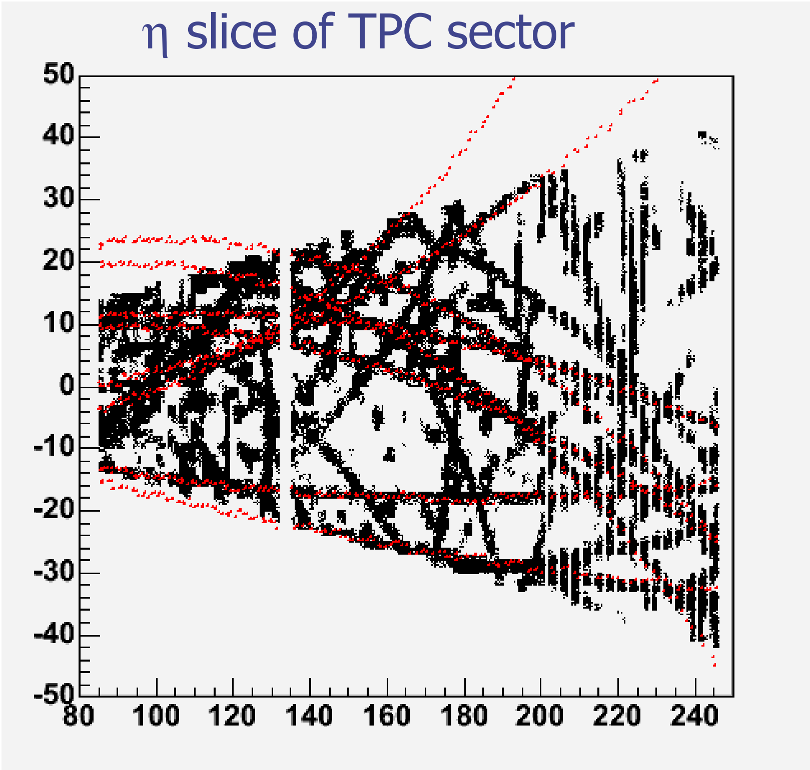
Hough Space variables

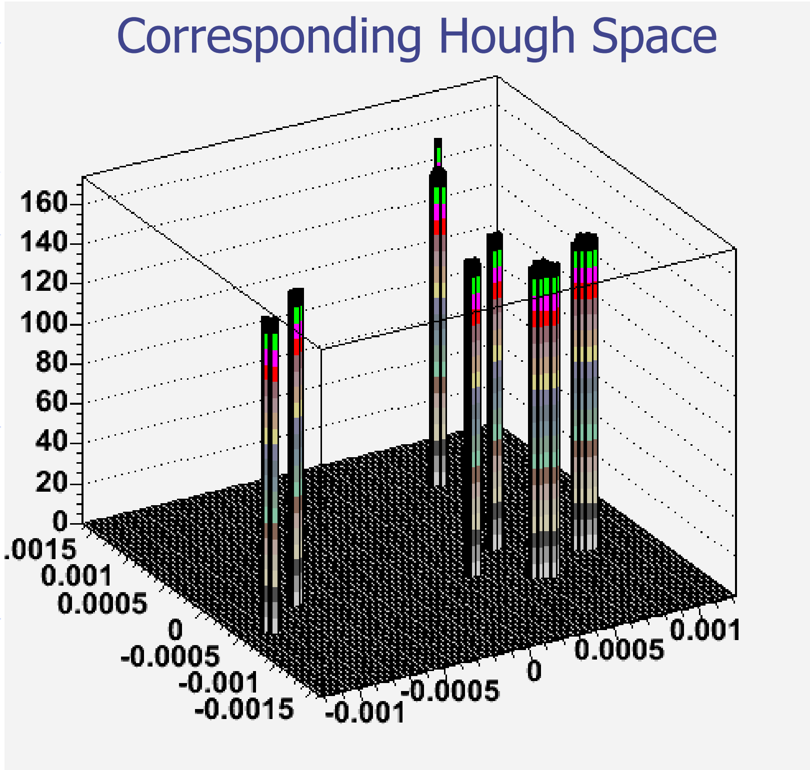
- One can use the variables $\alpha 1$ and $\alpha 2$ to define the Hough space
- In this way each space-point inside a TPC sector will be represented in the Hough space by a **straight line**:

  $$\alpha 1 = A + B\, \alpha 2$$

  Linear filling of the Hough space
- The parameters A and B are calculated in advance and used via LUTs
- In order to keep HT monotonic and Hough peaks uncorrelated: curve $\beta 1$ – in middle and curve $\beta 2$ – at the outer edge of the TPC sector

Example





- Uncorrelated and easily detectable Hough peaks
- Linear HT ⇒ Gain of 30-40% in the time consumption

Hough Space variables

- Limits on Hough space variables correspond to a track with minimum Pt[GeV/c] = B_{field}[T] which crosses the middle of the TPC sector

- Hough space binning is fixed to ~ twice the pad size in the corresponding TPC rows ⇒ 80(α1)x120(α2)x100(η)

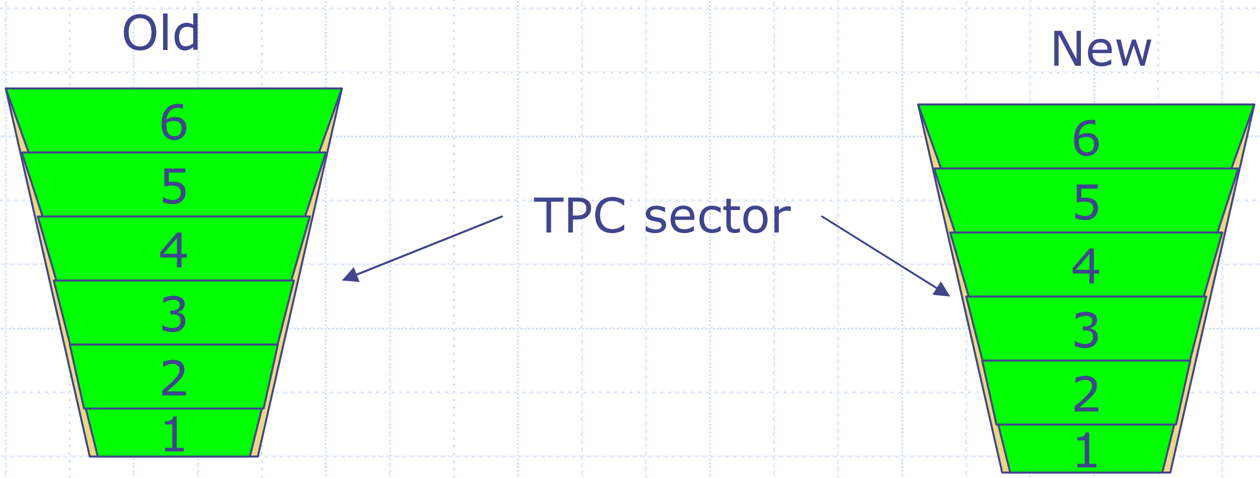
Recent improvements

- All the recent changes are aimed to speed up the code and do not affect the algorithm efficiency
- There are no revolutionary improvement – all the changes give an effect of 30-50%
- The overall speed-up factor is ~3

Recent improvements

- Change in the order in which the readout patches are processed
- Choose an order which allows the earliest possible removal of track candidates (Hough space bins)
- Why patches 6 and 3 before others? Digits in patch 6 – horizontal lines in the Hough Space, in patch 3 – vertical lines

  ⇒ the crossings of these lines gives sort of seeding



Recent improvements

- Selective filling of the Hough space:
  - For each bin of the hough space assign pointers to the closest possible track candidate (bin)
  - Update the pointers after each processed readout patch
  - Use the pointers to jump in the hough space during the filling process
- Floating operations used to calculate the cluster properties in the hough space ⇒ pre-calculated LUTs
  - Conformal mapper variables as a hough space variables
  - Therefore a TPC cluster is represented by 2 straight lines:

    ⇒ 2 offsets and 2 slopes

Results: Efficiency, resolution and timings

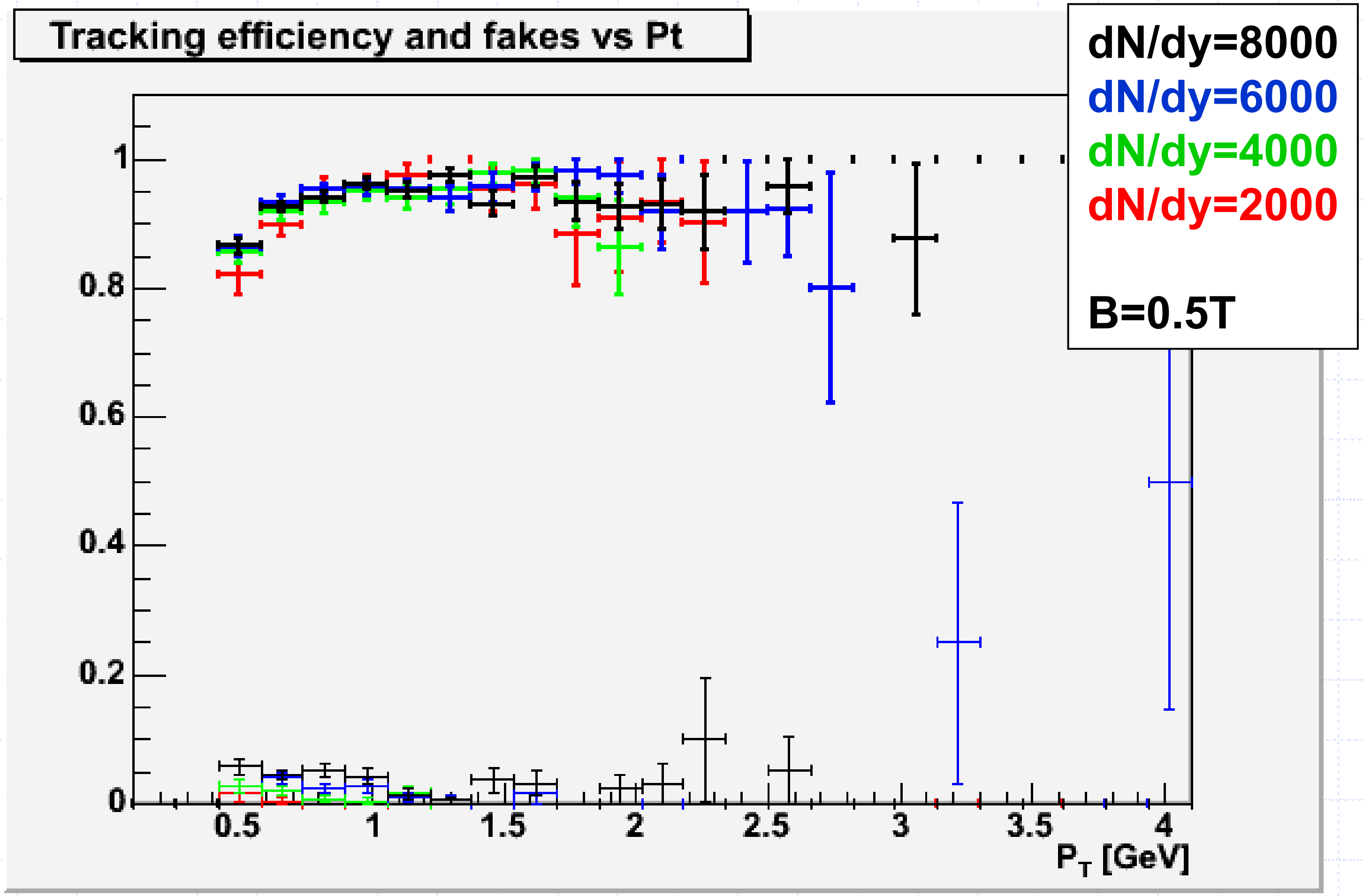
Definitions

- The method requires new definitions in order to determine the performance:
  - No clusters associated

    ⇒ assign only 1 MC label to each track
  - High occupancy (and therefore overlapping clusters) in general does not affect the track parameters, but cause appearance of "ghosts"

    ⇒ fakes tracks → ghost tracks
  - If more than 1 track with the same MC label, take randomly one as good and second as fake (or ghost)
- Good tracks – from offline comparison macro

Tracking Efficiency

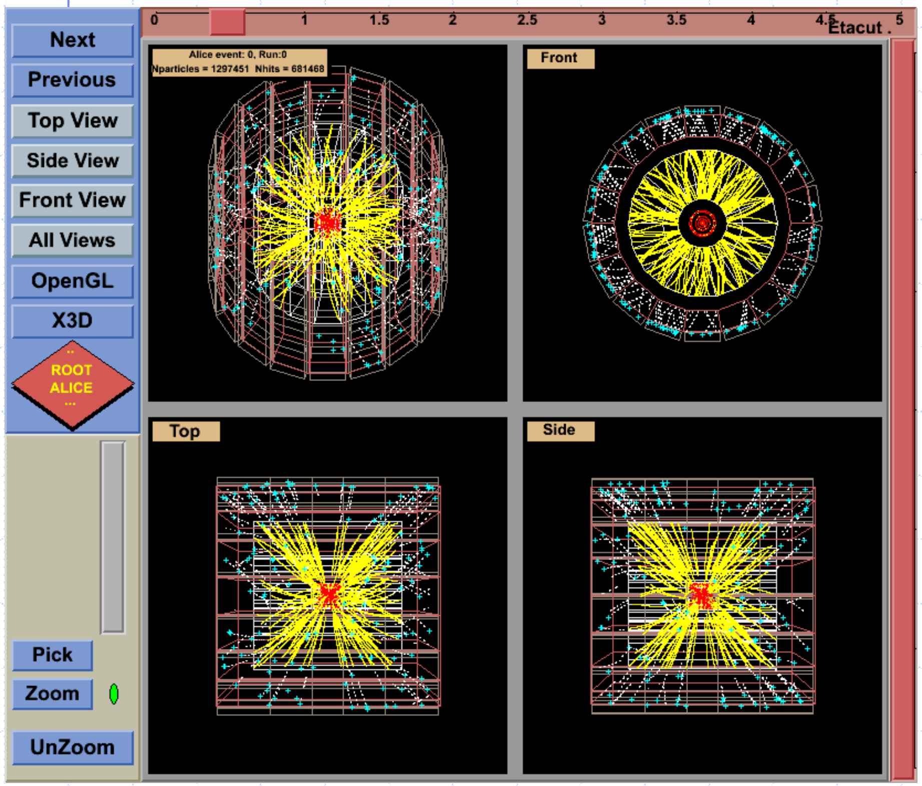


Inefficiency Sources

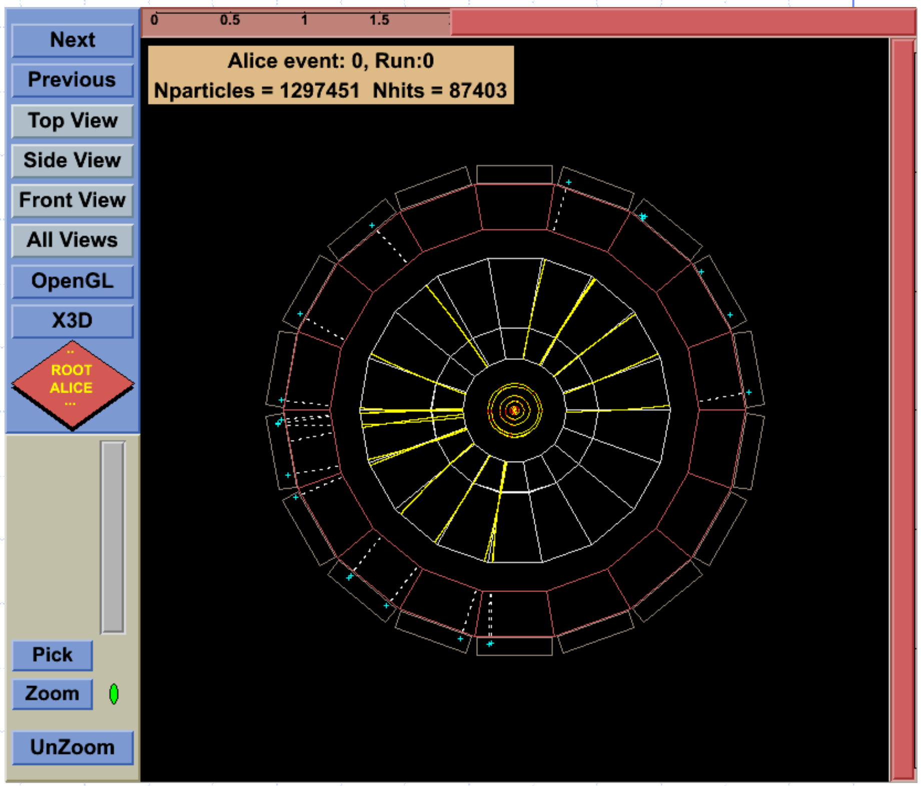
1. Merging of the tracks (1-2% for dN/dy=8000, 0.4T) when:
   - they overlap in the hough space
   - they are close to each other and one is removed during the track merging (both in hough space and η bins)
2. Low pt tracks at high η (->1).
   - The η bins efficiently get narrower
   - Mult.scat. in ITS & dead zone
   - η binning (during binning we assume straight tracks)
3. Tracks close to the TPC sector borders (affects mainly tracks with Pt>1-1.5GeV/c)

Inefficiency Sources

Low Pt tracks



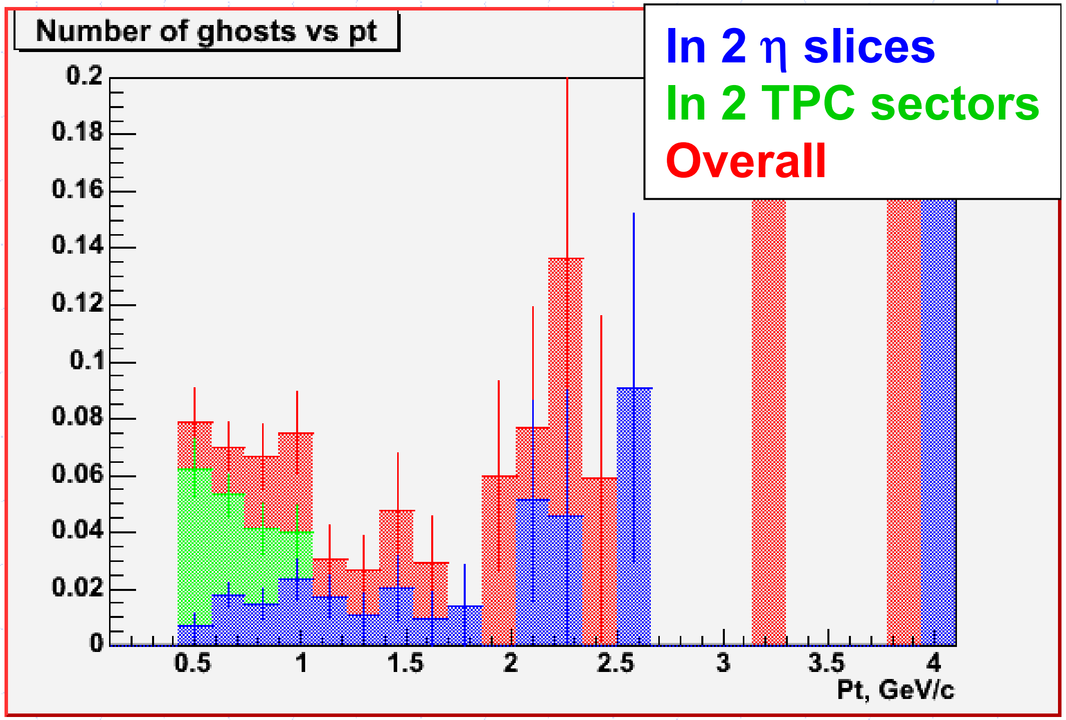
Tracks with 1.5<Pt<2 GeV/c



Ghost Tracks

- Tracks found in 2 η slices or 2 neighbor sectors can be further suppressed by more complex track merging procedure
- However ITS tracking "removes" almost completely these ghosts $\Rightarrow$ no real need in further merging

dN/dy=8000, 0.5T



Resolution

- Since the Hough space bin size ~1/Pt
  $\Rightarrow \Delta Pt/Pt \sim Pt + const.(mult.scat.)$
- **$\Delta Pt/Pt=(1.8 x Pt+1.0)\%$ (B=0.5T)**
- **$\sigma(\Psi)$=6.1mad; $\sigma(\eta)=5.5x10^{-3}$**
- No significant dependency on the event multiplicity can be seen – need more statistics

Timing performance

- The benchmarks were done on Itanium II machines (~1300 SpecInt's) – the present Alice GDCs
- Code compiled with icc8.0 with –O3
- Almost a factor of 3 improvement due to the latest improvements in the filling of the Hough space
- LUT initialization is done of event-by-event basis ⇒ more flexibility if one wants to adapt the HT resolution depending on the trigger

dN/dy	~0	2000	4000	6000	8000
LUT Init	120ms				
Hough Transform	0.7s (3ms/patch)	3.3s (15ms/patch)	5.9s (27ms/patch)	8.7s (40ms/patch)	11.3s (53ms/patch)

Conclusion and Outlook

- Hough Transform tracker shows very good efficiency and resolution (see also Constantin's transparencies on jet analysis)
- Taking into account the presented timing performance, one should consider seriously HT as a possible online tracking for HLT (details in my talk on online monitoring)
- The work on adding dEdx reconstruction is underway (see tomorrow's talk)
- Important feedback expected from the physics analysis of PDC'04 data
- The algorithm (together with HLT ITS tracker) will be tested in close to real conditions during the Alice computing DC in 2005