Online reconstruction of a TPC

as part of the continuous sampling DAQ of the $\bar{\text{P}}$ANDA experiment

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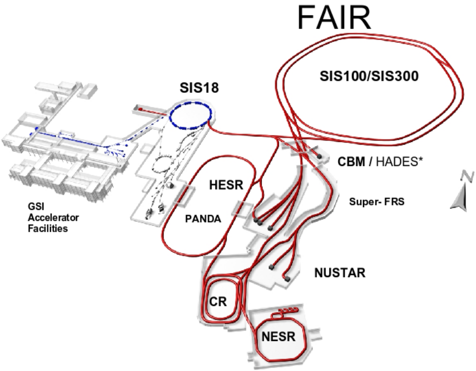
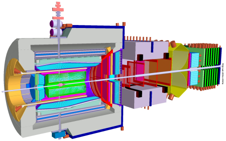
XV Conference on Computing in High Energy and Nuclear Physics

$\bar{P}$ANDA: Antiproton Annihilations at Darmstadt





- Facility for Antiproton and Ion Research (FAIR), GSI, Darmstadt, Germany
- High Energy Storage Ring (HESR)
- Antiproton beam in the range 1 GeV to 15 GeV
- Debunched beam - high duty cycle
- Internal proton target (pellet / cluster gas jet) or nuclear targets
- $2 \cdot 10^7$ $\bar{p}p$ annihilations per second
- TDR in preparation for 2008
- First physics data expected in 2013

Physics objectives

Strong interaction studies with antiprotons

The goal of $\bar{\text{P}}$ANDA is to perform precision measurements on the following topics:

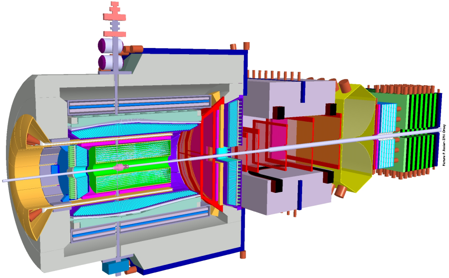
- Charmonium spectroscopy
- Search for gluonic excitations
- Charm in nuclei
- Hypernuclear physics
- Open charm physics

Prerequisites for precision:

- Low systematic errors
  - Good beam quality
  - Powerful detector system
- High statistics
  - High interaction rates
  - Study different channels simultanuously

The $\bar{\text{P}}$ANDA detector

$\bar{\text{P}}$ANDA is designed as a multipurpose detector, capable of exclusive measurements



- Fixed target geometry
- Large acceptance (nearly 4π)
- Target spectrometer (2T superconducting solenoid)
- Forward spectrometer (2Tm dipole magnet)
- Tracking system: Silicon vertex detector, central tracking chamber (STT or TPC), forward tracking chambers
- Particle ID: Cherenkov detectors (DIRC, RICH)
- High precision, high granularity electromagnetic calorimetry

Continuous sampling DAQ - foundations

- High annihilation rate: $2 \cdot 10^7 s^{-1}$
- Study several physics channels in parallel
- Complex event signatures
- Many different contributing subdetectors
- No hardware trigger
- Self triggering frontend electronics
- Synchronized by global time distribution system
- $\Rightarrow$ very high raw data rate (up to $\sim$ 1TB/s, zero suppressed)
- Preprocessing on the frontend level
  - Feature extraction
  - Data compression
- Staged computing farms
  - Event building
  - Pattern recognition
  - Flexible event selection
- Design values:
  - Input data rate after preprocessing $\sim$ 40GB/s
  - Rate to disk 200MB/s

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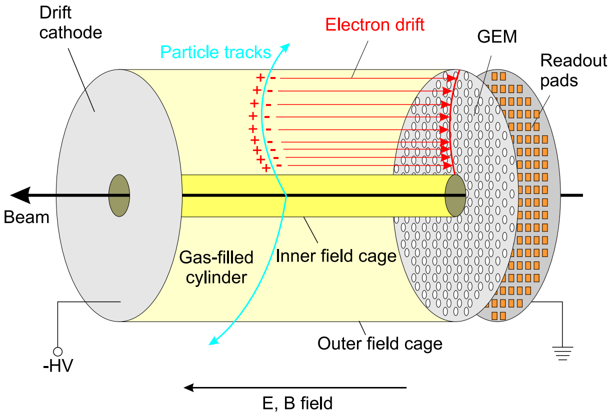
Continuously running time projection chamber
with GEM readout



Continuous mode:

- No external trigger
- No gating possible

Coordinates:

- (x, y) from pads
- drift time $t \Rightarrow z$
- $\hat{z} = t \cdot v_{\text{drift}}$

Parameters of the $\bar{\text{P}}$ANDA TPC (reference design)

- Radius: 15cm to 42cm
- Position: -40cm to +110cm from IP
- Driftlength 1.5m $\hat{=}$ 55μs
- E-field 400 V/cm
- Gas: Ne/CO_2 (90/10)
- Pads: $2 \times 2\text{mm}^2 \longrightarrow$ 100000 Ch.

Event mixing in the TPC - breaking the event paradigm

Why do we have to reconstruct the TPC online?

The problem

- Annihilation rate: $2 \cdot 10^7 s^{-1}$ - average time between events: 50ns
- $\sim$ 5 charged tracks per event ($\bar{p}p$ - annihilations)
- Drift length: 1.5m $\hat{=}$ 55μs
- Arrival times of electrons from one event: inside 55μs time-window
- Inside one drift time: up to $\sim$ 1000 events
- Continuous beam - continuous data stream from TPC
- Signals from several events arriving at the same time
- Events cannot be predefined by a hardware trigger

Necessary steps:

1. Work with a data stream.
2. Recognize individual tracks.
3. Define events.

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Software: simulation & reconstruction

- Event mixing is one key challenge
- Heavy software development ongoing to show feasibility
- TPC simulations with GEANT4
- BaBar framework (event based)
- Event mixing → new processing structures: data streams
- Reco working on data stream:

z-reconstruction

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z-reconstruction

Measure: $t_{signal} = t_{arrival}$

$z = t_{drift} \cdot v_{drift}$

$t_{signal} = t_0 + t_{drift}$

Reconstruct:

$\tilde{z} = t_{signal} \cdot v_{drift} = z + z_0$

with $z_0 = t_0 \cdot v_{drift}$

t_0 or z_0 from other detectors

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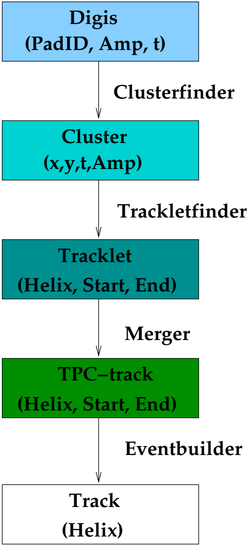

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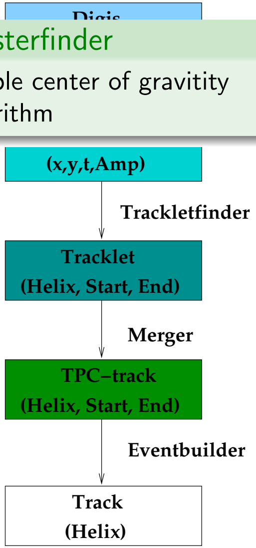

Clusterfinder

Simple center of gravity algorithm

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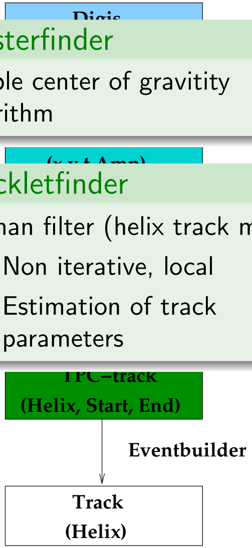
Kalman filter (helix track model)

- Non iterative, local
- Estimation of track parameters



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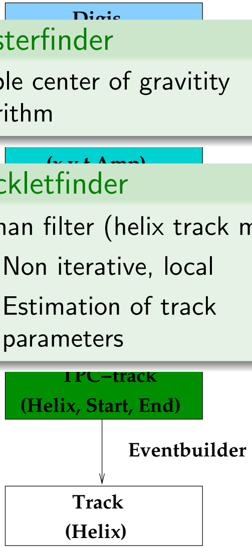

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Definition: Event deconvolution

- Goal: Find a set of tracks that belongs to one primary interaction.
- Each such set is called an *event*.

General procedure

- Reconstruct pieces of tracks
- Fast detectors: define event time
- TPC-tracks $\xleftarrow{\text{connect to}}$ hits in fast detectors
- Problem: combinatorics!

Use topology

- Target pointing
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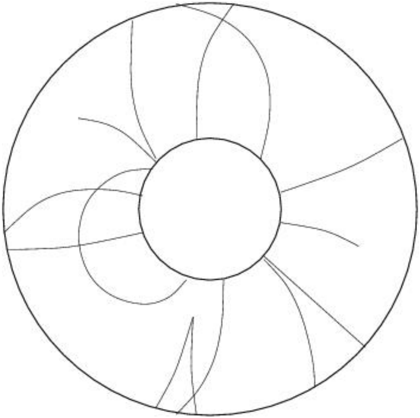

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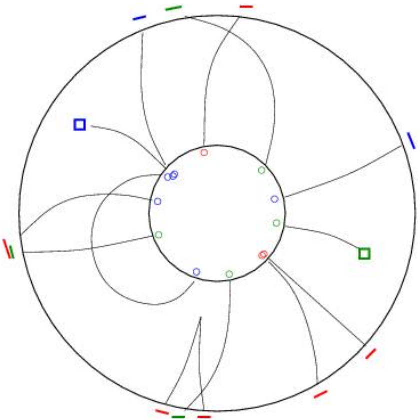

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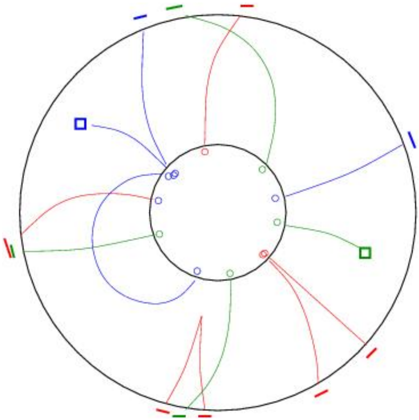

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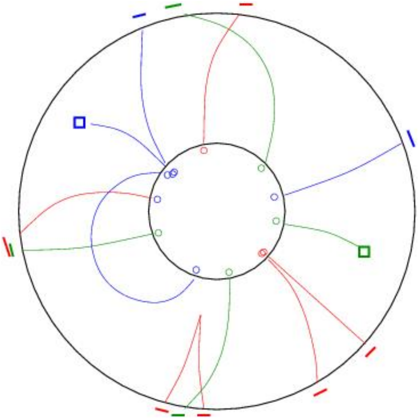

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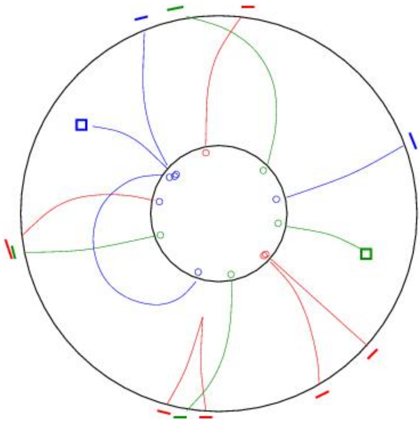
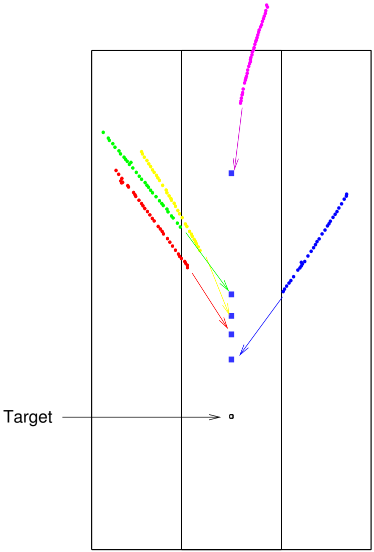


Target pointing

- Hypothesis: Track coming from IP (z=0)
- Extrapolate the helix to the z-axis
- $\Rightarrow$ offset z_0 $\Rightarrow$ event time t_0
- Simulations show:
  - resolution of $\sim$ 120ns is feasible
  - reduction of combinatorics by a factor of 200 at full rate



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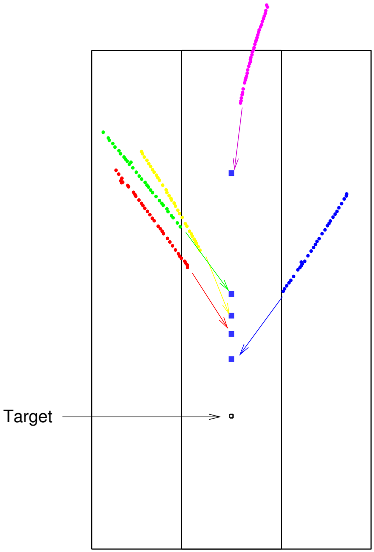

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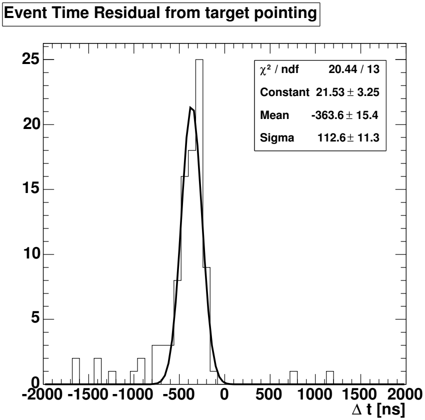

200 events of 1GeV pions at $\theta = 40^\circ$

Endcap penetration

- A lot of tracks go in forward direction (boost).
- Suppose a track is going through the forward endcap ($\theta < 20^\circ$).
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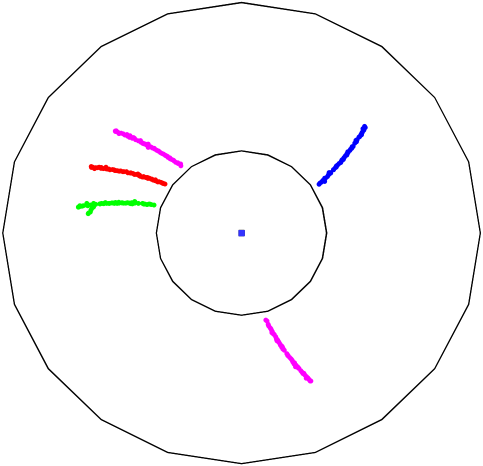

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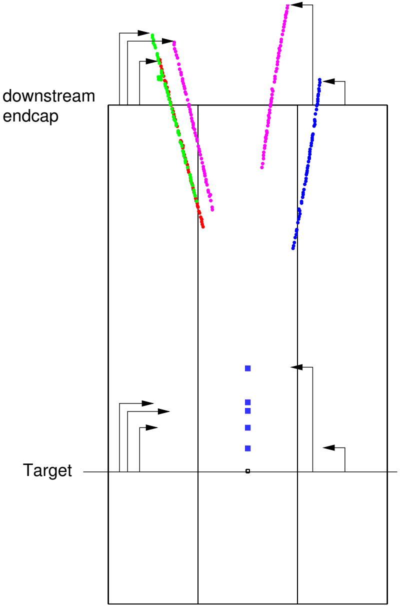

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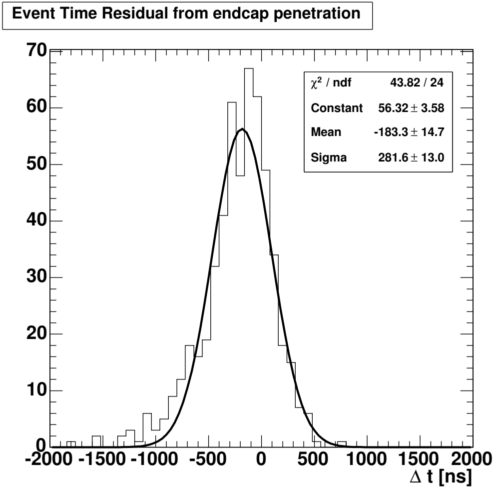

500 events of 1GeV pions at $\theta = 15^\circ$

Integration of the TPC into the DAQ

- For the event deconvolution tracks have to be found online in the TPC.
- Preprocessing on dedicated computing nodes close to frontends
- Data reduction by:
  - Clustering of hit pads ⇒ data reduction by factor 10
  - Huffman coding of hit data on a track (hit trains)
  - Parameterization of track pieces in the TPC (tracklet reconstruction)
- Parallel processing of subvolumes of the TPC
- Full track information available (at least) at later levels of data filter
- TPC information can be used for event selection in the software trigger
  - Multiplicities
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Conclusions and outlook

- The continuous operation of a TPC at high rates demands online reconstruction.
- Continuous sampling DAQ: define events in the online reconstruction.
- Exploiting constraints can significantly reduce combinatorics.
- Parallel processing schemes under development
- A continuously running TPC would be a new, powerful detector type!

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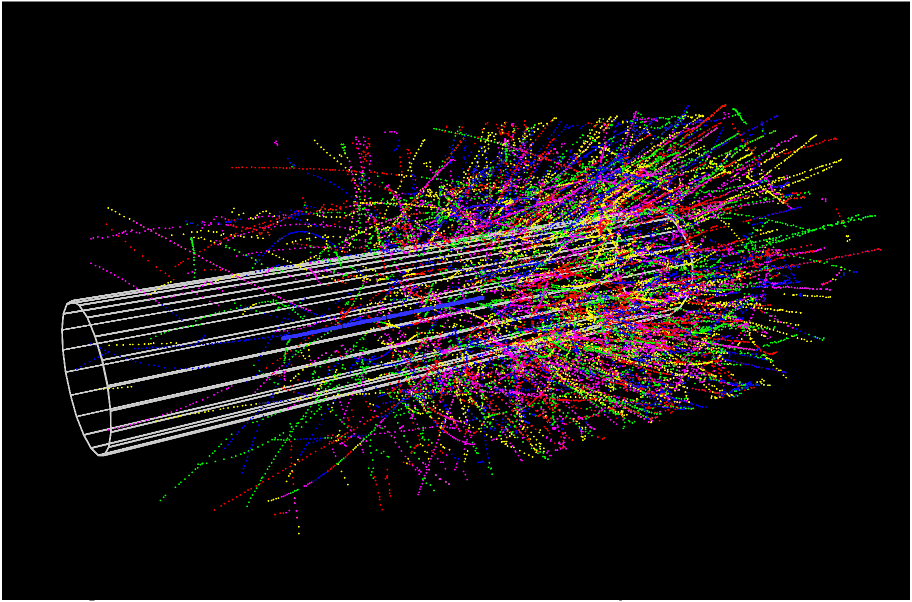
Reconstructed tracks

200 events DPM background @ $2 \cdot 10^7 s^{-1}$



Why a TPC?

Advantages

- Low material budget
  $X/X_0 \sim 1.6\%$
- Good momentum resolution
  $\delta p/p < 1\%$
- dE/dx: PID below 1.5GeV
  - Main background lies in this region
  - No other option to do PID here
- Intellectually challenging project