Reconstruction methods for the P̄ANDA TPC

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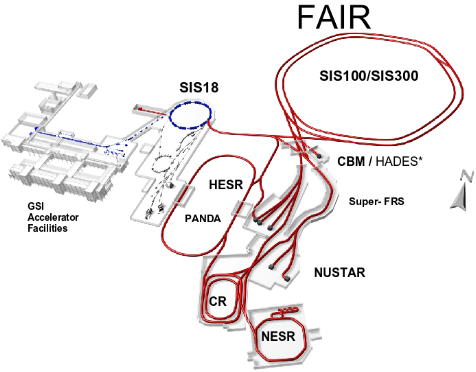
1. The $\bar{\text{P}}$ANDA experiment
    - Physics objectives
    - Detector layout
    - Continuous sampling DAQ concept

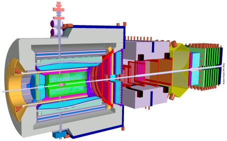
2. The $\bar{\text{P}}$ANDA TPC

3. TPC online reconstruction
    - Event mixing
    - Software tools
    - Event deconvolution
    - Integration of the TPC into the DAQ

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

$\bar{\text{P}}$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 P̄ANDA is to perform precision measurements on the following topics:

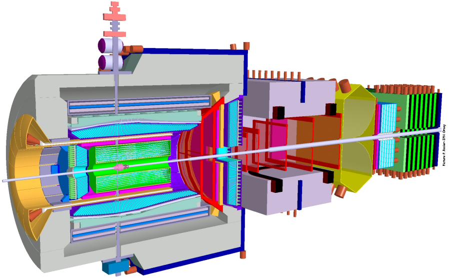
- Charmonium spectroscopy
- Search for gluonic excitations
- Charm in nuclei
- Hypernuclear physics
- Open charm physics

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



Picture: P. Rossier–IPN Orsay

- Fixed target geometry
- Large acceptance (nearly 4π)
- Target spectrometer (2 T superconducting solenoid)
- Forward spectrometer (2 Tm 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

Requirements on central tracker

- Almost 4π coverage, $\sim 1\%\ X_0$
- $\sigma_{r,\phi} \sim 150\ \mu$m, $\sigma_z < 1$ cm
- Momentum resolution of $\sim 1\%$
- TPC offers PID below 1 GeV

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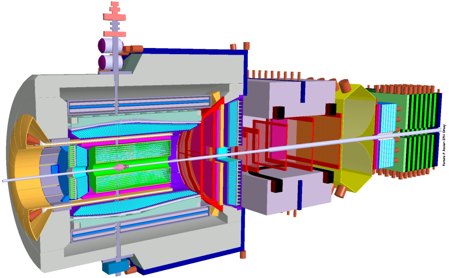

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Continuous sampling DAQ - foundations

- High annihilation rate: $2 \cdot 10^7\ \mathrm{s}^{-1}$
- 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 ~ 1 TB/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 ~ 40 GB/s
  - Rate to disk 200 MB/s

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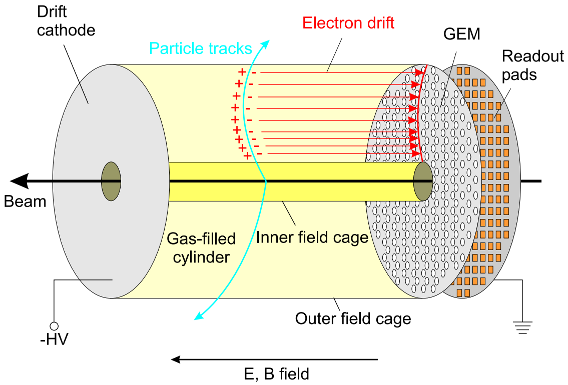
The P̄ANDA TPC

Continuously running time projection chamber
with GEM readout



Continuous mode:

- No external trigger
- No gating possible

Coordinates:

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

Parameters of the P̄ANDA TPC (reference design)

- Radius: 15 cm to 42 cm
- Position: -40 to +110 cm from IP
- Driftlength: 1.5 m $\hat{=}$ 55 μs
- E-field: 400 V/cm
- Gas: Ne/CO$_2$ (90/10)
- Pads: 2×2 mm^2 → 100 000 ch.

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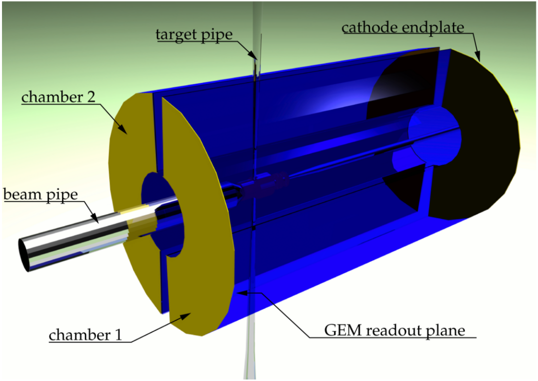

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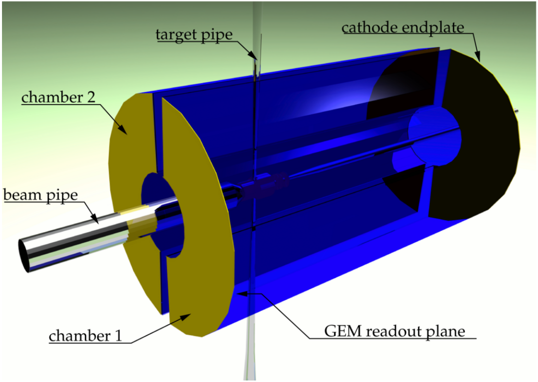

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Key challenges

- Continuous operation → built-up of space charge inside drift volume
- Raw data rates up to 1 TB/s → online data compression (e.g. hit trains)
- Event mixing → online reconstruction necessary

TPC online reconstruction

Event mixing in the TPC - breaking the event paradigm

Why do we have to reconstruct the TPC online?

The problem

- Annihilation rate: $2 \cdot 10^7\ \mathrm{s}^{-1}$ - average time between events: 50 ns
- ~ 5 charged tracks per event ($\bar{p}p$ - annihilations)
- Drift length: 1.5 m $\hat{=}$ 55 μs
- Arrival times of electrons from one event: inside 55 μs time-window
- Inside one drift time: up to ~ 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

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

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

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

Reconstruct:

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

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

t_0 or z_0 from other detectors

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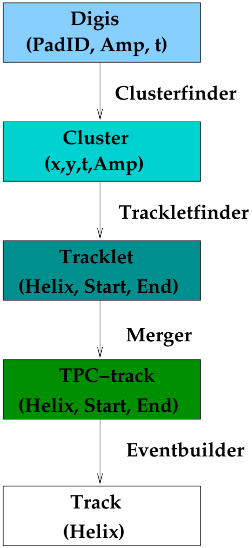

Digis
(PadID, Amp, t)

Clusterfinder

Cluster
(x,y,t,Amp)

Trackletfinder

Tracklet
(Helix, Start, End)

Merger

TPC−track
(Helix, Start, End)

Eventbuilder

Track
(Helix)

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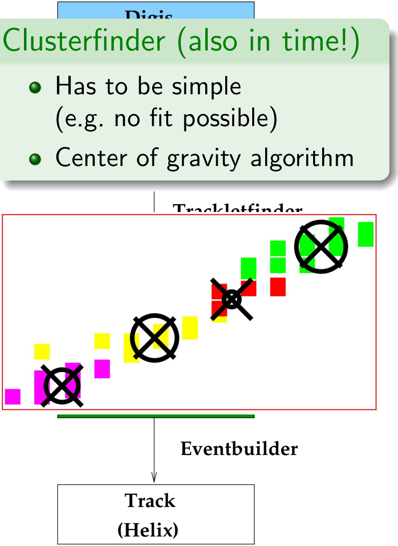

Clusterfinder (also in time!)

- Has to be simple (e.g. no fit possible)
- Center of gravity algorithm

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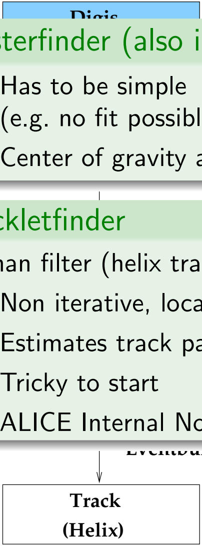

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Trackletfinder

Kalman filter (helix track model)

- Non iterative, local
- Estimates track parameters
- Tricky to start
- ALICE Internal Note 97-24

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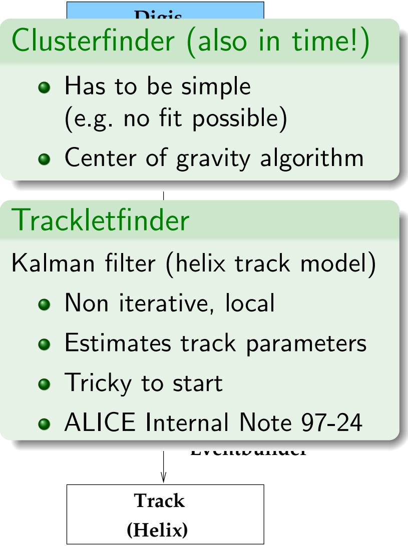

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Event deconvolution strategies - overview

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 $\xrightarrow{\text{connect to}}$ hits in fast detectors
- Problem: combinatorics!

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Event deconvolution strategies - overview

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

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- Reconstruct pieces of tracks
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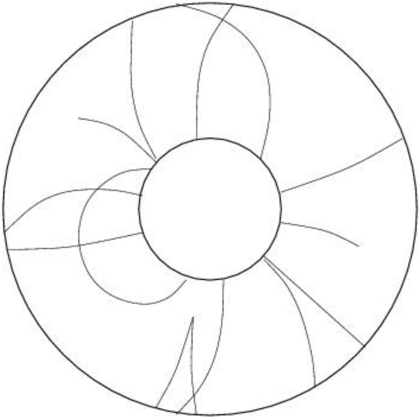

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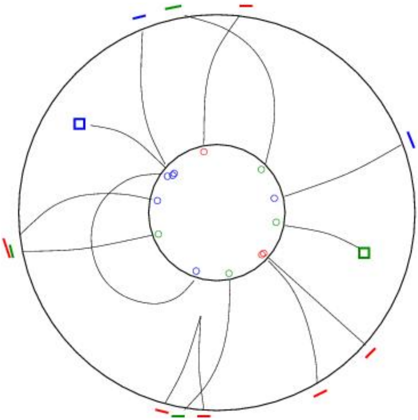

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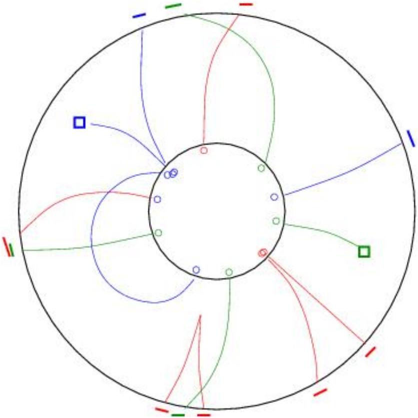

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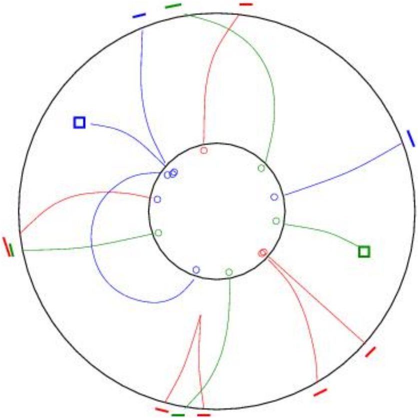

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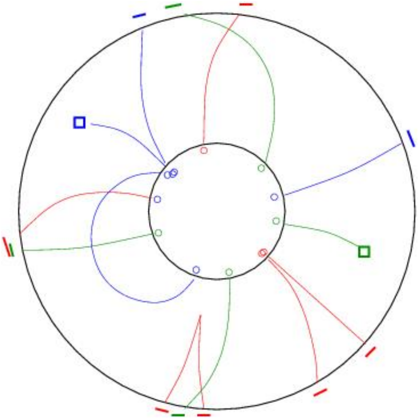
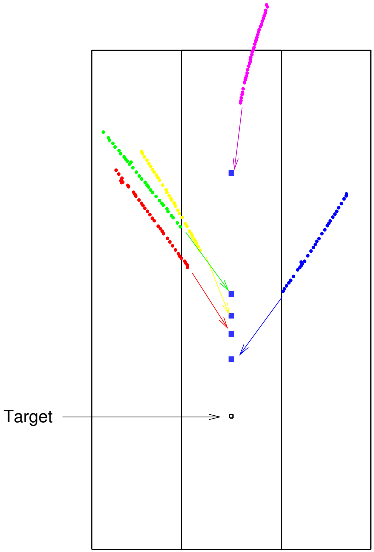


Target pointing

- 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 $\sim$ 120 ns is feasible
  - reduction of combinatorics by a factor of 200 at full rate



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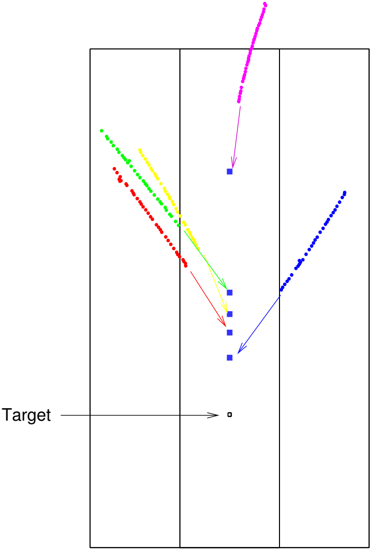

Target pointing

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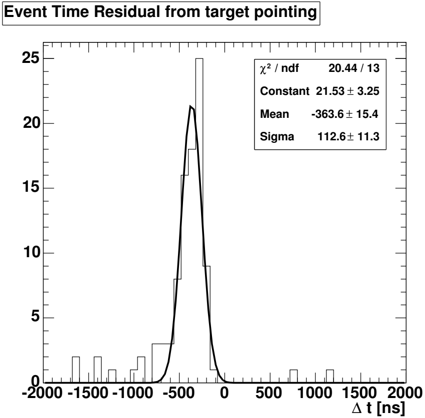
- Extrapolate the helix to the z-axis
- $\Rightarrow$ offset z_0 $\Rightarrow$ event time t_0
- Simulations show:
  - resolution of ~ 120 ns is feasible
  - reduction of combinatorics by a factor of 200 at full rate



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

Endcap penetration

- A lot of tracks go in forward direction (boost)
- Suppose a track is going through the forward endcap ($\theta < 20^\circ$)
- Recognize track endpoint position
- Idea: fix the *z* of the last hit to the position of the endcap
- Achieved resolution: ~ 280 ns

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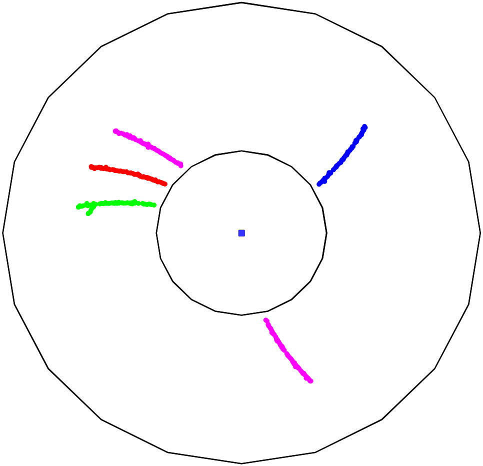

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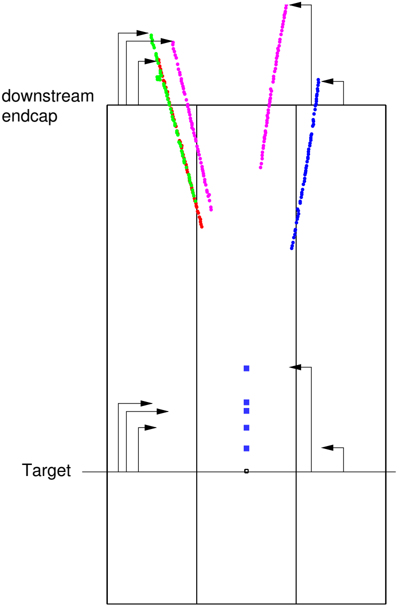

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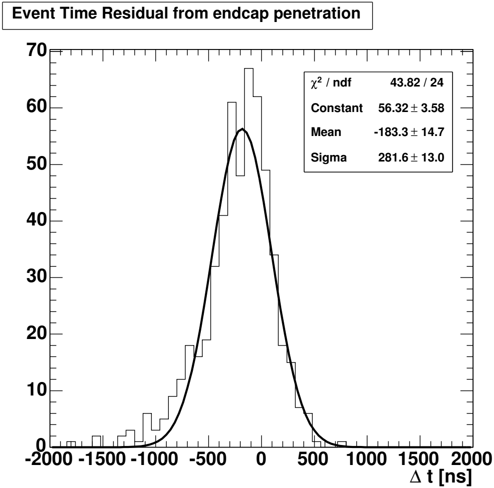

500 events of 1 GeV pions at $\theta = 15^\circ$

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
  - Momentum
  - Decay vertices of neutral particles (e.g Λ, K_s)

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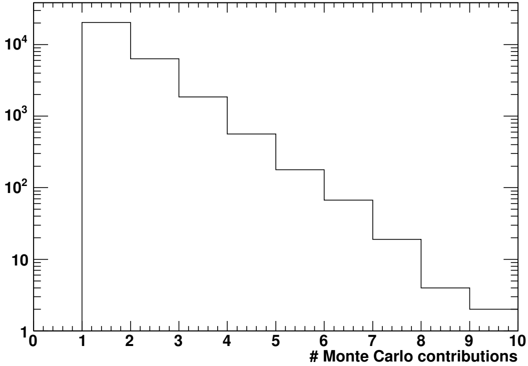
Further problems and outlook

- How to deal with B-field and E-field inhomogeneities during the online reconstruction? What is the interplay with the space charge?
- How to keep accurately the $\mathrm{d}E/\mathrm{d}x$ information for PID?
- How to deal with track crossings?



200 background events at full rate

Thank you!