Status of the TPC Simulation

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Outline

1. Improvements on tracking / **genfit**
2. Update on TPC momentum resolution status
3. Update on Space-Charge studies and correction

Improved Track-Fitting

General Improvements of Track-Fitting

- **Genfit** has been cleaned up & improved since March 09'
- **Floating Point Exceptions** in GEANE's Fortran code have been identified
- These problems have been fixed and will be in the next official **VMC release** (special thanks to L. Lavezzi)

Genfit in combination with GEANE track follower is a stable global track-fitter for $\overline{\mathrm{P}}$ANDA

Plenary talk C. Höppner, Wednesday 14:30
Long wrightup on genfit available on the $\overline{\mathrm{P}}$ANDA *wiki*

Update on TPC Momentum Resolution Studies

Reminder: Data Features

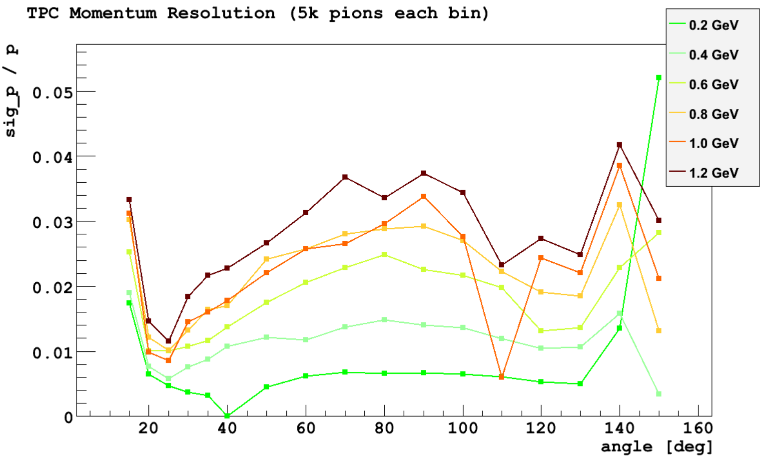
Data (MC and DIGI) still the same as 3 months ago:

- GEANT3 “ALICE” MC model
- 5000 pion (π^+) tracks for each (*momentum*, *angle*) - bin
- Tracks uniformly distributed in azimuth ϕ
- Full Digitization
- Reconstruction using **genfit** (**GEANE** trackrep)

- **TPC HITS ONLY**

Status of March

- Preliminary results shown at last collaboration meeting:



- Some combinations (momentum,angle) had persistent problems

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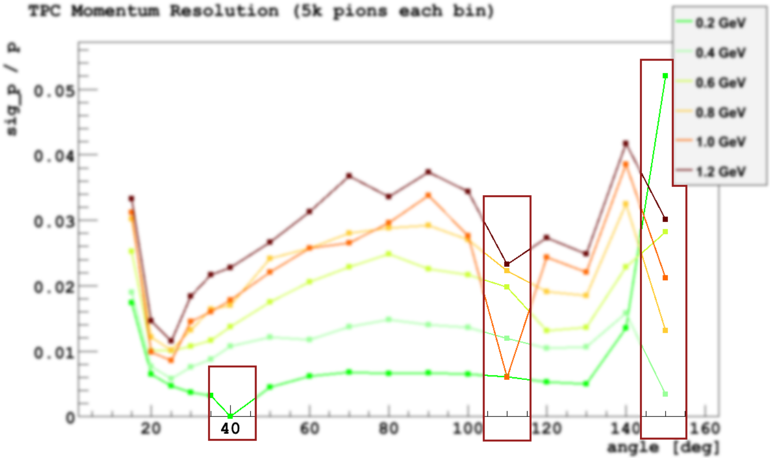

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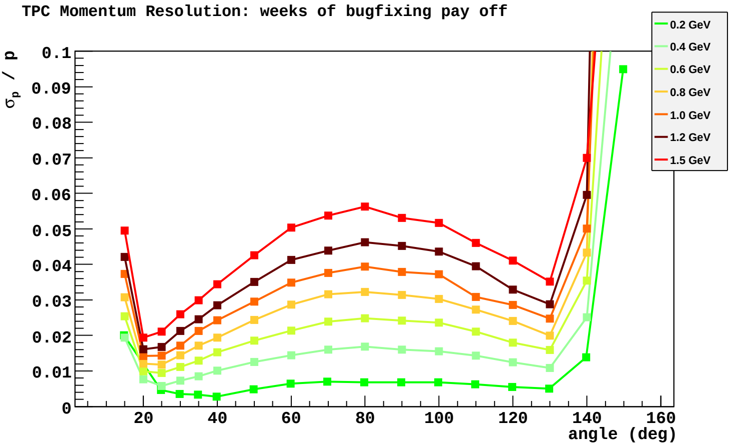
Current status

- After important fixes in GEANE:



- Results from automatic fitting, all problems solved

Summary Momentum Resolution

- **Consistency check:** Expression for curvature error (PDG book)

$$\delta k_{res} = \frac{\varepsilon}{L^2}\sqrt{\frac{720}{N+4}}$$

  these results correspond to a spatial resolution of $\varepsilon \sim 300\,\mu m$ (N = 35, L ∼ 26 cm)
- *Possible* optimization: FEE, PSA, clustering

Conclusion:

- Tracking using genfit and GEANE working reliably now for millions of events
- All anomalies in momentum resolution studies disappeared
- Results look nice and reasonable
- No drift distortion in this simulation - see SC part of this talk!

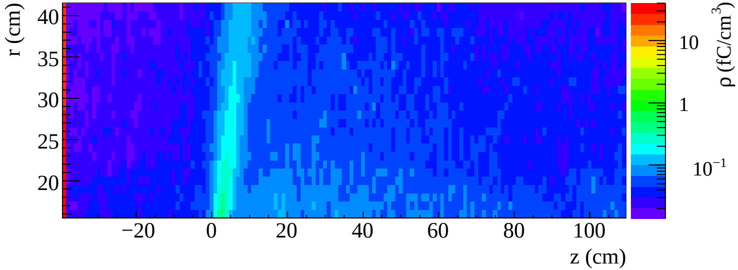
Space-Charge Correction with Lasers

General Approach

1. Simulate realistic space-charge distribution for the TPC
2. Obtain electrical distortion field
3. Calculate drift distortions of e^-
4. Apply method of recovery

1. Simulation of Space-Charge

- Space-charge ρ is simulated based on DPM generator data
- Assumptions:
  - **Azimuthal symmetry**
  - Small beam fluctuations



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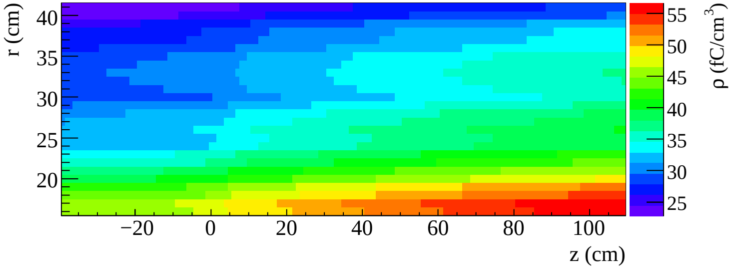

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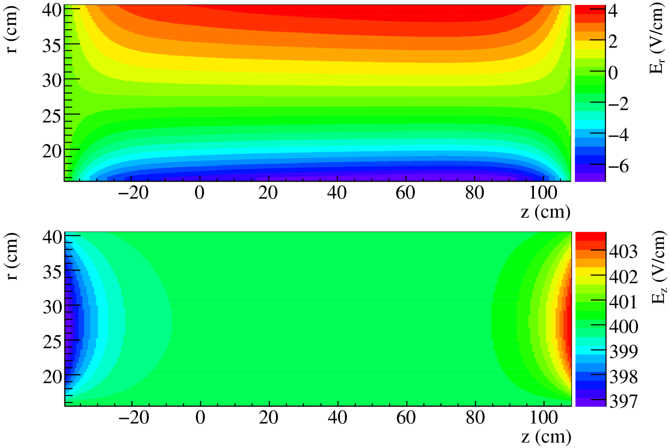
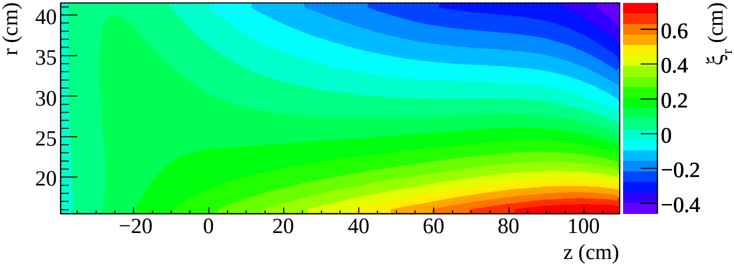
2. Electrical Distortion Field

- The distortion field is calculated using a FEM method (DOLFIN):



3. e^- Drift Distortions

- Drift distortions (compared to straight lines) of e^- are calculated by a 5^{th} order adaptive step-size Runge-Kutta algorithm



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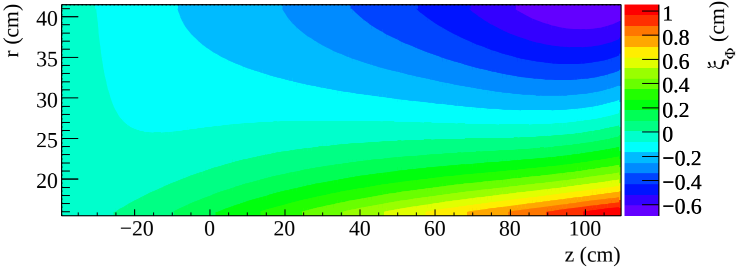


- Drift distortions of up to $\mathcal{O}(1\text{ cm})$ are reached

4. Reconstruction Challenge

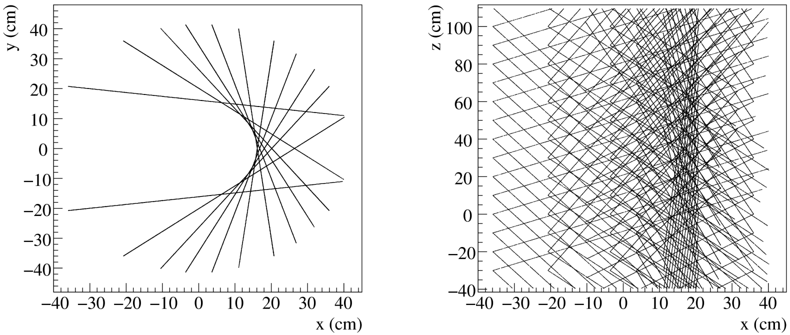
To correct for drift distortions one needs to measure them;
Possibilities:

1. Point sources on the back-plane:
   - Would only give the **integrated** drift deviations
2. Reconstruction via measured space-charge:
   - Use seen signals to infer space-charge distribution
   - Would not take drift dynamics of the **backdrifting ions** into account $\longrightarrow$ imperfect model of ion space-charge
3. **Laser system** would be able to directly measure drift distortions $\xi(x, y, z)$

SC Correction with Lasers - Proof of Principle

The Laser Mesh

- We used a simple laser mesh solely based on the requirement of full volume coverage and minimal beam crossings

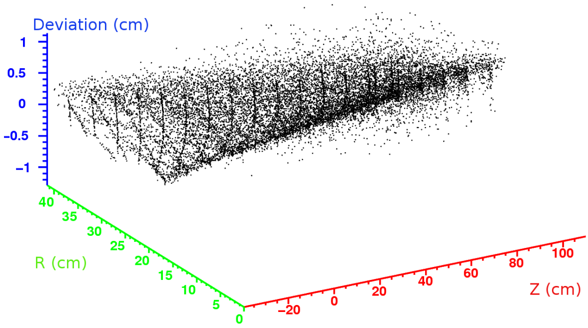


- Laser beams are modeled through ion density ($\sim 50\,e^-/cm$) and beam width (gaussian, $\sigma \sim 400\,\mu m$)
- **Offline simulation**

Laser Track Reconstruction

- Simple laser tracking is done based on known geometry
  - No track crossings are resolved

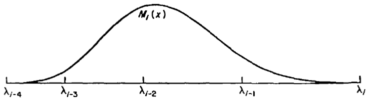
⟶ Direct measurement of the drift distortions



Example of a reconstructed laser event

Fitting & Smoothing

- Raw data f_r $(r = 1 \dots n_r)$ requires fitting and smoothing
- For this purpose a bi-cubic spline fitting algorithm has been implemented
- Principle:
  - Create mesh λ_i, μ_j of points over the data area ($h \times k$ over the data area + 8 on each side)
  - At each point elementary B-Splines $M_i(x)$, $N_j(y)$ are attached:



  - The complete spline has the defined representation

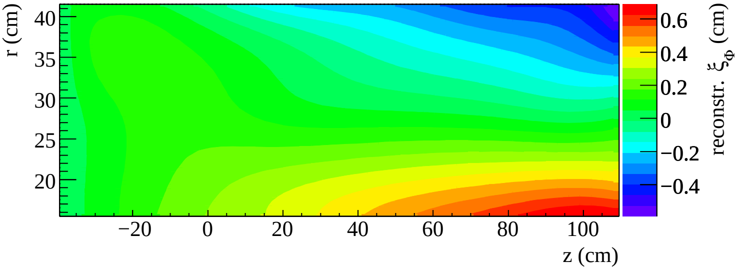
$$s(x, y) = \sum_{i=1}^{h+4} \sum_{j=1}^{k+4} \gamma_{ij} \, M_i(x) \, N_j(y)$$

  - **Fitting problem:** Find γ_{ij} that minimize

$$(s(x, y) - f_r)^2$$

Fitting & Smoothing II

- This equivalent to minimizing: $\mathbf{A}\,\gamma = \mathbf{f}$
  where $\mathbf{A}$ is the spline-matrix with n_r rows and $(h+4)(k+4)$ columns.
- If the data points are sorted in x (y), the matrix $\mathbf{A}$ has band structure
- Solve by invertion or Householder Transformations

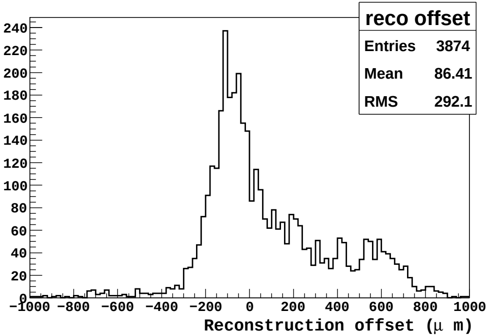


Example of reconstructed distortion map

- **No. of knots:** $5 \times 3 \longrightarrow$ higher smoothness, faster fit, lower accuracy
- **Fit performance:** ~ 15000 data points, fit time $\sim 1\,$s

Fit Quality

- Compare to original input distortion map to get a general understanding of the quality of our reconstruction
- **However:** Comparison is tricky because of different representations (**spline fit** vs. **lin. interpolated map**), # of knots, ...
- Direct comparison yields:



$\longrightarrow$ **Reconstruction uncertainty $\sim \mathcal{O}(200\,\mu m)$ (gauss fit)**

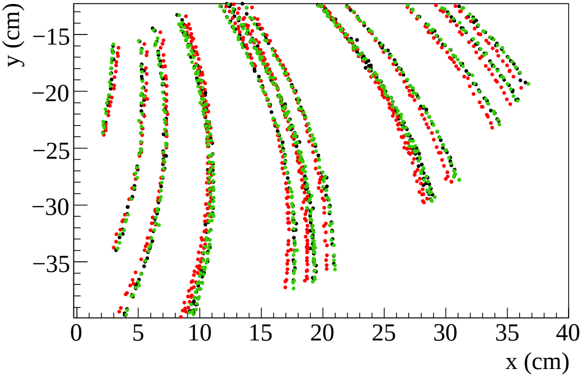
Correction of Physics Events

- Spline object is very small (only ~ 20 parameters) and fast to evaluate
  $\longrightarrow$ perfectly suited for fast correction
- Correction applied before Kalman Fitter
- Accuracy of prefit (e.g. during pattern recognition) for determining cluster position sufficient

- Results of example studies:

Results: Spatial Distortion Correction

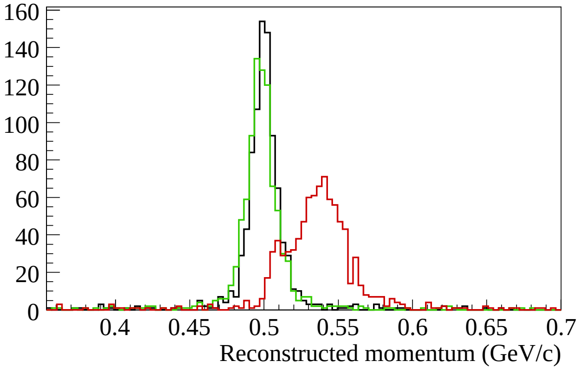
- Expected correction precision: $\sim 200\,\mu m$



Black: Ideal case, distortions turned off
Red: Distortions present, uncorrected
Green: Distortions present, **corrected**

Results: Impact on Momentum Reconstruction

- Example sample: 1000 pion tracks (π^+, 0.5 Gev / c), uniform in θ
- Asymmetric distortion map deforms and shifts momentum peak
- Correction algorithm fully recovers shape and position
- Applying gaussian fits reveals that the error introduced by correction is **below 1%** for both σ and mean



Conclusion & Outlook

Conclusion

1. Track Fitting:
   - Track fitting based on genfit is working reliably
   - Please attend **Christian Höppner's** talk on Wednesday for more information on genfit
2. Momentum Resolution Studies
   - Consistent and reasonable results available
   - Momentum resolution of TPC alone: $\boldsymbol{\sigma_p / p \sim 3\%}$ **@ 1.0 GeV / c**
3. Space-Charge Correction with Lasers
   - Correction method in place
   - Spatial & momentum resolution fully recovered
   - **Effect is under control**

Outlook

- 3 - dimensional studies for space-charges without azimuthal symmetry

- dE / dx algorithm based on genfit tracking has been implemented $\longrightarrow$ Work in progress

Backup Slides

Backup slide: TPC geometry

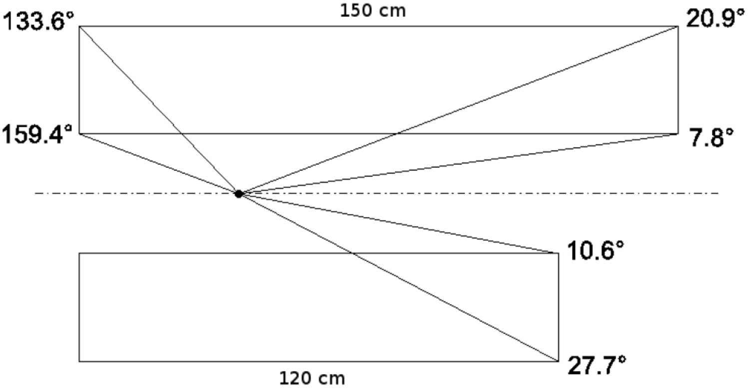


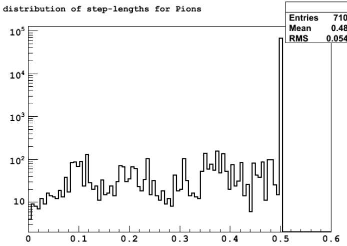
Figure: The two length options and resulting key angles

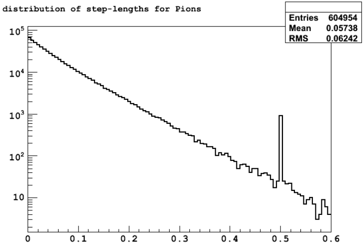
How does ALICE MC work?

GEANT3 ALICE:

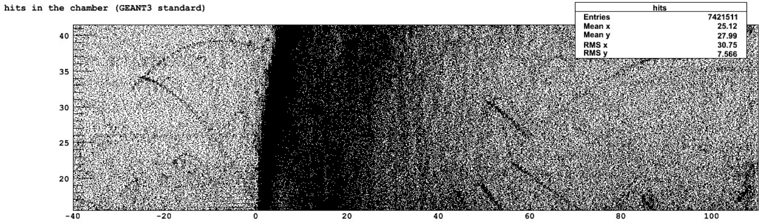
- Sample next step-length $\mathcal{L}$ from from pdf $f(x) = \frac{1}{\lambda}\exp^{(-\frac{x}{\lambda})}$

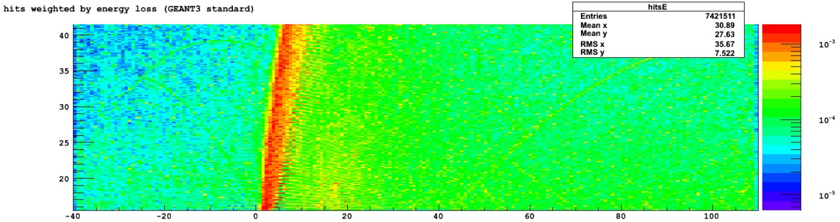
  $\mathcal{L} = -\lambda \ln(r)$ (λ: mean free path, r: random number $\in$ [0,1])
- Force GEANT to make a step there
- $\lambda(p) \propto (\frac{dE}{dx})^{-1}$ from normalized Bethe-Bloch parametrization
- Energy loss straggling directly obtained from a tuned Rutherford cross section





Backup slide: GEANT3 standard TPC hits





Backup slide: GEANT3 ALICE TPC hits