STT & PID

Peter Wintz for the PANDA-STT Group

PID Workshop, GSI, May-4th, 2018

STT & PID Outline

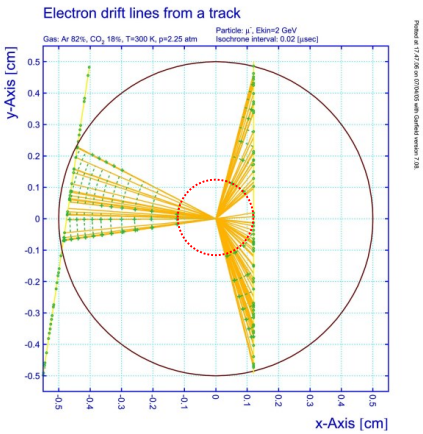
- Basics: PID with straws
- STT & PID by dE/dx
- Testbeams
- Data analysis & PID results
- Next steps

→ *Dedicated STT talk in CM 18/2 (tracking, PID)*

Straw Basics – Detection Method (1)

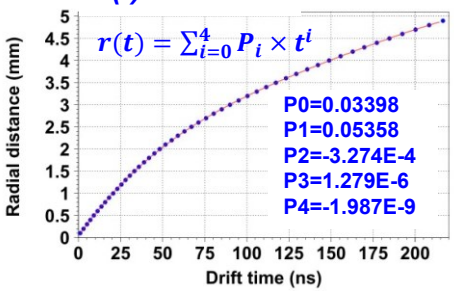
- Gas ionisation by charged particle (poisson distributed clusters)
- *⟨dE/dx⟩ ~ 2.5 keV/cm ~ 94 I.P./cm* in Argon (ntp) for MIP
- E-field between anode wire and cathode wall, e^- drift to wire
- Avalanche (plasma) by Coulomb collisions at thin wire ($E \propto 1/r$, $\varnothing \sim 20\mu m$, $A \sim 10^4$-10^5)
- Gas admixture (e.g. CO_2) to quench UV-photons from avalanche

Garfield simulation

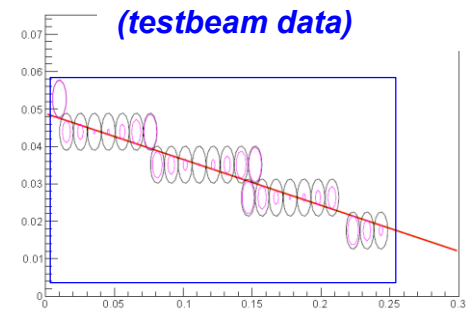


- Arrival time of earliest drift e^- yields shortest track distance to wire
- Signal electronics: low threshold (NL), fast peaking time
- Calibration of isochrone radius – drift time relation: $r_{iso}(t_{drift})$
- $r(t) = \Sigma P_i \times t_i$ charact. for gas props, non-lin. v_{drift} by E-field
- Resolve point on isochrone by multiple straws, hit by same track

r(t) relation



Track reconstruction (testbeam data)



- Isochrone resolution smeared by
  - ion cluster distribution (poisson), e-cloud diffusion, ..
  - straw tube geometry, wire centering, wire sag, ..
  - E-field, gas density & temperature, gas (ad-)mixtures, ..
  - electronics, signal prop., calibration SW, tracking SW (kalman), ..

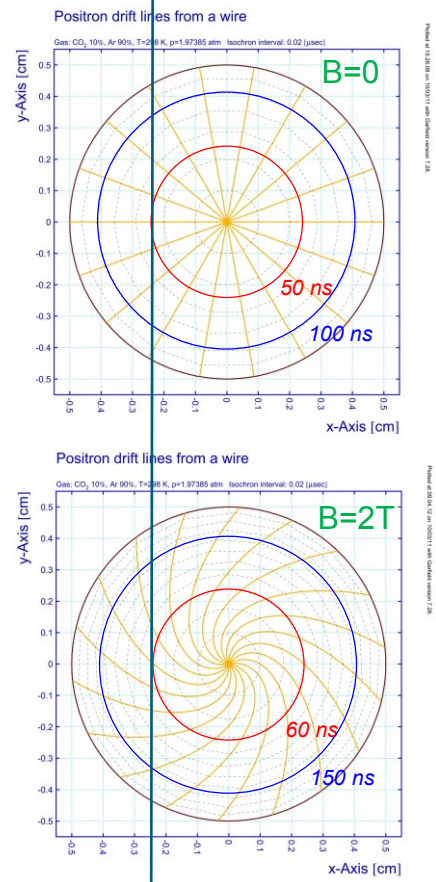
Straw Basics – Detection Method (2)

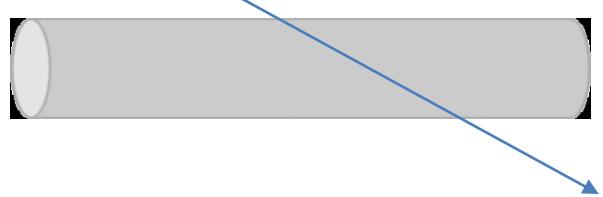
- PANDA solenoid magnetic field perpendicular to straw E-field
- Additional Lorentz angle *($F=q \cdot v \times B$)* for e- drift
- Spiral electron drift path instead of radial drift
- Longer drift paths & drift times (simulation for Ar/CO_2 @ 2 bar)

- Isochrone circle shape unchanged
- $r(t) = \Sigma P_i \times t_i$ relation, different P_i for non-magnetic & solenoid fie

- Stereo-angle (~ few degrees): still circle shape in good approx.

- Do not forget: straw is cylindrical object (3D)
- Track angle (θ) enters for track ionisation path length dE/dx
- Signal propagation along wire (~ 5 ns/m, damping)



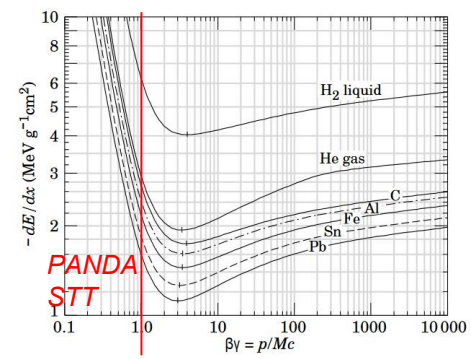


Charged particle

Straw Basics – Detection Method (3)

- Charge measurement to determine particle specific energy-loss *(dE/dx)* for PID
- Method: particle species (*mass*) determined by known momentum *p* and measured *dE/dx*
- *Bethe-Bloch:* $\langle -\frac{dE}{dx} \rangle \propto {}^{1}/_{v^2}$ up to $p/Mc \cong 1$, min. at $\sim p/Mc \cong 3$

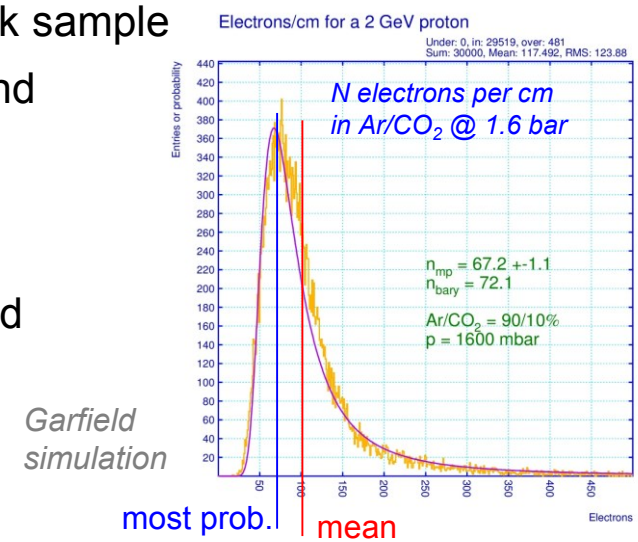
$$\left\langle -\frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



- *dE/dx* fluctuates (Landau): mean and most prob. *dE/dx* differ
- Long Landau tail by created δ- and other energetic electrons

- Use truncated mean as better *dE/dx* estimator per track
- Truncate ~15-50% of highest entries (=tail) in *dE/dx* track sample
- Then $dE/dx|_{trunc}$ shifted, but more gaussian distributed and
- $most\ prob. \frac{dE}{dx}/_{trunc} \cong mean\ \frac{dE}{dx}/_{trunc}$!

- Sometimes also small truncation of lowest entries is used

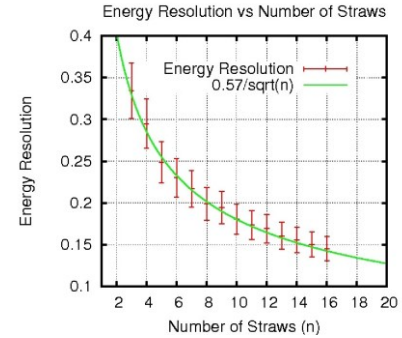


Straw Basics – Detection Method (4)

- Typical resolution reached: $\sigma_{dE/dx} < 10\%$ $\quad ({}^{\sigma}/_{mean})$
- Empirical relation (older) for resolution in Argon: ~ 11.5%

$$\frac{\delta I_{mp}}{I_{mp}} = 0.115 \left(\frac{1\,\text{mbar}}{Lp}\right)^{0.32} \left(\frac{Z_{Ar} I}{Z I_{Ar}}\right)^{0.32} \left(\frac{100}{n}\right)^{0.14} \quad \text{(FWHM)}$$

Blum, Riegler, Rolandi, Particle Detection with Drift Chambers



dE/dx resolution vs #straw hits (data), K. Pysz, STT-TDR

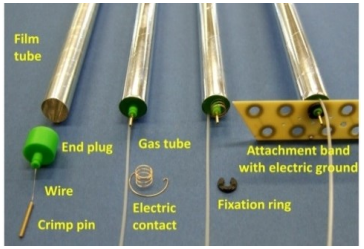
- STT: $\sigma_{dE/dx} \approx 10\%$ *(${}^{\sigma}/_{mean}$, n ~ 25 samples, L ~ 25 cm track length, p=2 bar)*
- TPC-ALICE: $\sigma_{dE/dx} \approx 5\%$ *(n = 159 samples, Neon gas, reference: W. Yu, Bari TRD Workshop)*

- dE/dx information by straws:
  - Measure charge in certain time intervall: ${}^{\sum Q}/_{\Delta t}$ and $\sum Q = f(\Delta t_{drift}(r), dx(r))$
  - No full charge integration, fast peaking time & cancellation of slow ion tail
  - Specific: non-linear e$^-$ drift $(v_{drift} \propto {}^{1}/_{r})$ and cylindr. gas ionis. volume (variable dx)

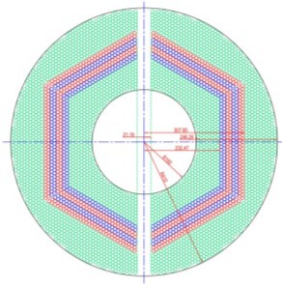
- PANDA-STT measures charge by signal width or signal area *(TDC or ADC)*

PANDA – STT

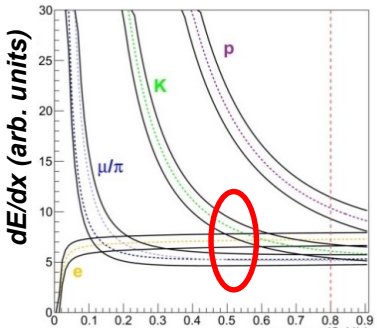
- 4224 straws in 19 axial (green) and 8 stereo (±3°) layers (blue/red)
  - 27µm Al-Mylar film, 1400 mm length, 10 mm diameter
  - Ar/CO_2 gas mixture at 2 bar pressure
- X/X_0 = 1.25% by self-supporting quad-layers
- Drift time readout & spatial resolution (σ_{xy} = 150µm, σ_z = 2-3 mm)
- Charge readout for PID by dE/dx (p/K/π < 1 GeV/c)
- Momentum resolution $\sigma(p)/p$ ~ 1-2% (@ 2T, STT+MVD)
- Continuous data stream readout (~ 15GB/s)
- Main input for real-time SW trigger (event ID)

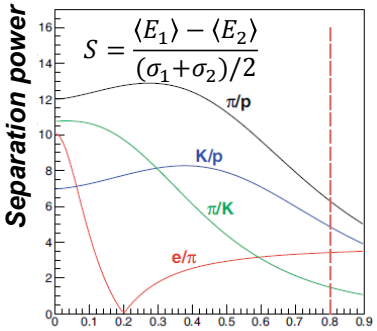


Straw materials

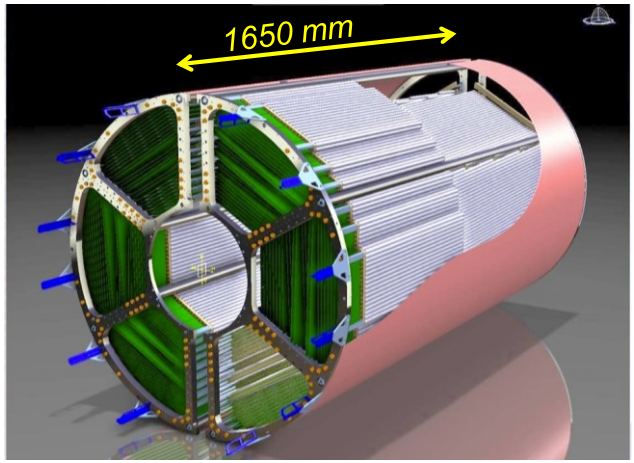


Straw layout





PID by dE/dx, simulation for STT (from TDR)



STT 3D – view

Testbeams in 2016/2018

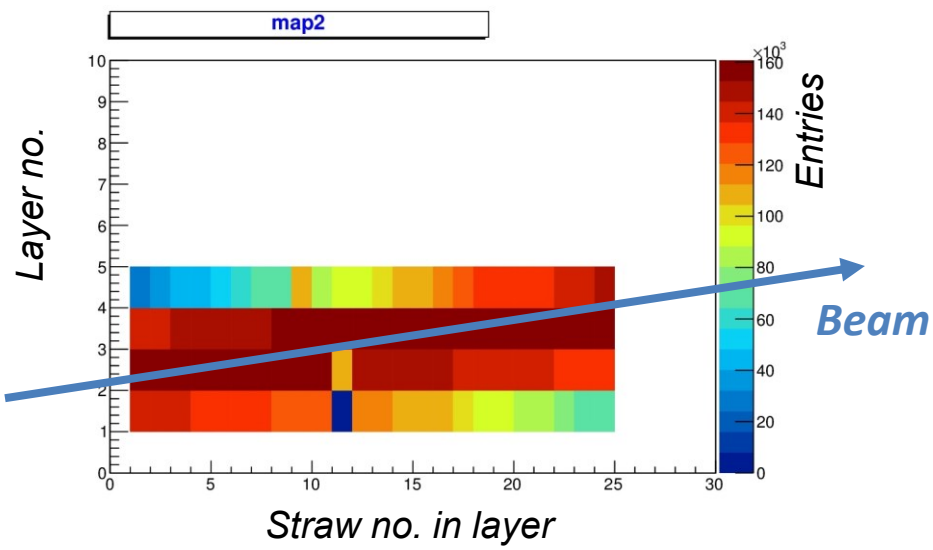
- New beam test area, counting rooms and various detector systems set up in 2016
- Two straw test systems installed for both readouts (TDC / ADC)
- Proton and deuteron beams, momentum range: 0.5 - 3.0 GeV/c
- Beams in 2016 (April/Dec) and 2018 (March/April)
- Covered dE/dx measurement range: ~ 5 - 50 keV/cm (= 1-10× MIP, in Ar/CO_2 at 2 bar)
- Straw setups with 24 straws per layer, several layers readout
- Tracks with (>) 24 hits, similar to PANDA-STT

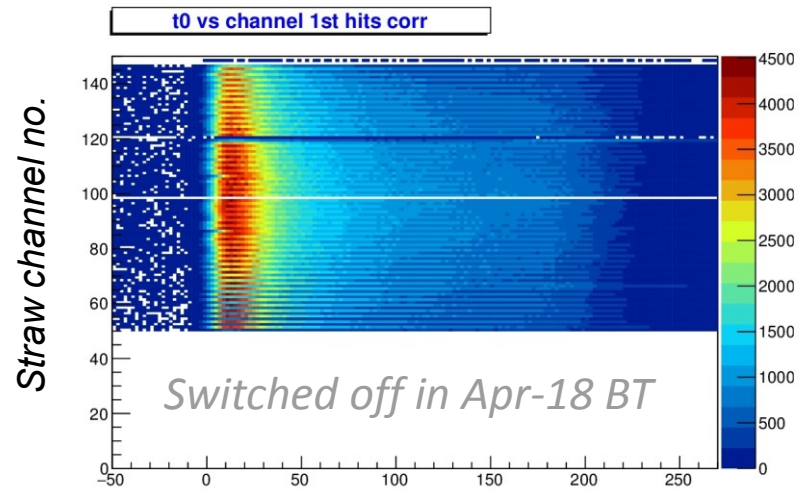
One of the two straw test systems.

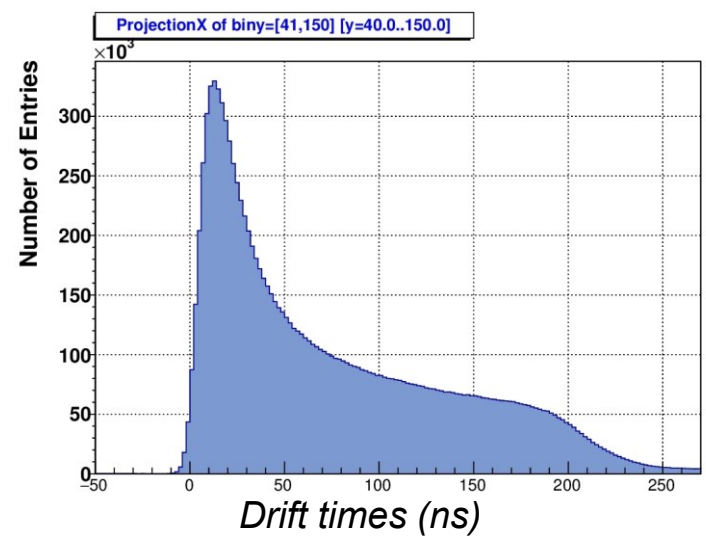
Test setups in new beam area. Beam from the back with ~2m beam line height.

Beamdata Analysis (1)

- Example: deuteron beam at 1.5 GeV/c (April 2018)
- Hitmap and beam position
- Drift time spectra (offset corrected)
- Tmax ~ 230ns
- Isochrone calibration r(t) done: → P_i

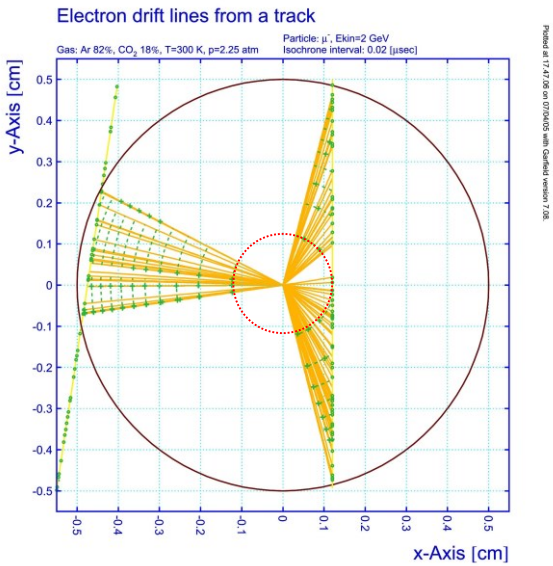


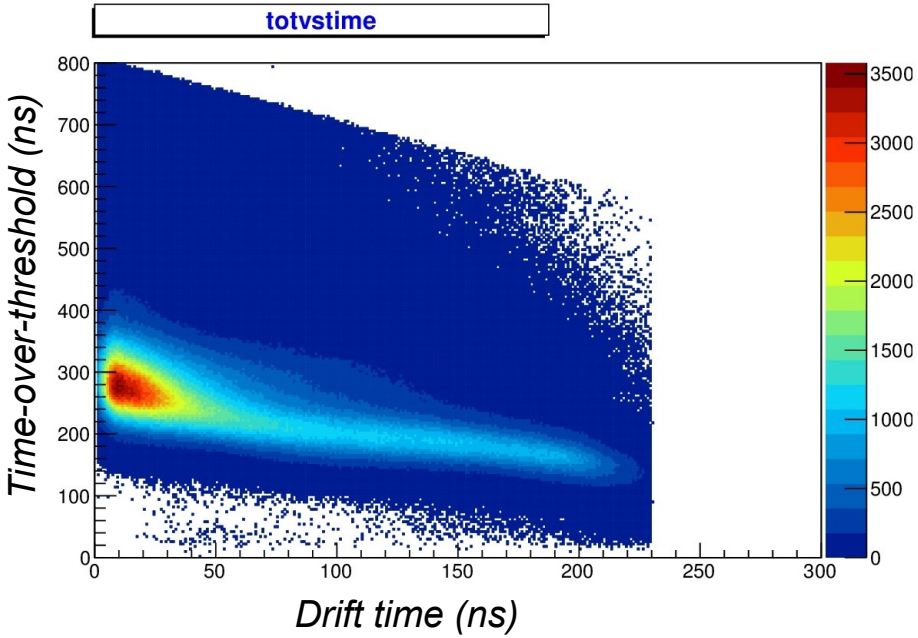


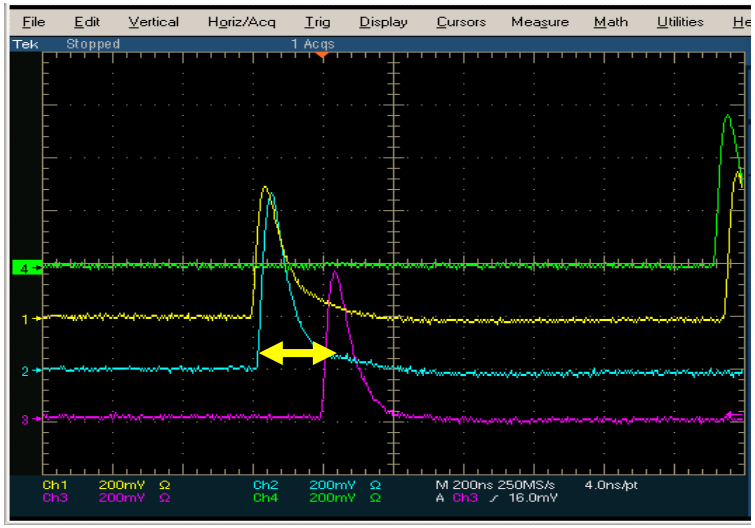


Beamdata Analysis (2)

- Charge information by time-over-threshold (pulse width, yellow arrrow)
- ToT is drift time dependent, varies over straw radius
- ToT higher close to wire (more $e^-/\Delta t$, $v_{drift} \propto 1/r$)

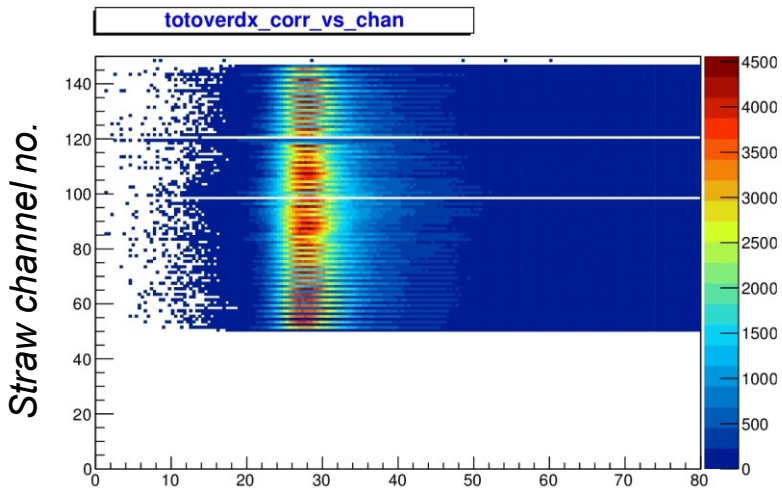


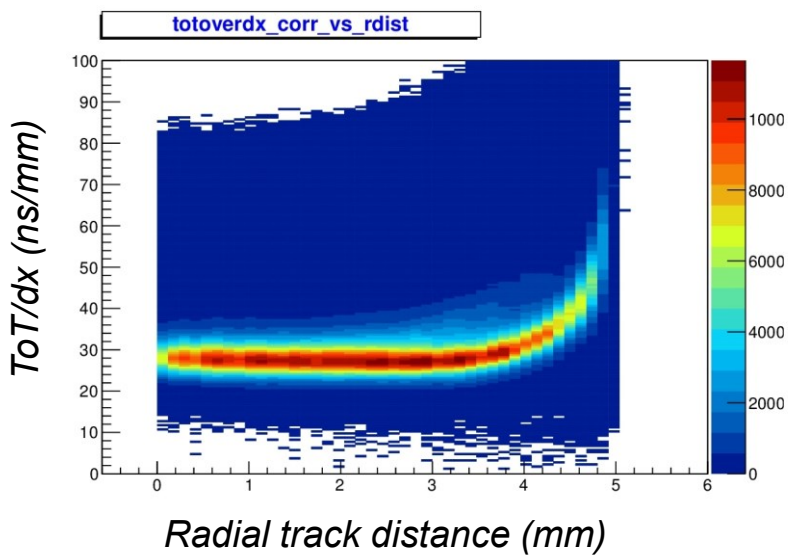


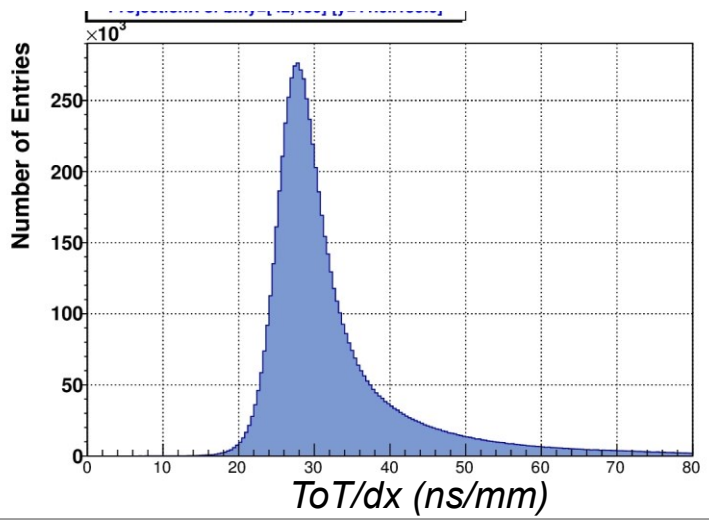


Beamdata Analysis (3)

- ToT/dx seems constant over larger radial distance (track to wire distance)
- ToT/dx distribution shows Landau-shape
- Determine truncation method
- Determine which observable for PID

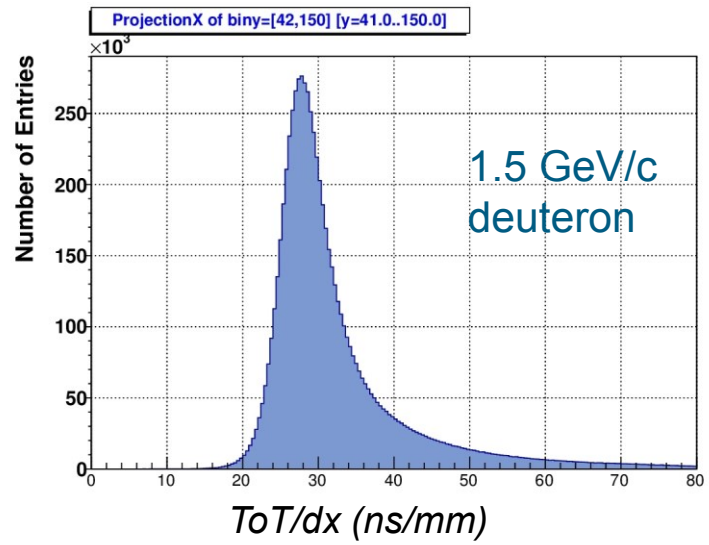


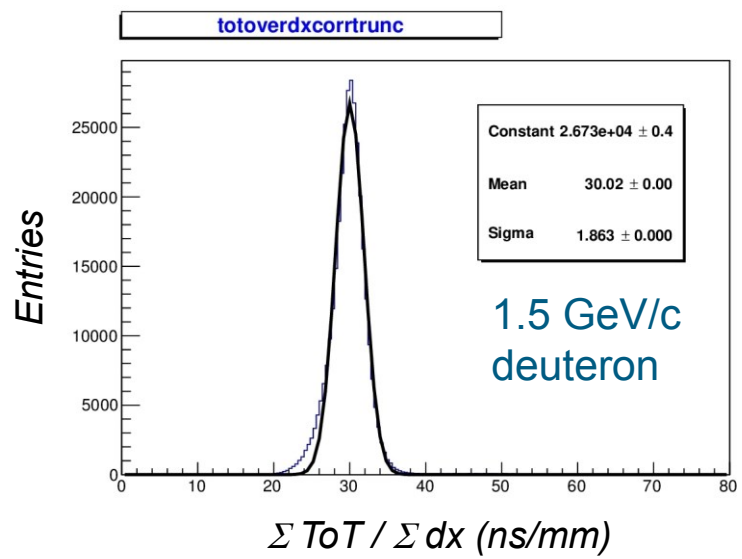




Beamdata Analysis (4)

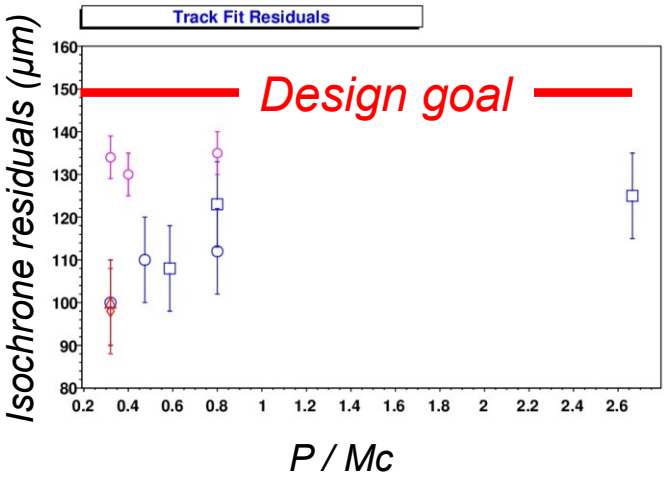
- ToT/dx distribution shows Landau-shape
- Truncation method:
  - truncate single ToT/dx hits
  - few with highest ToT/dx per track
  - fewer with lower ToT/dx per track
- ΣToT/Σdx per track seems good observable for PID
  - distribution highly gaussian

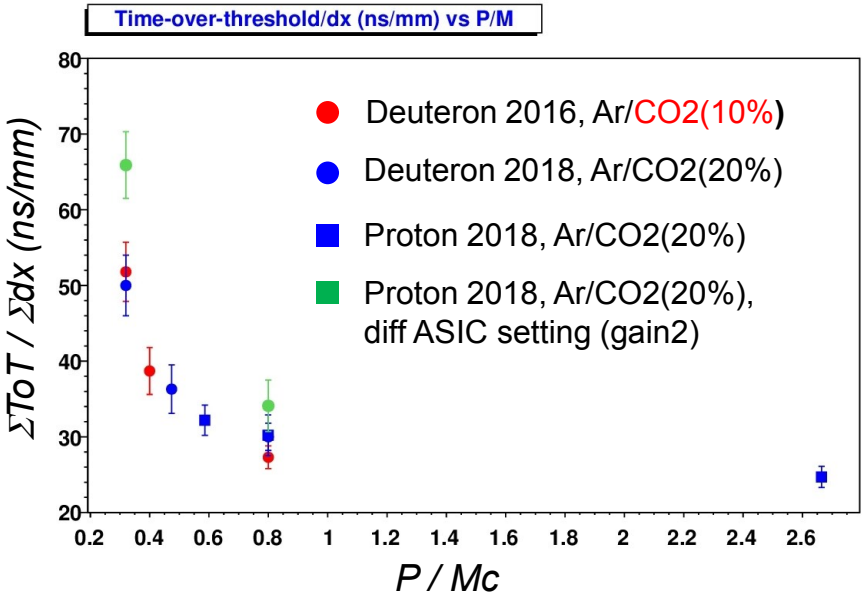


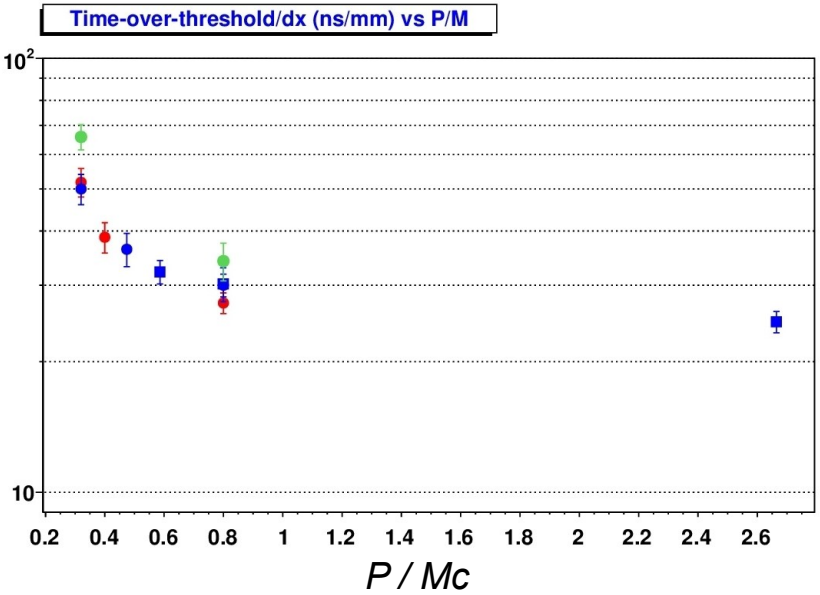


Beamdata Results

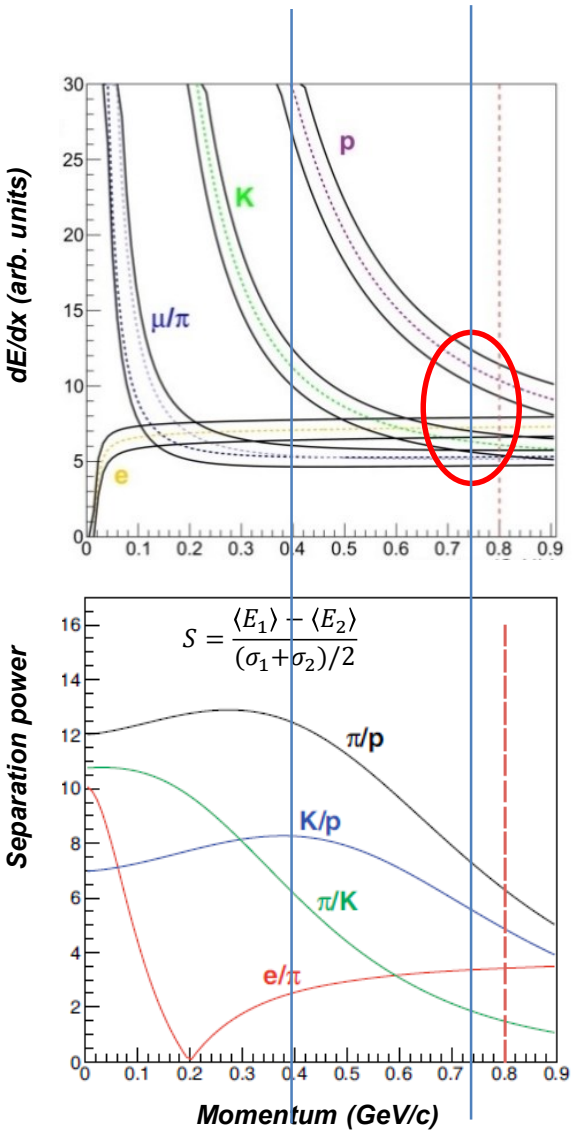
- Testbeam data 2016 & 2018
- Proton & deuteron beams, 0.6 – 2.5 GeV/c
- Same! ASIC settings (gain, thresh., low NL, ..)
- Separation ΣToT / Σdx for different P/M
- Resolution: 5.5 % – 9.0 % (analysis ongoing)
- (Spatial resolution not discussed today)







Results: PID By ToT



- ToT results (deuteron, proton beam & cosmics)
  - S ~ 3.3* (K/p @ 750 MeV/c, TDR: S ~ 5)
  - S ~ 5** (K/p @ 390 MeV/c, TDR: S ~ 8)
  - S ~ 9*** (π/p @ 300 MeV/c, TDR: S ~ 13)

*1.5 GeV/c deuteron, 2.5 GeV/c proton
**1.5 & 0.75 GeV/c deuterons
***0.6 GeV/c deut. & cosmics

- All TDR separation power w/ 10% dE/dx resolution and ADC readout

→ ~ 60-70% of TDR separation power reached by ToT

PID by dE/dx simulation for STT (from STT-TDR), 10% dE/dx resolution assumed, truncated mean method

Results Summary

- Concentration on ASIC/TRB readout here (analysis by Peter)
  - Particle separation observable used ΣToT/Σdx
  - Truncation method applied
  - Other PID observable might be possible (ToT drift time corrected ..)
  - Dynamical ToT range limited (pulse width $\leftrightarrow$ high rate capability)
  - Dynamical ToT range << dE/dx range

- ADC readout (expected) results & methods similar
  - WF sampling, full pulse shape $\rightarrow$ pulse shape integration
  - Larger dyn. range: pulse area instead of pulse width (ToT)
  - System set up ongoing, non-standard & completely new readout system layout
  - Results for FADC test system in TDR

Next Steps

- Input to simulation (proposal):
  - PID separation observable ΣToT/Σdx (trunc.) as function of P/Mc
  - Distributions (gaussian) from data

- Determine PID capability for simulated reactions
  - Single tracks $\rightarrow$ event (pairs of same particle species)
  - Simulation of PID reaction channels (with p/Kπ) *$\rightarrow$ Simulation group*

- Decision whether PID by ToT is sufficient for PANDA by event simulation

- Further optimisation of ToT/dx resolution, range now: 5.5 % - 9 % $\rightarrow$ 6 % (?)

- ADC readout ..

Thank you

for

your attention

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