SoLID Track Reconstruction

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SoLID Collaboration Meeting
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SoLID Tracking Considerations

- High rates $\mathcal{O}(1 \text{ MHz/cm}^2)$, high occupancies (20%) $\rightarrow$ moderately difficult environment
- Tracks not straight
- GEM readout coordinates not parallel between all planes (at least in current PVDIS design)
- Real-time track reconstruction desirable for level-3 trigger $\rightarrow$ want fast algorithm

Choice of Reconstruction Algorithm

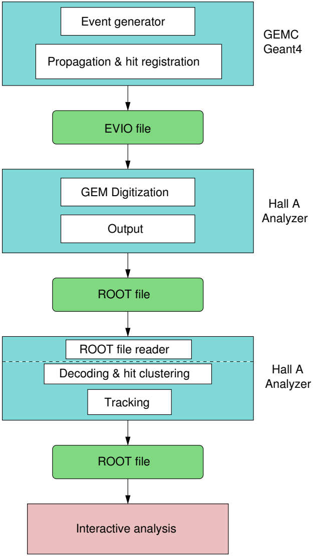
- Curved tracks, non-parallel coordinates → progressive algorithm (Kalman filter)
- Little expertise in Hall A, but in other halls → consult
- Very preliminary version exists (Xin Qian)
- This is a multi-year development effort (but we have the time)

This Talk: Track Reconstruction Feasibility Study

- Simplify the problem in simulation:
  - Rotate GEM strips in software → parallel coordinate axes
  - Simulate DIS signal without magnetic field → straight tracks
  - Background (simulated with field) added separately → can vary background level
  - Expect this still to demonstrate *feasibility* of track finding
- Use existing TreeSearch reconstruction (BigBite)
  - Available now
  - Well tested & integrated in Hall A analyzer
  - Shown to work with SBS GEM trackers at $\geq$ SoLID occupancies

Track Reconstruction Simulation

- `solgemc` EVIO files as digitization input (S. Riordan)
- GEM digitization based on SBS work (E. Cisbani, R. Holmes)
  - APV25 pulse shape
  - Background added with randomized time offset
  - No other detectors digitized yet
  - Generated data (tracks, vertices) passed through
- ROOT file interface
- Tracking



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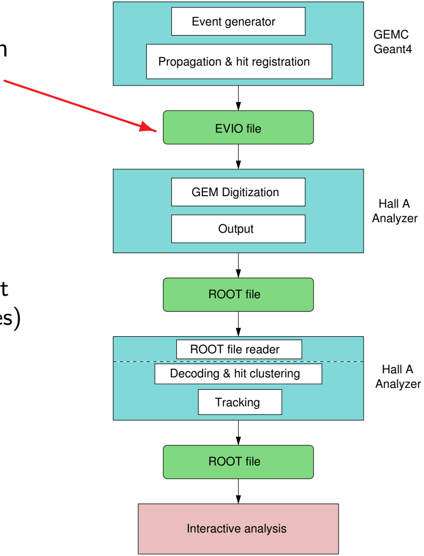

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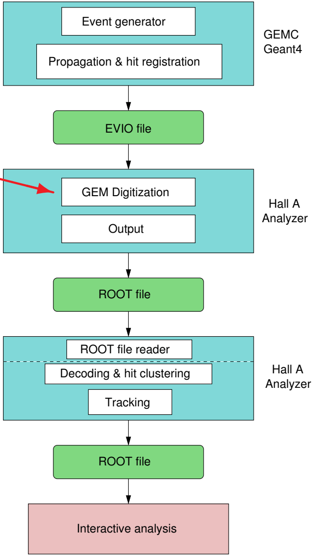

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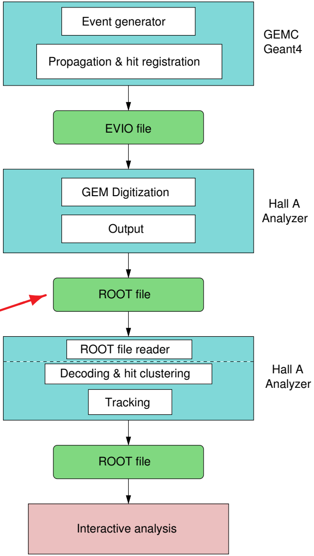

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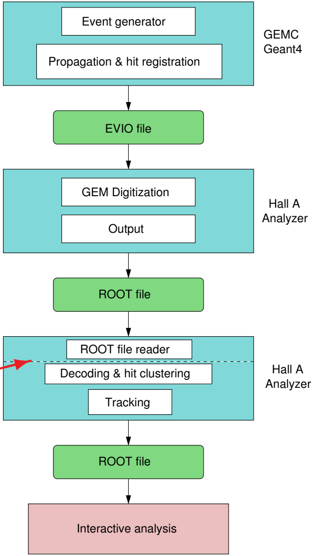

Track Reconstruction Simulation ("data challenge" ready)

- solgemc EVIO files as digitization input (S. Riordan)
- GEM digitization based on SBS work (E. Cisbani, R. Holmes)
  - APV25 pulse shape
  - Background added with randomized time offset
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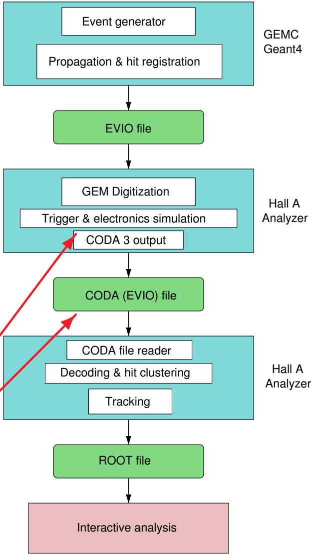
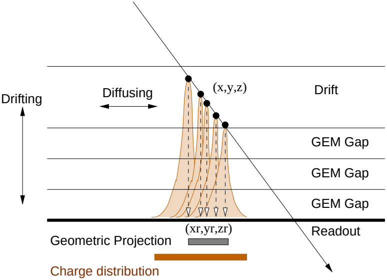
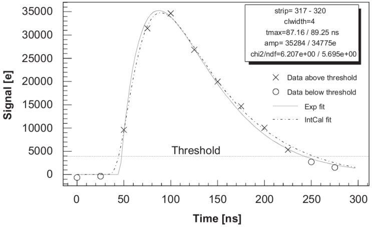
  - Generated data (tracks, vertices) passed through
- ROOT file interface
- Tracking
- Should eventually use actual DAQ format (CODA 3) for analyzer input



GEM & APV25 Digitization (adapted from SBS by Rich Holmes)

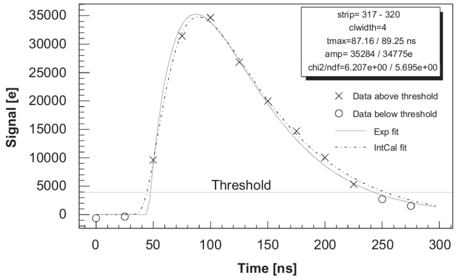
- GEMC outputs raw hits (energy deposition ΔE) in GEM layers
- GEM response tuned to match COMPASS observations
- Avalanche simulation:
  - Poisson-distributed number of ion pairs calculated from ΔE
  - Use geometric distribution for ionization probability along path
  - Assume constant-velocity diffusion and drift
  - Gaussian distribution of charge deposited on strips
- Shape output amplitude: $v = A\tau \exp(-\tau)$, record 3 samples in 25ns intervals





APV25 Pulse Shape Deconvolution & Noise Filtering

S. Gadomski *et al.*, NIM A 320, 217 (1992)



- For first-order RC circuit, signal amplitudes s_k can be deconvoluted using three measured values v_k:

$$s_k = w_1 v_k + w_2 v_{k-1} + w_3 v_{k-2}$$

$$w_1 = e^{x-1}/x, w_2 = -2e^{-1}/x, w_3 = e^{-x-1}/x, \text{ where } x = \Delta t/T_p$$

$$A \approx \sum_{k=1}^{3} s_k$$

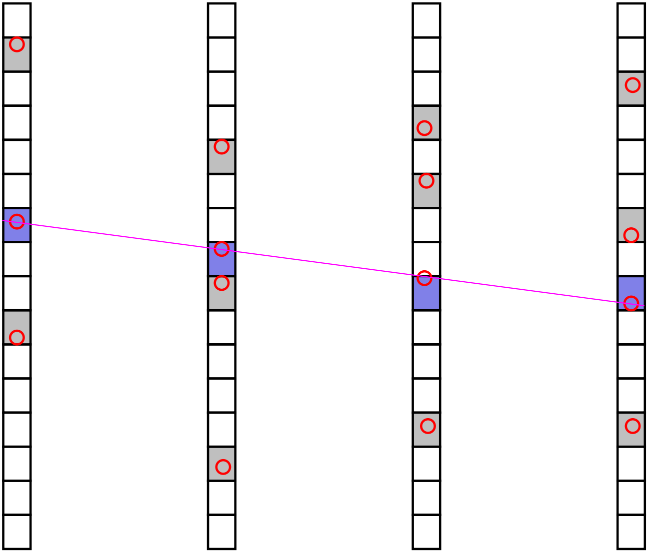
- Reject noise by cutting on ratios, $r_1 = v_3/v_1$ and $r_2 = v_2/v_1$, requiring rising slope

TreeSearch Algorithm

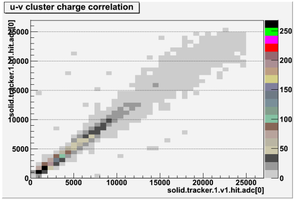
M. Dell'orso and L. Ristori, NIM A **287**, 436 (1990)

- Global algorithm (non-progressive)
- Recursive template matching
- Works in 2D only (one readout coordinate, "projection")
- Fast ($\mathcal{O}(\log N)$) and memory-efficient ($\mathcal{O}(10 \text{ MB})$)
- Independent of other detectors $\longrightarrow$ no seed needed
- Used by HERMES, Qweak, etc.

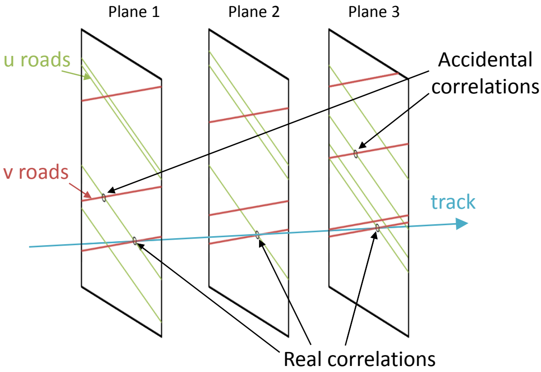
TreeSearch Illustration



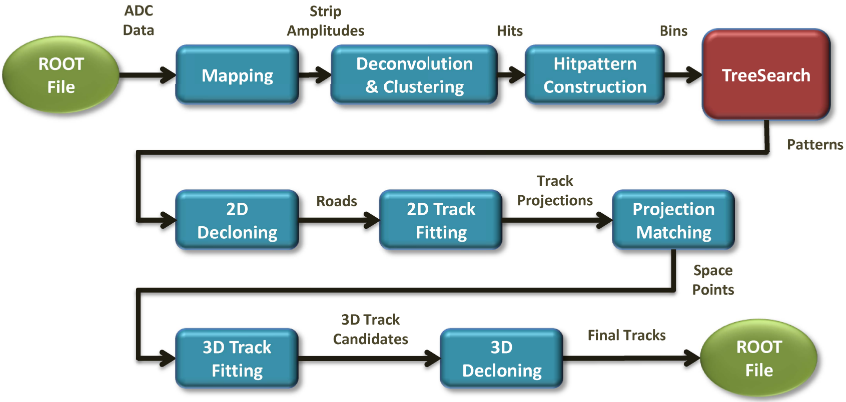
3D Matching



- Correlate roads from different projections via hit amplitude in shared readout planes
- Repeat for each readout plane along z
- Pair roads with the best overall correlation to get space points for 3D track fits
- Calorimeter hit helps resolve



TreeSearch Track Reconstruction Chain (GEM version)



MC Data Sets & Analysis Status

- Configuration
  - 40 cm LD_2 target in 11 GeV beam
  - PVDIS detector setup with 5 GEM planes
  - baffles (which?)
- "Signal Runs"
  - Generator: DIS
  - Only interactions of primary particle recorded
  - Available data sets

Primary particle	Field	Materials	# events w/GEM hits
μ^-	off	trackers	240k
μ^-	off	"all"	248k
e^-	on	"all"	14k

  - "Trackers" materials: only interactions with GEM trackers recorded ("ultra-clean data")

Background Simulation

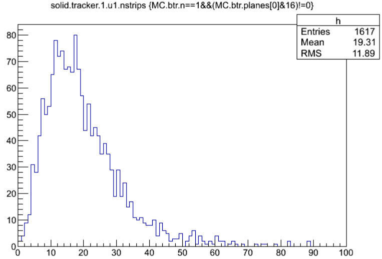
- "Background Runs"
  - Same configuration as for signal runs
  - Simulated 198 M background events (= electrons passing through target)
  - Production rate ≈ 40 M/hr
- Adding background to signal runs in digitization step
  - Approx. 86 M background events occur in 275 ns time window at 50 μA → 100% background
  - To reduce analysis time: fold background from 30 sectors into signal sector with random time offset per sector
  - Obviously not enough background events for any significant number of signal events → re-use events, but with different time randomization ("pseudo-statistical" background)
- Status
  - Digitization runs

Signal Data	Signal events	Backgr. strength	Digitization rate (signal events/hr)
μ^-/no field/all mats	10 k	25%	1250

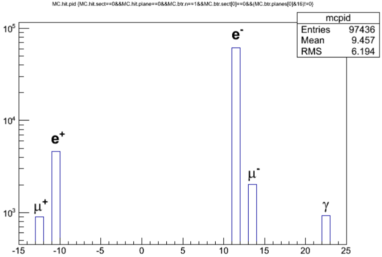
  - Time scales with background strength → est. 300 events/hr @ 100%
  - Older digitized data: 10% background, 4 GEM planes, no sector folding, time randomization bug

Strip Occupancy, 25% background, 5 GEM Planes

Number of strips above ADC threshold, sector 0 plane 0



PID of hits, sector 0 plane 0

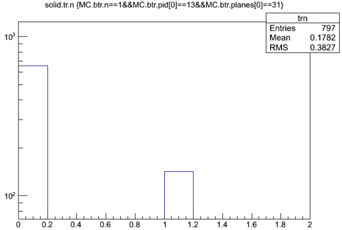


Filtered occupancies, 5 GEM setup, 25% background				
Plane	Mean # active	Total # strips	Occup. @ 25% (%)	Occup. @ 100% (%)
u1	19.3	753	2.6	10.2
v1	20.1	627	3.2	12.8
u2	13.8	945	1.5	5.8
v2	14.8	659	2.2	9.0
u3	12.2	921	1.3	5.3
v3	13.1	657	2.0	8.0
u4	8.5	1271	0.67	2.7
v4	8.8	1271	0.69	2.8
u5	8.1	1309	0.62	2.5
v5	8.5	1309	0.65	2.6

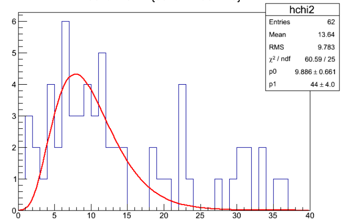
- First plane sees many slow electrons ($p < 1$ MeV)
- Estimated SBS raw occupancy $< 20\%$ in all planes $\longrightarrow$ estimated SoLID occupancies well below SBS

Tracking Efficiency For 25% Background

Number of tracks found for MC tracks crossing all planes



χ^2 of tracks with $n_{dof} = 6$



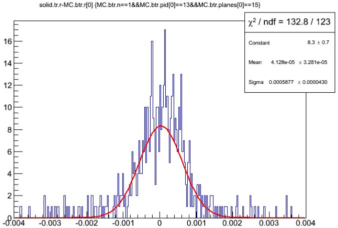
- **Apparently still buggy - alignment?**
- Track finding efficiency

$$\frac{142}{797} = 17.8\%$$

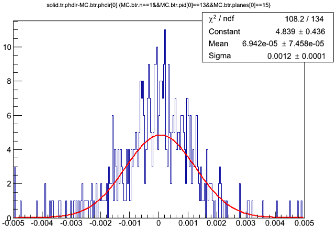
- This is this probability that an actual track will be "accurately" reconstructed.
- Experimental track finding probability will likely be higher because
  - Even "not accurately" reconstructed tracks might appear acceptable
  - Some ghost or secondary tracks might look like real tracks, too
- Ghost and secondary track rates not yet determined. Requires additional analysis code (in development).

Residuals (10% Background, 4 GEM Planes)

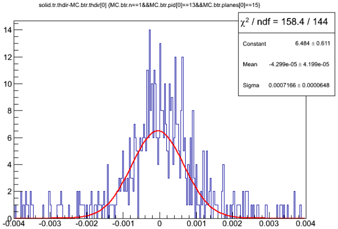
r-coordinate of crossing point in first GEM plane



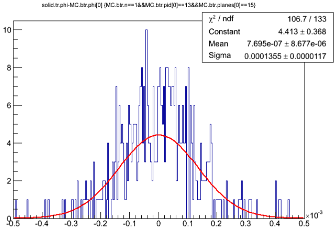
ϕ-coordinate of crossing point in first GEM plane



θ_{dir}: Polar angle of momentum



ϕ_{dir}: Azimuth of momentum



Tracking Performance vs. Background Level

(to be done)

Observations

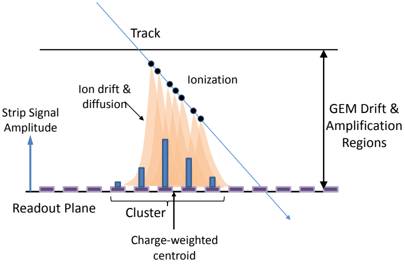
- Occupancies appear less than in SBS case. Encouraging.
- Tracking efficiency very low with 5-plane data $\rightarrow$ BUG?
- Ghosts and secondary track rates appear to be negligible (to be confirmed) $\rightarrow$ noise filtering is effective.
- Residuals look very reasonable (for 10% background)
- After fixing apparent bugs, need to run up to 100% background to avoid having to extrapolate (time-consuming)

Outlook: Program for Next 18–24 Months

- Re-run simulation with latest baffle design(s)
- Debug/finish feasibility study with TreeSearch. Demonstrate tracking at 100% background level
- Make GEM digitization more realistic (cluster size too small)
- Include all other detectors in digitization & analysis
- Develop progressive tracking algorithm
- Demonstrate curved track reconstruction feasibility, performance etc.

Backup Slides

GEM Hit Clustering



- Signals on adjacent readout strips typically belong to a single track crossing
- Sum signals to get
  - total hit amplitude
  - charge-weighted position centroid
- Currently use simple algorithm:
  - Look for local peak
  - When sequence "peak-valley-peak" is seen, split cluster at "valley"
  - Regardless of shape, limit clusters to a maximum size
- Improvements
  - Match hits by their pulse shape, *i.e.* timing centroid
  - Redo clustering after preliminary tracking (*e.g.* better cluster splitting)
  - . . . possibly more
- *NB:* Clustering does not necessarily have to be separate from tracking, could be integrated into a progressive tracking algorithm