Finding the needle in the haystack: a charmonium trigger for the CBM experiment

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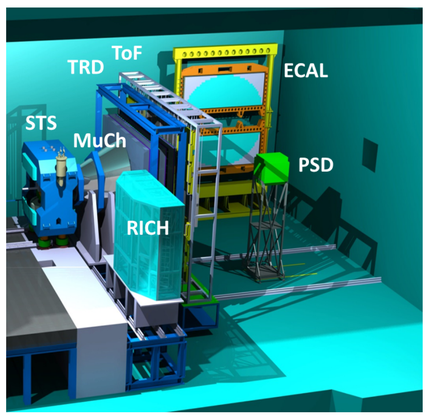
The Compressed Baryonic Matter experiment (CBM) at FAIR



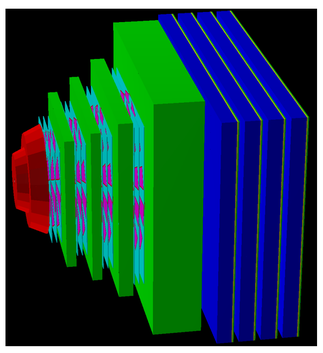
Goal

- To study the QCD phase diagram at high net baryon densities and moderate temperatures.
- SIS100 collision energies 2÷11 AGeV

Physics observables

- Rare probes: strange hadrons, charm hadrons, light vector mesons (rho, omega, phi), J/ψ mesons

Muon Chamber (MUCH)

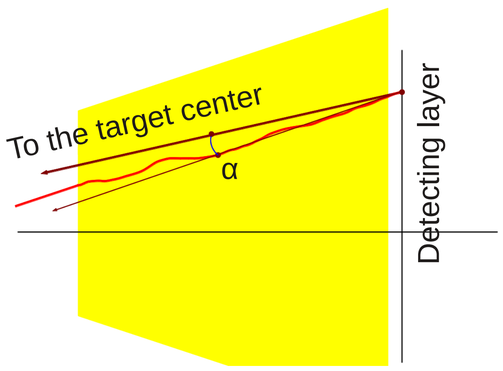


- 4 GEM stations
- 1 TRD station
- Thick absorber in front of each station for hadron background suppression

J/ψ mesons

- Charmonium (J/ψ mesons) is one of the most interesting observables for the CBM experiment
- Signal yield less than one in a million collisions
- Interaction rate up to 10 MHz
- Raw data rate up to 1 TB/s
- Storage rate is several GB/s
- Triggering software needed
- The decays $J/\psi \rightarrow \mu^+\mu^-$ can be triggered with the MUCH detector

General scheme



- Triggering is based on standalone track reconstruction in MUCH
- Linear model for tracks
- Tracks close to straight lines going from the target center
- Multiple scattering is accounted from an assumption for the initial energy
- Highland formula for the multiple scattering
- Bethe-Bloch formula for energy losses
- Track reconstruction take time measurement into account
- Triggering criteria are applied to the reconstructed tracks

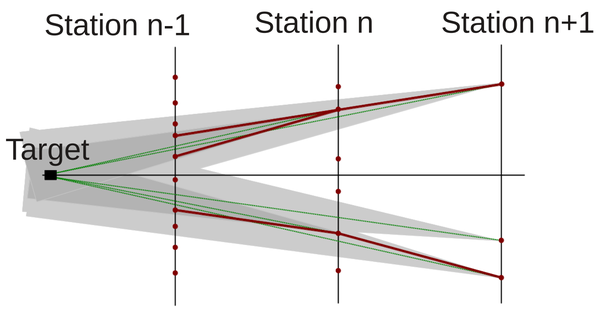
Highland formula:

$$\Theta_0 = \frac{13.6\text{MeV}}{\beta\, pc}\, z \sqrt{\frac{l}{X_0}}\left[1 + 0.038 \ln\frac{l}{X_0}\right]$$

Bethe-Bloch formula:

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

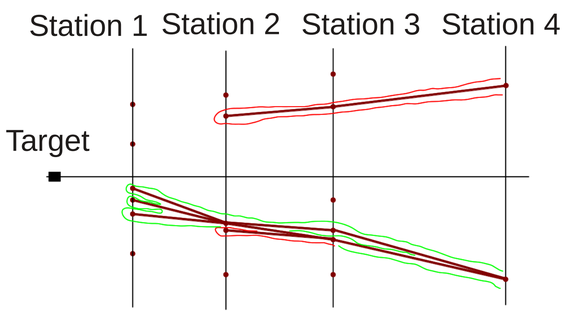
Track reconstruction



- Reconstruct tracklets w/o TRD hits
- Verify them with tracklets in TRD

Building tracklets w/o TRD hits

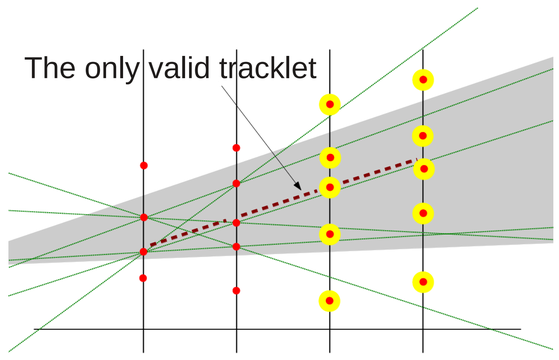
- Asymmetric cellular automaton (CA) algorithm
- 'Cells' are segments of straight lines connecting hits on adjacent stations



Asymmetric CA

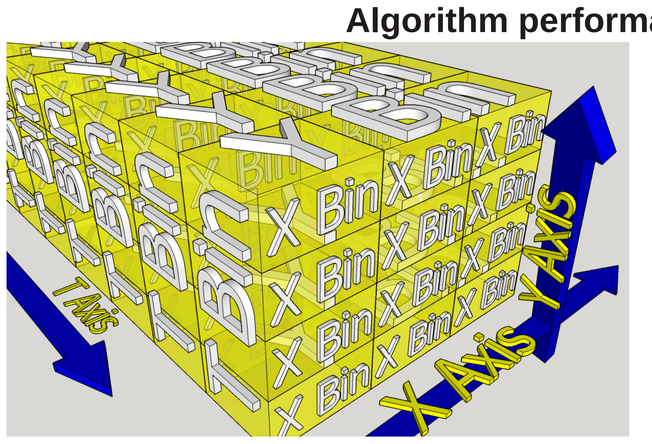
- Build straight line segments
- Find segment chains connecting the last station with the first
- In chain trees starting on the last station select the chain with the least χ2

TRD tracklet verification



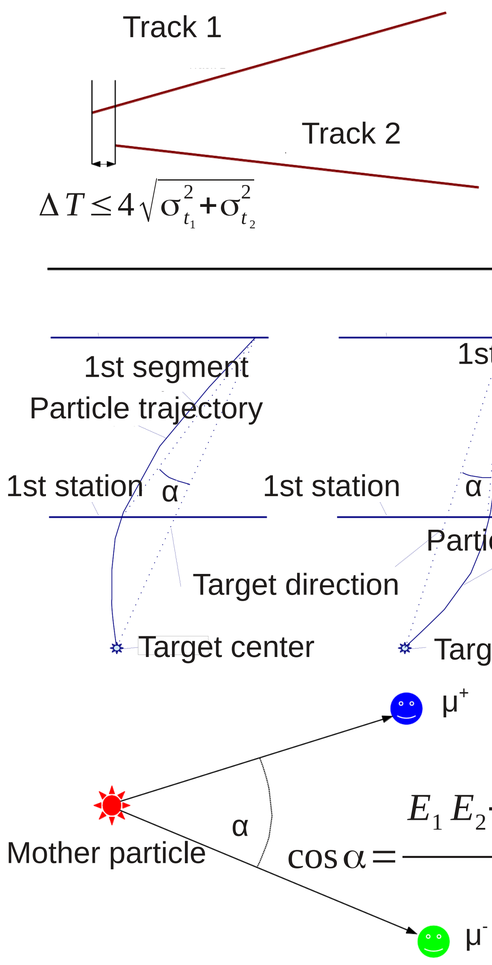
- Extrapolate reconstructed tracklet to the 1st and 2nd TRD layers
- Draw lines through all combinations of hits on these layers
- If there are hits in the vicinity of one of these lines on both 3rd and 4rd layers the tracklet is verified

Algorithm performance optimization



- Detecting station is a manifold in XY and Time (XYT) space
- Approximated with a rectangle
- The station rectangle is subdivided to smaller XYT bins
- Inspired by the bin sort algorithm
- Each bin contains only a very limited number of hits
- Composition and searches are extremely fast

Triggering criteria



- Two reconstructed tracks
- They belong to particles with different electric charge signs
- The angle between them exceeds a certain limit

Two tracks

Electric charge sign estimation

Must be a pair of tracks with different estimated charges

The angle between tracks must exceed a certain limit. This is a consequence of the relativistic formula

Conclusion

- For signal triggering efficiency tests: one PLUTO $J/\psi \rightarrow \mu^+\mu^-$ decay for an event + central Au+Au@10AGeV central collision (URQMD)
- For background suppression tests: minimum bias Au+Au@10AGeV collisions (URQMD)

- Background event reconstruction time: 4 μs
- Signal triggering efficiency: 83%
- Event suppression factor: 1/3800
- Data suppression factor: 1/1700

J/ψ trigger can be implemented with MUCH