Fast Global Tracking for the CBM Experiment at FAIR

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MMCP

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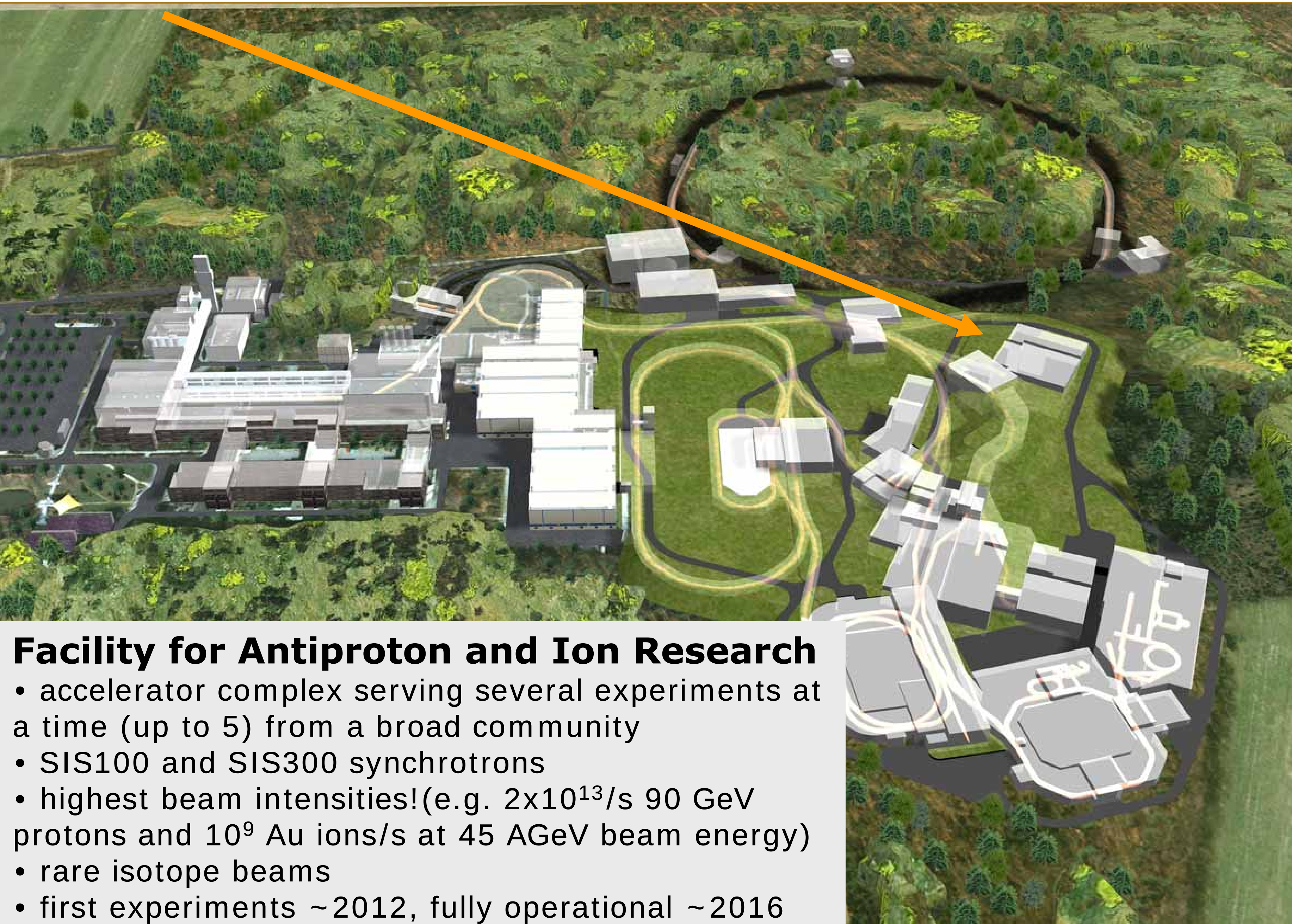
Outline

- Introduction of CBM
- The CBM detector:
  - for muon identification
  - for electron identification
- Track reconstruction
  - challenges
  - solution
  - results
- Speed up of the algorithms

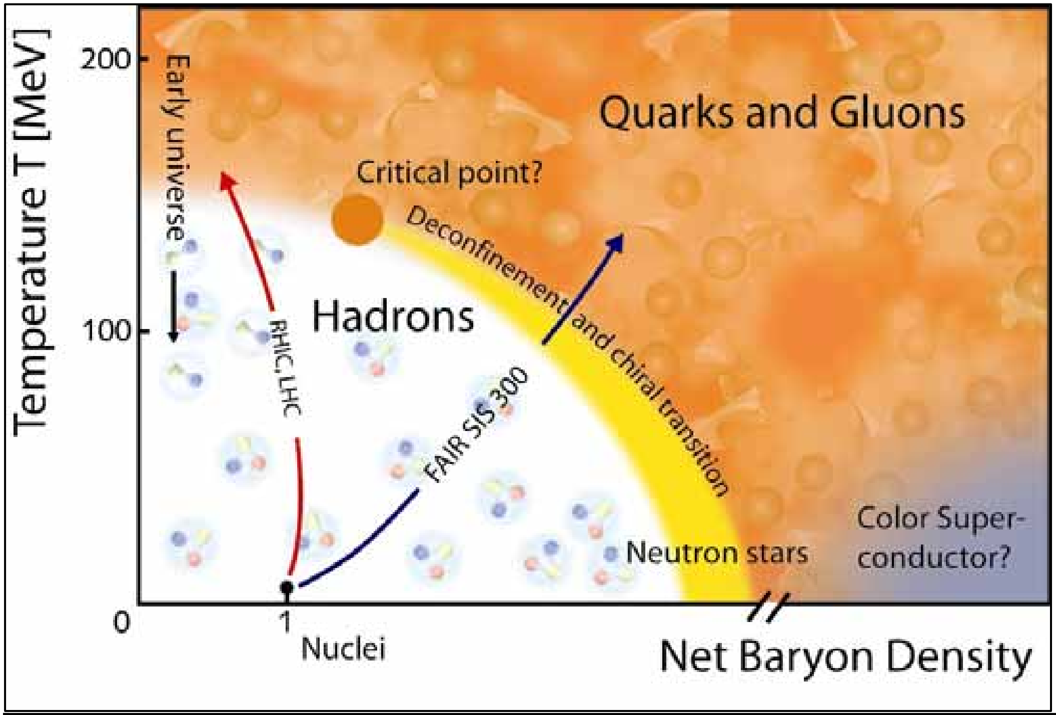
CBM at FAIR



Facility for Antiproton and Ion Research

- accelerator complex serving several experiments at a time (up to 5) from a broad community
- SIS100 and SIS300 synchrotrons
- highest beam intensities!(e.g. $2x10^{13}$/s 90 GeV protons and 10^9 Au ions/s at 45 AGeV beam energy)
- rare isotope beams
- first experiments ~2012, fully operational ~2016

CBM physics topics

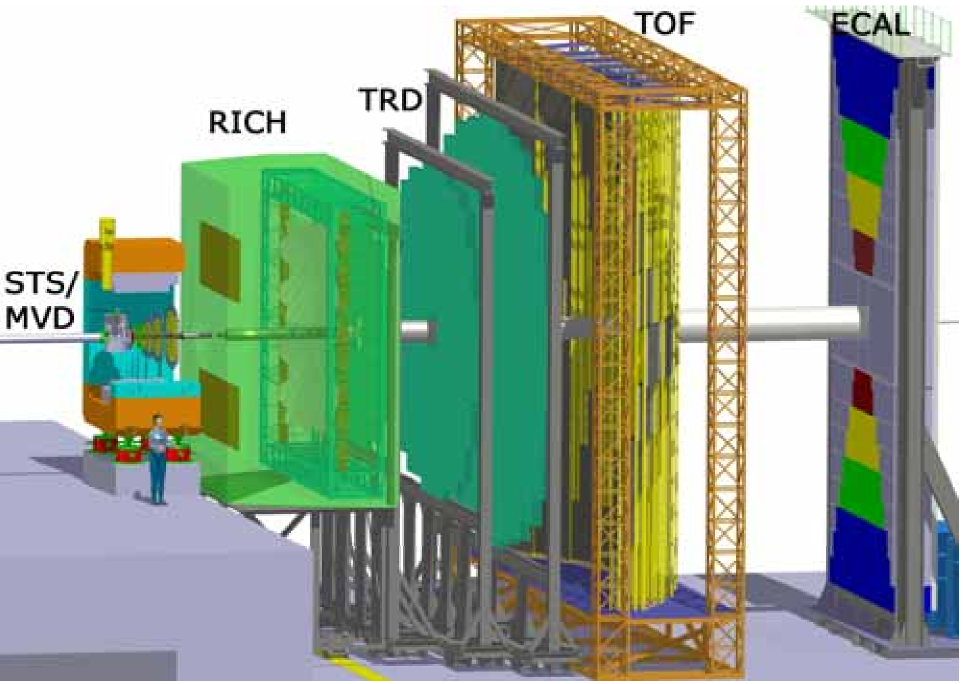


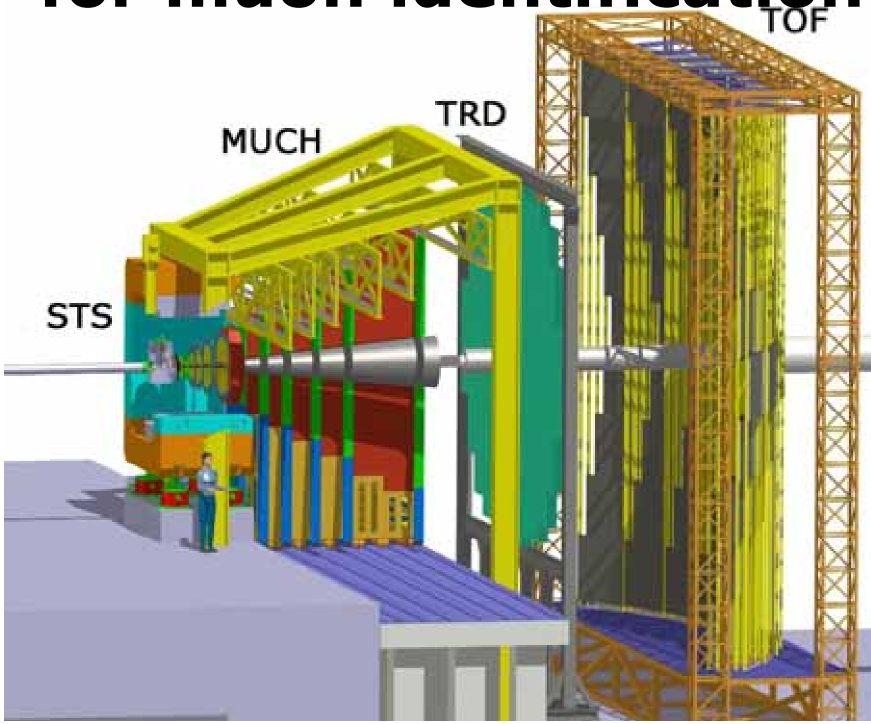
Exploration of the QCD phase diagram in regions of high baryon densities and moderate temperatures.

Physics Topics	**Observables**
In medium modifications of hadrons	ρ, ω, ϕ $\rightarrow$ $\mu^+\mu^-$ (e^+e^-) D^0, $D^\pm$, $D^\pm_s$, Λ_c
Deconfinement phase transition, **charm production at threshold**	K, Λ, Σ, Ξ, Ω D^0, $D^\pm$ $J/\Psi, \Psi'$ $\rightarrow$ μ^+ μ^- (e^+e^-)
Critical point	**Event by event fluctuations**

The CBM detector

for electron identification **for muon identification**





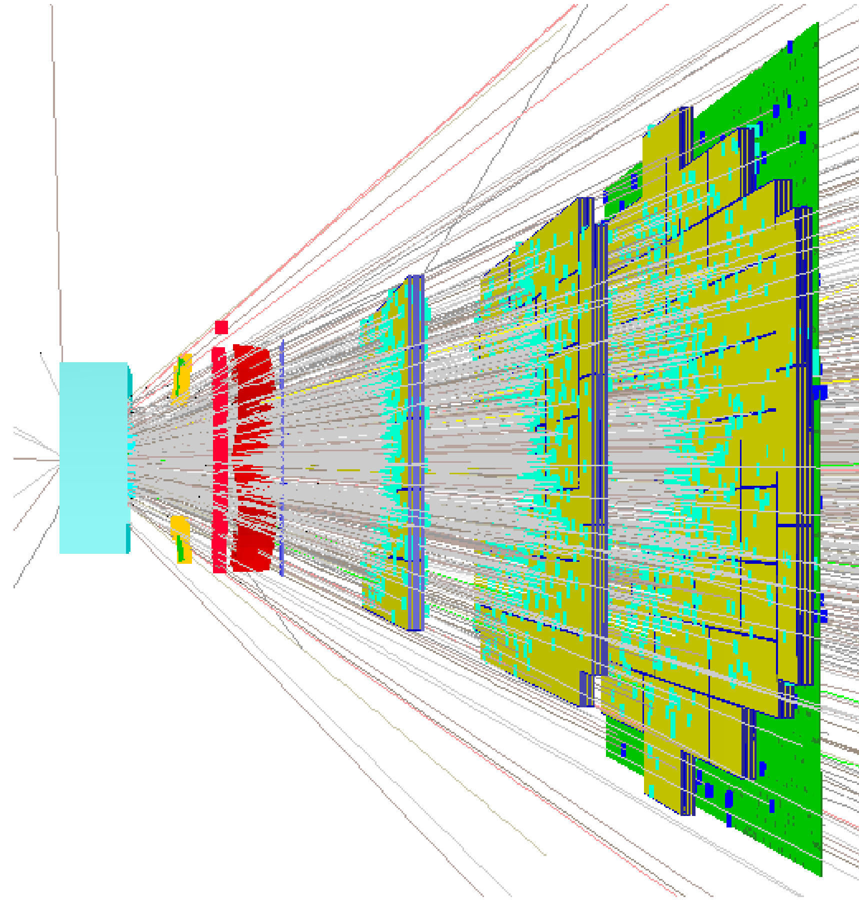
STS: track, vertex and momentum reconstruction
MVD: determination of secondary vertices
RICH: electron identification
MUCH: muon identification
TRD: global tracking and identification of electrons
TOF: time of flight measurement for hadron identification
ECAL: measurement of photons and neutral particles

Challenges for global tracking

- comprehensive measurement of hadron and lepton production in *pp, pA* and *AA* collisions from **8-45 AGeV** beam energy
- fixed target experiment

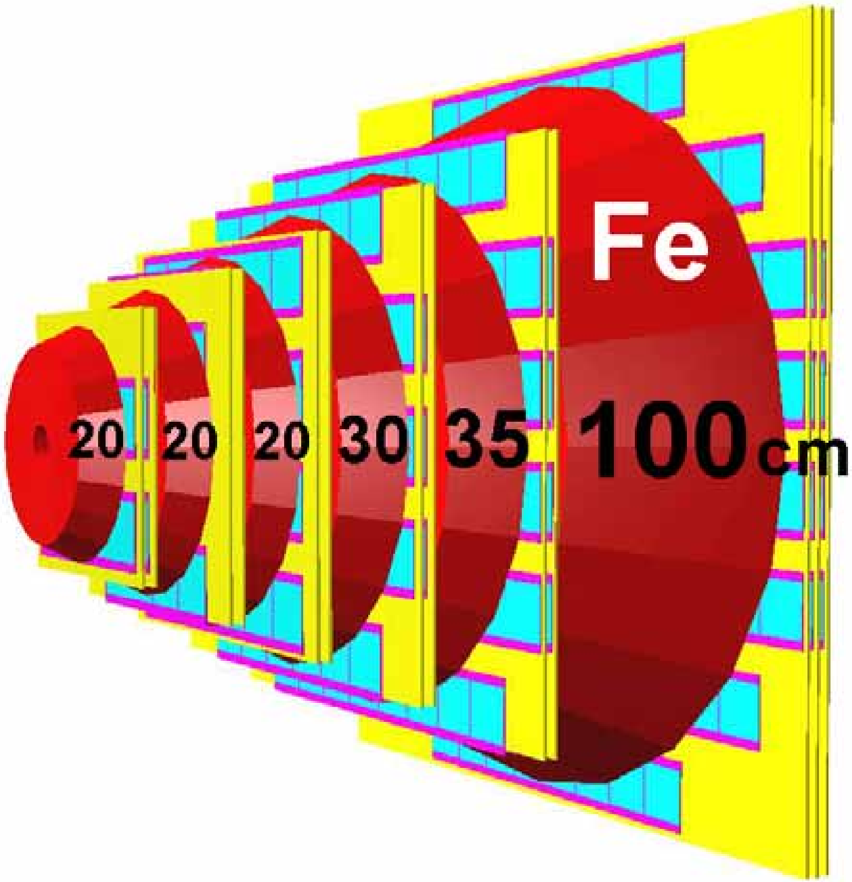
for CBM:

- up to **800** charged particles per reaction
- signal particles very rare (<J/psi> ~ 10^{-6}, branching ratio of low-mass vector mesons ~ 10^{-5})
- complex detector structure, overlapping sensors, dead zones in the detector
- large material budget



Central Au+Au collision at 25 *A*GeV (UrQMD + GEANT3)

The Muon detector (MUCH)



Choose alternating detector-absorber layout for continuos tracking of the muons through the absorber

Measurements of:

Low mass vector mesons
5 Fe absorbers (125 cm)
7.5 λ_I, p> 1.5 GeV/c

Charmonium
6 Fe absorbers (225 cm)
13.5 λ_I, p> 2.8 GeV/c

2(3) detector stations between the absorbers

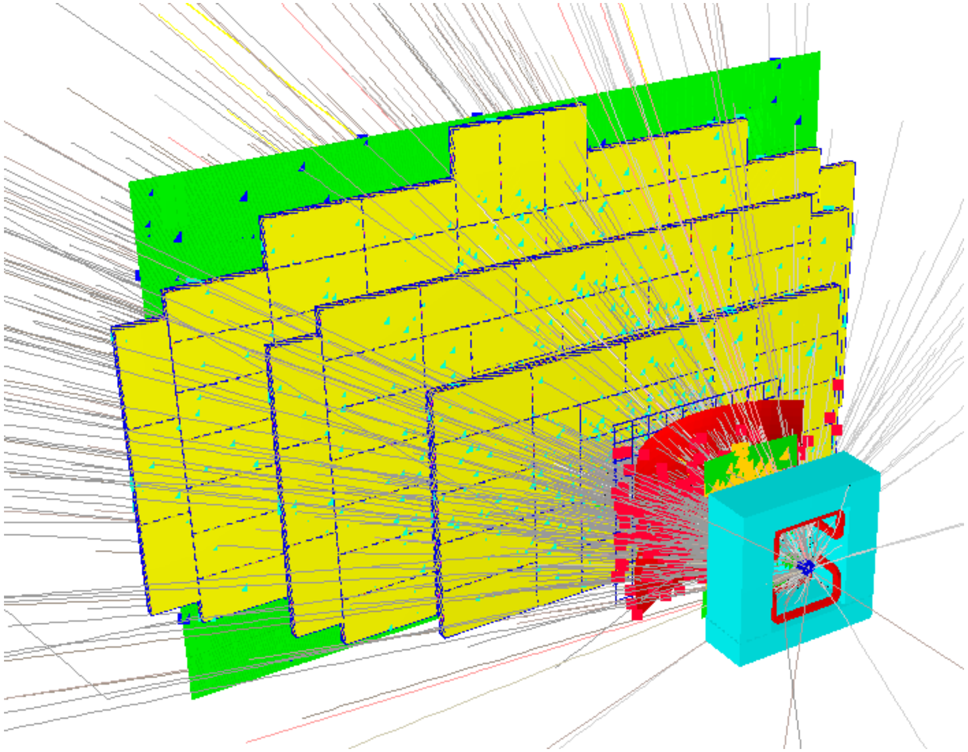
Detector challenges:

- High hit density (up to 1 hit per cm^2 per event)
- High event rates (10^7 events/s)
- Position resolution < 300 µm

→ use pad readout (e.g. GEMs), minimum pad size 1.4x2.8 mm^2.

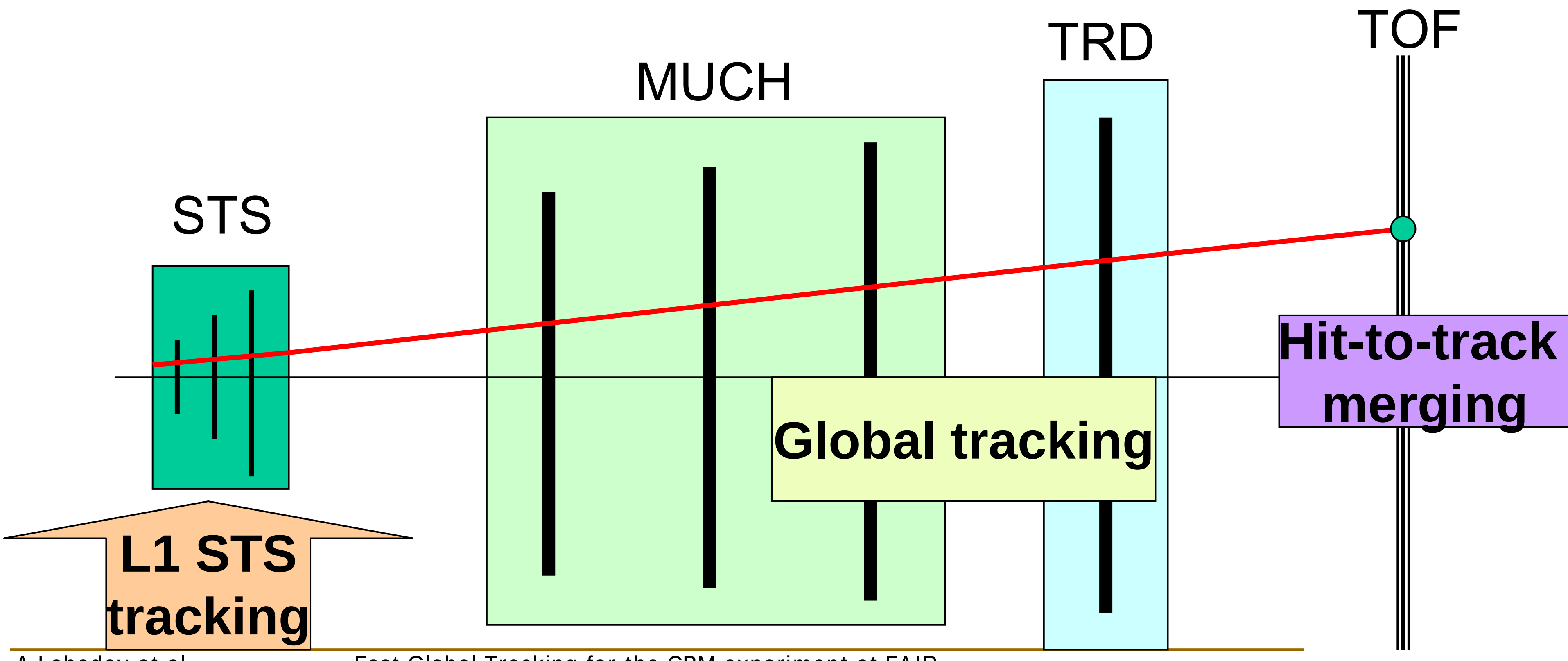
The TRD

- Tracking and electron identification via energy losses
- **12** identical layers grouped in **3** stations
- Layer=radiator+MWPC readout
- Stations: 5m, 7m, 9m
- Pad size: **0.03cm-0.05cm** across the pad and **0.27cm-3.3cm** along the pad



Global tracking

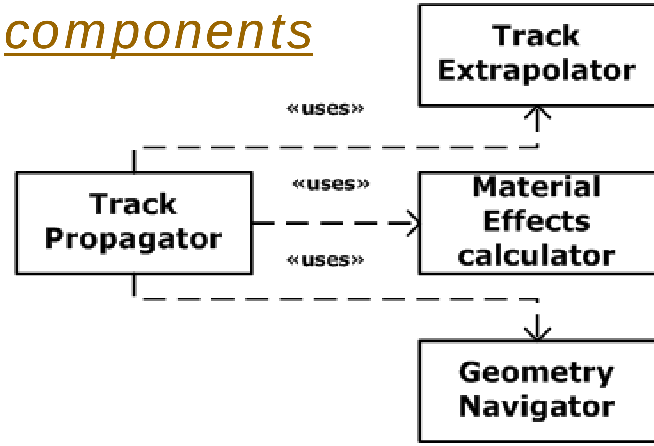
- STS tracking → Fast Cellular Automaton algorithm (see talk by I.Kisel)
- Global Tracking + TOF hit to track merging

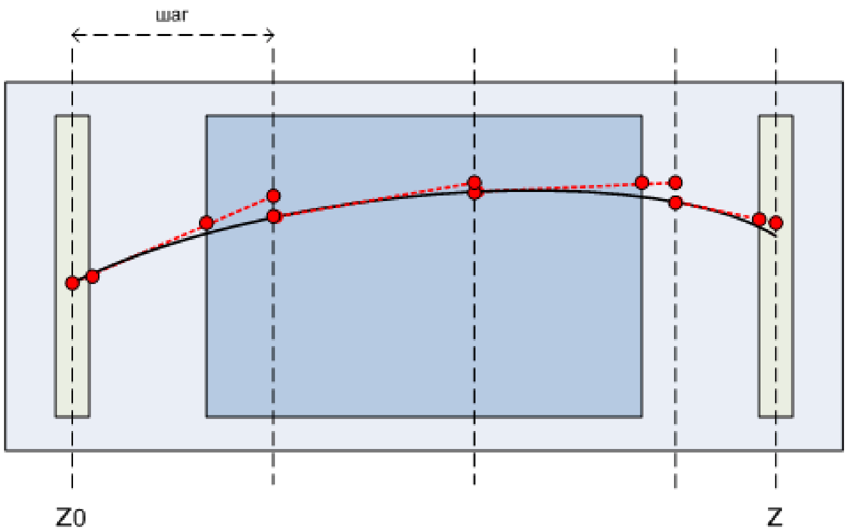


Track propagation

- ***Extrapolation.*** Two models:
  - Straight line in case of absence of magnetic field.
  - Solution of the equation of motion in a magnetic field with the 4th order Runge-Kutta method, with a parallel integration of the derivatives.
- ***Material Effects.***
  - *Energy loss* (ionization: Bethe-Bloch, bremsstrahlung: Bethe-Heitler, pair production)
  - *Multiple scattering* (Gaussian approximation)
- ***Navigation.***
  - Based on the *ROOT TGeoManager*.

Track propagation components





The Algorithm:

Trajectory is divided into steps. For each step:

Straight line approximation for finding intersections with different materials (geometry navigator)

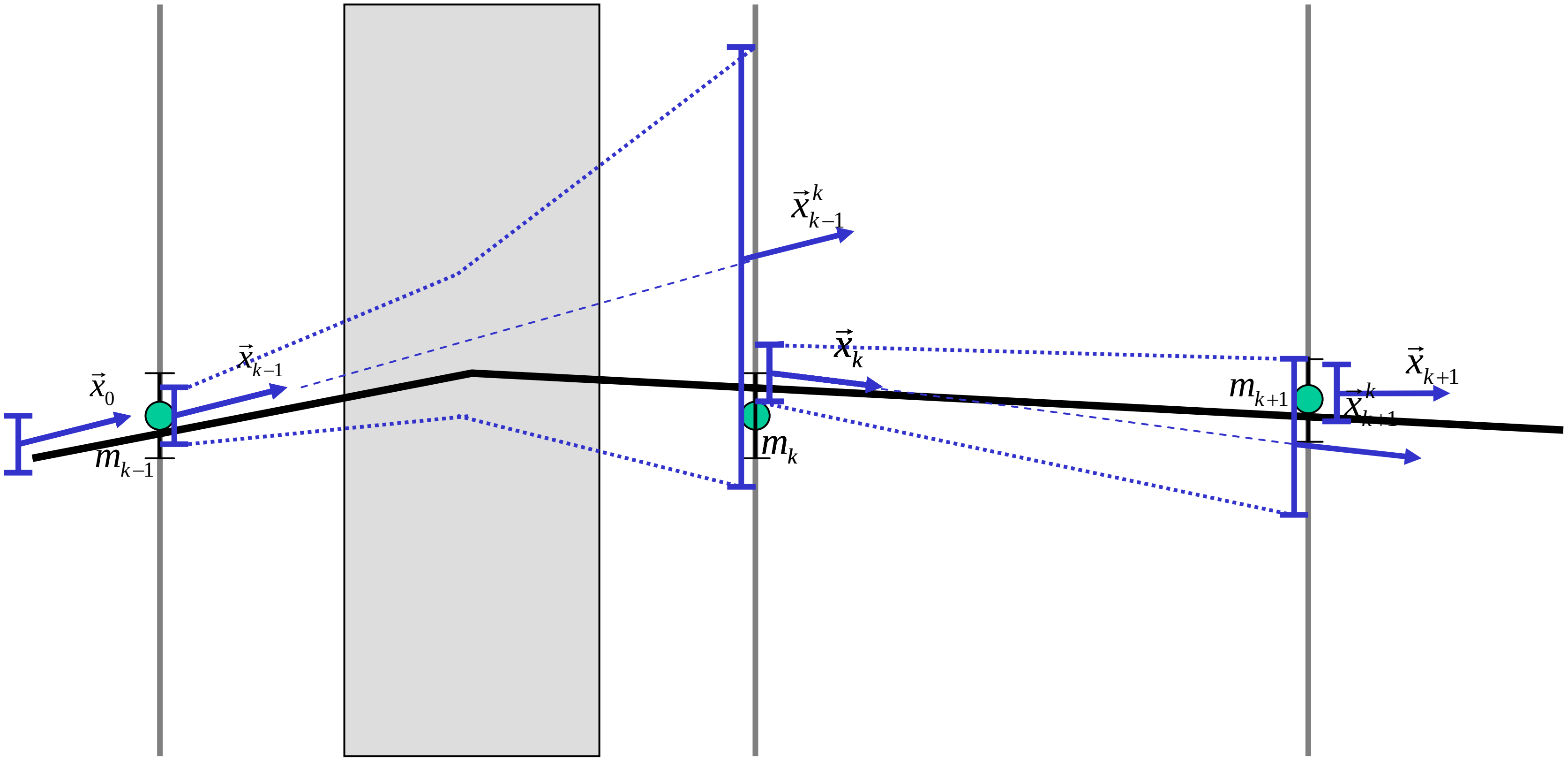
Geometrical extrapolation of the trajectory

Material effects are added at each intersection point

Algorithm of Global Tracking

- Initial seeds are tracks reconstructed in STS (L1 tracking)
- Tracking is based on
  - Track following
  - Kalman Filter (KF)
  - Validation gate
  - Different hit-to-track association techniques
- Two main steps:
  - Tracking
  - Global track selection

Track following and KF



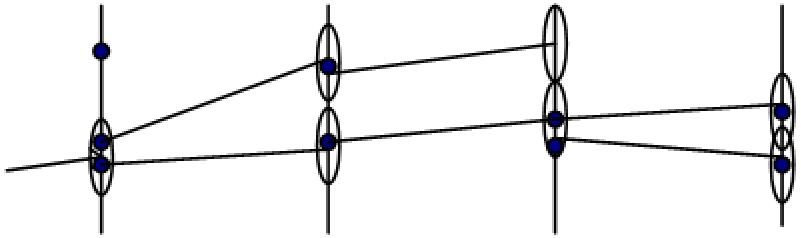
Validation gate

- Rejection of improbable hit-to-track pairings: select true hits with high degree of confidence
- Validation gate at station *k*: $v_k = r_k R^{-1} r_k^T < d$
  - d is the threshhold for rejecting the correct hit with a certain probability (depends on number of degrees of freedom, take from Chi2-tables)

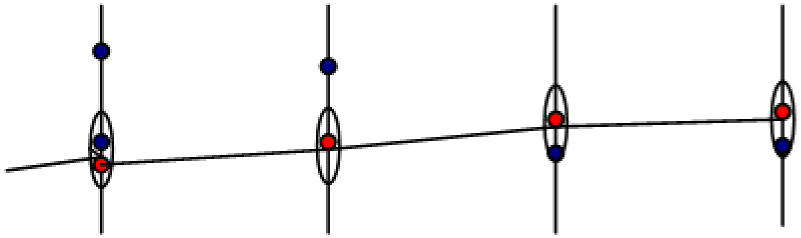
Degrees of Freedom	Probability										
	0.95	0.90	0.80	0.70	0.50	0.30	0.20	0.10	0.05	0.01	0.001
1	0.004	0.02	0.06	0.15	0.46	1.07	1.64	2.71	3.84	[illegible]	
2	0.10	0.21	0.45	0.71	1.39	2.41	3.22	4.60	5.99	[illegible]	10.83
3	0.35	0.58	1.01	1.42	2.37	3.66	4.64	6.25	7.82	[illegible]	13.82
4	0.71	1.06	1.65	2.20	3.36	4.88	5.99	7.78	9.49	13.28	18.47
5	1.14	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	15.09	20.52
6	1.63	2.20	3.07	3.83	5.35	7.23	8.56	10.64	12.59	16.81	22.46
7	2.17	2.83	3.82	4.67	6.35	8.38	9.80	12.02	14.07	18.48	24.32
8	2.73	3.49	4.59	5.53	7.34	9.52	11.03	13.36	15.51	20.09	26.12
9	3.32	4.17	5.38	6.39	8.34	10.66	12.24	14.68	16.92	21.67	27.88
10	3.94	4.86	6.18	7.27	9.34	11.78	13.44	15.99	18.31	23.21	29.59
	Nonsignificant								Significant		

Different hit-to-track assignment

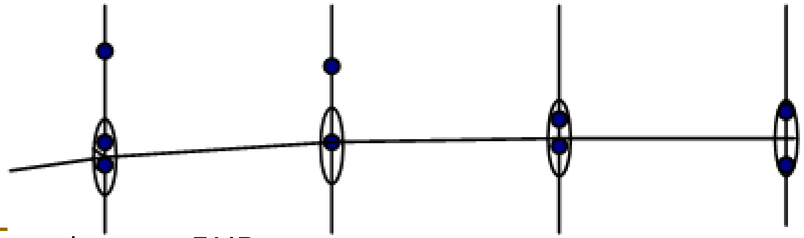
- Branching
  - Branch is created for each hit in the *validation gate*.



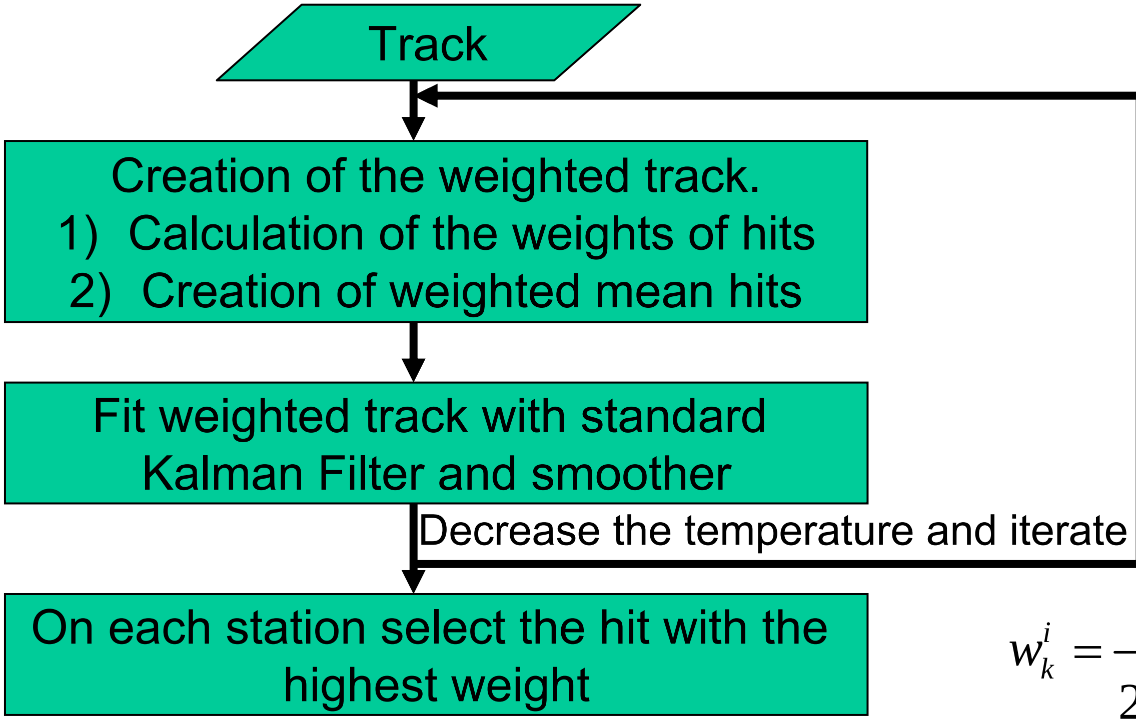
- Nearest Neighbor
  - The closest by a Euclidean *statistical distance* hit from a *validation gate* is assigned to track.



- Weighting
  - No track splitting, it collects all the hits in the *validation gate*.



Iterative hit selection and track fit



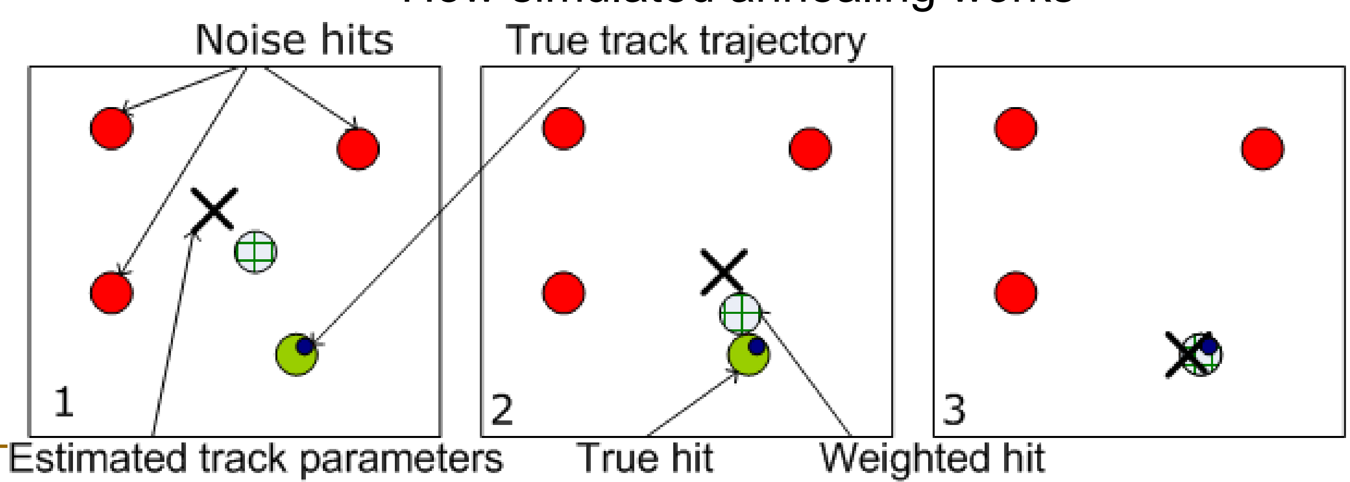
Weight function:

-For the 1st iteration weights are the same

-Starting from the 2nd iteration, weights are proportional to the *multivariate Gaussian distribution* and include temperature parameter T

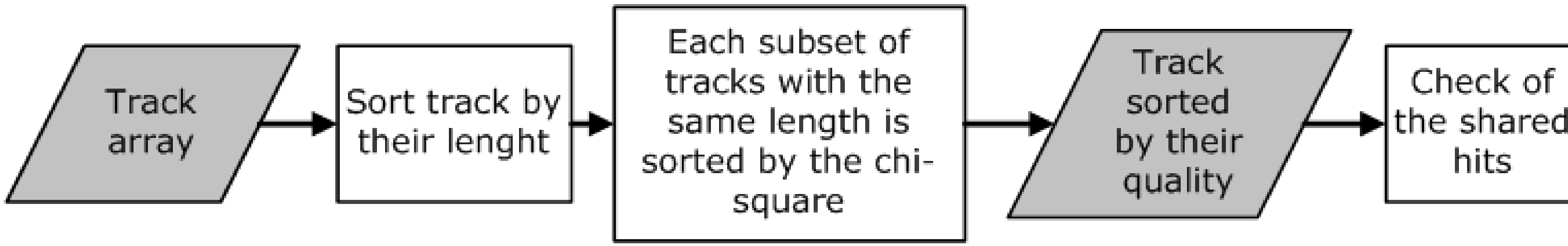
$$w_k^i = \frac{1}{2\pi * T \left|V_k^i\right|^{1/2}} \exp\left(-\frac{1}{2T} r_k^i (R_k^i)^{-1} (r_k^i)^T \right)$$

How simulated annealing works



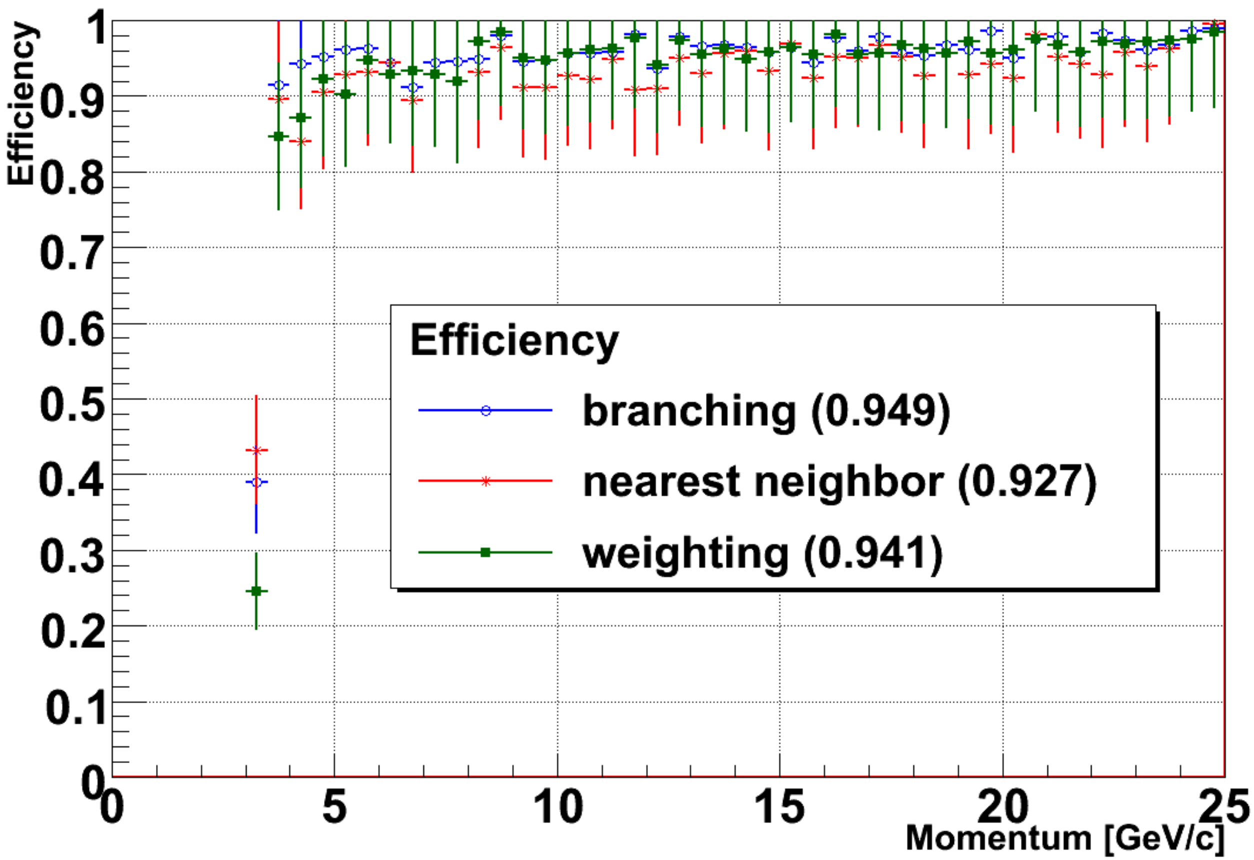
Track selection

– aim: remove clone and ghost tracks
– Tracks are sorted by their quality, obtained by chi-square and track length



– Check for shared hits
  - loop over tracks list which is sorted by quality
  - collect used hits
  - check for each new track the number of shared hits: if too many – reject track

Comparison of tracking methods



CBM setup for

muon

reconstruction

Events

1000 UrQMD at 25 AGeV + 10 mu in each event

Speed up [1]: number of branches

- **Motivation**: The main problem with branching algorithm is that its ***computational and memory*** requirements can grow with time and saturate computing system.
- **Solution**: Only a limited number of the nearest hits in the validation gate can start a new branch.

Maximum number of hits in the validation gate	30	20	15	10	7	5	4	3	2	1
Tracking efficiency, %	93.1	93.1	93.1	93.1	93.1	93.1	93.1	92.9	92.9	91.8
Time, s/event	1.9[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.52	0.44	0.34	0.20

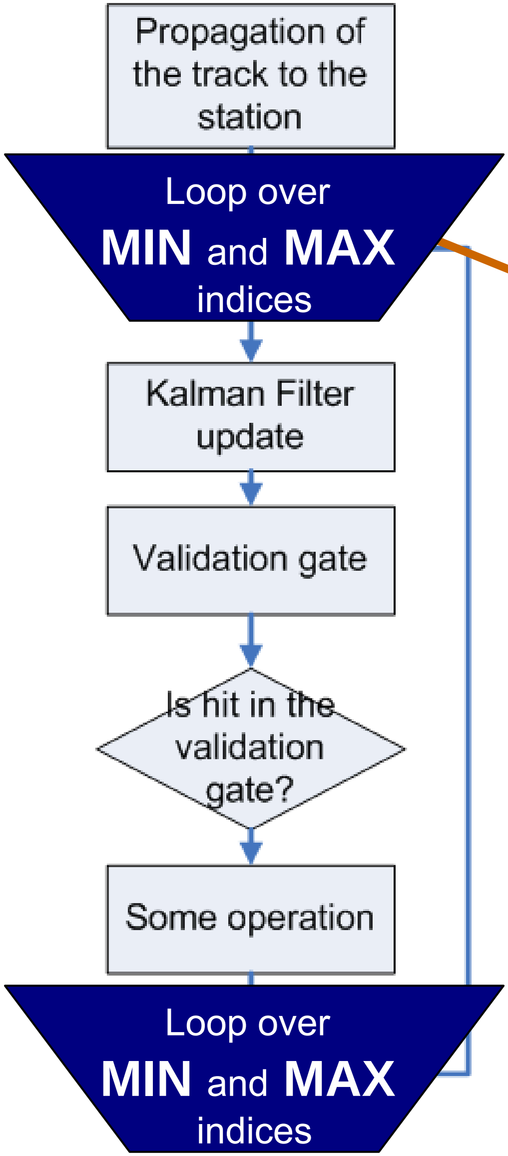
4 times faster!

MUCH tracking, UrQMD 25 AGeV Au-Au + 10 muons

CPU: Intel C2D P8400

Speed up [2]: fast search of hits

Motivation



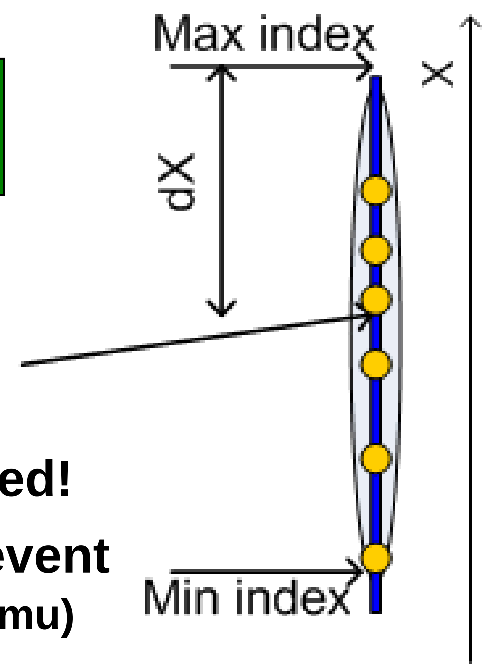
-Hits are sorted by x position

-Binary search is used to find Min and Max index

$$dX = k\sqrt{\sigma_{\mathrm{cov}}^2 + \sigma_{pos}^2}$$

σ_{pos} Maximum measurement error on the station

Fast search of hits



2 times increase in speed!

1.05 s/event -> 0.52 s/event

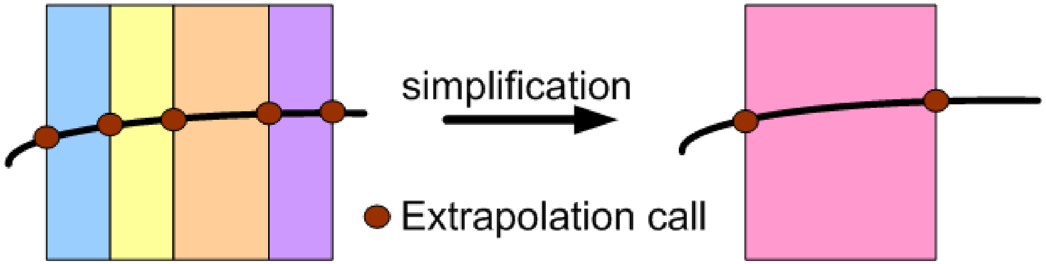
(MUCH tracking, UrQMD+10mu)

CPU: Intel C2D P8400

Speed up [3]: simple geometry

- MC geometry
  - Very detailed (800k nodes)
  - Navigation is based on the ROOT TGeo
- Simplified geometry
  - There is no need for detailed geometry for tracking purposes
  - Stations and passive materials are approximated as planes perpendicular to beam pipe
    - Reduction of number of nodes from 800k to 100
  - Navigation in such geometry is much more simple

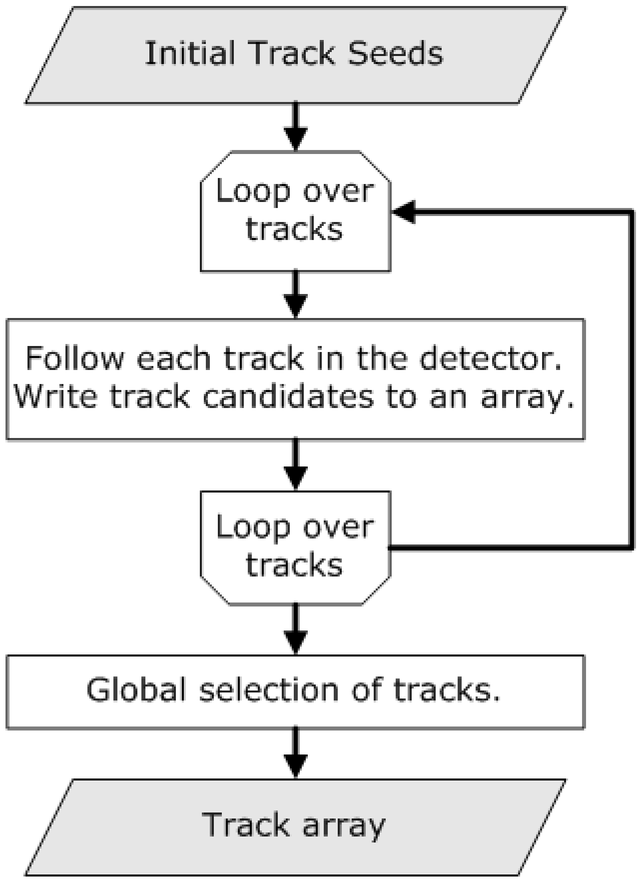
	Efficiency [%] / time [sec/event]		
	ROOT TGeo	Simplified	Speed up factor
Branching	**94.9 / 0.88**	**94.0 / 0.20**	**4.4**
NN	**92.6 / 0.20**	**92.2 / 0.06**	**3.3**
Weighting	**94.0 / 0.31**	**92.6 / 0.11**	**2.8**



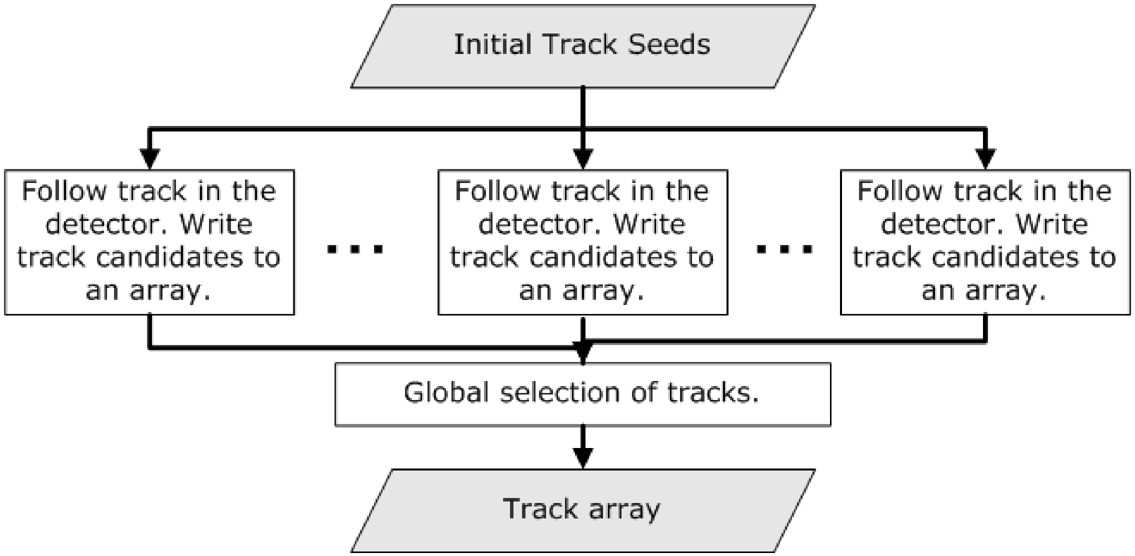
CPU: Intel C2D P8400

Multithreading for track following

Serial



Parallel



Library: *Intel Threading Building Blocks*

CPU: Intel C2D P8400 with **2 cores**

serial and parallel nearest neighbor method:

Serial: **0.06** sec/event

Parallel: **0.04** sec/event

Speed up factor: 1.59

Summary & Outlook

- Succesfully demonstrated that developed global tracking approaches are feasible with current CBM layout in a high track density
- First results of speed up show 20 times speed up factor

→ continue speed up optimization of the algorithm (SIMD, multithreading, magnetic field access...)

→ use established tracking routines for layout optimization