Reconstruction of short-lived particles in CBM

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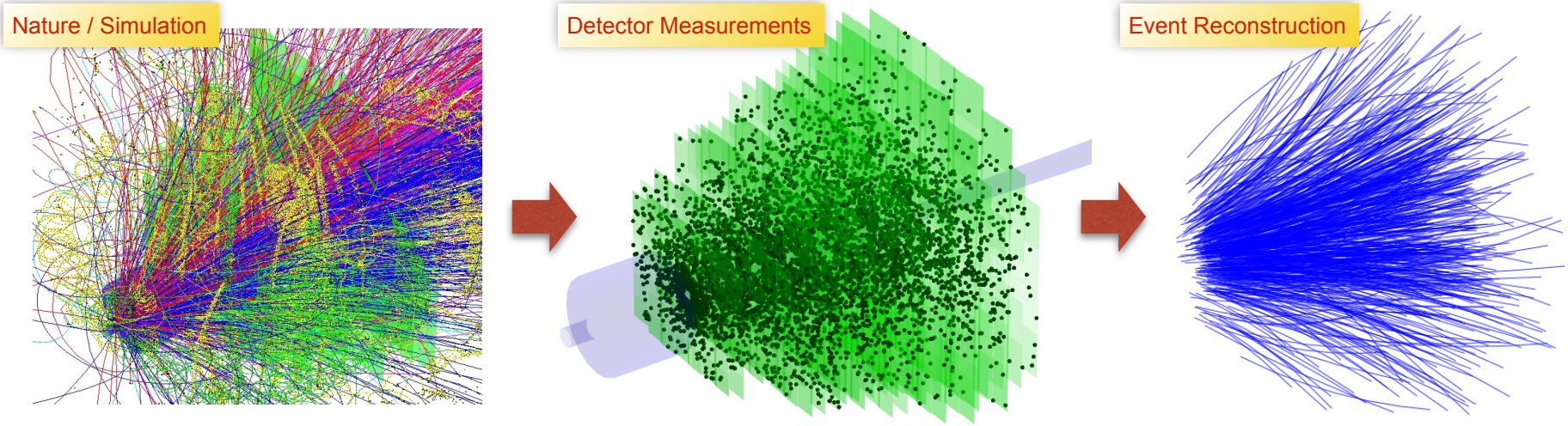
for the CBM Collaboration

Reconstruction Challenge in CBM at FAIR/GSI

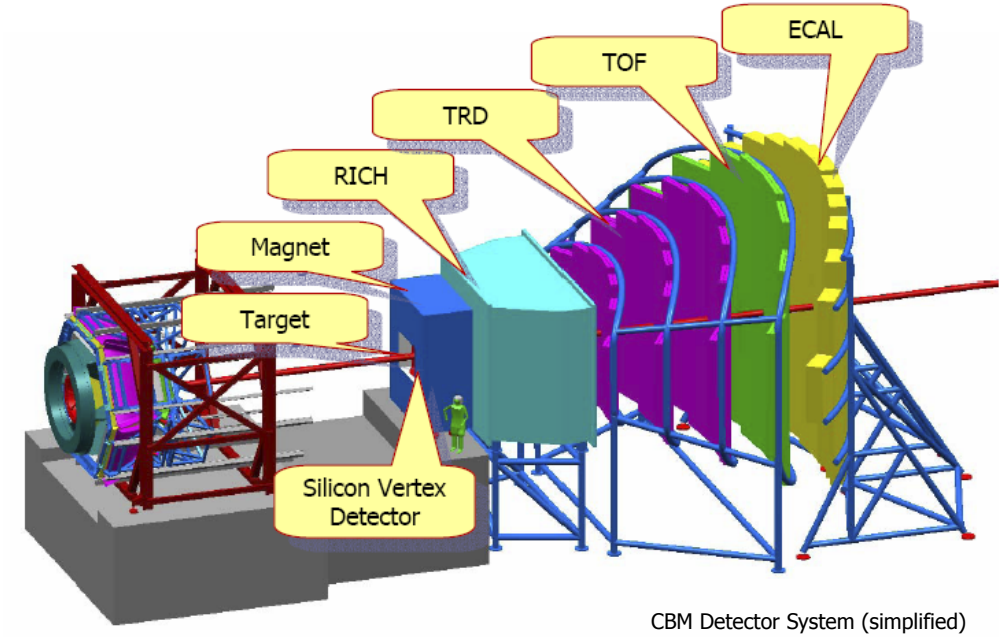


- Future fixed-target heavy-ion experiment
- 10^7 Au+Au collisions/sec
- ~ 1000 charged particles/collision
- Non-homogeneous magnetic field
- Double-sided strip detectors (85% fake space-points)

Full event reconstruction will be done
on-line at the First-Level Event Selection (FLES) and
off-line using the same FLES reconstruction package.

Cellular Automaton (CA) Track Finder
Kalman Filter (KF) Track Fitter
KF short-lived Particle Finder

All reconstruction algorithms are vectorized and parallelized.

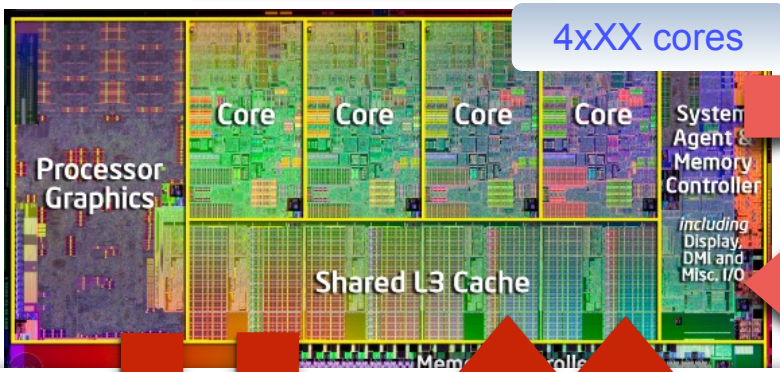


CBM Detector System (simplified)

Many-Core CPU/GPU Architectures

Intel/AMD CPU

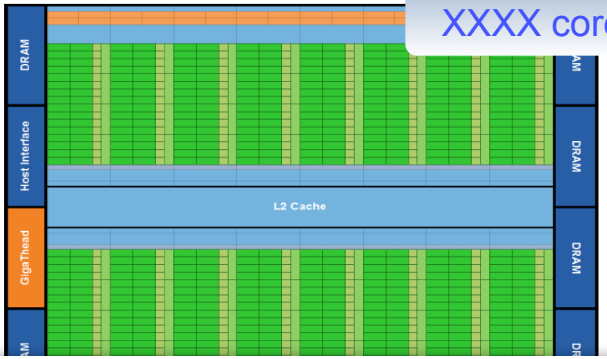
4xXX cores



- Optimiz… or lo…tency access…ache…ata sets
- Control …c for …-of-order and …cula…execution

Nvidia/ATI GPU

XXXX cores



…ptimized for data-parallel, throughput computation
…lore transistors dedicated to computation

Math

Memory

Parallelism

Math

Memory

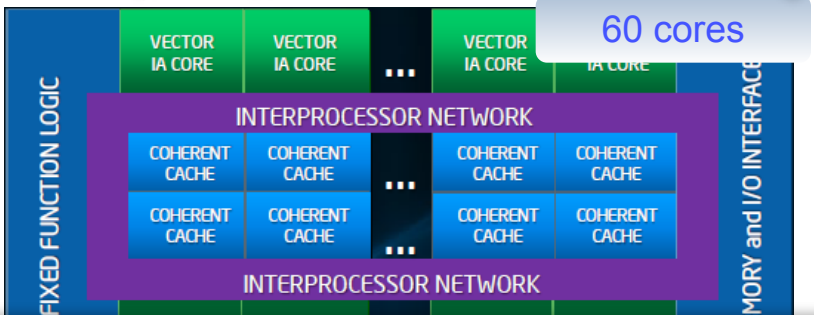
#Cores

Stability

Memory

Intel Phi

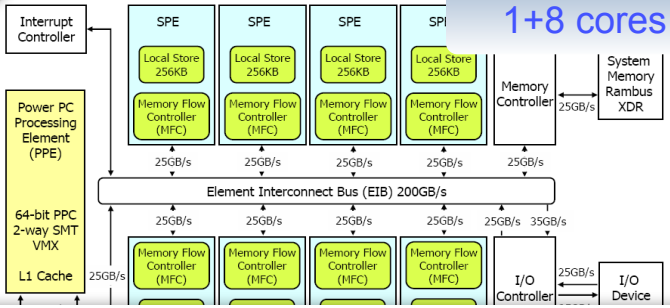
60 cores



- Many Integrated Cores architecture announced at ISC10 (June 2010)
- Based on the x86 architecture
- Many-cores + 4-way multithreaded + 512-bit wide vector unit

IBM Cell

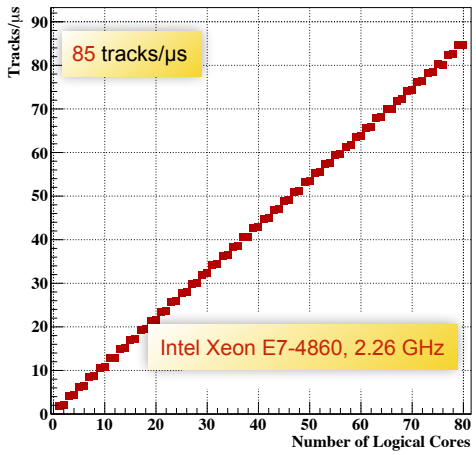
1+8 cores

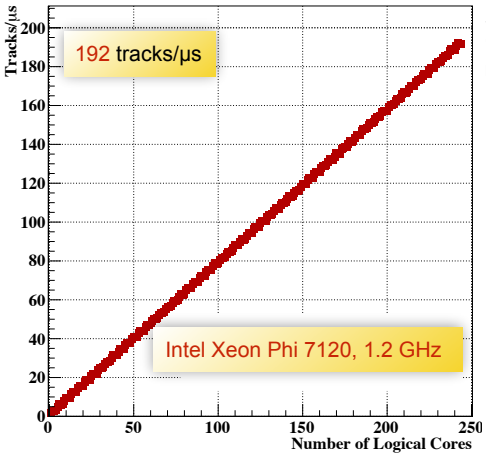


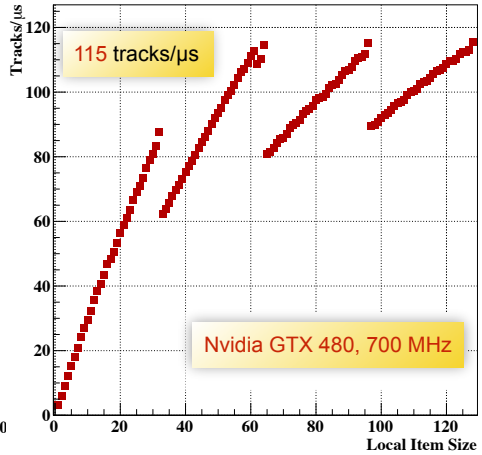
- General purpose RISC processor (PowerPC)
- 8 co-processors (SPE, Synergistic Processor Elements)
- 128-bit wide SIMD units

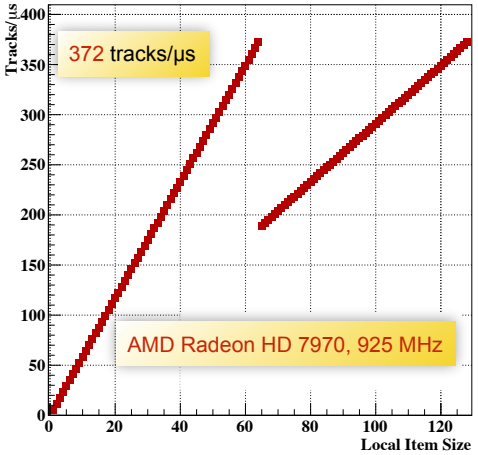
Future systems are heterogeneous, but using the same code

HPC Example: Kalman Filter (KF) Track Fit Library

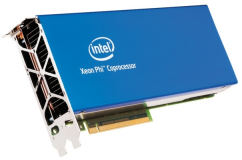








$8.5*10^7$ tracks/s



$19.2*10^7$ tracks/s

$11.5*10^7$ tracks/s

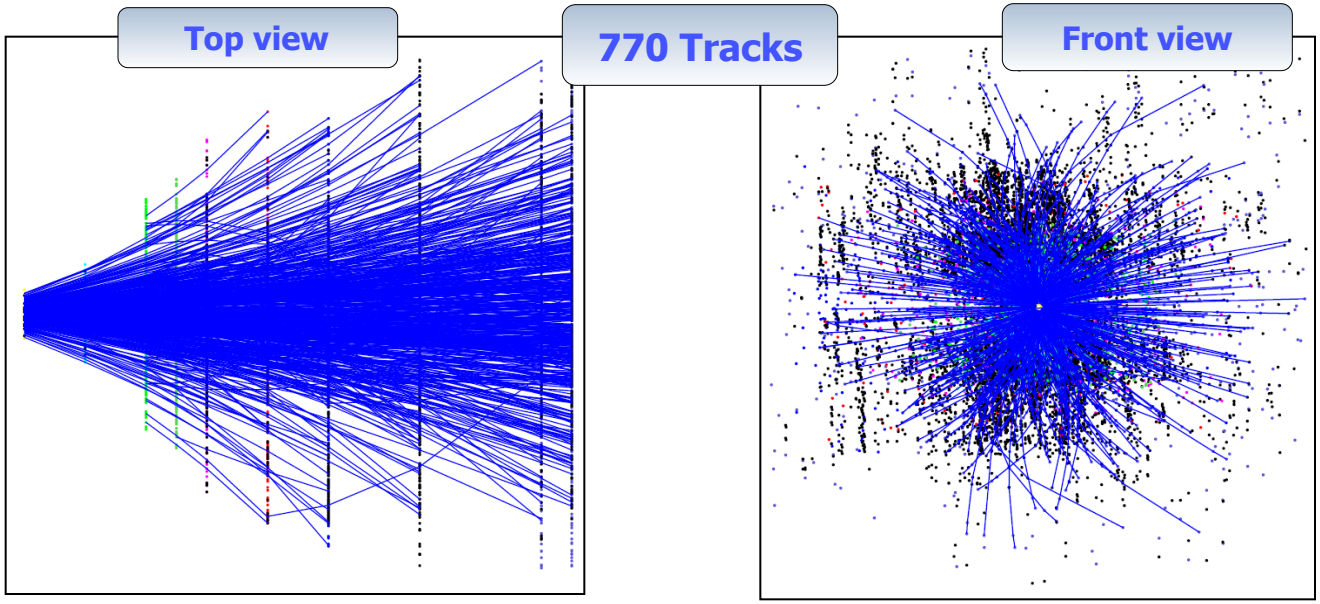
$37.2*10^7$ tracks/s

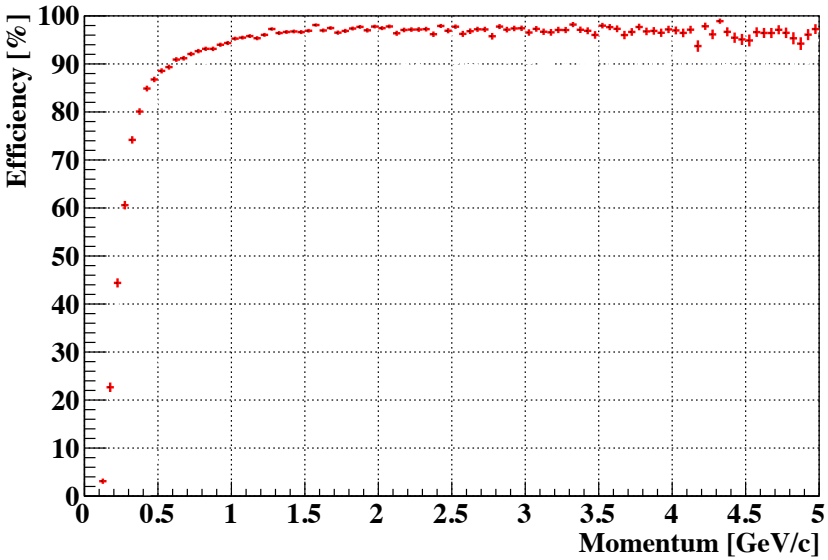
2 compute nodes with 2 AMD cards each = $2*(8+37+37)*10^7 = 164*10^7$ tracks/s = 10^7 events/s

- Scalability with respect to the number of logical cores in a CPU is one of the most important parameters of the algorithm.
- The scalability on the Intel Xeon Phi coprocessor is similar to the CPU, but running four threads per core instead of two.
- In case of the graphic cards the set of tasks is divided into working groups of size *local item size* and distributed among compute units (or streaming multiprocessors) and the load of each compute unit is of the particular importance.

Full portability of the Kalman filter library

Cellular Automaton (CA) Track Finder: Efficiency

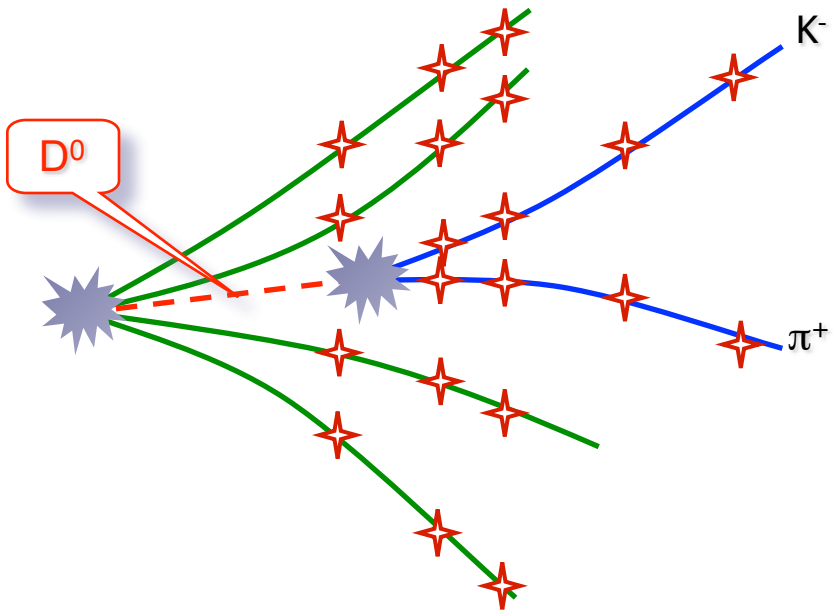




Track category	Eff, %
All tracks	90.9
Primary high-p	97.5
Primary low-p	92.6
Secondary high-p	91.1
Secondary low-p	63.8
Clone level	0.4
Ghost level	5.9
MC tracks found	134
Time, ms/ev	10

Efficient and stable event reconstruction

KF Particle: Reconstruction of Vertices and Decayed Particles



State vector

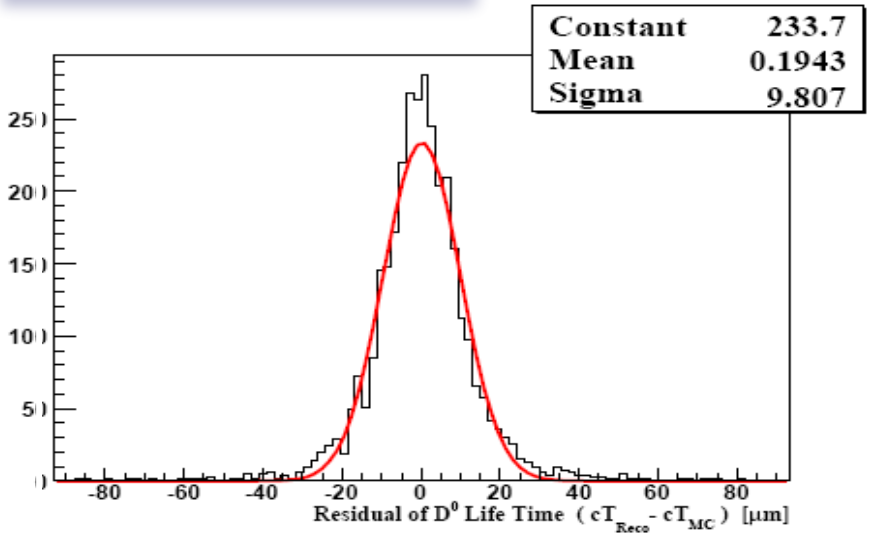
Position, direction, momentum and energy

$$r = \{ x, y, z, p_x, p_y, p_z, E \}$$

- Mother and daughter particles have the same state vector and are treated in the same way
- Geometry independent
- Kalman filter based

```
KFParticle K( track1, -321 ), pi( track2, 211 ); // Set daughters
KFParticle  D0( K, pi );                         // Construct mother
PrimVtx += D0;                                   // Improve primary vertex
D0.SetProductionVertex( PrimVtx );               // D0 is fully fitted
K.SetProductionVertex( D0 );                     // K is fully fitted
pi.SetProductionVertex( D0 );                    // pi is fully fitted
```

$x, y, z, p_x, p_y, p_z, E, m, L, c\tau$

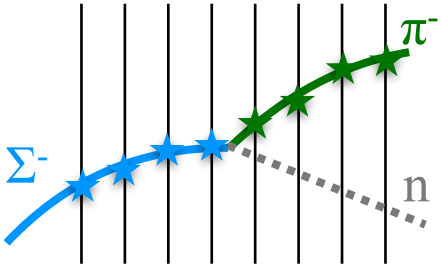


KFParticle provides uncomplicated approach to physics analysis (used in CBM, ALICE and STAR)

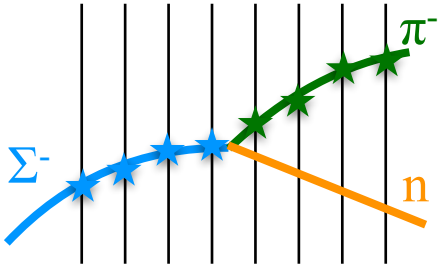
Missing Mass Method

- Σ^+ and Σ^- have only channels with at least one neutral daughter.
- A lifetime is sufficient to be registered by the tracking system: $c\tau$ = 2.4 cm for Σ^+ and $c\tau$ = 4.4 cm for Σ^-.
- Can not to be identified by the PID detectors.
- Identification is possible by the decay topology:

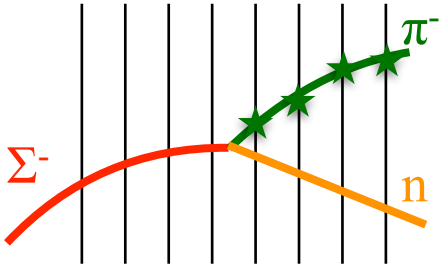
1. Find tracks of Σ and its charged daughter in STS and MVD

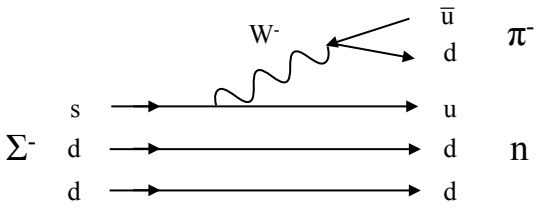


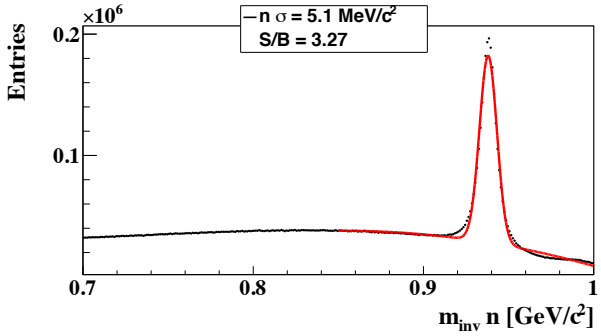
2. Reconstruct a neutral daughter from the mother and the charged daughter

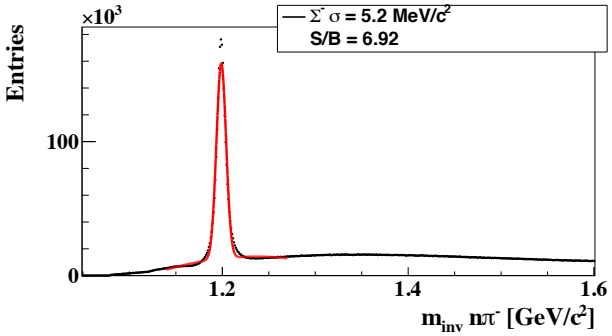


3. Reconstruct Σ mass spectrum from the charged and obtained neutral daughters

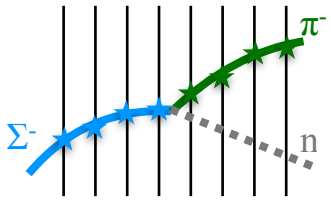








KF Particle Finder Algorithm

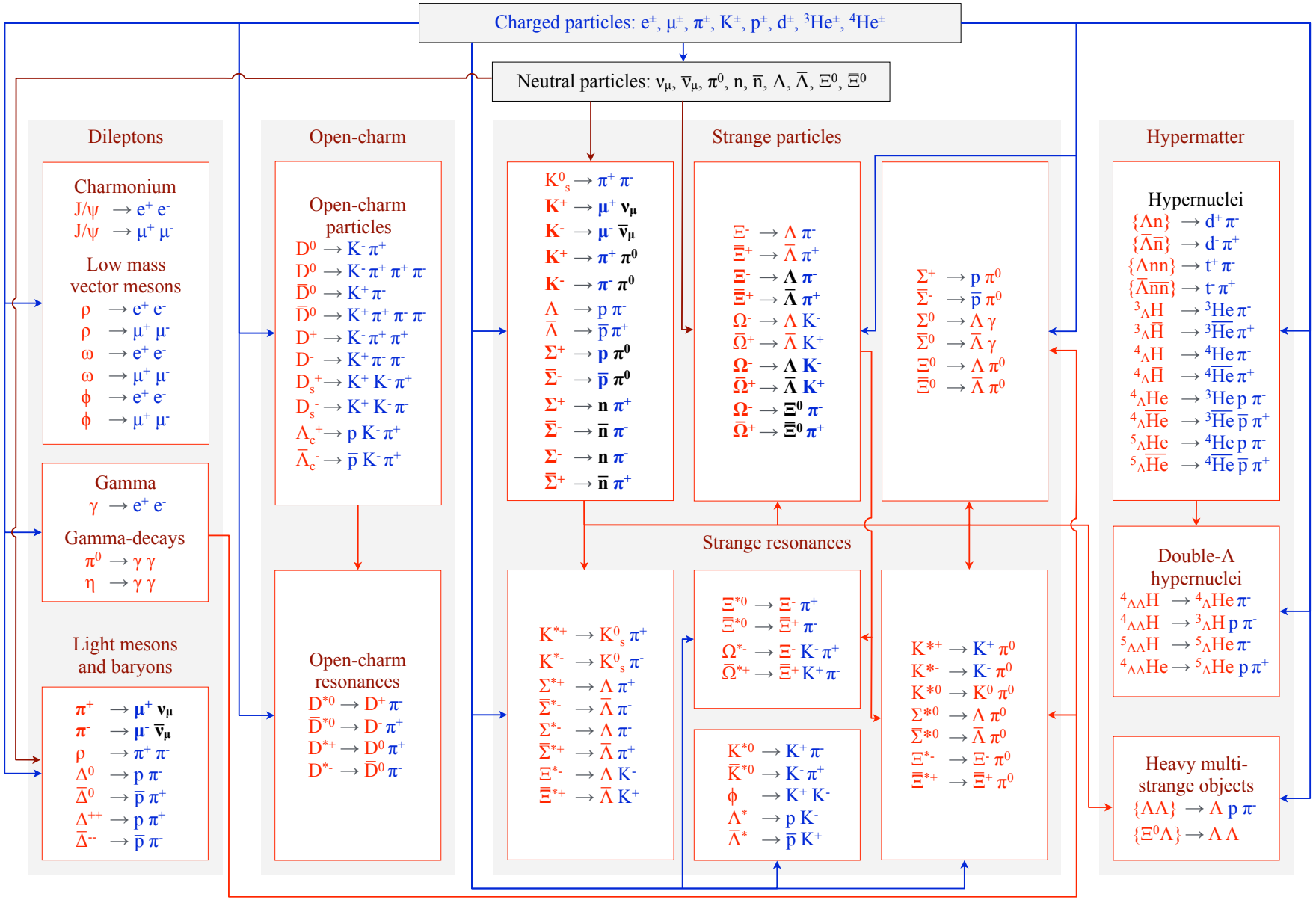


Selection criteria:
χ^2_{fit} – χ^2 given by a track fit
χ^2_{prim} – χ^2 distance to a primary vertex (PV)
χ^2_{geo} – χ^2 given by a particle fit
χ^2_{topo} – χ^2 of a particle fitted to PV

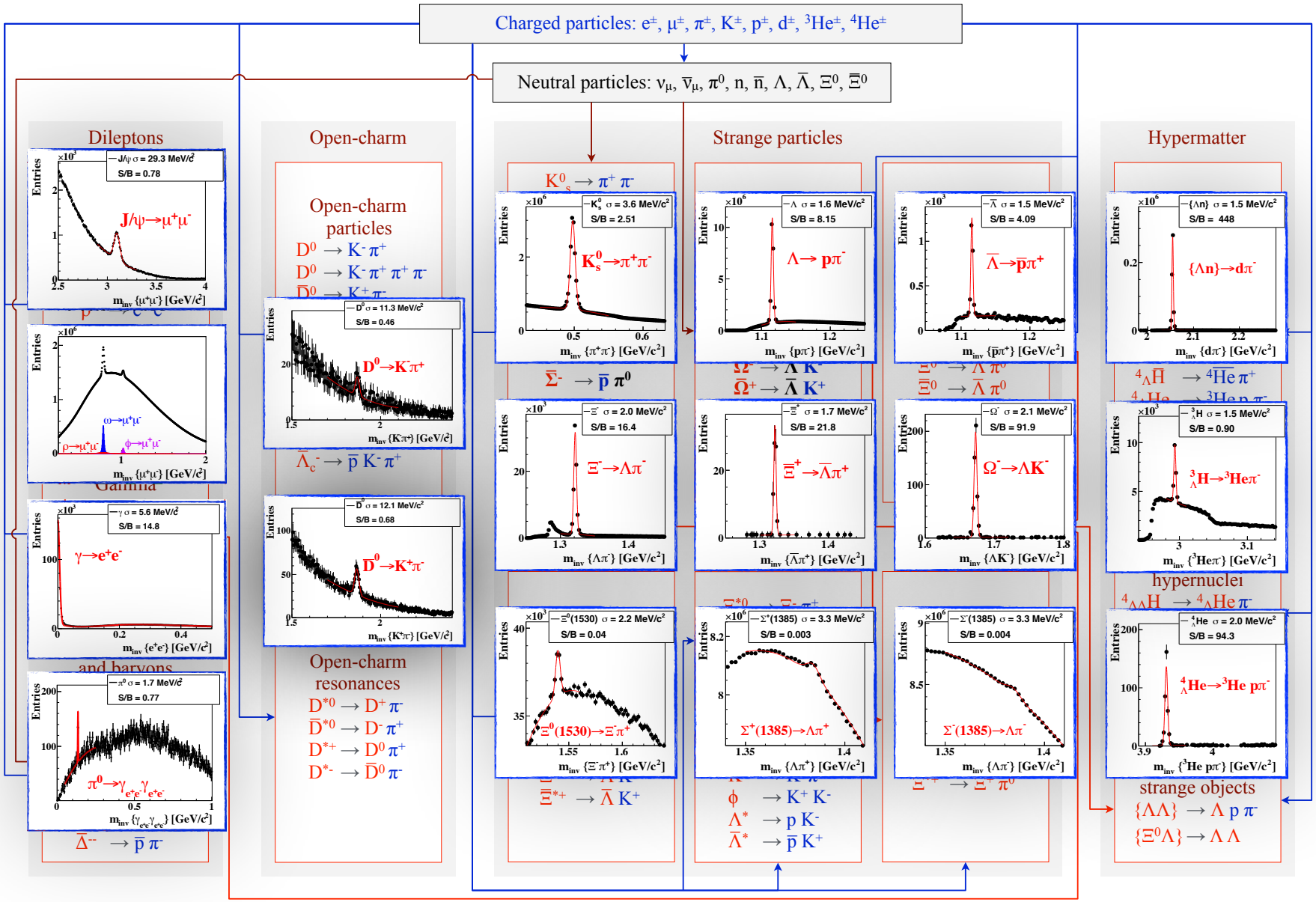
Tracks
χ^2_{fit}
Selected tracks
χ^2_{prim}
Secondary tracks
Primary tracks
Secondary neutrals
n, π^0, Λ, Ξ^0, ν_μ
Kink
Store
$\Sigma^{+/-}$, $\Xi^{+/-}$, $\Omega^{+/-}$, $K^{+/-}$, $\pi^{+/-}$
K^0_s, Λ and $\bar{\Lambda}$ candidates
χ^2_{geo}
Selected K^0_s, Λ and $\bar{\Lambda}$
Store
Selected K^0_s, Λ and $\bar{\Lambda}$
χ^2_{topo}, z_{vertex}
Secondary Λ and $\bar{\Lambda}$
Primary K^0_s, Λ and $\bar{\Lambda}$
checking mass
Ξ^-, Ξ^+, Ω^- and Ω^+ candidates
H-dibaryon candidates
Σ^{*+}, $\bar{\Sigma}^{*+}$, Σ^{*-} and Σ^{*-}, $\bar{K}^{*0}$, K^{*0}, $\bar{K}^{*-}$ and K^{*+} candidates
χ^2_{geo}, χ^2_{topo}, z_{vertex}
χ^2_{geo}, χ^2_{topo}, z_{vertex}
χ^2_{geo}
Selected Ξ^-, Ξ^+, Ω^- and Ω^+
Selected H
Selected Σ^{*+}, $\bar{\Sigma}^{*+}$, $\bar{\Sigma}^{*-}$ and Σ^{*-}, K^{*0}, $\bar{K}^{*0}$, K^{*-} and K^{*+}
Store

(1) $\Sigma^- \to n\pi^-$
(2) $\Sigma^+ \to n\pi^+$
(3) $\Sigma^+ \to p\pi^0$
(4) $\bar{\Sigma}^- \to \bar{n}\pi^-$
(5) $\bar{\Sigma}^+ \to \bar{n}\pi^-$
(6) $\bar{\Sigma}^+ \to \bar{p}\pi^0$
(7) $\Xi^- \to \Lambda\pi^-$
(8) $\bar{\Xi}^+ \to \bar{\Lambda}\pi^+$
(9) $\Omega^- \to \Lambda K^-$
(10) $\bar{\Omega}^+ \to \bar{\Lambda}K^+$
(11) $\Omega^- \to \Xi^0\pi^-$
(12) $\bar{\Omega}^+ \to \bar{\Xi}^0\pi^+$
(13) $\pi^+ \to \mu^+\nu_\mu$
(14) $\pi^- \to \mu^-\bar{\nu}_\mu$
(15) $K^+ \to \mu^+\nu_\mu$
(16) $K^- \to \mu^-\bar{\nu}_\mu$
(17) $K^+ \to \pi^+\pi^0$
(18) $K^- \to \pi^-\pi^0$

KF Particle Finder for Physics Analysis and Selection

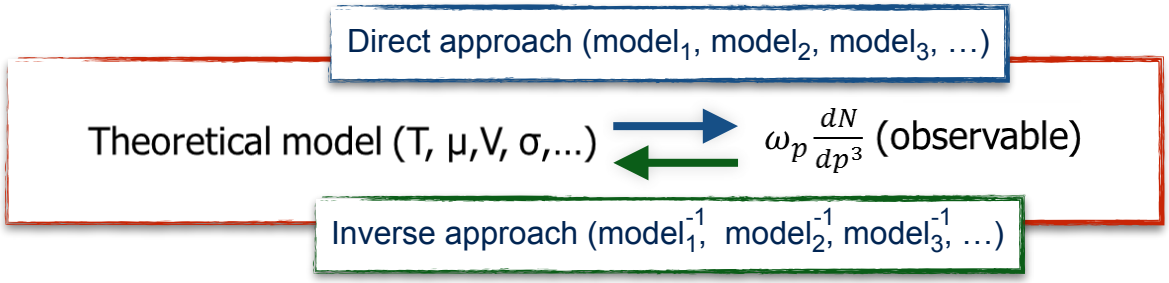


KF Particle Finder for Physics Analysis and Selection



CBM Online Physics Analysis

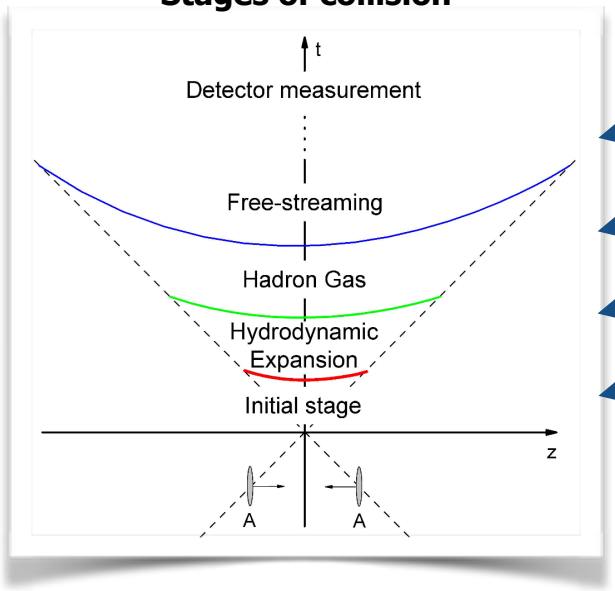
Extraction of parameters of theoretical models from measured data.



Motivation:

- determination of physical properties of QCD matter created in HIC (temperature, flow, phase transitions, …),
- obtain limits of applicability of different models

Stages of collision



Models for different stages

Final momentum spectrum (Blast-Wave, Tsallis, …)

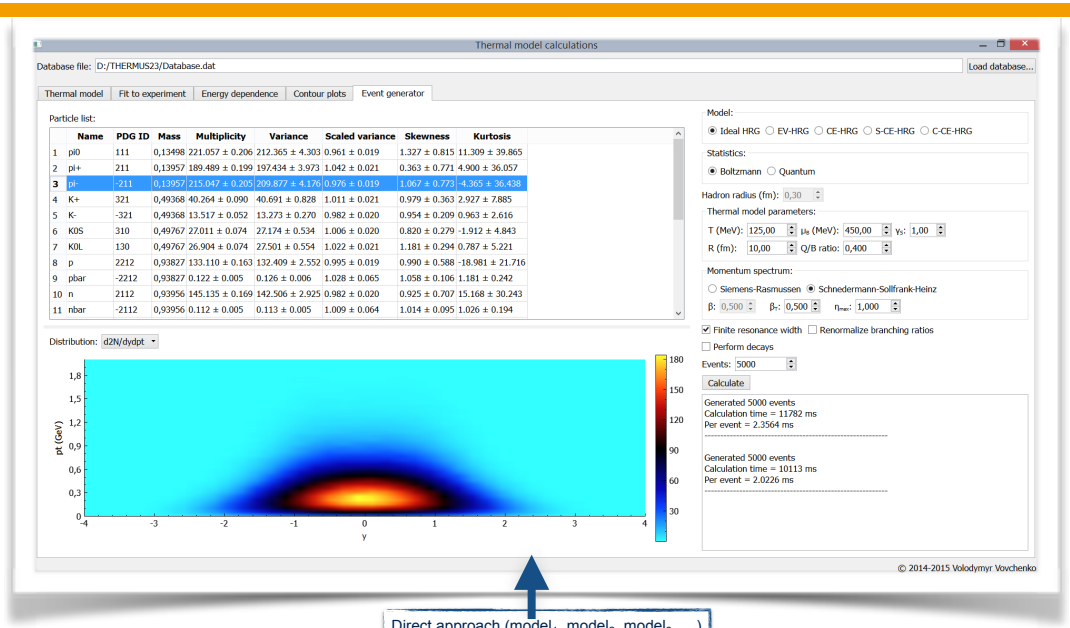
Statistical-thermal models for chemical freeze-out (ideal hadron gas, Van der Waals hadron gas, Hagedorn states, …)

Relativistic hydrodynamics (ideal, viscous; (0+1)D, (1+1)D, (3+1)D, …)

Initial stage (Glauber, CGC, …)

A package to extract the parameters of theoretical models in CBM experiment is implemented

CBM Online Physics Analysis

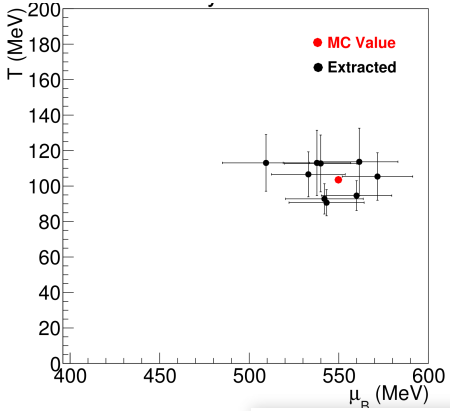


Direct approach (model$_1$, model$_2$, model$_3$, …)

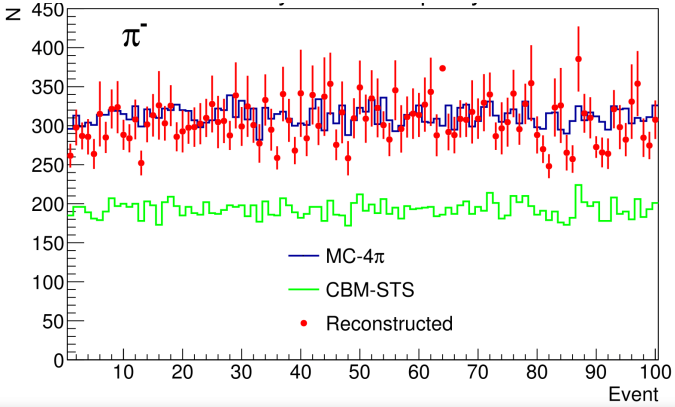
Theoretical model (T, μ,V, σ,…) $\rightleftarrows$ $\omega_p \frac{dN}{dp^3}$ (observable)

Inverse approach (model$_1^{-1}$, model$_2^{-1}$, model$_3^{-1}$, …)

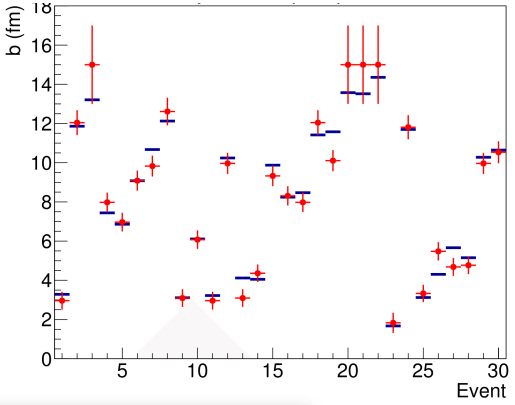
E.-by-E. extraction of T and μ_B (HRG)



E.-by-E. yield estimate incl. acceptance (Blast-Wave)



E.-by-E. impact parameter (Glauber)



A package to extract the parameters of theoretical models in CBM experiment is implemented

Summary

- The Kalman Filter track fit library is vectorized, parallelized and portable to CPU/Phi/GPU architectures.
- The Cellular Automaton track finder is vectorized and parallelized.
- The KF Particle package for reconstruction of short-lived particles has been developed.
- Online physics analysis approaches are under investigation.

More details:

- V. Akishina, 4D event reconstruction in the CBM experiment, PhD Thesis, Uni-Frankfurt, 2016
- M. Zyzak, Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR, PhD Thesis, Uni-Frankfurt, 2016