Kalman filter based approach for reconstruction of short-lived particles

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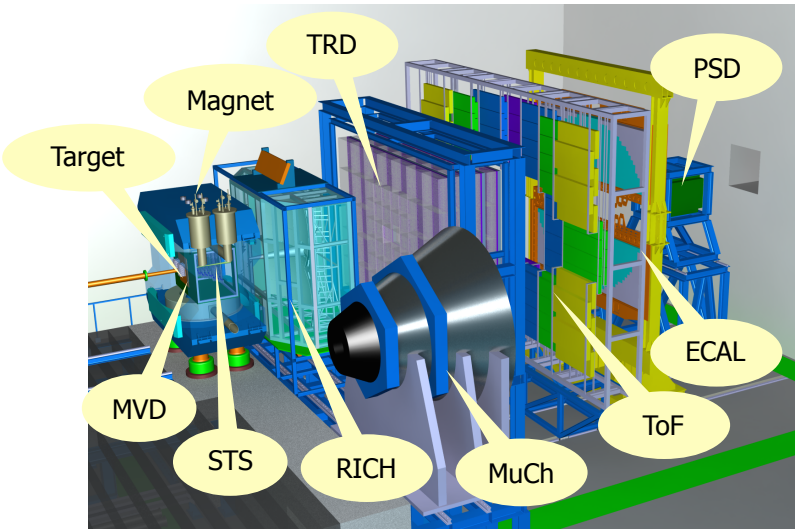
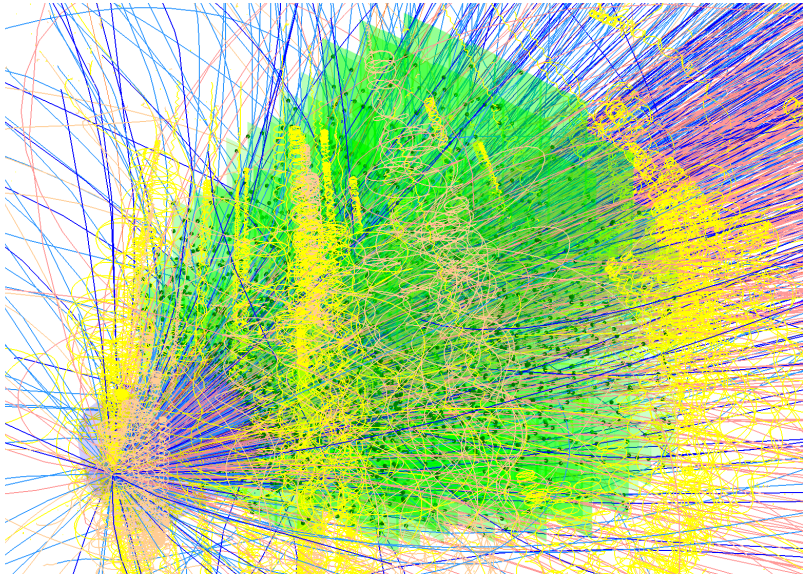
The CBM experiment



- CBM - future fixed-target heavy-ion experiment at FAIR, Darmstadt, Germany.
- 10^5-10^7 collisions per second.
- Up to 1000 charged particles/collision.
- Free streaming data.
- No hardware triggers.
- On-line event reconstruction and selection is required in the first trigger level.

- On-line reconstruction at the on-line farm with 60000 CPU equivalent cores.
- High speed and efficiency of the reconstruction algorithms are required.
- The algorithms have to be highly parallelised and scalable.
- CBM event reconstruction: Kalman Filter and Cellular Automaton.



Central AuAu UrQMD event at 25 AGeV

Concept of KF Particle

Concept:

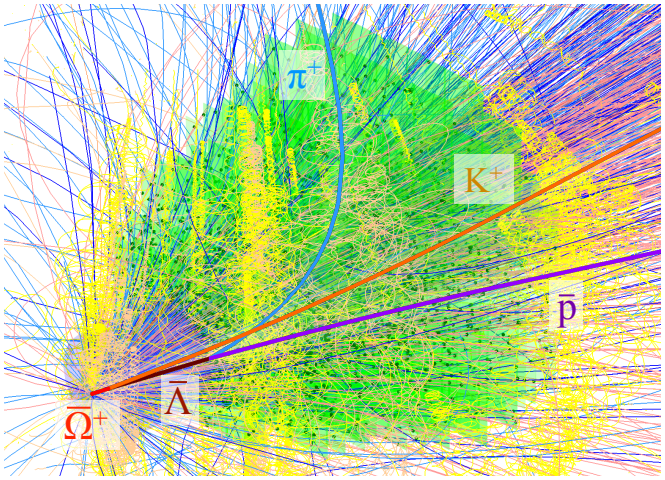
- Mother and daughter particles have the same state vector and are treated in the same way
- Geometry independent
- Kalman filter based

State vector — Position, momentum and energy

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

$$C = \langle r r^T \rangle$$

Covariance matrix



$$\bar{\Omega}^+ \rightarrow \bar{\Lambda}\, K^+$$
$$\hookrightarrow \bar{p}\, \pi^+$$

Functionality of the package:

- Construction of the particles from tracks or another particles
- Decay chain reconstruction
- Transport of the particles
- Simple access to the particle parameters and their errors
- Calculation of the distance to point

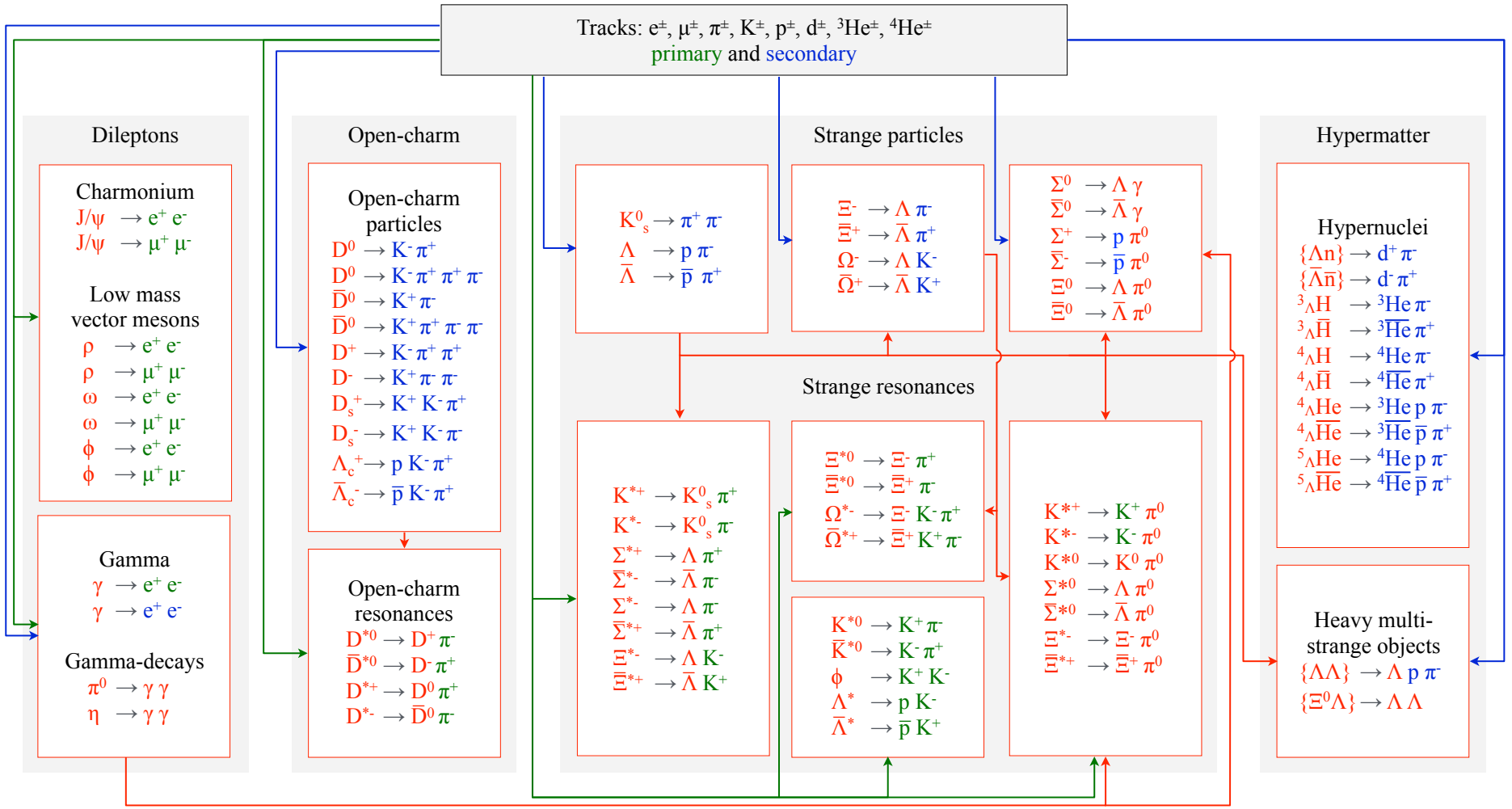
Functionality of KF Particle

Functions	CBM	ALICE	PANDA	STAR
Construction of mother particles	+	+	+	+
Addition and subtraction of the daughter particle to (from) the mother particle	+	+	+	+
+= and -= operators	+	+	+	+
Accessors to the physical parameters (mass, momentum, decay length, lifetime, rapidity, etc)	+	+	+	+
Transport: to an arbitrary point, to the decay and production points, to another particle, to a vertex, on the certain distance	+	+	+	+
Calculation of a distance: to a point, to a particle, to a vertex	+	+	+	+
Calculation of a deviation: from a point, from a particle, from a vertex	+	+	+	+
Calculation of the angle between particles	+	+	+	+
Constraints: on mass, on a production point, on a decay length	+	+	+	+
KF Particle Finder	+	+	+	+

Exactly the same package in all four experiments: CBM, ALICE, PANDA and STAR

Functionality covers all current needs of CBM

KF Particle Finder



- The input are reconstructed tracks.
- KF Particle Finder searches for short-lived particles combining tracks and reconstructed particles according to the PID hypothesis.

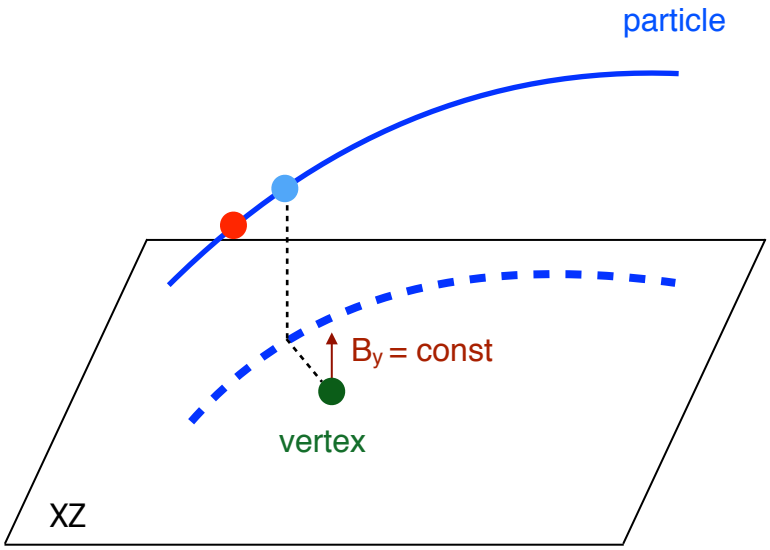
Point of DCA to a vertex

Assumptions:

- distance between the point of closest approach and particle is short;
- constant one-component field B_y, works well for short distances.

Point of closest approach between a particle and a vertex:

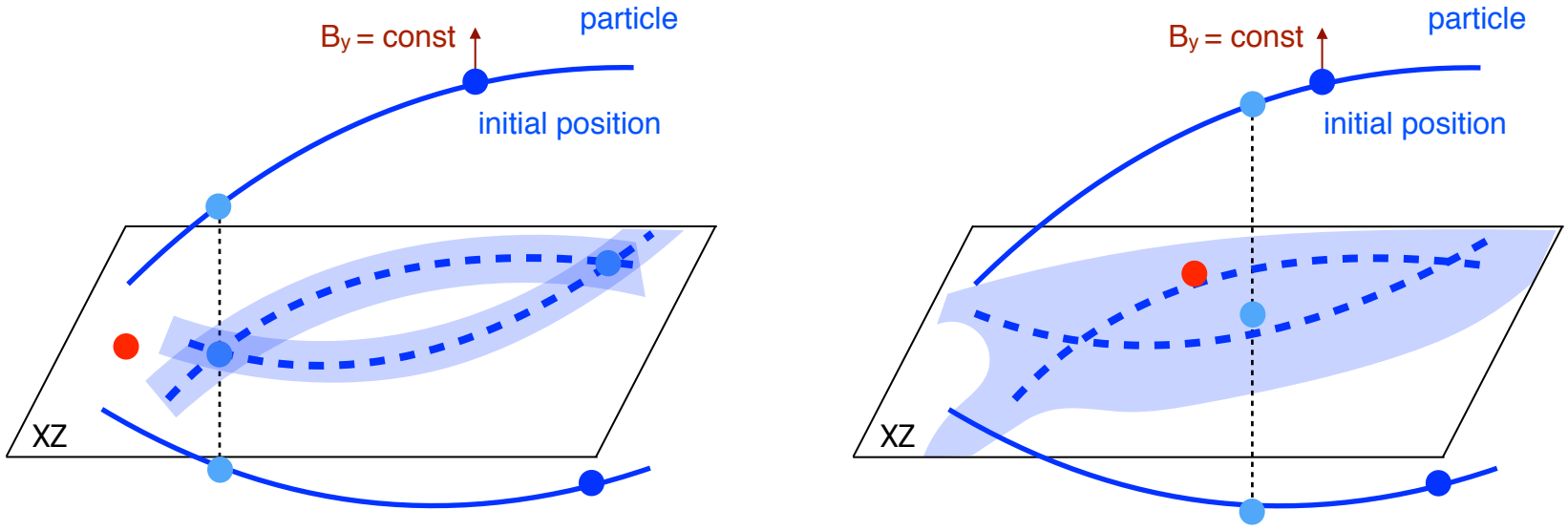
- find point in 2D (is solved analytically);
- transport particle to that point;
- assuming small distance between 2D and 3D point, find point in 3D by Taylor expansion.



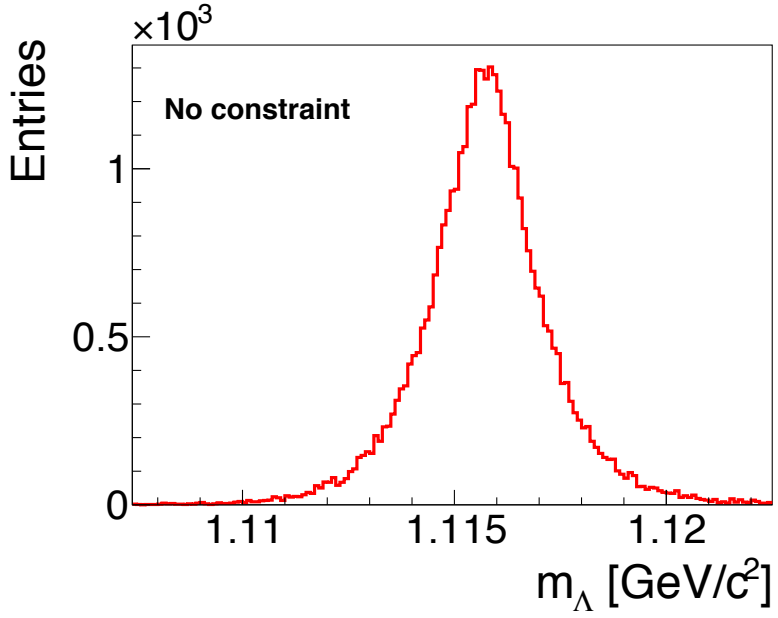
Point of DCA to a particle

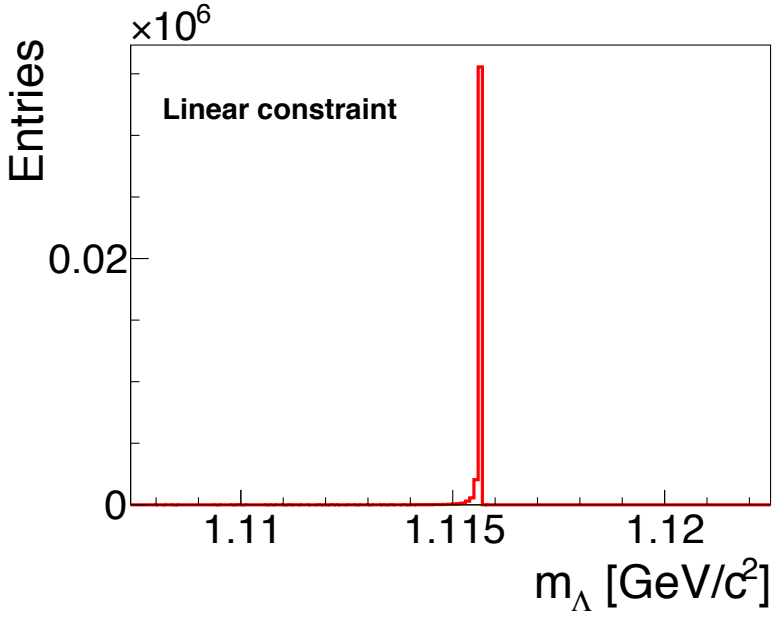
Assumptions:
- distance between the point of closest approach and particle is short;
- constant one-component field B_y, works well for short distances.

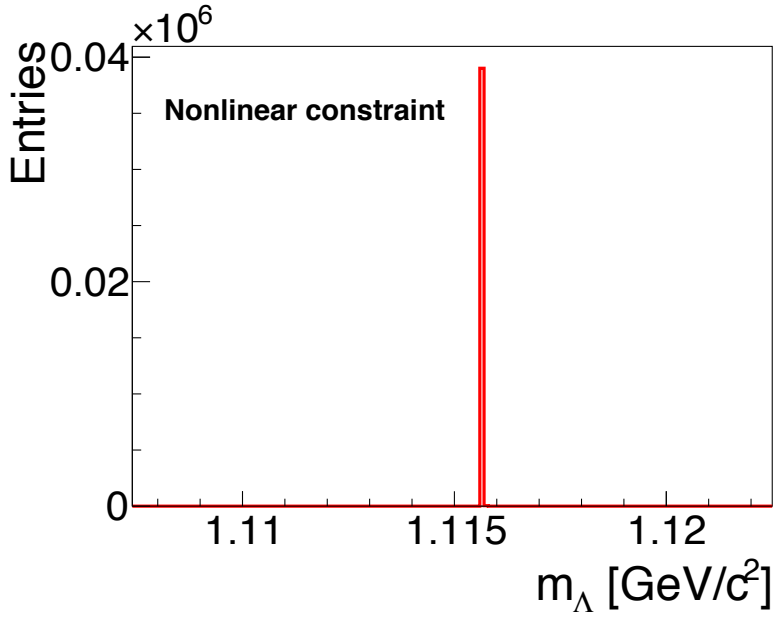
Point of closest approach between two particles:
- find 2 points in 2D (is solved analytically);
- if the points are well separated within the errors of tracks - select a point of the DCA tacking into account all 3 coordinates;
- if the points are equivalent within the errors - select a middle point;
- transport particles to that point;
- assuming small distance between 2D and 3D point, find point in 3D by Taylor expansion.



Mass constraint

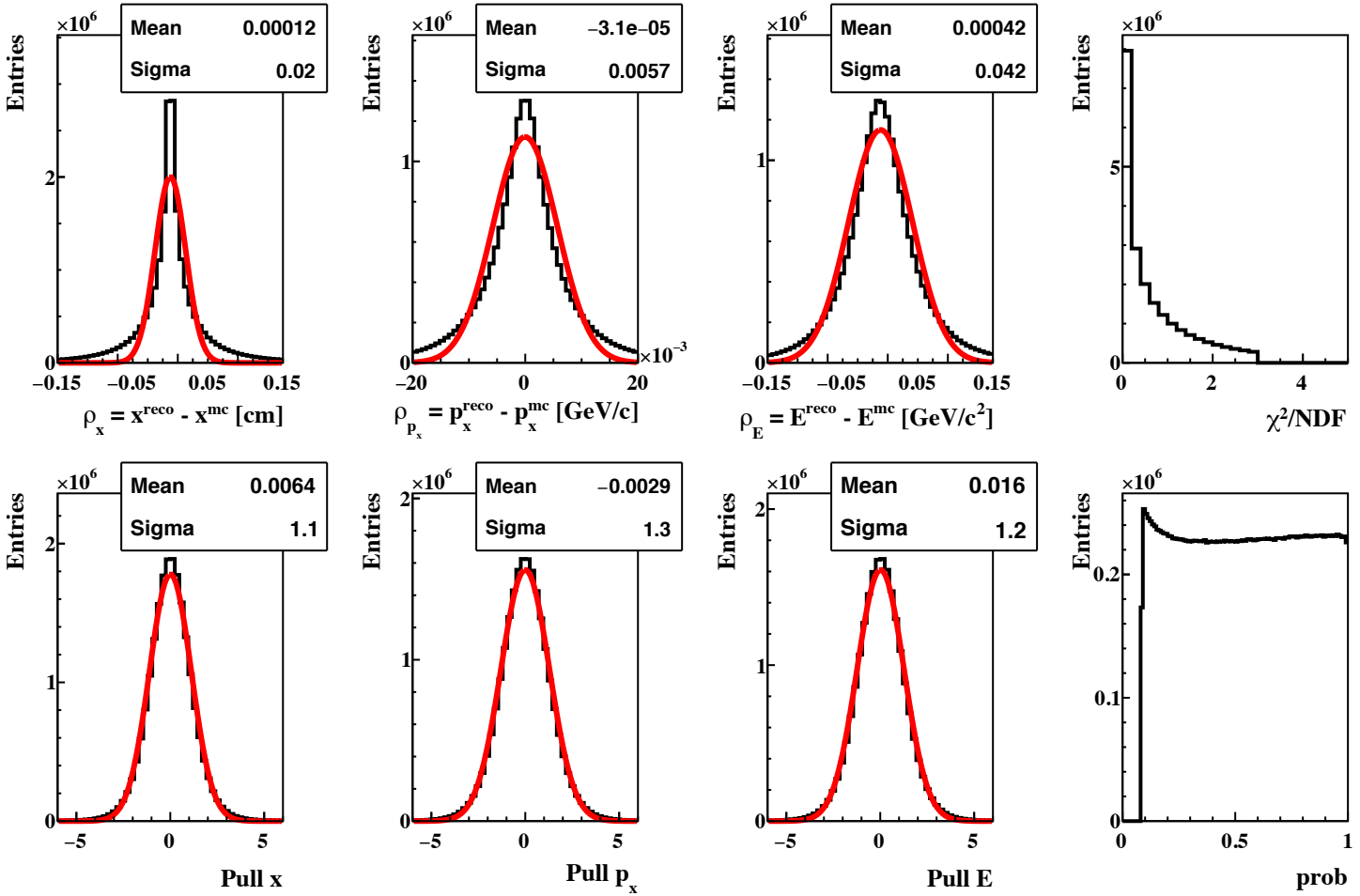






- The mass constraint is a powerful tool for decay chain reconstruction.
- Conventional method is a linearized mass constraint. However, it is approximate and can not guarantee the exact value of the parameter.
- Nonlinear approach is implemented in KF Particle for setting the exact mass constraint.

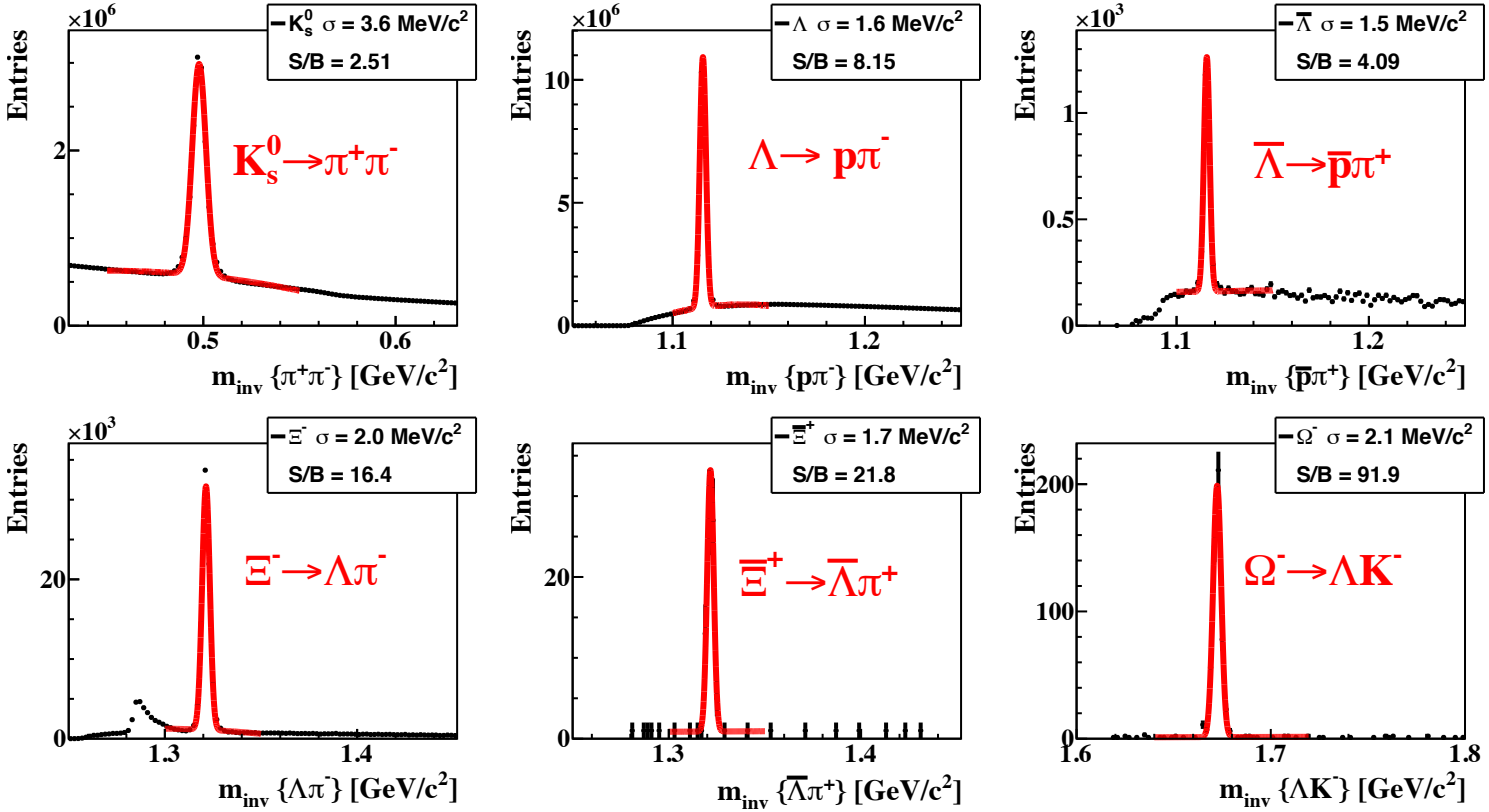
Fit quality



AuAu, 10 AGeV, 5M central UrQMD events, realistic PID

- The fit quality is demonstrated, for example, at Λ hyperon.
- Y and Z components have similar distribution to X.
- The KF Particle mathematics allow to obtain correct errors and, as a result, correct pulls (unbiased, width about 1), χ^2 and flat prob (p-value) distributions.

Reconstruction of strange and multi-strange particles

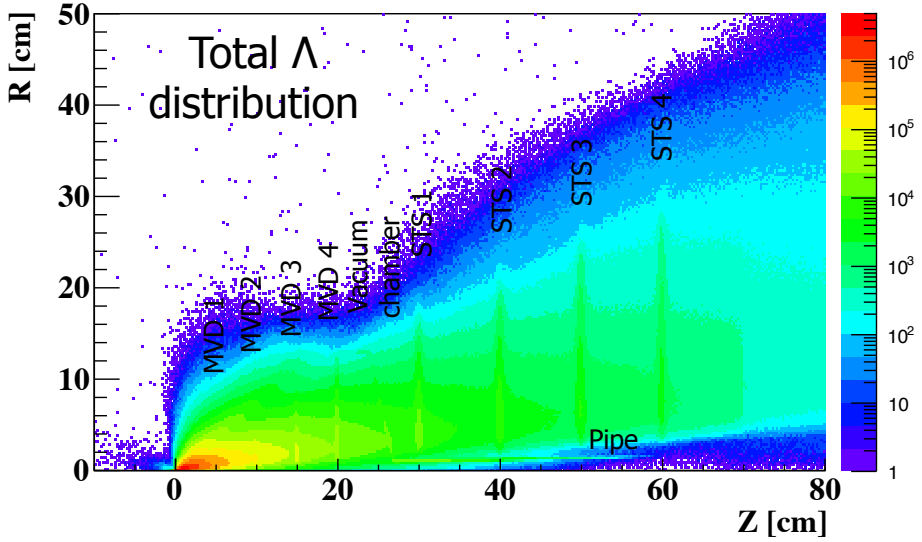


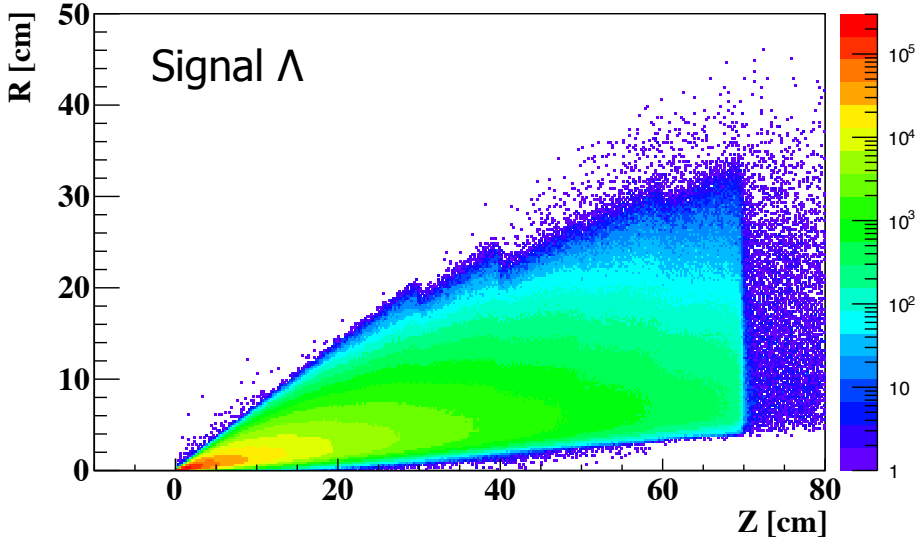
AuAu, 10 AGeV, 5M central UrQMD events, realistic PID

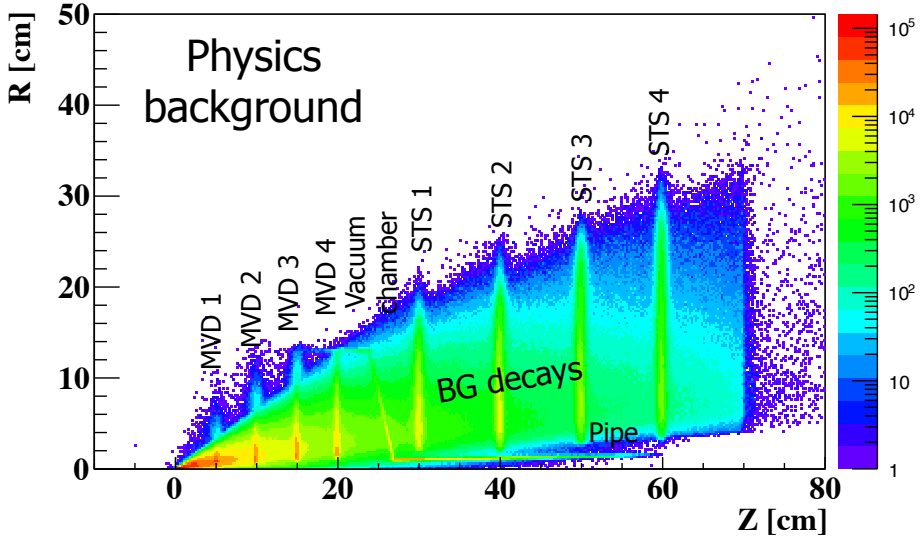
	K^0_s	Λ	$\bar{\Lambda}$	Ξ^-	$\bar{\Xi}^+$	Ω^-
ε_{method}, %	71.5	65.4	66.5	48.0	44.5	45.4
$\varepsilon_{4\pi}$, %	24.9	27.0	17.0	12.8	6.7	5.5
S/B	2.5	8.2	4.1	16.4	21.8	91.9

Mathematically correct procedures of KF Particle allow to collect spectra with high efficiency and signal to background ratio.

Tomography of the detector

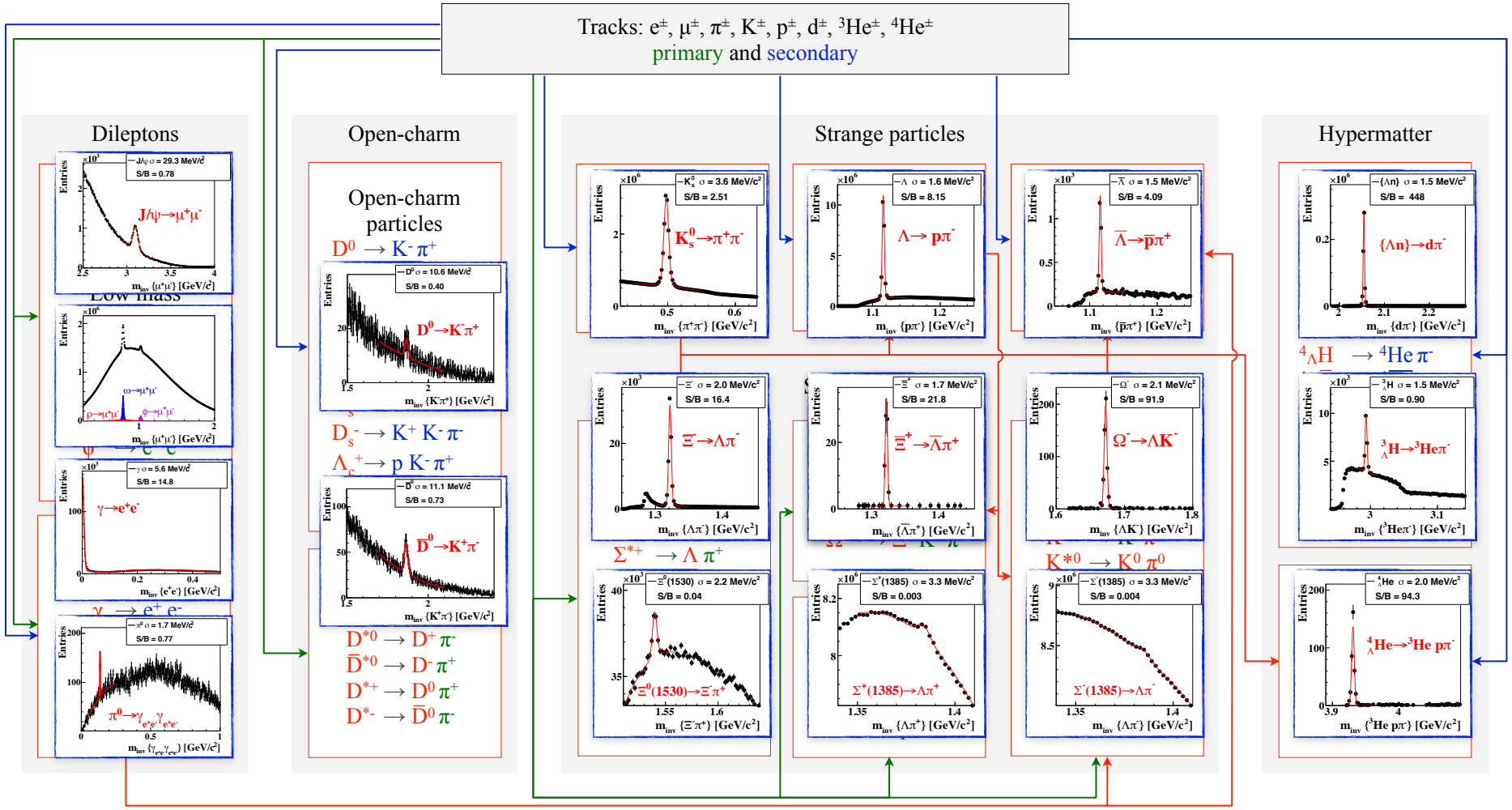






- High quality of the reconstruction allow to perform the detector tomography.
- The vertices on the stations are due to the interaction of the primary particles with the material.

KF Particle Finder: a tool for the CBM physics analysis



The sophisticated mathematics of KF Particle Finder is perfectly suited for the analysis of the whole range of the CBM physics

Summary and plans

Summary

- KF Particle package provides rich functionality for short-lived particles reconstruction.
- Use of the Kalman filter mathematics provides accurate and mathematically correct procedures for reconstruction of particles with high precision and efficiency.
- KF Particle Finder covers a wide range of short-lived particles for the CBM experiment.

Plans

- Add particle PID and selection based on the probabilistic methods.