Missing Mass Method for reconstruction of short-lived particles

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(for CBM Collaborations)

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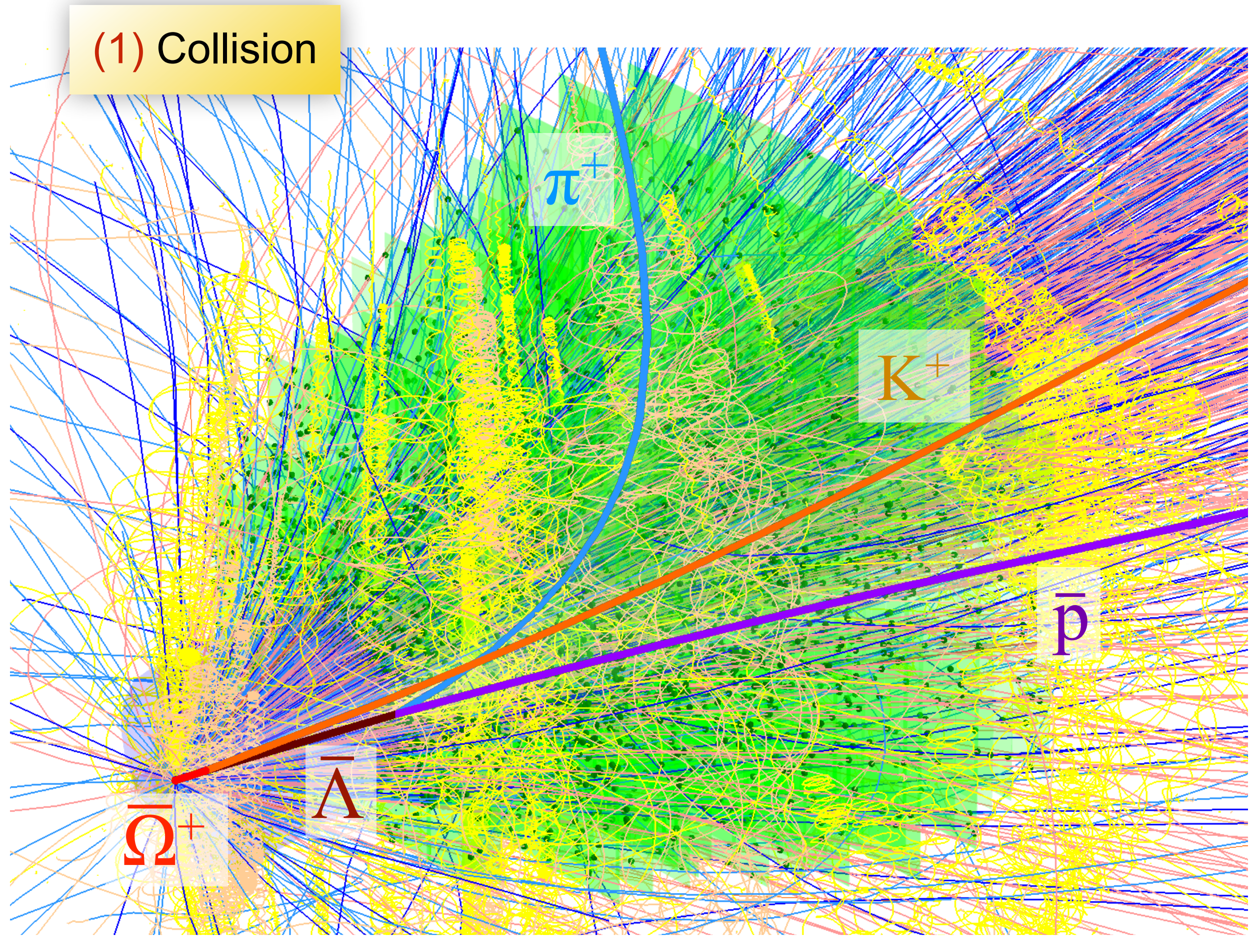
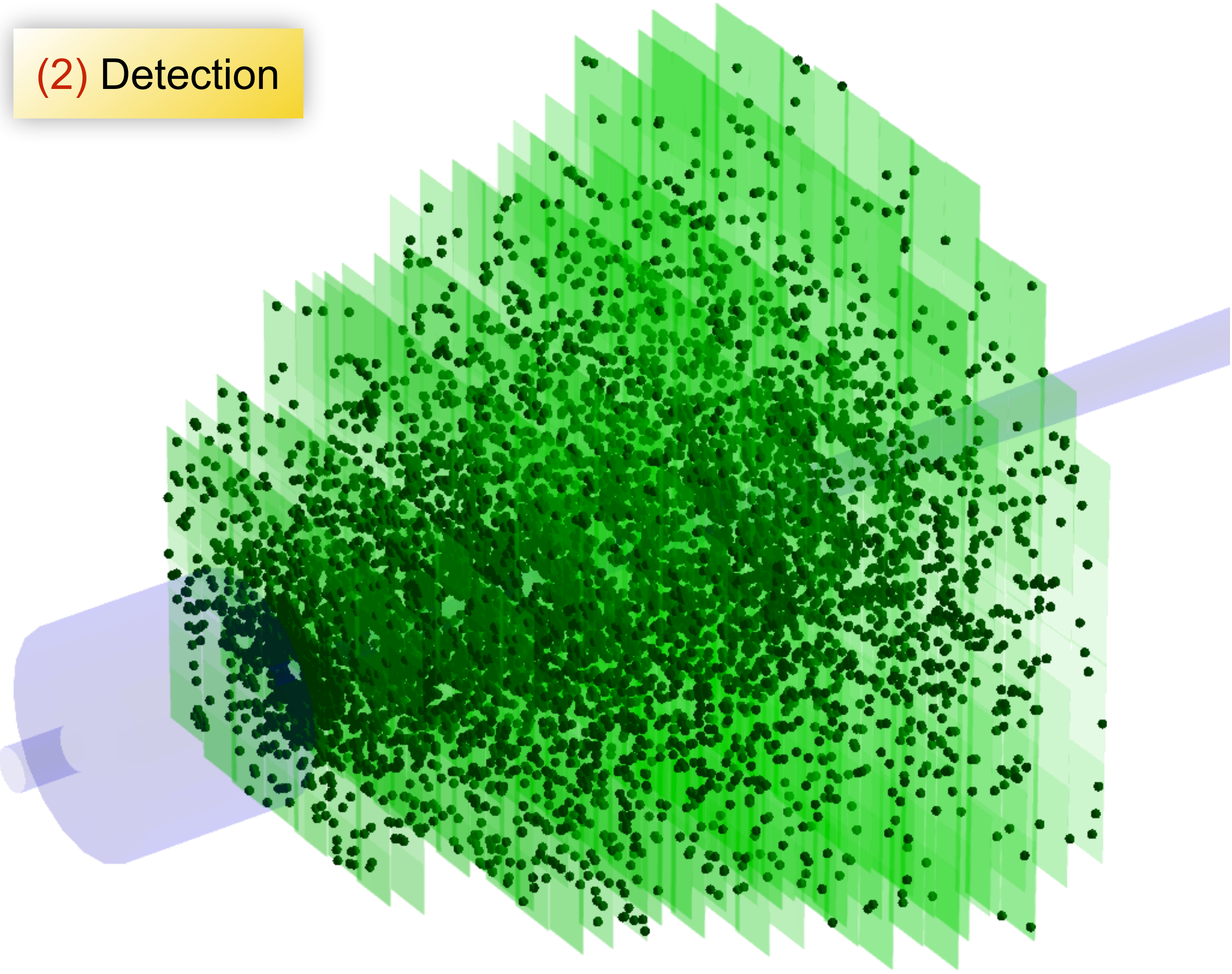
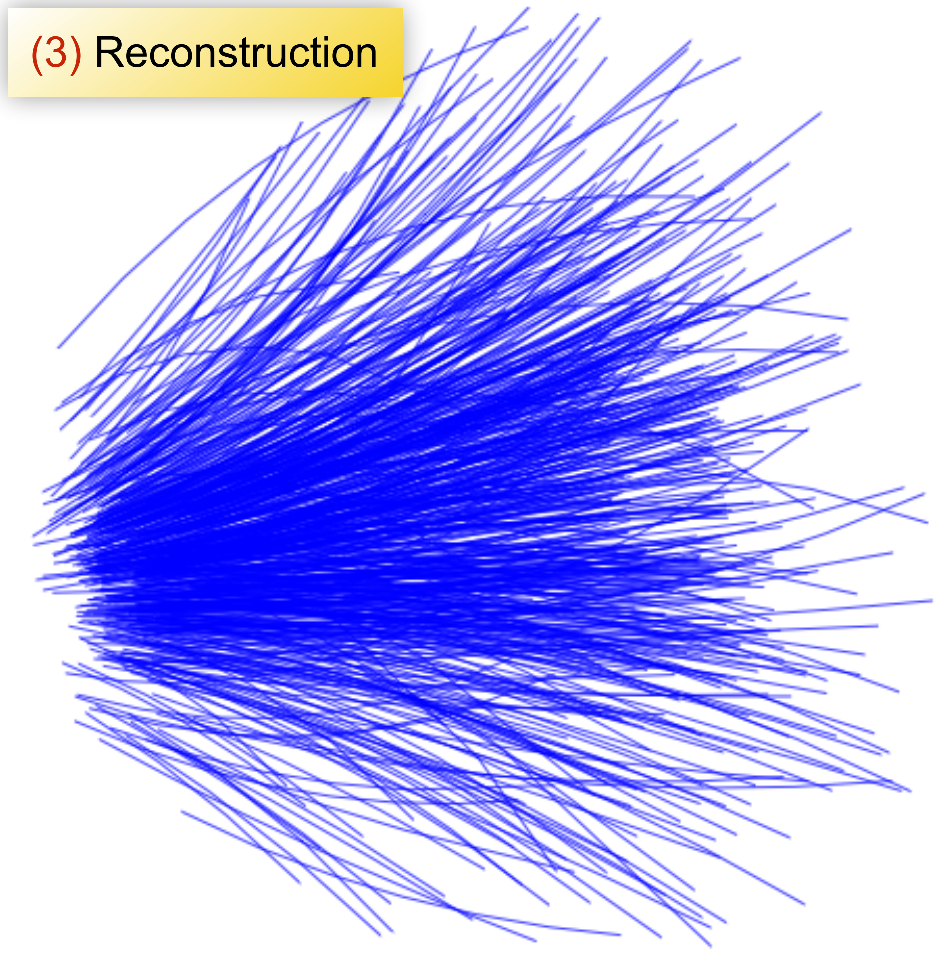
- CBM experiment
- KF Particle package
- Missing mass method
- Comparison with the conventional approach
- Summary

Reconstruction challenge in CBM



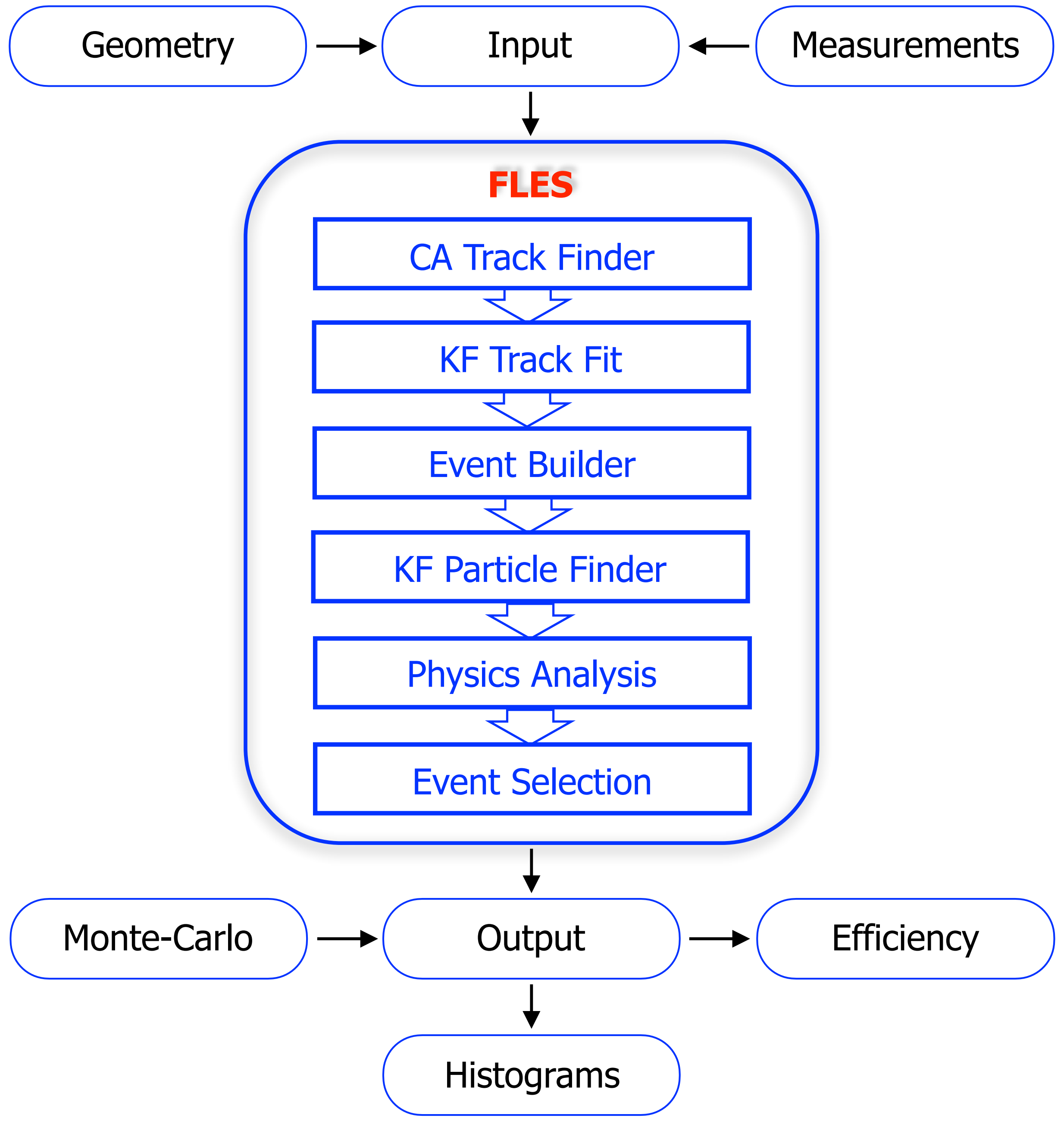




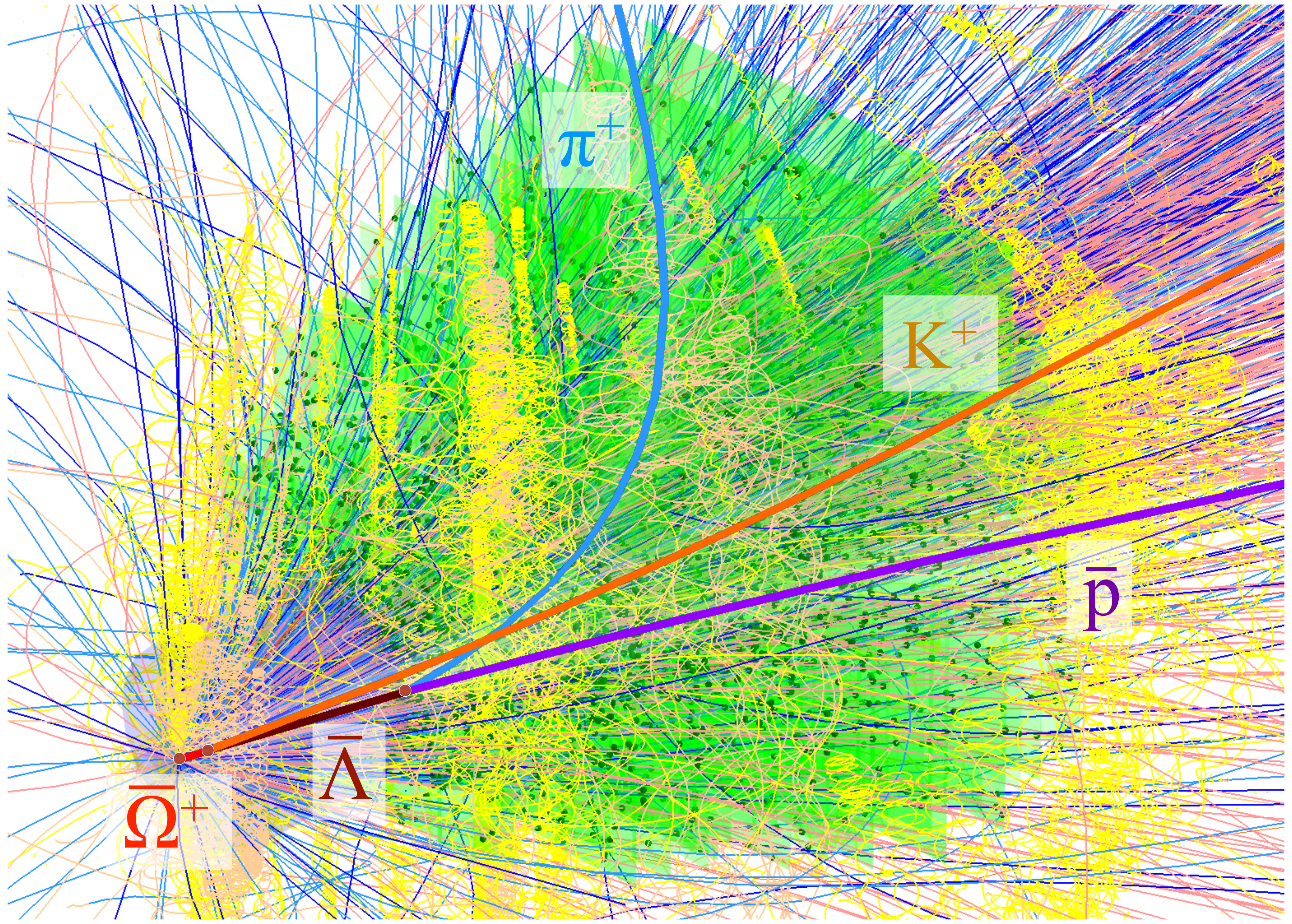
The full event reconstruction will be done on-line at the First-Level Event Selection (FLES) and off-line using the same FLES reconstruction package.

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

All reconstruction algorithms are vectorized and parallelized.



KF Particle: Reconstruction of short-lived particles



Simulated AuAu collision at 25 AGeV

$$\bar{\Omega}^+ \leftarrow \bar{\Lambda}\, K^+$$
$$\quad\quad\quad\quad \llcorner \bar{p}\, \pi^+$$

```
KFParticle Lambda(P, Pi);                  // construct anti Lambda
Lambda.SetMassConstraint(1.1157);          // improve momentum and mass
KFParticle Omega(K, Lambda);               // construct anti Omega
PV -= (P; Pi; K);                          // clean the primary vertex
PV += Omega;                               // add Omega to the primary vertex
Omega.SetProductionVertex(PV);             // Omega is fully fitted
(K; Lambda).SetProductionVertex(Omega);    // K, Lambda are fully fitted
(P; Pi).SetProductionVertex(Lambda);       // p, pi are fully fitted
```

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

State vector

$$\mathbf{C} = \langle \mathbf{r}\mathbf{r}^T \rangle = \begin{bmatrix} \sigma_x^2 & C_{xy} & C_{xz} & C_{xp_x} & C_{xp_y} & C_{xp_z} & C_{xE} \\ C_{xy} & \sigma_y^2 & C_{yz} & C_{yp_x} & C_{yp_y} & C_{yp_z} & C_{yE} \\ C_{xz} & C_{yz} & \sigma_z^2 & C_{zp_x} & C_{zp_y} & C_{zp_z} & C_{zE} \\ C_{xp_x} & C_{yp_x} & C_{zp_x} & \sigma_{p_x}^2 & C_{p_xp_y} & C_{p_xp_z} & C_{p_xE} \\ C_{xp_y} & C_{yp_y} & C_{zp_y} & C_{p_xp_y} & \sigma_{p_y}^2 & C_{p_yp_z} & C_{p_yE} \\ C_{xp_z} & C_{yp_z} & C_{zp_z} & C_{p_xp_z} & C_{p_yp_z} & \sigma_{p_z}^2 & C_{p_yE} \\ C_{xE} & C_{yE} & C_{zE} & C_{p_xE} & C_{p_yE} & C_{p_zE} & \sigma_E^2 \end{bmatrix}$$

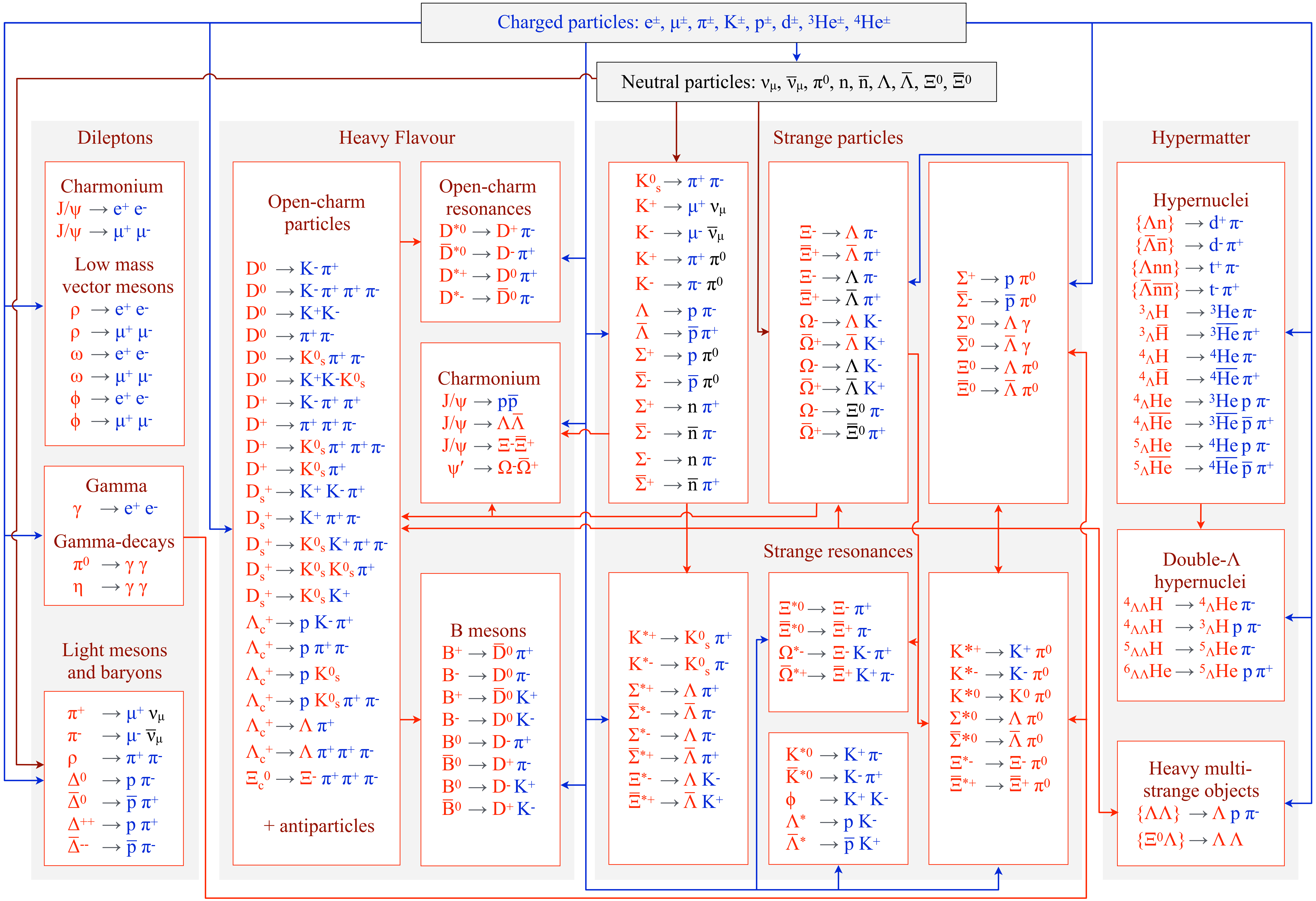
Covariance matrix

Features:

- KF Particle class describes particles by the state vector and the covariance matrix.
- Covariance matrix contains essential information about tracking and detector performance.
- The method for mathematically correct usage of covariance matrices is provided by the KF Particle package based on the Kalman filter (KF).
- Heavy mathematics of KF requires fast and vectorised algorithms.
- Mother and daughter particles are treated in the same way.
- The natural and simple interface allows two reconstruct easily complicated decay chains.
- The package is geometrically independent and can be adapted to different experiments (CBM, ALICE, STAR).

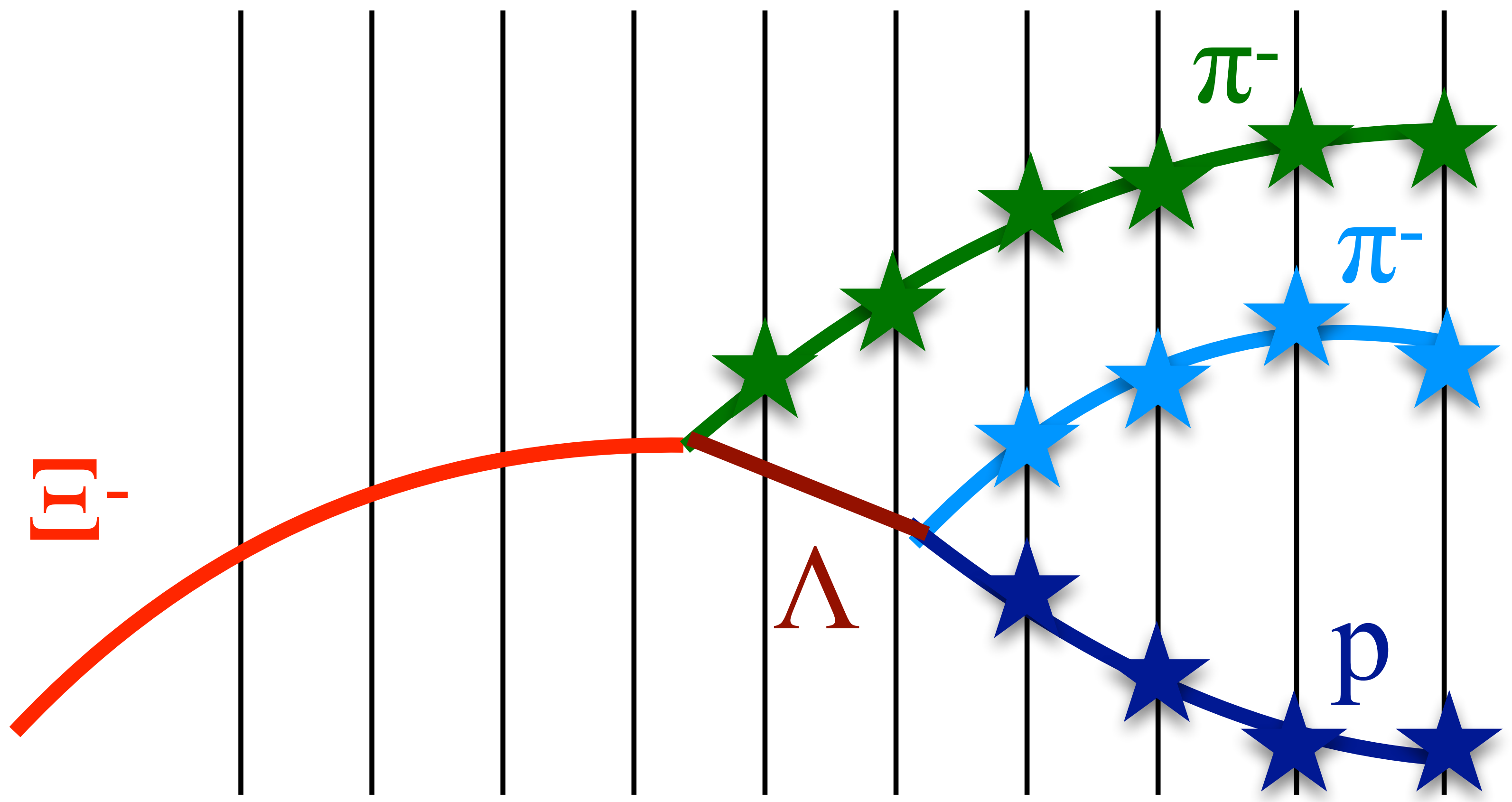
KF Particle provides a simple and very efficient approach to physics analysis

KF Particle Finder



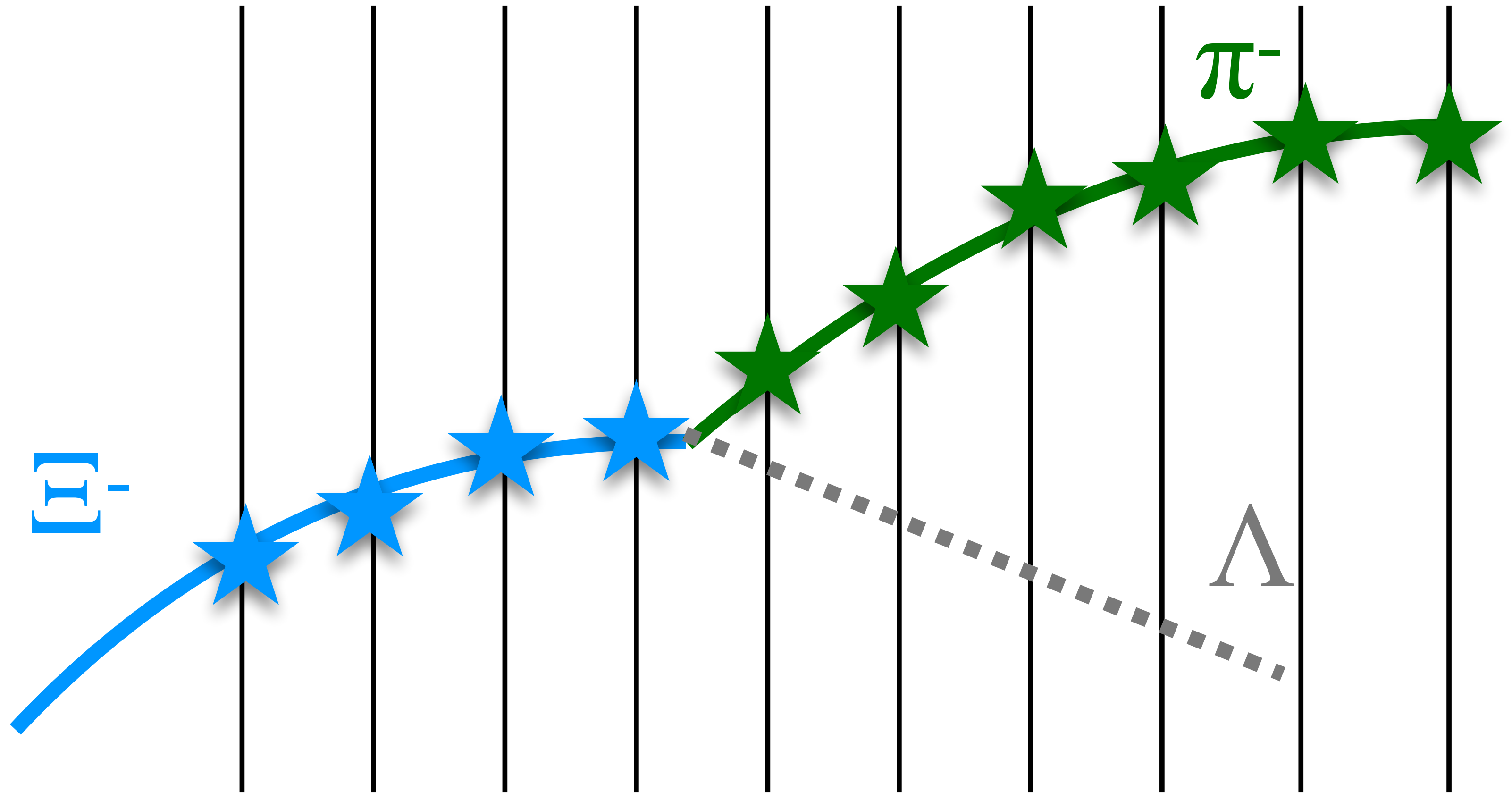
Methods for Reconstructions of Strange Particles

Conventional method



1. Find tracks of charged daughter from mother particle and both charged daughters from neutral particle in STS and MVD.
2. Reconstruct the neutral daughter from its charged daughters.
3. Reconstruct mother particle from the charged and obtained neutral daughters.

Missing mass method



1. Find tracks of mother particle and its charged daughter in STS and MVD.
2. Reconstruct the neutral daughter from the mother and the charged daughter particles.
3. Reconstruct mother particle from the charged and obtained neutral daughters.

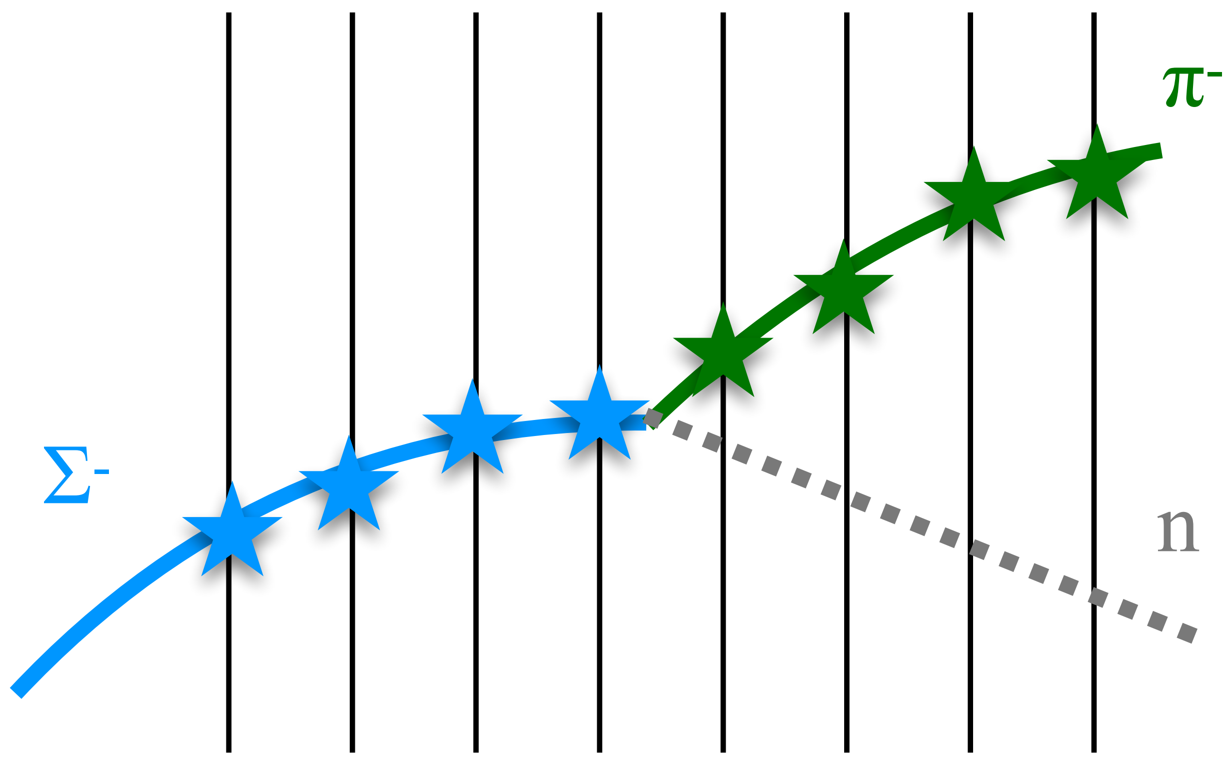
Missing mass method for reconstruction of Σ hyperons

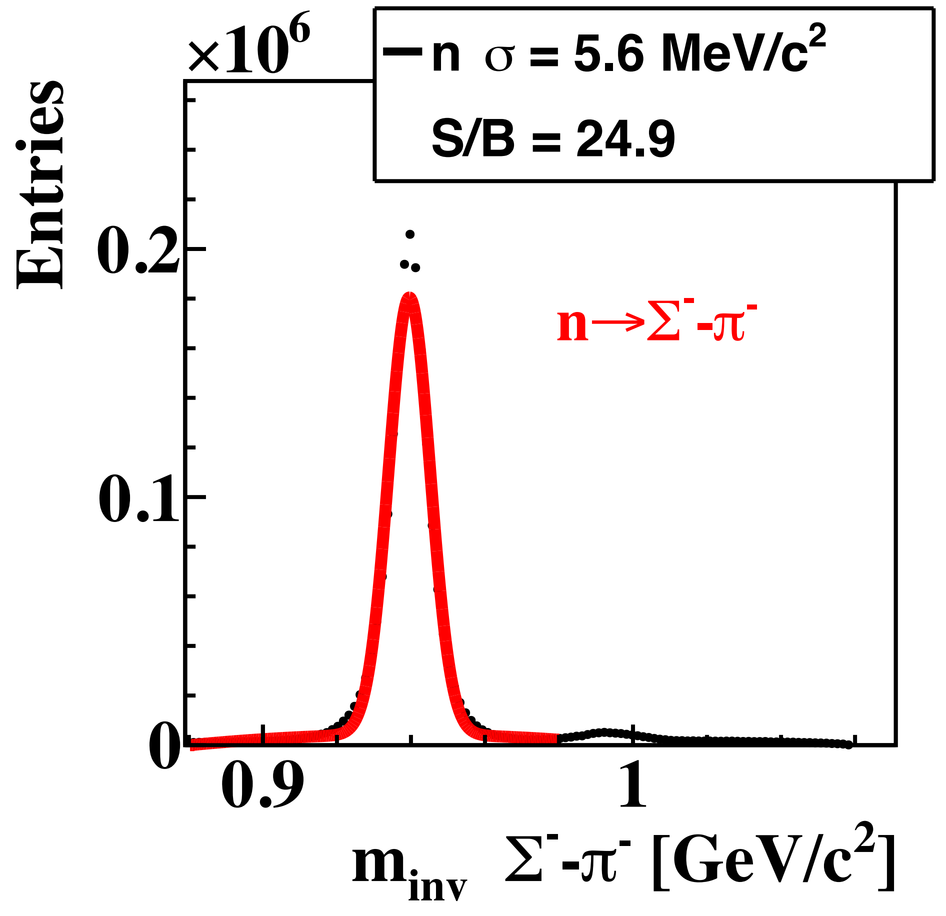
Σ^+ and Σ^- physics: completes the picture of strangeness production: abundant particles, carry out large fraction of strange quarks.

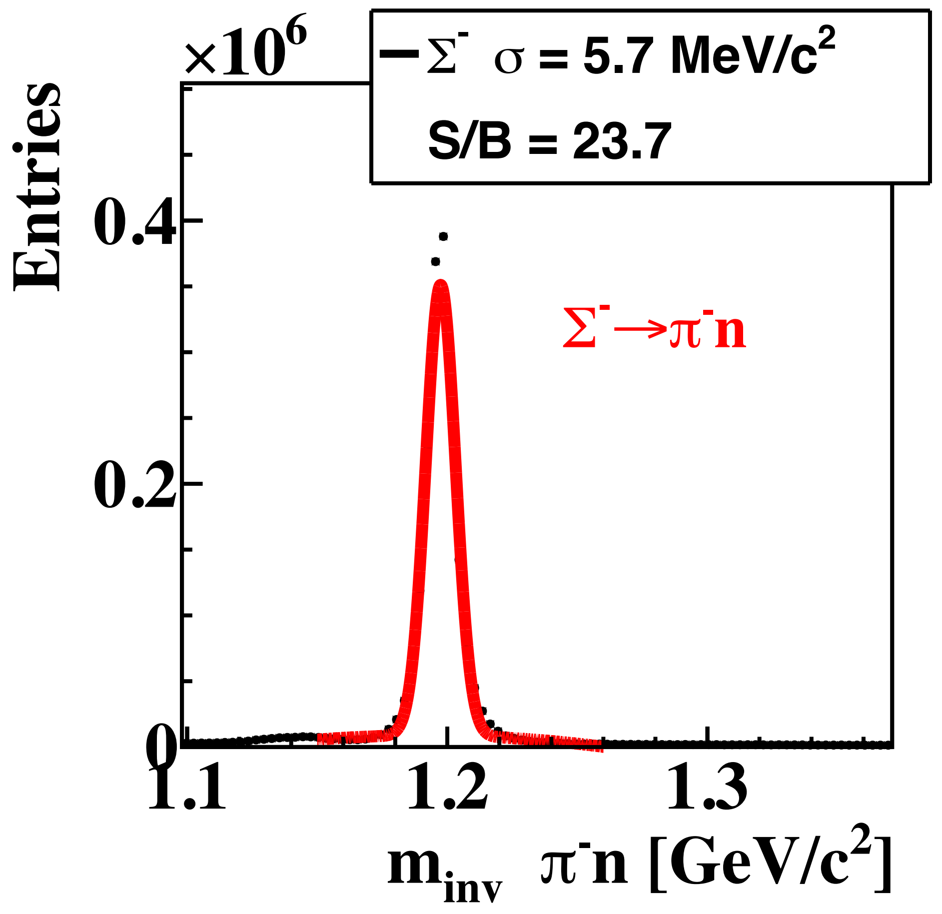
- Σ^+ and Σ^- have only channels with at least one neutral daughter.

$\Sigma^+ \rightarrow p\pi^0$	$\bar{\Sigma}^+ \rightarrow \bar{p}\pi^0$	BR = 51.6%
$\Sigma^+ \rightarrow n\pi^+$	$\bar{\Sigma}^+ \rightarrow \bar{n}\pi^-$	BR = 48.3%
$\Sigma^- \rightarrow n\pi^-$	$\bar{\Sigma}^- \rightarrow \bar{n}\pi^-$	BR = 99.8%

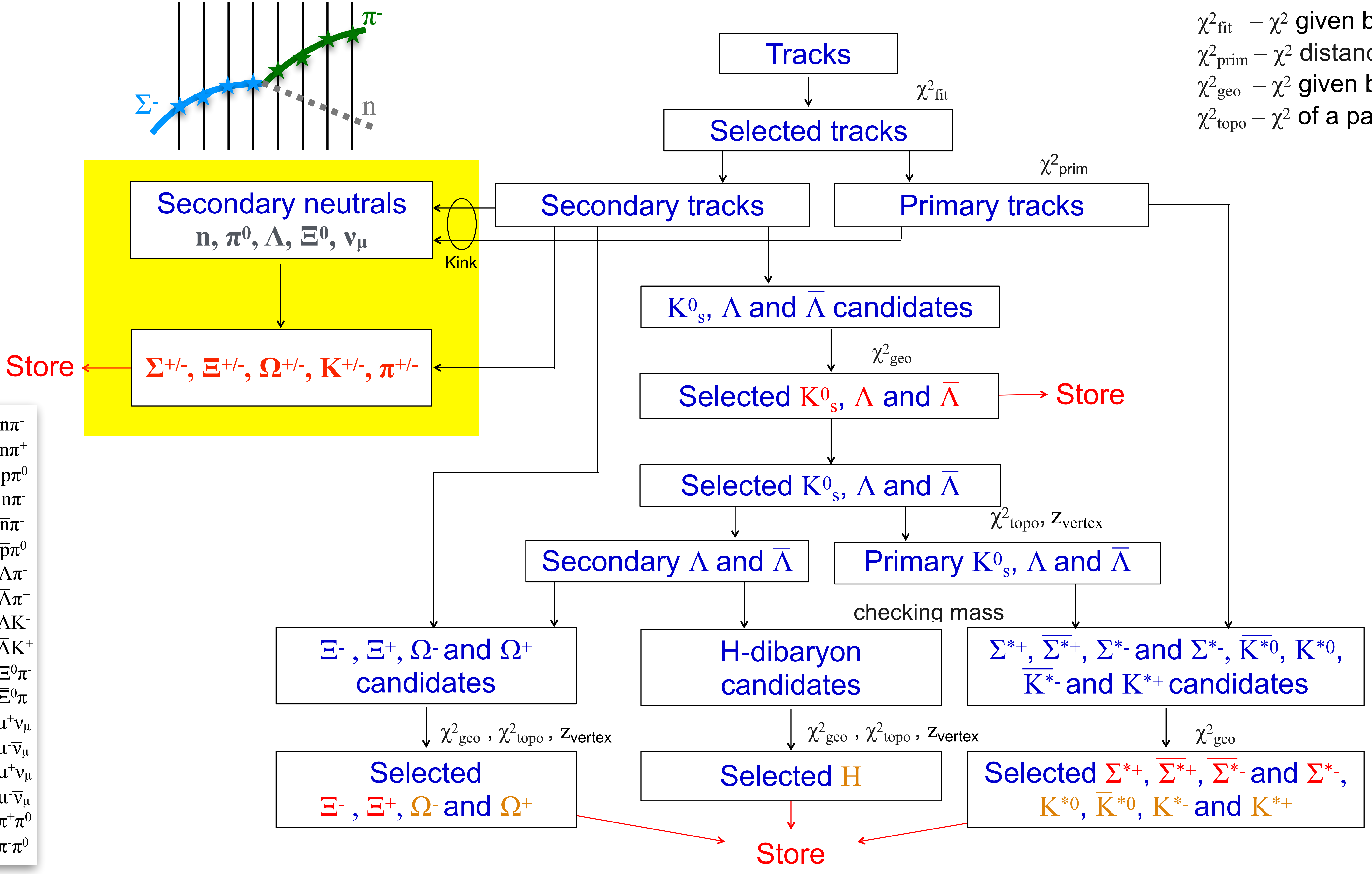
- Lifetime is sufficient to be registered by the tracking system: $c\tau$ = 2.4 *cm* for Σ^+ and $c\tau$ = 4.4 *cm* for Σ^-.
- Can not to be identified by the PID detectors.
- Identification is possible by the decay topology:







Extended KF Particle Finder Algorithm



Selection criteria:

χ^2_{fit} – χ^2 given by a track fit

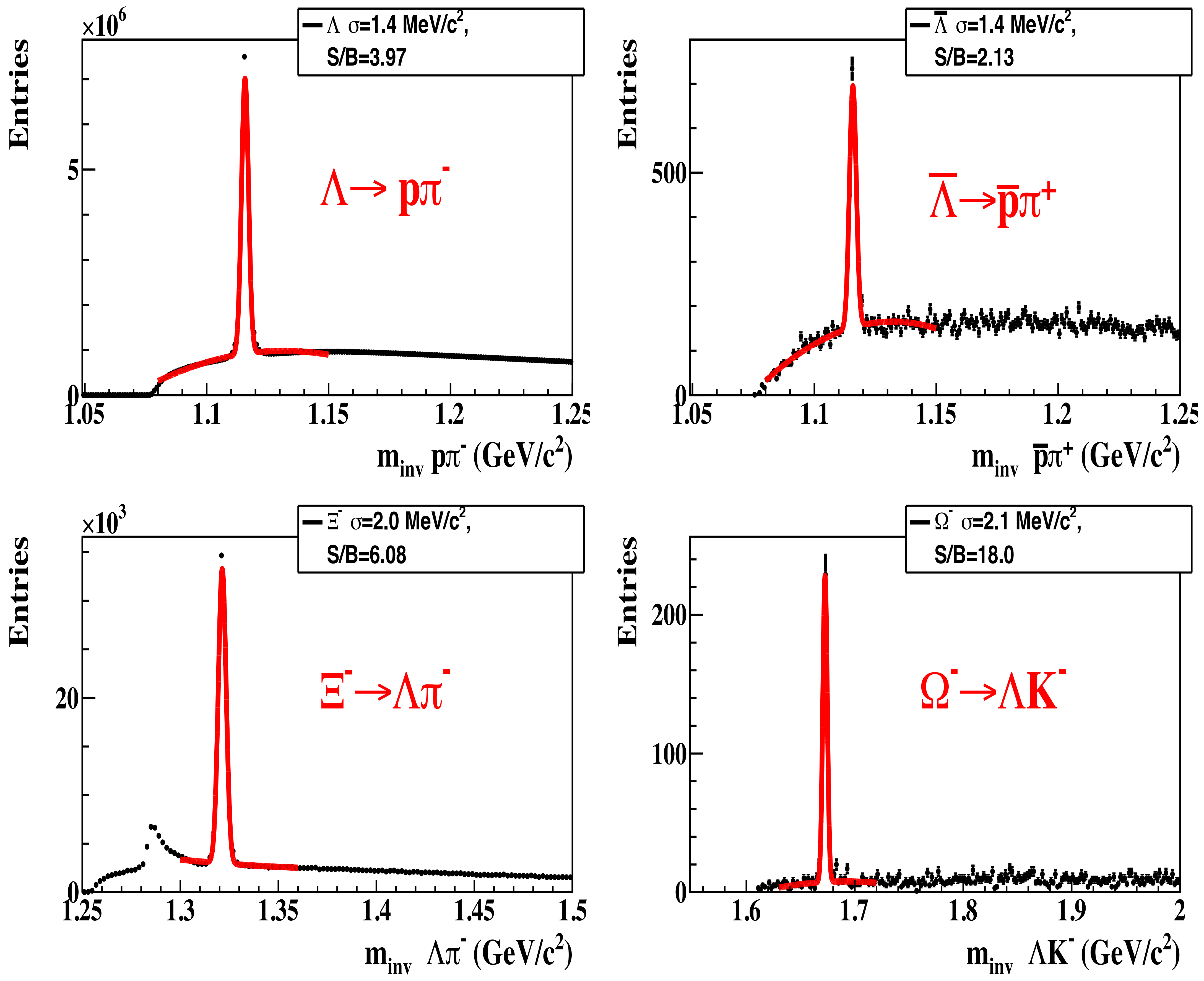
χ^2_{prim} – χ^2 distance to a primary vertex (PV)

χ^2_{geo} – χ^2 given by a particle fit

χ^2_{topo} – χ^2 of a particle fitted to PV

(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) $K^- \to \pi^-\pi^0$

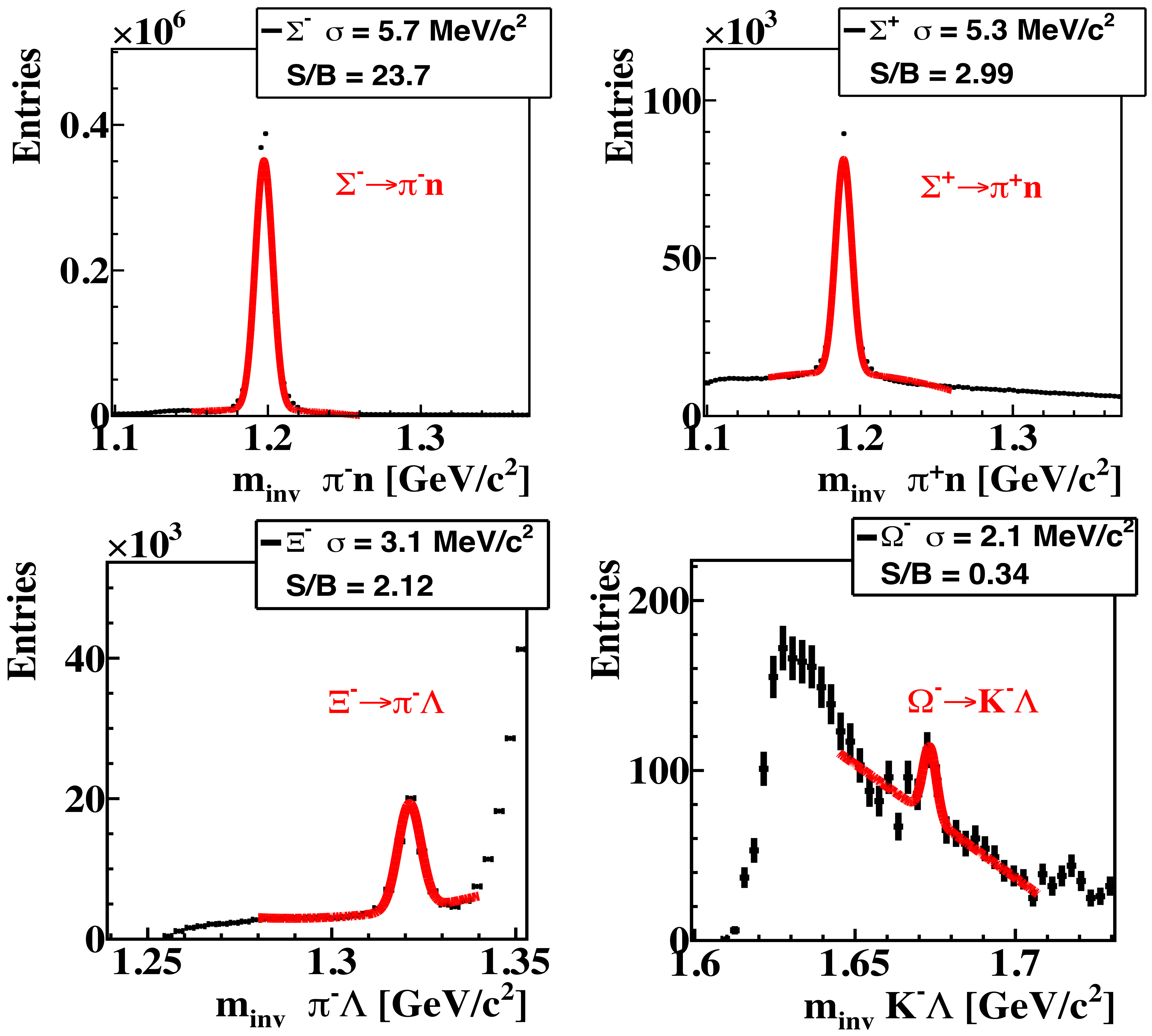
Strange particles by the conventional method



5M central AuAu UrQMD events at 10 AGeV

- CBM allows clean reconstruction of strange particle spectra.
- High efficiency with high significance and signal to background ratios.

Strange particles by the missing mass method



5M central AuAu UrQMD events at 10 AGeV

- In addition to conventional method the missing mass method is used to reconstruct strange particles.
- It opens access to the new physics:
  - Σ hyperons;
  - resonances with Σ daughter;
  - new channels of hypernuclei.
- More decay channels can be studied.
- Acceptance of the detector for strange particles is increased in this case.

Summary

- The CBM detector system is perfectly suitable for investigation of rare observables such as strange and multi-strange hyperons, resonances and hypernuclei.
- The FLES (First Level Event Selection) package will be used for full online event reconstruction and selection.
- Two independent approaches for reconstruction of strange particles are developed and implemented in FLES based on the conventional and missing mass methods.
- The missing mass method allows to cover an additional kinetic region and decay channels not visible for the conventional method, such as $\Xi^- \to \pi^- (\Lambda \to n\pi^0)$, $\Omega^- \to K^- (\Lambda \to n\pi^0)$.
- Both methods show high efficiency, significance and S/B rations. The results are comparable and can be used for systematic studies.

We will soon make our algorithms available under GPL license:

- the Kalman Filter to estimate trajectory parameters (0.5 μs/core/track);
- the Cellular Automaton for searching for particle trajectories in STS (100 μs/core/track);
- the Cellular Automaton for searching for particle trajectories in TPC (70 μs/core/track);
- the KF Particle Finder package with more than 150 decay channels implemented (100 μs/core/decay).

If you have an interest in these algorithms, please contact me.