SPD meeting,
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Reconstruction of short-lived particles in SPD experiment

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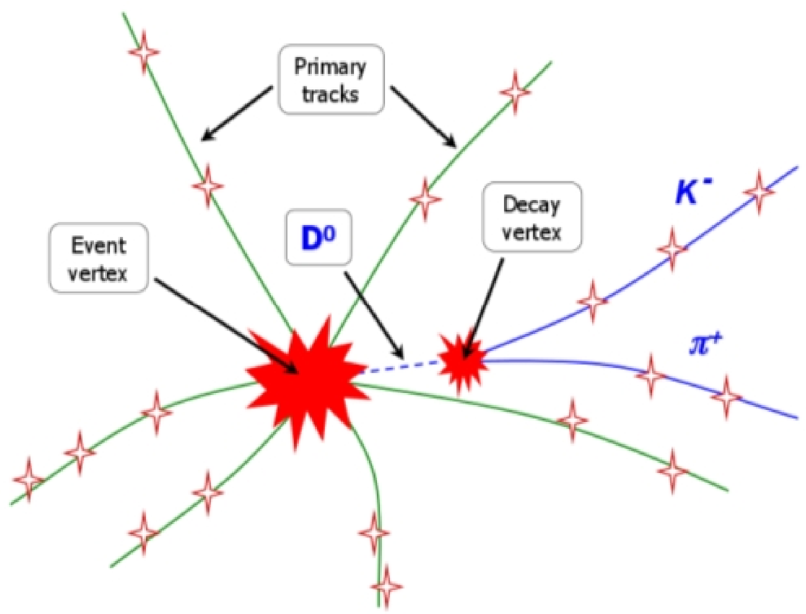
Introduction

- Particles, which are produced in a collision, can be divided into two groups: long-lived particles and short-lived particles.

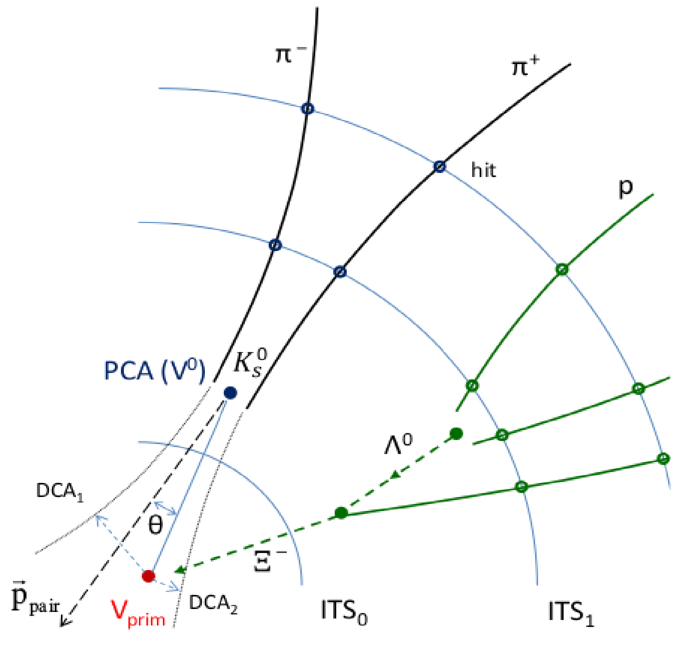
- Long-lived particles have a lifetime large enough to cross the tracking detector system of the experiment and to be registered directly ($e^{\pm}$, $p^{\pm}$ and particles with a large decay length $c\tau$, like muons, pions and $K^{\pm}$ mesons).

- Short-lived are those particles, which decay before or inside the tracking system and can be registered only indirectly: strange hyperons (Λ, Ξ, Ω), low mass vector mesons (ρ, ω, φ), charmed particles (D mesons, J/ψ) end etc.



Introduction

- General scheme of short-lived particles reconstruction:
  - fit tracks with Kalman filter methods (in our case);
  - select primary and secondary particles on the base of DCA (distance of closest approach) to PV or another methods;
  - reconstruct secondary vertex (as point of DCA between daughter particles trajectories)
  - finally, reconstruct of mother particle parameters based on parameters of daughter particles



- The special KF Particle package has been developed for the complete reconstruction of short-lived particles with their momentum, energy, mass, lifetime, decay length, rapidity, etc. Used in ATLAS, STAR, CBM and others experiments.
- Now this KF Particle package is installed in SPD (thanks Artur)

KF Particle package

Package has following properties:

- is based on Kalman filter mathematics;
- daughter and mother particles are described with the same set of parameters and are treated in exactly the same way;
- the package is geometry independent;
- daughter particles are added to the mother particle absolutely independently from each other
- the package allows reconstruction of decay chains
- the state vector of the particle includes 8 parameters => $\mathbf{r} = (x, y, z, Px, Py, Pz, E, s)$, where $s = l/p$ (distance normalized on the momentum, when a production point of particle is known, x,y,z – coordinates of first hit position)

KF Particle package

Algorithm of the short-lived particles reconstruction can be described as follows:

1. fit tracks with Kalman fitter (with PID hypothesis)

2. transform track parameters to KF Particle format **r** = (*x, y, z, Px, Py, Pz, E, s*)

3. reconstruct primary vertex (PV) with KF Particle package or provide PV itself

4. sort tracks (primary positive, primary negative, secondary positive, secondary negative) on the base of chi2 criteria:

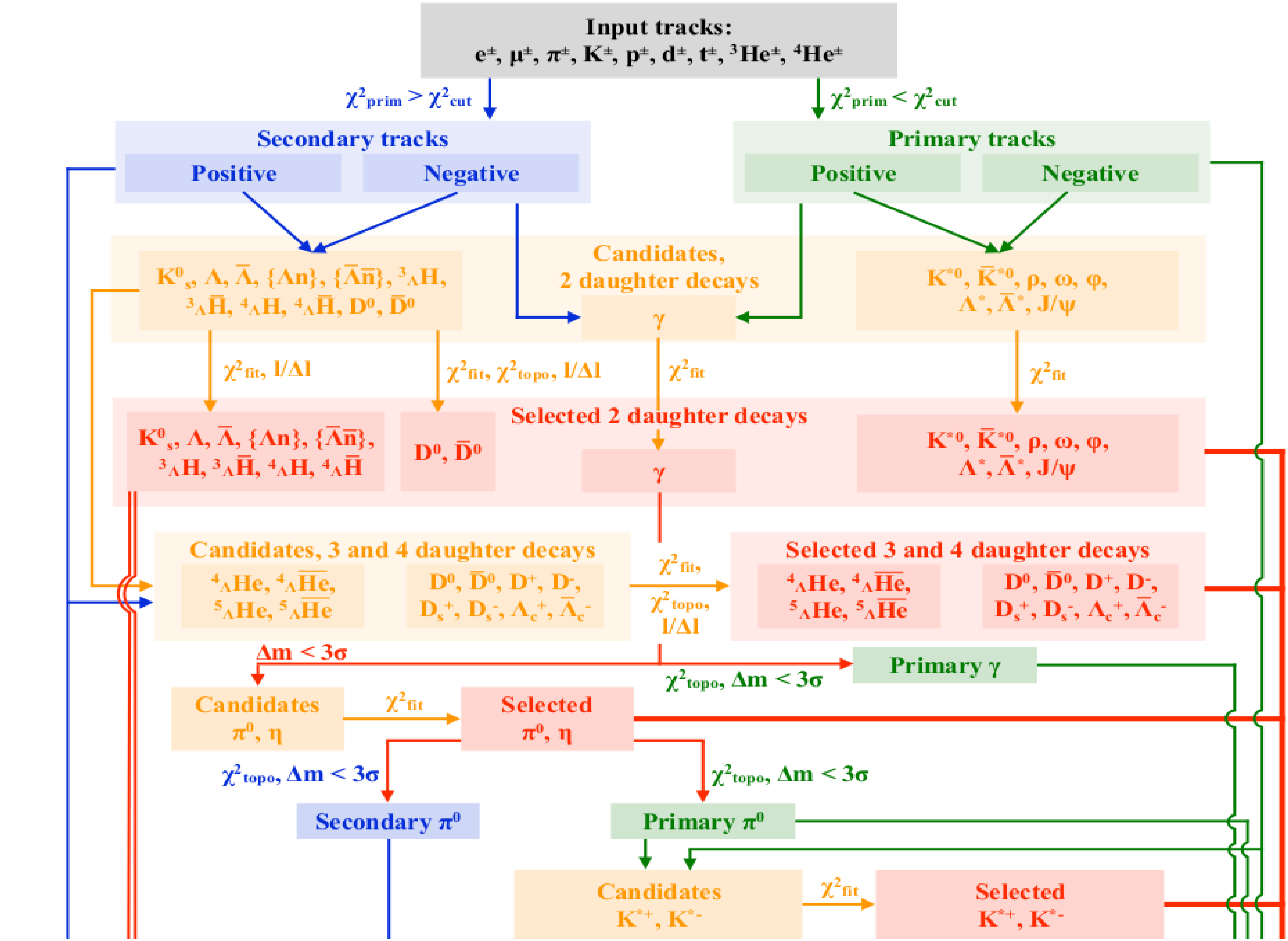
$$\chi^2_{prim} = \Delta\mathbf{r}^T (C_{track} + C_{PV})^{-1} \Delta\mathbf{r},$$

where Δr – distance between track and the primary vertex position, $\boldsymbol{C_{track}}$ is covariance matrix of a track and $\boldsymbol{C_{PV}}$ is a covariance matrix of primary vertex

5. initial approximation of the secondary vertex as DCA between secondary tracks

6. transport daughter particles to the initial secondary vertex approximation

7. calculate the momentum of the daughters and its covariance matrix at the approximated secondary vertex position and reconstruct the mother particle


Input tracks:
e±, μ±, π±, K±, p±, d±, t±, ³He±, ⁴He±
χ²prim > χ²cut
χ²prim < χ²cut
Secondary tracks
Positive
Negative
Primary tracks
Positive
Negative
Candidates,
2 daughter decays
K⁰s, Λ, Λ̄, {Λn}, {Λ̄n̄}, ³ΛH, ³ΛH̄, ⁴ΛH, ⁴ΛH̄, D⁰, D̄⁰
γ
K*⁰, K̄*⁰, ρ, ω, φ, Λ*, Λ̄*, J/ψ
χ²fit, l/Δl
χ²fit, χ²topo, l/Δl
χ²fit
χ²fit
Selected 2 daughter decays
K⁰s, Λ, Λ̄, {Λn}, {Λ̄n̄}, ³ΛH, ³ΛH̄, ⁴ΛH, ⁴ΛH̄
D⁰, D̄⁰
γ
K*⁰, K̄*⁰, ρ, ω, φ, Λ*, Λ̄*, J/ψ
Candidates, 3 and 4 daughter decays
⁴ΛHe, ⁴ΛH̄e, ⁵ΛHe, ⁵ΛH̄e
D⁰, D̄⁰, D⁺, D⁻, Ds⁺, Ds⁻, Λc⁺, Λ̄c⁻
χ²fit, χ²topo, l/Δl
Selected 3 and 4 daughter decays
⁴ΛHe, ⁴ΛH̄e, ⁵ΛHe, ⁵ΛH̄e
D⁰, D̄⁰, D⁺, D⁻, Ds⁺, Ds⁻, Λc⁺, Λ̄c⁻
Δm < 3σ
Primary γ
χ²topo, Δm < 3σ
Candidates
π⁰, η
χ²fit
Selected
π⁰, η
χ²topo, Δm < 3σ
χ²topo, Δm < 3σ
Secondary π⁰
Primary π⁰
Candidates
K*⁺, K*⁻
χ²fit
Selected
K*⁺, K*⁻

Primary vertex reconstruction precision

1. simulate 6 particles (muons) with momentum 1 GeV/c (3 positive and 3 negative) in vertex position (0, 0, 0) and constant magnetic field 10 kG:
   - with beam-pipe, vertex (silicon) and tracker (straw tube) material;
   - without material;
   - add space point resoution in 50 μm for vertex and 150 μm for straw tracker;

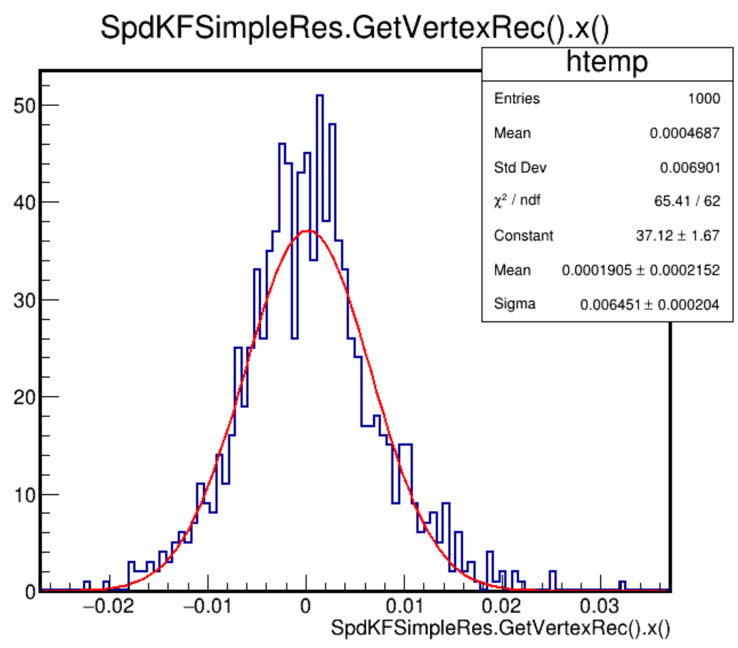
2. fit tracks with Kalman filter and reconstruct primary vertex

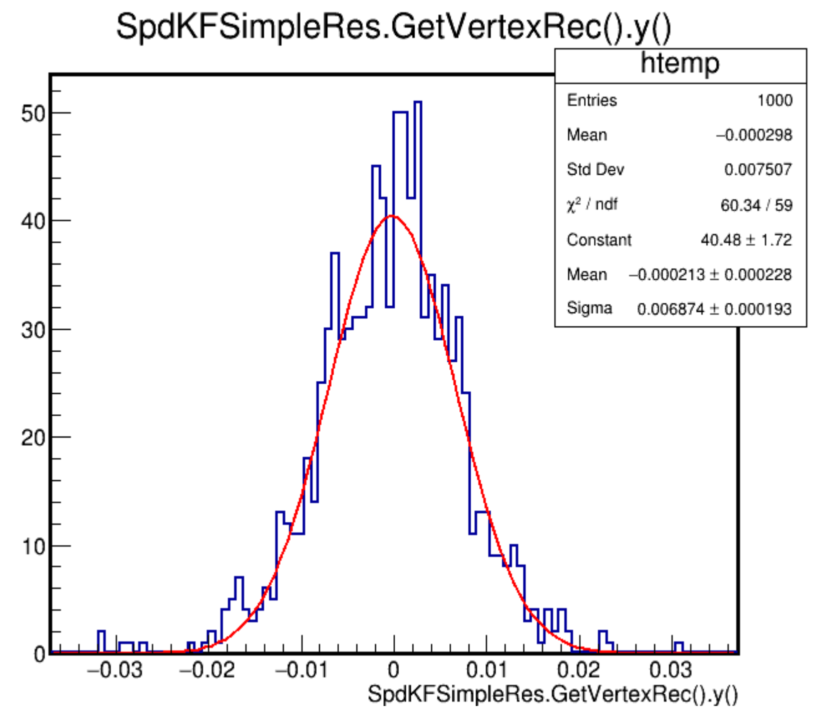
3. simulate 12 particles

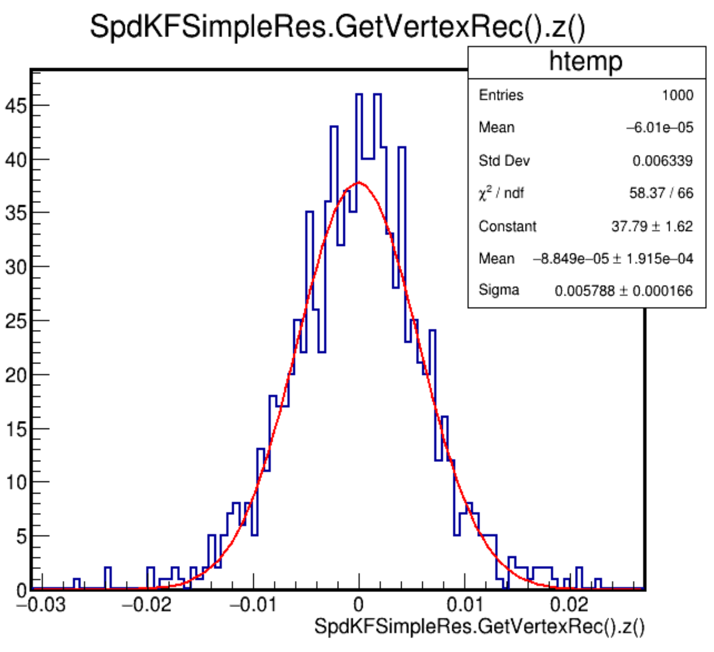
4. estimate DCA (distance of closest approach to PV)

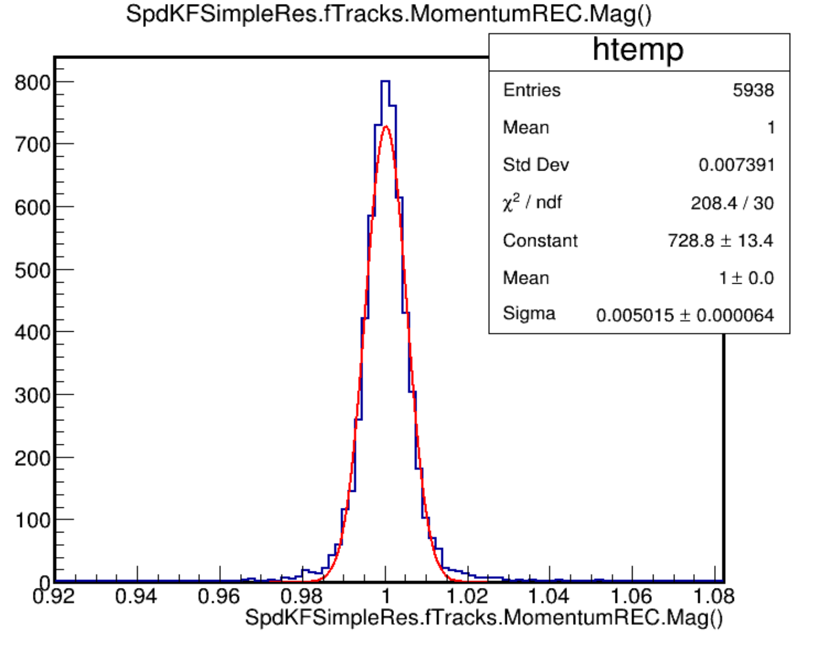
	σx (μm)	σy (μm)	σz (μm)	Δp/p (%)
no material	~47	~50	~45	~0.15
with material	~65	~68	~58	~0.5
12 particles with material	~44	~47	~40	
DCA with material	~93	~92	~90	

Primary vertex precision

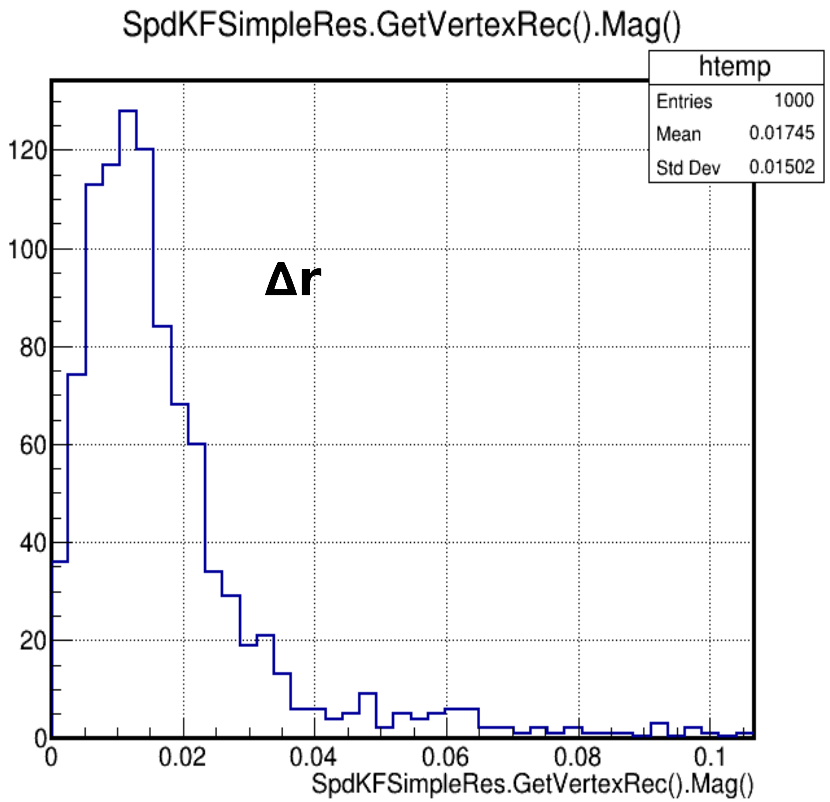


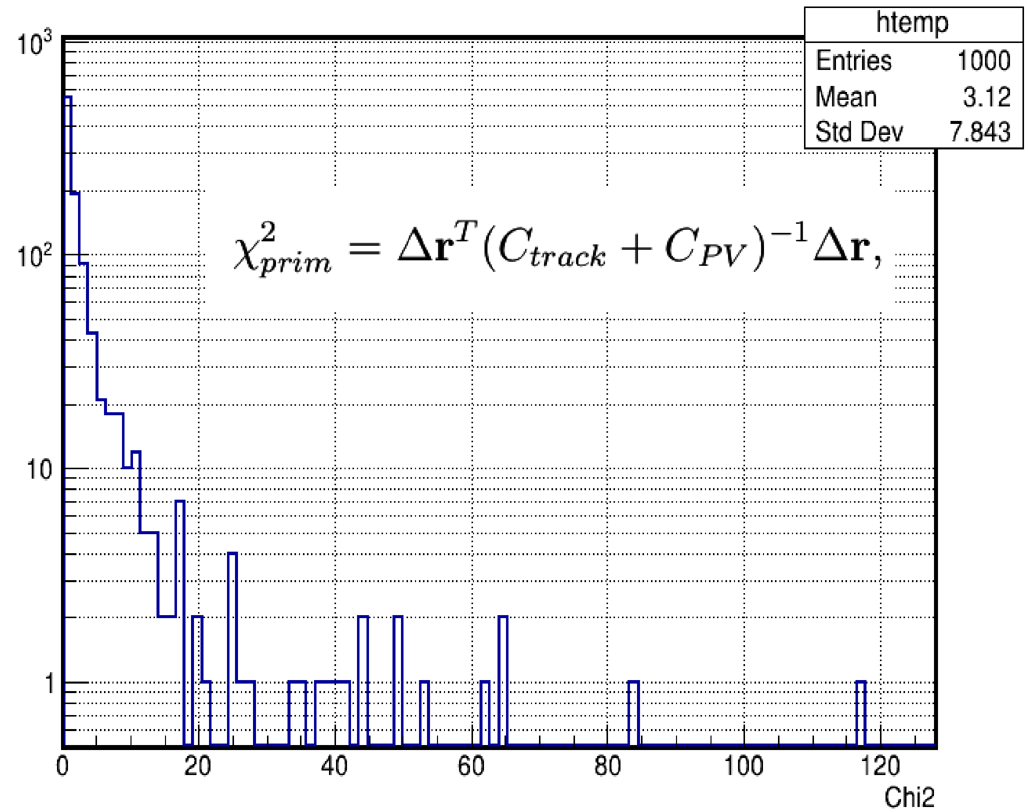






Primary vertex



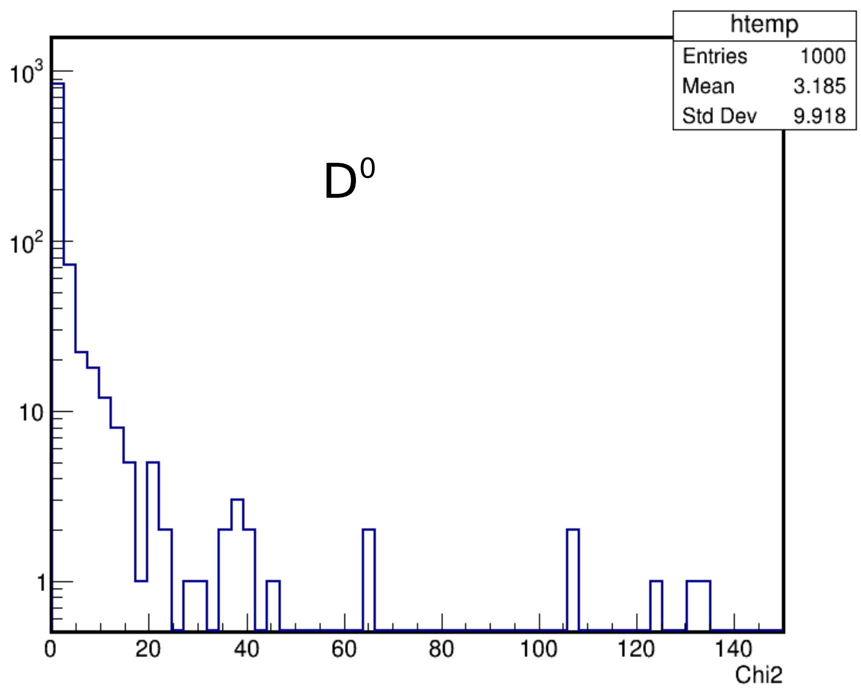


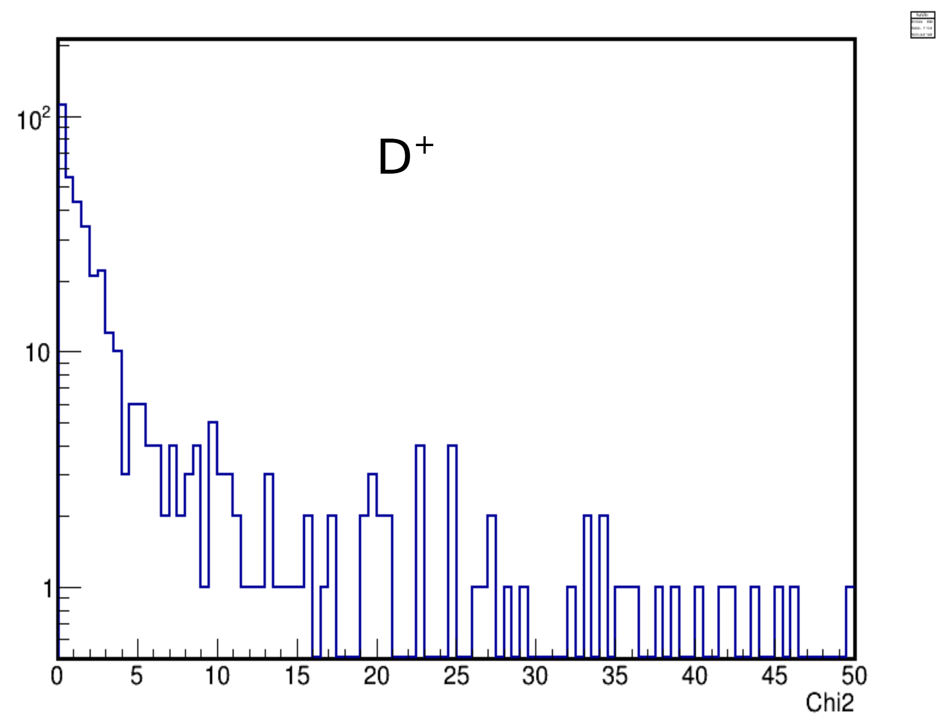
where Δr – distance between track and the primary vertex position, $\boldsymbol{C}_{\boldsymbol{track}}$ is covariance matrix of a track and $\boldsymbol{C}_{\boldsymbol{PV}}$ is a covariance matrix of primary vertex

Short-lived particle in SPD

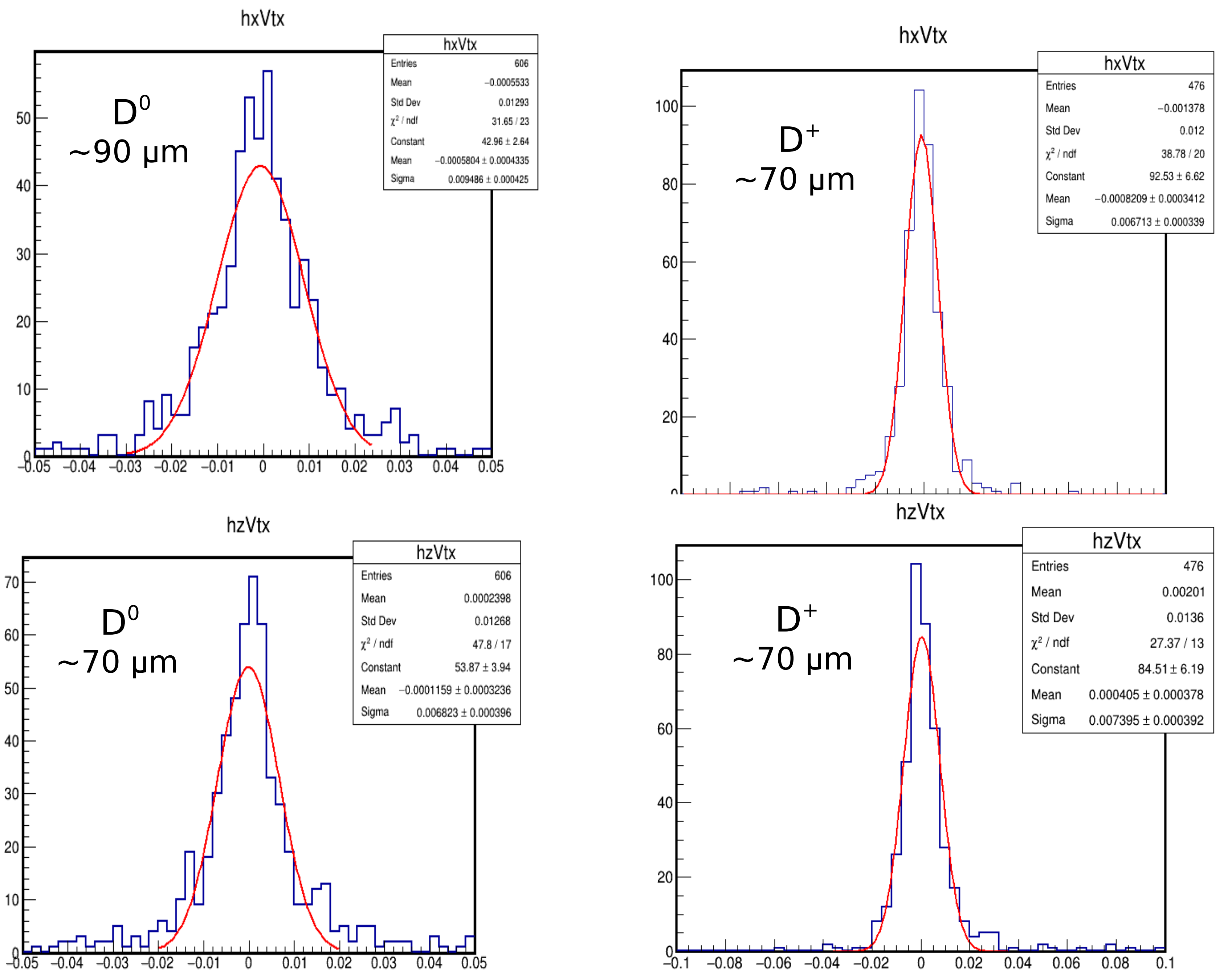
1. consider $D^0 \rightarrow K^- \pi^+$ => cτ = 122.9 μm
2. $D^+ \rightarrow K^- \pi^+ \pi^+$ => cτ = 311.8 μm
3. constant magnetic field 10 kG
4. ideal finder

Chi2 distribution at PV for daughter particles

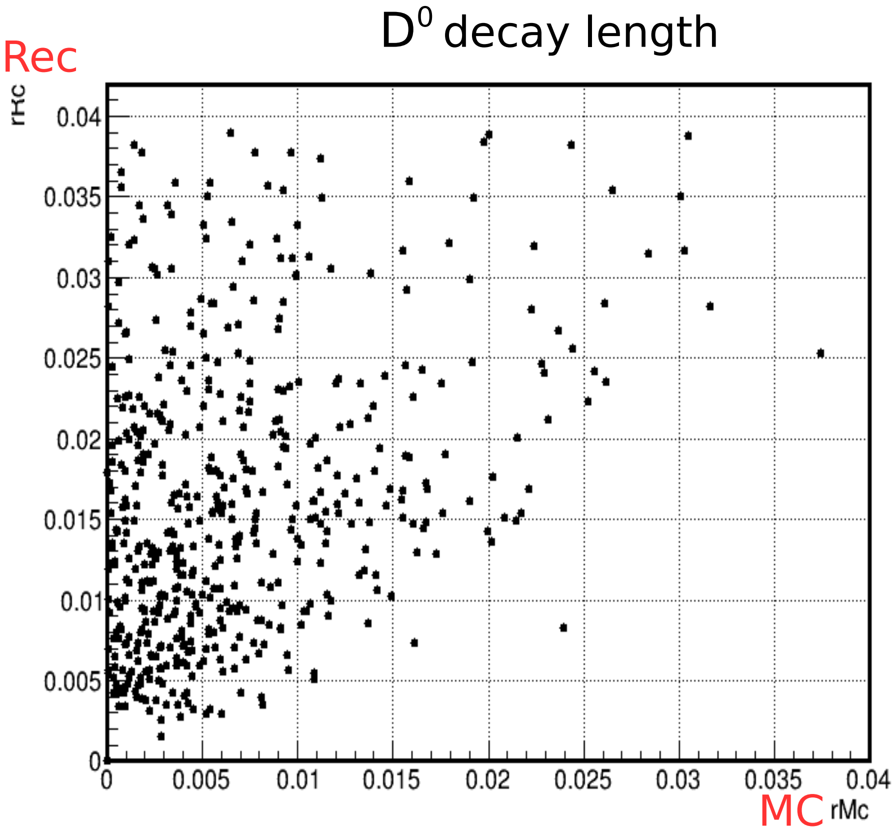


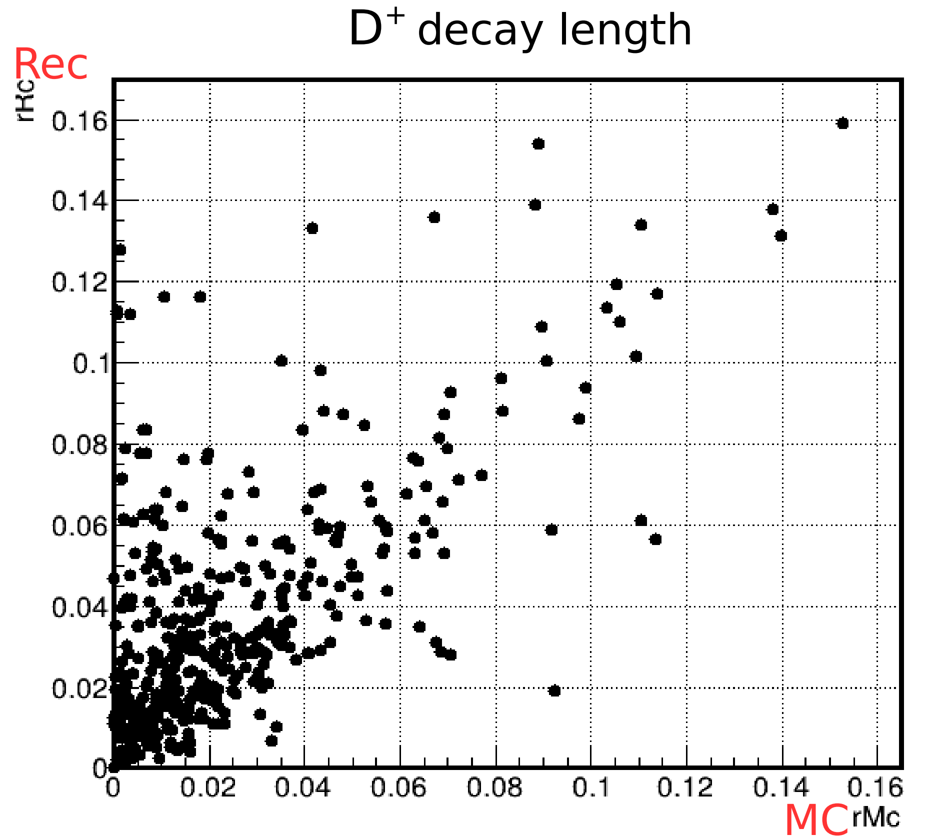


Secondary vertex precision

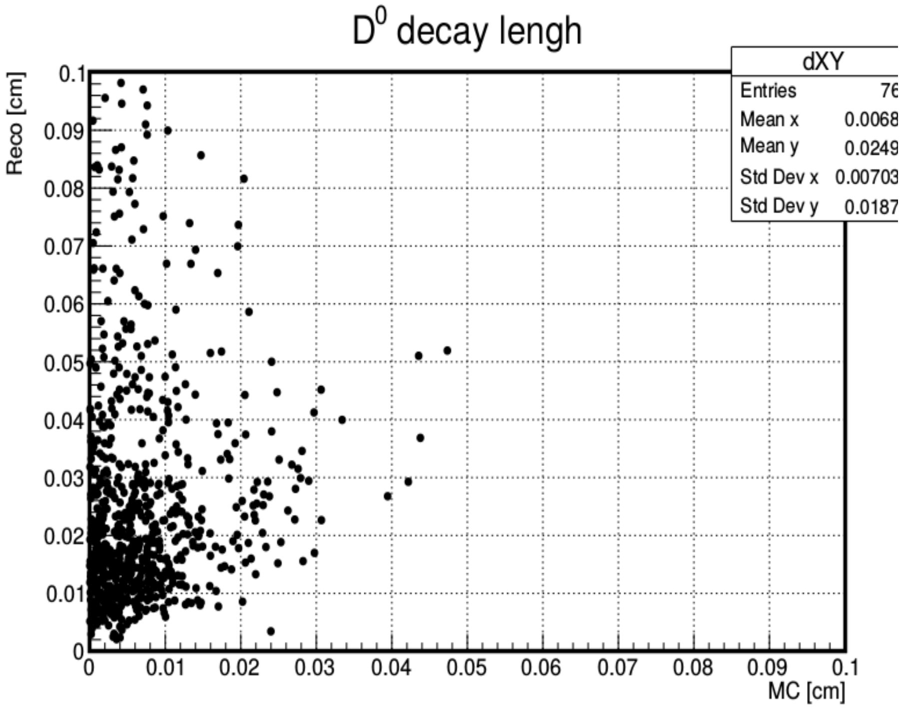


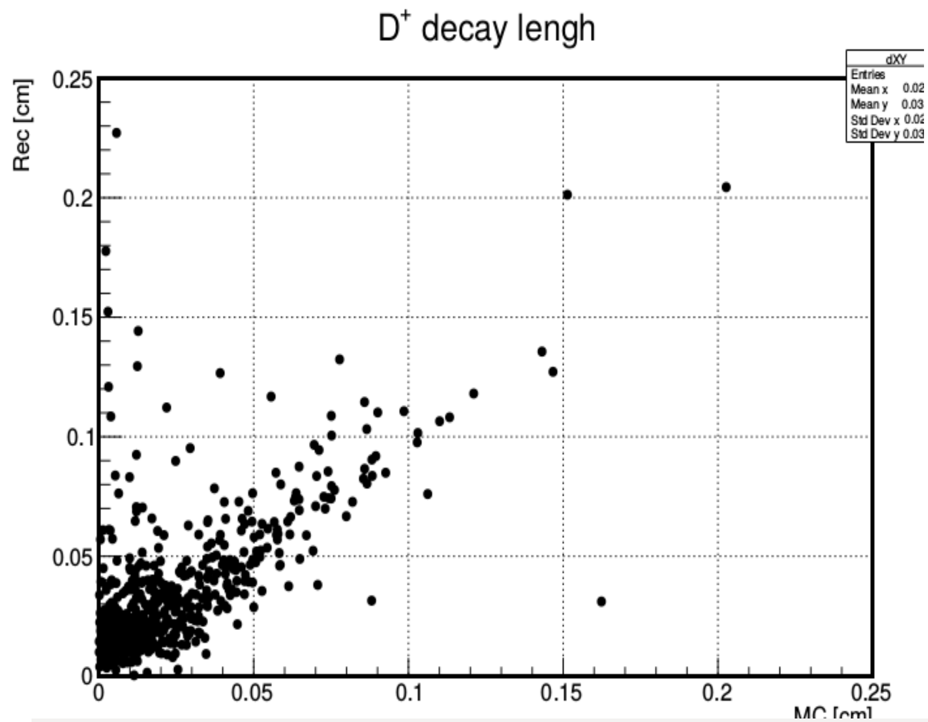
Secondary vertex decay length

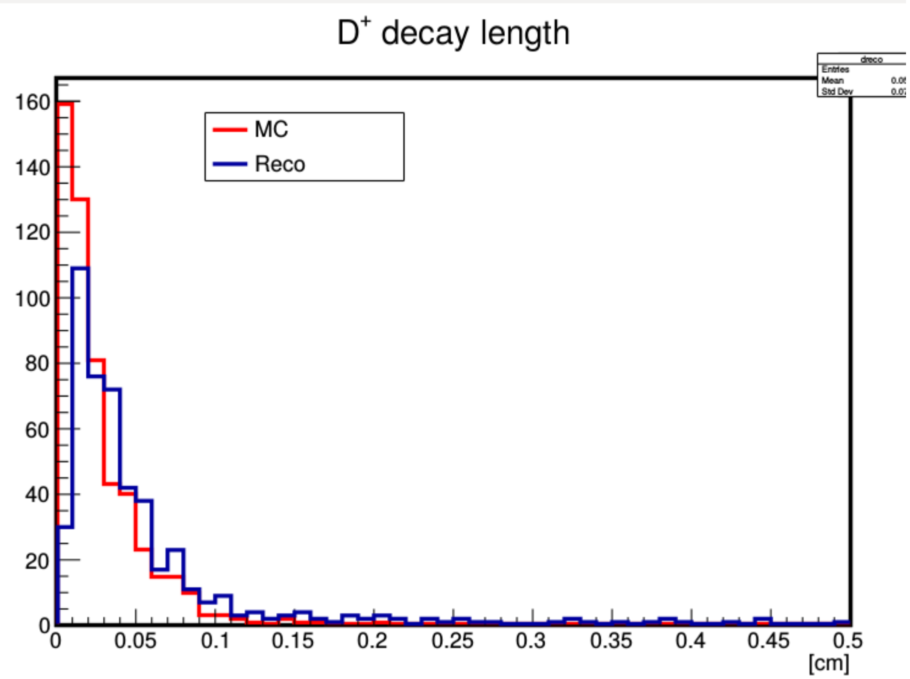




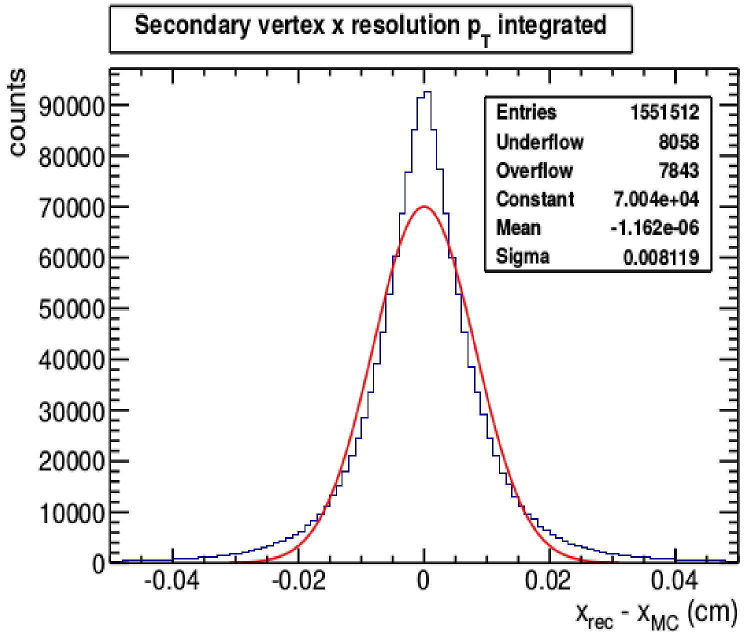
Secondary vertex decay length (CBM)







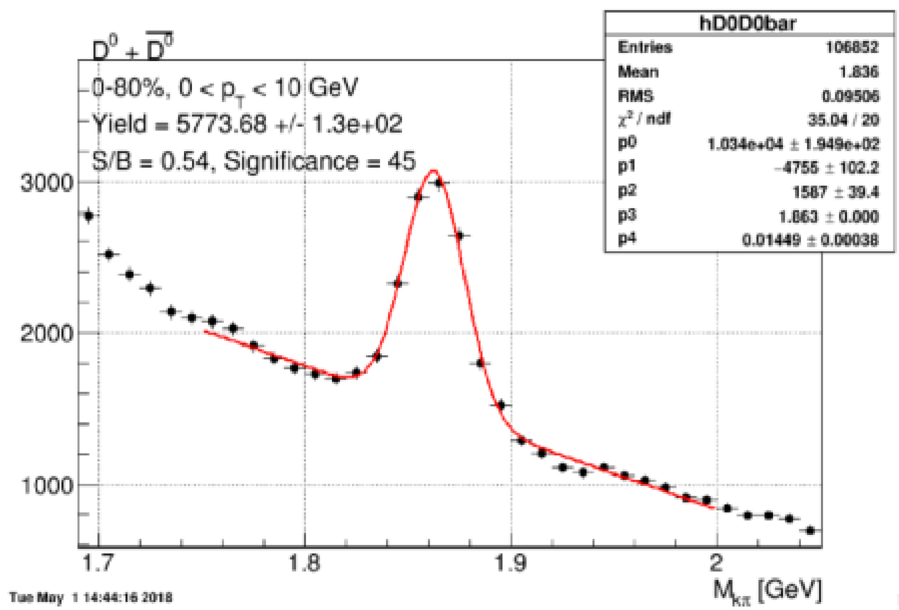
Secondary vertex (another experiments)



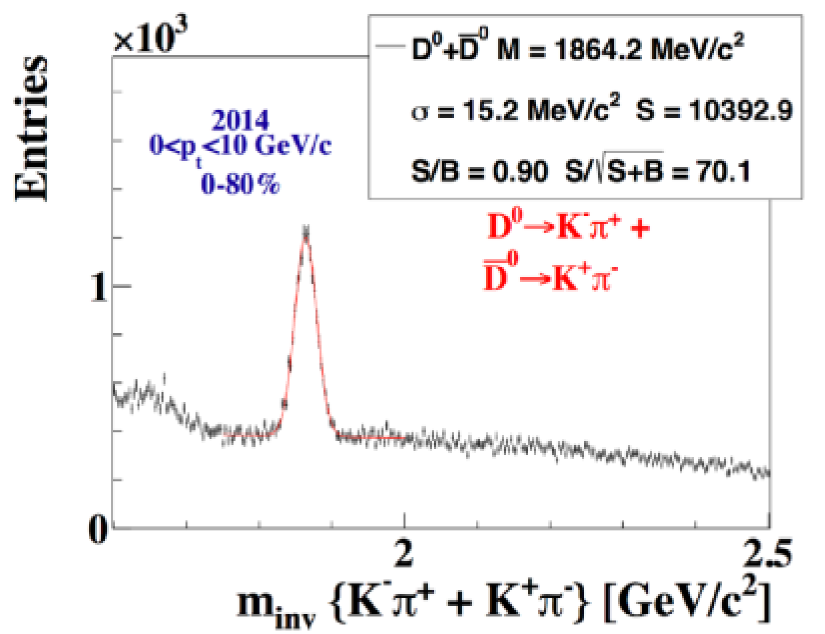
ATLAS secondary vertex precision $\sigma_x \sim 80$ μm

STAR

Standard reconstruction



KF Particle Finder



Results

1) KF Particle package for finding and reconstruction of short-lived particles
   is available in SPDroot

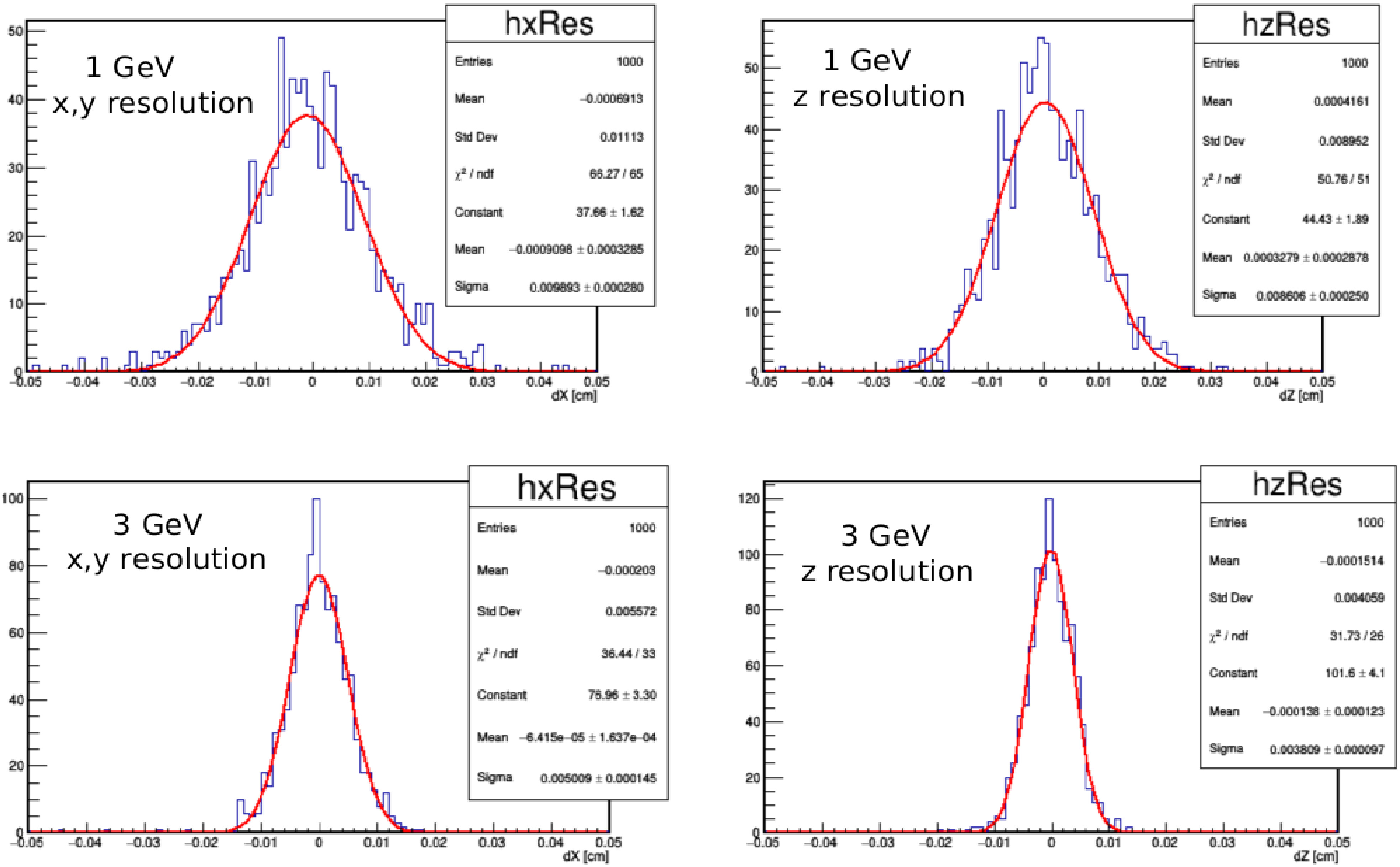
2) PID is important for KF Particle

3) first preliminary results of using KF Particle in SPD is presented

4) need to study and adjust the cuts for separation of short-live particle candidates

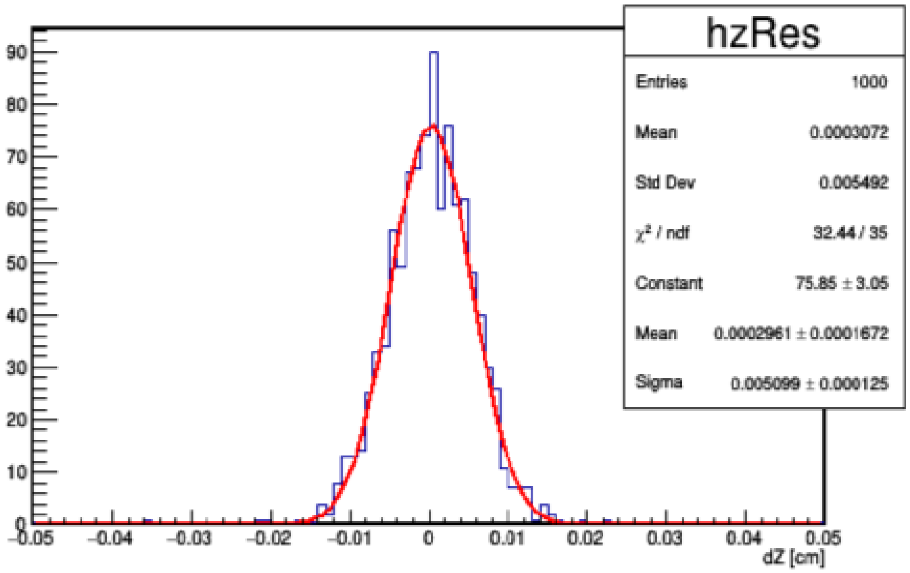
Backup slides

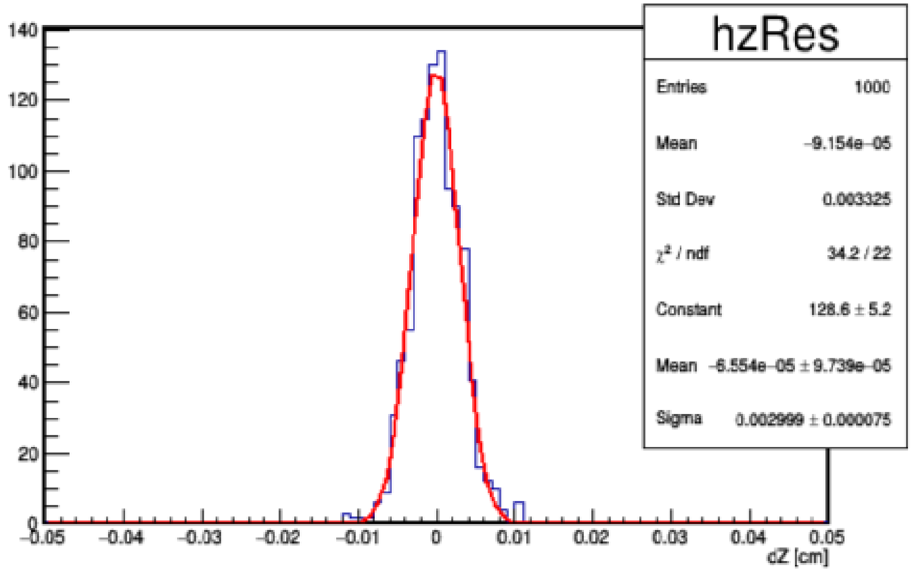
Vertex position resolution with vertex detector



x,y resolution ~100 μm for 1 GeV and ~50 μm for 3 GeV particles and
z resolution ~86 μm for 1 GeV and ~40 μm for 3 GeV particles

Vertex position resolution (in z) with vertex detector (25 μm precision)

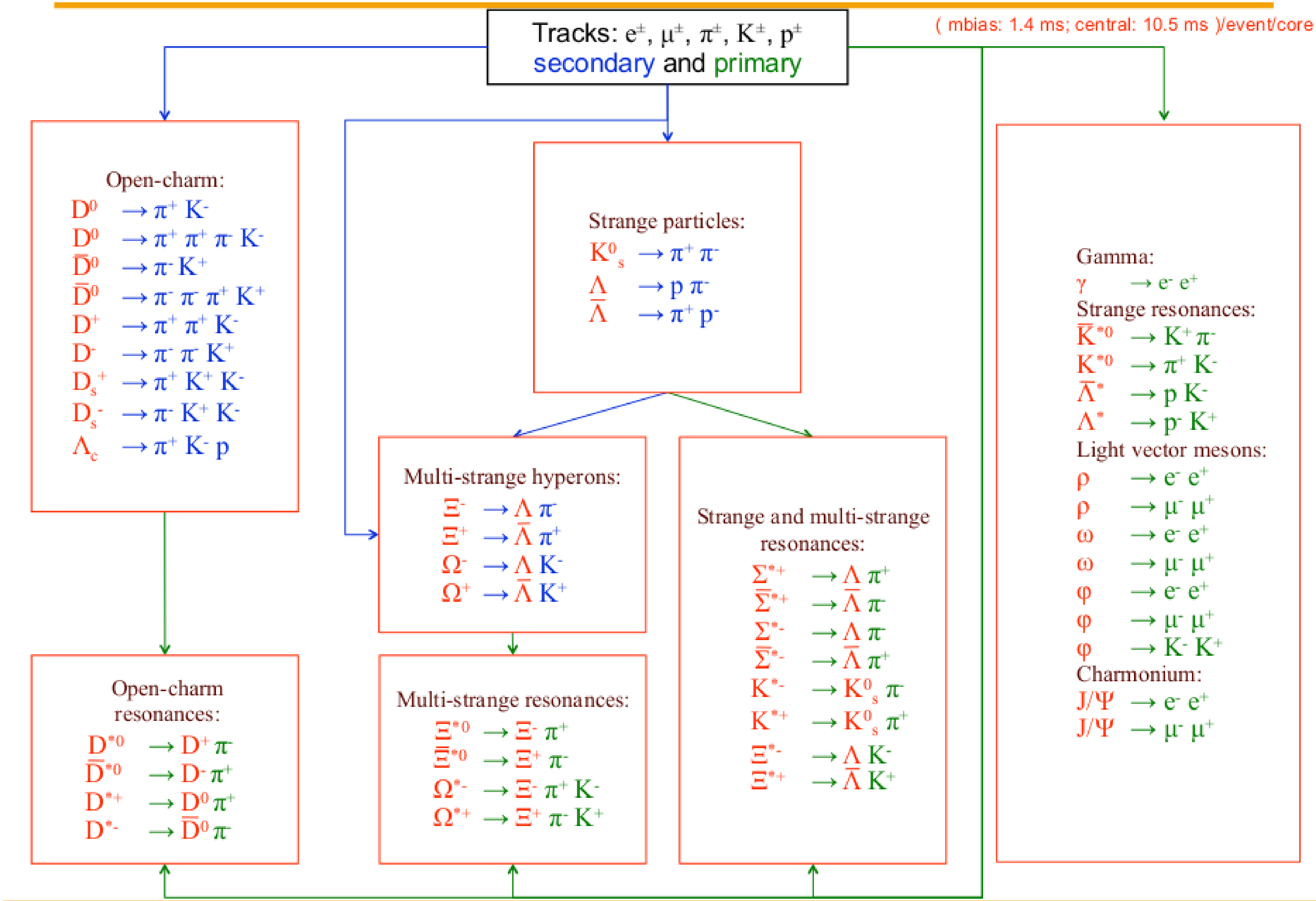




6 tracks with 150 μm space point resolution (in straw tracker) and vertex detector (silicon tracker) with 25 μm space resolution

Conclusion => primary vertex position resolution strongly depends on
vertex detector resolution:

- from 86 μm => 50 μm for 1 GeV track's momentum and
- from 40 μm => 30 μm for 3 GeV track's momentum if vertex detector resolution will change from 50 μm to 25 μm


(mbias: 1.4 ms; central: 10.5 ms)/event/core
Tracks: $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$
secondary and primary
Open-charm:
$D^0 \rightarrow \pi^+ K^-$
$D^0 \rightarrow \pi^+ \pi^+ \pi^- K^-$
$\bar{D}^0 \rightarrow \pi^- K^+$
$\bar{D}^0 \rightarrow \pi^- \pi^- \pi^+ K^+$
$D^+ \rightarrow \pi^+ \pi^+ K^-$
$D^- \rightarrow \pi^- \pi^- K^+$
$D_s^+ \rightarrow \pi^+ K^+ K^-$
$D_s^- \rightarrow \pi^- K^+ K^-$
$\Lambda_c \rightarrow \pi^+ K^- p$
Strange particles:
$K^0_s \rightarrow \pi^+ \pi^-$
$\Lambda \rightarrow p \pi^-$
$\bar{\Lambda} \rightarrow \pi^+ p^-$
Gamma:
$\gamma \rightarrow e^- e^+$
Strange resonances:
$\bar{K}^{*0} \rightarrow K^+ \pi^-$
$K^{*0} \rightarrow \pi^+ K^-$
$\bar{\Lambda}^* \rightarrow p K^-$
$\Lambda^* \rightarrow p^- K^+$
Light vector mesons:
$\rho \rightarrow e^- e^+$
$\rho \rightarrow \mu^- \mu^+$
$\omega \rightarrow e^- e^+$
$\omega \rightarrow \mu^- \mu^+$
$\varphi \rightarrow e^- e^+$
$\varphi \rightarrow \mu^- \mu^+$
$\varphi \rightarrow K^- K^+$
Charmonium:
$J/\Psi \rightarrow e^- e^+$
$J/\Psi \rightarrow \mu^- \mu^+$
Multi-strange hyperons:
$\Xi^- \rightarrow \Lambda \pi^-$
$\Xi^+ \rightarrow \bar{\Lambda} \pi^+$
$\Omega^- \rightarrow \Lambda K^-$
$\Omega^+ \rightarrow \bar{\Lambda} K^+$
Strange and multi-strange resonances:
$\Sigma^{*+} \rightarrow \Lambda \pi^+$
$\bar{\Sigma}^{*+} \rightarrow \bar{\Lambda} \pi^-$
$\Sigma^{*-} \rightarrow \Lambda \pi^-$
$\bar{\Sigma}^{*-} \rightarrow \bar{\Lambda} \pi^+$
$K^{*-} \rightarrow K^0_s \pi^-$
$K^{*+} \rightarrow K^0_s \pi^+$
$\Xi^{*-} \rightarrow \Lambda K^-$
$\Xi^{*+} \rightarrow \bar{\Lambda} K^+$
Open-charm resonances:
$D^{*0} \rightarrow D^+ \pi^-$
$\bar{D}^{*0} \rightarrow D^- \pi^+$
$D^{*+} \rightarrow D^0 \pi^+$
$D^{*-} \rightarrow \bar{D}^0 \pi^-$
Multi-strange resonances:
$\Xi^{*0} \rightarrow \Xi^- \pi^+$
$\bar{\Xi}^{*0} \rightarrow \Xi^+ \pi^-$
$\Omega^{*-} \rightarrow \Xi^- \pi^+ K^-$
$\Omega^{*+} \rightarrow \Xi^+ \pi^- K^+$

Boost Decision Tree