The liquid xenon barrel calorimeter of the CMD-3 detector

(particle identification using CMD-3’s liquid xenon calorimeter)

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LXe calorimeter of the CMD-3 detector

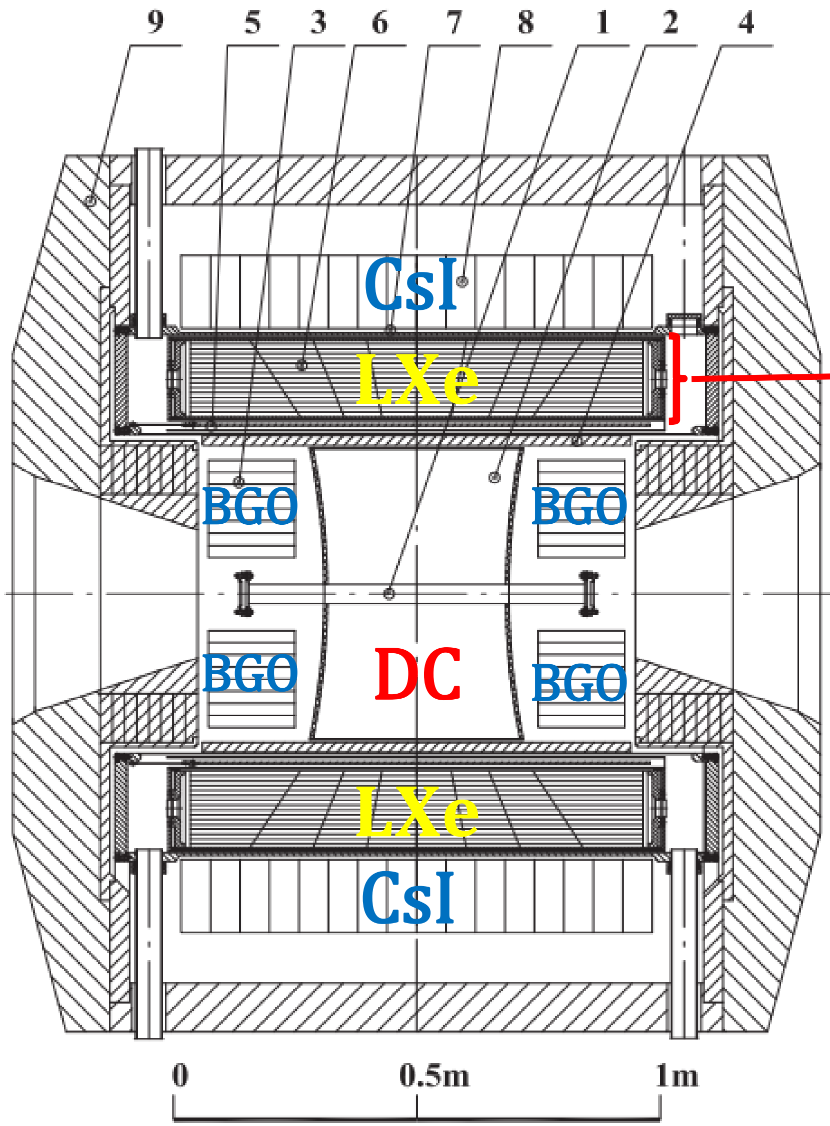
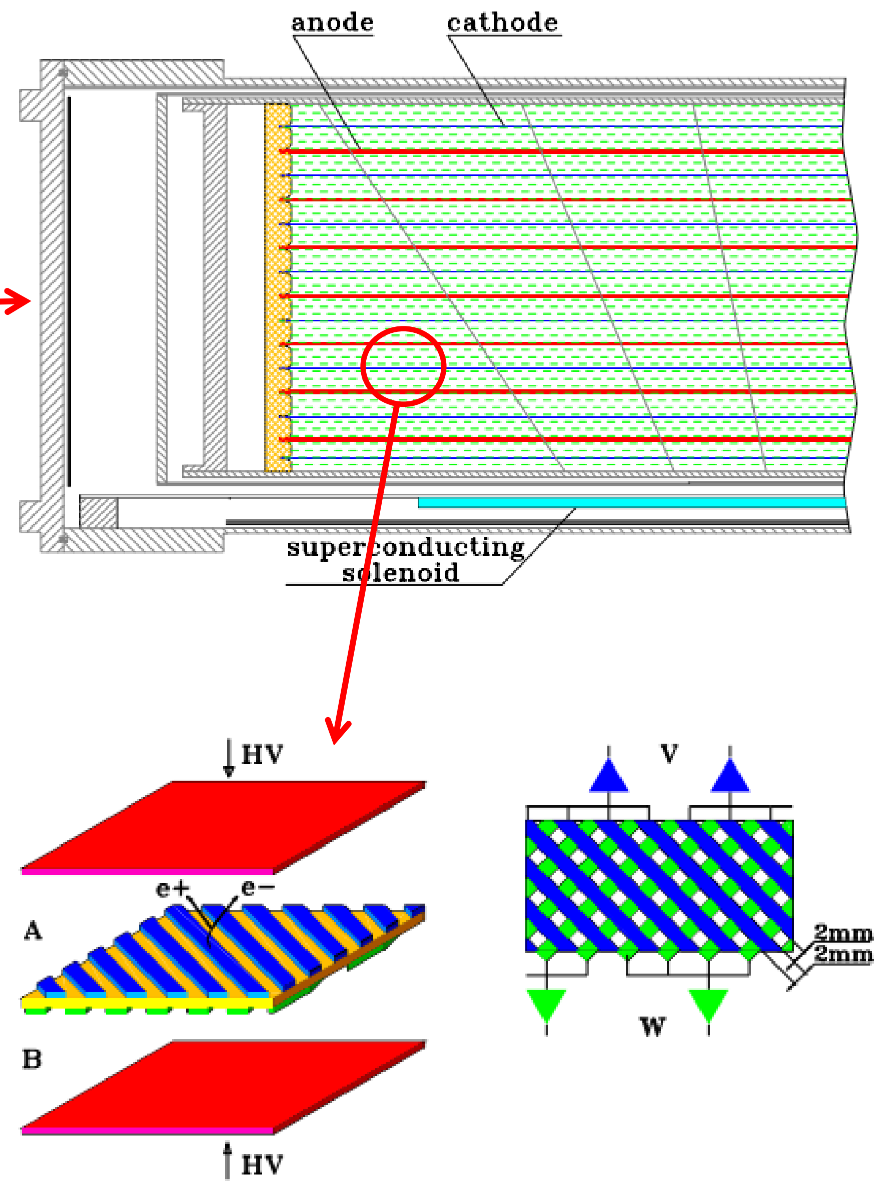
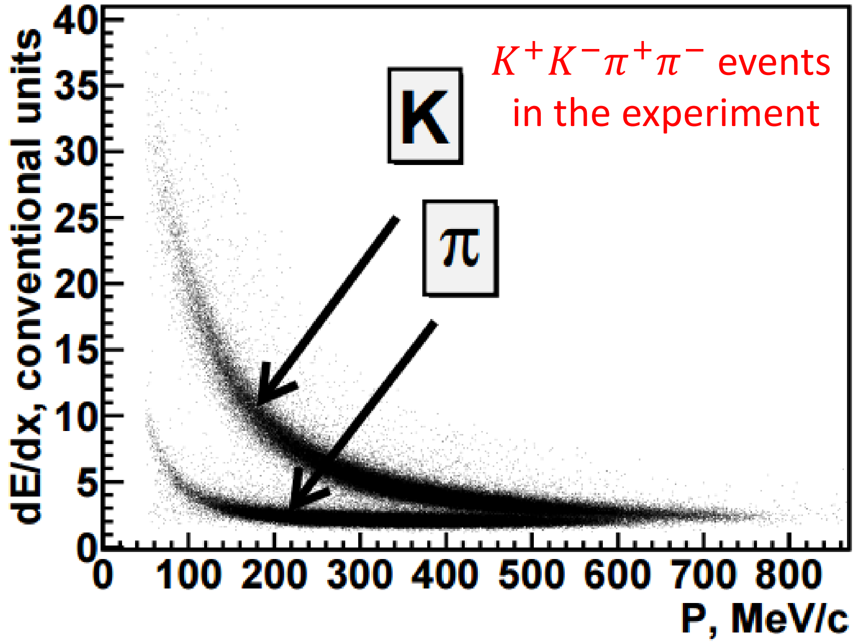


Fig. 1. 1 – beam pipe, 2 – drift chamber, 3 – BGO electromagnetic calorimeter, 4 – Z-chamber, 5 – SC solenoid ($0.13X_0$, 13 kGs), 6 – LXe electromagnetic calorimeter (the segmentation with "towers" specially shown), 7 – TOF system, 8 – CsI electromagnetic calorimeter, 9 – Yoke.



Motivation

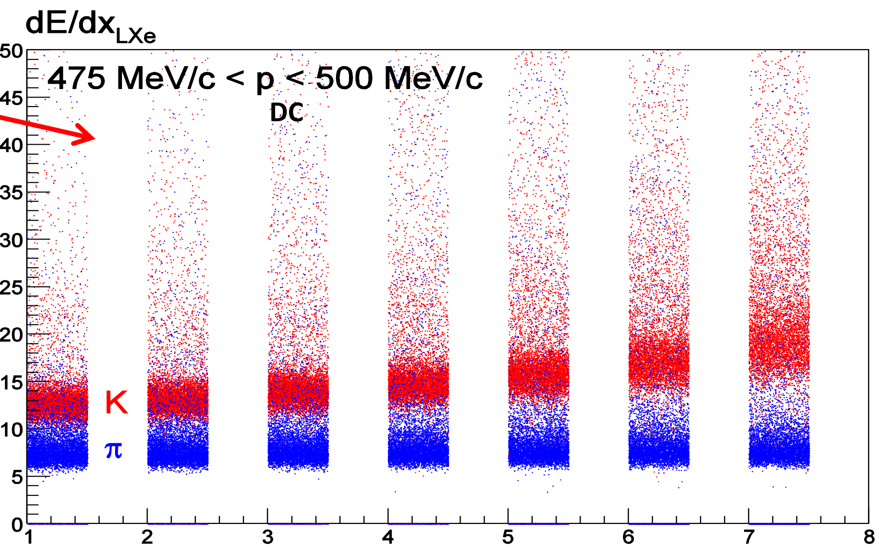
- Charged kaons/pions separation in CMD-3 is currently performed using dE/dx in the drift chamber (DC):

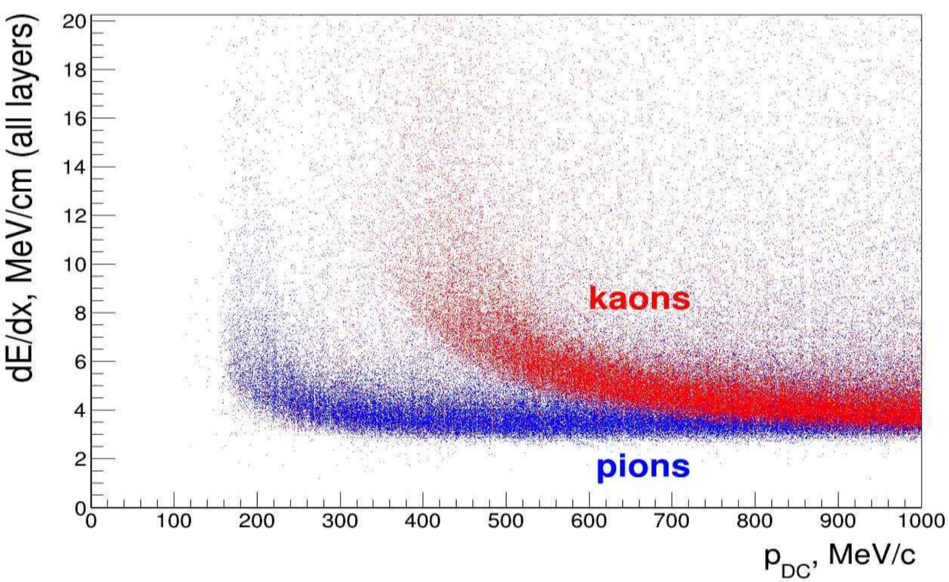


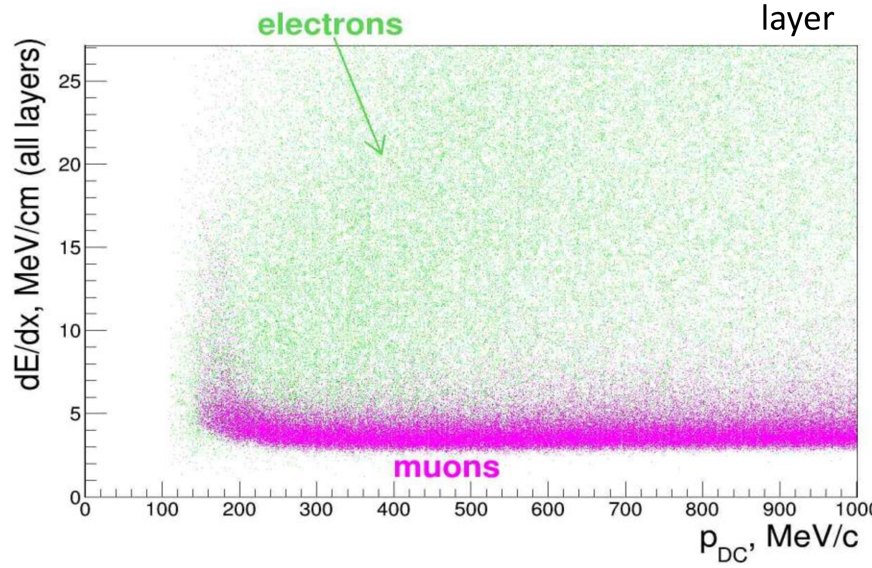
- Separation of **single** $K^{\pm}$ from $\pi^{\pm}$ ($\mu^{\pm}$) using dE/dx_{DC} is reliable only for $p < 500$ MeV/c
- For the **system** of four tracks (e.g. $K^+K^-\pi^+\pi^-$) dE/dx_{DC} together with energy-momentum conservation laws can provide us with enough clean sample of signal events even at the larger particles momenta (up to 700 MeV/c)
- For the final states $K^+K^-\pi^0\pi^0$, $K^+K^-\pi^0$ at high energies the usage of dE/dx_{DC} is insufficient for background suppression, for K^+K^- - almost useless
- **$\Rightarrow$ application of the dE/dx_{LXe} in 7 LXe layers for the task of particle identification**

General considerations

- Unlike DC the whole LXe calorimeter is not, generally, a thin layer (as the momentum loss $\Delta p \sim p$). For m.i.p. and $\theta_{DC} = \frac{\pi}{2}$ the energy deposition in LXe $E_{LXe} \sim 60$ MeV. But each layer individually can be considered as a thin layer (except for the very low particles momenta).
- dE/dx_{LXe} on the average increases layer by layer
- It is a lot of dead material before the LXe calorimeter ($0.13\,X_0$). Kaons with $p < 300$ MeV/c are stopped there
- dE/dx_{LXe} depends on the angle of penetration of the particle to the LXe
- In the LXe the kaon/pion interactions with the nuclei, as well as the decays of particles play important roles





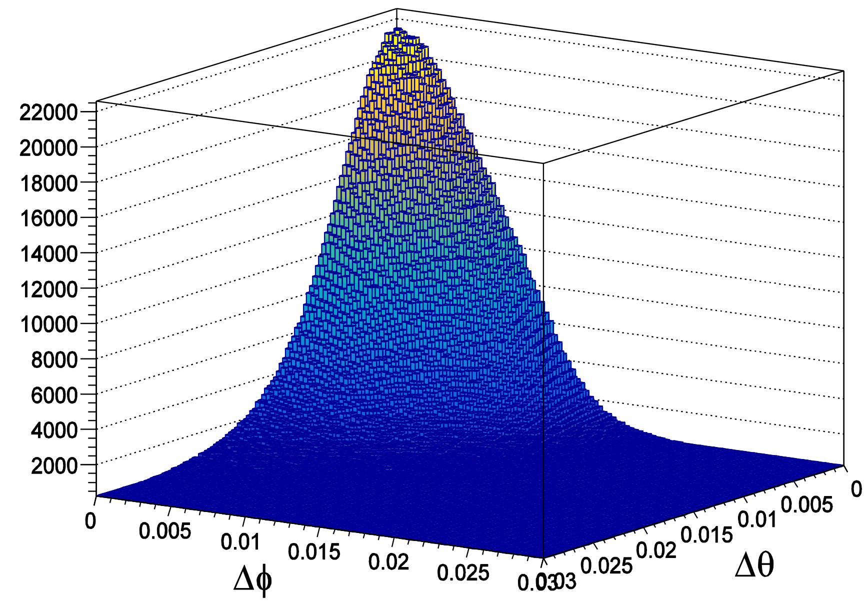


Binding of DC and LXe tracks

- From a simple kinematics of spiral motion one can obtain DC-track rotation angle and the expected (according DC) LXe cluster polar angle:

$$\varphi_{rotation} = \frac{q}{|e|}\arcsin\left(\frac{1.515 \cdot R_{LXe}[cm] \cdot B[T]}{p_{\perp}[MeV/c]}\right)$$

$$\theta_{LXe,expected} = arctg\left(\frac{R_{LXe}}{\left|z_{DC}+2R_{curv}ctg(\theta_{DC})\arcsin\left(\frac{R_{LXe}}{2R_{curv}}\right)\right|}\right)+$$
$$\pi(1\text{-sign}(z_{DC} + 2R_{curv}ctg(\theta_{DC})\arcsin\left(\frac{R_{LXe}}{2R_{curv}}\right)))$$



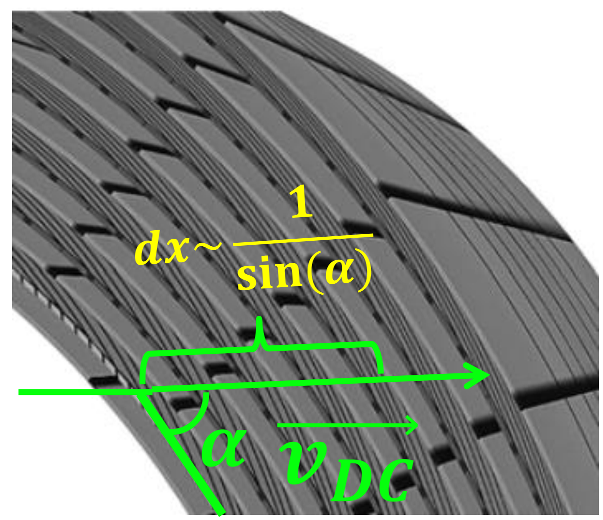
- Binding conditions:

$$|\Delta\varphi| = \left|\varphi_{LXe,\,measured} - \varphi_{DC,\,measured} + \varphi_{rotation}\right| < 0.03$$
$$|\Delta\theta| = \left|\theta_{LXe,\,measured} - \theta_{LXe,expected}\right| < 0.03$$

«good» track

- Energy deposition in the LXe layers most directly related to the parameter $dx \sim 1/\sin(\alpha)$, where α is an angle of penetration of the particle in the LXe:

$$\sin(\alpha) = \sin(\theta_{DC})\sqrt{1-\left(\frac{R_{LXe}}{2R_{curv}}\right)^2}$$



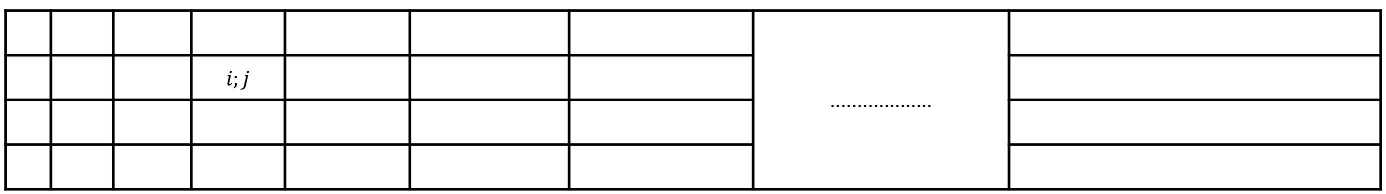
General idea of the particle identification procedure

- For each «good track» we should calculate 10 values of the responses of some multivariate classifier (taken from TMVA package), trained for the separation of the corresponding pairs of particles in the corresponding ranges Δp_i and $\Delta\left(\frac{1}{sin\alpha}\right)_j$:

	$e^{\pm}$	$\mu^{\pm}$	$\pi^{\pm}$	$K^{\pm}$
$\mu^{\pm}$	$Response_{ij}(\mu^{\pm}/e^{\pm})$	-	-	-
$\pi^{\pm}$	$Response_{ij}(\pi^{\pm}/e^{\pm})$	$Response_{ij}(\pi^{\pm}/\mu^{\pm})$	-	-
$K^{\pm}$	$Response_{ij}(K^{\pm}/e^{\pm})$	$Response_{ij}(K^{\pm}/\mu^{\pm})$	$Response_{ij}(K^{\pm}/\pi^{\pm})$	-
$p^{\pm}$	$Response_{ij}(p^{\pm}/e^{\pm})$	$Response_{ij}(p^{\pm}/\mu^{\pm})$	$Response_{ij}(p^{\pm}/\pi^{\pm})$	$Response_{ij}(p^{\pm}/K^{\pm})$

$p \in (40\ \mathrm{MeV/c}; 1100\ \mathrm{MeV/c})$

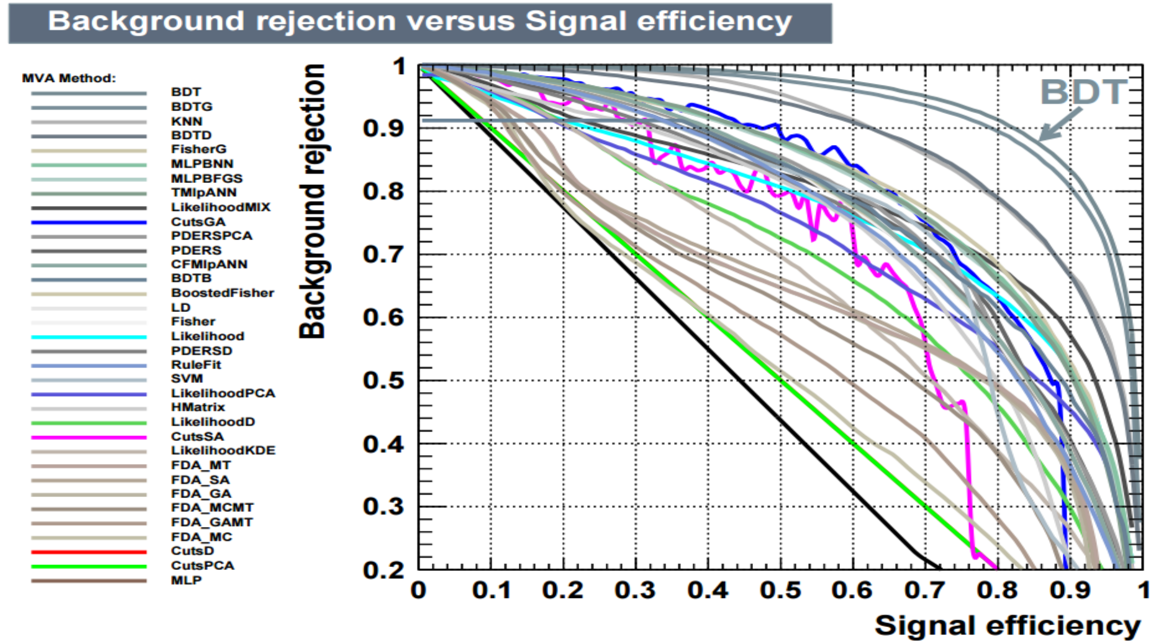
$\frac{1}{sin\alpha} \in (1; 1.4)$

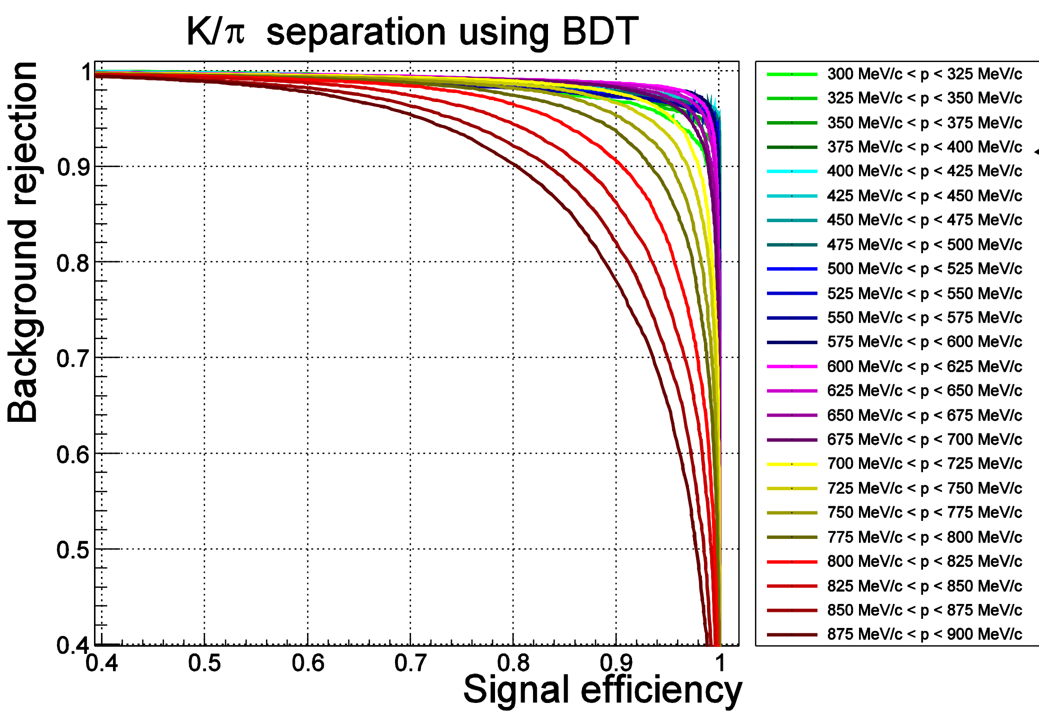


- We use uniform Δp_i and $\Delta\left(\frac{1}{sin\alpha}\right)_j$ partition
- To prepare the training ROOT trees for the classifier, we perform MC simulation uniformly with respect to p and $\frac{1}{sin\alpha}$

Searching for the most powerful classifier

- It makes sense to search it for the difficult task: e.g. K/π separation for $p \sim 870$ MeV/c
- We found that the globally most powerful classifier (at default settings) is BDT
- In addition it works faster than PDE, MLP etc.





ROC curves for the K/π separation in different momentum ranges

Example: selection of $e^+e^- \to K^+K^-$ events ($1.8\ \text{GeV} < \sqrt{s} < 2.0\ \text{GeV}$)

classifier training

Single $K^{\pm}$, $\pi^{\pm}$, $\mu^{\pm}$, $e^{\pm}$ are simulated with the momenta and angles, uniformly distributed in the ranges $p \in (40\ \text{MeV/c}; 1100\ \text{MeV/c})$, $\frac{1}{sin\alpha} \in (1; 1.4)$

- dE/dx_{LXe}[7]
- dE/dx_{DC}
- $Energy_{LXe}$
- $Energy_{CsI}$
- $Energy_{Cal}$
- $\widehat{\overrightarrow{v_{DC}}\overrightarrow{v_{LXe}}}$

BDT classifiers are trained (1056 classifiers in total)

classifier application

ROOT trees with

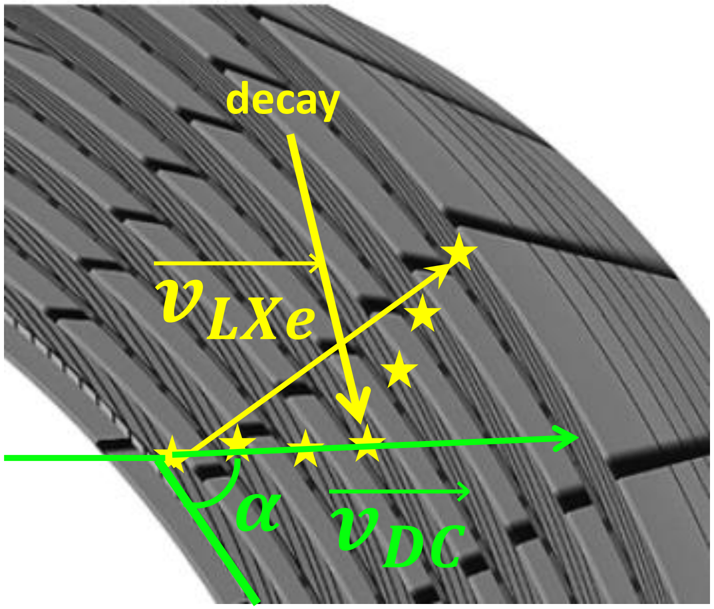
- Experimental data from 18 CMD-3’s energy points in the range $1.8\ \text{GeV} < \sqrt{s} < 2.0\ \text{GeV}$
- MC for the signal and the main background processes ($e^+e^- \to \pi^+\pi^-, \mu^+\mu^-,\ e^+e^-$) at each energy point

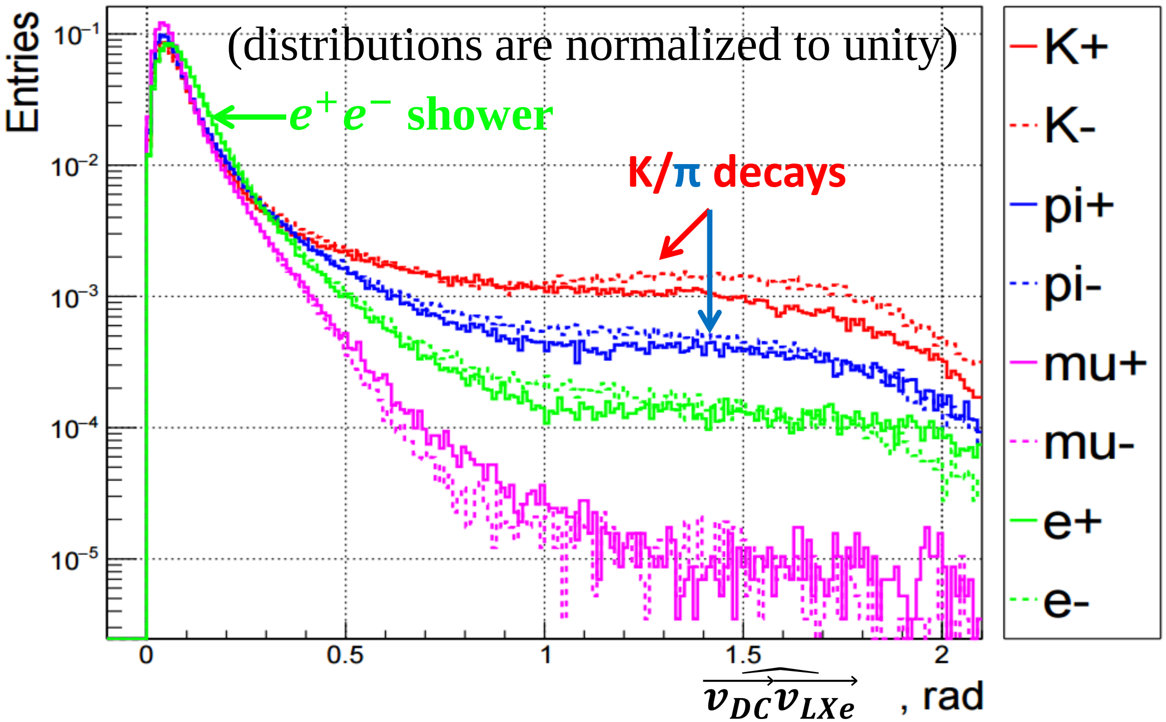
ROOT trees with 10 classifiers responses for each «good» track

Selection of the events with two oppositely charged collinear tracks:

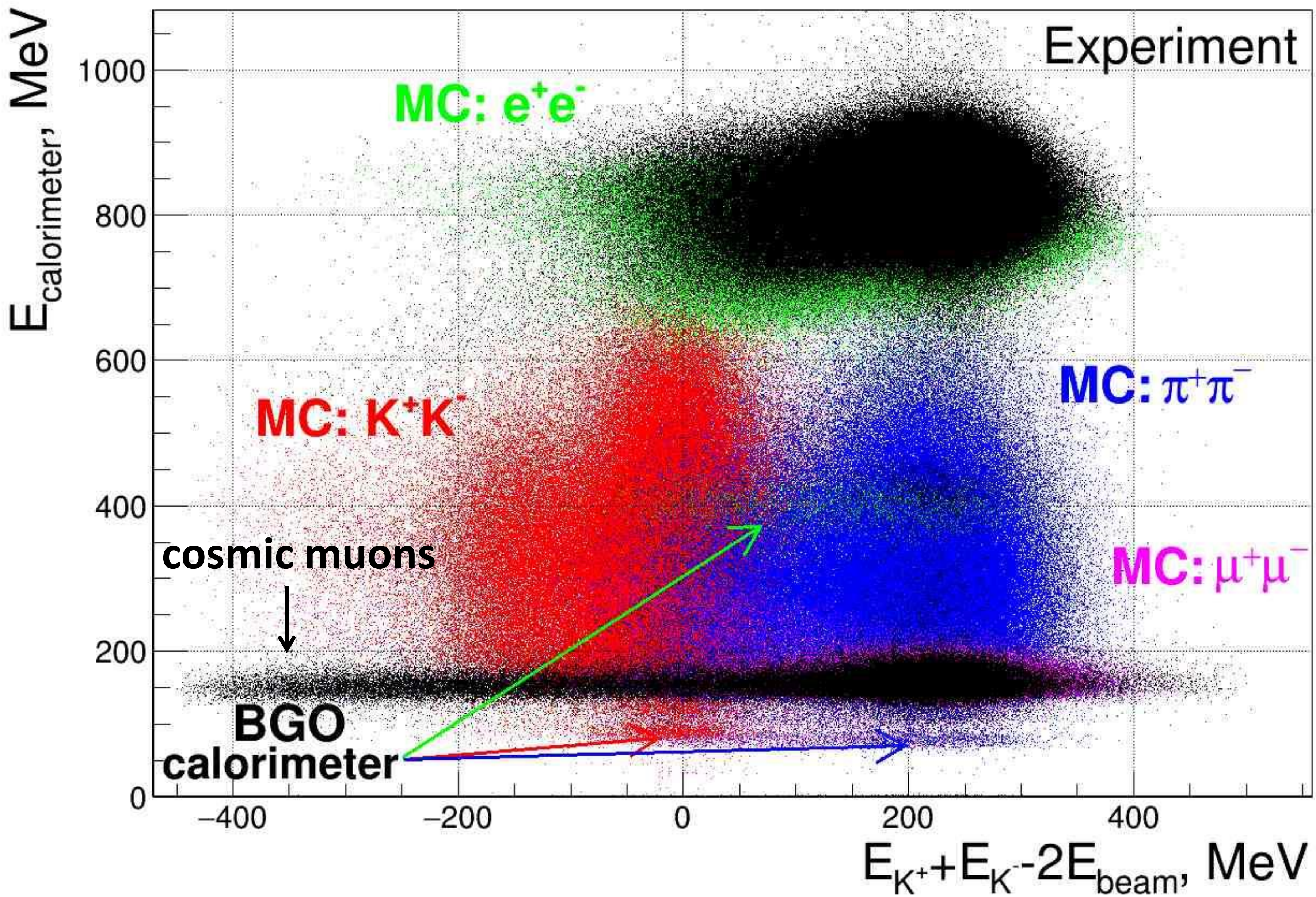
- $|\theta_{DC,1} + \theta_{DC,2} - \pi|$<0.25
- $||\varphi_{DC,1} - \varphi_{DC,2}| - \pi|$<0.15

DC-LXe non-collinearity angle ($\widehat{\vec{v}_{DC}\vec{v}_{LXe}}$)



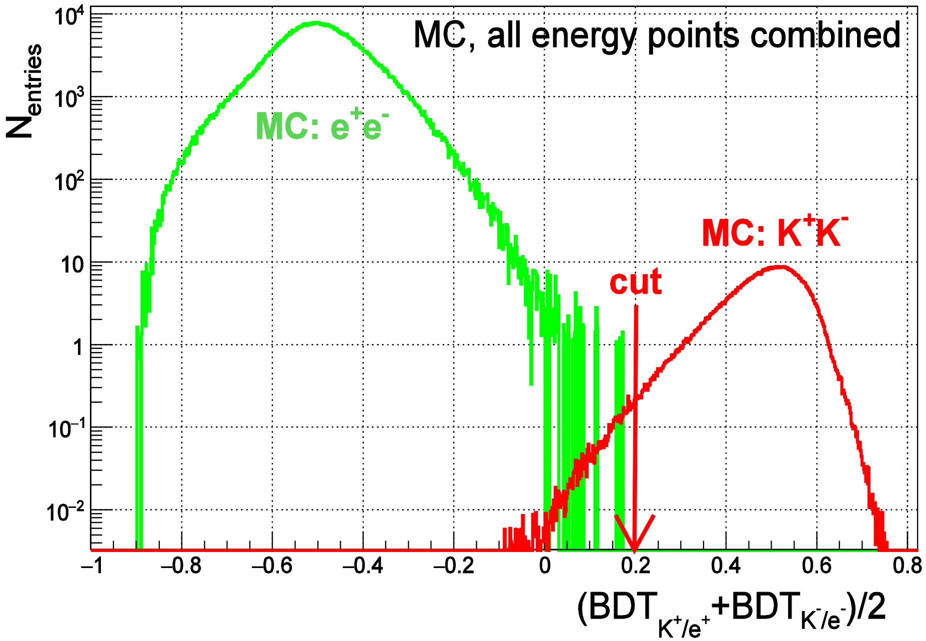


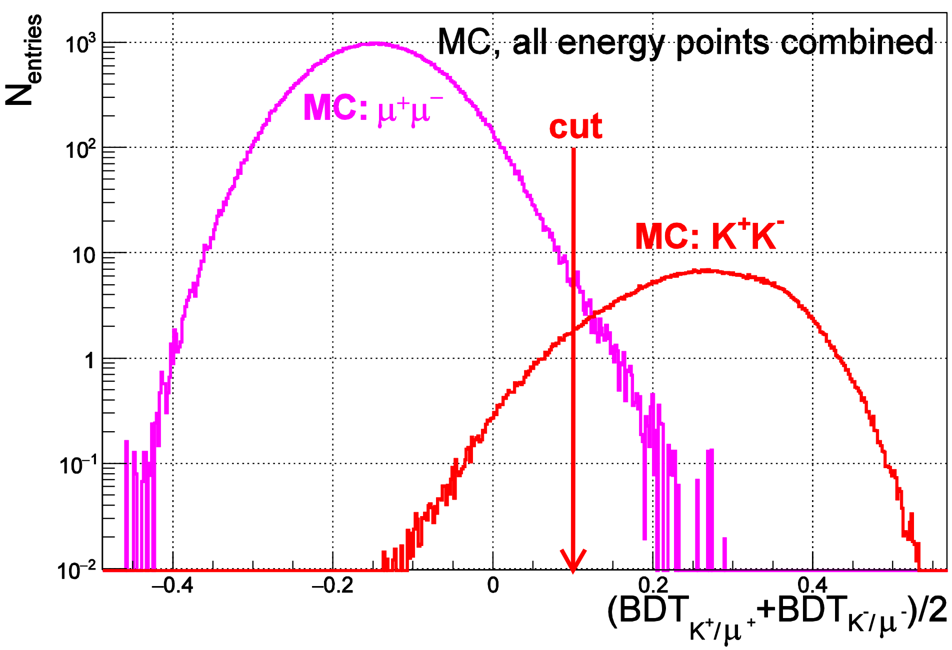
Selected events

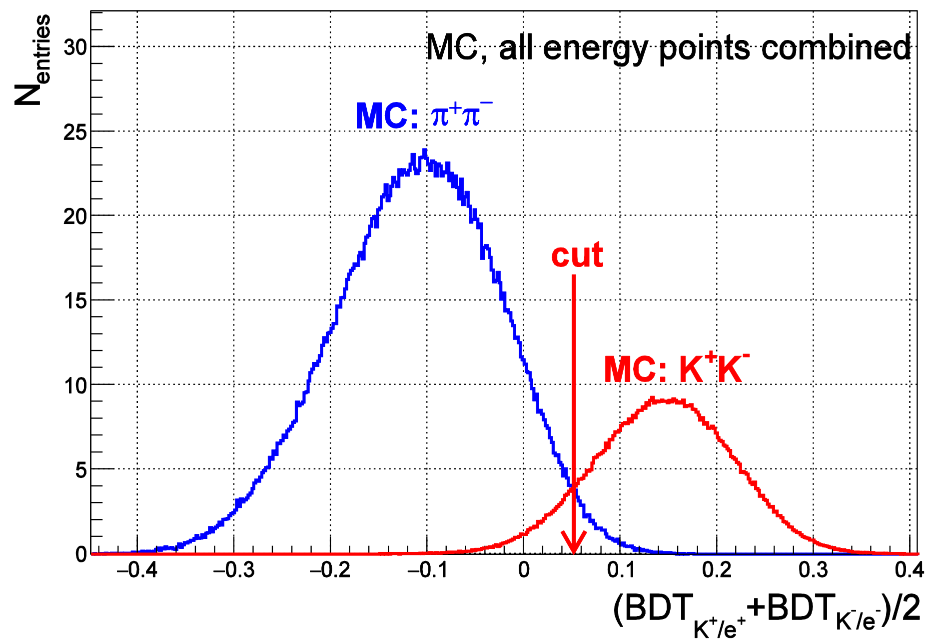


$K^{\pm} / e^{\pm}, \mu^{\pm}, \pi^{\pm}$ separation

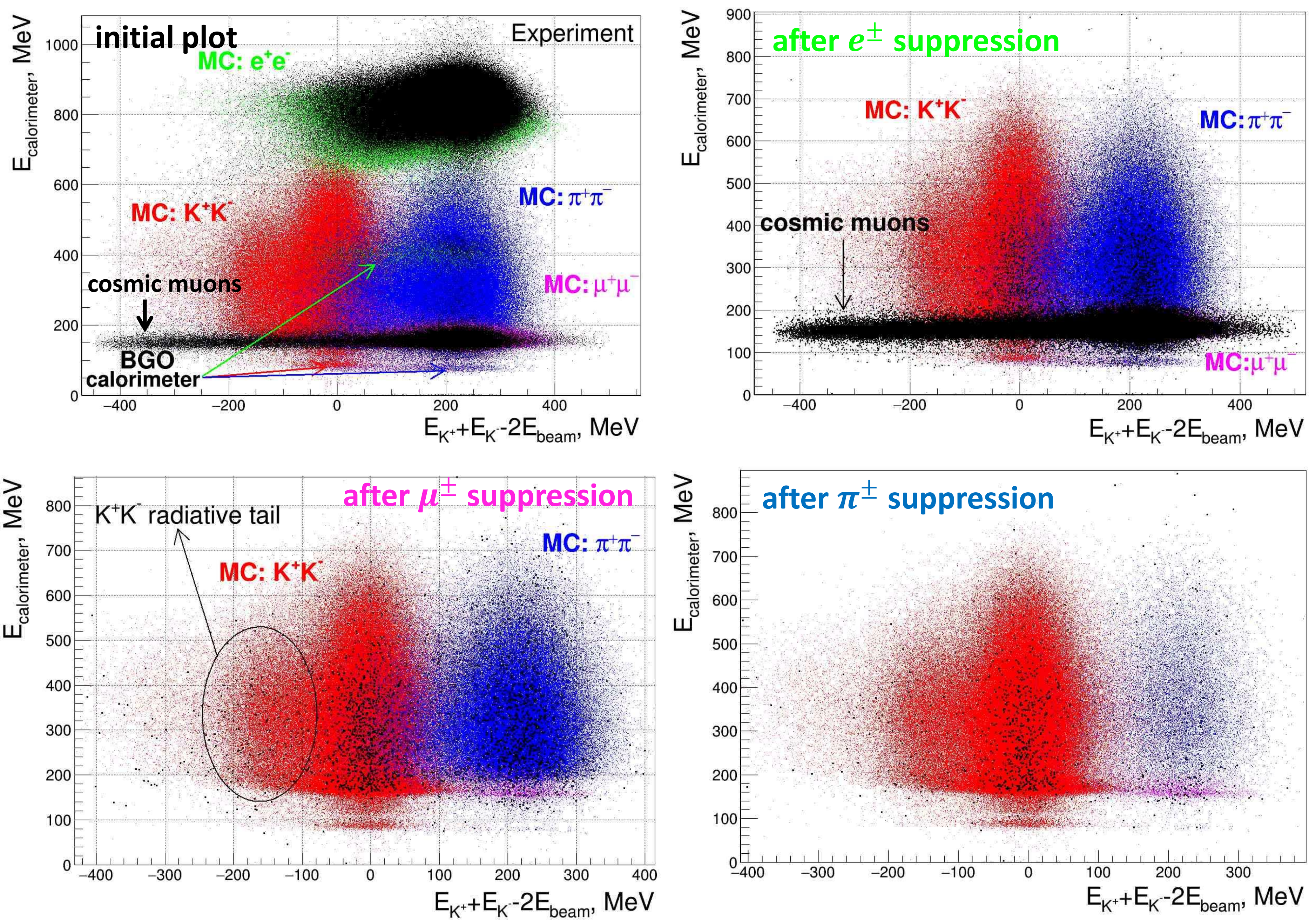
- Number of events in each histogram is weighted with the luminosity, process cross section and detection efficiency. All 18 energy points are combined







Backgrounds suppression



Plans

- partition Δp_i, as well as the MC simulation, not obligatory should be uniform in the momentum. The partition should only satisfy the conditions $\Delta p_i \sim \sigma_p$ and $\Delta p_i \sim \lambda_{min}$, where σ_p - the momentum resolution, λ_{min} is the minimal the characteristic scale of change of the momentum, on which there are noticeable changes in the distributions of the input variables of the classifier
- DC-tracks, for which the corresponding LXe-track in the liquid xenon was not found (which is typical for kaons and protons at low momenta) should also be added to the classifier
- Study of the MC-experiment differences (e.g. in LXe track reconstruction efficiency):

   1. For $K^{\pm}$: on the base of pure $K^{\pm}$ sample from $K^+K^-\pi^+\pi^-$ final state, selected using dE/dx_{DC} and energy-momentum conservation

   2. For $\mu^{\pm}$: on the base of cosmic muons

   3. For $e^{\pm}$: on the base of events of BhaBha scattering

   4. For $\pi^{\pm}$: on the base of $\pi^+\pi^-\pi^+\pi^-$ final state

   5. For $p^{\pm}$: on the base of p^+p^- events at low momenta; protons, ejected from the residual gas, at high momenta

- the addition of the information from the muon veto system to the classifier
- the addition of the 10 classifiers responses to the standard CMD-3's trees with reconstructed data and their use in the analyzes of the processes $e^+e^- \rightarrow K^+K^-$, $K^+K^-\pi^0$, $K_{S,L}K^{\pm}\pi^{\mp}$, $K^+K^-\pi^0\pi^0$, $K^+K^-\pi^+\pi^-$ etc.

Thank you for attention!