Search for the process $e^+e^- \to D^{*0}(2007)$ with the CMD-3 detector

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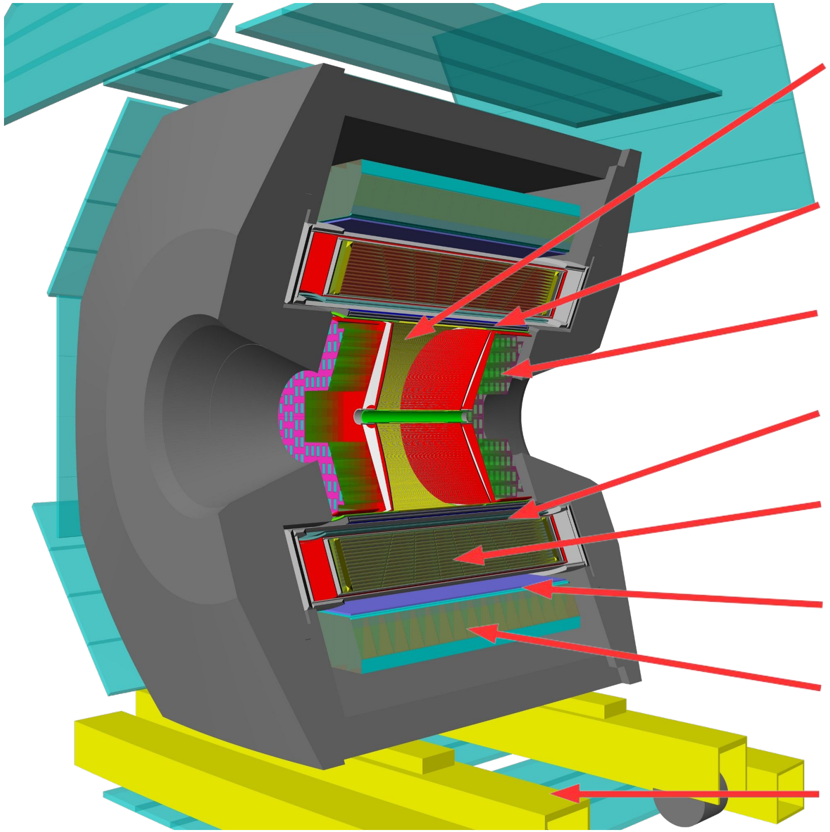
CMD-3 DETECTOR



Drift chamber (1218 hexagonal cells with sensitive wires, σ_φ=120μm, z-coordinate – charge division technique, σ_z=2 mm)

Z-chamber (start FLT, precise determination of z-coordinate σ_z=500μm, time resolution ~5 ns)

BGO calorimeter (680 BGO crystals, σE/E=8-4%, $13X_0$)

SC solenoid (1.3T, $0.08X_0$)

Lxe calorimeter (264 energy towers, 7 cathode layers, σ_z=2 mm, 5.4X0)

TOF (16 counters, time resolution ~ 1 ns)

CsI calorimeter (1152 CsI crystals, σE/E=5-3%, $8.1X_0$)

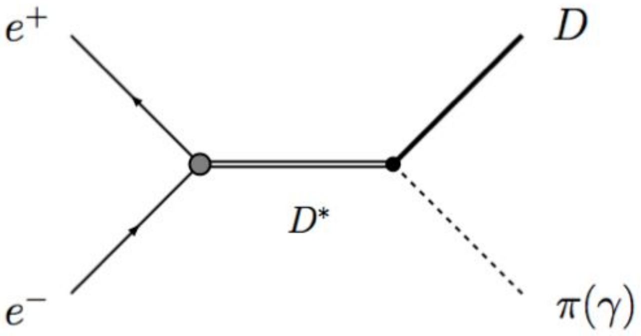
Muon system (8 octants, time resolution ~1ns)

Motivation

The process $D^{*0} \rightarrow e^+e^-$ is a good probe for New Physics. The estimation of the lower limit on the branching fraction in Standard Model $B_{D^* \rightarrow e+e-}$ ~ $(0.1 – 5)x10^{-19}$ is much smaller than in some models. For example in model with Z'-mediated gauge interactions branching fraction is $B_{D^* \rightarrow e+e-} < 2.5x10^{-11}$ [High Energ. Phys. (2015) 2015: 142.]. So far, there are no measurements of the upper limit.

The process $D^{*0} \rightarrow e^+e^-$ has clear advantages with respect to the $D^0 \rightarrow e^+e^-$ decay: the helicity suppression is absent, and a richer set of effective operators can be probed.

We use estimations for width and cross-section according to the following formulas [High Energ. Phys. (2015) 2015: 142.]:



$$\Gamma_0 = \Gamma(D^{*0} \to D^0\pi^0) + \Gamma(D^{*0} \to D^0\gamma)$$

$$\simeq \frac{\Gamma_+ \mathcal{B}_{D^{*+} \to D^0\pi^+}}{2} \left(\frac{\lambda(m^2_{D^{*0}}, m^2_{D^0}, m^2_{\pi^0})}{\lambda(m^2_{D^{*+}}, m^2_{D^0}, m^2_{\pi^+})} \right)^{3/2} \left(1 + \frac{\mathcal{B}_{D^{*0} \to D^0\gamma}}{\mathcal{B}_{D^{*0} \to D^0\pi^0}} \right) \simeq 60 \text{ keV}$$

$$\sigma(e^+e^- \to D\pi)_{\sqrt{s} \simeq m_{D^*}} \equiv \sigma_{D^*}(s) = \frac{12\pi}{m^2_{D^*}} \mathcal{B}_{D^* \to e^+e^-} \mathcal{B}_{D^* \to D\pi} \frac{m^2_{D^*}\Gamma_0^2}{(s - m^2_{D^*})^2 + m^2_{D^*}\Gamma_0^2}$$

The main idea of the analysis

There were collected 3.7 nb^{-1} and 21.67 nb^{-1} integral luminosity at the average energy in the center-of-mass system E=2006.62 MeV and 2007.05 MeV correspondingly with beam spreading ~ 1 MeV. The mass of the D^{*0} is equal to 2006.85 ± 0.05 MeV.

In this analysis we used two main modes of D^{*0} decay:

$D^{*0} \longrightarrow D^0\pi^0$ B=64.7 ± 0.9 %

$D^{*0} \longrightarrow D^0 \gamma$ B =35.3 ± 0.9 %

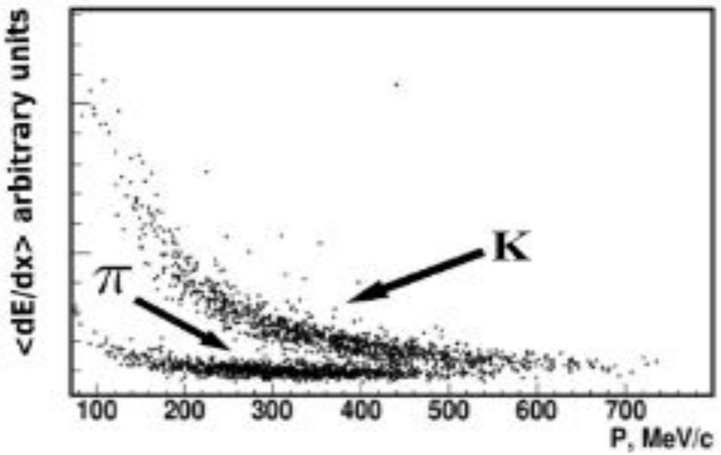
We reconstructed D^0 in modes $D^0 \longrightarrow K^-\pi^+\pi^-\pi^+$ (B= 8.22 ± 0.15%) and $D^0 \longrightarrow K^-\pi^+\pi^0$ (B=14.4 ± 0.5%).

Only one kaon in final state leads to low physical background.

The efficiency of the processes $D^{*0} \longrightarrow D^0\pi^0(\gamma)$ was assessed using MC simulation.

K/π separation

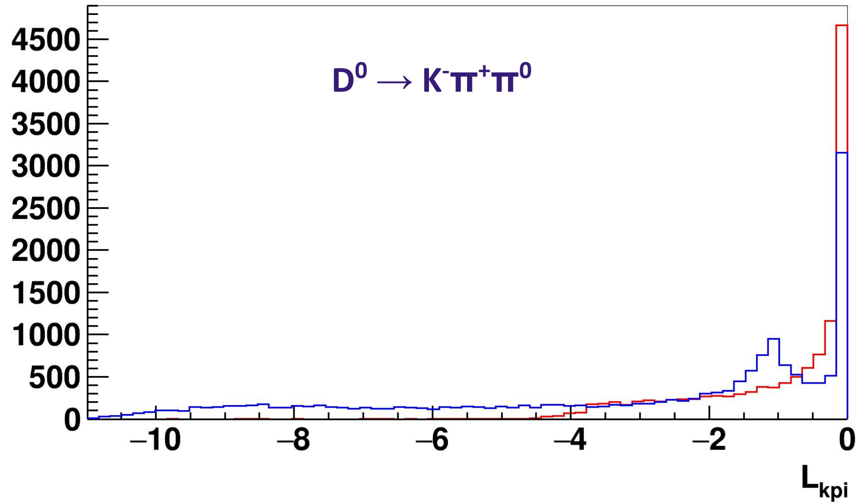
To perform kaon/pion separation, we use the probability density functions $f_{K/\pi}(p,dE/dx)$ for charged K/π with the momentum p to produce the energy losses dE/dx in the DC. The log-likelihood function (LLF) for the hypothesis that for i=(1,2,..,Ntracks) the particle with the momentum p_i and energy losses $(dE/dx)i$ is the particle of α_i type (α_i=K or π) is defined as:

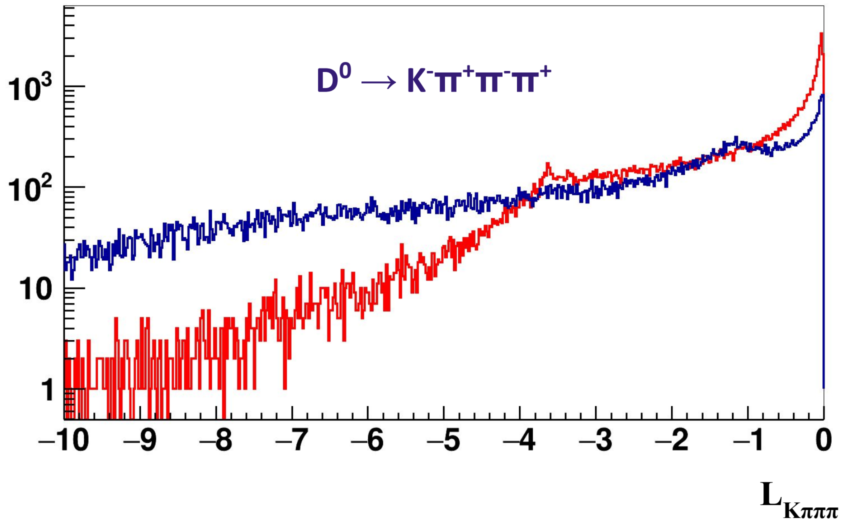


$$L_{\alpha_1,\alpha_2,\ldots,\alpha_{N_{tracks}}} = \sum_{i=1}^{N_{tracks}} ln\left(\frac{f_{\alpha_i}(p_i,(dE/dx)_i)}{f_K(p_i,(dE/dx)_i)+f_\pi(p_i,(dE/dx)_i)}\right)$$

We search for the combination of (α_1,α_2 ,α_3 ,α_4), for which LLF is maximum and assume that there are one kaon and three pions in event ($L_{k\pi\pi\pi}$).

K/π separation





The log-likelihood function is shown in the figure above. The red line corresponds to the signal events, the blue line – background.

Also we use condition on LLF for physical background suppression :

$L_{K\pi\pi\pi}$>-0.2 (all background)

$L_{KK\pi\pi}$<-3 (K+K-π+π- events)

$L_{\pi\pi\pi\pi}$<-3 (π+π-π+π- events)

$L_{K\pi}$>-1 (all background)

Kinematic selection conditions ($D^0 \to K^-\pi^+\pi^-\pi^+$)

We assign pion or kaon mass to each track and calculate total energy . The distribution of E_{tot} vs P_{tot} (total momentum of four particles) is presented in the figure on the right. Black points correspond to experimental data, rad points – simulation $D^{*0} \to D^0\pi^0$, blue points – simulation $D^{*0} \to D^0\gamma$.

Selection criteria are:

$D^{*0} \to D^0\pi^0$

$|Etot-141.6|< 40$ MeV

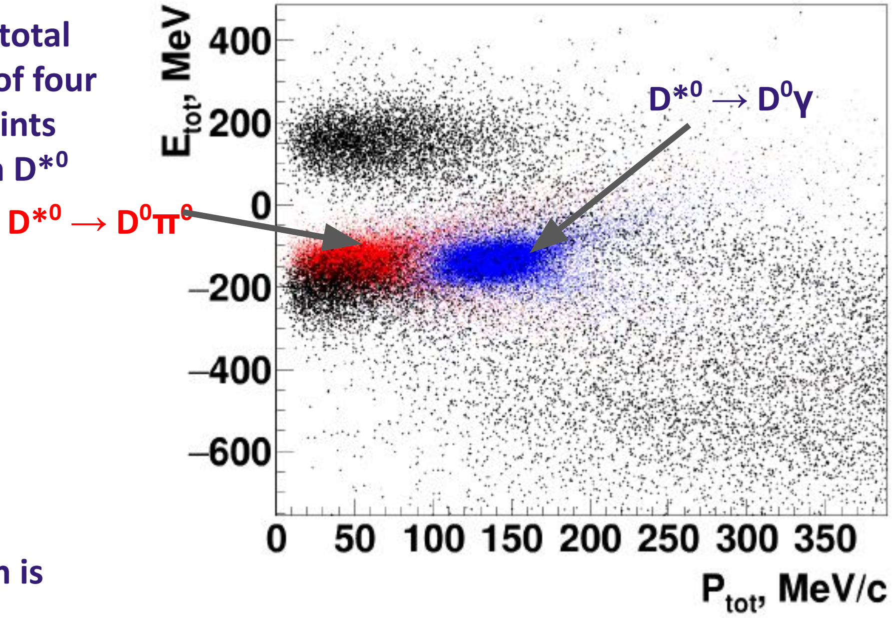
$|Ptot-46|< 50$ MeV/c

$D^{*0} \to D^0 \gamma$

$|Etot-136.6|< 40$ MeV

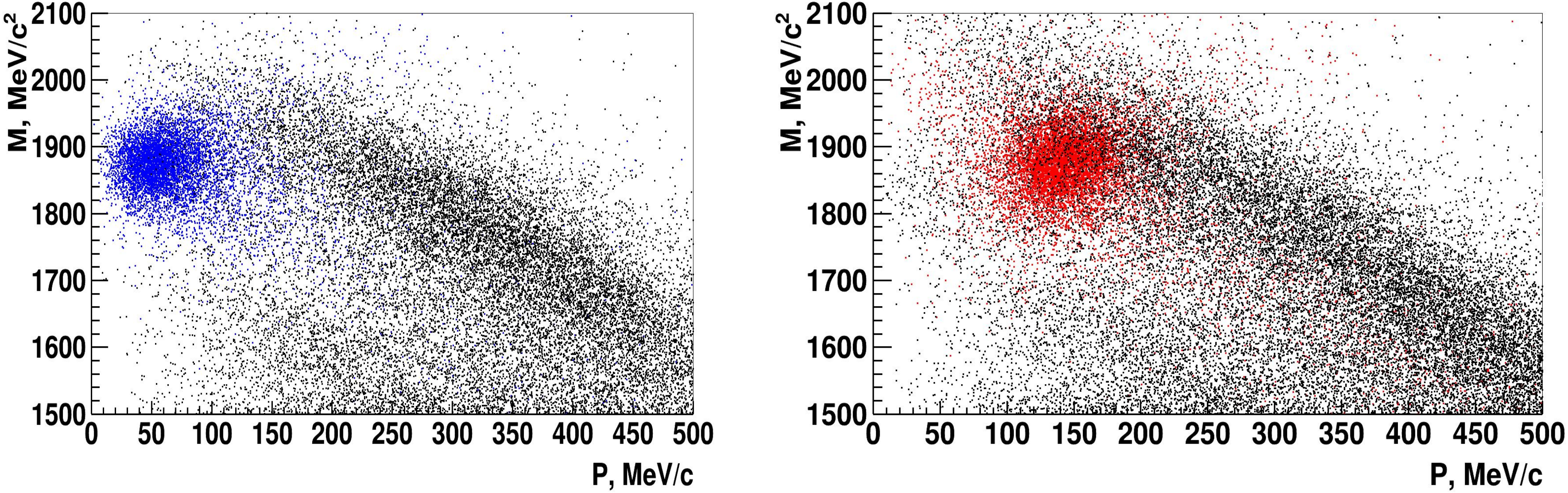
$|Ptot-138.6|< 50$ MeV/c

The efficiency after conditions on energy and momentum is about 25%.

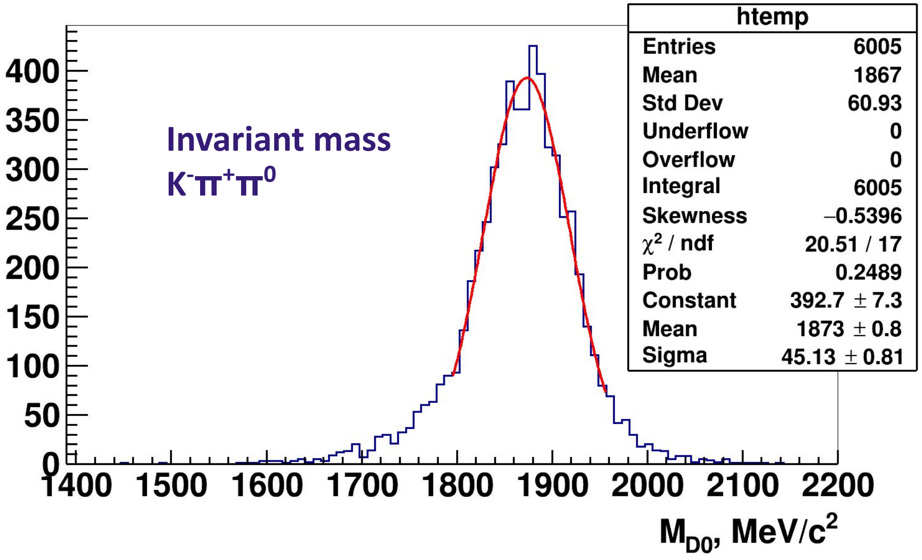


Kinematic selection conditions ($D^0 \to K^- \pi^+ \pi^0$)

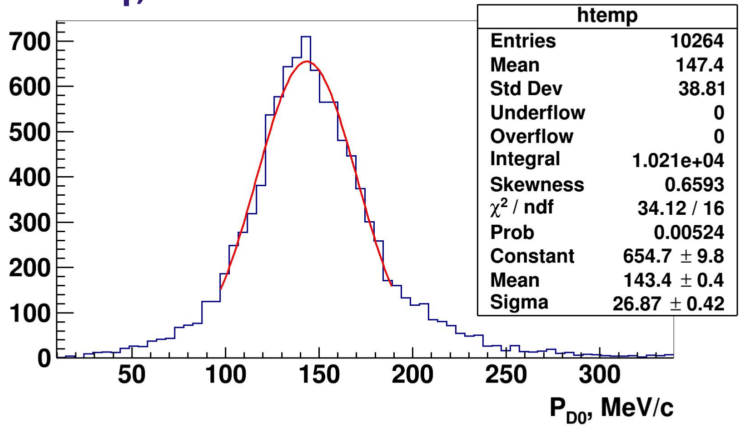
Invariant mass vs total momentum of candidates to $K^- \pi^+ \pi^0$ are presented in figures below.
Black points correspond to multihodran generator, blue points – $D^{*0} \to D^0 \pi^0$, red points – $D^{*0} \to D^0 \gamma$.



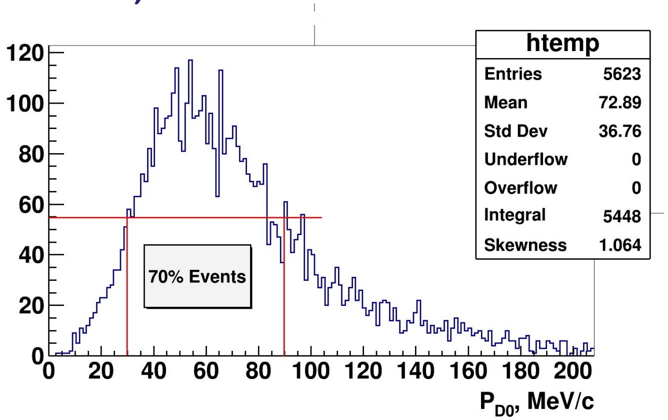
Kinematic selection conditions ($D^0 \rightarrow K^-\pi^+\pi^0$)



$D^{*0} \rightarrow D^0\,\gamma$, total momentum of $K^-\pi^+\pi^0$



$D^{*0} \rightarrow D^0\,\pi^0$, total momentum of $K^-\pi^+\pi^0$

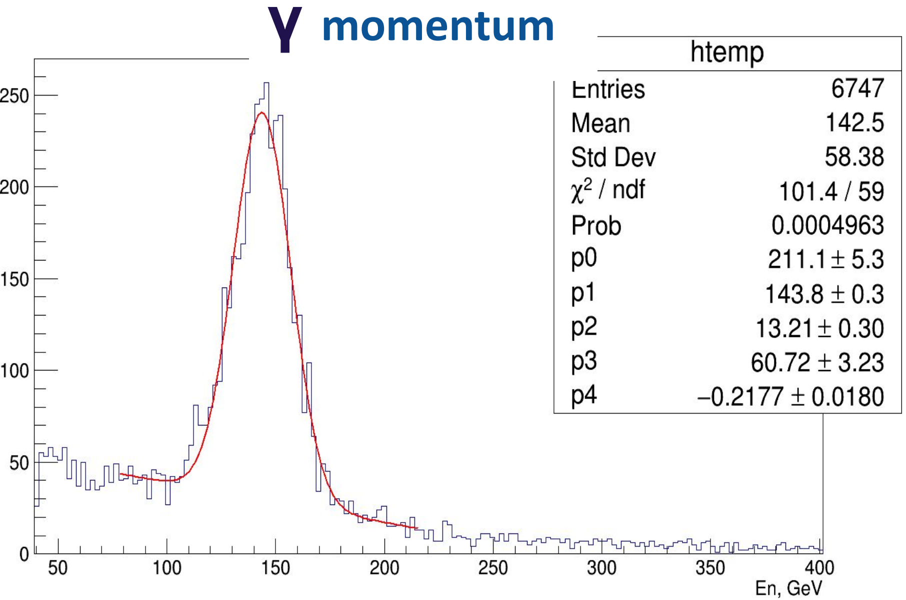


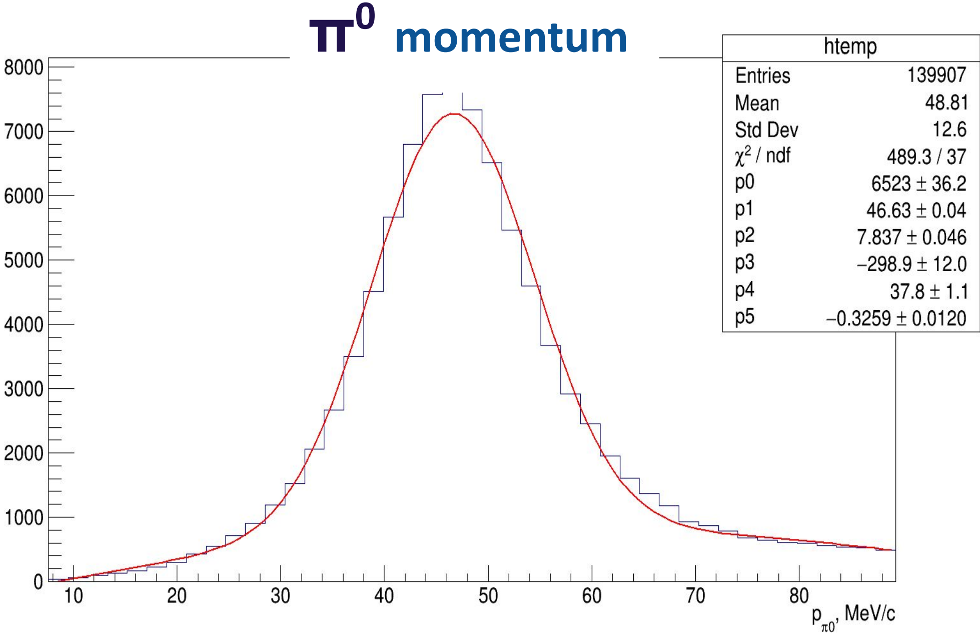
Selection criteria are:

- $|M_{K\text{-}\pi\text{+}\pi 0} - 1873| < 60$ MeV
- $D^{*0} \rightarrow D^0\,\gamma$: $|P_{D0} - 143| < 35$ MeV/c
- $D^{*0} \rightarrow D^0\,\pi^0$: 20 MeV/c $< P_{D0} <$ 90 MeV/c

The efficiency after conditions on energy and momentum is about 25%.

Kinematic selection conditions ($D^{*0} \rightarrow D^0\pi^0(\gamma)$)





It is necessary to have a photon with a momentum in the diapason:
P_γ = 143.8 ±30 MeV

It is necessary to have a π^0 with a momentum in the diapason:
$P_{\pi0}$ = 46.6 ± 20 MeV

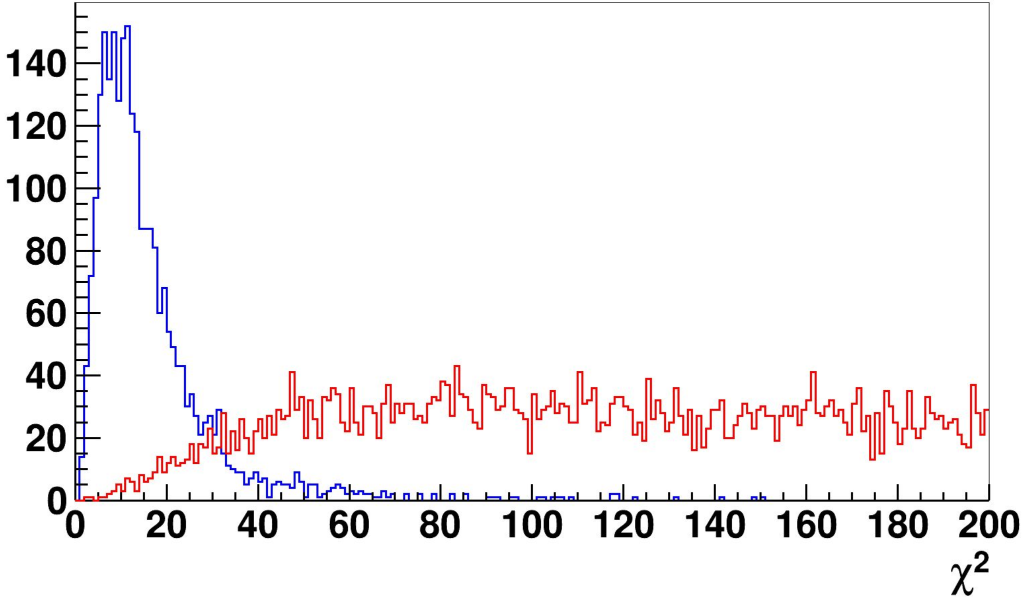
Kinematic fit $D^{*0} \rightarrow D^0\gamma$ ($D^0 \rightarrow K^-\pi^+\pi^0$)

For additional background suppression a kinematic fit is used with the following conditions:

- The invariant mass of two photons is equal to the mass of π^0,
- The invariant mass of $K^-\pi^+\pi^0$ is equal to the mass of D^0,
- Total energy of the particle system $\gamma K^-\pi^+\pi^0$ is 2*(beam energy),
- Total momentum of the particle system $\gamma K^-\pi^+\pi^0$ is zero.

The value of the chi-square is shown in the figure on the right. The red line corresponds to the background events, blue line corresponds to $D^{*0} \rightarrow D^0\gamma$ ($D^0 \rightarrow K^-\pi^+\pi^0$).

The condition is: $\chi^2<30$.



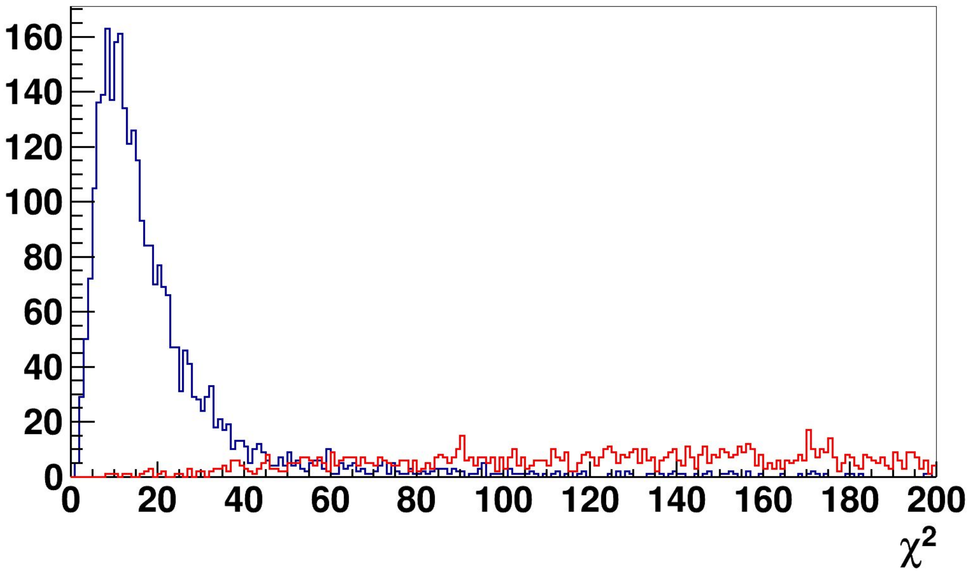
Kinematic fit $D^{*0} \to D^0\pi^0$ ($D^0 \to K^-\pi^+\pi^0$)

For additional background suppression a kinematic fit is used with the following conditions:

- The invariant mass of two photons is equal to the mass of π^0,
- The invariant mass of others two photons is equal to the mass of π^0,
- The invariant mass of $K^-\pi^+\pi^0$ is equal to the mass of D^0,
- Total energy of the particle system $\pi^0K^-\pi^+\pi^0$ is 2*(beam energy),
- Total momentum of the particle system $\pi^0K^-\pi^+\pi^0$ is zero.

The value of the chi-square is shown in the figure on the right. The red line corresponds to the background events, blue line corresponds to $D^{*0} \to D^0\pi^0(D^0 \to K^-\pi^+\pi^0)$.

The condition is: $\chi^2<40$.

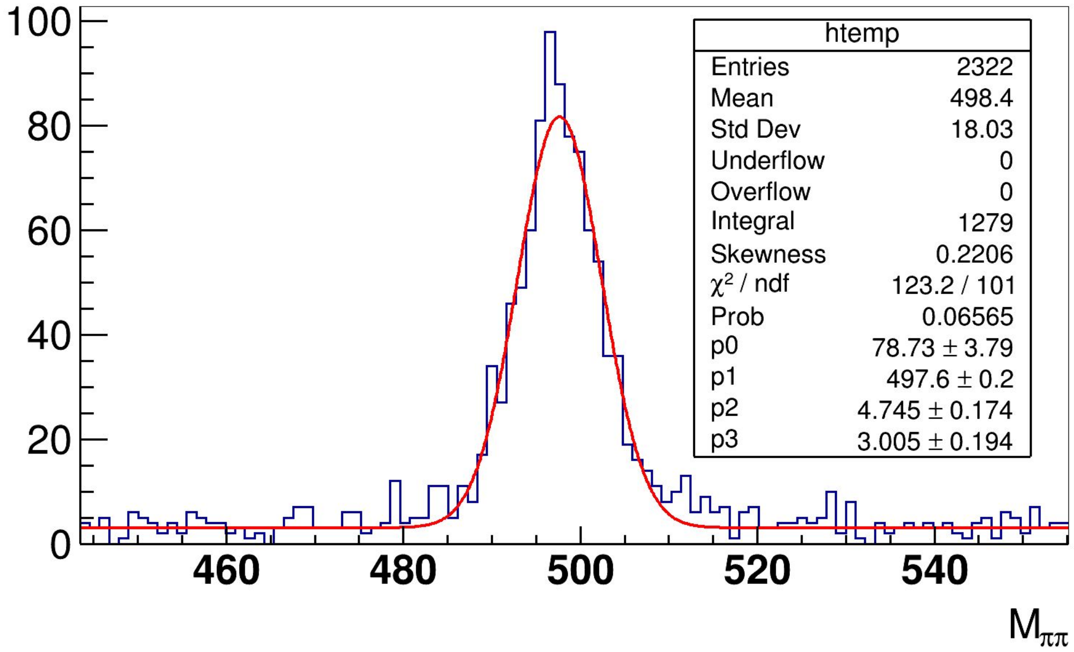


K_s suppression

According to simulation with multihadron generator main background processes are $e^+e^- \to K^-K^+\pi^-\pi^+$, $\pi^-\pi^+\pi^-\pi^+$, $\pi^-\pi^+\pi^-\pi^+\pi^0$, $3(\pi^-\pi^+)$, $2(\pi^-\pi^+\pi^0)$, $K^-K_s\pi^0\pi^+$,$K^-K_s\pi^0\pi^+$. For physical background with K_s suppression we use condition on invariant mass of two paions ($M_{\pi-\pi+}$):

$$|M_{\pi+\pi-} - 498| > 20 \text{ МэВ}.$$

Distribution of $M_{\pi+\pi-}$ for $K^-K_s\pi^0\pi^+$ and $K^-K_s\pi^0\pi^+$ events is presented in the figure on the right.



Upper limit calculation

The integrated production cross section is calculated using energy spread σ ($E_{c.m.}$) = 1 MeV and the radiator function F(x,E) [Sov.J.Nucl.Phys. 41, 466(1985)]

$$\sigma^f_{\rm int} = \int_0^{E_{\rm beam}} dE \int_0^1 \frac{1}{\sqrt{2\pi}\sigma_{\rm E_{c.m.}}} e^{-\frac{(\rm E_{c.m.}{}^{av.} - E)^2}{2\sigma^2_{\rm E_{c.m.}}}} \cdot F(x,E) \cdot \sigma^f(E(1-x))dx$$

Final formula for brunching fraction is:

$$\mathcal{B} = \frac{N}{L_{int} \cdot \epsilon_{D^{*0}\to f} \cdot \mathcal{B}_{D^{*0}\to f} \cdot \mathcal{B}_{D^0\to K^+\pi^-\pi^+\pi^-} \cdot C}$$

there N – number of candidate events, L – integrated luminosity, $\varepsilon_{D^*\to f}$ – efficiency, C – integral value.

$B_{D^{*0}\to D0\pi0}$ =0.65, $B_{D^{*0}\to D0\gamma}$= 0.35,

$B_{D0\to K\text{-}\pi\text{+}\pi0}$ = 0.14, $B_{D0\to K\text{-}\pi\text{+}\pi\text{-}\pi\text{+}}$ =0.08

$\varepsilon_{D^{*0}\to D0\pi0\to K\text{-}\pi\text{+}\pi\text{-}\pi\text{+}\pi0}$ = 10.4%, $\varepsilon_{D^{*0}\to D0\gamma\to K\text{-}\pi\text{+}\pi\text{-}\pi\text{+}\gamma}$ = 10.1%, $\varepsilon_{D^{*0}\to D0\gamma\to K\text{-}\pi\text{+}\pi0\gamma}$ = 4.6%, $\varepsilon_{D^{*0}\to D0\pi0\to K\text{-}\pi\text{+}\pi0\pi0}$ = 4.5%,

C = 73901 pbn^{-1} .

$N_{D^{*0}\to D0\pi0\to K\text{-}\pi\text{+}\pi\text{-}\pi\text{+}\pi0}$ = 5±7, $N_{D^{*0}\to D0\gamma\to K\text{-}\pi\text{+}\pi\text{-}\pi\text{+}\gamma}$ = 8±5, $N_{D^{*0}\to D0\gamma\to K\text{-}\pi\text{+}\pi0\gamma}$ = 4±7, $N_{D^{*0}\to D0\pi0\to K\text{-}\pi\text{+}\pi0\pi0}$ = 1±2.

We obtain the result $B(D^{*0}\to e^+e^-)$< 3.7*10-7 at 90% C.L. using Bayesian Approach.