

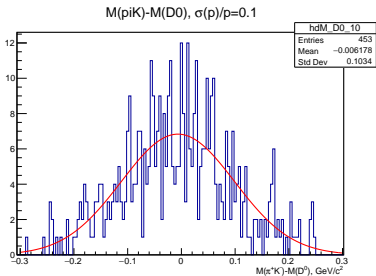
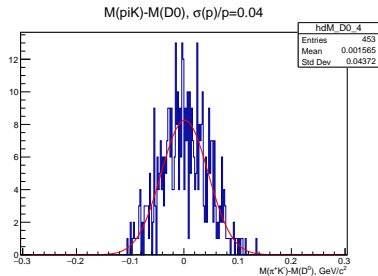
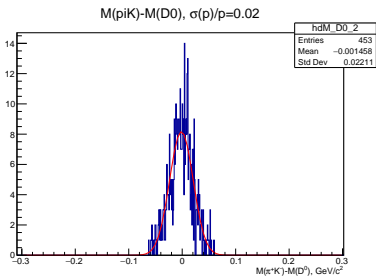
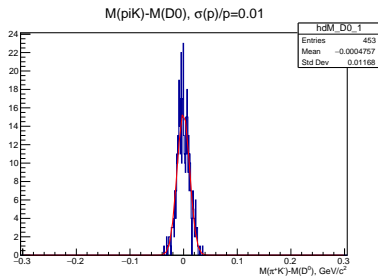
Criteria to select open-charm events by the online filter

Mikhail Zhabitsky, JINR

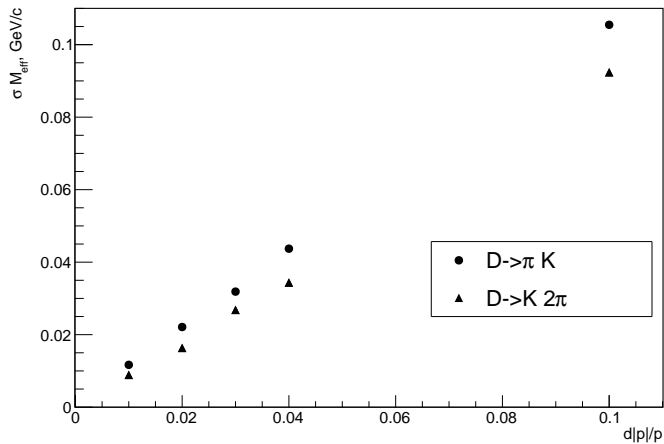
26.01.2022

- pythia8.303 ($p + p$, $\sqrt{s} = 27$ GeV, SoftQCD=on)
- Channels of interest:
 - $D^0 \rightarrow \pi^+ K^-$ (0.0395 ± 0.0003) at $x_F > 0.2$
 - $D^+ \rightarrow 2\pi^+ K^-$ (0.094 ± 0.002) at $x_F > 0.2$
- PID in endcaps
- Kinematic cuts in D^0 center-of-mass system
- D-meson events tagging:
 1. $D\bar{D}$ -pairs
 2. $D^{*+} \rightarrow D^0 \pi^+$
 3. $\Lambda_c^+ \bar{D}$
- Charge multiplicities
- Study is focused on data-reduction by the online-filter

$D^0 \rightarrow K^- \pi^+$: resolution



100M pp-interactions



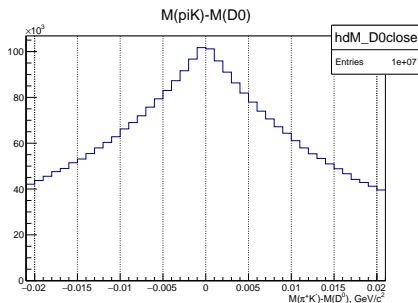
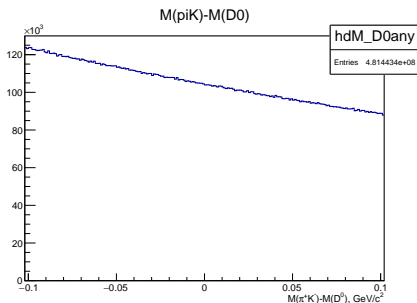
$D^0 \rightarrow K^- \pi^+$: combinatorial background

Worst-case scenario: only pos/neg charges are distinguished:

Any $x^+ y^-$ are treated as $\pi^+ K^-$

tracks selection: $p > 0.15$ GeV/c, $p_T/p > 0.1$

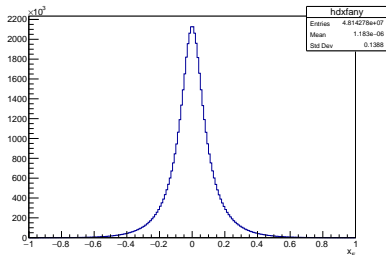
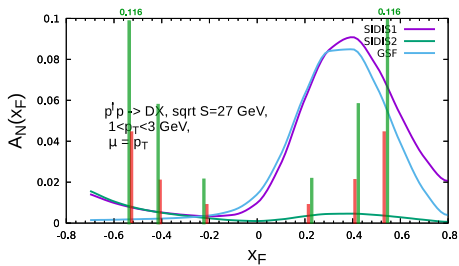
any x_F



$M(x^+ y^-) = M(\pi K)$, $|M(\pi K) - M(D^0)| < 0.15$ GeV/c: approx. $\pm 3\sigma$ at $\sigma_p/p = 0.05$.

Probability of pos. trigger decision: **0.56** (per 1 pp-interaction)

$D^0 \rightarrow K^- \pi^+$: x_F



Events of interest: $x_F = \frac{p_z}{p_{z,\max}} > 0.2$

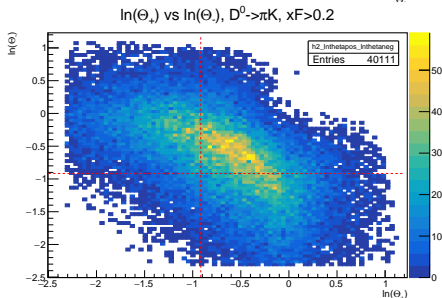
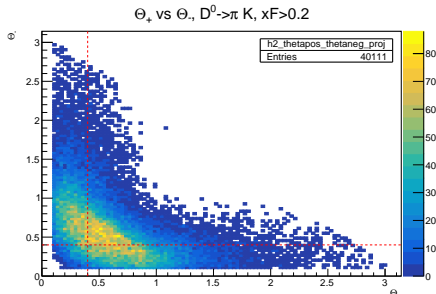
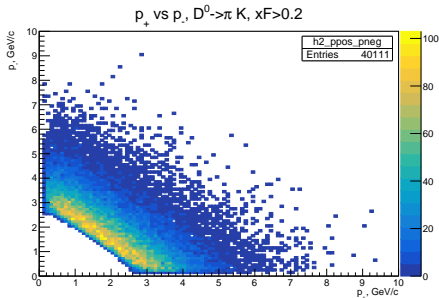
Probability of pos. trigger decision:

any x_F : 0.56

$|x_F| > 0.2$: 0.29

$D^0 \rightarrow K\pi$: kinematics

tracks selection: $p > 0.15 \text{ GeV}/c$, $p_T/p > 0.1$, $x_F > 0.2$

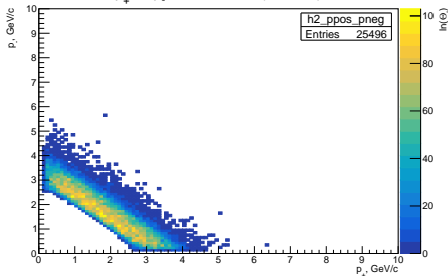


Statistics:

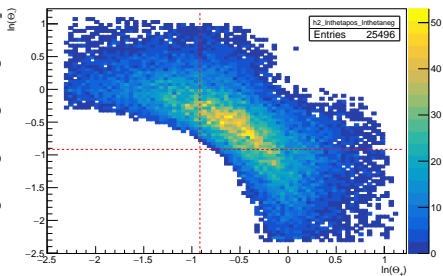
$3.6 \cdot 10^{10}$ pp -interactions
(approx. 3 hours at 3 MHz)

$D^0 \rightarrow K\pi$: kinematics

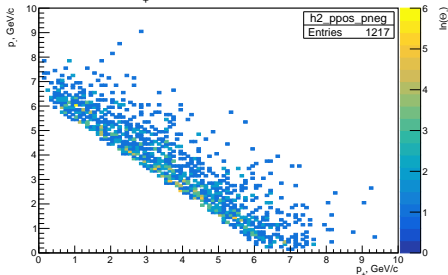
p_+ vs p_- , $D^0 \rightarrow \pi K$, $x_F \in (0.2, 0.3)$



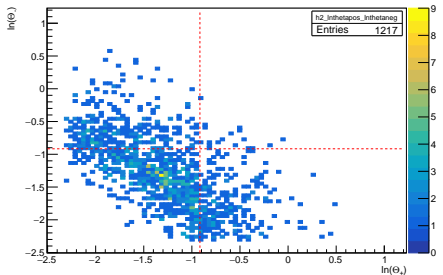
$\ln(\Theta_+)$ vs $\ln(\Theta_-)$, $D^0 \rightarrow \pi K$, $x_F \in (0.2, 0.3)$



p_+ vs p_- , $D^0 \rightarrow \pi K$, $x_F > 0.5$



$\ln(\Theta_+)$ vs $\ln(\Theta_-)$, $D^0 \rightarrow \pi K$, $x_F > 0.5$

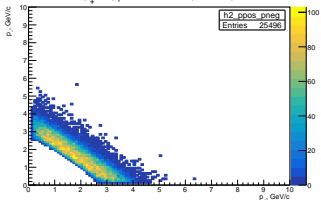


$D^0 \rightarrow K\pi$: signal vs combinatorial background

$x_F \in (0.2, 0.3)$:

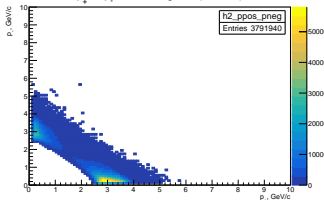
Signal ($3.6 \cdot 10^{10}$)

p_+ vs p_- , $D^0 \rightarrow \pi K$, $x_F \in (0.2, 0.3)$



bg (10M pp-collisions)

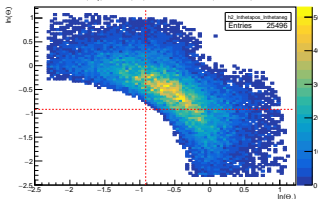
p_+ vs p_- , $D^0 \rightarrow \pi K$ bg, $x_F \in (0.2, 0.3)$



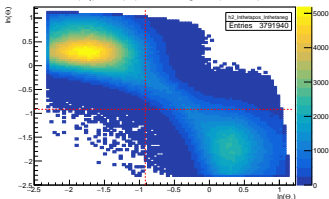
Trigger rate: 0.20

Main Bg combinations:
 $p\pi^-$: 1.1M
 $\pi^+\pi^-$: 1.9M
 πK : 0.4M
other: 0.4M

$\ln(\theta_+)$ vs $\ln(\theta_-)$, $D^0 \rightarrow \pi K$, $x_F \in (0.2, 0.3)$



$\ln(\theta_+)$ vs $\ln(\theta_-)$, $D^0 \rightarrow \pi K$ bg, $x_F \in (0.2, 0.3)$

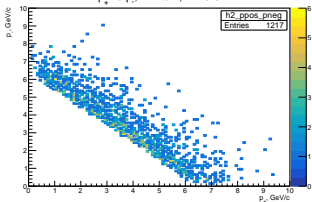


$D^0 \rightarrow K\pi$: signal vs combinatorial background

$x_F > 0.5$:

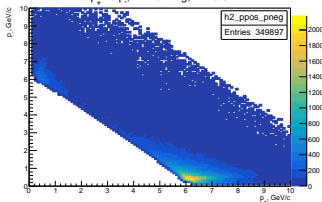
Signal ($3.6 \cdot 10^{10}$)

p_+ vs p_- , $D^0 \rightarrow \pi K$, $x_F > 0.5$



bg (10M pp-collisions)

p_+ vs p_- , $D^0 \rightarrow \pi K$ bg, $x_F > 0.5$



Trigger rate: 0.026

Main Bg

combinations:

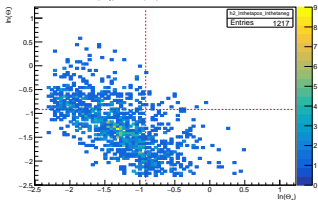
$p\pi^-$: 0.21M

$\pi^+\pi^-$: 0.09M

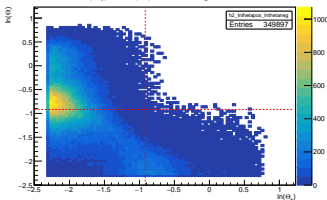
πK : 0.02M

other: 0.03M

$\ln(\theta_+)$ vs $\ln(\theta_-)$, $D^0 \rightarrow \pi K$, $x_F > 0.5$



$\ln(\theta_+)$ vs $\ln(\theta_-)$, $D^0 \rightarrow \pi K$ bg, $x_F > 0.5$

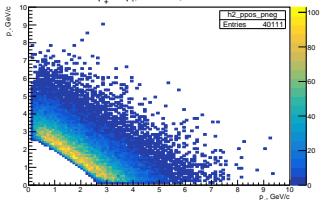


$D^0 \rightarrow K\pi$: signal vs combinatorial background

$x_F > 0.2$:

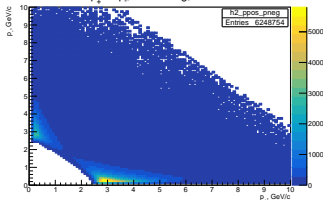
Signal ($3.6 \cdot 10^{10}$)

$p_+ \text{ vs } p_-, D^0 \rightarrow \pi K, x_F > 0.2$



bg (10M pp-collisions)

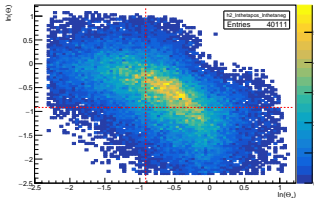
$p_+ \text{ vs } p_-, D^0 \rightarrow \pi K \text{ bg}, x_F > 0.2$



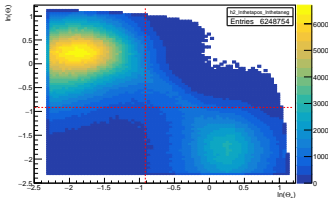
Trigger rate: 0.29

Main Bg combinations:
 $p\pi^-$: 2.9M
 $\pi^+\pi^-$: 2.2M
 πK : 0.6M
other: 0.6M

$\ln(\theta_+) \text{ vs } \ln(\theta_-), D^0 \rightarrow \pi K, x_F > 0.2$



$\ln(\theta_+) \text{ vs } \ln(\theta_-), D^0 \rightarrow \pi K \text{ bg}, x_F > 0.2$

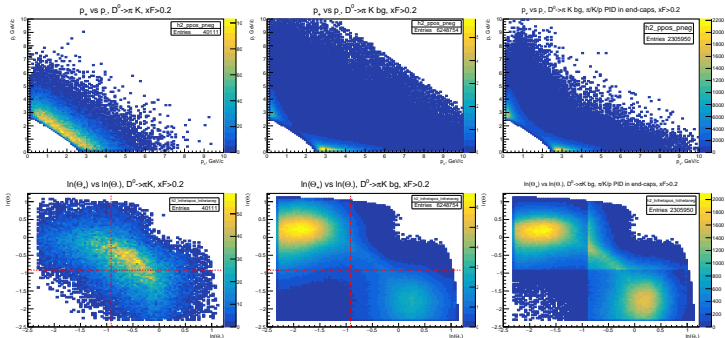


Cherenkov ID in end-caps

$x_F > 0.2$:

Signal ($3.6 \cdot 10^{10}$)

bg (10M pp-collisions)



Trigger rate: 0.15

Main Bg combinations:

$p\pi^-$: 0.2M

$\pi^+\pi^-$: 1.8M

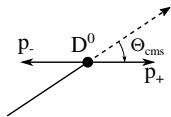
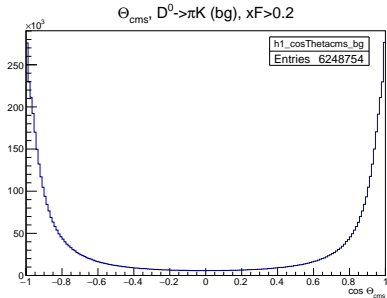
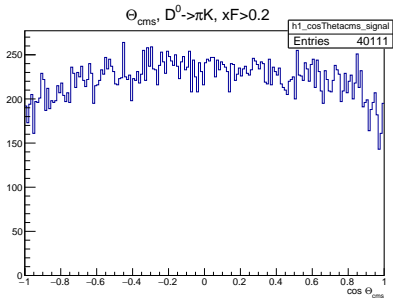
πK : 0.3M

other: 0

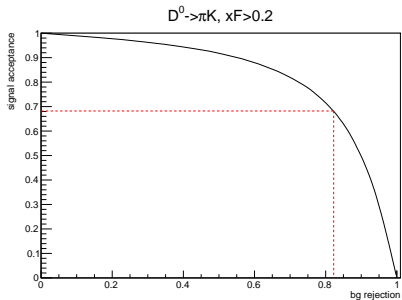
Trigger rate for $x_F > 0.2$, Cherenkov ID in end-caps:

	no ID	no protons	$\pi/K/p$
	0.29	0.20	0.15

$D^0 \rightarrow K\pi$: CMS kinematics



$$\sigma(\cos(\Theta_{\text{cms}})) \approx 0.02$$

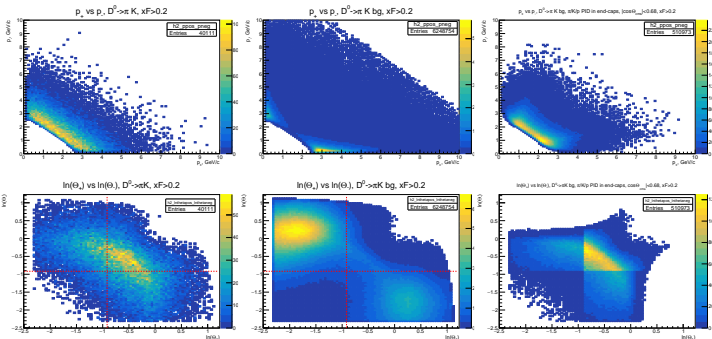


Suppress forward/backward kinematics in CMS

$$x_F > 0.2, \quad |\cos \Theta_{\text{cms}}| < 0.68:$$

Signal ($3.6 \cdot 10^{10}$)

bg (10M pp-collisions)



Trigger rate: 0.039

Main Bg combinations:

$p\pi^-$: 0.1M

$\pi^+\pi^-$: 0.3M

πK : 0.08M

other: 0

Approx. 0.5 of events: both tracks are in the barrel

Trigger rate for $x_F > 0.2$, Cherenkov ID in end-caps

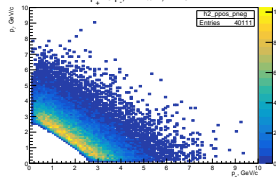
	no ID	no protons	$\pi/K/p$
$\forall \cos \Theta_{\text{cms}}$	0.29	0.20	0.15
$ \cos \Theta_{\text{cms}} < 0.68$	0.074	0.053	0.039

Acceptance due to cuts on forward/backward kinematics in CMS

$x_F > 0.2$, no Cherenkov PID, $|\cos \Theta_{cms}| < 0.68$:

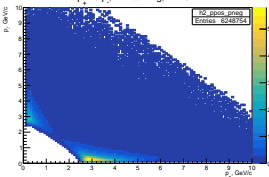
Signal ($3.6 \cdot 10^{10}$)

$p_+ \text{ vs } p_-, D^0 \rightarrow \pi K, x_F > 0.2$

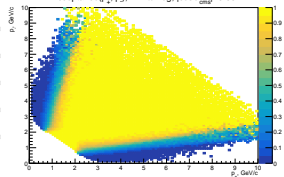


bg (10M pp-collisions)

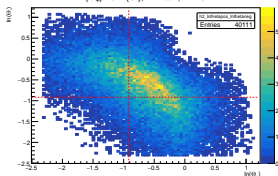
$p_+ \text{ vs } p_-, D^0 \rightarrow \pi K \text{ bg}, x_F > 0.2$



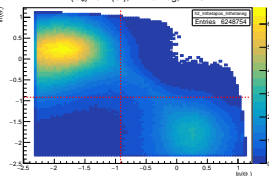
Acceptance(p_+, p_-), $D^0 \rightarrow \pi K \text{ bg}, |\cos \Theta_{cms}| < 0.68$



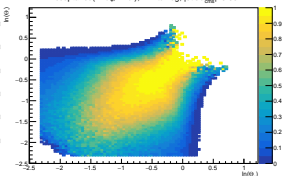
$\ln(\theta_+) \text{ vs } \ln(\theta_-), D^0 \rightarrow \pi K, x_F > 0.2$



$\ln(\theta_+) \text{ vs } \ln(\theta_-), D^0 \rightarrow \pi K \text{ bg}, x_F > 0.2$

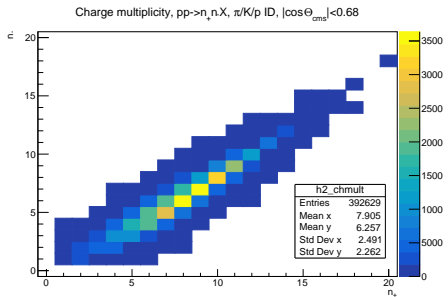
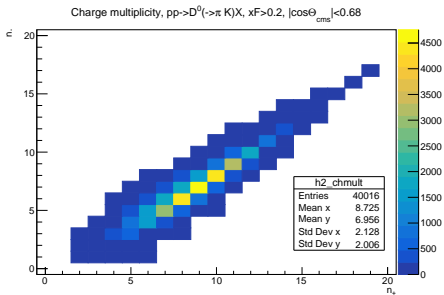


Acceptance($\ln \theta_+, \ln \theta_-$), $D^0 \rightarrow \pi K \text{ bg}, |\cos \Theta_{cms}| < 0.68$

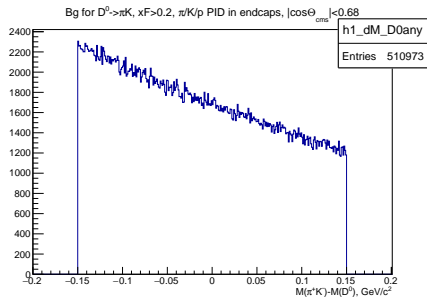
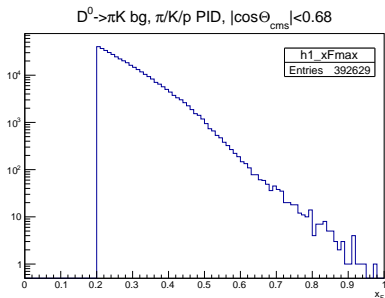


Charged tracks (charge multiplicities)

$x_F > 0.2$, $\pi/K/p$ PID in end-caps, $|\cos\Theta_{\text{cms}}| < 0.68$

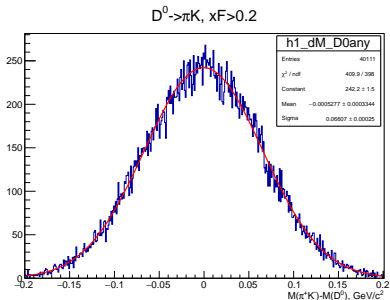


$M_{\pi K}$ for survived bg events

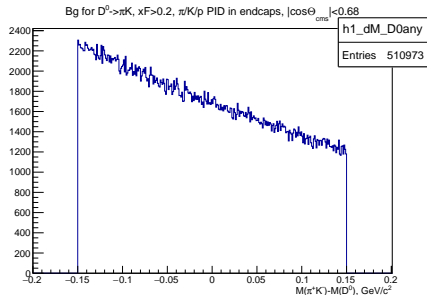


Range of accepted $ M_{\pi K} - M_{D^0} $	1.5σ	3σ	6σ
Rate of pos. triggers	0.022	0.039	0.073

$M_{\pi K}$: signal vs bg



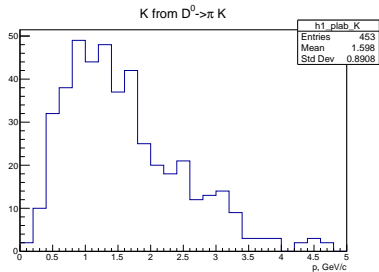
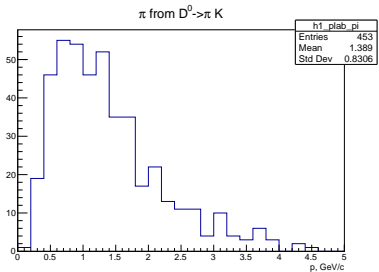
3 hours

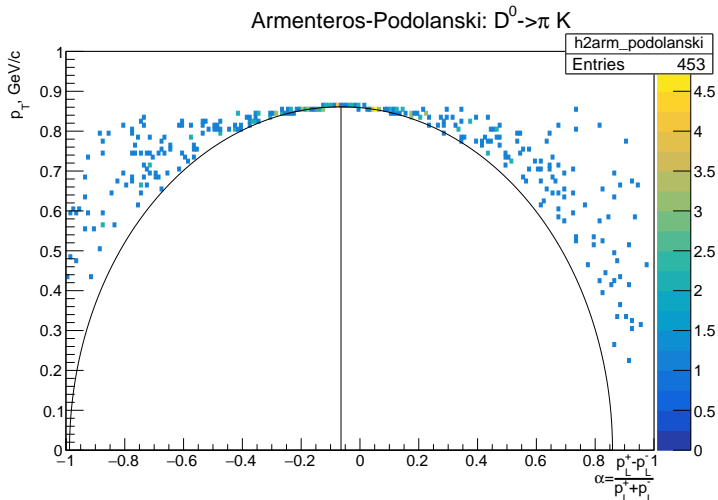


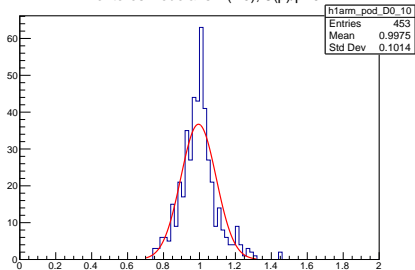
3 seconds

- Resolution on $M_{\pi K}$ is not sufficient to reduce flux of bg events
- Particle ID by Cherenkov detectors in end-caps can suppress background by a factor (1.5...2)
- Criteria on the CMS angle between the decay axis and momentum of D: suppress background by a factor (3...4) while retaining 0.7 of true D^0 -events
- Criteria on charge multiplicity ($|n_+| + |n_-|$): small gain
- D-meson events tagging:
doesn't seem promising within the online-filter
- Particle identification ($\pi/K/p$) in the barrel part?
- Overall bg suppression by a factor (15...20) is achievable
- Analysis of bg reduction for $D^\pm \rightarrow K^\mp 2\pi^\pm$ is ongoing.

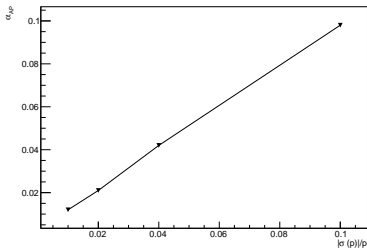
$D^0 \rightarrow \pi K$: π/K spectra





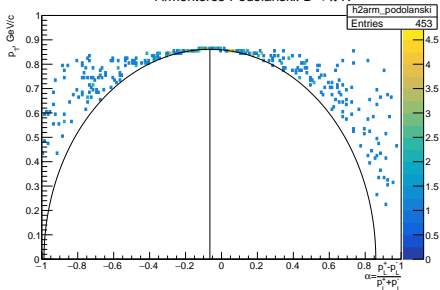
Armenteros-Podolanski (D0), $\sigma(p)/p=0.1$ 

Arm.-Podolanski

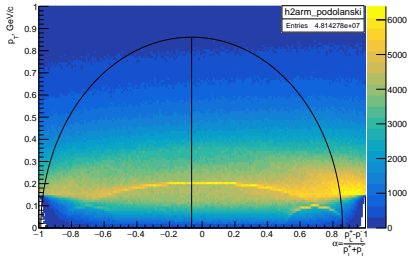


$$D^0 \rightarrow \pi K$$

Armenteros-Podolanski: $D^0 \rightarrow \pi K$



Armenteros-Podolanski: $B_g(\pi, K)$



Channels of interest:

$$D^0 \rightarrow \pi^+ K^- \quad (0.0395 \pm 0.0003)$$

$$D^+ \rightarrow K^- 2\pi^+ \quad (0.094 \pm 0.002)$$

- $pp \rightarrow D\bar{D}X$: complete reconstruction of D -mesons
- $D^{*+} \rightarrow D^0\pi^+$ (0.677)
 D^{*+} width: 83.4 ± 1.8 keV
- $pp \rightarrow \Lambda_c^+ \bar{D}X$ with $\Lambda_c^+ \rightarrow p + X$ (≈ 0.5)

Rate of charmed events per 1M pp -collisions at 27 GeV/c

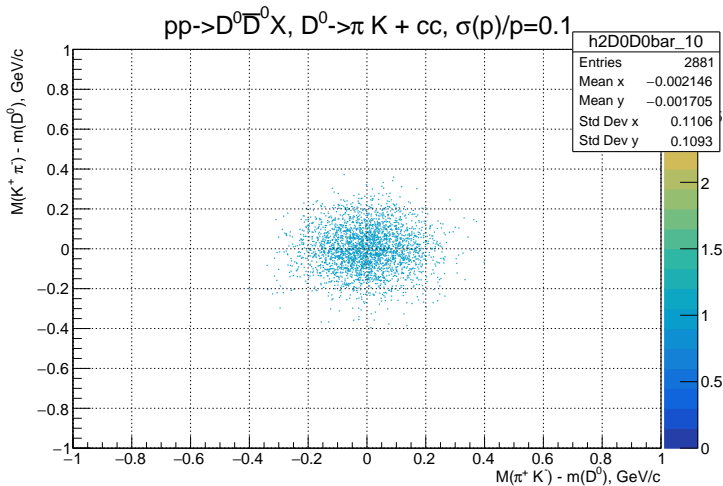
D^+X	24.0	$D^{*+}X$	16.7
D^-X	30.8	$D^{*-}X$	19.9
D^0X	48.5	$D^{*0}X$	16.2
\bar{D}^0X	59.2	$\bar{D}^{*0}X$	21.4
D_s^+X	7.2		
D_s^-X	10.4		
Λ_c^+X	22.7		
Λ_c^-X	2.5		

Associated D -meson production:

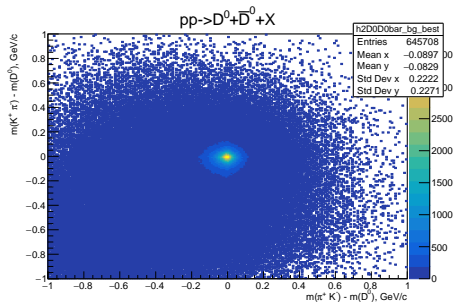
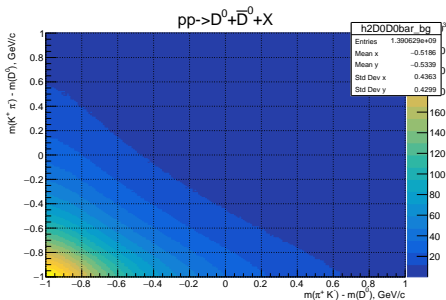
D^+D^-X	8.5		
$D^+\bar{D}^0X$	12.5		
D^0D^-X	14.3	$\Lambda_c^+D^-X$	5.8
$D^0\bar{D}^0X$	29.2	$\Lambda_c^+\bar{D}^0X$	12.6

Note: expected rate of inelastic collisions 3 MHz

$pp \rightarrow D^0 \bar{D}^0 X$: true events

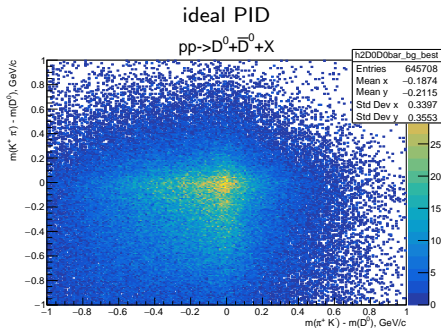
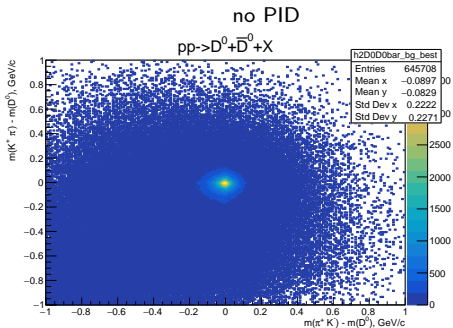


$pp \rightarrow D^0 \bar{D}^0 X$: combinatorial background



No PID, resolution $\frac{\sigma_P}{P} = 0.1 \Rightarrow 0.32$ — probability to find bg ($\pi^+ K^-$ & $\pi^- K^+$)

$pp \rightarrow D^0 \bar{D}^0 X$: combinatorial background



	$\frac{\sigma_P}{P} = 0.1$	$\frac{\sigma_P}{P} = 0.02$
no PID	0.32	0.05
ideal PID	0.01	0.0005

Use of $\bar{D}^0(D^0)$ coincidences

- Signal

$$P(pp \rightarrow \bar{D}^0 X) = 6.0 \cdot 10^{-5}$$

$$\frac{P(pp \rightarrow \bar{D}^0 D^0 X)}{P(pp \rightarrow \bar{D}^0 X)} = 0.5$$

$$P(D^0 \rightarrow \pi^+ K^-) = 0.04$$

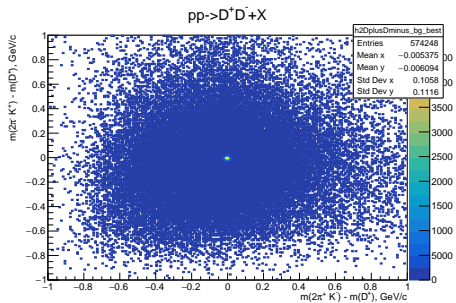
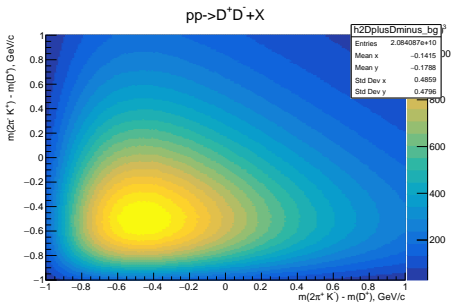
Geometrical acceptance $pp \rightarrow \bar{D}^0 D^0 X$: 0.94

Signal events' reduction factor is about 50.

- Background

$\frac{\sigma_P}{P}$	$P(m(h^+ h^-) - m(D^0) < \Delta M)$	both comb. < ΔM	reduction factor
0.1	0.52	0.32	1.6
0.01	0.17	0.018	9

$pp \rightarrow D^+ D^- X$: combinatorial background



Use of $D^- (D^+)$ coincidences

- Signal

$$P(pp \rightarrow D^- X) = 3.1 \cdot 10^{-5}$$

$$\frac{P(pp \rightarrow D^+ D^- X)}{P(pp \rightarrow D^- X)} = 0.3$$

$$P(D^+ \rightarrow 2\pi^+ K^-) = 0.094$$

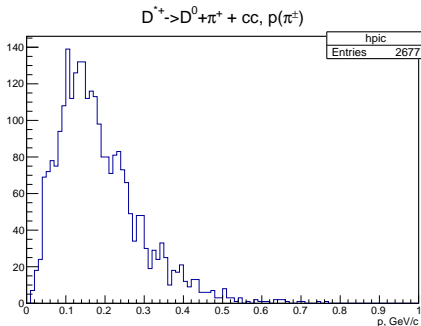
Geometrical acceptance $pp \rightarrow D^+ D^- X$: 0.92

Signal events' reduction factor is about 30.

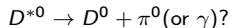
- Background

$\frac{\sigma_B}{P}$	both comb. $< \Delta M$
0.1	0.46
0.01	0.18

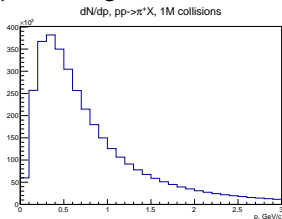
$D^* \rightarrow D + \pi^\pm$ chains



- D^* are abundant
- $\Gamma \sim 0.1$ MeV
- But outgoing charged pion is too soft

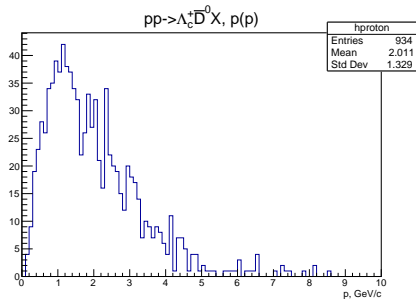
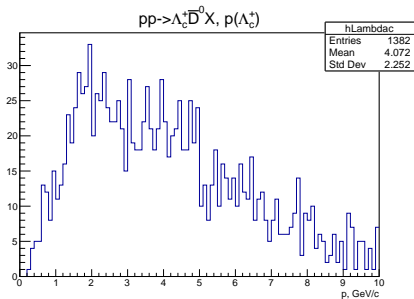


Spectra of bg π^+ :



$pp \rightarrow \Lambda_c^+ \bar{D} X$ with $\Lambda_c^+ \rightarrow p + X$

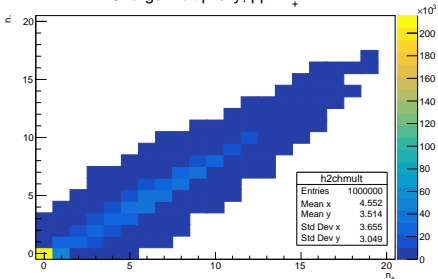
$pp \rightarrow \Lambda_c^+ \bar{D}^0 X$ with $\Lambda_c^+ \rightarrow p + X$ (≈ 0.5)



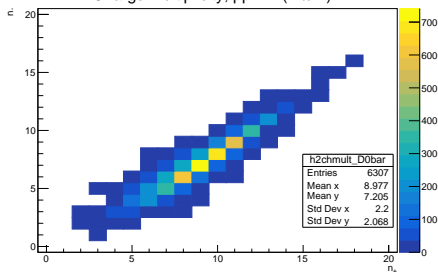
Λ_c^+ are concentrated to the beam axis

Charged tracks (charge multiplicities)

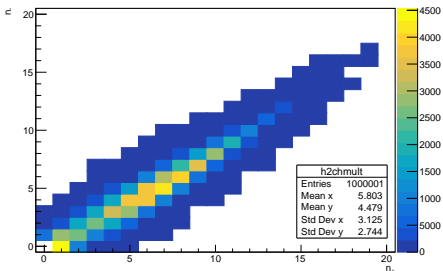
Charge multiplicity, $pp \rightarrow n_+ n_X$



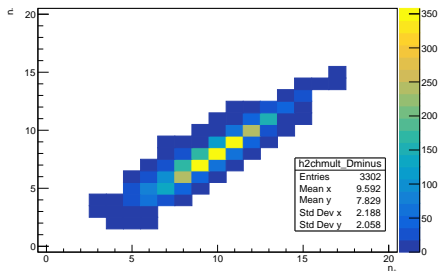
Charge multiplicity, $pp \rightarrow \bar{D}^0 (-\pi K) X$



Charge multiplicity, $pp \rightarrow n_+ n_X$

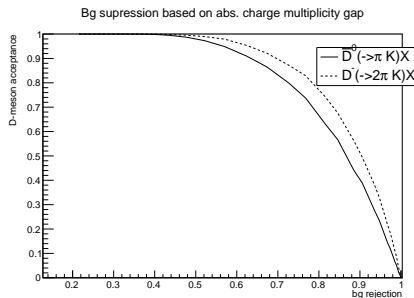
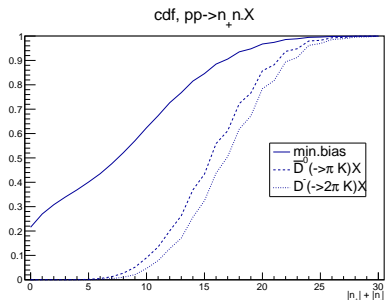


Charge multiplicity, $pp \rightarrow \bar{D}^0 (-2\pi K) X$



Charge multiplicities

$$n_{\text{ch}} = |n_+| + |n_-|$$



Note: in min.bias no charged tracks within acceptance = 0.22 of events

Bg suppression by factor (3...4) while keeping (0.9...0.8) of D -meson events

$J/\Psi \rightarrow \mu^+ \mu^-$ selection criteria (I.Denisenko):

- Muons are identified by RS
- Muons momenta $p > 1.5 \text{ GeV}/c$
- ...

Main combinatorial background: $\pi^\pm \rightarrow \mu^\pm \nu_\mu$

Expected rate of bg. events ($\mu^+ \mu^-$ at a range of 4 m):

0.14 at $p > 0.15 \text{ GeV}/c$;

0.003 at $p > 1.0 \text{ GeV}/c$;

0.0007 at $p > 1.5 \text{ GeV}/c$.

Not a point of concern