Criteria to select open-charm events by the online filter

Mikhail Zhabitsky, JINR

18.01.2022

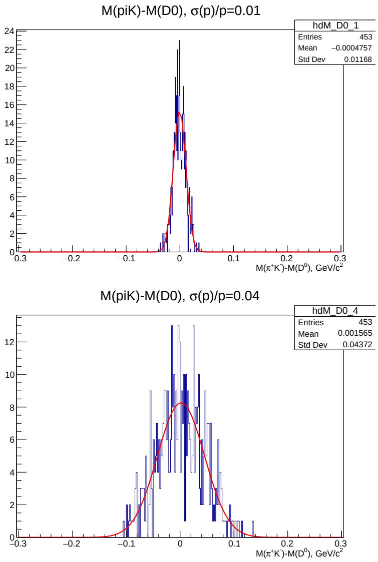
Minimum-bias events

- pythia8.303 ($p + p$, $\sqrt{s} = 27$ GeV, SoftQCD=on)
- Channels of interest:

  $D^0 \to \pi^+ K^-$ (0.0395 ± 0.0003) at $x_F > 0.2$

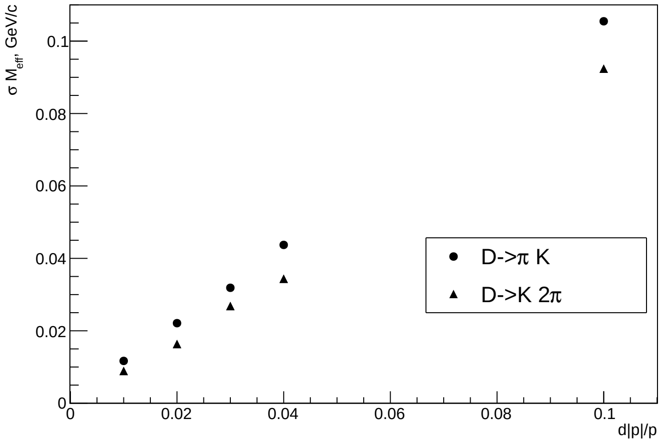
  $D^+ \to 2\pi^+ K^-$ (0.094 ± 0.002) at $x_F > 0.2$
- PID in endcaps
- Kinematic cuts in D^0 center-of-mass system
- D-meson events tagging:
  1. $D\bar{D}$-pairs
  2. $D^{*+} \to D^0 \pi^+$
  3. $\Lambda_c^+ \bar{D}$
- Charge multiplicities
- Study is focused on data-reduction by the online-filter

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



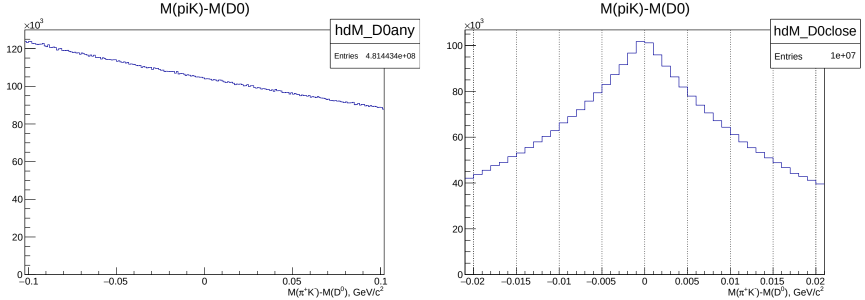
100M pp-interactions

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



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

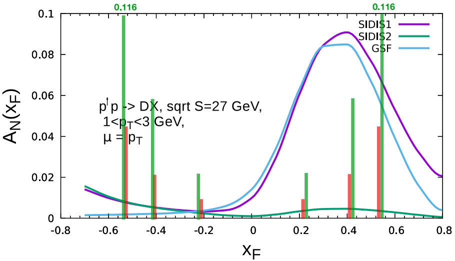
Worst-case scenario: only pos/neg charges are distinguished:
Any x^+y^- are treated as π^+K^-
tracks selection: $p > 0.15$ GeV$/c$, $p_T/p > 0.1$
any x_F

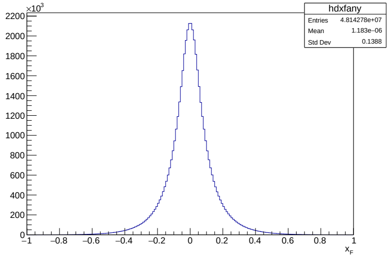


$M(x^+y^-) = M(\pi K)$, $|M(\pi K) - M(D^0)| < 0.15$ GeV$/c$: $\pm 3\sigma$ at $\sigma_p/p = 0.05$.

Probability of pos. trigger decision: 0.56

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



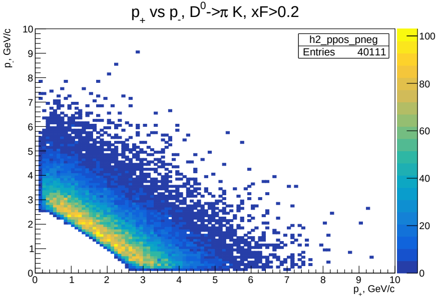


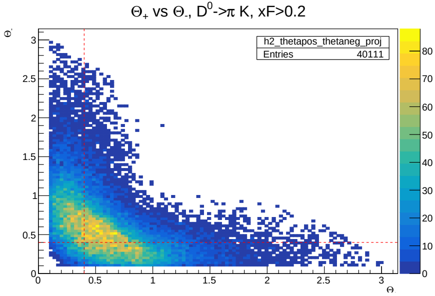
Events of interest: $x_F = \frac{p_z}{p_{z,\mathbf{max}}} > 0.2$

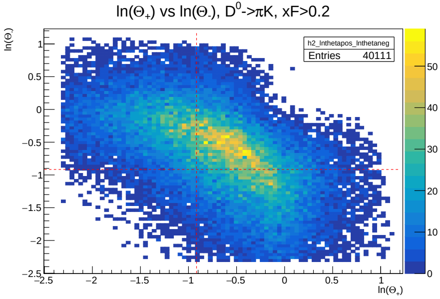
Probability of pos. trigger decision:
any x_F: 0.56
$x_F > 0.2$: 0.29

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

tracks selection: $p > 0.15$ GeV$/c$, $p_T/p > 0.1$, $x_F > 0.2$



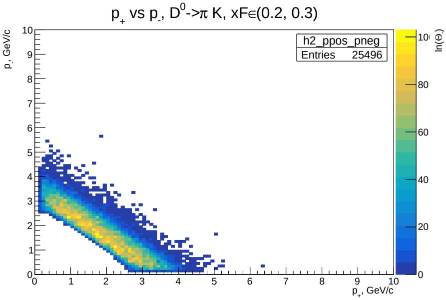


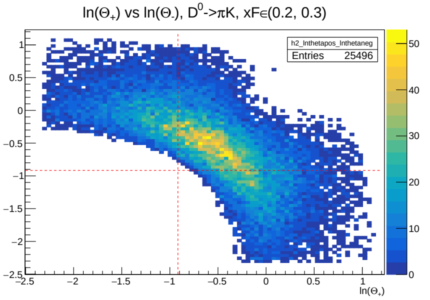


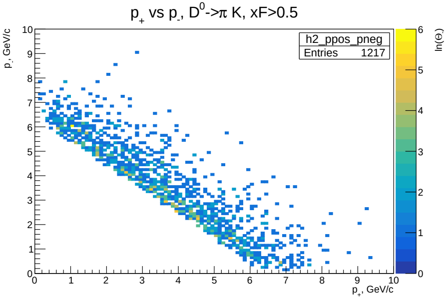
Statistics:

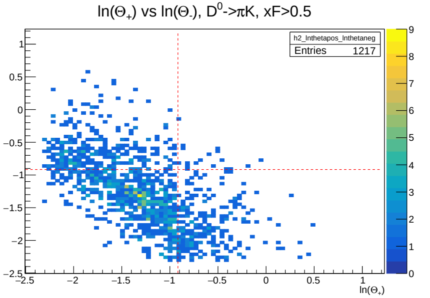
$3.6 \cdot 10^{10}$ *pp*-interactions
(approx. 3 hours at 3 MHz)

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





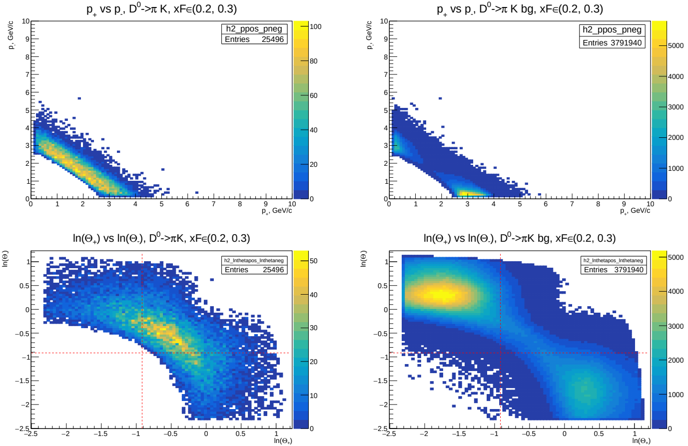




$D^0 \to K\pi$: signal vs combinatorial background

$x_F \in (0.2, 0.3)$:

Signal ($3.6 \cdot 10^{10}$) | bg (10M pp-collisions)



Trigger rate: 0.20

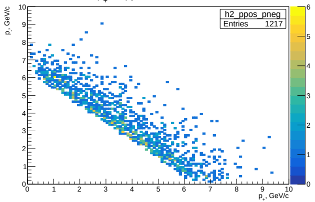
Main Bg combinations:
$p\pi^-$: 1.1M
$\pi^+\pi^-$: 1.9M
πK: 0.4M
other: 0.4M

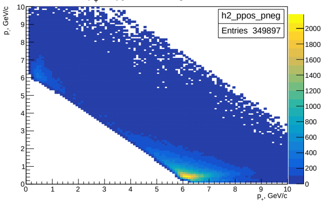
$D^0 \to K\pi$: signal vs combinatorial background

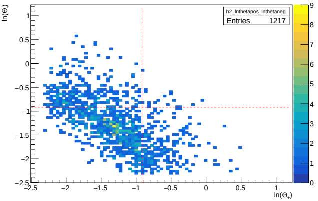
$x_F > 0.5$:

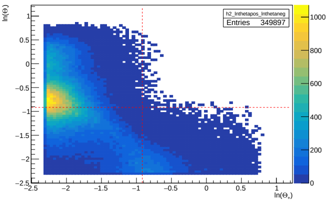
Signal ($3.6 \cdot 10^{10}$)

bg (10M pp-collisions)









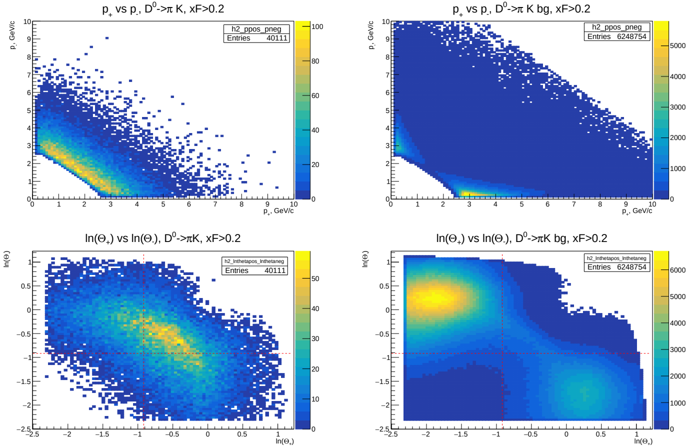
Trigger rate: 0.026

Main Bg combinations:
$p\pi^-$: 0.21M
$\pi^+\pi^-$: 0.09M
πK: 0.02M
other: 0.03M

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

$x_F > 0.2$:

Signal ($3.6 \cdot 10^{10}$) bg (10M pp-collisions)



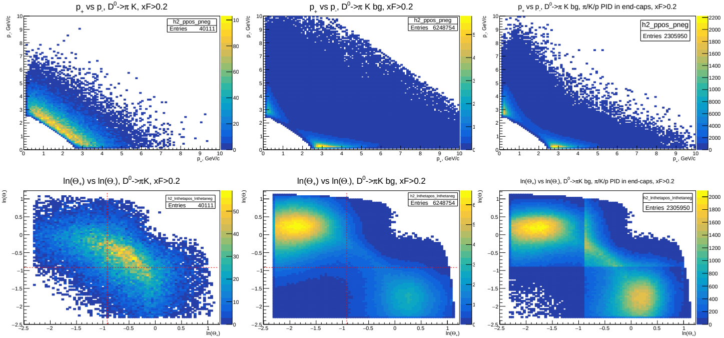
Trigger rate: 0.29

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

Cherenkov ID in end-caps

$x_F > 0.2$:

Signal ($3.6 \cdot 10^{10}$) bg (10M pp-collisions)



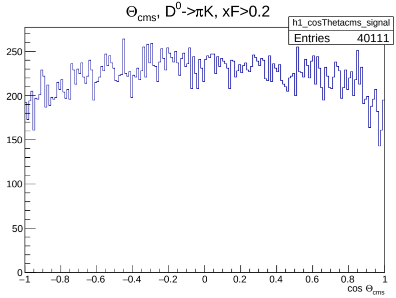
Trigger rate: 0.15

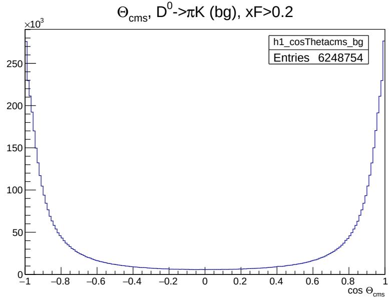
Main Bg combinations:
$p\pi^-$: 0.2M
$\pi^+\pi^-$: 1.8M
πK: 0.3M
other: 0

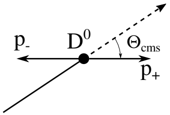
Trigger rate for $x_F > 0.2$, Cherenkov ID in end-caps:

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

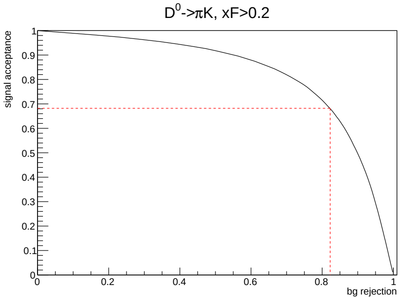
$D^0 \to K\pi$: CMS kinematics







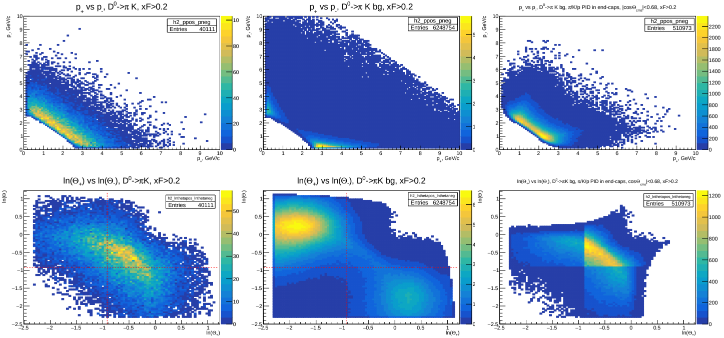
$$\sigma(\cos(\Theta_{\mathbf{cms}})) \approx 0.02$$



Suppress forward/backward kinematics in CMS

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

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

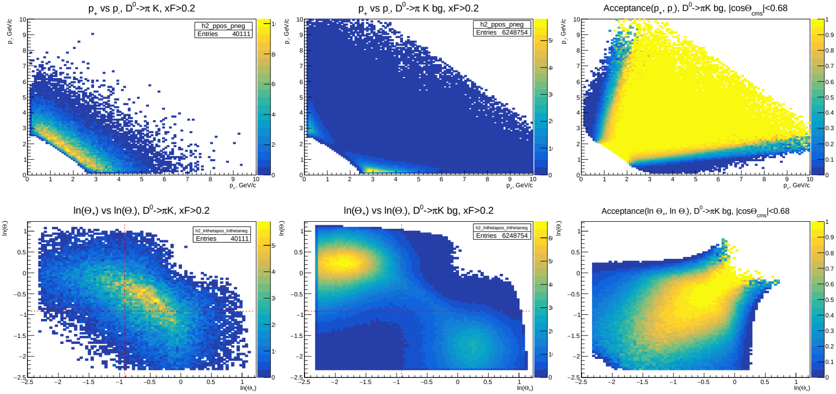
Trigger rate for $x_F > 0.2$, Cherenkov ID in end-caps

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

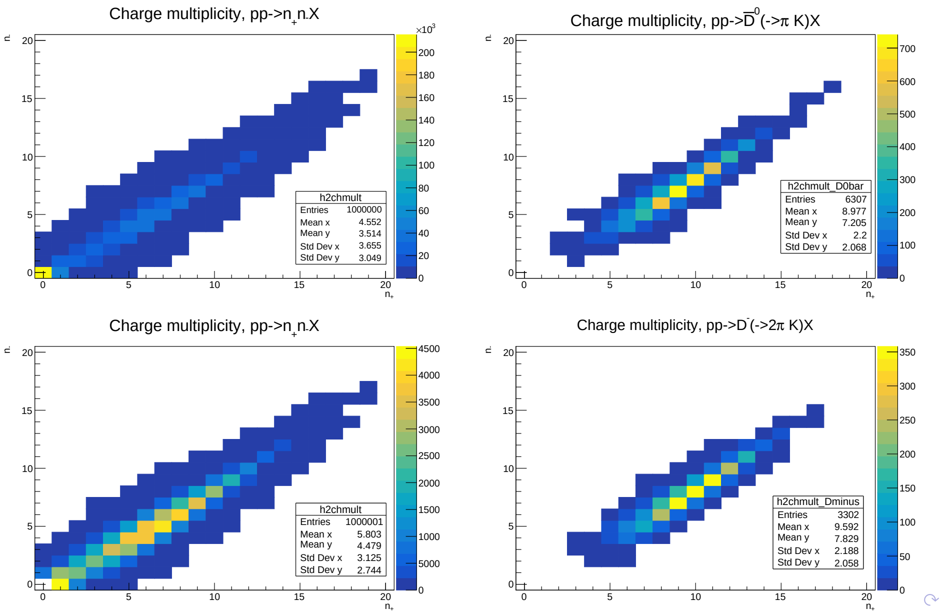
Acceptance due to cuts on forward/backward kinematics in CMS

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

Signal ($3.6 \cdot 10^{10}$) bg (10M pp-collisions)

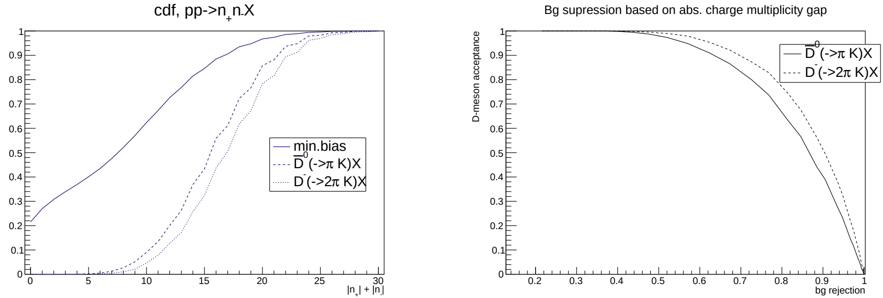


Charged tracks (charge multiplicities)



Charge multiplicities

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

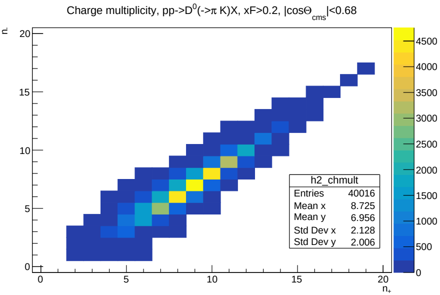


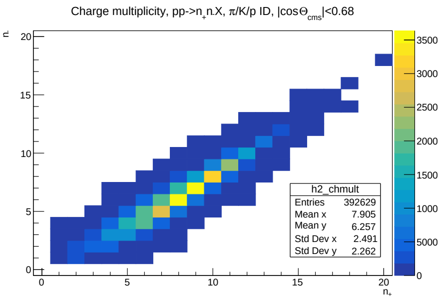
Note: in min.bias no charged tracks within acceptance = 0.22 of events

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

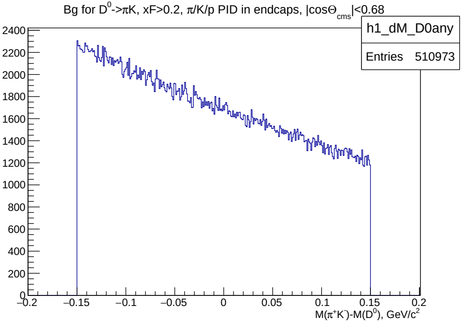
Charged tracks (charge multiplicities)

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





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



Range of accepted $\lvert M_{\pi K} - M_{D^0} \rvert$		
1.5σ	3σ	6σ
0.022	0.039	0.073

$\mu^+\mu^-$-combinations (background)

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

- Muons are identified by RS
- Muons momenta $p > 1.5$ GeV/c
- ...

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

Expected rate of bg. events ($\mu^+\mu^-$ at a range of 4 m):
0.14 at $p > 0.15$ GeV/c;
0.003 at $p > 1.0$ GeV/c;
0.0007 at $p > 1.5$ GeV/c.

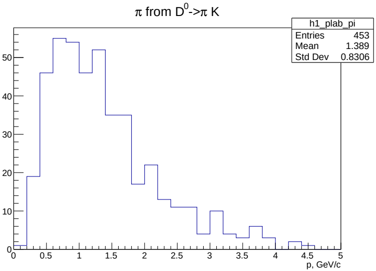
Not a point of concern

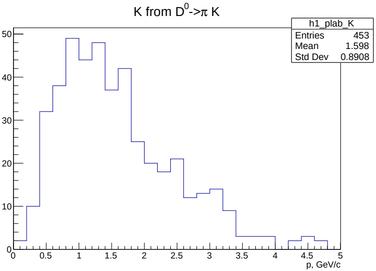
Conclusions

- 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 $(1.5 \ldots 2)$
- Criteria on the CMS angle between the decay axis and momentum of D: suppress background by a factor $(3 \ldots 4)$ while retaining 0.7 of true D^0-events
- Criteria on charge multiplicity $(|n_+| + |n_-|)$: small gain
- D-meson events tagging:

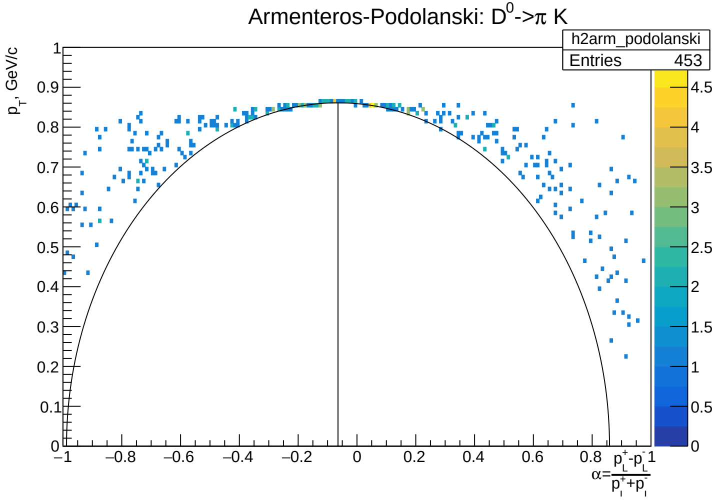
  doesn't seem promising within the online-filter
- Particle identification $(\pi/K/p)$ in the barrel part?
- Overall bg suppression by a factor $(15 \ldots 20)$ is achievable

$D^0 \to \pi K$: π/K spectra



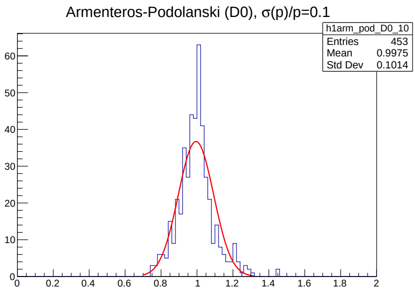


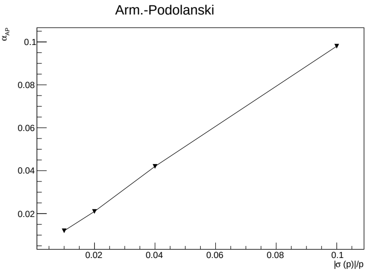
$D^0 \to \pi K$



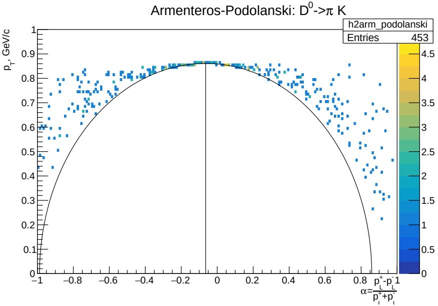
Armenteros-Podolanski: D0->π K
h2arm_podolanski
Entries 453
pT, GeV/c
α=(pL+-pL-)/(pL++pL-)

$D^0 \to \pi K$

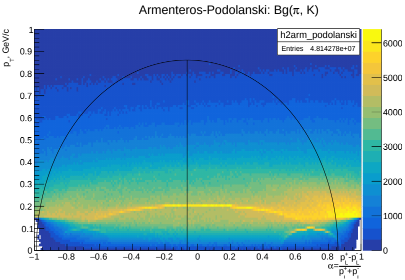

Armenteros-Podolanski (D0), σ(p)/p=0.1
h1arm_pod_D0_10
Entries 453
Mean 0.9975
Std Dev 0.1014
0 10 20 30 40 50 60
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2


Arm.-Podolanski
α_{AP}
0.02 0.04 0.06 0.08 0.1
|σ (p)|/p

$D^0 \to \pi K$



Armenteros-Podolanski: D0->π K
h2arm_podolanski
Entries 453
p_T, GeV/c
α=(p+_L-p-_L)/(p+_l+p-_l)



Armenteros-Podolanski: Bg(π, K)
h2arm_podolanski
Entries 4.814278e+07
p_T, GeV/c
α=(p+_L-p-_L)/(p+_l+p-_l)

D-Event-tagging:

Channels of interest:

$D^0 \to \pi^+ K^-$ (0.0395 ± 0.0003)

$D^+ \to K^- 2\pi^+$ (0.094 ± 0.002)

- $pp \to D\bar{D}X$: complete reconstruction of D-mesons
- $D^{*+} \to D^0 \pi^+$ (0.677)

  D^{*+} width: 83.4 ± 1.8 keV
- $pp \to \Lambda_c^+ \bar{D} X$ with $\Lambda_c^+ \to p + X$ (≈ 0.5)

Rate of charmed events

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

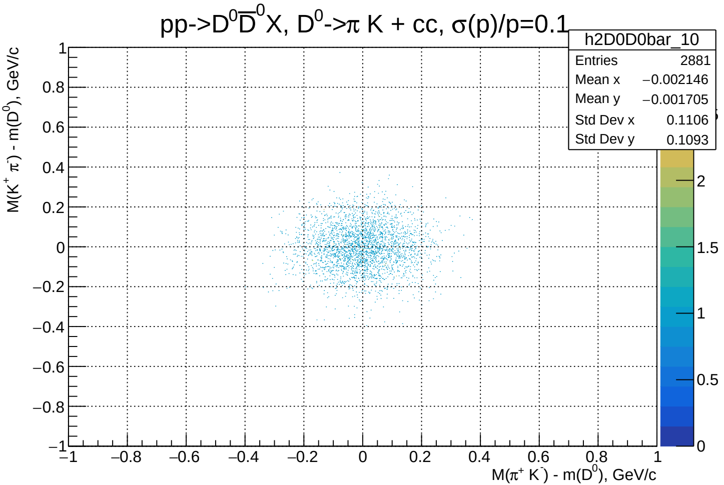
D^+X	24.0	$D^{*+}X$	16.7
D^-X	30.8	$D^{*-}X$	19.9
D^0X	48.5	$D^{*0}X$	16.2
$\bar{D}^0X$	59.2	$\bar{D}^{*0}X$	21.4
D_s^+X	7.2		
D_s^-X	10.4		
Λ_c^+X	22.7		
Λ_c^-X	2.5		

Associated D-meson production:

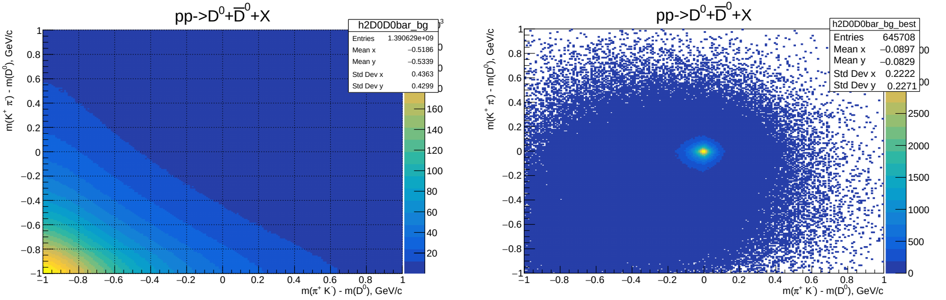
D^+D^-X	8.5		
$D^+\bar{D}^0X$	12.5		
D^0D^-X	14.3	$\Lambda_c^+D^-X$	5.8
$D^0\bar{D}^0X$	29.2	$\Lambda_c^+\bar{D}^0X$	12.6

Note: expected rate of inelastic collisions 3 MHz

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



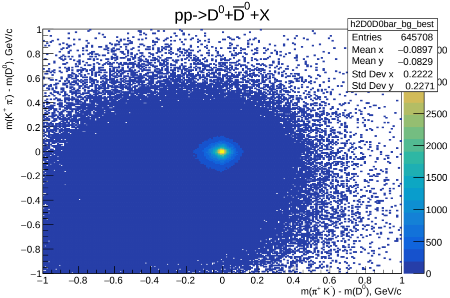
$pp \to D^0 \bar{D}^0 X$: combinatorial background



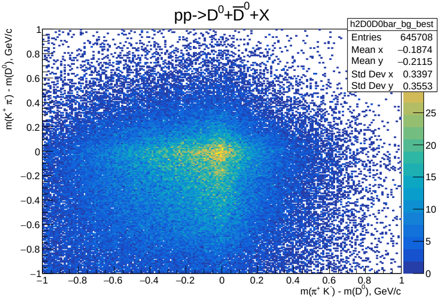
No PID, resolution $\frac{\sigma_p}{p} = 0.1 \quad \Rightarrow \quad$ 0.32 — probability to find bg $(\pi^+ K^- \& \pi^- K^+)$

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

no PID



ideal PID



	$\frac{\sigma_p}{p} = 0.1$	$\frac{\sigma_p}{p} = 0.02$
no PID	0.32	0.05
ideal PID	0.01	0.0005

$pp \to D^0 \bar{D}^0 X$ (signal vs bg)

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

- Signal

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

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

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

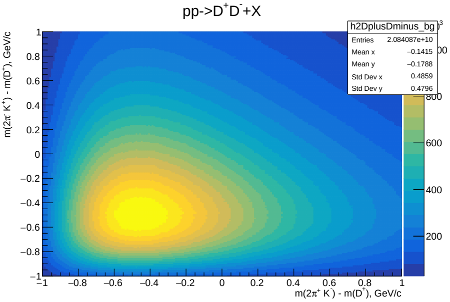
  Geometrical acceptance $pp \to \bar{D}^0 D^0 X$: 0.94

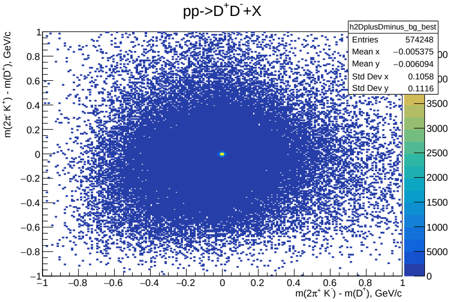
  Signal events' reduction factor is about 50.

- Background

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

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





$pp \to D^+D^-X$ (signal vs bg)

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

- Signal

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

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

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

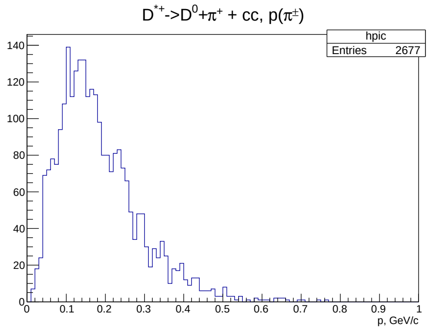
  Geometrical acceptance $pp \to D^+D^-X$: 0.92

  Signal events' reduction factor is about 30.

- Background

$\frac{\sigma_p}{p}$	both comb.$< \Delta M$
0.1	0.46
0.01	0.18

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

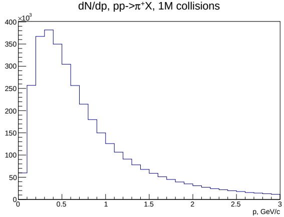


$D^{*+} \to D^0 + \pi^+$

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

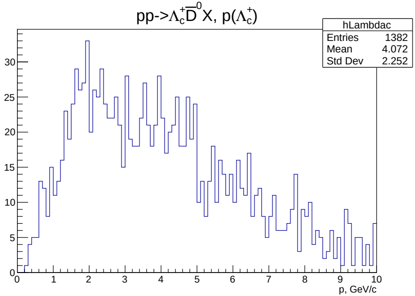
$D^{*0} \to D^0 + \pi^0$(or γ)?

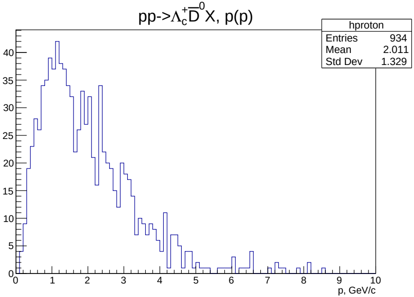
Spectra of bg π^+:



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

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





Λ_c^+ are concentrated to the beam axis