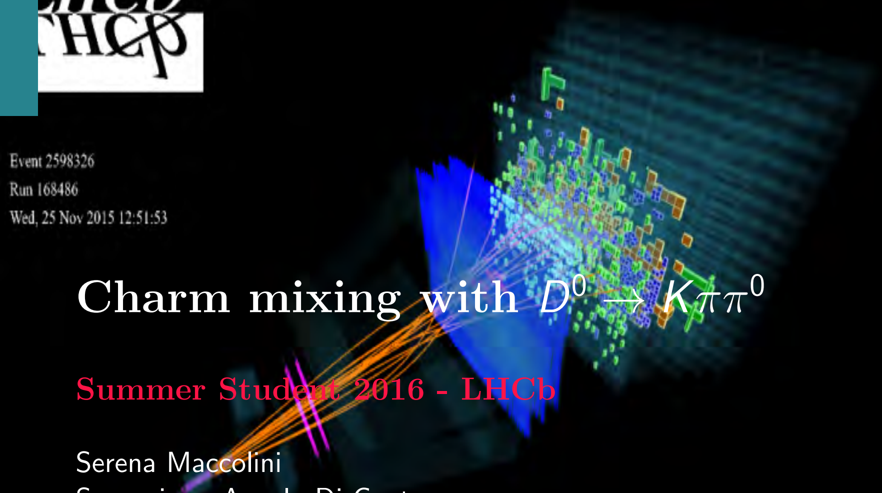


Charm mixing with $D^0 \to K\pi\pi^0$

Summer Student 2016 - LHCb

Serena Maccolini
Supervisor: Angelo Di Canto

August 30, 2016

About me

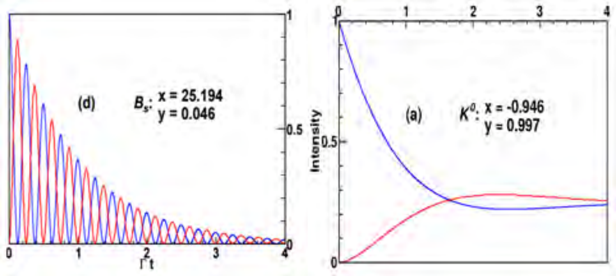
- I'm from Italy!
- Bachelor in Physics at University of Bologna.
- Now I'm an undergraduate student in Nuclear and Subnuclear Physics.

Mixing of neutral mesons

- Flavour and mass eigenstates are different.

$$|P_{1,2}\rangle = p\,|P^0(t)\rangle \pm q\,|\bar{P}^0(t)\rangle$$

- This causes $P^0 \leftrightarrow \bar{P}^0$ transitions described by



$$x = \frac{m_1 - m_2}{\Gamma}$$

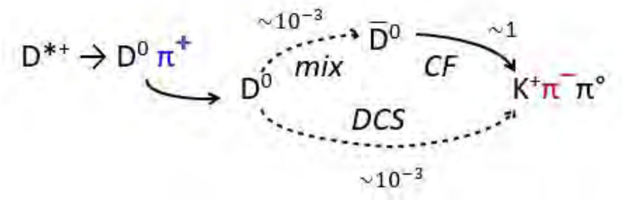
$$y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

$$|\langle P^0(0)|P^0(t)\rangle|^2 \propto e^{-\Gamma t}[\cosh(y\Gamma t) + \cos(x\Gamma t)]$$

$$|\langle P^0(0)|\bar{P}^0(t)\rangle|^2 \propto e^{-\Gamma t}[\cosh(y\Gamma t) - \cos(x\Gamma t)]$$

How can you measure mixing?

- Look at rate of wrong-sign (WS) $D^* \to D^0(\to K\pi\pi^0)\pi_S$ decays with respect to right-sign (RS) decays.



- Time-dependent analysis to disentangle mixing from DCS rate.

$$R(t) = \frac{WS(t)}{RS(t)} \approx R_D + \alpha\sqrt{R_D}y'\left(\frac{t}{\tau}\right) + \frac{x^2+y^2}{4}\left(\frac{t}{\tau}\right)^2$$

$$y' = y\cos(\delta) - x\sin(\delta)$$

- Most of the sensitivity to mixing comes from the interference term.

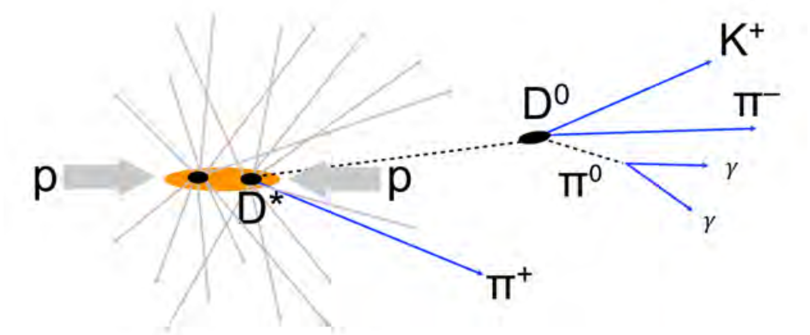
Dataset and event selection

Dataset

- Started to look at 2012 data

Resolved π^0
$\gamma\gamma$ in different clusters of the ECAL.

Merged π^0
$\gamma\gamma$ in the same cluster of the ECAL.



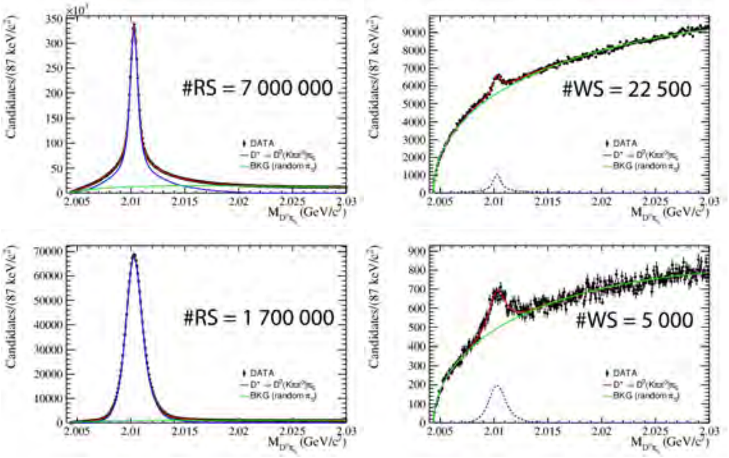
Selected candidates

In addition to provide the flavour at production, the **D* decay** also helps to reject lots of background (very small Q-value).

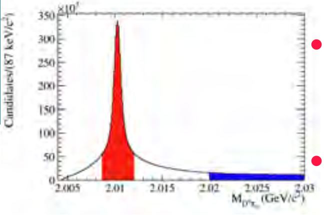
Resolved π^0

Merged π^0

The **background** is given by correct D^0 but wrong π_S



BDT training



- Implement a BDT selection to suppress the large **random**-π background of the **WS** sample.
- Train on **RS** data (more abundant and cleaner)

- Identify input variables that have good **separation** between signal and background but also **low correlation** with $M_{D^0\pi_S}$ and with Dalitz plot.

Resolved π^0:

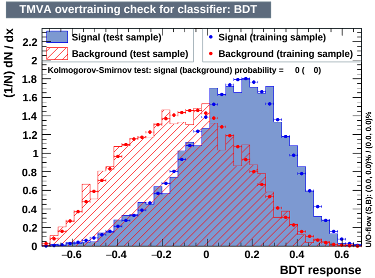
Variable	$< S^2 >$
$p_T(D^0)$	8.3%
$cos\theta_{XY}(p_{K\pi} vs p_{\pi^0})$	6.5%
$CL(\pi^0)$	4.8%
$P(\pi_S \to \pi)$	3.0%
$\log(\text{DTF1\_V}\chi^2)$	2.5%

Merged π^0:

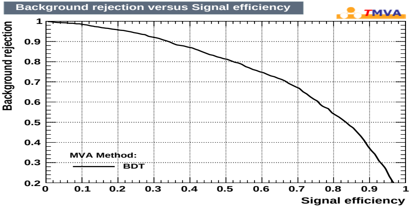
Variable	$< S^2 >$
$p_T(\pi_S)$	7.4%
$P(\pi_S \to \pi)$	6.7%
$p(\pi_S)$	1.6%
$\log(\text{DTF1\_V}\chi^2)$	0.1%

BDT distribution and ROC curve

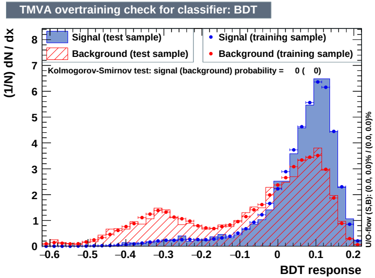
Resolved π^0:



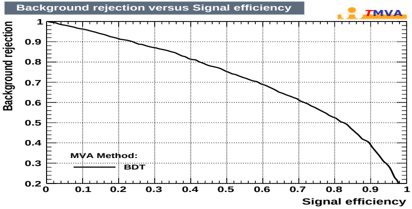
BDT separation: 0.184



Merged π^0:

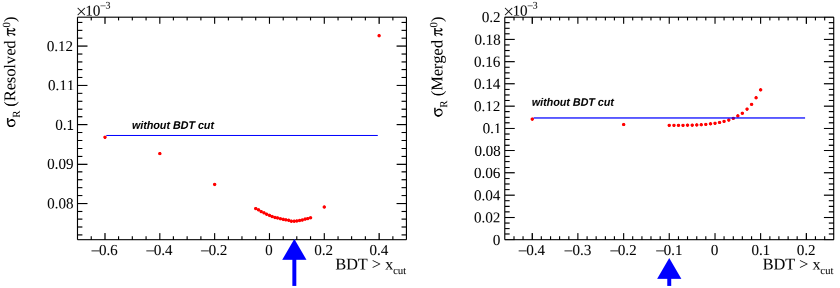


BDT separation: 0.151



BDT optimization

Choose the BDT cut that minimises the uncertainty of the time integrated WS/RS ratio.

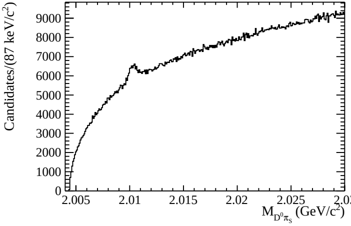


20% improvement in precision for candidates with resolved π^0, while only a marginal gain for the merged sample.

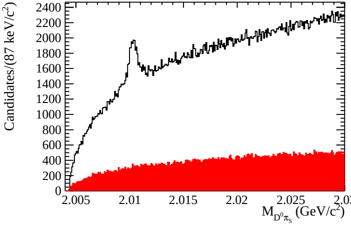
Overlap betwen WS and RS candidates

Additional background reduction when removing WS candidates whose D^0 is also used to recunstruct a good RS candidate.

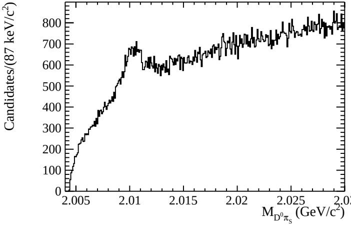
Resolved π^0



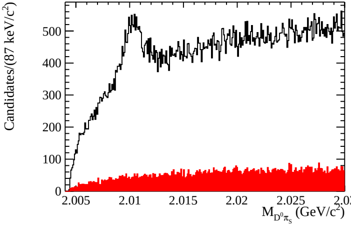
$\Rightarrow$



Merged π^0



$\Rightarrow$



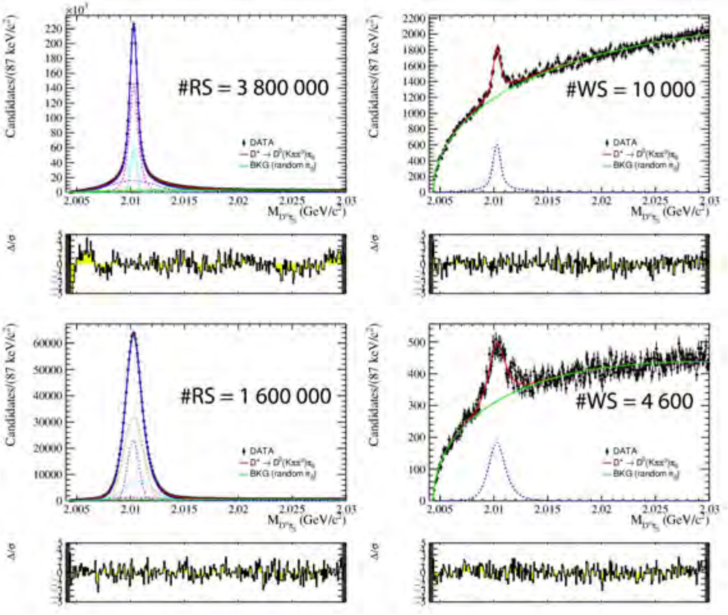
Overlapped WS candidates

Final samples

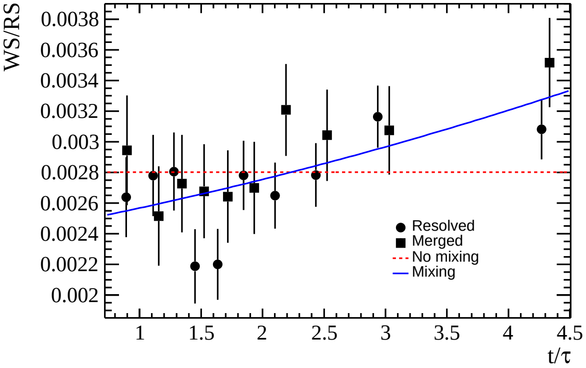
Resolved

In WS fitting, the signal shape is fixed with RS values.

Merged



Time-dependent WS/RS ratio



No mixing:

Parameter	Fit result
R_D	$(XX \pm 0.0058)\%$

$$\chi^2_0/NDF = 30.3/19$$

Mixing:

Parameter	Fit result
R_D	$(XX \pm 0.034)\%$
$\alpha y'$	$(XX \pm 0.62)\%$
$1/4(x^2 + y^2)$	$(XX \pm 0.0055)\%$

$$\chi^2_2/NDF = 16.1/17$$

$$\Delta\chi^2/\Delta_{NDF} \rightarrow 3.3\sigma$$

$$R(t) \approx R_D + \alpha\sqrt{R_D}y'\left(\frac{t}{\tau}\right) + \frac{x^2+y^2}{4}\left(\frac{t}{\tau}\right)^2$$

Conclusion and future projects

First attempt to measure $D^0 - \bar{D}^0$ mixing using $D^0 \to K\pi\pi^0$ decays at LHCb:

- Results seem to be competitive with other measurements of these decays, but will have a marginal impact on the world average.
- Could increase sensitivity with more statistics and/or a time-dependent Dalitz-plot analysis.
- **Left to be done:** look at Run 2 data and particularly at the 2016 sample (higher cross-section and dedicate triggers)

Year	N_{RS}/L (fb)
2012	2'700'000
2015	6'400'000
2016	?

Thank you!

D^0 mixing formalism

- Eigenstate can have different masses and decay width

$$|D_{1,2}\rangle = p\,|D^0(t)\rangle \pm q\,|\bar{D}^0(t)\rangle$$

$$x = \frac{m_1 - m_2}{\Gamma} \;\; y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} \text{ with } \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

- The time evolution is described by

$$|D^0(t)\rangle = g_+\,|D^0(0)\rangle + \frac{q}{p} g_-\,|\bar{D}^0(0)\rangle$$

$$|\bar{D}^0(t)\rangle = g_+\,|\bar{D}^0(0)\rangle + \frac{q}{p} g_-\,|D^0(0)\rangle$$

with

$$g_+(t) = e^{-\imath Mt - \Gamma t/2} \cos\left(\frac{x}{2}\Gamma t - \frac{\imath y}{2}\Gamma t\right)$$

and

$$g_-(t) = e^{-\imath Mt - \Gamma t/2}\imath \sin\left(\frac{x}{2}\Gamma t - \frac{\imath y}{2}\Gamma t\right)$$

Dataset and event selection

Dataset

- 2012 sample candidates reconstructed using `DstarToHHPi0_Kpipi0_R_Line` and `DstarToHHPi0_Kpipi0_M_Line` from `Stripping21`, `Stripping24` and `Stripping26`.

Decay Tree Fitter

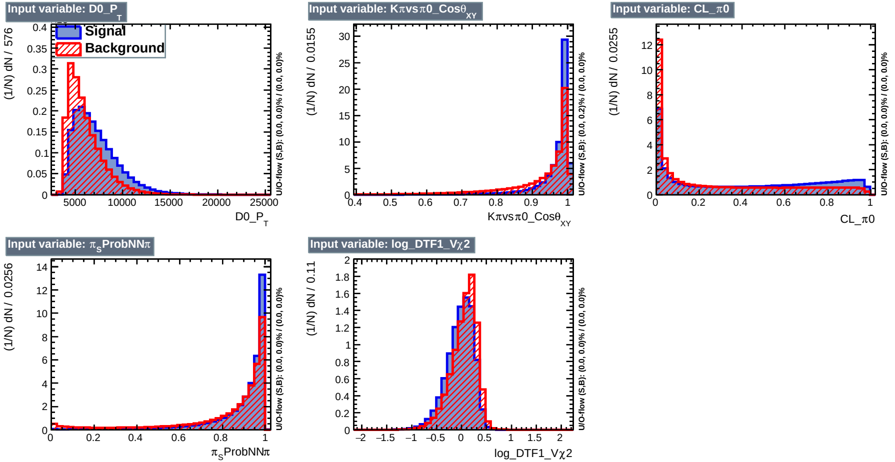
- constraining the $D^0\pi_S$ vertex to the primart vertex
- constraining the π^0 mass to the PDG value.

Additional cuts

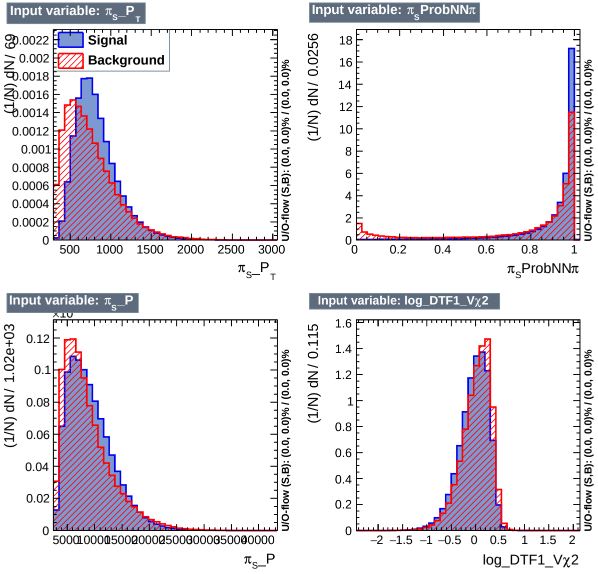
- $KPID_K > 8$;
- $\pi PID_K < -5$;
- $D^0 IP\chi^2 < 9$.

- $1825 < M_{D^0} < 1910$ MeV (resolved π^0)
- $1800 < M_{D^0} < 1950$ MeV (merged π^0)

BDT training variables distributions
(Resolved)

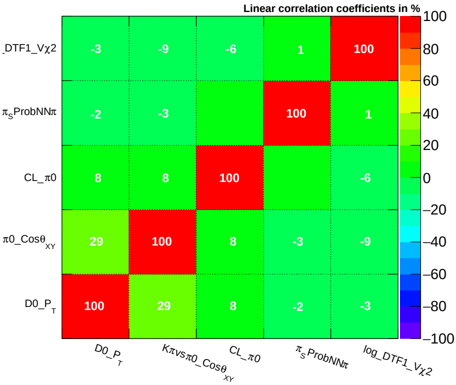


BDT training variables distributions
(Merged)

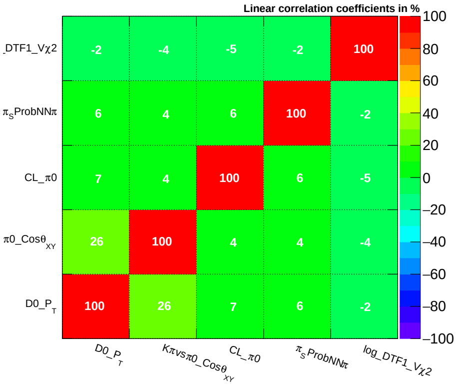


BDT training variables correlation matrices (Resolved)

Correlation Matrix (background)

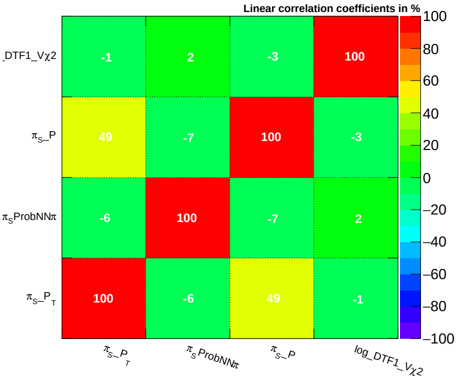


Correlation Matrix (signal)

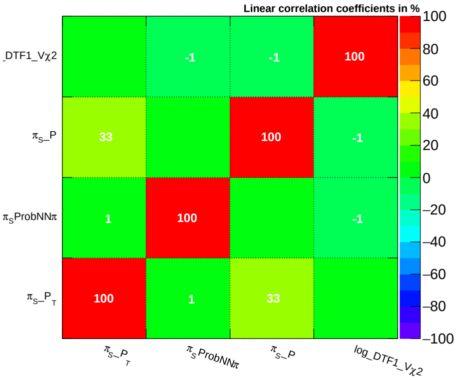


BDT training variables correlation matrices (Merged)

Correlation Matrix (background)



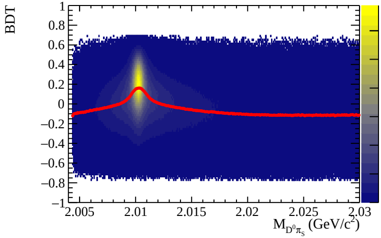
Correlation Matrix (signal)

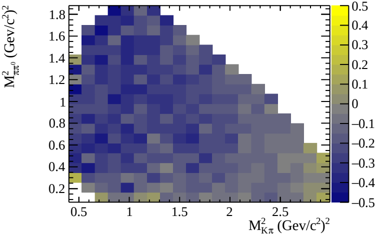


Low correlation of BDT

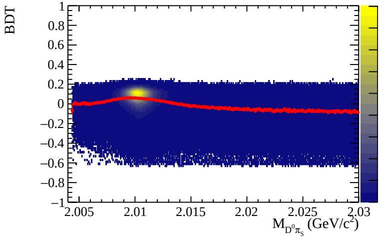
check with $M_{D^0\pi_S}$ and Dalitz plot

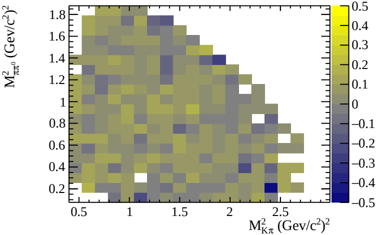
Resolved π^0:





Merged π^0:





The fit

- The **signal** is parametrize with a linear combination of a Johnson SU distribution and three Gaussian distributions.

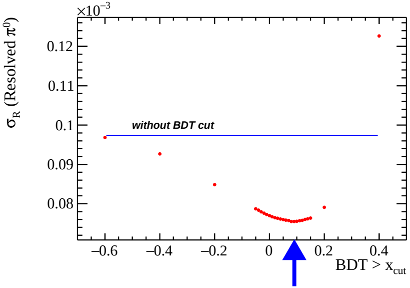
Johnson SU: trasformation of the normal distribution

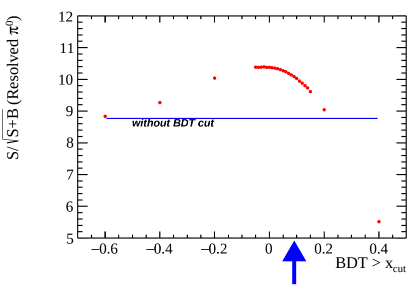
$$z = \gamma + \delta \sinh^{-1}\left(\frac{x-\xi}{\lambda}\right) \text{ where } z \sim \mathcal{N}(0,1).$$

- The **background**, given by a random soft pion π_S, is parametrized using the function:

$$(m - m_0)^{\alpha} e^{\beta(m-m_0)} \text{ with m}=M_{D^0\pi_S} \text{ and } m_0 = m_{D^0} + m_{\pi}.$$

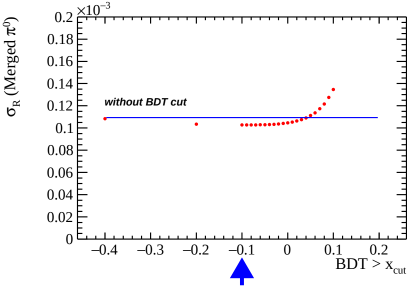
BDT optimization
Resolved

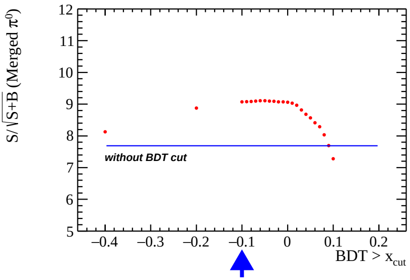




→ I found the minimum uncertainty for BDT_{cut} **= 0.09**

BDT optimization
Merged





→ I chose BDT_{cut} = **-0.1**

The uncertainty has not improved but the significance has.