Università degli Studi di Perugia/INFN Perugia

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Measurement of Tracking Efficiency using the D^* slow π helicity with the CMS detector at LHC

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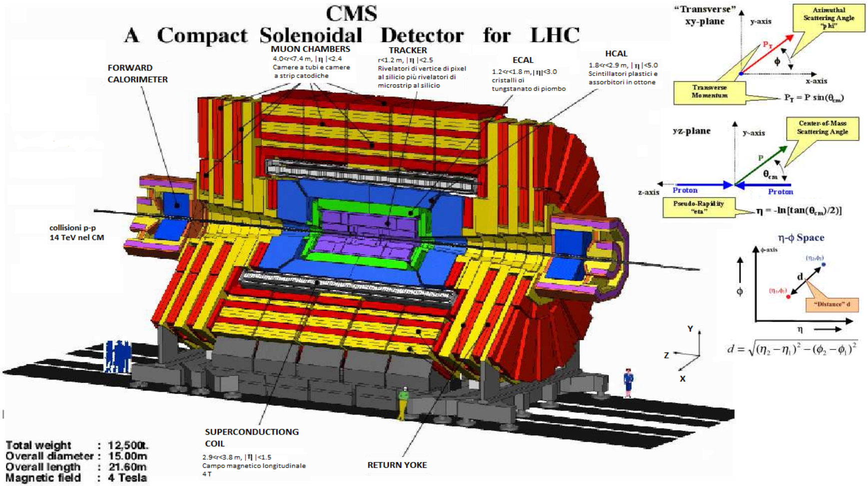
Outline

The motivations and goal of the analysis

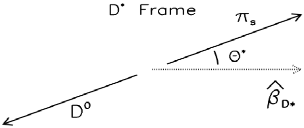
- CMS is one of the 4 detectors which operates at LHC
- It is important to study the properties and performances of the detector
- The aim of the analysis is to characterize the relative tracking efficiency for charged hadrons at low momentum as a function of lab momentum ($\varepsilon(p, m)$)
- A method relied on the slow pion (π_s) helicity measurement in the D^* rest frame in the decay channel $B^0 \to D^* \ell \nu \to (D^0 \pi_s) \ell \nu \to ((\pi K) \pi_s) \ell \nu$ is used
- The measurement is useful for all the physics analyses where it is necessary to evaluate the number of tracks

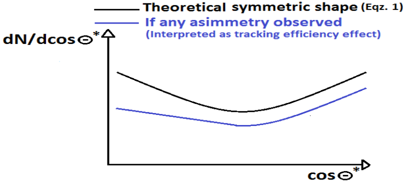
The CMS detector



The physical idea and the method

- $D^* \to D^0\pi_s$ in the D^* frame





- $\frac{dN}{dcos\theta^*} = N(1+\alpha cos^2\theta^*)$ (1) (Quantities with * in D^* Frame)
- $E_{\pi_s} = \gamma_{D^*}(E^*_{\pi_s} + \beta_{D^*} p^*_{\pi_s} cos\theta^*)$ (2), $E^*_{\pi_s} = 145.0$ MeV, $p^*_{\pi_s} = 39.3$ MeV
- p_{D^*} (k bin) e $cos\theta^*$ (n bin)
- $D_{nk} = \#$ of events in bin nk
  $S_{nk} = \#$ of expected events in bin nk.
  $S_{nk} = \varepsilon(p_{\pi_s}, m) \cdot (\frac{dN}{dcos\theta^*})_k$
- Find $\varepsilon(p_{\pi_s}, m)$ minimizing $\chi^2 = \sum_{nk} \frac{(D_{nk}-S_{nk})^2}{\sigma^2_{D_{nk}}}$ (3)

Used datasets and strategy of reconstruction

- Energy in CM = 7 TeV
- For data
  Primary dataset triggering at least a muon
  Recorded Luminosity: $\sim 34(pb^{-1})$
  Total Events read: $\sim 43 \cdot 10^6$
- For Monte Carlo
  Sample which describes QCD events with semileptonic decays from b-jets.
  σ of production = O(10)mb.
  Total Events read: $\sim 3 \cdot 10^6$
- Reconstruction in 2 steps:
  1. Selection of candidated tracks
  2. Selection of candidated events

1. Selection of candidated tracks

Cuts on quality of tracks

- $\chi^2 < 2.5$
- $\#$ of hits > 5

Geometrical cuts

- $|\eta| < 2.4$
- Selection of Primary Vertex with highest number of tracks.
  $|d_{xy}| < 0.1$ cm
  $|d_z| < 1$ cm

Cinematics cuts

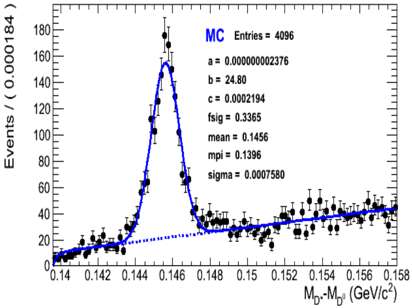
- $p_T > 0.6$ GeV/c
  $p_T > 0.25$ GeV/c (For candidates of π_s)

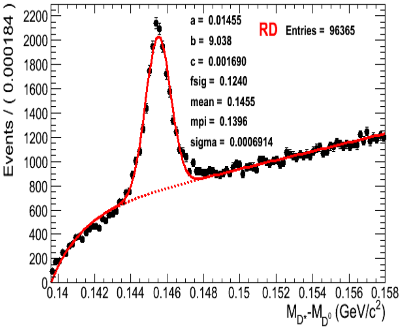
2. Selection of candidated events and helicity measurement

- For $B^0 \to D^{*-}\ell^+\nu \to (\bar{D}^0\pi^-)\ell^+\nu \to ((\pi^- K^+)\pi^-)\ell^+\nu$ (or its charge conjugate)
  - $\bar{D}^0$ selection
    - Pair of tracks with opposite charge $(\pi^- K^+)$
    - Invariant mass within 25 MeV$/c^2$ of D^0 mass
    - Vertex constrained kinematic fit
  - D^{*-} selection
    - Candidates of π^- with charge opposite to K^+ candidate
    - Invariant mass for ΔM = M(K$\pi\pi$) - M(Kπ) < 0.158 GeV$/c^2$
    - For each event one triplet (K$\pi\pi$) with the minimum $\chi^2 = (\frac{M(K\pi)-M_{D^{0-}_{PDG}}}{\sigma_{\bar{D}^0}})^2 + (\frac{M(K\pi\pi)-M_{D^{*-}_{PDG}}}{\sigma_{D^{*-}}})^2$
    - $D_p^{*-} > 5.725$ GeV/c
  - B^0 selection
    - $\Delta R_{\overrightarrow{p_{D^*}},\vec{p_\ell}} < 0.25$
    - Lepton with minimum $\Delta R_{\overrightarrow{p_{D^*}},\vec{p_\ell}}$, lepton charge opposite to π charge and $p_T > 5$ Gev/c
- Helicity measured as: $\cos\theta^* = \hat{p^*_{\pi_s}} \cdot \hat{p_{D^*}}$

Signal and Background Extraction

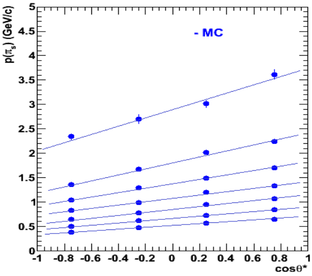
- An unbinned Maximum Likelihood fit has been executed to $M_{D^*} - M_{D^0}$ candidates with the model:
  $M = f \cdot [Gaussian] + (1-f) \cdot [(1 - e^{-\frac{\Delta M - mpi}{c}}) \cdot (\frac{\Delta M}{mpi})^a + b \cdot (\frac{\Delta M}{mpi} - 1)]$
  $f =$ fraction of signal

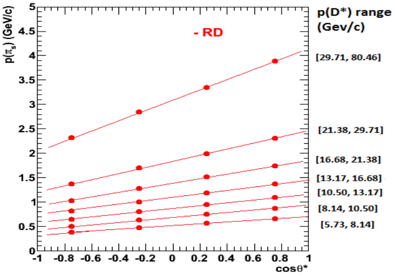




Bin division

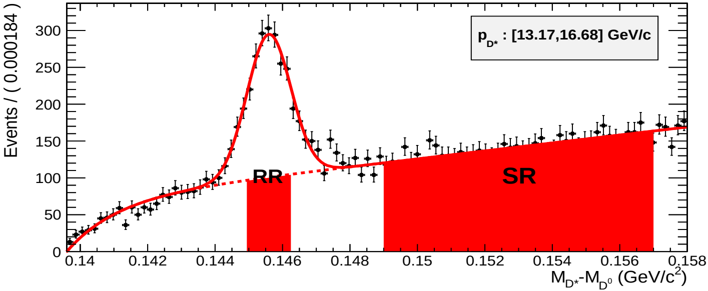
- p_{D^*} bin: Edge values found requiring for each bin 2000 entries (S+B) in a σ around resonance peak
  7 bins : $[5.73, 8.14, 10.50, 13.17, 16.68, 21.38, 29.71, 80.46]$ GeV/c
- $cos\theta^*$ bin: Uniform division, 4 bins
- $E_{\pi_s} = \gamma_{D^*}(E^*_{\pi_s} + \beta_{D^*} p^*_{\pi_s} cos\theta^*)$ (2)





Background subtraction procedure

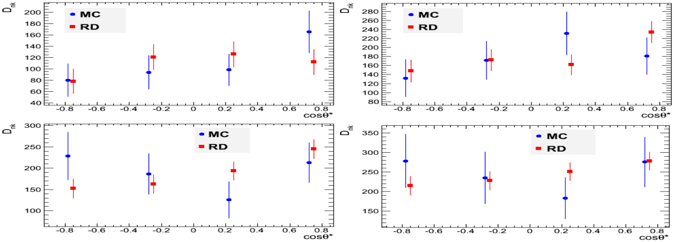
1. Selection of 2 regions:
   Resonance region (RR): $\pm$ 1 σ around peak
   Sideband region (SR): $[0.149, 0.157]$ GeV/c^2
2. Estimate of the background contribution in the RR and normalization of $\frac{dN}{dcos\theta^*}$ in SR to these background events
3. Subtraction bin by bin between $\frac{dN}{dcos\theta^*}$ in RR and normalized $\frac{dN}{dcos\theta^*}$ in SR



Corrected helicity distributions in RR

- The tracking efficiency effect is higher at lower p_{D^*} and p_{π_s} values

	$p_{D^*}: [5.73, 8.14]\, Gev/c$	$p_{D^*}: [8.14, 10.50]\, Gev/c$
$\cos\theta^* = -1$:	$p_{\pi_s} = 0.34\ Gev/c$	$p_{\pi_s} = 0.45\ Gev/c$
$\cos\theta^* = +1$:	$p_{\pi_s} = 0.70\ Gev/c$	$p_{\pi_s} = 0.93\ Gev/c$



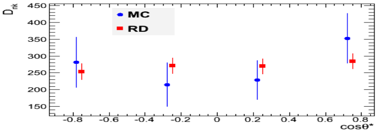
	$p_{D^*}: [10.50, 13.17]\, Gev/c$	$p_{D^*}: [13.17, 16.68]\, Gev/c$
$\cos\theta^* = -1$:	$p_{\pi_s} = 0.57\ Gev/c$	$p_{\pi_s} = 0.71\ Gev/c$
$\cos\theta^* = +1$:	$p_{\pi_s} = 1.17\ Gev/c$	$p_{\pi_s} = 1.47\ Gev/c$

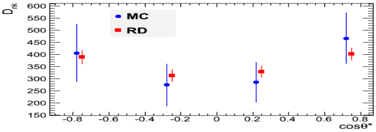
Corrected helicity distributions in RR

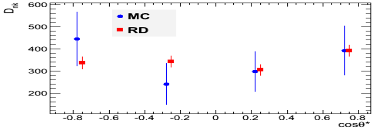
p_{D^*} : $[16.68, 21.38]\, Gev/c$ $\quad$ p_{D^*} : $[21.38, 29.71]\, Gev/c$

$\cos\theta^* = -1$: $p_{\pi_s} = 0.92\ Gev/c$ $\quad$ $p_{\pi_s} = 1.22\ Gev/c$

$\cos\theta^* = +1$: $p_{\pi_s} = 1.86\ Gev/c$ $\quad$ $p_{\pi_s} = 2.46\ Gev/c$







p_{D^*} : $[29.71, 80.46]\, Gev/c$

$\cos\theta^* = -1$: $p_{\pi_s} = 2.1\ Gev/c$

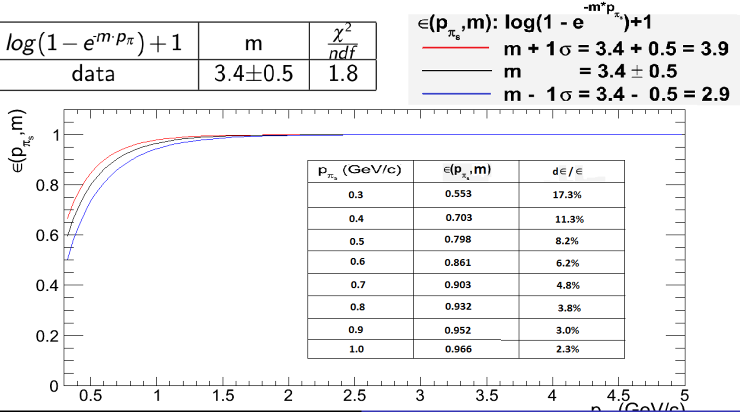
$\cos\theta^* = +1$: $p_{\pi_s} = 4.1\ Gev/c$

Fit of efficiency for data

- We want to minimize $\chi^2 = \sum_{nk} \frac{(D_{nk} - S_{nk})^2}{\sigma^2_{D_{nk}}}$

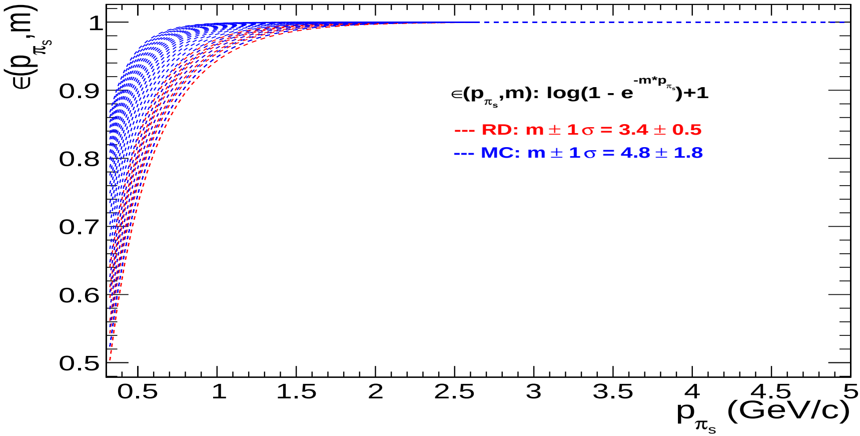
  D_{nk} (entries in the bin nk); $\sigma_{D_{nk}}$ (corresponding error);
  $S_{nk} = \varepsilon(p_\pi, m)_{nk} \cdot N_k(1 + \alpha_k cos\theta_n^2)$, $\varepsilon(p_\pi, m) = log(1 - e^{-m \cdot p_\pi}) + 1$

$log(1 - e^{m \cdot p_\pi}) + 1$	m	$\frac{\chi^2}{ndf}$
data	3.4±0.5	1.8



p_{π_s} (GeV/c)	$\epsilon(p_{\pi_s},m)$	$d\epsilon/\epsilon$
0.3	0.553	17.3%
0.4	0.703	11.3%
0.5	0.798	8.2%
0.6	0.861	6.2%
0.7	0.903	4.8%
0.8	0.932	3.8%
0.9	0.952	3.0%
1.0	0.966	2.3%

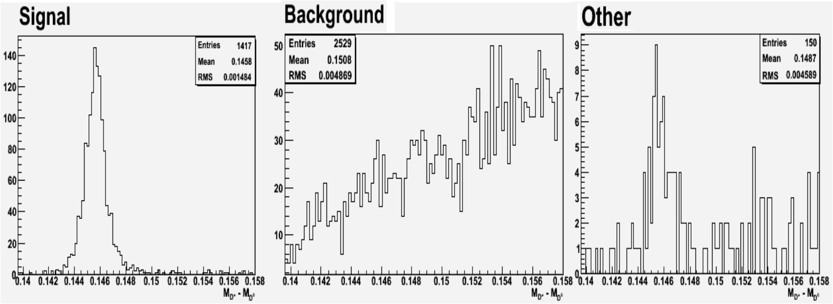
Data vs MC


$\epsilon(p_{\pi_s},m)$
$\epsilon(p_{\pi_s},m)$: $\log(1 - e^{-m*p_{\pi_s}})+1$
--- RD: $m \pm 1\sigma = 3.4 \pm 0.5$
--- MC: $m \pm 1\sigma = 4.8 \pm 1.8$
1
0.9
0.8
0.7
0.6
0.5
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
p_{π_s} (GeV/c)

- A measure of the relative tracking efficiency for charged hadrons at low momentum as a function of lab momentum ($\varepsilon(p,m)$) has been presented
- It is important to understand the properties and performances of the detector and it is useful for lots of physics analyses
- The method relied on the slow pion (π_s) helicity measurement in the D^* rest frame in the decay channel $B^0 \to D^* \ell \nu \to (D^0 \pi_s) \ell \nu \to ((\pi K) \pi_s) \ell \nu$ has been used
- The final result has been derived by fitting the data with the model $\varepsilon(p_\pi, m) = log(1 - e^{-m \cdot p_\pi}) + 1$.
  A value of m = 3.4$\pm$0.5 is obtained
- With 2011 statistics a lower statistical error is expected with the possibility to study $\varepsilon(p, \eta, m)$

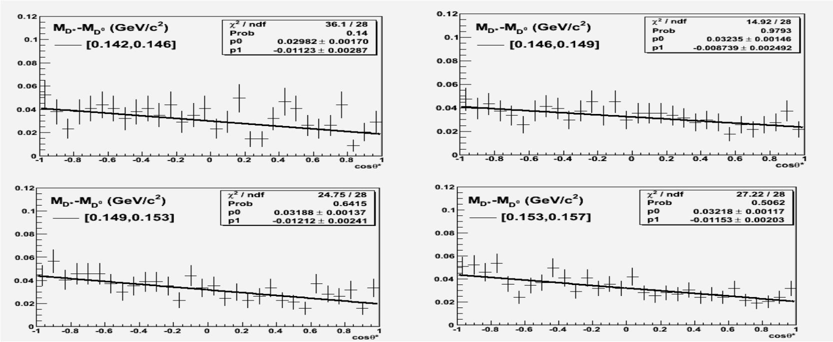
Separation of signal and background

- The purpose is to show that $\frac{dN}{dcos\theta^*}$ is independent from $M_{D^*} - M_{D^0}$ background
- Remembering our final state, $\pi^- K^+ \pi_s^- \ell^+ \nu$, 3 samples can be distinguished using Monte Carlo information (4096 events)
  Signal: $\pi^- K^+ \pi_s^-$ matched ~ 34 %
  Background: No particles matched. ~ 62 %
  Other: All other cases of matching. ~ 4 %



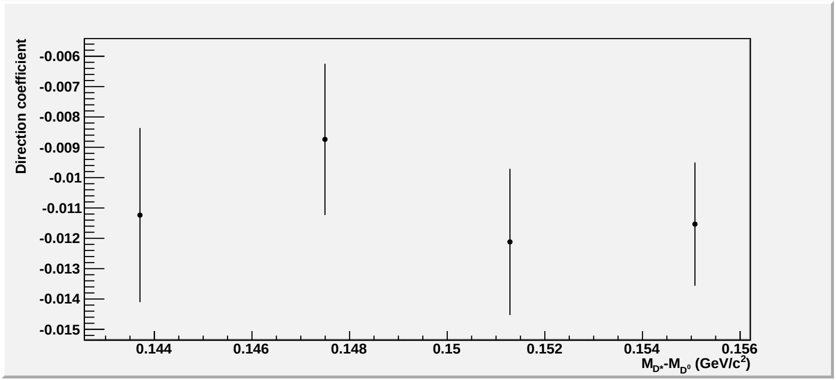
Fit of slow π helicity distributions in different regions of $M_{D^*} - M_{D^0}$

- Some regions of $M_{D^*} - M_{D^0}$ for the Background are selected and $\frac{dN}{dcos\theta^*}$ normalized to 1 is fitted



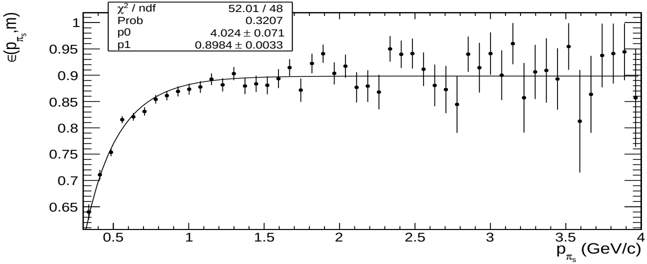
Direction coefficient vs $M_{D^*} - M_{D^0}$

- The direction coefficient of the line used previously in the fit is plotted versus $M_{D^*} - M_{D^0}$



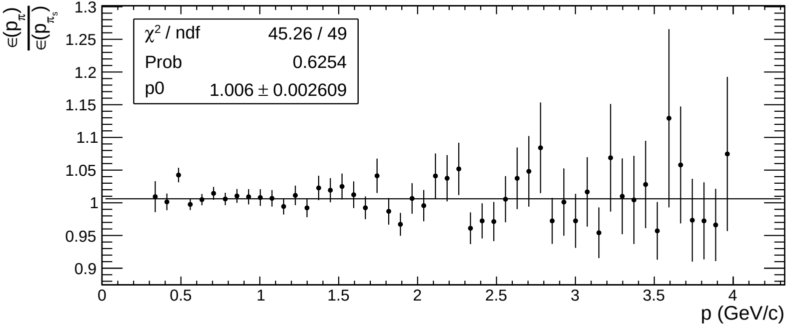
Efficiency from counting for π_s

- For $B^0 \to D^*\ell\nu \to (D^0\pi_s)\ell\nu \to ((\pi K)\pi_s)\ell\nu$:
  $\varepsilon(p_{\pi_s}, m) = \frac{N(\pi_s^{Reco}|(\pi,K,\ell)^{Reco})}{D(\pi_s^{Gene}|(\pi,K,\ell)^{Reco})}$
  $N(\pi_s^{Reco}|(\pi,K,\ell)^{Reco})$ = #Evt with reco π_s, π, K, ℓ associated to corresponding gen particles in $|\eta| < 2.4$
  $D(\pi_s^{Gene}|(\pi,K,\ell)^{Reco})$ = #Evt with reco π, K, ℓ associated to the corresponding gen particles in $|\eta| < 2.4$ and generated π_s in $|\eta| < 2.4$
- Model for $\varepsilon(p_{\pi_s}, m) = log(1 - e^{m \cdot p_{\pi_s}}) + 1$



Comparison of the efficiencies of π_s and π

- $\varepsilon(p_\pi, m) = \frac{N(\pi^{Reco})}{D(\pi^{Gene})}$
  $N(\pi^{Reco}) = \#$Evt with reco π associated to corresponding gen particles in $|\eta| <2.4$
  $D(\pi^{Gene}) = \#$Evt with generated π in $|\eta| <2.4$



Closure test with associated tracks (CT1)

Some closure tests are performed to check the validity of the model and of the technique for studying the tracking efficiency

- Independent ways to extract $\varepsilon(p_{\pi_s}, m)$ must be consistent
- Same fitting method
  - p_{D^*} (k bin) e $\cos\theta^*$ (n bin)
  - D_{nk} = # of events in bin nk
    S_{nk} = # of expected events in bin nk.
    $S_{nk} = \varepsilon(p_{\pi_s}, m) \cdot (\frac{dN}{dcos\theta^*})_k$
  - Find $\varepsilon(p_{\pi_s}, m)$ minimizing $\chi^2 = \sum_{nk} \frac{(D_{nk} - S_{nk})^2}{\sigma^2_{D_{nk}}}$
- $\frac{dN}{dcos\theta^*}$ measured with all reco π_s, π, K, ℓ associated to corresponding gen particles in $|\eta| < 2.4$

$log(1 - e^{-m \cdot p_\pi}) + 1$	m	$\frac{\chi^2}{ndf}$
CT1	4.4±0.5	0.9
SIPi	4.02±0.07	1.1

Closure test with Signal sample (CT2)

- Event selection criteria must not bias the result
- Same fitting method
- $\frac{dN}{dcos\theta^*}$ measured with the Signal sample separeted above (See slide 13, left plot)

$log(1 - e^{-m \cdot p_\pi}) + 1$	m	$\frac{\chi^2}{ndf}$
CT2	4.6±0.9	1.3
CT1	4.4±0.5	0.9
SIPi	4.02±0.07	1.1

Closure test with Signal+Background sample (CT3)

- The result must not suffer any background subtraction
- Same fitting method
- $\frac{dN}{dcos\theta^*}$ measured with Signal+Background samples separeted above (See slide 13, left+middle plots), after the background subtraction

$log(1-e^{-m \cdot p_\pi})+1$	m	$\frac{\chi^2}{ndf}$
CT3	4.55±1.33	1
CT2	4.6±0.9	1.3
CT1	4.4±0.5	0.9
SIPi	4.02±0.07	1.1

Closure test with data reconstructed with combinatorial selection (CT4)

- The result must be consistent without using gen level information
- Same fitting method
- $\frac{dN}{dcos\theta^*}$ measured after selection of events, fit of signal and background and background subtraction (same as for data).

$log(1-e^{-m \cdot p_\pi})+1$	m	$\frac{\chi^2}{ndf}$
CT4	4.8±1.8	0.8
CT3	4.55±1.33	1
CT2	4.6±0.9	1.3
CT1	4.4±0.5	0.9
SIPi	4.02±0.07	1.1

Offline cut variation

- The fit has been repeated varying one by one the cuts on D_p^{*-}, $Muon_{p_T}$, $\Delta R_{\overrightarrow{p_{D^*}},\overrightarrow{p_\ell}}$ within 10% of their original value during the selection of events.
- The module of the difference between the new and old value is considered

	m new	m old	$\Delta m =$ |m new-m old|
$D_p^{*-} > 5.725$			
-10%	3.35±0.51	3.36±0.49	0.01
+10%	3.30±0.48	3.36±0.49	0.06
$Muon_{p_T} > 5$			
-10%	3.41±0.58	3.36±0.49	0.05
+10%	3.38±0.49	3.36±0.49	0.02
$\Delta R_{\overrightarrow{p_{D^*}},\overrightarrow{p_\ell}} < 0.25$			
-10%	3.34±0.50	3.36±0.49	0.02
+10%	3.40±0.46	3.36±0.49	0.04

- The sistematic error is $\sqrt{(Max\Delta m_{D_p^{*-}})^2 + (Max\Delta m_{Muon_{p_T}})^2 + (Max\Delta m_{\Delta R_{\overrightarrow{p_{D^*}},\overrightarrow{p_\ell}}})^2} = 0.09$