Charmed baryon spectroscopy with D^0p and D^+p final states at LHCb experiment

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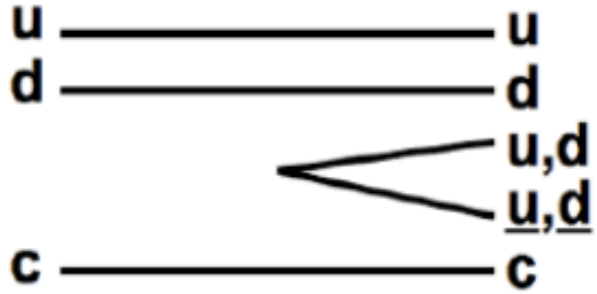
Our Study

- Inclusively prompt produced Dp combinations, in orden to study excited charmed baryons
- Large combinatorics (main component to fight with)
- 2011 and 2012 data are included

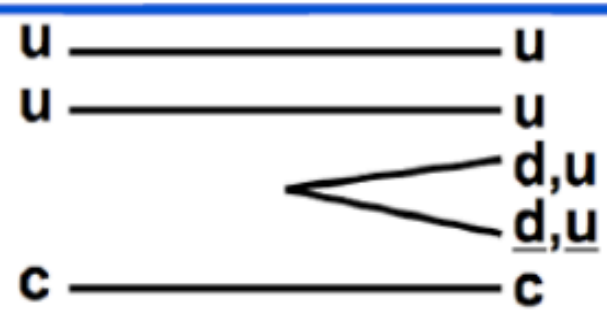
LO-Diagrams with a D-Meson

$\Lambda_c^{+'}$, $\Sigma_c^{+'}$



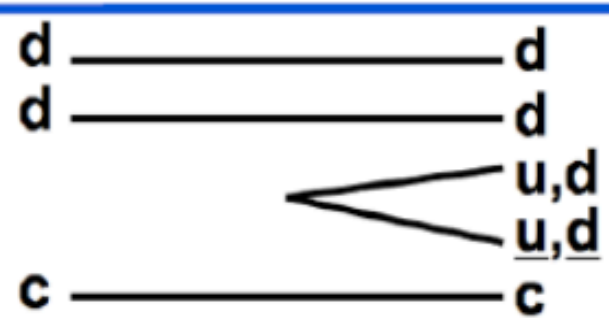
$D^{(*)0}p$, $D^{(*)+}n$,
$D^{(*)0}\Delta^{+}$, $D^{(*)+}\Delta^{0}$

$\Sigma_c^{++'}$



$D^{(*)+}p$,
$D^{(*)0}\Delta^{++}$, $D^{(*)+}\Delta^{+}$

$\Sigma_c^{0'}$

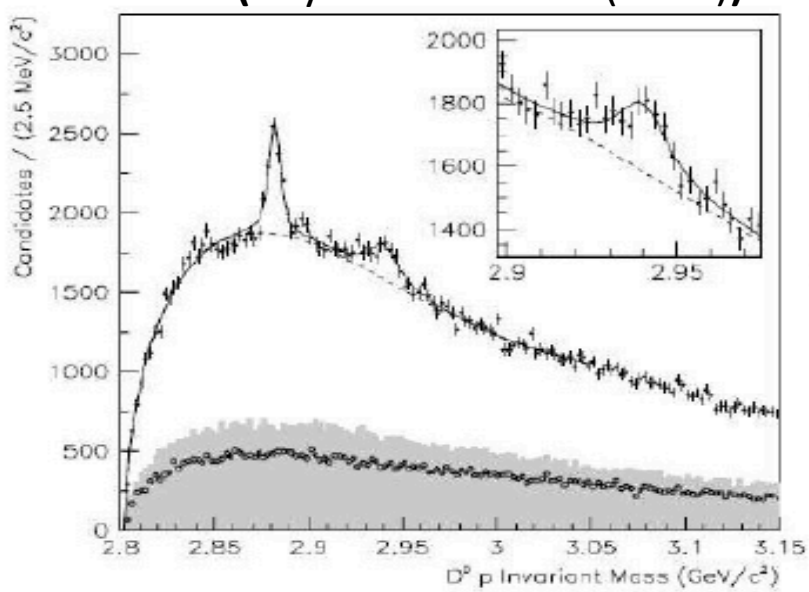


$D^{(*)0}n$,
$D^{(*)0}\Delta^{0}$, $D^{(*)+}\Delta^{-}$

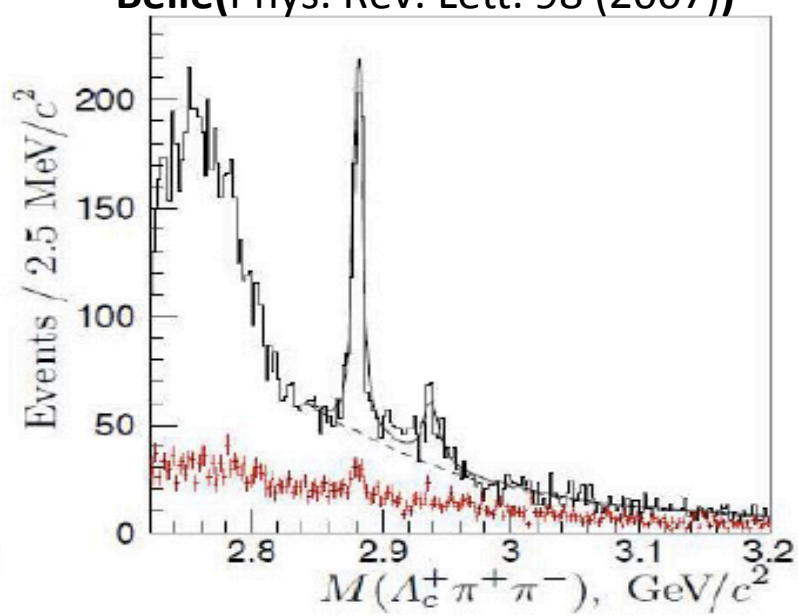
Known states (at present) to decay in our modes

Final state	Known	Possible dominant
$D^0 p$	$\Lambda_c(2880)^+$ [6], $\Lambda_c(2940)^+$ [6]	Λ_c^+ and Σ_c^+ excited
$D^0 \overline{p}$	None	-
$D^+ p$	None	Σ_c^{++} excited
$D^+ \overline{p}$	None	-

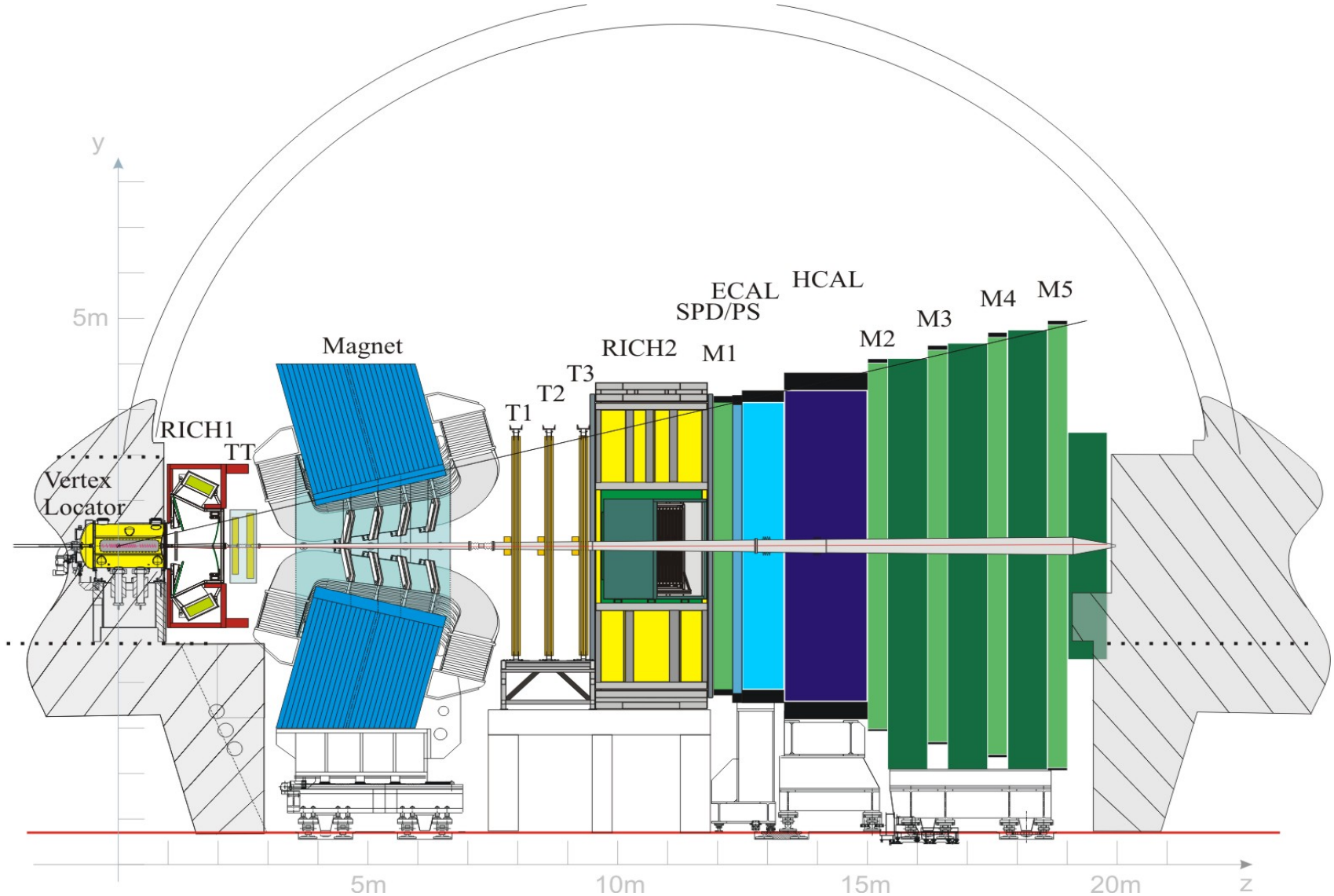
Babar (Phys. Rev Lett. 98 (2007)**)**



Belle(Phys. Rev. Lett. 98 (2007)**)**



LHCb Detector

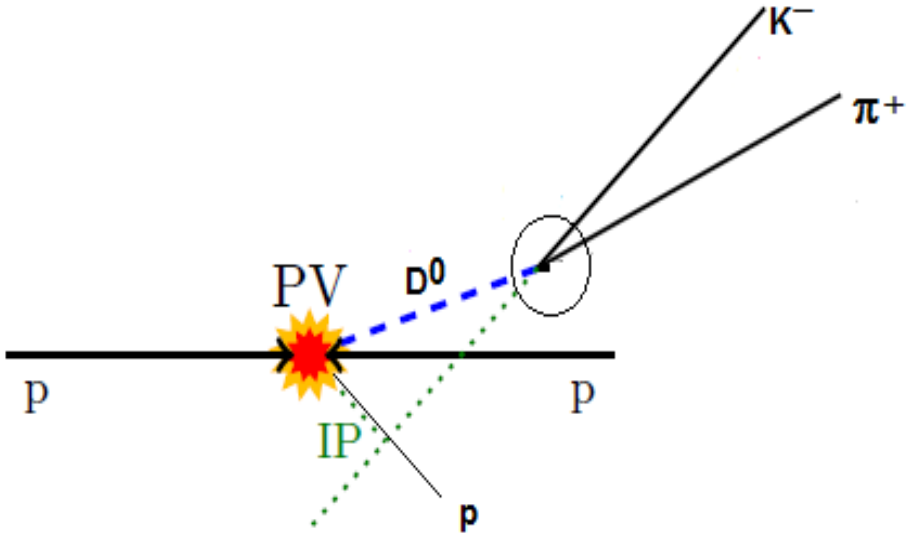


Stripping Selection

Kinematic Variables (P, M, E, Inv Mass)

Geometric Variables

- **Decay vertex location**
- **Primary vertex (PV) location**
- **Flight distance**
- **The cosine of the angle between primary vertex and vertex dacay with D momentum**



Particle Identification (PID) variables provide information in the particle identification obtained by each sub system of LHCb

- **LL: log Likelihood**
- **DLL (ex: DLL(p-K) = LL(p)-LL(k))**
- **ProbNN(p), ProbNN(k), ProbNN(π)**

Stripping Selection

The StrippingCharmedAndCharmedStrangeSpectroscopy.py line selects D mesons

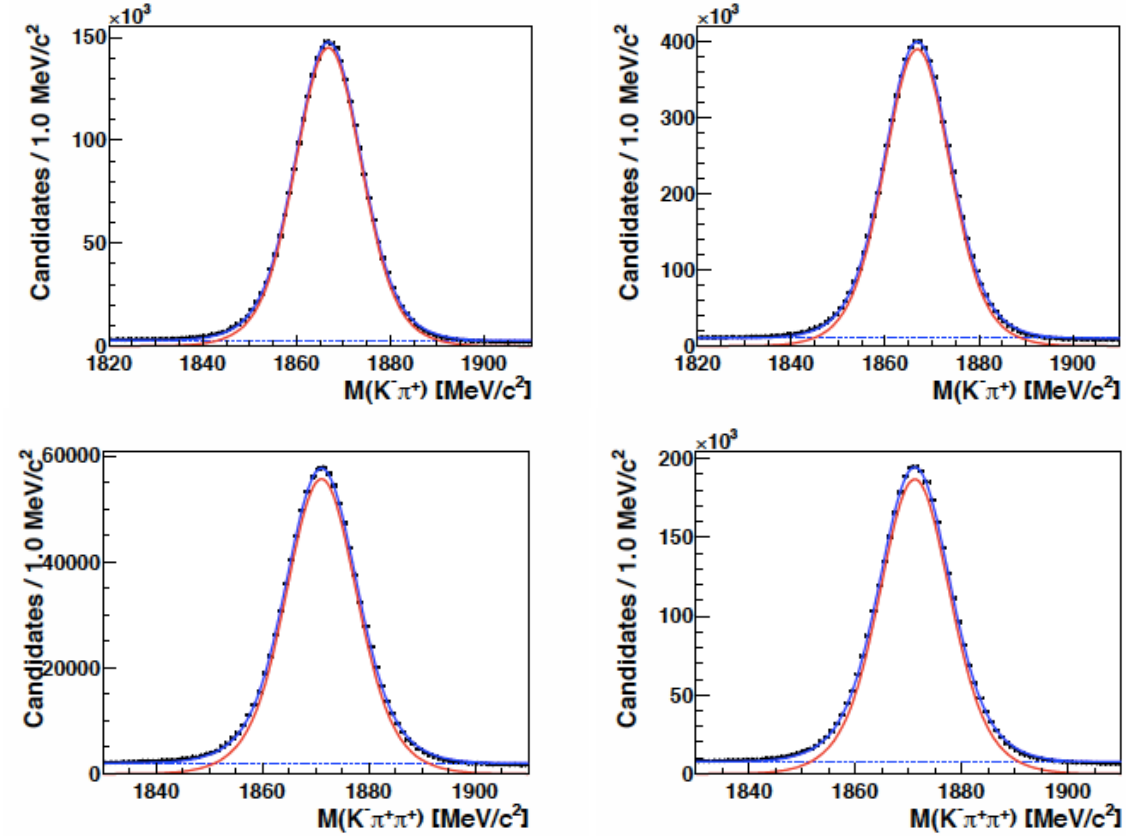
Track selection k, π, p

- X^2 probability of track fit > 0 .0001
- PT>250 MeV
- DLL(K - π)) > 5 for kaons
- DLL(K - π)) < 5 fo pions

D^0 -> K^- π^+ & D^+ -> K^- π^+ π^+

- Cos(Direction angle) > 0.99999
- Minimum χ^2 distance < 16
- χ^2(IP related PV)> 25
- Cut vertex fit χ^2/ndf < 8

Signal selected within ± 3σ

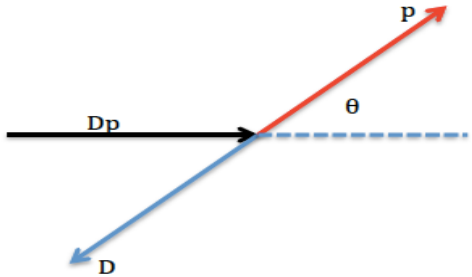


Protons candidates

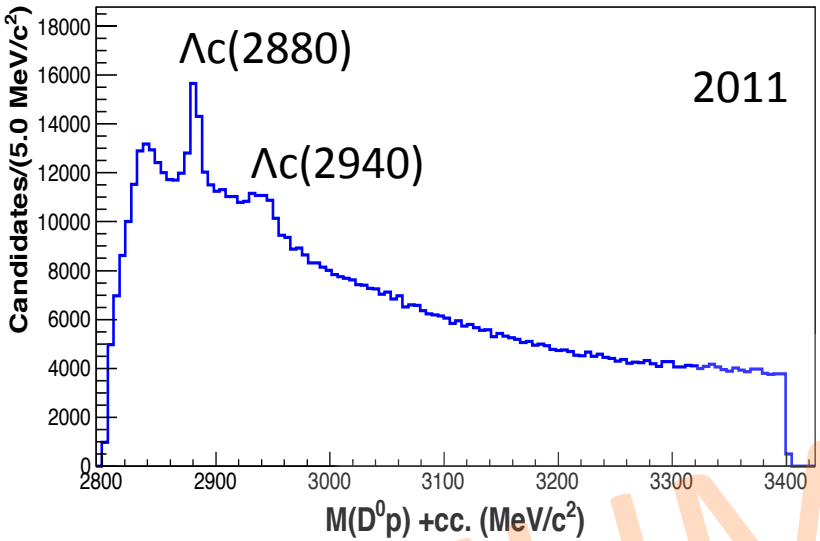
- DLL(p – (K & π)) > 15

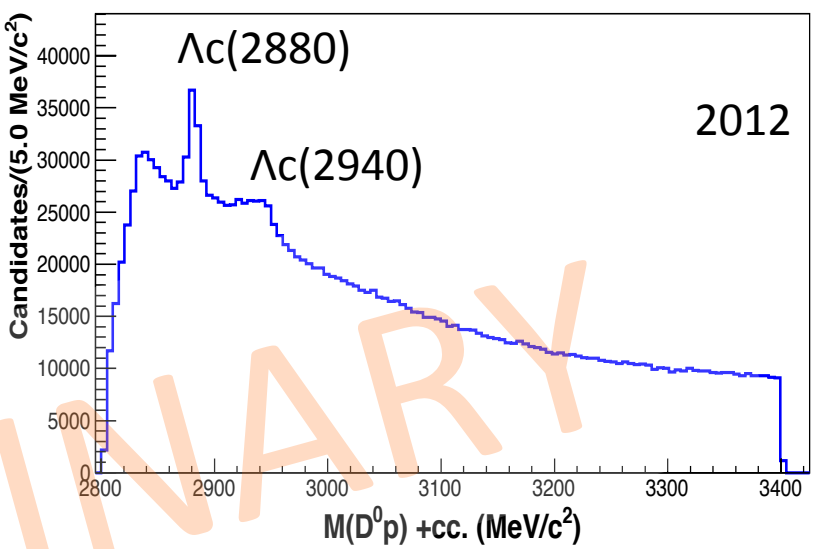
Dp Candidates

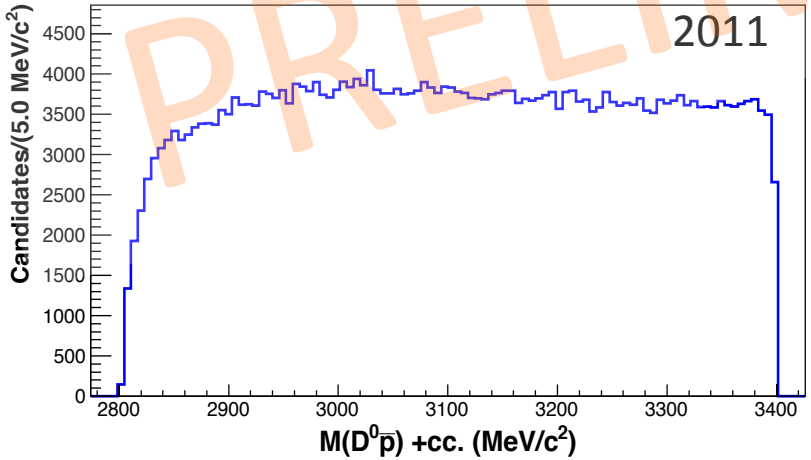
- cos θ > 0
- Clone removal

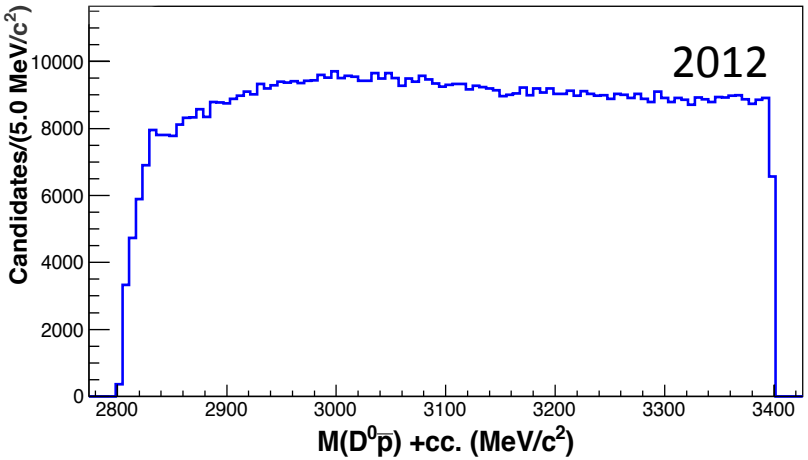


D^0p and $D^0\underline{p}$



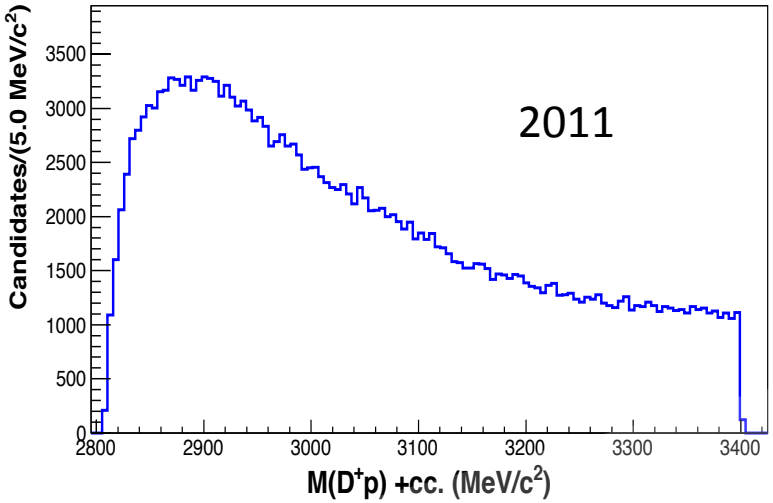


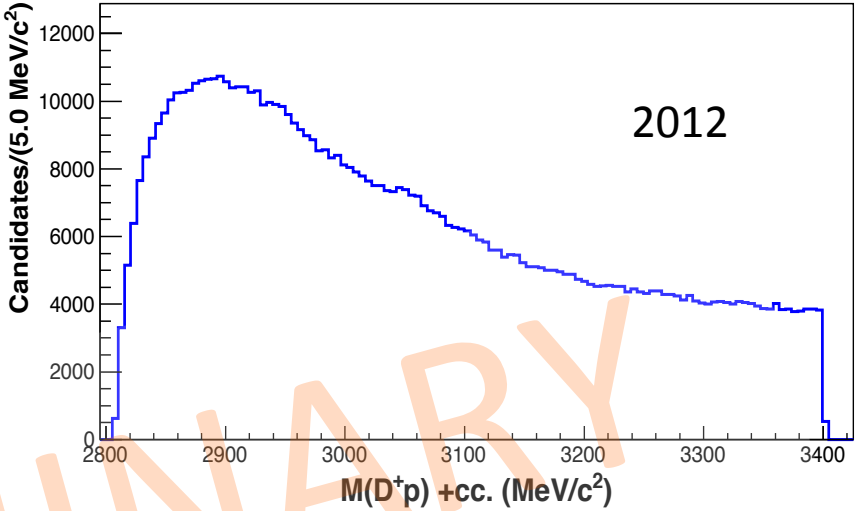


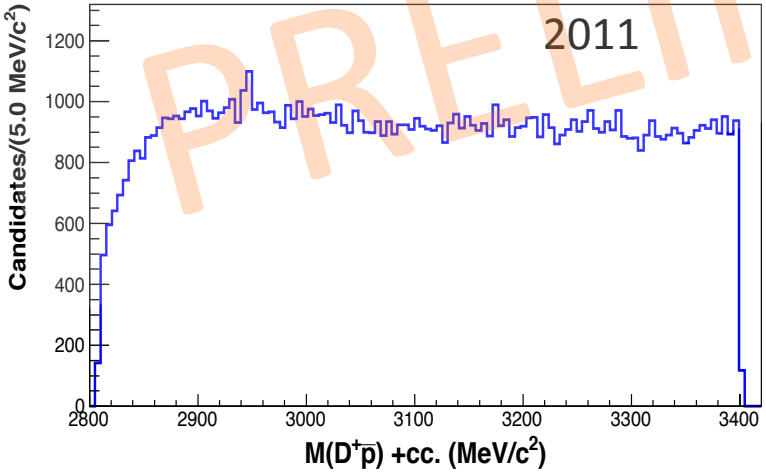


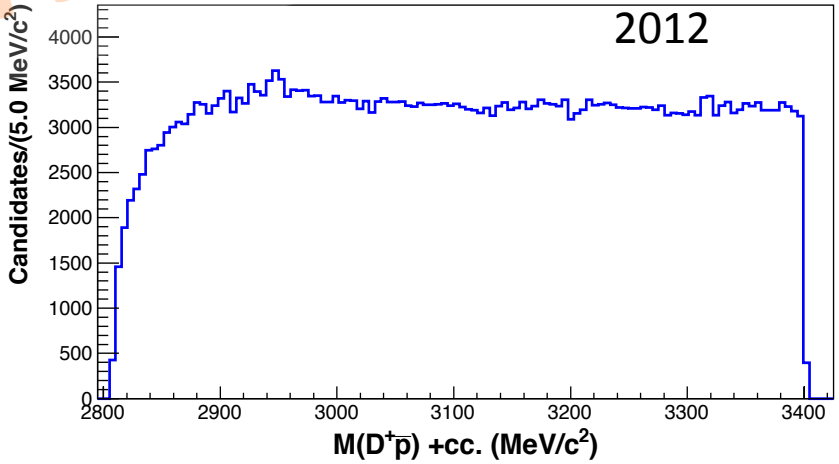
PRELIMINARY

D^+p and $D^+\underline{p}$







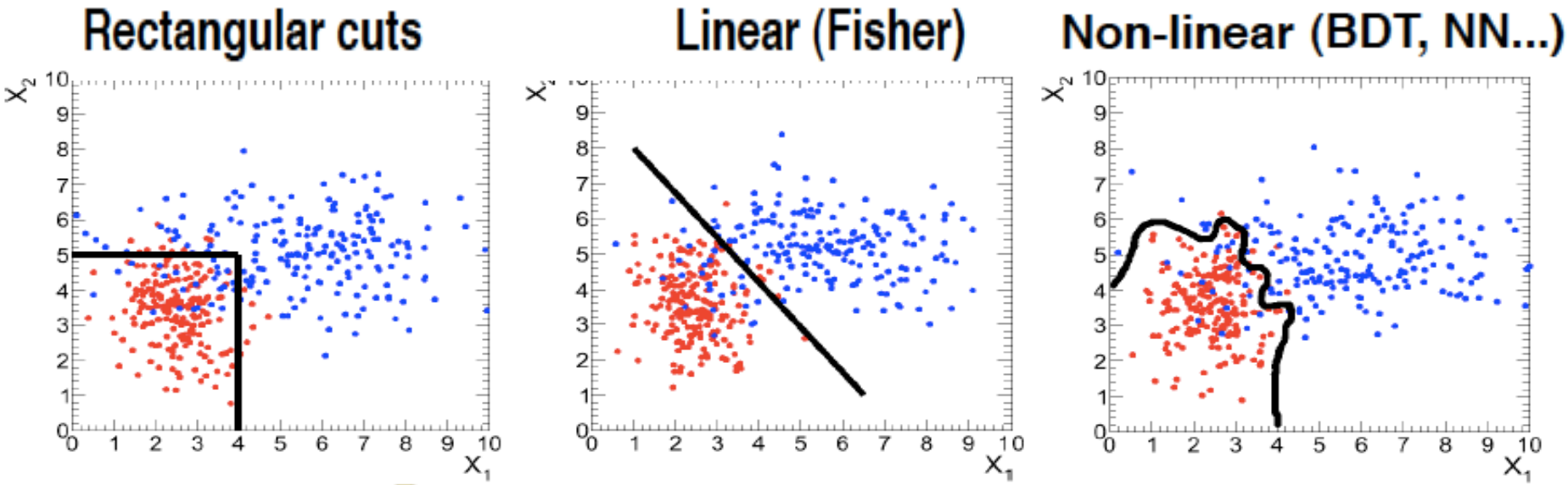


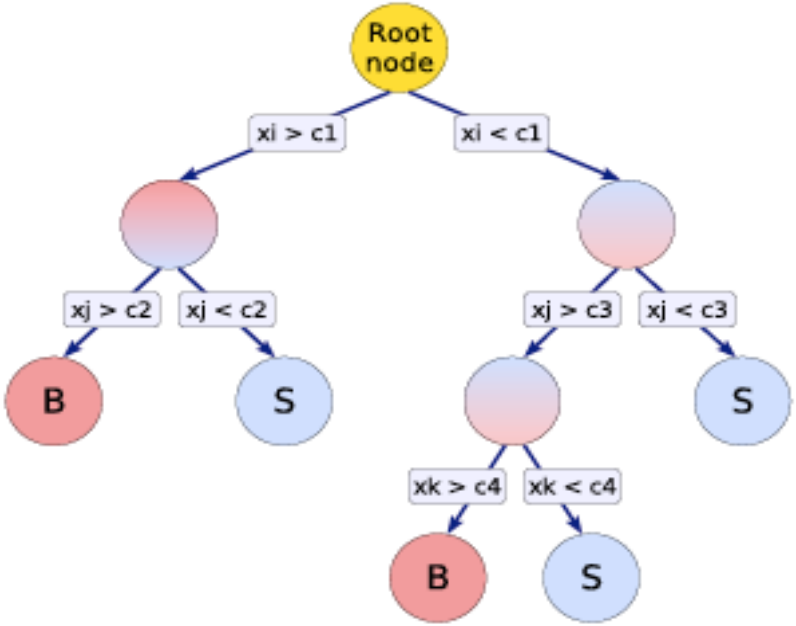
PRELIMINARY

Our Study

- Prompt spectroscopy selection criteria, previously chosen through a cut-based approach in channels with final states as $D^0\pi^+$, $D^+\pi^-$, $D^{*+}\pi^-$ (arXiv:1311.7364), D^+K_s, D^0K^- (arXiv:1207.6016v1)
- BDT method to reduce the background and optimize the signal events.
- Signal component: Use $\Lambda_c(2880)$ signal sWeighted for optimization
- Background component: Random D^0p events reconstruction.
- SAME SELECTION FOR D^+p (we use same kinematic variables)

Boosted Decision Tree (BDT)

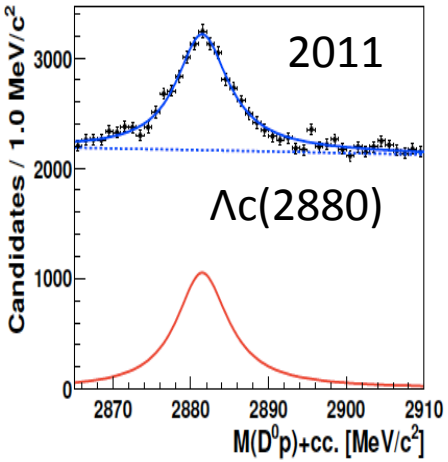


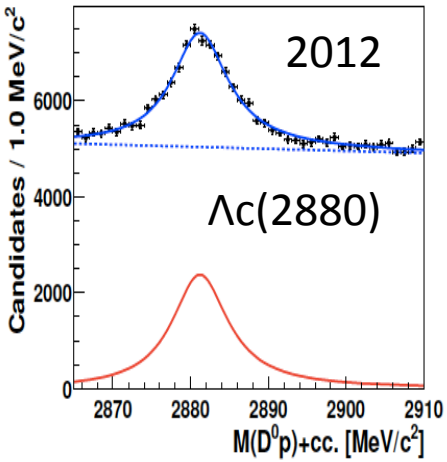


- **BDT Is a multi variable method to classify events of signal and background**
- **A decision tree is a binary tree: a sequence cuts paving the phase space of input variables**

BDT: Signal & Bkg Component

Signal Component BDT

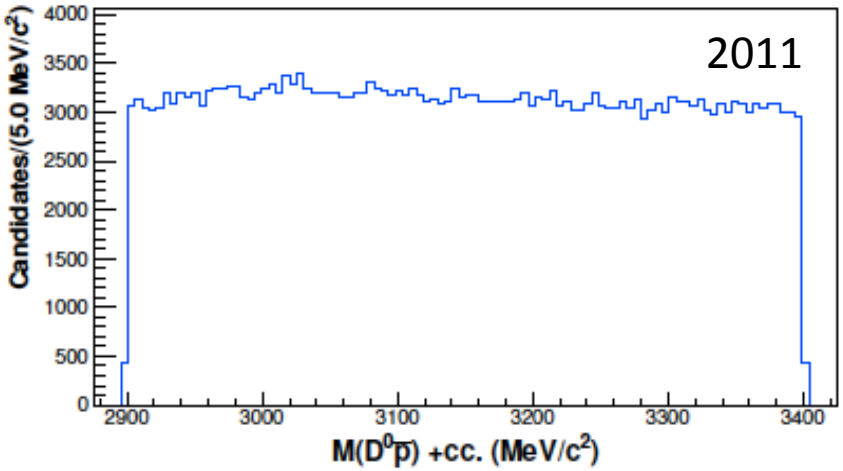


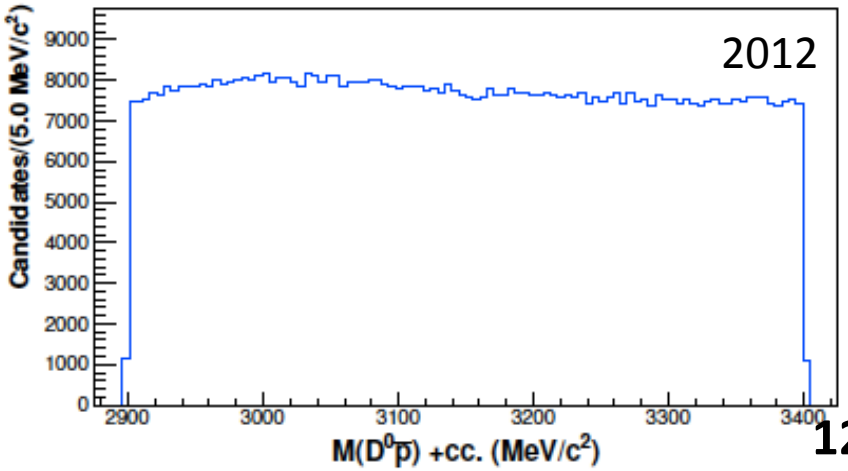


Signal PDF: Breit Wigner
Bkg PDF : Exponential

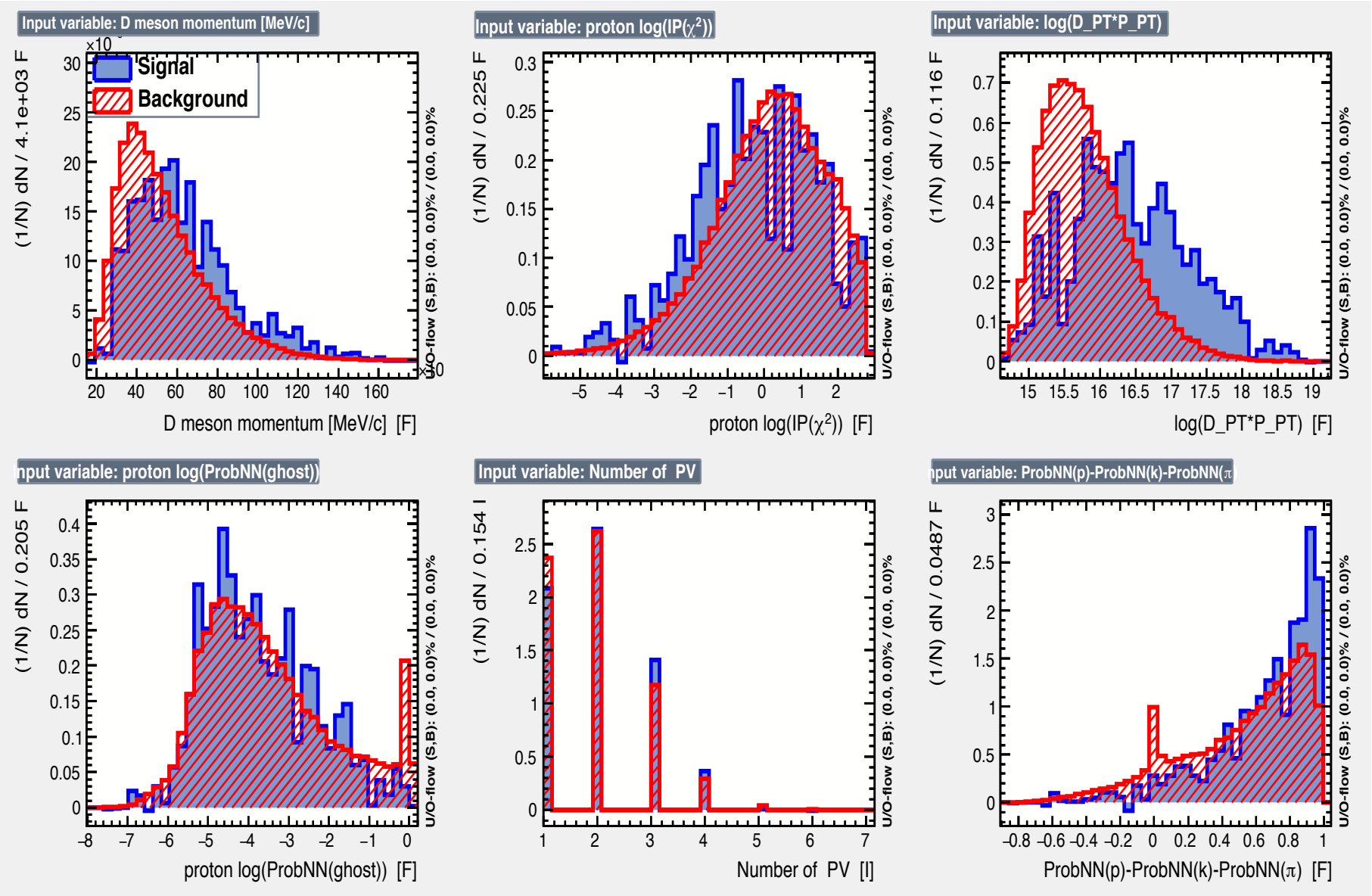
Parameters	2011	2012
N_s	11829.7 ± 560.5	28569.2 ± 937.4
m(MeV)	2881.41 ± 0.12	2881.13 ± 0.09
Γ(MeV)	8.12 ± 0.45	8.77 ± 0.33
N_b	93063.8 ± 631.5	225673 ± 1037.14
$c(\mathrm{MeV}^{-1})$	$(-6.48 \pm 0.45) \times 10^{-4}$	$(-8.71 \pm 0.20) \times 10^{-4}$

Bkg Component BDT

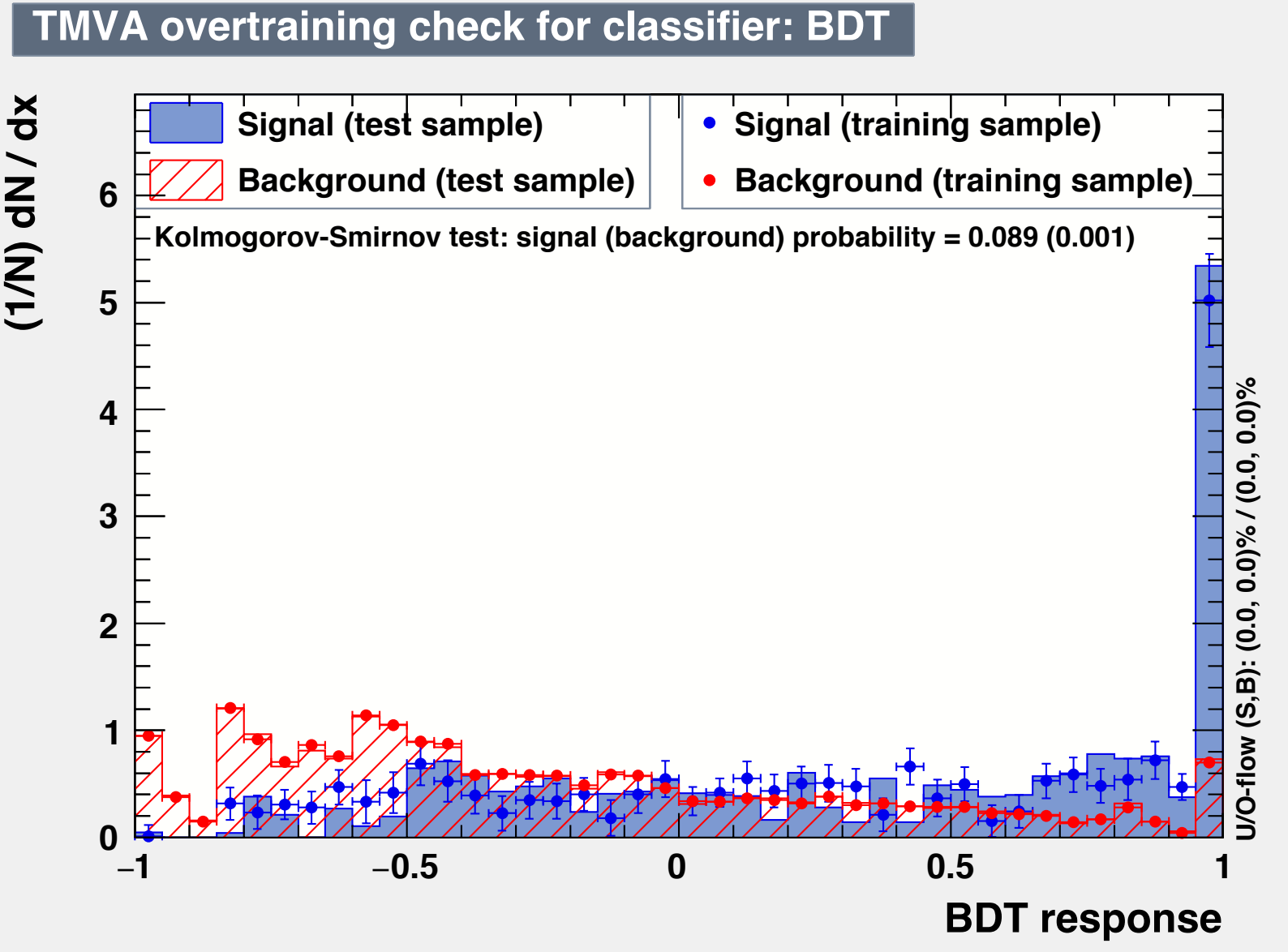




BDT: Input Variables



BDT: 2011


TMVA overtraining check for classifier: BDT
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.089 (0.001)
(1/N) dN / dx
0
1
2
3
4
5
6
–1
–0.5
0
0.5
1
BDT response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

BDT: 2012

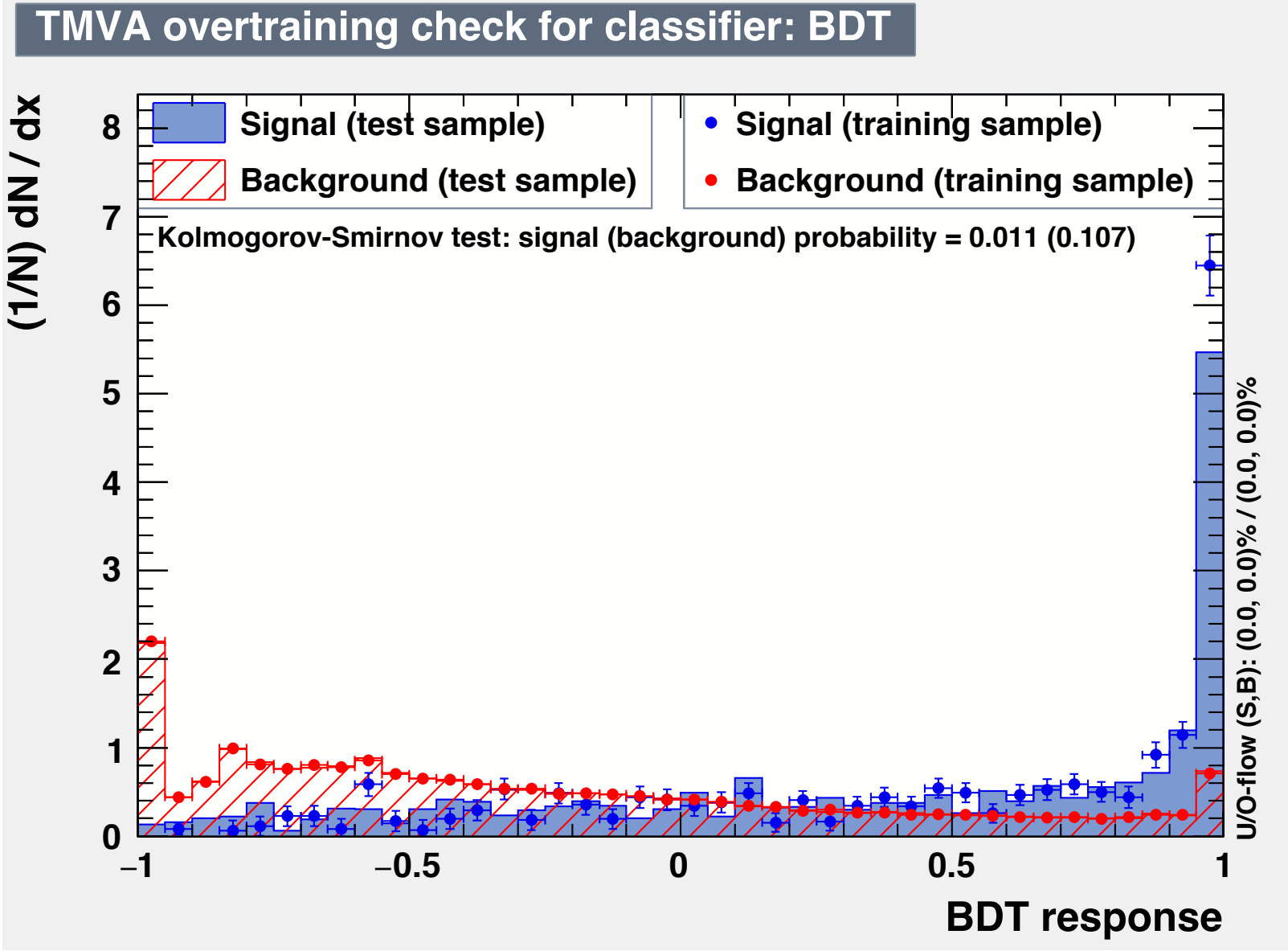
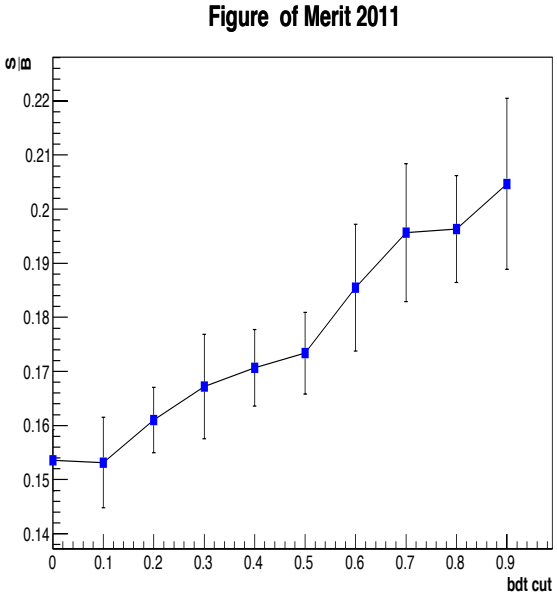
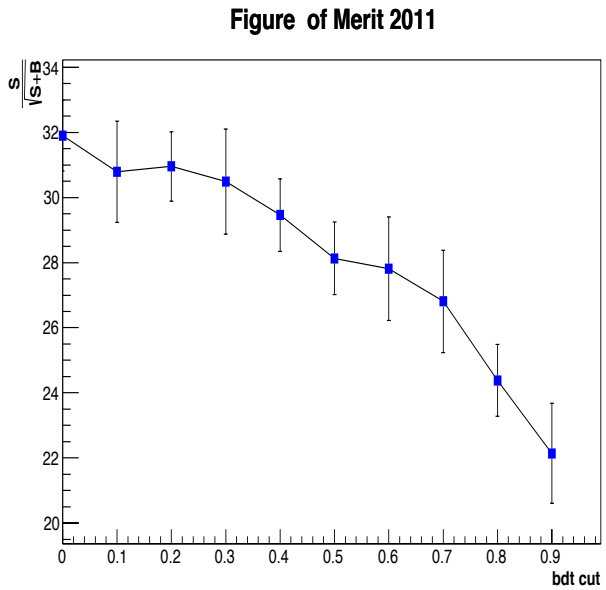
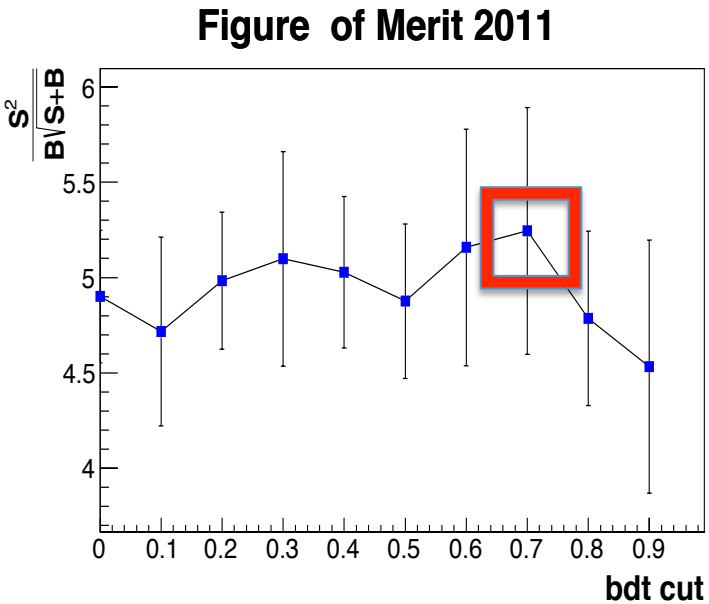
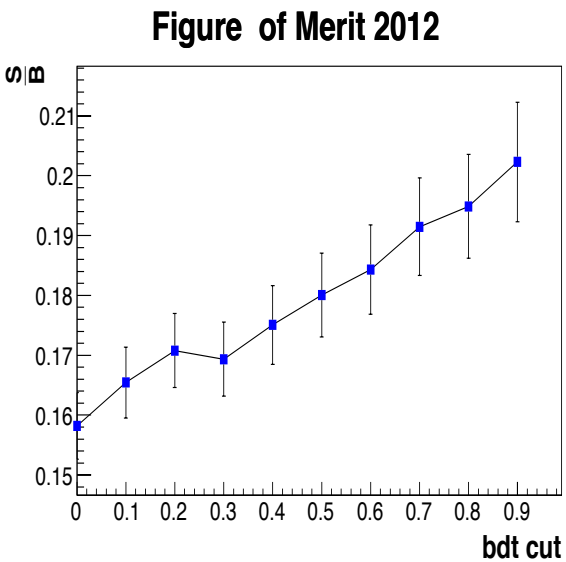

TMVA overtraining check for classifier: BDT
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.011 (0.107)
(1/N) dN / dx
BDT response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
0
1
2
3
4
5
6
7
8
–1
–0.5
0
0.5
1

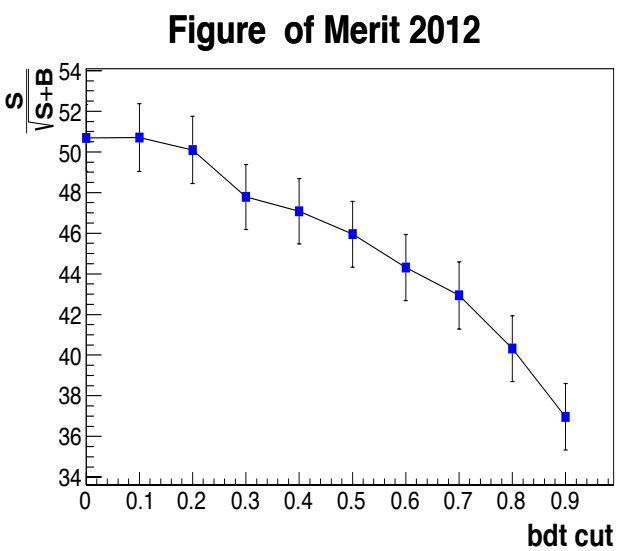
Figure of Merit 2011-2012

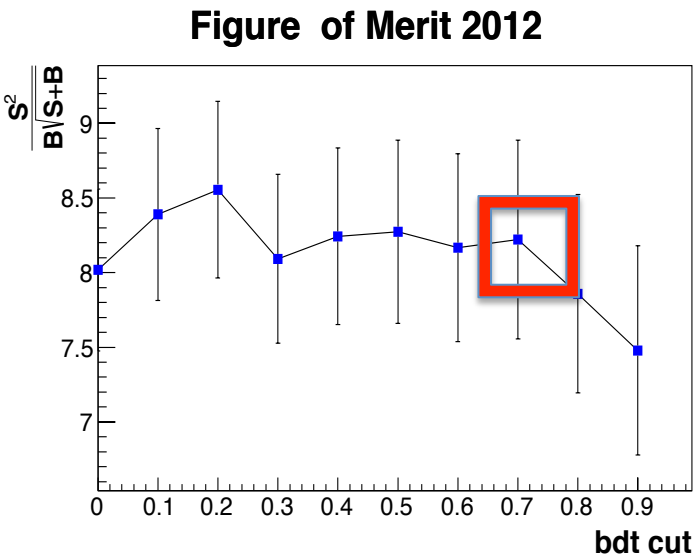












BDT Cut= 0.7 is applied to study a DP samples

PDF Fits 2011-2012 sample

Signal description

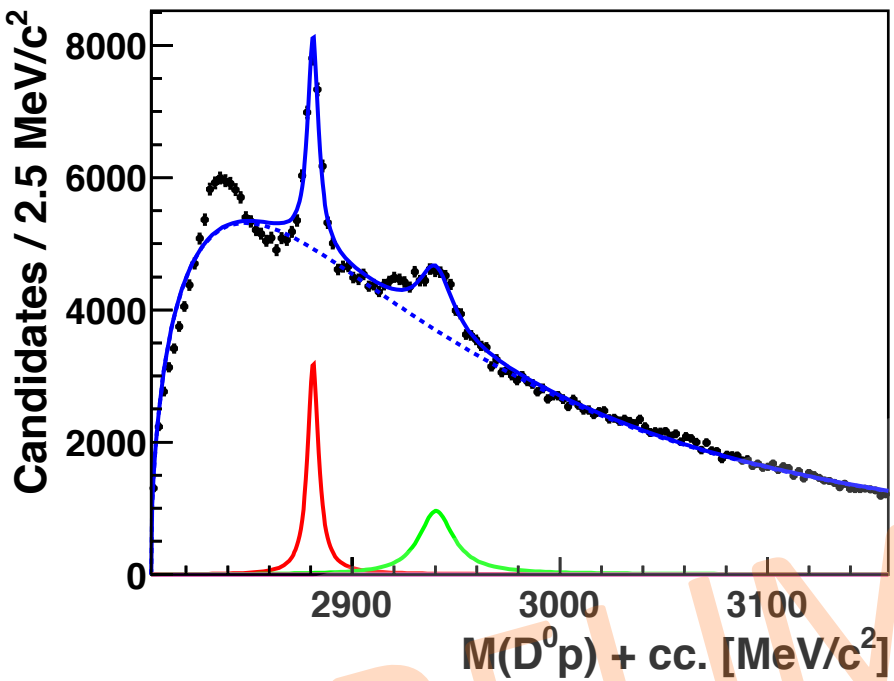
$$\mathrm{BW}(x; m, \Gamma) = 2x\mathrm{PS}(x, m_1, m_2) \times \frac{1}{(x^2 - m^2)^2 + m^2\Gamma^2}$$

Background description

$$\mathrm{PS}(x, m_1, m_2) \times (x - x_0)^p \times \exp\left\{c_1\left(1 - \frac{x_0}{x}\right) + c_2^2\left(1 - \frac{x_0}{x}\right)^2\right\}$$

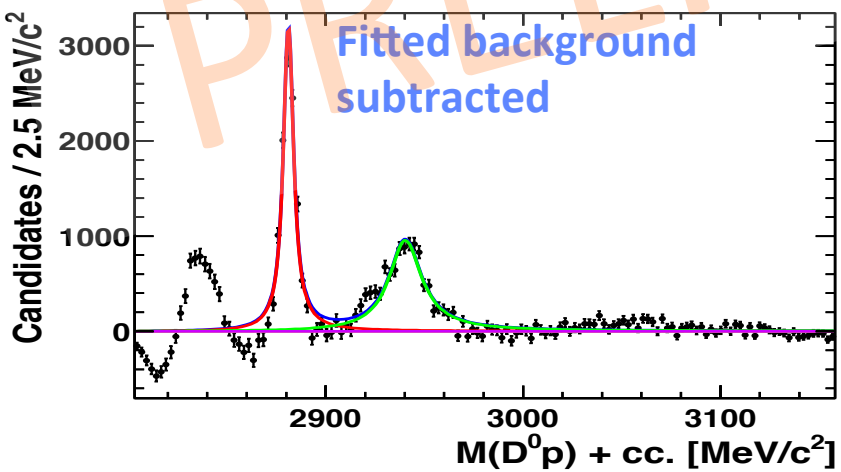
$$\mathrm{PS}(x; m_1, m_2) = \frac{1}{2x}\sqrt{(x^2 - (m_1 + m_2)^2)(x^2 - (m_1 + m_2)^2)}.$$

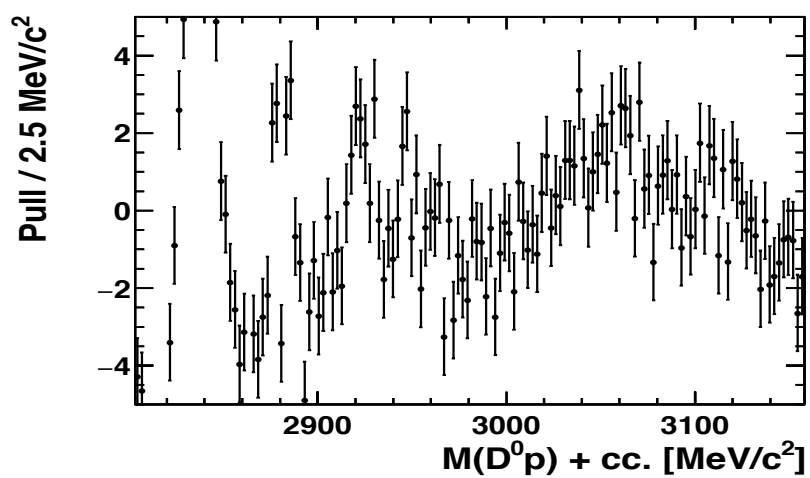
Fits D^0p



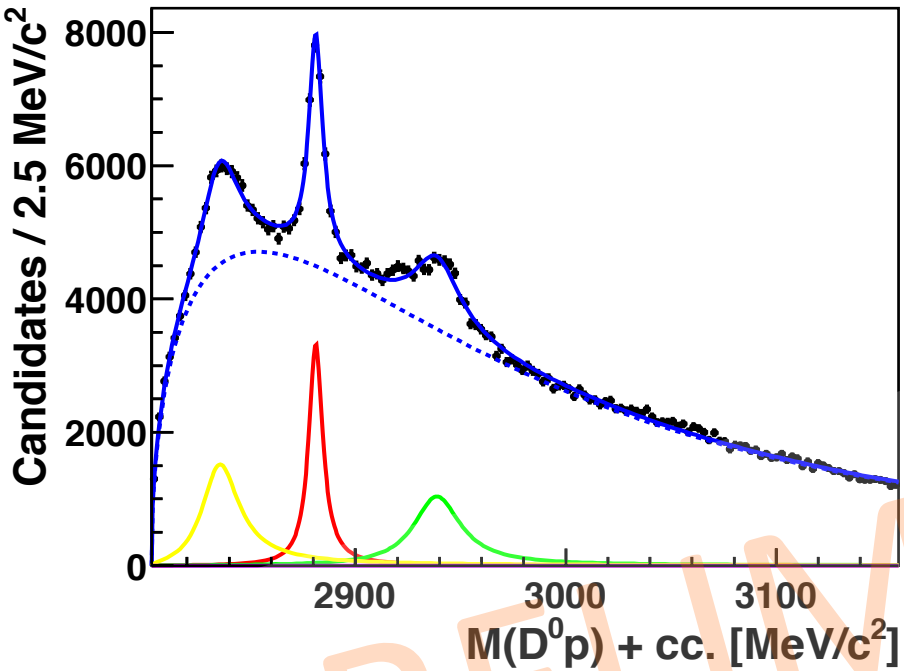
N_{2880}	12668 ± 355
$m_{2880}(\mathrm{MeV}/c^2)$	2881.09 ± 0.08
$\Gamma_{2880}(\mathrm{MeV}/c^2)$	6.3 ± 0.24
N_{2940}	11810 ± 629
$m_{2940}(\mathrm{MeV}/c^2)$	2940.1 ± 0.4
$\Gamma_{2940}(\mathrm{MeV}/c^2)$	20.11 ± 1.2
χ^2	293.5
ndf	153

PRELIMINARY





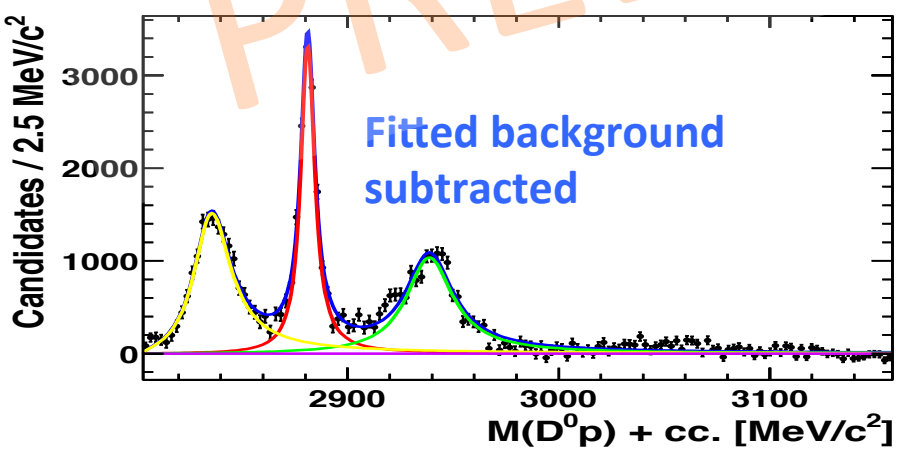
Fits D^0p

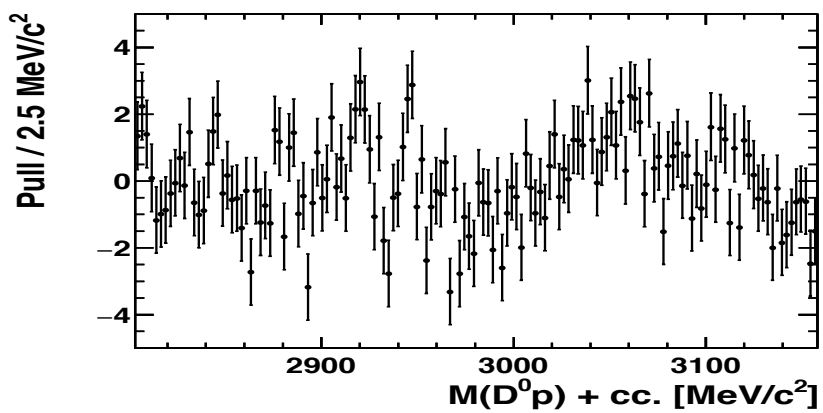


N_{2880}	16662 ± 456
$m_{2880}(\mathrm{MeV}/c^2)$	2881.41 ± 0.12
$\Gamma_{2880}(\mathrm{MeV}/c^2)$	8.12 ± 0.45
N_{2840}	19467 ± 1259
$m_{2840}(\mathrm{MeV}/c^2)$	2834.9 ± 0.3
$\Gamma_{2840}(\mathrm{MeV}/c^2)$	21.4 ± 1.2
N_{2940}	16854 ± 891
$m_{2940}(\mathrm{MeV}/c^2)$	2938.4 ± 0.5
$\Gamma_{2940}(\mathrm{MeV}/c^2)$	27.0 ± 1.6
χ^2	158.7
ndf	156

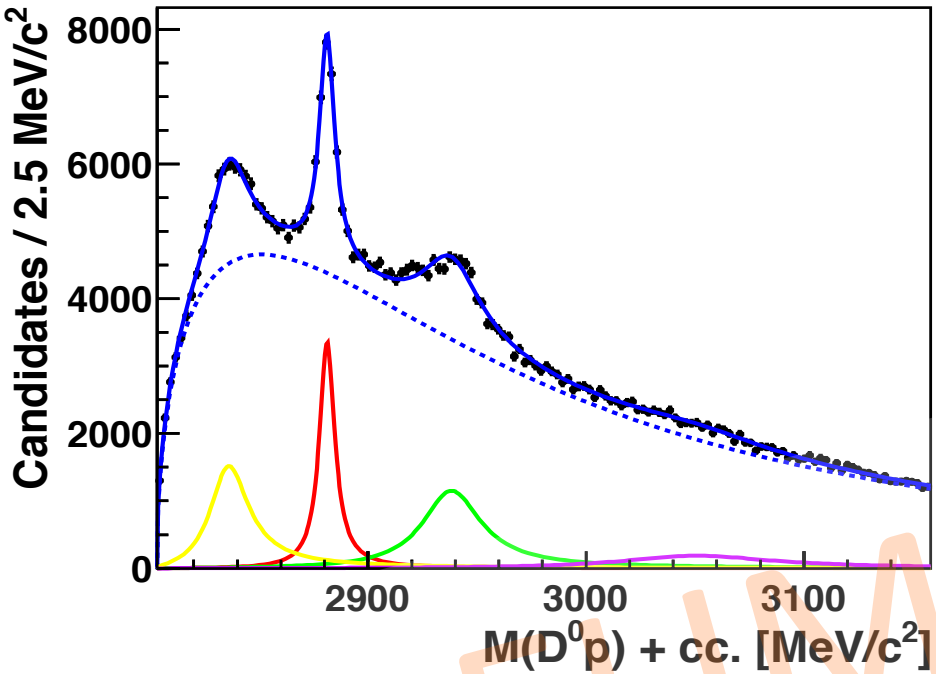
χ^2/ndf: 293.5/153 → 158.7/156
improvement $\Delta\chi^2 \sim 135$

PRELIMINARY





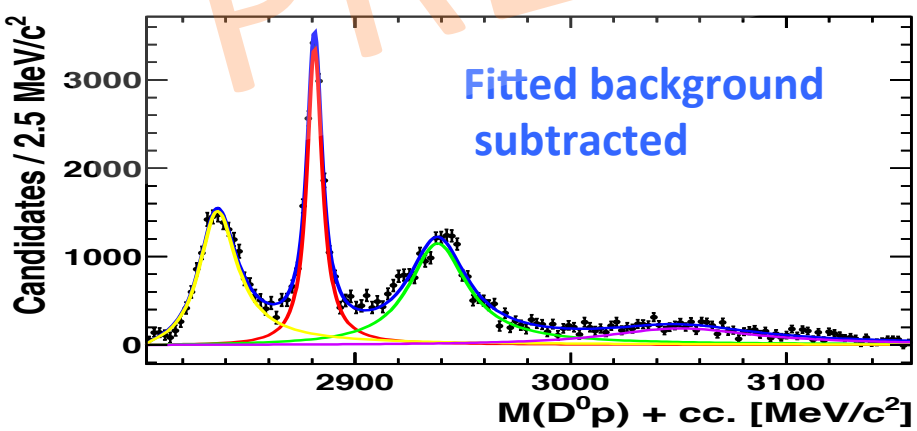
Fits D^0p

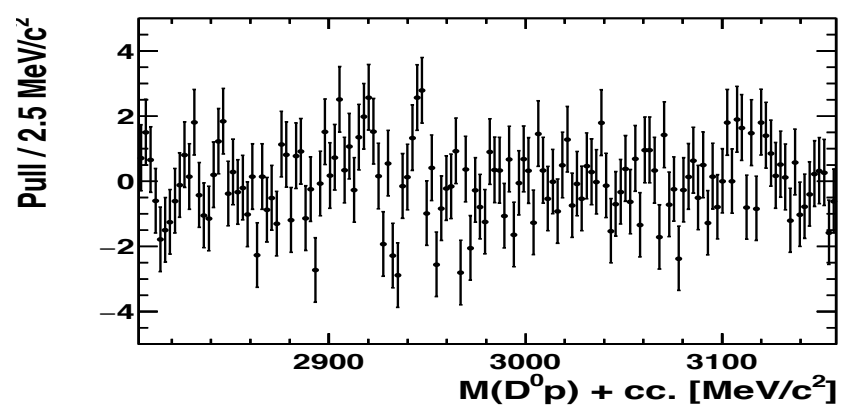


N_{2880}	17846 ± 533
$m_{2880}(\mathrm{MeV}/c^2)$	2881.11 ± 0.09
$\Gamma_{2880}(\mathrm{MeV}/c^2)$	8.51 ± 0.31
N_{2840}	19577 ± 1243
$m_{2840}(\mathrm{MeV}/c^2)$	2835.29 ± 0.35
$\Gamma_{2840}(\mathrm{MeV}/c^2)$	21.6 ± 1.17
N_{2940}	22514 ± 890
$m_{2940}(\mathrm{MeV}/c^2)$	2937.7 ± 0.4
$\Gamma_{2940}(\mathrm{MeV}/c^2)$	32.8 ± 0.13
N_{3050}	8048 ± 1412
$m_{3050}(\mathrm{MeV}/c^2)$	3048.7 ± 3.9
$\Gamma_{3050}(\mathrm{MeV}/c^2)$	84.6 ± 4.8
χ^2	131.6
ndf	159

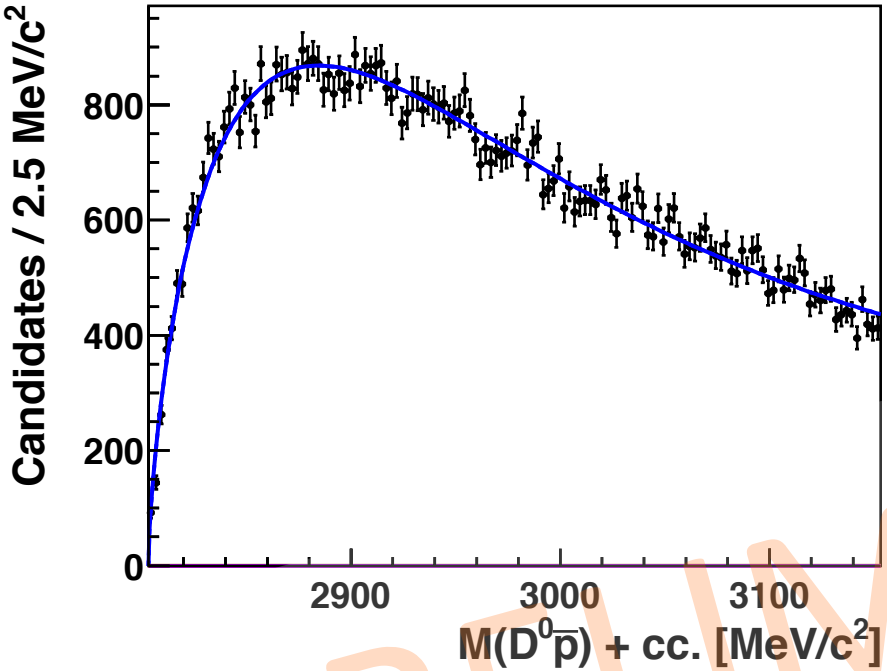
X^2/ndf: 158.7/156 ➔ 131.6/159
improvement ΔX^2 ~ 27

PRELIMINARY





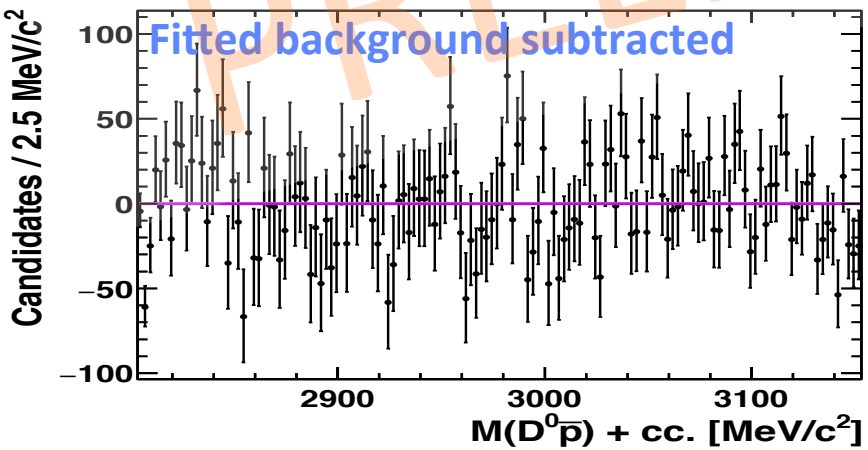
Fits $D^0\underline{p}$

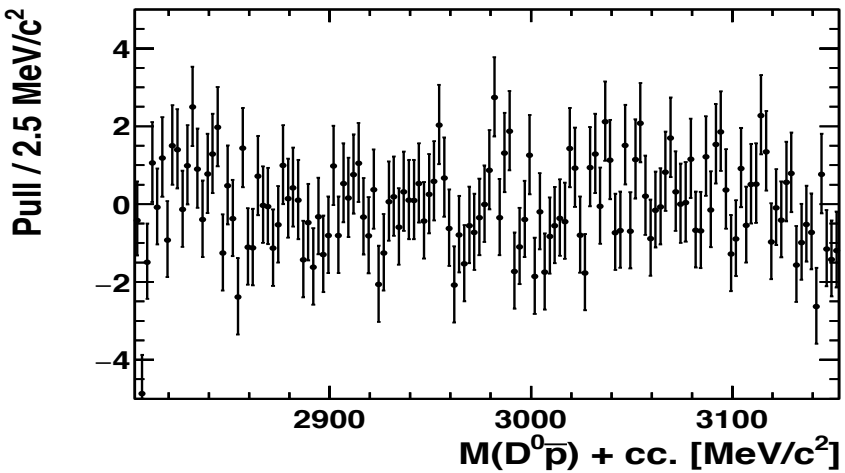


No evidence of new structures

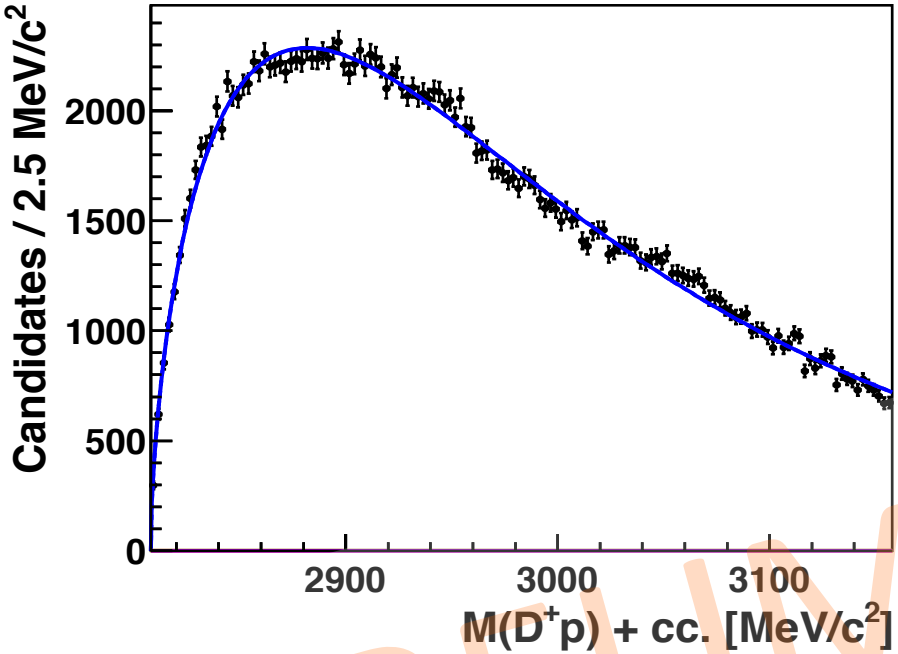
Parameters	$D^0\bar{p}$
N_b	91658 ± 303
c_1	-29.7 ± 1.2
c_2	7.3 ± 0.45
p	0.21 ± 0.01
χ^2	151.4
ndf	144

PRELIMINARY



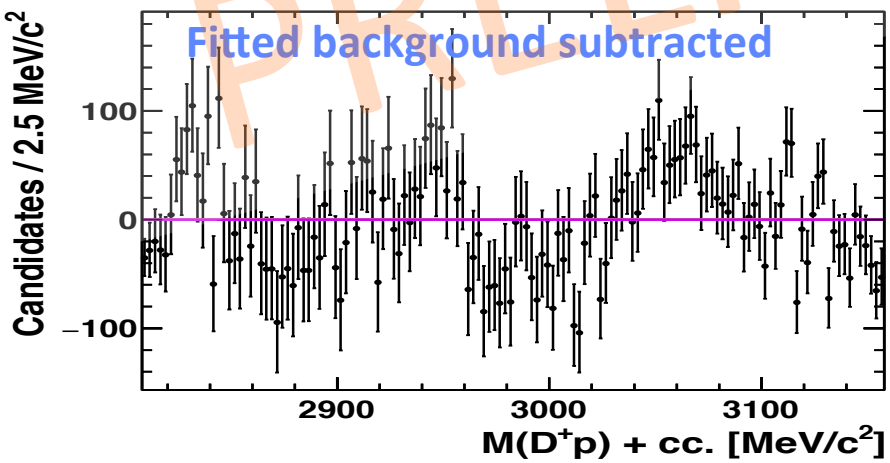


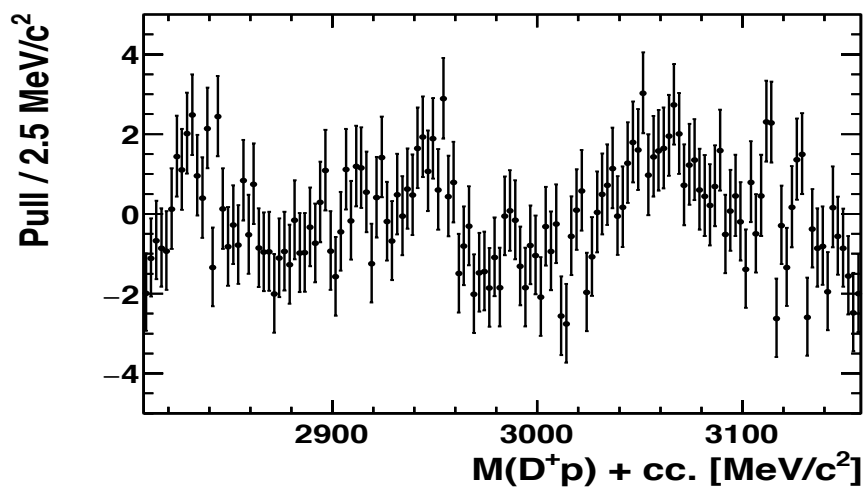
Fit D^+p



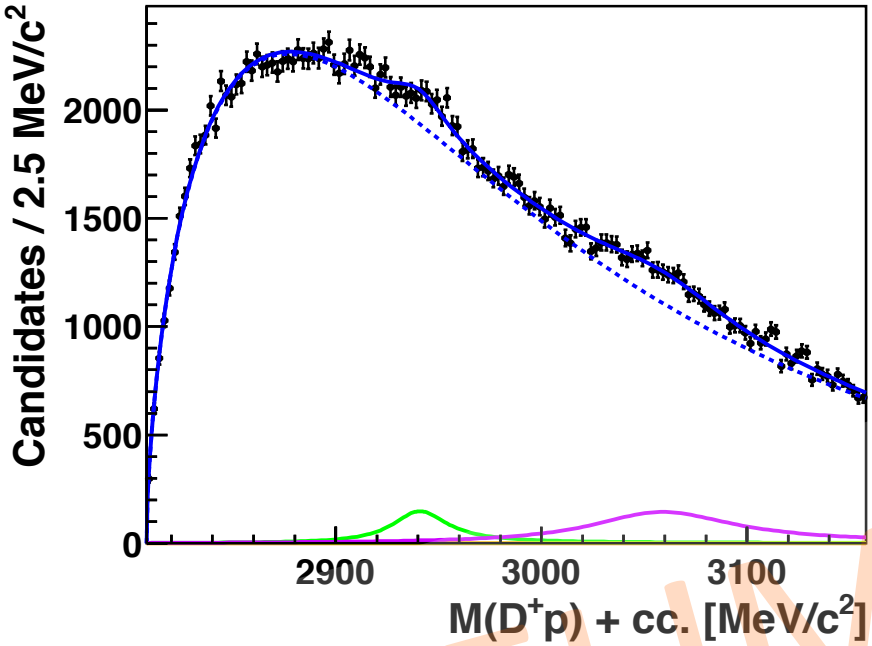
Parameters	D^+p
N_b	218041 ± 467
c_1	-25.7 ± 089
c_2	1.4 ± 2.5
p	0.129 ± 0.001
χ^2	151.4
ndf	144

PRELIMINARY





Fit D^+p



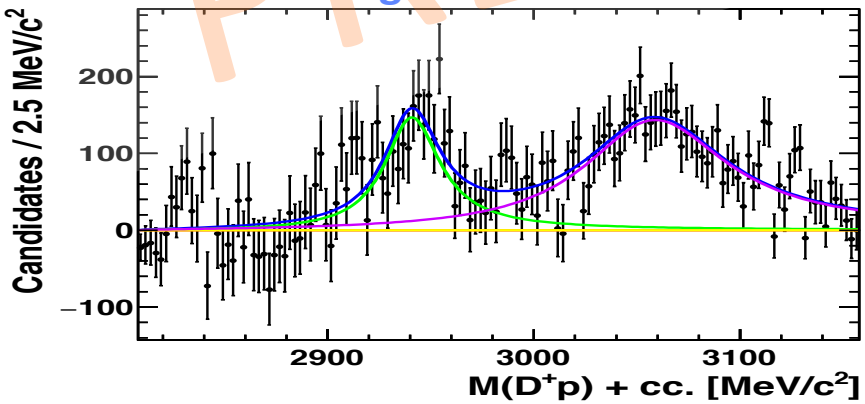
N_{2940}	2831 ± 531
$m_{2940}(\mathrm{MeV}/c^2)$	2940.3 ± 0.3
$\Gamma_{2940}(\mathrm{MeV}/c^2)$	32.8(fixed)
N_{3050}	6004 ± 716
$m_{3050}(\mathrm{MeV}/c^2)$	3056.7 ± 3.9
$\Gamma_{3050}(\mathrm{MeV}/c^2)$	84.6(fixed)
χ^2	112.8
ndf	148

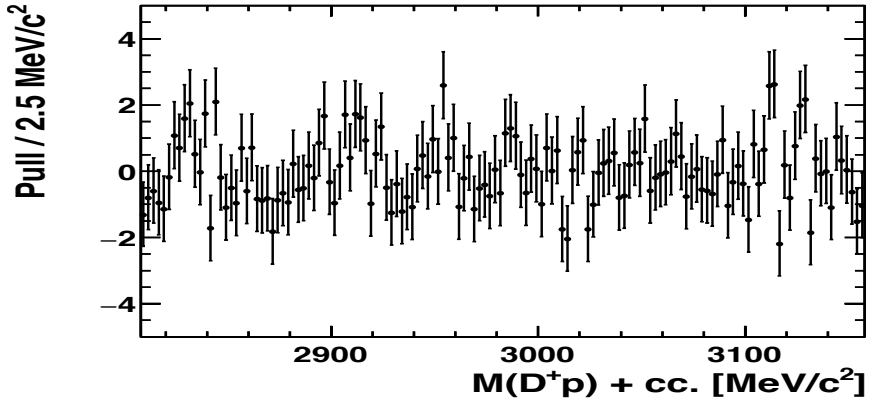
X^2/ndf: 151.4/144 → 112.8/148

Improvement ΔX^2 ~ 39

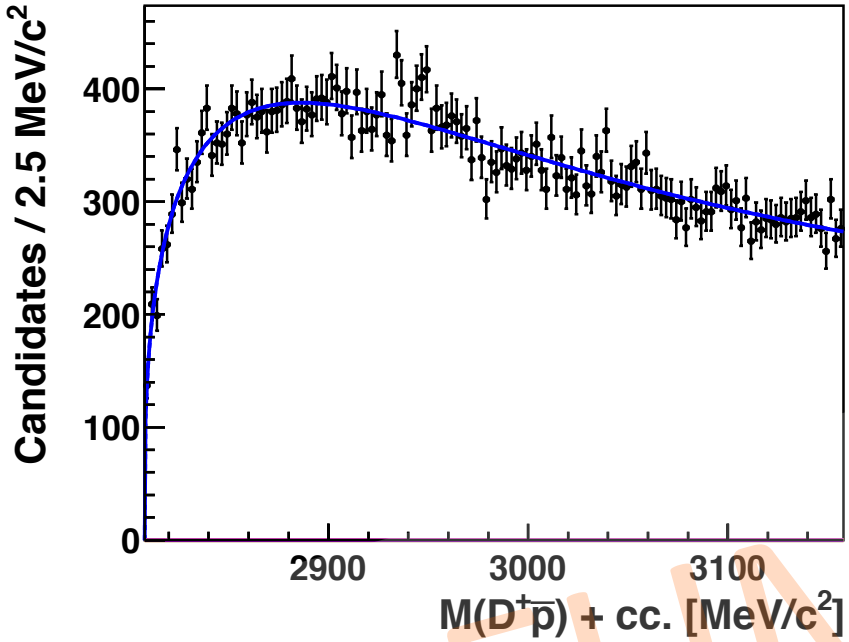
PRELIMINARY

Fitted background subtracted



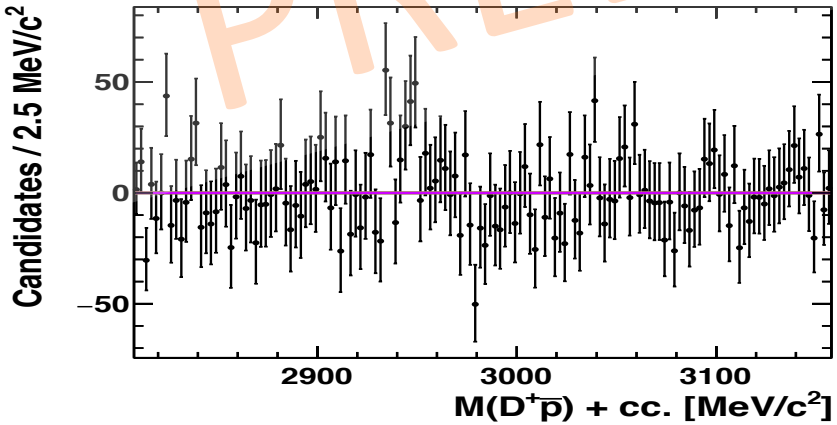


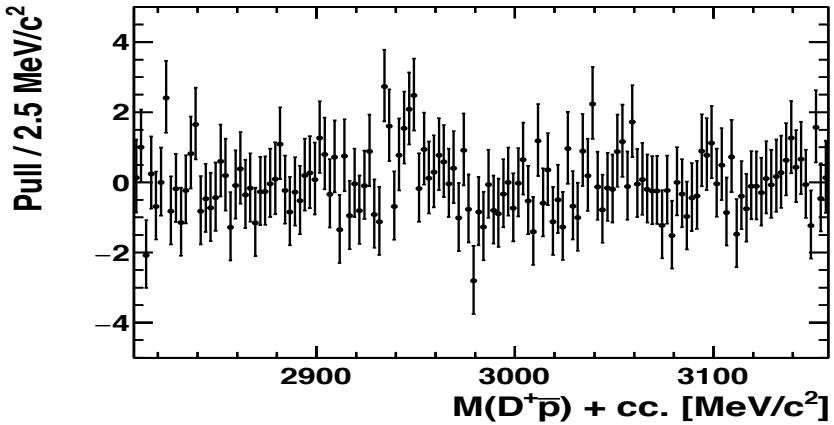
Fit $D^+\underline{p}$



Parameters	$D^+\bar{p}$
N_b	46627 ± 216
c_1	-15.1 ± 1.4
c_2	5.63 ± 0.77
p	0.16 ± 0.02
χ^2	97.8
ndf	144

Fitted background subtracted





PRELIMINARY

Conclusions

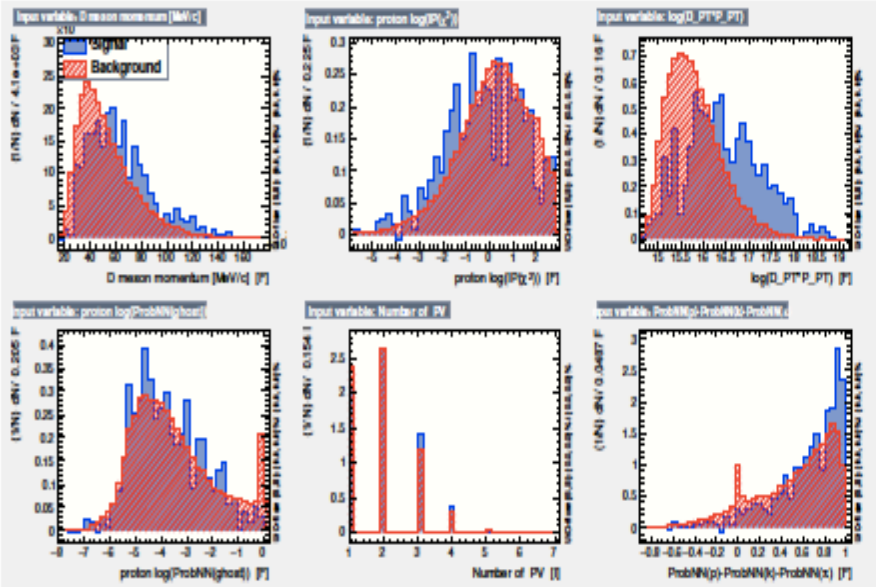
- Clear evidence of structure in 2840 MeV in D^0p. Most probably be Λc family.
- A structure in 3050 MeV D^0p sample is found.
- A structure in 2940 and 3050 MeV in D^+p samples are found (isospin partners of the D^0p states?)
- No clear evidence of structures on $D^0\underline{p}$ and $D^+\underline{p}$ samples are found

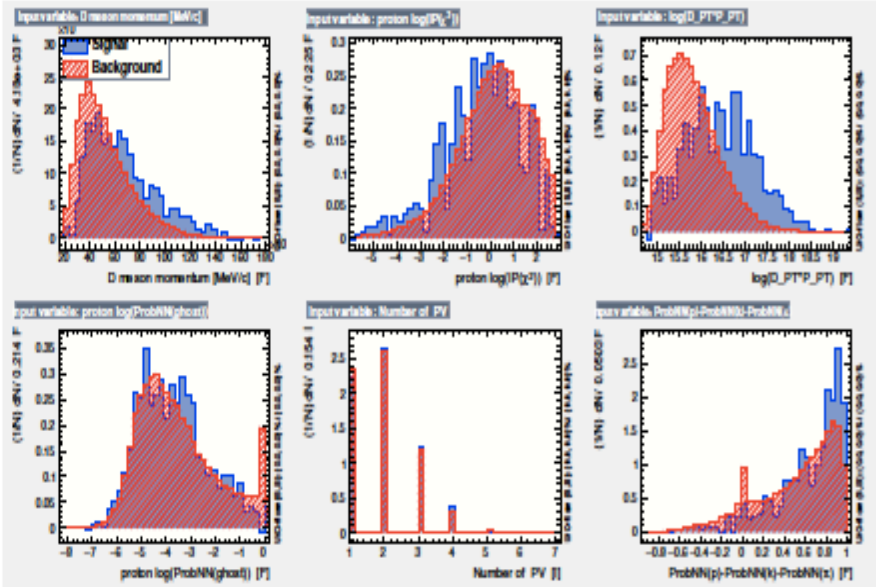
References

- [1]BABAR collaboration, Auber *et al. A precision measurement of Λc baryon mass*. Phys. Rev. D75(2005)
- [2]BABAR collaboration, Aubert *et al*. *Observartion of a charmed baryon decaying to* D^0p *at a mass near 2.94* GeV/c^2. Phys. Rev Lett. 98 (2007)
- [3]Belle collaboration, K. Abe *et al*. *Experimental constraints of the possible* J^p *quantum numbers of the* $\Lambda c(2880)^+$. Phys. Rev. Lett. 98 (2007)
- [4]https://twiki.cern.ch/twiki/bin/view/LHCb/TupleToolKinematic
- [5]LHCb collaboration, D. Milanés et al, *Study of inclusive produced Dp and Dp system at the LHCb experiment*, LHCb-ANA, april 2014

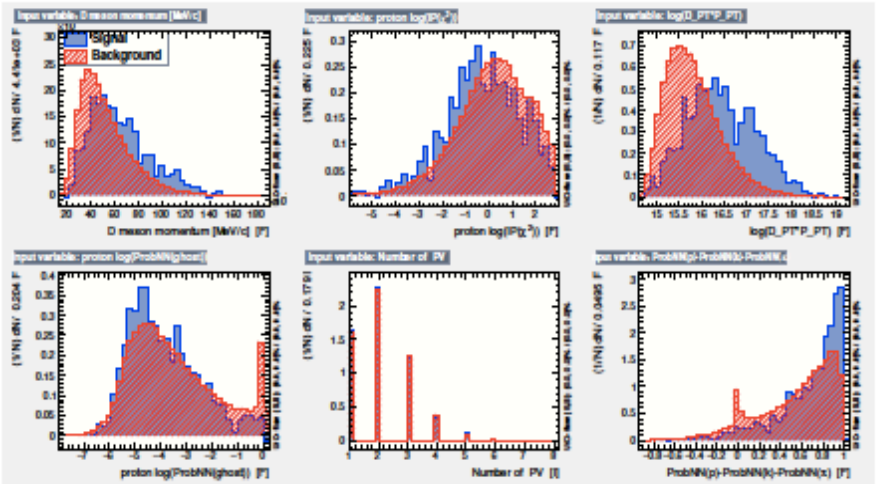
BDT: Input Variables

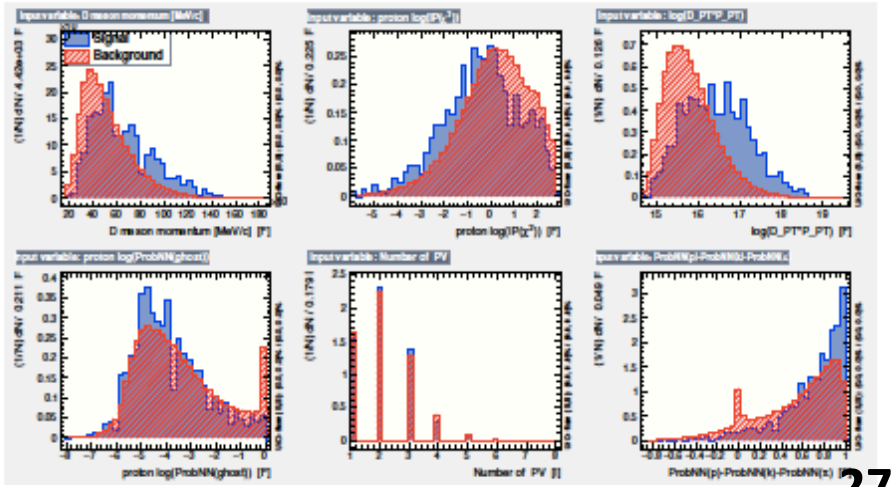
2011 BDT1 and BDT 2





2012 BDT1 and BDT 2





BDT: Rank Variables

2011 BDT 1 and BDT 2

Rank	Variable	Variable Importance
1	log(D_T*P_T)	6.266e-01
2	D_P	2.164e-01
3	logP_NNg	7.481e-02
4	P_NNp-P_NNpi-P_NNk	4.362e-02
5	logP_IPCHI2	3.261e-02
6	NPV	5.952e-03

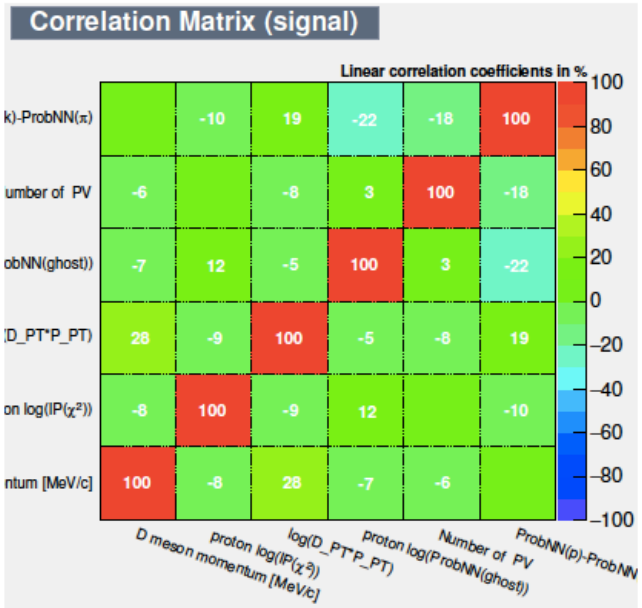
Rank	Variable	Variable Importance
1	log(D_T*P_T)	6.227e-01
2	D_P	2.163e-01
3	logP_NNg	7.383e-02
4	P_NNp-P_NNpi-P_NNk	4.103e-02
5	logP_IPCHI2	3.695e-02
6	NPV	9.174e-03

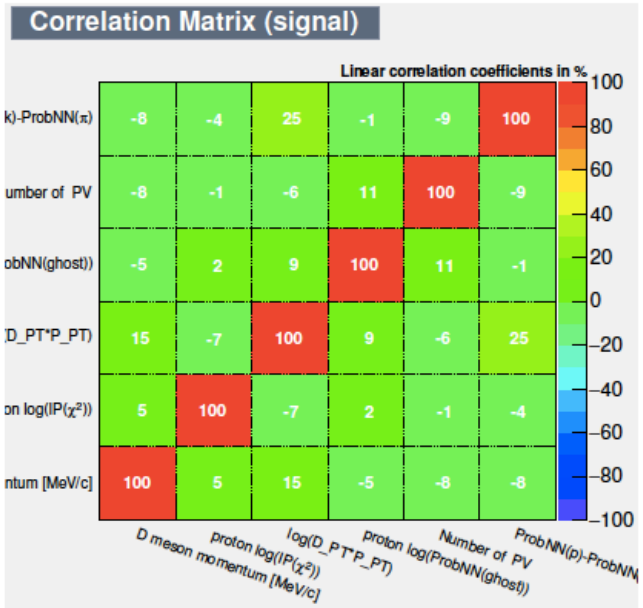
2012 BDT 1 and BDT 2

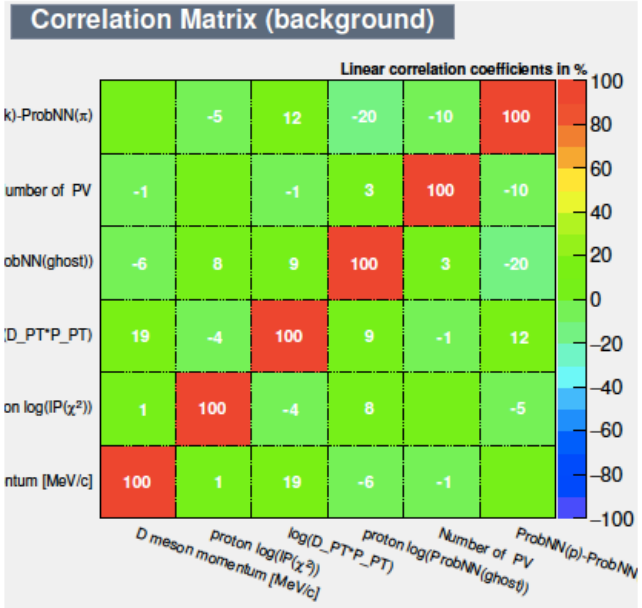
Rank	Variable	Variable Importance
1	log(D_T*P_T)	6.629e-01
2	D_P	2.160e-01
3	logP_NNg	5.212e-02
4	P_NNp-P_NNpi-P_NNk	4.342e-02
5	logP_IPCHI2	1.936e-02
6	NPV	6.193e-03

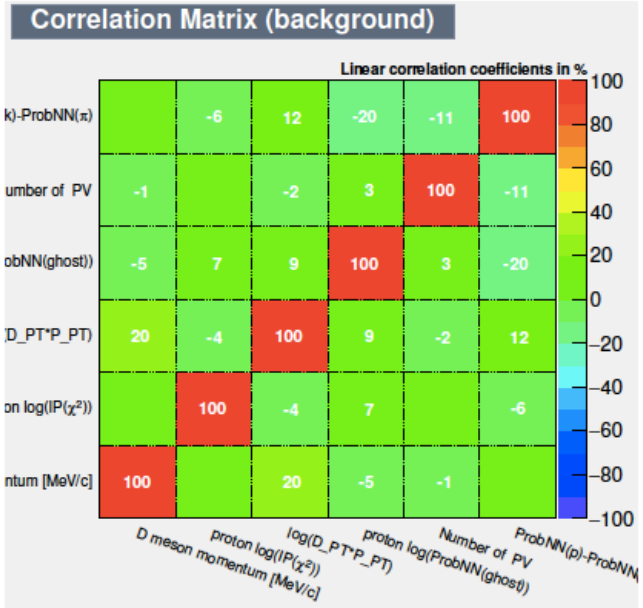
Rank	Variable	Variable Importance
1	log(D_T*P_T)	6.371e-01
2	D_P	2.270e-01
3	logP_NNg	5.940e-02
4	P_NNp-P_NNpi-P_NNk	4.524e-02
5	logP_IPCHI2	2.824e-02
6	NPV	3.087e-03

BDT: Correlation Matrix 2011

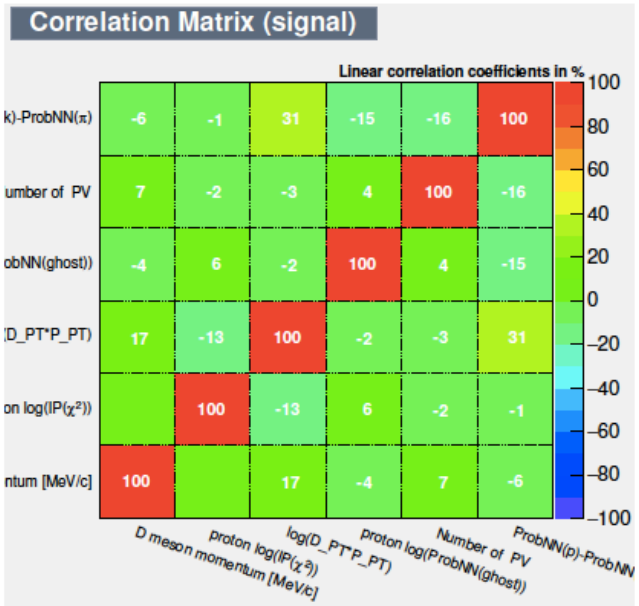


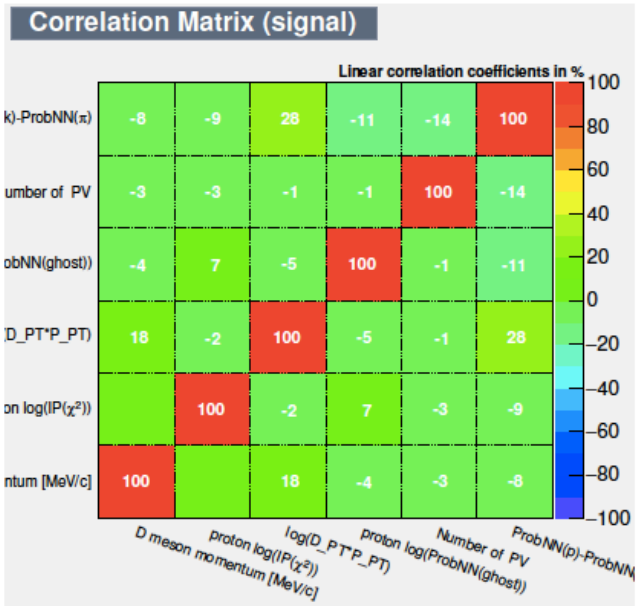


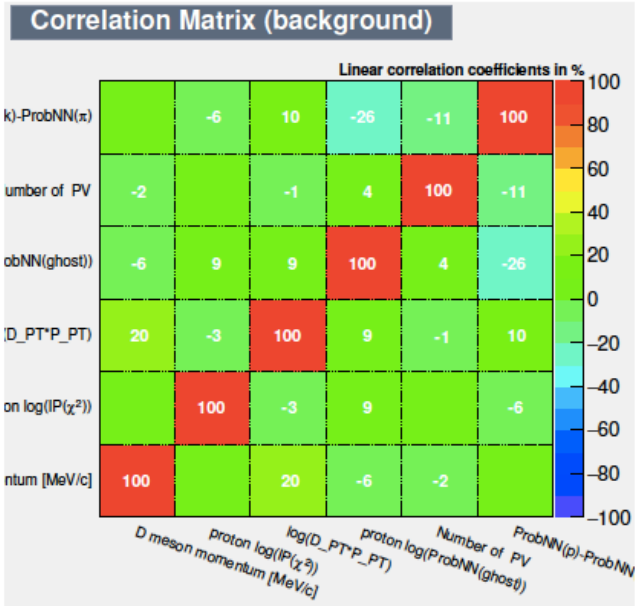


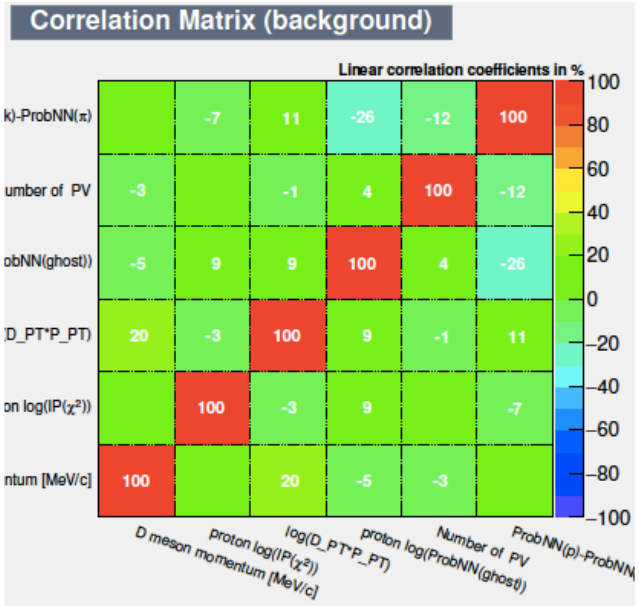


BDT: Correlation Matrix 2012









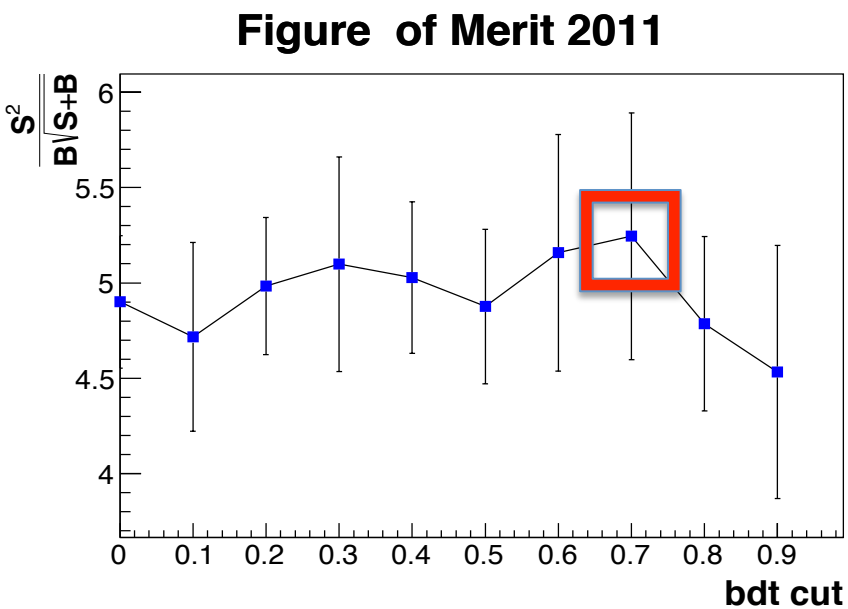
BDT: Train and Test Sample

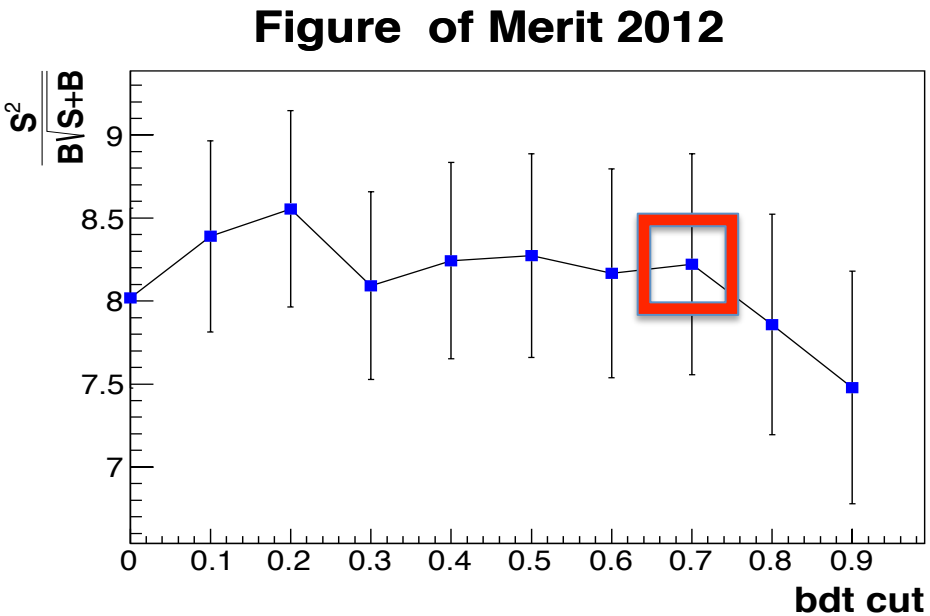
- Random uniform number (0,1) is included in 2011 and 2012 data.
- Samples are splitted into two sub samples with this random number.
- One sub sample is used as train in the other sub sample and viceversa.
- One BDT comes out for each sub sample.
- A Kolmogorov test criterium is applied for two BDTs
- Applying BDT from one sub sample to the other one and viceversa we obtain our final BDT

To do list

- Simultaneous fit to both samples, including mass resolution effects
- Fit stability studies
- Systematic uncertainties
- Proper computation of significances of new states
- ANA documentation

Figure of Merit 2011-2012





BDT Cut= 0.7 is applied to study a DP samples