Search for Exotics in B decays at LHCb

Graduate Physics Seminar

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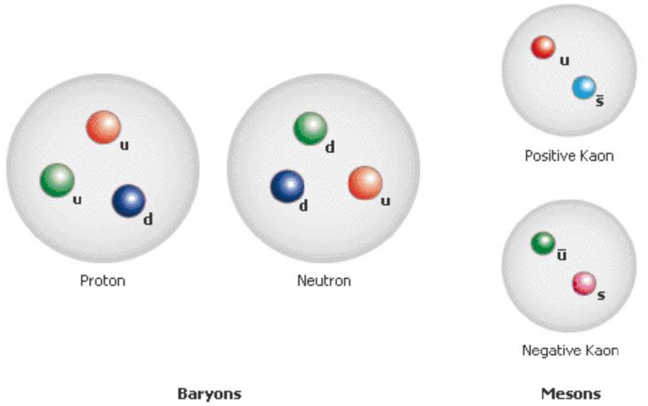

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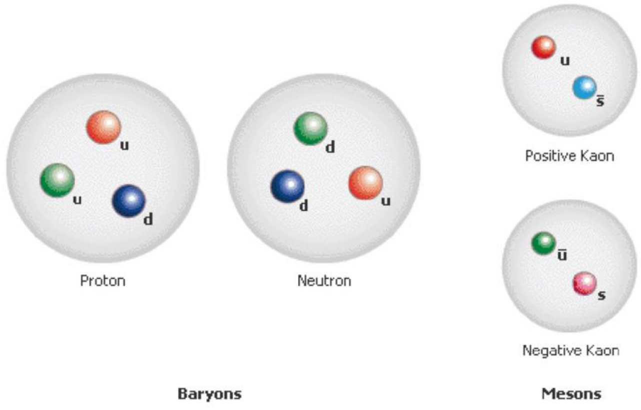

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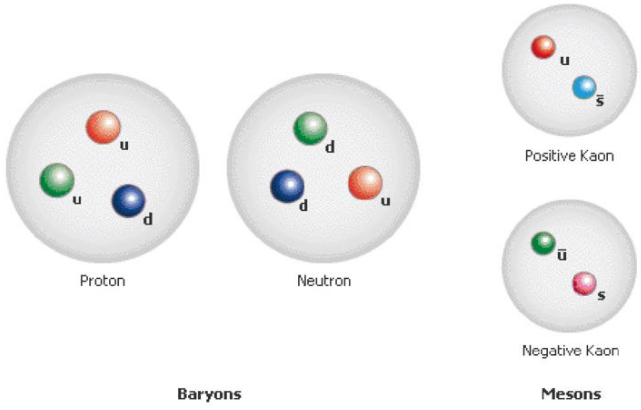

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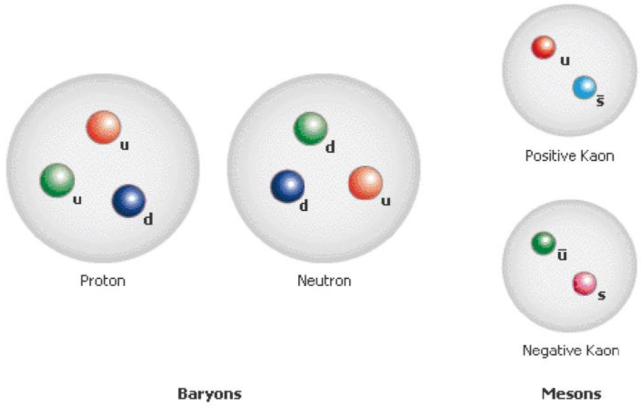
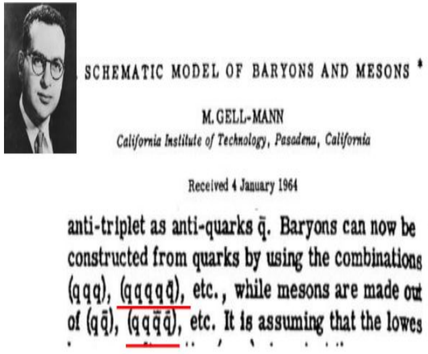
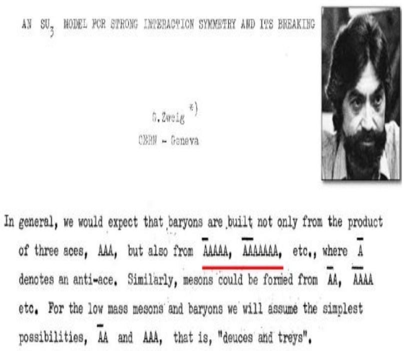
- More complex structures?







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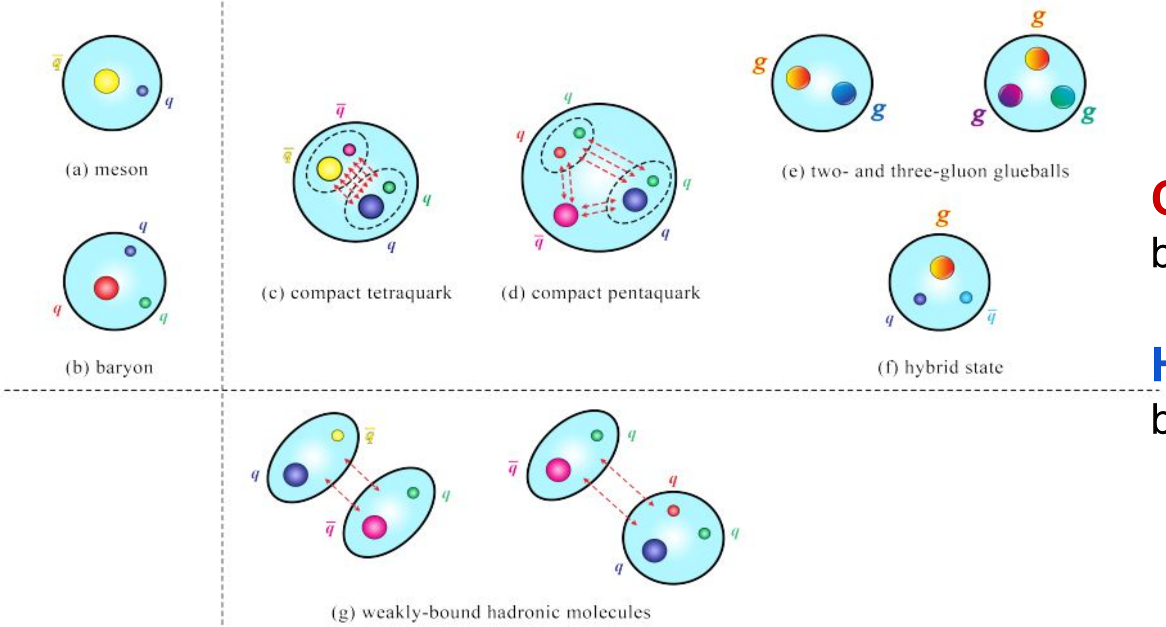

Compact Multi-quark : Tightly bound directly by strong interactions.

Hadronic Molecular : Weakly bound by residual strong interaction

Motivation for search :

- **Based purely on experimental observation** :
  - X(3872), accidental discovery by Belle as a narrow peak in the $J/\psi\pi^+\pi^-$ invariant mass distribution
  - Many other resonances such as X(3940), observed in experimental data, do not fit into conventional states with no theoretical predictions.
    - Their J^{PC} are unknown.
    - Various decay modes are un-measured.
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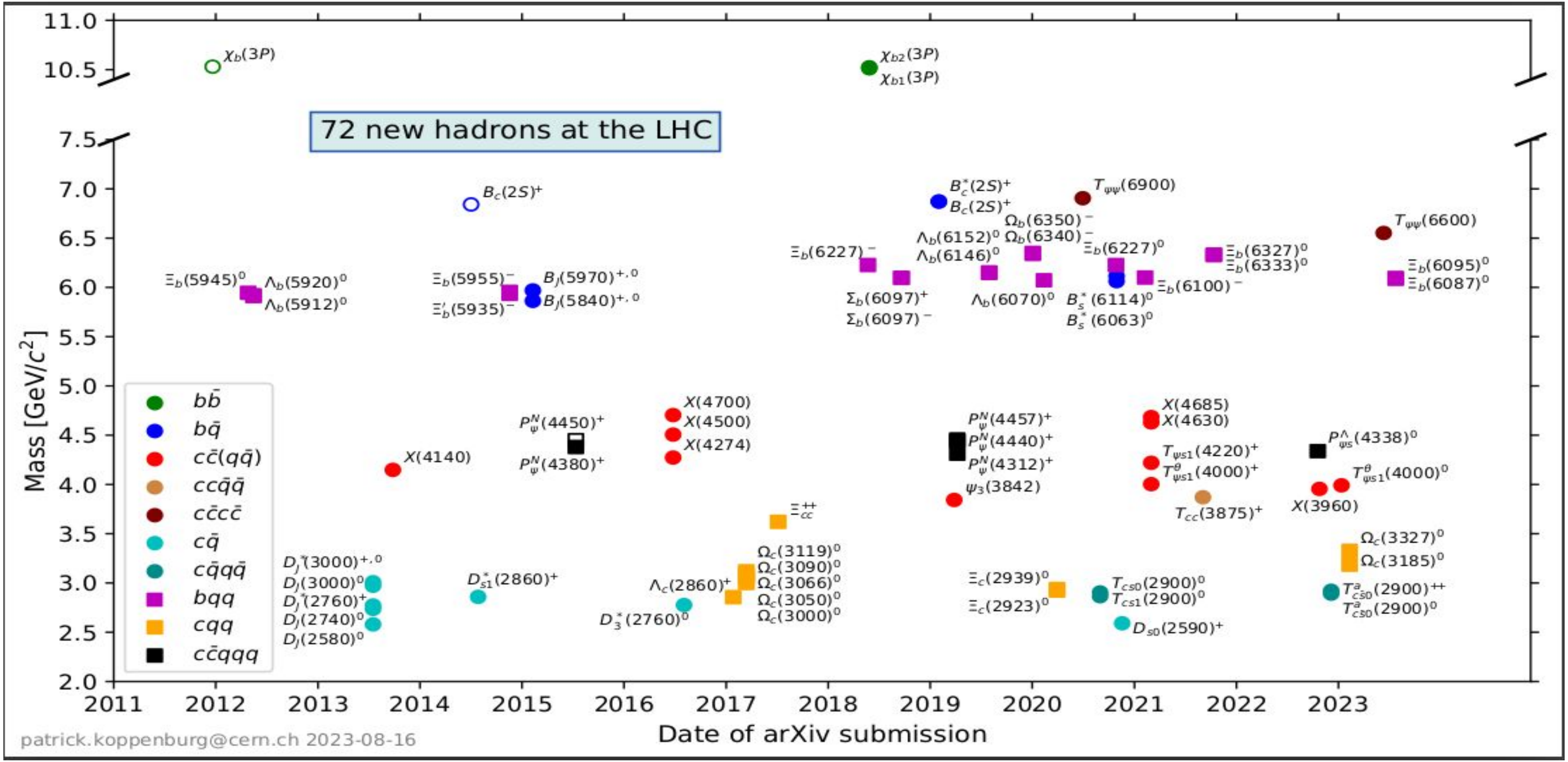
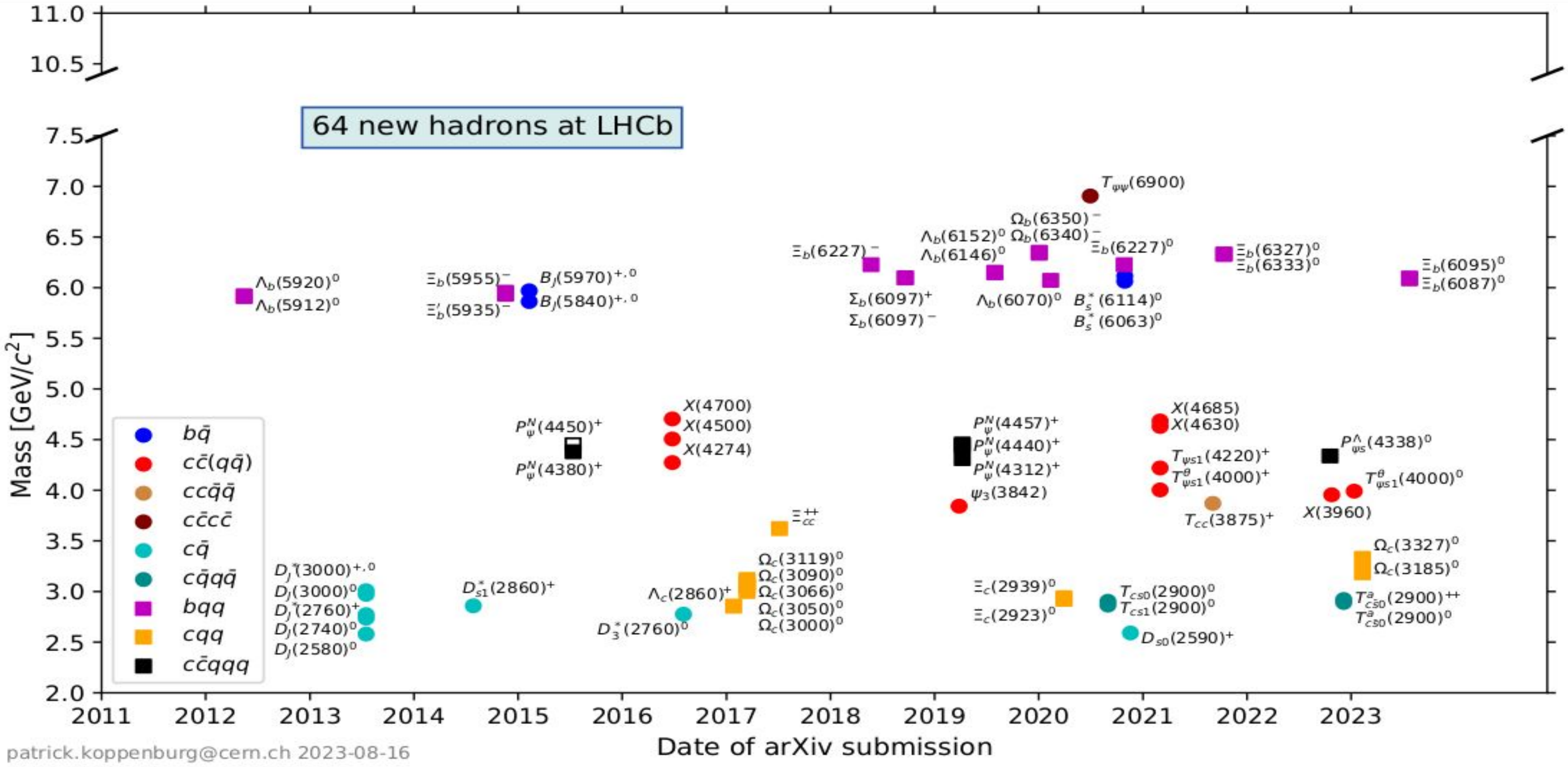
- **Based on theoretical predictions** :
  - If the X(3872) were a conventional $c\bar{c}$ state, transitions to the χ_{cJ} should be very small ; in contrast to tetra-quark or molecular state.
  - Measuring pionic transitions $X(3872) \rightarrow \chi_{c1}\pi^0$ could distinguish between various interpretations

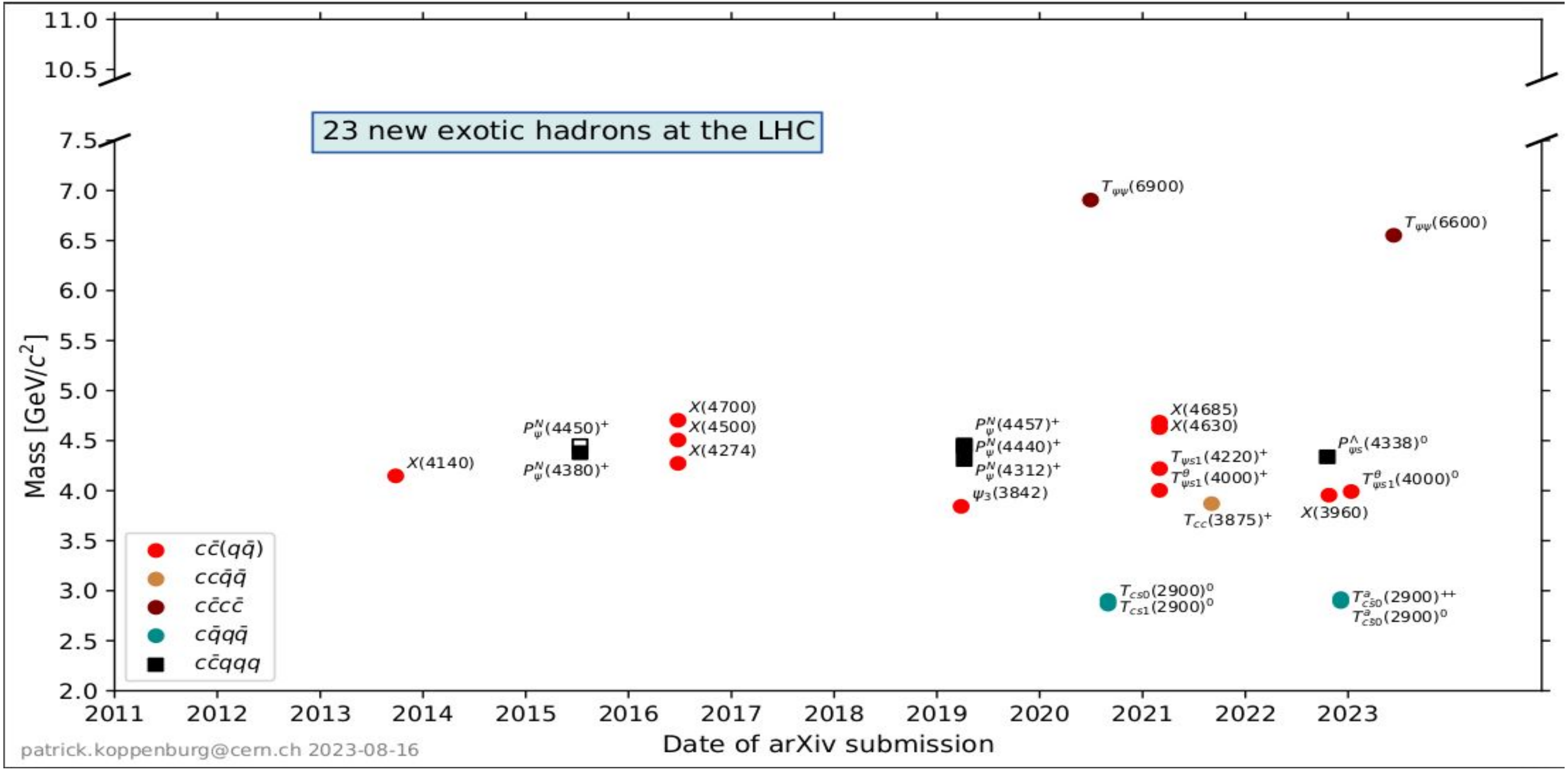
Hadron Spectroscopy at LHC



Hadron Spectroscopy at LHCb

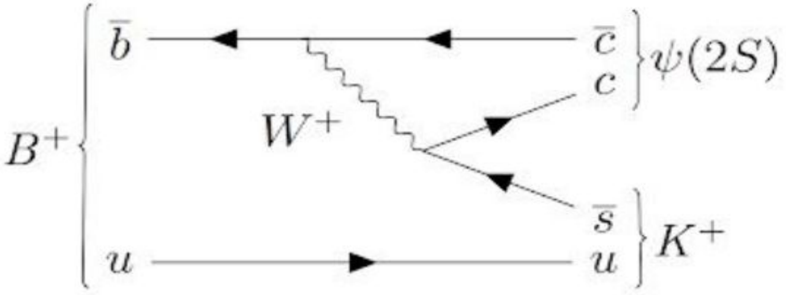


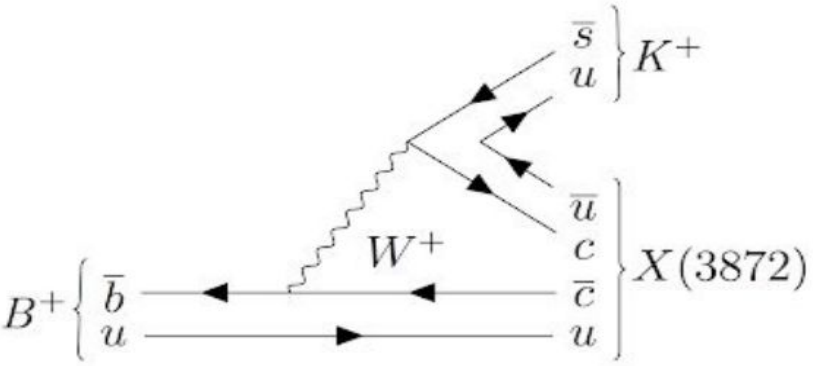
Exotic Hadrons at LHC



B decays

- B meson produced in high-energy Hadron Collisions : $p\bar{p}$ and pp
- Each $b\bar{b}$ quark of a pair, hadronizes separately.
- B meson are a **$\bar{b}$** and **u,d,s, or c** quark : **B^+, B^0, B_s**, and **B_c**
- B - flavored hadrons decay via generation-changing processes
- Dominant decay mode of a B quark is **$b \rightarrow cW^-$**
- Forms charmed mesons or **$c\bar{c}$** (charmonium).

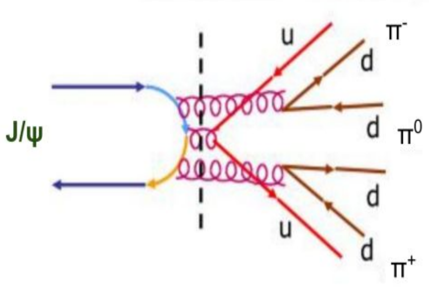




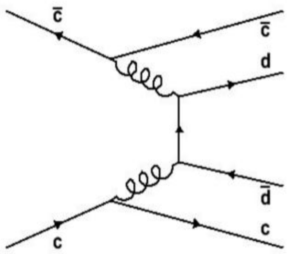
My PhD work is dedicated to search for exotics in charmonium ($c\bar{c}$) sector at LHCb.

Why Charmonium?

- Have reliable predictions of expected conventional states.
- Charm : lightest 'heavy' quark - $m_c >> \Lambda_{QCD}$ - can determine $c\bar{c}$ spectrum with simple non-relativistic Q-M treatment.



OZI-suppressed

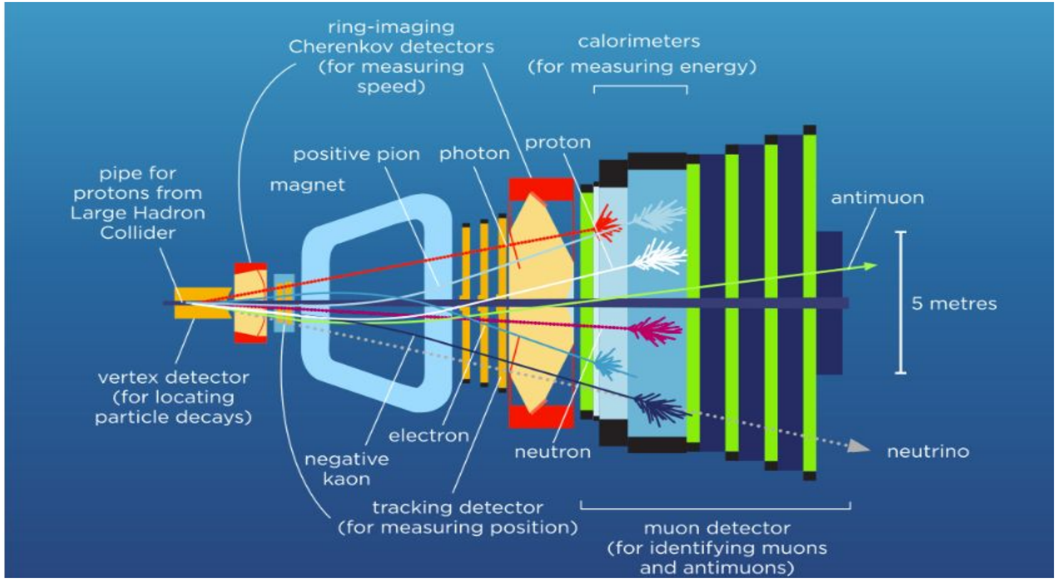


OZI-allowed

- Decays of conventional $c\bar{c}$ states with masses below open charm threshold $m_{D\bar{D}}$ are OZI suppressed - states are narrow and well separated.
- Above the open charm threshold OZI allowed processes dominate wider resonances but still significantly narrower than light quark states.

Why LHCb?

- Largest data sample of b and c hadrons
- Triggers optimised for final state particles J/Ψ(1S) and Ψ(2S).
- Dedicated computational tools available for thorough search of exotics.



Run	Years	Lum. $[\text{fb}^{-1}]$	$\sqrt{s}$ [TeV]	$\sigma_{b\bar{b}}$ $[\mu\text{b}]$	$\sigma_{c\bar{c}}$ $[\mu\text{b}]$
1	2011-12	3.0	7,8	70	1400
2	2015-17	3.8	13	150	2400
2	2018	2.2	13		

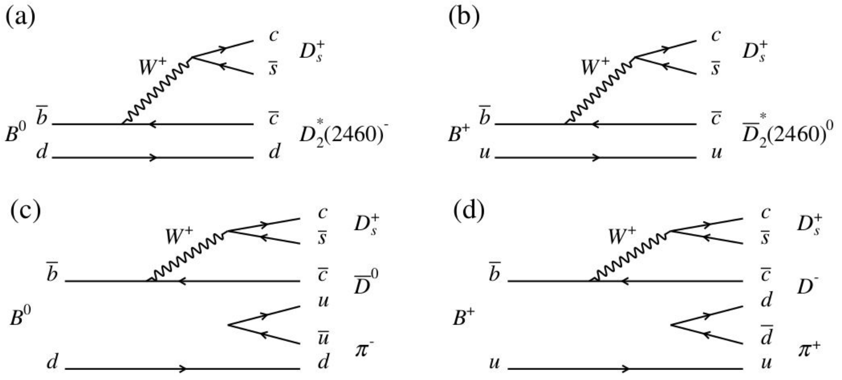
- Single arm forward spectrometer : $2 < \eta < 5$
- Impact parameter resolution: $\sigma_{IP} \approx 20\mu m$
- Momentum resolution:
  - $\frac{\Delta P}{P} \backsim 0.5 - 1\%$

- Efficient hadronic identification.
- PID separation K , p from π:
  - $\epsilon(K \to K) \approx 95\%$ and $\epsilon(\pi \to K) \approx 5\%$
  - $\epsilon(p \to p) \approx 95\%$ and $\epsilon(\pi \to p) \approx 5\%$

Tetra-Quarks

Open Charm

- Either only c or only $\bar{c}$, non zero net charm content.
- $T^*_{cs0}(2870)^0$ and $T^*_{cs1}(2900)^0$
- $T^+_{cc}(3875)$: ccud



$B^0 \to \overline{D}^0 D_s^+ \pi^-$ $\quad$ $B^+ \to D^- D_s^+ \pi^+$

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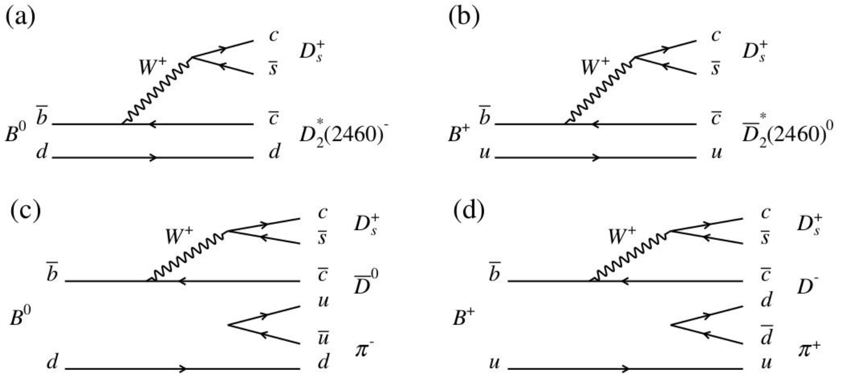
Hidden Charm

- $c\bar{c}$ pairs, zero net charm content.
- 2 Fully charm $T_{\psi\psi}(6900)^+$: $cc\overline{cc}$
- $P^{\Lambda}_{\psi s}(4459)^0$,$T^{\theta}_{\psi s1}(4000)^+$......



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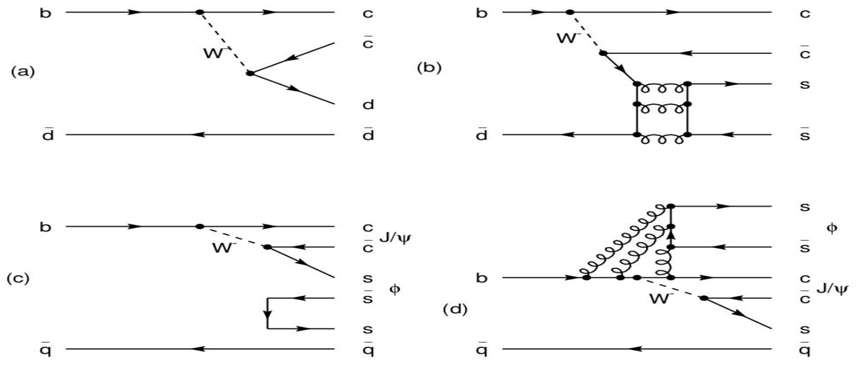

$B^0 \to J/\psi \phi K_S^0$

Methodology

- Decay : **$B^0 \rightarrow J/\psi(1S)\ \pi^+\ \pi^-\ \pi^-\ K^+$**

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- Now a fit is performed on the data with proper models for signal and background, usually gaussian for former and exponential for later.

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- If decay occur via exotic / resonance state : structures observed as enhancements in intermediate particle mass combinations.

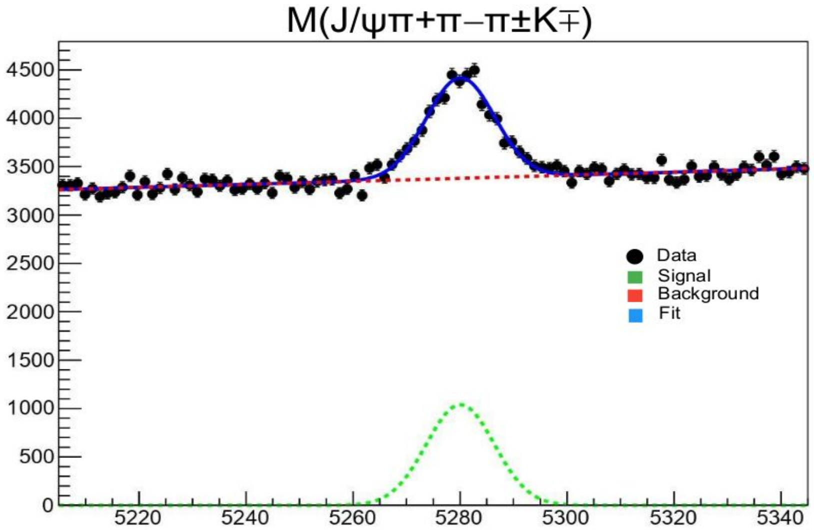
First Analysis : $B^0 \rightarrow J/\psi(1S)\ \pi^+\ \pi^-\ \pi^-\ K^+$

- $B^0 \rightarrow J/\psi(1S)\ \pi^+\pi^-\pi^-K^+$
  - $X^\pm \rightarrow \psi(3770)\pi^\pm$ (M. Ablikim et al. (BESIII Collaboration) Phys. Rev. D 100, 032005)
  - New decay mode of B^0 (excluding resonant contribution)
  - General Idea : Possible observation of either new or previously un-confirmed exotic resonances and decay modes.
- We are interested in structures in :
  - **Y** = m $(J/\psi\pi^+\pi^-)$
  - **X** = m $(J/\psi\pi^+\pi^-)\ \pi^\pm$
- Cut based selection is applied on the reconstructed data.

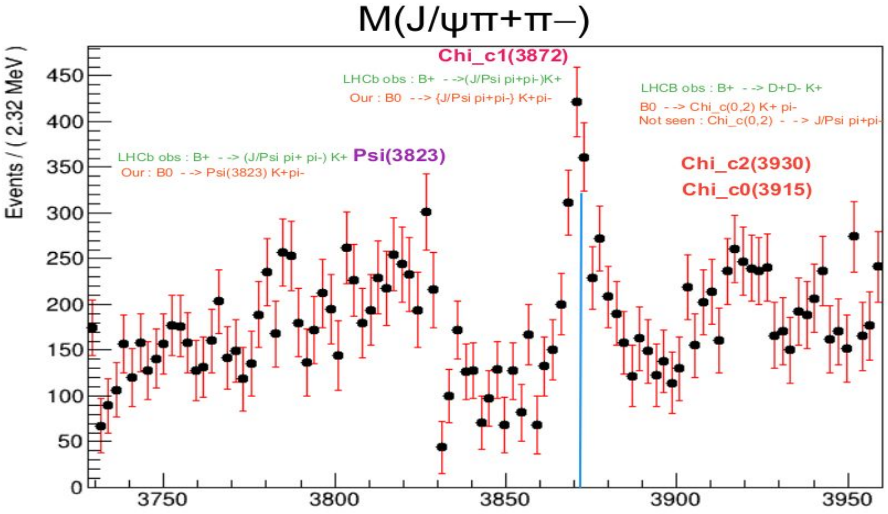
Y mass range	
Particle	Range
$\psi(2S)$	$<$ 3726 MeV (I)
Y (3770, 3823,...)	3726 - 3990 MeV (II)
Y (4040, 4160, 4230)	$>$ 3990 MeV (III)

- Fit performed on J/ψ constrained B mass
- S-weights are used to fit J/ψ constrained Y and X mass.
- We look for B meson signal and possibility of structures in invariant mass combinations of daughter particle.

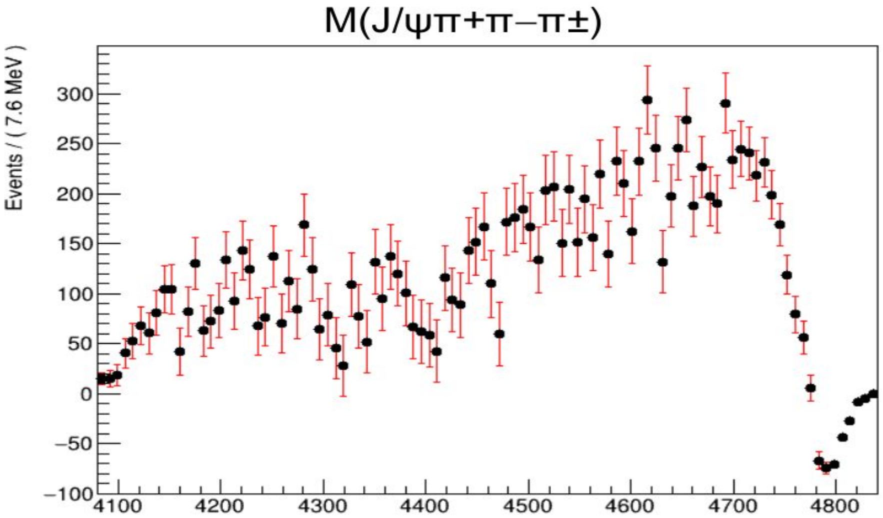
Range II :



M(J/ψπ+π−π±K∓)
Data
Signal
Background
Fit



M(J/ψπ+π−)
Events / (2.32 MeV)
Chi_c1(3872)
LHCb obs : B+ - ->(J/Psi pi+pi-)K+
Our : B0 - -> {J/Psi pi+pi-} K+pi-
LHCB obs : B+ - -> D+D- K+
B0 - -> Chi_c(0,2) K+ pi-
Not seen : Chi_c(0,2) - - > J/Psi pi+pi-
LHCb obs : B+ - -> (J/Psi pi+ pi-) K+ Psi(3823)
Our : B0 - -> Psi(3823) K+pi-
Chi_c2(3930)
Chi_c0(3915)



M(J/ψπ+π−π±)
Events / (7.6 MeV)

First Analysis : $B^0 \rightarrow J/\psi(1S)\ \pi^+\ \pi^-\ \pi^-\ K^+$

Range I : B0 → (ψ(2S) → (J/ψ(1S) → μ+ μ−)π+ π−)π− K+

First Analysis : $B^0 \to J/\psi(1S)\ \pi^+\ \pi^-\ \pi^-\ K^+$

Range I : B0 → (ψ(2S) → (J/ψ(1S) → μ+ μ−)π+ π−)π− K+

Range II : B0 → (**ψ(3823)** → (J/ψ(1S) → μ+ μ−)π+ π−)π− K+

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Range I : B0 → (ψ(2S) → (J/ψ(1S) → μ+ μ−)π+ π−)π− K+

Range II : B0 → (**ψ(3823)**) → (J/ψ(1S) → μ+ μ−)π+ π−)π− K+

B0 → (**χ_{c1}(3872)**) → (J/ψ(1S) → μ+ μ−)π+ π−)π− K+

First Analysis : $B^0 \rightarrow J/\psi(1S)\ \pi^+\ \pi^-\ \pi^-\ K^+$

Range I : $B0 \rightarrow (\psi(2S) \rightarrow (J/\psi(1S) \rightarrow \mu+\ \mu-\ )\pi+\ \pi-\ )\pi-\ K+$

Range II : $B0 \rightarrow (\psi(3823) \rightarrow (J/\psi(1S) \rightarrow \mu+\ \mu-\ )\pi+\ \pi-\ )\pi-\ K+$

$B0 \rightarrow (\chi_{c1}(3872) \rightarrow (J/\psi(1S) \rightarrow \mu+\ \mu-\ )\pi+\ \pi-\ )\pi-\ K+$

$B0 \rightarrow (\chi_{c0}(3915) \rightarrow (J/\psi(1S) \rightarrow \mu+\ \mu-\ )\pi+\ \pi-\ )\pi-\ K+$

First Analysis : $B^0 \to J/\psi(1S)\ \pi^+\ \pi^-\ \pi^-\ K^+$

Range I : B0 $\to$ (ψ(2S) $\to$ (J/ψ(1S) $\to$ μ+ μ−)π+ π−)π− K+

Range II : B0 $\to$ (**ψ(3823)** $\to$ (J/ψ(1S) $\to$ μ+ μ−)π+ π−)π− K+

B0 $\to$ (**χ_{c1}(3872)** $\to$ (J/ψ(1S) $\to$ μ+ μ−)π+ π−)π− K+

B0 $\to$ (**χ_{c0}(3915)** $\to$ (J/ψ(1S) $\to$ μ+ μ−)π+ π−)π− K+

B0 $\to$ (**χ_{c2}(3930)** $\to$ (J/ψ(1S) $\to$ μ+ μ−)π+ π−)π− K+

First Analysis : $B^0 \to J/\psi(1S)\ \pi^+ \pi^- \pi^- K^+$

Range I : B0 $\to$ ($\psi(2S)$ $\to$ ($J/\psi(1S)$ $\to$ $\mu+\ \mu-$)$\pi+\ \pi-$)$\pi-$ K+

Range II : B0 $\to$ (**$\psi(3823)$**) $\to$ ($J/\psi(1S)$ $\to$ $\mu+\ \mu-$)$\pi+\ \pi-$)$\pi-$ K+

B0 $\to$ (**$\chi_{c1}(3872)$**) $\to$ ($J/\psi(1S)$ $\to$ $\mu+\ \mu-$)$\pi+\ \pi-$)$\pi-$ K+

B0 $\to$ (**$\chi_{c0}(3915)$**) $\to$ ($J/\psi(1S)$ $\to$ $\mu+\ \mu-$)$\pi+\ \pi-$)$\pi-$ K+

B0 $\to$ (**$\chi_{c2}(3930)$**) $\to$ ($J/\psi(1S)$ $\to$ $\mu+\ \mu-$)$\pi+\ \pi-$)$\pi-$ K+

Range III :B0 $\to$ ($\psi(4160)$ $\to$ ($J/\psi(1S)$ $\to$ $\mu+\ \mu-$)$\pi+\ \pi-$)$\pi-$ K+

Second Analysis : $B^0 \rightarrow J/\psi(1S)\pi^+\pi^-\pi^0\pi^-K^+$

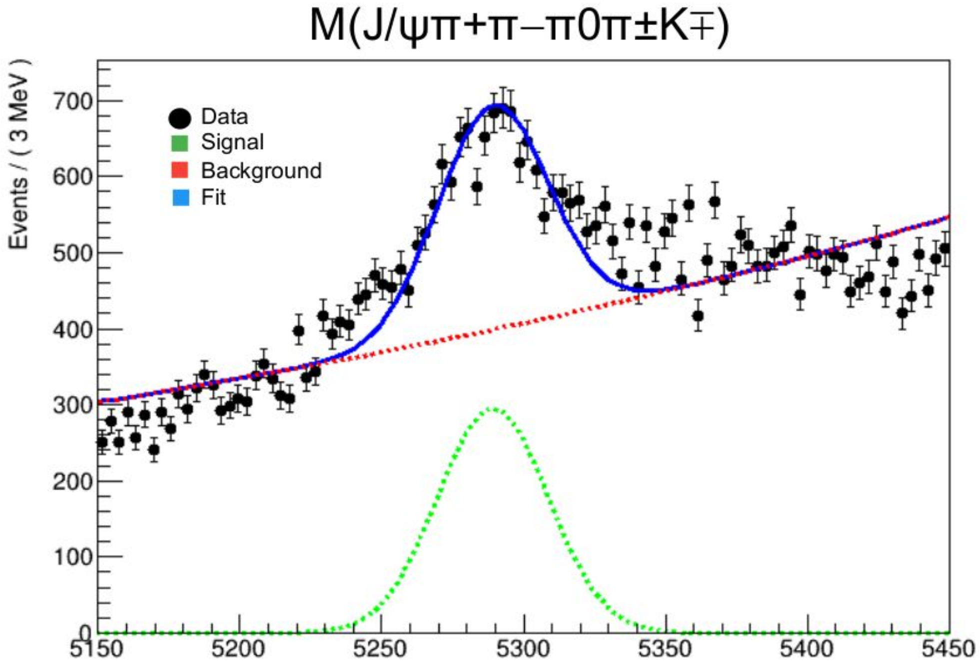
- **$B^0 \rightarrow J/\psi(1S)\pi^+\pi^-\pi^0\pi^-K^+$**
  - **X (3940) → $J/\psi\omega(782)$** in **$B^+ \rightarrow \omega J/\psi K^+$** (BELLE/BABAR)
  - $\Psi(4230) \rightarrow J/\psi\pi^+\pi^-\pi^0$
  - **New decay mode of B^0**

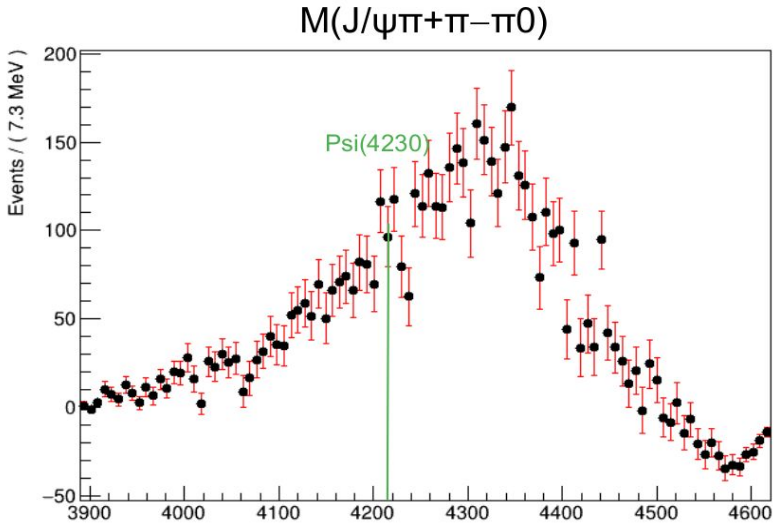
$(J/\psi\pi^+\pi^-)$ Mass	
Decay	Range
$B^0 \rightarrow \psi(2S)\pi^0\pi^-K^+$	3680 - 3700 MeV
$B^0 \rightarrow J/\psi(1S)\pi^+\pi^-\pi^0\pi^-K^+$	$<$ 3680 MeV $>$ 3700 MeV

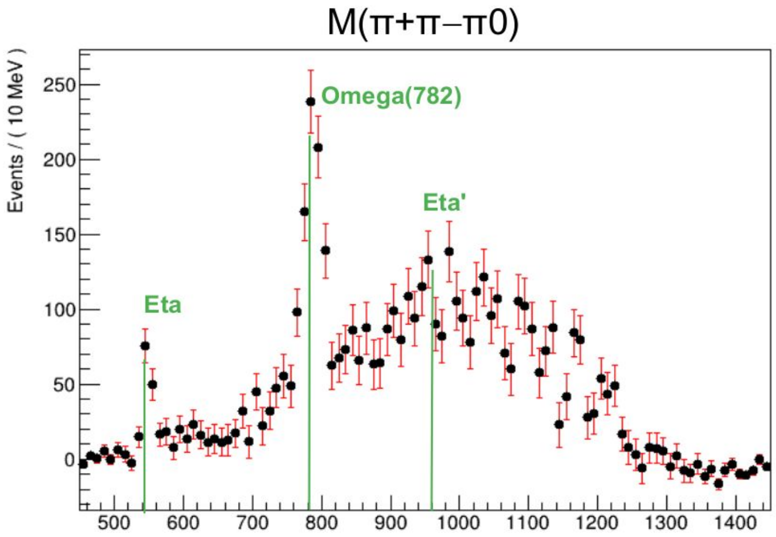
- 2 different reconstruction :
  - First :
    $B^0 \rightarrow (J/\psi\pi^+\pi^-\pi^0)\pi^+K^-$
  - Second :
    $B^0 \rightarrow (J/\psi(\omega \rightarrow \pi^+\pi^-\pi^0))\pi^+K^-$
  - Resolved Pions used i.e. $\pi^0 \rightarrow \gamma\gamma$

Additional Cuts		
Particle	Parameter	Selection
ω	$M(\pi^+\pi^-\pi^0)$	742 - 822 MeV

Results : $B^0 \rightarrow (J/\psi\pi^+ \pi^- \pi^0)\pi^+ K^-$







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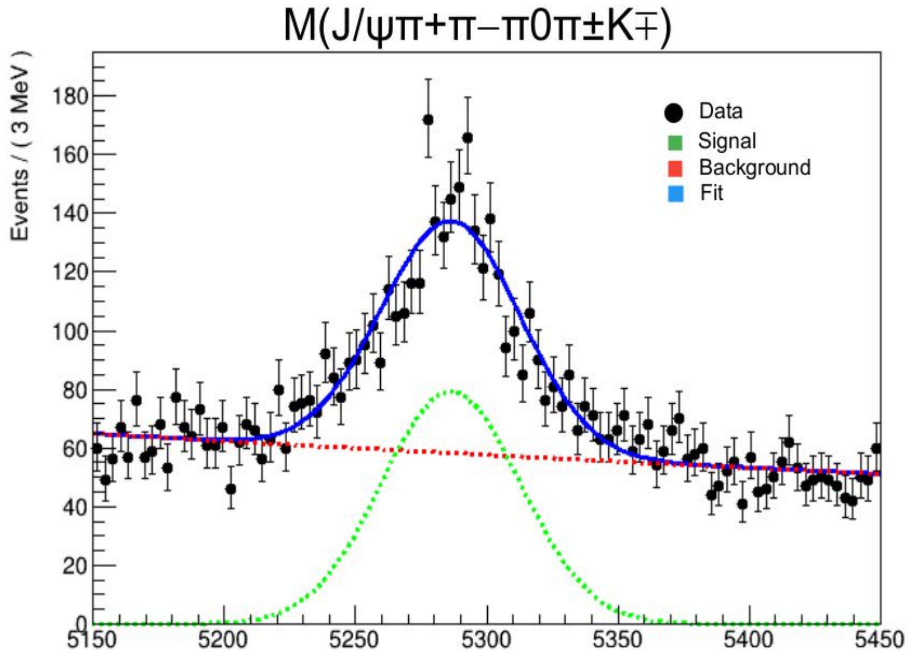
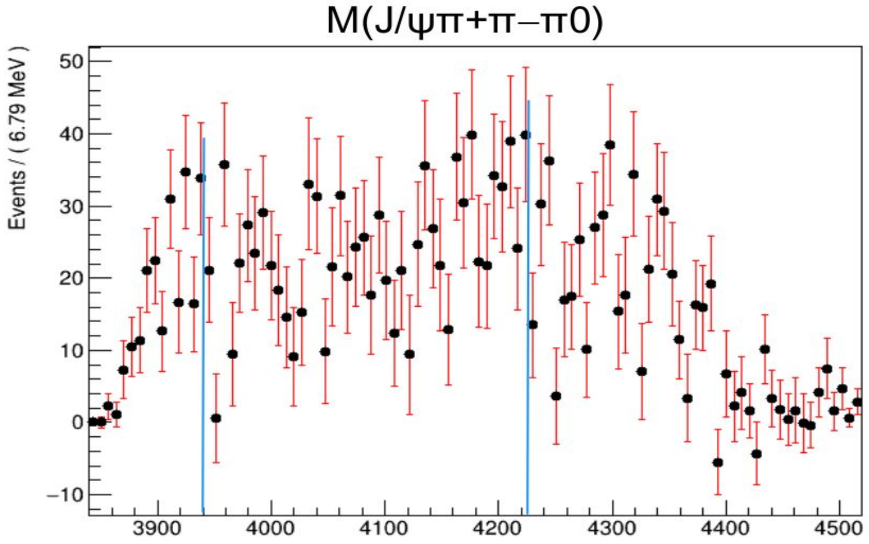
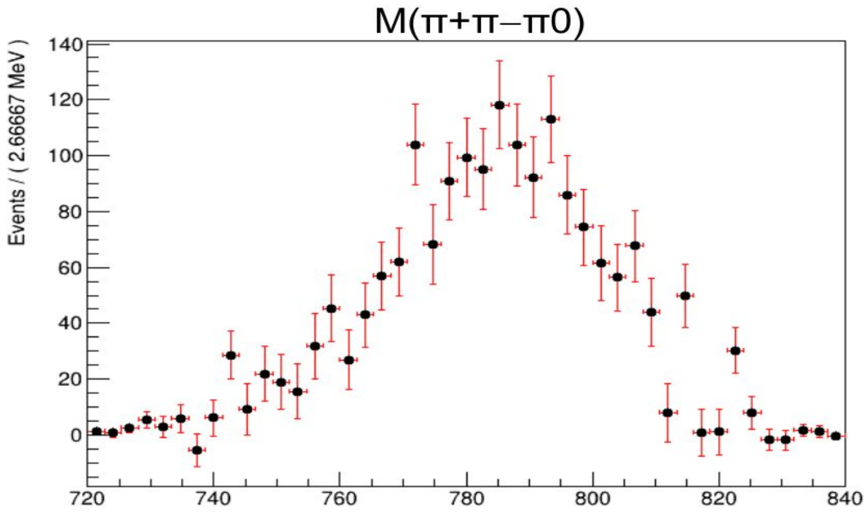
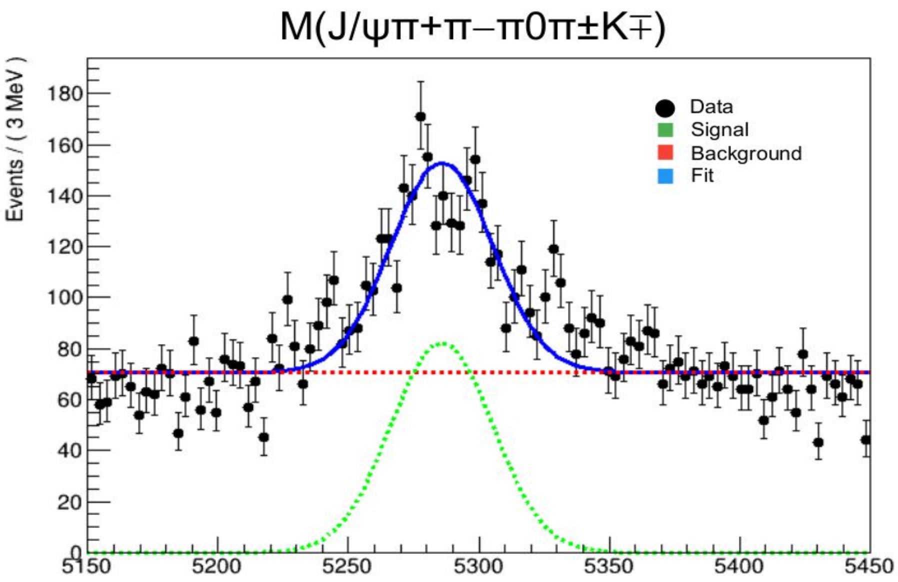


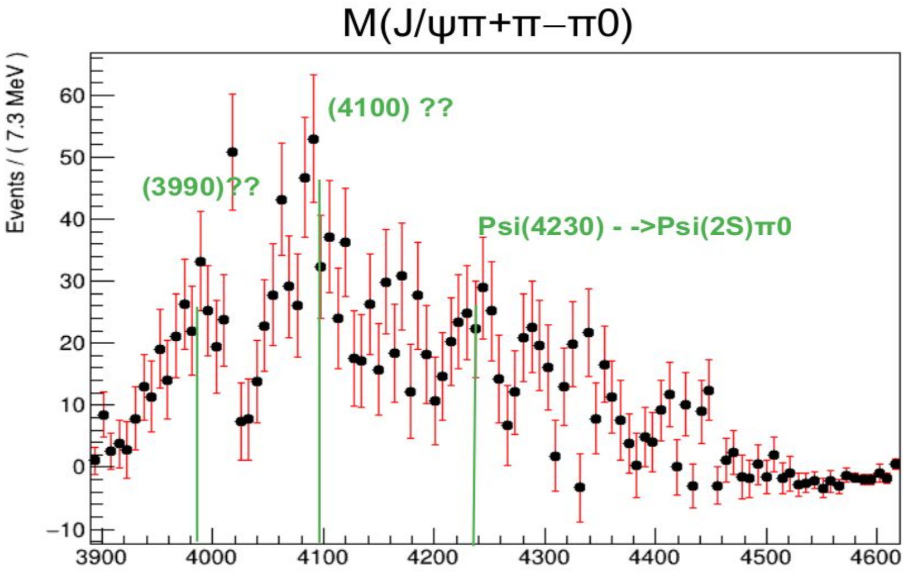




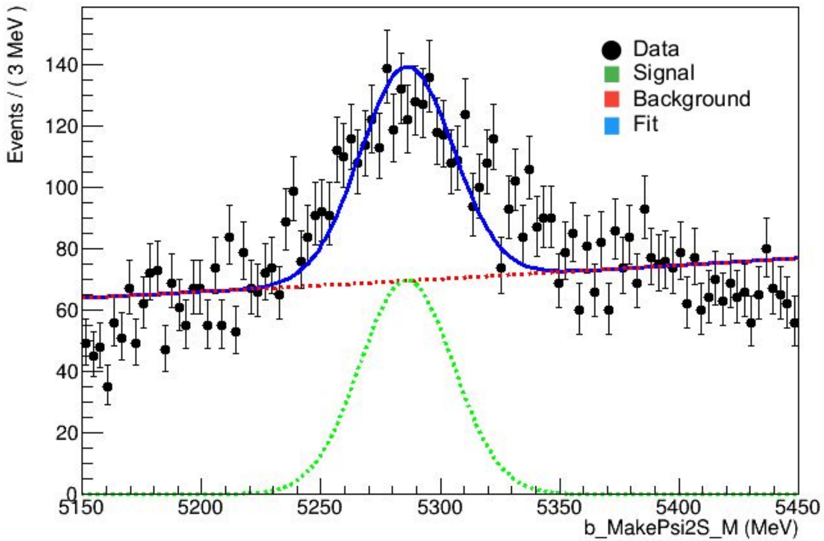
Third Analysis : $B^0 \rightarrow (\psi(2S)\pi^0)\pi^- K^+$

- $J/\psi\pi^+ \pi^- \pi^0$ can also occur via $(\psi(2S) \rightarrow J/\psi\pi^+\pi^-)\pi^0$
- Earlier studies veto out the contribution but we observed significant B0 signal.
- New Channel : $B^0 \rightarrow \psi(2S)\pi^0 \pi^+ K^-$ with $\psi(2S) \rightarrow (J/\psi\pi^+\pi^-)$

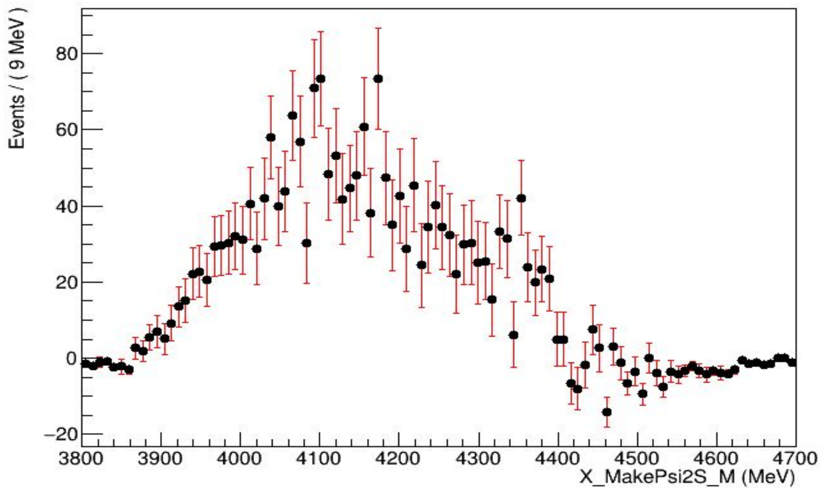




- To have an independent measurement of new observed B0 decay, we reconstructed **$B^0 \to \psi(2S)\pi^0 \pi^+ K^-$** with $\psi(2S) \to \mu^+\mu^-$
- Signal was observed and will be included in the measurement of the branching fraction of the B decay.



- Producing MC events has a cost: 6000 Euro per 10M generic b events
- We asked : 180M in total, yet



Let’s summarise…..

We have observed 3 new decay modes of B meson and plan to measure their branching fractions.

$B^0 \rightarrow (J/\psi(1S)\ \pi^+\ \pi^-)\pi^-\ K^+$

- Use MC to enhance observation of χ_{c0}(3915) and χ_{c2}(3930) decaying to $J/\psi\pi^+\pi^-$
- Possible new decay mode or observation of a new Z state.

$B^0 \rightarrow (J/\psi\pi^+\ \pi^-\pi^0\ )\pi^+K^-$

- Observed structure around masses :
  - **X (3940)**$\rightarrow J/\psi\omega$
  - **X (4160)**$\rightarrow J/\psi\omega$
  - **ψ(4230)**$\rightarrow J/\psi\pi^+\ \pi^-\ \pi^0$

$B^0 \rightarrow (\psi(2S)\pi^0)\pi^-K^+$

- Possible observation of exotic resonances.

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- Vast amounts of data characterized by multiple variables : Automated algorithms for learning from data - **Machine learning**
- **Supervised learning** : classifier is presented only with training events for which it knows “discriminating variables” and “class label”.

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- **Boosting** : goal is to combine weak classifiers into a new, more stable one, with a smaller error rate and better performance

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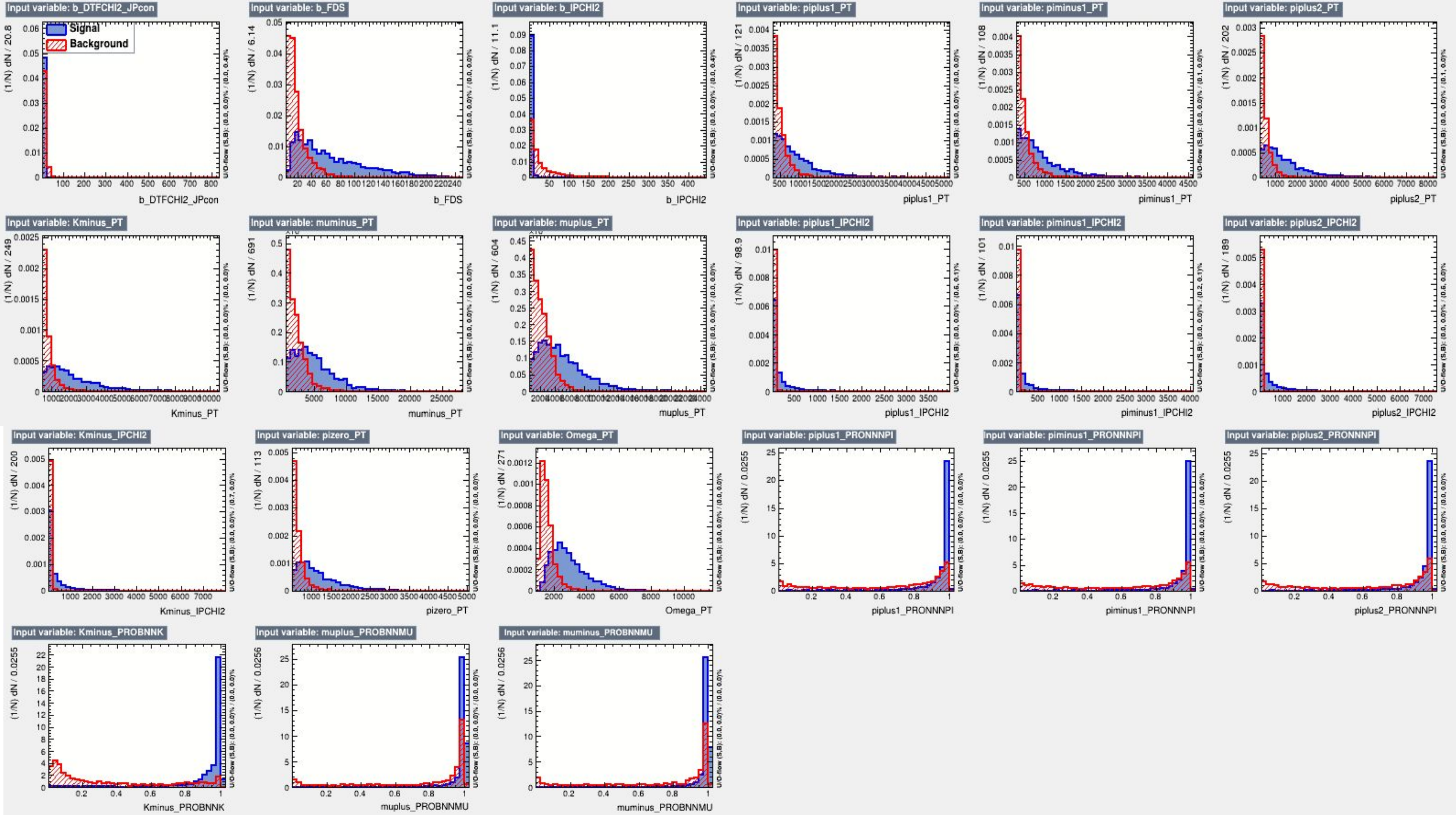
Signal
Background
Input variable: b_DTFCHI2_JPcon
b_DTFCHI2_JPcon
Input variable: b_FDS
b_FDS
Input variable: b_IPCHI2
b_IPCHI2
Input variable: piplus1_PT
piplus1_PT
Input variable: piminus1_PT
piminus1_PT
Input variable: piplus2_PT
piplus2_PT
Input variable: Kminus_PT
Kminus_PT
Input variable: muminus_PT
muminus_PT
Input variable: muplus_PT
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Input variable: pizero_PT
pizero_PT
Input variable: Omega_PT
Omega_PT
Input variable: piplus1_PRONNNPI
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Input variable: piplus2_PRONNNPI
piplus2_PRONNNPI
Input variable: Kminus_PROBNNK
Kminus_PROBNNK
Input variable: muplus_PROBNNMU
muplus_PROBNNMU
Input variable: muminus_PROBNNMU
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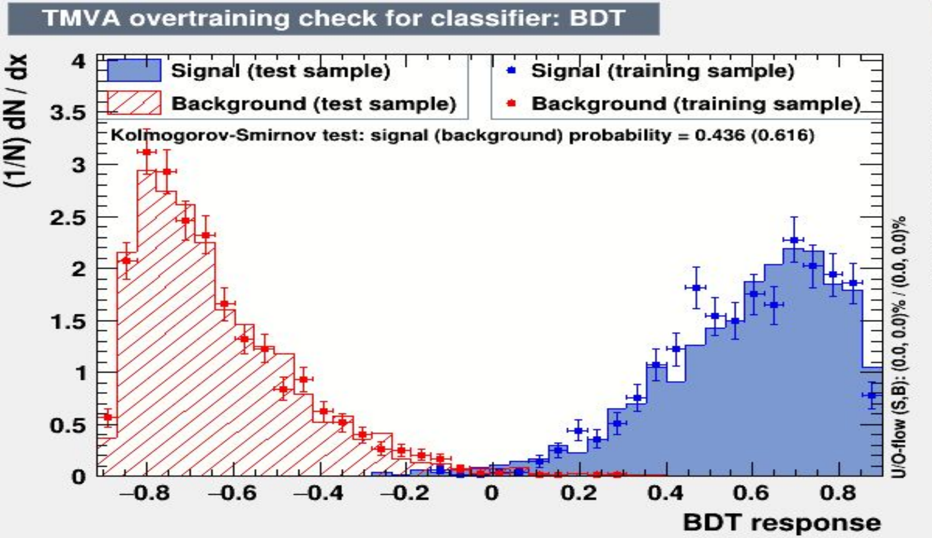

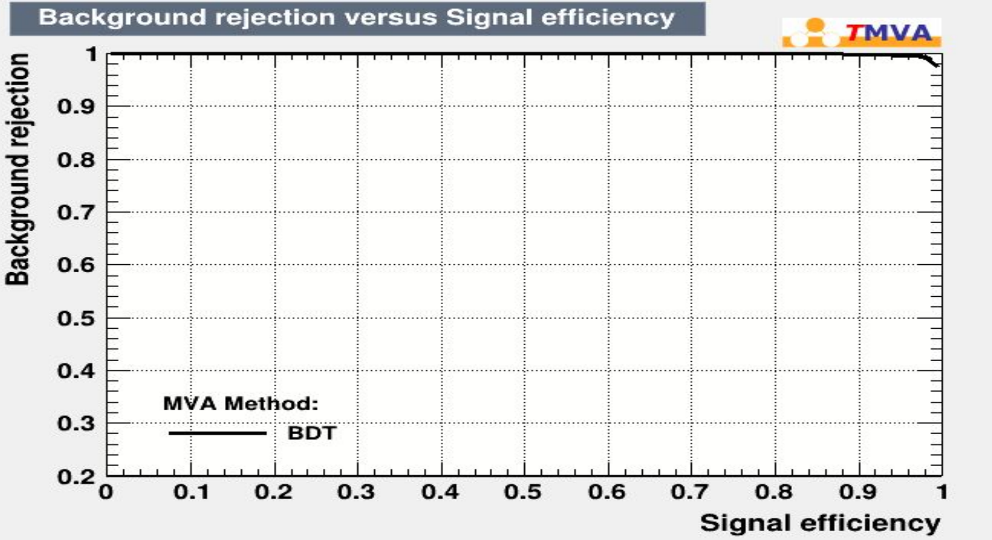

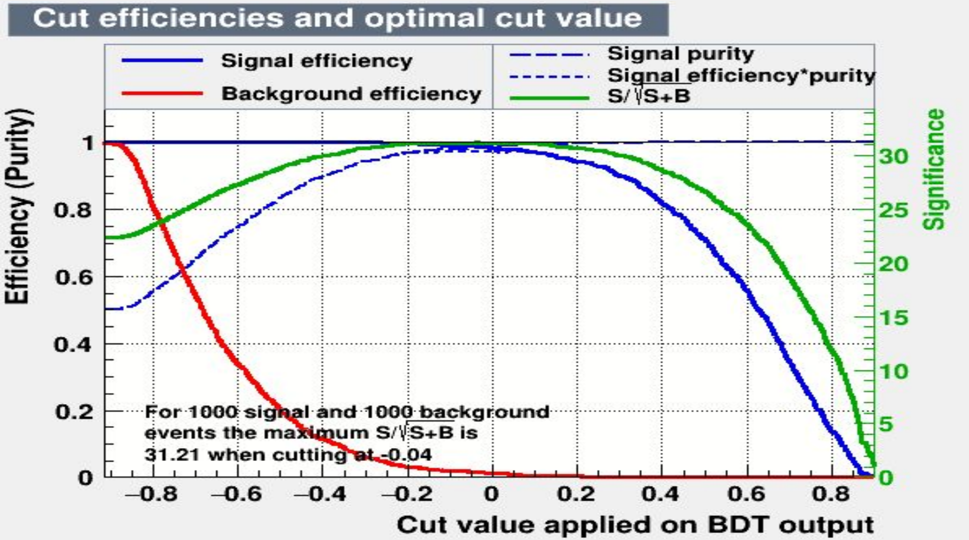

- Apply training on whole data set, each run separately.
- “Friend” this training output event by event with data.
- New variable produced : BDT variable associated with every event.
- Values vary between : 0 and 1

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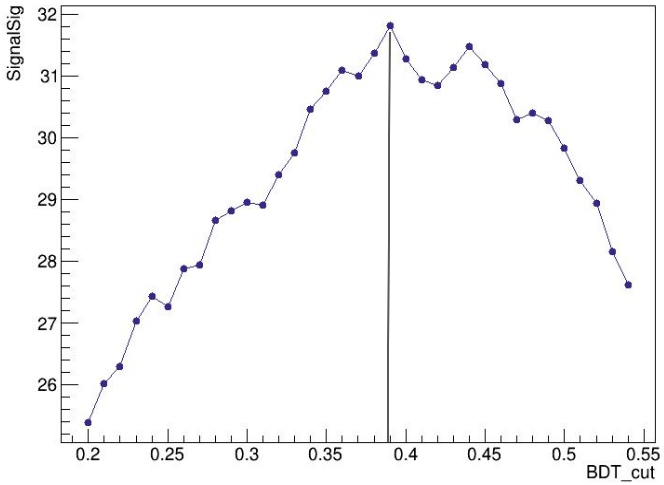
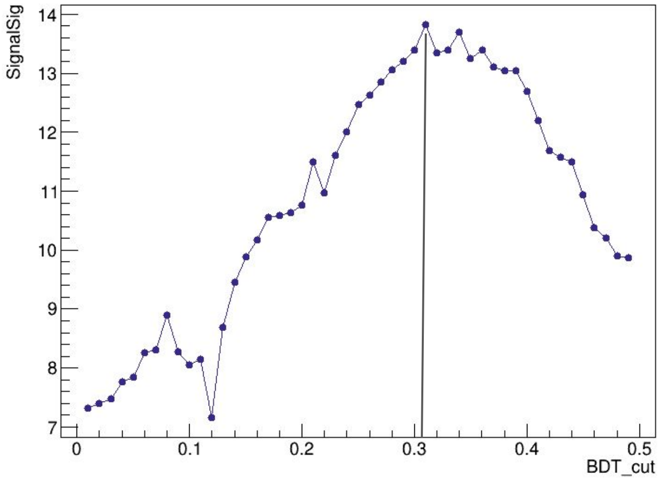


RUN II



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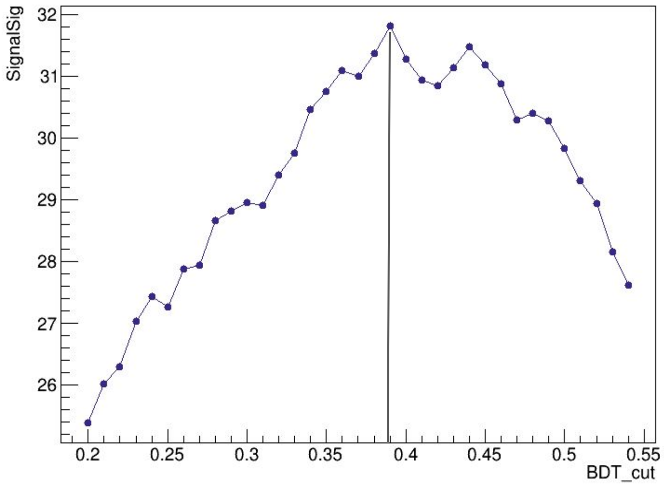

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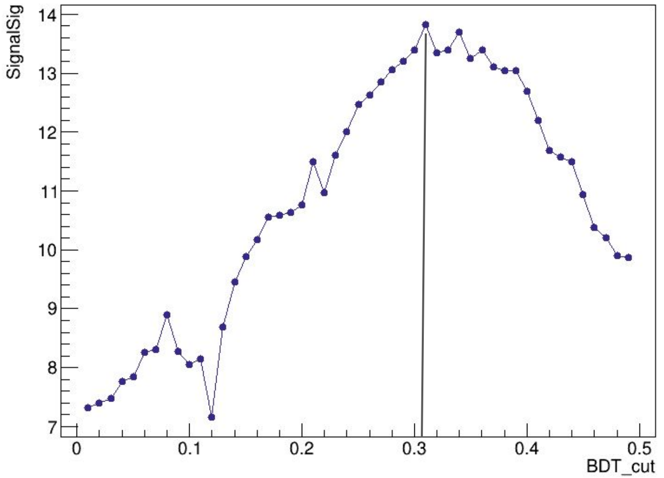

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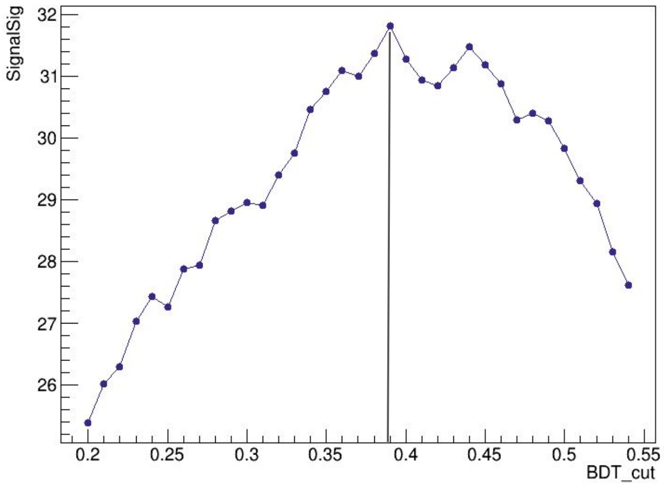
But first, lets look at B0 invariant mass…..

RUN I



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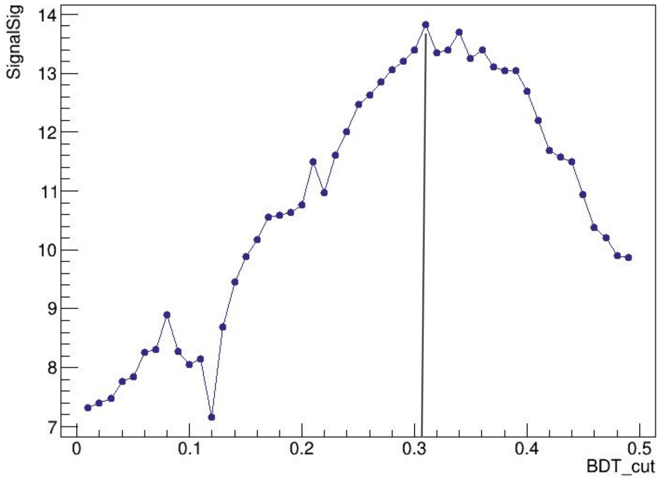

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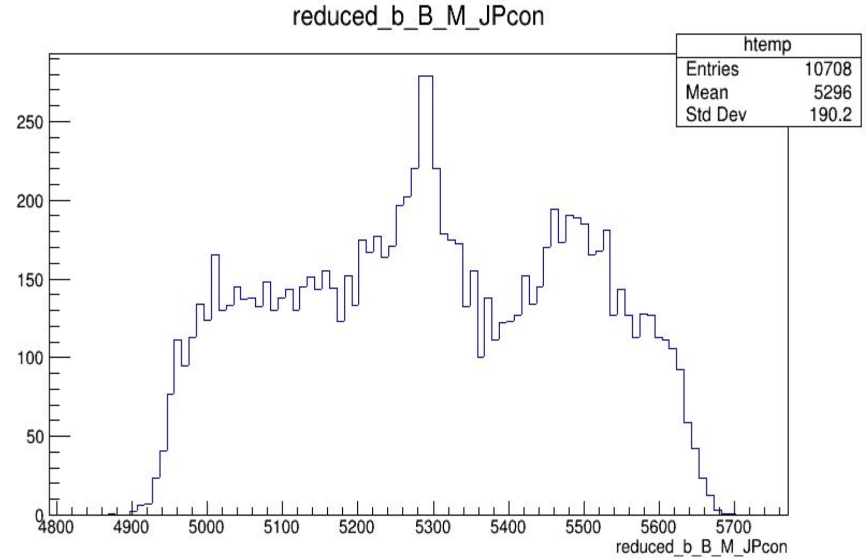

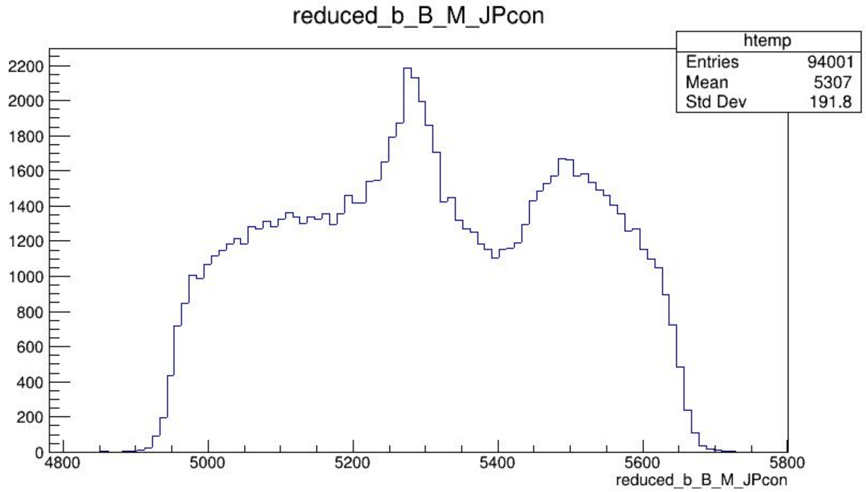

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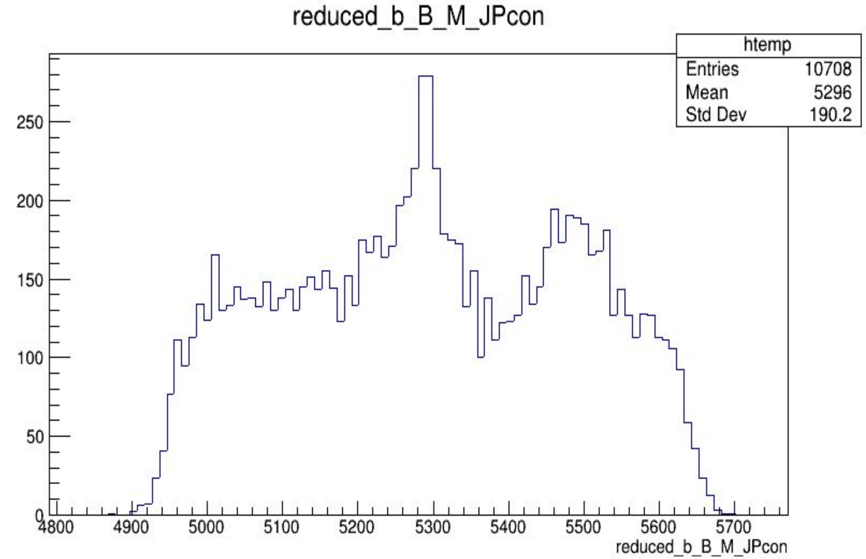

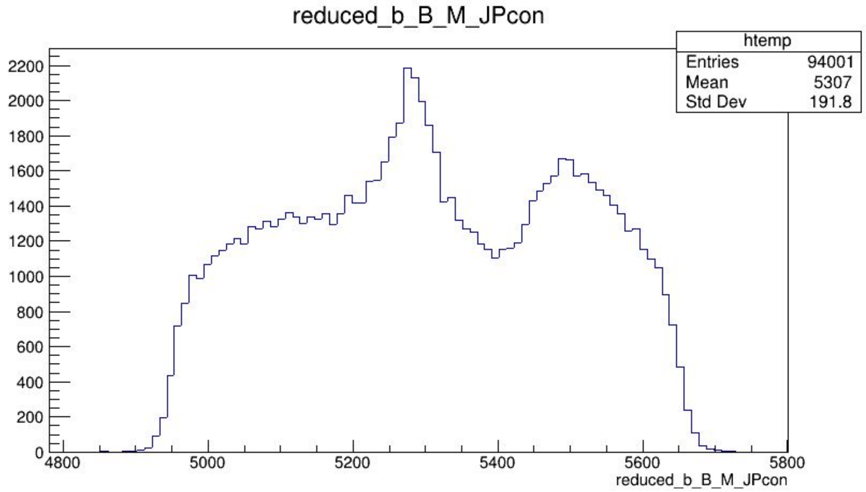

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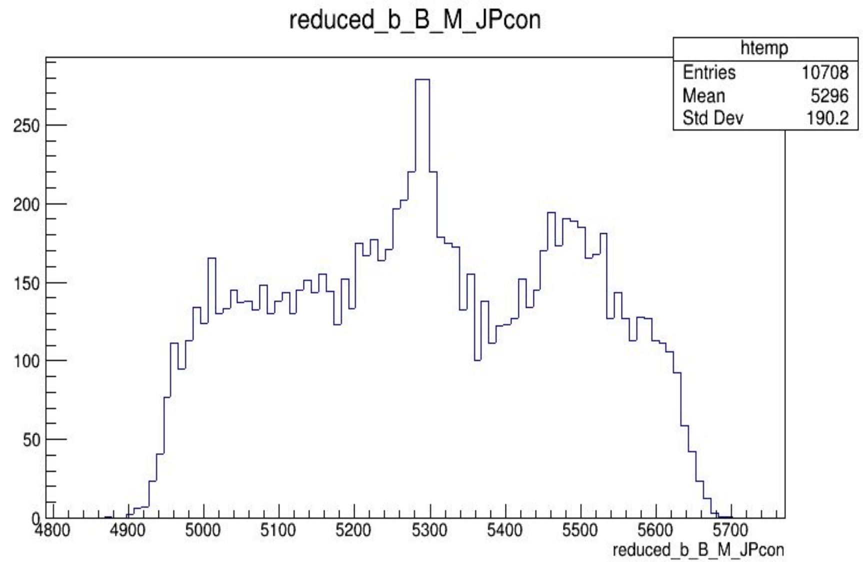

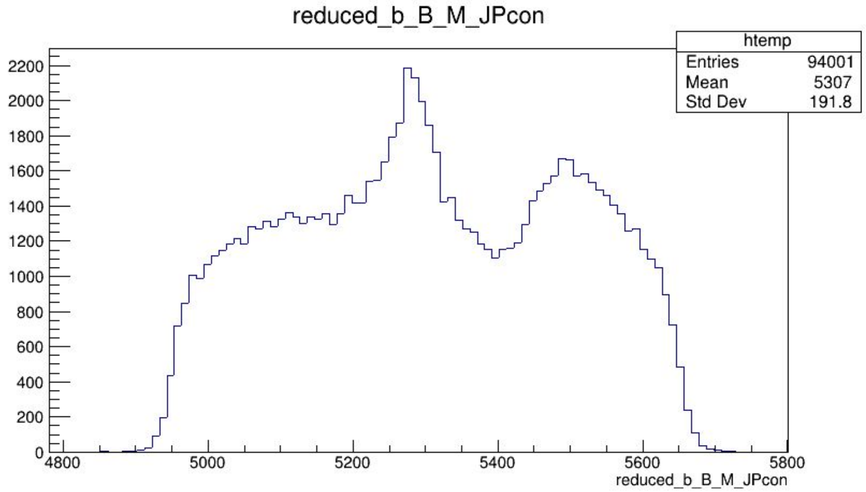

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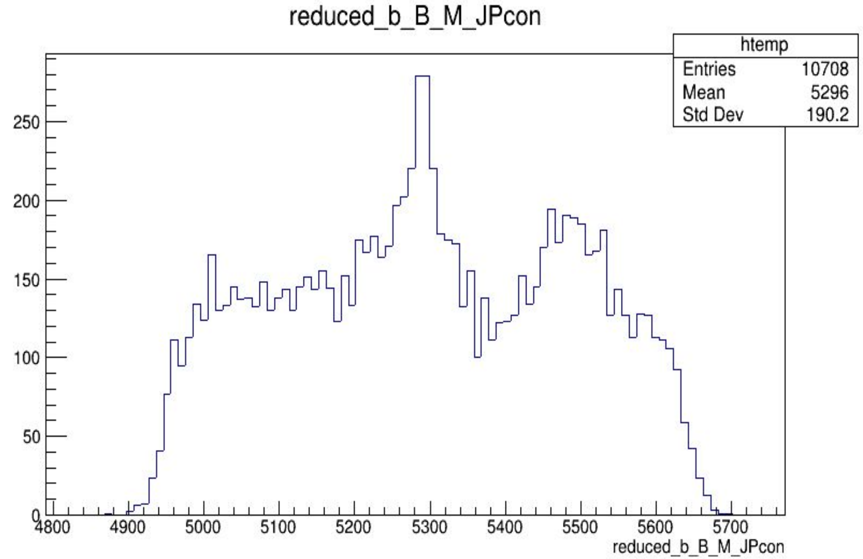

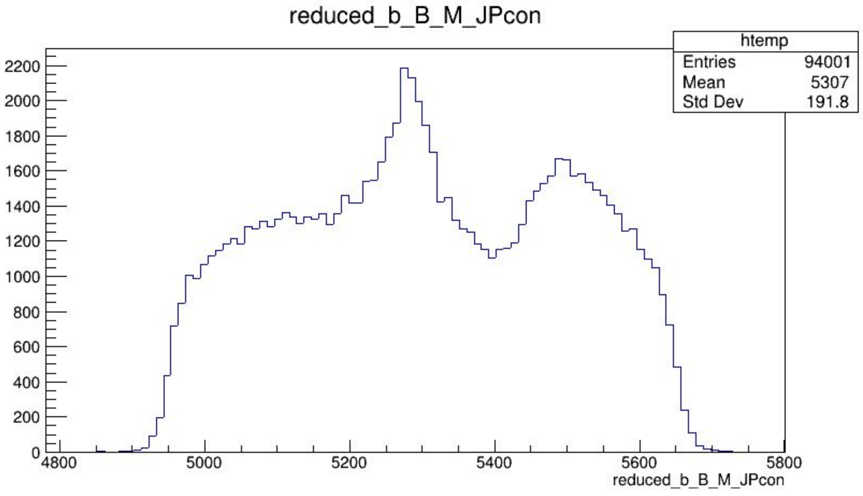

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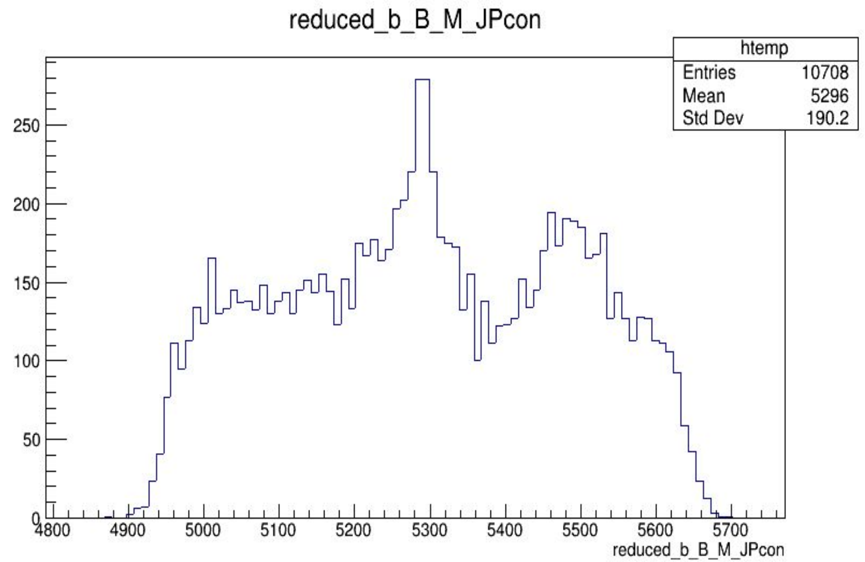

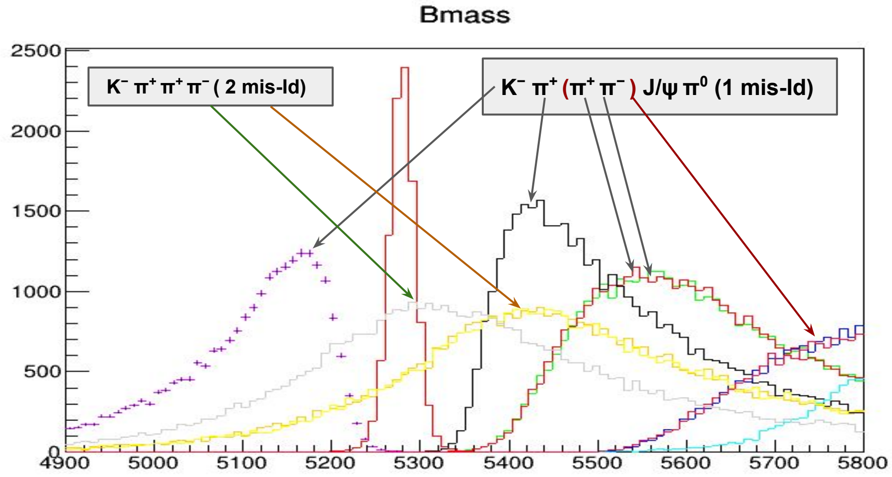

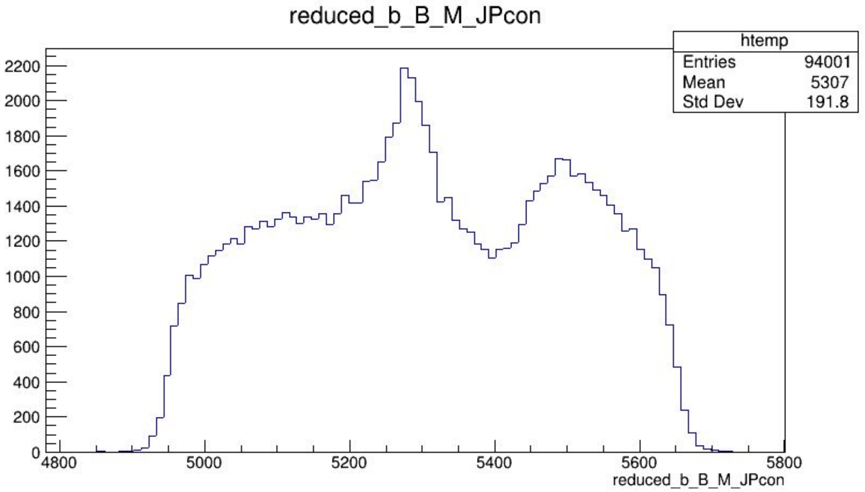

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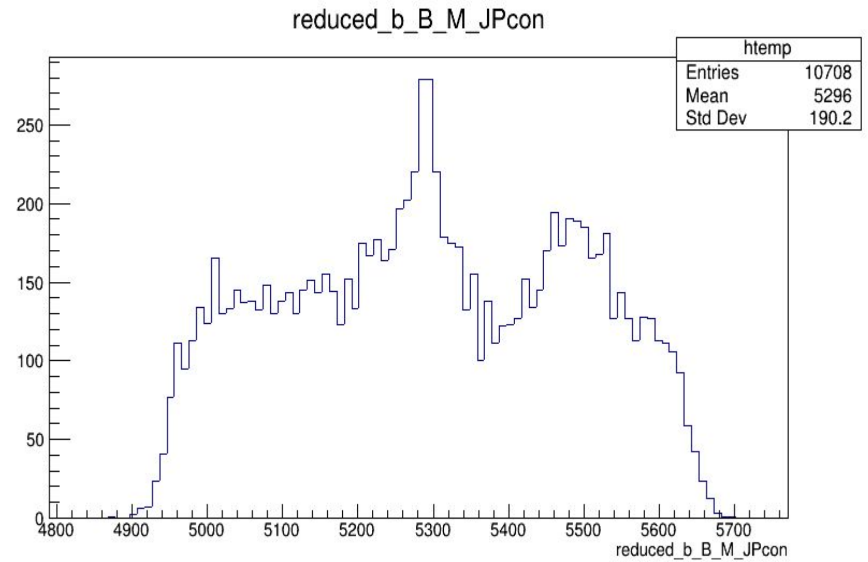

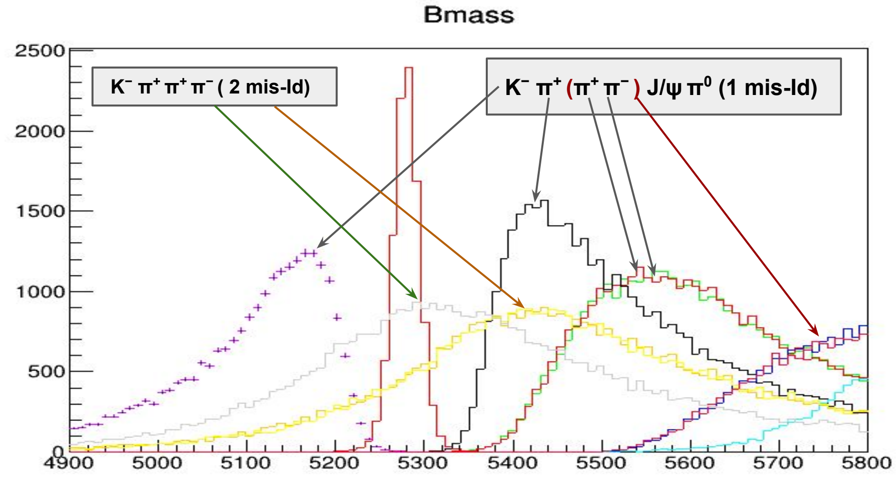

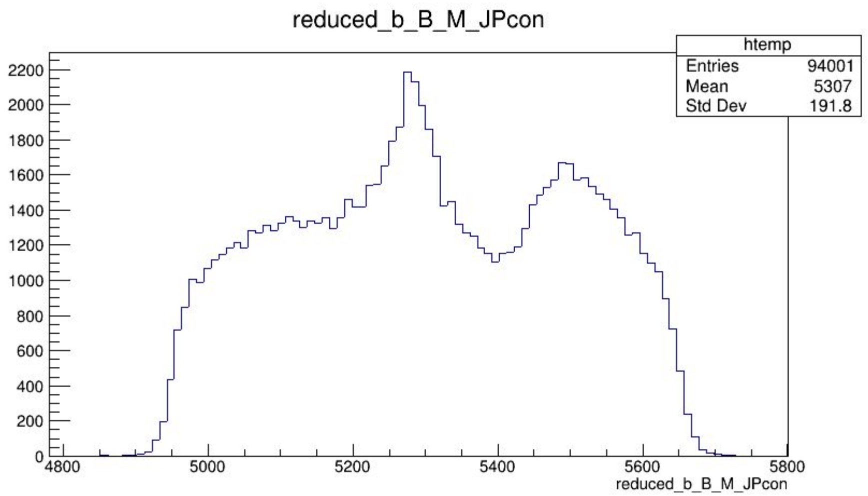

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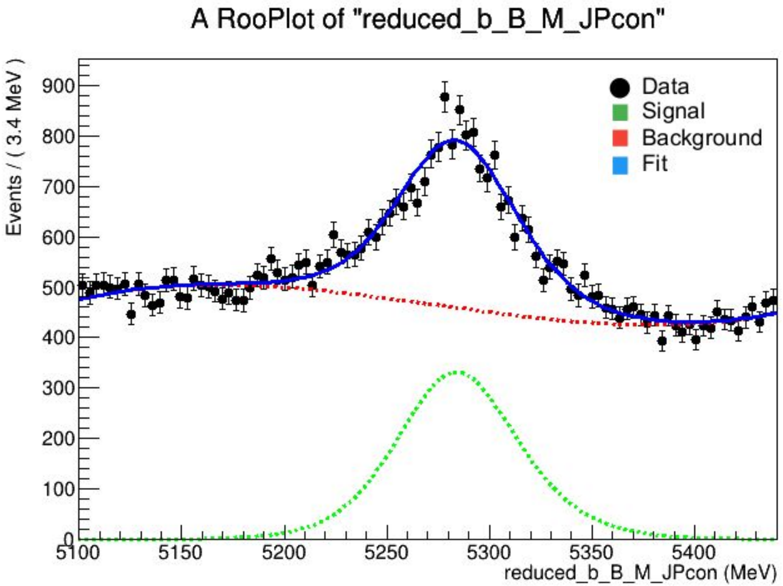


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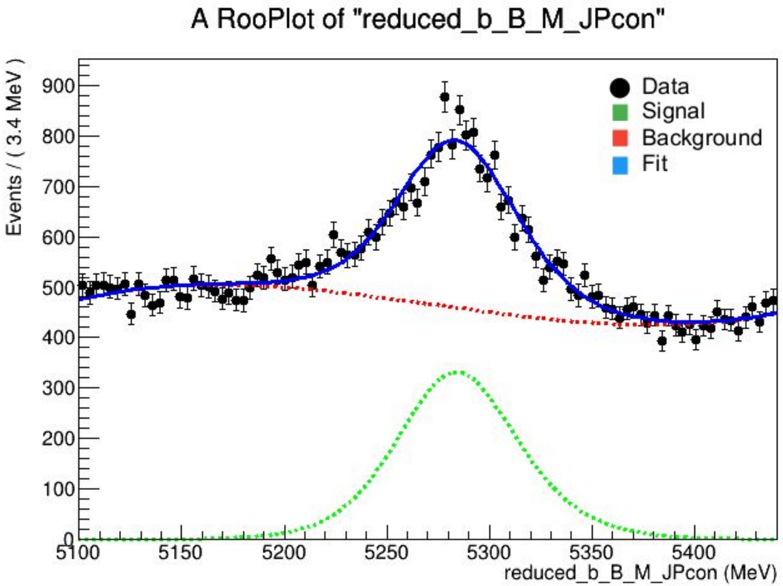
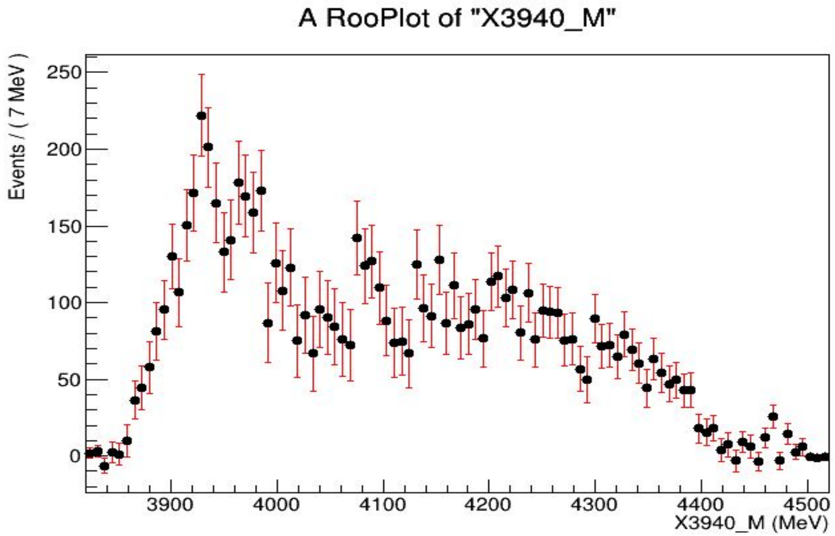
Minuit2Minimizer : Valid minimum - status = 0
FVAL  = -220915.295159876056
Edm   = 0.000329056443562910673
Nfcn  = 407
BYield    = 46525.8      +/-   567.62    (limited)
SYield    = 7527.53      +/-   532.867   (limited)
lambda    = 66.0257      +/-   3.68714   (limited)
mu        = 5279.53      +/-   0.998792  (limited)
p0        = -0.0734254   +/-   0.00934656        (limited)
p1        = -0.00563422  +/-   0.01637   (limited)
p2        = 0.0434292    +/-   0.00963522        (limited)
```

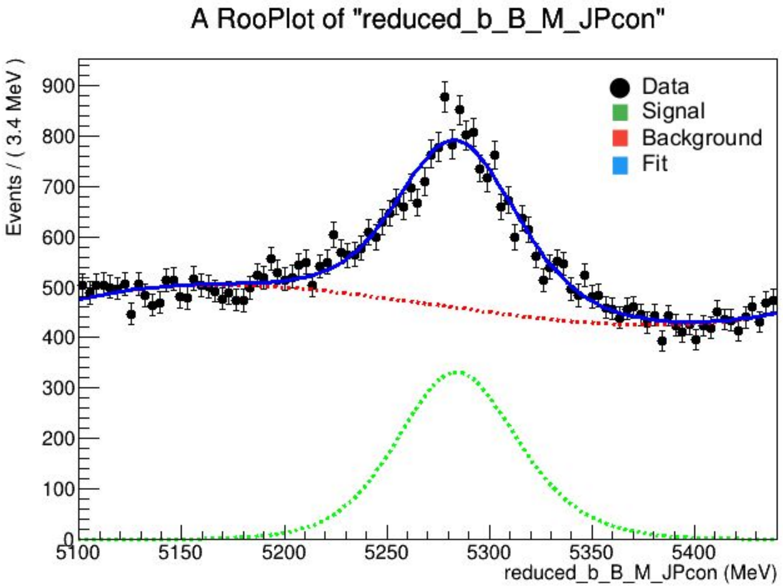
Results : $B^0 \rightarrow (J/\psi\ \omega)\pi^+K^-$



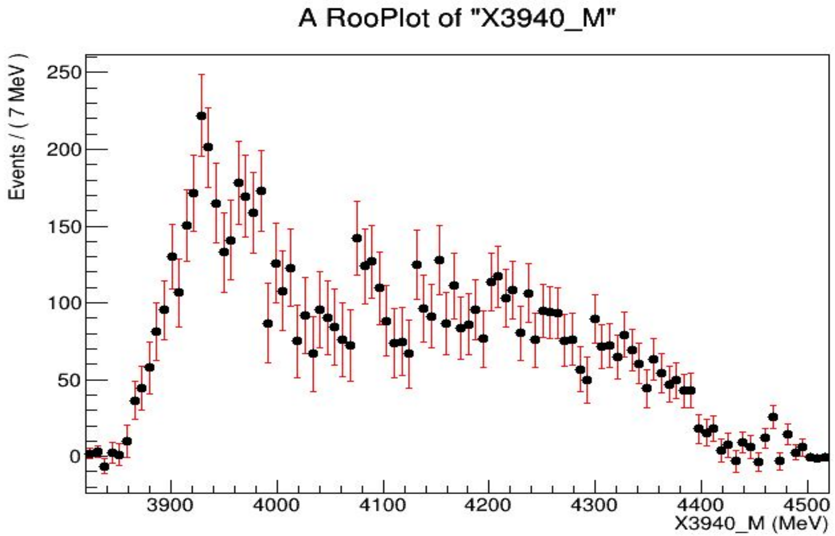

```
Minuit2Minimizer : Valid minimum - status = 0
FVAL  = -220915.295159876056
Edm   = 0.000329056443562910673
Nfcn  = 407
BYield     = 46525.8      +/-   567.62    (limited)
SYield     = 7527.53      +/-   532.867   (limited)
lambda     = 66.0257      +/-   3.68714   (limited)
mu         = 5279.53      +/-   0.998792  (limited)
p0         = -0.0734254   +/-   0.00934656        (limited)
p1         = -0.00563422  +/-   0.01637   (limited)
p2         = 0.0434292    +/-   0.00963522        (limited)
```

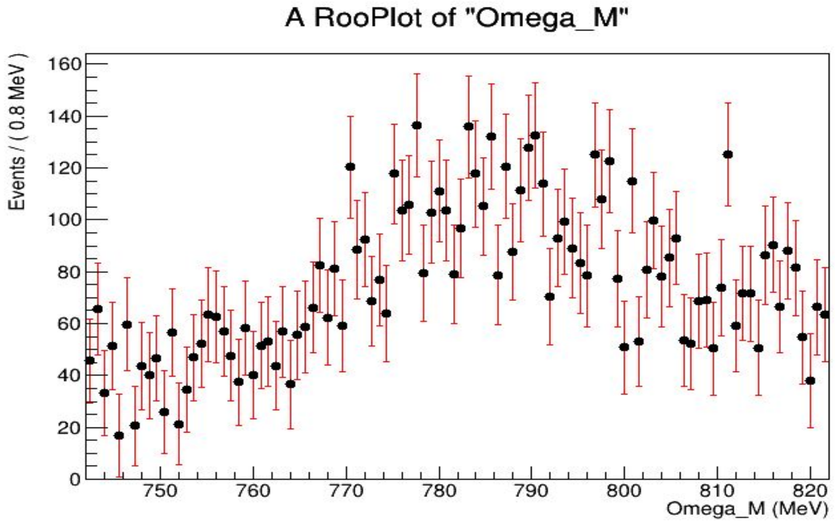


Results : $B^0 \rightarrow (J/\psi\ \omega)\pi^+K^-$



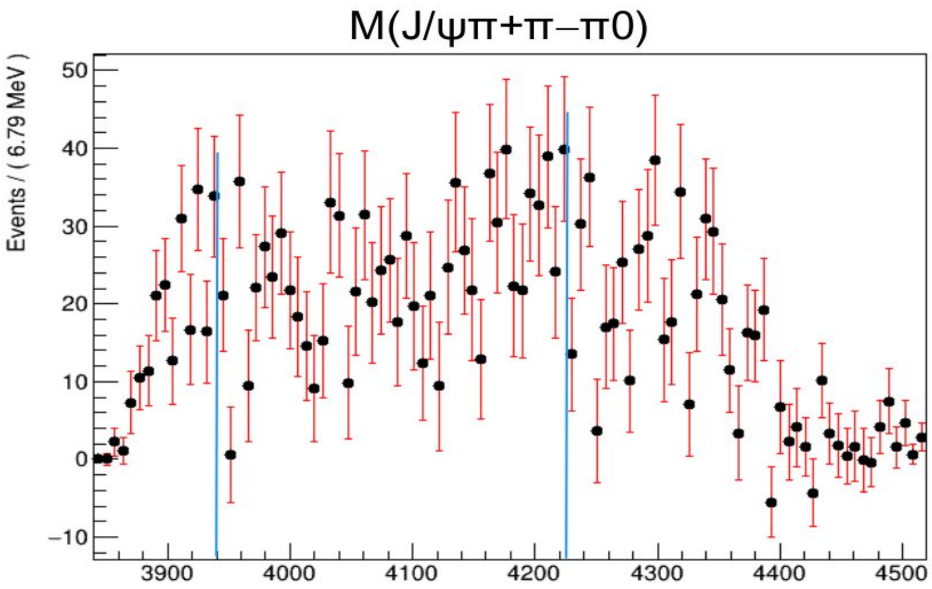

```
Minuit2Minimizer : Valid minimum - status = 0
FVAL  = -220915.295159876056
Edm   = 0.000329056443562910673
Nfcn  = 407
BYield     = 46525.8       +/-   567.62    (limited)
SYield     = 7527.53       +/-   532.867   (limited)
lambda     = 66.0257       +/-   3.68714   (limited)
mu         = 5279.53       +/-   0.998792  (limited)
p0         = -0.0734254    +/-   0.00934656        (limited)
p1         = -0.00563422   +/-   0.01637   (limited)
p2         = 0.0434292     +/-   0.00963522        (limited)
```

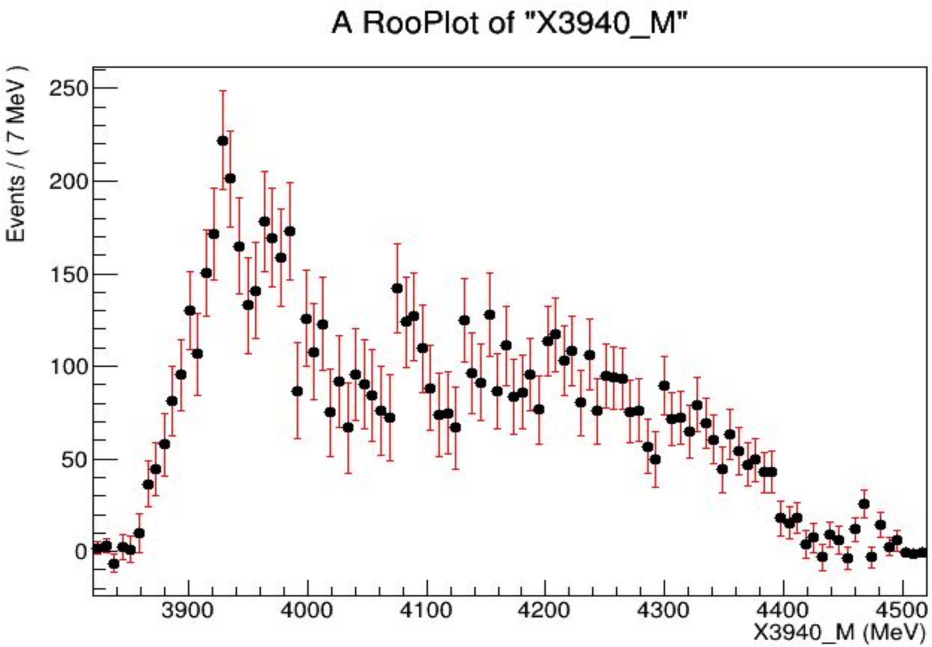


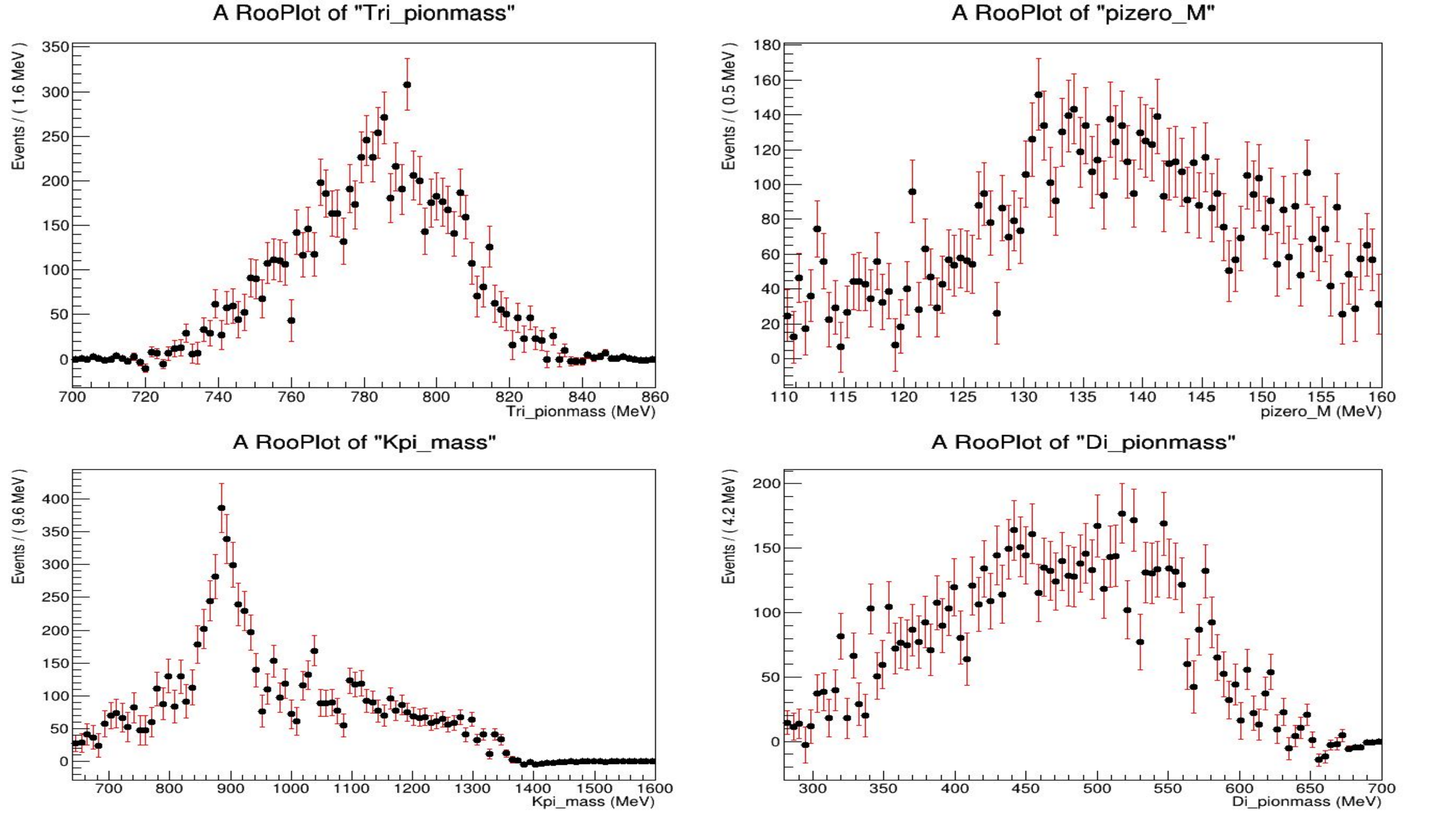


Cut based selection

BDT selection

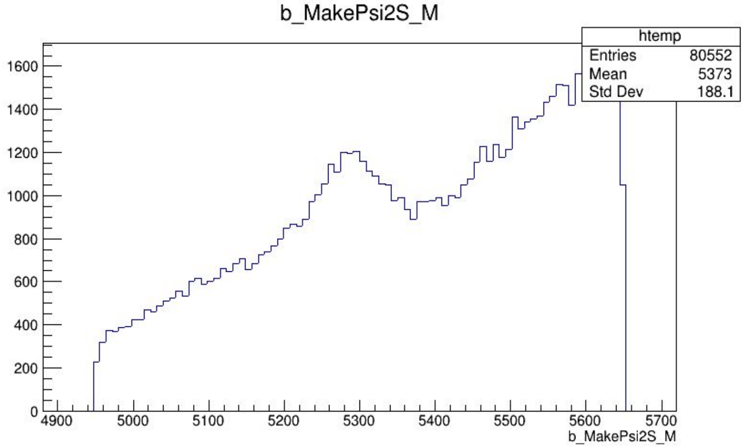





A RooPlot of "Tri_pionmass"
Events / (1.6 MeV)
Tri_pionmass (MeV)
A RooPlot of "pizero_M"
Events / (0.5 MeV)
pizero_M (MeV)
A RooPlot of "Kpi_mass"
Events / (9.6 MeV)
Kpi_mass (MeV)
A RooPlot of "Di_pionmass"
Events / (4.2 MeV)
Di_pionmass (MeV)

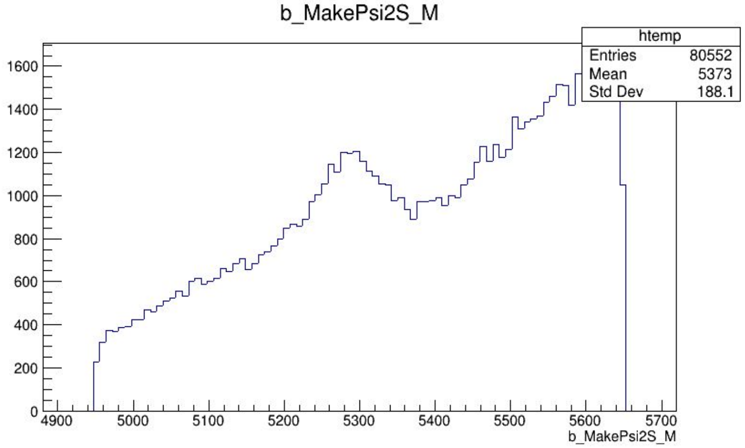
$B^0 \to (\psi(2S)\pi^0)\pi^- K^+$ with $(\psi(2S) \to \mu^+ \mu^-)$

- Interesting case :

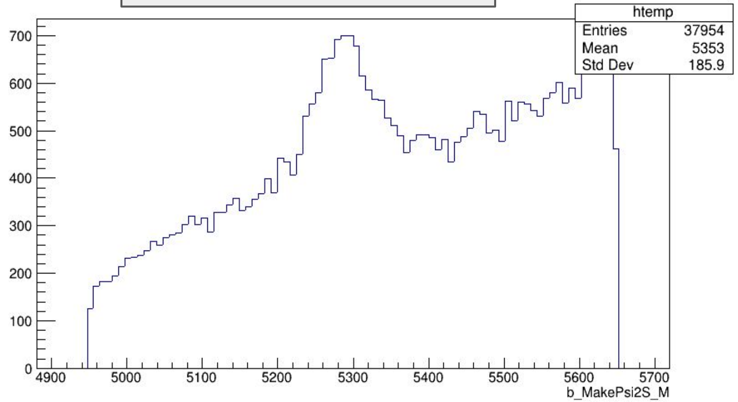


$B^0 \rightarrow (\psi(2S)\pi^0)\pi^- K^+$ with $(\psi(2S) \rightarrow \mu^+ \mu^-)$

- Interesting case :

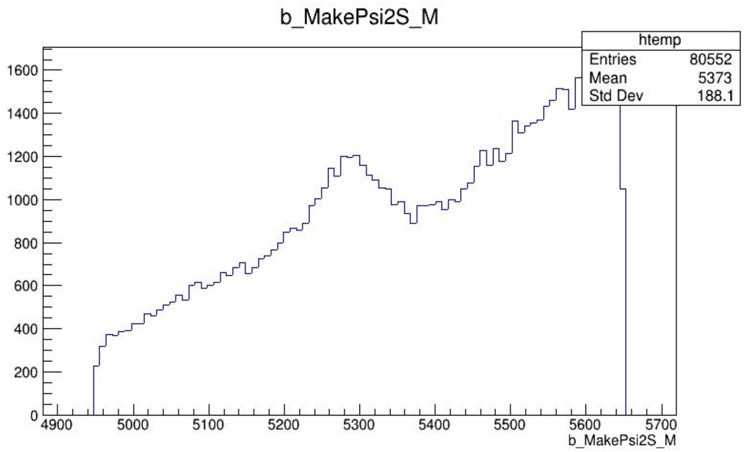


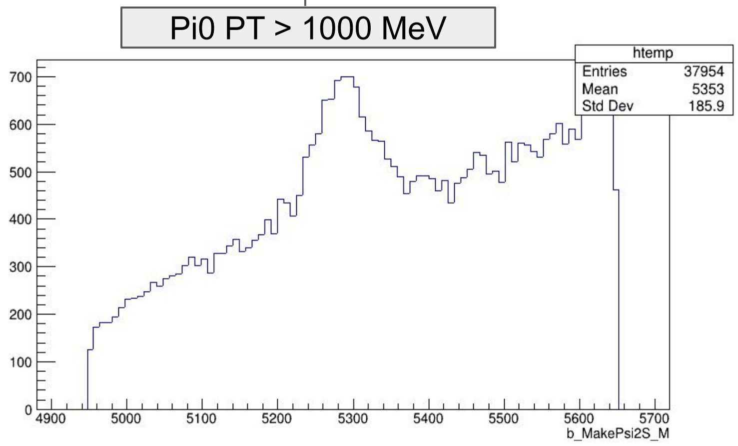
Pi0 PT > 1000 MeV

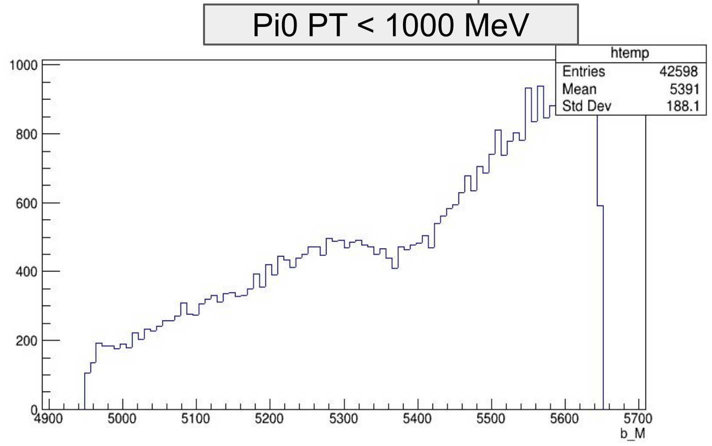


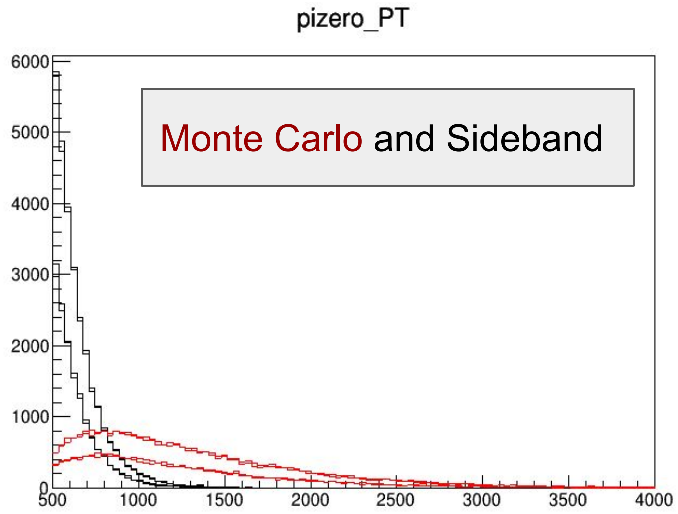
$B^0 \rightarrow (\psi(2S)\pi^0)\pi^-K^+$ with $(\psi(2S) \rightarrow \mu^+ \mu^-)$

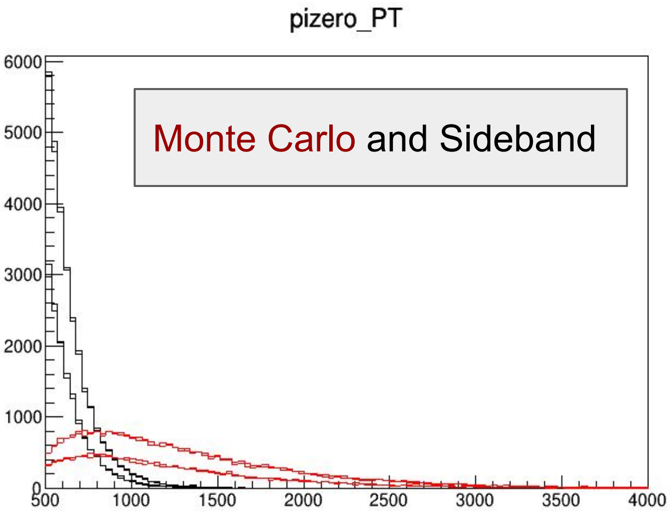
- Interesting case :

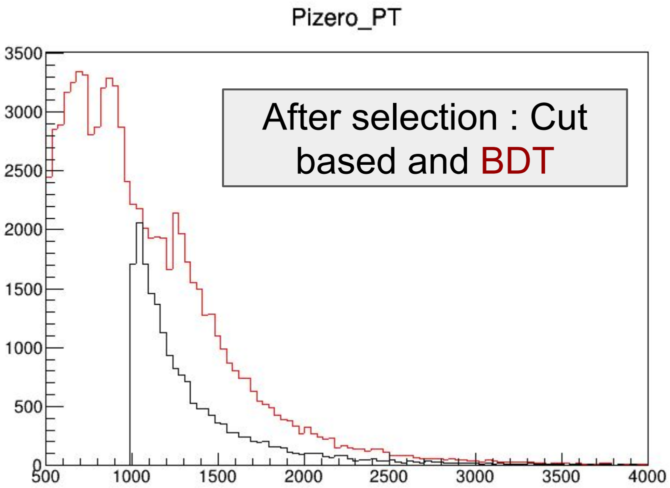


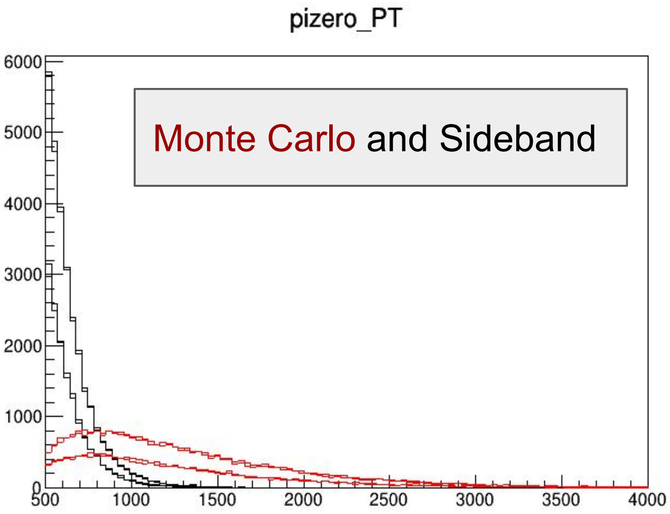


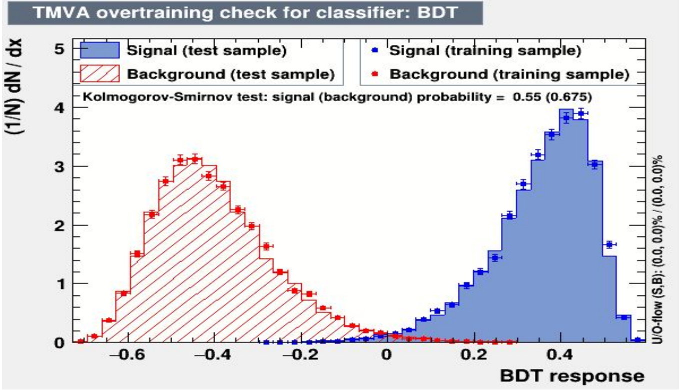


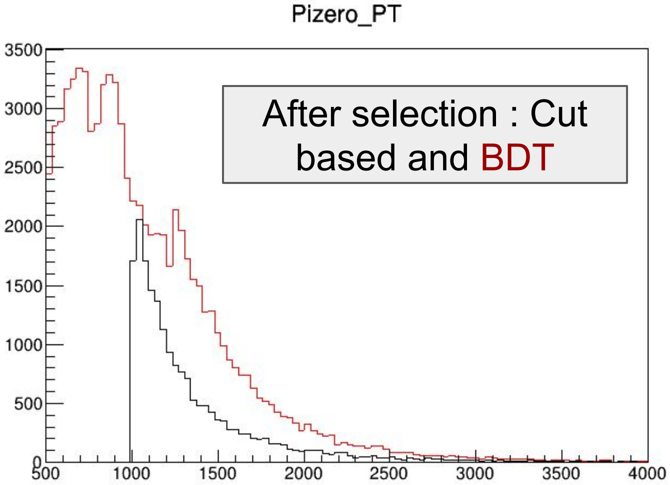

pizero_PT
Monte Carlo and Sideband
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
2500
3000
3500
4000

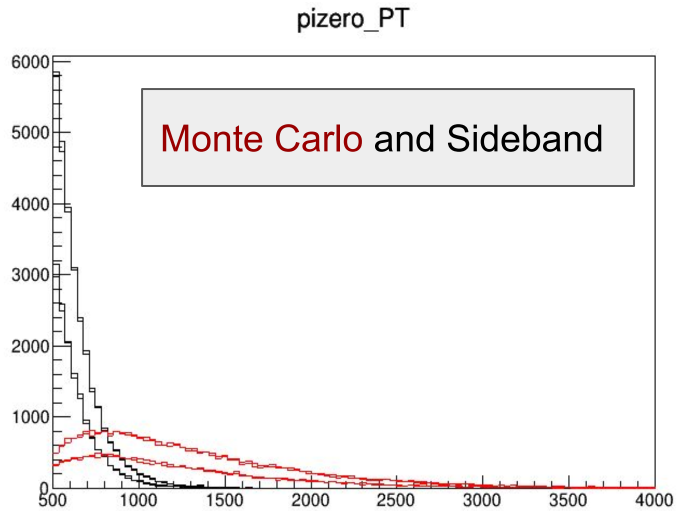

pizero_PT
Monte Carlo and Sideband
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
2500
3000
3500
4000

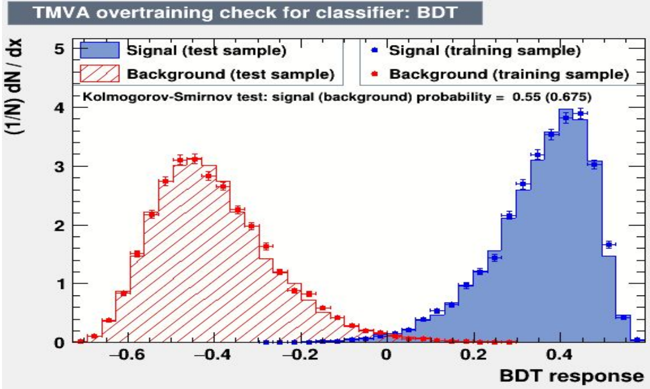

Pizero_PT
After selection : Cut based and BDT
3500
3000
2500
2000
1500
1000
500
0
500
1000
1500
2000
2500
3000
3500
4000

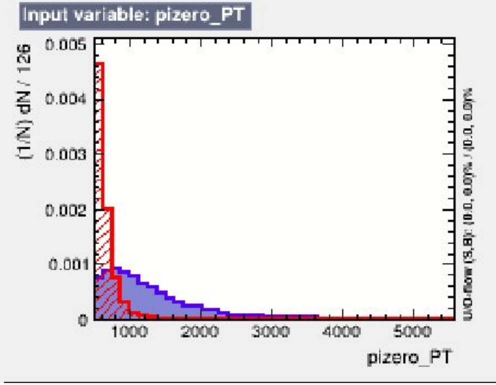

pizero_PT
Monte Carlo and Sideband
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
2500
3000
3500
4000

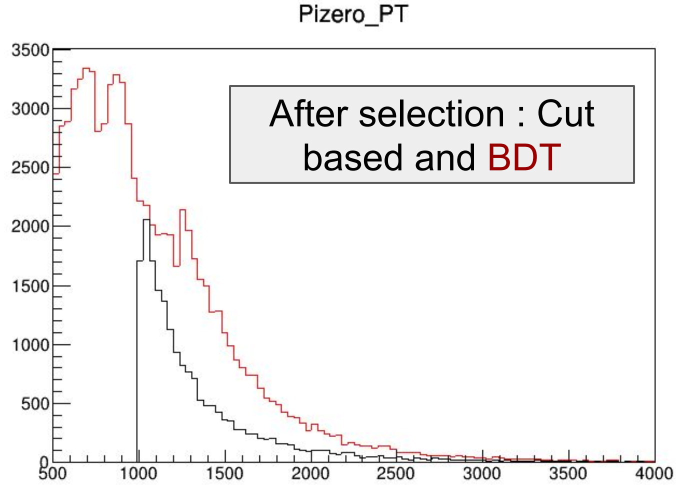

TMVA overtraining check for classifier: BDT
(1/N) dN / dx
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.55 (0.675)
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDT response
−0.6
−0.4
−0.2
0
0.2
0.4

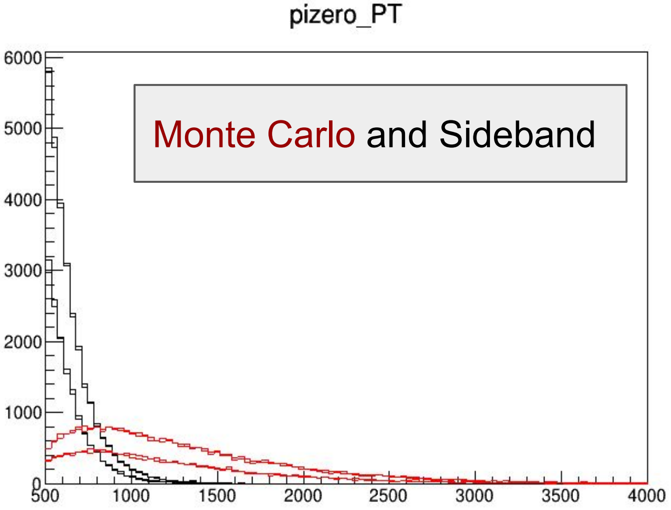

Pizero_PT
After selection : Cut based and BDT
3500
3000
2500
2000
1500
1000
500
0
500
1000
1500
2000
2500
3000
3500
4000

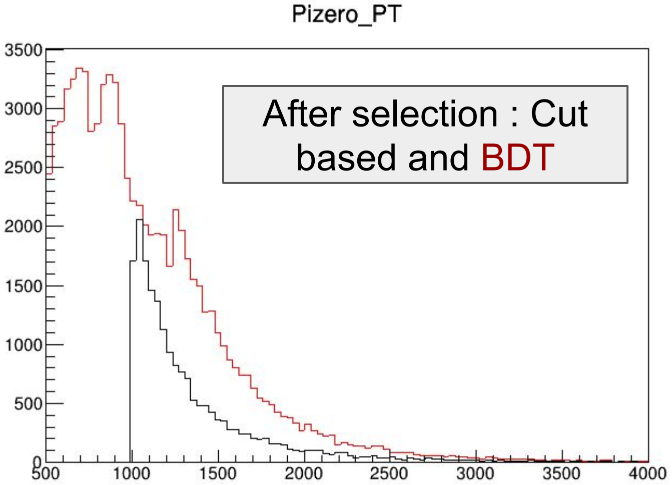

pizero_PT
Monte Carlo and Sideband
0
1000
2000
3000
4000
5000
6000
500
1000
1500
2000
2500
3000
3500
4000

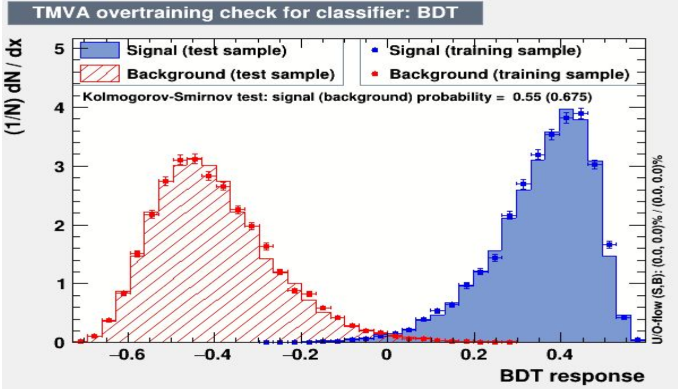

TMVA overtraining check for classifier: BDT
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.55 (0.675)
(1/N) dN / dx
BDT response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
−0.6
−0.4
−0.2
0
0.2
0.4

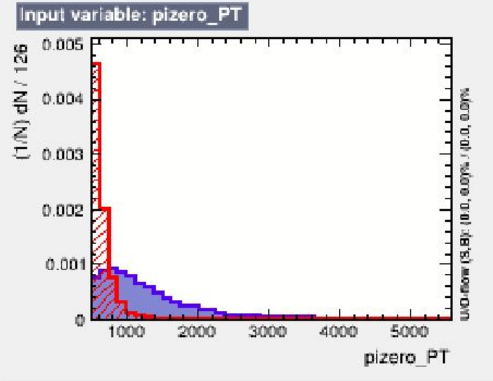

Input variable: pizero_PT
(1/N) dN / 126
pizero_PT
0.005
0.004
0.003
0.002
0.001
0
1000
2000
3000
4000
5000

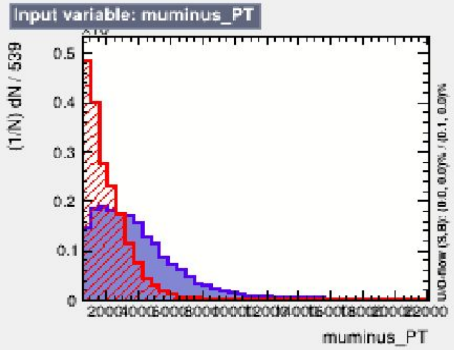

Pizero_PT
After selection : Cut based and BDT
0
500
1000
1500
2000
2500
3000
3500
500
1000
1500
2000
2500
3000
3500
4000

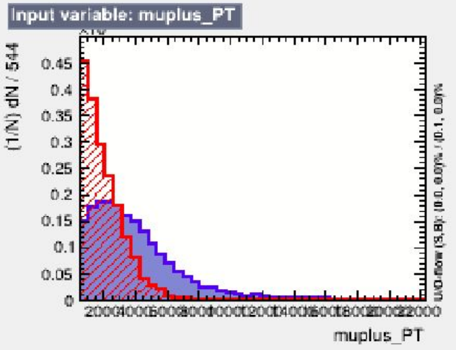

pizero_PT
Monte Carlo and Sideband
0
1000
2000
3000
4000
5000
6000
500
1000
1500
2000
2500
3000
3500
4000

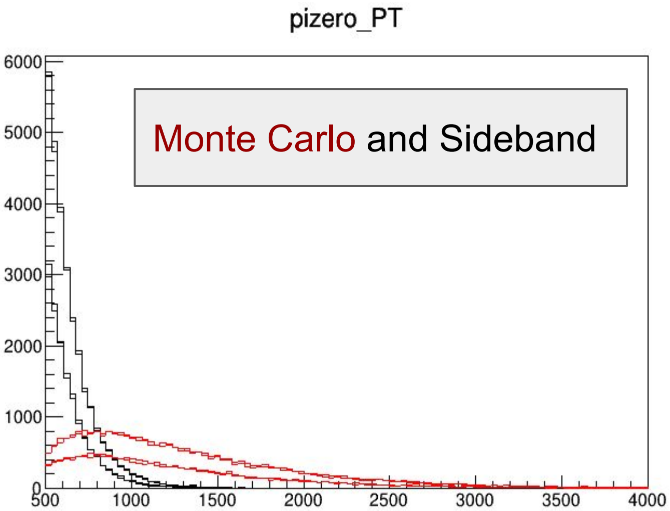

Pizero_PT
After selection : Cut based and BDT
0
500
1000
1500
2000
2500
3000
3500
500
1000
1500
2000
2500
3000
3500
4000

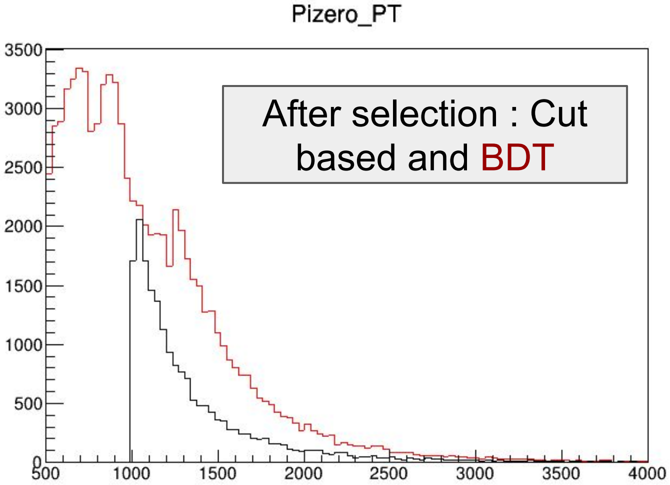

TMVA overtraining check for classifier: BDT
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.55 (0.675)
(1/N) dN / dx
BDT response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
−0.6
−0.4
−0.2
0
0.2
0.4

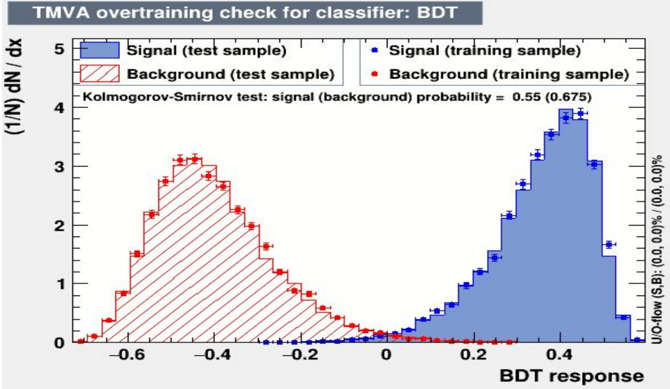

Input variable: pizero_PT
(1/N) dN / 126
pizero_PT
0.005
0.004
0.003
0.002
0.001
0
1000
2000
3000
4000
5000

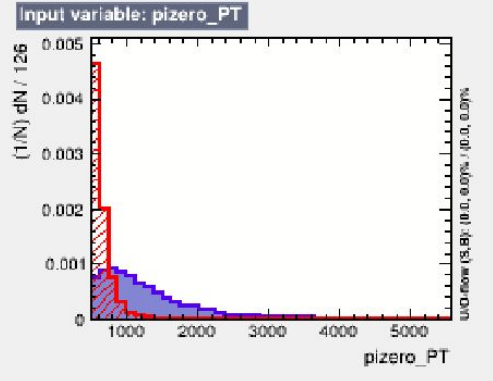

Input variable: muminus_PT
(1/N) dN / 539
muminus_PT
0.5
0.4
0.3
0.2
0.1
0

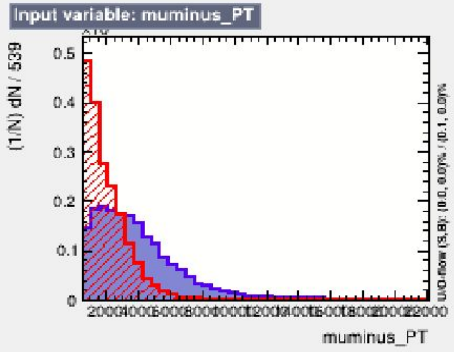

Input variable: muplus_PT
(1/N) dN / 544
muplus_PT
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

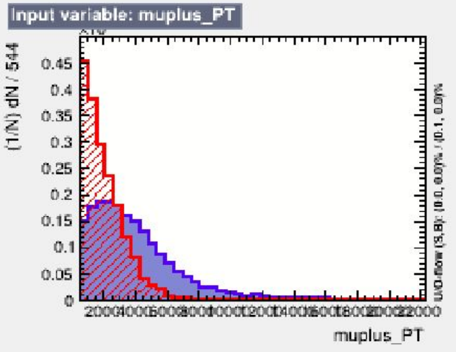

pizero_PT
Monte Carlo and Sideband

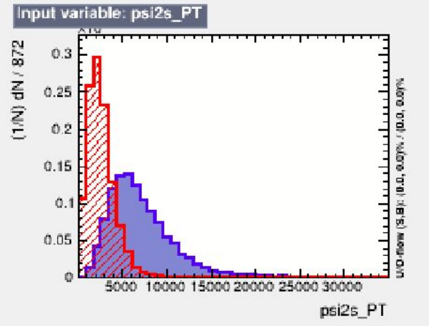

Pizero_PT
After selection : Cut based and BDT

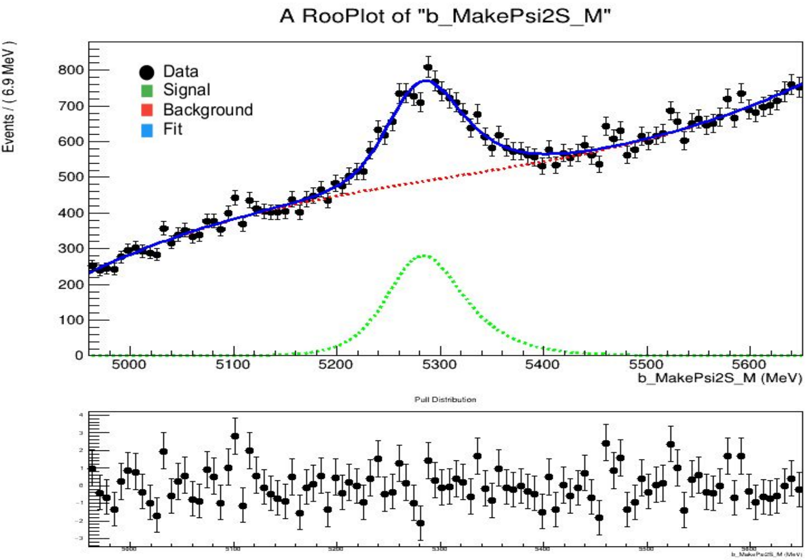

TMVA overtraining check for classifier: BDT
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.55 (0.675)
(1/N) dN / dx
BDT response

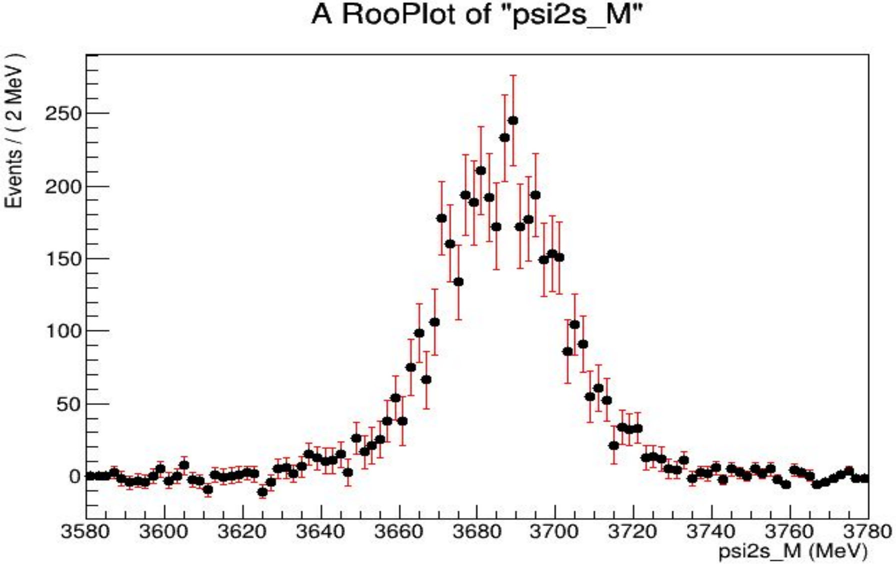

Input variable: pizero_PT
(1/N) dN / 126
pizero_PT

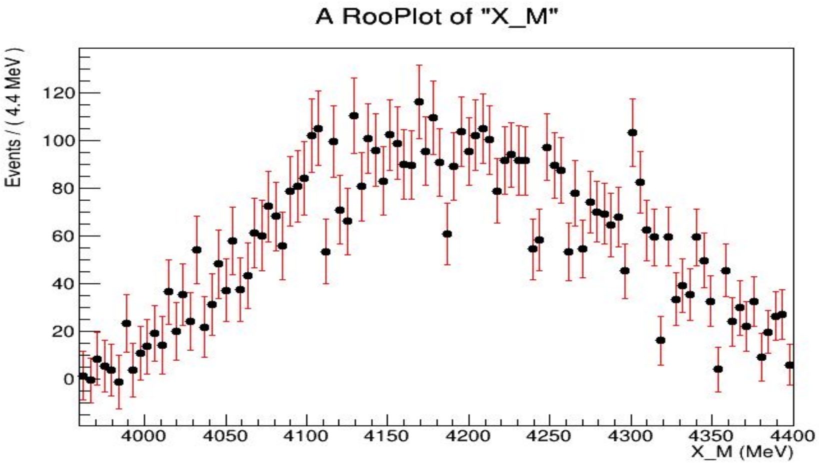

Input variable: muminus_PT
(1/N) dN / 539
muminus_PT

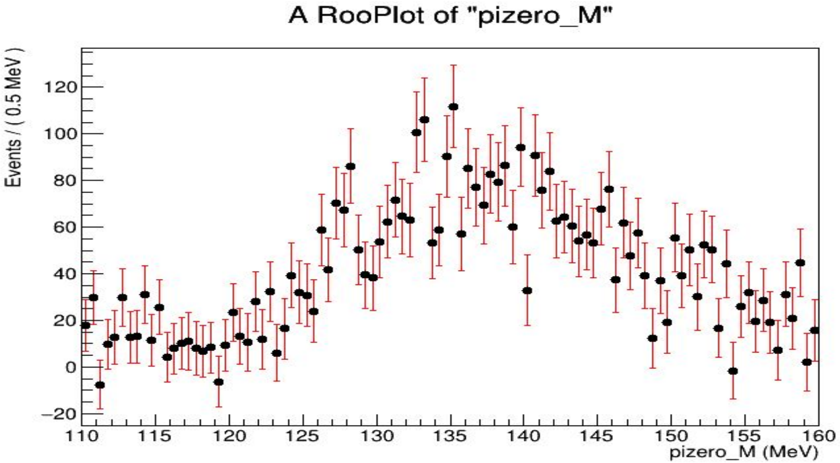

Input variable: muplus_PT
(1/N) dN / 544
muplus_PT

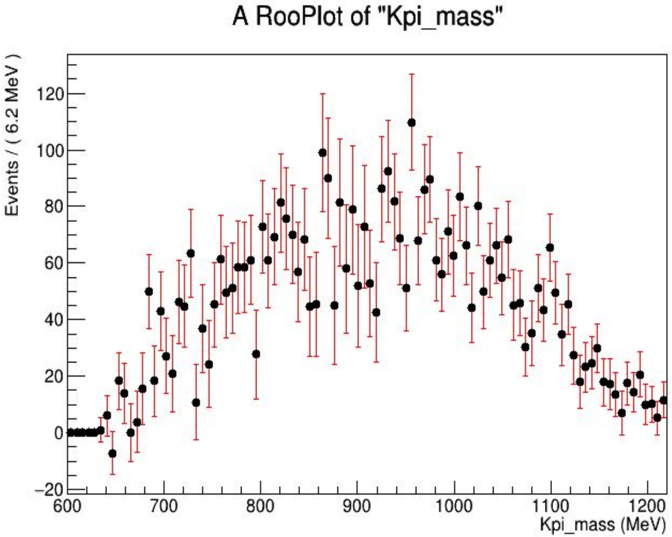

Input variable: psi2s_PT
(1/N) dN / 872
psi2s_PT


A RooPlot of "b_MakePsi2S_M"
Data
Signal
Background
Fit
Events / (6.9 MeV)
b_MakePsi2S_M (MeV)
Pull Distribution

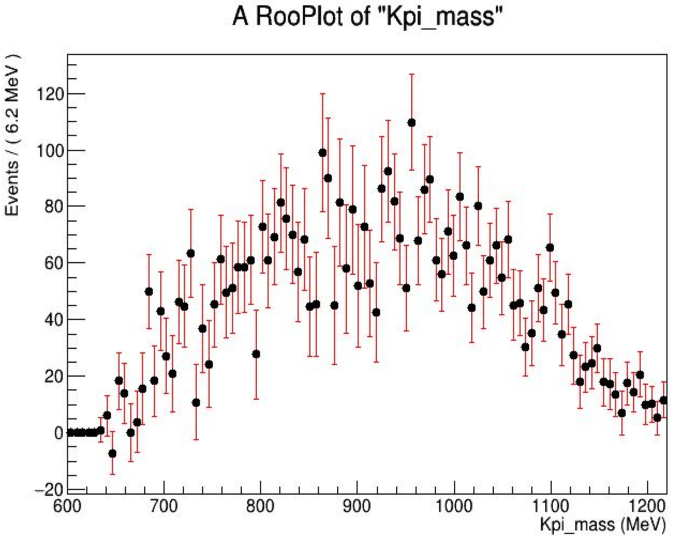

A RooPlot of "psi2s_M"
Events / (2 MeV)
psi2s_M (MeV)

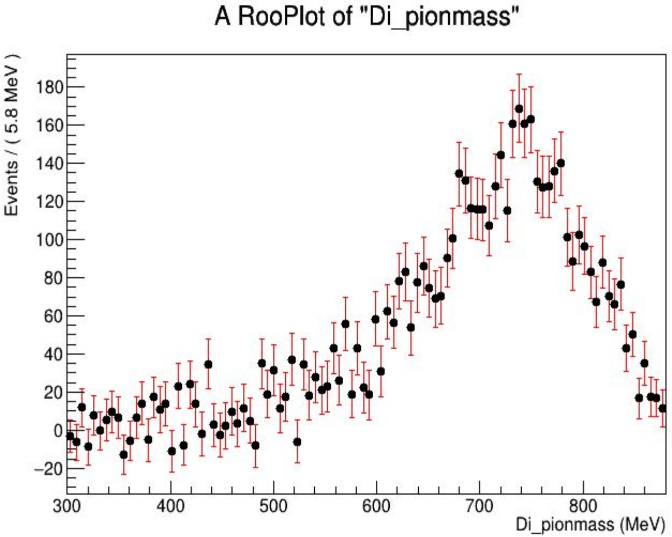

A RooPlot of "X_M"
Events / (4.4 MeV)
X_M (MeV)


A RooPlot of "pizero_M"
Events / (0.5 MeV)
pizero_M (MeV)



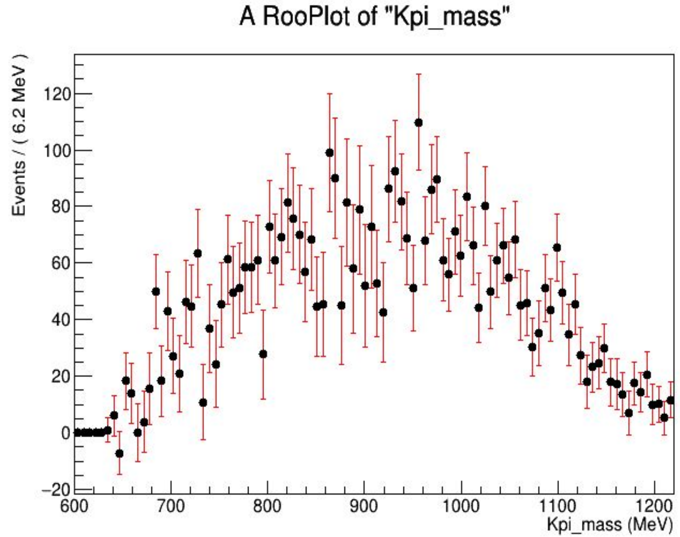
Missing K* contribution!

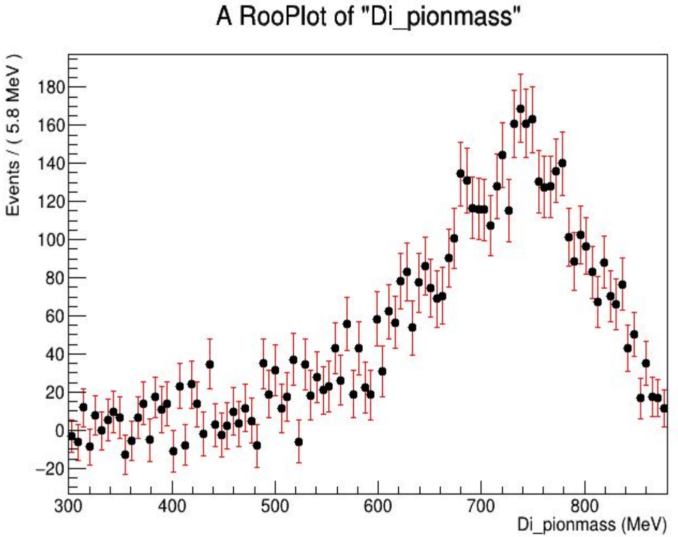




Missing K* contribution!

Peaking structure from charged Rho meson!!!

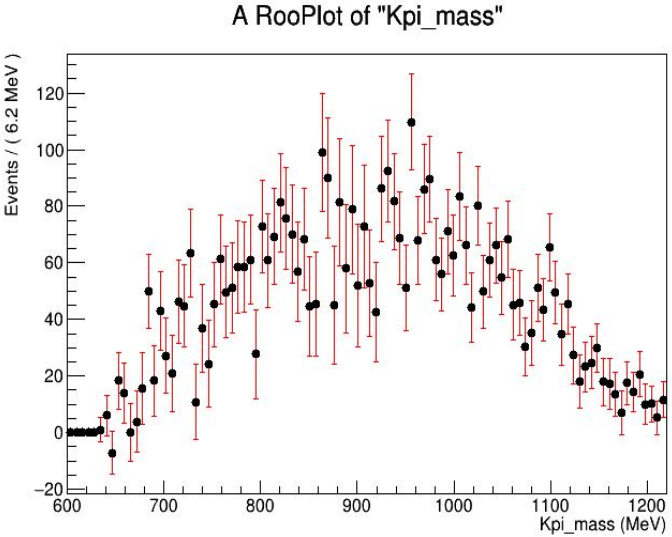




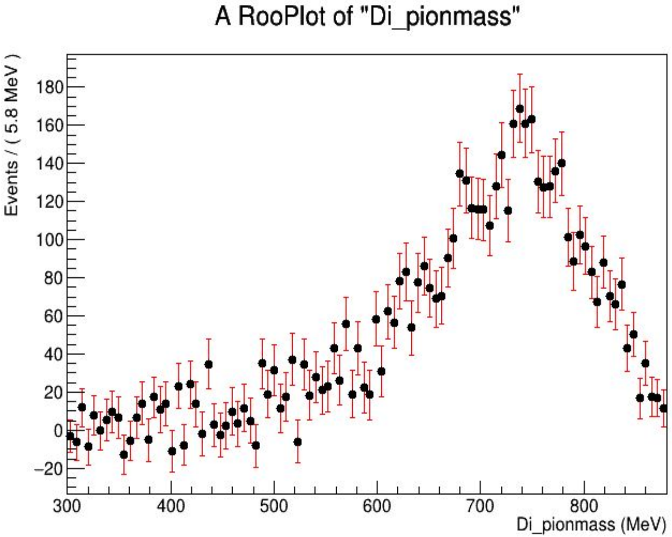
Missing K* contribution!

Peaking structure from charged Rho meson!!!

- Instead of **$B^0 \rightarrow (\psi(2S)\pi^0)\ \pi^- K^+$**



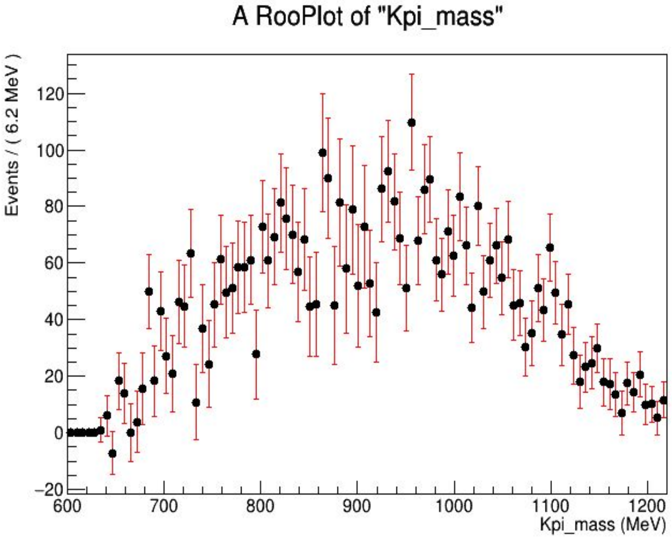
The deacy prefers to go via Rho meson



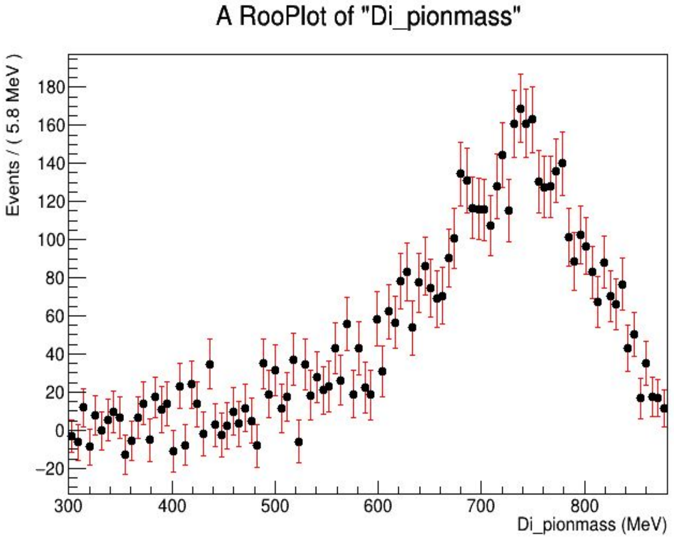
Missing K* contribution!

Peaking structure from charged Rho meson!!!

- Instead of **$B^0 \rightarrow (\psi(2S)\pi^0)\ \pi^- K^+$**
- Major contribution to ginal goes via : **$B^0 \rightarrow \psi(2S)\ \rho^- K^+$ with $\rho^- \rightarrow \pi^0\ \pi^-$**



The deacy prefers to go via Rho meson



Missing K* contribution!

Peaking structure from charged Rho meson!!!

- Instead of **$B^0 \rightarrow (\psi(2S)\pi^0)\ \pi^- K^+$**
- Major contribution to ginal goes via : **$B^0 \rightarrow \psi(2S)\ \rho^- K^+$ with $\rho^- \rightarrow \pi^0\ \pi^-$**
- The problem is : MC without rho used for optimisation data that prefers rho!!

To summarise, we have made observation of 2 new decay modes of B0 meson along with presence of signatures from exotic tetraquarks as intermediate states.

Future Plans

- For each decay mode, perform PID correction for Kaons and pions.
- Identify sources of problematic structures in the B mass distribution and remove them.
- Another task would be to measure the branching fraction of each decay mode with systematic and statistical errors with respect to a reference channel.
- We also plan for the possibility of launching an amplitude analysis for the second decay withf exotic structures X(3940), X(4140) and ψ(4230).

Lot more to do!!

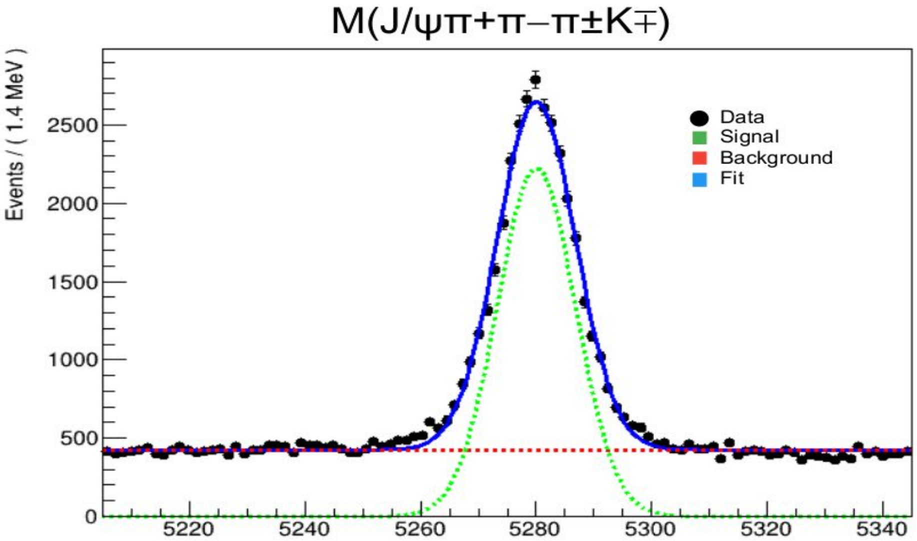
BACK UP

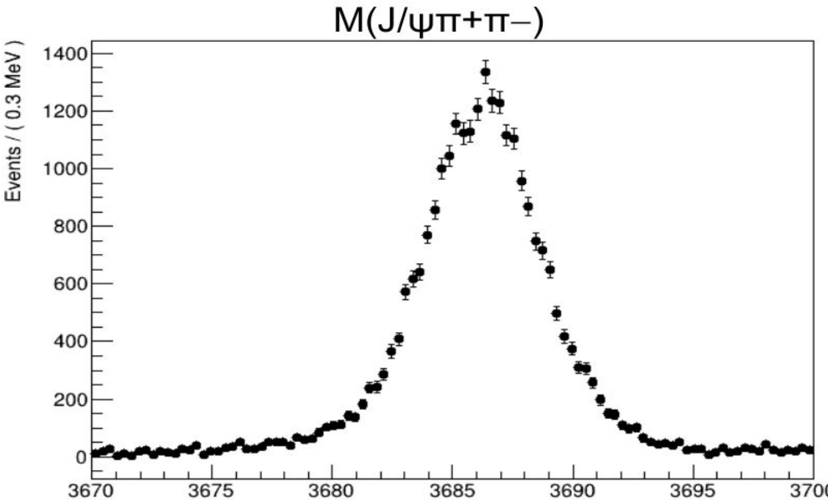
Decay I :

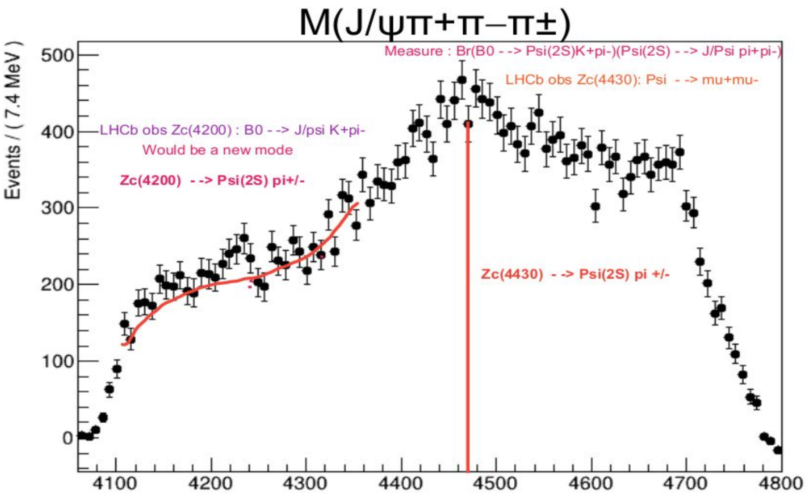
Selection Cuts		
Particle	Parameter	Selection
$\mu^{\pm}$	PROBNNMU	> 0.5
	χ^2 IP	> 10
$\pi^{\pm}$	PROBNNPI	> 0.4
	p_T	> 400 MeV
	P	> 3200 MeV
$K^{\pm}$	η	2 - 5
	P	> 3200 MeV
	PROBNNK	> 0.15
B_0	M (J/ψ constrained)	5200 - 5350 MeV
	χ^2DTF (J/ψ constrained)	< 5
	χ^2 IP	< 9
	FDS	> 5

Pre-Selection Cuts		
Particle	Parameter	Selection
$\mu^{\pm}$	p_T	> 550 MeV
J/ψ	M($\mu^+\mu^-$)	3056 - 3136 MeV
$\pi^{\pm}$	p_T	> 300MeV
Y ($\psi(3770)$)	AM	3500-4500 MeV
X ($Z_c(4200)$)	M	< 5000 MeV
B_0	BPVLTIME	> 0.25 ps
	M	4950 - 5650 MeV

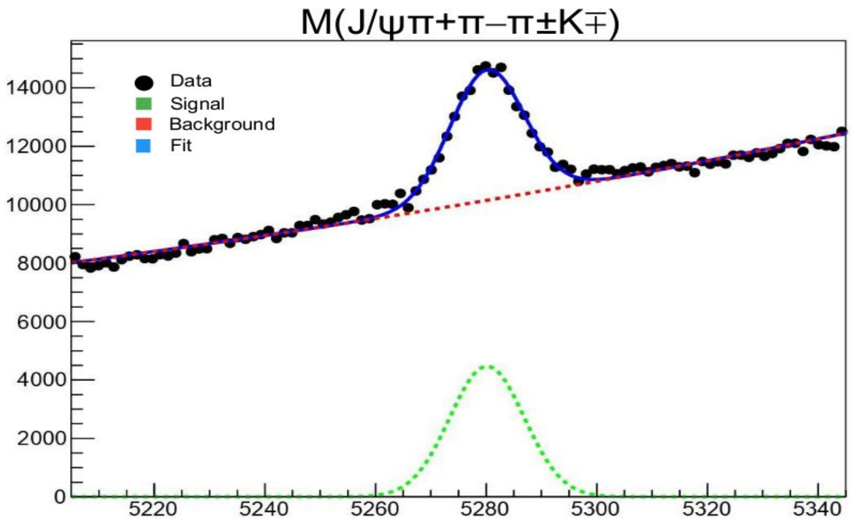
Range I :

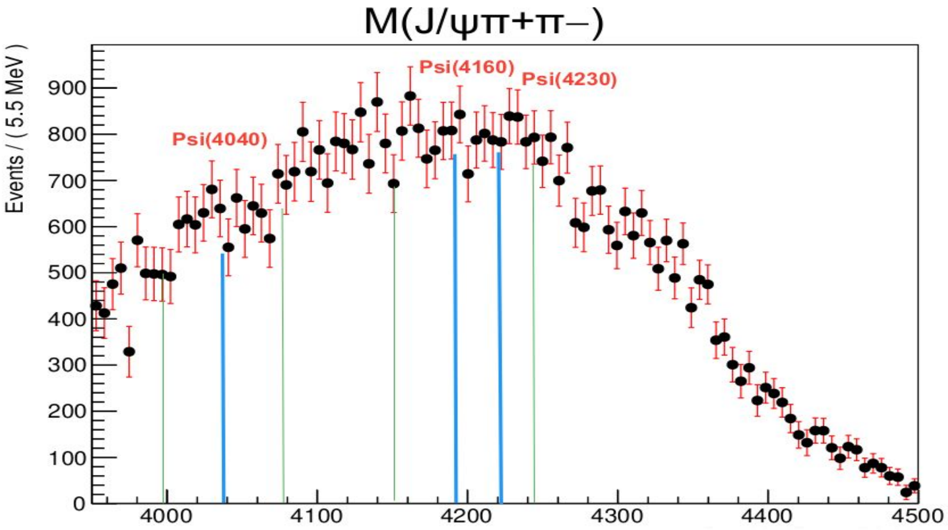

M(J/ψπ+π−π±K∓)
Events / (1.4 MeV)
Data
Signal
Background
Fit
0
500
1000
1500
2000
2500
5220
5240
5260
5280
5300
5320
5340

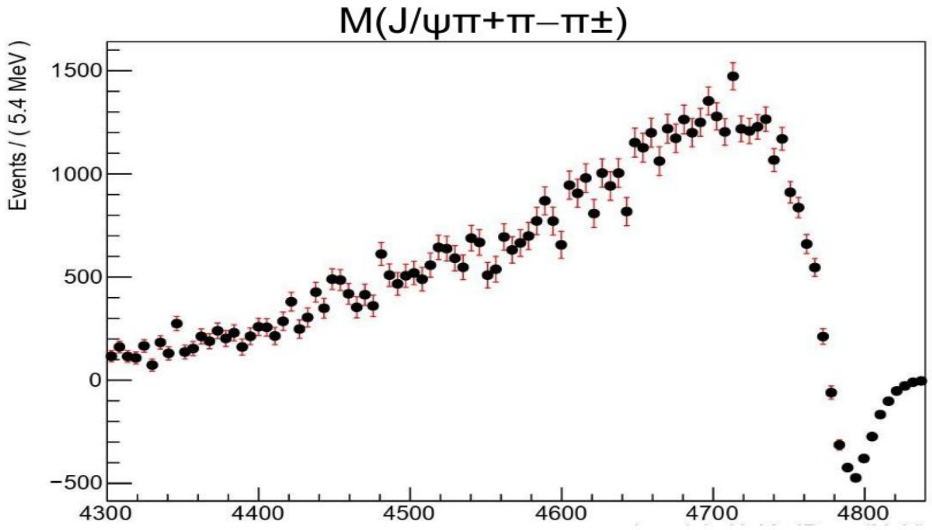

M(J/ψπ+π−)
Events / (0.3 MeV)
0
200
400
600
800
1000
1200
1400
3670
3675
3680
3685
3690
3695
3700


M(J/ψπ+π−π±)
Measure : Br(B0 - -> Psi(2S)K+pi-)(Psi(2S) - -> J/Psi pi+pi-)
LHCb obs Zc(4430): Psi - -> mu+mu-
LHCb obs Zc(4200) : B0 - -> J/psi K+pi-
Would be a new mode
Zc(4200) - -> Psi(2S) pi+/-
Zc(4430) - -> Psi(2S) pi +/-
Events / (7.4 MeV)
0
100
200
300
400
500
4100
4200
4300
4400
4500
4600
4700
4800

Range III :


M(J/ψπ+π−π±K∓)
Data
Signal
Background
Fit
14000
12000
10000
8000
6000
4000
2000
0
5220
5240
5260
5280
5300
5320
5340


M(J/ψπ+π−)
Events / (5.5 MeV)
Psi(4040)
Psi(4160)
Psi(4230)
900
800
700
600
500
400
300
200
100
0
4000
4100
4200
4300
4400
4500


M(J/ψπ+π−π±)
Events / (5.4 MeV)
1500
1000
500
0
−500
4300
4400
4500
4600
4700
4800

Selection Cuts		
Particle	Parameter	Selection
$\mu^{\pm}$	PROBNNMU	> 0.5
	χ^2 IP	> 10
$\pi^{\pm}$	PROBNNPI	> 0.4
	p_T	> 400 MeV
	P	> 3200 MeV
	χ^2 IP	> 4
π^0	p_T	> 1000MeV
$K^{\pm}$	η	2 - 5
	P	> 3200 MeV
	PROBNNK	> 0.15
	χ^2 IP	> 4
B_0	M (J/ψ constrained)	5150 - 5450 MeV
	χ^2DTF (J/ψ constrained)	< 5
	χ^2 IP	< 9
	FDS	> 5

Decay II

- Fit performed on J/ψ constrained B mass
- S-weights extracted from signal region.
- We look for B meson signal and possibility of structures in invariant mass combinations of daughter particle.