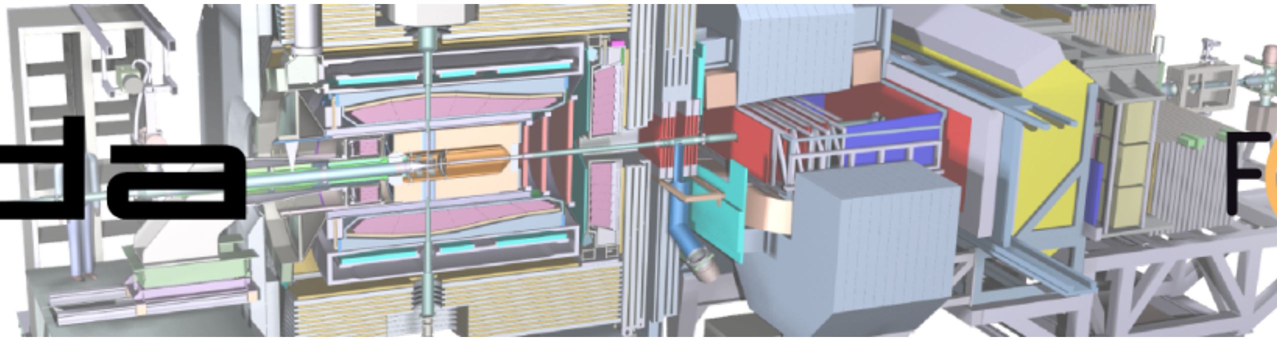

Feasibility Study of Z(4430)

PANDA-CM, March 10th, 2021

10.03.2021

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Introduction

- The situation formed around the theoretical interpretation of the $Z_c(3900)$ resonance does not differ considerably from activities intending to explain features of Z(4430). There are attemps to treat it as the tightly bound diquark-antidiquark state, as the four-quark bund state composed of conventional mesons.

- The interesting idea was suggested to consider the $Z_c(3900)$ and Z(4430) resonances as the ground and first radially excited states of the same diquark-antidiquark multiplet. The main decay channels of these resonances:

$$Z_c^{\pm}(3900) \rightarrow J/\psi\,\pi^{\pm}\,,\; Z^{\pm}(4430) \rightarrow \psi'\pi^{\pm}$$

- By looking at those main decay channels, and also by observation that the mass difference between 1S and 2S states $m_{\psi'} - m_{J/\psi}$ is approximately equal to the mass splitting $m_Z - m_{Z_c}$.

- The charmonium-like resonance $Z_c(3900)$ and its excited state Z(4430) are among the particles that are serious candidates for double heavy tetraquarks [1].

Introduction

- For a first time in 2008, the Belle Collaboration reported a distinct peak in the $\pi^{\pm}\psi'$ invariant mass distribution in $B \rightarrow K\pi^{\pm}\psi'$ decay. The measured mass and width were $M = 4433 \pm 4(\text{stat})2(\text{syst})$ MeV and $\Gamma = 45^{+18}_{-13}(\text{stat})^{30}_{-13}(\text{syst})$ MeV [2].

- The Belle Collaboration then, during the observation of a new charmonium like state $Z_c^+(4200)$, in addition, they found evidence for $Z^+(4430) \rightarrow J/\psi\,\pi^+$ [2, 3].

- In the first independent confirmation by LHCb Collaboration, its spin-parity was assigned as 1^+. The mass of the resonance, $4475 \pm 7^{+15}_{-25}$ MeV, and its width, $172 \pm 13^{+37}_{-34}$ MeV, were measured [2, 4].

- According to PDG, mass and width of $Z(4430)$ is;

$c\bar{c}$ MESONS
(including possibly non-$q\bar{q}$ states)

INSPIRE search

$Z_c(4430)$ $I^G(J^{PC}) = 1^+(1^{+-})$ *G, C* need confirmation.
was $X(4430)^{\pm}$

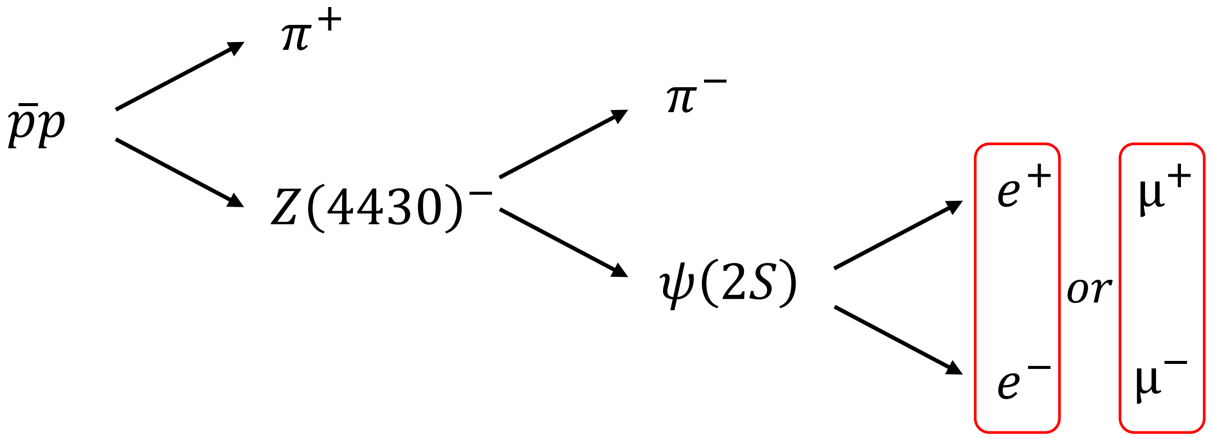
Properties incompatible with a $q\bar{q}$ structure (exotic state). See the review on non-$q\bar{q}$ states. First seen by CHOI 2008 in $B \rightarrow K\pi^+\psi(2S)$ decays, confirmed by AAIJ 2014AG, and confirmed in a model-independent way by AAIJ 2015BH. Also seen by CHILIKIN 2014 in $B \rightarrow K^+\pi J/\psi$ decays. J^P was determined by CHILIKIN 2013 and AAIJ 2014AG.

$Z_c(4430)$ MASS	4478^{+15}_{-18} MeV
$Z_c(4430)$ WIDTH	181 ± 31 MeV

Decay Modes

Mode		Fraction (Γ_i/Γ)	Scale Factor/ Conf. Level	P (MeV/c)
Γ_1	$\pi^+\psi(2S)$	seen		711
Γ_2	π^+J/ψ	seen		1162

Monte Carlo Simulation



- Two intermediate resonances ($Z(4430)^-$ and $\psi(2S)$),
- Four final state particles : $\pi^+, \pi^-, e^+ and\ e^-$ (or μ^+ and μ^-).

Event Generation

- Following the decay chain given in the previous slide, we defined a decay file by selecting decaying particles/resonances from evt.pdl file inside of PandaROOT software.

- PHSP and VLL models and noPhotos were used from EvtGen.

- That file ''pp_ZC4430_ee_nophot.dec'' will specify the signal decay channel.

- From this decay channel as we can see in the decay file, in the next slides there are results for e+ e- as final state particles.

pp_Zc4430Minus_ee_nophot.dec 〉 No Selection

```
noPhotos

Decay pbarpSystem1
  1.0     Z_c(4430)- pi+   PHSP;
Enddecay

Decay Z_c(4430)-
  1.0     psi(2S) pi-   PHSP;
Enddecay

Decay psi(2S)
  1.0     e+ e-   VLL;
Enddecay

End
```

Event Generation

- Shell script for producing events for Z(4430).
- We can produce signal or background events by only changing ‘’prefix’’.
- We are producing events as 10k packets up to 1M (for now).
- In the next slides, there are results for Z(4430) analysis with 30k events produced.

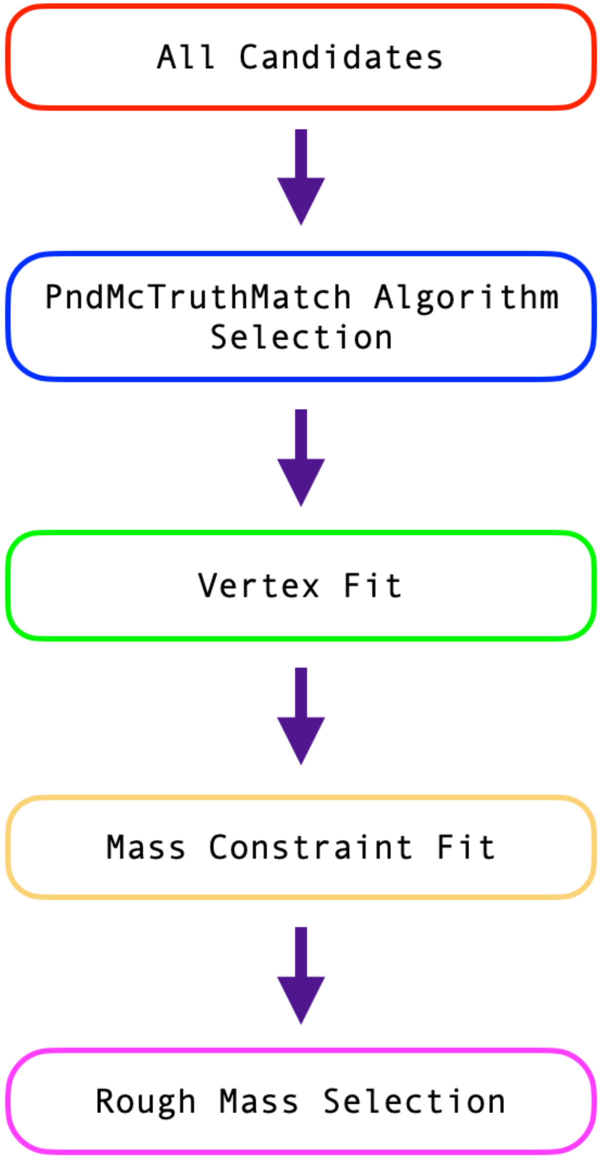
z4430_runall_signal.sh

z4430_runall_signal.sh 〉 No Selection

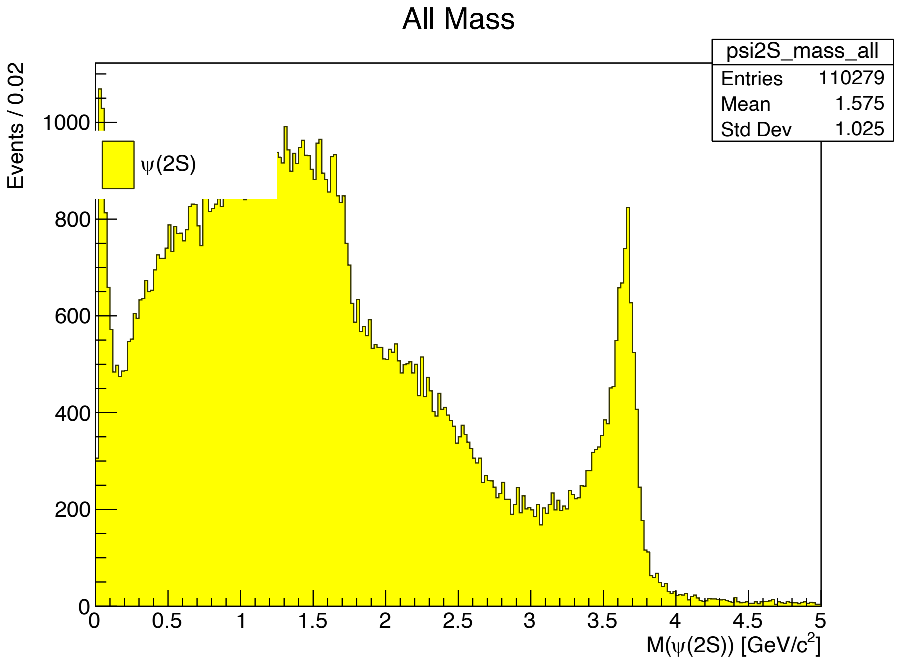
```bash
#!/bin/bash
. ../../../build/config.sh
nev=10000
prefix="signal" # signal | bkg

if [[  "$prefix" == "signal"  ]];  then
prefix="signal_pp_Zc4430Minus_ee_nophot_1_"$nev
input="decfiles/pp_Zc4430Minus_ee_nophot.dec"
elif [[  "$prefix" == "bkg"  ]]; then
prefix="dpm_pp_Zc4430Minus_ee_nophot_1_"$nev
input="decfiles/dpm_Z4430Minus_ee"
fi

pbeam=15.0
geantVersion="TGeant4"

if test "$1" != ""; then
  nev=$1
fi

if test "$2" != ""; then
  prefix=$2
fi

if test "$3" != ""; then
  input=$3
fi

if test "$4" != ""; then
  pbeam=$4
fi

if test "$5" != ""; then
  geantVersion=$5
fi

root -l -b -q  tut_sim.C\($nev,\"$prefix\",\"$input\",$pbeam\,\"$geantVersion\"\)
root -l -b -q  tut_aod.C\($nev,\"$prefix\"\)
```

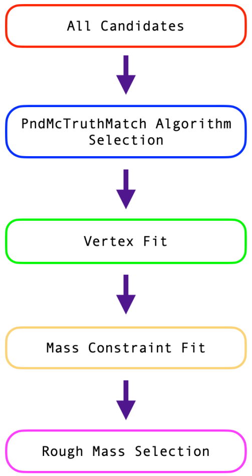
Reconstruction Algorithm & Strategy

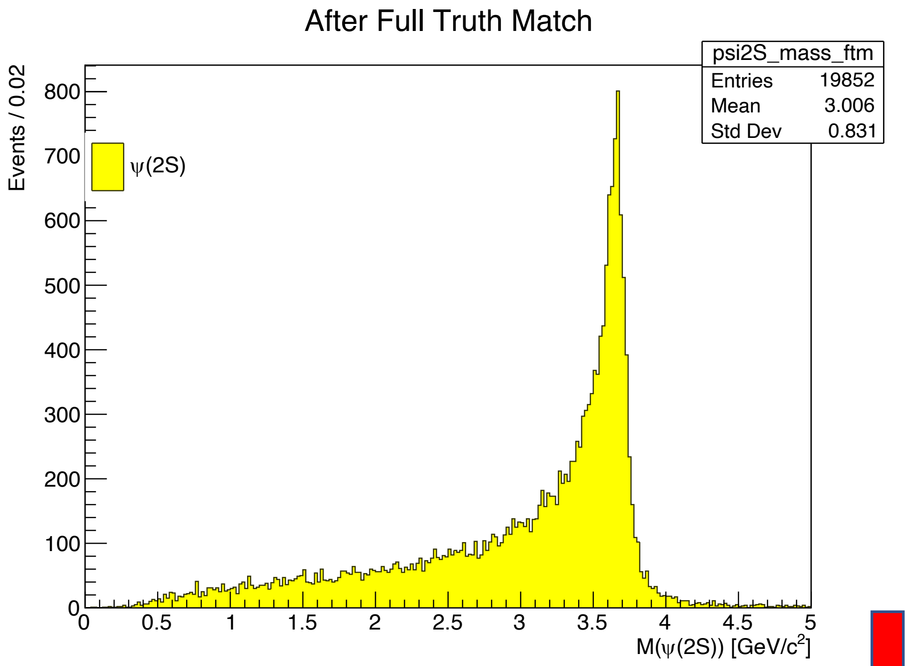
- For particle reconstruction, we used an algorithm to select particles like in this scheme. After each cut/selection algorithm, reconstructed mass was remaked.
- At first, no cuts and nothing applied, just all reconstructed mass for that particle.
- Secondly, we applied McTruthMatch algorithm to select particles.
- After that, McTruthMatch filtered candidates were gathered and Vertex Fit ($p>0.01$) applied to them.
- Then, after these two filters, candidates were also applied Mass Constraint Fit which is also $p>0.01$.
- Lastly, after all that selection algorithm filters, last survived particle candidates were also applied a Rough Mass cut about ± 0.25 GeV with ''RhoMassParticleSelector''.

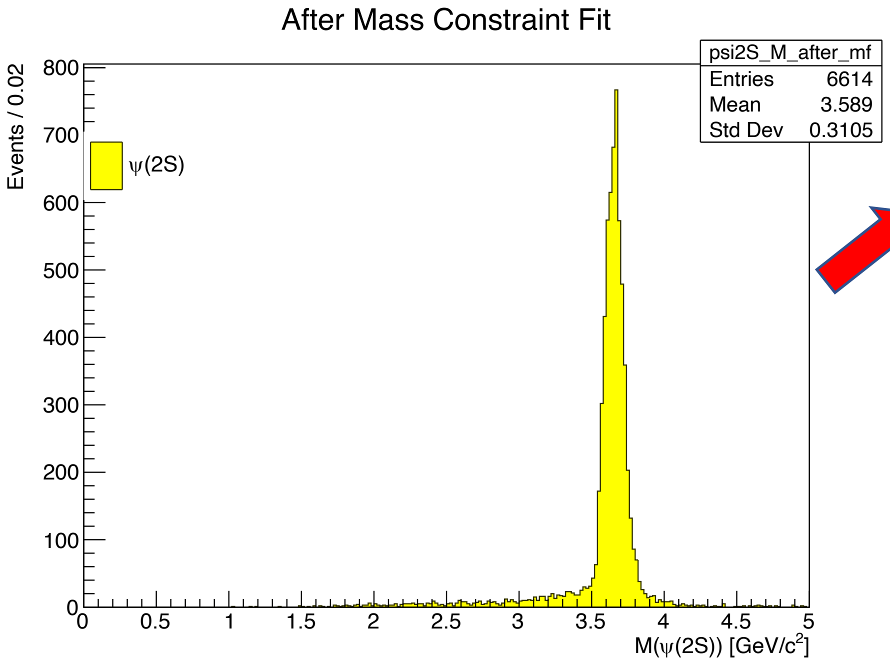


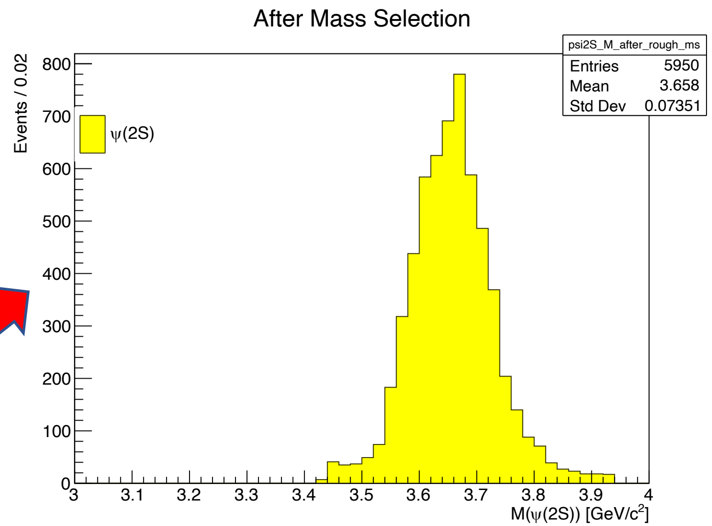
Analysis : ψ(2S) Mass Reco.

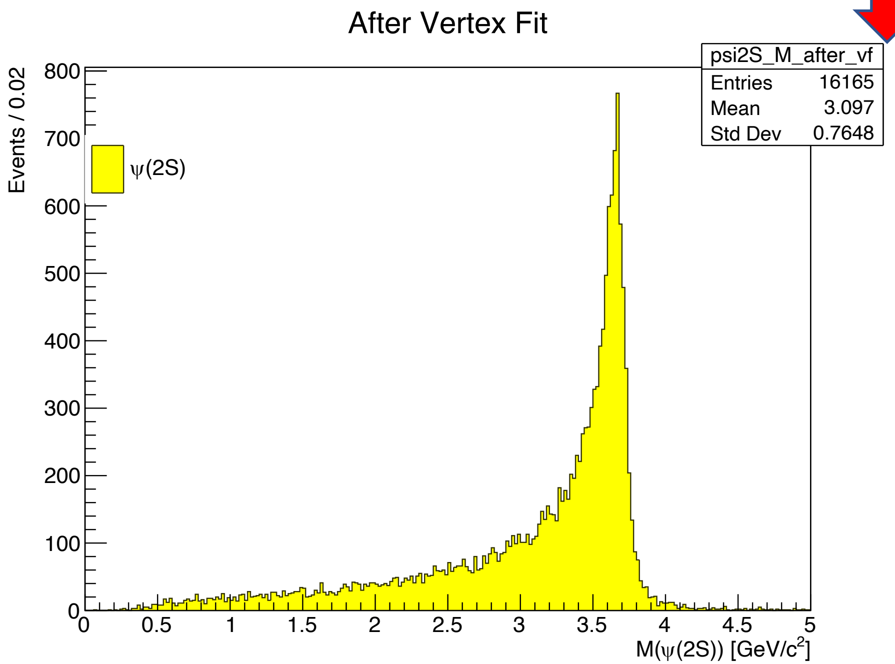






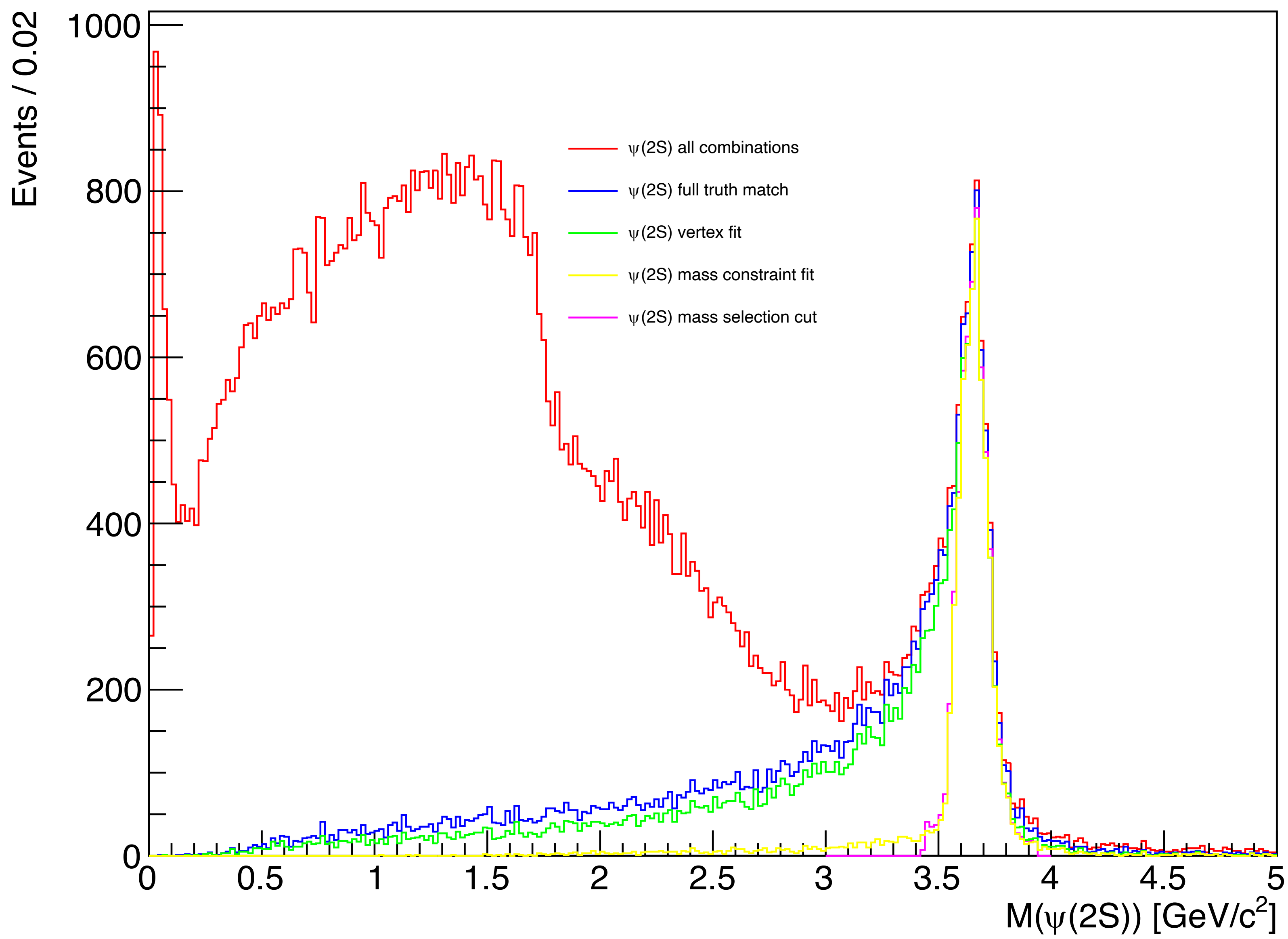


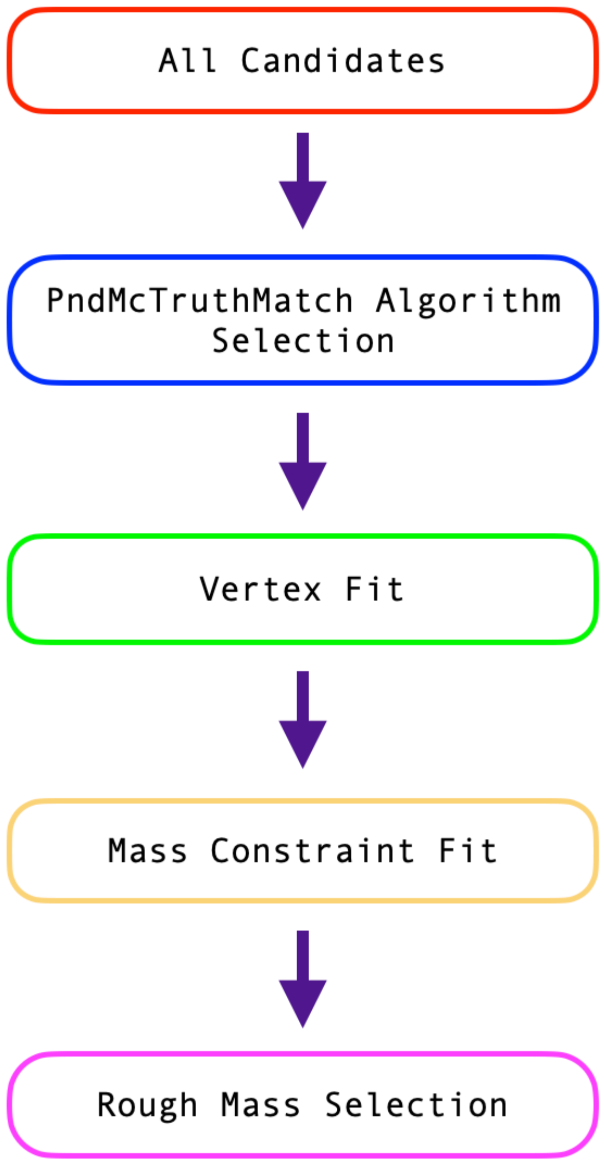




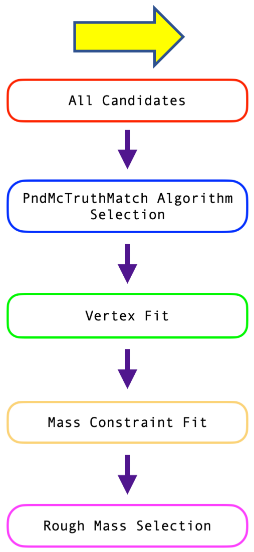
ψ(2S) Mass : 3686.10$\pm$0.06 MeV

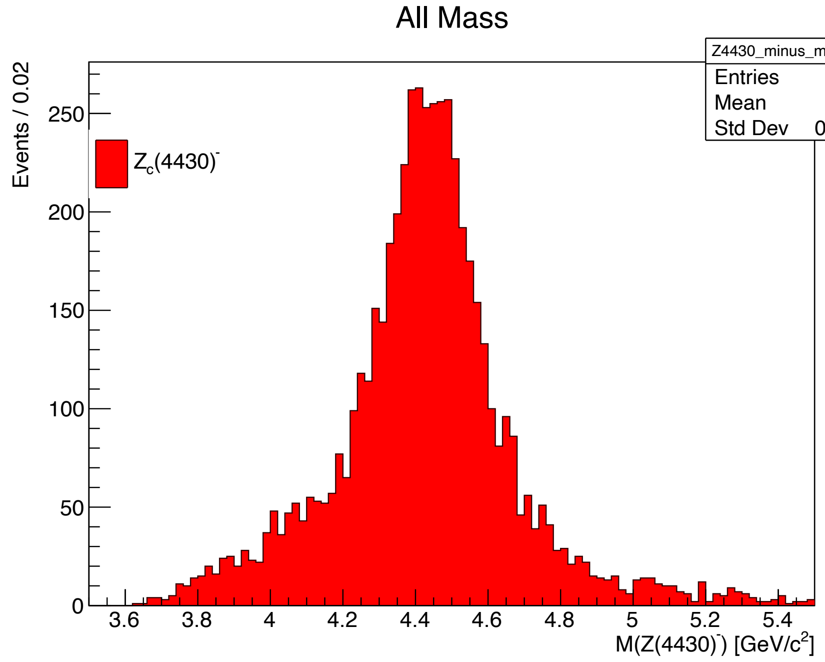
Reconstruction Algorithm & Strategy: $\psi(2S)$

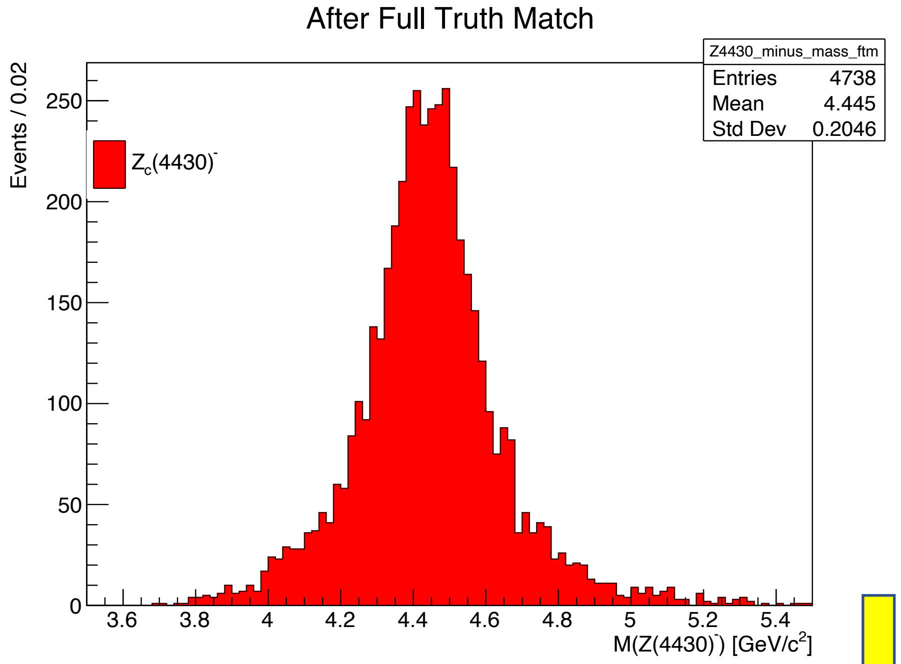


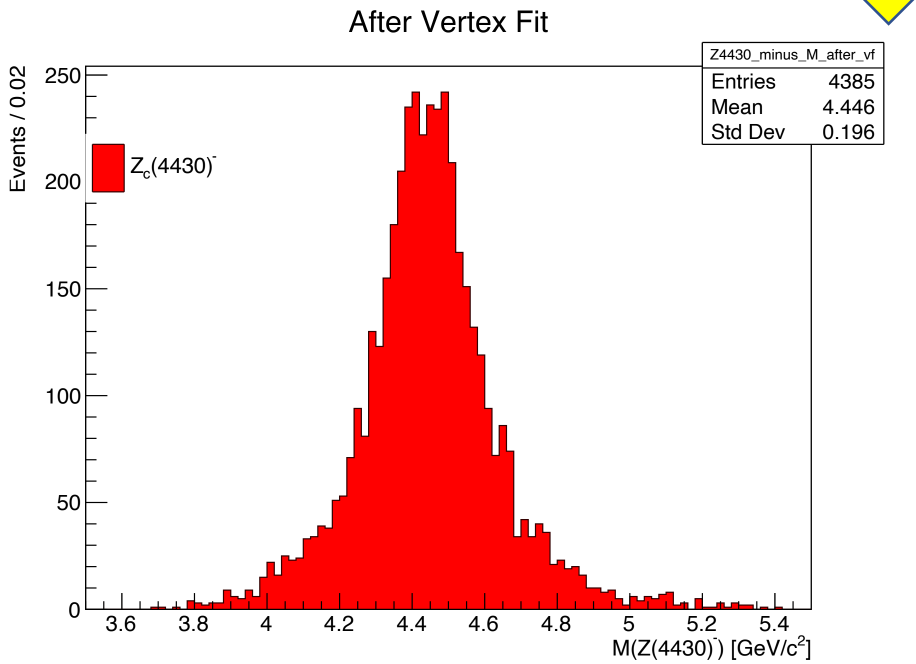


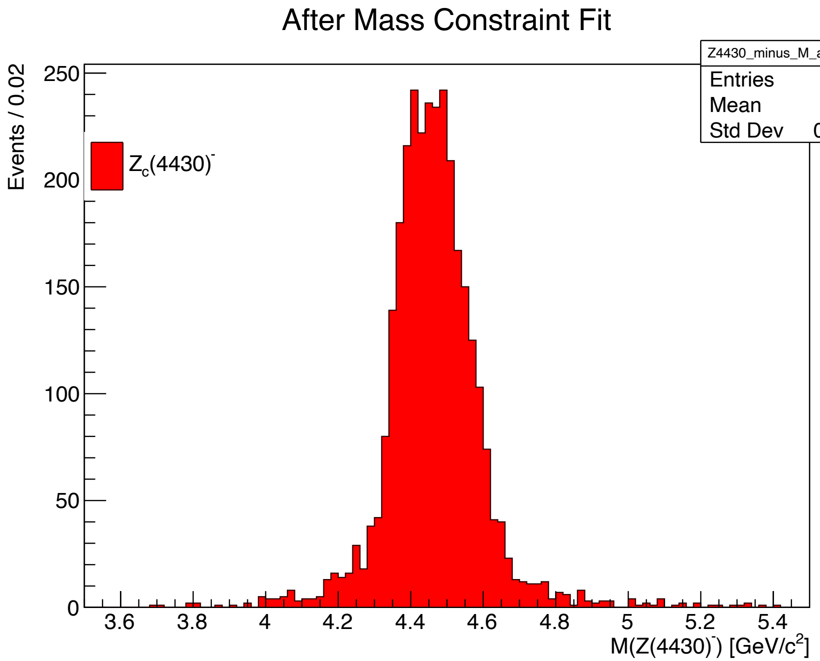
Analysis : Z(4430) Mass Reco.

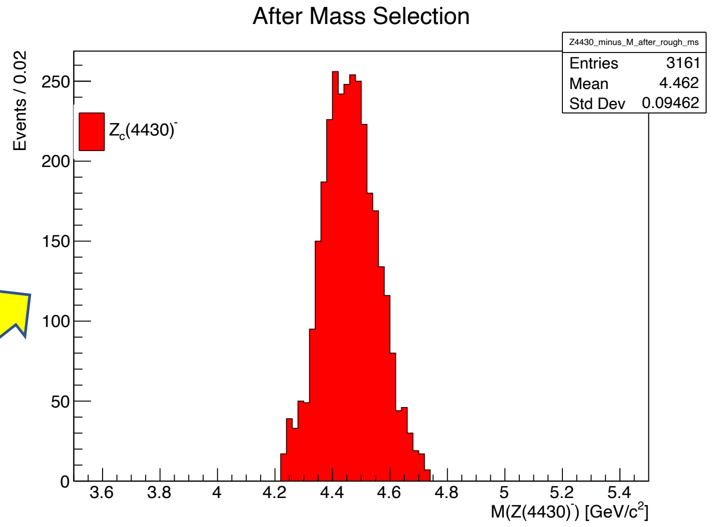






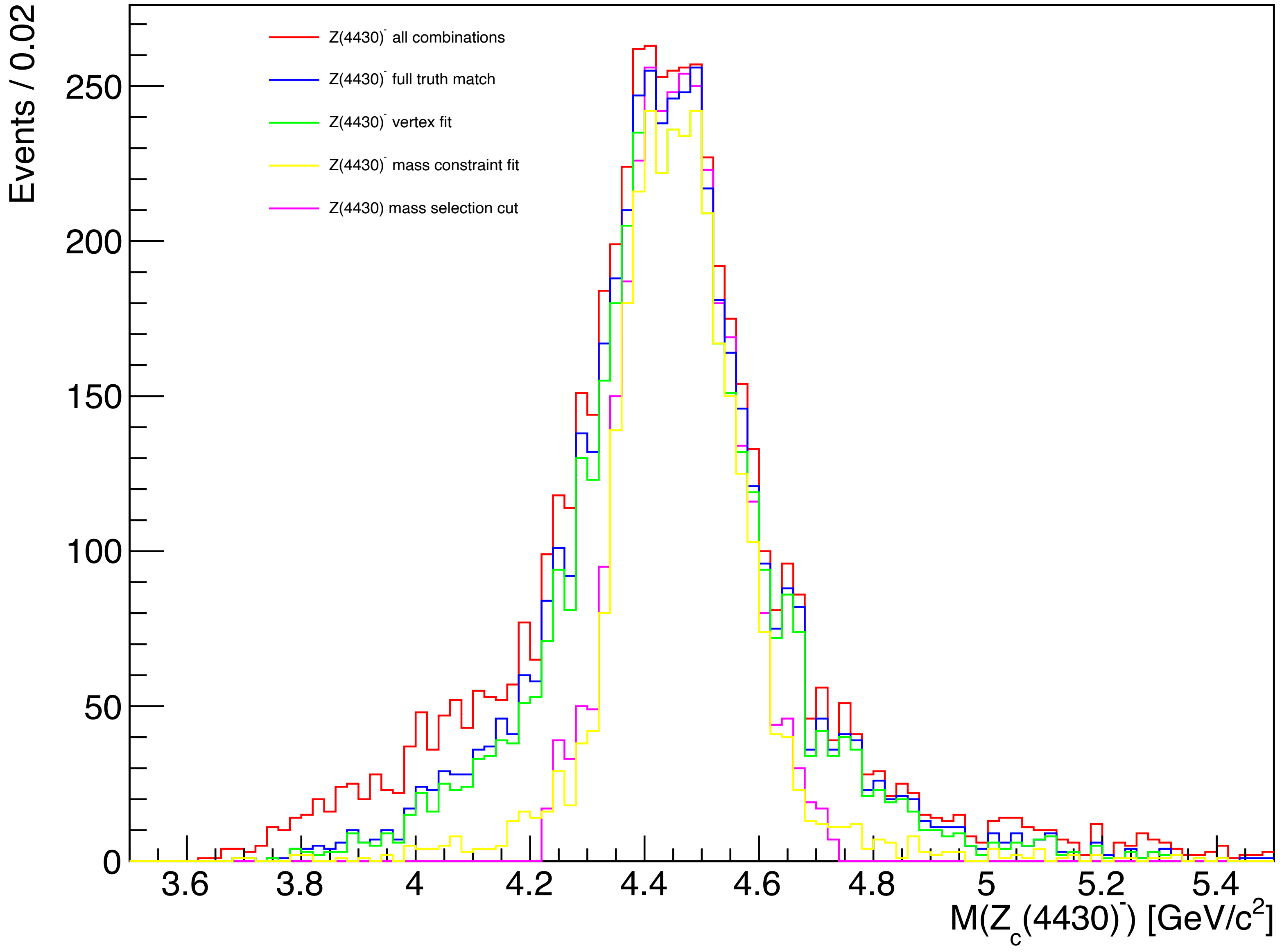


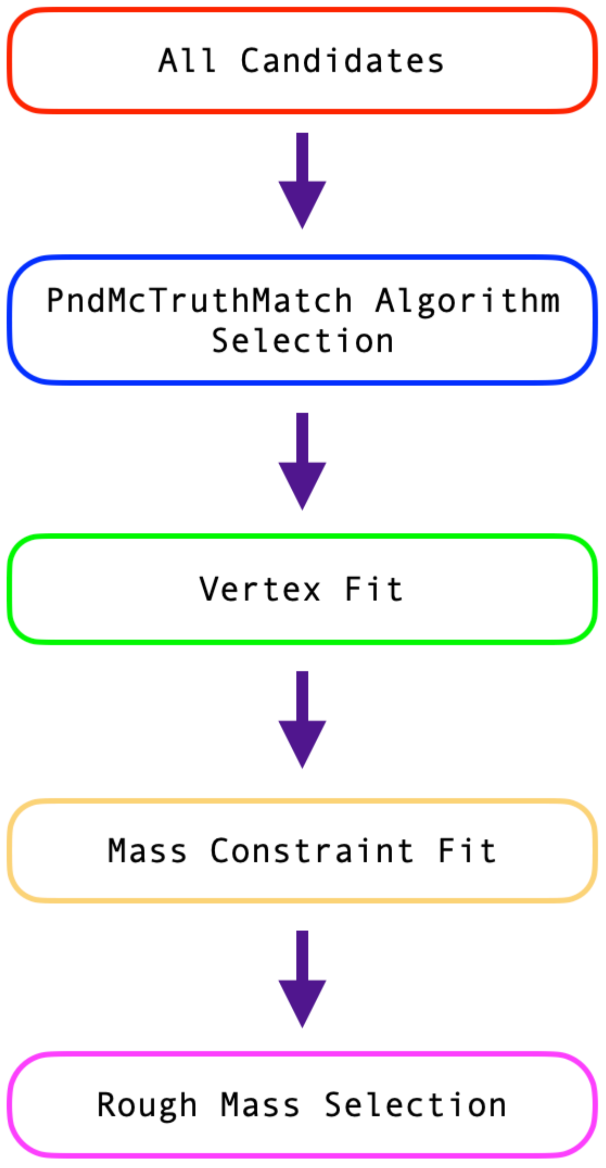




$Z(4430)$ Mass : $4478\,^{+15}_{-18}$ MeV

Reconstruction Algorithm & Strategy: Z(4430)





Reconstruction Algorithm & Strategy

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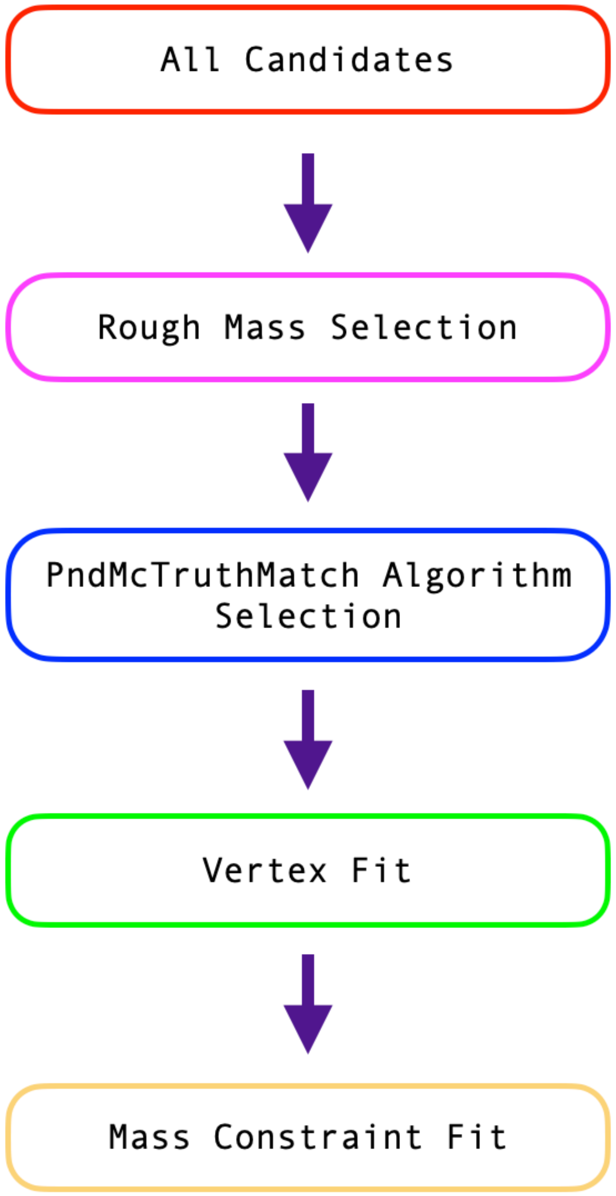
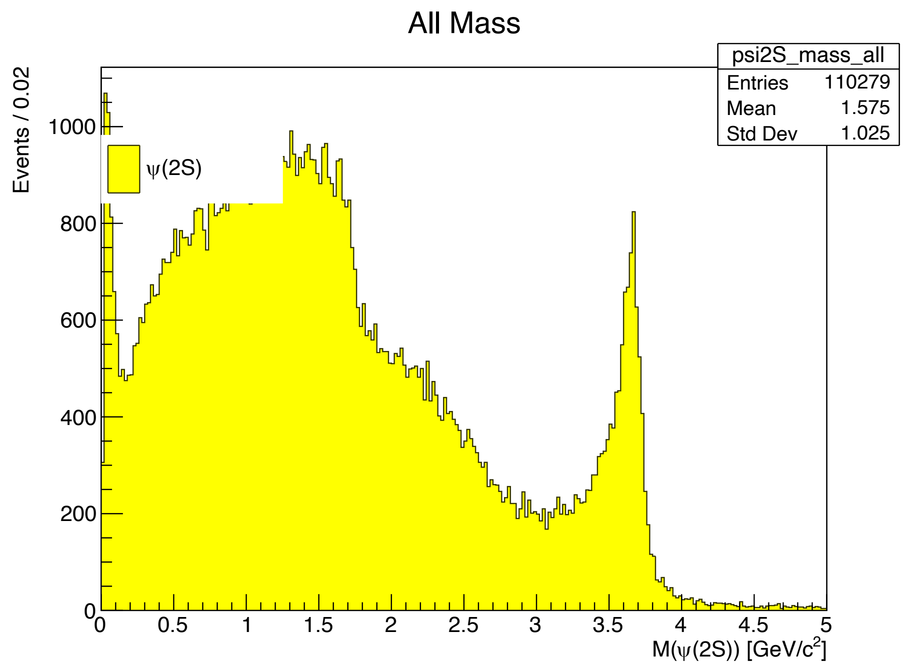
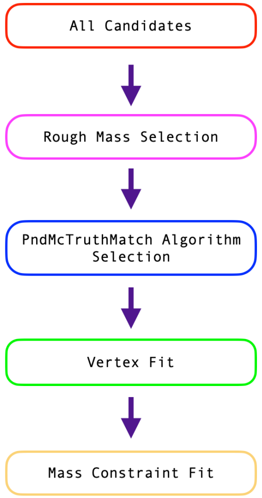
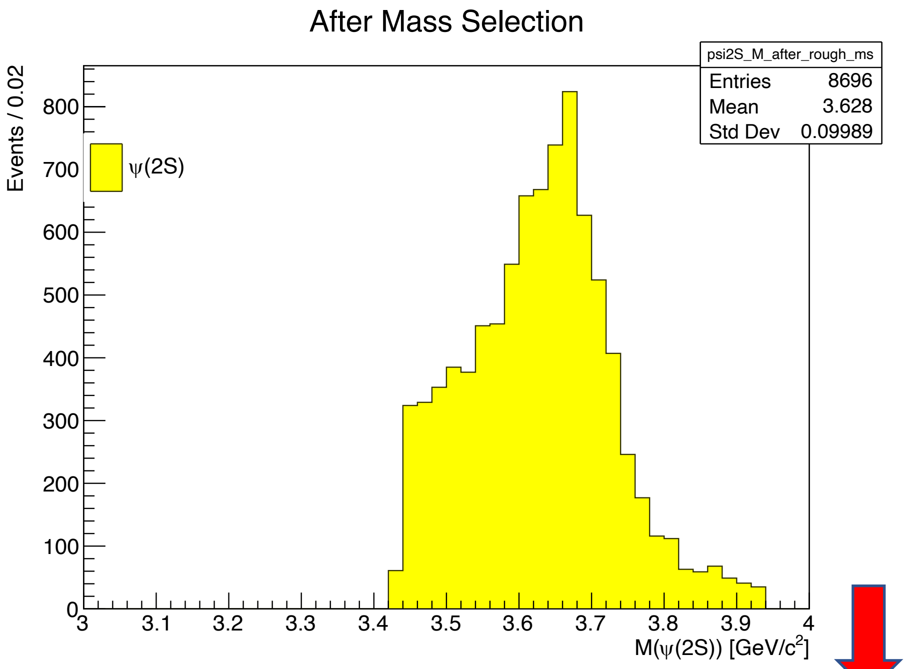
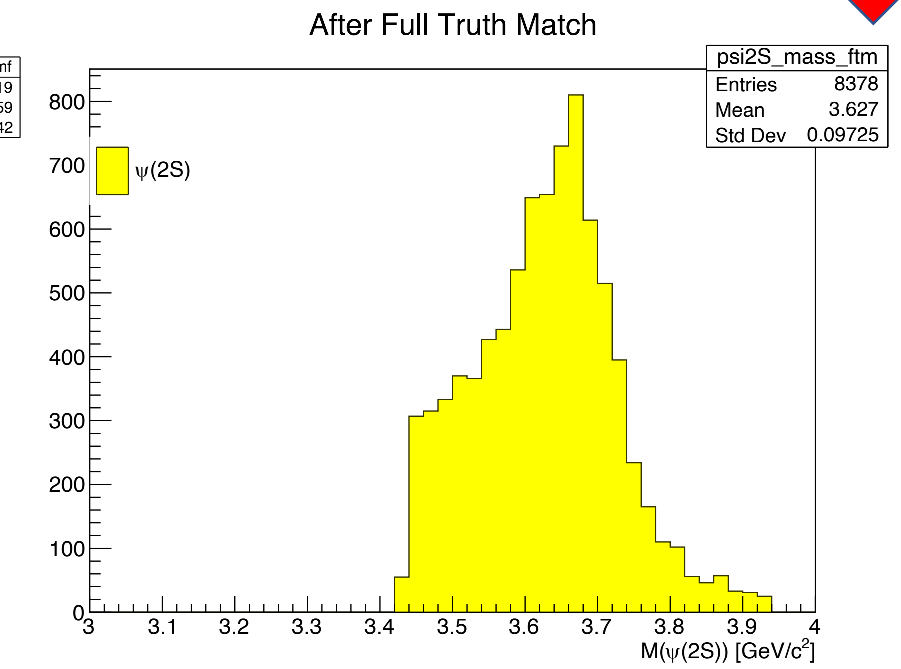


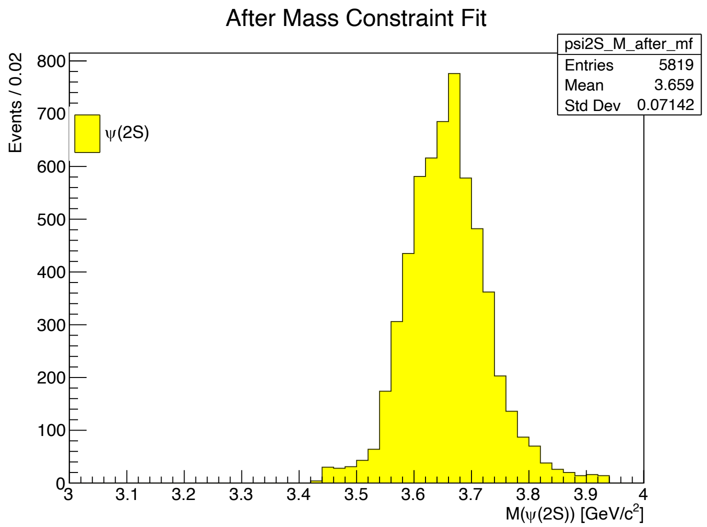
Analysis : $\psi(2S)$ Mass Reco.



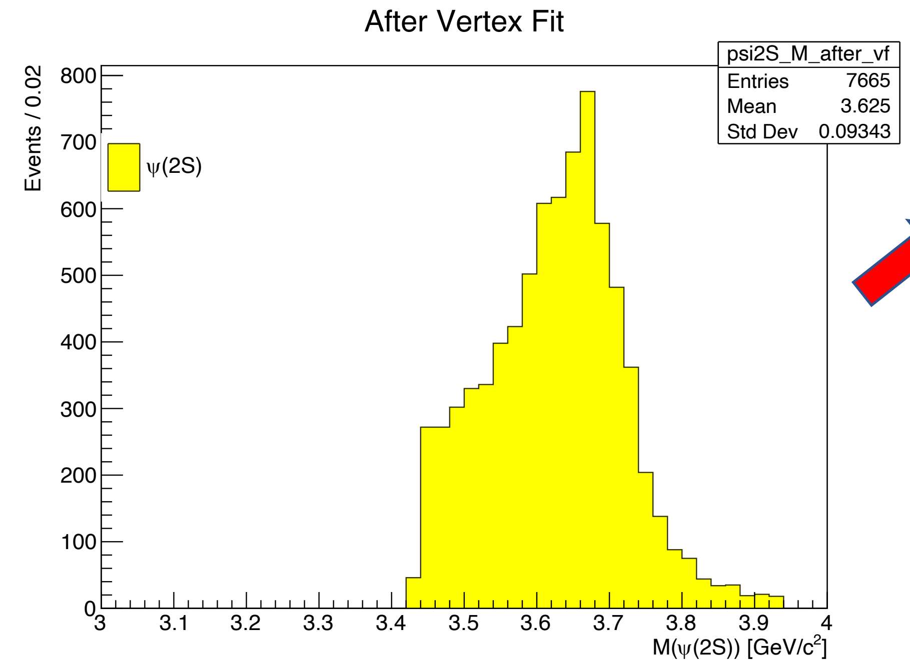




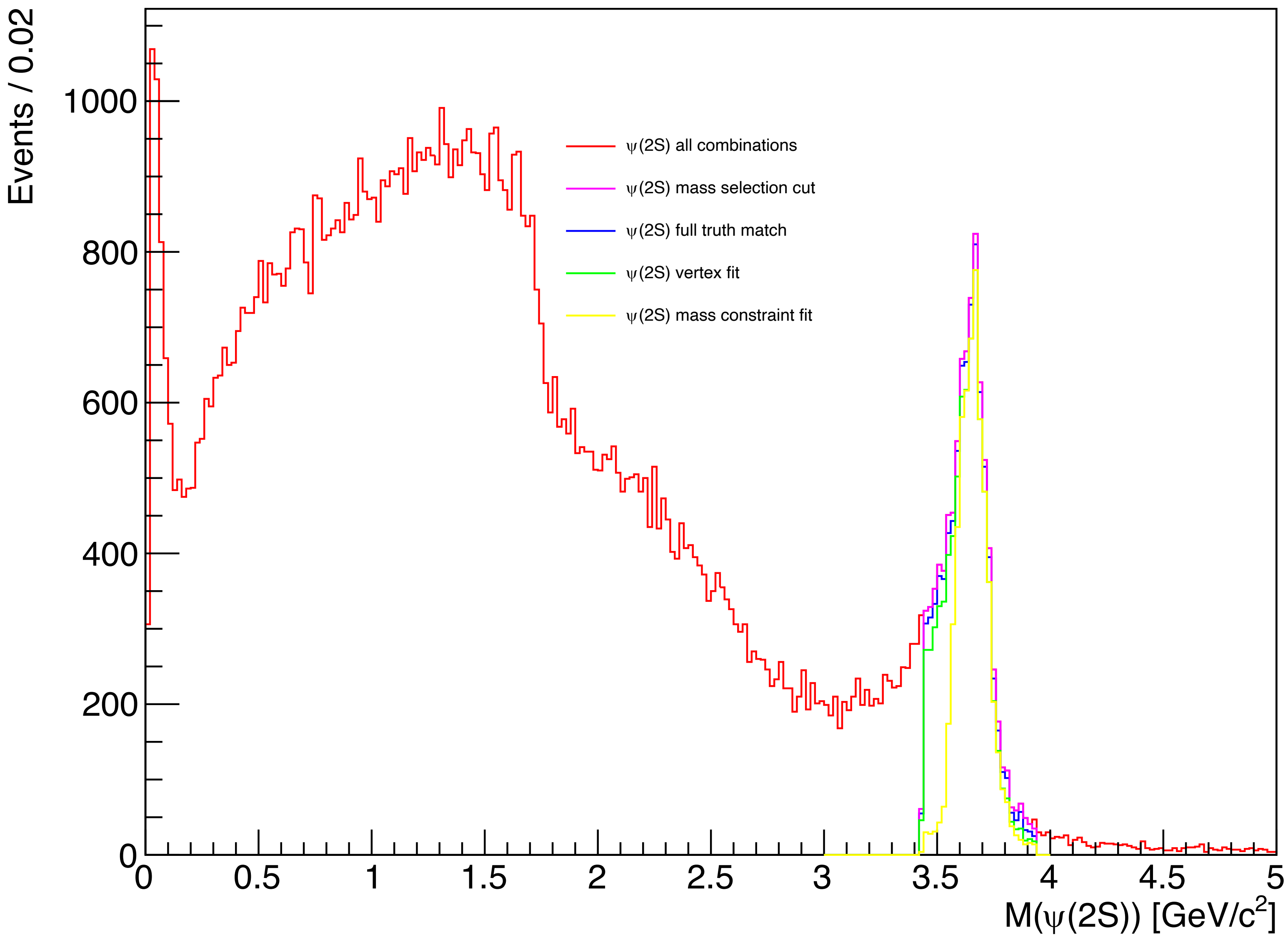


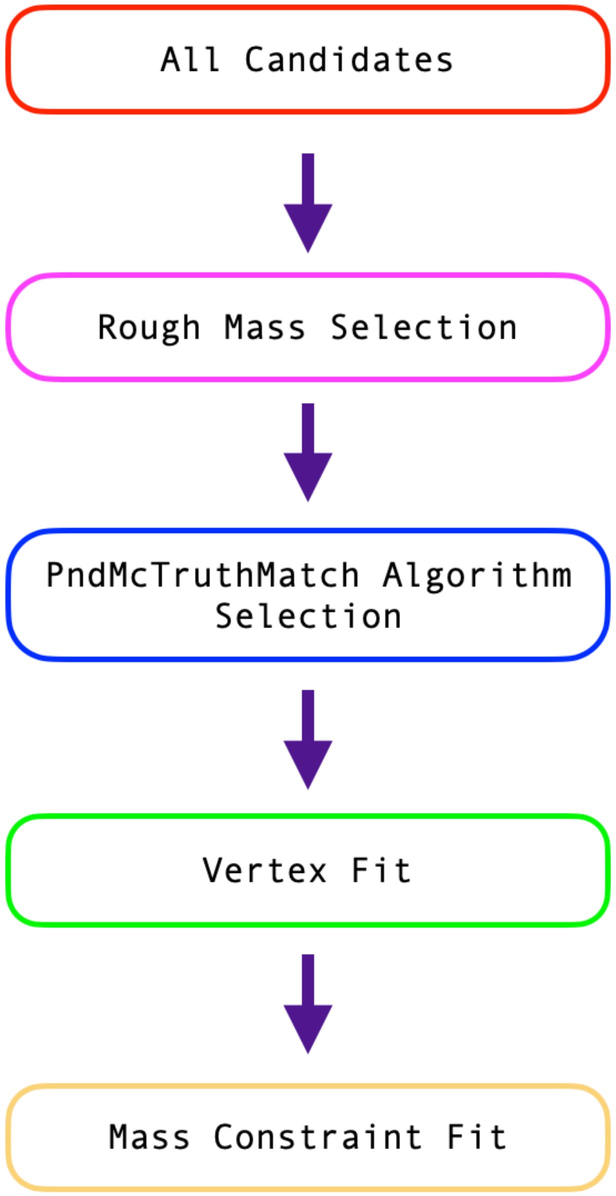


$\psi(2S)$ Mass : 3686.10$\pm$0.06 MeV

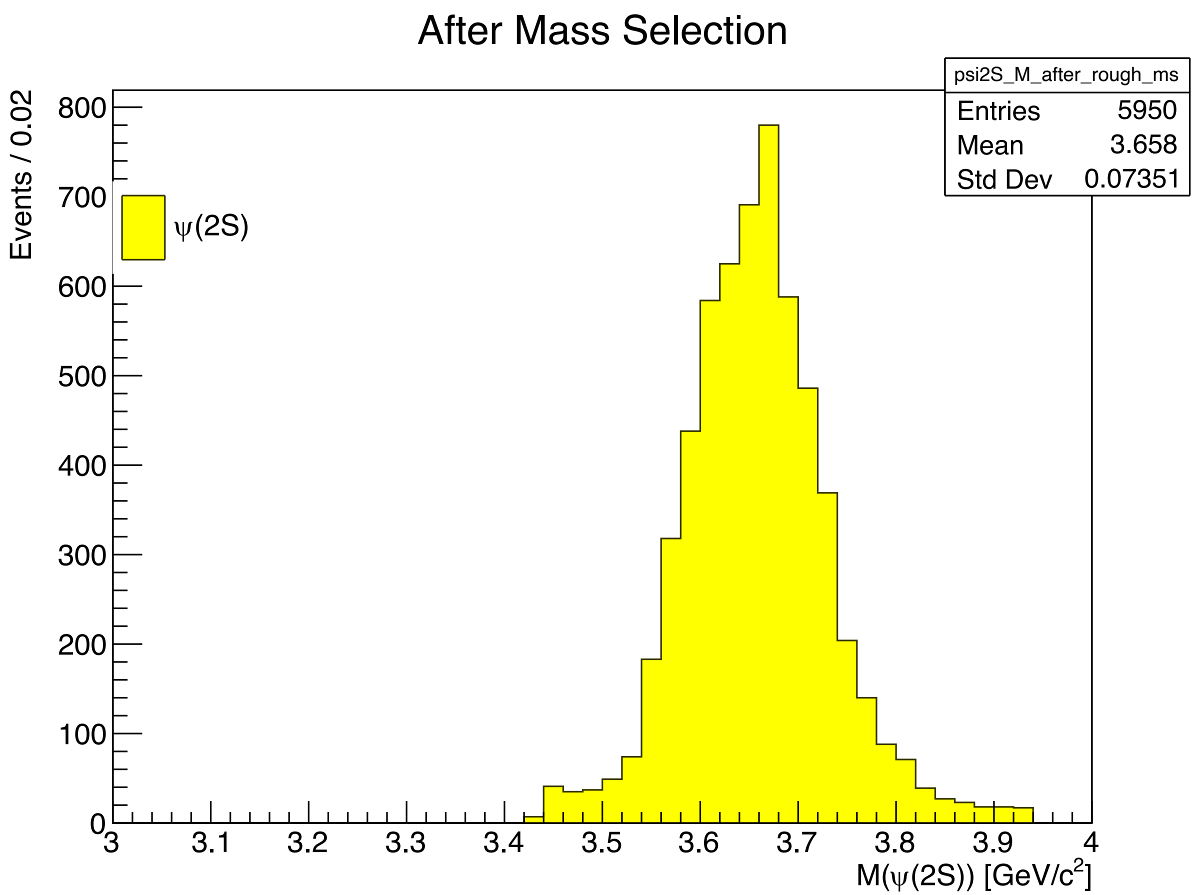


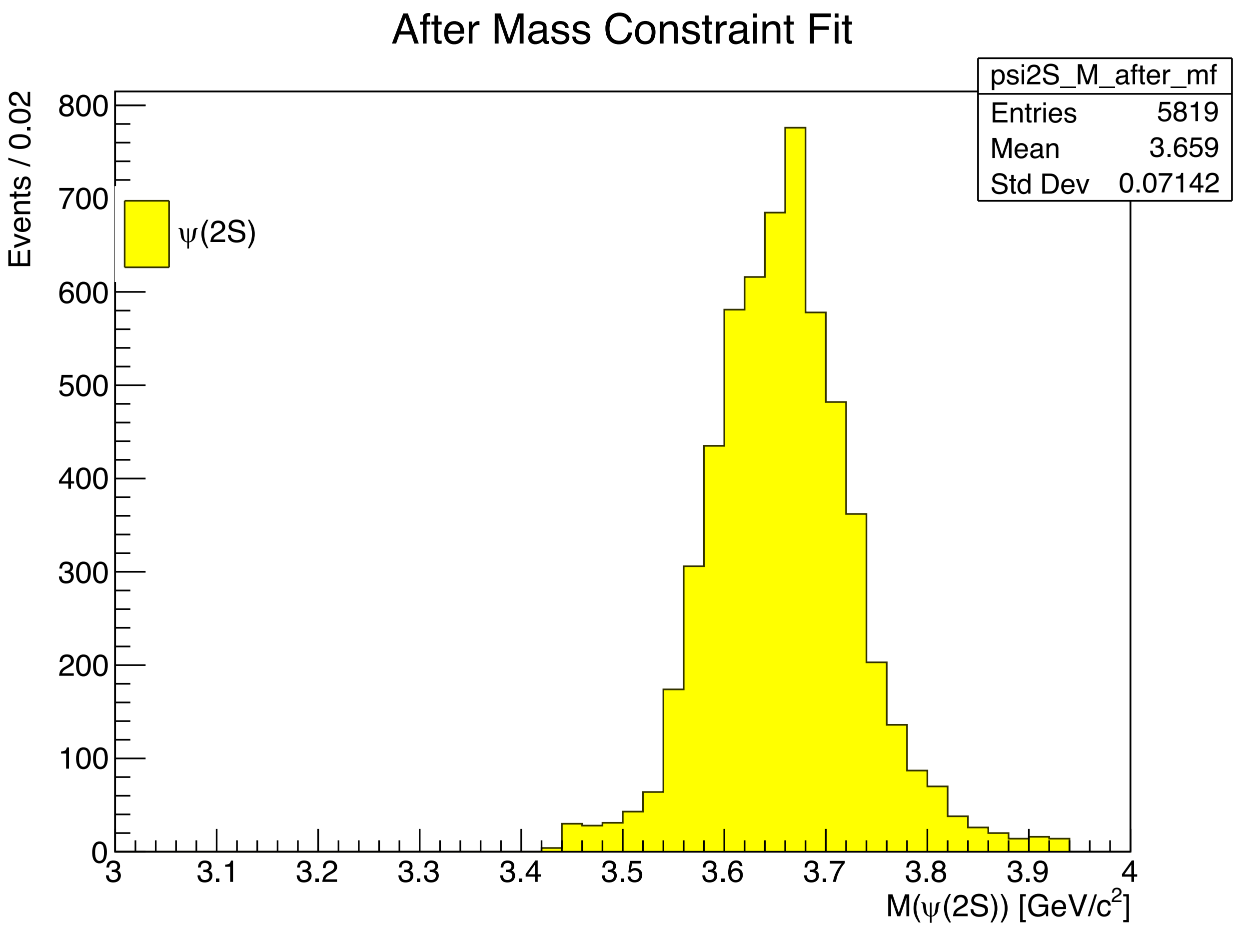
Reconstruction Algorithm & Strategy: $\psi(2S)$





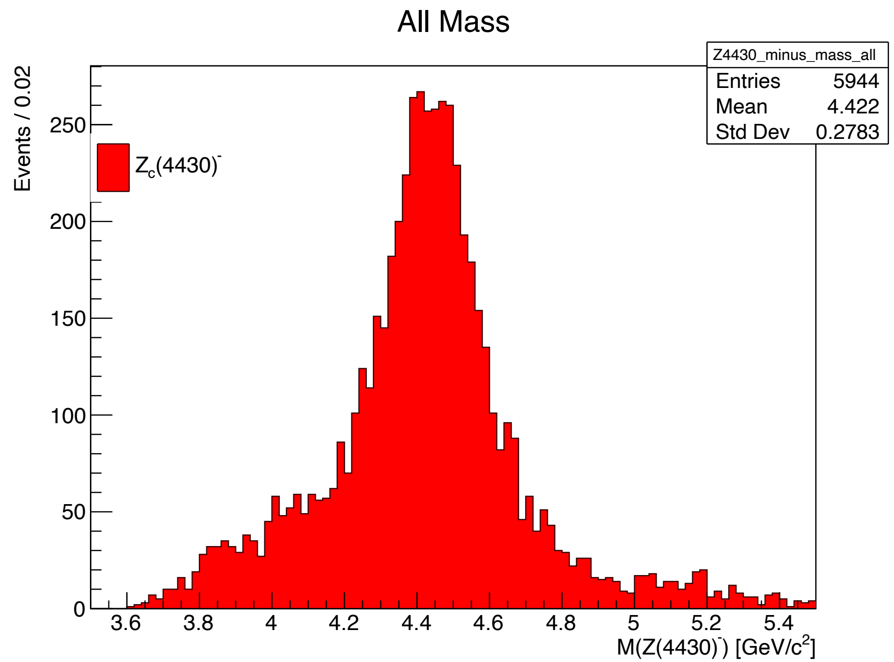
Analysis : ψ(2S) Mass Reco. (Compare)

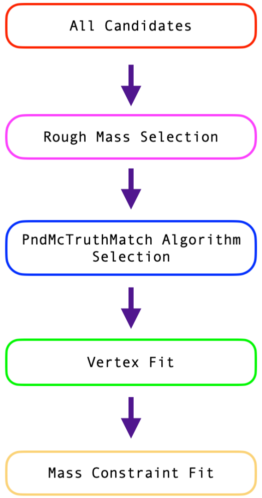


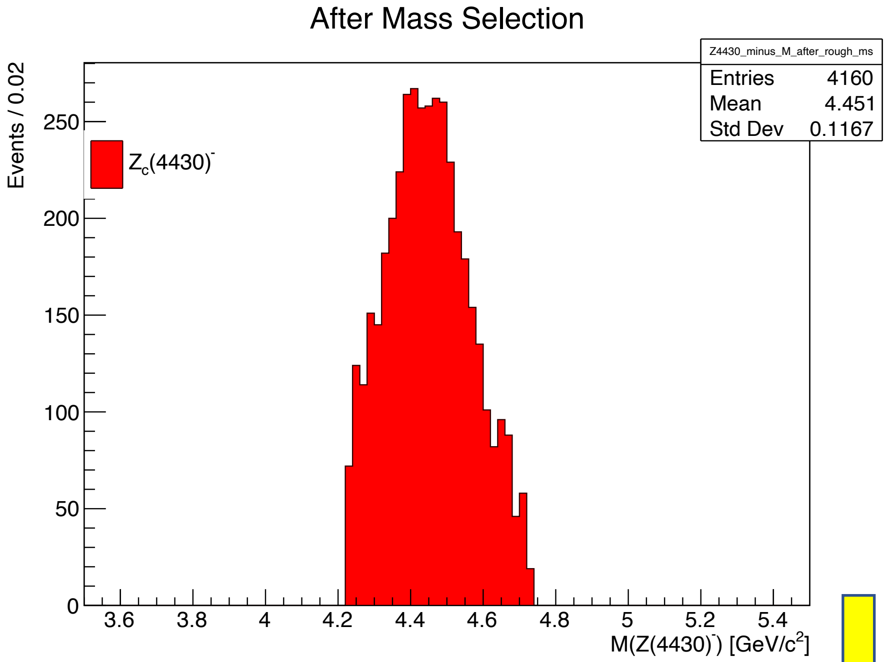


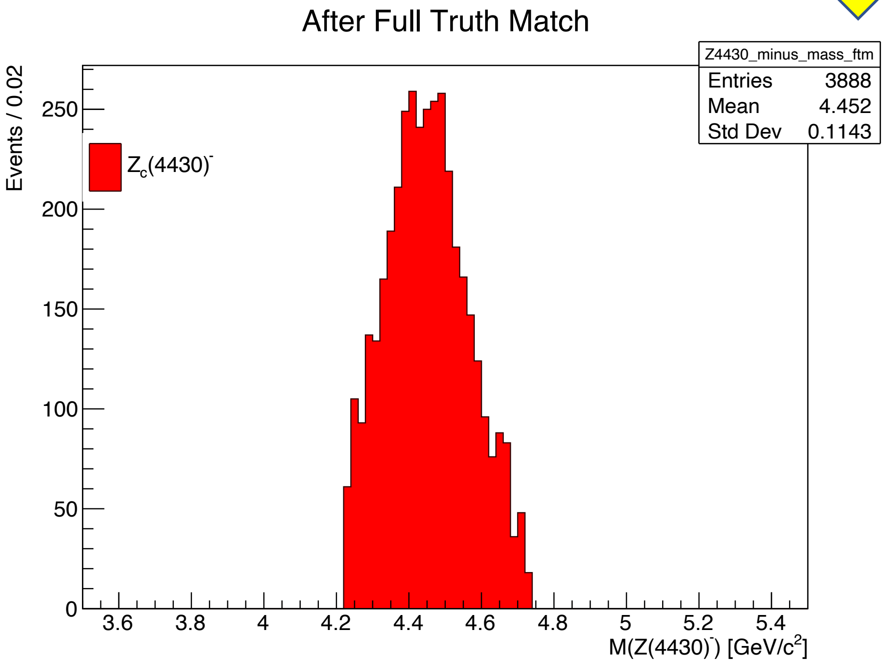
ψ(2S) Mass : 3686.10$\pm$0.06 MeV

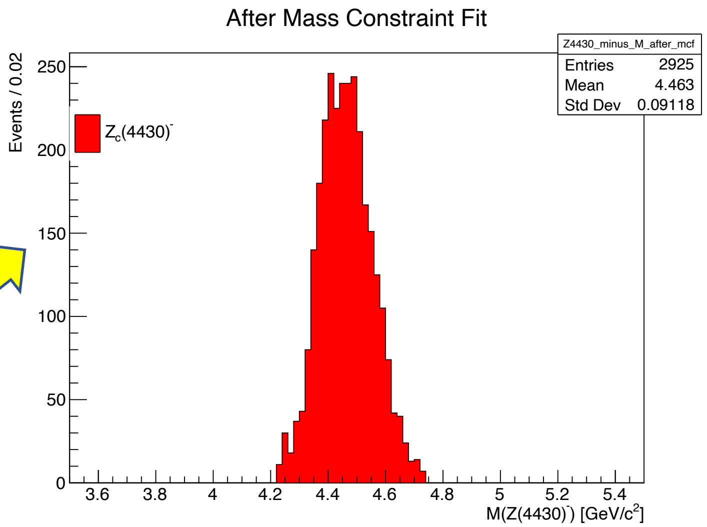
Analysis : $Z(4430)$ Mass Reco.



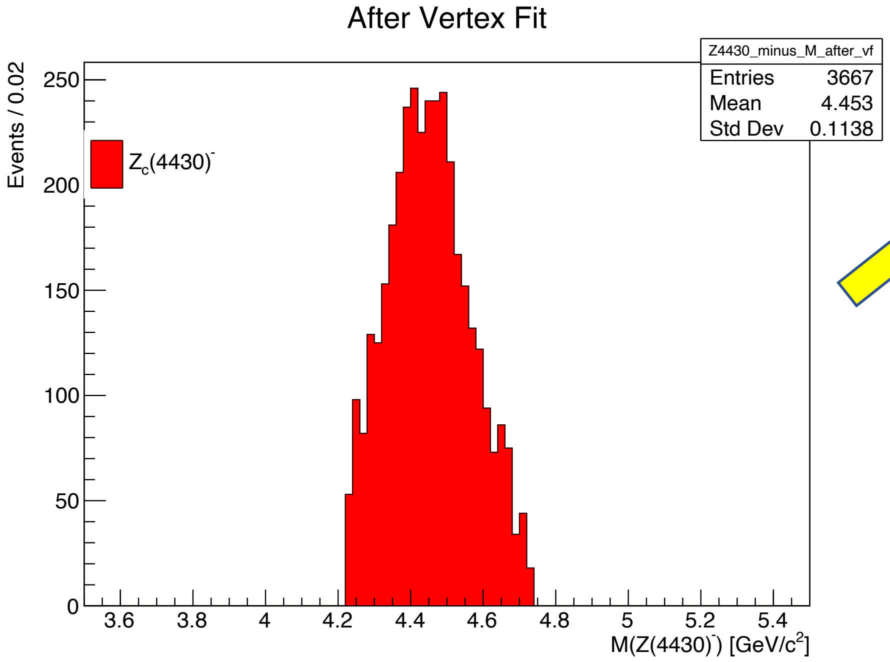




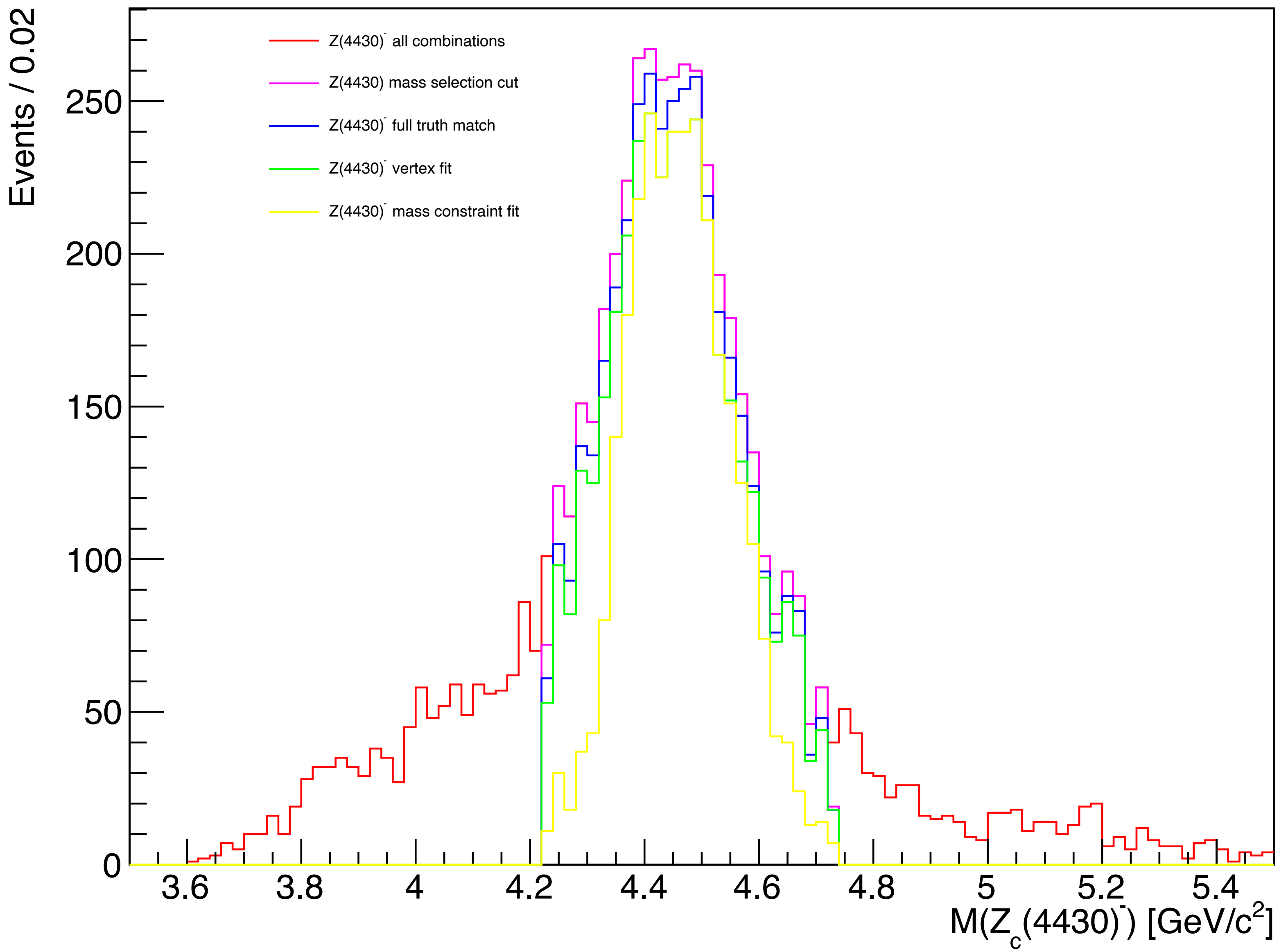


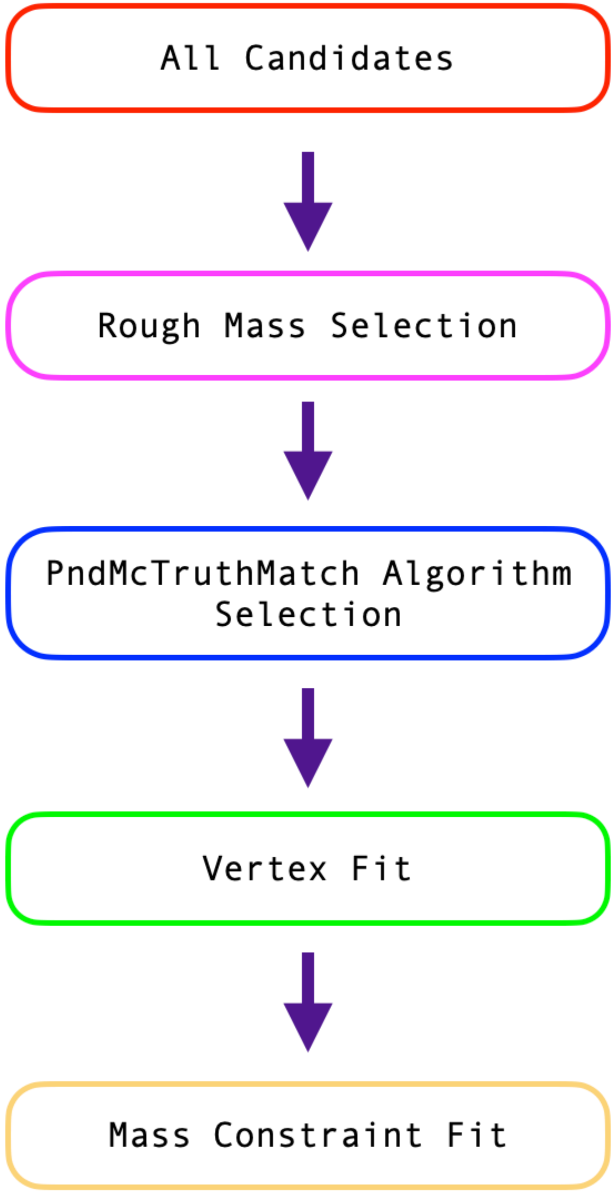


$Z(4430)$ Mass : $4478\,^{+15}_{-18}$ MeV

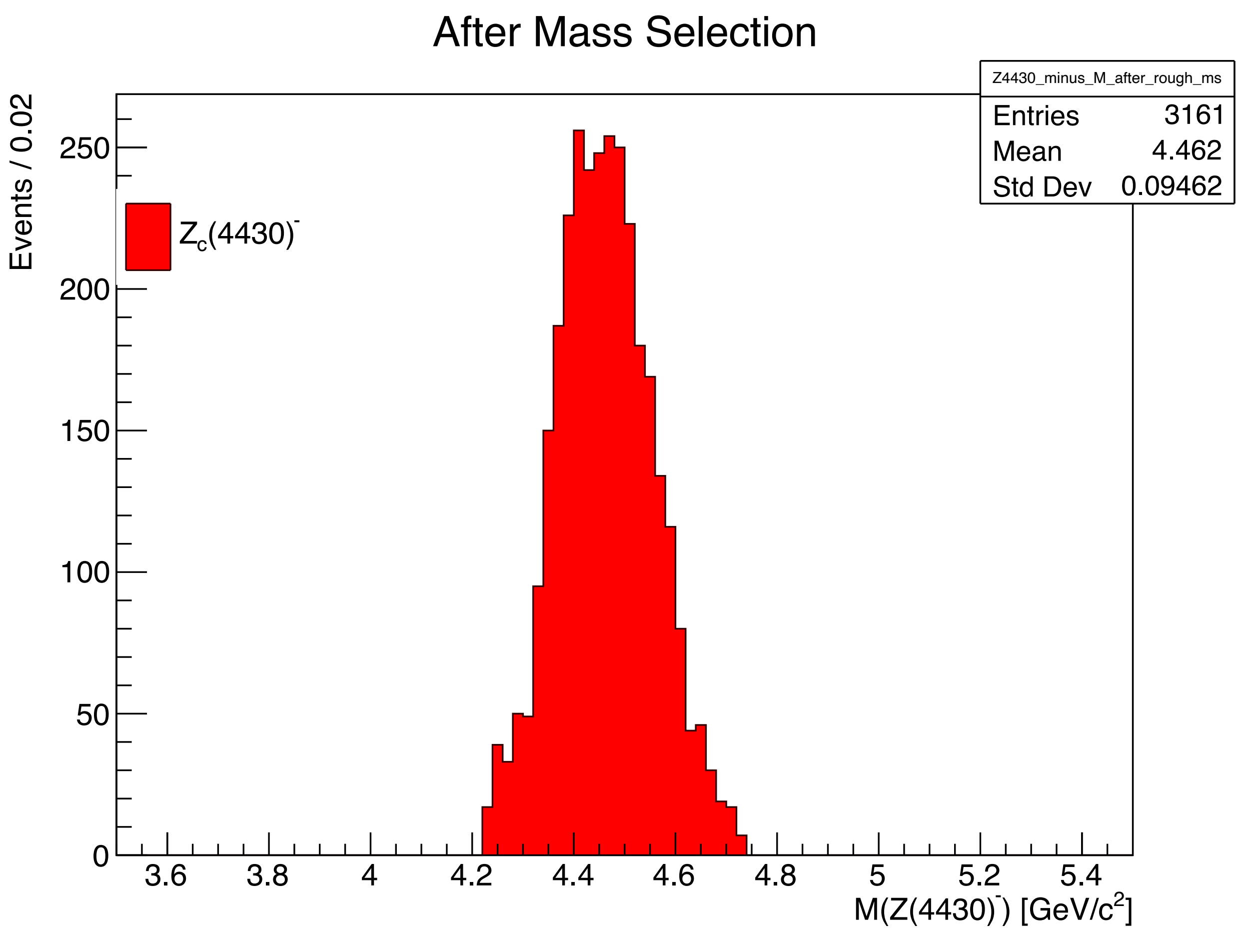


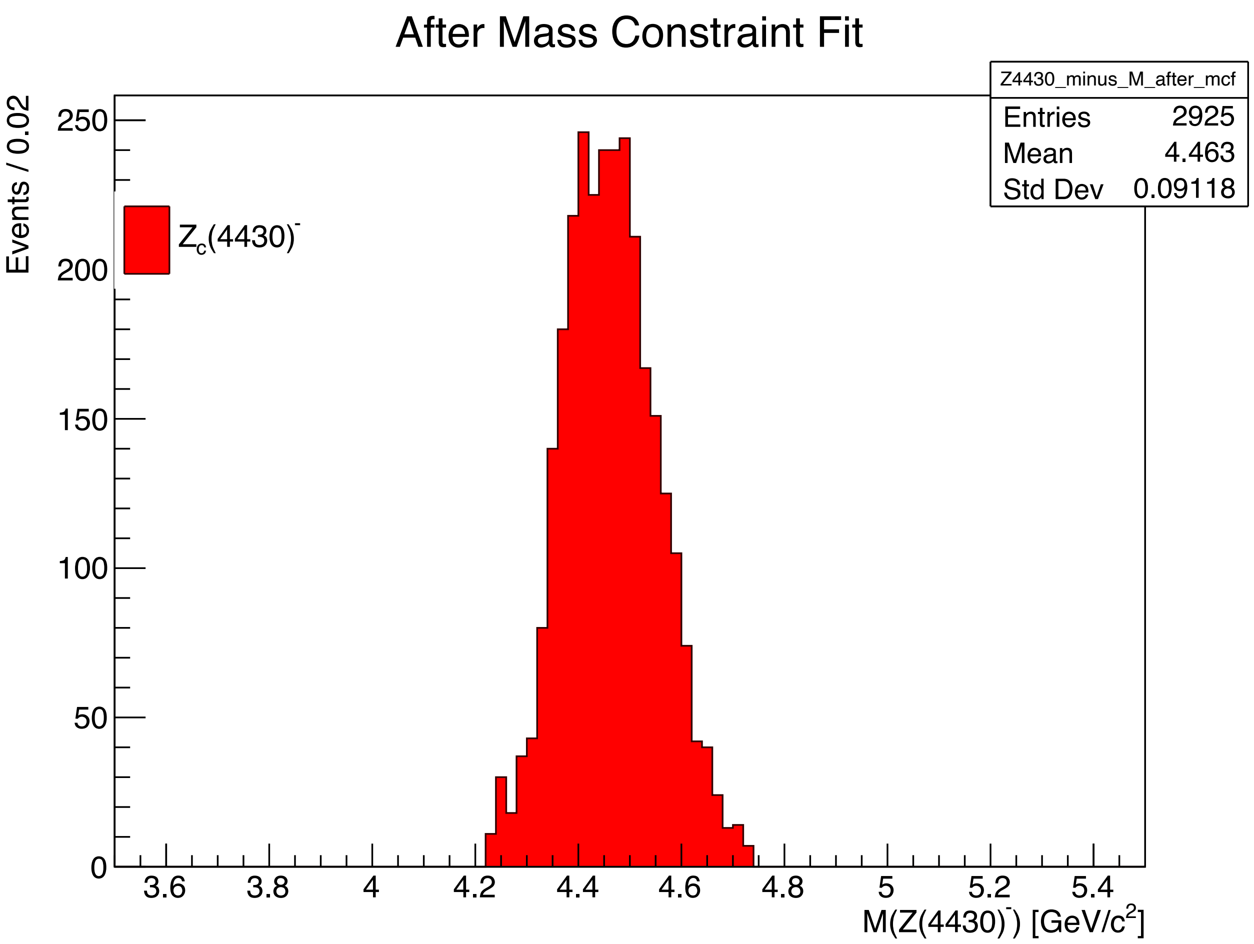
Reconstruction Algorithm & Strategy: Z(4430)





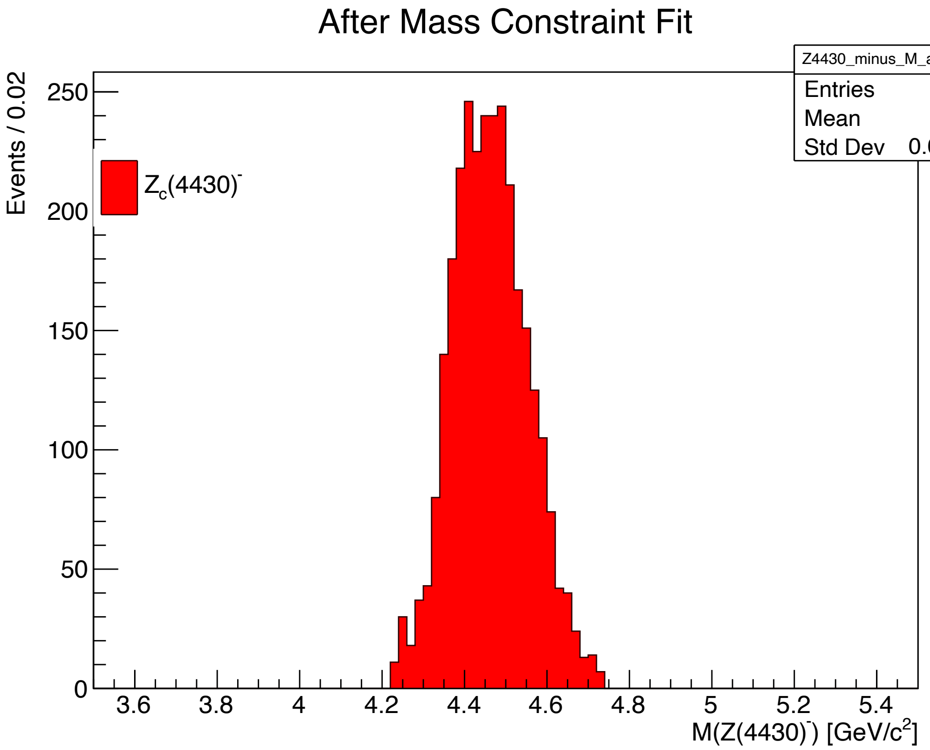
Analysis : $Z(4430)$ Mass Reco. (Compare)

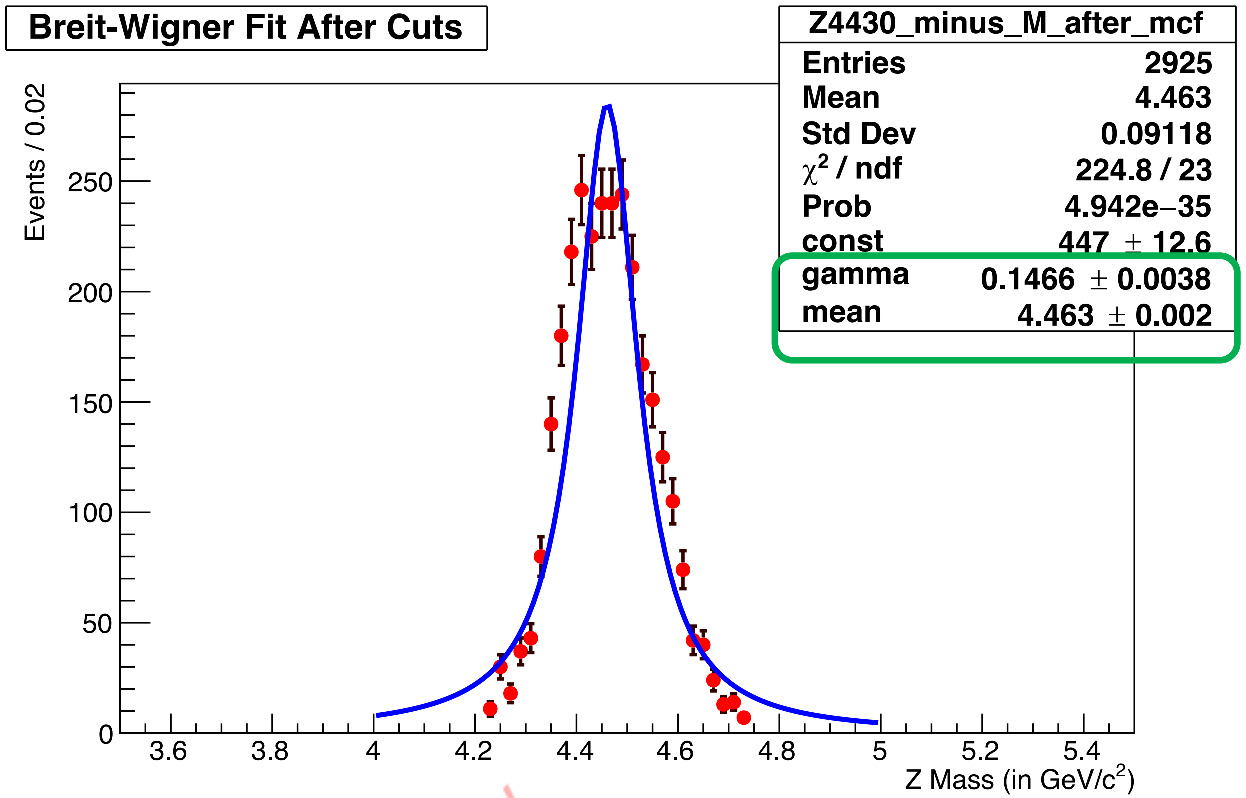




$Z(4430)$ Mass : $4478\,^{+15}_{-18}$ MeV

Analysis : $Z(4430)$ Width






```
*------------------------------------------------------------------------------------------------------------
* 21.04.2020 Updated by K. Goetzen. The format and convention are based on the current evt.pdl and PDG 2019
* - Updated particle data from http://pdg.lbl.gov/2019/mcdata/mass_width_2019.mcd and http://pdglive.lbl.gov
* - Ordering according to http://pdg.lbl.gov/2008/reviews/montecarlorpp.pdf
*------------------------------------------------------------------------------------------------------------
*
* [basic]        name                         id         mass/GeV       width/GeV      max_Dm/GeV    3*charge 2*spin lifetime*c/mm  PythiaId
add  p Particle  Z_c(4430)-                -99210443  4.4780000e+00  1.8100000e-01  1.8100000e+00    -3      2  0.0000000e+00  -99210443
```

PRELIMINARY

$Z(4430)$ Mass : 4463 $\pm$ 2 MeV

$Z(4430)$ Width : 146.6 $\pm$ 31 MeV

$Z(4430)$ Mass : 4478 $^{+15}_{-18}$ MeV

$Z(4430)$ Width : 181 $\pm$ 31 MeV

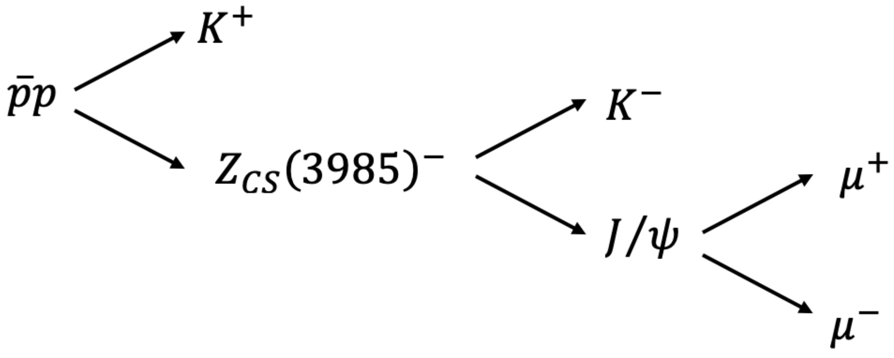
Analysis : $Z_{cs}(3985)$

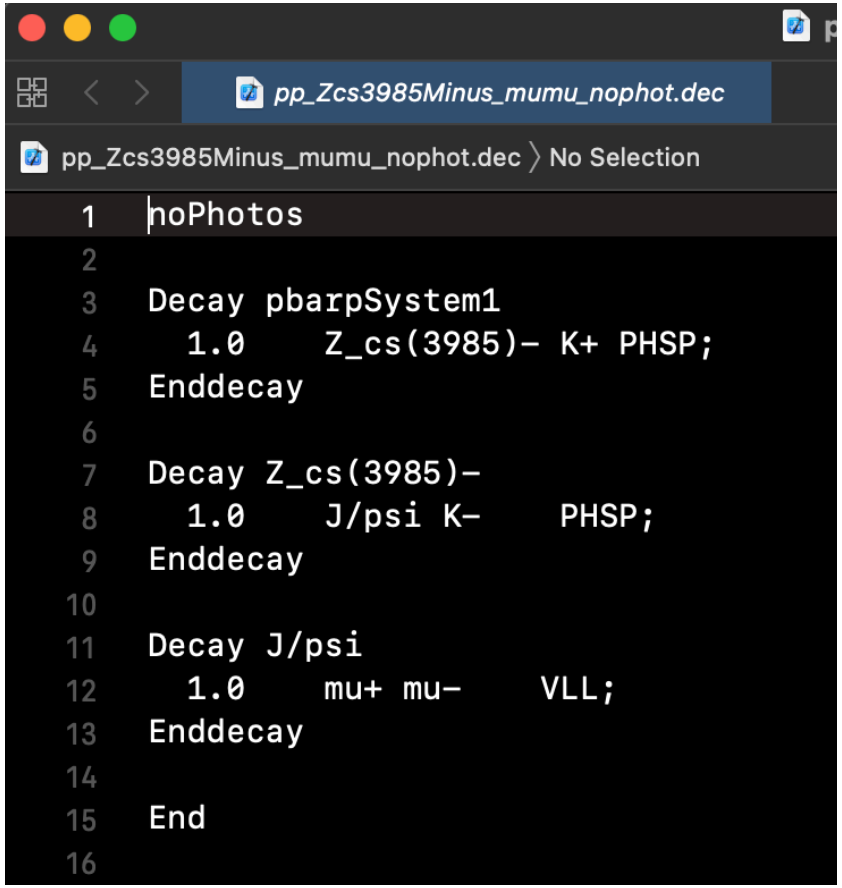
- We tried to implement newly proposed $Z_{cs}(3985)$ to the “evt.pdl” file in PandaROOT (EvtGen).

```
* [xyz cc-like]  name                      id         mass/GeV       width/GeV      max_Dm/GeV    3*charge 2*spin lifetime*c/mm  PythiaId
```

```
add  p Particle  Z_cs(3985)-              -59  3.9825000e+00  1.2800000e-02  1.2800000e-01    -3      2  0.0000000e+00        -59
```

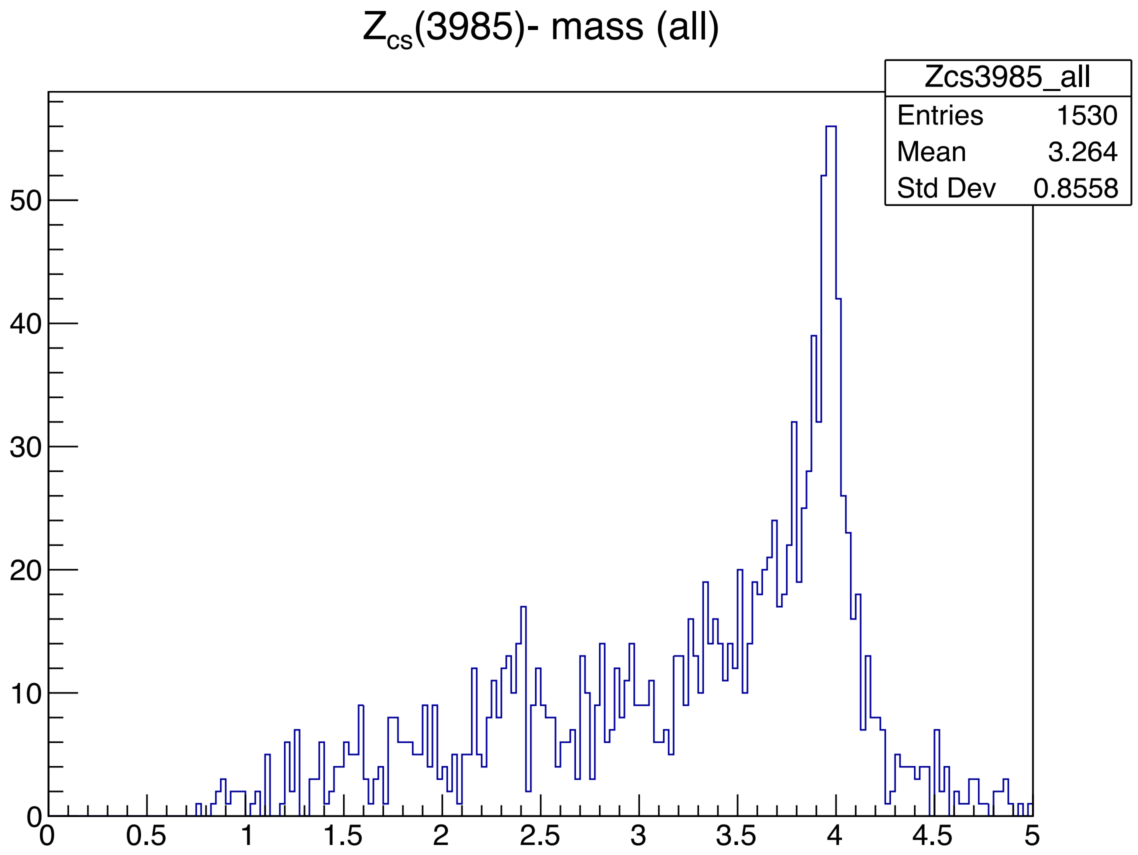
- By changing and adding $Z_{cs}(3985)$ to the EvtGen we will be able to produce some example data with this decay file:

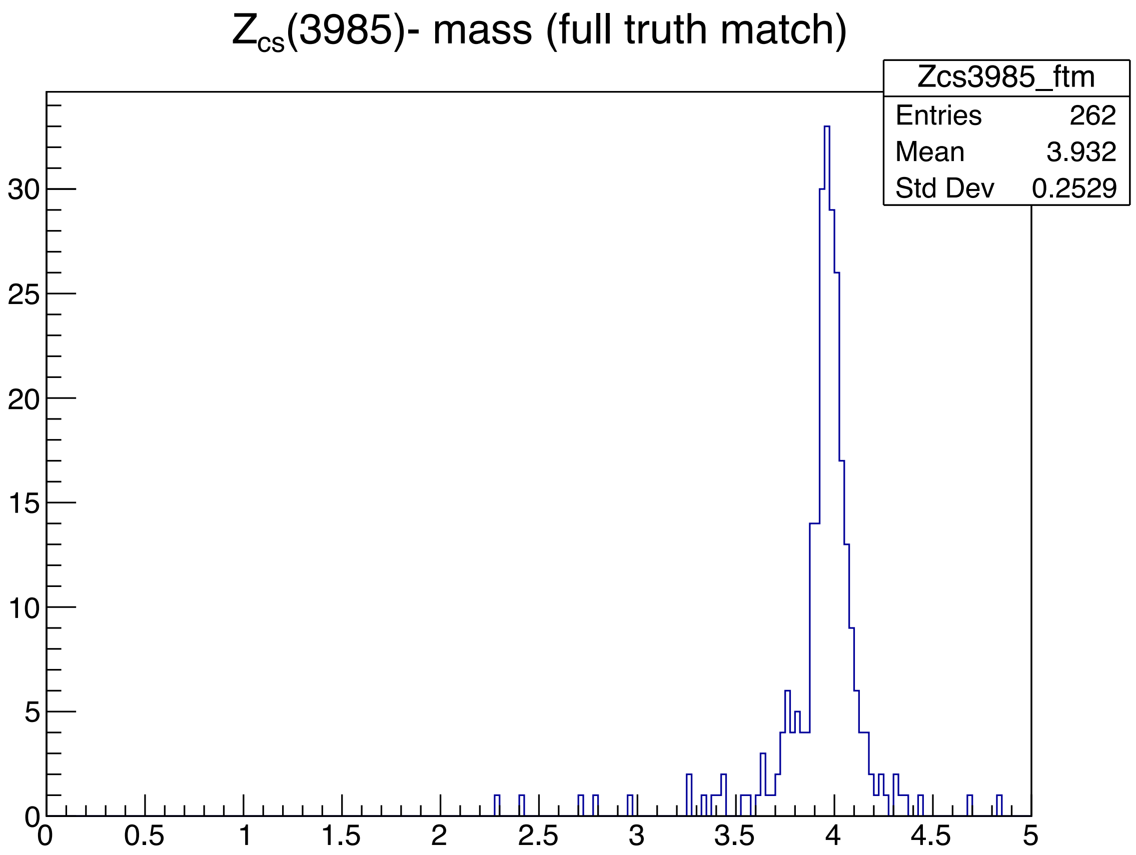





```
noPhotos

Decay pbarpSystem1
  1.0     Z_cs(3985)- K+ PHSP;
Enddecay

Decay Z_cs(3985)-
  1.0     J/psi K-     PHSP;
Enddecay

Decay J/psi
  1.0     mu+ mu-     VLL;
Enddecay

End
```

Analysis : Z_{cs}(3985)





Data Productions Ongoing

- Produced 1M events from each decay mode on our Linux Server PC

$Z_c(3900)^-$

$$\begin{tikzcd}
 & & \pi^+ & & \\
\bar{p}p \arrow[r] & \psi(4260) \arrow[ur] \arrow[dr] & & \pi^- & \\
 & & Z_c(3900)^- \arrow[ur] \arrow[dr] & & e^+ \\
 & & & J/\psi \arrow[ur] \arrow[dr] & \\
 & & & & e^-
\end{tikzcd}$$

$$\begin{tikzcd}
 & & \pi^+ & & \\
\bar{p}p \arrow[r] & \psi(4260) \arrow[ur] \arrow[dr] & & \pi^- & \\
 & & Z_c(3900)^- \arrow[ur] \arrow[dr] & & \mu^+ \\
 & & & J/\psi \arrow[ur] \arrow[dr] & \\
 & & & & \mu^-
\end{tikzcd}$$

$Z_c(3900)^+$

$$\begin{tikzcd}
 & & \pi^- & & \\
\bar{p}p \arrow[r] & \psi(4260) \arrow[ur] \arrow[dr] & & \pi^+ & \\
 & & Z_c(3900)^+ \arrow[ur] \arrow[dr] & & e^+ \\
 & & & J/\psi \arrow[ur] \arrow[dr] & \\
 & & & & e^-
\end{tikzcd}$$

$$\begin{tikzcd}
 & & \pi^- & & \\
\bar{p}p \arrow[r] & \psi(4260) \arrow[ur] \arrow[dr] & & \pi^+ & \\
 & & Z_c(3900)^+ \arrow[ur] \arrow[dr] & & \mu^+ \\
 & & & J/\psi \arrow[ur] \arrow[dr] & \\
 & & & & \mu^-
\end{tikzcd}$$

Data Productions Ongoing

- Produced 1M events from each decay channel on our Linux Server PC

Z(4430)$^-$

$$\bar{p}p \to \pi^+ \, Z(4430)^-, \quad Z(4430)^- \to \pi^- \, \psi(2S), \quad \psi(2S) \to e^+ e^-$$

$$\bar{p}p \to \pi^+ \, Z(4430)^-, \quad Z(4430)^- \to \pi^- \, \psi(2S), \quad \psi(2S) \to \mu^+ \mu^-$$

Z(4430)$^+$

$$\bar{p}p \to \pi^- \, Z(4430)^+, \quad Z(4430)^+ \to \pi^+ \, \psi(2S), \quad \psi(2S) \to e^+ e^-$$

$$\bar{p}p \to \pi^- \, Z(4430)^+, \quad Z(4430)^+ \to \pi^+ \, \psi(2S), \quad \psi(2S) \to \mu^+ \mu^-$$

Data Productions Ongoing

- Produced 1M events from each decay channel on our Linux Server PC

$Z_{cs}(3985)^-$

$$\bar{p}p \to K^+ \, Z_{cs}(3985)^-, \quad Z_{cs}(3985)^- \to K^- \, J/\psi, \quad J/\psi \to e^+ e^-$$

$$\bar{p}p \to K^+ \, Z_{cs}(3985)^-, \quad Z_{cs}(3985)^- \to K^- \, J/\psi, \quad J/\psi \to \mu^+ \mu^-$$

Data Productions Ongoing

- **Producing DPM Background data at beam momentum (pbeam) = 8.5454 GeV/c for $Z_c(3900)$.**

- **Producing DPM Background data at maximum pbeam 15.0 GeV/c for Z(4430) and $Z_{cs}(3985)$.**

- **We already produced at least 1M events for each particle and decay mode as well as we also aiming to produce at least 10M events for DPM background soon.**

Discussion & Outlook

- For this Z(4430) analysis study, we are aiming to find particle widths accurately by fitting the reconstructed candidates via Breit-Wigner fit function.

- At this moment, after some problems, now we are producing some big data on our Dell Server PC. 1M events for $Z_c(3900)^+$, $Z_c(3900)^-$, $Z(4430)^+$, $Z(4430)^-$ and $Z_{cs}(3985)^-$ have already been produced.

- We are also targeting to produce at least 10M DPM events for initial analysis study. Producing ongoing.

- After producing some big data, signal-to-background ratio and reconstruction efficiency studies will be done with further analysis.

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THANK YOU FOR YOUR ATTENTION!