Measurement of the $e^+e^- \to \pi^+\pi^- h_c$ cross section

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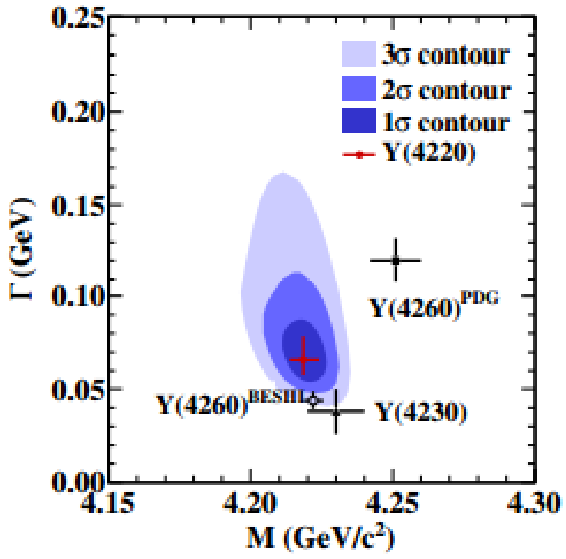
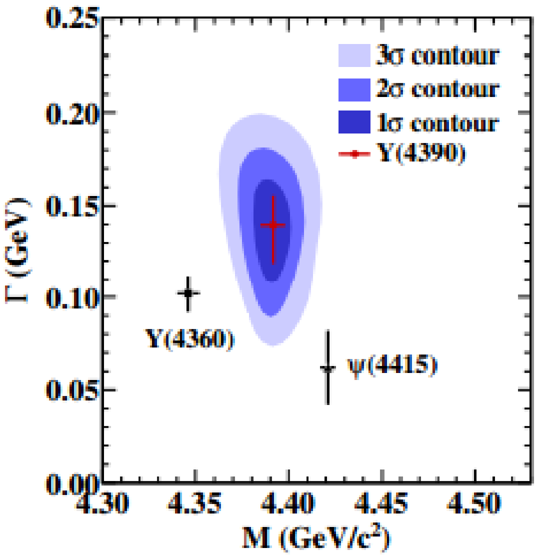
Outline

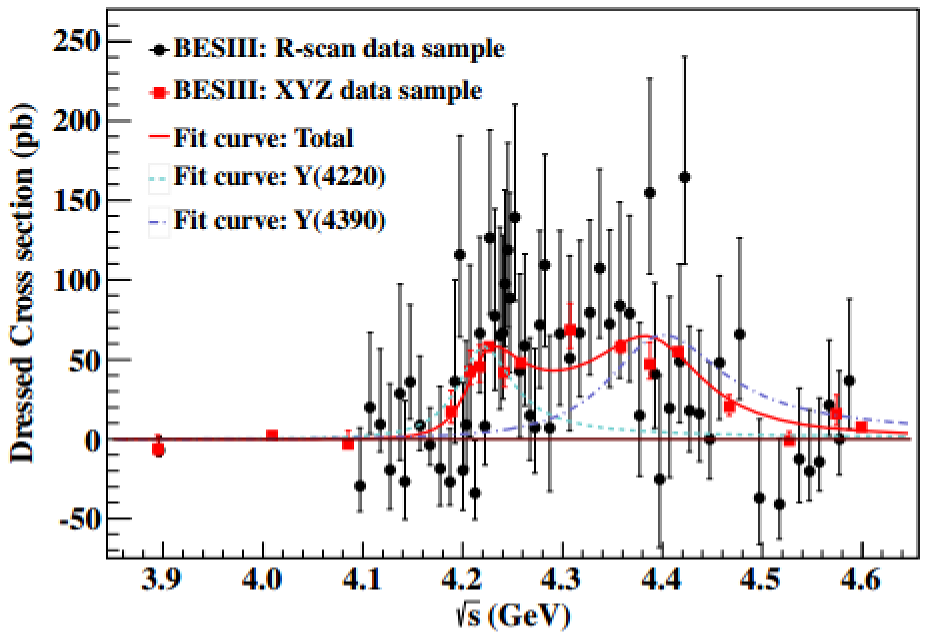
- Motivation & data set
- Event selection
- Fitting
- Looking for Z_c status
- Next to do

Motivation

- The cross section of $\pi^+\pi^-h_c$ at 79 energy within 3.9-4.6 GeV have been measured
- Two structures are observed around 4.220 and 4.380 GeV/c^2

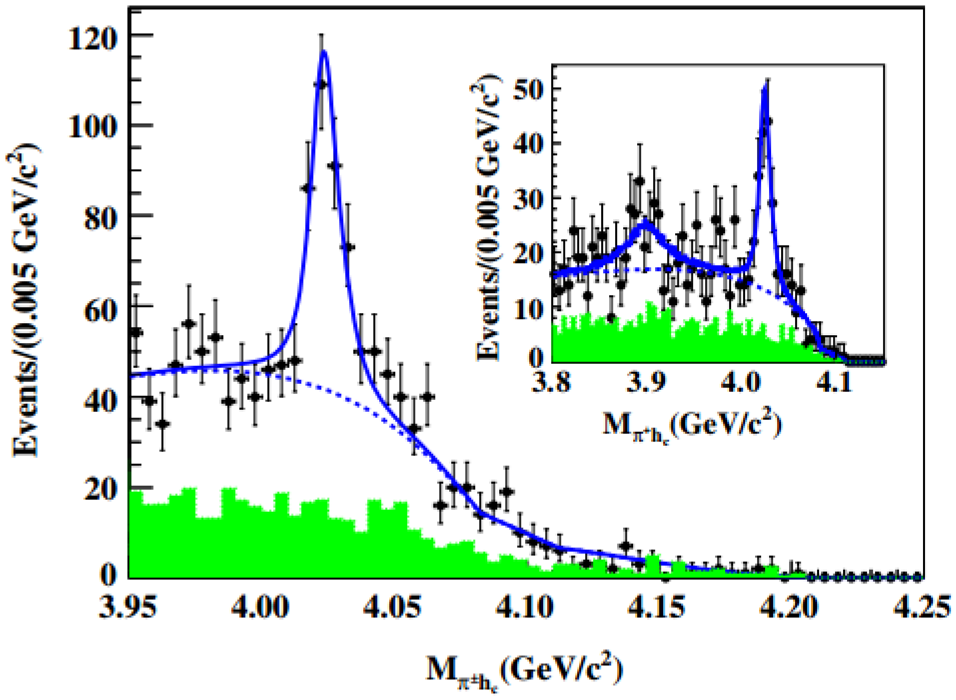






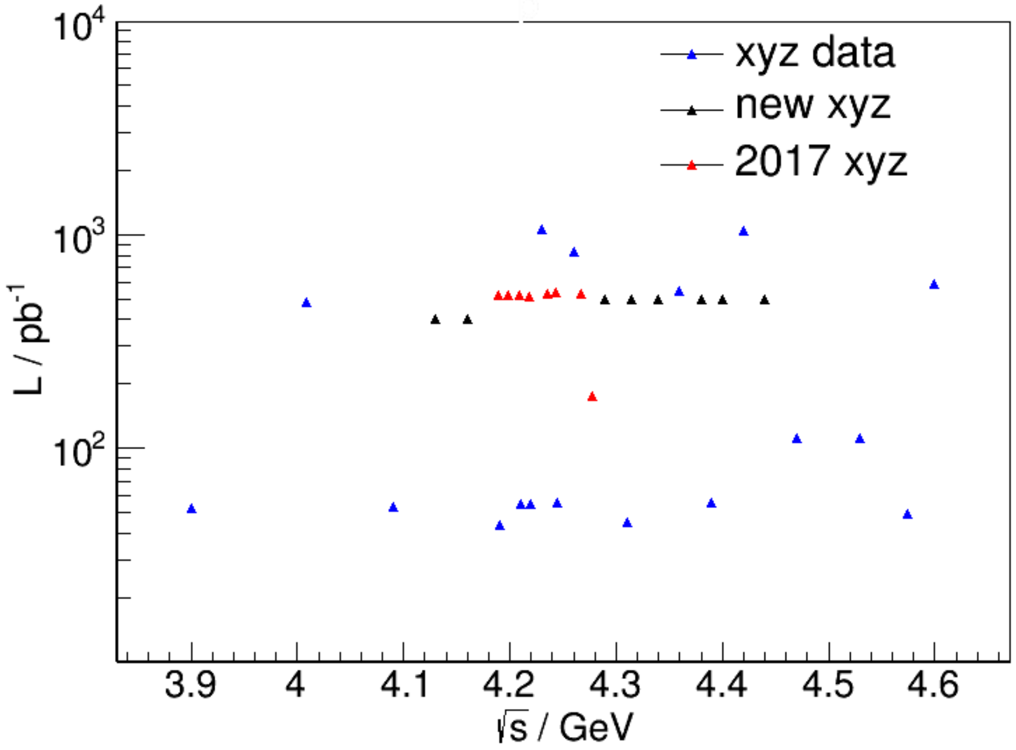
Motivation

- In the mass spectrum of $\pi^{\pm}h_c$, a charged charmonium-like resonance $Z_c(4020)$ is observed (6.4σ).
- A structure at 3.9 GeV is seen (2.1σ).



Motivation

- Using new XYZ sample taken at 2017 and this year
  - Previous vacancy is filled
  - Statistic is higher



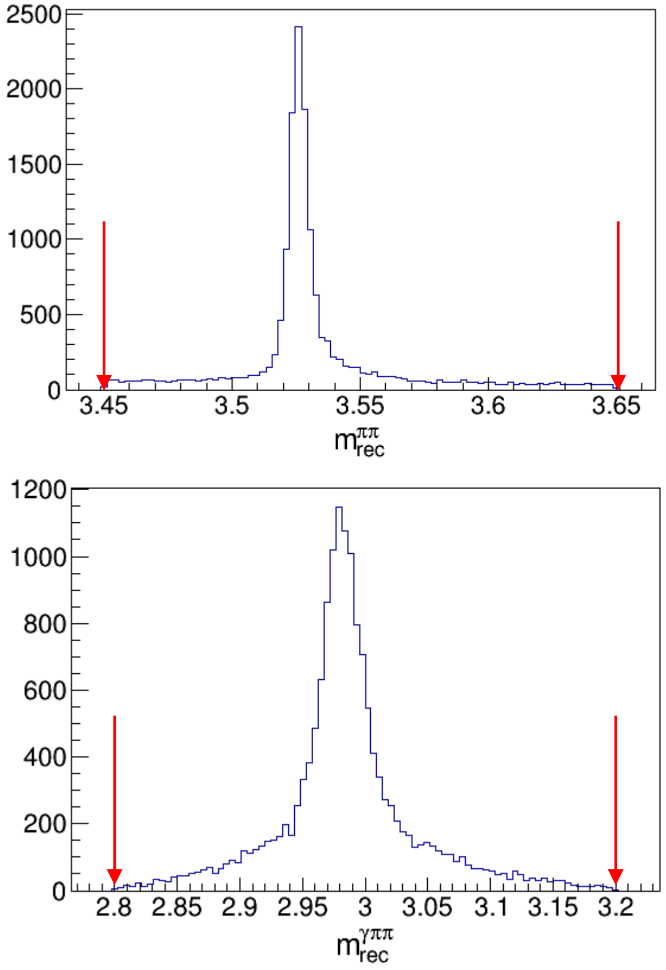
Event selection

- Target channel : $e^+e^- \to \pi^+\pi^- h_c \to \pi^+\pi^-\gamma\eta_c$
    - η_c is reconstructed using 16 channels
    - $K_s \to \pi^+\pi^-$
    - $\pi^0/\eta \to \gamma\gamma$
- 16 channels are divided to three classes:
    - $\eta_c \to$ charged particles
    - $\eta_c \to$ charged particles + π^0/η
    - $\eta_c \to$ charged particles + K_s

η_c decay mode
$p\bar{p}$
$\pi^+\pi^-K^+K^-$
$\pi^+\pi^-p\bar{p}$
$2(\pi^+\pi^-)$
$2(K^+K^-)$
$3(\pi^+\pi^-)$
$K^+K^-2(\pi^+\pi^-)$
$K^0_SK^\pm\pi^\mp$
$K^0_SK^\pm\pi^\mp\pi^+\pi^-$
$K^+K^-\pi^0$
$p\bar{p}\pi^0$
$K^+K^-\eta$
$\pi^+\pi^-\eta$
$\pi^+\pi^-\pi^0\pi^0$
$2(\pi^+\pi^-)\eta$
$2(\pi^+\pi^-\pi^0)$

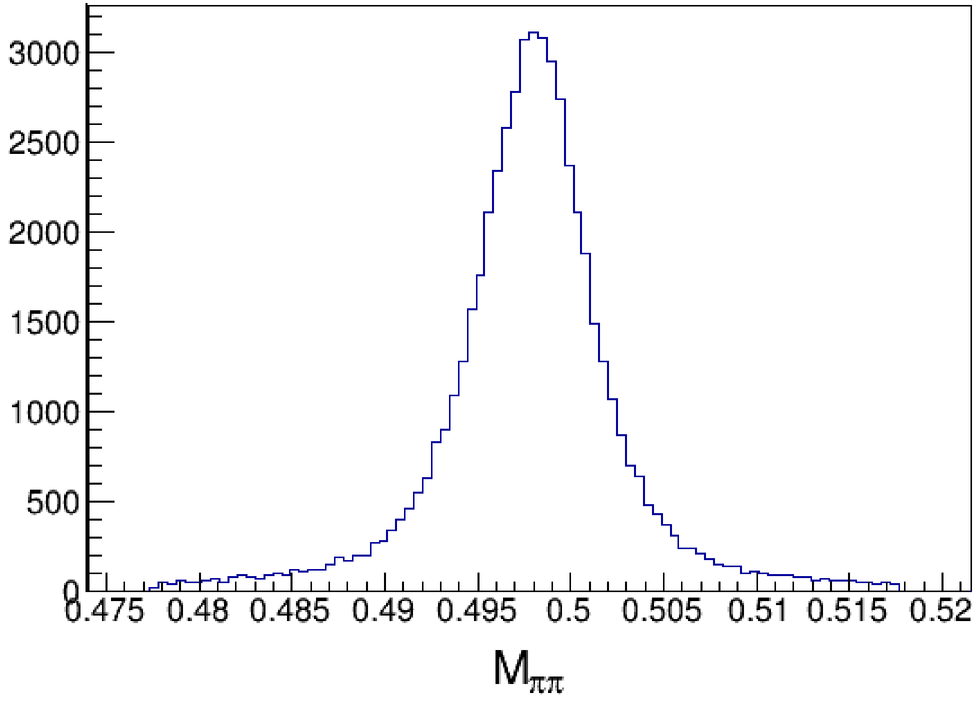
Event selection

- Good charged tracks
  - V_{xy} < 1 cm, $|V_z|$ < 10 cm
  - $|\cos\theta|$ < 0.93
- Good photon
  - E_γ > 25 MeV (barrel) OR E_γ > 50 MeV (end caps)
  - 0 < TDC < 14
- Exact number of good charged tracks
- Minimum limit for number of good photons
- Build a $\gamma\pi^+\pi^-$ list
  - 3.45 GeV/c^2 < $m_{rec}^{\pi\pi}$ < 3.65 GeV/c^2
  - 2.8 GeV/c^2 < $m_{rec}^{\gamma\pi\pi}$ < 3.2 GeV/c^2



Event selection

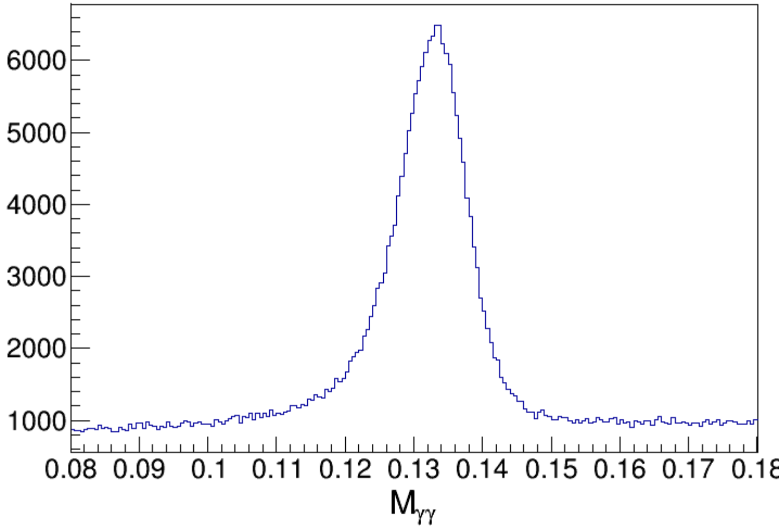
- For Ks channels
  - Combine two tracks and get a virtual track from vertex fit
  - The virtual track is fitted to IP
  - decay length : $L/\sigma_L > 2$
  - $| M_{\pi\pi} - M_{Ks} | < 20$ MeV/c^2
- Store a combination with minimum χ^2
  - $\chi^2 = \chi^2_{4c} + \Sigma\chi^2_{PID}$

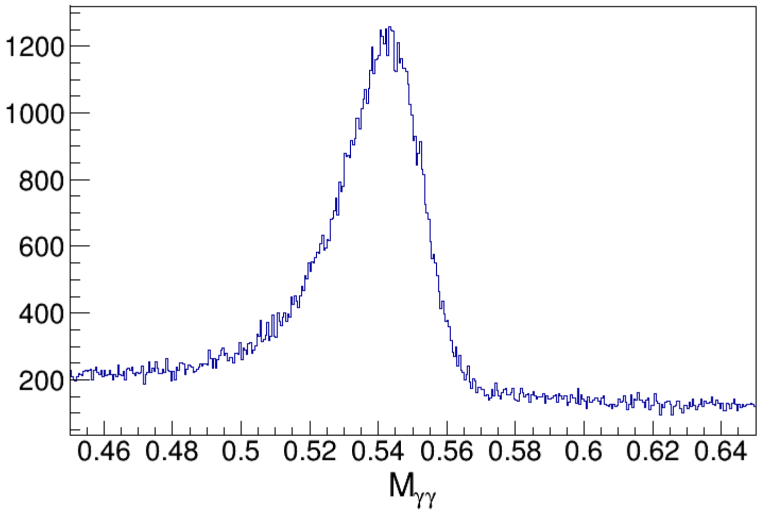


Event selection

- For channels with π^0/η :
- π^0 and η mass window : $|M_{\gamma\gamma} - M_{\pi/\eta}| < 15$ MeV/c^2
- Store a combination with minimum χ^2
  - $\chi^2 = \chi^2_{4c} + \Sigma\chi^2_{PID} + \chi^2_{1c}$

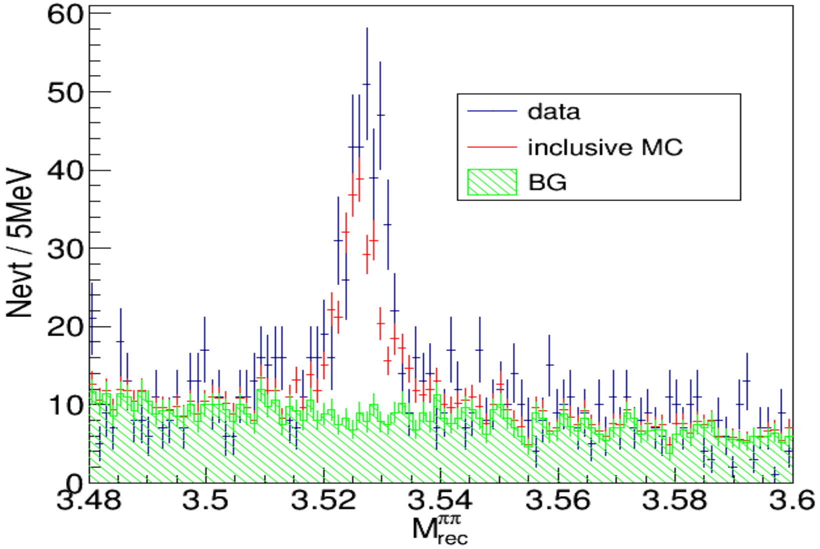
- For channels with only charged tracks:
- Store a combination with minimum χ^2
  - $\chi^2 = \chi^2_{4c} + \Sigma\chi^2_{PID}$

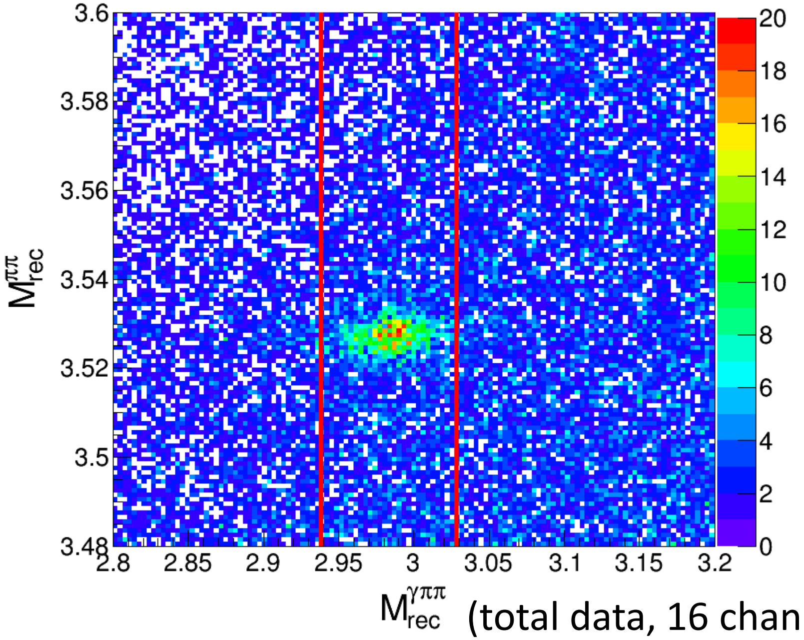




Event selection

- Further selections after re-combination : χ^2 and mass window for η_c
  - π^0/η channels : $\chi_{4c}^2 < 20$, $|M_{\gamma\pi\pi}^{rec} - M_{\eta c}| < 45$ MeV/c^2
  - Other channels : $\chi_{4c}^2 < 35$, $|M_{\gamma\pi\pi}^{rec} - M_{\eta c}| < 50$ MeV/c^2
- The background is studied using inclusive MC at 4.237 GeV
  - No peaking background
  - The agreement is good



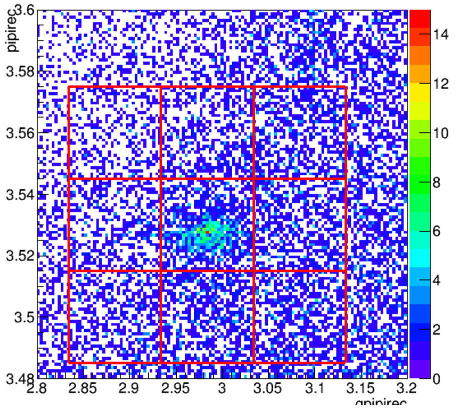


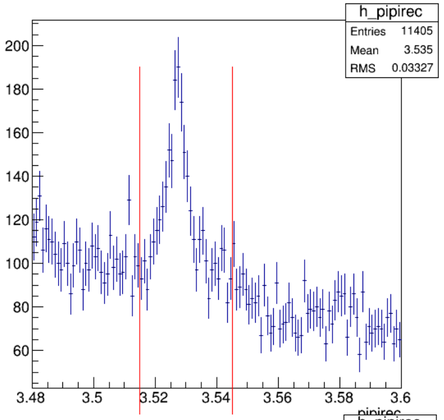
(total data, 16 channels)

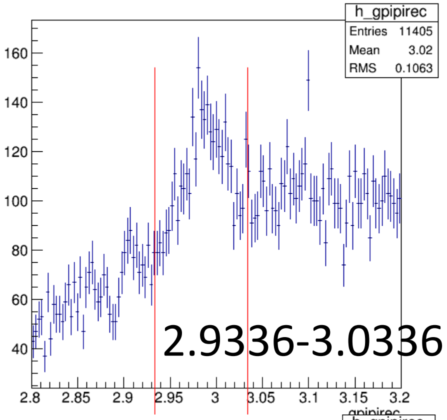
Optimization

- The optimization is done using data sample
  - The definition of signal/sideband region for different channels is shown below

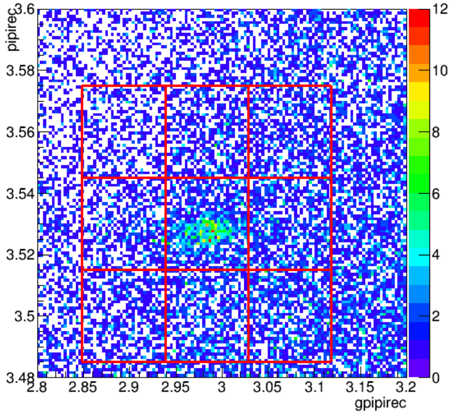
Ks/C

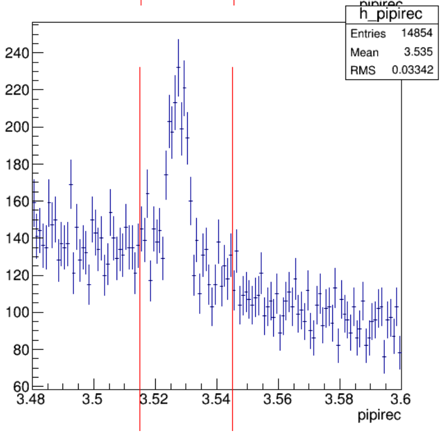


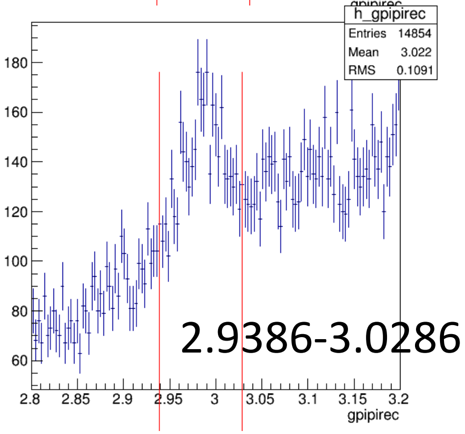




N





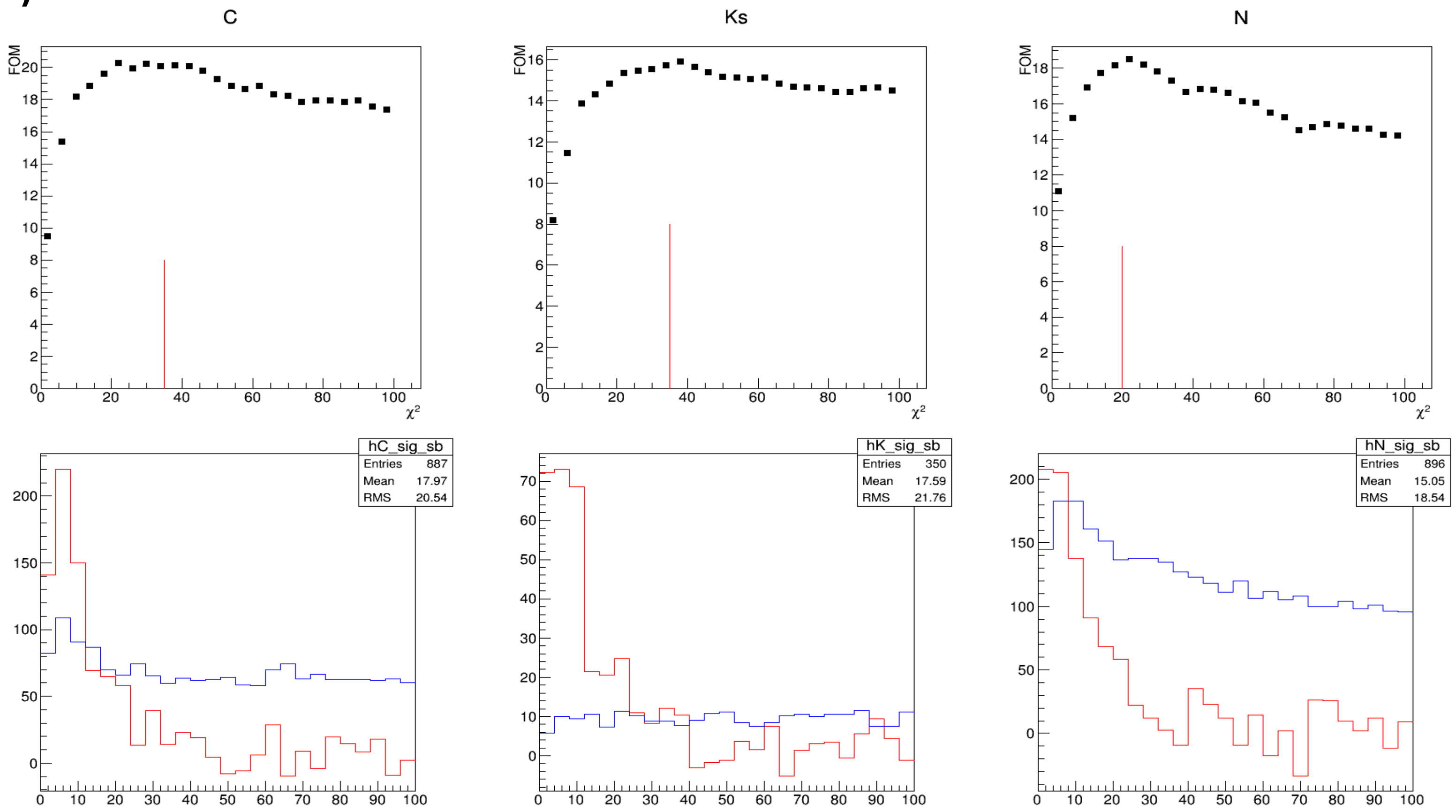


Optimization

- The optimization of χ^2 requirement is done using total data sample
  - FOM = S/sqrt(S+B)

FOM distribution

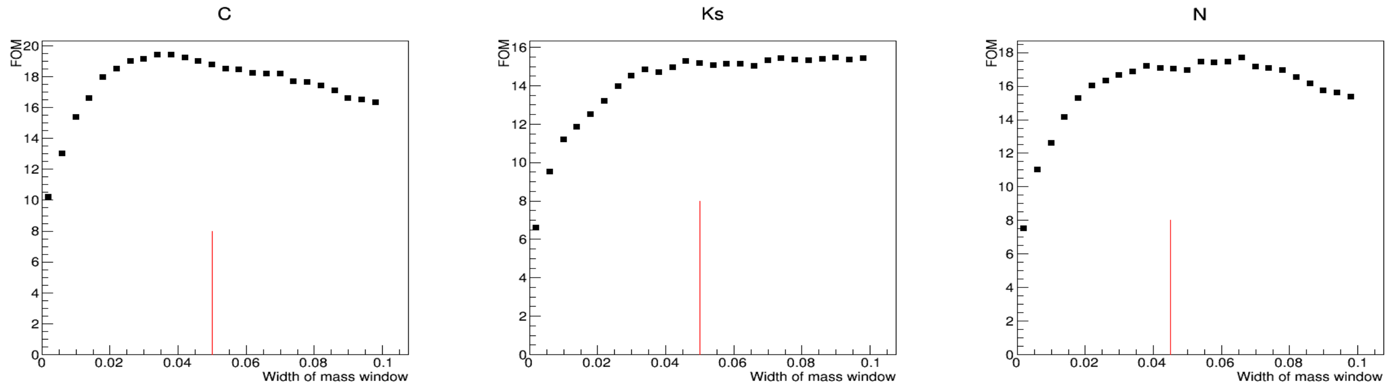
χ^2 distribution of
Signal-sideband
sideband



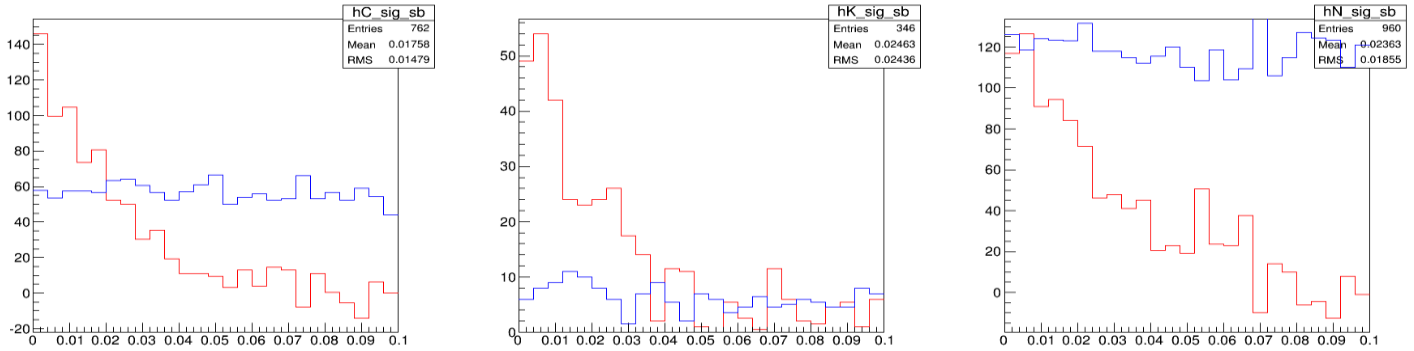
Optimization

- The optimization of mass window is done using total data sample
  - Use default χ^2 cut (35 for C/Ks channels and 20 for N channels)

FOM distribution

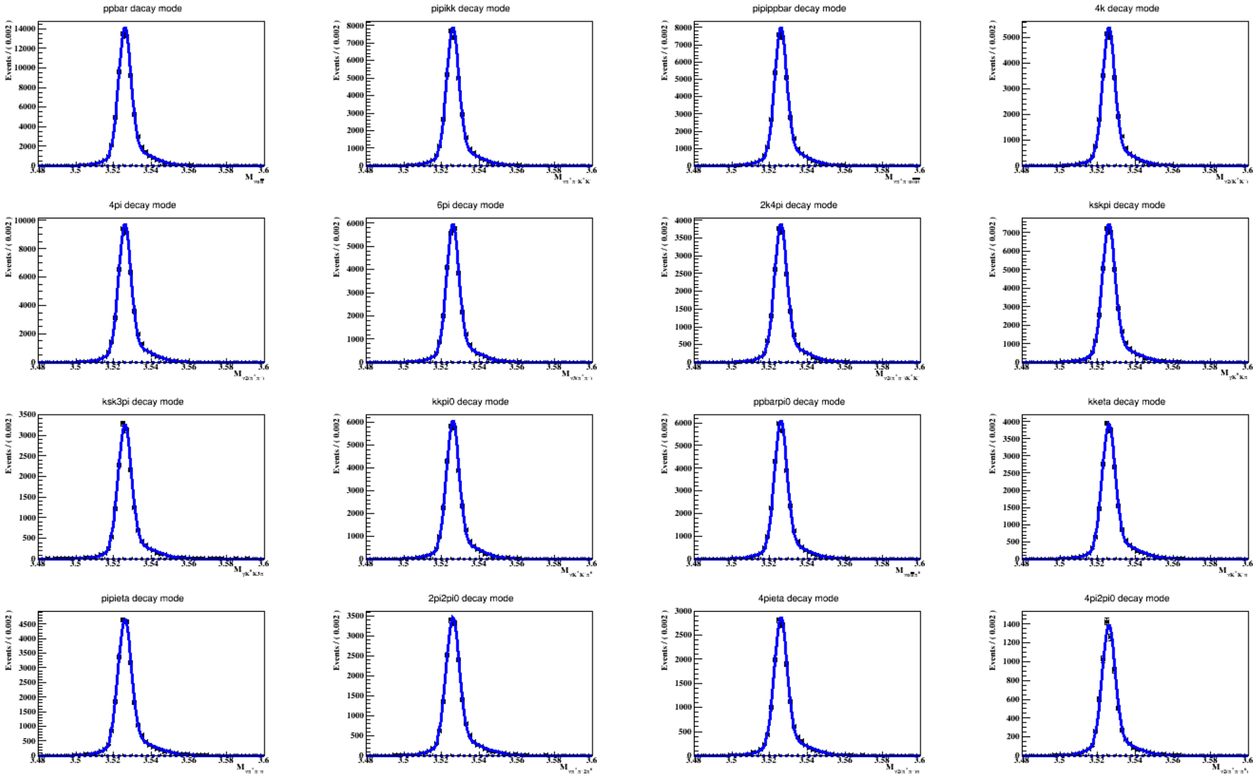


$|M_{\gamma\pi\pi}^{rec} - M_{\eta c}|$ distribution of
Signal-sideband
sideband



Fitting

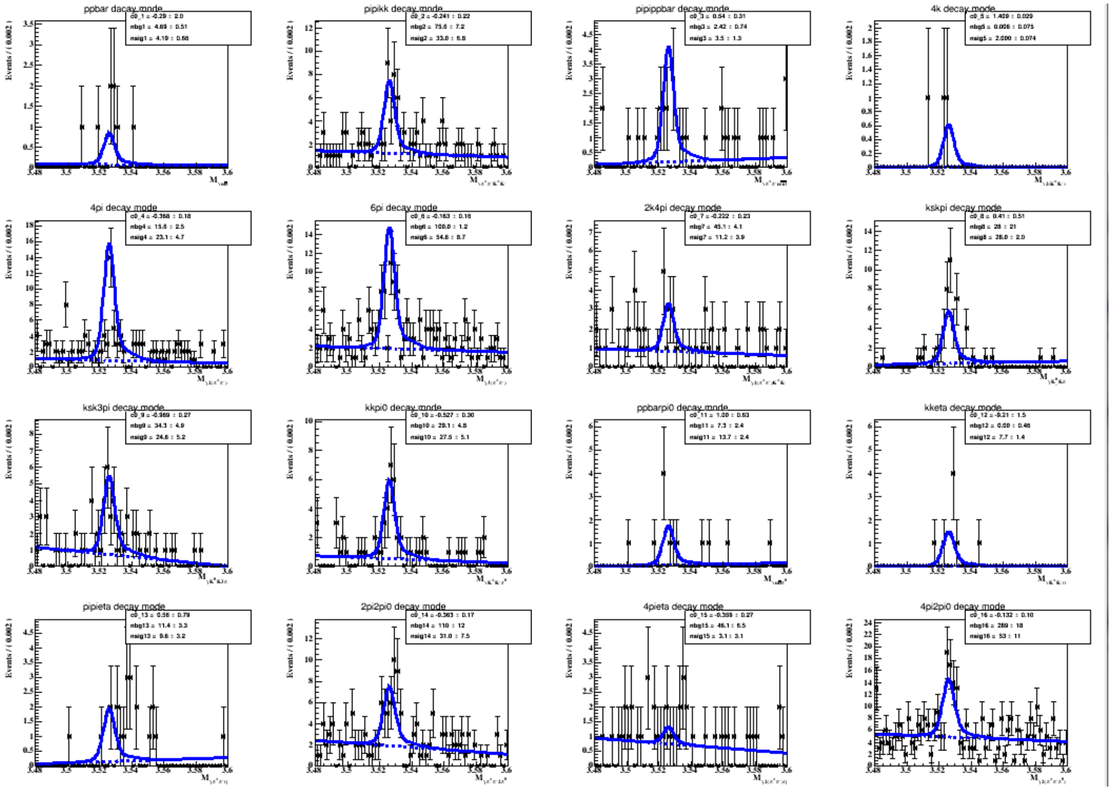
- Fit $M_{\pi\pi}^{rec}$ of MC simulation to extract resolution
  - BW convolved with a double-Gaussian
  - Simultaneous fit



$M_{\pi\pi}^{rec}$ of MC simulation at 4.237 GeV

Fitting

- Fit $M_{\pi\pi}^{rec}$ of data to extract signal
  - BW convolved with a double-Gaussian + linear function
  - The difference of between data and MC can be estimated by using MC convolve with a Gaussian
  - Here simply use MC shape



$M_{\pi\pi}^{rec}$ of data at 4.237 GeV

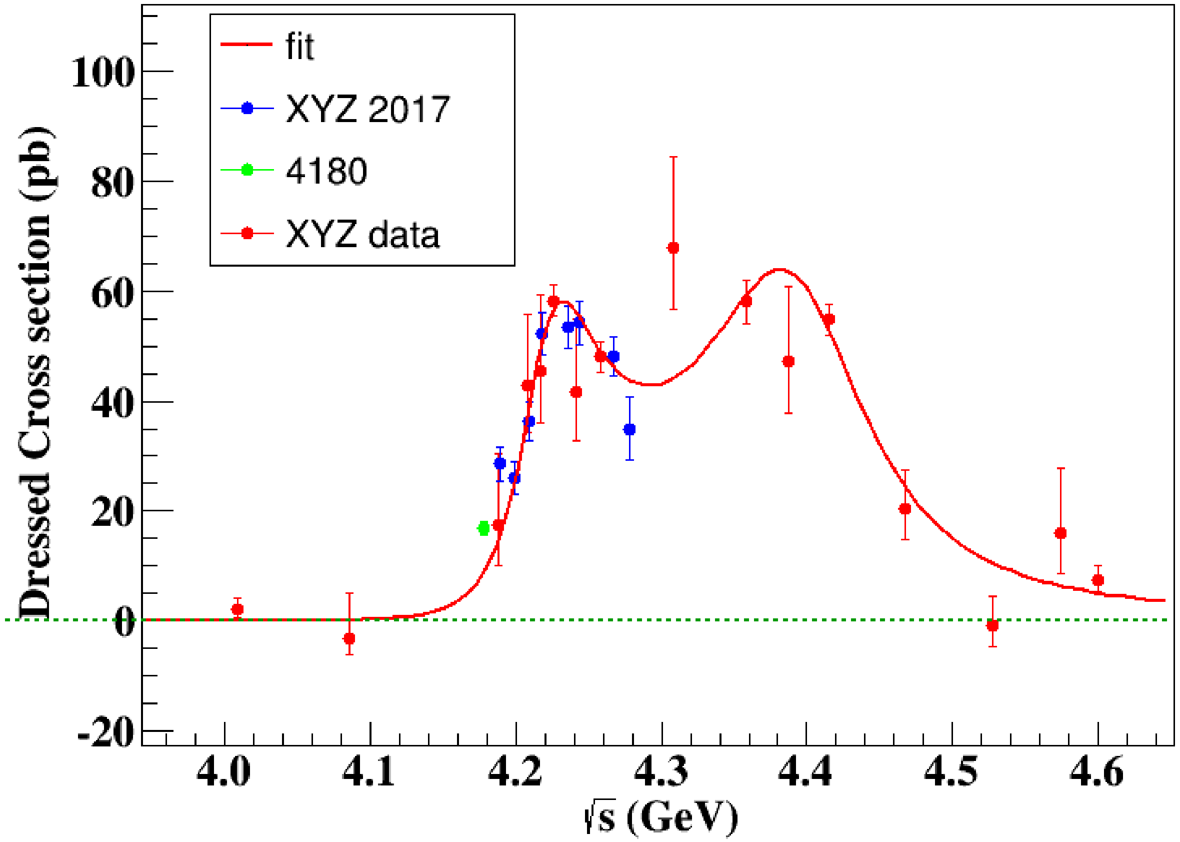
Fitting

- Use previous line-shape as input
- Not far from previous result

Ecms / GeV	N_{signal}	$\Sigma Br_i * \varepsilon_i(\%)$	$(1+\delta)$	Lumi	σ(pb)
4180	570.3 ± 37.7	3.092	0.711	3189.0	15.1 ± 1.0
4190	159.8 ± 17.6	3.112	0.713	521.9	25.4 ± 2.8
4200	148.9 ± 16.8	3.192	0.711	523.7	23.2 ± 2.6
4210	198.8 ± 18.9	3.097	0.713	511.2	32.3 ± 3.1
4220	286.9 ± 21.0	3.094	0.723	508.2	46.4 ± 3.4
4237	329.6 ± 23.3	3.194	0.763	528.9	47.5 ± 3.4
4246	339.6 ± 24.1	3.108	0.785	532.7	48.2 ± 3.4
4270	306.7 ± 22.0	3.025	0.832	529.3	42.9 ± 3.1
4280	73.6 ± 12.2	2.972	0.843	174.5	31.2 ± 5.2

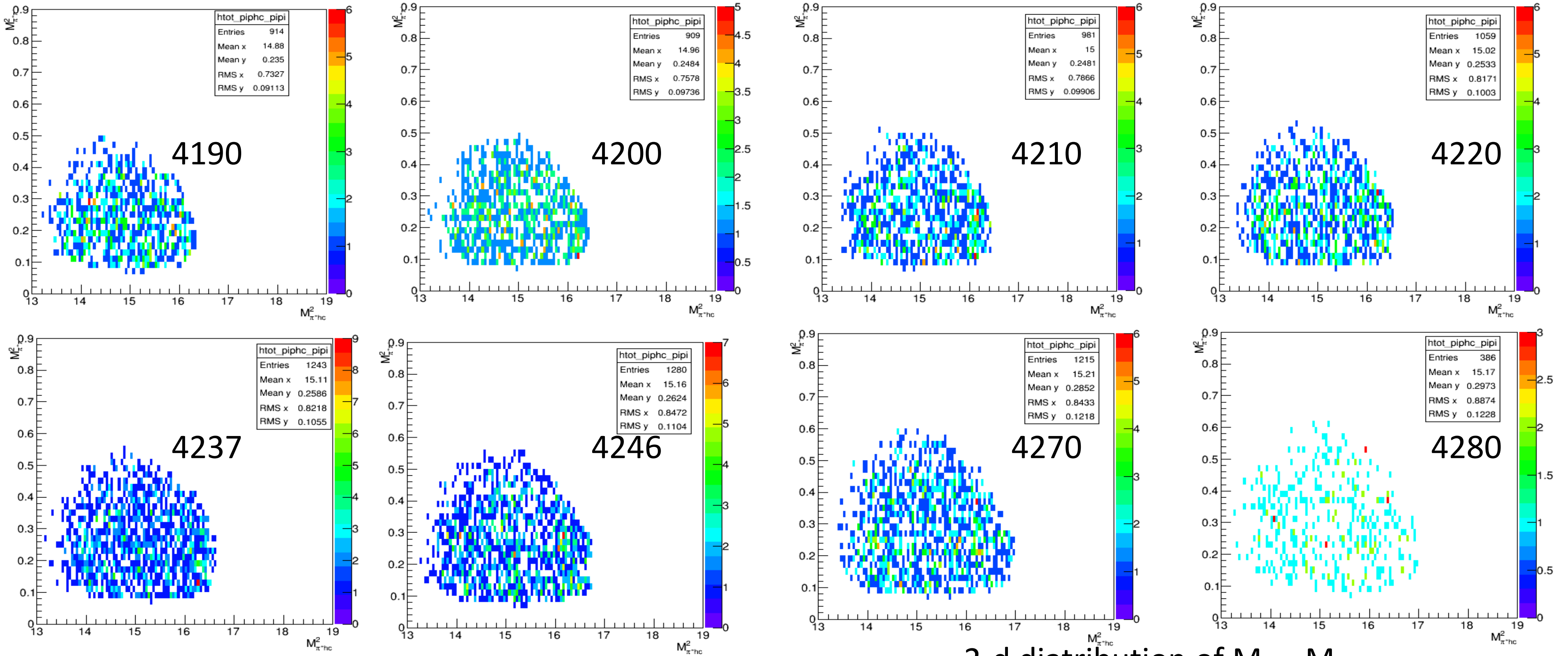
Fitting

- New results (before iteration) are close to previous fit curve



Looking for Zc status

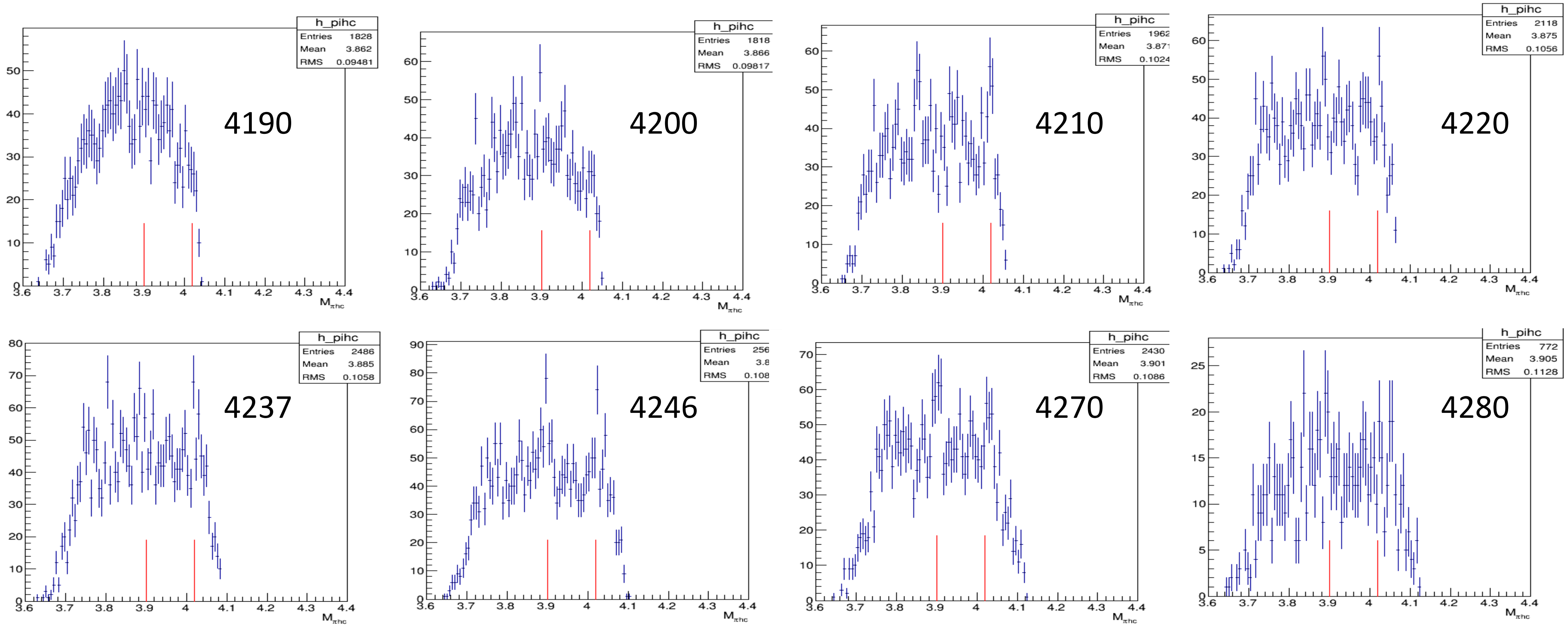
- Sum 16 channels up at 8 energy points



2-d diatribution of $M_{\pi hc}$ $M_{\pi\pi}$

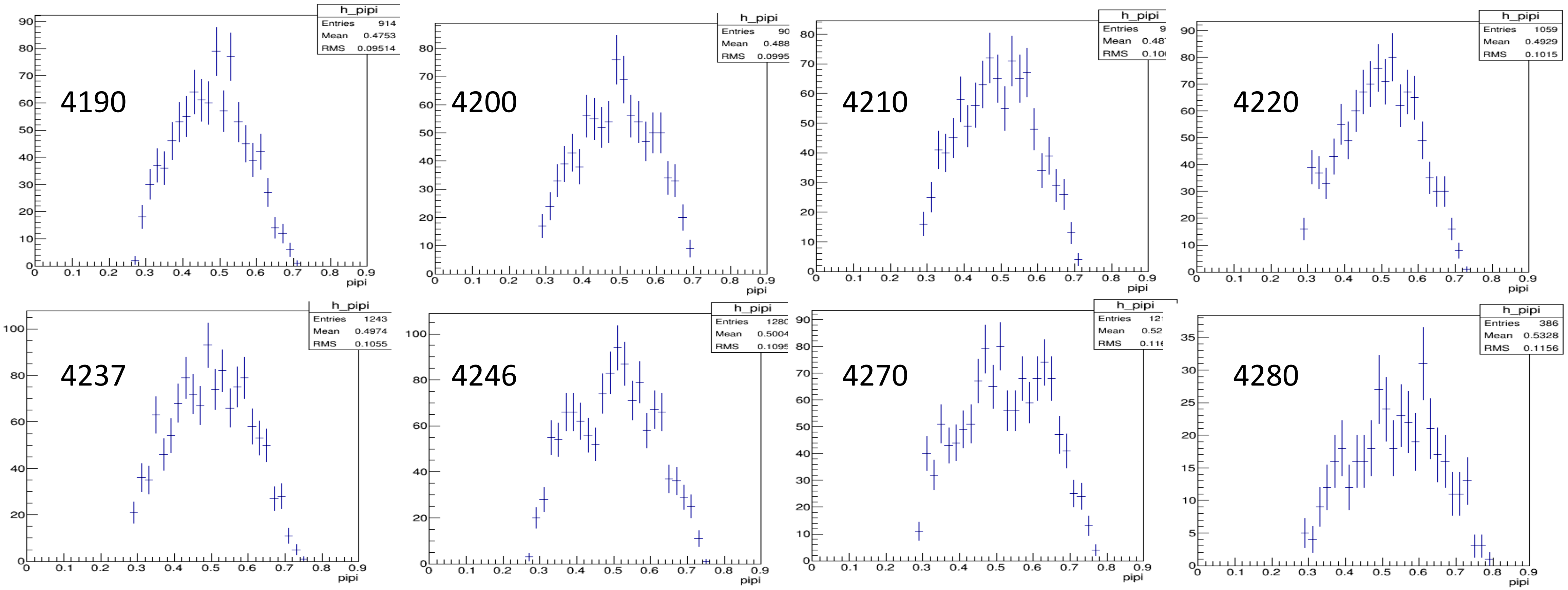
Looking for Zc status

- $M_{\pi hc}$, sum 16 channels up at 8 energy points



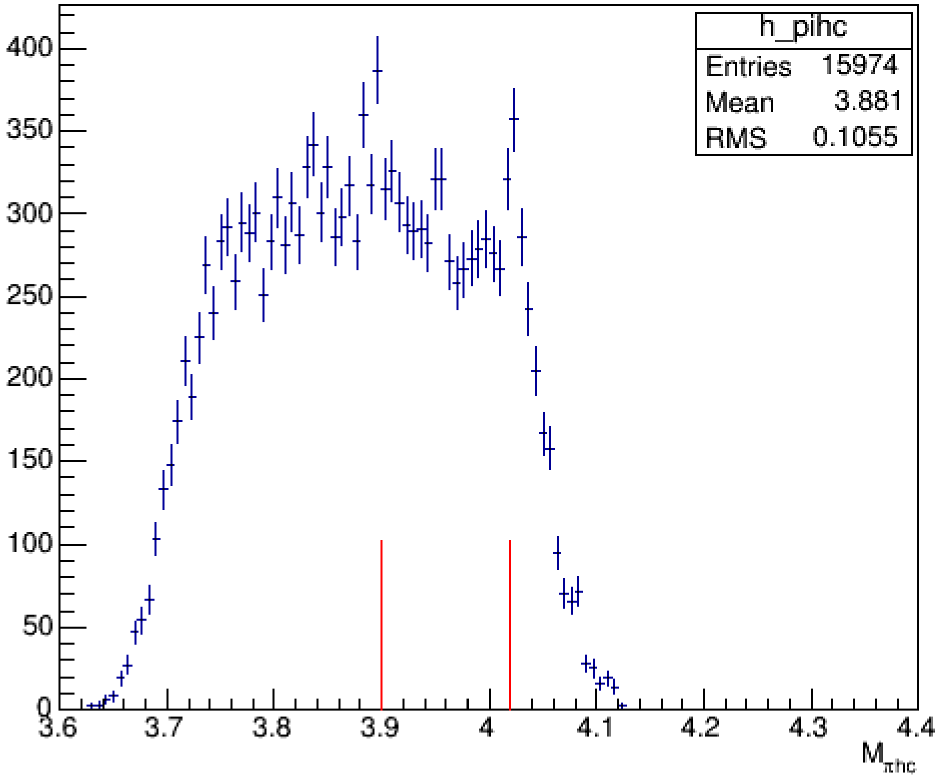
Looking for Zc status

- $M_{\pi\pi}$, sum 16 channels up at 8 energy points
- This distribution seems correlated to Ecms



Looking for Zc status

- Background level is high
- Structures can be seen if adding channels and data points up



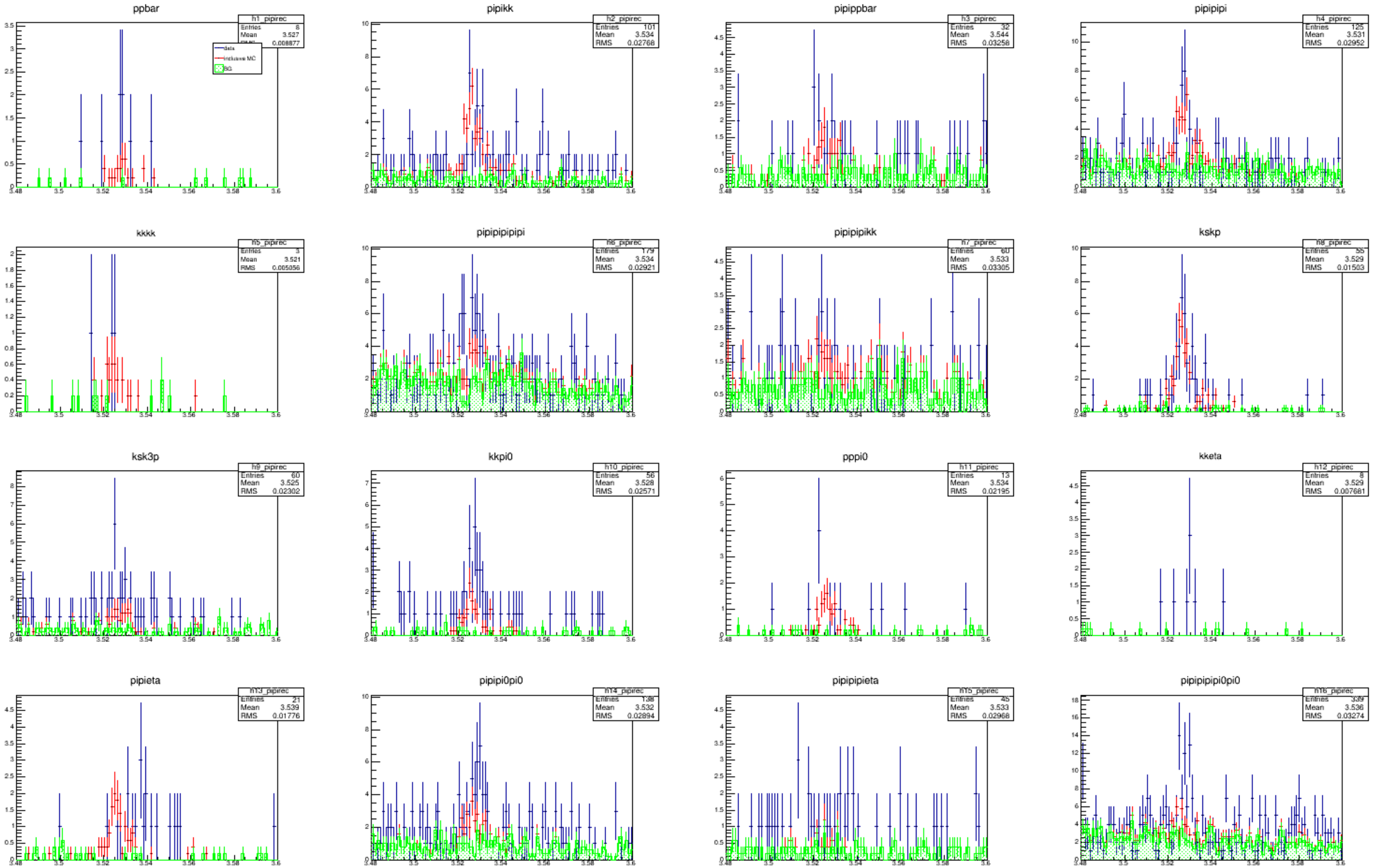
Next to do

- Further selection optimization
- Study data-MC difference on the resolution of $M_{\pi\pi}^{rec}$

Thank you !

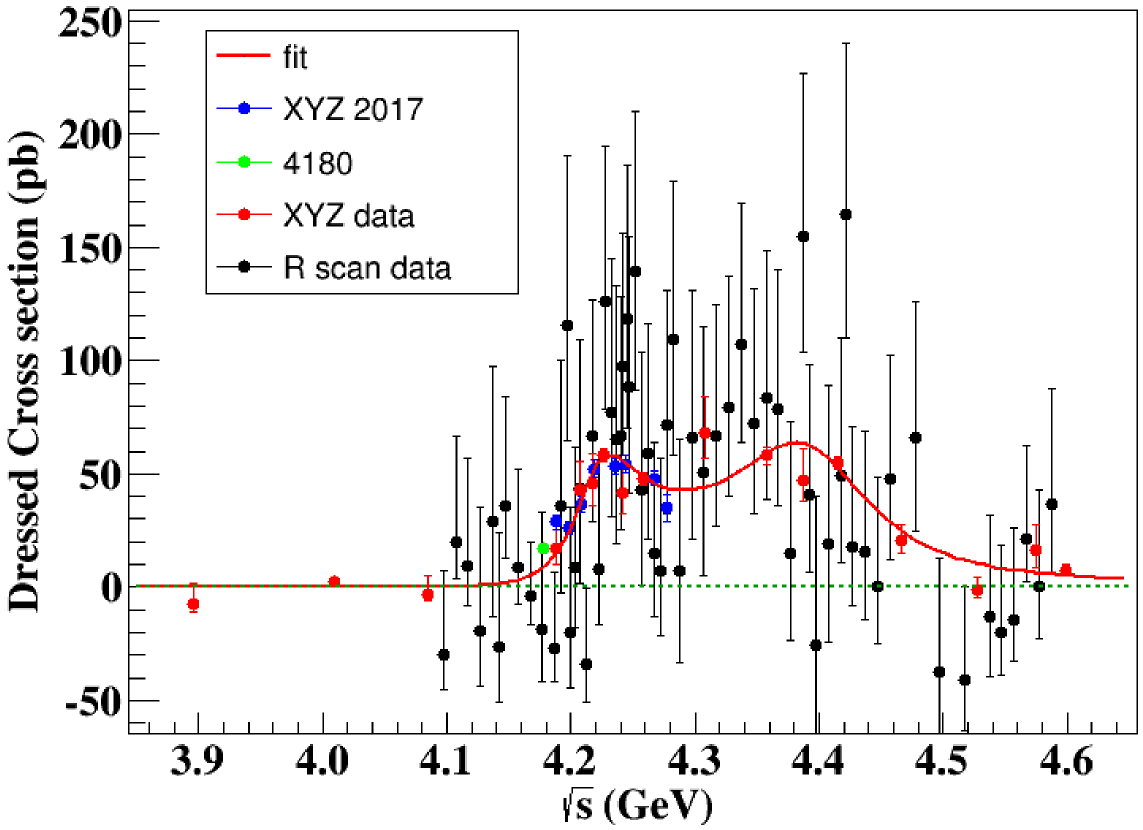
Back up

Compare data with inclusive MC at 4.237 GeV



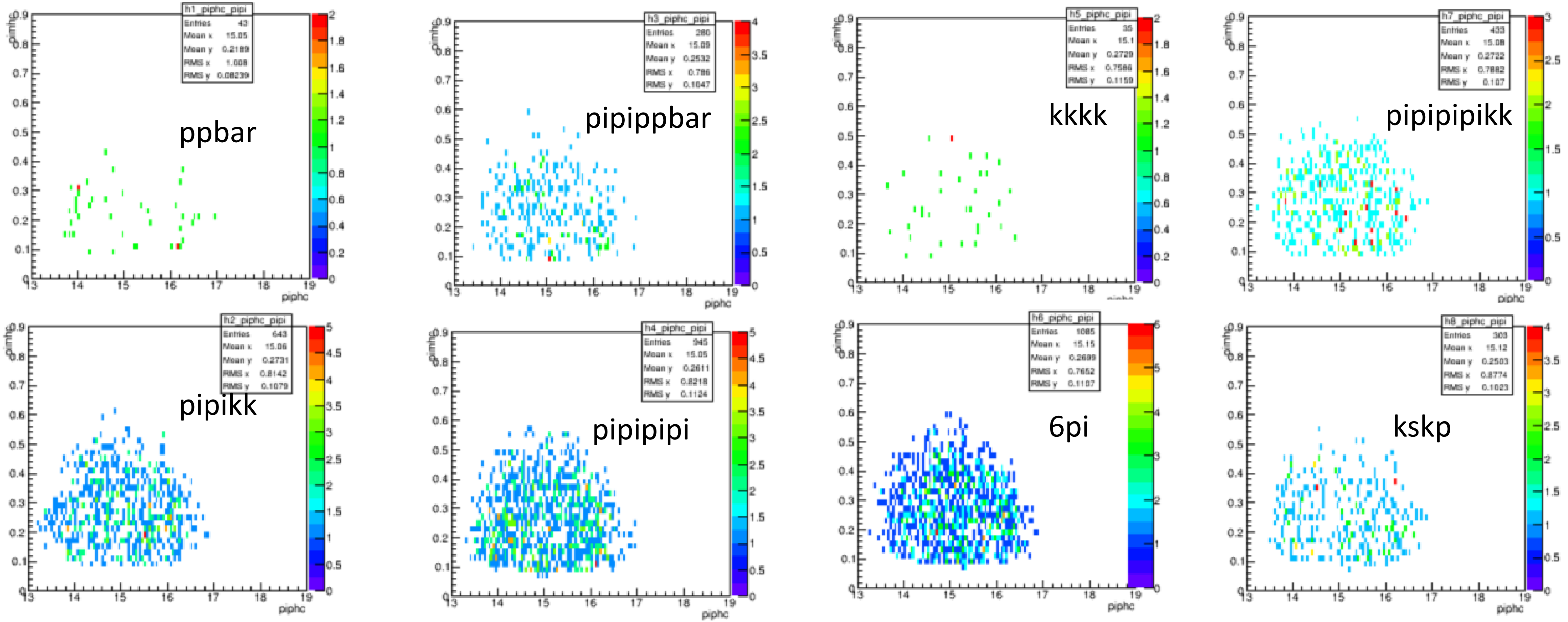
Back up

If include R-scan points



Back up

- Sum 8 energy points up



Back up

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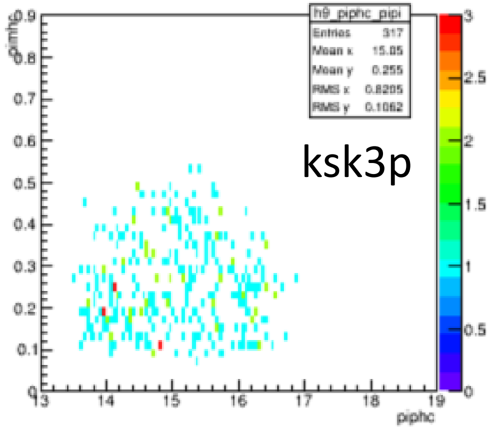

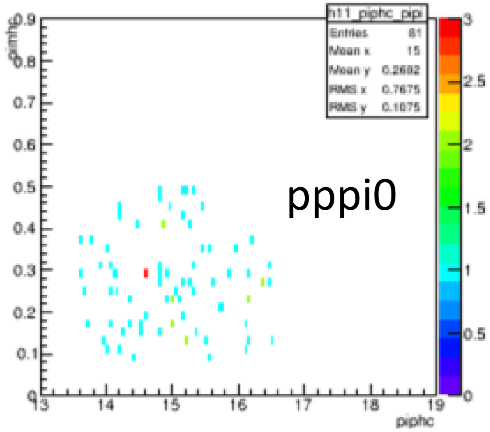

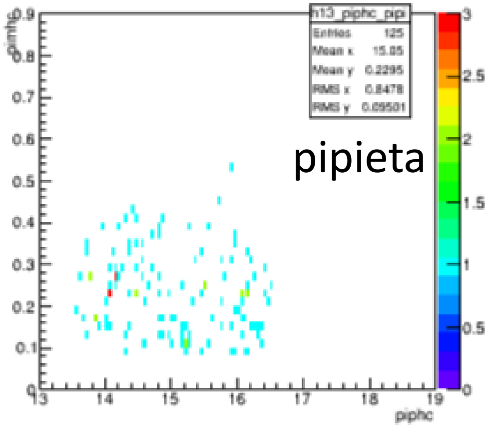

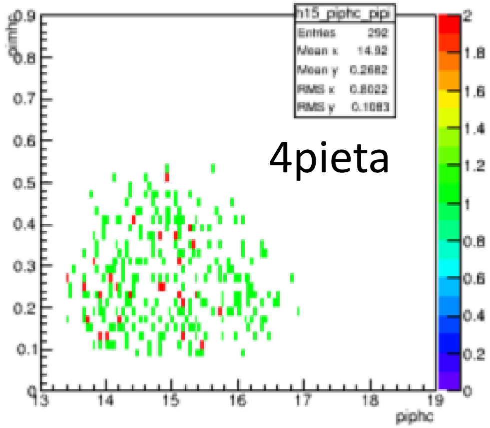

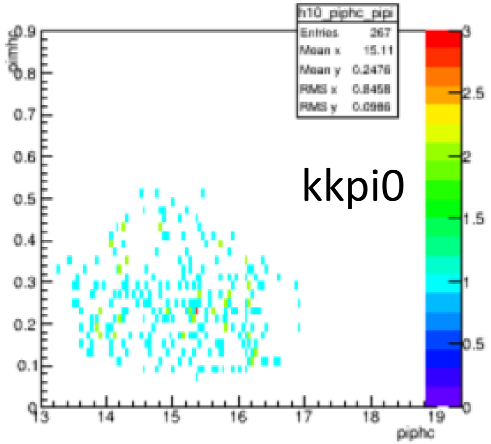

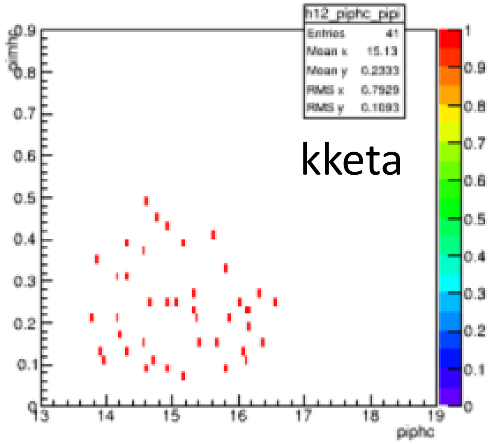

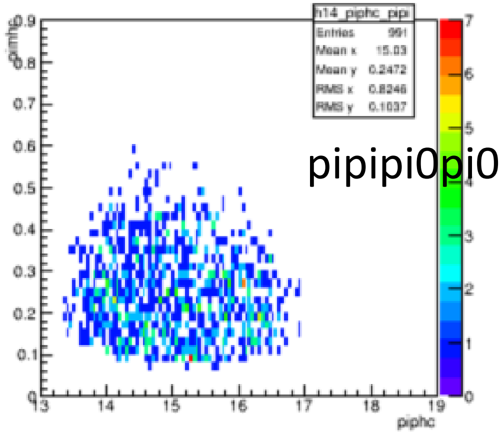

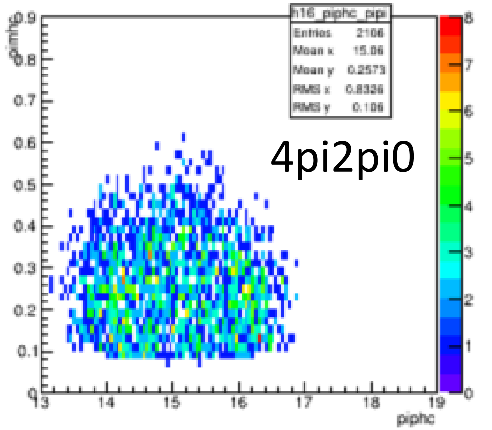

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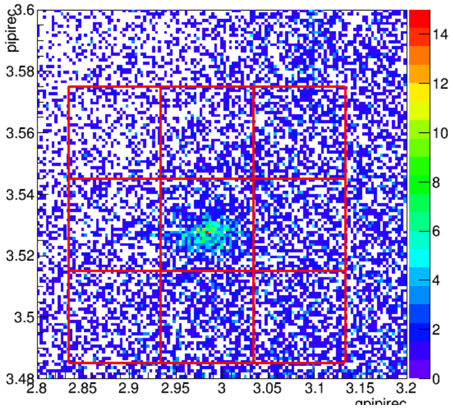
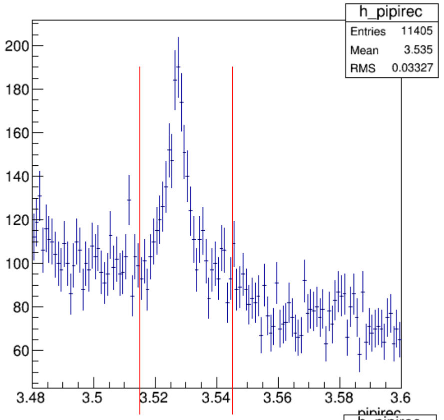
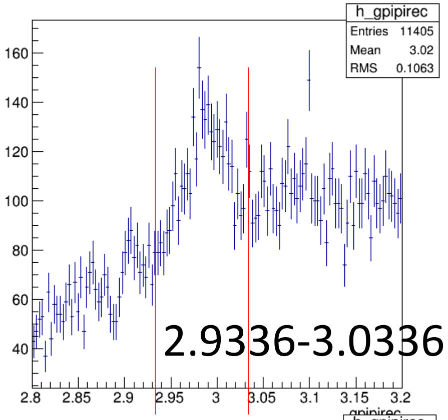
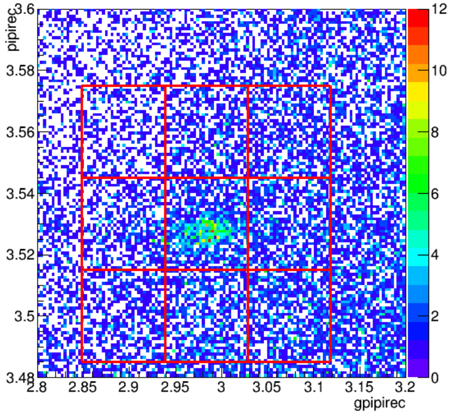
Ks/C

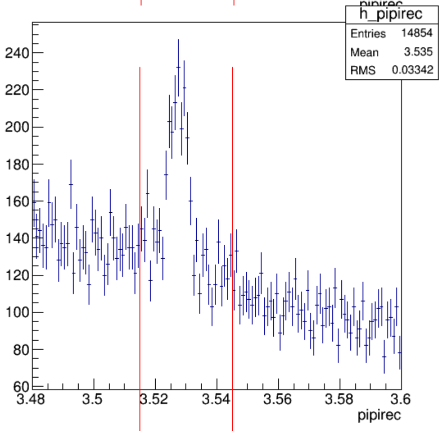


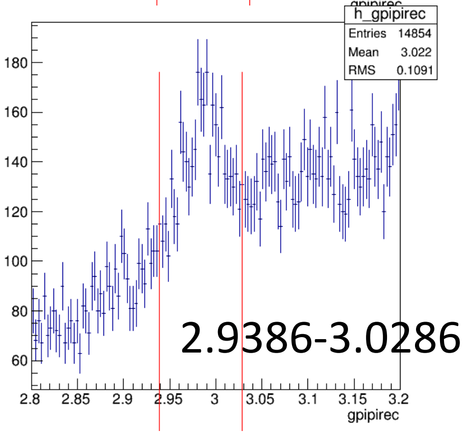




N







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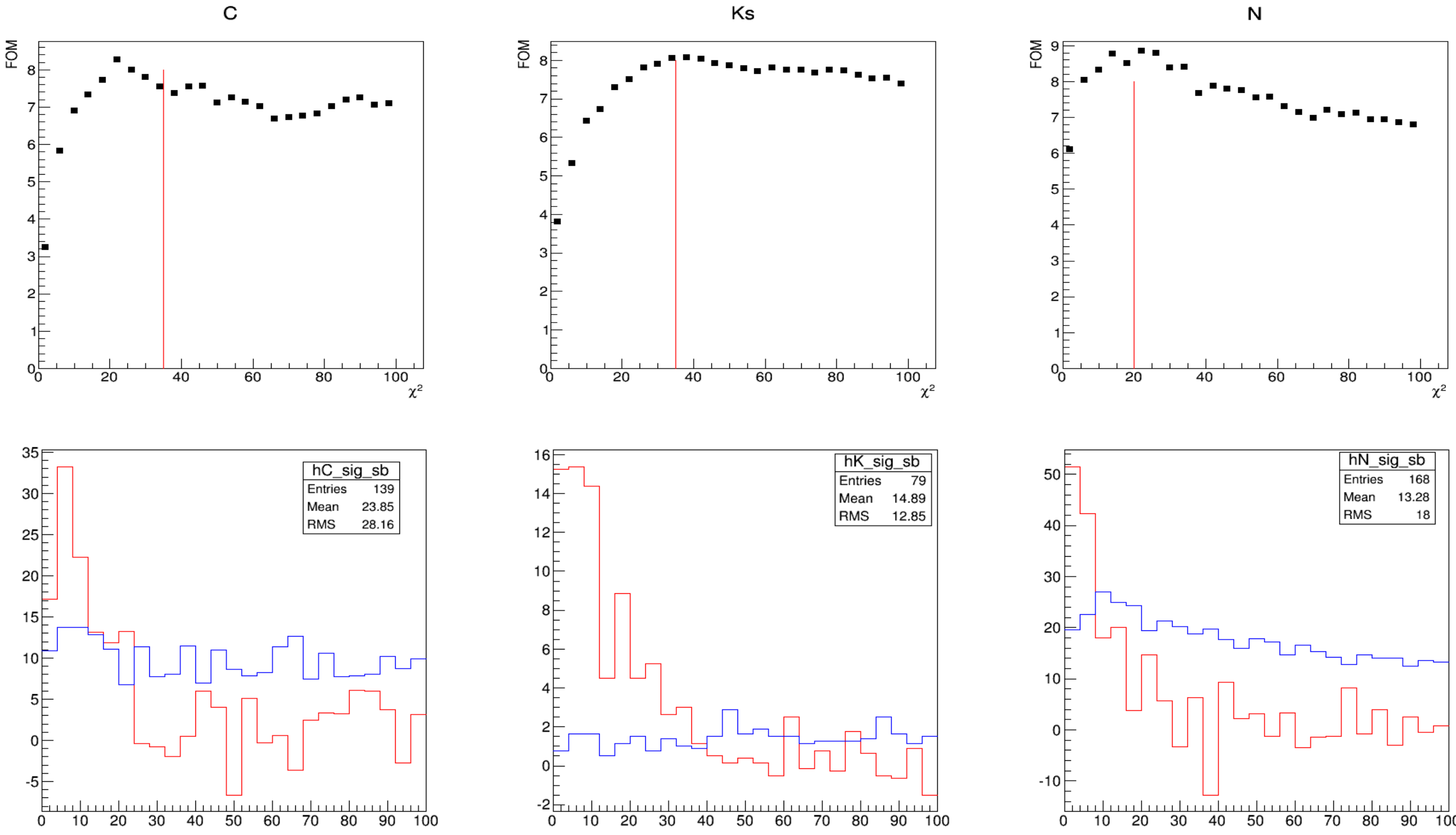
FOM distribution

χ^2 distribution of
Signal-sideband
sideband



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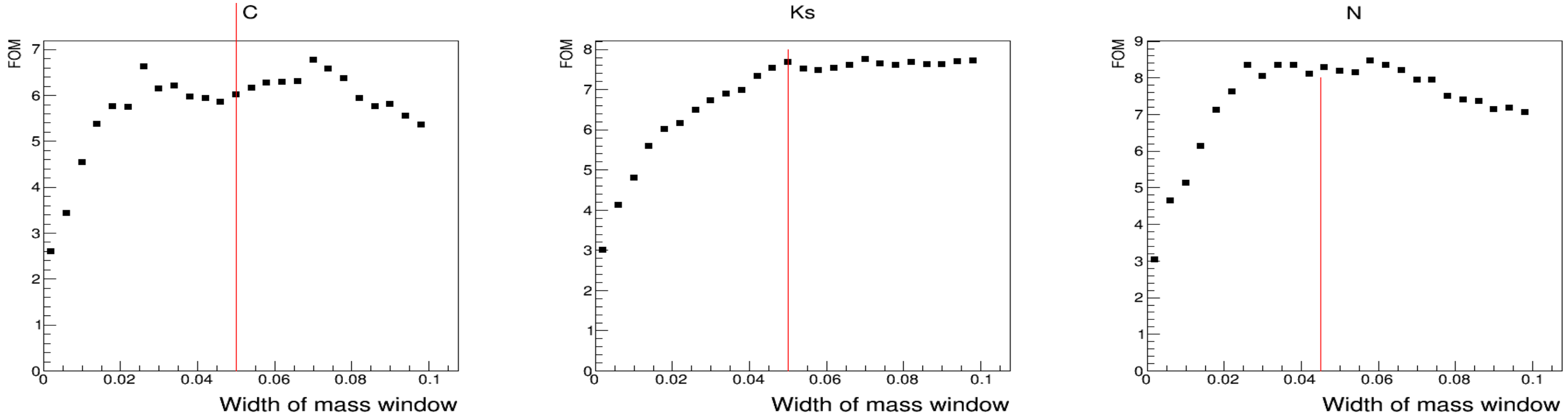
FOM distribution



$|M_{\gamma\pi\pi}^{rec}$ - $M_{\eta c}|$ distribution of
Signal-sideband
sideband