Study of the relative phase of psi(2S) using $e^+e^- \rightarrow \pi\pi J/psi$ final state

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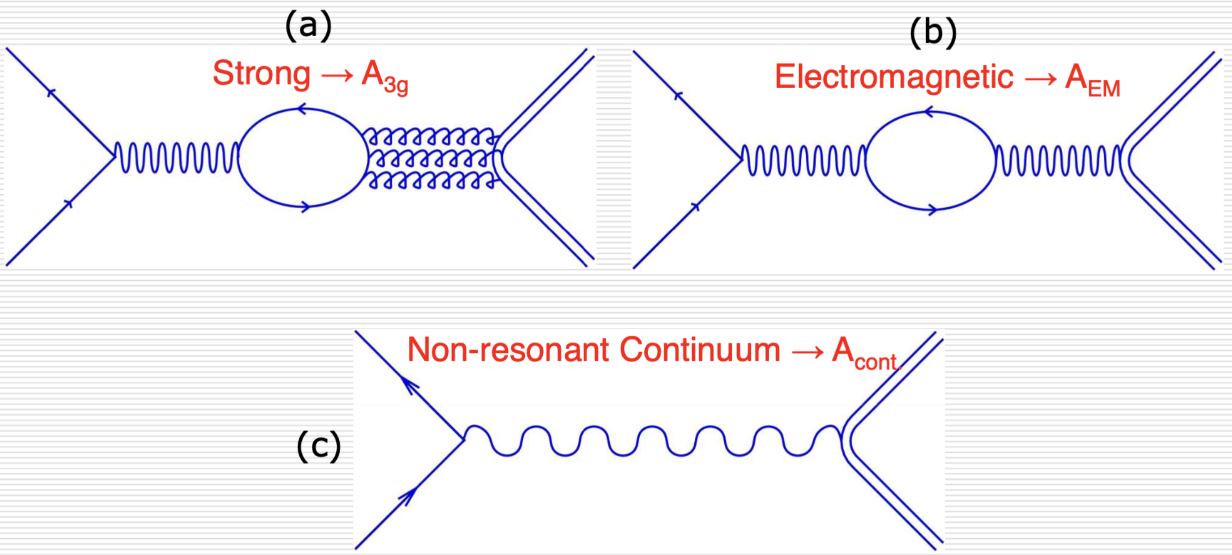
好久不见
Long time no see

BESIII Italia – September 2022 - Torino

Relative phase between strong and EM decay amplitudes

Vector Quarkonium Decay Mechanisms



(a) $e^+e^- \to J/\psi \to$ *hadrons* via strong mechanism (b) via em mechanism

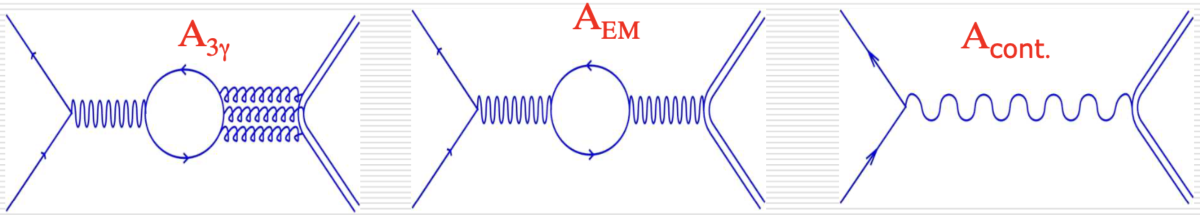
(c) non-resonant $e^+e^- \to$ *hadrons* via a virtual photon.

pQCD regime: all amplitudes real (apart BW resonance behaviour),

while data are as if there is an additional i in front of the BW

Relative phase between strong and EM decay amplitudes

Model independent from interference in q^2 behavior



$$\sigma_{born} = |A_{3g} + A_{EM} + A_{cont}|^2 = ||A_{3g}|e^{i\varphi} + |A_{EM} + e^{i\varphi'} A_{cont}||^2$$

Actually $\Phi_{meas} = \Phi - \delta_{cont}$ and $|\Phi_{meas}|$ only is measured, since it is difficult to get the sign

But also http://arxiv.org/abs/1505.03930v2 by Mo, Ping, Yuan

Additionally, phase in psi(2S) → VP different from J/psi → VP.
If confirmed, possible origin of ρ-π puzzle

Datasets and Luminosity

Data Collected in 2018: psi(2S) scan

Requested Energy (MeV)	Requested Luminosity (nb^{-1})	Run number	Energy (MeV)	Spread (MeV)	Luminosity (nb^{-1})
3580	85	55375-55461	3581.543 ± 0.060	1.493 ± 0.060	85665.6
3670	85	55462-55541	3670.158 ± 0.063	1.410 ± 0.053	84719.7
3681	85	55542-55635	3680.144 ± 0.061	1.517 ± 0.060	84814.5
3683	55	55636-55662	3682.752 ± 0.115	1.710 ± 0.104	28668.3
-	-	55663-55690	3684.224 ± 0.119	1.547 ± 0.122	28651.6
3685.5	25	55691-55716	3685.264 ± 0.105	1.478 ± 0.111	25982.8
3686.6	25	55717-55737	3686.496 ± 0.120	1.594 ± 0.117	25055.1
3690	70	55738-55795	3691.363 ± 0.075	1.541 ± 0.074	69374.6
3710	70	55796-55859	3709.755 ± 0.074	1.460 ± 0.075	70326.7

Added the "old" continuum point at 3.65 GeV

Boss version 7.0.4 – Using KKMC for each energy
20k e^+e^- → pi^+ pi^- J/psi → pi^+ pi^- e^+ e^-
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3685.5	25	55691-55716	3685.264 ± 0.105	1.478 ± 0.111	25.342 ± 0.046
3686.6	25	55717-55737	3686.496 ± 0.120	1.594 ± 0.117	24.481 ± 0.045
3690	70	55738-55795	3691.363 ± 0.075	1.541 ± 0.074	68.647 ± 0.076
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Luminosity with Bhabha and two photons

https://indico.ihep.ac.cn/event/13433/contribution/5/material/slides/0.pdf

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20k $e^+e^- \rightarrow$ pi$^+$ pi$^-$ J/psi $\rightarrow$ pi$^+$ pi$^-$ e^+ e^-
20k $e^+e^- \rightarrow$ pi$^+$ pi$^-$ J/psi $\rightarrow$ pi$^+$ pi$^-$ mu$^+$ mu$^-$

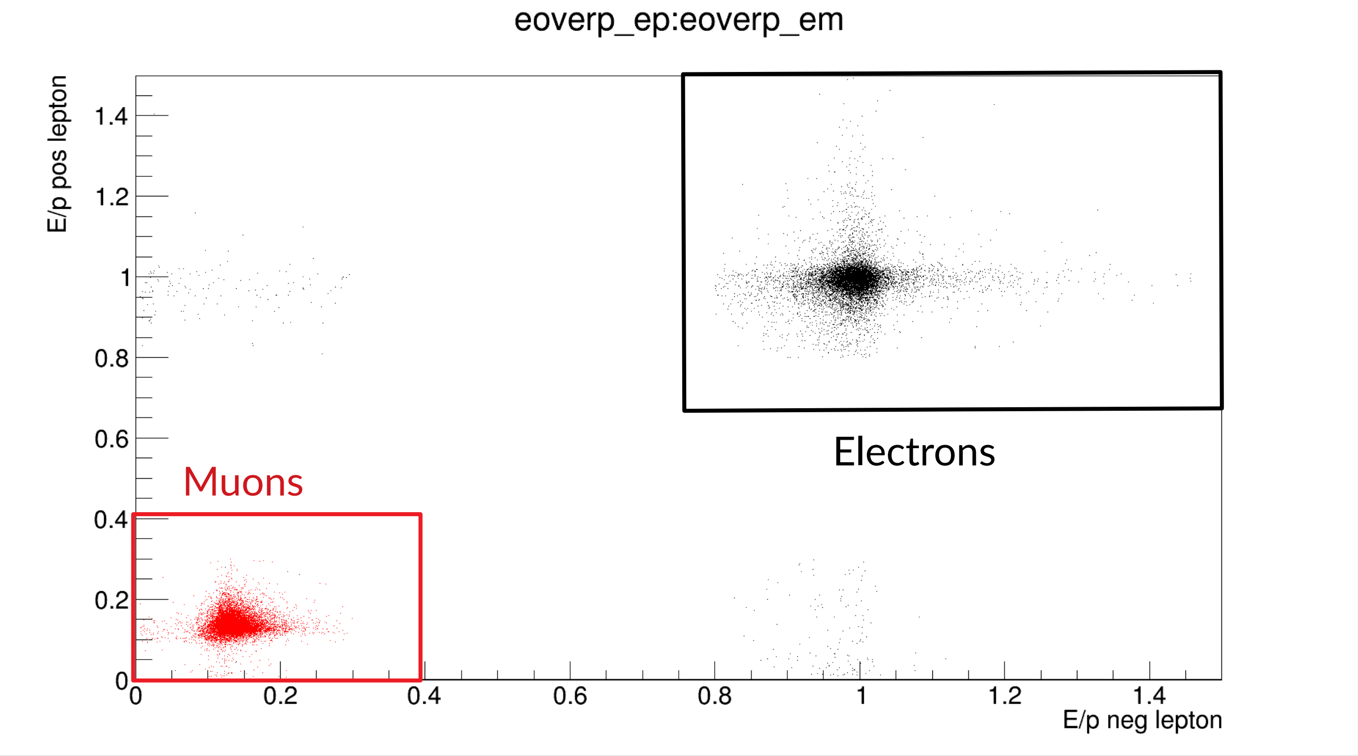
https://indico.ihep.ac.cn/event/13433/contribution/5/material/slides/0.pdf

Event Selection

- Event selection follows similar criteria of other $\pi\pi J/psi$ final state analyses
- Event Selections:
  - 4 charged tracks with 0 net charge
  - $|\cos\theta| < 0.93$
  - $|V_{z,poca}| < 10$ cm
  - $|V_{xy,poca}| < 1$ cm
  - **p** > 1.06 – track is a lepton
  - **p** < 0.45 – track is a pion
  - 4C kinematic fit is applied

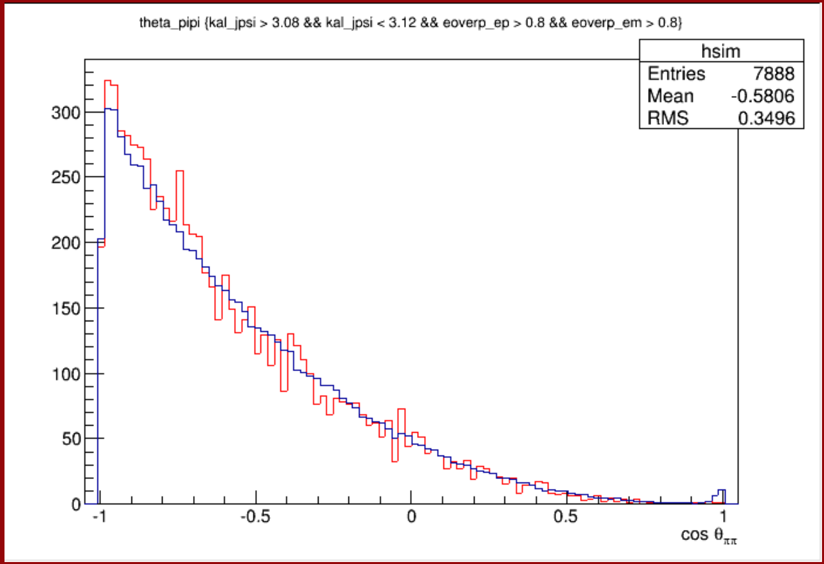
- Radiative Bhabha and radiative dimuons background are suppressed by a cut on the opening angle between the two pions ($\cos|\theta_{pipi}| < 0.98$) and non-radiative Bhabha events are further suppressed with a cut on the opening angle between the two lepton ($\cos|\theta_{ee}| < 0.98$).

Leptification

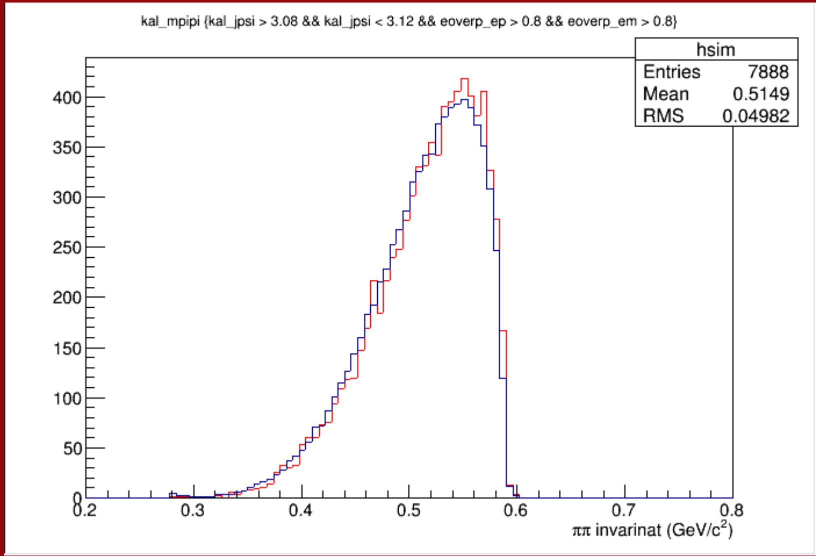


Difference of the response in the EMC allows to separate electrons and muons

“Typical plots” @ 3.686 GeV

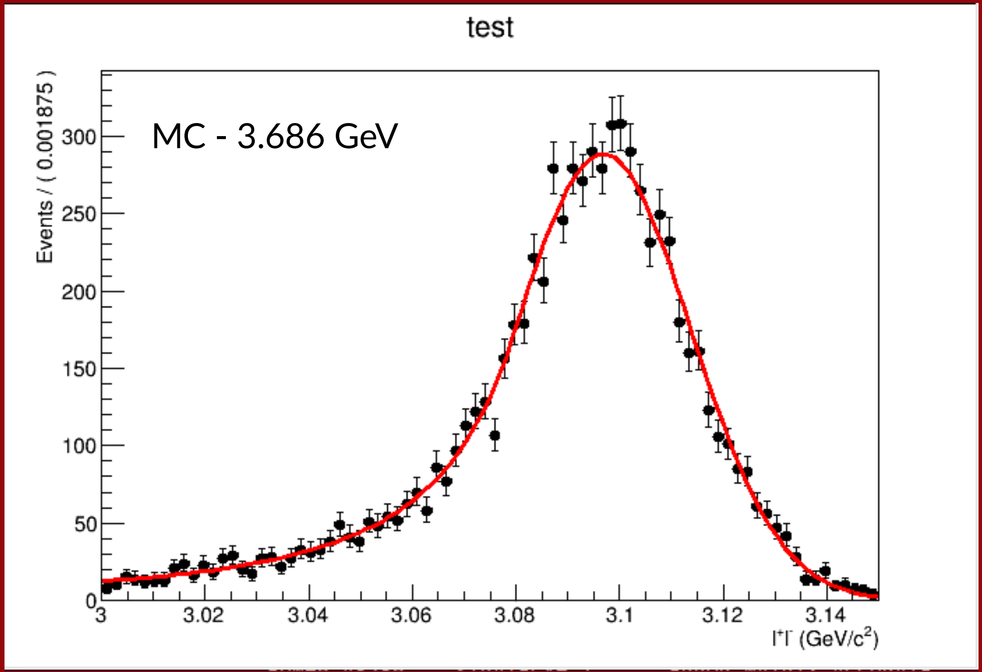


Angle between pions



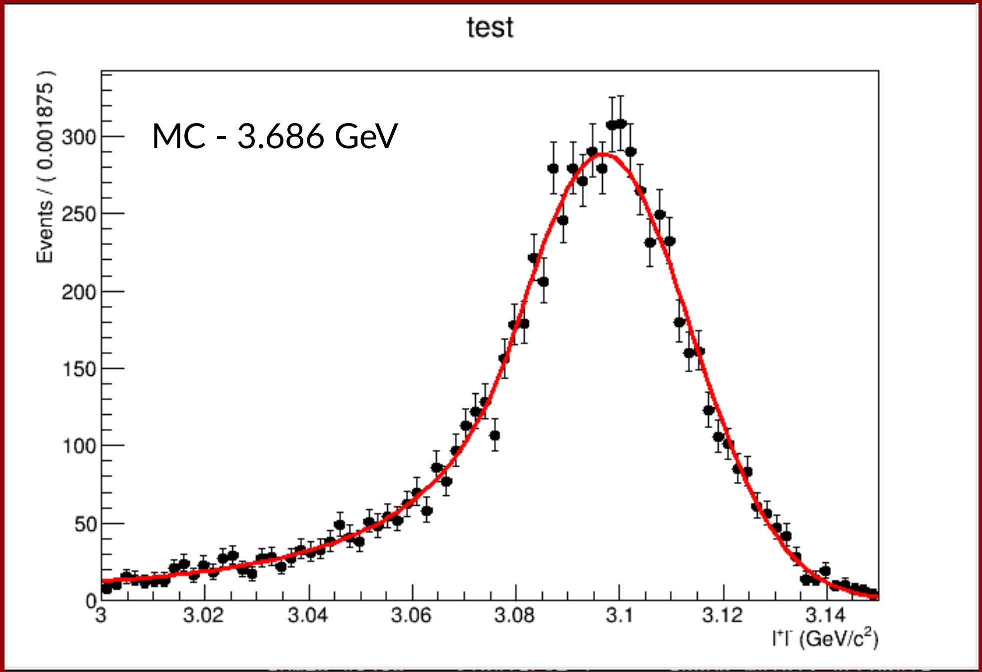
ππ invariant mass

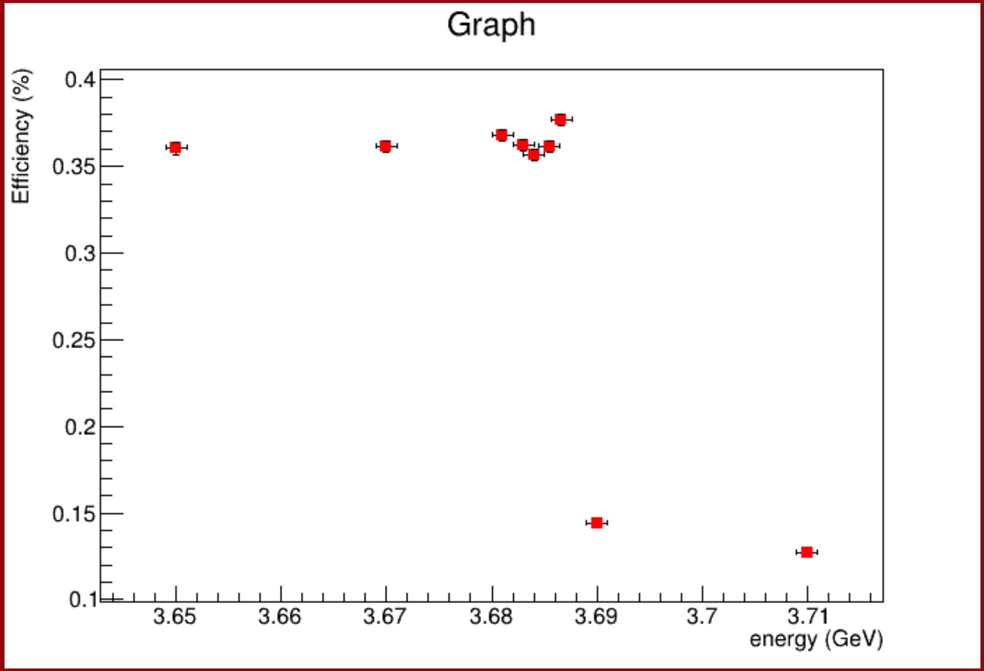
Electronic final state



New fitting function:
Crystal Ball +
0^{th} Chebychev

Electronic final state





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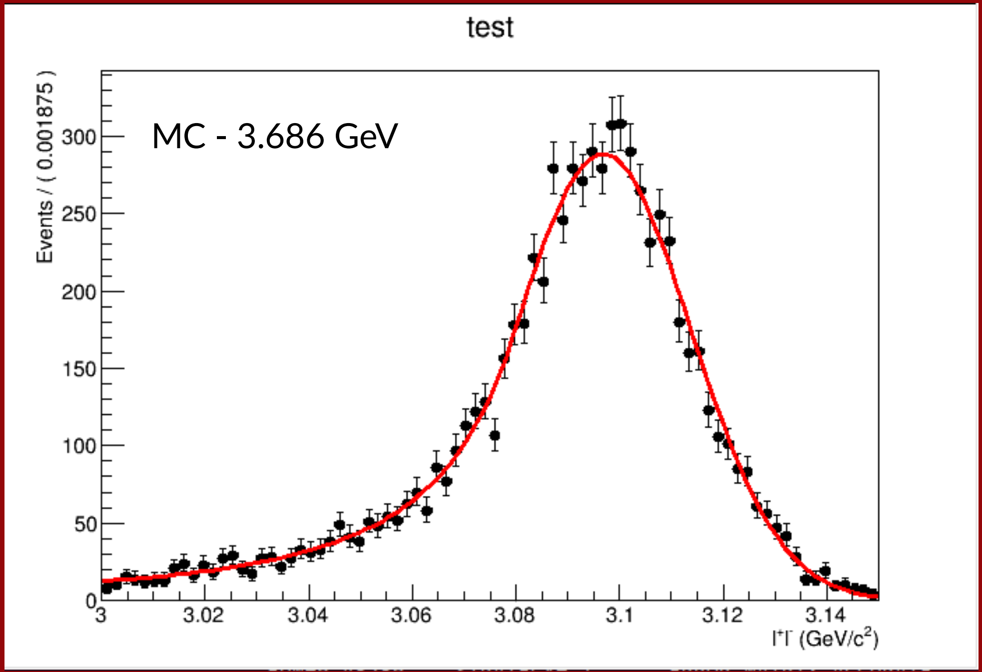

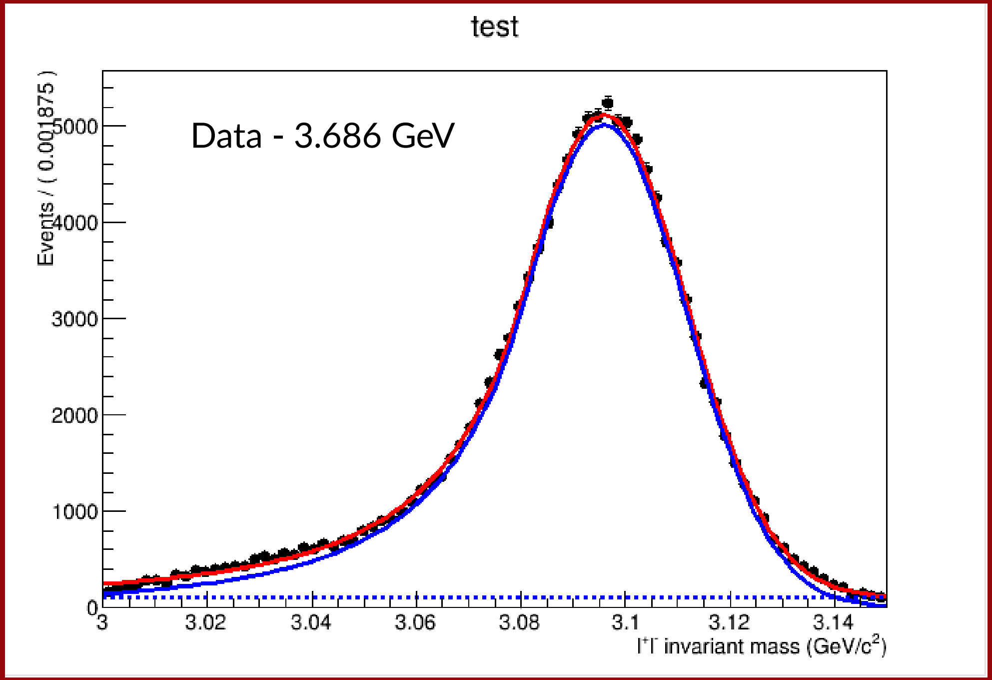

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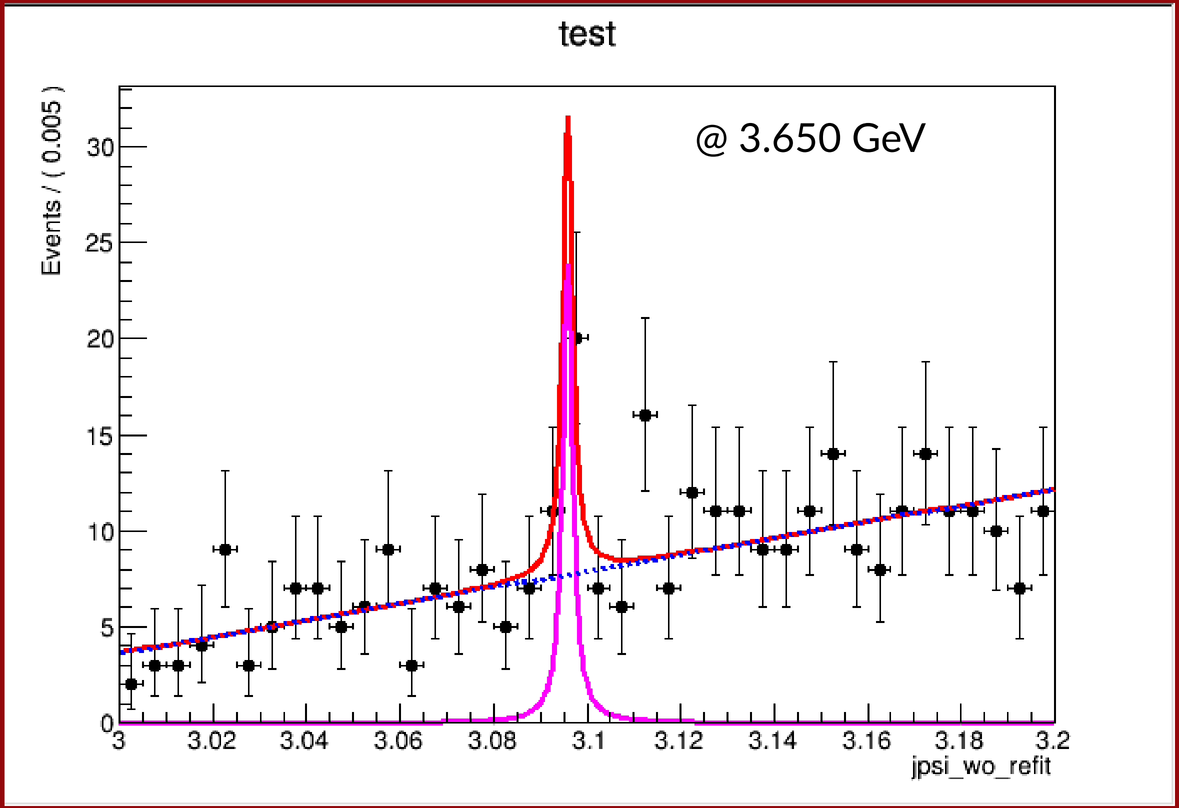
A “special” point



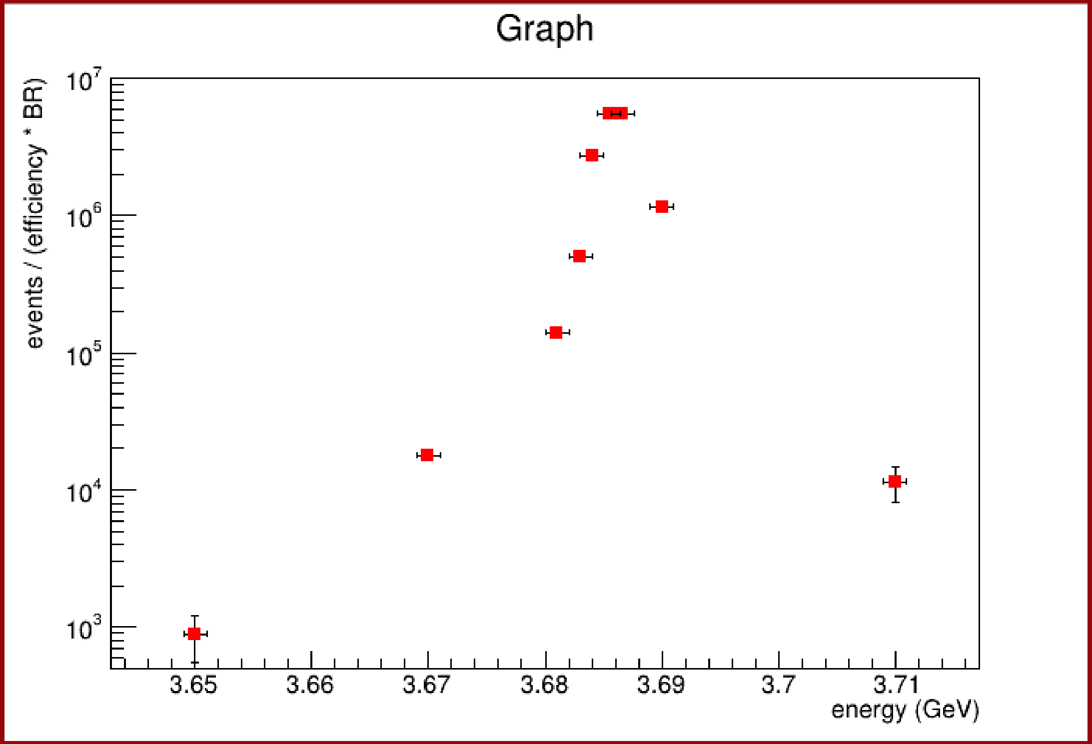
Fitting function:

fixed mass Breit-Wigner + 1th Chebychev

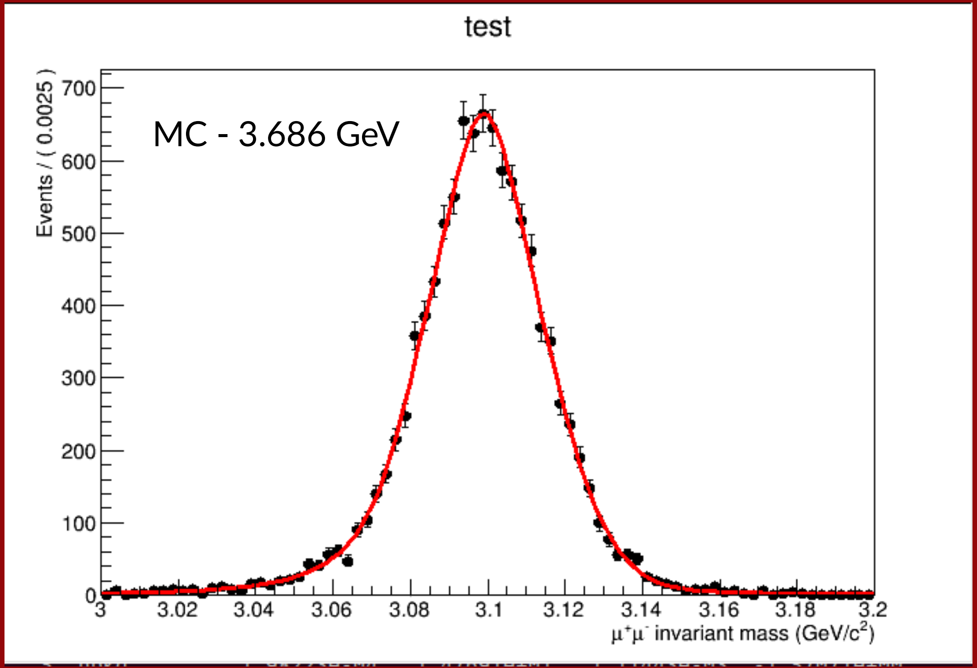
Hint of pipi J/psi also @ 3.65 GeV

Helpful to constrain continuum

“Observed” cross section in e^+e^- final state

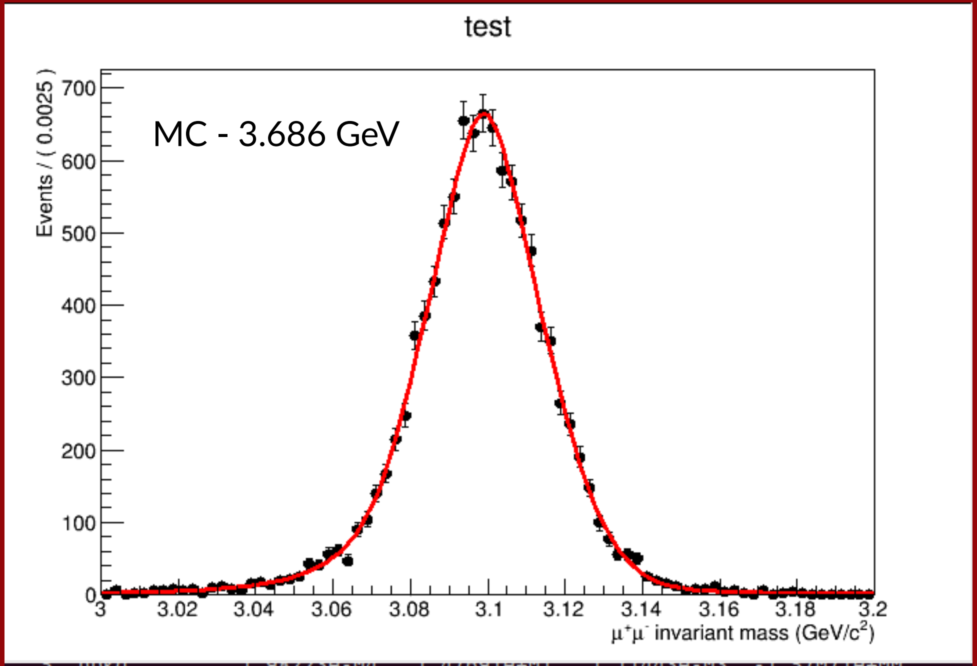


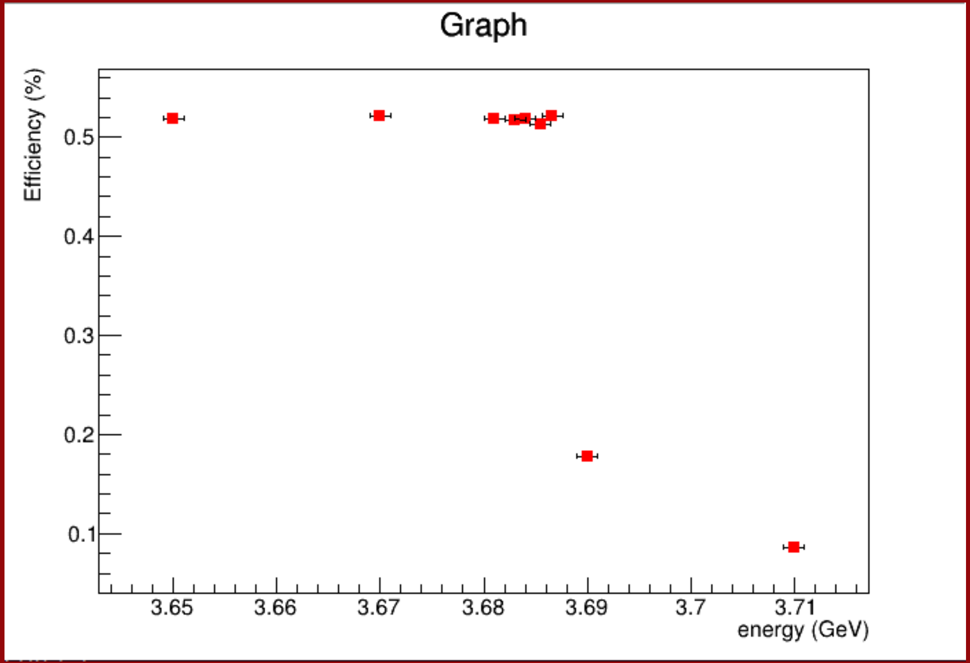
Muonic final state



Fitting function:
Crystal Ball + BW +
0^{th} Chebychev

Muonic final state





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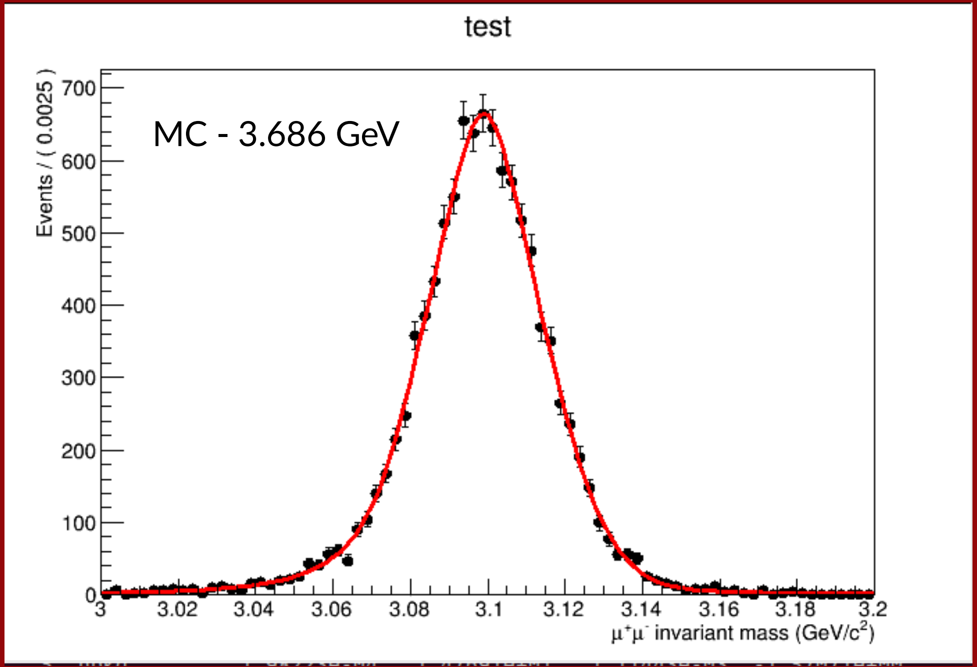
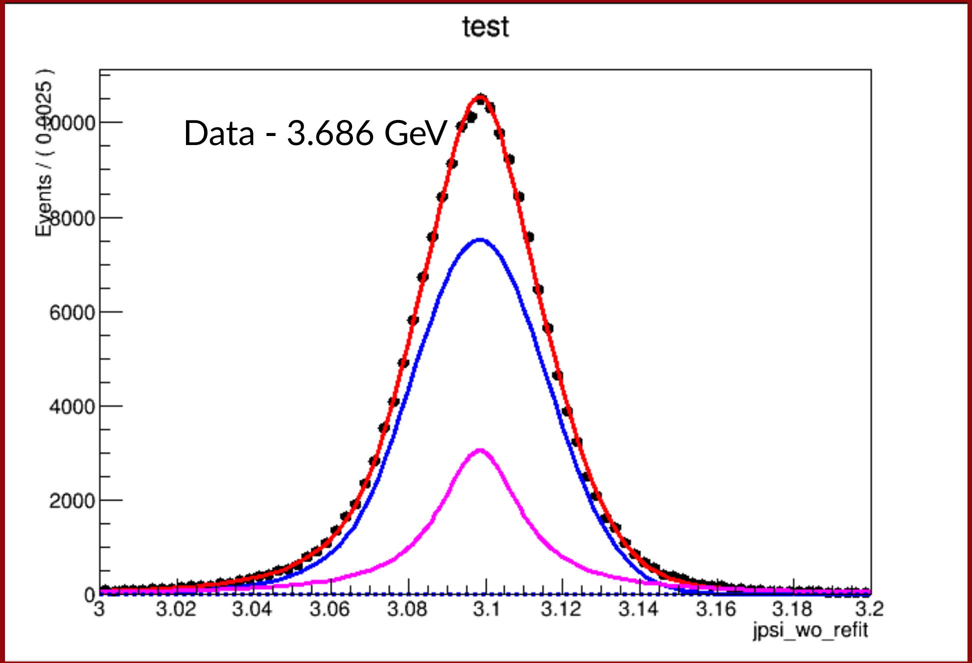
Muonic final state





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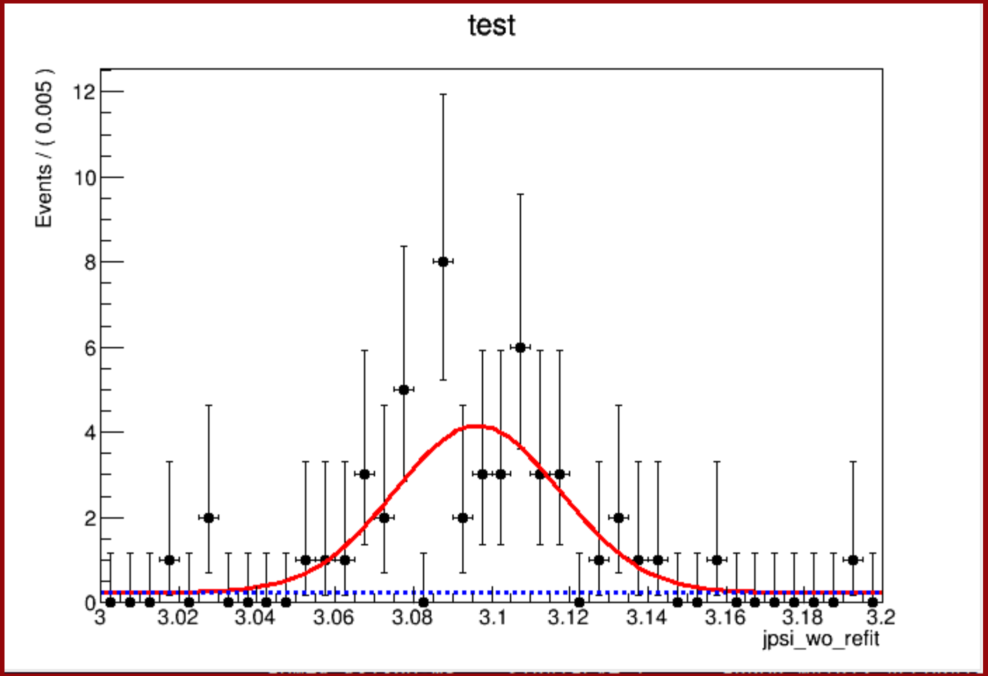

Hint of pipi J/psi also @ 3.65 GeV

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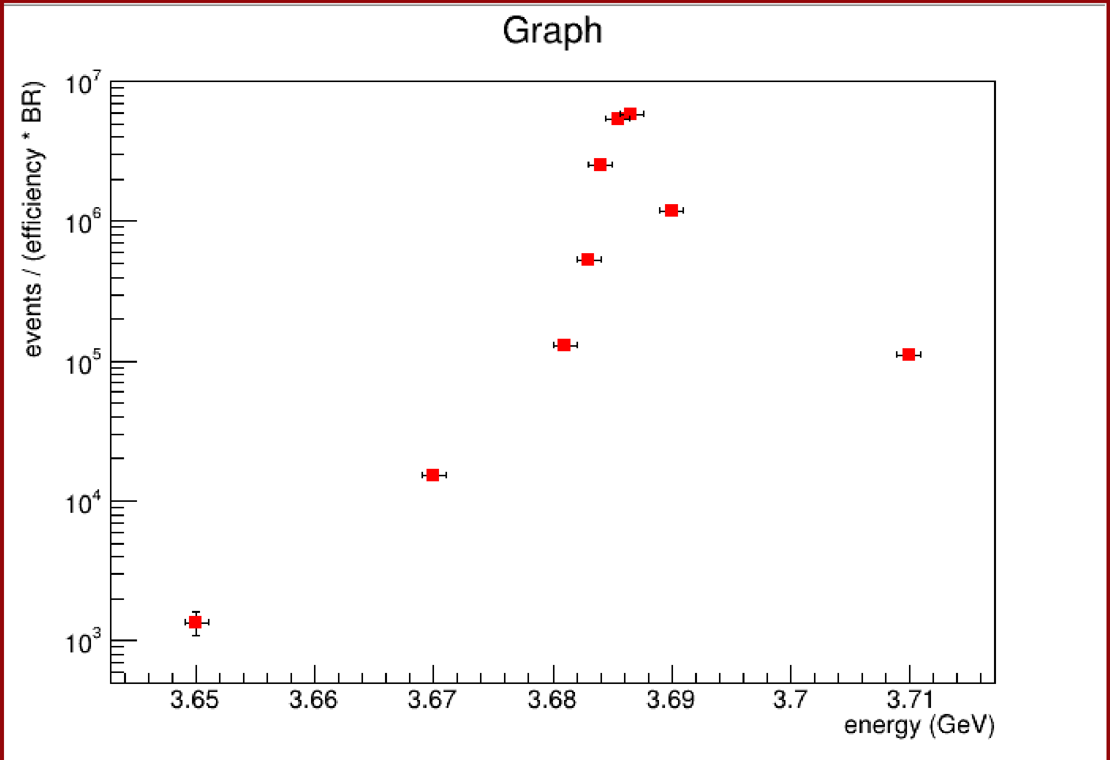
“Observed” cross section in $\mu^+\mu^-$ final state



Towards the phase extraction

From the amplitudes...

The starting formula is the Born cross section of the process $e^+e^- \to h$

$$\sigma(W) = |\mathscr{A}(W)|^2 \,,$$

with the amplitude

$$\mathscr{A}(w) = D\,\frac{S e^{i\phi} + E}{M - W - i\,G} - C\left(\frac{3\,\text{GeV}}{W}\right)^3 ,$$

and the real and positive parameters

$$G = \Gamma/2\,, \qquad D = \frac{\Gamma/2}{M}\sqrt{12\pi\,B_{\text{in}}}\,, \qquad C = \sqrt{\sigma_{\text{cont}}}\,, \qquad E = \sqrt{C^2\,\frac{B_{\text{in}}}{\sigma_{\mu\mu}}} = \sqrt{\frac{\sigma_{\text{cont}} B_{\text{in}}}{\sigma_{\mu\mu}}}\,.$$

Continuum by power law

$$\sigma_0 = (3000)^{PWW}\,\sigma(3000)$$

Credits: Simone Pacetti

...to the Born cross section

$$\sigma(W;B_{\text{out}},\phi,\sigma_{\text{cont}}) = \text{Re}^2\left[\mathscr{A}(W)\right] + \text{Im}^2\left[\mathscr{A}(W)\right]$$

$$= \left\{ D\frac{\left[\left(\sqrt{B_{\text{out}}-E^2\sin^2(\phi)}-E\cos(\phi)\right)\cos(\phi)+E\right](M-W)}{(M-W)^2+G^2} \right.$$

$$\left. - D\frac{\left(\sqrt{B_{\text{out}}-E^2\sin^2(\phi)}-E\cos(\phi)\right)\sin(\phi)G}{(M-W)^2+G^2} - \sqrt{\sigma_{\text{cont}}}\left(\frac{3\,\text{GeV}}{W}\right)^3 \right\}^2$$

$$+ \left\{ D\frac{\left(\sqrt{B_{\text{out}}-E^2\sin^2(\phi)}-E\cos(\phi)\right)\sin(\phi)(M-W)}{(M-W)^2+G^2} \right.$$

$$\left. + D\frac{\left[\left(\sqrt{B_{\text{out}}-E^2\sin^2(\phi)}-E\cos(\phi)\right)\cos(\phi)+E\right]G}{(M-W)^2+G^2} \right\}^2 .$$

$$\delta\mathcal{B} = 2\sqrt{\frac{\sigma_0}{\sigma_\psi}}A_s\sin\varphi.$$

Interference effect on BR
(with respect to no interference effect)

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And to the observed cross section

To Fit the Line-Shape: To incorporating the the effect of radiative function $F(x, W)$ and Energy Spread S_E in the fit, the dressed Born cross section is modified as;

1. Incorporating the radiative correction $F(x, W)$:
   $\sigma'(W) = \int_0^{1-\left(\frac{W_{\min}}{W}\right)^2} dx F(x, W)\sigma(W\sqrt{1-x})$
2. Energy spread S_E is included by convolving with Gaussian function by set the width of S_E. The Born cross section becomes:
   $\sigma''(W) = \int_{W-nS_E}^{W+nS_E} \frac{1}{\sqrt{2\pi}S_E} \exp\left(\frac{-(W-W')^2}{2S_E^2}\right) \sigma'(W')\, dW$

Observed xs!

Minimization Function: The fitting parameters are obtained by means of χ^2-minimization as:

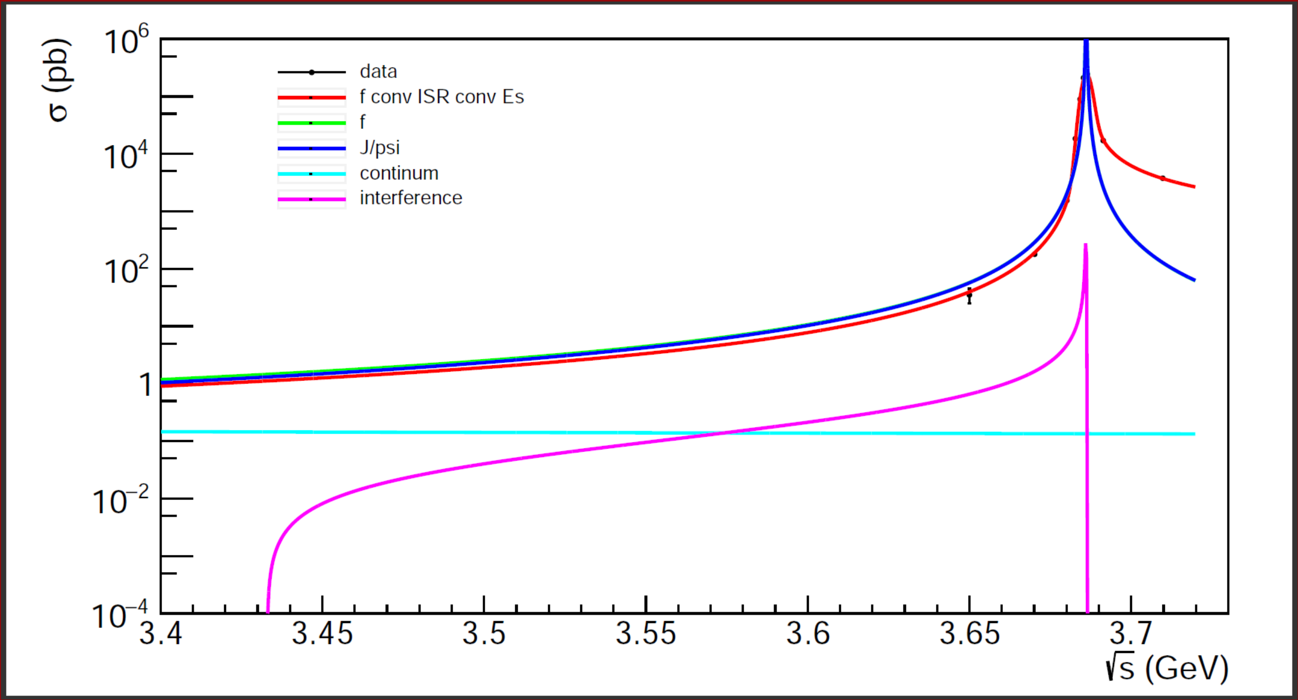
$$\chi^2_{\min} = \sum_{i=1}^{15} \frac{\left(\sigma_i^{\text{obs}} - \sigma''(W_i)\right)^2}{\left(\Delta\sigma_i^{\text{obs}}\right)^2 + \left[\left(\sigma''\left(W_i + \frac{\Delta W_i}{2}\right) - \sigma''\left(W_i - \frac{\Delta W_i}{2}\right)\right)\right]^2},$$

where error along X-axis, is projected along the Y-axis.

Credits: Muzaffar

First fit

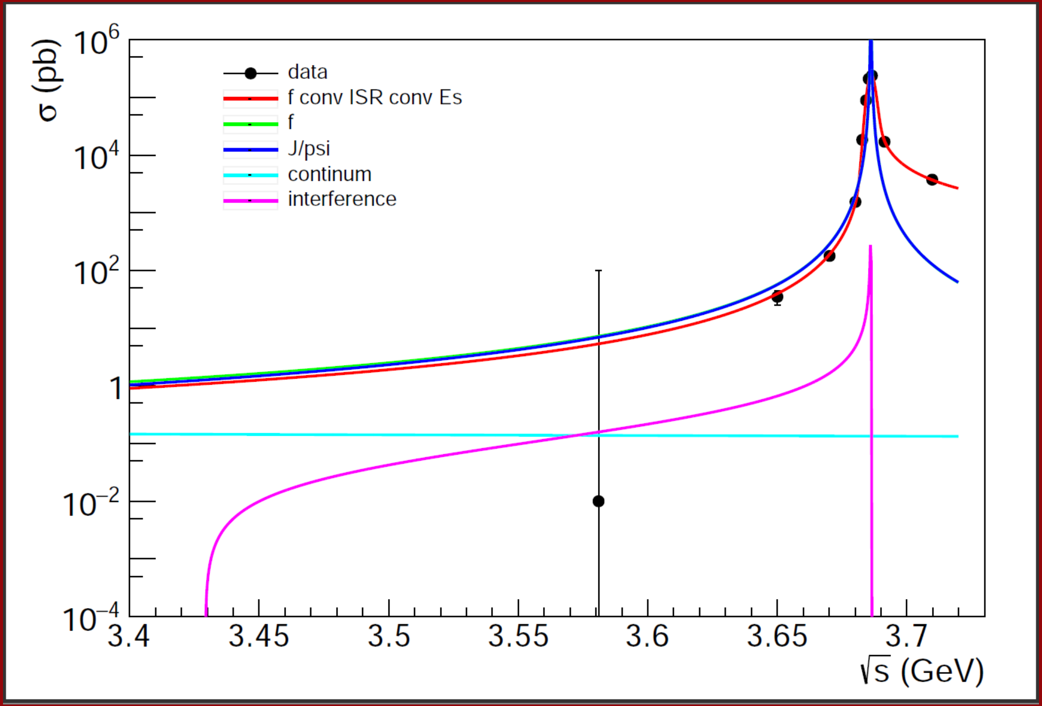
Using only the J/psi → μμ final state. Efficiency without ISR.



BR = 0.392 +/- 0.004
phi_s = (112 +/- 133.2)°
cont(3.5GeV) = (0.02 +/- 8.9) pb
Spread = (1.35 +/- 0.02) MeV

Second fit

Using only the J/psi → μμ final state, adding a "tentative" upper limit on 3.581 GeV.
Efficiency without ISR.



Free parameters are BR, σ(3.5 Gev), phase, Spread, but results do not improve

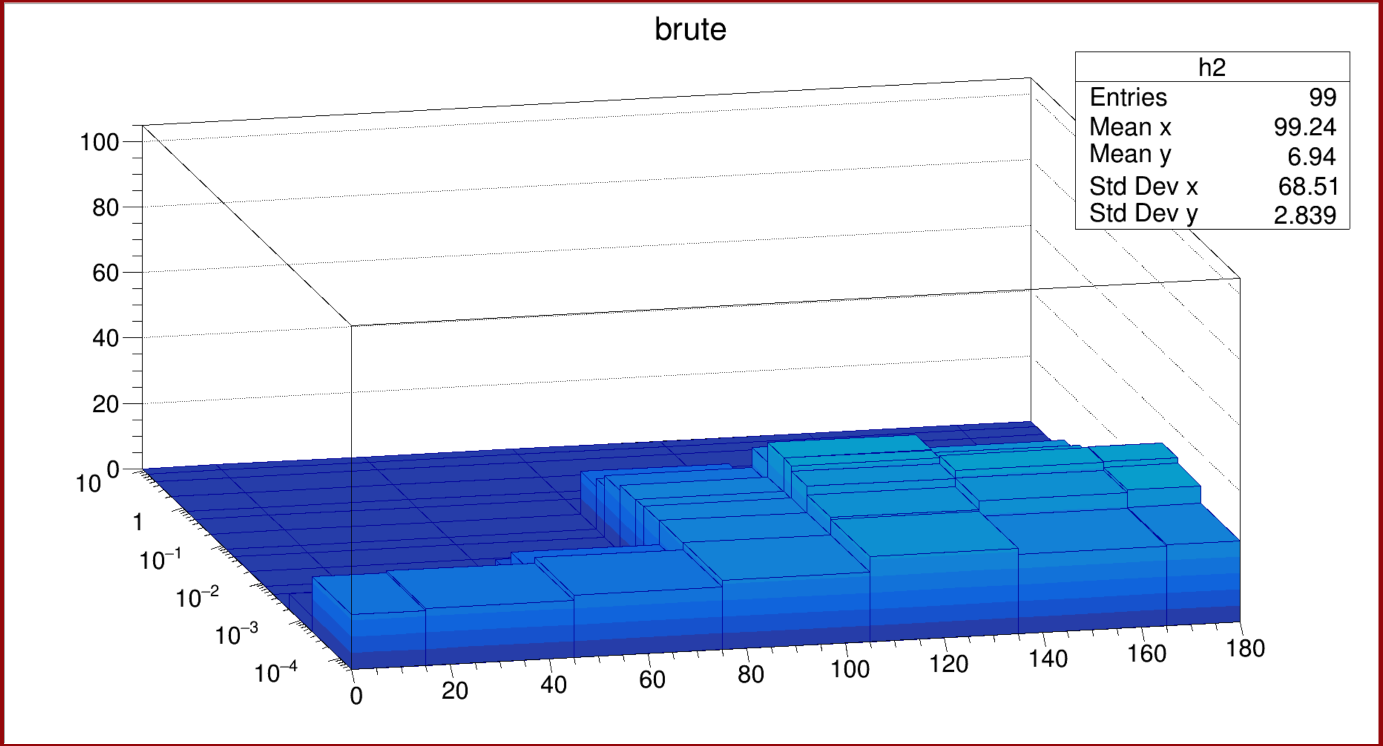
A “personal” MINUIT

- Preliminary study to understand large error on the phase
  - Several tests by hand

- Result: effect is due to the large uncertainty on the continuum

- Proposed test: “Brute force” parameters scan

Results of the scan



Found a minimum for:

- Continuum ~ 0.003 pb
- Phase ~ 150°

But, still large plateau around, so large uncertainties.

It is possible to set upper limit for continuum with this fit around 0.3 pb

Still not satisfactory since BR deviates from well known result. → Check ISR with ConExc

!

Further steps

- Test additional points using τ threshold and χ_{c1} data to try to constrain better the continuum
  - Also update few points with more recent data
- Test ConExc in simulation to have better description of ISR in simulation
- Continue testing the fit

Further steps - II

During the discussion, I have received few comments from LI Haibo:

- To improve statistics, test reconstruction of only the pipi and search for J/psi in the recoil mass
- Evaluate the effect of the psi(3770) tail at high center-of-mass energies, also using the psi(3770) fast scan
- He stressed the importance to understand whether there is a continuum process, that may be related to BESIII (slightly) higher R measurement wrt to pQCD predictions

Thanks!!!