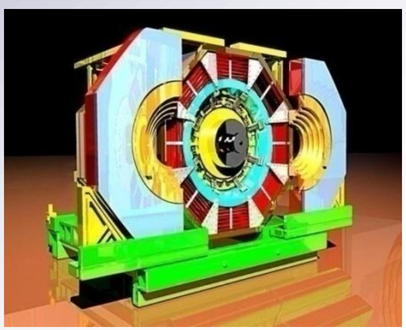
Relative Phase between Strong and EM Decays at BESIII and CLEOc

Marco Destefanis

Università degli Studi di Torino

on behalf of the BESIII Collaboration



Quarkonium 2013

The 9th International Workshop on Heavy Quarkonium

IHEP, Beijing, April 22-26, 2013

Overview

- BESIII experiment

- Motivation

CLEOc and SND results

- Investigated processes

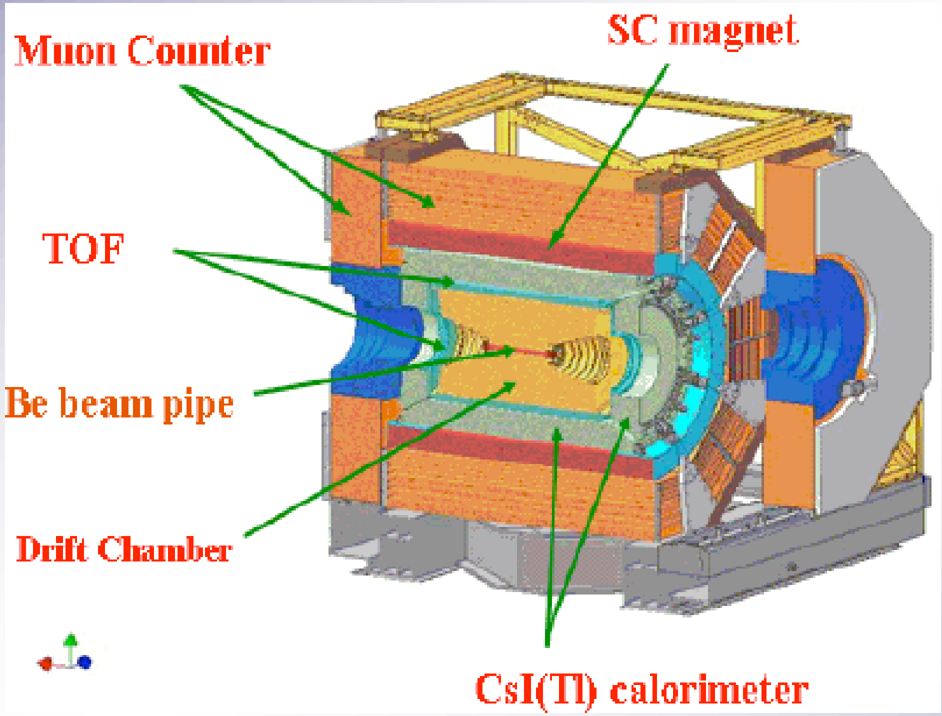
- Summary

The BESIII Experiment @ IHEP

BEijing Spectrometer III

e^+e^- collisions

$\sqrt{S}$ tuned depending on energy



Physics program

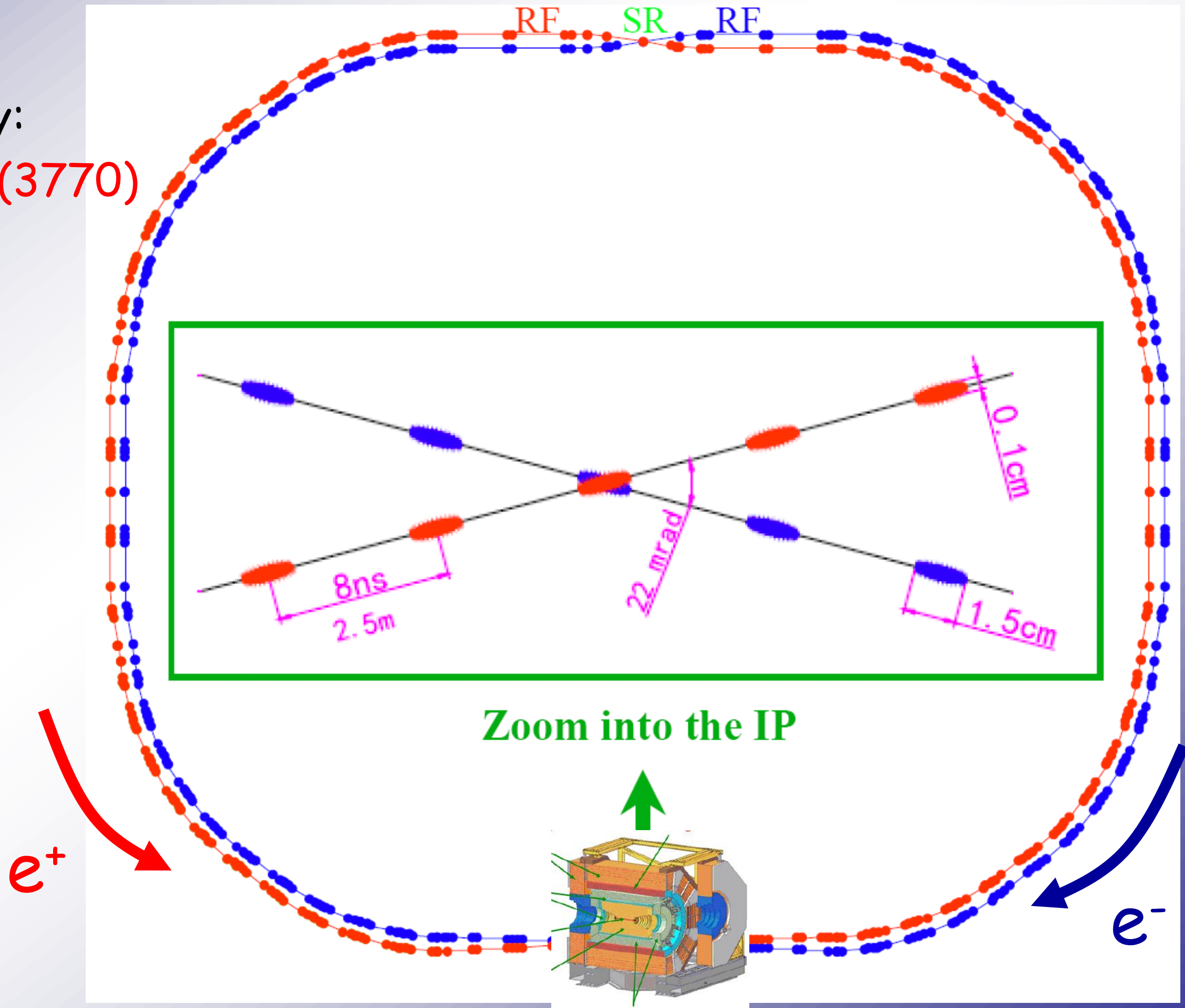
- Charmonium Physics
- D-Physics
- Light Hadron Spectroscopy
- τ-Physics
- ...

D.M. Asner et al, Physics at BES-III, arXiv:0809.1869v1 [hep-ex] (2008)

BEPCII Storage Rings

Beijing Electron-Positron Collider II

- Beam energy:
  1.0-2.3 GeV
- Design Luminosity:
  $1\times10^{33}\ cm^{-2}s^{-1}$
- Achieved Luminosity:
  $\sim 6.5\times10^{32}\ cm^{-2}s^{-1}$ @ ψ(3770)
- Optimum energy:
  1.89 GeV
- Energy spread:
  5.16×10^{-4}
- No. of bunches:
  93
- Bunch length:
  1.5 cm
- Total current:
  0.91 A
- Circumference:
  237m



BESIII Detector

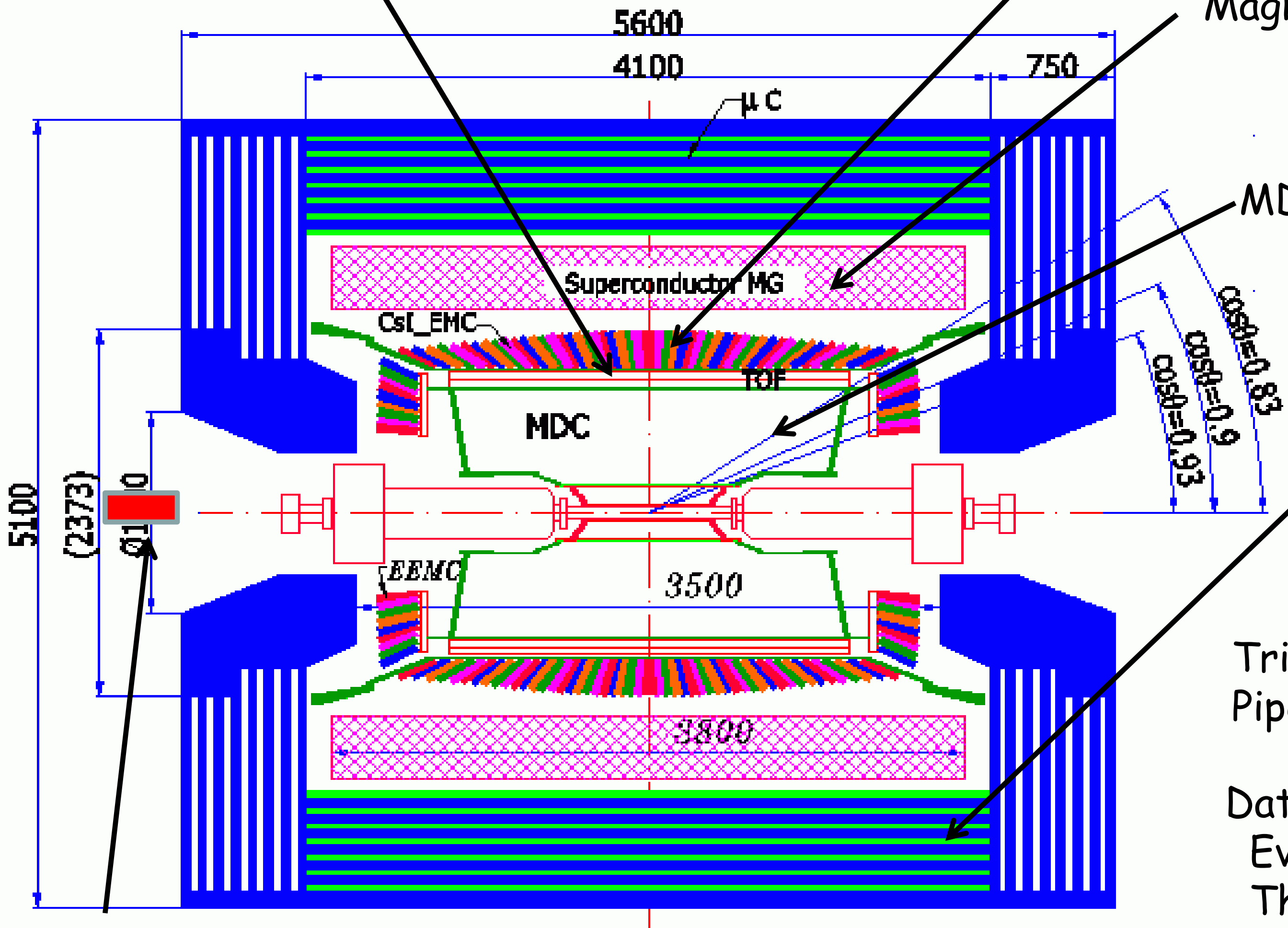
TOF:
σ_T = 80 ps Barrel
110 ps Endcap

EMC: CsI crystals, 28 cm
$\Delta E/E$ = 2.5% @1 GeV
σ_z = 0.6 cm/$\sqrt{E}$

Magnet: 1T Superconducting

MDC: small cell & He gas
σ_{xy} = 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

Muon: 9 layer RPC



Trigger: Tracks & Showers
Pipelined; Latency = 2.4 ms

Data Acquisition:
Event rate = 3 kHz
Thruput ~ 50 MB/s

Zero Degree Detector (ISR)

J/ψ Strong and Electromagnetic Decay Amplitudes

Resonant contributions

$\Gamma_{J/\psi} \sim 93\text{KeV} \rightarrow \text{pQCD}$

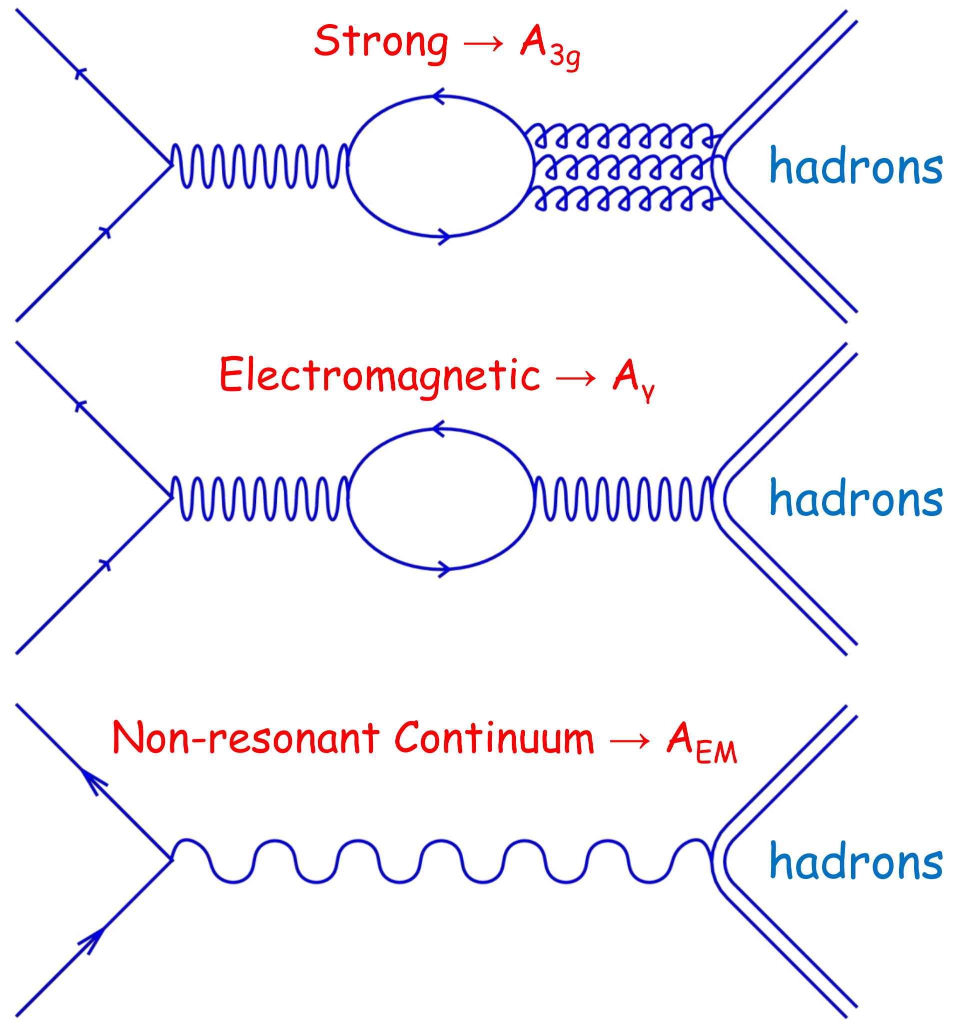
pQCD: all amplitudes almost real [1,2]

QCD -> $\Phi_p \sim 10$ [1]

Non-resonant continuum

pQCD regime

$A_{EM} \in \Re$



[1] J. Bolz and P. Kroll, WU B 95-35.
[2] S.J. Brodsky, G.P. Lepage, S.F. Tuan, Phys. Rev. Lett. 59, 621 (1987).

J/ψ Strong and Electromagnetic Decay Amplitudes

- If both real, they must interfere ($\Phi_p \sim 0°/180°$)
- On the contrary $\Phi_p \sim 90° \rightarrow$ No interference

$J/\psi \rightarrow N\bar{N}$ ($\frac{1}{2}^+\frac{1}{2}^-$) $\Phi_p = 89° \pm 15°$ [1]; $89° \pm 9°$[2]

$J/\psi \rightarrow$ VP (1^-0^-) $\Phi_p = 106° \pm 10°$ [3]

$J/\psi \rightarrow$ PP (0^-0^-) $\Phi_p = 89.6° \pm 9.9°$ [4]

$J/\psi \rightarrow$ VV (1^-1^-) $\Phi_p = 138° \pm 37°$ [4]

- Results are model dependent
- Model independent test:

interference with the non resonant continuum

[1] R. Baldini, C. Bini, E. Luppi, Phys. Lett. B404, 362 (1997); R. Baldini et al., Phys. Lett. B444, 111 (1998)
[2] M. Ablikim et al., Phys. Rev. D 86, 032014 (2012).
[3] L. Kopke and N. Wermes, Phys. Rep. 174, 67 (1989); J. Jousset et al., Phys. Rev. D41,1389 (1990).
[4] M. Suzuki et al., Phys. Rev. D60, 051501 (1999).

J/ψ Strong and Electromagnetic Decay Amplitudes

$J/\psi \to N\bar{N}$

Favoured channel 3g match $3q\bar{q}$ pairs

Without EM contribution p = n, due to isospin

EM contribution amplitudes have opposite sign,
like magnetic moments

$BR_{n\bar{n}}$ expected $\sim \frac{1}{2} BR_{p\bar{p}}$

$$R = \frac{Br(J/\psi \to n\bar{n})}{Br(J/\psi \to p\bar{p})} = \left| \frac{A_{3g} + A_\gamma^n}{A_{3g} + A_\gamma^p} \right|^2$$

$A_{3g}, A_\gamma \in \Re$ R<<1

$A_{3g} \perp A_\gamma$ $R \approx 1$

But the BR are almost equal according to BESIII[1]:

$BR(J/\psi \to p\bar{p}) = (2.112 \pm 0.004 \pm 0.027) \cdot 10^{-3}$

$BR(J/\psi \to n\bar{n}) = (2.07 \pm 0.01 \pm 0.14) \cdot 10^{-3}$

- Suggests 90° phase

[1] M. Ablikim et al., Phys. Rev. D 86, 032014 (2012).

Cross section for $e^+e^- \rightarrow \pi^+\pi^-\pi^0$

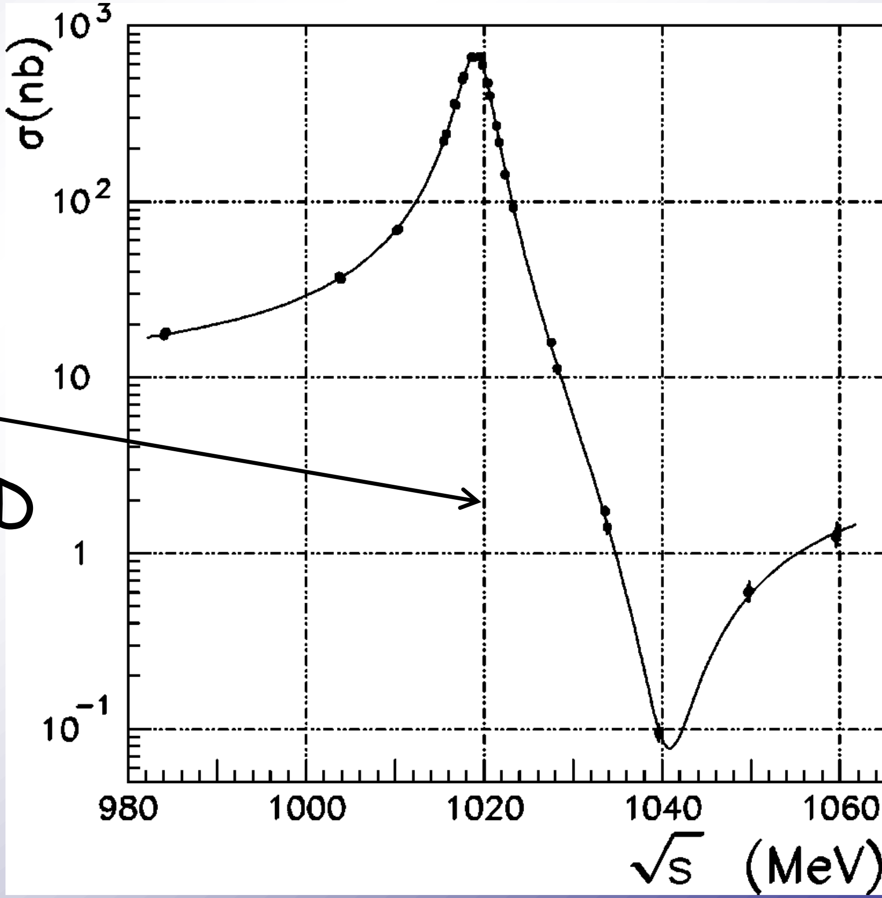
Interference of φ(1020) amplitudes @ SND experiment[1]

Shape indicates full interference path

phase ~ 180°

φ decay in agreement with PQCD

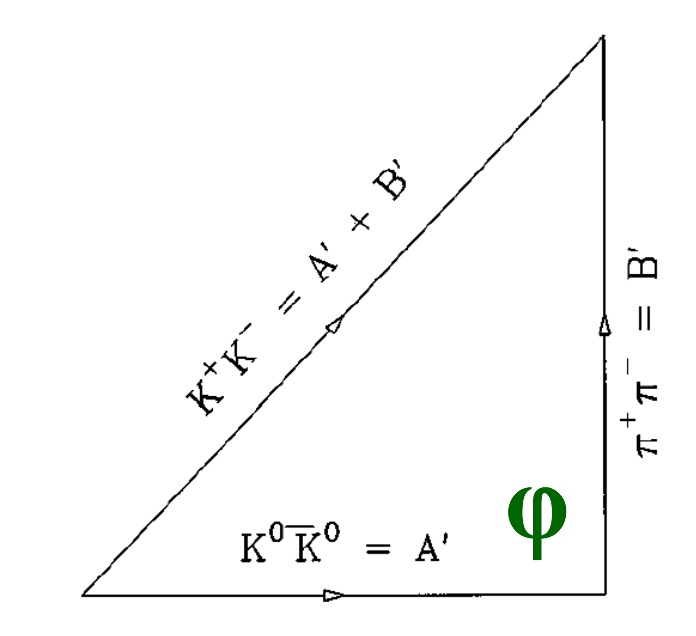
A_{3g} and A_{EM} are both real



[1] M.N. Achasov et al., PRD 63, 072002 (2001).

Phase Reconstruction @ CLEOc

- 3.08 M ψ(2S)   5.63 pb^{-1} CLEO III + CLEOc
- Background 20.7 pb^{-1} @ sqrt(s) = 3.671 GeV
- Decay to Pseudoscalar Pairs (PP)
  - $\pi^+\pi^-$ A_γ
  - $K_S^0 K_L^0$ A_{3g}
  - K^+K^- $A_{3g} + A_\gamma$
- Angular distribution: $\sin^2\theta$
- Background: QED processes ($e^+e^- \rightarrow \gamma\gamma, l^+l^-$)



Combinatorial via sidebands

S. Dobbs et al., Phys. Rev. D 74, 011105 (2006).

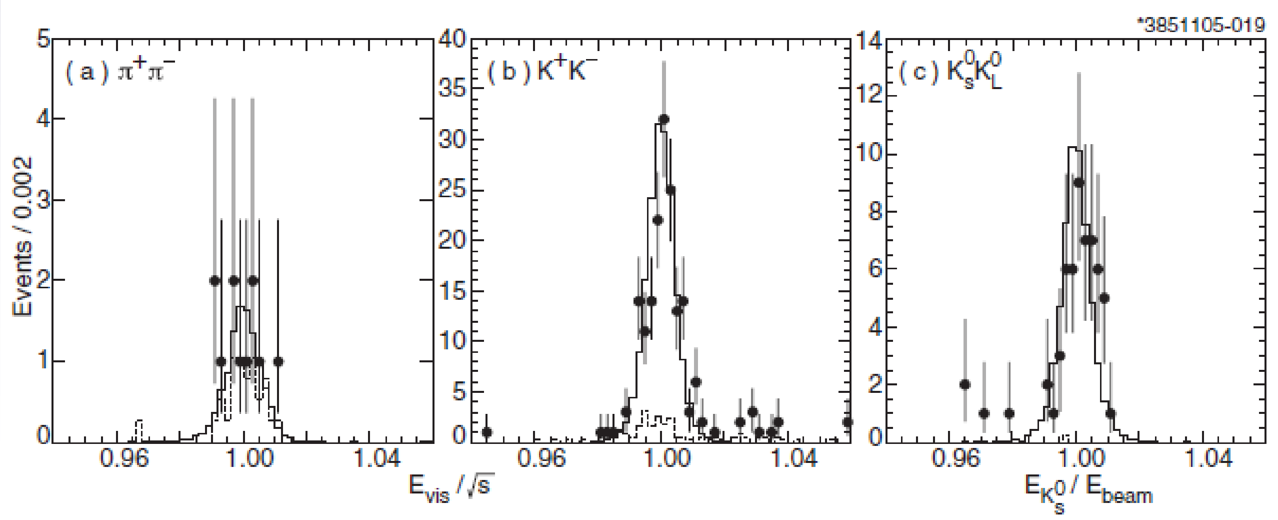
Phase Reconstruction @ CLEOc

$B_{\pi+\pi-} = (1.04 \pm 0.23)\,10^{-5}$ ⟵ Charged π FF

$B_{K+K-} = (6.3 \pm 0.7)\,10^{-5}$

$B_{K_S^0 K_L^0} = (5.8 \pm 0.9)\,10^{-5}$

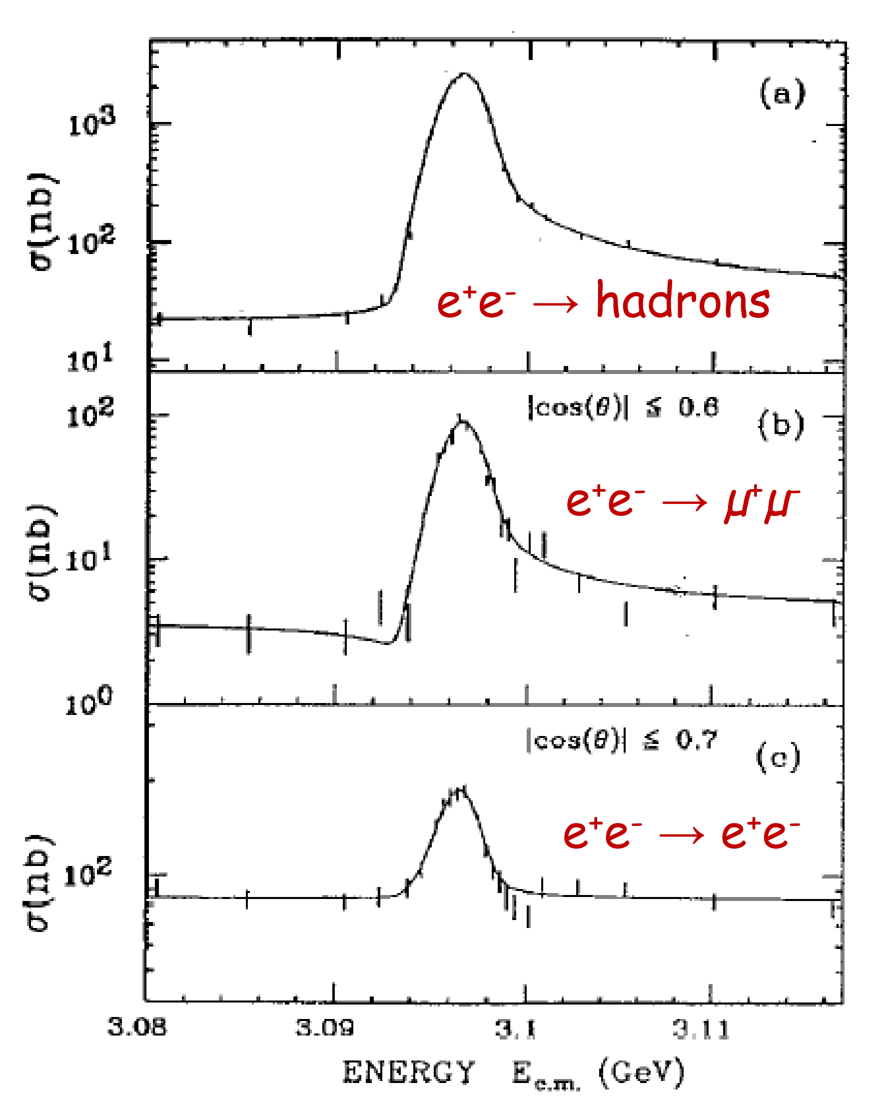
- $R(\psi(2S)) = \frac{A_{3g}}{A_\gamma} = \sqrt{\frac{B_{K_S^0 K_L^0}}{\rho B_{\pi+\pi-}}} = 2.5 \pm 0.4$ $\rho = (p_K/p_\pi)^3$
- $\Delta(\psi(2S)) = \cos^{-1}\left(\frac{B_{K+K-} - B_{K_S^0 K_L^0} - \rho B_{\pi+\pi-}}{2\sqrt{B_{K_S^0 K_L^0}\,\rho B_{\pi+\pi-}}}\right) = (95 \pm 15)°$



E_{vis} = event energy

S. Dobbs et al., Phys. Rev. D 74, 011105 (2006).

Was an Interference Already Seen?



Yes

without the strong contribution

J.Z. Bai et al., Phys. Lett. B 355, 374-380 (1995)

Investigated Processes

- Inclusive scenario: does not see anything

The phase is there, but the mean goes to 0

Interference $\propto \langle f \mid 3g \rangle^* \langle f \mid \gamma \rangle$

Sum over all the final states $\sum \langle 3g \mid f \rangle \langle f \mid \gamma \rangle$

Closure approximation $\sum \mid f \rangle \langle f \mid \approx 1$

But $\langle 3g \mid \gamma \rangle \cong 0$ orthogonal states

If we sum over all the channels, the interference ≈ 0

Investigated Processes

- Exclusive scenario: could see interference effects

- e^+e^+ -> J/ψ -> $p\bar{p}$, $n\bar{n}$ $N\bar{N}$

  BR ~ 2.17×10^{-3} σ_{cont}~ 11 pb

- e^+e^- -> J/ψ -> $\rho\pi$ VP

  BR ~ 1.69% σ_{cont}~ 20 pb

- e^+e^- -> J/ψ -> $2(\pi^+\pi^-)\pi^0$

  BR ~ 5.5% σ_{cont}~ 500 pb

Investigated Processes

- Exclusive scenario: could see interference effects also on

- e^+e^- -> J/ψ -> $\pi^+\pi^-$
- e^+e^- -> J/ψ -> K^+K^-
- e^+e^- -> J/ψ -> $K^0\overline{K}^0$

proposed and under study [1]

All the other channels for free

Even number of π: strong decay forbidden

-> interference must be seen

[1] H. Czyz, and J. Kühn, Phys. Rev. D80: 034035 (2009)

Continuum Cross Section

$$\sigma \propto \frac{1}{S} FF^2$$

$p\bar{p}$

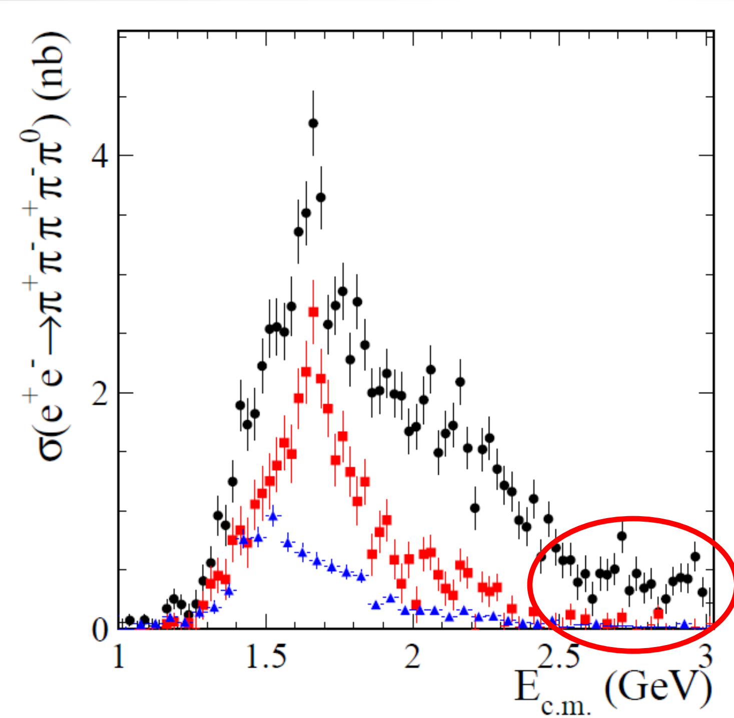
$$\sigma \propto \frac{1}{W^{10}}$$

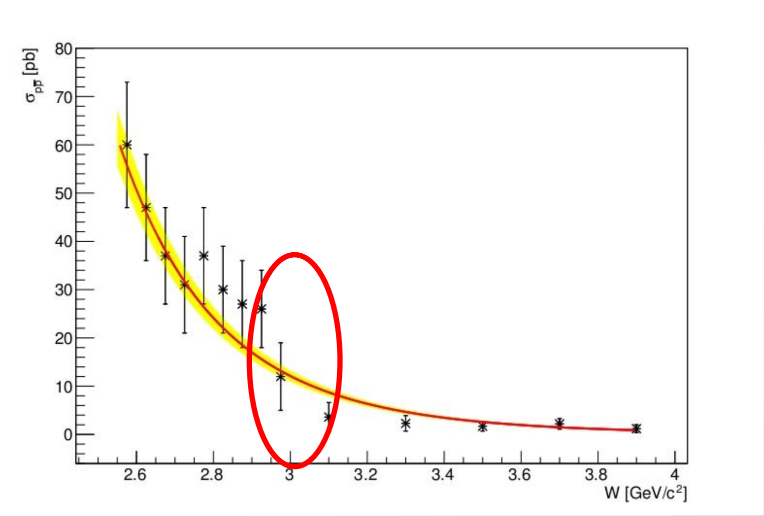
$\sigma_{cont} \sim 11$ pb

5π

$$\sigma \propto \frac{1}{W^{0}}$$

$\sigma_{cont} \sim 500$ pb

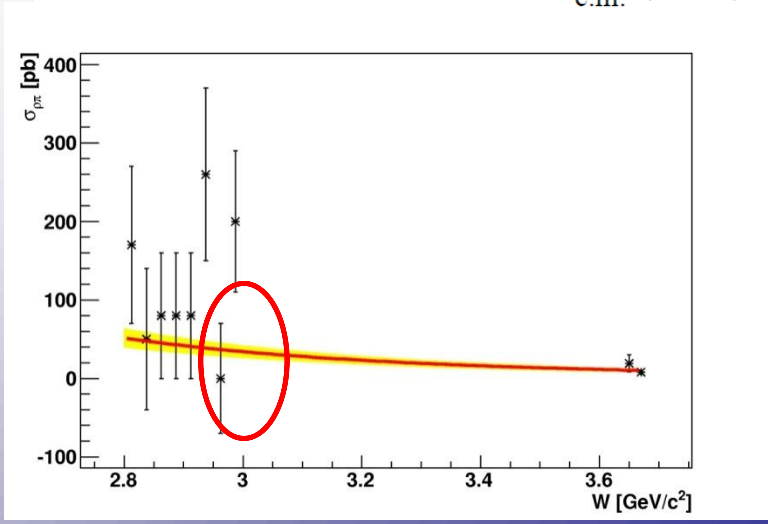




$\rho\pi$

$$\sigma \propto \frac{1}{W^{6}}$$

$\sigma_{cont} \sim 20$ pb



V. Druzhinin et al., Rev. Mod. Phys. 83, 1545 (2011) ; B. Aubert et al., Phys. Rev. D73,012005 (2006)

Phase Generator

- Event generator
- Monte-Carlo method (100000 iterations)
- Cross section evaluation at each point
- Beam spread gaussian (0.93 MeV)
- Radiative correction (simple model to be optimized)
- Max radiation 300 MeV (~20% E_{CM})
- Cross section:

$$\sigma[nb] = 12\pi B_{in} B_{out} \left[\frac{\hbar c}{W}\right]^2 \cdot 10^7 \cdot \left| -\frac{C_1 + C_2 e^{i\varphi}}{W - W_{ris} + i\Gamma_{ris}/2} + C_3 e^{i\varphi} \right|^2$$

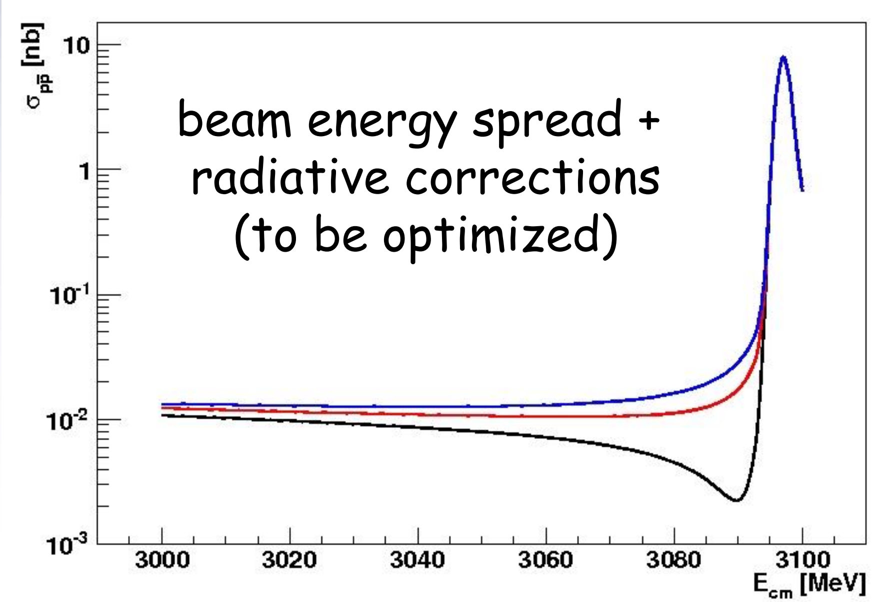
Simulated Yields for $e^+e^- \to p\bar{p}$

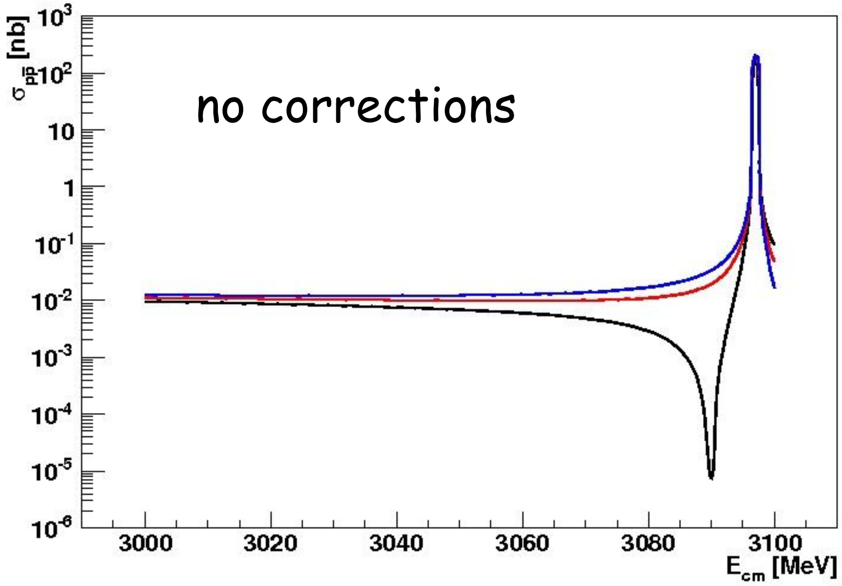
— $\Delta\varphi = 0°$ (black)

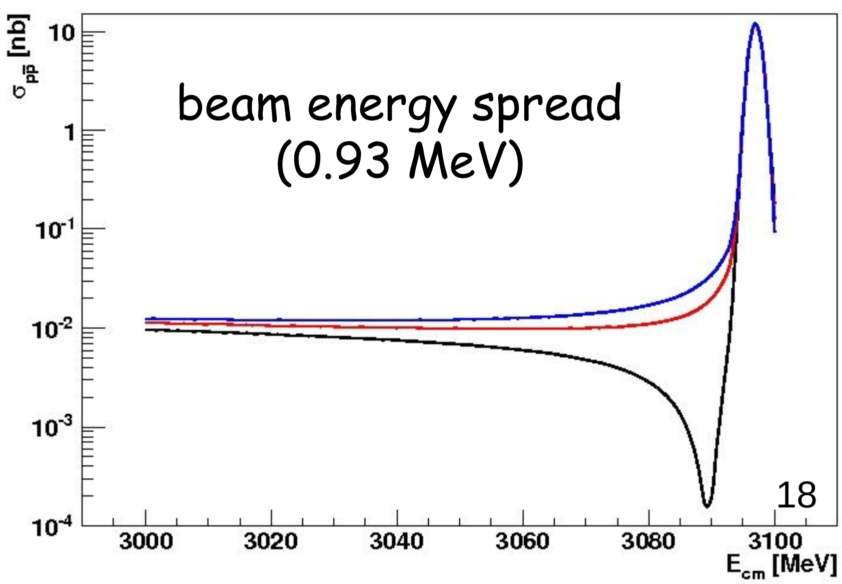
— $\Delta\varphi = 90°$ (red)

— $\Delta\varphi = 180°$ (blue)

continuum reference
$\sigma \sim 11$ pb







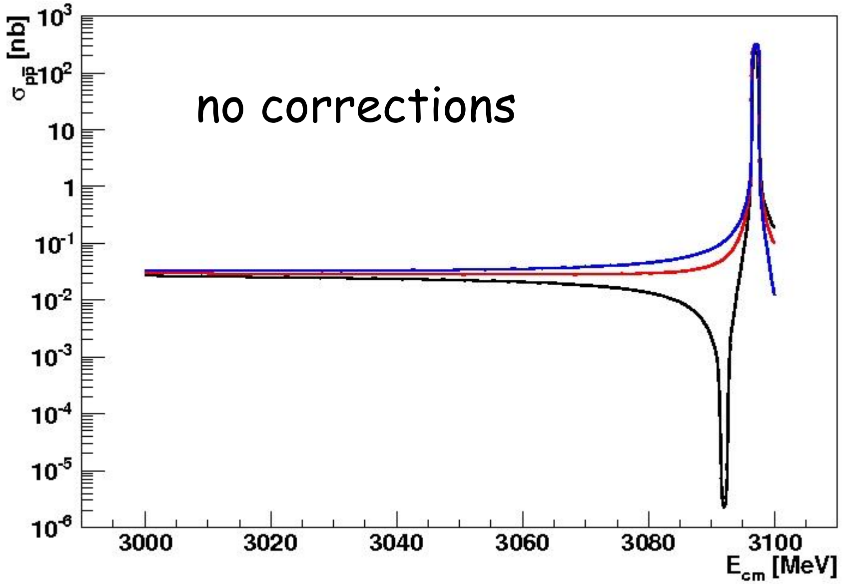
Simulated Yields for $\bar{p}p \to \mu^+\mu^-$

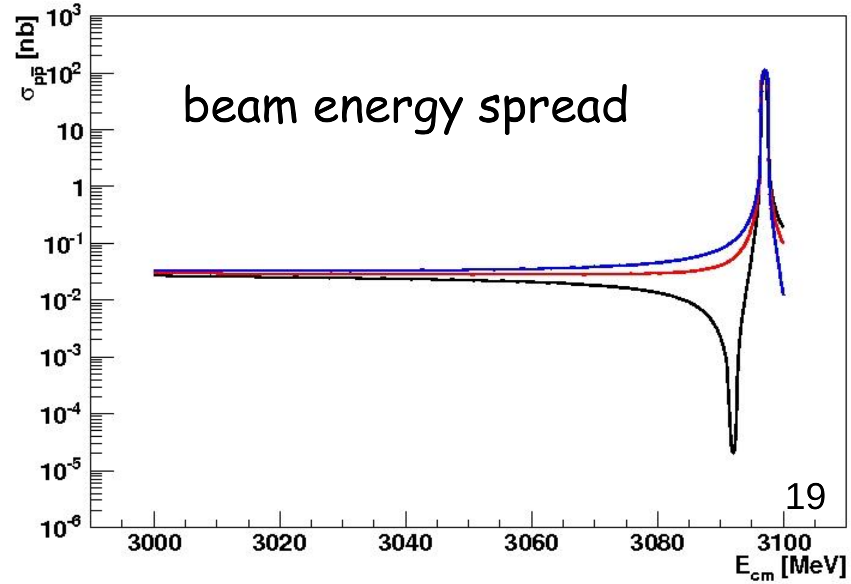
— $\Delta\varphi = 0°$ (black line)

— $\Delta\varphi = 90°$ (red line)

— $\Delta\varphi = 180°$ (blue line)

continuum reference
$\sigma \sim 18$ pb



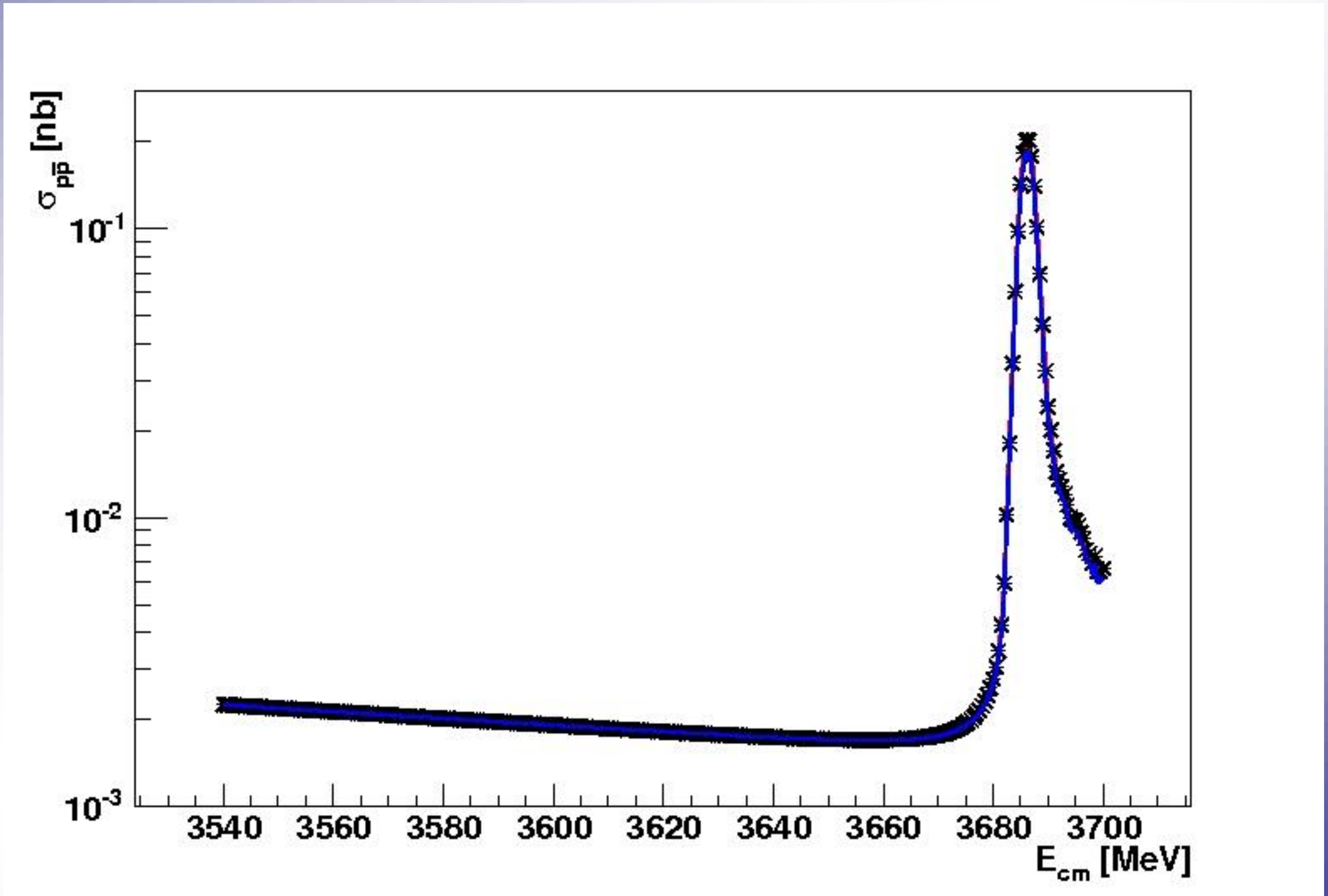


Phase Sign

$p\bar{p}$

* red: $\Delta\varphi = -90°$
  blue: $\Delta\varphi = +90°$

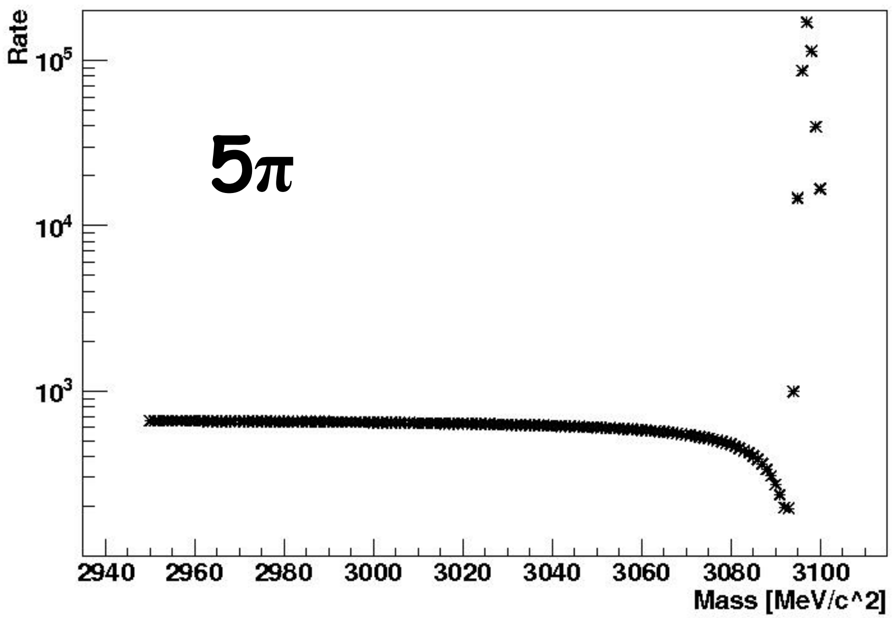
Maximum differences at the 1% level

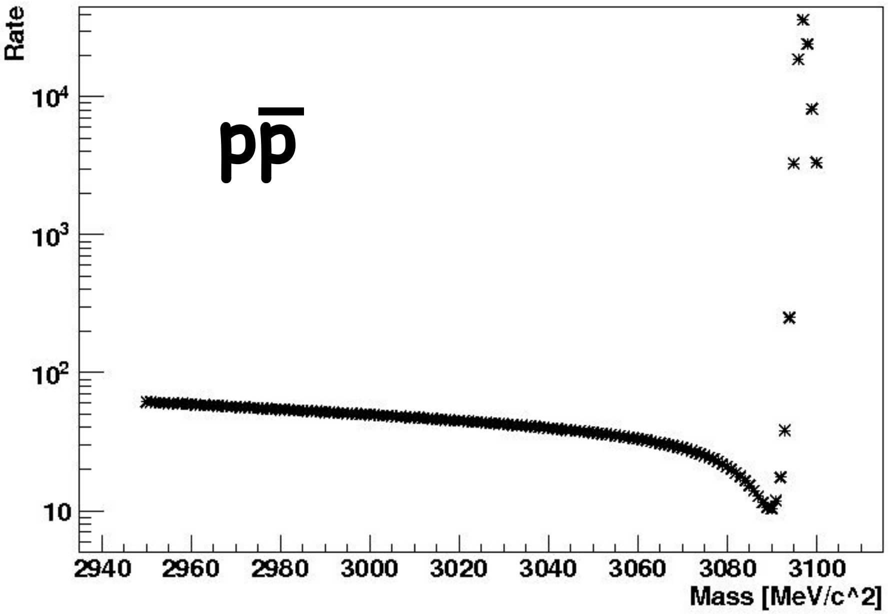


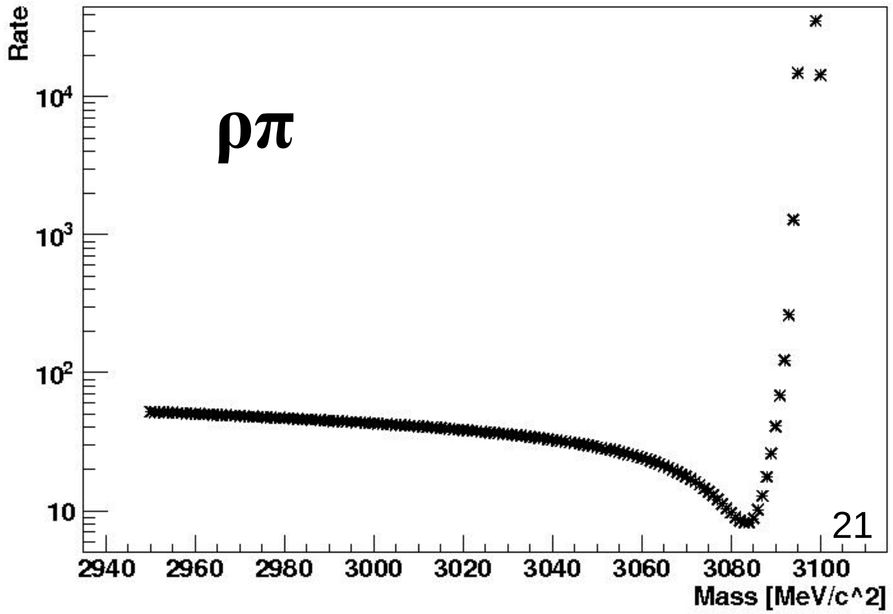
Energy Points Choice

Depends on the process

Maximum interference: 0°





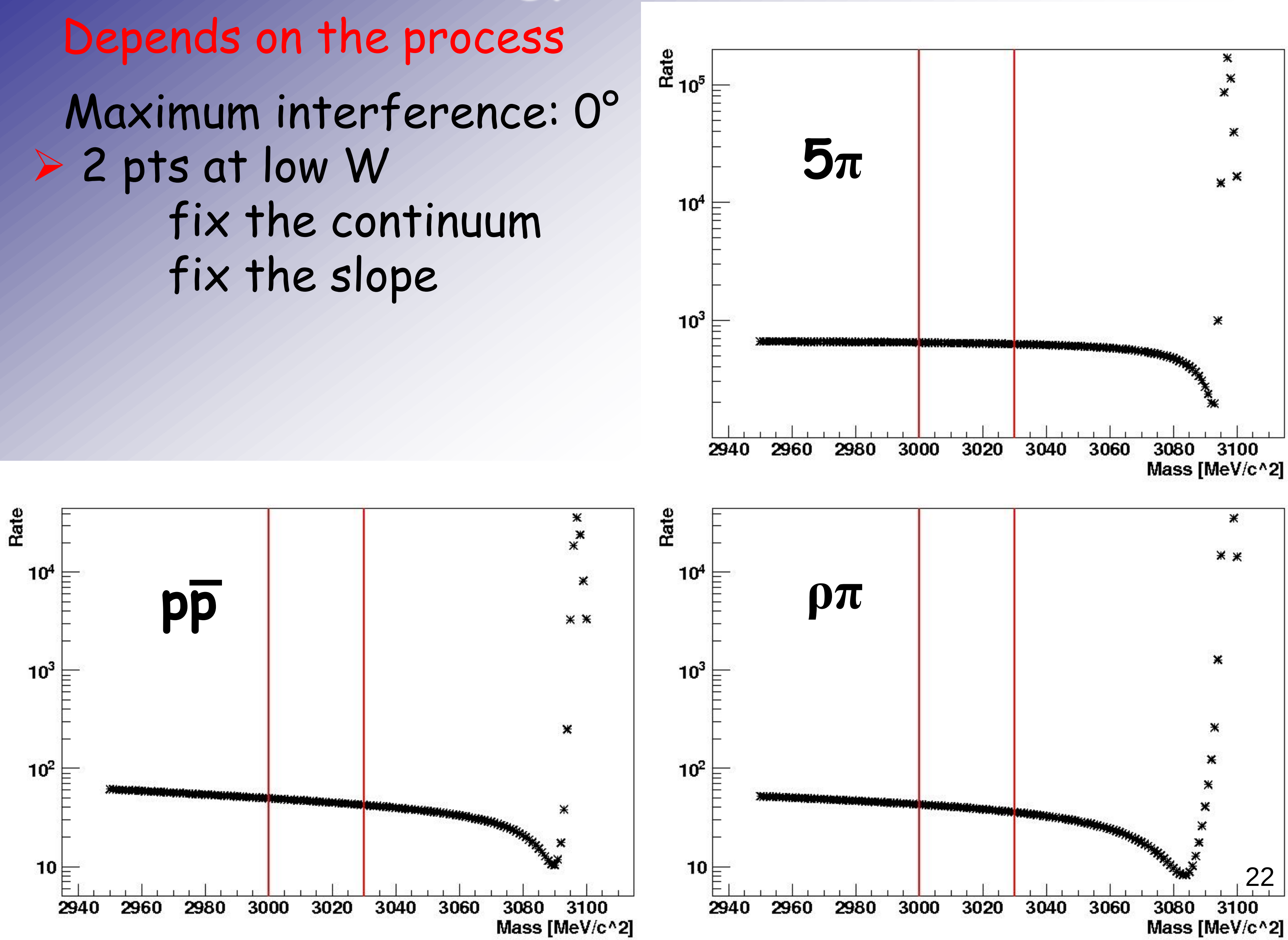


Energy Points Choice

Depends on the process

Maximum interference: 0°

- 2 pts at low W
  - fix the continuum
  - fix the slope

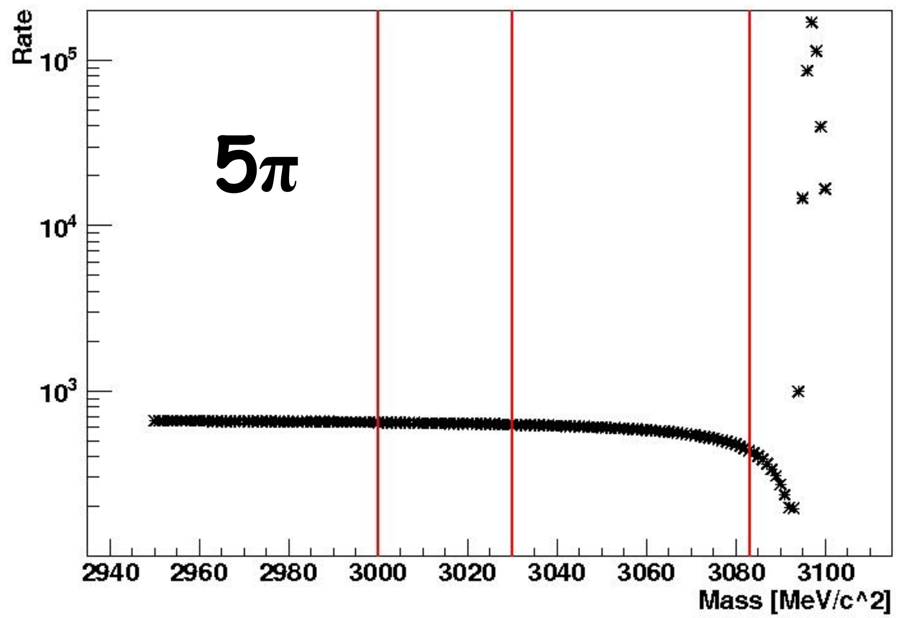


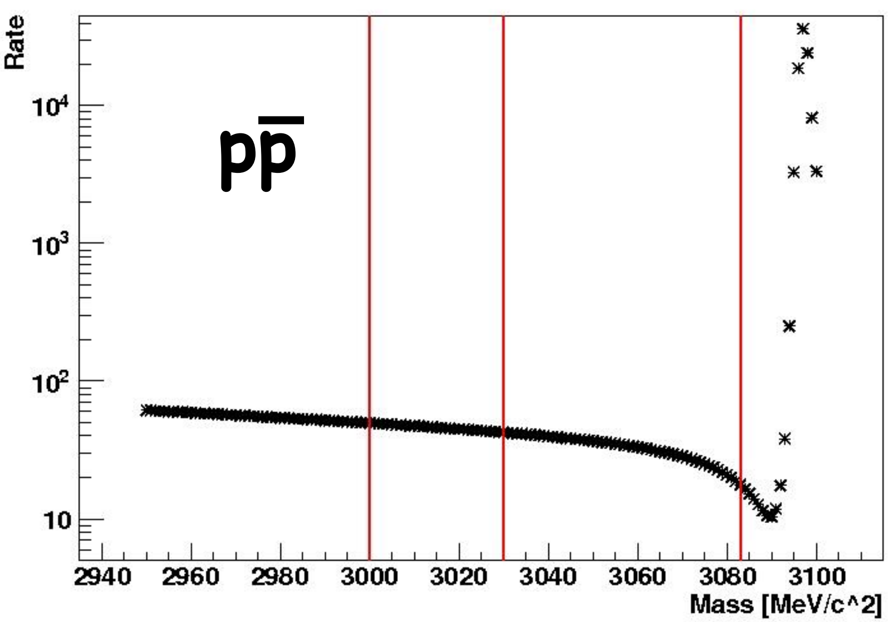
Energy Points Choice

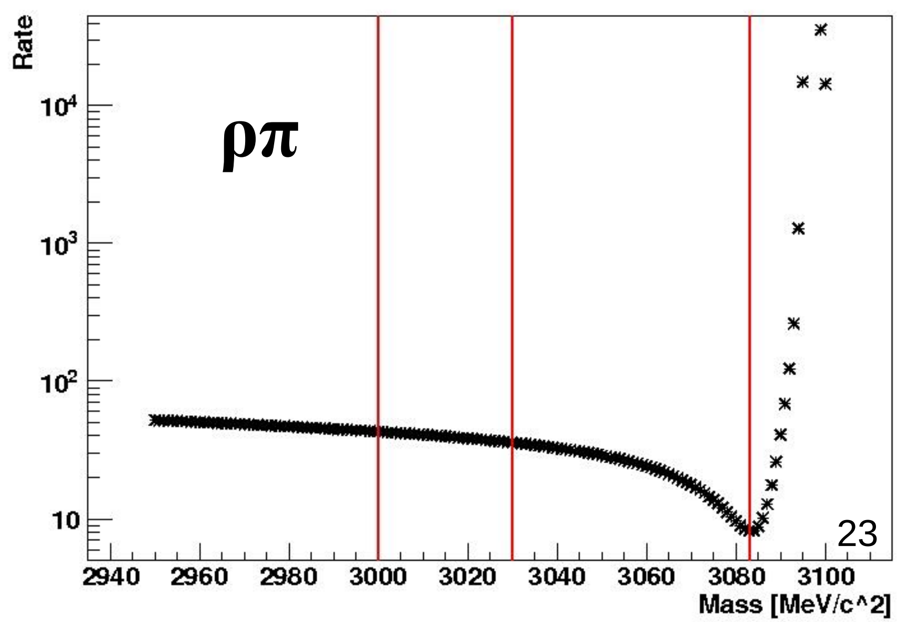
Depends on the process

Maximum interference: 0°

- 2 pts at low W
  - fix the continuum
  - fix the slope
- 2 pts at deep positions





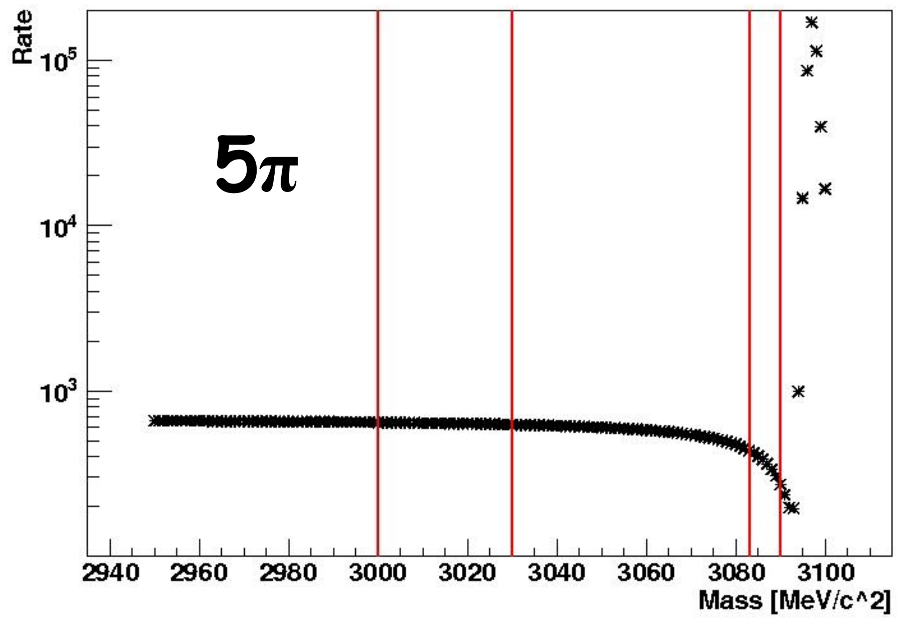


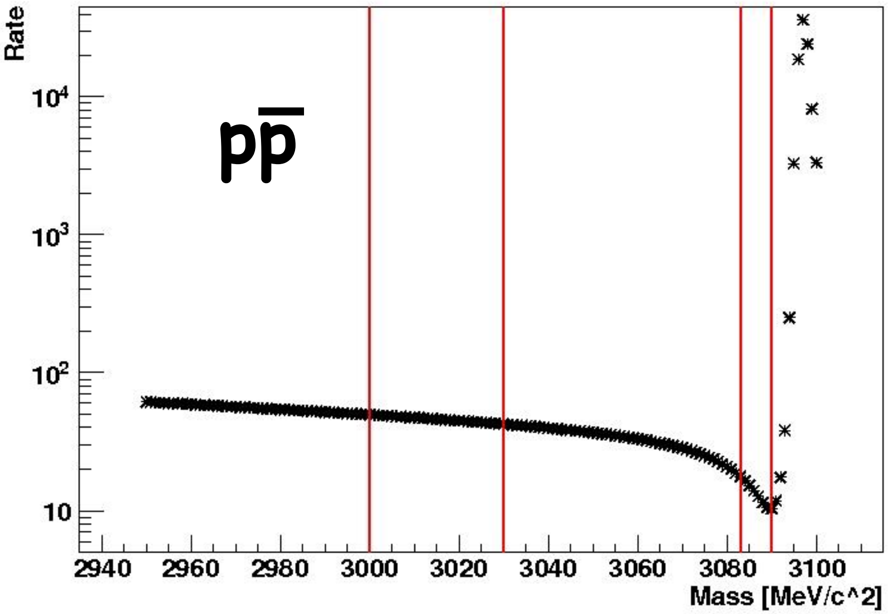
Energy Points Choice

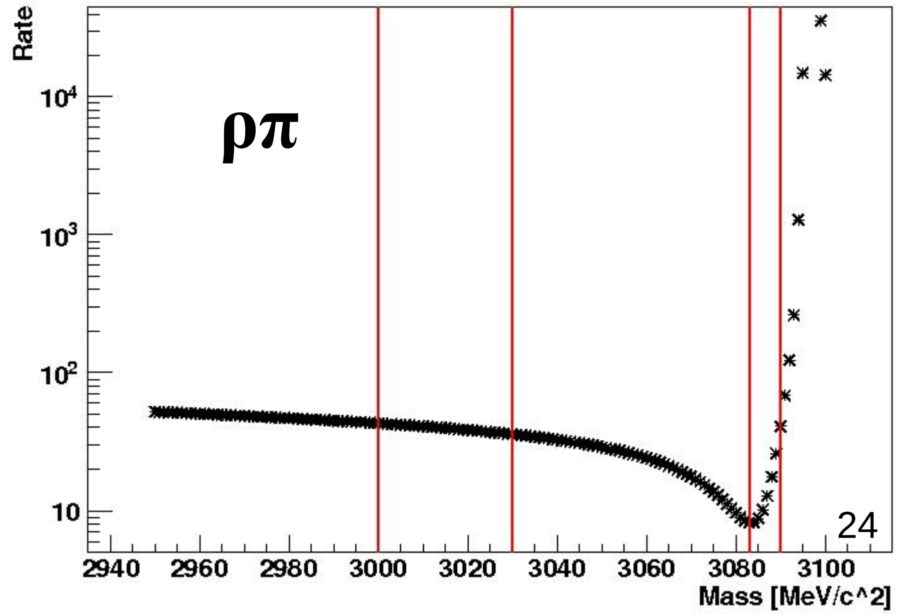
Depends on the process

Maximum interference: 0°

- 2 pts at low W
  - fix the continuum
  - fix the slope
- 2 pts at deep positions





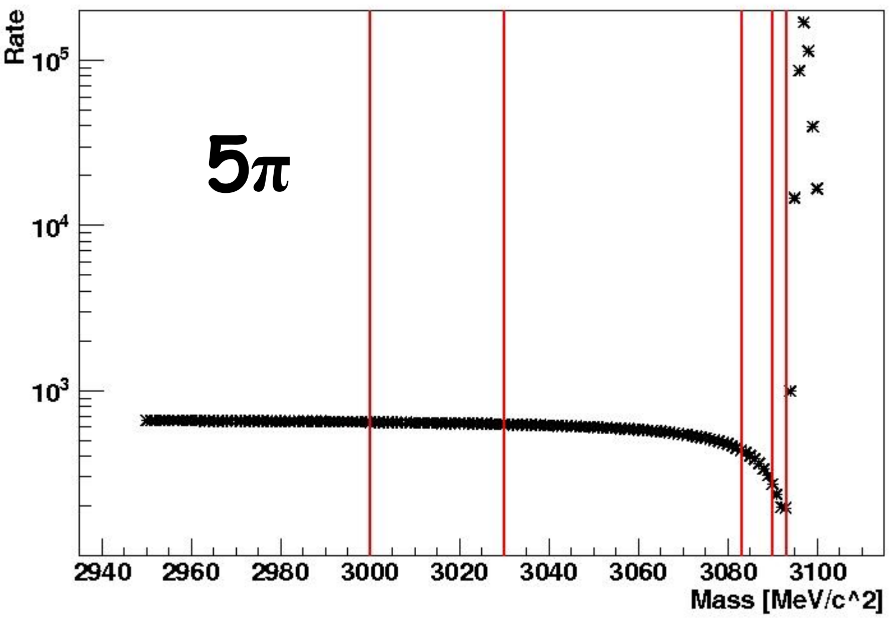


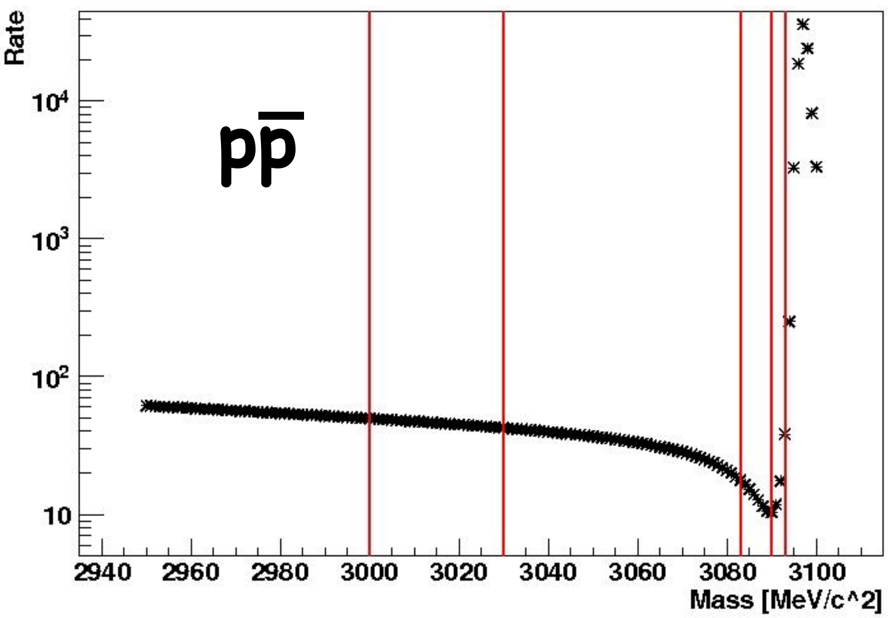
Energy Points Choice

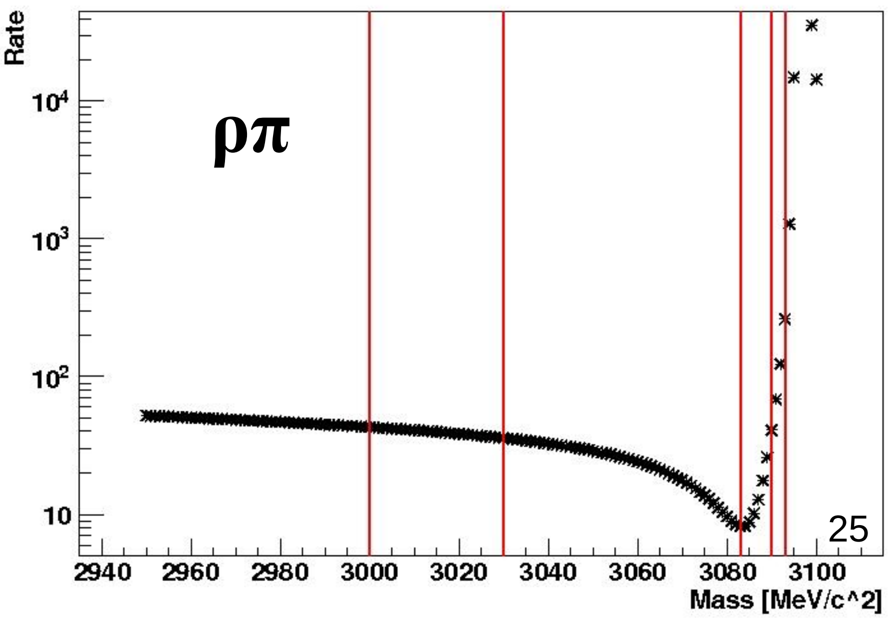
Depends on the process

Maximum interference: 0°

- 2 pts at low W
  - fix the continuum
  - fix the slope
- 2 pts at deep positions
- 1 pt Beginning of the BW







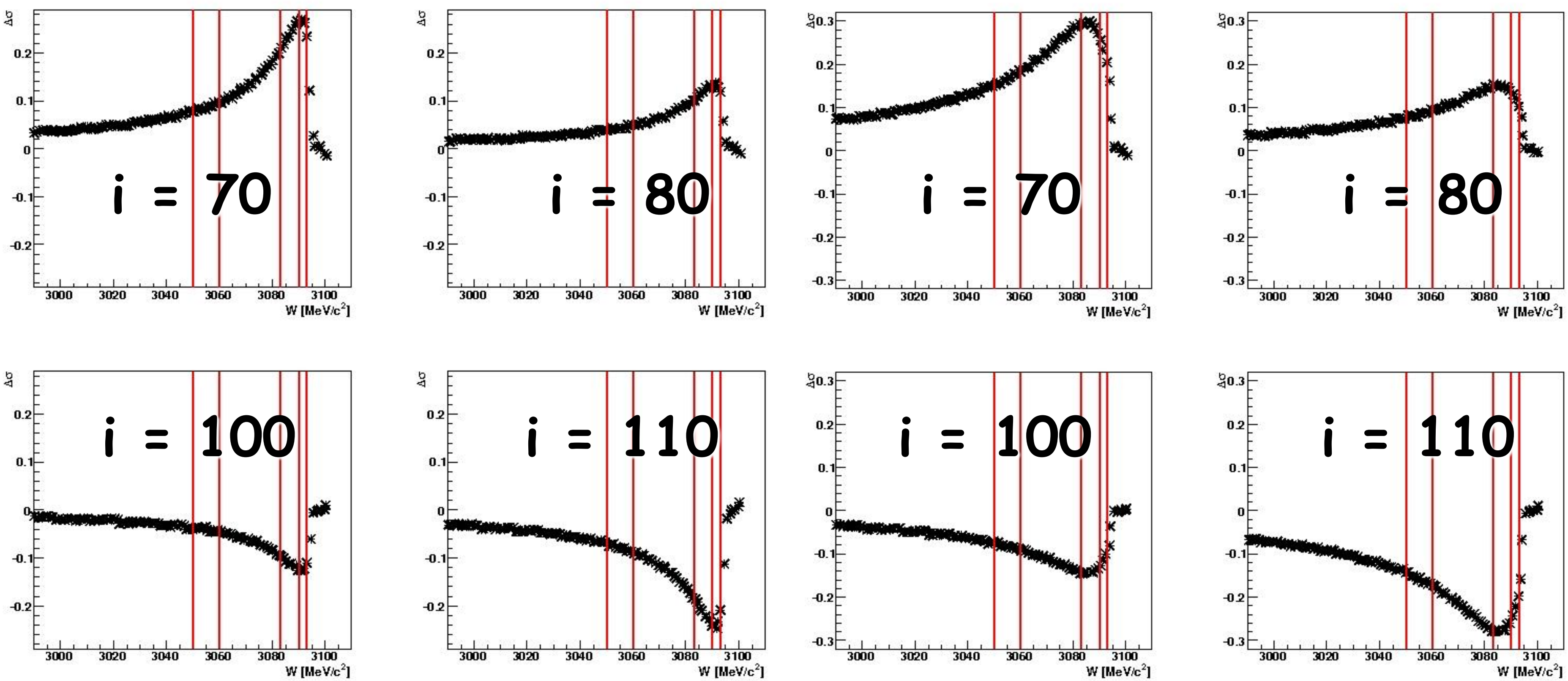
Energy Points Choice

- What happens at 90°

Gradient calculation $(\sigma_{90}-\sigma_i)/\sigma_{90}$

The deep corresponds roughly to the maximum gradient

$p\bar{p}$ **$\rho\pi$**



Energy Points Choice

3050 MeV

3060 MeV

3083 MeV

3090 MeV

3093 MeV

Luminosity Hypothesis

- 5 values of Luminosity:
  $8.6 \cdot 10^{31}$, 10^{32}, $2 \cdot 10^{32}$,
  $5 \cdot 10^{32}$, 10^{33} [$cm^{-2}s^{-1}$]
- Time: 1 day = 86400 s
- Injection efficiency = 0.8

Integrated Luminosity

$L_{int}/day = L \cdot T \cdot \varepsilon_{inj}$

$6 \cdot 10^{36}$, $6.9 \cdot 10^{36}$,

$1.4 \cdot 10^{37}$, $3.5 \cdot 10^{37}$,

$6.9 \cdot 10^{37}$ [cm^{-2}]

- Reconstruction efficiency

  $p\bar{p}$ = 0.67
  $\rho\pi$ = 0.38
  5π = 0.20

- Rate = $L \cdot T \cdot \varepsilon_{inj} \cdot \varepsilon_{rec} \cdot \sigma$

Precision of the Fit

Statistical error for:

$p\bar{p}$ circle

$\rho\pi$ triangle

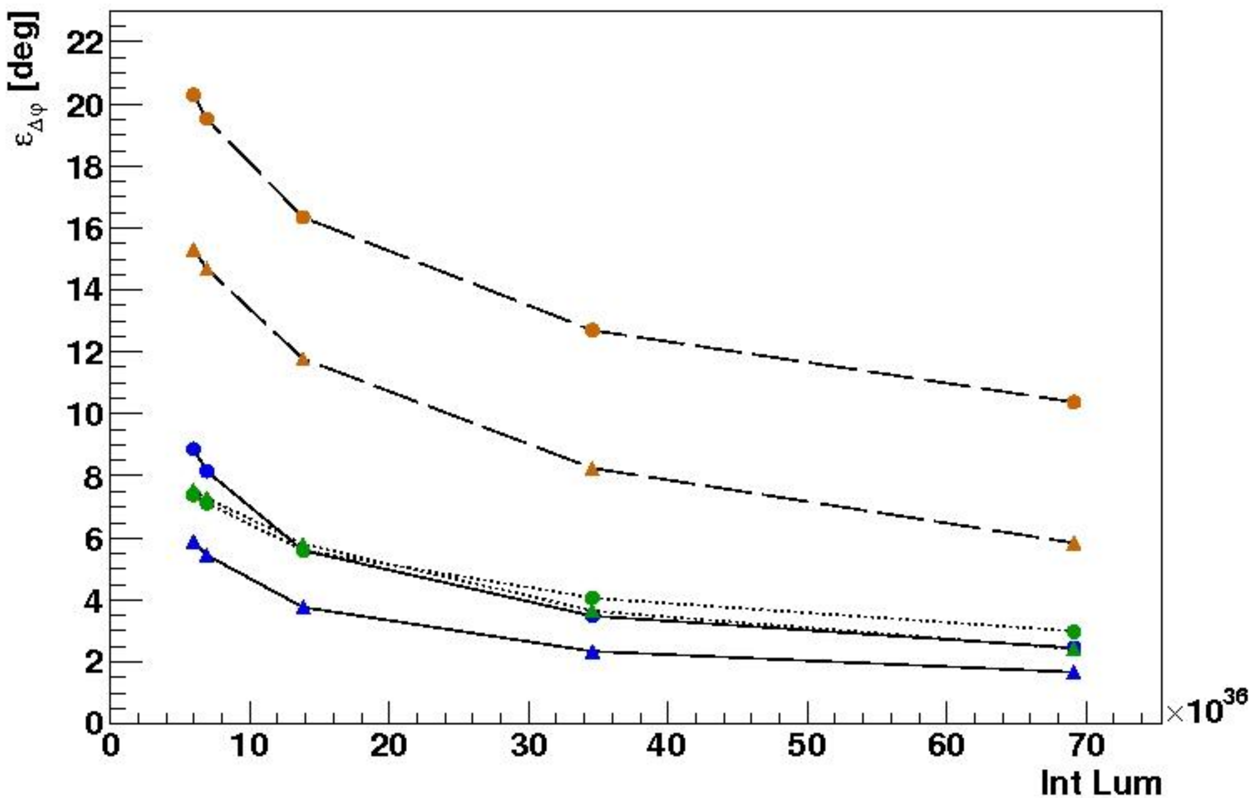
.... 10°

——— 90°

– – – – 170°

2 parameters:

φ and σ_{cont}



170°

- Lower sensitivity

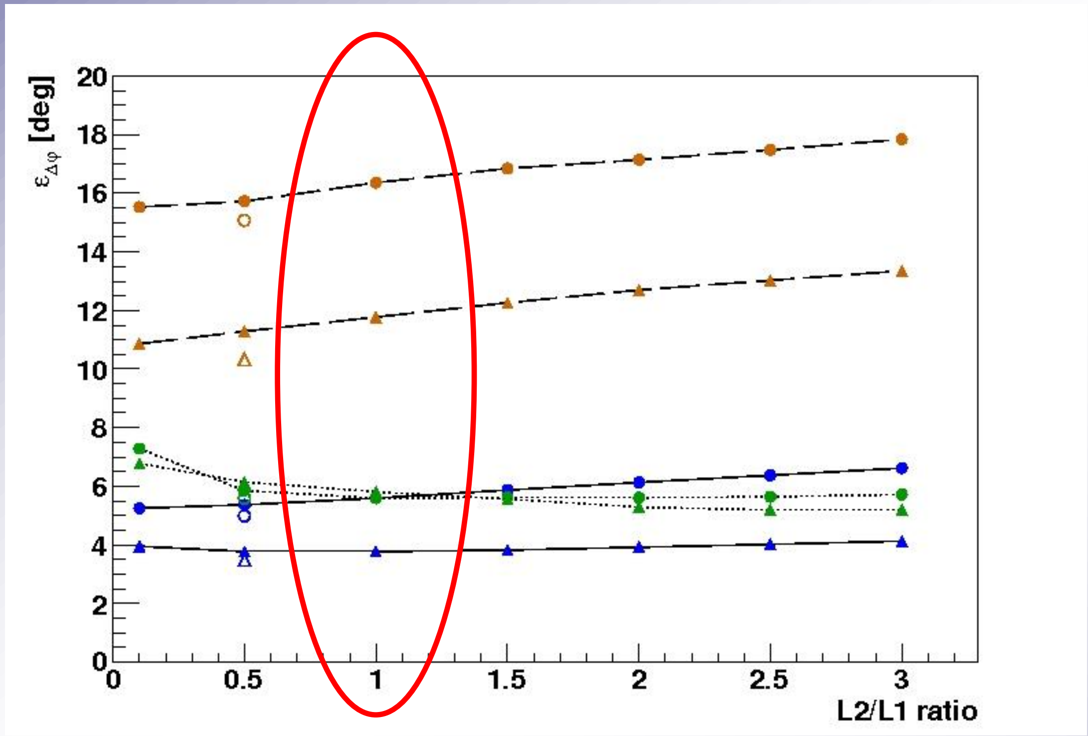
(No 0°-90° and 90°-180° symmetry)

Fit results

5 days $L_{int} = 1.4 \times 10^{37}$ [cm^{-2}]

points: 3050,3060, 3083,3090, 3093 MeV

$\ell_1 : \ell_1 : \ell_2 : \ell_2 : \ell_1$



Statistical error:

$p\bar{p}$ circle

$\rho\pi$ triangle

.... 10°

——— 90°

— — — — 170°

Open points:

1:1:0.5:0.5:2

Very low sensitivity to Luminosity ratios

Best and simplest choice: 1:1:1:1:1

$p\bar{p}$

J/ψ Scan

$\Delta\varphi = +90°$

σ_{cont} = 11 pb $B_{out} = 2.17 \cdot 10^{-3}$

3 parameters:

φ, σ_{cont} and B_{out}

Points	Par	Inj. eff.	Δφ [°]	Δσ [pb]	ΔB_{out}
5	3	0.7	29.3	1.3	$0.7 \cdot 10^{-3}$
5	3	0.8	26.7	1.3	$0.7 \cdot 10^{-3}$
6	3	0.8	6.1	0.9	$0.4 \cdot 10^{-5}$
12	3	0.7	6.3	0.9	$0.7 \cdot 10^{-4}$
12	3	0.8	5.9	0.9	$0.7 \cdot 10^{-4}$

3 parameters: 3096.9 needed

(1 point more with high statistics)

J/ψ Phase

Energy requested [MeV]	Energy collected [MeV]	L_{int} [pb^{-1}]
3050	3046	14.0
3060	3056	14.0
3083	3086	16.5
3090	3085	14.0
3093	3088	14.0
3097	3097	79.6

PRELIMINARY

J/ψ Phase – Real Data

Ecm(GeV)	(pb^{-1})
3.0500	14.895±0.029
3.0600	15.056±0.030
3.0830	4.759±0.017
3.0856	17.507±0.032
3.0900	15.552±0.030
3.0930	15.249±0.030
3.0943	2.145±0.011
3.0952	1.819±0.010

Ecm(GeV)	(pb^{-1})
3.0958	2.161±0.011
3.0969	2.097±0.011
3.0982	2.210±0.011
3.0990	0.759±0.007
3.1015	1.164±0.010
3.1055	2.106±0.011
3.1120	1.719±0.010
3.1200	1.261±0.009
3.0969	79.6

B.X. Zhang, Luminosity measurement for J/psi phase and lineshape study.

$e^+e^- \to \mu^+\mu^-$ Phase Reconstruction

2 good charged tracks:

- |Rxy|<1cm, |Rz|<10cm;
- $|\cos\theta|<0.8$.

No good neutral tracks in EMC:

- 0<T<14 (x50 ns)
- $E_\gamma>25$MeV ($|\cos\theta|<0.8$), $E_\gamma>50$ MeV ($0.86<|\cos\theta|<0.92$)
- $\theta_{\gamma,\mathrm{charged}}<10^o$.

Vertex fit to impove the momentum resolution:

- $\chi^2_{vertex}<100$.

Veto e^+e^-:

- Each charged track has an energy deposit in EMC;
- E/p<0.25.

Veto cosmic rays:

- $\Delta T=|Tof(\mu^+)-Tof(\mu^-)|<0.5$

Momentum window cut:

- $|p_{\mu\pm}-p_{the}|<3\sigma$

Leptonic decay

Contributions from A_γ and A_{EM}

$e^+e^- \to 2(\pi^+\pi^-)$ Phase Reconstruction

4 good charged tracks:

|Rxy|<1cm, |Rz|<10cm.

Vertex fit to improve the momentum resolution.

Veto bkg from γ-conversion ($2(e^+e^-)$):

All angles between π^+ and π^-, $10^o<\theta_{\pi+\pi-}<170^o$.

Veto events which have multi-tracks:

Minimum angle between $(\pi^+\pi^-)$ pairs: $\theta(\pi^+\pi^-,\pi^+\pi^-)>170^o$.

G-Parity

Contributions from A_γ and A_{EM}

$e^+e^- \to 2(\pi^+\pi^-)\pi^0$ Phase Reconstruction

4 good charged tracks:

- |Rxy|<1cm, |Rz|<10cm.

At least 2 good neutral tracks in EMC:

- 0<T<14 (x50 ns);
- E_γ>25MeV (|cosθ|<0.8), E_γ>50 MeV (0.86<|cosθ|<0.92)
- $\theta_{\gamma,charged}$<10°.

PID for each charged track:

- prob(π)>prob(K)

Vertex fit:

- χ^2_{vertex}<100.

3-C kinematic fit:

- Loop all photons, choose the combination with the minimum χ^2_{3C}(<200).

π^0 selection:

- |M($\gamma\gamma$)-0.135|<0.02 GeV/c2

$$|\cos\theta(\pi^0)_{decay}| = \frac{|E_{\gamma1} - E_{\gamma2}|}{p_{\pi^0}} < 0.9$$

Multi-combination from intermediate processes

Contributions from A_γ and A_{EM}

ppbar Events Reconstruction

2 good charged tracks:

- $|Rxy| < 1$ cm, $|Rz| < 10$ cm;
- back-to-back tracks: $178° < \theta < 180°$;
- $p < 2$ GeV/c;
- $|\cos| < 0.92$

Analysis in Barrel + End Cap.

M. Ablikim et al., Phys. Rev. D 86, 032014 (2012).

ISR Radiative Corrections

Comparison of different generators

- KKMC Phase Space
- KKMC $1 + \cos^2\theta$
- ConExc
- Babayaga

ISR on/off

Check at each energy point

Reconstruction Efficiency and Systematic Errors

Summary

- J/ψ decay amplitude phase: 0° (theory) but 90° (data)
- Energy points collected: 3046, 3056, 3086, 3085, 3088
- Statistical significance enough to discriminate between different theoretical predictions
- Precision of fit → Luminosity dependence
- Analysis is ongoing

Next Steps

- Complete the presented analysis
- Analyze more final states
- More refined ISR evaluation