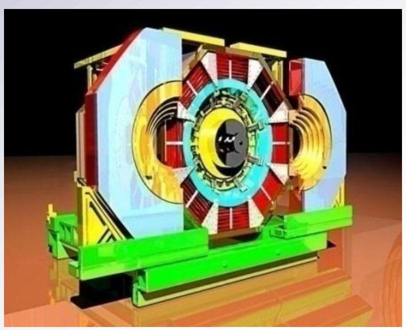
Measuring the Phase between Strong and EM J/ψ Decay Amplitudes

Marco Destefanis

Università degli Studi di Torino

on behalf of the BESIII Collaboration



XXI International Baldin Seminar on High Energy Physics Problems

Relativistic Nuclear Physics & Quantum Chromodynamics

September 10-15, 2012

Overview

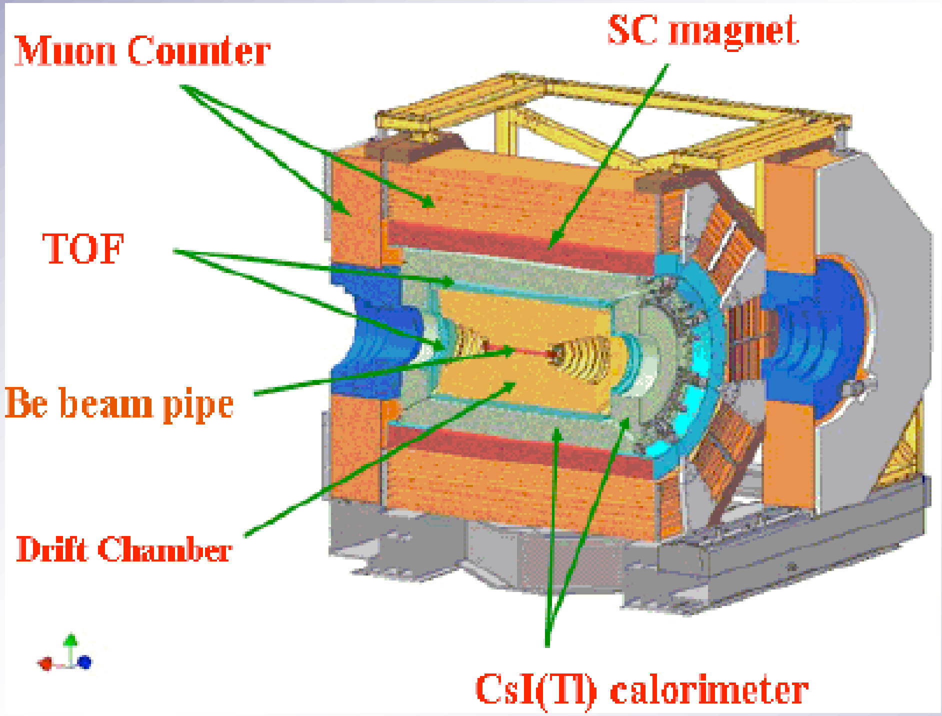
- BESIII experiment
- Motivation
- Investigated processes
- Energy points
- Required Luminosity
- Summary

The BESIII Experiment @ IHEP

BEijing Spectrometer III

e^+e^- collisions

$\sqrt{S}$ tuned depending on energy



Physics program

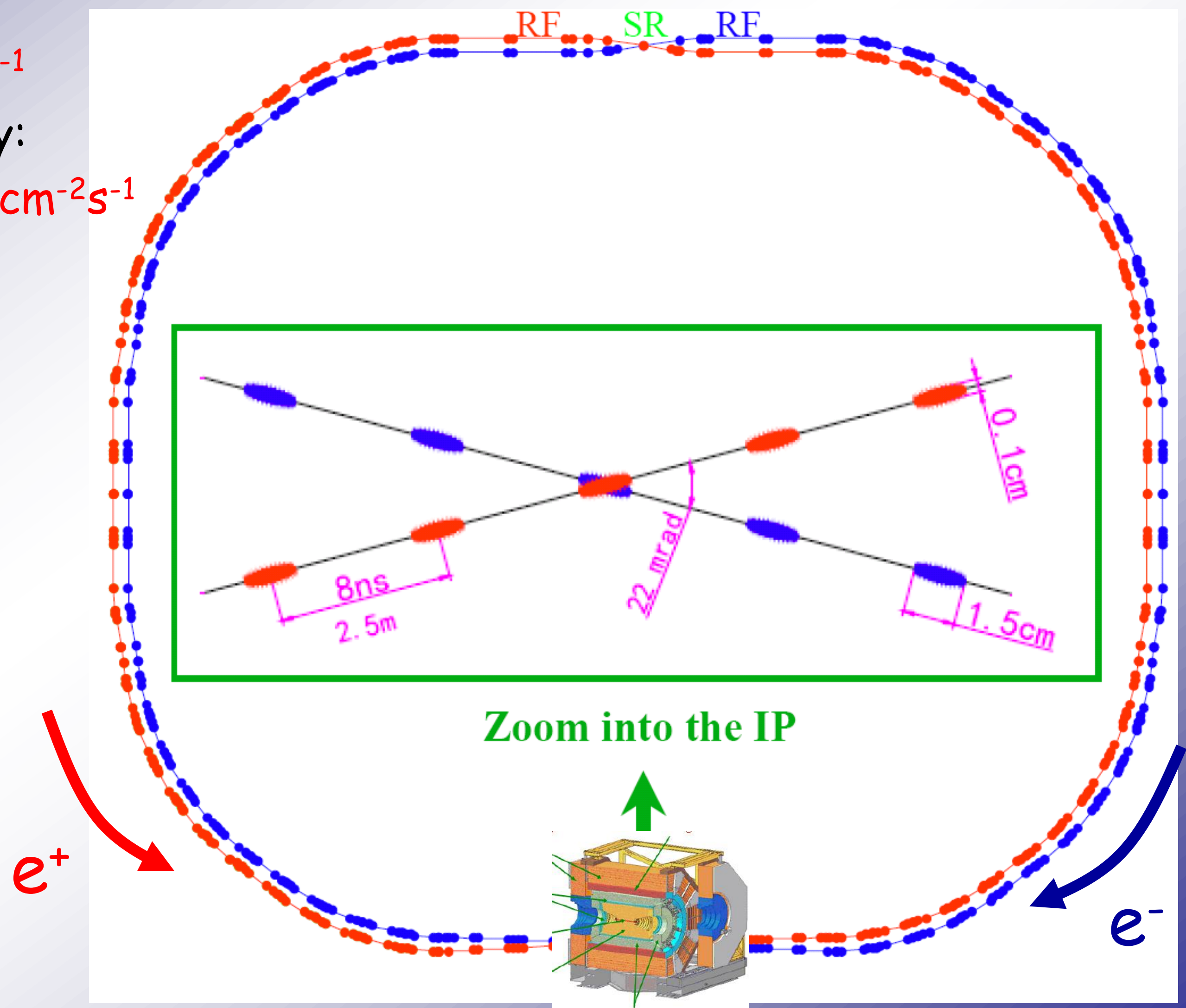
- Charmonium Physics
- D-Physics
- Light Hadron Spectroscopy
- τ-Physics
- ...

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:
  1×10^{33} $cm^{-2}s^{-1}$
- Achieved Luminosity:
  ~ 0.65×10^{33} $cm^{-2}s^{-1}$
- 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

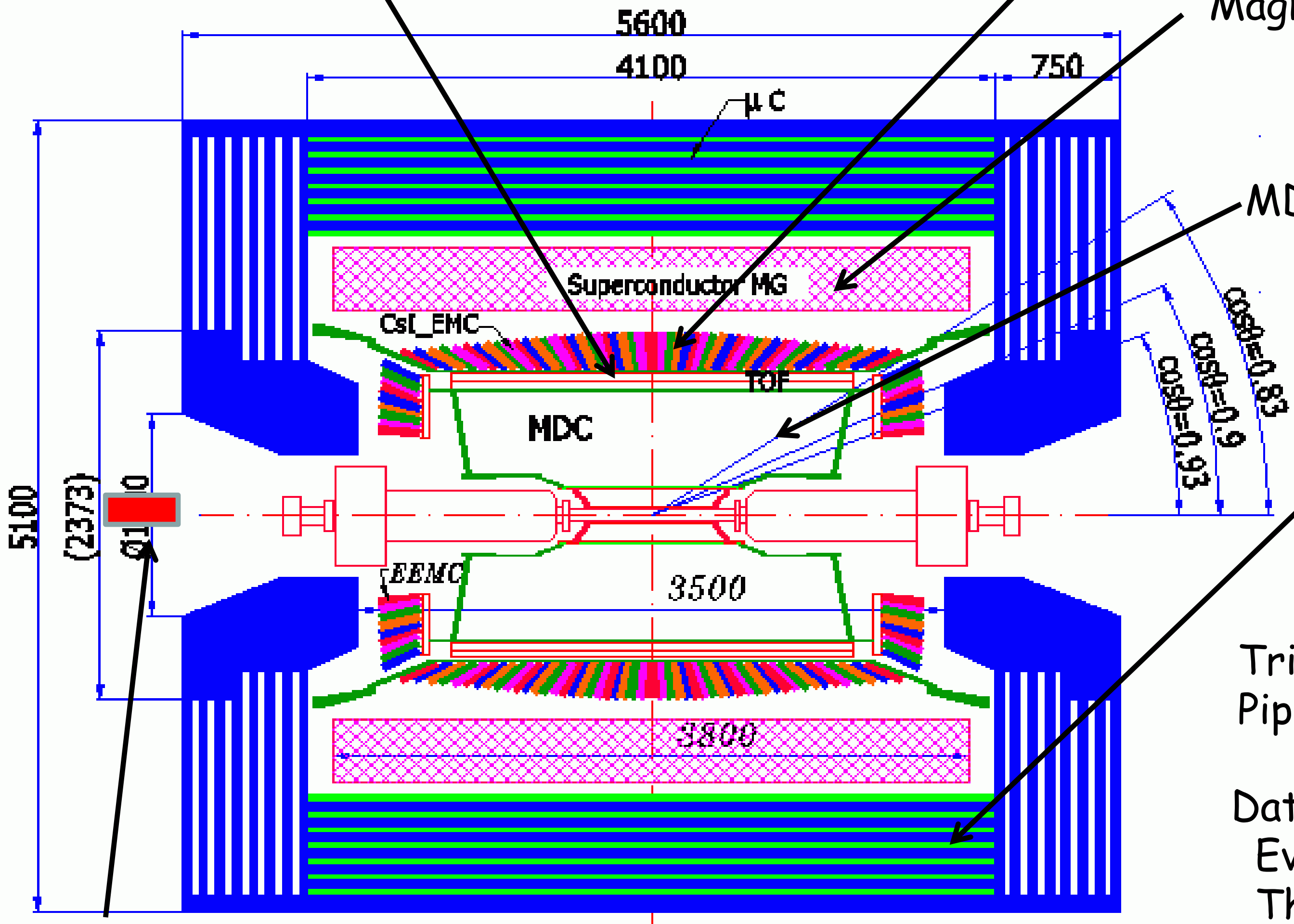
TOF:
σ_T = 80 ps Barrel
110 ps Endcap

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

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

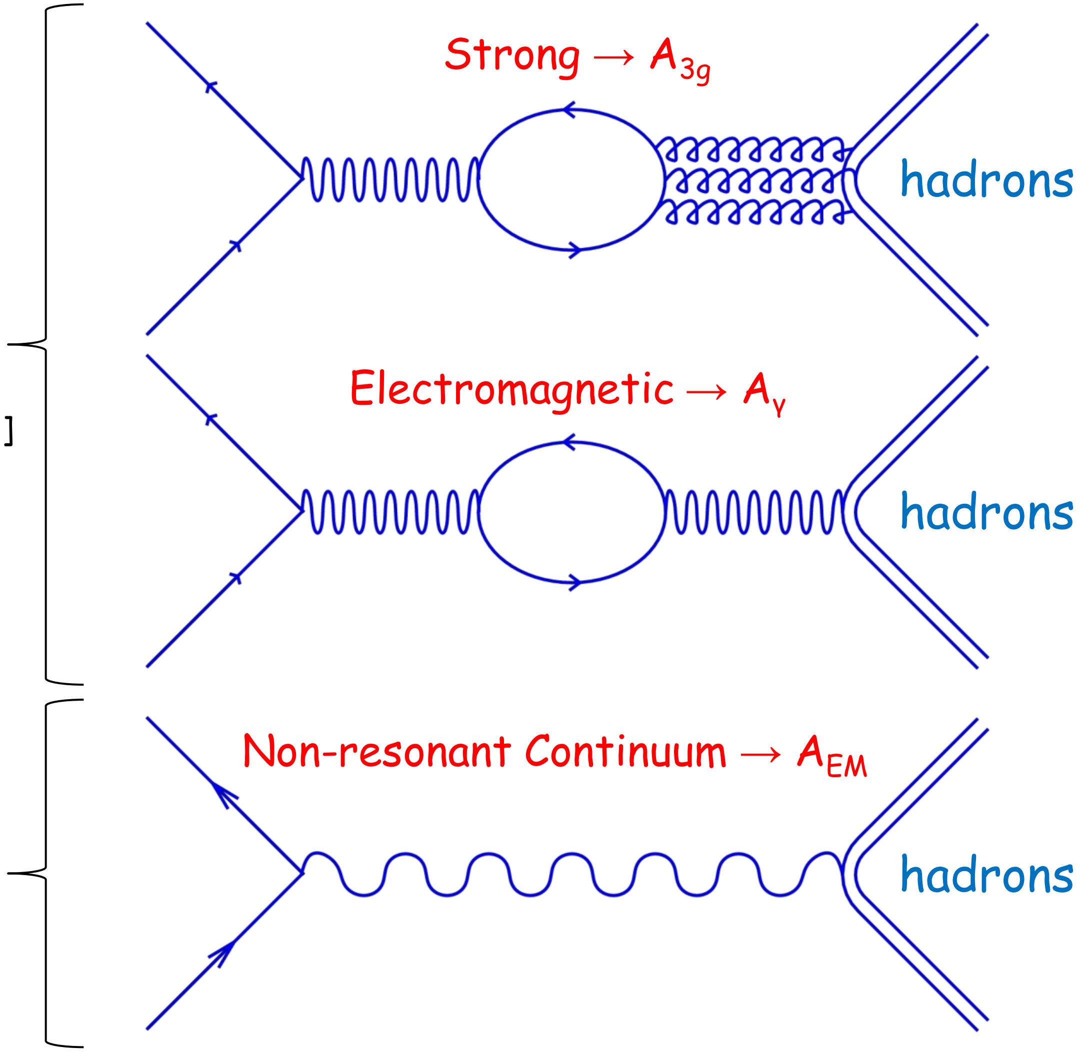
pQCD: all amplitudes almost real [1,2]

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 (Φ_p ~ 0° /180°)
- On the contrary Φ_p ~ 90° → 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] J.M. Bian et al., J/ψ -> ppbar and J/ψ -> nnbar measurement by BESIII, to be published on PRD
[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

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

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 ~ ½ $BR_{p\bar{p}}$

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

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

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

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

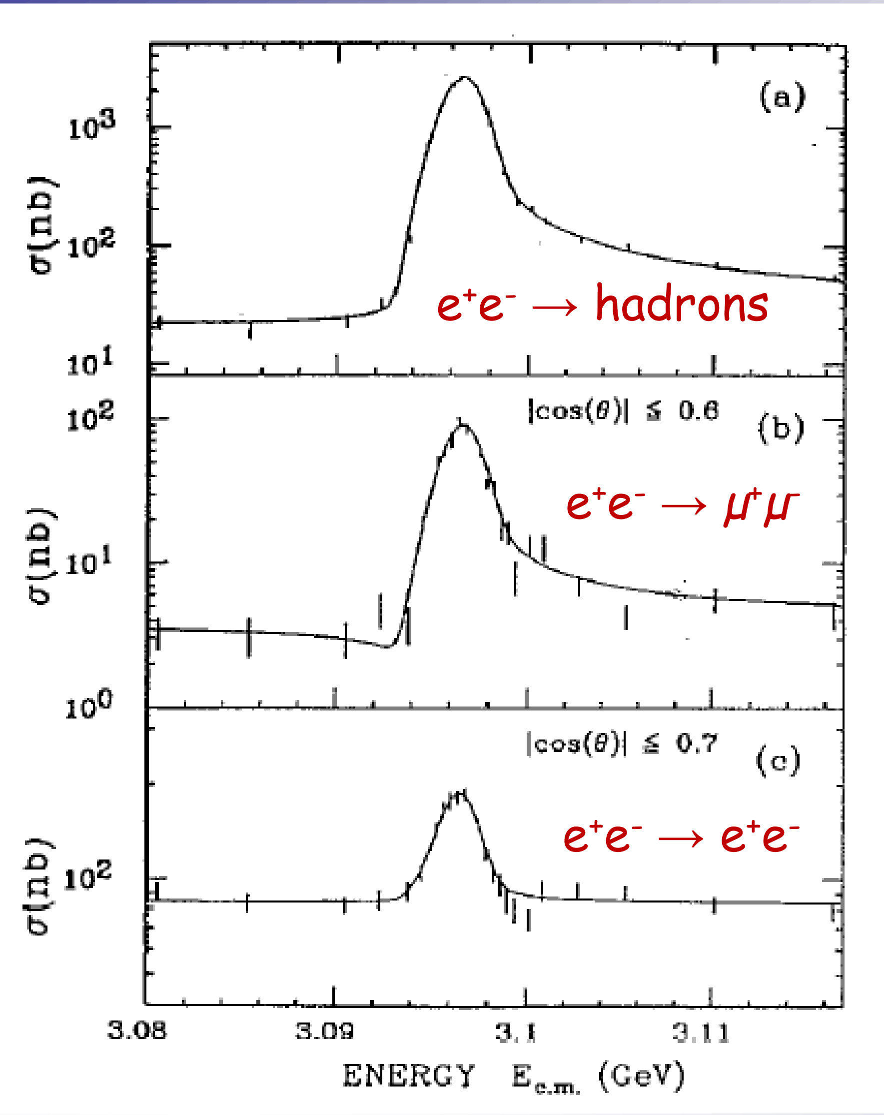
$BR(J/\psi \rightarrow p\bar{p}) = (2.112 \pm 0.004 \pm 0.027) \cdot 10^{-3}\%$

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

- Suggests 90° phase

[1] J.M. Bian, J/ψ -> ppbar and J/ψ -> nnbar measurement by BESIII, accepted for pubblication PRD

Was an Interference Already Seen?



Yes

without the strong contribution

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

Investigated Processes

- Inclusive scenario: does not see anything

The phase is there, but the mean goes to 0

Interference $\propto \langle f \,|\, 3g\rangle^{*} \langle f \,|\, \gamma\rangle$

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

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

But $\langle 3g \,|\, \gamma\rangle \cong 0$ 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

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

$p\bar{p}$

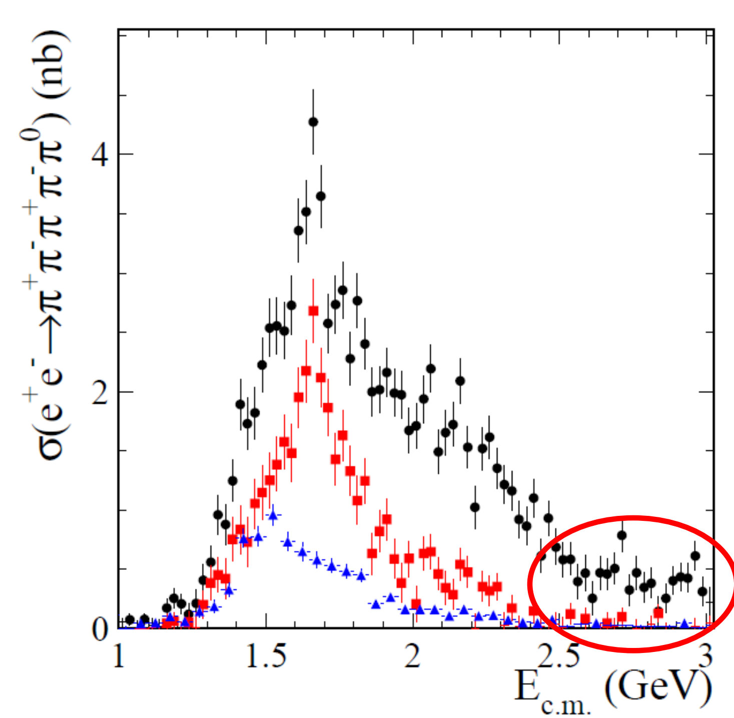
$$\sigma \propto \frac{1}{W^{10}}$$

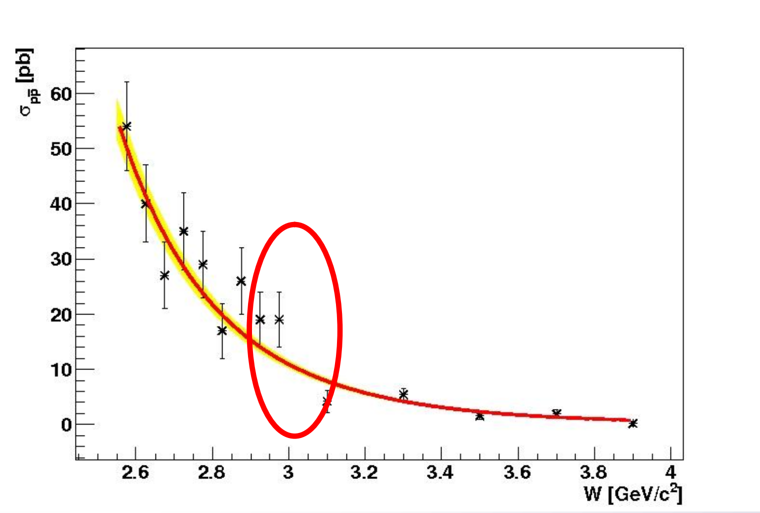
σ_{cont}~ 11 pb

5π

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

σ_{cont}~ 500 pb

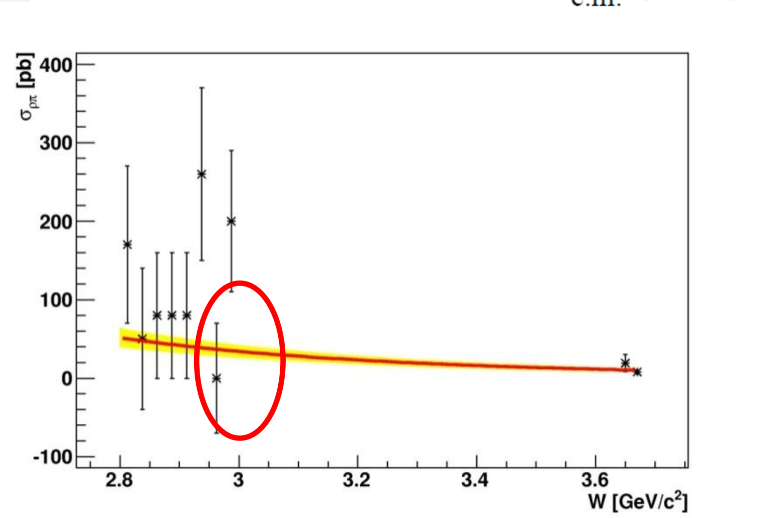




ρπ

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

σ_{cont}~ 20 pb



V. Druzhinin, E. Solodov, BABAR Analysis Document # 2446 (2011)

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:

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

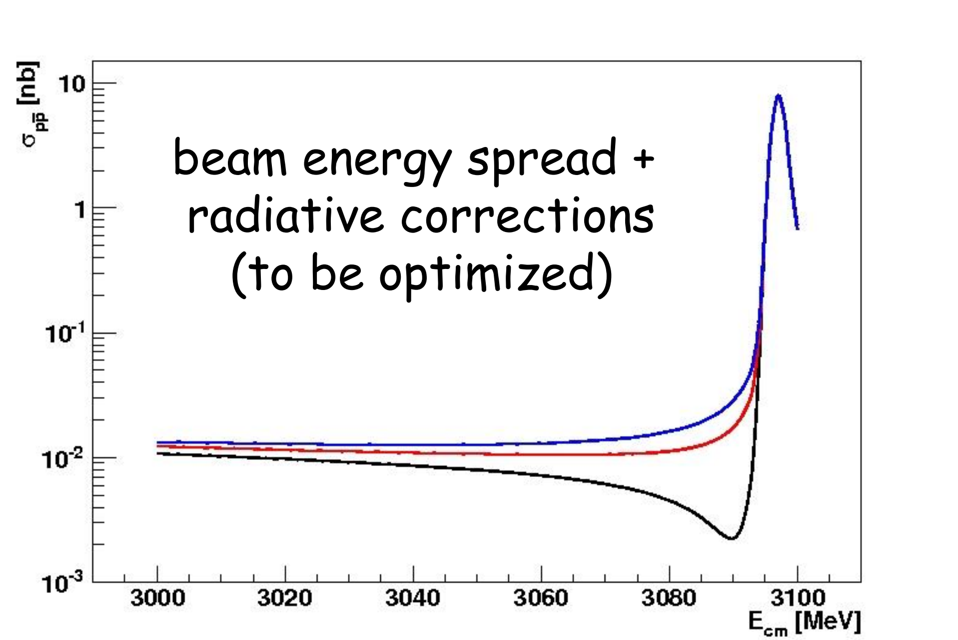
Simulated Yields for $e^+e^- \to p\bar{p}$

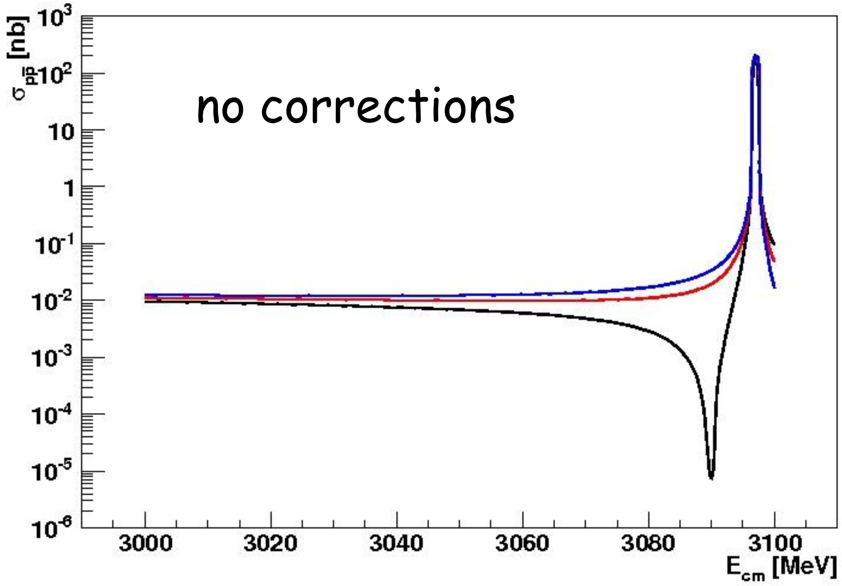
— $\Delta\varphi = 0^\circ$

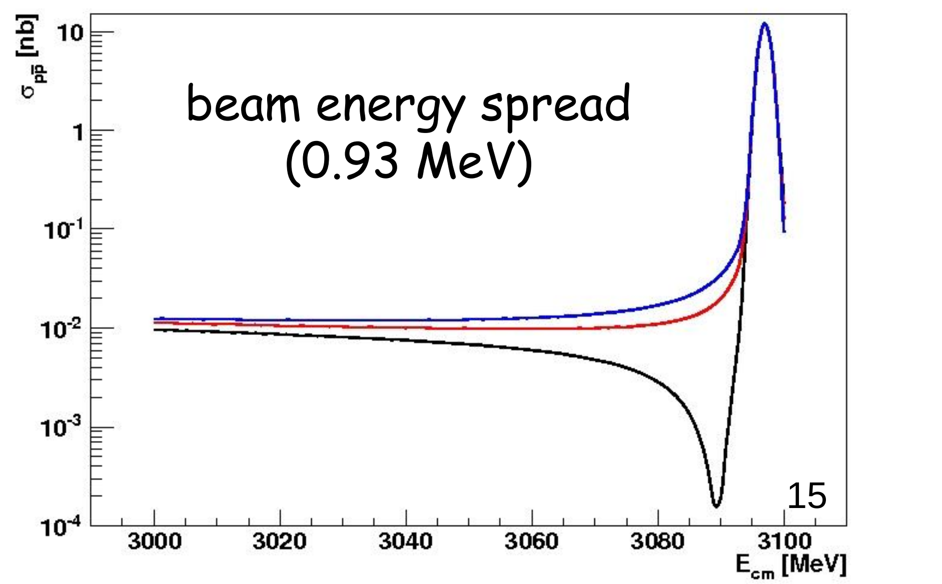
— $\Delta\varphi = 90^\circ$

— $\Delta\varphi = 180^\circ$

continuum reference
$\sigma \sim 11$ pb







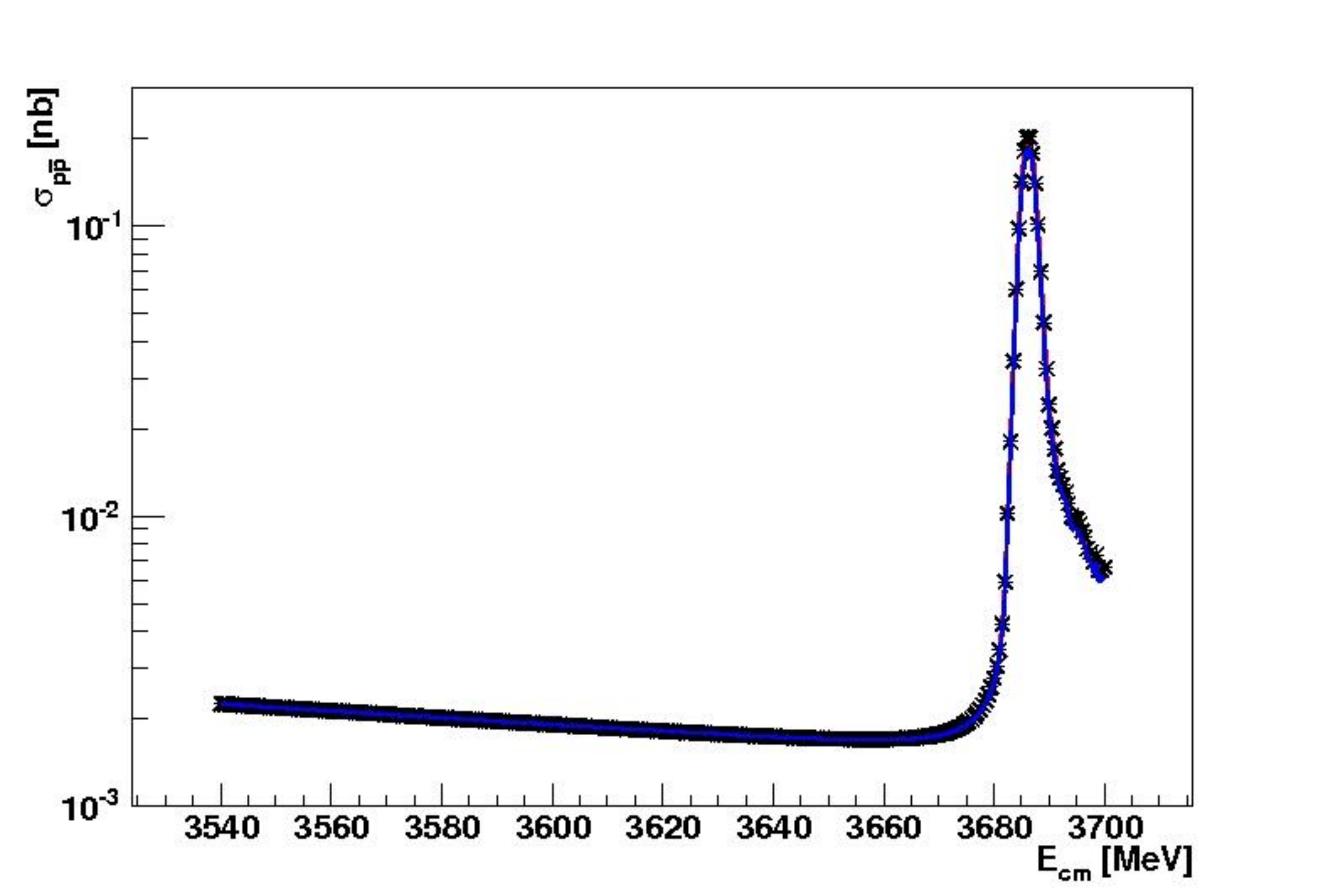
Phase Sign

$p\bar{p}$

* red: $\Delta\varphi = -90^\circ$

blue: $\Delta\varphi = +90^\circ$

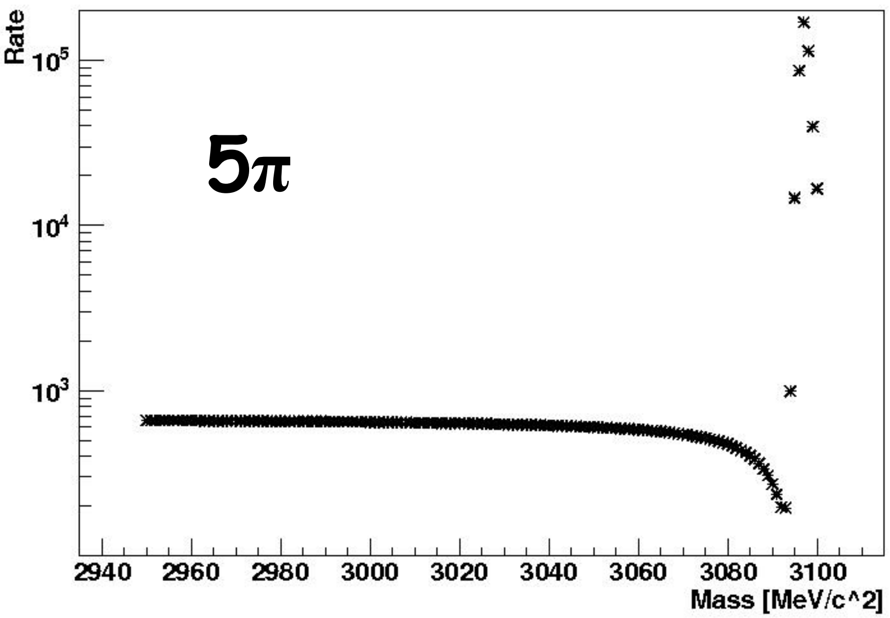
Maximum differences at the 1% level

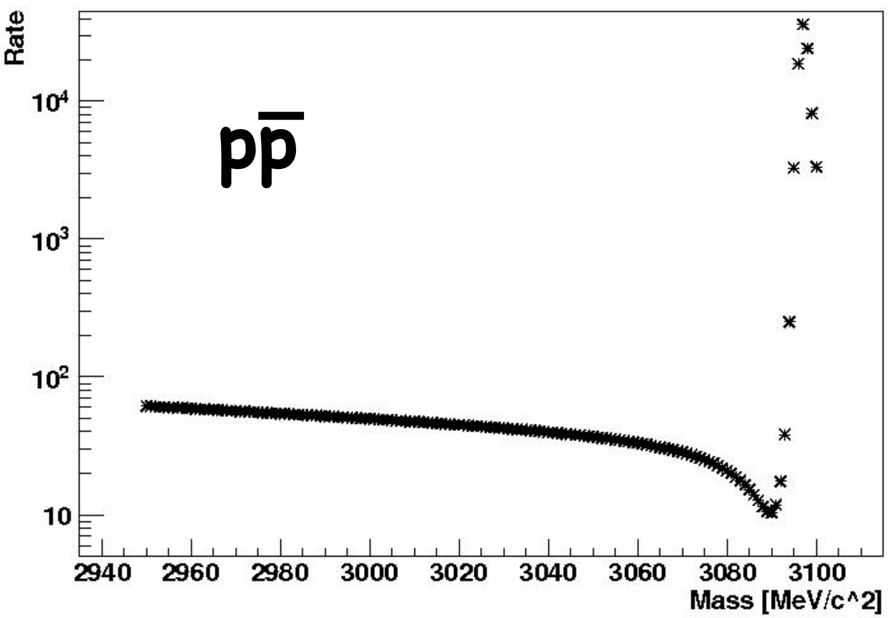


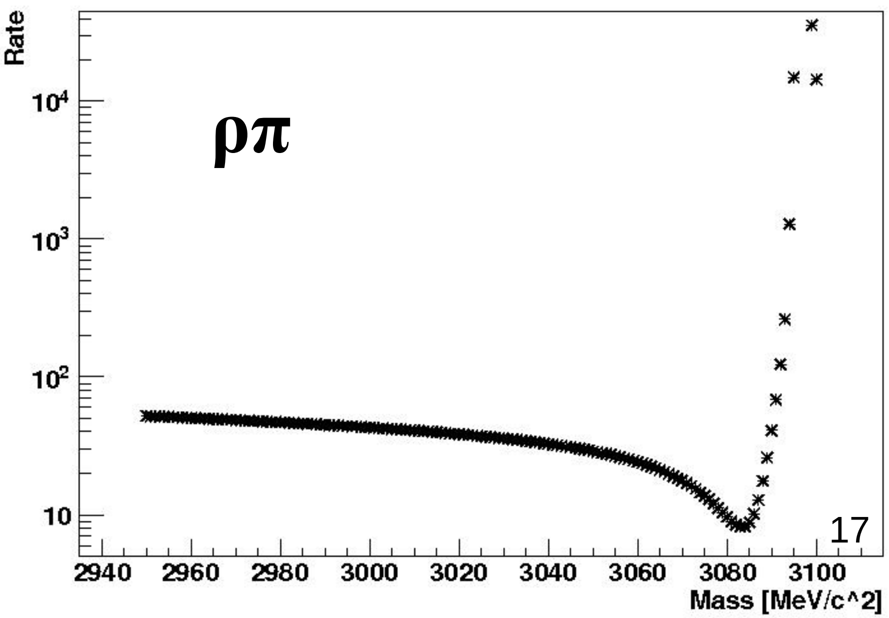
Energy Points Choice

Depends on the process

Maximum interference: 0°





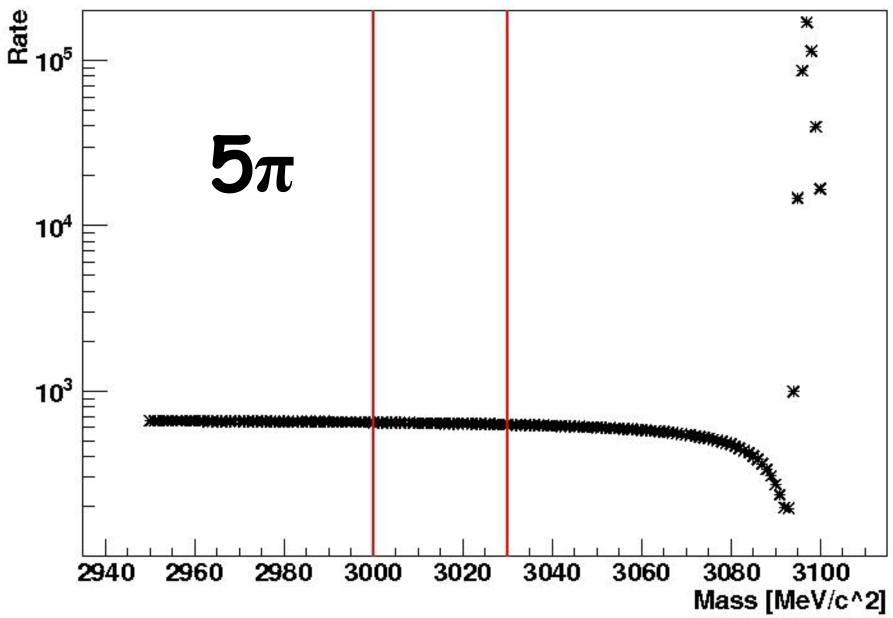


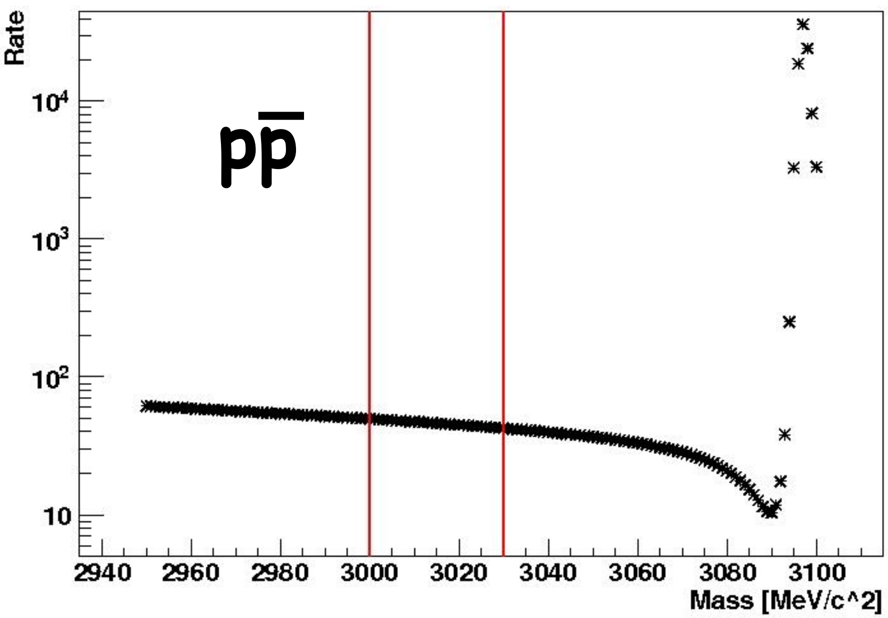
Energy Points Choice

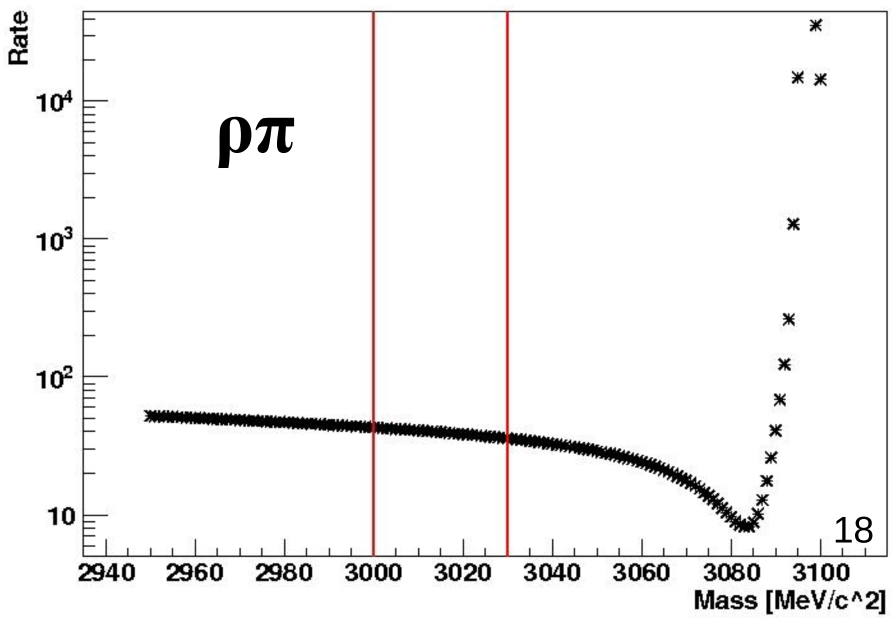
Depends on the process

Maximum interference: 0°

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





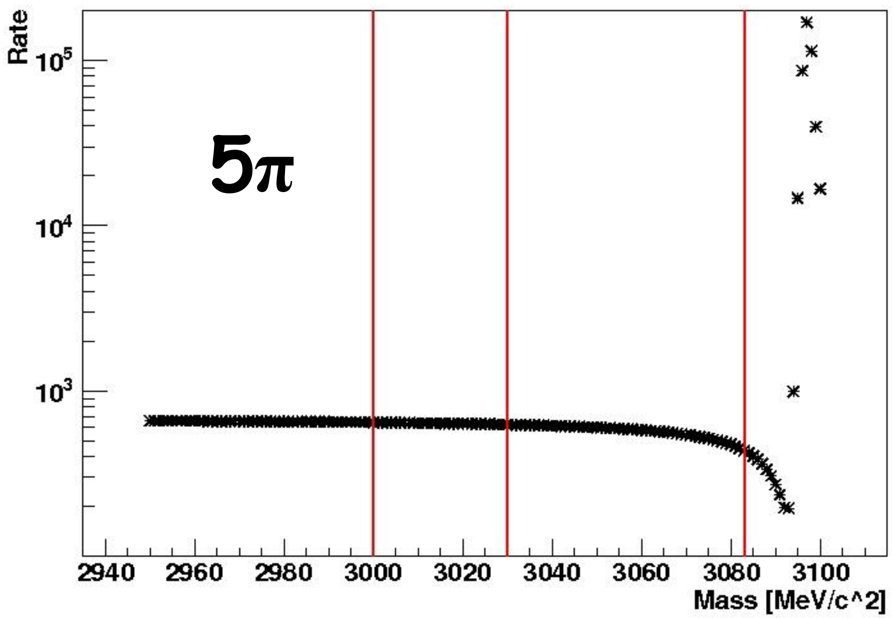


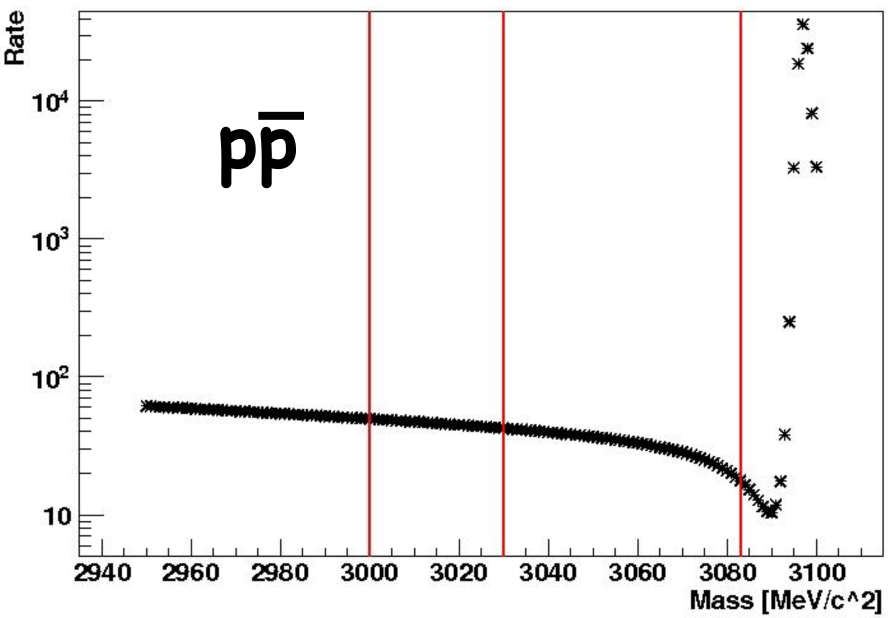
Energy Points Choice

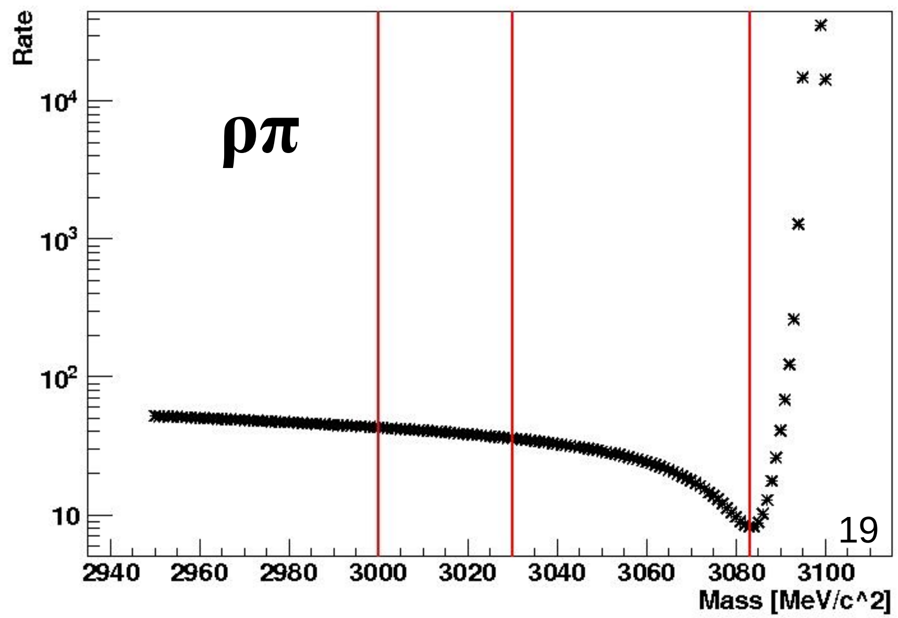
Depends on the process

Maximum interference: 0°

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





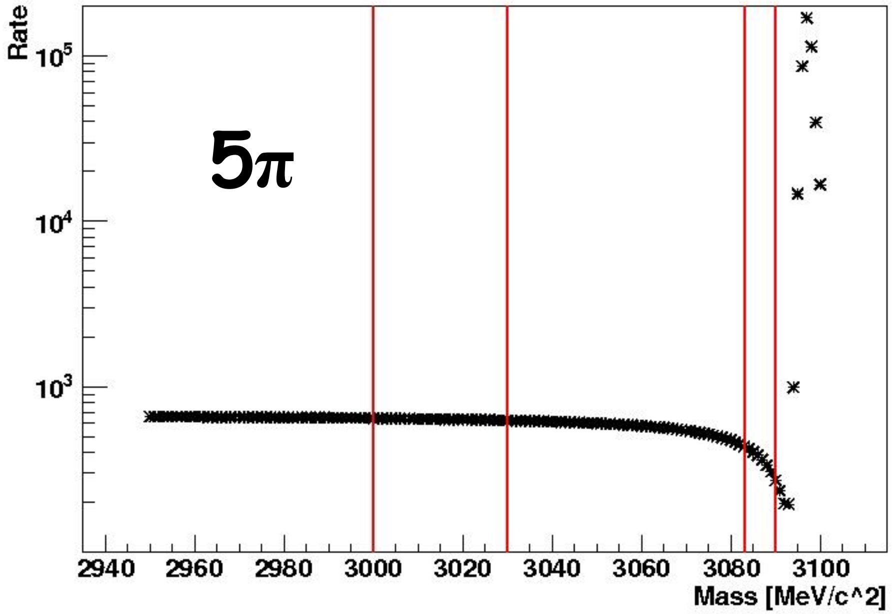


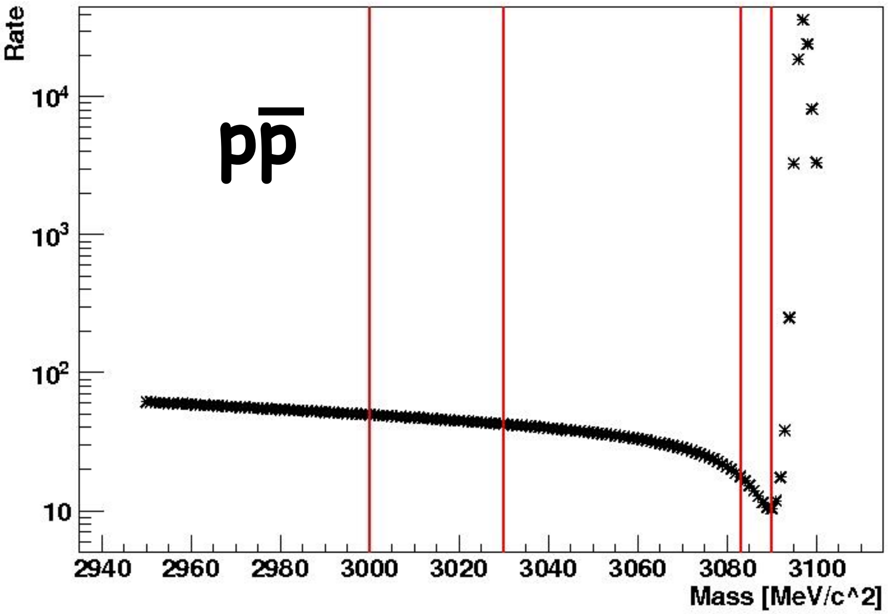
Energy Points Choice

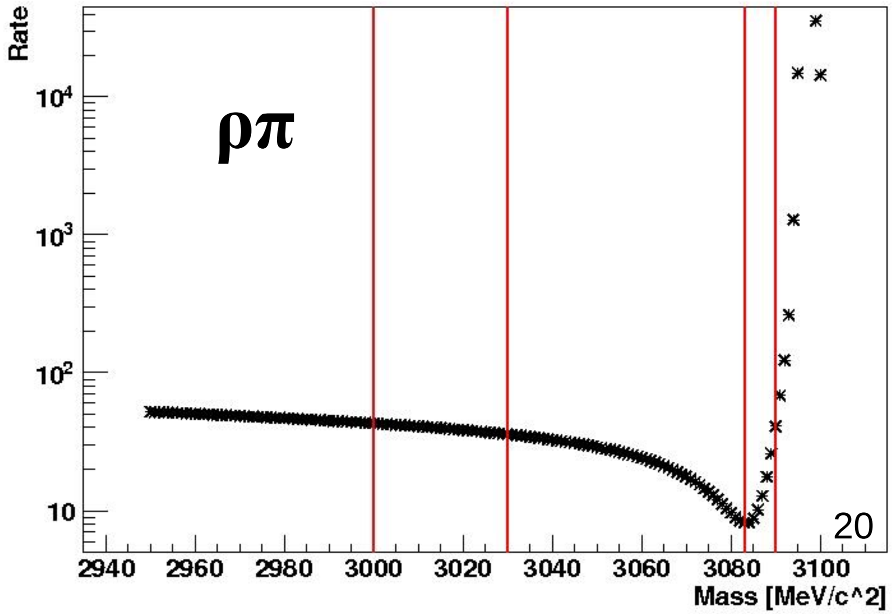
Depends on the process

Maximum interference: 0°

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





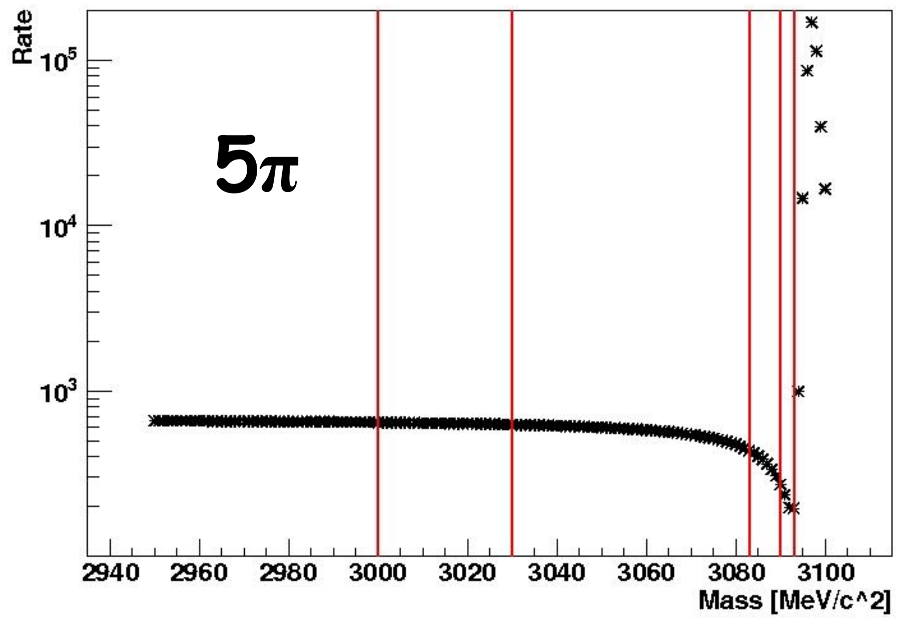


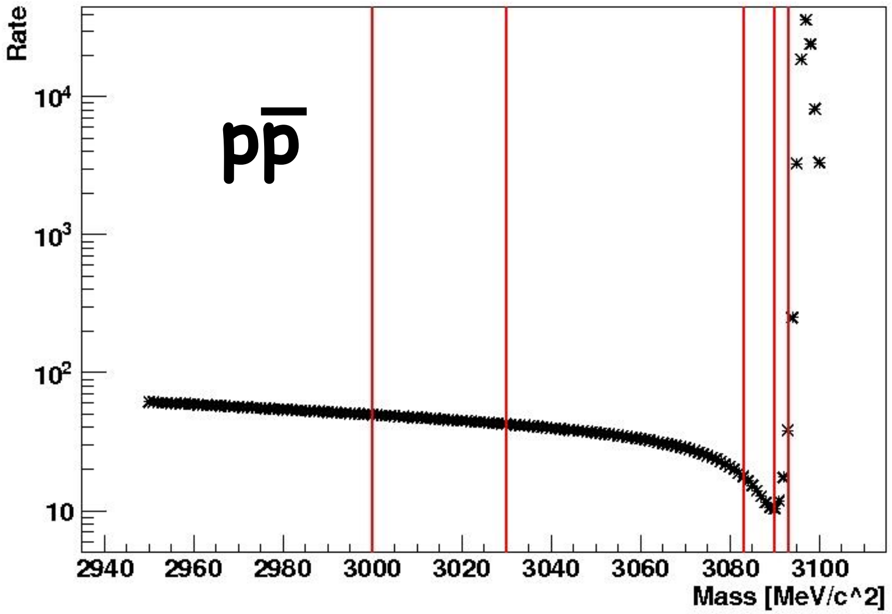
Energy Points Choice

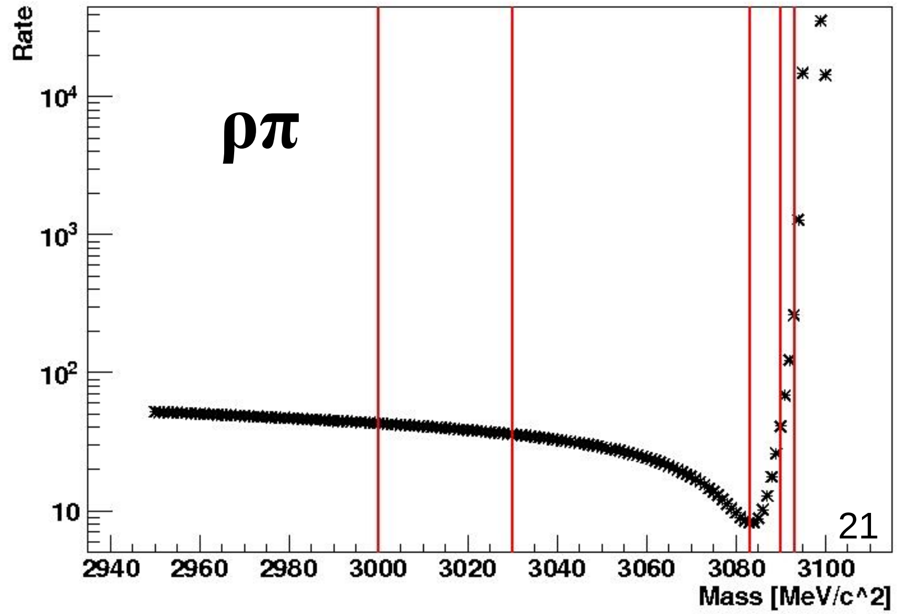
Depends on the process

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







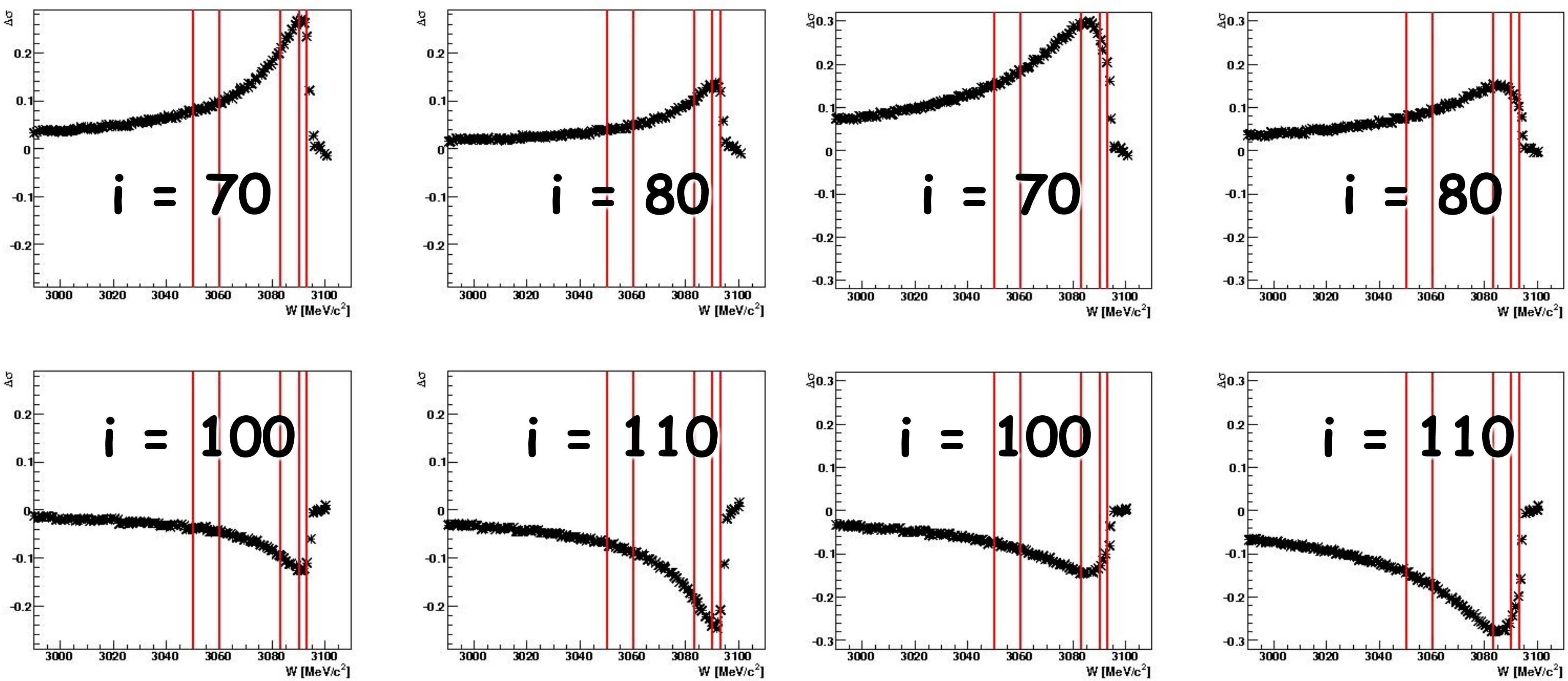
Energy Points Choice

- 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

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

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

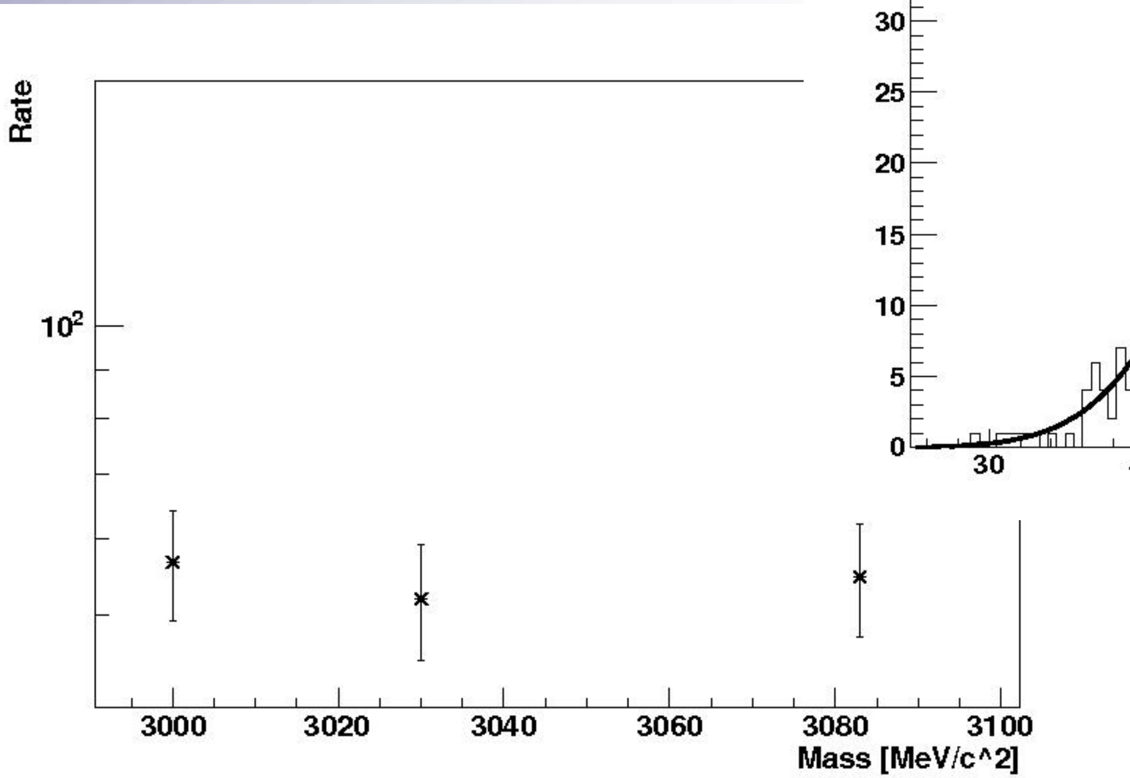
Fit procedure

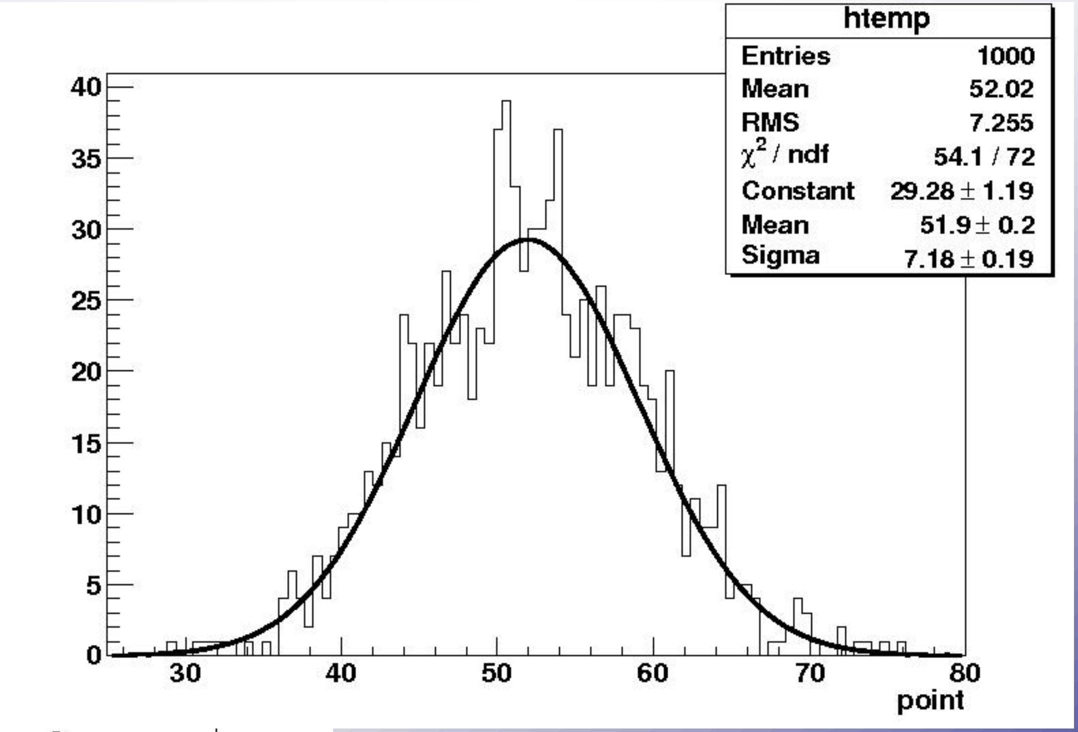
$p\bar{p}$

90° case L = 10^{32}

Smear each point 100 times

Error bars: $\sqrt{nev}$





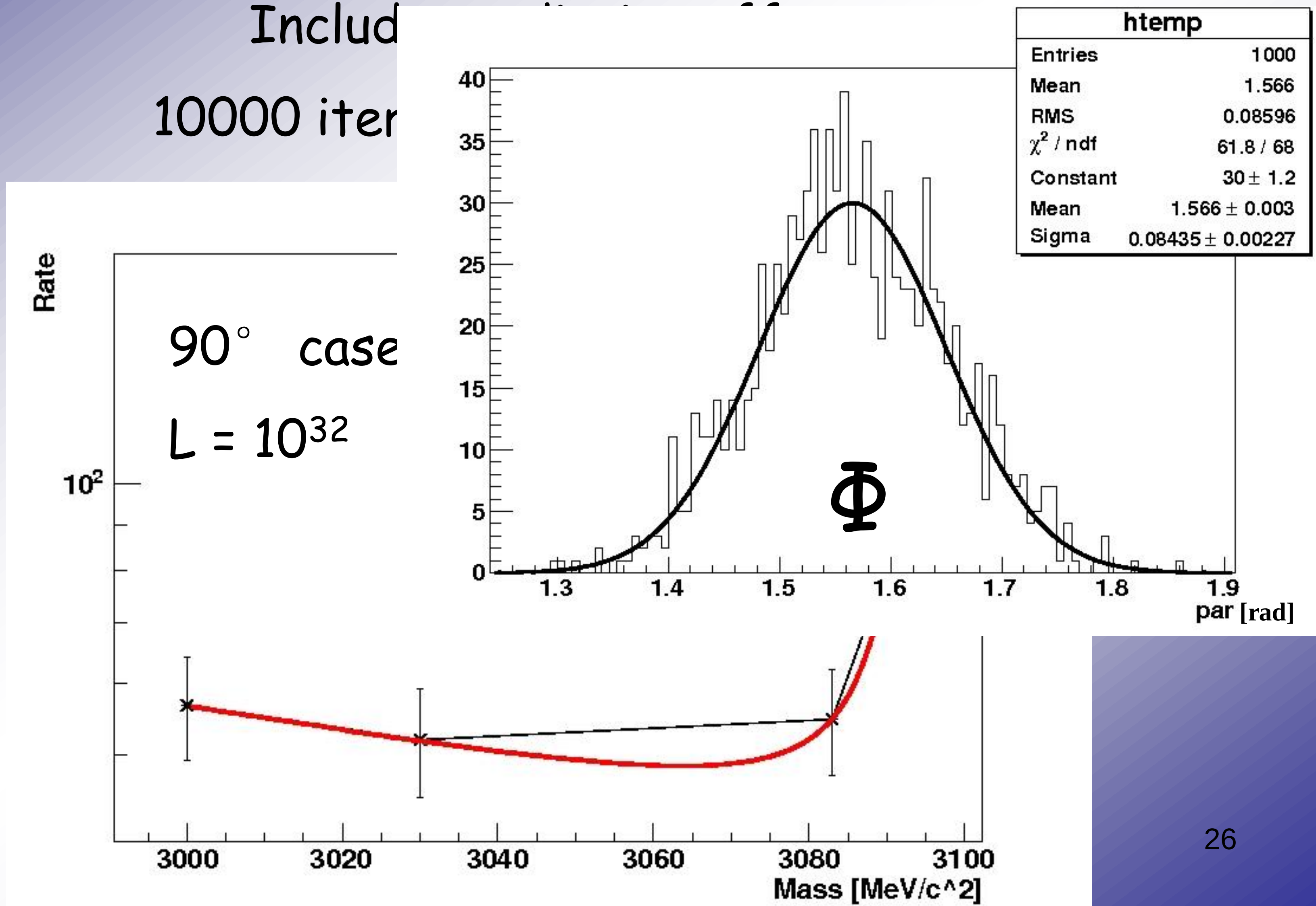
Fit procedure

$p\bar{p}$

Fit done with Monte-Carlo method

Includ

10000 iter



Precision of the Fit

Statistical error for:

$p\bar{p}$ circle

$\rho\pi$ triangle

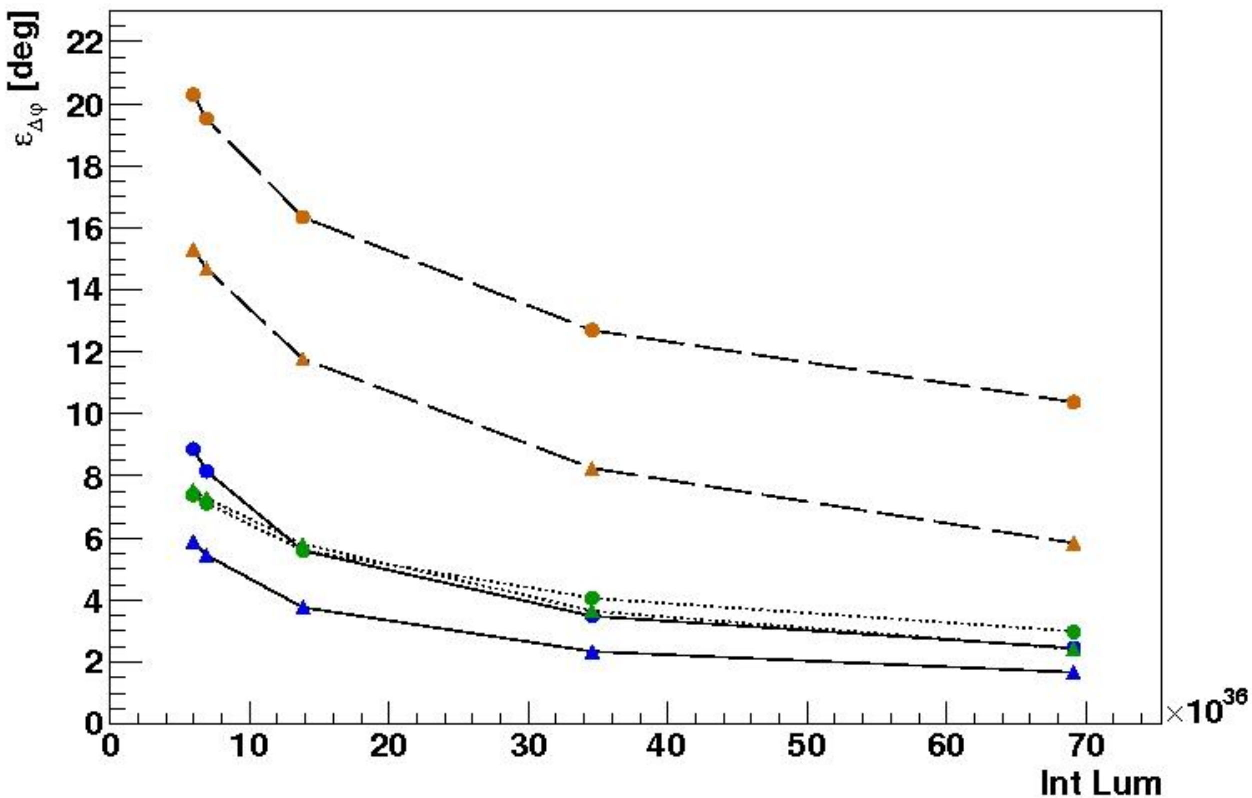
.... 10°

——— 90°

– – – – 170°

2 parameters:

φ and σ_{cont}



170°

- Lower sensitivity

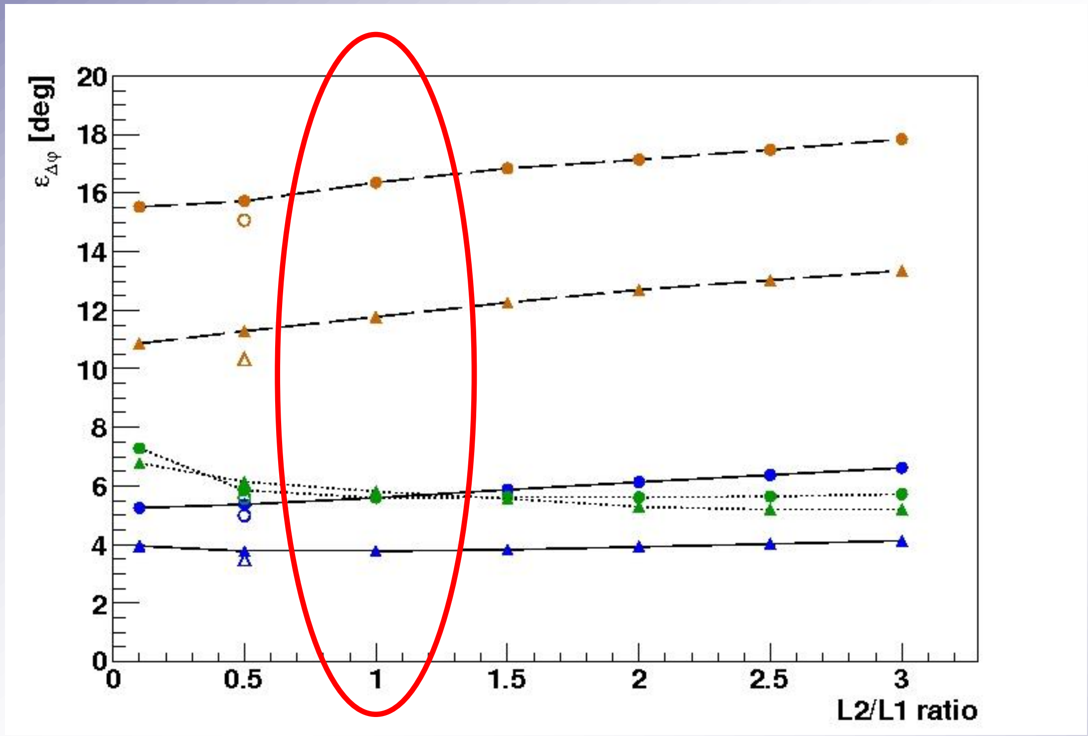
(No 0° -90° and 90° -180° symmetry)

Fit results

5 days L_{int} = 1.4x10^{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

J/ψ Scan

$p\bar{p}$

$\Delta\varphi = +90^\circ$

$\sigma_{cont} = 11$ pb

$B_{out} = 2.17 \cdot 10^{-3}$

2 parameters:

φ and σ_{cont}

Points	Par	Inj. eff.	$\Delta\varphi$ [°]	$\Delta\sigma$ [pb]	ΔB_{out}
5	2	0.7	6.0	1.0	/
5	2	0.8	5.6	0.9	/
12	2	0.7	6.3	0.9	/
12	2	0.8	5.9	0.9	/

2 parameters: better the 5 points of the phase

$p\bar{p}$

J/ψ Scan

$\Delta\varphi = +90^\circ$

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

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 [MeV]	L [$cm^{-2}s^{-1}$]	Inj. Eff.	Time	L_{int} [pb^{-1}]
3050	$2 \cdot 10^{32}$	0.80	24 h	13.824
3060	$2 \cdot 10^{32}$	0.80	24 h	13.824
3083	$2 \cdot 10^{32}$	0.80	24 h	13.824
3090	$2 \cdot 10^{32}$	0.80	24 h	13.824
3093	$2 \cdot 10^{32}$	0.80	24 h	13.824
Σ			5 days	~ 70

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

Summary

- J/ψ decay amplitude phase: 0° (theory) but 90° (data)
- Energy points choice: 3050, 3060, 3083, 3090, 3093
- Energy points collected: 3046, 3056, 3086, 3085, 3088
- Phase sign cannot be disentangled
- Fit routine (3 parameters)
- Statistical significance enough to discriminate between different theoretical predictions
- Precision of fit → Luminosity dependence
- More Luminosity better than more data points
- Best choice: 1:1:1:1:1

Next Steps

- Analyze the real data collected in the 2012 run

Backup Slides

BESIII Collaboration

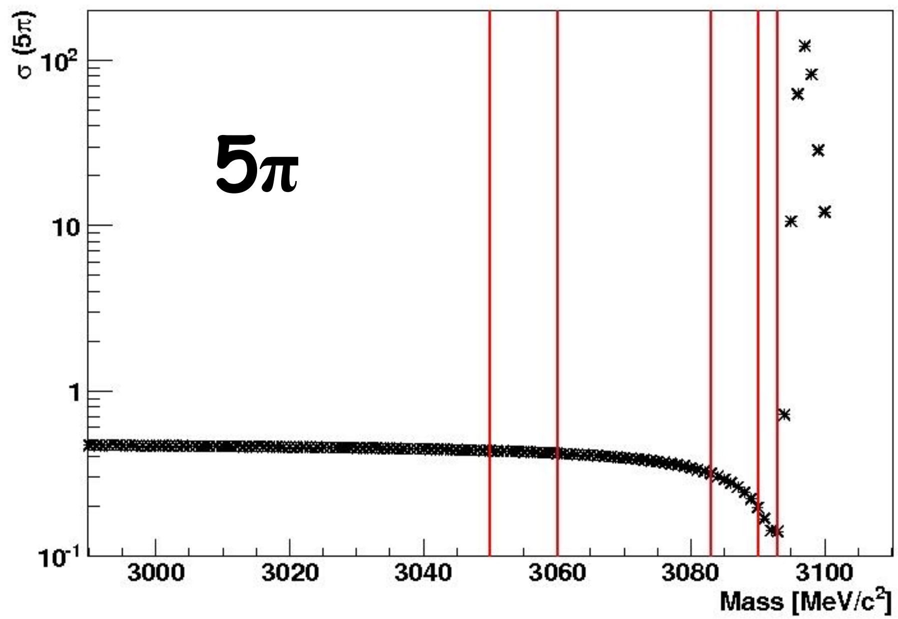
> 300 physicists
49 institutions from 10 countries

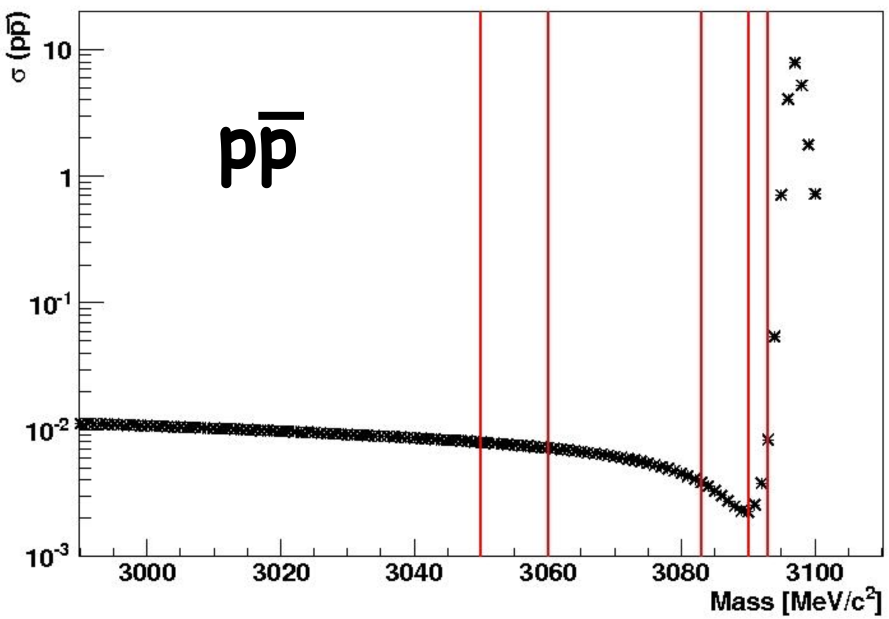
Energy Points Choice

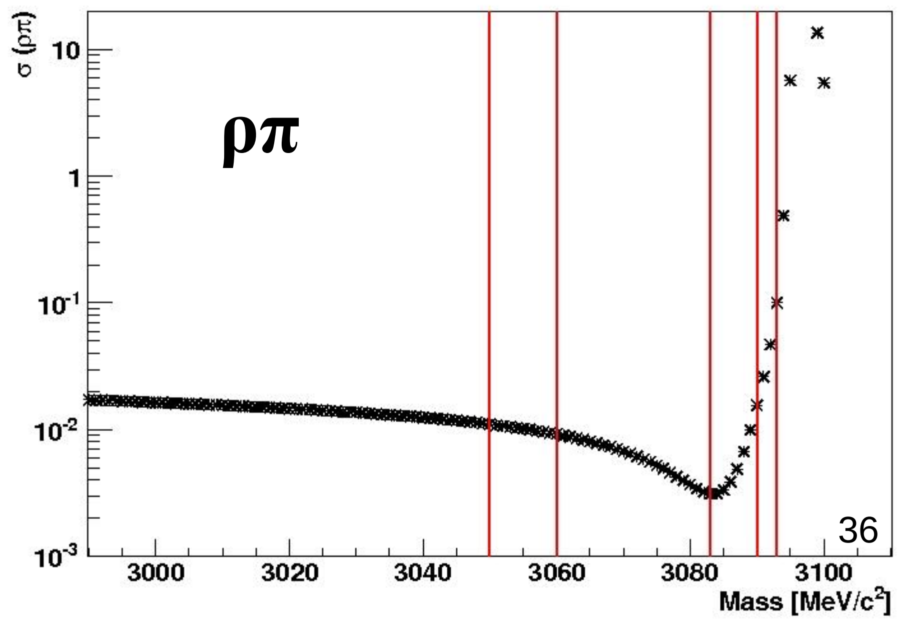
Depends on the process

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







J/ψ Scan

Table 11: The estimated values of BEPCII luminosity $\mathcal{L}$ ($\times 10^{33} cm^{-2} s^{-1}$) and data taking time T (hour), integrated luminosity L (pb^{-1}) at each energy point if N^{obs}_{had} hadronic events are collected in a sample. Assume that the optimized luminosity is $\mathcal{L}^* = 0.45 \times 10^{33} cm^{-2} s^{-1}$ at $E^*_b = 1.890$ GeV.

No.	E_{cm}(GeV)	$\mathcal{L}_i(10^{33} cm^{-2} s^{-1})$	ϵ_{dt}	ϵ_{hd}	N^{obs}_{had}	T_i(hours)	$L_i(pb^{-1})$	$\sum T_i$(hours)	$\sum L_i(pb^{-1})$
1	3.0500	0.150	0.66	0.68	10000	2.20	0.63	2.20	0.63
2	3.0600	0.152	0.67	0.68	10000	2.15	0.63	4.34	1.26
3	3.0830	0.156	0.69	0.69	10000	2.01	0.63	6.35	1.88
4	3.0900	0.158	0.70	0.69	10000	1.86	0.59	8.22	2.48
5	3.0930	0.159	0.70	0.69	10000	1.57	0.50	9.79	2.98
6	3.0945	0.159	0.70	0.69	10000	1.15	0.37	10.94	3.35
7	3.0955	0.159	0.70	0.69	10000	0.72	0.23	11.66	3.58
8	3.0969	0.160	0.70	0.69	10000	0.40	0.13	12.06	3.71
9	3.0995	0.160	0.70	0.69	10000	0.31	0.10	12.37	3.81
10	3.1020	0.161	0.70	0.69	10000	0.69	0.22	13.06	4.03
11	3.1070	0.162	0.70	0.69	10000	1.31	0.43	14.38	4.46
12	3.1150	0.164	0.70	0.69	10000	1.69	0.56	16.06	5.02

$L_{int} = 13.8$ [pb^{-1}]

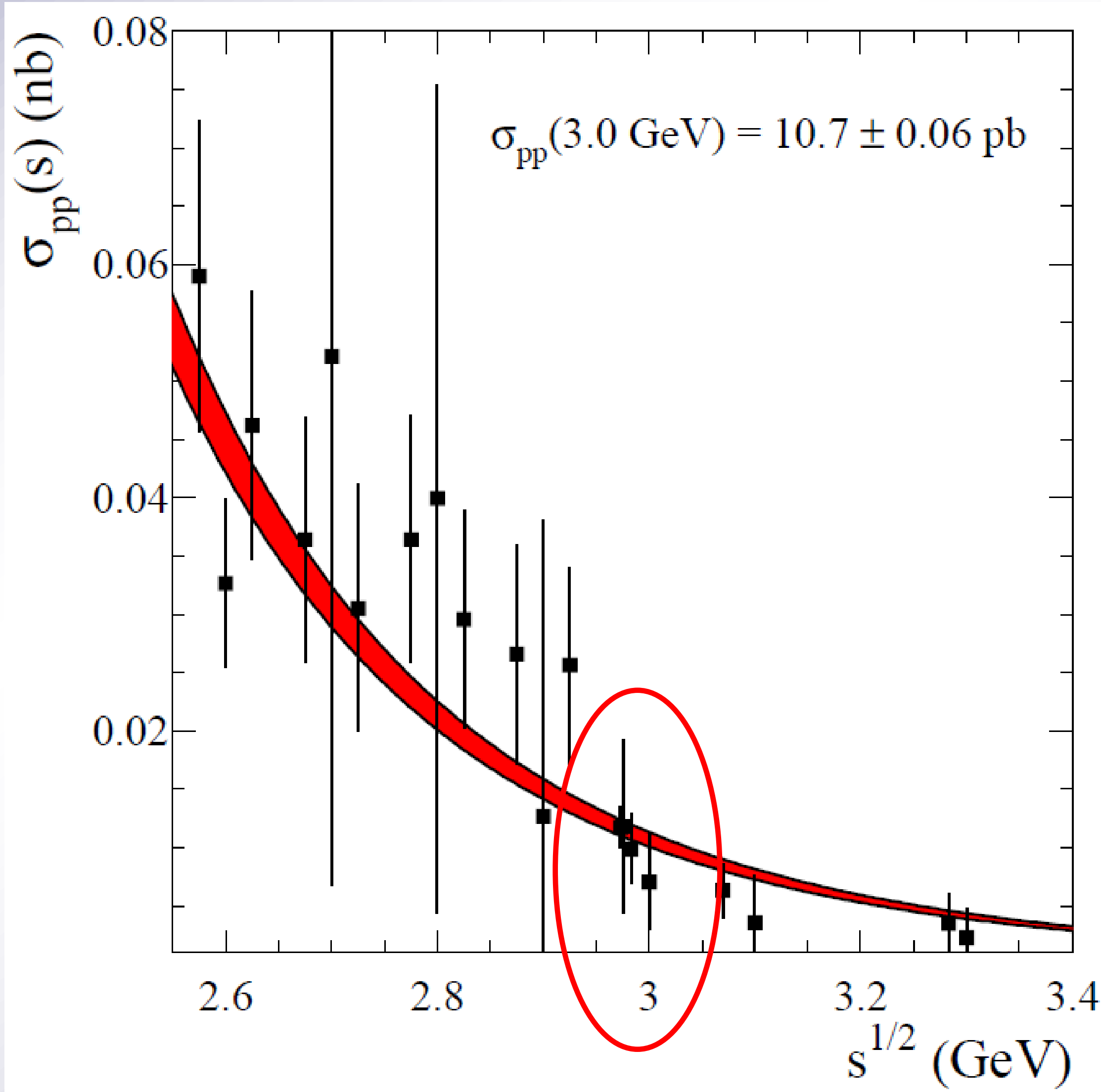
Continuum Cross Section ($p\bar{p}$)

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

$$S = W^2 \qquad FF \propto \frac{1}{W^4}$$

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

σ_{cont}~ 11 pb

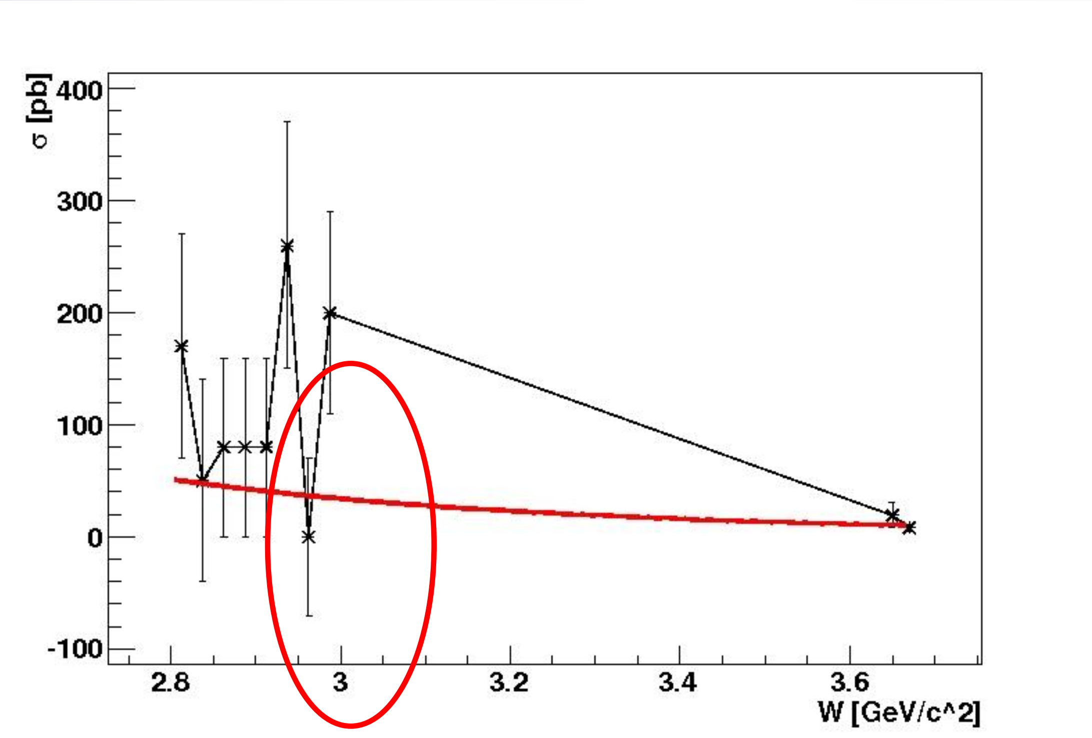


Continuum Cross Section ($\rho\pi$)

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

$$S = W^2 \qquad FF \propto \frac{1}{W^2}$$

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



σ_{cont}~ 20 pb

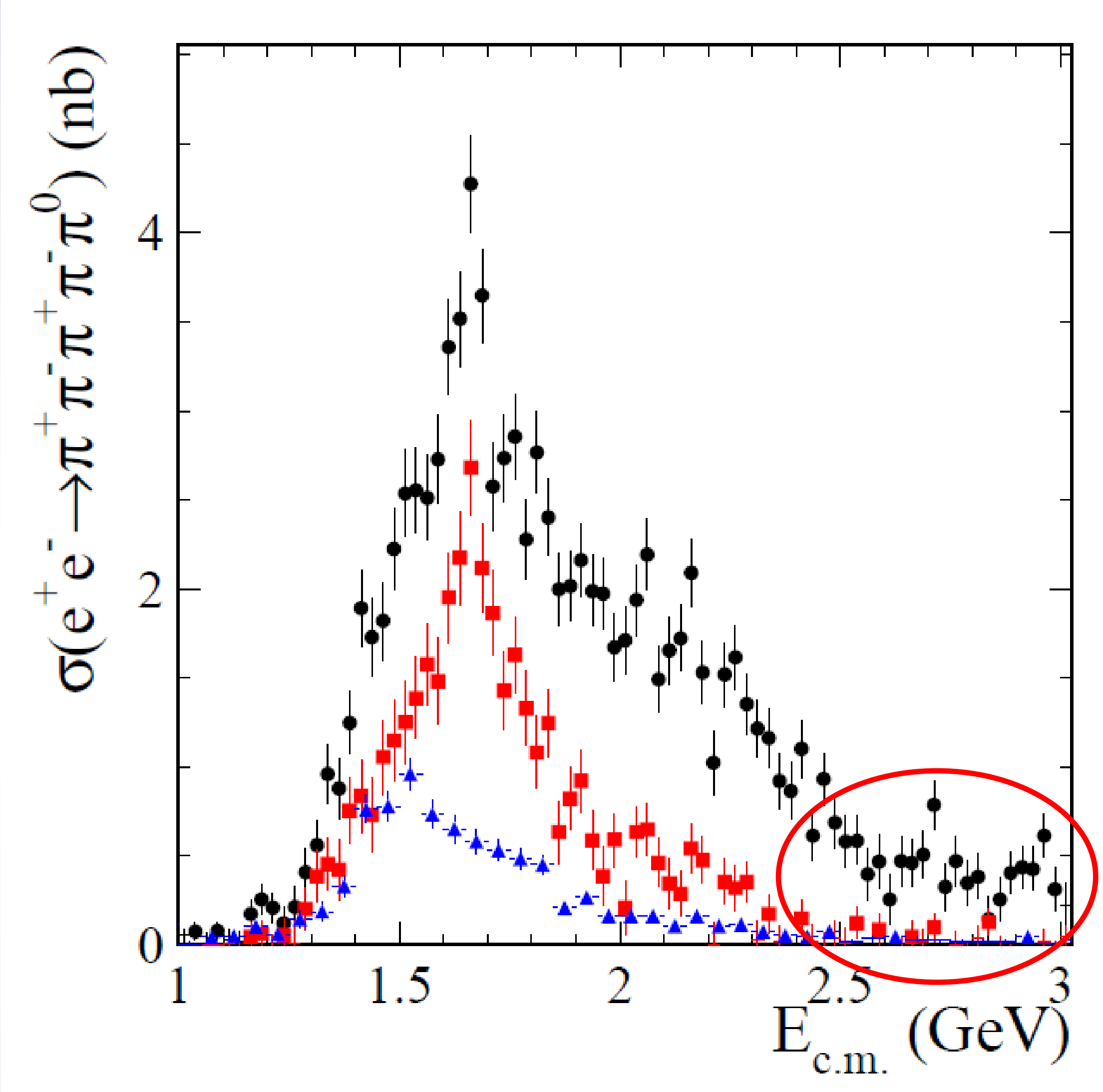
Continuum Cross Section (5π)

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

Flat behavior

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

σ_{cont}~ 500 pb



arXiv:1105.4975v2 [hep-ex], BABAR Collaboration (2011).