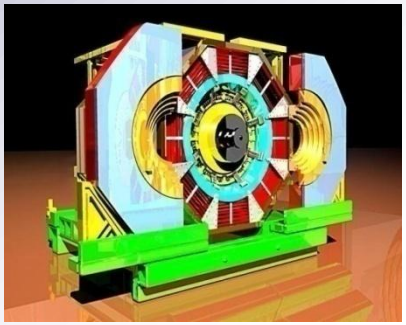
Measuring the Phase between Strong and EM J/ψ Decay Amplitudes

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

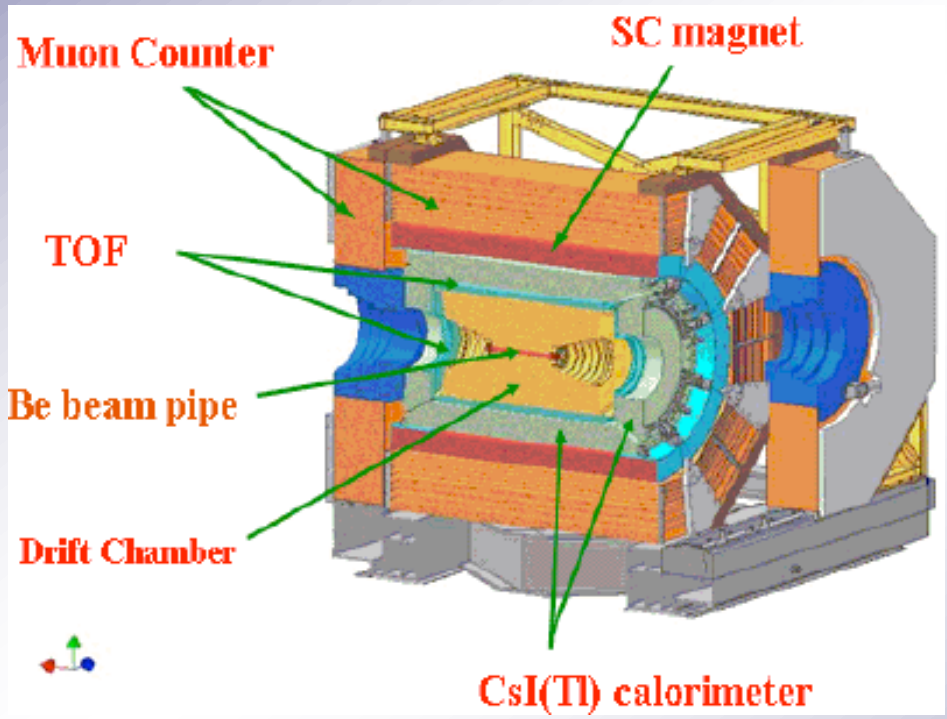
- BESIII experiment
- Motivation
- Investigated processes
- Energy points
- Required Luminosity
- Summary

The BESIII Experiment @ IHEP

BEijing Spectrometer III

e^+e^- collisions

$\sqrt{S}$ tuned depending on energy



Physics program

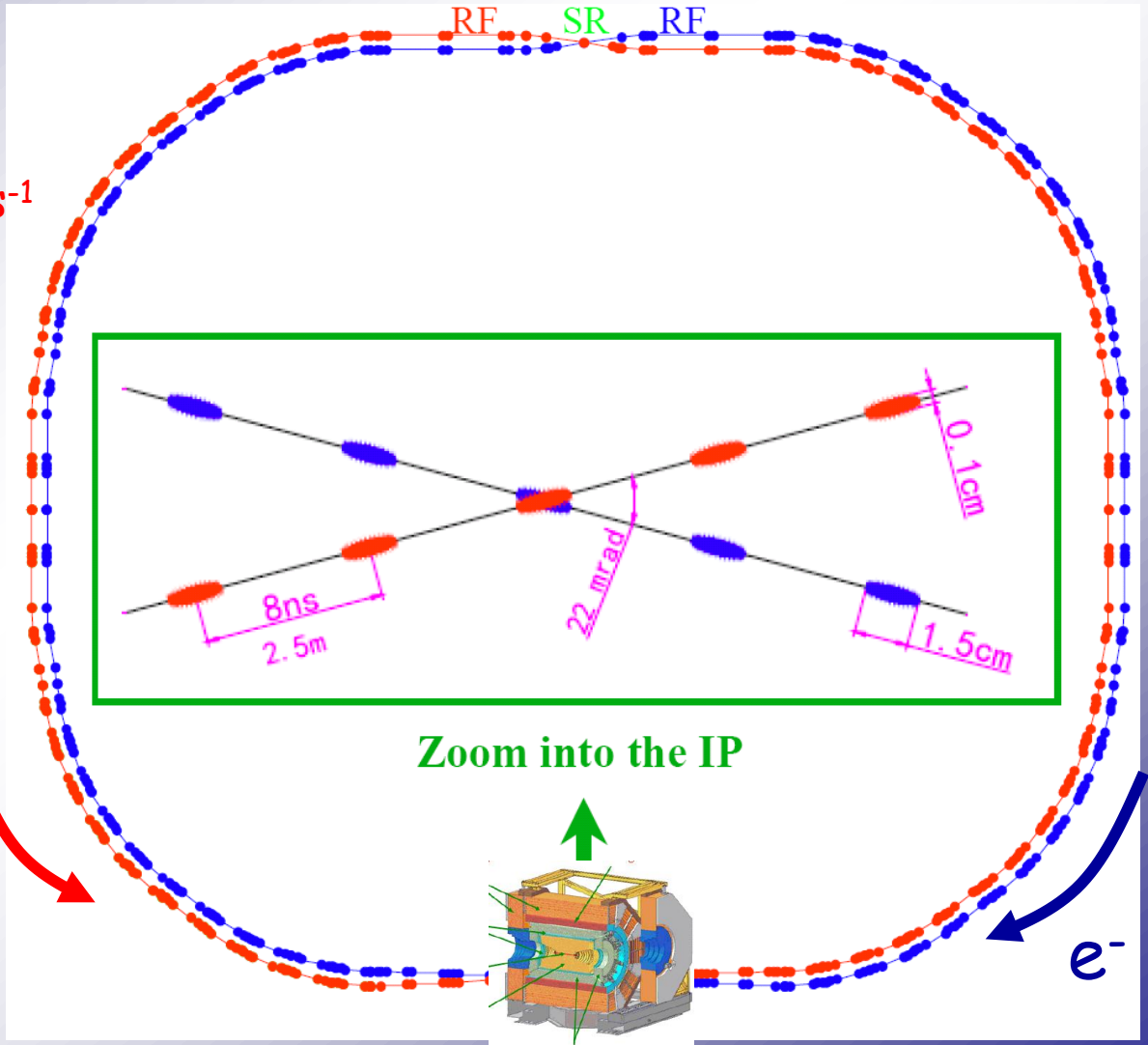
- Charmonium Physics
- D-Physics
- Light Hadron Spectroscopy
- τ-Physics
- ...

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:
  $\sim 0.65\times10^{33}$ $cm^{-2}s^{-1}$
- 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

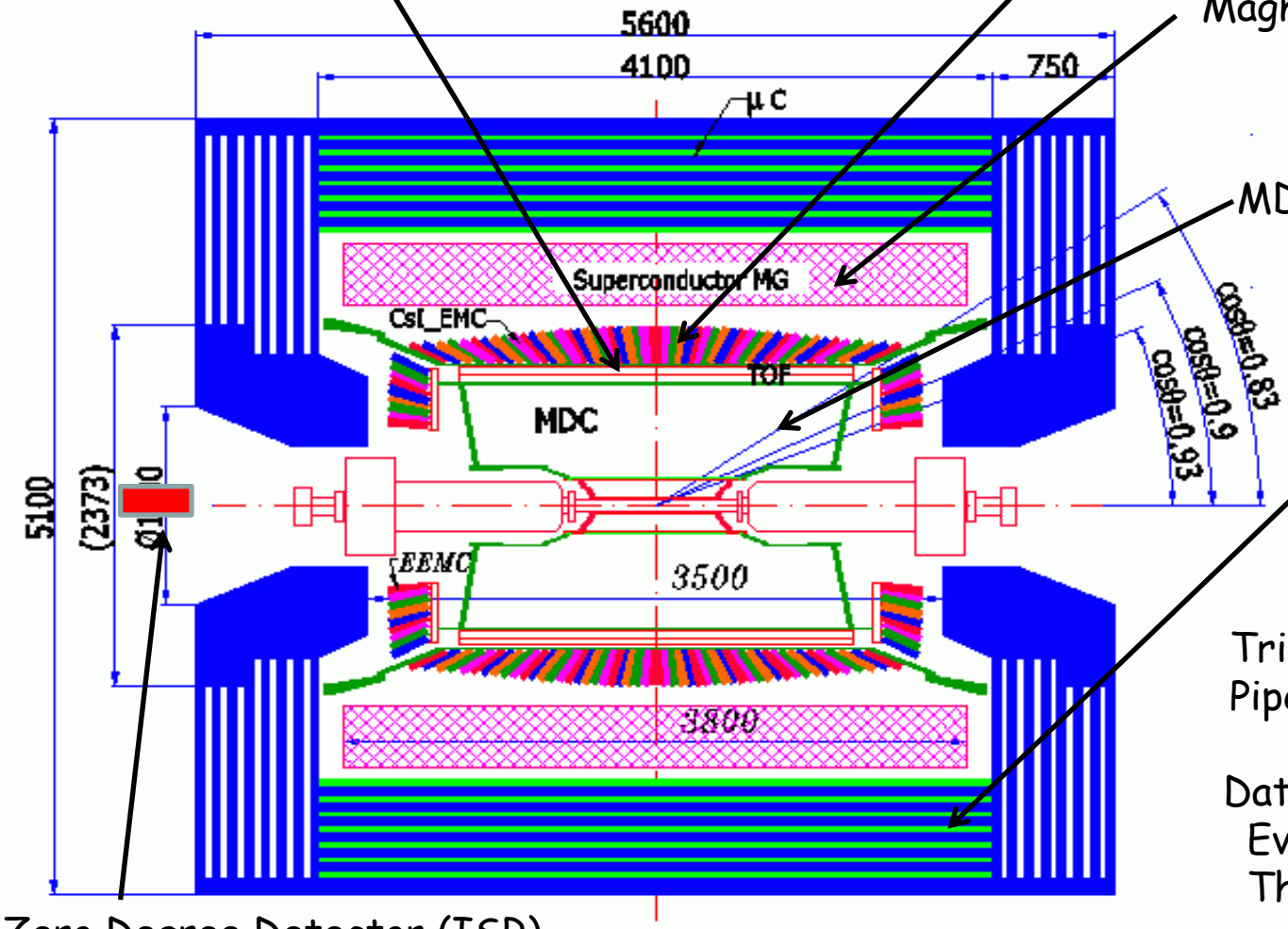


BESIII Detector

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

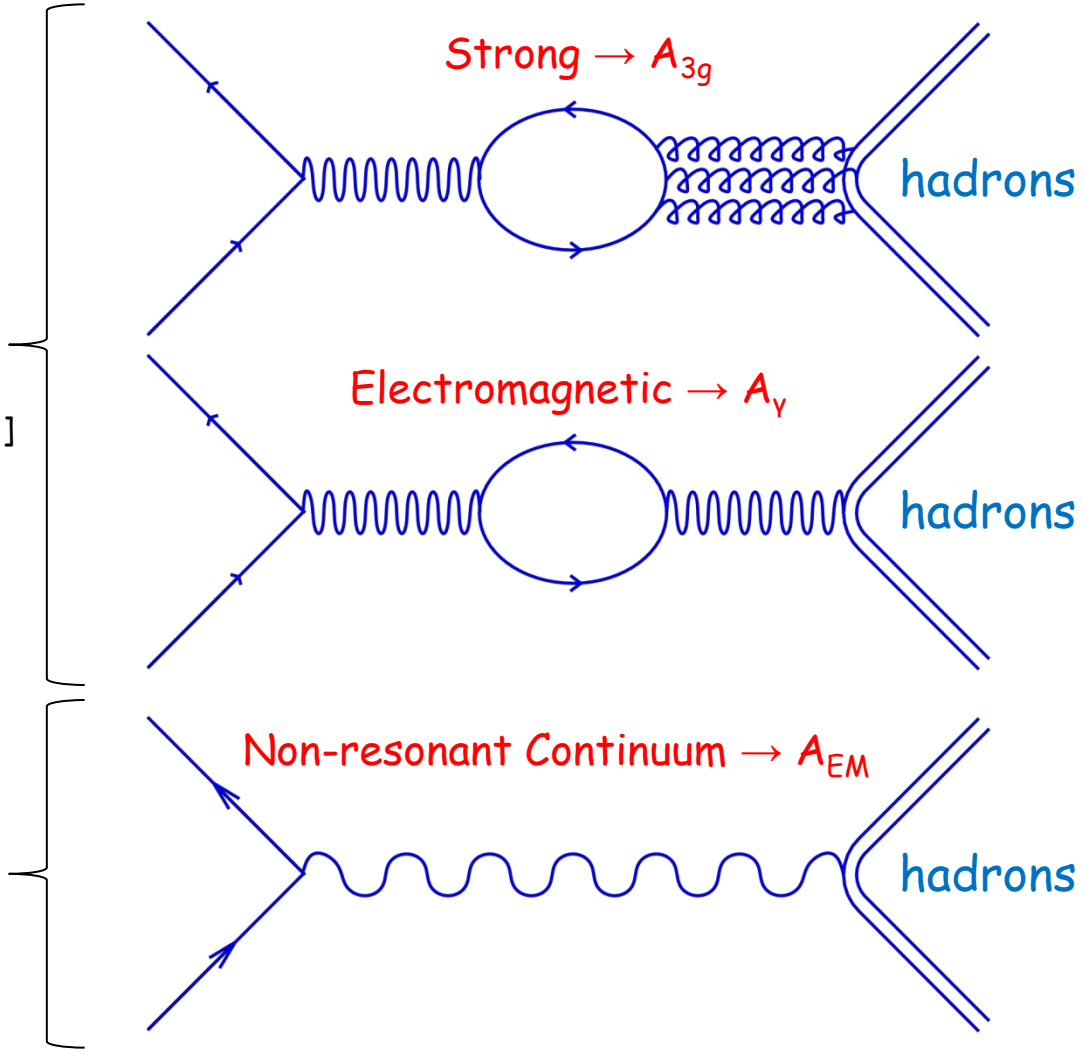
pQCD: all amplitudes almost real [1,2]

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 ($\Phi_p \sim 0°/180°$)
- On the contrary $\Phi_p \sim 90°$ → No interference

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

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

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

$J/\psi \to$ 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

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

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 ~ ½ $BR_{p\bar{p}}$

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

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

$A_{3g} \perp A_\gamma$ R ≈1

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

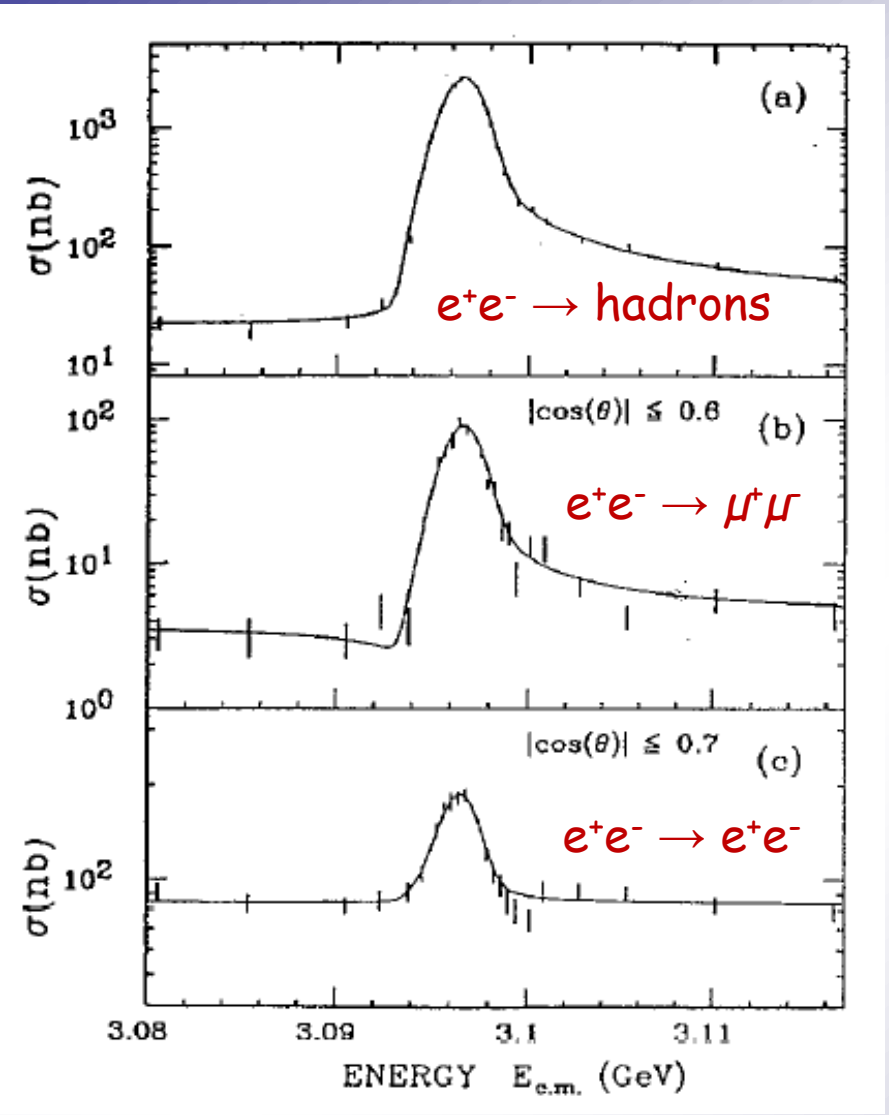
$BR(J/\psi \to p\bar{p}) = (2.112 \pm 0.004 \pm 0.027)\cdot 10^{-3}$

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

- Suggests 90° phase

[1] J.M. Bian, J/ψ -> ppbar and J/ψ -> nnbar measurement by BESIII, to be published on PRD

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

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

- $e^+e^+ \rightarrow J/\psi \rightarrow p\bar{p}, n\bar{n}$ $N\bar{N}$

  BR ~ 2.17×10^{-3} σ_{cont}~ 11 pb

- $e^+e^- \rightarrow J/\psi \rightarrow \rho\pi$ VP

  BR ~ 1.69% σ_{cont}~ 20 pb

- $e^+e^- \rightarrow J/\psi \rightarrow 2(\pi^+\pi^-)\pi^0$

  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

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

$p\bar{p}$

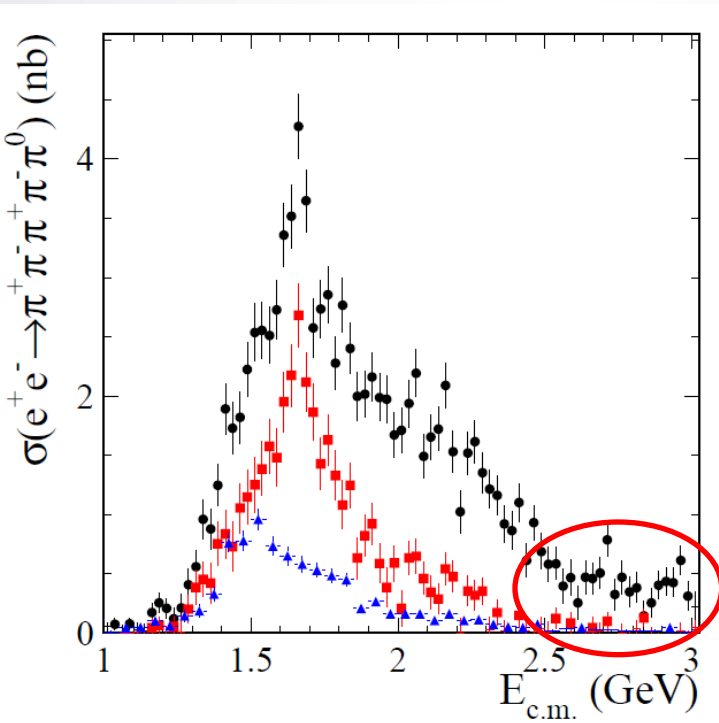
$$\sigma \propto \frac{1}{W^{10}}$$

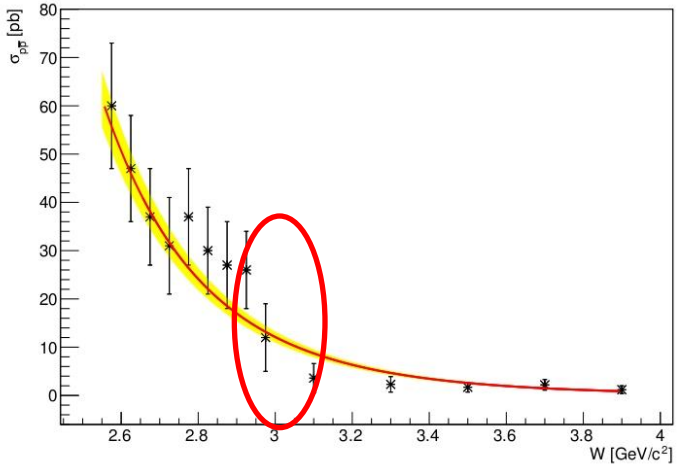
σ_{cont}~ 11 pb

5π

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

σ_{cont}~ 500 pb

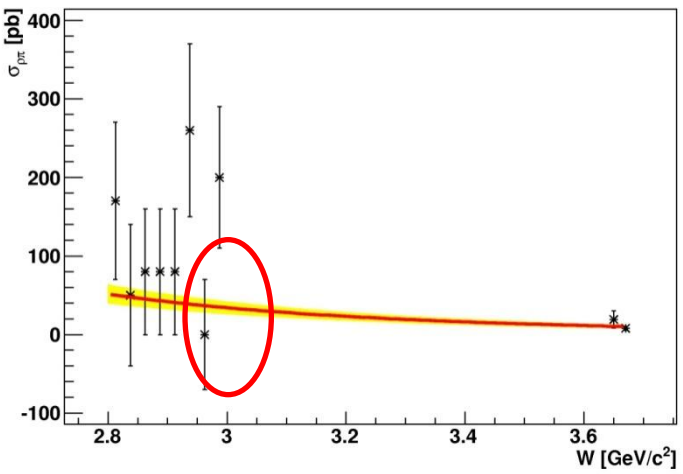




$\rho\pi$

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

σ_{cont}~ 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:

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

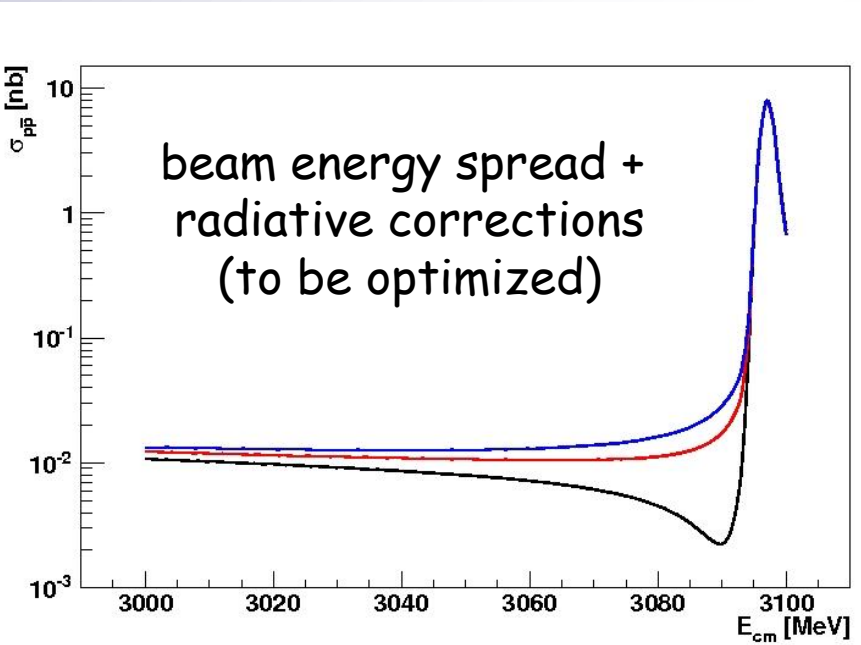
Simulated Yields for $e^+e^- \to p\bar{p}$

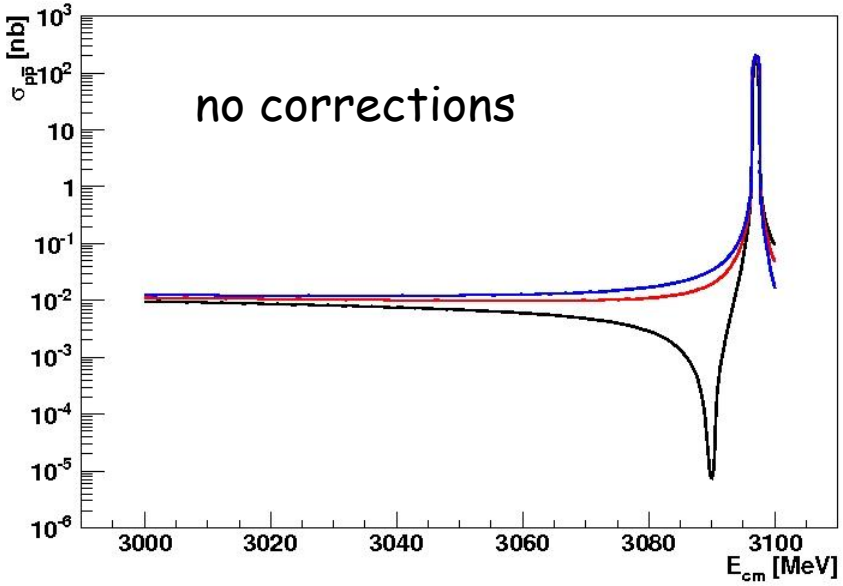
— $\Delta\varphi = 0°$

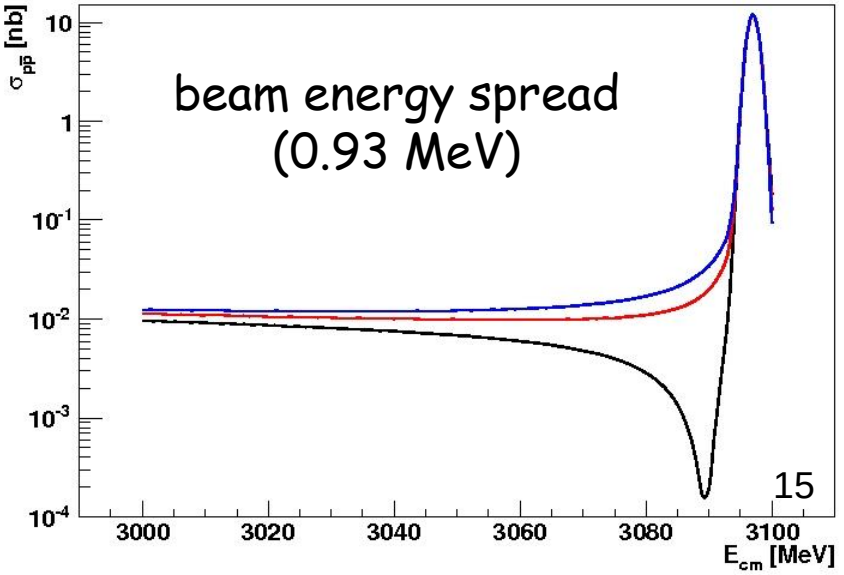
— $\Delta\varphi = 90°$

— $\Delta\varphi = 180°$

continuum reference
$\sigma \sim 11$ pb







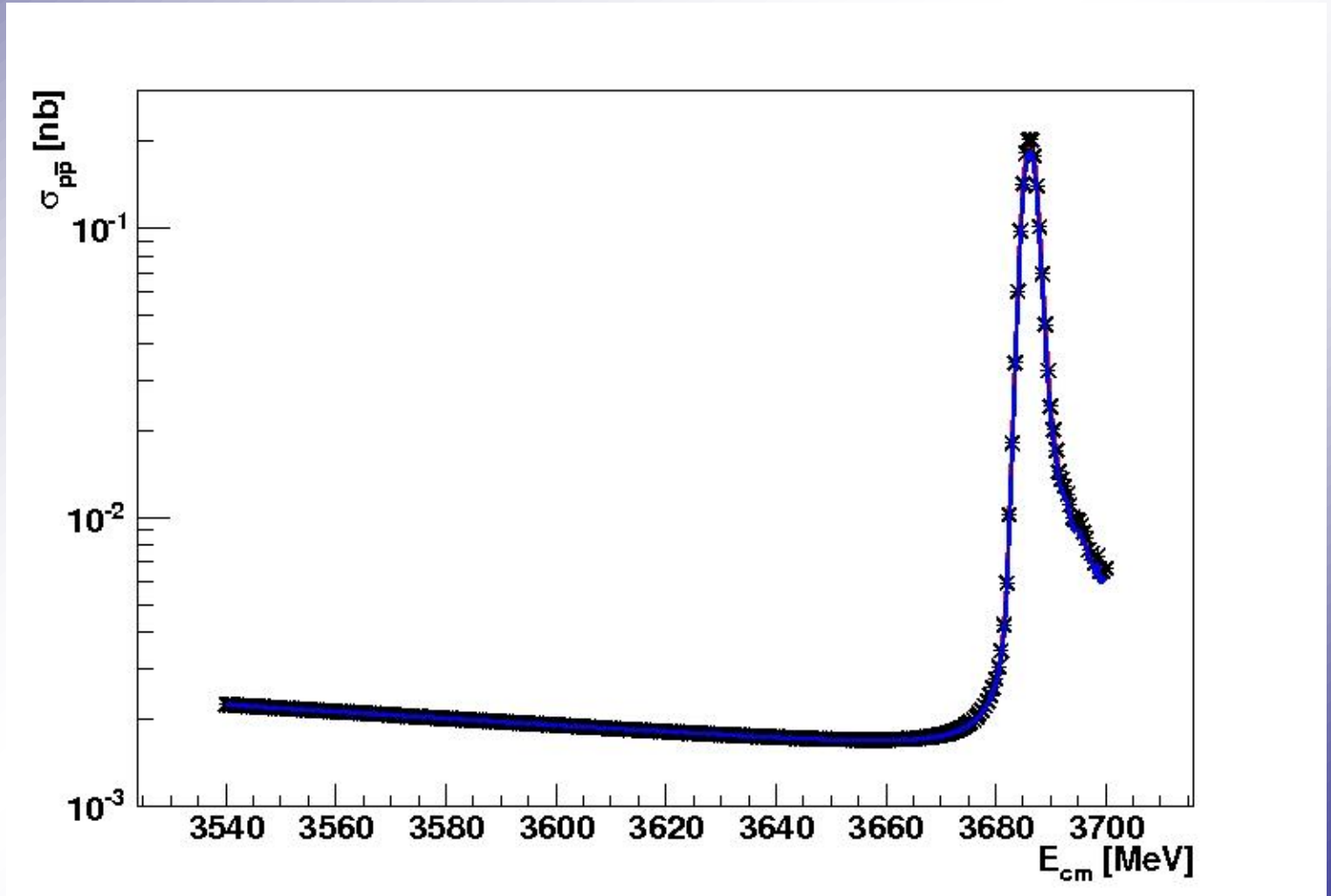
Phase Sign

$p\bar{p}$

* red: $\Delta\varphi = -90°$

blue: $\Delta\varphi = +90°$

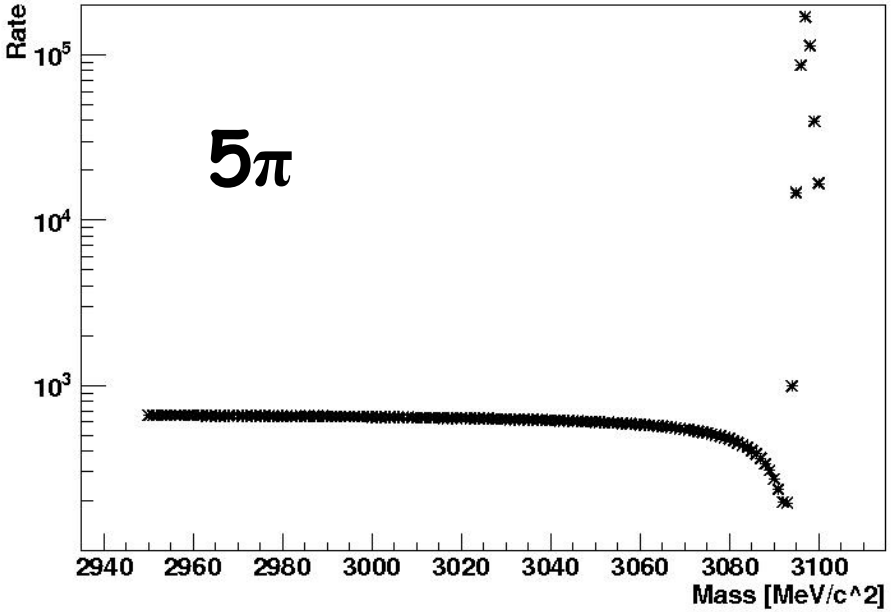
Maximum differences at the 1% level

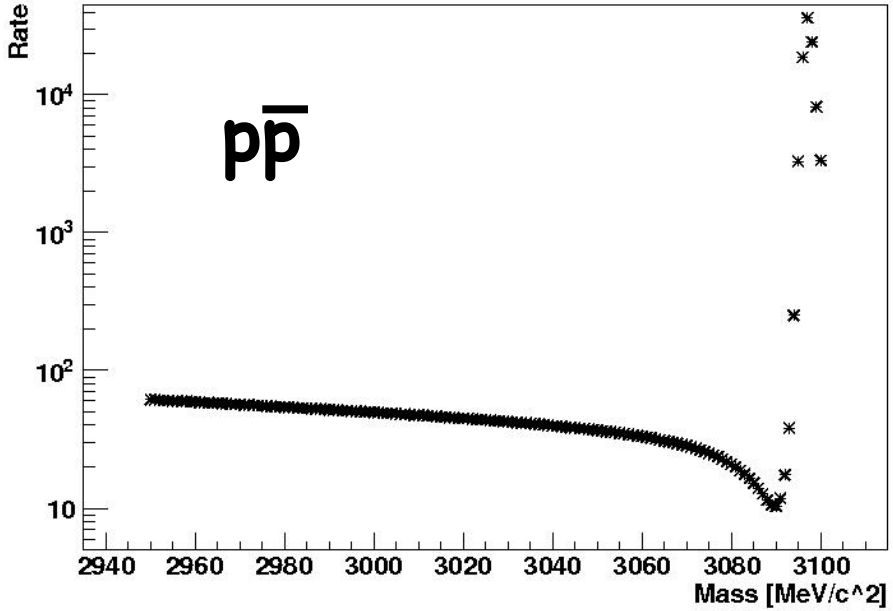


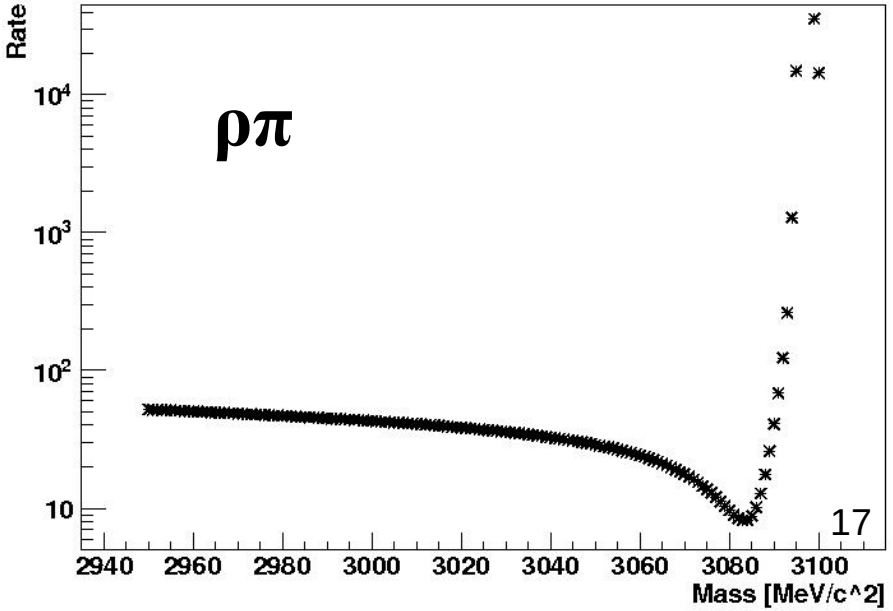
Energy Points Choice

Depends on the process

Maximum interference: 0°





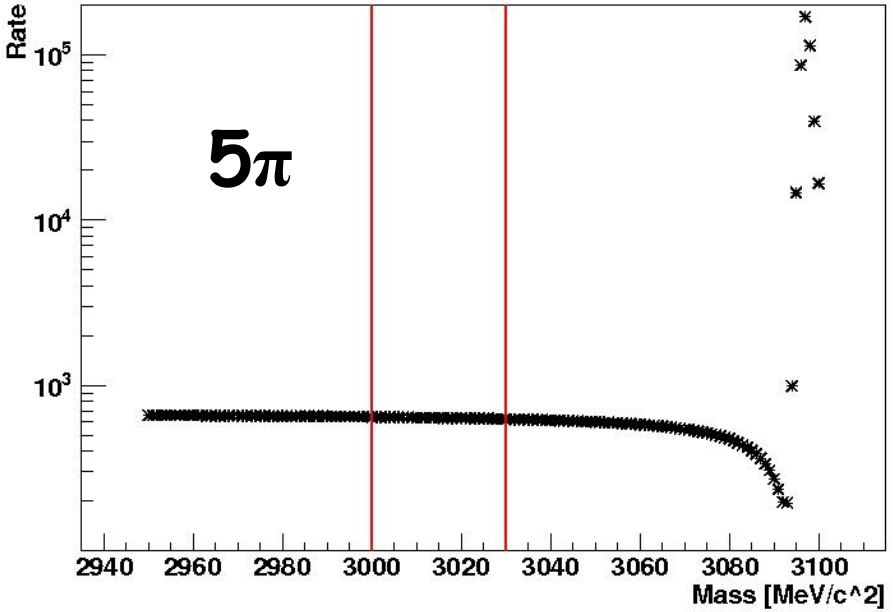


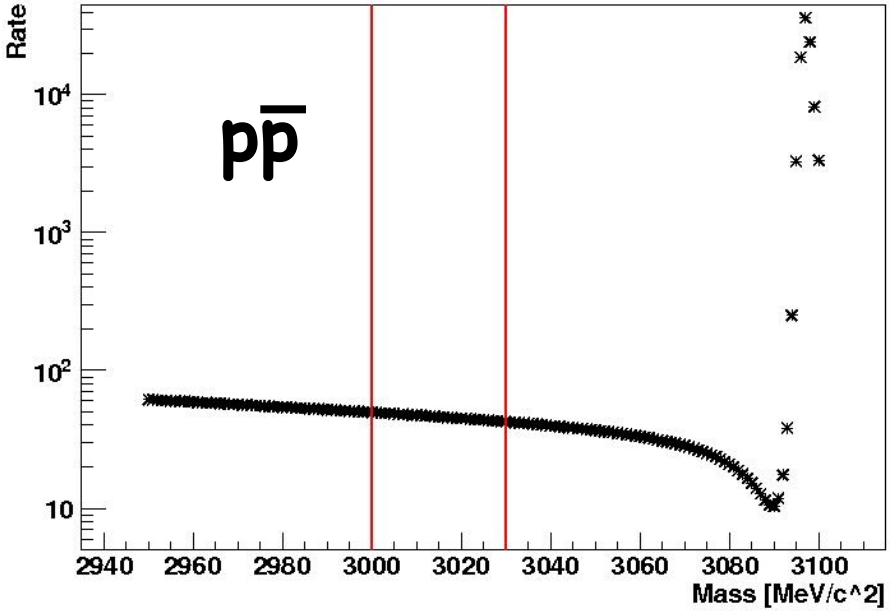
Energy Points Choice

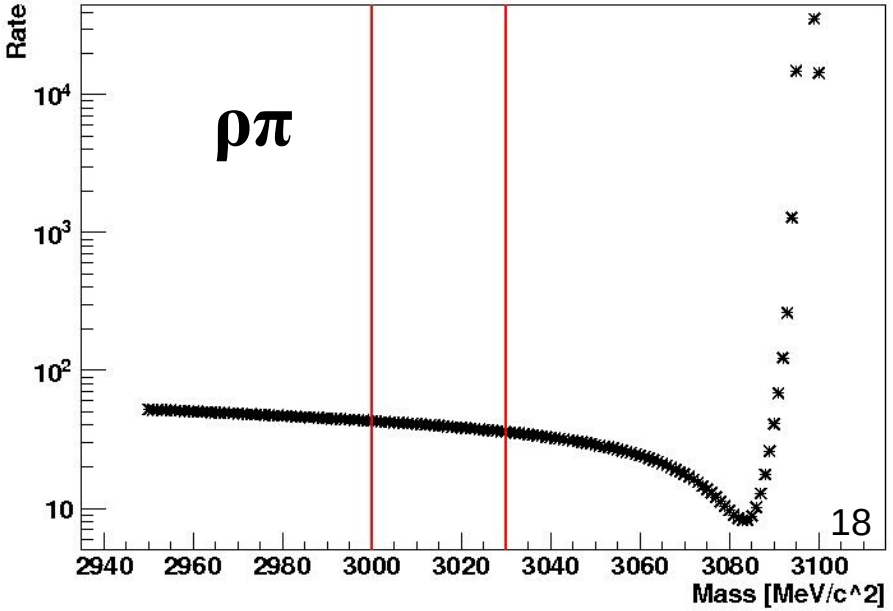
Depends on the process

Maximum interference: 0°

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





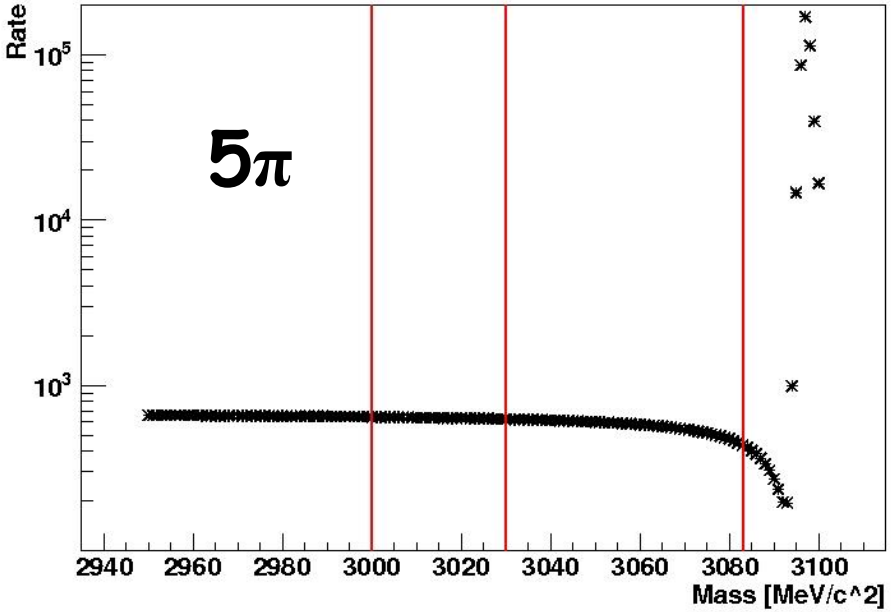


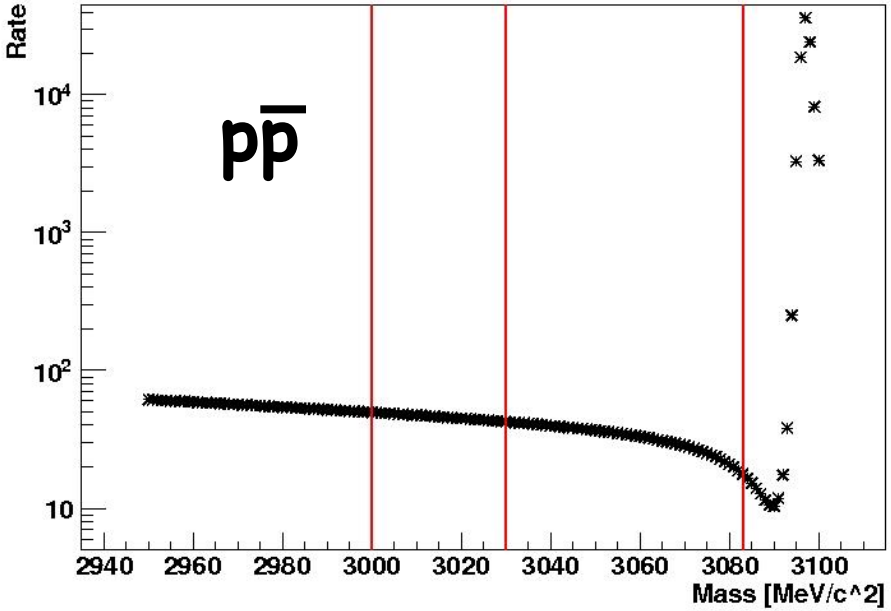
Energy Points Choice

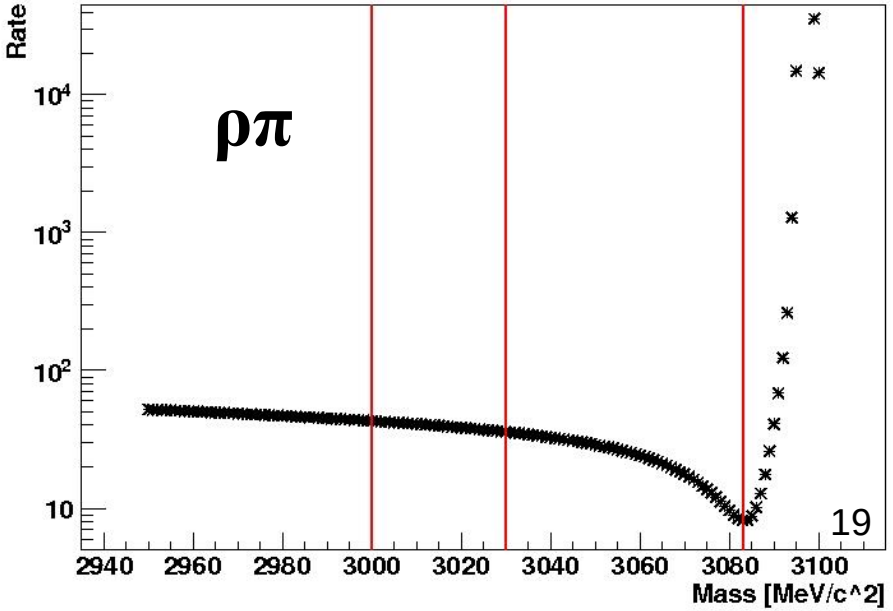
Depends on the process

Maximum interference: 0°

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





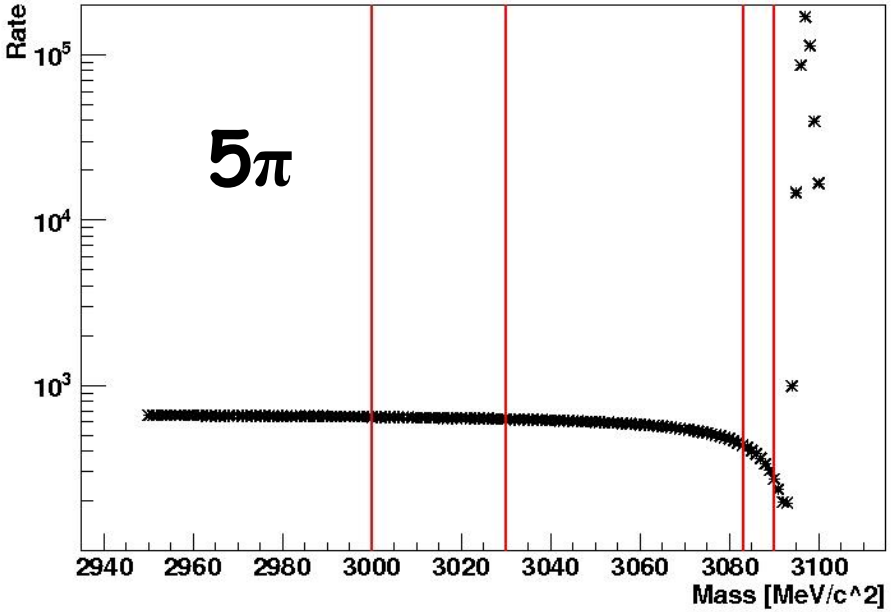


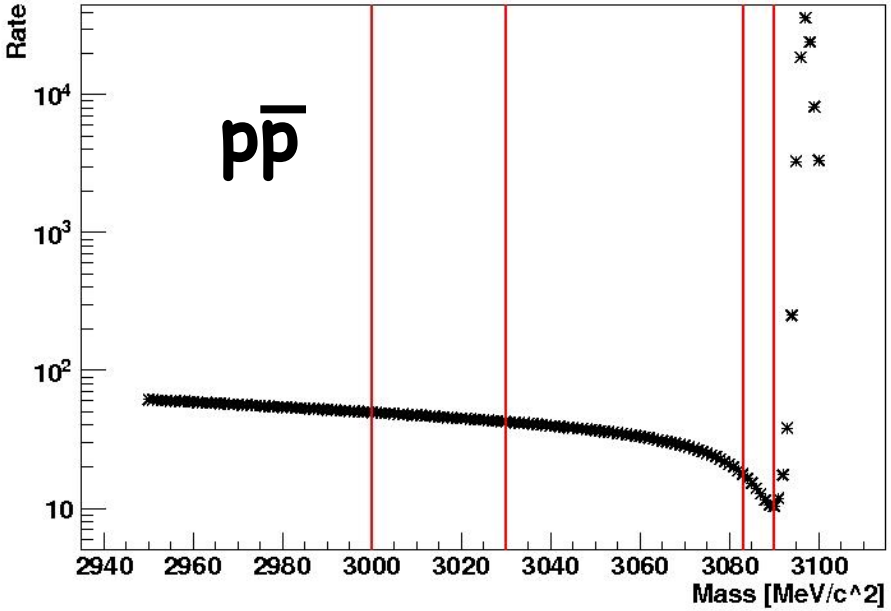
Energy Points Choice

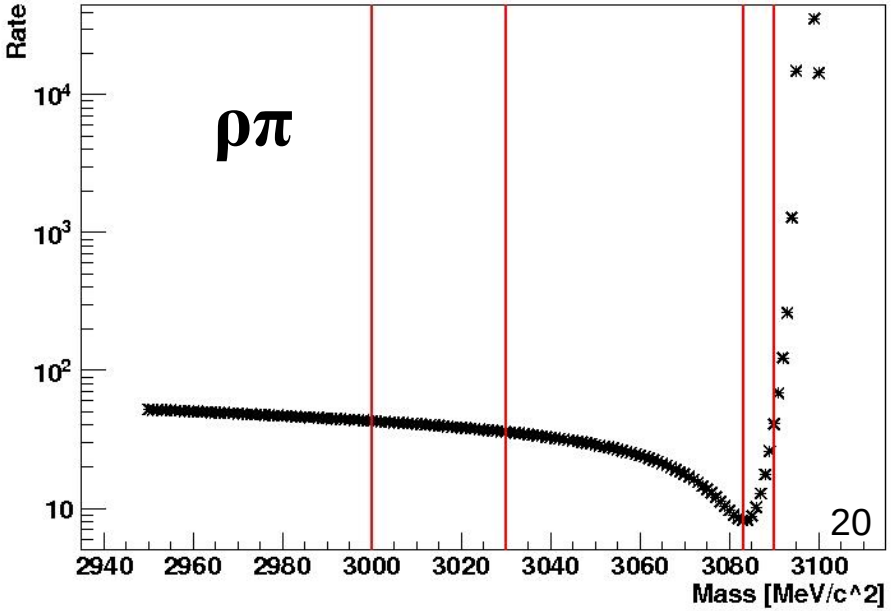
Depends on the process

Maximum interference: 0°

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





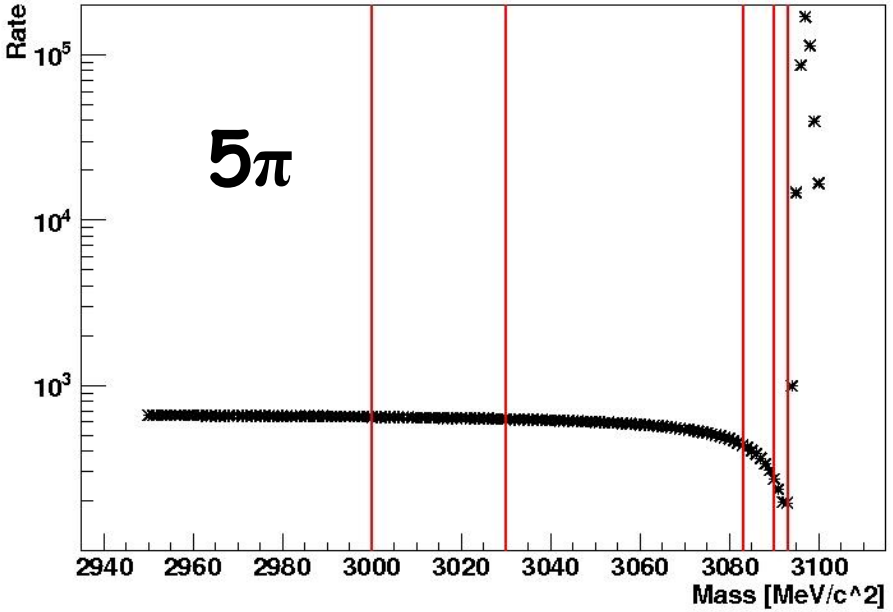


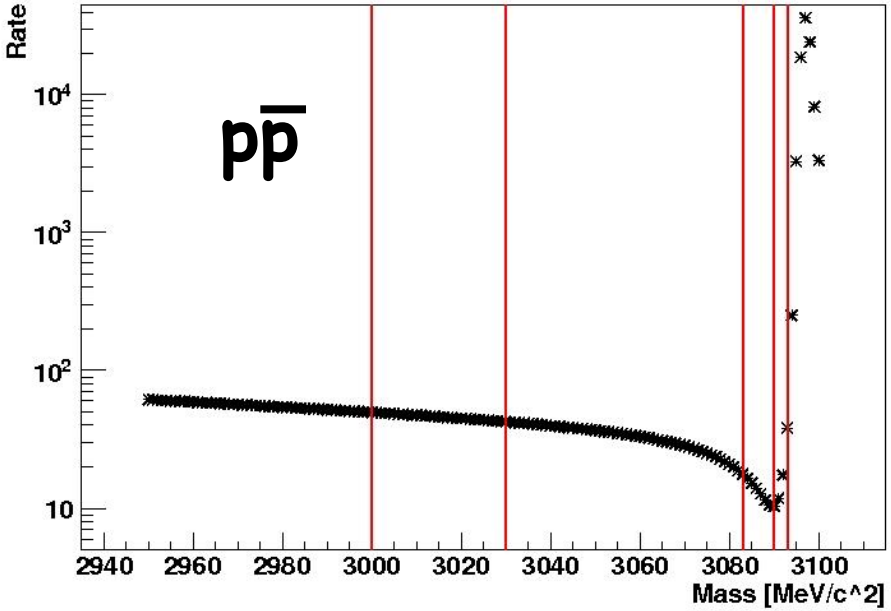
Energy Points Choice

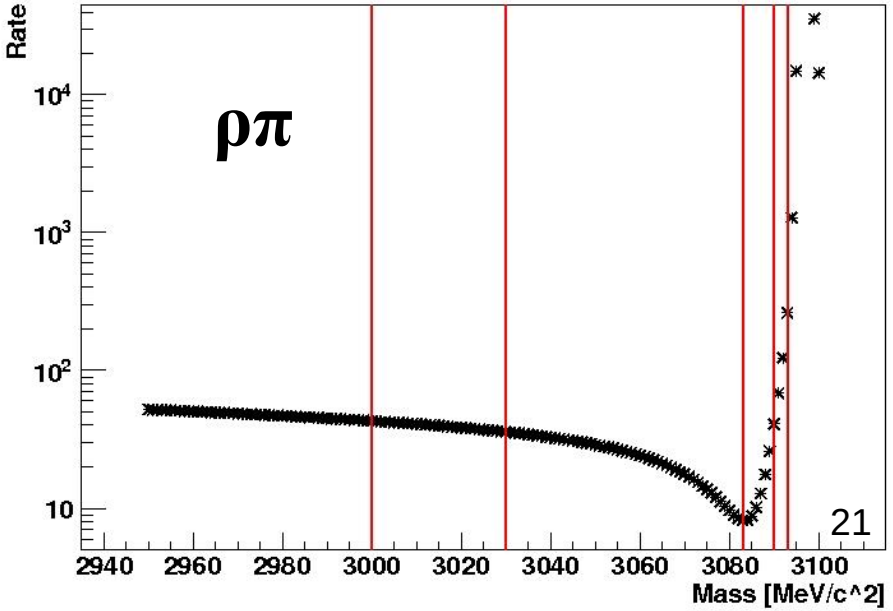
Depends on the process

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







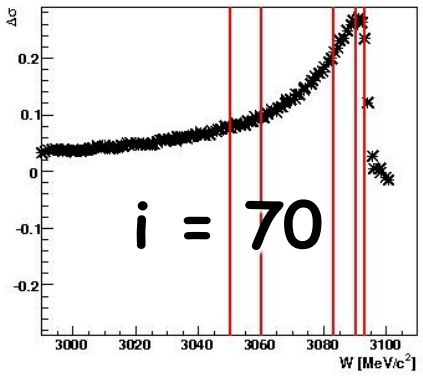
Energy Points Choice

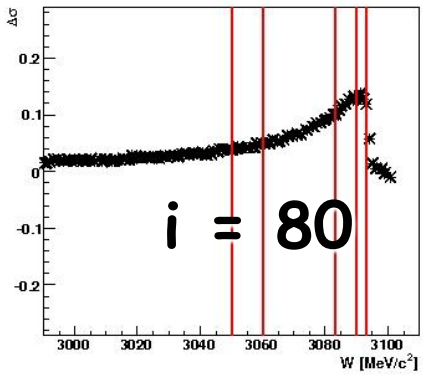
- What happens at 90°

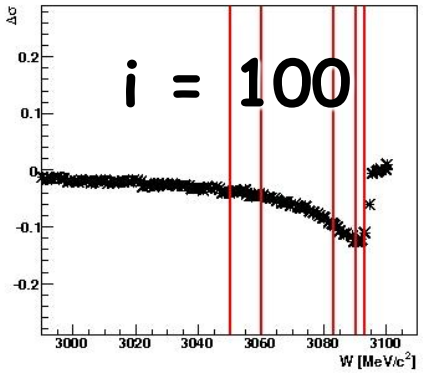
Gradient calculation $(\sigma_{90}-\sigma_i)/\sigma_{90}$

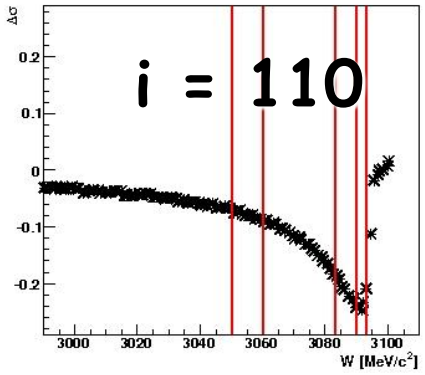
The deep corresponds roughly to the maximum gradient

$p\bar{p}$

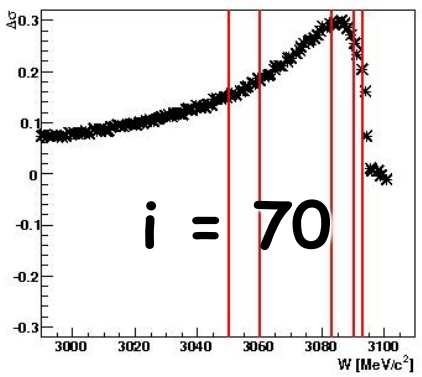


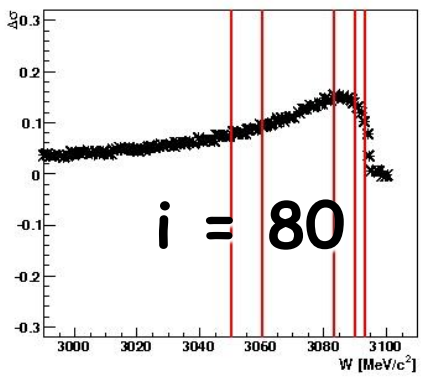


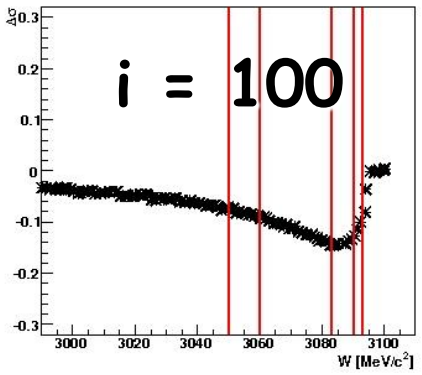


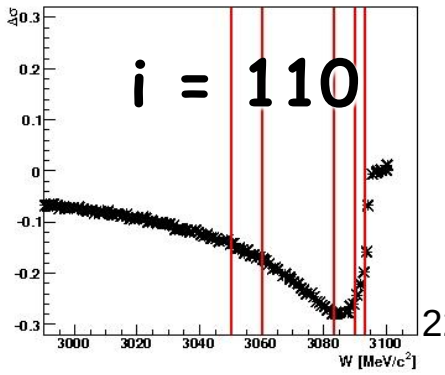


$\rho\pi$









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

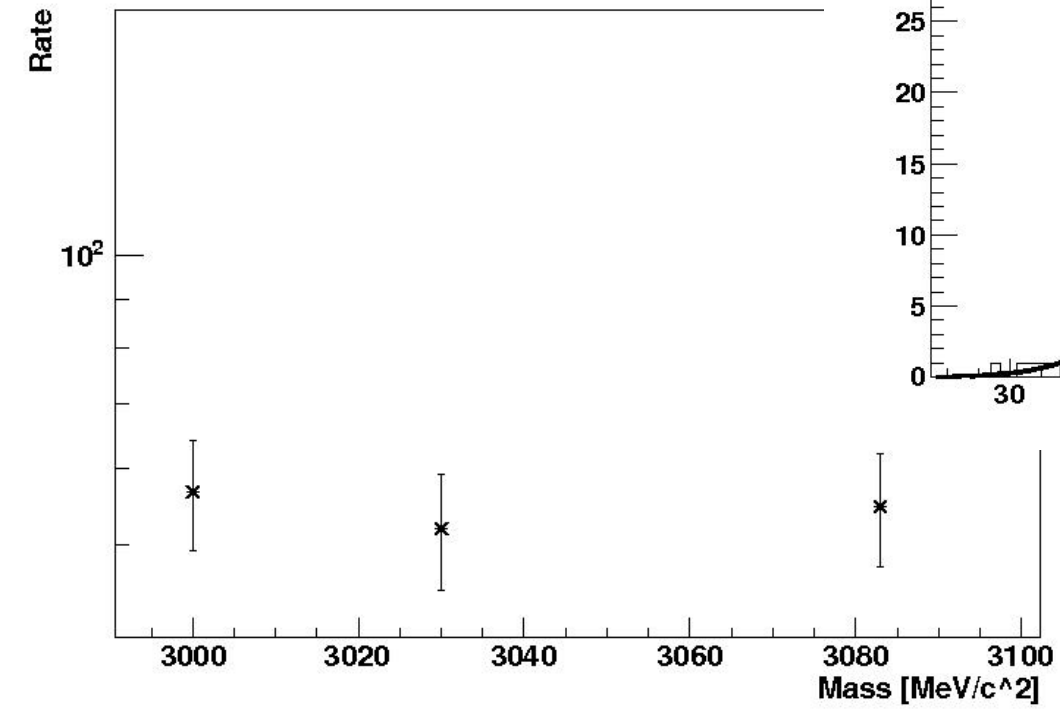
Fit procedure

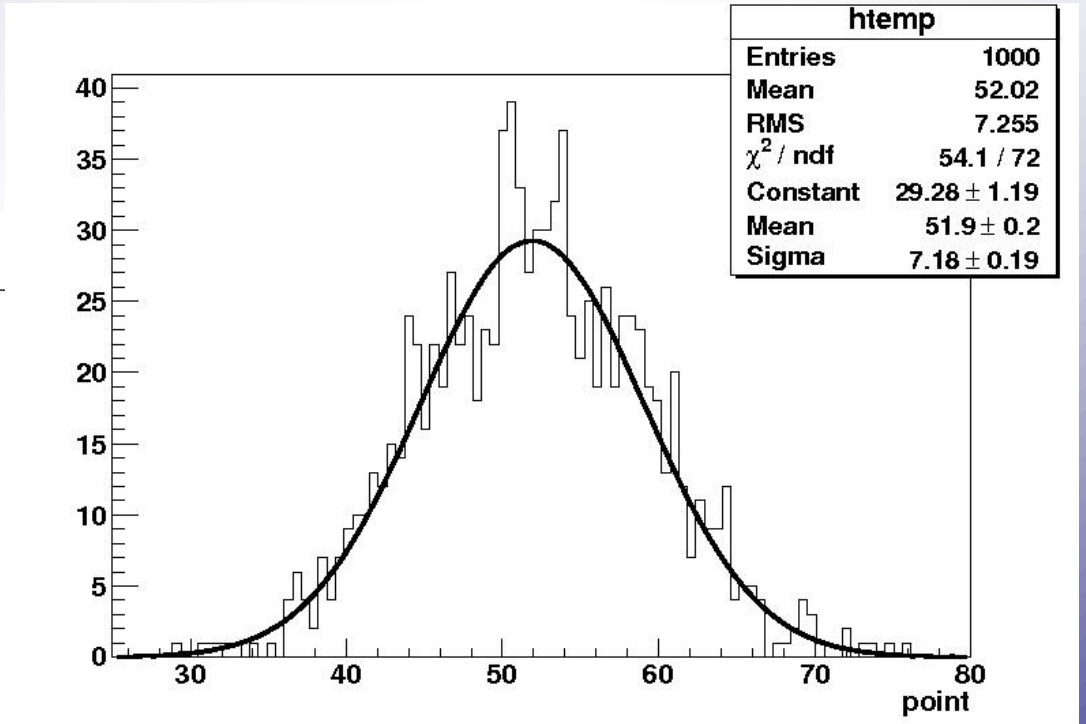
$p\bar{p}$

90° case $L = 10^{32}cm^{-2}s^{-1}$

Smear each point 100 times

Error bars: $\sqrt{nev}$





Fit procedure

$p\bar{p}$

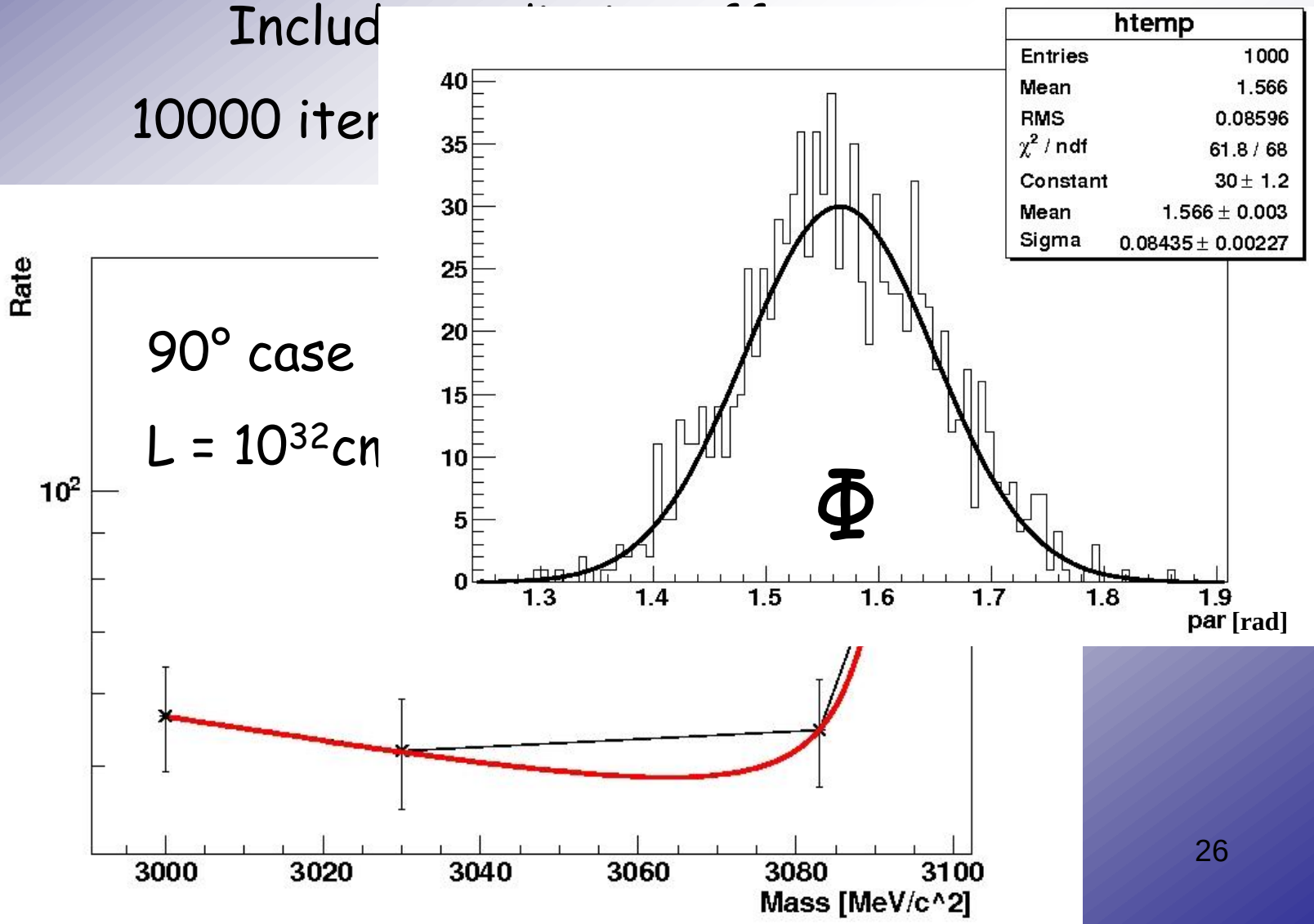
Fit done with Monte-Carlo method

Includ

10000 iter

90° case

L = 10^{32}cm



Precision of the Fit

Statistical error for:

$p\bar{p}$ circle

$\rho\pi$ triangle

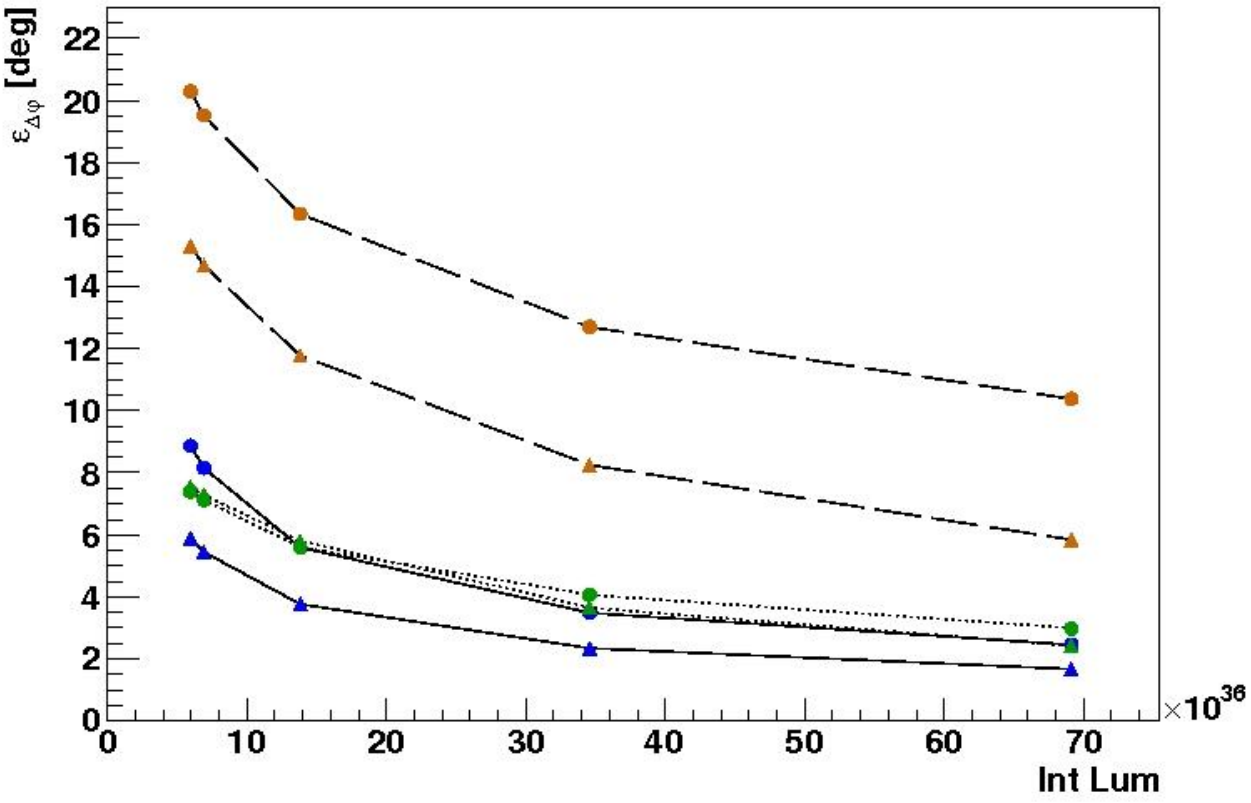
..... 10°

——— 90°

– – – – 170°

2 parameters:

φ and σ_{cont}



170°

- Lower sensitivity

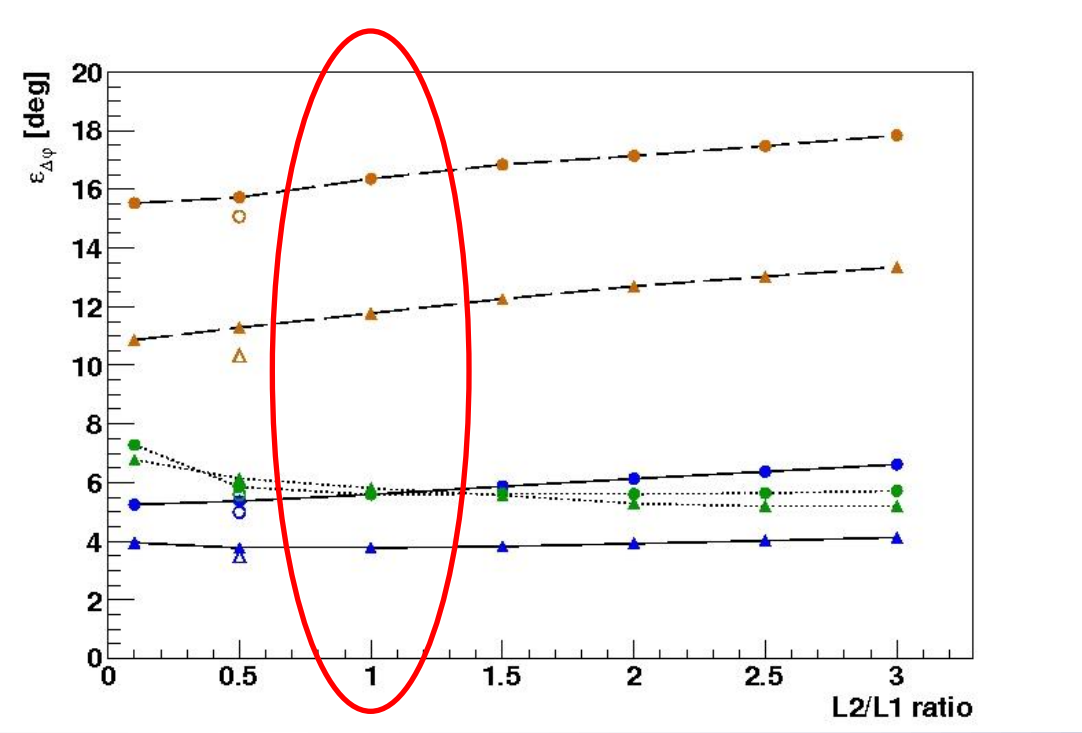
(No 0°-90° and 90°-180° symmetry)

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

$p\pi$ 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

$p\bar{p}$

$\Delta\varphi = +90°$

2 parameters:

φ and σ_{cont}

σ_{cont} = 11 pb

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

Points	Par	Inj. eff.	Δφ [°]	Δσ [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

J/ψ Scan

$p\bar{p}$

$\Delta\varphi = +90°$

3 parameters:

φ, σ_{cont} and B_{out}

σ_{cont} = 11 pb

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

Points	Par	Inj. eff.	$\Delta\varphi$ [°]	$\Delta\sigma$ [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

PRELIMINARY

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