Imaginary Charmonium Decay Widths ?

A proposal for PANDA

The BESIII Italian Collaboration [1,2,3,4,5]

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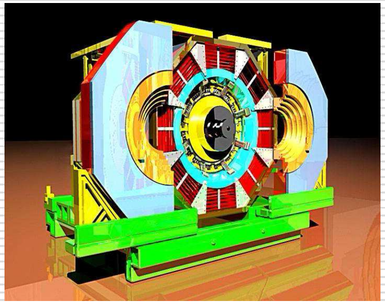
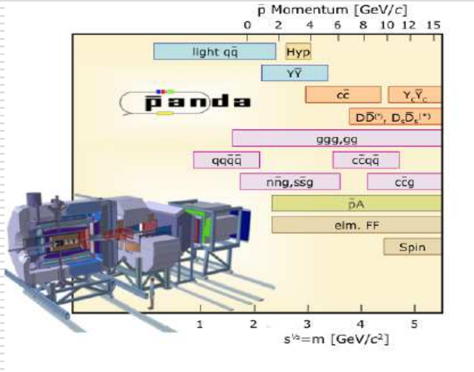


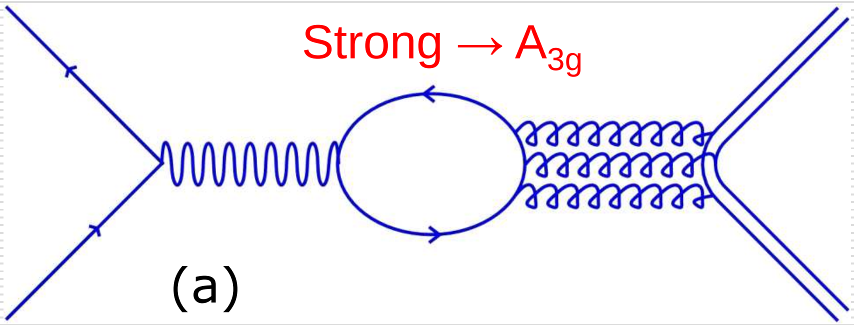


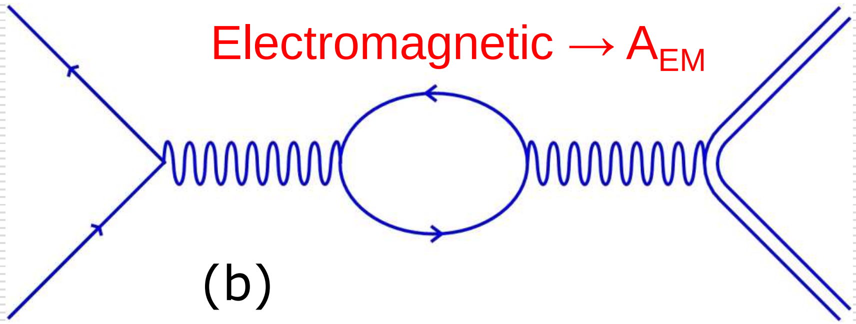
October 7th, 2014, Orsay (France)

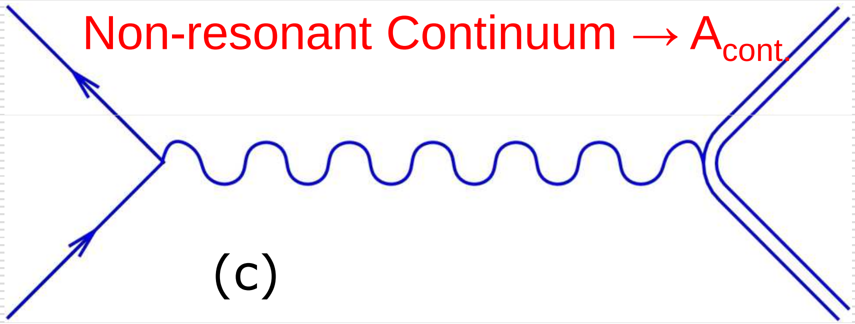
Outline

- Vector Charmonium decay mechanisms
- J/ψ strong imaginary decay widths, experimental evidences:
  - Vector+Pseudoscalar, Pseudoscalar+Pseudoscalar: $|\Phi| \sim 90^0$
  - Energy scan, close to the J/ψ looking for interference, by BESIII: $|\Phi| \sim 90^0$
  - A possible way to get the continuum phase
- Controversial evidences for $\psi'(2S)$
- $\psi''(3770)$ experimental evidences : $\Phi \sim -90^0$
- A model for strong imaginary decay widths
- **A proposal for PANDA: a ppbar -> J/ψ -> hadrons / $\mu\mu$ scan**

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

Experimental Evidences for Imaginary Strong Decay Widths

Model dependent experimental evidences (old data)

SU3 and SU3 Breaking in 1^-0^-, 0^-0^-, 1^-1^- decay : $\Phi \sim 90^\circ$

$J/\Psi \to VP\ (1^-0^-)$ $\Phi = 106^\circ \pm 10^\circ$ [1]

$J/\Psi \to PP\ (0^-0^-)$ $\Phi = 89.6^\circ \pm 9.9^\circ$ [2]

$J/\Psi \to VV\ (1^-1^-)$ $\Phi = 138^\circ \pm 37^\circ$ [2]

More recently:

If $A(e^+e^- \to nn_{bar}) \sim - A(e^+e^- \to pp_{bar})$ [3]

$B(nn_{bar})/B(pp_{bar}) = 0.98 \pm 0.08 \to \Phi \sim 89^\circ \pm 8^\circ$ [4] (BESIII)

[1] L. Kopke and N. Wermes, Phys. Rep. 174, 67 (1989); J. Jousset et al., Phys. Rev. D41,1389 (1990).

[2] M. Suzuki et al., Phys. Rev. D60, 051501 (1999).

[3] FENICE Coll. NP B517(1998)3, SND Phipsi Rome, Sep (2013).

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

VP decay
updated and revisited

SU3 and SU3 Breaking Amplitudes

Use reduced amplitudes $B=B_0 / P^{*\,3}$

Process $J/\psi \to$	Amplitude
$\rho^+\pi^-, \rho^0\pi^0, \rho^-\pi^+$	$g+e$
$K^{*+}K^-, K^{*-}K^+$	$g(1-s)+e$
$K^{*0}\bar{K}^0, \bar{K}^{*0}K^0$	$g(1-s)-2e$
$\omega\eta$	$(g+e)X_\eta + \sqrt{2}rg(\sqrt{2}X_\eta + Y_\eta)$
$\omega\eta'$	$(g+e)X_{\eta'} + \sqrt{2}rg(\sqrt{2}X_{\eta'} + Y_{\eta'})$
$\phi\eta$	$(g(1-2s)-2e)Y_\eta + rg(\sqrt{2}X_\eta + Y_\eta)$
$\phi\eta'$	$(g(1-2s)-2e)Y_{\eta'} + rg(\sqrt{2}X_{\eta'} + Y_{\eta'})$
$\rho^0\eta$	$3eX_\eta$
$\rho^0\eta'$	$3eX_{\eta'}$
$\omega\pi^0$	$3e$
$\phi\pi^0$	0

J/Ψ
Vector +Pseudoscalar

Parameter		Fit
SU_3 strong Amplitude	g	7.22 ± 0.38
SU_3 breaking strange	s	0.18 ± 0.04
SU_3 breaking DOZI	r	-0.04 ± 0.02
E.M. Amplitude	e	0.75 ± 0.04
Phase	f	**81.51± 6.75**

J/ψ

Vector + Pseudoscalar

Decay	Amplitude	PDG x10⁴	Fit x10⁴	$\Delta\chi^2$
$\rho^0\,\pi^0$	$g\,e^{i\phi} + e$	169.0 ±15.0	133.00	1.13
$K^{*+}\,K^-$	$g\,(1-s)\,e^{i\phi}+e$	51.2 ± 3.0	51.5	0.01
$K^{*0}\,K^0$	$g\,(1-s)e^{i\phi} - 2e$	43.9 ± 3.1	48.5	0.48
$\omega\,\eta$	$(g\,X+d)e^{i\phi}+eX$	17.4 ± 2.0	18.5	0.06
$\phi\,\eta$	$(g\,(1-2s)Y+d)e^{i\phi}-2eY$	7.5 ± 0.8	3.9	4.02
$\rho\,\eta$	$3eX$	1.9 ± 0.2	2.2	0.30
$\omega\,\pi$	$3e$	4.5 ± 0.5	4.1	0.11
$\omega\,\eta'$	$(g\,X'+d')e^{i\phi}+eX'$	7.0 ± 7.0	11.9	0.10
$\phi\,\eta'$	$(g\,(1-2s)Y'+d`)e^{i\phi}-2eY'$	4.0 ± 0.7	6.1	1.87
$\rho\,H$	$3eX'$	1.1 ± 0.2	1.1	0.04

PP decay
updated and revisited

Pseudoscalar Pseudoscalar Decay Revisited

- Open question about $J/\Psi \to \pi\pi$ decay, since pure em :

  $B^{\pi\pi} = |E^{\pi\pi}|^2$, , while

  $B^{\pi\pi}$ = **(1.47± .23) 10^{-4}** *from PDG*

  $|E^{\pi\pi}|^2 = B^{\mu\mu}\, \sigma(e^+e^- \to \pi^+\pi^-)/\sigma(e^+e^- \to \mu\mu) =$

  = **(0.46 ± .23) 10^{-4}** *extrapolated from BaBar*

  $B^{\pi\pi} \neq |E^{\pi\pi}|^2$ by 3 s.d.

- $\pi\pi$ cross section slope B ,

  asymptotically it is expected B= -2-4 x n_q = -6

  $B^{\pi\pi}$ ~ - 10 ± 2

Pseudoscalar Pseudoscalar Decay Revisited

- It is possible to avoid $\pi\pi$ and complications from s quark by means of KK BR's and $|E^{KK}|$ only

- $B^{+-} = |S|^2 + |E^{+-}|^2 + 2\,|S||E^{+-}| \cos\Phi$
  $B^{SL} = |S|^2 + |E^{SL}|^2 - 2\,|S||E^{SL}| \cos\Phi$

- $|E^{+-}|^2 = B^{\mu\mu}\, \sigma(e^+e^- \to K^+K^-)/\,\sigma(e^+e^- \to \mu\,\mu)$
  $|E^{SL}|^2 \sim 0$, since $\sigma(e\,e \to K_S\,K_L) << \sigma(e\,e \to K^+\,K^-)$
  $\sigma(e^+\,e^- \to K_S\,K_L) \sim 0.6$ pb at J/Ψ
  $B^{+-} = (2.37 \pm 0.31)\,10^{-4}$ $B^{SL} = (1.66 \pm 0.26)\,10^{-4}$
  $|E^{+-}|^2 = (1.3 \pm 0.6)\,10^{-4}$ *from BaBar*
  $\Phi = 83.7^0 \pm 9.0^0$

The ψ' Puzzle

Ψ'

Vector + Pseudoscalar

Parameter		Fit
SU_3 strong Amplitude	g	0.49 ± 0.04
SU_3 breaking strange	s	-0.04 ± 0.13
SU_3 breaking DOZI	r	-0.04 ± 0.08
E.M. Amplitude	e	0.18 ± 0.02
Phase	f	**159.± 12.**

χ^2/DFR =0.96

Φ at the Ψ' from K*(892)K Decay Only

- $K^*(892)$ K decay: possible to avoid SU_3 assumptions and complications from s quark mass, since CLEOc measured the continuum cross sections
- CLEOc (arXiv:hep-ex/0509011v2):

  $\sigma(e\, e \to K^{*0}\, K^0 + cc) = (23.5 \pm 5.3)$ pb at W=3.67 GeV

  $\sigma(e\, e \to K^{*+}\, K^- + cc) \sim (1 \pm 0.9)$ pb

  $|E^{+-}|^2 \sim 0.1\text{x}10^{-5}$ $|E^{00}|^2 \sim 28.\text{x}10^{-5}$

- $B^{+-} = (1.7 \pm 0.8)\text{x}10^{-5}$ $B^{00} = (10.9 \pm 2.0)\text{x}10^{-5}$

  $B^{+-} = |S|^2 + |E^{+-}|^2 + 2\text{x}|S||E^{+-}| \cos\Phi$

  $B^{00} = |S|^2 + |E^{00}|^2 - 2\text{x}|S||E^{00}| \cos\Phi$

  $\Phi = 159^0 \pm 24^0$ again like VP !

Pseudoscalar Pseudoscalar Decay

- Ψ' :

  $B^{+-} = (6.30 \pm 0.70)\ 10^{-5}$ $\quad B^{SL} = (5.26 \pm 0.25)\ 10^{-5}$

  $|E^{+-}|^2 = (0.7 \pm 0.4)\ 10^{-5}$ *from BaBar*

  $\Phi = 95^0 \pm 11^0$ **(6.3~ 5.26+0.7+3.8xcosΦ)**

- **But Nambu wrote Ψ' might be different !**
  (PRL 34(1975), 1645)

Experimental evidences for $\Psi(3770)$ imaginary strong decay widths

ψ''(3770):

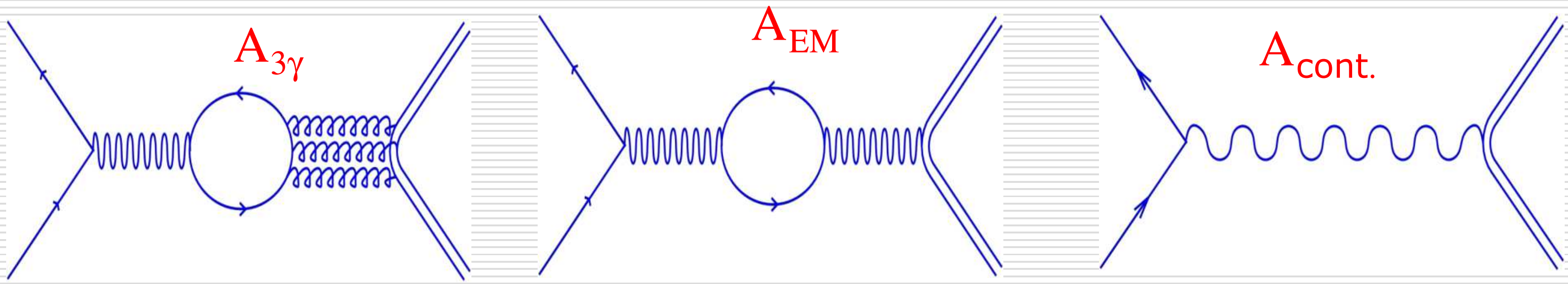
- non DDbar (small) -> throught the interfence with continuum
- For a wide resonance Φ from interference at the peak

  - $2|A_{3g}|/\Gamma_{tot}$ sin Φ x continuum

- CLEOc and BESIII: $\Phi \sim$ **- 90˚** , since continuum sign

decay	continuum	Ψ''(3770)	sign	
$\rho\,\pi$	13.1±2.8	7.4±1.3	-	CLEOc, PRD 73(2006)012002
$\phi\,\eta$	2.1±1.6	4.5±0.7	+	CLEOc, PRD 73(2006)012002
$p\,\underline{p}$	0.74±0.08	0.4±0.02	-	BESIII Y.Liang, Nov (2012)

Model independent
from interference in q^2 behavior

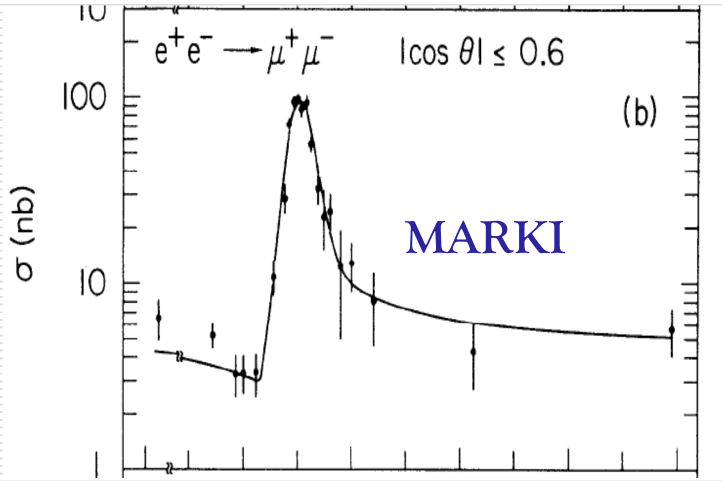


$$\sigma_{born} = |A_{3g} + A_{EM} + A_{cont}|^2 = ||A_{3g}|e^{\iota\varphi} + |A_{EM} + e^{\iota\varphi'} A_{cont}||^2$$

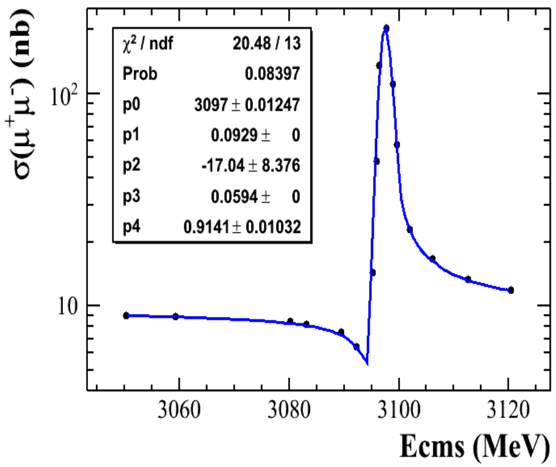
Actually $\Phi_{meas} = \Phi - \delta_{cont}$ and $|\Phi_{meas}|$ only is measured, since it is difficult to get the sign

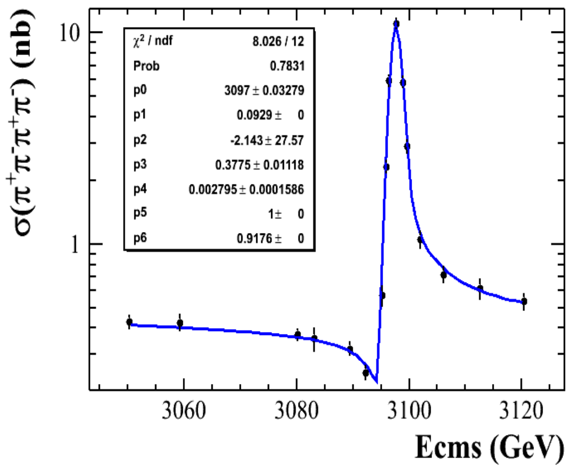
The full interference between A_{EM} and A_{cont} has been observed , as expected, at MARKI(1975), BESII (1995), KDER (2010).

1/2 photon propagators require $\varphi' = 180^{o}$

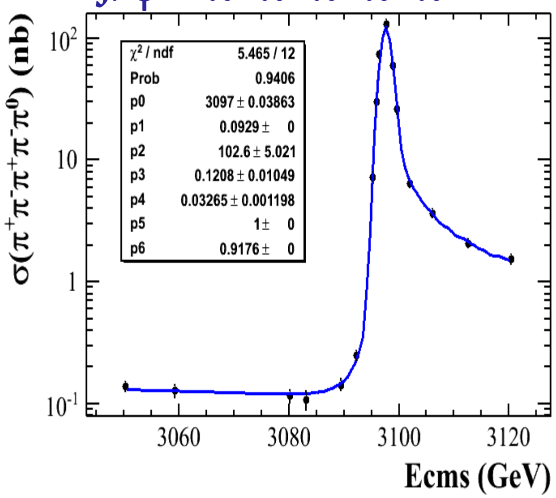


BESIII J/Ψ scan

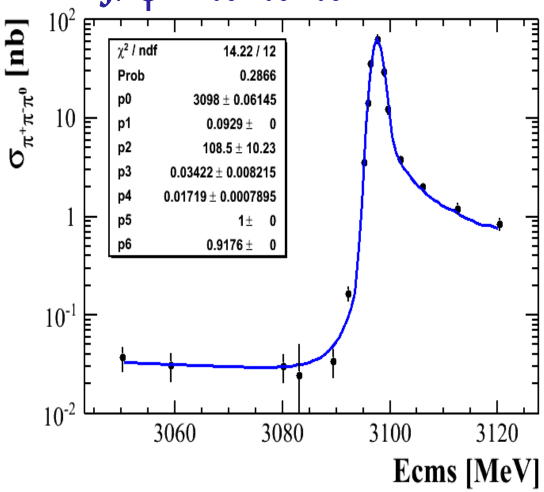




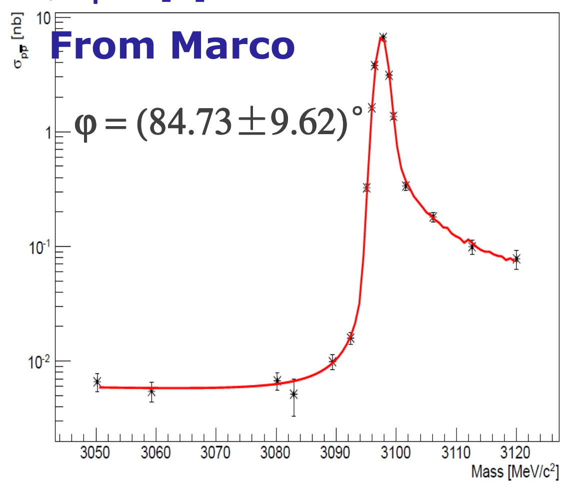
J/ψ→π+π−π+π−π0



J/ψ→π+π−π0

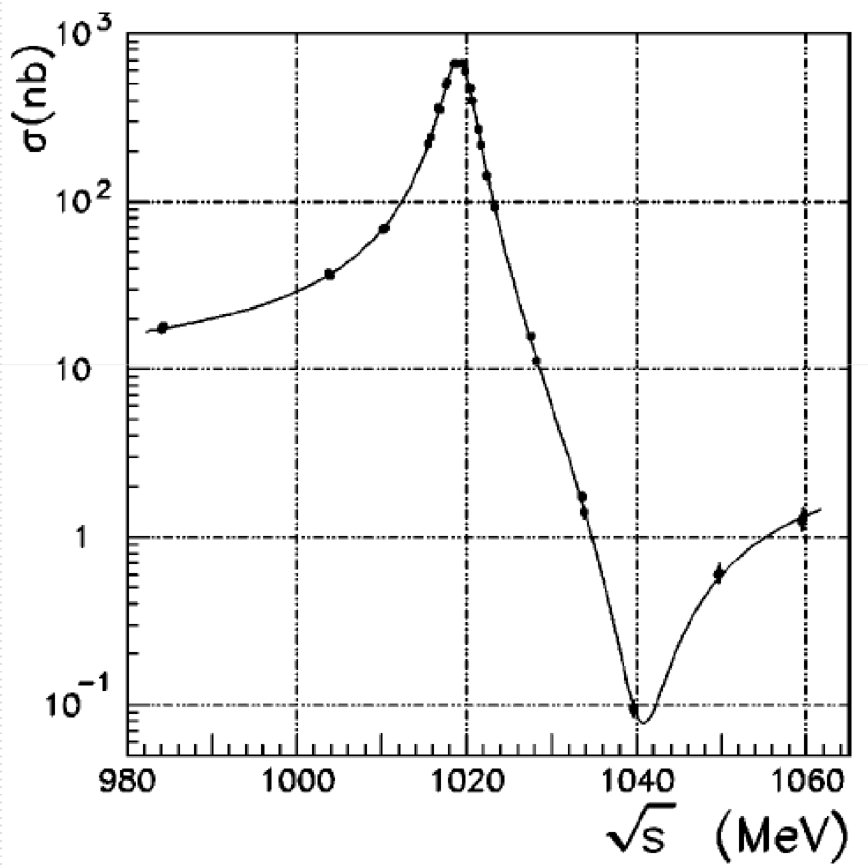


J/ψ→pp



The interference pattern is not always the same.

$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ @ VEPP2M



φ~180°

Phys. Rev.D 63, 072002

A possible way to get the continuum phase (work in progress)

Continuum phase d(s)

- Continuum amplitudes should be almost real : $\delta(s) \sim 0^0$ or 180^0

- Logarithm Dispersion Relations
  relating modulus $|F(s)|^2 \sim \sigma(s)$ and $\delta(s)$ might help:

$$\delta(s) = -\frac{\sqrt{s-q_t^2}}{\pi}\,\mathrm{PV}\int_{q_t^2}^{\infty}\frac{\ln|F(t)/F(0)|}{(t-s)\sqrt{t-q_t^2}}\,dt\,,$$

$$\delta(s) = -\frac{\sqrt{s-q_t^2}}{\pi}\,\mathrm{PV}\int_{q_t^2}^{\infty}\frac{\ln|F(t)/F(0)|}{(t-s)\sqrt{t-q_t^2}}\,dt\,,$$

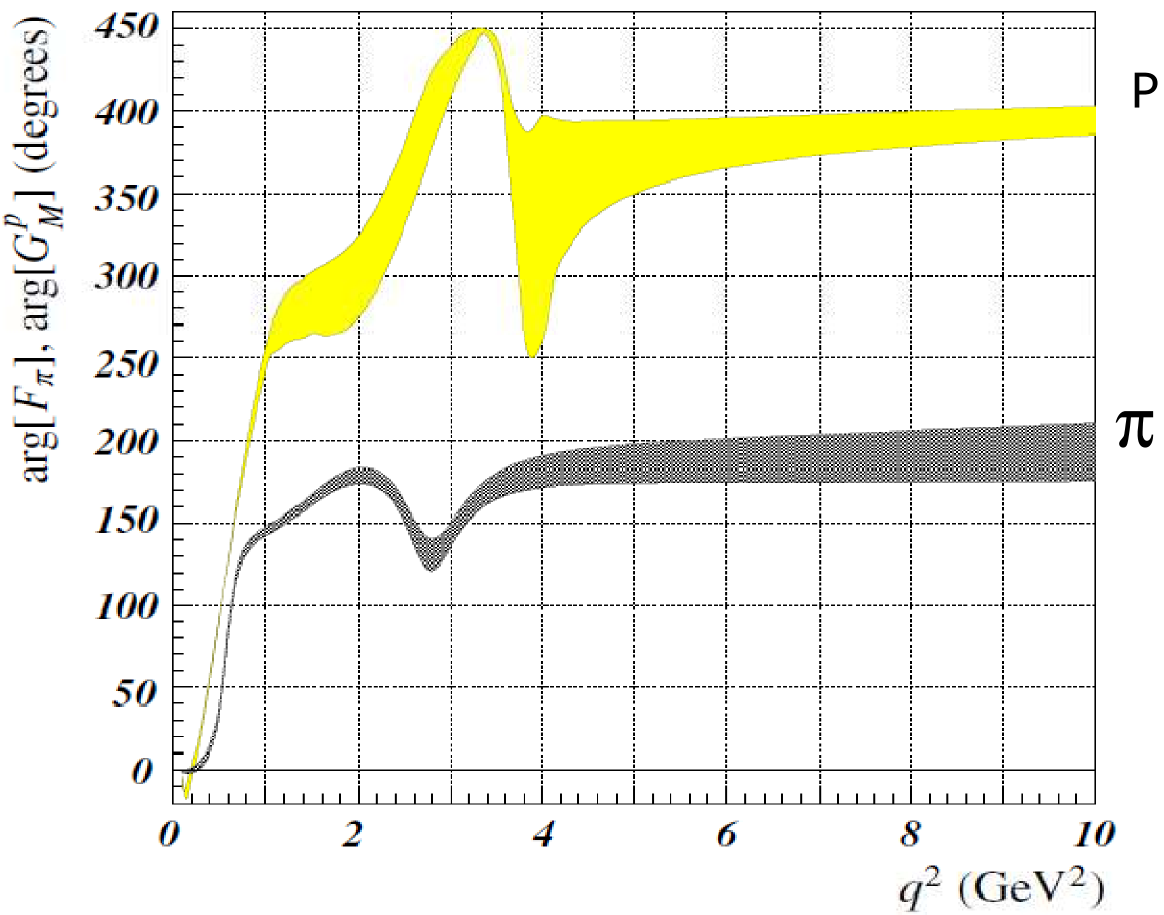
- Check: phase as expected, if $|F(s)|^2 \sim$ BW $\sim \sigma(s)$ / IPS

- Applied to $\sigma\,(e^+e^- \to pp_{bar})$ (unphysical region): $\delta(s) \sim 360^0$
  $\sigma\,(e^+e^- \to \pi\pi)$: $\delta(s) \sim 180^0$
  $\sigma\,(e^+e^- \to 3\,\pi)$: $\delta(s) \sim 180^0$ (?)

- If $\delta\,(s)$ ‡ 0 and it is known how 180^0 or 0^0 is asymp reached,
  from $|\Phi_{meas}| = |\phi - \delta|$ the sign (+/- 90^0) might be established

$\pi^+ \pi^-$ and pp_{bar} (throught the unphysical region.) phases

(S.Pacetti, R. Baldini… EPJC 11(1999)709… long time ago)



Open Issues related to Unitarity

- **No explanation for imaginary strong decay J/ Ψ widths has been put forward until now**
- J/ Ψ description as a Breit Wigner might have some difficulties , dealing with imaginary decay widths
- Optical theorem : $\text{Im}\, T_{el} = W/8\pi \cdot \sigma_{tot}$ implies $\text{Im}\, T_{el} > 0$
- Γ(J/ Ψ -> pp_{bar}) imaginary: $\text{Im}\, T_{el}$(pp_{bar} -> J/ Ψ -> pp_{bar}) < 0
- pp_{bar} continuum could restore unitarity, even if unrelated to J/ Ψ
- Looking for a different J/ Ψ description
- σ_{el}(pp_{bar} -> J/Ψ -> hadrons) : a test of the following model

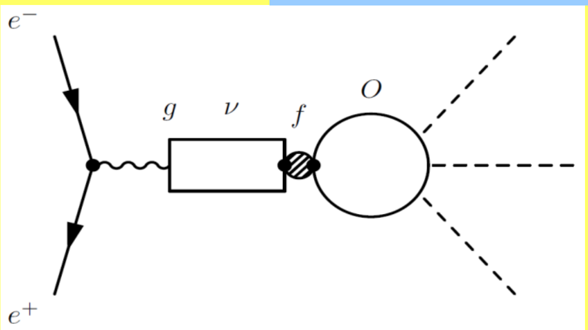
A model to explain imaginary widths

Quarkonium OZI breaking decay

as Freund and Nambu (PRL 34(1975), 1645)

- Quarkonium as a superposition of
  - A narrow V (coupled to the virtual photon, but not directly to hadrons)
  - A wide one (a glueball O) (not coupled to leptons i.e. to a virtual photon, but strongly coupled to hadrons)

***f* is the coupling between ν and $\mathcal{O}$**



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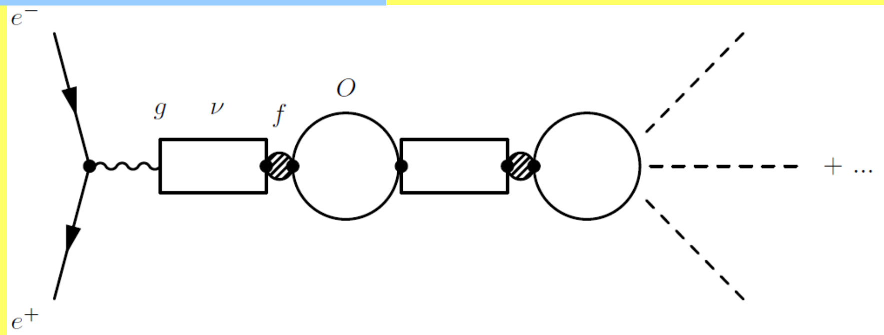


iterated in f

Quarkonium OZI breaking decay

as Freund and Nambu (PRL 34(1975), 1645)

- Quarkonium as a superposition of V and O:

$$A_{strong} = G_e V^{-1} f O^{-1} G_f + G_e V^{-1} f O^{-1} f V^{-1} f O^{-1} G_f + \text{iterations}$$
$$= G_e V^{-1} f O^{-1} G_f /(1 - V^{-1} O^{-1} f^2) = G_e f G_f /(V O - f^2)$$

- $A_{em} = G_e V^{-1} G_l + G_e V^{-1} f O^{-1} f V^{-1} G_l + \text{iterations}$

$$= G_e O G_f /(V O - f^2)$$

- An infinity of radial O recurrences

- This model mainly used to try to explain $Br(\psi') / Br(J/\psi)$ anomalies
  S. J. Brodsky, G. P. Lepage, S. F. Tuan, PRL 59, 621(1987)
  W.S. Hou, C.Y. Ko, NTUTH-97-11, 1997

Narrow V and wide glueball O superposition

P.J.Franzini, F.J.Gilman, PR D32, 237 (1985)

$$A_{strong} = \frac{\sqrt{\Gamma_{ee}} M_V M_O f \sqrt{\Gamma_O}}{(M_V^2 - W^2 - iM_V\Gamma_V)(M_O^2 - W^2 - iM_O\Gamma_O) - M_V M_O f^2}$$

assuming $\Gamma_O >> \Gamma_{J/\psi}$, $f^2 \sim \Gamma_O (\Gamma_{J/\psi} - \Gamma_V)$

$$A_{strong} \sim \frac{i\sqrt{B_{ee}}\ M_V f\ \sqrt{B_h}}{M_{J/\Psi}^2 - W^2 - iM_{J/\Psi}\Gamma_{J/\Psi}} \qquad A_{em} = \frac{\sqrt{B_{ee}}\ M_V \Gamma_{J/\Psi}\ \sqrt{B_{em}}}{M_{J/\Psi}^2 - W^2 - iM_{J/\Psi}\Gamma_{J/\Psi}}$$

- **The additional 90º phase is naturally achieved**
- J/ψ shape reproduced if: $|f| \sim$ 0.012 GeV , $M_O \sim M_{J/\psi}$, $\Gamma_O \sim$ 0.5 GeV
- nly far from the J/ψ (no contradiction with BES, PR 54(1996)1221)
- ψ ''(3770) decay phases agree with Nambu suggestion.
- **ψ ' unclear; ψ ' -> J/ψ ππ (?)**

SND $\Phi \to \pi^+ \pi^- \pi^0$

SND measured $\Phi \rightarrow \pi^+\pi^-\pi^0$.

ϕ interferes with ω and ω' tails:

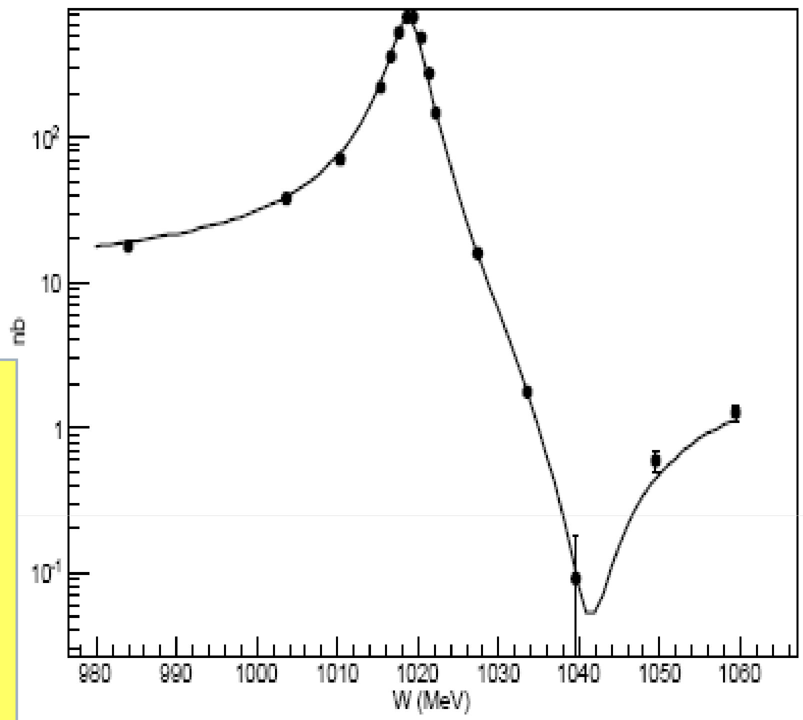
$\varphi \sim 180$ (interference dip is after the Φ)

Fit SND Φ and continuum data with

f = - 0.016 GeV (close to J/Ψ !)

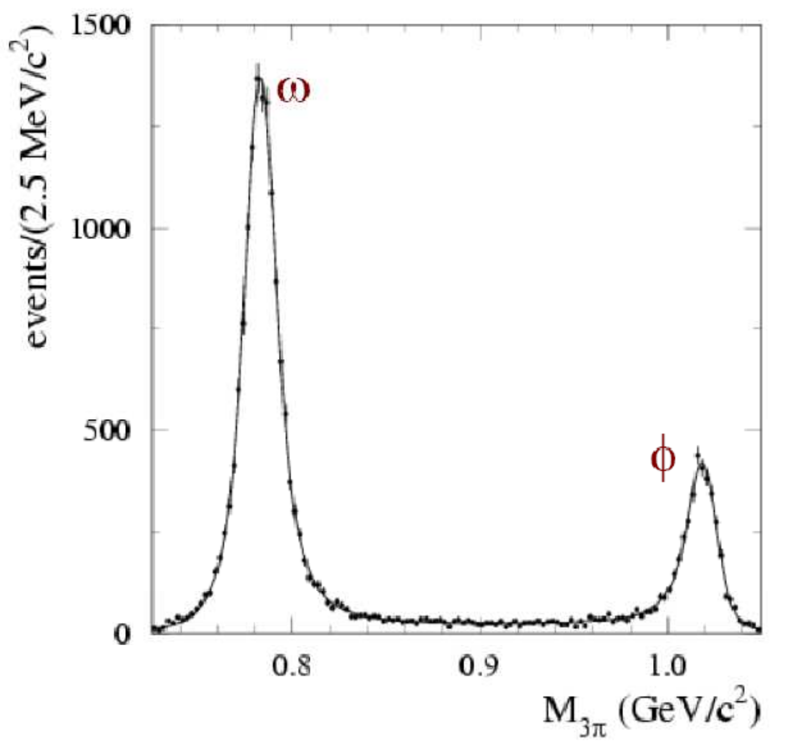
M_O = 1.34 GeV

$\Gamma_O \sim$ 0.5 GeV

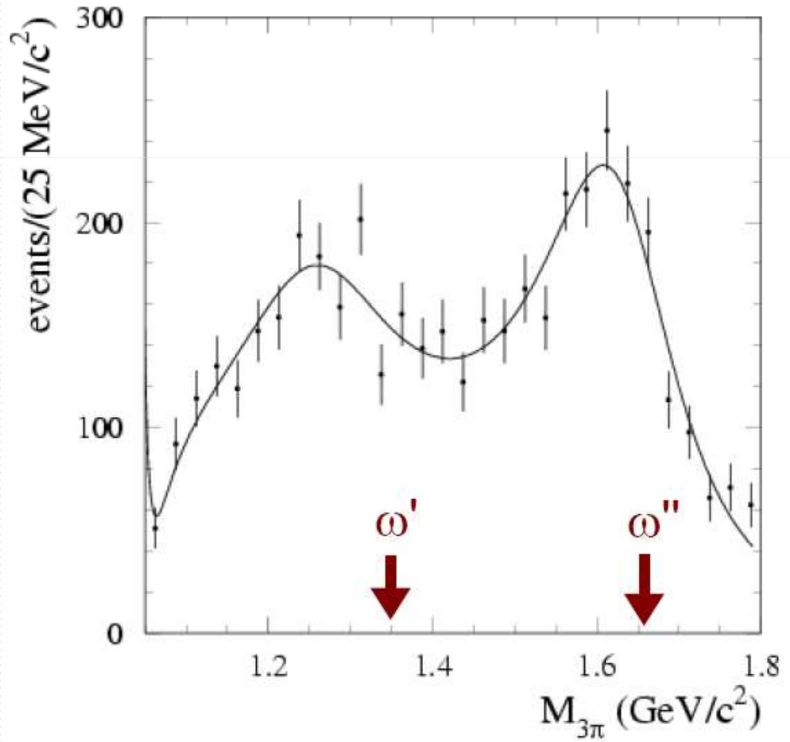


SND data on 3π and present model prediction

BaBar $\pi^+ \pi^- \pi^0$ PR D 70,072004(2004)



BaBar found indeed an unexpected resonance (O ?) at 1.35 GeV , wide 0.45 GeV



Masses and widths

$$M_{\omega'} = (1350 \pm 20 \pm 20)\ \mathrm{MeV}/c^2$$
$$\Gamma_{\omega'} = (450 \pm 70 \pm 70)\ \mathrm{MeV}/c^2$$
$$M_{\omega''} = (1660 \pm 10 \pm 2)\ \mathrm{MeV}/c^2$$
$$\Gamma_{\omega''} = (230 \pm 30 \pm 20)\ \mathrm{MeV}/c^2$$

A proposal for PANDA:
a J/Ψ scan

A Proposal for PANDA

- Expected σ (p p_{bar} -> J/Ψ –> hadrons) ~ 1 μb

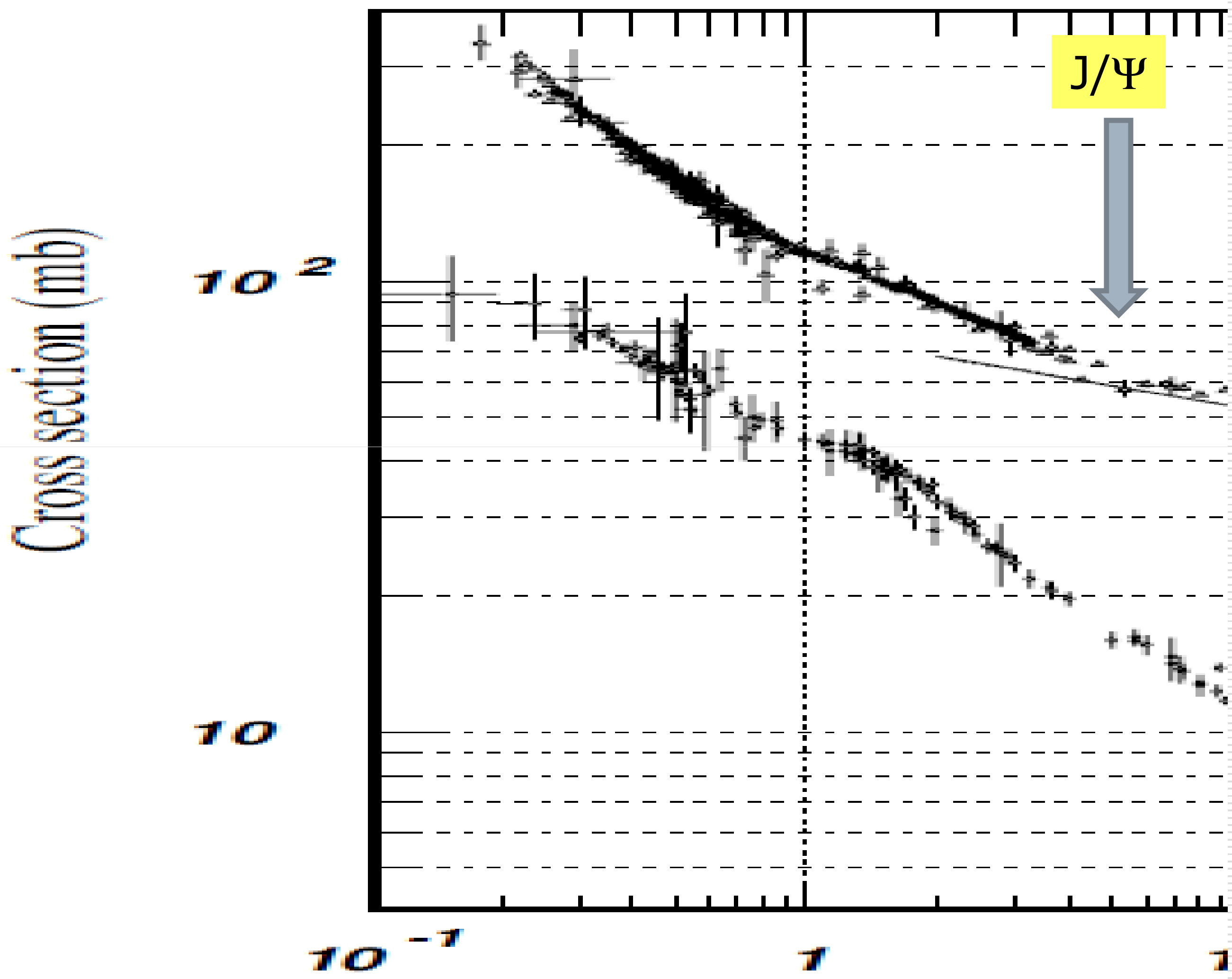
  while σ (p p_{bar} -> hadrons) ~ 70 mb

- No J/ Ψ exclusive production evidence in present data

  (too small cross section + p p_{bar} c.m. energy spread)

- Different mechanism in inclusive or exclusive production:
  - Inclusive production: direct coupling to gluons or virtual photon
  - Exclusive production: hadronic -> apply FN model

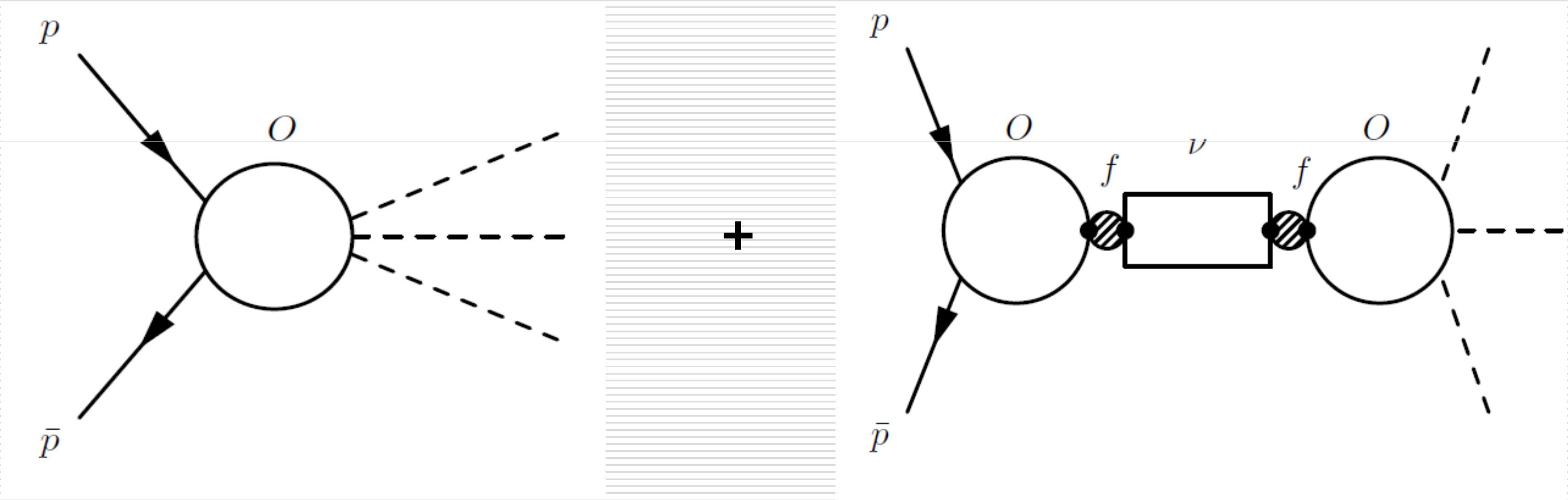
p p_{bar} Total and Elastic cross section (PDG2012)



P_{lab}

A Proposal for PANDA

Contributions to p p_{bar} -> J/Ψ -> hadrons, according to the FN model



A Proposal for PANDA

- $A = G_P\, O^{-1}\, G_h + G_p\, O^{-1}\, f\, V^{-1}\, f\, O^{-1}\, G_h$ + iterations

  $A = G_p\, O^{-1}\, G_h \,/\, (1 - V^{-1}\, O^{-1}\, f^2)$

  $A = G_P\, G_h\;\; V \,/\, (V\, O - f^2)$

- Still assuming
  - $\Delta W \sim \Gamma_{J/\Psi}$ -> $(M_O{}^2 - W^2)/M_O << \Gamma_O$
  - $f^2 \sim \Gamma_O\, (\Gamma_{J/\Psi} - \Gamma_V)$
  - Amplitudes $p\, p_{bar}$ -> V , V-> $p\, p_{bar}$ negligeable
  - Interference with background $J^P = 1^-$ to be included yet

A Proposal for PANDA

- According to the FN approach

$$\sigma_{FN} = \frac{B_p \ \left[(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_V)^2)\right] \ B_h}{(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_{J/\Psi})^2}$$

Taking into account that $\Gamma_V << \Gamma_{\vartheta/\Psi}$

$$\sigma_{FN} = \frac{B_p \ (M^2_{J/\Psi} - W^2)^2 \ B_h}{(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_{J/\Psi})^2}$$

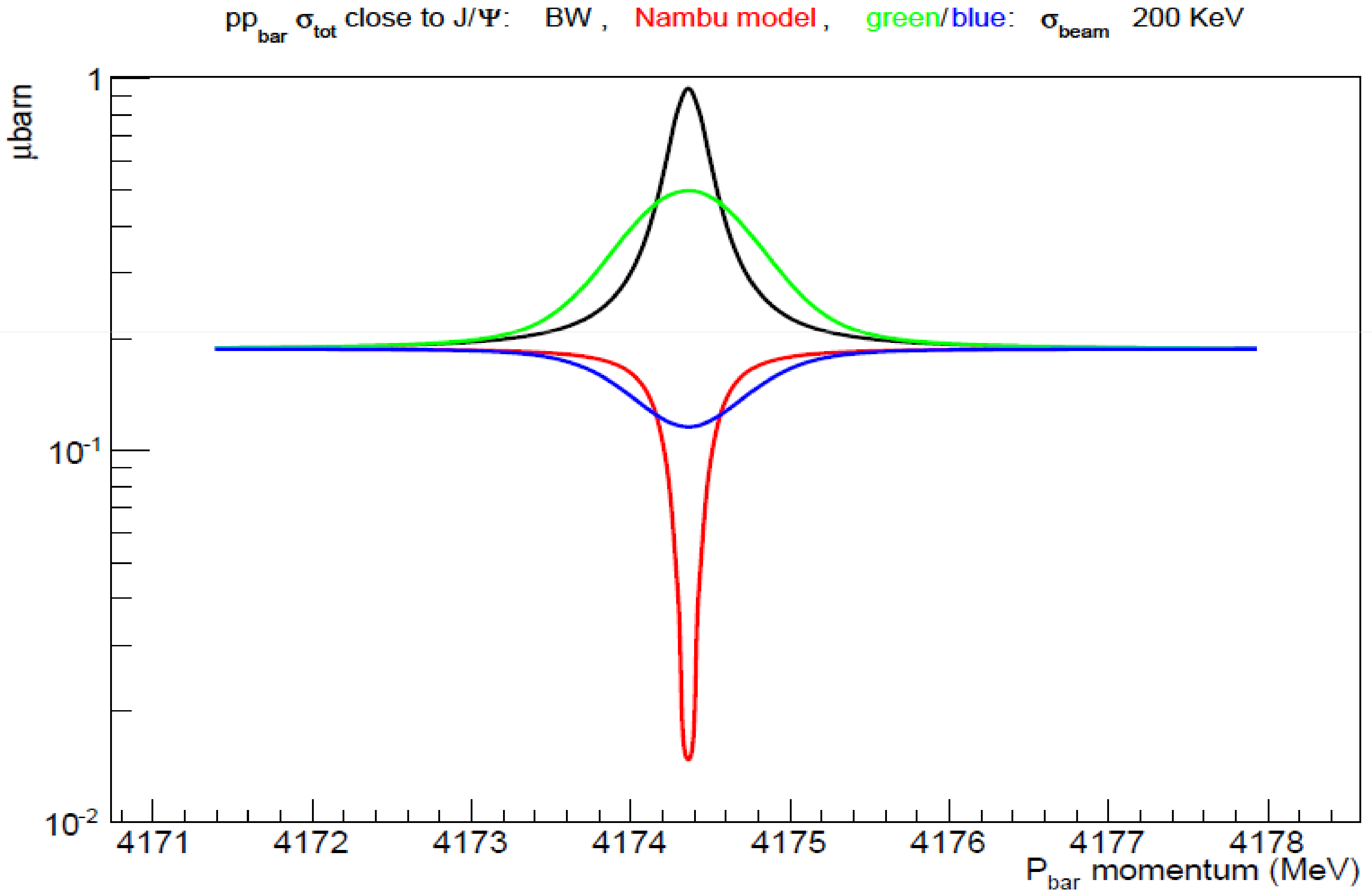
a zero -> a dip in σ_h

- To be compared to a Breit Wigner

$$\sigma_{BW} = \frac{B_p \ \Gamma^2_{J/\Psi} \ B_h \ M^2_{J/\Psi}}{(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_{J/\Psi})^2}$$

A Proposal for PANDA

PANDA inv mass resolution: small beam energy spread and no ISR



A Proposal for PANDA

- Rough $J^P=1^-$ estimation pp_{bar} background σ at P_{pbar} ~ 4 GeV :
- $\sigma\,(J^P=1^-) \sim 0.5\,\sigma\,$(S wave)
- $\sigma_{tot} \sim$ Black Disk $= 2\pi R^2 = 2\pi/P^2\ \Sigma_l\,(2l+1)$
- $l_{max} \sim R\,P \sim 25$
- S wave $\sim 0.5\ \sigma_{tot} / l_{max}^2 \sim 40\ \mu b$ $\quad(\sigma_{J/\Psi} \sim 1.5\ \mu b)$
- Background amplitude R+iI, should be mostly imaginary :
  $I \sim 5 \times A_{J/\Psi}$, $\quad I >> R$

- $J^P=1^-$ background heavily interferences with the J/Ψ

  Some channel might have a much better J/Ψ/background ratio:
  $3\,\pi$, $5\,\pi$,... ?

A Proposal for PANDA

- $J^P=1^-$ background interference with FN :

$$\propto \frac{[(M^2-W^2)^2+\Gamma_{J/\Psi}\Gamma_V M^2]\, I - \left(\Gamma_{J/\Psi}-\Gamma_V\right)M(M^2-W^2)R}{(M^2-W^2)^2+\Gamma_{J/\Psi}M}$$

- The term prop. to I should increase the expected dip, since I>0
- The term prop. to R expected small and affected by beam spread

- $J^P=1^-$ background interference with a BW:

$$\propto \frac{(\Gamma_{J/\Psi}M)^2]\, I + M^2(M^2-W^2)R}{(M^2-W^2)^2+\Gamma_{J/\Psi}M}$$

- The term prop. to I should increase the expected peak
- The term prop. to R has to be evaluated

A Proposal for PANDA

- Rough estimation of the integrated luminosity:
  - Signal ~ 0.2÷0.4 μb , depending on σ_{beam} ~ 200÷100 KeV
  - Background ~ 5 $\cdot 10^4$ μb
  - L ~ 10^{31} cm^{-2} sec^{-1}

- S ~ n · √B , after T -> 0.2 · T · L ~ n √ (5 $\cdot 10^4$ · T · L)

  T ~ few months, if n ~ 4, assuming a 10 points scan

  (efficiency and dead time to be included)

- Much less time might be needed for some channels: 3 π , 5 π , ..

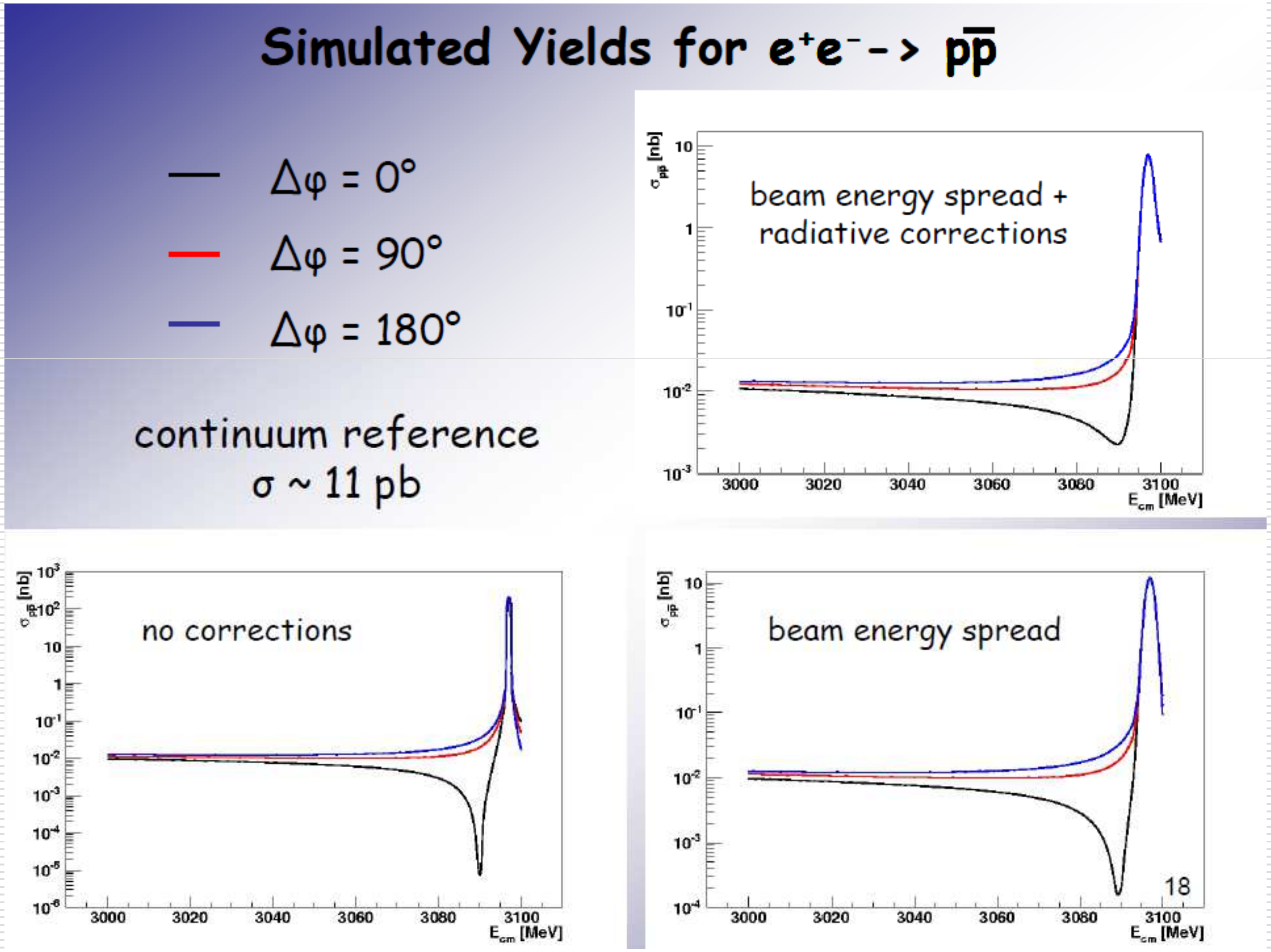
- Of course time is available for any other measurement at J/Ψ

A Proposal for PANDA

Marco Destefanis already proposed to look for $J/\Psi \to \mu\mu$ in PANDA , exploiting the very good inv mass resolution (no ISR)

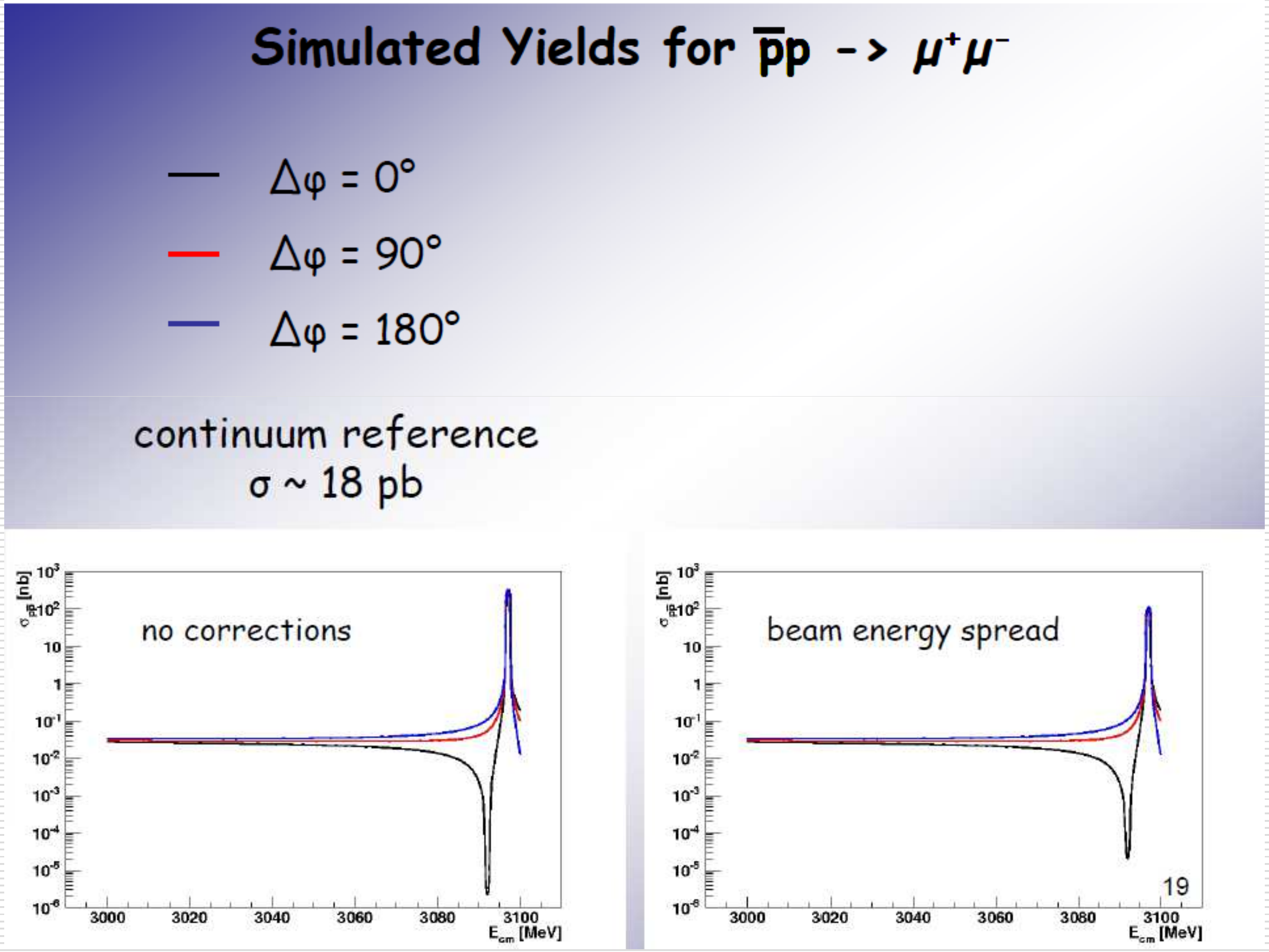
J/Ψ invariant mass resolution in e+e--> p p_{bar} in BESIII

(Marco Destefanis at STORI11)



J/Ψ invariant mass resolution in p p_{bar}-> μμ in PANDA

(Marco Destefanis at STORI11)



Conclusions

- Unexpected imaginary J/Ψ strong decay widths ($\Phi \sim |90^0|$)
- Updated VP and PP J/Ψ decays data point out this result
- J/Ψ scan by BESIII seems to confirm that $\Phi \sim |90^0|$
- Ψ(2S) present data contradictory-> Ψ(2S) scan by BESIII
- Ψ''(3770) present data suggest $\Phi \sim -90^0$
- A model under development to explain this unexpected phase

Conclusions

- A proposal for PANDA:
  - $p\ p_{bar}$ -> J/Ψ -> hadrons   seen as a dip
  - $p\ p_{bar}$ -> J/Ψ -> $\mu\mu$, ee   seen as a peak

  (exploiting PANDA very good inv. mass resolution)

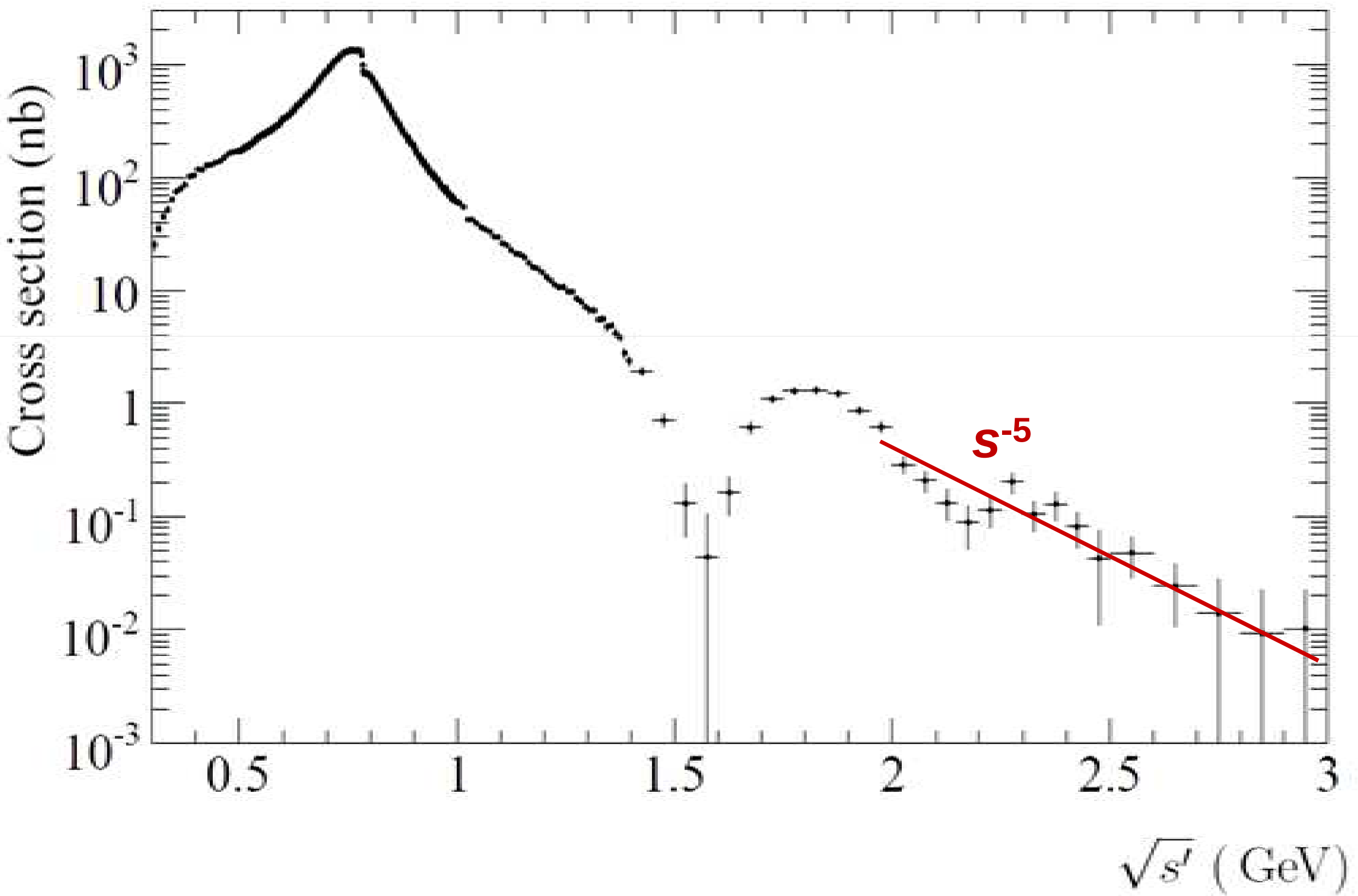
- However a better evaluation of the interference with the $J^P=1^-$ background is needed

Thanks for
your attention

(谢谢)

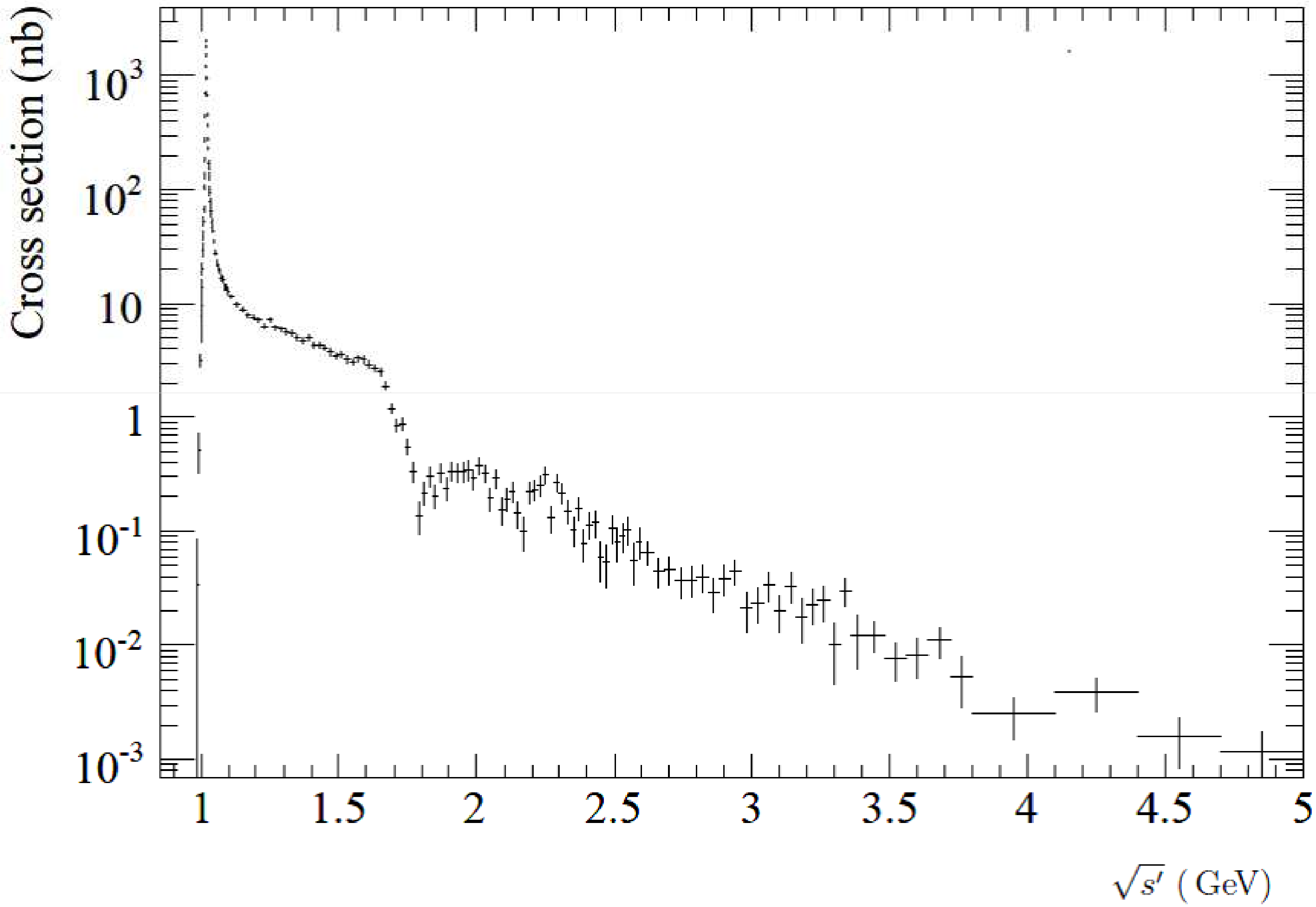
BaBar: $e^+e^- \to \pi^+ \pi^-$ cross section

arXiv:1205.2228v1

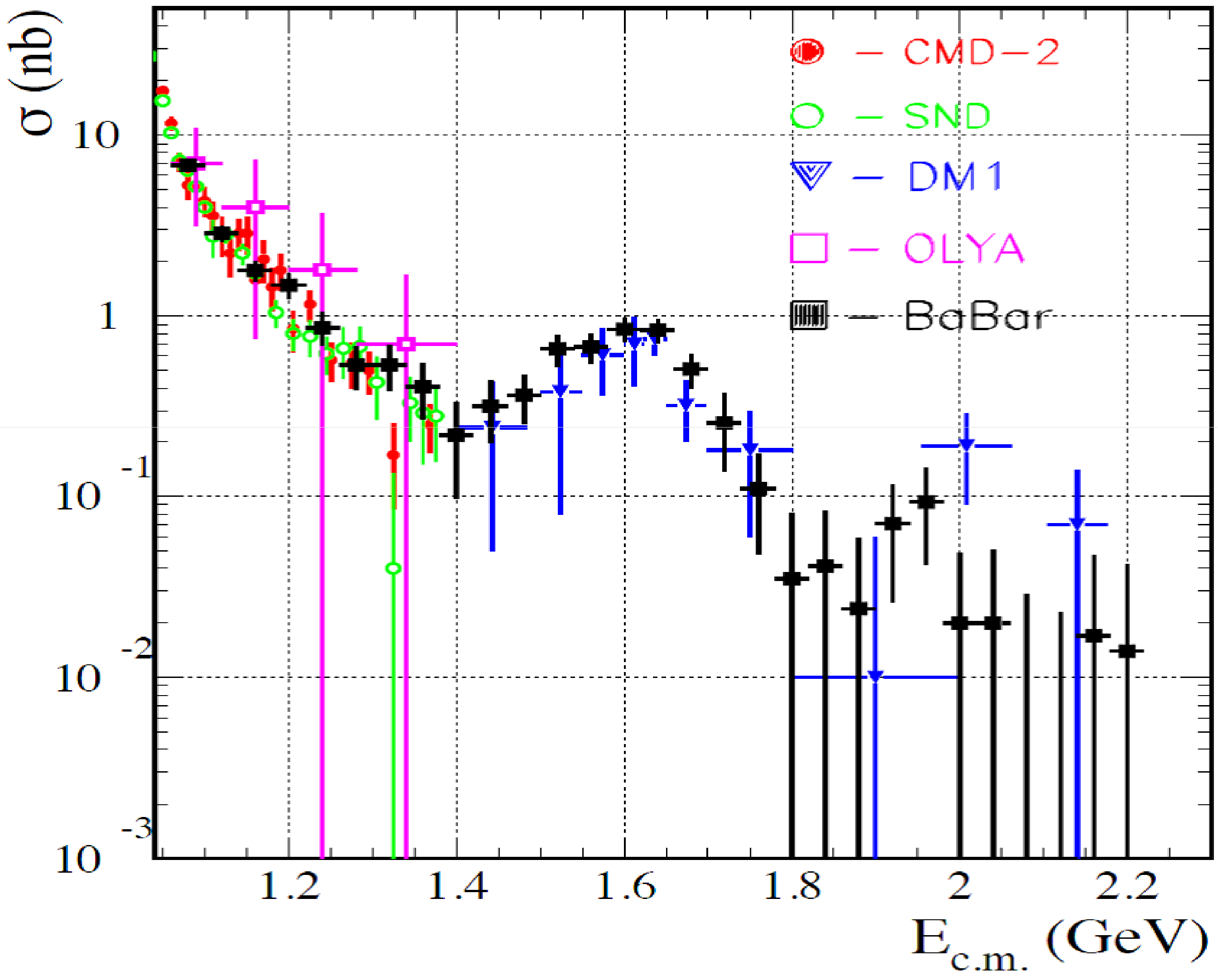


$e^+ e^- \rightarrow K^+ K^-$

arXiv:1306.3600v1



$e^+ e^- \rightarrow$ KS KL



Summary of fit results

Channel	$M_{J/\psi}$	Γ (KeV)	φ'
$\mu+\mu-$	3097.33±0.01	92.9 (fixed)	0° (fixed)
$\pi+\pi-\pi+\pi-$	3097.46±0.03	92.9 (fixed)	(–2.14±27.59)°
$\pi+\pi-\pi+\pi-\pi0$	3097.50±0.04	92.9 (fixed)	0° (fixed)
$\pi+\pi-\pi0$	3097.50±0.06	92.9 (fixed)	0° (fixed)
pp	0.3+3096.9	—	—
Channel	**Φ**	**Br_{out}**	**Br_{PDG}**
$\mu+\mu-$	—	5.94×10^{-2} (fixed)	5.94×10^{-2}
$\pi+\pi-\pi+\pi-$	—	$(3.04\pm0.17)\times10^{-3}$	$(3.55\pm0.23)\times10^{-3}$
$\pi+\pi-\pi+\pi-\pi0$	(102.6±5.1)°	$(3.55\pm0.13)\times10^{-2}$	$(4.1\pm0.5)\times10^{-2}$
$\pi+\pi-\pi0$	(108.4±10.1)°	$(1.87\pm0.08)\times10^{-2}$	$(2.07\pm0.12)\times10^{-2}$
pp	(84.73±9.62)°	$(1.90\pm0.05)\times10^{-3}$	—

Channel	σ_{cont} (nb)	S_E (MeV)	
$\mu+\mu-$	—	0.92±0.01	
$\pi+\pi-\pi+\pi-$	0.465±0.014	0.92 (fixed)	
$\pi+\pi-\pi+\pi-\pi0$	0.153±0.013	0.92 (fixed)	
$\pi+\pi-\pi0$	0.040±0.010	0.92 (fixed)	
pp	0.006±0.001	0.92±0.01	