Initial State Radiation Physics at BaBar

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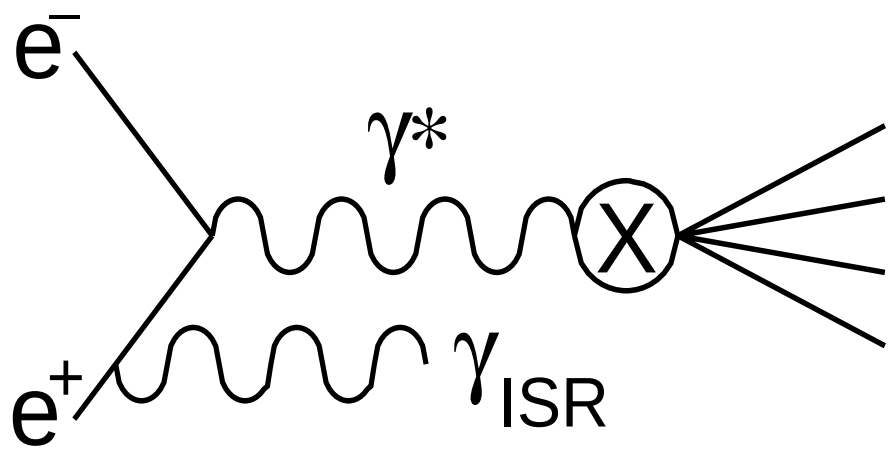
For the BaBar Collaboration

- **ISR, g_μ–2, $\alpha(M_Z)$, and BaBar**
- **Baryon Form Factors** — $e^+e^- \to p\bar{p}$, $\Lambda^0\bar{\Lambda}^0$, $\Lambda^0\bar{\Sigma}^0$, $\Sigma^0\bar{\Sigma}^0$
- **Pionic Final States** — $e^+e^- \to \pi^+\pi^-\pi^0$, $2\pi^+2\pi^-$, $\pi^+\pi^-2\pi^0$, $2\pi^+2\pi^-\pi^0$, $3\pi^+3\pi^-$, $2\pi^+2\pi^-2\pi^0$
- **Final States with Kaons** — $e^+e^- \to K^+K^-\pi^0$, $K^\pm K^0\pi^\pm$, $K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $2K^+2K^-$, $K^+K^-2\pi^+2\pi^-$
- **The Charmonium Region** — $e^+e^- \to J/\psi\pi^+\pi^-$, $J/\psi\gamma\gamma$, $D\bar{D}$, $\psi(2S)\pi^+\pi^-$
- **Inclusive ISR** — $e^+e^- \to$ hadrons for $\sqrt{s} < 6.5$ GeV
- **Summary**

Initial State Radiation (ISR) in e^+e^- Annihilations



- $e^+e^- \rightarrow \gamma_{ISR} e^+e^- \rightarrow \gamma_{ISR}\gamma^* \rightarrow \gamma_{ISR} X$
- X is any allowed (hadronic) system, e.g.
  - → a resonance with $J^{PC}=1^{--}$
  - → 2 particles/resonances with compatible Quantum Numbers
  - → 3, 4, ... particles
  - → 2 (or more) "jets"
- The cross section is: $d\sigma(s,s',\theta_\gamma) / ds'd\cos\theta_\gamma = W(s,s',\theta_\gamma)\cdot\sigma(s')$
- The radiator function W is known to ~1%
- Measure $\sigma(e^+e^- \rightarrow X)$ as a function of $m = m_{\gamma^*} = m_X = E_{CM} = \sqrt{s'}$

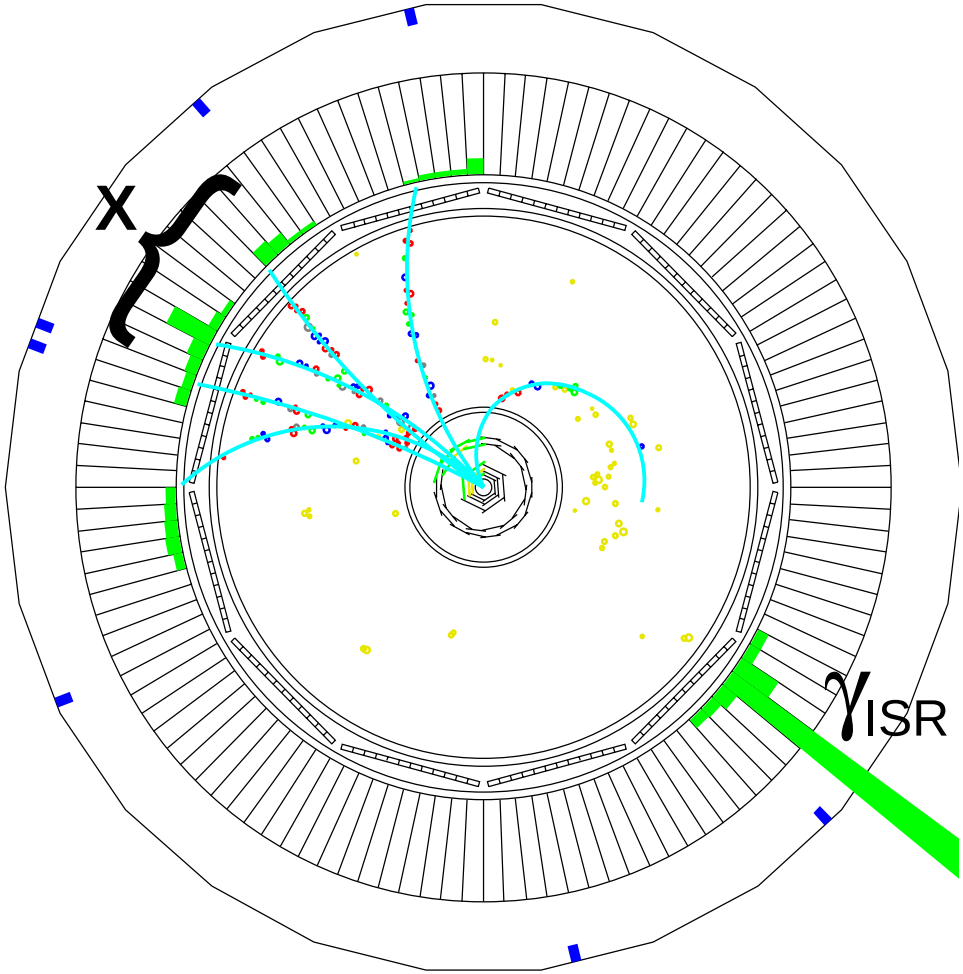
- ISR gives simultaneous access to a continuous, wide s' range in a single experiment

  → Very small point-to-point systematic errors

- If the γ_{ISR} is detected then the hadronic system X is also well contained in the detector

  → Minimal acceptance issues

  → Measure the full angular distributions and other event structure variables



- The hadronic system X is boosted

  → Can measure all the way down to threshold with high efficiency

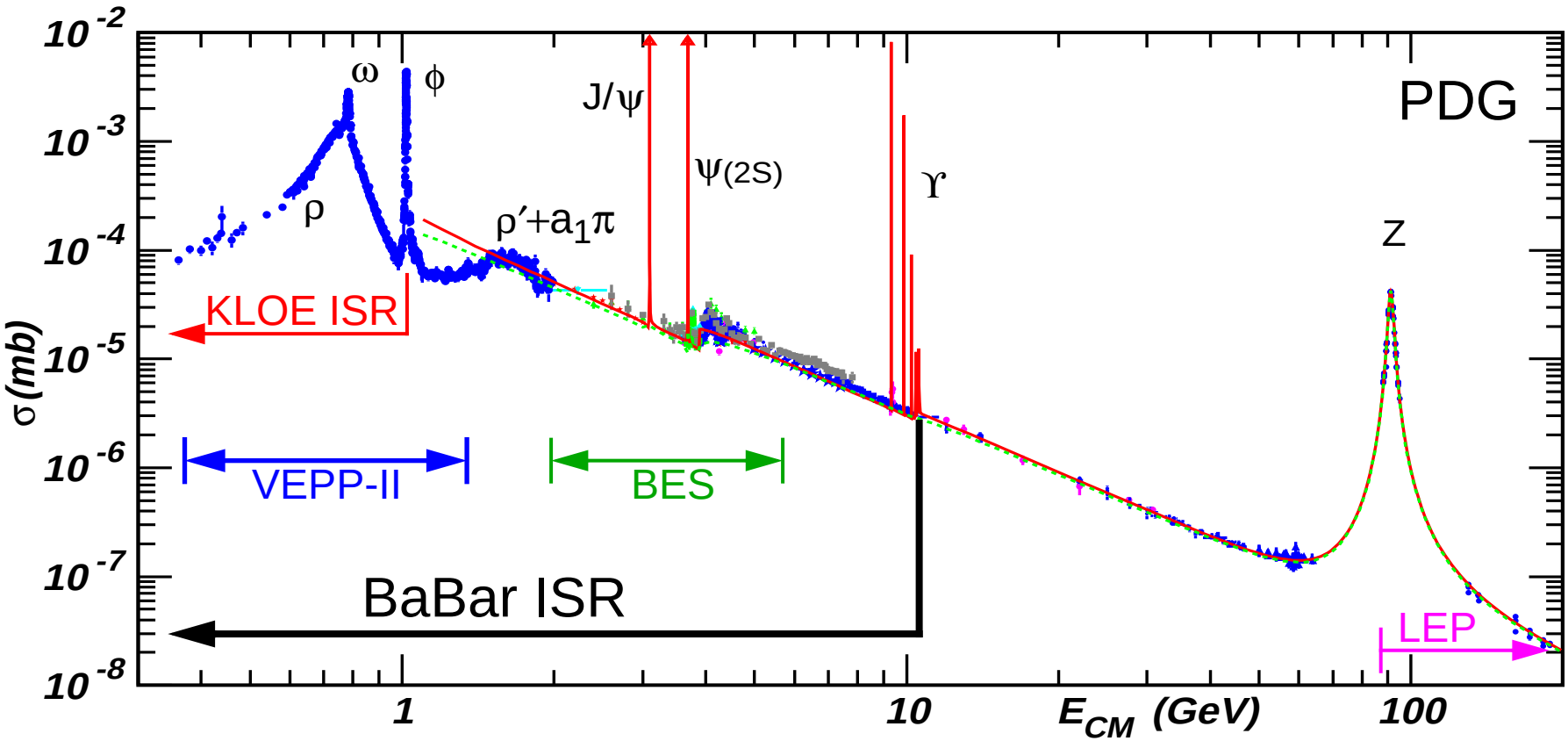
- And also:

  → mass resolution is worse than a typical colloder E_{CM} spread

  → requires very high luminosity at the nominal E_{CM}

The $e^+e^- \rightarrow$ hadrons Cross Section

- Has been measured over a broad range of energies



- Precise measurements from KLOE, VEPP-II, BES, LEP
- Perturbative QCD works at high E_{CM}, $e^+e^- \rightarrow q\bar{q}(g) \rightarrow$ jets
- Lots of interesting structure at very low E_{CM} and ~4 GeV
- Theoretical g_μ–2, $\alpha(M_Z)$ need better input data for E_{CM}<12 GeV

- g_μ–2, $\alpha(M_Z)$ calculations involve many hadronic loop diagrams
  - → these cannot (yet) be calculated from first principles
  - → but can be related through the optical theorem to the total hadronic cross section σ_{had}, ...
  - → and the correction $\Delta_{had}(s) \propto \int K(s)\sigma_{had}(s)ds$ where K(s) is the appropriate kernel

- The g_μ–2 kernel peaks stongly at low s
  $\alpha(M_Z)$ is much broader

Region (GeV)	ρ	$\omega,\phi,\psi,\Upsilon$	1–2	2–5	5–12	>12	Total
Relative error on σ_{had} (%)	0.9	3.1	15	5.9	3.1	0.2	1.3
$\Delta\alpha_{had}$ err($\times 10^5$)	3.1	5.7	23.4	22.5	11.8	2.4	35
Δg_{had} err($\times 10^{10}$)	3.3	1.4	1.9	0.6	0.2	–	3.9

→ g_μ–2 needs precise measurements for $\sqrt{s} < 2$ GeV

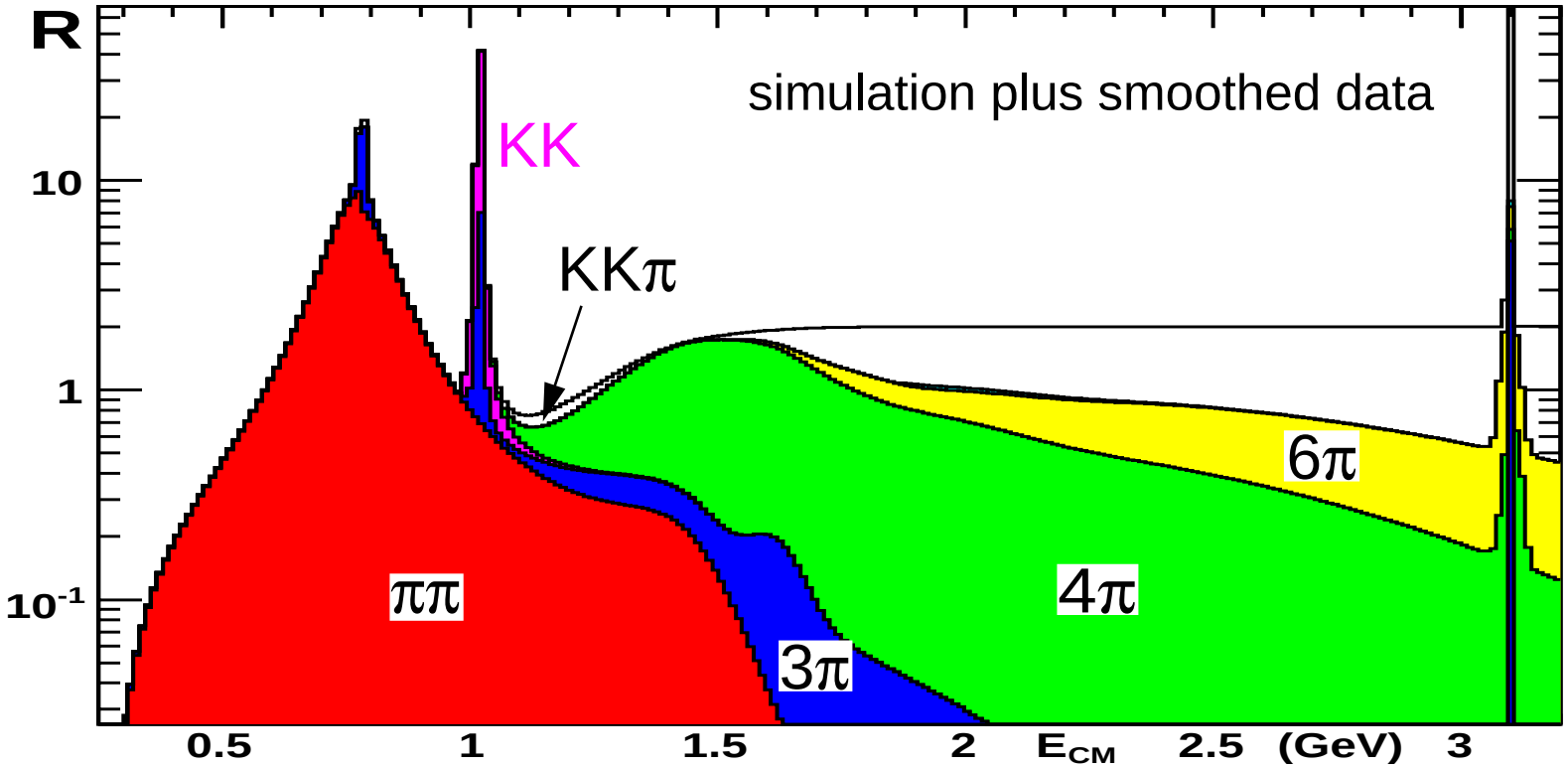
→ $\alpha(M_Z)$ needs (big) improvement in the (1-5)5-12 GeV range

What do we measure?

- Pick a final state X and isolate it
- Measure the cross section $\sigma_X(m)$ and $R_X = \sigma_X(m)/\sigma_{\mu\mu}(m)$
  - $\rightarrow$ R is input to the g_μ–2, $\alpha(m_Z)$ integrals
  - $\rightarrow$ spectroscopy, BFs of (new) 1^{--} states
  - $\rightarrow$ extract form factors if $X = h\bar{h}$, $h_1 h_2$
  - $\rightarrow$ tests of QCD in m-dependence $\leftarrow$ also measure at 10.6 GeV
- Study the resonant substructure
  - $\rightarrow$ σ, FFs for "exclusive" submodes
  - $\rightarrow$ quantum #s through correlations, angular distributions
  - $\rightarrow$ discover new resonances
- More general substructure
  - $\rightarrow$ general features might expose interesting dynamics
  - $\rightarrow$ at what E_{CM} do the events become "jetty"?
  - $\rightarrow$ ....

The ISR program at BaBar

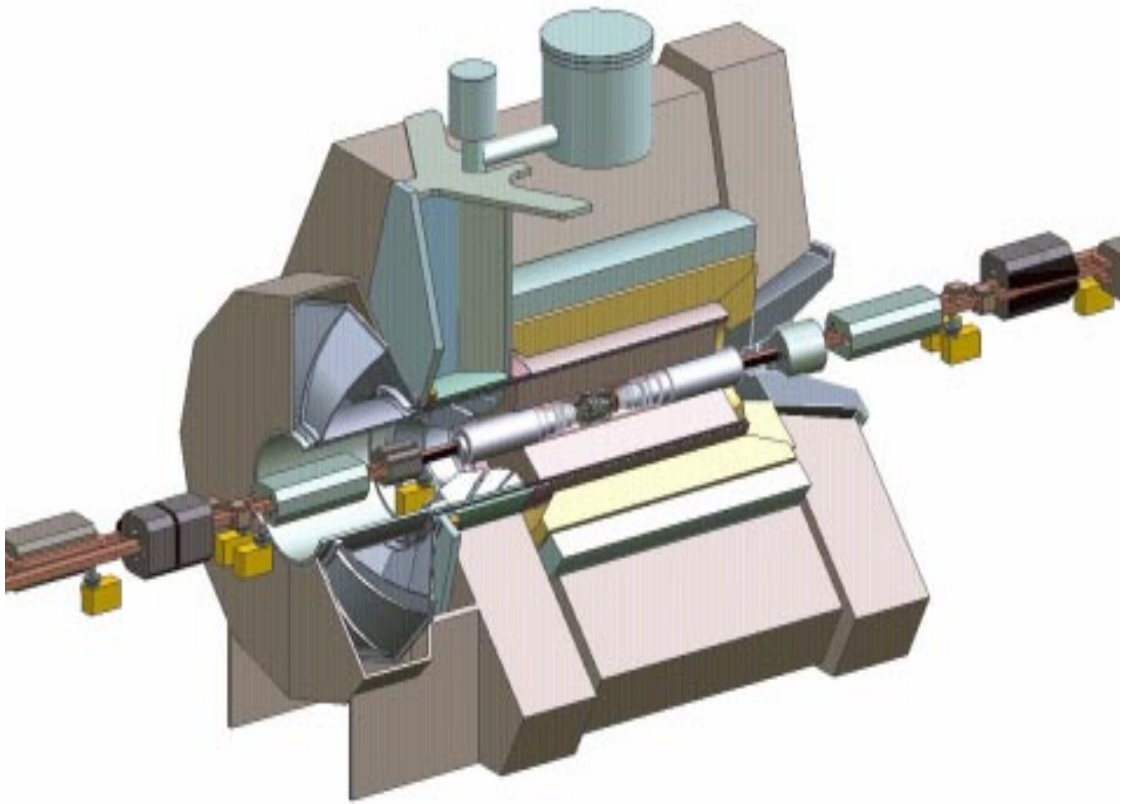
- Measure exclusive final states up to ~4.5 GeV, inclusive to ~7 GeV



- Published: $\mu^+\mu^-$, $p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Lambda\bar{\Sigma}$, $\Sigma\bar{\Sigma}$, $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0/\eta$, $K^+K^0\pi^-$, $4\pi^\pm$, $2K^\pm 2\pi^\pm$, $2K^\pm 2\pi^0$, $4K^\pm$, $4\pi^\pm\pi^0/\eta$, $2K^\pm 2\pi^\pm\pi^0/\eta$, $6\pi^\pm$, $4\pi^\pm 2\pi^0$, $2K^\pm 4\pi^\pm$, $J/\psi\pi^+\pi^-$, $\psi(2S)\pi^+\pi^-$, $D\bar{D}$
- Preliminary: $\pi^+\pi^-\pi^0\pi^0$, $J/\psi\gamma\gamma$
- In progress: $\pi^+\pi^-$, K^+K^-, $p\bar{p}h^+h^-$, $J/\psi h(h')$, $D^*\bar{D}$, inclusive,...

The BaBar Experiment

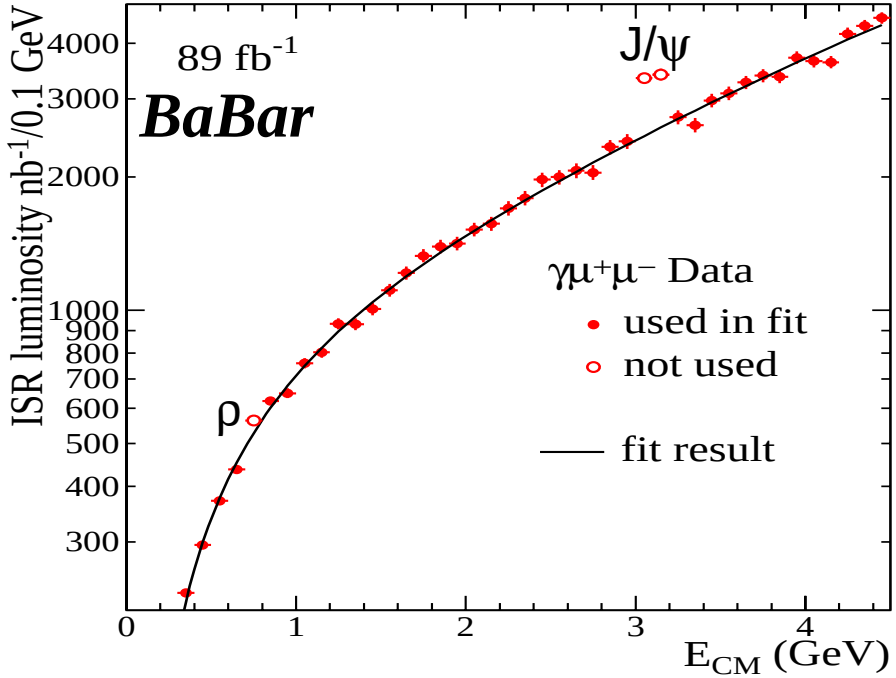
- e^+e^- collider, $\sqrt{s}$~10.6 GeV
- Different beam energies:
  - → E_{e^-} = 9.0 GeV
  - → E_{e^+} = 3.1 GeV
  - → c.m.-lab boost, $\gamma\beta$=0.56
- Asymmetric detector
  - → c.m. frame acceptance
    $-0.9 \sim \cos\theta^* \sim 0.85$
    wrt e^- beam
  - → detects ~15% of ISR γ
  - → contains ~50% of evts with fwd/bwd γ_{ISR}

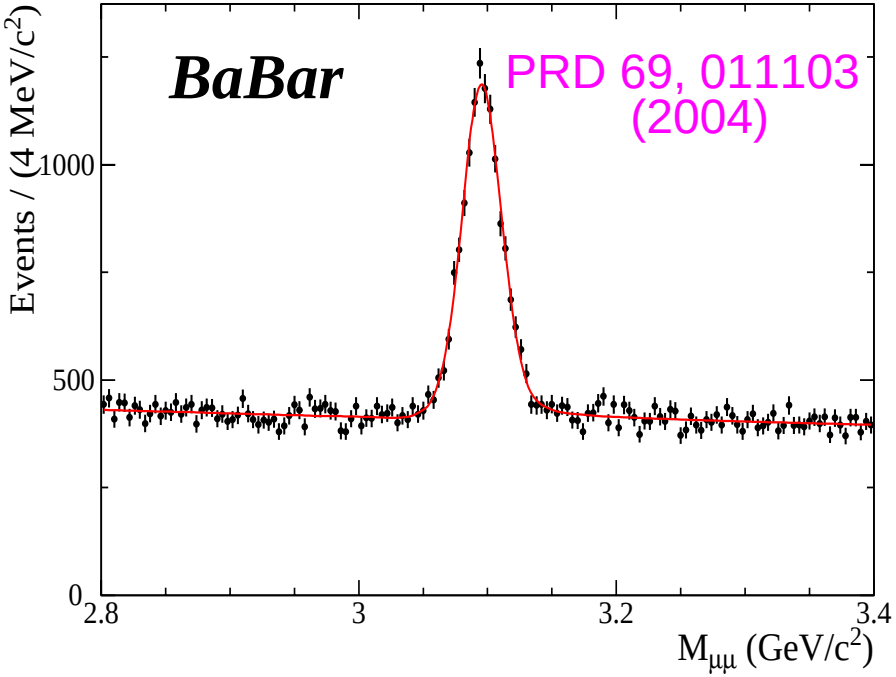


- with excellent performance
  - → Good tracking, mass resolution
  - → Good γ, π^0 recon.
  - → Full e,μ,π,K,p ID
- High luminosity:
  - → ~ 520 fb^{-1} accumulated
    - ↔ 1.7 billion $e^+e^- \to q\bar{q}$ events
    - ↔ 17 million $e^+e^- \to \gamma_{ISR}J/\psi$
    - ↔ 12 million $e^+e^- \to \gamma_{ISR}\rho^0$
  - → 89–384 fb^{-1} used here

The equivalent ISR Luminosity

- Can be calculated from the measured luminosity or derived for our γ_{ISR} acceptance using $e^+e^- \to \gamma_{ISR}\mu^+\mu^-$ events



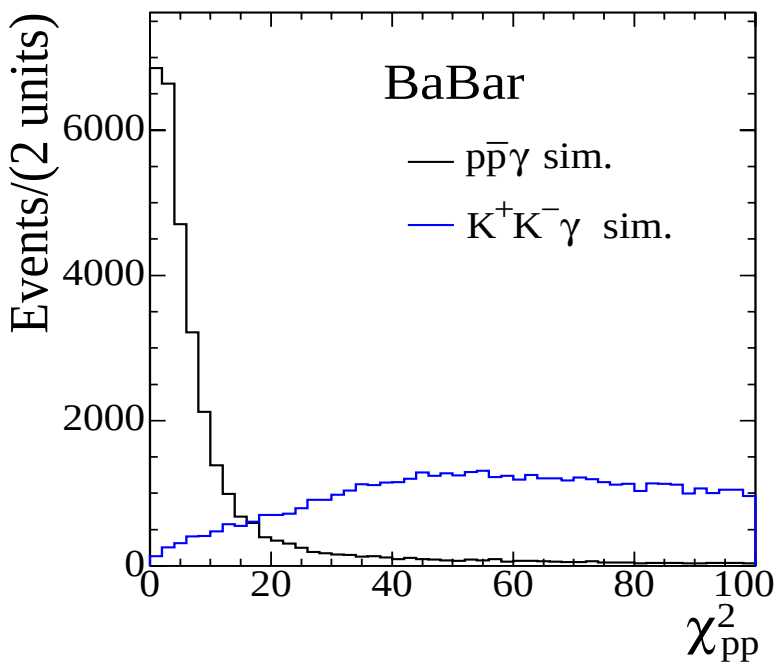


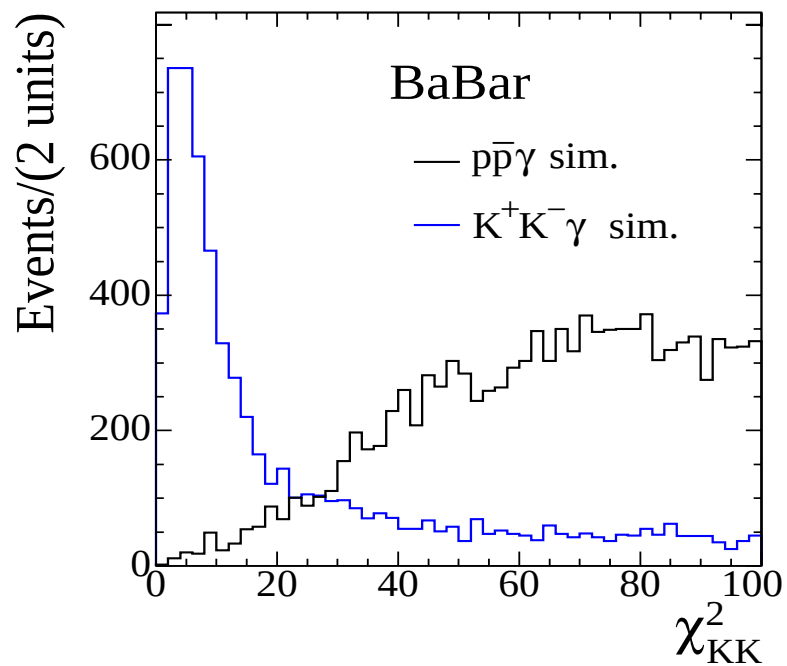
- In each 100 MeV window near
  1 GeV, we have accumulated > 4 pb^{-1}
  3 GeV >14 pb^{-1}

- This mode also gives a nice constraint on the J/ψ width:
  89 fb^{-1}, PDG B_{ee}, $B_{\mu\mu} \to \Gamma_{J/\psi} = 93.7 \pm 3.5$ keV;
  with CLEO 96.1±3.2 keV, dominate world avg.

Baryon Form Factors

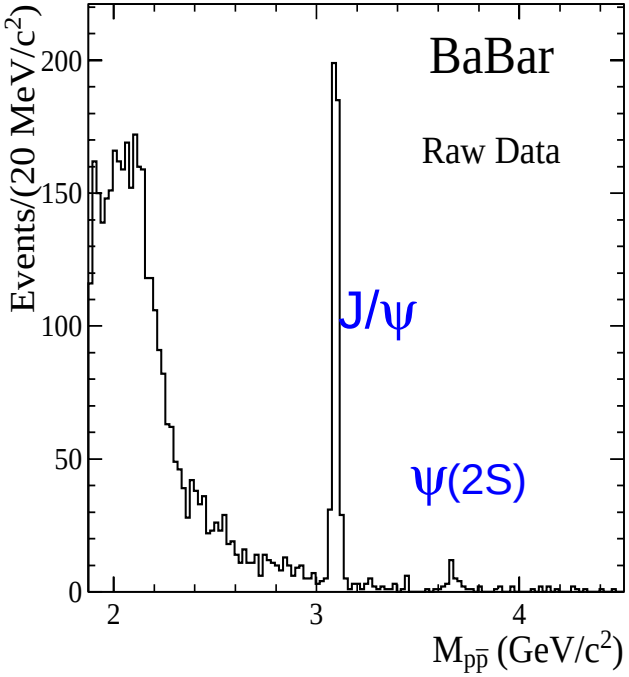
- $e^+e^- \to p\bar{p}$: Event selection: 240 fb^{-1} PRD 73, 012005 (06)
  - → require exactly two tracks, ID'd as p and $\bar{p}$, plus a hard γ
  - → perform kinematic fits to various hypotheses
  - → select events with $\chi^2_{p\bar{p}\gamma}<30$ and $\chi^2_{K^+K^-\gamma}> 30$

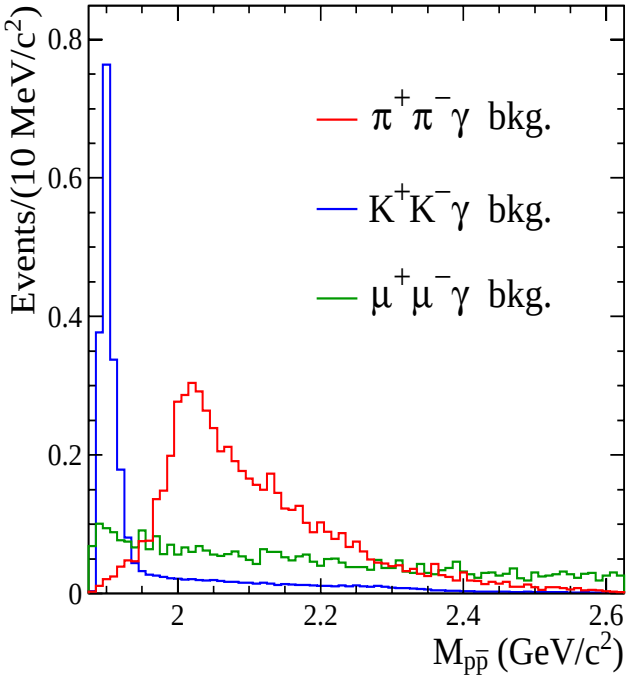


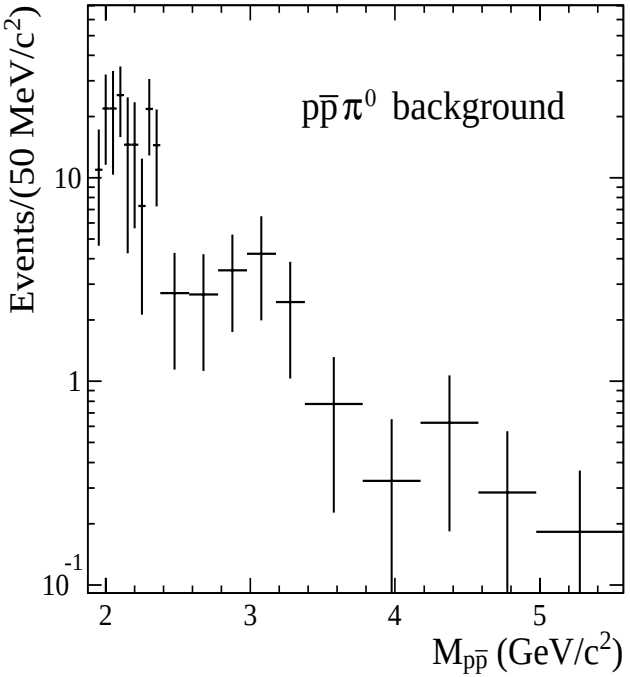


- Backgrounds from ISR $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-
  - → measure $\chi^2_{h^+h^-\gamma}$ distributions for identified $h'^+h'^-$ events in data
  - → mass dependence from measured cross sections
  - → misidentification rates from well-known resonances, ρ, ϕ, J/ψ, ...

- Background from $e^+e^- \to p\bar{p}\pi^0$ at 10.6 GeV
  $\to$ rate measured in the data by combining the γ_{ISR} with other γs
  $\to$ normalize a simulation to the π^0 peak



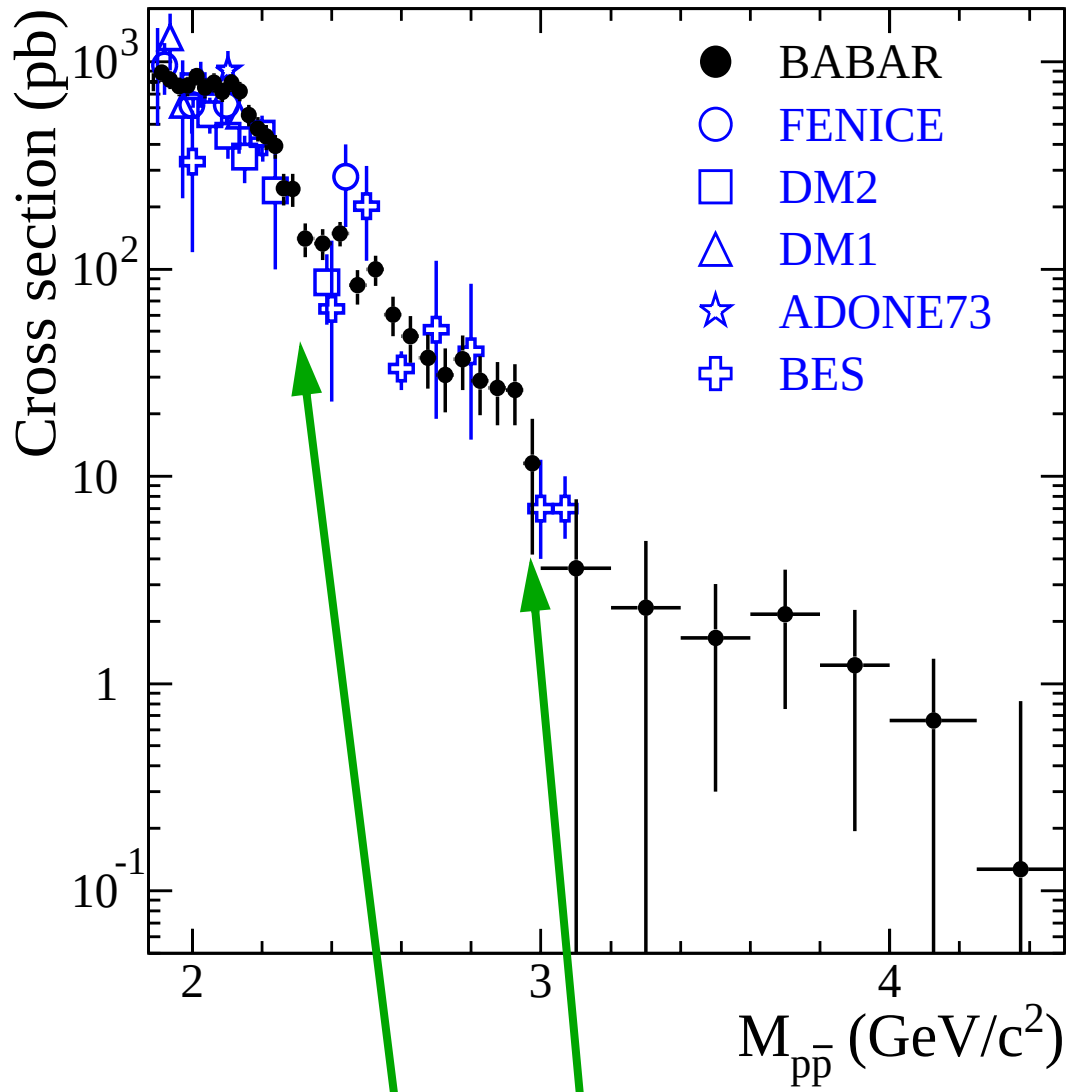




- Background from other ISR processes ($p\bar{p}\pi^0(\pi^0)$, ...)
  $\to$ measured in the data – small
- Check that these backgrounds saturate the high $\chi^2_{p\bar{p}\gamma}$ region
  $\to$ in this channel, they do
  $\to$ if not, derive remaining background from a χ^2 control region
- Subtract backgrounds, correct for efficiency, and...

- calculate the cross section
  - → measured from $p\bar{p}$ threshold to 4.5 GeV in one experiment
  - → Very small point-to-point systematic errors; those shown are essentially statistical
  - → the "normalization" error is not shown; it is:

    5% at threshold; increases smoothly to 10% at 4.5 GeV
  - → we are consistent with all previous results
  - → our measurements make it much easier to see structure
  - → ...for example the rather sharp steps at 2.25, 3 GeV

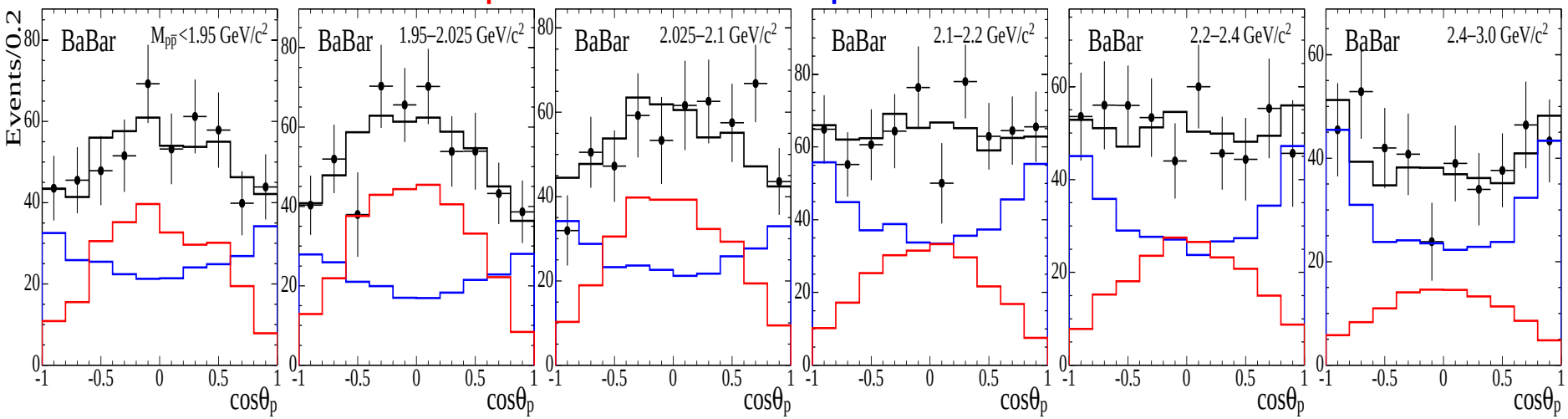


- can describe in terms of electric and magnetic form factors

$$\sigma(s) \propto H_M(\theta_p,s)|G_M(s)|^2 + 2m_p^2 H_E(\theta_p,s)|G_E(s)|^2/s$$

→ full acceptance allows allows good production angle msmt.

→ fit using $H_E \approx \sin^2\theta_p$, $H_M \approx 1+\cos^2\theta_p$ from simulation



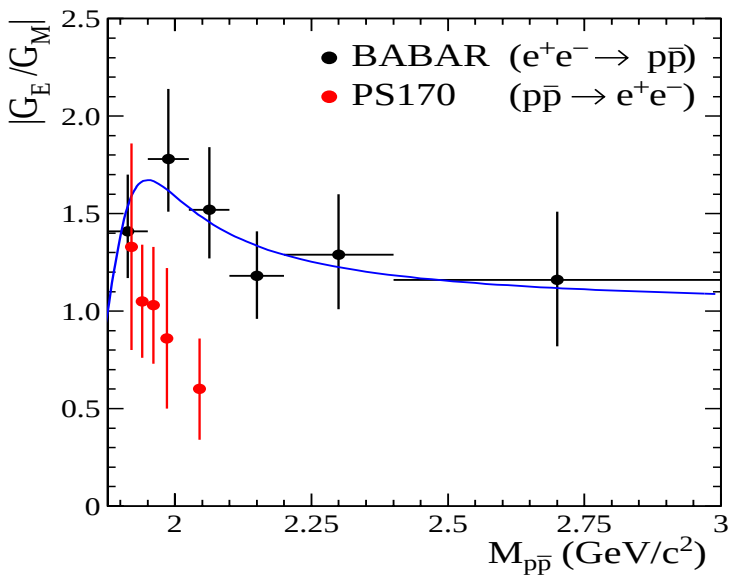
→ we find $G_E > G_M$ at low E_{CM}

→ becoming consistent at high E_{CM}

→ we are ~inconsistent with PS170

→ space-like measurements are <1

→ the blue curve is empirical, it:
=1 at threshold (as it must)
describes our data



- define the effective form factor, F

$$\sigma(s) \propto (1 + 2m_p^2/s)\,|F|^2$$

→ compare with $p\bar{p} \to e^+e^-$

→ consistent with pQCD at high s

→ steep rise near threshold

→ several similar near-threshold features have been seen in

B decays and

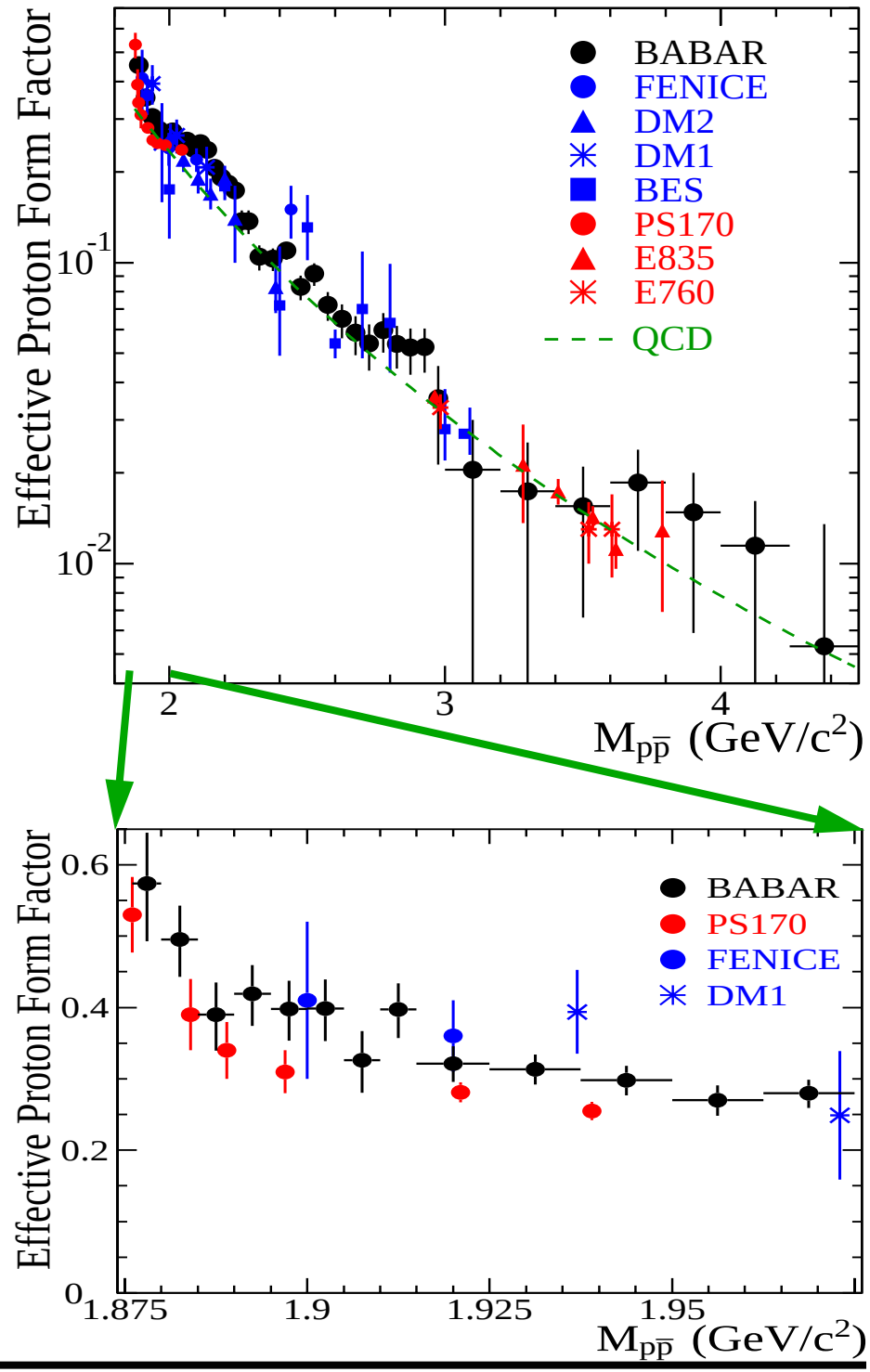
J/ψ decays;

all need to be understood

→ the coulomb correction is not included here

→ ...but can only explain the first two bins

→ ...and indicates a plateau in the form factor from threshold to ~2.18 GeV



- $e^+e^- \to \Lambda^0\overline{\Lambda}^0, \Lambda^0\overline{\Sigma}^0, \Sigma^0\overline{\Sigma}^0$: 230 fb^{-1} To appear in PRD

  → events with $\Lambda^0 \to p\pi^-$ and $\overline{\Lambda}^0 \to \overline{p}\pi^+$ candidates, plus a hard γ

  → p or $\overline{p}$ identified, no track identified as a $K^{\pm}$

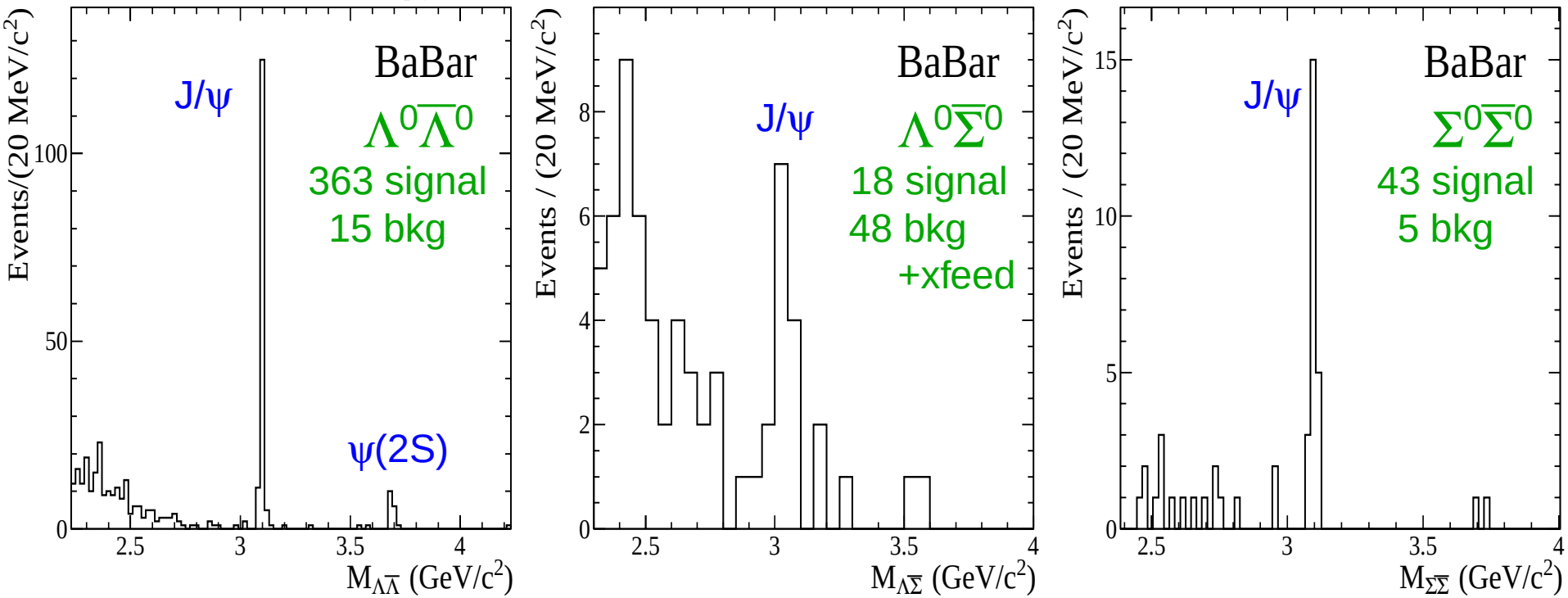
  → both masses 1104–1128 MeV/c^2; sidebands for background

  → add γs to form Σ^0, $\overline{\Sigma}^0$ candidates

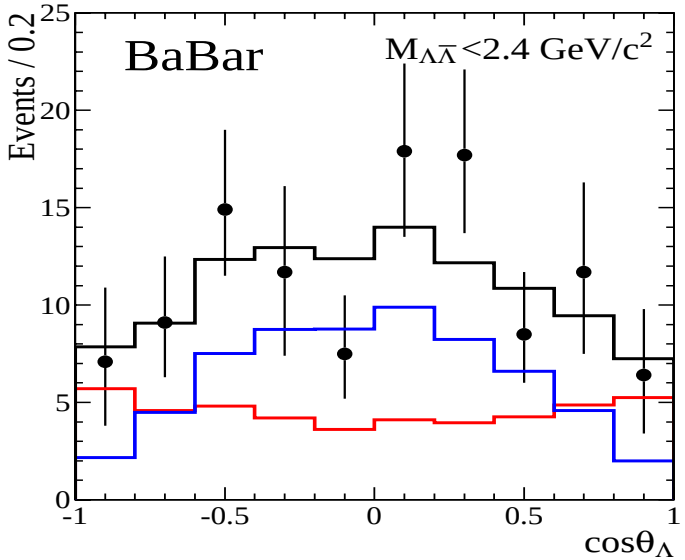
  → kinematic fits including Λ^0, Σ^0 mass constraints

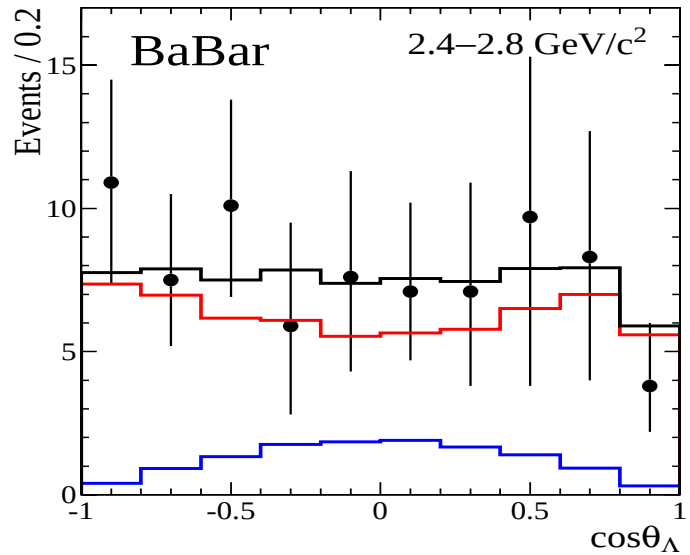
  → distinguish channels based on best χ^2

  → events with $\chi^2<20$



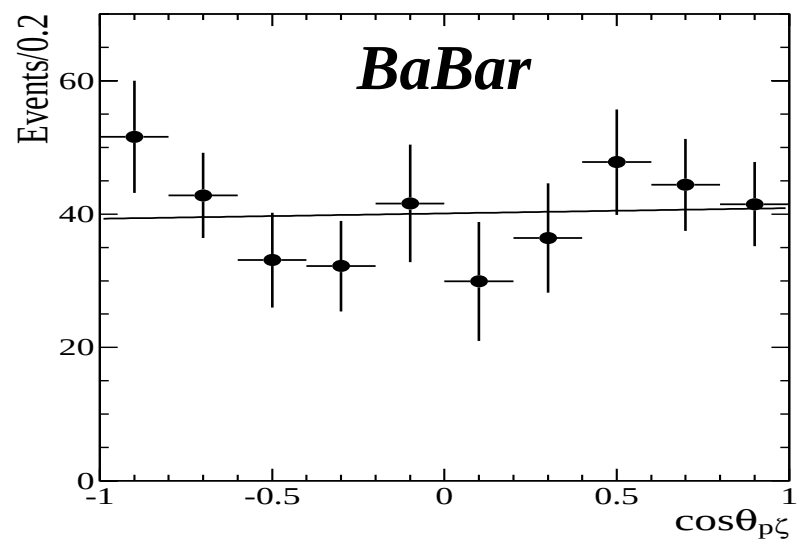
- Production angle for (non-J/ψ) $\Lambda^0\overline{\Lambda}^0$ events



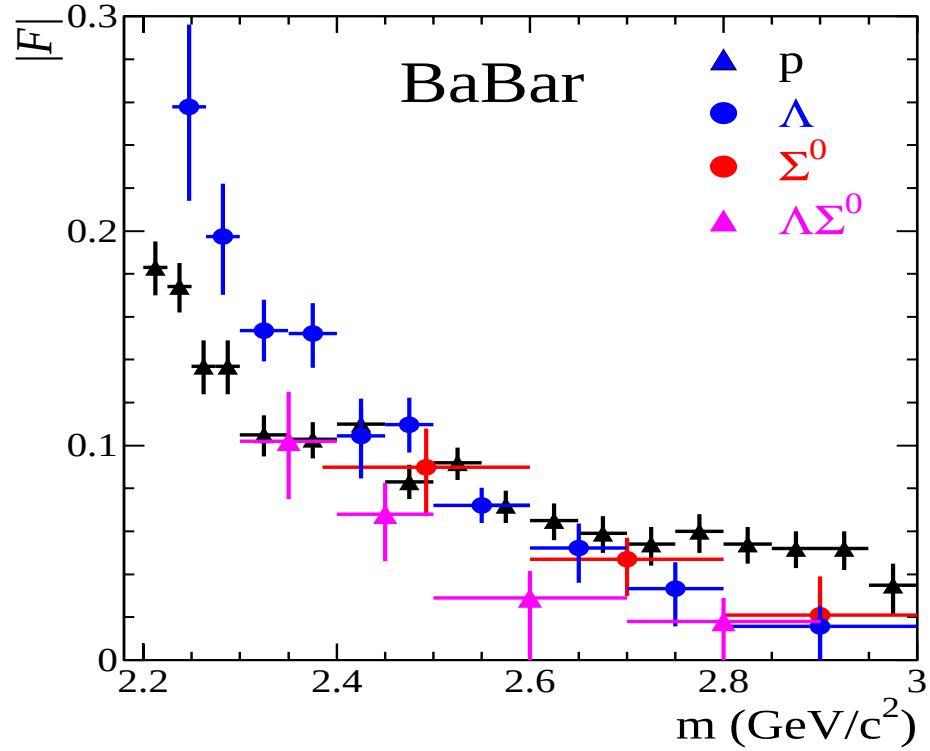


→ $|G_E/G_M| = 1.73^{+0.99}_{-0.57}$; $0.71^{+0.66}_{-0.71}$, consistent with proton results

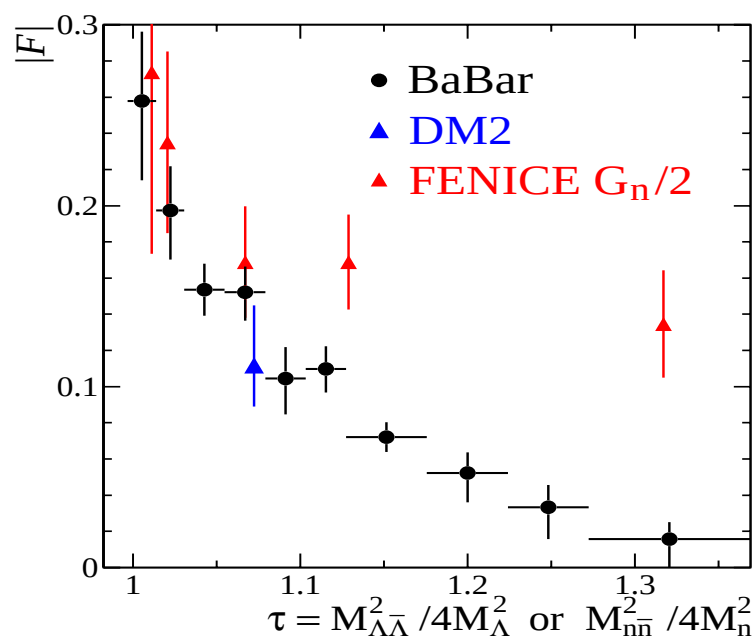
- Λ^0 polarization in non-J/ψ $\Lambda^0\overline{\Lambda}^0$ events
  - → arises for nonzero relative phase between G_E and G_M
  - → normal to production plane
  - → fitted slope 0.020±0.097
  - → $-0.22 < P_\Lambda < 0.28$ @90% CL
  - → $-0.76 < \sin\phi < 0.98$ @90% CL



- Effective Form Factors
  - → all show rising behavior near threshold
  - → values are consistent at all masses, although within rather large errors
  - → need more data to test the "expected" universality at high masses



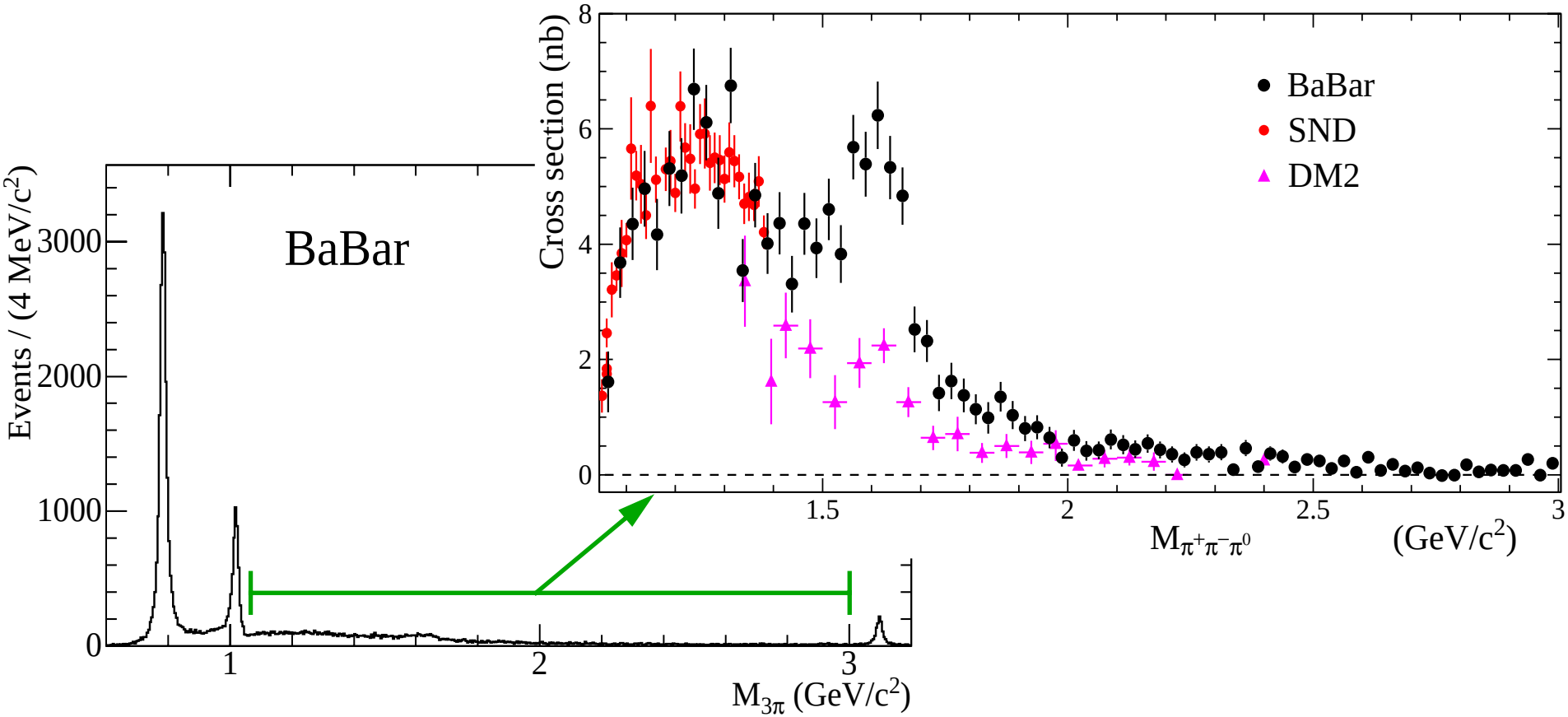
- Comparison of F_Λ with the previous measurement and F_n
  - → only one previous F_Λ point
  - → no other Σ or ΣΛ measurement
  - → neutron and Λ magnetic FFs related by U-spin ,
  - → ...up to mass corrections ...



Pionic Final States

- $e^+e^- \to \pi^+\pi^-\pi^0$

89 fb^{-1} PRD 70, 072004 (04)



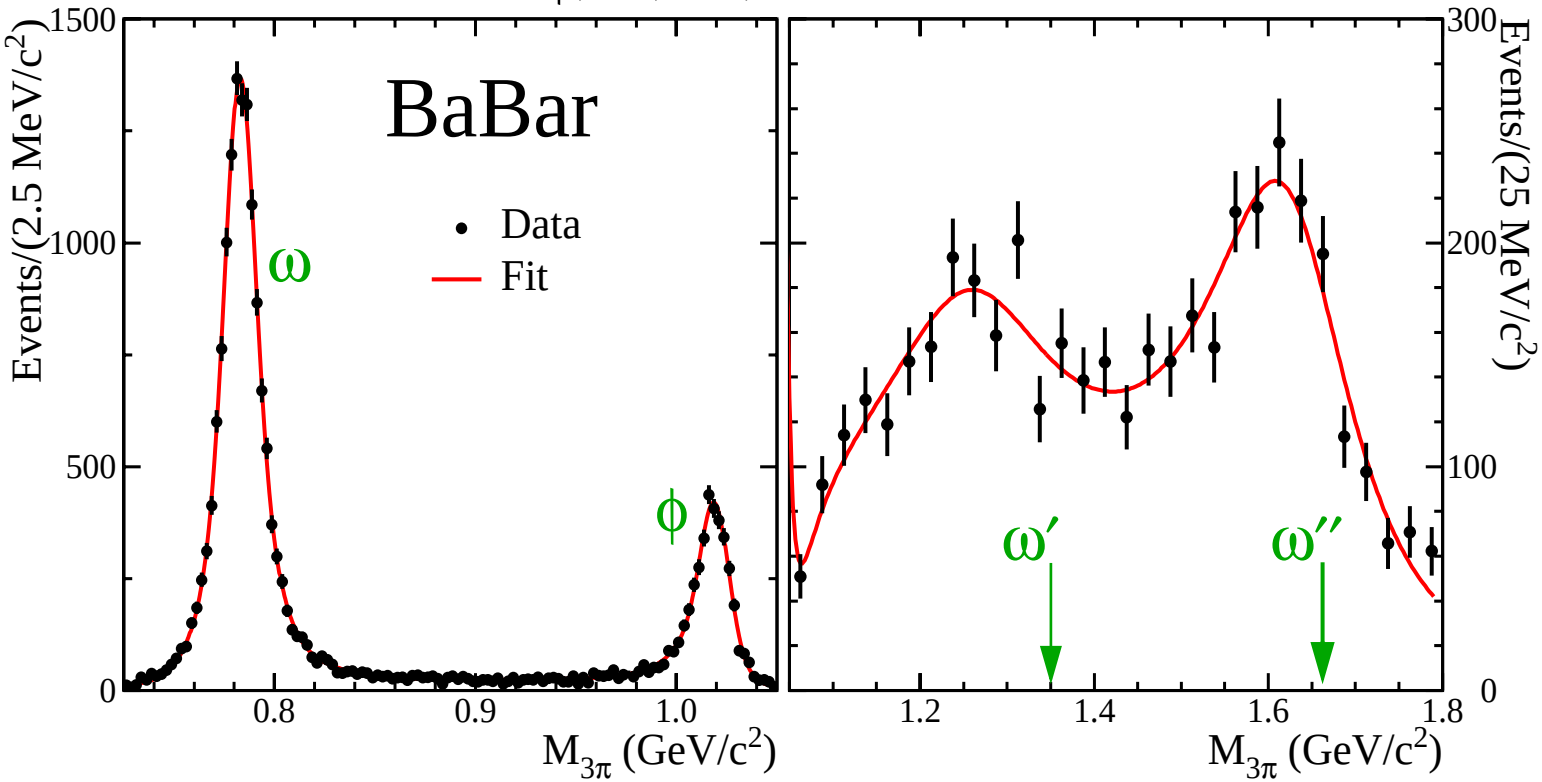
→ dominated by resonances: ω, ϕ, J/ψ, ...plus excited ω?

→ consistent with previous, precise data in ω/ϕ region

→ inconsistent with DM2 data at 1.35–2 GeV

⇒ can interpret in terms of excited ω resonances

- fit to cross section with ϕ, ω, ω', ω'' resonances



→ "best" measurements of ω', ω''

→ ...though relative phases must be assumed

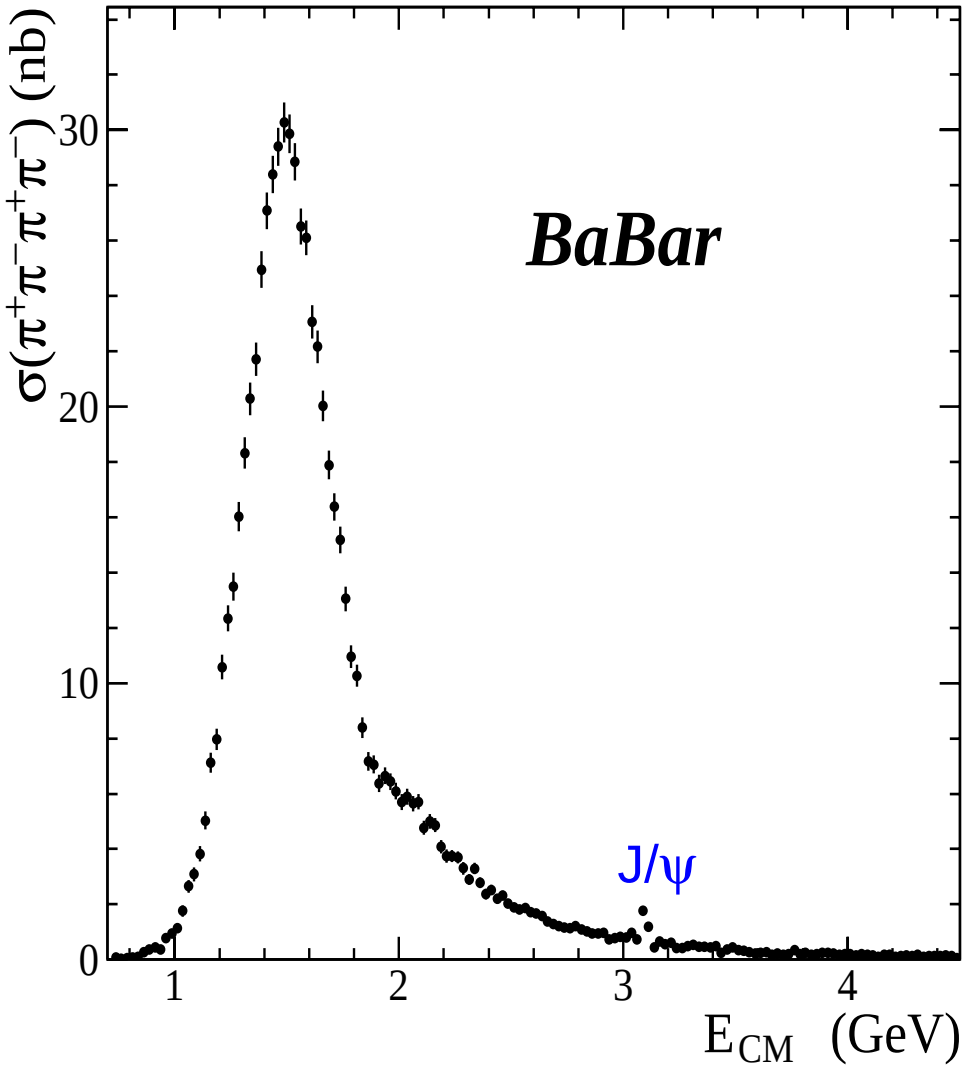
	Mass (MeV/c^2)	Γ (MeV)	$B_{ee}\times B_{3\pi}$ ($\times 10^{-6}$)	$\phi-\phi_\omega$
ω	782	8.7	67.0 ±2.8	–
ϕ	1019	4.3	43.0 ±2.2	163°
ω'	1350±28	450±98	0.82±0.08	180°
ω''	1660±10	230±36	1.30±0.14	0°

fixed to world average values

fitted

fixed to assumed values

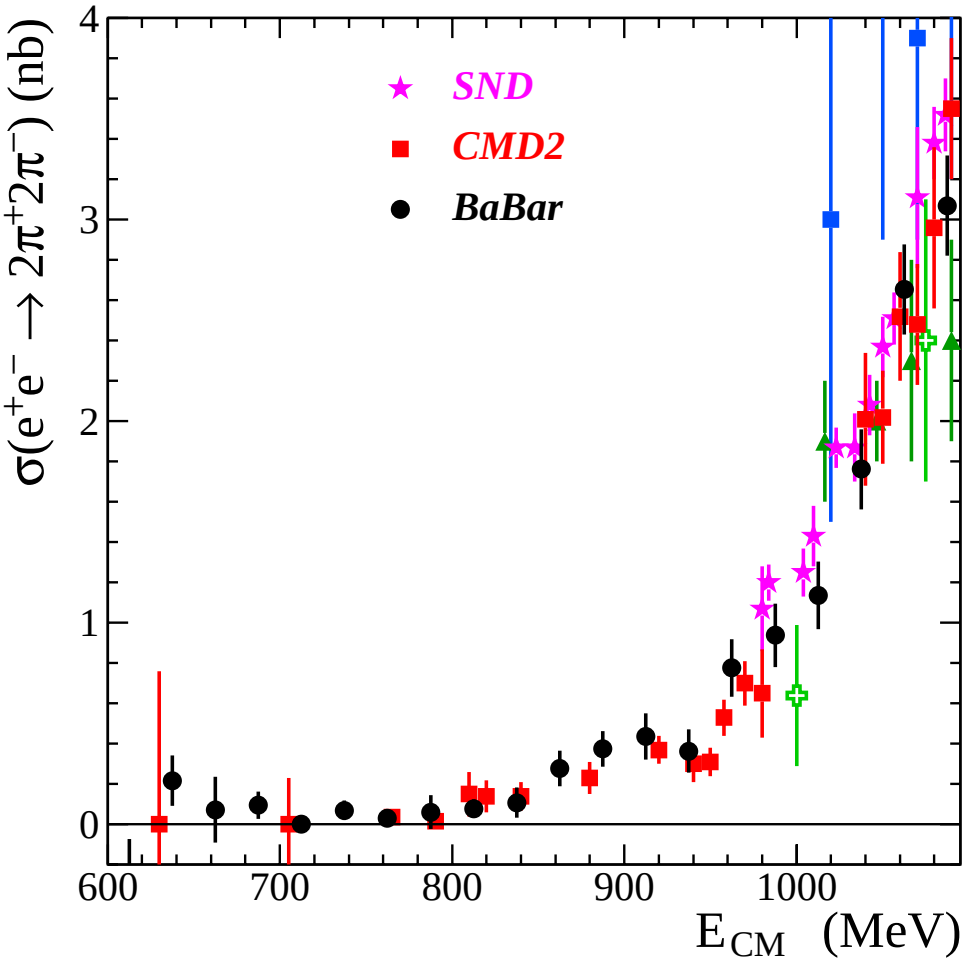
- $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ 89 fb^{-1} PRD 71, 052001 (05)
- Cross section
  - → from threshold to 4.5 GeV in one experiment
  - → the large-scale structure measured precisely
  - → only narrow structure is J/ψ
  - → this represents ~half the total hadronic σ at 1.5 GeV
  - → 5% overall systematic over most of range improves the error on g_μ–2
- Substructure
  - → main peak mostly $a_1(1260)\pi$
  - → $f_0(1370)\rho^0$ seen, could give the structure around 2 GeV



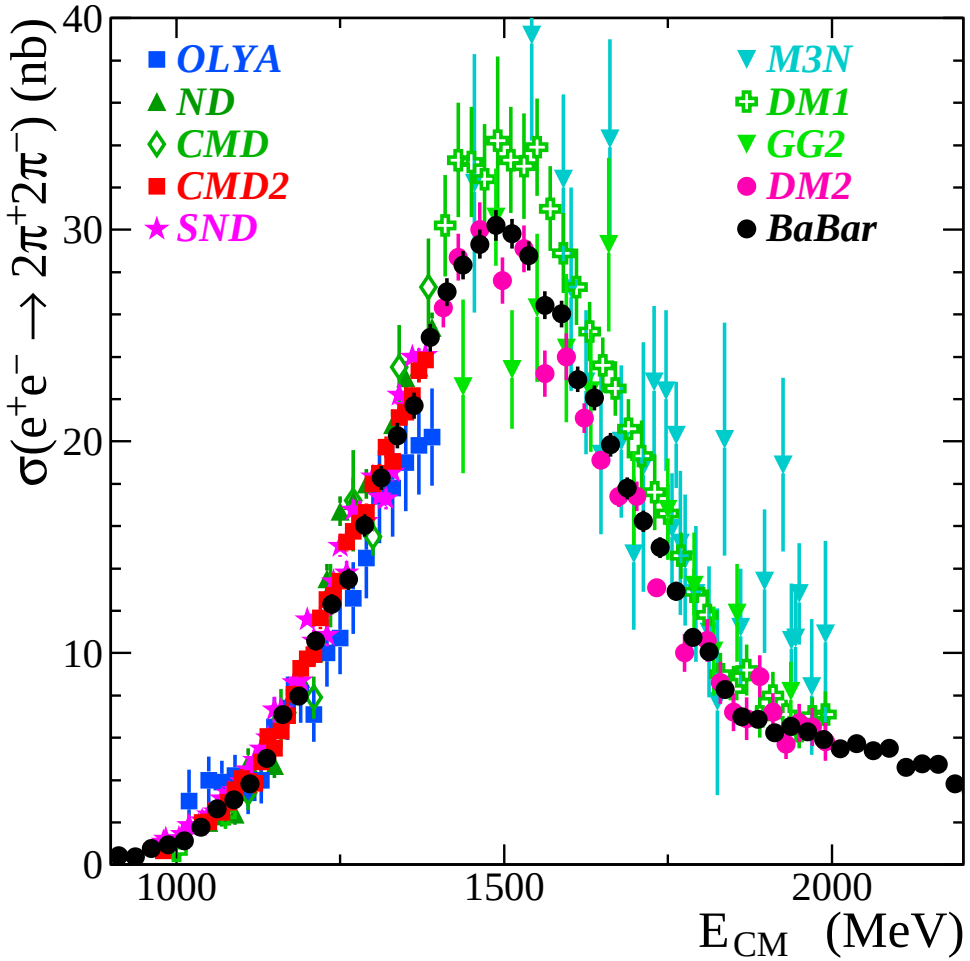
⇒ with more data, can study substructure in E_{CM} bins

- Comparison with previous results:

near threshold



main peak



→ consistent with all previous results

→ the best measurement for $E_{CM} < 0.75$ GeV; 12% relative systematic error

→ competitive for 0.75–1.4 GeV

→ best for 1.4–2 GeV

→ first and only measurement for $E_{CM} > 2$ GeV

- $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$

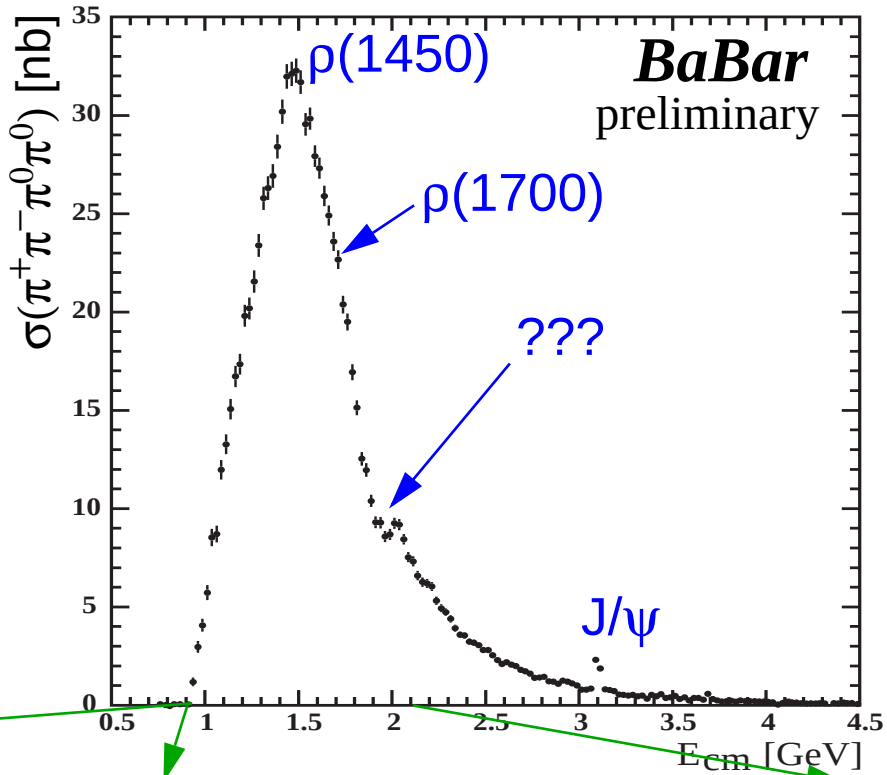
239 fb^{-1} Preliminary

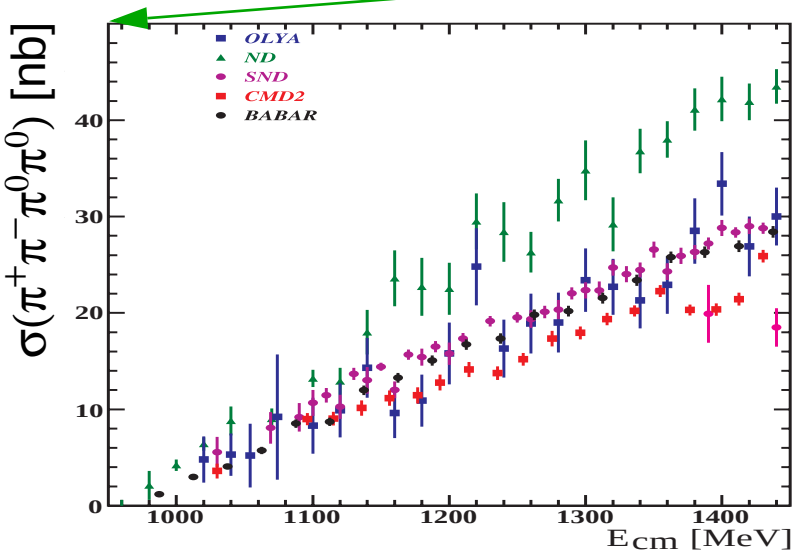
→ cross section consistent with previous results

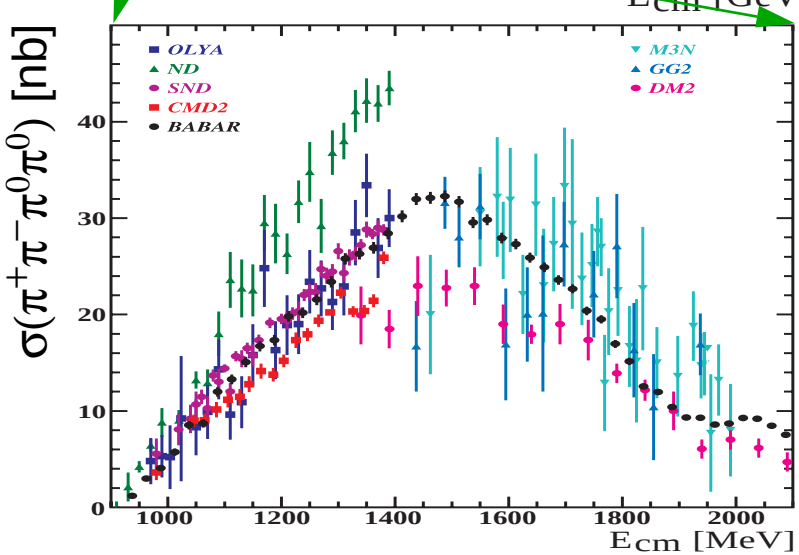
→ competitive / best / first measurement for E_{CM} < 1.4 / <2.4 / >2.4 GeV

→ at peak, σ~half the total σ_{had}

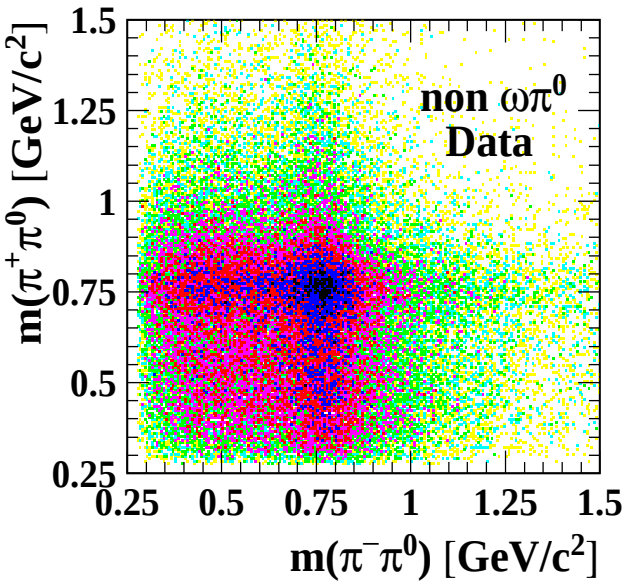
→ 8% (eventually ~5%) error over peak region helps with the error on g_μ–2

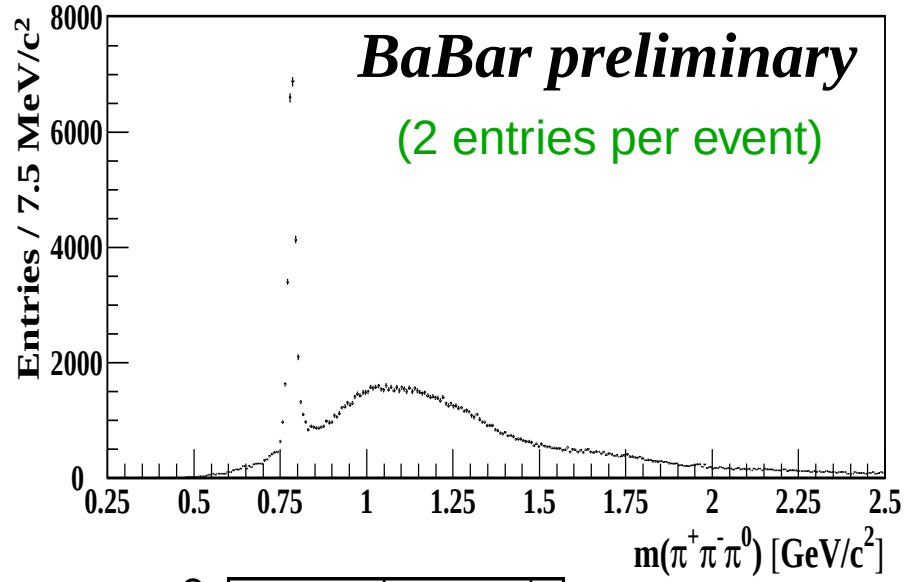


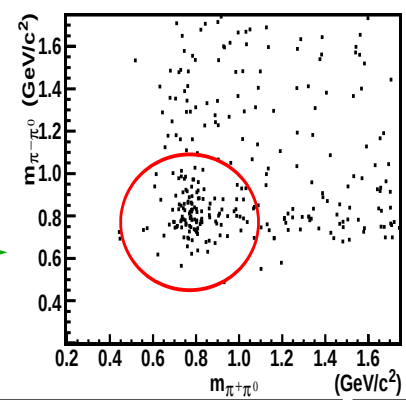


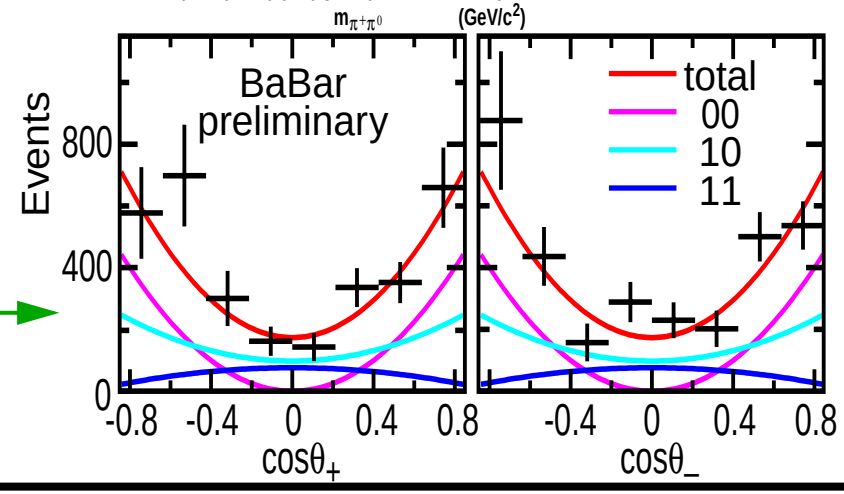


- Structure dominated by the $\omega\pi^0$ and $a_1(1260)\pi$ channels
  → as seen previously
- We also see $\rho^0 f_0$ and $\rho^+\rho^-$









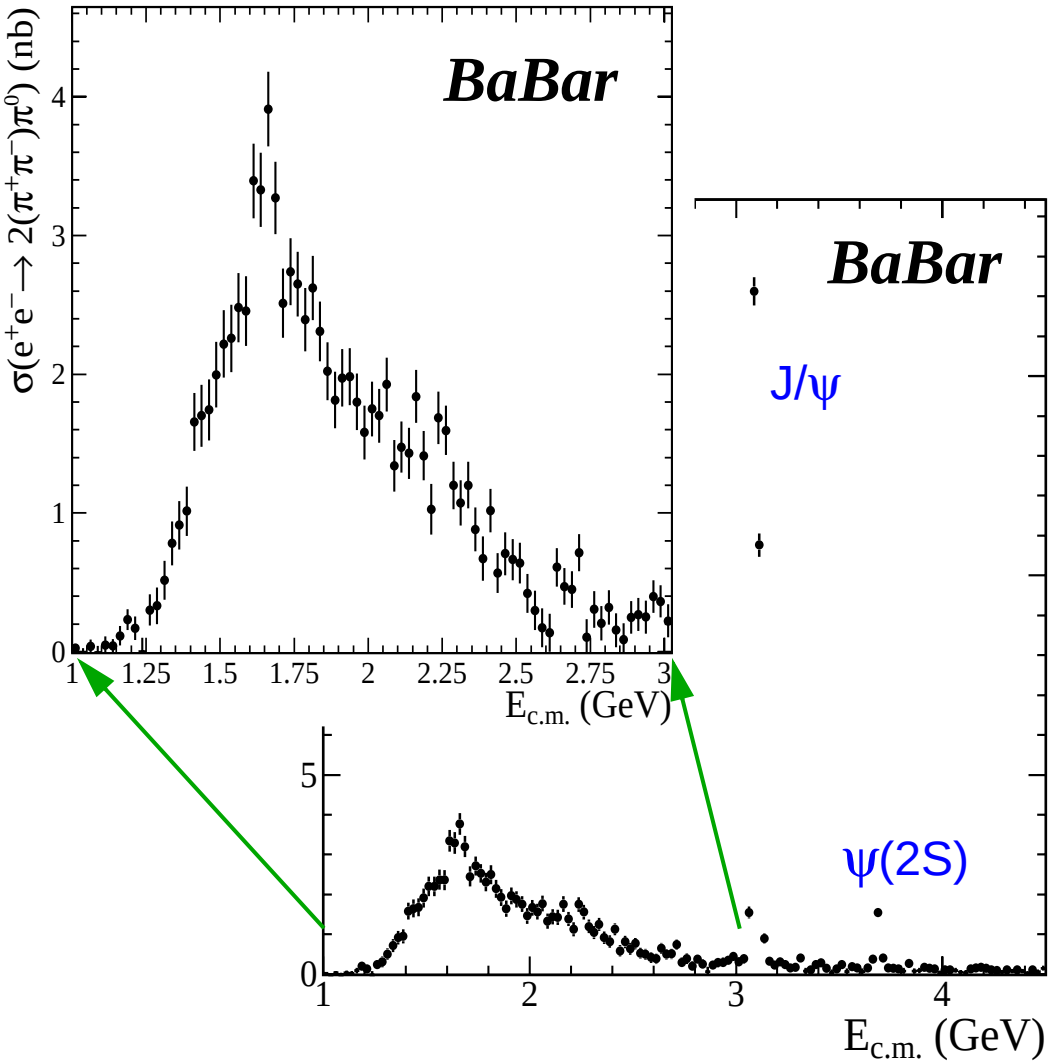
→ unexpected?

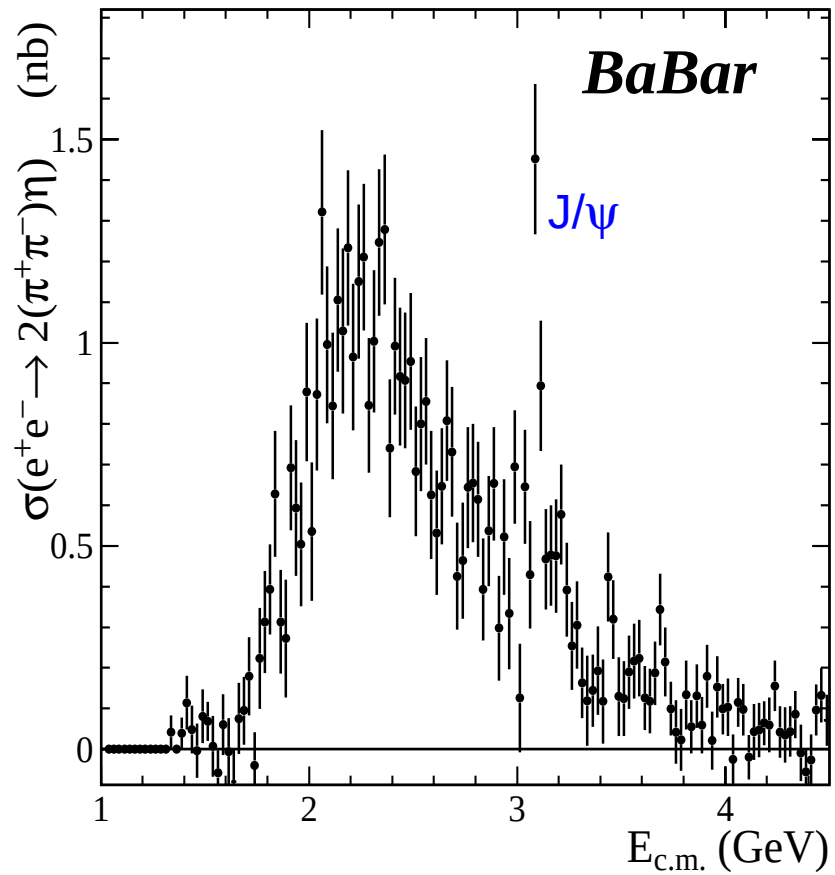
→ working on the $\rho^+\rho^-$ cross section, structure vs. E_{CM}

→ both unique tests of QCD

→ at 10.6 GeV we see more than the one expected helicity state....

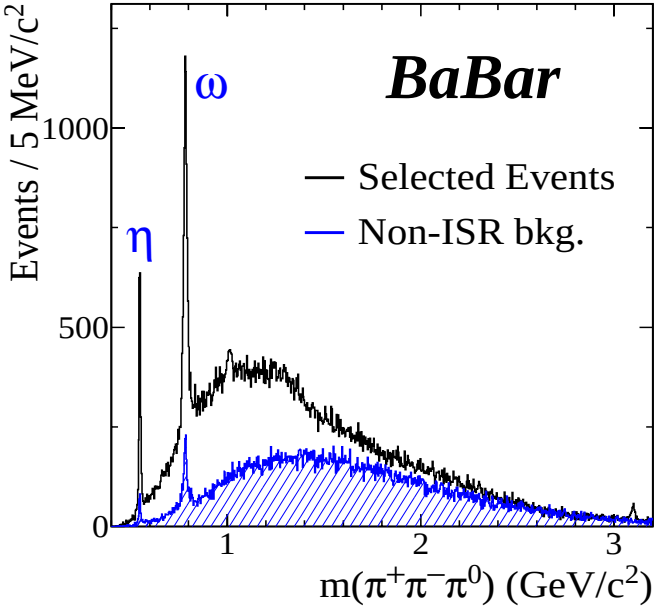
- $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0,\ \pi^+\pi^-\pi^+\pi^-\eta$ 232 fb^{-1} PRD 76, 092005 (07)
- cross sections

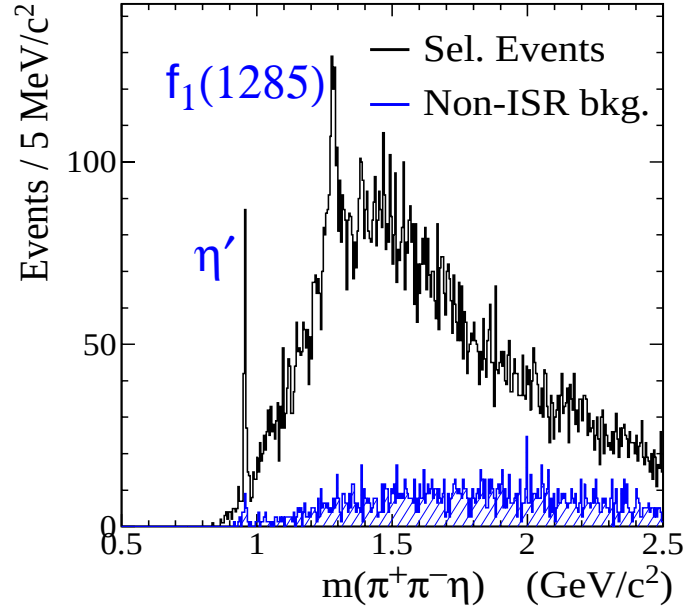




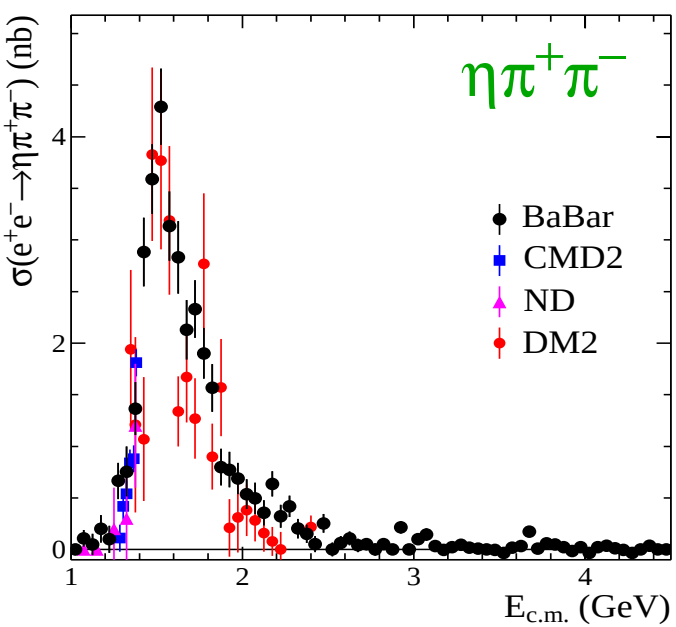
→ first inclusive measurements of these modes

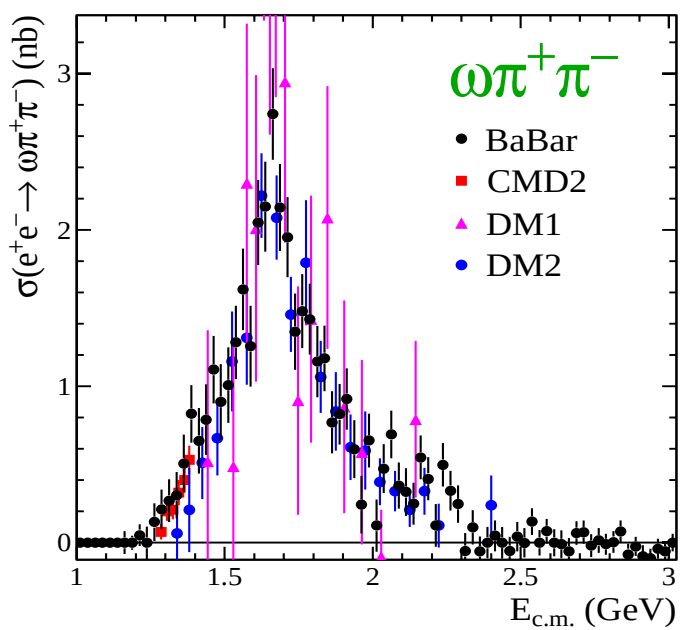
- substructure
  - → several clear peaks
  - → the $\pi^+\pi^-\pi^+\pi^-\pi^0$ mode is:
    - ~20% $\eta\pi^+\pi^-$, mostly $\eta\rho^0$
    - ~40% $\omega\pi^+\pi^-$
    - then almost all $\rho^0\rho^+\pi^-$





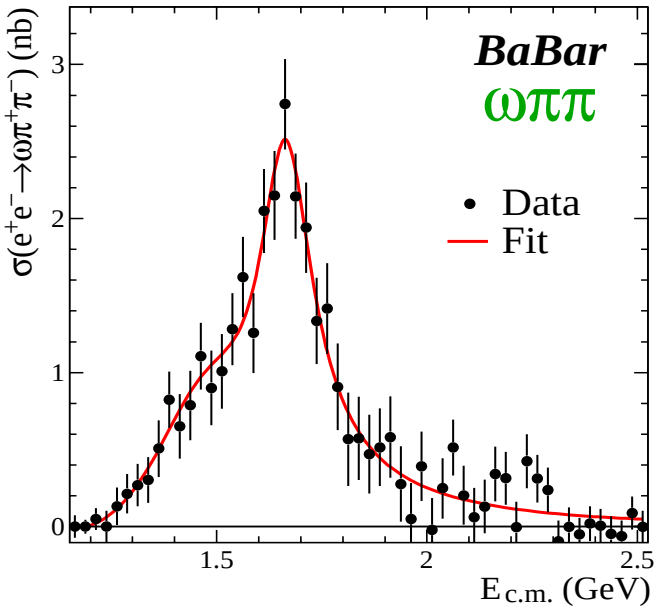
→ disentangling the various contributions is fun ...

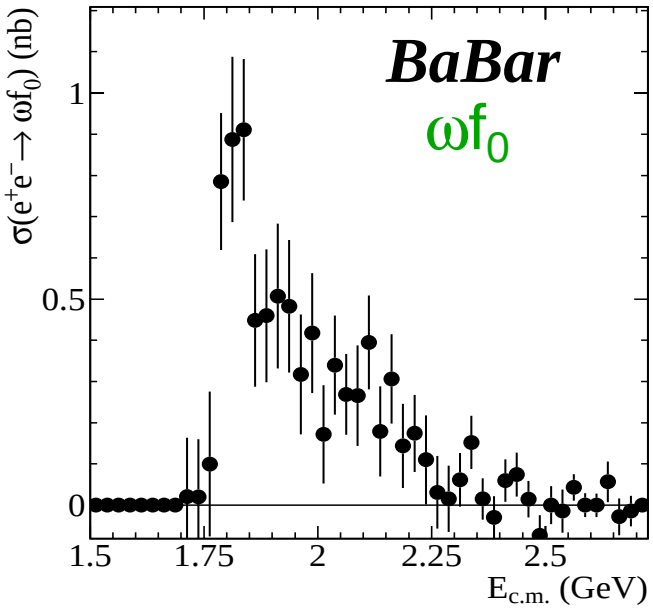




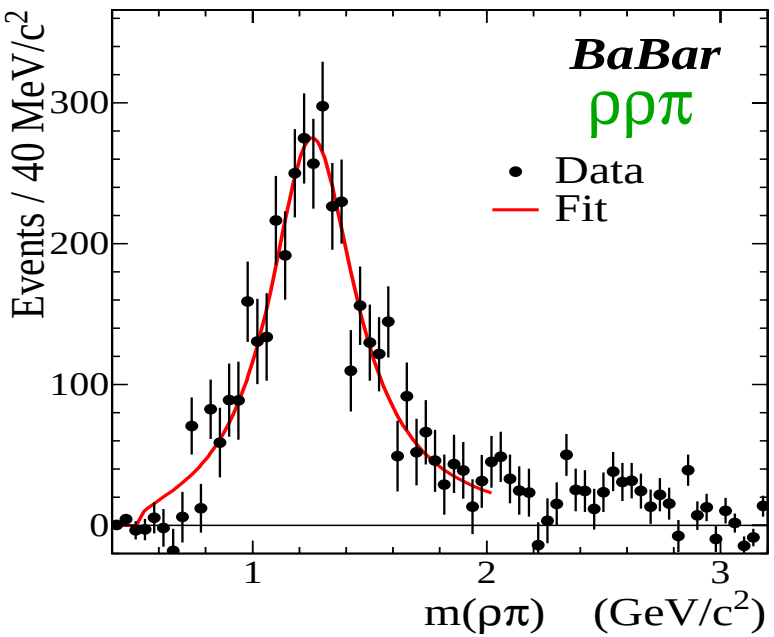
→ the $\eta\pi^+\pi^-$ and $\omega\pi^+\pi^-$ modes are consistent with and improve on previous measurements

- spectroscopy
  - → $\omega\pi^+\pi^-$ contains some $\omega f_0(980)$
  - → the rest is well described by ω' and ω'' with parameters consistent with those from our measurement in the $\pi^+\pi^-\pi^0$ mode





→ establishing the $\rho\pi$ mass recoiling against a ρ is also fun ...



→ looks like a single resonance; a single Breit-Wigner fit gives:

$m = 1243 \pm 12 \pm 20$ MeV/c^2 and
$\Gamma = 410 \pm 31 \pm 30$ MeV

→ consistent with $\pi(1300)$ or $a_1(1260)$

→ more data, angular analysis may tell

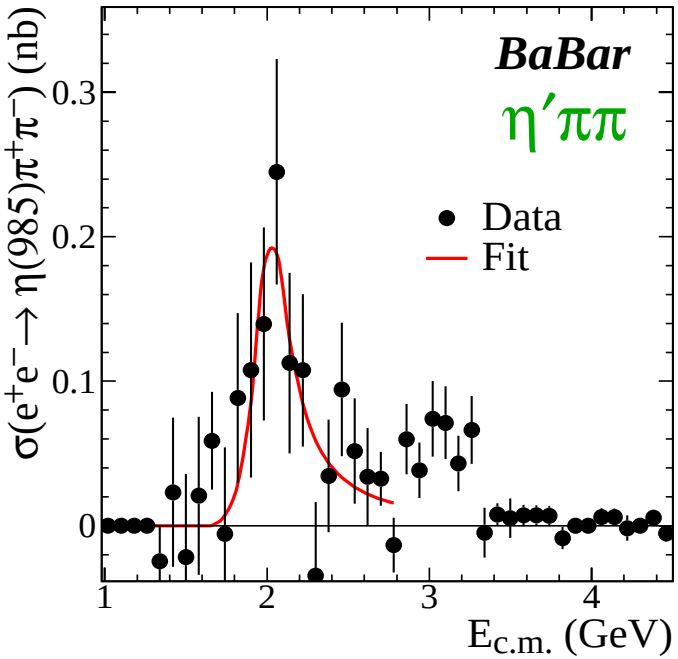
- more spectroscopy

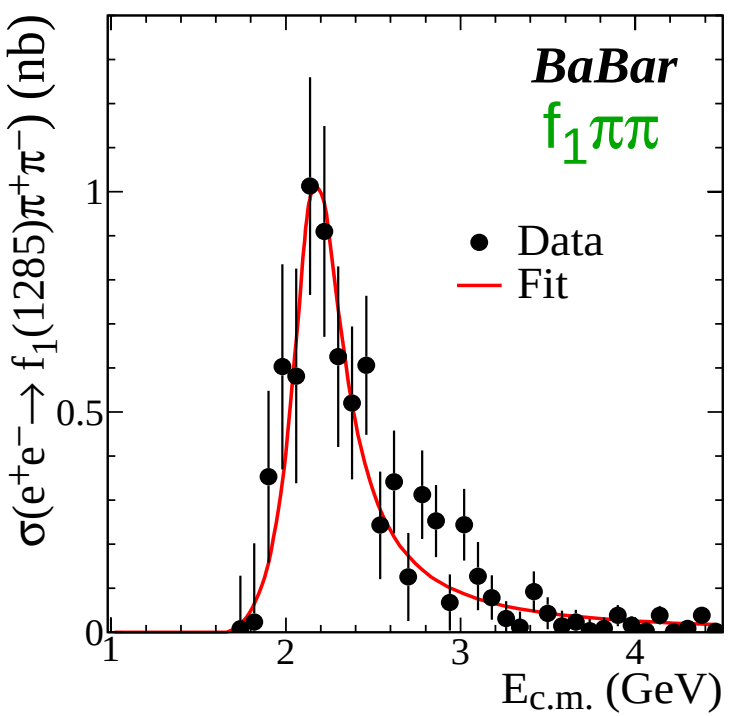
→ $\pi^+\pi^-\pi^+\pi^-\eta$ contains $\eta(958)\pi^+\pi^-$

→ Single BW fit gives:

$m = 1.99 \pm 0.08$ GeV/c^2 and
$\Gamma = 0.31 \pm 0.14$ GeV

→ is this the $\rho(2150)$?





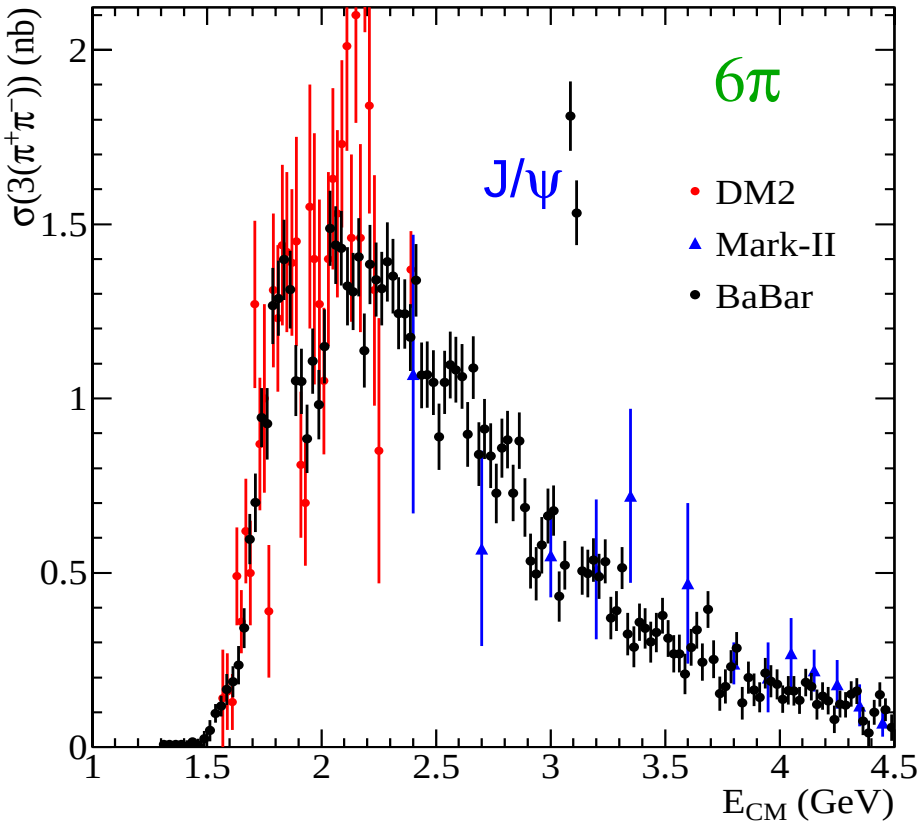
→ ...and $f_1(1285)\pi^+\pi^-$; single Breit-Wigner fit gives:

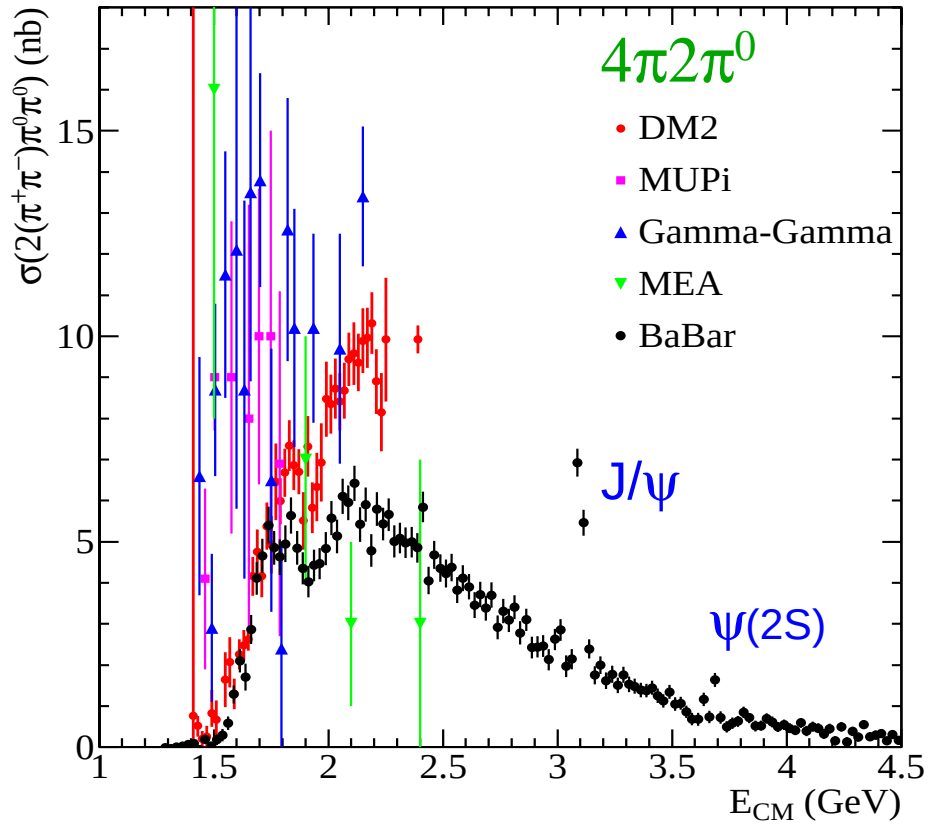
$m = 2.15 \pm 0.04 \pm 0.05$ GeV/c^2,
$\Gamma = 0.35 \pm 0.04 \pm 0.05$ GeV

→ or is this the $\rho(2150)$?

→ more data, angular analysis will tell

- $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$ 232 fb^{-1} PRD 73, 052003 (06)
- Cross sections





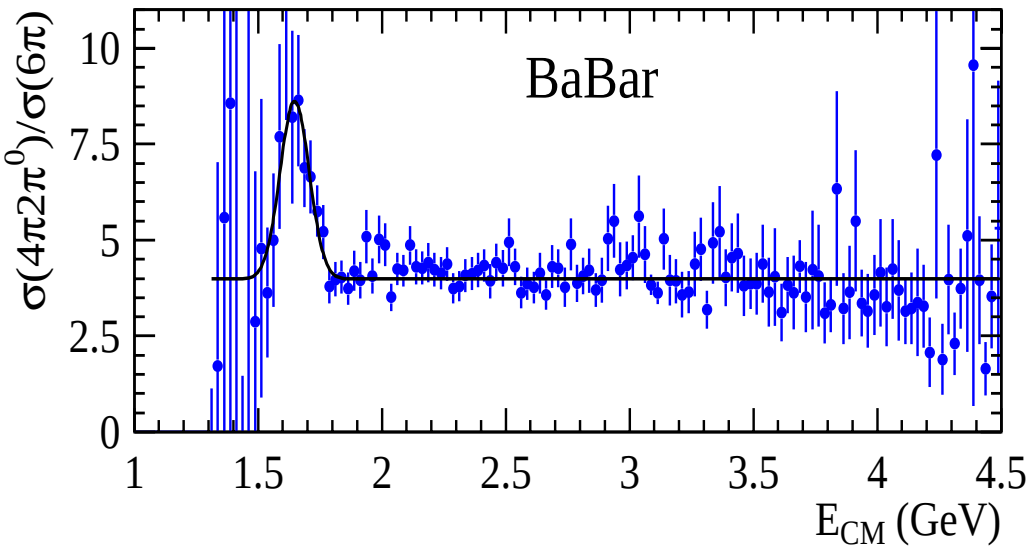
→ large improvements in both measurements

→ dips at ~1950 MeV confirmed; also seen by FOCUS

→ the 6-charged mode has very little substructure, ~1ρ^0 per event

→ ...but the 4-charged mode has a rich substructure, including $\omega\eta$, $\omega\pi^+\pi^-\pi^0$, $\eta\pi^+\pi^-\pi^0$ submodes, signals for $\rho^\pm$, ρ^0, $f_0(980)$, ...

- The $2(\pi^+\pi^-)\pi^0\pi^0$:$3(\pi^+\pi^-)$ ratio
  - → is flat and ...
  - → =4 except where the $\omega\eta$ submode contributes
  - → a challenge to understand
  - → will keep studying, do a coupled-channel analysis



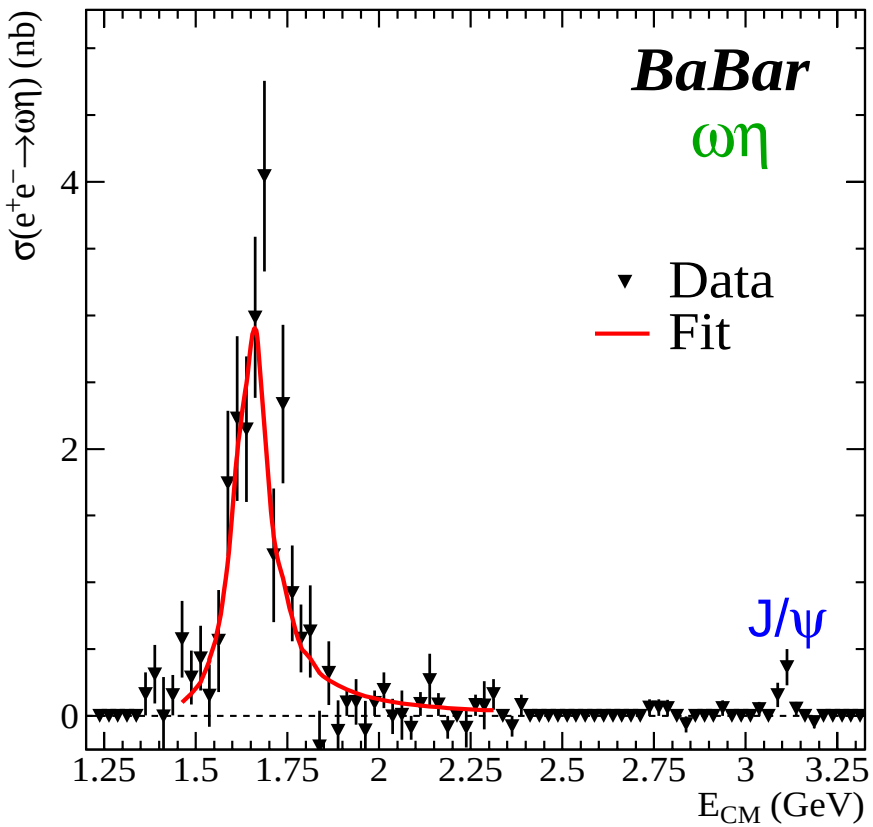
- The $\omega\eta$ submode
  - → is easy to isolate, use sidebands to subtract background
  - → the cross section is dominated by two resonances, J/ψ and something with

    $m = 1645 \pm 8$ MeV/c^2

    $\Gamma = 114 \pm 14$ MeV
  - ⇒ is it the $\omega(1650)$? (Γ=315)

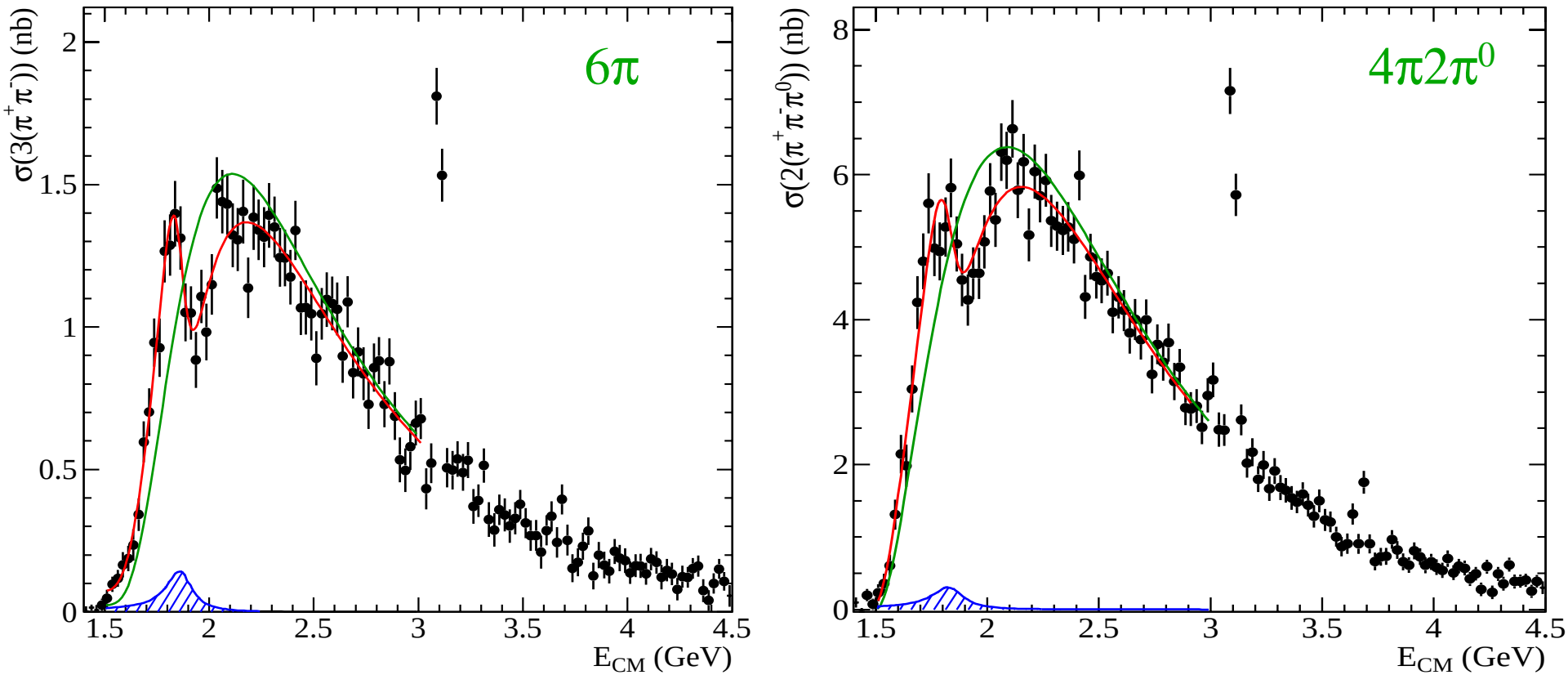
    ...or the $\phi(1680)$?

    ...or something new...?



- What is causing the dip at 1950 MeV?

  → we don't know, so let's fit a resonance



→ fitted parameter values for our two modes are consistent

→ combined: m =1870±20 MeV/c^2, Γ=150±20 MeV, $\delta\phi$ = 9±15°

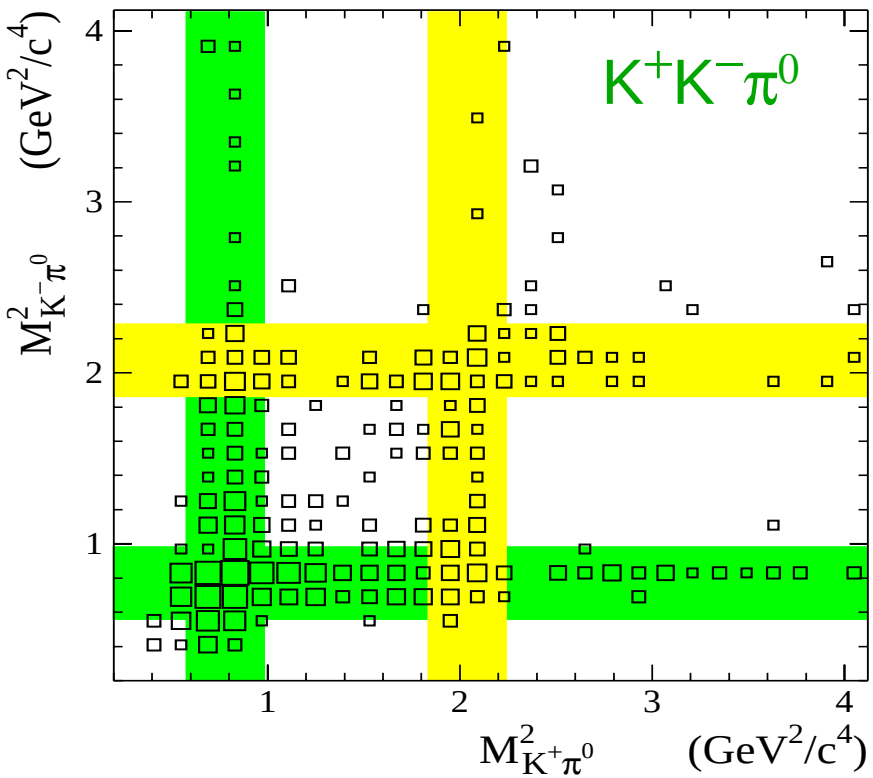
→ inconsistent with FOCUS (1910±10 MeV/c^2, 37±13 MeV)

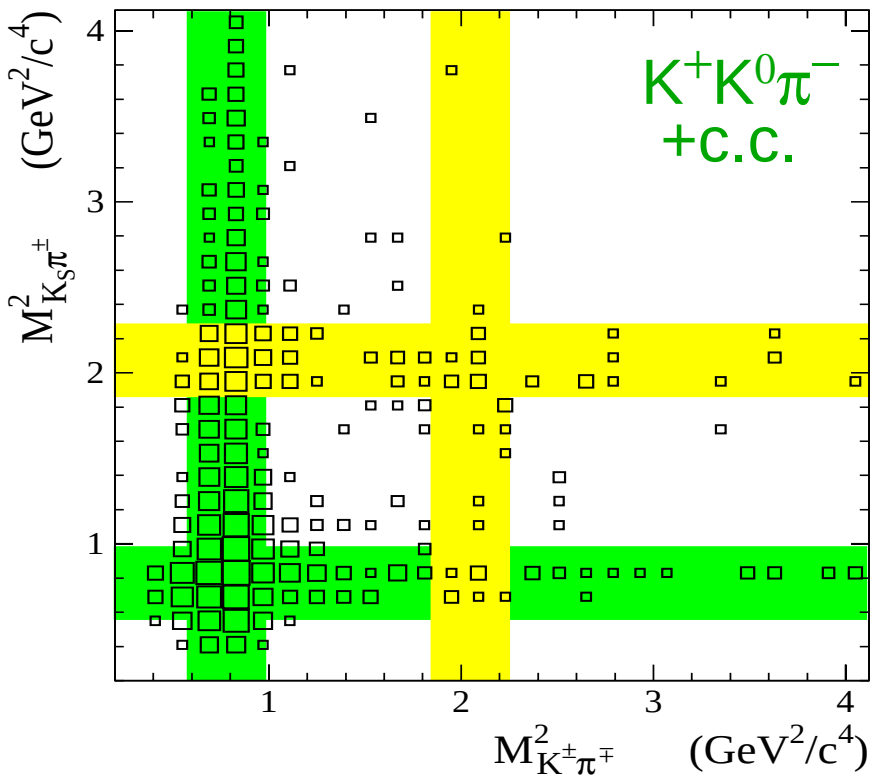
⇒ is this the "same" as the dip in the $\pi^+\pi^-\pi^0\pi^0$ modes?

⇒ or is something(s) else going on?

Final States with Kaons

- $e^+e^- \to K^+K^-\pi^0, K^+K_S\pi^-, K^+K^-\eta$ 232 fb^{-1} arXiv:0710.4451, subm. to PRD
- Dalitz plots for the $KK\pi$ modes



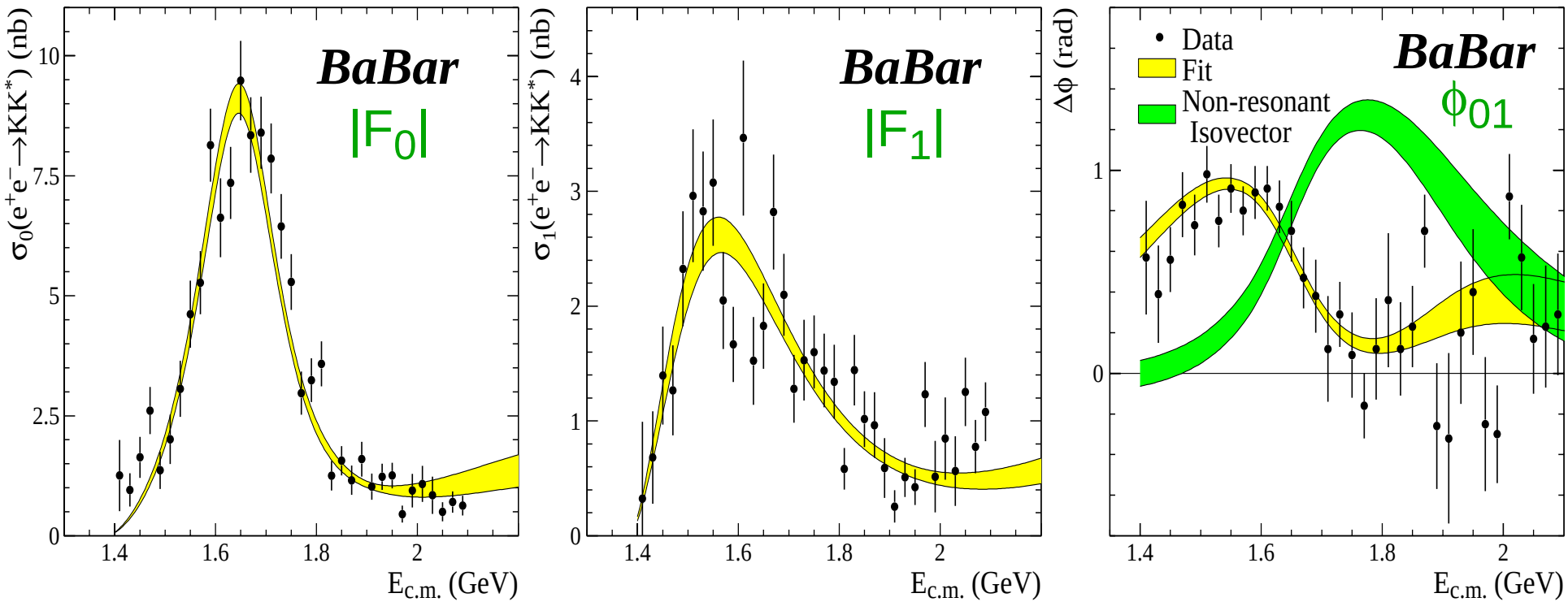


→ both dominated by $K^*(890)$, some $K_2^*(1430)$ also present

→ $K^{*+}K^-$ (left): symmetric DP, access to $|F_0–F_1|$

→ $K^{*0}K_S$ (right): asymmetric DP, access to $|F_0|$, $|F_1|$, ϕ_{01}, where $F_{0(1)}$ is the isoscalar(vector) amplitude, ϕ_{01} their phase diff.

- Performing a global fit in E_{CM} bins



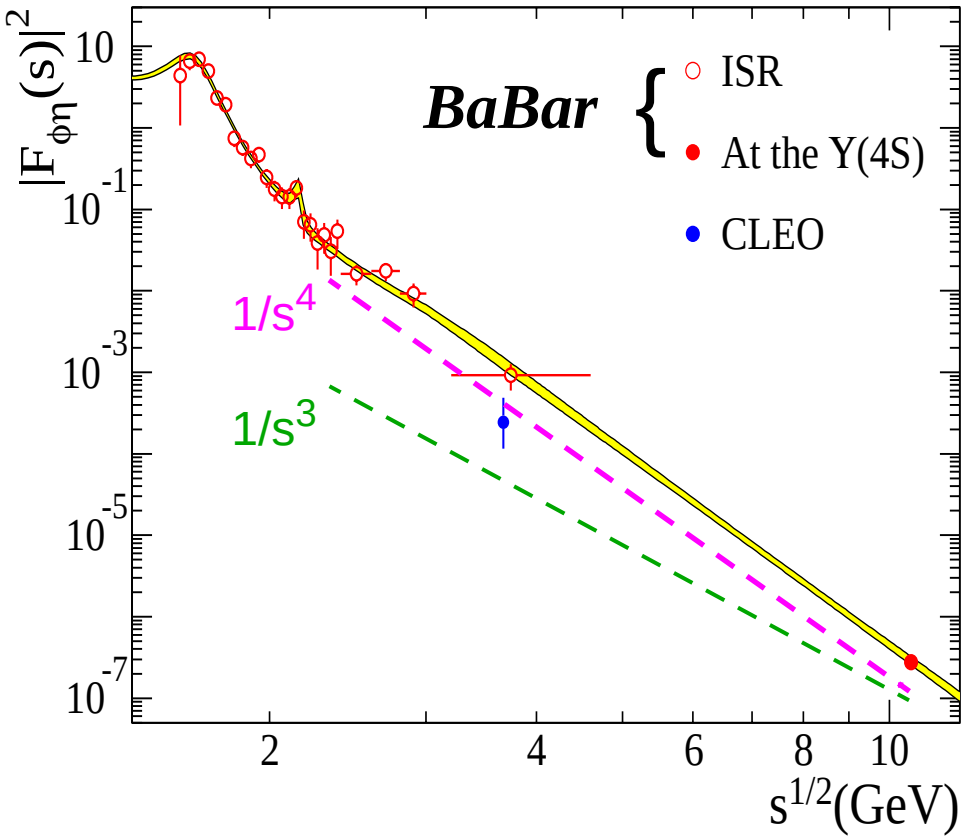
→ isoscalar and isovector channels dominated by resonances:

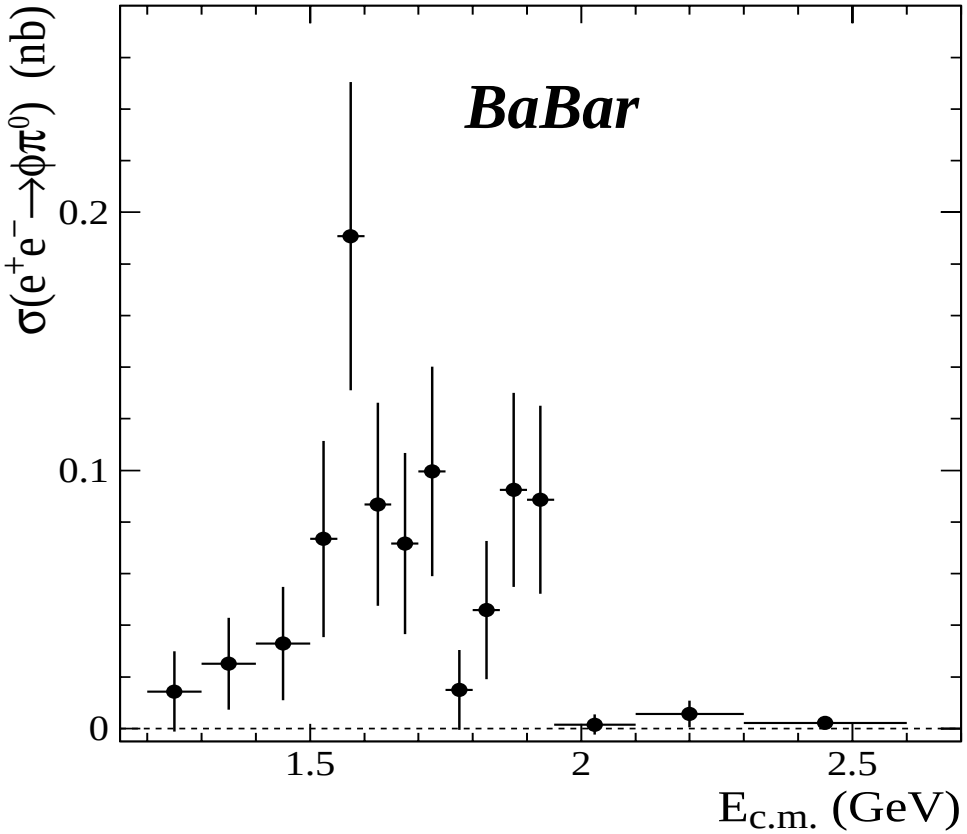
$m = 1708 \pm 47$	1505 ± 20	MeV/c^2
$\Gamma = 322 \pm 178$	418 ± 25	MeV

→ consistent with $\phi(1680)$ $\rho(1500)$

→ purely nonresonant isovector excluded by ϕ_{01}

- We also see the $\phi\eta$ and $\phi\pi^0$ channels





→ $\phi\eta$ included in above global fit

→ shows a strong $\phi(1680)$

→ also a Y(2175) signal with 2.5σ

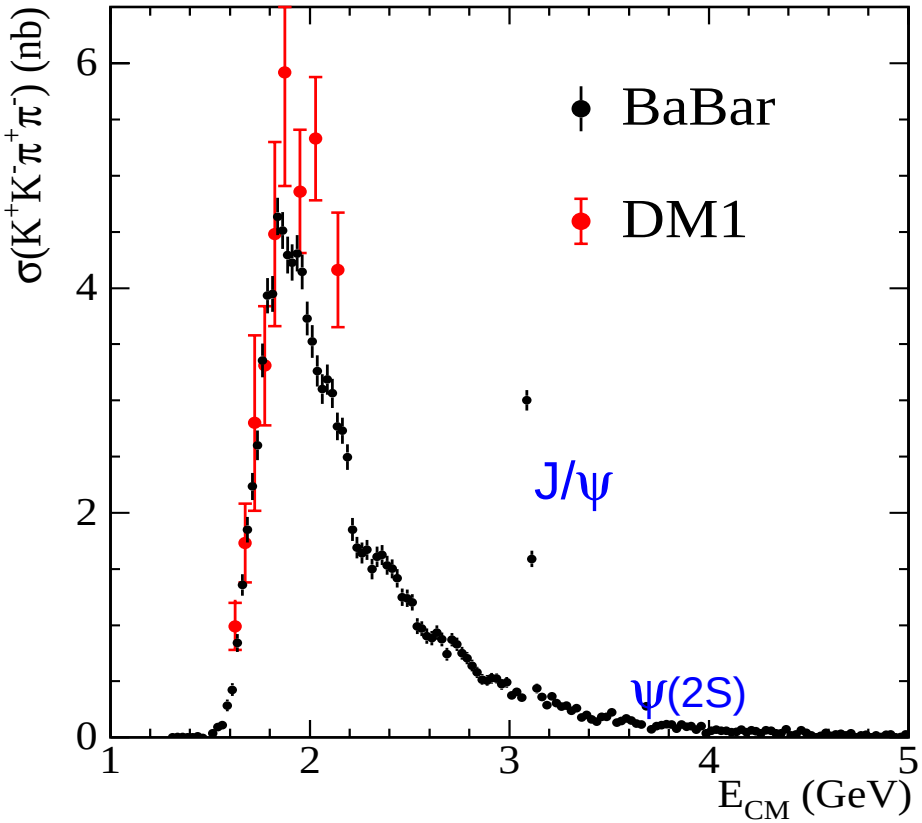
→ including our measurement at 10.6 GeV gives a new test of QCD: the data prefer s^{-4} strongly over s^{-3}

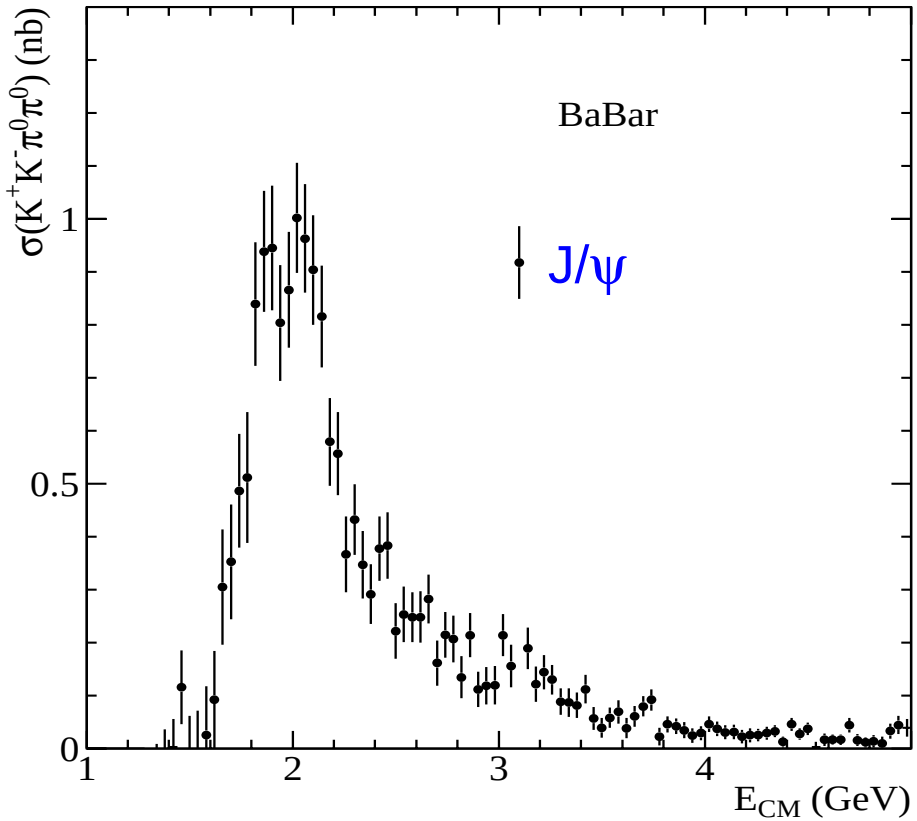
→ $\phi\pi^0$ is OZI suppressed

→ pure isovector; broad structure at 1600 can't be the $\pi(1600)$

→ does the 2.9σ bump at 1900 correspond to the dips in other modes(s)?

- $e^+e^- \to K^+K^-\pi^+\pi^-, K^+K^-\pi^0\pi^0$ 232 fb^{-1} PRD-RC 74 091103 (06)
- Cross sections





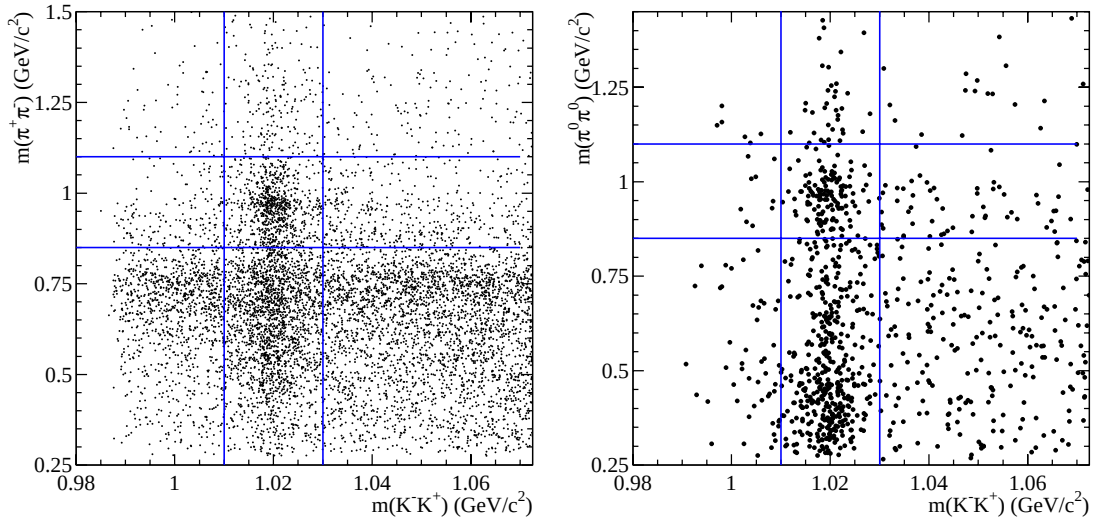
→ huge improvement for $K^+K^-\pi^+\pi^-$, first for $K^+K^-\pi^0\pi^0$

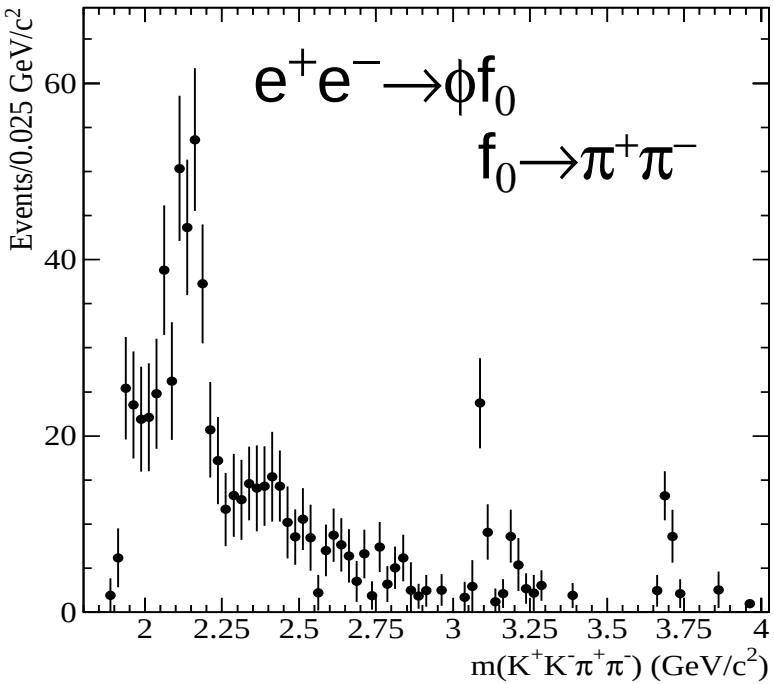
→ rich substructure dominated by $K^*(892)K\pi$, with substantial $K_1(1270)^+K^-$, $K_1(1400)^+K^-$, $\phi\pi^+\pi^-$, $\rho^0K^+K^-$, and more

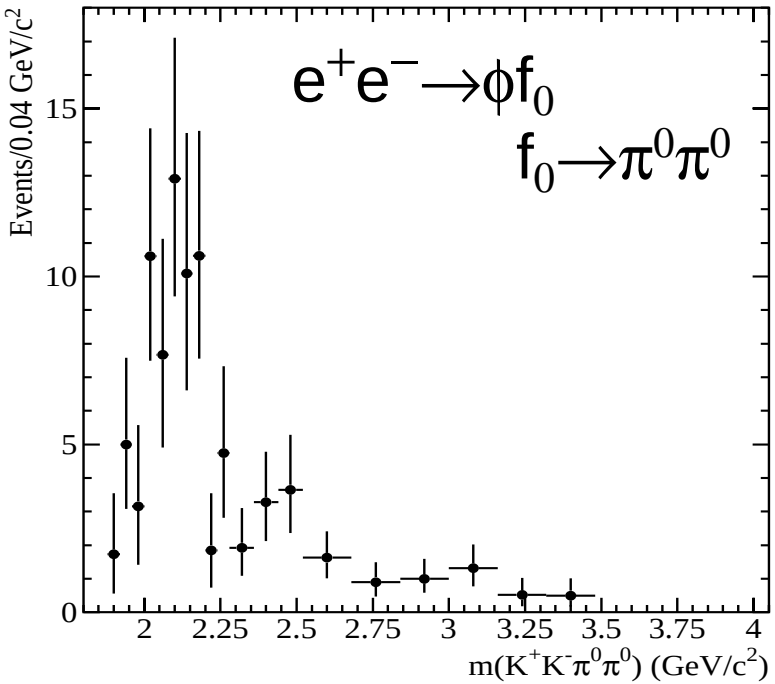
→ several hints of structure, e.g. at ~2 GeV ↔ $\phi f_0(980)$ threshold

→ since ϕ, $f_0(980)$ are both narrow, this submode can be studied...

- The $\phi f_0(980)$ submode:
  - → visible in m_{KK} vs. $m_{\pi\pi}$ scatter plots
  - → extract yield by fitting the m_{KK} distribution in each E_{CM} bin in a $m_{\pi\pi}$ slice around the f_0 mass







- → background from $\phi\pi\pi$ <10%
- → threshold behavior inconsistent with a typical, smooth function

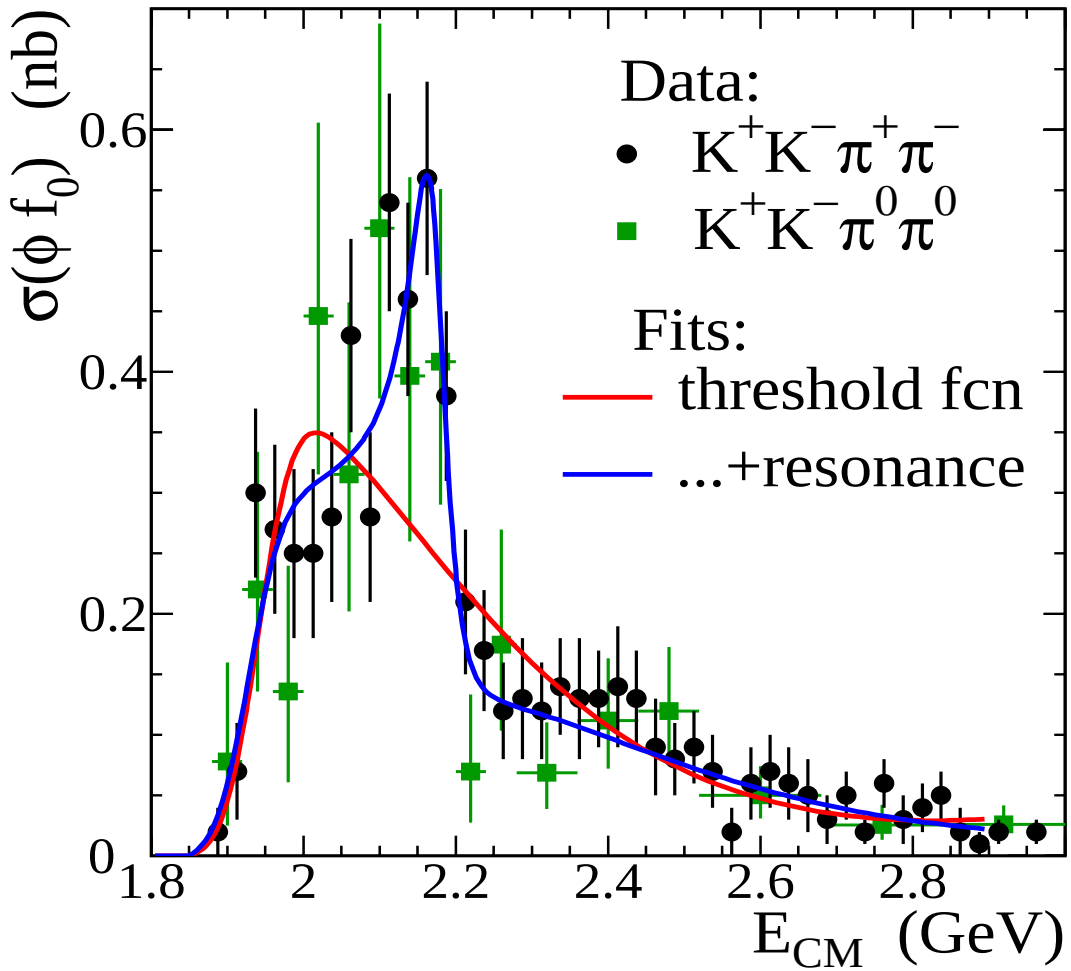
- Convert to cross sections
  - → behavior near threshold unchanged
  - → $\pi^+\pi^-$ and $\pi^0\pi^0$ modes give consistent results
  - → can be described by adding a resonance; a fit yields:

    m = 2175±18 MeV/c^2

    Γ = 58±26 MeV

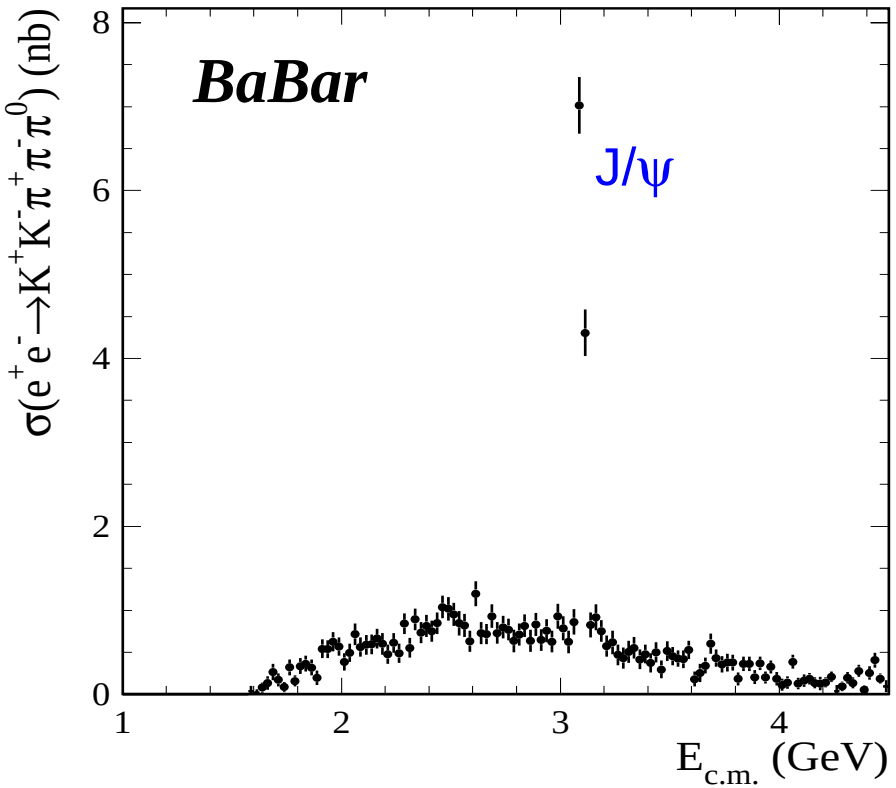
    ϕ = –36±56° wrt non-res

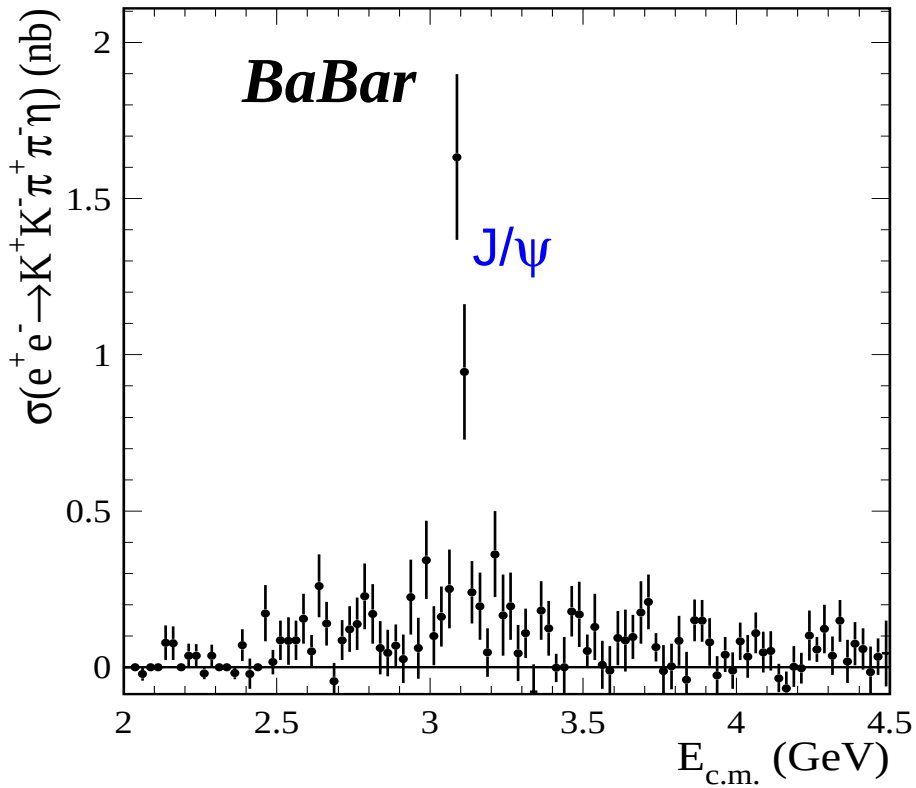
    5.6σ significance



- → very interesting mass region, just below $\Lambda\bar{\Lambda}$ threshold
- → is this a new state?
- → is it analogous to the Y(4260)?
- → need more data, other modes to understand structure in detail

- $e^+e^- \to K^+K^-\pi^+\pi^-\pi^0$, $K^+K^-\pi^+\pi^-\eta$ 232 fb^{-1} PRD 76, 092005 (07)
- Cross sections





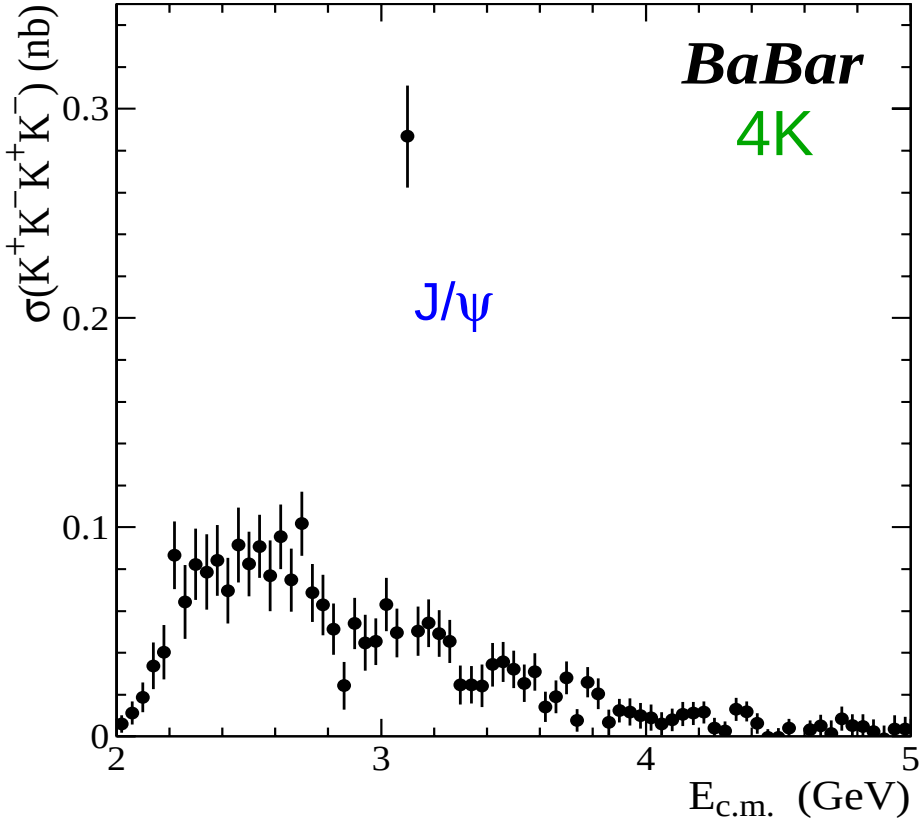
→ first measurements

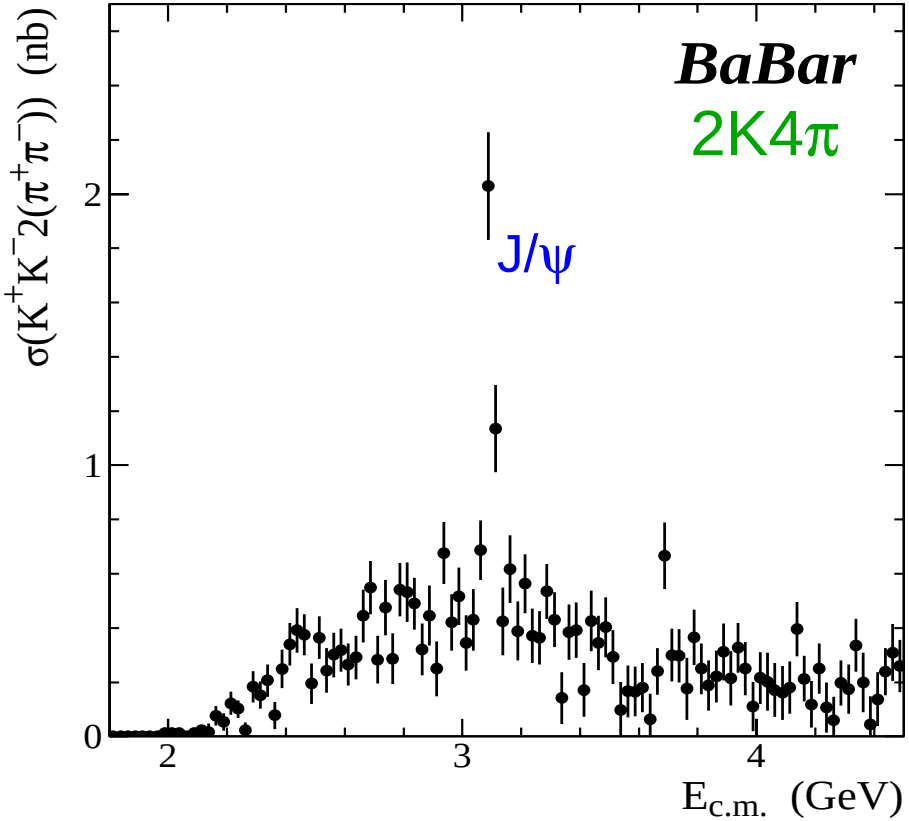
→ the $K^+K^-\pi^+\pi^-\pi^0$ mode has strong ϕ, η and ω

→ measured $\phi\eta$ cross section; consistent with $K^+K^-\eta$ mode

→ the $K^+K^-\pi^+\pi^-\eta$ mode shows strong ϕ, η' and a $\phi\eta'$ channel

- $e^+e^- \to K^+K^-K^+K^-$ 232 fb^{-1} PRD 76, 012008 (07)
- $e^+e^- \to K^+K^-\pi^+\pi^-\pi^+\pi^-$ 232 fb^{-1} PRD 73, 052003 (06)
- Cross sections





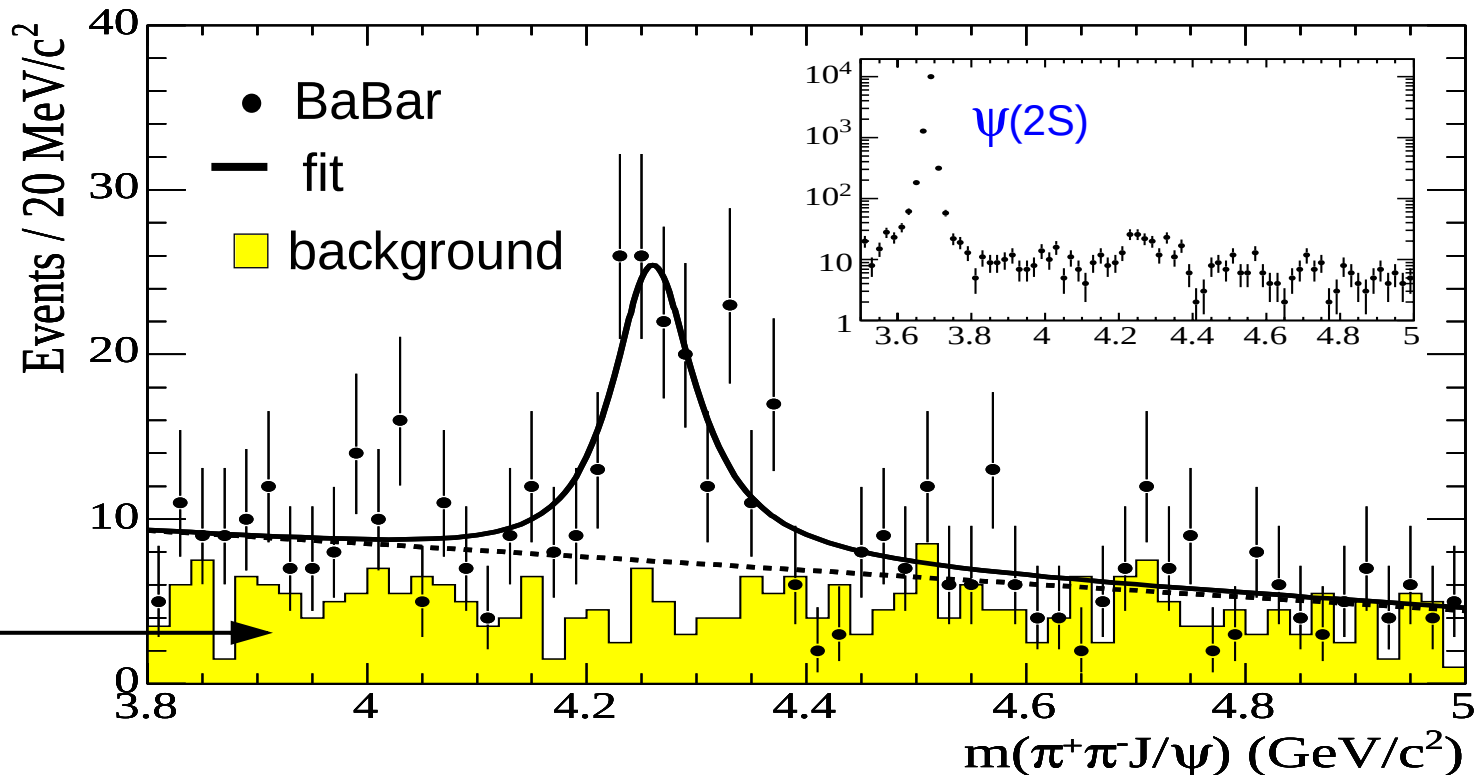
→ first measurements

→ the $K^+K^-K^+K^-$ mode has a strong ϕ, but no other substructure

→ the $K^+K^-\pi^+\pi^-\pi^+\pi^-$ mode has a complex substructure with a strong $K^*(890)$, but a weak ϕ

The Charmonium Region

- $e^+e^- \to J/\psi\pi^+\pi^-$ 233 fb^{-1} PRL 95, 142001 (05)
  - → detection of γ_{ISR} not required, as $J/\psi \to e^+e^-, \mu^+\mu^-$ is quite clean
  - → huge $\psi(2S)$ signal used to optimize cuts on missing mass, p_t, ...
- E_{CM} distribution of selected events



from J/ψ sidebands

- → is there non-resonant production? → inconclusive
- → do heavy ψ states decay this way? → inconclusive
- → are there new (charmonium) state(s) → yes! (maybe)

- What is the Y(4260)??

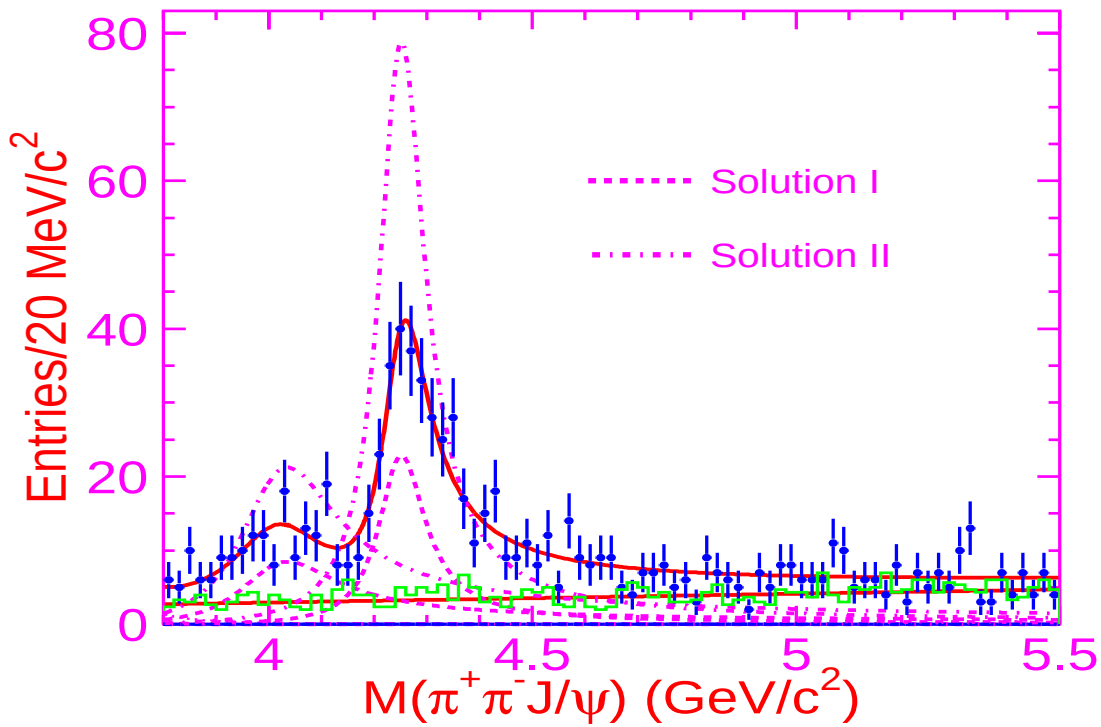
  → single resonance fit gives M~4260 MeV/c^2, Γ~90 MeV

  → a wide $c\bar{c}$ state above $D\bar{D}$ threshold shouldn't decay to $J/\psi\pi\pi$

  → there is a dip in R at this energy...

  → confirmed by CLEO (point at one E_{CM}) PRL 96, 162003 (06)

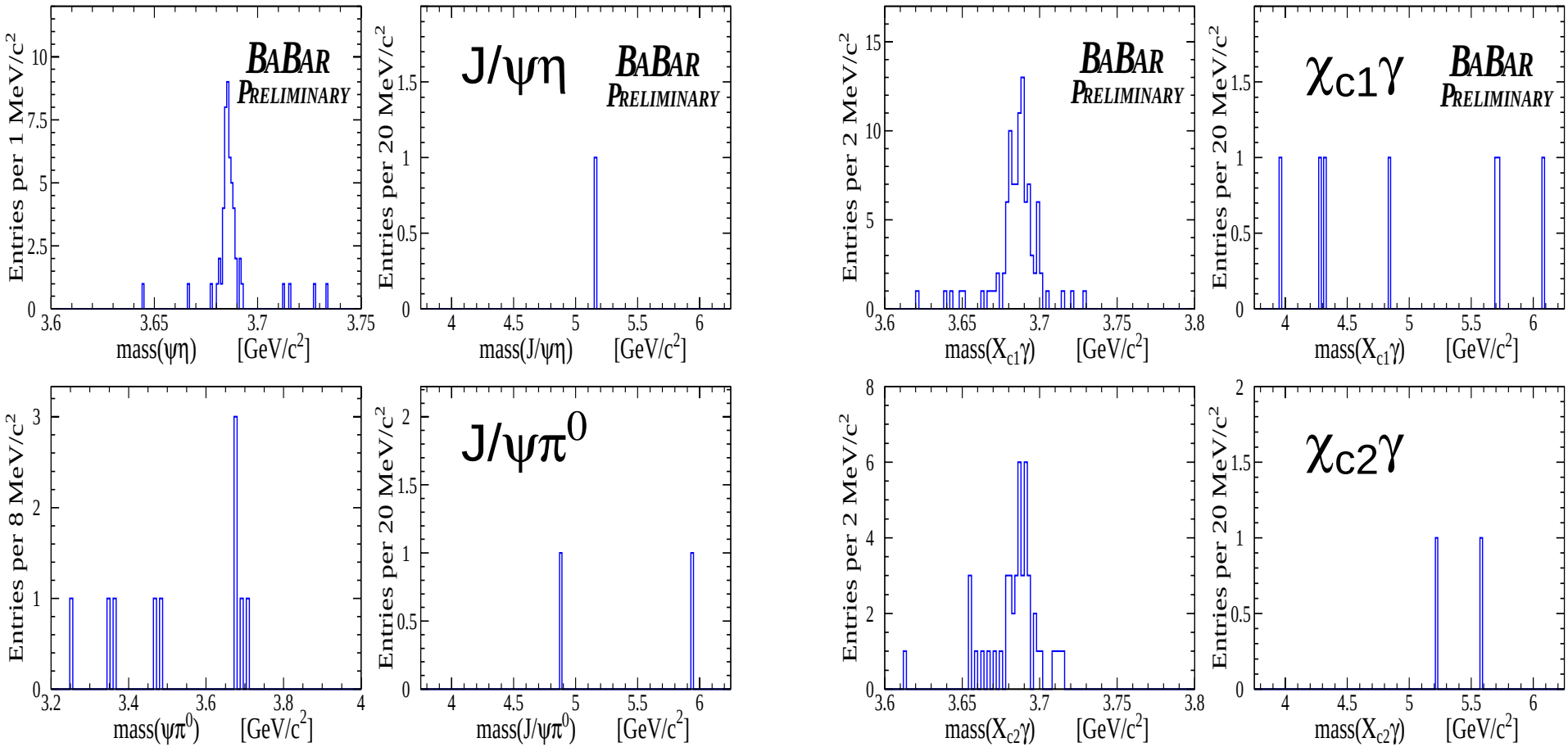
  and Belle PRL 99, 182004 (07)



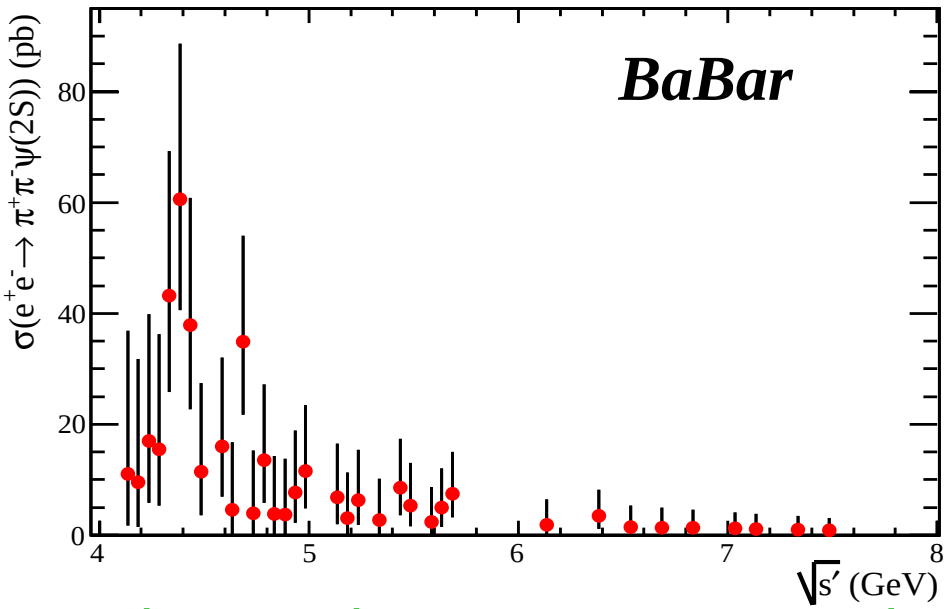
⇒ is there is more than one state? What are they?

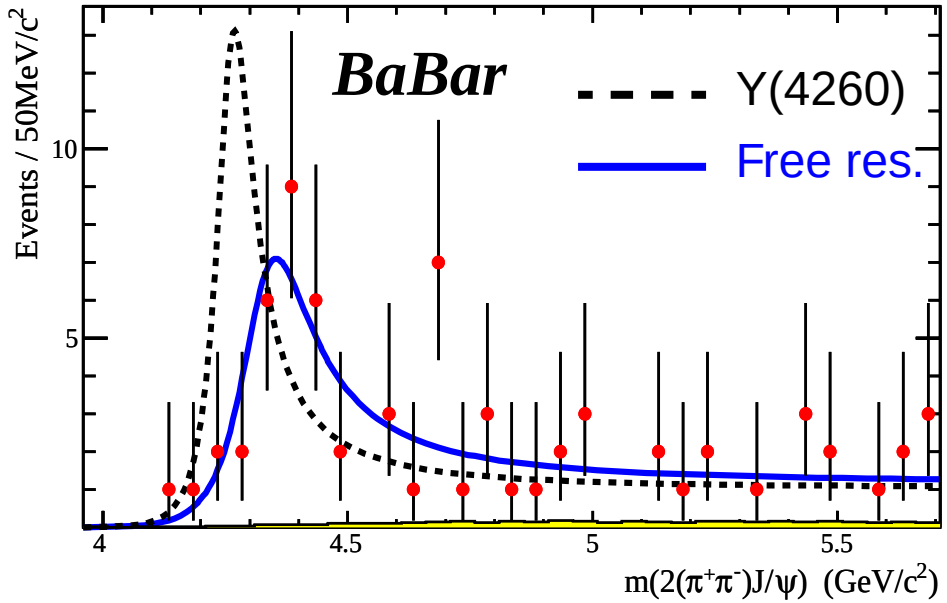
⇒ much theoretical speculation – need more experiment

- Further studies of the Y(4260)
  - → searches in B decays → inconclusive PRD 73, 011101 (06)
  - → above ISR modes ($\phi\pi\pi$, $p\bar{p}$, ...) → no signal
  - → ISR studies of $J/\psi\gamma\gamma$ → no signal hep-ex/0608004



- $e^+e^- \to \psi(2S)\pi^+\pi^-$ 298 fb^{-1} PRL 98, 212001 (07)
- Yield and cross section



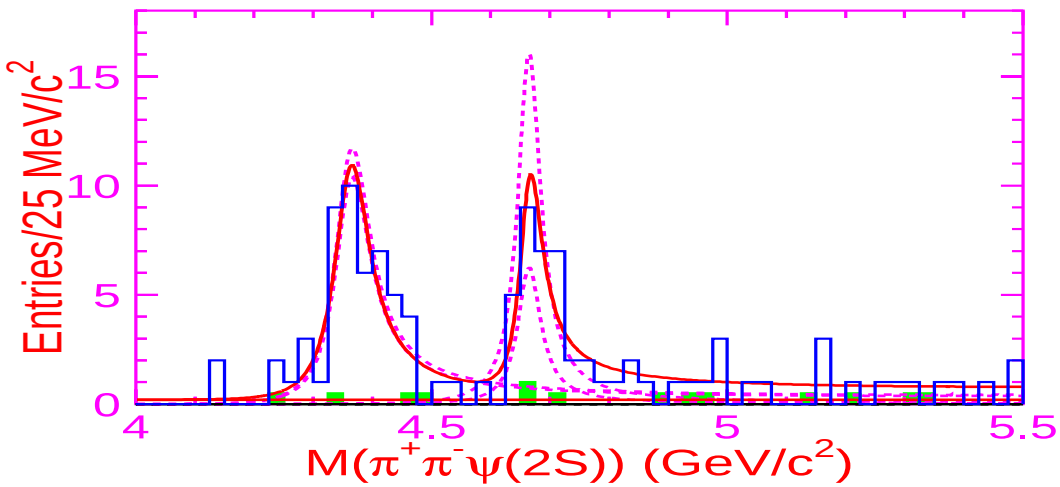


→ interesting structure near threshold...

→ ...but it's NOT the Y(4260): M~4325 MeV/c^2, Γ~170 MeV

⇒ ...and Belle finds 2 states in this region...

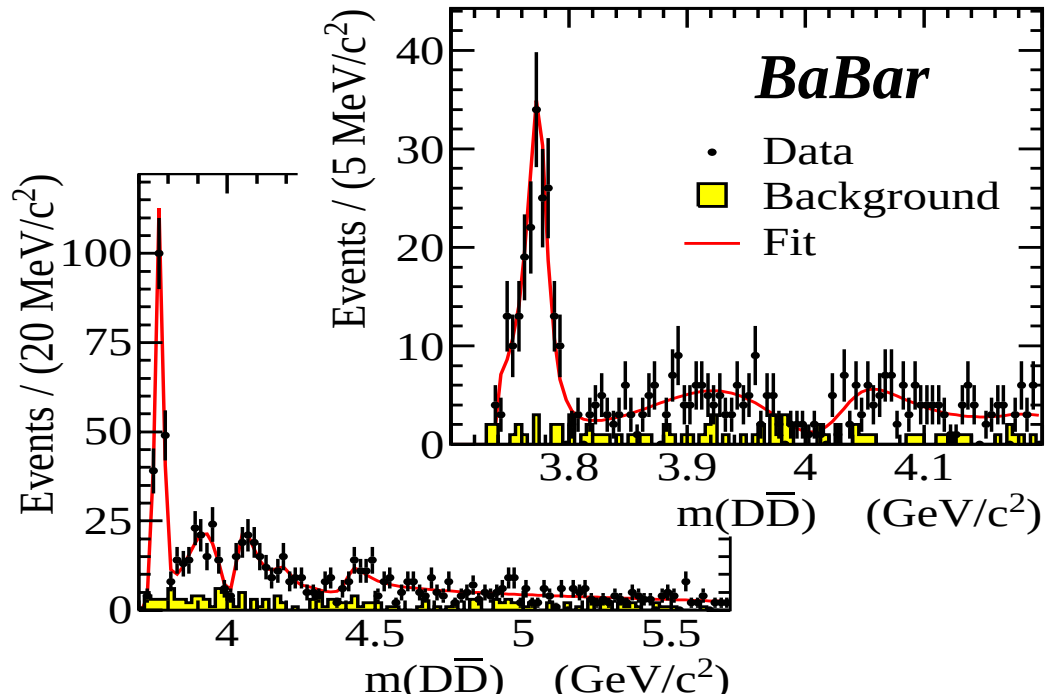
PRL 99, 142002 (07)



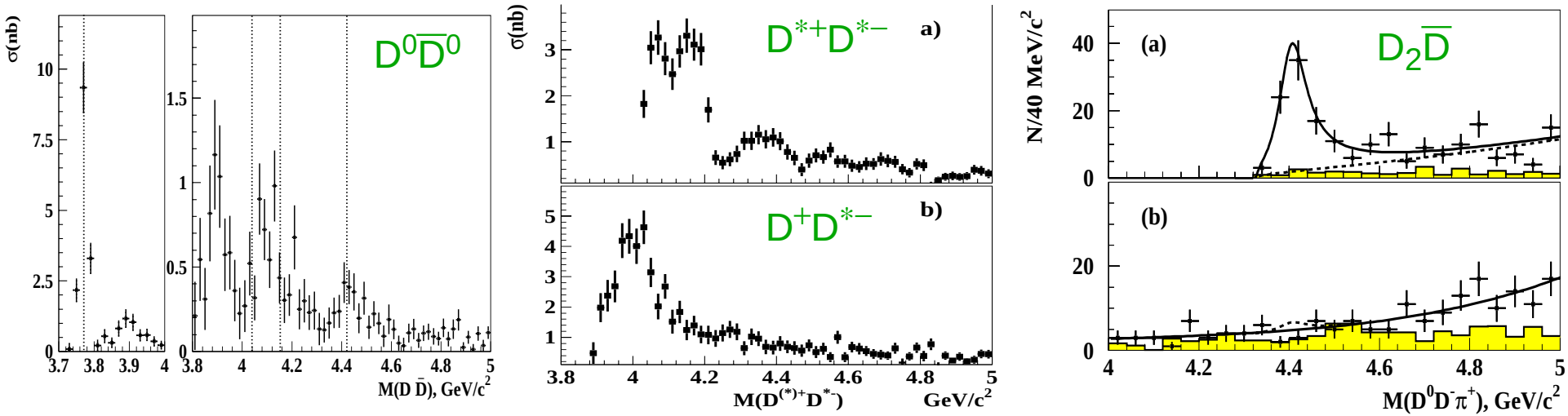
- $e^+e^- \to D\bar{D}, D\bar{D}^*$

384 fb^{-1} PRD-RC 76, 111105 (07)

- Cross section
  - → plenty of structure
  - → all previously known ψ states are seen
  - → ...and they interfere
  - → no sign of the Y(4260), Y(4360), ...
  - ⇒ improved understanding of known states

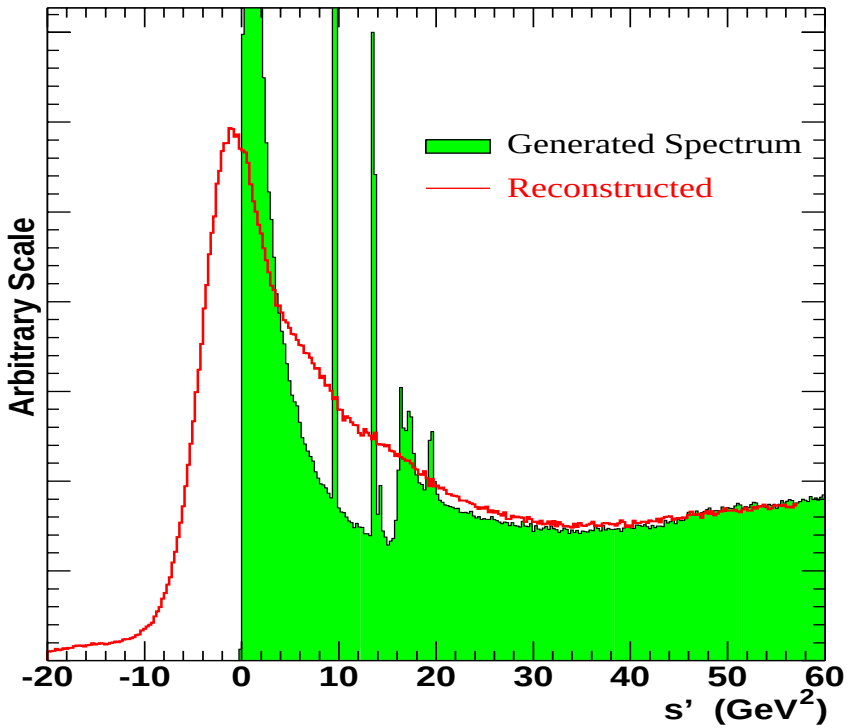


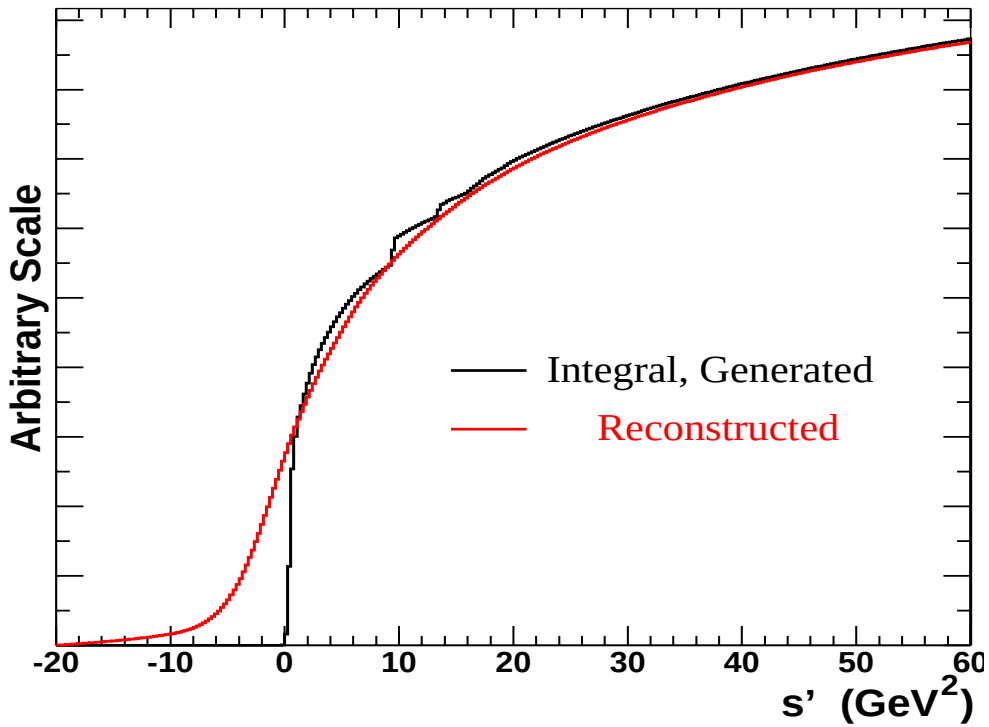
⇒ Belle has some interesting similar results



Inclusive Cross Section via ISR

- Can we measure the total $e^+e^- \to$ hadrons cross section with ISR?
  - $\to$ select events with a hard photon recoiling against "stuff"
  - $\to$ problem: photon energy resolution is not great

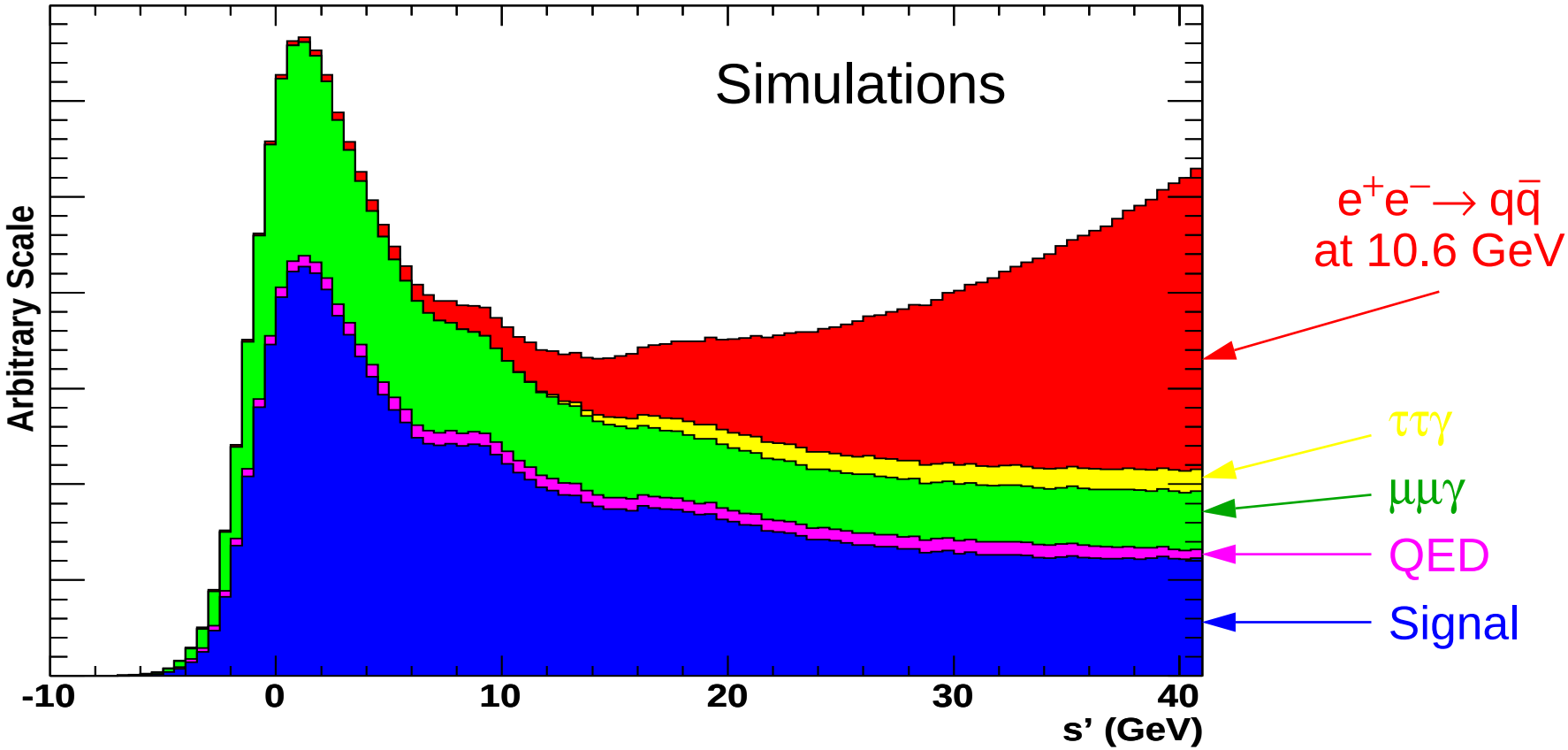




  - $\to$ but we can measure the integral nicely
  - $\to$ ...and the integral convolved with the kernel for $\alpha_{QED}(M_Z^2)$
  - $\to$ (but the g_μ–2 kernel is too sharply peaked...)

- Let's see what we can do ...

  → applying some simple selection criteria, backgrounds are high

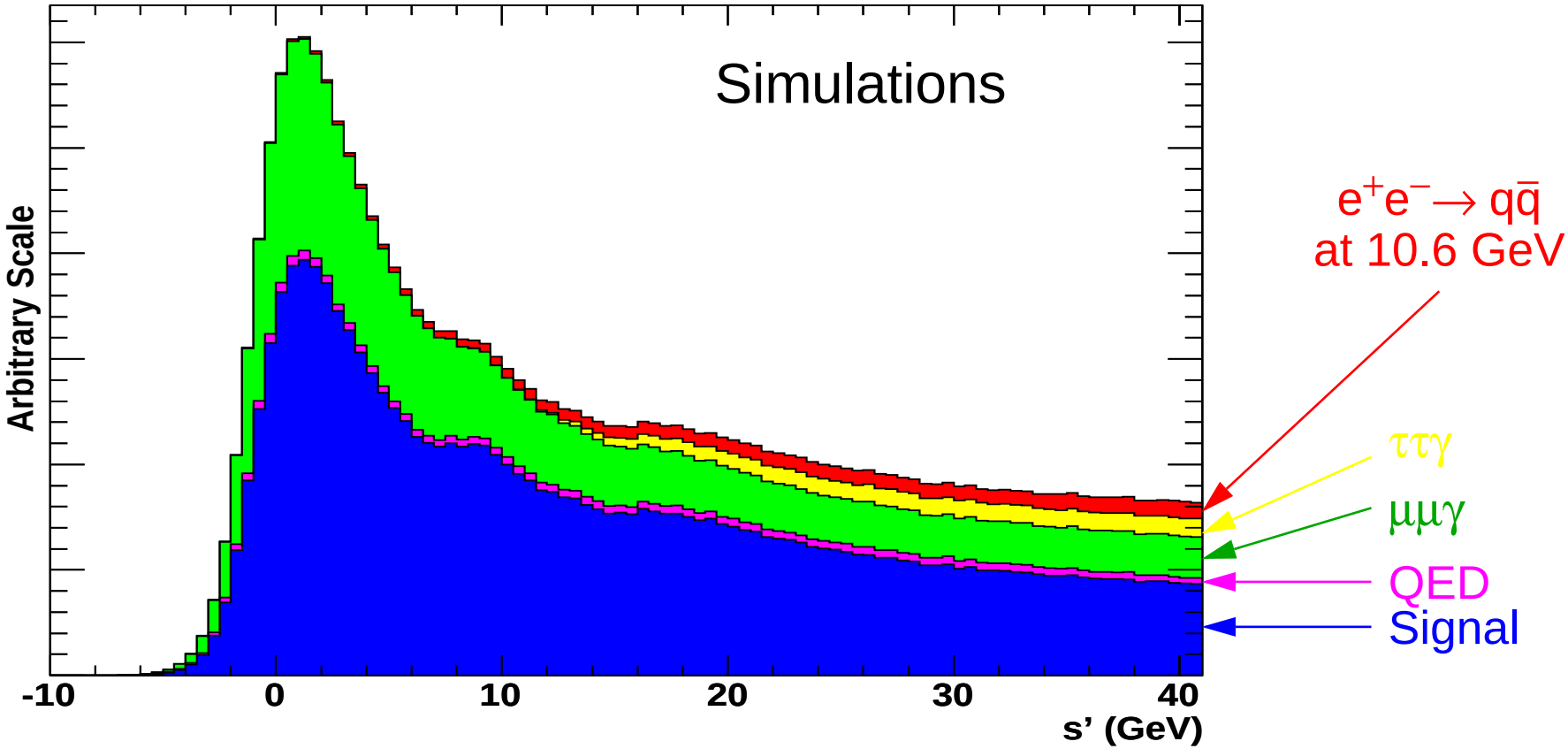


→ strategy: keep well understood radiative $\mu^+\mu^-$ and $\tau^+\tau^-$ events to maximize efficiency; subtract them later

→ use data to characterize, suppress and measure the remaining background from $q\bar{q}$ events

→ much work on detector response to photons, π^0, η, η', ω, K_L, neutrons, event shapes, other backgrounds, ...

- The current status is ...



→ backgrounds are now manageable, but must be understood very well before subtraction

→ this is in progress; we expect a 3.5-4.5% measurement of the hadronic contribution to $\alpha_{QED}(M_Z^2)$ from $\sqrt{s'}$<6.5 GeV

→ current errors are 15 (6)% in the 1-2 (2-5) GeV region, so this measurement should be quite useful

J/ψ and ψ(2S) Branching Fractions

- We observe J/ψ and/or ψ(2S) peaks in many of the above studies

  → measure BF(J/ψ→f)×Γ_{ee}, use PDG Γ_{ee} to obtain

J/ψ →	BaBar BF (%)	PDG 2004	Other since 2004
$p\bar{p}$	0.222±0.016	0.217±0.008	
$\Lambda\bar{\Lambda}$	0.192±0.021	0.130±0.012	0.203±0.015 BES
$\Sigma^0\bar{\Sigma}^0$	0.116±0.026	0.127±0.017	0.133±0.011 BES
$\pi^+\pi^-\pi^0$	2.18 ±0.19	1.50 ±0.20	2.09 ±0.12 BES
$K^{*+}K^-$	0.52 ±0.04	0.50 ±0.04	
$K^{*0}\bar{K}^0$	0.48 ±0.06	0.42 ±0.04	
$K^+K^-\eta$	0.087±0.015	–	
$\pi^+\pi^-\pi^+\pi^-$	0.361±0.037	0.40 ±0.10	0.353±0.031 BES
$K^+K^-\pi^+\pi^-$	0.609±0.073	0.720±0.230	
$\phi\pi^+\pi^-$	0.098±0.013	0.080±0.012	0.109±0.013 BES
$\phi\pi^0\pi^0$	0.585±0.162	–	
$\pi^+\pi^-\pi^+\pi^-\pi^0$	5.46 ±0.34	3.37 ±0.26	
$\omega\pi^+\pi^-$	0.97 ±0.08	0.72 ±0.10	
$\eta\pi^+\pi^-$	0.040±0.017	–	
$\pi^+\pi^-\pi^+\pi^-\eta$	0.235±0.044	–	0.226±0.028 BES

useful / competitive / best / dominant measurement

→ ...continued

$J/\psi \to$	BaBar BF (%)	PDG 2004	Other since 2004
$K^+K^-\pi^+\pi^-\pi^0$	1.92 ±0.17	1.2 ±0.3	
$\phi\eta$	0.14 ±0.06	0.065±0.007	0.090±0.009 BES
ωK^+K^-	0.136±0.051	0.19 ±0.04	
$K^+K^-\pi^+\pi^-\eta$	0.47 ±0.07	–	
$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$	0.440±0.041	0.40 ±0.20	
$\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$	1.65 ±0.21	–	
$\omega\pi^+\pi^-\pi^0$	0.40 ±0.07	–	
$\omega\eta$	0.147±0.044	0.158±0.016	0.235±0.027 BES
$K^+K^-K^+K^-$	0.67 ±0.14	–	
$K^+K^-\pi^+\pi^-\pi^+\pi^-$	0.509±0.055	0.31 ±0.13	
$\phi\pi^+\pi^-\pi^+\pi^-$	0.177±0.037	0.160±0.032	

useful / competitive / best / dominant measurement

→ ...or BF($\psi(2S)\to f$)$\times\Gamma_{ee}$, use PDG Γ_{ee} to obtain

$\psi(2S)\to$	BaBar BF (%)	PDG 2004	Other since 2004
$p\bar{p}$	0.033±0.009	0.0236±0.0024	
$\Lambda\bar{\Lambda}$	0.060±0.015	0.0181±0.0034	
$\phi\pi^+\pi^-$	0.027±0.011	0.0150±0.0028	
$\pi^+\pi^-\pi^+\pi^-\pi^0$	1.20 ±0.11	0.30 ±0.08	0.261±0.019 CLEO
$\omega\pi^+\pi^-$	0.122±0.033	0.0048±0.0009	0.082±0.009 CLEO
$\pi^+\pi^-\pi^+\pi^-\eta$	0.12 ±0.06	–	0.127±0.011 CLEO 0.117±0.018 BES
$K^+K^-\pi^+\pi^-\pi^0$	0.18 ±0.05	–	
$K^+K^-\pi^+\pi^-\eta$	0.13 ±0.07	–	
$\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$	0.53 ±0.17	–	
$K^+K^-\pi^+\pi^-\pi^+\pi^-$	0.21 ±0.10	–	

useful / competitive / best / dominant measurement

Summary

- The very high luminosity of the B factories has (re)opened several interesting areas of elementary particle physics

- At BaBar we have exploited initial state radiation to
  - $\rightarrow$ study e^+e^- annihilations at E_{CM} from threshold to ~5 GeV
  - $\rightarrow$ improve our knowlege of R, g_μ–2, $\alpha(M_Z)$
  - $\rightarrow$ study baryon form factors, find $G_E > G_M$ at low E_{CM}
  - $\rightarrow$ improve spectroscopy of excited ω, ϕ states
  - $\rightarrow$ discover new states/structures at m~2175, 4260, 4400 MeV

- In the future, many new, improved studies planned
  - $\rightarrow$ update current results with full data set
  - $\rightarrow$ additional exclusive modes under study or consideration
  - $\rightarrow$ in particular, hope to reach 1% uncertainty on $e^+e^- \rightarrow \pi^+\pi^-$
  - $\rightarrow$ inclusive measurements