Study of dynamics of $\pi\pi$ transitions among $\Upsilon(3S)$, $\Upsilon(2S)$ and $\Upsilon(1S)$ in CLEO

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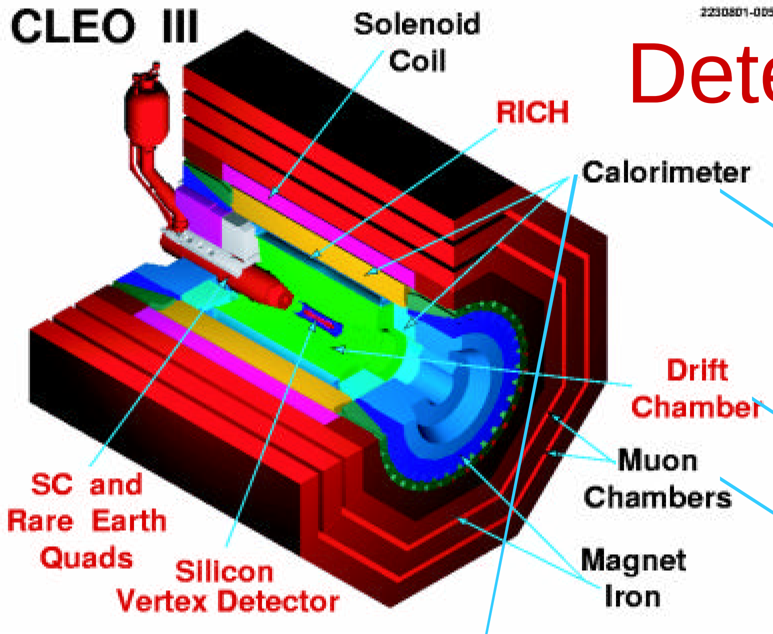
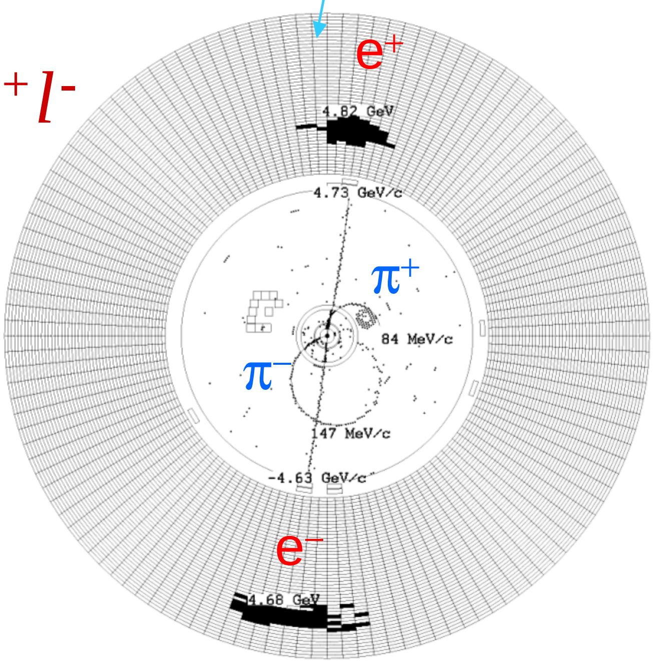
Detector and events

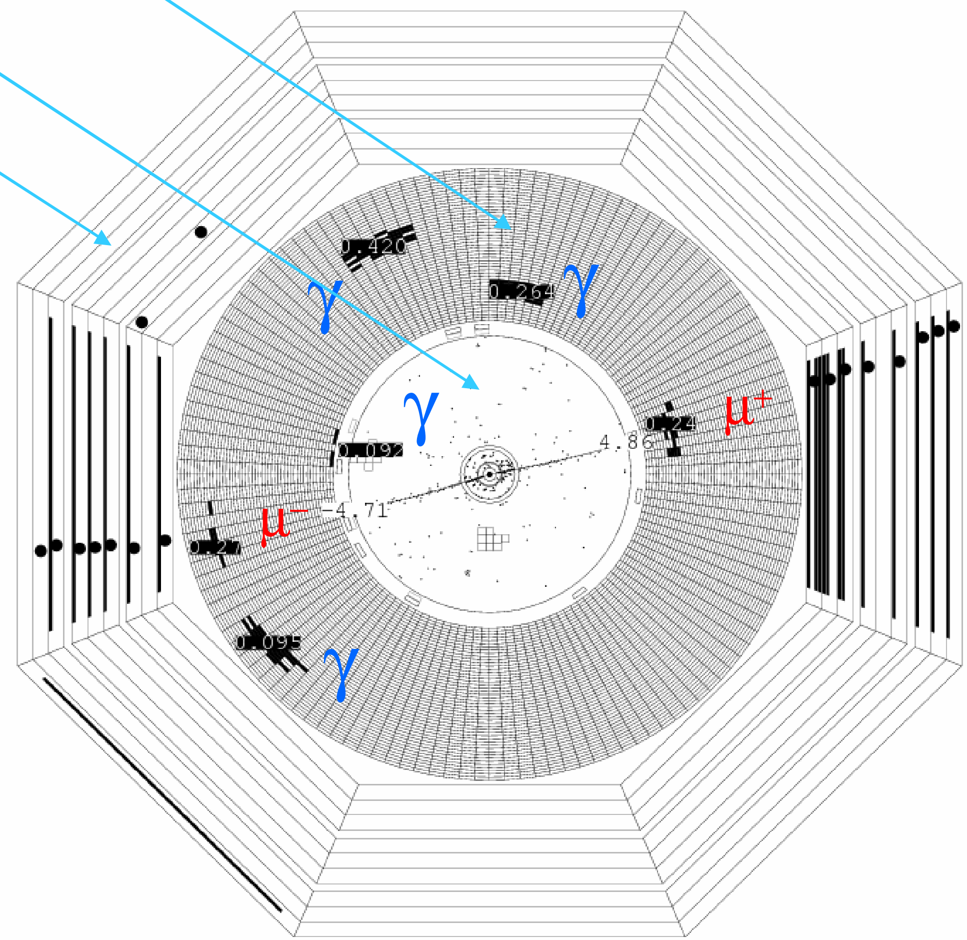
$\Upsilon' \to \pi\pi\Upsilon,\ \Upsilon \to l^+l^-$



$\pi^+\pi^- \ l^+l^-$

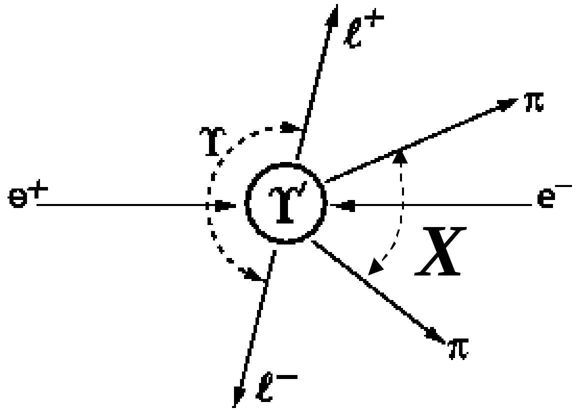


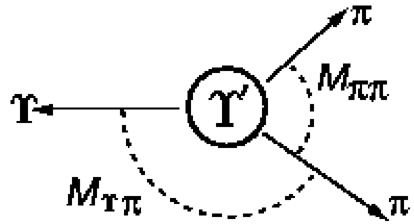
$\pi^0\pi^0 \ l^+l^-$



Dalitz variables

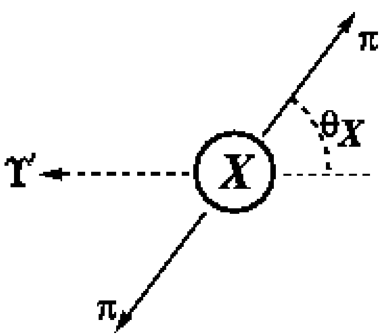
- Three body decay: ϒ'→ϒππ. If no coupling of ππ system to ϒ's polarizations then only 2 degrees of freedom.





$$q^2 = M_{pp}^{\ 2}$$

$$r^2 = M_{\Upsilon p}^{\ 2}$$



$$\cos q_X = \frac{M_{\Upsilon(2S)}^{\ 2} + M_{\Upsilon(1S)}^{\ 2} + 2m_p^{\ 2} - q^2 - 2r^2}{\sqrt{\Lambda_3(M_{\Upsilon(2S)}^{\ 2}, M_{\Upsilon(1S)}^{\ 2}, q^2)\frac{q^2 - 4m_p^{\ 2}}{q^2}}}$$

$$\Lambda_3(a,b,c) = a^2 + b^2 + c^2 - 2ab - 2bc - 2ca$$

- Use q^2, $\cos q_X$

Matrix element

- Heavy (b$\underline{\text{b}}$) and light (ππ) degrees of freedom should approximately factorize
- Furthermore, since pions emitted in these transitions are soft, general structure of the matrix element can be constrained from **chiral symmetry** (PCAC) [Brown,Cahn PRL, 35, 1 (75)] in non-relativistic limit:

$$M = \mathrm{A}(e'\cdot e)(q^2 - 2m_p{}^2) + \mathrm{B}(e'\cdot e)E_1E_2 + \mathrm{C}[(e'\cdot q_1)(e\cdot q_2) + (e'\cdot q_2)(e\cdot q_1)]$$

e', e – Polarization vectors of parent and daughter ϒ states

q_1, q_2 – Four-vectors of pions, E_1, E_2 – their energies in parent ϒ rest frame

$$q^2 = (q_1 + q_2)^2 \equiv M_{pp}{}^2$$

$$2q_1\cdot q_2$$

No cosθ$_X$ dependence!

Lorentz invariant form:

$$E_1E_2 \sim [(P'\cdot q_1)(P\cdot q_2) + (P'\cdot q_2)(P\cdot q_1)]$$

P', P – Four-vectors of parent and daughter ϒ

Depends on both q^2 and cosθ$_X$

Couples pions to ϒ's polarizations

- Form factors A,B,C expected to be approximately constant (and real in the strict chiral limit)

Initial Theory

$$M = A(e'\cdot e)(q^2 - 2m_p^{\ 2}) + B(e'\cdot e)E_1E_2 + C[(e'\cdot q_1)(e\cdot q_2) + (e'\cdot q_2)(e\cdot q_1)]$$

- In **Multipole Expansion** model, the 3rd term involves magnetic interactions (spin flip) and can be neglected compared to the leading E1*E1 transition [Yan PR,D22,1652 (80)].

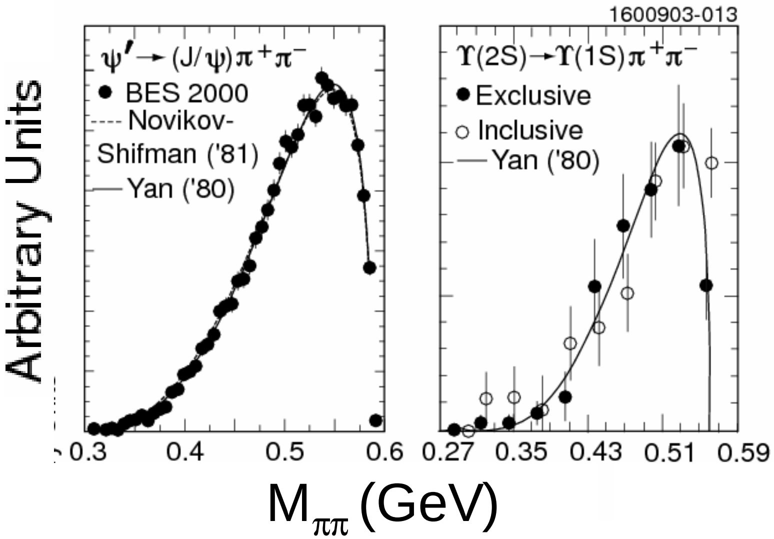
$$C \approx 0$$

- In QCD-motivated calculation of soft-pion piece in E1*E1 transition, expect S-wave to dominate in the **non-relativistic limit** producing M($\pi\pi$) distribution similar to the one due to the 1st term
[Voloshin,Zakharov,PRL,45,688(80); Novikov, Shifman, ZP,C8,43(81)]

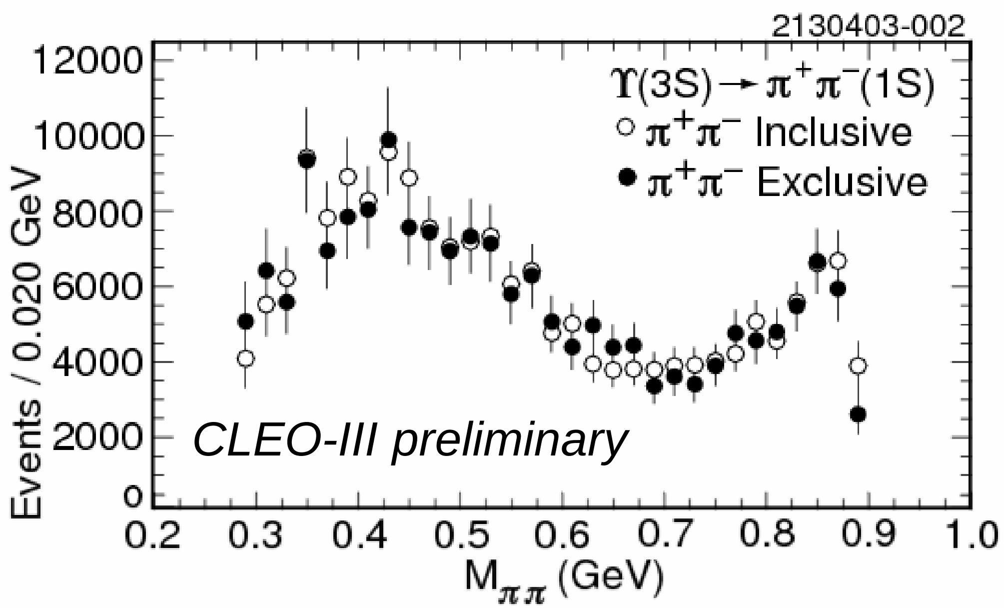
$$|A| \gg |B|$$

- Consistent with the phenomenological observation by Brown&Cahn, that M($\pi\pi$) in $\psi(2S)\rightarrow J/\psi(1S)\pi\pi$ was well reproduced by assuming B=C=0

- Observation of $\Upsilon(2S)\rightarrow\Upsilon(1S)\pi\pi$ with the same M($\pi\pi$) distribution was a great success of this theoretical framework and reinforced A-dominance dogma



$\Upsilon(3S)\rightarrow\Upsilon(1S)\pi\pi$ Anomaly



- Observation of double-peak structure of $M(\pi\pi)$ was proclaimed anomalous

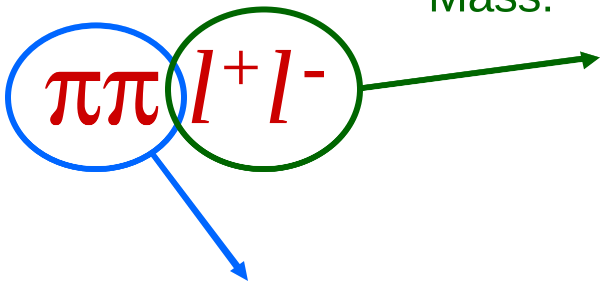
- A large body of theoretical work trying to explain the origin of this anomaly:
  - Large final state interactions [Belanger,DeGrand,Moxhay,PR,D39,257(89);Chakravarty,Kim,Ko,PR,D50,389(94)]
  - σ-meson in $\pi\pi$ system [Komada,Ishida,Ishida,PL,B508,31(01);PL,B518,47(01);Uehara Prog.Theor.Phys.109,265(03)]
  - Exotic $\Upsilon\pi$ resonance [Voloshin,JTEP Lett.,37,69(83);Belanger et al ,PR,D39,257(89); Anisovich,Bugg,Sarantsev,Zhou,PR,D51,4619(95); Guo,Shen,Chiang,Ping,NP,A761,269(05).]
  - Ad hoc constant term in amplitude [Moxhay,PR,D39,3497(89)]
  - Coupled channel effects [Lipkin,Thuan,PL,B206,349(88);Zhou,Kuang,PR,D44,756(91)]
  - 3^3S_1-n^3D_1 mixing [Chakravarty,Kim,Ko,PR,D48,1212(93)]
  - Relativistic corrections [Voloshin,PR,D74,054022(06)]

- Observed distributions of $M(\pi\pi)$ in $\Upsilon(4S)\rightarrow\Upsilon(1S)\pi\pi$ and $\Upsilon(4S)\rightarrow\Upsilon(2S)\pi\pi$ add to the interest (see the next talk!)

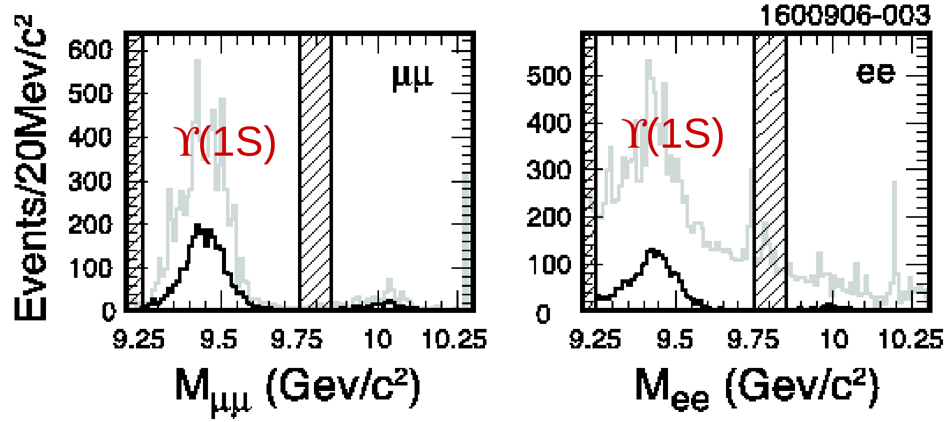
This analysis

- Much larger statistics for Υ(3S)→Υ(1S)ππ, Υ(3S)→Υ(2S)ππ than previously available.
  - 1.14 fb^{-1} at ¡ (3S): 5M ¡ (3S) with CLEO-III detector
- Analyze also Υ(2S)→Υ(1S)ππ present in the same Υ(3S) data sample (produced via Υ(3S)→Υ(2S)X, X=ππ or γγ):
  - 0.5M ¡ (2S)
- Perform 2D fit of A,B (and C) to [q^2, cosq_X] instead of 1D analysis of $m_{\pi\pi}$
  - Assume A,B (and C) constant, but allow them to be complex
- Better experimental insight into decay structure of ππ transitions!

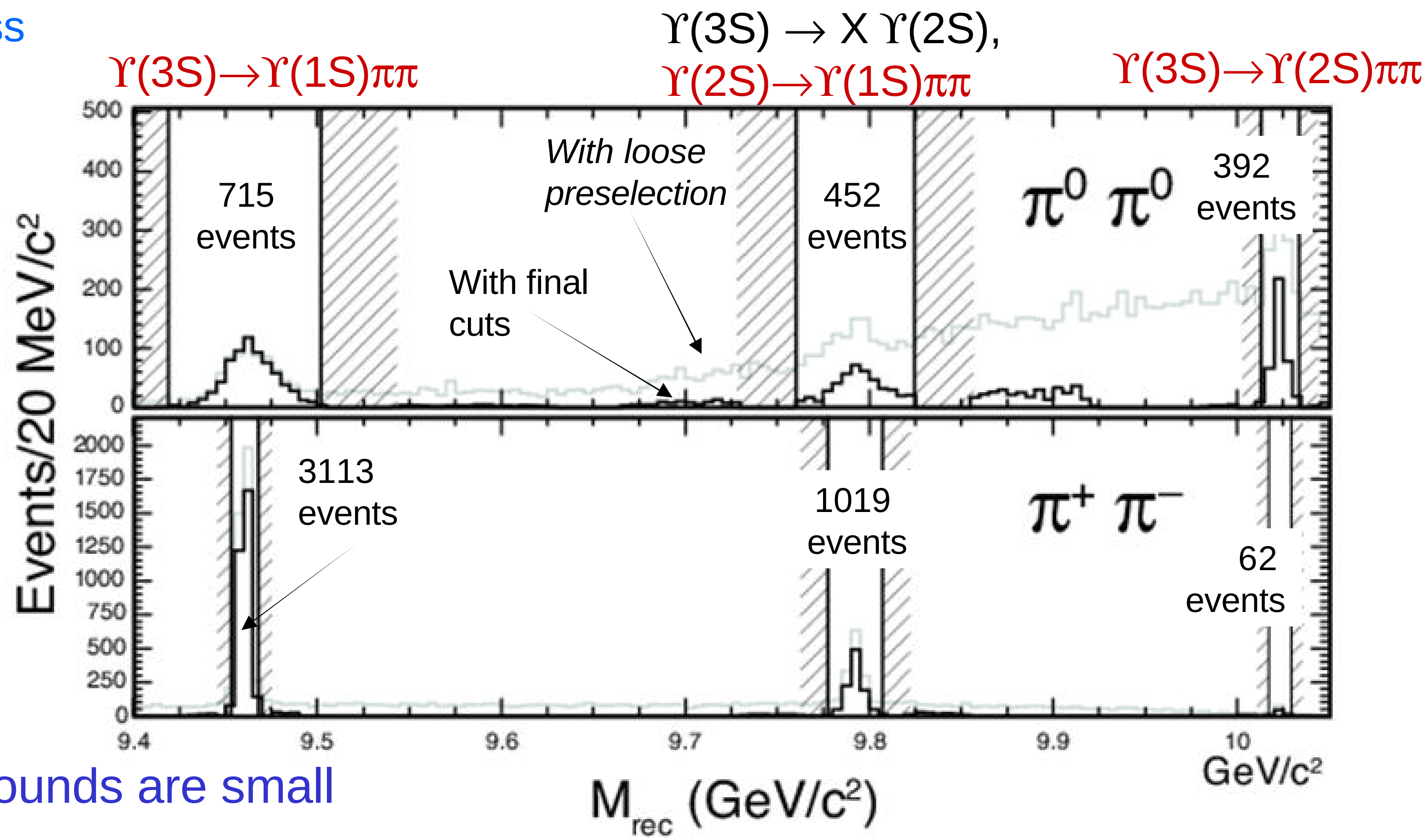
Signal selection



Di-lepton Mass:



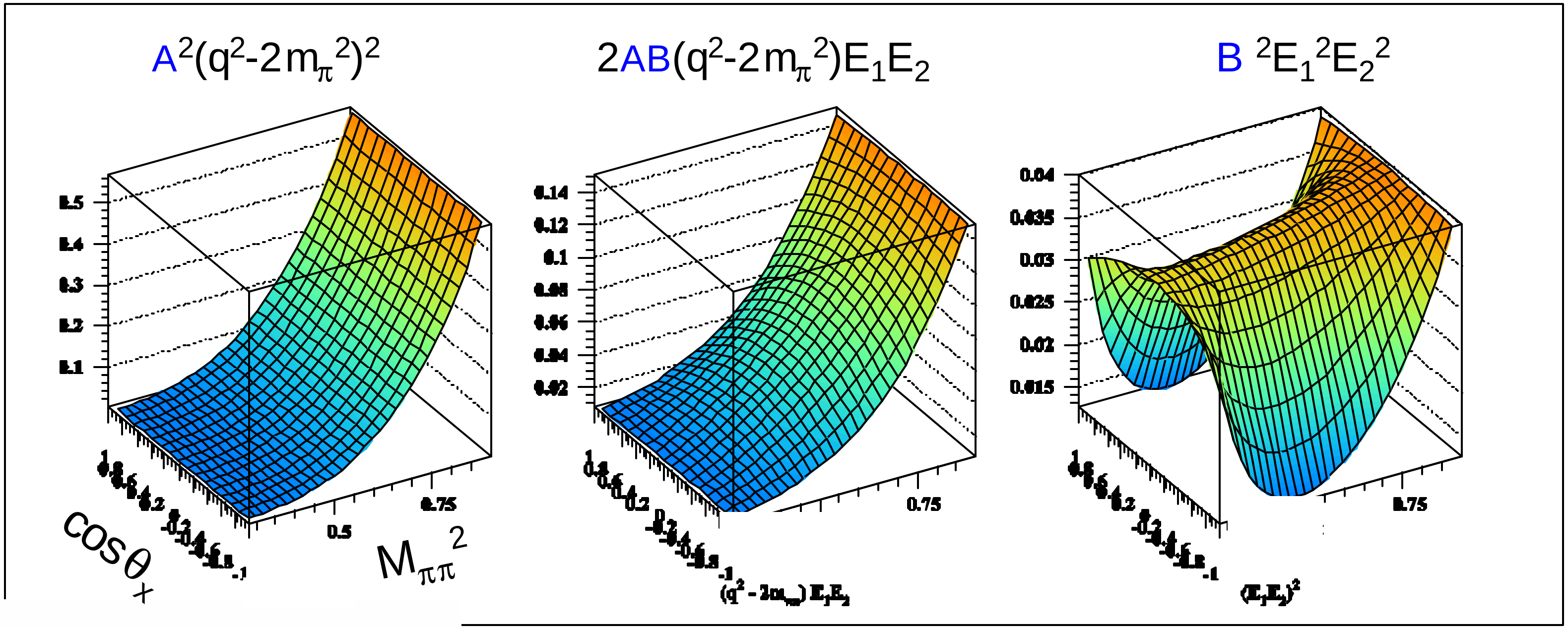
Recoil mass against $\pi\pi$:



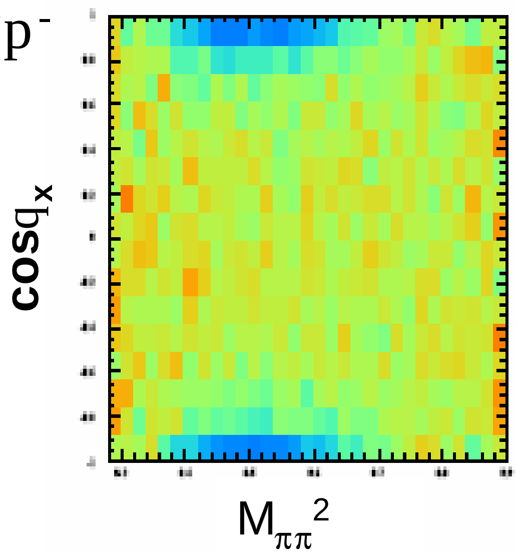
- Backgrounds are small

Expected "Dalitz" Plot Distributions

Matrix Elements Squared



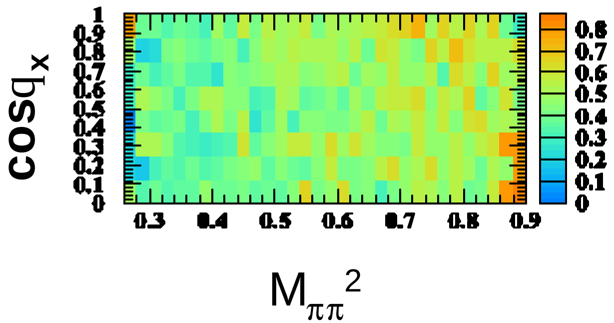
p⁺p⁻



Efficiency

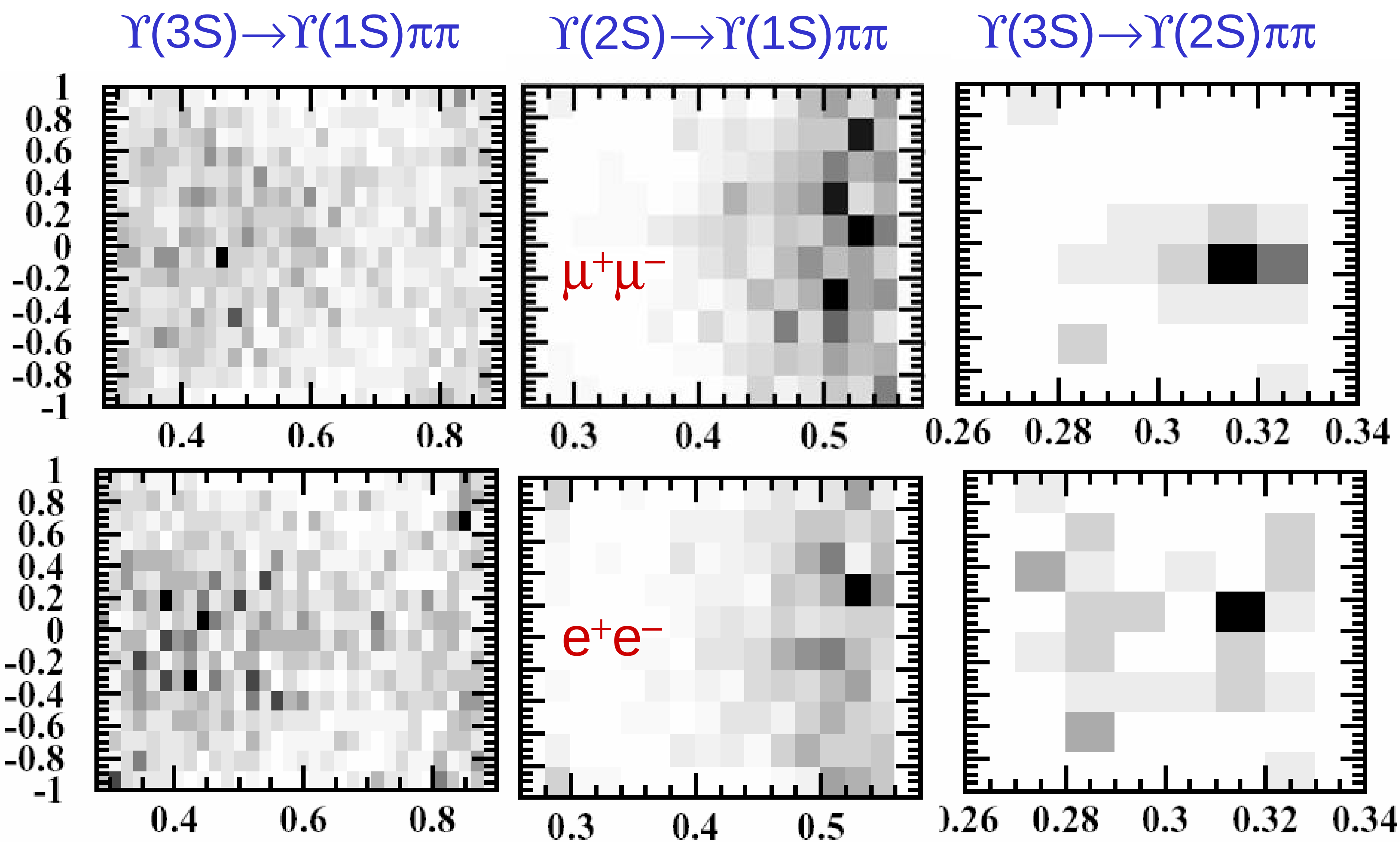
(MC)

p⁰p⁰



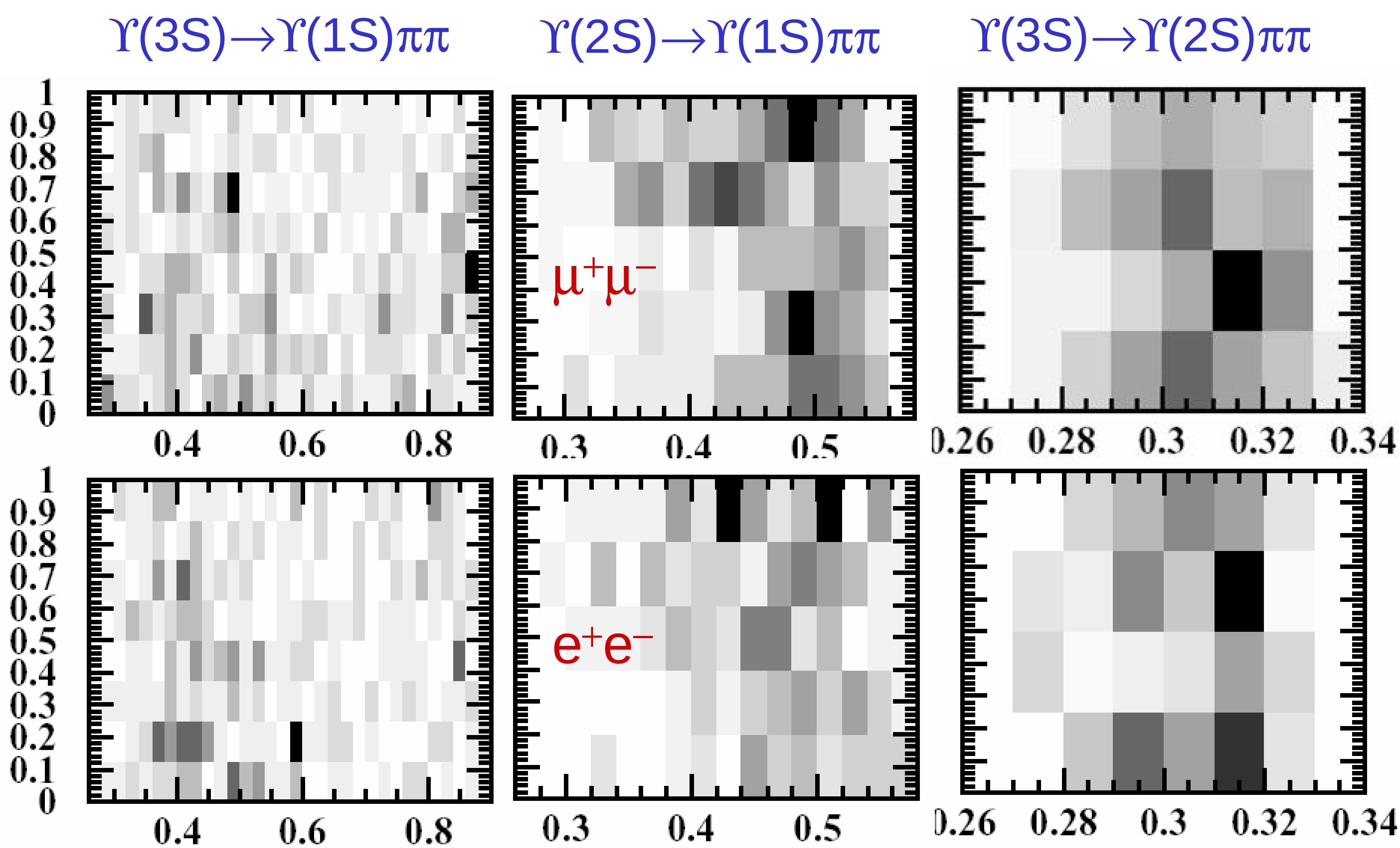
Efficiency taken into account in the fit, including MC statistical errors.

$\pi^+\pi^-$ data



cosq_X vs. $M_{\pi\pi}$

$\pi^0\pi^0$ data



$\cos q_X$ vs. $M_{\pi\pi}$

Results for $\Upsilon(3S)\rightarrow\Upsilon(1S)\pi\pi$ with C = 0

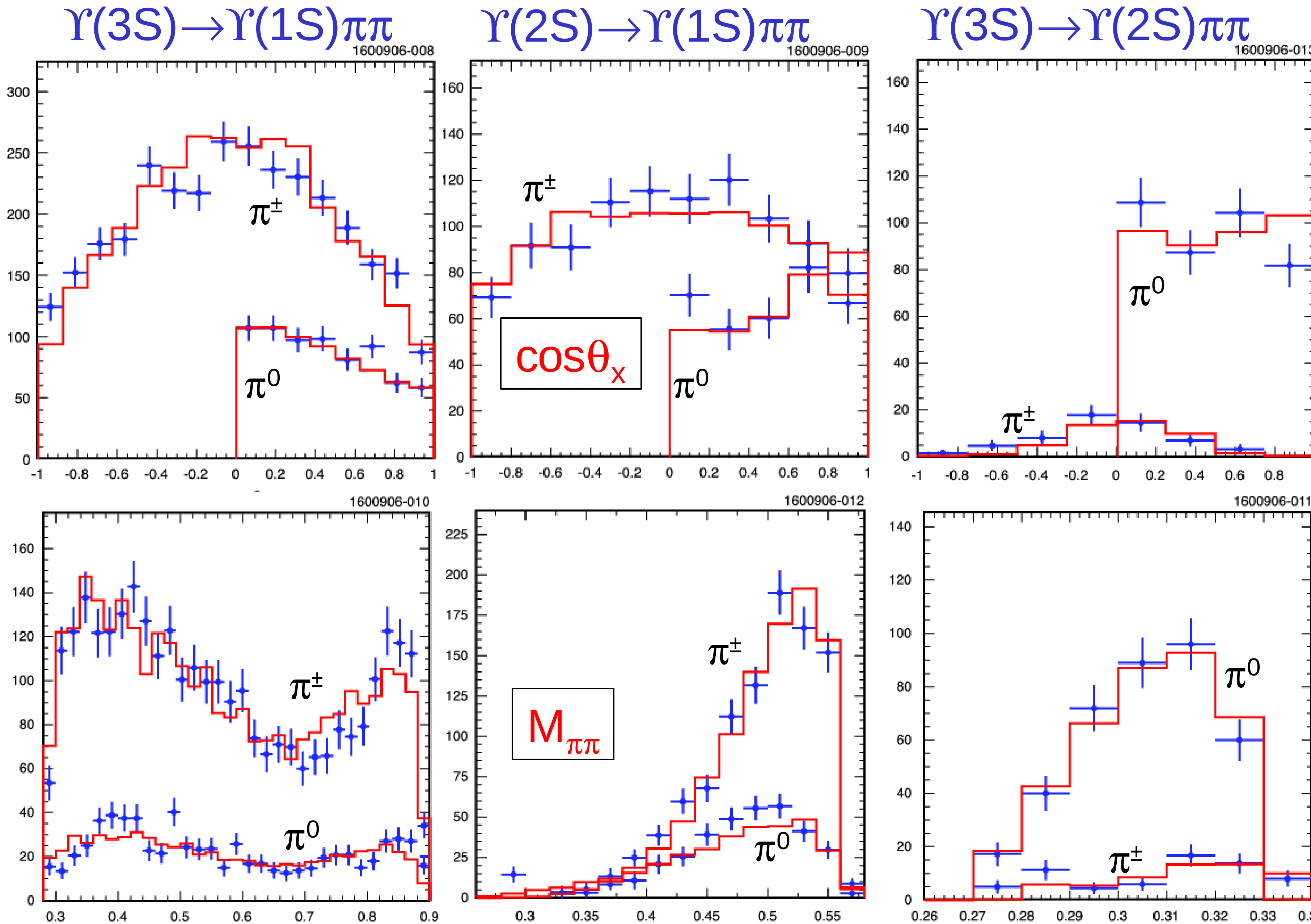
Statistical errors only

	Pions	Lep's	Re(B/A)	Im(B/A)
Individual fits	p^+p^-	**e^+e^-**	-2.53 ± 0.05	+1.18 ± 0.08
	p^+p^-	m^+m^-	-2.51 ± 0.04	+1.16 ± 0.06
	p^0p^0	**e^+e^-**	-2.52 ± 0.09	+1.07 ± 0.15
	p^0p^0	m^+m^-	-2.43 ± 0.09	+1.31 ± 0.16
Comb fit	pp	**l^+l^-**	-2.52 ± 0.03	+1.19 ± 0.05

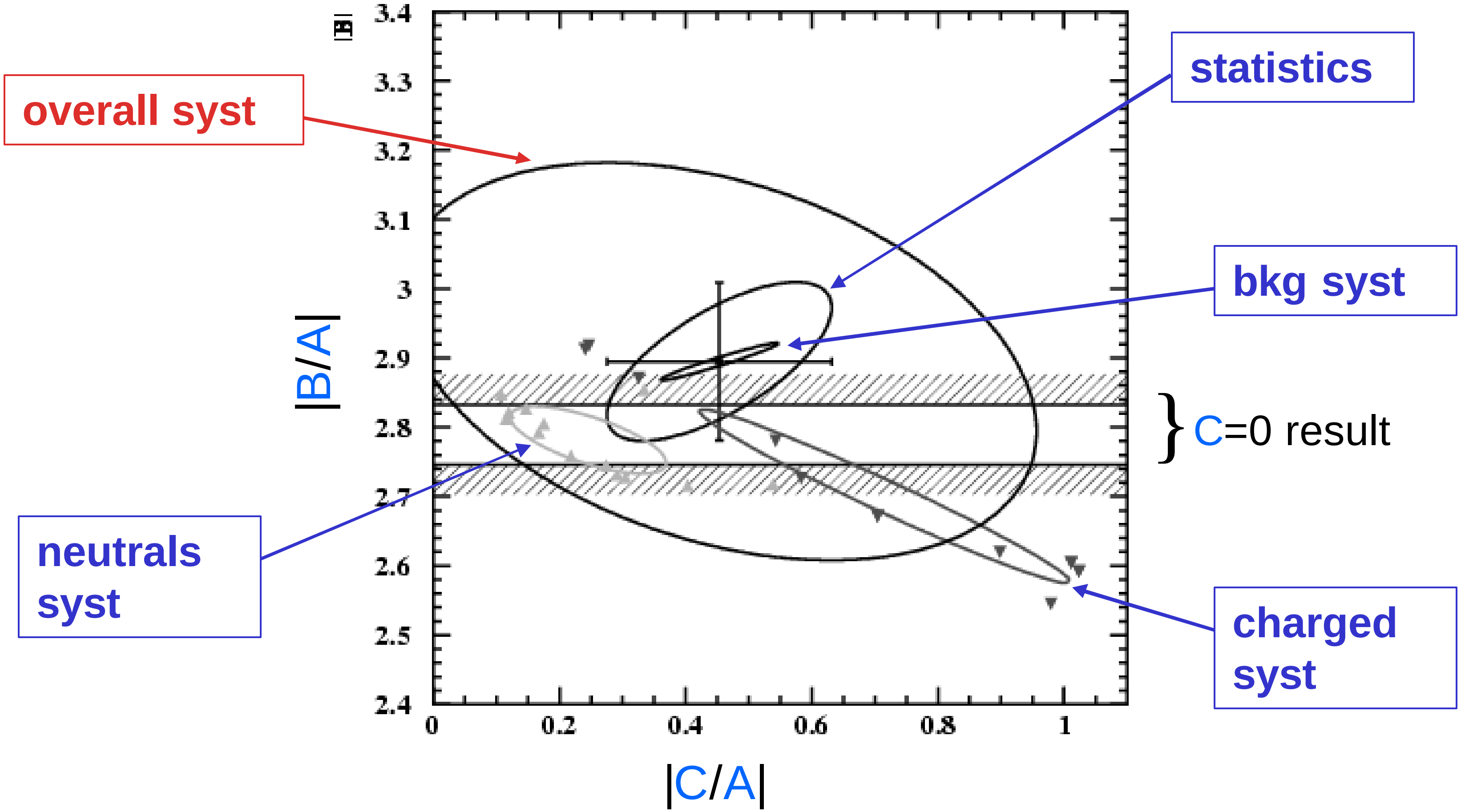
Good checks of systematic effects

based on isospin symmetry and lepton universality.

Projections: fit vs data (C = 0)



Allowing C term in the fit to Υ(3S)→Υ(1S)ππ



- |C/A| « |B/A| as theoretically expected
- Given statistical and systematic errors there is no evidence that C-term (spin flip) is needed: |C/A| = 0.45±0.18±0.36 (<1.1 90% CL).

Results

- Allowing C-term

Errors include systematic uncertainty

	|C/A|	|B/A|
$\Upsilon(3S)\to\Upsilon(1S)\pi\pi$	0.45±0.40	2.89±0.25

- Assume no spin-flip transitions (C=0)

	Re(B/A)	Im(B/A)	|B/A|	Arg(B/A)
$\Upsilon(3S)\to\Upsilon(1S)\pi\pi$	-2.52±0.04	1.19±0.07	2.79±0.05	155±2°
$\Upsilon(2S)\to\Upsilon(1S)\pi\pi$	-0.75±0.15	0.00±0.11	0.75±0.15	180±9°
$\Upsilon(3S)\to\Upsilon(2S)\pi\pi$	-0.39±0.33	0.0±1.1	0.4±1.1	---

Preliminary!

S,D-wave decomposition

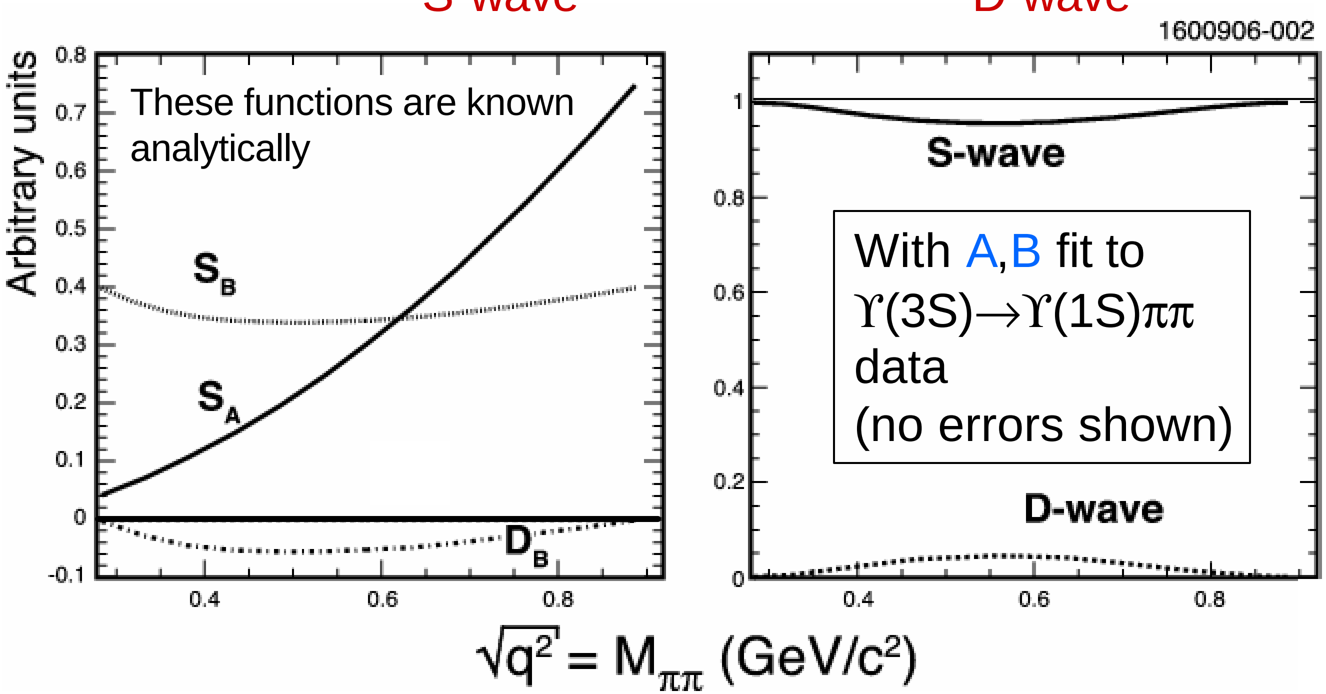
- We can extract a fraction of S- and D-wave components implied by our fits:

$$M = A\, f_A(q^2) + B\, f_B(q^2, \cos\theta_X)$$

$$= \left[A\, S_A(q^2) + B\, S_B(q^2) \right] Y_{00} + B\, D_B(q^2)\, Y_{20}(\cos\theta_X)$$

S-wave D-wave

Amplitude



Fraction of amplitude squared

- D-wave contribution is small, as expected

Conclusions

- Di-pion transitions among $\Upsilon(3S)$, $\Upsilon(2S)$ and $\Upsilon(1S)$ are well described by a matrix element constrained by Chiral Symmetry for soft pion system, with form-factor parameters being complex and constant across the Dalitz plot.

- No evidence for significant coupling to heavy quark spins, as expected ($|C/A|=0.45\pm0.40$).

- The $\Upsilon(3S)\rightarrow\Upsilon(1S)\pi\pi$ anomaly explained by a large 2nd term in the chiral matrix element ($|B/A|=2.8\pm0.1$) with a non-trivial phase ($\arg(B/A)= 155\pm2^{o}$).
- This term is smaller, but still significant in $\Upsilon(2S)\rightarrow\Upsilon(1S)\pi\pi$ ($|B/A|=0.75\pm0.12$, $\arg(B/A)= 180\pm9^{o}$).