Light Hadron Physics at Super τ-charm factory

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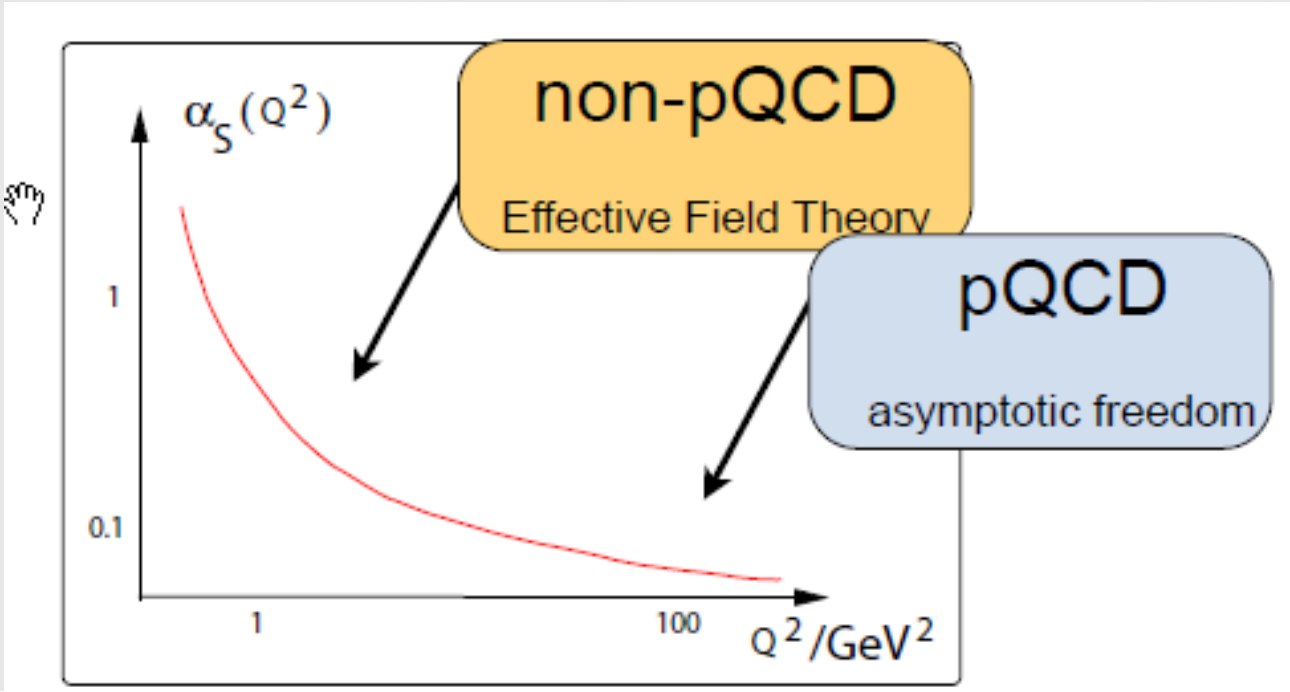
OUTLINE

- Why light hadron physics?
- What we can do at STCF ?
  - search for exotics
  - study of strangeonia
  - search for rare charmonium decays
  - light meson decays
- Summary

Why light hadron physics ?

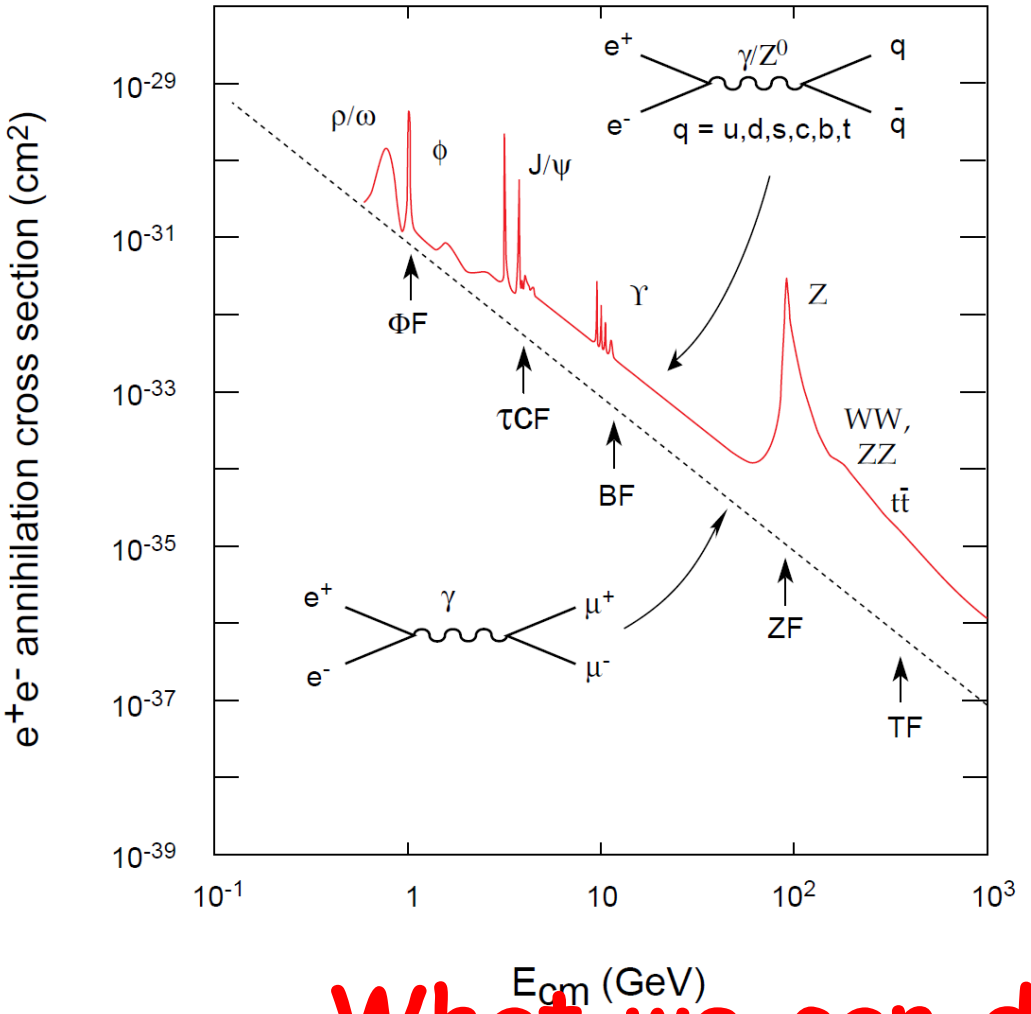


"That [intermediate distance] scale is the richest phenomenologically, and is certainly the crux region to understand...what QCD is really about. And at the heart of the subject is the hadron spectrum, in particular the spectrum built from light quarks. (...) **Without question, there is a great need... for a new round of experiments,...**"

James D. Bjorken (2000)

Super τ-charm factory

L= ~10^{35} $cm^{-2}s^{-1}$



So far BESIII:

- ~10^9 J/ψ events
- ~5×10^8 ψ' events

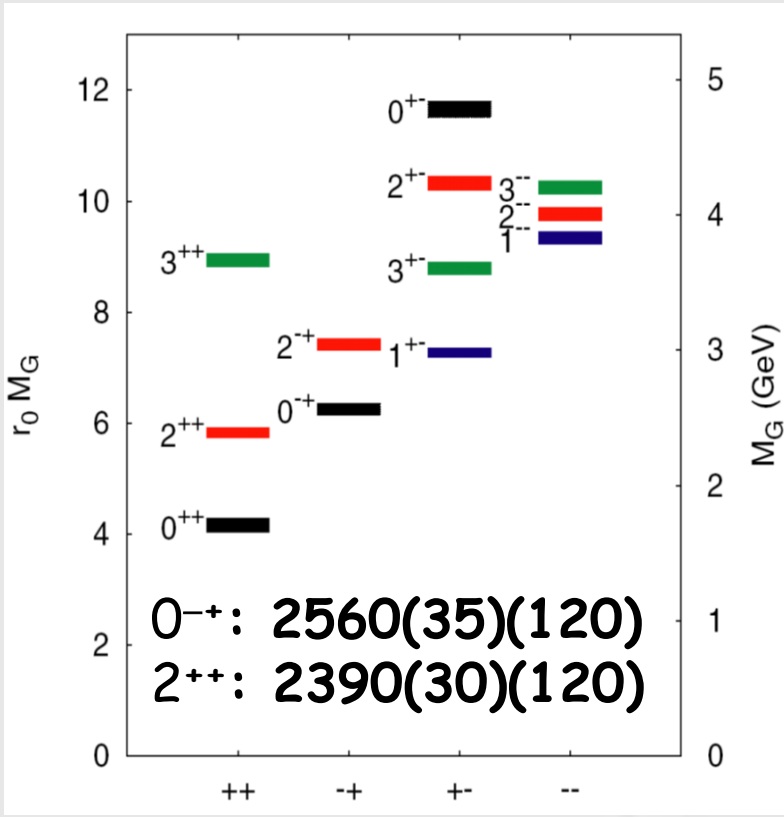
STCF: L= ~10^{35} $cm^{-2}s^{-1}$

- 10^{12} J/ψ events/year
- 3×10^{11} ψ' events/year

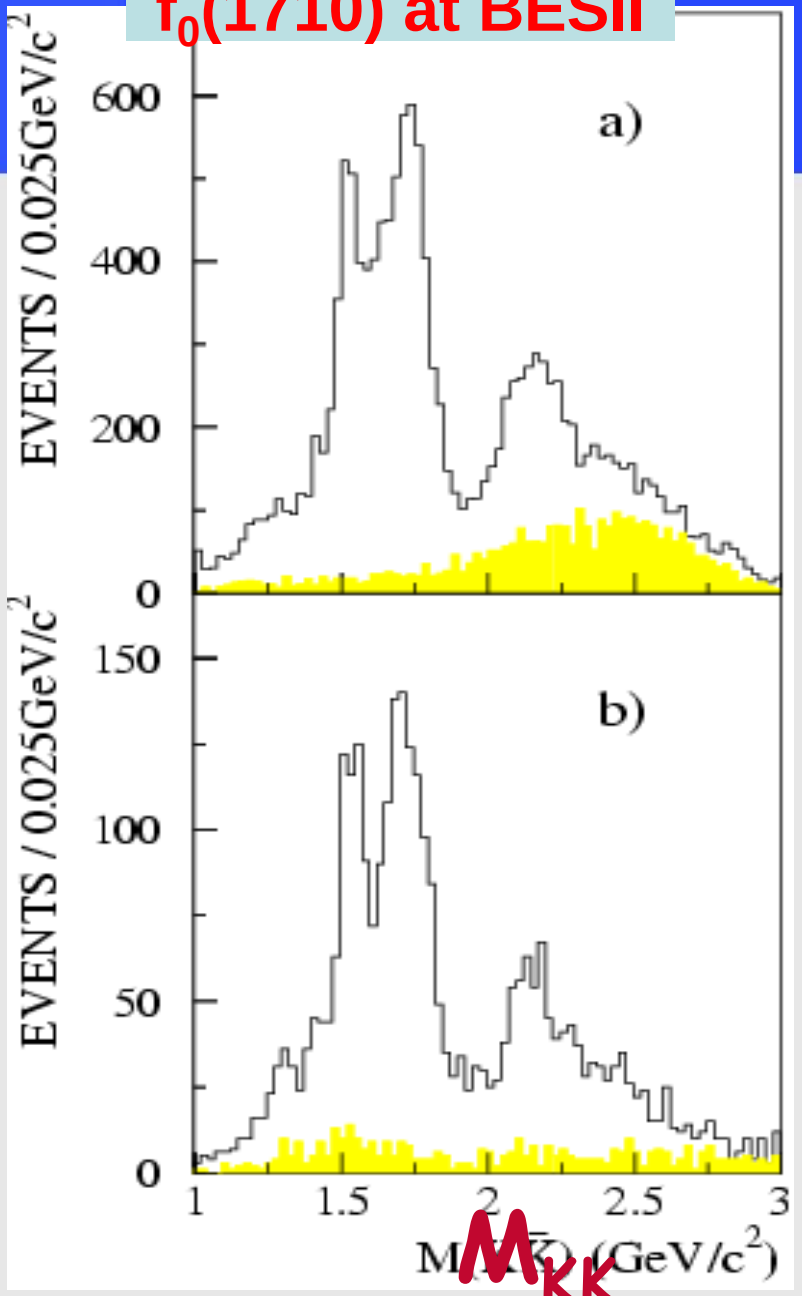
What we can do at STCF ?

search for exotics
(glueballs, exotics,multi-quark states …)

- QCD: glueballs should exist
- candidates:
$f_0(1405), f_0(1500), f_0(1710)$
- difficult to verify:
  - not easy to distinguish from $q\bar{q}$ meson, eg. same J^{PC}, mixing
  - dynamics not clear, eg. Width
- Where are they?
  - rich production in J/Ψ radiative decays ?
  - what can we learn from BESIII ?

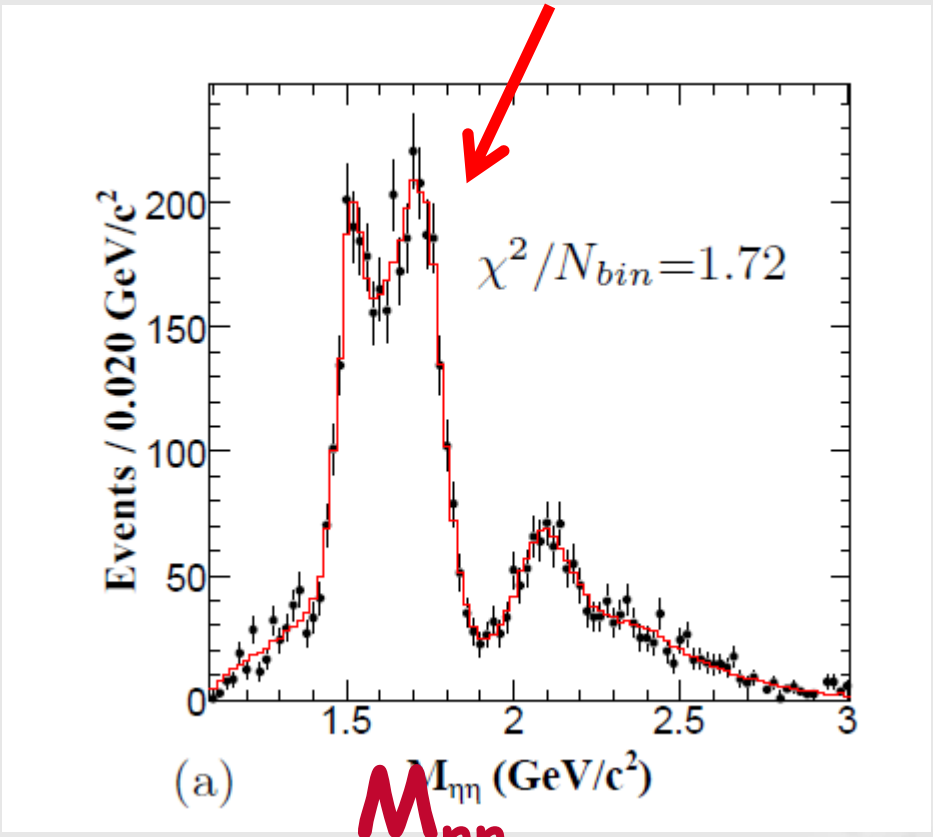


$f_0(1710)$ at BESII



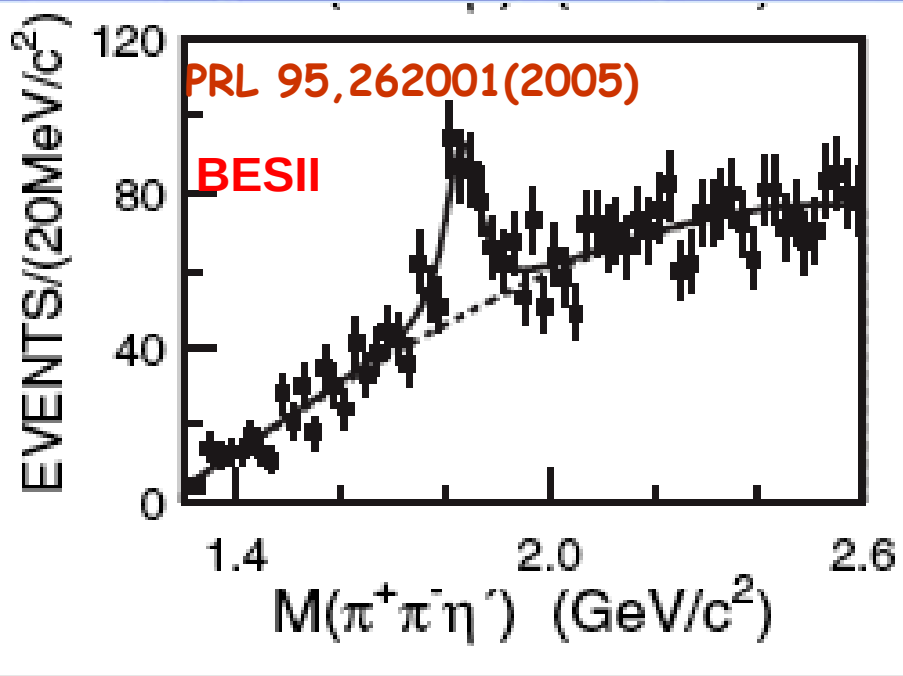
M_{KK}

$f_0(1710)$ at BESIII



$M_{\eta\eta}$

Confirmation of X(1835) and Observation of two new structures

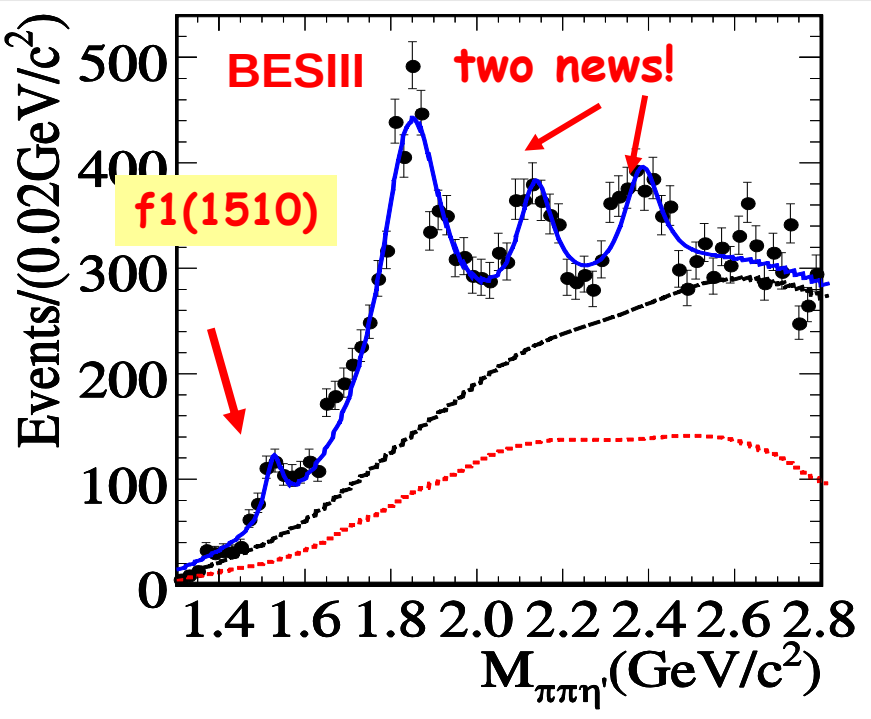


$BESII\ result(\text{Stat. sig.} \sim 7.7\sigma)$:

$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst)MeV$

$\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst})\text{MeV}$

PRL 106, 072002(2011)



$J/\psi \to \gamma\eta'\pi^+\pi^-$

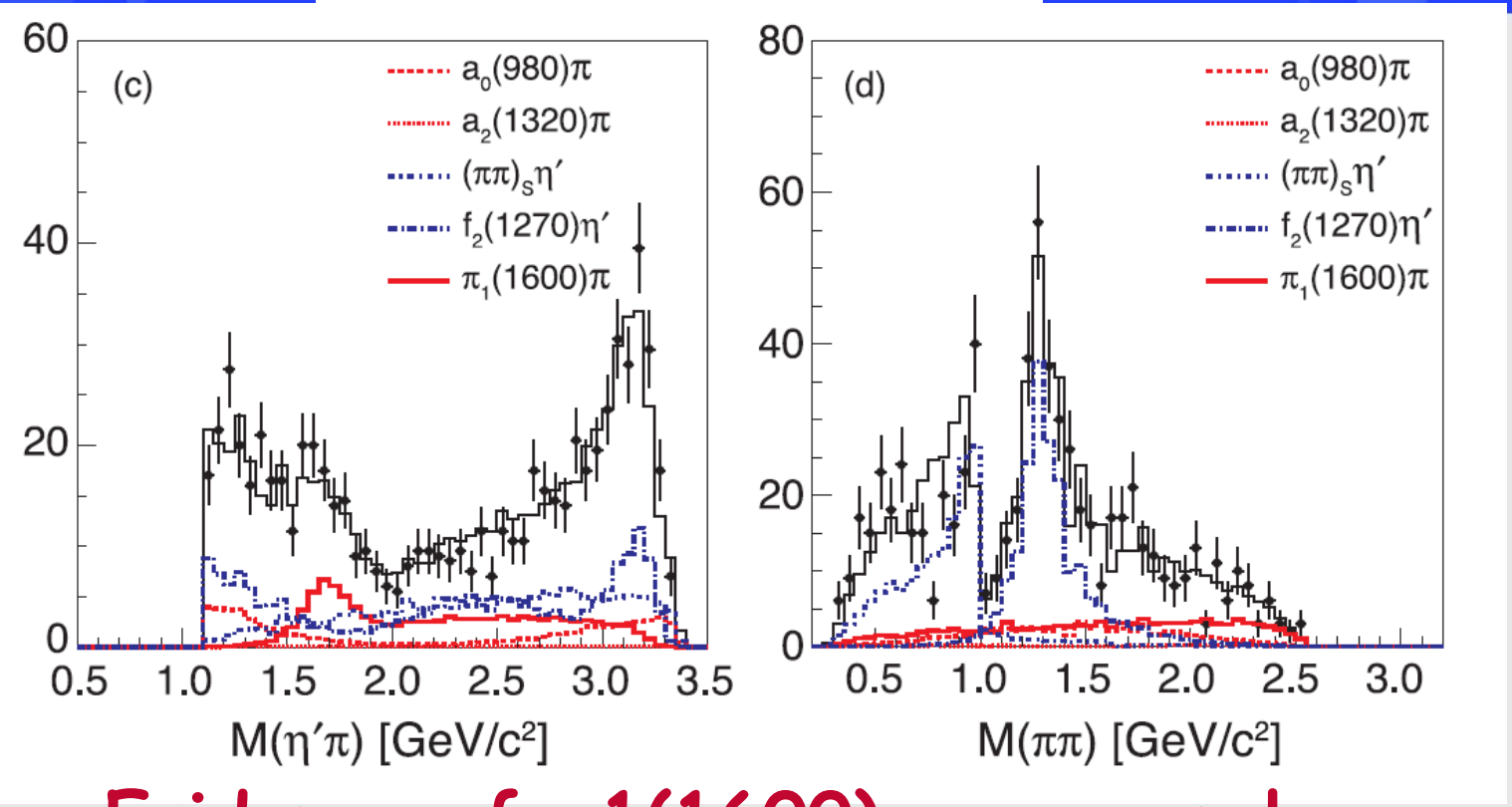
$\eta' \to \eta\pi^+\pi^-$

$\eta' \to \gamma\rho$

search for exotics
($J^{PC}=0^{--},0^{+-},1^{-+},2^{+-},3^{-+},\ldots$)

- J^{PC} exotic particles: beyond the naive quark model
- easily to distinguish from others due to the exotic J^{PC}
- production rate and dynamics are not well understood
- candidates?
  - $\pi 1(1400)$
  - $\pi 1(1600)$

CLEO $\chi_{c1} \to \eta' \pi^+ \pi^-$ 2.59×10^7 $\psi(2S)$



Evidence of $\pi 1(1600)$ was seen !

χ_{cJ}: an important source for light hadron physics!

Exotics: What we can do at STCF ?

- Established $\pi 1(1600)$ at BESIII ?
- BESIII: ~0.5 billion ψ' events are sufficient to confirm it

- What we can do at STCF ?
  - Search for its patterns
  - Expect to make a clear exotics spectroscopy finally

Why Strangeonia?

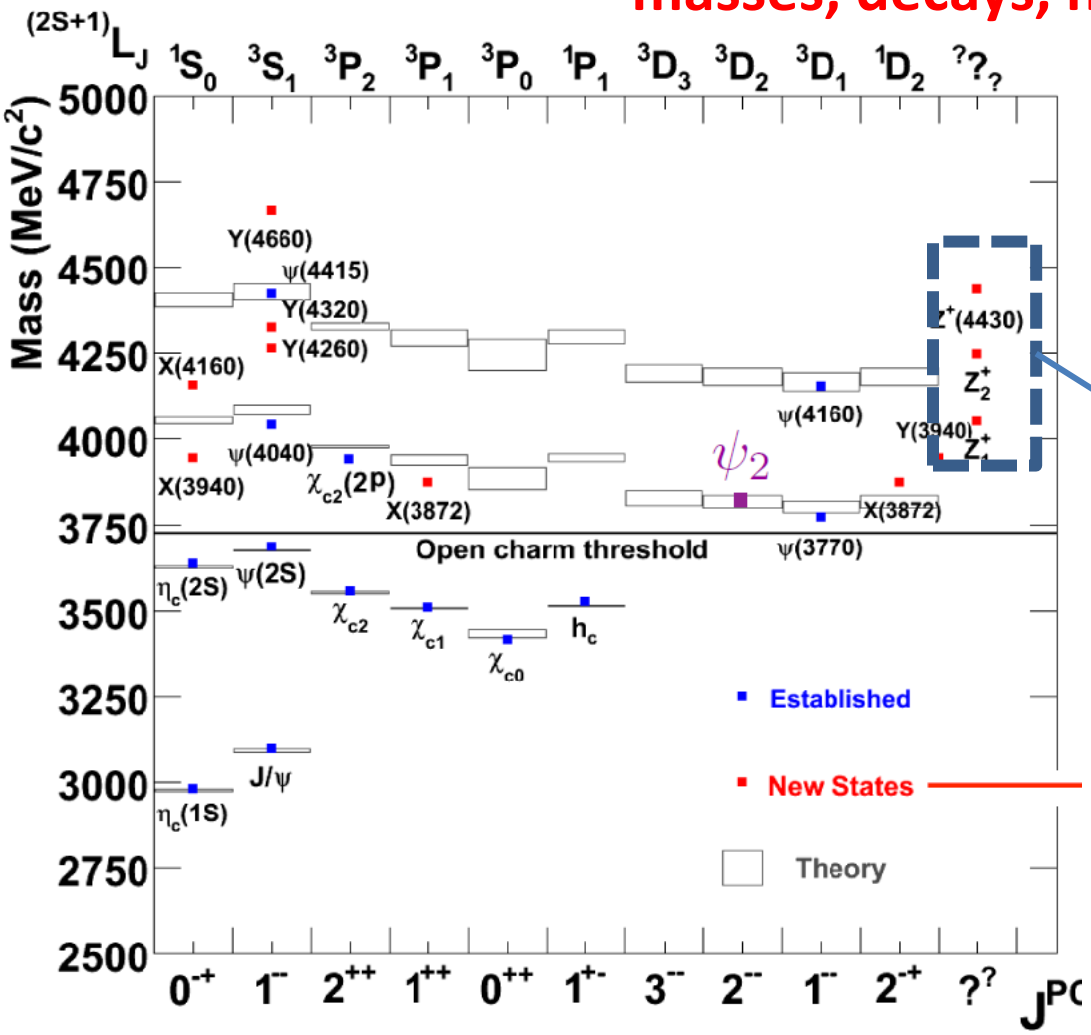
- Like charmonia, a similar pattern for the strangeonia is expected

- But much less well understood, most of them have not been observed yet

- Strangeonia serve as a bridge between short and large distance behavior of QCD confinement potential

XYZ ($c\bar{c}$) States –

Contradictions to the Quark Model: masses, decays, net charge



Serious "sorting out" and "understanding" to do

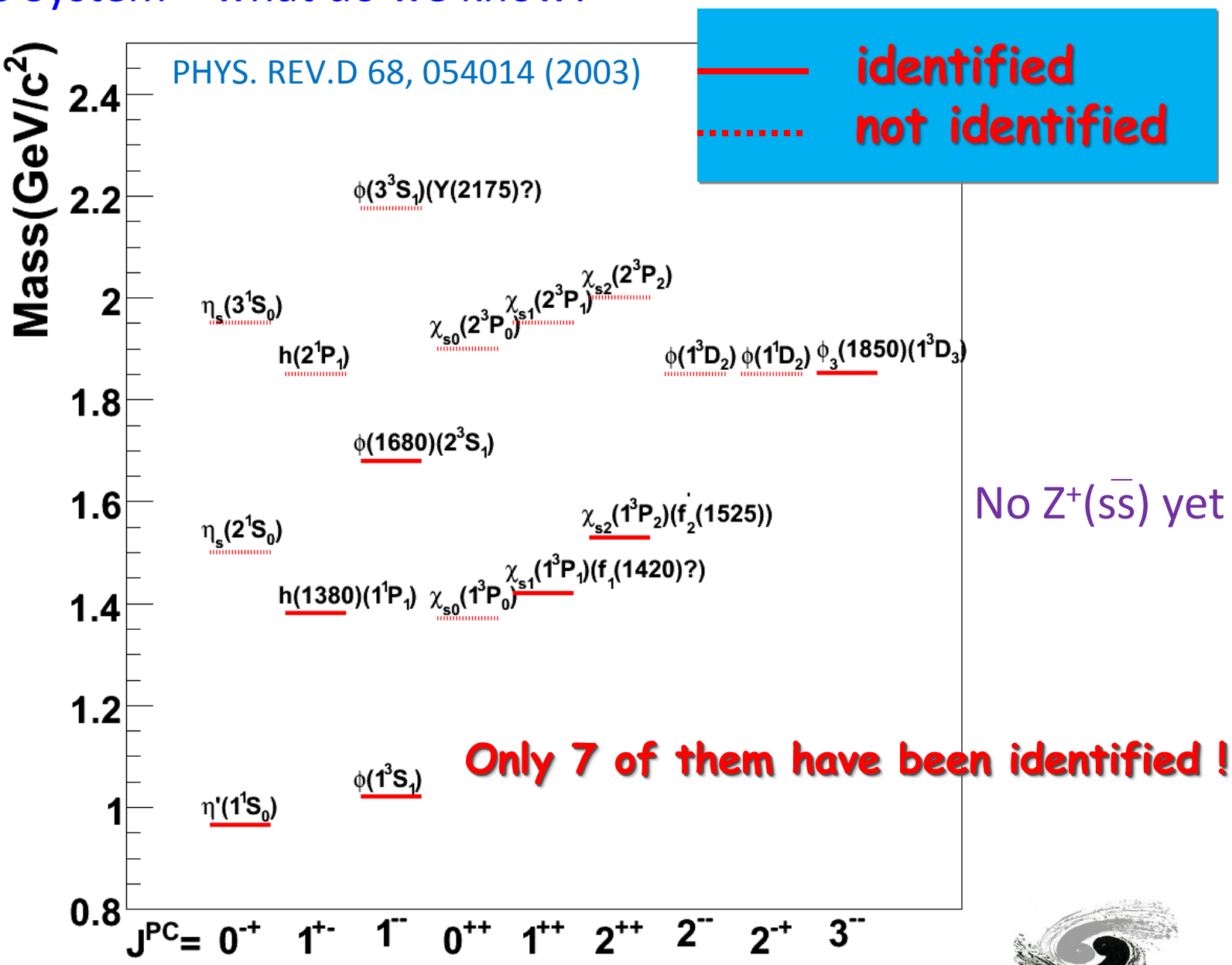
"Can not be regular mesons"

Bottomonium spectrum
C.Z. Yuan's talk

Leo Piilonen, Charm 2012

Talk from Prof. Lou at "双清论坛"

$S\bar{S}$ System – what do we know?



No $Z^+(s\bar{s})$ yet

Only 7 of them have been identified !

S. S. Fang

$s\bar{s}$ States –

Also listed in JLAB physics program

- Like charmonia & bottomonia, a similar pattern for the strangeonia can be expected
- Most of results were reported about 20~30 years ago.

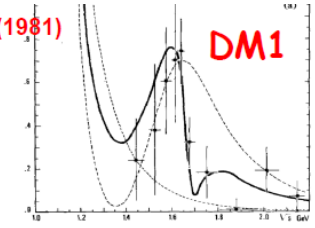
- $\phi(1680)$
- e+e- production (M~1680)

first observed by DM1

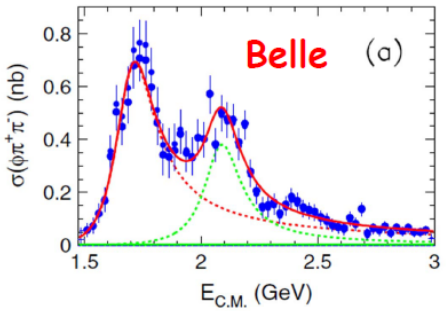
.....

latest results from Belle and Babar

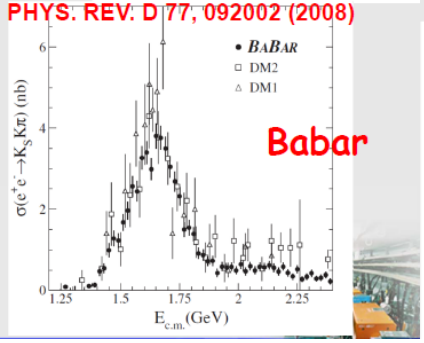
PHYS. LETT B99, 261(1981)



PHYS. REV. D 80, 031101(R) (2009)



PHYS. REV. D 77, 092002 (2008)



- a new ϕ-like state: Y(2175)

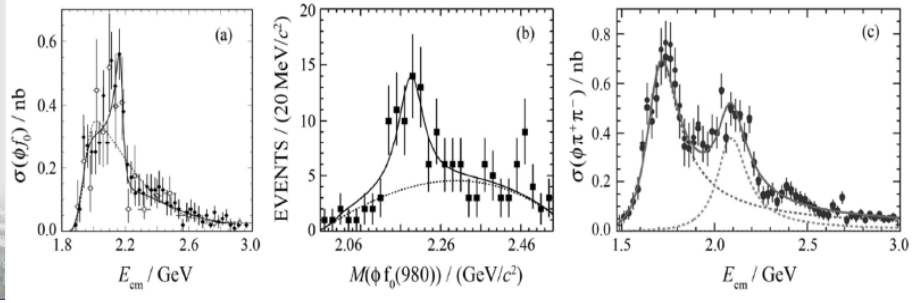
first observed by Babar

confirmed by Belle and BESII

Phys Rev, D74 : 091103(2006)

Phys Rev, 2009, D80 : 031101.

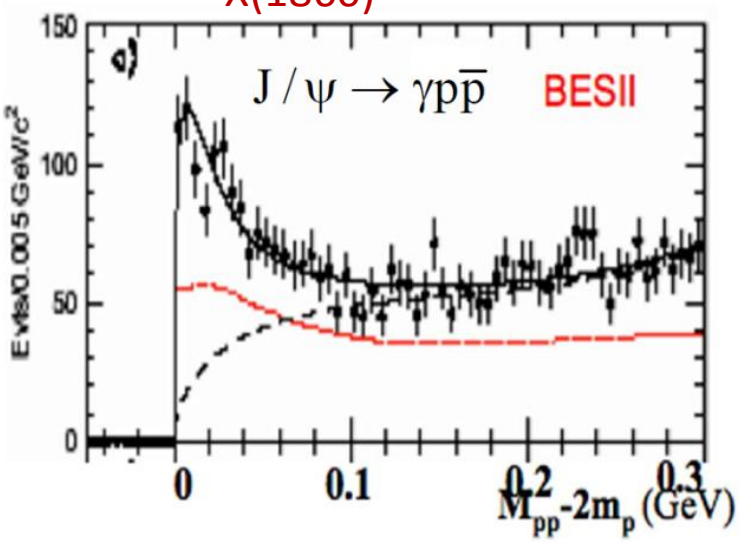
Phys. Rev Let t ,100:102003(2008)



- But much less well understood, most of strangeonia have not been observed yet
- Strangeonia serve as a bridge between short and large distance behavior of QCD confinement potential

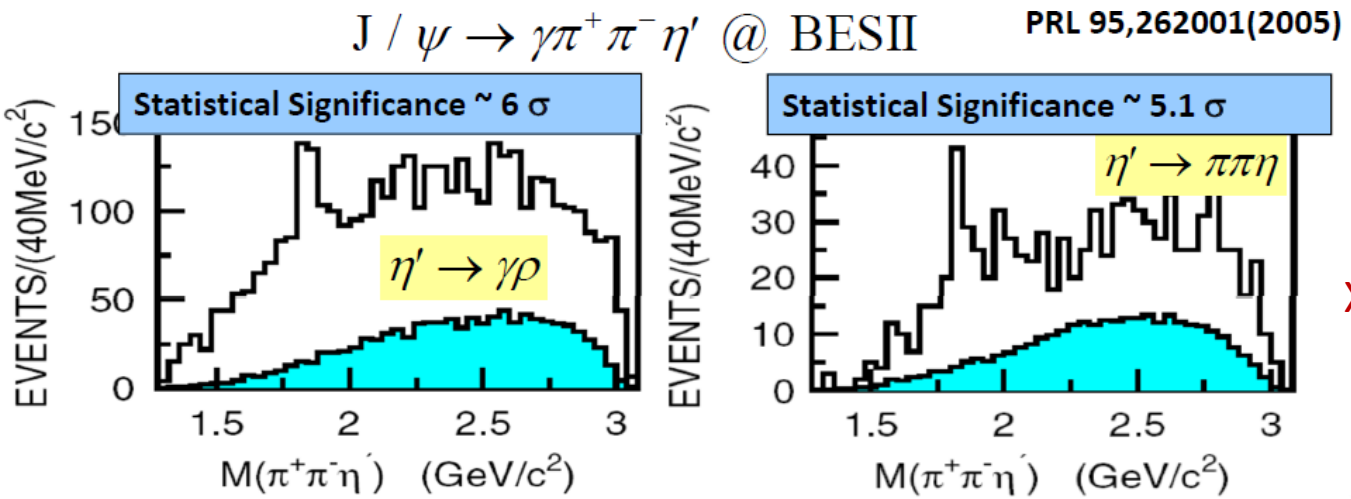
$s\bar{s}$ States –

X(1860)



BESIII has seen several new states.

Any ($s\bar{s}$) or even XYZ($s\bar{s}$)?



X(1835)

XYZ ($s\bar{s}$) States with BESIII– Ideas and Directions

- Main decay modes ($^3P_0$ model)
  - KK, K*K, K*K*, $\phi\eta$.....
- Proposed analysis

  $J/\psi(\psi') \rightarrow K^+K^-\eta,\ K^+K^-\eta',\ KK^*\eta,\ KK^*\eta',\ \phi\eta\eta,\ \phi\eta\eta'$

  $\gamma\ KK^*,\ \gamma\ K^*K^*,\ \gamma\ K^+K^-\eta,\ \gamma\ K^+K^-\eta'$ .....

Search for $Z^+(s\bar{s})$ via $(\phi,\eta)\pi^+$

Search for new (ss) states via $e^+e^- \rightarrow (\phi,\eta)(s\bar{s})$

.....

Rare Charmonium decays

- a window to search for physics beyond the SM
  - Semileptonic decays
  - Two body hadronic decays
  - Invisible decays
  - Test of fundamental symmetries, eg. C, CP, LFV

H.B. Li, S.H. Zhu, Chinese Physics C36,932(2012)

Semileptonic decays

Theoretical predictions

decay mode	Ref. [4]	Ref. [5]	Ref. [6]	Ref. [7]
$J/\psi \to D_s^- l^+ \nu + c.c.$	26	20	3.5	11.:
$J/\psi \to D_s^{*-} l^+ \nu + c.c.$	42	32	11	34.7
$J/\psi \to D^- l^+ \nu + c.c.$	1.4	1.2	0.14	1.1
$J/\psi \to D^{*-} l^+ \nu + c.c.$	2.3	2.0	0.73	3.4

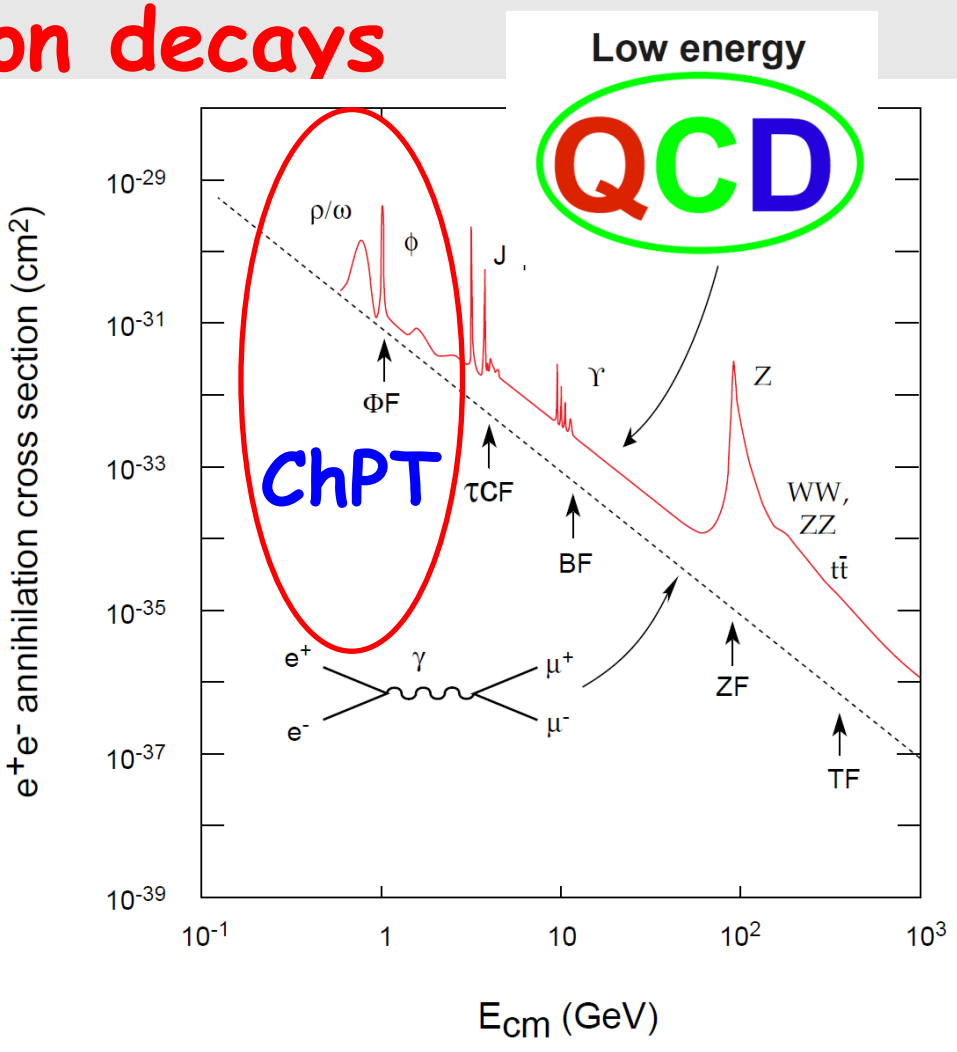
($\times 10^{-10}$)

- ✓ Branching fraction at a level of 10^{-9} -10^{-10}
- ✓ Expected to be observed at STCF

Light Meson Decays

- **Charmonium decays also offer important insight into light meson decays**

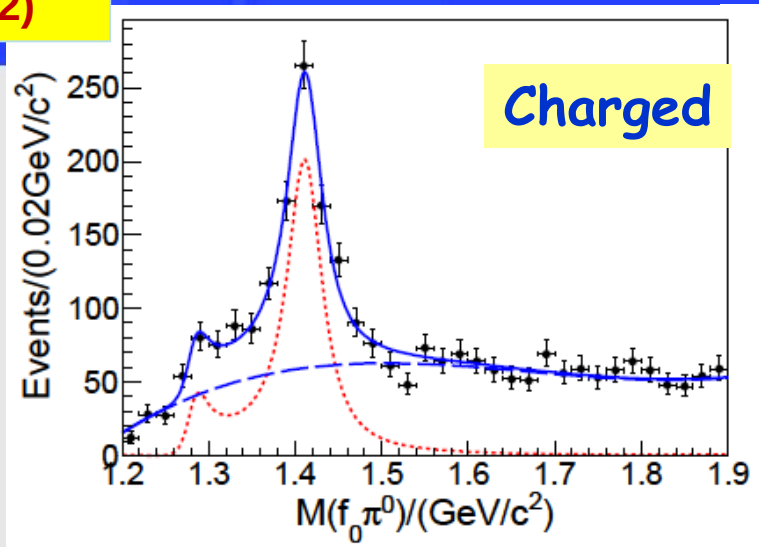
- Pseudo-scalar octet(nonet)
  - $\pi^{\pm}$, π^0
  - $K^{\pm}$, K^0, $\overline{K^0}$
  - $\eta(, \eta')$
- Vector nonet
  - ρ^0, $\rho^{\pm}$, ω
  - K^*, ϕ
- Scalars
  - $f_0(500)$ or σ, $f_0(980)$, a_0
- .....

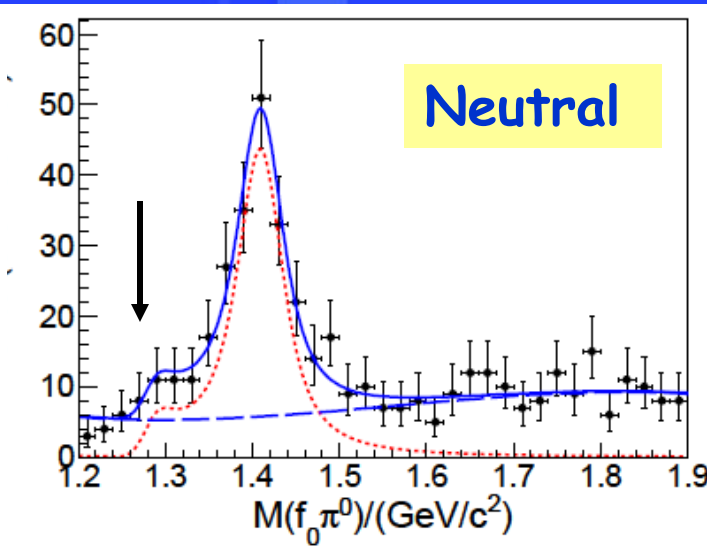


Large isospin violation in η(1405) decay

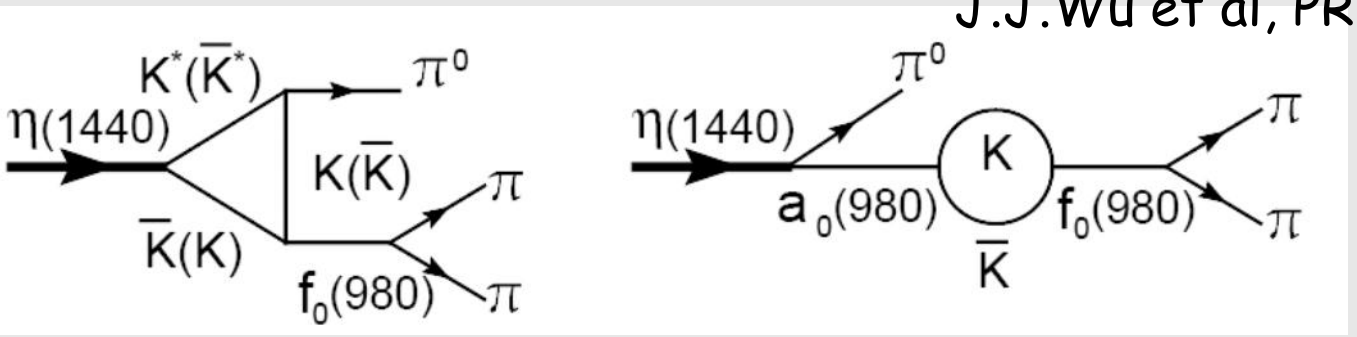
PRL 108, 182001 (2012)

Charged:
f0(980)→$\pi^+\pi^-$
Neutral
f0(980)→$\pi^0\pi^0$



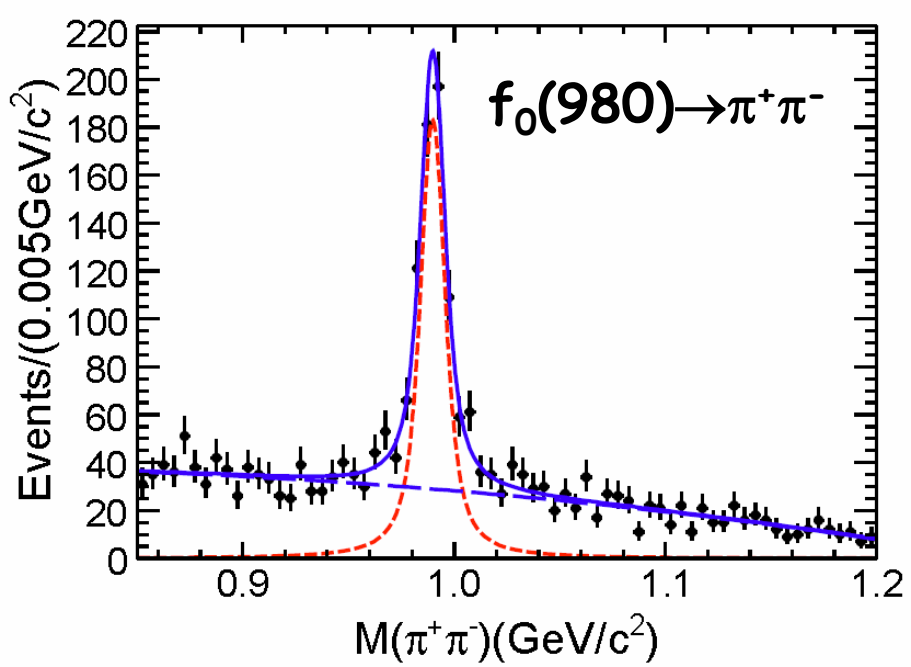


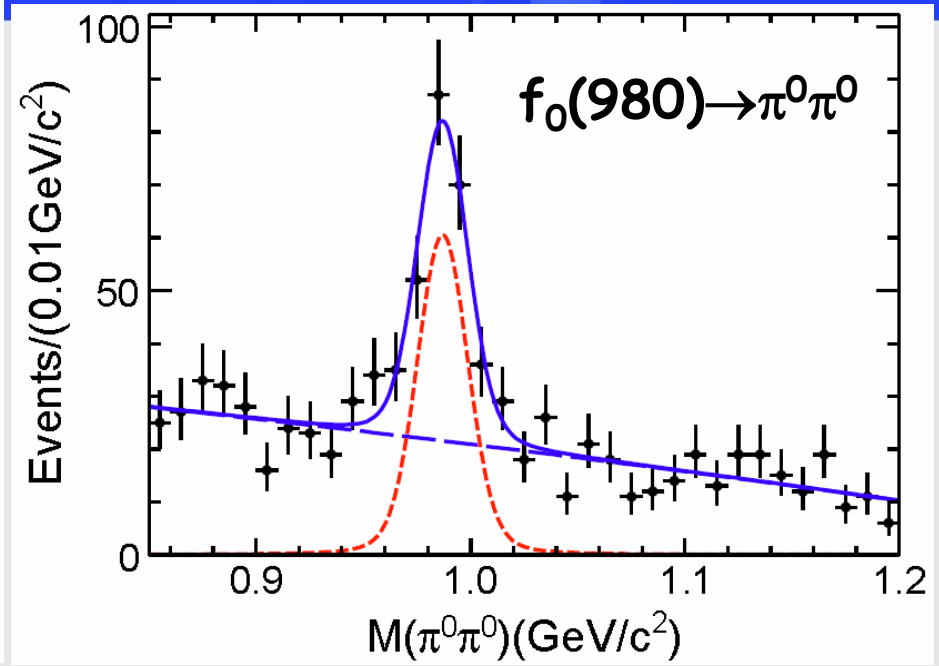
J.J.Wu et al, PRL 108, 081803(2012)



K*K pair in TS is almost on-shell, together with mixing explain the narrow $f_0(980)$, and large isospin violation.

Anomalous line shape of $f_0(980)$ in $J/\psi \to \gamma 3\pi$





$M = 989.9 \pm 0.4 \text{MeV}/c^2$
$\Gamma = 9.5 \pm 1.1 \text{ MeV}/c^2$

$M = 987.0 \pm 1.4 \text{MeV}/c^2$
$\Gamma = 4.6 \pm 5.1 \text{ MeV}/c^2$

Surprising result:

PRL 108, 182001 (2012)

very narrow $f_0(980)$ width: <11.8 MeV/c^2@90% C.L.

much narrower than the world average (PDG 2010: 40-100 MeV/c^2)

η /η′ Physics

- Still listed in many facilities' physics program (KLOE, WASA-at-COSY, CB at MAMI, GlueX, BESIII …)
- **η/η′ : a rich physics field**
  - Unique place to test fundamental symmetries in QCD at low energy
  - Probe physics beyond the SM

$\eta/\eta' \to 2\gamma$	chiral anomaly
$\eta/\eta' \to \pi^+\pi^-\pi^0$	quark masses
$\eta' \to \gamma\pi^+\pi^-$	box anomaly
$\eta/\eta' \to \pi\pi$	CP violation
$\eta/\eta' \to \mu^+\mu^-\pi^0$, $e^+e^-\pi^0$	C violation
$\eta/\eta' \to \mu e$	LF violation
……	

Precise test of ChPT !

η´ decays

Mode		Fraction (Γ_i/Γ)			Confidence level
Charge conjugation (C), Parity (P), Charge conjugation × Parity (CP), or Lepton Family number (LF) violating modes					
Γ_{23}	$\pi^0\gamma$	C	$<$ 9	$\times 10^{-5}$	CL=90%
Γ_{24}	$\pi^+\pi^-$	P,CP	$<$ 1.3	$\times 10^{-5}$	CL=90%
Γ_{25}	$2\pi^0$	P,CP	$<$ 3.5	$\times 10^{-4}$	CL=90%
Γ_{26}	$2\pi^0\gamma$	C	$<$ 5	$\times 10^{-4}$	CL=90%
Γ_{27}	$3\pi^0\gamma$	C	$<$ 6	$\times 10^{-5}$	CL=90%
Γ_{28}	3γ	C	$<$ 1.6	$\times 10^{-5}$	CL=90%
Γ_{29}	$4\pi^0$	P,CP	$<$ 6.9	$\times 10^{-7}$	CL=90%
Γ_{30}	$\pi^0 e^+ e^-$	C	[a] $<$ 4	$\times 10^{-5}$	CL=90%
Γ_{31}	$\pi^0 \mu^+ \mu^-$	C	[a] $<$ 5	$\times 10^{-6}$	CL=90%
Γ_{32}	$\mu^+ e^- + \mu^- e^+$	LF	$<$ 6	$\times 10^{-6}$	CL=90%

- ~10^9 η/η' in J/ψ decays at STCF
- sensitivity will be at a level of ~10^{-8}

Γ_{20}	$4\pi^0$	$<$ 5	$\times 10^{-4}$	90%
Γ_{21}	$e^+ e^-$	$<$ 2.1	$\times 10^{-7}$	90%
Γ_{22}	invisible	$<$ 9	$\times 10^{-4}$	90%

Summary

- Super τ-charm factory provides a unique environment for light hadron physics

- Rich physics in light hadrons
  - search for exotics → QCD
  - study of strangeonia → Quark model
  - search for rare decays → test of fundamental symmetries
  - light meson decays → test of ChPT
  - Search for missing baryons

- Next step : sensitivity checks with MC ?

Any excellent ideas are welcome !