BESII物理成果

苑 长 征
（代表BES合作组)
中国科学院高能物理研究所

第十届全国粒子物理学术会议
2008年4月26-29日，南京

北京正负电子对撞机(BEPC)和北京谱仪(BES)

1998年来设计工作在粲偶素物理能区的世界上唯一的e^+e^-对撞实验。

$L_{peak}=10^{31}/cm^2/s$

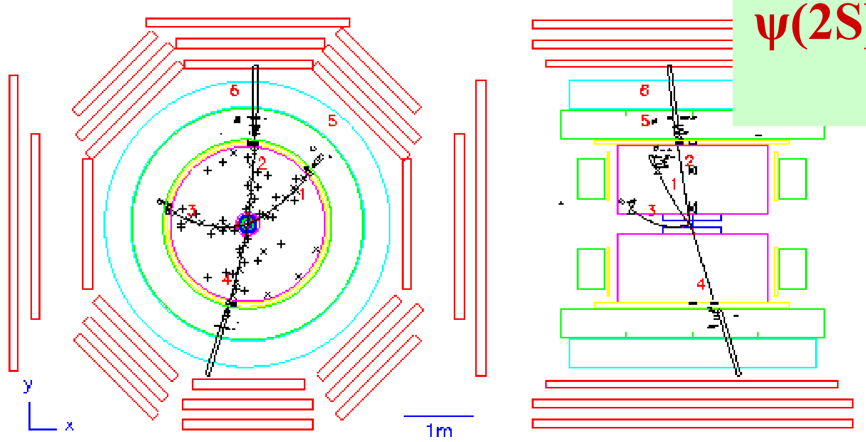
中国科学院高能物理研究所

BESII data samples

Data	BESII	CLEOc
J/ψ	58 M	--
ψ'	14 M	25 M (2006)
ψ''	33 pb^{-1}	~800 pb^{-1} (2006-07)
Continuum	6.4 pb^{-1} ($\sqrt{s}$=3.65 GeV)	21 pb^{-1} ($\sqrt{s}$=3.67 GeV)

	Performance
$\sigma p/p$	$1.7\%/\sqrt{1+p^2}$
$\sigma E/E$	$22\% /\sqrt{E}$
PartID	dE/dx+TOF
Coverage	80%

BESII



A typical event in BES detector
$\psi(2S) \rightarrow J/\psi \pi^+\pi^-$
$J/\psi \rightarrow e^+e^-$

BESII在PRL, PRD, PLB等刊物发表100余篇论文！

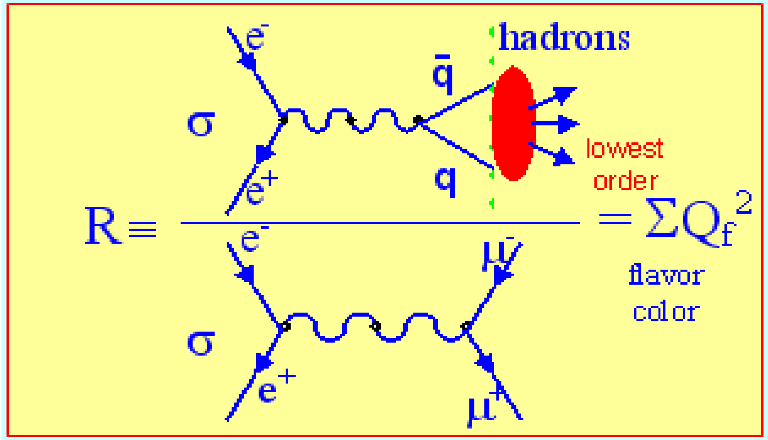
部分成果 (按发表顺序)

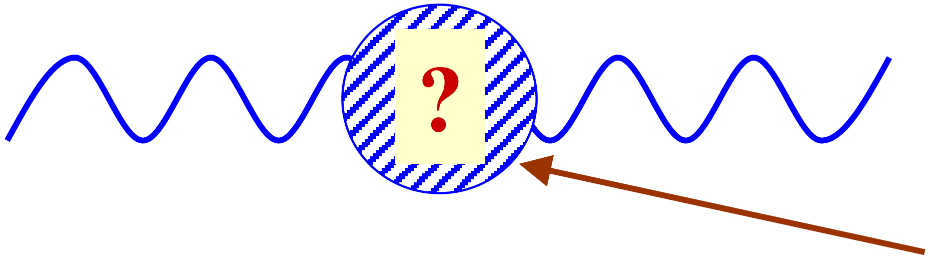
- 大范围R值扫描
- 发现X(1859)/X(1835)
- 研究标量介子
- “ρπ疑难”和“12%规则”
- 寻找五夸克态
- 发现ψ’’ non-DDbar 衰变
- 暗物质寻找

更多成果见历届会议报告!

R值测量

R值是粒子物理中直接证明夸克味与色量子数的最基本的物理量，以及正负电子湮没产生强子的概率。





最基本的理论问题，但需要实验的输入！

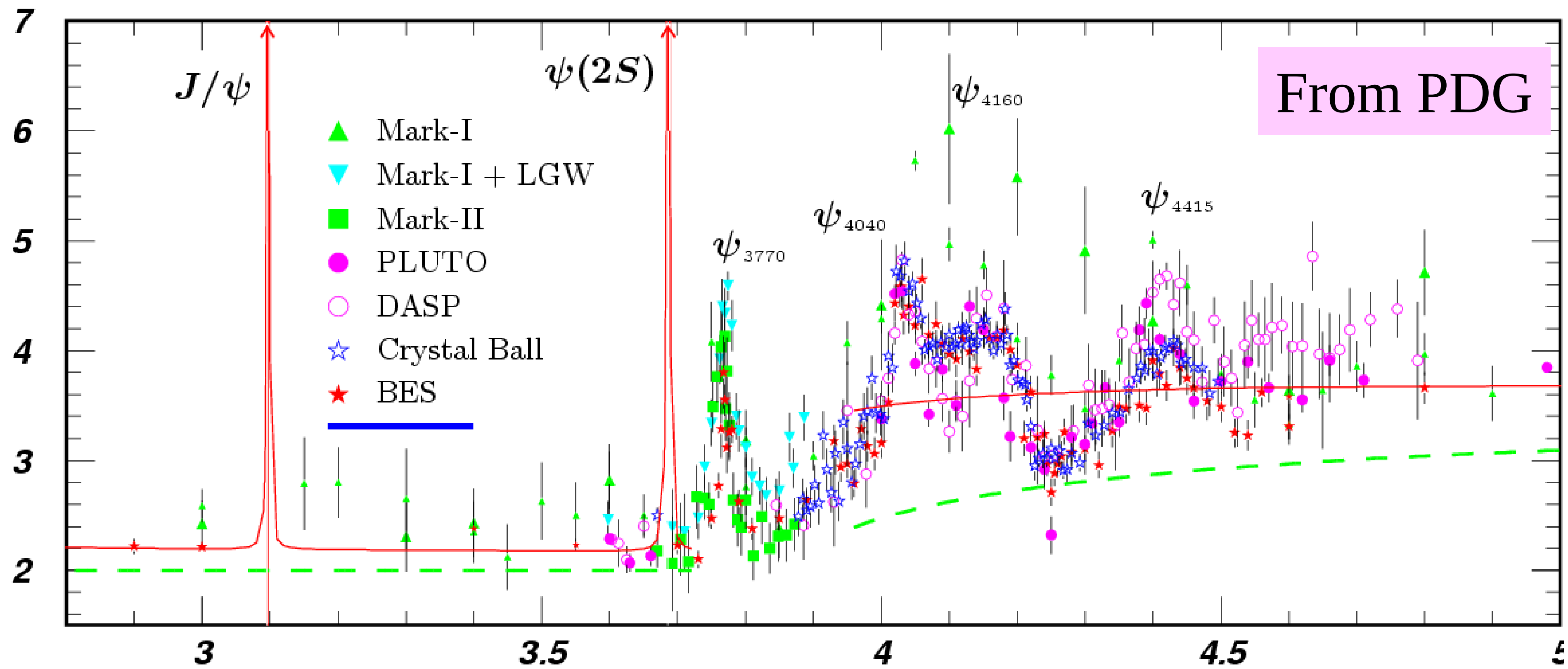
- 理解真空性质，完整理解粲偶素能谱

标准模型精确检验实验和理论研究都与**R**值测量精度密切相关：

- ➢ 电磁跑动耦合常数$\alpha_{QED}(s)$：电磁相互作用强度参数；
- ➢ **Higgs**粒子：标准模型对**Higgs**质量的拟合；
- ➢ μ子反常磁矩**(g-2)**：检验标准模型最灵敏、最精确的实验；

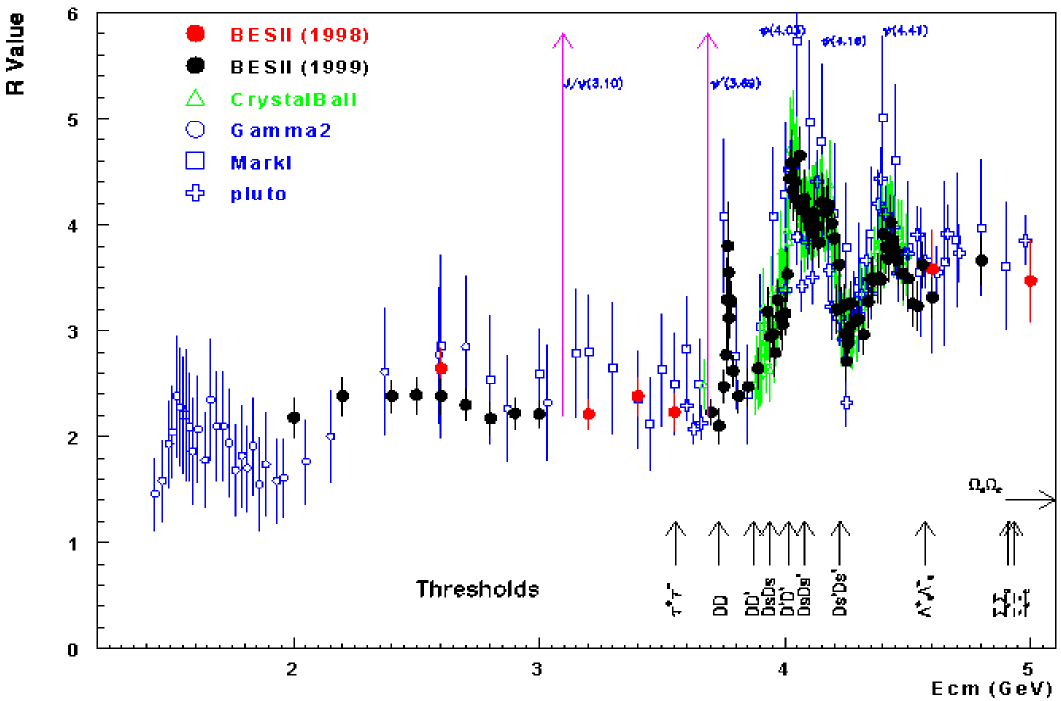
R值/ψ激发态

R



2.0-5.0 GeV 能区数据贫乏，粲介子阈值以上粲偶素能谱研究很差！1998-99，两轮R值扫描，91个能量点。

实验结果



PRL84, 594 (2000)
PRL88, 101802 (2002)

- **BES**测量结果平均误差为**6.6%**，精度比国外同能区实验提高了**2-3**倍
- **3.7-4.5GeV**能量范围的精细扫描使粲能区共振结构更为清晰

BES的R值成果对标准模型计算的不确定性大大减小：

- $\alpha_{QED}(s)$

BES实验前：

$$\alpha^{-1}(M_Z^2) = 128.902 \pm 0.090$$

$$\Delta\alpha_{had}^{(5)}(M_Z^2) = (280 \pm 7) \times 10^{-4}$$

BES实验后：

$$\alpha^{-1}(M_Z^2) = 128.945 \pm 0.060$$

$$\Delta\alpha_{had}^{(5)}(M_Z^2) = (275.5 \pm 4.6) \times 10^{-4}$$

- a_μ

BES实验前：

$$a_\mu^{had} = (696.7 \pm 15.6) \times 10^{-10}$$

BES实验后：

$$a_\mu^{had} = (697.4 \pm 10.5) \times 10^{-10}$$

$$a_\mu^{exp} - a_\mu^{th} \approx (22 \pm 11) \times 10^{-10}$$

BES增强了在该能区使用pQCD的信心，理论预言精度进一步提高。

标准模型对Higgs质量的拟合

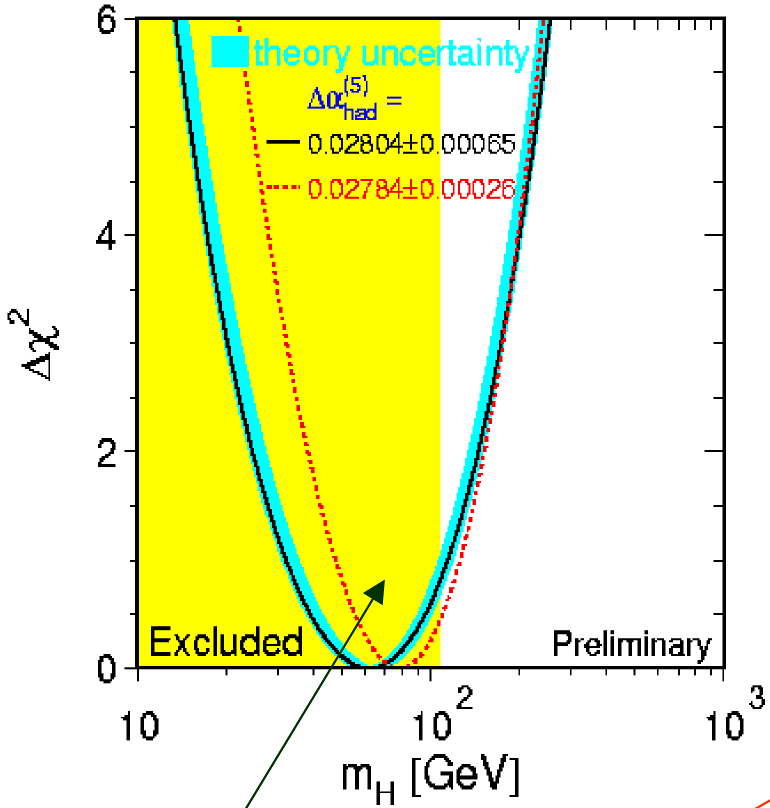
$m_H = 62^{+53}_{-30}\ GeV$

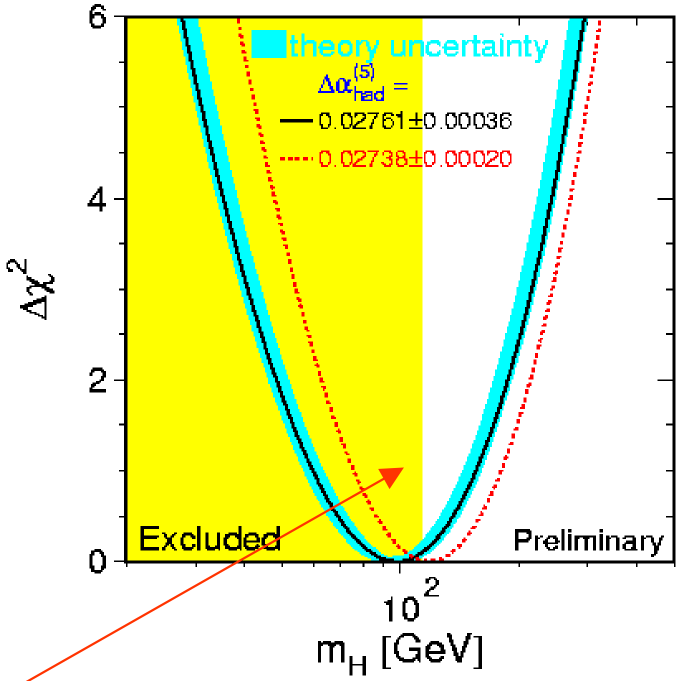
$m_H < 170\ GeV$

(95% C.L.)

$m_H = 98^{+58}_{-38}\ GeV$

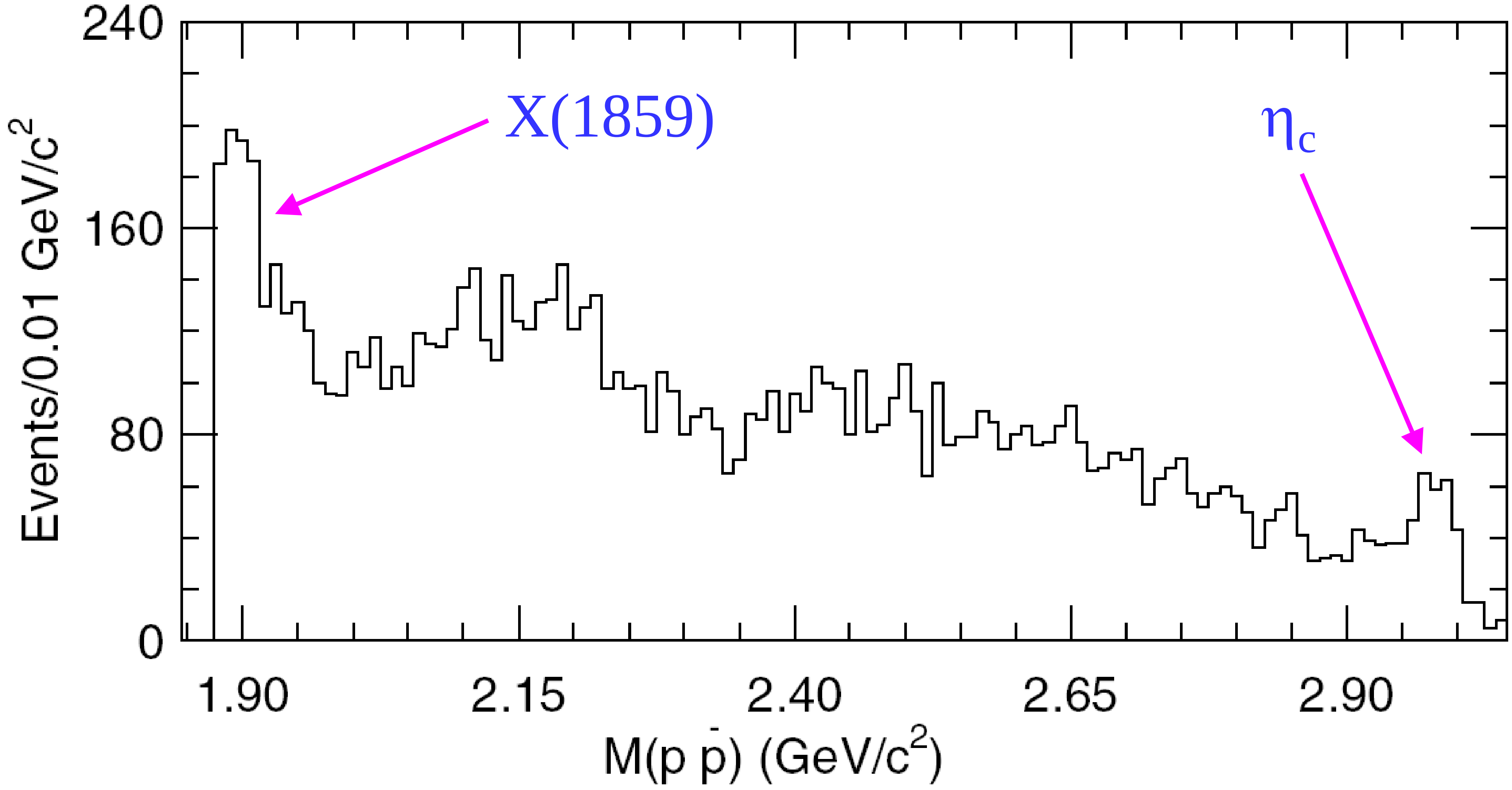
$m_H < 212\ GeV$





把**BES**的**R**值结果带入标准模型进行拟合，发现**Higgs**粒子质量的最可几值由原来的**62GeV**上升为**98GeV**,质量上限由原来的**170GeV**改变为**212GeV**，与欧洲核子中心几个实验组曾报告可能的**Higgs**粒子质量为**115GeV**的结果相容。**BES**的**R**测量结果对实验上寻找**Higgs**粒子产生了极重要的影响。

X(1859) in $J/\psi \rightarrow \gamma p\bar{p}$



PRL91, 022001 (2003)

X(1859) in J/ψ→γppbar

Assuming $J^{PC} = 0^{-+}$:

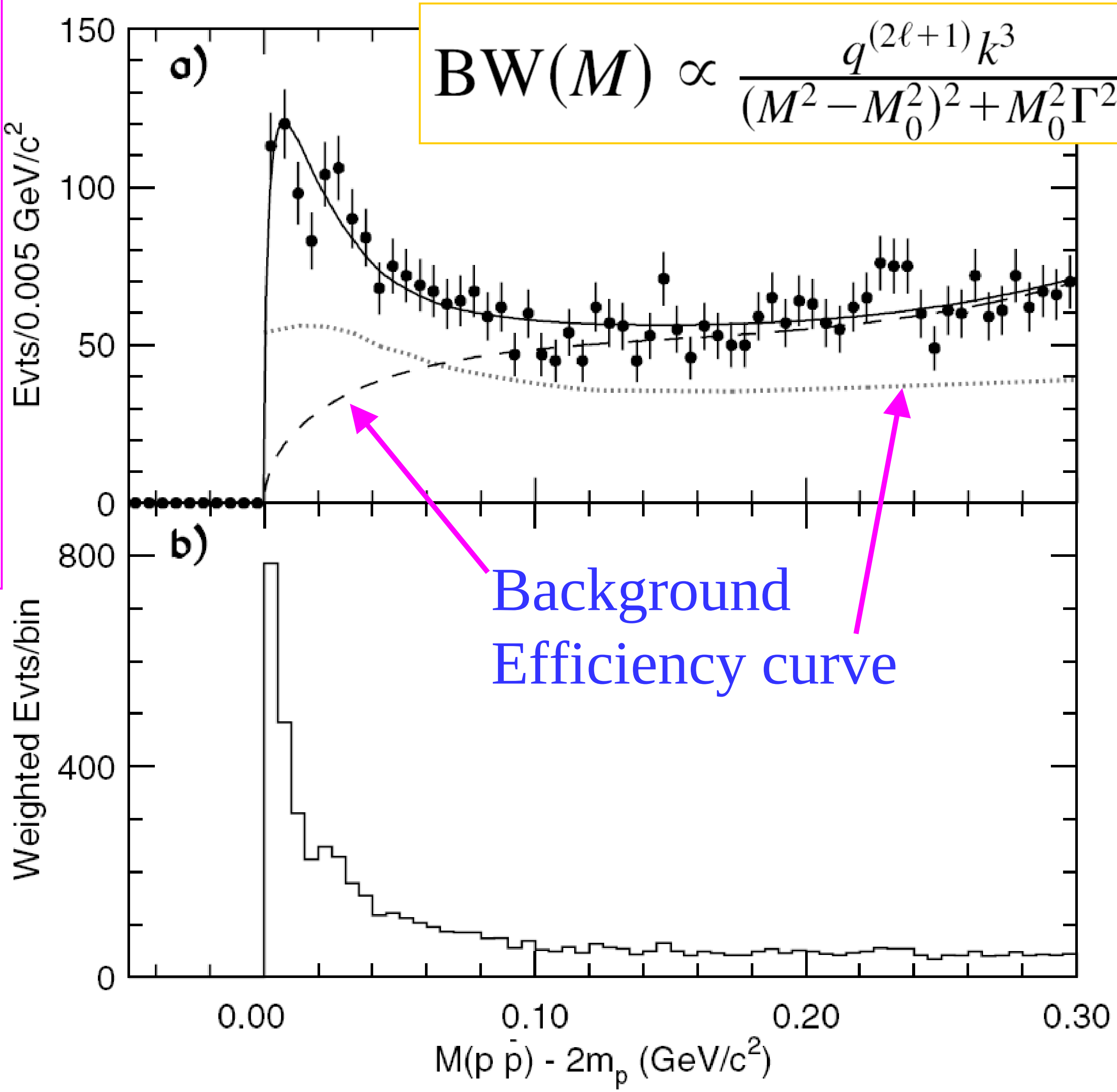
$N^{signal} = 928 \pm 57$

$M = 1859^{+3+5}_{-10-25}$ MeV

$\Gamma < 30$ MeV @ 90% C.L.

$B(J/\psi \to \gamma X \to \gamma p\bar{p}) = (7.0 \pm 0.4^{+1.9}_{-0.8}) \times 10^{-5}$

$$\mathrm{BW}(M) \propto \frac{q^{(2\ell+1)} k^3}{(M^2 - M_0^2)^2 + M_0^2 \Gamma^2}$$



The nature of the structure is unknown and there are many possibilities.

PRL91, 022001 (2003)

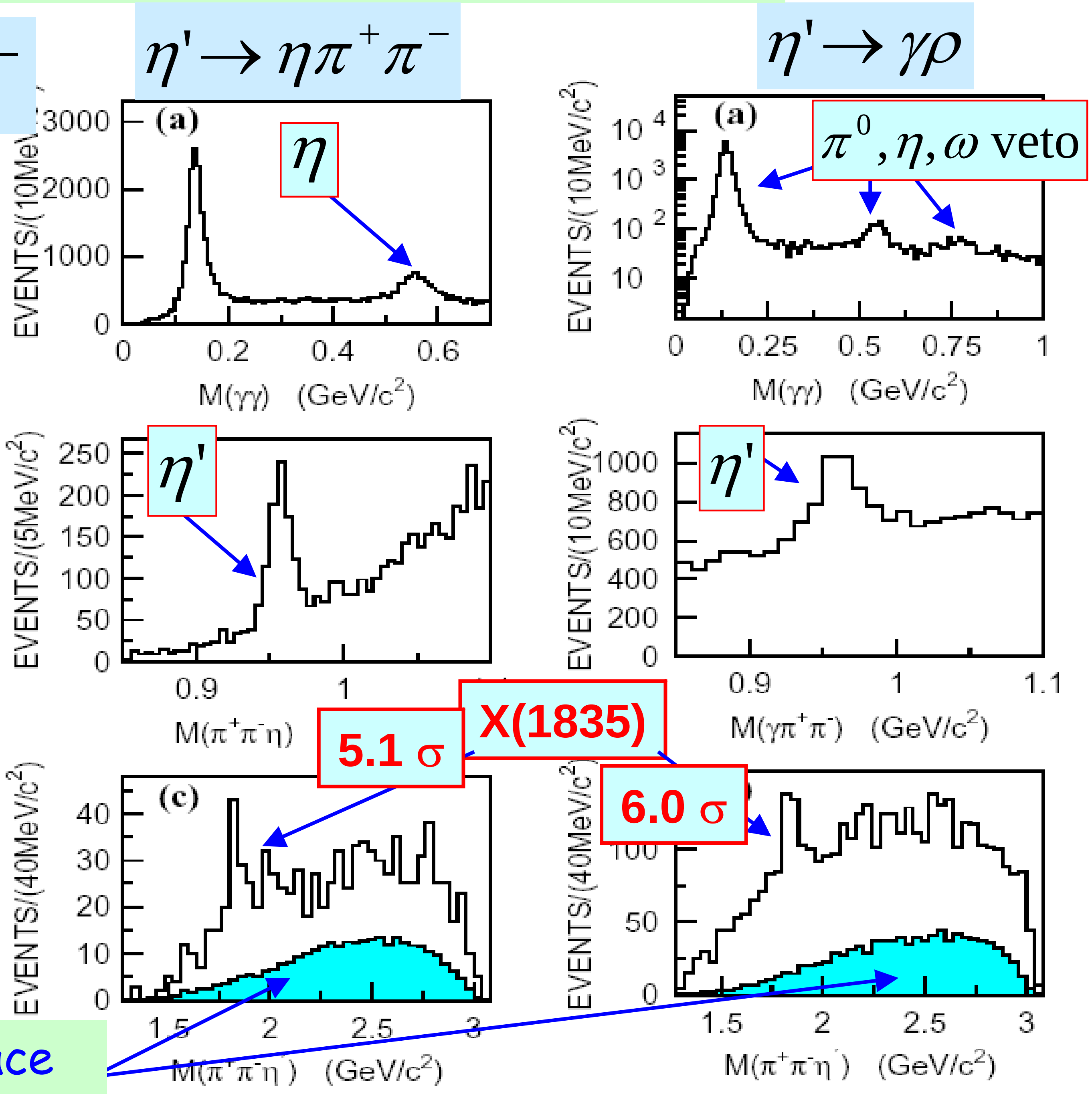
Observation of X(1835)

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

Data selection:

- $\gamma\gamma$ mass cut
- part ID
- kinematic fit
- η' mass cut

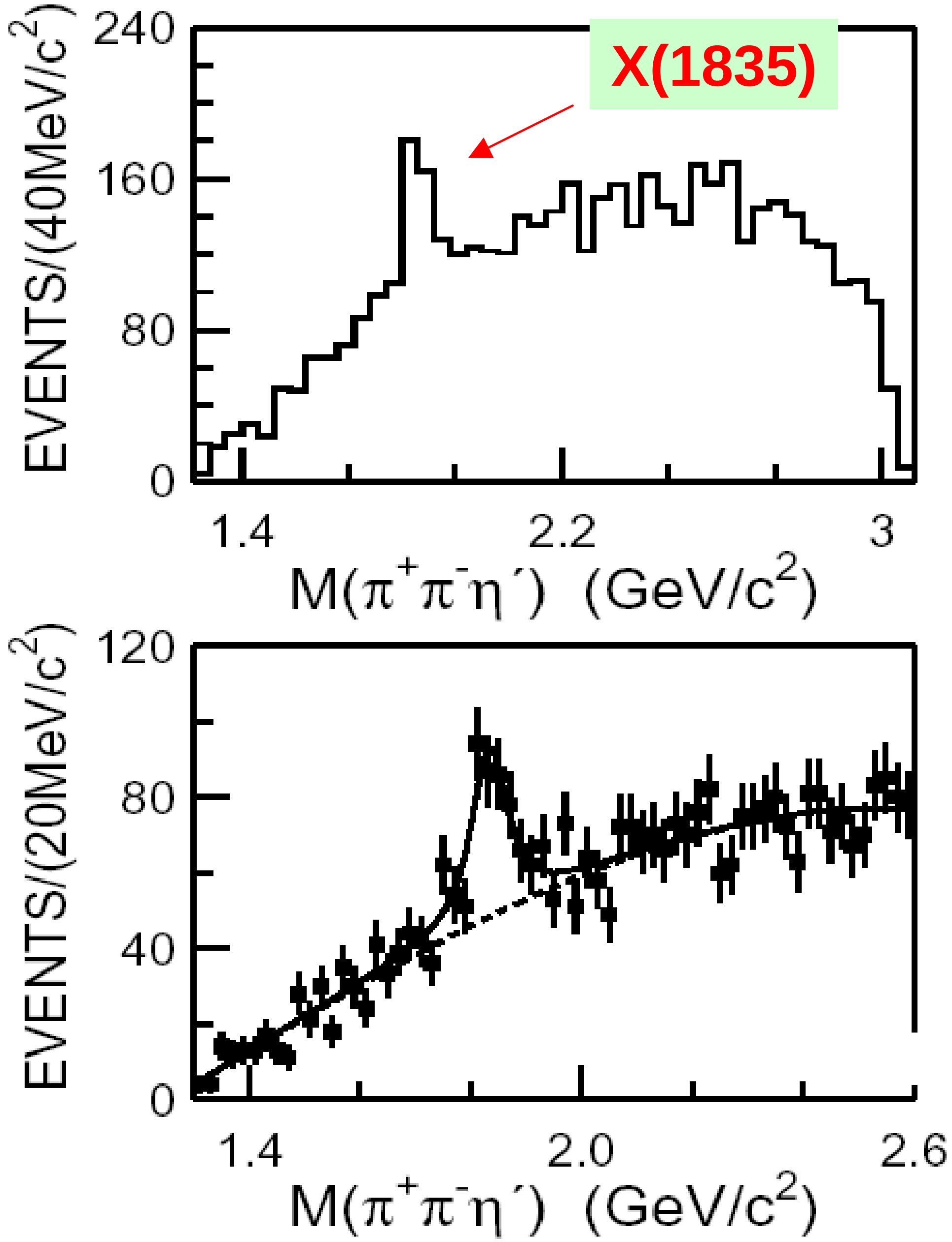
PRL95, 262001 (2005)



Shape of phase space

Combine two η′ decay modes

PRL95, 262001 (2005)



Fit with BW + polynomial backgrounds, considering mass resolution.

Statistical significance: 7.7σ

Mass res. ~ 13 MeV
Efficiency ~ 4%

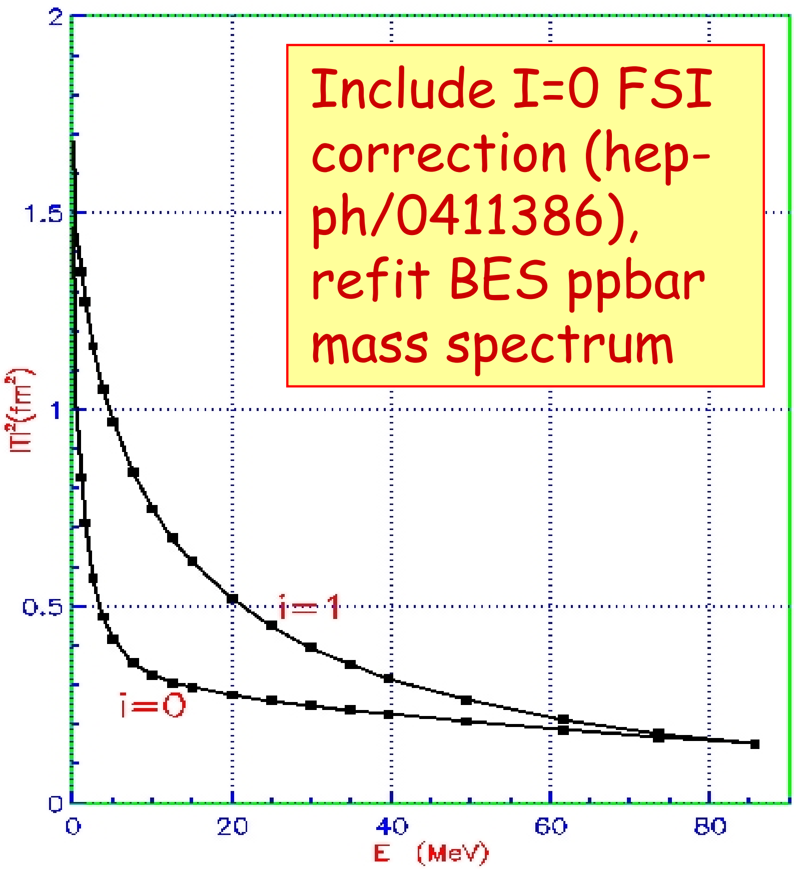
$N_{obs} = 264 \pm 54$

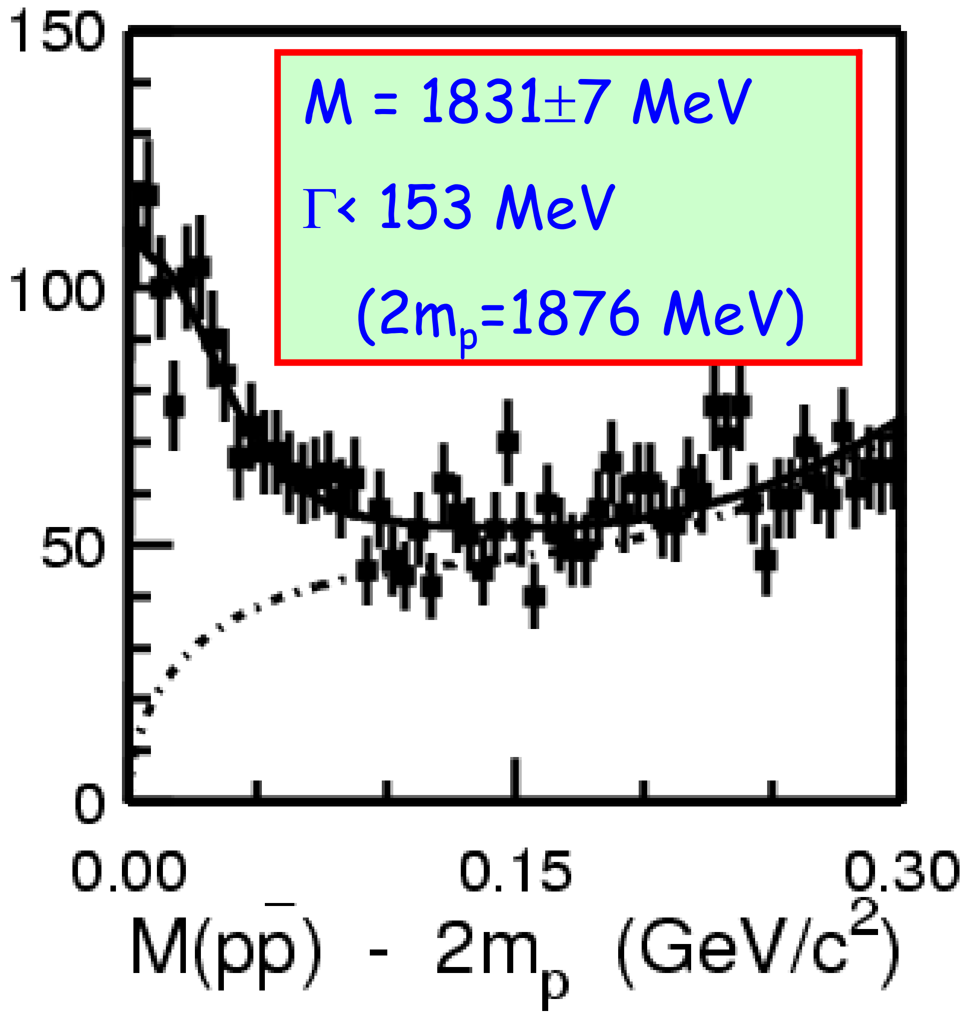
$M = 1833.7 \pm 6.1 \pm 2.7\ \mathrm{MeV/c^2}$

$\Gamma = 67.7 \pm 20.3 \pm 7.7\ \mathrm{MeV/c^2}$

$$B(J/\psi \to \gamma X)B(X \to \pi^+\pi^-\eta') = (2.2 \pm 0.4 \pm 0.4)\times 10^{-4}$$

X(1835)=X(1859)?





X(1835):

$M = 1833.7 \pm 6.7$ MeV

$\Gamma = 67.7 \pm 21.7$ MeV

- Mass agree
- Width not contradict
- No J^P in both cases

What is X(1835)?

Further arguments support X(1835)=X(1859)=ppbar bound state:

- **ppbar bound state couples to $\eta'\pi\pi$ large**
  [G.J.Ding and M.L. Yan, PRC72, 015208 (2005)]
- **ppbar bound state couples to ppbar strong**
  [S.L. Zhu and C.S. Gao, hep-ph/0507050]

$$B(J/\psi \to \gamma X)B(X \to \pi^+\pi^-\eta') = (2.2 \pm 0.4 \pm 0.4)\times 10^{-4}$$

$$B(J/\psi \to \gamma X)B(X \to p\bar{p}) = (7.0 \pm 0.4^{+1.9}_{-0.8})\times 10^{-5}$$

More data, more experiments, more information needed

- **mass and width, most importantly J^P**
- **more decay modes**
- **more theoretical calculations**

Light scalars

- Many scalars found in experiments
- Do the sigma and kappa really exist?
- Have we seen scalar glueball already?

There are many experimental results from BES ---
(theorists (will) give interpretations)

- States in J/ψ decays
  - phi pi pi/phi K K
  - omega pi pi/omega K K
  - gamma pi pi/gamma K K
  - K K pi pi (the kappa)
- Sigma in $\psi' \to \pi^+\pi^- J/\psi$
- χ_c decays
  - Pair production of scalars

$f_0(600)$ or σ

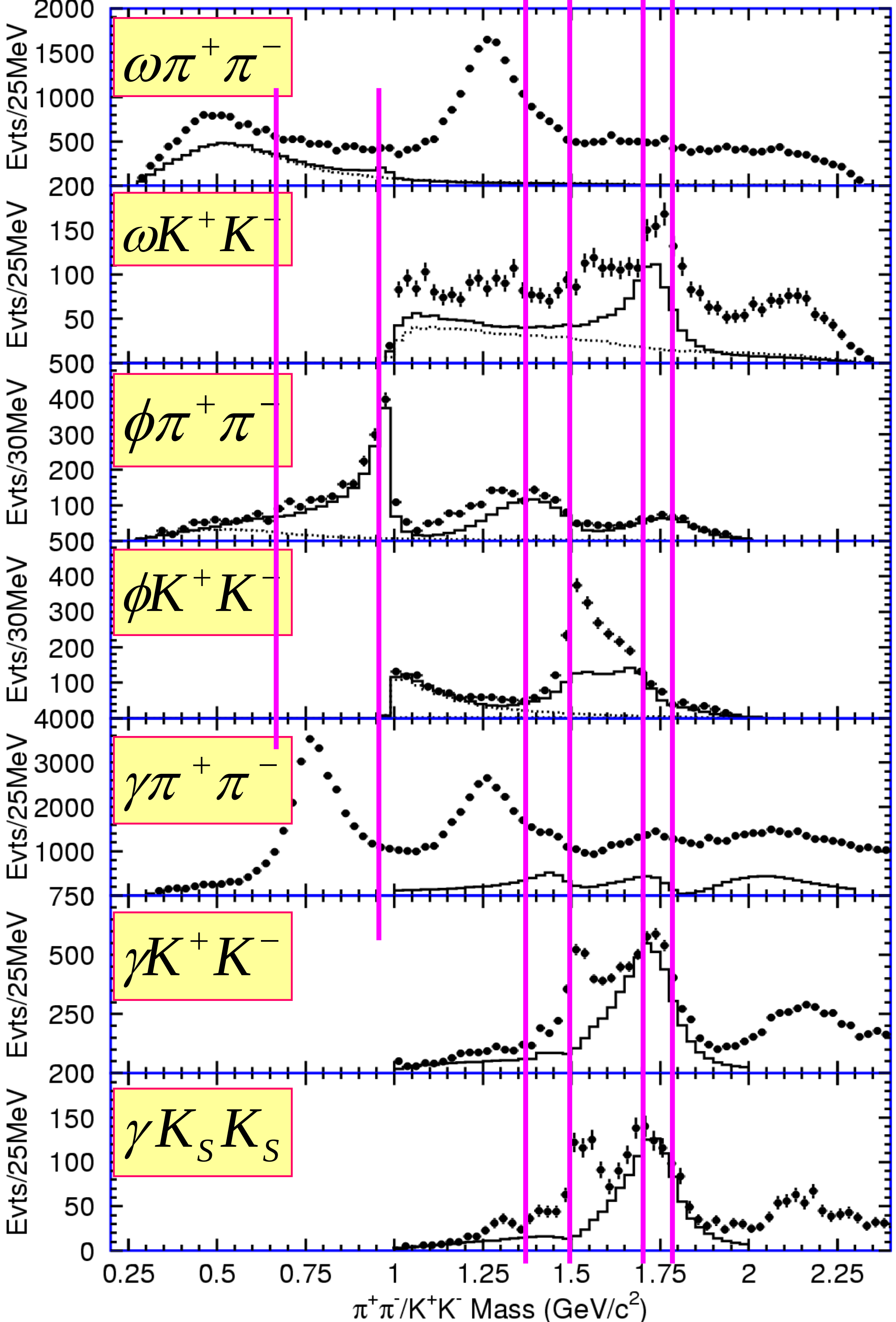
$f_0(980)$

$f_0(1370)$

$f_0(1500)$

$f_0(1710)$

$f_0(1790)$



The scalars

$f_0(600)$ or σ:

$f_0(980)$:

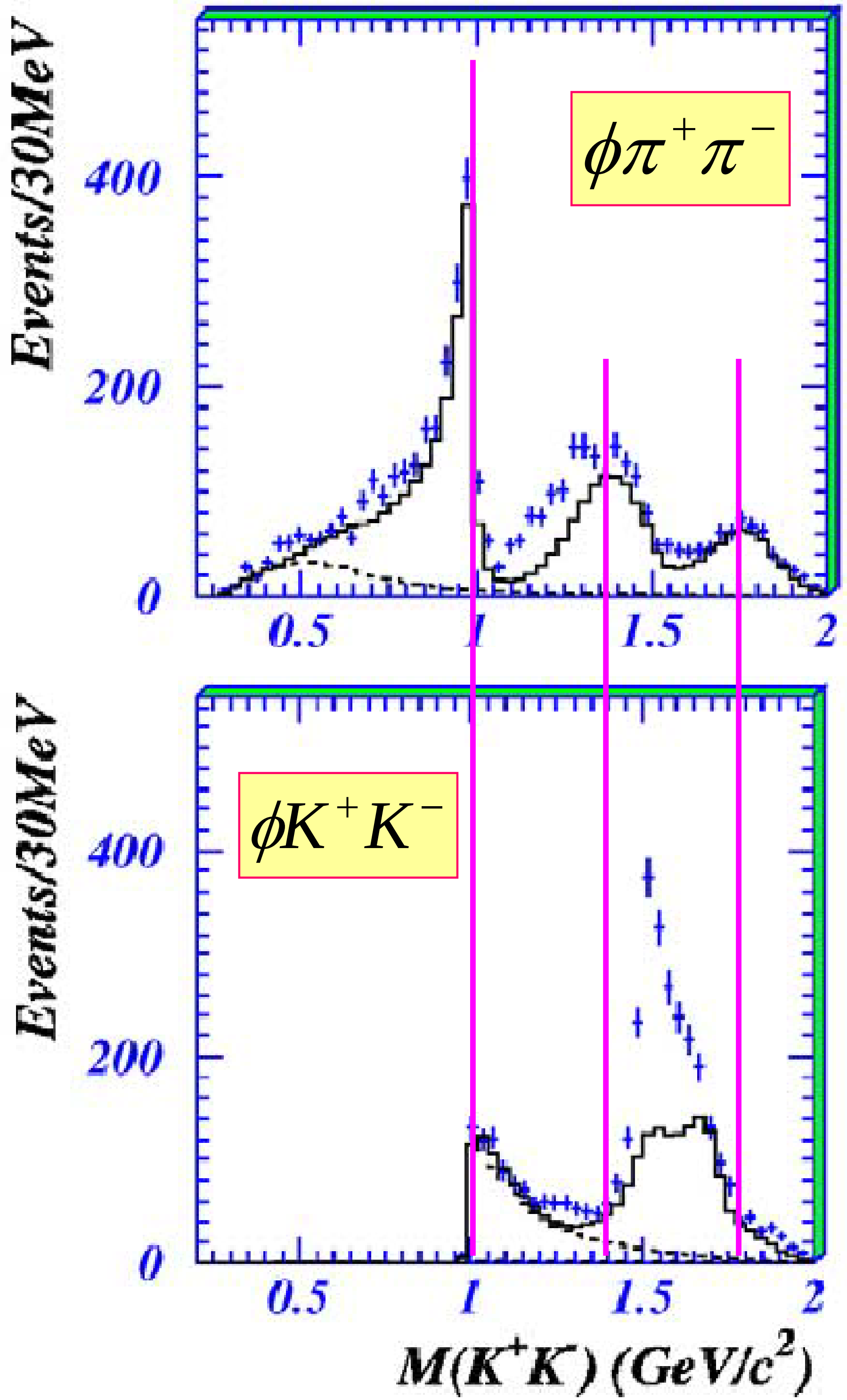
$f_0(1370)$:

$f_0(1500)$:

$f_0(1710)$:

$f_0(1790)$:

PLB 607 (2005) 243
PLB 603 (2004) 138
PLB 598 (2004) 149
PRD 68 (2003) 052003
PLB 642 (2006) 441



PLB 607 (2005) 243

$f_0(980)$ parameters:

$$M = 965 \pm 8 \pm 6 \text{ MeV}$$

$$g_{\pi\pi} = 165 \pm 10 \pm 15 \text{ MeV}$$

$$\frac{g_{KK}}{g_{\pi\pi}} = 4.21 \pm 0.25 \pm 0.21$$

$f_0(1370)$ peak seen!

$$M = 1350 \pm 50 \text{ MeV}$$

$$\Gamma = 265 \pm 40 \text{ MeV}$$

Observation of $f_0(1790)$?

$$M = 1790^{+40}_{-30} \text{ MeV}$$

$$\Gamma = 270^{+60}_{-30} \text{ MeV}$$

Couplings to γ, ω, and ϕ in J/ψ decays, and decays to $\pi^+\pi^-$ and K^+K^- reveal its nature!

Scalar	$B(\phi S, S\to\pi\pi)(10^{-4})$	$B(\phi S, S\to KK)(10^{-4})$
$f_0(600)/\sigma$	1.6 ± 0.6	0.2 ± 0.1
$f_0(980)$	5.4 ± 0.9	4.5 ± 0.8
$f_0(1370)$	4.3 ± 1.1	0.3 ± 0.3
$f_0(1500)$	1.7 ± 0.8	0.8 ± 0.5
$f_0(1710)$	--	2.0 ± 0.7
$f_0(1790)$	6.2 ± 1.4	1.6 ± 0.8

$$B(J/\psi \to \gamma f_0(1710) \to \gamma K\bar{K}) = (9.6^{+3.5}_{-1.9})\times 10^{-4}$$

$$B(J/\psi \to \omega f_0(1710) \to \omega K^+K^-) = (6.6\pm1.3)\times 10^{-4}$$

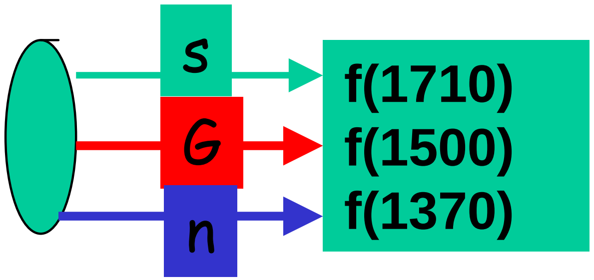
$$\frac{BR(f_0(1710)\to\pi\pi)}{BR(f_0(1710)\to K\bar{K})} < 0.13 \quad @95\%CL$$

Use of these information can be found in

PRD71, 094022 (2005)
PLB631, 22 (2005)
arXiv: 0710.4452 ...

The mixing of the scalars

Idea available long time ago,
a recent analysis in
PRD71, 094022 (2005)
By Frank Close and Qiang Zhao



$$
\begin{aligned}
|f_0(1710)\rangle &= 0.39|G\rangle + 0.91|s\bar{s}\rangle + 0.13|n\bar{n}\rangle \\
|f_0(1500)\rangle &= -0.73|G\rangle + 0.37|s\bar{s}\rangle - 0.57|n\bar{n}\rangle \\
|f_0(1370)\rangle &= 0.56|G\rangle - 0.12|s\bar{s}\rangle - 0.82|n\bar{n}\rangle \ ,
\end{aligned}
$$

The mass of the scalar glueball is about
1.46-1.52 GeV in the same scheme.

H.D.Politzer 和 "12%规则"

PRL30, 1346 (1973)→通过检验→2004年诺贝尔奖

$$\beta(g) = -\left(\frac{22}{3}c_1 - \frac{8}{3}c_2\right)g(g/4\pi)^2 + O(g^5)$$

+M. Appelquist, PRL34, 43 (1975)→?

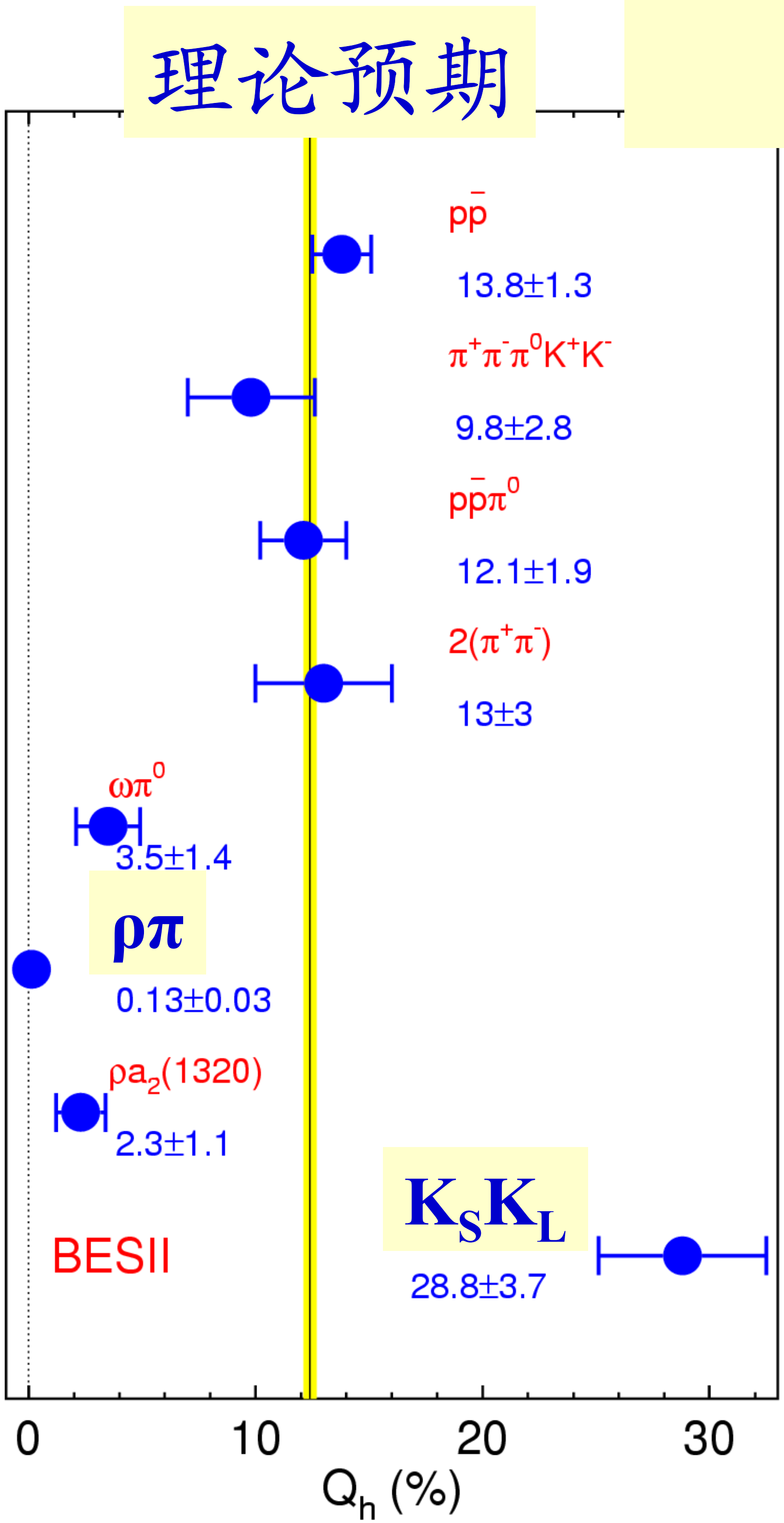
著名的"12%规则"!

$$Q_h = \frac{B_{\psi(2S)\to h}}{B_{J/\psi\to h}} = \frac{B_{\psi(2S)\to e^+e^-}}{B_{J/\psi\to e^+e^-}} \approx 12\%$$

ψ(2S)与J/ψ唯一的差别是主量子数不同，"12%规则"是一个干净、简单的理论推论，预期普遍成立。

"规则"的破坏意味着强相互作用中非常基本的、不为人知的规律的存在！

强烈压低与反常增强



1. 多数过程满足“12%规则”

2. 首次观测到ψ(2S) →ρπ，发现强烈压低；比“12%规则”压低近两个量级

3. 首次观测到ψ(2S) →K_SK_L，相对于理论预期反常增强！

9 种理论模型被实验所排除

系统研究了各种两体、三体和多体衰变末态

☛矢量－赝标量	反常压低
☛赝标量－赝标量	反常增强
☛矢量－张量	反常压低
☛多介子末态	反常压低或正常
☛含重子对末态	反常压低或正常
☛等等40多个衰变末态	

13种对破坏“12%规则”过程进行解释的理论模型

其中 9 种被我们的实验所排除，与实验结果不符！

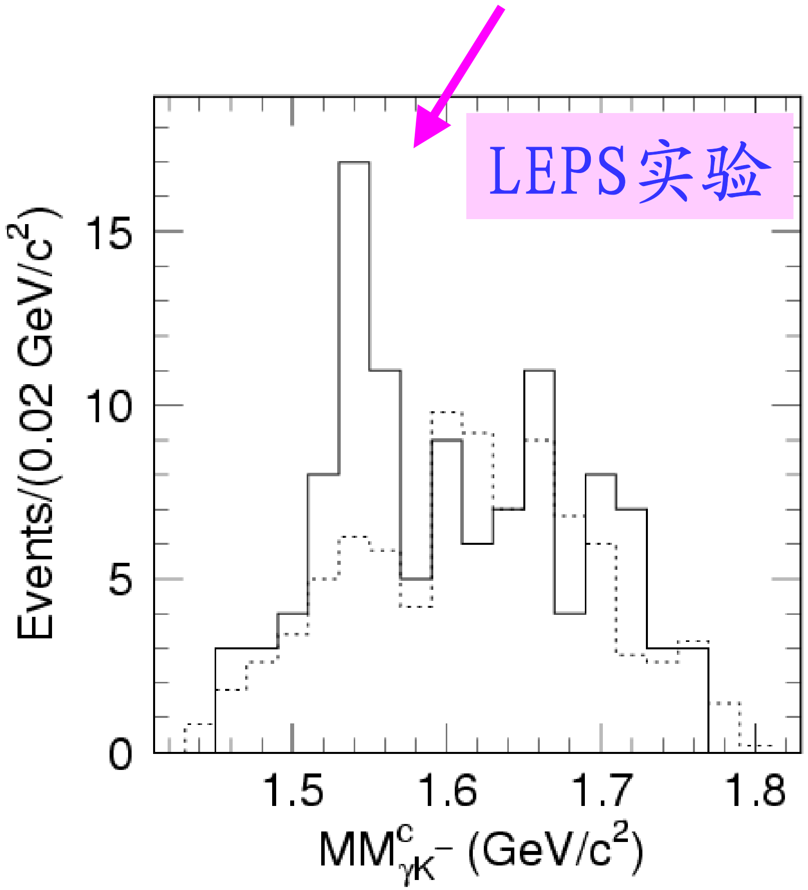
没有理论模型对反常增强做出预言！

Recent review, see hep-ph/0611214

否认五夸克态存在

普通物质：
　　介子：两个夸克
　　重子：三个夸克

其它新物质形态存在吗？

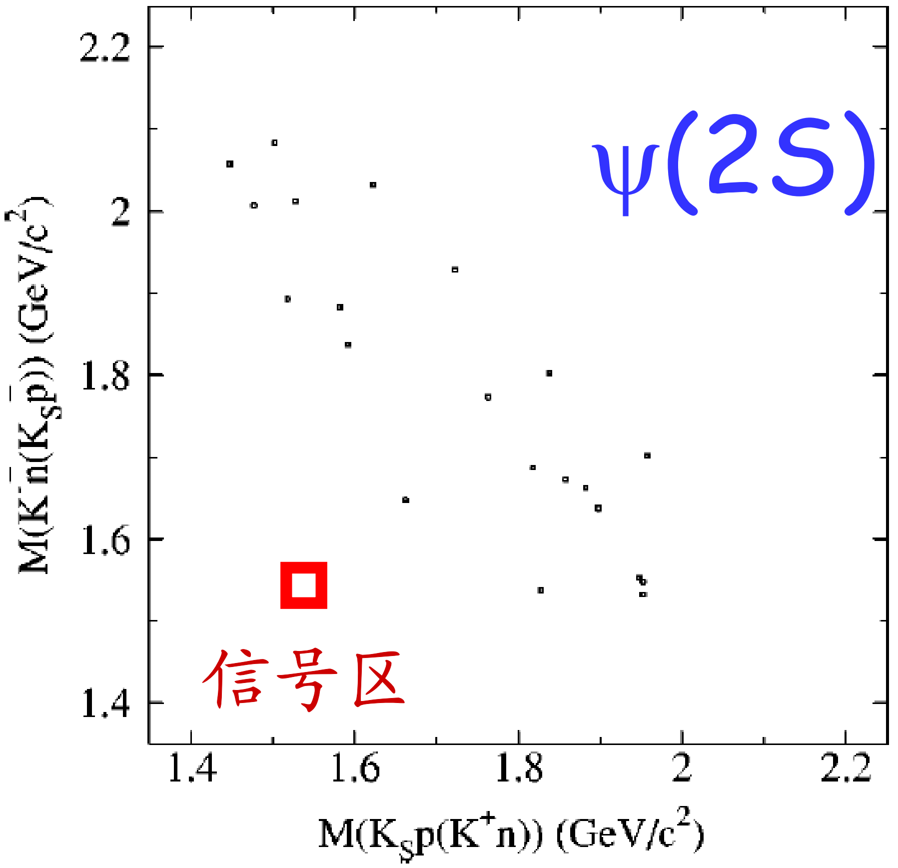


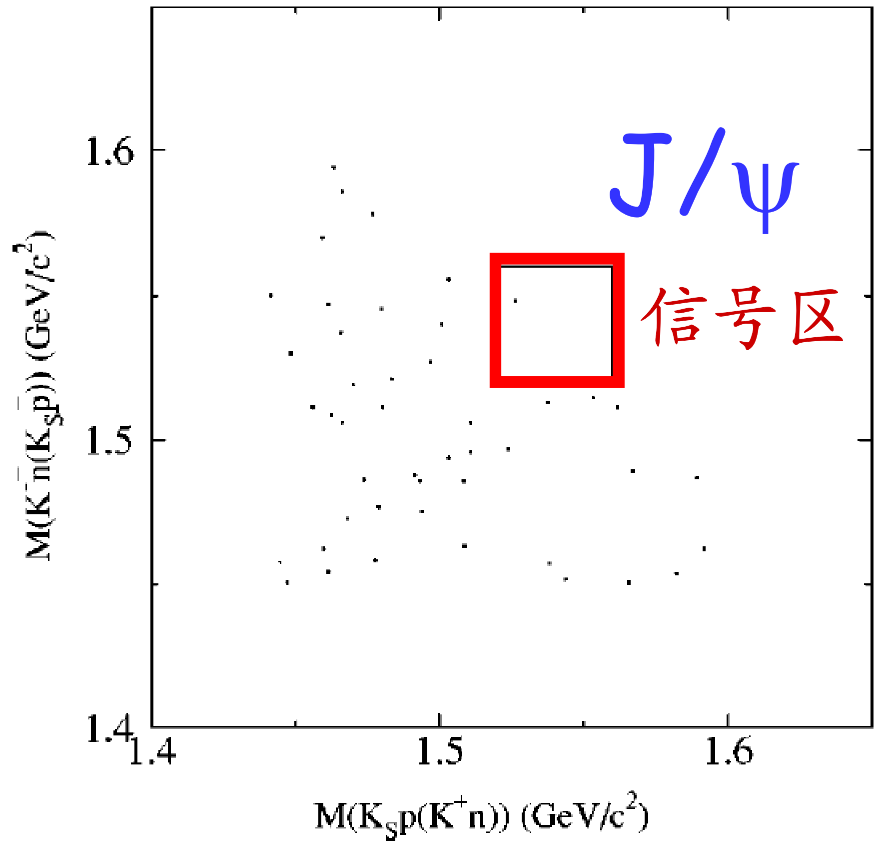
2003年，日本LEPS实验组观测到Θ(1540)，认为是五夸克态，理论和实验一时轰动—新物质形态的发现！

同年，6家实验观测到同样的信号！

两年间，理论文章15篇／月递增！

BES数据中未观测到五夸克态



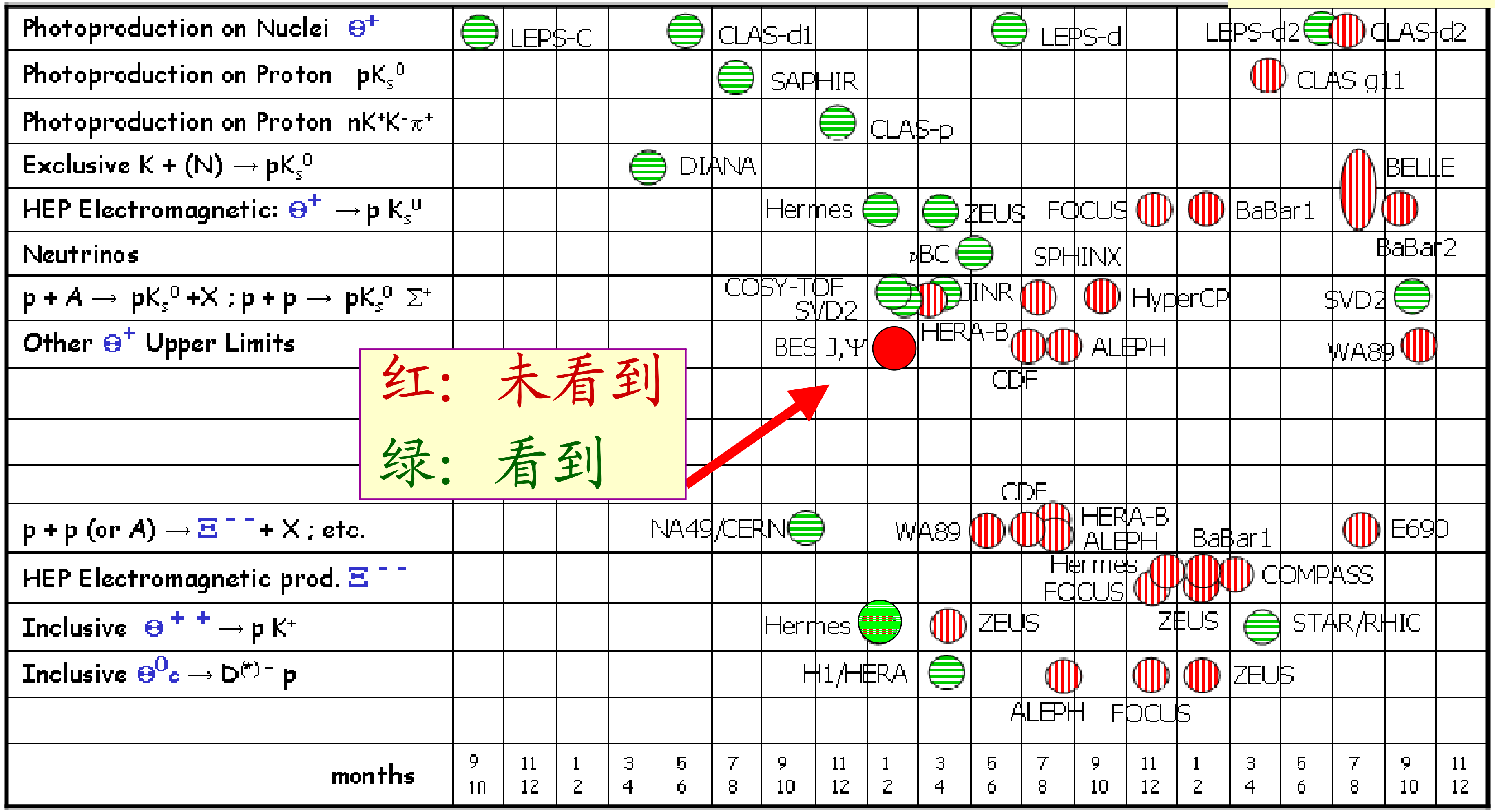


Select ψ'' and J/ψ→K_SpKn+c.c., search for single Θ production or pair production. Very few events observed, in agreement with the background fluctuation.

PRD70, 012004 (2004)

否认五夸克态存在

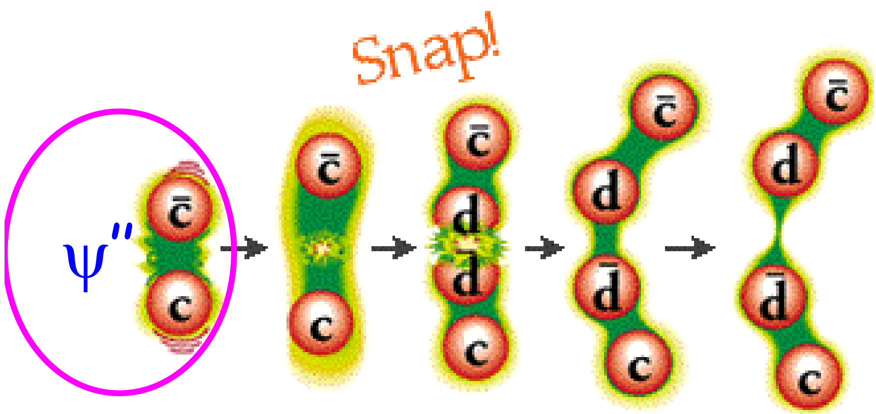
Schumacher
PANIC'05



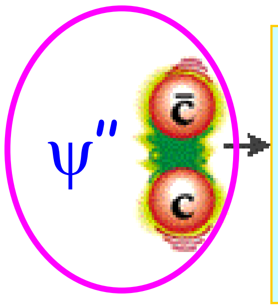
BES首家报道了五夸克态Θ(1540)不存在的实验事实！
继BES之后，五夸克态不存在的实验结果越来越多，
目前看来Θ(1540)极有可能是统计涨落造成的！

ψ'' decays

- ψ''(3770) is above the open charm threshold, expected decay predominantly into charmed mesons.
- However, old experimental results indicate big charmless decays [11.6nb for $\sigma(e^+e^- \to \psi'')$, 7.1nb for $\sigma(e^+e^- \to \psi'' \to \text{charm})$]



- Search for exclusive decay modes
  - Transitions to lower mass charmonia
  - Decays to light hadrons
- Inclusive measurements
  - total hadronic cross section
  - Total D cross section



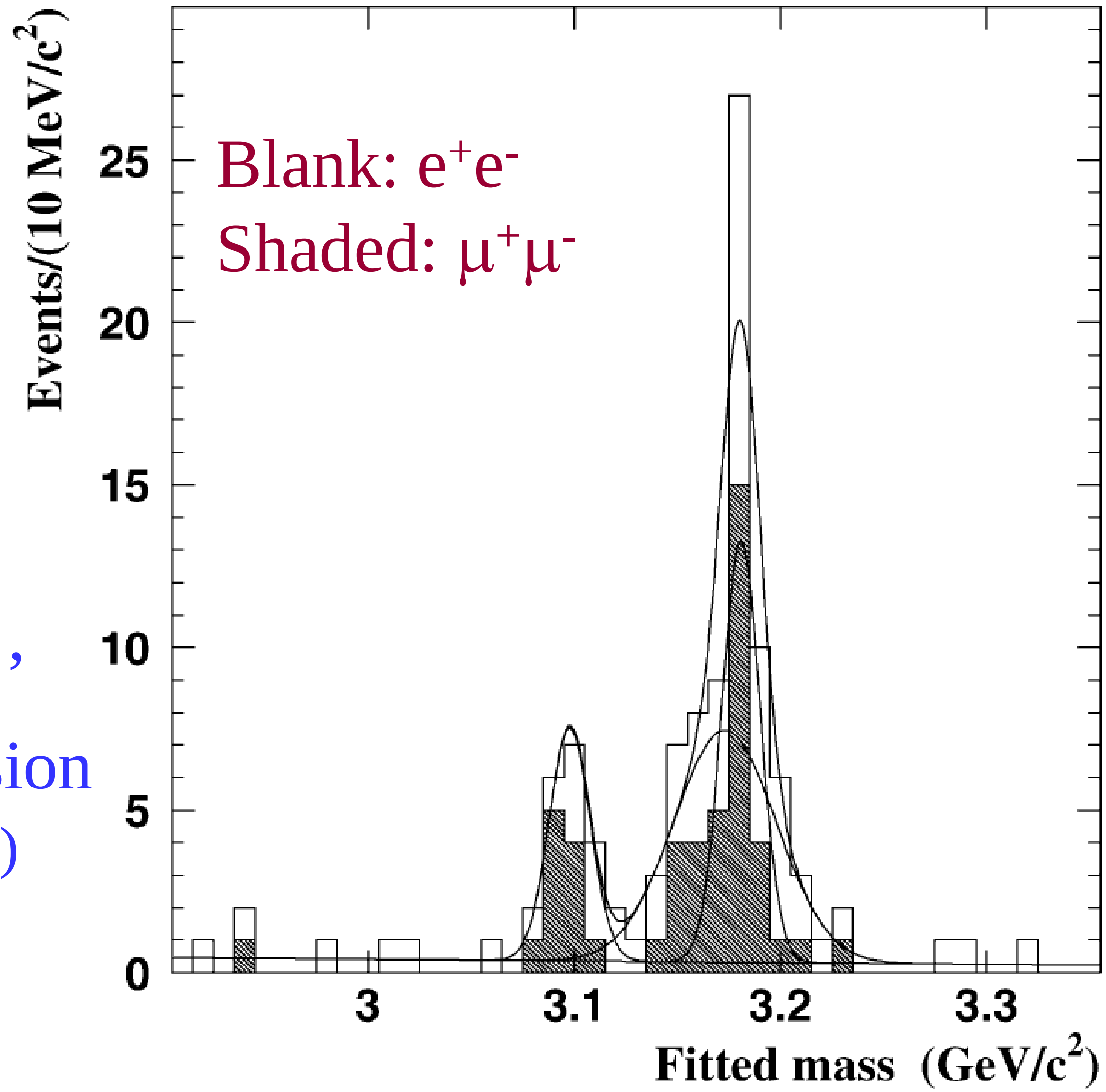
Low mass charmonium?
Light hadrons?

Observation of $\psi'' \rightarrow \pi^+\pi^- J/\psi$

- $N^{obs} = 17.8 \pm 4.8$
- $N^{bkg} = 6.0 \pm 1.4$
- $N^{signal} = 11.8 \pm 5.0$

- $BR = (0.34 \pm 0.14 \pm 0.09)\%$
- $\Gamma = (80 \pm 33 \pm 23)$ keV

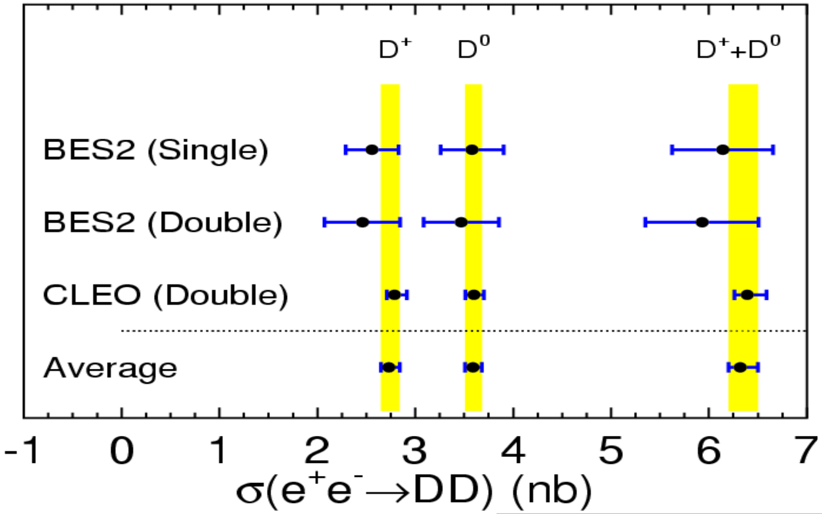
- First non-DDbar decay of ψ''
- Agree with multipole expansion
  – Kuang: PRD65, 094024 (2002)
- Confirmed by CLEOc later
  – $BR = (0.189 \pm 0.020 \pm 0.020)\%$ [PRL96, 082004 (2006)]

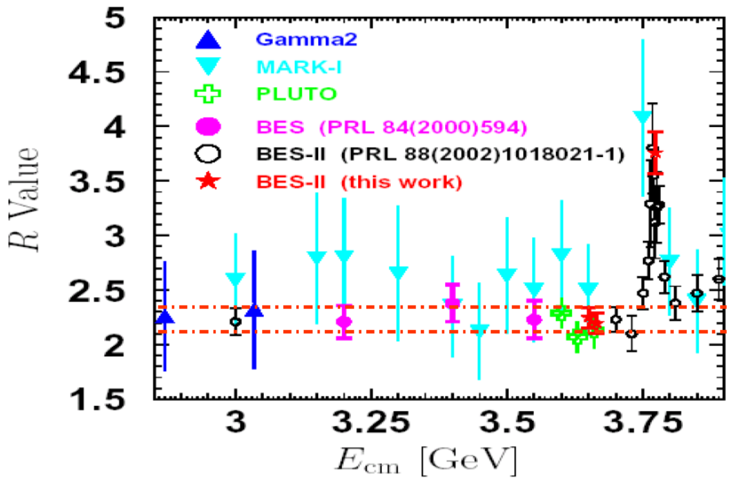


PLB605, 63 (2005)

Search for inclusive ψ″ charmless decays

CLEO:
 PRL95, 121801 (2005)
 PRL96, 092002 (2006)
BES:
 PLB659, 74 (2008)
 NPB727, 395 (2005)
 PLB603, 130 (2004)





CLEOc:

R values at 3.671 and 3.773 GeV ⇒

$\sigma(e^+e^- \to \psi'') = (6.38 \pm 0.08^{+0.41}_{-0.30})$ nb

$\sigma(e^+e^- \to non-D\bar{D}) = (-0.01 \pm 0.08^{+0.41}_{-0.30})$ nb

$B(\psi'' \to non-D\bar{D}) < 11\%$ @90% C. L.

BESII:

R values at 3.65, 3.665 and 3.773 GeV ⇒

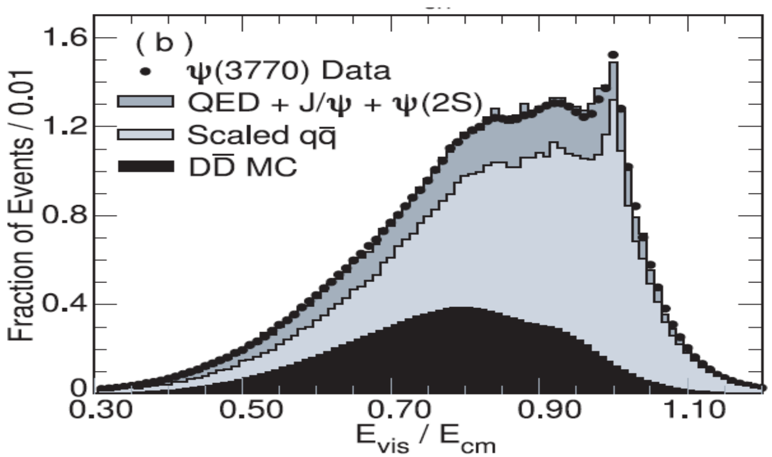
$B(\psi'' \to non-D\bar{D}) = (14.5 \pm 1.7 \pm 5.8)\%$

Cross section scan around ψ″ peak ⇒

$B(\psi'' \to non-D\bar{D}) = (16.4 \pm 7.3 \pm 4.2)\%$

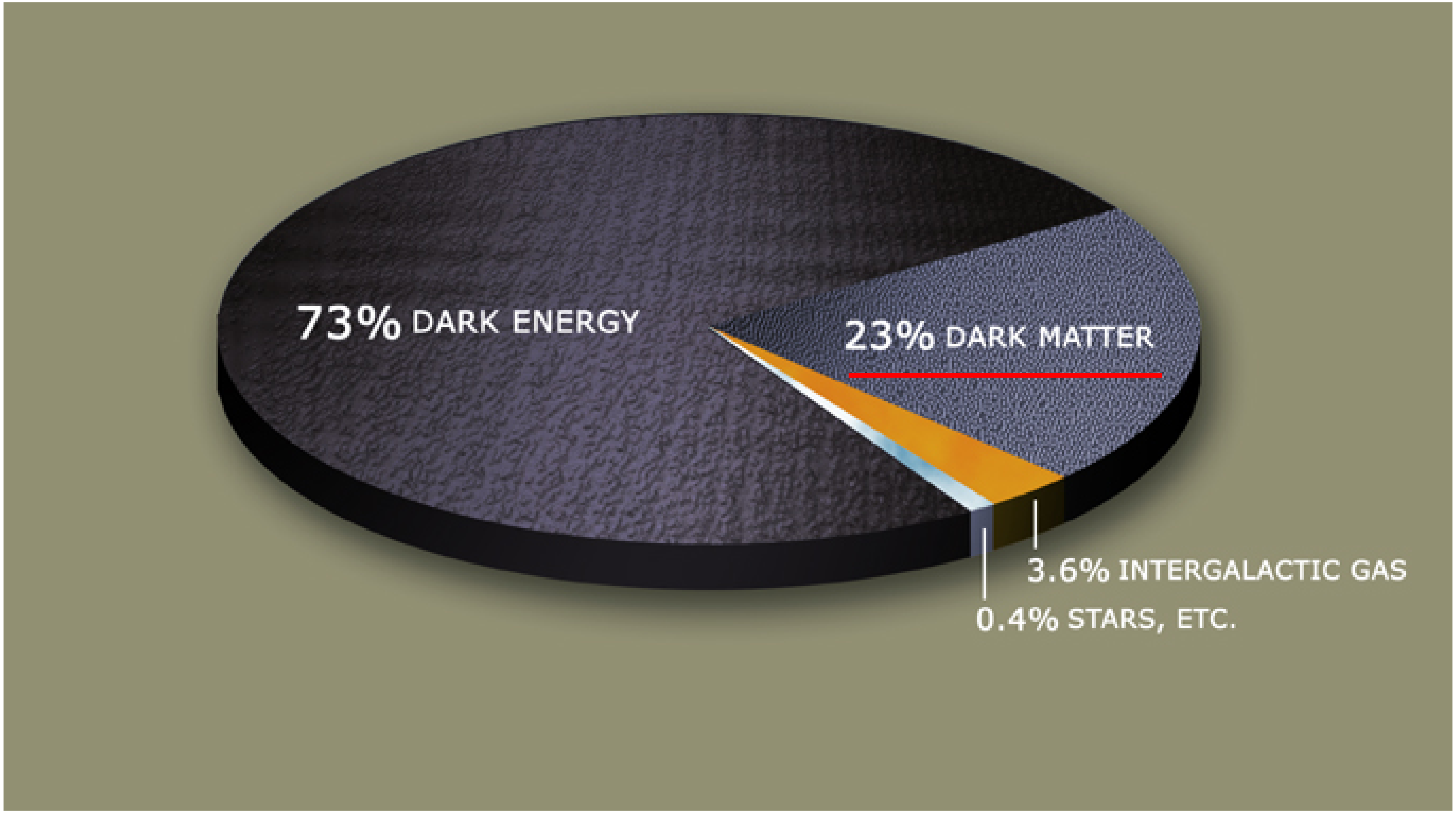
Leading particle momentum ⇒

$B(\psi'' \to non-D\bar{D}) = (15.1 \pm 5.6 \pm 1.8)\%$



DDbar x-sections agree
Non-DDbar: not inconsistent
 (interference important)
Three BES measurements give similar results.

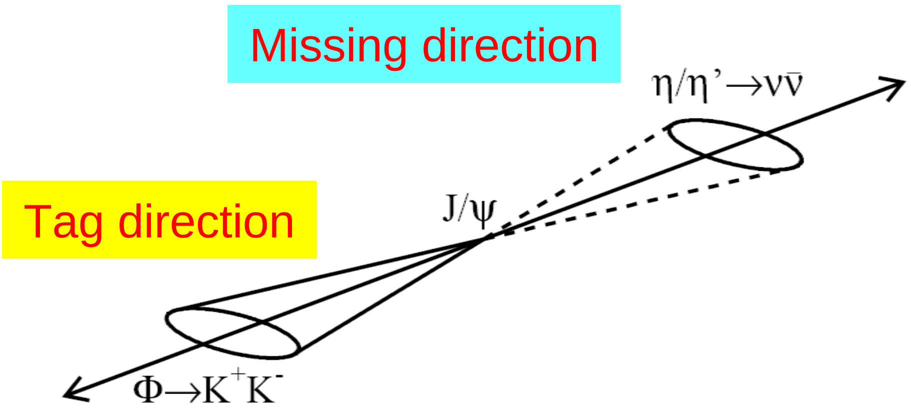
Search for invisible particles



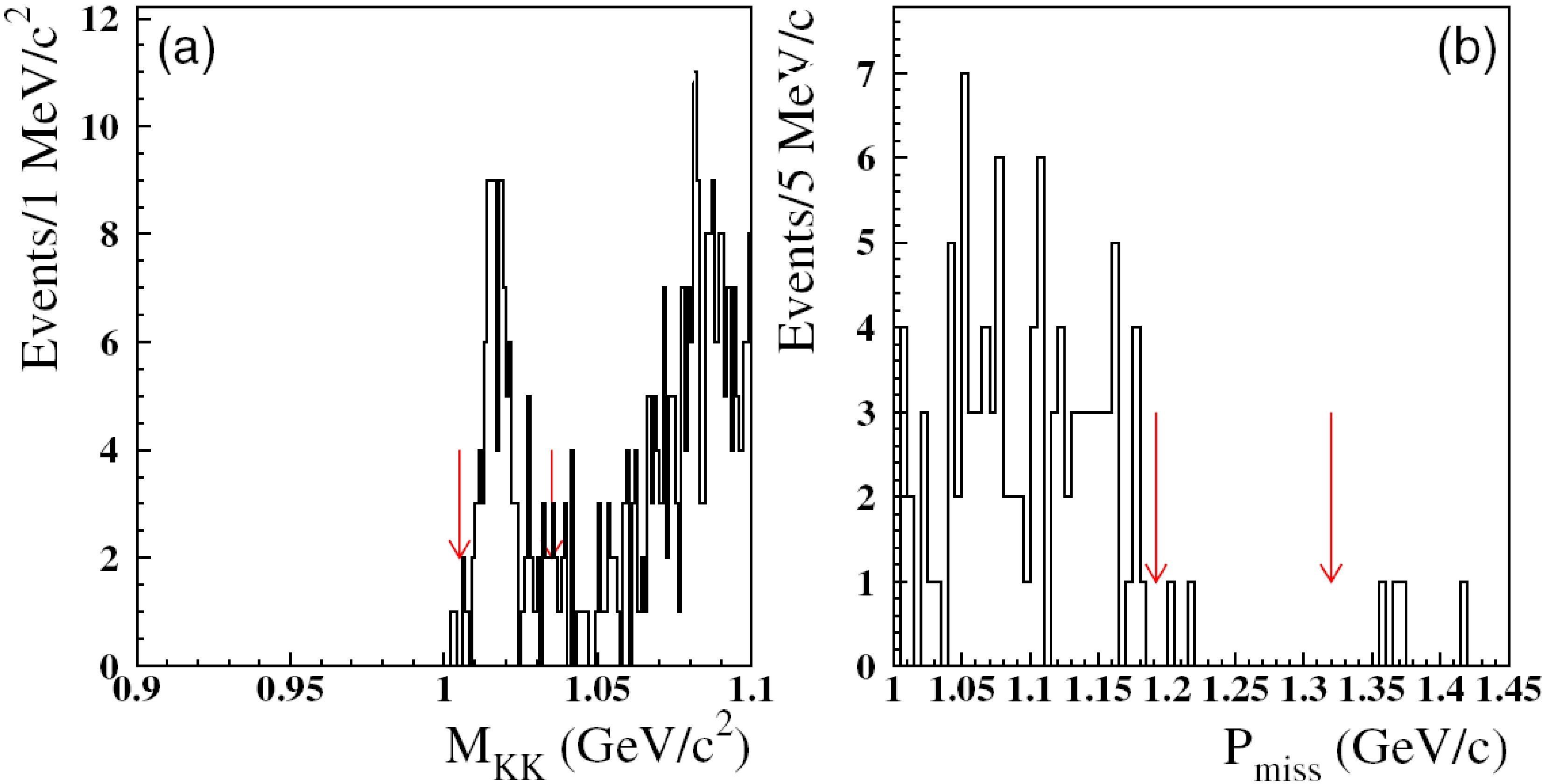
WIMPs are good dark matter candidates, they may show themselves in particle decays into invisible final states!

$J/\psi \rightarrow \phi\eta, \phi\eta'$

PRL97, 202002 (2006)



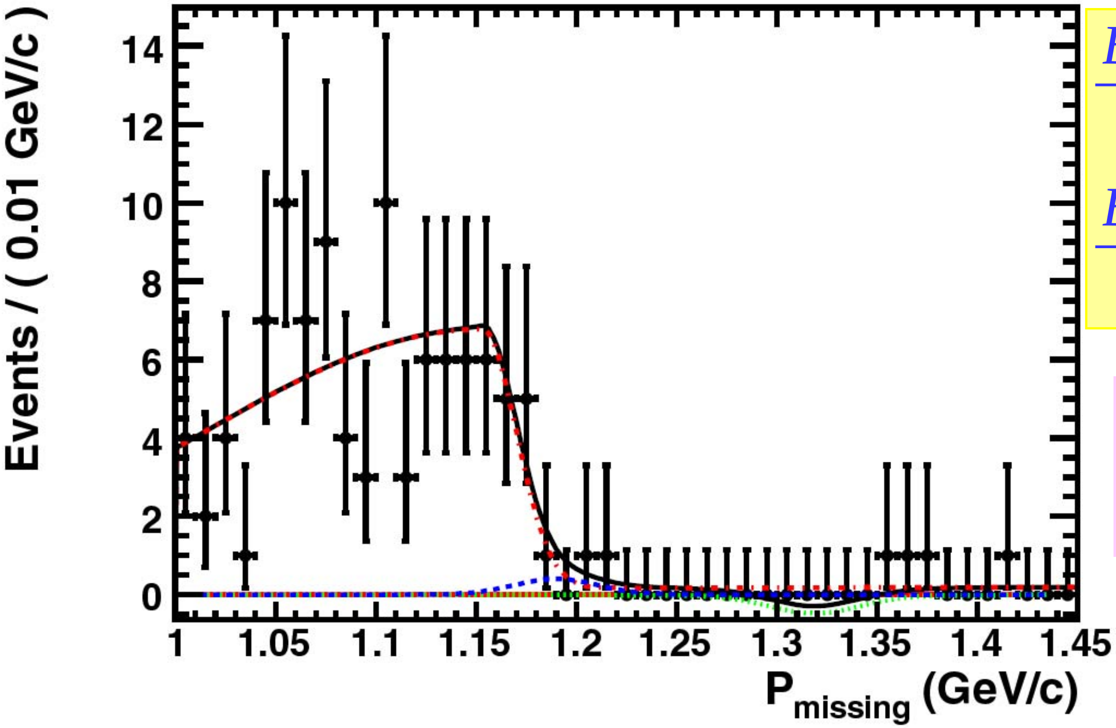
- Two good charged Kaons
- No hits outside of 30^0 cone
- $\cos(\theta_{missing}) < 0.7$
- $1.005 < M(K^+K^-) < 1.035$ GeV;



Search for η/η' → invisible decays in J/ψ → φη/η'

An unbinned extended Maximum Likelihood Fit:

$$\mathcal{L}(N^{\eta}_{sig}, N^{\eta'}_{sig}, N_{bkgd}) = \frac{e^{-(N^{\eta}_{sig}+N^{\eta'}_{sig}+N_{bkgd})}}{N!} \times \prod_{i=1}^{N}[N^{\eta}_{sig}\mathcal{F}^{\eta}_{sig}(P^{i}_{miss}) + N^{\eta'}_{sig}\mathcal{F}^{\eta'}_{sig}(P^{i}_{miss}) + N_{bkgd}\mathcal{F}_{bkgd}(P^{i}_{miss})],$$



$$\frac{BR(\eta \to invisible)}{BR(\eta \to \gamma\gamma)} < 1.7\times10^{-3}\ @90\%C.L.$$

$$\frac{BR(\eta' \to invisible)}{BR(\eta' \to \gamma\gamma)} < 6.7\times10^{-2}\ @90\%C.L.$$

B(η→invisible) < 6.4×10^{-4} @90% C.L.

B(η'→invisible) < 1.4×10^{-3} @90% C.L.

B. McElrath, PRD 72, 103508 (2005)

B(η → χχ) ~ 7.4×10^{-5}

B(η' → χχ) ~ 8.1×10^{-7}

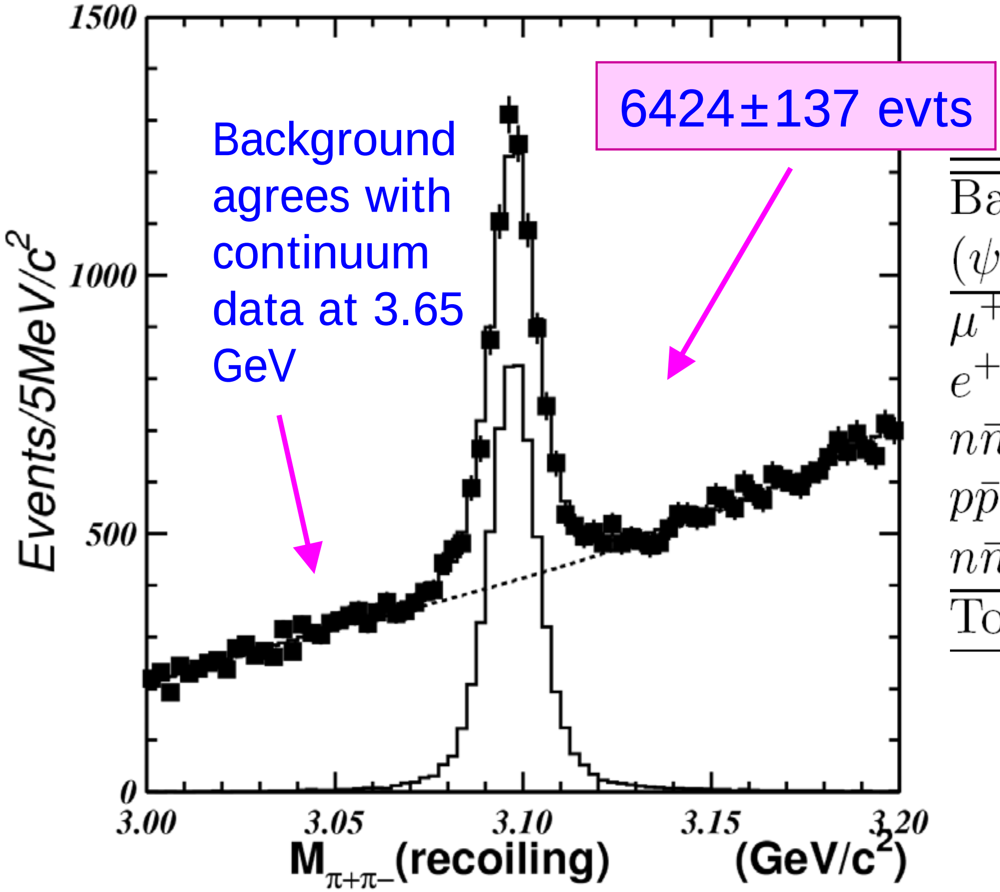
PRL97, 202002 (2006)

J/ψ→invisible

arXiv: 0710.0039 [hep-ex]
PRL (in press)

- $\psi(2S) \to \pi^+\pi^- J/\psi$ as a J/ψ sample by tagging $\pi^+\pi^-$

Select two low momentum pions, and require no other particles in detector.



Peaking background

Background channel ($\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to$)	Efficiency (%)	Expected N_{bg}
$\mu^+\mu^-$	0.964	2543 ± 254
e^+e^-	0.907	2393 ± 240
$n\bar{n}$	10.46	1011 ± 85
$p\bar{p}$	0.434	42 ± 13
$n\bar{n}\pi^0$	0.486	29 ± 10
Total		6018 ± 514

Lower limit of N_{bkg}

$$\frac{B(J/\psi \to \text{invisible})}{B(J/\psi \to \mu^+\mu^-)} < 0.012 \quad @90\% \text{ C.L.}$$

More stringent constraint on NEW physics parameters: (U-boson c-quark/LDM coupling)

P. Fayet, Phys. Rev. D **74**, 054034 (2006).
P. Fayet, Phys. Rev. D **75**, 115017 (2007).

总　　结

- BESII运行10年来在R值测量、强子谱、粲偶素、粲物理以及新物理寻找等方面取得了重要物理结果

- 仍然有一些分析在进行中，结果即将报道

- 2008年夏即将运行的BESIII将有更好的前景（参见李海波报告）

谢谢！