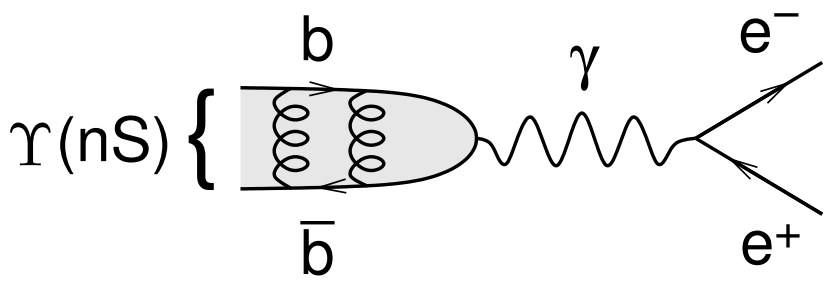
Di-electron Widths of the Υ(1S), Υ(2S), and Υ(3S)



Jim Pivarski

Cornell University

CLEO Collaboration

Motivation for a New High-Precision Measurement

- Di-electron width $\boldsymbol{\Gamma_{ee}}$ is a basic parameter of the Υ meson

- "Golden-mode" test of high-precision Lattice QCD

- This test is relevant for CKM element V_{td}

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Staggered-quark formalism makes QCD simulations with realistic u, d, s masses possible

Allows few-percent calculations of observables such as $\boldsymbol{\Gamma_{ee}}$

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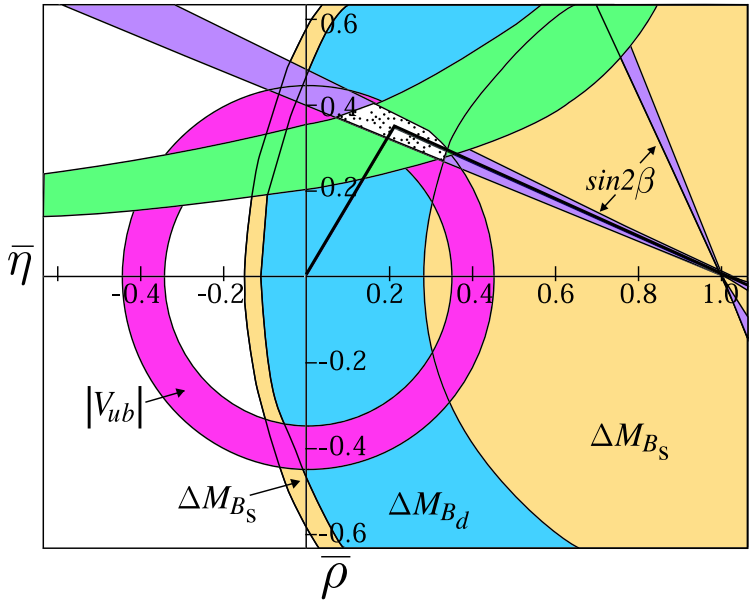
- This test is relevant for CKM element V_{td}

f_B is a QCD factor that obfuscates V_{td} (blue band)

$\boldsymbol{\Gamma_{ee}}$ and f_B share: NRQCD action
staggered-quark formalism
but not: heavy-light quark asymmetry
axial vector coupling

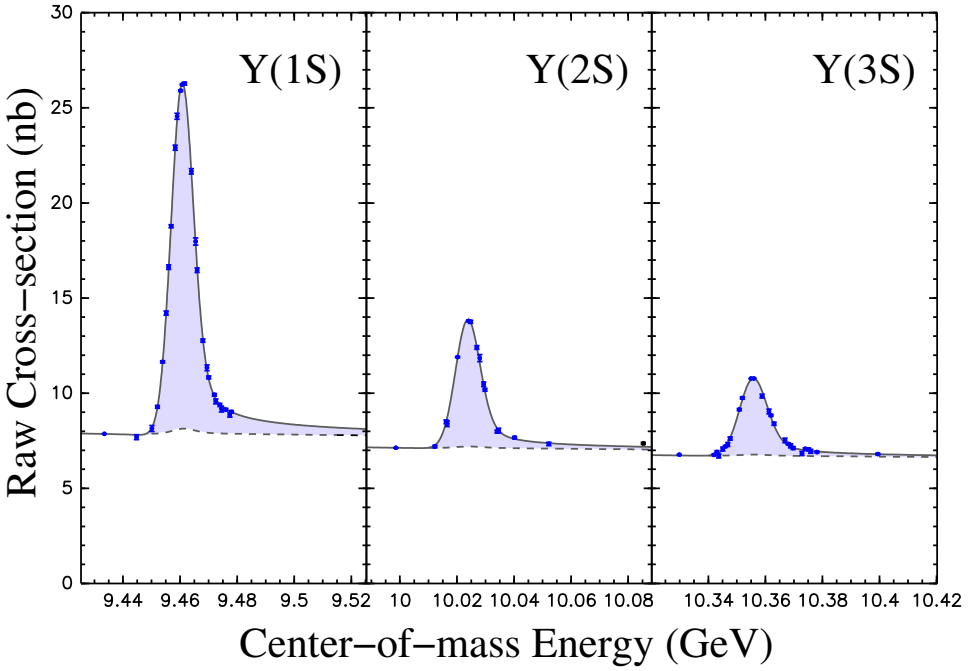


Complementary with f_D: see Topher Cawlfield's talk

Method

Determine $\Upsilon \to e^+e^-$ decay rate by measuring $e^+e^- \to \Upsilon$ cross-section

$$\Gamma_{ee} = \frac{M\Upsilon^2}{6\pi^2} \int \sigma(e^+e^- \to \Upsilon)\, dE$$



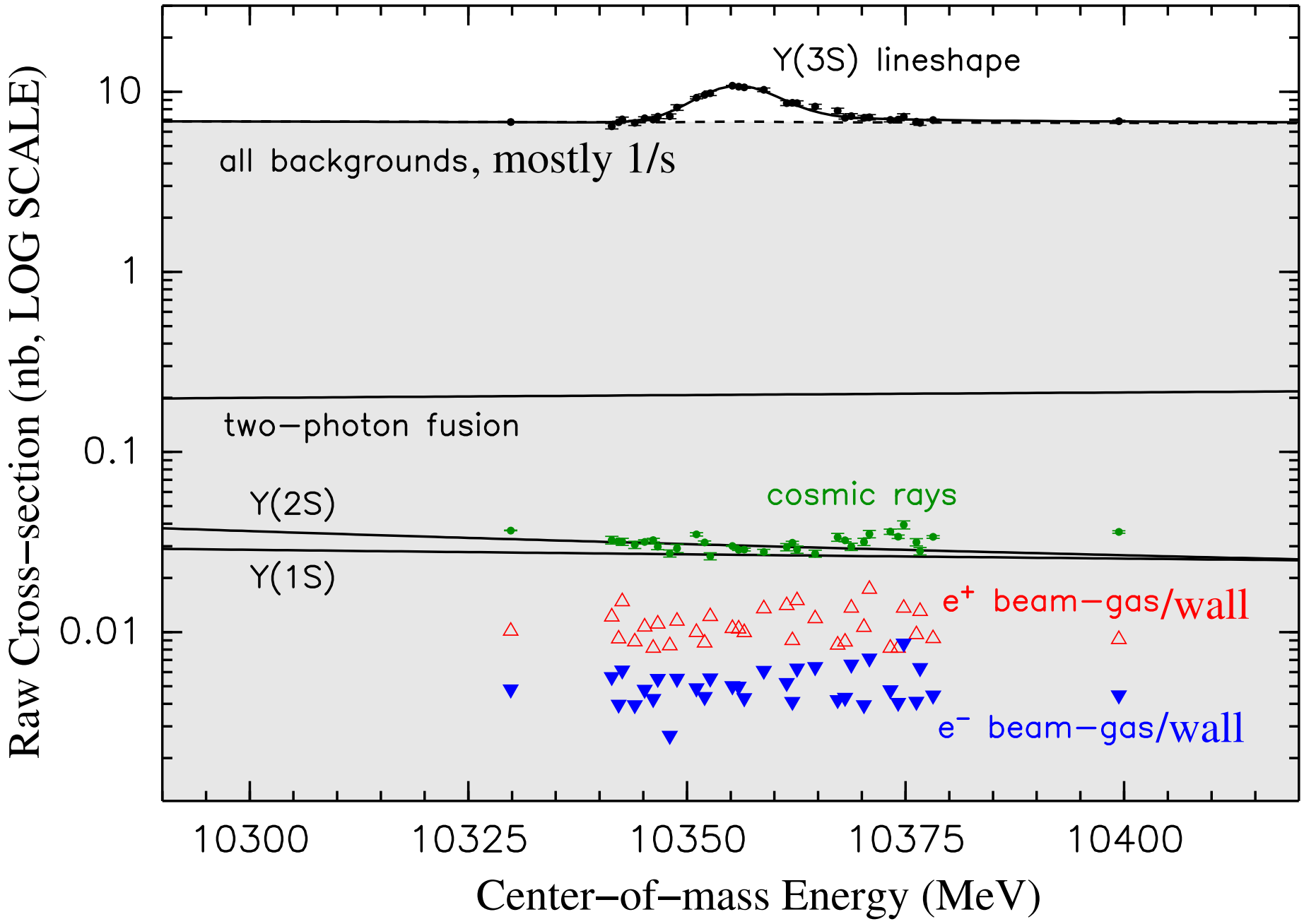
Cornell Electron Storage Ring

Integrated Luminosity (on+off peak)		
$\Upsilon(1S)$	0.27+0.19 fb^{-1}	4.9 million
$\Upsilon(2S)$	0.08+0.41 fb^{-1}	0.5 million
$\Upsilon(3S)$	0.22+0.14 fb^{-1}	0.9 million

Measure $\sigma(e^+e^- \to \Upsilon \to \text{hadrons})$ at several beam energies

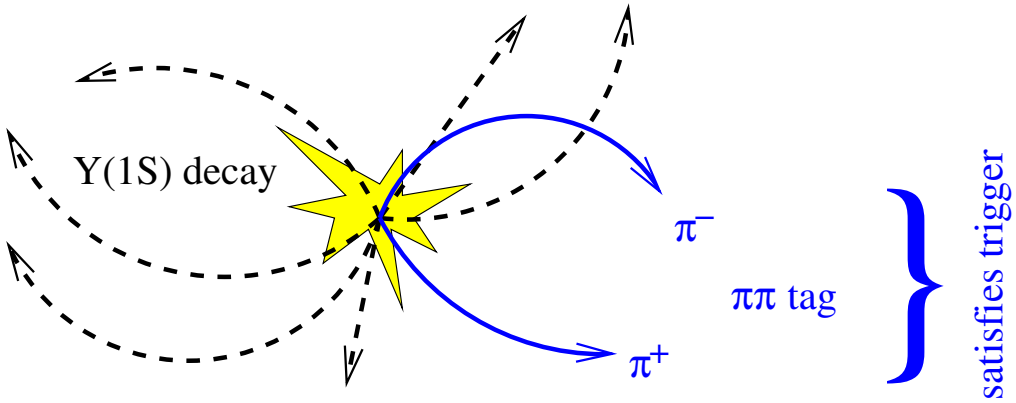
Integrate spectrum without initial-state radiation convolution

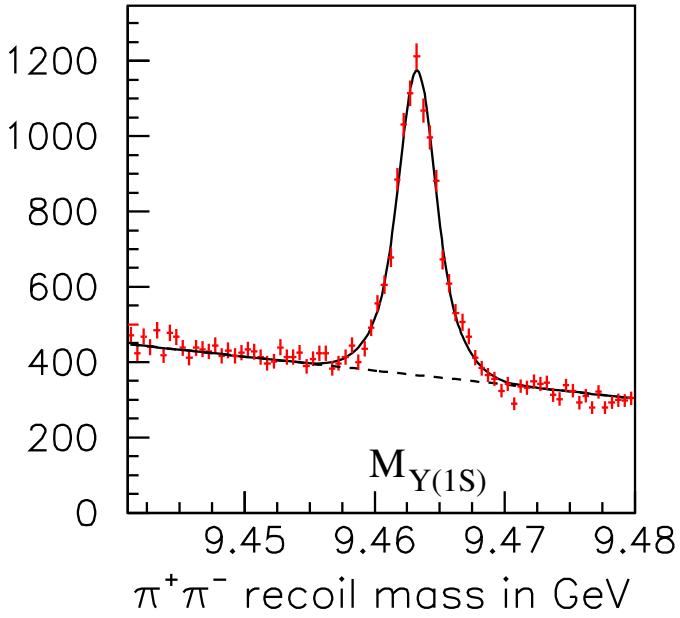
Backgrounds



Efficiency

- Select $\Upsilon(2S) \to \pi^+\pi^-\ \Upsilon(1S)$ by $\pi^+\pi^-$ recoil mass





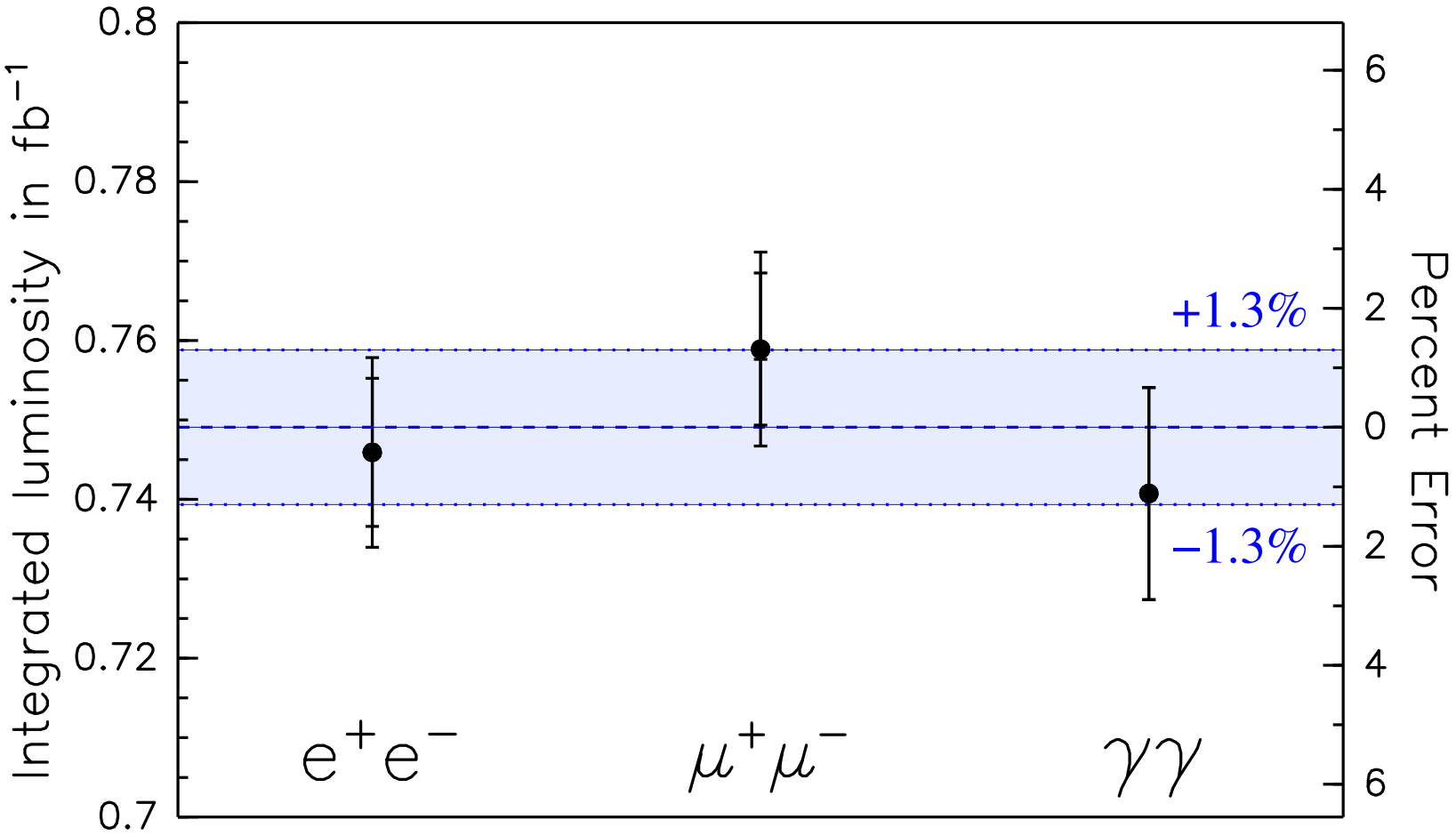
- Set of $\Upsilon(1S)$ events is unbiased, includes all decays

- $\Upsilon(1S)$ efficiency $=$ #pass/#total $=$ (97.8 $\pm$ 0.5)%

- For $\Upsilon(2S)$ and $\Upsilon(3S)$ efficiency, we extrapolate using Monte Carlo

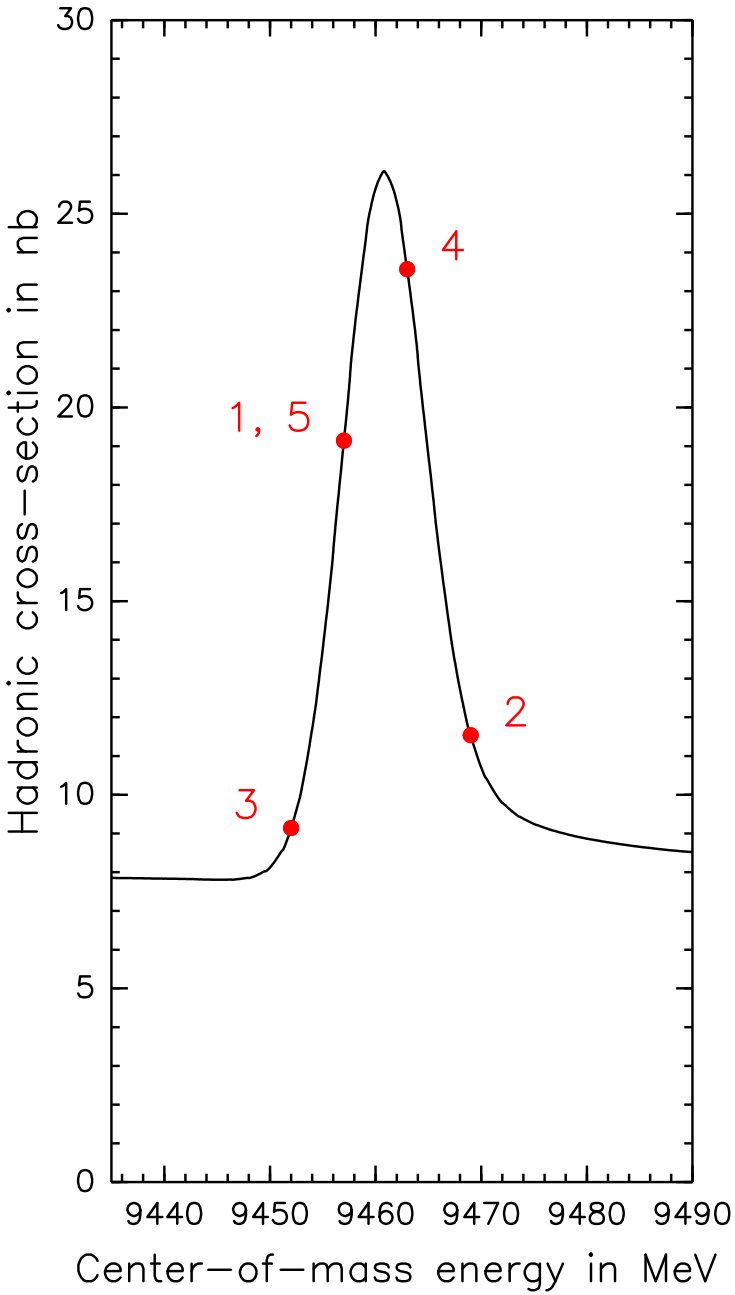
Integrated Luminosity

- Count $e^+e^- \to e^+e^-$ events and compare with theoretical cross-section
- Check overall scale with $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \gamma\gamma$

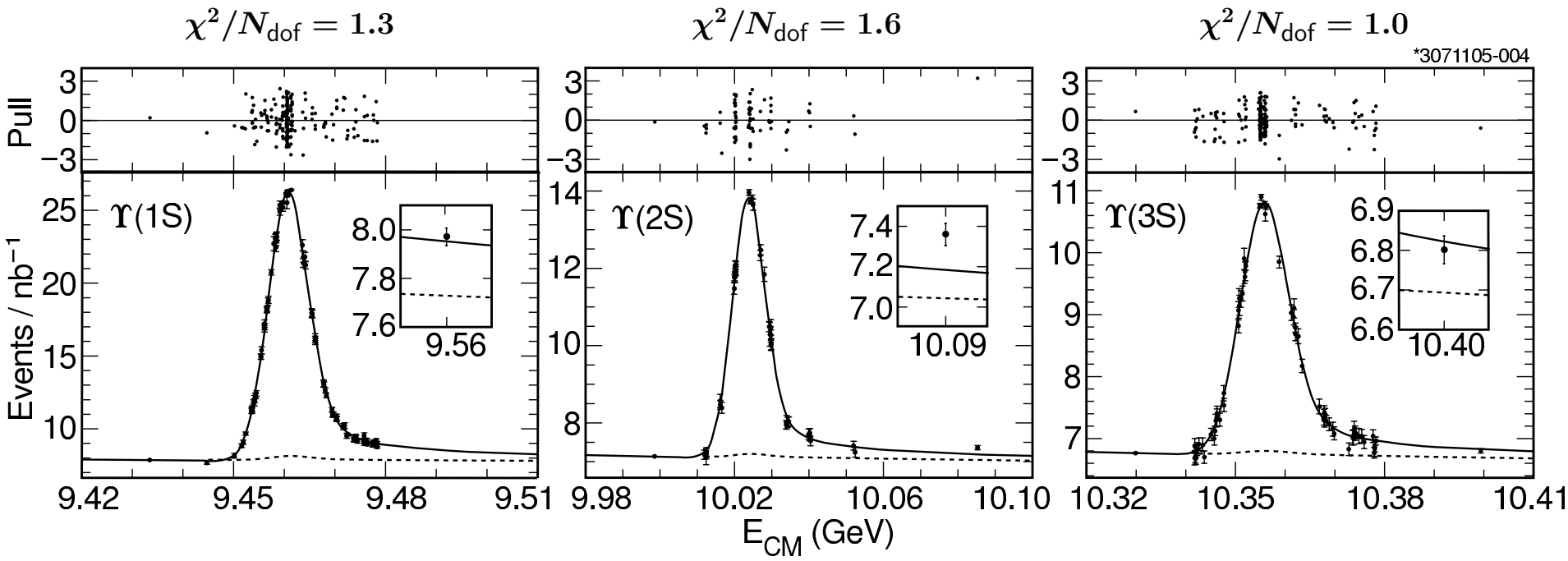


Beam Energy Uncertainty

- Beam energy determined by dipole magnet measurement
- Calibration drifts with time (0.5 MeV/month)
- Each resonance completely scanned in 48 hours (repeated scans for statistical precision)
- Measurements alternated above and below resonance peak
- Point of high slope repeated (1 & 5): convert cross-section reproducibility into beam energy reproducibility
- $\Rightarrow$ 0.07 MeV uncertainty in center-of-mass differences, 0.2% in Γ_{ee}



Fit Results



			Statistical	Systematic
$\Gamma_{ee}(1S)$	=	1.354 ± 0.004 ± 0.020 keV	0.3%	1.5%
$\Gamma_{ee}(2S)$	=	0.619 ± 0.004 ± 0.010 keV	0.7%	1.6%
$\Gamma_{ee}(3S)$	=	0.446 ± $\underbrace{0.004}_{\text{stat}}$ ± $\underbrace{0.007}_{\text{syst}}$ keV	1.0%	1.5%

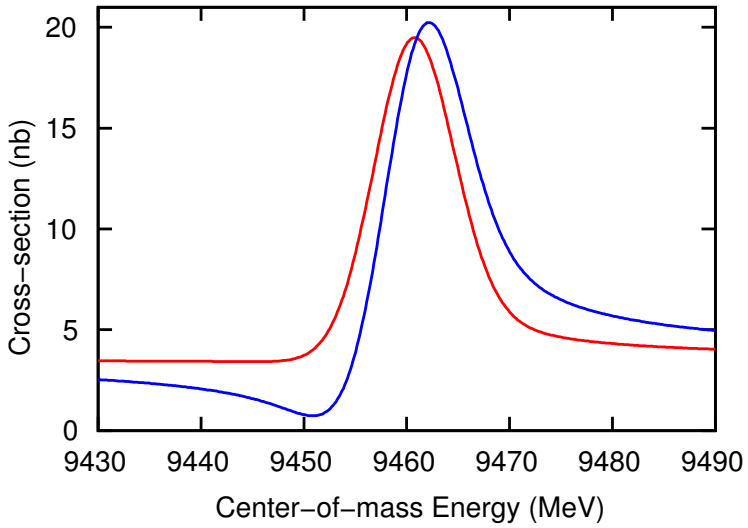
Interference with Continuum Hadrons

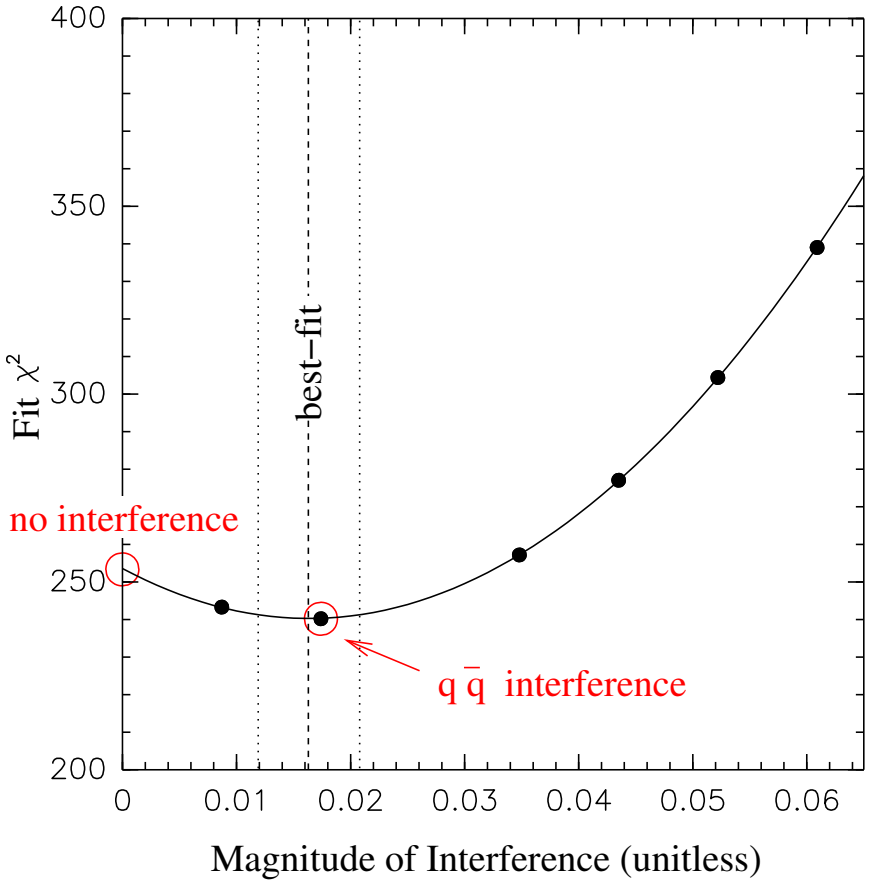
Interference between $e^+e^- \to \Upsilon \to q\bar{q}$ and $e^+e^- \to q\bar{q}$ matters

Phase difference cycles through resonance: destructive interference below resonance, constructive above

Our fit prefers $q\bar{q}$-interference over no-interference by 3.7 standard deviations

red: no interference
blue: exaggerated interference





Summary of Uncertainties

*Common to all resonances

Contribution to Γ_{ee}	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Correction for leptonic modes	0.2%	0.2%	0.3%
Hadronic efficiency*	0.5%	0.5%	0.5%
Xe^+e^-, $X\mu^+\mu^-$ correction	0	0.15%	0.13%
Overall luminosity scale*	1.3%	1.3%	1.3%
Bhabha/$\gamma\gamma$ inconsistency	0.4%	0.4%	0.4%
Beam energy measurement drift	0.2%	0.2%	0.2%
Fit function shape	0.1%	0.1%	0.1%
χ^2 inconsistency	0.2%	0.6%	0
Total systematic uncertainty	1.5%	1.6%	1.5%
Statistical uncertainty	0.3%	0.7%	1.0%
Total	1.5%	1.8%	1.8%

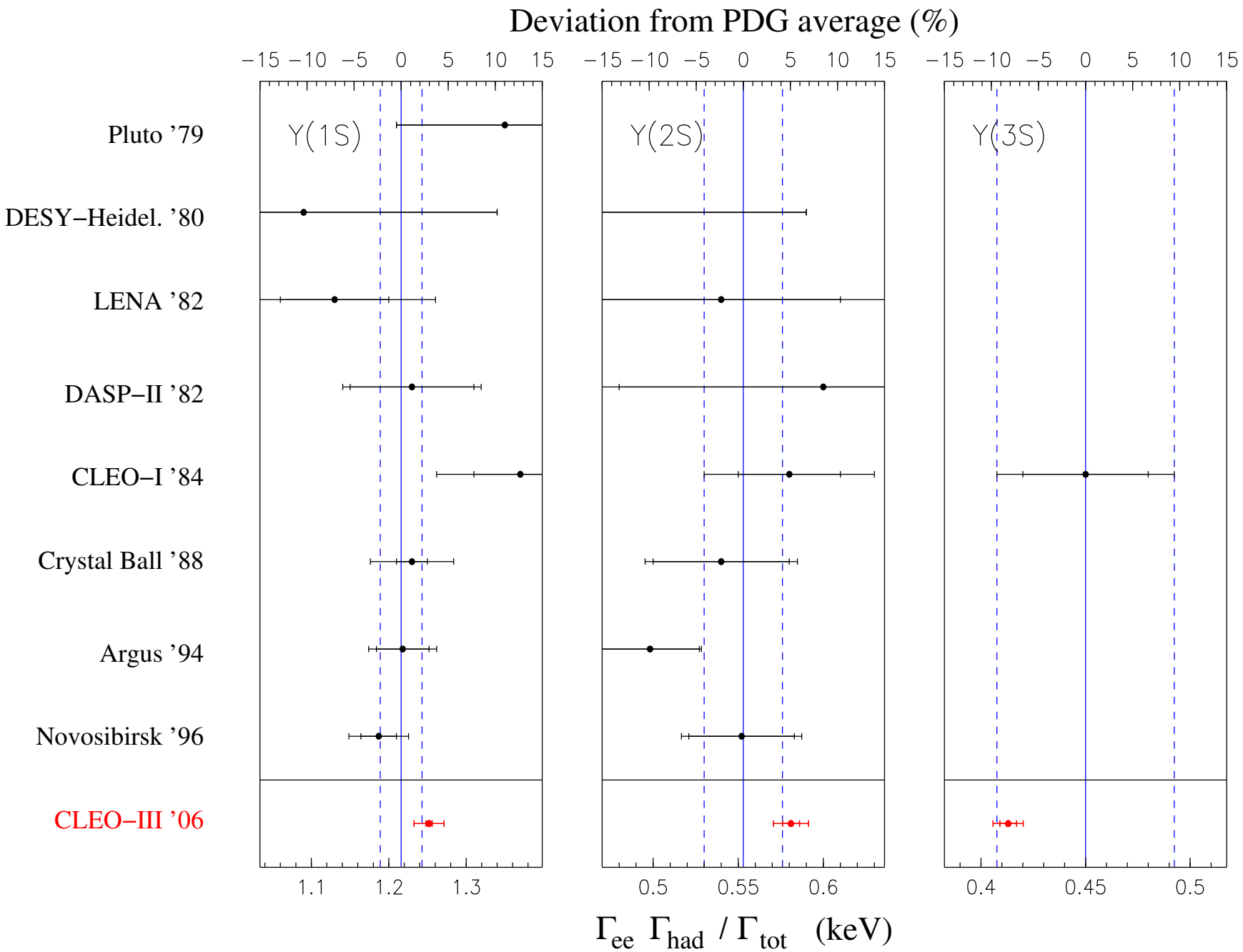
Results!

$\Gamma_{ee}(1S)$	$=$	$1.354 \pm 0.004 \pm 0.020$ keV	1.5%
$\Gamma_{ee}(2S)$	$=$	$0.619 \pm 0.004 \pm 0.010$ keV	1.8%
$\Gamma_{ee}(3S)$	$=$	$0.446 \pm 0.004 \pm 0.007$ keV	1.8%
$\Gamma_{ee}(2S)/\Gamma_{ee}(1S)$	$=$	$0.457 \pm 0.004 \pm 0.004$ keV	1.2%
$\Gamma_{ee}(3S)/\Gamma_{ee}(1S)$	$=$	$0.329 \pm 0.003 \pm 0.003$ keV	1.3%
$\Gamma_{ee}(3S)/\Gamma_{ee}(2S)$	$=$	$0.720 \pm 0.009 \pm 0.007$ keV	1.6%
$\Gamma(1S)$	$=$	$54.4 \pm 0.2 \pm 0.8 \pm 1.6$ keV	3.3%
$\Gamma(2S)$	$=$	$30.5 \pm 0.2 \pm 0.5 \pm 1.3$ keV	4.6%
$\Gamma(3S)$	$=$	$18.6 \pm 0.2 \pm 0.3 \pm \underbrace{0.9}_{\mathcal{B}_{\mu\mu}}$ keV	5.2%

Γ_{ee}: hep-ex/0512056, to be published in Phys. Rev. Lett. (March 2006)

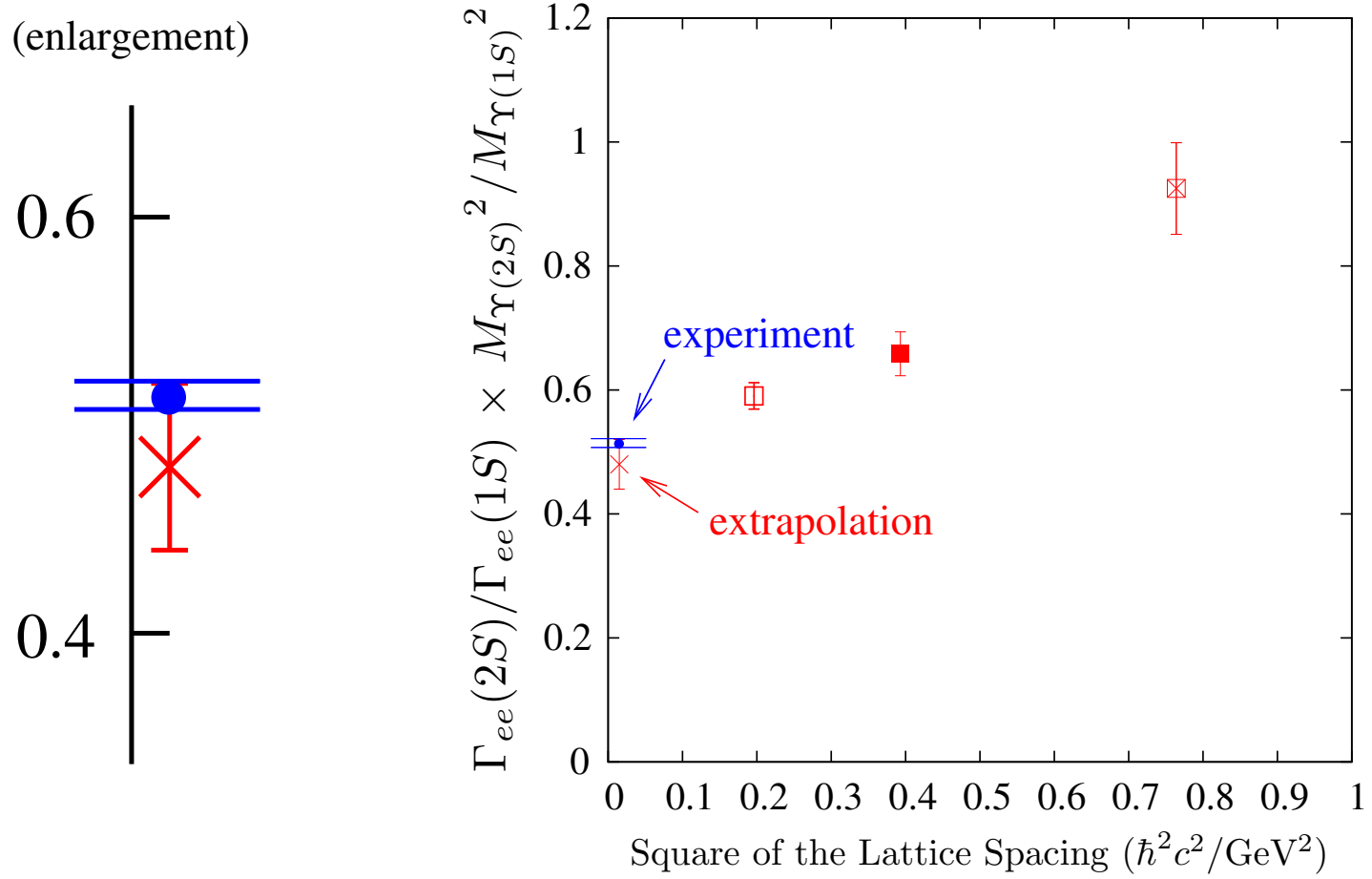
$\mathcal{B}_{\mu\mu}$: G.S. Adams *et al.* (CLEO Collaboration), Phys. Rev. Lett. **94**, 012001 (2005)

History


Deviation from PDG average (%)
−15 −10 −5 0 5 10 15
Y(1S)
Y(2S)
Y(3S)
Pluto ’79
DESY−Heidel. ’80
LENA ’82
DASP−II ’82
CLEO−I ’84
Crystal Ball ’88
Argus ’94
Novosibirsk ’96
CLEO−III ’06
1.1 1.2 1.3
0.5 0.55 0.6
0.4 0.45 0.5
$\Gamma_{ee}\ \Gamma_{had}\ /\ \Gamma_{tot}$ (keV)

Comparison with Lattice QCD

- Lattice QCD results are preliminary
- Final results will have few percent precision in $\Gamma_{ee}(nS)/\Gamma_{ee}(mS)$ and ∼10% in $\Gamma_{ee}(nS)$



Lattice QCD A. Gray *et al.* [HPQCD Collaboration], Phys. Rev. D **72**, 094507 (2005)

Experiment hep-ex/0512056, to be published in Phys. Rev. Lett. (March 2006)
and J. Pivarski, Cornell University, Ph.D. thesis