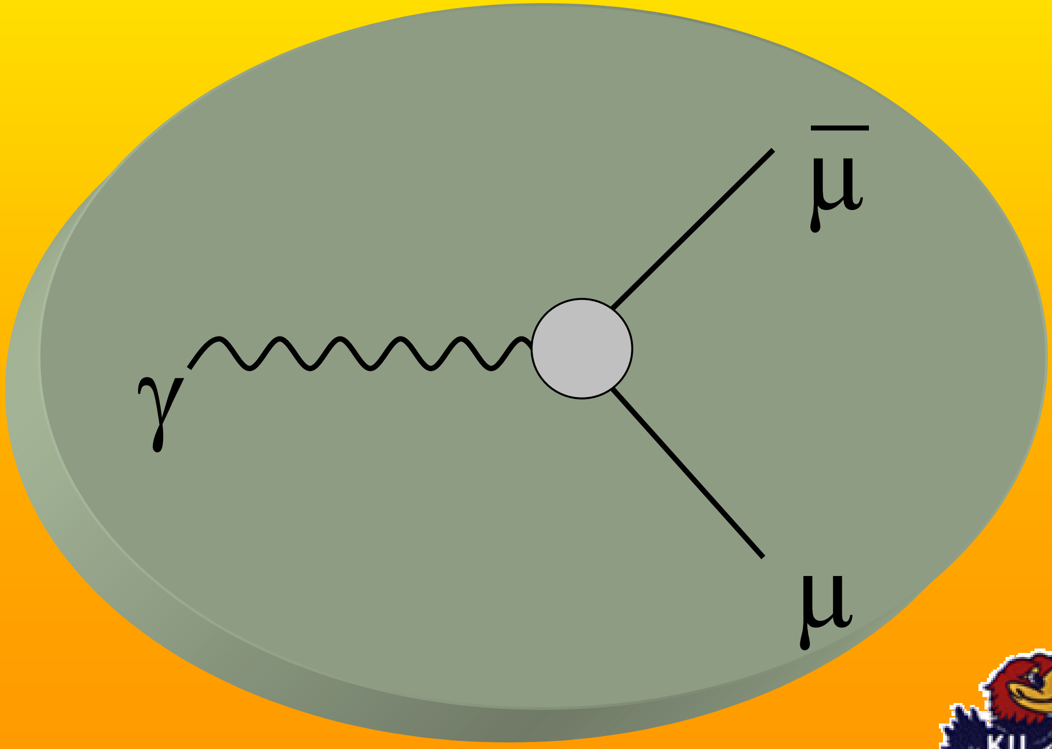
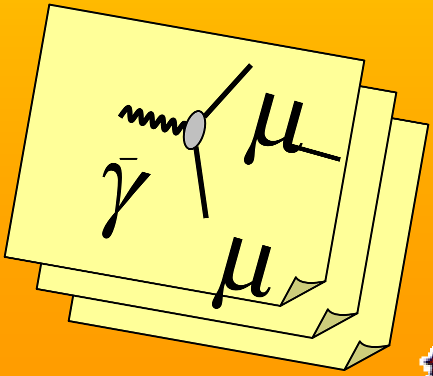
Explaining the Muon Magnetic Moment Anomaly

Rainer Schiel
with
John Ralston



Outline

- a_μ: Experiment vs Theory
- Hadronic Contribution ...Previously Overlooked
- Consequences



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The Muon Magnetic Moment

$$\vec{\mu} = g\frac{e}{2m}\vec{S}$$

Magnetic moment

Landé g-factor
(expect "2" for Dirac particle)

Charge over
twice the mass

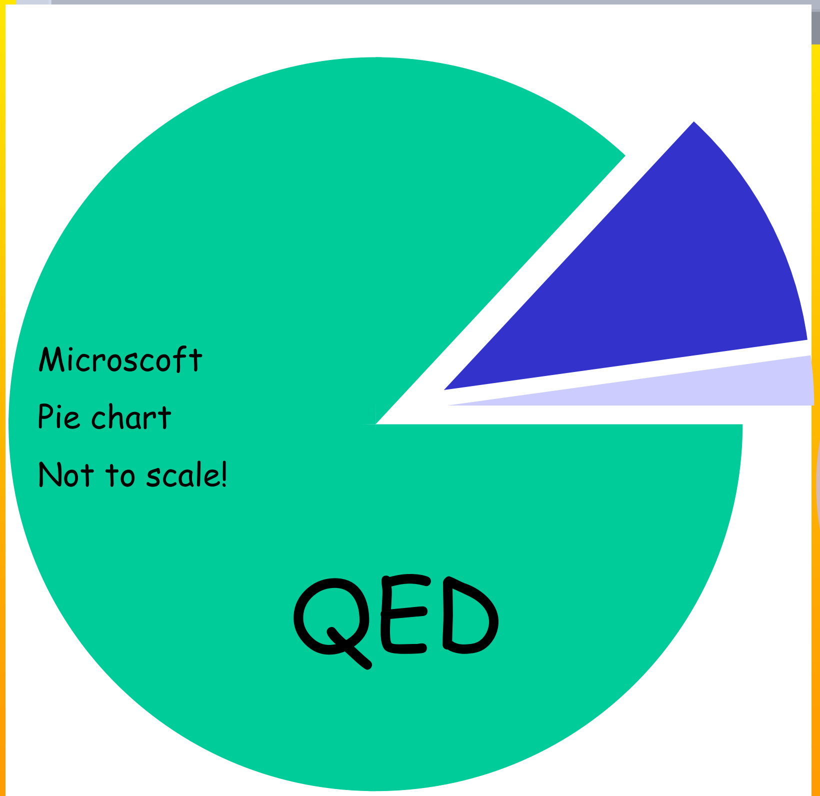
Spin

Magnetic moment anomaly:

$$a_\mu = \frac{g-2}{2}$$

- $a_\mu^{exp} = (11659208.0 \pm 6.3)10^{-10}$
- $a_\mu^{theory} = (11659180.0 \pm 5.1)10^{-10}$

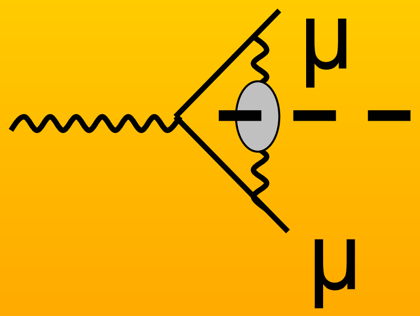
Expt -BNL 2006; Theory - Hagiwara et al, Davier et al, Jagerlehner …



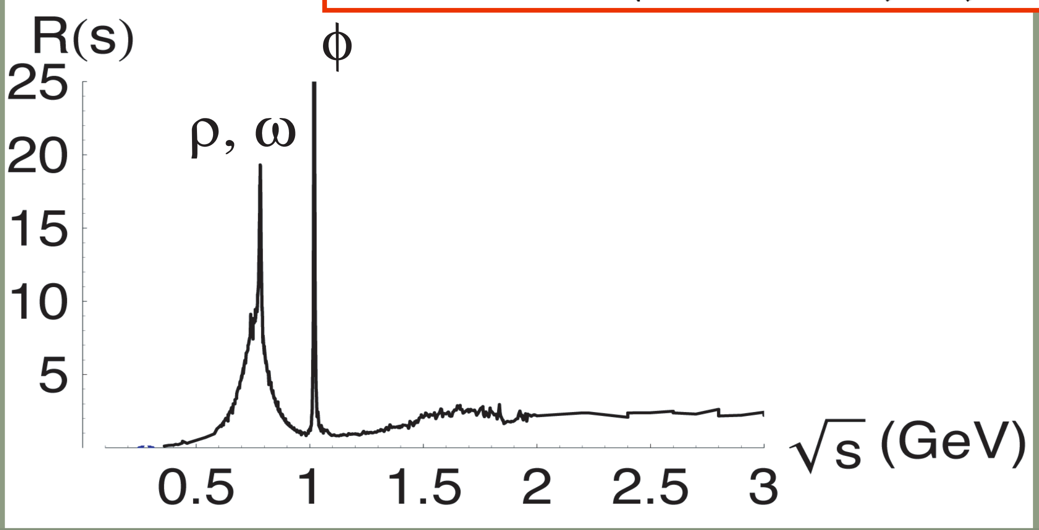
hadronic vacuum polarization
$(689.4 \pm 4.6)10^{-10}$

hadronic contributions

$$a_\mu^{had,LO} = \frac{\alpha^2}{3\pi^2}\int_{4m_\pi^2}^{\infty} ds \frac{K(x(s))}{s} R(s)$$



$$R(s) = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



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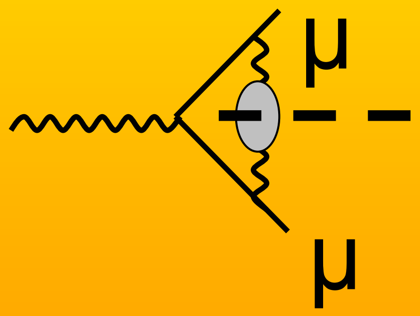
and the famous kernel is…

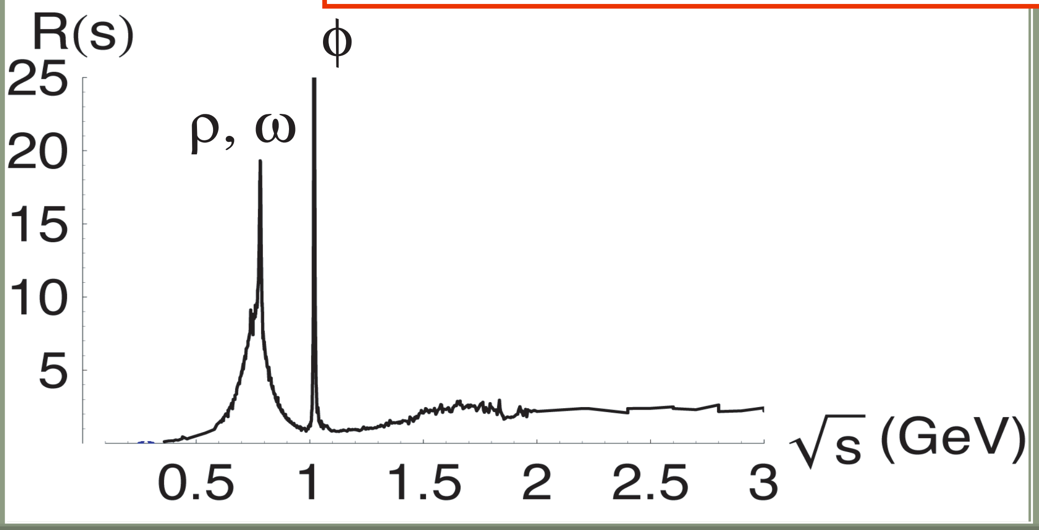
$$
\begin{aligned}
K(x) &= x^2\left(1-\frac{x^2}{2}\right) \\
&+ (1+x)^2\left(1+\frac{1}{x^2}\right)\left(\ln(1+x)-x+\frac{x^2}{2}\right) \\
&+ \frac{1+x}{1-x}x^2\ln x; \\
x &= (1-\beta_\mu)/(1+\beta_\mu); \\
\beta_\mu &= \sqrt{1-4m_\mu^2/s}.
\end{aligned}
$$

hadronic contributions

$$a_\mu^{had,LO} = \frac{\alpha^2}{3\pi^2}\int_{4m_\pi^2}^{\infty} ds \frac{K(x(s))}{s} R(s)$$

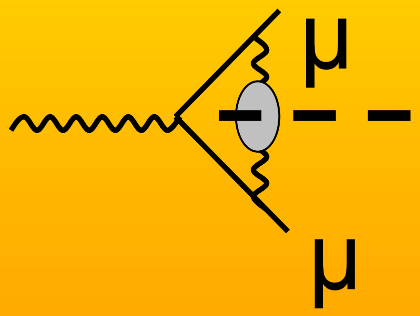
$$R(s) = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

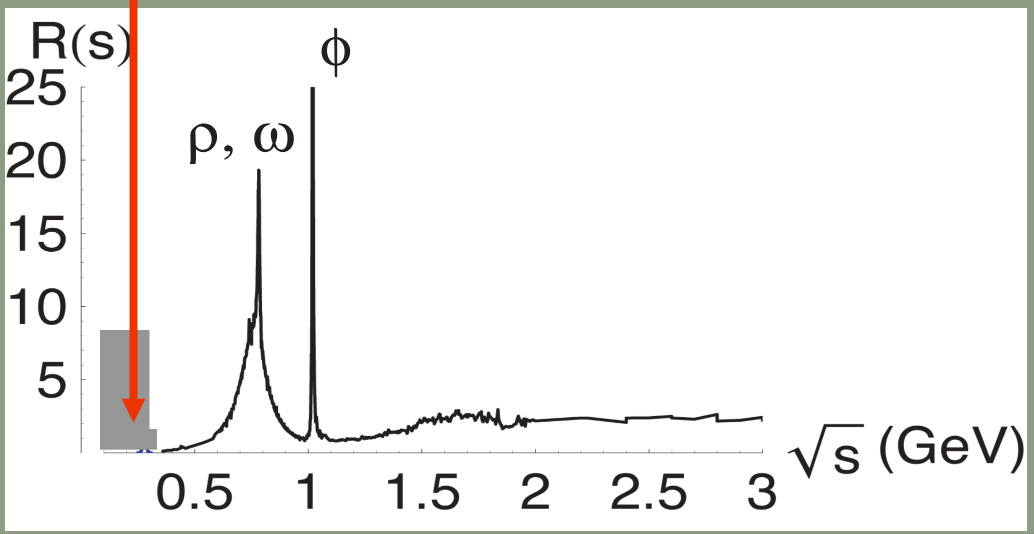




hadronic contributions

$$a_\mu^{had,LO} = \frac{\alpha^2}{3\pi^2}\int_{s_{min}}^{\infty} \mathrm{d}s \frac{K(x(s))}{s} R(s)$$





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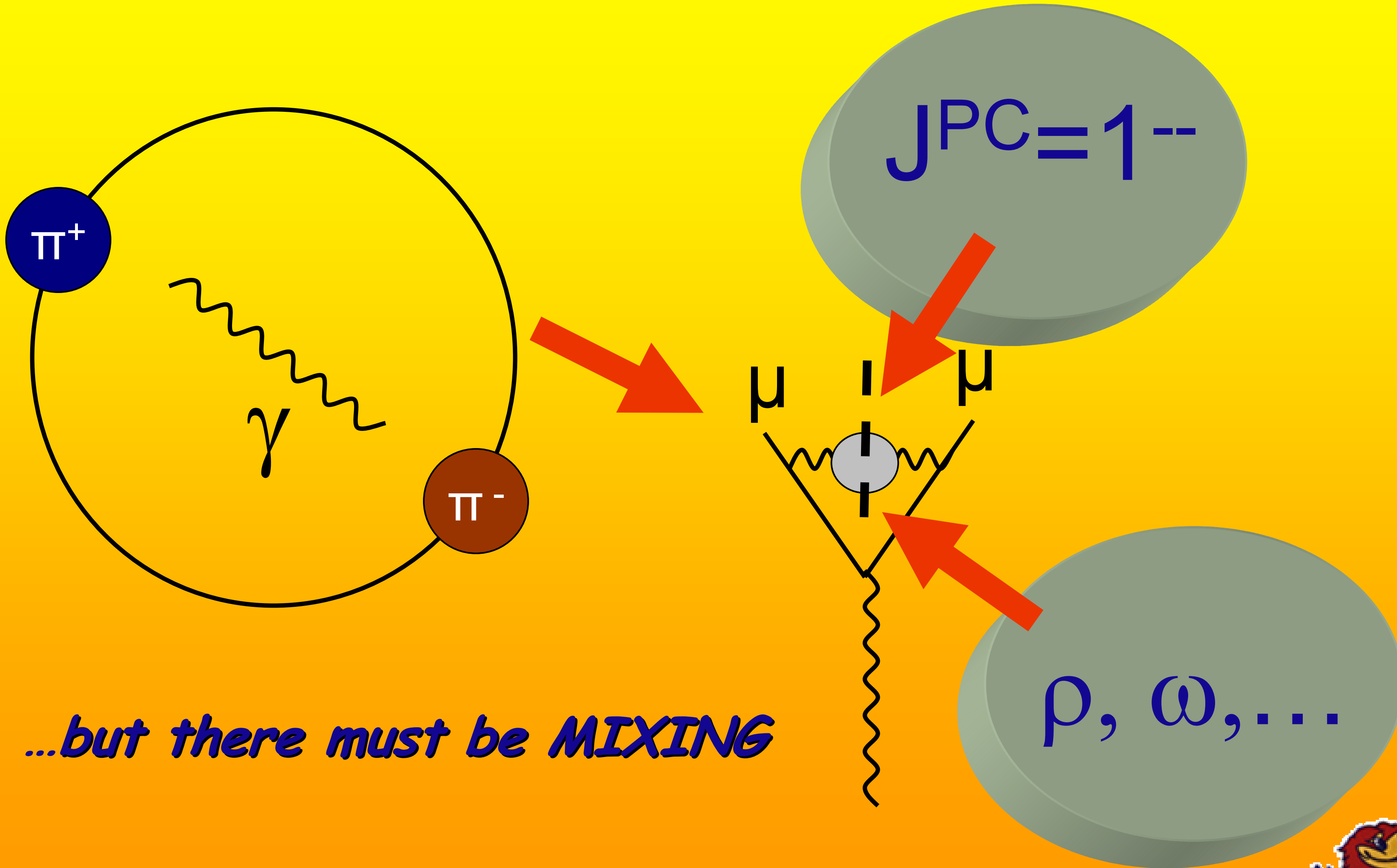
$\pi^+ - \pi^-$ "atoms" are *pionium*



…but there must be MIXING

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2 state mixing !

Pirhonium

$$\begin{pmatrix} |\pi_2/\rho\rangle \\ |\rho\rangle \end{pmatrix} = \begin{pmatrix} cos\beta & sin\beta \\ -sin\beta & cos\beta \end{pmatrix} \begin{pmatrix} |\tilde{\pi}_2\rangle \\ |\tilde{\rho}\rangle \end{pmatrix}$$

physical — bare

$$H_{int} = \begin{pmatrix} m_{\tilde{\pi}_2} & m_{ix} \\ m_{ix} & m_{\tilde{\rho}} \end{pmatrix}$$

bare atomic state…

$$R_{\tilde{\pi}_2}(r) = \frac{1}{\sqrt{24}}\frac{r}{a_0^{5/2}}e^{-r/2a_0}$$

bare mass = 2 m_π -13.6 eV / 2^2 (m_π/2 m_e)…
…fixes one mixing parameter

diagonalize…

$$\tan\beta = \frac{1}{2m_{ix}}\left(m_{\tilde{\rho}} - m_{\tilde{\pi}_2} - \sqrt{(m_{\tilde{\rho}} - m_{\tilde{\pi}_2})^2 + 4m_{ix}^2}\,\right)$$

$\Gamma(\pi_2/\rho \rightarrow e^+e^-)$ = 28 eV …fixes second parameter

mass eigenvalues…

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bare atomic state...

$$R_{\tilde{\pi}_2}(r) = \frac{1}{\sqrt{24}} \frac{r}{a_0^{5/2}} e^{-r/2a_0}$$

bare mass = 2 m_π -13.6 eV / 2^2 (m_π/2 m_e)...
...fixes one mixing parameter

279.11 MeV

diagonalize...

$$\tan\beta = \frac{1}{2m_{ix}}\left(m_{\tilde{\rho}} - m_{\tilde{\pi}_2} - \sqrt{(m_{\tilde{\rho}} - m_{\tilde{\pi}_2})^2 + 4m_{ix}^2}\right)$$

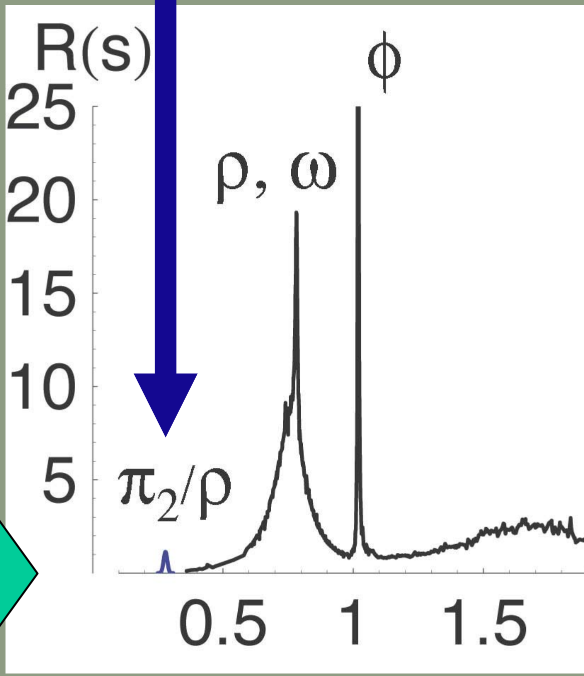
$\Gamma(\pi_2/\rho \to e^+e^-)$ = 28 eV ...fixes second parameter

mass eigenvalues...

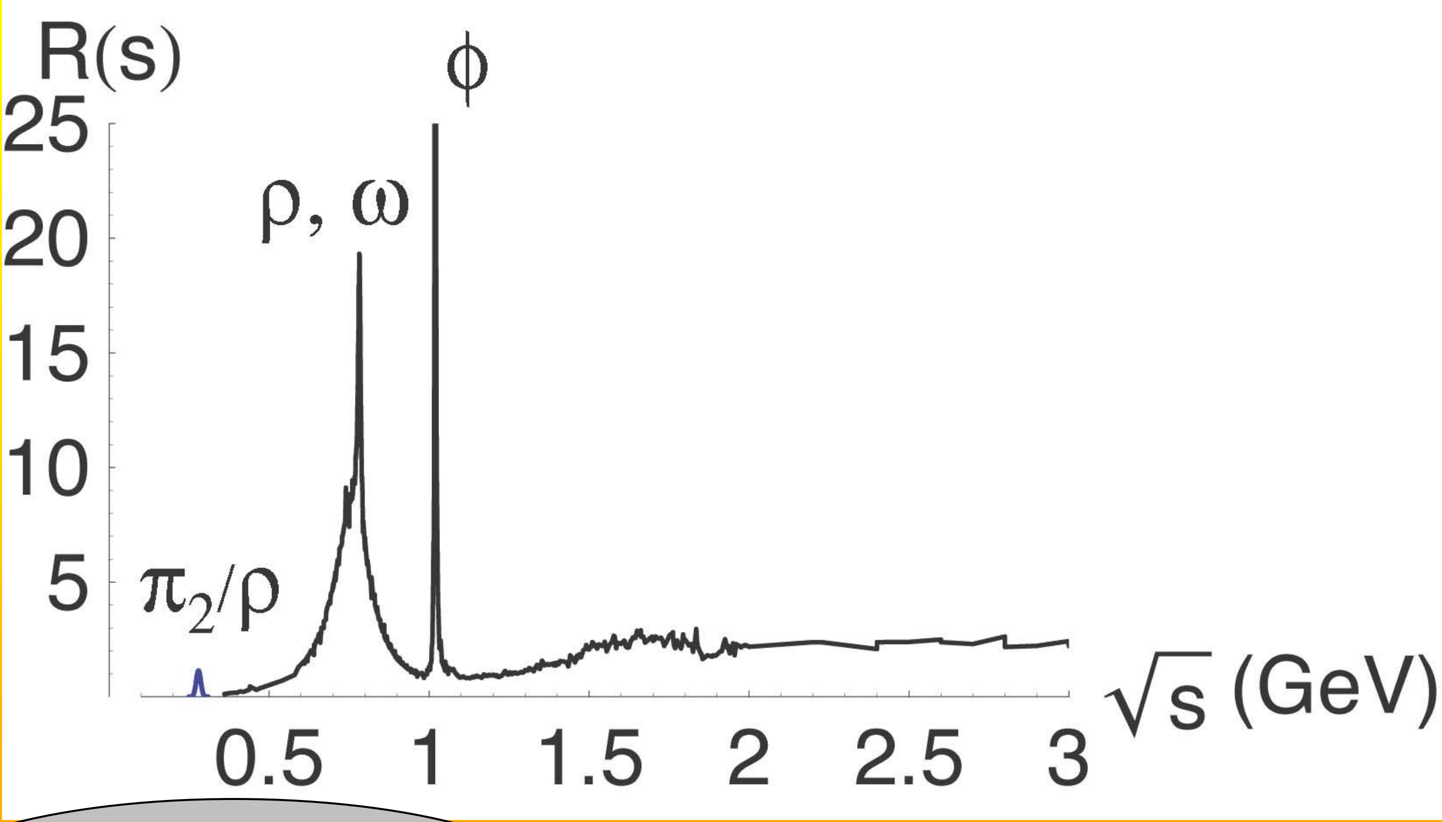
m_ρ =775 MeV... fixes last parameter

$$\sin\beta = 0.81\%$$

$$\beta = 0.46^\circ$$



Pirhonium contribution



$$\sin\beta \approx 0.81\%$$

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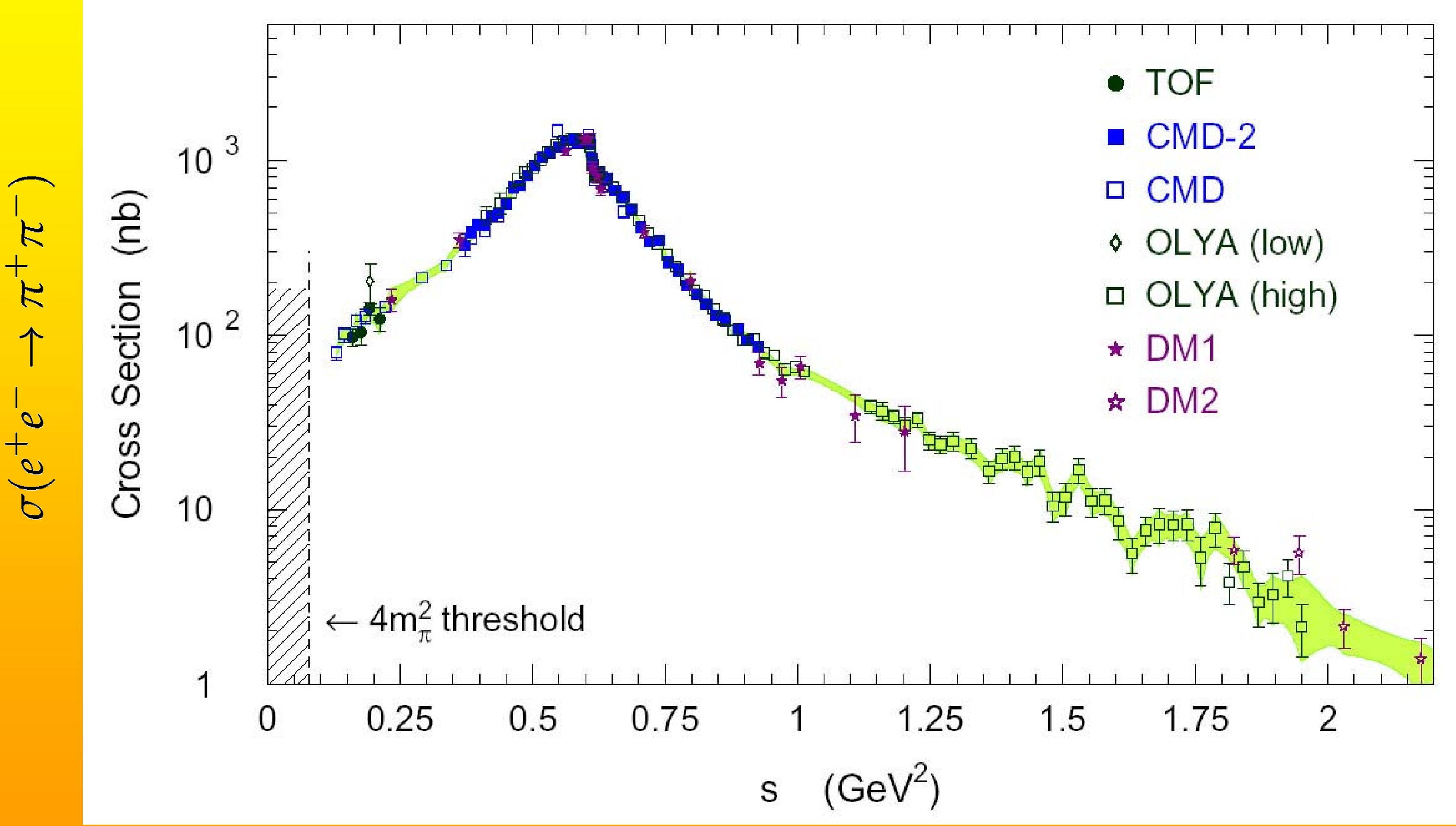
The unexplored…low-s ! data



(Davier et al., 2002)

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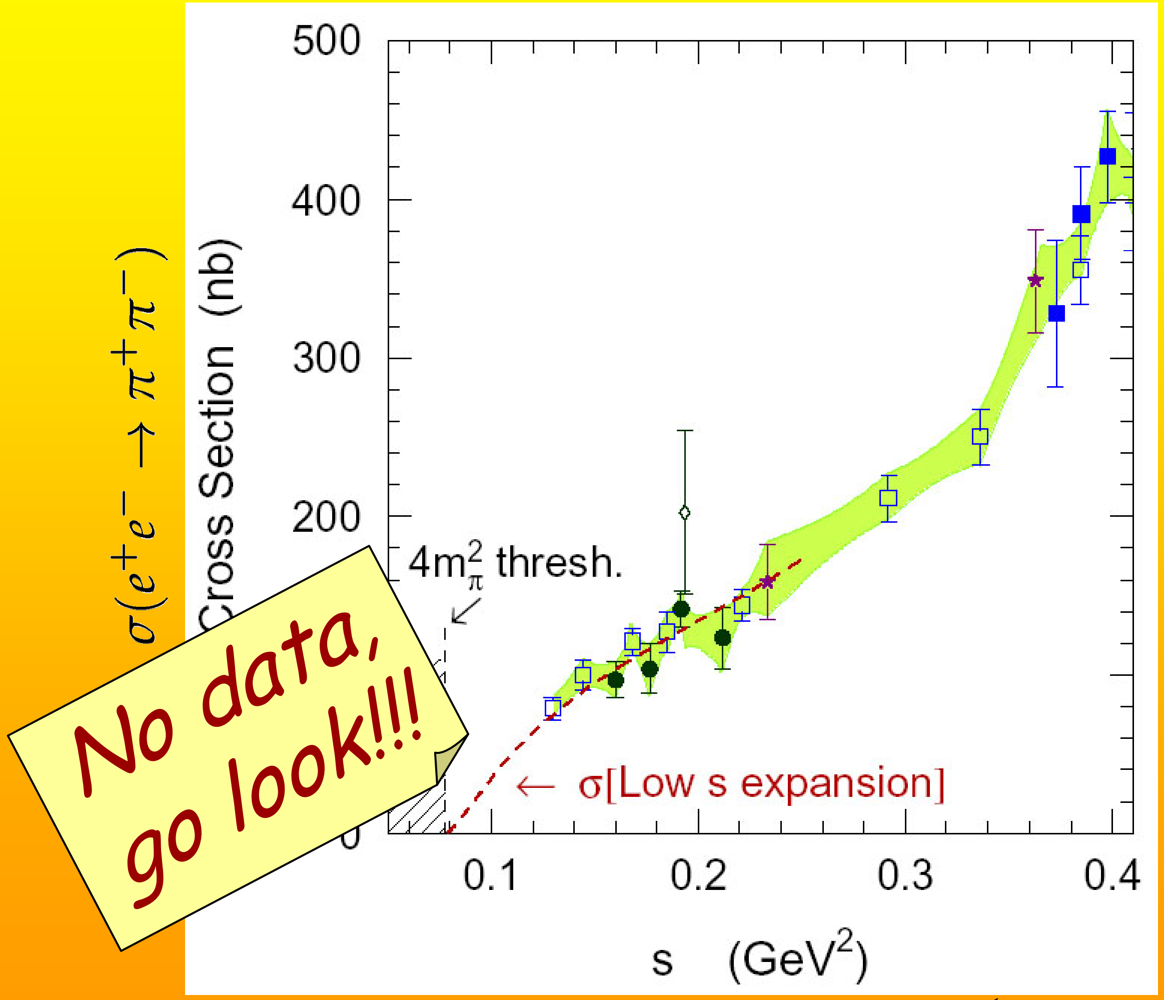
Very, very low-s data



(Davier et al., 2002)

Predicted Decay Channels

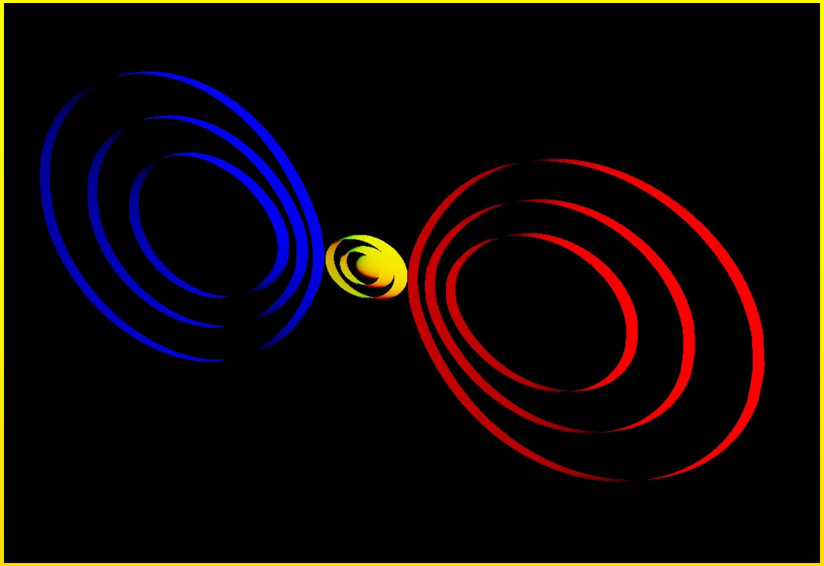
$$\Gamma(\pi_2/\rho \to e^+e^-) \sim 28\, eV$$

$$\Gamma(\pi_2/\rho \to \mu^+\mu^-) \sim 18\, eV$$

$$\Gamma(\pi_2/\rho \to \pi^0\pi^0) \sim 150\, keV$$

(estimates based on phase space only!)

Conclusions



- Pirhonium explains the muon magnetic moment anomaly
- Mixing with the ρ of order 1% is sufficient
- There is no doubt this particle exists: the burden of proof is reversed!

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