

Standard Model Predictions for Heavy-Flavor Physics

SUSY 2007
Karlsruhe, July 2007

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Outline

Recent progress in standard model predictions:

Muon $g-2$

$b \rightarrow s + \text{gamma}$

$b \rightarrow s + \text{leptons}$

$B_s \rightarrow \text{muon anti-muon}$

Expected experimental progress:

Muon \rightarrow electron + gamma

Muon-electron conversion

Electron and muon EDM

Muon g-2

The E821 experiment published final results for μ^+ and μ^- (Phys. Rev. D73 (2006) 072003)



$$a_{\mu}^{\text{exp}} = \frac{g-2}{2} = 116\,592\,080\,(63) \cdot 10^{-11}$$

Loop effects in the lepton sector: muon $g-2$

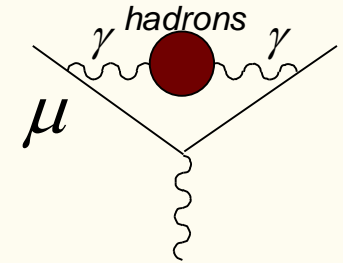
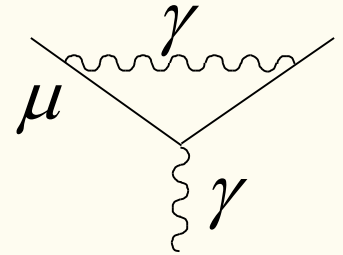
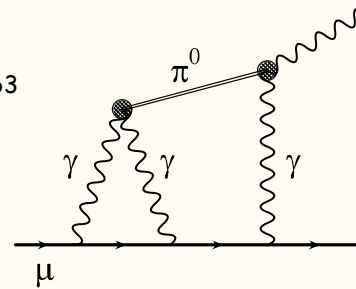
Units: 10^{-11}

QED **116 584 719 (1)**

Hadronic

LO **6 908 (44)**
 NLO **- 98 (1)**
 LBL **120 (40)**

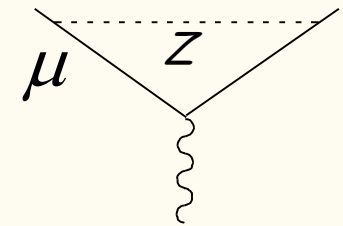
hep-ph/0701163



Electroweak **154 (3)**

Experiment **116 592 080 (63)**

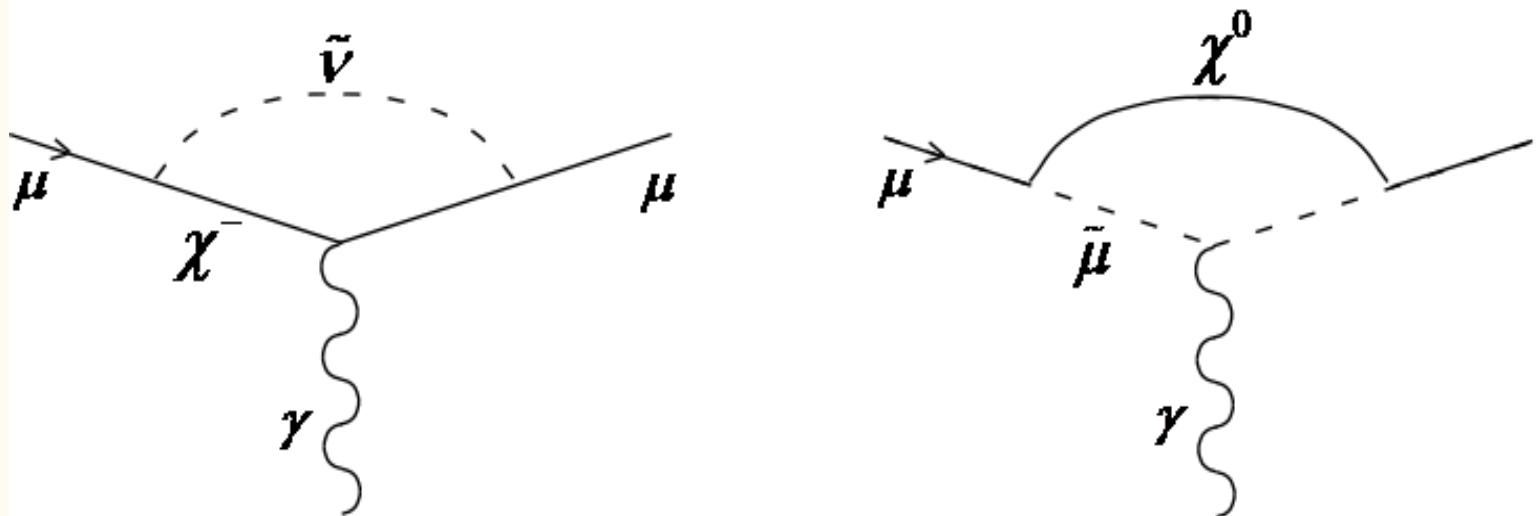
Experiment - SM Theory = 277 (87) (3.2 σ deviation)



+SuSy?

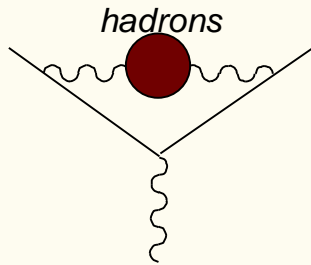
Harbinger for New Physics?

SUSY is a possible explanation!



$$\Delta a_{\mu}^{\text{SUSY}} \simeq 130 \left(\frac{100 \text{ GeV}}{m_{\text{SUSY}}} \right)^2 \tan \beta$$

Hadronic vacuum polarization contribution



$$\Delta a_{\mu}^{\text{had}} \sim \int \frac{ds}{s} \tilde{\sigma}(e^{+}e^{-} \rightarrow \text{hadrons})$$

Ongoing effort to improve low-energy data

Recent compilations: Davier hep-ph/0701163, Jegerlehner hep-ph/0703125

Persisting disagreements:

$e^{+}e^{-}$ vs. tau, in 2π and 4π channels; is this an experimental issue?

new tau data coming from BaBar and Belle

$e^{+}e^{-}$ direct vs. radiative return (shape of spectrum):

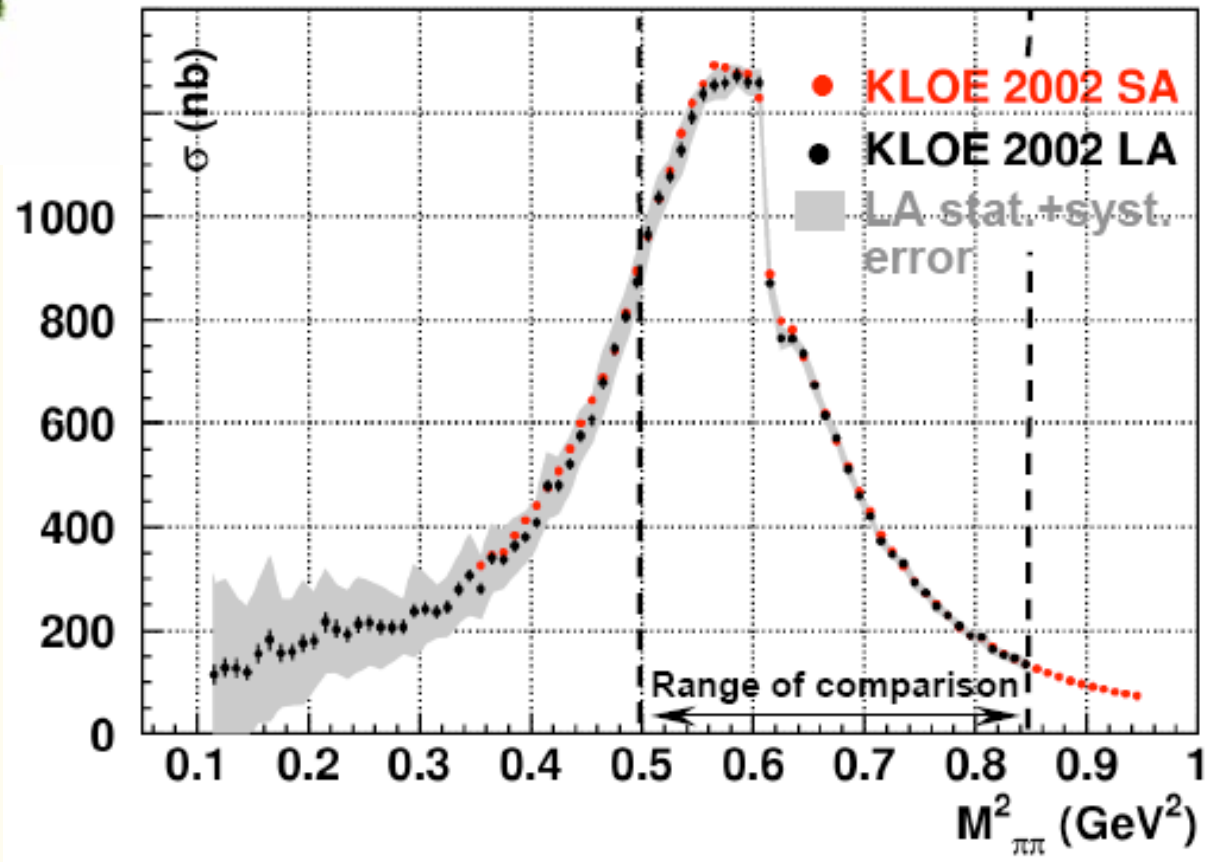
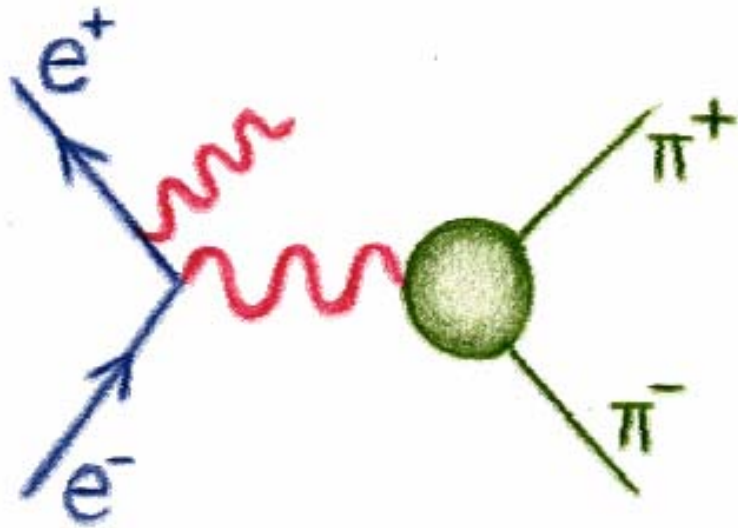
new data coming from KLOE and BaBar

Good news: agreement between CMD-2 and SND in Novosibirsk.

Eventually BaBar plans to cover the whole low-energy region up to 10 GeV; also new machine at Novosibirsk, VEPP2000.

New results from KLOE presented last week at EPS Manchester

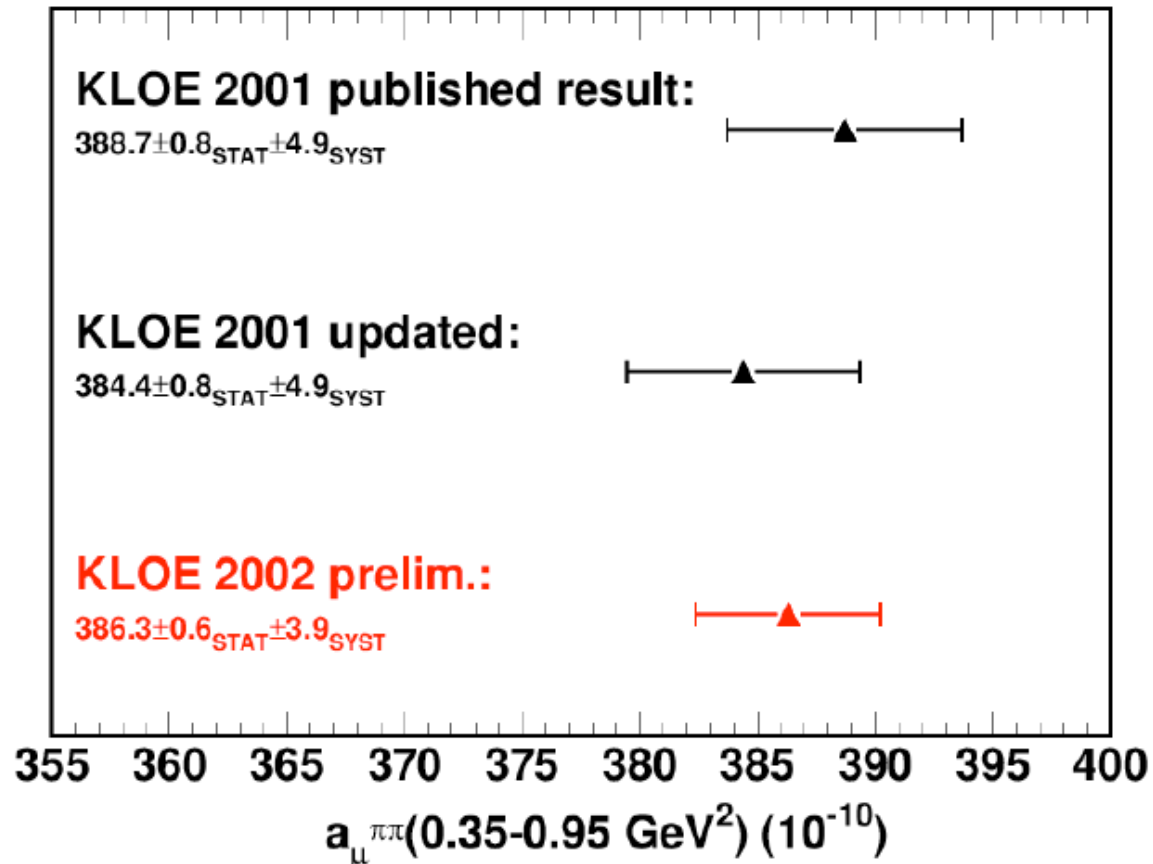
Stefan E. Müller



New results from KLOE presented last week at EPS Manchester

Summary of the small angle results:

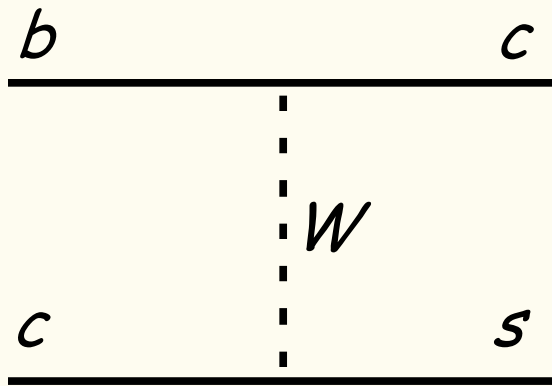
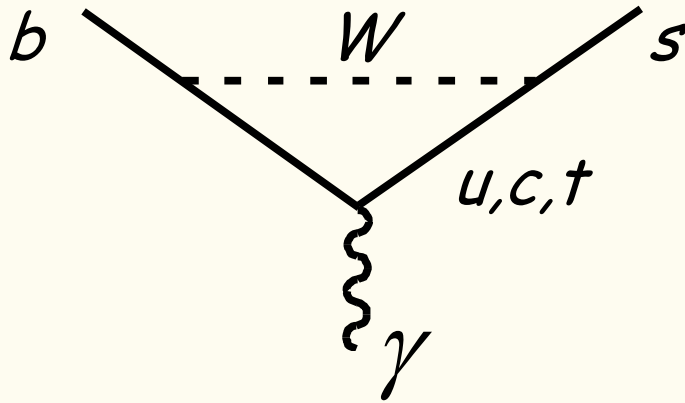
Preliminary!!!



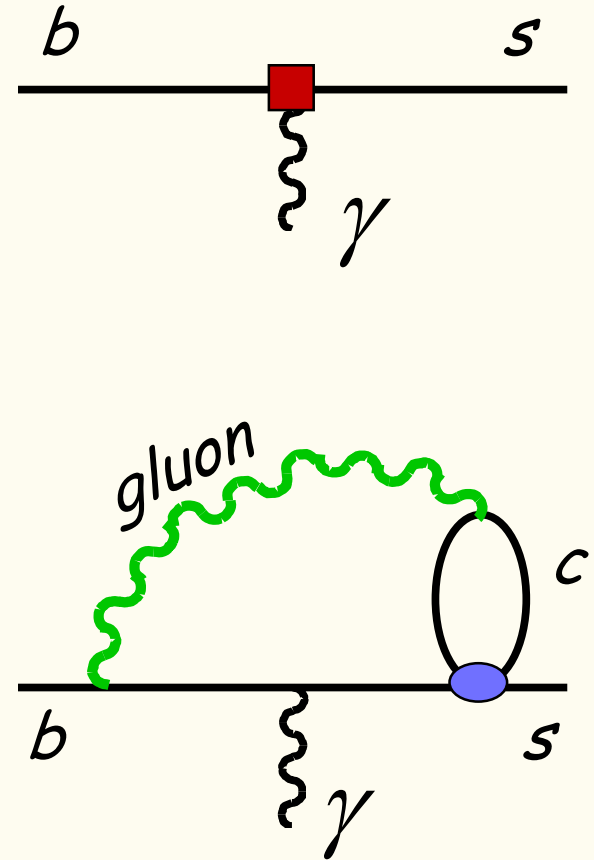
Jegerlehner (hep-ph/0703125): $\Delta a_{\mu} = a_{\mu}^{\text{exp}} - a_{\mu}^{\text{the}} = (28.7 \pm 9.1) \cdot 10^{-10}$

Using new KLOE result would increase difference from 3.2σ to 3.4σ

$b \rightarrow s + \text{gamma}$



Effective theory



QCD effects:

~ triple the rate; and
introduce uncertainty in the SM prediction

QCD effects

NLO completed 2002

NNLO: international collaboration, first estimate:

PRL 98, 022002 (2007)

PHYSICAL REVIEW LETTERS

week ending
12 JANUARY 2007

Estimate of $\mathcal{B}(\bar{B} \rightarrow X_s \gamma)$ at $O(\alpha_s^2)$

M. Misiak,^{1,2} H. M. Asatrian,³ K. Bieri,⁴ M. Czakon,⁵ A. Czarnecki,⁶ T. Ewerth,⁴ A. Ferroglia,⁷ P. Gambino,⁸
M. Gorbahn,⁹ C. Greub,⁴ U. Haisch,¹⁰ A. Hovhannisyanyan,³ T. Hurth,^{2,11} A. Mitov,¹² V. Poghosyan,³
M. Ślusarczyk,⁶ and M. Steinhauser⁹

$$BR(\bar{B} \rightarrow X_s \gamma; E_\gamma > 1.6 \text{ GeV}) \quad [10^{-4}]$$

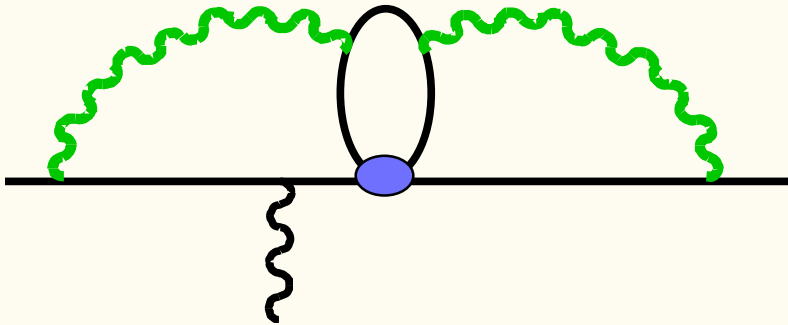
	Experiment	Theory	
2002	3.12(41)	3.57(30)	NLO
2007	3.55(26)	3.15(23)	NNLO

hep-ph/0207131

hep-ph/0609232

Theoretical challenges

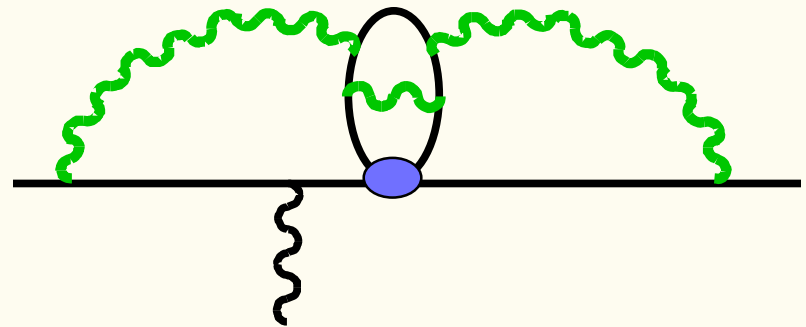
Very involved perturbative calculations



Extrapolation in charm mass:
Misiak & Steinhauser (2006)

m_c dependence:
Boughezal, Czakon, Schutzmeier (2007)

Four-loop anomalous dimensions
Czakon, Haisch, Misiak (2006)

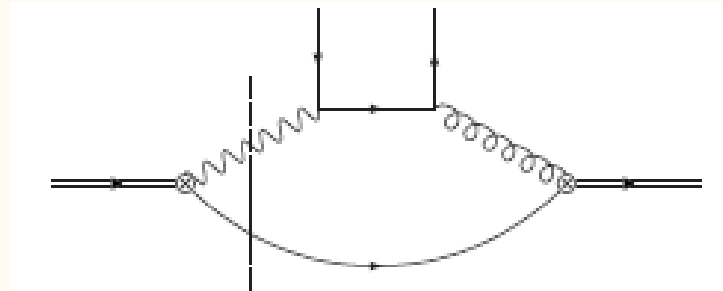


More theoretical challenges

Experiments sensitive to energetic photons only \rightarrow
operator product expansion breaks down; sensitivity
to rather low scales.

Neubert (2005)
Becher & Neubert (2006)

Non-perturbative effects, e.g.



Lee, Neubert, Paz (2006)

\rightarrow main theoretical uncertainty, $\sim 5\%$

$b \rightarrow s l^+ l^-$

Richer structure: also chirality-conserving

Different structure of logarithms: NNLO prediction already known

(Bobeth, Gambino, Gorbahn, Haisch;
Huber, Lunghi, Misiak, Wyler)

Non-zero q^2 : challenging non-perturbative effects

Two interesting regions:

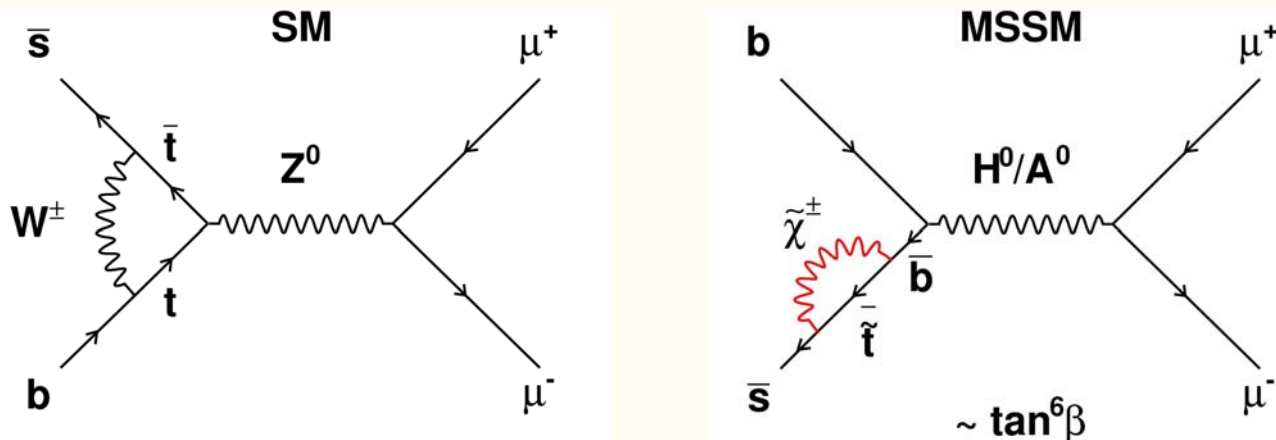
small q^2 ($< 6 \text{ GeV}^2$)

large q^2 ($> 14 \text{ GeV}^2$)

Recent study by Ligeti & Tackmann: normalize to $B \rightarrow X_u l \nu$

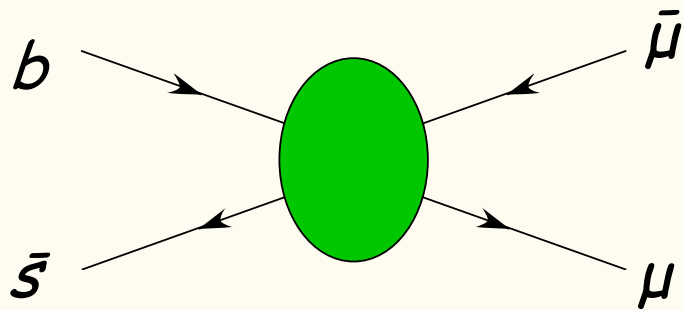
$B_s \rightarrow \mu^+ \mu^-$

Similar short-distance physics as in $B \rightarrow X_s \mu^+ \mu^-$,
but only chirality-changing;
Very different hadronic mechanism:
pure spectator effect.

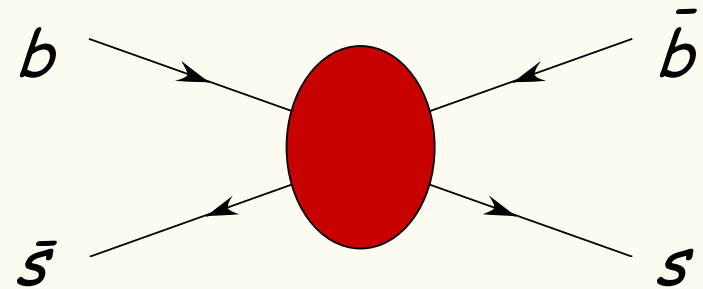


Depends on the meson wave function.
Related to B_s mixing!

$B_s \rightarrow \mu^+ \mu^-$ vs. B_s -anti- B_s mixing



$$BR(B_s \rightarrow \mu^+ \mu^-)$$



$$\Delta M_s$$

measured, $17.8 \pm 0.1/\text{ps}$

The two processes can be related with only a small hadronic uncertainty (Buras 2003). SM prediction:

$$BR(B_s \rightarrow \mu^+ \mu^-) = 3.4(4) \cdot 10^{-9}$$

Present experimental bound:

$$BR(B_s \rightarrow \mu^+ \mu^-) < 7.5 \cdot 10^{-8}$$

90%

D0 (2007)
Similarly CDF

Coming up at the low-energy frontier...

...before or besides the LHC:

Muon \rightarrow electron+gamma

Muon-electron conversion?

Muon EDM? (Note: exciting prospects in electron EDM)

What does the muon $g-2$ tell us about new physics?

Possibly large EDM:

$$a_{\mu}^{\text{NP}} \frac{e}{2m} \bar{\mu} \sigma \cdot F \mu \rightarrow d^{\text{CP}} \frac{e}{2m} \bar{\mu} \gamma_5 \sigma \cdot F \mu$$

$$a_{\mu}^{\text{NP}} \sim 10^{-9} \rightarrow d^{\text{CP}} \frac{e}{2m} \sim a_{\mu}^{\text{NP}} \frac{e}{2m} \sim 10^{-9} e \cdot \text{fm} = 10^{-22} e \cdot \text{cm}$$

Similar encouragement for lepton flavor violation:

$$a_{\mu}^{\text{NP}} \frac{e}{2m} \bar{\mu} \sigma \cdot F \mu \rightarrow \frac{e}{2m} \bar{e} (f_M + f_E \gamma_5) \sigma \cdot F \mu$$

$$f_{M,E} \sim a_{\mu}^{\text{NP}} \cdot \delta$$

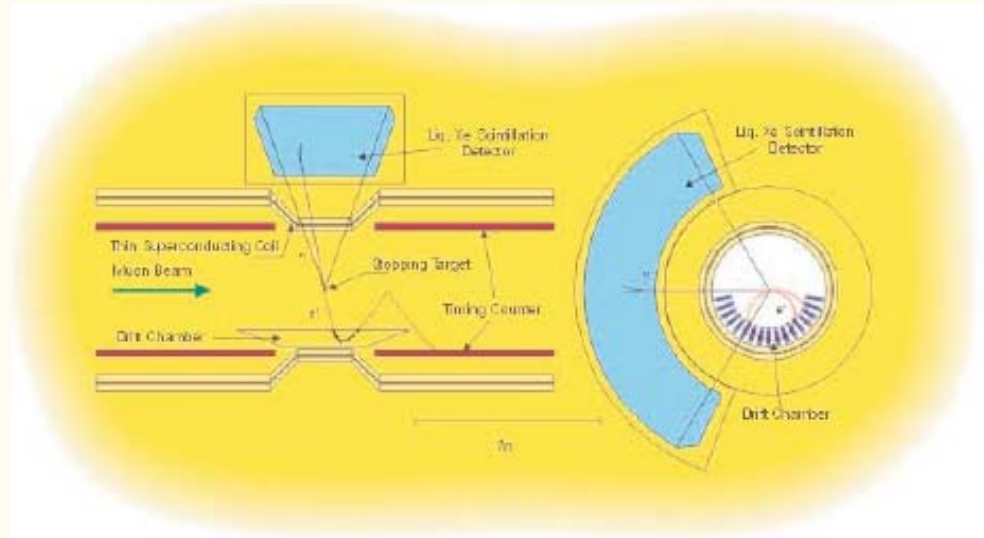
$$BR(\mu \rightarrow e\gamma) \sim 10^{-3} \delta^2$$

Muon decay to an electron and photon $\mu \rightarrow e\gamma$

Present bound (MEGA @ Los Alamos): $BR(\mu \rightarrow e\gamma) < 10^{-11}$

Planned sensitivity (MEG @ Paul Scherrer Institute)

$(1-2) \times 10^{-13}$



Note: unusual QED suppression $\sim 15\%$ (large log of the new physics scale Λ)

$$\Gamma(\mu \rightarrow e\gamma) \approx \left(1 - \frac{8\alpha}{\pi} \ln \frac{\Lambda}{m_\mu}\right) \Gamma^{(0)}(\mu \rightarrow e\gamma)$$

Status of the MEG experiment

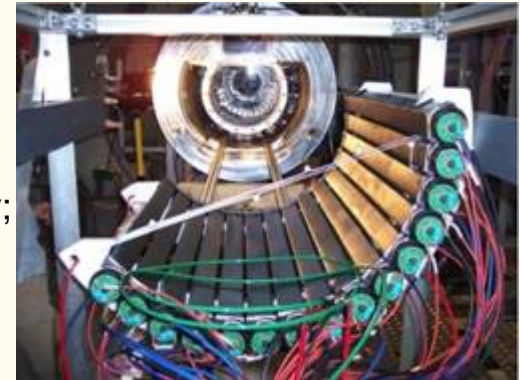


Liquid Xenon Gamma-Ray Detector:

The cryostat now ready and the photo tubes are being installed to start up operation toward the end of August

Timing Counters:

Final assembly in Italy; Installation planned at the end of August



Drift Chambers:

Ready and currently being installed at the beam line; cosmic ray test soon



Engineering run
in October 2007!

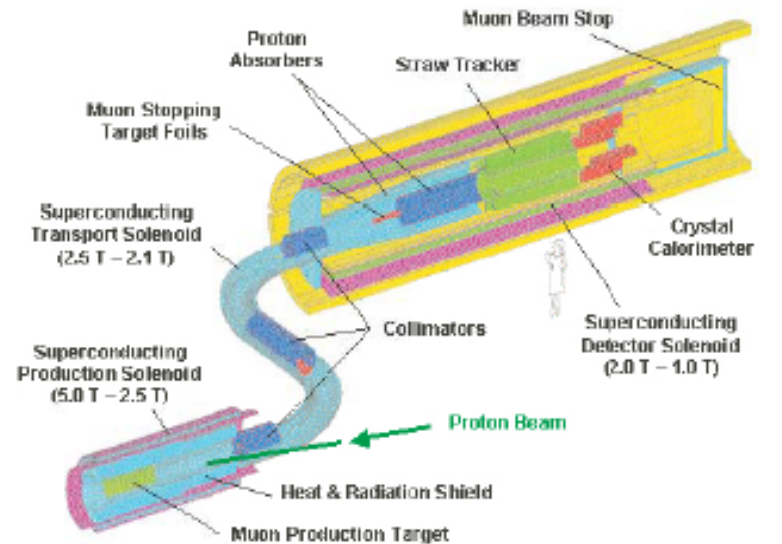
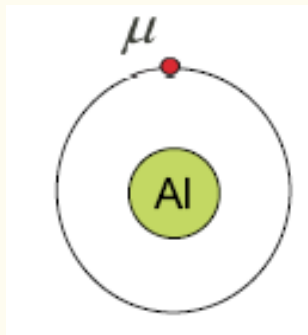
Muon-electron conversion

"The best rare process"

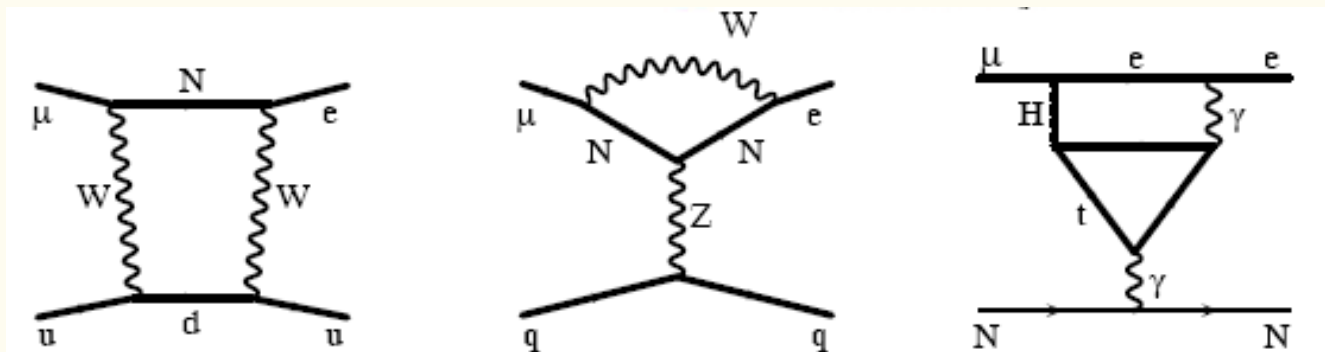
No accidental bkgd

(single monochromatic e^-);

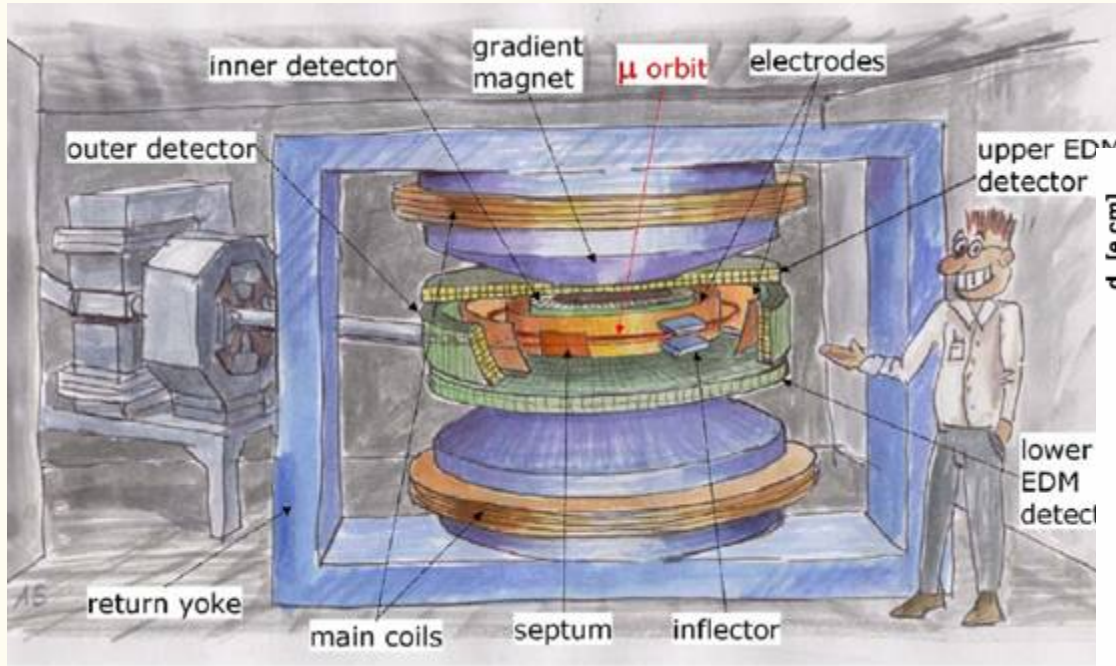
10^{-17} sensitivity envisioned



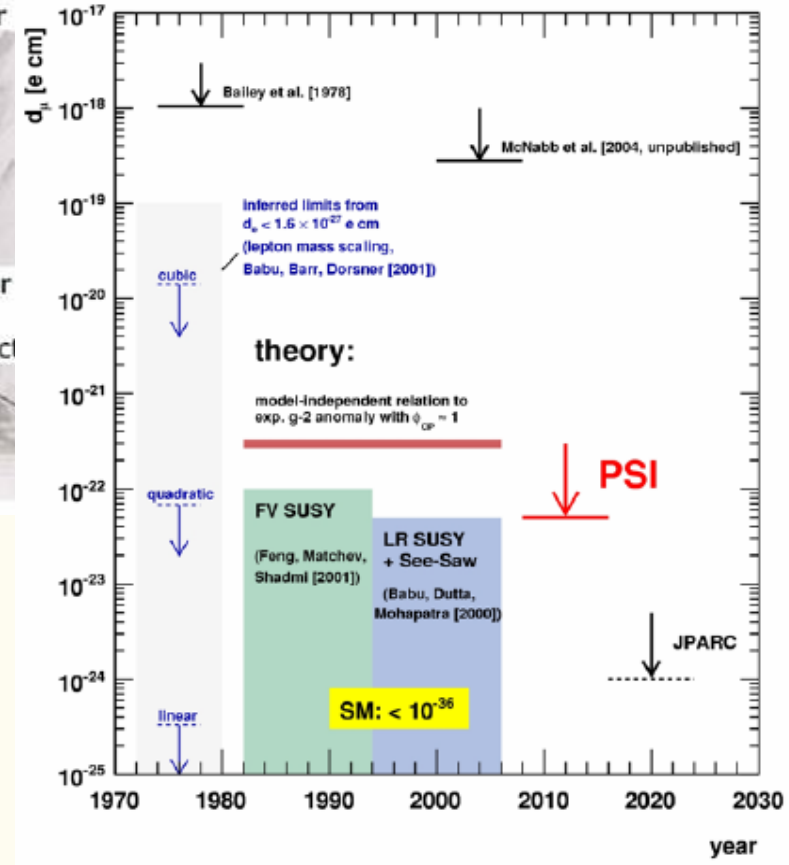
Variety of mechanisms:



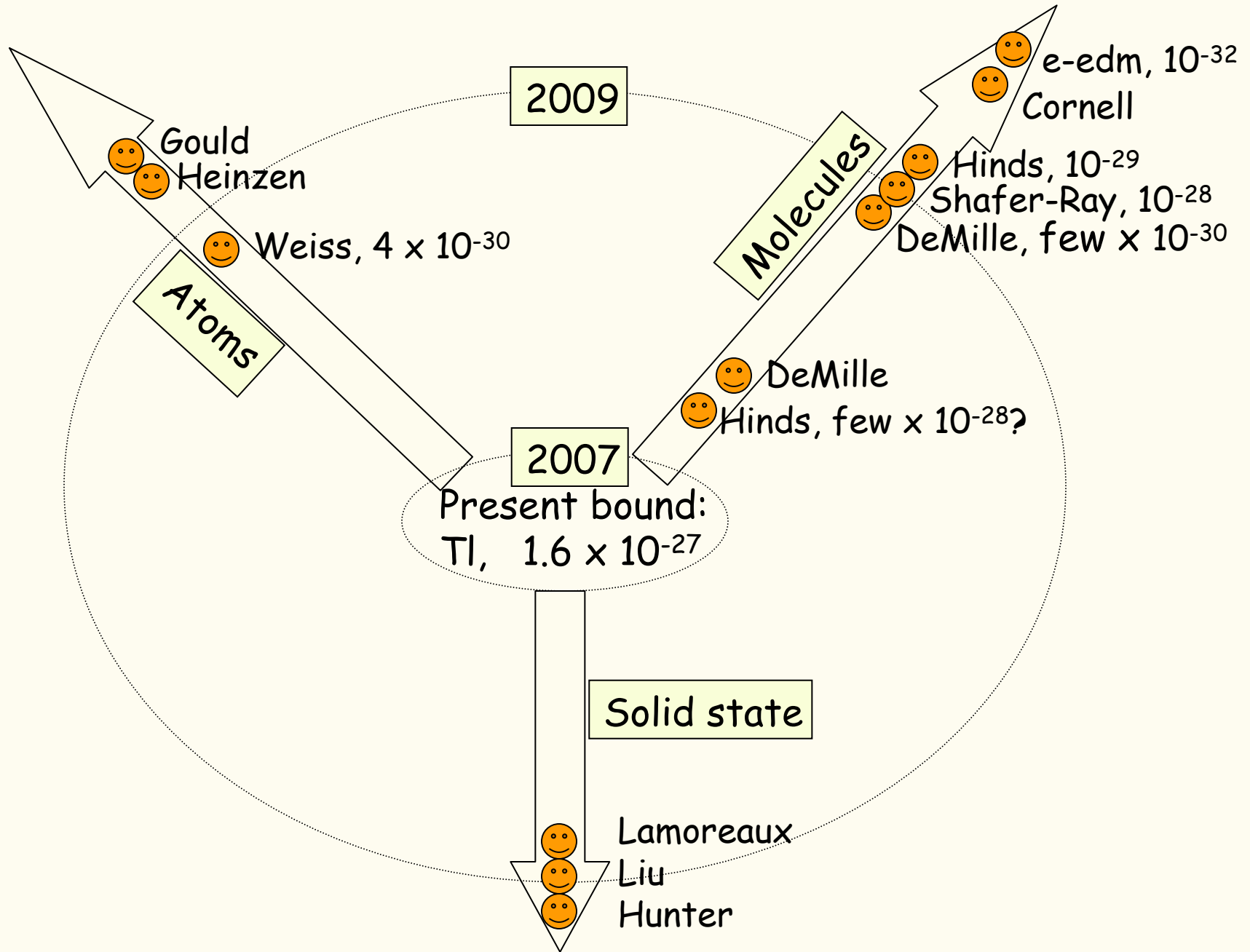
Proposal for a muon EDM measurement at PSI



$$d_\mu < 5 \times 10^{-23} \text{ e cm}$$



Upcoming progress in electron EDM



Summary

Clear discrepancy in $g-2$: $\sim 3\sigma$

In $b \rightarrow s + \text{gamma}$, SM@NNLO also falls short of measurement, less significant $\sim 1\sigma$

New theoretical ideas in $B_s \rightarrow \mu\mu$, $b \rightarrow s l^+ l^-$

New measurements of electron EDM, $\mu \rightarrow e \gamma$ soon. Case for muon EDM measurement.