THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

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*PRISMA Cluster of Excellence*

# Puzzles in Low-Energy Precision Physics

## The quest for future experimental investigation

Istituto Nazionale di Fisica Nucleare

***Juliet and Paolo Fest***

***LNF Frascati 30 May 2013***

# *The Success of the Year 2012*

**July 2012**
**Higgs discovery**
**→ Last particle of the Standard Model discovered**

# *Puzzles at low Energies*


1) **Anomalous magnetic moment of the muon $(g\text{-}2)_\mu$**
   → **discrepancy btw. SM prediction and direct measurement (3 … 4 σ)**

2) **Electroweak mixing angle $\sin^2\theta_W$**
   → **3σ discrepancy btw. LEP and SLC results**

**Furthermore: Proton Radius Puzzle**

**……. Flavour Physics (→ next talk by Giancarlo)**

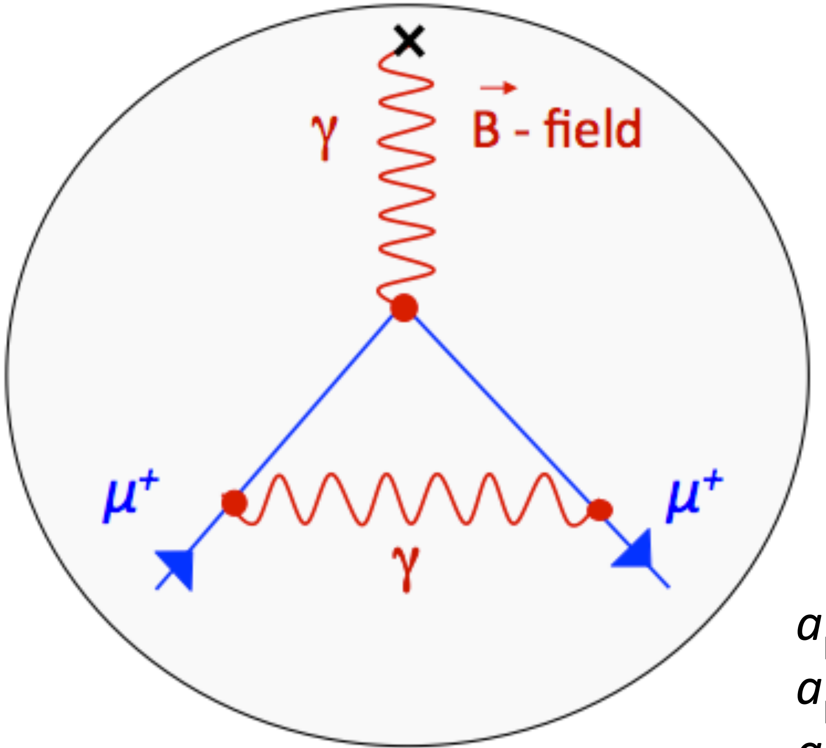
# The Anomalous Magnetic Moment of the Muon $(g\text{-}2)_\mu$

# *Muon Anomalous Magnetic Moment: $(g\text{-}2)_\mu$*

**Magnetic Moment: $\vec{\mu} = \mu_B \; g \; \vec{S}$**

$a_\mu = (g\text{-}2)_\mu / 2 = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had} = (\,11\,659\,180.2 \pm 4.9\,) \cdot 10^{-10}$

Davier et al. PRL 2011




$a_\mu^{QED} = (11\,658\,471.809 \pm 0.015) \cdot 10^{-10}$

$a_\mu^{weak} = (15.4 \pm 0.2) \cdot 10^{-10}$

$a_\mu^{strong} = (693.0 \pm 4.9) \cdot 10^{-10}$

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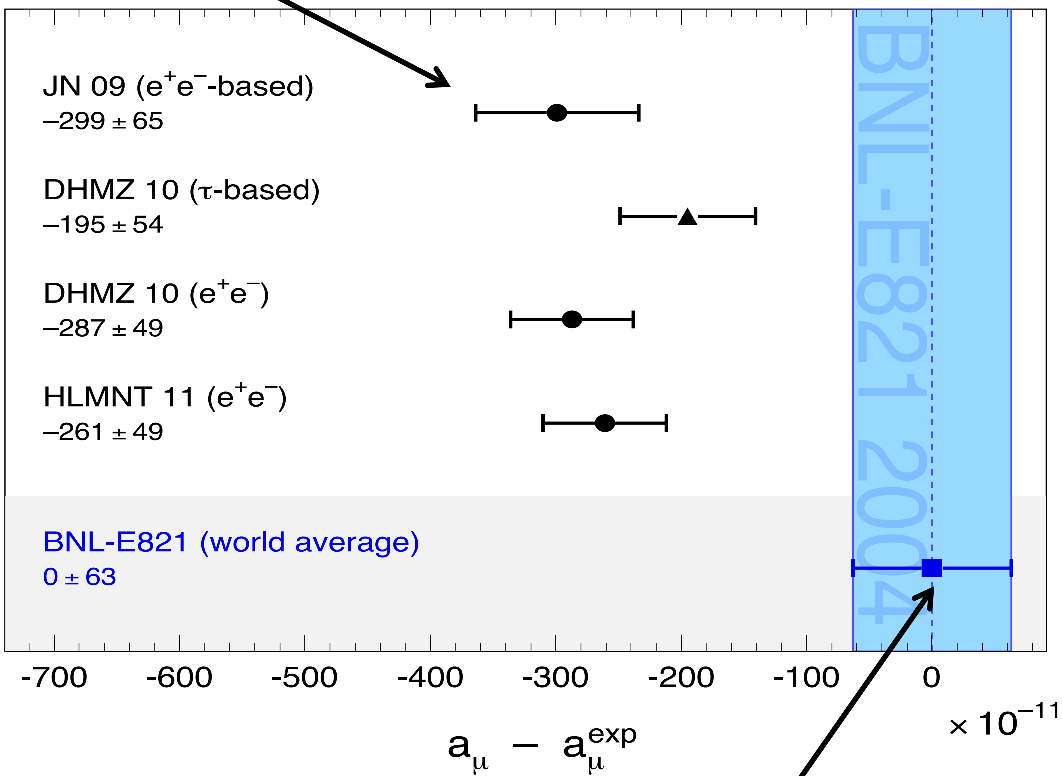



**$\Delta a_\mu = a_\mu^{exp} - a_\mu^{SM} =$**

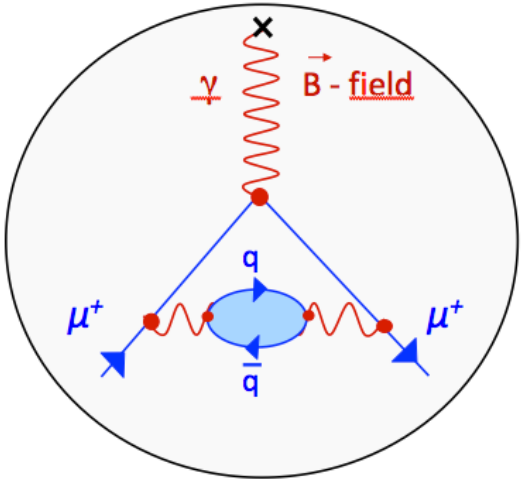
**$(28.7 \pm 8.0) \cdot 10^{-10}$ $(3.6\,\sigma)$**

**Error(s) or New Physics ?**

**E821 measurement $a_\mu^{exp} = (\,11\,659\,208.9 \pm 6.3\,) \cdot 10^{-10}$**

# *Hadronic Cross Section and $(g\text{-}2)_\mu$*

***Hadronic Vacuum Polarisation***

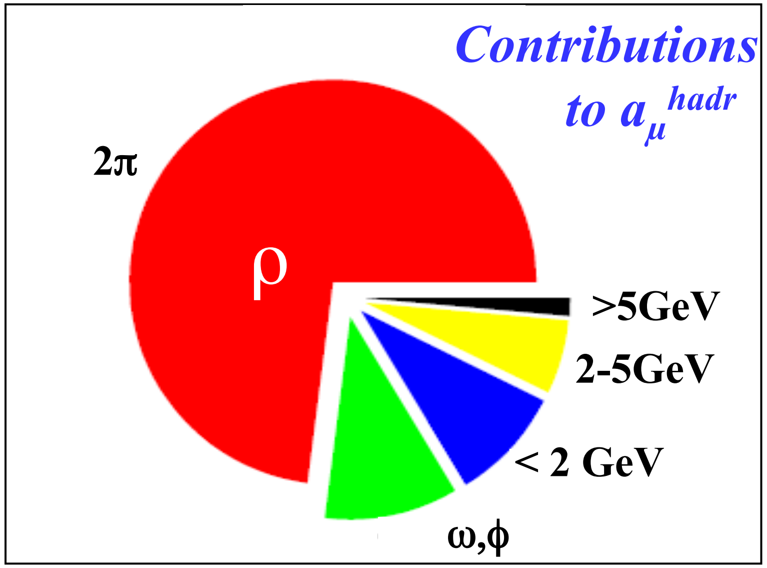



$$a_\mu^{had} = \frac{1}{4\pi^3} \int_{4m_\pi^2}^{\infty} ds\, K(s)\, \sigma_{had}$$

Intrinsically ~ 1 / s²
makes low energy contrib.
especially important

**Hadronic cross section related to hadronic vacuum polarization contribution to $(g\text{-}2)_\mu$**

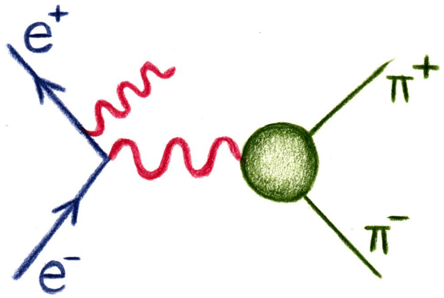
**1995:**
**2nd DAPHNE Physics Handbook**
**P. Franzini: Measure R @ KLOE**
**→ Major part of $a_\mu^{had}$ !**

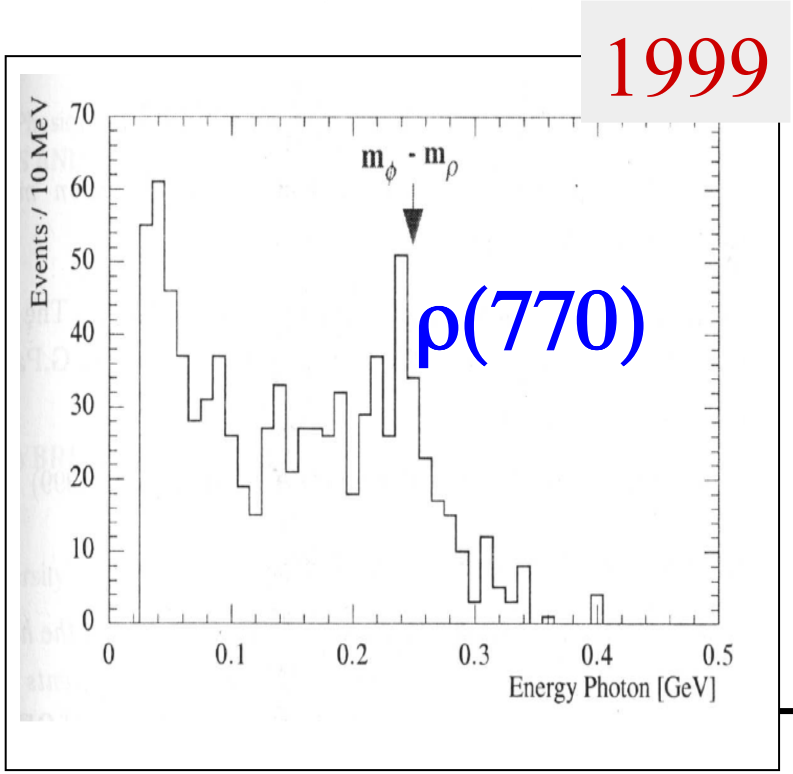


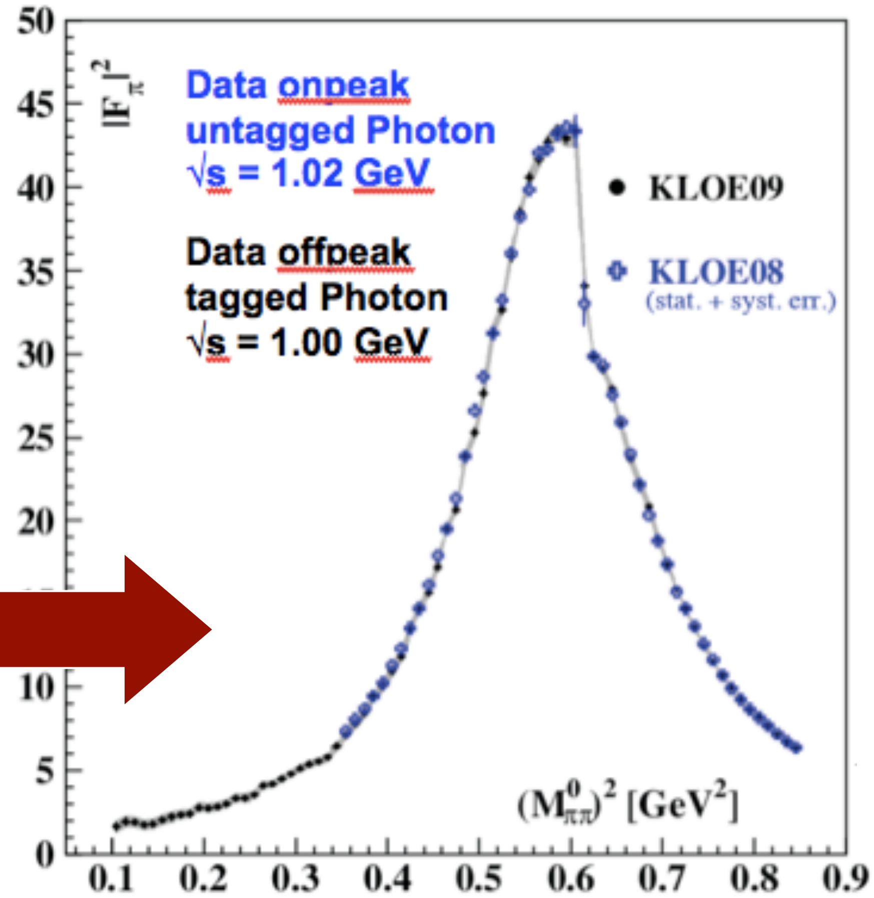

**Karlsruhe workshop 1997**

# *ISR Method for Measuring R at KLOE*

**ISR measurement e+e- → π+π−**



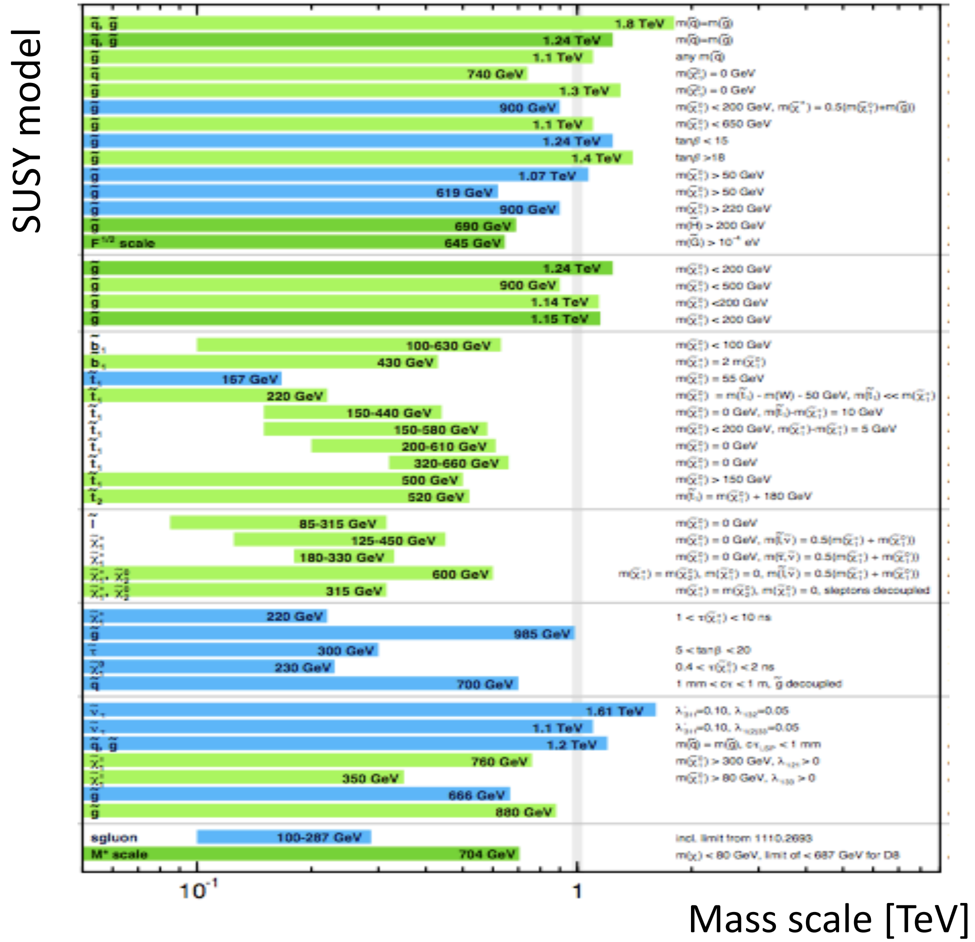




**Wolfgang Kluge:**
**"ISR - a success Story!"**

# *Supersymmetry and (g-2)$_\mu$ ?*

$$\Delta a_\mu^{\mathrm{SUSY}} \approx +13 \cdot 10^{-10}\, \mathrm{sgn}(\mu) \left( \frac{100\ \mathrm{GeV}}{m_{\mathrm{SUSY}}} \right)^2 \tan\beta \quad = 28 \times 10^{-10}$$



# *Supersymmetry and $(g\text{-}2)_\mu$ ?*

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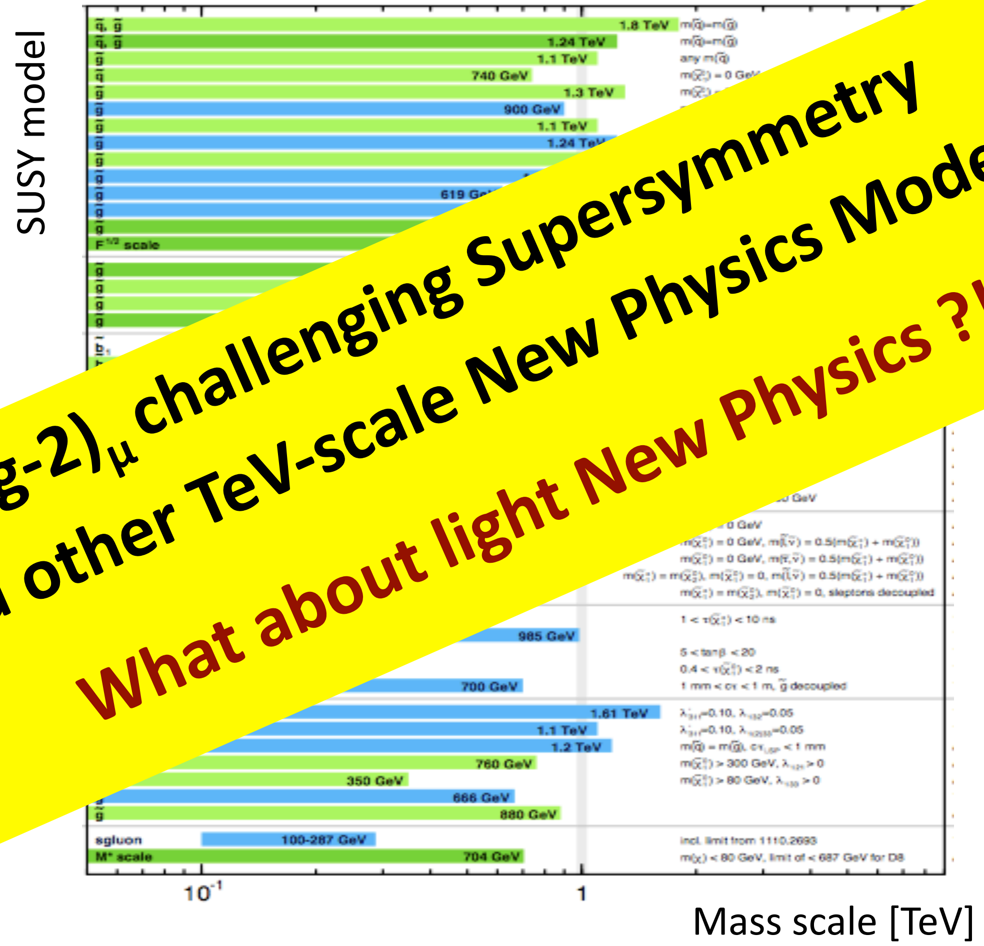



**$(g\text{-}2)_\mu$ challenging Supersymmetry**
**and other TeV-scale New Physics Models!**

**What about light New Physics ?!**

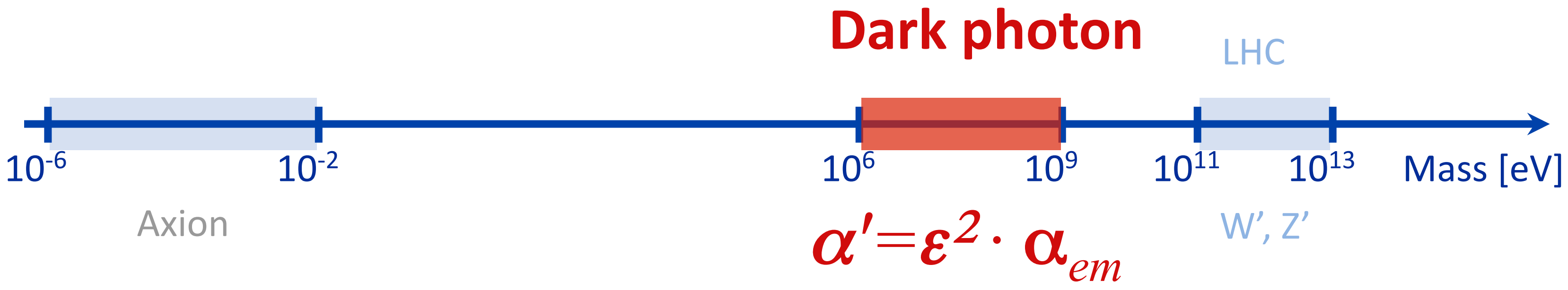
# A Solution for

# the $(g\text{-}2)_\mu$ Puzzle?

# Dark Photons?

# *Dark Photon Search*

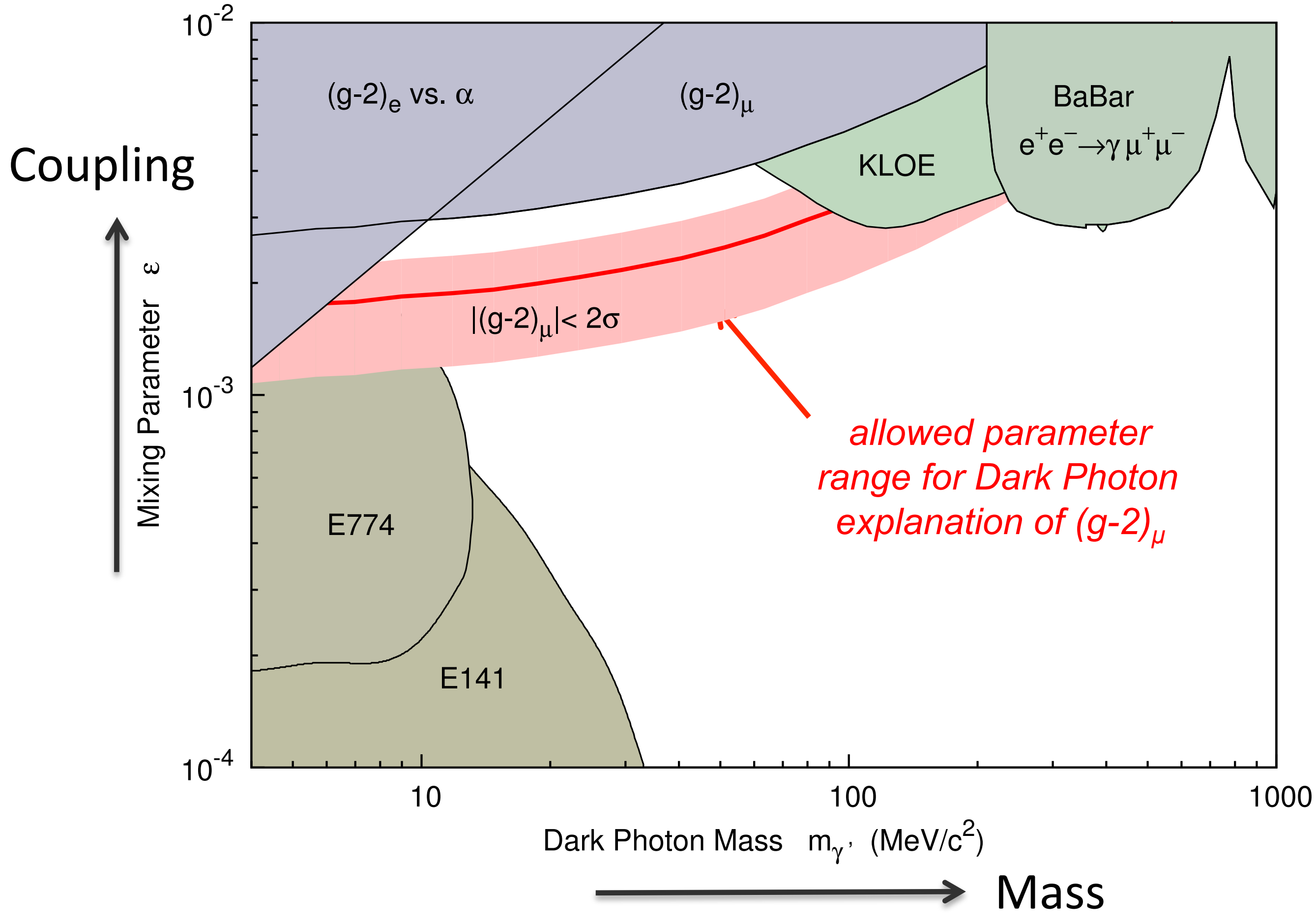
**New massive force carrier of extra $U(1)_d$ gauge group; predicted in almost all string compactifications**

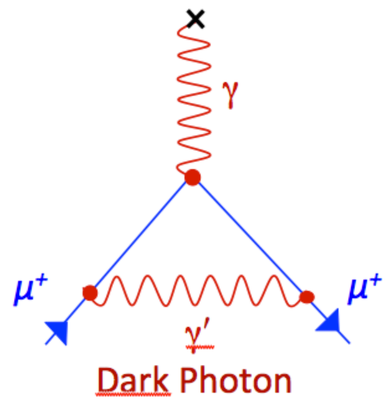



**Search for the O(GeV/c$^2$) mass scale in a world-wide effort**

- Could explain large number of **astrophysical anomalies**
  Arkani-Hamed et al. (2009)
- Could explain presently seen **deviation of 3.6$\sigma$ between $(g\text{-}2)_\mu$** Standard Model prediction and direct $(g\text{-}2)_\mu$ measurement
- Could eventually explain the **proton radius puzzle**

# *The $(g\text{-}2)_\mu$ Parameter Range*



# *A1 Spectrometers@Mainz*

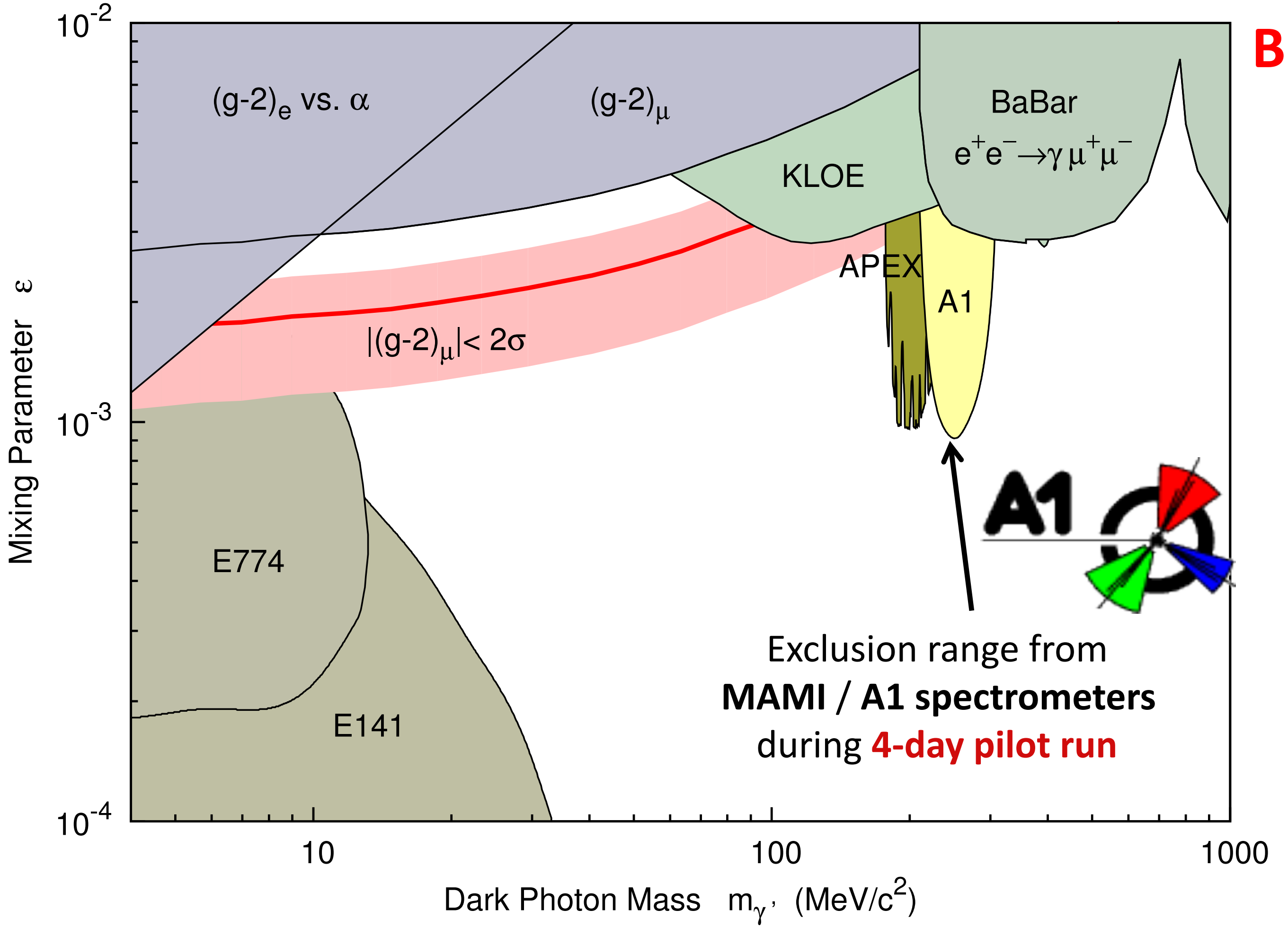
Bjorken, Essig, Schuster, Toro (2009)

**Low-energy, high-intensity accelerators are ideally suited for Dark Photon searches**

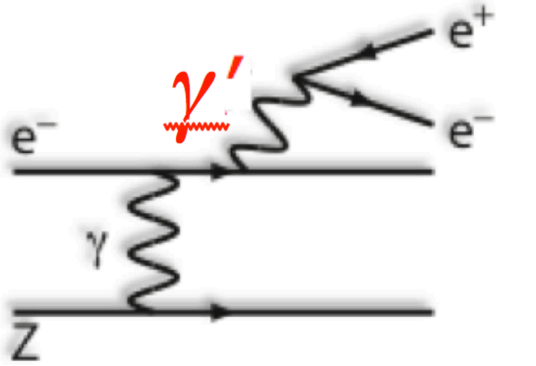
**→ MAMI: $E_\gamma$ < 1.6 GeV**

**A1 High Resolution Spectrometers**
**high momentum resolution ~$10^{-4}$**

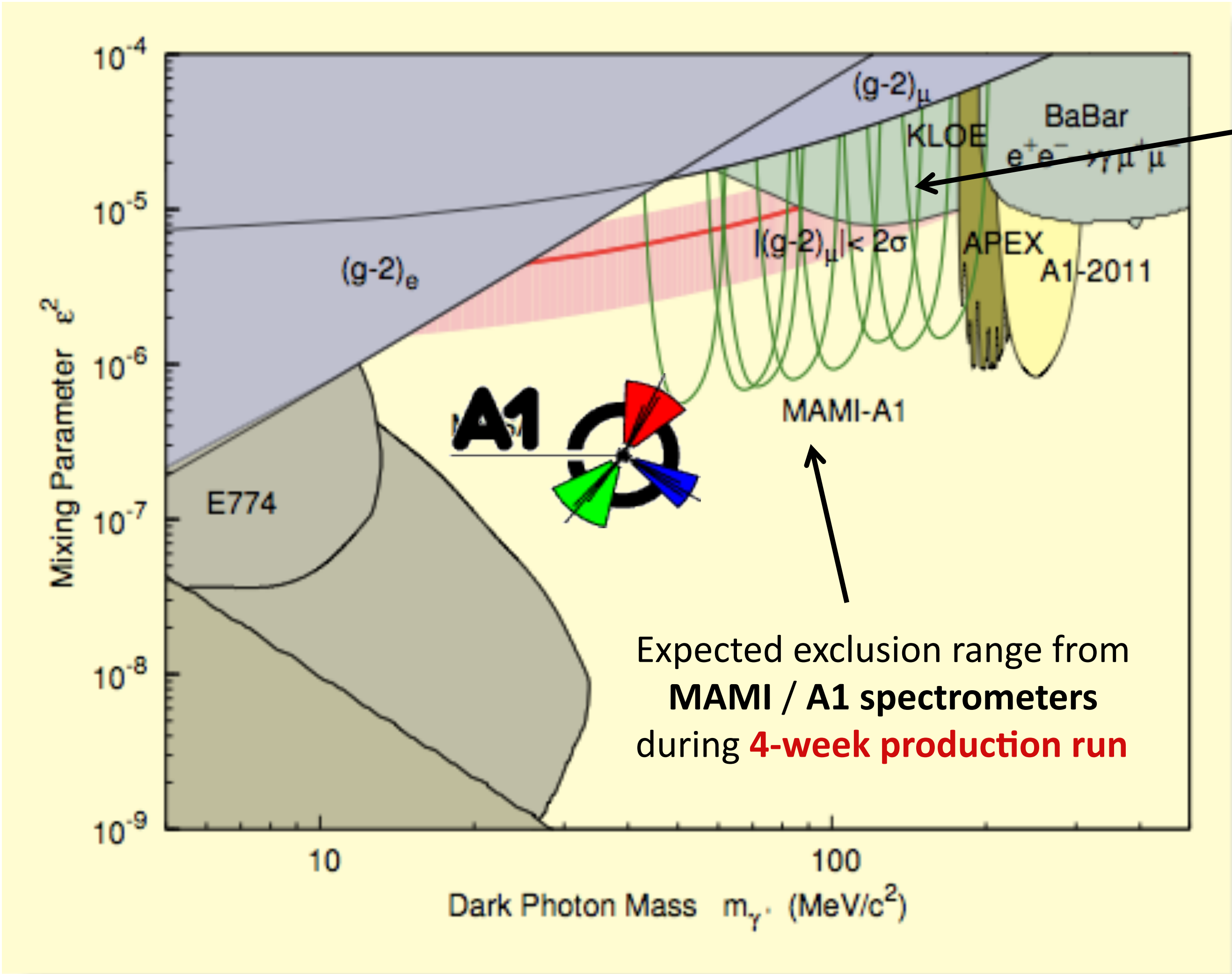
# *Results from A1@MAMI Pilot Run (2010)*




**Bump hunting in $m_{e+e-}$**



# *MAMI Predictions for 2012/13 Runs*



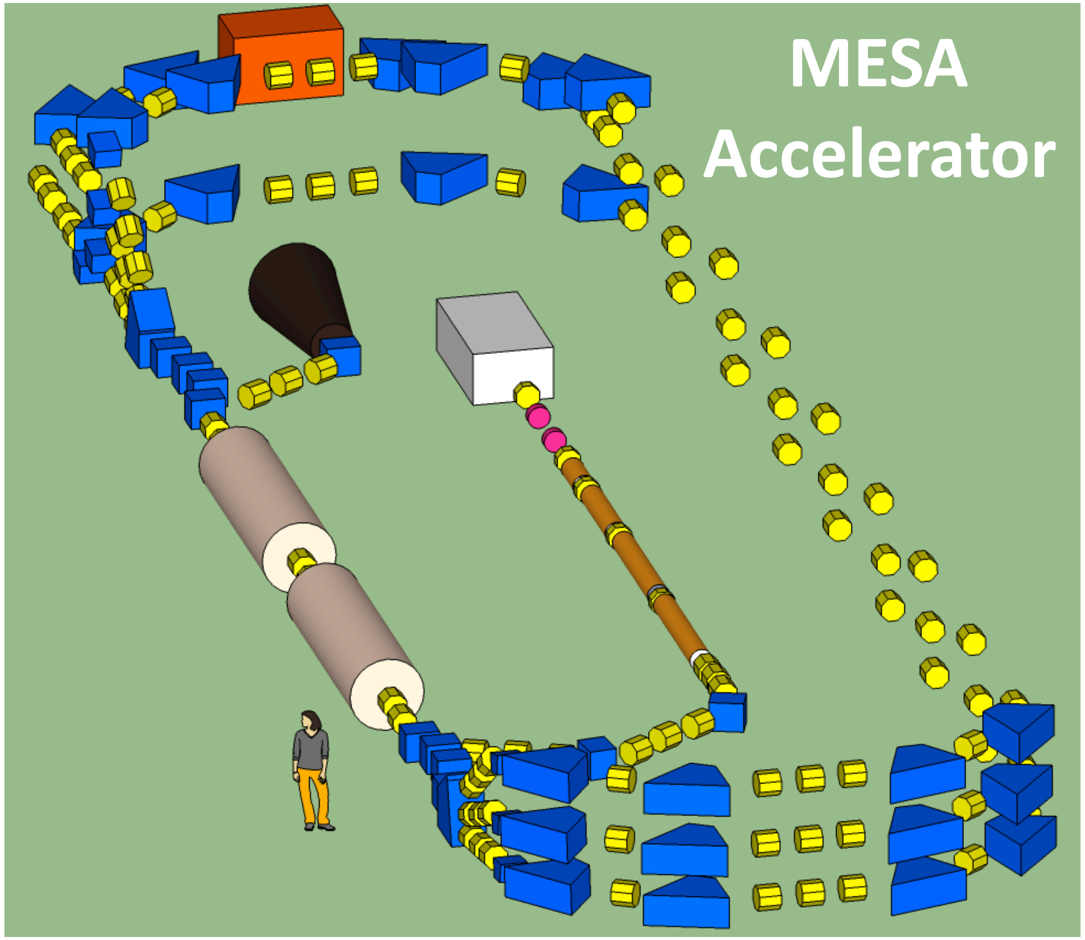
# *MESA Accelerator*

## Mainz Energy-Recovering Superconducting Accelerator

**$E_{max}$ = 200 MeV**
**$I_{max}$ = 10 mA**

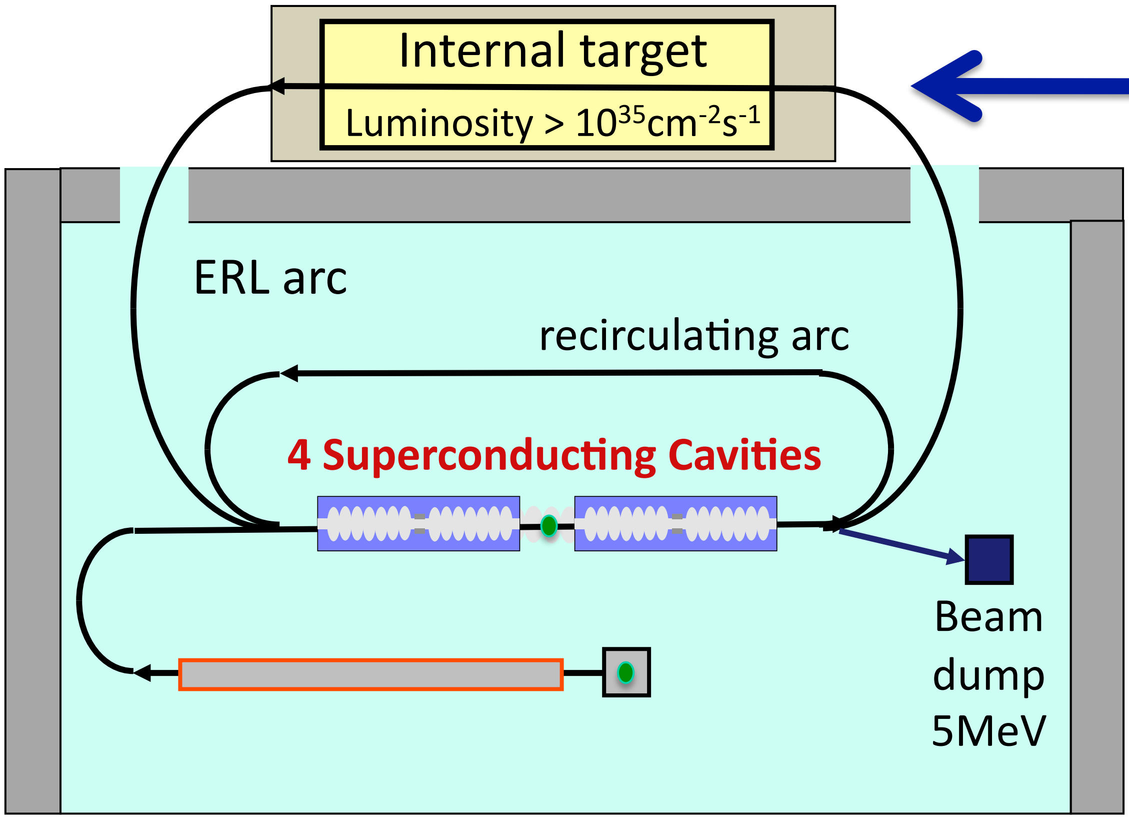
**2 Modes:**
- **Internal Gas Target (ERL mode)**
- **Extracted Beam (Non-ERL mode)**

PRiSMA



# *Accelerator MESA (ERL mode)*

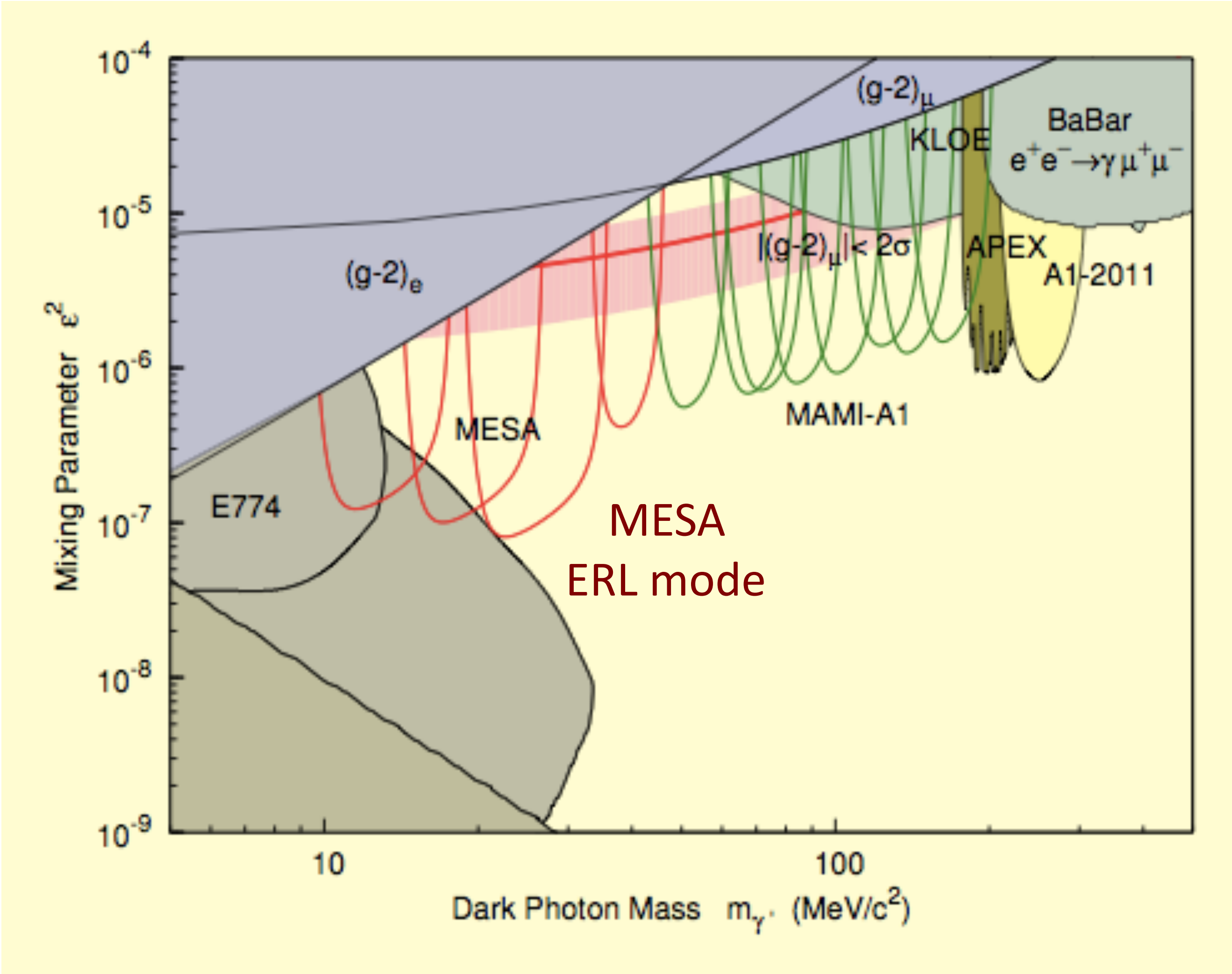
**Energy-Recovering (ERL) mode:**
**105 MeV beam energy @ 10 mA**




**Projects:**

- **Dark Photon**
- **Proton Radius**
- **Nuclear physics**
- **.....**

# *MESA Accelerator*



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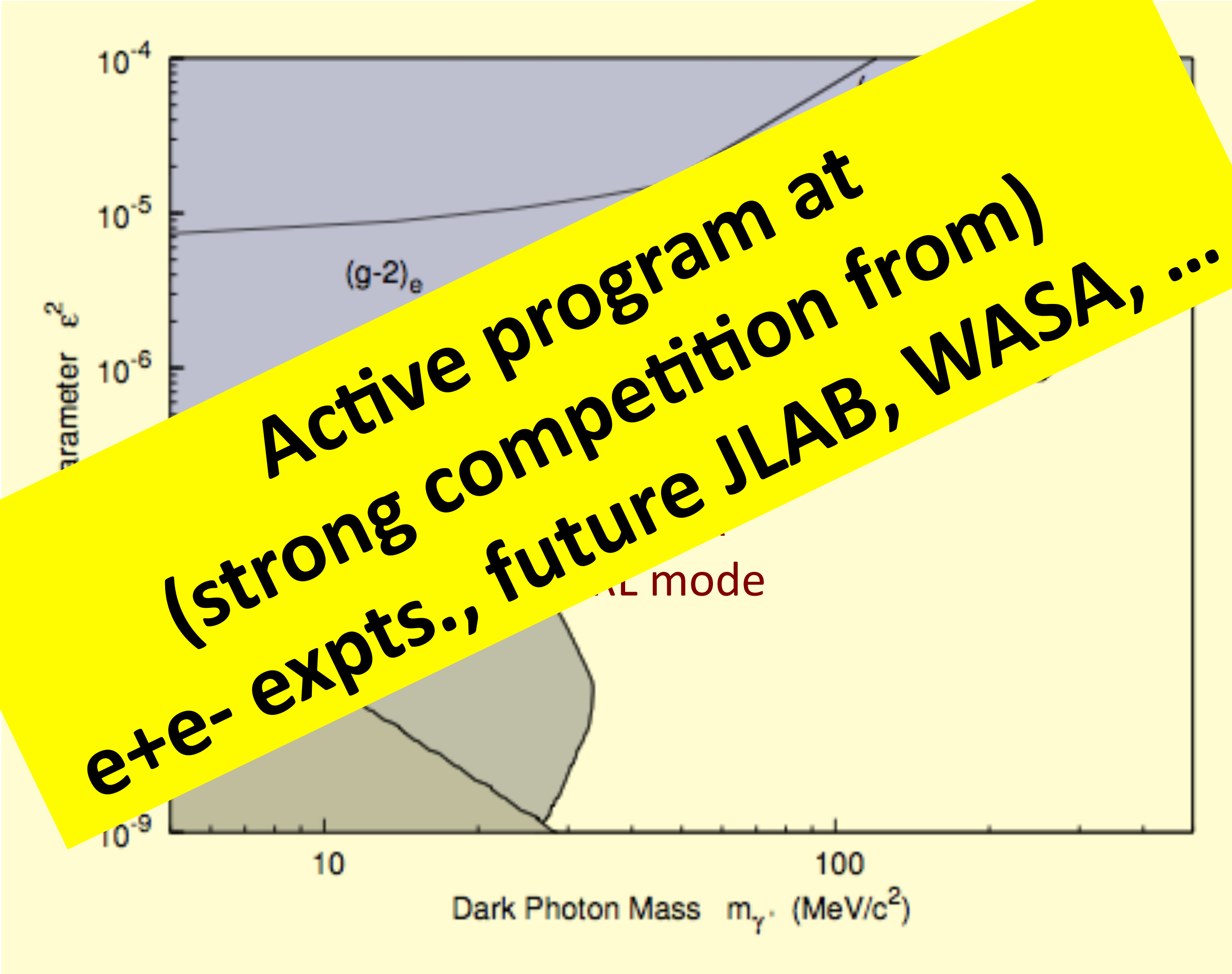



**Active program at (strong competition from) e+e- expts., future JLAB, WASA, ...**

Flagship expt. at MESA

# A Precision Measurement of $\sin^2\Theta_W$ at MESA

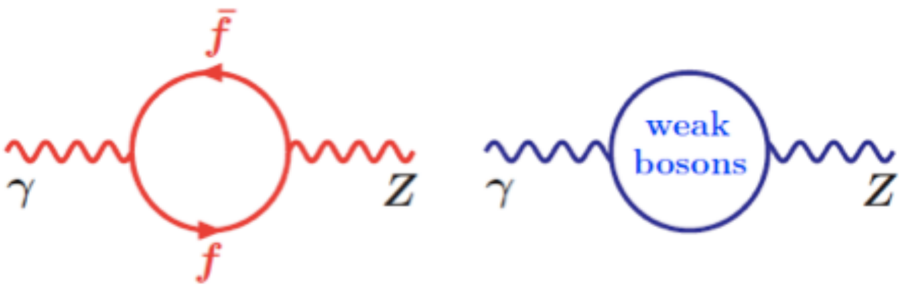
# $sin^2\theta_W$ within the Standard Model and beyond

**Probably the key parameter of the SM:**
**The Electroweak mixing angle $\theta_W$**

$$\sin^2\Theta_W = (e/g)^2 = 1 - (M_W/M_Z)^2$$

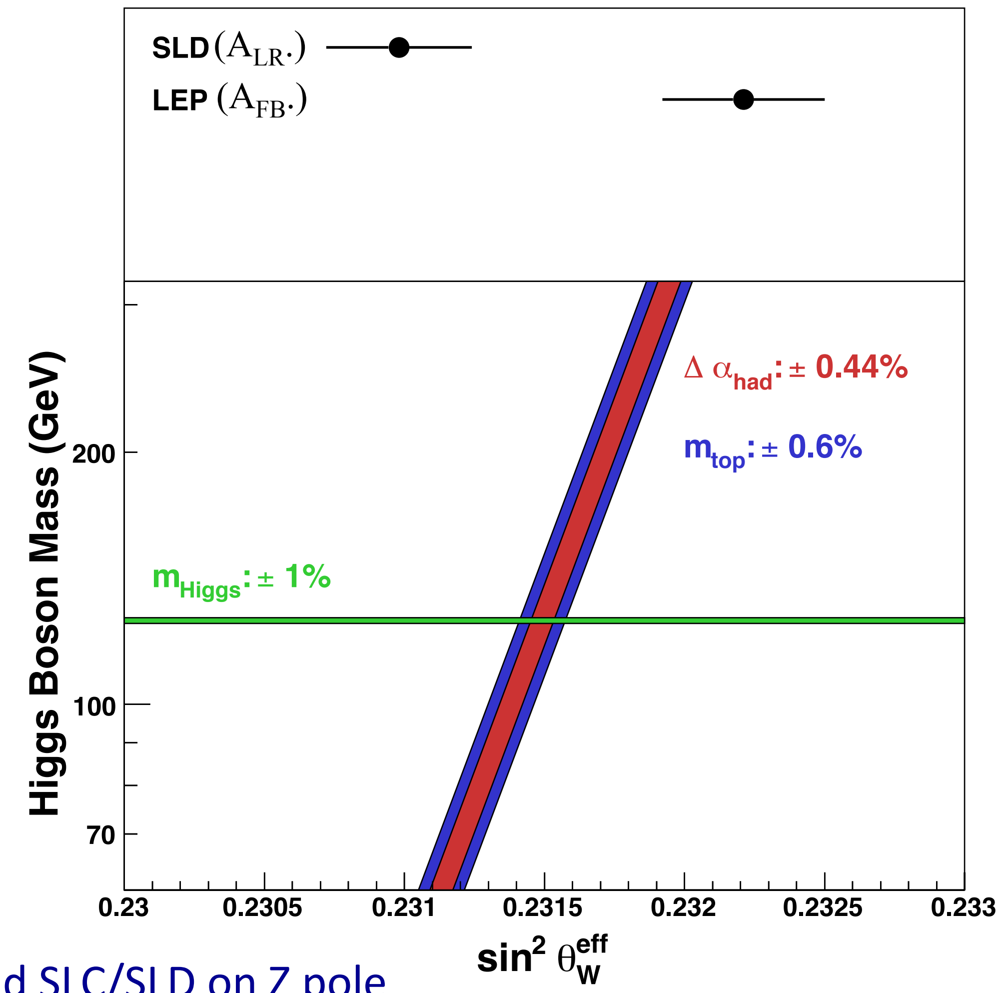
**Incorporates:**
**$SU(2)_L x U(1)_Y$ + Higgs Mechanism+ Renormalizability**

**EW corrections strongly correlated with masses of top quark, Higgs, New Physics!**




**Low $Q^2$ → High sensitivity to New Physics**

# *EW Precision Physics after Higgs Discovery*




**Experimental status**:

- 2 precision measurement at LEP and SLC/SLD on Z pole
- Low Energy experiments (e-e- , Neutrino scattering, APV)

# *A Low-$Q^2$ Measurement of $sin^2\theta_W$ at MESA*

## Scattering of longitudinally polarized electrons on protons

→ **Z boson exchange** in electron-proton scattering introduces **parity-violating effect**

→ Measure **parity-violating Left-Right cross section asymmetry $A_{LR}$**

$$A_{LR} = \frac{\sigma(e\uparrow) - \sigma(e\downarrow)}{\sigma(e\uparrow) + \sigma(e\downarrow)} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}(Q_W - F(Q^2))$$

hadron structure

$$Q_W = 1 - 4\sin^2\theta_W(\mu)$$

**MESA goal (extracted beam mode):**

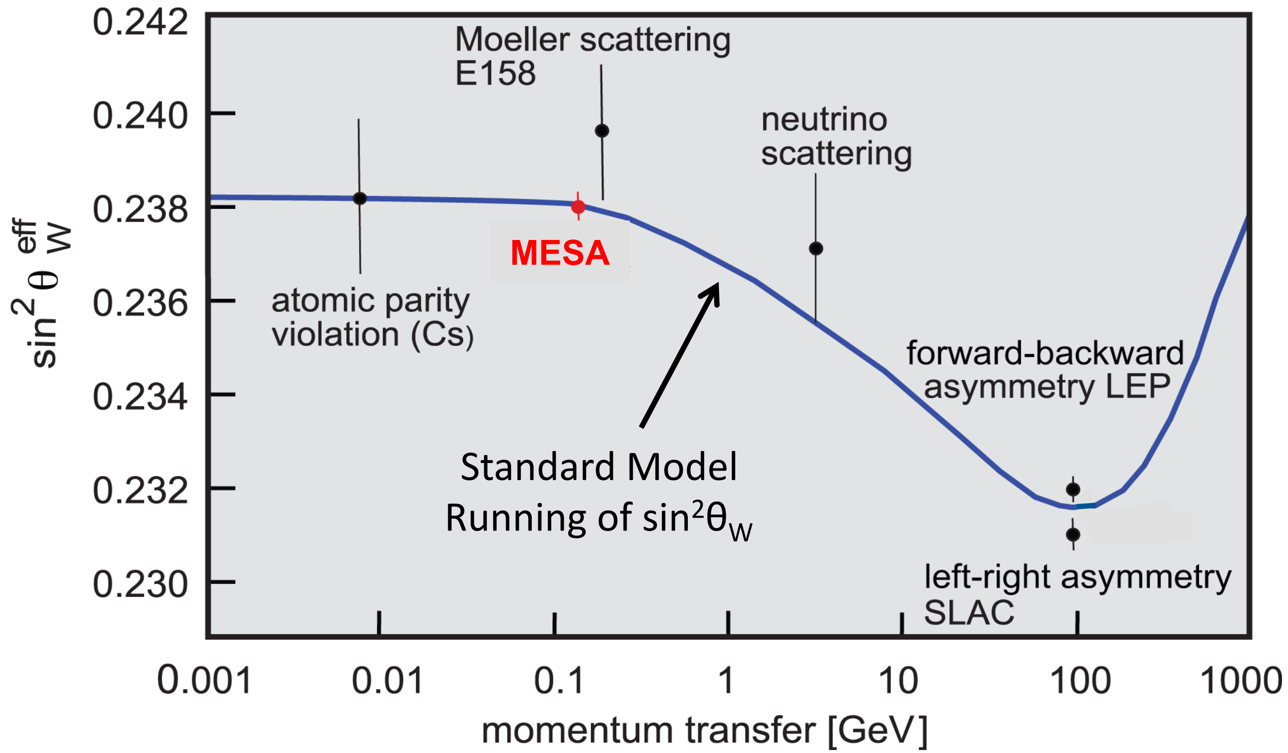
**Measure parity-violating Left-Right asymmetry $A_{LR}$ of 20 x $10^{-9}$ with 1.8% precision**

# *MESA contribution to $sin^2\theta_W$*

**Why low beam energies?**

→ **Dramatically reduced hadronic uncertainties** from γZ box diagrams (QWEAK 1.2 GeV)
→ At low energies there is a **significantly enhanced sensitivity to resolve New Physics**

**MESA: $\Delta sin^2\theta_W$ = 4 x $10^{-4}$**



# *MESA contribution to $sin^2\theta_W$*

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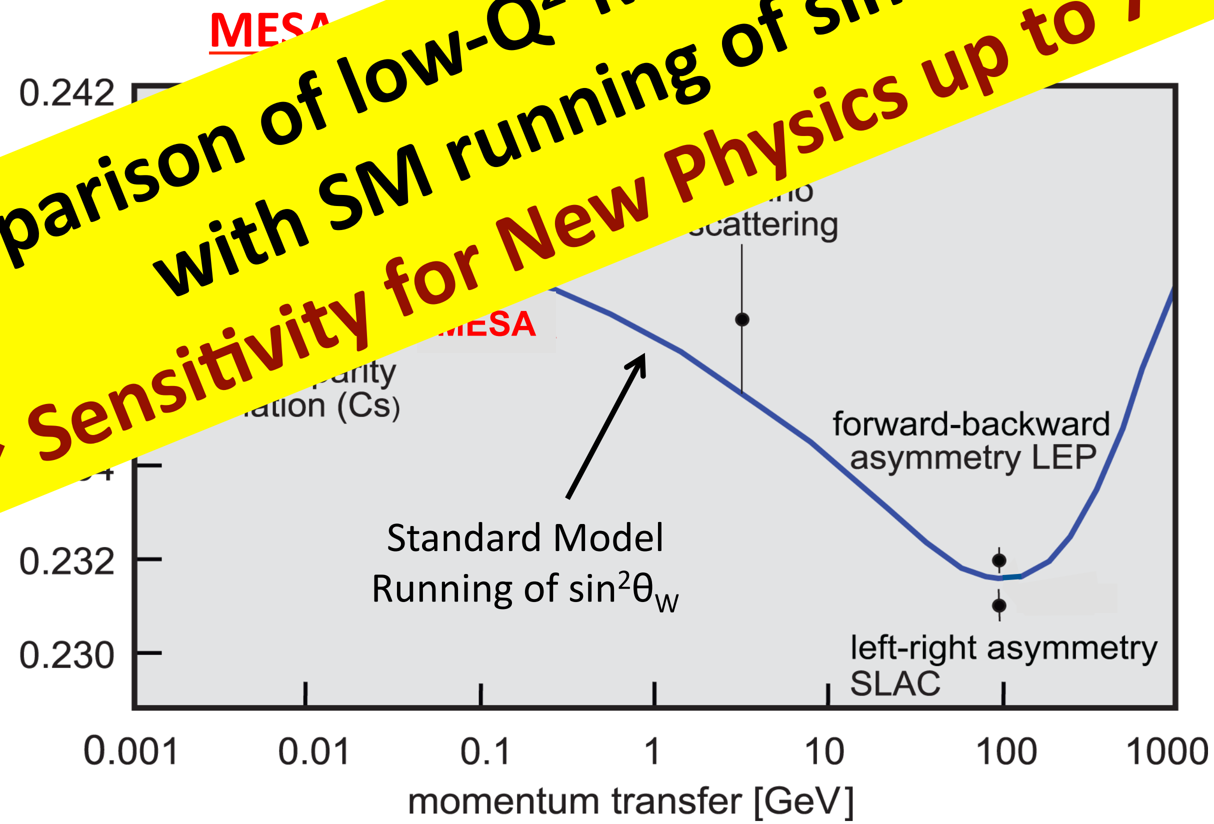


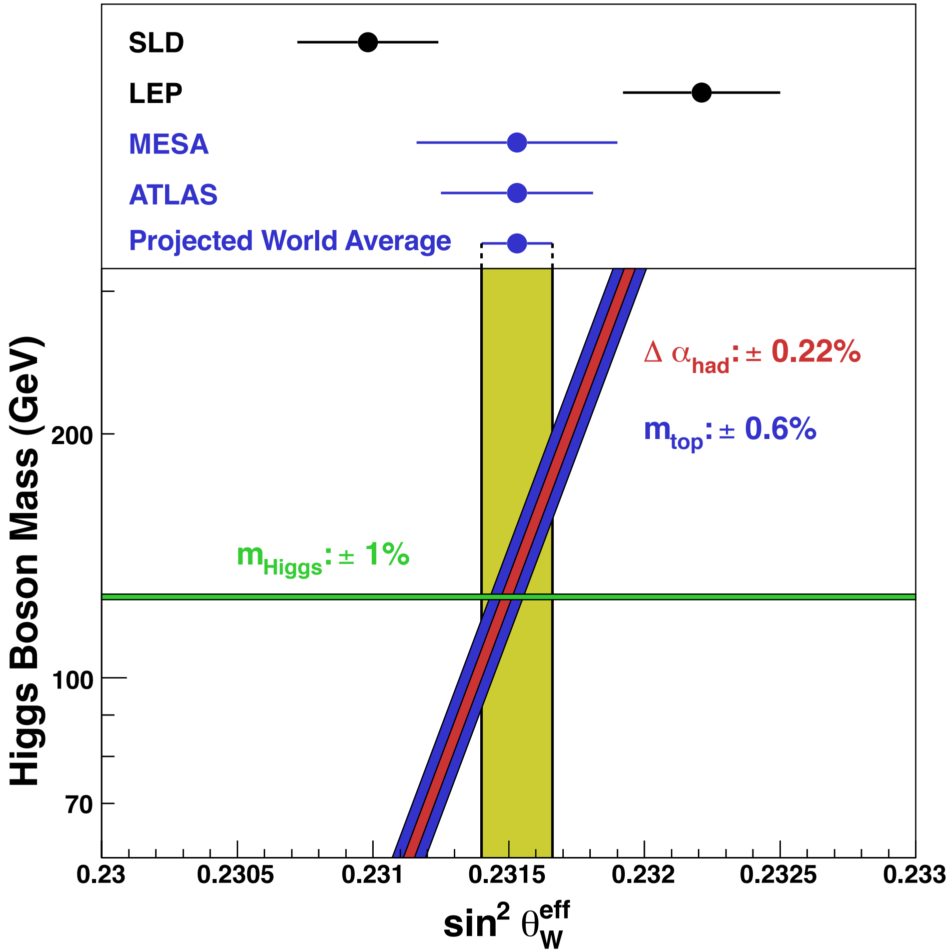

**Comparison of low-$Q^2$ MESA measurement with SM running of $\sin^2\theta_W$**

**→ Sensitivity for New Physics up to 7 TeV!**

# *Possible Scenarios 2017+*

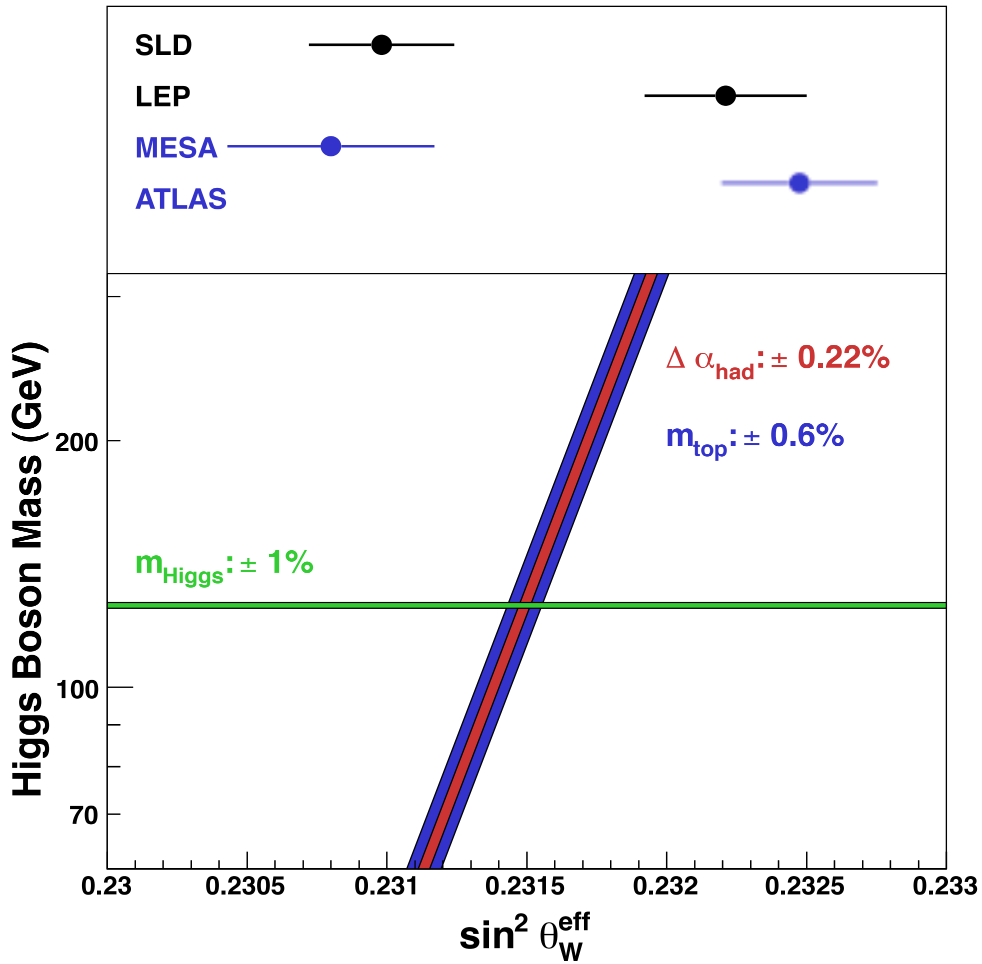
**Scenario**:

Metastable universe → No Physics beyond the SM



# *Possible Scenarios 2017+*

**Scenario**:
Physics beyond the SM



# Conclusions

# *Conclusions*

**PRECISION FRONTIER at low energies:**

**Complementary program in the LHC era**

**Puzzles?** **New Physics?**

**Many thanks for the leadership!**

**Happy Birthday Juliet and Paolo!**