Theoretical framework to analyze searches for hidden light gauge bosons in electron scattering fixed target experiments

based on: TB, H. Merkel, M. Vanderhaeghen, arXiv:1303.2540

Tobias Beranek

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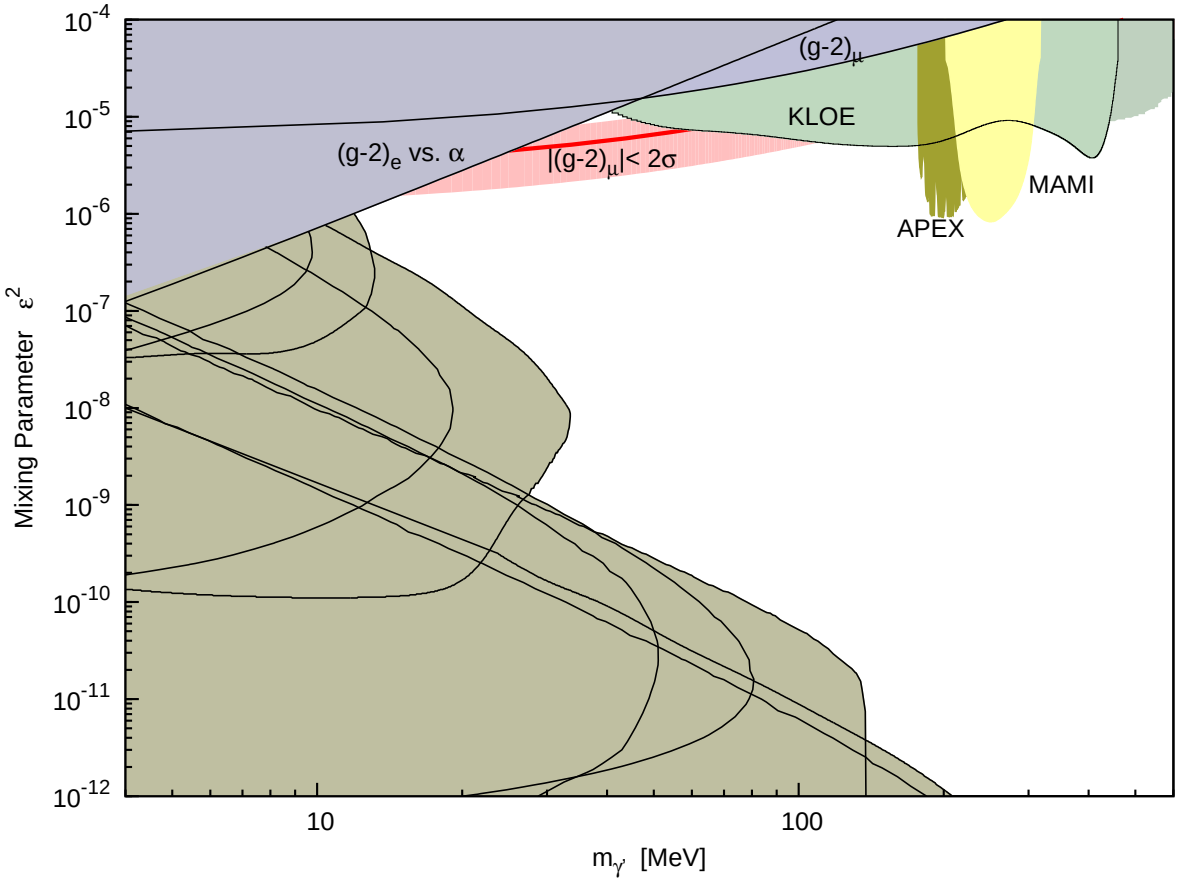
Workshop to Explore Physics Opportunities with Intense, Polarized Electron Beams up to 300 MeV ,
Cambridge, 14.03. - 16.03.2013

The γ' Parameter Plane for Visible Decays



Pospelov (PRD 80)
Bjorken et al. (PRD 80)
MAMI (PRL 106)

APEX (PRL 107)
Blumlein, Brunner (PLB 701)
KLOE (PLB 706, PLB 720)

Gninenko (PRD 85, PLB 713)
Davoudiasl et al. (PRD 86)
Andreas et al. (PRD 86)

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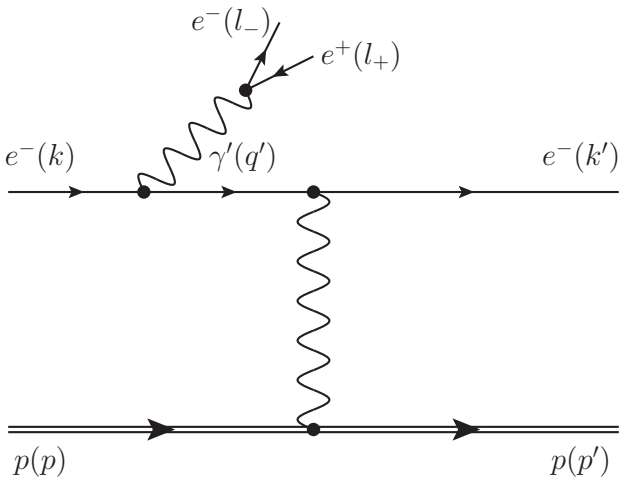
γ' Production from $ep \to epe^+e^-$



timelike γ' (TL)

$$\mathcal{M}_{\gamma',TL} \propto \frac{\varepsilon^2}{q'^2 - m^2_{\gamma'} + i m_{\gamma'} \Gamma_{\gamma'}}$$

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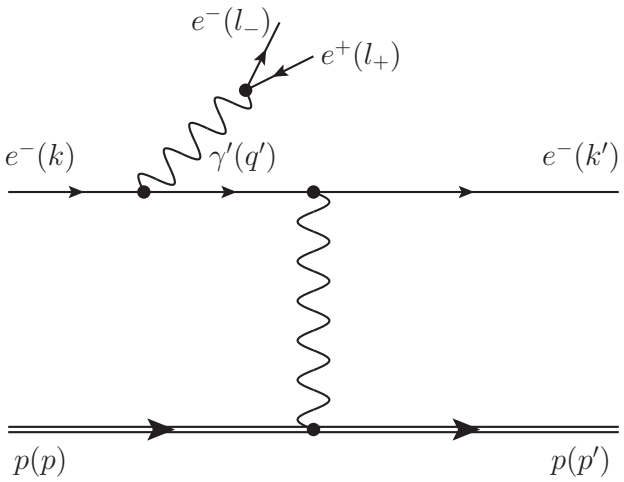

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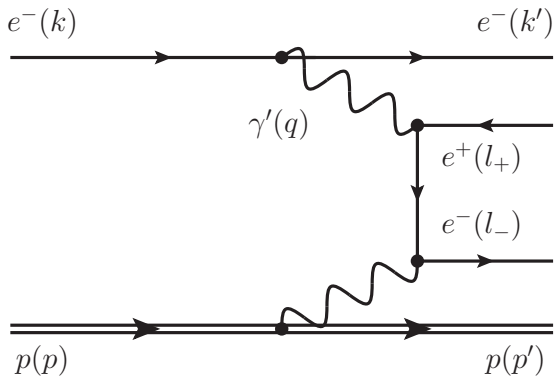

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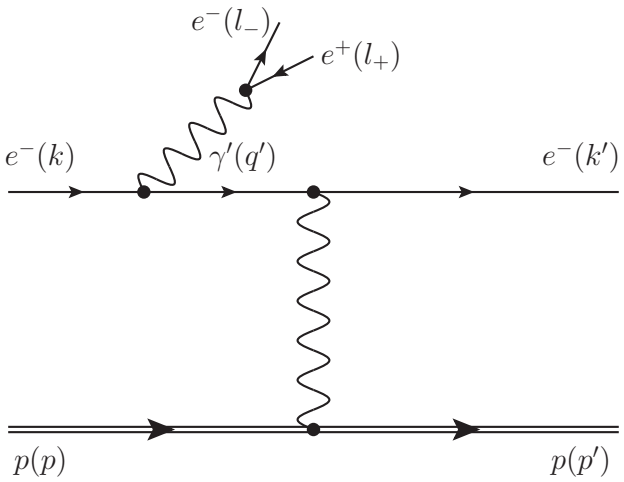

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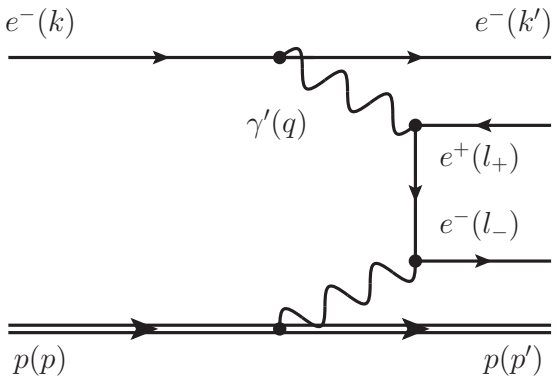


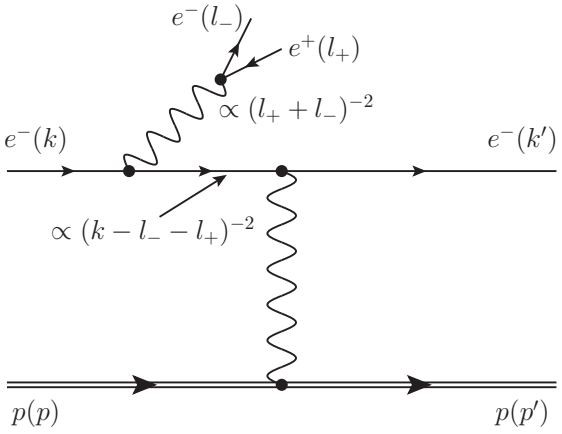
spacelike γ' (SL)

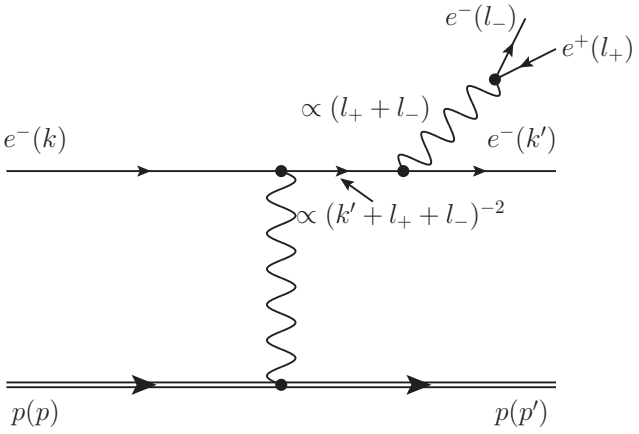
$$\mathcal{M}_{\gamma',TL} \propto \frac{\varepsilon^2}{q'^2 - m^2_{\gamma'} + i m_{\gamma'} \Gamma_{\gamma'}}$$

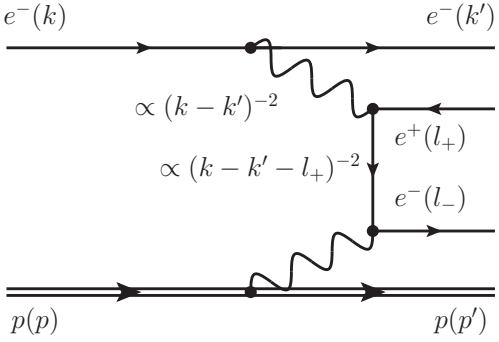
$$\mathcal{M}_{\gamma',SL} \propto \frac{\varepsilon^2}{q^2 - m^2_{\gamma'}}$$

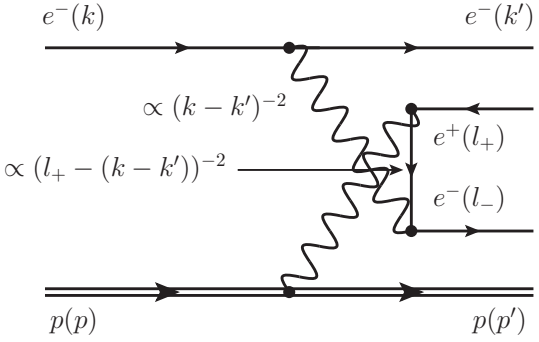
$\Gamma_{\gamma'}$ decay width of γ' : $\mathcal{O}$(eV), if only SM decay allowed
Signal: γ' will appear as **sharp resonance** from **timelike** production

QED background: Direct diagrams (D)

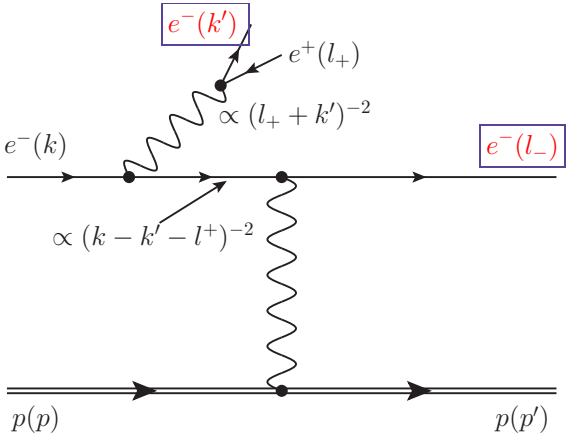


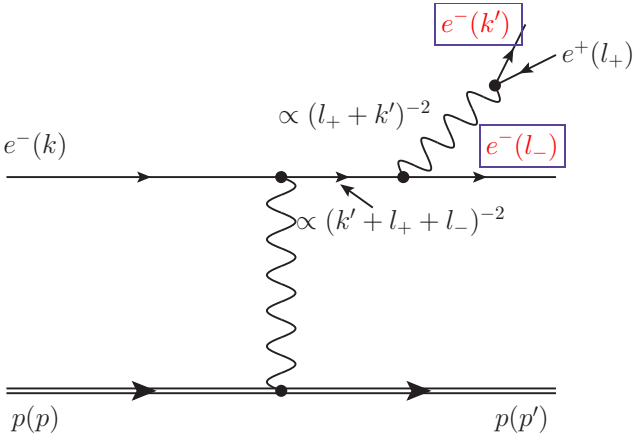


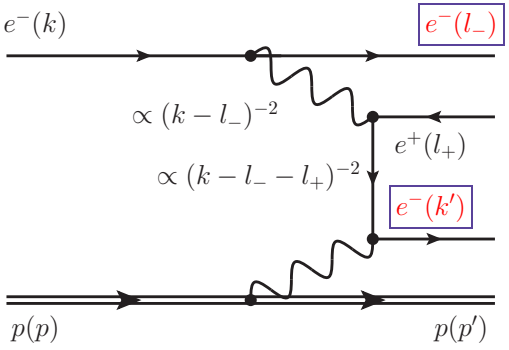


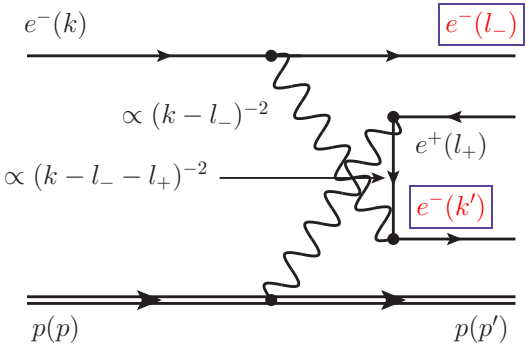


QED background: Exchange diagrams (X)

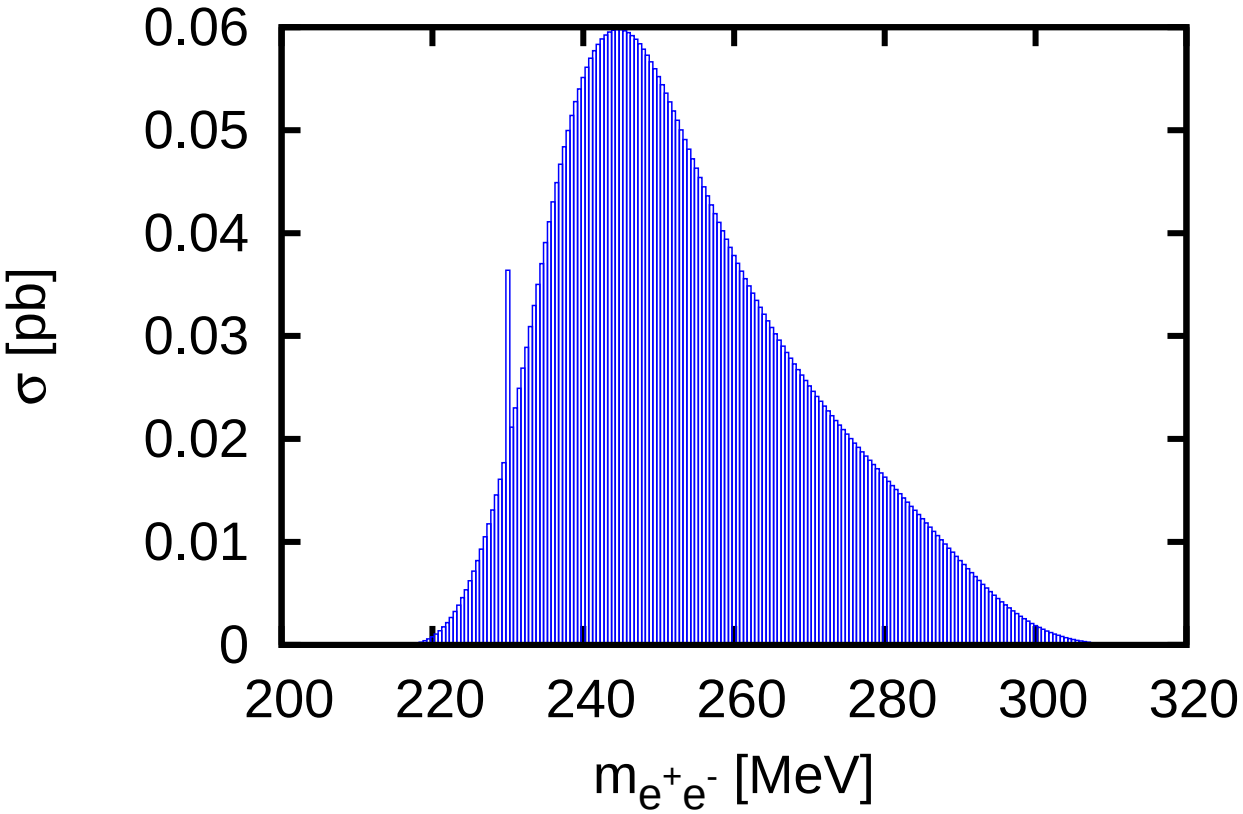








Background vs. Signal



- Assume: $m_{\gamma'} = 230\,\text{MeV}$, $\varepsilon^2 = 10^{-4}$
- Excess in 1 bin at $m_{e^+e^-} = 230\,\text{MeV}$

Exclusion Limit Calculation

- **Approximation** of cross section ratio $\frac{\sigma_{\gamma'}}{\sigma_\gamma^{TL}} = \frac{3\pi}{2N}\frac{\varepsilon^2}{\alpha}\frac{m_{\gamma'}}{\delta m}$ (Bjorken, Essig, Schuster, Toro, PRD 80)
- **Experimental Quantity:** $\sigma_{\gamma'+\gamma} \propto \left|\mathcal{M}_\gamma + \mathcal{M}_{\gamma'}\right|^2$

  $\Rightarrow$ **Decompositon:** $\sigma_{\gamma'+\gamma} = \sigma_\gamma + \sigma_{\gamma'} + \sigma_{\text{int}}$

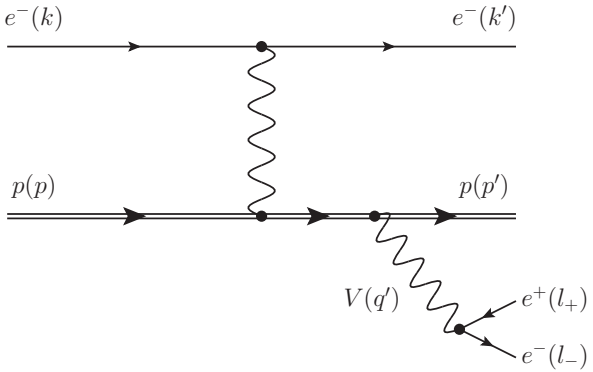
ε^2 Exclusion Limit from Data

$$\varepsilon^2 = \underbrace{\left(\frac{\sigma_{\gamma'+\gamma}}{\sigma_\gamma} - 1\right)}_{\text{experimental limit}} \overbrace{\frac{\sigma_\gamma}{\sigma_\gamma^{\text{TL}}}}^{\text{theory input}} \frac{2\,N\,\alpha}{3\pi}\frac{\delta m}{m_{\gamma'}}$$

$\Rightarrow$ How well do we know σ_γ?

$\rightarrow$ approximation of hadronic current, radiative corrections...

QED Background: Double Virtual Compton Scattering



Double virtual Compton scattering amplitude:

- **Heavy nucleus** target: **negligible** (large target mass); in the approximation used: low computing effort
- **Proton**: can be **notable** contribution, cross checked with VCS data

Double VCS contribution is **included**

Technical Challenges

Experiments have finite acceptances

$\Rightarrow$ Evaluate $\Delta\sigma = \int \frac{d\sigma}{d\left|\vec{l_+}\right| \, d\Omega_+ \, d\Omega_- \, d\Omega_{e'} \, dq'^2}$ within the exp. limits

Problem: 8-fold numerical integration and integrand contains several **strongly peaked structures**

Key Question:

Try to do calculation as "exact" as possible or apply approximations? $\rightarrow$ "exact"

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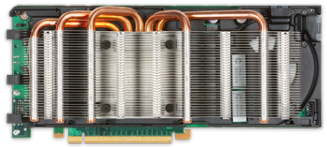
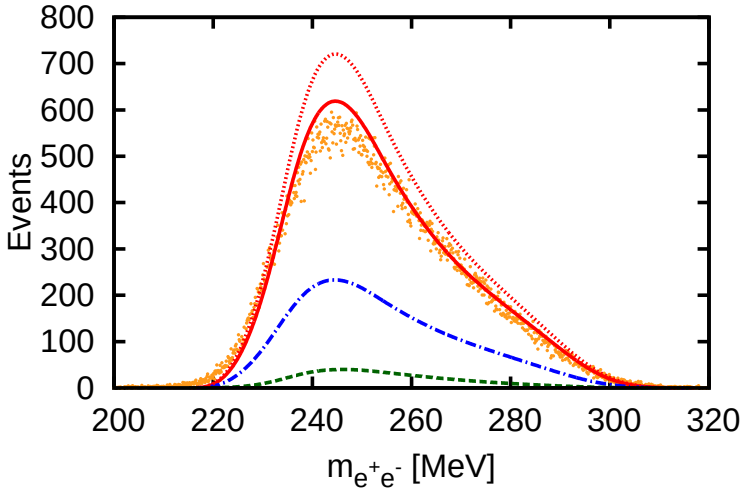
Run calculations on
General Purpose Graphics Processing Units (GPGPU)



(nvidia Tesla)

MAMI 2010 (I)

MAMI test run 2010 (Merkel et al. (A1), PRL106)



- Data and theory in **good agreement**
- Radiative corrections are crucial to describe the data accurately

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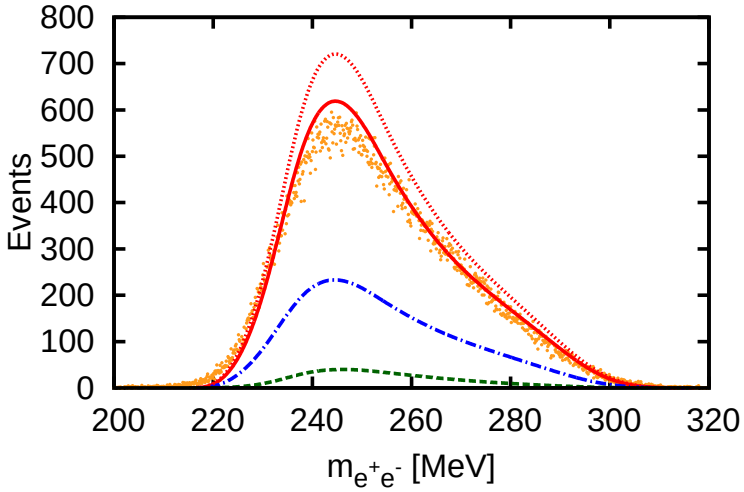
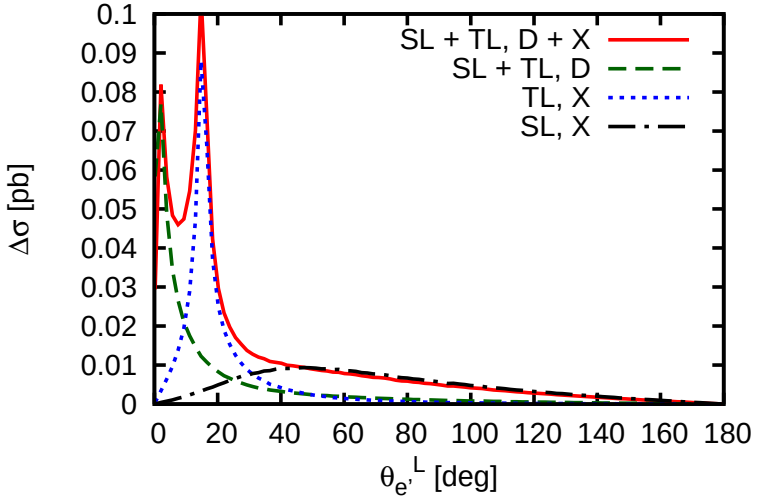
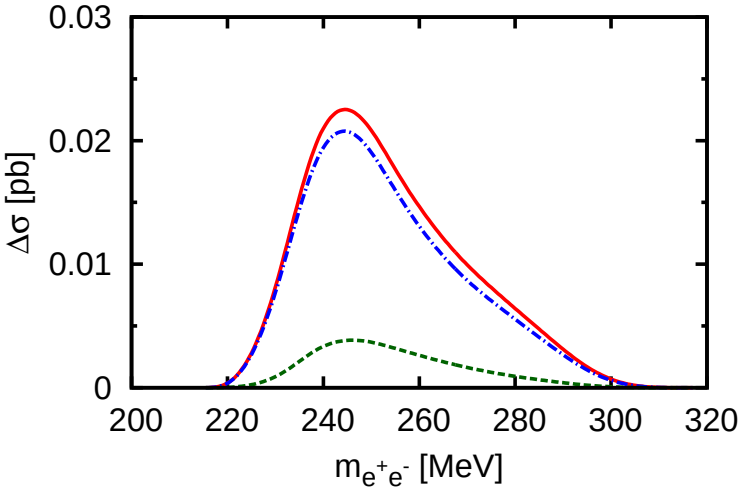




- Data and theory in **good agreement**
- Radiative corrections are crucial to describe the data accurately
- **Large contribution** from **exchange** term

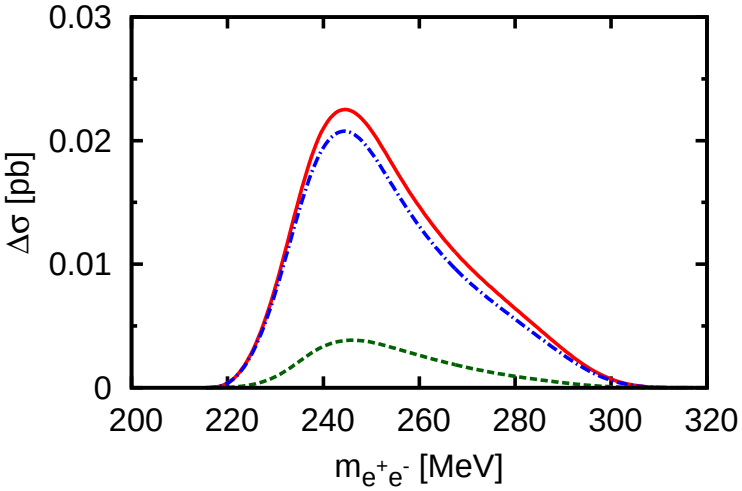
MAMI 2010 (II)



direct

- Direct: SL background dominating

MAMI 2010 (II)



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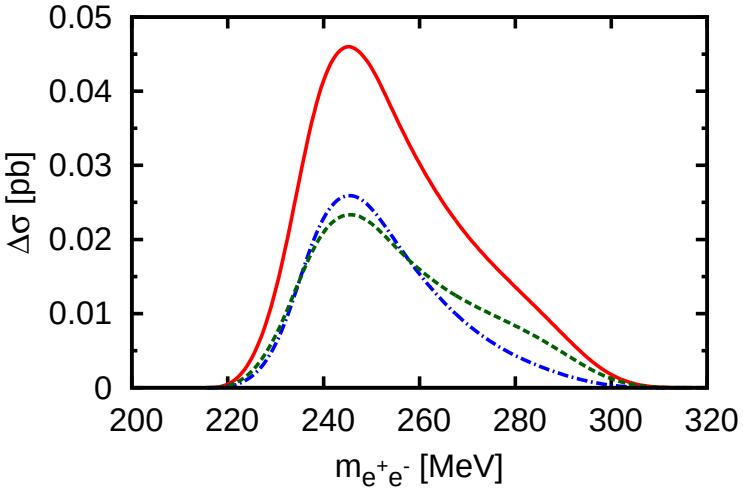
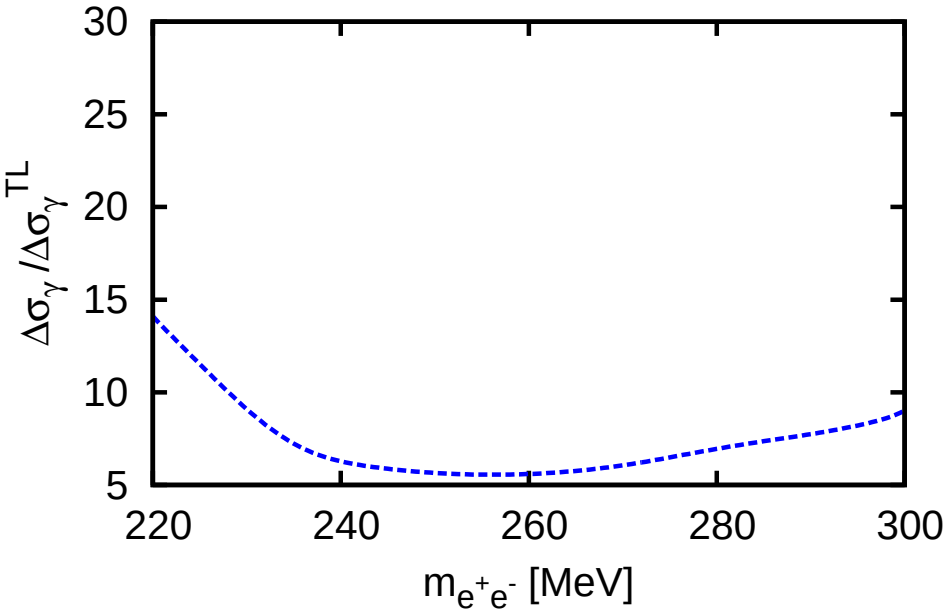


exchange

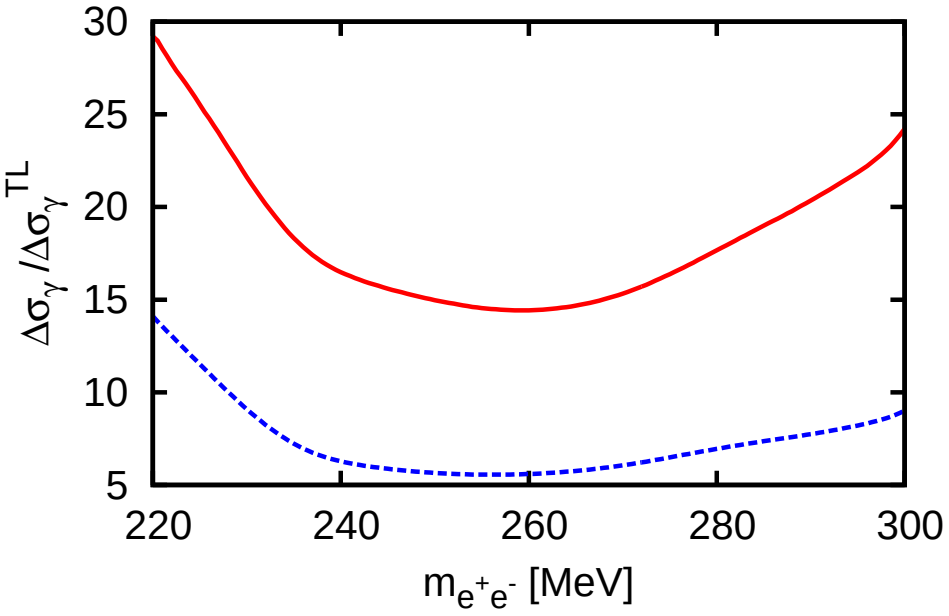
- Direct: SL background dominating
- Exchange: SL and TL contribution of comparable size
- Background from **exchange term twice as large as direct** contribution

MAMI 2010 (III)



- $\Delta\sigma_\gamma^D/\Delta\sigma_\gamma^{TL} \simeq 5 - 15$

MAMI 2010 (III)



- $\Delta\sigma_\gamma^D / \Delta\sigma_\gamma^{TL} \simeq 5 - 15$
- $\Delta\sigma_\gamma^{D+X} / \Delta\sigma_\gamma^{TL} \simeq 15 - 25$

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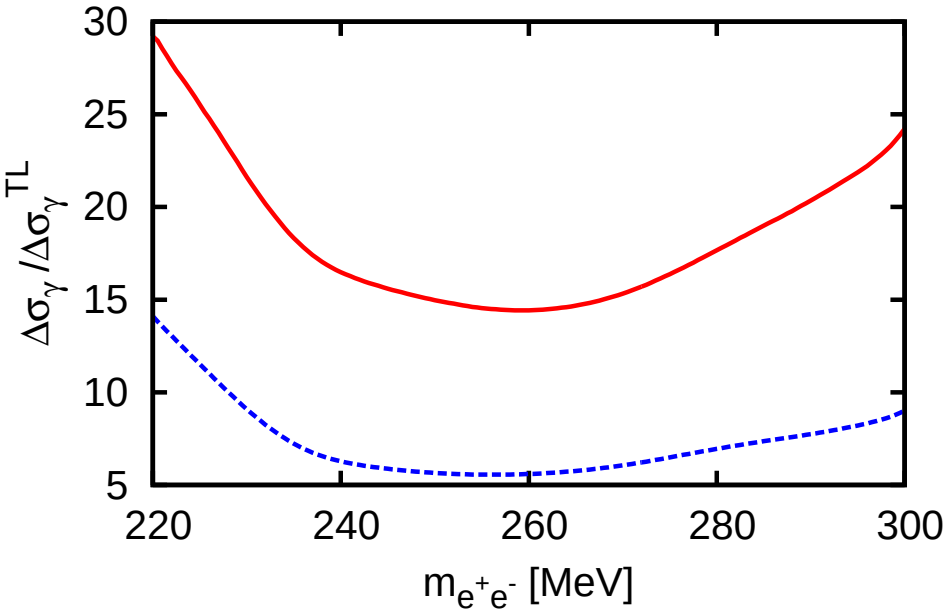
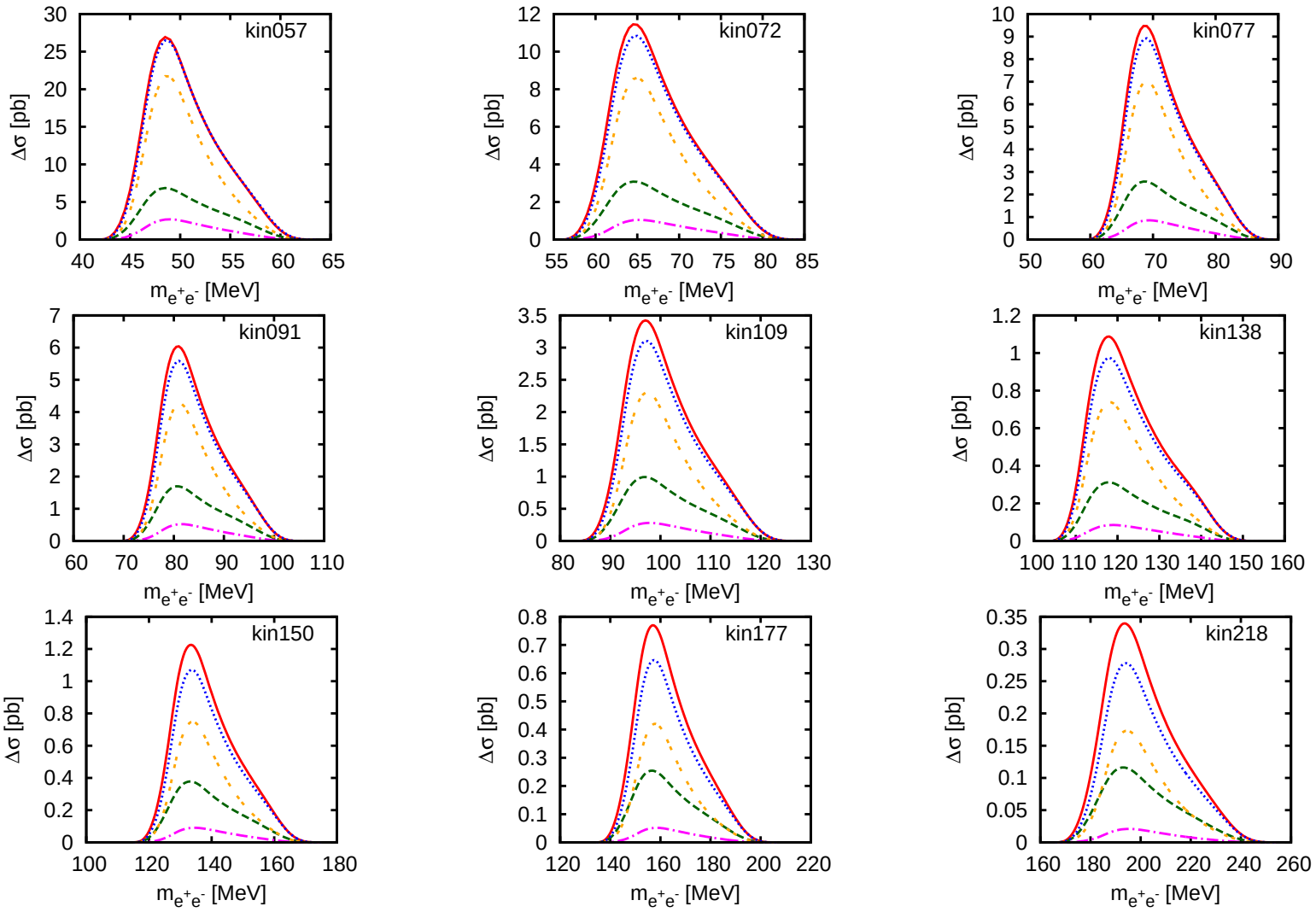


- $\Delta\sigma_\gamma^D/\Delta\sigma_\gamma^{TL} \simeq 5 - 15$
- $\Delta\sigma_\gamma^{D+X}/\Delta\sigma_\gamma^{TL} \simeq 15 - 25$
- exchange contribution increases $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{TL}$ by $\simeq$ factor 2 - 3

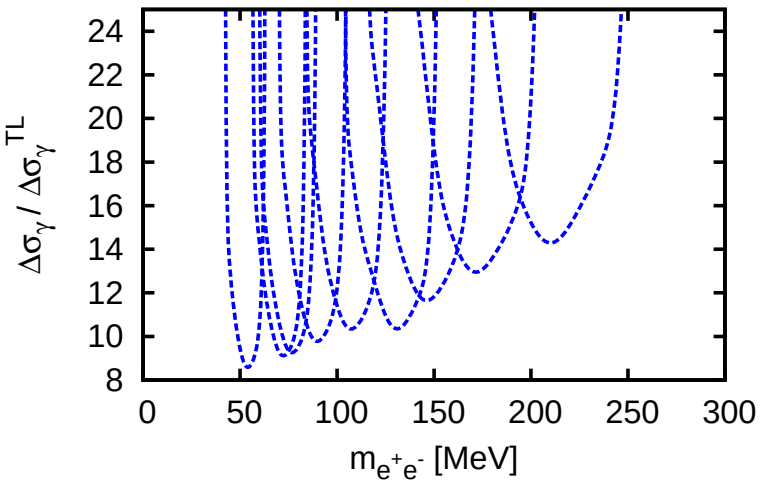
MAMI 2012 (I)

Invariant mass distributions for kinematics centered around $m_{e^+e^-} = 57 - 218\,\text{MeV}$



Solid: TL+SL, X+D. Dotted: TL+SL, X. Double-dashed: SL, X. Dashed: TL+SL, D. Dashed-dotted: TL, D

MAMI 2012 (II)



- $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{\mathrm{TL}} \simeq 10 - 15$

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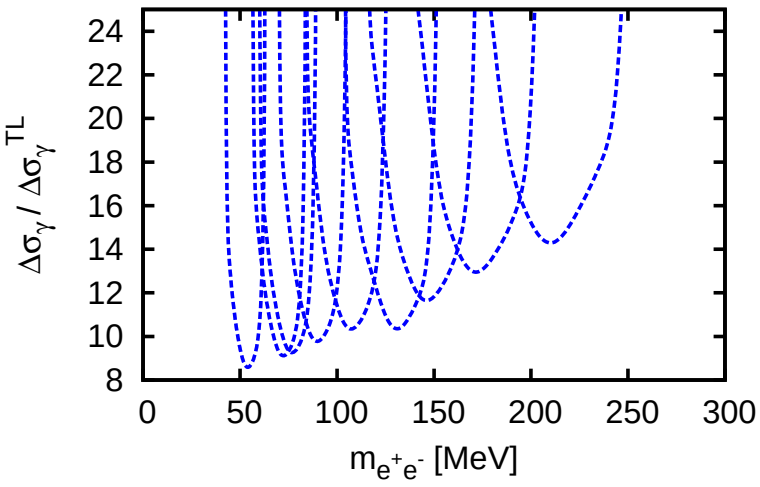
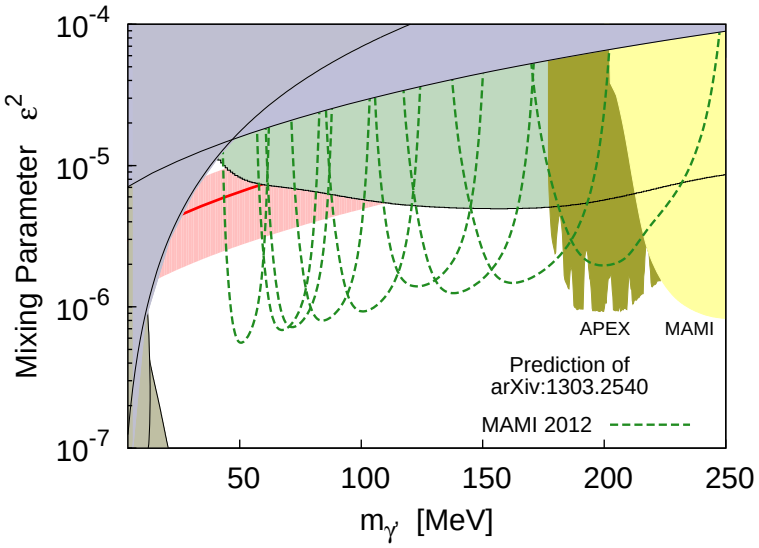
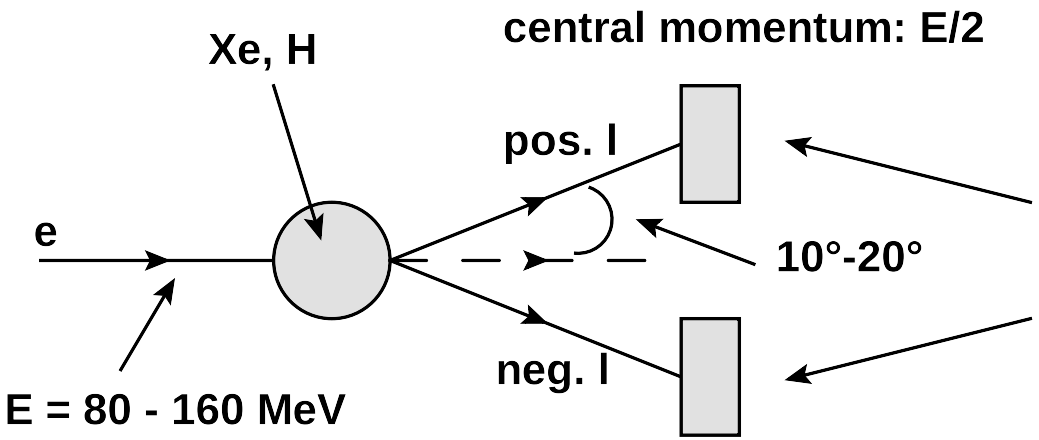


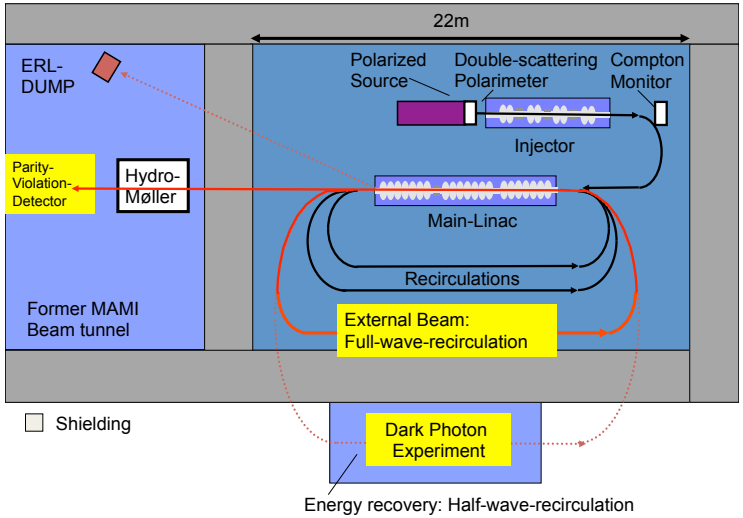


- $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{\mathrm{TL}} \simeq 10 - 15$
- Assumed luminosity of $\sim 10\,\mathrm{fb}^{-1}$ per setting
- **A1 will cover** a large region of the $(g-2)_\mu$ welcome band

γ' Search at MESA: Feasibility Study (I)

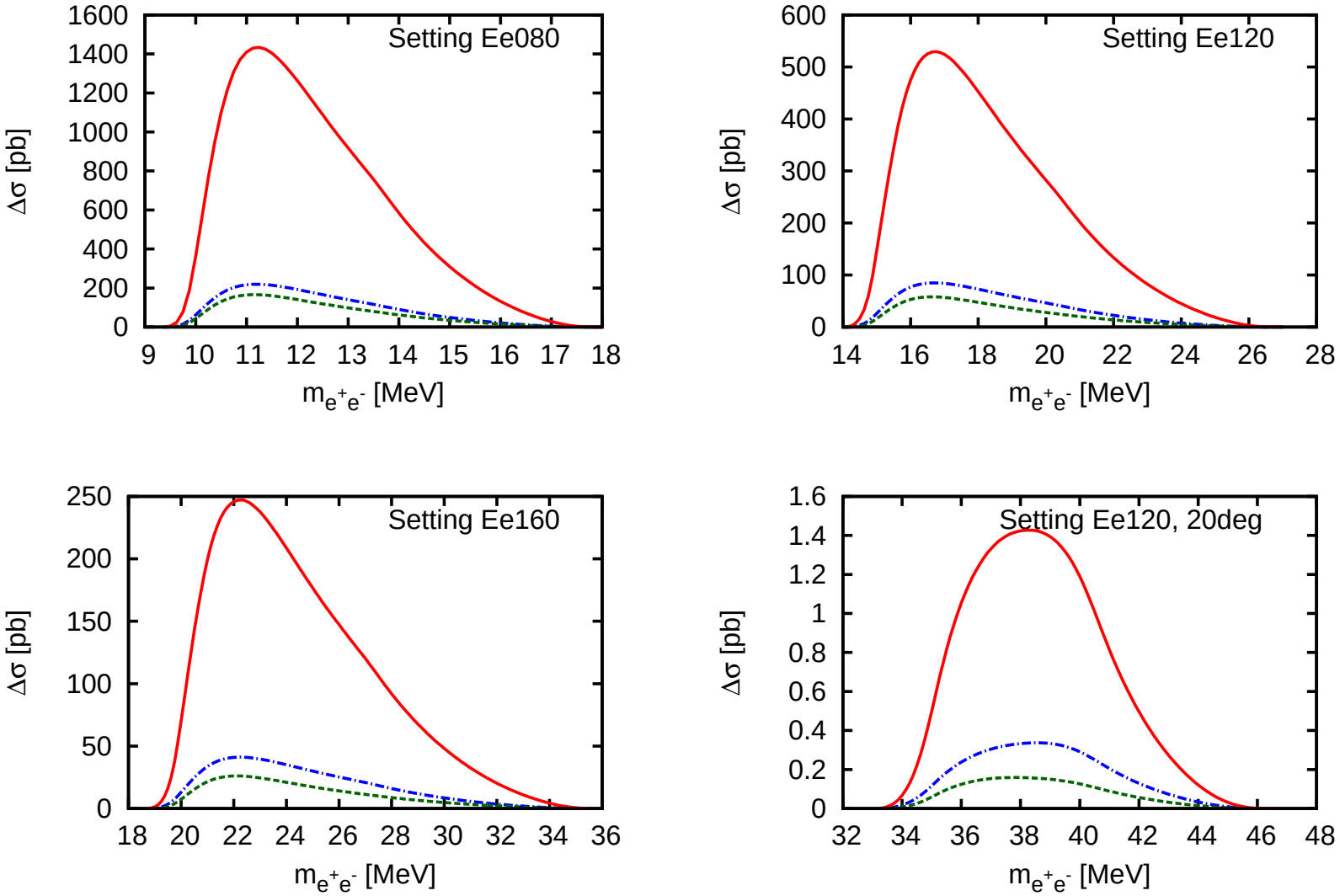


acceptances:
momentum: 5%
horizontal angle: 50 mrad
vertical angle: 50 mrad



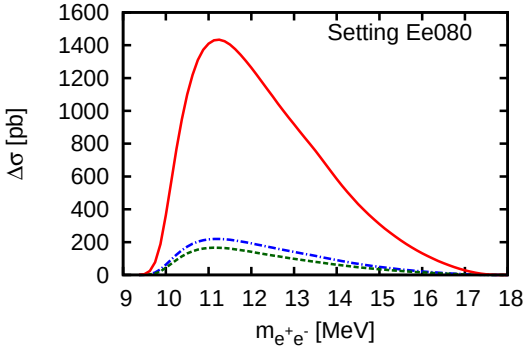
- Use two small spectrometers
- Beam energies: 80, 120, 160 MeV
- Scattering angle: 10° and for higher masses 20°
- Xenon or Hydrogen as target

γ' Search at MESA: Feasibility Study (II)

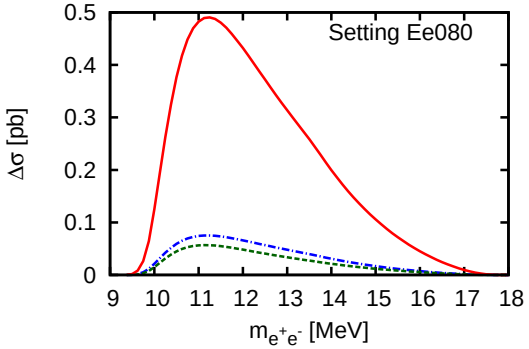


γ' Search at MESA: Feasibility Study (III)

Xenon or Hydrogen target?



Xe

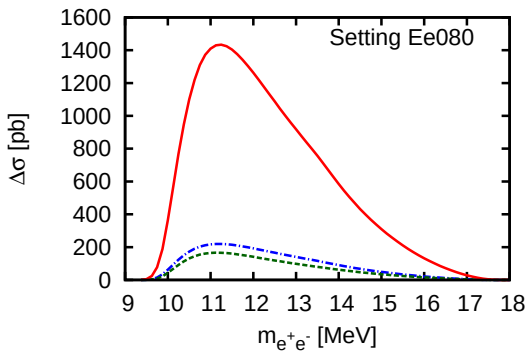


p

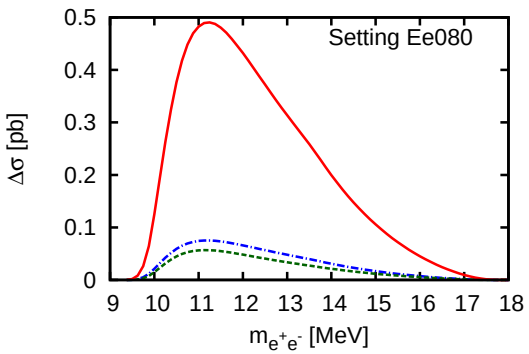
- $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{\mathrm{TL}}$ does not seem to be affected by kind of target
- ***Xe*** cross section by $\boldsymbol{Z^2 = 54^2}$ **enhanced**

γ' Search at MESA: Feasibility Study (III)

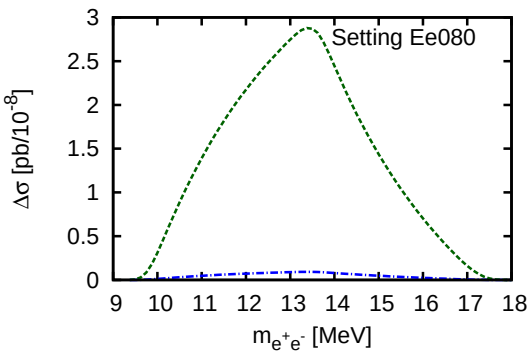
Xenon or Hydrogen target?



Xe



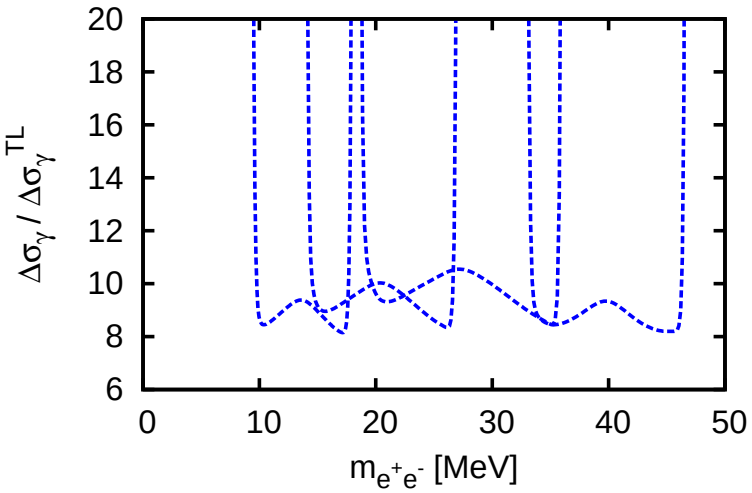
p



p, VCS

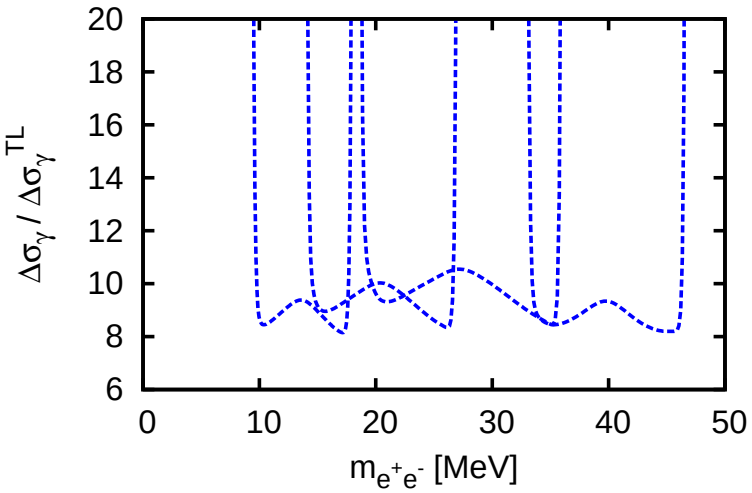
- $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{\mathrm{TL}}$ does not seem to be affected by kind of target
- ***Xe*** cross section by $\boldsymbol{Z^2 = 54^2}$ **enhanced**
- no notable effect from VCS contribution in case of protons

γ' Search at MESA: Feasibility Study (IV)



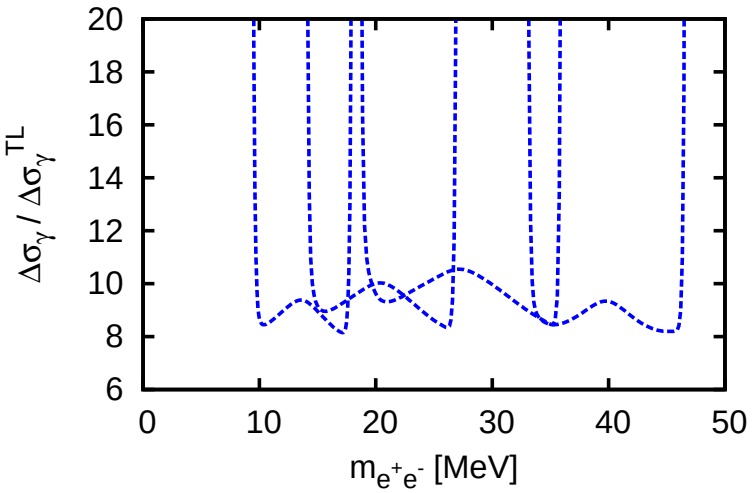
- $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{\mathrm{TL}}$ between 8 - 10

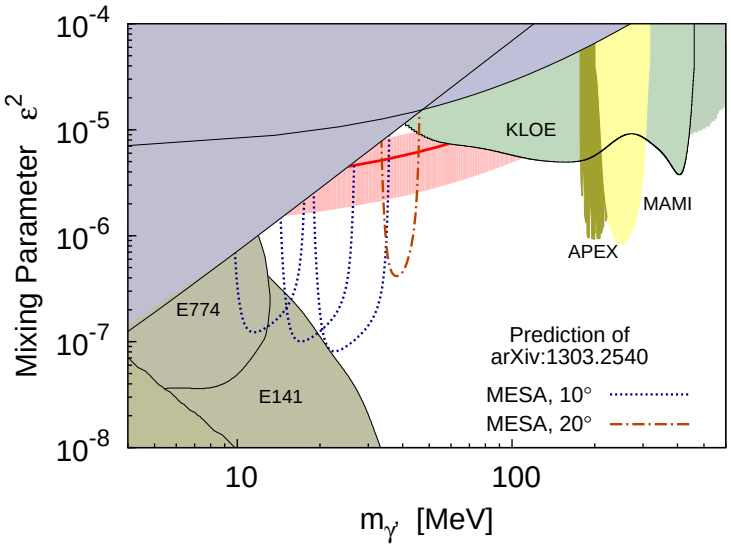
γ' Search at MESA: Feasibility Study (IV)



- $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{\mathrm{TL}}$ between 8 - 10
- Suggestion: Xe target and 3 month of beam time

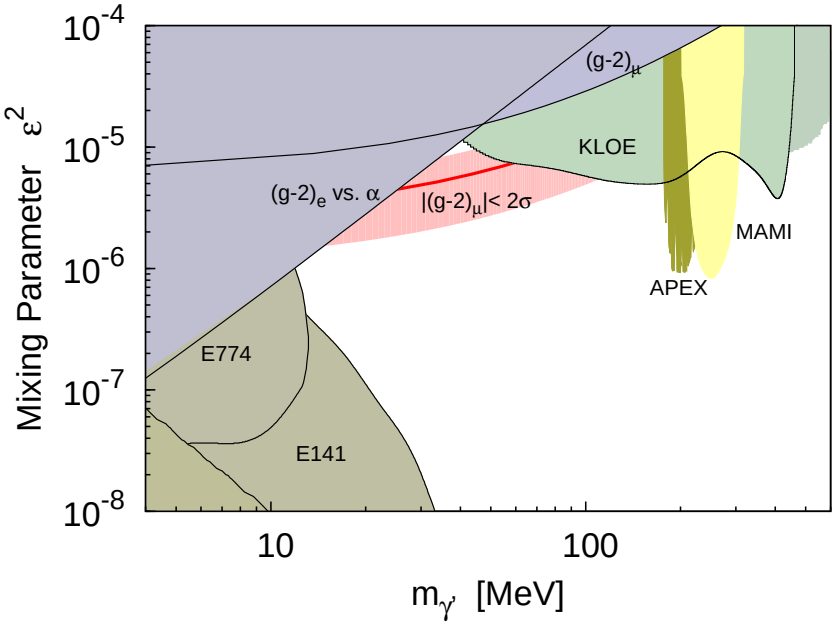
γ' Search at MESA: Feasibility Study (IV)



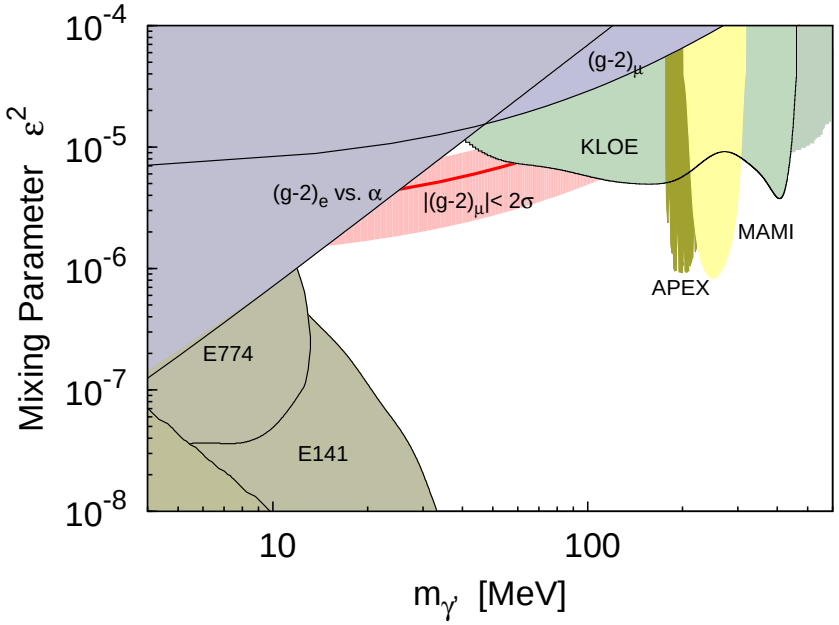


- $\Delta\sigma_\gamma/\Delta\sigma_\gamma^{\mathrm{TL}}$ between 8 - 10
- Suggestion: Xe target and 3 month of beam time
- **MESA covers low $m_{\gamma'}$ region** of the $(g-2)_\mu$ welcome band

Conclusions & Outlook



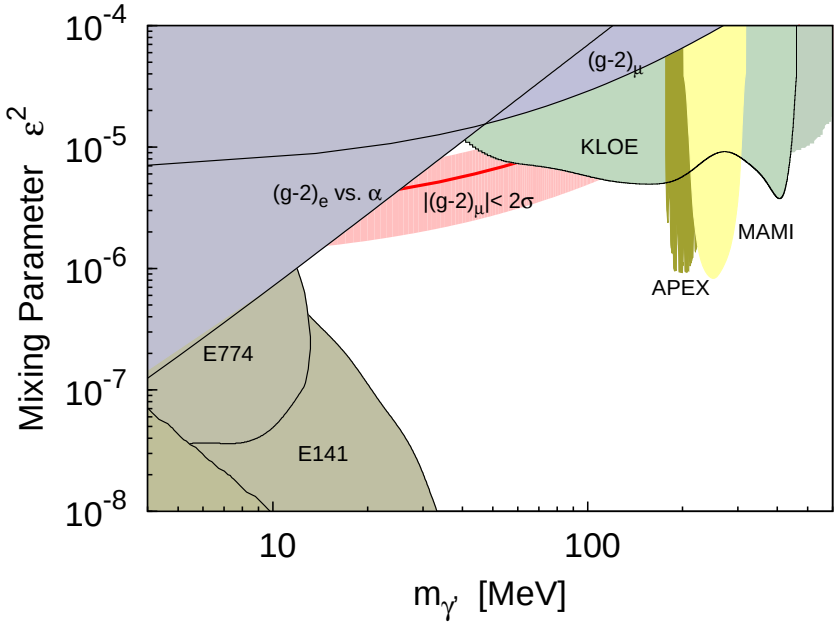
Conclusions & Outlook



Conclusions:

Study of the underlying processes to high accuracy

Conclusions & Outlook

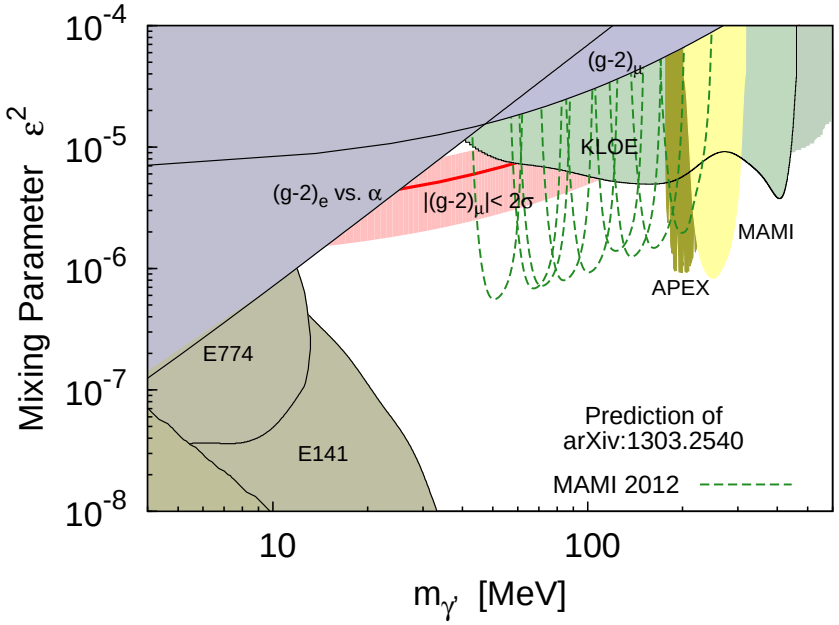


Conclusions:

Study of the underlying processes to high accuracy

Comparison with data: good agreement

Conclusions & Outlook



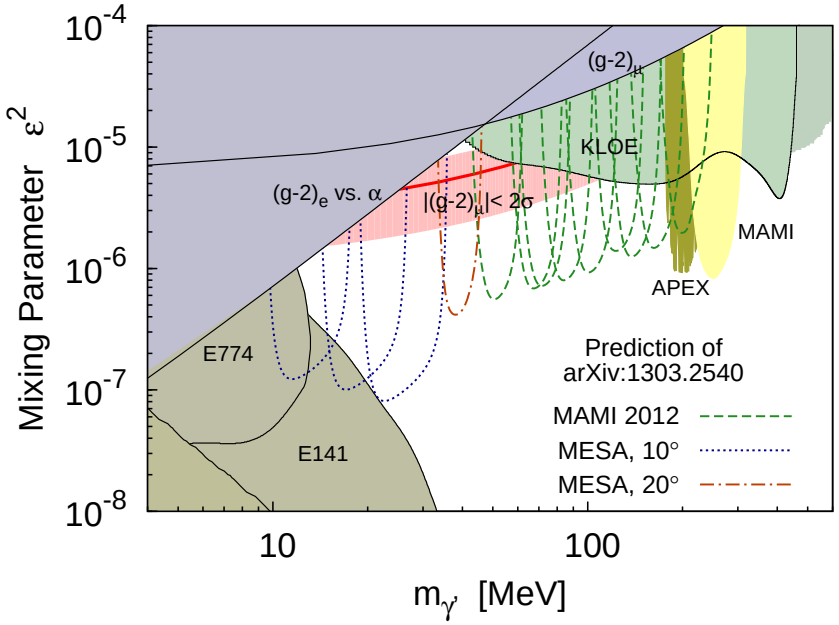
Conclusions:

Study of the underlying processes to high accuracy

Comparison with data: good agreement

Predictions for MAMI

Conclusions & Outlook



Conclusions:

Study of the underlying processes to high accuracy

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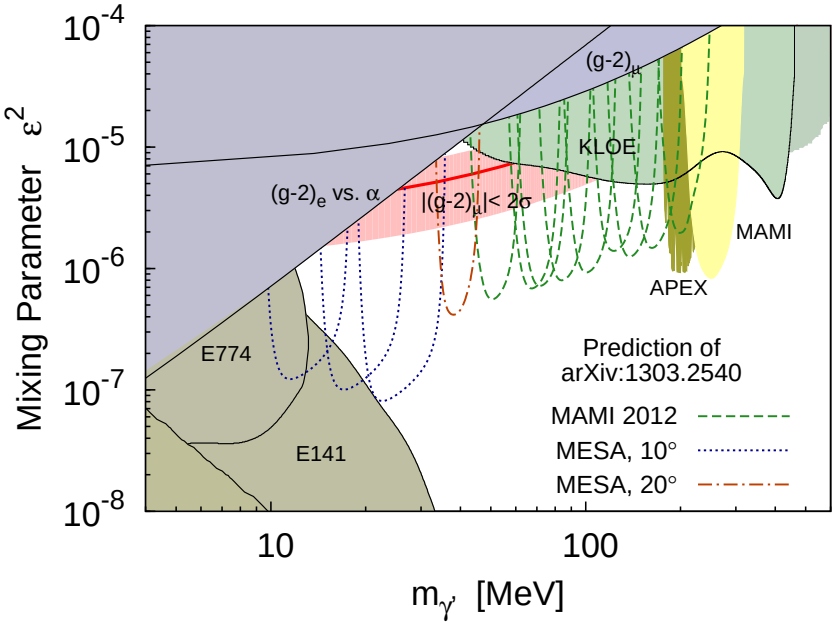
Predictions for MAMI and MESA

Conclusions & Outlook



Conclusions:

Study of the underlying processes to high accuracy

Comparison with data: good agreement

Predictions for MAMI and MESA

Outlook:

Analsyis of 2012 MAMI run data underway

Further Experiments planned at MAMI and JLAB (APEX, HPS, DarkLight)

Low mass γ' search by MESA