

# Searches for Hidden Sector Photons at Mainz

Recent Developments in Theory and Experiment

Theory: TB, Merkel, Vanderhaeghen, arXiv: 1303.2540

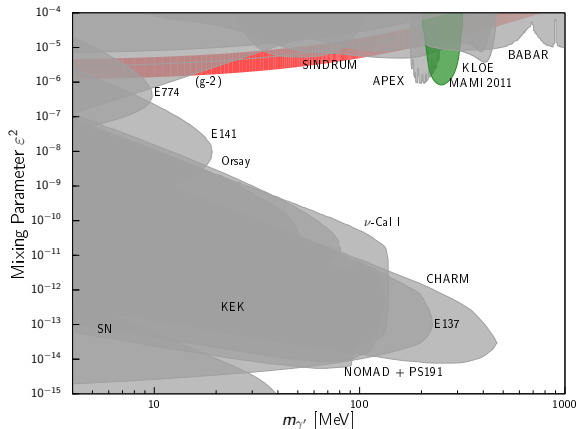
Tobias Beranek

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Intensity Frontier Workshop 2013 ,  
Argonne, 25.04. - 27.04.2013



# The $\gamma'$ 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)

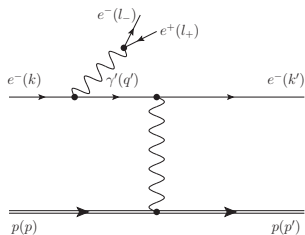
Gninenko (PRD 85, PLB 713)

Davoudiasl et al. (PRD 86)

Andreas et al. (PRD 86)



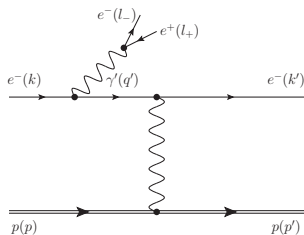
# $\gamma'$ Production from $ep \rightarrow epe^+e^-$



timelike  $\gamma'$  (TL)

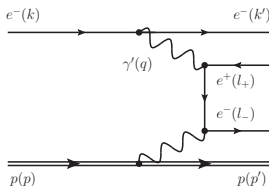
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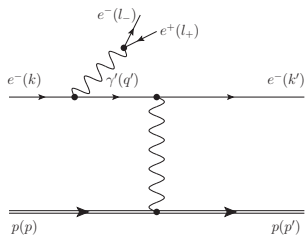
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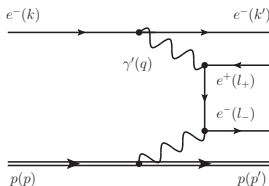
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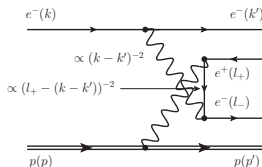
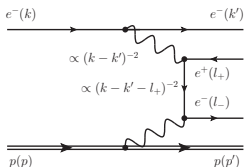
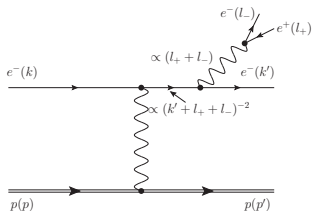
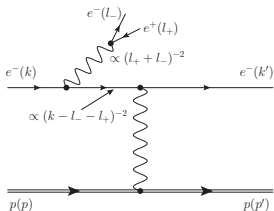
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$$\mathcal{M}_{\gamma', SL} \propto \frac{\epsilon^2}{q^2 - m_{\gamma'}^2}$$

$\Gamma_{\gamma'}$  decay width of  $\gamma'$  :  $\mathcal{O}(\text{eV})$ , if only SM decay allowed

**Signal:**  $\gamma'$  will appear as **sharp resonance** from **timelike** production

# QED background: Direct diagrams (D)



**+ exchange diagrams (X):  $e^-(k') \leftrightarrow e^-(L_-)$ :**  
 Contribution is large when signal is large

# Exclusion Limit Calculation

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

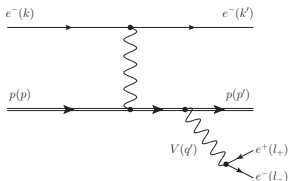
## $\epsilon^2$ Exclusion Limit from Data

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

$\Rightarrow$  How well do we know  $\sigma_{\gamma}$ ?

$\rightarrow$  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**

⇒ Evaluate  $\Delta\sigma = \int \frac{d\sigma}{d|\vec{l}_+| d\Omega_+ d\Omega_- d\Omega_{e'} dq'^2}$  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? → “exact”

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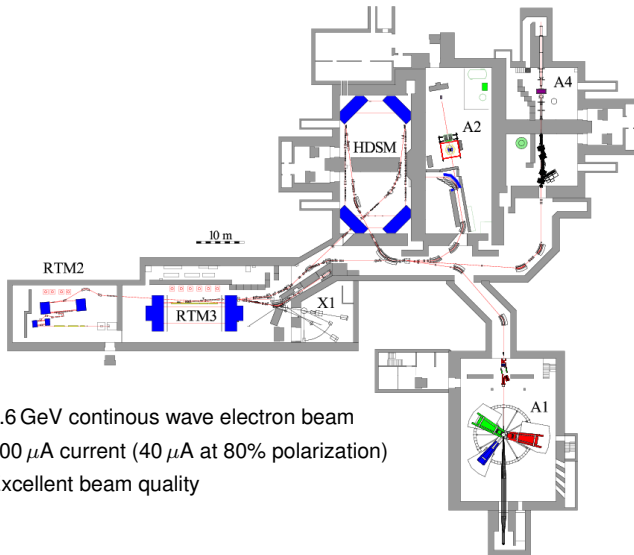
Run calculations on

**General Purpose Graphics Processing Units (GPGPU)**



(nvidia Tesla)

# The MAInz Microtron (MAMI)



- 1.6 GeV continuous wave electron beam
- 100  $\mu\text{A}$  current (40  $\mu\text{A}$  at 80% polarization)
- Excellent beam quality

# A1: Spectrometer setup at MAMI



## Spectrometer A:

$$\begin{aligned} \alpha &> 20^\circ \\ p &< 735 \frac{\text{MeV}}{c} \\ \Delta\Omega &= 28 \text{ msr} \\ \Delta p/p &= 20\% \end{aligned}$$

## Spectrometer B:

$$\begin{aligned} \alpha &> 8^\circ \\ p &< 870 \frac{\text{MeV}}{c} \\ \Delta\Omega &= 5.6 \text{ msr} \\ \Delta p/p &= 15\% \end{aligned}$$

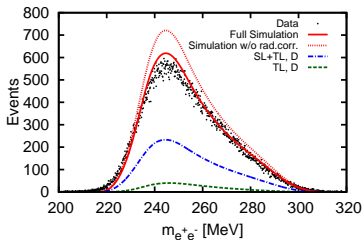
## Spectrometer C:

$$\begin{aligned} \alpha &> 55^\circ \\ p &< 655 \frac{\text{MeV}}{c} \\ \Delta\Omega &= 28 \text{ msr} \\ \Delta p/p &= 25\% \end{aligned}$$

$$\delta p/p < 10^{-4}$$

# MAMI 2010 (I)

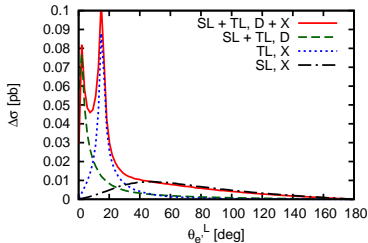
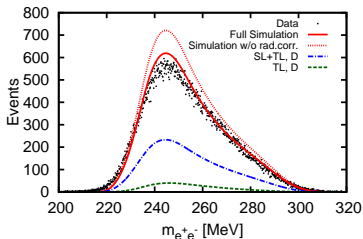
MAMI test run 2010 (Merkel et al. (A1), PRL106)



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

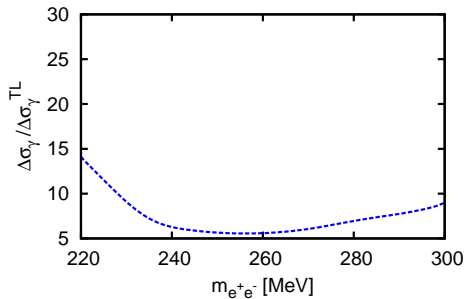
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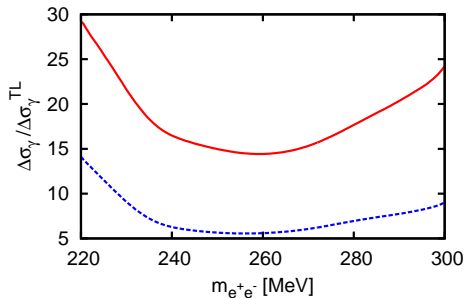
- Data and **theory** in **good agreement**
- Radiative corrections are crucial to describe the data accurately
- **Large contribution** from **exchange** term

# MAMI 2010 (II)



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

# MAMI 2010 (II)

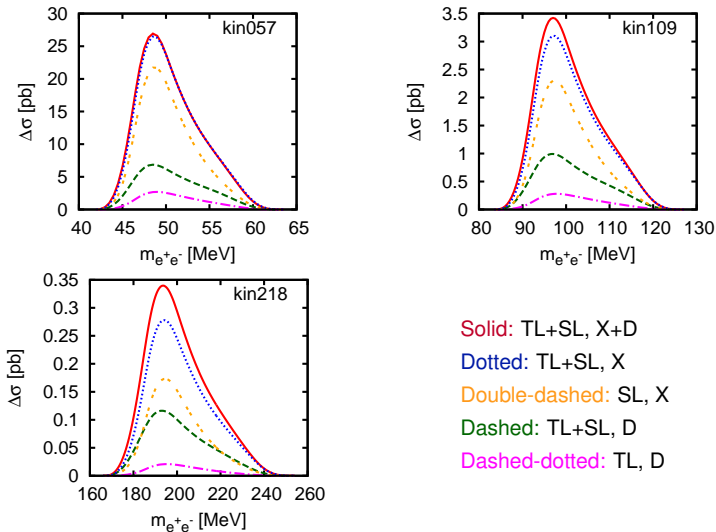


- $\Delta\sigma_\gamma^D / \Delta\sigma_\gamma^{\text{TL}} \simeq 5 - 15$
- $\Delta\sigma_\gamma^{D+X} / \Delta\sigma_\gamma^{\text{TL}} \simeq 15 - 25$
- exchange contribution increases  $\Delta\sigma_\gamma / \Delta\sigma_\gamma^{\text{TL}}$   
 by  $\simeq$  factor 2 - 3

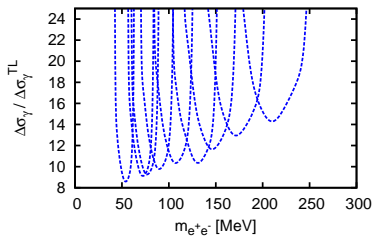


# MAMI 2012 (I)

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

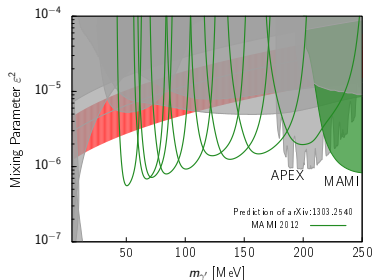
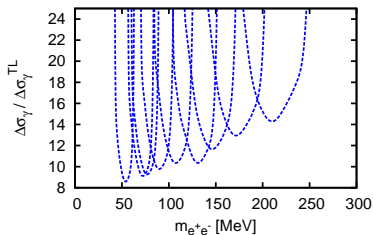


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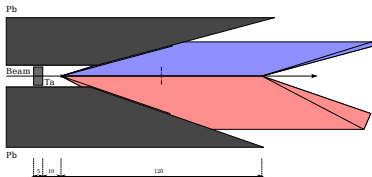
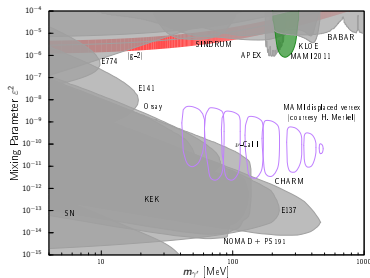
●  $\Delta\sigma_\gamma / \Delta\sigma_\gamma^{\text{TL}} \simeq 10 - 15$

# MAMI 2012 (II)



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

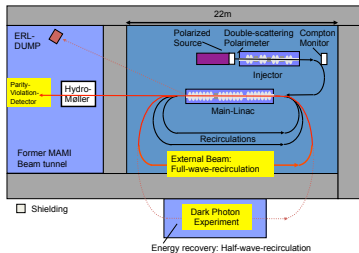
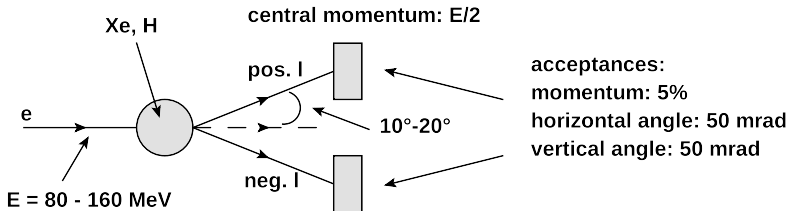
# MAMI 201X



## Future Plans at MAMI

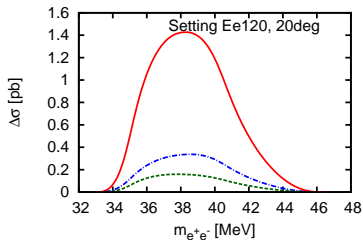
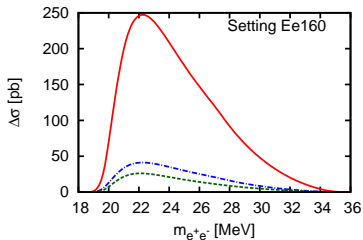
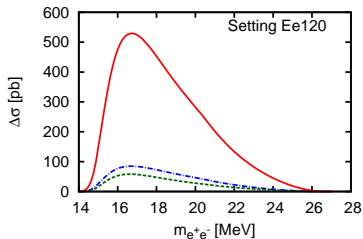
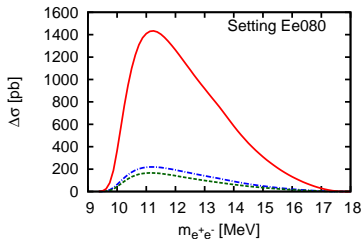
- **New run** covering the 2012 kinematics: will be done in **2013**
- **Displaced Vertex Search:** **underway**, Ph.D. project started
- Plan: Install septum magnets to reach **lower masses** with A1

# $\gamma$ Search at MESA: Feasibility Study (I)

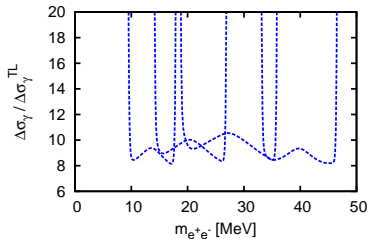


- Use two small spectrometers
- Beam energies: 80, 120, 160 MeV
- Scattering angle:  $10^\circ$  and for higher masses  $20^\circ$
- Xenon or Hydrogen as target

# $\gamma$ Search at MESA: Feasibility Study (II)

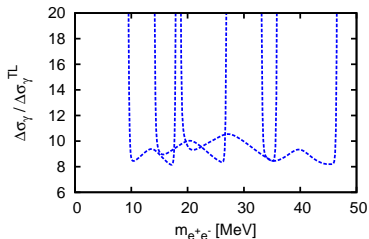


# $\gamma'$ Search at MESA: Feasibility Study (III)



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

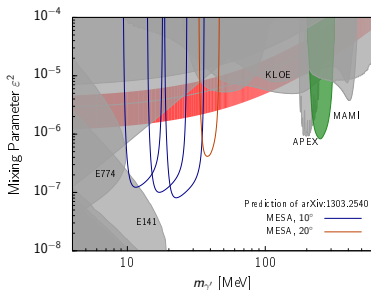
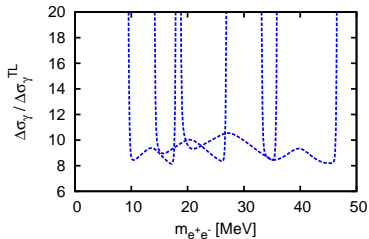
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- Suggestion: Xe target and 3 month of beam time

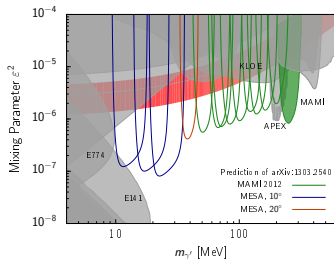


# $\gamma'$ Search at MESA: Feasibility Study (III)



- $\Delta\sigma_\gamma / \Delta\sigma_\gamma^{\text{TL}}$  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:

### Theory

Study of the underlying processes to high accuracy

Comparison with data: good agreement

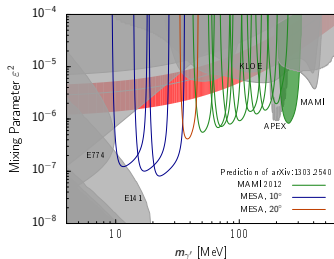
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### Experiment

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## Outlook:

### Theory

Application of calculations to other experiments (APEX, HPS, DarkLight)

Study of other channels, e.g. rare Kaon decays (TB, Vanderhaeghen, PRD87)

### Experiment

Displaced vertex search program started

Go to lower masses with A1

Measurement at MESA