LOHENGRIN
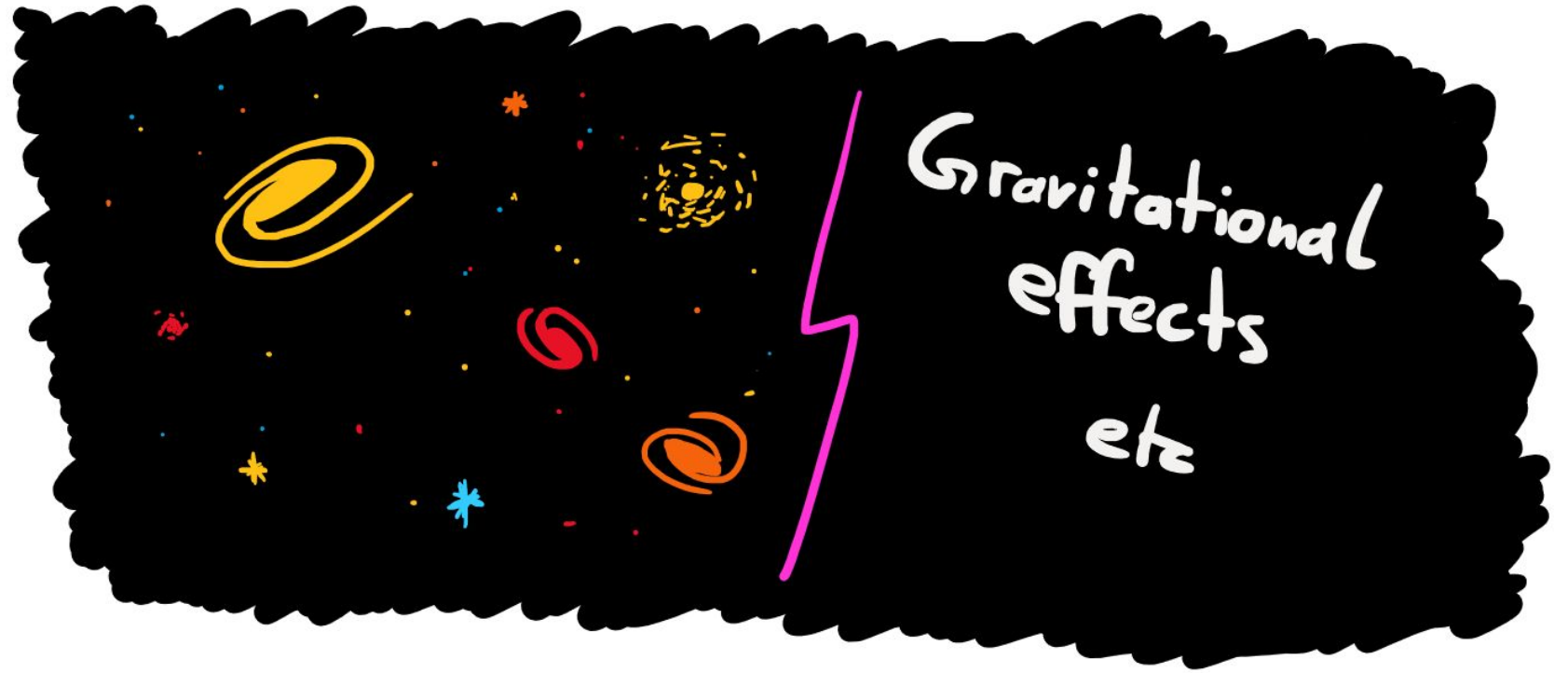
Towards unveiling hidden photons with ELSA

Martin Schürmann

BCTP, University of Bonn

Dark Matter

Dark Matter

Dark Matter

The Dark Photon

Minimal Dark Photon:

$$\mathscr{L} \supset \underbrace{-\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m_{A'}^2 A'_\mu A'^\mu}_{\substack{\text{spontaneously broken } U(1)_D \\ \text{'Dark Photon'}}} \underbrace{-\frac{\varepsilon}{2}F'_{\mu\nu}F^{\mu\nu}}_{\substack{\text{kinetic mixing} \\ \text{'portal interaction'}}} \underbrace{-g_D A'_\mu J_D^\mu}_{\substack{\text{interactions with} \\ \text{dark sector} \\ \text{matter fields}}}$$
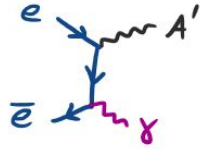
Relevant interactions:

$$\mathscr{L}_{\text{int}} \supset \sum_{\{f \mid Q_f \neq 0\}} \varepsilon Q_f A'_\mu \bar{f}\gamma^\mu f$$
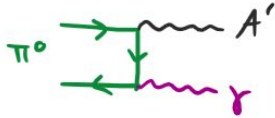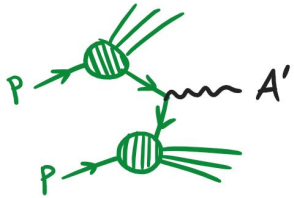
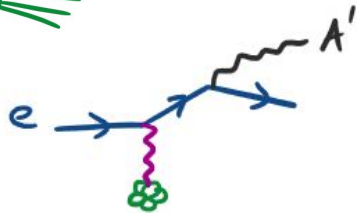# Dark Photon Searches

Production Mechanisms

Annihilation
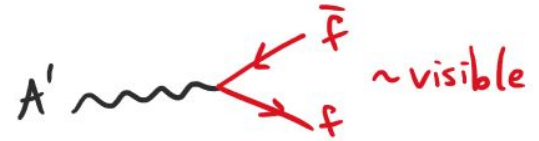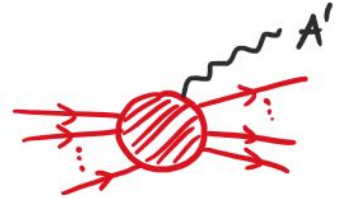
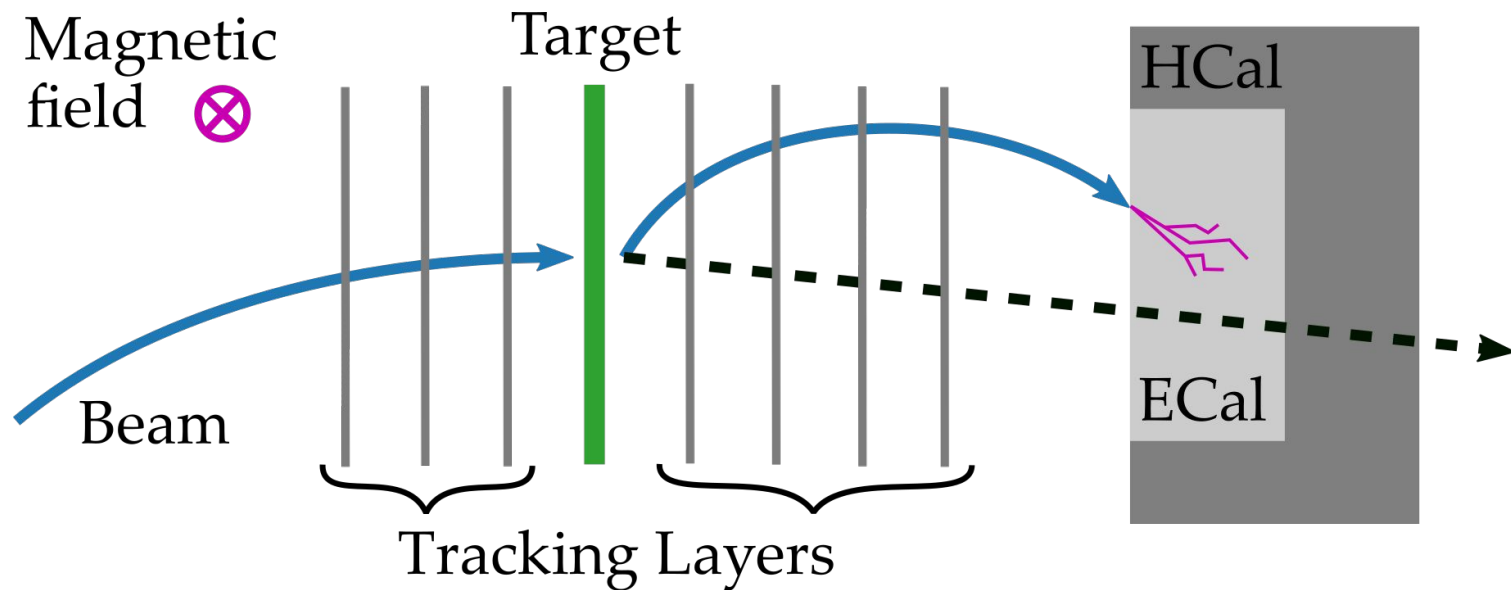Meson decays

Drell-Yan

Bremsstrahlung

Search Techniques

Bump hunts

Displaced vertices

Missing energy

LDMX

Light Dark Matter eXperiment

ELSA

ELectron Stretcher Accelerator

BGO-OD

TOF walls
drift chambers
tracking detectors
BGO calorimeter
tagger
spectrometer magnet
beam dump

hadron physics experiments

polarized target

Crystal Barrel

Mini-TAPS
tagger

Møller polarimeter

CB detector

Compton polarimeter
(for internal beam)

photon camera

beam dump

booster synchrotron
0.5 GeV - 1.6 GeV

irradiation area

EKS

LINAC 1
(20 MeV)

electron gun

DESY cavity

Mott polarimeter

electron gun

pol. e⁻ source
(50 keV)

LINAC 2
(26 MeV)

test area

extraction septa

superconducting solenoid

PETRA cavities

tune jump quadrupole

stretcher ring
0.5 GeV - 3.2 GeV

injektion septa

tune jump quadrupole

skew quadrupoles

half cell of stretcher ring

M   Q   BPM

synchrotron light diagnosis beam line

beam line for detector tests

extraction septa

Trafo

Lüftungs-anlage

Transport-schacht

■	Dipol (horizontal)
■	Dipol (vertikal)
■	Quadrupol
■	Skew-Quadrupol
■	Sextupol
■	Combined-Function-Magnet
■	Solenoid
■	Hochfrequenz

0 m   5 m   10 m   15 m

Theory Predictions

Fundamental 2 → 3 process:

Theory Predictions

Approximated 2 → 2 process:

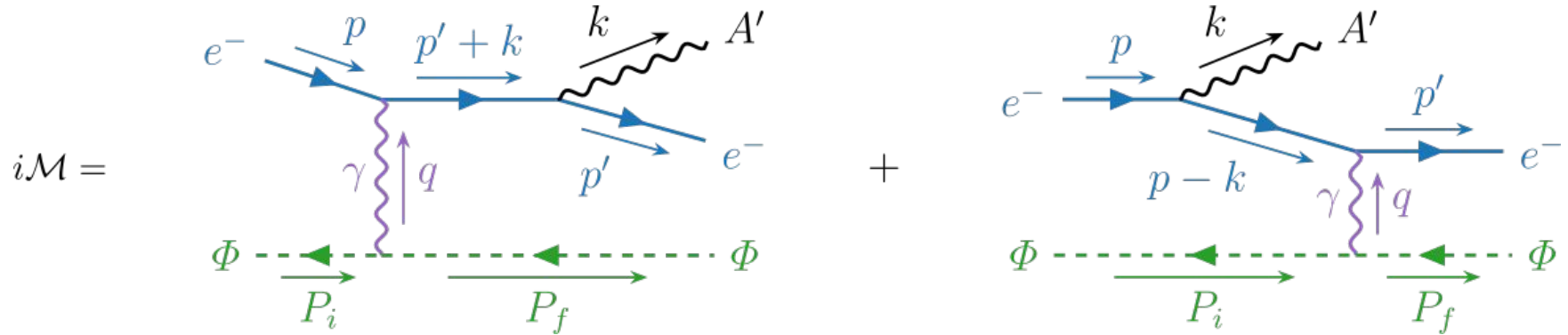$i\mathcal{M} =$ (first diagram) $+$ (second diagram)
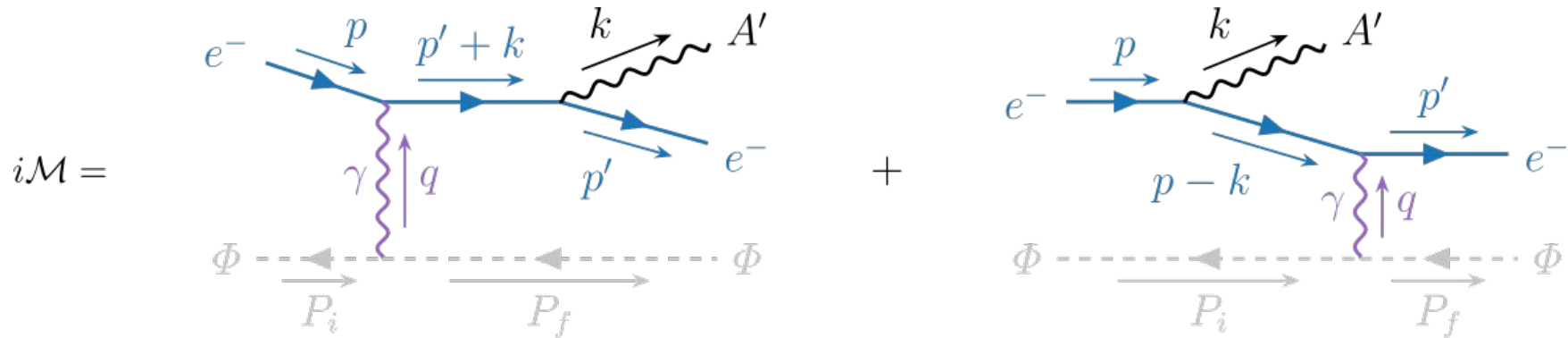
+ Analytic expressions

– $\mathcal{O}(1)$ relative errors

– Wrong kinematics

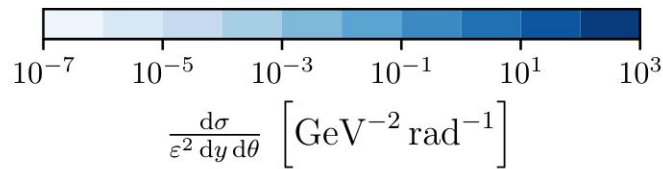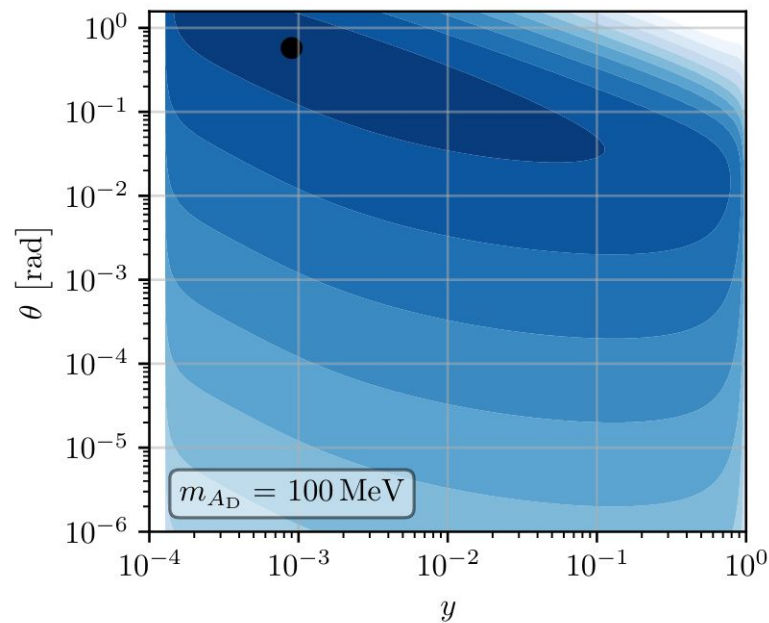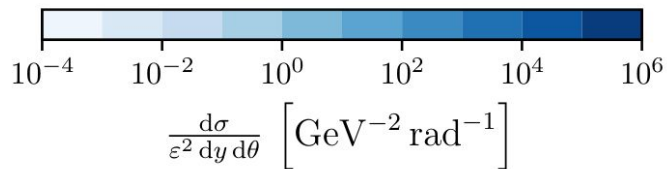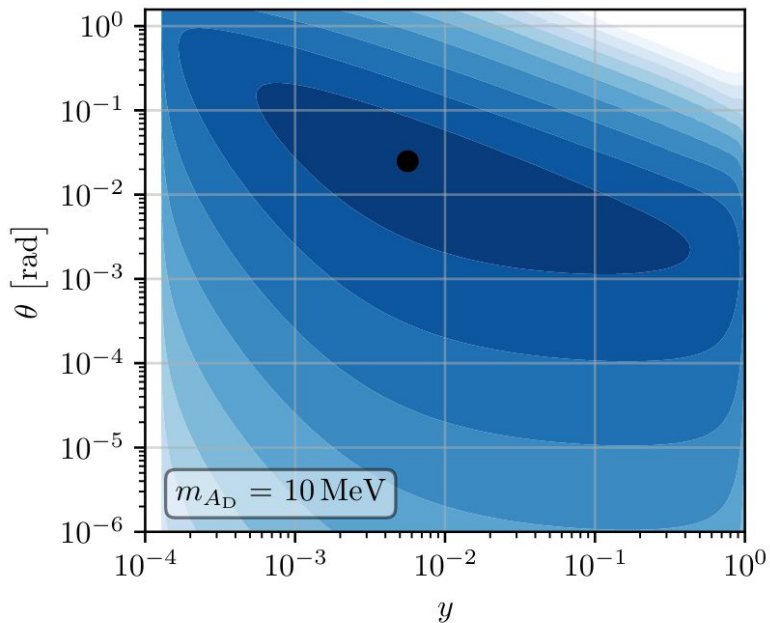# Theory Predictions

Fundamental $2 \rightarrow 3$ process:

$$i\mathcal{M} =$$

- $\Phi(x)$: scalar EFT for heavy target nucleus

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y\,\mathrm{d}\theta} = \frac{\varepsilon^2 e^6 \, E \left|\vec{p}\,'\right| \sin\theta}{1024\pi^4 M^2 |\vec{p}| V} \int_{\tau_{\min}}^{\tau_{\max}} \mathrm{d}\tau \, \frac{F(\tau)^2}{\tau^2} \int_0^{2\pi} \mathrm{d}\phi_q \, \overline{\left|\mathcal{A}_{A'}\right|^2}$$
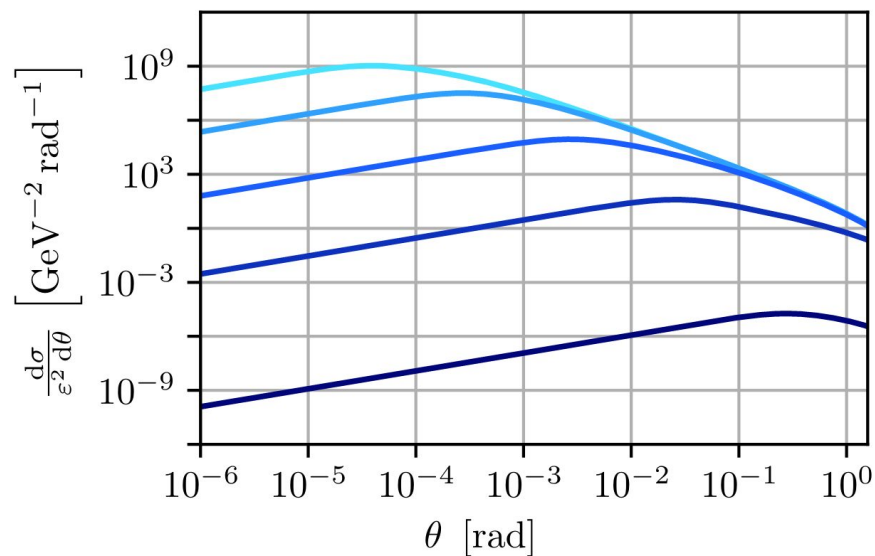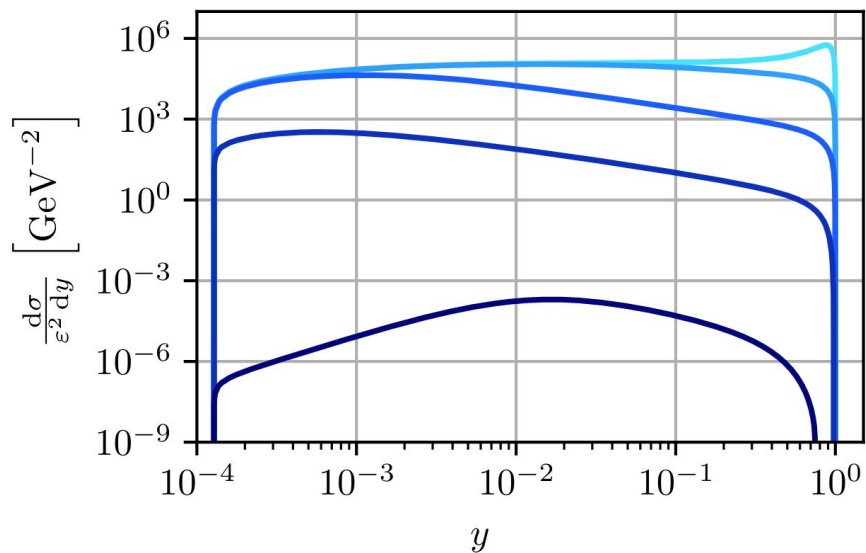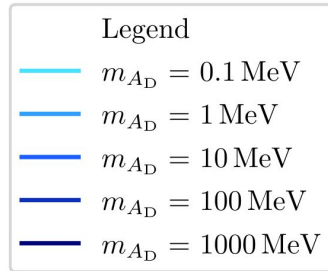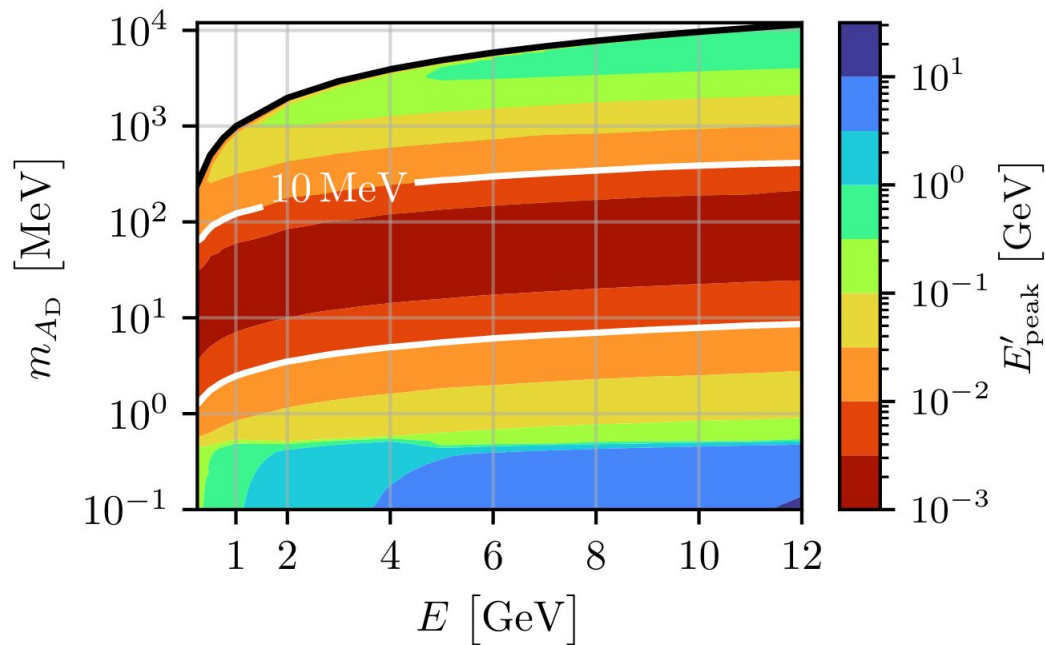
ETL Signal Characteristics

E = 4 GeV with tungsten target

ETL Signal Characteristics

$E = 4\,\text{GeV}$ with tungsten target

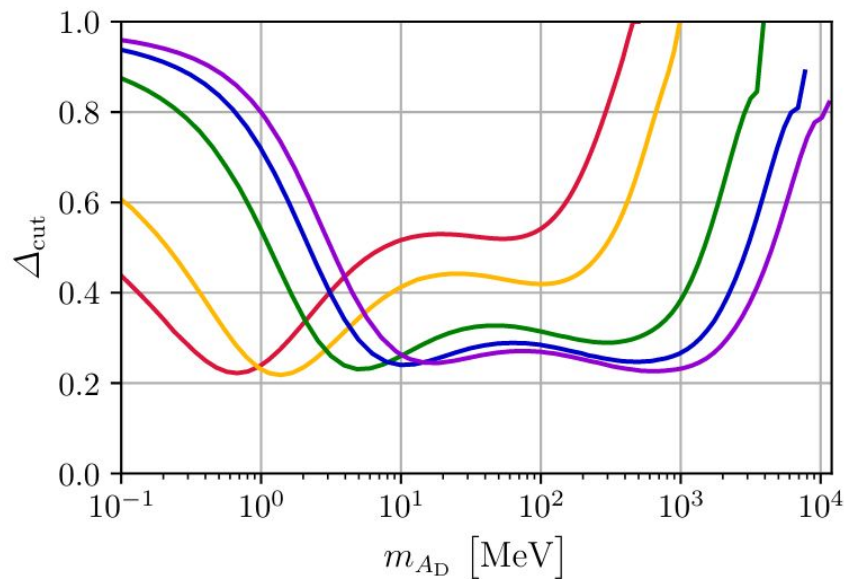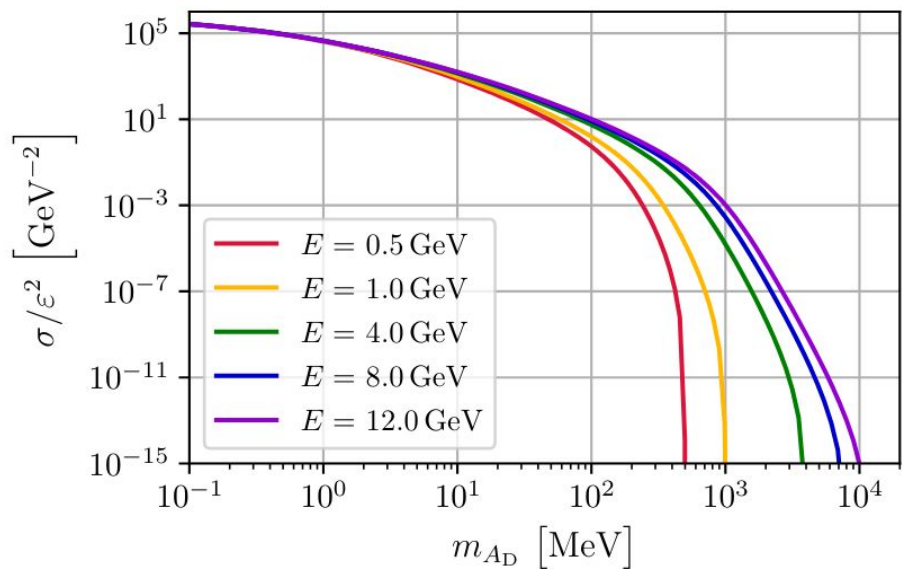# ETL Signal Characteristics

Tungsten target

ETL Signal Characteristics

Tungsten target

$$\mathcal{Q}_{\mathrm{obs}} \equiv \left\{ (y, \theta) \,\middle|\, y \in [0.0125, 0.95],\ \theta \in [10^{-3}, 0.7] \right\}$$

$$\Delta_{\mathrm{cut}} = \frac{\sigma - \sigma_{\mathrm{obs}}}{\sigma} = 1 - \frac{\sigma_{\mathrm{obs}}}{\sigma}$$
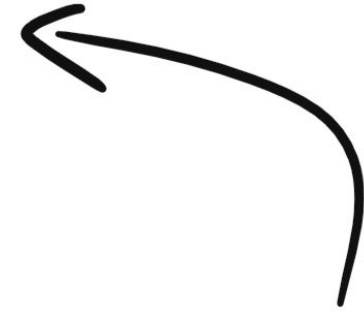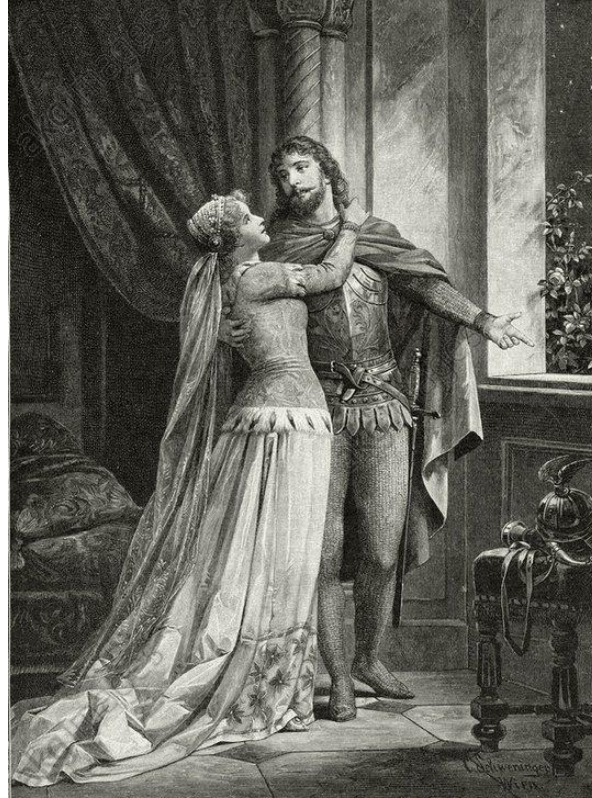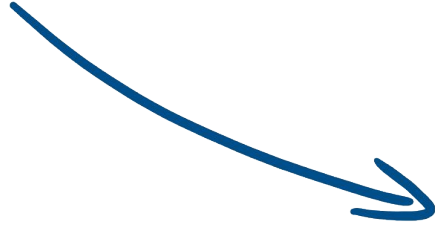
Subsequent Work

- Trajectories of signal electrons

  - Improving detector design and more accurate $\mathcal{Q}_{\mathrm{obs}}$

- Behavior of dominant background processes

  - $e^- \, \Phi \to e^- \, \Phi$
  - $e^- \, \Phi \to e^- \, \Phi \, \gamma$
  - ...

- Generic Lorentz objects: $\quad \mathscr{L}_{\mathrm{int}} = -e\varepsilon \times \begin{cases} \phi \bar{\ell}\ell & \text{scalar,} \\ i\widetilde{\phi}\bar{\ell}\gamma^5\ell & \text{pseudoscalar,} \\ A'_\mu \bar{\ell}\gamma^\mu\ell & \text{vector,} \\ B'_\mu \bar{\ell}\gamma^\mu\gamma^5\ell & \text{axialvector.} \end{cases}$

- ...

Why 'LOHENGRIN'?

ELSA

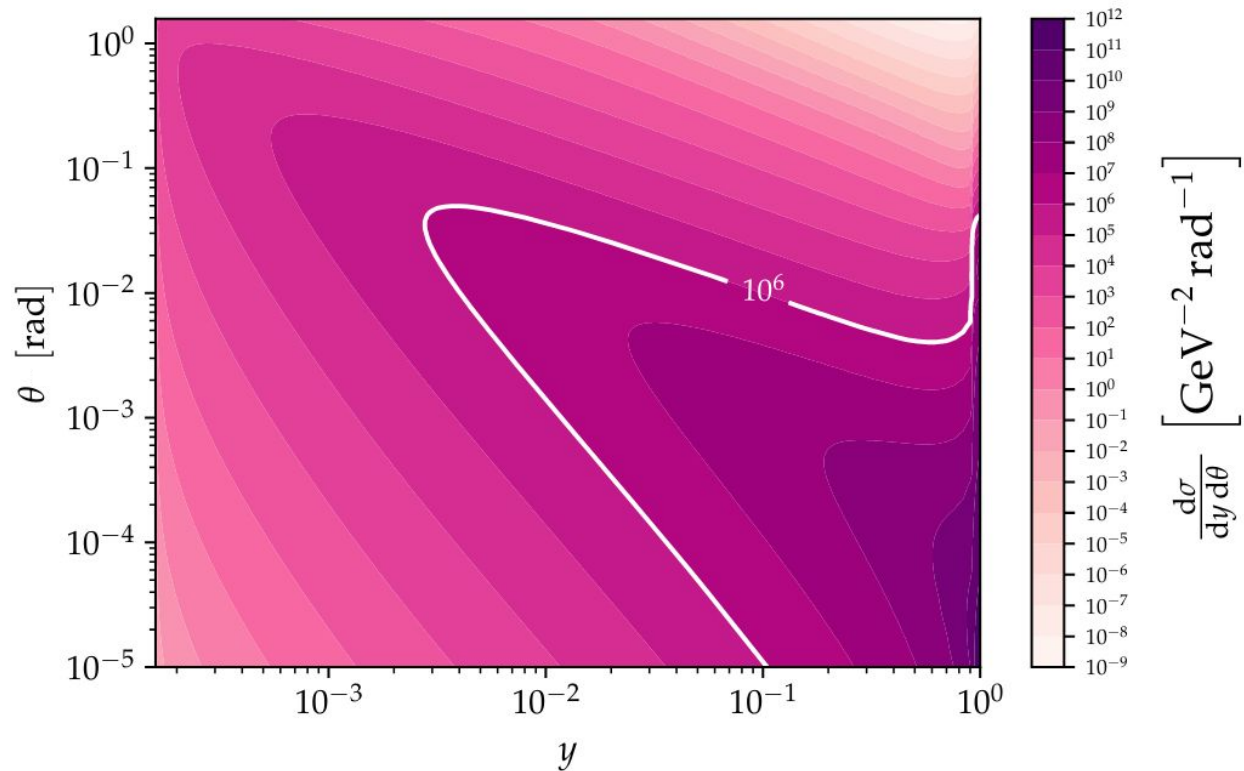LOHENGRIN

Questions?

The Dark Photon

Dark Photon:

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m^2_{A'}A'_\mu A'^\mu - \frac{\sin\varepsilon_Y}{2}F'_{\mu\nu}B^{\mu\nu} - g_D A'_\mu J^\mu_D$$

Relevant interactions:
$$\mathcal{L}_{\text{int}} = -A^D_\mu \left(\sum_f g_f^{A_D} \bar{f}\gamma^\mu f + g_D^{A_D} J^\mu_D \right)$$

$$g_{\ell_L}^{A_D} = \frac{e\varepsilon_Y}{2\cos\theta_W}\frac{2m^2_Z\cos^2\theta_W - m^2_{A'}}{m^2_Z - m^2_{A'}} \qquad \text{and} \qquad g_{\ell_R}^{A_D} = \frac{e\varepsilon_Y}{\cos\theta_W}\left(1 - \frac{m^2_Z\sin^2\theta_W}{m^2_Z - m^2_{A'}}\right)$$

ETL QED Background

$E = 4$ GeV with tungsten target

ETL Signal Characteristics

$E = 4$ GeV with tungsten target