Dark photon search feasibility study

Simon Taylor/JLab

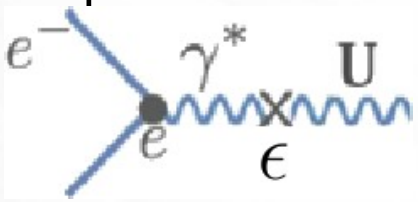
- Introduction to U-boson physics
  - Current constraints on mass and coupling to SM matter
  - η decay as a probe
- Simulation and reconstruction of $\eta \rightarrow \gamma e^+ e^-$ with GlueX
  - Electron/positron identification
  - Full event reconstruction
  - Kinematic fitting
  - Experimental sensitivity

Dark photons

- Theories postulate “dark” force beyond Standard Model (SM)
  - U-boson (“dark photon”)= gauge boson of “dark” $U(1)_d$
  - Ordinary matter is neutral under this gauge group

- Lagrangian: additional “kinetic mixing” term between SM photons and dark photons

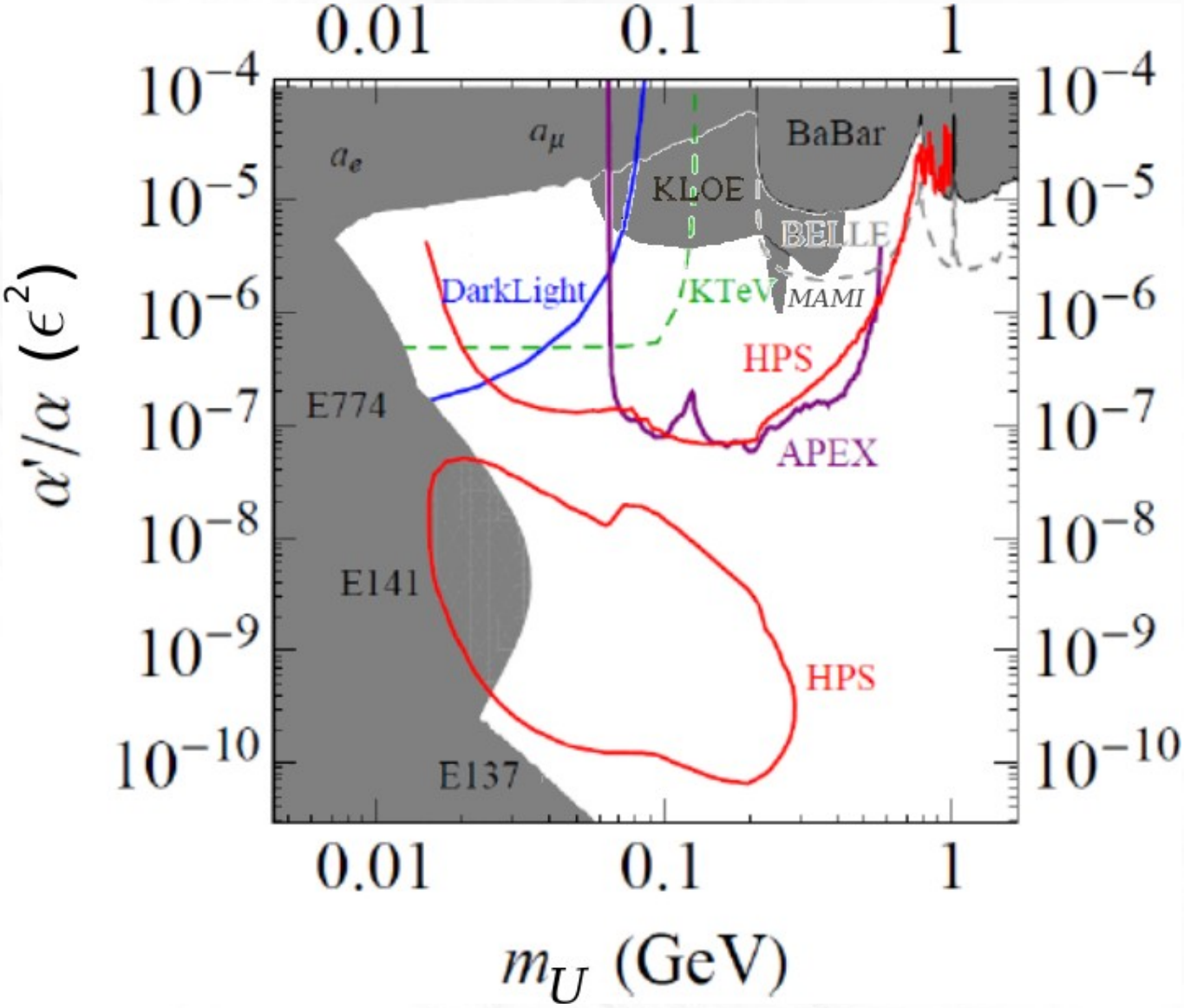
$$\mathcal{L}_{\mathrm{kin-mix}} = -2\epsilon F_d^{\mu\nu} F_{\mu\nu}.$$



  - $\epsilon \leq 10^{-3}$, assuming originates from loops of heavy particles

- Expected decay: $U \rightarrow \ell^+\ell^-$
- Spontaneous symmetry breaking: $M_U \sim 1\ \mathrm{MeV} - 1\ \mathrm{GeV}$

U-boson constraints



Meson decays as dark photon probes

Reece & Wang, 2010

$$\frac{\mathrm{S}}{\sqrt{\mathrm{B}}} \approx \sqrt{n_X}\frac{\epsilon^2 \times \mathrm{BR}(X \to Y + \gamma) \times \mathrm{BR}(U \to \ell^+\ell^-)}{\sqrt{\mathrm{BR}(X \to Y + \gamma^* \to Y + \ell^+\ell^-)}}\sqrt{\frac{m_U}{\delta m}\log\left(\frac{m_X - m_Y}{2m_\ell}\right)}.$$

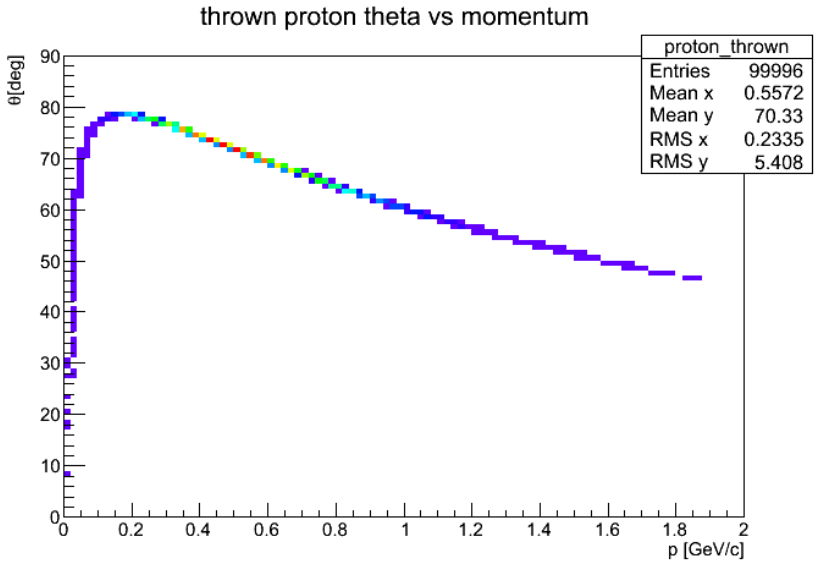
S/√B =5

$X \to YU$	n_X	$m_X - m_Y$ (MeV)	$\mathrm{BR}(X \to Y + \gamma)$	$\mathrm{BR}(X \to Y + \ell^+\ell^-)$	$\epsilon \leq$
$\eta \to \gamma U$	$n_\eta \sim 10^7$	547	$2 \times 39.8\%$	6×10^{-4}	2×10^{-3}
$\omega \to \pi^0 U$	$n_\omega \sim 10^7$	648	8.9%	7.7×10^{-4}	5×10^{-3}
$\phi \to \eta U$	$n_\phi \sim 10^{10}$	472	1.3%	1.15×10^{-4}	1×10^{-3}
$K_L^0 \to \gamma U$	$n_{K_L^0} \sim 10^{11}$	497	$2 \times (5.5 \times 10^{-4})$	9.5×10^{-6}	2×10^{-3}
$K^+ \to \pi^+ U$	$n_{K^+} \sim 10^{10}$	354	-	2.88×10^{-7}	7×10^{-3}
$K^+ \to \mu^+ \nu U$	$n_{K^+} \sim 10^{10}$	392	6.2×10^{-3}	$7 \times 10^{-8\,a}$	2×10^{-3}
$K^+ \to e^+ \nu U$	$n_{K^+} \sim 10^{10}$	496	1.5×10^{-5}	2.5×10^{-8}	7×10^{-3}

Simulation of $\eta \rightarrow \gamma e^+ e^-$ events

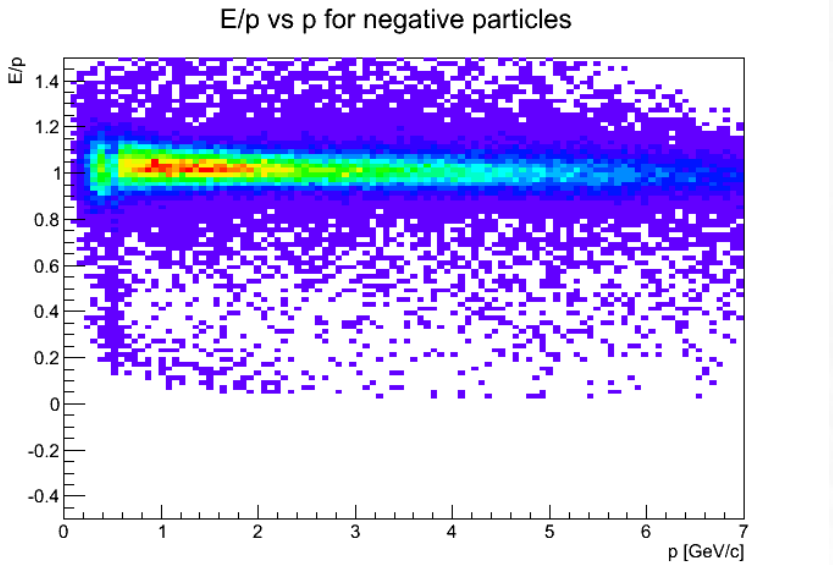
- Goal: study feasibility of U-boson (dark photon) discovery experiment with GlueX detector
  - $\eta \rightarrow \gamma U$, $U \rightarrow e^+ e^-$
  - Largest, non-reducible background = η Dalitz decay
- Generated 100,000 Dalitz-like events
  - $\gamma p \rightarrow \eta p$, E_γ =8.4-9.0 GeV
  - Laget production model
  - 3-body phase space for decay

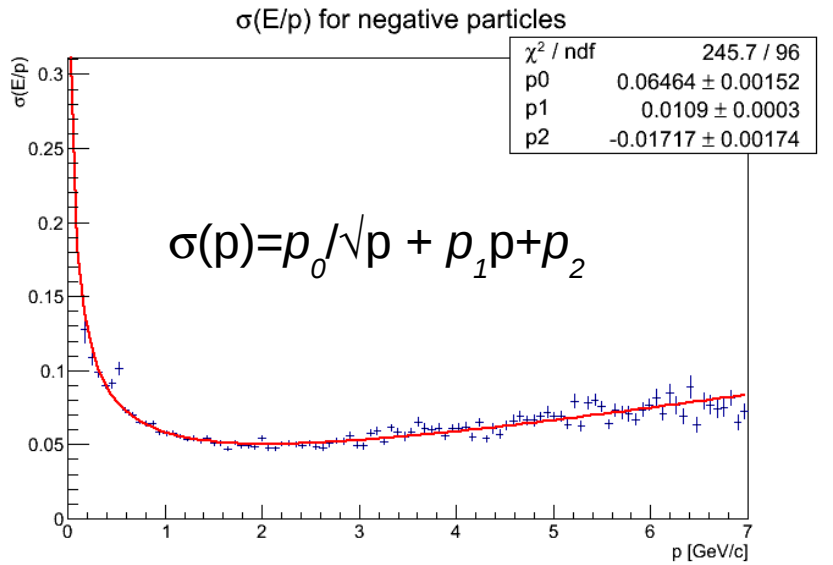
Protons head toward CDC, e^+,e^- both in FDC...

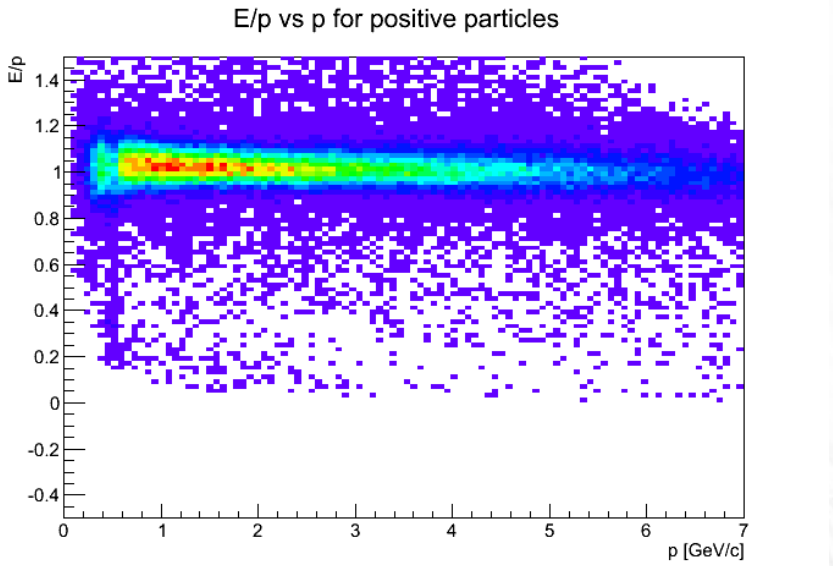


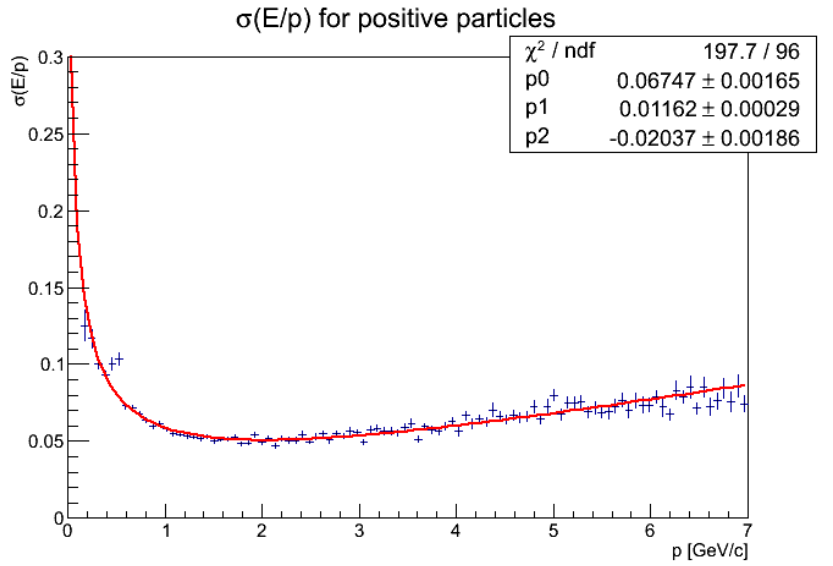
Electron/positron identification

- Measure E/p ratio using shower energy in FCAL and momentum in FDC



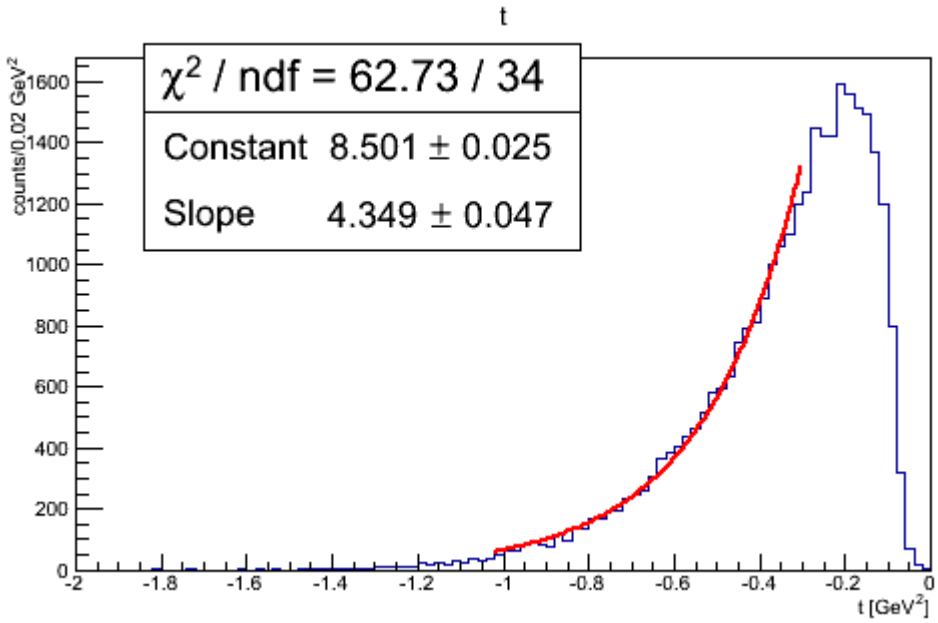


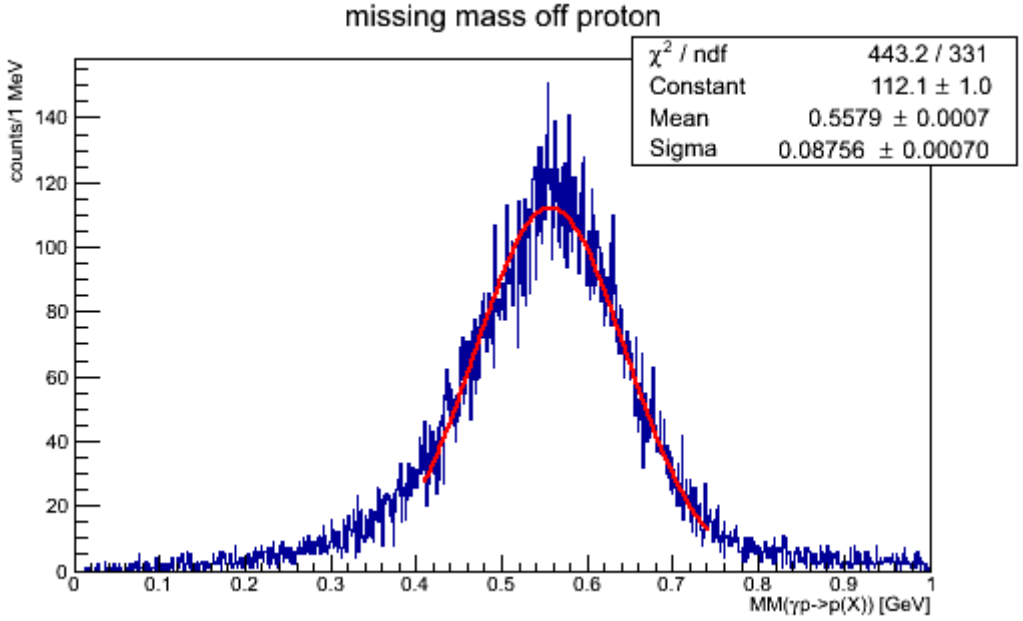


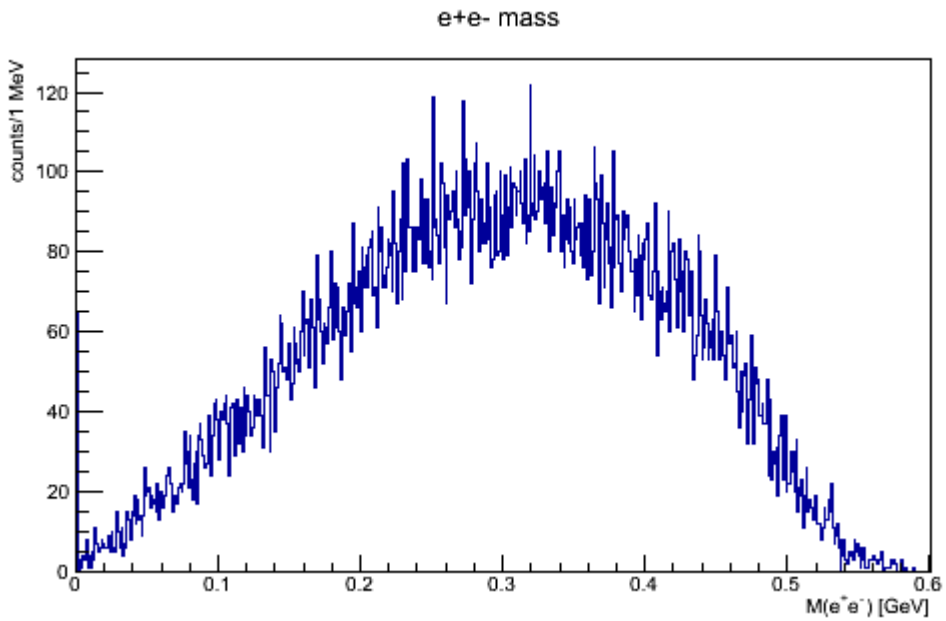


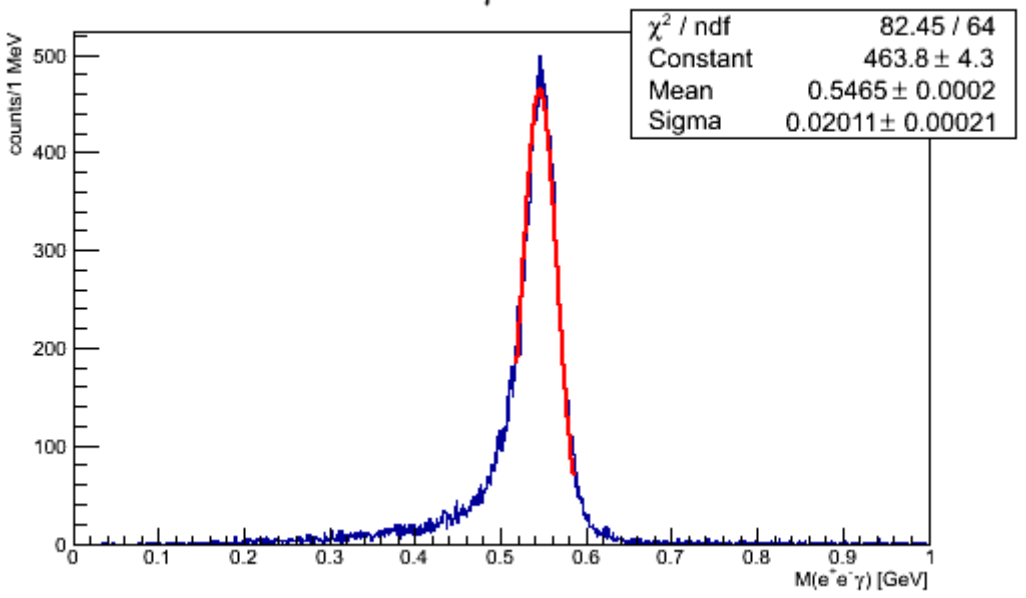
Full event reconstruction

- Plugin using ANALYSIS library
- Topology: e^+, e^-, one photon, recoil proton



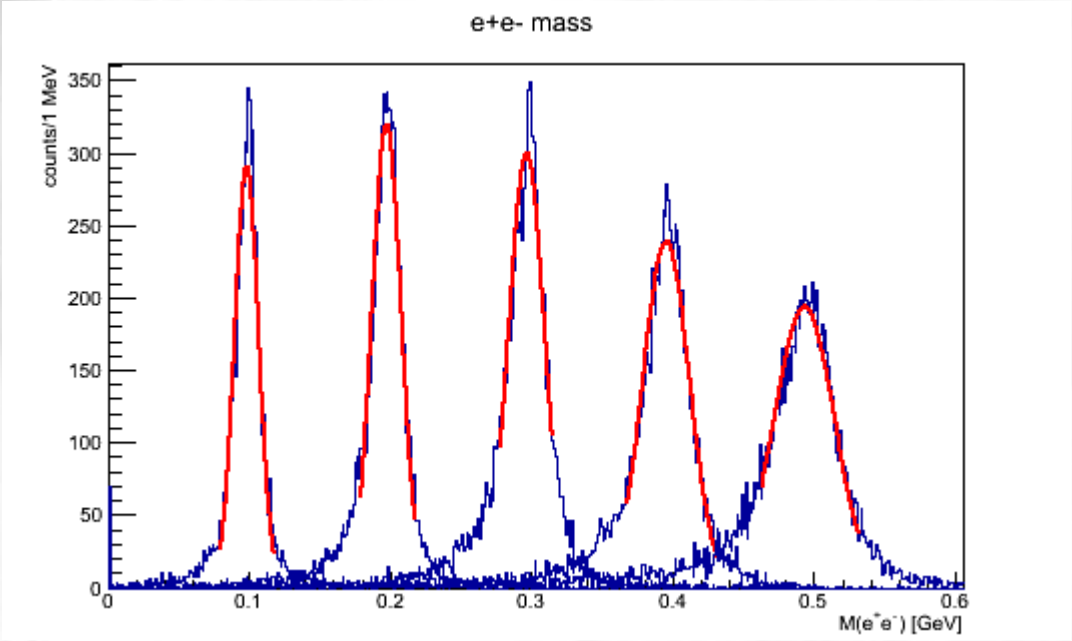


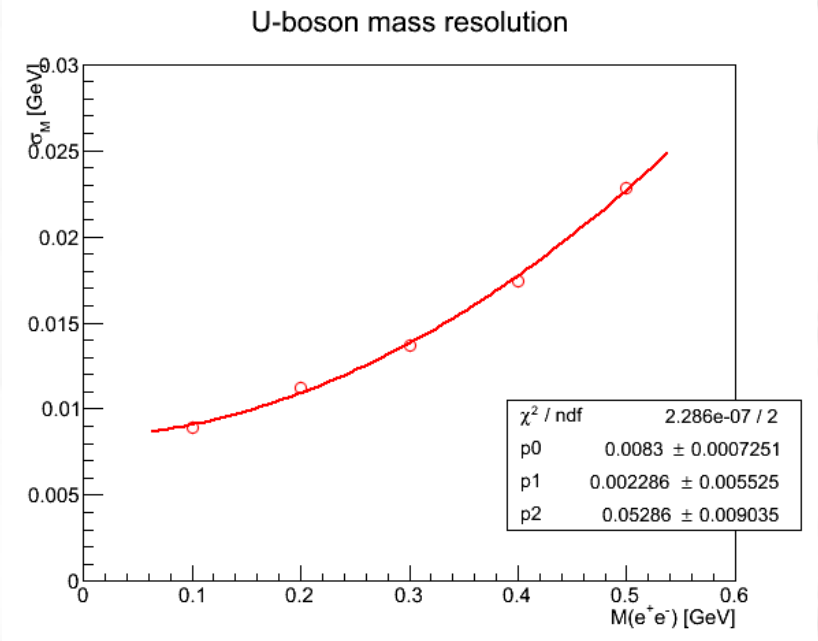




U-boson mass scan

- Zero-width, using 9 GeV photon beam

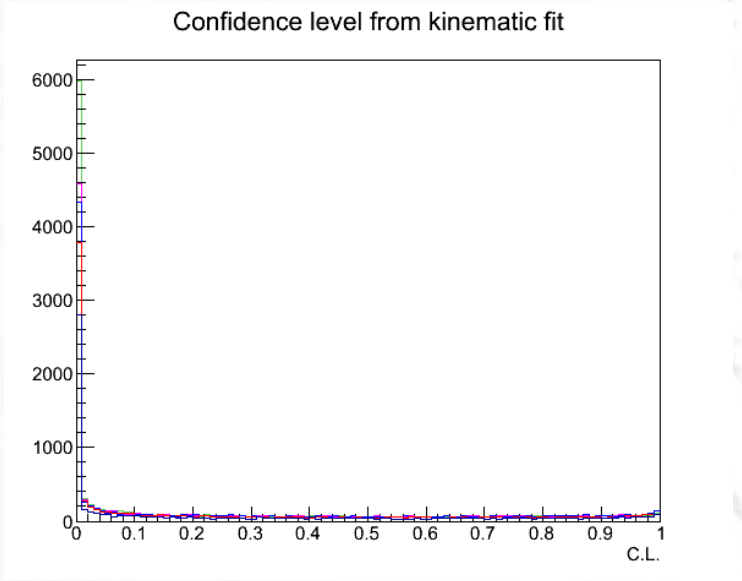


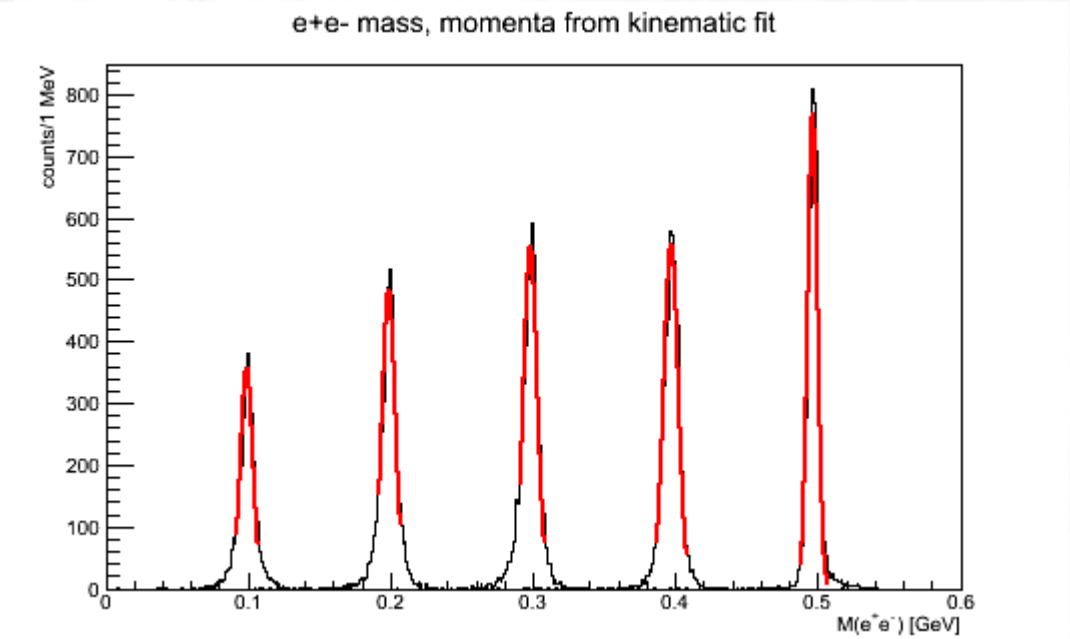


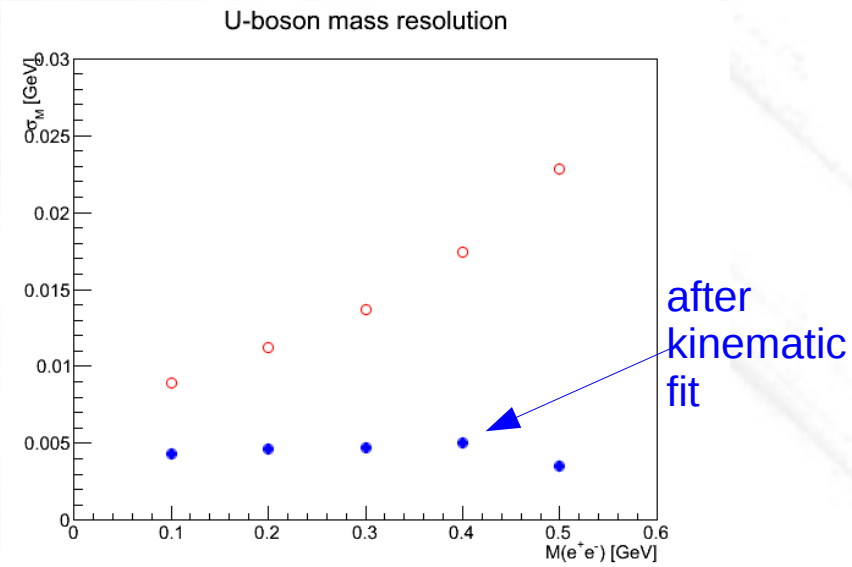
Kinematic fitting

- Energy + momentum conservation
- pη primary vertex
- $e^+e^-\gamma$ vertex

Require CL>0.01

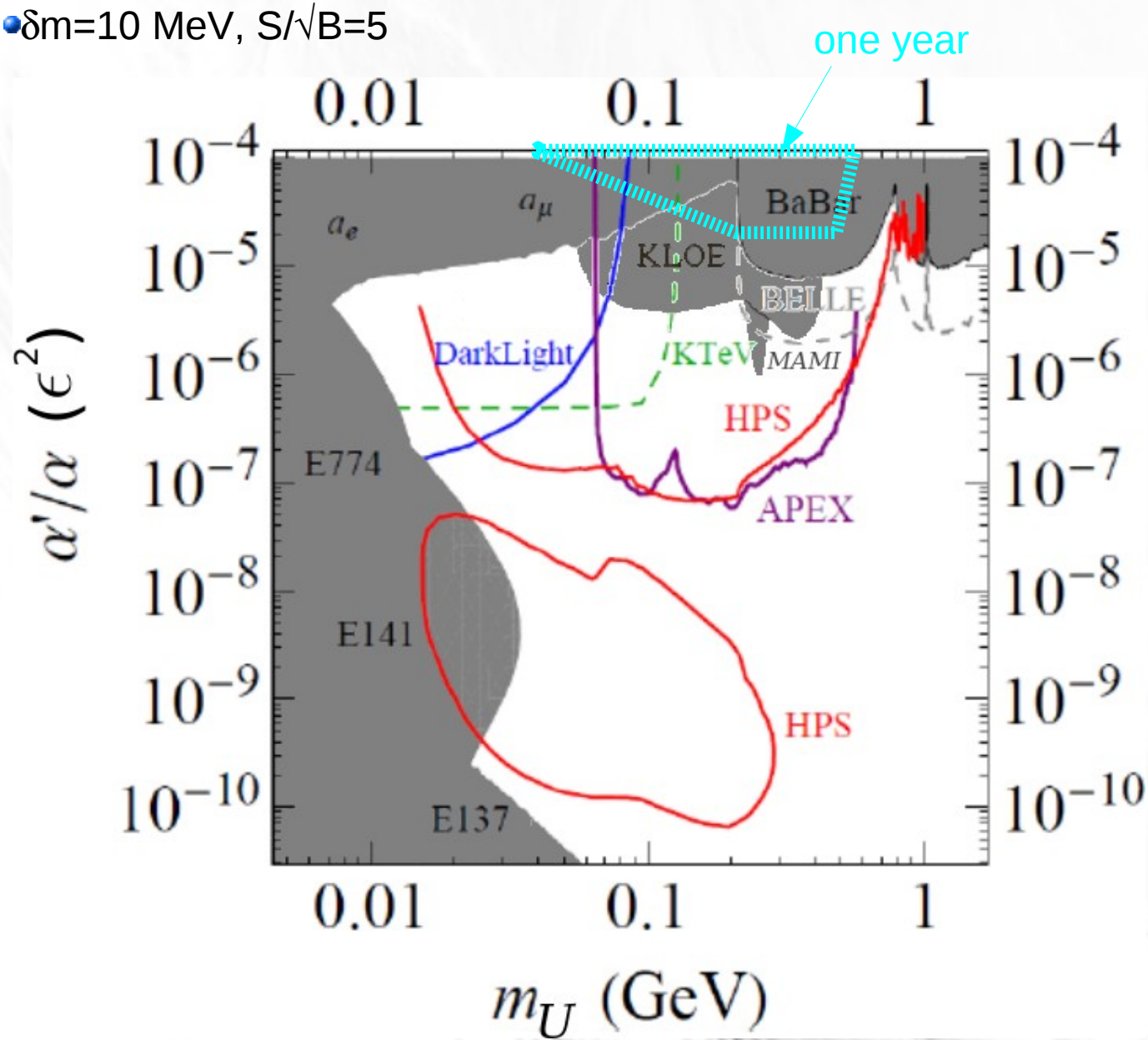






Experimental sensitivity

- Number of η's produced ~3×10^7 /year (gold radiator, η proposal)
- Acceptance+reconstruction efficiency ~ 0.18 @ E_γ~9 GeV
- δm=10 MeV, S/√B=5



Conclusion

- Identification of the final state is feasible
- ... but after a year's worth of running, we will not have the sensitivity to probe the parts of the ϵ^2 vs M_U space that have not already been excluded...