RECENT HIDDEN SECTOR SEARCHES AT *BABAR*

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on behalf of the *BABAR* Collaboration

HARVEY MUDD COLLEGE

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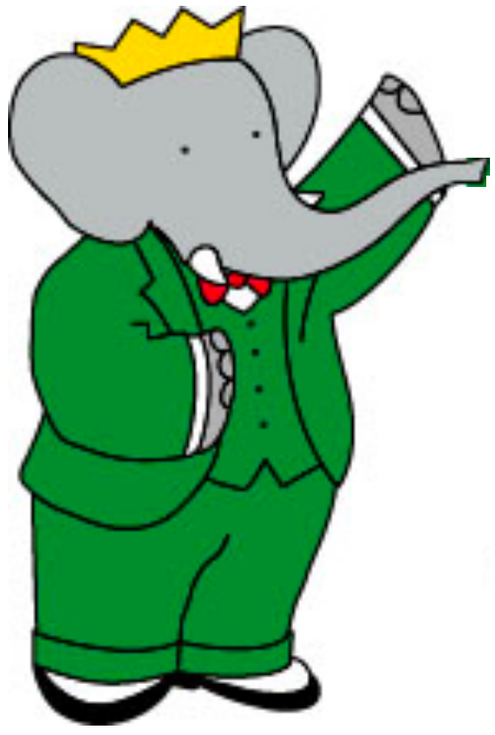
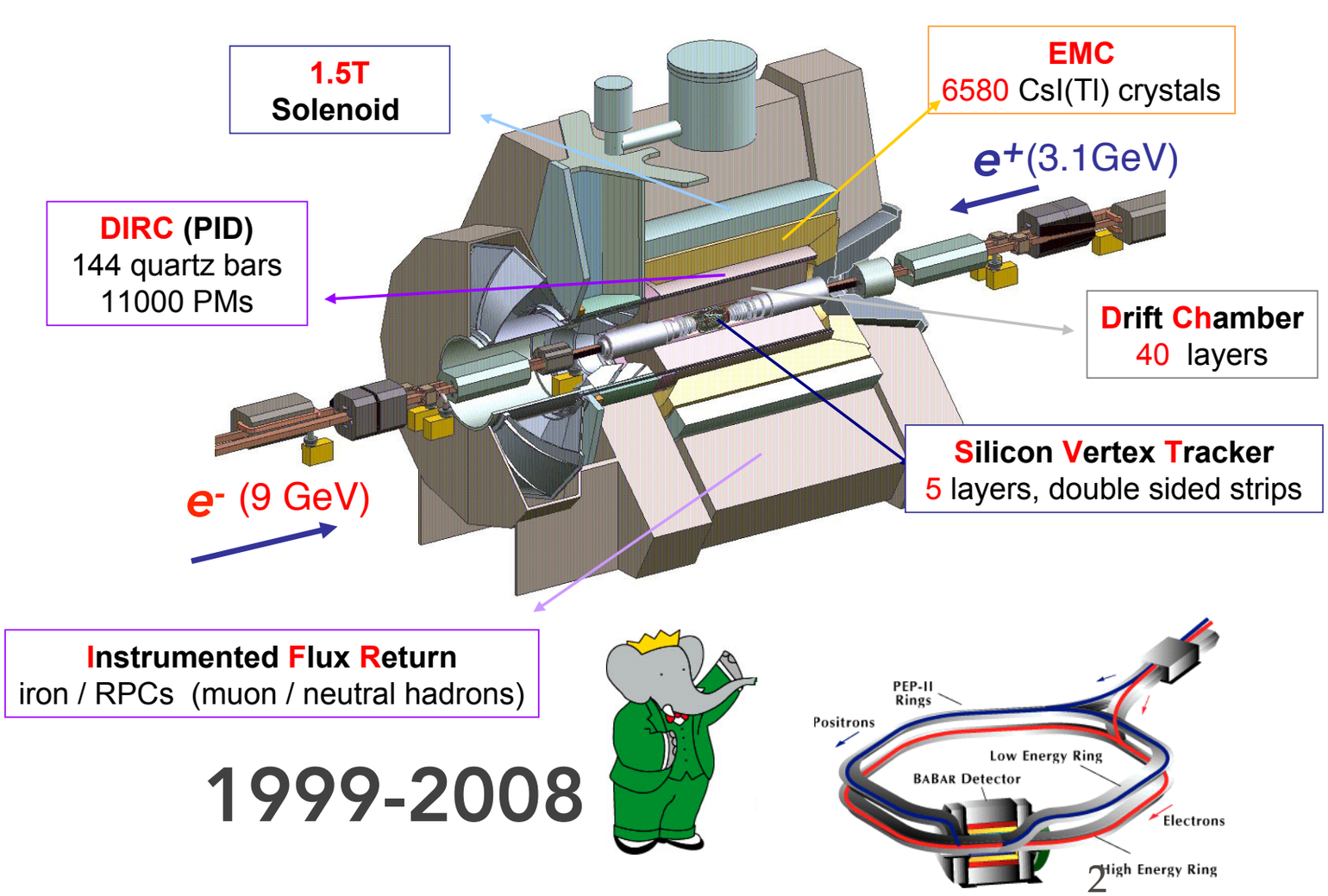


HIDDEN SECTORS @ B-FACTORIES

- For viable thermal dark matter at the GeV scale, need **new mediators** between DM and SM (Lee, Weinberg 1977)
- Phenomena of hidden sectors can be much richer than WIMP models!

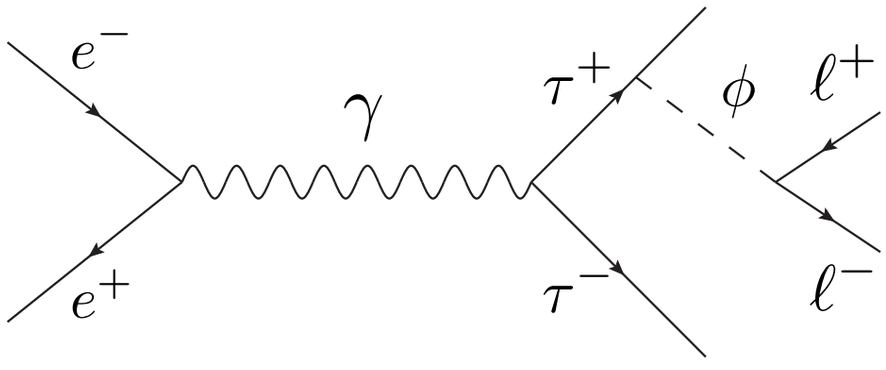


- *B*-factories designed to study *b* quarks at $\sqrt{s} = 10.58\ \mathrm{GeV}$
- High luminosity, low background compared to hadron colliders

DARK LEPTOPHILIC SCALAR

- Strong constraints on dark photons and dark Higgs bosons motivates searches for non-minimal mediator couplings
- **Dark leptophilic scalar:** scalar with mass-proportional coupling to leptons, suppressed coupling to quarks. Muon *g*-2 still viable!

Batell *et al.*, 1606.04943 [PRD]

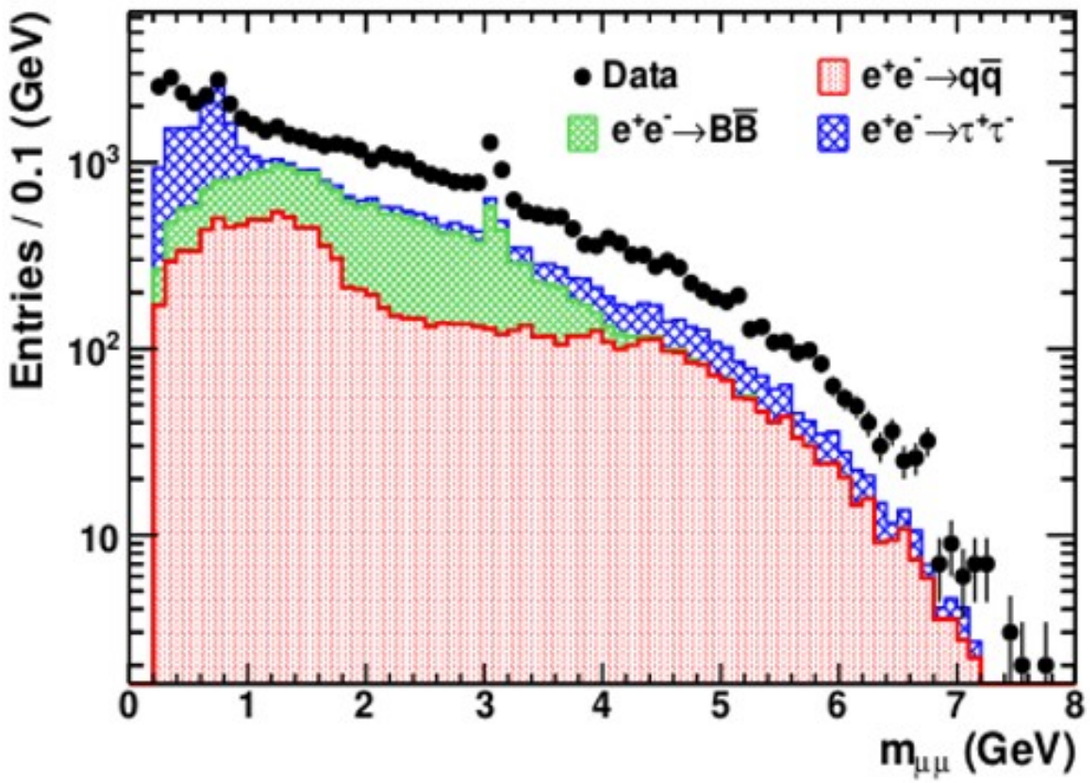


- Scalar produced in association with taus, decays to heaviest accessible lepton

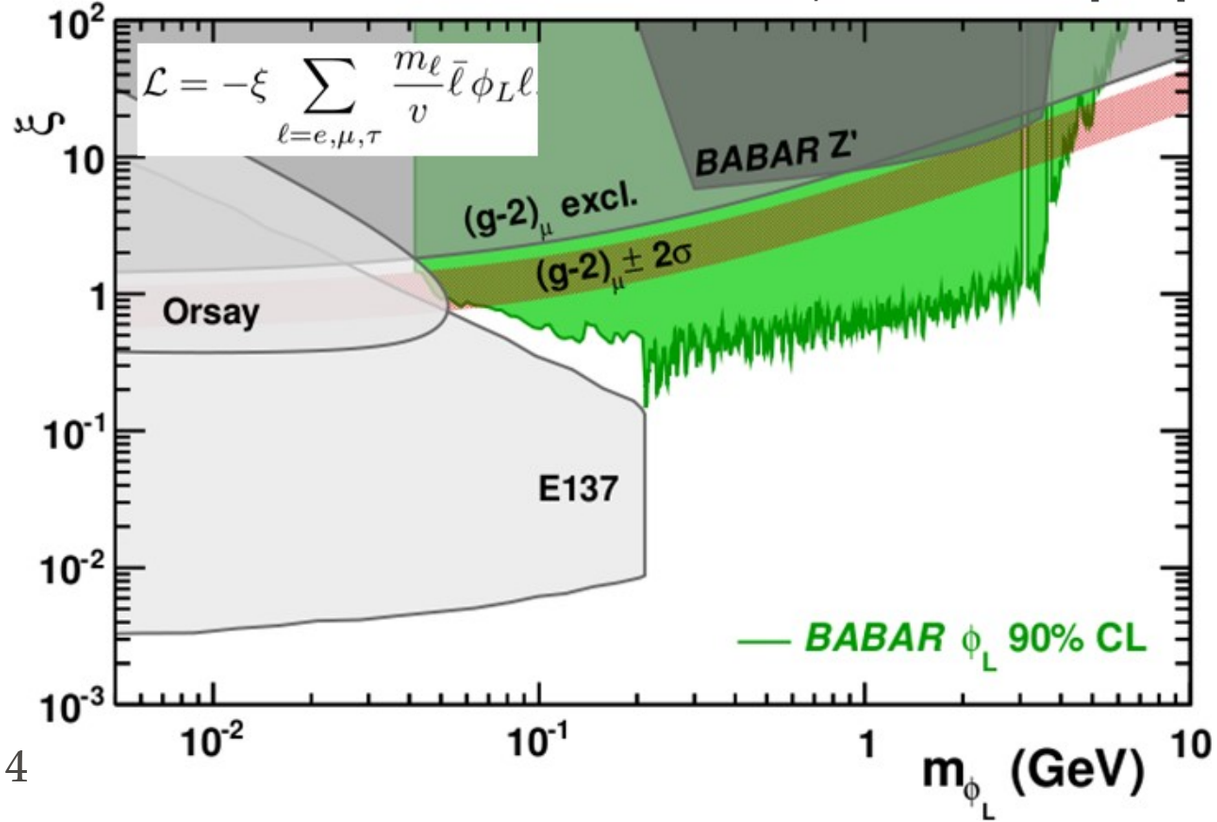
- We reconstruct dilepton resonance in association with two single-track tau decays, train BDTs to separate signal from background

DARK LEPTOPHILIC SCALAR

- Do fits with narrow signal resonance template and continuum background (and, where relevant, peaks for π^0, J/ψ, $\psi(2S)$)
- No significant signal, we set 90% CL limits on the cross section and leptophilic scalar coupling constant
- Significantly improve on existing limits, close almost all remaining muon *g*-2 parameter space at low mass



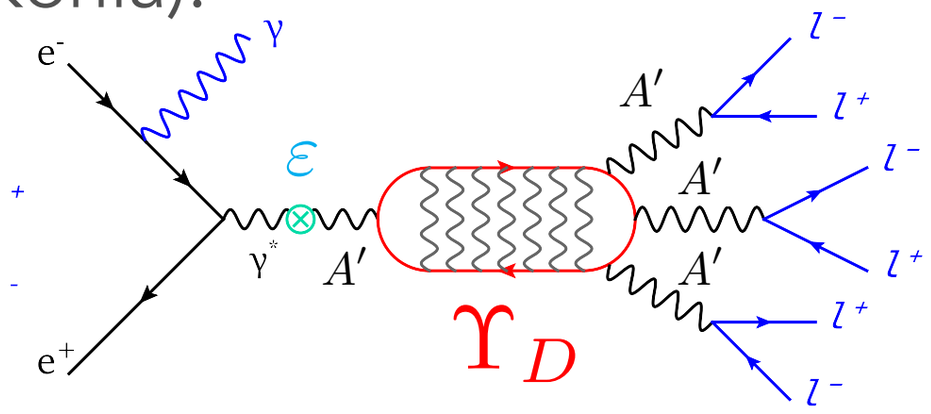
BABAR, 2005.01885 [PRL]



DM BOUND STATE: DARKONIUM

- Consider a DM coupled to dark photon: if coupling in hidden sector is large, can form DM bound states (darkonia)!

- We search for the lightest vector darkonium, Υ_D, which decays into 3 dark photons, A'



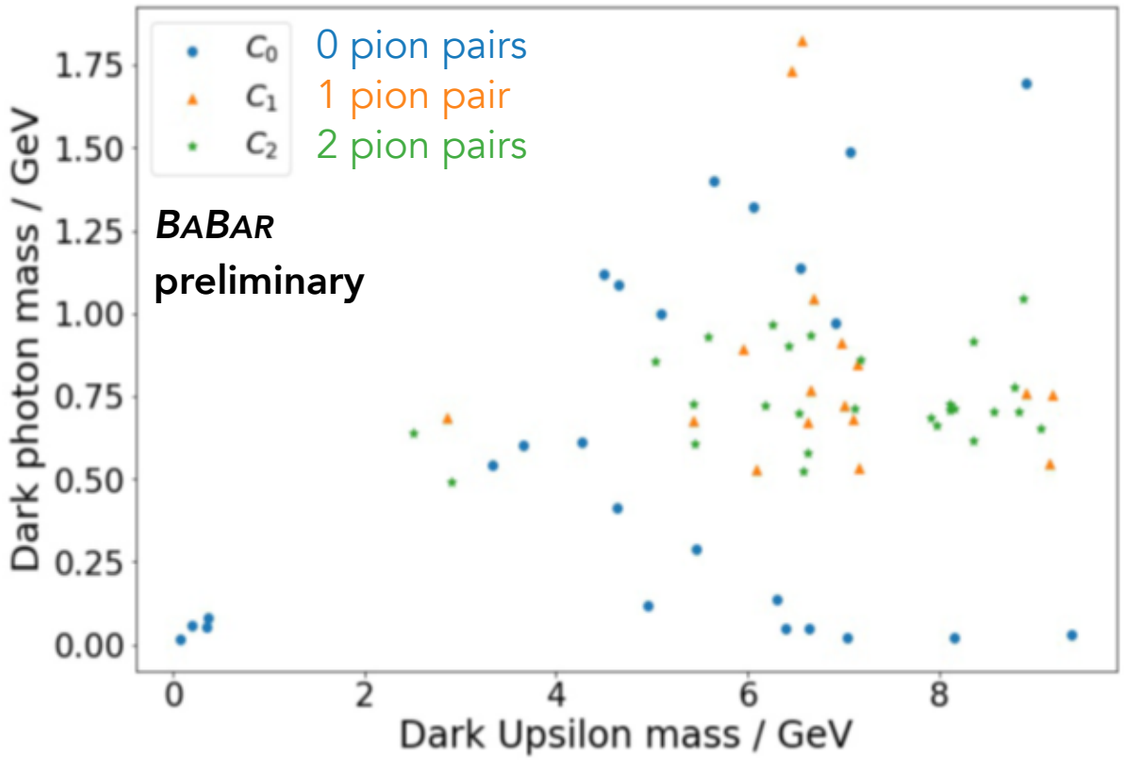
- We reconstruct dark photon decays into electron, muon, or pion pairs of similar mass, with at least one lepton pair

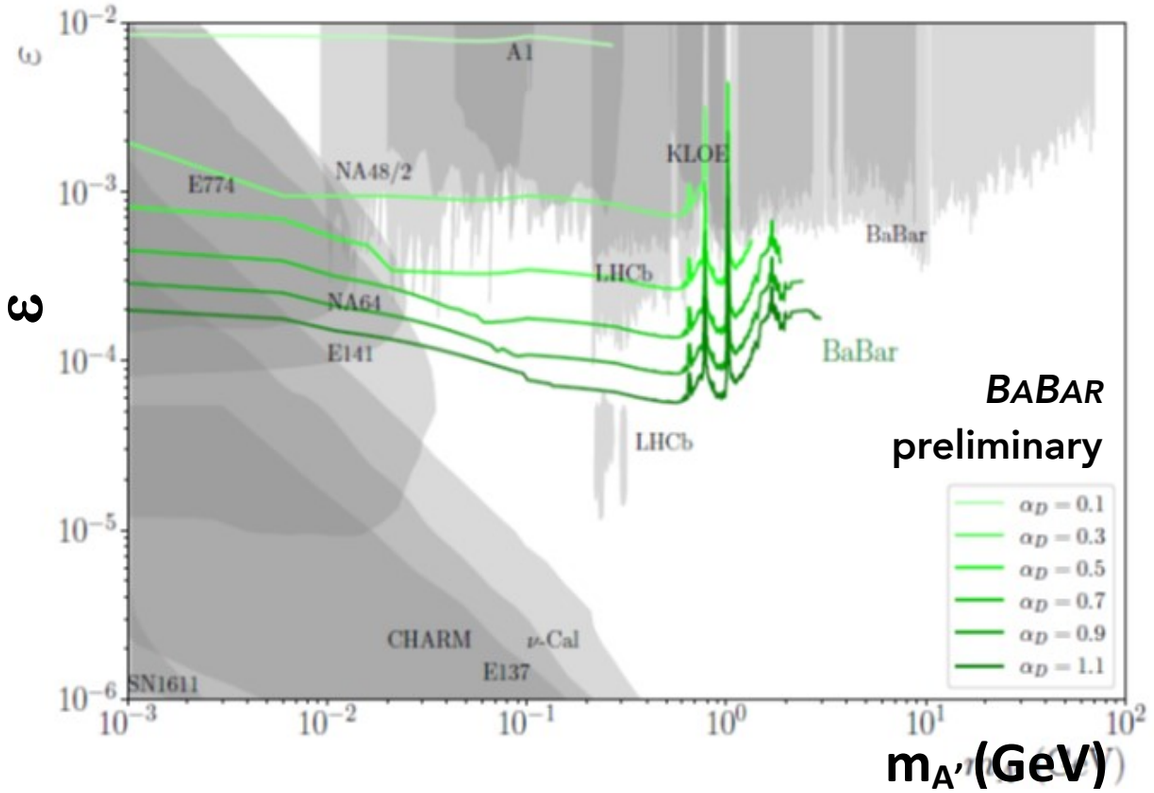
- Reconstructed Υ_D must be consistent with recoil off massless photon, should see photon if emitted in detector acceptance

- Train MVAs to further improve signal purity for different final states

DARKONIUM RESULTS

- Consider window around each mass in the $\Upsilon_D - A'$ plane, estimate background from adjacent windows

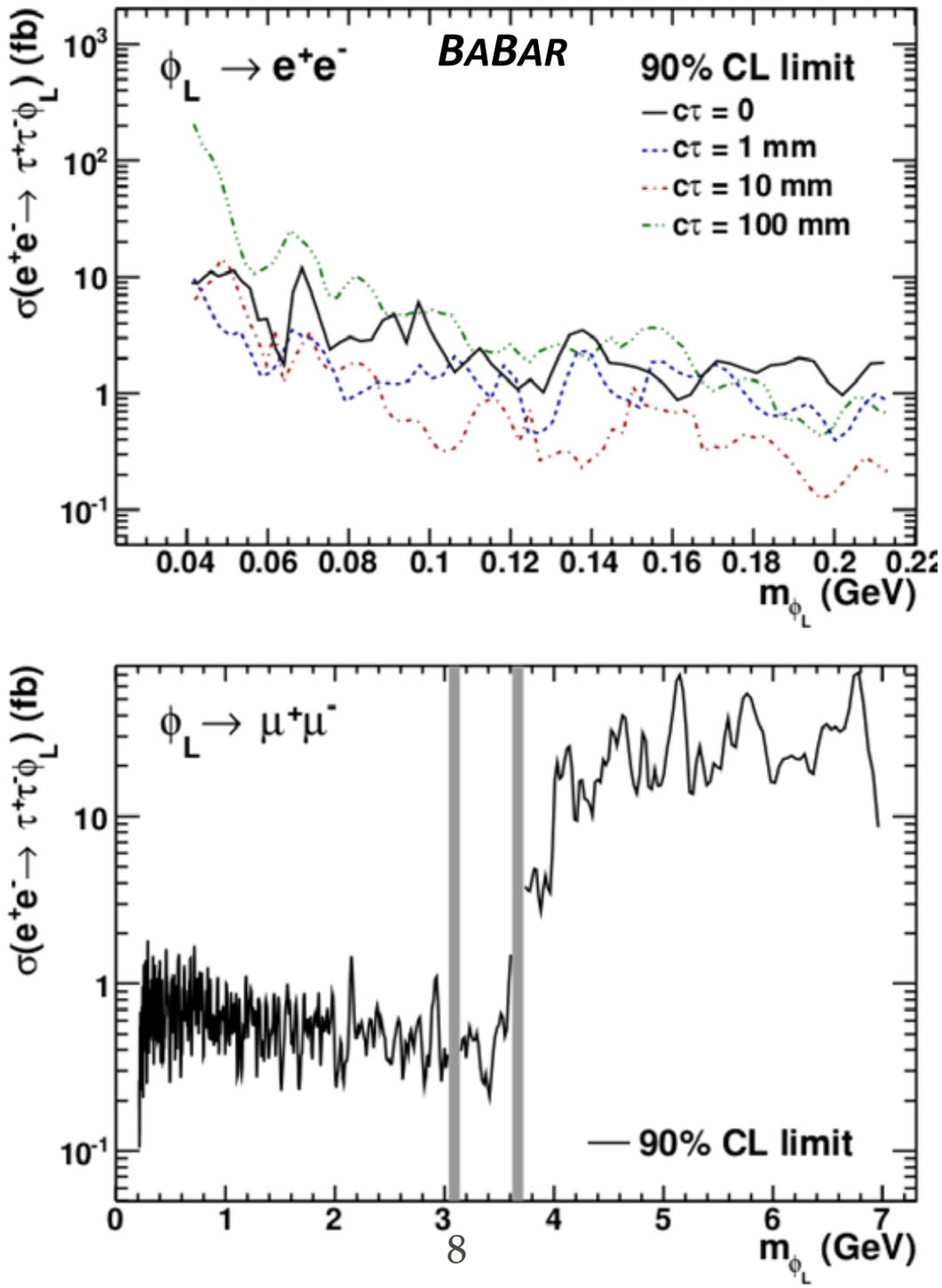




- No significant signal, set 90% CL limit on kinetic mixing ε as function of DM coupling
- Improve on current constraints!

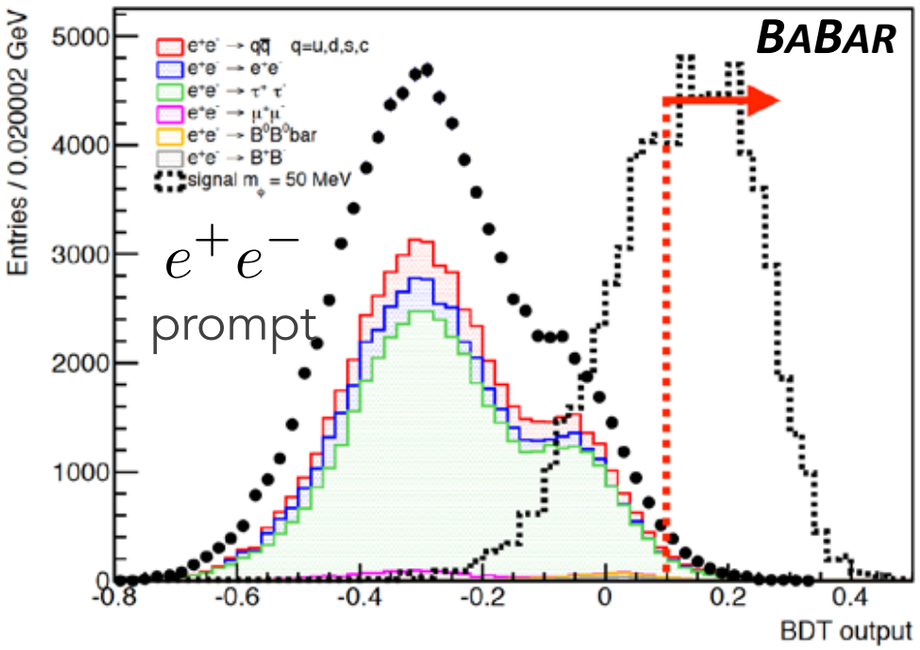
BACKUP SLIDES

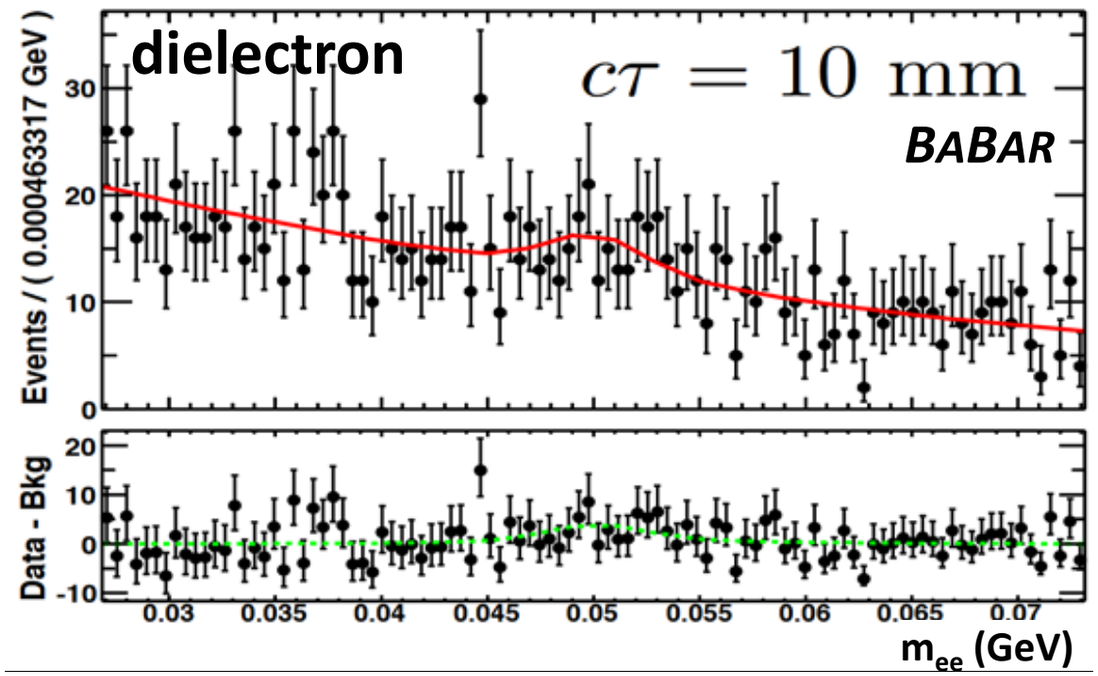
LEPTOPHILIC SCALAR LIMITS

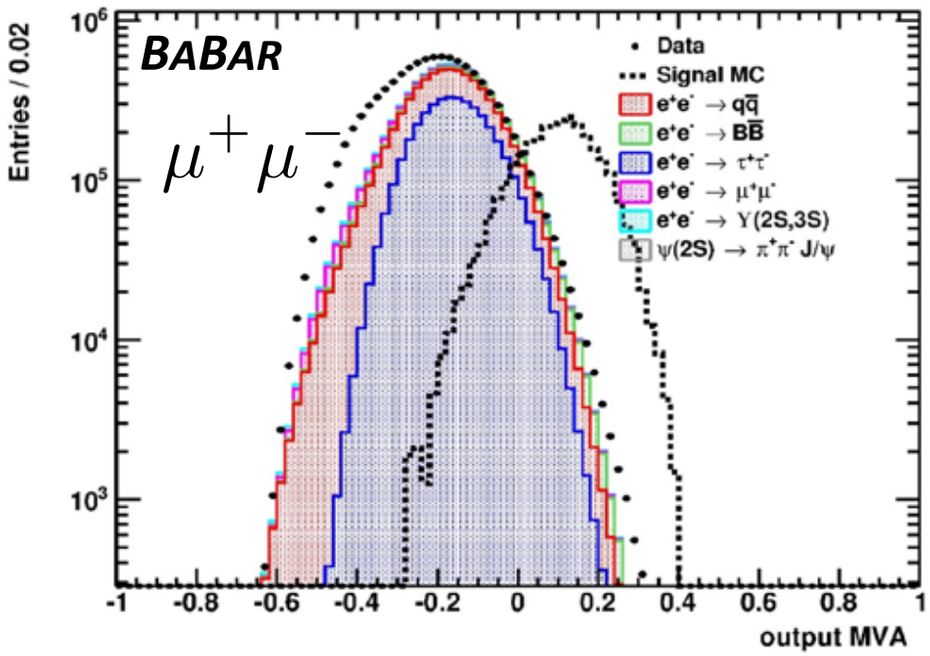


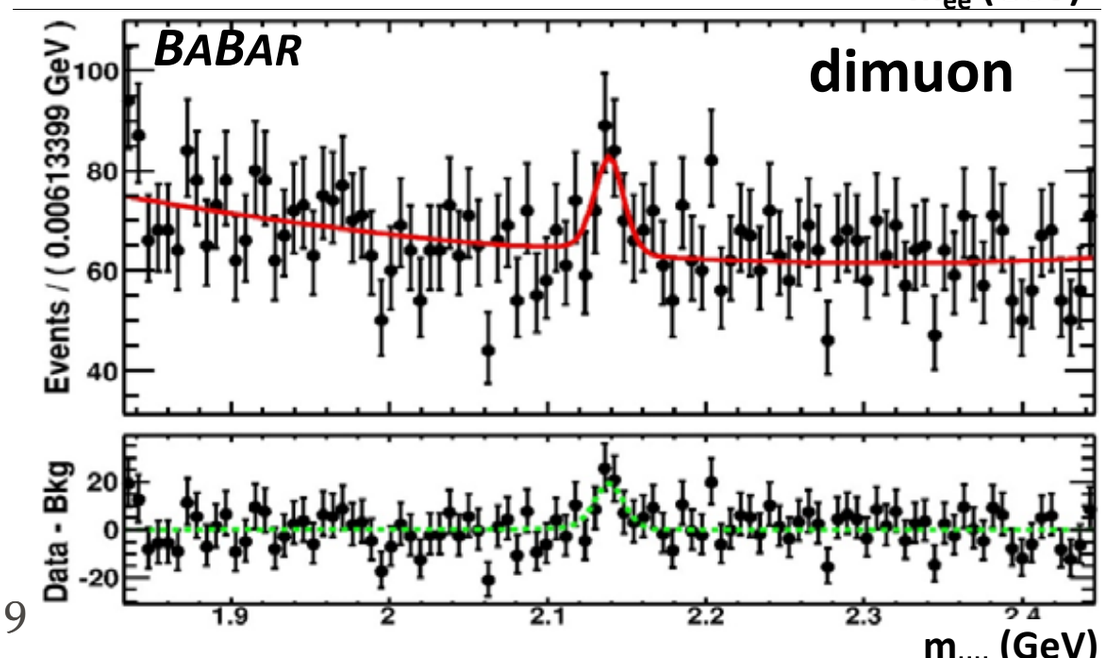
LEPTOPHILIC SCALAR

- Use MC-independent model for background, look for **narrow** peak



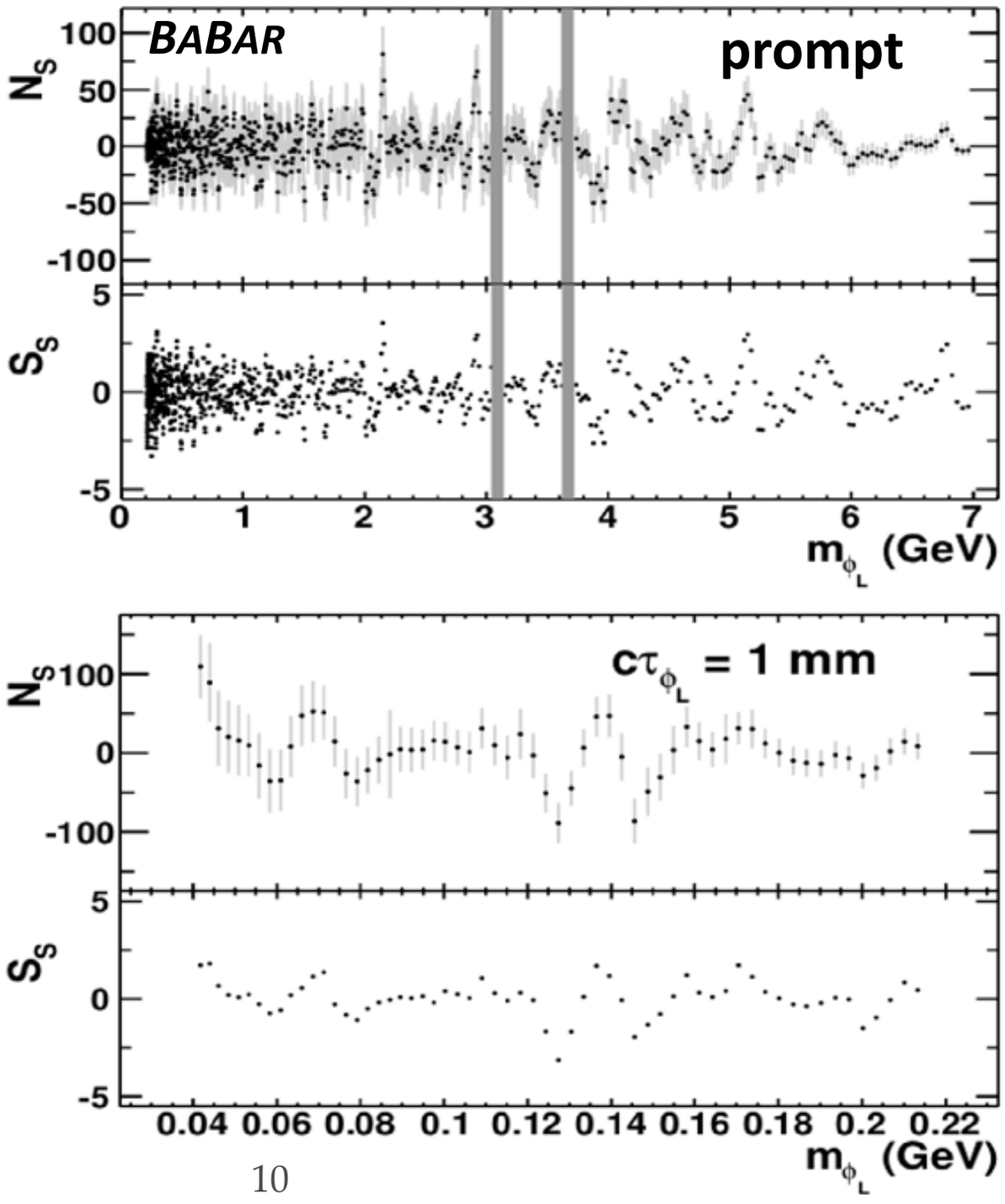






DARK LEPTOPHILIC SCALAR

- Signal extraction



DARK LEPTOPHILIC SCALAR

- BDT inputs:

TABLE I: List of variables used as input to the dimuon boosted decision trees.

Ratio of second to zeroth Fox-Wolfram moment of all tracks and neutrals.
Invariant mass of the four track system, assuming the pion (muon) mass for the tracks originating from the tau (ϕ_L) decays.
Invariant mass and transverse momentum of all tracks and neutrals.
Invariant mass squared of the system recoiling against all tracks and neutrals.
Transverse momentum of the system recoiling against all tracks and neutrals.
Number of neutral candidates with an energy greater than 50 MeV.
Invariant masses of the three track systems formed by the ϕ_L and the remaining positively or negatively charged tracks.
Momentum of each track from ϕ_L decays.
Angle between the two tracks produced by the tau decay.
Variable indicating if a track has been identified as a muon or an electron by PID algorithm for each track.

TABLE II: List of variables used as input to the dielectron boosted decision trees.

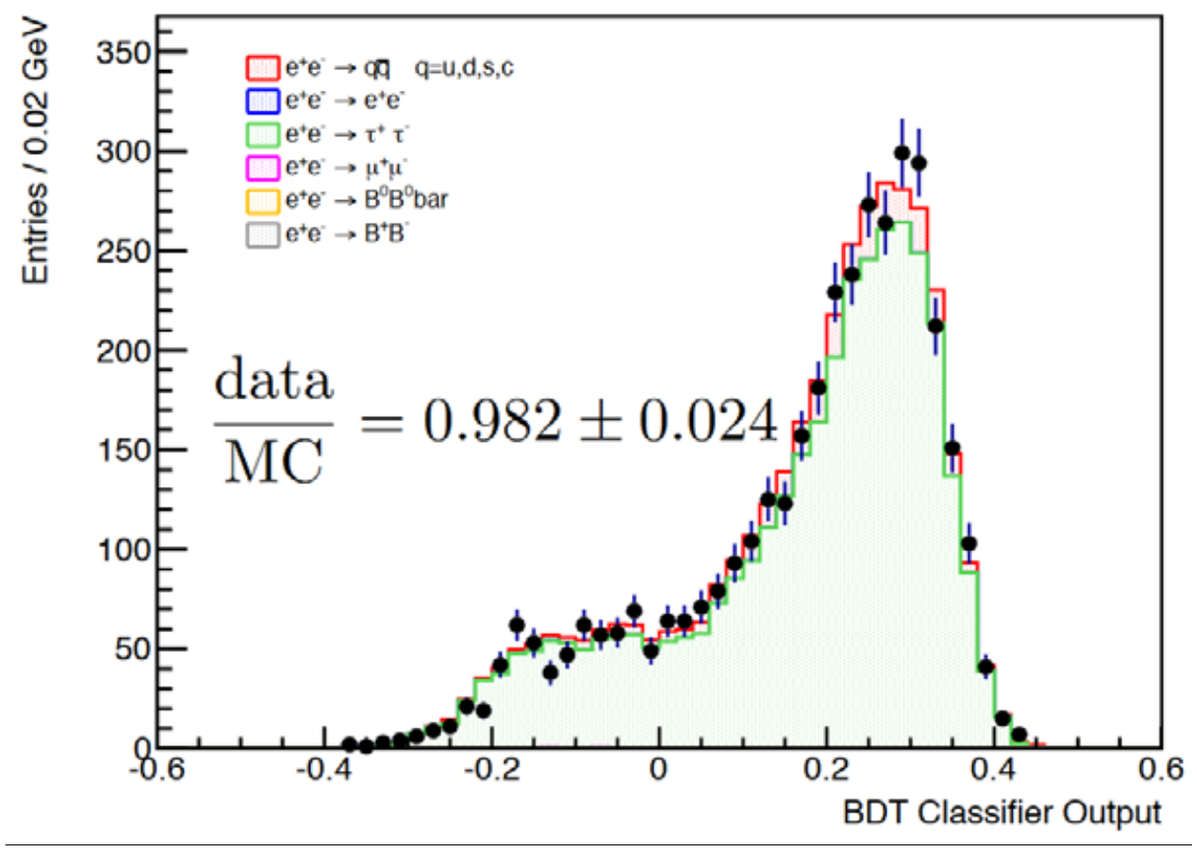
Transverse momentum of the system recoiling against all tracks and neutrals.
Energy of the system recoiling against all tracks and neutrals.
Number of tracks identified as electron candidates by a PID algorithm applied to each track.
Angle between ϕ_L candidate momentum and closest track produced in tau decay.
Angle between ϕ_L candidate momentum and farthest track produced in tau decay.
Angle of ϕ_L candidate relative to the beam in the center-of-mass frame.
Angle between the two tracks produced by the tau decay.
Angle between ϕ_L candidate and nearest neutral candidate with $E > 50$ MeV.
Energy of nearest neutral candidate (with $E > 50$ MeV) to ϕ_L candidate.
Total energy in neutral candidates, each of which has an energy greater than 50 MeV.
Distance between beamspot and ϕ_L candidate vertex.
Uncertainty in the distance between beamspot and ϕ_L candidate decay vertex.
ϕ_L candidate vertex significance, defined by the beamspot-vertex distance divided by its uncertainty.
Angle between the ϕ_L candidate momentum, and line from beamspot to ϕ_L decay vertex.
Distance of closest approach to beamspot of e^- in ϕ_L candidate.
Distance of closest approach to beamspot of e^+ in ϕ_L candidate.
Transverse distance between ϕ_L decay vertex and best-fit common origin of τ candidates and ϕ_L candidate.
χ^2 of the kinematic fit to the ϕ_L and τ candidates constraining their origin to the same production point.
χ^2 of the kinematic fit of the ϕ_L candidate with the constraint that the e^+e^- pair is produced from a photon conversion in detector material.
Dielectron mass for ϕ_L candidate when re-fit with the photon conversion constraint.

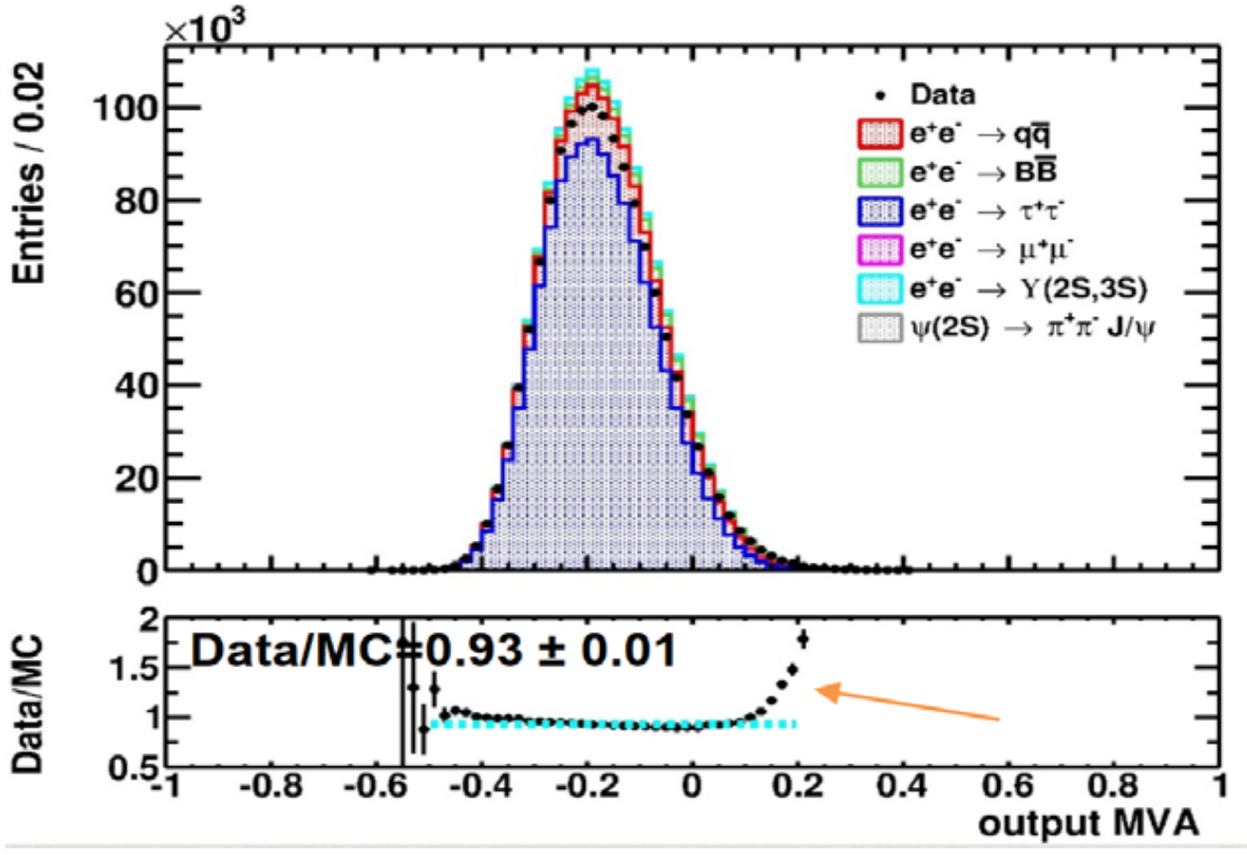
DARK LEPTOPHILIC SCALAR

- Signal efficiency validation & correction:

$\tau^- \to \pi^- \nu_\tau K_S,\ K_S \to \pi^+\pi^-$

$p_T^{recoil} > 2\ \mathrm{GeV}$

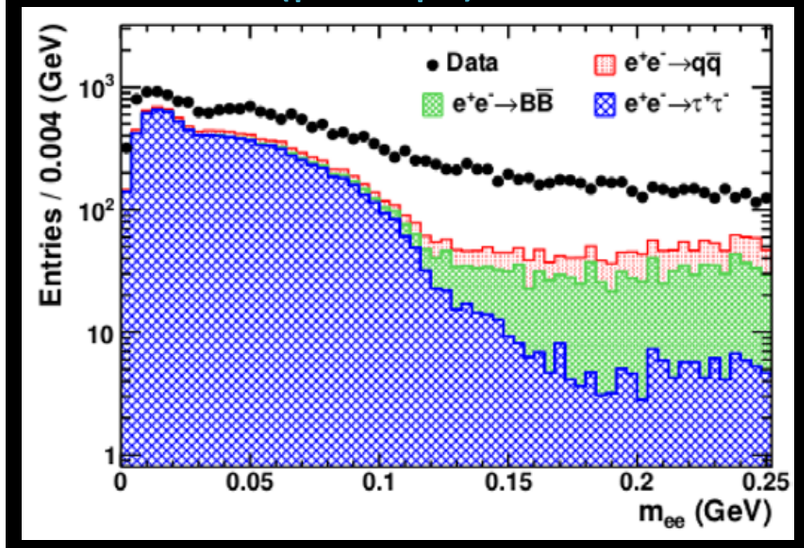




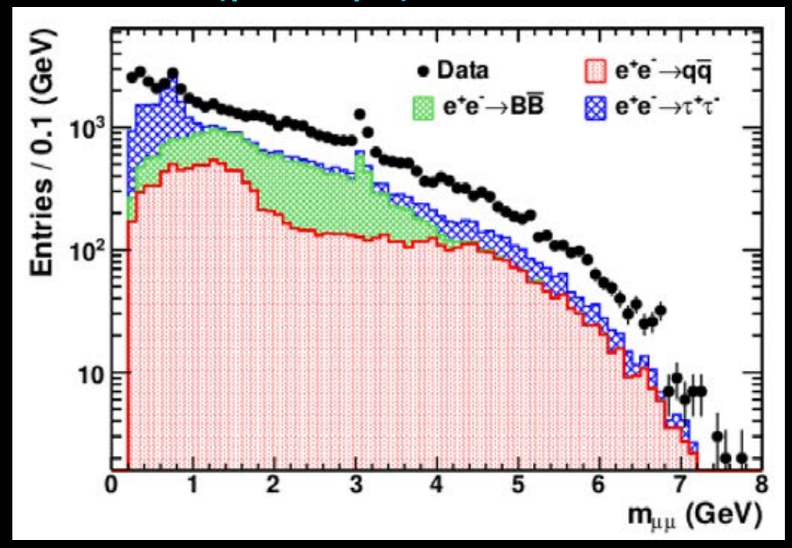
DARK LEPTOPHILIC SCALAR

- Invariant mass distributions:

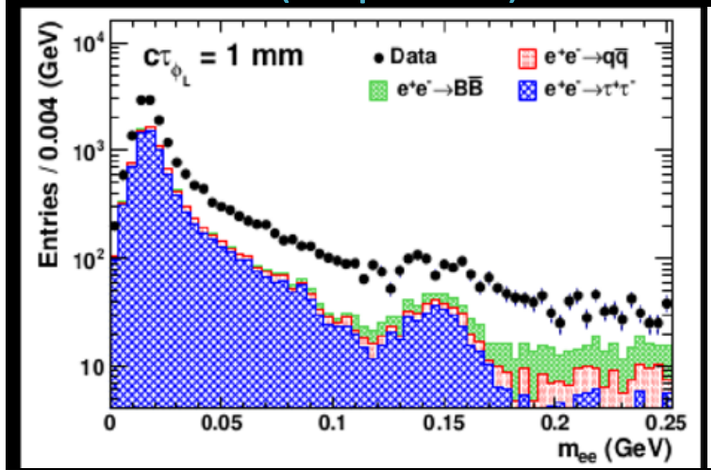
Dielectron (prompt)

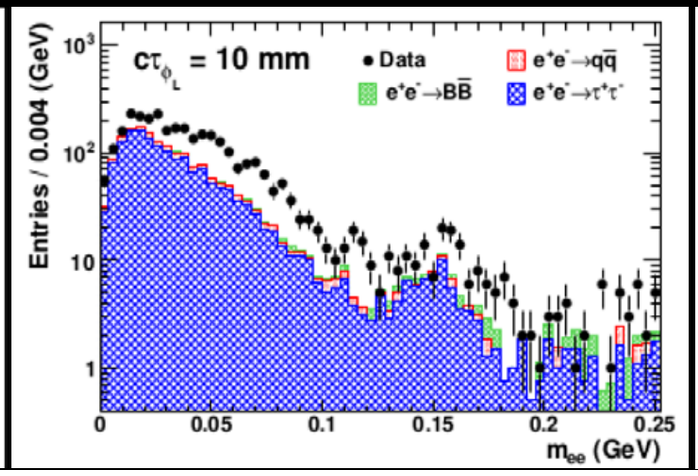


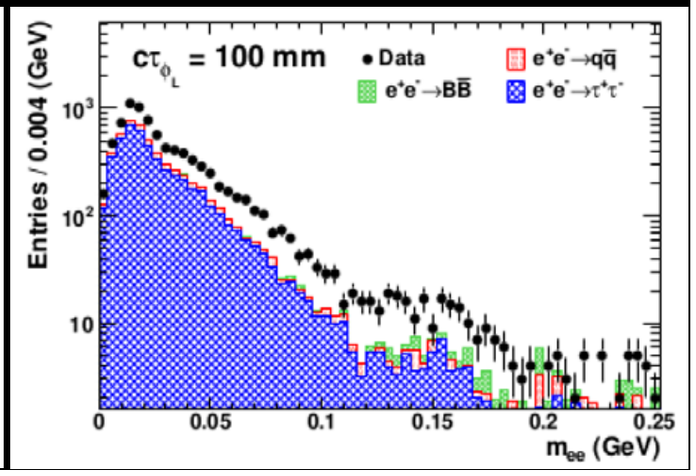
Dimuon (prompt)



Dielectron (displaced)



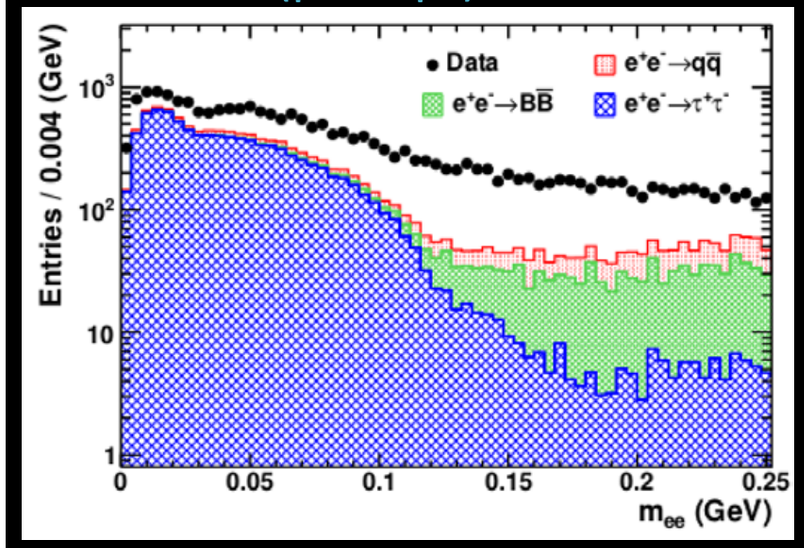




DARK LEPTOPHILIC SCALAR

- Invariant mass distributions:

Dielectron (prompt)



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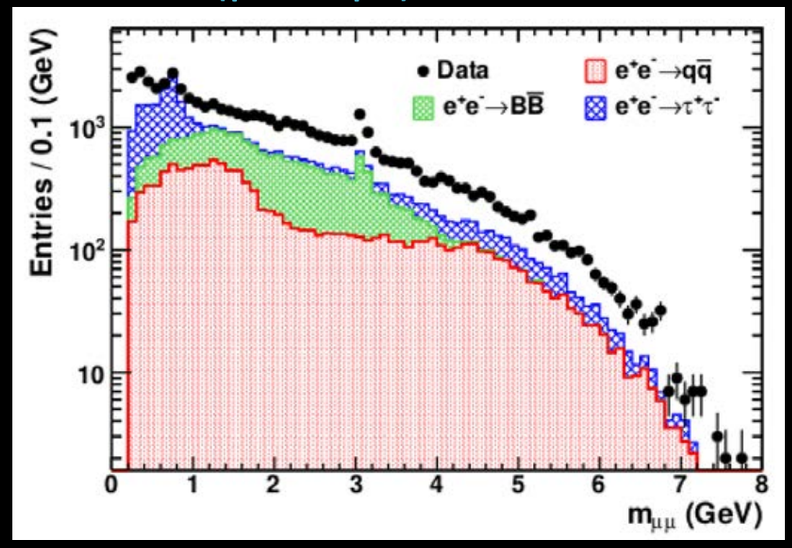

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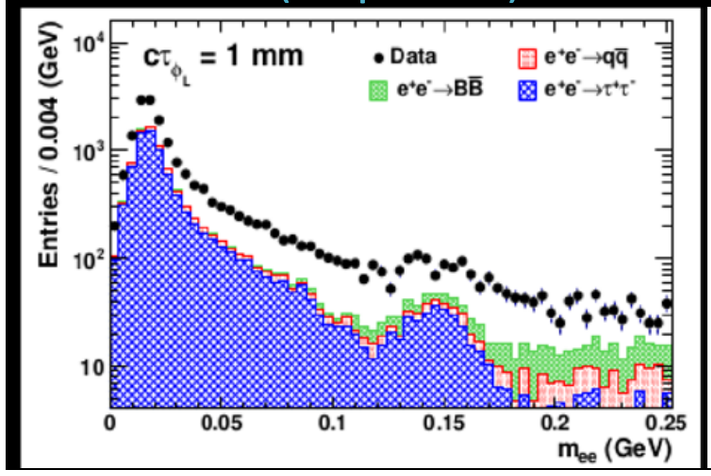

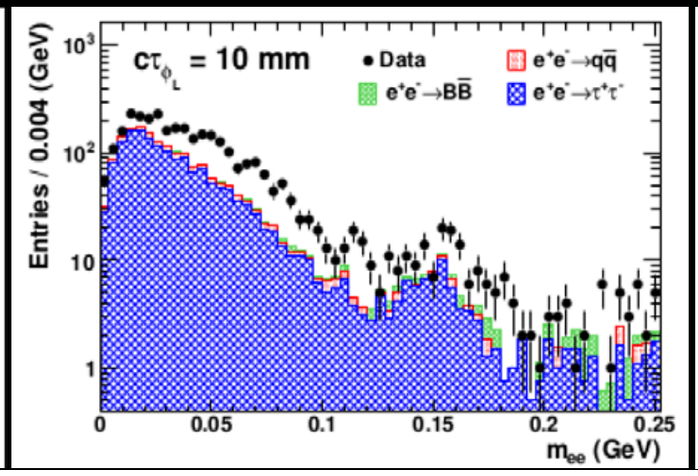

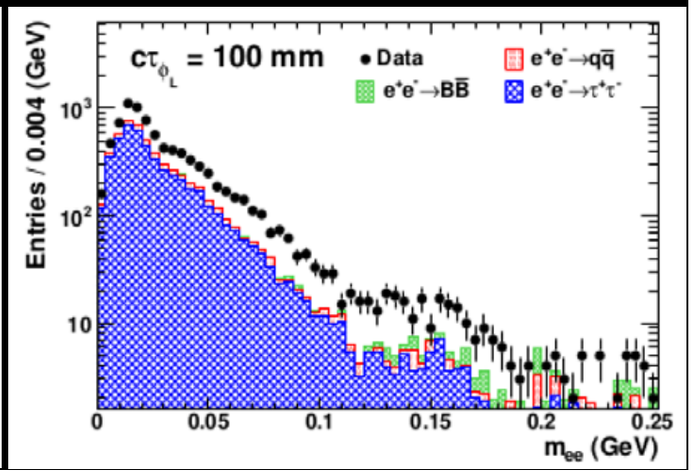

DARKONIUM MVA

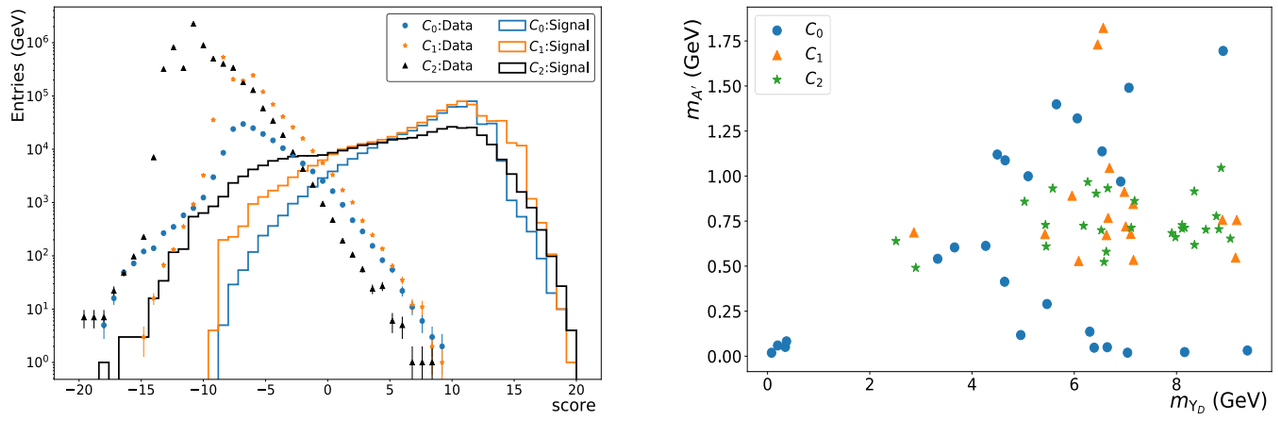

Figure: Analysis performance for prompt dark photon decays. Left: MVA score distribution. Right: mass distribution of observed events passing all selection criteria.

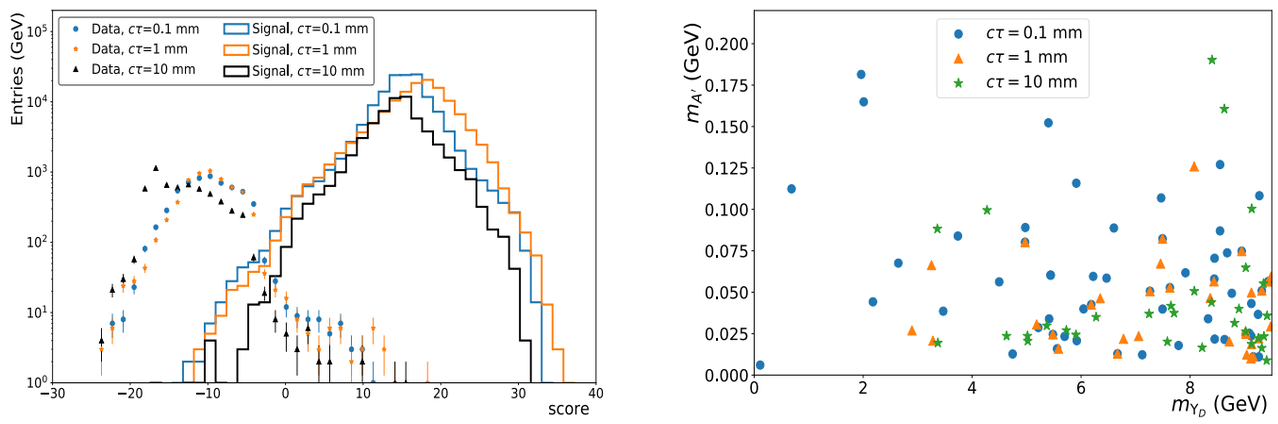

Figure: Analysis performance for displaced dark photon decays. Left: MVA score distribution. Right: mass distribution of observed events passing all selection criteria.

CROSS SECTION LIMITS

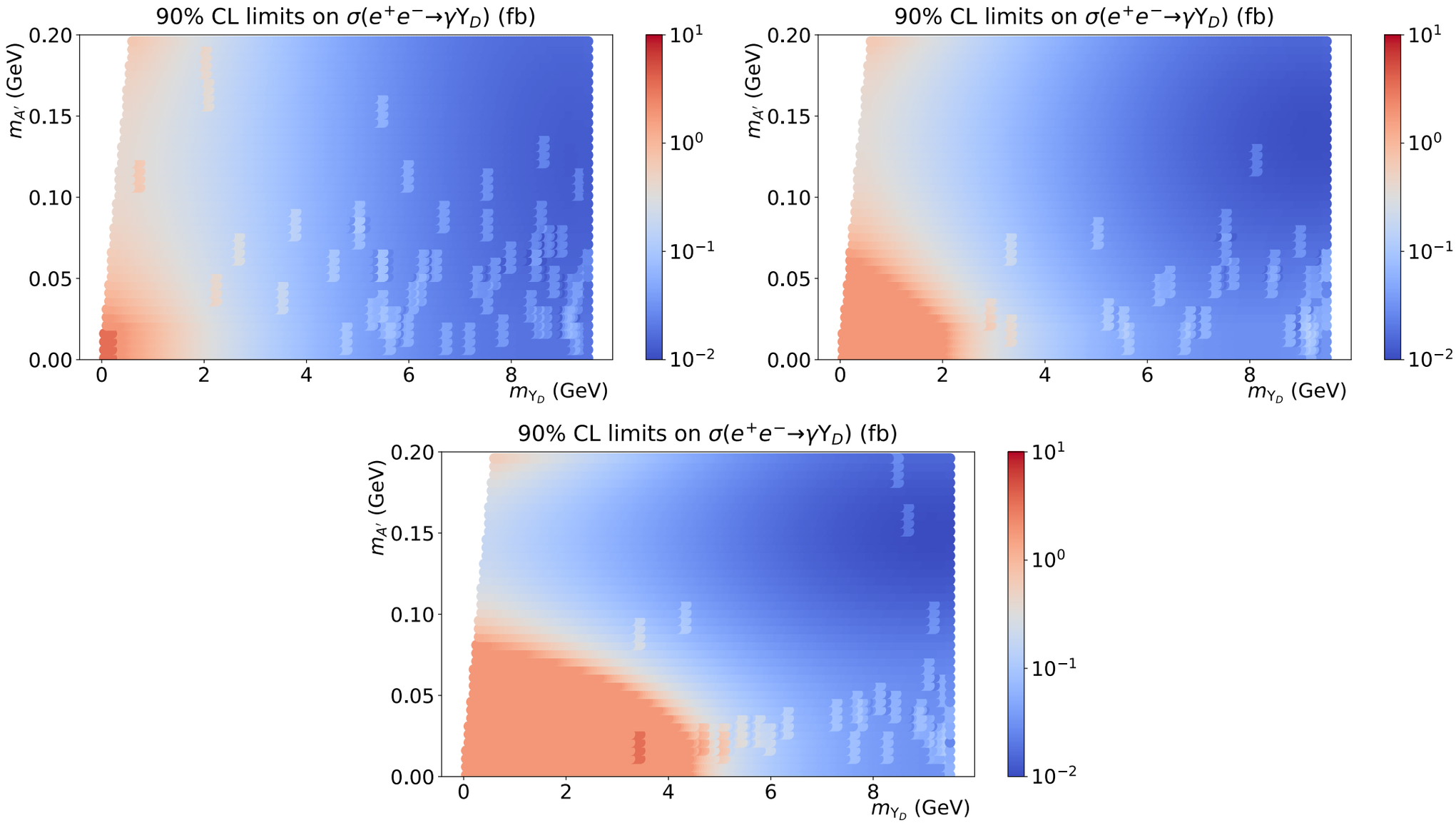

Figure: The 90% CL upper limits on the $e^+e^- \to \gamma\Upsilon_D$ cross-section for dark photon lifetimes corresponding to (top left) $c\tau_{A'} = 0.1\,\mathrm{mm}$, (top right) $c\tau_{A'} = 1\,\mathrm{mm}$, and (bottom) $c\tau_{A'} = 10\,\mathrm{mm}$.