A Step-by-Step Guide to Projecting Vertexing Reach

Matt Solt

(Remote) Analysis Workshop for 2019 Data

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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Introduction

- Summary for what is needed for 2019, and the basic steps needed
- Details of calculating signal expectation for 10% data for 2016
  - I’m showing some old plots. Not the “final” answer, but close to it
- There are key differences between projecting reach for “well understood” data (2016) and “new” data (2019)
  - Only ‘L0L0’ projections are possible for 2019, I do all categories for 2016
  - Hit efficiencies are incorporated for 2016, they can’t be for 2019
  - 2016 is a data-driven (except for acceptances and radiative fraction), 2019 must be MC-driven
  - Additional background and additional tail cannot be accounted for in the 2019 reach estimate
- At the end, discuss the assumptions we want (or need) to make for an initial reach estimate

Summary of Ingredients for Initial 2019 Estimate

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- Background MC:
  - Tridents
- Acceptance:
  - Displaced A' MC
- Radiative Fraction:
  - Tridents
  - Radiatives
  - Wabs
- Mass Resolution:
  - Displaced A' MC

*Do we want beam overlay for an initial estimate? Discuss this at the end

Summary of Steps for Initial 2019 Estimate

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- Obtain zcut from large background MC
  - Generate large background MC, enough to fit tails
  - Apply energy-scaled cuts from 2016
  - Scale up background fit by lumi, select the z at 0.5 expected events
- Acceptance:
  - Generate displaced A' MC: ~80 - 250 MeV
  - Apply scaled cuts from 2016
- Radiative fraction and mass resolution are fairly trivial
  - Apply scaled cuts from 2016
  - We can't get the e+e- rate from data. What do we do with this?
- Compute expected A' rates as function of mass and ε (I will show this process for 2016), reach contour is at 2.3 expected events

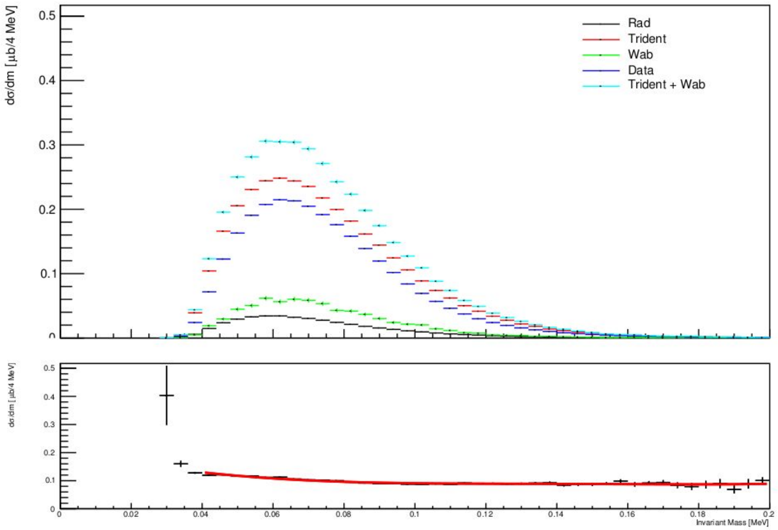
*Note: What is presented here is not necessarily mathematically rigorous. The intent is to show the practical steps needed to get the correct answer that we are confident in.

Step 1: Find the A' Production Rate

- Find the Radiative Fraction
  - Use tridents, wabs, and radiatives
  - Use the same "new" method as bump hunt
- The cuts used for radiative fraction are preselection plus a few other common cuts shared between categories (no layer 1 requirements yet!)

$$f_{rad} = \frac{\frac{dN_{\gamma^*}}{dm}}{\frac{dN_{bkg}}{dm}} = \frac{\frac{dN_{\gamma^*}}{dm}}{\frac{dN_{tri}}{dm} + \frac{dN_{wab}}{dm}}$$

Cut Description	Requirement
Preselection	-
Layer 2 Requirement	e^+ and e^- have L2 hit
Tight Vertex Quality	$\chi^2_{unc} < 4$
Radiative Cut	$V_{0p} > 2.0$ GeV



Step 1: Find the Production Rate

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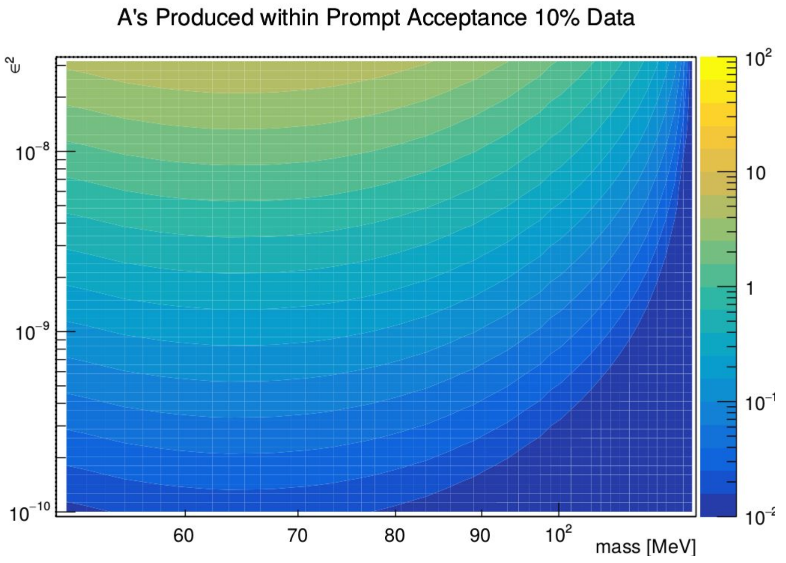
- N_{bin} number of e+e- events in small bin of size $\delta m_{A'} = 1 MeV$
- ϵ_{bin} signal efficiency associated with mass window size 2.8 σm
- $f_{rad} N_{bin} \frac{3\pi\epsilon^2}{2N_{eff}\alpha} \frac{m_{A'}}{\delta m_{A'}} \epsilon_{bin}$ is the total expected A' rate within prompt acceptance
- This is shown on the right



Step 2: Calculate the Truth Signal Shape + Normalize

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- The “prompt” rate of A’s must be “spread out” over some z distribution as a function of mass and ε
- The truth signal shape distributed in z is $e^{(z_{targ}-z)/\gamma c\tau}$
- To get the correct normalization, the total integral must integrate to unity, divide the signal shape by $\gamma c\tau$ to achieve this.

$$\int_{z_{targ}}^{\infty} \frac{e^{(z_{targ}-z)/\gamma c\tau}}{\gamma c\tau} dz = 1$$

- (Production rate) x $\frac{e^{(z_{targ}-z)/\gamma c\tau}}{\gamma c\tau}$ gives the correct signal truth distribution

Step 3: Incorporate Acceptance Effects

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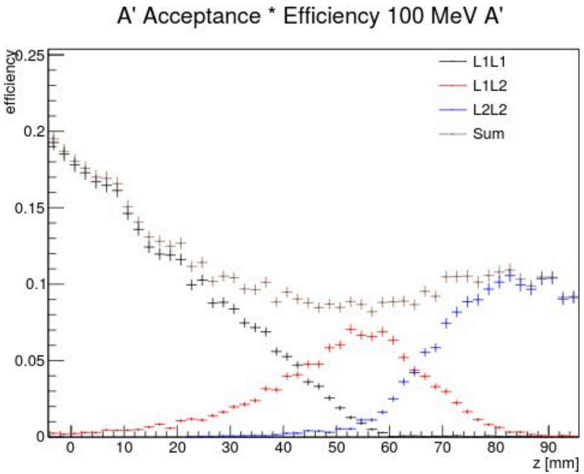
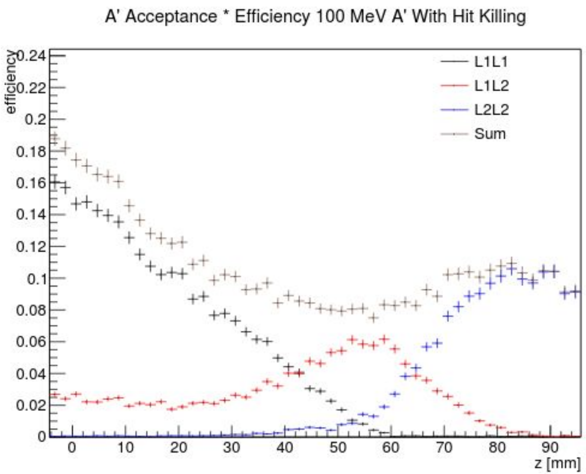
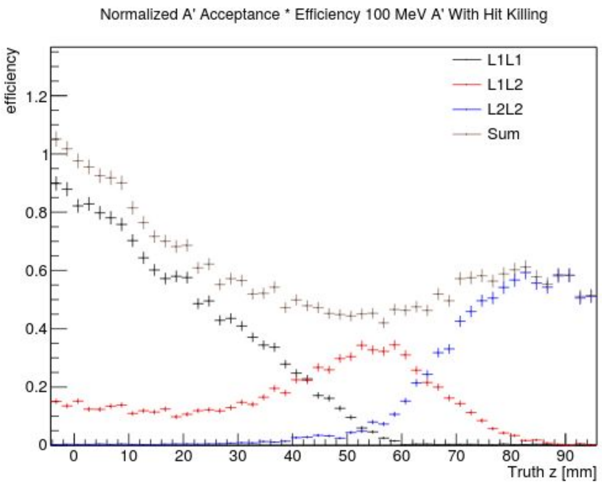
- We need the acceptance x efficiency as a function of z: $\epsilon_{vtx}(z, m_{A'})$
- Taking the number of produced A's, several things can happen once it is displaced:
  - Both e+e- particles have an L1 hit (L1L1)
  - Exactly one of the e+e- particles have an L1 hit (L1L2)
  - Neither e+e- particles have an L1 hit (L2L2)
  - The event migrates to another category due to incorporating post-reconstruction hit efficiencies for L1 as a function of track slope, or the event is eliminated
  - The event is eliminated due to further cuts

Step 3: Incorporate Acceptance Effects

- 1. Divide analysis into 3 categories L1L1, L1L2, L2L2
- 2. Run slope-dependent hit killing algorithm
- 3. Obtain 3 new categories of L1L1, L1L2, and L2L2. The sum of these is normalized to unity at the target (by fitting the distribution). $\epsilon_{vtx}(z_{targ}, m_{A'}) = 1$







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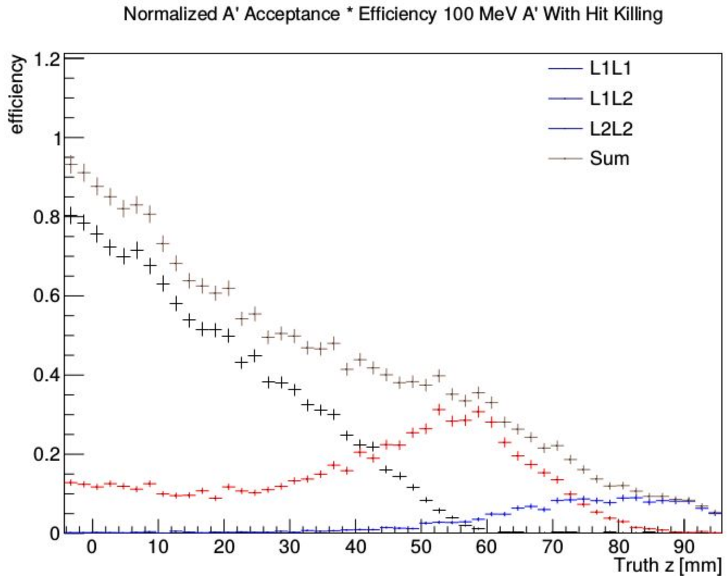
- 4. Do the remaining cuts on each of these categories (isolation cut, impact parameter cut, V0 projection to the target)
- 5. To get intermediate values of mass and z, a 2D linear interpolation is performed



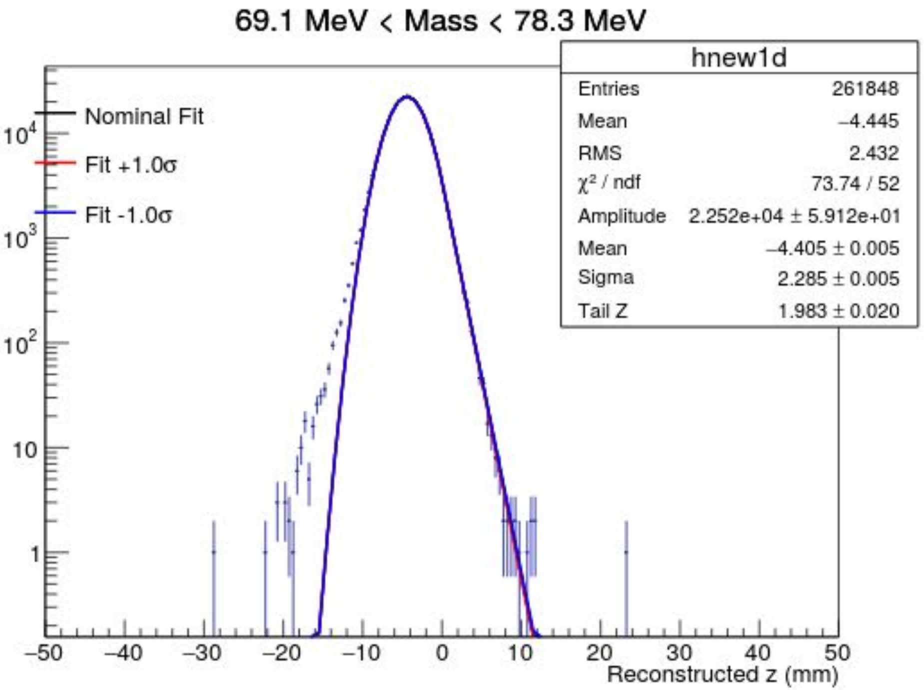
Step 4: Obtain Zcut

- Divide z distributions in slices of mass for data
- Fit each slice with a gaussian plus exponential tail

$$F\left(\frac{z - z_{mean}}{\sigma_z} < b\right) = Ae^{-\frac{(z - z_{mean})^2}{2\sigma_z^2}}$$

$$F\left(\frac{z - z_{mean}}{\sigma_z} >= b\right) = e^{-\frac{b^2}{2} - b\frac{z - z_{mean}}{\sigma_z}}$$

Gaussian Core
+
Exponential Tail



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Gaussian Core

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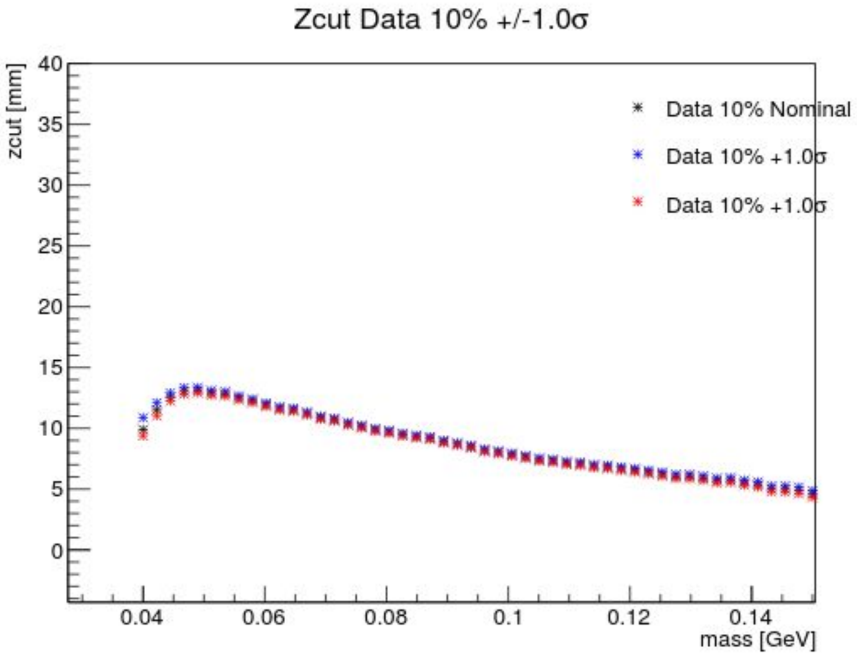
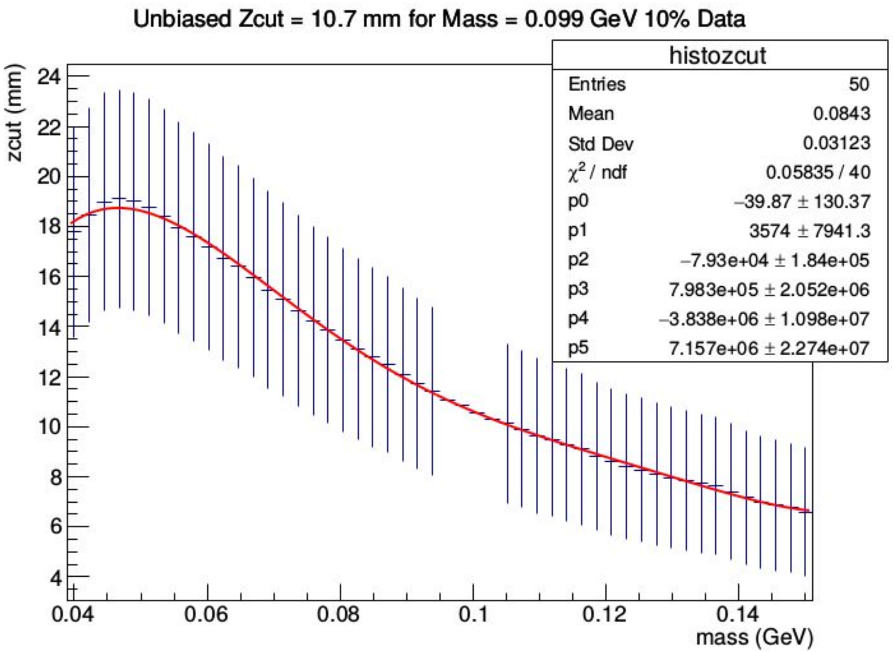
Exponential Tail

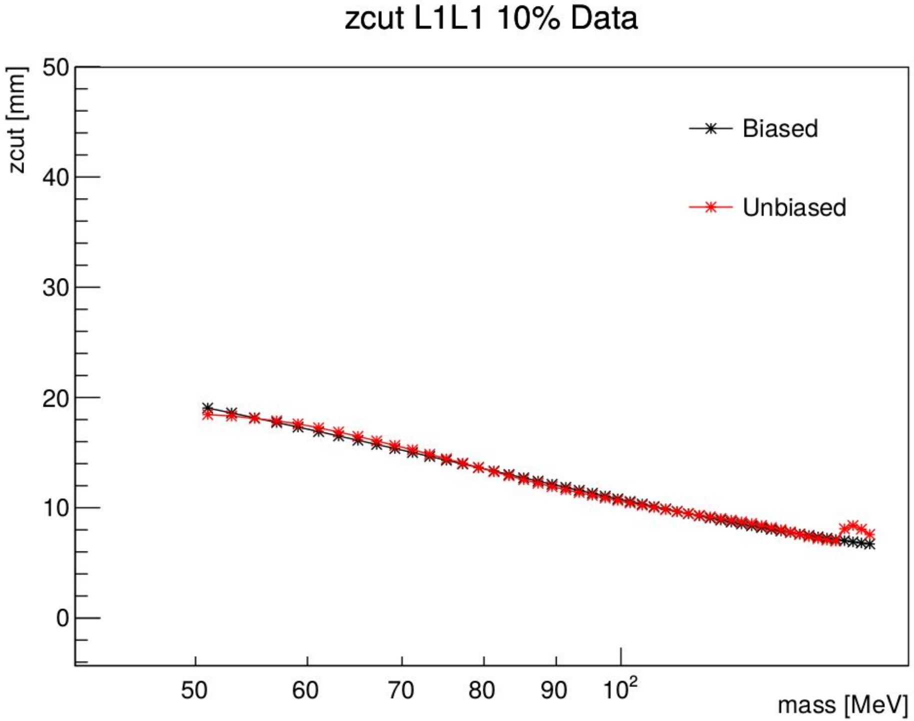
- Zcut is where you expect 0.5 background events in a given mass slice



Step 4: Obtain Zcut

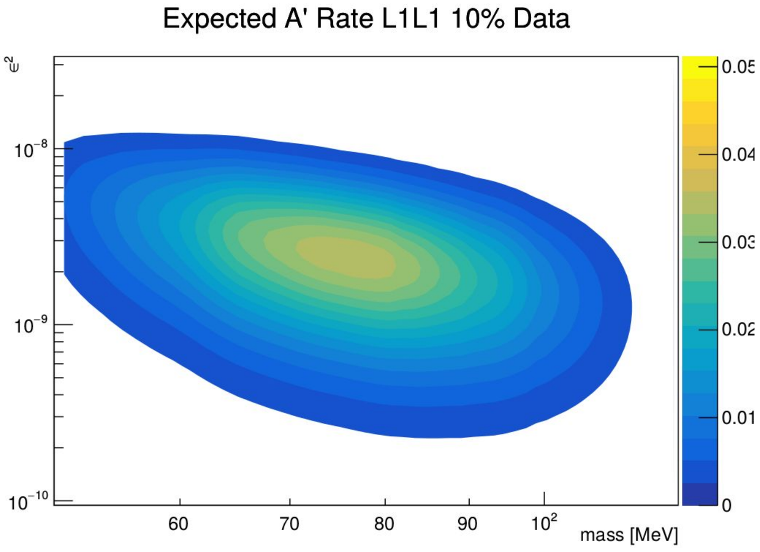
- The last step for determining zcut is to do so in an unbiased way
- Fit the mass sidebands and then interpolate into the search window

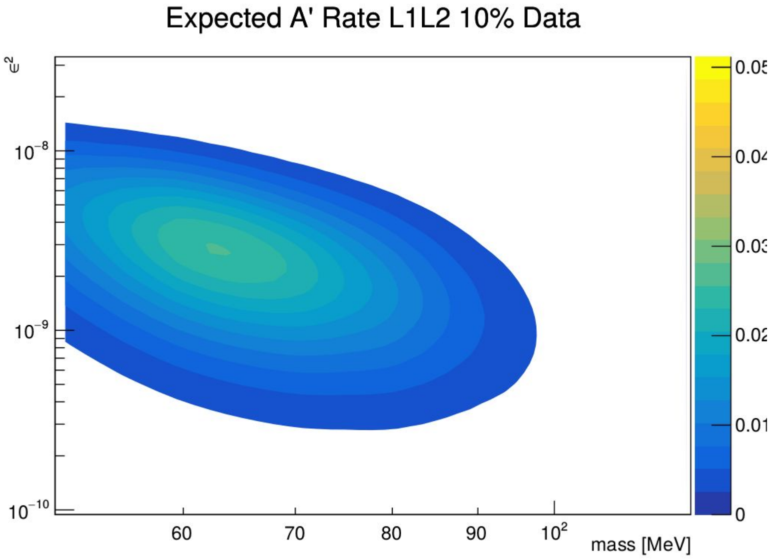




Step 5: Compute Expected A' Rate

$$s_{bin,zCut} = \text{“Prompt” rate (mass,}\varepsilon\text{)} \int_{zCut}^{zMax} \text{Truth Shape (mass,}\varepsilon\text{,z)} \; \text{Acceptance (mass,z)} \, dz$$





*These are not the final answers for 10% 2016 Data

Step 5: Compute Expected A' Rate

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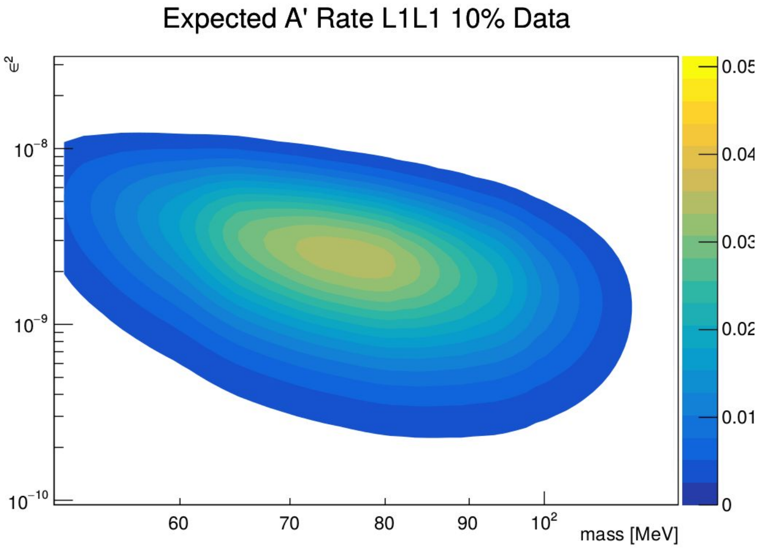
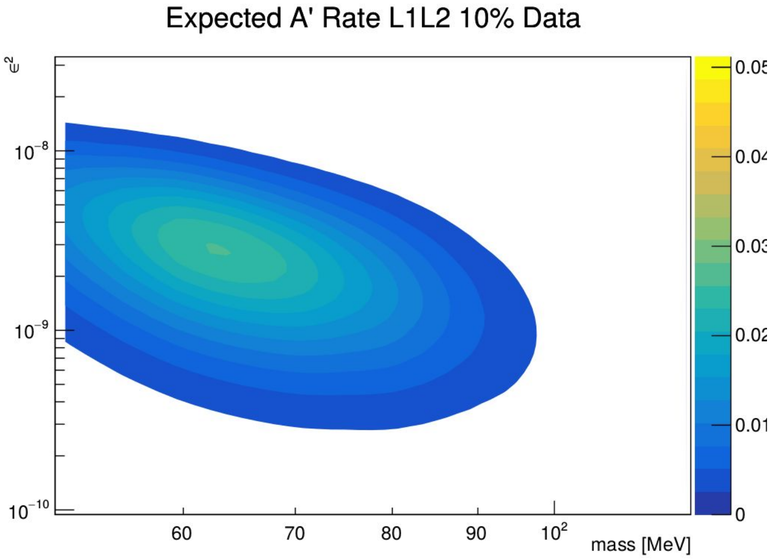
$$s_{bin,zCut} = f_{rad} N_{bin} \frac{3\pi\epsilon^2}{2N_{eff}\alpha} \frac{m_{A'}}{\delta m_{A'}} \epsilon_{bin} \int_{zCut}^{zMax} \frac{e^{(z_{targ}-z)/\gamma c\tau}}{\gamma c\tau} \epsilon_{vtx}(z, m_{A'}) dz$$





*These are not the final answers for 10% 2016 Data

Step 6: Scale to Correct Luminosity

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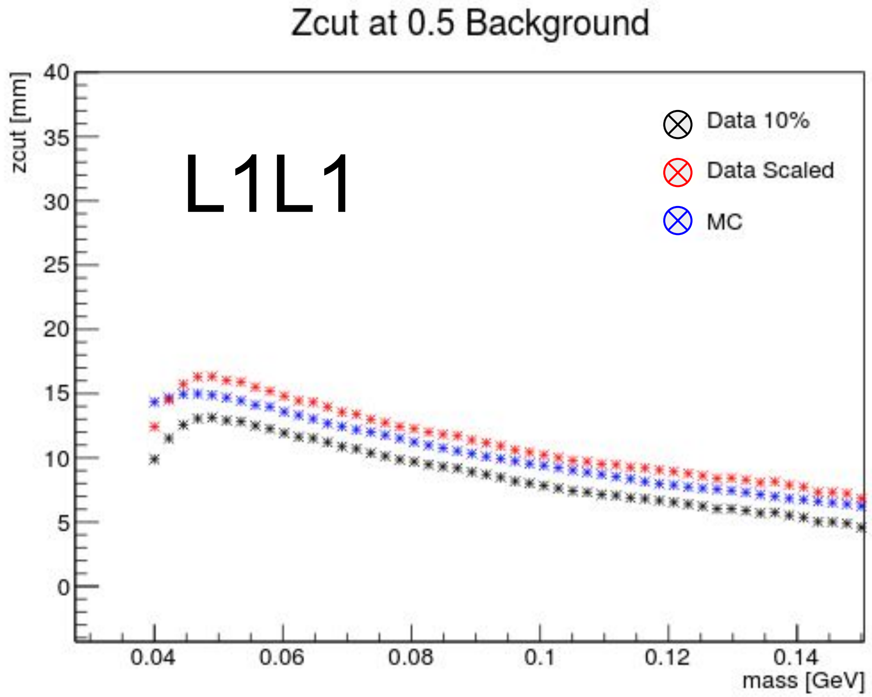
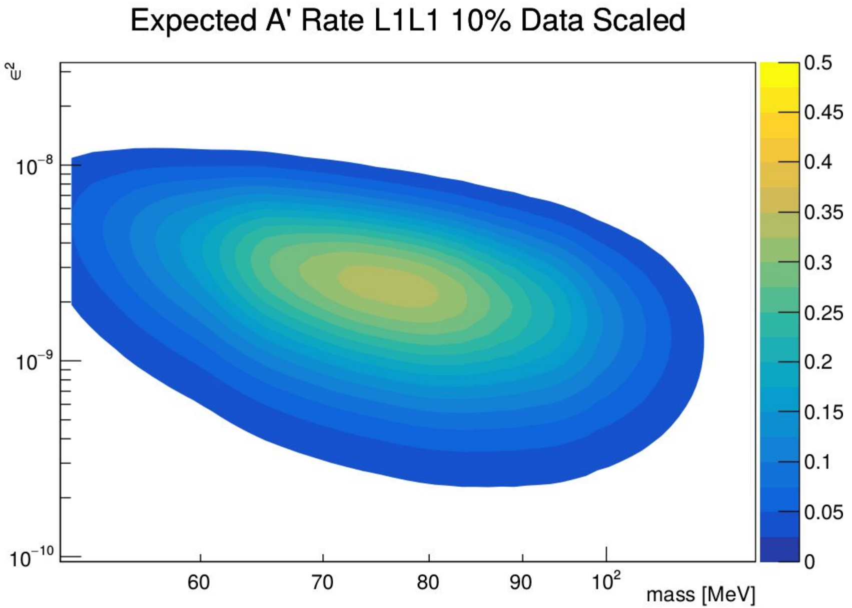
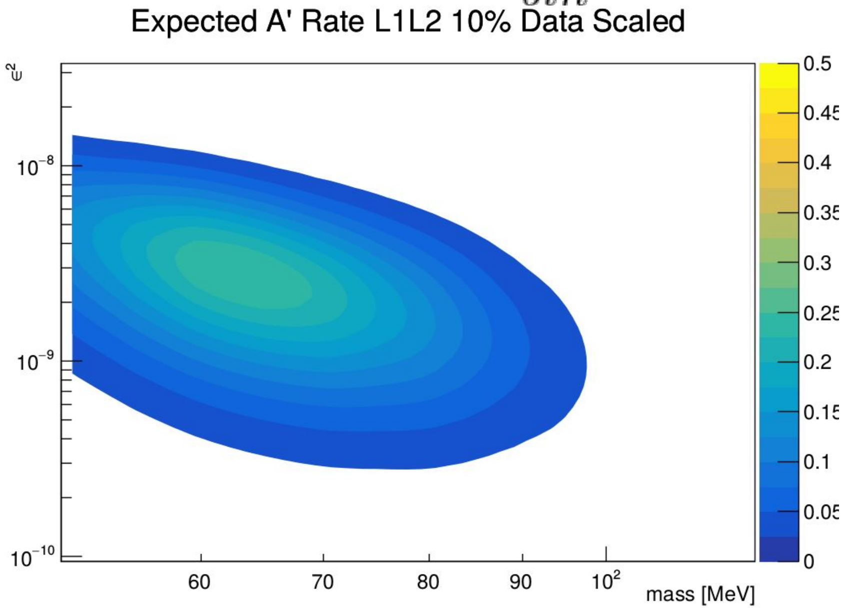
- Scaling the expected rate requires two additional steps
  - Scale the background model and recompute zcut



Step 6: Scale to Correct Luminosity

- Scaling the expected rate requires two additional steps
  - Scale the background model and recompute zcut
  - Scale the expected number of e+e- pairs in each mass bin N_{bin}





*These are not the final answers for 100% 2016 Data

Conclusion

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- Discussion - These are my recommendations for assumptions for 2019:
  - Only L0L0 category is possible at this point
  - Zcut (lumi-scaled) and expected radiative rates must be derived from MC
  - The same (energy-scaled) cuts should be used from 2016 except possibly:
    - The isolation cut if no beam background (see below)
    - The impact parameter cuts - though this does have an impact on zcut
  - We must neglect hit efficiency effects (many of these may be recovered in L0L1, L1L1, etc. categories)
  - We must assume 0.5 background event per mass bin in the signal region using the simplistic background fit. Additional background must be neglected
  - I think beam overlay for background MC is overkill at this point. It has little effect on fitting the core, and even the tails, of the background. The exception is for A's if we want the efficiency associated with the isolation cut.