Layer 0 Upgrade Detector

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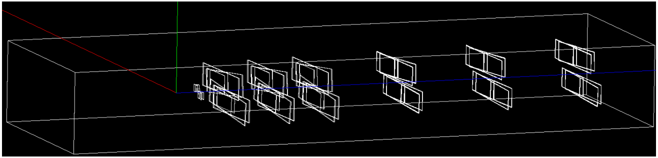
Introduction

- HPS is **planning on upgrading the existing SVT by adding another tracking layer** between the target and current 1st layer
- This should drastically **improve our vertexing reach**
- Tracking layers 2 and 3 are also being moved towards the beam for increased long-lived A' acceptance
- **Reach comparison** for the first layer hit requirements as well as other relevant simulations are presented
- Increased backgrounds studies due to upgrade are also presented

L0 Upgrade Simulation Dimensions

- Layer 0 sensor will contain 256 channels per sensor (no intermediate strip), an axial and stereo sensor on top/bottom and positron/electron side. Each sensor is 10 x 14.08 mm and strips are 200 microns in simulation (aiming for 150 microns)
- Nominal has 640 readout channels (with intermediate strip), an axial stereo sensor on top/bottom and positron/electron side for layers 4-6. Each sensor is 100 x 38.4 mm and strips are 250 microns



L0 Monte Carlo

- A lot of computing time spent on L0 MC (thanks Brad), lots of troubleshooting, and still a few issues to be solved
- **tritrig-wab-beam** - wabs with beam background combined with tridents with beam background at enhanced rate
  - Normalized by trident rate $155 \frac{1}{nb}$ (about 13% of 2015 total luminosity at 0.5 mm) for both nominal and L0 (direct comparison)
  - wabs are NOT enhanced, so these are underestimated. Eventually will have the correct proportions
  - Skeptical of this normalization (probably about 75% luminosity over-estimate) based on rates compared to tritrig + wab and wab-beam-tri and data
  - Goal is to obtain total 2015 luminosity at 0.5 mm
  - Used to fit vertex tails to compute zcut, rate is used for reach plots

L0 Monte Carlo (cont.)

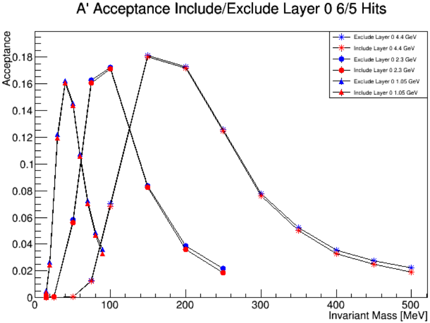
- **Pure wabs, radiatives, and tridents (tritrig)**
  - Used to compute radiative fraction ($\frac{radiatives}{wabs+tridents}$)
  - MG5 radiatives for L0 are on the way
- **wab-beam-tri** - closest MC we have to beam
  - 30 s of beam for L0; 10 s of beam for nominal
  - Used for backround studies - trigger rates, occupancies, wab conversion rates, and beam background rates
- **Prompt and displaced A's**
  - Used for acceptance and efficiency studies and mass resolution

L0 Studies

- Acceptance (prompt A's)
- Invariant Mass (Displaced A's)
- Displaced Efficiency $\frac{A's\ Detectable\ after\ cuts}{A'\ truth}$ (Displaced A's)
- Vertex Tail Fitting and Z Cuts
- Reach Plots for First Layer Hit Requirements
- Future Plans for Reach Plots Using Other Layer Requirements
- Backgrounds
  - Increased converted wabs due to L0 and moving L2/L3
  - Occupancies (in the near future)
- Detailed plots here: **L0 Plots**

Acceptance

- **Geometrical acceptance** for prompt A's as a function of mass for 1.05 GeV, 2.3 GeV, and 4.4 GeV beam energies
- The comparison is 5 hits in the nominal detector compared to 6 hits in L0 detector



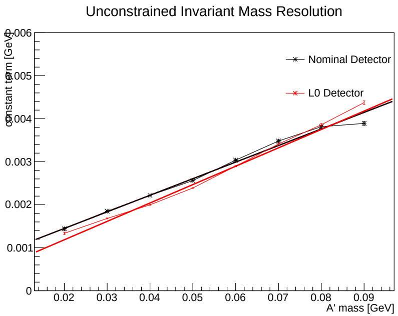
Cuts

- Analysis divided into **mutually exclusive layer requirement** categories
  - Nominal total reach = L1L1 + L1L2 + L2L2
  - Upgrade total reach = L0L0 + L0L1 + L1L1 + L1L2 + L2L2 + L0L2
- L0 Track $\chi^2 < 35$ and shared hits must be less than 4
- Current **cuts eliminate about 20% more A' and background in L0**

Trigger type	"pairs-1" trigger
Track-cluster matching (position)	$\chi^2_{match} < 10$
Track-cluster matching (time)	$\lvert t_{cl} - t_{trk} - 43\rvert < 4$ ns
Cluster time coincidence	$\lvert t_{cl}(e^-) - t_{cl}(e^+)\rvert < 2$ ns
Top-bottom requirement	$\mathrm{sign}(y_{cl}(e^-)) \neq \mathrm{sign}(y_{cl}(e^+))$
Elastics cut	$p(e^-) < 0.75E_{beam}$
Momentum sum cut	$p_{tot}(e^+e^-) < 1.15E_{beam}$
Radiative cut	$p_{tot}(e^+e^-) > 0.8E_{beam}$
Layer 1 requirement	layer 1 hits for both tracks
Track quality	$\chi^2_{trk} < 30$
Beamspot constraint	$\chi^2_{bsc} < 10$, $\chi^2_{bsc} - \chi^2_{unc} < 5$
Layer 1 isolation	see text
Momentum asymmetry	$\lvert p(e^-) - p(e^+)\rvert / (p(e^-) + p(e^+)) < 0.4$
Positron DOCA	$d_0(e^+) < 1.5$ mm

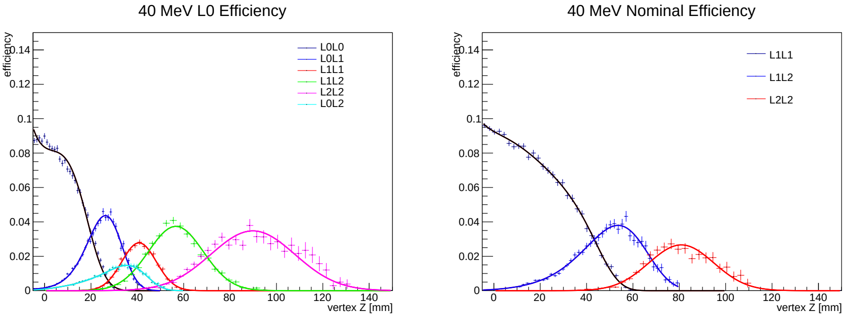
Mass Vertex Resolution Improvement

- **Displaced A' mass resolution** for unconstrained V0s



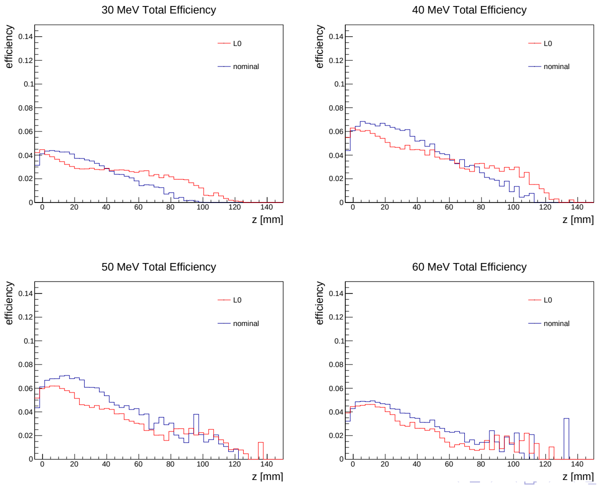
Long-lived A' Efficiency Improvement

- Moving in L2 and L3 **improves efficiency for long-lived A's** (only visible in L1L2 and L2L2 layer requirements)
- Ultimately improves reach for low ϵ^2 A's (after enough statistics)



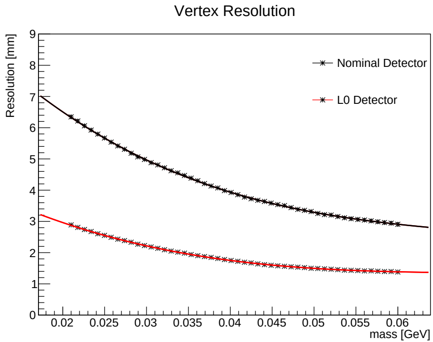
Long-lived A' Efficiency Improvement (cont.)

- Total efficiency sums efficiency of exclusive layer requirements



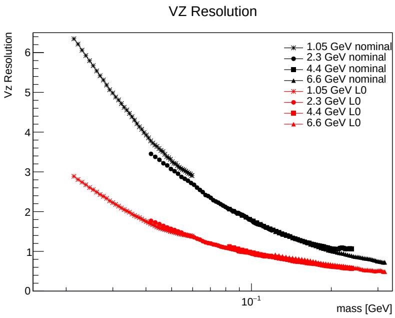
Vertex Resolution Improvement

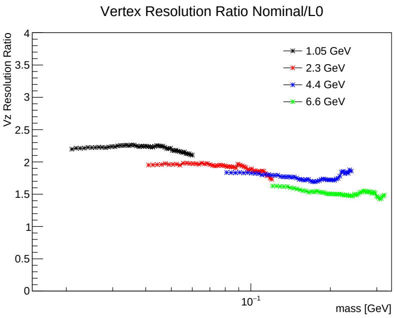
- **Vertex resolution improves by about a factor of 2** for 1.05 GeV(dependent on mass and beam energy)



Vertex Resolution Improvement All Energies

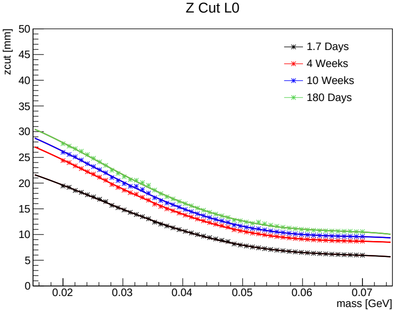
- Background are dominated by multiple scattering which decreases with increasing momentum
- L0 vertex resolution improvement decreases slightly with increasing beam energy (still a very good improvement!)

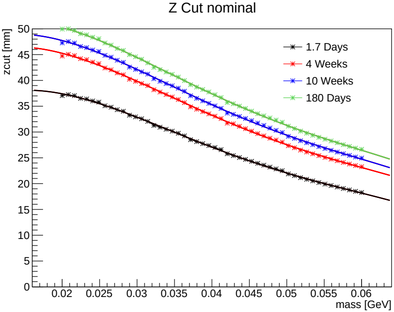




Improved Z Cuts

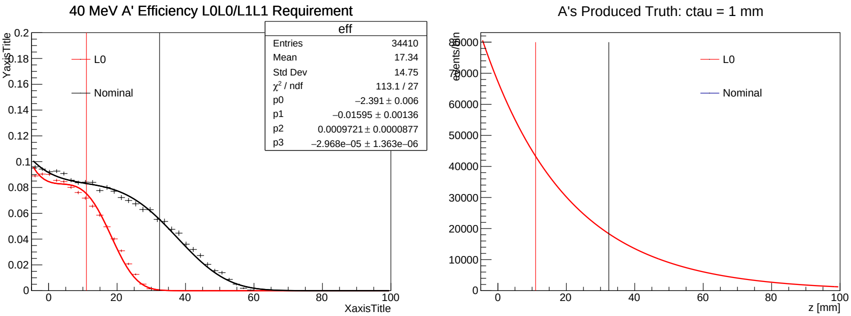
- Improved vertex resolution causes **improved z cuts** (by about the same factor)
- Z cuts for L0 (left) and nominal (right) at various luminosities





Effect of Improved Z Cut

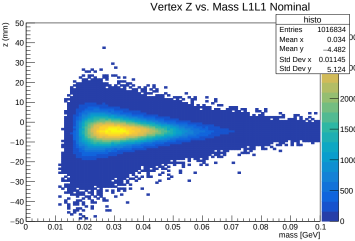
- A' decays are exponential in z, so the **number of detectable A's increases dramatically** for lower Z Cut
- Efficiency after cuts and acceptance with z cuts (left), produced A's (right)

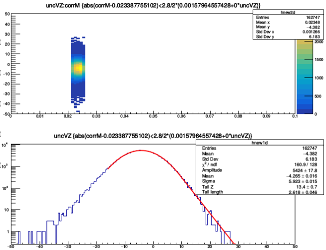


Procedure for Obtaining Reach - Determining Z Cuts

- Fit function $B(z)$ to tritrig distribution after cuts (Gaussian with non-Gaussian tail)
- Scale function for desired luminosity, z cut is where $B(z) = 0.5$ events in a mass bin of 2.6 times mass resolution

$$B(z;\bar{z},\sigma,b,l) = \begin{cases} e^{-\frac{(z-\bar{z})^2}{2\sigma^2}} & \text{if } z \le \bar{z}+b, \\ e^{-\frac{b^2}{2\sigma^2}-(z-\bar{z}-b)/l} & \text{if } z \ge \bar{z}+b \end{cases}$$

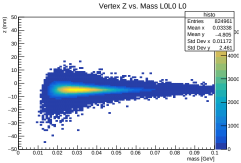


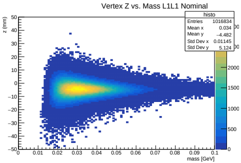


Procedure for Obtaining Reach - Calculating Detectable A's

$$\mu s(z) = (N_{A'}\epsilon_{reco}(z_{targ}))\frac{e^{\frac{z_{targ}-z}{\gamma c\tau}}}{\gamma c\tau}\frac{\epsilon_{reco}(z)}{\epsilon_{reco}(z_{targ})}\epsilon_{cut}(z) \qquad (1)$$

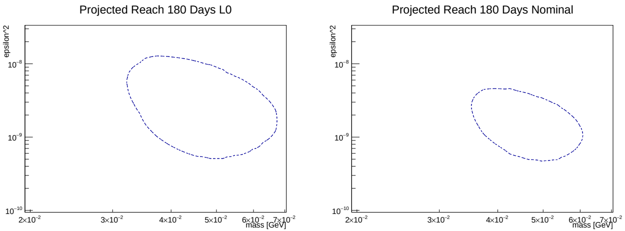
- Number of detectable events is simply $\int_{z_{cut}}^{z_{max}} \mu s(z)dz$ (essentially efficiency(z) * acceptance(z) * number of A's(z))
- Reach contours are defined at the 90% confidence level which is 2.3 expected events



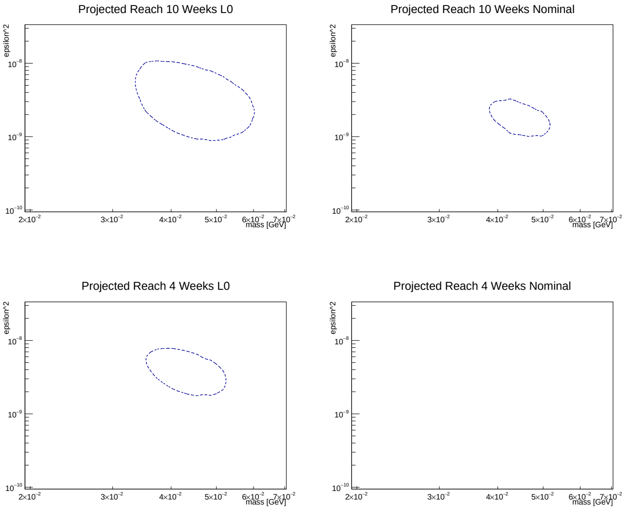


Reach Plot L0L0/L1L1 Comparison

- The procedure of requiring hits in the first layer is well understood (thanks to Sho and Holly)
- Reach plots compare L0L0 in ugrade detector vs L1L1 in the nominal detector (for a direct comparison we need L0L0 + L0L1 + L1L1 for upgrade detector, so we are underestimating our reach)

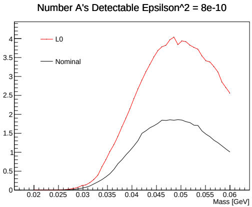


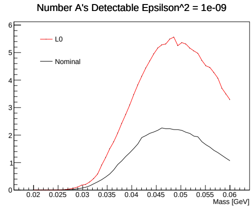
Reach Plot L0L0/L1L1 Comparison (cont.)

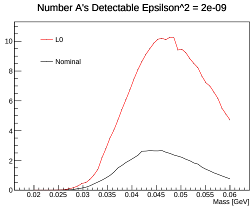


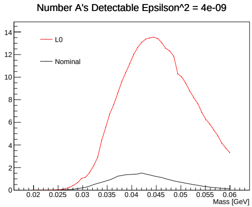
Number A's Detectable L0L0/L1L1

- Number of detectable A's past all cuts comparing L0L0 for L0 and L1L1 for nominal at 180 days



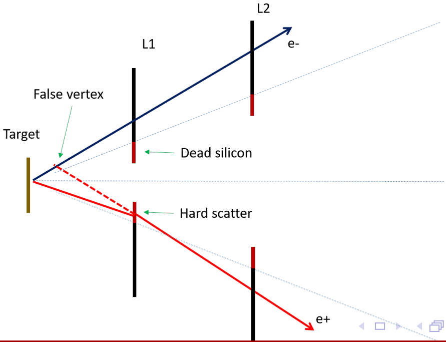






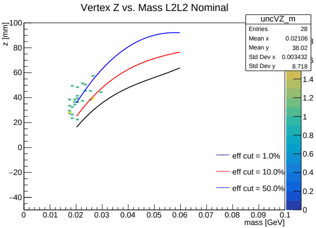
Difficulty With Other Layer Requirements

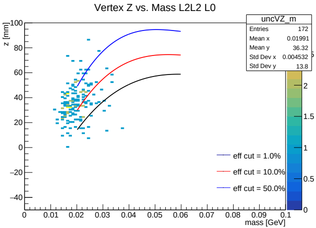
- Backgrounds due to hit **inefficiencies are cut out by extrapolating track to active sensor** (inefficiencies are NOT present in MC)
- Remaining background is due to a **hard scatter in the dead silicon** into the acceptance of the rest of the tracker



Difficulty With Other Layer Requirements (cont.)

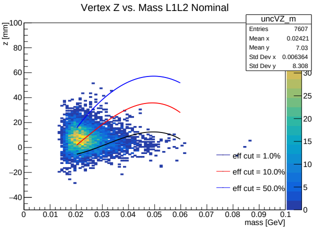
- Shifts peak of the distribution towards larger z
- Curves show the fraction of efficiency curve (i.e. the 10% curve is the $z_{0.10}$ is the solution to $\frac{\int_{z_{targ}}^{z_{0.10}} eff(z)dz}{\int_{z_{targ}}^{z_{max}} eff(z)dz} = 0.10$)
- Higher mass has larger z efficiency curves (may not even need zcut)

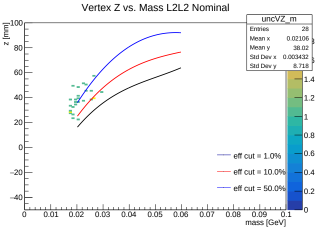




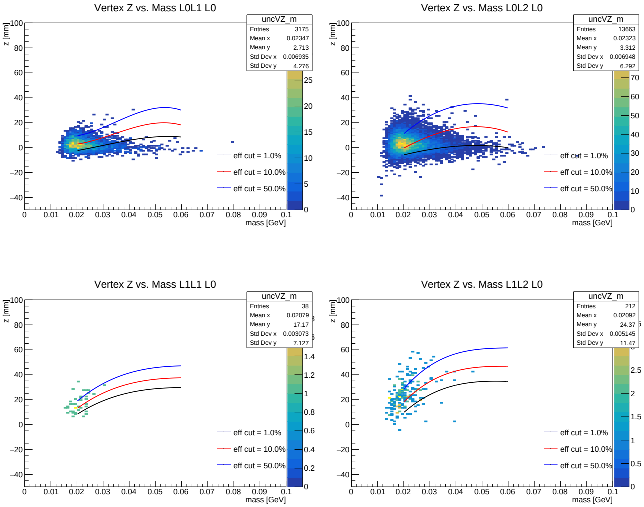
Other Layer Requirements Vz vs. Mass Nominal

- Can we trust this MC? Does this agree with data?
- In data, L1L2 has 30,000 events and L2L2 has 250 events at 120 1/nb (compared to 155 1/nb in MC)
- In the near future, **add the correct proportion of wabs and tighten up track extrapolation cut**



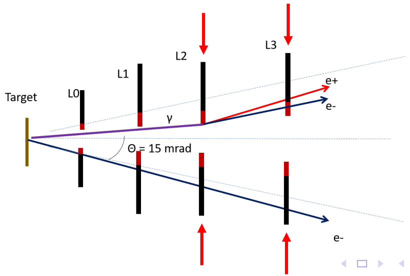


Other Layer Requirements Vz vs. Mass Upgrade Detector



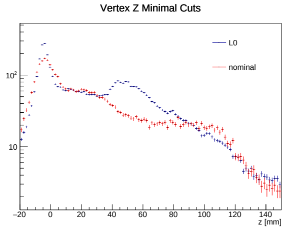
Backgrounds

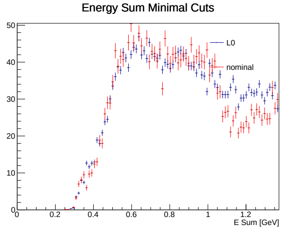
- Backgrounds produced at the target remain the same in upgrade detector
- Increased multiple scattering due to silicon (L0) in tracker which is accounted for in the previous analysis
- **Increased converted wabs due to extra silicon** (L0) and moving silicon into **lower angular acceptance** (L2 and L3)
- **Trigger rate is 30 kHz for L0 and 22 kHz for nominal**



Backgrounds - Increased Wabs due to L0

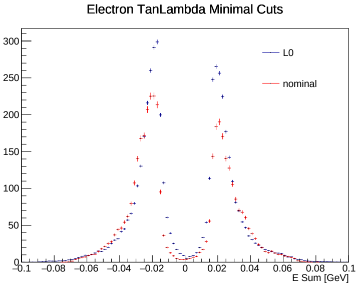
- Only beamspot χ^2 (for bad track fits) and isolation cuts (for mis-hits) are present
- There is clearly a large rate increase at L0 due to converted wabs
- The remainder of **vertexing cuts eliminates these events**

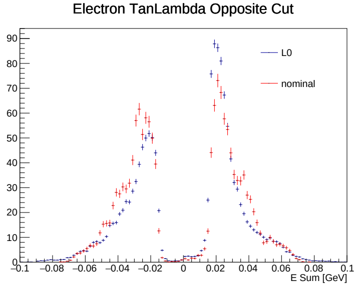




Backgrounds - Increased Wabs due to L2 and L3

- Large rate increase for electrons below 15 mrad (due to L2 and L3 moving towards the beam)
- Requiring opposite volumes of electrons/positrons **minimizes this rate increase**





Future Work

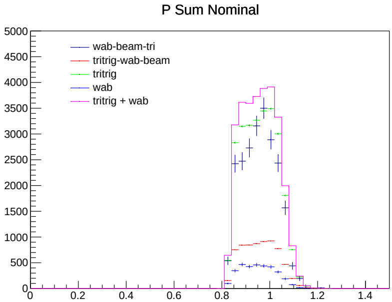
- **Mix correct fraction of wabs into the MC** and solve other MC issues
- More carefully optimize cuts for L0, currently cutting out too many events (also solve other minor problems)
- Obtain total reach from all exclusive layer requirements (very challenging)
  - Vertex pulls and impact parameter cuts seem promising
- Recoil electron acceptance studies and occupancy studies
- **Do it all again for 2.3 GeV!**
- Open for ideas (but not too open...)

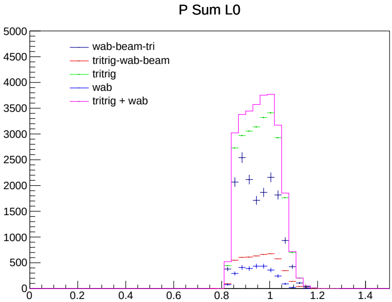
Conclusion

- Adding a tracking layer between the target and current first layer **improves vertex resolution by about a factor of 2** in all relevant beam energies, and hence improves the zcut
- By simply requiring first layer hits, the **L0 detector shows a drastic improvement in reach** compared to the current setup for 1.05 GeV
- It is reasonable to say that **reach will improve significantly for other relevant beam energies**
- Moving in tracking layers 2 and 3 in by 0.8 mm **improves displaced A' detection acceptance**
- Mass resolution also improves slightly, and **background rates are manageable**
- It is recommended that **L0 production proceed ASAP** (Tim)

Backup Slides

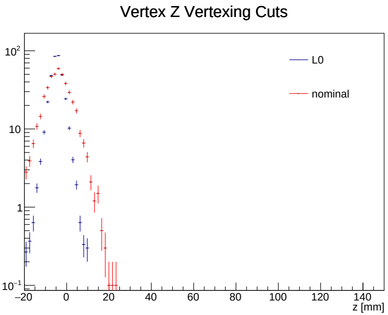
- MC Rate Comparisons





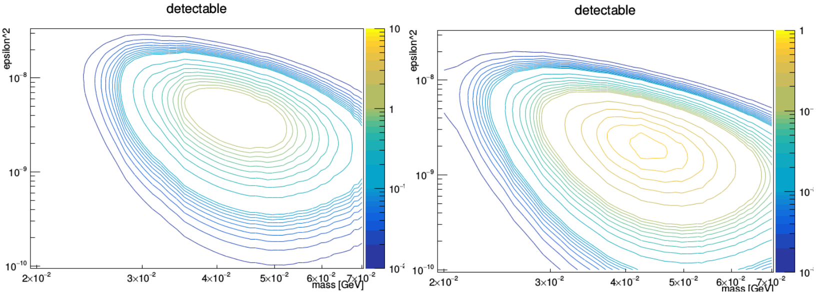
Backup Slides

- Vertex Z for background simulation using vertexing cuts



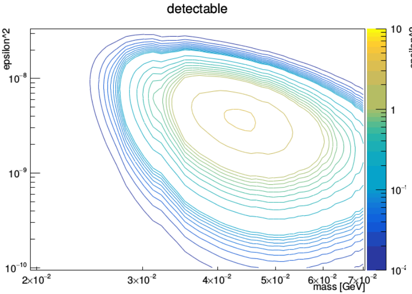
Backup Slides

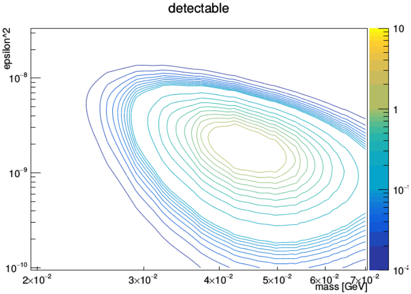
- Number of A’s detectable for 4 weeks for L0 (left) and nominal (right)



Backup Slides

- Number of A's detectable for 10 weeks for L0 (left) and nominal (right)





Backup Slides

- Number of A's detectable for 180 days for L0 (left) and nominal (right)