Searching for a Resonance with HPS

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On behalf of the Heavy Photon Search Collaboration

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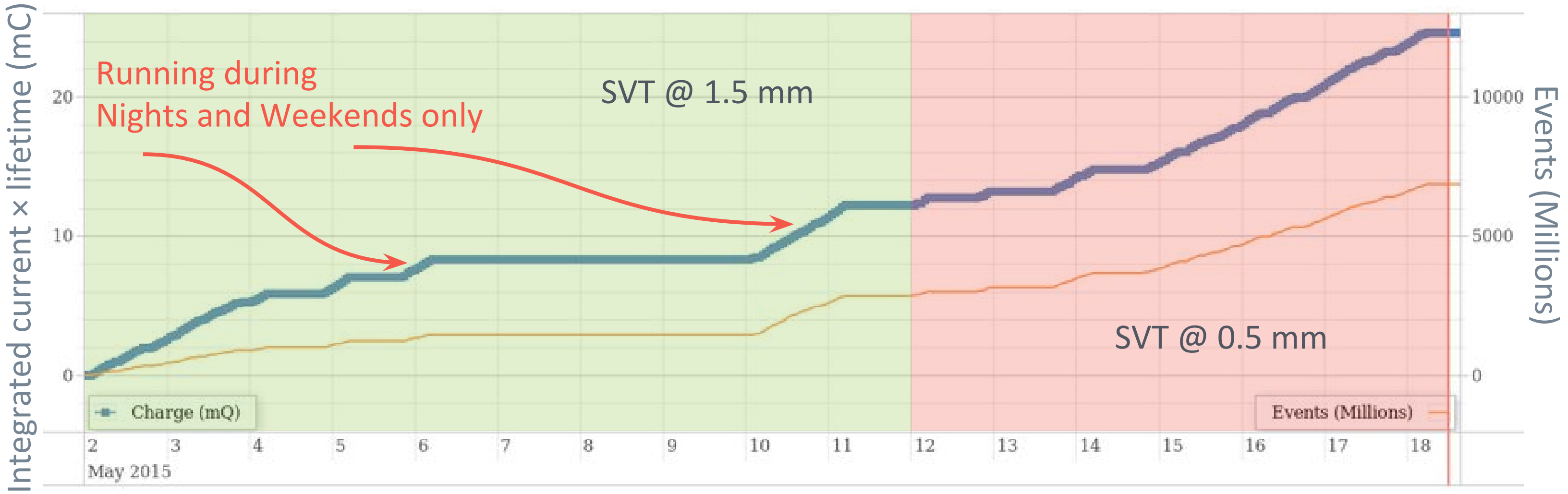
The HPS Engineering Run

The HPS Engineering Run took place in the Spring of 2015 at JLab using a 50 nA, 1.056 GeV electron beam

- ✔ Goal: Understand the performance of the detector and take physics data.
- ✔ Data was taken with the Silicon Vertex Tracker (SVT) in two configurations: active edge at 1.5 mm and 0.5 mm from the beam plane.
- ✔ Total data taken: ~1000 nb^{-1} with the SVT at 1.5 mm and ~1165 nb^{-1} at 0.5 mm



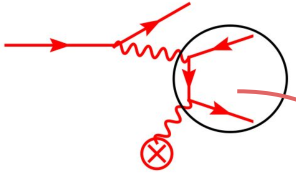
This results shown in this talk used ~74 nb^{-1} of the unblinded data taken at 0.5 mm
Results using the full dataset will be published in the spring.

e+e- Invariant Mass Reconstruction

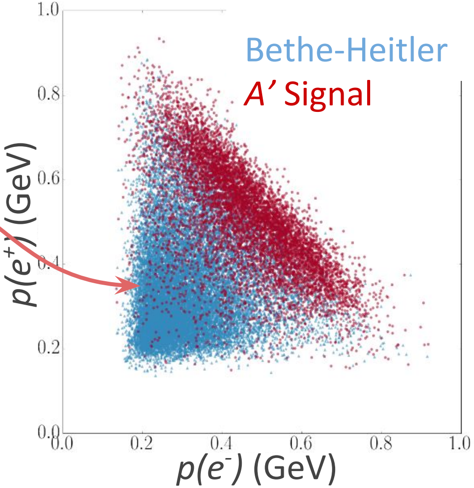
The search for an *A′* involves looking for a narrow resonance in the e^+e^- invariant mass spectrum on top of a large, continuous background composed of several components

Physics Backgrounds

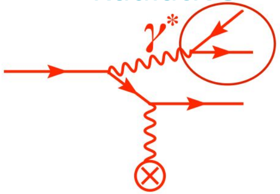
Bethe-Heitler



Dominant, but most lies below the A′ signal region.



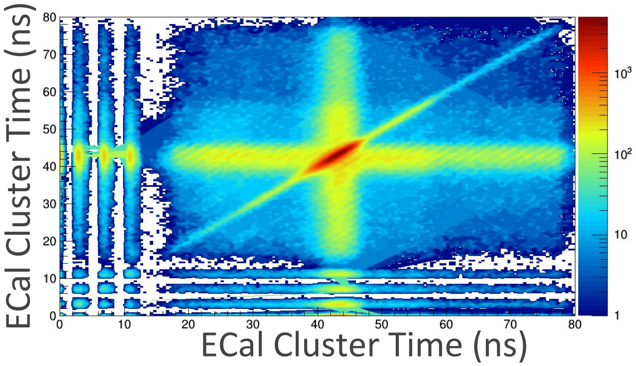
Radiative



Irreducible. Kinematically identical to A′ but can be used to understand expected *A′* rates.

$$\frac{d\sigma(e^- Z \to e - Z(A' \to l^+ l^-))}{d\sigma(e^- Z \to e - Z(\gamma^* \to l^+ l^-))} = \frac{3\pi\epsilon^2}{2N_{eff}\alpha}\frac{m_{A'}}{\delta m}$$

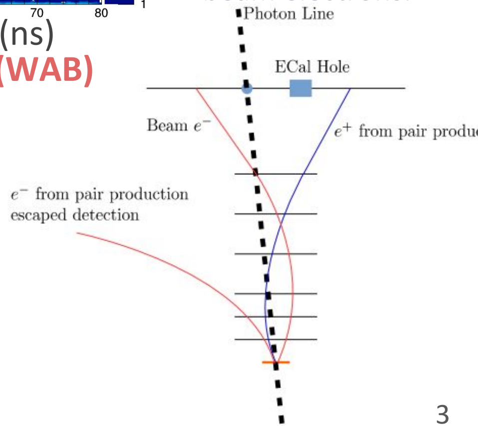
Accidentals



True e+e- pairs will have time-coincident clusters in the calorimeter. Can suppressed using time cuts and cuts used to remove scattered beam electrons.

Wide Angle Bremsstrahlung (WAB)

Conversions of photons produced in the target and first few layers of the SVT can mimic a trident e+e- pair

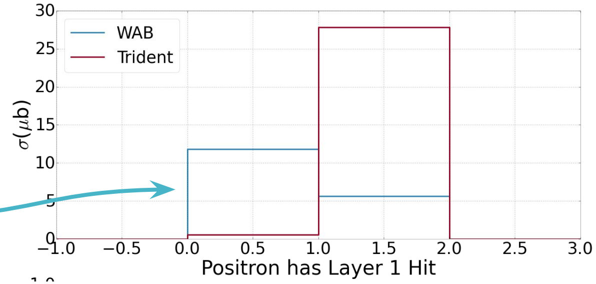


Supressing Wide Angle Bremsstrahlung

Missing Layer 1 Hit

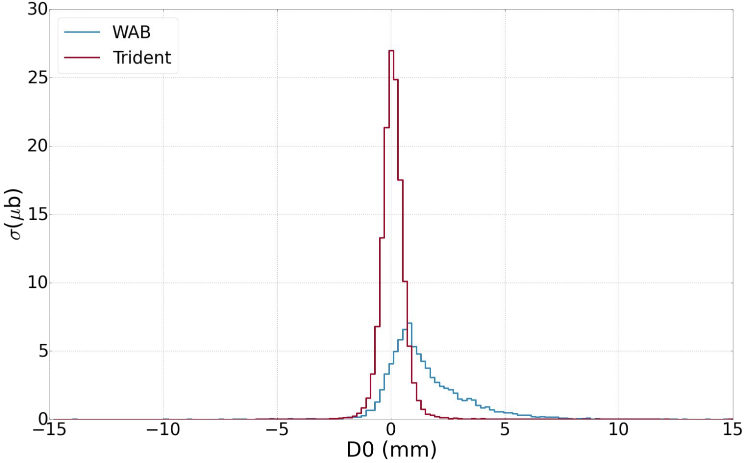
A majority of conversions will occur in layer 1 of the Silicon Vertex Tracker → positron will be missing a layer 1 hit

Layer 1 requirement removes 68% of WABS from final event sample!



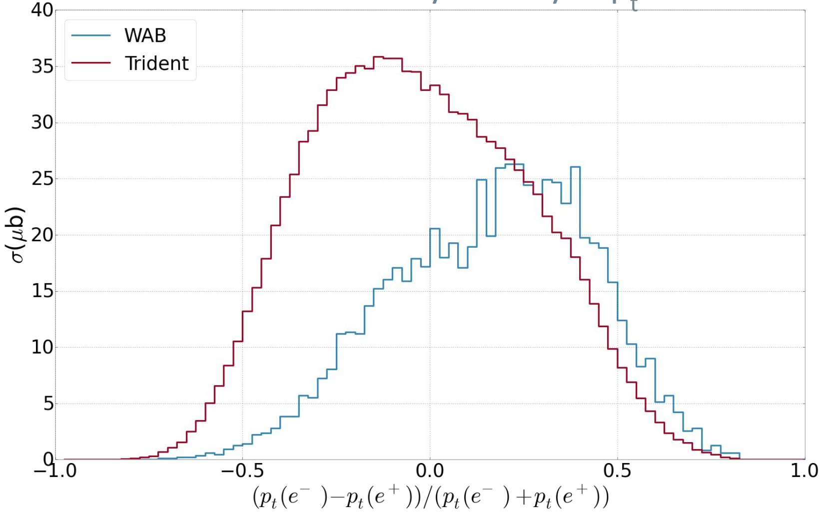
Positron Track Distance of Closest Approach

If a conversion occurs in the silicon, the positron track will extrapolate to the side of the nominal target position.



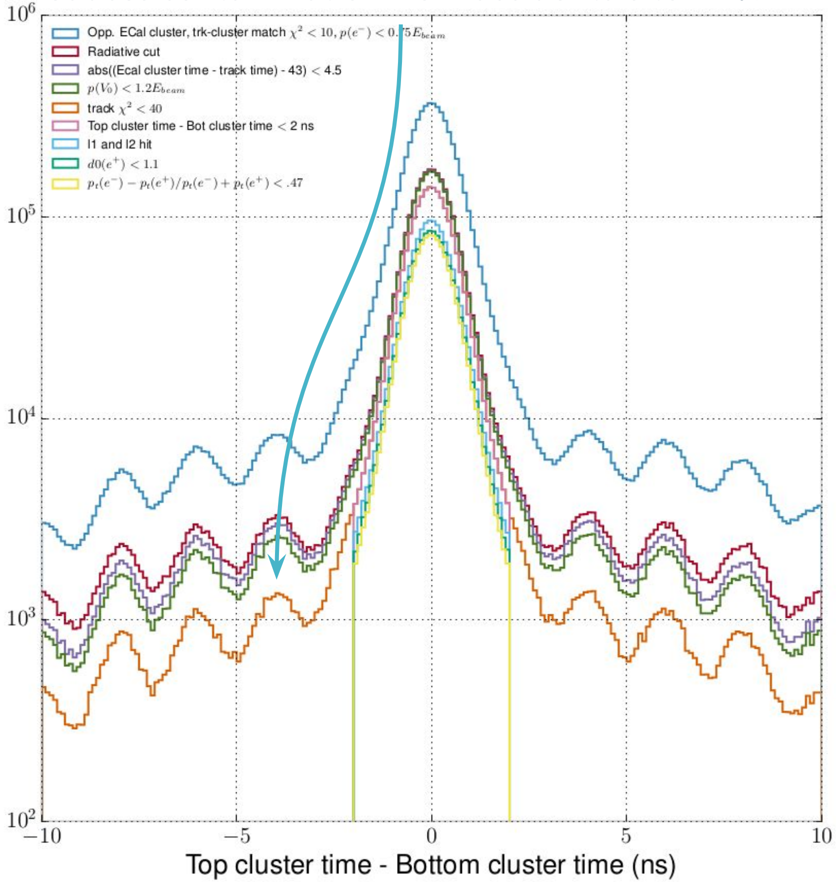
P_t Asymmetry

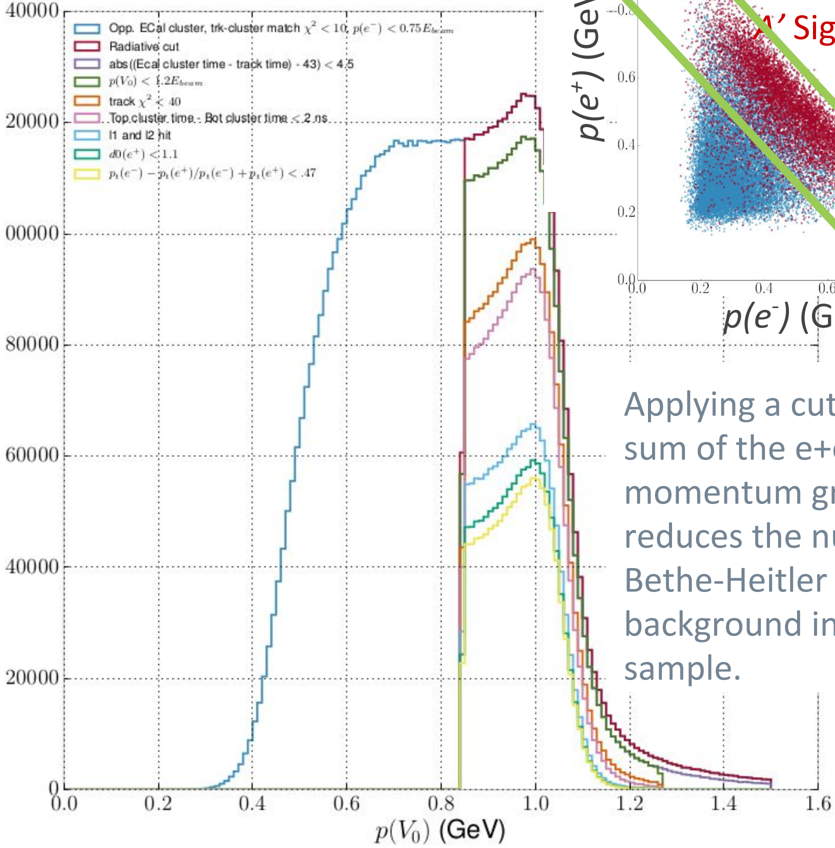
Because the positron is produced in a conversion, there will be an asymmetry in p_t

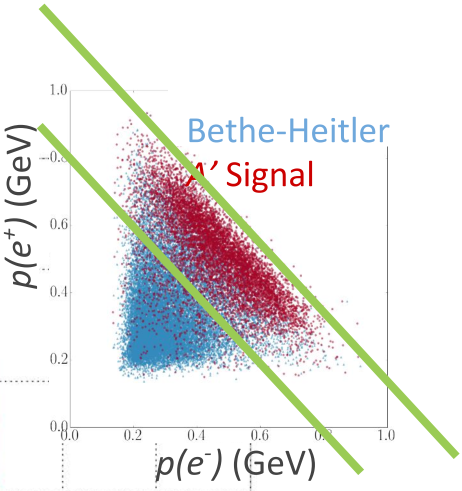


Final Selection

Apply kinematic and goodness of track and vertex fit cuts to clean up accidentals.
Reduces contamination from accidentals to < 1%

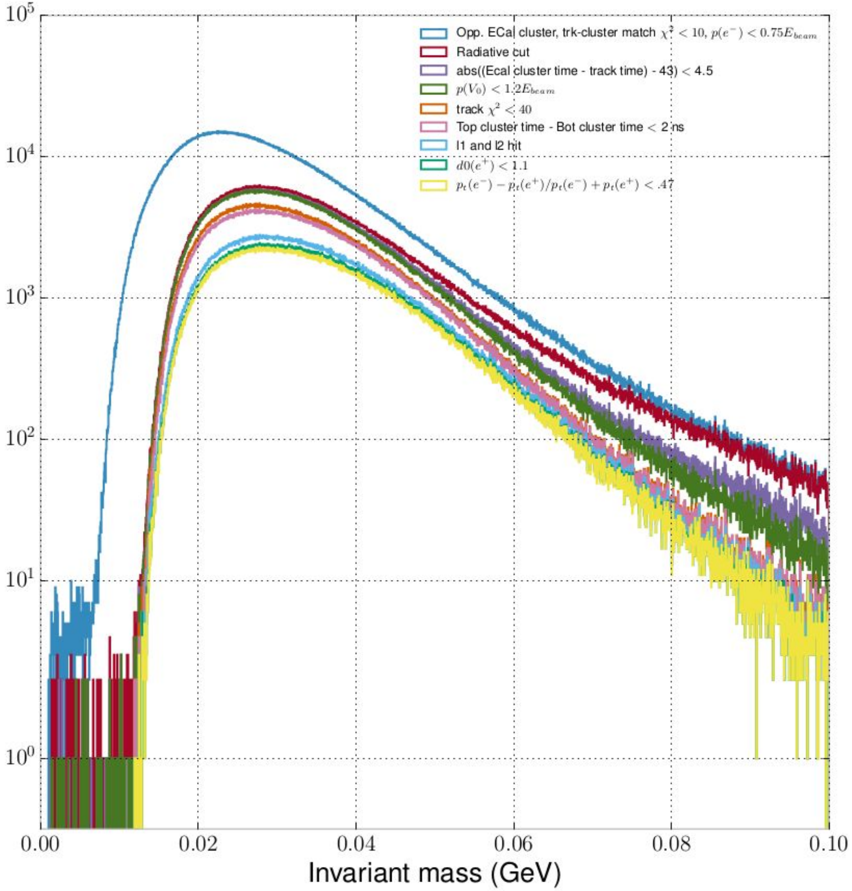






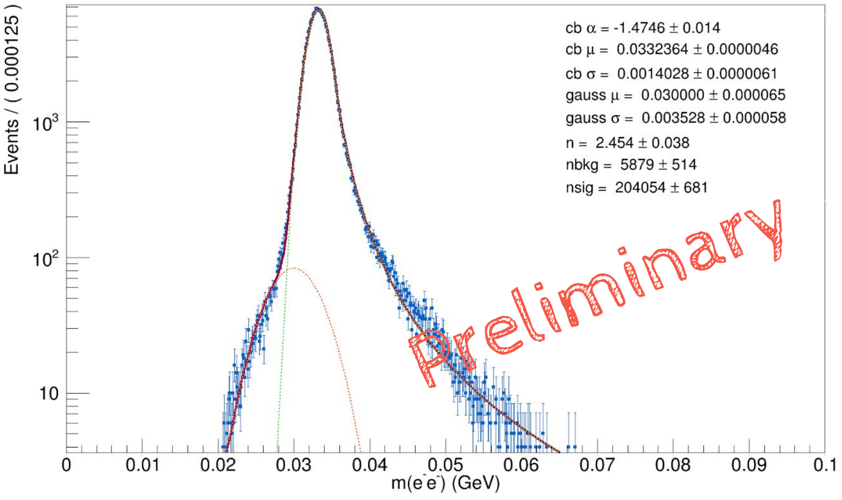
Applying a cut on the sum of the e+e- pair momentum greatly reduces the number of Bethe-Heitler background in our final sample.

Final Selection

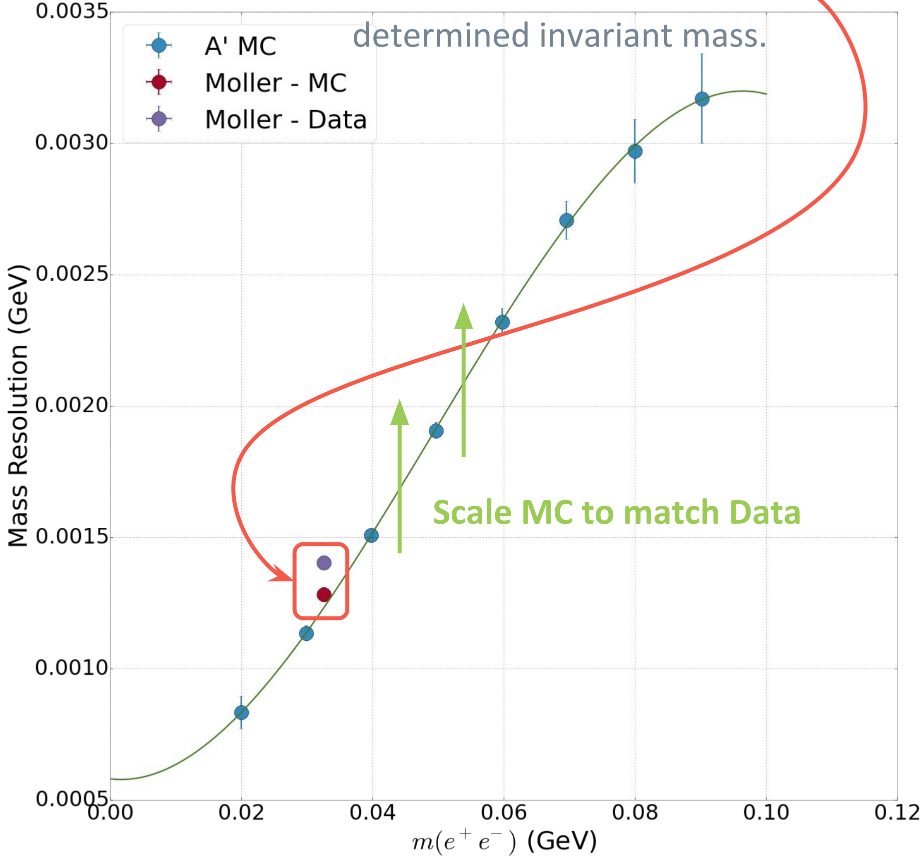


Mass Resolution

- ✔ Determined the resolution as a function of mass using *A′* and Møller Monte Carlo
- ✔ From data, use the Møller invariant mass distribution to measure the mass resolution
- ✔ Scale the MC mass resolution parameterization to match the data observation.

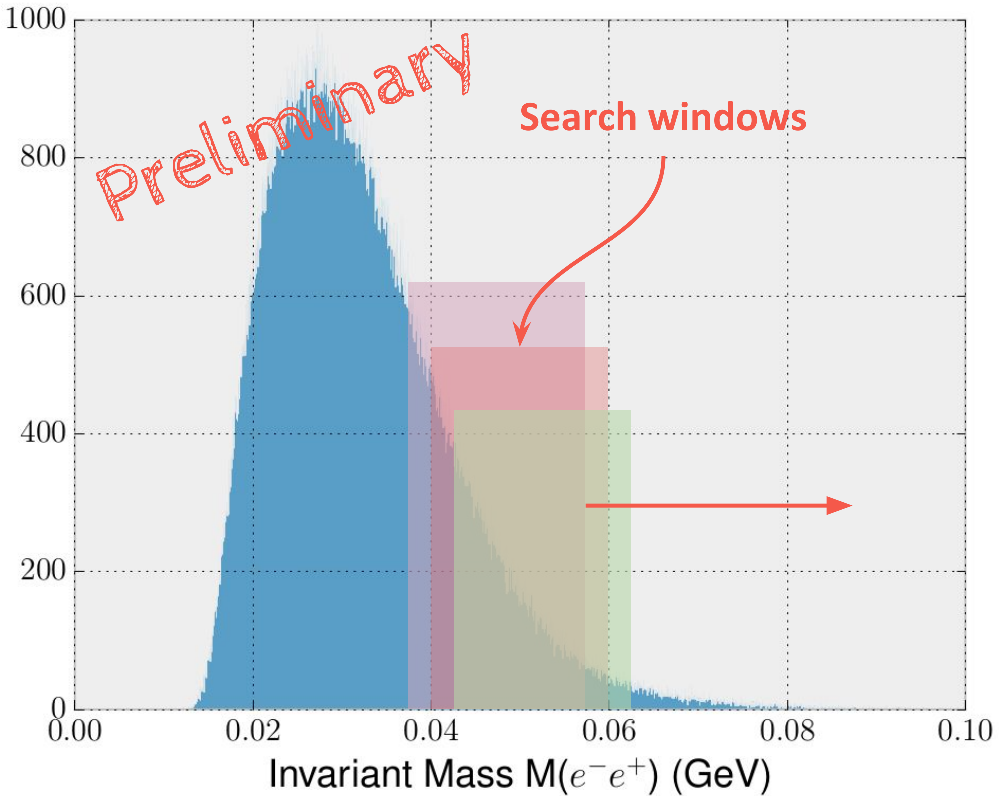


Data Møller invariant mass is within 10% of Monte Carlo determined invariant mass.



Resonance Search Overview

- ✔ Search for a resonance in the mass range between 17 MeV and 90 MeV by scanning the **e^+e^-** invariant mass spectrum
  - ✔ Pseudo-experiments are used to set the optimal search window
- ✔ Maximize the Poisson likelihood within the range using a composite model with the signal described as a **Gaussian** and a **7th order Chebyshev polynomial to model the background**
- ✔ Use Likelihood ratio to quantify significance of any excess i.e. “bump”
- ✔ Determine the 2σ signal upper limit at each mass hypothesis by inverting the likelihood ratio
- ✔ Translate the signal upper limit into the coupling-mass phase space



Fit Results

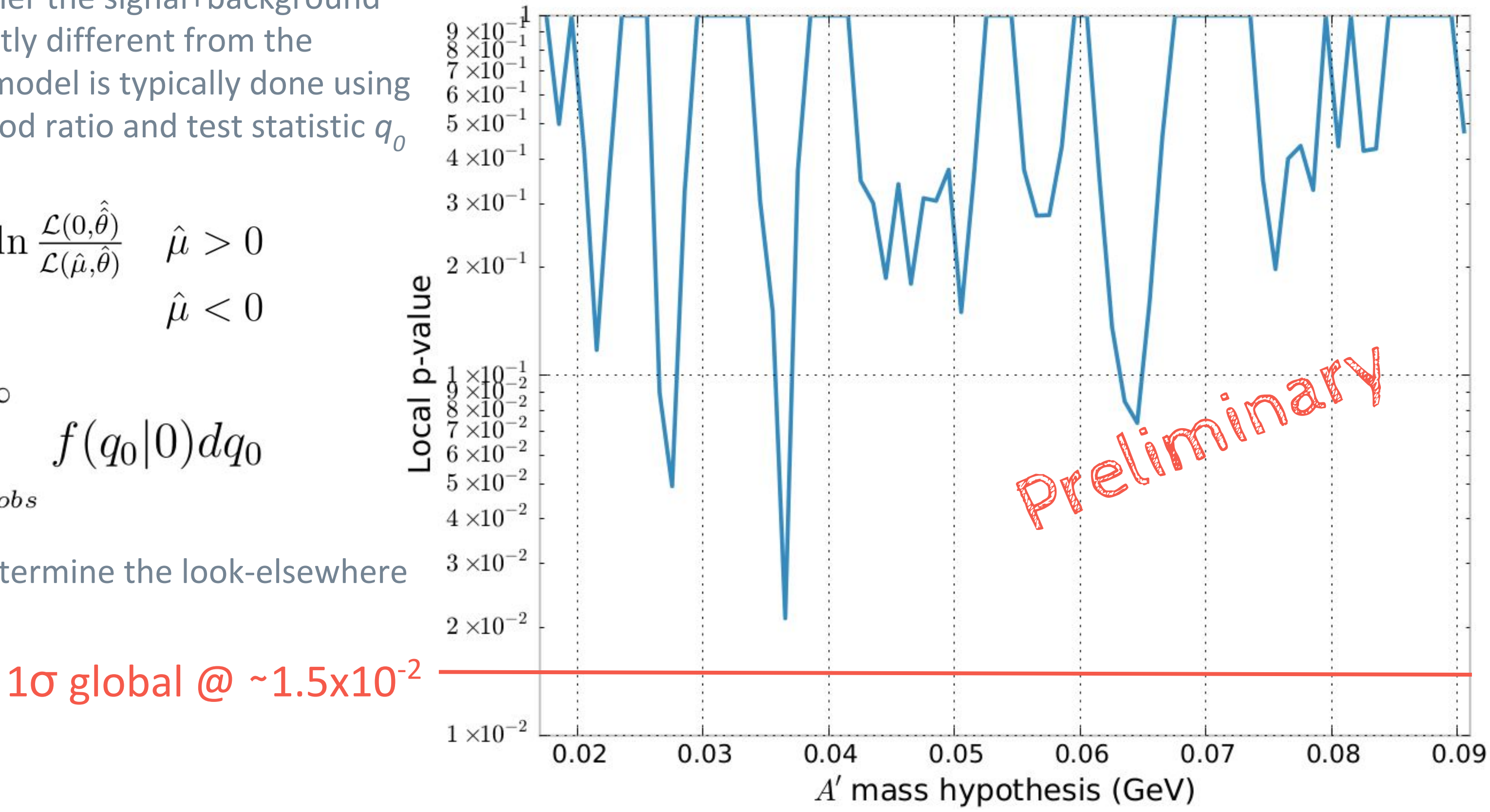
No significant bump was found!

Establishing whether the signal+background model is significantly different from the background-only model is typically done using the profile likelihood ratio and test statistic q_0

$$q_0 = \begin{cases} -2\ln \frac{\mathcal{L}(0,\hat{\hat{\theta}})}{\mathcal{L}(\hat{\mu},\hat{\theta})} & \hat{\mu} > 0 \\ 0 & \hat{\mu} < 0 \end{cases}$$

$$p = \int_{q_{0,obs}}^{\infty} f(q_0|0)dq_0$$

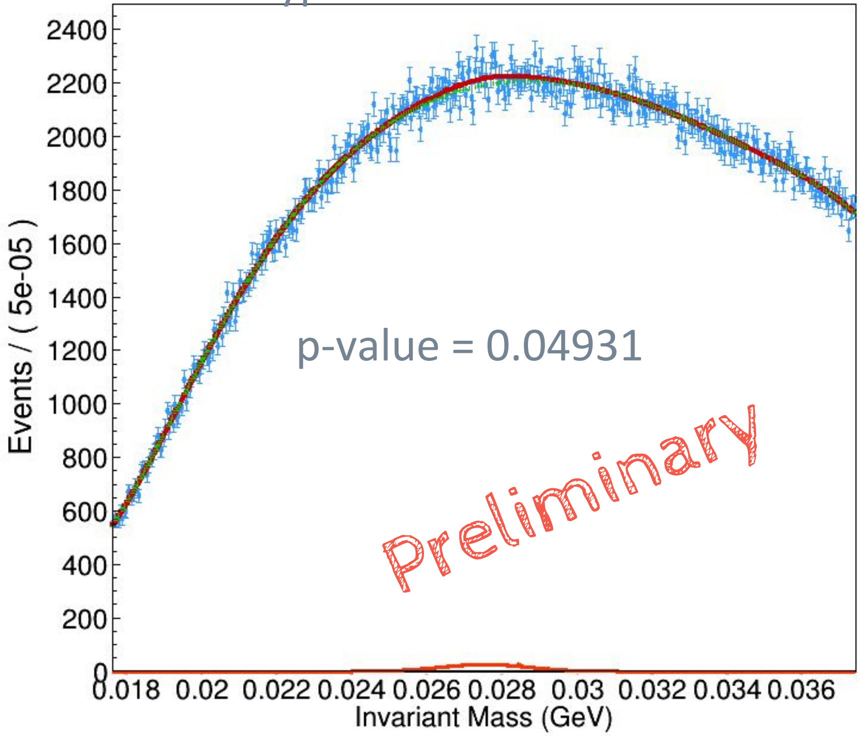
Use toy MC to determine the look-elsewhere correction



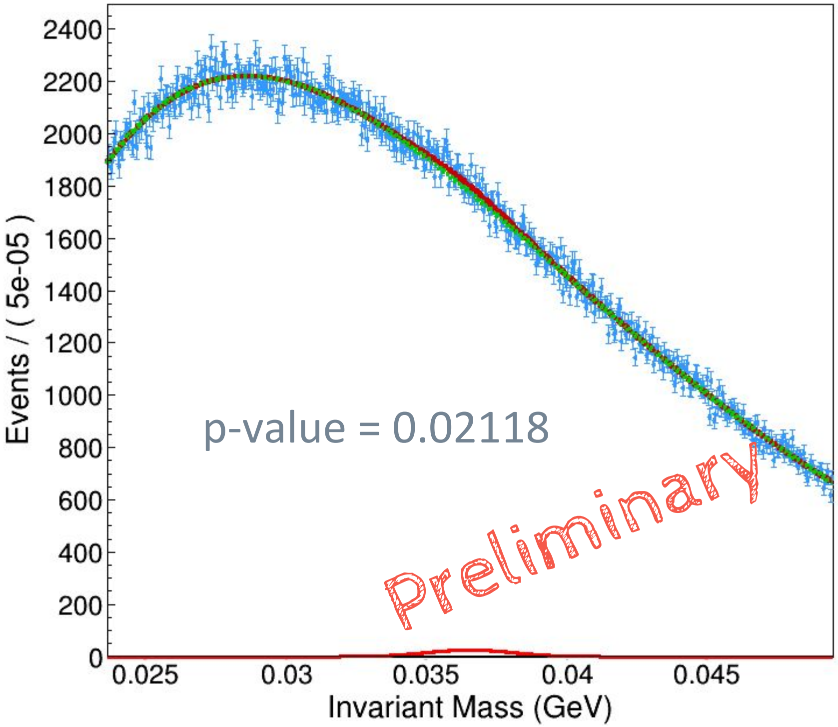
Most Significant Bumps

The two bumps with the smallest p-values

Mass hypothesis = 27.525 MeV

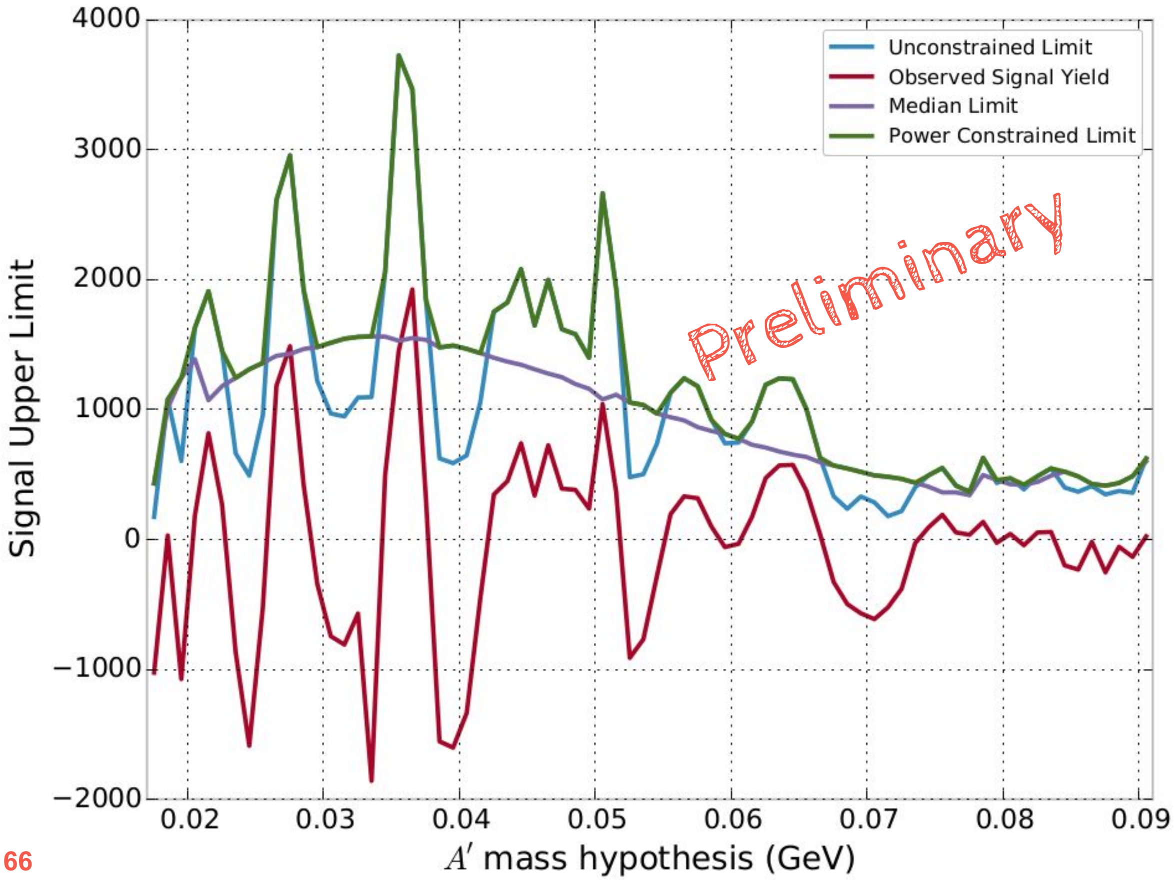


Mass hypothesis = 36.525 MeV



Power Constrained 2σ Limits

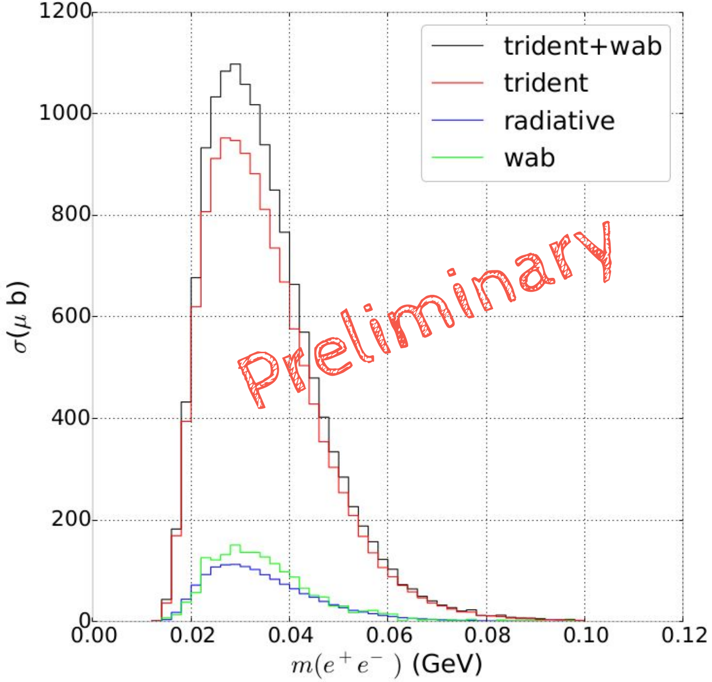
Use power constrained limits ⟶ Require that the experiment has enough sensitivity to a signal yield before excluding

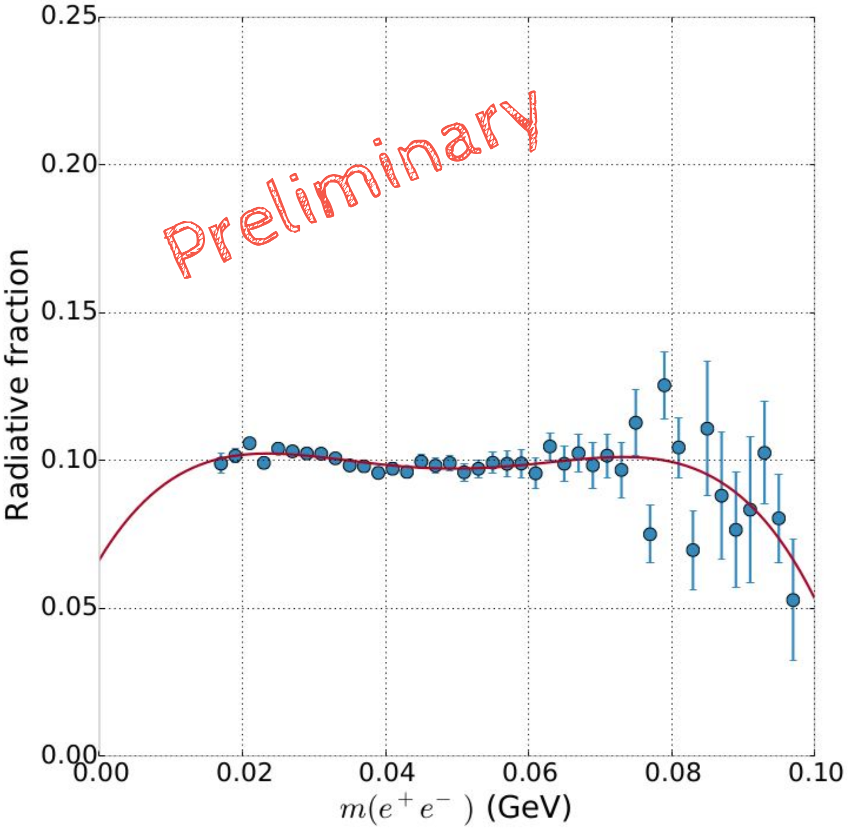


Power Constrained Limits: arXiv:1105.3166

Radiative Fraction

Translating the signal upper limit into the mass-coupling phase space requires knowledge of the fraction of radiatives events in our event sample ⟶ use Monte Carlo to parametrize the radiative fraction as a function of mass.





Upper Limit on Coupling Strength

Upper Limit

$$\left(\frac{\alpha'}{\alpha}\right)_{max} = \left(\frac{S_{max}/m_{A'}}{f \cdot \Delta B/\Delta m}\right) \times \left(\frac{2N_{\text{eff}}\alpha}{3\pi}\right)$$

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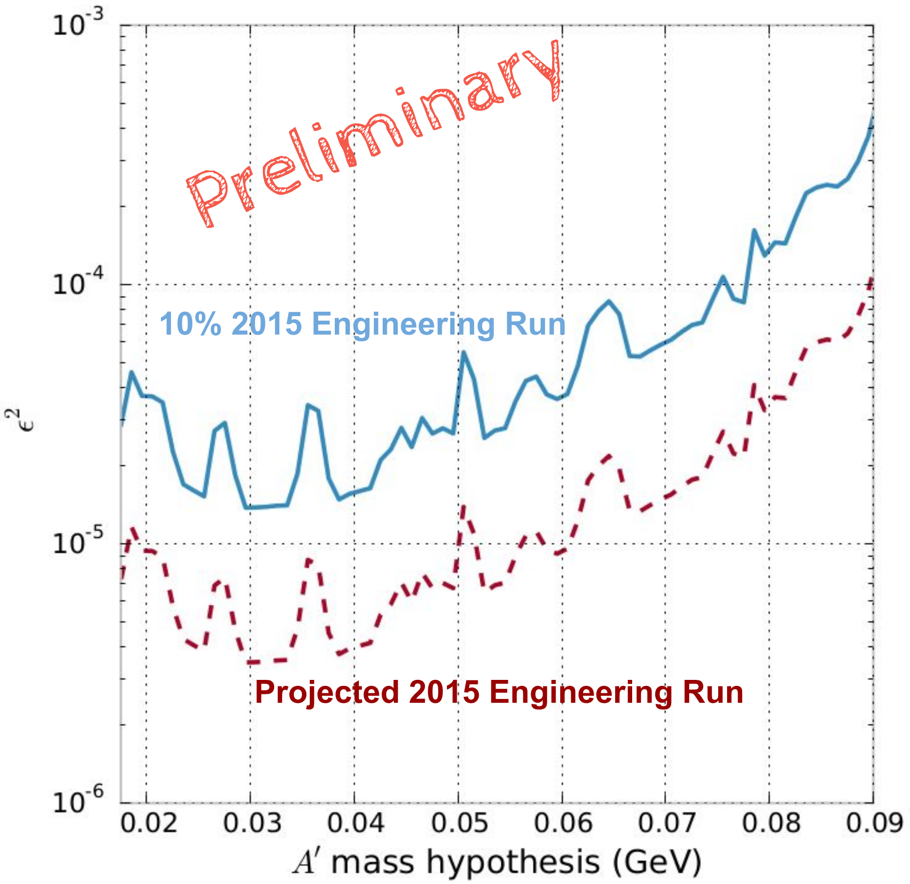
Radiative fraction

Background/MeV

No new territory is expected to be covered using the 1.7 PAC days of engineering run data ⟶ **The 2018 run will.**



Conclusion

A resonance search for an A' with a mass ranging between 17 MeV and 90 MeV and decaying to an e^+e^- pair was performed using the unblinded portion (~10% of the data) of the 2015 HPS engineering run dataset (1.7 beam days).

- ✔ **No significant signal was found**
- ✔ Preliminary, 2σ upper limits on the square of the *A'* coupling were set at the level of 10^{-4}

A resonance search using the full dataset will be published this spring.