Sensitivity Studies for the Planned X(16.7)-Boson Test with the MEG II Apparatus

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The Anomaly

Observation in Beryllium

An anomaly in the pair production

$$^{8}\text{Be}^{*} \rightarrow\ ^{8}\text{Be} + ee$$

was observed. The results could be explained by a new boson ("X-Boson", "Fifth Force", "$X(16.7)$") at an energy of $16.7 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV.

A. J. Krasznahorkay et al., PRL 116, 042501 (2016)

Observation in Helium

A similar anomaly is observed in Helium. This anomaly hints to the same particle ($16.84 \pm 0.16(\text{stat}) \pm 0.20(\text{syst})$ MeV).

A. J. Krasznahorkay et al., arXiv 1910:10459

The X-Boson Search

Signal and Background

- **Signal:** X-Boson decay

$$^7\text{Li}(p, X)^8\text{Be}, \quad X \to ee$$

- **Background 1:** Internal Pair Conversion (IPC)

$$^7\text{Li}(p, ee)^8\text{Be}$$

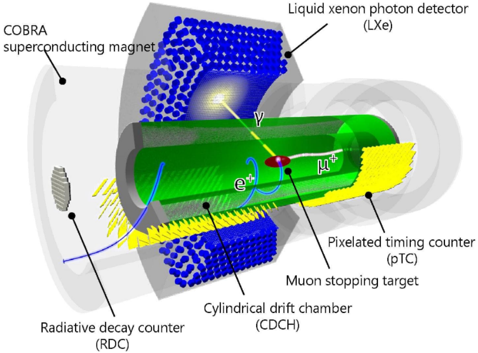
- **Background 2:** External Pair Conversion

$$^7\text{Li}(p, \gamma)^8\text{Be}, \quad \gamma \to ee$$

Reject external pair conversion via vertex cuts, require good resolution on the invariant mass to see X-Boson excess.

The MEG II Experiment

Looking for $\mu \to e\gamma$ down to a BR of $6 \cdot 10^{-14}$



Detect:

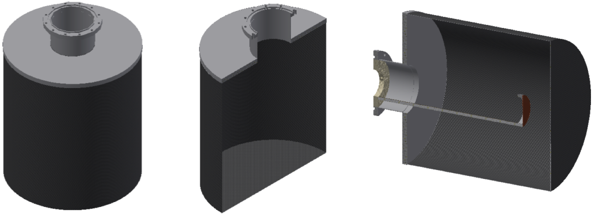
- 52.8 MeV photon
- 52.8 MeV positron
- back-to-back
- in time coincidence

The highly performing spectrometer for low energy positrons can be used for X-Boson searches by replacing the muon stopping target.

Adjustment 1: Large Vacuum Chamber

Motivation

- Reduce multiple scattering in material between target and drift chamber.
- Gain space around target: Cooling and vertex constraint in vacuum.



Dimensions: Radius 14 cm, Lenght 30 cm, Thickness 200 μm

Heat dissipation through target arm? Data-taking only during main accelerator shutdown period.

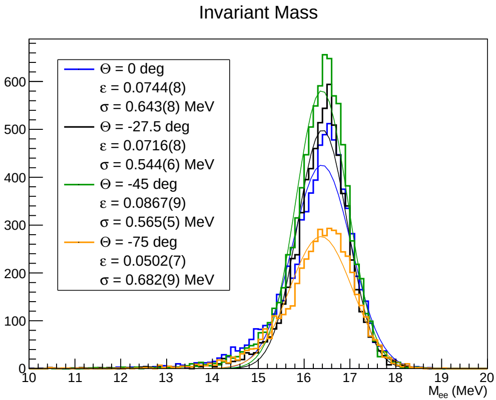
Adjustment 2: Lithium Target Structure

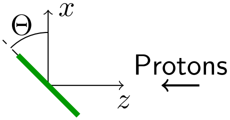
Questions for the target design:

- **Substrate:** Aluminium or Copper? Thickness?
- **Support Structure:** Material (Al, Cu)? Size? electron reconstruction vs. heat dissipation.
- **Flange Connection:** Heat dissipation.
- **Target Orientation:** Tilt? Rotation?

Tradeoff between particle physic ideals and engineering constraints has to be made.

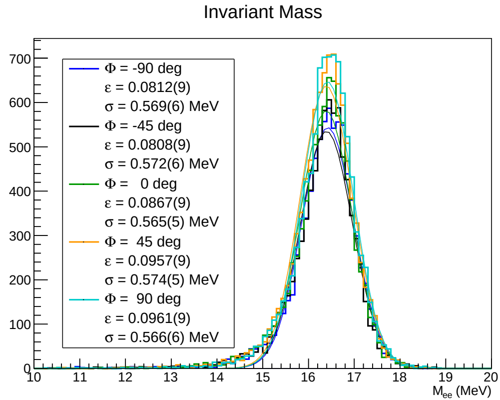
Target Tilt Angle

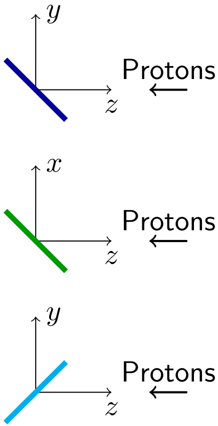




Tilting by -45° seems a viable option. Is there a preferred orientation?

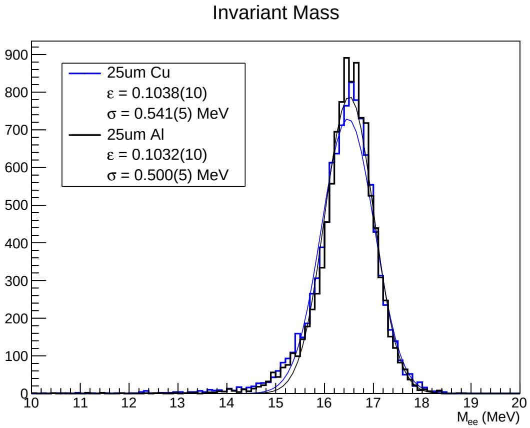
Target Orientation





Efficiency prefers target facing away from drift chamber sectors not read out.

Target Substrate Material



Aluminium is preferred terms of resolution. Check feasibility from engineering point of view.

Insights on the Geometry

Particle Physics Point of View

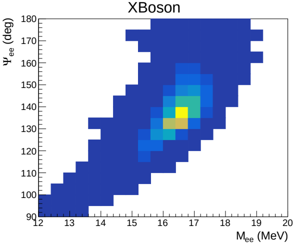
Best performance (efficiency, resolution) for a target

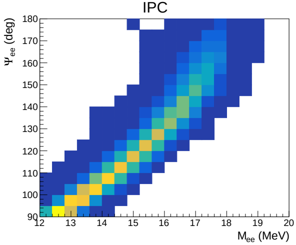
- … tilted around 45°, Lithium Oxide surface facing away from drift chamber sectors not read out.
- … with a thinner substrate.
- … with a substrate made of aluminium.

Optimal Target Structure to be used.

- Orientation as favoured by resolution and efficiency.
- Copper substrate of 25 μm thickness.
- Layer of 10 μm Lithium Oxide.
- Used for the simulation henceforth.

Binned Data in Two Dimensions



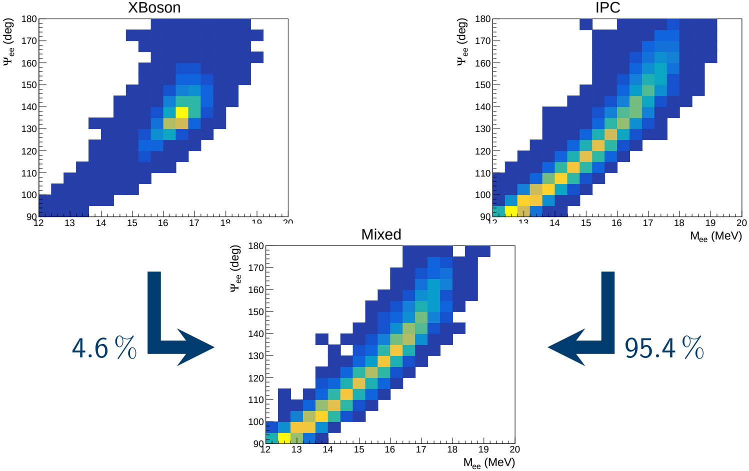


$\frac{BR(^7\text{Li}\ (p,X)\ ^8\text{Be})}{BR(^7\text{Li}\ (p,\gamma)\ ^8\text{Be})}$	$5.8 \cdot 10^{-6}$
Efficiency	$12\,\%$

$\frac{BR(^7\text{Li}\ (p,ee)\ ^8\text{Be})}{BR(^7\text{Li}\ (p,\gamma)\ ^8\text{Be})}$	$3.9 \cdot 10^{-3}$
$p(\Psi_{ee} > 70°)$	$19\,\%$
Efficiency	$2\,\%$

Resample by randomly picking values from the distributions according to branching ratios and detection efficiencies.

Binned Data in Two Dimensions



Need to identify the X-Boson peak on top of the IPC spectrum

Fitting Procedure

Fitting the Background

Bins excluded for the background fit if both criteria match:

- Bin centres between 120° and 160°
- Bin centres between 15 MeV and 18 MeV

The spectrum obtained from the IPC simulation is used, leaving only one multiplicative constant free to fit.

Computing Residuals

For each bin, the residuals between the resampled, mixed distribution and the scaled IPC spectrum are computed.

Looking for the most significant excess. Check invariant mass, relative angle and correlated histogramms individually.

Estimating Significance and Runtime

Significance

The significance is estimated by:

$$s = \frac{N_{\text{signal}}}{\sqrt{N_{\text{total}}}} = \frac{\sum N_i - N_i^{\text{IPC}}}{\sqrt{\sum N_i}}$$

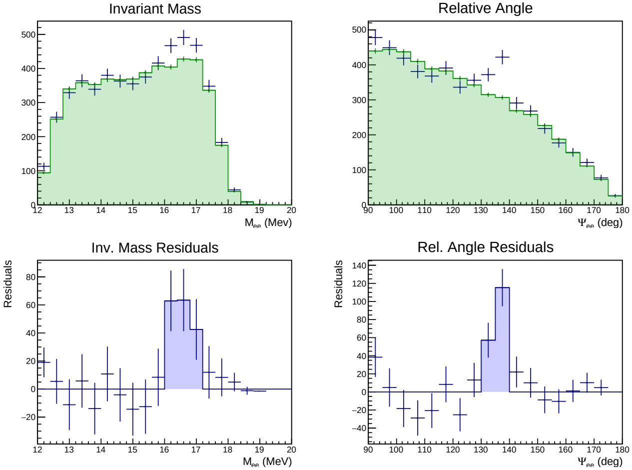
Runtime Estimation

The total IPC rate is estimated to:

- 10 Hz - 30 Hz @ 1 μA (Pen and paper rescaling)
- 28.9 Hz @ 1 μA (Simulation based)

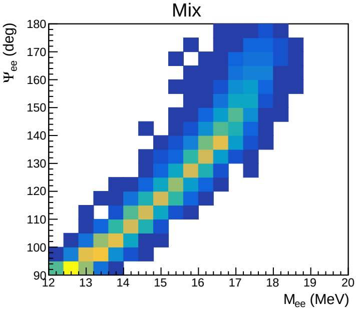
Use the conservative rate estimate to find the time needed to achieve a $s = 5$ excess.

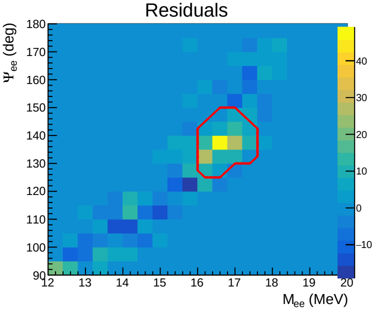
Residual Plots



Repeat multiple times and consider look-elsewhere effect.

Residual Plot for Correlated Search

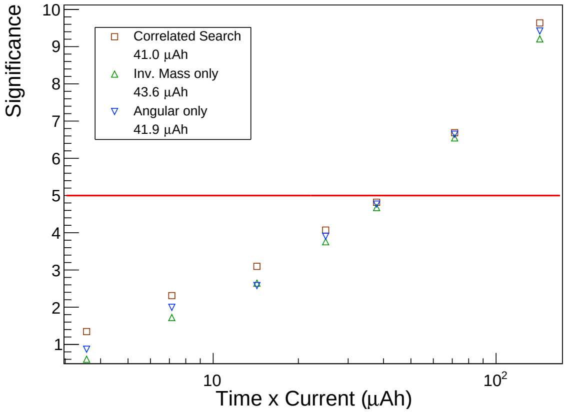




Determine the search contour (red) based on 100 tries. Apply it to another 100 tries.

Repeat for different amount of events. Translate number of events to runtime.

Significance and Runtime



Need ≈40 h of pure measuring time. Build-up and calibration not included. Still shorter than $\mathcal{O}$(months) shutdown period.

Conclusion

The General Idea

An anomaly was observed in the pair production from an excited Beryllium state. It hints towards a new boson. A test of this anomaly is foreseen with the MEG II apparatus.

Simulation Insights

- The optimal target geometry is a 10 μm Lithium Oxide layer on a 25 μm copper substrate, slanted by 45°.
- A 5σ excess is expected to show up after about 40 hours of measuring time at 1 μA proton beam current.

Outlook

We aim to prepare for a measurement at the start of next year before HIPA startup. Otherwise a year later.