Calibration Study of PRad Experiment

Maxime Levillain

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U.S. DEPARTMENT OF ENERGY
JSA
Jefferson Lab
Thomas Jefferson National Accelerator Facility

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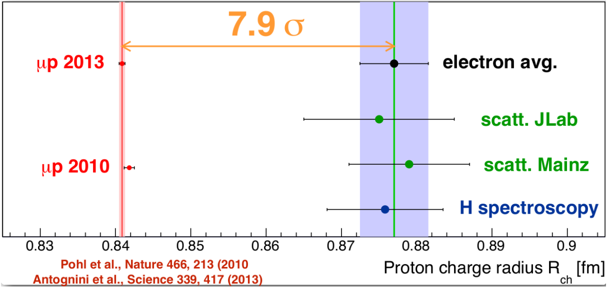
The Proton Radius Puzzle

- The proton radius r_p impacts all electromagnetic constants: R_∞, α...
- Primordial in nuclear ans atomic physics and spectroscopy

$\rightarrow$ $\sim 8\sigma$ discrepancy with muonic hydrogen measurement



$r_p(e^-) = 0.8770 \pm 0.0045 fm$ $r_p(\mu^-) = 0.8409 \pm 0.0004 fm$

Extraction from *ep* Scattering

PRoton Radius

- Previous measurement from *ep* scattering suffer from large uncertainties

→ Need new experiment with:
  - Controlled systematics (calibration/resolution/efficiency and radiative corrections)
  - Extraction over a large Q^2 domain ($2 \cdot 10^{-4}$ to $6 \cdot 10^{-2}\text{GeV}^2$)

- Extraction from Born cross-section:

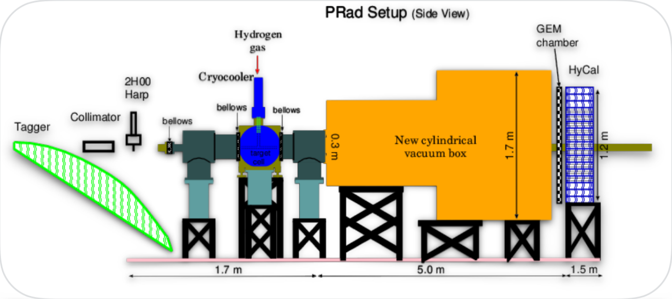
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left(G_E^{p\,2}(Q^2) + \frac{\tau}{\epsilon} G_M^{p\,2}(Q^2) \right)$$

with: $\tau = Q^2/(4M_p^p)$, $\epsilon = (1 + 2(1+\tau tan^2\theta/2))^{-1}$

and $\left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \frac{\alpha^2(1-\beta^2 sin^2(\theta/2))}{4k^2 sin^4(\theta/2)}$

$$\rightarrow\ < r_p^2 >= -6 \frac{dG_E^p(Q^2)}{dQ^2}\Big|_{Q^2=0}$$

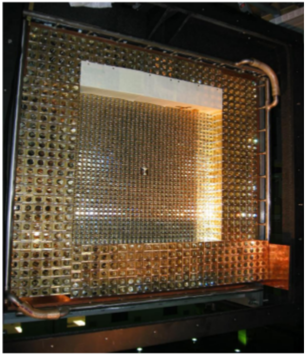
PRad Setup



- Electron beam or tagged photon beam at $\sim$ 1GeV or $\sim$ 2GeV
- Windowless, high density H_2 gas flow target ($1.8 \cdot 10^{18}\, H\, atoms/cm^2$)
- Vacuum box, one thin window at downstream
- Two Large area Gas Electron Multipliers (improve angle resolution)
- High resolution and high efficiency, Hybrid calorimeter (HyCal)

Hybrid Calorimeter - HyCal

- Central part:
  - 34 x 34 matrix of $PbWO_4$ detectors
  - dimension of block: 2.077 x 2.075 x 18 cm^3
  - 2 x 2 blocks removed from the middle
- Peripheral part:
  - 576 Leadglass detectors
  - dimension of block: 3.815 x 3.815 x 45 cm^3



Calibration Method

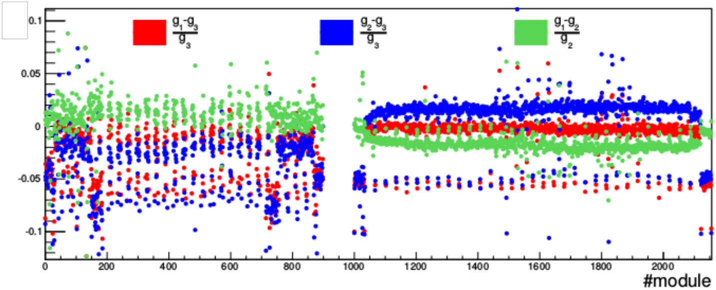
- Iterative method:

$$gain_{module}(n+1) = gain_{module}(n) / < E_{measured} / E_{expected} >$$

- Two different calibration:
  - Snake scan with 200-1050 MeV photon beam moved in front of each module
    $\rightarrow$ study of resolution, efficiency and non linearity
    ($E_{expected} = E_{\gamma}$ and $E_{measured} = E_{cluster}$)
  - Calibration during production periods with Møller and *ep* events
    ($E_{expected} = E_{\text{Møller}}(\theta)$ or E_{beam} and $E_{measured} = E_{cluster}$)

Cross-checks

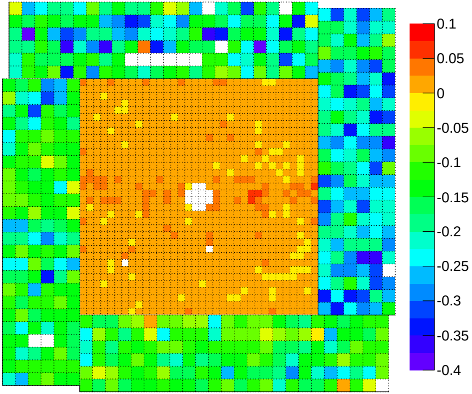
- 3 different calibrations:
  - with fortran clustering code from primex analysis software
  - with fortran clustering code embedded in c++ PRad software
  - with c++ clustering code
- Differences observed especially in the transition region



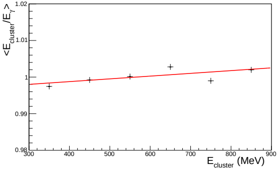
→ Differences of clustering in edges and transition regions

Non-Linearity of modules w.r.t. $E_{cluster}$

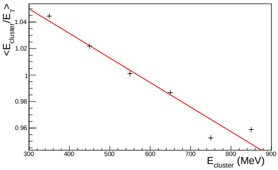
$$< E_{cluster}/E_{\gamma} >= \alpha \cdot E_{cluster} + \beta$$



PbWO$_4$



Leadglass

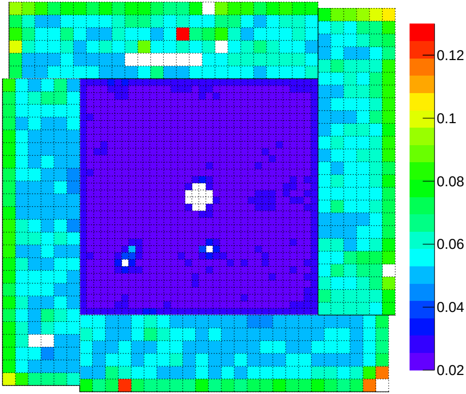


→ Non-linearity for leadglass modules has to be taken into account in the reconstruction

PbWO$_4$	Leadglass
0.01 GeV^{-1}	-0.17 GeV^{-1}

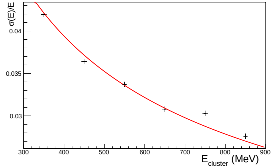
Resolution

$$\frac{\sigma(E)}{E} = \frac{r}{\sqrt{E\,(GeV)}}$$

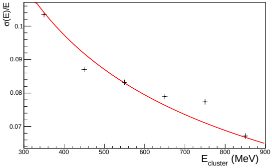


→ Expected results achieved

PbWO$_4$



Leadglass

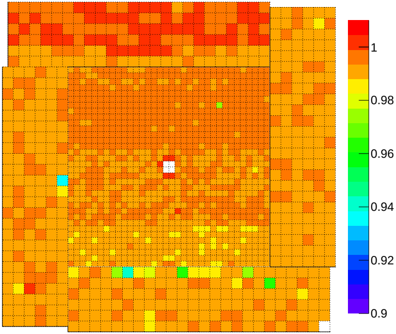


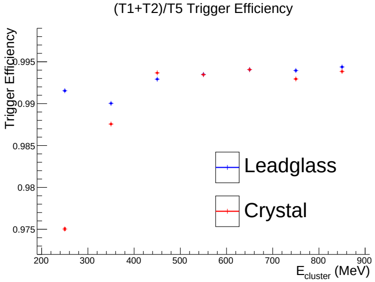
PbWO$_4$	Leadglass
0.025 %	0.061 %

Efficiency Study

- 3 triggers:
  2: TotalSum > 1: LeadGlassSum > 5: Tagger

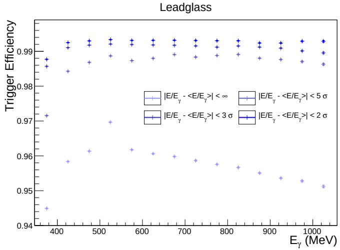
$$\epsilon = \frac{N_1 + N_2}{N_1 + N_2 + N_5}$$

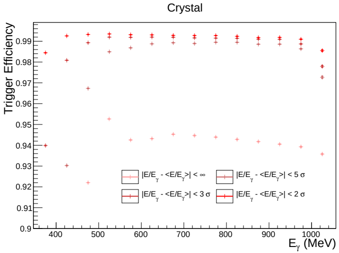


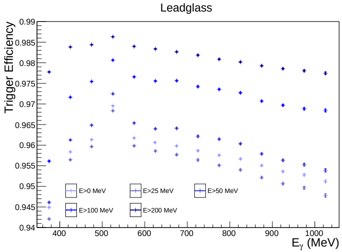


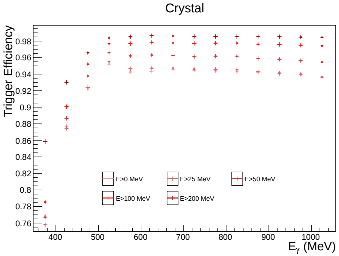
- Plateau from 450 MeV with an efficiency of 0.994
- Good uniformity

Results with different selections









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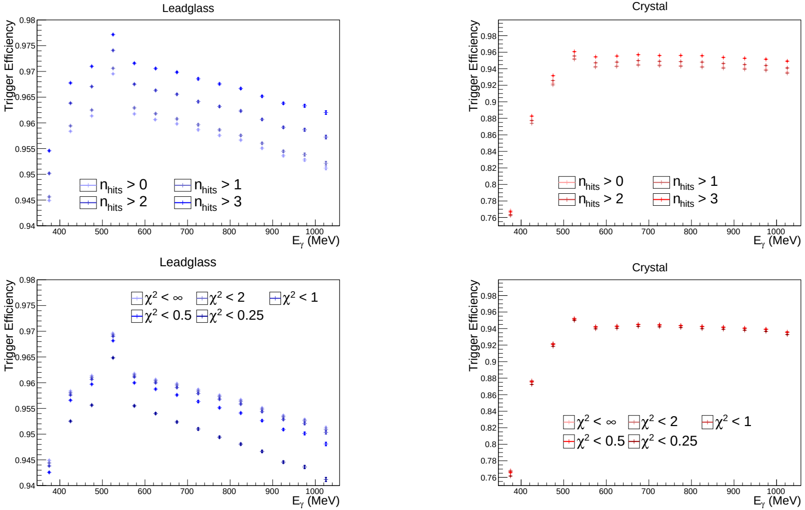

Summary

- PRad succesfully took data on May - June 2016
- Snake Calibration performed
  - Target resolution achieved
  - Very good efficiency
- Production Calibration on progress