Alpha background rejection in DEAP-3600 using pyrene

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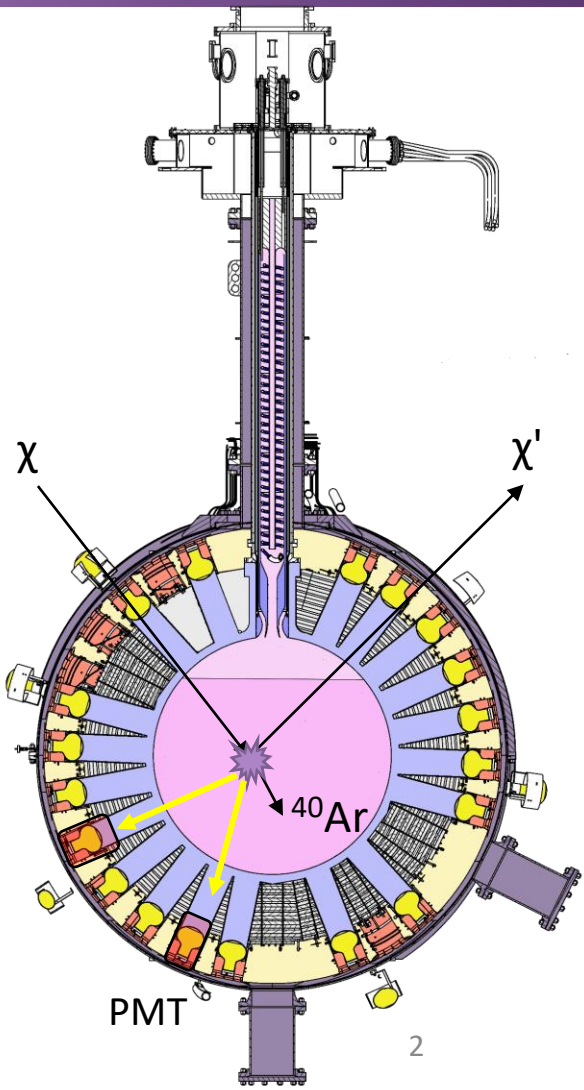
Carleton UNIVERSITY

2021 CAP Virtual Congress

June 10th, 2021

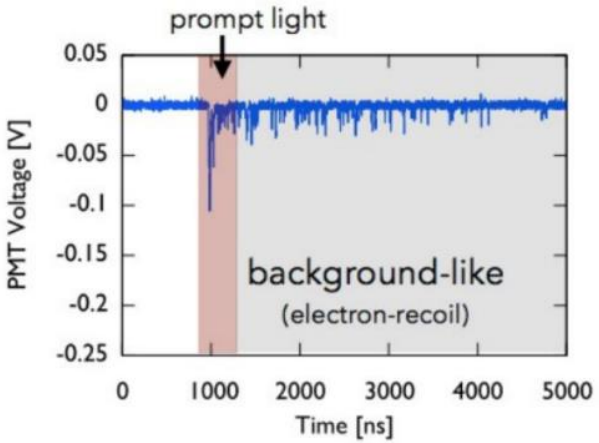
DEAP-3600

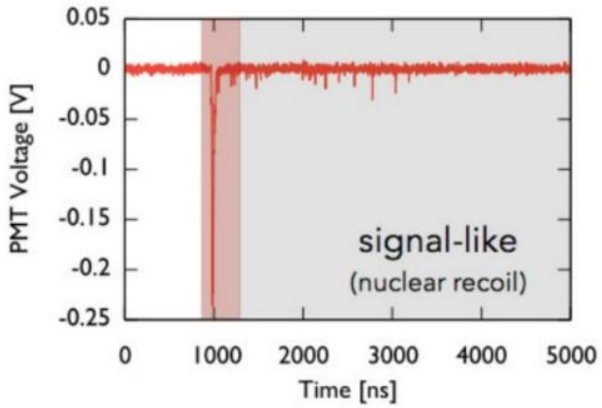
- Liquid argon based dark matter detector
- Located in SNOLAB, Sudbury, Canada
- Dark matter Experiment using Argon Pulseshape discrimination
- >3 tonnes target mass of LAr in acrylic vessel
- Collected data from 2016-2020; upcoming hardware upgrades this year



Backgrounds in DEAP

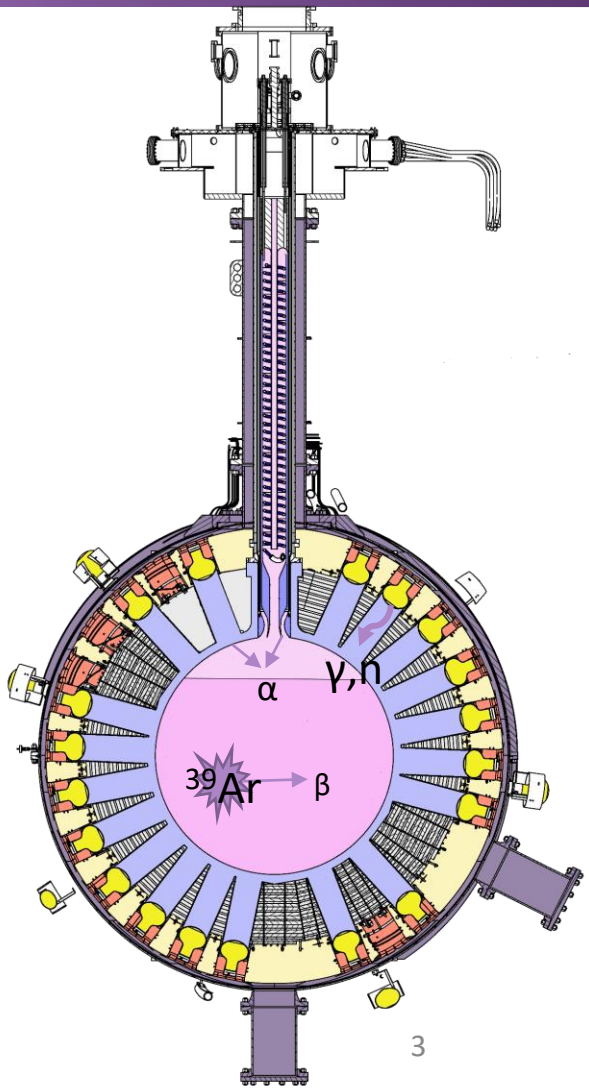
- Beta decays from ^{39}Ar
- Gammas and neutrons from PMT glass
- Alpha decays from radon progeny in acrylic





$$F_{prompt} = \frac{\Sigma_{t=-28\ ns}^{60\ ns} PE(t)}{\Sigma_{t=-28\ ns}^{10\ \mu s} PE(t)}$$

PSD!



Backgrounds in DEAP

- Beta decays from ^{39}Ar
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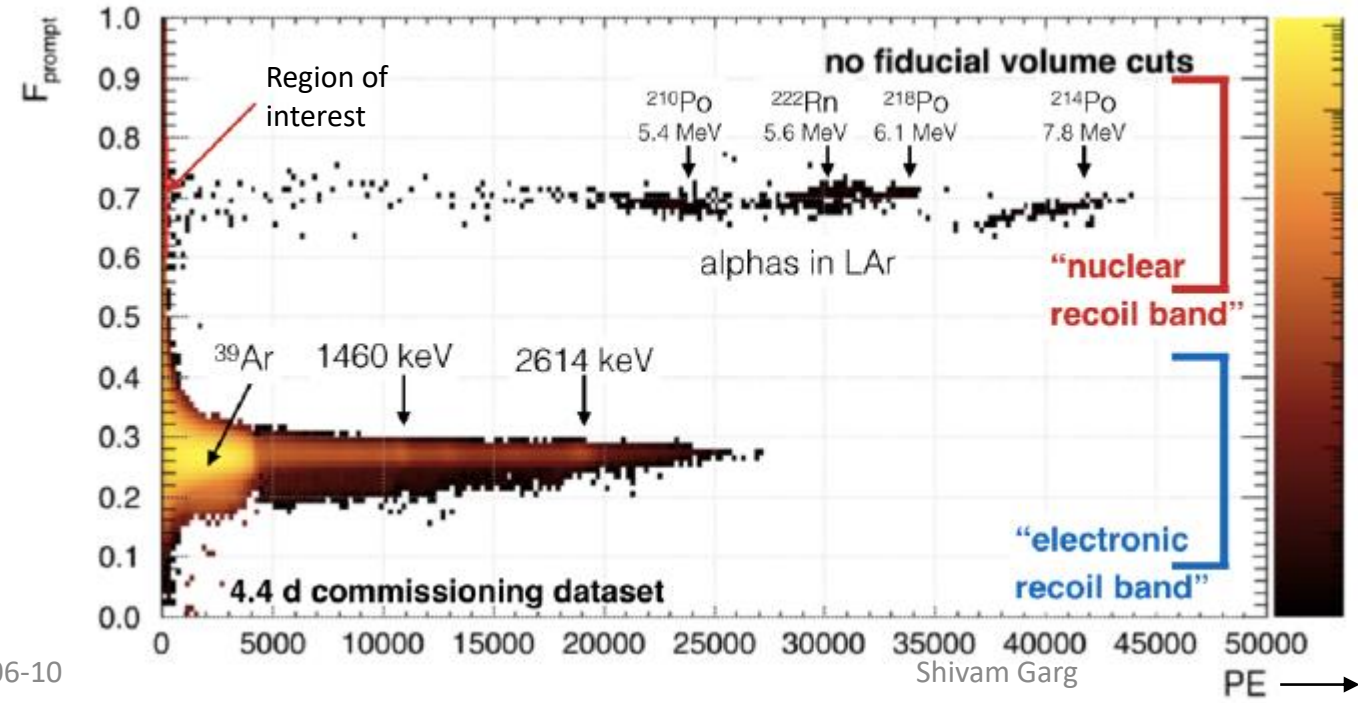
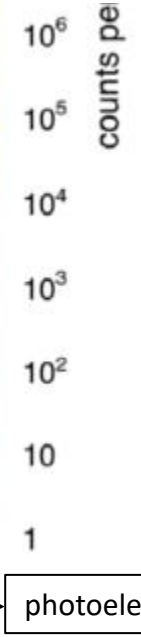
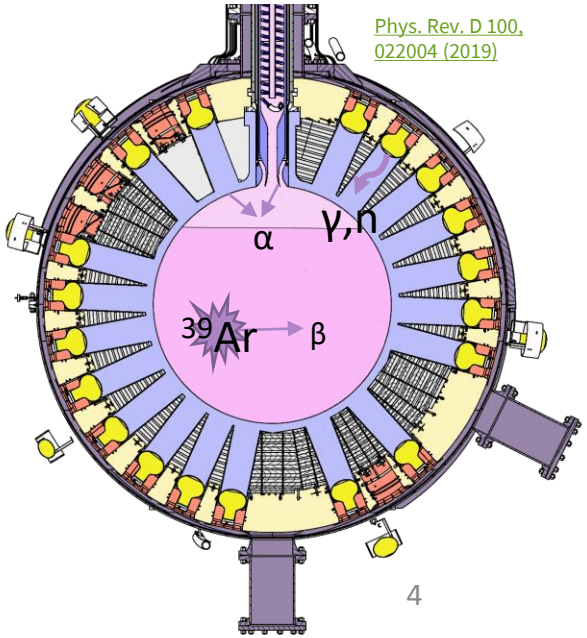
	Source	N^{CR}	N^{ROI}
β/γ's	ERs	2.44×10^9	0.03 ± 0.01
	Cherenkov	$<3.3 \times 10^5$	<0.14
n's	Radiogenic	6 ± 4	$0.10^{+0.10}_{-0.09}$
	Cosmogenic	<0.2	<0.11
α's	AV surface	<3600	<0.08
	AV Neck FG	28^{+13}_{-10}	$0.49^{+0.27}_{-0.26}$
	Total	N/A	$0.62^{+0.31}_{-0.28}$



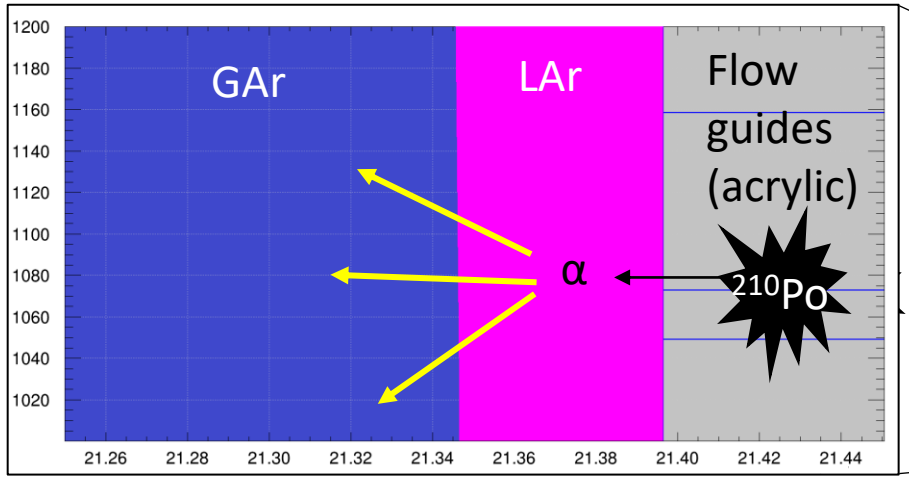


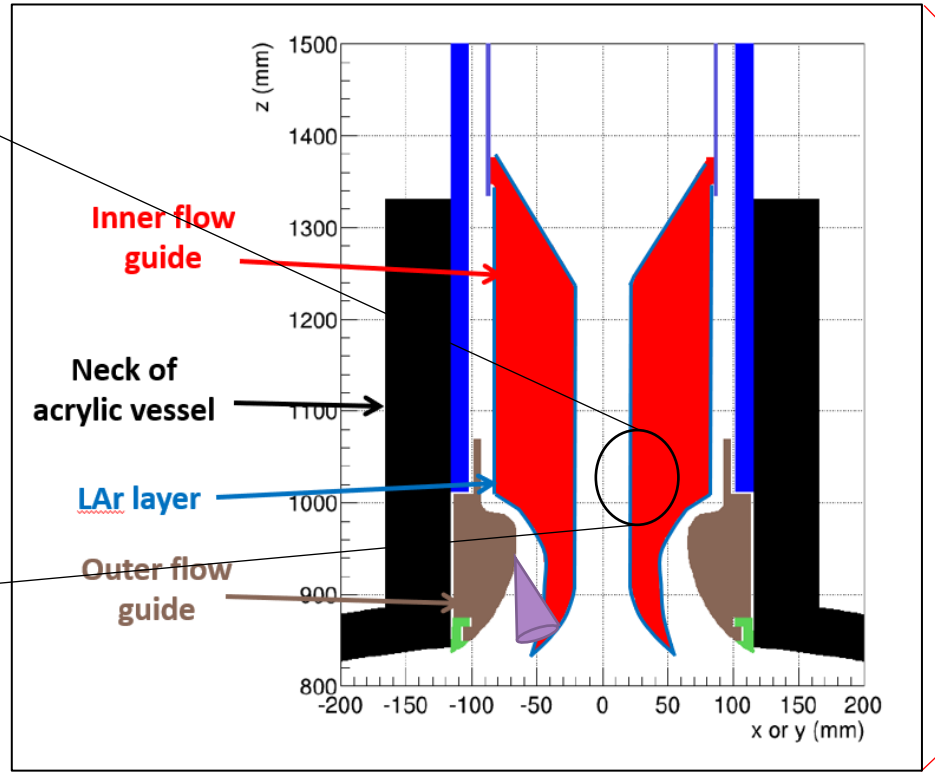


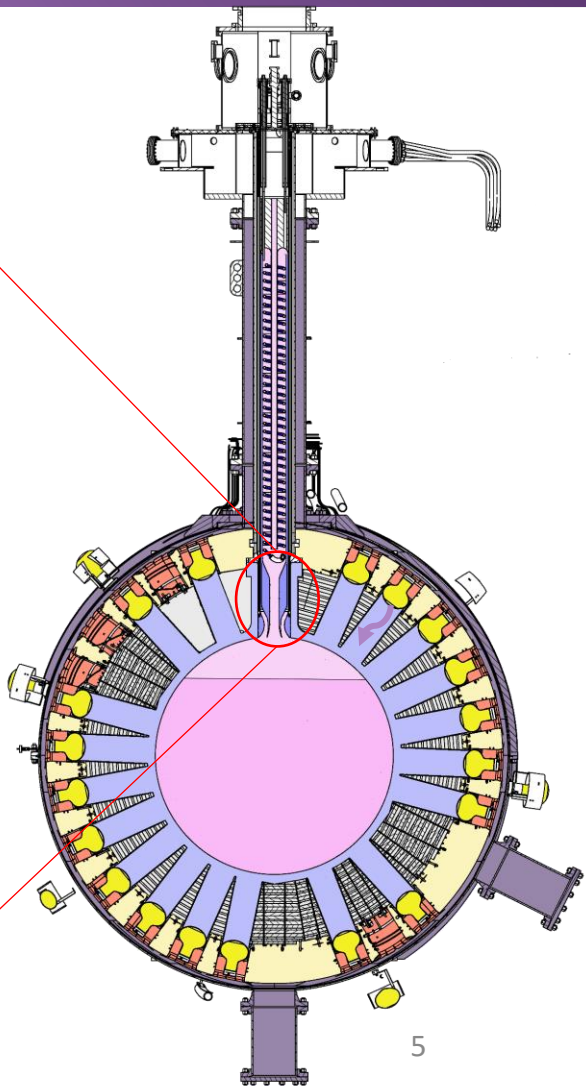
Phys. Rev. D 100, 022004 (2019)

Neck alphas

- Alpha decays from radon progeny in acrylic



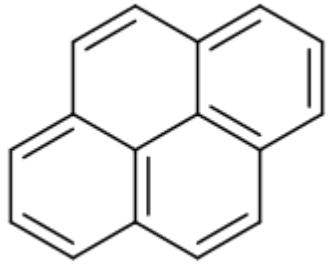


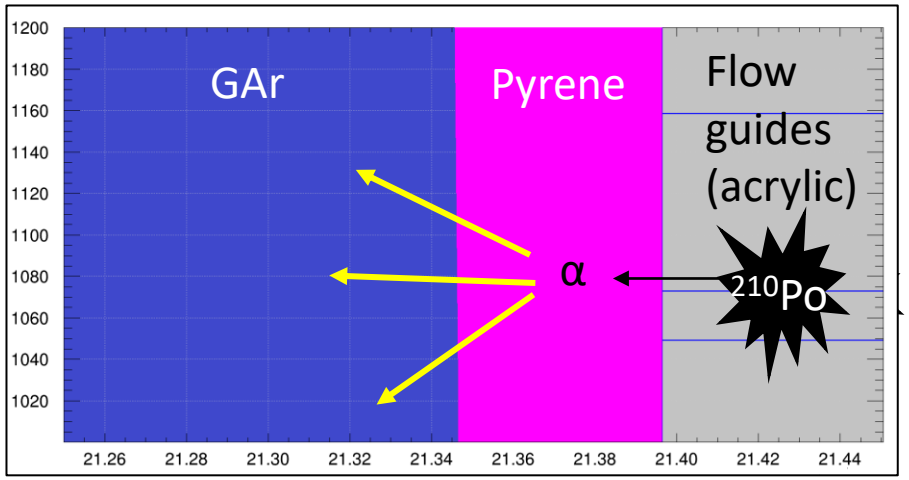


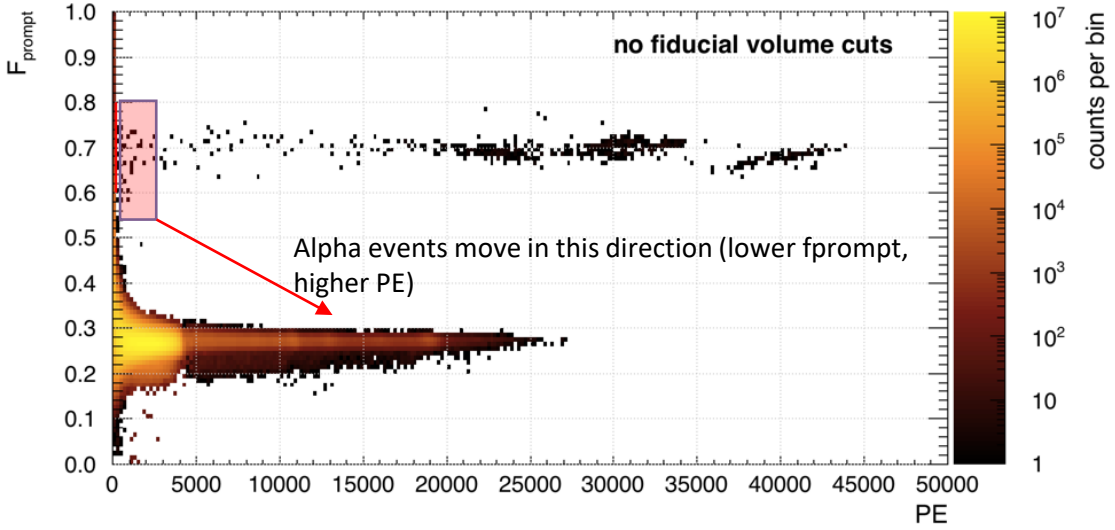
Shadowed neck events may enter the WIMP ROI

Pyrene

- Pyrene is a slow wavelength shifter
  slow = long time constant => prompt light will decrease
  => fprompt decreases
- Pyrene coated flowguides to be installed during hardware upgrades to mitigate neck alpha backgrounds



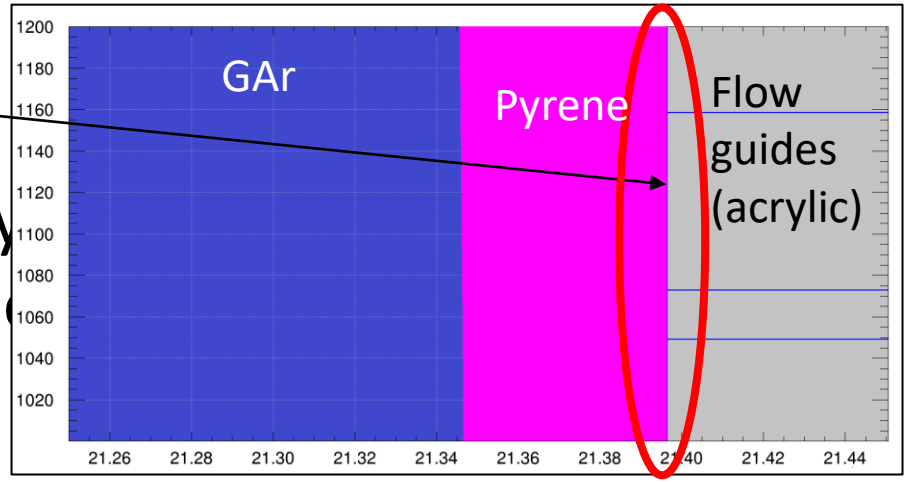




Goal

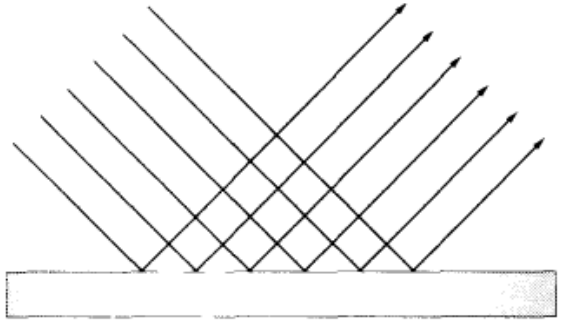
- Qualify the optics of components in the neck
- Relevant parameters
  - Surface roughness
  - Refractive index of pyrene/acrylic
  - Wavelength shifting time constant of py
  - Wavelength shifting light yield of pyren
  - Scintillation light yield of pyrene
  - Scintillation time constant of pyrene
  - Opacity
  - ……

See Hicham's (R3-6) talk for more about the time constant and light yield

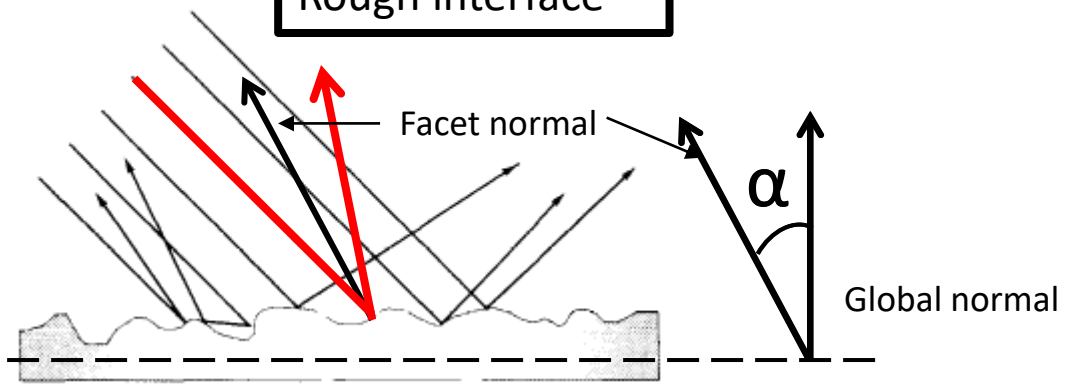


UNIFIED model in GEANT4

Flat interface



Rough interface



Fresnel equations

$$r_\perp \equiv \left(\frac{E_{0r}}{E_{0i}}\right)_\perp = \frac{n_i \cos\theta_i - n_t \cos\theta_t}{n_i \cos\theta_i + n_t \cos\theta_t}$$

$$r_\parallel = \frac{n_t \cos\theta_i - n_i \cos\theta_t}{n_i \cos\theta_t + n_t \cos\theta_i}$$

$$R_\perp = r_\perp^2$$

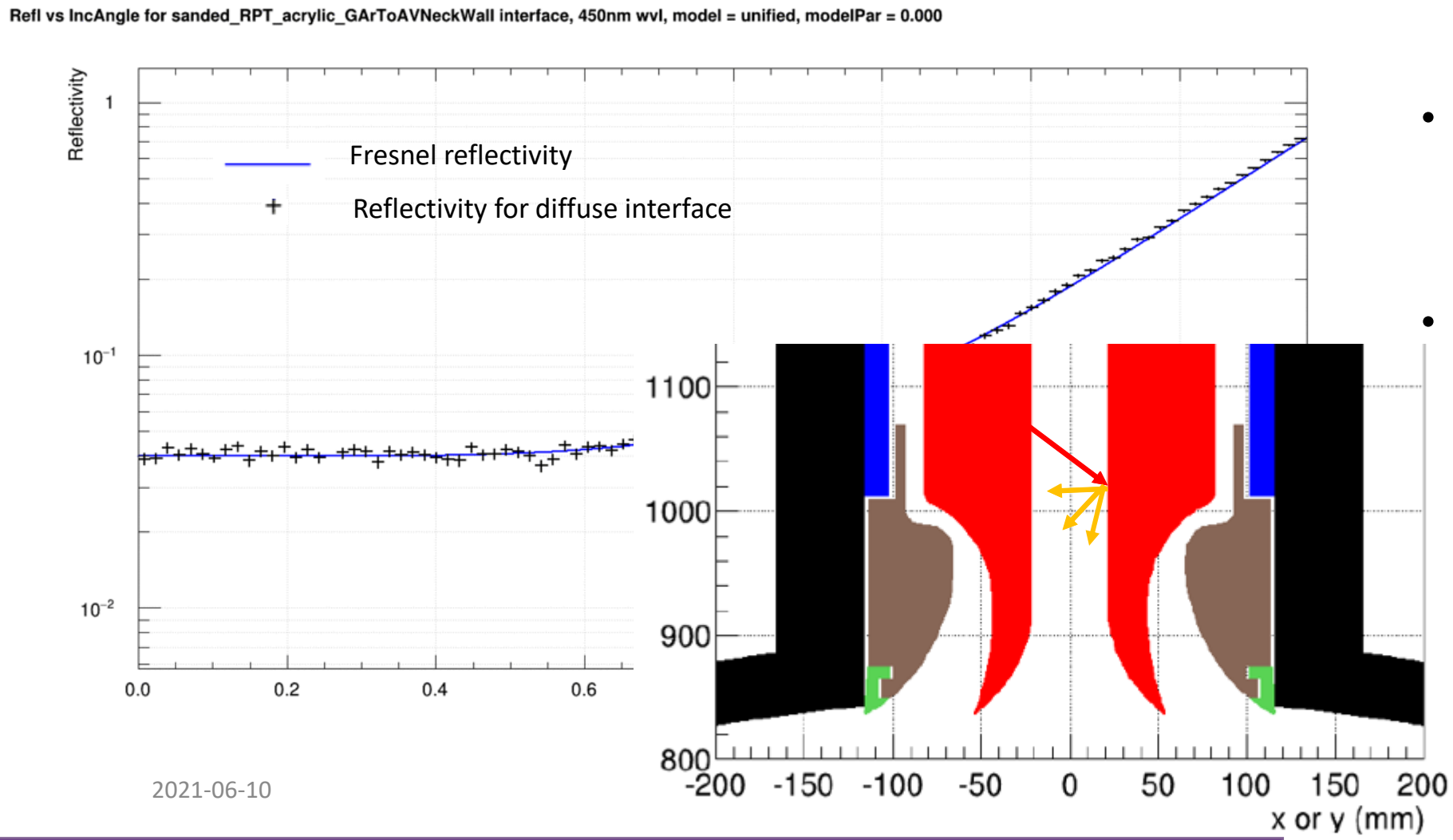
$$R_\parallel = r_\parallel^2$$

$$R_{Total} = \frac{R_\parallel + R_\perp}{2}$$

See Hecht Ch.4

- UNIFIED model's main parameter – σ_α
  (more about UNIFIED model here doi: 10.1109/NSSMIC.1996.591410)
- $\alpha \sim \text{Gaus}(\alpha; 0, \sigma_\alpha) * \sin(\alpha)$
- High σ_α => more diffuse reflections
  Low σ_α => more specular reflections

Why surface roughness matters

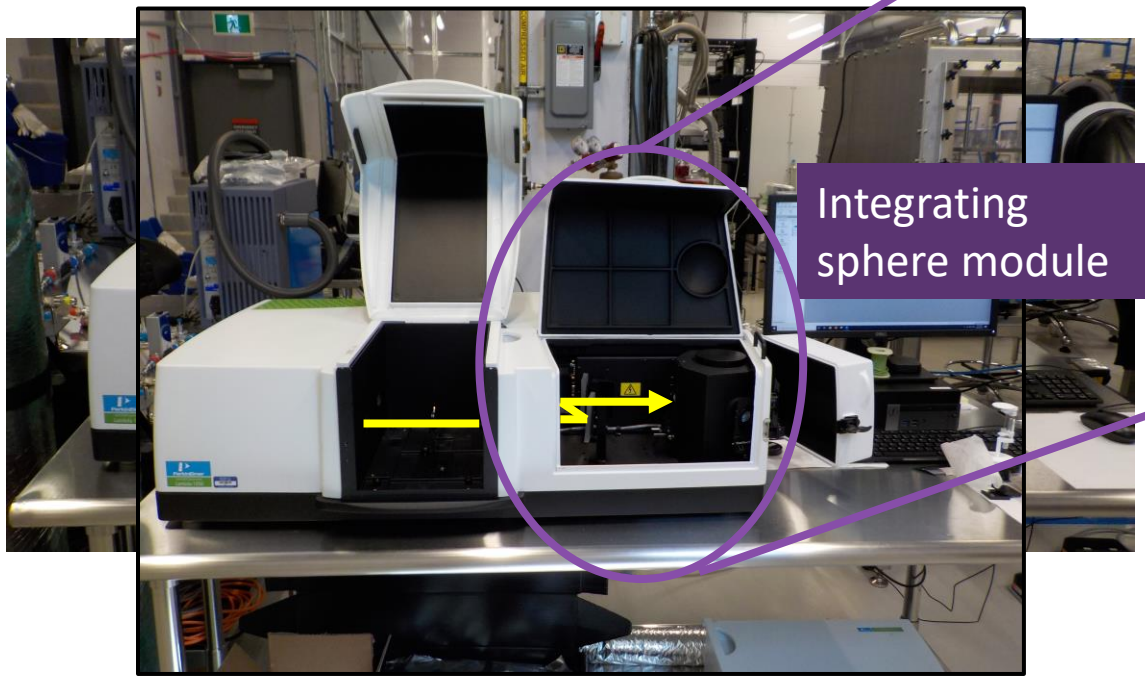


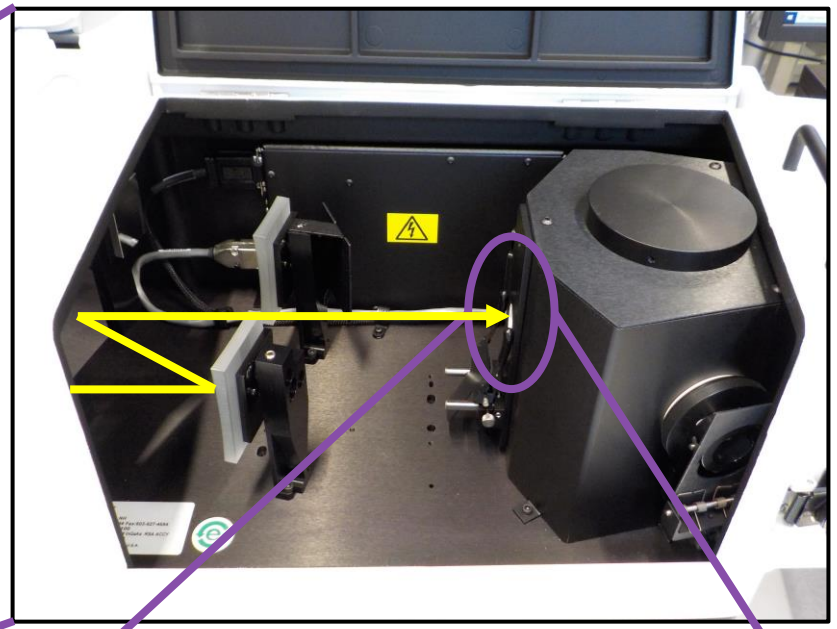
- Reflectivity curve changes significantly as a function of sigma_alpha
- Changing reflectivity affects the path of photons through the neck (which ultimately changes the number of photons reaching the PMTs)

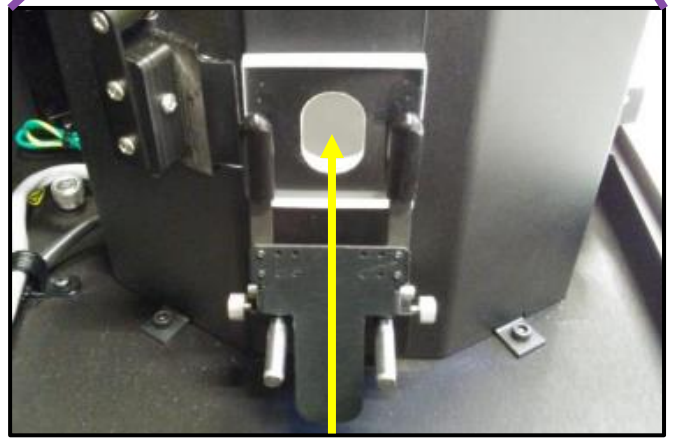
We measure reflectivity (transmittance), fit out sigma_alpha

Spectrophotometer

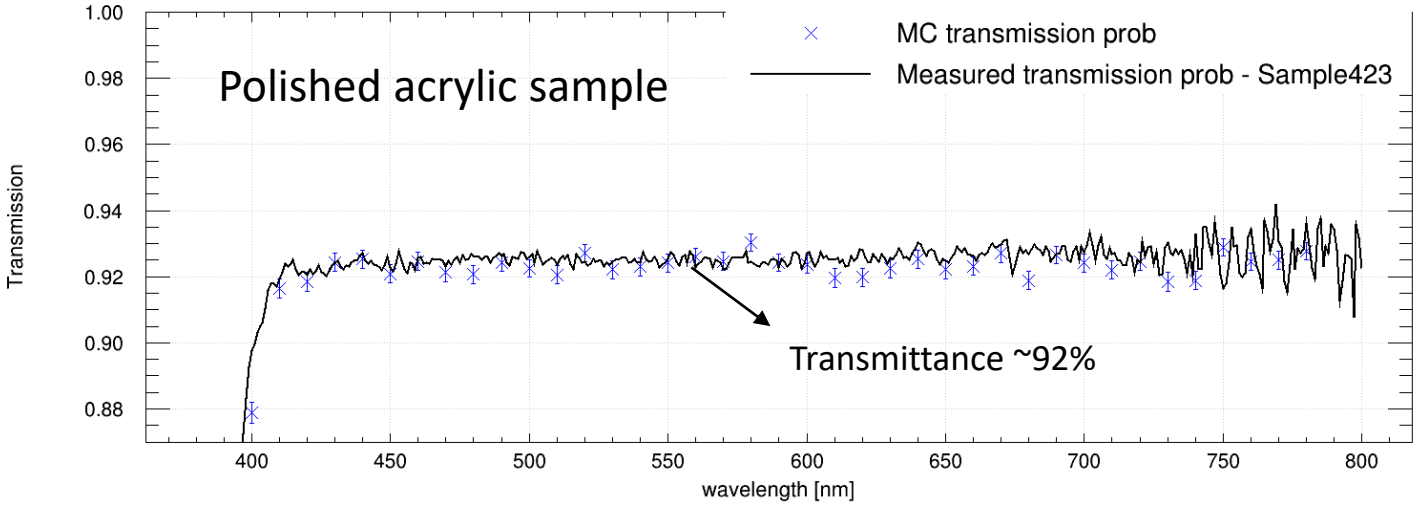
- PerkinElmer Lambda 1050 spectrophotometer at COLD Lab, Carleton
  (Image credits – Jeff Mason)

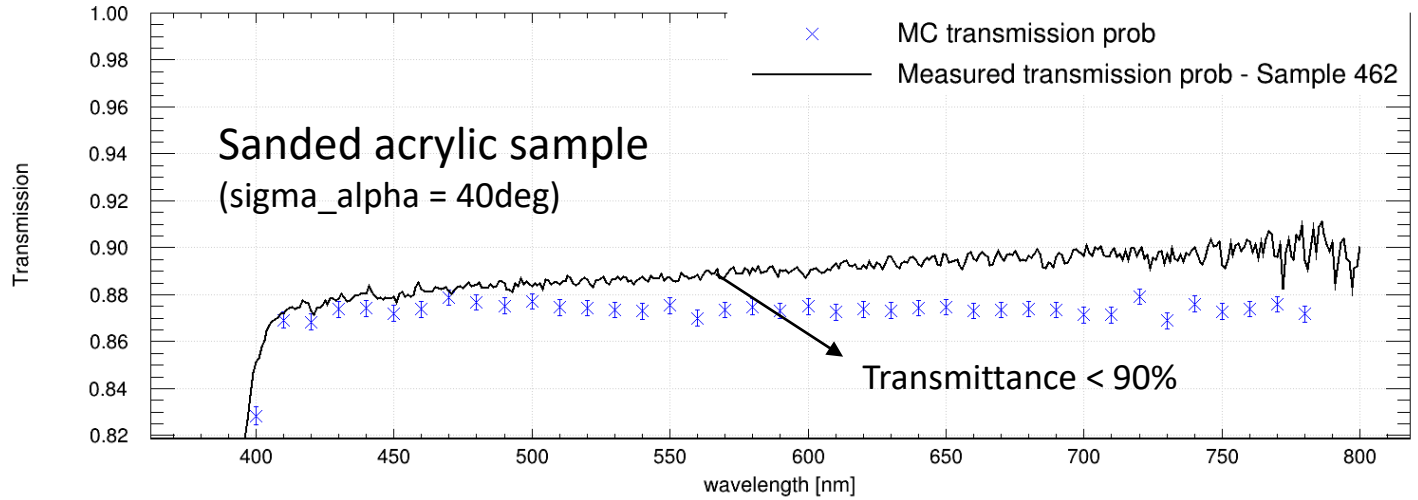


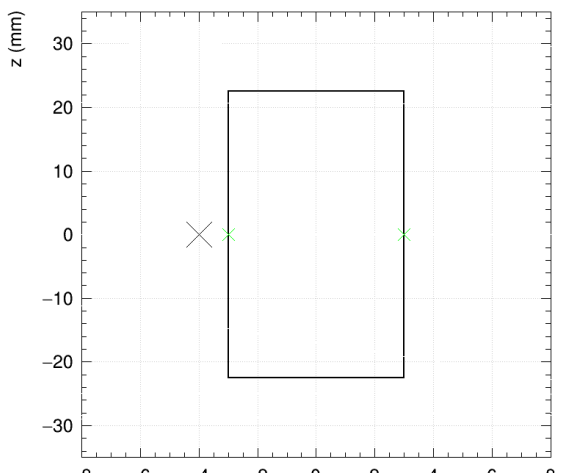




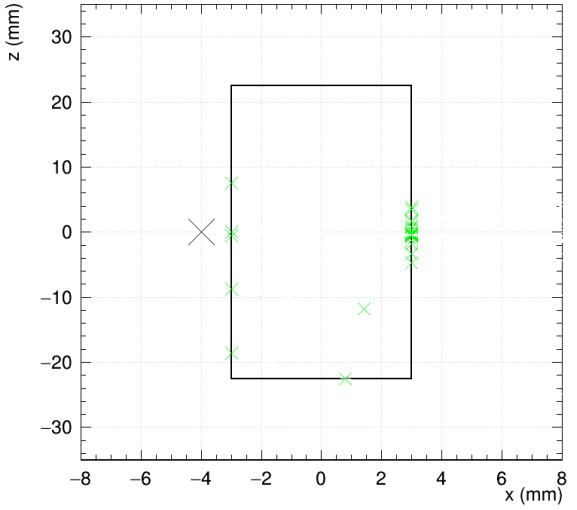
Finding sigma alpha







$$MC\ transmission\ prob = \frac{Photons\ with\ x > 0}{Total\ incident\ photons}$$



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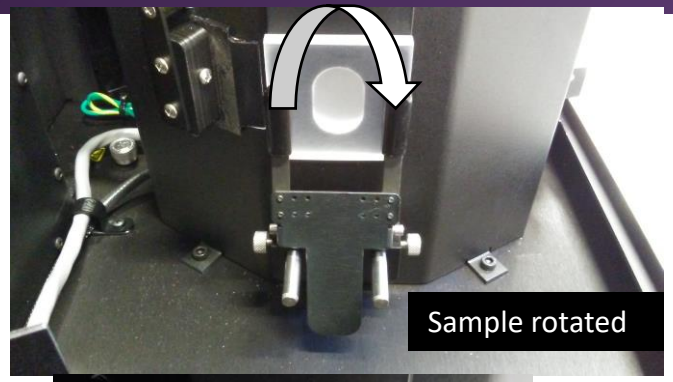
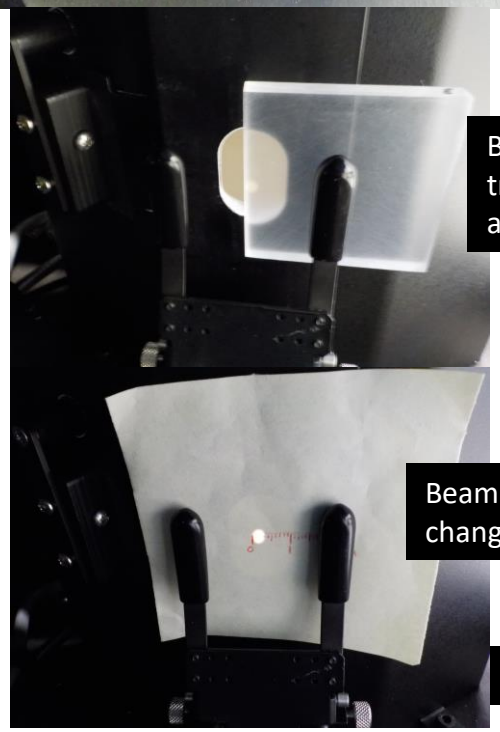


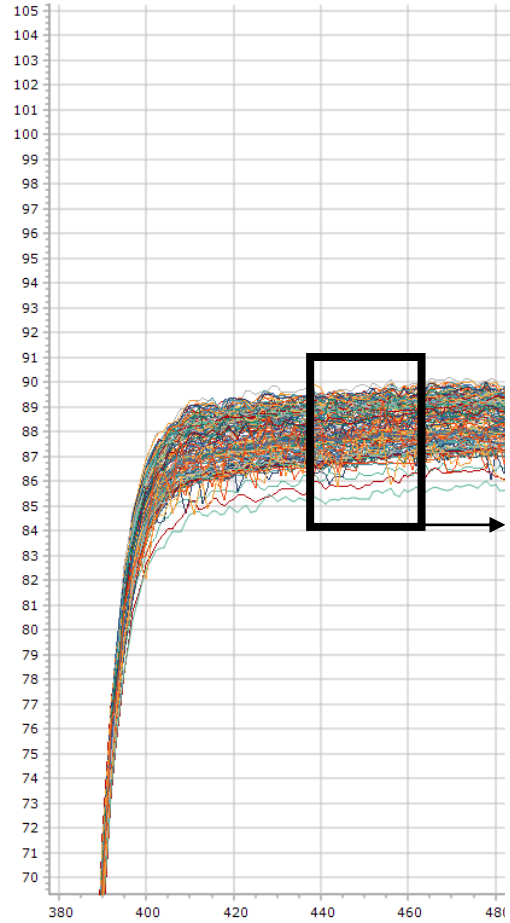
Sample rotated

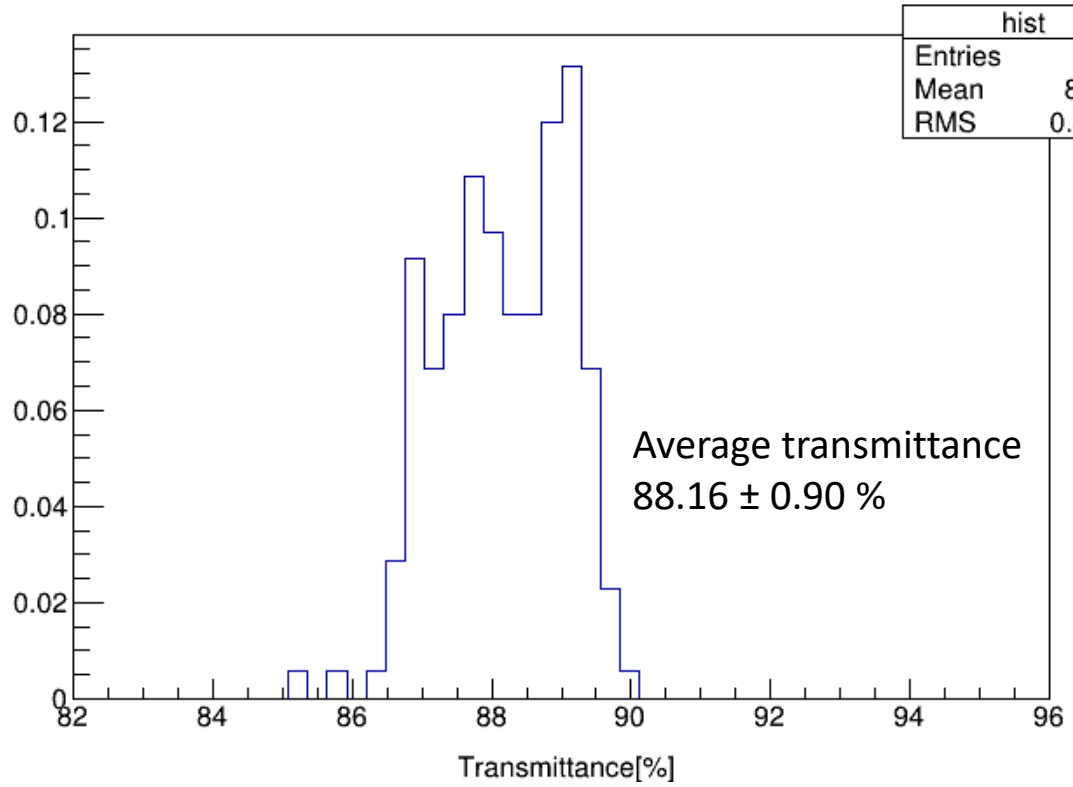


Beam spot translated across sample

Beam size changed

Multiple samples used





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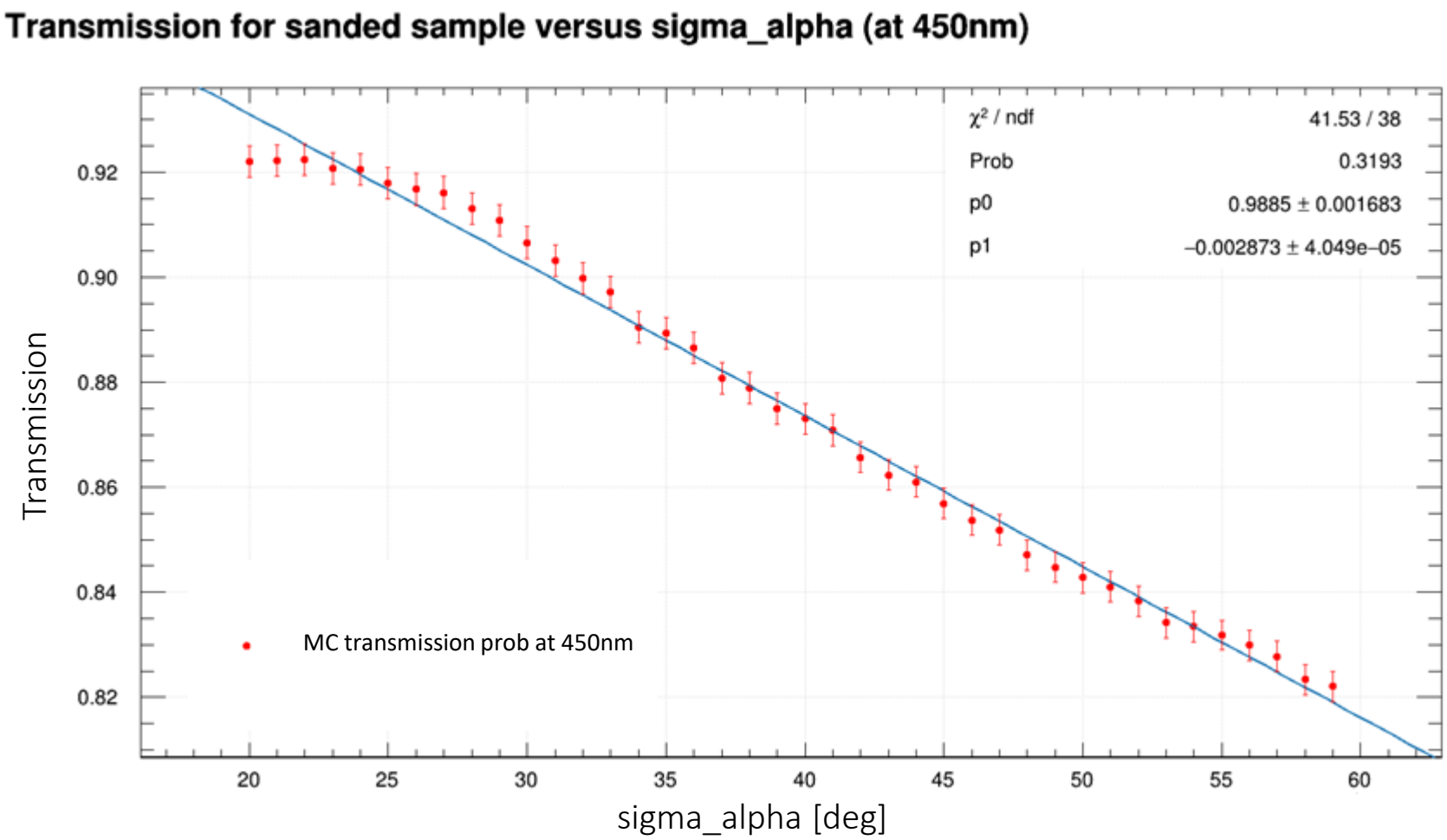

- Simulated acrylic samples with different sigma_alphas
- sigma_alpha = 37.2 ± 3.1 degrees

Conclusion

- Slow wavelength shifter on DEAP neck flowguides being implemented as part of hardware upgrades to mitigate the dominant detector background (neck alphas). Allows powerful discrimination of neck backgrounds
- Developed detailed optical model of surfaces and benchmarked at COLD Lab, Carleton
- Preliminary sigma alpha value = 37.2 ± 3.1 degrees describes the acrylic surface well
- More sample data needed to study systematics (ongoing)
- Full optical model with uncertainties will be used to characterize detector backgrounds
- Thanks for listening!