EXO-200 Chroma Simulation Report

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Outline

Goal:

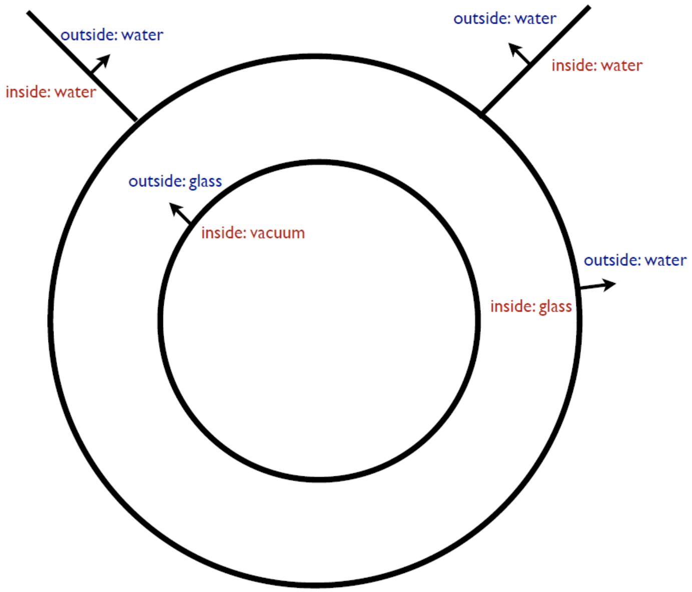
- Constrain the optical parameters of the material of the detector, cross-checking with experimental results
- Calculate the QE of LAAPDs used in EXO-200

Outline:

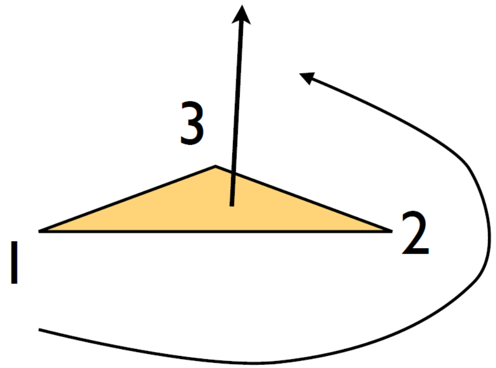
- Chroma vs GEANT 4
- Geometry and other simulation set-ups
- Lightmap matching and χ^2 analysis
- Discussions and Outlook

Chroma VS GEANT 4

2D view of a surface-based modelling example



Oriented triangles, direction by right-hand rule



	CPU	GPU
Model #	Intel Core i7-920	NVIDIA GeForce GTX 580
Transistors	0.731 billion	3 billion
Clock rate	2.66 GHz	1.544 GHz
Peak FLOPS	85 GFLOPS	1544 GFLOPS

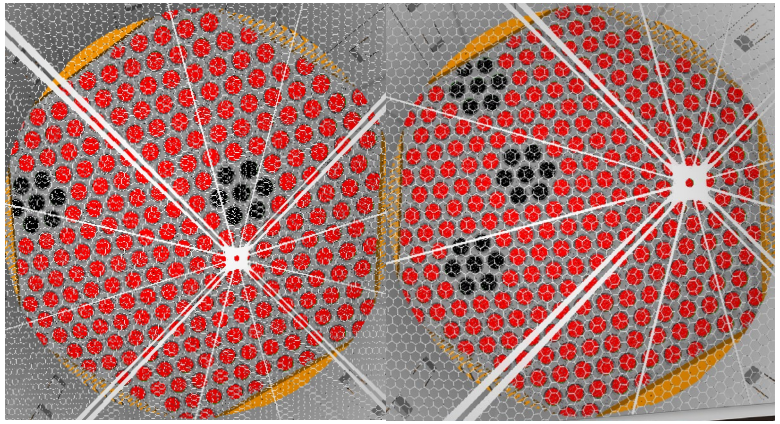
Comparison of the same-end CPU and GPU for Chroma testing, FLOPS = single precision floating point operations per second

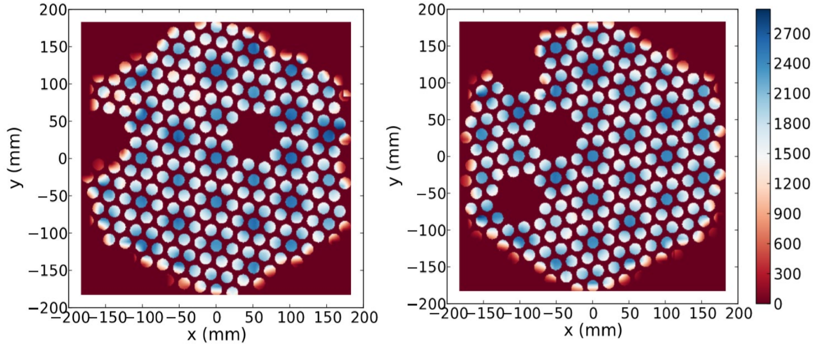
- **Efficient modelling**
  - Surface-based instead of solid-based
  - Oriented triangles
  - Optimization of the data structures for tracking
- **GPU parallelization**
  - Simultaneous simulation of discrete photons
- **Summary**
  - ~200x faster photon propagation

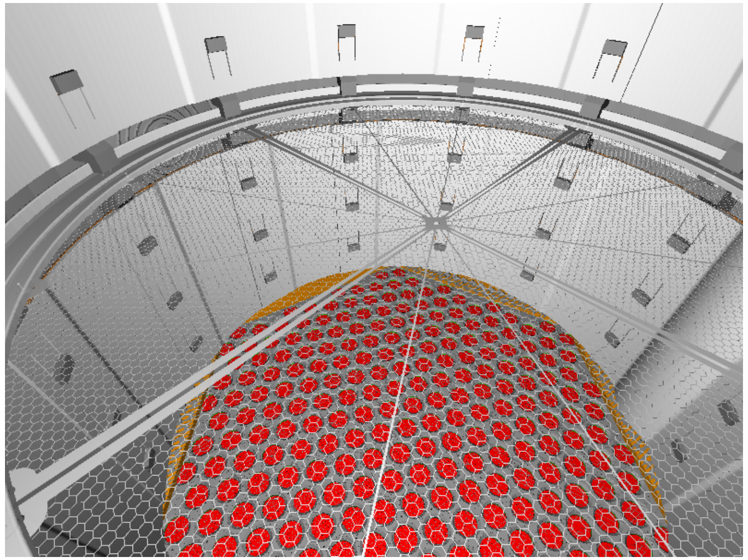
S. Seibert and A. LaTorre. (2011). Fast Optical Monte Carlo Simulation With Surface-Based Geometries Using Chroma

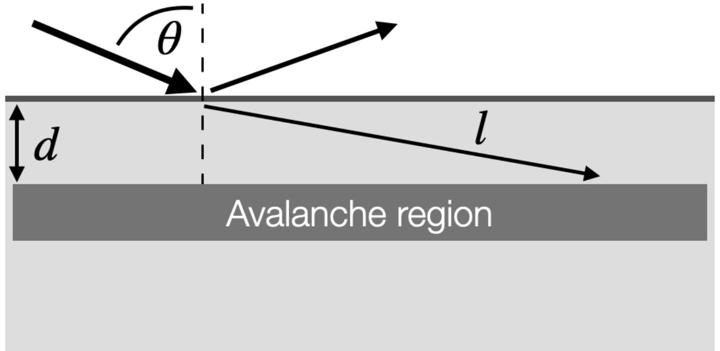
Geometry

G. Anton et al. Phys. Rev. Lett. 123, 161802 (2019)

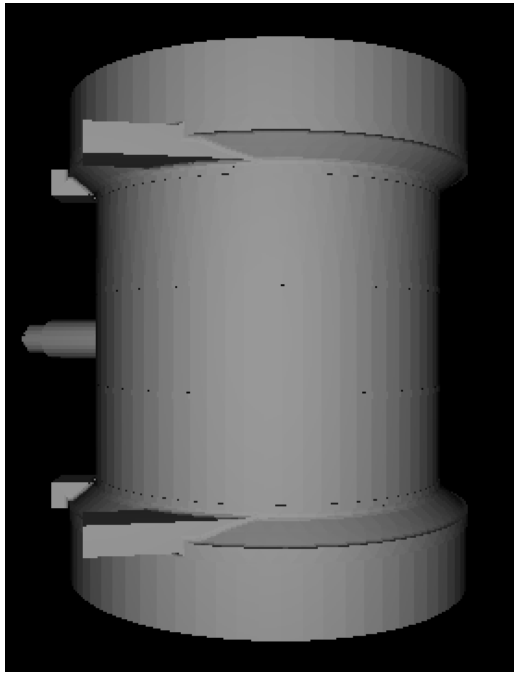




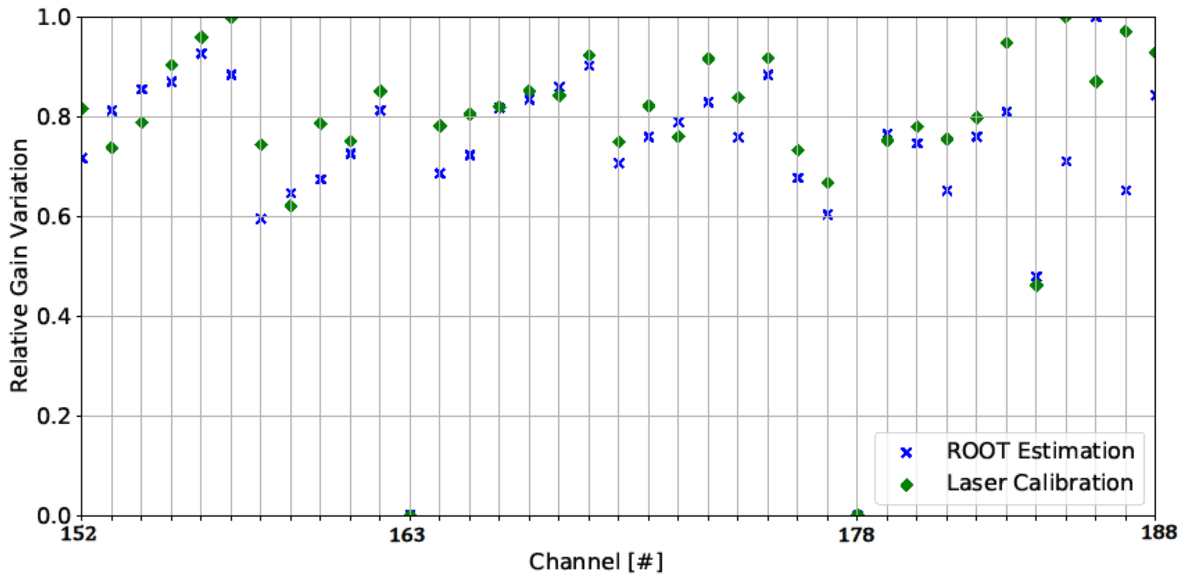




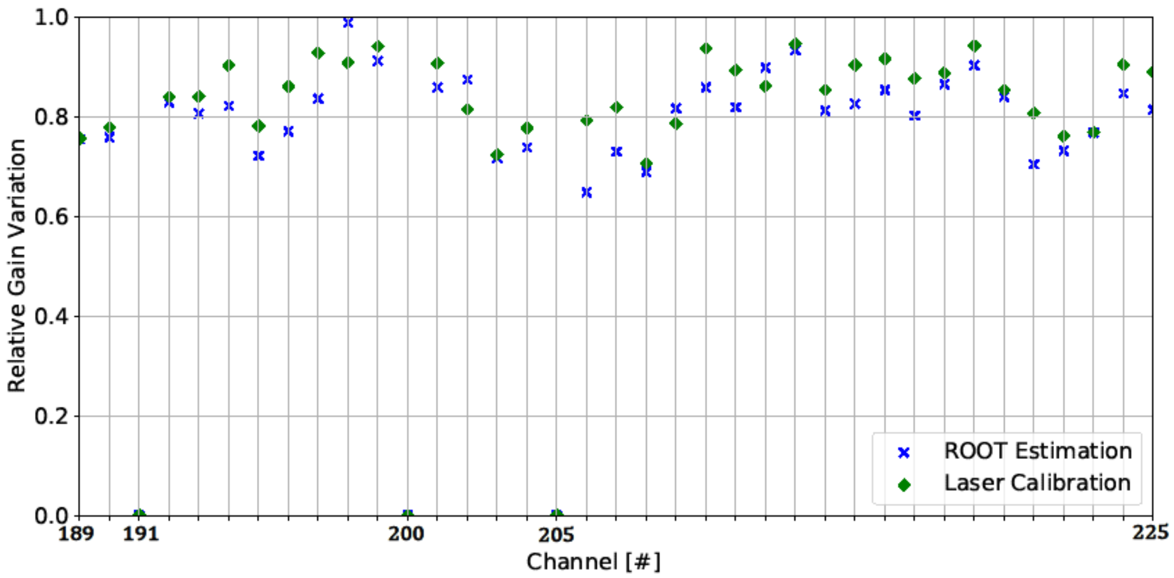
- **Geometric details included**
- Disabled detection of dead LAAPDs
- Angle-dependent reflectivity of LAAPDs (measured by Erlangen group)
- Complete cathode



Gain variation



LAAPDs on TPC 1 at z = 180mm

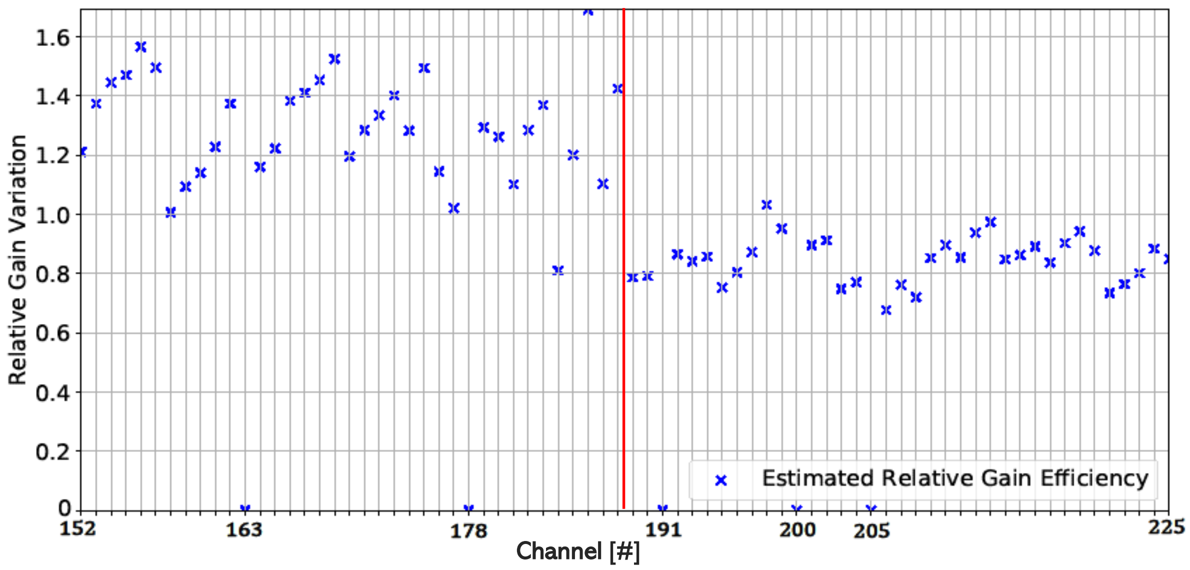


LAAPDs on TPC 2 at z = -180mm

- Estimated gain variation from channel-by-channel ROOT lightmap at z coordinates near the TPC end planes
- Good accordance between individual TPCs
- Unit of Laser Calibration: ADC counts/photon
- Added gain variation from laser calibration

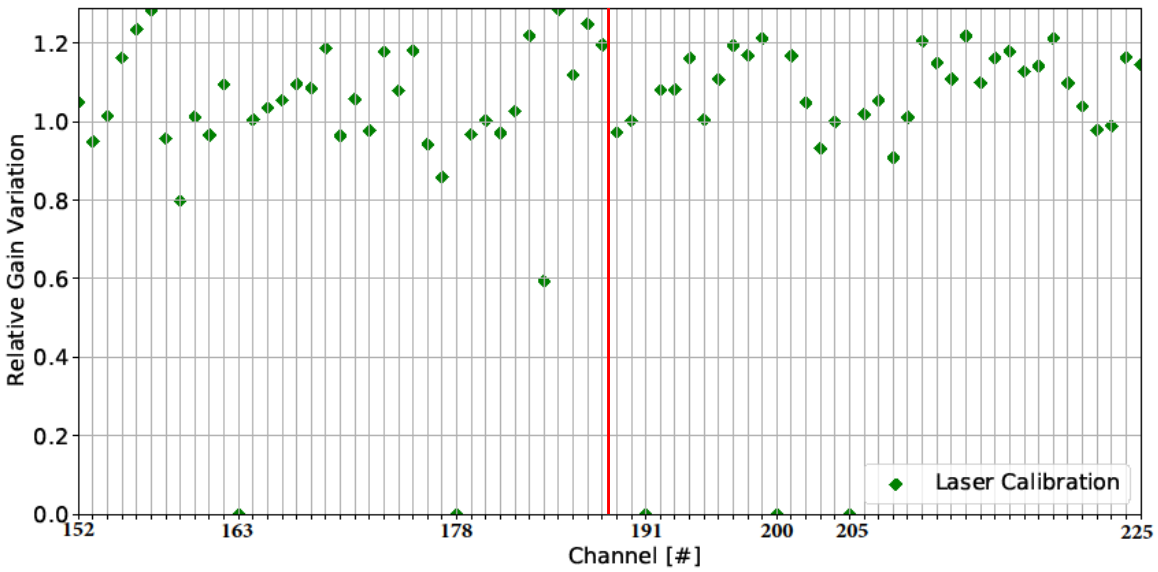
Gain variation and asymmetry

Red line split TPC1 and TPC2 channels



Estimated gain efficiency for all channels

Red line split TPC1 and TPC2 channels



Laser calibrated gain efficiency for all channels

- Asymmetry appears when comparing 2 TPCs together
- Cannot be compensated by gain variation alone

Baseline parameters

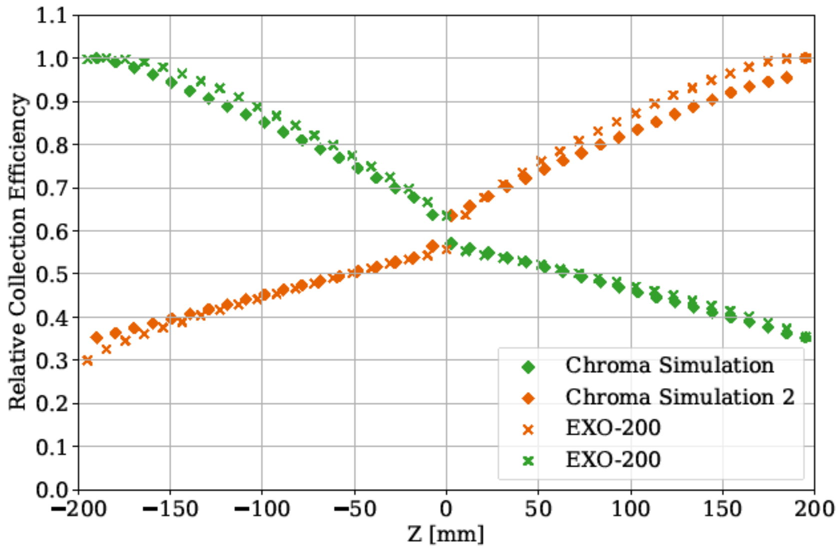
	Re(n)	Im(n)	Absorption length [mm]	Scattering length [mm]	Density [g/cm^3]
LXe	1.6951		20000	300	2.942
Copper	0.94		100	100	8.96

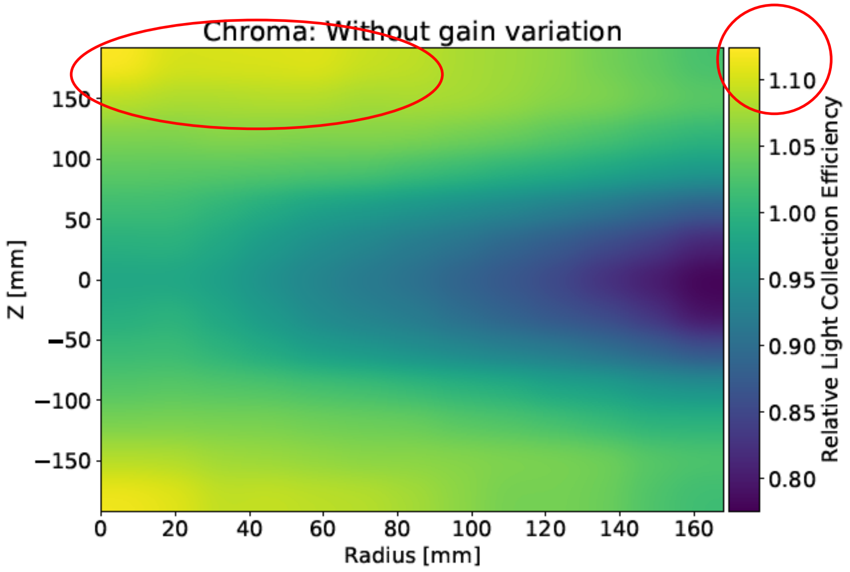
	Absorption [%]	Specular reflectivity [%]	Diffusive reflectivity [%]
PTFE	5	0	95
EXO Cathode (Phosphor Bronze)	60	40	0
EXO UV Wires (Phosphor Bronze)	60	40	0
APD Plane ($Al+MgF_2$)	10	90	0
Acrylic*	50	50	0

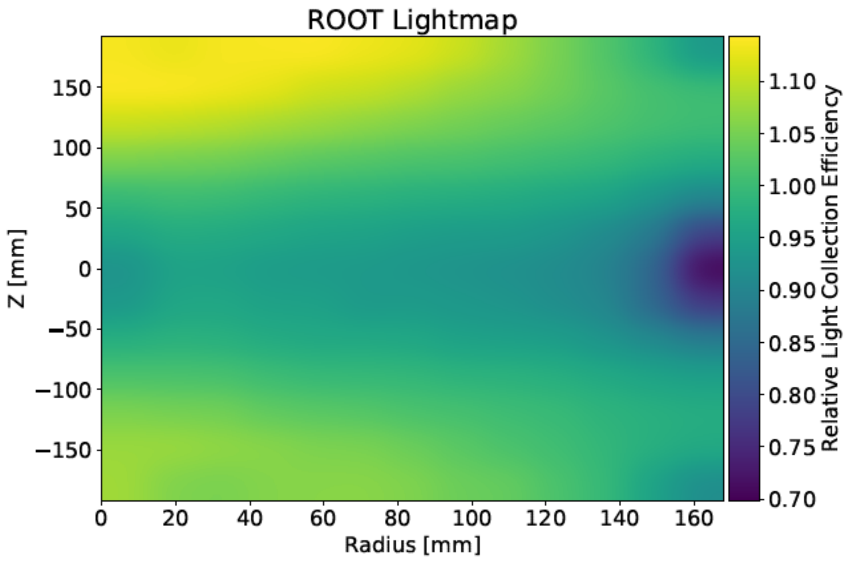
- **Materials to further constrain on**
- LAAPDs surface uses angle-dependent reflectivity from Erlangen group measurements

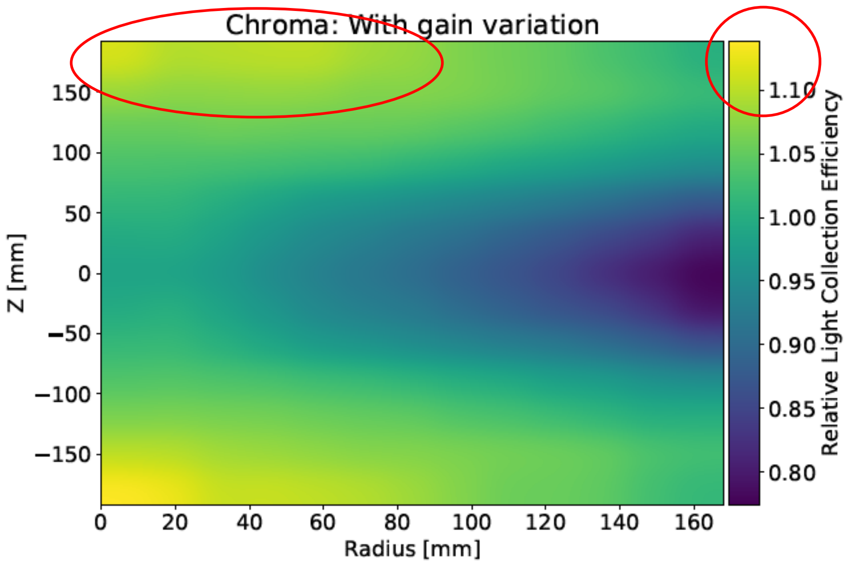
* Acrylic-made connectors/insulators have small solid-angle exposure inside EXO-200

Lightmaps at baseline





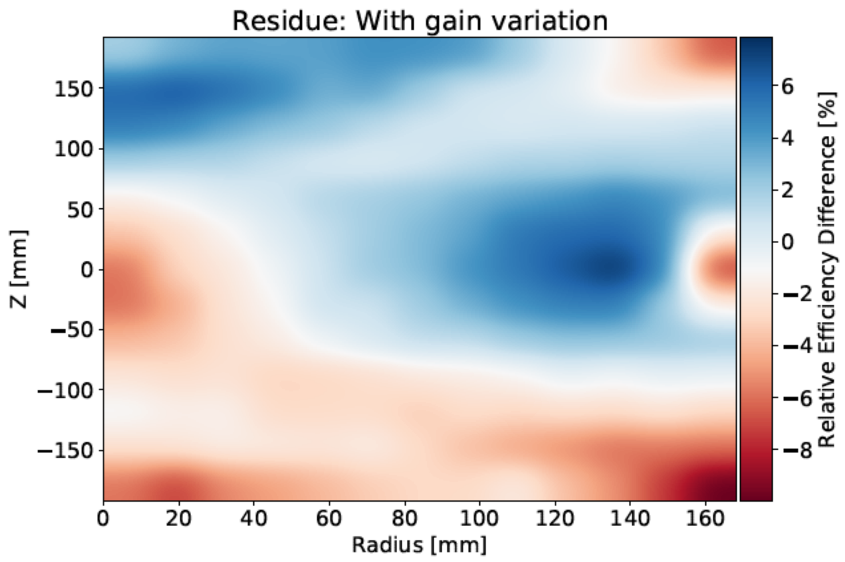


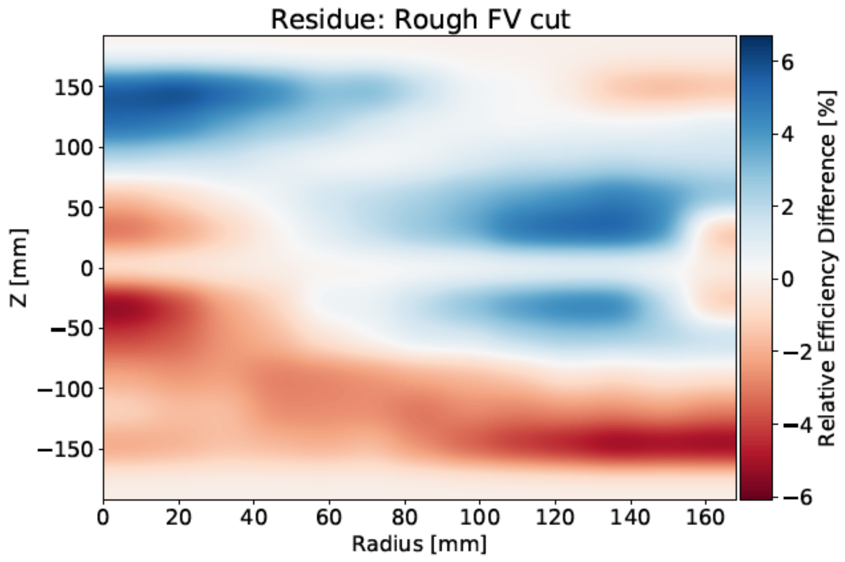


- Uses averaged ROOT file (not the channel-by-channel file)
- With no absolute scale, 2D lightmaps are normalized by the overall mean, 1D lightmap normalized by the maximum in individual TPC
- Cut made: R ≤ 168 mm, |z| ≤ 192 mm

- Optical asymmetry appears in 2D lightmap
- Slightly enhanced optical asymmetry after gain addition

Residues and cuts



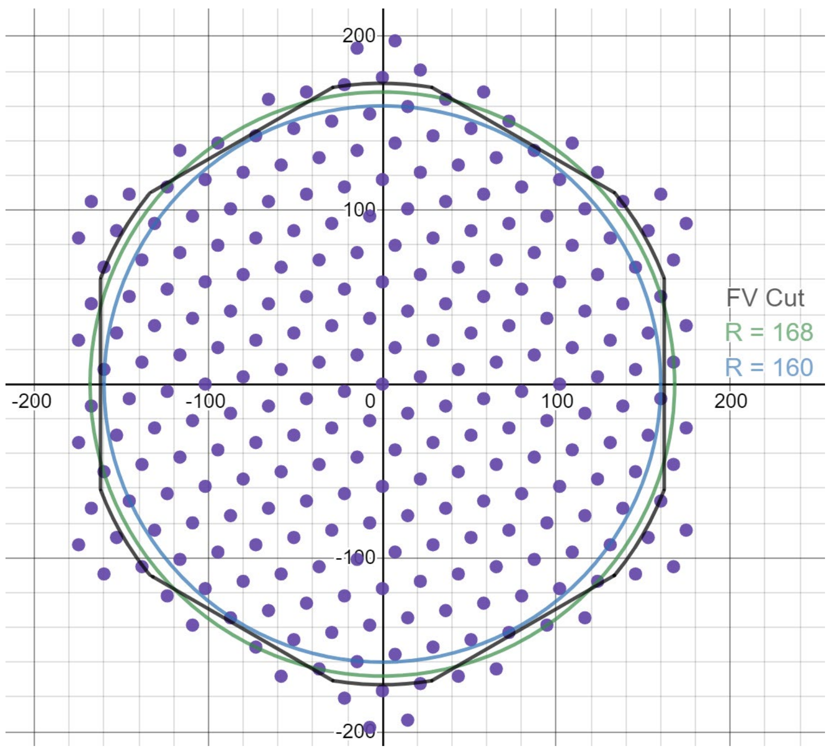


- **Residue**
- Calculated as the absolute error between ROOT and Chroma lightmap, i.e. ROOT − Chroma

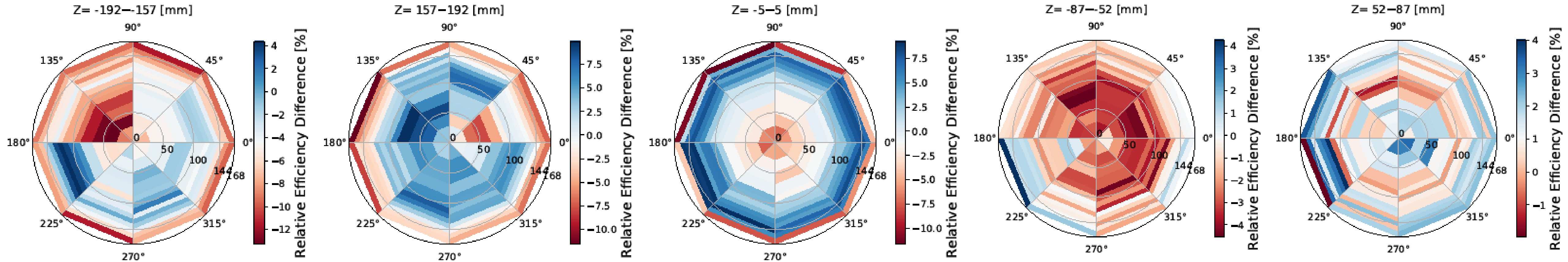
- **Cut made**
- $R \leq 168$ mm, $|z| \leq 192$ mm
- Residue ~ 8.91% < 10%

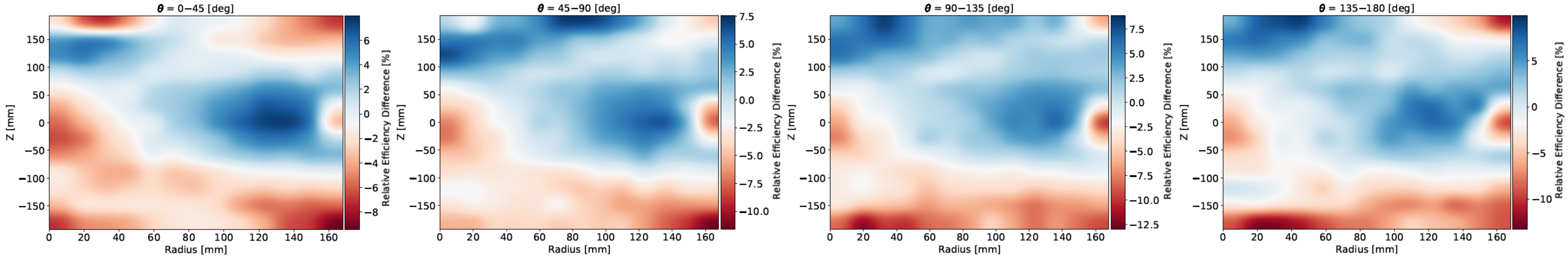
- **Standard FV cut**
- Hexagon with apothem of 162 mm
- At least 10 mm away (±181 mm) from the anode (±191 mm) and cathode wire planes
- Aggressive residue ~ 6.38%, with ~ 20mm more cut at the anodes, ~10mm less cut at the cathode

$R - \phi$ comparison between cuts on modeled APD Plane

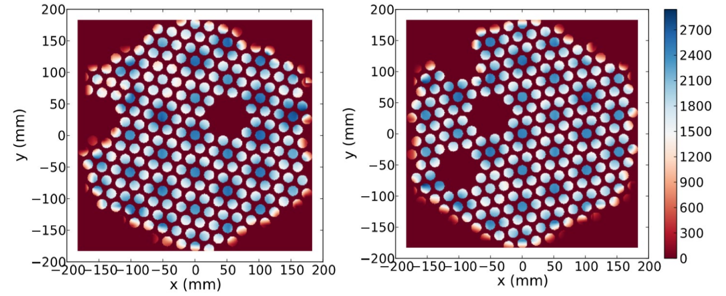


Residues in 3D





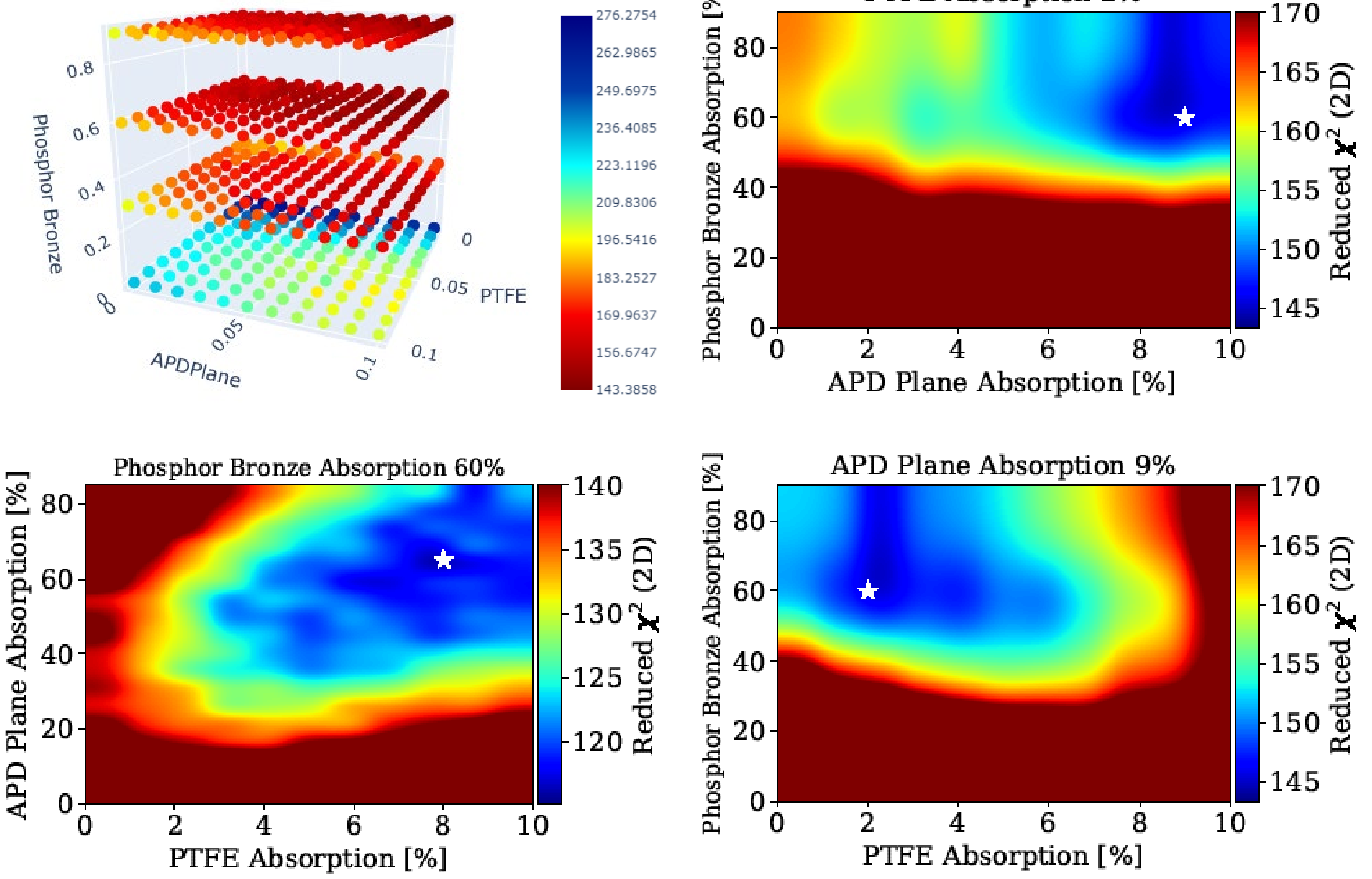
- Greater variation in ϕ near the anodes
- May be attributed to the distributions of dead APDs
- Other possible asymmetries among PTFE slices



χ^2 analysis and best fit parameter

- **3D scan of the free parameters**
- PTFE, absorption VS diffusive reflectivity
- Phosphor bronze (anode and cathode wires), absorption VS specular reflectivity
- Al+MgF2 (APD Plane), absorption VS specular reflectivity
- **Reduced χ^2 calculation**
- $\chi^2 = \frac{1}{N} \sum_i \frac{(O_i - C_i)^2}{\sigma_i^2}$
- O_i, ROOT lightmap
- C_i, Chroma simulation
- N (DOF), # of non-empty bins
- σ_i, statictical error on the mean, i.e std of efficiency distribution, ~0.1% ≪ ~10% residue
- Large reduced χ^2 from ignored yet dominant systematics error

4D summary plot



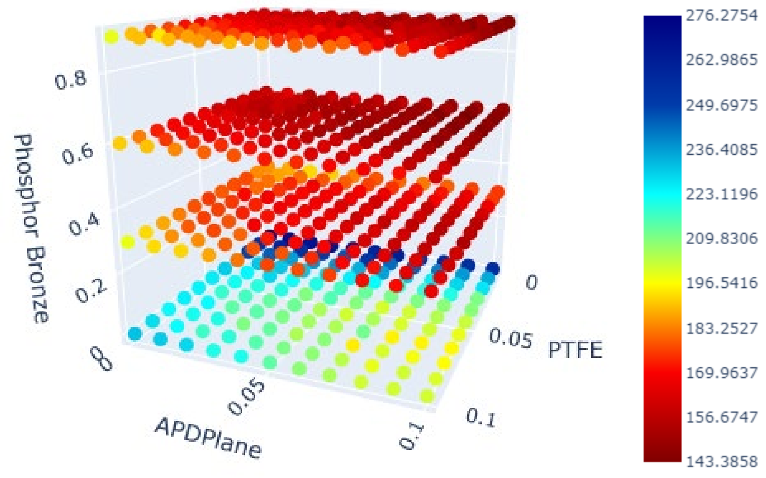
χ^2 analysis and best fit parameter

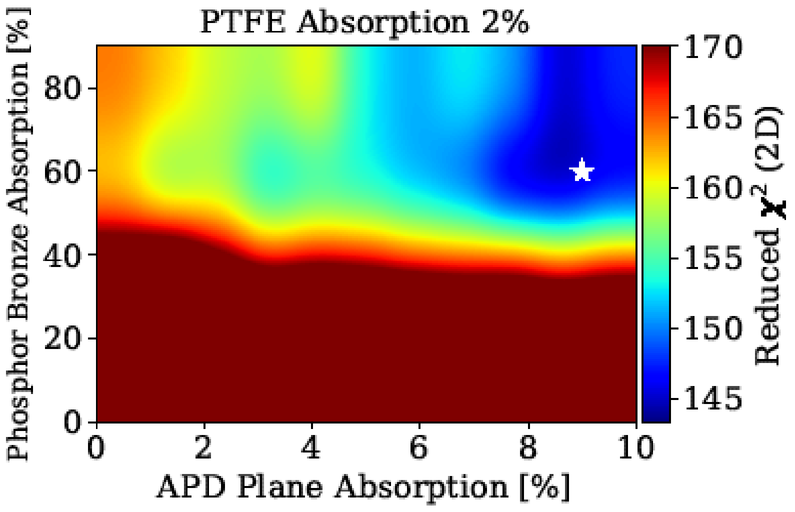
- **3D scan results**

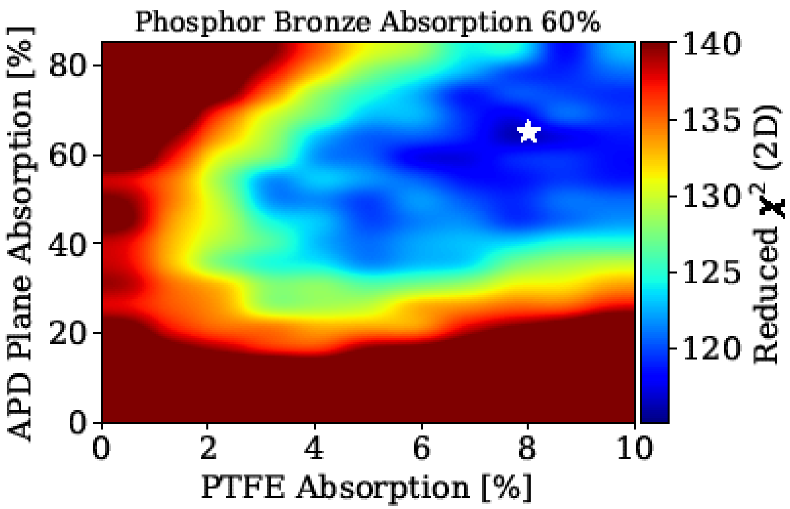
- Phosphor bronze property can be readily chosen as fixed
- The extended scan of PTFE VS APD Plane shows unexpected: 1. irregularity 2. correlation
- Maybe attributed to: 1. close intervals, 2. overall scaling of absorption, 3. parametrization difference between residue and χ^2 test
- Current best fit from scan:

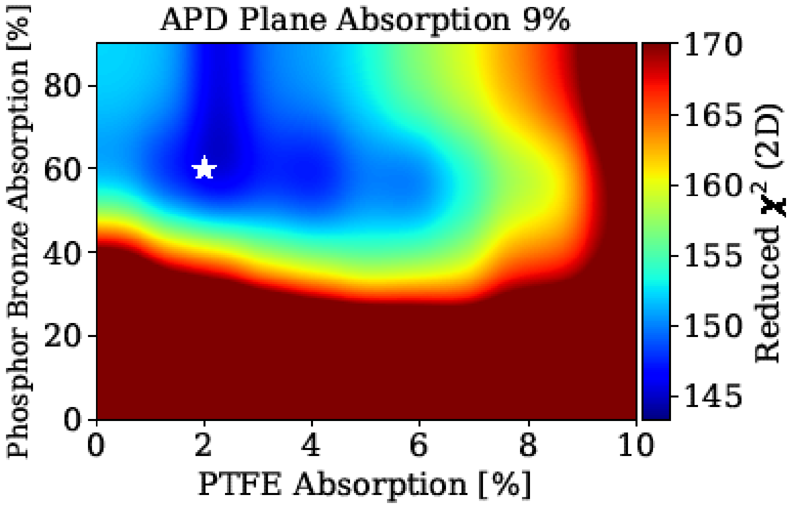
	Absorption [%]	Specular reflectivity [%]	Diffusive reflectivity [%]
PTFE	8	0	92
Phosphor Bronze	60	40	0
APD Plane	65	35	0

4D summary plot





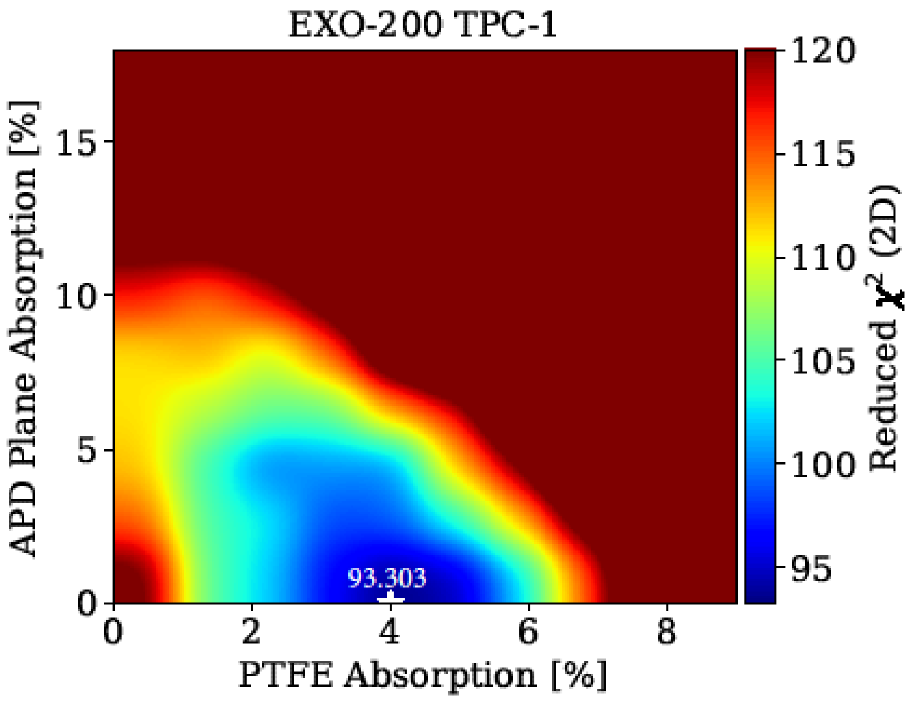




Discussions and Outlook

- **Current status & future challenges**
- Found a baseline fit that yields sub-10% residue
- Constrain the parameters to find a physical best fit
- **Relationship between PTFE and APD Plane parameters**
- Finish the extended scan of PTFE against APD Plane
- Use channel-by-channel lightmap to gain position-dependent information between APD Plane and PTFE
- Consider optical asymmetry via TPC-independent PTFE and APD Plane
- Consider more relationships such as PTFE specular reflectivity VS APD Plane specular reflectivity
- Material independence in 3D
- **Reduced χ^2 scale**
- Approximate systematic error with residue from the best fit
- **Convert to the standard FV cut**

Anti-correlation between APD Plane and PTFE from individual TPC evaluation



Acknowledgements

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- And everyone here for listening.

Thanks