Center for Frontiers in Nuclear Science

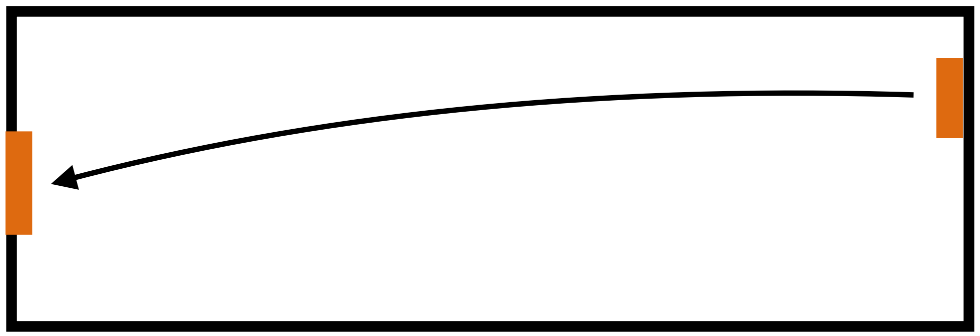
Overview of the Diffuse Laser System for the sPHENIX TPC

Ross Corliss

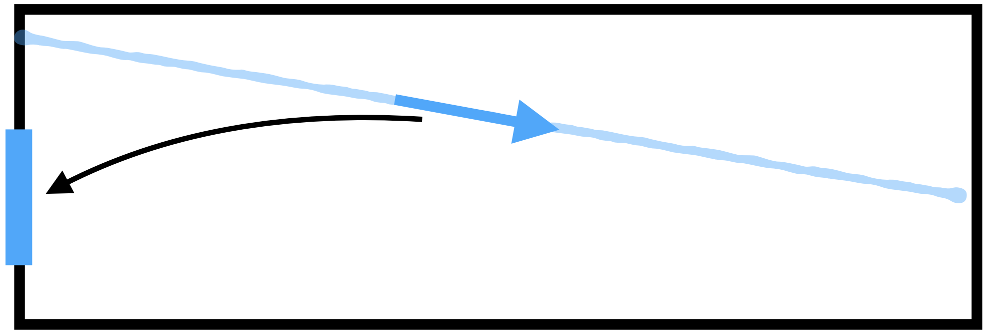
Stony Brook University

Measuring TPC Distortions

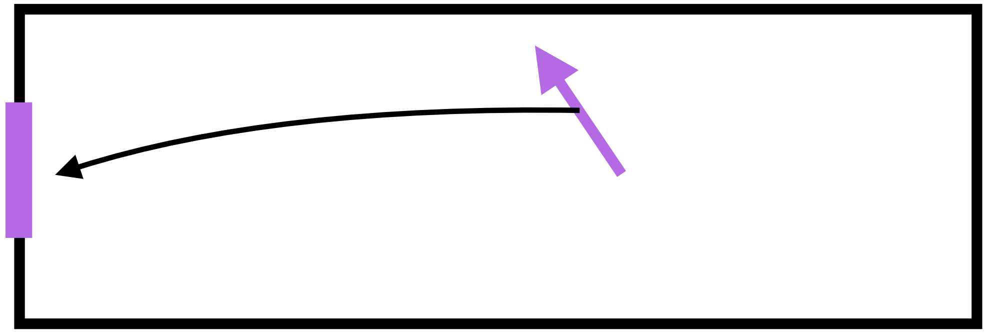
- Central Membrane Stripes: illuminated with diffused UV laser (**kHz**), produces clusters at known position, integrates over whole distortion column



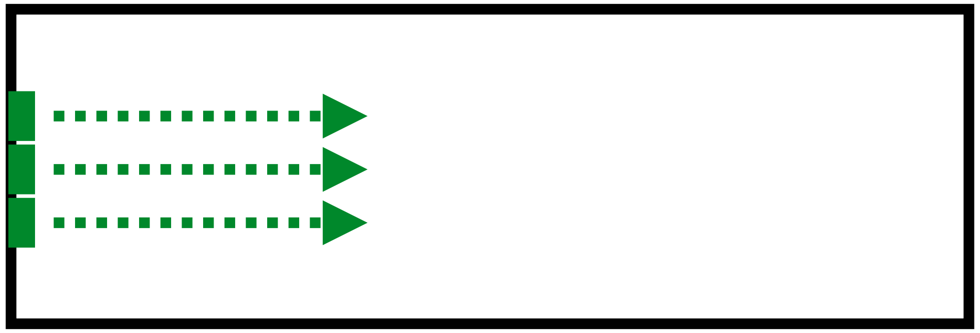
- Line Lasers: endcap UV laser (*eff <Hz) ionizes along known trajectory, clusters integrate over partial column



- Tracks: (*eff. ~Hz) produces clusters at uncertain position extrapolated from inner tracking, integrates over partial column

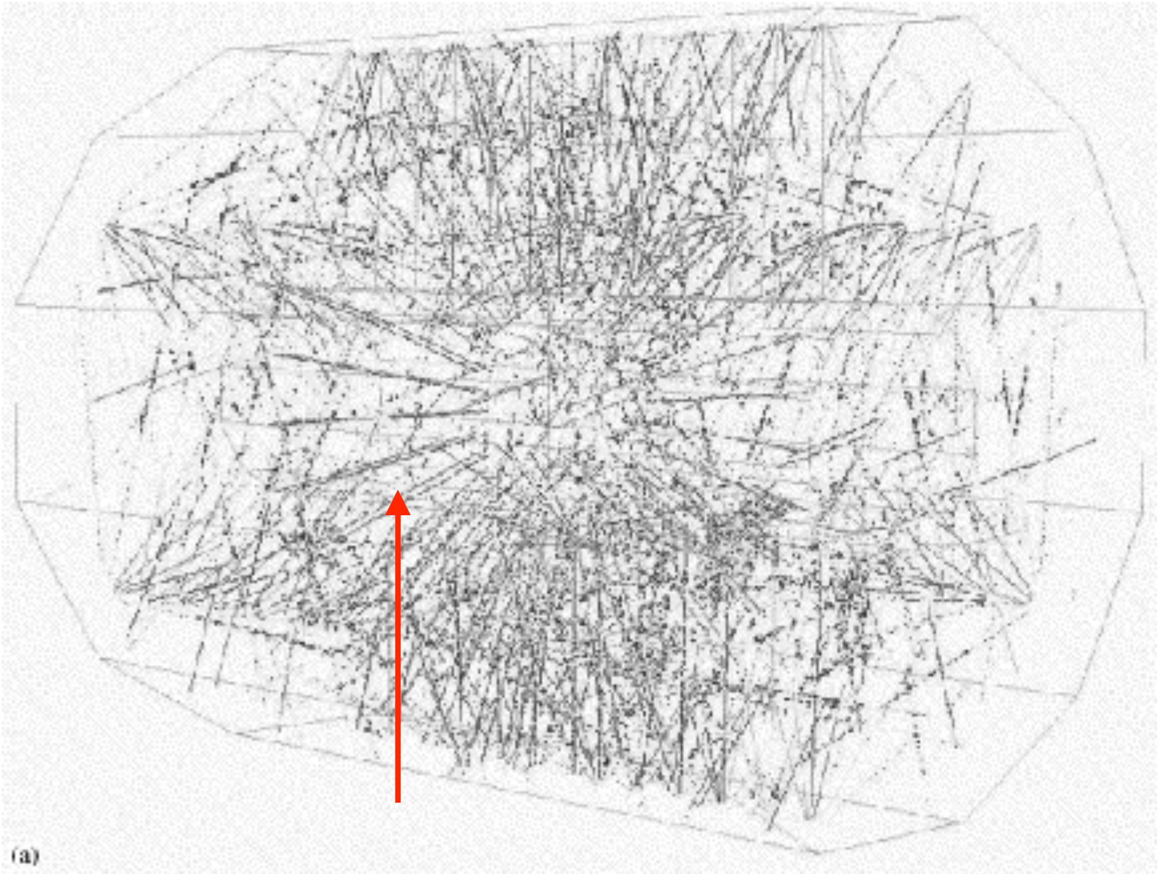


- Digital current: infers spacecharge current from electrons at readout (kHz), computes distortions from charge using binned 3D model.



Diffuse Laser Systems

- Using electrons from CM is common in TPCs:
  - STAR: Radial Al stripes on carbon/Kapton CM illuminated by defocused laser = phi and z info
  - ALICE: Fully Al CM surface illuminated by scattered laser light = z info
  - sPHENIX: cm-scale Al pads on ENiG CM illuminated by diffuse laser light = r, phi, z info



STAR event display with CM stripes visible

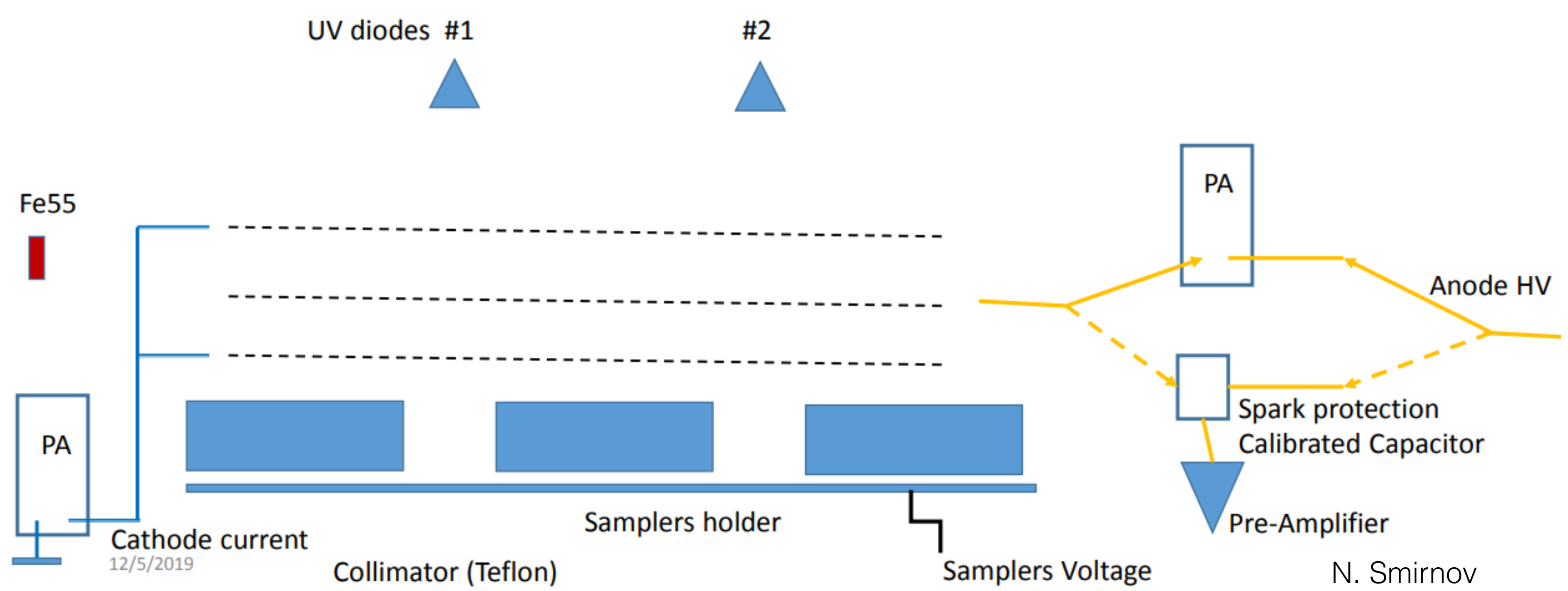
Membrane Materials

- Want high QE pads, relative to CM surface
- Tested Aluminum pads bonded to ENiG CM vs Al-on-Cu baseline

pad	surface	yield ratio
Al	Cu	175
Al (evap.)	ENiG	**240**

- Yield better with ENiG (and less sensitive to Cu handling)

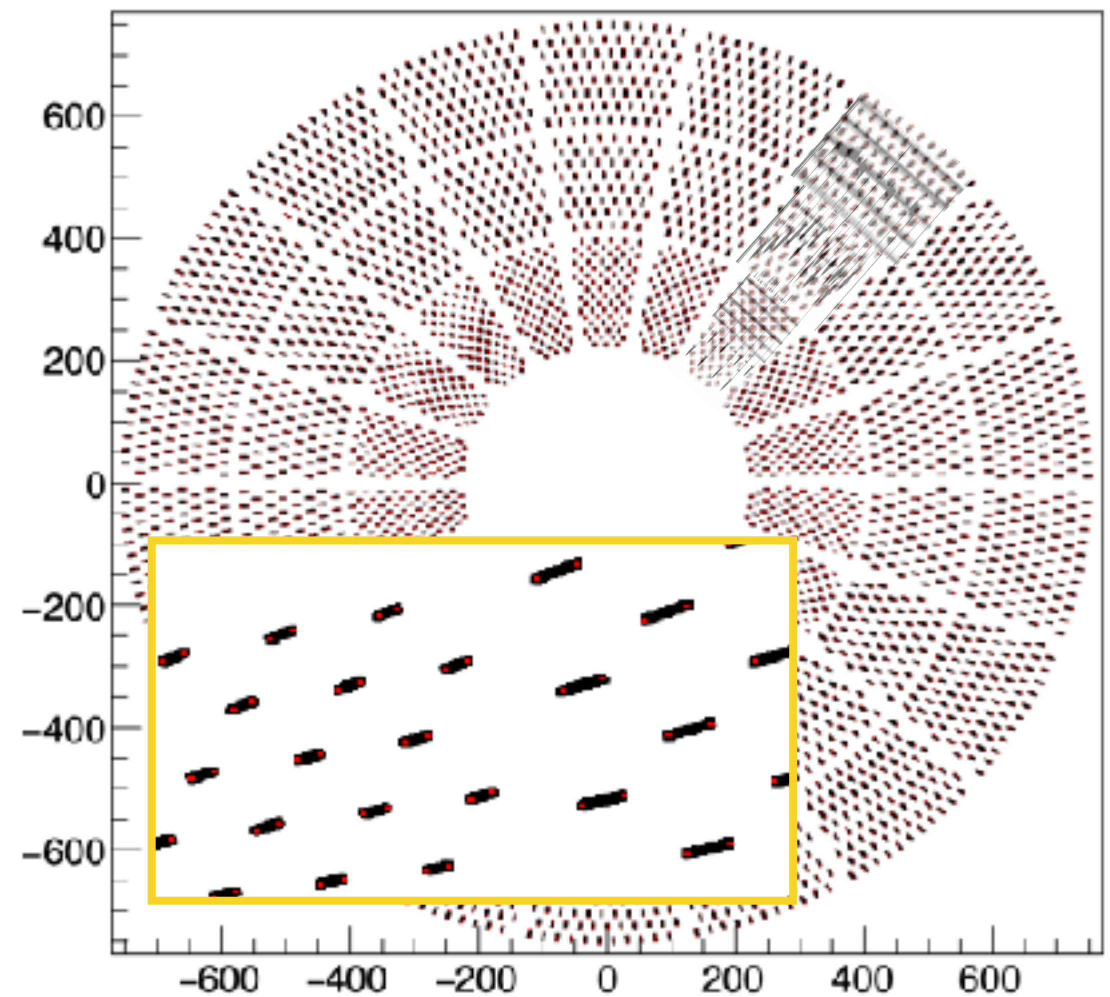
Setup at Yale, UV diodes (257 nm, 6 deg. Cone) +
MWPCh + PA (FLUKE-189, 10 MΩ)



Membrane Stripe Layout

- Aluminum pads bonded to ENiG CM
- Sara Kurdi (SBU) generated the layout and is developing CM in sPHENIX simulation
- Pad spacing generously larger than expected diffusion
- Radial extent matched to readout pads for optimal charge sharing
- Phi extent ~1mm, but adjustable to provide uniform dQ/dR
- Target photoelectric emission of **100 e-/cm** -- ~2x most probable MIP value (*!!!!)
- Some pads widened in phi to provide unambiguous pattern in reco:

- CM illuminated by laser routed via fiber and diffused internal to the TPC



$$\delta_{\text{spacing}} = 8\sigma_{\text{diff.}} + 3\left(\frac{\Delta\theta}{N_C N_{PPC}/N_R}\right)$$

$$\sigma_{\text{diff.}} = 0.6\text{mm}/R$$

$$\Delta\theta = \text{width of module} = 30\,\text{deg}$$

$$N_C = N_{\text{cards in module}} = \{6, 8, 12\}$$

$$N_{PPC} = N_{\text{pads per card}} = 256$$

$$N_R = N_{\text{rows in module}} = 16$$

Determining Nominal Electron Yield

- UV laser @ 266 nm is above work function for Aluminum, so electron yield is proportional to number of photons striking the strip

$$(e_\gamma \approx 4.5 \text{ eV})\&(\text{WF}_{\text{Al}} \approx 4.0) \Rightarrow (N_e \approx N_\gamma)$$

- MIP yield is ~50e/cm along beam. Charge density projected onto readout plane increased varying with inclination angle.

$$N_{e,\text{Ne}}/cm = 43, N_{e,\text{CF}_4}/cm = 100$$

$$N_{\text{MIP}}/cm = 0.5\ N_{e,\text{Ne}}/cm + 0.5\ N_{e,\text{CF}_4}/cm \approx 72/cm$$

- Assuming fixed width, strip e/cm is linearly proportional to photon density.

$$N_{CM}/\text{cm} = \sigma_\gamma \Delta Y_{\text{stripe}}$$

- Design for higher charge density to ensure centroid can be accurately determined. Safe because Poisson distribution doesn't have the same high-end tail as the MIP distribution
- Additional factor of 2 to account for maximal case of charge sharing between adjacent radial pads at readout

$$2 \times 2 \times N_{\text{MIP}} = N_{CM}$$

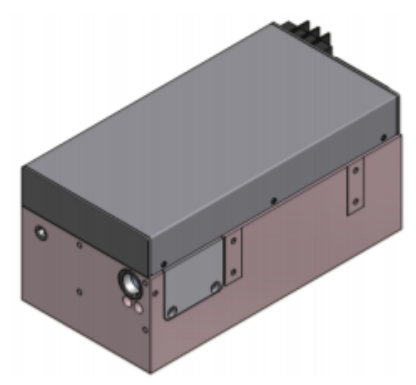
$$2 \times 2 \times 72 = \sigma_\gamma 0.1\text{cm}^2$$

- Resulting desired yield is 288 e/cm, hence photon density of **2880γ/cm²** at nominal strip width

Laser Source

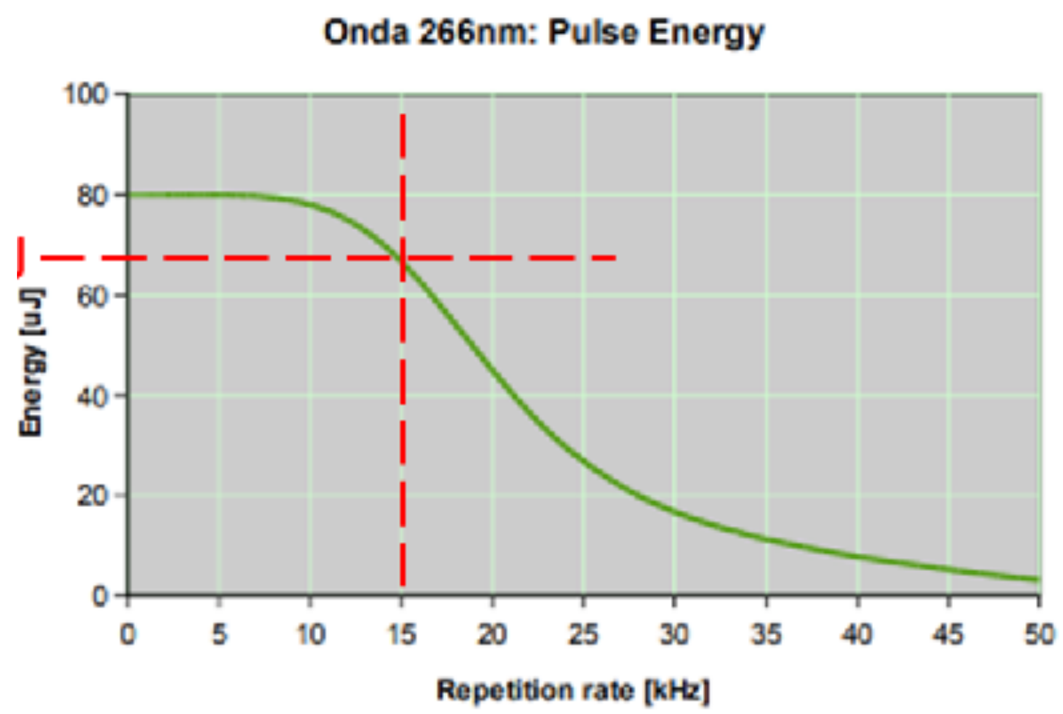
Onda 266nm | **Spec. #: ND18603**

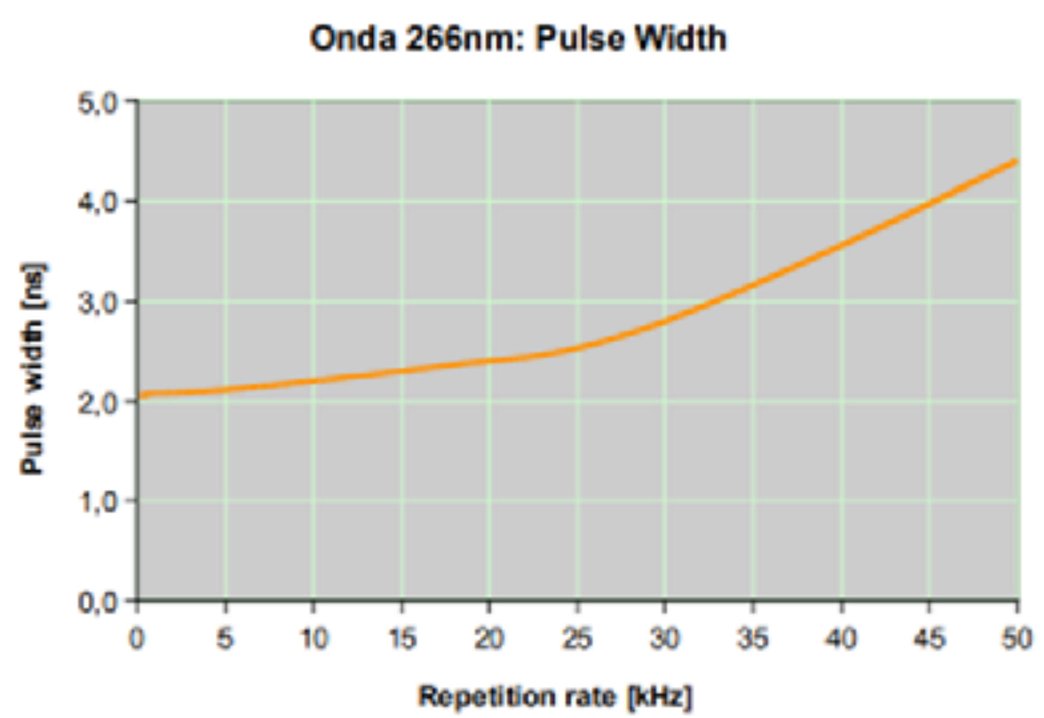
High Peak Power Diode Pumped Solid State Laser

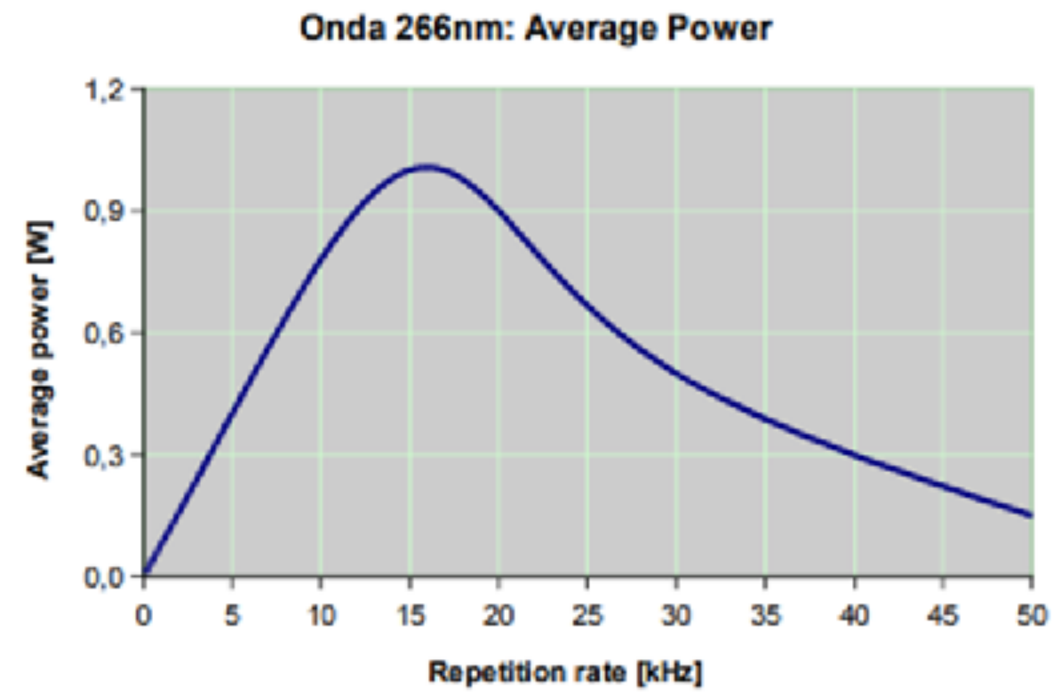


FEATURES

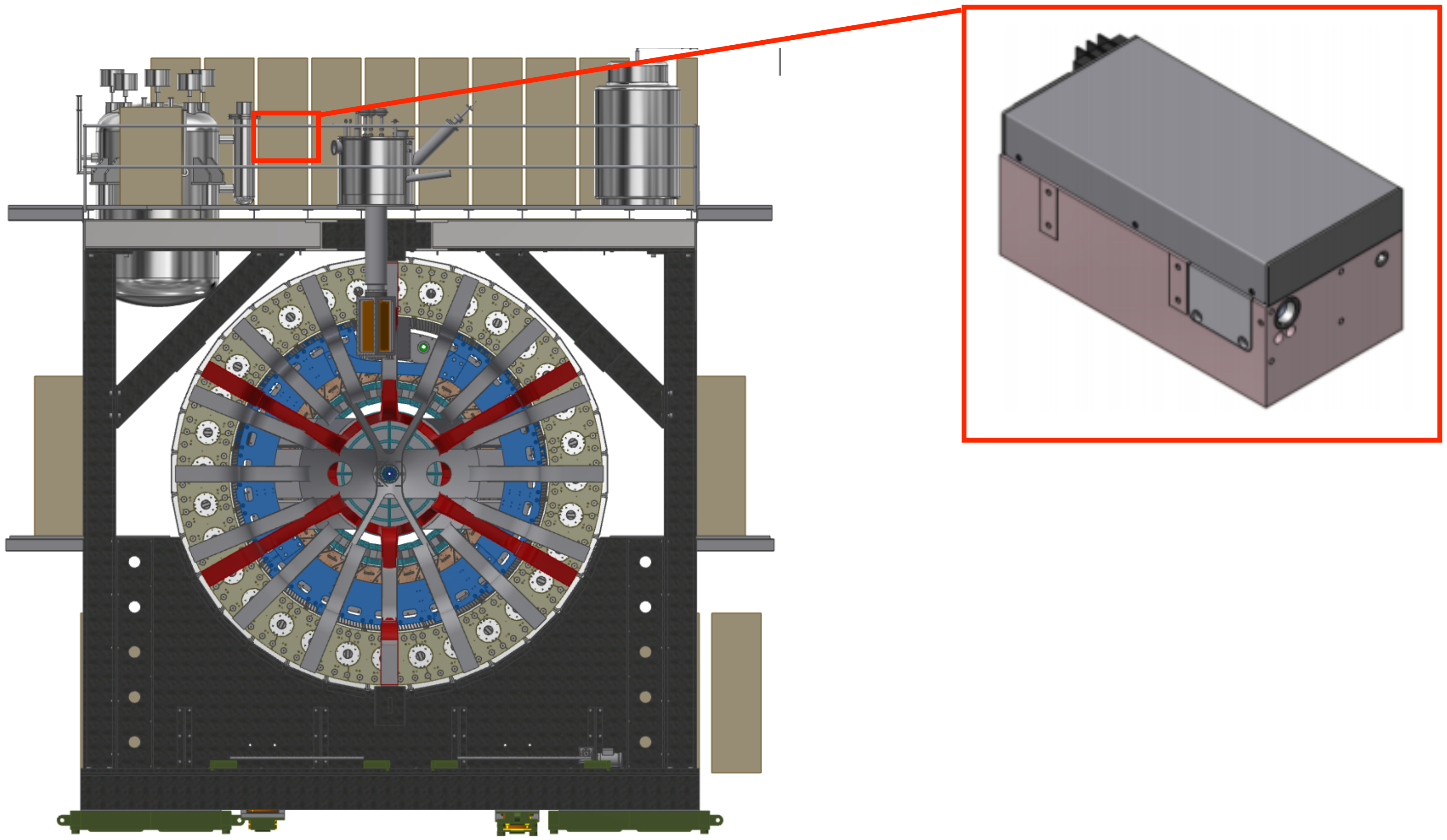
_Up to 80 uJ
_Short pulse duration
_Q-Switching : up to 50 kHz
_All solid state design
_Air Cooled
_Low heat waste







Laser Coupling

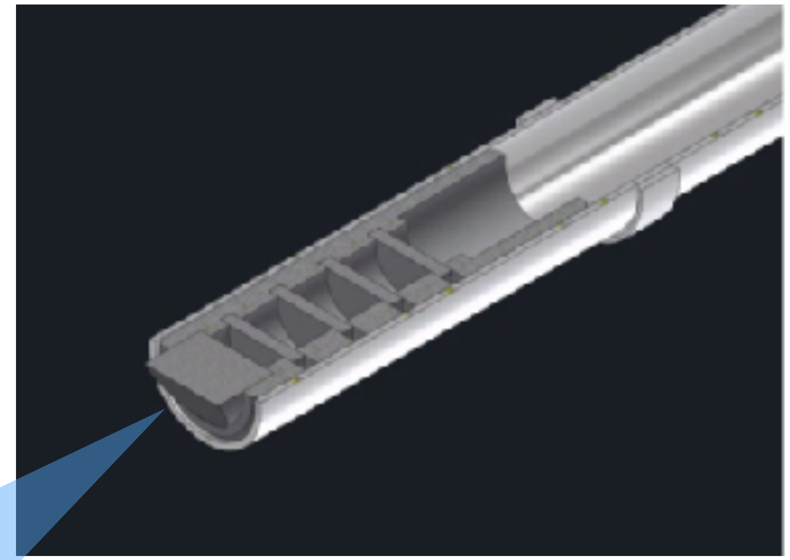


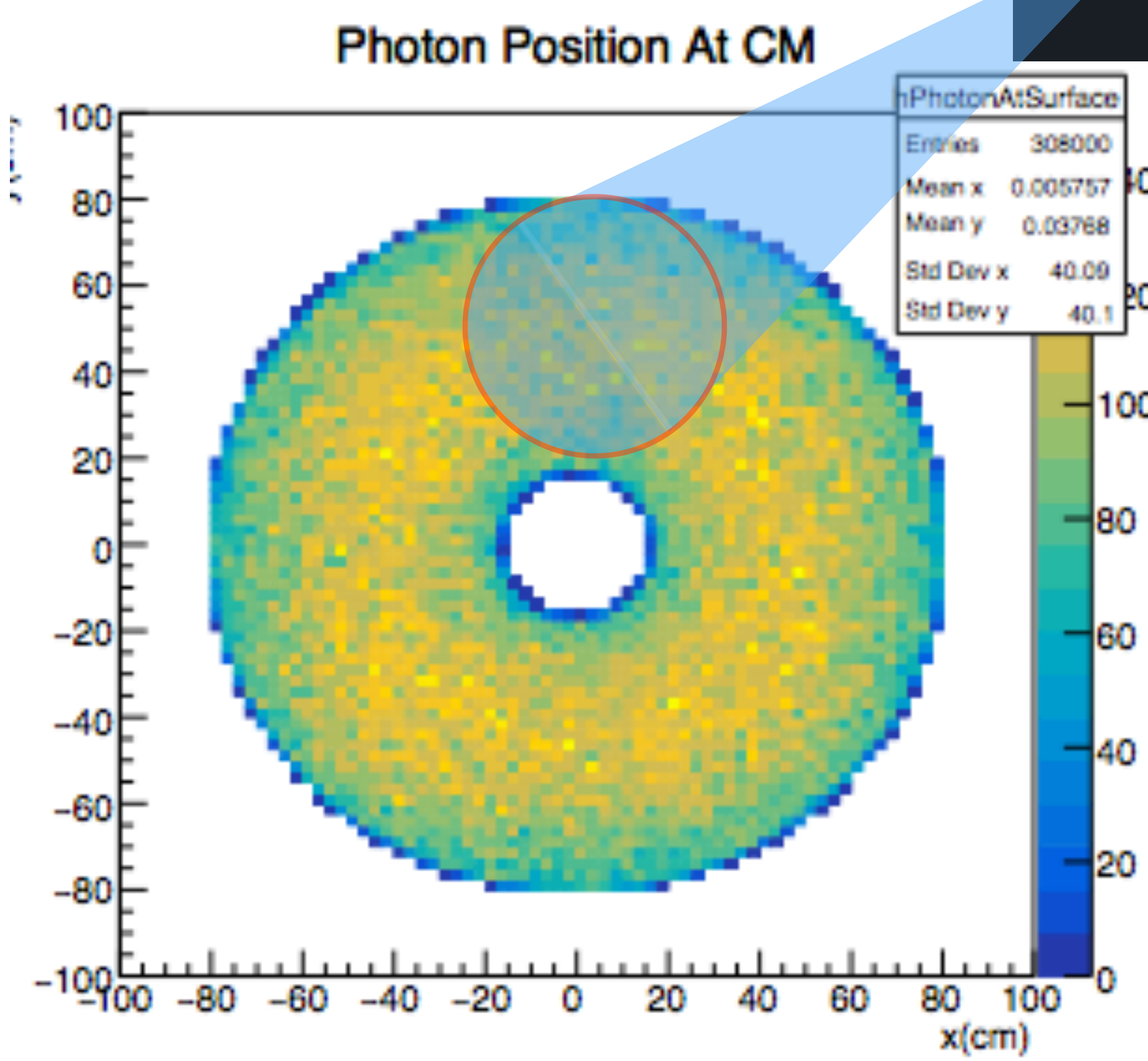
Input	% of Input	R	T	Output
100%	9.1%	90.9%	9.1%	9.1%
90.9%	10.0%	10.0%	81.8%	9.1%
81.8%	11.1%	11.1%	72.7%	9.1%
72.7%	12.5%	12.5%	63.6%	9.1%
63.6%	14.3%	14.3%	54.5%	9.1%
54.5%	16.7%	16.7%	45.5%	9.1%
45.5%	20.0%	20.0%	36.4%	9.1%
36.4%	25.0%	25.0%	27.3%	9.1%
27.3%	33.3%	33.3%	18.2%	9.1%
18.2%	50.0%	50.0%	9.1%	9.1%
9.1%	100.0%	100.0%	0.0%	9.1%

- **Custom splitter directly couples to laser**
- **Reflectivity of each mirror selected to send equal intensity to each of 12 fibers.**
- **Light transmission efficiency ~ 98%**
- **Possible losses in fibers: bends, twists, scatters**

Laser Diffusion

- Cassette holding fiber and diffusers/optics threaded through Wagon Wheel port (Dan Cacace's talk)

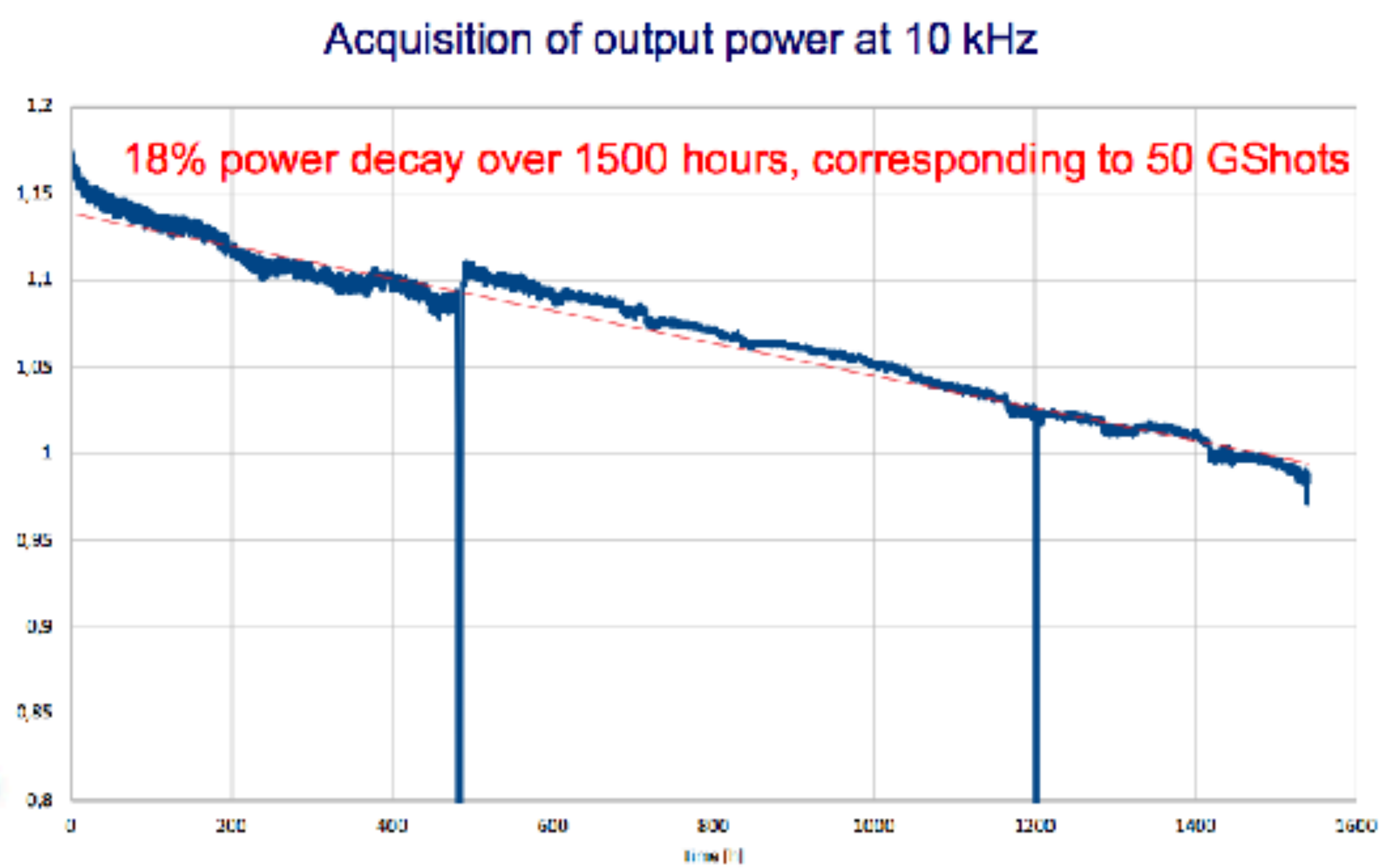




- Optics optimized for intensity and uniformity on CM (Nikhil Kumar's talk)
- CM stripe width adjusted to correct nonuniformity

Laser Lifetime

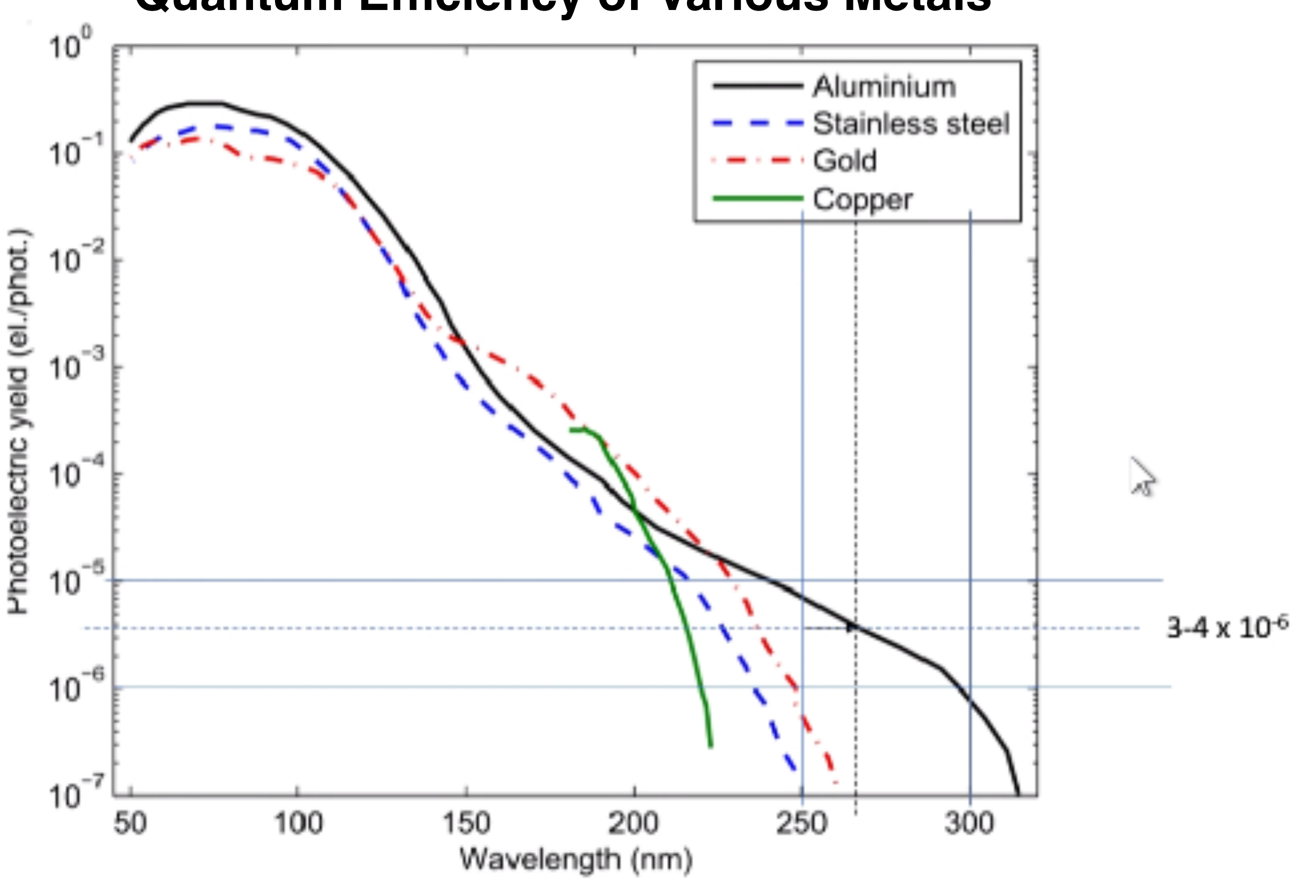
- Vendor tested at 10kHz for extended period
- >1.0W --> 0.92W @1k hours, -->0.77W @ 2k hours (83 days)
- Degradation is in single component (FHG) which can be replaced
- Quoted laser specs build-in this decay



Light Budget

- Custom splitter couples nearly all light into system
- Unavoidable losses in diffusion and strip QE
- Aluminum QE should be measured to confirm.
- Strip widths can be modified to account for moderate additional losses

Quantum Efficiency of Various Metals

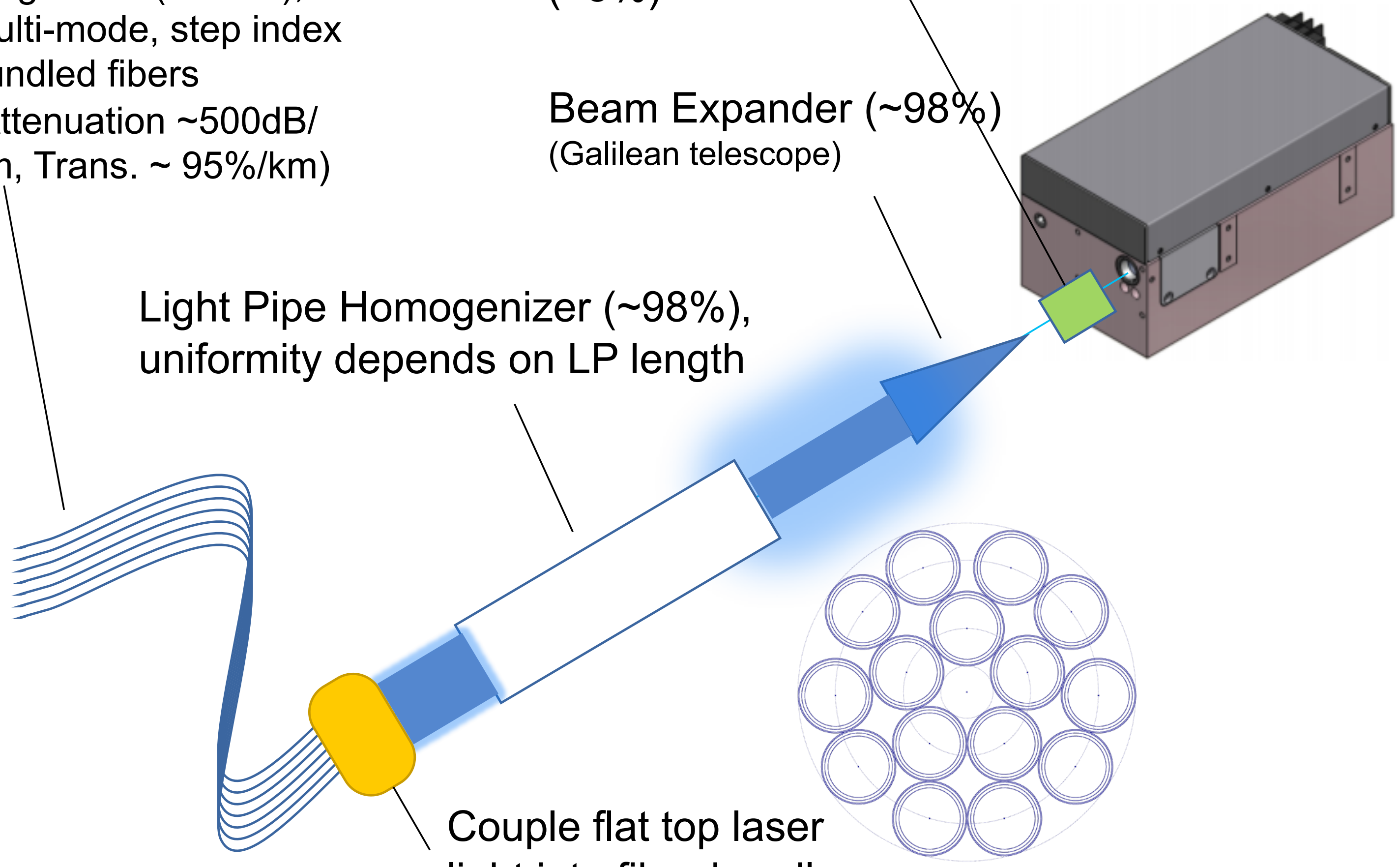


	Step	Surviving Fraction
	Pulse energy @ 15 kHz	67 uJ
	N photons per pulse	8.9e+13
Laser Routing	beam pickoff	95%
Laser Routing	splitter	98%
Laser Routing	radiation mode losses	95%
Laser Routing	scattering/absorption	95%
	N photons @ cassettes	7.5e+13
Diffuser	absorption scattering geometric losses	>25%
	N photons @ CM	>1.8e+13
CM	Al Quantum Efficiency	**>3e-6**
CM	per cm^2 CM area	~1/17850
	N photons / cm^2	**>3100**
	N photons/cm @1mm	**>310**

Summary

- Diffuse laser system will illuminate TPC central membrane, allowing direct monitoring of space charge distortions on time scales not available in other approaches
- Rack-mounted laser routed via fibers to ports on north and south wagon wheels
- Laser lifetime sufficient for our needs
- Light losses before diffuser stage very likely sufficient for our needs, prototype studies planned.
- Laser light diffusion studied and optimized, uniformity and intensity sufficient for our needs (see Nikhil Kumar's talk)
- Design of fiber/optics holder advanced, no show-stoppers (see Dan Cacace's talk)

Alternate Laser Coupling



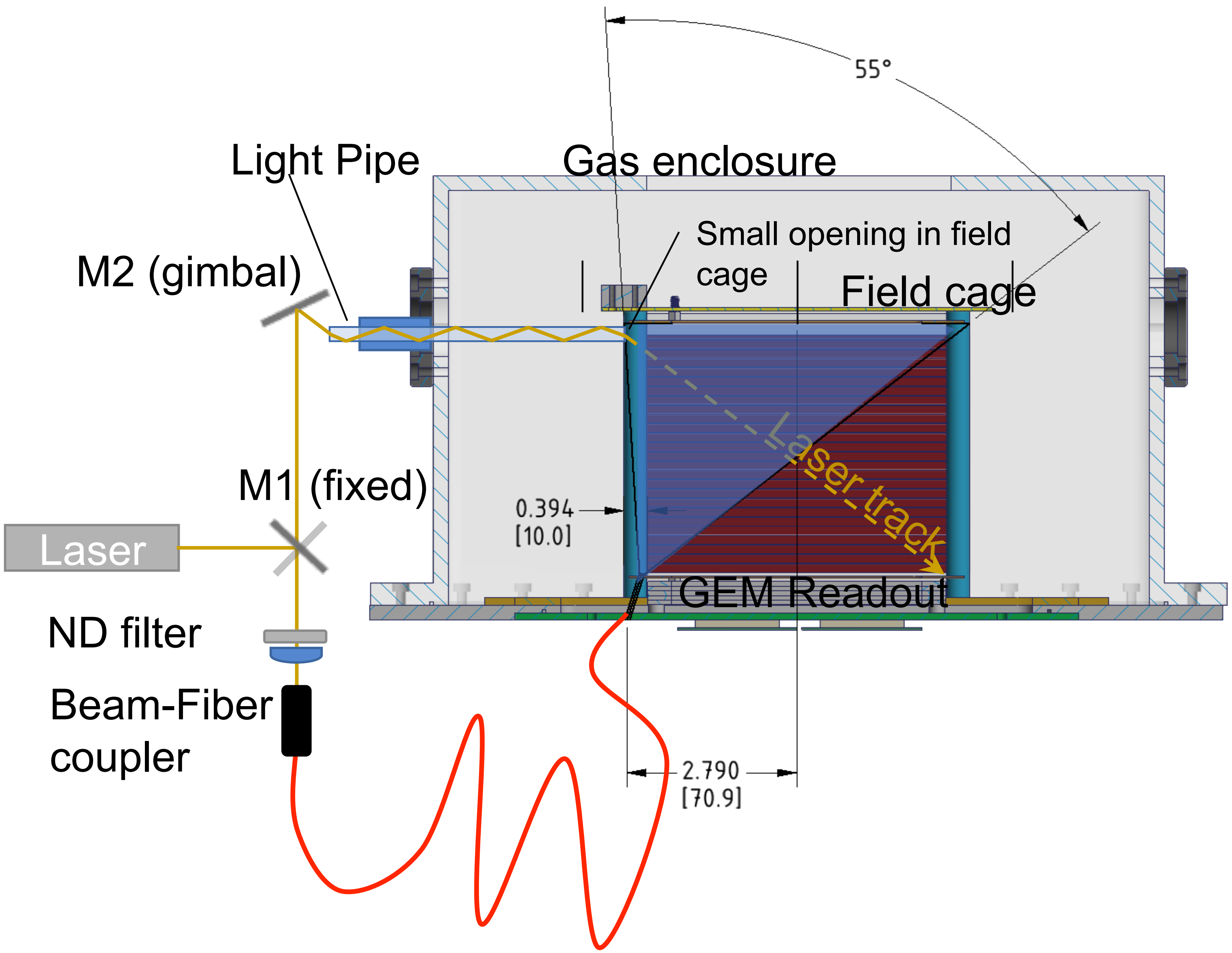
	Step	Surviving Fraction
	Pulse energy @ 15 kHz	67 uJ
	N photons per pulse	8.9e+13
	beam pickoff	95%
	expander	98%
Laser	homogenizer	98%
	bundle coupling	**50%**
	spare fibers	12/15
	radiation mode losses	95%
	scattering/absorption	95%
	N photons @ cassettes	2.9e+13
	absorption	
Diffuser	scattering	>25%
	geometric losses	
	N photons @ CM	>7.3e+12
CM	Al Quantum Efficiency	**>3e-6**
	1/ cm² CM area	~1/17850
	N photons / cm²	**>1200**
	N photons/cm @1mm	**>100**

Fiber Bundle

- **12 fibers +3 spare per TPC half route to individual ports**
- **Homogenizer coupled directly into bundle aperture**
- **Light collection efficiency ~ packing efficiency if homogenous and angles < fiber aperture (0.22)**
- **Possible losses in fiber bends, twists, scatter**

Membrane Prototype Testing

- Al-ENiG membrane can be tested in the TPC prototype at BNL
- UV laser already on hand for directed laser studies



Electron Yield for 90/10

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- Additional factor of 2 to account for maximal case of charge sharing between adjacent radial pads at readout

$$2 \times 2 \times N_{\text{MIP}} = N_{CM}$$
$$2 \times 2 \times 50 = \sigma_\gamma 0.1\text{cm}^2$$

- Resulting target yield is 200 e/cm, hence photon density of **2000γ/cm^2**