Luminosity Calorimeter Technologies

- SiW - Silicon-tungsten sampling calorimeter (current Si tech)
- Quartz Fiber – Cerenkov longitudinal sampling (CMS HF)
- Gas Cerenkov – Cerenkov longitudinal sampling (new)
- Parallel Plate Avalanche Ch – gas sampling (current)
- $PbWO_4$ – Continuous scintillating (CMS ECAL)

The Problem

- Bunch crossing (warm) 1.4 ns
- “ (cold) 337 ns
- Radiation dose ~100 MRad/y
- Pairs produced / crossing ~ 200 TeV

  <E> ~ 4 GeV

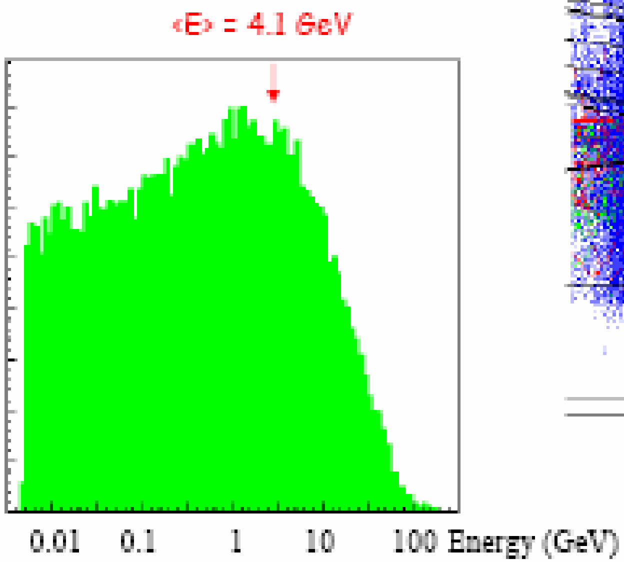
  <x,y> ~ several cms
- Must see 250 GeV Bhabha e+e-
- Must veto 2-gamma background events

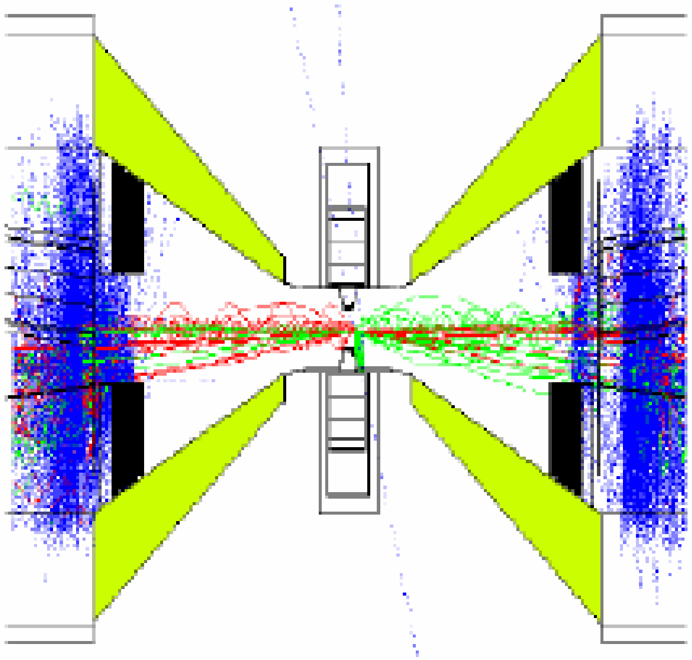
IP background calculation:

Takashi Maruyama, SLAC

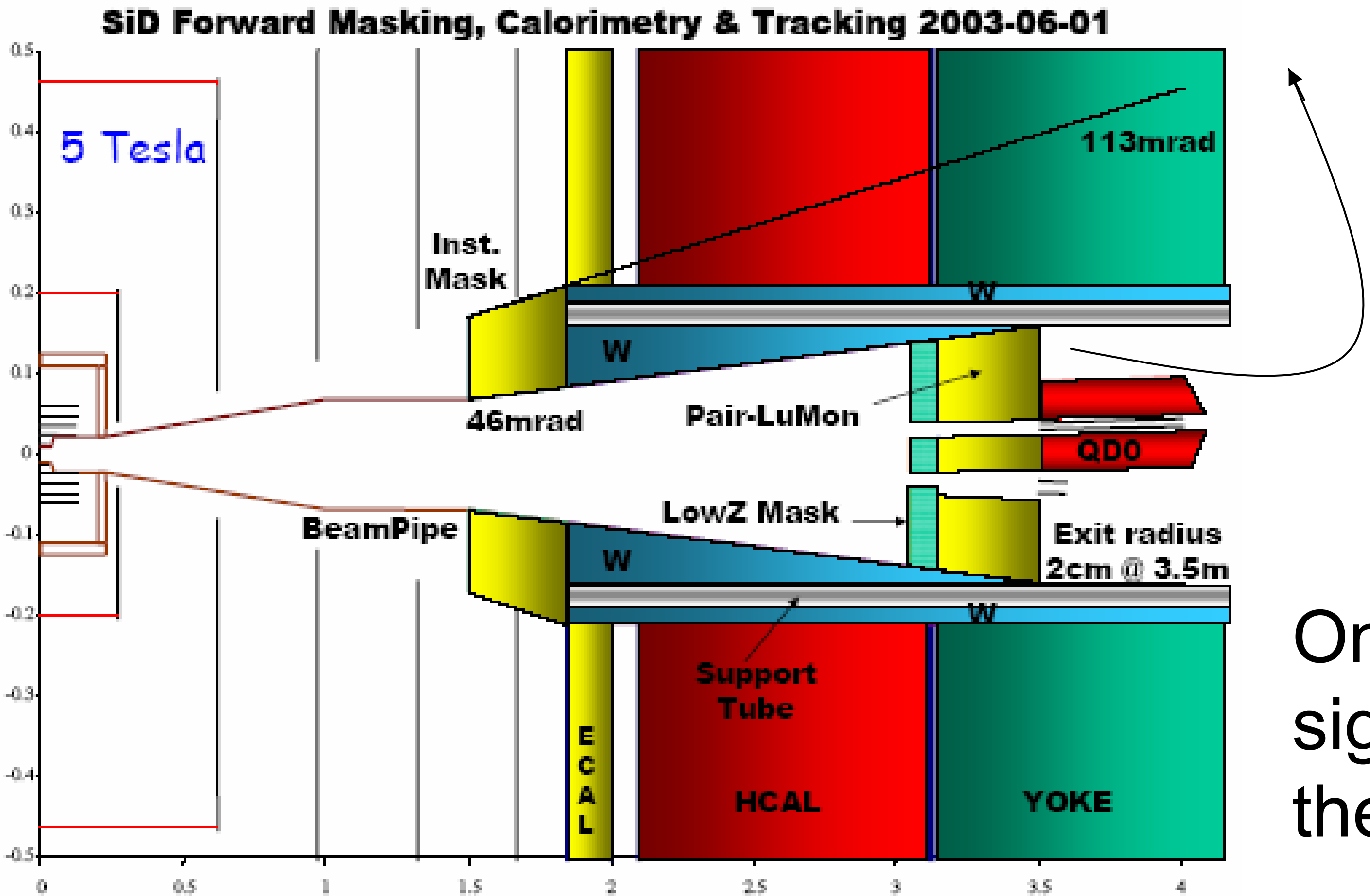
e+ e- Pairs from e+ e- Collisions

With Current NLC IP Beam Parameters:
e+ or e- = 49,000/bunch
<E> = 4.1 GeV
E_total = 199,000 GeV





Signal path: calorimeter to behind yoke



Only take signals out the back….

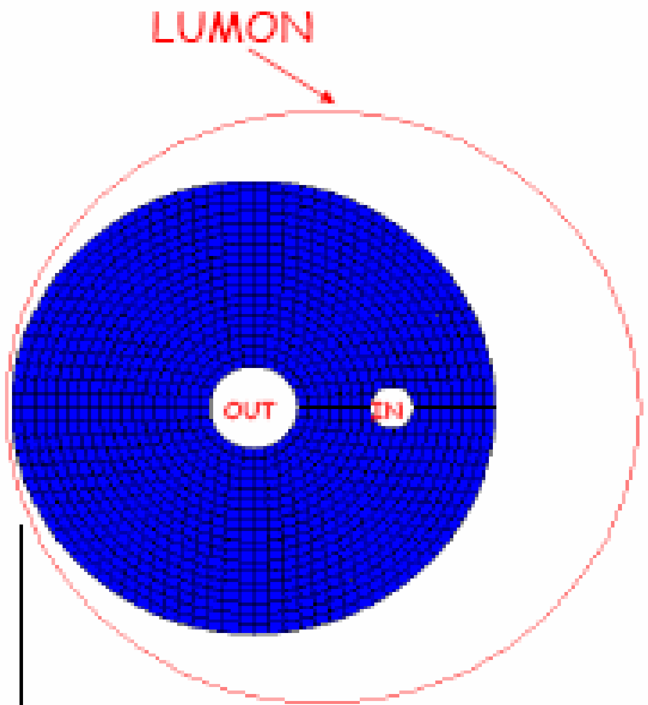
Si-W: 50 layers 2 mm W + 0.3 mm Si

(M.Breidenbach, T.Maruyama, …)

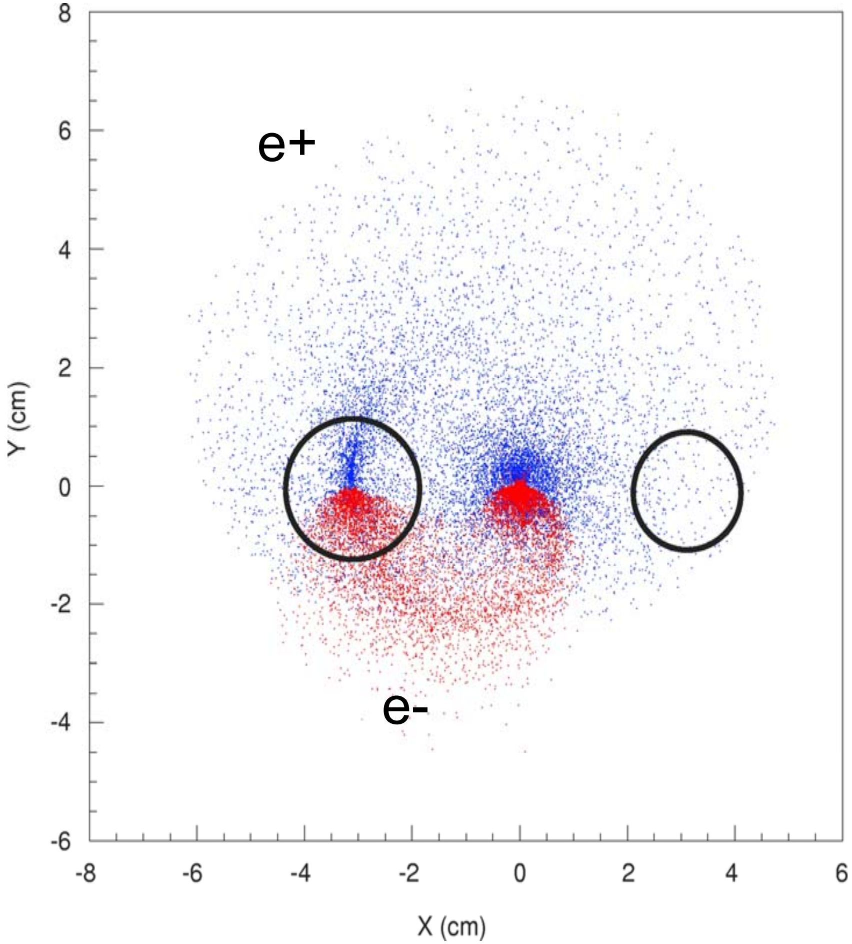
Strengths: known technology, fine granularity, well simulated and well understood.

Weaknesses: Si may be radiation-soft, electron-hole drift is slow; recovery time long (compared to 1.4 ns).

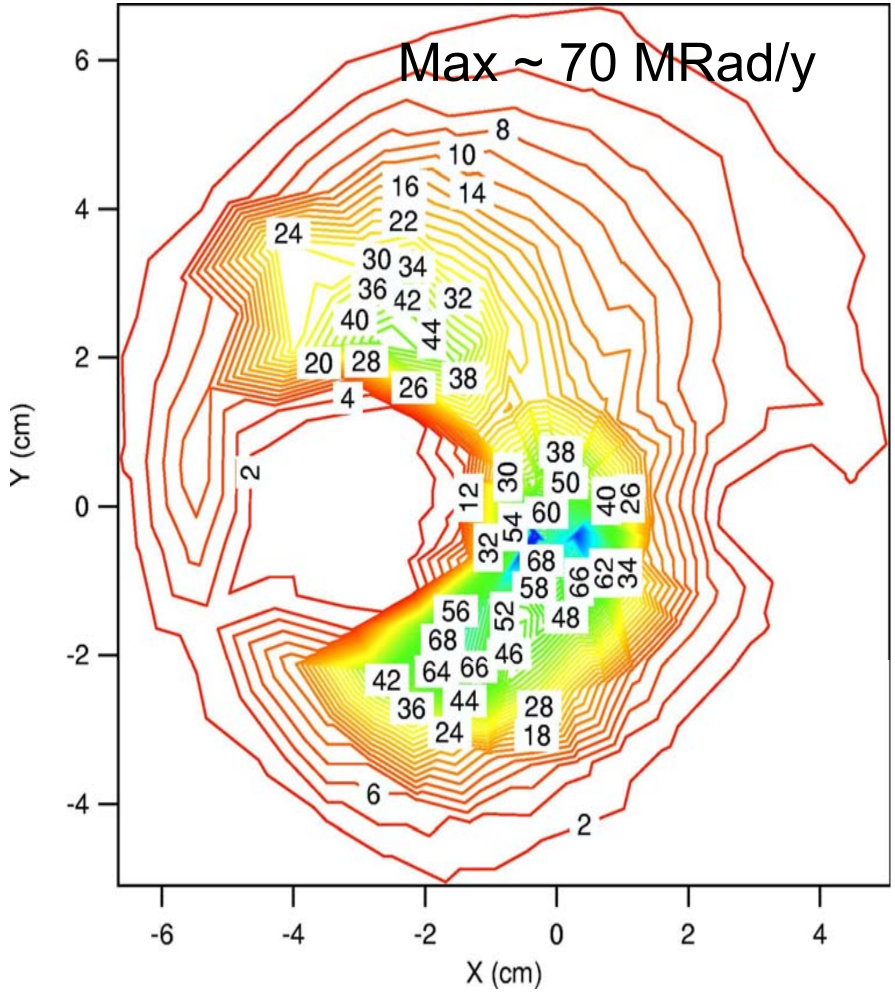
- Zeuthen r-φ segmentation
- Rin = 1.0 cm
- Rout = 2.0 cm



SiW dose

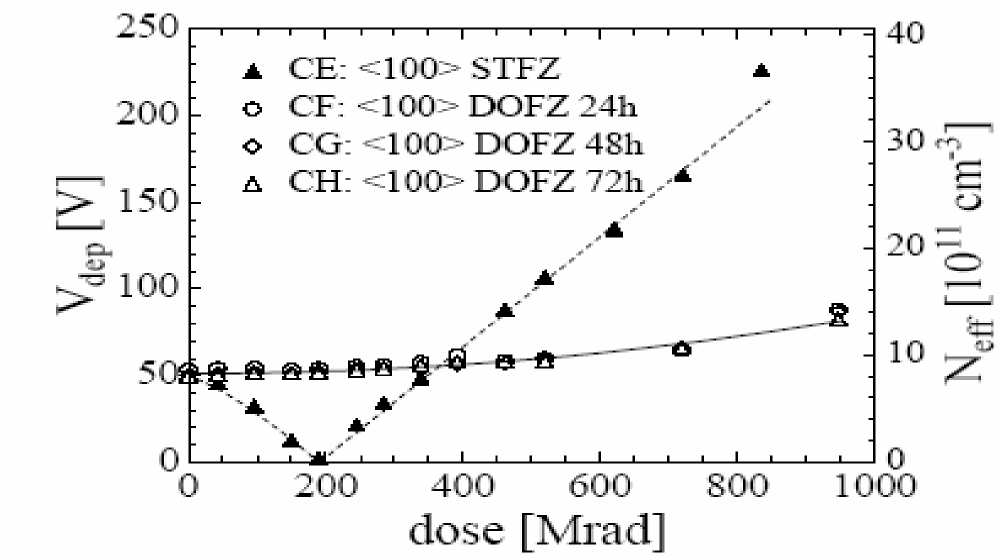


e+
e-
Y (cm)
X (cm)
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6



Max ~ 70 MRad/y
Y (cm)
X (cm)
8
10
16
14
24
22
30
34
36
42
32
40
44
20
28
26
38
4
2
12
30
54
50
60
40
26
32
68
58
66
62
34
56
52
48
68
46
42
64
66
36
44
28
24
18
6
2

Results from RD50: Si is OK up to 1 Grad (M. Moll, RD50/2003/001)



Si → diamond (Wolfgang Lohmann)

Table 2: Properties of Diamond, 4H-SiC, Si and GaN crystals.

Property	Diamond	4H-SiC	Si	GaN
E_g [eV]	5.5	3.27	1.12	3.39
μ_e [cm^2/Vs]	1800	800	1500	1000
μ_h [cm^2/Vs]	1200	115	450	30
e-h energy [eV]	13	8.4	3.6	~8-10
Displacem. [eV]	43	25	13-20	~10-20
Density [g/cm^3]	3.52	3.21	2.33	6.15
Radiation length X_0 [cm]	12.2	8.7	9.4	2.7
e-h pairs / X_0 [10^6 cm^{-1}]	4.4	4.5	10.1	~2-3

Most remarkable fact: oxygenated Si is impervious to electromagnetic radiation damage, i.e., OK for LC, and not OK for p's and π's, i.e., not OK for LHC.

Quartz Fiber Calorimetry

(Spanier, Bugg & Onel, Winn)

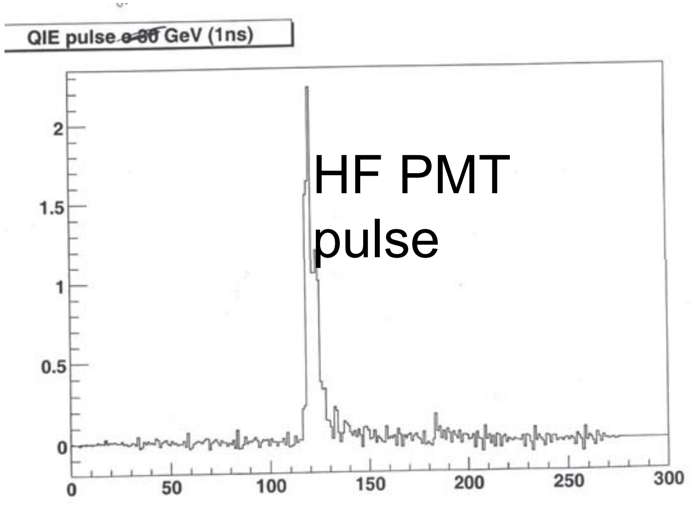
Strengths: well understood (CMS-HF), fast and radiation-hard.

Weaknesses: time spread of signal ~ 1ns (almost OK); radiation hardness ~ 1 Grad (almost OK).

"Rapunzel" →

CMS-HF quartz fiber
Nural Akchurin, TTU

The quartz fiber Hadronic Forward (HF) calorimeter of CMS is completely understood. Energy resolution, spatial resolution, radiation damage, Cerenkov light budget at all stages, uniformity, etc.



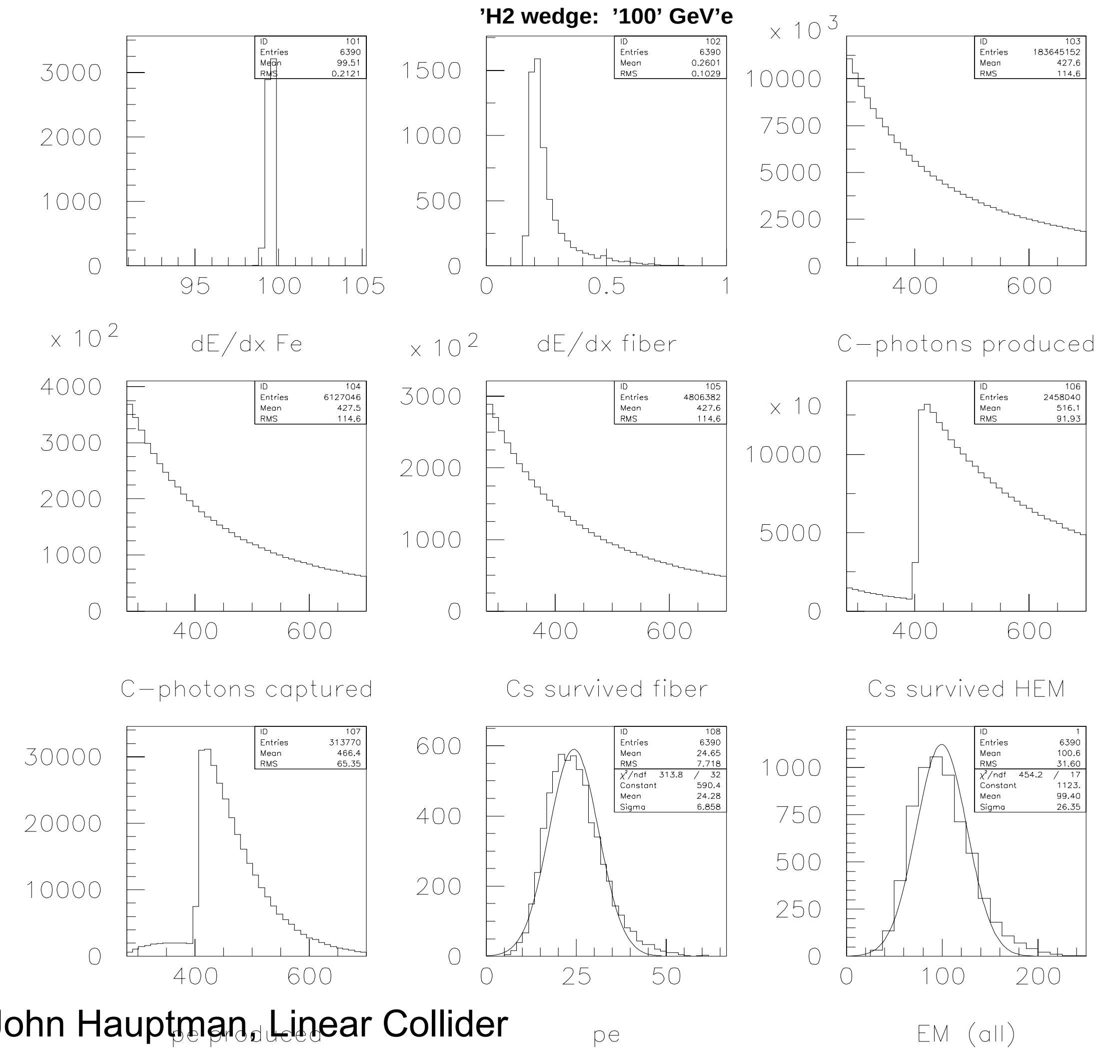
t (ns) →

Fast for the 25-ns LHC

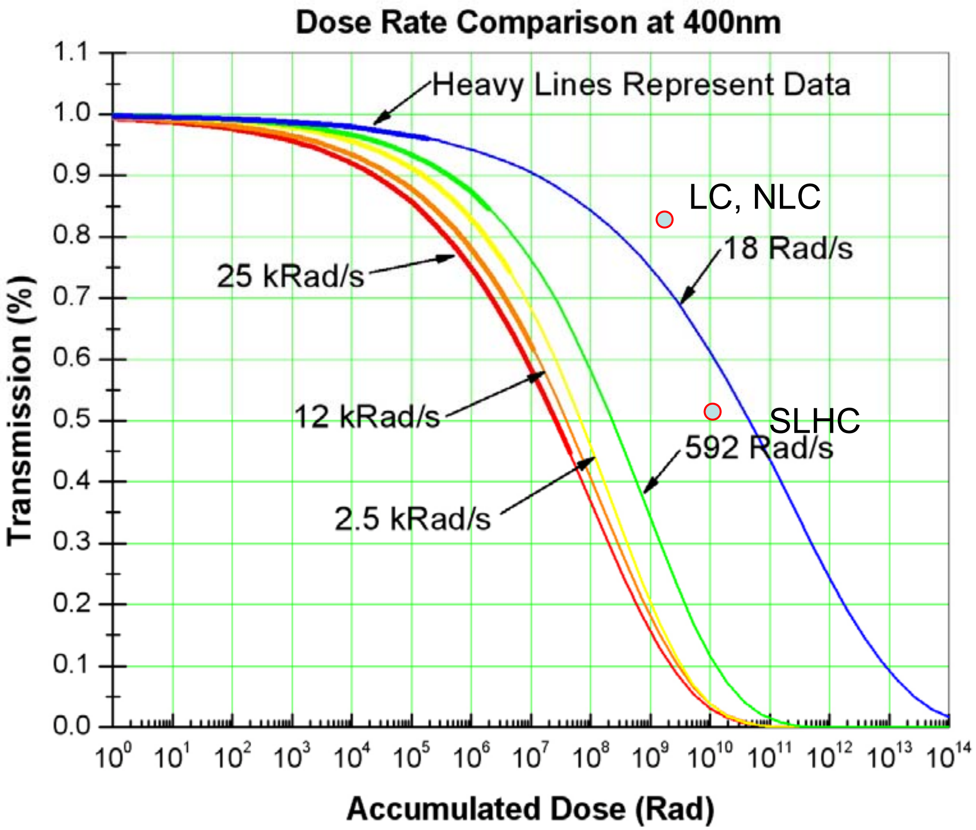
Slow for the 1.4-ns warm LC

Detailed understanding of everything in HF

Cerenkov photon budget at every physical stage of this new quartz fiber calorimeter



Quartz Transmission vs. Dose & Dose Rate



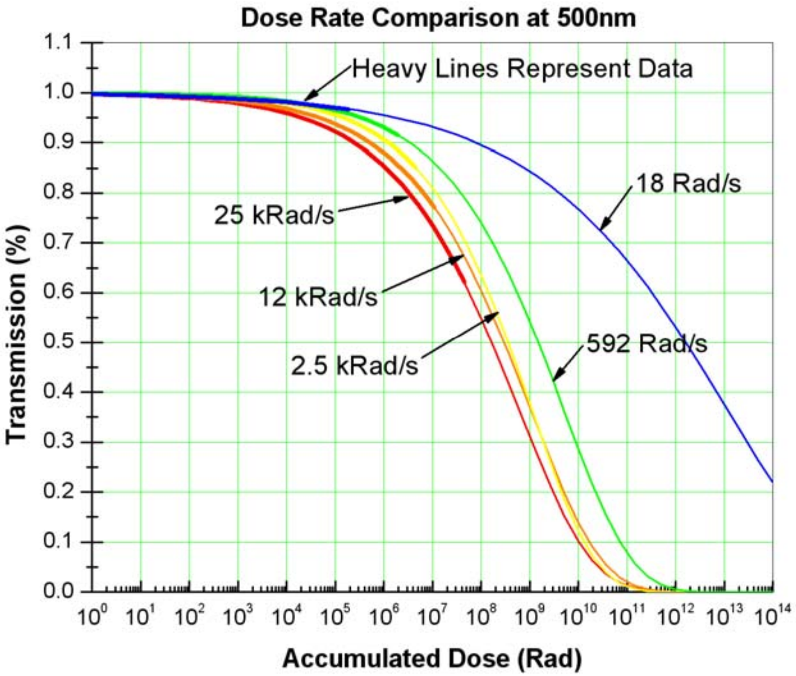
Ray Thomas, Texas Tech University – using an electron accelerator

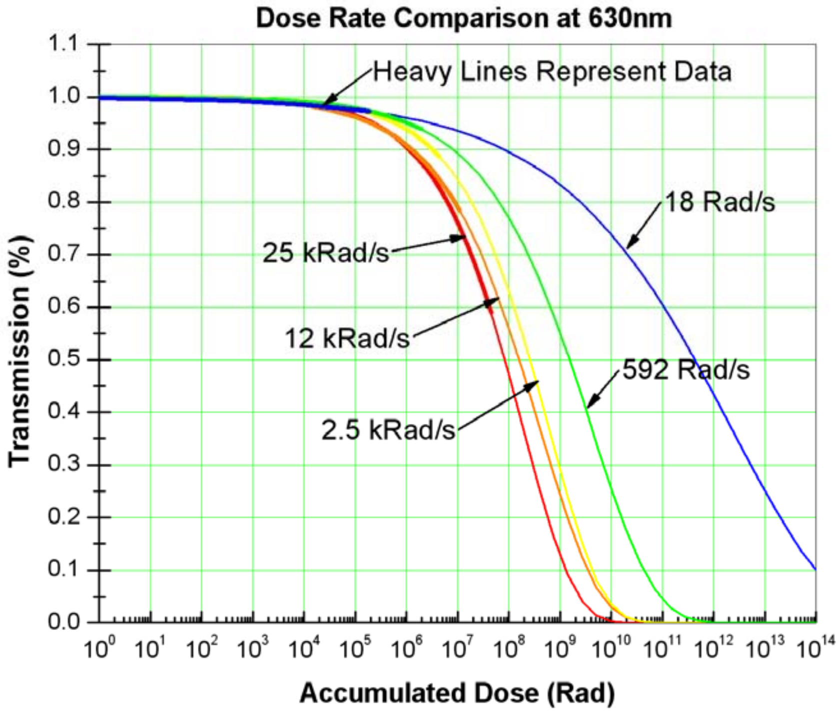
ray.thomas@ttu.edu

$1/\lambda_{atten} = \alpha D^{\beta}$

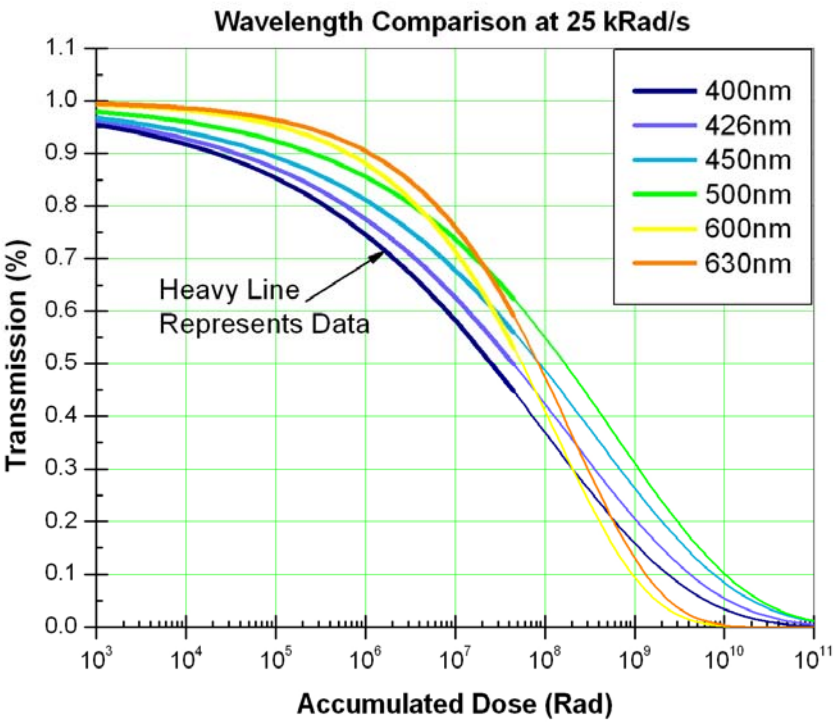
D (MRad), $\alpha,\beta \sim 0.3$

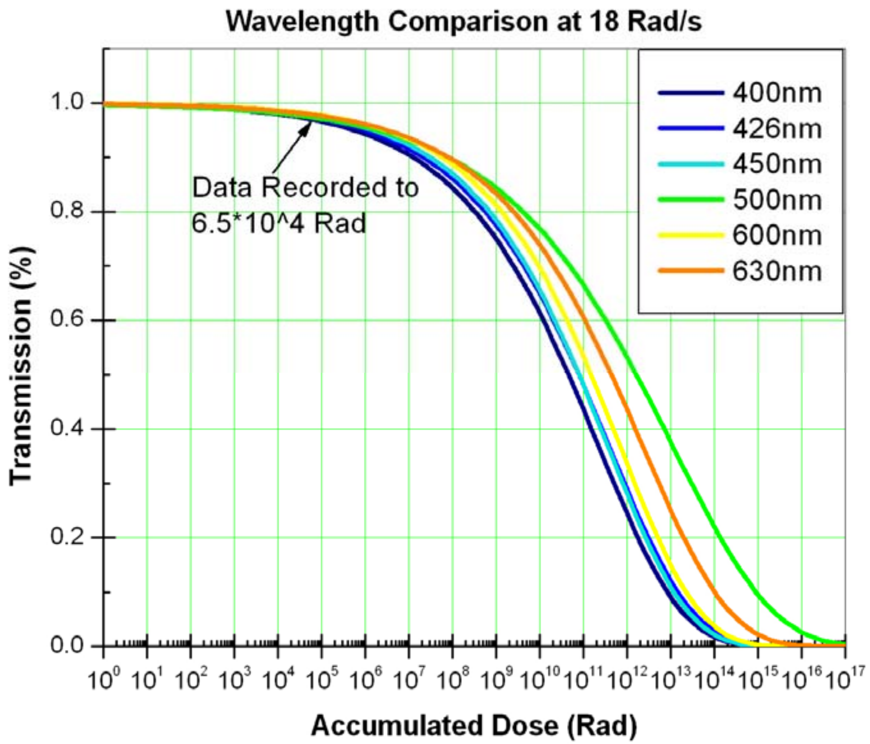
And, at two more wavelengths



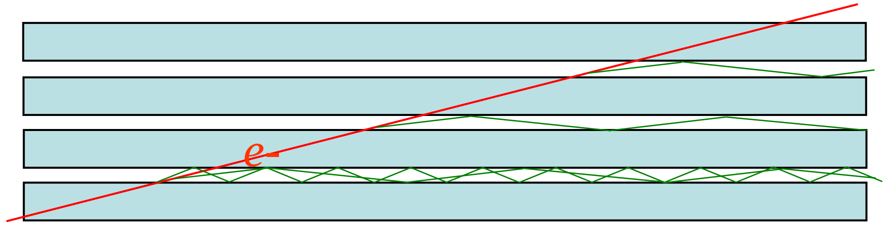


And, for each wavelength at two dose rates





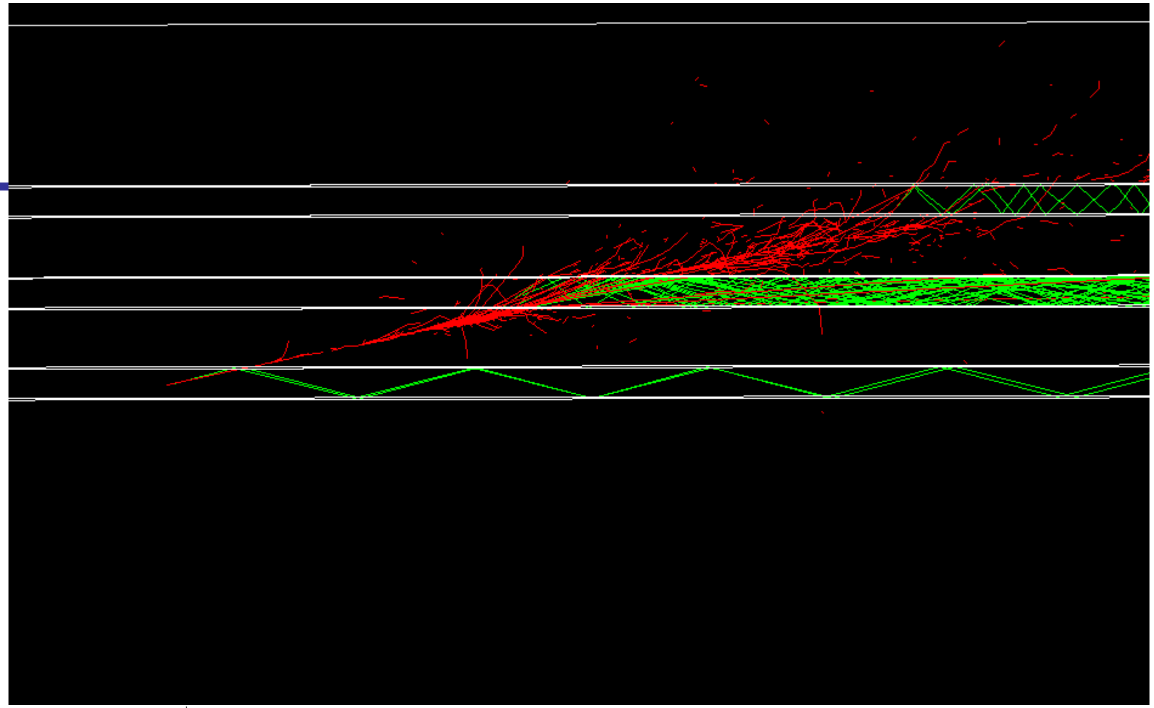
Gas Cerenkov: Basic idea



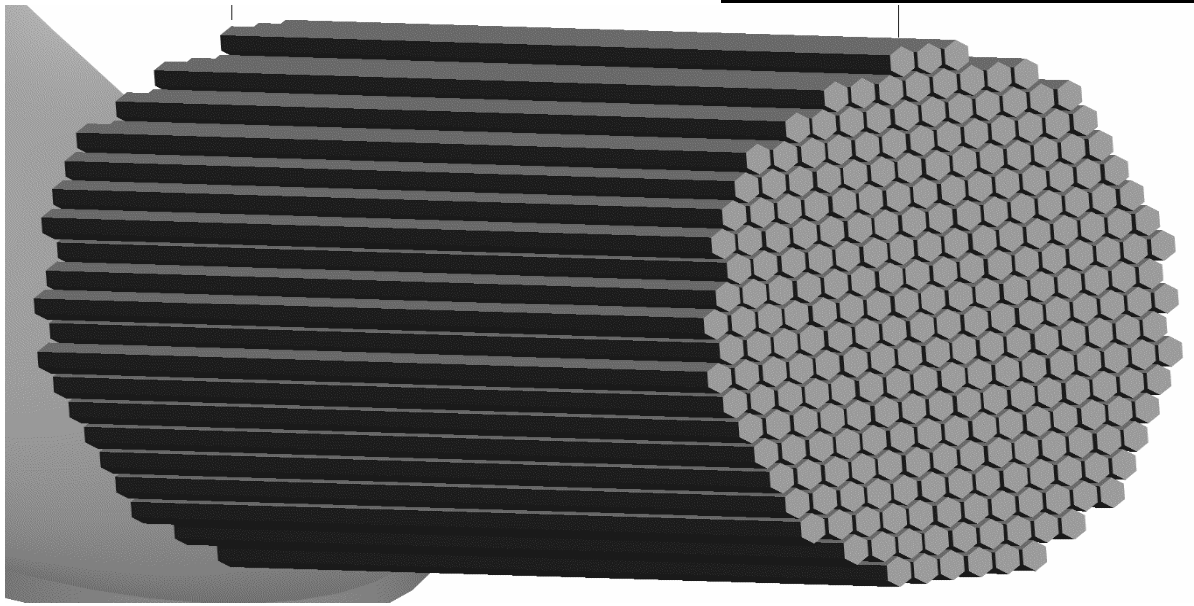
- Shower particles generate Cerenkov light in gas between highly reflective metallic walls.
- Gas refractive index n = 1+δ, where $\delta \sim 0.001$ for most gases at STP.
- Cerenkov angle is small: $\sin\theta_{\breve{C}} \approx \sqrt{2\delta} \approx .05$
- Cerenkov threshold is high: $E_{th} \approx \dfrac{m_e}{\sqrt{2\delta}} \approx 11.2\ \text{MeV}$
- Cerenkov photons co-move with e+/- in a 15 ps pancake

Very radiation-hard: only gas and metal.

Does not "see" IP γ,e backgrounds nor radioactivation below10-20 MeV



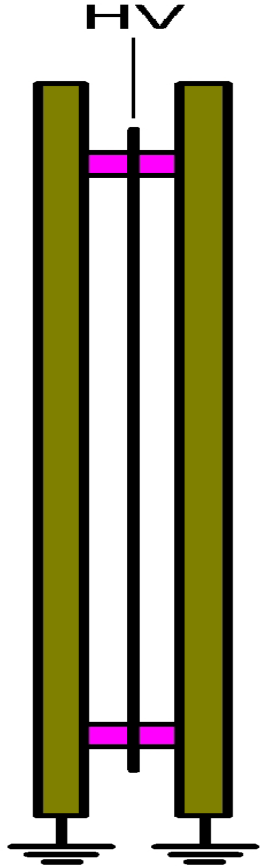
Hex simulation



Parallel Plate Avalanche Chamber (PPAC)

(Onel, Norbeck)

- Low pressure gas, ~ 20 torr
- Plates at ~700 V
- Signal generation ~ 3 ns
- Positive ions take ~ 1 μs



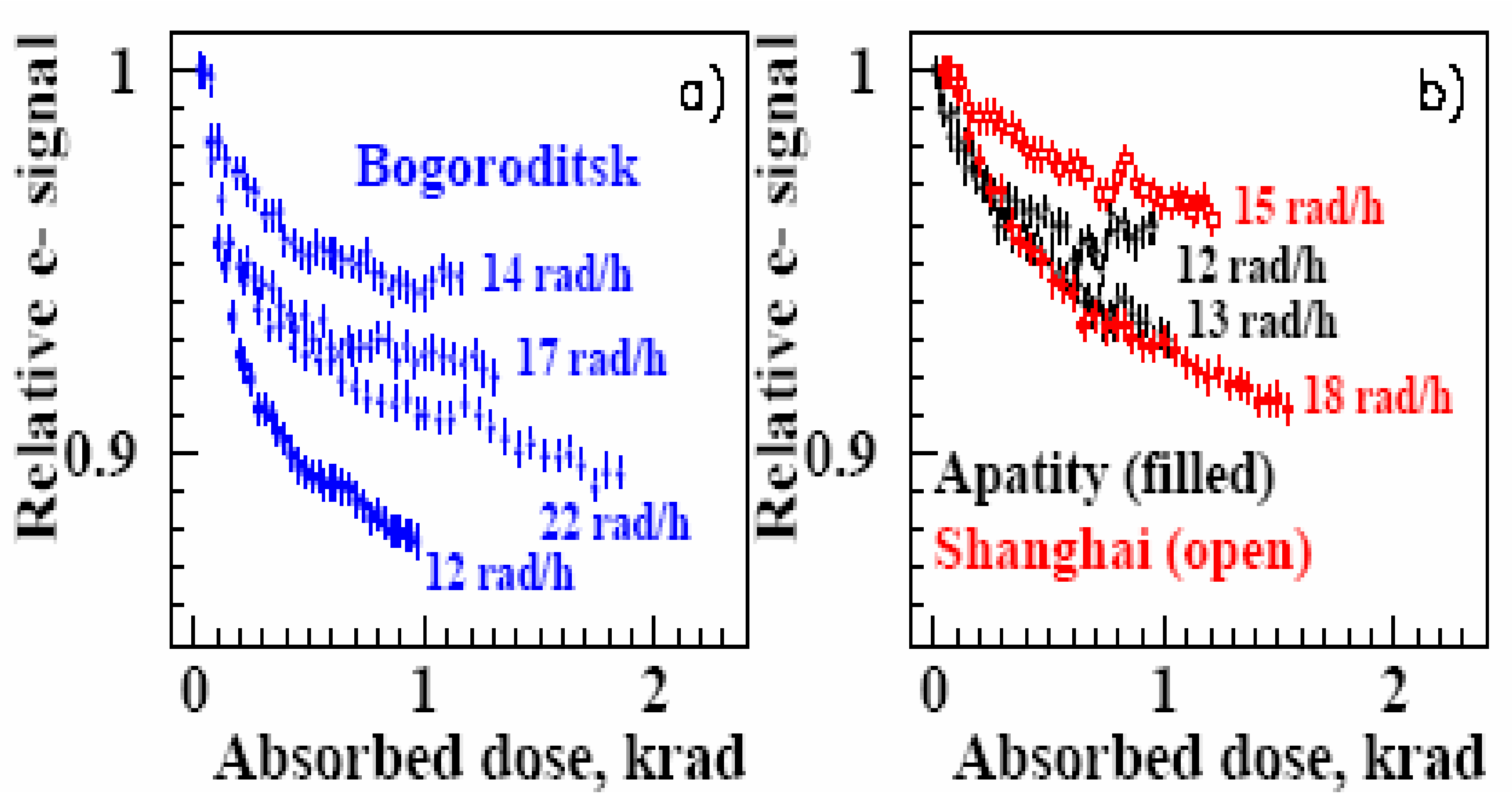
PPACs are well understood and, for non-organic gases, would suffer little radiation damage.

$PbWO_4$ Crystals: CMS ECAL

- Well understood, tested.
- Signal generation ~ 10 ns
- Signal recovery ~ 25 ns
- QA problems during manufacture solved.
- Radiation hardness undergoing testing for time dependence of signal and signal loss.

"Study of Radiation Damage in Lead Tungstate Crystals Using Intense High Energy Beams", V.A. Batarin, et al., 5 Oct 02, hep-ex/0210011

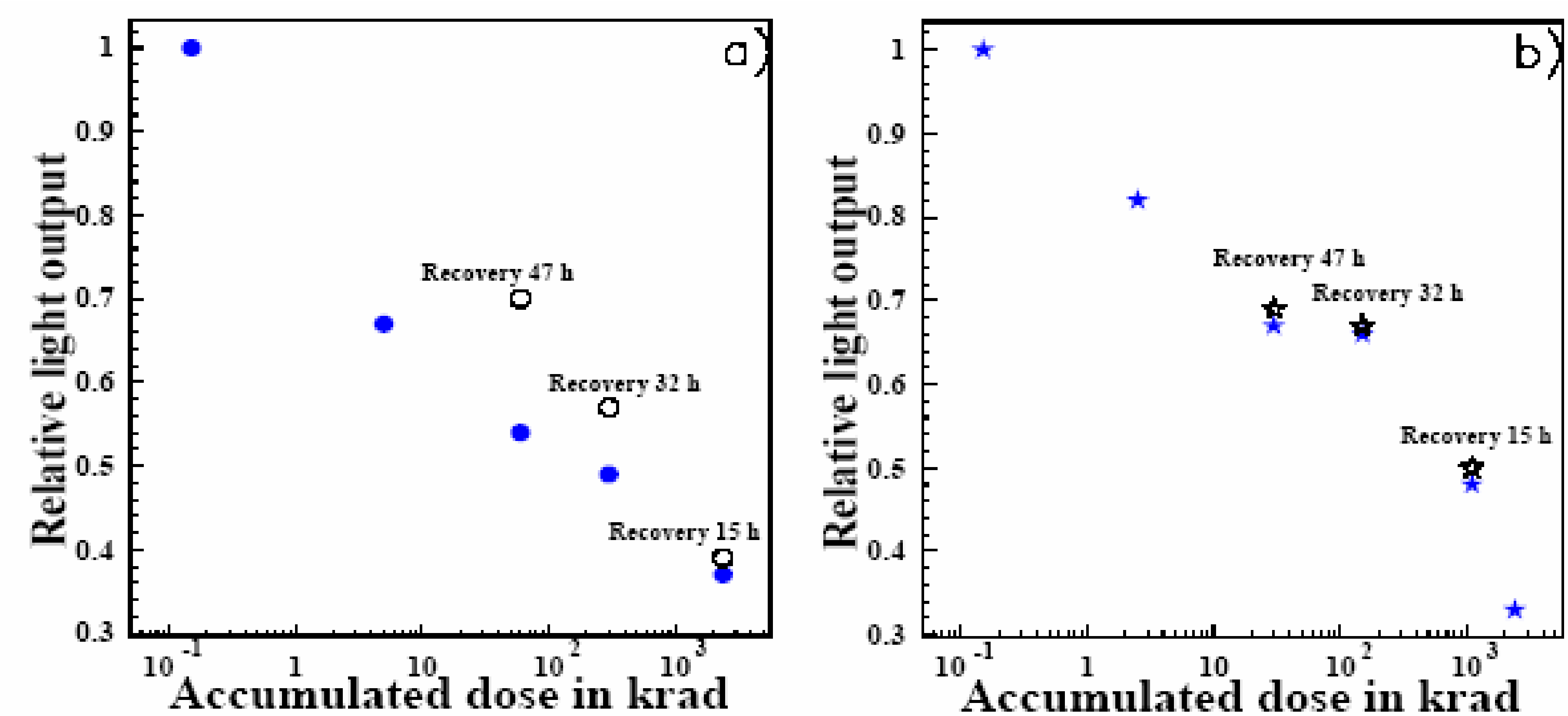
(Note Bene: these dose rates are far below the 10 Rad/s for a LC luminosity monitor).



27 GeV e-

"Study of Radiation Damage in Lead Tungstate …",
ibid., Batarin, V.A., *et al.*,

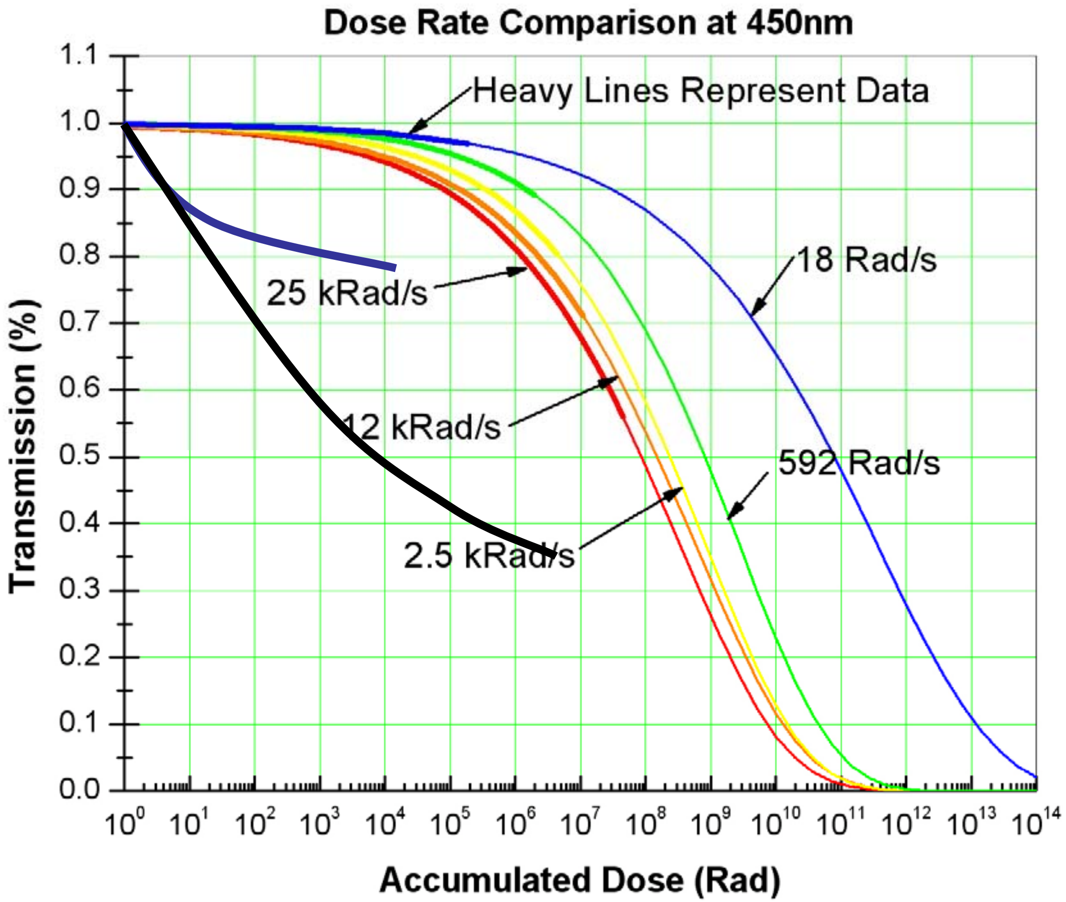
27 GeV e- beam



Radiation hardness: $PbWO_4$ compared to quartz fiber

27 GeV e-

Batarin, et al.



Time scales (ns)

	Si-W	Quartz fiber	Gas Cerenkov	PPAC	PbWO4
Signal generation	3	~0	~0	1.65	10
Signal trans-mission	3	1	.3	5	2
Recovery time	5	2	1	1000	25
DAQ time		1	1	?	1

Radiation Hardness

	Si-W	Quartz fiber	Gas Cerenk	PPAC	PbWO4
Dose-to- Death	1 GRad	10 GRad	100 GRad	?	0.1 GRad
Signal loss per 0.1 GRad	1%	12%	1%	?	90%
Other potential signal losses	on-wafer circuitry	-	R<1.0 10%	?	?
Main weakness	defect generation	optical damage	optical transport	positive ions	optical damage

Grade A, B, …,→F

	Si-W	Quartz fiber	Gas Cerenkov	PPAC	PbWO4
Time	B	B	A	F	C
Radiation hardness	A	A	A	B	F
Physics strength	A	B	C	C	B
Risk = 1/success	B	A	D	D	B

Necessary R&D and beam tests…

Si-W	(1) radiation damage tests – see TTU work above (2) expose a few Si layers to 1.4 ns test beam
Quartz fiber	(1) test in 1.4 ns test beam (2) test sensitivity to low energy e's in IR
Gas Cerenkov	(1) manufacture smooth metallic surfaces (2) test in 1.4 ns test beam
PPAC	(1) test multilayer PPAC in "hot" source, first. If Δt<5ns, (2) expose to 1.4 ns test beam
$PbWO_4$	(1) radiation hardness at 100 MRad level – see TTU work (2) test for time scale of recovery in fast beam

Summary

- Good ideas, but any contender must be dosed (at SLAC or elsewhere) at high rate and to high dose levels.
- Proponents must produce a “dose-to-death” number. This is not easy.
- We need an estimate of the additional dose to the luminosity monitor not associated with bunch crossings.
- For the warm LC, signal generation and recovery times should allow integration over only 1-2 bunches, not more, for the critical early stages of tuning the linac beams. The luminosity made depend on bunch number …
- Timing constraints are largely absent for the cold machine with 337 ns bunch spacing.