R&D considerations for Large Water Detector project for DUSEL

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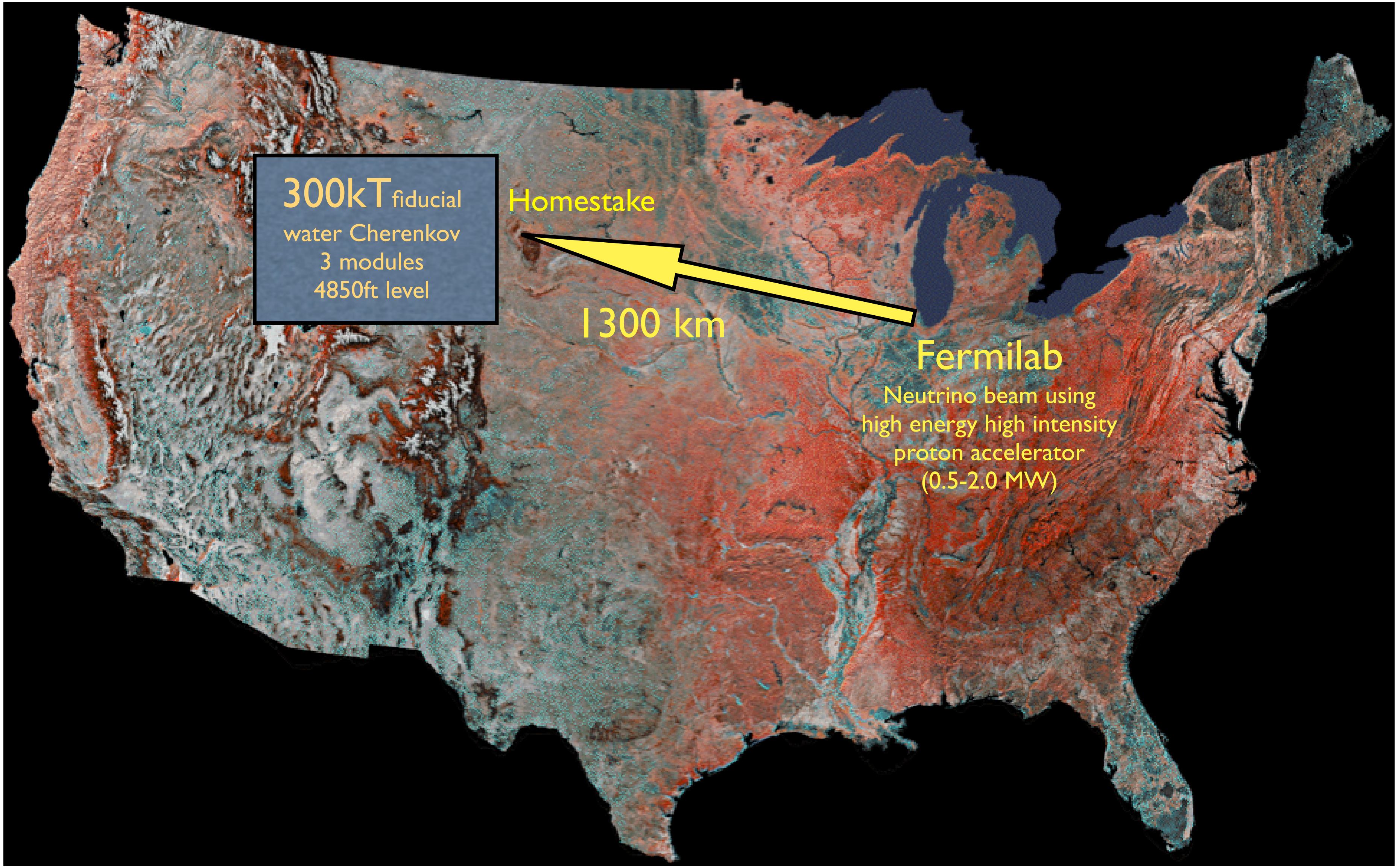
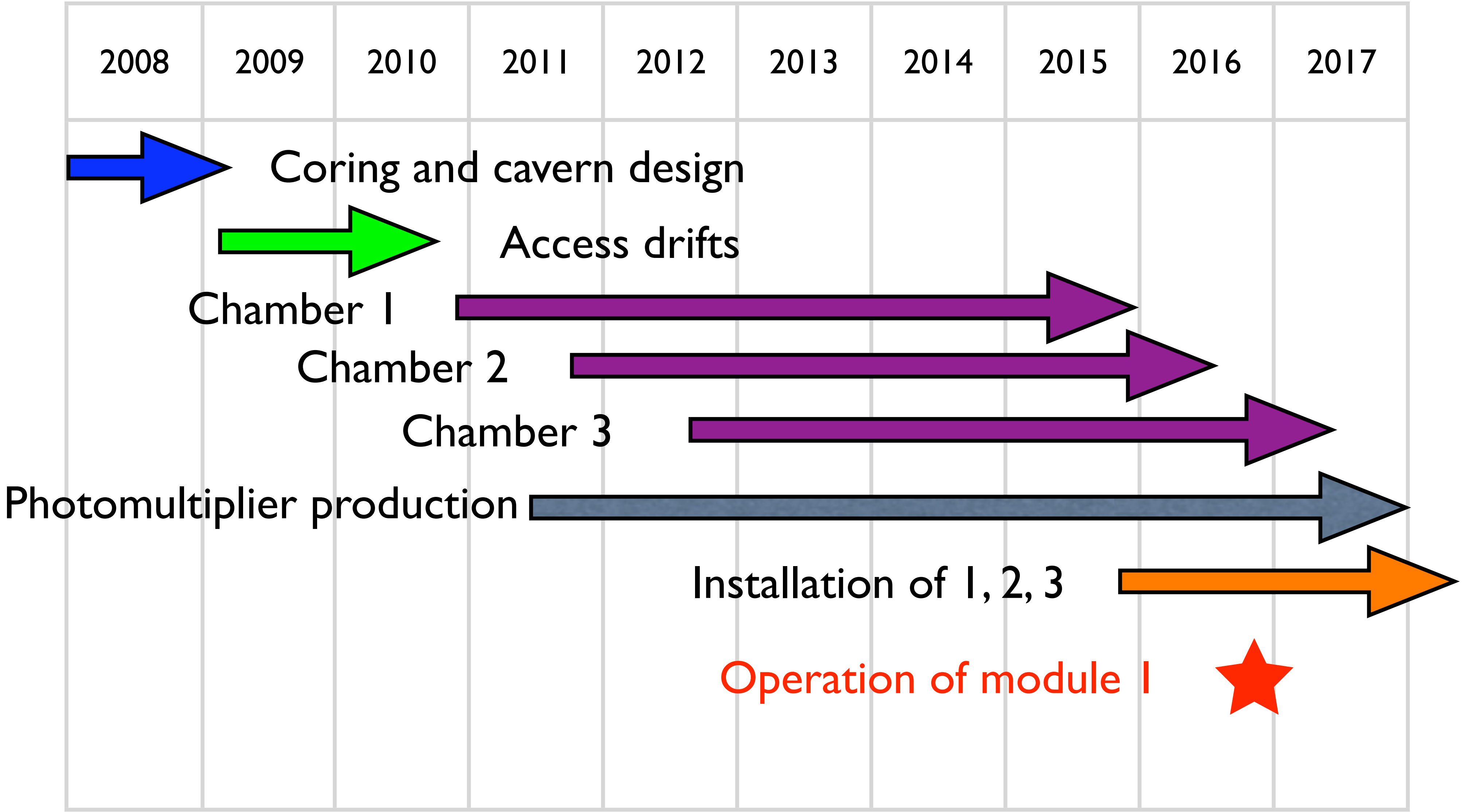
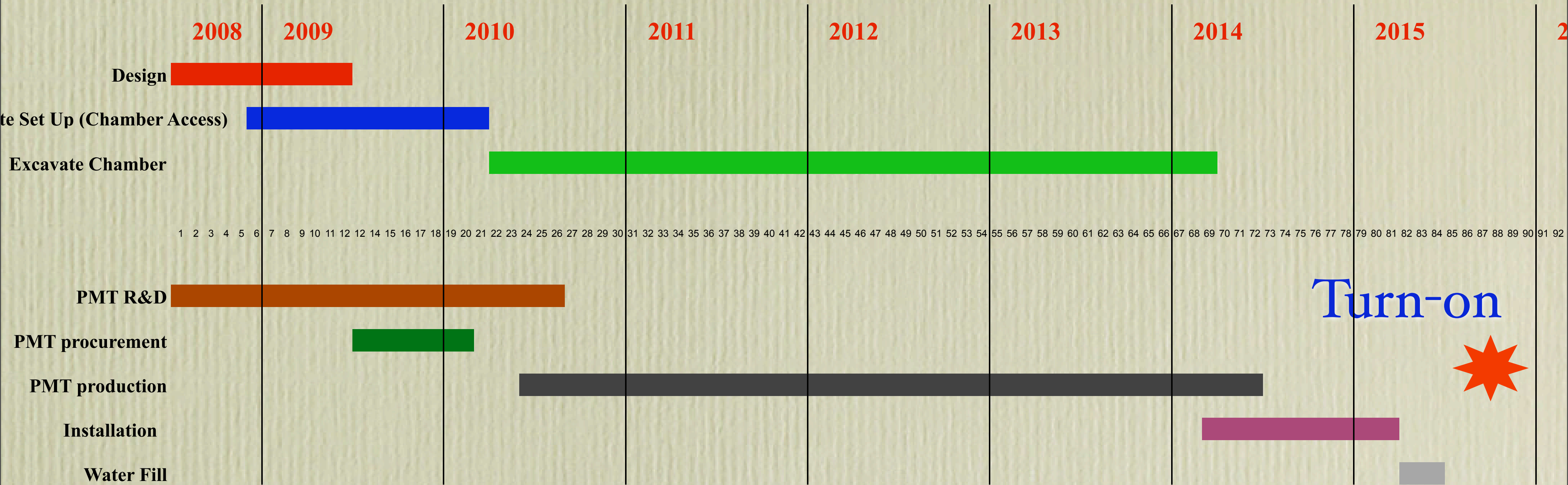

300kT fiducial
water Cherenkov
3 modules
4850ft level
Homestake
1300 km
Fermilab
Neutrino beam using
high energy high intensity
proton accelerator
(0.5-2.0 MW)



2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Coring and cavern design
Access drifts
Chamber 1
Chamber 2
Chamber 3
Photomultiplier production
Installation of 1, 2, 3
Operation of module 1

Technically limited schedule for a single 100 kT fiducial detector

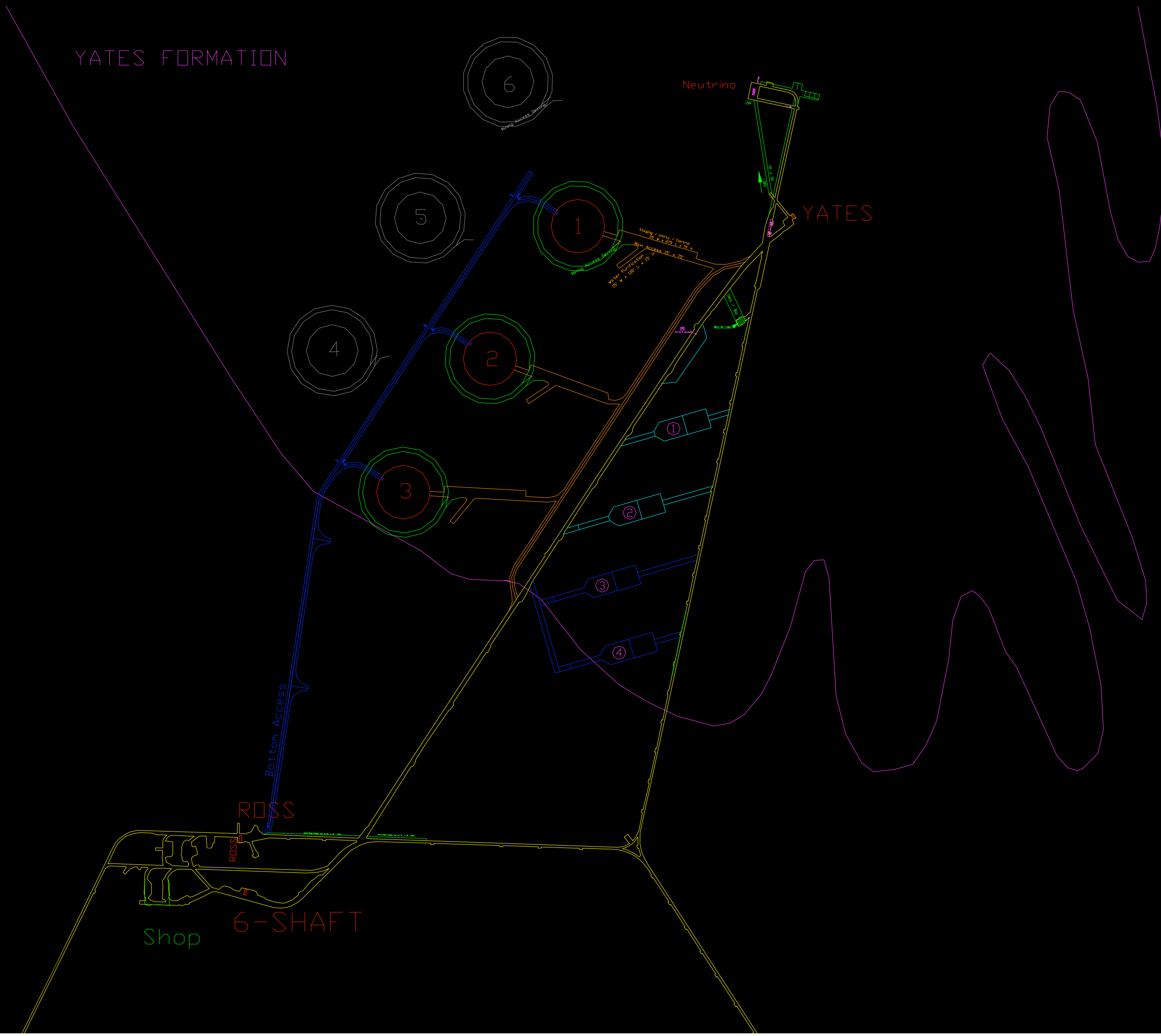


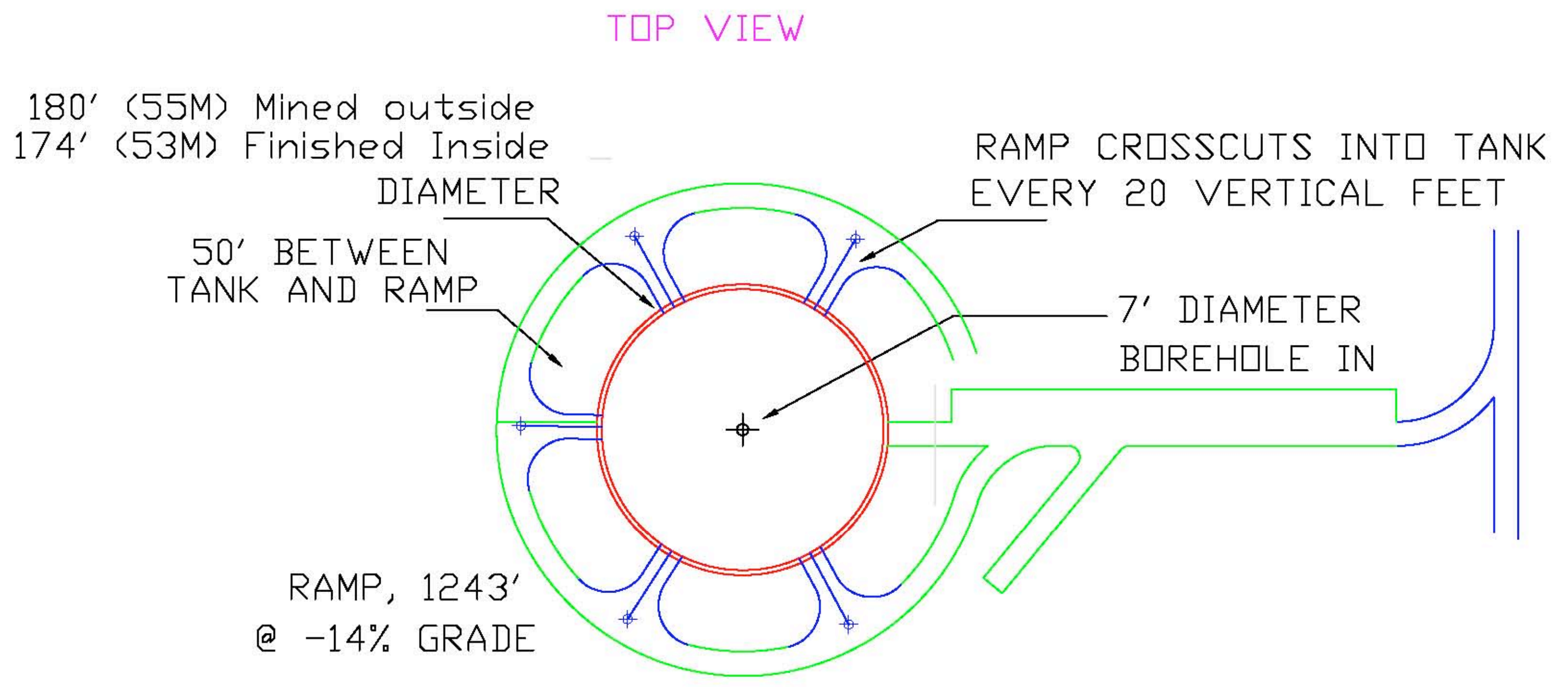
Comments: Phototube production is slowed down to match construction of 1 module only.
Schedule is strictly technical. Does not account for review process. See KTLesko talk
PMT testing facility, water system procurement and installation, and other items are not shown here.

- Tube production is slowed to match excavation. Tube production is NOT the limiting factor.
- For simplicity, water system, PMT testing, electronics, etc. are not shown.
- For 300 kT the time need not be tripled.

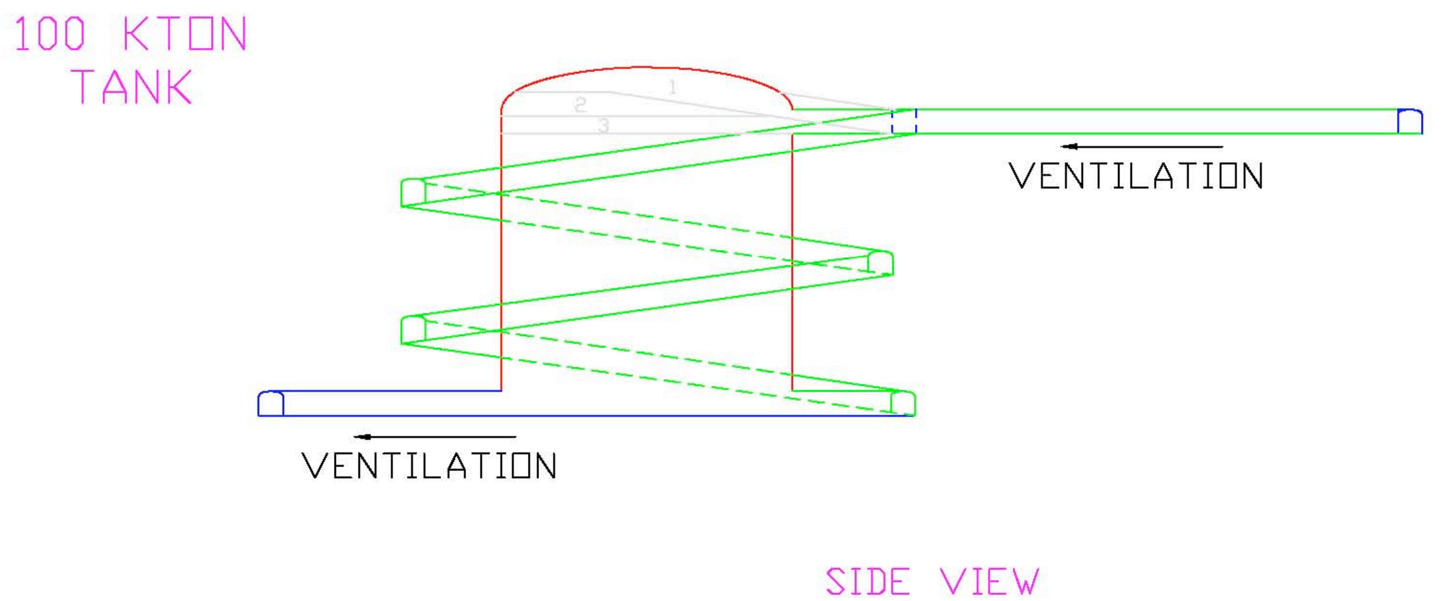
MEGATON MODULAR MULTI-PURPOSE NEUTRINO DETECTOR

✓ Modular Configuration

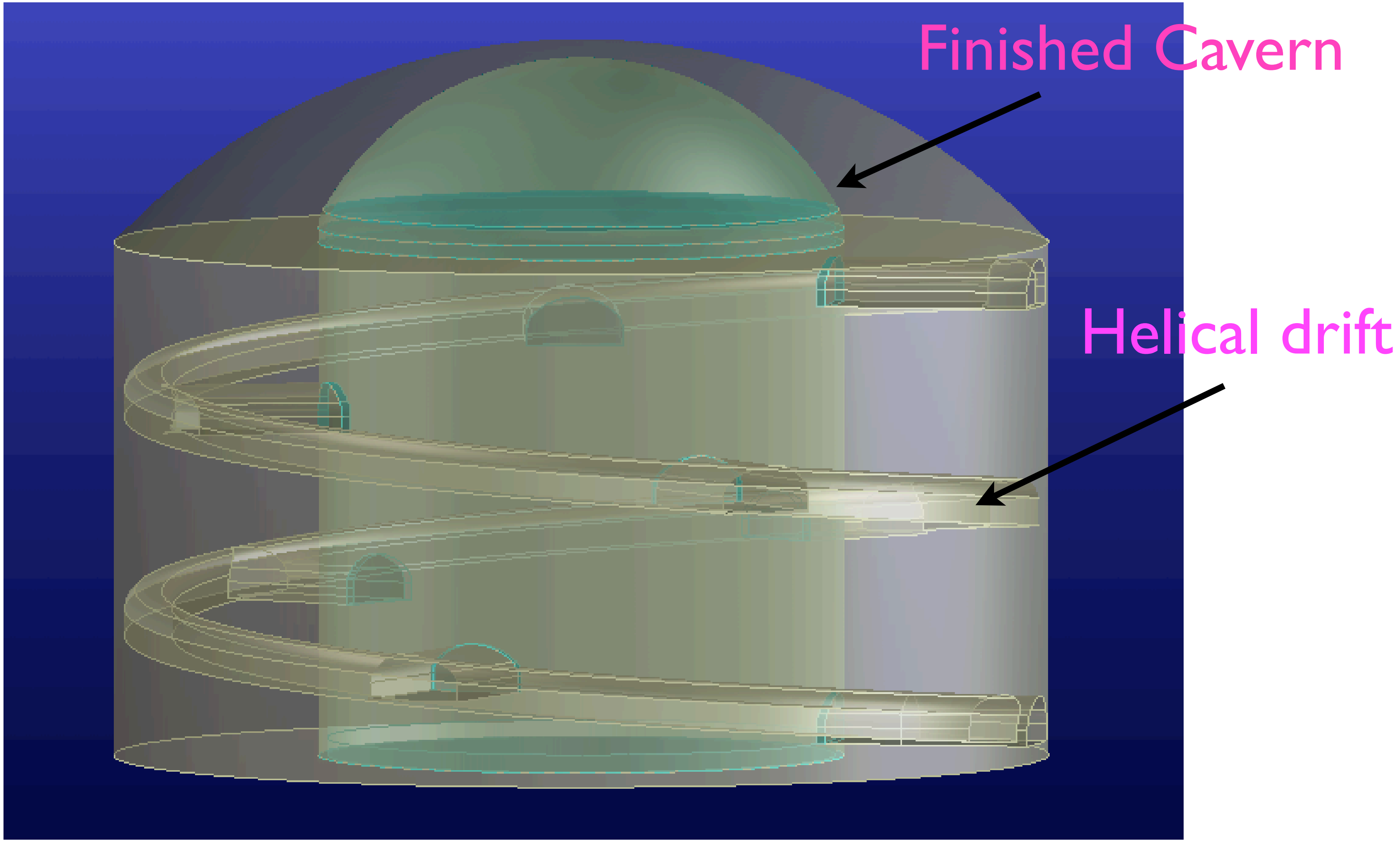




Muon Rate ~ 0.1 Hz/chamber



Large Cavern for DUSEL (M. Laurenti)



Cavity Stability

- Proposal to NSF in place for detailed study. Proposal went thru UPenn. It involves geotechnical scientists from Penn State, Wisconsin, Berkeley. ~$2M/2 yrs. includes coring at 4850 ft and modeling. Could be modified to include work for liquid argon cavities at other locations in Homestake.

- Some experience exists in Homestake (See Bill Pariseau)

- Initial Rock stability evaluation done in 2001 by NIOSH Spokane laboratory and RESPEC
- INITIAL STABILITY STUDY OF LARGE OPENINGS FOR THE NATIONAL UNDERGROUND SCIENCE LABORATORY AT THE HOMESTAKE MINE, LEAD, SD Doug Tesarik, Jeff Johnson, Karl Zipf, Jr., Kenneth Lande. NARMS - TAC 2002: Mining and Tunnelling Innovation and Opportunity, Vol. 1, pp 157-163 R. Hammah et al Eds.,Toronto, University of Toronto Press

One time costs over next 3 yrs

- 100kT estimate on next page does not include R&D and one time costs that are needed to establish the entire facility for the megaton-class detector.

Item	Cost	Source
Chamber design and coring	$0.76M	Laurenti
Access tunnels	$4.5M	Laurenti
Contingency	$2.6M	50% of above
Mining + other equip.	$10.0M	Laurenti
PMT+Elec. R&D	$4.0M	Prel. Eng.+Subcontracts
Water/materials R&D	$2.0M	Preliminary
Contingency (non-civil)	$3.2M	Equip. has quotes
Total	$27.1M	FY2007

Summary cost for 100kT(do not triple for 300kT)

Item	Cost	Source
Single Cavity construction	$28.1M*	Laurenti
contingency 30%	$8.4M	Preliminary Reviews
PMT(50000 chan)	$46.7M	Auger, NNN05, etc.
Electronics, cables	$10.65M	UPenn+SNO
Installation	$8.75M	Conceptual
Water, DAQ, testing, etc.	$11.4M	Quote, made for 300kT
Contingency(non-civil)	$25.0M	>30% for some items
Total	$139M	FY2007

* Cost and schedule reviewed by RESPEC, does not have rock disposal

PMT cost in current plan

	Cost for one
28 cm dia PMT	$933
Installation/PM	$175
Electronics/PM	$127
Cable/PM	$86
Total per PMT	$1317

50000 PMTs per 100 kT tank => 25% coverage
Sanity checks: Auger PMT cost $629/each for 5000 units with 9 inch diameter. Base and install cost additional $175. Other costs have basis with SNO actual costs with adjustments for differences.

Items for this talk

- Comments on software (Mainly from Brett Viren)
- Photo-multiplier R&D at BNL
- Collaboration with others: universities, international.
- Some very advanced ideas.

Software (BViren)

- Perhaps the most important and complex technical system for the water Cherenkov detector. Includes simulation, calibration, reconstruction.
- Many limitations in current software packages including openness and availability.
- I suggest that there be a subgroup immediately working on this.

Meta requirement: architecture

a) No organization - let it evolve organically
* Historically the "Physicists Way"
* Fastest short term results
* Individual star programmers, confused users
* Progressively harder to maintain
* Not suited for easy collaboration and code sharing
* Reinvents wheels

b) Select existing or develop new software framework
* Requires commitment from all developers.
* Need champion experts (or those that can become expert)
* Significant up-front development/learning costs
* Long term maintenance is relatively easy
* Easy for non-experts to contribute, extend, modify
* Steal those wheels that work, invent where needed
* Likely candidate: Gaudi (general) + GiGa (Geant4sim) frameworks

** Expertise in HEP comunity (LHC exps, Minerva, Daya Bay)
** Code available, CERN support
** Core developers open to helping other exps.

For now there is time to start with either (a) or (b).
Long term, (b) is prefered.

Simulation

Detector simulation requirements

* Flexibility - easily simulate different designs:

  ** geometry:
  *** grossly different designs (w/ or w/out OD)
  *** different parametrized values (50m diameter tank vs. 53m)
  *** discrete differences (10% vs. 25% vs. 40% PMT coverage)

  ** optical parameters
  *** attenuation length
  *** material reflectivities

  ** PMTs
  *** PMT to PMT QE differences
  *** Nonuniformities
  *** Earth's B-field

* Acuracy - must correctly simulate all salient features and not rely on scaling/reweighting assumptions.

Electronics simulation requirements.

* Initially enough to have "dummy" hit->adc/tdc conversion
* Able to swap in different single-PE responses
* Support alternative readouts: eg. flash-ADC.

Reconstruction

Reconstruction requirements:

* Adaptability - must work at a basic level with each different designs.

* Optimization - different designs may have different "local maxima" of performance. Reconstruction needs to be able to find these to prove the design's worth.

* Modularity - decouple orthogonal reconstruction algorithms. Allow competing algorithms to run side-by-side. Allow iterative running of reconstruction modules.

Visualization requirements:

* Geometry validation - need ways to confirm detector geometry is as expected.

* Reconstruction - event displays and intermediate data visualization needed to understand and develop reco. code.

PMT R&D

- Issues are: making 150000 tubes in 6 years time, their efficiency, and their pressure performance.
- If PMTs can stand higher pressure, the cavern can be taller => more fiducial volume.
- Have had meetings with Photonis and Hamamatsu: no barrier to PMT production except money.

PMT considerations

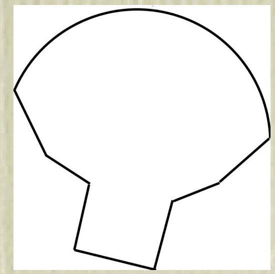
	10 inch R7081	20 inch R3600
Number (25% cov)	~50000	~14000
QE	25%	20%
CE	~80%	~70%
rise time	4 ns	10 ns
Tube length	30 cm	68 cm
Weight	1150 gm	8000 gm
Vol.	~5 lt	~50 lt
pressure rating	0.7Mpa	0.6Mpa
∢ coverage/pmt	0.6 deg	1.1 deg
∢ granularity	1.0 deg	2.1 deg

Tube production

Glass

Stamped metal and wire parts

First assembly
vacuum deposition of metal platings
Graded seal

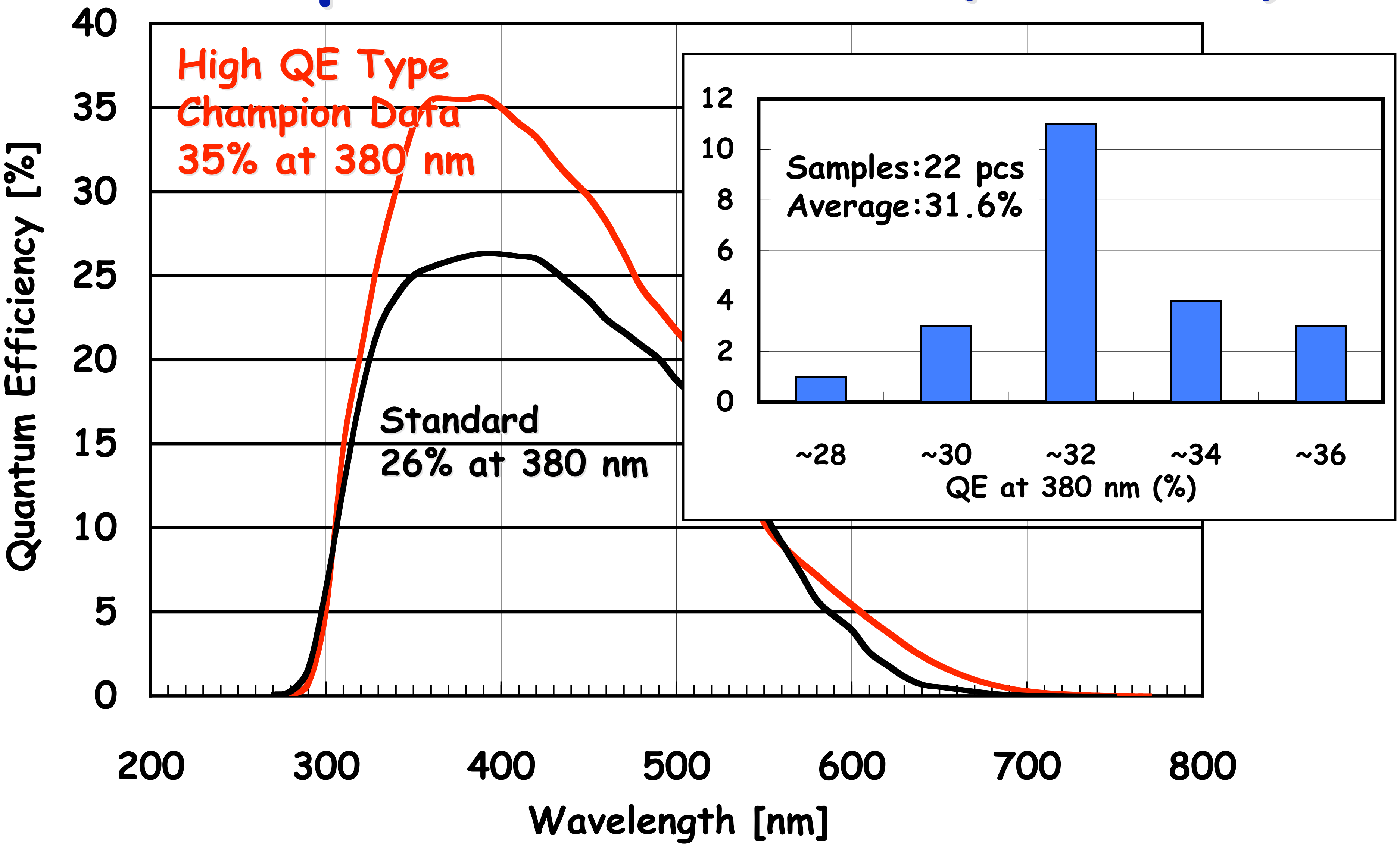


Final vacuum
Cathode deposition

Final assembly of 10 inch tubes needs lab space of 30’x30’; six stations with 6 pmts/station; 1 full day => 36tubes/day = icecube production.
tripling this rate is not difficult

HPK and Photonis are NOT concerned about their ability to manufacture at this rate

Example data R7081 (10 inch)



Goal of development is 43%

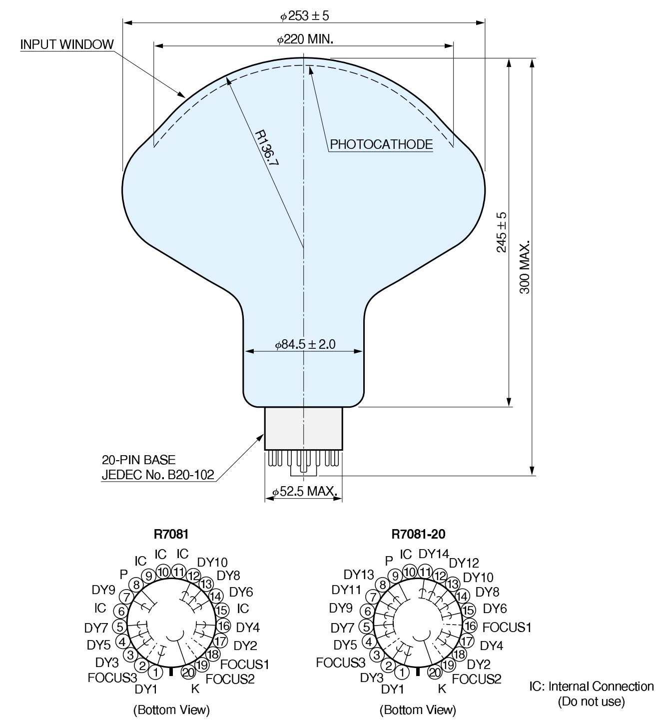
M.Diwan

SPECIFICATIONS

Type No.	Cathode Sensitivity: Luminous (2856 K) Min. (µA/lm)	Cathode Sensitivity: Luminous (2856 K) Typ. (µA/lm)	Cathode Sensitivity: Radiant at 420 nm Typ. (mA/W)	Cathode Sensitivity: Blue Sensitivity Index (CS 5-58) Min.	Cathode Sensitivity: Blue Sensitivity Index (CS 5-58) Typ.	Cathode Sensitivity: Quantum Efficiency at 390 nm Typ. (%)	Anode Sensitivity: Luminous (2856 K) Typ. (A/lm)	Anode Sensitivity: Radiant at 420 nm Typ. (A/W)	Anode Sensitivity: Gain Typ.	Anode Sensitivity: Applied Voltage for Typical Gain Typ. (V)
R5912	40	70	72	6.0	9.0	22	700	7.2×10^5	1.0×10^7	1500
R5912-02	40	70	72	6.0	9.0	22	70 000	7.2×10^7	1.0×10^9	1700
R7081	40	80	80	6.0	10.0	25	800	8.0×10^5	1.0×10^7	1500
R7081-20	40	80	80	6.0	10.0	25	80 000	8.0×10^7	1.0×10^9	1700
R8055	35	60	65	5.5	8.0	20	600	6.5×10^5	1.0×10^7	1500
R3600-02	35	60	65	5.5	8.0	20	600	6.5×10^5	1.0×10^7	2000
R7250	35	60	65	5.5	8.0	20	600	6.5×10^5	1.0×10^7	2000

NOTE: Anode characteristics are measured with the voltage distribution ratio shown below.
(   ): Measured with the special voltage distribution ratio (Tapered Divider) shown below.

●R7081, R7081-20



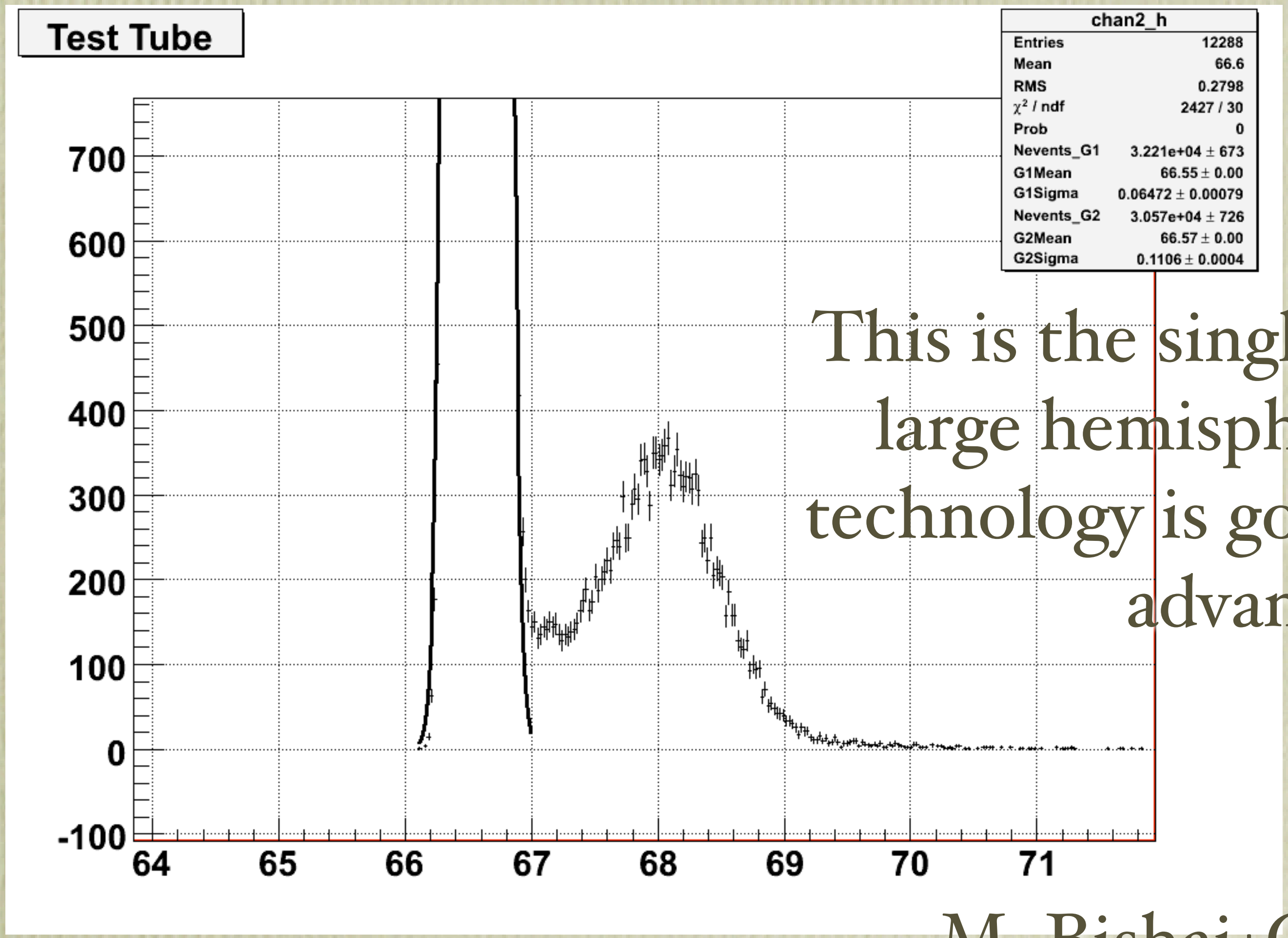
Type No.	Maximum Ratings: Supply Voltage: Anode to Cathode (V)	Maximum Ratings: Supply Voltage: Anode to Last Dynode (V)	Maximum Ratings: Average Anode Current (mA)	Maximum Ratings: Operating Ambient Temperature (°C)	Maximum Ratings: Storage Temperature (°C)	Maximum Ratings: Pressure (MPa)	Direct Interelectrode Capacitances: Anode to Last Dynode (pF)	Direct Interelectrode Capacitances: Anode to All Other Dynodes (pF)
R5912	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R5912-02	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R7081	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R7081-20	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R8055	2500	300	0.1	-30 to +50	-30 to +50	0.15	approx. 10	approx. 20
R3600-02	2500	300	0.1	-30 to +50	-30 to +50	0.6	approx. 36	approx. 40
R7250	2500	300	0.1	-30 to +50	-30 to +50	0.6	approx. 10	approx. 15

We are focussed on the R7081 tube
It is more efficient than the R3600.
25% *R7081 => 35% *R3600

BNL R&D focus on two items

- Pressure
- Field susceptibility and general electronic testing of large tubes.

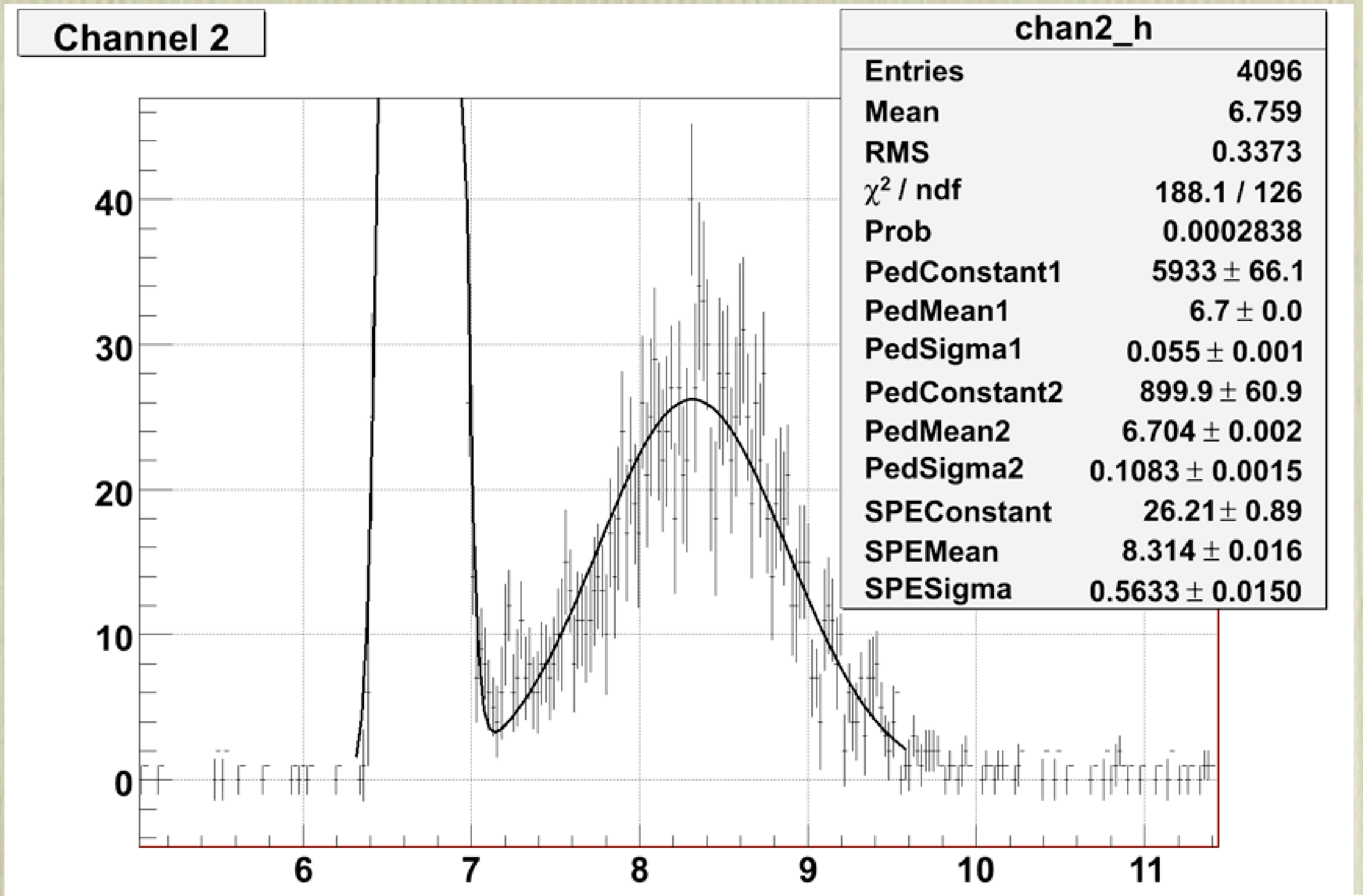
Photonis XP1806 (8 inch)



This is the single PE response of a large hemispherical tube. This technology is going through steady advancement.

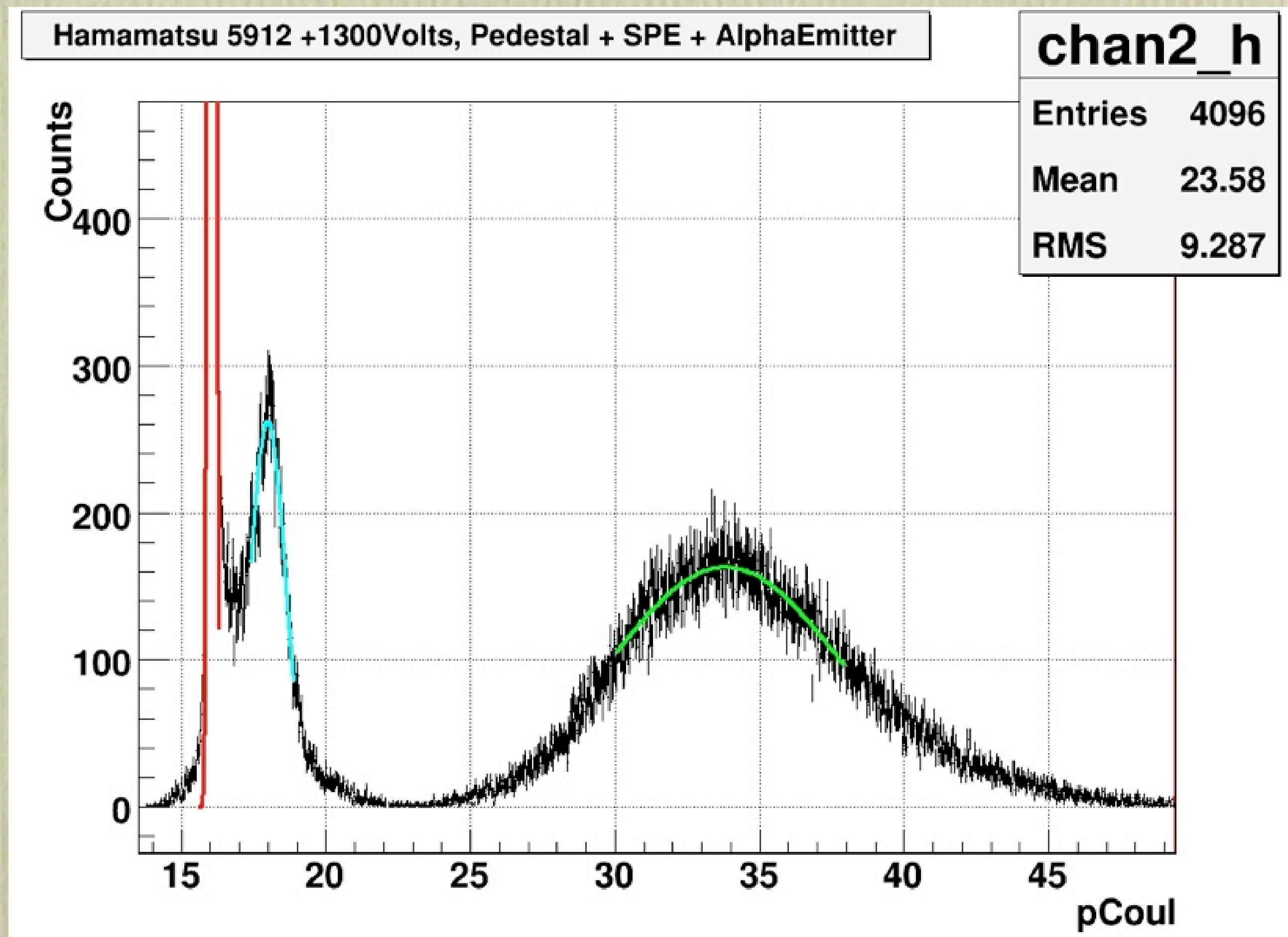
M. Bishai+G. Wille (BNL)

single PE



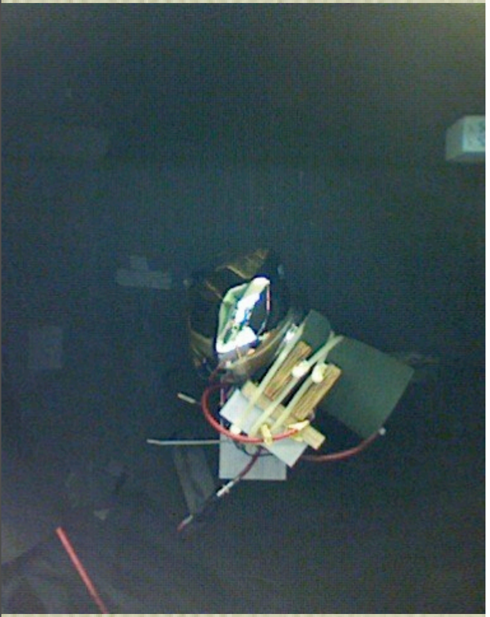
Channel 2
chan2_h
Entries 4096
Mean 6.759
RMS 0.3373
χ² / ndf 188.1 / 126
Prob 0.0002838
PedConstant1 5933 ± 66.1
PedMean1 6.7 ± 0.0
PedSigma1 0.055 ± 0.001
PedConstant2 899.9 ± 60.9
PedMean2 6.704 ± 0.002
PedSigma2 0.1083 ± 0.0015
SPEConstant 26.21 ± 0.89
SPEMean 8.314 ± 0.016
SPESigma 0.5633 ± 0.0150
40
30
20
10
0
6
7
8
9
10
11

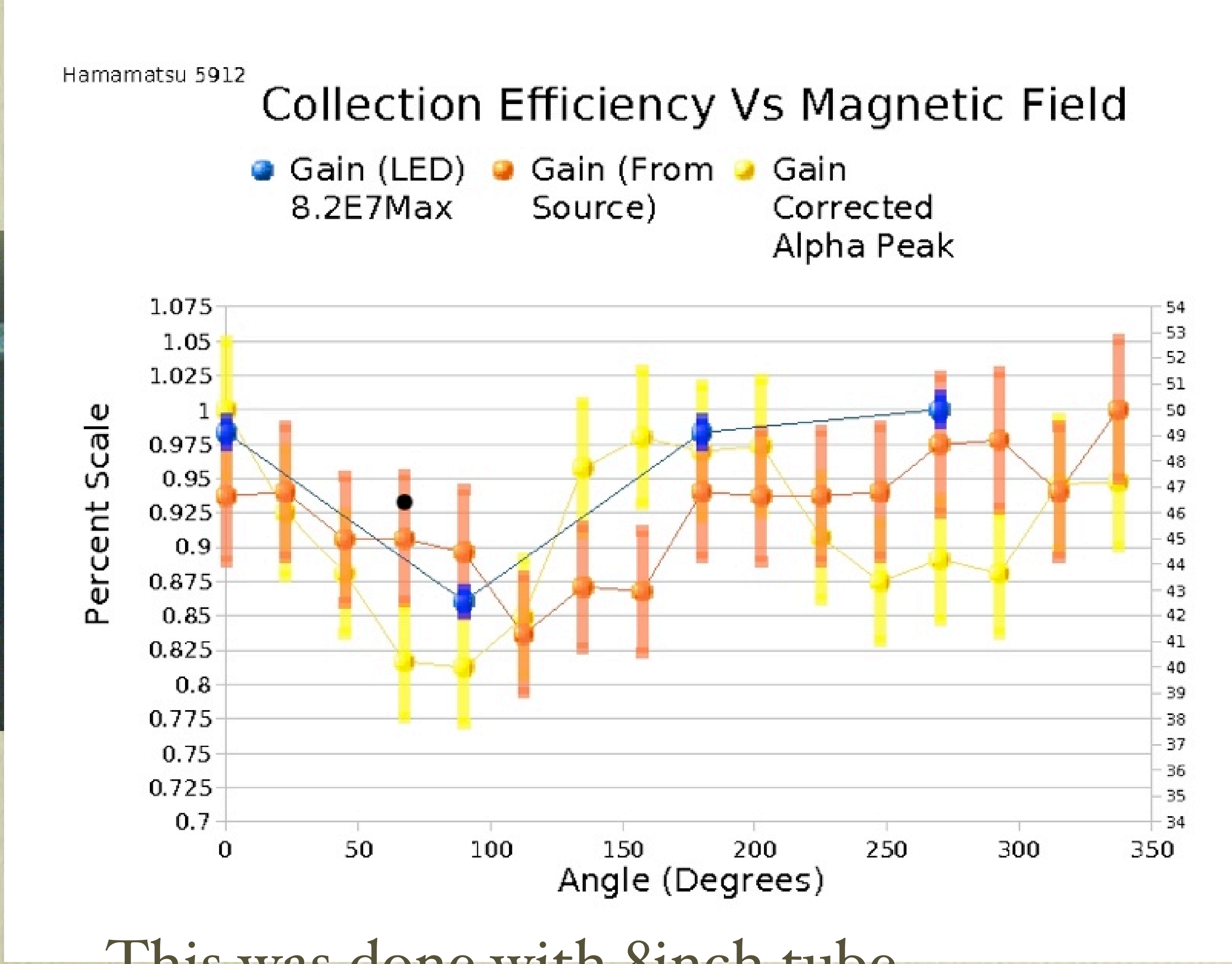
Source



Hamamatsu 5912 +1300Volts, Pedestal + SPE + AlphaEmitter
chan2_h
Entries 4096
Mean 23.58
RMS 9.287
Counts
0
100
200
300
400
15
20
25
30
35
40
45
pCoul

Bfield sensitivity

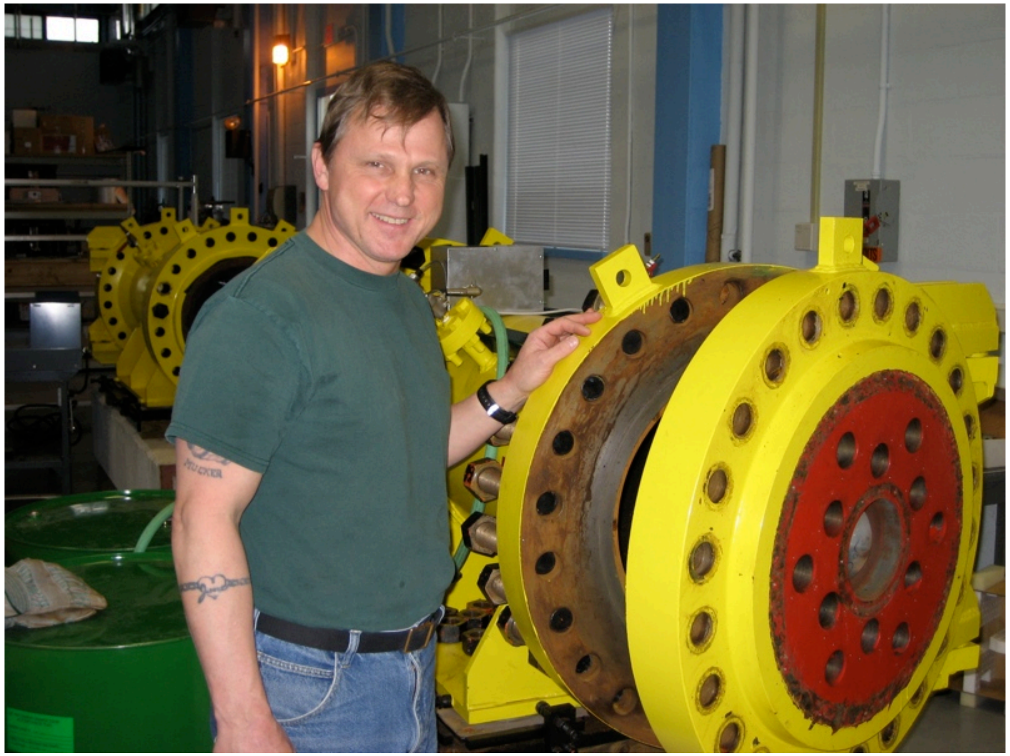


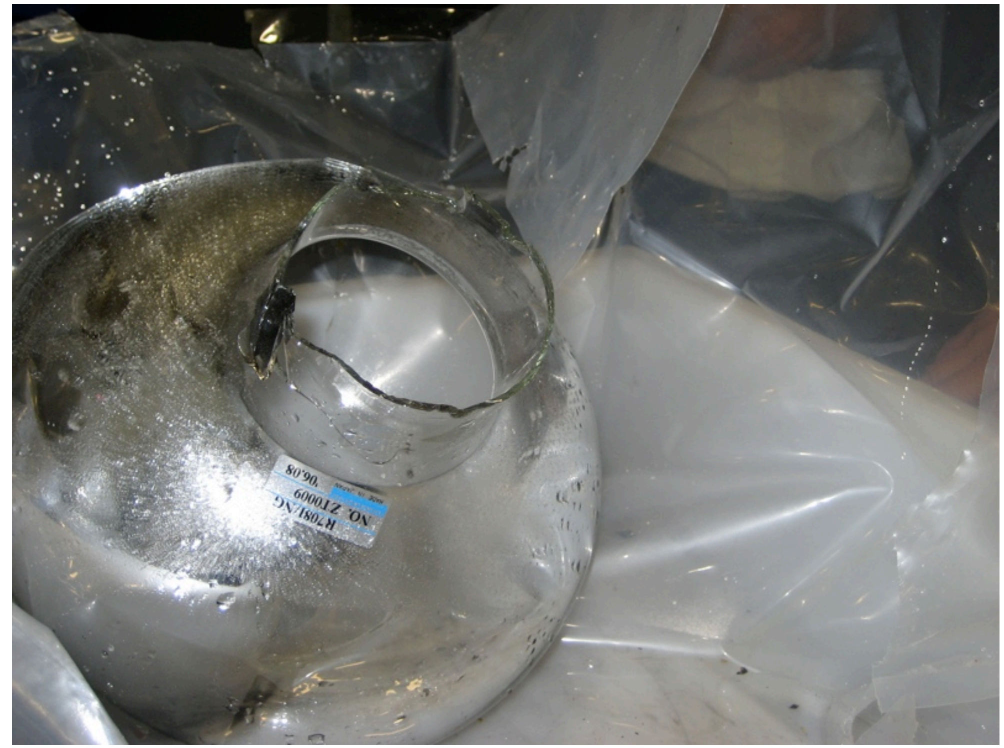


M. Bishai,
G. Willie

This was done with 8inch tube.

Pressure testing





Have 32 phototubes from Hamamatsu. Pressure vessel from BNL. Evolving testing protocol.

Hamamatsu rating is ~7atm. Tested this tube until it broke at 148 psi (~10atm)

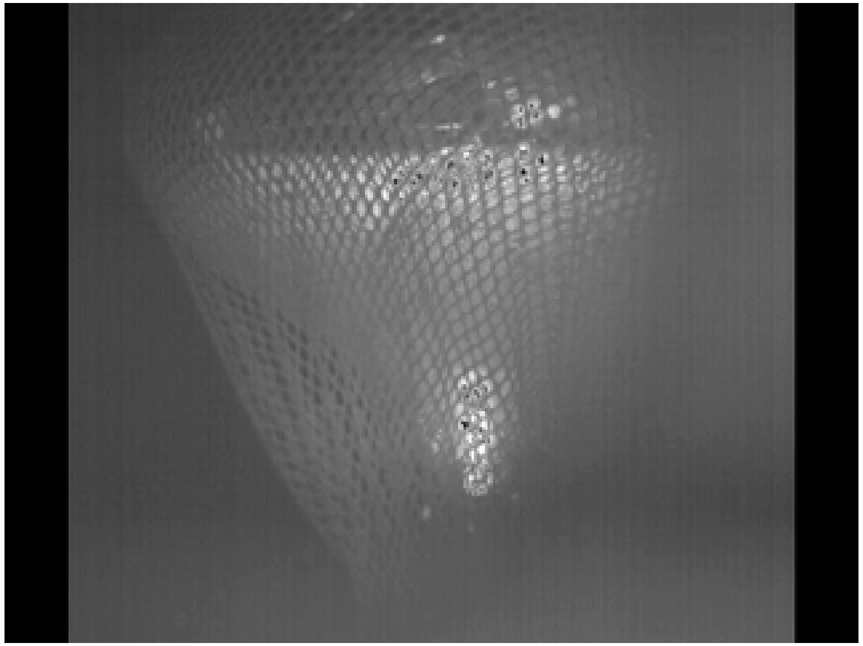
Data so far

PMT	size	Break Press
R7081/ng 1	10inch	148 psi
XP1807 1	12 inch	92 psi
xp18060 1	8 inch	35 psi
R7081 2	10 inch	cycled 132psi
R7081 3	10 inch	cycled 132 psi
R7081 4	10 inch	cycled 132 psi
R7081/lowr1	10 inch	205 psi
R7081/lowr 2	10 inch	218 psi

Hamamatsu tested 3 R7081 upto ~10 atm.
One broke at 10 atm,
On each tube, there is data on glass thickness, pressure pulse duration, etc.

What kind of information ?

- Pressure at implosion
- Implosion process. (fast motion movie), photos
- Pressure pulse

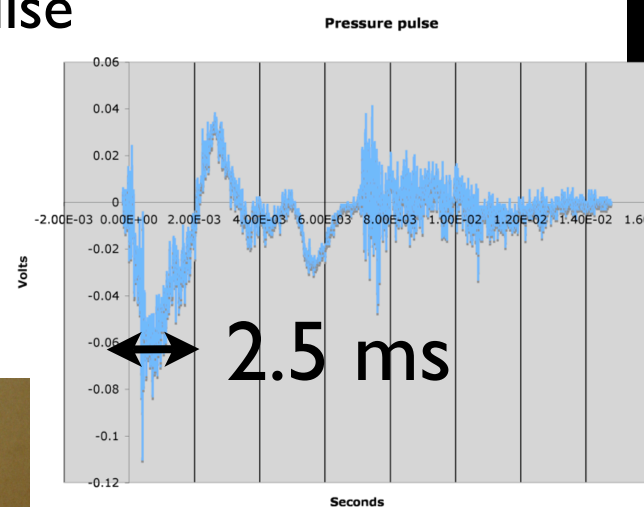


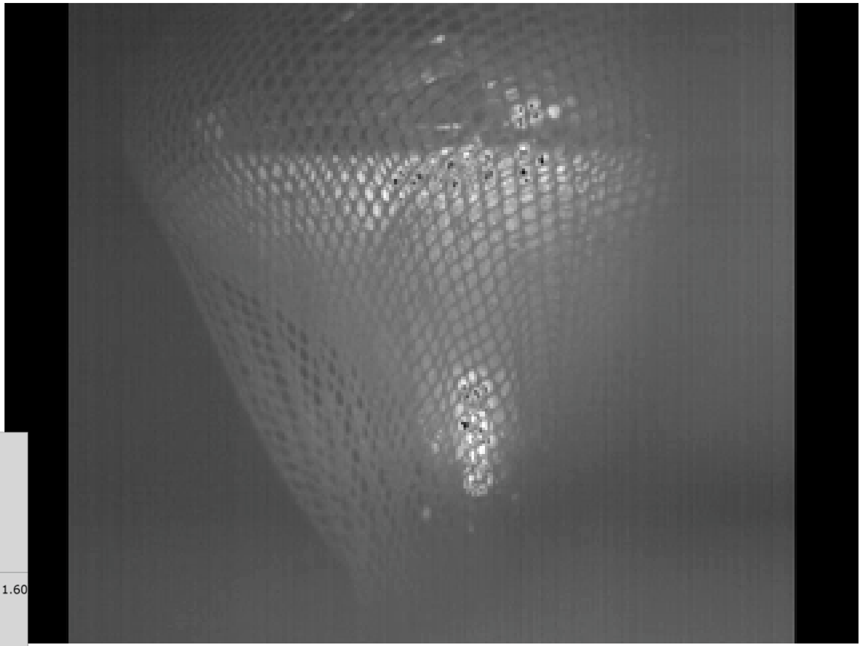
↔ 2.5 ms

Breakage
at pins

What kind of information ?

- Pressure at implosion
- Implosion process. (fast motion movie), photos
- Pressure pulse





Breakage at pins

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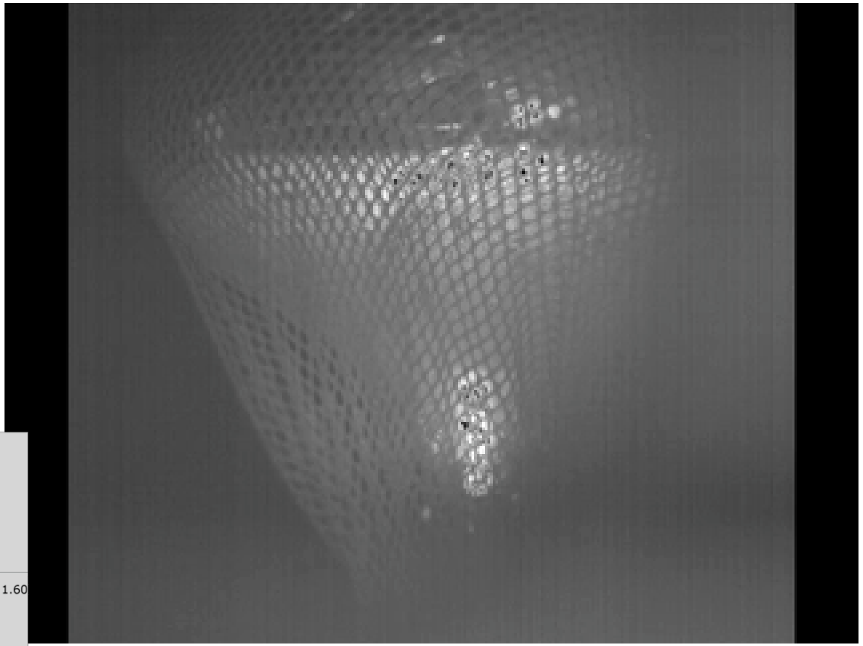

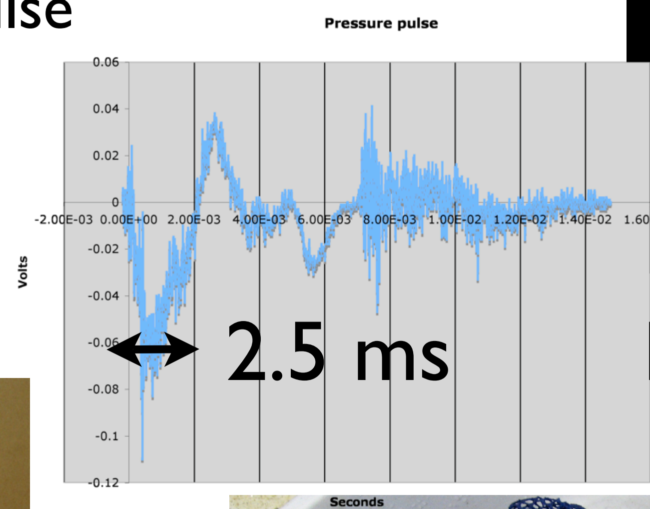

Breakage at pins

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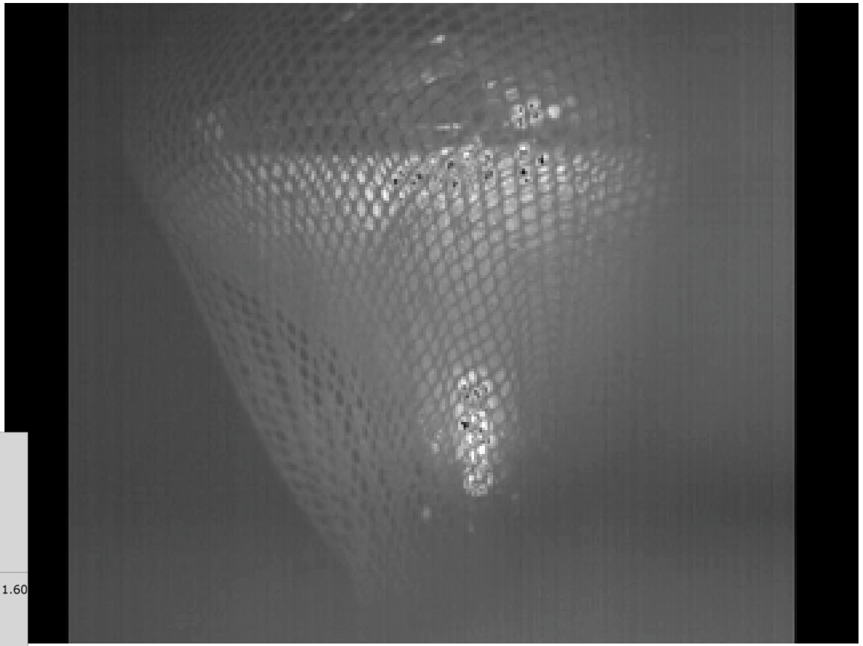
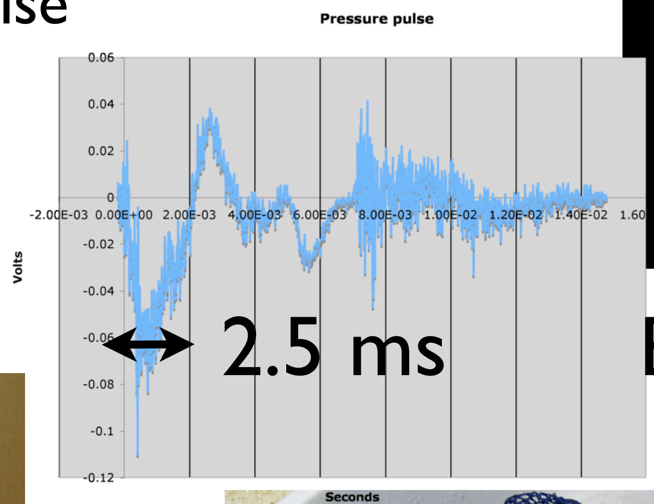
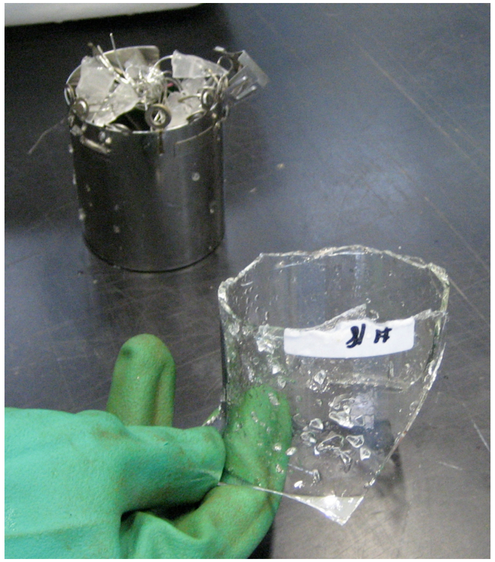




Breakage at pins



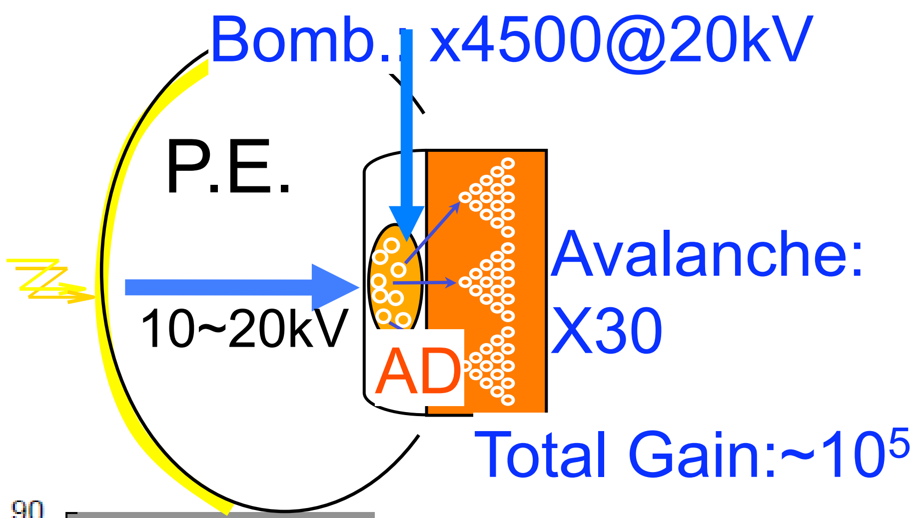
University and International participation

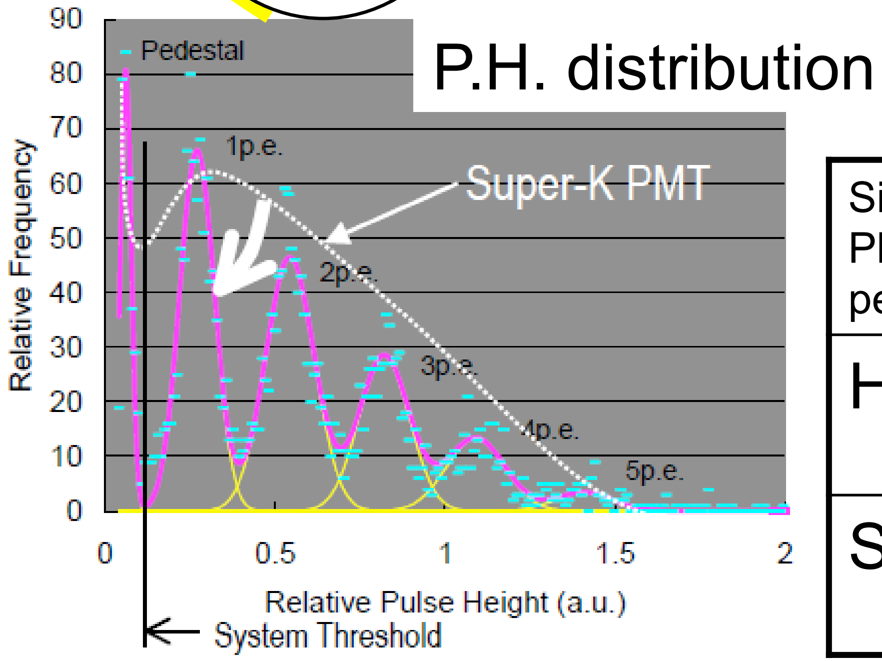
- At the Lead meeting discussion started on collaborative R&D with Universities: UCI, Duke, UPenn, BU,
- There was a visit to Italy by MD, KTLesko, and others to Catania, and Gran Sasso in March. Student exchange with Catania in progress.
- International agreement in progress with IPN, Orsay on PMT R&D. (Orsay has special arrangement with Photonis). BNL will provide pressure tank for electronics testing. French funding in place.

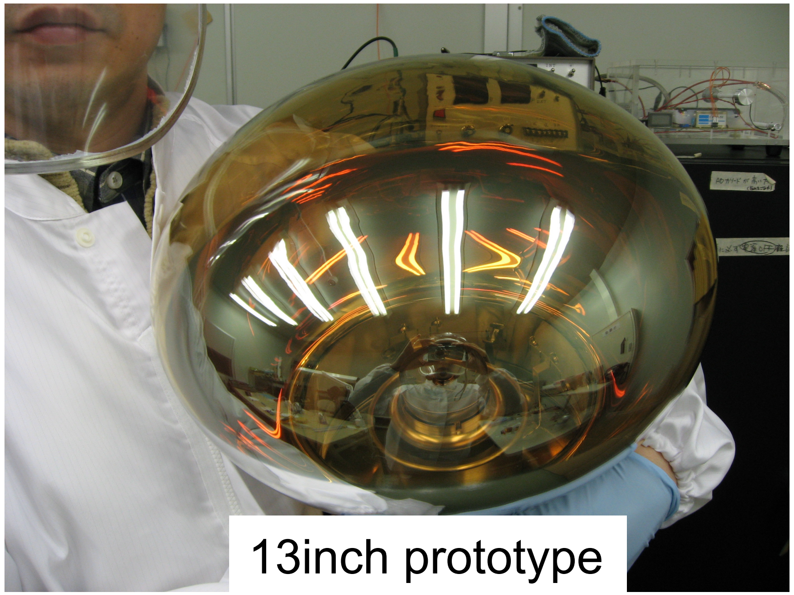
What can be done with more resources ?

- BNL could act as coordinator with US institutions. BNL will only focus on what we can do best.
- BNL will create a system for large scale PMT testing: need to test 10-20 units. Must develop automated testing unit for gain, QE uniformity and field sensitivity. ~$200k/2yrs
- BNL will continue pressure testing. Need support for technical help and some instrumentation (Fast camera): ~$150k/2yrs. Need to expand engagement with tube vendors.
- Also need effort in modeling of the pressure pulse. Perhaps with Orsay.
- Software: It is best to have several university groups lead the software effort. But we could provide the infrastructure. It is well suited to our role and will lead to structure to the collaboration. Probably need ~2 FTE (postdoc level) support.
- Electronics: BNL could generate the conceptual plan for the electronics (a strength of the instrumentation division), but this needs support.
- Very advanced R&D: we have been toying with the idea of a hybrid Tube that can do directional measurement. This first needs some simulation effort.

Hybrid Avalanche Photo Detector







Single Photoelectron performance	Time resolution	Pulse height resolution
HAPD	190ps	24%
SK PMT	2300ps	150%

Slide from Hamamatsu via Hank Sobel

Summary

- Software work should be started immediately.
- PMT R&D is in progress. There is considerable development in place at BNL, especially on pressure testing.
- Helpful to have more people involved and other setups.