HPT Workshop Summary for MAP 2014 Spring Workshop

Patrick Hurh, Fermilab, May 29, 2014

5th High Power Targetry Workshop

Fermilab, Batavia, Illinois - USA, May 20th – 23rd, 2014

indico.fnal.gov/event/HPT14

The High Power Targetry (HPT) Workshop series brings together interested scientists and engineers from the international community, in particular those operating or designing high power targets.

TOPICS

Target Design Challenges
Radiation Damage and Material Limits
Target Facility Simulation Challenges
Target/Beam Monitoring & Instrumentation
Target Facility Challenges

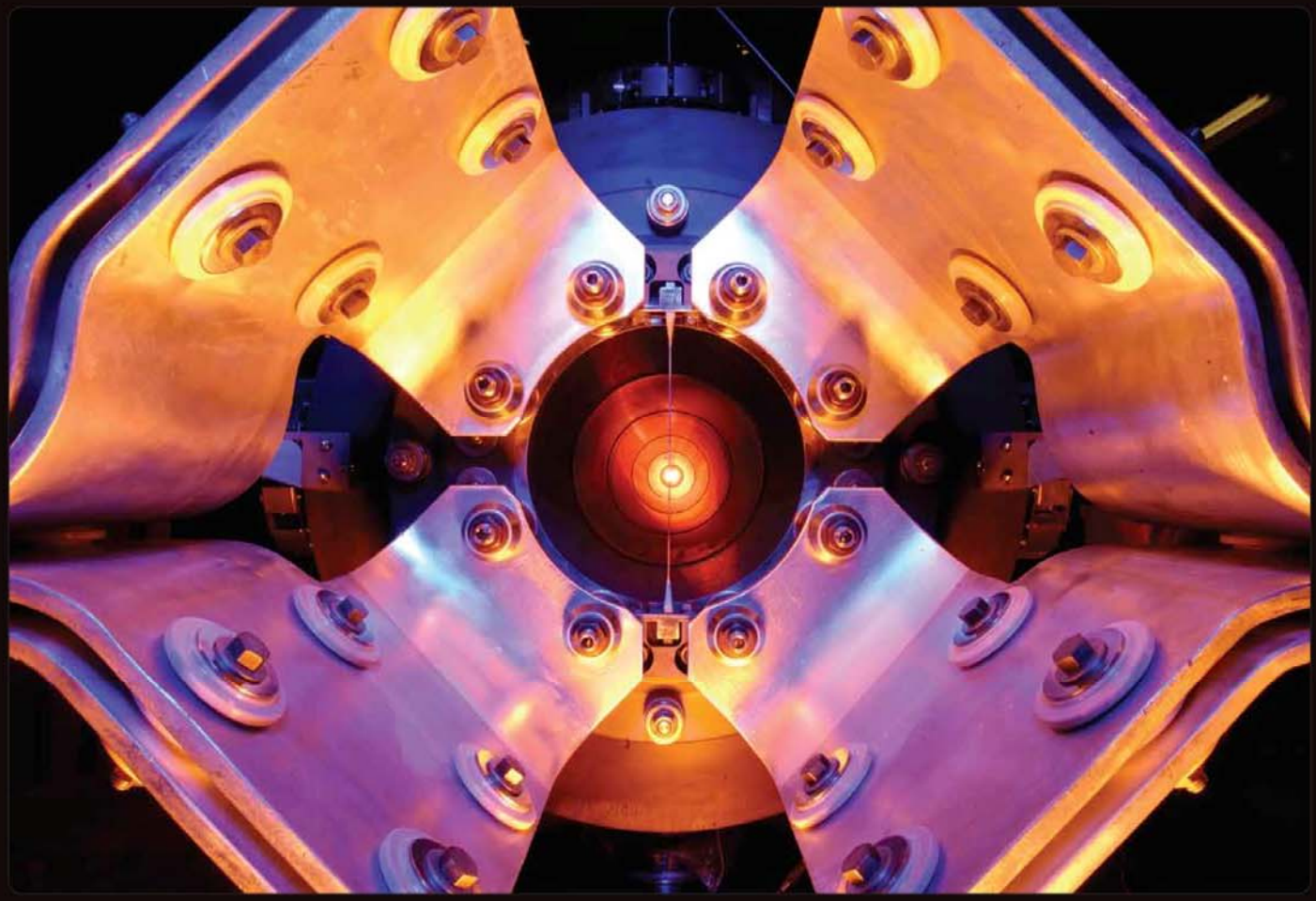
Program Committee

Chair: Harold Kirk (BNL)
Chris Densham (RAL)
Katsuhiro Haga (J-PARC)
Patrick Hurh (FNAL)
Jerry Nolen (ANL)
Kirk McDonald (Princeton)
Nikolai Mokhov (FNAL)
Francois Plewinski (ESS)
Bernie Riemer (ORNL)
Thierry Stora (CERN)
Helmut Weick (GSI)
Michael Wohlmuther (PSI)

Local Organizing Committee

Chair: Patrick Hurh
Kavin Ammigan
Brian Hartsell
Cynthia Sazama
Suzanne Weber
Robert Zwaska

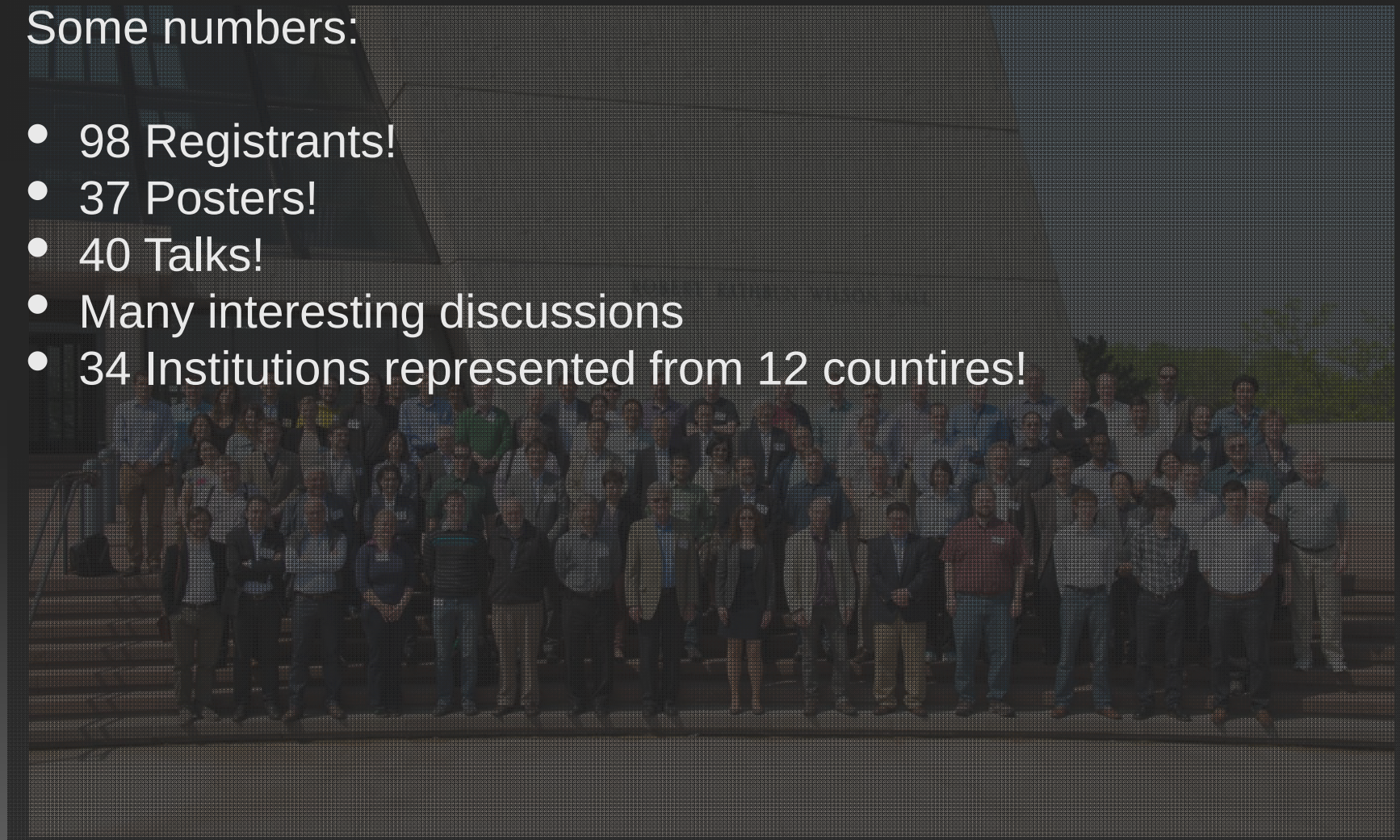
Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science | RaDIATE



Successful Workshop!

Some numbers:

- 98 Registrants!
- 37 Posters!
- 40 Talks!
- Many interesting discussions
- 34 Institutions represented from 12 countires!



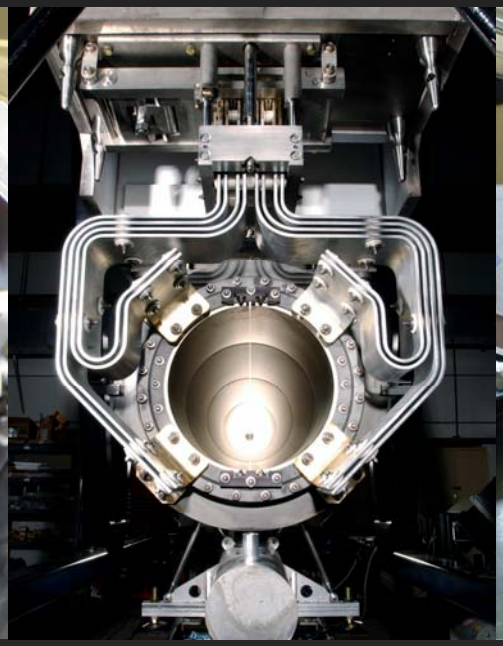
Thanks to:

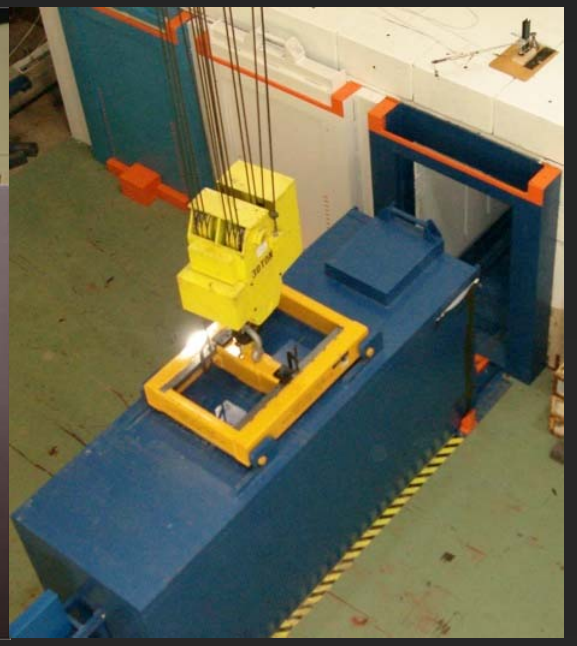
- The Program Committee
- The Local Organizing Committee
  - Brian Hartsell
  - Kavin Ammigan
  - Bob Zwaska
- Fermilab
  - Conference Office
    - Cynthia Sazama
    - Suzanne Weber
    - Melody Saperston

Targetry: A Vital Cog of the Accelerator Machine

- *Recently major accelerator facilities have been limited in beam power not by their accelerators, but by their target facilities*
  - *"When things go wrong, they can really go wrong" - Me*
  - *"The SNS accelerator power is restricted today by the targets" – M. A. Plum, IPAC'13*
  - *"When you have no spare, you must repair" – J. Hylen, NuMI-MINOS, 2009*

High Power Targetry Scope

- Target
  - Solid, Liquid, Rotating, Rastered
- Other production devices:
  - Collection optics (horns, solenoids)
  - Monitors & Instrumentation (high radiation/temperature)
  - Primary Beam window
  - Absorbers/Collimators
- Facility Operations:
  - Remote Handling
  - Shielding & Radiation Transport
  - Air Handling
  - Cooling Systems
  - Waste stream

Focus Sessions

- Target Design Challenges
  - C. Densham, B. Riemer
- Radiation Damage and Material Limits
  - Y. J. Lee, S. Maloy
- Target Facility Simulation Challenges
  - O. Caretta, N. Mokhov
- Target/Beam Monitoring & Instrumentation
  - T. Shea, K. Thomsen
- Target Facility Challenges
  - K. Haga, R. Losito

1. Some talks and posters interesting to MAP
2. Summary of Conclusions and Future Directions

Survey of Target Facility Landscape: Neutrino Beam Facilities

5th High Power Targetry Workshop
Jim Hylen / Fermilab
May 20, 2014

Operating Conventional Neutrino Beams

- BNB (FNAL)
- T2K (JPARC) – beam power being upgraded 750 kW ~2017
- NUMI (FNAL) – beam power being upgraded 700 kW end of 2015

Proposed Conventional Neutrino Beams

- LBNE (FNAL) – 2023/2024 - has DOE CD-1 approval
- CENF
- LBNO LAGUNA CN2PY
- ESSnuSB

Proposed not-so-conventional Neutrino Beams

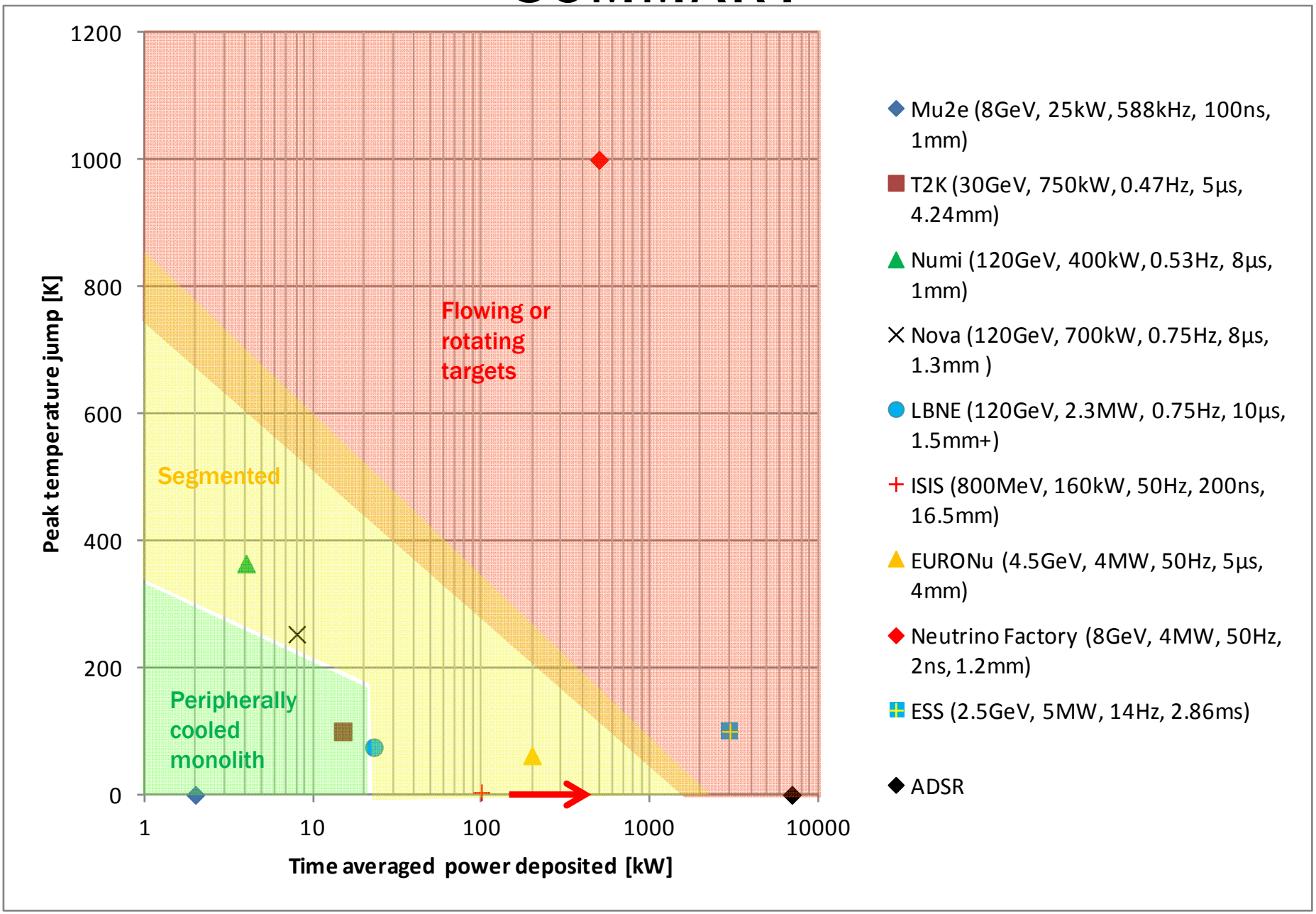
- IsoDAR & DAEδALUS – cyclotron, decay at rest
- NUSTORM – neutrions from muon decay rather than pion decay
- Beta beams (neutrinos from decay of accelerated isotopes)

http://indico.fnal.gov/event/HPT14

Target Design Challenges

	Target Design Challenges Kick-off Talk	*Mr. Bernard RIEMER*	
	Wilson Hall - One West	13:10 - 13:20	
	Target challenges for the next generation of neutrino facilities	*Dr. ottone CARETTA*	
	Wilson Hall - One West	13:20 - 13:45	
	Thermal, Mechanical and Fluid Flow Challenges of the FRIB Primary Beam Dump*	*Dr. Mikhail AVILOV*	
14:00	*Wilson Hall - One West*	13:45 - 14:10	
	Design, optimisation and operation of beam intercepting devices for CERN's fixed-target physics	*Dr. Marco CALVIANI*	
	Wilson Hall - One West	14:10 - 14:35	
	Discussion		
15:00	*Wilson Hall - One West*	14:35 - 15:10	
	Break		
	Wilson Hall - Atrium	15:10 - 15:30	
	Thermo-Mechanical Analysis of ISIS TS2 Spallation Target	*Mr. Dan WILCOX*	
	Wilson Hall - One West	15:30 - 15:55	
16:00	**Study of a new high power spallation target concept**	*Dr. Yong Joong LEE*	
	Wilson Hall - One West	15:55 - 16:20	
	High Power Targets and Performance Optimization versus costs or How much shall one pay for a useful neutron?	*Dr. Franz GALLMEIER*	
	Discussion & wrap-up		
17:00	*Wilson Hall - One West*	16:45 - 17:20	

HEAT REMOVAL AND THERMAL STRESS SUMMARY



Caretta Talk (Tues 13:20)

Neutron Economy at SNS

- 1.4 MW SNS produces: 2×10^{17} n/s
- Thermal neutrons at beamline start: 2×10^{12} n/s
- Neutrons at sample position (white): 2×10^{11} n/s
- Neutrons at sample (chopped): 2×10^{10} n/s
- Neutrons scattered: 2×10^{8} n/s
- Neutrons counted: 5×10^{7} n/s

Neutron counted/Neutrons produced: 3×10^{-10}

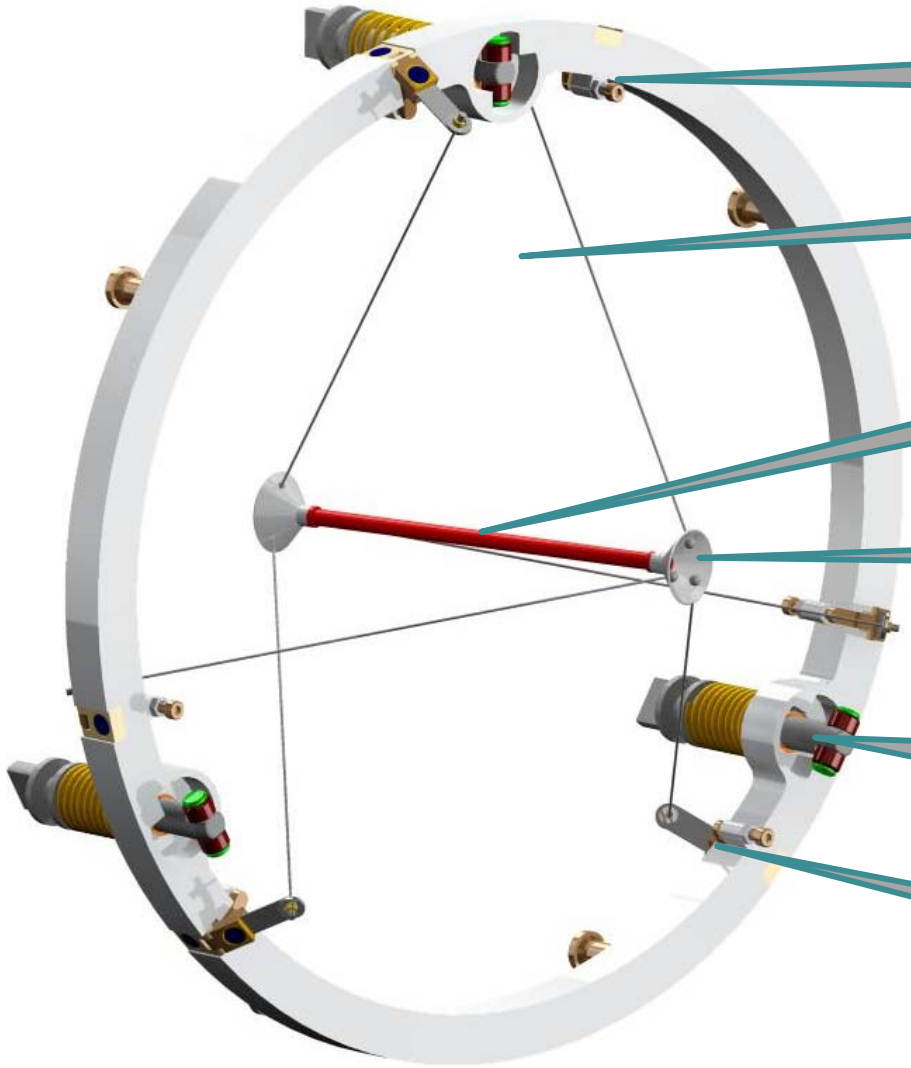
Is higher power best path to higher physics output?

http://indico.fnal.gov/event/HPT14

Radiation Damage & Material Limits

08:00	**RADIATION DAMAGE AND MATERIAL LIMIT: ILLUSTRATION OF A WAY TO CODIFY RULES WITH RCC-MRx CODE**	*Mrs. CECILE PETESCH*	
	Wilson Hall - One West		08:00 - 08:30
	Dose Limit Philosophies Implemented at the Spallation Neutron Source	*Dr. David MCCLINTOCK*	
	Wilson Hall - One West		08:30 - 08:50
	Discussion-Design Limits		
09:00	*Wilson Hall - One West*		08:50 - 09:05
	Design and Development of a High Temperature Radiatively Cooled Tungsten Target for Mu2e	*Dr. Chris DENSHAM*	
	Wilson Hall - One West		09:05 - 09:25
	HiRadMat at CERN SPS - A dedicated in-beam test facility	*Dr. Adrian FABICH*	
	Wilson Hall - One West		09:25 - 09:45
	Discussion: Design and Target Development		
	Wilson Hall - One West		09:45 - 09:55
10:00	**Coffee Break**		
	Wilson Hall - Atrium		09:55 - 10:10
	Irradiation damage on material for FRIB project	*Dr. Frederique PELLEMOINE*	
	Wilson Hall - One West		10:10 - 10:30
	Experimental investigation of beryllium: plans and current results within the RaDIATE collaboration	*Dr. Viacheslav KUKSENKO*	
	Ion-irradiation induced degradation of thermo-mechanical properties of carbon-based materials	*Dr. Marilena TOMUT*	
11:00	*Wilson Hall - One West*		10:50 - 11:10
	Mechanical Test Techniques for Small Specimens	*Dr. Mychailo TOLOCZKO*	
	Wilson Hall - One West		11:10 - 11:30
	Post Irradiation Examination of an Alloy 718 Beam Window	*Dr. Stuart MALOY*	
	Wilson Hall - One West		11:30 - 11:50

Target conceptual design



Titanium mounting ring

Refractory metal spokes

Radiatively cooled Tungsten target

Refractory metal hubs

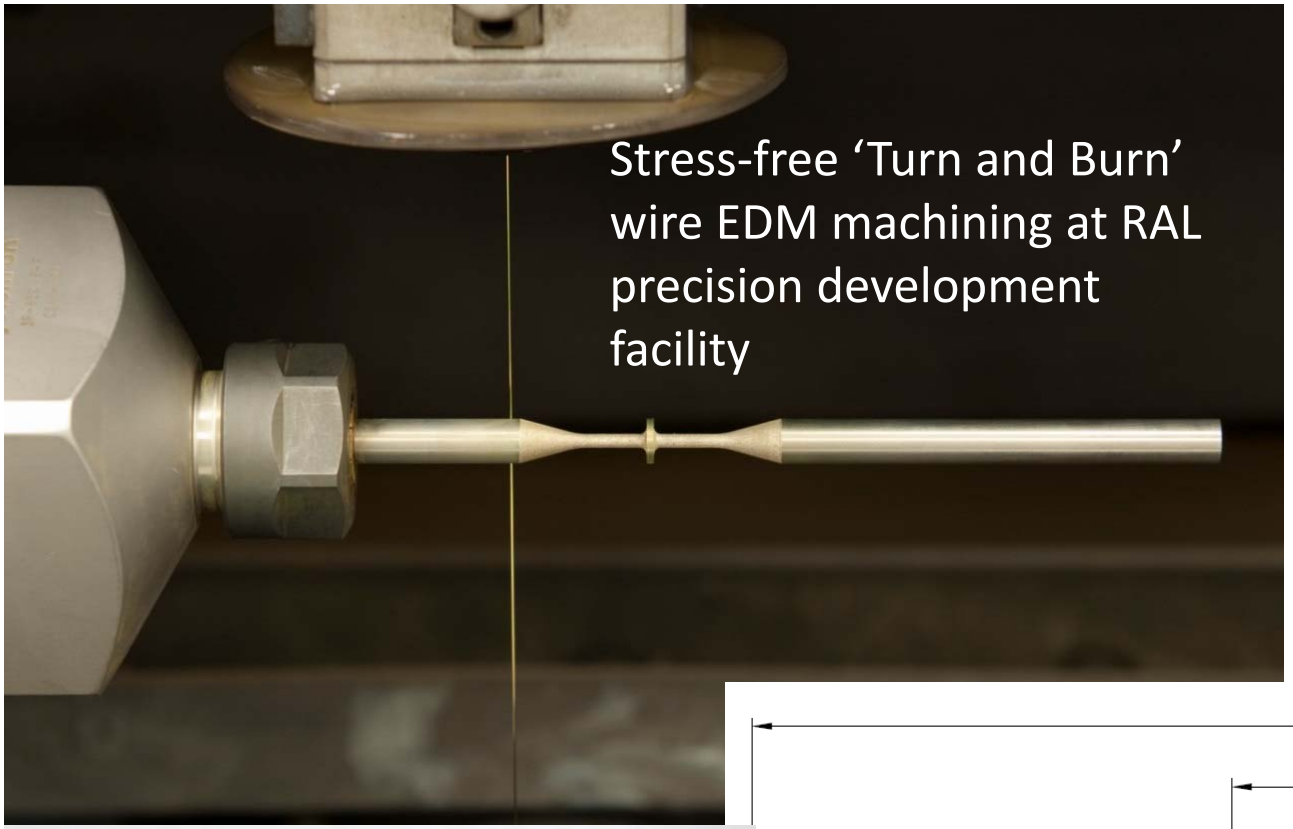
Mounting wheel to HRS remotely operable locking mechanism (Fermilab concept)

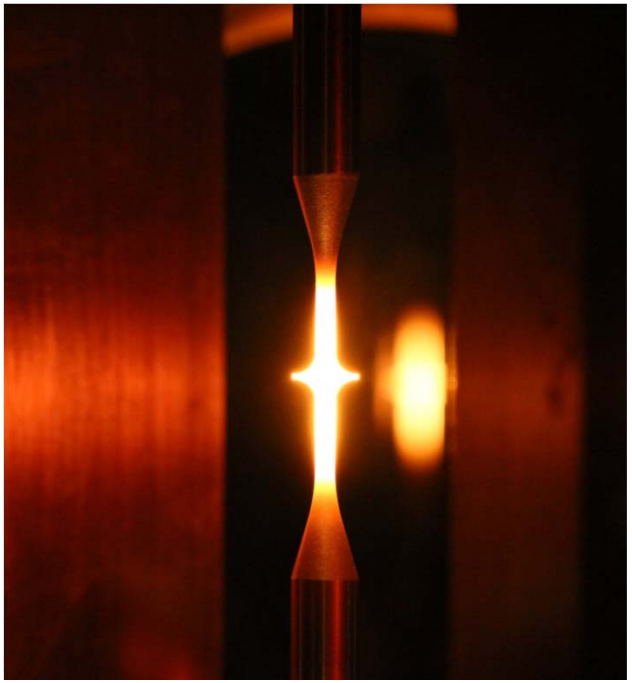
Spoke tensioners

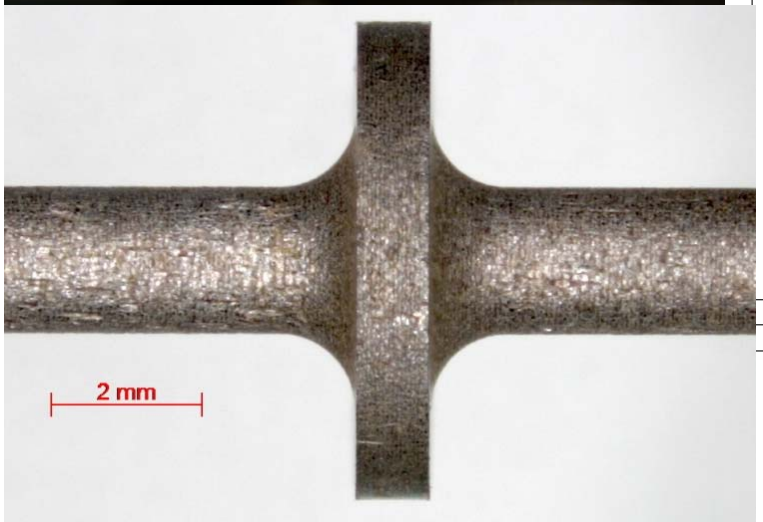
Densham Talk (Weds 09:05)

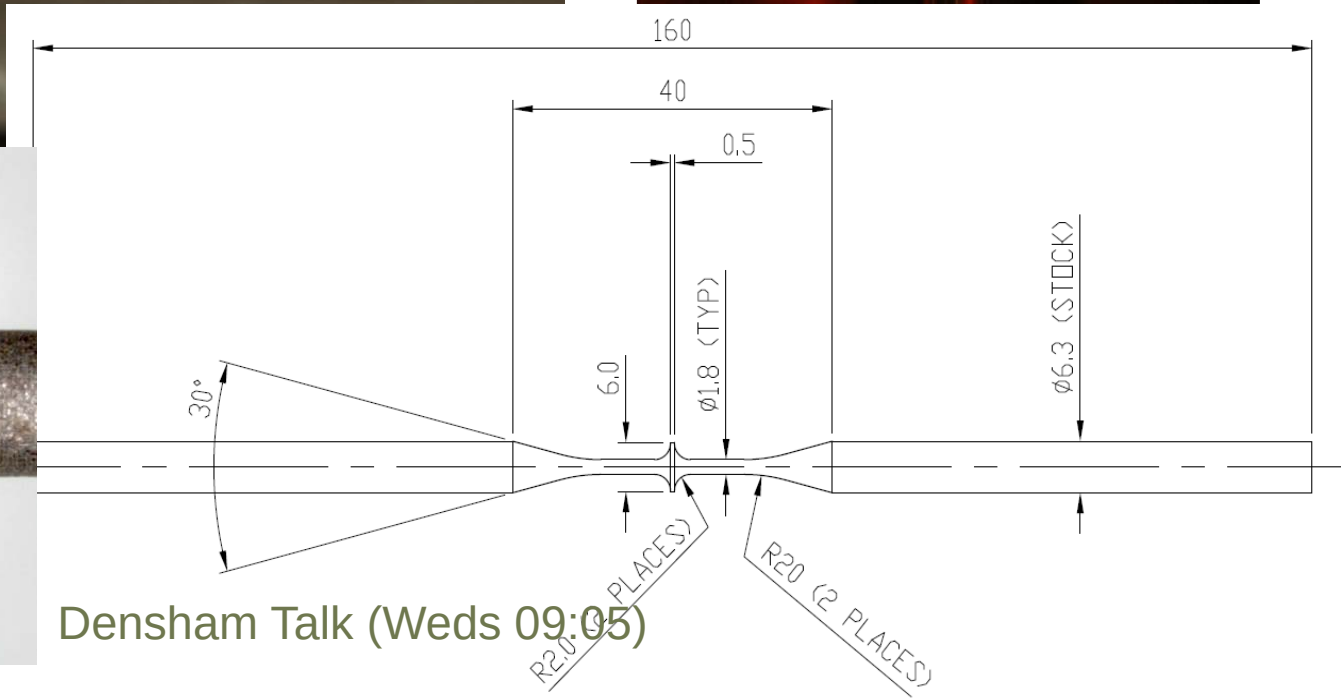
Science & Technology Facilities Council

Tungsten Lifetime Test Samples









Densham Talk (Weds 09:05)

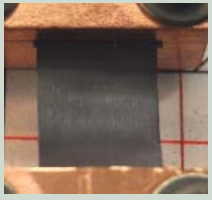
Radiation Damage Studies in Graphite
Annealing of Damage at High Temperature (> 1300ºC)

1 A - 350°C
10^{14} cm^{-2}

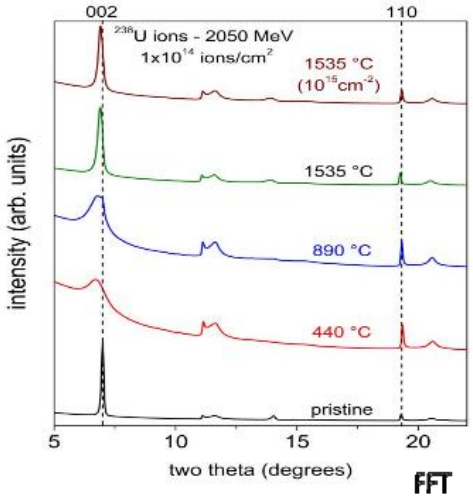
11 A - 750°C
10^{14} cm^{-2}

25 A - 1205°C
10^{14} cm^{-2}

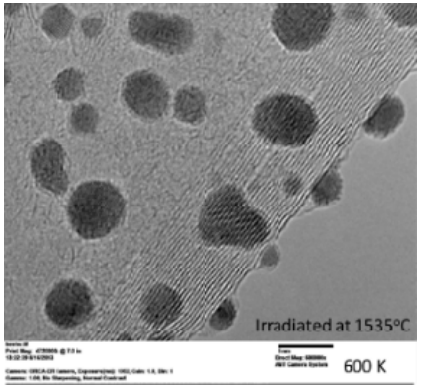
35 A - 1635°C
10^{15} cm^{-2}



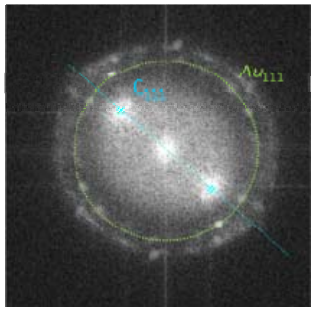
X-Ray Diffraction analyses

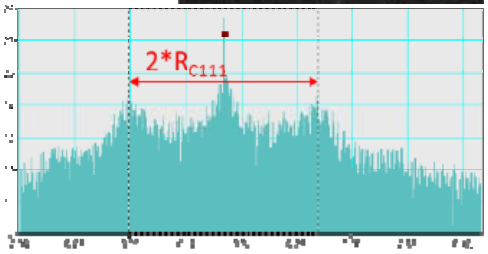


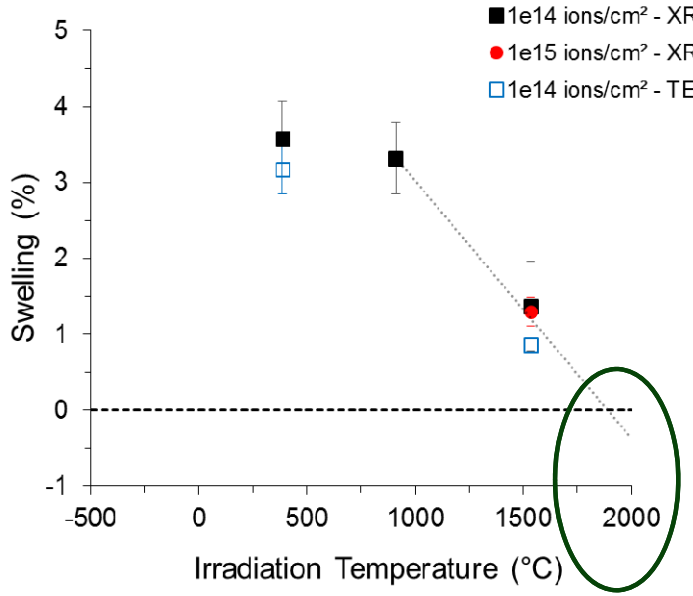
TEM analyses



FFT





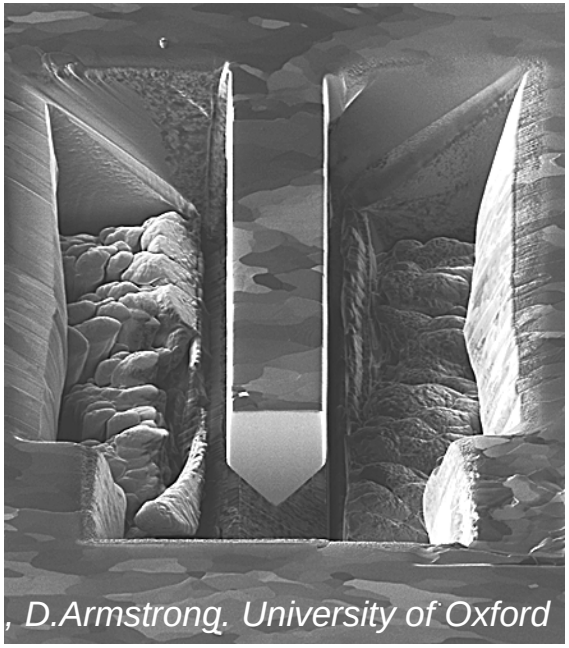


Swelling is completely recovered at 1900ºC

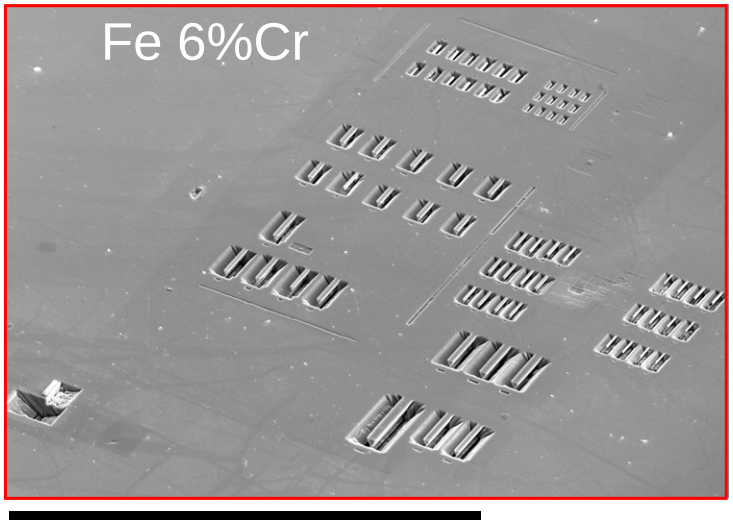
Pellemoine Talk (Weds 10:10)

Why use micro-cantilever testing?

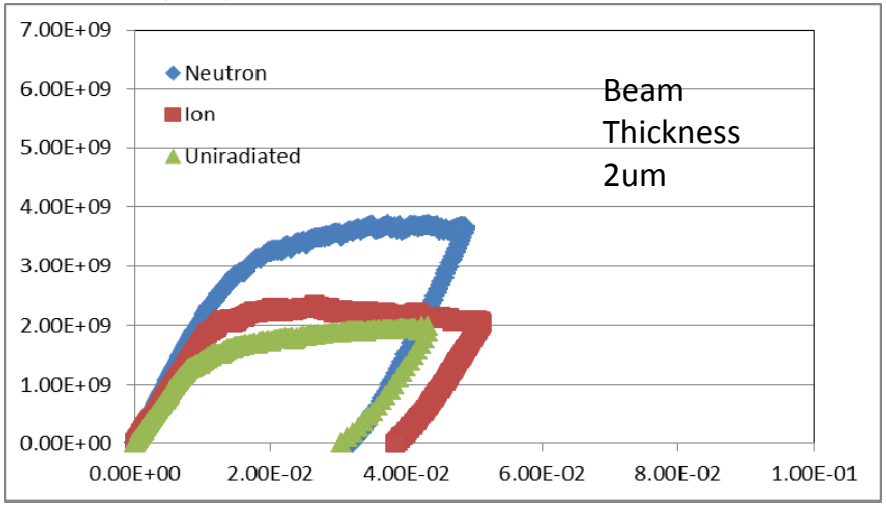
- Useful where only small samples are available (implanted layer)
- Need for a sample design that can be machined in surface of bulk samples
- Geometry that can be manufactured quickly and reproducibly



Chris Hardie
University of Oxford



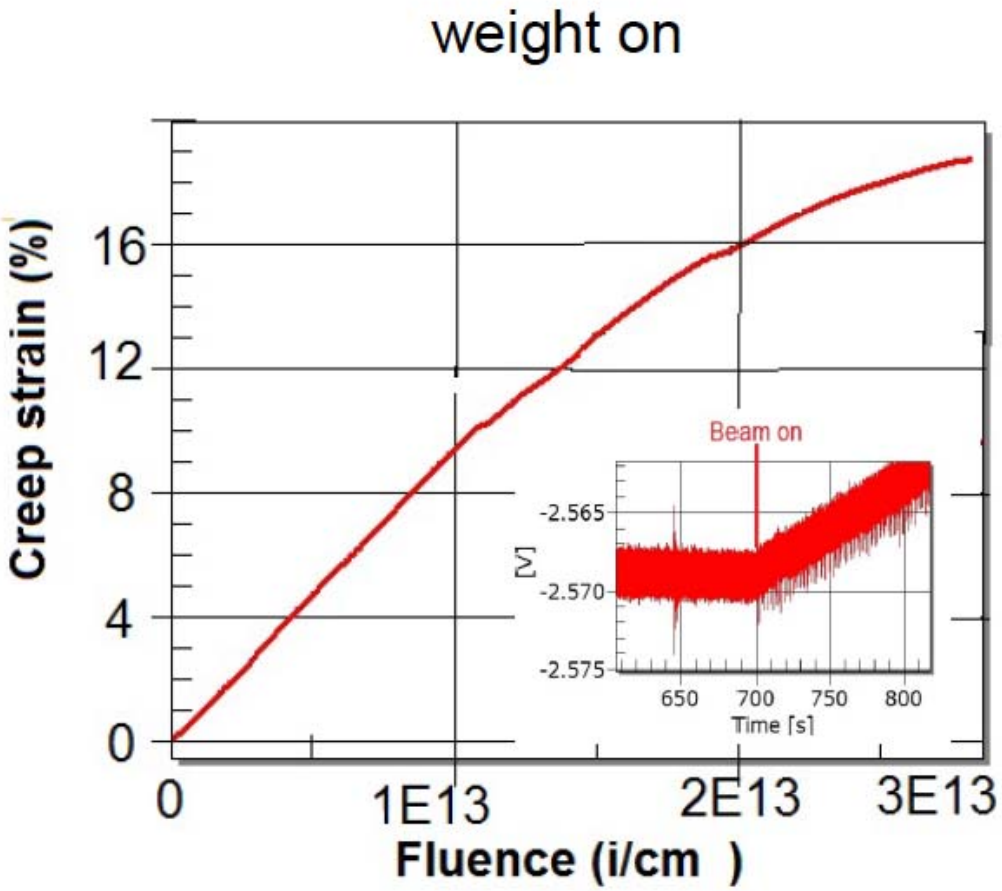
Stress (Pa)



Kuksenko Talk (Weds 10:30) Strain

Radiation induced creep measurements on flexible graphite

Au, 4.8 MeV/u



Tomut Talk (Weds 10:50)

http://indico.fnal.gov/event/HPT14

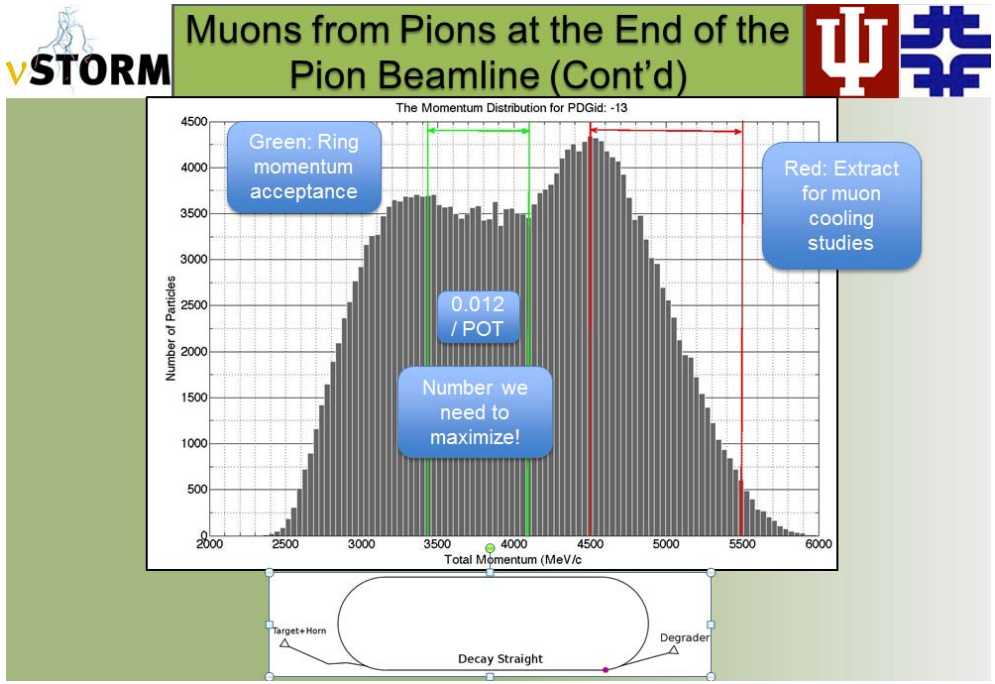
Target Facility Simulation

	Magnetic horn design optimization for nuSTORM *Wilson Hall - Ramsey Auditorium*	*Mr. Ao LIU* 13:20 - 13:45
	Beam-Induced Effects in Targets and Uncertainties in their Modeling *Wilson Hall - Ramsey Auditorium*	*Dr. Nikolai MOKHOV* 13:45 - 14:10
14:00	**Modified Moliere's Screening Parameter and its Impact on Calculation of Radiation Damage** *Wilson Hall - Ramsey Auditorium*	*Dr. Sergei STRIGANOV* 14:10 - 14:35
	Discussion 1 *Wilson Hall - Ramsey Auditorium*	*Dr. Nikolai MOKHOV* 14:35 - 15:20
15:00	**Coffee Break** *Wilson Hall - Atrium*	15:20 - 15:40
	MARS15 study of the Energy Production Demonstrator Model for Megawatt proton beams in the 0.5 – 120 GeV energy range	*Dr. Vitaly PRONSKIKH*
16:00	**Towards the simulation of proton beam induced pressure waves in liquid metal using the Multiple Pressure Variables (MPV) approach**	*Ms. Jana R. FETZER*
	LIEBE: Design of a molten metal target based on a Pb-Bi loop at CERN-ISOLDE. *Wilson Hall - Ramsey Auditorium*	*Mrs. Melanie DELONCA* 16:30 - 16:55
17:00	**The development of new concept for CADS spallation target** *Wilson Hall - Ramsey Auditorium*	*Prof. Lei YANG* 16:55 - 17:20
	Discussion 2 *Wilson Hall - Ramsey Auditorium*	*Otto CARETTA* 17:20 - 17:40

Ao Liu (Fermilab, Indiana University):
Horn Optimization for nuSTORM

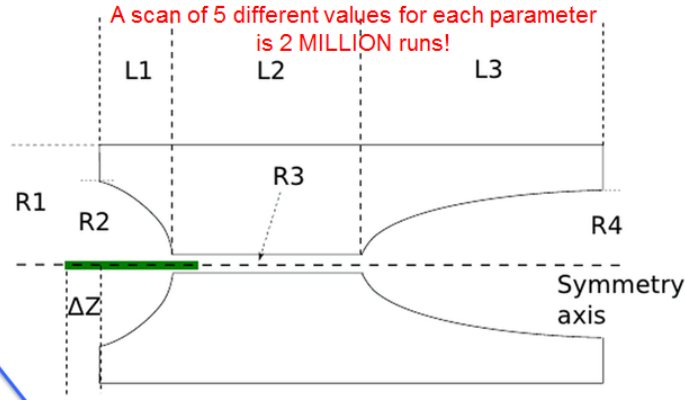
1. nuSTORM benefits from the optimization:
   Expect 8.3% more neutrino flux, with a 38 cm Inconel target;
   Expect 16% more flux, with a 46 cm Inconel target.

2. Other horn-based projects – e.g. LBNE:
   Algorithm is expected to work if the objectives are known;
   Algorithm may be less complicated and faster, if no beamline tracking is needed;
   MOGA allows adding other constraints to obtain a more realistic design + optimization



A python-mpi code to run the Genetic Algorithm (GA), to improve the individuals

- Different individuals are different combinations of parameters
- They give different objective values
  - (Different horns yield different N_{π} and $N_{\mu,end}$)
- Objectives to be maximized / minimized
  - (Max. N_{π} and $N_{\mu,end}$)
- Parameter constraints;
  - (Current in horn, neck radius, etc.)

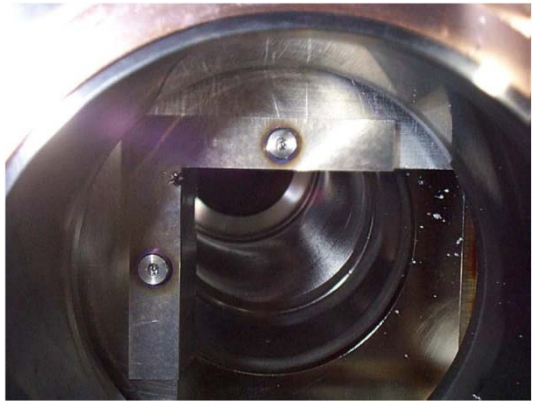


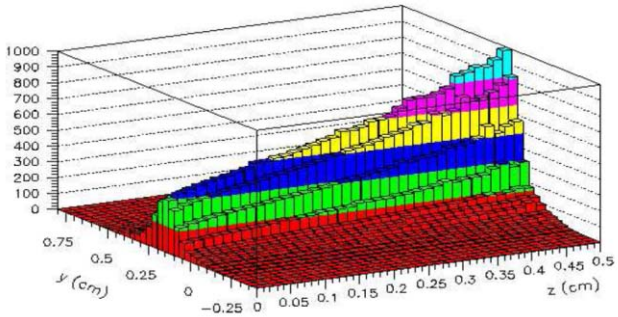
- An individual horn is a combination of the above parameters, and horn the current (9 parameters);
- Select parents based on the objectives, produce offspring;
- Parameters are treated like "genes" – genes of children are the crossover and mutation of the parents' genes;
- Eventually, the whole population will be improved, i.e. gives larger N_{π} and $N_{\mu,end}$

Nikolai Mokhov (Fermilab):

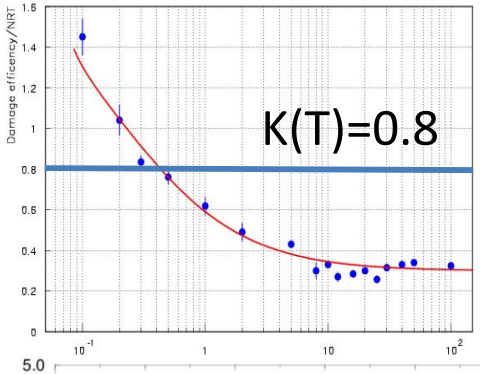
Beam-Induced Effects in Targets and Uncertainties in Modeling

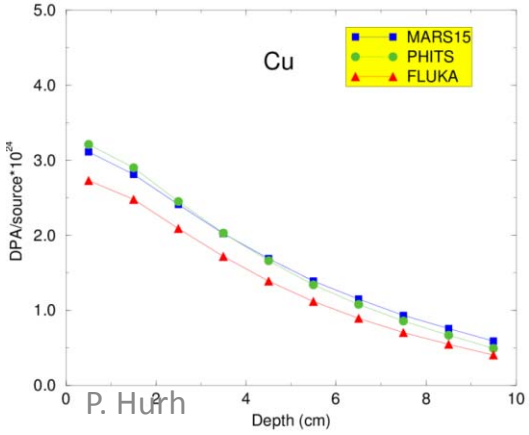
1. Thermal shocks and quasi-instantaneous damage
2. Insulation property deterioration due to dose buildup
3. Radiation damage to inorganic materials due to atomic displacements (DPA) and helium production
4. Capabilities (impressive) and uncertainties (steadily decreasing) of modern simulation codes used to study these effects
5. Link of calculated quantities (DPA, dose, fluence etc.) to observable changes in critical properties of materials remains on the top of the wish-list. **Mission impossible?**
6. **Discussion**

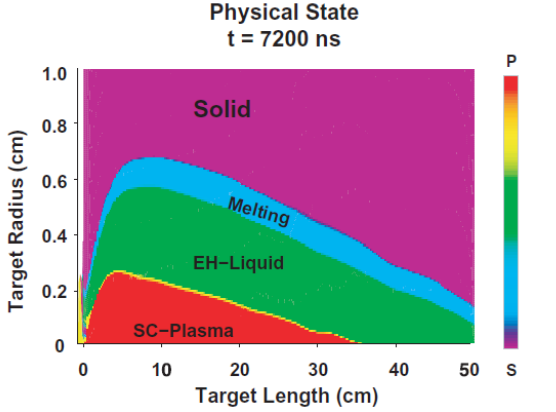


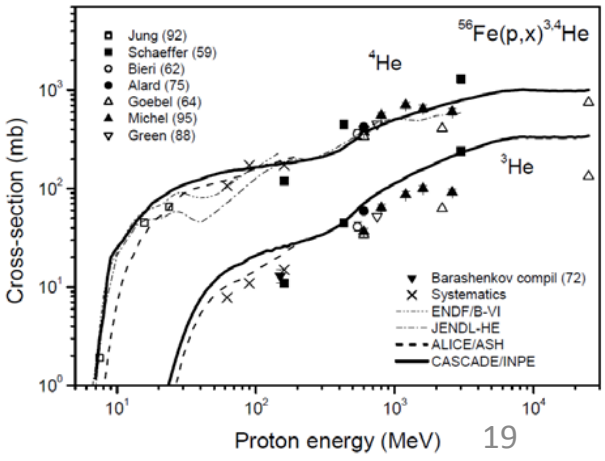


Displacement efficiency k(T)







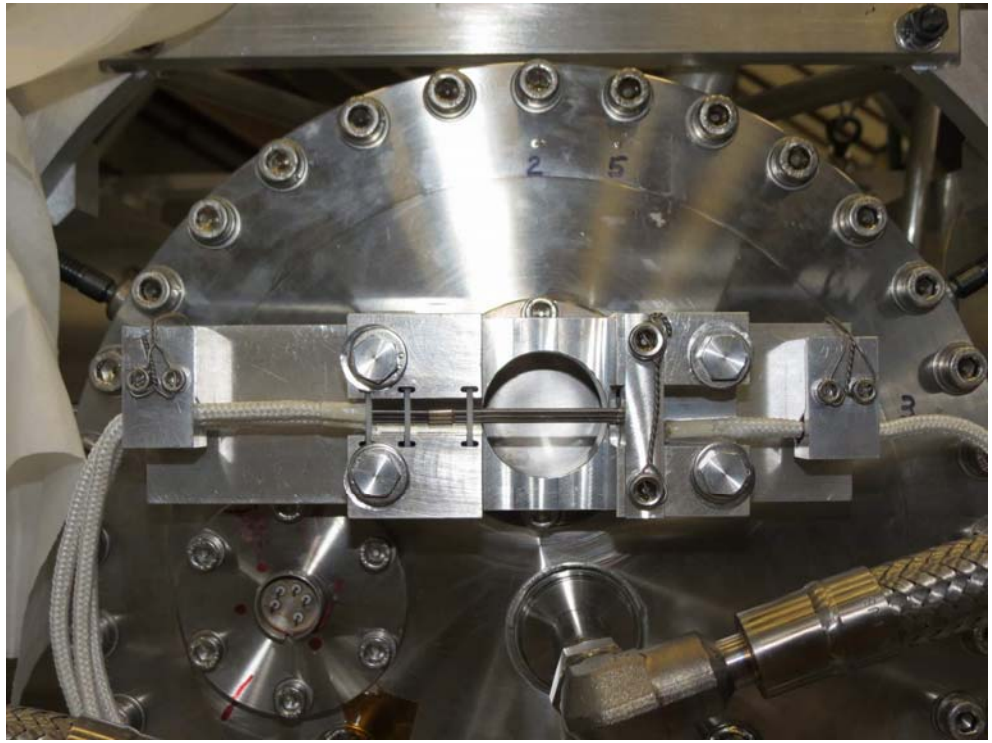


Target & Beam Instrumentation

08:00	**Proton beam monitors at JSNS of J-PARC**	*Dr. Shin-ichiro MEIGO*	
	Wilson Hall - One West		08:00 - 08:30
	Instrumentation Discussion 1		
	Wilson Hall - One West		08:30 - 08:40
	Monitoring beam position at the NuMI target with a thermocouple system	*Dr. James HYLEN*	
	Wilson Hall - One West		08:40 - 09:00
09:00	**The Radiochemical Detector**	*Dr. Bob ZWASKA*	
	Wilson Hall - One West		09:00 - 09:20
	Instrumentation Discussion 2 - Focus on New Techniques	*Knud THOMSEN et al.*	
	Wilson Hall - One West		09:20 - 10:00
10:00	**Coffee Break**		
	Wilson Hall - Atrium		10:00 - 10:20
	Integrating Safety into the LIEBE Pb-Bi loop target at CERN-ISOLDE	*Mrs. Ana-Paula BERNARDES*	
	Wilson Hall - One West		10:20 - 10:40
	VIMOS, New Experience with a Dedicated Optical Safety System	*Dr. Knud THOMSEN*	
	Wilson Hall - One West		10:40 - 11:00
11:00	**Experience with the SNS* Target Imaging System**	*Dr. Willem BLOKLAND*	
	Wilson Hall - One West		11:00 - 11:20
	Instrumentation Discussion 3 - Focus on Target Protection with Introduction by Tom Shea	*Thomas SHEA et al.*	
12:00	*Wilson Hall - One West*		11:20 - 12:20

Thermocouple Device at NuMI

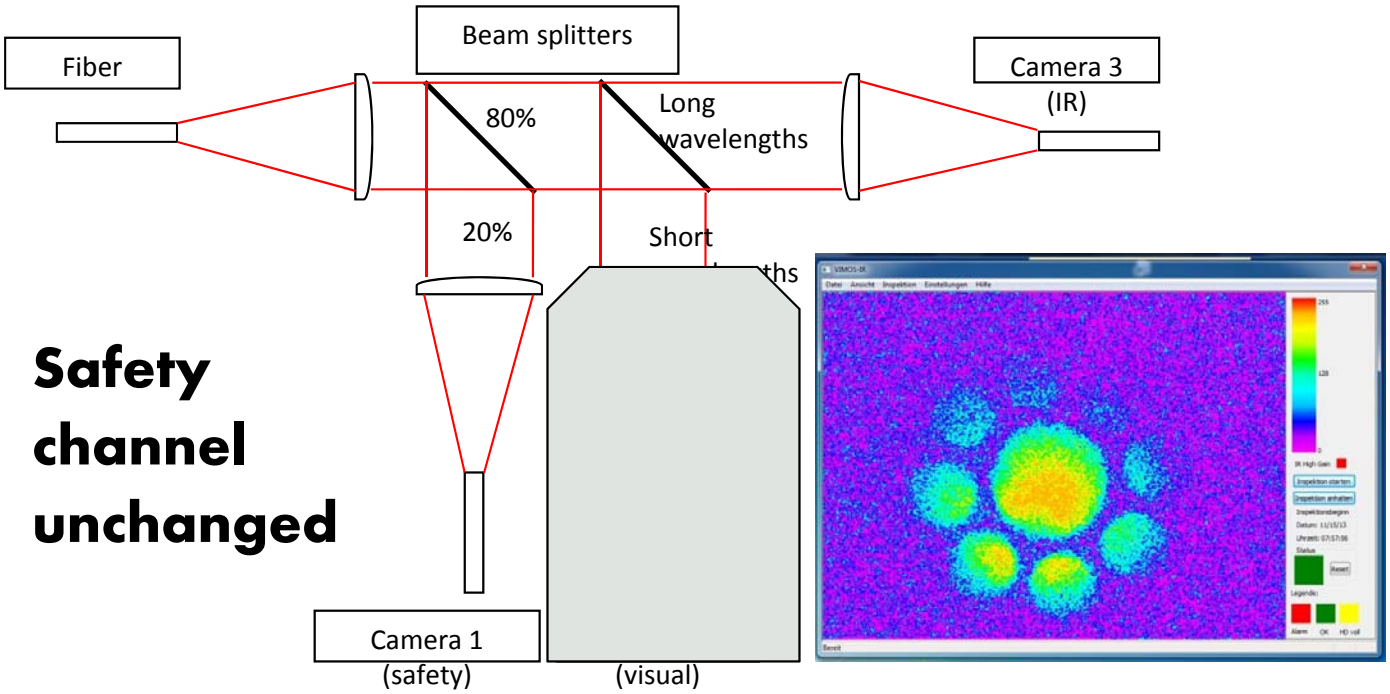
- New device to monitor proton beam position on NuMI target
- Beryllium rods and thermocouples demonstrated ability to monitor beam position to better than 0.1 mm accuracy
- **Simple, robust device that many attendees could see during the tour.**



Hylen Talk (Thurs 08:40)

Imaging Solution at PSI

Issue transporting short wavelengths in fiber bundle



- Diagnostics' short-wavelength camera removed, but Filter left in place.
- IR - Signal with reduced short-wavelength contamination alone serves as basis for diagnostics
- Increased sensitivity for lower temperatures / currents
- More linear response could still be reached
- **Try to do all optics with mirrors only**

http://indico.fnal.gov/event/HPT14

Target Facility Challenges

08:00	**Practical Experiences from Remote Handling in Fusion** *Wilson Hall - One West*	*Dr. Alan ROLFE* 08:00 - 08:40
	The IFMIF/EVEDA Target Facility Design – From CDR to IIEDR *Wilson Hall - One West*	*Dr. Friedrich GROESCHEL* 08:40 - 09:10
09:00	**The remote handling maintenance process of IFMIF target assembly** *Wilson Hall - One West*	*Dr. Gioacchino MICCICHè* 09:10 - 09:40
	Activated Waste Reduction and Design for Remote Maintenance *Wilson Hall - One West*	*Mr. Richard BENNETT* 09:40 - 10:10
10:00	**Discussion on remote handling** *Wilson Hall - One West*	*Dr. Roberto LOSITO et al.* 10:10 - 10:20
	Coffee Break *Wilson Hall - Atrium*	10:20 - 10:40
	Handling ESH Issues of a Water-cooled Proton Beam-on-Liquid Lithium Stripper Film Experiment *Wilson Hall - One West*	*Yoichi MOMOZAKI* 10:40 - 11:10
11:00	**NuMI Target Hall Reconfiguration for NOvA** *Wilson Hall - One West*	*Mr. Salman TARIQ* 11:10 - 11:40
	Target chase: Pros and Cons of different technical solutions *Wilson Hall - One West*	*Dr. Marco CALVIANI* 11:40 - 12:10
12:00	**Discussion on Target facilities challenges** *Wilson Hall - One West*	*Mr. Katsuhiro HAGA et al.* 12:10 - 12:20

5th High Power Target Workshop
https://indico.fnal.gov/conferenceDisplay.py?confId=7870

Target enclosures: pro & cons of various solution

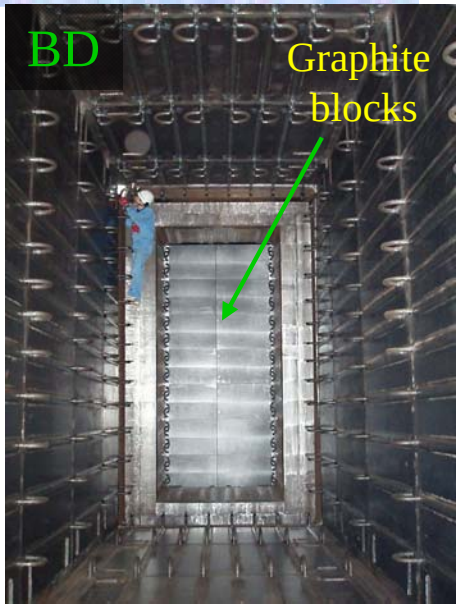
Brainstorming session

M. Calviani (CERN)

With major contributions from: **J. Hylen (FNAL)**, **T. Ishida & T2K team (KEK/J-PARC)**, **H. Vincke**, C. Strabel, P. Vojtyla (CERN)

Calviani Talk (Fri 11:40)

Helium Vessel Construction



rge
t
nclo
res
. pro
&
cons

http://indico.fnal.gov/event/HPT14

Posters interesting to MAP?

- Uniform irradiation of an extended target by high power beam.
  - Dr. TSOUPAS, Nicholaos
- CENF target thermo-mechanical study
  - Ms. VENTURI, Valentina
- Beryllium material tests: HiRadMat windows and NOvA fins
  - ATHERTON, Andrew
  - Dr. AMMIGAN, Kavin
  - HARTSELL, Brian
- LBNE 1.2MW Target Conceptual Design
  - HARTSELL, Brian
- A High-Power Target system for the Production of Intense Muon Beams
  - Prof. MCDONALD, Kirk
- PNNL Beam Window and Target Analyses
  - Mr. GATES, Robert
- Radiological Calculations on the LBNE Neutrino Beamline
  - Dr. REITZNER, Diane
- Tritium Mitigation for the LBNE Beamline
  - Dr. REITZNER, Diane
- Design and test of a graphite target system for in-flight fragment separator
  - Dr. KIM, Jong-Won

HPTW Conclusions and Future Directions (in no particular order)

- More radiation damage data is needed
  - Need to coordinate testing activities
  - Generate common database
  - "Standardize" techniques and parameters to validate comparisons
    - across irradiation types (energy, dose rate, temperature)
    - across testing techniques (micro-, mini-, macro-mechanics)
  - RaDIATE Collaboration may fill this need
- Need to move toward unified design standard for target component and system design incorporating radiation damage effects
  - Similar to RCC-MRx code (French nuclear power code)

HPTW Conclusions and Future Directions (in no particular order) (2)

- Facilities need to include flexibility to perform PIE (Post-Irradiation Examination) on components in order to gain the most benefit for targetry component lifetimes
- MC codes that calculate DPA should be more explicit:
  - Recoil atom energies
  - DPA (standard) – ASTM NRT calculation with fixed displacement efficiency (0.8)
  - DPA (physical) – NRT calculation with energy dependent displacement efficiency
  - Complete descriptions of origins of key parameters, such as displacement threshold energy (measurement, estimate, calculation)
- Computational capabilities are now at the point that MC simulation codes can start to work with Molecular Dynamics codes to predict radiation damage effects

HPTW Conclusions and Future Directions (in no particular order) (3)

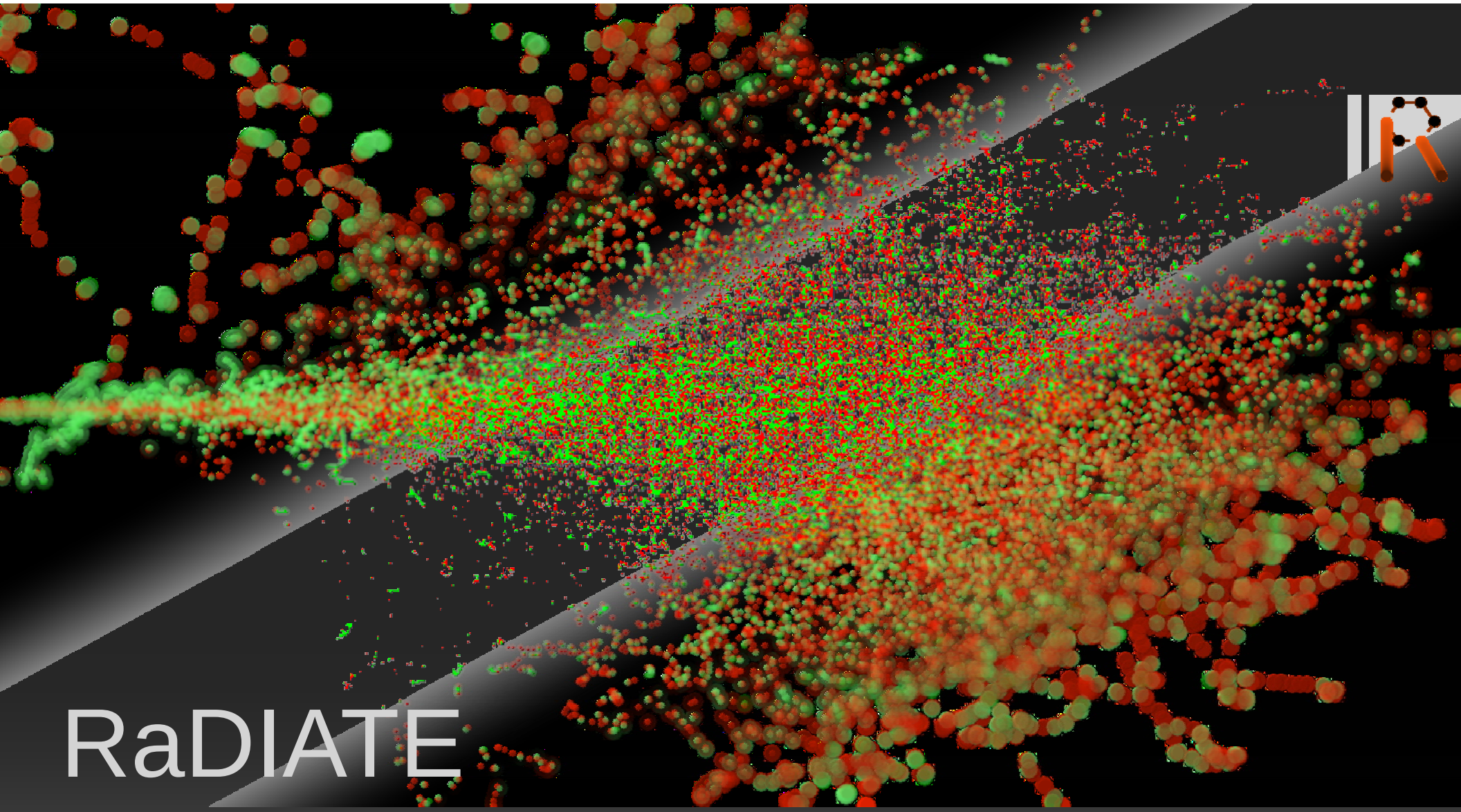
- Compared to the accelerator upstream, no target station appears to have a comprehensive instrumentation suite
  - More extensive thermal instrumentation
  - Improved beam profile and position monitoring
  - More robust inputs to target protection system (rastering example)
  - More…
- Limited collaboration between target facilities on instrumentation and across broader community
  - Significant opportunity here

HPTW Conclusions and Future Directions (in no particular order) (4)

- Remote Handling:
  - Embed into design to save money/time
  - Recovery from accidental situation is about 80% of design time
  - If components designed completely for RH, then operations take the same time or less then with human
    - If not, 5 to 10 times more!
  - Simplify design
  - Code of practice?
- Environmental issues
  - Reduce waste
    - Try to declassify waste as much as you can (volume reduce, store to decay)
  - Tritium confinement
    - Creation and migration needs simulations and benchmarking
  - Handle short lived isotopes
    - Air handling needs to provide for decay time
  - Flexibility necessary to solve early problems (but costly)
  - He, air or vacuum?
    - Depends on specific layout of facilities and local legislation

My general observations

- Trend toward optimizing solid targets before making the leap to liquid metal targets (lithium being the exception)
- Trend to staging beam power upgrades
- Recognition of experts globally that successful construction and operation of HPT facilities demands development of HPT as a core institutional competency (infrastructure, experience, development)
  - Need to instill that viewpoint in management (Laboratory Directorates) and funding agencies (DOE)
- The HPT community is strong, vibrant and growing!



RaDIATE

1st Annual Collaboration Meeting

May 19 2014

Welcome and News & Notes

http://www-radiate.fnal.gov/

Radiation Damage In Accelerator Target Environments

Next Stop: Oxford! (HPTW 2016 at RAL)