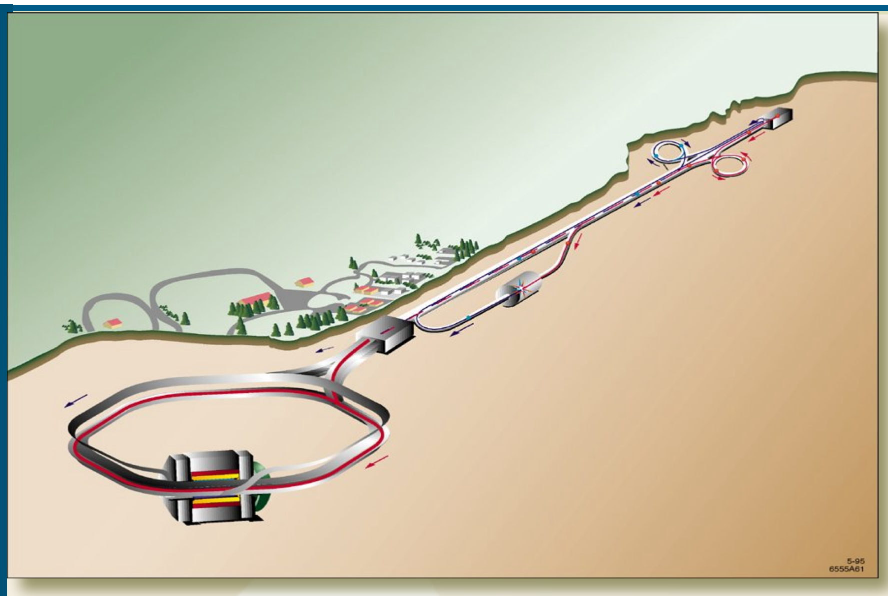
Vacuum Experience in High-Intensity Electron Machines



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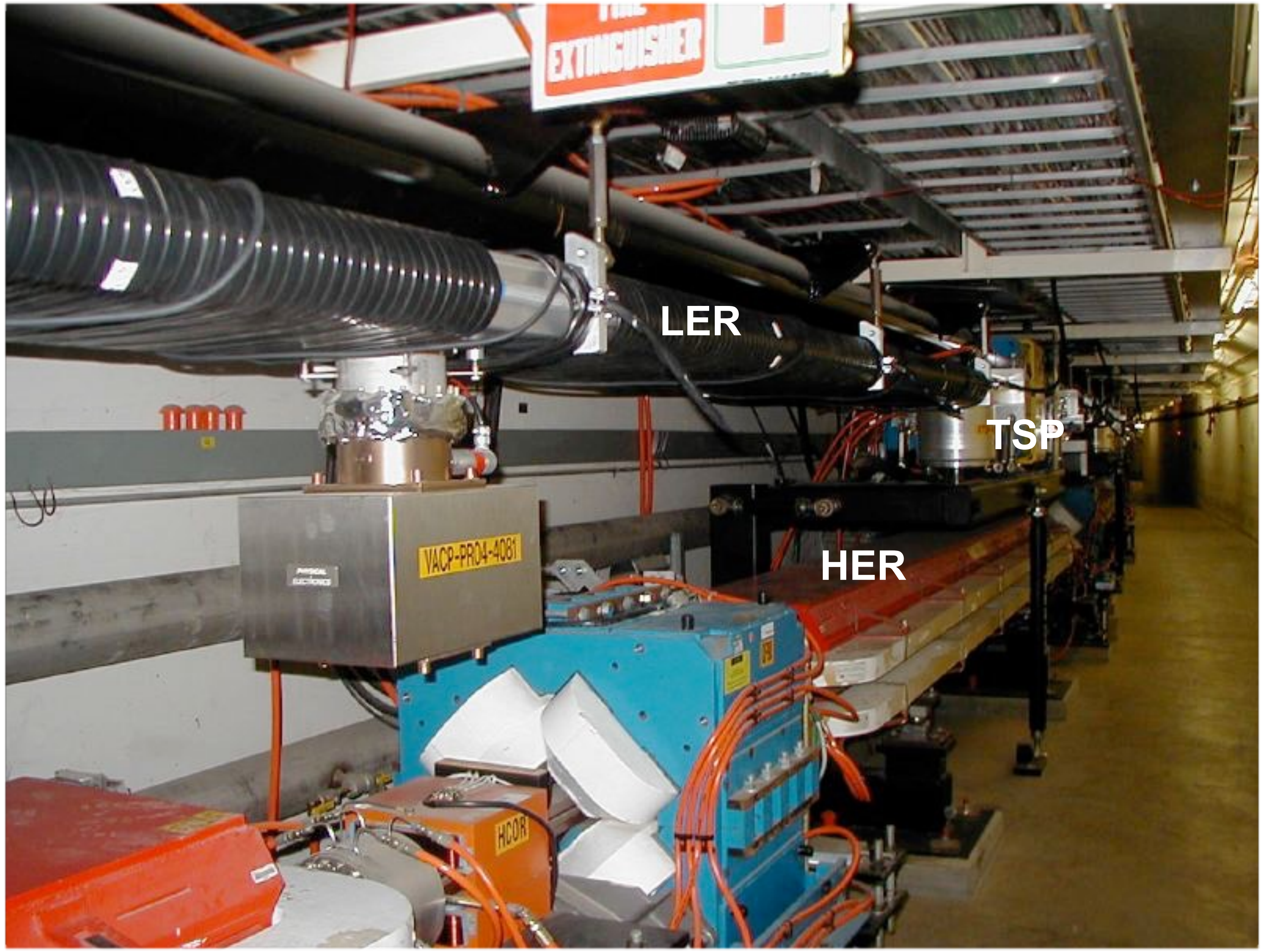
J. Carter. for the APS-U vacuum team

Machine Parameters

	Design HER	Design LER	Achieved (delivery) HER (e^-)	Achieved (delivery) LER (e^+)
Energies e– / e+ (GeV)	8.973	3.119	8.973	3.119
Currents e– / e+ (A)	0.75	2.14	**1.95**	**3.02**
Number of bunches	1658		**1722**	
Bunch currents e– / e+ (mA)	0.45	1.29	**1.24**	**2.09**
Bunch spacing (m)	1.26		**1.26**	
IP spot size σ_x^* / σ_y^* (μm)	155	4.7	147	5
Bunch length (0 current) (mm)	10		11.0	11.5
Rf Voltage (MV)	18	3	**16.5**	**4.5(5.4)**
Rf Stations * # cavities	5*4	2*2	3*4+8*2	**4*2**
Luminosity ($\times 10^{33}$/cm^2/sec)	3.0		**12.0**	
Tune shift horiz. e– / e+	0.03	0.03	0.059	0.09
Tune shift vert. e– / e+	0.03	0.03	0.074	0.055
Beam crossing angle	0 (head-on)		0 (head-on)	

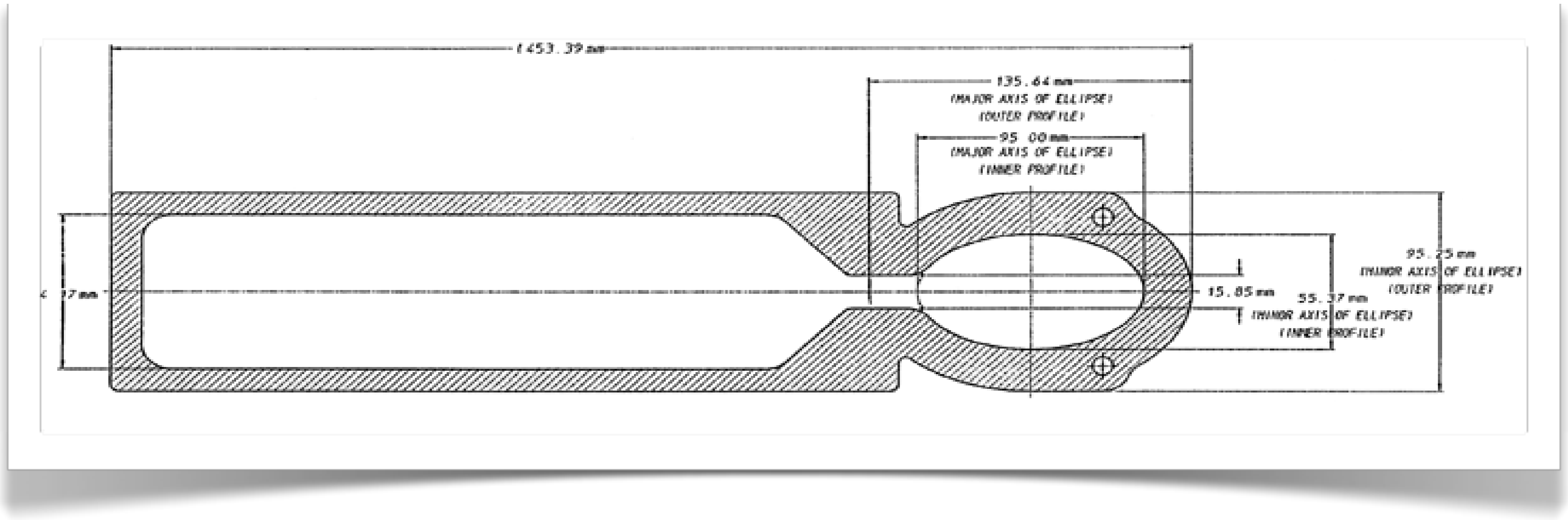
PEP Tunnel



PEP-II Vacuum System

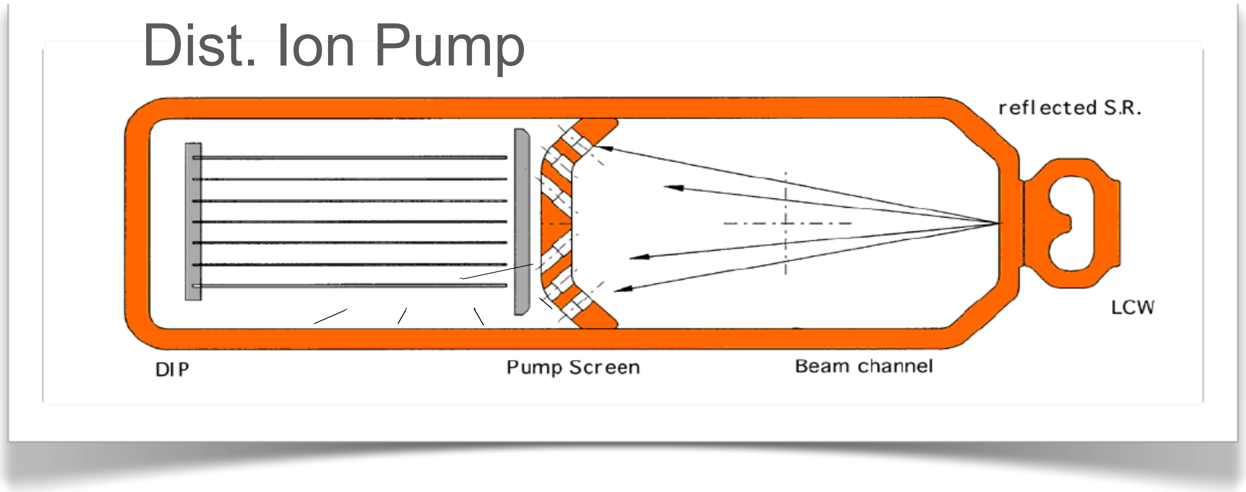
LER, e^+

- Al extrusion, TiN coated
  - with antechamber for synchrotron radiation, discrete photon stops with localized Ti sublimation pumps
    baked & glow-discharge cleaned before installation



HER, e^-

- Cu extrusion with photon stop along outside
  - distributed ion pumps in dipole field (DIPs)
  - baked & glow-discharge cleaned before installation

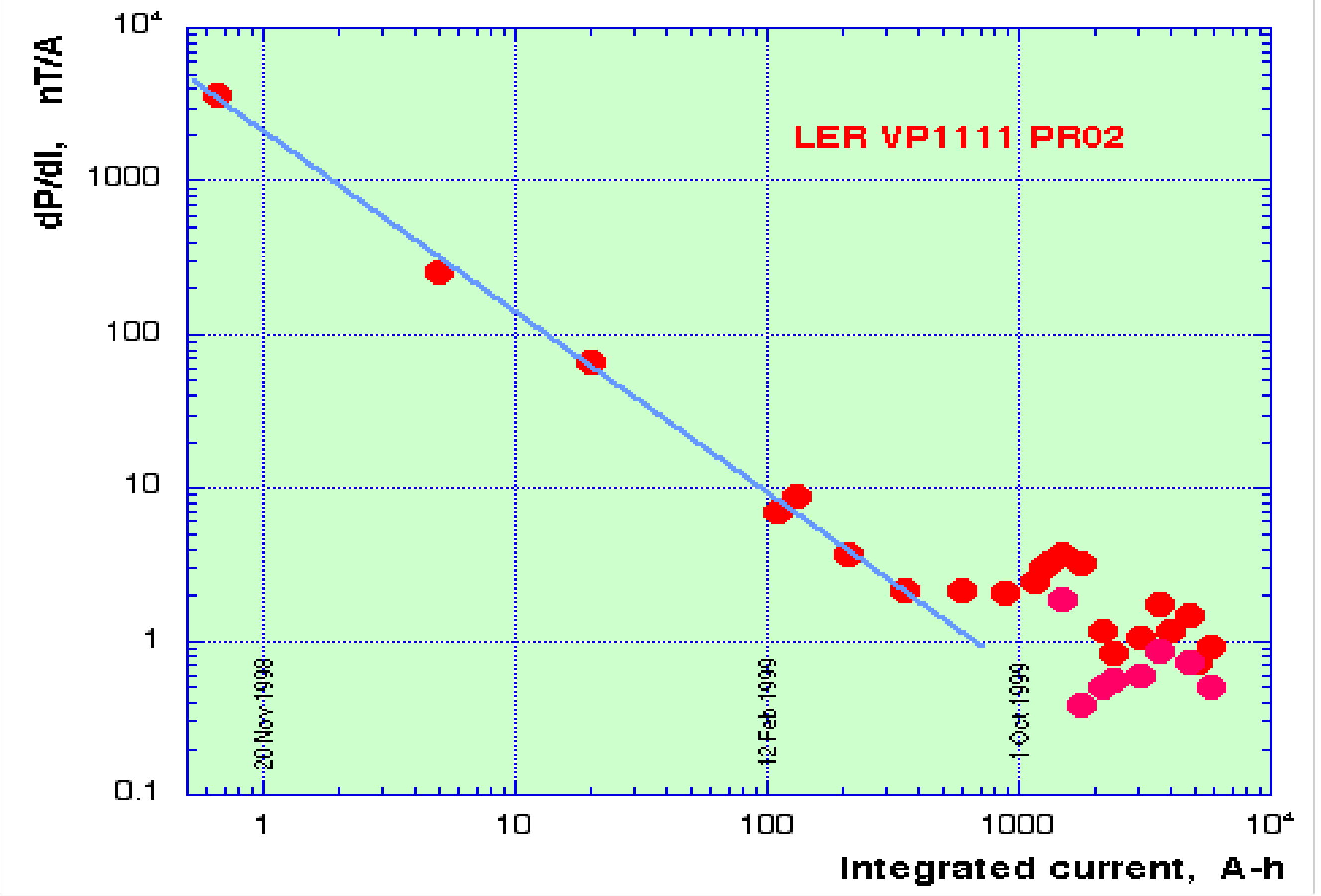


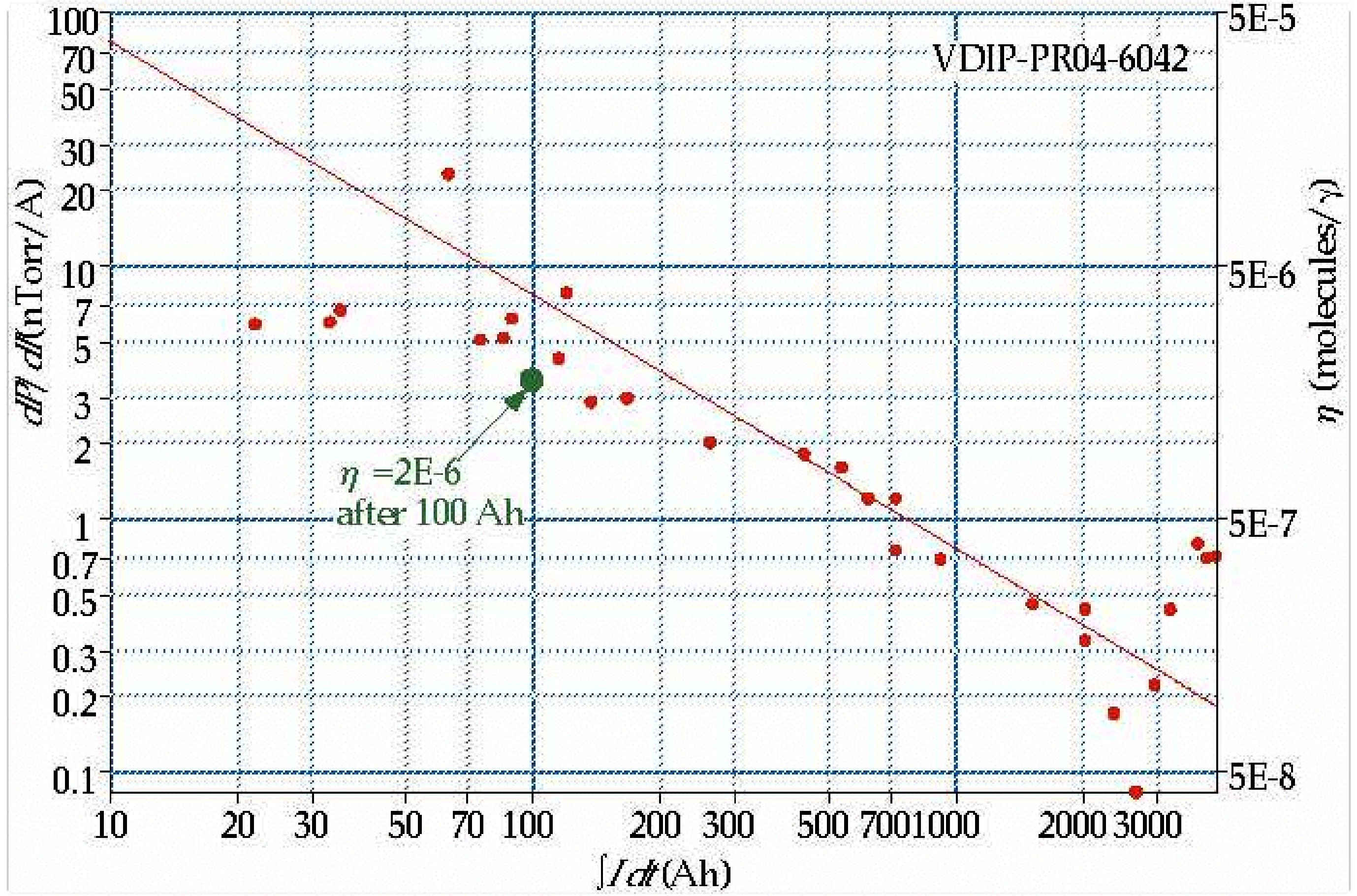
The Cu chamber shields the X rays quite effectively.

Vacuum Scrubbing

- Despite the discrete photon stops, the LER has scrubbed at a similar rate as the HER.

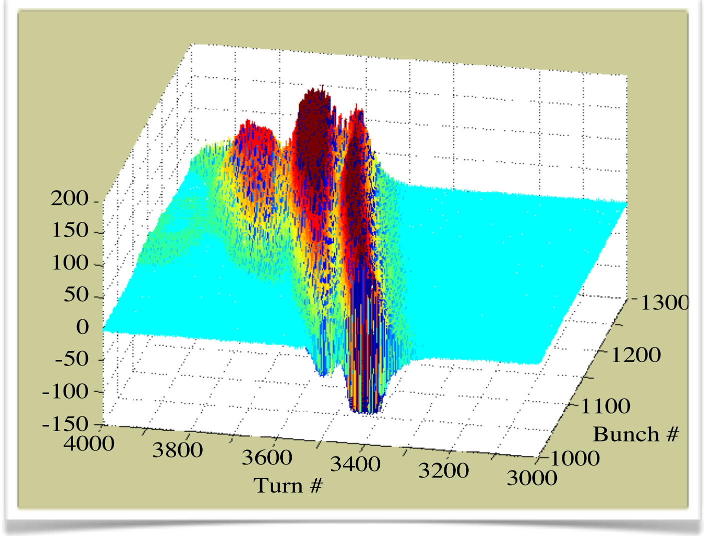
- The HER system has scrubbed as predicted in the CDR
  - Photon desorption coefficient η ≤ 2E-6 achieved after 200 Ah exposure



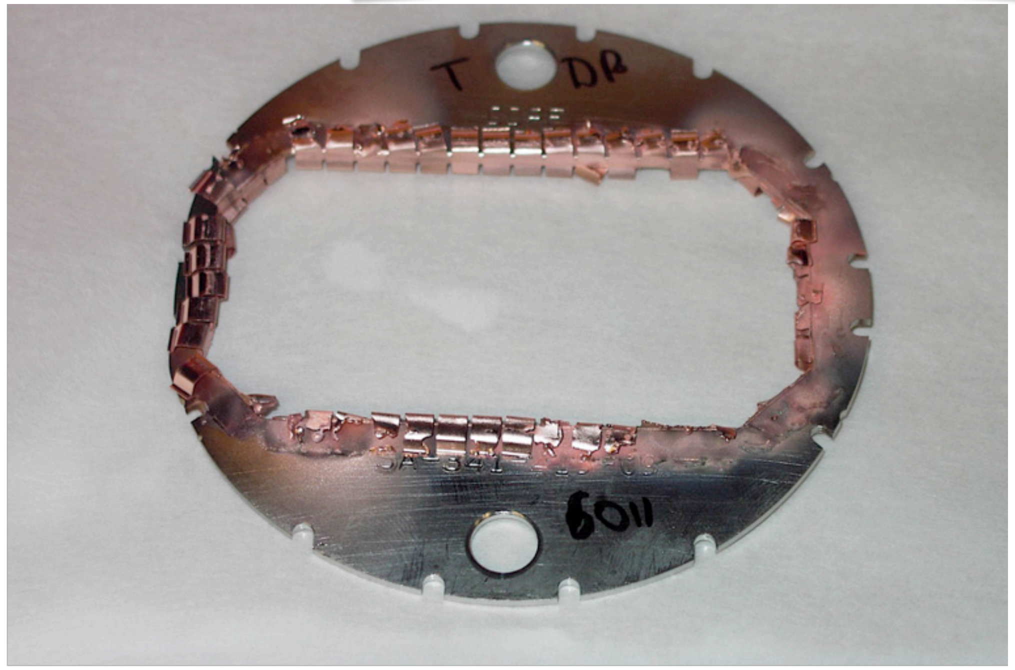


High Current Issues

transverse mode 5–10 instability

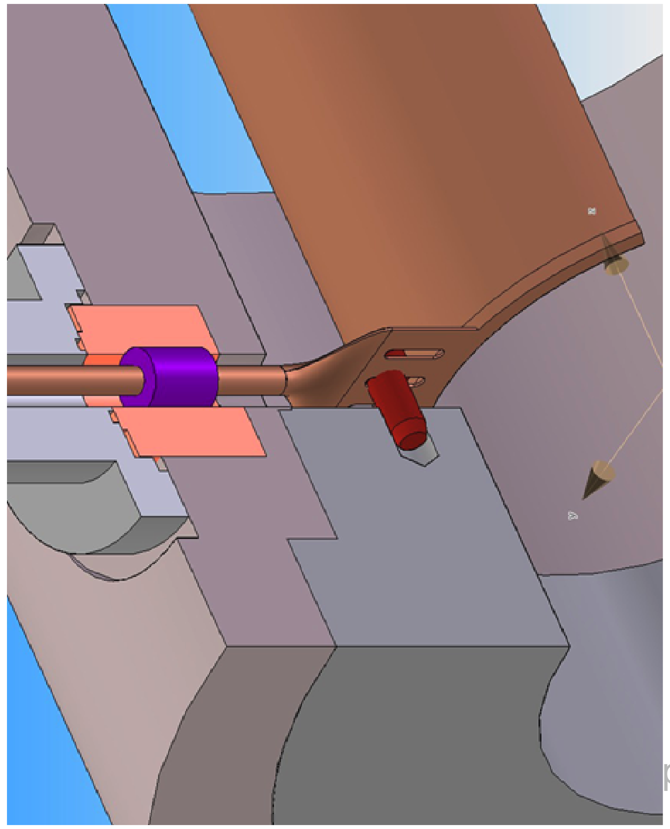


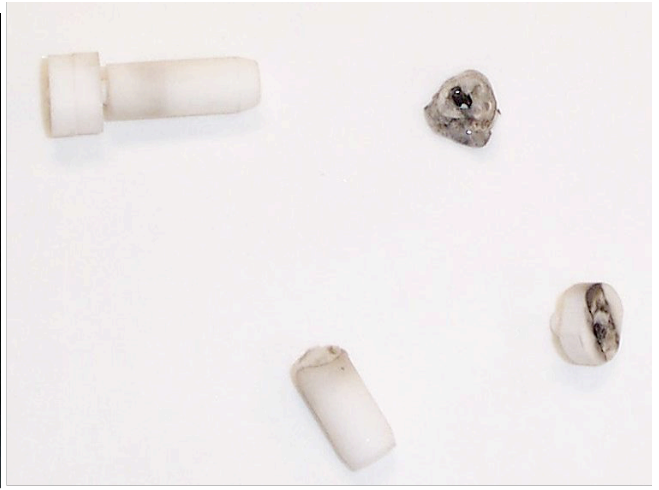
- Flexible rf seals can burn up & arc causing beam instability



- Dimensions change with temperature
  - bellows resonances
  - Bellows screens (liners) can transmit rf power
    - esp. when beam-related (TM) modes get converted to TE modes
    - Collimators can convert modes quite efficiently

- Sparse bunch patterns have a richer spectrum
  - and for wideband impedance the heating is $\hat{I}*I_{av}$, short bunches can be dangerous.

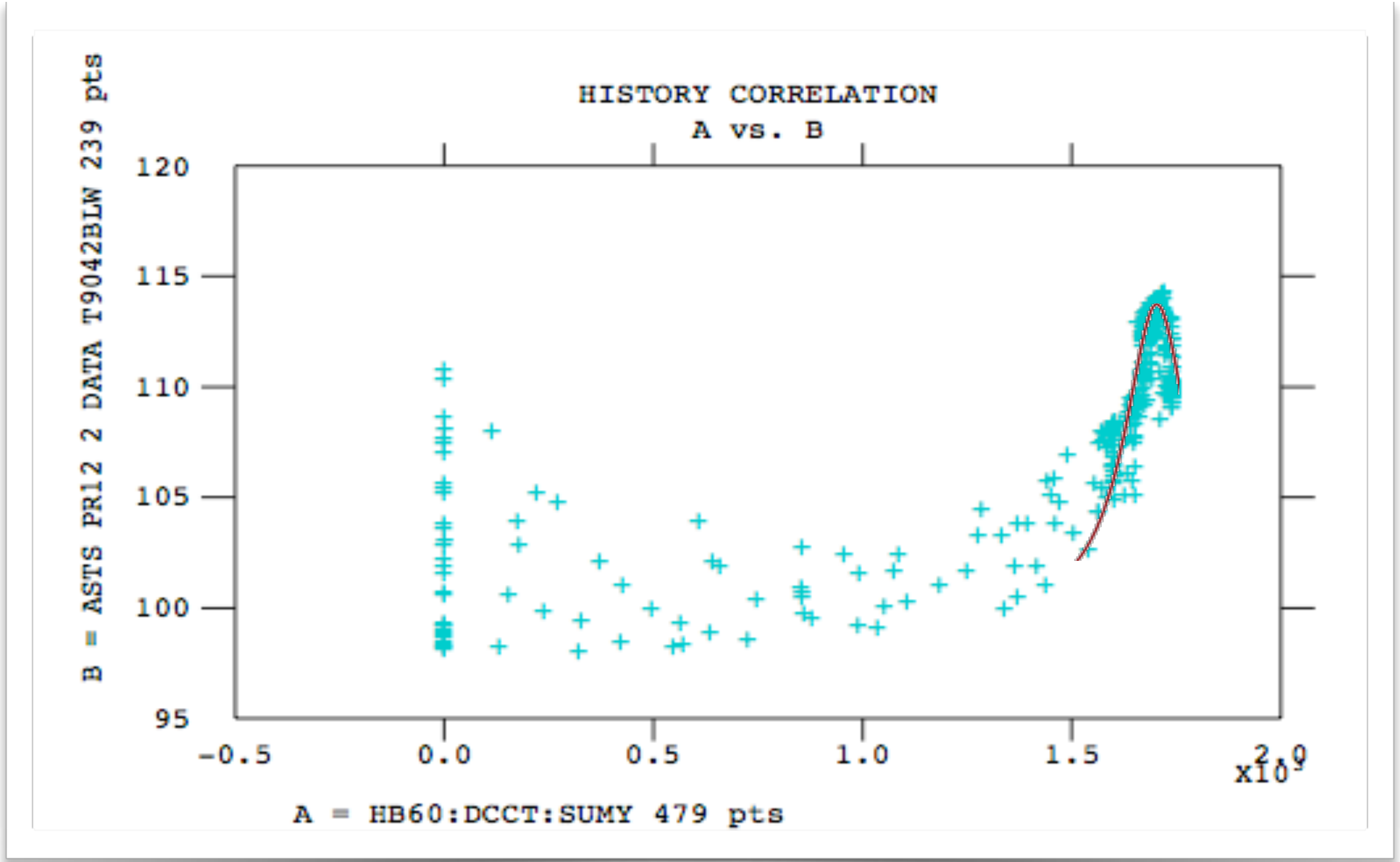




Bellows Resonances

- Some rf power penetrates through the shield => heating of convolutions esp. when a resonant mode is excited
  - eventually, fans were installed at most bellows.

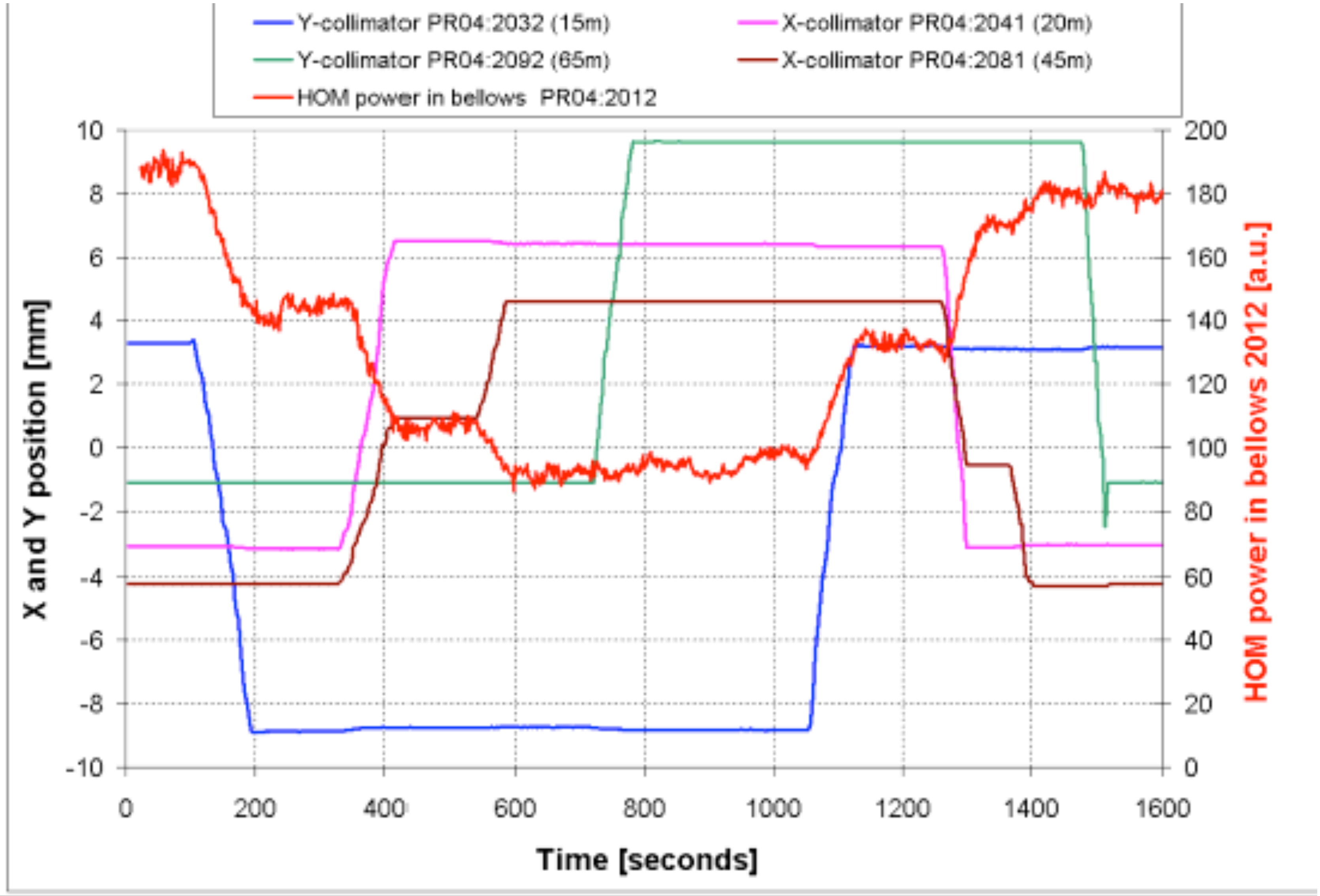
PEP-II HER



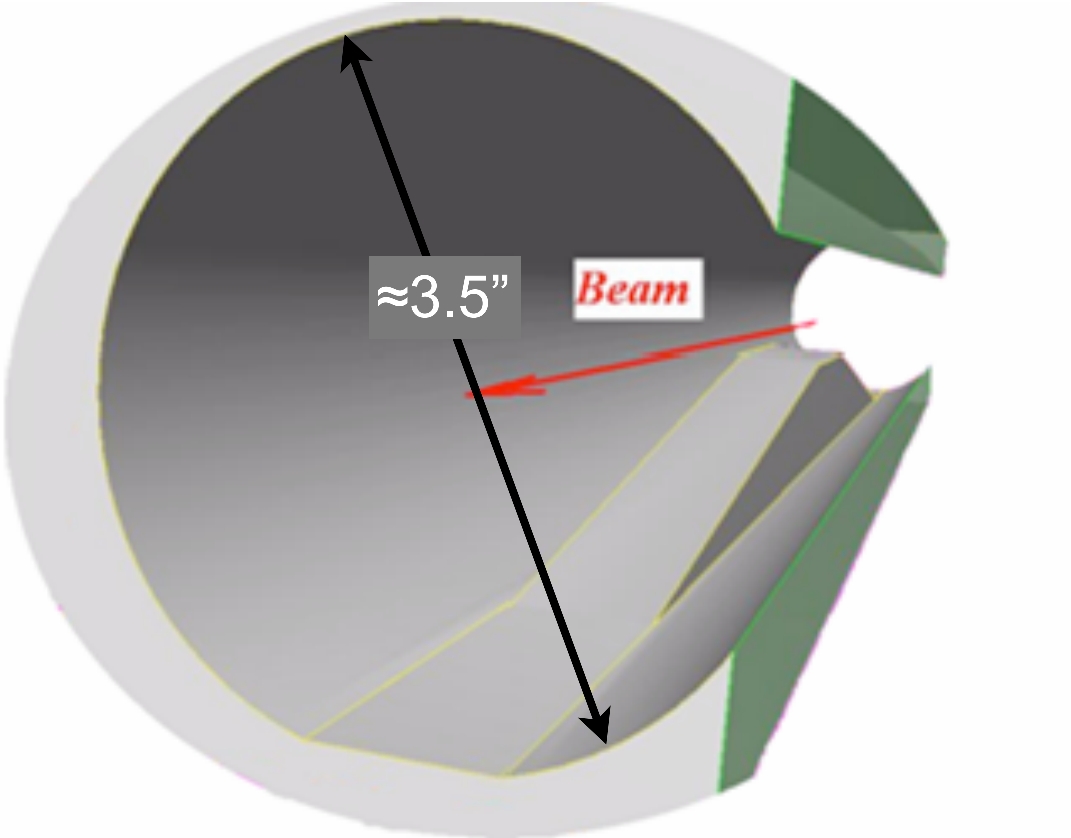
Collimator-Induced HOM Power (PEP-II LER)

S. Novokhatski

- Orbit-dependent heating in bellows was observed and traced back to beam-collimator effects
  - HOM power could travel 10s of m. Penetrates rf liners. Not easily seen in CST as it is from converted beam modes



PEP-II style fixed collimator



TSP Connector burn

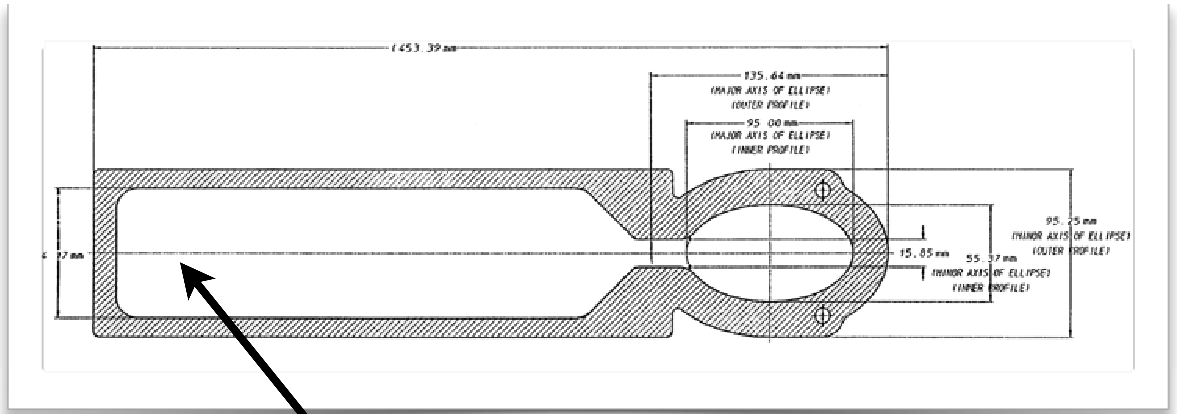
S. Novokhatski

- This (& only this!) TSP connector kept burning up at high beam current.
- Upstream collimator converts modes, these get into the TSP & fry the connector insulation, µwave style!
- small ferrite block near connector used for power measurement

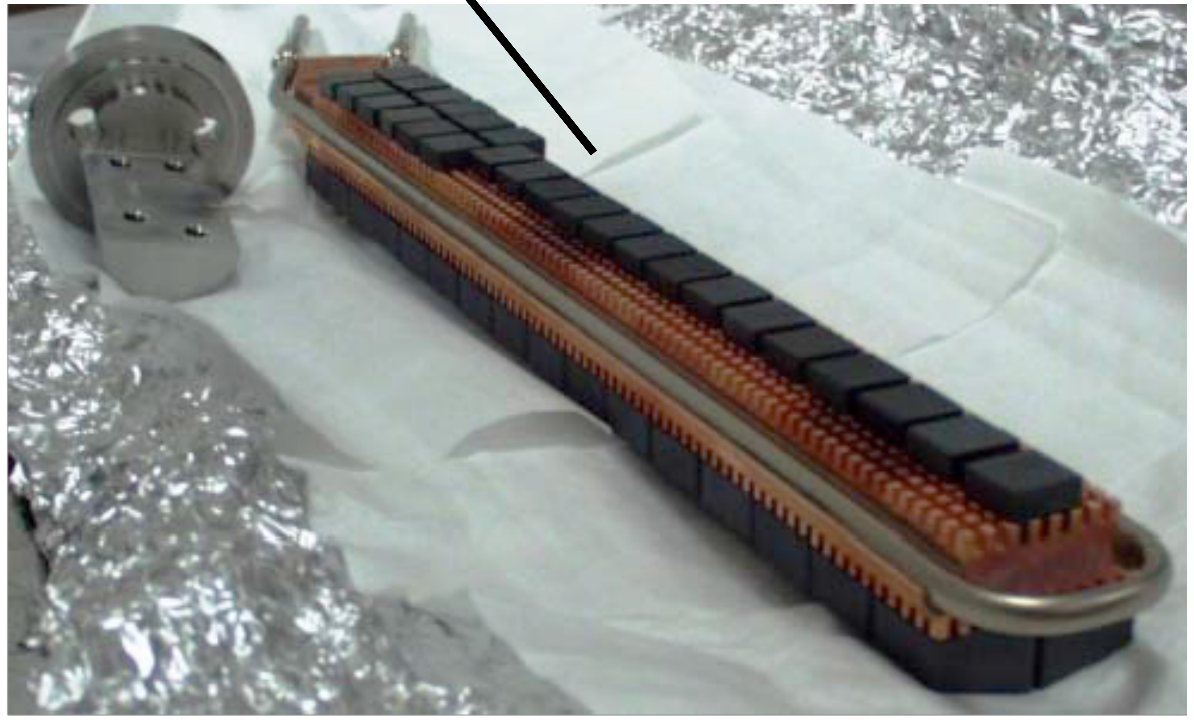
HOM absorber mitigation

S. Novokhatski

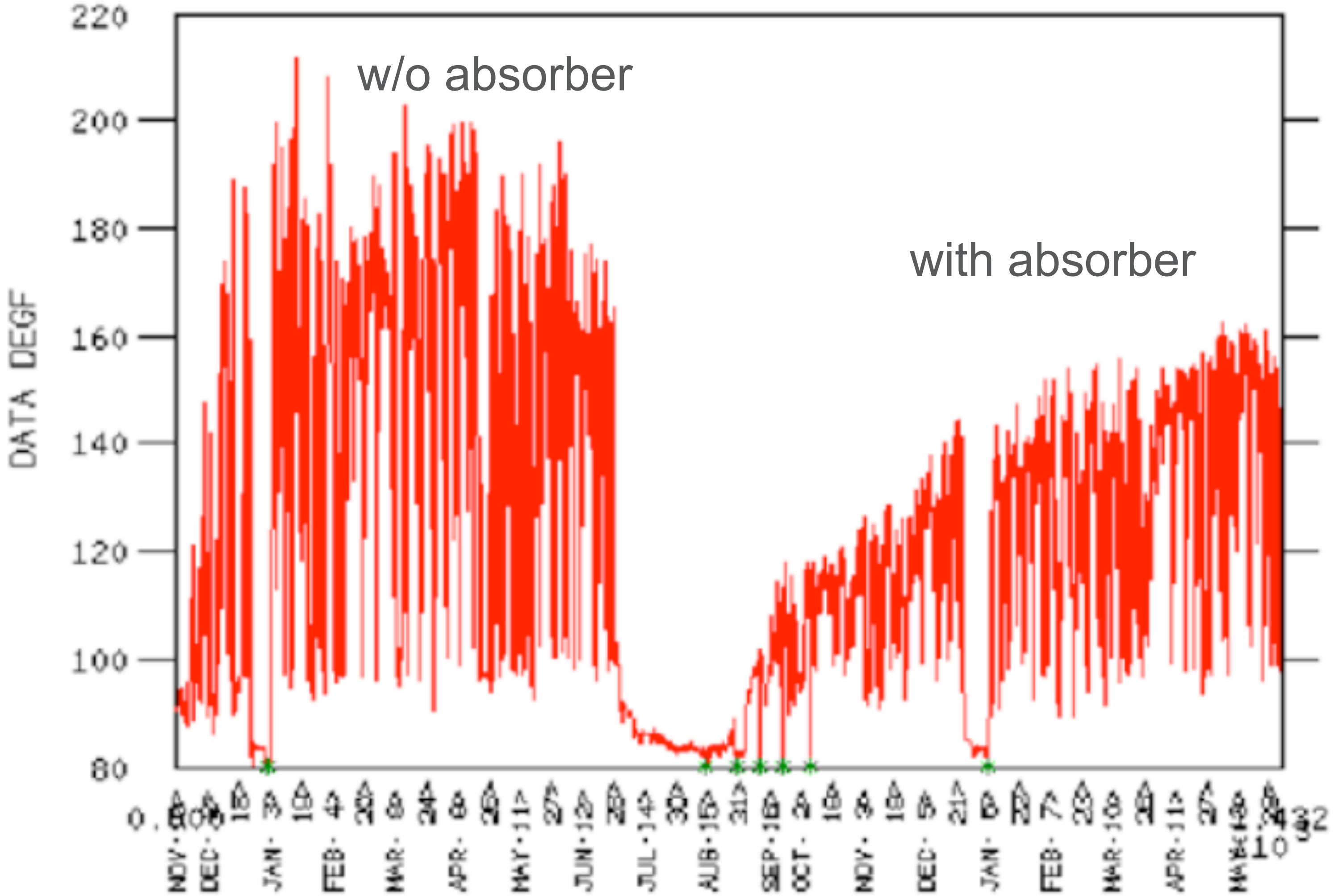
- An HOM absorber installed in the chamber upstream of this TSP reduced the power



installed here



Temperature for similar beam currents for 2 run periods (measured on a tile outside of TSP).



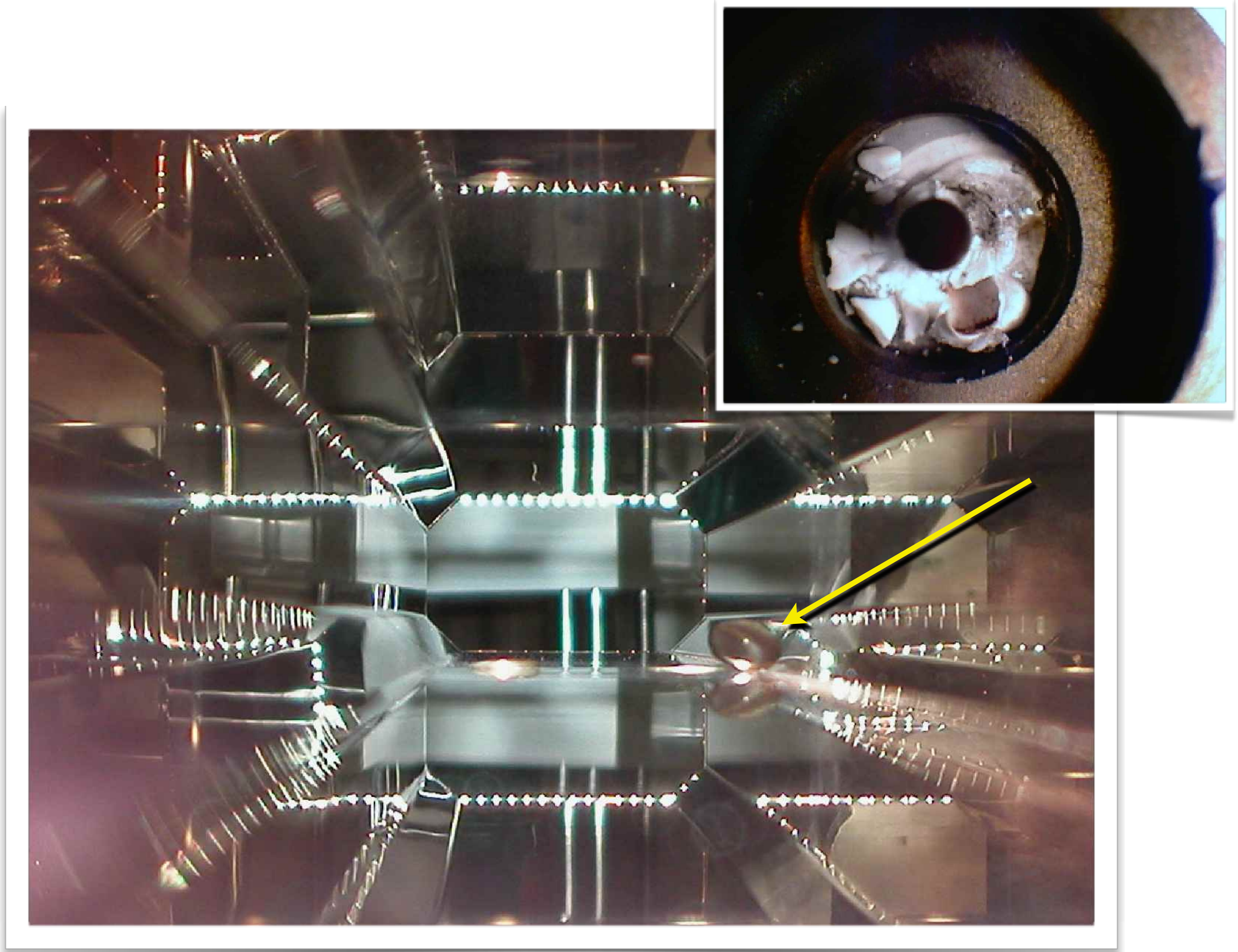
BPMs Falling (LER) when Shortening Bunches

BPMs extract power at a 7 GHz resonance

Damage at 5.4 MV rf: buttons fell off feedthrough

Buttons were SS, press-fit to Mo pin.

Fit loosened as buttons got hot

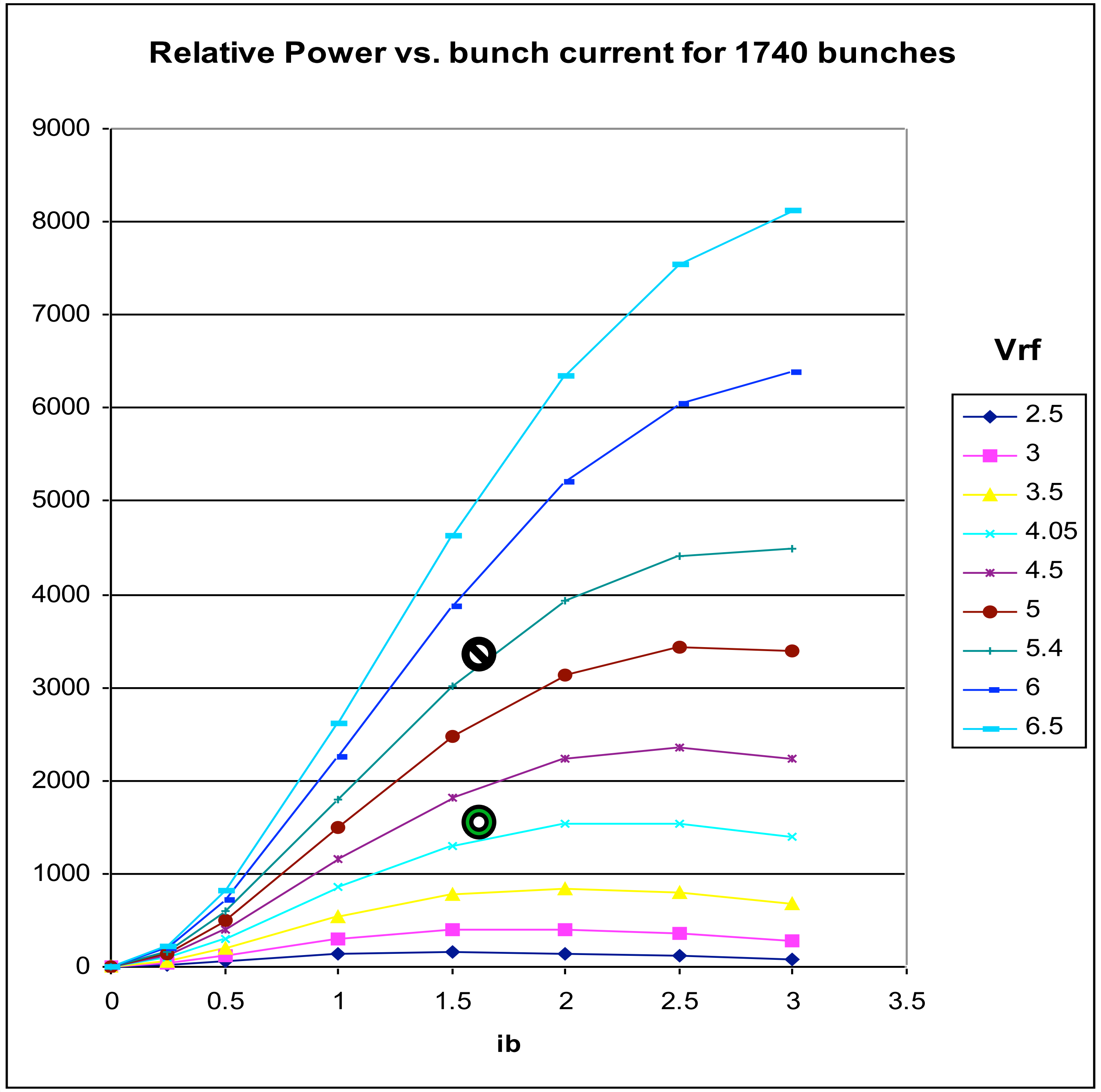


LER BPM Heating

- Increase Vrf by ≈25%, power to BPMs doubles(!)

- Fix: replaced all 14-mm LER BPM buttons with 7 mm ones
- Where not possible, pull off the buttons(!)

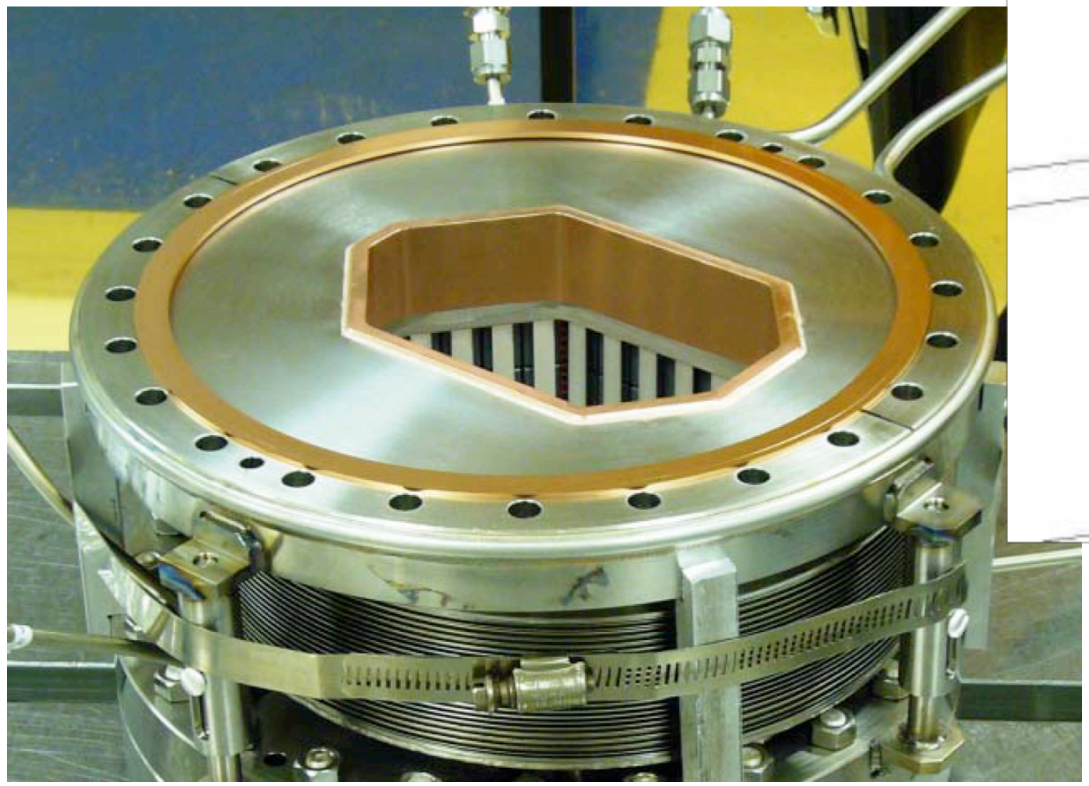
S. Ecklund

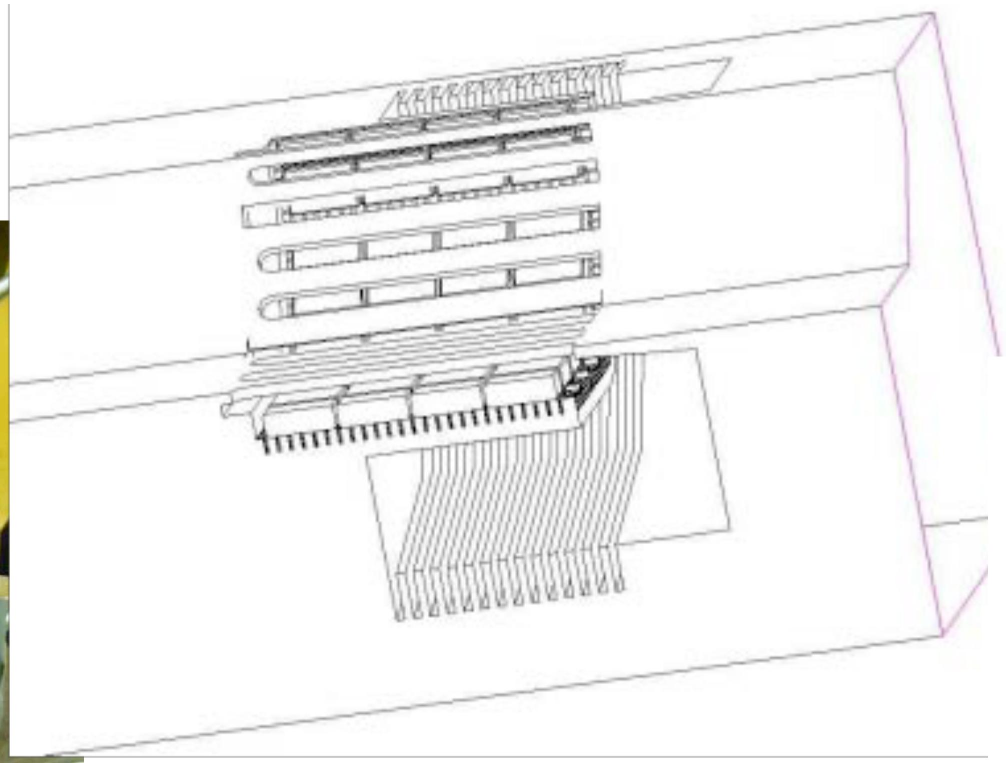


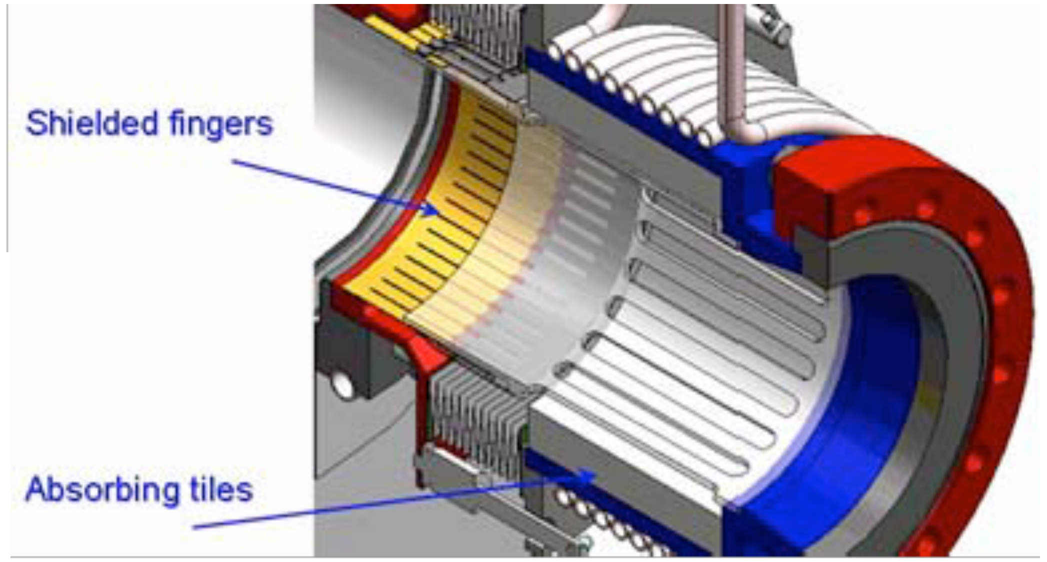
Absorber Bellows

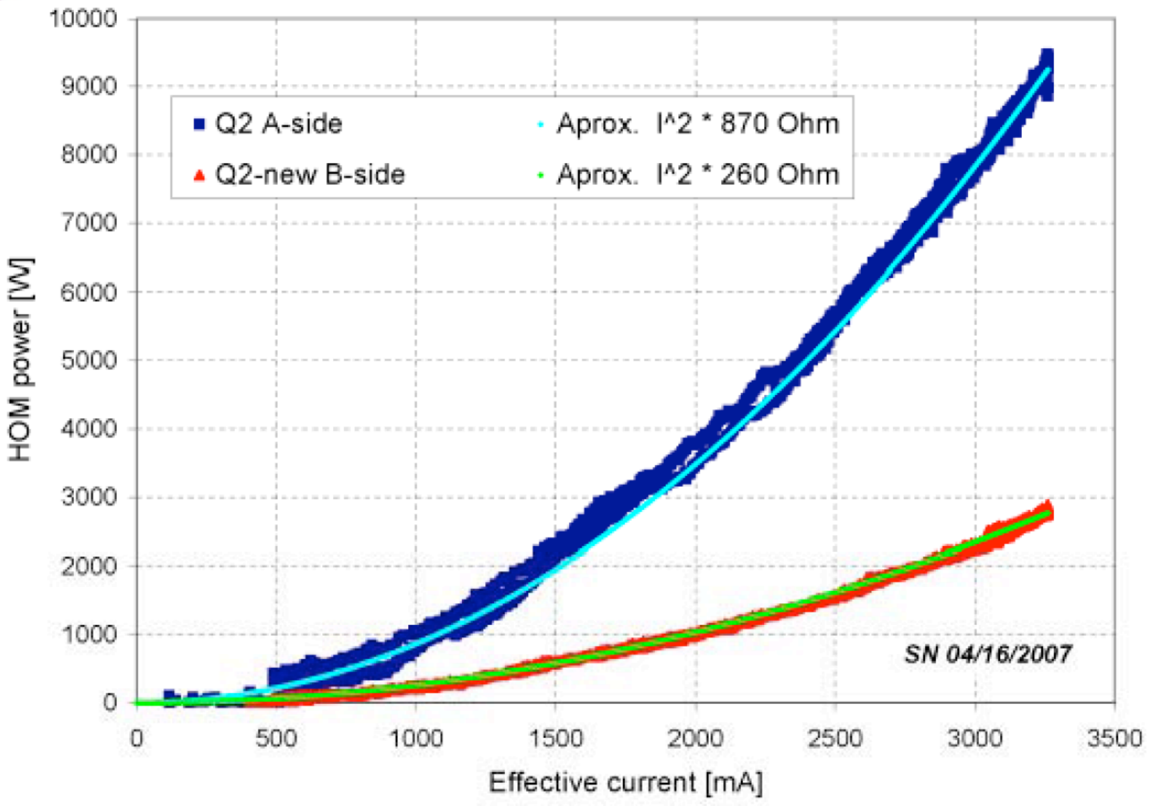
Novokhatski, Weathersby, Kurita

- Significant heating in the IR caused us to look for ways to absorb the HOM power.
  - Using a lossy ceramics allows for efficient cooling
  - Rf shield protects absorber from direct (TM) beam modes.
  - New “Q2” bellows showed the effectiveness of the method









APS-U vacuum system

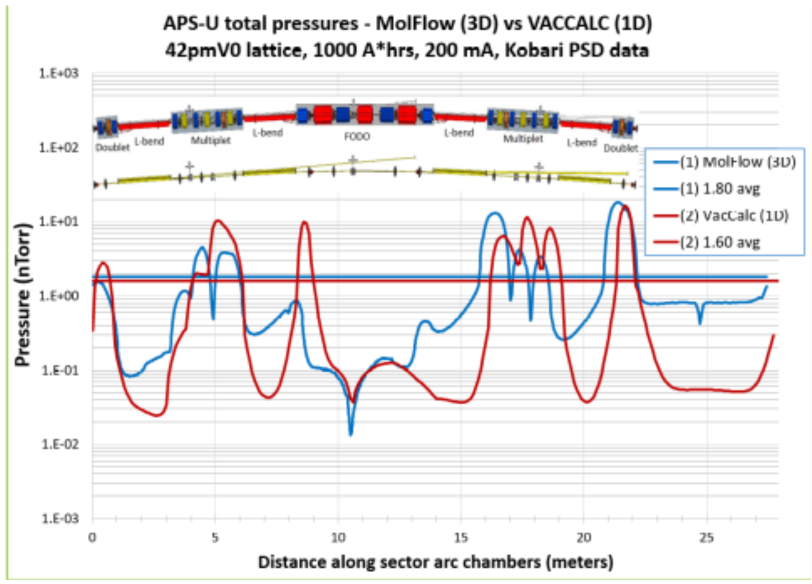
- The APS-U vacuum system differs significantly form the PEP-II vacuum system:
  - 200 mA *vs* 2 to 3 A (but bunch charge 15.6 nC (4.1 mA) in 48 bunch mode)
  - much smaller apertures (22 mm ø *vs* ≈ 90 by 50 mm ø)
  - lower linear power density (0.8 MV/turn vs 3.6 MV/turn energy loss in PEP-II HER)
  - but rf shields much closer to beam, much stronger coupling.

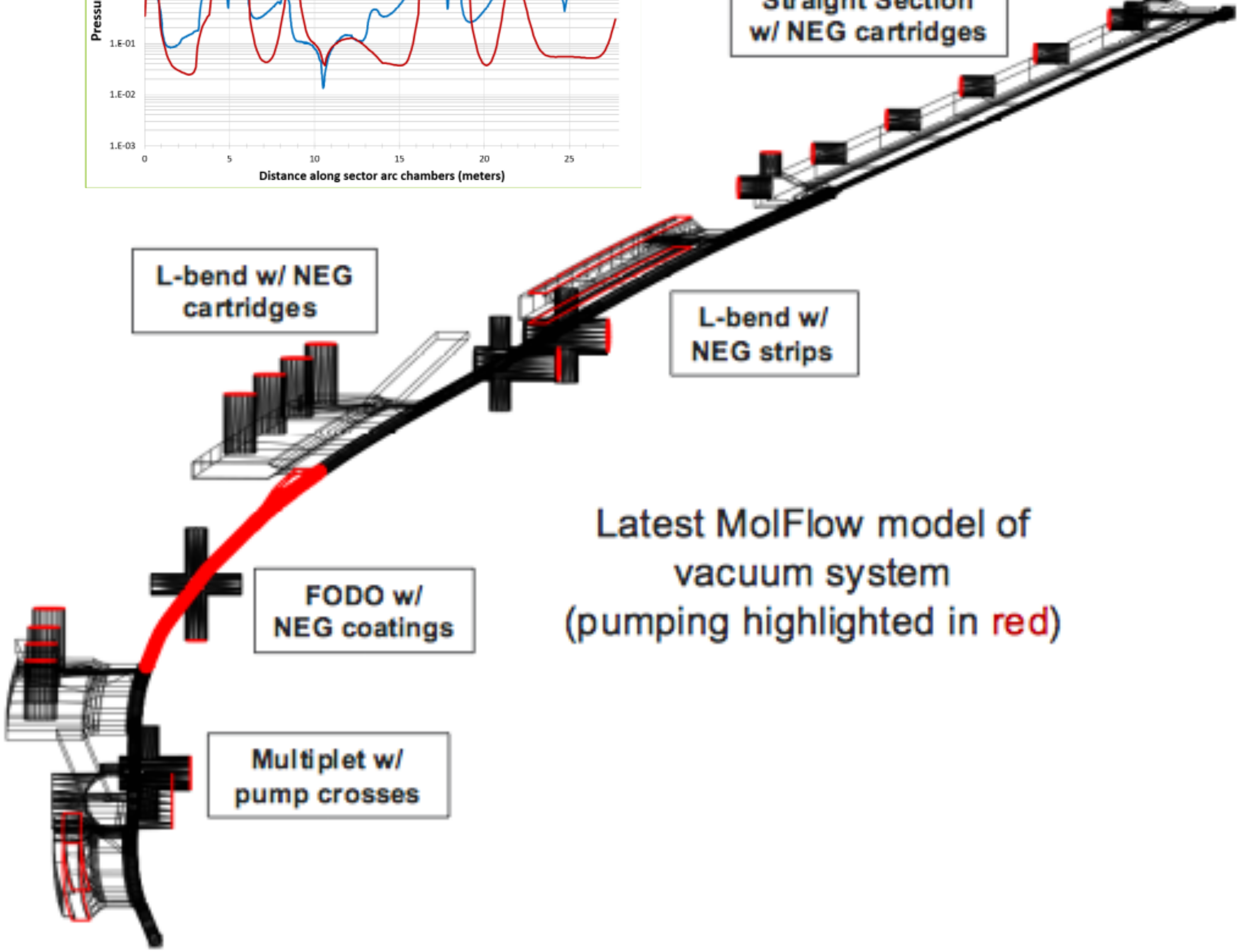
- Technology has progressed significantly in the essentially 30 years
  - NEG coatings are now fairly common esp, in light sources, important for small apertures
  - more widespread use of advanced materials like CuCrZr
  - much stronger modelling tools available nowadays.
    - AP tools like elegant allow to model impedance effect to a surprising degree of detail.
    - ANSYS in widespread use
    - CST routinely used for analysis of vacuum components
    - Synrad/MolFlow in common use for pressure analysis

J. Carter

Vacuum System Analysis

- Vacuum Pressure Analysis
  - Multiplet analysis tools evaluate design, predict performance of conditioning system
  - Process, assumptions, and results documented in report
  - Distributed pumping by NEG strips or NEG coatings where possible
  - 1D w/ VacCalc
    - Takes time to account for all inputs in a spreadsheet but then easy to modify/compare
    - Can't incorporate photon scattering
  - 3D w/ MolFlow
    - 3D models can be modified on CAD side
    - Takes time to build models, account for all surface facets, run Monte-Carlo results until smooth
    - No assumptions for conductance



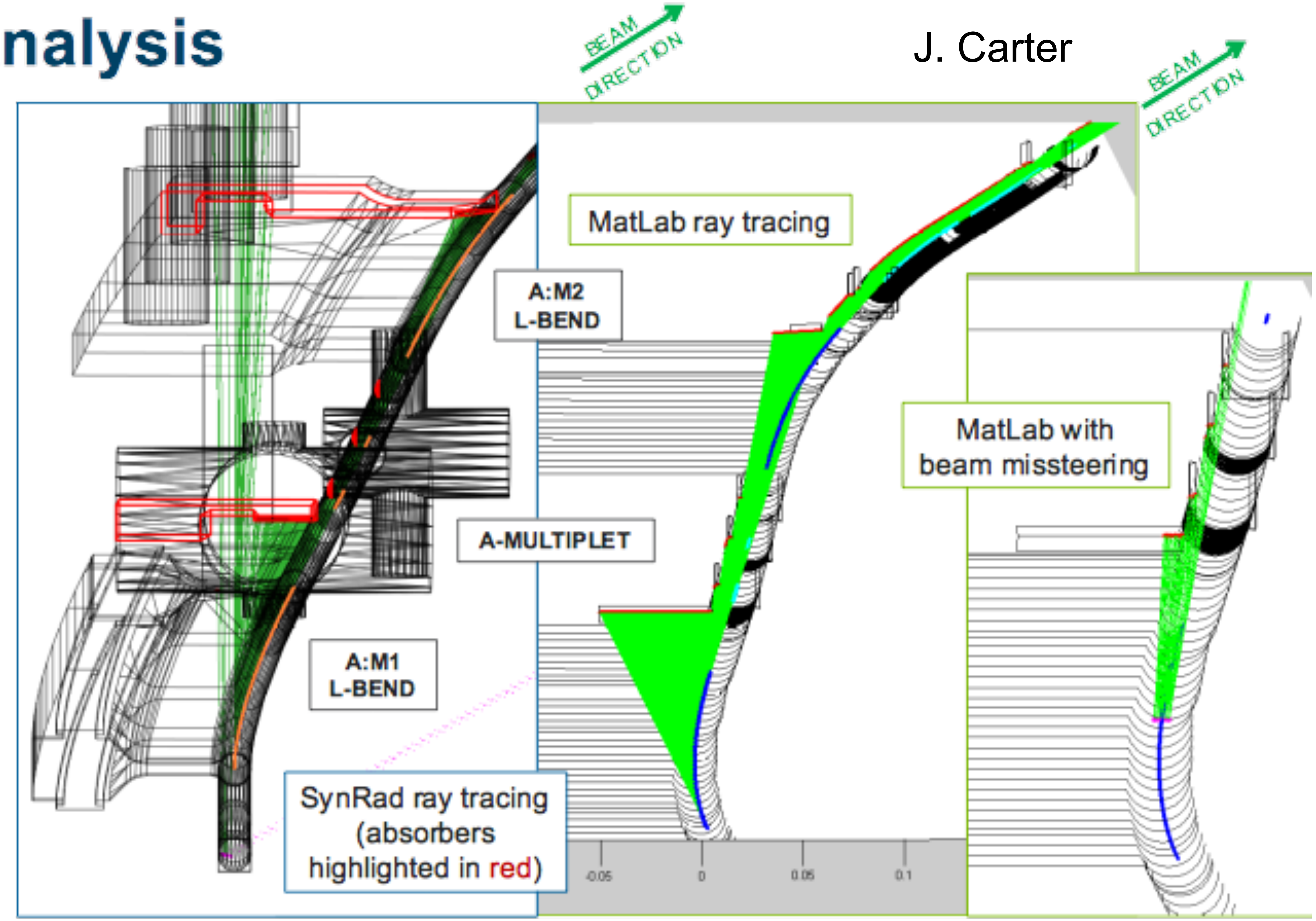


Latest MolFlow model of vacuum system (pumping highlighted in red)

Vacuum System Analysis

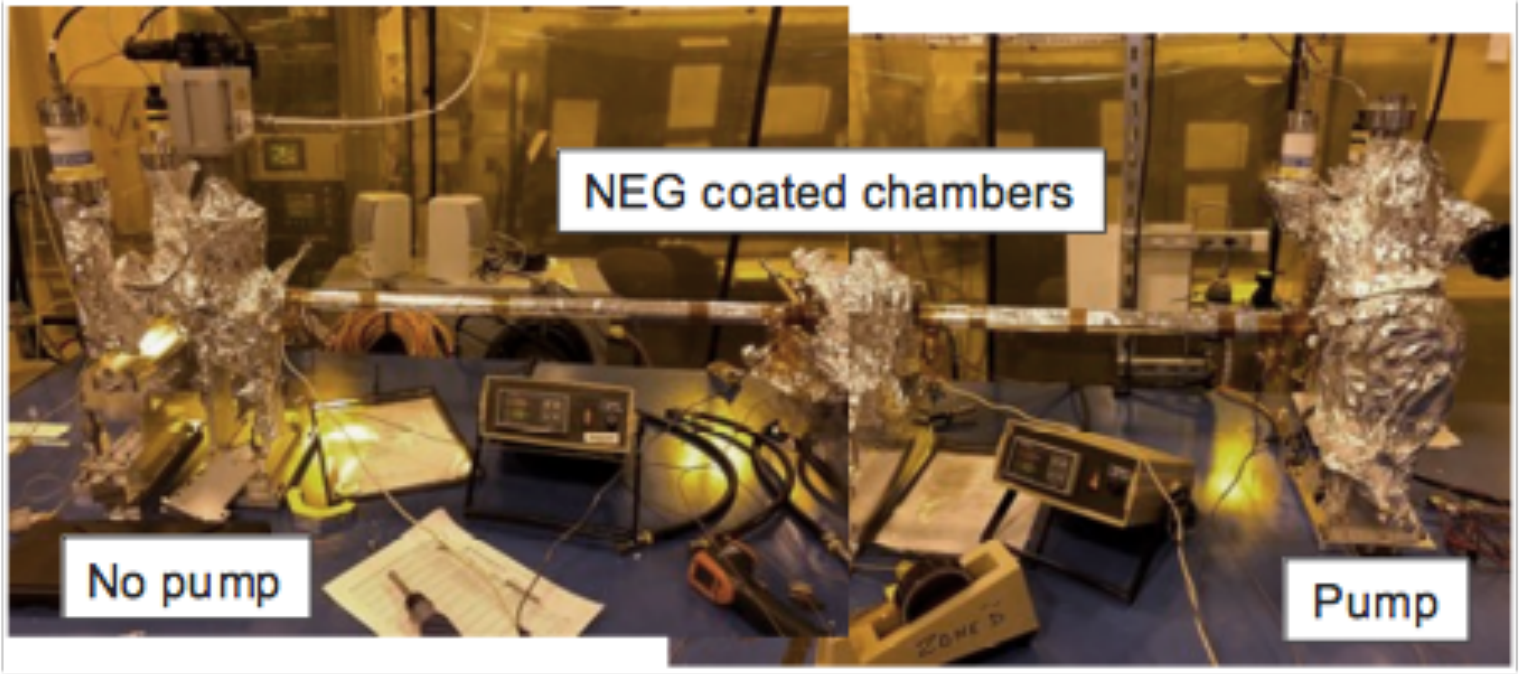
J. Carter

- 3D Ray Tracing
  - Ray tracing compared with 3 separate tools:
    - 2D layout: takes time to lay out and break down
    - SynRad: quickest to modify, compares to 2D
    - 3D matlab: explore missteering, verify 'perfect steering' case to 2D and SynRad
  - Better understanding of ray tracing and missteering helps ensure robust shielding within narrow apertures

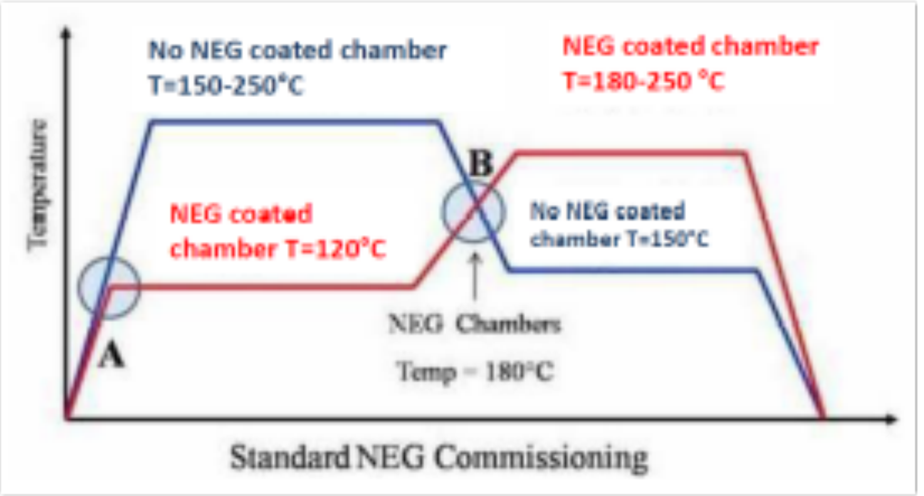


Highlights of R&D

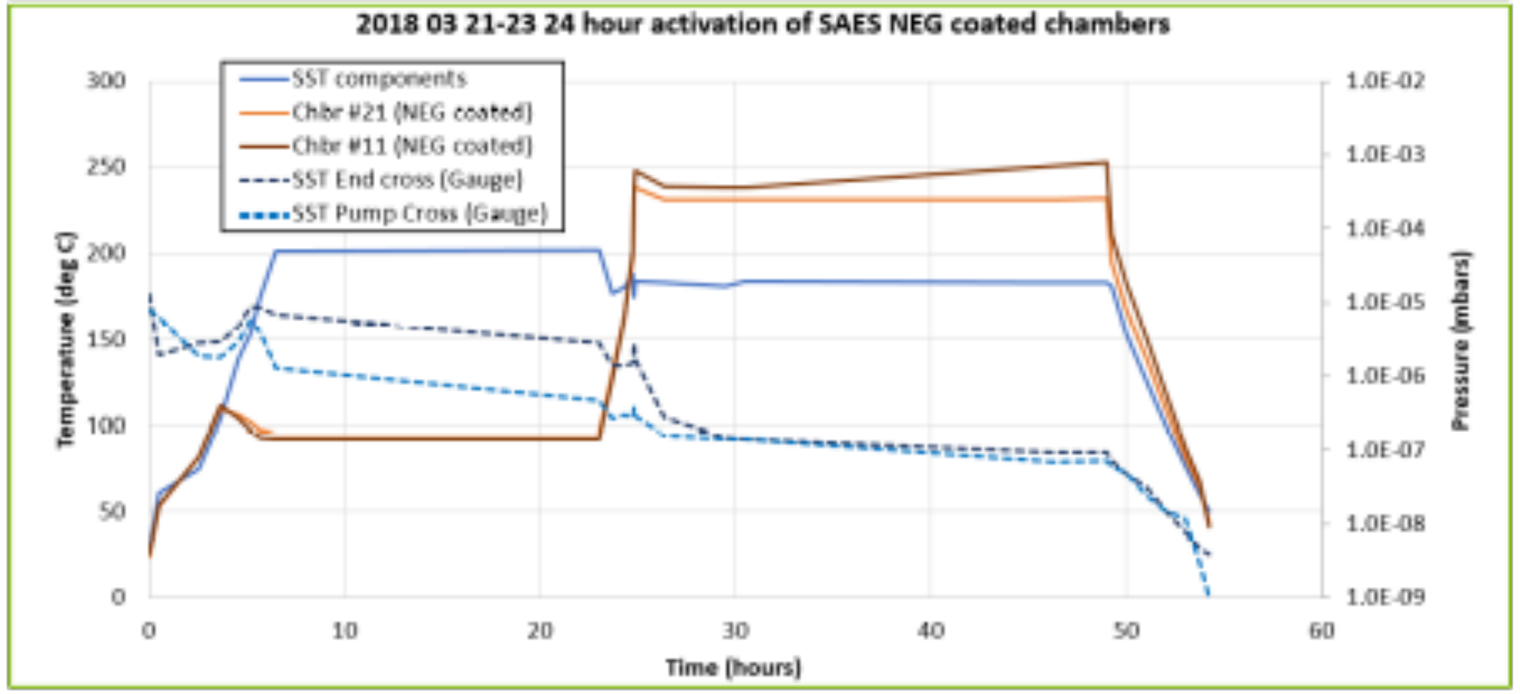
- NEG coated chamber activation
  - Copper chambers activated after 1+ year storage
  - Activation within mixed system of coated and non-coated components demonstrated with careful temperature cycling
  - Propose removing FODO gate valves (2 of 4 total) for large savings ($2.6M in budget) which some could be put toward additional NEG coatings



NEG activation test stand



SAES Getters proposed NEG activation cycle



NEG activation, temperatures and pressures

Gate valve locations

Beam Direction

Conclusion

- B-Factories posed significant challenges to the vacuum system
  - Addressed by a number of mitigations like beam-line HOM absorbers, BPM replacements & others
- Low-emittance light sources do not reach the same raw beam currents but (in case of APS-U) they have challenges in comparatively high bunch charges.
- NEG coating development is now comparatively widespread and enables the use of very small apertures.
- The availability of powerful analysis tools and large amounts of computing cycles do allow to design to tighter margins than we used 25 years ago.
  - While the technology is established, the devil is in the details that require a lot of attention.

References

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