Jefferson Lab Strategic Planning

Accelerator Division

Andrew Hutton
Associate Director

Accelerator Mission

What is or should be the mission statement of your division?

- The Accelerator Mission is to advance the capability of Jefferson Lab to carry out world-class nuclear science and, more broadly, to develop Jefferson Lab's expertise in technologies associated with high-power superconducting linacs

- The goals to achieve the mission deliver results in four strategic areas:
  1. Operate and upgrade the JLab accelerator facilities
  2. Prepare the future evolution of nuclear physics experimentation at Jefferson Lab
  3. Expand Jefferson Lab's core accelerator competencies to support DOE Office of Science projects and other partnerships
  4. Attract and educate the next generation of accelerator scientists and engineers

Scope of Current Activities 1

What is it that your division does, what is your current scope of work?

- Operate and upgrade the JLab accelerator facilities
  - Maintain energy capability
    - C-50 program
  - Improve beam quality for Users
    - Parity quality
    - Maximum current
  - Support the 12 GeV Upgrade Project
    - Accelerator physics design
    - Construct ten C-100 cryomodules
    - Extraction system design
    - Prepare to meet the 12 GeV project commissioning milestones
  - Prepare to commission 12 GeV nuclear physics program

Scope of Current Activities 2

What is it that your division does, what is your current scope of work?

- Prepare the future evolution of nuclear physics experimentation at Jefferson Lab
  - Design a Medium-energy Electron Ion Collider (MEIC) which could be built at Jefferson Lab
  - Collaborate with BNL and MIT on generic electron-ion collider R&D
  - Develop the capability to produce positron beams (PEPPo)

Scope of Current Activities 3

What is it that your division does, what is your current scope of work?

- Expand Jefferson Lab's core accelerator competencies to support DOE Office of Science projects and other partnerships
  1. Reduce the electric power requirements for superconducting linacs
  2a. Increase the maximum gradient, with equal or lower cryogenic requirements
  2b. Develop reliable long-lifetime photo-guns that provide high-current polarized and unpolarized electron beams
  2c. Develop advanced recirculated and energy recovery linac designs and technologies
  3. Collaborate on projects using SRF technology to grow our capabilities
  4. Develop new cavity types for different uses
  5. Exploit TEDF to maximize beneficial impact for SRF, Industry and the DOE complex

Scope of Current Activities 4

What is it that your division does, what is your current scope of work?

- Attract and educate the next generation of accelerator scientists and engineers
  - Provide opportunities for high school and undergraduate science students to be exposed to accelerator science
  - Maintain the number of doctoral students in accelerator science
  - Strengthen collaboration with the Center for Accelerator Science at ODU and the Idaho Accelerator Center at ISU
  - Provide instructors at the United States Particle Accelerator School
  - Attract female and minority students to accelerator science
    - Successful for females
    - Actively seeking collaborations with minority-serving institutions

Unique Capabilities

What facilities/capabilities/expertise does your group offer that is unique, world class?

- Only high-power CW electron accelerators in the world
  - CEBAF
  - FEL
- Injector test stand
  - Will be expanded during the Test Lab refurbishment
- High-polarization, high-current beams
- New SRF facility (TEDF), which incorporates and improves the capabilities of the existing Test Lab
  - Highly experienced SRF workforce
    - Scientists, engineers and technicians
  - Track record in delivering large SRF projects
    - SNS superconducting proton cavities
    - C-100 cryomodules for the 12 GeV Project
- World-leading cryogenics group

Synergy

Discuss how you think your division contributes to the missions of other parts of the lab. Can you do more?

- Develop “on-demand” capabilities to meet CEBAF user needs
  - Beamline design and commissioning for new experiments
  - Improvements in parity quality of beams
    - 1 kHz polarization reversal
- Operations and SRF support to FEL
  - Could be augmented
- SRF training of young engineers
  - Hiring production engineers rather than design engineers
  - We should improve mentoring of engineers in SRF technology
- Bringing Cryogenics Group into other projects
  - Cryogenics and SRF could (and should) work closer together
    - Integrated cryogenic/SRF designs for new projects

Vision for the Future

What do you see your division contributing to/doing in the future? What could you be doing?

1. Operate and upgrade the JLab accelerator facilities
   - Continue with 12 GeV and succeeding on-site facilities
2. Prepare the future evolution of nuclear physics experimentation at Jefferson Lab
   - Continue MEIC design
   - Prepare alternatives
3. Expand Jefferson Lab's core accelerator competencies to support DOE Office of Science projects and other partnerships
   - Be the provider of choice for SRF accelerators world-wide
   - Associate other core competencies with SRF to expand our capabilities
4. Attract and educate the next generation of accelerator scientists and engineers
   - Continue at about the same level

Proposals

1. Operate and upgrade the JLab accelerator facilities
   - Positron Brainstorming – Arne Freyberger
2. Prepare the future evolution of nuclear physics experimentation at Jefferson Lab
   - JLab Upgrades – Geoff Krafft
3. Expand Jefferson Lab's core accelerator competencies to support DOE Office of Science projects and other partnerships
   - AD Town Meeting – Bob Rimmer
   - CASA Geoff Krafft
   - Source Group 5-year plan – Matt Poelker
   - Multi-droplet demo – Alex Bogacz
   - Neutron Program – Andrew Hutton
4. Attract and educate the next generation of accelerator scientists and engineers
   - Strategic Planning Education – Hari Areti

Positron Brainstorming

Arne Freyberger
Director, Accelerator Operations

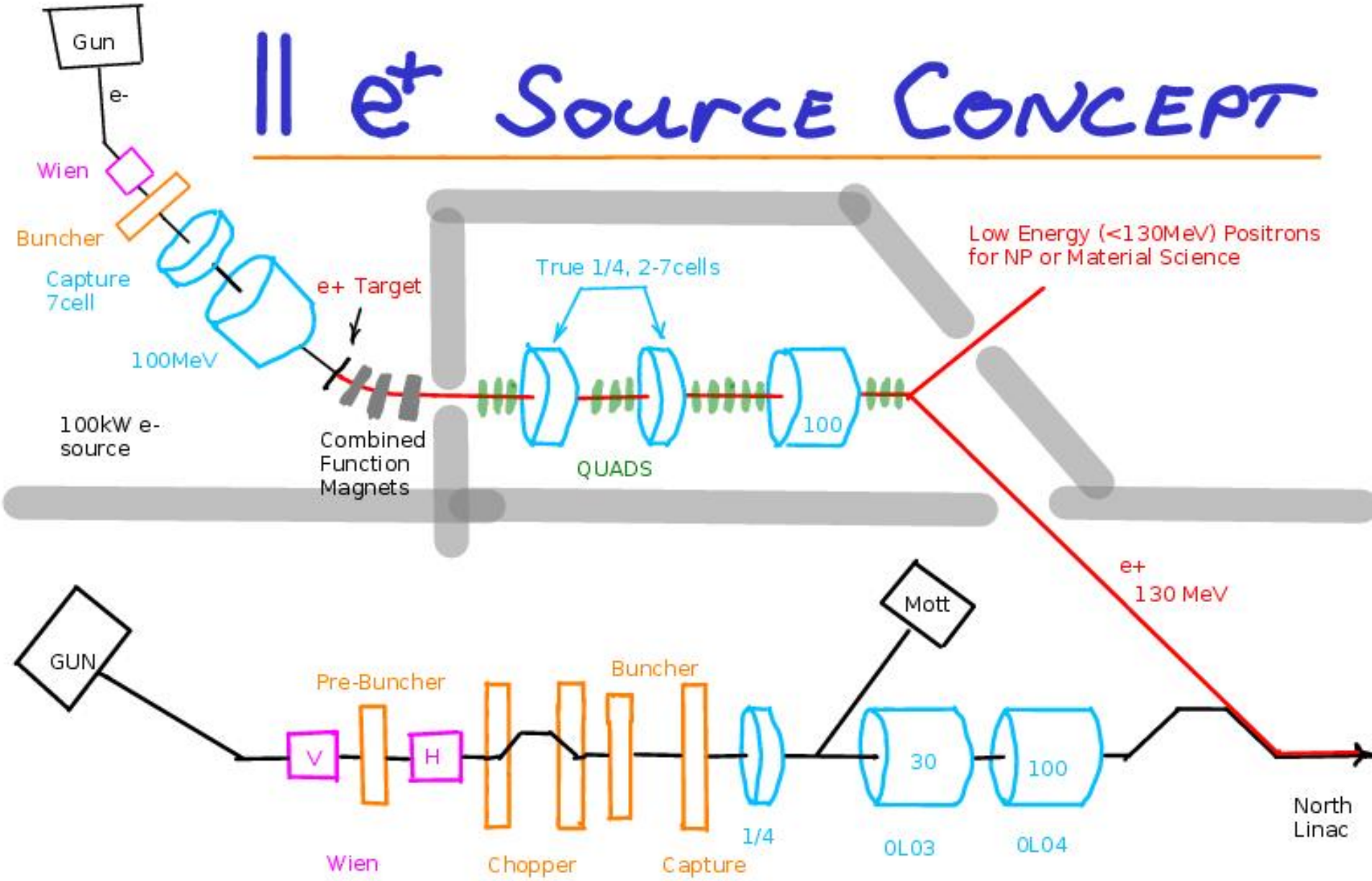
Positron Facility at JLAB

- Parallel to existing Injector:
- Simultaneous Low energy Positron beam for MS and CEBAF electron operations for NP
- Positron beam quality sufficient for insertion into the North Linac for acceleration up 12GeV for NP positron program
- Duplicate Gun -> 100MeV, 1mA (100kW)
- CW polarized positron source with currents in the microAmpere range.

12 GeV NP Physics:

- Deep Virtual Compton Scattering
- Two Photon Exchange
- Heavy Photon Searches

e+ Source Concept



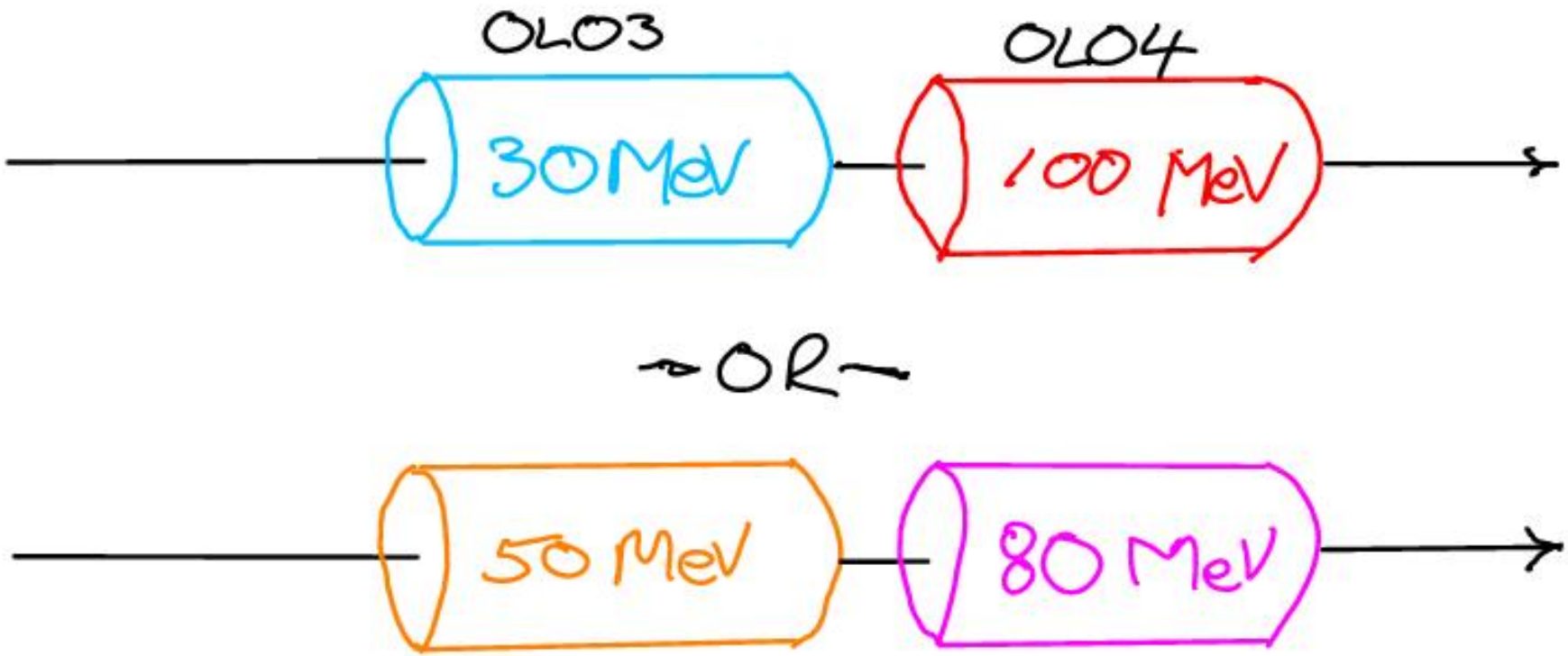
Positron production and capture concept from S. Golge Thesis

Positron Timeline

- Positron parameters and plan defined by May 2012
  - Material Science parameters
  - Nuclear Physics parameters
  - Rough plan from parameters to realization
- Dec. 2013 Conceptual Design Complete
- Rough cost estimate $(30 +/- 30)M

THE INJECTOR UPGRADE

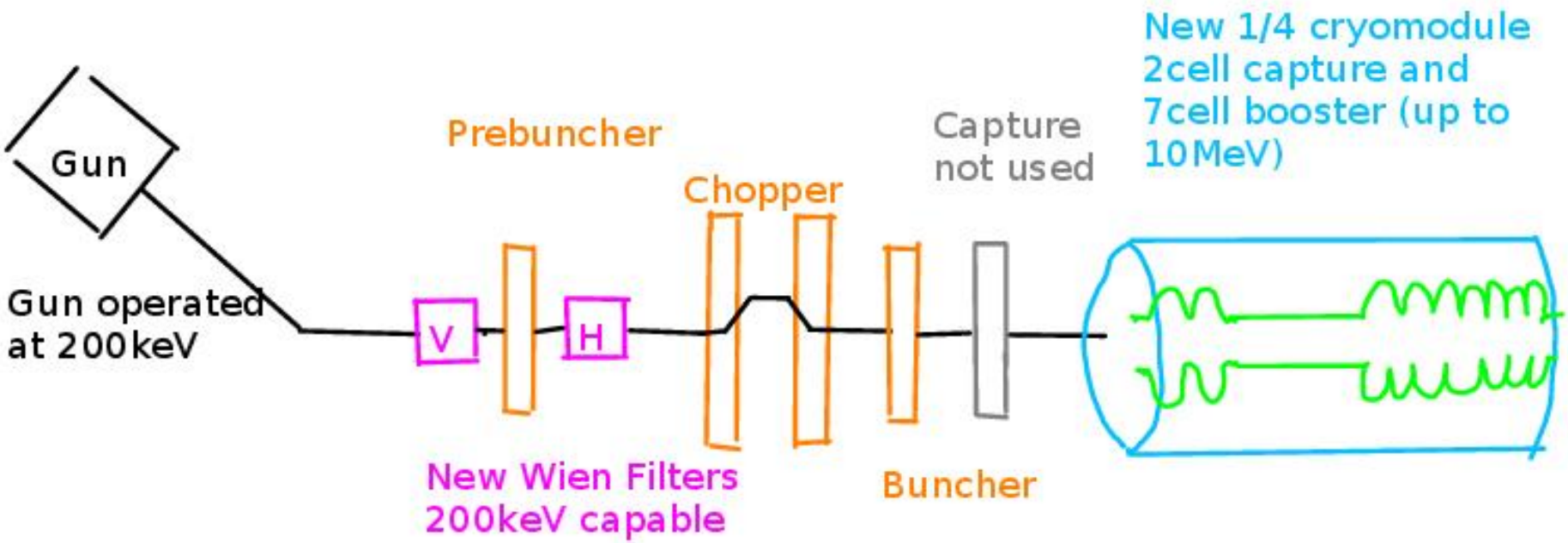
PHASE I: UPGRADE ENERGY FOR 12 GeV CEBAF (~130MeV)



Needed by the time 12GeV commissioning expects to recirculate beam

INJ UPGRADE: II

PHASE II: PARITY QUALITY BEAMS FOR 12GeV (2016 →)

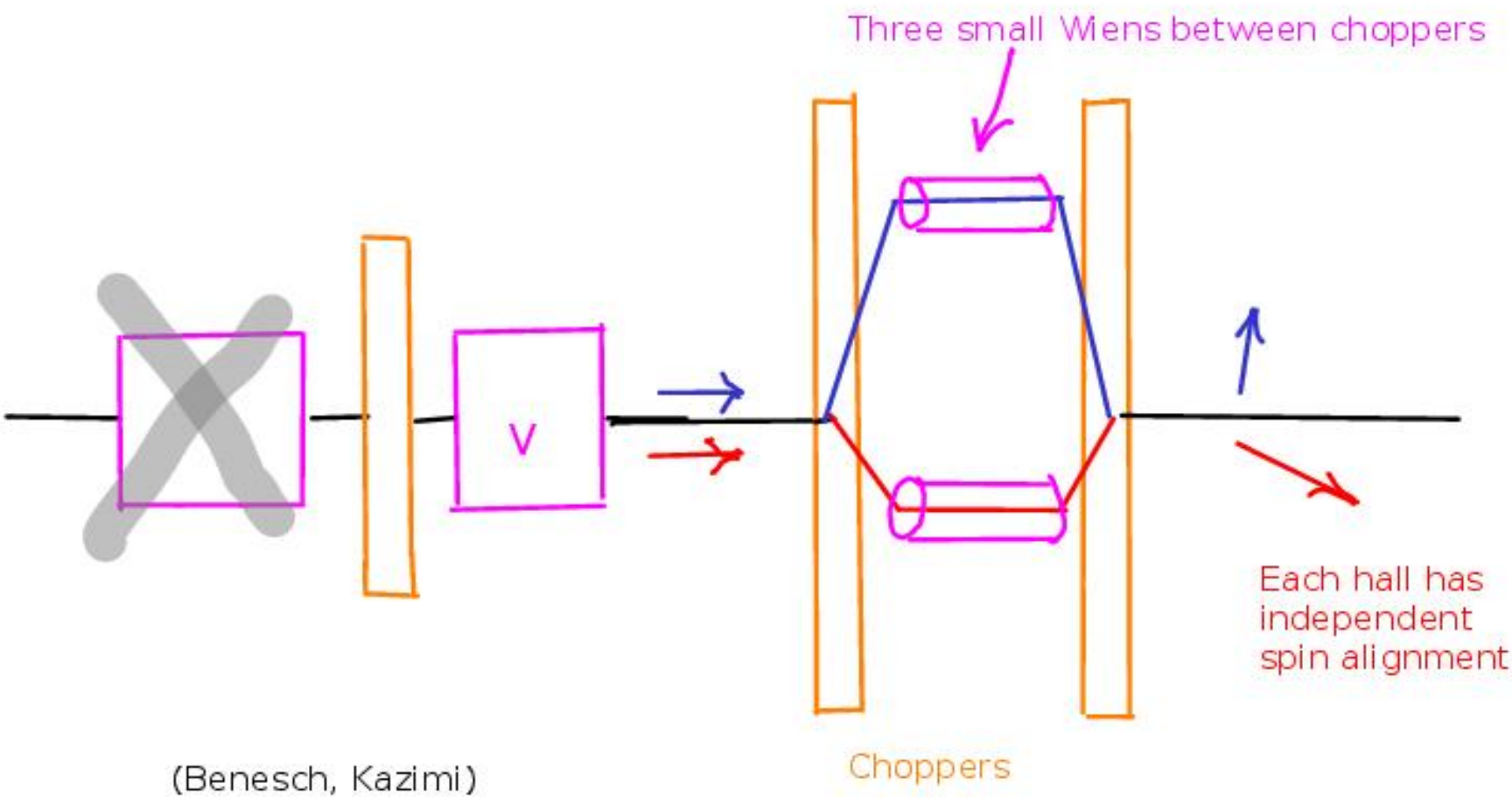


Prebuncher, Chopper, Buncher upgraded for 200keV operations

PSS and magnets also upgrade for 200keV operations

INJ UPGRADE III

Phase III: Independent spin alignment capability



(Benesch, Kazimi)

Injector Upgrade

- Strongly desirable to test new components, 200keV Wiens, ¼ cryomodule, PSS before installing on CEBAF
- Timeline
  - Before 12GeV commissioning, 0L03/0L04 upgraded to deliver 130MeV
  - 2015'ish Parity Quality Upgrade components fully quality in external facility
  - 2016 Parity Quality Upgrade installed on CEBAF
  - Three Wien concept still too exploratory to commit to a date, but initial modeling looks promising.

Low Energy Electrons for NP

There have been several new ideas for NP experiments that require electrons in the 10-200MeV range:

- Heavy Photon search with 10mA internal gas target
- Bubble chamber experiment at 10MeV
- Parity measurements with 100-200MeV electron beams
- Positron Source Development (PEPPo)

Two Birds and One Stone

(NP experiments with <200MeV electrons) + (need for a 10+MeV capable injector test facility) = FEL

- Incremental cost of operating the FEL would be small, power/cryogens are already paid for.
- It would diminish the need to upgrade the TEST Lab injector cave.
- FEL injector would need to be upgraded to a polarized source
- (May be) Incompatible with Light Source developments: Is it time to move on?

Nuclear Physics Beyond the 12 GeV Upgrade

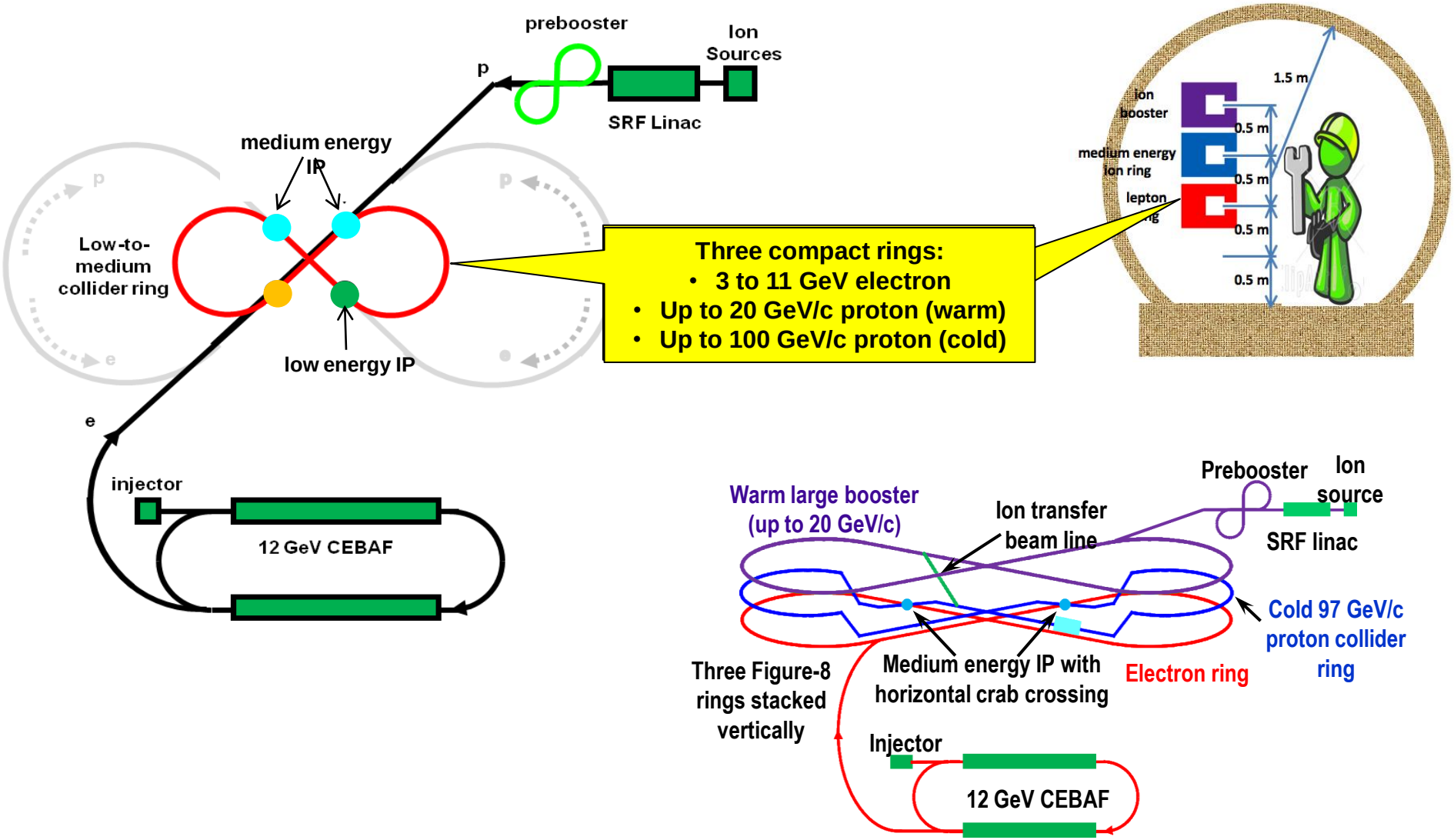
G. A. Krafft, D. Douglas, Y. Roblin, and Y. Zhang

Jefferson Lab User Workshop
Strategic Planning Exercise
December 19, 2011

OUTLINE

- MEIC
- Fixed Target Possibilities
- Nuclear Physics at the FEL
- Conclusion

MEIC Layout


prebooster
Ion Sources
p
SRF Linac
medium energy IP
Low-to-medium collider ring
low energy IP
e
injector
12 GeV CEBAF
Three compact rings:
• 3 to 11 GeV electron
• Up to 20 GeV/c proton (warm)
• Up to 100 GeV/c proton (cold)
1.5 m
ion booster
0.5 m
medium energy ion ring
0.5 m
lepton
0.5 m
0.5 m
Warm large booster (up to 20 GeV/c)
Ion transfer beam line
Prebooster
Ion source
SRF linac
Cold 97 GeV/c proton collider ring
Three Figure-8 rings stacked vertically
Medium energy IP with horizontal crab crossing
Electron ring
Injector
12 GeV CEBAF

MEIC Design Goals

- **Energy**
  - —Full coverage in *s* from a few hundreds to a few thousands
    Bridges the gap between 12 GeV CEBAF and HERA/LHeC
  - —Electron 3 to 11 GeV, proton 20 to 100 GeV, ion 12 to 40 GeV/u
  - —Design point: **60 GeV proton on 5 GeV electron**

- **Ion species**
  - —Polarized light ion: p, d, ^{3}He and possibly Li
  - —Un-polarized ions up to A = 200 or so (Au, Pb)

- **Detectors**
  - —Up to three interaction points, two for medium energy (20 to 100 GeV)
  - —One ***full-acceptance*** detector (primary), ***7 m*** between IP & 1st final focusing quad
  - —One ***high luminosity*** detector (secondary), ***4.5 m*** between IP and 1st final focusing quad

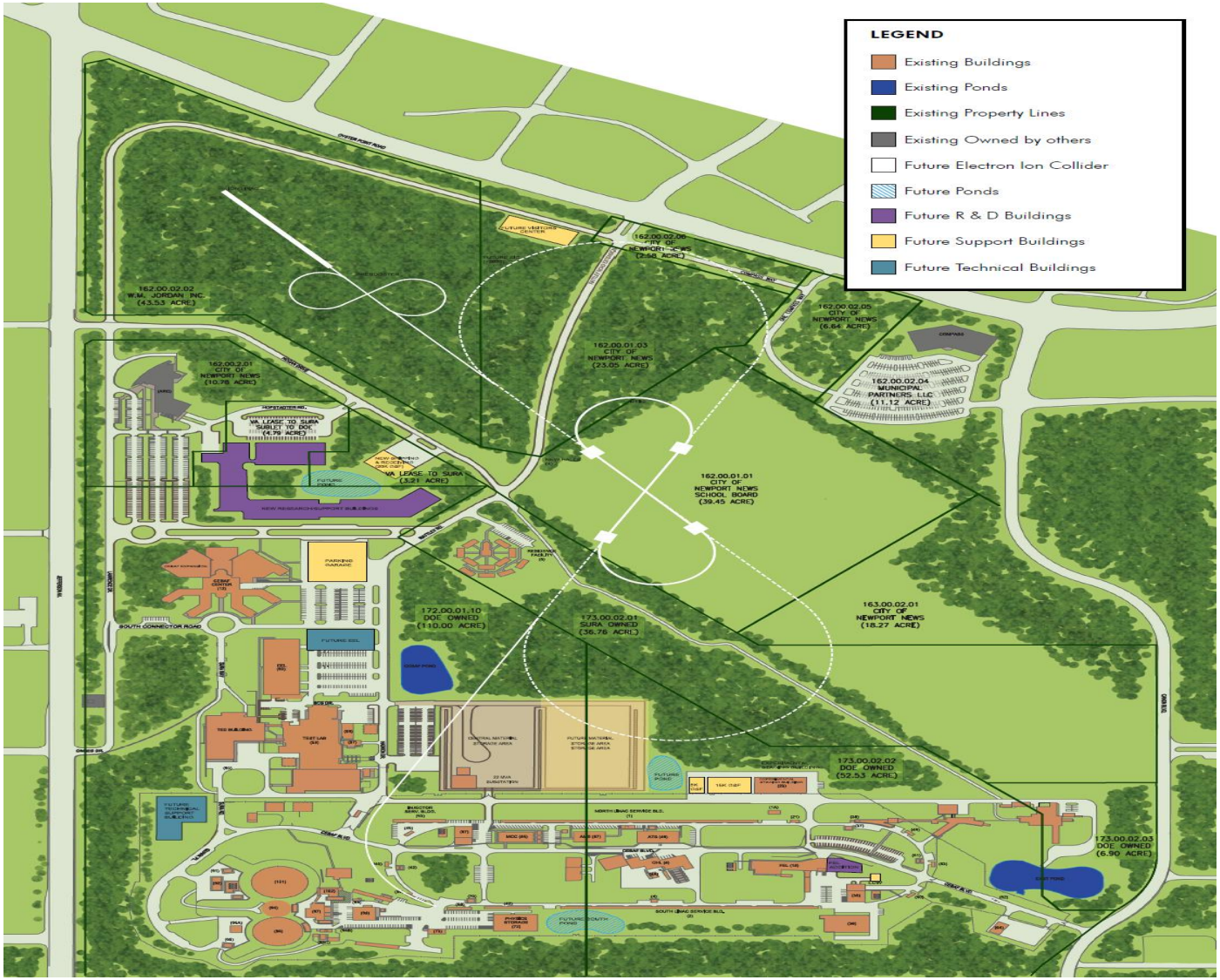
MEIC Design Goals

- **Luminosity**
  - —About 10^{34} cm^{-2} s^{-1} (e-nucleon) per interaction point
  - —Maximum luminosity should optimally be around s = 2000 GeV^2
- **Polarization**
  - —Longitudinal at the IP for both beams, transverse at IP for ions only
    - Spin-flip of both beams
    - All polarizations >70% desirable
- **Upgradeable to higher energies and luminosity**
  - —20 GeV electron, 250 GeV proton and 100 GeV/u ion
- **Positron beam highly *desirable***
  - —Positron-ion collisions with similar luminosity

Full Acceptance Detector Parameters

		Proton	Electron
Beam energy	GeV	60	5
Collision frequency	MHz	750	750
Particles per bunch	10^{10}	0.416	2.5
Beam Current	A	0.5	3
Polarization	%	> 70	~ 80
Energy spread	10^{-4}	~ 3	7.1
RMS bunch length	cm	10	7.5
Horizontal emittance, normalized	µm rad	0.35	54
Vertical emittance, normalized	µm rad	0.07	11
Horizontal β*	cm	10	10
Vertical β*	cm	2	2
Vertical beam-beam tune shift		0.014	0.03
Laslett tune shift		0.06	Very small
Distance from IP to 1st FF quad	m	7	3.5
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	5.6	

MEIC/ELIC Site Plan By Jlab Facilities



Transverse Emittance* and Energy Spread†

DBA option

Area	$\delta p/p$ [$\times 10^{-3}$]	ε_x [nm]	ε_y [nm]
Chicane	0.5	4.00	4.00
Arc 1	0.05	0.41	0.41
Arc 2	0.03	0.26	0.23
Arc 3	0.035	0.22	0.21
Arc 4	0.044	0.21	0.24
Arc 5	0.060	0.33	0.25
Arc 6	0.090	0.58	0.31
Arc 7	0.104	0.79	0.44
Arc 8	0.133	1.21	0.57
Arc 9	0.167	2.09	0.64
Arc 10	0.194	2.97	0.95
Hall D	0.18	2.70	1.03

Damping

Sync. Rad.

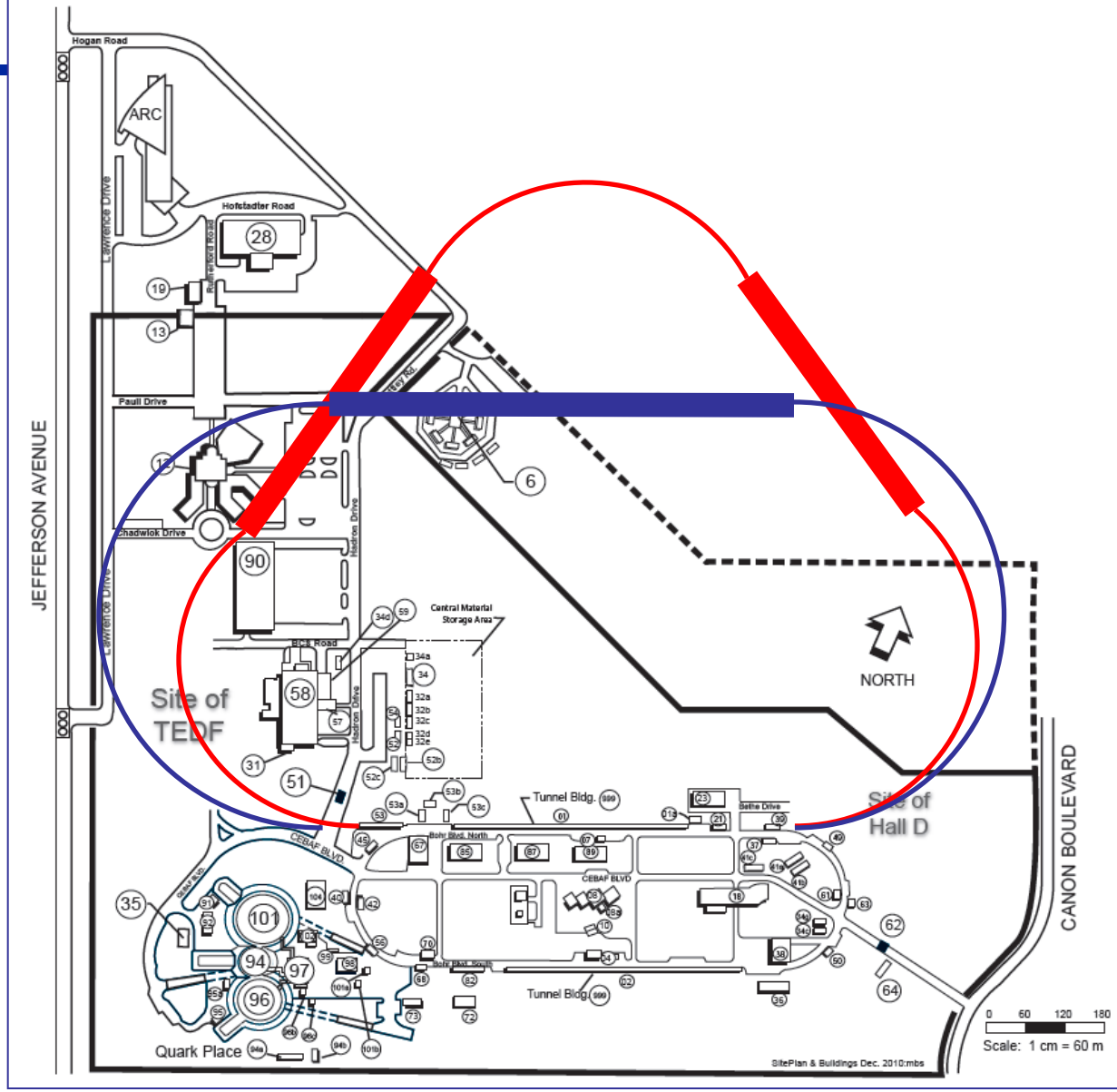
*** Emittances are geometric**
† Quantities are rms

Cases Explored

- 24 GeV Recirculated Linac in present tunnel
  - —Average current de-scoped another factor of 2 (40 μA/hall) due to dump (get it back with new dump?)
  - —Magnet layout and types roughly the same as now, but now completely new!
  - —Need 20 "C150s" and 10 C100s, and 20 C50s, yielding just 2.5 GeV per linac pass
- 50 GeV Site Filler
  - —Same dumps 20 μA/hall maximum, for 100 μA/hall must energy recover or build 5 MW beam dumps
  - —Arcs are Th. Min. Emit. (TME), Normal Conducting
  - —Optimize shape, pass #, and cryomodule energy gain (C200s?) for lowest cost, as done for CEBAF

SITE PLAN

Jefferson Lab



Polarization Loss

- **Spin precession per 180 degree bend**

$$\Delta\Phi = \frac{g-2}{2}\frac{E_{bend}}{mc^2}\pi$$

- **For 9 arcs**

$$\Delta\Phi \approx 45\frac{g-2}{2}\frac{E_{linac}}{mc^2}\pi$$

- **Polarization angle spread yields dilution**

$$\sigma_\Phi \approx o\left(\Delta\Phi\frac{\sigma_E}{E}\right)$$

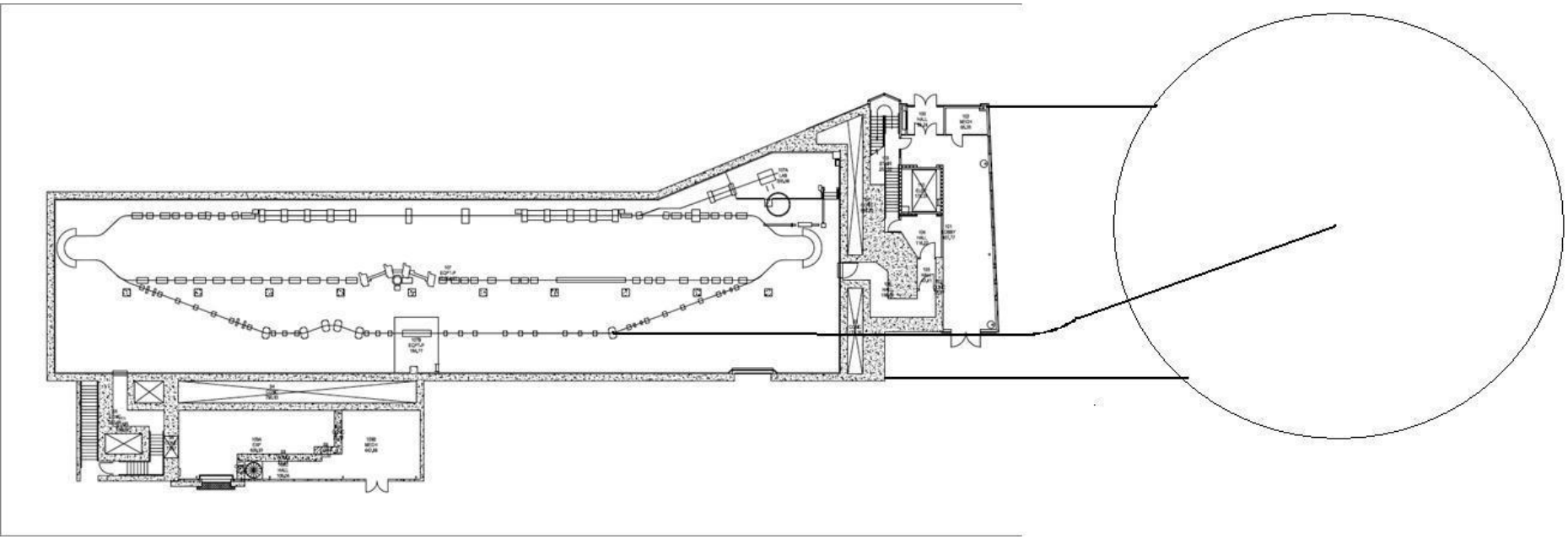
$$P > P_0\cos\left(\Delta\Phi\frac{\sigma_E}{E}\right) \quad \%\,\text{correction to}\; P^2\; o\left(\Delta\Phi\frac{\sigma_E}{E}\right)^2$$

- **Fixed By Vertical Polarization in Accelerator?**

Expected Beam Parameters

		6 GeV	12 GeV	24 GeV	50 GeV
Energy @ A, B, C	GeV	6	11	25	50
Energy @ D	GeV	NA	12	27	NA
Mode		CW	CW	CW	CW
Total Current	μA	200	85	40 80 with 2 MW Dump	20 100 with ERL?
Beam Power/Dump	MW	1	1	1	1
Emittance (unnormalized,*rms*)	nm-rad	<1	2.7	86	40
Relative Energy Spread (*rms*)	10^{-3}	0.025	0.2	1.1	2.2
Dilution Parameter ($\delta\varphi/\pi$)	%	0.5	2.4	26	110
Spot Size (*rms*)	mm	0.2	0.2	0.7	0.6

JLAB Hall “E”



Comments on Hall E

- An appropriately retrofitted injector could provide polarized beam
- Machine design energy is 210 MeV, but energy reach with C100s would be 300 MeV (Magnets have considerable reserve, running at only 7 kG at 210)
- Dipoles exist (LIPSS at the moment) for the short arc to be used for spectrometer/energy stabilization. No modification to the UV transport would be required
- Likely need a couple dozen quads, power supplies, diagnostics, etc. Maybe 5M$ total plus building and detector

Conclusions

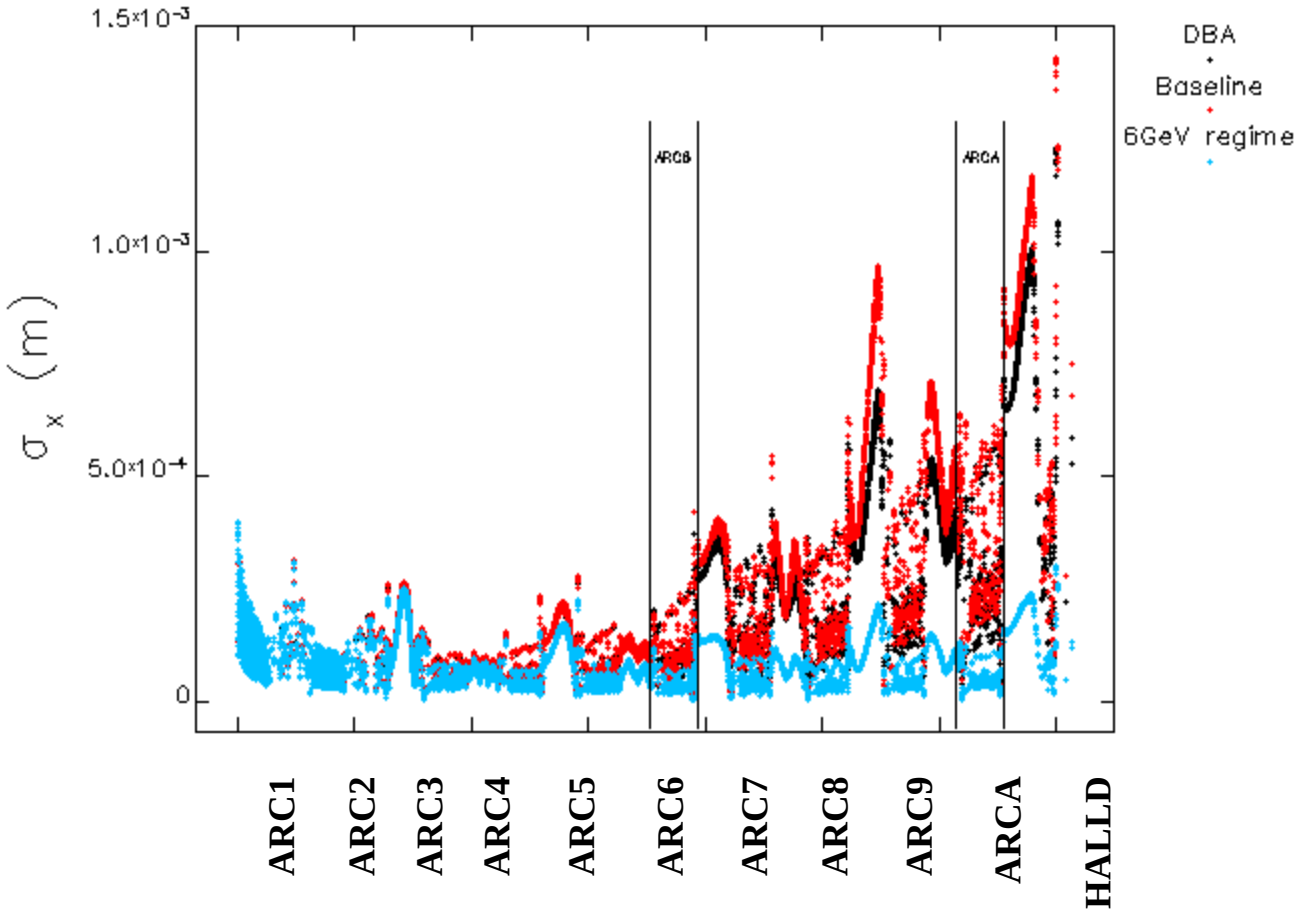
- **Efforts on MEIC collider continue and rapid progress is being made**
- **A 24 GeV CEBAF-like machine in the present tunnel should be possible. Would require further upgrades to the beam acceleration system and a completely new (normal conducting) complement of magnets**
- **The CEBAF site could support a larger 50 GeV scale fixed target machine. Polarization and emittance dilution imply completely new layout is required. Transverse polarization may be needed in the accelerator. Would be better performing at 24 GeV**
- **The FEL may have promising low energy nuclear physics applications**

EIC Advisory Committee Report

- **"Jefferson Lab has made significant advances in the design of the hadron injector and storage ring"**
- **"Performance deliverables in terms of energies and luminosities have converged" (between Jefferson Lab and Brookhaven designs)**
- **Recommend look at space charge effects**
- **Recommend examine electron cloud effects**
- **Dynamic aperture of chromaticity correction schemes**
- **Generic Comments**
  - The ion sources required are beyond the state of the art
  - Beam cooling is required for both projects and is highly non-trivial. MEIC uses a more conventional system.

- **We will be putting more effort into beam cooling studies**

From 6 GeV to 12 GeV



Emittance Growth By Scaling

- **Beam emittance growth over a section of beam line due to synchrotron radiation (ODU Lectures)**

$$\Delta\varepsilon_u = \frac{55 C_\gamma \hbar \left(mc^2\right)^2}{64\pi\sqrt{3}} \gamma^5 \int ds \frac{H}{\rho^3}$$

- **For a FODO lattice**

$$\int ds \frac{H}{\rho^3} = \frac{\alpha}{\rho}\theta^3 \frac{l_b}{l_{b,0}} \left[\frac{<H>}{\rho\theta^3}\right]$$

where α is the bending angle of the beam line, equals to π for a half circle, $\vartheta = l_b/\rho$ is bending angle of a dipole, l_b/l_{b0} is the packing factor of the FODO cell, $[<H>/\rho\vartheta^3]$ only depends on phase advance of the FODO cell

- **In this case**

$$\Delta\varepsilon_u \sim \frac{\gamma^5 \vartheta^3}{\rho} \sim \frac{\gamma^5}{\rho^4} \sim \frac{E^5}{\rho^4}$$

- **Comparing the 12 GeV case and a potential 50 GeV accelerator: E increased by a factor of 45/11=4.09 and ρ increased by a factor of 3, then emittance growth scales by a factor of $4.09^5/3^4 \sim 14$**

Energy Spread by Scaling

- **Energy spread after passing a section of circular beam line with uniform 180 degree bend**

$$\frac{(\delta E)^2}{E^2} = \frac{55 r_e}{48\sqrt{3}\pi}\frac{\hbar c}{mc^2}\gamma^5 \int \frac{ds}{\rho^3} = \frac{55\pi r_e}{24\sqrt{3}\pi}\frac{\hbar c}{mc^2}\frac{\gamma^5}{\rho^2}$$

- **Thus,**

$$\frac{\delta E}{E} \sim \frac{E^{5/2}}{\rho}$$

- **Comparing 12 GeV and 50 GeV CEBAF, after last arc**

  E increased by a factor of 45/11=4.09,

  ρ increased by a factor of 3,

  then

  δE/E increased by a factor of $4.09^{5/2}/3=11.3$

AD Town Meeting

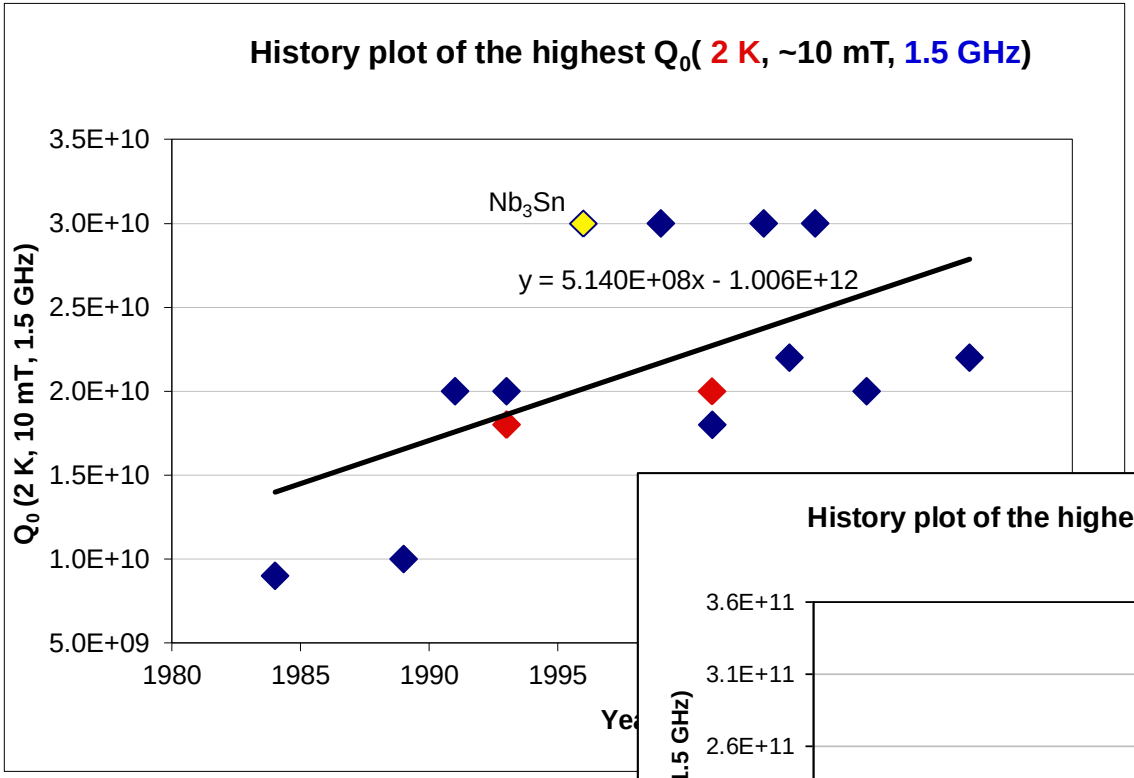
Robert Rimmer

Director, Institute for SRF Science & Technology

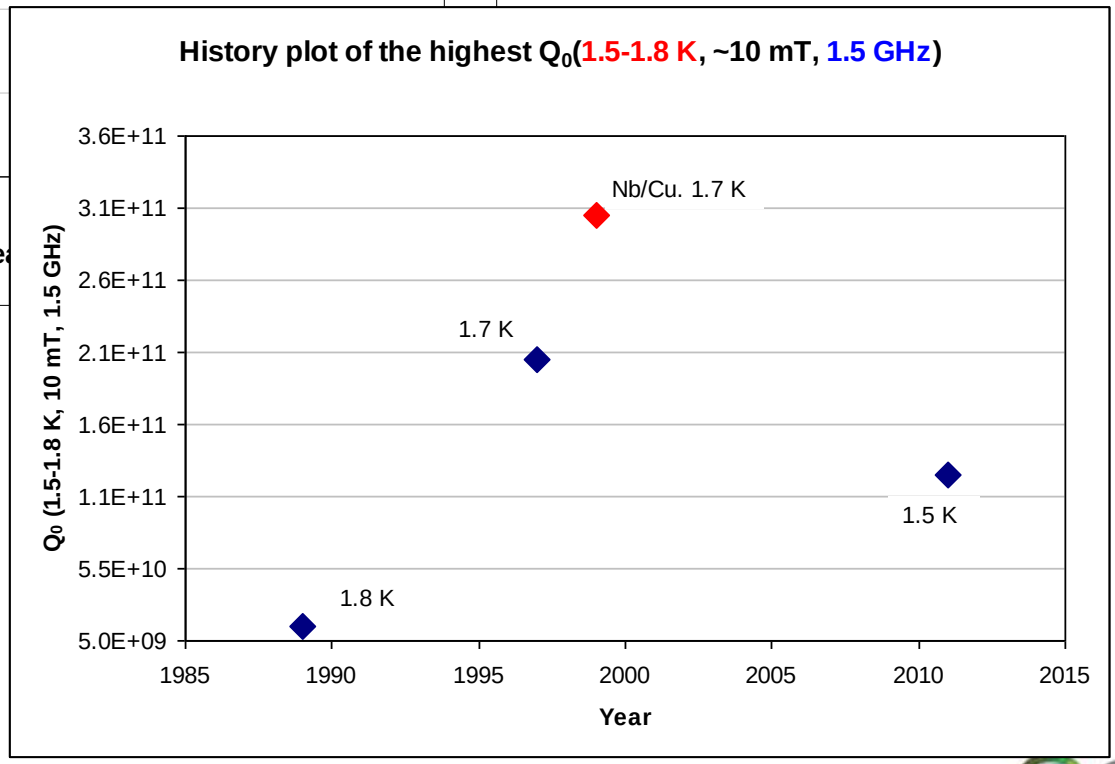
1. Reduce the cryogenic requirements

- **Why?**
  - Cryogenic systems represent a major fraction of capital and operating (energy) costs of SRF based facilities.
  - For large facilities the way forward is via increased Q_o at 2K or lower, more efficient SRF structures, more efficient cryogenic plant.
  - For small projects operation at 4K with low-frequency, high impedance structures may be viable, significantly reducing the capital costs.
- **Where would we like to be?**
  - 5 years: Qo = $2x10^{10}$ at 2K, 1.5 GHz, 20 MV/m with Nb
  - 10 yr: Qo = 10^{11} @ 2K, 1.5 GHz, 20 MV/m, 10^{10} @ 4K-> new materials
  - 20 years: HTS materials @ 77K with low residual resistance
- **How do we get there?**
  - Short term: Process improvements (EP, elimination of Q slope and field emission, furnace treatments), design changes, magnetic shielding
  - Long term: new structures, new materials e.g. Nb_3Sn, HTS materials
- ***Who benefits? Everyone!***

Low field Qo at 2K, 1.5 GHz



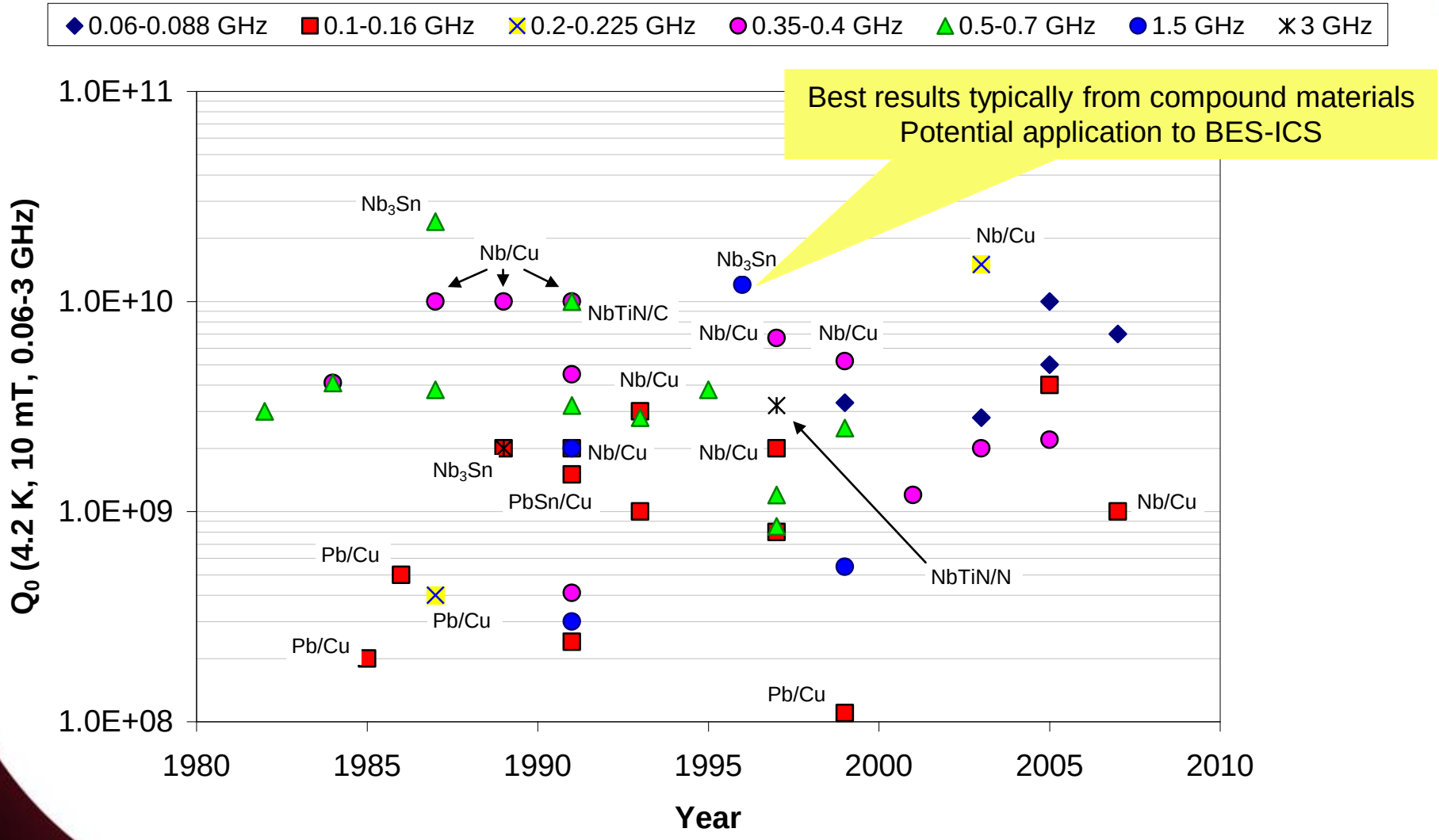
Charts by Gigi Ciovati



Low field Qo at 4K

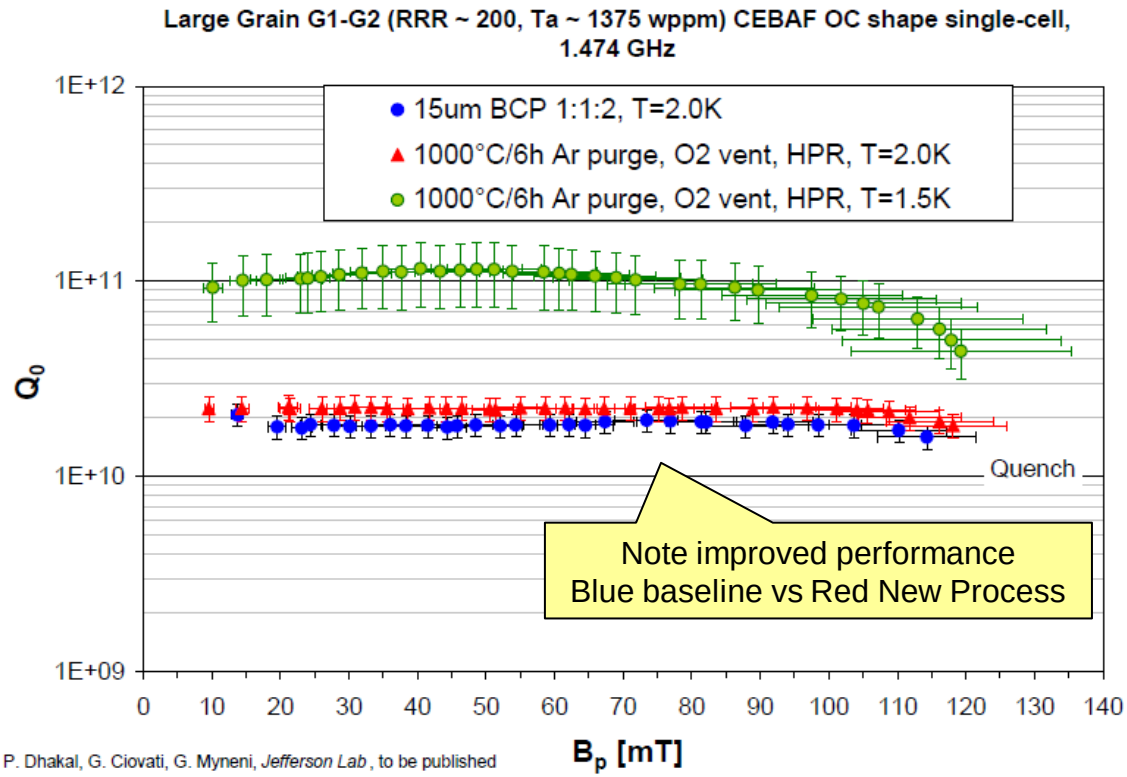
Chart by Gigi Ciovati

History plot of the highest Q_0(4.2 K, ~10 mT, 0.06-3 GHz)



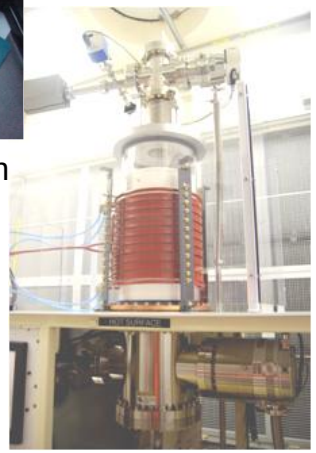
E.g.: Q_o improved by ingot material and furnace treatment

Work in progress



P. Dhakal, G. Ciovati, G. Myneni, *Jefferson Lab*, to be published

Large Grain

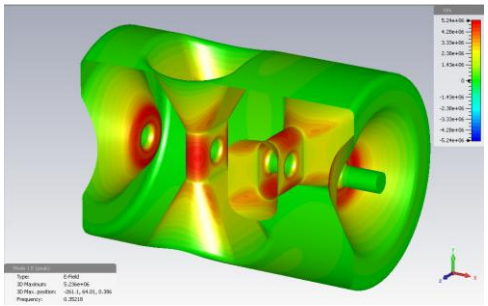


Induction coil used for heating the cavity

Cavity in Fixture prior to furnace treatment

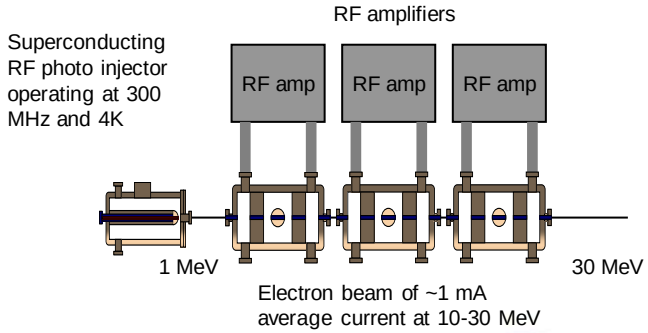
1b. Low frequency 4K solution (ICS)

- ***Why :*** Simplified cryogenics and reduced capital cost
  - potential for R&D in Universities & Industry
- ***Target Specification***
  - 5 year "proof of Principle" Dynamic 35W CW/cavity
  - 10 Year – goal is to get first machines in use
  - 20 year – Commercialization
- ***How :***
  - new Cryostat Design + low frequency Spoke Cavity
  - Evaluate new materials, plasma cleaning
- ***End users include :***
  - *Universities, Industry, National Labs*
  - *Photons, Neutrons, Ion Therapy, Isotope Production*
- ***Funding :*** ARRA, BES, WFO
- ***Partnerships*** – ODU, MIT, PKU, IHEP, ESS



JLab double spoke cavity

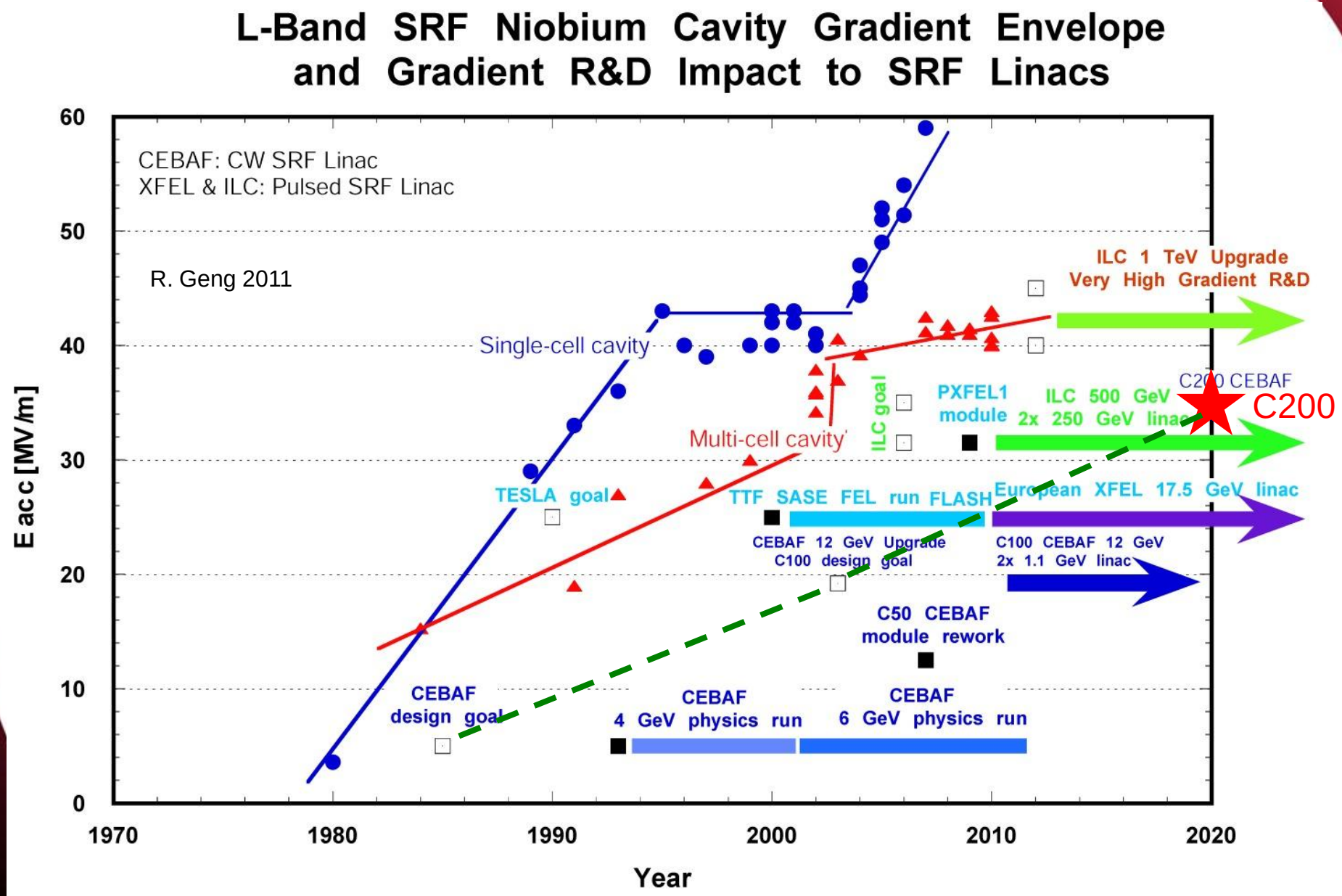
PKU spoke cavity



2. Increase the maximum gradient, with equal or lower cryogenic requirements

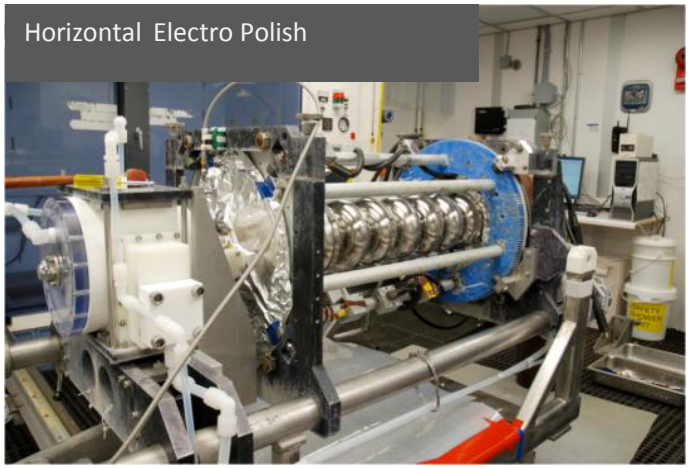
- ***Why? :*** Gradient drives machine size for high energy facilities
  - Maximizing gradient minimizes capital cost
  - Pushing the limits of gradient expands design options in other areas
- ***Target Specification:***
  - 5 year - 45 MV/m in 9 Cells, VTA Qo >1.0E+10 (100MV/m surface field, 190 mT)
  - 10 Year- 100 MV/m in R&D, "C200" Cavities & Cryomodule (35 MV/m, $4x10^{10}$)
  - 20 year – yet to be determined (historically doubles every ~10 years)
- ***How :*** through development of improved and more robust Chemical Processes, new structures and new materials
- ***End users include :***
  - all accelerators worldwide, particularly energy frontier machines (ILC, Muon collider)
- ***Funding & Partnerships*** : ILC, and NP
  - In future new sources of funding needed

Historical trends in cavity gradient

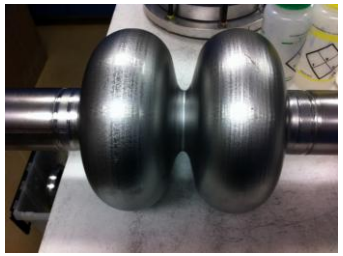


Jefferson Lab

2. Improve Gradient - *Photo Gallery*



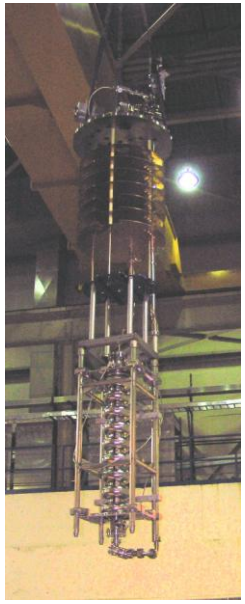
Ichiro



Seamless

Vertical Electro polish Cabinet

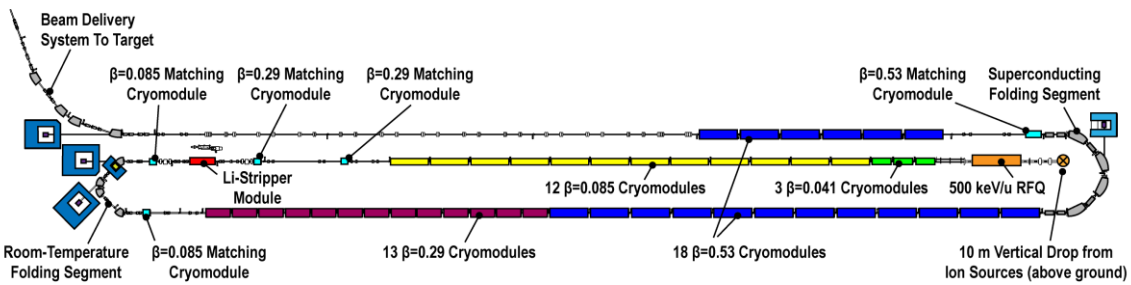
Barrel polisher



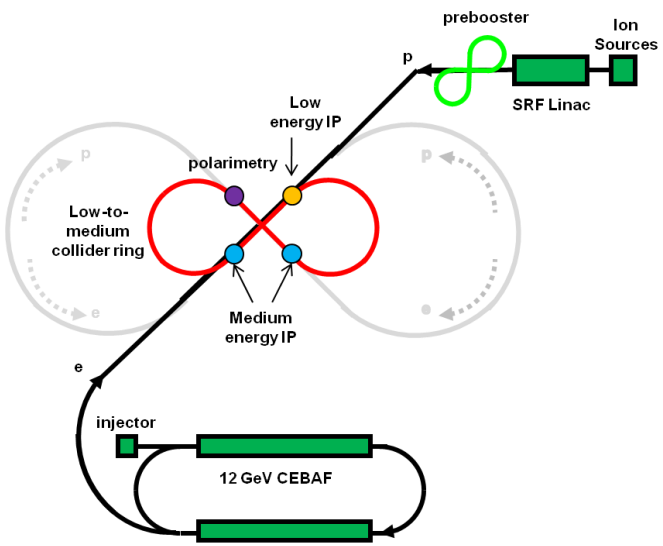
Vertical test

3. Collaborate on projects using SRF technology to grow our capabilities

- ***Why ?:***
  - Supplement and expand our core competencies
    - Electrons, protons, ions, positrons, muons, 2K and 4K, CW and pulsed
  - Maintain staffing levels and skills on challenging tasks
  - Continuous improvement of capabilities and facilities
- ***Highest Priority:*** **FRIB, MEIC**



FRIB - entering production phase

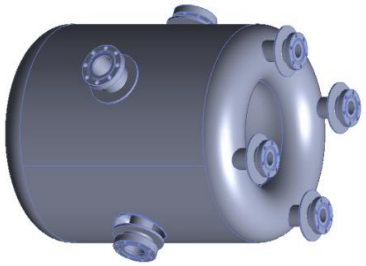


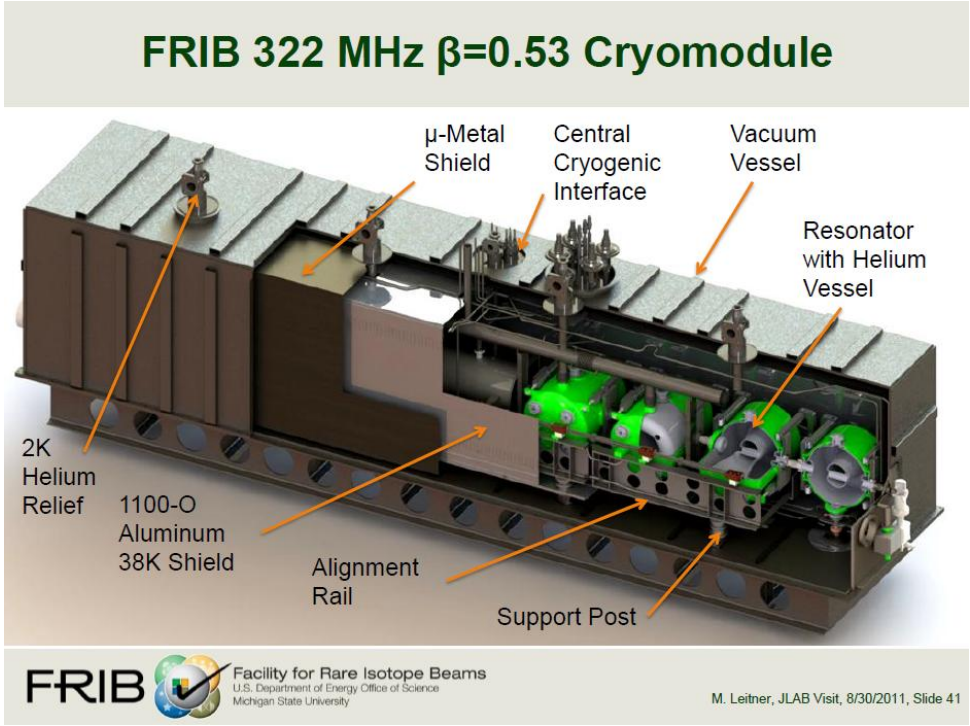
MEIC - in R&D phase

E.g.: FRIB at MSU

*Photos Courtesy Matthaeus Leitner, MSU

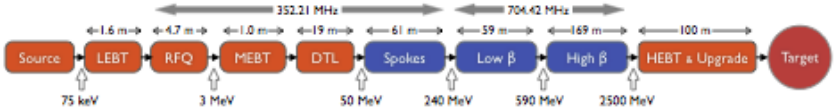
- ***Why*** :
  - In support of an NP Project
  - Gain expertise in half-wave cavities and box cryostat
- ***Target :***
  - Prototype Cavity Process & Production Proposal FY 12
  - Production Cavity Process could start FY 14 (147 β=0.53)
  - Potential for Cryomodule assembly starting FY 15 (18 β=0.53 CM)



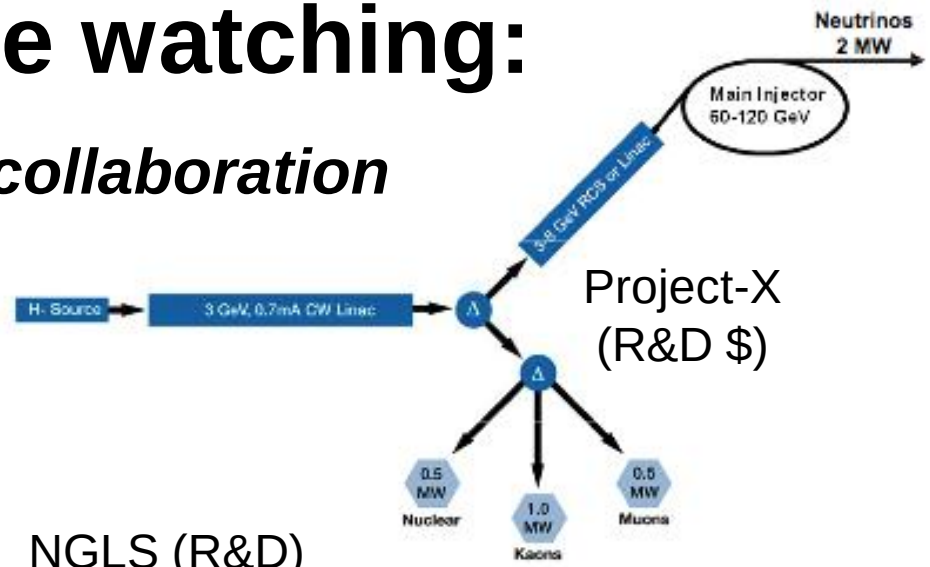


Other projects we are watching:

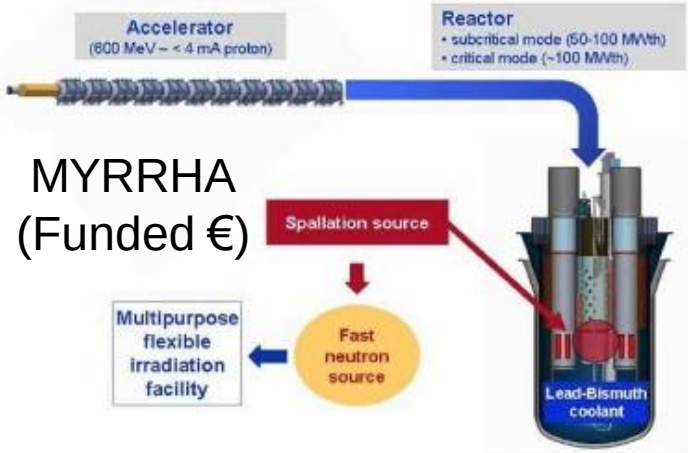
- ***Exploring opportunities for collaboration***



ESS (Funded €)

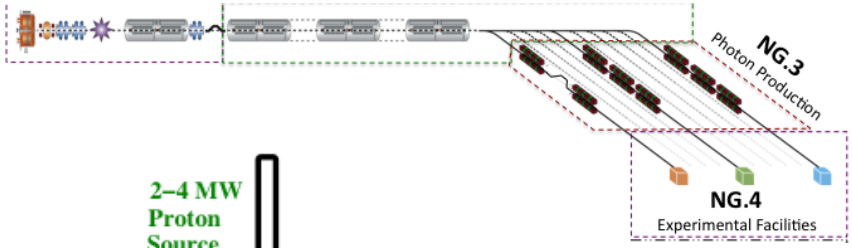


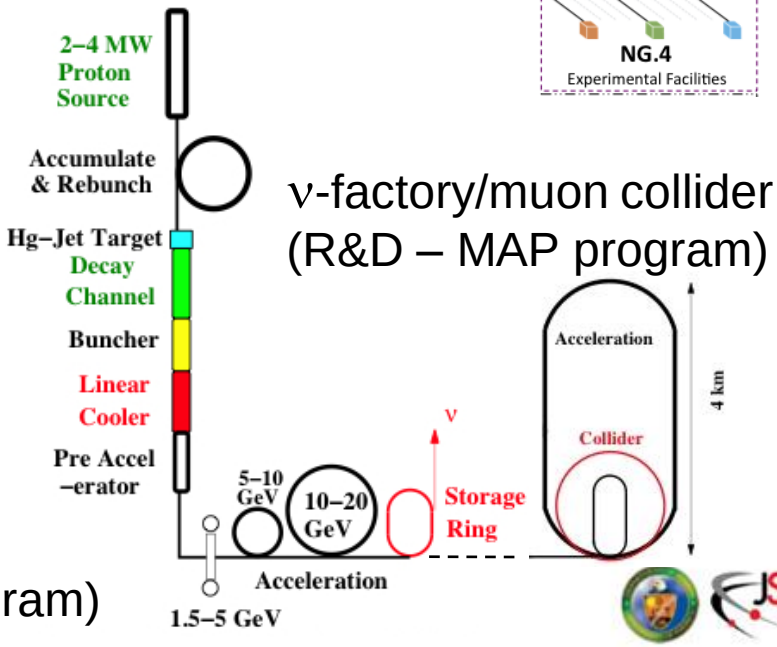
Project-X
(R&D $)



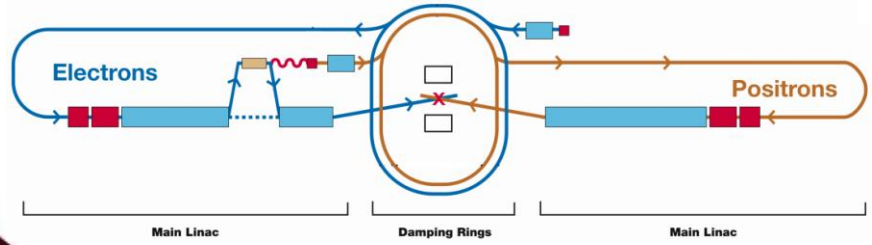
MYRRHA
(Funded €)

NGLS (R&D)





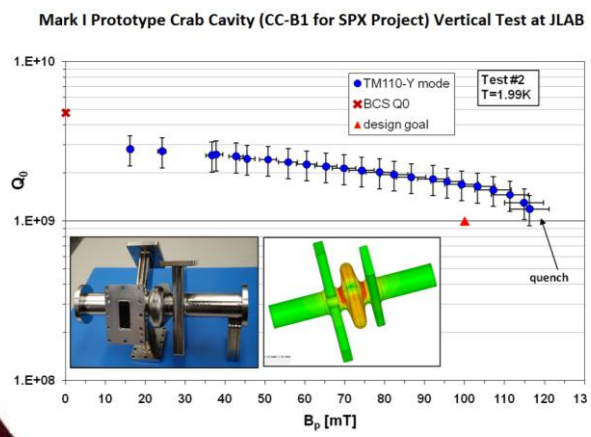
ν-factory/muon collider
(R&D – MAP program)



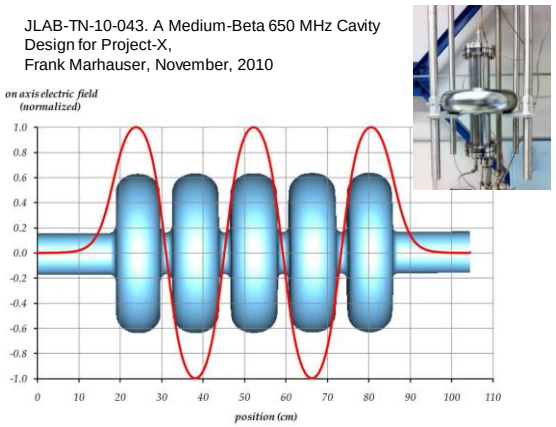
ilc (R&D –GDE/ ART program)

4. New Designs Optimized for specific uses

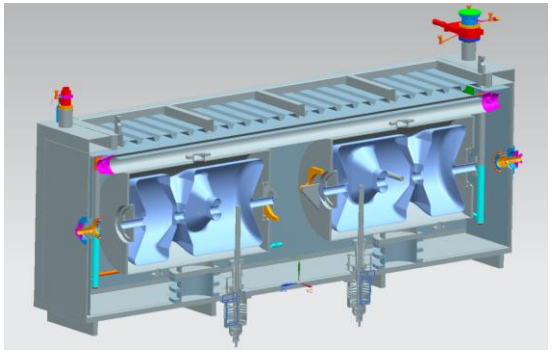
- **Why:**
  - Provide full service SRF design, prototyping, delivery and support to all DOE departments, other agencies, industry and international partners
- **How:**
  - Cavity & Cryomodule designs optimized for reduced Capital & Operating Cost
  - Capability from Concept to Cost Effective Finished Product
  - β=1, High Current, β<1, electrons, protons, muons, etc.
- **Examples:** ANL SPX module, Project-X 650 MHz cavity, ICS module, RF gun.



ANL SPX



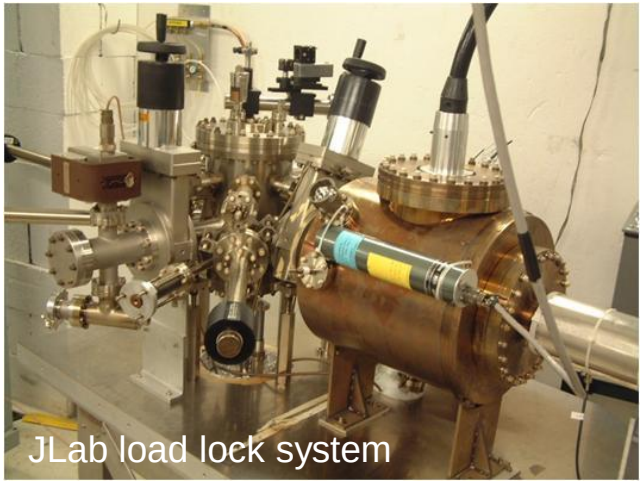
Project-X



ICS spoke cryostat concept

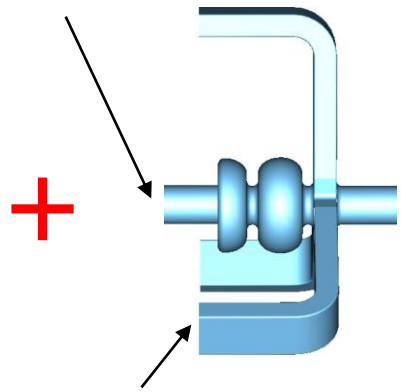
4b. SRF photocathode gun - *best of all worlds!*

- High frequency, high gradient, CW or high duty factor, high vacuum, high current, low emittance



Courtesy Matt Poelker

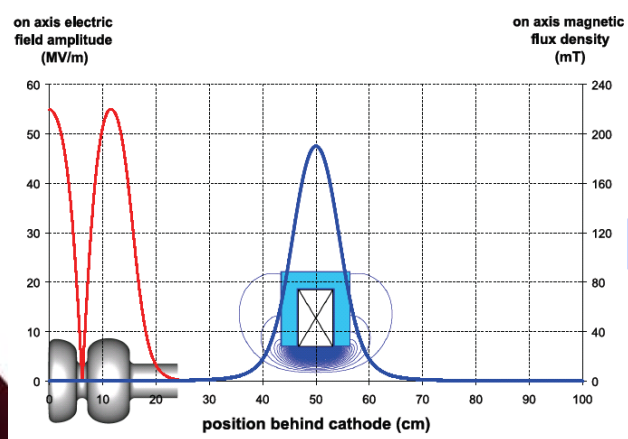
FPC and demountable cathode from load-lock



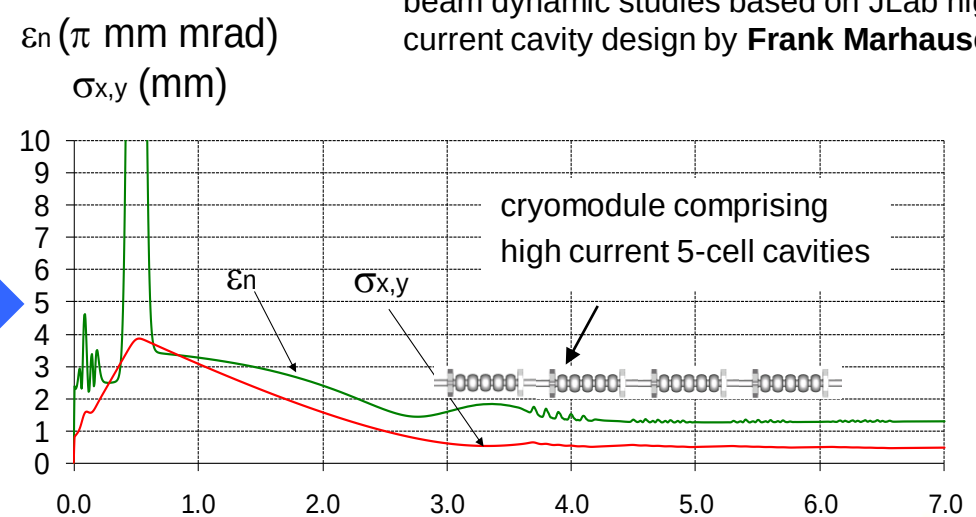
HOM end group

Parameter	Value	Unit
Start		
Bunch charge	1	nC
Cathode material	Cs_2Te	
Thermal energy	1	eV
Normalized thermal emittance	0.82	π mm mrad
Laser spot size	2.88	mm
Laser pulse length (flat top)	40	ps
Exit		
Rms beam size	0.5	mm
Normalized transverse emittance	1.3	π mm mrad

Preliminary design (1497 MHz 1.6-cell gun) and beam dynamic studies based on JLab high-current cavity design by **Frank Marhauser** 2008

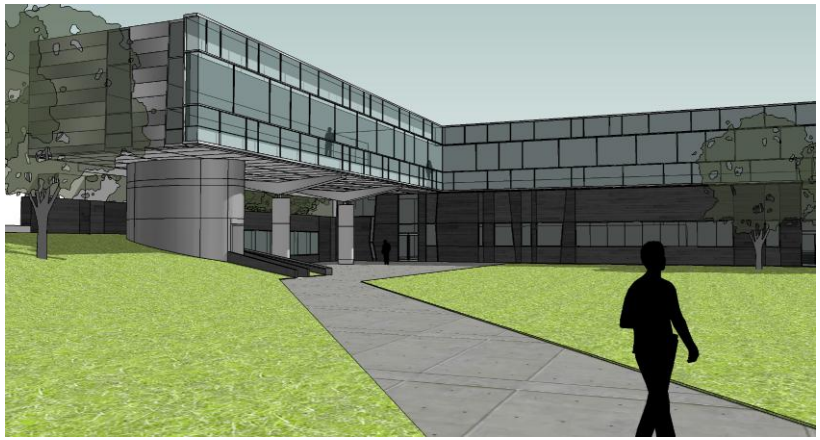


Split photo-injector



5. Exploit TEDF for maximum benefit

- **TEDF will be shared by with multiple organizations in JLAB**
  - SRF Institute ~ 38 K sq ft (~same as before), same VTA and Test cave
  - Better layout, world class clean room, UPW and R&D facilities
  - Injector Group in expanded test cave, Physics Experimental Areas~ 8K sq ft
  - Engineering - to be co-located with SRF



- **TEDF will be a good opportunity to work more closely with industry**
  - Continue to partner with small businesses in TEDF to provide testing and support
  - Train and transfer cryomodule know how to industry
  - Take more advantage of industry capabilities for future projects

SRF Priority Project/Initiative Matrix

"Good to go "
Work to be done

			Key Initiatives				
Projects		Funding	**1. Reduce Cryogenic Requirements**	**2. Increase Maximum Gradients**	**3. Collaborations to grow our capabilities**	**4. Develop new structures**	**5. Exploit TEDF for Maximum benefit**
1	12 GEV	NP	Qo= 9X 10(8)	Gradient=19 MV/m	N.A.	New 7-cell LL	Before TEDF
2	ICS	BES	4K Operation by Nb3Sn & Plasma Cleaning	Achieved	ODU, MIT, PKU…	Spoke Cavity not made before	Available for project
3	FRIB	NP	Working with Cryo group	Achieved At MSU	Proposals under discussion FRIB	MSU half-wave Box cryostat	Available for project
4	MEIC	NP	4K vs 2K Linac & rings	Achieved	BNL, ANL	Ion complex Ring cavities Crab cavities	Available for project
5	"C200" Next Gen CEBAF	NP	Qo > 1X10(10)	Gradient =35MV/m	May use for other projects	May need improved cavities	Available for project
6	SRF Gun	TBD	N.A.	Critical to eliminate field emission	Muons Inc & others	New gun structure with load lock system	Available for project
7	SBIR/WFO	multi			New & enhanced technologies		Involve industry

Prioritization in progress for each area subject to funding
(SRF technology roadmap document)

Jefferson Lab
JSA

Source Group 5 year Plan

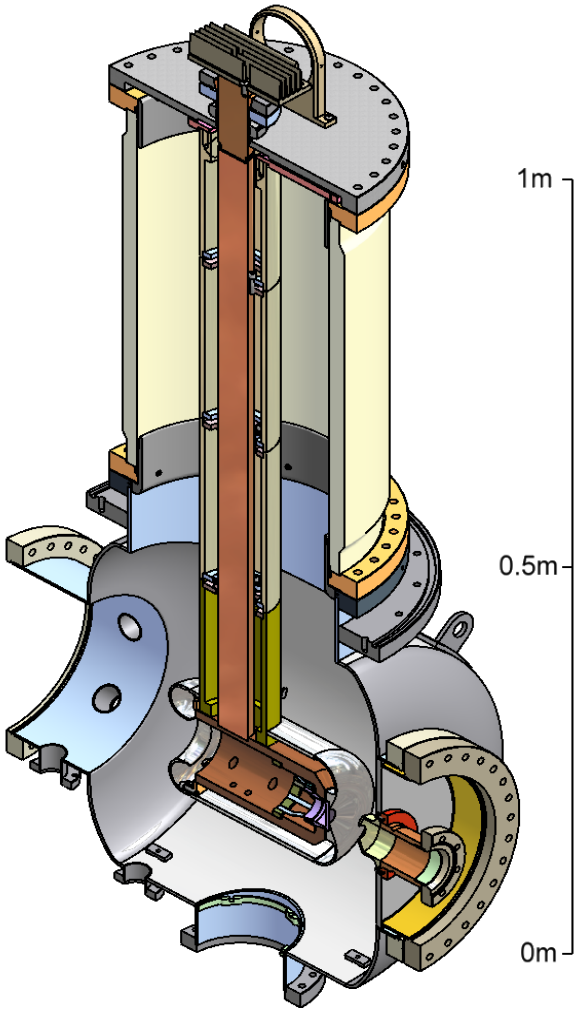
Matt Poelker

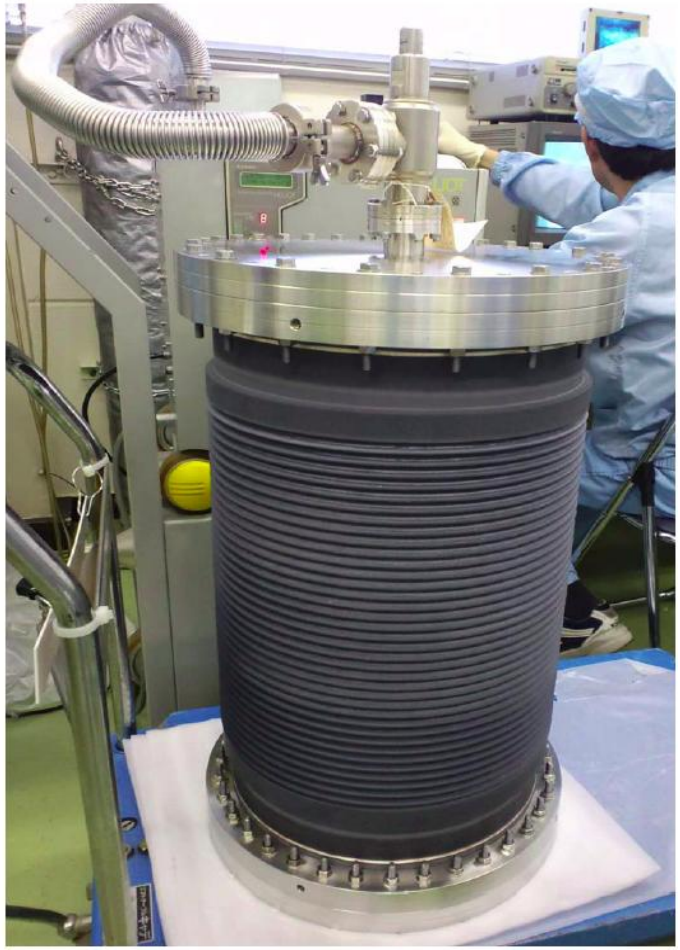
Director, Center for Advanced Studies of Accelerators

Source-Group 5-Year Plan

- Extend the inverted gun design to higher voltage: 350kV +
- ELIC and eRHIC polarized source: photocathodes with high polarization and high QE, improved operating lifetime at high current **(sustained mA average current)**
- Compact 10MeV electron source
  - 200kV gun at CEBAF with SRF capture section and 7-cell
  - SRF gun for high bunch charge applications (work with SRF Institute)
  - Accelerator R&D projects: compact ERL, 4K CM
  - Need improved Test Cave with LHe
- Low Energy NP at CEBAF and Injector Test Cave (positrons, bubble chamber experiments)
- Support NP at FEL, e.g., install a polarized electron source, PV experiments, etc.,

Cornell 750 kV Gun



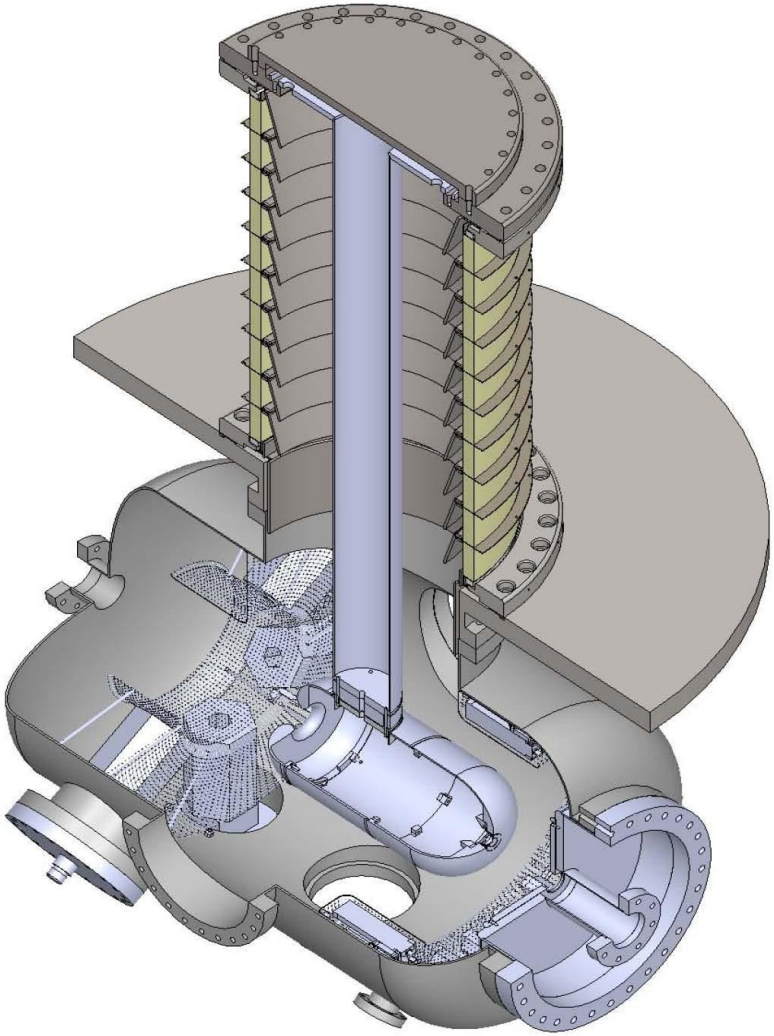


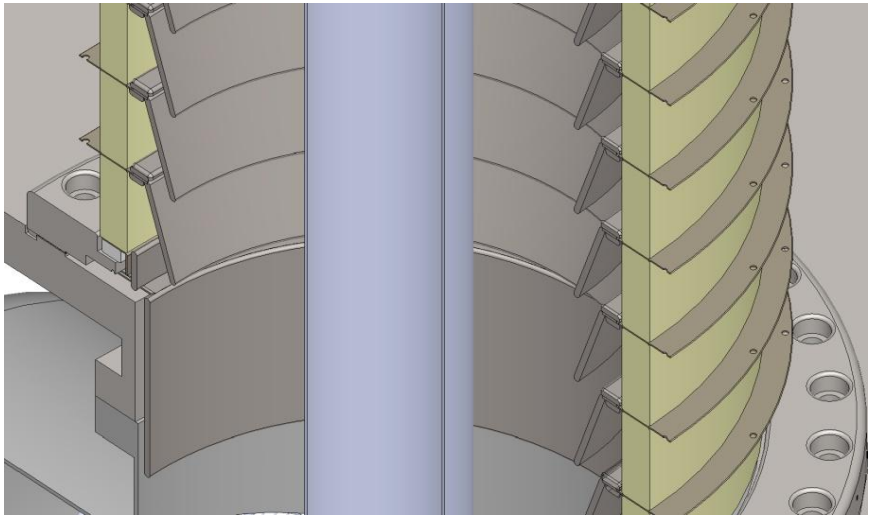
- Ceramic with bulk resistivity and improved braze design installed
- Measured resistivity of 6.45 x 10^{10} Ohm-cm gives 30 μA current draw at 500 kV
- Ceramic by Morgan, brazing and welding by Kyocera

Similar initiatives at JLab FEL and Daresbury ERLP

Courtesy Bruce Dunham, Cornell

500 kV photocathode DC gun at JAEA

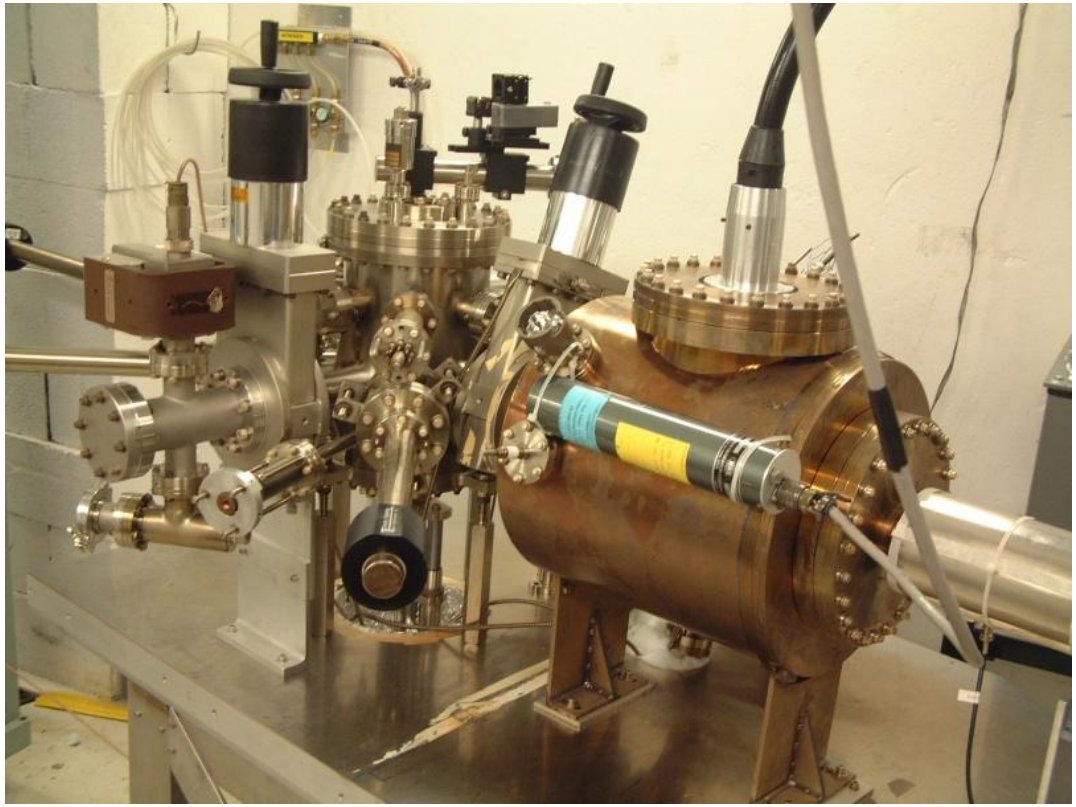


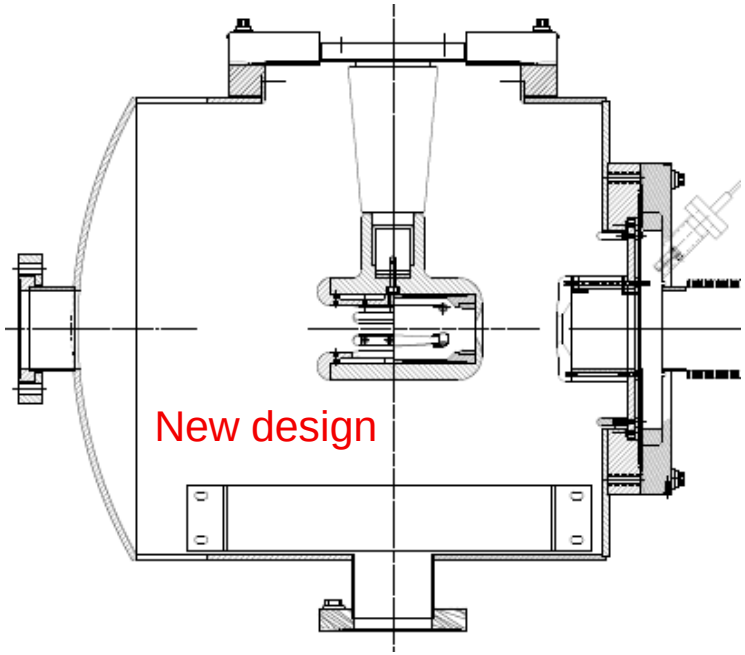


- High DC voltage >= 500kV
  - ✓ CockCroft Walton power supply
  - ✓ Segmented insulator with guard rings
  - High voltage testing
- Electrodes and vacuum
  - Cathode and anode electrodes
  - ✓ Low outgassing material (titanium)
  - NEG pumps

Courtesy N. Nishimori

The CEBAF 200kV Inverted Gun



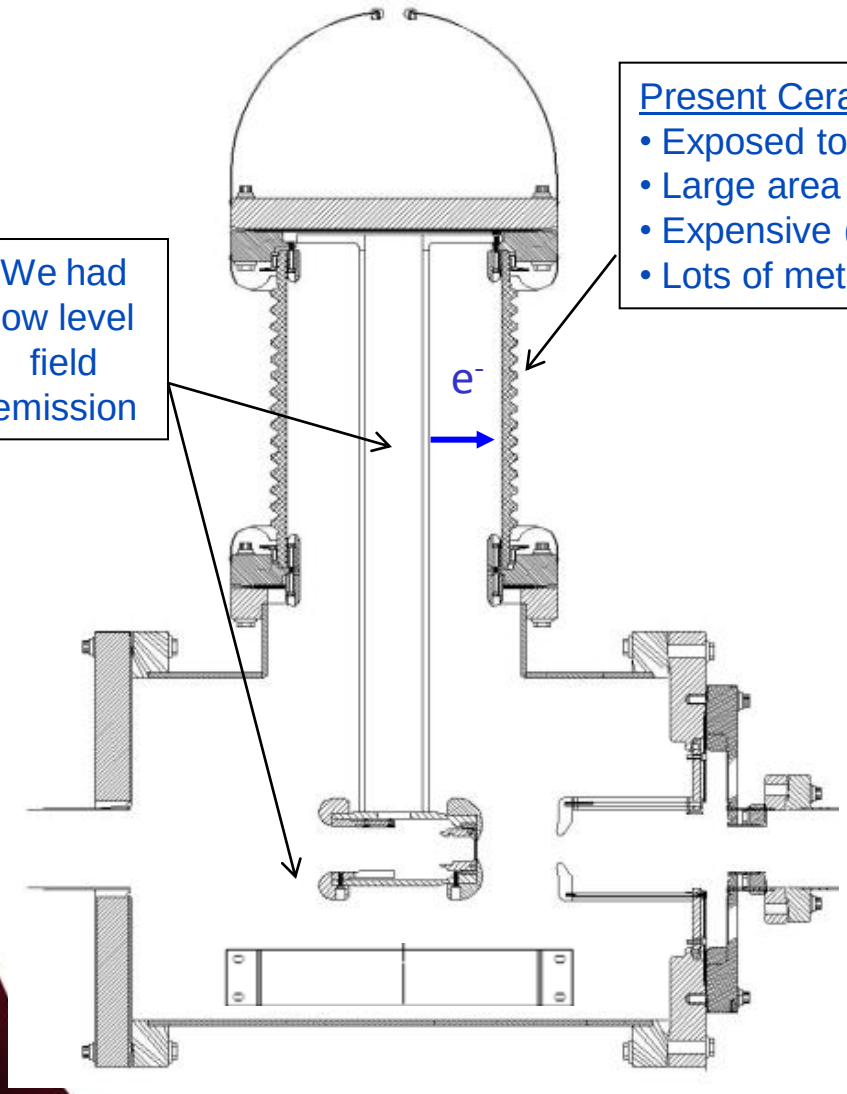


Higher voltage = better beam quality.

The inverted design might be the best way to reach voltages > 300kV

Old Gun Design

New "Inverted" Design

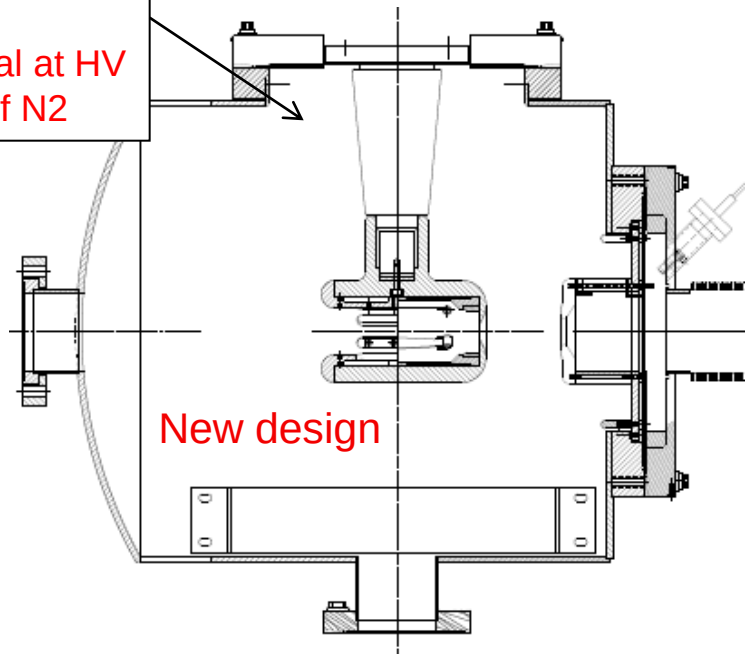


We had low level field emission

Present Ceramic
- Exposed to field emission
- Large area
- Expensive (~$50k)
- Lots of metal at HV

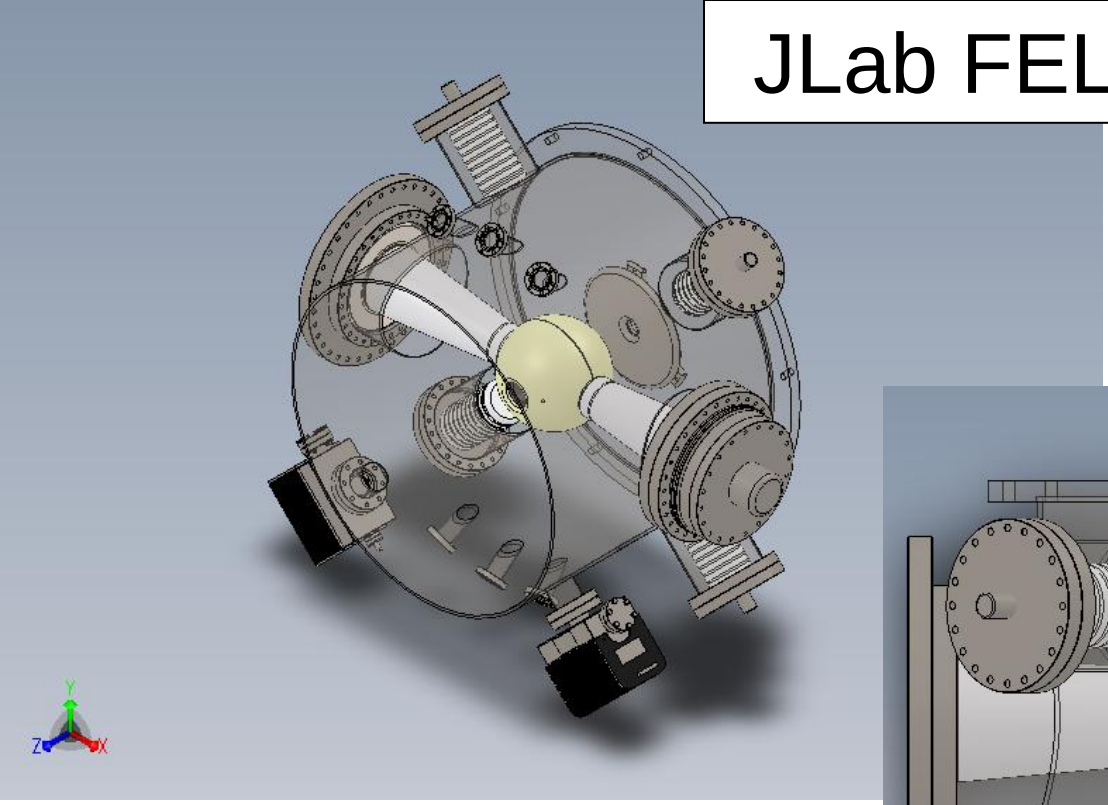
Medical x-ray technology

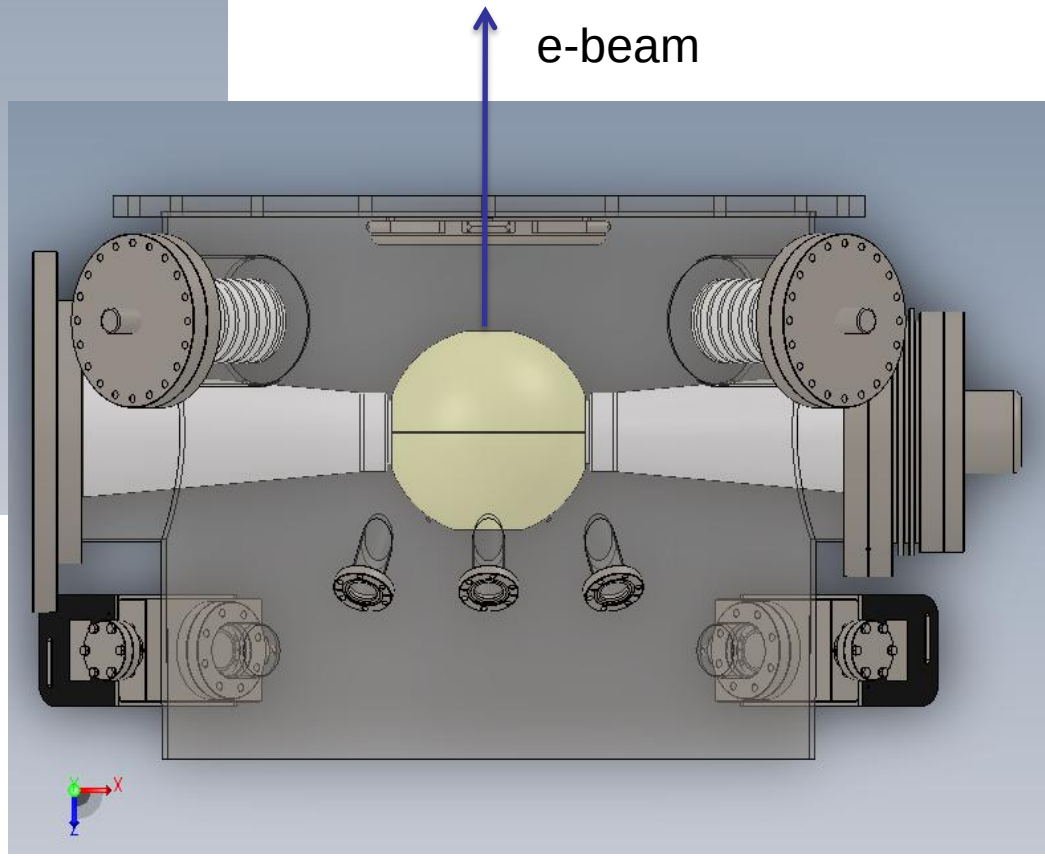
New Ceramic
- Compact
- ~$5k
- Less metal at HV
- No SF6 of N2



Move away from "conventional" insulator used on most GaAs photoguns today – expensive, months to build, prone to damage from field emission.
High gradient locations not related to beam optics, lots of metal to polish

JLab FEL 500kV inverted gun



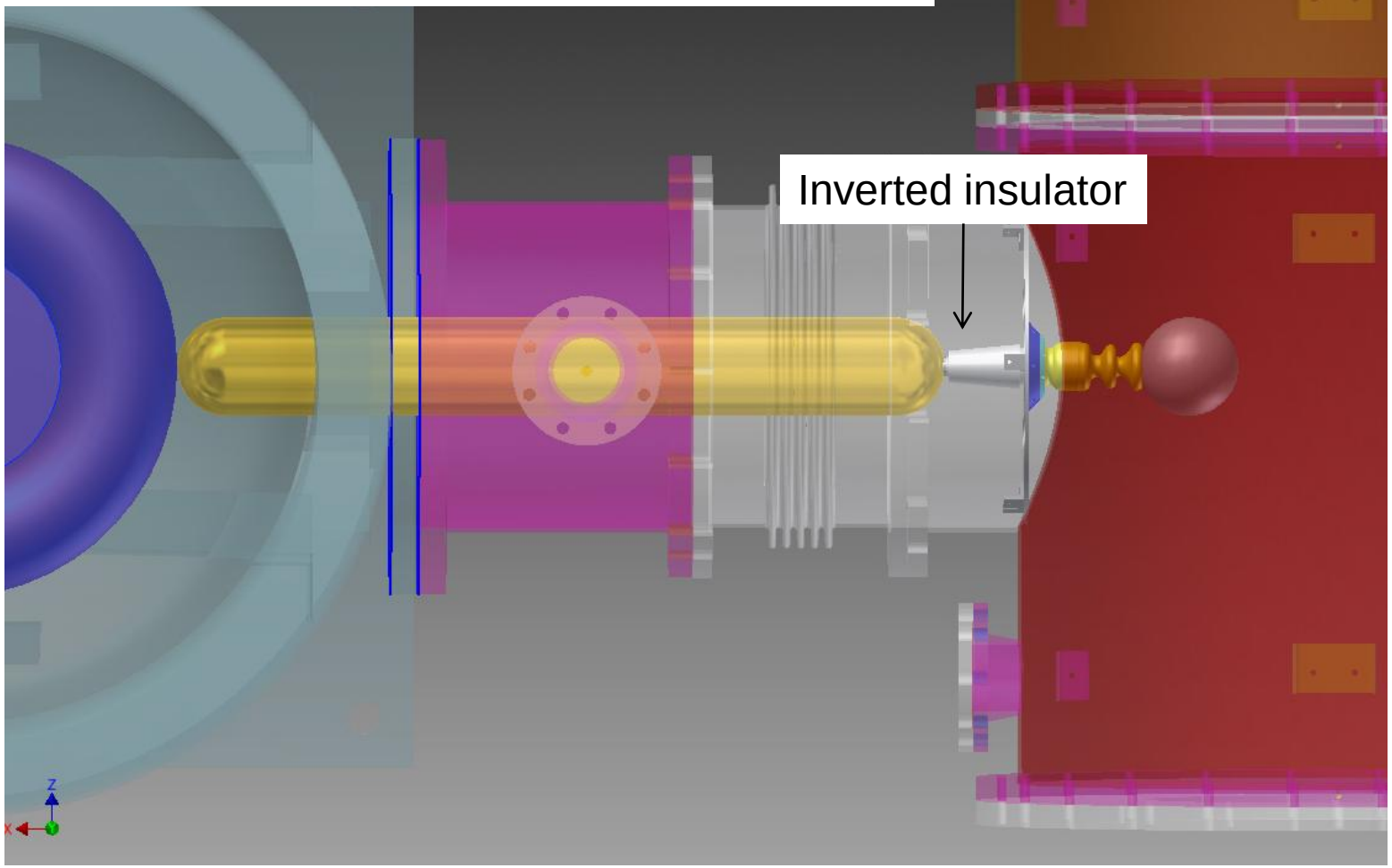


- Condition to 600kV, operate at 500kV
- 3x bigger inverted insulator compared to CEBAF gun
- One insulator for HV: one for cooling
- Niobium electrode – no diamond paste polishing
- Work in-progress

Courtesy: M. Marchlick, G. Biallis, C. Hernandez-Garcia, D. Bullard, P. Evtushenko, F. Hannon, and others from JLab-FEL

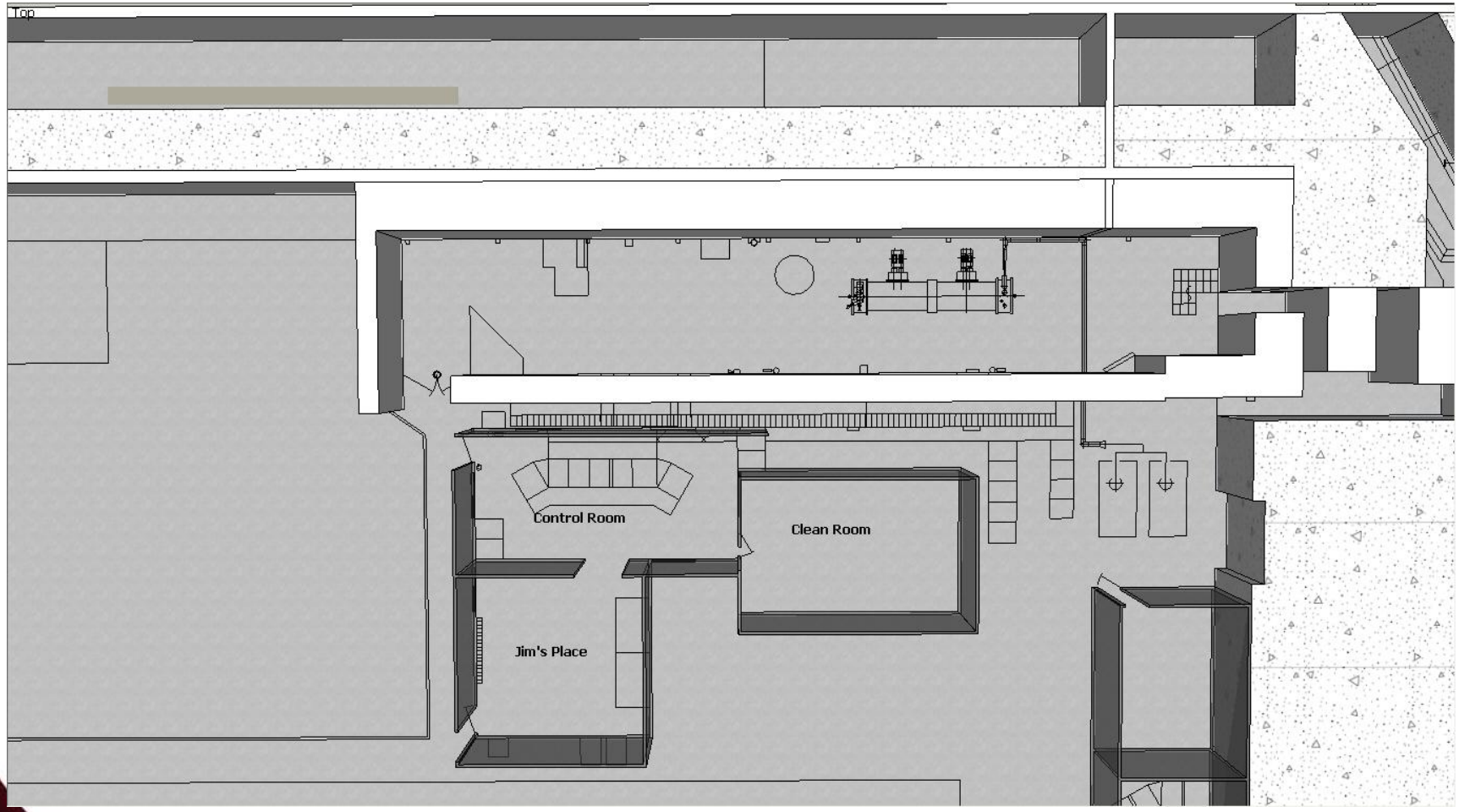
HV Issues: inside and outside the gun

600 kV supply at FEL gun test stand, with SF6 tank

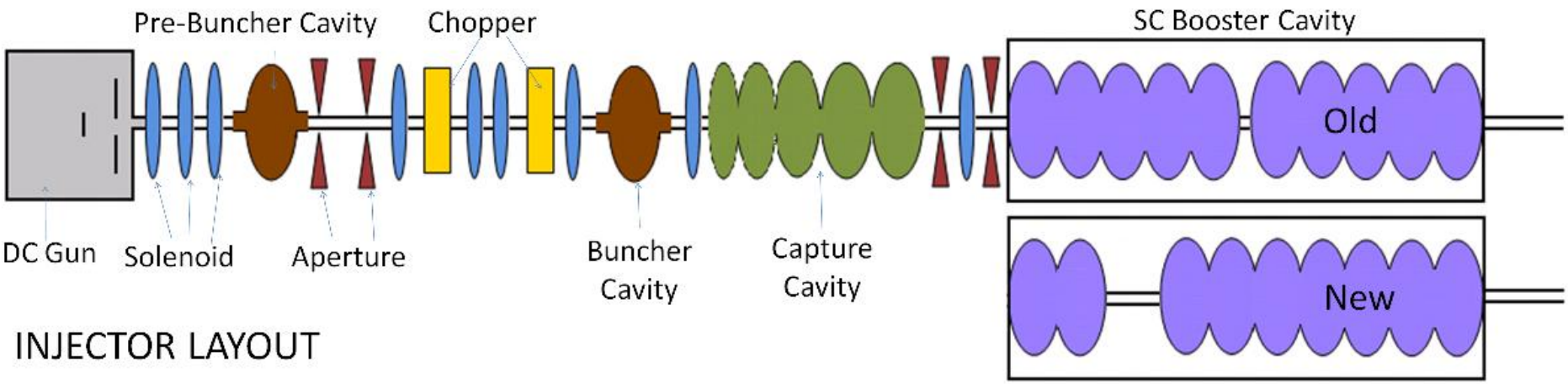


Learn to apply high voltage without breakdown, dielectric plug inside insulator,
Then we will address the field emission problems inside the gun

Injector Test Cave: MeV Test Facility

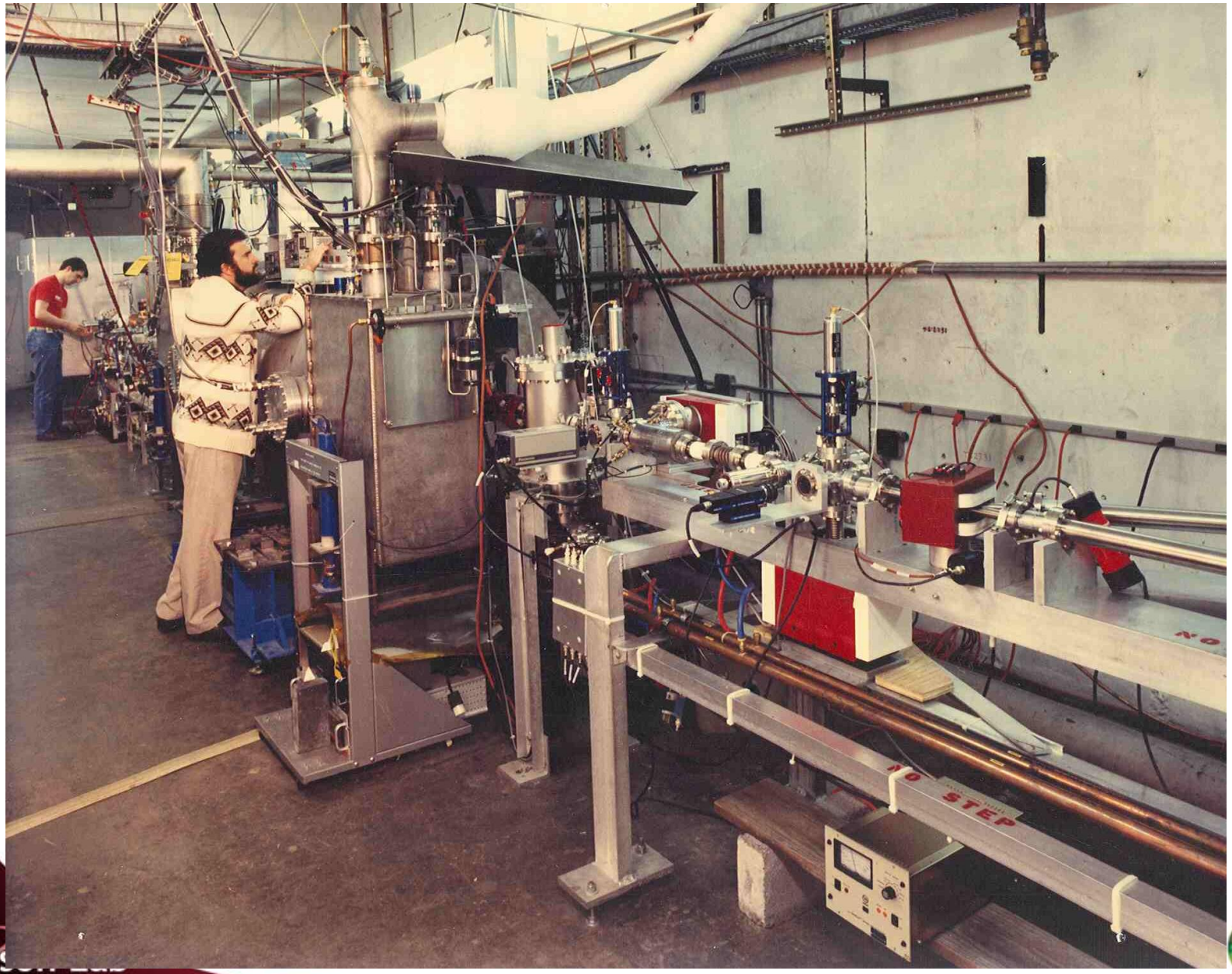


Commission the New Injector

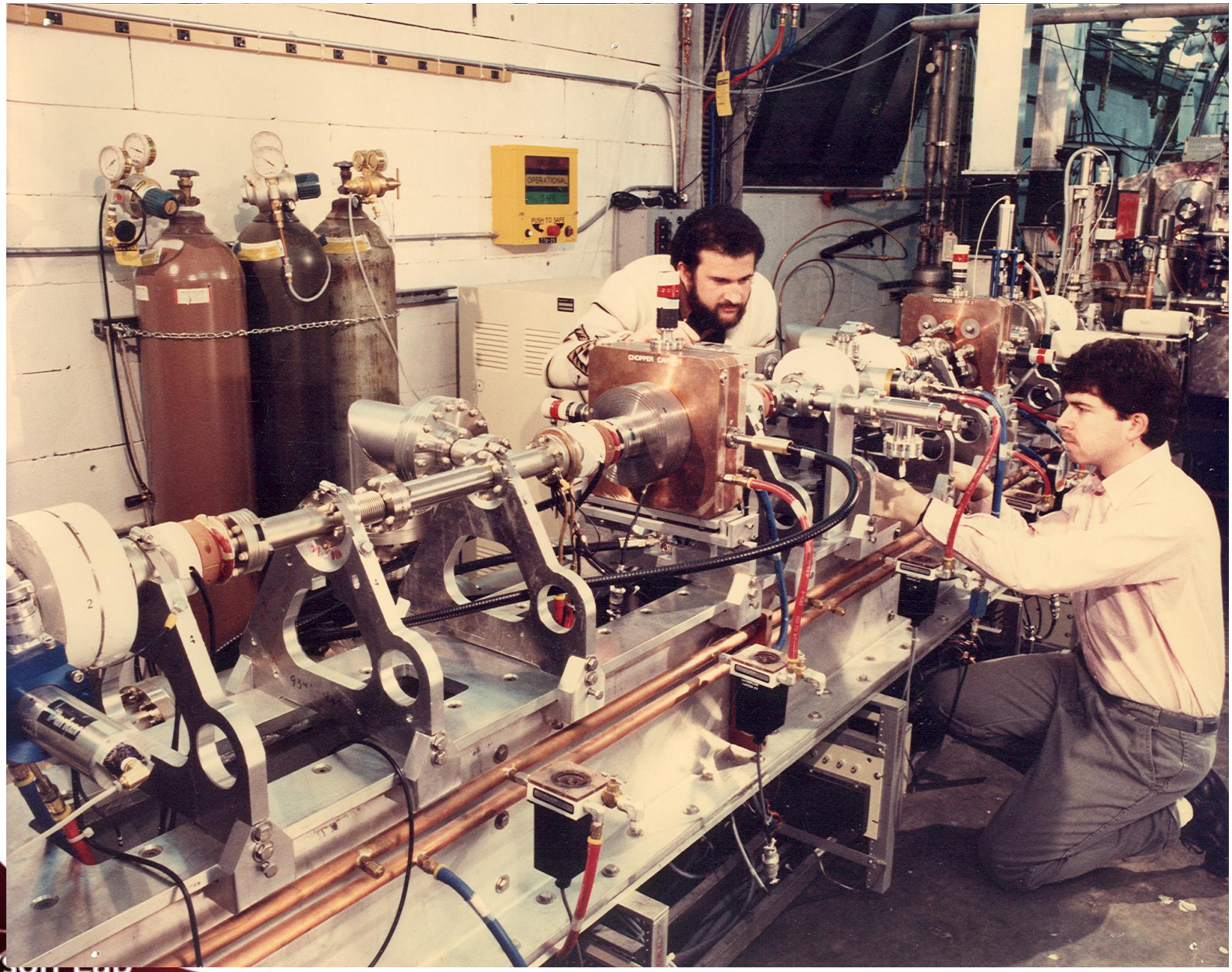


New 1/8CM will eliminate x/y coupling, and we should get more position damping for parity violation experiments

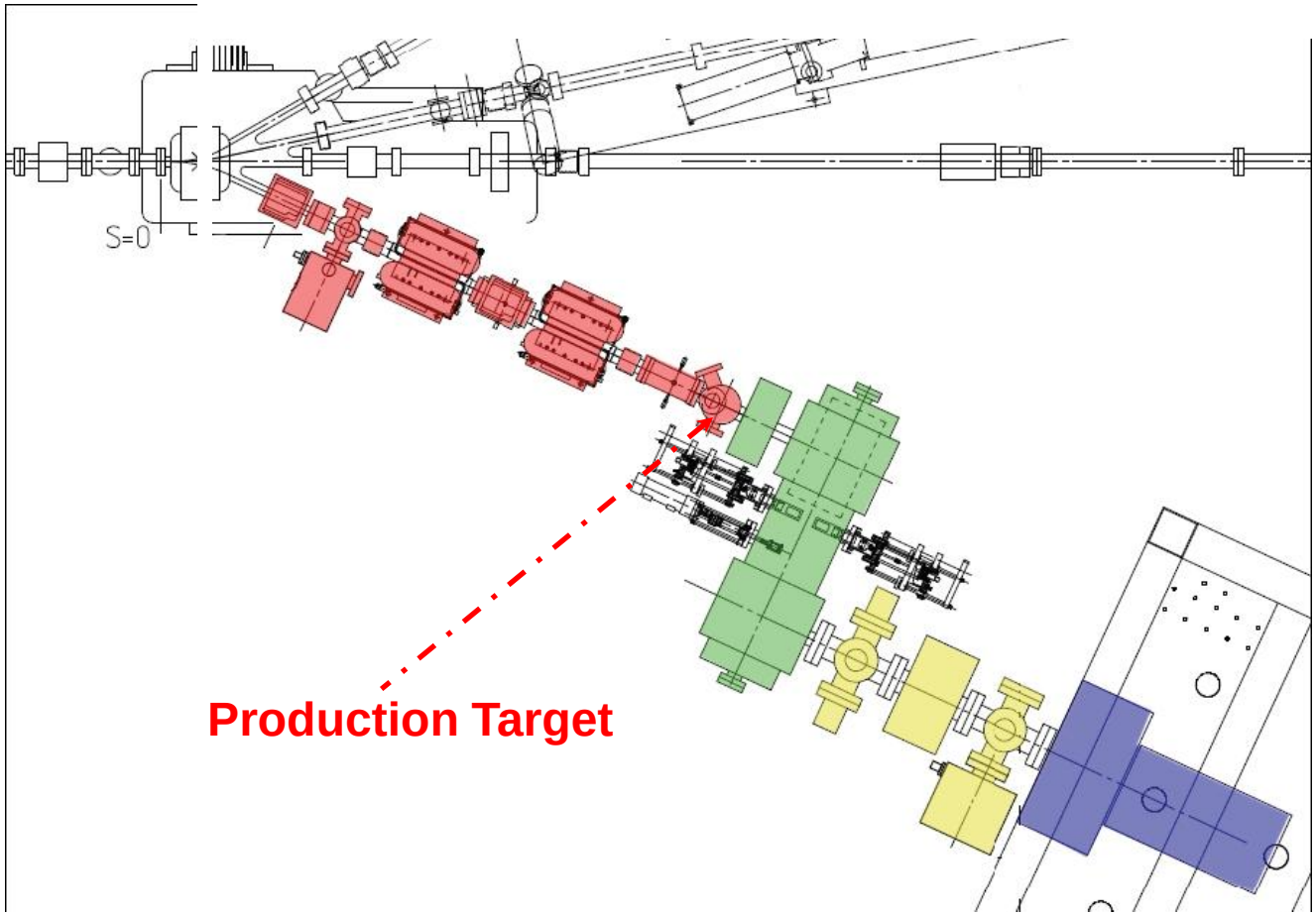
Test Cave with T-Gun and 1/4CM: 1991



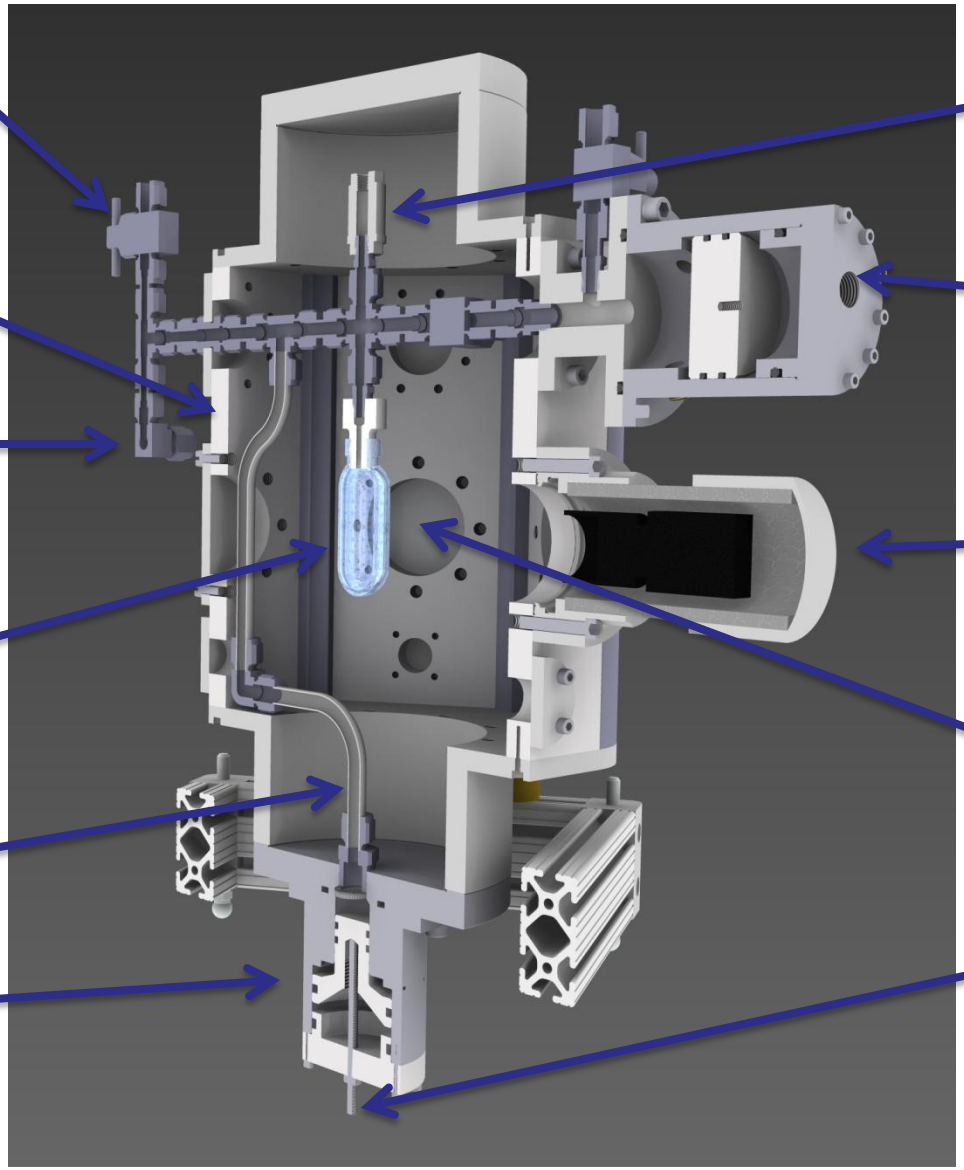
Test Cave with T-Gun and 1/4CM: 1991



The PEPPo experiment @ JLab



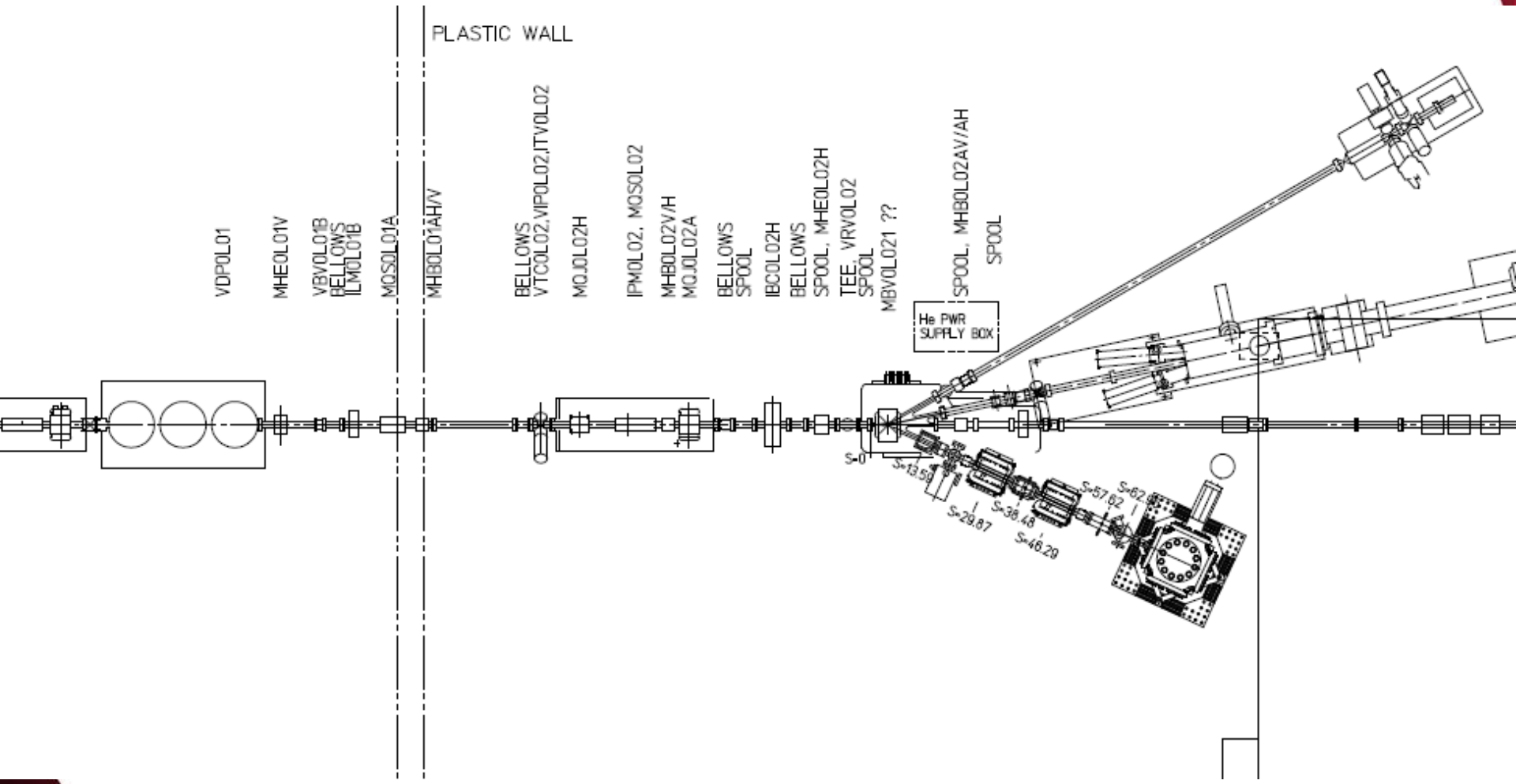
C_4F_{10} bubble chamber for JLab



Courtesy of B. DiGiovine

Argonne National Laboratory

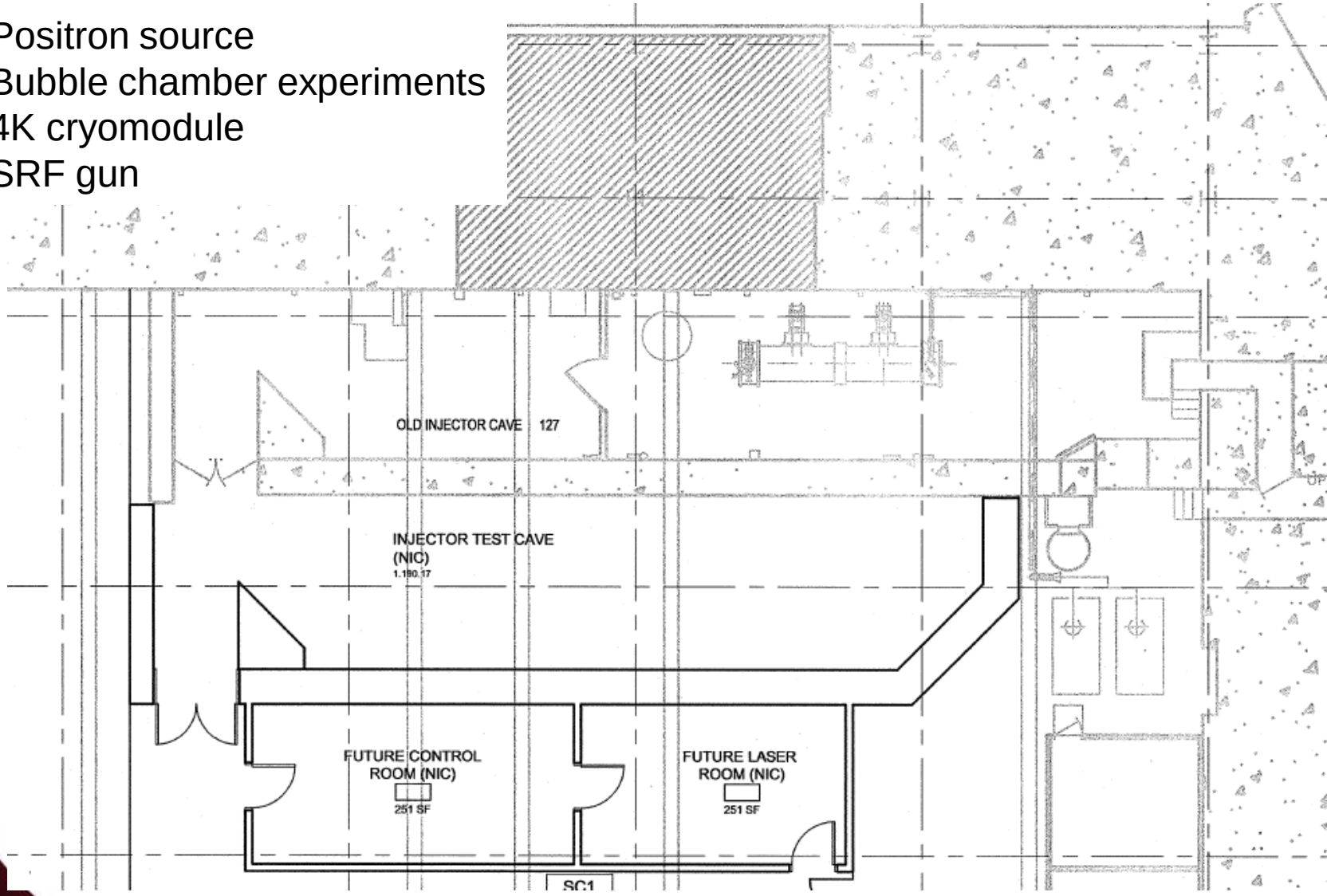
Water bubble chamber at JLab injector



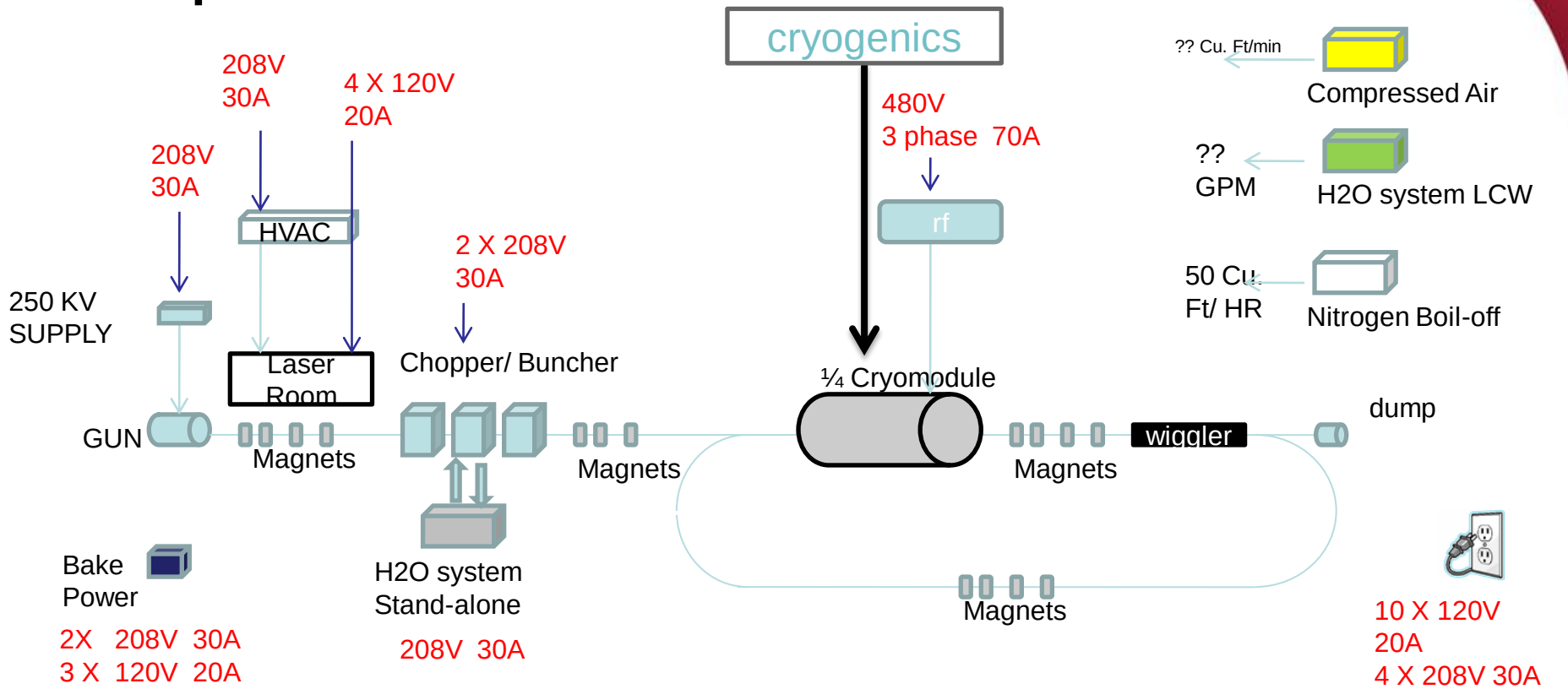
Courtesy of J. Grames, D. Machie

More Space for Accelerator R&D, Physics

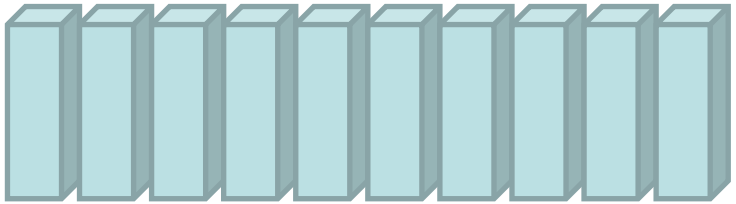
Positron source
Bubble chamber experiments
4K cryomodule
SRF gun



Compact ERL

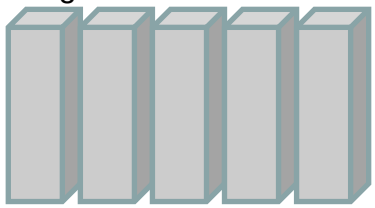


10 fully loaded equipment racks. DAQ and control room computer terminals



Ten racks, 120V 20 Amp service each

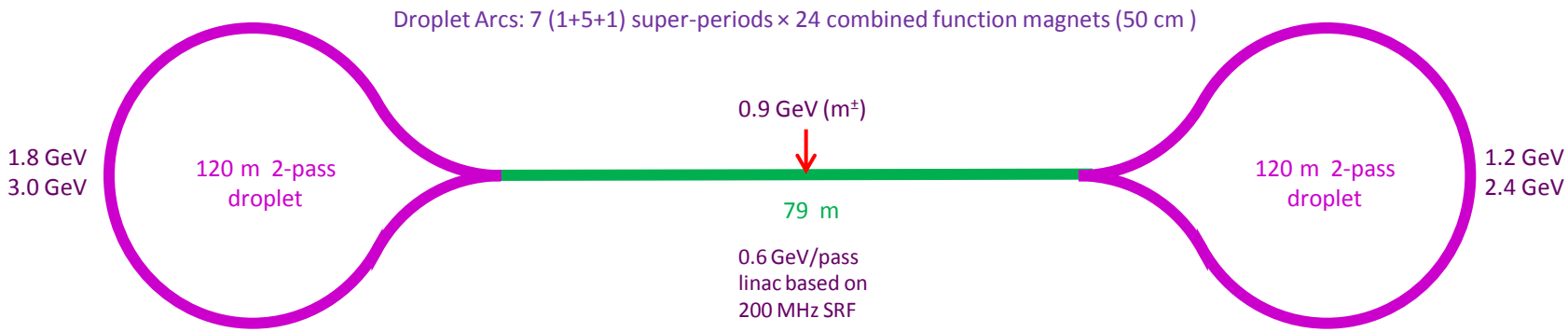
Trim Rack Power Supplies for all magnets



Five racks, 208V 30A service each

Lighting
5 X 120V
20A

Size-down: IDS Muon RLA to Electron Demo



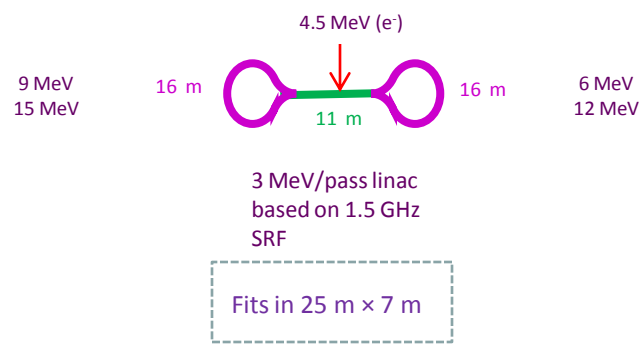
B	2.6 Tesla
G	45 Tesla/m

B	1 .7 Tesla
G	28 Tesla/m

energies reduced by factor of 200 (m_m/m_e)

size reduced by factor of 7.5 (1500/200)

B	975 Gauss
G	170 Gauss/cm



B	638 Gauss
G	110 Gauss/cm

Electron Demo of Multi-pass Arc Muon RLA

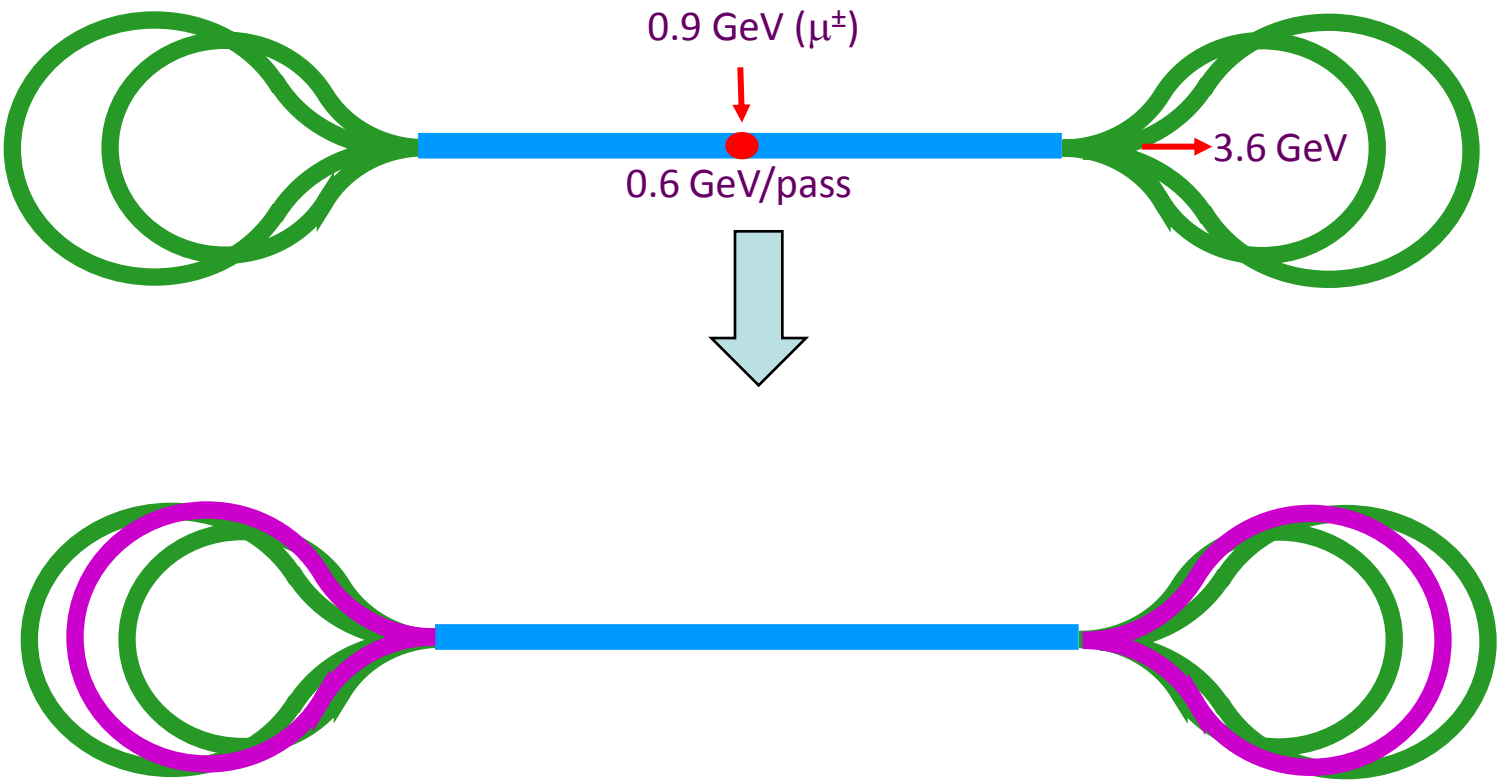
Alex Bogacz

Kevin Beard, Muons Inc.

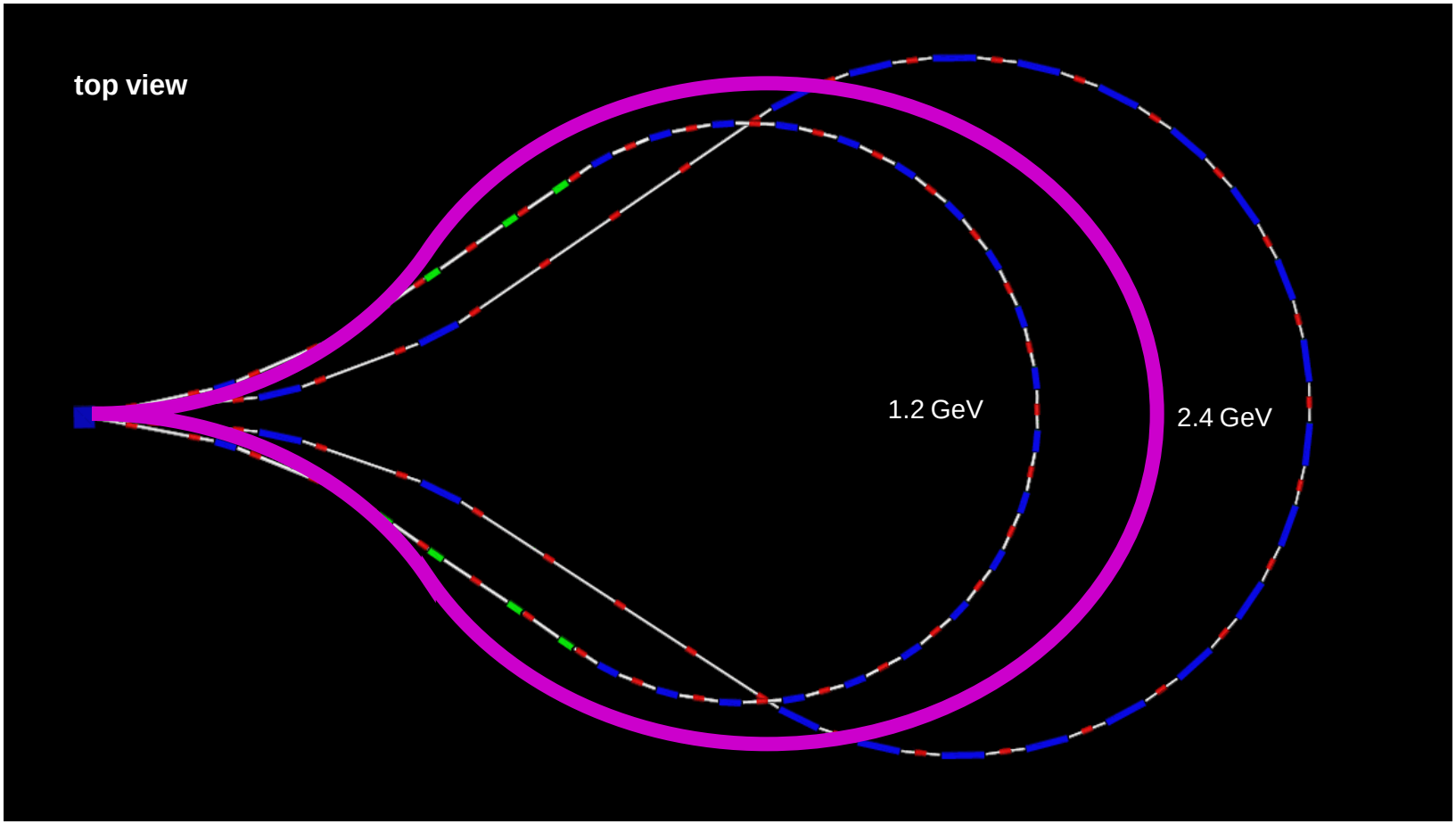
Vasiliy Morozov, Yves Roblin, Jefferson Lab

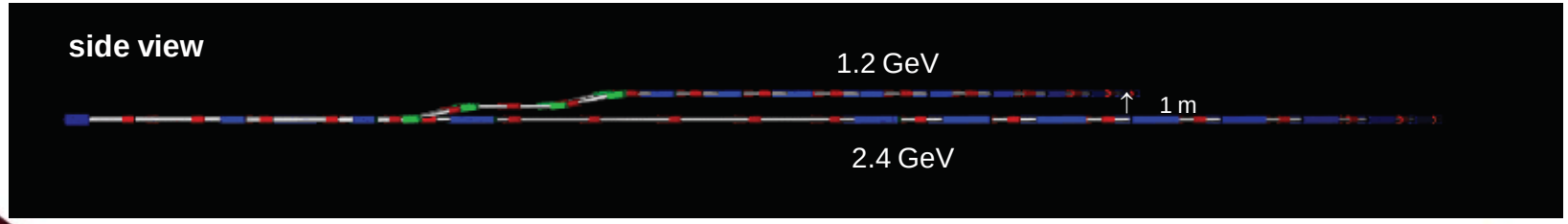
Jefferson Lab

‘Dogbone’ RLA with Two-pass Arcs



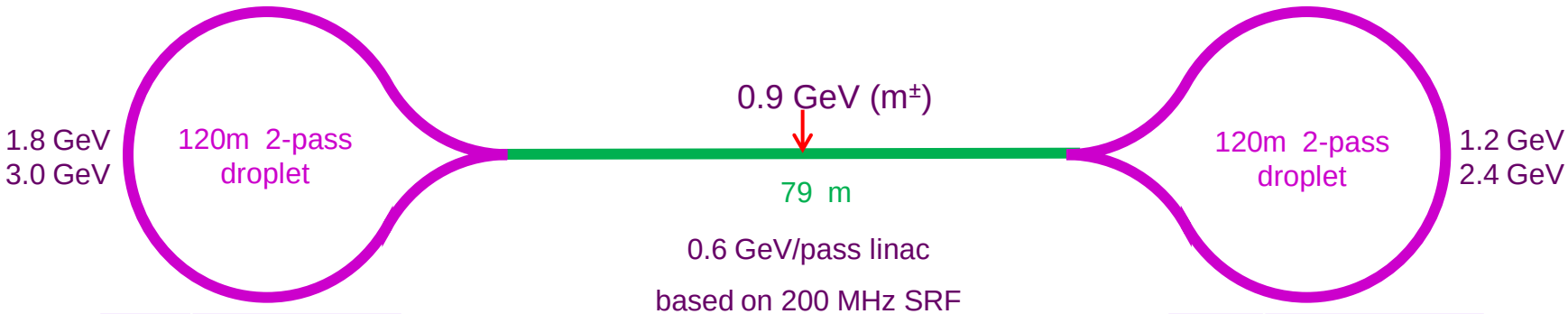
Conventional Single-pass Droplet Arcs





Size-down: IDS Muon RLA to Electron Demo

Droplet Arcs: 7 (1+5+1) super-periods × 24 combined function magnets (50 cm)



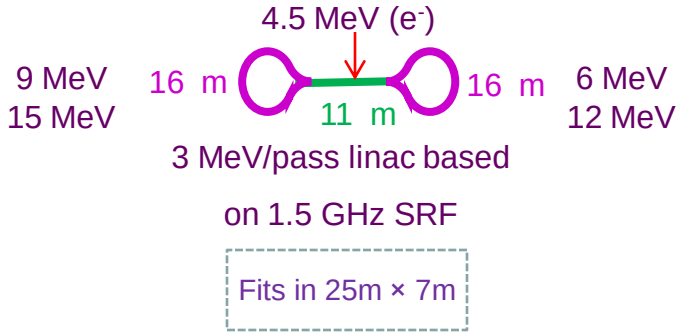
B	2.6 Tesla
G	45 Tesla/m

B	1 .7 Tesla
G	28 Tesla/m

energies reduced by factor of 200 (m_m/m_e)

size reduced by factor of 7.5 (1500/200)

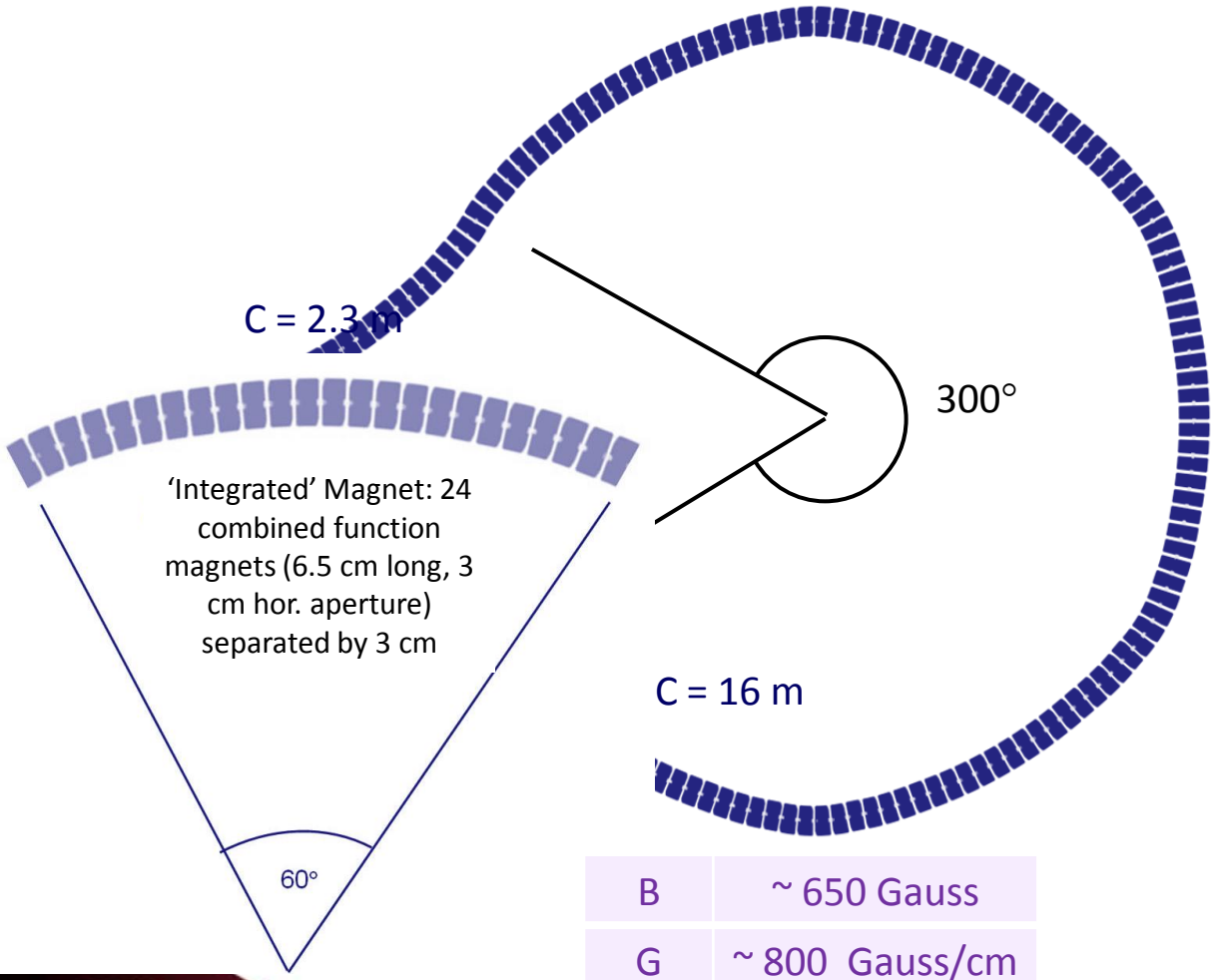
B	975 Gauss
G	1275 Gauss/cm



B	638 Gauss
G	825 Gauss/cm

Droplet Arc Architecture (6/12 MeV/c)

7 super-periods (1 out +5 in +1 out)



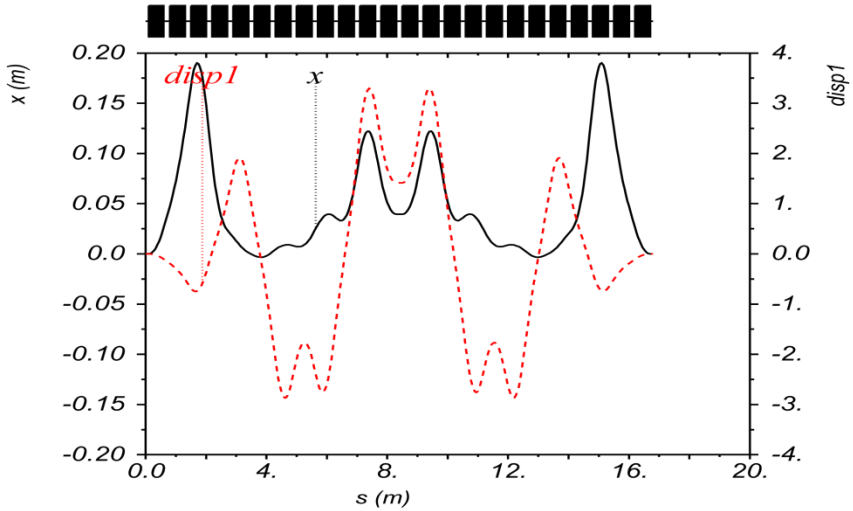
B	~ 650 Gauss
G	~ 800 Gauss/cm

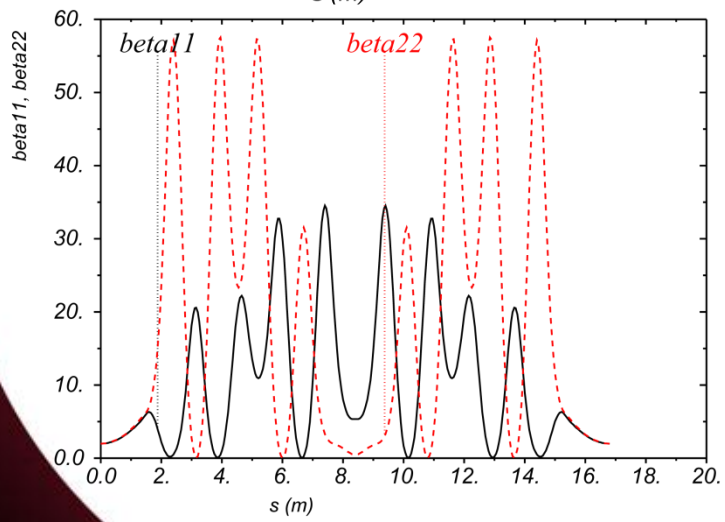
G	[kGauss/cm]
BO01	0
BO02	0
BO03	0.548888
BO04	-0.690966
BO05	0.796576
BO06	-0.627358
BO07	0.596019
BO08	-0.596693
BO09	0.652984
BO10	-0.777233
BO11	0.689622
BO12	-0.523101

× 2 × 7

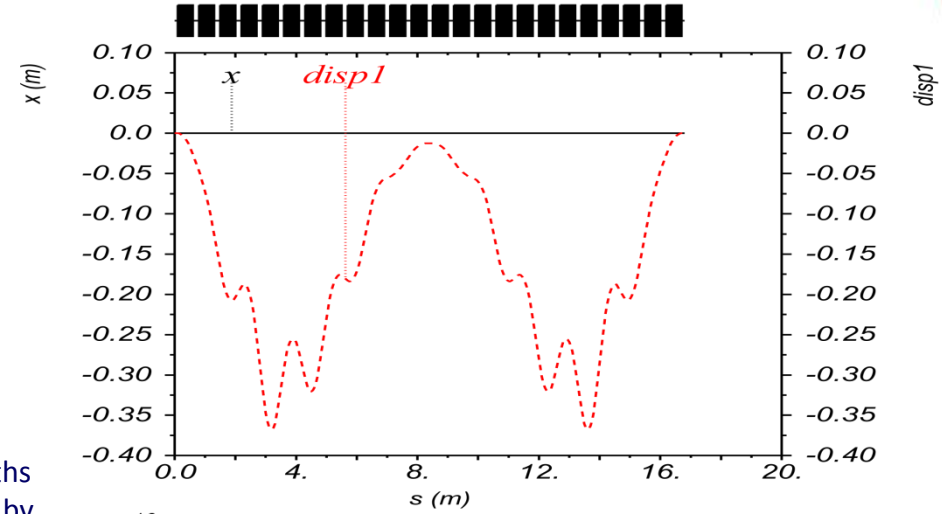
Super-period Optics for $P_2 / P_1 = 2$

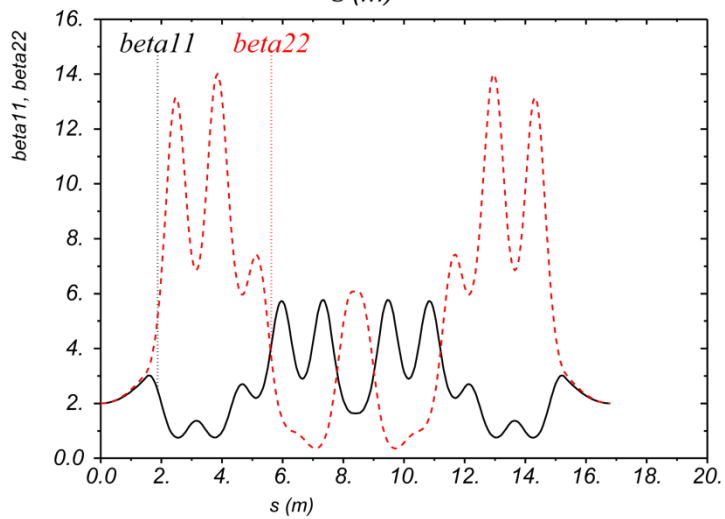
P_1 (6 MeV/c)





P_2 (12 MeV/c)





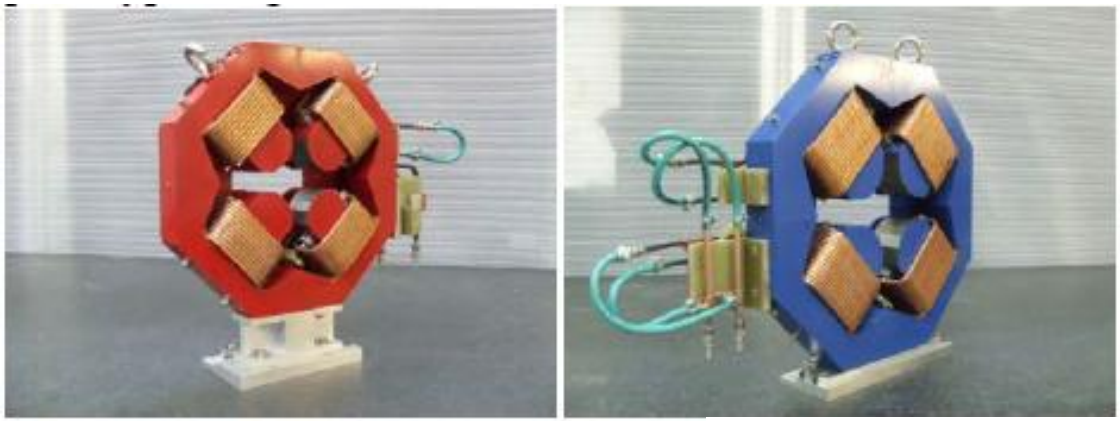
all lengths reduced by factor of 7.5

EMMA Non-Scaling FFAG Demo

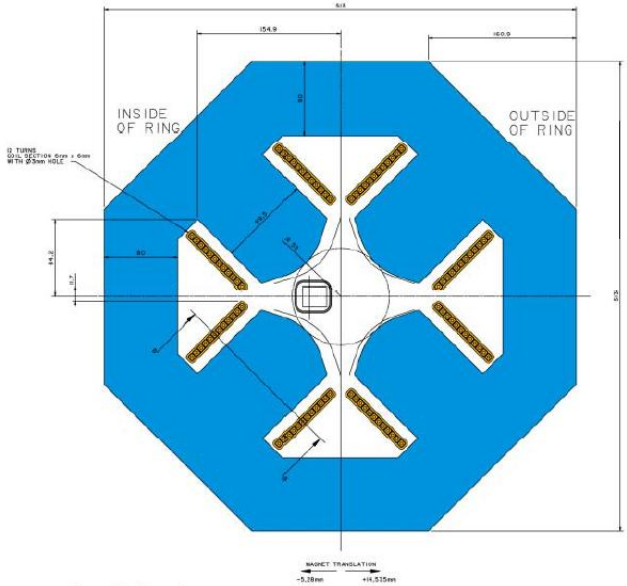
WEPC156 Proceedings of EPAC08, Genoa, Italy

DEVELOPMENT AND ADJUSTMENT OF THE EMMA QUADRUPOLES

N.Marks, B.J.A.Shepherd, ASTeC / Cockcroft Institute, STFC Daresbury Laboratory, Warrington, UK
B. Leigh, F. Goldie, M.J.Crawley, Tesla Engineering, Storrington, Sussex, UK



Parameter	F magnet	D magnet	Units
Integrated gradient	-0.387	0.347	T
Inscribed radius	37	53	mm
Current	213.4	263.5	A
Turns in coil	11	11	
Yoke thickness	55	65	mm
Pole width	73	100	mm
Horizontal movement range	-2.711 +2.604	-5.28 +14.535	mm
Offset from magnetic centre	7.507	34.025	mm
Required good field region	-32…+16	-56…-10	mm

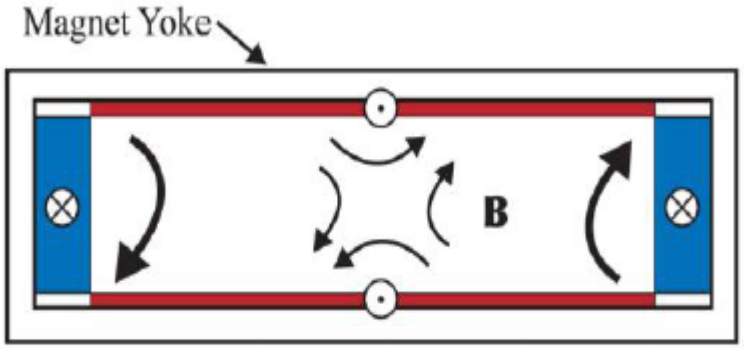


Combined Function Panofsky Quad

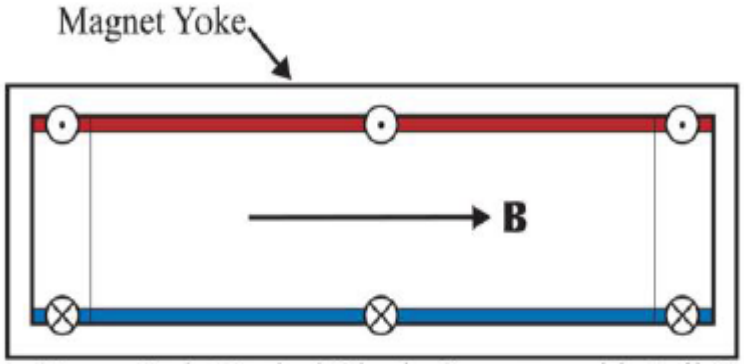
PAC 20007 Proceedings

COMBINED PANOFSKY QUADRUPOLE & CORRECTOR DIPOLE *

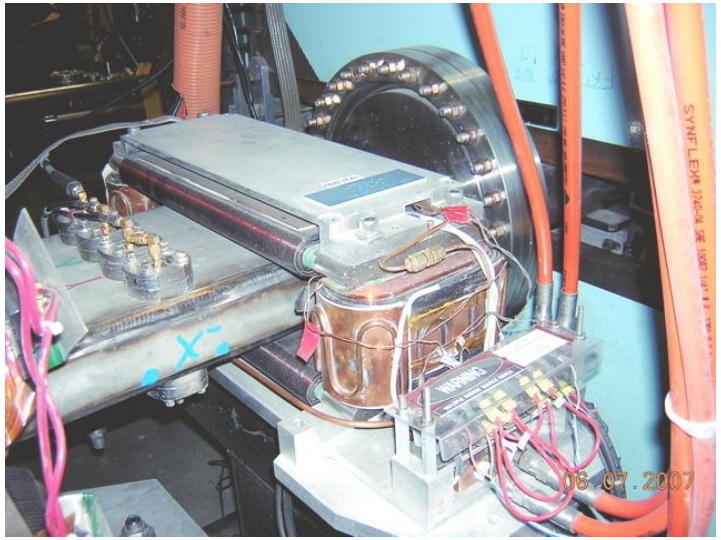
George H. Biallas#, Nathan Belcher, David Douglas, Tommy Hiatt, Kevin Jordan, Jefferson Lab,



Rectangular Panofsky Quadrupole with Coil Currents
(Looking Downstream, Focusing Electrons)



Window Frame Style Vertical Dipole Corrector with Coil Currents
(Looking Downstream, Bending Electrons Up)



George Biallas

Conclusions

- Electron model of multi-pass arc Muon RLA - **JEMMRLA**
  - Efficient use of RF (4.5 passes)
  - No switchyard - single droplet arc on each side of the linac
- Demonstration of a new kind of fixed field accelerator
  - Rapid acceleration for future muon facilities (Neutrino Factory and Muon Collider
- Proof of concept for multi-pass arcs based on combined function magnets
  - Possible medical application for gantry design

Future Initiative:

Develop a Neutron Program

Why Neutrons?

- Neutrons can be produced rather effectively by colliding 50-100 MeV electrons on a solid target (tungsten is best)
- Neutrons are produced more or less isotropically (equally distributed in all directions)
- Possible uses are:
  - Neutron damage studies for nuclear reactor components
  - Studies of cross-sections for nuclear reactors
  - Production of radio-isotopes for medical use
    - Diagnostics and treatment
  - Low power tests of ADS (Accelerator Driven Systems)
    - An accelerator is used for transmutation of nuclear waste or coupled to a sub-critical nuclear reactor to produce power with fewer nuclear byproducts with a shorter half-life

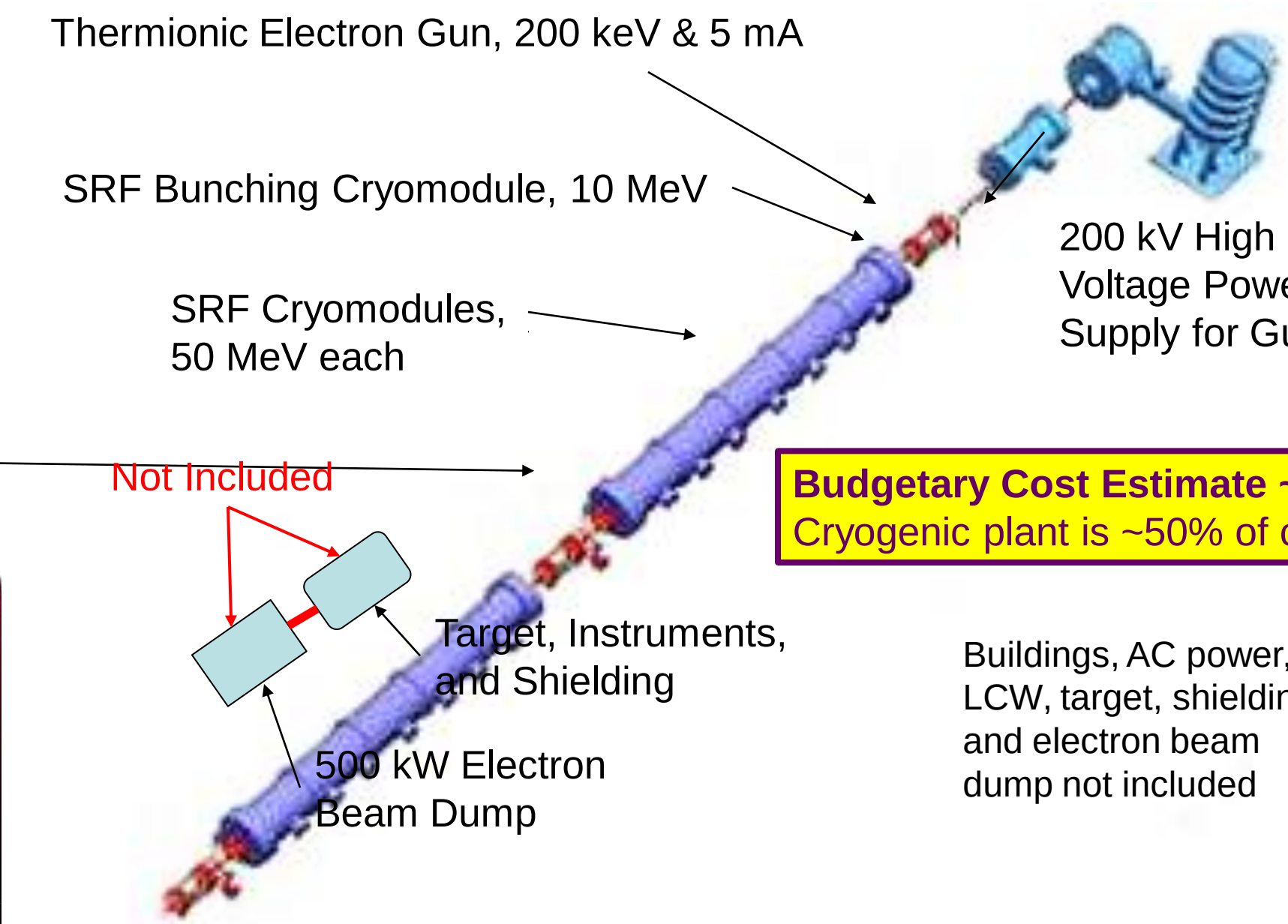
INSIGHTS at Idaho National Lab

Intense Neutron Source Independent Gamma, Hydraulics, and Temperature Separate-Effects

INSIGHTS

- JLab and IAC have been collaborating since 2007 with a jointly funded Faculty Appointment in Accelerator Physics at ISU
- INL contacted IAC (Idaho Accelerator Center at ISU) to design and construct a neutron source for INSIGHTS
  - INL would like 10^{15} neutrons/sec
- I contacted Doug Wells, Director of the IAC, to help with INSIGHTS
  - We reached an agreement on assignment of tasks
    - JLab would lead construction of the accelerator
      - JLab would lead hardware checkout with IAC support
    - IAC would take responsibility for target and facility design
    - IAC would take responsibility for beam commissioning and later operation, whether it is sited at IAC or INL
      - IAC would lead beam commissioning with JLab support
      - IAC would operate and maintain the facility

Proposed Electron Accelerator for Idaho National Laboratory 100 MeV, 500kW



Budgetary Cost Estimate ~$50M
Cryogenic plant is ~50% of cost!

Buildings, AC power, LCW, target, shielding, and electron beam dump not included

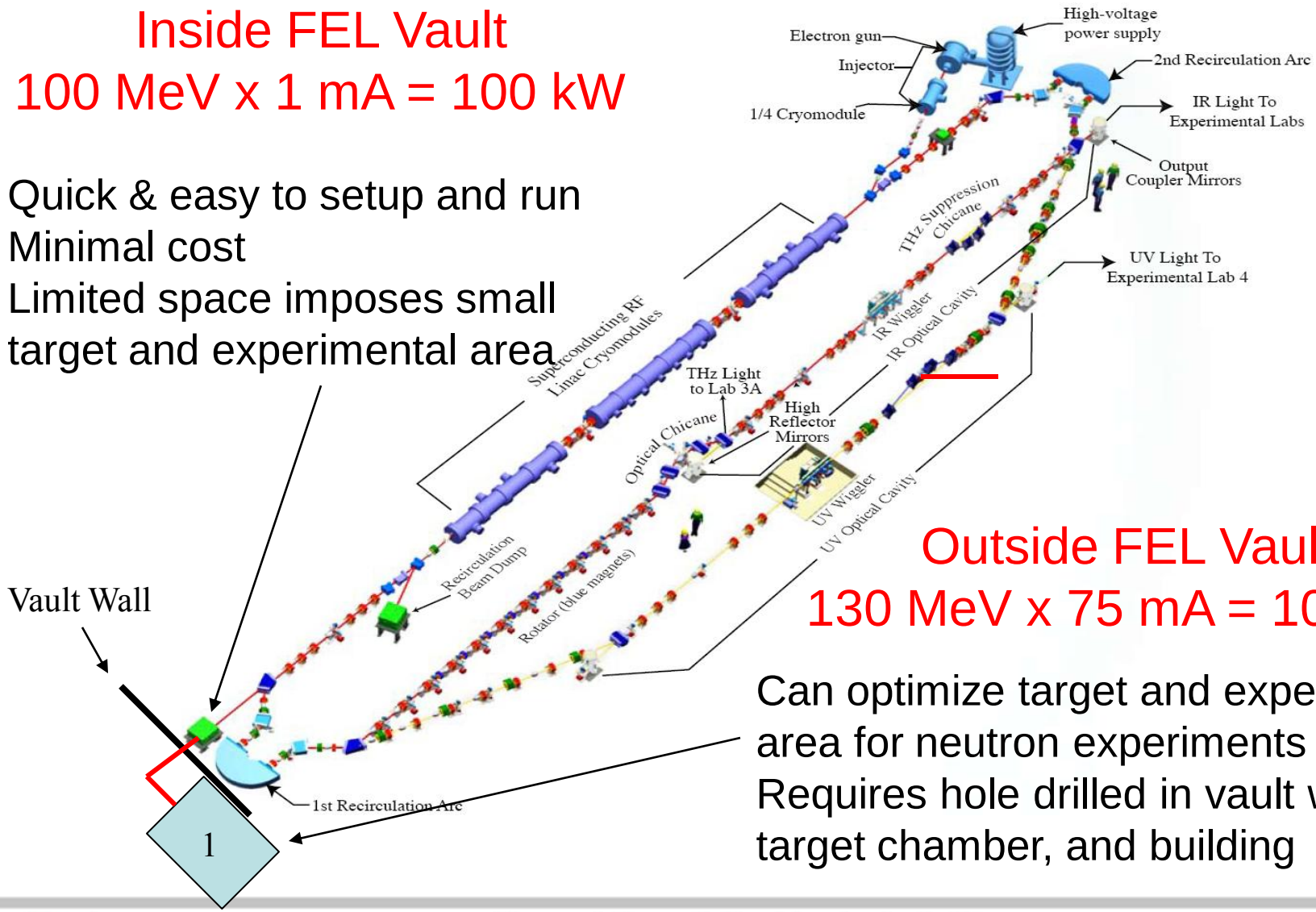
An Ideal Project

- Design the INSIGHTS accelerator as a prototype high-availability ADS driver **(CLEAN)**
  - High availability would be good for INL
    - Provide arbitrary beam interrupt patterns to evaluate the effect on fuel rods and other nuclear materials
  - Would be good for all ADS applications
    - Provides real-life experience
    - Success would reinforce conclusions of White Paper
    - Positive feedback from INL would be more convincing than anything the accelerator builders can say!
- Provides information on all aspects of accelerator reliability
  - Status of accelerator technology
  - Requirements of targets and nuclear materials

Possible Demo Locations with FEL

Inside FEL Vault
100 MeV x 1 mA = 100 kW

Quick & easy to setup and run
Minimal cost
Limited space imposes small target and experimental area



Outside FEL Vault
130 MeV x 75 mA = 100 kW

Can optimize target and experimental area for neutron experiments
Requires hole drilled in vault wall, new target chamber, and building

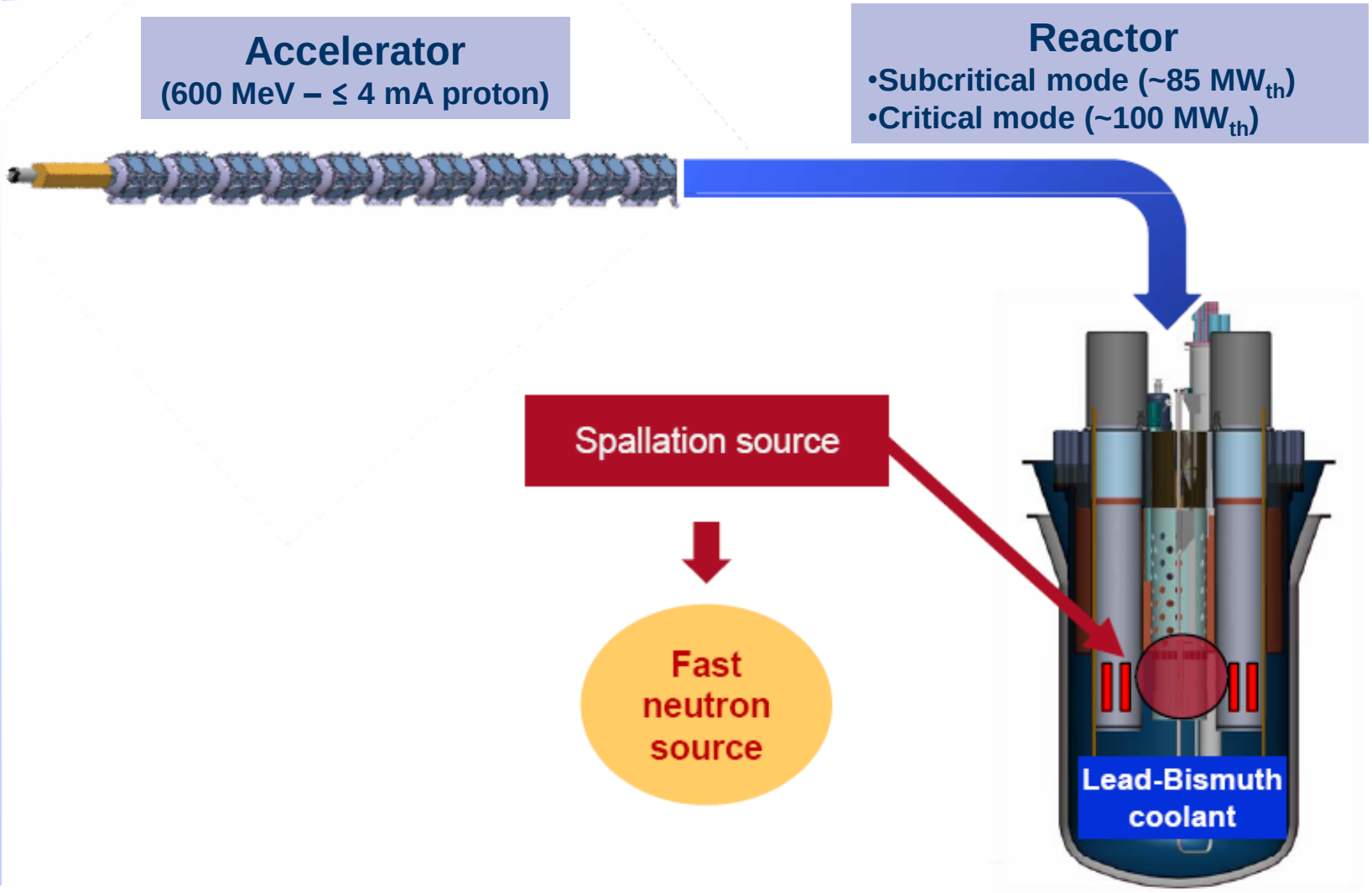
Isotope Production with an Electron Linac

Isotope Production

- IAC has patents on producing some interesting isotopes via e-γ interactions
  - Most interesting is Cu 67 which is both a treatment isotope and can be detected by standard hospital scanning machines
    - Accuracy of delivery can be checked
  - This isotope is cleared for clinical trials, but no-one has succeeded in producing the required specific activity
  - I contacted Tim Hallman to see whether he would accept a joint proposal from JLab and ISU for producing Cu 67
    - Tim was interested
      - Doug Wells is preparing a pre-proposal
      - First tests using a copper linac at IAC
      - Later, use a version of the ICS cryomodule

ADS and MYRRHA

MYRRHA Concept



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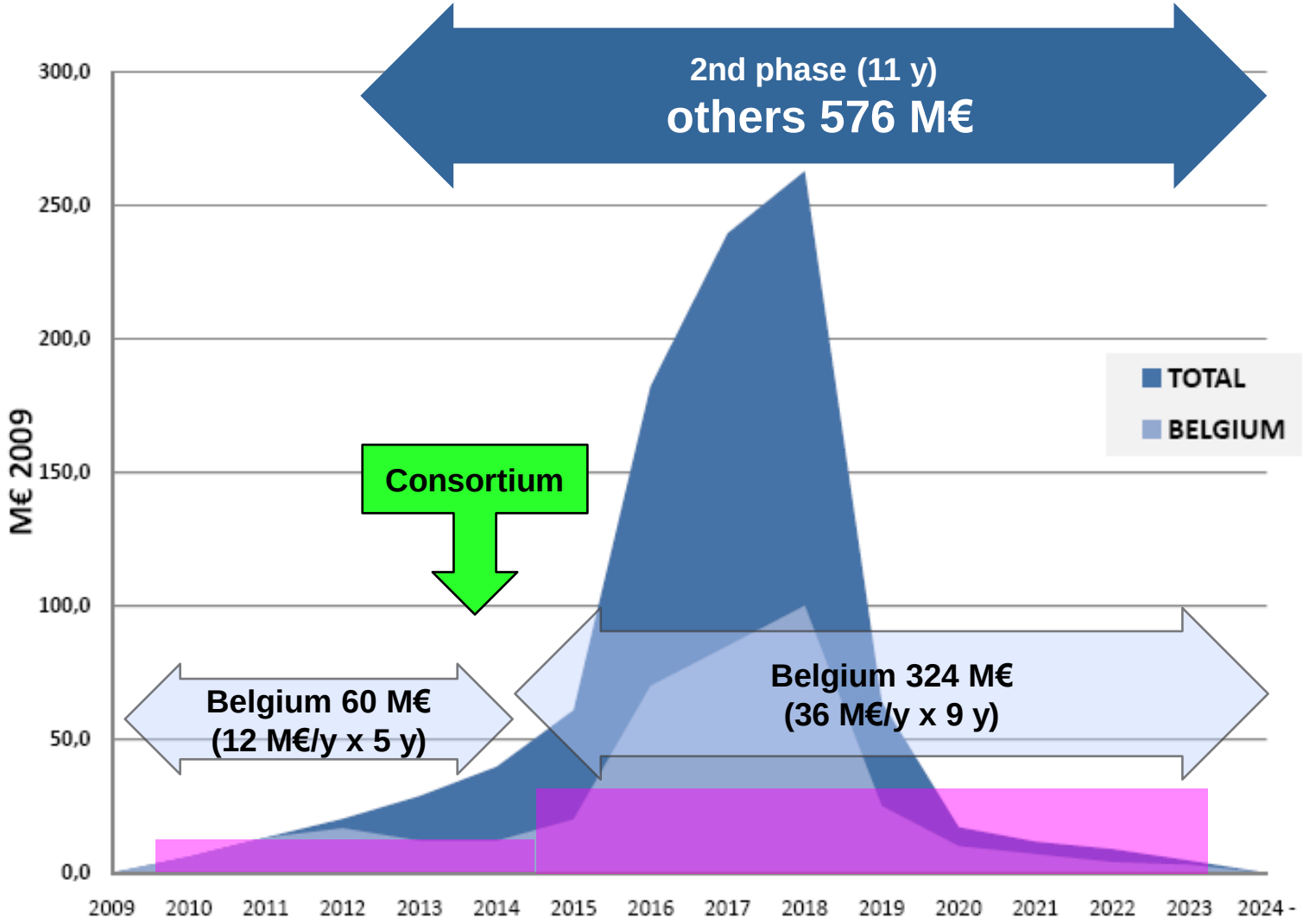
Belgian commitment: secured
International consortium: under construction



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US Participation in MYRRHA

- US participation in MYRRHA would provide a way for the DOE to explore ADS, with the advantage that Belgium is taking responsibility for nuclear regulatory approval
- Andrew's (ambitious) goal:
  - The US would develop enabling technologies for the MYRRHA SRF linac, with JLab having a key lead role in the USA
    - Other DOE labs and other institutions would be integrated into the US effort
- Andrew's (even more ambitious) goal:
  - JLab contribution would be funded by DOE as an "in-kind" contribution to MYRRHA

Strategic Planning Education

Hari Areti

Education Goals

- Four specific goals
  - Align education of next generation of accelerator physicists and engineers with research interests of Accelerator Division
  - Attract promising undergraduates into accelerator science and technologies
  - Launch an accelerator operator training program
  - Increase “Under Represented Minority” (URM) and other minorities participation in the field

Graduate and Undergraduate Students

- Graduate students
  - Assist and strengthen lab's missions specific research
  - Extend research to future possibilities
  - Provide Intellectual stimulation of staff scientists
  - Help attract talented staff to JLab
- Undergraduates
  - Future graduate students
  - Increase probability that undergraduates choose accelerator physics and technology as a career path (NSF and JSA initiatives funds)
    - REU Examples: Kirsten Dietrick, now at ODU
    - Potential: 3 other current students

Graduate Student contributions: Examples

- Center for Injectors and Sources
  - Jonathan Dumas (Universite Joseph Fourier) - *Feasibility Studies of a Polarized Positron Source based on the Bremsstrahlung of Polarized Electrons*
- SRF Institute
  - Hui Tian (College of William and Mary) - *Surface Studies on Niobium for Superconducting Radio Frequency (SRF) Accelerator (*now in the SRF Institute)
  - Daniel Bowring (University of Virginia) - *Multilayer Thin Films for SRF Accelerating Cavities* University of Virginia
- CASA
  - Guimei Wang (Peking University) - *Beam line design and beam physics study of Energy Recovery Linac Free Electron Laser at Peking University*
  - Hisham Sayed (old Dominion University) - *Compensation Techniques in Accelerator Physics*

Undergraduate contributions: Examples

- Center for Injectors and Sources
  - Brian Josey (University of New Mexico) – *Simulation and characterization of solenoid analyzing magnet for PePPo experiment*
- SRF Institute
  - Rachel Bernick (Cornell University) *Characterizing Piezoelectric Tuners for Microphonics Compensation*
- CASA
  - Justin Dolph (Bridgewater College) - *Electron Cloud Buildup in MEIC*

Current Status

- Graduate students mentored by Accelerator Staff
  - Equivalent of 1.5 supported by sources other than JLab
  - Equivalent of 3.5 supported by funding through JLab
  - 12 directly supported by Accelerator Division

- Undergraduate students mentored by Accelerator Staff
  - 4 - 6 students/summer (supported by NSF's REU, DOE's SULI programs)
  - 2 - 3 students during/school year (supported by JSA Initiatives)

5 to 10 Years

- Graduate Students
  - Maintain the number at about the same level
  - Reduce the number directly supported by Accelerator Division by 25%
    - Reduction to be achieved by assisting collaborating institutions in attracting funding
- Undergraduate Students
  - Maintain the funding support from the ODU's NSF REU grant, JLab's DOE SULI program, and JSA initiatives funding
  - Attempt to include Hampton University's REU students

ODU Collaboration: Next 5 years

- Help strengthen CAS at ODU

	Present	5 year goal
Tenured faculty	2	≥ 4
Tenure track faculty	0	≥ 2
Post-docs	1	≥ 2
Graduate Students	10	12

PEOPLE

	Present Support	5 year goal
Tenured faculty	1.5 + 0.5 = 2	≥ 4
Tenure track faculty	0	≥ 2
Post-docs	1	≥ 2
Graduate Students	5 + 5 = 10	12

FUNDING

ODU

JLAB

ODU Collaboration: 5 - 10Years

- Help CAS integration with other ODU department to benefit Jefferson Lab research interests through interdisciplinary programs
  - Engineering – Mechanical and Electrical
  - Applied mathematics
  - Computer science
- Present
  - 4 Engineering Graduate Students
    - 2 with Injector Group
    - 2 associated with CAS

Expanding Collaborations: 5-10 years

- Virginia
  - Partner with Virginia Commonwealth University, Nuclear Engineering – potential for Accelerator Driven Systems (ADS)
- Outside Virginia
  - Idaho Accelerator Center – potential for ADS and medical accelerators
- Goal is to help form
  - A consortium of University groups (starting with ODU, VCU, ISU) with Jlab's Acc. Div. acting as a catalyst
    - Offering Accelerator physics and accelerator engineering programs (interdisciplinary)
    - Attracting funding from agencies such as NSF, DOE, NIH(?)
    - Collaborating with industry

Expanding Collaborations: 5-10 years

- Focus on Pan American
  - Mexico
    - Developed curriculum and helped organize the First Mexican Particle Accelerator School
    - Jlab staff gave lectures
    - Have an agreement for hosting students – A consortium of Mexican Universities will select and partially fund graduate students to study in the US (A. Castillo now at ODU)
    - Expect to help launch accelerator physics offerings at the universities and assist in acquiring a research accelerator
  - Looking forward
  - Work with colleagues in Chile and Brazil– both Accelerator and Nuclear Physics, using or slightly modifying the model with Mexico
    - For us - Source of good students
    - For them - Help acquire research accelerators

Operator Training Program (next 5 years)

- Work with local community colleges to train operators
  - Provide theoretical foundation
    - Basic Accelerator Physics
    - Diagnostics
    - Controls
    - Accelerator systems such as (vacuum, magnets, including Safety systems)
  - Hands on training on the accelerator when possible

Working with TNCC to explore possibilities

Benefits other DOE labs as well

Minority Participation: 5 Years

- Partner with Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions
  - To encourage graduate student participation in accelerator physics and engineering research
  - To engage minority undergraduates in accelerator physics and engineering projects

Try to recruit at least one URM graduate student/year on average

Try to recruit at least one URM undergraduate student/year on average

Lost Opportunities

Were there expansion opportunities/synergies that you missed or that you have not been able to capitalize on? What were they, and what was the obstacle that kept you from realizing that opportunity? Are there lessons to be learned from that experience? Are there likely future opportunities in the same or similar areas?

- Power limitation of 12 GeV Upgrade (1 MW instead of 2 MW)
- Excessive time taken to access non-NP funding makes it extremely difficult to plan and execute the statement of work
  - US-Japan funds
  - CRADAs
  - Some companies now wary of dealing with JLab because of the excessive delays in accessing funds
    - Small businesses have cash-flow problems
- We have rarely lost a contract for external work
  - Occasionally we obtained less than we would have liked
    - Project X
  - Obtaining a contract from Europe has some problems
  - We have never received funds from China or India as part of a collaboration or as WFO

Required New Initiatives

What research, projects or preliminaries would you need to pursue or put in place to achieve the visions above? This should include internal to the lab as well as external.

1. Operate and upgrade the JLab accelerator facilities
   - Fund SRF TEDF equipment to complete robust R&D capability
   - Restore cryogens to the Injector Test Cave to provide a fully capable Injector Test Stand
   - Equipment to populate CTF Expansion (~FY15)
   - RF Test Infrastructure for ITF, CMTF, etc
   - Next generation RF Sources for test facilities

Required New Initiatives – part deux

2. Prepare the future evolution of nuclear physics experimentation at Jefferson Lab

- **Positron Source** - Injector tunnel parallel to existing CEBAF Injector + related utilities
- **Low Energy Positron Program** - Additional underground Experimental Hall
- **24 GeV CEBAF** - New ARC magnets + Additional Acceleration to yield 2.5 GeV per linac pass + related utilities
- **50 GeV CEBAF** - Additional Cryomodules + new ARC magnets + new tunnel + related utilities
- **MEIC** – Ion Complex + Collider + Accelerator + tunnels + related utilities
- **Low Energy Nuclear Physics Program** - FEL to run 1 milliAmp beam for Qweak – requires Hall E
- **Horizontal test cryostat** (SRF)
- **Second CMTF**
- **Exploit ESR II** for Injector Test Facility, Positron Source, and Second CMTF

Required New Initiatives – part trois

3. Expand Jefferson Lab's core accelerator competencies to support DOE Office of Science projects and other partnerships
   - Build a temporary annex to Injector Test Cave to fit the Recirculated Linear Accelerator (RLA) Electron Demo (25m x 7m shielded hall w/ injection @ 3MeV)
4. Attract and educate the next generation of accelerator scientists and engineers

Interlocking Block Wall

- Blocks developed for use as crowd or traffic control
- Can be filled with water or sand
- Used at Integrated Waste Management Project (Idaho) as shielding wall (link)

- Pre-cast, Interlocking Modular Shielding Blocks
  - Potential for short term experimental spaces(link)