Experience in Academia-Industry Collaboration on Accelerator Projects in North America

W. T. Weng
Brookhaven National Laboratory

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Outline

1. Introduction
2. Examples in Accelerator Projects
   LCLS, CLS, ISAC-II, CEBAF-II,
   ILC, RHIC
3. Examples in Accelerator R&D Programs
   SCM, Muon Cooling, LPAF
4. Summary and Lessons

1. Introduction

Reasons and advantages of industrial collaboration

- Proven technology, performance, quality, and cost
- Continuation of supply, maintenance, and upgrade
- Existing expertise and equipments for engagement of finite duration
- Good practice of quality, cost and schedule control
- Competitive bid for best quality and price
- Trial and perfection of pilot technology and process
- Collaboration on development of new ideas and technology

It is impossible to cover all activities, instead, I will present few examples to illustrate the practices and lessons

Undulator of LCLS at SLAC

LCLS PM Undulator

15 Gev electron beam

112 m undulator in

33 sections, 3.4 m

Period/gap 30/6.8 mm

X-ray ~ 1.2 Anstron

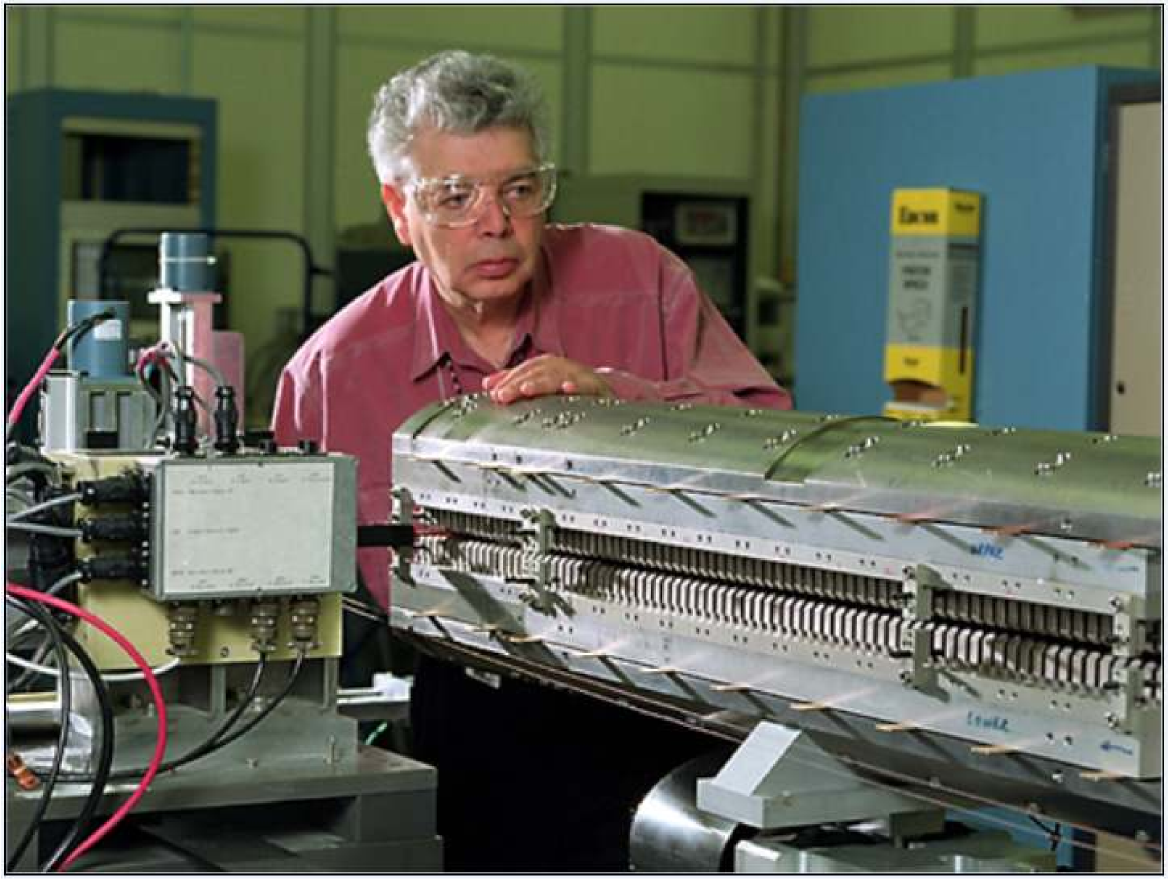
cost $250 K each

Total $9.5M

by, Hi-Texh, Metalex

Shin-Etsu (magnet)

Partner with ANL



Pedestals and Interface plates @ Hi-Tech

Undulator system of LCLS

Collaboration between

SLAC and ANL

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Support & Motion Systems

- Support & Motion Systems (Girders) - 38
  - 1st articles 1.04.03.03.04.03
  - Production 1.04.03.04.03
- Fixed Supports – (Pedestals) - 38
  - 1st articles plus production 1.04.03.08.02
- Awarded to Hi-Tech Mfg. in May 2007
  - Girders subcontracted to Metalex Mfg.

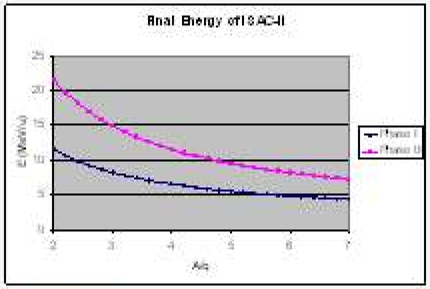
CLS Major Contracts - Booster

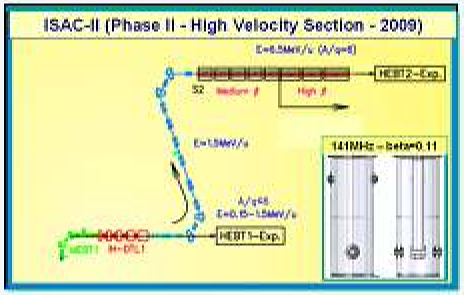
- First major technical contract awarded to Danfysik
  - CLS supplied nominal lattice design
  - Used to validate cost estimates for storage ring
  - Forced development of facility standards and guidelines
  - Allowed CLS staff to focus on storage ring system design
  - “Turn-key” System included:
    - All magnets supplied, pre-aligned on girders
    - All power supplies
    - RF system
    - Vacuum chambers
    - Diagnostics
  - Included installation supervision and commissioning assistance
  - Supply excluded control system, vacuum pumps
- Awarded in 2000 January
- Installation complete in 2002 July
- Commissioning tests complete in 2002 September

CLS Booster Extraction Area

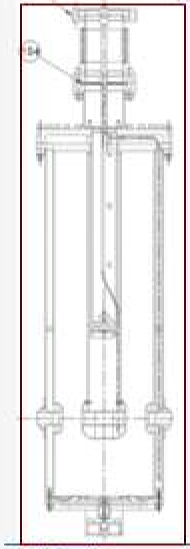
ISAC-II Phase II Linac

- Goal is to boost the energy of the heavy ions above the Coulomb barrier for all masses
- Total superconducting installation voltage of >40MV





Phase II QWR (Beta=0.11)



Parameter	Units	Value
Frequency	MHz	141.44
E_p/E_a		4.9
B_p/E_a	mT/ (MV/m)	10
β_0		0.11
$G=R_sQ_0$	Ω	26

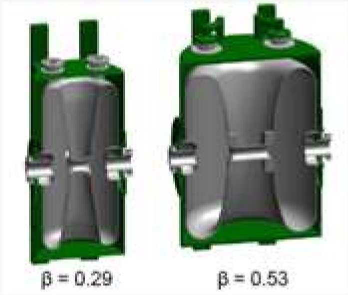
ISAC-II Specification		
P_{cav}	W	7
V_{eff}	MV	1.1
E_a	MV/m	6
E_p	MV/m	30
B_p	mT	60

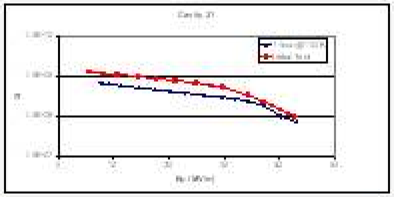
Choose the fabricator

- Write the contract
  - In general the contract will be a technical specification without a performance requirement
    - Not practical since performance based on more than just fabrication and welding (parameters outside contractors control)
      - Performance contract would be expensive
  - Work with the contractor through the mechanical design stage
    - Establish QA procedure early and tweek if required
- Set the schedule
  - Allow time in the schedule for prototyping, analysis of the results and review before proceeding to production

Fabrication - prototyping

- How many prototypes and vendors
  - Depends on resources and size of project
    - 10% of final cavity quantities for each cavity type is reasonable
    - More than one vendor if possible – gives more flexibility during production tender
- Fabrication sequence
  - Work out frequency tuning sequence to arrive at final frequency – build into parts initial sizing
  - Frequency steps should move from coarse to fine to arrive within range of the coarse tuner
- Testing
  - Should plan sufficient testing period to fully characterize all prototype cavities
    - Rf performance, df/dp, Lorentz detuning, Q-disease, microphonics





PAVAC as sole supplier for technology transfer

Two prototype and 20 production cavities were ordered

Cost is $65K/cavity

RF system was installed to be commissioned soon

It also involves in the manufacturing of 1.3 GHz cavity for ILC

TRIUMF

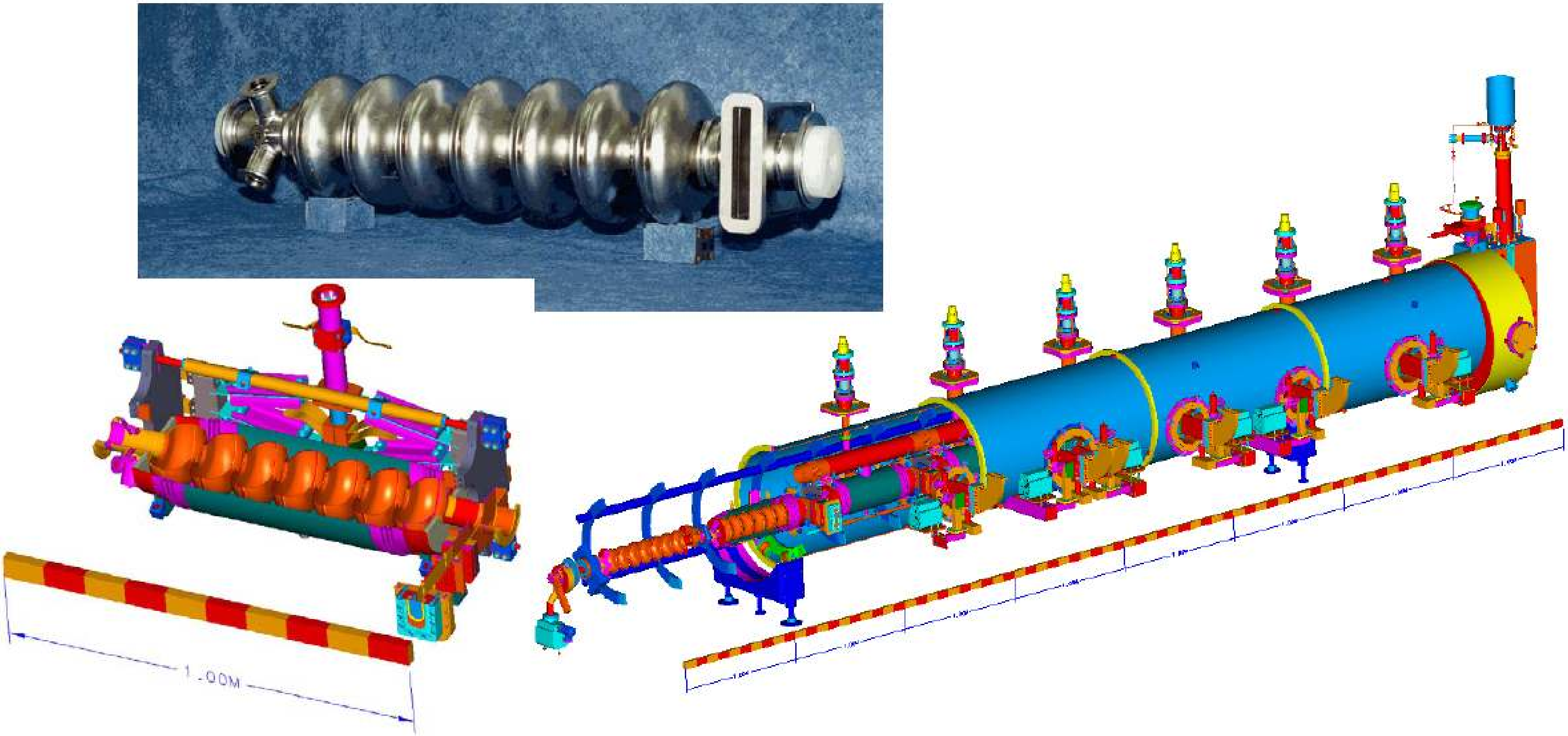
Fabrication - Production

- Keep communication open with vendor
- Frequent site visits
- Depending on vendor may require technical support – pre-weld etching, rf tuning, post production surface treatment
- Work collaboratively to try to stick to schedule
- Follow established QA procedure
- Test cavities as they are produced if possible to look for systematic trends that may feed back on the production process

April 20, 2010 Bob Laxdal, TTC, FNAL 25

CEBAF-II Acceleration System (Cryomodule, RF, Cryogenics)

- **All major contracts have been placed**
- **Cavities are being fabricated by vendor**
- **First cavity string will be complete at JLab in ~September**



CEBAF-II Acceleartion System (Cryomodule, RF, Cryogenics)

Needs 86 cavities
At 22 MeV/m
ACCEL was chosen for value
Among 2 bidders

Needs 84 cold tuner
Incodema was chosen among
8 bidders

20 Cryogenic end cans
Eden Cryogenics was chosen
Among 4 bidders

ILC SRF Cavity Development

ILC calls for SRF cavity to reach 35 MeV/m in vertical test, and 31.5MeV/m in horizontal cryomodule test with about 80% yield by 2012,

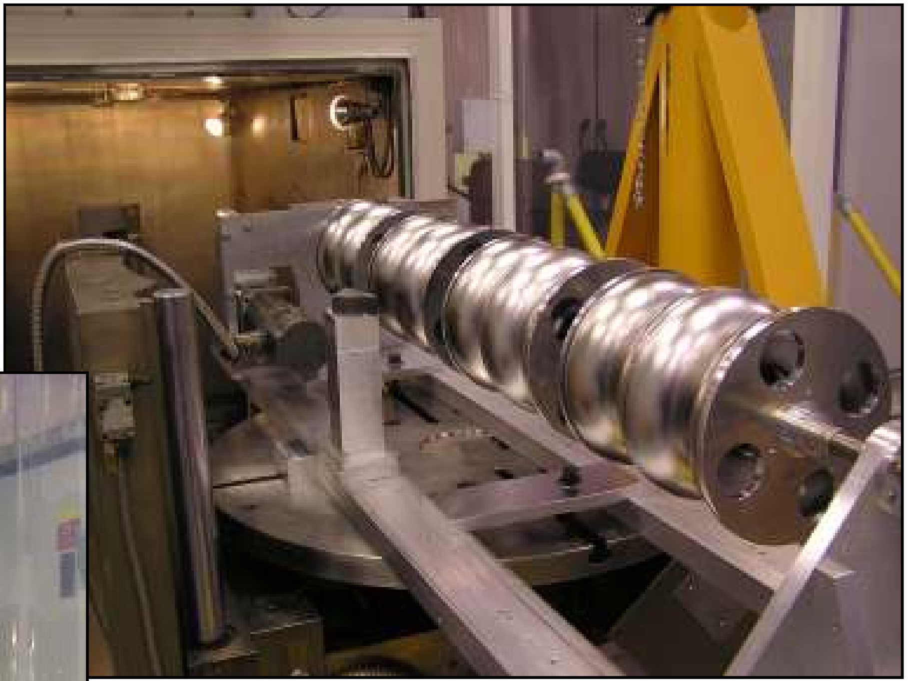
Starting in FY2007, FNAL began to construct a SRF production and testing facility to be completed in 2012 with total investment of about \$120M, as well as about additional \$50M for technology transfer and procurement to US Industries

AES produced 4 cavities in 2007 (Lot 1), 6 in 2009 (Lot 2), 6 in 2010 (Lot 3), and 20 more in 2011-2012

The performance of the cavity produced by AES in Long Island, designed and processed at FNAL/JLAB/ANL, improved from 30% yield in 2007 to 60% in 2009, meeting interim goal set by GDE. A great example of productive academia-industry collaboration in recent time.

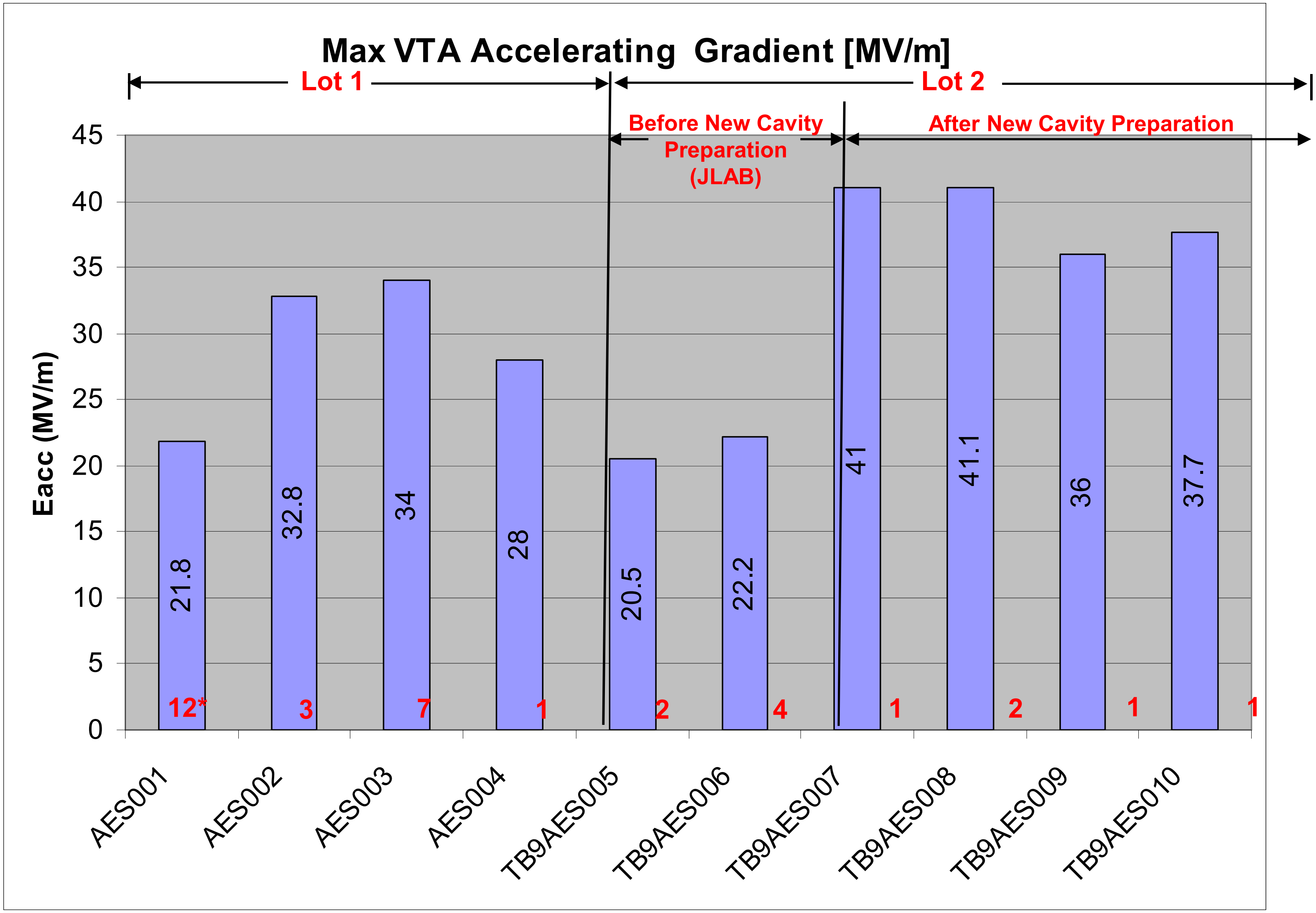
Cavity Assembly – Lot 2

Cavity Final Assembly
(5 Welds in 1 Pumpdown)



4 Double Dumbbells Being Assembled
(4 Welds in 1 Pumpdown)

AES Cavity Test Results (Lots 1 and 2)

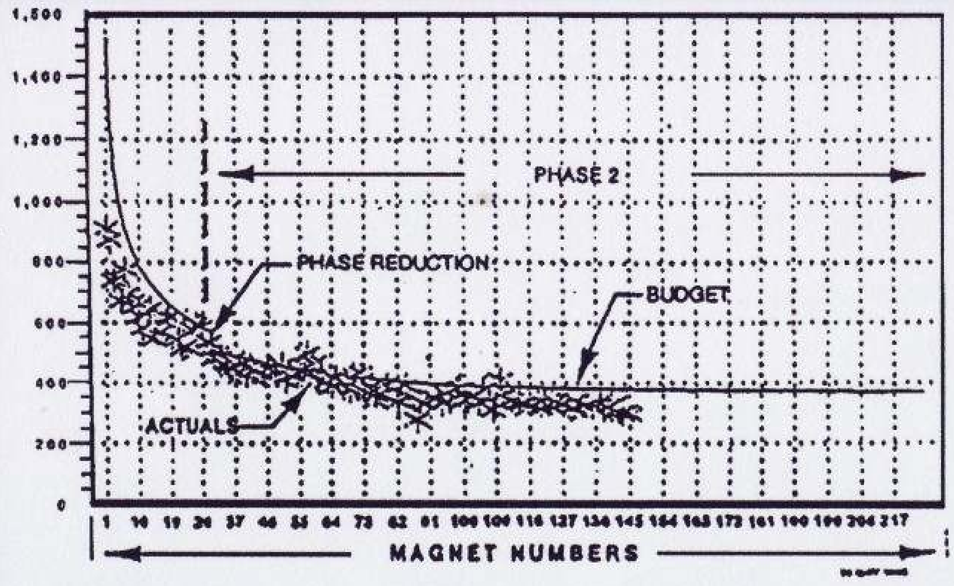


*** Test # for Best Single Test Result for Each Cavity**

Dipoles in RHIC Tunnel

Improving Rate of Production– Learning Curve

- **Grumman/(AES)** experience in the RHIC D and Q Magnet Program
  - High quantity of deliverables - (373) Dipoles & (432) Quadrupoles
  - High rate of delivery - (1) Dipole & (2) Quadrupoles per day
  - Large quantity of detail part feeders to major assembly
  - Technology transfer from laboratory to industry prior to start of fabrication
  - A total of (256) producability improvements resulting in enhanced quality and cost reductions were approved by BNL and implemented.
  - Assembly time was reduced from 900 to 300 hours with huge cost saving
  - Delivery of magnet in Cryomodule
  - Cost plus first 30 units, then fixed cost for the rest
  - No magnet failure



RHIC dipole magnet program. Unit performance - production

3. Examples of accelerator R&D Collaboration with Industries

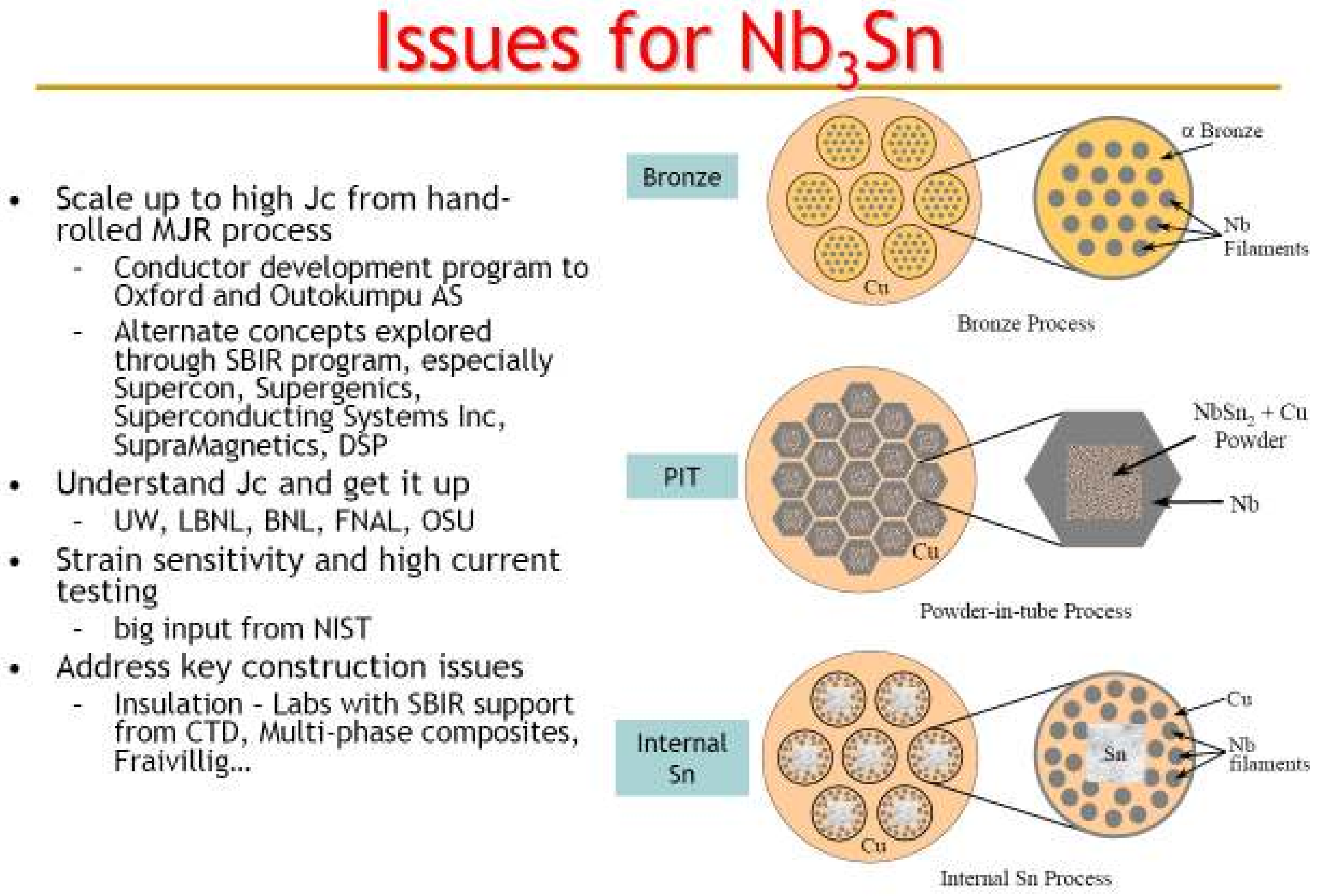
SBIR/STTR of US Program

2.5% of operating budget for SBIR
($18.0M/HEP, $138M/DOE, FY2010)

Phase-I, $100K, 9 Months, for Feasibility (52/145 in 99)
Phase-II, $750K, 24 Months, for Development (23/45 in 99)

0.3% for STTR($2.0M/HEP, $17M/DOE, FY2010)

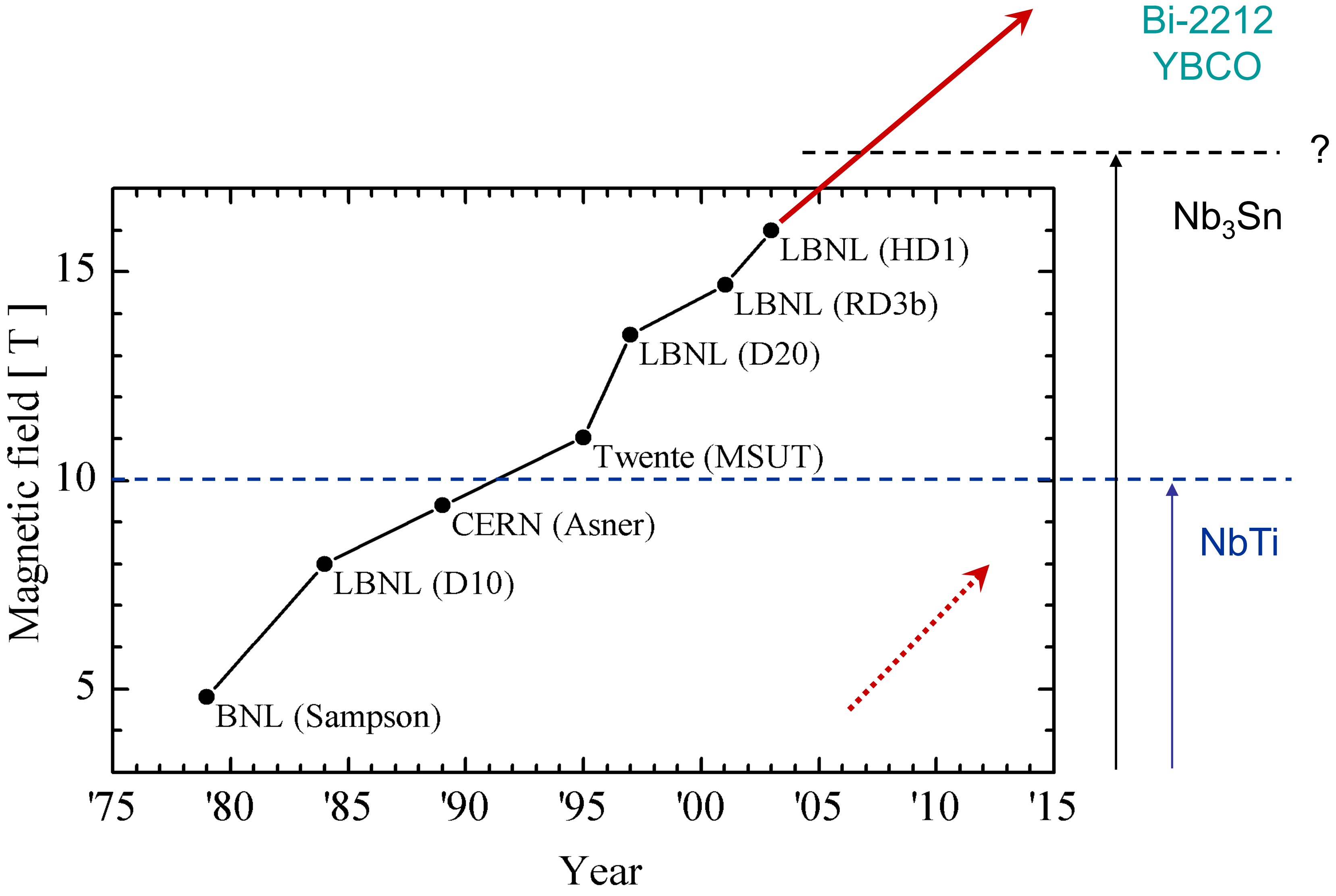
SCM Cable Development



Issues for Nb_3Sn

- Scale up to high Jc from hand-rolled MJR process
  - Conductor development program to Oxford and Outokumpu AS
  - Alternate concepts explored through SBIR program, especially Supercon, Supergenics, Superconducting Systems Inc, SupraMagnetics, DSP
- Understand Jc and get it up
  - UW, LBNL, BNL, FNAL, OSU
- Strain sensitivity and high current testing
  - big input from NIST
- Address key construction issues
  - Insulation - Labs with SBIR support from CTD, Multi-phase composites, Fraivillig...

Progress of SC magnet R&D



SCM Cable by NHMFL and OST

OST was awarded a ITER SC cable contract with total price of about $60M

Major Nb_3Sn achievements

The world's most powerful pulsed superconducting magnet, the150 ton 13 T (approximately 260 thousand times more powerful than the earth's magnetic field) ITER CS Model. The magnet consists of two modules, the inner module fabricated in the US and the outer fabricated in Japan. The two coils were combined at the Naka Fusion Research Establishment test facility of the Japan Atomic Energy Research Institute, JAERI. Photo courtesy of and copyright retained by JAERI.

A 21.3 T Nb_3Sn based superconducting magnet manufactured by Oxford Instruments plc. for a high resolution 900 MHz NMR system by Varian, Inc.. Image courtesy of Oxford Instruments, plc.

Larbalestier – Marx Panel – Fermilab – February 15, 2006

6-D Helical Cooling by Muon, Inc

Compact 6-D cooling

Automatic emittance exchange

Gas-filled RF cavity

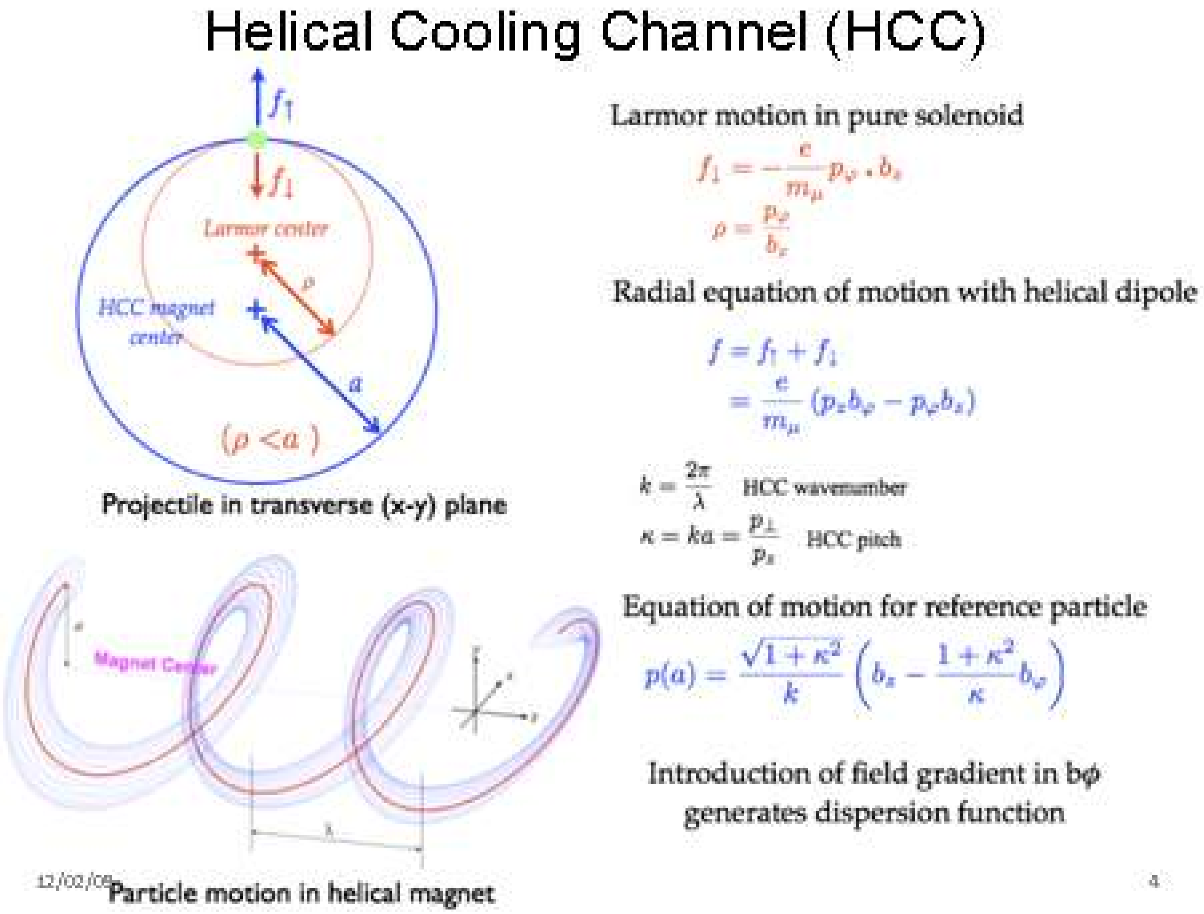
Serve as absorber,

High gradient, high Q

Thin pressure window

10**5 merit factor in 300m

Prototype to be built for Muon Collider application



Helical Cooling Channel (HCC)

Projectile in transverse (x-y) plane

Particle motion in helical magnet

12/02/08

Larmor motion in pure solenoid

$$f_\perp = -\frac{e}{m_\mu} p_\varphi \cdot b_z$$

$$\rho = \frac{p_\varphi}{b_z}$$

Radial equation of motion with helical dipole

$$f = f_\uparrow + f_\perp = \frac{e}{m_\mu}(p_z b_\varphi - p_\varphi b_z)$$

$k = \frac{2\pi}{\lambda}$ HCC wavenumber

$\kappa = ka = \frac{p_\perp}{p_z}$ HCC pitch

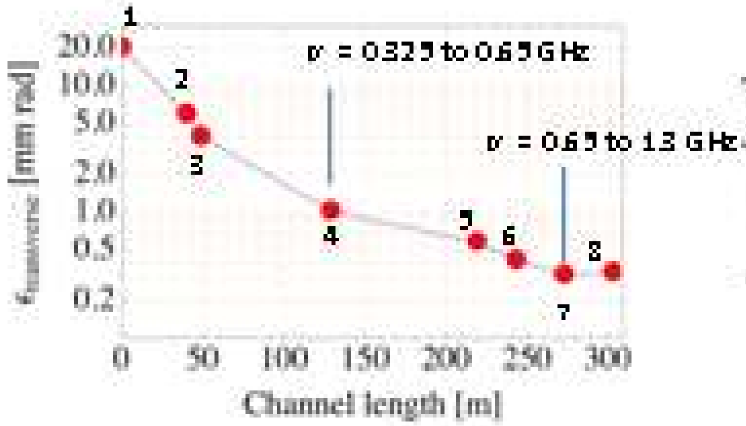
Equation of motion for reference particle

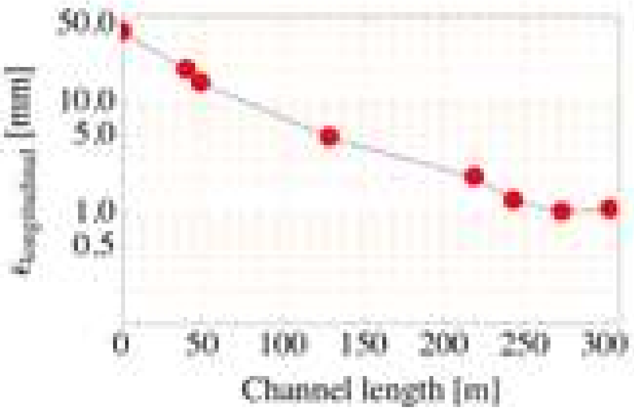
$$p(a) = \frac{\sqrt{1+\kappa^2}}{k}\left(b_z - \frac{1+\kappa^2}{\kappa} b_\varphi\right)$$

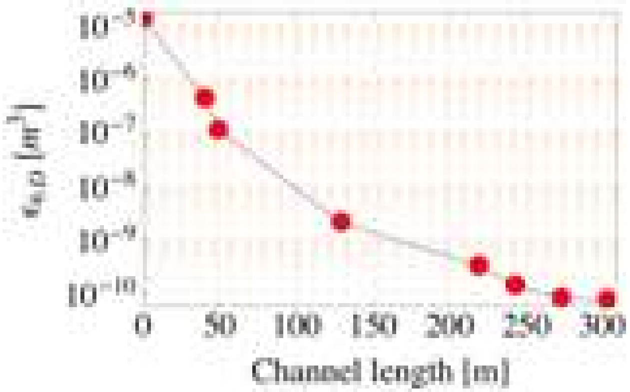
Introduction of field gradient in bϕ generates dispersion function

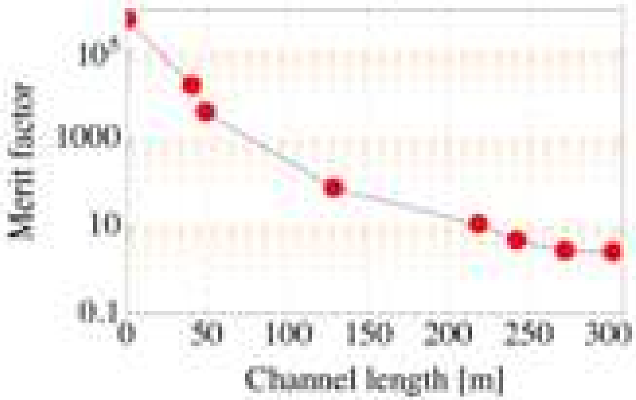
4

Emittance evolution









Merit factor = $\varepsilon_{6D,init}/\varepsilon_{6D,final}$ × Transmission ε

Laser-plasms acceleration, L’Oasis at LBL

30 September 2004

International weekly journal of science

nature

www.nature.com/nature

Dream beam

The dawn of compact particle accelerators

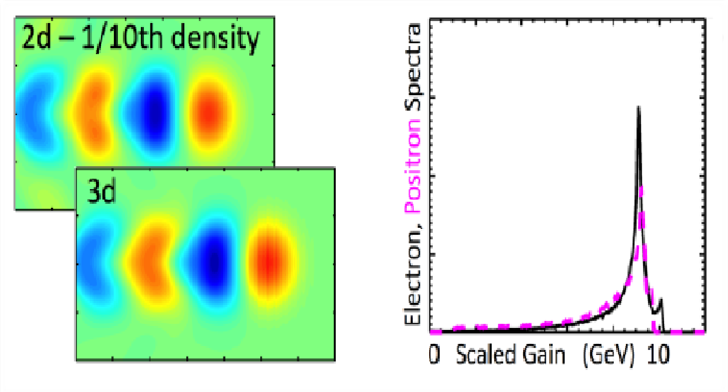
Disease control
Europe plays catch-up

The Earth’s hum
Sounds of air and sea

Protein folding
Escape from the ribosome

Human ancestry
One from all and all from one

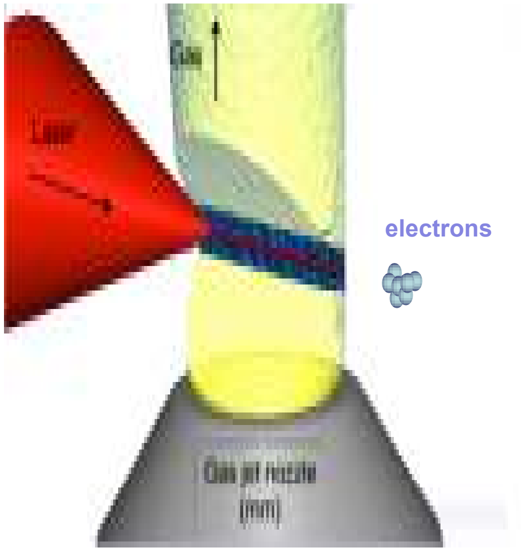
- Plasma accelerators challenge computing due to nonlinear laser/plasma evolution
- VORPAL – developed at TechX via SBIR, models physics of LPA’s:
  - Particle in cell or fluid plasma + envelope/boost reduced (fast) codes
  - Production runs on 10’s of k-cores
  - State of art structure, and now addressing GPUs/new architectures
  - SciDAC colaboration development

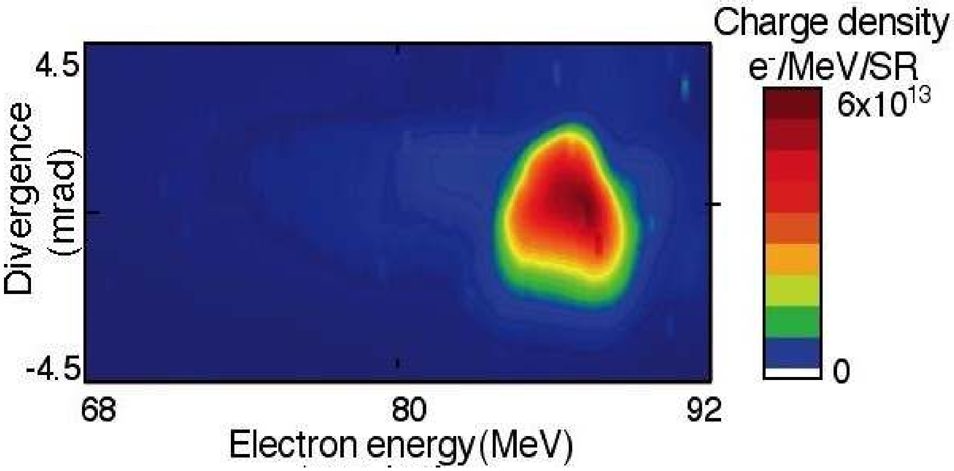


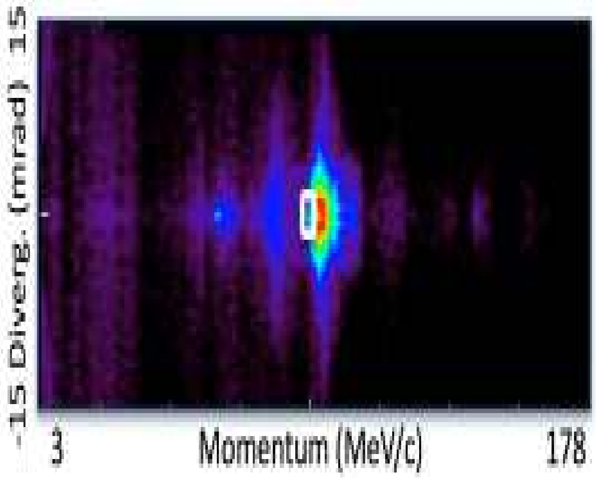
Crucial to wakefield accelerator progress:

- Physics of self-trapped beams, emittance & GeV scaling1
- Downramp injector3
- Design of colliding pulse injector
- Design of 10 GeV stages for BELLA4

10 TW laser, 2mm plasma @ 2x1019/cc







VORPAL accurately model bunch for optimal acceleration parameters through plasma capillary and predict

Gradient ~ 10 GeV/m
Divergence, 3 mrad
dE/E ~ 4%
Epeak ~ 170 meV

4. Summary

A. Good practices for industrial contract;

- Start activity early, it always takes longer than you expect
- Good and mature design of systems and components
- Well written specs and contract to minimize change
- Competitive bidding from many qualified firms to reduce cost
- Add bonus/penalty clauses to control schedule
- Frequent and effective communication and site visit
- Cost plus for initial testing units, then fixed price(RHIC approach)

B. Frequently encountered problems;

- Design/scope changes
- Personnel changes at industry
- Bad communication and record keeping
- Bankrupts of firm
- Sub-standard product needs rework
- Uncertain/varying foreign exchange rate

4. Summary

C. Possible reasons of difficulty in US industrial collaboration in accelerator construction;

- Decline in industrial base
- Unwillingness of big industry to engage
- Complexity in government regulation
- Insufficient number of accelerator projects

D. Robust industrial participation in long term accelerator R&D in US for future projects

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