TWO OPTIONS: 316L SS (FMB, Berlin)
COPPER (SLAC/outside shops)

SS: BESSY-II, ANKA, SLS, CLS, DIAMOND
Cu: B-Factory HER, KEK-B, LINACS, RF Cavities

Outline of Presentations

1. Overview of SPEAR 3 chamber geometry

2. Accelerator Performance Issues
   - Dynamic Pressure
   - Mechanical Properties
   - Impedance
   - Interlocks
   - Orbit Feedback
   - Accelerator Physics Studies

3. SS/Cu (Ben Scott, Ed Daly)
   - performance & construction detail
   - cost
   - schedule

4. System Comparison (Nadine Kurita)
ROUGH COST: 215m @ $15/km = $3.2 M

TOTAL ARTICLE: 63
3 @ MATCH CELL-B/Spare (SET OF 3)
6 @ MATCH CELL-B (SET OF 3)
3 @ MATCH CELL-A/Spare (SET OF 3)
6 @ MATCH CELL-A (SET OF 3)

1 @ Standard Cells (SET OF 3)
42 @ Standard Cells

STANDARD AND MATCHING CELL CHAMBERS

SPAR & VACUUM SYSTEM:
# SYSTEM PERFORMANCE ISSUES

1. **Vacuum Quality**
   - initial bakeout
   - -100 A-h clean-up
   - dynamic pressure: 1.5 nT N$_2$ @ 500 ma
   - recovery from vacuum breaks
   - weld/joint/corrosion/integrity

2. **Mechanical Chamber Stability**
   - magnet clearance/vacuum loading/creep
   - BPM stability vs. power load ($20 \mu$m, $5 \mu$m)

3. **Chamber Impedance**
   - low resistive wall impedance
   - discontinuity/impedance budget
   - stored energy in slot (BPM signal distortion)

4. **Safe Current & Interlock System**
   - high passive safe current/dipole radiation
   - minimum interlock system complexity

5. **Corrector Magnets**
   - field penetration (-3dB > 30 Hz)
   - <5% transverse asymmetry for $\pm$ 2 mm
   - equal frequency response all correctors

6. **Accelerator Physics**
   - maximum current w/o ID’s
   - orbit distortion/correction/feedback/quad shunts
   - injection tuning
   - high current impedance studies
   - turn-by-turn measurements

**Other Issues**
1. power supply ripple attenuation
2. fluorescent backscatter power
3. radiation suppression
4. activation or radiation damage

<table>
<thead>
<tr>
<th>Material</th>
<th>(\text{Cu}/or)(\text{either})</th>
</tr>
</thead>
<tbody>
<tr>
<td>either</td>
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</table>
** Requires CuNi! Inserts under corrector magnets
* Requires flame-spray copper coating, Id protection

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<tr>
<th>Device</th>
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<tr>
<td>Copper</td>
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<td>SS</td>
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(no Interlocks Required)

Passive Safe Operating Current (mA)

- Power loading and operations favors Cu
- Manufacture and operation demonstrated
- Same absorbers, pumps, bellows, flanges
- Either material works for SPEAR 3

SUMMARY OF ACCELERATOR PHYSICS ISSUES
SPEAR 3 VACUUM SYSTEM

SST Girder Chambers

- Chamber Concept:
  - Chamber layouts - girder - naming of chambers
  - Individual chambers
  - Principle of cooling system, x-section showing Cu cladding

- Costs

- Schedule
ID fan collimator and copper cladding are principal differences.

Additional to SPEAR 3 design, possibly requiring prototyping are:

- Pattern
- On prototype PNDB encountered problems with warpage from welding
- Similar design to ANKA
  - Proven technology
  - Ease of modifications and field repair - etc. Fix leak in weld joint
  - Rigid SST BPM blocks
  - Material transitions at absorbers only

(2) ma with water cooled SST only, or 5 ma with 1 mm copper cladding
  - Copper collimator at ID fan exit -- 63 ma
  - Attainable through 1 mm thick copper cladding
  - Dipole mislaser: 60 ma
  - Power distribution for vertical mislaser

Safe run current (no inter lock): 450 ma

Design Features:

**SPEAR 3 VACUUM SYSTEM**
SPEAR 3 VACUUM SYSTEM

Design Features:

- Chamber X-section:
  - ± 17 x 42 mm - 2 mm clearance over ± 15 x 40 mm beam stay clear
  - Absorbers designed for orbit distortion limits:
    Hor. ± 10 mm & 1.3 mrad
    Vert. ± 6 mm & 0.8 mrad
- SST/Cu cladding acceptable for correctors
- Slot height to antechamber: 12 mm standard, 15 mm at ID exit fan collimator
- Deflection under vacuum: specify < 0.02”/side. Initial analysis of BM-2 acceptable
- Weight:
  BM-1 = 410 lbs
  QFC = 270
  BM-2 = 540 lbs
- Tolerances
  - ± 1 mm flatness, 0.5 mm length, 2 mm dipole bend radius, < 0.004” flange perpendicularly
SPEAR 3 VACUUM SYSTEM

SPEAR 3 --- Lin. Pwr in Girder Chb. (vert. misteer to rf slot)
3GeV, 50mA

-------- BM-2 CHB --------

QUAD CHB

-------- BM-1 CHB --------

Distance from BM-2 field (in)

Linear Pwr (W/cm)
Sp3 Vacuum System

- Flux - zinc chloride or, halogen free
- Gemini - SA (SnAg), first MP 425F, MP 550F eutectic
- Tests - soldering water lines - 170 feet per girder

Application rate approx. 5 kg/hr
Prepare surface by sand blasting - surface stress
Density > 90% (polished sample)
Adhesion - 2000 psi + tested by firing in H2 furnace
Properties
- Cladding - 20 Kg per girder
- SSR estimate of copper cladding and soldering water lines
value added tax

research into design time or the photo-type VAT is approximately 16% however we may not have to pay this on the 27K/18 Girders

shipping assuming 10,000lb will be approx 1.00$ /lb air freight

Spear 3 Vacuum System
# SPEAR 3 VACUUM SYSTEM

## 4/28/99 ESTIMATE - SST GIRDER CHAMBER

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<th>ITEM</th>
<th>QTY</th>
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<th>M &amp; S</th>
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<td>123</td>
<td>99</td>
<td>300</td>
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<td>35%</td>
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<tr>
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<td>119</td>
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**JULY 1998 ESTIMATE -- ITEMS NOW COVERED IN 4/28 ESTIMATE**

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<td>Supports - on girder</td>
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<tr>
<td>Fixtures - weld, move, install</td>
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<td></td>
<td>54</td>
<td>119</td>
<td>50</td>
<td>42%</td>
</tr>
</tbody>
</table>

**SCOPE:**
- 15 Standard chamber (prototype treated as a spare)
- 3 ea Matching - type 1 and 2
- Not included - absorbers and masks
- ED & I & labor reduced from July 98 estimate - vendor will deliver complete baked out chambers
When you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind.

- Lord Kelvin

Book ‘em, Dan-O.

- Jack Lord
Outline

- Schedule
- Cost
- Manufacturing
- Design Approach & Layout
- Primary Requirements & Specifications
- Assumptions & Constraints
Assumptions & Constraints

- **Assumptions**
  - Budget taken from July 98 CDR Estimate
  - SLAC Electron Beam Welder & Bldg 031 Large Clean Room Available for Build Cycle
    - Approx. 18 Months from MAR-00 to NOV-01
  - Cost Estimates for BM-2 chamber are applicable to QFC & BM-1

- **Constraints**
  - Maximum Effort/Minimal Time - Is a Copper Chamber Feasible?
    - Developed Designs of Critical Areas, not Entire Chamber
      - Chamber Halves
      - Correctors
      - BPMs
      - EB Weld Joints
    - Cost Estimate
      - Outside Shops Quoted BM-1 Chamber Machining
      - Engineering Estimates for Balance of Parts & Assembly
  - Consistent With Existing Systems
    - No (or at most Minor) Perturbation to existing BSC, pumps & absorbers, magnets, girder and facilities layouts
  - Fixed Budget & Schedule
    - Down starts in April 2002
### Copper Vacuum Chamber Considerations

#### Vacuum Performance
- Bake-Out Temperature: ≤ 200°C
- Thermal Outgassing Rate: Similar to SST
- Atomic Oxygen Test: Met, 500 °C

#### Thermal
- Maximum Passive Safe Operating Current
- Positive Operational Experience in PEP-II HER Arcs

#### Mechanical
- BM-2 Estimated Weight: <500 lbs.
- Section Modulus: Larger than formed chamber
- Deflections & Stresses for Chamber (Deflection Dominated Problem)
  - Weld Stresses: μ/1.5 mm
  - Tolerance Budget: μ/1.5 mm per side
  - Machining: 0.5 mm allowed for twist & bow
  - Assembly: μ/0.5 mm Alignment

#### Fast Feedback & Operations
- Resistive Wall for Copper Lower Than SST
Vacuum System Gas Loads:

**Photon Stimulated Desorption & Thermal Outgassing Rates**

- $\eta_{\text{PSD}} = 2 \times 10^{-6}$ molecules/photon
- Data from PEP-II CDR by Foerster at BNL

- $\eta_{\text{SST}} = 5 \times 10^{-13}$ Torr*liter/sec/cm$^2$
- $\eta_{\text{CU}} = 1 \times 10^{-12}$ Torr*liter/sec/cm$^2$
- Data from Patton Survey of over 50 averaged values
## Comparison
### Passively Safe Current Limits

<table>
<thead>
<tr>
<th>Case Description</th>
<th>SS Only (mA)</th>
<th>SS w/ cu (mA)</th>
<th>SS w/ cu &amp; Collimator (mA)</th>
<th>Cu (mA)</th>
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<td>67</td>
<td>67</td>
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<tr>
<td>Nominal</td>
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<tr>
<td>Worse case mis-steer</td>
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<td>1255</td>
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<td><strong>Dipole-Dipole (Top of Chamber)</strong></td>
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<td>Worse case mis-steer</td>
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<td><strong>Wiggler BL6, 1.1 T (Strike at 11mm vert)</strong></td>
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<td><strong>Wiggler BL6, 1.64 T (Strike at 11mm vert)</strong></td>
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<td>Nominal</td>
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<tr>
<td>Worse case mis-steer</td>
<td>2</td>
<td>5</td>
<td>63</td>
<td>63</td>
</tr>
</tbody>
</table>
Temperature (°C)

- Copper melts at ~1100°C
- SST melts at ~1400°C

Time to melt chamber - >500 msec vs. 100 msec for SST in splices

Reliability

- 50 mA vs. 50 mA for Copper Slug Design

Maximize Safe Current

- Mis-steps allowed at full current without IDs

Maximize Safe Dipole Current

Thermal Performance
Structural Analysis

Copper Chamber, no ribs
less than 0.013" of deflection at slot

1/8" SS, with ribs
less than 0.018" of deflection at slot
SPEAR 3 H/V Correctors

- 0.63 mm Laminations, dI/dt=5300/7500 A/s for Fast Feedback
- Independent magnet vs. added to quadrupoles or sextupoles
- 0.16 m Long, 45 mm aperture
- 1.5 mrad Horizontal Steering, 1 mrad Vertical Steering
Correctors: Field Penetration

- Field Modulation Creates Eddy Currents in Chamber which in turn reduce field strength inside vacuum chamber

- Horizontal Steering Field (Vertical Field Lines) is Limiting Case
  - Plating Produces Asymmetry which can be corrected by compensating plates

- Preliminary MAFIA Analysis of Peak Field at Beam Passage Centerline:
  - SST Chamber - 0.05 T, Acceptable Symmetry
  - SST w/ 1mm Cu Plating - 0.030 T, Compensate Asymmetry
  - Copper - Really Low (based on last runs)
  - Cu-Ni Splice - 0.04 T, Acceptable Symmetry
Design Layout: QFC Chamber Assembly

End View with Flange Adapter Removed

QFC Assembly: Shown with water lines, coil pockets, BPM holes, TSP port and opening for absorber on top.
Remove some as-manufactured chamber supports to girder will

Water cooling lines are routed through pole space above and below chamber

Pole clearance will be re-evaluated to account for magnet, chamber and

Magnet Coils = 3.0 mm per side
Magnet Poles = 2.0 mm per side

Local Clearances: (Very Tight...)

Provide clearance for Machined chamber has pole pockets to

Design Layout: Chamber in Quadrupole Sextupole Magnets
Design Layout: Machined Chamber Halves (Clamshell Approach)

Machined from Plate:
- BM-2 options:
  - Three piece per half - split where bend radius starts
    - Range: $3.6K to $5.25K (2 quotes)
    - Delivery: 6 to 12 wks ARO/ARM
  - One piece per half - no lap joints
    - Range: $5.5K to $7.7K (3 quotes)
    - Delivery: 12 to 31 wks ARO/ARM
- QFC as one piece per half
- BM-1 as one or three pieces like BM-2

Procurement Schedule:
- Material Lead Time: approx. 16 wks from mill
- Duration of Procurement:
  - From 18 to 47 weeks APO to receive full order
  - All Vendors had staggered shipment schedule
Tabs on outside for restraining absorbent pads 
Machine pockets, bump holes, splice cutout 
Vertical Milling Machine with ball nose end mill 
Machine all inside features 
3 Axis Horizontal Drilling Mill, 87° travel - 1 index 
Water jet cut to rough shape 
Purchase rolled plates @ desired thickness to nest 

Machining Process (Champ)
Design Layout: Eddy Current Break in AFC

- Vertical Wall
- OFHC Copper
- Cu-Ni Break
- Vertical Wall
- OFHC Copper

Two Cu-Ni Splice Places
Design Layout: BPM Weld Joint

- Similar to PEP-II HER Arc Quad Chamber BPM Weld Joints (~200 sets)

- BPM Housing Material:
  - CuproNickel 70/30 Electronic Grade

- Comparison of Chamber Wall Thickness:
  - 0.200” Nominal (3.1 mm) for SPEAR3
  - 0.197” Nominal (5 mm) for PEP-II

- BPM Support Block Required for Mount & Position
to provide cooling
Conductor EB Welded
Copper Magnet

Parts
Machined Chamber
Sheet Metal &

Welded Joints
Chamfering EB
Technically
An Example of

EB Joints in Q2 Chamber - Flange Adapter Weld
EB Weld Sequence

First Set-up
- Perform Axial Welds (no flip)

Second Set-up
- Tack fixtured components
- Flip chamber
- Tack & weld
- Flip & weld

Set-up #1, Two Axial Welds
Set-up #2, Weld Flange Adapters
Set-up #2, CuNi Splice
Set-up #1, Two Axial Welds
Set-up #2, Cooling Bar
Set-up #2, BPM
Set-up #2, Weld Flange Adapters
EB Joints in Q2 Chamber - Axial Welds

- EB Can minimize distortion compared with other techniques

- Additional weld beads can be placed to correct certain types of distortion (e.g. bowing, curvature)
EB Joints in Q2 Chamber - Additional Tooling

0 Process Tooling
  ☀ 1st Weld Set-Up
    ➢ Axial frame for stiffening during welding
  ☀ 2nd Weld Set-Up
    ➢ Local clamps for bpms, Cu-Ni break, Flange Adapters, Cooling Lines

0 Part & Assembly Size Limitations
  ☀ Primarily due to valve opening in Load Lock
  ☀ Main Chamber is 6’ Wide
  ☀ Load Lock & Run-Out Chamber Length not an issue
<table>
<thead>
<tr>
<th>Item</th>
<th>Est. 1999 Estimate</th>
<th>May 1999 Estimate - Copper Girder Chamber</th>
<th>Estimated Costs Compared Against Budget</th>
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<td>Analysis of Standard &amp; Matching Chambers</td>
<td>Fri 5/7/99</td>
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<td>Mon 10/4/95</td>
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<td>Tue 11/30/95</td>
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<td>Tue 4/4/00</td>
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<td>Tue 4/18/00</td>
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<td>Chamber Production</td>
<td>Wed 4/15/00</td>
<td>Tue 11/27/01</td>
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<td>13</td>
<td>Vacuum Processing</td>
<td>Wed 6/14/00</td>
<td>Tue 12/25/01</td>
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<td>14</td>
<td>Chambers Ready For Installation</td>
<td>Tue 8/8/00</td>
<td>Tue 1/22/02</td>
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<td>15</td>
<td>First Chambers RFI</td>
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<td>Last Chambers RFI</td>
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<td>Tue 1/22/02</td>
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<td>17</td>
<td>Six Month Down Begins</td>
<td>Mon 4/1/02</td>
<td>Fri 9/27/02</td>
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Comparison and Summary

May 6, 1999

Nadine Kurita
Technical

- **SS w/ Cu Insert & Cu Plating**
  - **Technical Performance**
    - Safe Running Current
      - Insertion Device: 63 mA
      - Dipole: 60 mA
    - Time to melt: >500 msec
    - Thermal Stability
    - Collective Effects/Impedance
      - Meets current impedance budget & may not need for feedback with 2% chromaticity
    - Correctors
      - Acceptable with Cu Coating and compensating plates
    - Interlock BPM's for Dipole and ID's
    - Vacuum performance

- **Copper Chamber**
  - **Technical Performance**
    - Safe Running Current
      - Insertion Device: 63 mA
      - Dipole: >500 mA
      - Less components at risk for failure
    - Time to melt: >500 msec
    - Thermal Stability: improved
    - Collective Effects/Impedance
      - Increase beam stability threshold and reduce the need for feedback
    - Correctors
      - Better than SS with CuNi Insert
    - Interlock ID BPM's only --> reducing complexity and cost of interlock system
    - Vacuum performance comparable to SS
## Budget

- **Stainless Steel/Cu Chamber**
  - **Cost**
    - ~$300K less than Copper
    - Final cost is fixed after RFP

- **Copper Chamber**
  - **Cost**
    - Within CDR Budget
    - Labor Cost Control at SLAC
    - $100K savings for decrease in complexity of interlock system
    - $??? savings for machine maintenance and check out time over operational years

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<tr>
<th></th>
<th>ED&amp;I</th>
<th>M&amp;O</th>
<th>LABOR</th>
<th>TOTAL</th>
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Engineering Summary

- **Stainless Steel** allows
  - no need for a corrector splice,
  - lower cost and cost contingency,
  - greater schedule risk,
  - plasma spraying of copper

- **Copper** allows
  - greater thermal stability,
  - higher safe operation current, \(\Rightarrow\) greatly reducing chance for a failure,
  - decrease the complexity and cost of the interlock system,
  - increase beam stability threshold and reduce the need for feedback,
  - more control over the schedule,
  - higher cost risk, but can be monitored regularly.

- **Both designs** meet physics requirements
- **Both designs** are on schedule
- **Both designs** can be built for the CDR Estimate
Schedule

Manufacturing

More manpower to expedite

Able to modify staffing in shops & hire

Less schedule contingency required

SSRL Local Vendors

Ready for installation Jan 02

Final Design Review Oct 99

Copper Chamber

Schedule

Stainless Steel/Cu Chamber

Schedule

- No SRL control of schedule
- Unknown contingency
- Foreign Source/Sub-Contractors
- Ready for installation Jan 02
- Easy - procurement package: only 4 months
- Final delivery date hinges on FDR and
  RFP: Ready by Sept 99
- FDR Review (FDR) Sept 99