How to operate Spectrometer and Dump safely?


A. Overview, General Information
B. Information on special Components
C. Philosophy of Optics & Layout
D. Status, Time Schedule
E. Questions, Next Steps
A: Overview
A: General Information

Tasks of this Section

1.) Spectrometer,
   • measure energy with accuracy of:
     relative energy spread \((\Delta p/p)_{\text{rel}} \leq 1 \cdot 10^{-4}\)
     absolute energy measurement \((\Delta p/p)_{\text{abs}} \approx 1 \cdot 10^{-3}\)
   • momentum acceptance \((\Delta p/p)_{\text{max}} \geq \pm 3\%\)

2.) Beam Dump, i.e. absorb beam with:
   • beam energy \(E_0 \leq 1.6\) GeV
   • bunch train population \(N_t \leq 4 \cdot 10^{13}\) e-
   • bunch train repetition \(\nu_t \leq 10\) Hz
     \(\Rightarrow\) average beam current \(I_{\text{ave}} \leq 64\) μA
     average beam power \(P_{\text{ave}} \leq 102\) kW
     energy per bunch train \(W_t \leq 10.2\) kJ

Geometry of this Section

• 7° tilt of deflection plane wrt. vertical plane
• 19° = 331.6 mrad deflection angle of dipole
  \(\Rightarrow D(s) \approx s/3\) (s: drift space behind dipole)

• main axes of components in beam line
  \(\parallel\) and \(\perp\) wrt. deflection plane
• quite „crowded“ region,
  3 beam lines close together
• re-use old TTF1 dump and modify by:
  40cm front part extension
  ⇒ average heating in Al reduced
  slow beam sweeping \( r_{\text{slow}} = 2 \text{cm} \)
  ⇒ average heating in C and Al reduced
  • beam spot at dump entrance \( \sigma_x \cdot \sigma_y \geq 1 \text{mm}^2 \)
  ⇒ instantaneous heating in C max. \( \approx 250 \text{K} \)
  • max. temperatures just after bunch train
    in graphite \( \leq 400 \text{°C} \) (+200K w/o sweep)
    in aluminum \( \leq 250 \text{°C} \)
  • dump operates at normal atmosphere
  • design on basis of 2GeV / 130kW
  ⇒ limit for \( P_{\text{ave}} \) at const. power density:

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<thead>
<tr>
<th>( E_0 [\text{GeV}] )</th>
<th>0.4</th>
<th>0.8</th>
<th>1.2</th>
<th>1.6</th>
<th>2</th>
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<tbody>
<tr>
<td>limit of ( P_{\text{ave}} [\text{kW}] )</td>
<td>87</td>
<td>108</td>
<td>120</td>
<td>125</td>
<td>130</td>
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</table>

• 2 (1 + 1 spare) modified absorbers ready
  1 absorber is installed in place

Temperature profile in dump
right after bunch train passage
(M. Maslov et al.)

Steady-State + Pulse Full Length = 165 cm (added block length = 40 cm)
B: Beam Exit Window (1)

1.) General Design Concept (M. Maslov, Protvino)
   - C-Ti-C sandwich
     Ti: + for cyclic stress & vacuum tight, bad thermal conductor
     C: supports Ti and transports heat to external cooling
   - Limits: \((\Delta T_{\text{inst}})_{\text{max}} \leq 250K\) in Ti, \(T_{\text{abs}} \leq 400^\circ\)C in C & Ti

2.) Instantaneous Heating
   \[
   (\Delta T_{\text{inst}})_{\text{max}} = \frac{1}{\rho} \frac{dE}{dz} \cdot (\frac{dN}{dA})_{\text{max}} \cdot \frac{1}{e} \cdot (\frac{dN}{dA})_{\text{max}} = \frac{N_i}{2\pi\sigma^2}
   \]
   lower limit of spot size at window with factor 5 safety
   \[
   \Rightarrow (\frac{dN}{dA})_{\text{max}} \leq 1.3 \cdot 10^{12} \text{ e-}/\text{mm}^2 \Leftrightarrow \sigma_x \cdot \sigma_y \geq 5\text{mm}^2
   \]

3.) Equilibrium Heating
   a) with 2cm sweep
   \[
   (\Delta T_{\text{eq}})_{\text{max}} = \frac{1}{\rho} \frac{dE}{dz} \cdot \rho \cdot \frac{l_{\text{ext}}}{e} \cdot \frac{1}{2\lambda} \cdot \ln\left(\frac{R_{\text{sweep}}}{R_{\text{ave}}}ight)
   \]
   b) without sweep
   \[
   (\Delta T_{\text{eq}})_{\text{max}} = \frac{1}{\rho} \frac{dE}{dz} \cdot \rho \cdot \frac{l_{\text{ext}}}{e} \cdot \frac{1}{4\lambda} \cdot \ln\left(1 + \frac{R_{\text{sweep}}^2}{2\sigma^2}\right)
   \]
   * \Rightarrow good thermal contact between Ti-C important

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<tr>
<th></th>
<th>((\Delta T_{\text{inst}})_{\text{max}}) [K]</th>
<th>((\Delta T_{\text{eq}})_{\text{max}}) [K]</th>
<th>Power dissip. [W/mm]</th>
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<tr>
<td></td>
<td>with sweep</td>
<td>without sweep</td>
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<tr>
<td>(\sigma^2)</td>
<td>5mm²</td>
<td>1mm²</td>
<td></td>
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<tr>
<td>C</td>
<td>39</td>
<td>195</td>
<td>16.3</td>
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<tr>
<td>Ti</td>
<td>57</td>
<td>285</td>
<td>43.2</td>
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</table>

* assumes no heat transfer to C

Protvino Construction
Ti-C contacts are pressed only

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<tr>
<th></th>
<th>(\rho) [g/cm³]</th>
<th>(c) [J/(g·K)]</th>
<th>(\lambda) [W/(m·K)]</th>
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<tbody>
<tr>
<td>C</td>
<td>1.7</td>
<td>0.8</td>
<td>70</td>
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<tr>
<td>Ti</td>
<td>4.5</td>
<td>0.55</td>
<td>17</td>
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</table>
4.) DESY exit window construction (T. Wohlenberg)
   - take geometry from Protvino design, but
     braze Ti and C together instead of pressing
     
     pressed: $\approx 0.14 - 0.25 \text{ W/(cm}^2\cdot\text{K})$
     brazed: $\geq 0.8 \text{ W/(cm}^2\cdot\text{K})$
     $\Rightarrow$ improved and long term stable thermal contact
   - all brazing pre-tests were successful
   - construction finished
     all parts manufactured for 2 windows
     $\Rightarrow$ brazing of 1. final window starts now
   - venting the small volume between dump and window
     with dry nitrogen gas, $\approx 1$-10 l/day
     $\Rightarrow$ protection of atmosphere side of window against
     aggressive substances like ozone or NO$_x$
   - 1 complete Protvino window is at DESY and serves
     as fall back solution
B: Slow Sweeper

- A sextupole magnet is modified, to give 3 dipoles (1-1', 2-2', 3-3') rotated by 120°. This results in a space-saving rotating dipole field.

- Driver for the 3 power supplies is built by MKK. The 3 outputs are 120° shifted in phase but have the same amplitude. The sweep frequency is approximately 1 Hz, but of course, it is not synchronous with the bunch train repetition.

- A HERA-e sextupole type HSK is used. The bore is Ø=96 mm, the iron length is 280 mm, and the maximum current is 45 A.

- B-field measurement and calculation have been done, but not yet evaluated.
C: Layout

Layout Goals + Given Space
⇒
Position of Components
No Room to Play!
**C: Layout Goals**

1.) Dispersion at Diagnostics: No Quad Influence & as Large as Possible

⇒ diagnostics in drift as far as possible from D6DUMP

\[ \text{OTR res.} \geq 50\mu m \ \& \ \text{(Δp/p)rel} \leq 1 \cdot 10^{-4} \rightarrow D_{\text{OTR}} \geq 0.5m \ \Leftrightarrow \ s \geq 1.5m \]

2.) Momentum Acceptance ≥ ±3% ⇒ Dispersion limiting Quad Q10DUMP as close as possible to D6DUMP

45mm aperture radius → \( D_{\text{max}} \leq 45mm/3\% = 1.5m \ \Leftrightarrow \ s \leq 4.5m \)

3.) Beam Conditions at Window:

a) \( D \approx 0 \) (beam pos. independent of dipole variation)

b) \( \frac{dN}{dA}_{\text{max}} \leq 1.3 \cdot 10^{12} \text{ e-/mm}^2 \) (inst. heating)

⇒ 2 large apert. Quads Q10DUMP & Q11DUMP behind diagnostics

use QC: bore Ø=100mm, \( l_{\text{iron}} = 1m, I_{\text{max}} = 350A, (k \cdot l)_{\text{max}} = 2.76/m @1.6\text{GeV/c} \)

4.) Pure Drift ≥ 2.5m between Sweeper and Dump ⇒ Sweeper is last Magnet

5.) Dispersive Behaviour of Spectrometer (except sign) independent of

whether the beam comes from EXP or BYP

⇒ 1 Quad Q4DUMP exactly between D1DUMP and D6DUMP

requires fixed strength of \( k \cdot l = 0.83/m \) \( \Leftrightarrow \ g \cdot l = 5.6T @2\text{GeV/c} \)

use TQF: bore Ø=70mm, \( l_{\text{iron}} = 340mm, I_{\text{max}} = 250A, (g \cdot l)_{\text{max}} = 6.38T \)

6.) β-Focus at OTR at least in dispersive plane, required only during Δp/p measurement at reduced \( N_t \)!
C: Optics Philosophy

- Q10/Q11DUMP should also have fixed strength (like Dipoles, Sweeper and Q4DUMP)
  \[ \Rightarrow \text{Field of all Spectrometer Magnets scales linear with Momentum} \]

- 2 Operation (Optics) Modes
  
  **Mode A: Full Intensity Mode** without OTR screen measurement requires

  A1 a: \( D(\text{window}) \approx 0 \text{m}, \) b: \( D(D6DUMP) = 0 \text{m} \) & \( D^*(D6DUMP) = -D^*(D1DUMP) \)  
  b) is task of Q4DUMP

  A2: \( (\beta_x \cdot \beta_y)^{0.5} \approx 8000 \text{m at window}, \) because 
  \[ \left( \frac{dN}{dA} \right)_{\text{max}} = 1.3 \cdot 10^{12} \frac{e^{-}}{\text{mm}^2} \geq \frac{N_t}{2\pi \sigma_z \sigma_y} \Rightarrow \sqrt{\beta_x \cdot \beta_y} \geq \frac{N_t \cdot \gamma}{2\pi \cdot \epsilon_n \cdot \left( \frac{dN}{dA} \right)_{\text{max}}} \]
  
  for \( \epsilon_n = 2 \cdot 10^{-6} \text{m}, \gamma = 3200 (1.6 \text{GeV}/c), N_t = 4 \cdot 10^{13} \)

  **Mode B: OTR \( \Delta p/p \) Measurement**, few bunches \( \rightarrow N_t \) strongly reduced (e.g. 30 bunches=30 \cdot 4nC= 7.5 \cdot 10^{11} )

  B1: same as A1)

  B2: \( (\beta_x \cdot \beta_y)^{0.5} \approx 150 \text{m at window}, \) for \( \epsilon_n = 2 \cdot 10^{-6} \text{m}, \gamma = 3200 (1.6 \text{GeV}/c), N_t = 7.5 \cdot 10^{11} \)

  B3: beam size at OTR must be dominated by dispersion, i.e \( D_{\text{OTR}} \cdot \left( \Delta p/p \right)_{\text{min}} \gg \sqrt{\beta_{\text{OTR}} \cdot \epsilon_n / \gamma} \)
  \[ \Rightarrow \beta_y \approx 0.1 \text{m at OTR}, \] for \( D_{\text{OTR}} = 0.8 \text{m}, \Delta p/p = 10^{-4}, \epsilon_n = 10 \cdot 10^{-6} \text{m}, \gamma = 400 (200 \text{MeV}/c) \)

- Optics at the output of EXP or BYP has to be adjusted, in order to fulfill Mode A or B

  beam from EXP: optics calc. (M. Koerfer) show feasibility

  Q10: \( k \cdot l = \text{const} = -1.04/\text{m}, \) Q11: \( k \cdot l = \text{const} = +2.68/\text{m} \)

  \[ \rightarrow \text{more detailed studies necessary:} \]

  e.g. beam from BYP, tolerances wrt. energy- and optic-error

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<tr>
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<th>at OTR</th>
<th>at window</th>
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<tbody>
<tr>
<td>( \beta_x )</td>
<td></td>
<td>( \approx 8000 \text{m} )</td>
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<tr>
<td>( \beta_y )</td>
<td></td>
<td>( \approx 8000 \text{m} )</td>
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<tr>
<td>( \beta_x )</td>
<td>( 90 \text{ m} )</td>
<td>( \approx 0 )</td>
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<tr>
<td>( \beta_y )</td>
<td>( 300 \text{ m} )</td>
<td>( \approx 2000 \text{ m} )</td>
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D: Status (1)

MAGNETS

- all magnets are at DESY (TDC, QC, TQF, mod. HSK, CV)
- alignment of survey marks wrt. poles: TDC, CV to be done
- B-measurements finished by end of feb.03

SUPPORTS

Region D1Dump to D6Dump
- construction not finished, expected by end feb.02

Region D6Dump to Q10Dump, i.e. Diagnostics Area
- construction not yet started! → perhaps need help here
  expected start mid feb.03,
  but overlap with DESY shut-down activities

Q10&11Dump
- construction finished end aug.02
- both supports are manufactured and at DESY

Region RD13Dump to Exit Window
- construction almost finished
  completion expected by mid feb.03

DIAGNOSTICS

OTR, (SCREEN/9Dump)
- chamber ready and cleaned
- 2 opt. windows NW100 exist
- mover & opt. system not ready yet

Stripline BPM, (BPM/9Dump)
- complete unit (+2 bellows) from TTF1 exists

Button BPM’s, (BPM/5&15Dump)
- chambers constructed (→ remaining vac. syst)
  order for manufacturing pending
- delivery buttons beg. mar.03

TOROID, (Toroid/8Dump)
- chamber construction ready
  manufacturing status?

SEM, (Sem/8Dump)
- installation not decided
- chamber exists from TTF1
  but grid may be modified (45°, 2 planes)
- dummy chamber is foreseen alternatively
D: Status (2)

**VACUUMCHAMBERS (except Diagn)**

for D1&6DUMP, TDC
- construction finished jun.02
- presently manufactured at FMB (Berlin)
- delivery expected end jan.03

**EXIT WINDOW**
- first DESY window expected mid mar.03
- Protvino window exists at DESY since feb.02

**Remaining SYSTEM**
- construction of all chambers finished end nov.02
- order for manufacturing pending

ALL vacuum parts must undergo special cleaning procedures
DUMP section has to fulfill standard: „particle-free“
### D: Status (3)

**Rough Schedule, Status: Jan 03**

**Section: TTF2-DUMP**

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<th>FEB 03</th>
<th>MAR 03</th>
<th>APR 03</th>
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<th>JUN 03</th>
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<td>construction</td>
<td>manufacturing</td>
<td>install in tunnel</td>
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<td>Diagnostics Region !</td>
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<td>manufacturing</td>
<td>install in tunnel</td>
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<td>Q10&amp;Q11Dump</td>
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<td><strong>MAGNETS</strong></td>
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<td>B-measurements</td>
<td>install chamber (see chamber)</td>
<td>install in tunnel</td>
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<td>align survey. marks</td>
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<td><strong>DIAGNOSTICS</strong></td>
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<td>OTR (Screen/9Dump) chamber</td>
<td>clean &amp; vac. test</td>
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<td>mover &amp; screen ?</td>
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<td>optical system ?</td>
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<td>Stripline BPM (BPM/9Dump)</td>
<td>clean &amp; vac. test</td>
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<td>Button BPM's (BPM/5&amp;15Dump)</td>
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- D: Status (3) associated with ext. costs not yet approved

D: Questions, Next Steps

Main Questions

• How are we really sure that the beam size at the window is not too small?
  → rely on optics and magnet settings
  → measure window temperature at position of beam by IR-radiation

• How are we really sure that the beam is cleanly guided to the dump?
  → BPM’s (BPM/15Dump directly in front of exit window)
  → beam loos detection in combination with dedicated limiting apertures

Next Steps

• Work on optics
• Concentration on controls