Development of Pulse Magnets for Injection and Abort Systems

T. Mori (KEK)
SuperKEKB Review
Mar. 4, 2014
Construction Schedule

- **Phase 1**
  - The new HER injection/abort system is installed
    - This is urgent issue & main topic of this talk
  - The KEKB LER injection/abort system is preserved
    - DR is not ready at the beginning of Phase 1
      - Emittance is large; new LER system doesn’t work well for Phase 1
    - The LER current must be low to protect the abort window (< 500mA)

- **Phase 2**
  - The new LER injection/abort system is installed
    - DR is ON
    - New LER chambers have smaller apertures than those of KEKB
      - They should be installed at the same time not to make cavity structures
      - New injection channel can’t be used for large emittance beam of Phase 1
## List of BT Pulsed Magnets

<table>
<thead>
<tr>
<th></th>
<th>MR-BT</th>
<th>DR-BT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Injection</td>
<td>Abort</td>
</tr>
<tr>
<td></td>
<td>HER</td>
<td>LER</td>
</tr>
<tr>
<td>H-kicker</td>
<td>6(3+3)</td>
<td>6(3+3)</td>
</tr>
<tr>
<td>V-kicker</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Septum</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Quad</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Injection</td>
<td>Extraction</td>
</tr>
<tr>
<td></td>
<td>HER</td>
<td>LER</td>
</tr>
<tr>
<td></td>
<td>2(1+1)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

- 5 horizontal kickers for HER abort considered
- Pulse uniformity problem (shown in later slides)
Method & Parameters

- 2 candidates for HER
  - Baseline: betatron injection; same as KEKB
  - Backup: synchrotron injection

- Injection system:
  - 2 kicker systems to make injection bump ($\pi$ phase advance)
  - Kicker pulse: 2$\mu$s
  - Kicker pulse height fluctuation affecting the height of the bump: 1mm
  - Effective septum width: 3.5mm (KEKB: 5mm)
    - Including non-uniform field region
  - Totally 4.5mm gap required by hardware

- Injection parameters are determined according to ring & Linac parameters
Parameters for Betatron Injection

- Required ring aperture for beam \((2.5\sigma_{xl})\) injection is calculated as function of \(\beta_{xl}\)
  - \(\alpha_{xR} = 0\) is assumed
  - \(\beta_{xl}\) is determined at minimum ring aperture

### Ring parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_{xR})</td>
<td>7.93</td>
</tr>
<tr>
<td>(\beta_{xR})</td>
<td>100m</td>
</tr>
<tr>
<td>(\varepsilon_{xR})</td>
<td>(4.6 \times 10^{-9}) m</td>
</tr>
<tr>
<td>(\varepsilon_{xl})</td>
<td>(1.46 \times 10^{-9}) m</td>
</tr>
</tbody>
</table>

### Injection parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta x)</td>
<td>7.8mm</td>
</tr>
<tr>
<td>(\Delta x')</td>
<td>-0.62 mrad</td>
</tr>
</tbody>
</table>
We plan to install BPM on injection channel

Increase of $K_1$ increases the risk of wall hit

Betatron injection orbit can be designed with current HER optics & hardware designable

Synchrotron injection orbit also designed; almost same as betatron injection
Septum Magnet Prototype

<table>
<thead>
<tr>
<th></th>
<th>HER</th>
<th>LER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Septum conductor width</td>
<td>1mm</td>
<td></td>
</tr>
<tr>
<td>Effective septum width</td>
<td>3.5mm</td>
<td></td>
</tr>
<tr>
<td>Gap</td>
<td>8mm</td>
<td></td>
</tr>
<tr>
<td>Core length</td>
<td>1m</td>
<td>790mm</td>
</tr>
</tbody>
</table>

MR beam duct mockup (SUS430)

Pickup coil

0.5mm Si-steel sheet
Field Measurement

- Field profile with SUS430 duct is fine
- Leakage field sufficiently suppressed
- Necessary and sufficient design
- Simulation study for shim shape on going
Power Supply for Septum

- Upgrade for SuperKEKB
  - Thyristor $\rightarrow$ Inverter (IGBT)
  - Transistor $\rightarrow$ De-Qing unit
    - Controlled charge timing; double trigger driven
    - High precision auxiliary charger introduced
- Current R&D issue
  - Pulse stability is not perfect:
    - fluctuation $> 1 \times 10^{-3}$ seen in beginning 1-2 seconds
    - De-Qing drift?
Kickers for MR Injection

- Magnets and power supplies will be reused
- Issues
  - Thyratrons (1 thyatron/kicker)
    - KEKB type (EEV CX1154C) is expected to be exchanged every year with 25Hz injection
      - Long lifetime type (EEV CX1826A) (is already installed in HER for test)
        - 6-year achieved in KEKB, CX1154C lifetime in KEKB: 3-year with 5 – 10Hz continuous inj.
        - Demerit: price × 2
    - Another candidates
      - Replaced by semiconductor device (Si thyristor, solid state thyratron, etc?)
      - Pulse compression circuit (Rise time 5μs → 1μs) (Standard thyristors + saturable inductance)
  - Beam chambers
    - No upgrade planned for Phase 1
    - HER
      - Heat generation on fringe part is possible
        - Cu or Cu-coated kovar fringe is considered
    - LER
      - 3 chambers are planned to be exchanged for Phase 2
  - Waveform shaping circuit
    - Radiation tolerance unknown
    - Placed under the kicker magnet

Spec. of MR injection kickers

<table>
<thead>
<tr>
<th>Type</th>
<th>Window frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>Ferrite</td>
</tr>
<tr>
<td>Max voltage</td>
<td>32kV</td>
</tr>
<tr>
<td>Max current</td>
<td>2kA</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>Half sine</td>
</tr>
<tr>
<td>Pulse width</td>
<td>~2μs</td>
</tr>
</tbody>
</table>

T. Mimashi
MR ABORT
Abort Kickers

- Magnet
  - Newly designed & constructed

- Ceramic beam camber
  - HER
    - Single ceramic (hollow type ceramic for water channel)
    - Sleeve: kovar + 100μm Cu coat
    - Problem: Ti wire evaporation coating failed
      ➞ Sputtering system constructed for 5μm Ti coat
  - LER
    - Double ceramic tube
    - Sleeve: Cu
    - Problem: many vacuum leaks during fabrication
      ➞ Sleeve structure changed

- Entire Ti coated inner wall surface
  - Selected by the achievement on KEKB
  - Stripped coat with high current beam is not trivial

- Power supply
  - Pulse shaping issue
  - Radiation hardness of pulse transformer
Kicker Magnet Construction
# Ceramic Chamber

<table>
<thead>
<tr>
<th></th>
<th>HER</th>
<th>LER</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEKB</td>
<td>0.29kW</td>
<td>0.56kW</td>
</tr>
<tr>
<td>SuperKEKB</td>
<td>1.8kW</td>
<td>2.7kW</td>
</tr>
</tbody>
</table>

No local heating observed

*Figure: Ceramic chamber heat test*
Sputtering System

- Parameter tuning
  - Current rate
    - 60 hours/chamber
  - $B = 160$ Gauss
  - $V \approx 300V$
  - $I = 300 mA$
Issue

- Radiation hardness problem
  - 200mm polyethylene for neutron reduction
  - 7mm Pb shield
Output Current of Power Supply

Inductance 4.5μH/165Ω+940pF
Voltage 39.3kV
(W/ additional inductance)

Peak 1750Ap(103%)
Flat 1700A(100%)
Rise time (2%-90%): 150ns
⇒ Sufficient

10μs-flat: 8.8% Drop (it is not fatal)
⇒ 1 – 2mm shift on abort window
⇒ Target: <5%
DR INJECTION & EXTRACTION
DR Injection & Extraction Arrangements

Extraction

Septum

Injection

Septum
### DR Injection & Extraction Septa

<table>
<thead>
<tr>
<th></th>
<th>Injection</th>
<th>Extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection angle (mrad)</td>
<td>80</td>
<td>103</td>
</tr>
<tr>
<td>No. of magnet</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Field strength (T)</td>
<td>0.36</td>
<td>0.47</td>
</tr>
<tr>
<td>Type</td>
<td>Eddy-current</td>
<td>Eddy-current</td>
</tr>
<tr>
<td>Aperture (mm)</td>
<td>70(H)x24(V)</td>
<td>98(H)x30(V)</td>
</tr>
<tr>
<td>Core length (mm)</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Coil turns</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Septum thickness (mm)</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Waveform</td>
<td>Full-sine</td>
<td>Full-sine</td>
</tr>
<tr>
<td>Pulse width (μs)</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Peak Current (A)</td>
<td>8000</td>
<td>5700</td>
</tr>
<tr>
<td>Max repetition rate (Hz)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Stability</td>
<td>&lt;1E-3</td>
<td>&lt;1E-4</td>
</tr>
</tbody>
</table>

- RF system near Ext. septum requires pressure $< 10^{-7}$Pa
- Out vacuum septum for extraction
- Power supplies are same type as MR septa
Summary of Remaining R&D Issues

- **MR injection**
  - Septum
    - Stability of power supply
    - Shim shape study
  - Kicker
    - Thyatron lifetime issue: long life type is planned to be used
    - Radiation tolerance for pulse shaping circuit

- **MR abort**
  - Ceramic chamber: Ti sputtering
  - Power supply: pulse shaping & radiation hardness

- **DR injection/extraction**
  - Septum
    - Design
  - Kicker
    - Power supply R&D
Thank you for your attention.
MR INJECTION
Need for synchrotron injection

- Very low survival rate with betatron injection into HER is expected
  - If offset $\Delta x$ from IP for betatron oscillation,
  - Kicked vertically by beam-beam force from the colliding beam

- Synchrotron oscillation $\Rightarrow$ no offset $\Delta x$ ($\because \eta^* = 0$)

Tracking example with beam-beam interaction

Survive: 24%

* Finite $y$-amplitude
  $\Rightarrow$ Large beam-beam kick
  $\because$ Hour-glass effect

Synchrotron injection (as a backup option of betatron inj.)
Dispersion & Momentum spread

- Dispersion by matching
  - $\eta = -1.6 \text{ [m]}$
  - $\varepsilon_x = 4.6 \text{ [nm]}$

- Momentum spread
  - $\sigma_{\delta I} = 0.1 \text{ [%]}$ is assumed
Synchrotron injection orbit

- Almost same as betatron injection case, only slightly tighter.

**Injection param. | Value**

<table>
<thead>
<tr>
<th>Kicker height</th>
<th>29mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope angle</td>
<td>−1.89 mrad</td>
</tr>
<tr>
<td>$K_1$ (Ql4E)</td>
<td>0.1437</td>
</tr>
<tr>
<td>Height at Ql4E</td>
<td>30mm</td>
</tr>
<tr>
<td>$3\sigma_{xR}$</td>
<td>1.5mm</td>
</tr>
<tr>
<td>$\Delta x$</td>
<td>7.2mm</td>
</tr>
<tr>
<td>$\Delta x'$</td>
<td>−0.52 mrad</td>
</tr>
</tbody>
</table>

Synchrotron injection orbit can also be designed.
Acceptance for Synchrotron Injection

Synchrotron injection is intended to avoid stored beam blow up by injection beam

\[ \Delta X = \eta \delta_0 = n_I \beta_I \varepsilon_I + (\eta_I \sigma_{\delta I})^2 + w_{\text{eff}} + n_R \beta_R \varepsilon_R + (\eta \sigma_{\delta R})^2 \]

- \( w_{\text{eff}} \sim 5[\text{mm}](\text{KEKB}) \)
- SuperKEKB parameters
  - \( \beta_R = 60[\text{m}] \)
  - \( \varepsilon_R = 4.6[\text{nm}] \)
  - \( \sigma_{\delta R} = 0.059[\%] \)
  - \( n_R = 3.0 \)
  - \( \beta_I = 20[\text{m}] \)
  - \( \varepsilon_I = 1.46[\text{nm}] \)
  - \( \sigma_{\delta I} = 0.1[\%] \)
  - \( n_I = 2.5 \)

- \( \delta_0 = (p_I - p_R)/p_R \)
- \( \delta_0 + 2 \sigma_{\delta I} = 0.65[\%] \) (by Y. Ohnishi)
- \( \eta = -1.6[\text{m}] \) (Achieved, so far)
Injection Kicker magnet

(Total 12 thyatrons are used)

- KEKB continuous injection (5〜10Hz)
  - > SKEKB 25Hz injection
  - KEKB: life time of thyatron (CX1154C) -> 3 years
- SuperKEKB: life time of thyatron: 1 year?

Three possibilities
1. Use long life thyatron (CX1826A)
2. Replace thyatron to semiconductor device
   - (SI thyristor? or commercial available Solid State Thyatron Replacement?)
3. Standard Thyristors + Saturable inductance (Pulse compress circuit) 5μsec -> 1μsec

We chose (1) Long Life thyatron for HER (CX1826A has been used for 6 years in KEKB)
MR ABORT
Abort optics with DC sextupole

- Instead of pulsed quadrupoles, a DC sextupole is used for enlarging the horizontal beam size.
- A DC sextupole is installed between the abort kickers and the abort window. The deflected beam feels an additional quadrupole kick effectively.
- Another DC sextupole is needed to make a pair of sextupoles for cancellation of the geometrical nonlinearity.

The pair of Sextupoles is connected by / or - / transformation.
Abort system of KEKB

- **Horizontal abort kickers** kick the stored beam out of vacuum chamber (Rise time ~ 500ns)
  - Beam is extracted through **Ti window** to the atmosphere before entering **Lambertson magnet**
- **Vertical kicker** sweeps beam vertically: energy deposit on Ti window is diffused
- The beam is bent downward by **Lambertson** and leads to **Dump**

Abort fail-safe system
- DCCT detects current
- Weak bend shut down
- Beam scatters all around
Abort system of SuperKEKB

KEKB
Horizontal kicker: fast kick to abort window
Vertical kicker: slow sweep vertically

SuperKEKB
• Low emittance beam has higher possibility of destroying abort window than KEKB beam
• Enlarging horizontal beam size required additionally

LER
Horizontal kicker: fast kick to the Abort window
Vertical kicker: slow sweep vertically
PULSED quadrupole: enlarge the horizontal beam size

HER
Horizontal kicker: fast kick to the Abort window
Vertical kicker: slow sweep vertically
DC sextupole: enlarge the horizontal beam size

Abort fail-safe system like KEK is also designed

Power density maximum at turning points!!

Schematic view of new beam profile on abort window

6μm shift
Abort Beam Optics with Betatron Injection

Abort kickers
Abort sextupole
Abort window
Beam dump

$e^-$ Beam

N. Iida

Development of Pulse Magnets for Injection and Abort Systems, T. Mori, MAC2014
Matching:
\[ \beta_x^1 = \beta_x^2 \]
\[ \beta_y^1 = \beta_y^2 \]
\[ \nu_x^1 - \nu_x^2 = 1.5 \]
\[ \nu_y^1 - \nu_y^2 = 1.0 \]

1: AbortSext(1)
2: AbortSext(2)

\[ \eta_x = 0 \]
at the center of the sexts.

\[ \varepsilon_x = 4.511\text{nm} \]
\[ \varepsilon_y = 11.28\text{pm} \]

Emittance change is negligible.
Dynamic apertures & Touschek lifetimes are tested with insertion of a pair of sextupoles.

The lifetime is optimized for each sextupoles.
Case 1: \( K^2 = 0 \) (W/o sextupoles) \( \tau = 610 \) [s]
Case 2: \( K^2 = 2.777 \) \( \tau = 600 \) [s]
Case 3: \( K^2 = 4.528 \) \( \tau = 620 \) [s]

No performance drop found.

Y. Ohnishi
Abort Beam Optics for Synchrotron injection

**HER Abort S3xt+Kicker Optics**

- $\Delta x (LB) = 15$ (mm)
- $\Delta y (LB) = 120$ (mm)
- $\beta_x = 4.56$ nm
- $\beta_y = 38$ (mm)

Parameters:
- $K_0 (FAH1) = -1.84$ (mrad)
- $K_0 (FAV) = -1.12$ (mrad)
- $K_2 (FSXAB1) = -1.24$ (m^2)

---

**Diagram:**

- e- Beam
- Beam dump
- Abort kickers
- Abort sextupole
- Abort window
Her Optics for Synchrotron injection

Matching:

\[ \beta_x^1 = \beta_x^2 \]
\[ \beta_y^1 = \beta_y^2 \]
\[ \nu_x^1 - \nu_x^2 = 1.5 \]
\[ \nu_y^1 - \nu_y^2 = 1.0 \]

1: AbortSext(1)
2: AbortSext(2)

\[ \eta_x = 0 \]
at the center of the sexts.

\[ \varepsilon_x = 4.646 \text{nm} \]
\[ \varepsilon_y = 11.62 \text{pm} \]

Emittance changes are negligible.
Protection from Coherent Oscillation

- Avoiding abort beams hit outside of abort window
- Vertical
  - Acceptance determined by vertical mask
  - Coherent oscillation amplitudes:
    - LER: $4.7 \times 10^{-8}$ m
    - HER: $3.8 \times 10^{-8}$ m
  - Amplitudes small enough: no protection applied
- Horizontal
  - Max. displacement at abort window calculated
    - $(\text{orbit}) + 3.5\sigma_x + \eta\delta (1\%) + \text{(coherent oscillation)}$
    - HER: 50 mm
    - LER: 47.6 mm
  - Coherent oscillation amplitudes
    - HER: 6.8 mm ($6\sigma_x$)
    - LER: 6.8 mm ($5\sigma_x$)
  - 5 or $6\sigma_x$ coherent oscillation amplitudes make interlock BPM trigger abort signal
Protection from Coherent Oscillation

- Abort beam may hit outside of abort window
- Vertical oscillation
  - Vertical acceptance determined by vertical mask
  - Vertical amplitudes:
    - LER: $4.7 \times 10^{-8}$ m
    - HER: $3.8 \times 10^{-8}$ m
  - Amplitudes small enough: no protection
- Horizontal oscillation
  - (orbit) $+ 3.5\sigma_x + \eta\delta (1%) + (\text{coherent oscillation})$
  - Max. amplitudes at abort window
    - HER: 50 mm
      - Synchrotron入射: Coherent振動 = 6.8 mm = 5.7\(\sigma_x\)
      - Betatron入射: Coherent振動 = 6.8 mm = 6.2\(\sigma_x\)
    - LER: 47.6 mm
      - Coherent振動 = 6.5 mm = 5.4\(\sigma_x\)
- Coherent oscillation amplitudes
  - HER: 6.8 mm (6\(\sigma_x\))
  - LER: 6.5 mm (5\(\sigma_x\))
- $5 - 6\sigma_x$ coherent oscillation amplitudes trigger abort signal
Power Supply

**Issues**

- Pulse compress circuit
  - We could get enough rise time (< 200nsec), but 10μsec flatness is not enough.

- Add dummy inductance to the coil
  - Flatness is improved from 14.6% -> 8.8%  (or better)
<table>
<thead>
<tr>
<th></th>
<th>LER</th>
<th>HER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Current (Horizontal kicker)</td>
<td>1.4kA (4GeV) 1.46kA(4.16GeV)</td>
<td>1.26kA (7GeV) 1.55kA (8.6GeV)</td>
</tr>
<tr>
<td>Maximum current of Power supply</td>
<td></td>
<td>1.7kA</td>
</tr>
<tr>
<td>Current drop</td>
<td></td>
<td>8.8%</td>
</tr>
<tr>
<td># of kicker magnets</td>
<td>Horizontal 1 Vertical 1 Pulsed quad 2</td>
<td>Horizontal 4 Vertical 1</td>
</tr>
</tbody>
</table>
Output Current of Power Supply

Inductance 4.5μH/165Ω+940pF
Voltage 39.3kV
(W/ additional inductance)

(500A/div,500ns/div)
Peak 1750Ap(103%)
Flat 1700A(100%)
Rise time (2%-90%) 150ns
⇒ Sufficient

Whole pulse
(500A/div,5μs/div)
10μs 8.8% Drop
Output Current

- Peak: 2250 Ap (110%)
- Flat: 2050 A (100%)
- Rise Time (2%-90%): 150 ns

Inductance: 2.2 μH / 165 Ω + 940 pF
Voltage: 37.0 kV

Whole Pulse
- (500 A/div, 5 μs/div)
- 10 μs Drop: 14.6%
DR INJECTION/EXTRACTION
Kickers for DR Injection/Extraction

- Power supply study on going
  - Both rising & falling times should be fast for other bunches
## Machine Parameters

<table>
<thead>
<tr>
<th>2013/July/29</th>
<th>LER</th>
<th>HER</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>4.000</td>
<td>7.007</td>
<td>GeV</td>
</tr>
<tr>
<td>I</td>
<td>3.6</td>
<td>2.6</td>
<td>A</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>2,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bunch Current</td>
<td>1.44</td>
<td>1.04</td>
<td>mA</td>
</tr>
<tr>
<td>Circumference</td>
<td>3,016.315</td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>$\varepsilon_x/\varepsilon_y$</td>
<td>3.2(1.9)/8.64(2.8)</td>
<td>4.6(4.4)/12.9(1.5)</td>
<td>nm/pm</td>
</tr>
<tr>
<td>Coupling</td>
<td>0.27</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>$\beta_x^<em>/\beta_y^</em>$</td>
<td>32/0.27</td>
<td>25/0.30</td>
<td>mm</td>
</tr>
<tr>
<td>Crossing angle</td>
<td>83</td>
<td></td>
<td>mrad</td>
</tr>
<tr>
<td>$\alpha_p$</td>
<td>3.18x10^{-4}</td>
<td>4.53x10^{-4}</td>
<td></td>
</tr>
<tr>
<td>$\sigma_s$</td>
<td>8.10(7.73)x10^{-4}</td>
<td>6.37(6.30)x10^{-4}</td>
<td></td>
</tr>
<tr>
<td>$V_c$</td>
<td>9.4</td>
<td>15.0</td>
<td>MV</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>6.0(5.0)</td>
<td>5(4.9)</td>
<td>mm</td>
</tr>
<tr>
<td>$\nu_s$</td>
<td>-0.0244</td>
<td>-0.0280</td>
<td></td>
</tr>
<tr>
<td>$\nu_x/\nu_y$</td>
<td>44.53/46.57</td>
<td>45.53/43.57</td>
<td></td>
</tr>
<tr>
<td>$U_0$</td>
<td>1.86</td>
<td>2.43</td>
<td>MeV</td>
</tr>
<tr>
<td>$\tau_{x,y}/\tau_s$</td>
<td>43.2/21.6</td>
<td>58.0/29.0</td>
<td>msec</td>
</tr>
<tr>
<td>$\xi_x/\xi_y$</td>
<td>0.0028/0.0881</td>
<td>0.0012/0.0807</td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>8x10^{35}</td>
<td></td>
<td>cm^{-2}s^{-1}</td>
</tr>
</tbody>
</table>