
A ~770 page document which
- presents accelerator design
- summarizes outcomes of accelerator physics studies
- includes description of accelerator systems, providing basis for ongoing cost estimate
- evaluates required improvements in BNL/RHIC infrastructure

The public release will be coordinated with the Lab management and DOE.
Physics at eRHIC


Polarization, ions, together with its luminosity and $\sqrt{s}$ coverage, make the US-EIC a unique facility.
Design Goals

• Collision luminosity $\sim 10^{33}-10^{34} \text{ cm}^{-2}\text{s}^{-1}$
  (exceeding HERA luminosity by 2 orders of magnitude)

• Electron, proton, $^3$He and d polarization $>70\%$;
  • electrons: longitudinal at IPs;
  • hadrons: longitudinal and transverse;
  • complex e-h spin patterns

• Large acceptance detector
  with elements integrated in the IR for forward particle detection

• Wide center-of-mass energy span: 29-140 GeV, e-p
  29-89 GeV/n, e-ion
eRHIC Design Concept

- Based on RHIC ion complex:
  - Polarized protons from OPPIS
  - Ions, polarized 3He and d, from EBIS
  - Booster and AGS injectors
  - Acceleration/storage in RHIC Yellow

- Adding an electron complex, in RHIC tunnel
  - Polarized electron source
  - 400 MeV linac
  - Rapid-cycling synchrotron
  - 5 to 18 GeV storage ring

- Large acceptance detectors
  - At IP6 and IP8

Electron Ion Collider – eRHIC
eRHIC Luminosity

*in terms of its limiting factors*

\[ \mathcal{L} \propto H \frac{1 + K_y}{\sqrt{K_y}} \sqrt{\gamma_\text{e} \gamma_\text{p} I_\text{e} I_\text{p}} \]

\[ \xi_{x,y,e,p} = \frac{r_{e,p}}{2\pi} \frac{N_{p/b,e/b}}{\gamma_{e,p} \epsilon_{x,y,e,p}} \frac{1}{1 + K_{y,x}} \]

Ingredients for high Lumi:
- large number of bunches
- high bunch charge
- operation at beam-beam tune-shift limit
- small \( \beta^* \) and short bunches
- flat beams at IP
- crab crossing

\(~1\) (hourglass, Xing angle)

aspect ratio \( \sigma_x/\sigma_y \sim 0.1 \): flat bunches \( \rightarrow \) greater

\[ \xi_{x,y,e,p} \leq 0.1 \quad (e: \text{KEK-B}) \]
\[ \leq 0.015 \quad (p: \text{RHIC}) \]

\[ \xi_{xe} \xi_{ye} \xi_{xp} \xi_{yp} \]

\( \beta^*_{xe} \beta^*_{xp} \) small, 5~10 cm
\(~1\) m \( \leftarrow \sigma'_x < 0.7\text{mrad} \)

0.4~0.8 m
Chroma<30%

\( \beta^*_{ye} \beta^*_{yp} \)

200MeV/c detector acceptance
eRHIC luminosity / summary

Parameters:

- **Nominal luminosity, \(10^{34}\):**
  - small hadron emittances (strong hadron cooling mitigates IBS)
  - 1320 bunch store
  - 10 MW SR

- **Moderate luminosity, \(4.4 \times 10^{33}\):**
  - 660 bunch store
  - e, p vertical emittances relaxed

Parameters for “initial luminosity” of \(10^{33}\) at 105 GeV \(E_{\text{CM}}\):
  - 290 bunch store
  - lower p and e beam current (3 MW SR)

"Initial luminosity": Parameters achievable after a short time of commissioning, still satisfying the minimum requirements of the EIC physics program as described in the EIC White Paper.
Interaction region for luminosity goals

- Large detector acceptance
  → no accelerator components within ±4.5m of IP

- Strong focusing at IP

- 22 mrad (crab-)crossing, for
  - space for forward n detector & rear luminosity γ-detector,
  - synchrotron radiation clearance
  - short-range separation

- Management of synchrotron radiation:
  - no electron bends on the forward side
  - large aperture electron magnets on rear side absorbing SR far from IP
  - masks against backscattered SR photons

- Electron chicane on rear side, for
  - luminosity measurements and electron tagging
**BNL/Jlab R&D effort:** designing, building and testing a short prototype based on existing Nb$_3$Sn coils (from LARP work) actively shielded by new NbTi coil.

**Q1pF, active shield**
- 140 T/m
- 8.6 T peak field

Central region. Showing quadrupoles and B0 spectrometer dipole with shielded e-beam

**B0 hadron spectrometer magnet, 1.3 T.**
Electron beam path and Q1EF quadrupole are encompassed within active shield (SC dipole).

**Q1R, Tapered coil**
Nearly constant gradient along entire length, although tapered coil
IR Crab Cavity R&D

The experience from the LHC crab cavity program directly benefits eRHIC design (frequencies are similar).

- Same designs for e and h beams
- Frequency $338 \text{ MHz} = 12 \times 360 \times f_{\text{rev}}$
- Voltage, ion / electron: up to 12 / 5 MV

Cavity design at BNL.
Prototype under experimentation at CERN SPS.
New systems

Design

R&D
Experience from both SLC PES high charge gun and JLab inverted guns.

- eRHIC requires: 10 nC, 1 Hz, polarization levels ~ SLC’s.

Simulations show that the 2.856 GHz 400 MeV pre-injector meets the requirements.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge [nC]</td>
<td>10</td>
</tr>
<tr>
<td>Frequency [Hz]</td>
<td>1</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>400</td>
</tr>
<tr>
<td>Normalized emittance [mm-mrad]</td>
<td>55</td>
</tr>
<tr>
<td>Bunch length [psec]</td>
<td>6</td>
</tr>
<tr>
<td>$dp/p$</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>polarization [%]</td>
<td>85</td>
</tr>
</tbody>
</table>

Sub-R&D items:
- Achieve and measure XHV
- High power laser
- Ion back bombardment
- Surface charge limit measurement
- Lifetime as the function of charge
- Beam halo reduction studies
- Cathode cooling

Spin considerations in pre-injector

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Energy acceptance</th>
<th>Realizable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole+solenoid</td>
<td>&gt;100 MeV</td>
<td>Small</td>
</tr>
<tr>
<td>Wien filter</td>
<td>&lt; 400 KeV</td>
<td>Large</td>
</tr>
</tbody>
</table>
RCS – Full Energy Injector

- Accelerates 400 MeV, 10 nC bunches from the linac, to full collision energy, 5-18 GeV
  100~200 ms acceleration ramp & 1 Hz repetition rate

- RF system:
  normal-conducting 563 MHz cavities (located at IR10), total voltage 72 MV.

- Stainless steel vacuum chamber

**Polarization:**

- *Polarization loss during the ramp to 18 GeV, including 1 mm rms orbit error, is <2%.*

**Polarization transport in RCS**

* Expand a circular 96-period ring, onto RHIC 6-fold footprint
* Choose \([Q_y]=51\) to avoid resonances \(\gamma = kP \pm [Q_y]\)
Electron Storage Ring

- Based on accelerator technologies of B-factories and HERA
- Polarization up to 85% at injection, 70% average
- Composed of six FODO arcs, 60°/cell for 5 & 10 GeV and 90°/cell at 18 GeV
- “Super-bend” arc bends for emittance and damping decrement control (1.25x10^-4) to allow large beam-beam tune shift parameter
- Swap-out injection for maximized polarization
Storage Ring Component Design

Various components have been subject to preliminary design

- 2-cell, 2K cryomodule, 563 MHz, 3MV/cell
- 12 cryomodules at 10 MW SR limit
- 2x 500 kW adjustable fundamental power couplers.
- 4x SiC Beamline HOM Absorbers
- Multibeam IOT power source.

Vacuum chamber

- from CuCrZr Alloy
  Good thermal and mechanical properties, easily available at reasonable price
- Integrated NEG pumping
Electron Polarization at Store

- Spin diffusion:

- Diffusion time constant $\tau_D$:

$$
\tau_{eq} = \left( \frac{1}{\tau_{ST}} + \frac{1}{\tau_D} \right)^{-1}
$$

and $\tau_D \approx 60$ min.

- $\tau_{ST} \sim 30$ min., $\tau_D \sim 60$ min.

yield $\tau_{eq} = 20$ min.

- Average polarization:

- $P_{eq} = P_{ST} \frac{\tau_{eq}}{\tau_{ST}}$ and $P_{ST} \sim 90\%$ yield

bunch $P_{eq} = 60\%$

- $P(0) \sim 85\%$ and $P_{eq} = 60\% \rightarrow$ compatible with store $<P> = 70\%$
Hadrons: Present RHIC Complex

$2.5\text{ bln RHIC hadron complex:}$

- 4.2K cryogenic Facility
- 3.8 km tunnel
- Service buildings outside the tunnel
- Detector Halls STAR and PHENIX
- Only place in the world with high energy polarized proton beams
- Collided dxAu, CuxCu, UxU, pxAl, etc.

Machine performance increases over the years through improvement/upgrade projects.
Increasing Proton Intensity and Repetition Rate

<table>
<thead>
<tr>
<th>Proton parameters</th>
<th>Present RHIC</th>
<th>eRHIC nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam current, mA</td>
<td>330</td>
<td>1000</td>
</tr>
<tr>
<td>Bunch frequency, MHz</td>
<td>9.4</td>
<td>112.6</td>
</tr>
<tr>
<td>Peak current, A</td>
<td>12</td>
<td>24</td>
</tr>
</tbody>
</table>

Level of eRHIC proton current is similar to HL-LHC upgrade.

**Cryo-load**

from short-bunch induced resistive heating: **reduce to <1 W/m**

**Electron cloud**

- **Beam scrubbing** is an efficient tool based on LHC experience
- Under evaluation, to reduce SEY (<1.2):
  - Amorphous C coating (using the tooling developed for Cu-coating)
  - Laser-engineered grooving

**In-situ copper coating of RHIC stainless steel pipe**

Required hardware upgrades:
- New injection kickers (<12 ns rise time)
- RF system upgrade (bunch splitting and compression)

Magnetron mole for coating long narrow tubes has been designed and built.
State-of-the-art Polarization at RHIC

- **Methods to accelerate and manipulate polarized bunches in RHIC:**
  - 2 full snakes to preserve polarization during energy ramp
  - 2 pairs of rotators control orientation of polarization at IP6 and IP8
  - Orbit and betatron tune control

- **State-of-the-art:**
  - Up to 60% polarization at 255 GeV, $1.8 \times 10^{11}$ protons/bunch to experiments,
  - At $2.8 \times 10^{11}$ p/b: 66% polarization out of AGS (charge-induced vertical emittance increase).
Proton and $^3$He polarization at eRHIC

- Achieve $>$ 70% out of AGS at $2.8 \times 10^{11}$ ppb (vs. 66% today): gain from emittance preservation and higher source polarization.

- Achieve $\sim$100% polarization transmission to 275 GeV:
  - Today’s 100% transmission to 100 GeV and $\sim$15% loss to 255 GeV indicate resonance strength threshold in $0.18 \sim 0.45$.
  - Snake efficiency is $\propto N$ snake $\rightarrow$ 6 snakes push threshold beyond $3 \times 0.18$, well $> 0.45$.

- A 6-snake arrangement yields 100% transmission
  - of p, beyond 275 GeV
  - of $^3$He, to 170 GeV/n region

Figure 5.26: Zgoubi simulation results with various snake combinations and beam emittances for intrinsic resonances at $G_\gamma = -411 + Q$ ($\gamma \approx 91$) and $G_\gamma = -393 - Q$ ($\gamma \approx 101$)
Polarized proton & $^{3}\text{He}^{2+}$ in RHIC Injectors

• An AC dipole is under installation in Booster
  - to overcome intrinsic spin resonances.
  - This opens up possibility of raising injection energy in the AGS for improved polarization transmission, both p and $^{3}\text{He}$.

• Demonstration/AC-dipole operation with polarized protons next Fall, 2019

In the AGS:
  two 35%+15% partial snakes generate large enough spin tune gap so that both betatron tunes can be put into gap to avoid all depolarizing resonances.
Helium-3 Source

• Requirements:
  - $2 \times 10^{11} \, ^3\text{He}^{2+}$ in a 10 $\mu$s pulse (~4.0 mA)
  - Polarization > 70%
  - Spin flip every pulse
  - Compatibility with EBIS operation for heavy ion physics.

• Plan:
  EBIS upgrade including injector solenoid, Operation 2019-2020.
Ongoing Design Studies

- Increase IR crossing angle to 25 mrad:
  - reduce magnet design challenges (no NbSn\(_3\) needed; BNL Direct Wind can be used on nearly all magnets)
  - more compact design (smaller electron beta-max)

- Use both RHIC rings, for (i) acceleration to top energy and (ii) storage
  - minimize store interruptions
  - increase of average luminosity even without high energy cooling

- e-storage ring vertically stacked above the hadron ring: more efficient use of the tunnel space.
Strong Hadron Cooling R&D

Goal: $\tau_{\text{cool}} < 1\text{h at } 275\text{ GeV}$

- Different methods of strong hadron cooling are being explored. DOE funded studies are underway in different labs (ANL, BNL, JLAB, FNAL, SLAC)

- Micro-bunched electron beam cooling with 2 plasma amplification stages is being developed by BNL/SLAC collaboration. Required cooling rates can be achieved with $\sim$100 mA electron current in 150 MeV 3-turn ERL-based accelerator.

- CeC with FEL amplifier PoP experiment has been carried on at RHIC. Possible continuation of the experiment using Plasma-Cascade amplification.

- Bunched Beam Electron Cooling based on an electron storage ring also explored. Ampere scale beam current is required.
High-Current ERL R&D

- The CBETA facility is under construction in Cornell University (a BNL-Cornell collaboration)

- Successful test of beam through a fractional FFA arc was performed in April-May, 2018.

- Full commissioning effort starts March 2019.

Electron Current up to 320mA in the linac
Bunch charge Q of up to 2nC
Bunch repetition rate 1.3GHz/N
Beams of 100mA for 1 turn and 40mA for 4 turns

FFA recirculating pass
42, 78, 114, 150 MeV

Beam image after fractional FFA arc
Thank you for your attention
Backup slides
The eRHIC Electron-Ion Collider is recognized to have the potential to realize new understanding and discoveries regarding the nature of visible matter in our universe.

• The 2015 DOE/NSF Long Range Plan (LRP) for Nuclear Science [2] recommends an EIC as the highest priority new facility to be initiated for the field.

  “In summary, the committee concludes that an EIC is timely and has the support of the nuclear science community.”
In summary: the new elements to be added to the existing RHIC complex

• A low frequency photocathode e-gun delivering 10 nC bunches, >80% polarized, at 1 Hz repetition rate

• A 400 MeV normal-conducting S-band LINAC

• A 5 to 18 GeV rapid cycling synchrotron (RCS) in the RHIC tunnel

• A high intensity, spin-transparent 5 to 18 GeV electron storage ring in the RHIC tunnel with superconducting RF cavities

• A high luminosity interaction region that allows for a full acceptance detector and for longitudinal polarization

A second interaction region is possible and feasible

• A 150 MeV CW ERL for strong hadron cooling
eRHIC Hadron Requirements

- Beam parameter requirements:
  - Higher number of bunches (290; almost tripled from presently used 110)
  - Smaller bunch length (10 cm instead of present 40 cm)
  - Flat beams
  - Higher energy (275 GeV instead of present 255 GeV)
  - High polarization (70%) of protons and $^3$He ions

- Required ring modifications
  - Removal of DX magnets (to allow for higher energy) (WBS 6.07.05)
  - Interaction Region straightens (from D6 to D6) (WBS 6.06.02)
  - Injection system upgrade (for increased number of bunches)
  - Frequency matching with electron beam (by using shorter arc for 41 GeV)
  - RF system upgrade (for shorter bunches)
  - Increase of number of Snakes (to reach required polarization)
  - Beam instrumentation upgrade (for higher peak current)
  - Copper and amorphous-Carbon beam pipe coating (for reducing cryo-heat load and electron cloud effects)
Polarized deuteron at eRHIC

• Could happen first (whereas helion is priority).
• \( G = -0.14 \)
  - weak resonances, \( |\varepsilon_{\text{intr.}}| < 0.002 \)
  - in small number, \( |G\gamma| \) range: 1.9 → 20.9

• Techniques foreseen for transmission:
  - harmonic orbit correction/excitation (cf. Booster, AGS),
  - partial snake (15 T.m…), AC dipole

• Longitudinal polarization at IP:
  harmonic orbit, at integer \( G\gamma \) (with proper phasing of
  \( y \)-normal spin closed orbit \( n_0 \))
**Spin matching**, a set of additional constraints to the IR optical setting, is required for preserving polarization in the presence of the rotators.
IR Design Developments

Rear Systems

Forward systems
Helium-3 Polarization at eRHIC

• Transverse $^3$He bunch emittance is comparable to proton’s (2.5 $\mu$m)

• Resonances are stronger by $(G_{^3He}/Gp)^{1.5} = 4.18 / 1.79 \approx 1.5$, yet snakes are $G_{^3He}/Gp \approx 2.3$ as strong.

• On the other hand:
  - resonance spectrum is denser
  - imperfection and intrinsic resonances overlap, this affects polarization (excites snake resonances)

• Simulations show that
  - 2 snakes do not maintain polarization upon crossing $G\gamma = -411 + Q_y$ ($\gamma \approx 91$)
  - $G\gamma = -393 - Q_y$ ($\gamma \approx 101$).
  - a 6-snake configuration preserves polarization towards $G\gamma = 717 + Q_y$ ($\gamma \approx 180$) region.

Figure 5.26: Zgoubi simulation results with various snake combinations and beam emittances for intrinsic resonances at $G\gamma = -411 + Q$ ($\gamma \approx 91$) and $G\gamma = -393 - Q$ ($\gamma \approx 101$).
Critical Decision CD0: based on pCDR, declare mission need for an EIC, supported by a technical plan to realize it

CD1: based on CDR.
eRHIC Infrastructure

New systems

10 o’clock
e: Ring SC-RF, RCS RF; h: SC-RF, cooling (ERL), dump

12 o’clock
e: Ring SC-RF, RCS RF; h: SC-RF, cooling (ERL), dump

IR12 ← 2
h: Blue arc for low-E operation

2 o’clock
e injector: source+400MeV linac; e injection to RCS; e-beam dump; h: instrumentation

4 o’clock
h: 112/563MHz NC-RF; injection via Blue arc

8 & 6 o’clock
Share luminosity Detector and IR magnets; e, h: 2K crab cavities; e: SC solenoid spin rotators

Hadron beams from RHIC injectors
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal Luminosity (hadron cooling)</th>
<th>Moderate Luminosity</th>
<th>&quot;Initial Luminosity&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center-of-Mass Energy [GeV]</td>
<td>104.9</td>
<td>105</td>
<td>104.9</td>
</tr>
<tr>
<td>Energy [GeV]</td>
<td>275</td>
<td>10</td>
<td>275</td>
</tr>
<tr>
<td>Number of Bunches</td>
<td>1320</td>
<td>660</td>
<td>290</td>
</tr>
<tr>
<td>Particles per Bunch [10^{11}]</td>
<td>0.6</td>
<td>1.51</td>
<td>1.02</td>
</tr>
<tr>
<td>Beam Current [A]</td>
<td>1.0</td>
<td>2.5</td>
<td>0.37</td>
</tr>
<tr>
<td>Horizontal Emittance [nm]</td>
<td>9.2</td>
<td>20.0</td>
<td>17.9</td>
</tr>
<tr>
<td>Vertical Emittance [nm]</td>
<td>1.3 ✈ cooling</td>
<td>1.0</td>
<td>8.5</td>
</tr>
<tr>
<td>Hor. $\beta$-function at IP $\beta_x^*$ [cm]</td>
<td>90</td>
<td>42</td>
<td>90</td>
</tr>
<tr>
<td>Vert. $\beta$-function at IP $\beta_y^*$ [cm]</td>
<td>4.0</td>
<td>5.0</td>
<td>5.9</td>
</tr>
<tr>
<td>Hor./Vert. Fractional Betatron Tunes</td>
<td>0.305/0.31</td>
<td>0.08/0.06</td>
<td>0.3/0.31</td>
</tr>
<tr>
<td>Horizontal Divergence $\delta\sigma_x^*/ds$ [mrad]</td>
<td>0.101</td>
<td>0.219</td>
<td>0.124</td>
</tr>
<tr>
<td>Vertical Divergence $\delta\sigma_y^*/ds$ [mrad]</td>
<td>0.179</td>
<td>0.143</td>
<td>0.380</td>
</tr>
<tr>
<td>Horizontal Beam-Beam Parameter $\xi_x$</td>
<td>0.013 ✈ cooling</td>
<td>0.064</td>
<td>0.015</td>
</tr>
<tr>
<td>Vertical Beam-Beam Parameter $\xi_y$</td>
<td>0.007 ✈ cooling</td>
<td>0.1</td>
<td>0.005</td>
</tr>
<tr>
<td>IBS Growth Time longitudinal/horizontal [hr]</td>
<td>2.19/2.06</td>
<td>-</td>
<td>10.1/9.2</td>
</tr>
<tr>
<td>Synchrotron Radiation Power [MW]</td>
<td>-</td>
<td>9.18</td>
<td>-</td>
</tr>
<tr>
<td>Bunch Length [cm]</td>
<td>5</td>
<td>1.9</td>
<td>7</td>
</tr>
<tr>
<td>Hourglass and Crab Reduction Factor [16]</td>
<td>0.87</td>
<td></td>
<td>0.74</td>
</tr>
<tr>
<td>Luminosity [$10^{34} \text{cm}^{-2}\text{sec}^{-1}$]</td>
<td>1.05</td>
<td>0.44</td>
<td>0.105</td>
</tr>
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</table>

"Initial luminosity" parameters: Parameters achievable after a short time of commissioning, still satisfying the minimum requirements of the EIC physics program as described in the EIC White Paper.
### Au-e maximum luminosity parameters
(with strong hadron cooling)

<table>
<thead>
<tr>
<th>Species</th>
<th>Au ion</th>
<th>electron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>110</td>
<td>10</td>
</tr>
<tr>
<td>Bunch intensity ([10^{10}])</td>
<td>0.05</td>
<td>15.1</td>
</tr>
<tr>
<td>No. of bunches</td>
<td>1320</td>
<td></td>
</tr>
<tr>
<td>Beam current [A]</td>
<td>0.65</td>
<td>2.5</td>
</tr>
<tr>
<td>RMS norm. emit., (h/v) [(\mu m)]</td>
<td>5.0/0.36</td>
<td>391/20</td>
</tr>
<tr>
<td>RMS emittance, (h/v) [nm]</td>
<td>43/3.1</td>
<td>20/1</td>
</tr>
<tr>
<td>(\beta^*), (h/v) [cm]</td>
<td>90/4</td>
<td>193/12</td>
</tr>
<tr>
<td>IP RMS beam size, (h/v) [(\mu m)]</td>
<td></td>
<td>197/11.1</td>
</tr>
<tr>
<td>(K_x)</td>
<td></td>
<td>17.9</td>
</tr>
<tr>
<td>RMS (\Delta \theta), (h/v) [(\mu rad)]</td>
<td>219/278</td>
<td>102/92</td>
</tr>
<tr>
<td>BB parameter, (h/v) ([10^{-3}])</td>
<td>3/2</td>
<td>43/47</td>
</tr>
<tr>
<td>Long. bunch area [eV·sec]</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>RMS bunch length [cm]</td>
<td>7</td>
<td>1.9</td>
</tr>
<tr>
<td>RMS (\Delta p/p) ([10^{-4}])</td>
<td>6.2</td>
<td>5.5</td>
</tr>
<tr>
<td>Max. space charge</td>
<td>0.004</td>
<td>negl.</td>
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<tr>
<td>Piwinski angle [rad]</td>
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<td>1.1</td>
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<tr>
<td>Long. IBS time [h]</td>
<td>0.30</td>
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<tr>
<td>Transv. IBS time [h]</td>
<td>0.77</td>
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<tr>
<td>Hourglass and Crab reduction factor</td>
<td>0.85</td>
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<tr>
<td>e-N Luminosity ([10^{33} cm^{-2}sec^{-1}])</td>
<td>4.72</td>
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