# Lattice Options Comparison for a DLSR Injector

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## Introduction

The PETRA IV project toward a diffraction limit synchrotron light source at 6 GeV features an ultra low emittance storage ring with strong sextupoles and a small dynamic aperture. The limited dynamic aperture presents challenges for the injectors, in particular in the case of an off-axis injection. The emittance of the injected beam shall be rather small to achieve high injection efficiency, whether it is an on-axis injection of the full charge or an off-axis top-up injection.

Presently, the injector chain for PETRA III consists of an electron gun, followed by the 450 MeV LINAC II, the accumulator PIA, and the booster DESY II. DESY II's equilibrium emittance is 350 nm-rad at 6 GeV, which is too high for PETRA IV's injection. Therefore, a new low emittance accelerator is needed to prepare the injected beams. This ring, named DESY IV, may serve different functions in the injector chain, depending on the chosen injection scenario: a high-intensity or a top-up booster, a high energy accumulator, or a hybrid mode. Their features are listed as follows.

## DESY IV Options

1. **Full intensity booster**
   This machine has to deliver very strong intensity charge with acceptable emittance (<30nm-rad at 6 GeV).The required charge can be as high as 8 nC per bunch in the Timing mode. The challenges involve the collective instabilities at low energies. Therefore it is advantageous to raise the input energy.

2. **Booster for accumulation**
   In this machine a smaller amount of charge is prepared to be topped-up to PETRA IV. The machine requires very low emittance for off-axis injection in PETRA IV. The challenge is to reach the very low emittance (<10nm-rad) necessary for accumulation given PETRA IV's limited dynamic aperture.

3. **High energy accumulator**
   The accumulator ring operates constantly at 6 GeV and needs an effective kicker leverage and an accept-able emittance (<30nm-rad). Another accelerator is needed to prepare 6 GeV beams. If the beam emittance is low enough, the off-axis injection in the storage ring could also be possible.

4. **Hybrid mode**
   In this option the machine can accumulate the beam at mid-energies and then accelerate the beam to 6 GeV. This will complicate the operation and increase the time for beam preparation. Another accelerator is also needed to prepare the mid-energy beams

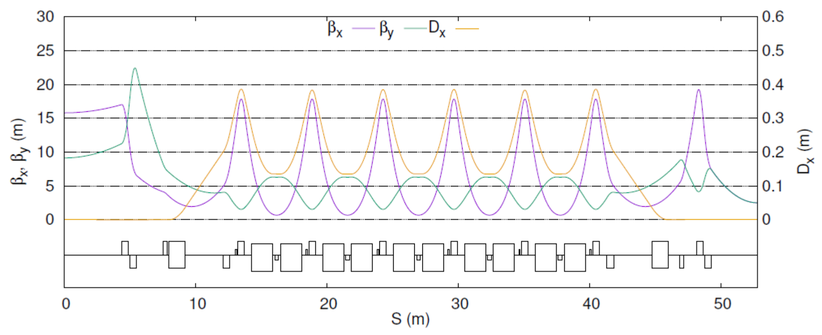
## Lattice Parameters

| Lattice | 3h3l | 10BA |
|---|---|---|
| Periodicity | 3 | 8 |
| Circumference (m) | 316.8 | 316.8 |
| Harmonic Number | 528 | 528 |
| Straight Length (m) | 3*8.8+3*7 | 8*5.7 |
| Working Tune (H/V) | 17.37 / 12.15 | 22.22 / 8.32 |
| Natural Chromaticity (H/V) | -41.8 / -13.8 | -24.2 / -23.8 |
| Momentum Compaction (1E-3) | 3.17 | 1.35 |
| Damping Partition Jx | 2.56 | 2.21 |
| Beta Function β* (H/V) | 15.8 / 9.1 | 8.9 / 2.1 |
| At Beam Energy 6 GeV | | |
| Energy Loss per Turn (MeV) | 6.55 | 6.76 |
| Natural Emittance (nm-rad) | 19.1 | 5.5 |
| Equil. Energy Spread (1E-3) | 2.64 | 1.99 |
| RF Voltage (MV) | 12 | 12 |
| Equil. Bunch Length (mm) | 20 | 9.9 |
| Damping Time (H/V/L) (ms) | 0.8 / 1.9 / 4.5 | 0.9 / 1.9 / 2.4 |

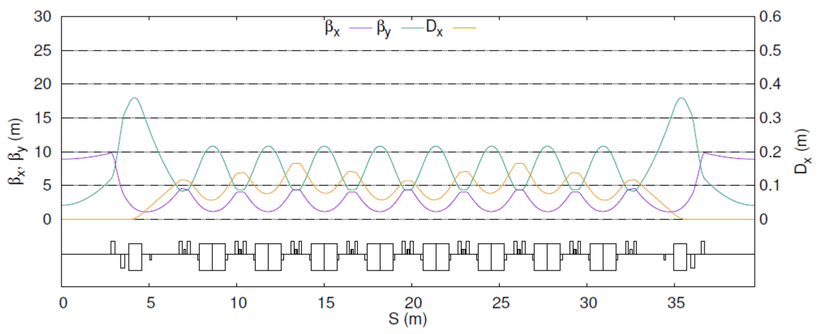
- The first lattice (named 3h3l) is a lattice dedicated to the booster option. It acquires the full intensity beam from a LINAC and accelerates it to 6 GeV.
- The second one (named 10BA), featuring a lower emittance is a dedicated accumulator operated 6 GeV.

## Lattice Optics

### 3h3l

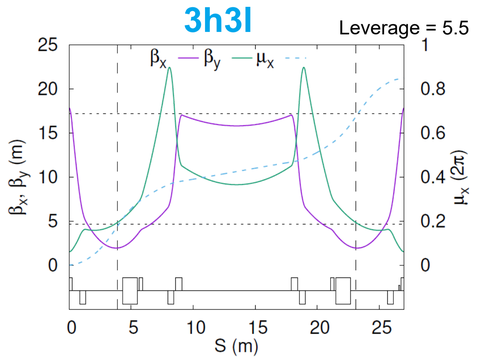



### 10BA

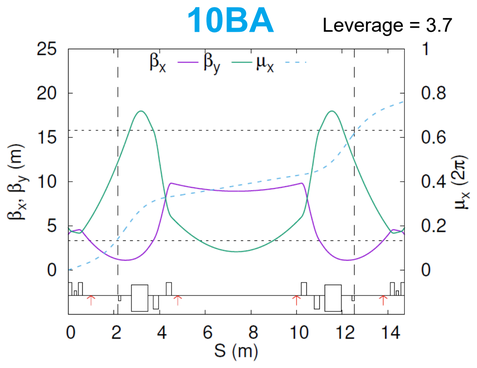



## Orbit Bump

### 3h3l

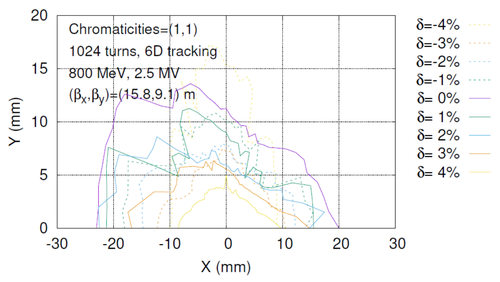



### 10BA

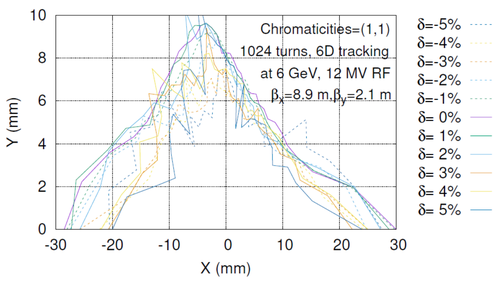



## Dynamic Aperture

### 3h3l




### 10BA




## Pro-and-cons

**High energy accumulator**

- Better injection efficiency into PETRA IV
- Smaller magnet apertures and thus smaller magnets
- Magnets can go into saturation
- DC magnet power supplies (more economical)
- Easier tuning & control of the optics at the fixed energy
- Requires a new electron gun otherwise the intensity accumulation time is a concern
- Requires running DESY II in the injector chain (reliability)
- Higher operating complexity
- Can mitigate intensity limitations (CB stability, beam loading) with multiple injections thanks to a fast ramp in DESY II
- Compatible with DESY II that can contribute with test beam programme

**High intensity booster**

- Lower injection efficiency into PETRA IV due to the larger emittance and longer bunch length
- Larger magnets with larger apertures
- Less number of magnets
- Ramping magnet power supplies
- Requires a new electron gun and upgrade linac to 800 MeV
- Doesn't need DESY II in operation
- Lower operating costs
- DESY II and DESY IV share the same linac
- Compatible with DESY II that can contribute with test beam programme

## Beam Stability

- A test impedance model

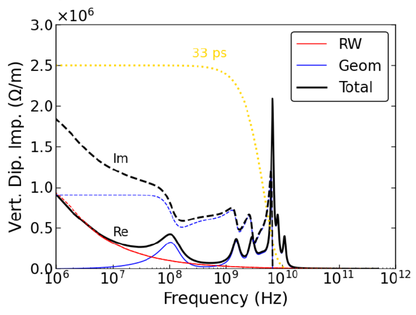



Table 3: Intensity limitations of DESY-IV options. TMCI threshold $Q_{th}$ is computed for a single-bunch. Coupled-bunch growth time $\tau_{CB}$ is computed for the 20-bunch trains of the Brightness mode with $Q = 1.5$ nC. Chromaticity $\xi = 0$. Synchrotron damping time, $\tau_{SD}$ is provided for comparison.

| Effect | Energy | 3h3l | 10-BA |
|---|---|---|---|
| $Q_{th}$ | 800 MeV | 8.7 nC | 3.8 nC |
| $Q_{th}$ | 6 GeV | 150 nC | 65 nC |
| $\tau_{CB}$ | 800 MeV | 10500 turn | 8000 turn |
| $\tau_{CB}$ | 6 GeV | $4 \times 10^4$ turn | $4 \times 10^4$ turn |
| $\tau_{SD}$ | 800 MeV | $7.5 \times 10^5$ turn | $7.5 \times 10^5$ turn |
| $\tau_{SD}$ | 6 GeV | 1780 turn | 1780 turn |

## Conclusion

The 10BA lattice is a dedicated beam accumulator at higher energies, and another accelerator is mandatory for the preparation of 6 GeV beams. It has the 528 magnets with stronger strengths. The power consumption of ring's magnets and RF is larger than for the 3h3l option. Its low momentum compaction factor brings instability problems at low energies, but its low emittance is very beneficial to the option of the booster for accumulation in PETRA IV. The 10BA lattice also can be operated in the hybrid mode.

The 3h3l lattice has 222 ramping magnets with moderate strengths. Its 19 nm-rad emittance and high intensity limit meet the requirement of the full intensity booster of PETRAIV. Although it has higher emittance, it can be a booster for accumulation in PETRA IV via the emittance rotation scheme by skew quadrupoles. It can also be operated as an accumulator at 6 GeV or in the hybrid mode. The lattice has no obvious weakness, and therefore it is considered as a baseline lattice.