# CEPC Radiation Protection

Zhongjian MA, Guangyi TANG, Haoyu SHI, Yadong DING, Mingyang YAN

19/11/2019

The 2019 International Workshop on the High Energy Circular Electron Positron Collider @ IHEP

# Content

- Radiation protection design recall
- Radiation shielding for synchrotron radiation
- Dump and dump transfer line design
- Summary

# Content

- Radiation protection design recall
- Radiation shielding for synchrotron radiation
- Dump and dump transfer line design
- Summary

# Radiological impact considerations

- Radiation protection design procedure

Operation mode → Source term → Shielding design → Dose optimization → Dose monitoring and access control

- Main shielding consideration aspects

| Impact factors | Characteristics |
|---|---|
| Synchrotron radiation | Radiation damage to magnet coil<br>Over heat load to ventilation system<br>Formation of ozone and nitrogen oxides in the air<br>Slightly activation to the material around |
| Random beam loss | Cause secondary radiation inside the tunnel<br>Determine the bulk shielding thickness |
| Hot spots | Like collimation locations, dump and transfer line, injection/extraction point |
| Radiological impact to environment | Dose from stray radiation emitted during machine running<br>Radionuclides in the cooling water, underground water, tunnel air, soil<br>Radioactivity analysis for the solid components and waste |

# Shielding Design Criteria

- Basic Rules of Radiation Protection
  - Justification, Limitation, Optimization
- Annual dose limit adopted by different owners

| Owners | Public | radiation workers | |
|---|---|---|---|
| | | B | A |
| Eu-Directive | <1mSv | <6mSv | <20mSv |
| France | <1mSv | <6mSv | <20mSv |
| Switzerland | <1mSv | <20mSv | |
| CERN from 2004 | <0.3mSv | <6mSv | <20mSv |
| CERN until 2004 | <0.3mSv | <20mSv | |
| China | <1mSv | <20mSv | |
| IHEP | <0.1mSv | <5mSv | |

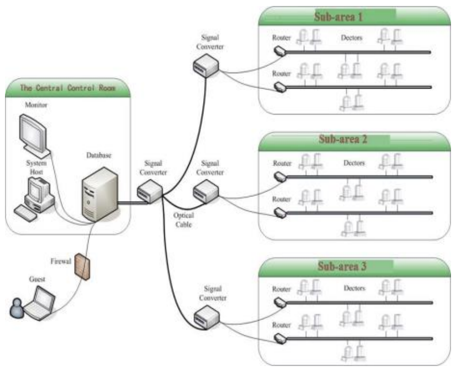
# Radiation dose monitor system(RDMS)

- Goal: guarantee the radiation level of workplace and the environment around complies with relevant regulations.
- State of the art system: once radiation level exceeds the set critical value, monitors would sound the alarm.
- Main includes:
  - Data acquisition program
  - Workplace monitoring program
  - Environmental monitoring program
  - Personal dose monitoring program
  - Management of radioactive components

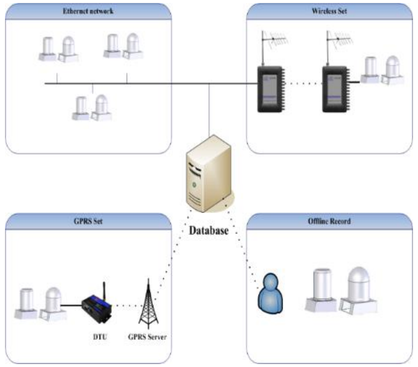
# RDMS & PPS & EHS

RDMS provides remote supervision, long term database storage and off-line data analysis

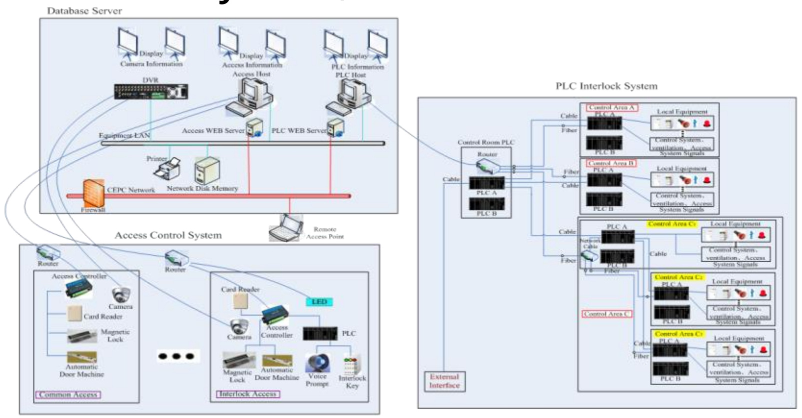
PPS (Personal Protection System) Includes PLC system, access control system, database server




System framework




Date communication methods




Schematic diagram of the PPS

- A pre-research project was established to solve the problem of saturation for neutron measurement at high instantaneous dose rate.
- More radiation detection methods was investigated and co-researched for future radiation detection
- PPS system was now mainly designed by Accelerator Control staff
- More detailed information about RDMS, PPS and EHS(Environment, Health and Safety considerations) can refer CDR Chapter 7.3 and Chapter 10.

# Content

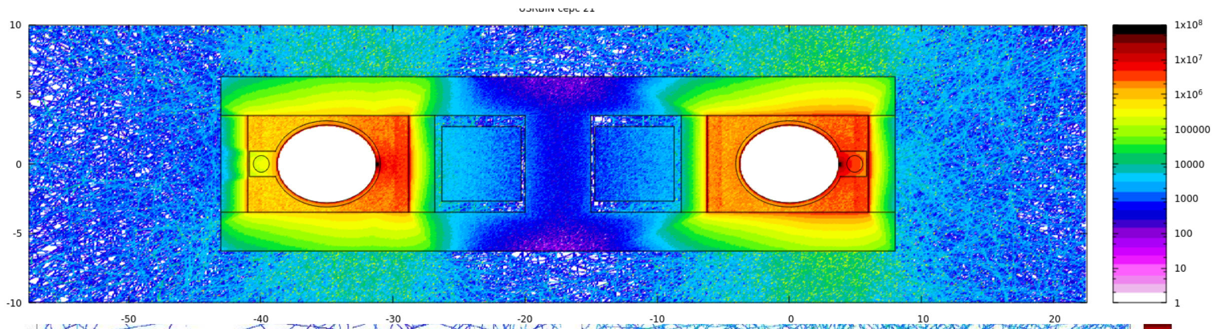
- Radiation protection design recall
- Radiation shielding for synchrotron radiation
- Dump and dump transfer line design
- Summary

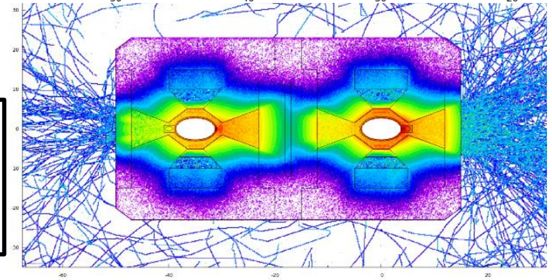
# Synchrotron radiation _ design updates

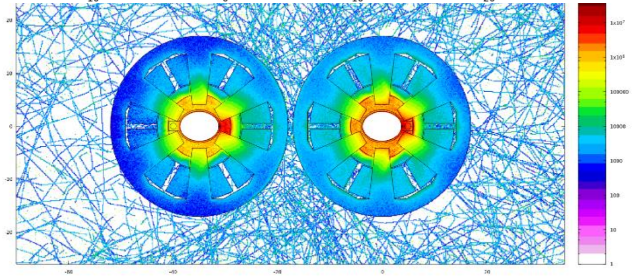
- First designed for 10 years machine operation in condition of 30MW&120GeV
- Operation scenario changed: 10 years running @ 50MW&120GeV and 3 years running @ 50MW&175GeV
- The person in charge of this issue is transferred from Haoyu Shi and Yadong Ding to Guangyi Tang.

| Parameters | Symbols | Values | | Units |
|---|---|---|---|---|
| Beam energy | E | 120 | 175 | GeV |
| Beam current | I | 17.8 | 3.95 | mA |
| Bending radius | ρ | 10.7 | 10.7 | km |
| Power per unit length | P | 453.9 | 455.6 | W/m |
| Critical Energy | Ec | 0.358 | 1.111 | MeV |

Parameters of synchrotron radiation





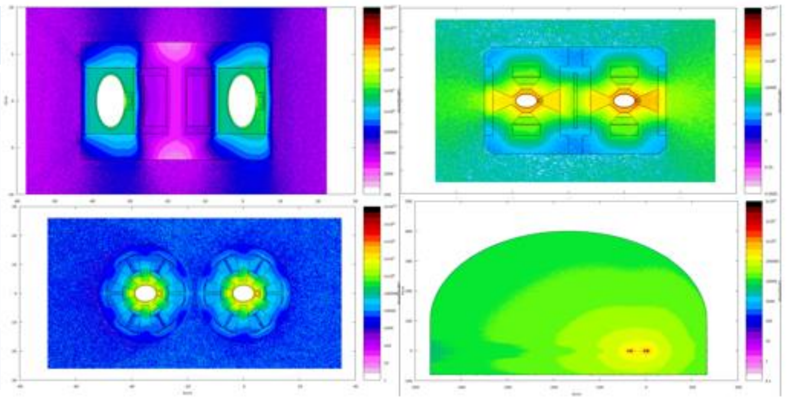


**CDR: 2cm lead was added to shield the Synchrotron Radiation to make sure the accumulated dose on the magnet coil well below the dose limit in operation of 120GeV@30MW**

# Synchrotron radiation _ design updates

- Re-calculated the absorber dose of insulators of coil: Ethylene Oxide (Oxirane) the results were consistent with CDR
- Optimization was conducted through:
  - Detailed analyze the spectrum of SR, divided and weighted the high energy part to study the radioactive characteristics of the beam pipe
  - Iterative optimization of the lead thickness according to different machine operation modes for the whole lifetime

| Magnets | Dose/(Gy/Ah) | | | |
|---|---|---|---|---|
| | 120GeV | | 175GeV | |
| | average | maximum | average | maximum |
| Dipole | $(2.6 \pm 0.2) \times 10^4$ | $(3.5 \pm 0.2) \times 10^4$ | $(2.7 \pm 0.1) \times 10^4$ | $(4.0 \pm 0.2) \times 10^4$ |
| Quadrupole | $(4.0 \pm 0.5) \times 10^4$ | $(10 \pm 5) \times 10^4$ | $(2.6 \pm 0.5) \times 10^4$ | $(9 \pm 5) \times 10^4$ |
| Sextupole | $(9.0 \pm 1.6) \times 10^4$ | $(13 \pm 1) \times 10^4$ | $(12 \pm 3) \times 10^4$ | $(23 \pm 13) \times 10^4$ |



# Content

- Radiation protection design recall
- Radiation shielding for synchrotron radiation
- Dump and dump transfer line design
- Summary

# Parameters for dump and transfer line design

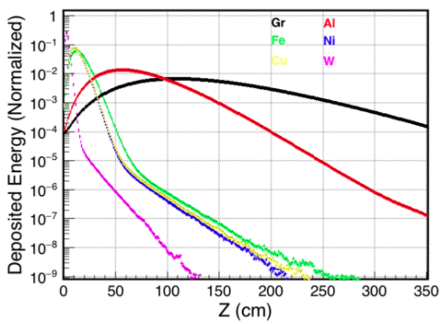
- The designed beam dump should have the capability to absorb an energy ranging form 0.7MJ/beam to 7 MJ/beam;
- A dedicated design for the beam dump system and transfer tunnels is going on
  - Including the dilution system, beam absorb system and shielding blocks
  - Coordinate with accelerator physics group, mechanical system and radiation protection group
  - Fail-safety design principle should be considered for abnormal operation and for machine commission and operation in different model;
- The assumed dumping frequency now is once per day;
  - For heating analysis and radiation simulation

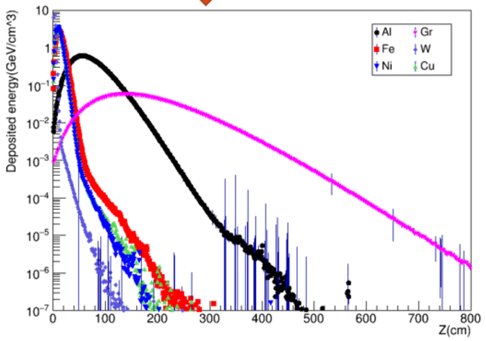
1. Z operation is most critical for beam power on absorbers-our base design;
2. Other operations has higher energy and longer beam dissipation
3. **Should be optimized suitable for different operation modes without big changes**

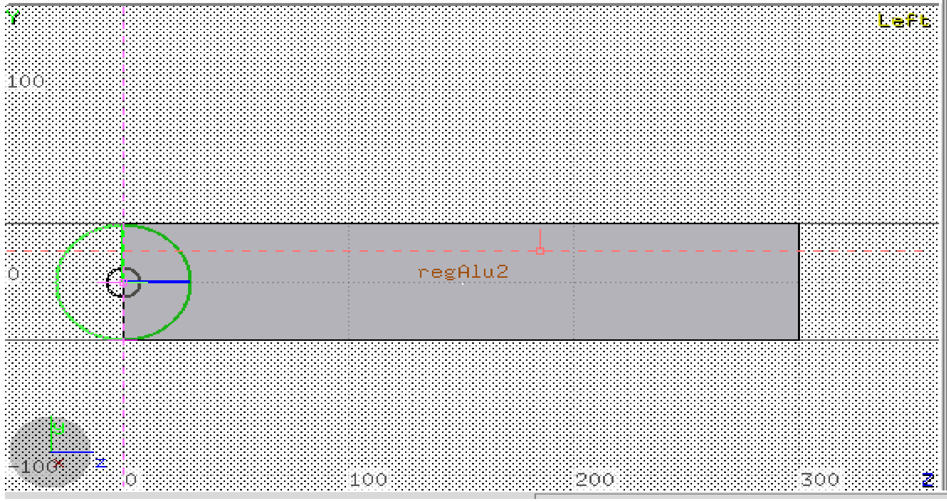
| Operation Modes | Eenrgy/ GeV | Bunch No. | Charge per Bunch /nC | Beam size at extraction point X/Y | Beam dump duration / s | Energy Stored in the tunnel / MJ |
|---|---|---|---|---|---|---|
| | | | | | Dump all the electrons in one cycle | Energy per electron*Electron No. |
| Higgs | 120 | 242 | 24 | 0.5mm/0.02mm | | 0.70 |
| W | 80 | 1524 | 19.2 | 0.33mm/ 0.02mm | 3.33E-04 | 2.34 |
| Z | 45.5 | 12000 | 12.8 | 0.19 mm/0.02mm | | 6.99 |

# Reference for dump design

| | Maximum temperature rise per bunch | |
|---|---|---|
| | Ref. 1 | ours (statistical uncertainty only) |
| Graphite | 0.5°C | 0.1±0.00003°C |
| Iron | 2.0°C | 1.8±0.0006°C |
| Tungsten | 13.0°C | 14.±0.007°C |




WET3AH3 Proceedings of eeFACT2016, Daresbury, UK

EXTRACTION LINE AND BEAM DUMP FOR THE FUTURE ELECTRON POSITRON CIRCULAR COLLIDER*

Armen Apyan†, ANSL, Yerevan, Armenia
Katsunobu Oide, KEK, Tsukuba, Japan
Frank Zimmermann, CERN, Geneva, Switzerland

*Abstract*

The conceptual design of an extraction line and beam dump for the future electron positron circular collider is presented. The proposed extraction line, consisting of abort kicker system, spoilers and beam diagnostics apparatus transports the electron and positron beams to the main beam dumps. The beam must be spread over a large surface in order not to damage the beam dump and the window, which separates the ring from the dump. The extraction line redistributes bunches at different location on the face of beam dump. Monte Carlo simulations using FLUKA have been performed to estimate the distribution of energy deposition on the window and beam dump to find the optimal absorber and its dimensions.

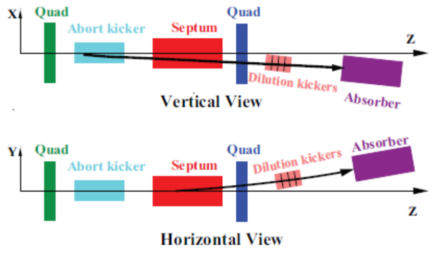
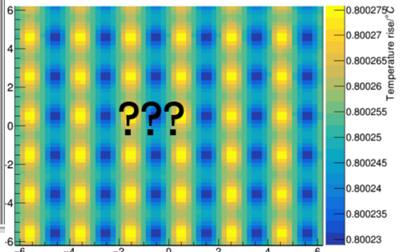
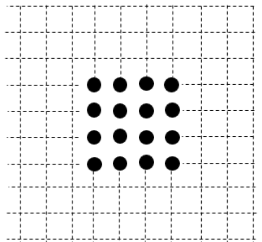
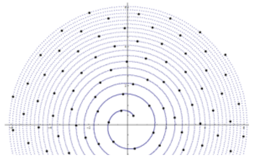



Figure 1: Schematic layout of the extraction system. The horizontal extraction kicker and vertical bending septum magnet are marked in yellow and red, respectively.

| Materials | Temperature rise/°C | | | |
|---|---|---|---|---|
| | 2cm | 1cm | 0.5cm | 0.1cm |
| Aluminum | 0.8 | 3.2 | 12.8 | 296 |
| Graphite | 0.6 | 2.5 | 10.0 | 220 |
| Iron | 2.3 | 9.1 | 36.5 | 899 |
| Nickel | 2.8 | 11.2 | 44.9 | 1111 |
| Copper | 3.2 | 12.7 | 51.0 | 1259 |
| Tungsten | 14.7 | 59.0 | 235.9 | 5892 |



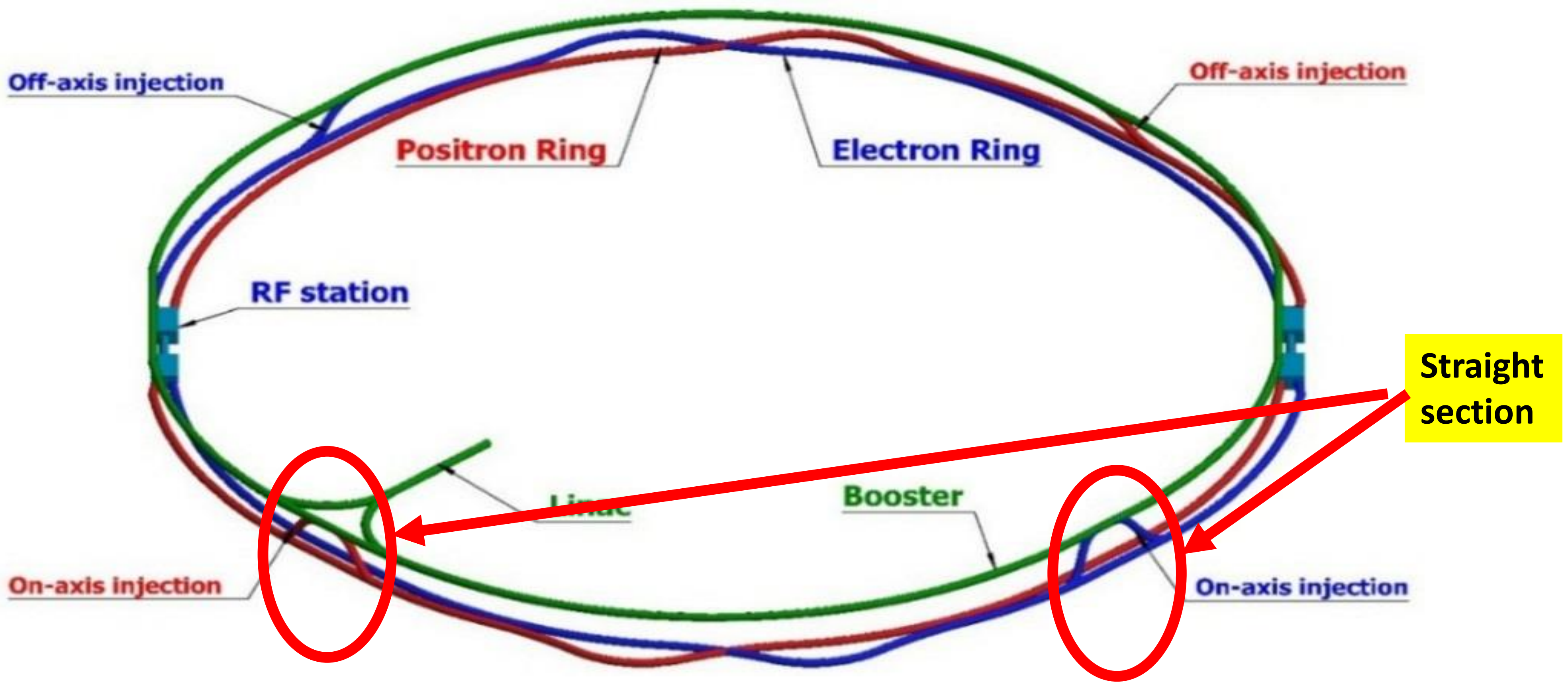





- Cylinder structure is our basic design
- Graphite, aluminum, iron, copper, nickel and tungsten are considered as our absorber material
- The beam is spread over the front surface of the dump in a rectangular pattern by means of horizontal and vertical dilution kicker magnets.

**Ref. 1: Proceedings of eeFACT2016**
**Ref. 2: slide: Advanced Beam dump for Fcc-ee**

# Location of dump system

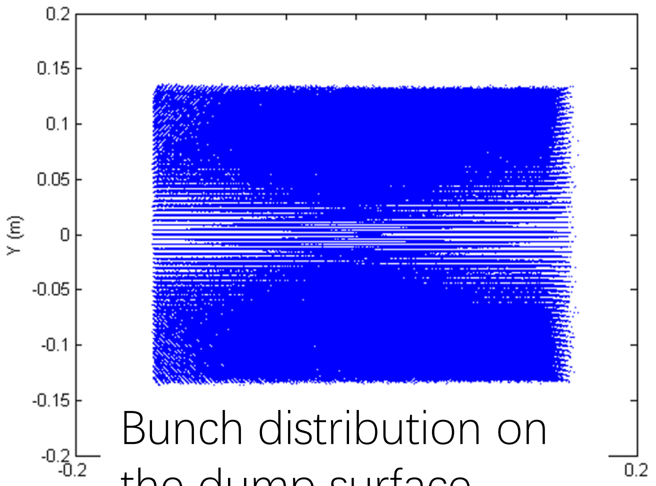


# Dump Lattice design

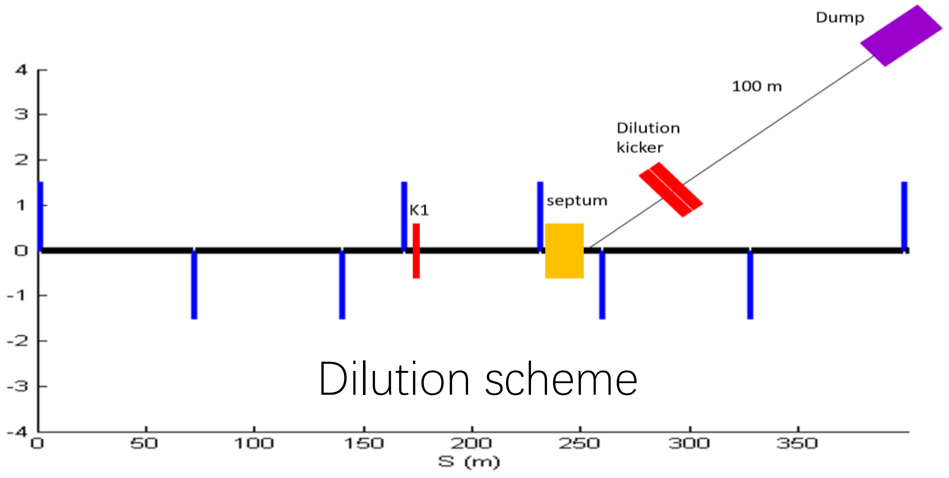
A set of kicker magnets has been used to dilute the beam horizontally and vertically

① The Bunch distribution on the dump surface is first assumed to be 25cm x 25cm; Each bunch 2D-Gaussian: $\sigma\_x \sim 3mm$, $\sigma\_y \sim 0.3mm$;

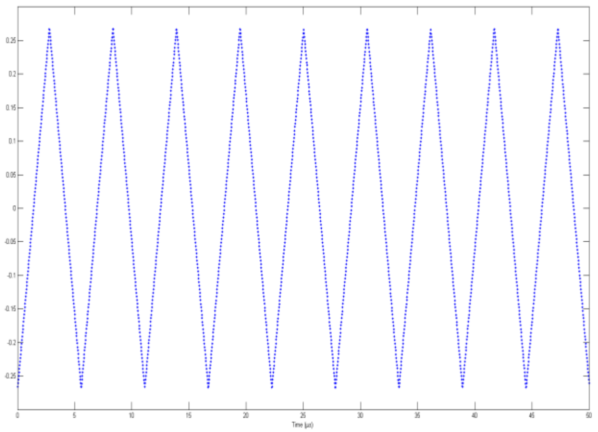
② This is an iterative design between AP, Magnet group, RP to finally fix the lattice design, dilution system, transfer tunnel length;

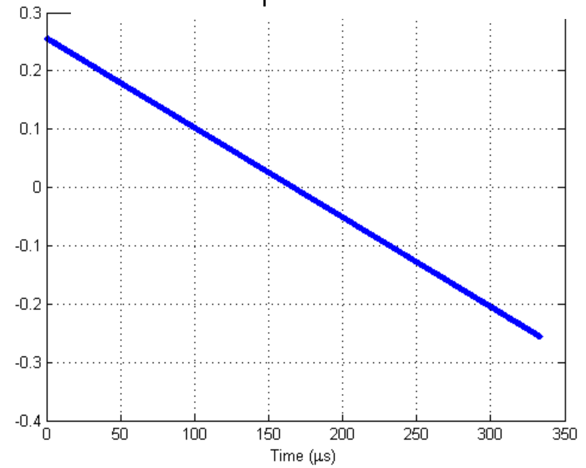



Bunch distribution on the dump surface




Dilution scheme





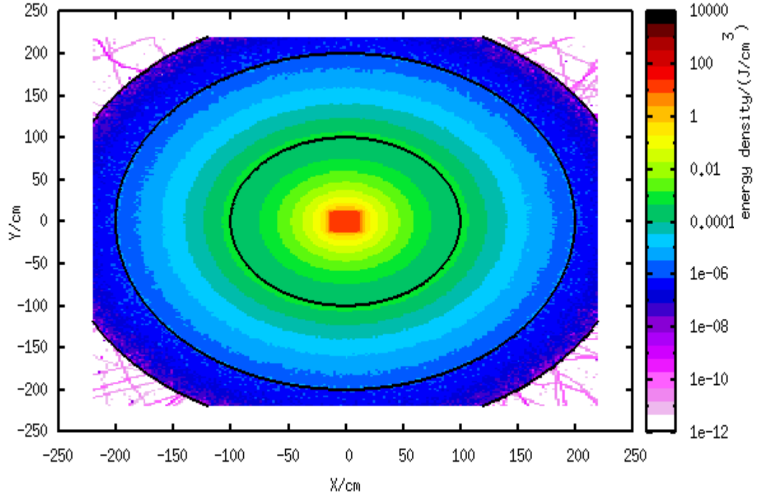

| Magnet | Length | angle |
| --- | --- | --- |
| septum | 20 m | 35 mrad |
| K1 | 2 m | 0.37 mrad |
| Dilution kicker | 10 m | 1.3 mrad |

Dilution kicker requirement:

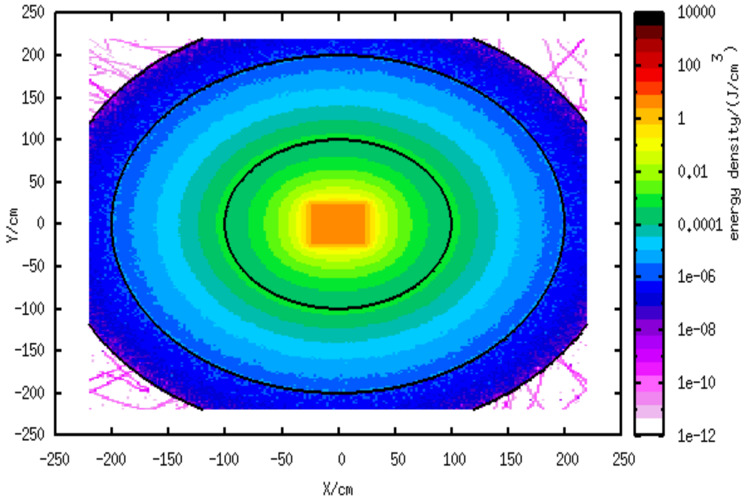
1. Horizontal kicker should periodic oscillate 50 times in 300 us
2. Vertical kicker should reduce from max value to minimum in 300 us

# Maximum energy deposition and temperature rise in the dump surface with different dilution size

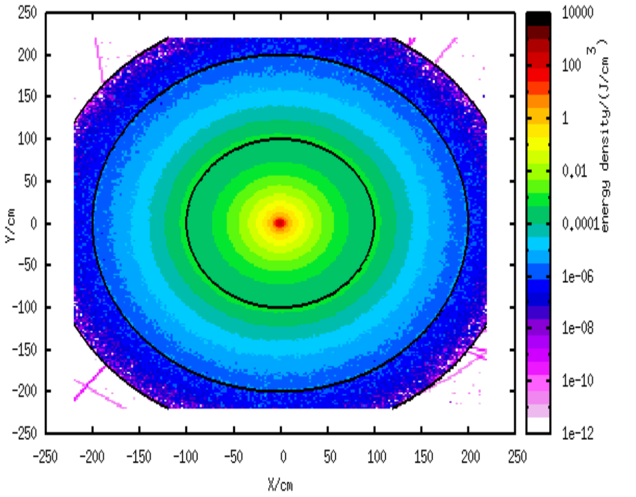
- Bunch separation: 2.5mm
  - Temperature rise: $64 \pm 1$℃



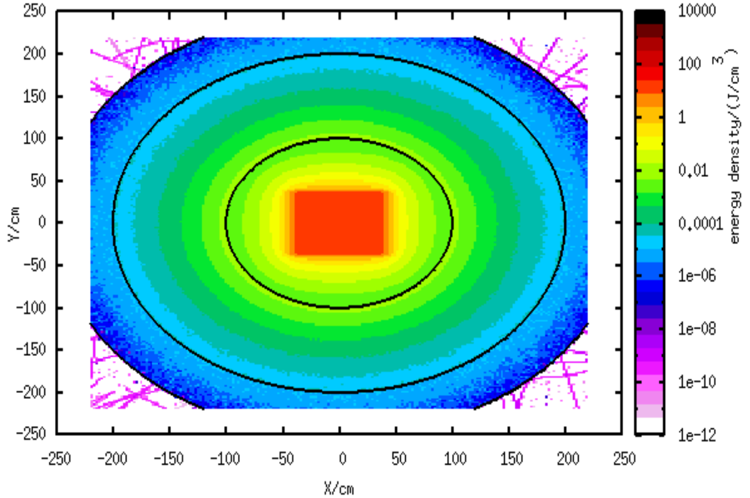

- Bunch separation: 5mm
  - Temperature rise: $18 \pm 2$℃



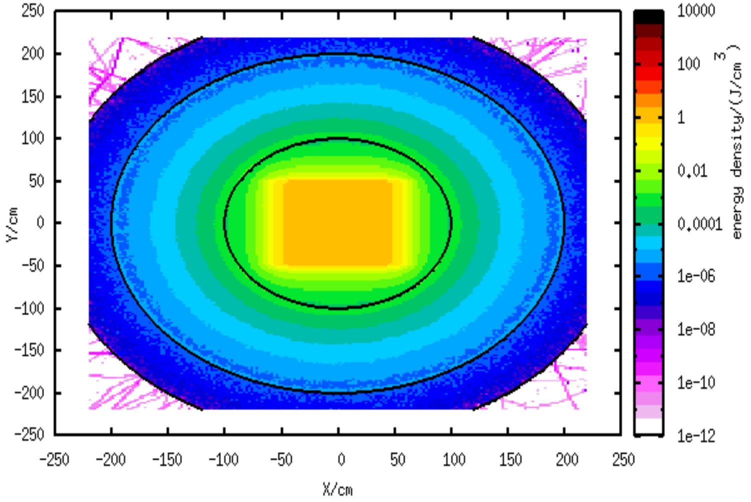

- Bunch separation: 0.5mm
  - Temperature rise: $1274 \pm 6$℃

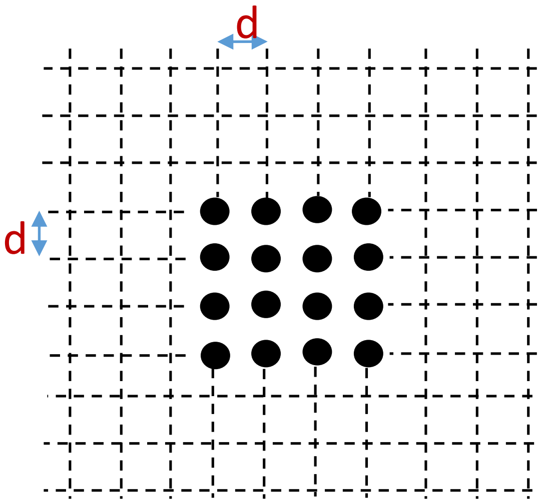



- Bunch separation: 7.5mm
  - Temperature rise: $9 \pm 3$℃




- Bunch separation: 10mm
  - Temperature rise: $7 \pm 4$℃



# Heat analysis

| | Temperature rise/℃ | | | | |
|---|---|---|---|---|---|
| | 0.5mm | 2.5mm | 5mm | 7.5mm | 10mm |
| Graphite | $432 \pm 4$ | $24 \pm 1$ | $7 \pm 1$ | $4 \pm 2$ | $2 \pm 1$ |
| Aluminum | $1274 \pm 6$ | $64 \pm 1$ | $18 \pm 2$ | $9 \pm 3$ | $7 \pm 4$ |
| Iron | $6730 \pm 22$ | $298 \pm 4$ | $80 \pm 3$ | $39 \pm 2$ | $23 \pm 2$ |

Methods and simulation procedure used here:

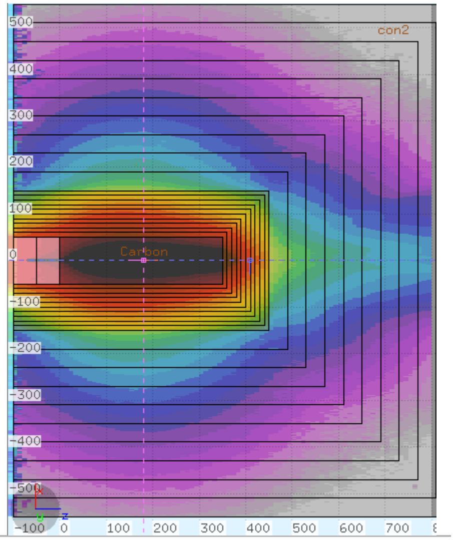
1. The whole information about beam profile on the dump surface was transferred to Source.f used in FLUKA
2. Analyzed the maximum energy deposition in proposed absorbed material in the bin range of beam size(x/y is about 1/0.1mm)
3. Temperature rise was got from thermal conduction formula

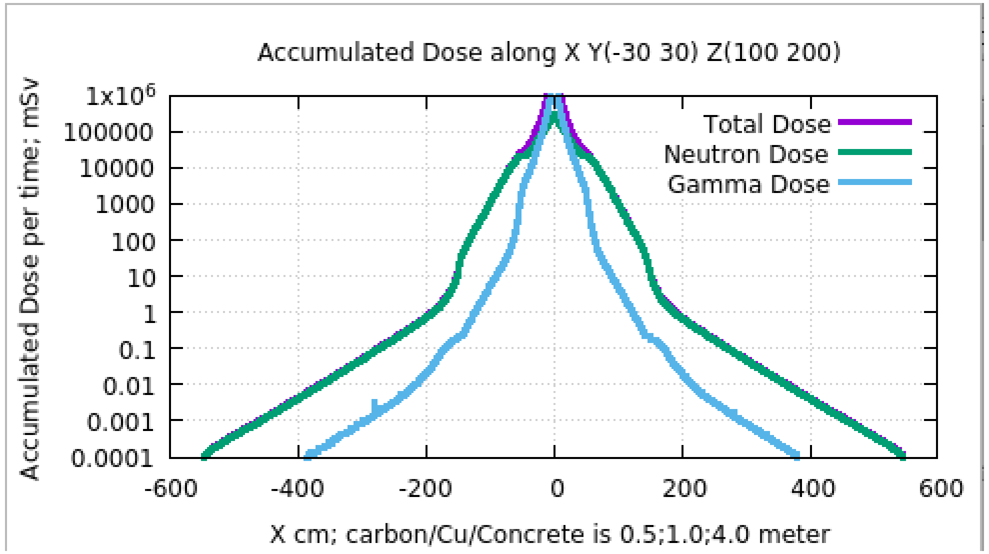
Under process:

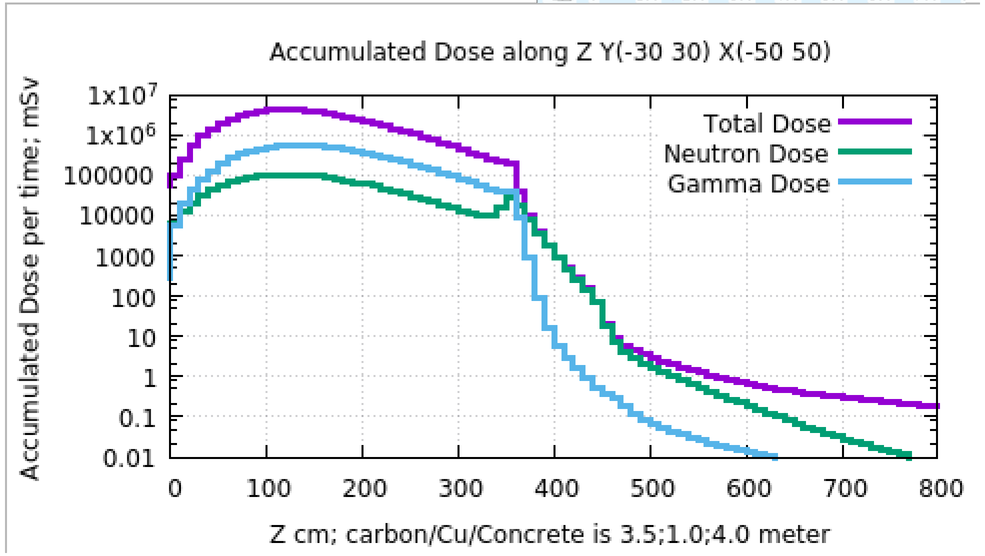
- Heat and mechanical stress analysis for the absorber material is under simulation through ANSYS supported by mechanical staff
- The same dump used for other operation modes will be checked step by step;

# Shielding thickness for absorber

1. A cylindrical dump with absorber core and surround shielding was adopted to get an idea about the space dimensions of dump cavern;
    - R=0.5m&L=3.5m for Carbon absorber; with 1m Cu and 4m Concrete surrounded;
2. Get results of accumulated dose in different locations;
3. Information about the needed space for dump itself-preliminary
    - Adopted dose limit as 10 mSv per beam loss at the start point;
    - Transverse size is 3 meters; longitudinal size is 5 meters;



# Summary

- Shielding for synchrotron radiation has been crosschecked and more actual structure will be developed for further simulation
- A basic analysis procedure for dump and transfer line has been established, heat analysis for the dump absorber and dimensions for dump cavern will be verified and fixed
- Radiological impact to the environment is the main considering issue in the next step

End!
Many thanks!