Karlsruhe Institute of Technology

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Accelerator Physics WS24/25

Case Study (Submission: 14.02.2025)

General Remarks

- Completing the case study is necessary to pass the class.
- Please work in groups of three to four students.
- You will present your work in a short oral presentation at the end of the case study period.
- Goal of the case study is to review the lecture, get insights into realistic accelerator designs and apply your knowledge to realistic cases.
- Please focus on a realistic design and reason your design choices in the presentation.
- Designing an accelerator will be an iterative process. We recommend to use tools like Jupyter notebook (Python), Pluto (Julia), Matlab, your favorite speadsheet software, or similar to do and redo your computation as you progress.
- If you have any questions, feel free to contact your lecturers or the teaching assistants anytime.

Please choose one of the following topics:

1 $t\bar{t}$ factory

Because of the high mass of the top quark ($m = 172.5\,\mathrm{GeV/c}$), the colliding beams need high beam energies. That is why studies of the top quark have been done rarely in the past. To get a high measurement accuracy, better statistics are needed. Therefore a new accelerator for the production of $t\bar{t}$ pairs in collision experiments shall be designed.

1.1 Requirements for your design

- 1×10^6 events per year with an assumed machine availability of 75 %. Each collision will produce not more than five $t\bar{t}$ pairs.
- The cross section for pp or $p\overline{p}$ collisions as a function of $\sqrt{s}$ is given in Figure 1.
- The circumference of the accelerator is limited to 6 km.
- The energy stored in the beam is limited to 50 MJ.
  The beam current is limited to 1 A.

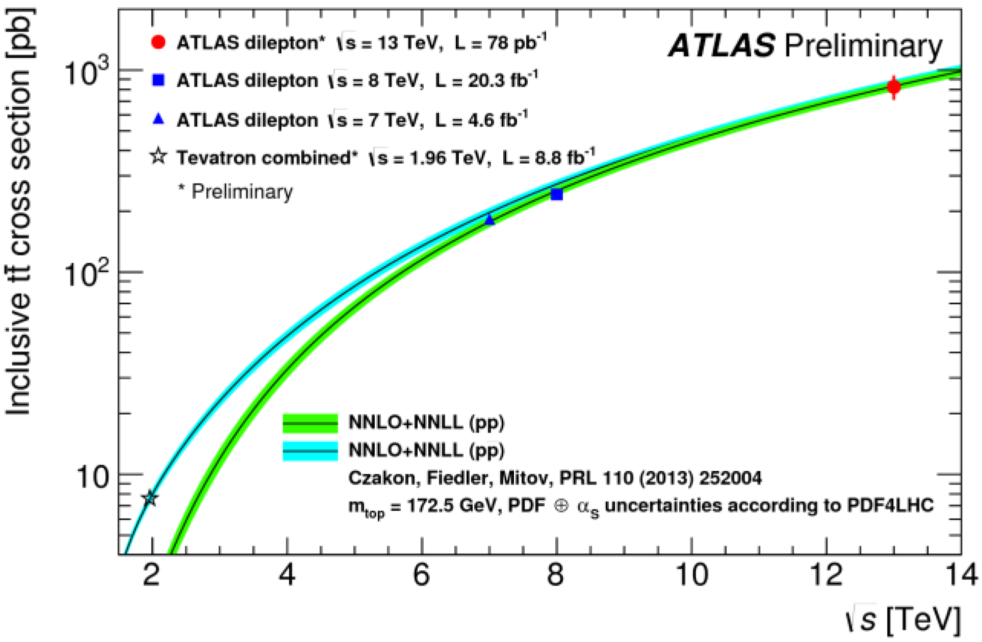

Figure 1: Cross section for pp (green) and $p\overline{p}$ (blue) (ATLAS)

1.2 Hints

- Choose particles species, beam energy, decide on 1 or 2 beam pipes.
- What luminosity do you need? What beam intensity, number of bunches and emittance? (Assume constant luminosity.)
- Design the global layout: Think of arc and straight sections. How many experiments do you foresee?
- Choose an appropriate lattice? Propose a realistic cell design.
- What kind of beam diagnostics do you need?
- What is the synchrotron radiation power and how much energy do you loose each turn?
- Give approximations for the momentum compaction factor, the bunch lengths, the transition energy and the ramping time
- What pre-accelerators do you need?
- How large are beam-beam effects?

2 FEL

Design a free electron laser (FEL) with short pulses in the X-ray spectrum.

A typical use case for an FEL is the imaging of molecules, which sets boundary conditions for the machine. Synchrotron radiation with wavelengths smaller than the atom sizes (about 0.5 Å) are required. In order to not damage the molecules, the exposure time shall be less than 10 fs. To visualize dynamic processes, the repetition frequency should exceed 100 Hz.

2.1 Parameters

- Start with a radiation power of about 30 GW.
- Optimization goals include the reduction of power consumption and length of the machine.

2.2 Hints

Remember what an FEL is made of:

- Electron gun: Start with the PITZ gun (parameters in Tab. 1).
- Accelerating structure: Choose an accelerating structure.
- Chicanes: Are used to reduce the bunch lengths
- Insertion devices: Start your design with a permanent magnet undulator and think about how radiated power relates to the undulator parameters.
- Beam optics: Focusing elements are needed between the insertion devices to maintain beam quality.
- Beamline: Not necessary to design here, as parameters are derived from the beamline.

Table 1: **PITZ gun design** for a medium average current

Single bunch charge	1.0	nC
Single bunch rep. rate	4.5	MHz
Length of bunch train	600.0	s
Bunch train rep. rate	10.0	Hz
Total bunch charge per second	27.0	C/s
Beam energy at exit	140.0	MeV
Normalized emittance	0.9	mm mrad
RF frequency	1.3	GHz