Particle Accelerators: LHC and CLIC/ILC

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LHC Requirements

- Have tunnel, want highest possible proton energy!
- High Energy: 7 TeV protons (~1 TeV/parton)
  - requires 1200 dipoles with 8.3 T magnetic field
  - limiting technology
  - primary RD issue + industrialization
- High Luminosity ($10^{34}/cm^2s$) to see rare events
  - Higgs
  - Light supersymmetric particles

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Some Implications

- Large currents
  - circulating current is 0.58 A
  - 2808 bunches with 1.15 x 10^{11} protons each
  - Instabilities and feedback systems
- Humongous beam power:
  - 360 MJ/beam
    - 1000 tons of water falling off a church tower
    - 80000 bars of Marabou chocolate at 4.2 kJ
  - Beam loss handling and beam dump are critical

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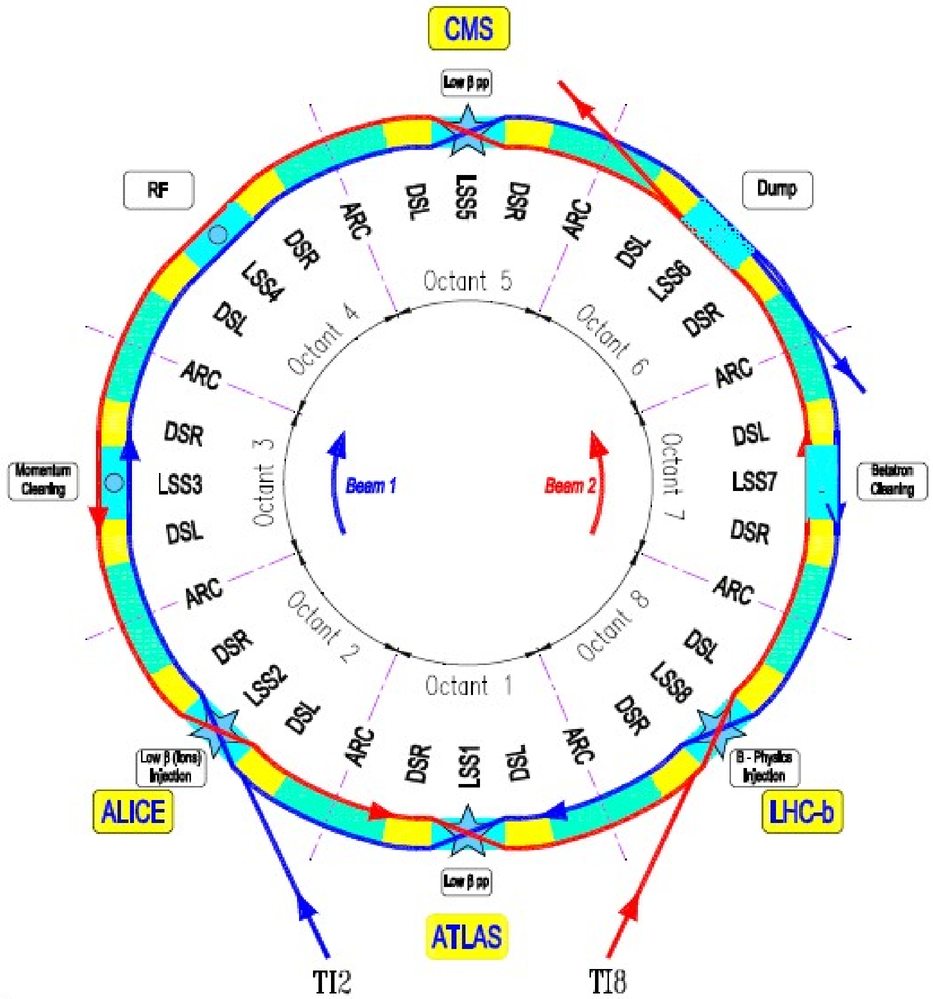
Some more Implications

- Small spots at IP
  - 16.7 µm RMS
  - maintain in collision
  - beam-beam effect
- Many parasitic collisions
- Synchrotron radiation
  - 3.6 kW per ring
  - beam screen to shield s.c. magnets at 1.8 K

Realization



- Four physics IR (ATLAS, CMS, LHCb, Alice)
- One RF acceleration
- Two collimation (transverse and momentum
- Beam dump

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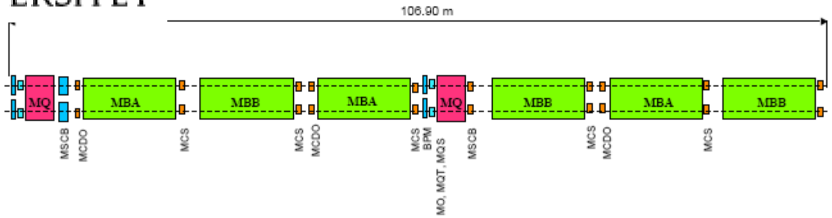
The LHC arcs



MQT: trim quadrupole

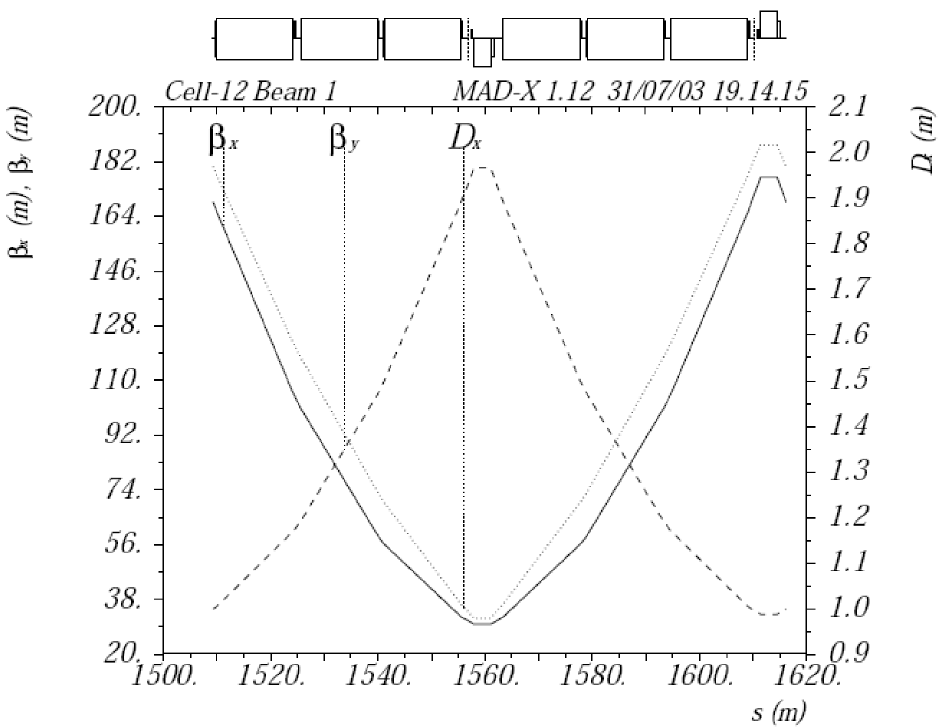
MQS: skew trim quadrupole

MO: lattice octupole

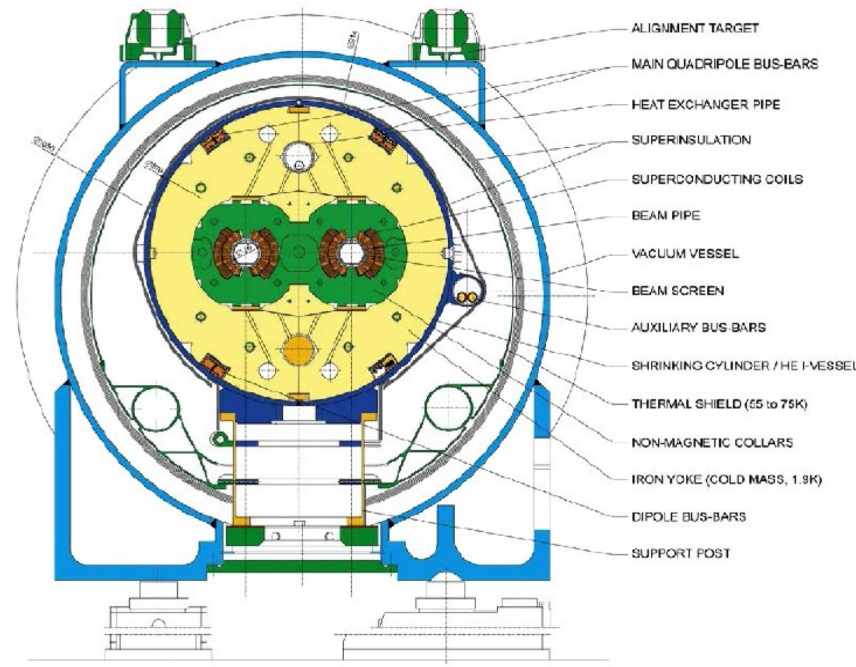
MSCB: sextupole (skew sextupole) + orbit corrector

MCS: spool piece sextupole

MCDO: spool piece octupole + decapole



- Crossection of main dipole, ~15 m long



- Nominal Bfield: 8.3 T
- Stored energy: 8.1 MJ

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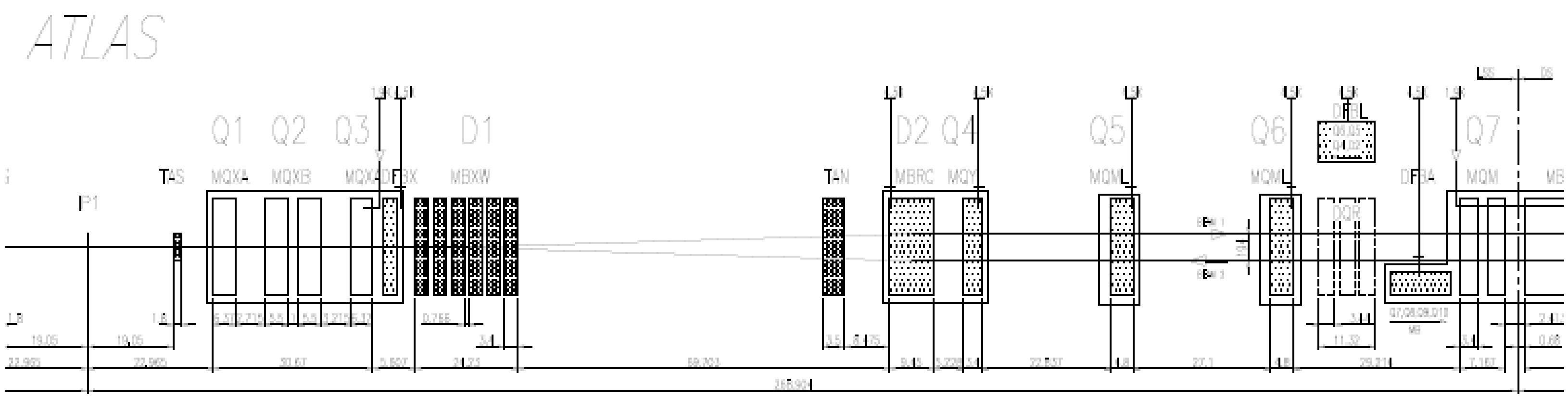
ATLAS and CMS Insertion



IP | Triplet | Matching section | Dispersion suppressor

- Triplet: final demagnification
- D1: separation of beams
- Matching 1: adjust periodic arc-optics to mini-beta optics
- Matching 2: interpolate injection optics to luminosity optics ("the squeeze")
- Dispersion suppressor: adapt the periodic dispersion in the ars to small values or zero

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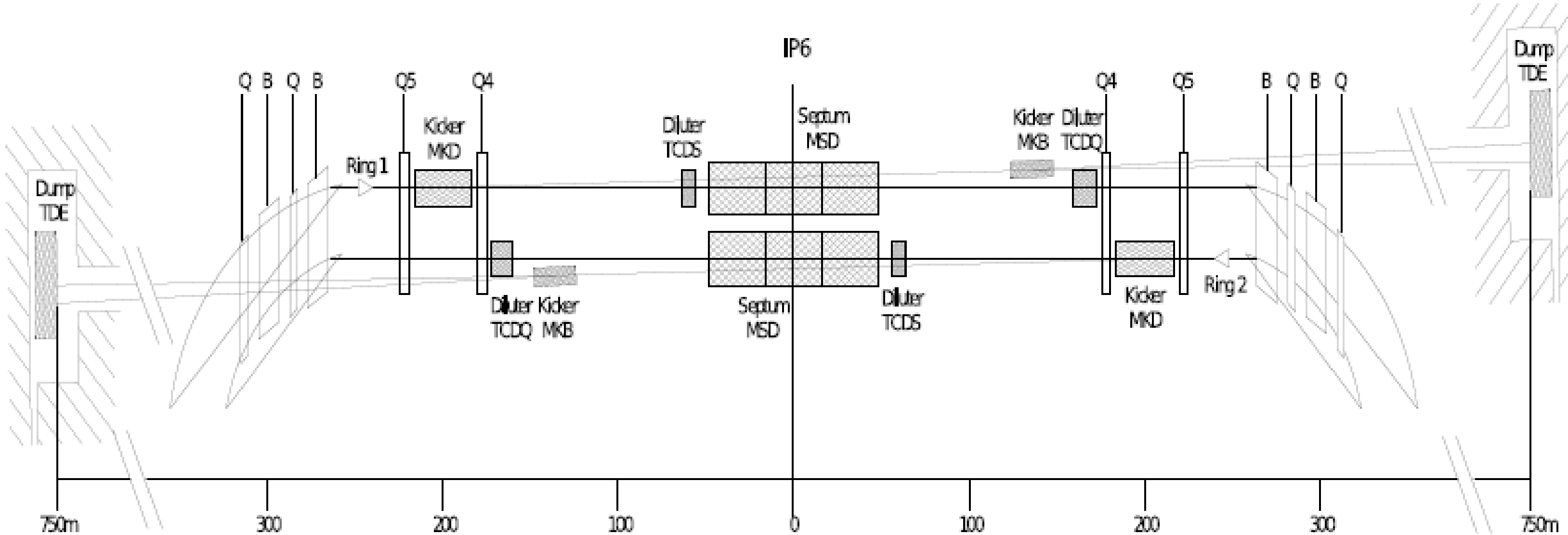
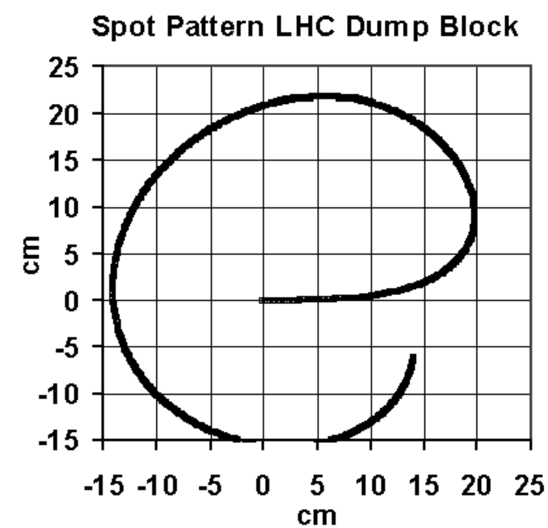
Momentum and Betatron cleaning

- Occupies two out of eight interaction regions
- Needed because
  - losses in s.c. arcs can quench the magnets
  - background for detectors
- Caused by magnet imperfections, power supply ripple, beam-beam, parasitic crossings, IBS, beam-gas interaction
- Warm magnets in the cleaning sections
- Primary and secondary collimators, jaws at ~ 6σ

Beam dump

LHC, JINST 3, S08001





- Dispose of 350 MJ/beam in controlled way
- Kicker gap in the bunch train
- 15 kicker magnets to deflect the beam
- 15 Septum magnets
- Dilution kickers
- Composite carbon window
- Carbon core beam dump surrounded by (ISR) iron dipole yokes filled with concrete

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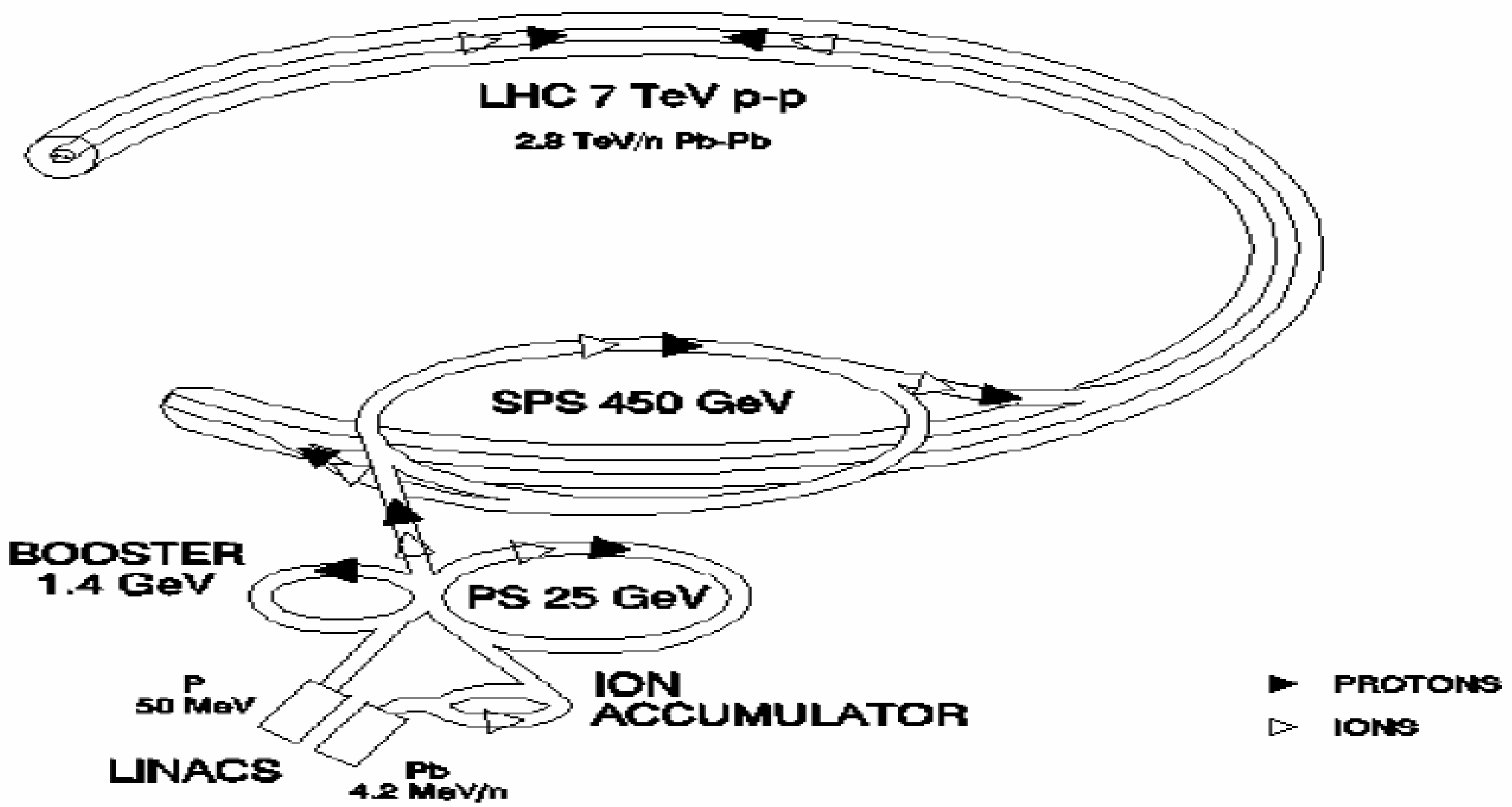
Injector chain



- Linac → PS-booster → PS → SPS → LHC
- Separate initial sections for protons and lead

LHC cycle

- Luminosity lifetime ~ 15 h, needs filling once or twice a day.
- But filling takes time
  - Filling PS takes 3.6 s
  - Filling SPS takes 21.6 s
  - Filling one LHC beam needs 12 SPS cycles @21.6 s → 4 min/beam
  - Injection setup (pilot beams + checks) → 16 min
- Ramping from 450 GeV to 7 TeV takes 20 min
- Ramping down take also 20 min
- Checks and squeeze at flattop takes about 10 min
- Total time from flattop to flattop takes at least 70 min
- Experience from HERA: It takes typically 6 times as long!

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Beyond LHC

- sLHC: it's still LHC, right?
- Lepton collider to increase the available energy per parton and get cleaner events
  - Muon collider (limited lifetime)
  - Linear electron-positron collider
- ILC: super conducting RF (35 MV/m) gradient, energy limited to about 250+250 MeV
- CLIC: normal conducting RF (100 MV/m) with energy up to 1.5+1.5 TeV (~50 km long)

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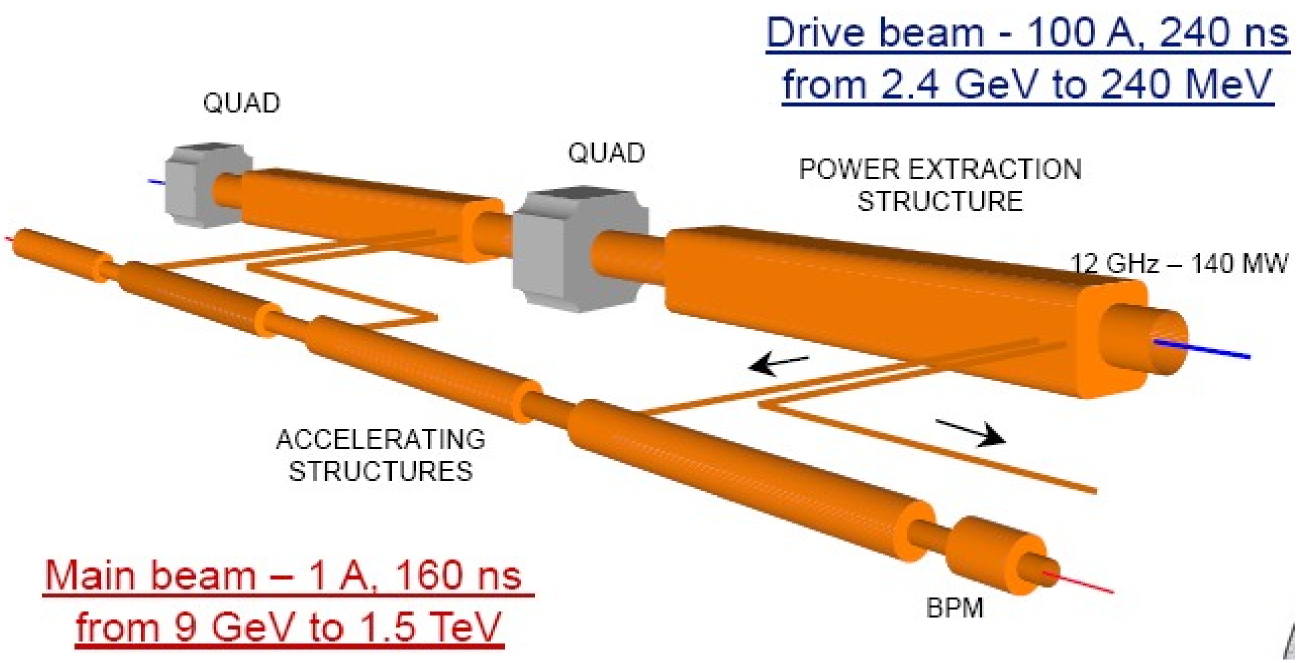
CLIC Requirements

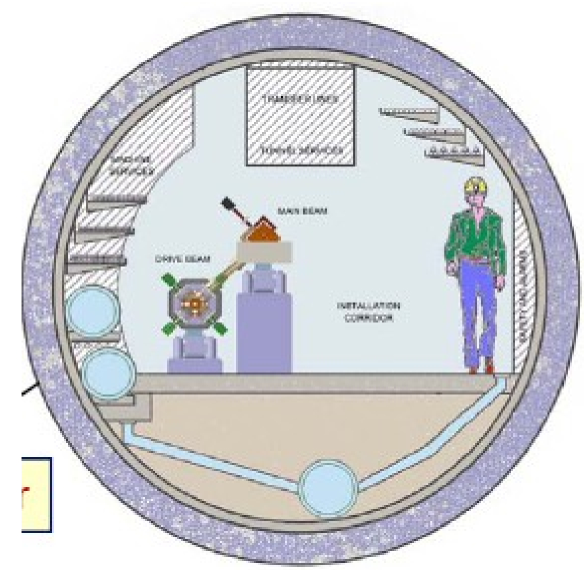
- High energy: 1.5+1.5 TeV
- Same high luminosity: n x $10^{34}/cm^2s$
- Lower rep.rate 100 Hz vs. 10 kHz in LHC
- Shorter bunch trains
- Need to achieve luminosity by making very small beam size at IP (1 x 100 nm)
- Requires high accelerating gradient (100 MeV/m) to keep length within reasonable limits

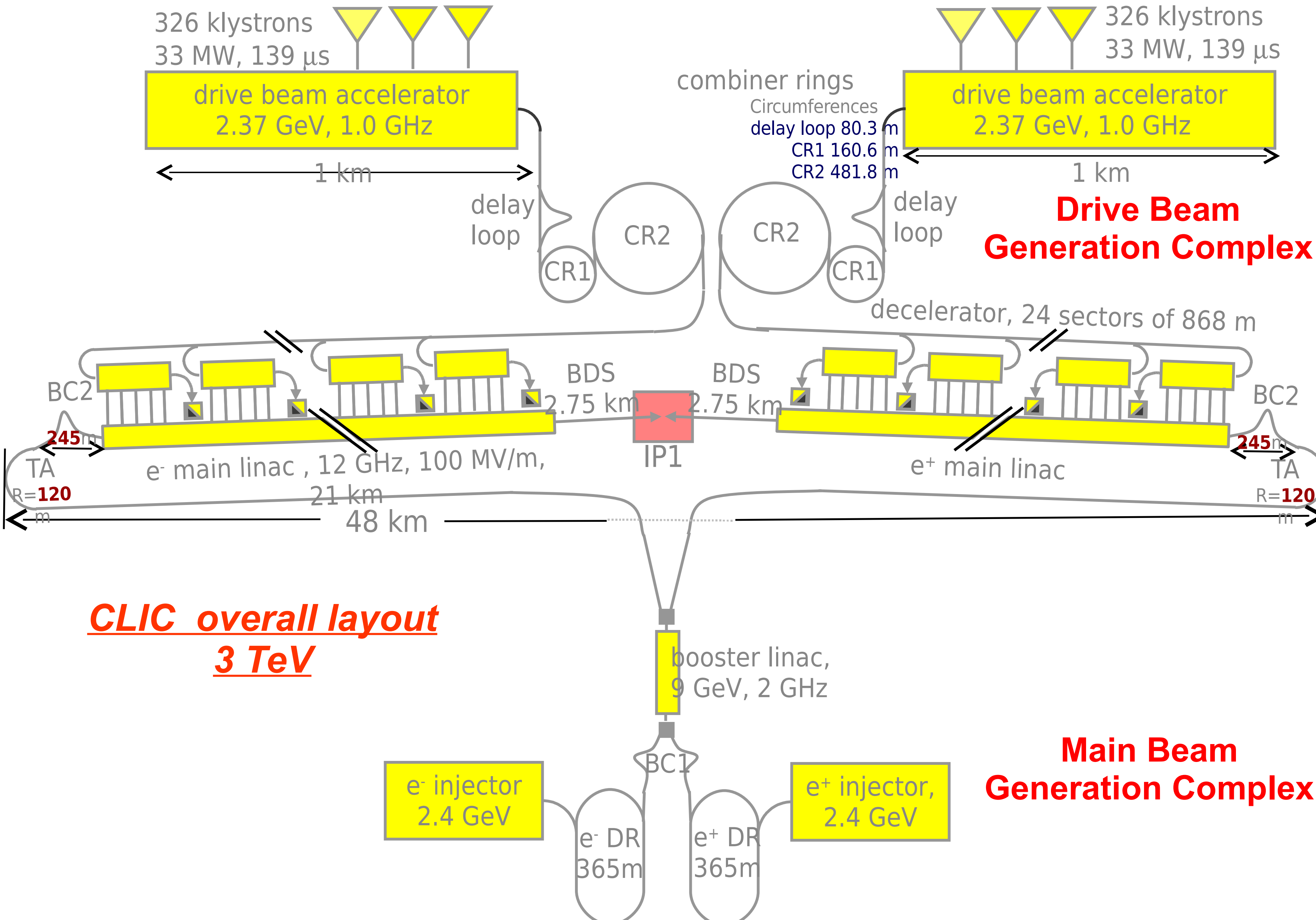
Two-beam acceleration

It's long: 144000 RF accelerating-structures

- putting a klystron next to a few structures won't do
- need to deliver RF-power in an effcient way
- Decelerate high-intensity drive-beam and use the microwaves to accelerate low-intensity main-beam to very high energies







CLIC overall layout
3 TeV

from JP Delahaye, CLIC07 worksop

CLIC Drive-beam Layout

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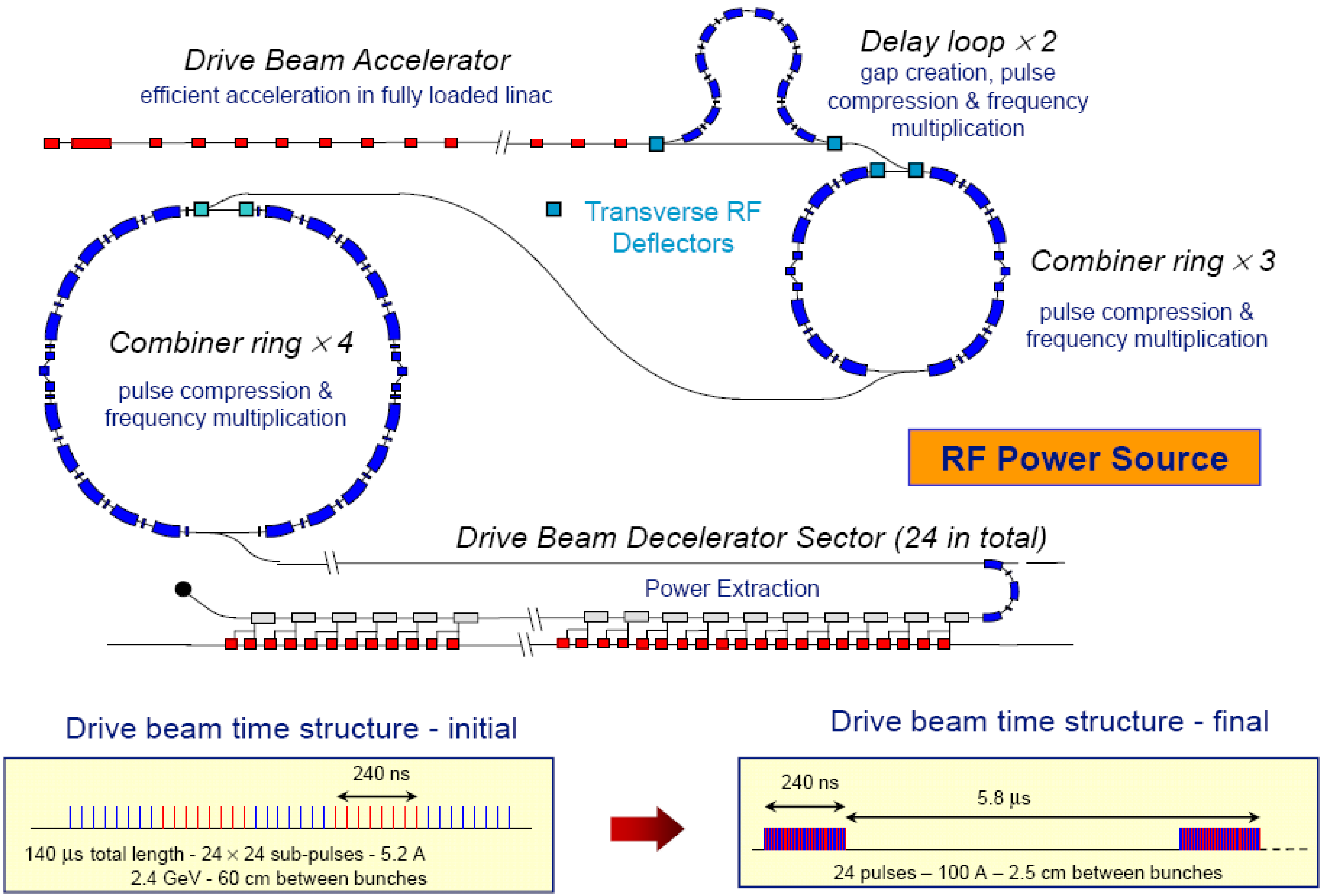
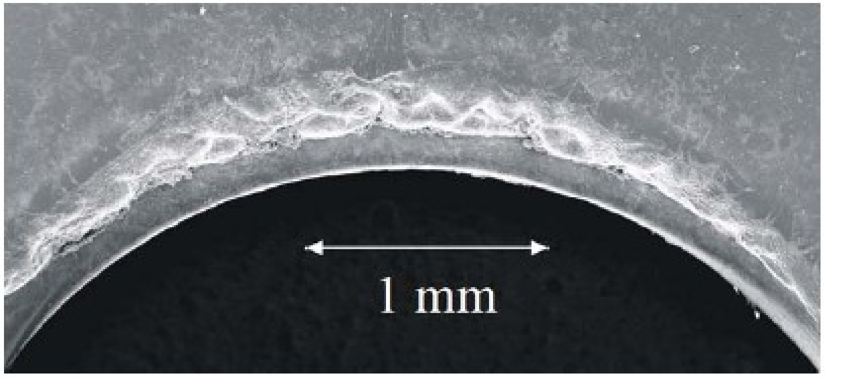


Problems



Microscopic image of damaged iris

- RF-breakdown
  - High power levels in structures leads to discharges
  - effect on beam → luminosity and reliability
- Small RF-structures
  - beam interacts with the environment → wakefields
  - requires careful control
  - otherwise the emittance will grow enormously and spoil the luminosity
- Nano-meter spotsizes require nm alignment tolerances of the FF quadrupoles

CLIC: achieving nm spots

- Damping rings to prepare initial small emittances
- Emittance preservation in the linac
  - extreme alignment tolerances
  - control of wakefield effects
- Extreme demagnification of the beam size to ~100nm x 1nm very strong quadrupoles
- Chromatic correction sections
- Stabilization of FF magnets to sub-nm tolerance
- Collimation and diagnostics essential

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Summary

- I hope you roughly understand
  - how accelerators work
  - basic concepts such as emittance and dispersion
  - the critical parameters of accelerators
  - what happens during accelerator operation
  -
  -
- how the design requirements for LHC and CLIC are realized in the machines