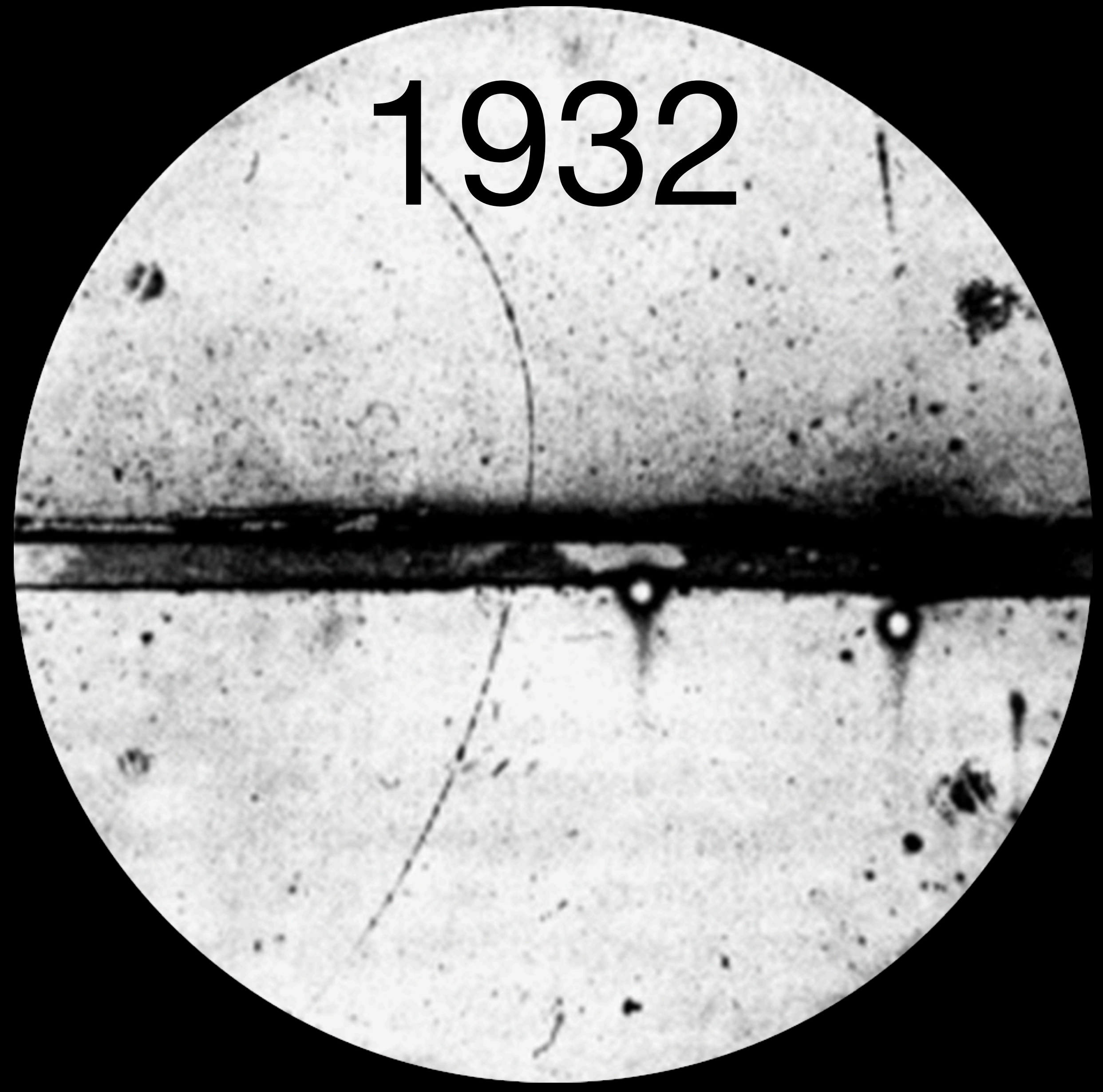
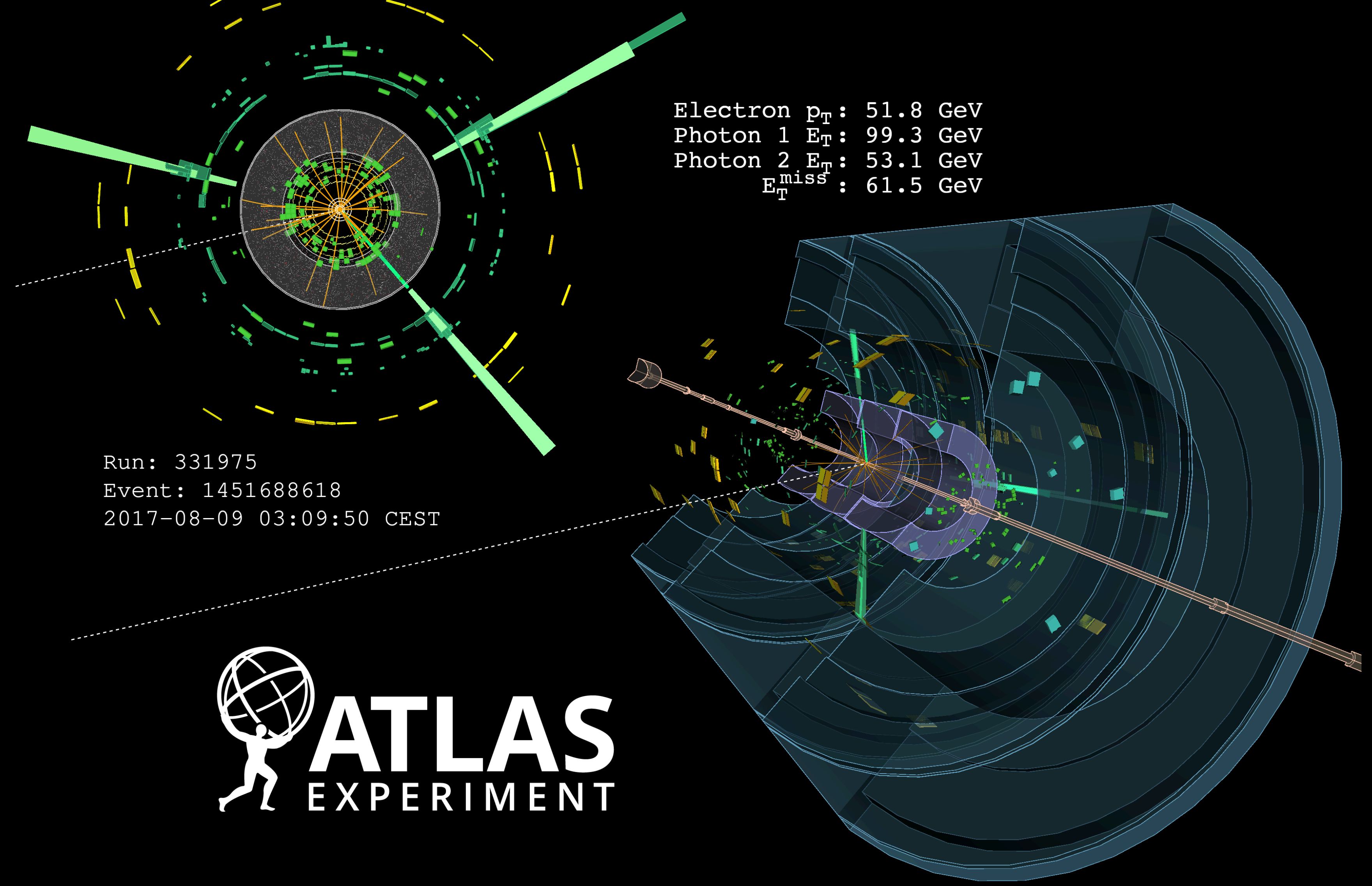
PHYS 7363 - Experimental Particle Detection and Detectors I



2017



Particle detectors are the workhorses of experimental physics. In this course, we'll dive deep into their physics, exploring the incredible evolution of our experimental techniques over the past nine decades. You'll gain a solid understanding of *particle detection* and *identification*, examine the intricate designs of modern detectors, and learn how machine learning is being harnessed to push the boundaries of detector design. If you're intrigued by how we "see" subatomic particles, this course is for you!

Detect Identify Measure

To discuss prerequisites (and any questions on the content of the course), please contact me: saptaparnab@smu.edu

Schedule

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
October	6 ✅ 1.5 hours	7	8 ✅ 1.5 hours	9	10	11	12
	13 ✅ 1.5 hours	14	15 ✅ 1.5 hours	16	17 ✅	18	19
	20	21	22	23 ✅ 1.5 hours	24 ✅ 1.5 hours	25	26
	27: Midterm	28	29 ✅ 1.5 hours	30	31 ✅ 1.5 hours	1	2
November	3 ✅ 1.5 hours	4	5 ✅ 1.5 hours	6	7 ✅ 1.5 hours	8	9
	10 ✅ 1.5 hours	11	12 ✅ 1.5 hours	13	14 ✅ 1.5 hours	15	16
	17 ✅ 1.5 hours	18	19 ✅ 1.5 hours	20	21 ✅ 1.5 hours	22	23
	24 ✅ 1.5 hours	25	26	27	28	29	30
December	1 ✅ 1.5 hours	2	3	4	5 ✅ 1.5 hours	6	7
	8	9	10	11	12	13	14

As you prepare your slides…

- Clearly write down the main points that you want to convey
- Include illustrations
- Make the big picture clear
- Highlight your own work
  - Focus on the “why” and then the “how”
  - Did you hit your target
  - What did you learn in the process
  - What were the major challenges
  - What are the major takeaways
- Some tips: https://courses.physics.illinois.edu/phys596/fa2013/Lectures/EffectiveScientificPresentations_FA13.pdf

Cyclotron

Proposed by Ernest Lawrence and patented in 1932

① Ion source (negative charges here)

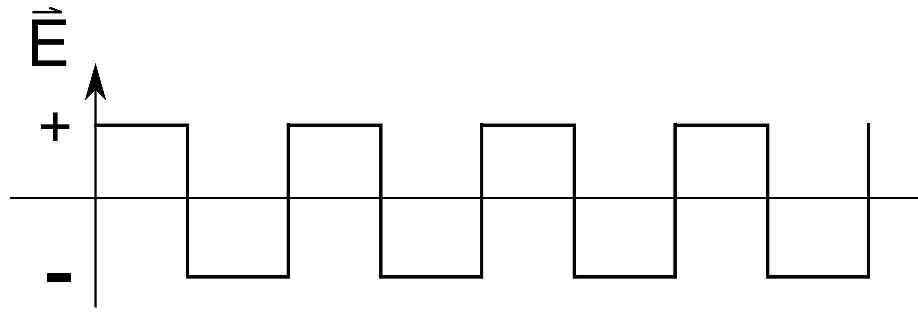
② Accelerated ions

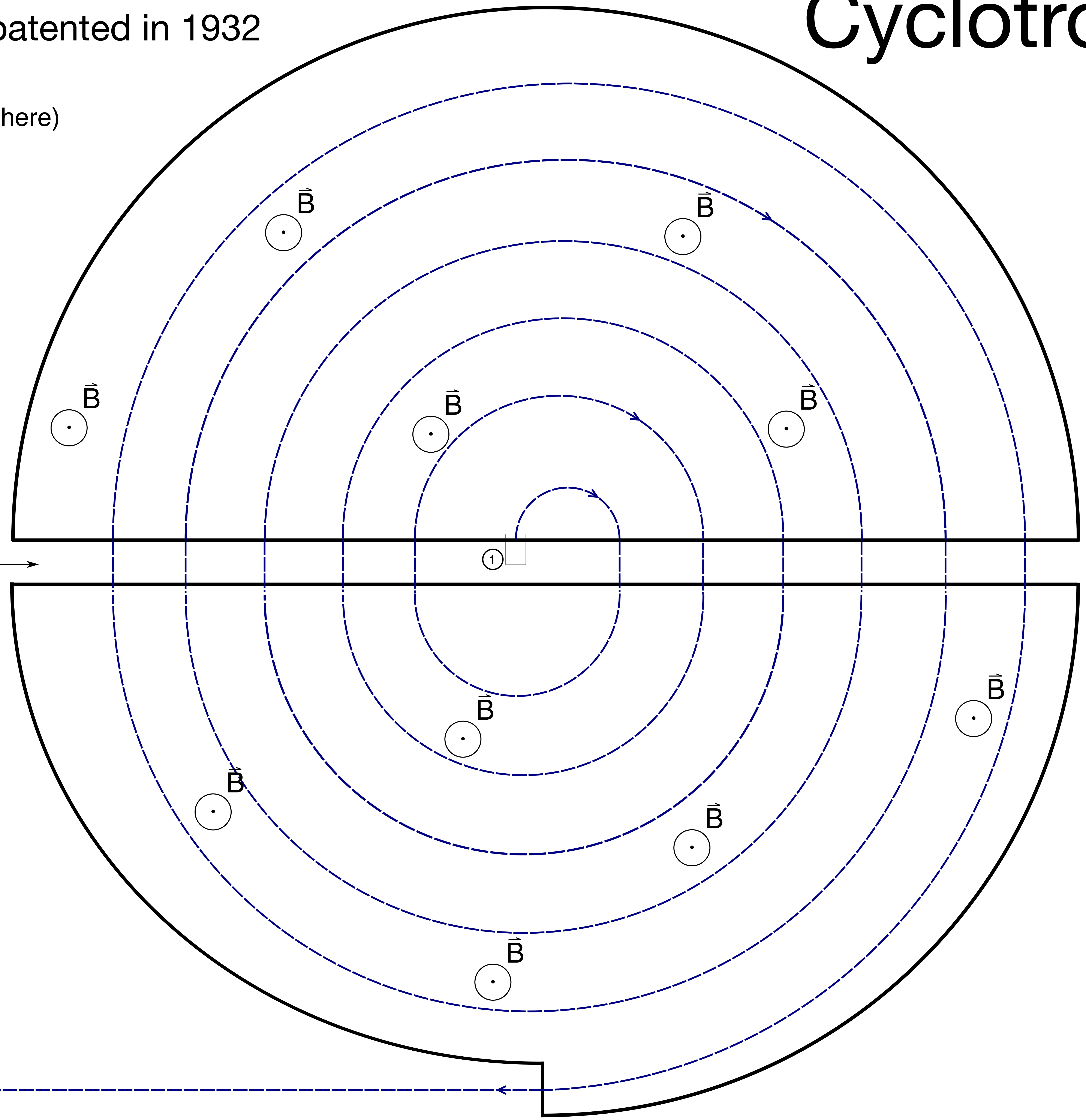
$\vec{B}$ Magnetic field

$\vec{E}$ Electric field

$$\overrightarrow{F} = q\overrightarrow{E} + qv \times \overrightarrow{B}$$

B field acts perpendicular to the direction of motion

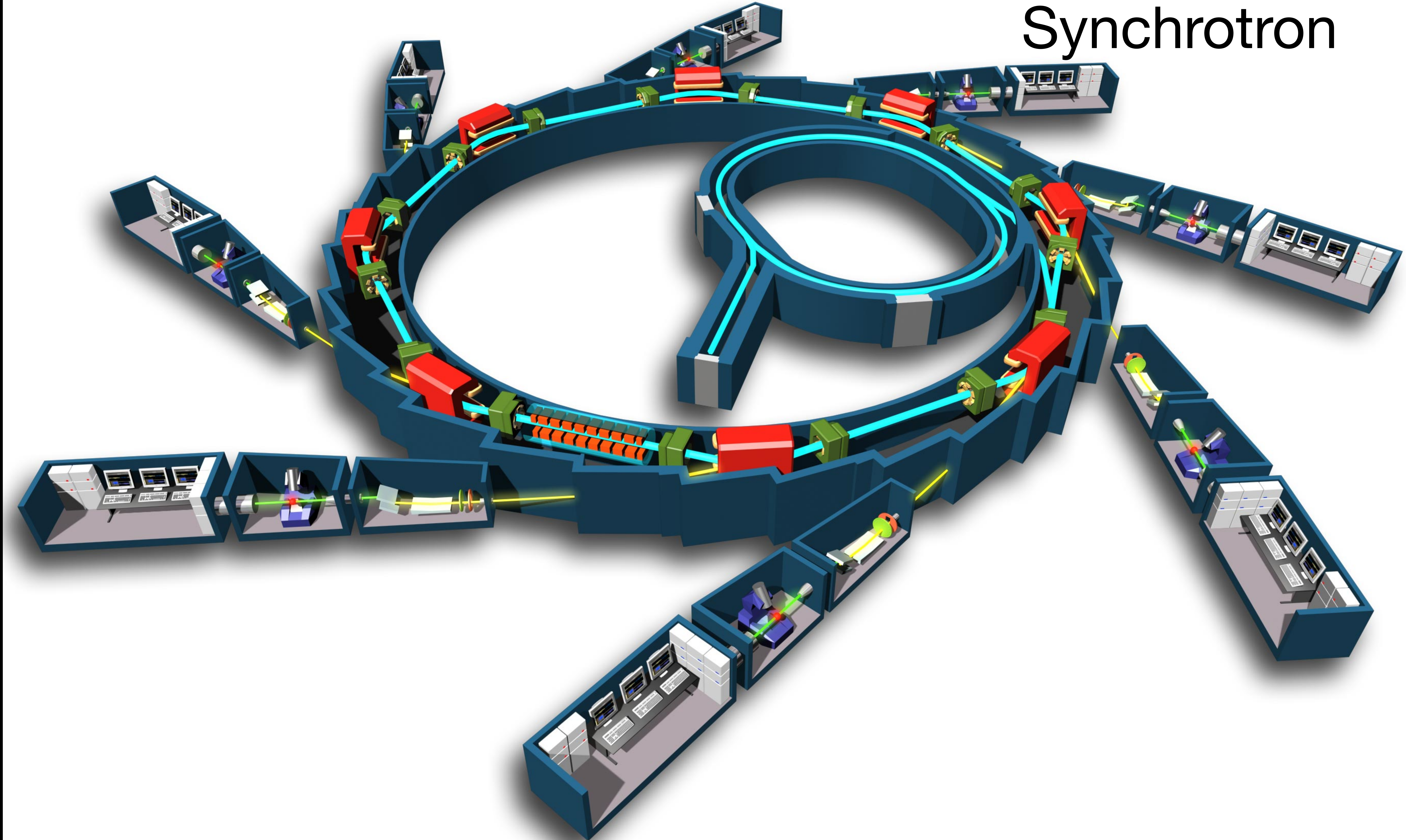




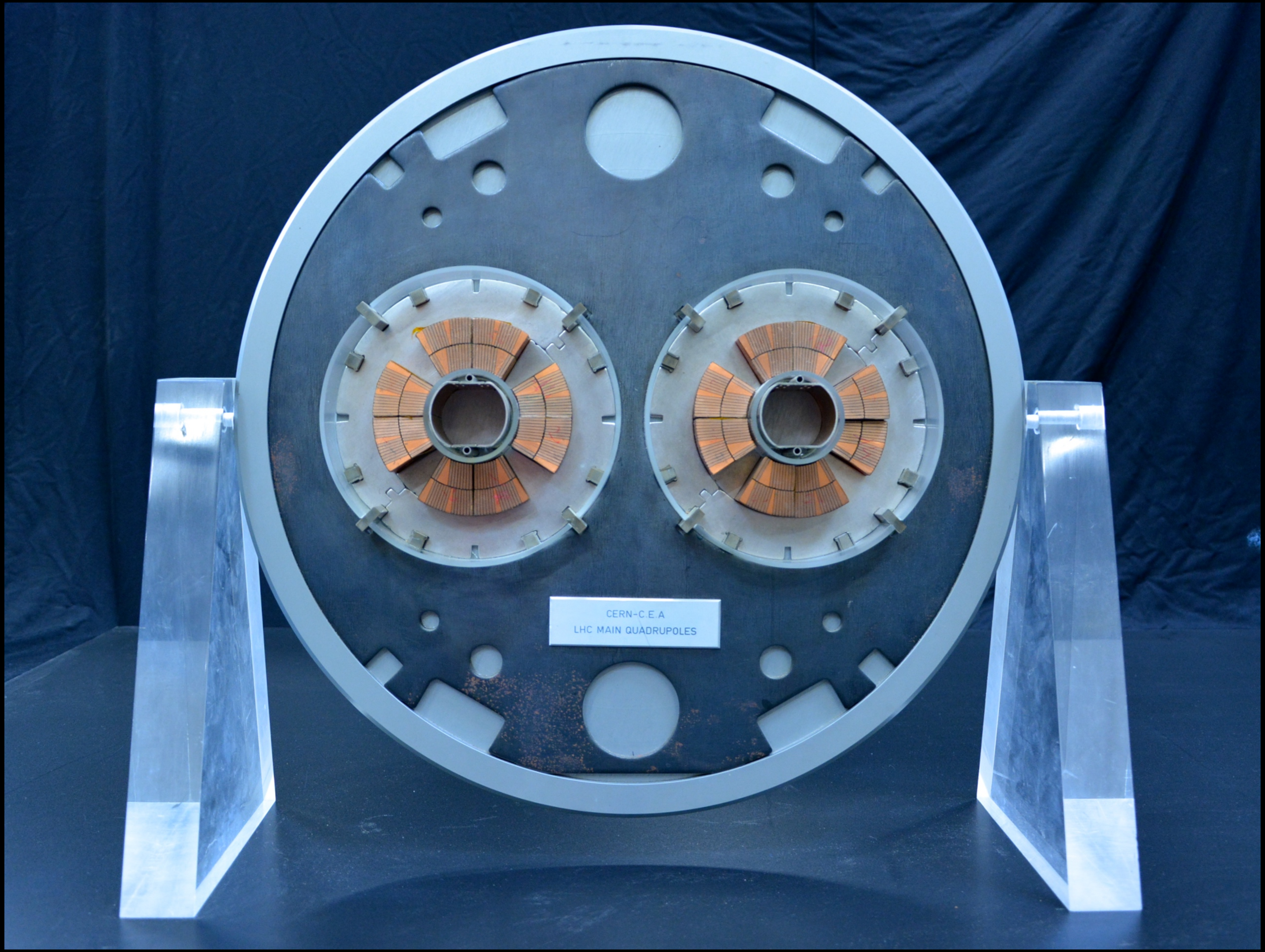
$$\text{Kinetic } E = \frac{1}{2}mv^2 = \frac{q^2B^2R^2}{2m}$$

R = radius at which the energy is determined

Synchrotron



LHC magnets



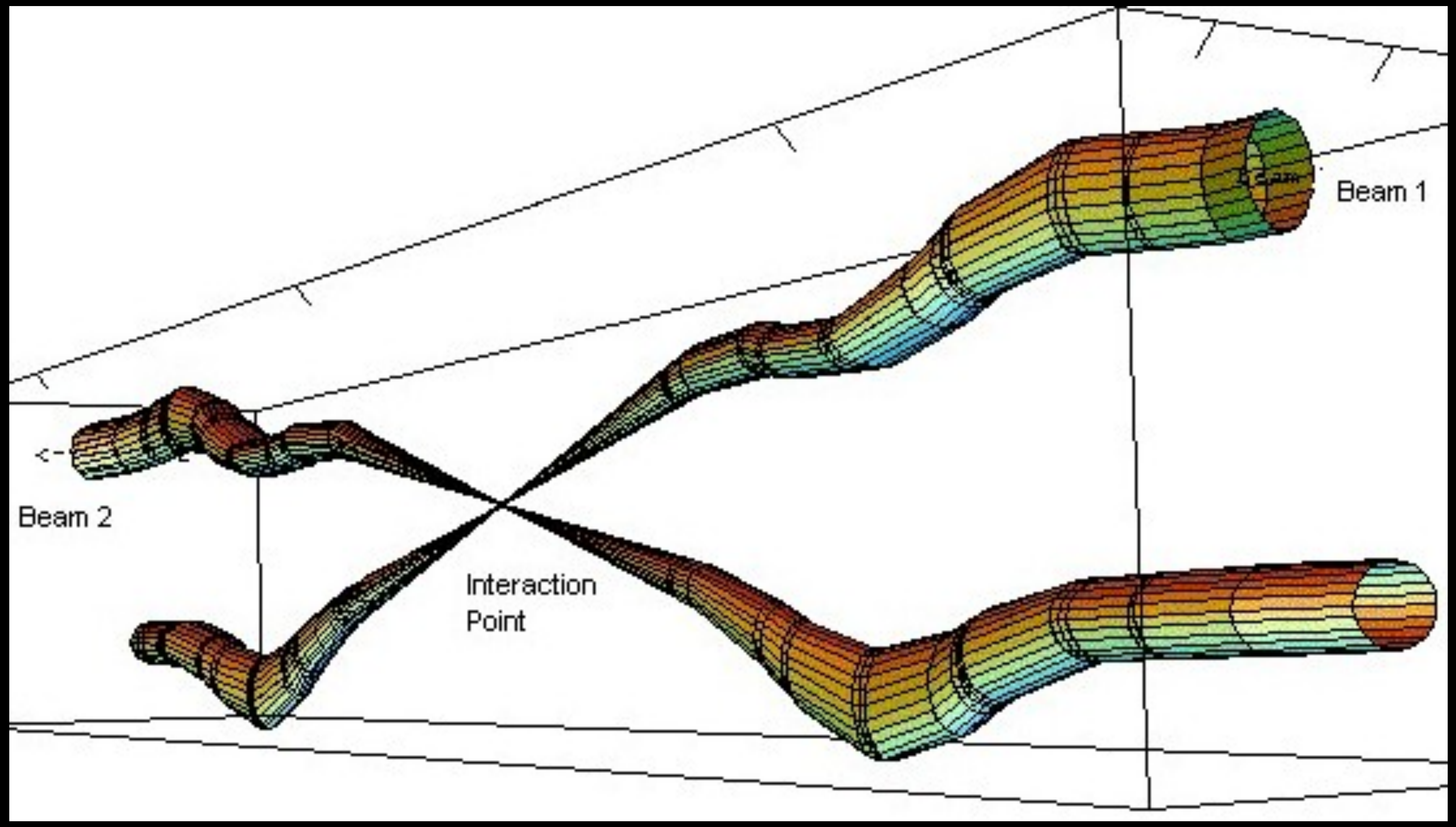
A quadrupole focusing magnet

- Use a quadrupole magnet to focus beams
- Quadrupole magnets focus the proton beams
    - Squeeze them so that more particles collide when the beams cross paths
- Precision needed analogous to colliding two knitting needles launched from either side of the Atlantic Ocean

To recapitulate…

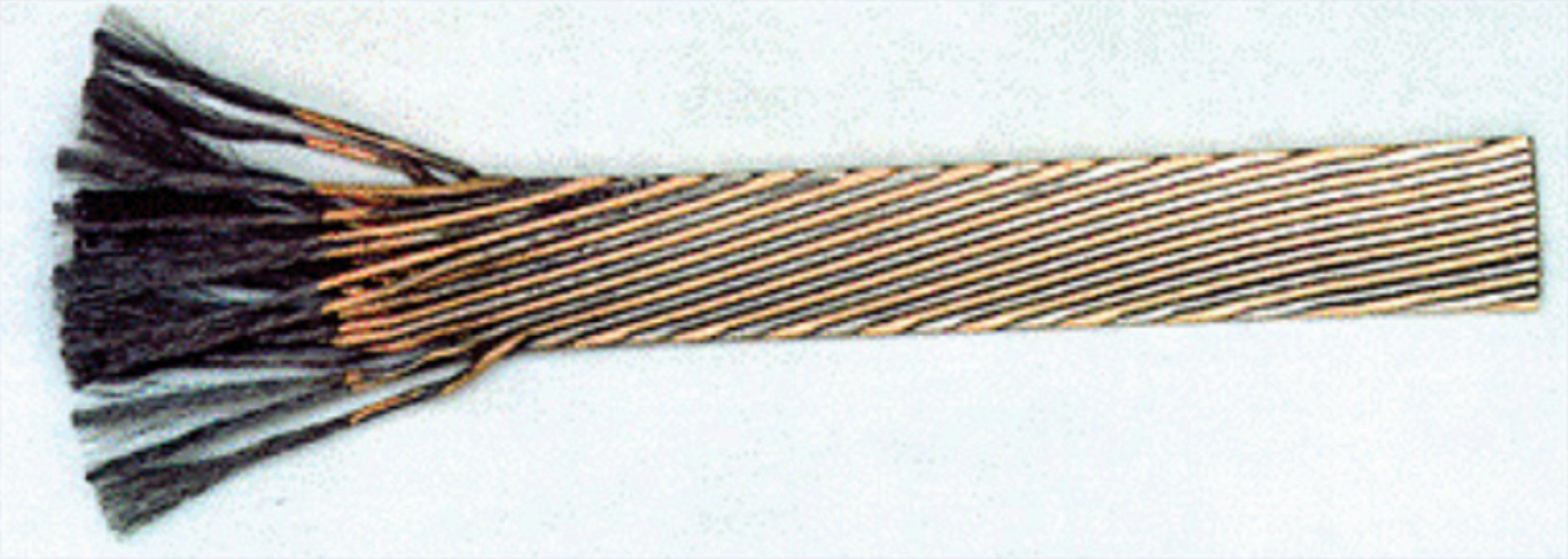
- Two kinds of magnets needed

1. Dipole magnets to bend the beams of protons
2. Quadrupole magnets to focus the proton beams at the detectors



The super conducting cables

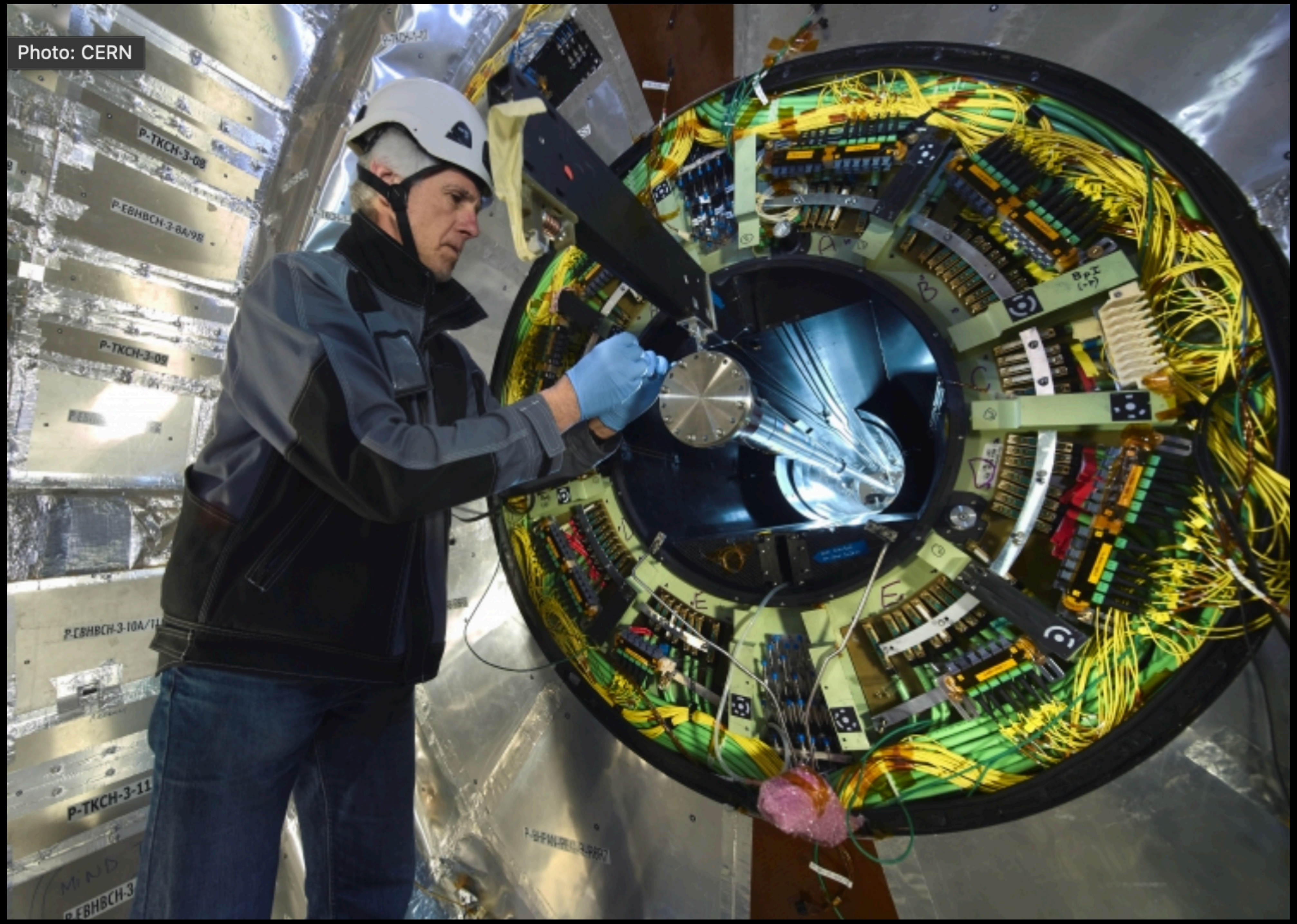
- Super conducting filament made with niobium-titanium alloy (Nb-Ti)
  - Workhorse of superconductivity
  - Other alloys were being tested simultaneously (niobium-tin Nb_3Sn)
  - Practical choice won but simultaneous tests of other materials crucial for future projects



View of the flat side, with one end etched to show the Nb-Ti filaments

The LHC beams and the vacuum

- Inside the LHC, two particle beams travel at the speed of light in opposite directions
- Housed inside beam pipes
- Beam pipes kept at ultrahigh vacuum
- Emptier than interstellar space
- Largest vacuum system in the world - 104 km of piping

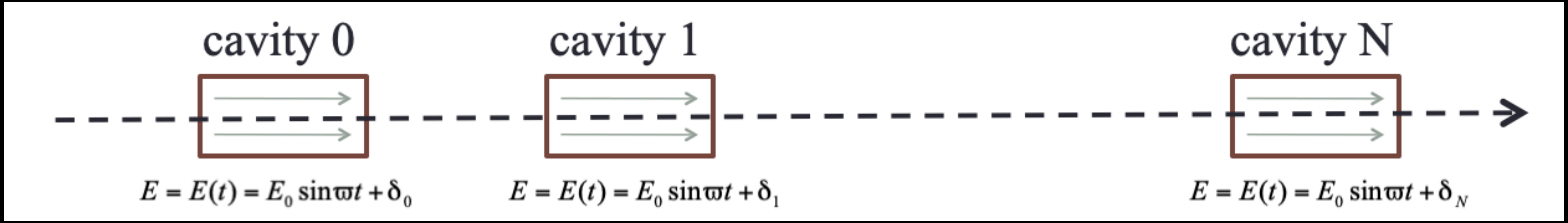


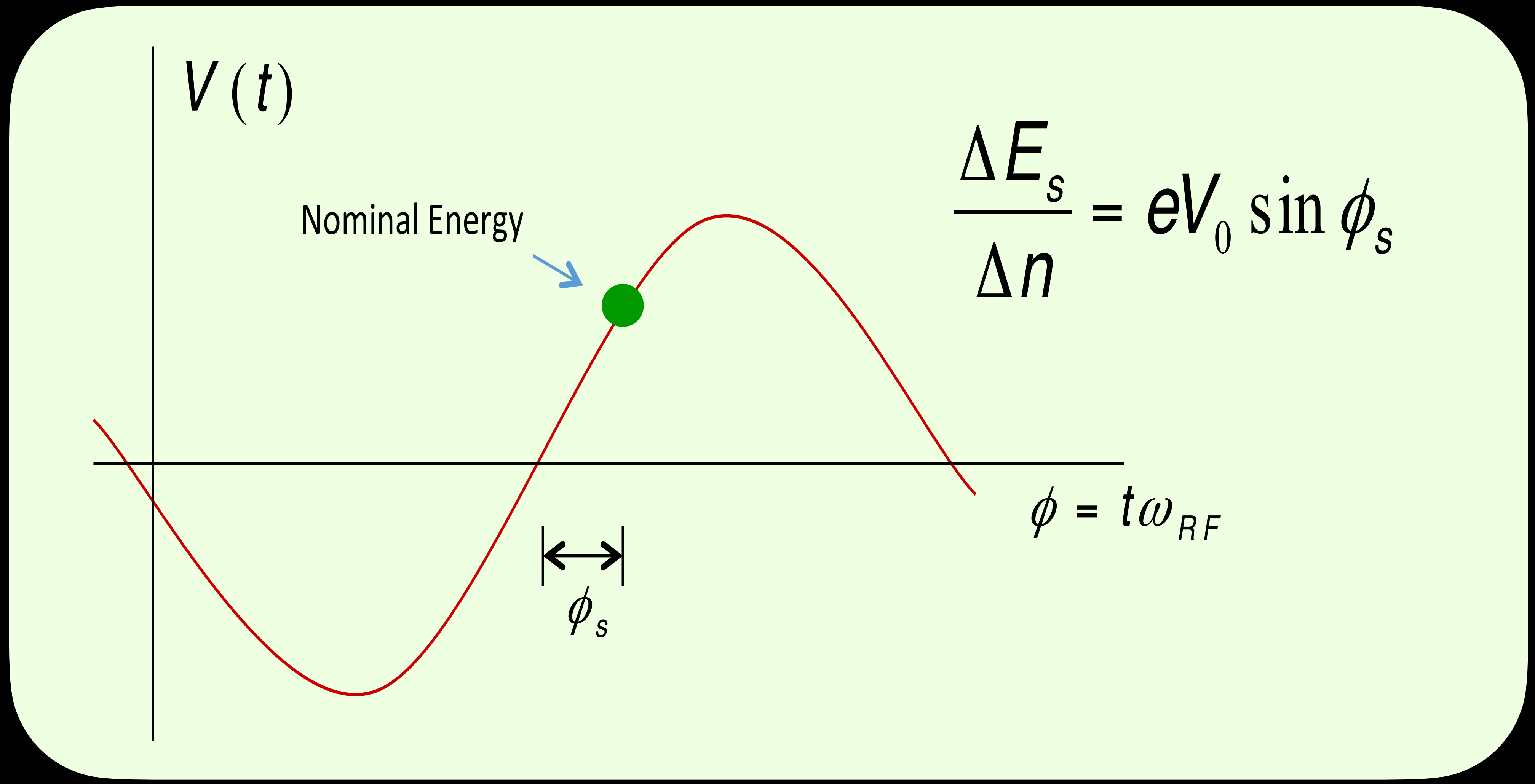
Powering the LHC

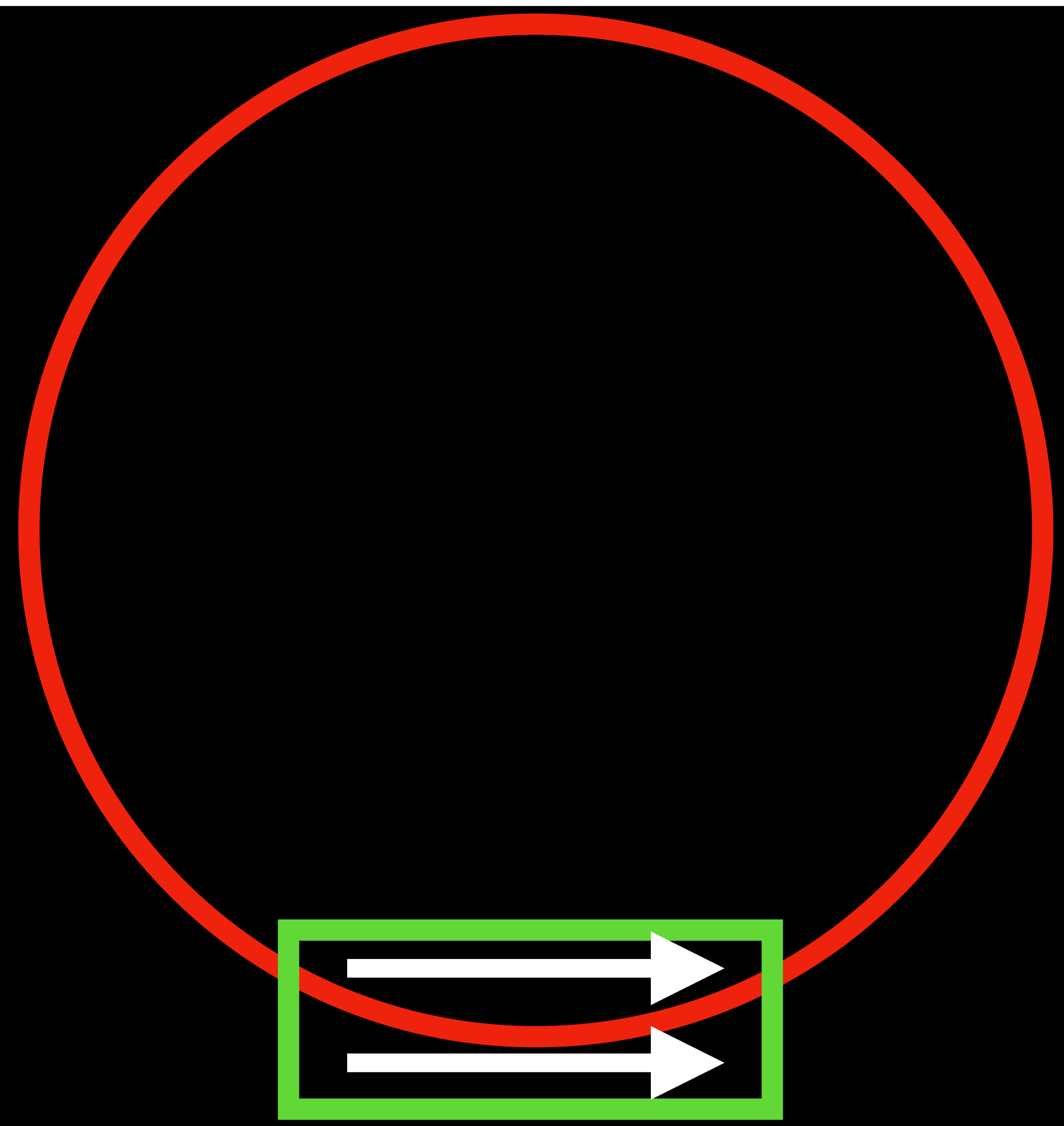
- CERN uses 1.3 terawatt hours of electricity annually
  - Enough power to fuel 300,000 homes for a year
- At peak usage, $1/3^{\text{rd}}$ energy used to power the nearby city of Geneva in Switzerland
- Glitch free stable power needed
- Powered by two different national grids
  - 1,000 high-voltage circuit-breakers
  - Modernization of electrical installations continuously underway

Accelerator basics — the electric field

- Generally accelerate particles using structures that generate time varying electric fields (Radio Frequency cavities) either:
  - in a linear arrangement or
  - a circular ring



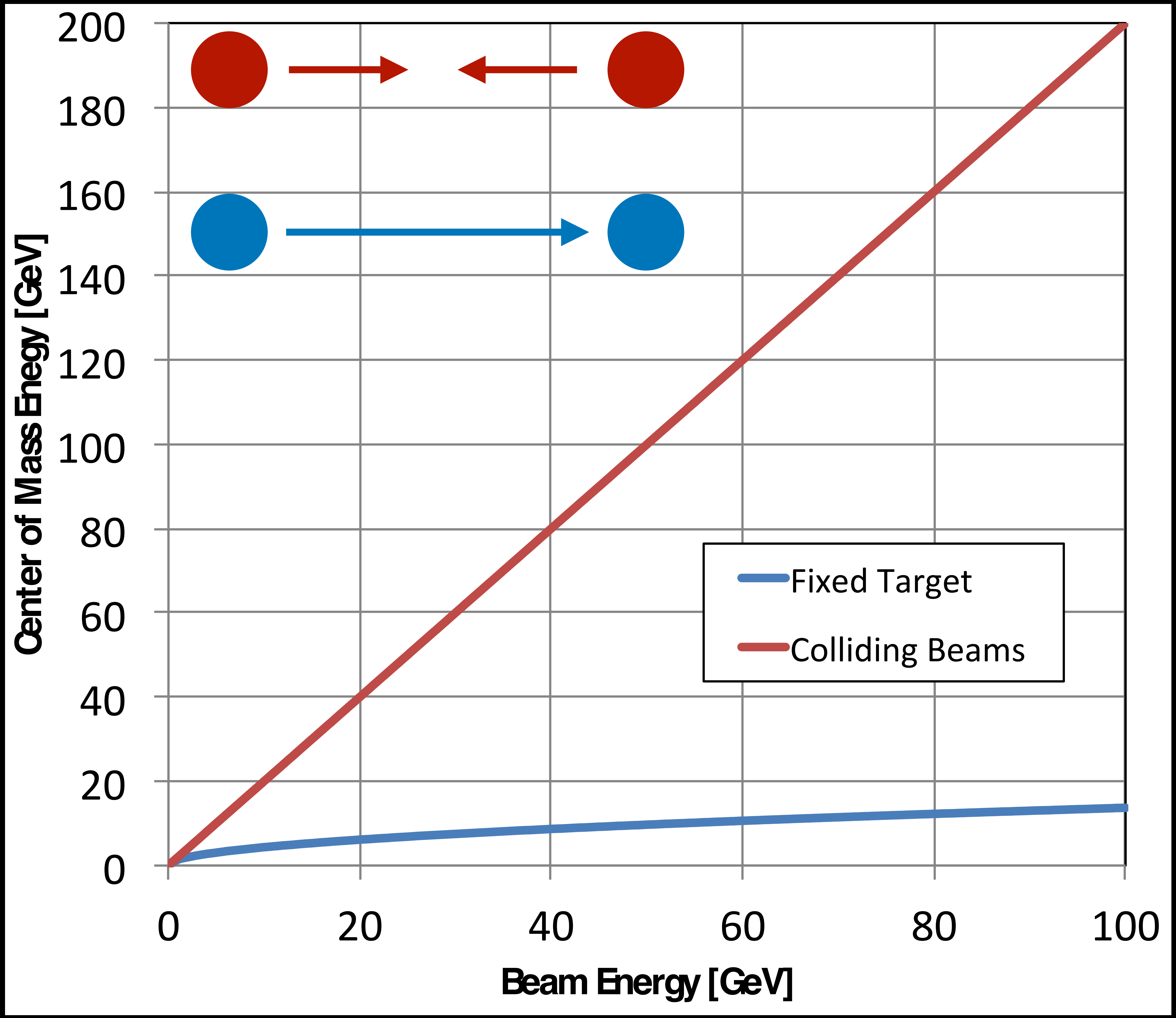




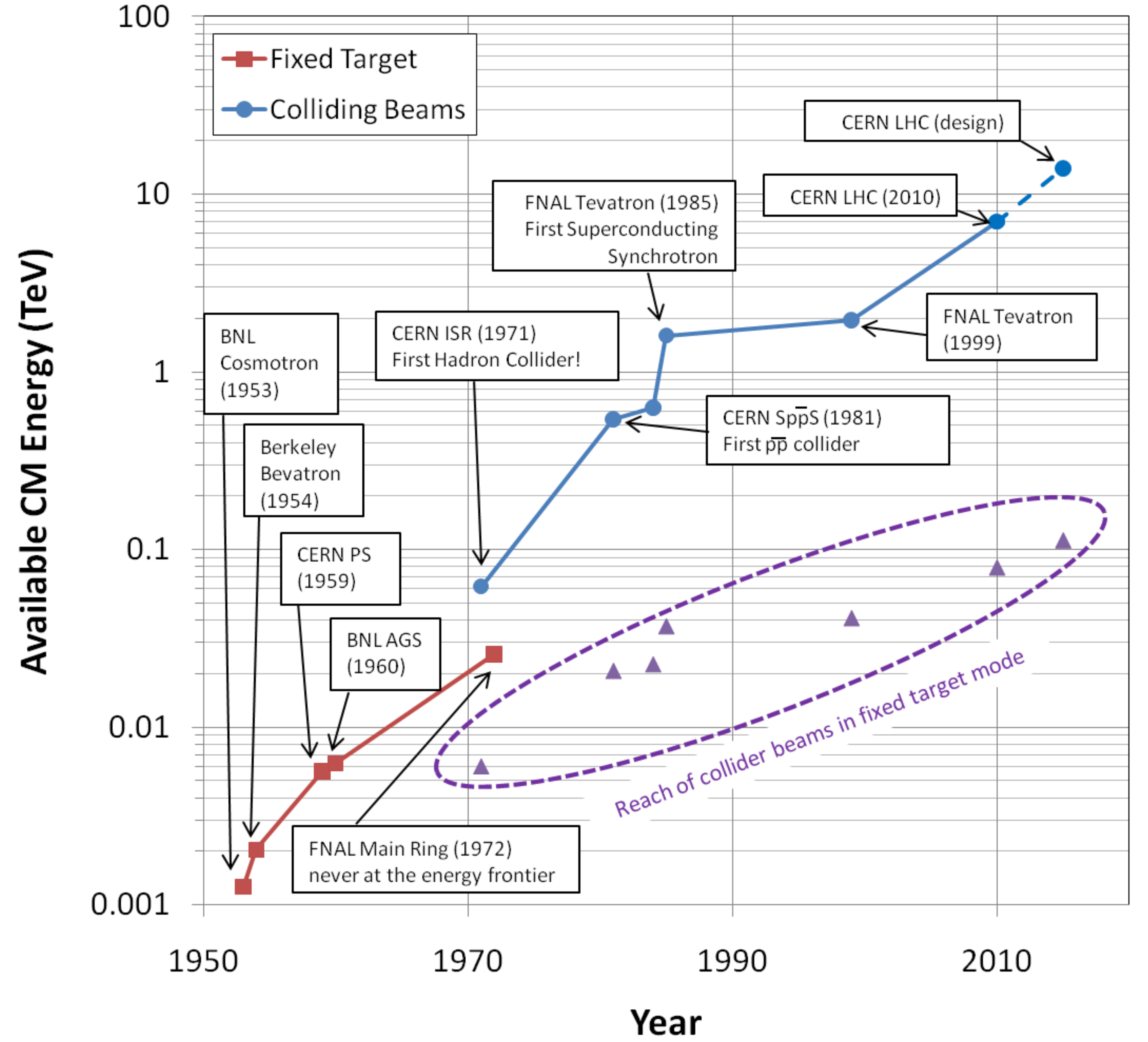
In both cases, phase the RF so a nominal arriving particle will see the same accelerating voltage and therefore get the same boost in energy

Accelerator basics — the collider

- If the beam hits a stationary proton, the center of mass energy is:
  - $E_{CM} = \sqrt{2E_{beam}m_{target}c^2}$
  - $E_{CM} = 2E_{beam}$
- To get the 14 TeV CM design energy of the LHC with a single beam on a fixed target would require that beam to have an energy of 100,000 TeV!
  - Would require a ring 10 times the diameter of the Earth!!
- We have to collide beams!

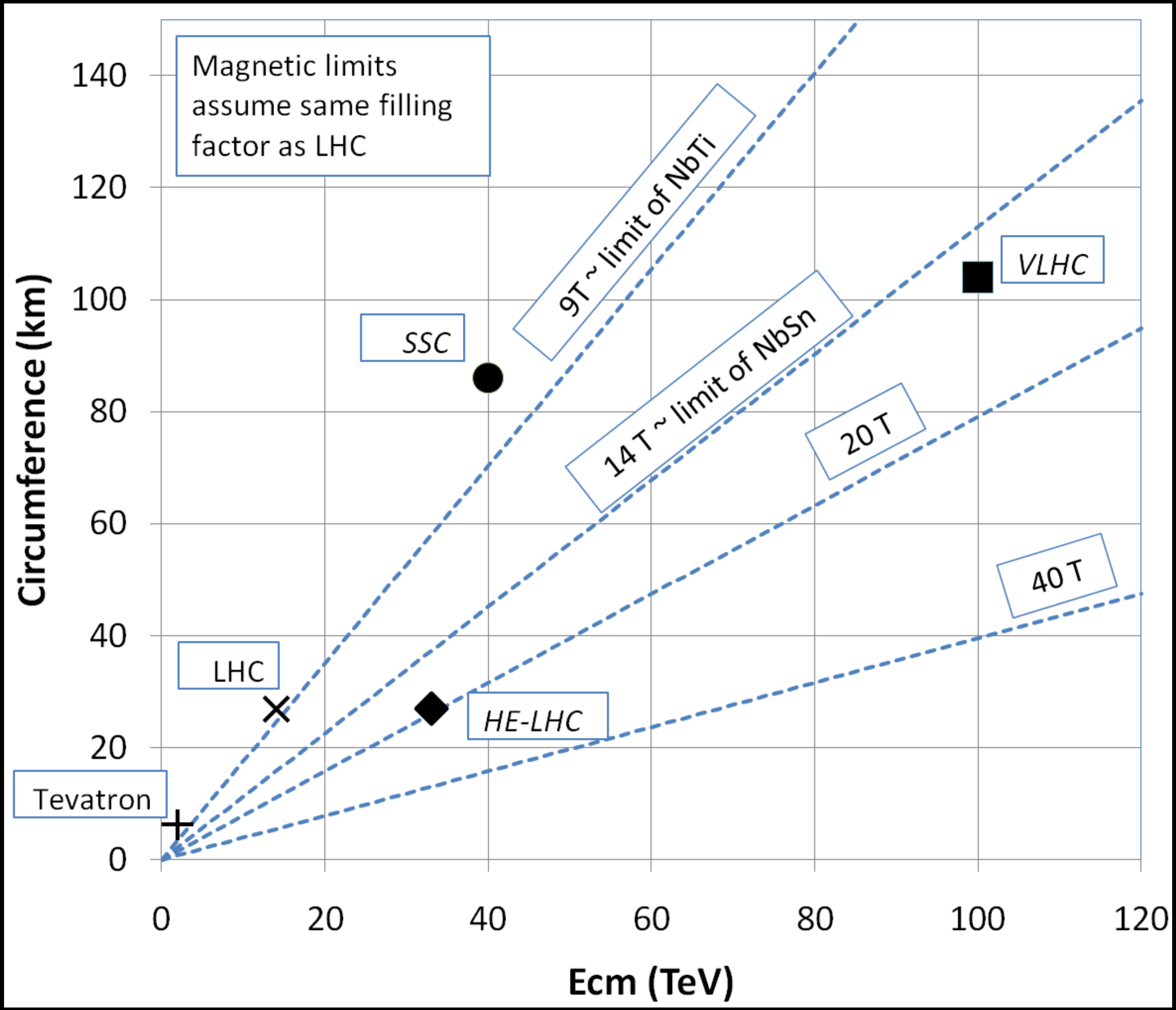


Development

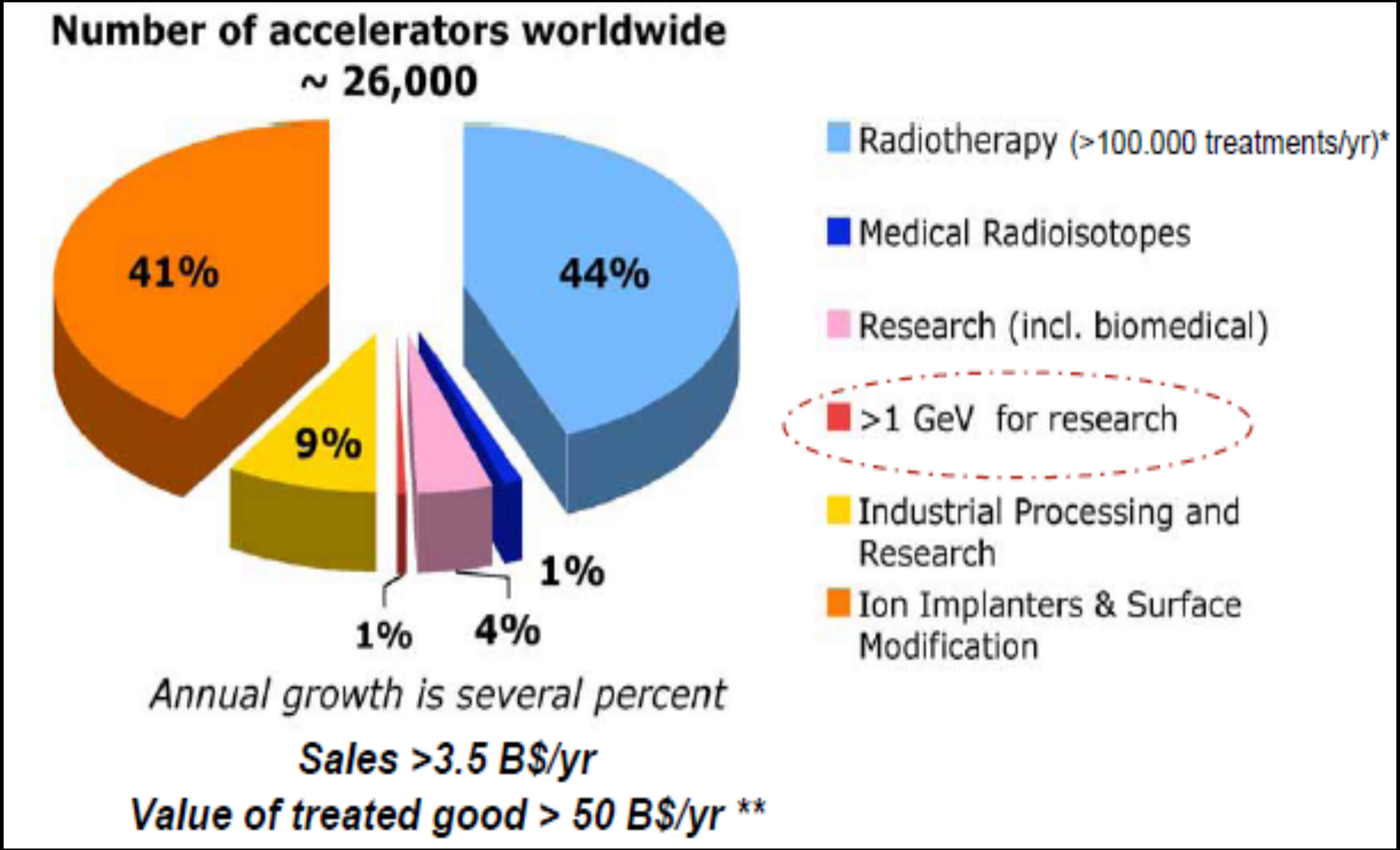


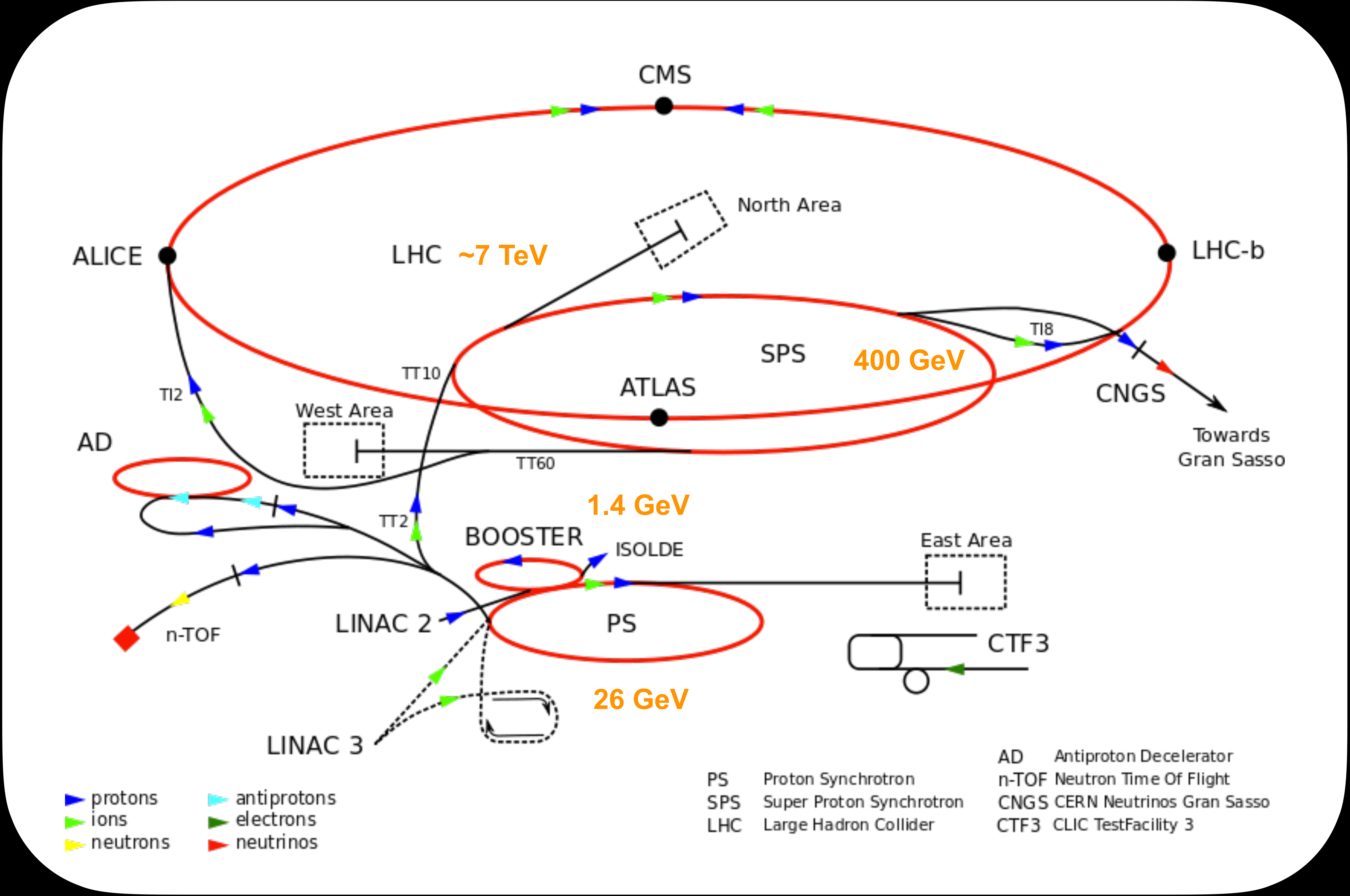
Limitations

- The energy of Hadron colliders is limited by feasible size and magnet technology. Options:
  - Get very large (~100 km circumference)
  - More powerful magnets (requires new technology)

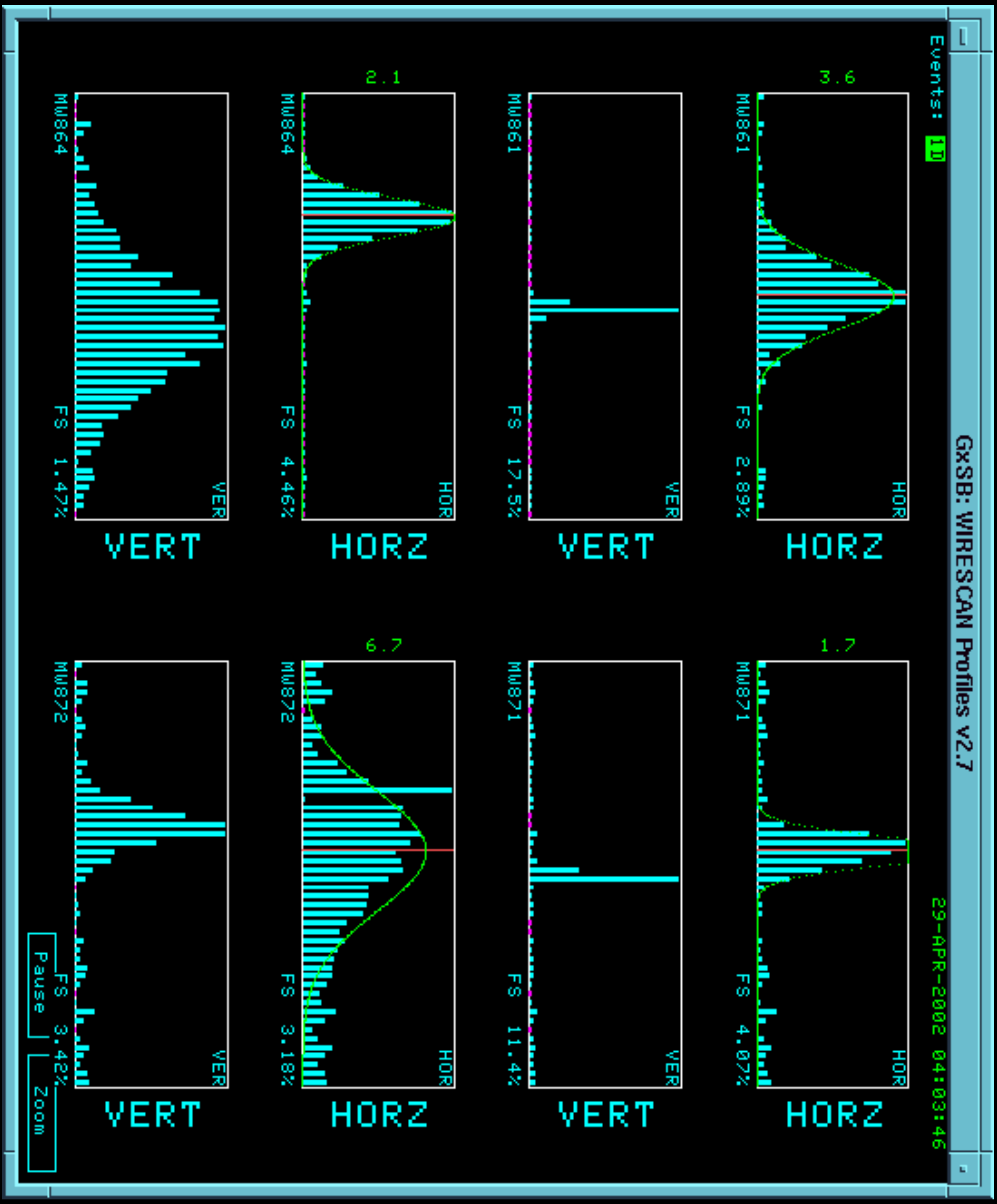


Other uses of accelerators




CMS
North Area
ALICE
LHC
~7 TeV
LHC-b
TI8
SPS
400 GeV
TT10
TI2
ATLAS
CNGS
West Area
Towards
Gran Sasso
AD
TT60
1.4 GeV
TT2
BOOSTER
ISOLDE
East Area
n-TOF
LINAC 2
PS
CTF3
26 GeV
LINAC 3
protons
ions
neutrons
antiprotons
electrons
neutrinos
PS Proton Synchrotron
SPS Super Proton Synchrotron
LHC Large Hadron Collider
AD Antiproton Decelerator
n-TOF Neutron Time Of Flight
CNGS CERN Neutrinos Gran Sasso
CTF3 CLIC TestFacility 3

- Beam profiles in beam lines can be measured using secondary emission multiwires (MW’s)
- Can measure beam profiles in a circulating beam with a “flying wire scanner”, which quickly passes a wire through and measures signal vs time to get profile



Luminosity

- The relationship of the beam to the rate of observed physics processes is given by the "Luminosity"
  - $Rate = L\sigma$
- Standard unit for Luminosity is $cm^{-2}s^{-1}$
- Standard unit of cross section is "barn"=10^{-24} cm^2
- Integrated luminosity is usually in $barn^{-1}$, where $b^{-1} = (1\ \text{sec}) \times (10^{24}\text{cm}^{-2}\text{s}^{-1})$
- $nb^{-1} = 10^9\ b^{-1}$, $fb^{-1}=10^{15}\ b^{-1}$
- L is often expressed as $10^{\text{large exponent}}$ like 34, 10^{34} collisions per cm^2

Luminosity of colliding proton beams

- For equally intense Gaussian beams
  - Collision frequency:
    - $L = f \dfrac{N_b^2}{4\pi\sigma^2} R$
    - f = collision frequency
    - N_b = particles in a bunch
    - R = geometrical factor (crossing angle)
    - σ = Transverse size (RMS)
  - Using $\sigma^2 = \dfrac{\beta^* \epsilon_N}{\beta\gamma} \approx \dfrac{\beta^* \epsilon_N}{\gamma}$
    - $L = f_{\text{rev}} \dfrac{1}{4\pi} n_b N_b^2 \dfrac{\gamma}{\beta^* \epsilon_N} R$
      - f_{rev} = collision frequency
      - n_b = number of bunches
      - β^* = betatron function at collision point, low values preferred