LHC and Hadron Collider Physics

CSU-NUPAX/CERN IRES Program

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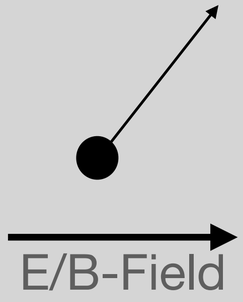
Feb 15th and 17th, 2022

What is a Particle?

Classical



Quantum Mechanics

$$\psi_n(x) = \sqrt{\frac{1}{2^n\, n!}} \cdot \left(\frac{m\omega}{\pi\hbar}\right)^{1/4} \cdot e^{-\frac{m\omega x^2}{2\hbar}} \cdot H_n\left(\sqrt{\frac{m\omega}{\hbar}}x\right),$$

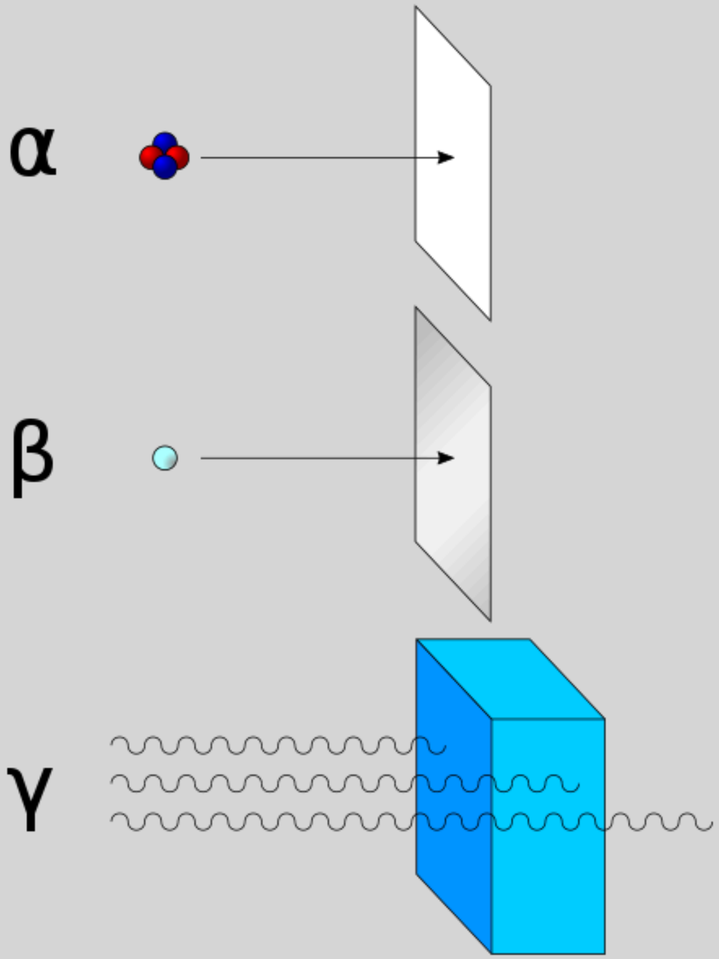
Does NOT play nice
with special relativity

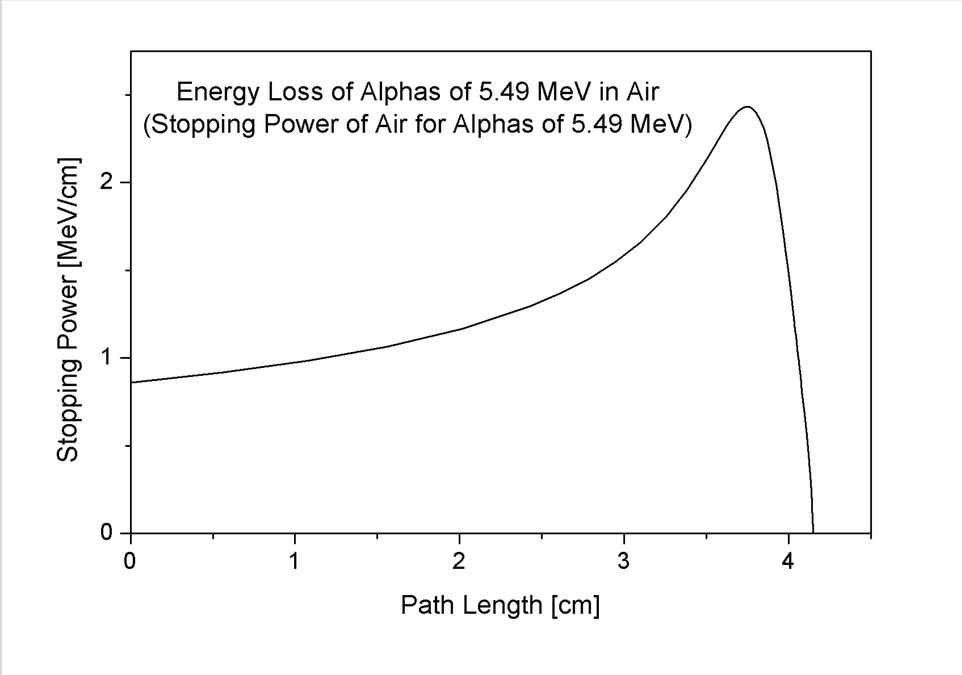
Quantum Field Theory

$$\hat{\phi}(\mathbf{x},t) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\sqrt{2\omega_{\mathbf{p}}}} \left(\hat{a}_{\mathbf{p}} e^{-i\omega_{\mathbf{p}} t + i\mathbf{p}\cdot\mathbf{x}} + \hat{a}^\dagger_{\mathbf{p}} e^{i\omega_{\mathbf{p}} t - i\mathbf{p}\cdot\mathbf{x}}\right).$$

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)\,(\partial^\mu \phi) - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4,$$

Rutherford+Villard (1899)





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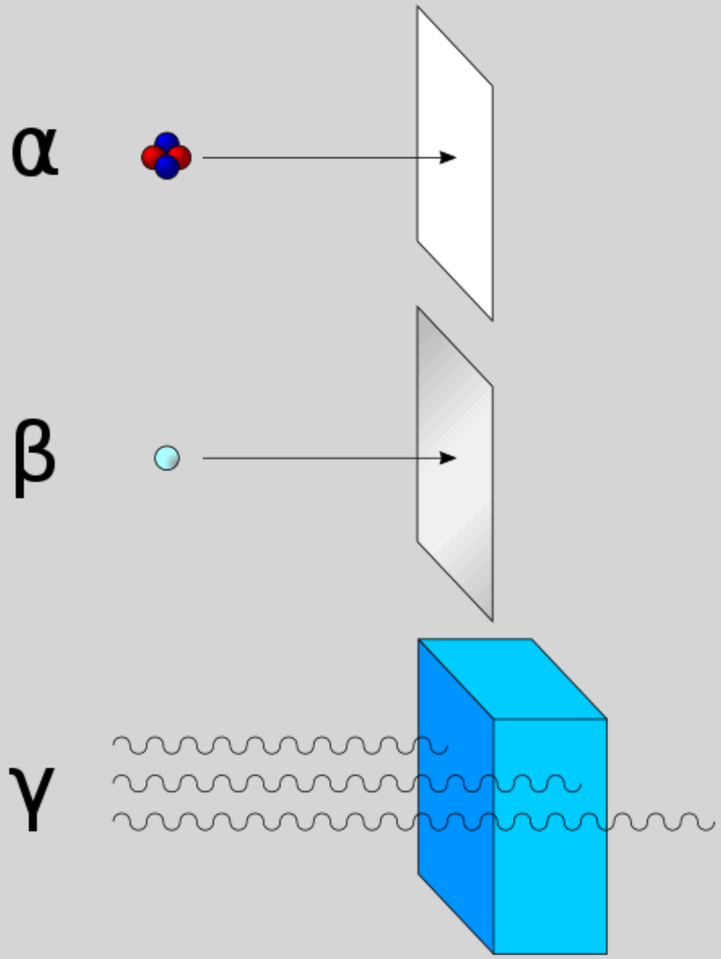
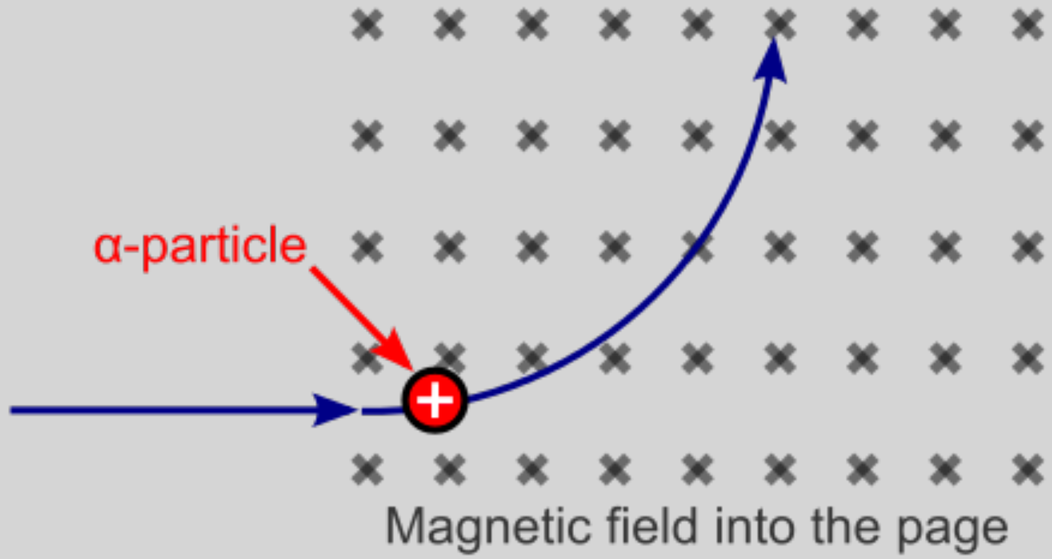
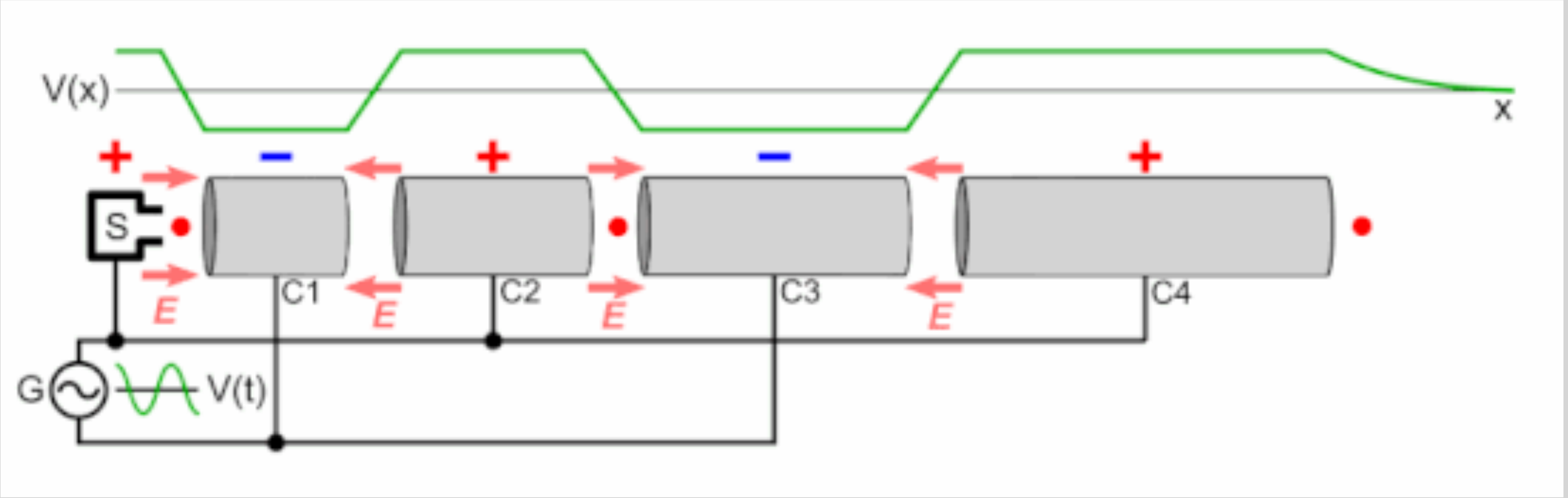


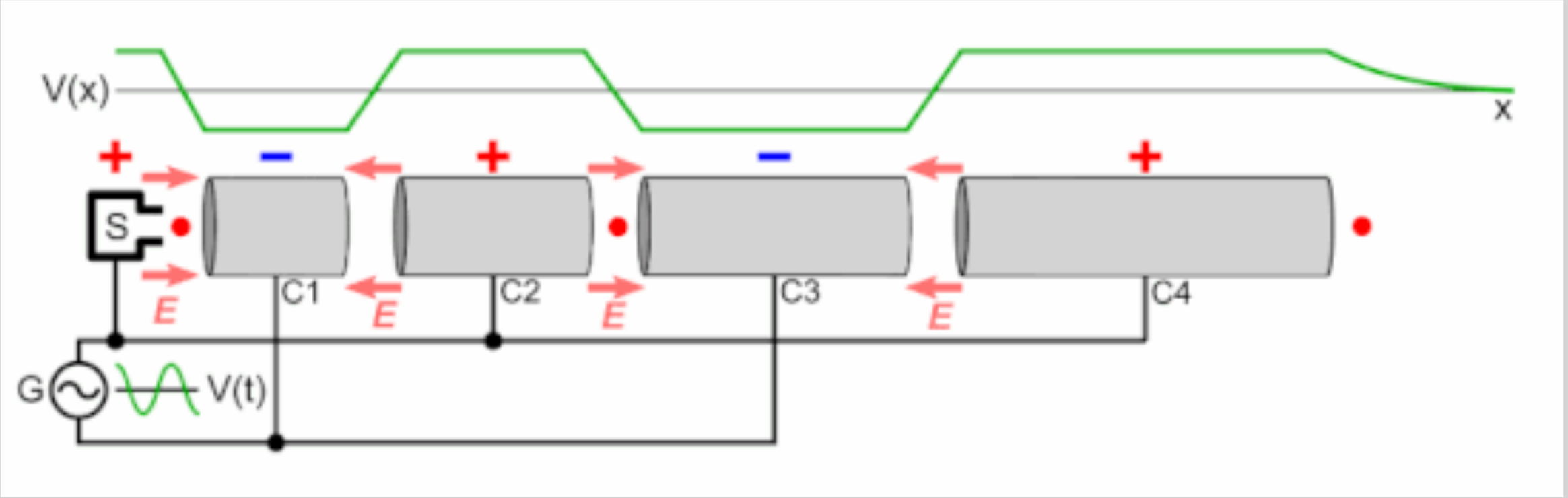


Accelerators

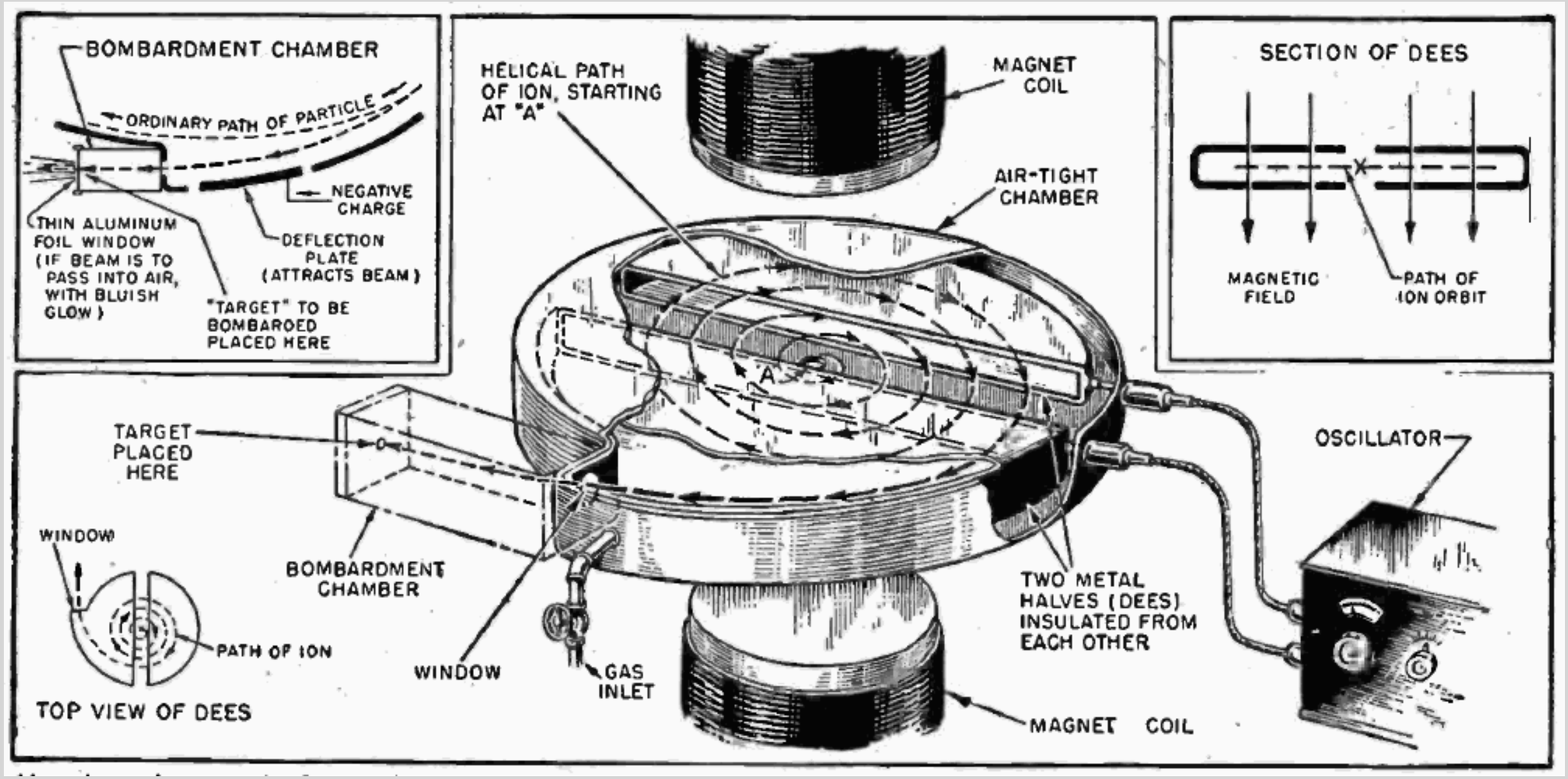
Linear Accelerators (1924)



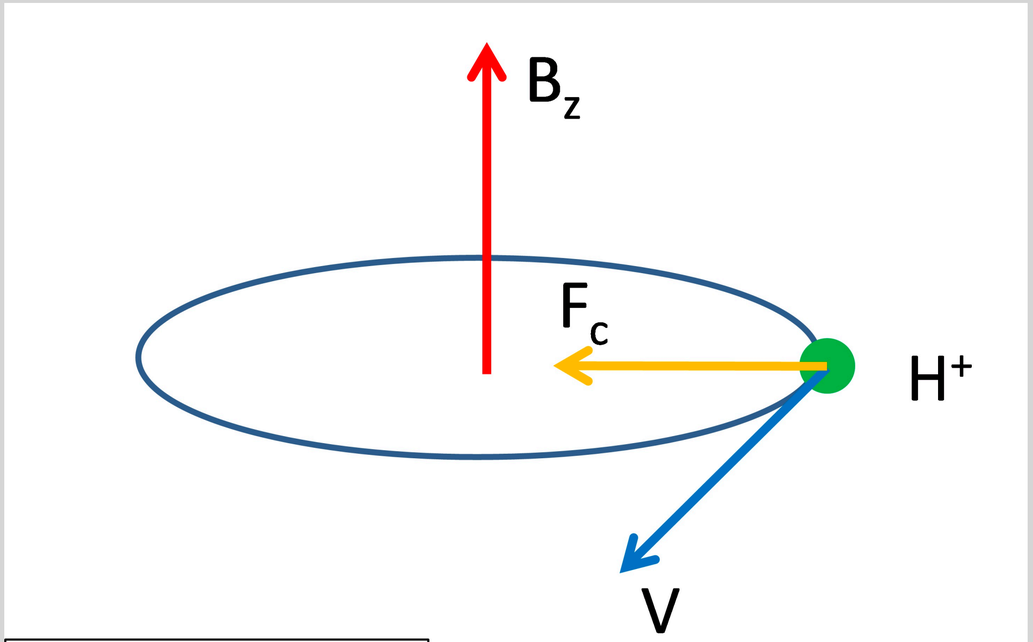
Linear Accelerators (1924)



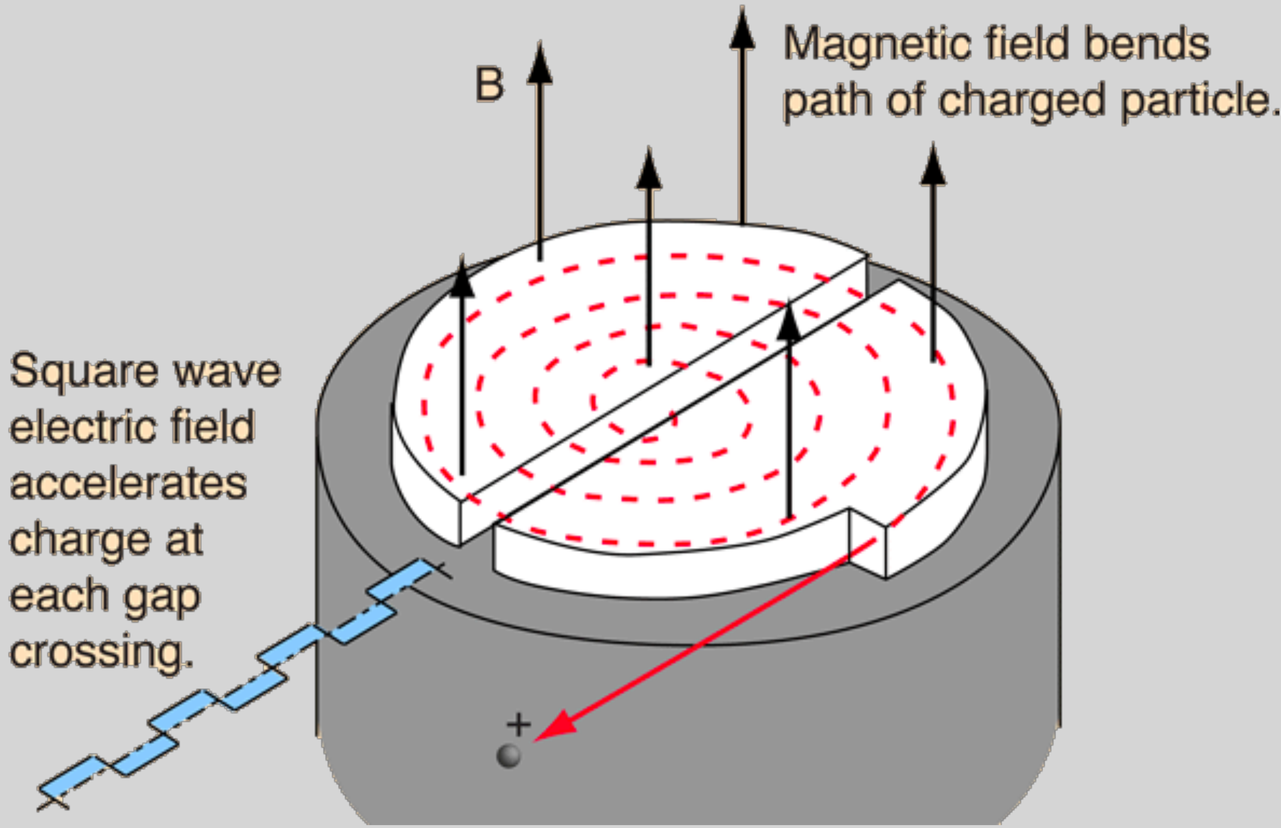
Cyclotron (1930)



Cyclotron (1930)



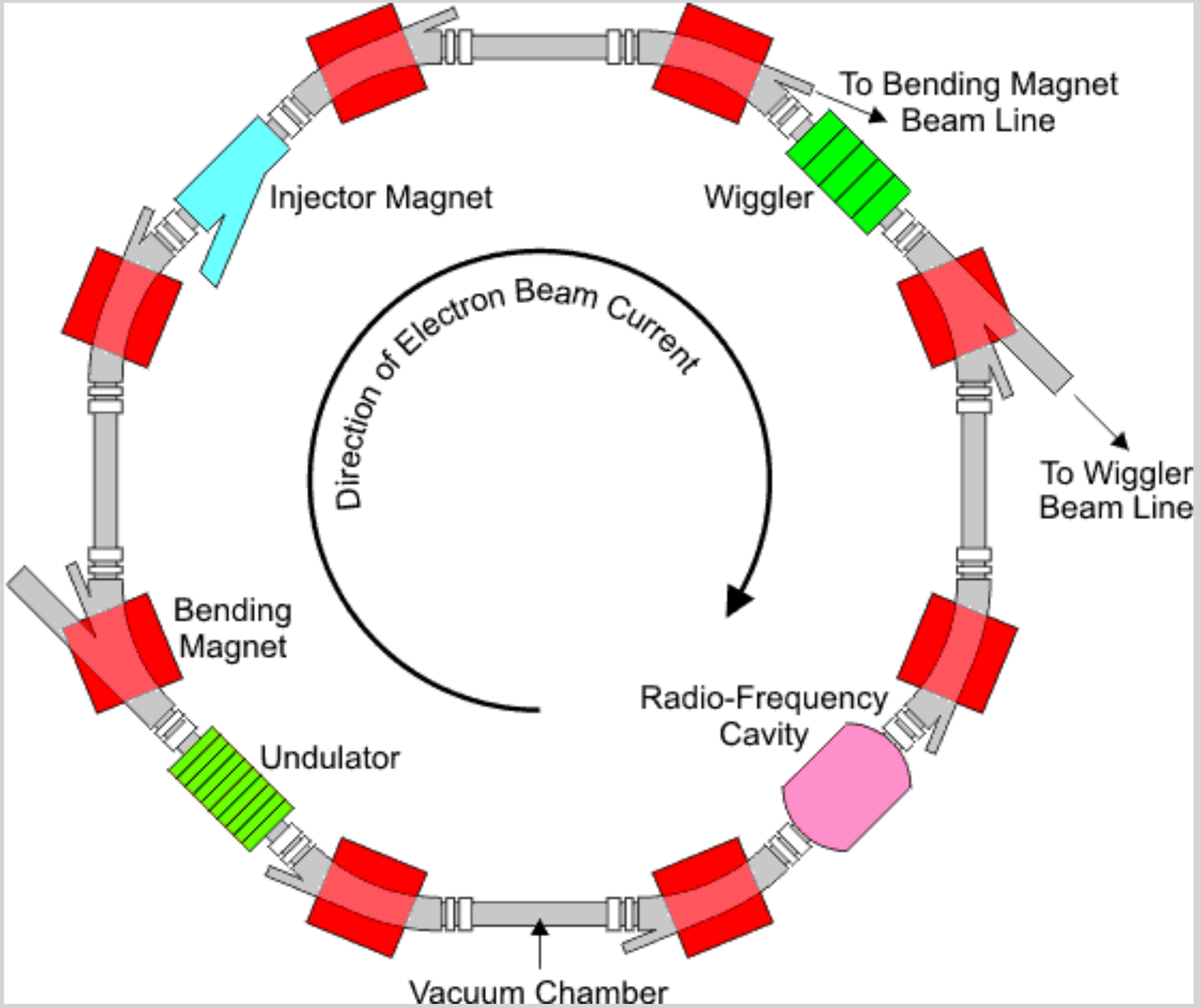
$$\frac{mv^2}{r} = qvB \Rightarrow \omega = \frac{v}{r} = \frac{qB}{m}$$



Synchrotron (1945)

Power Carried by Synchrotron Radiation

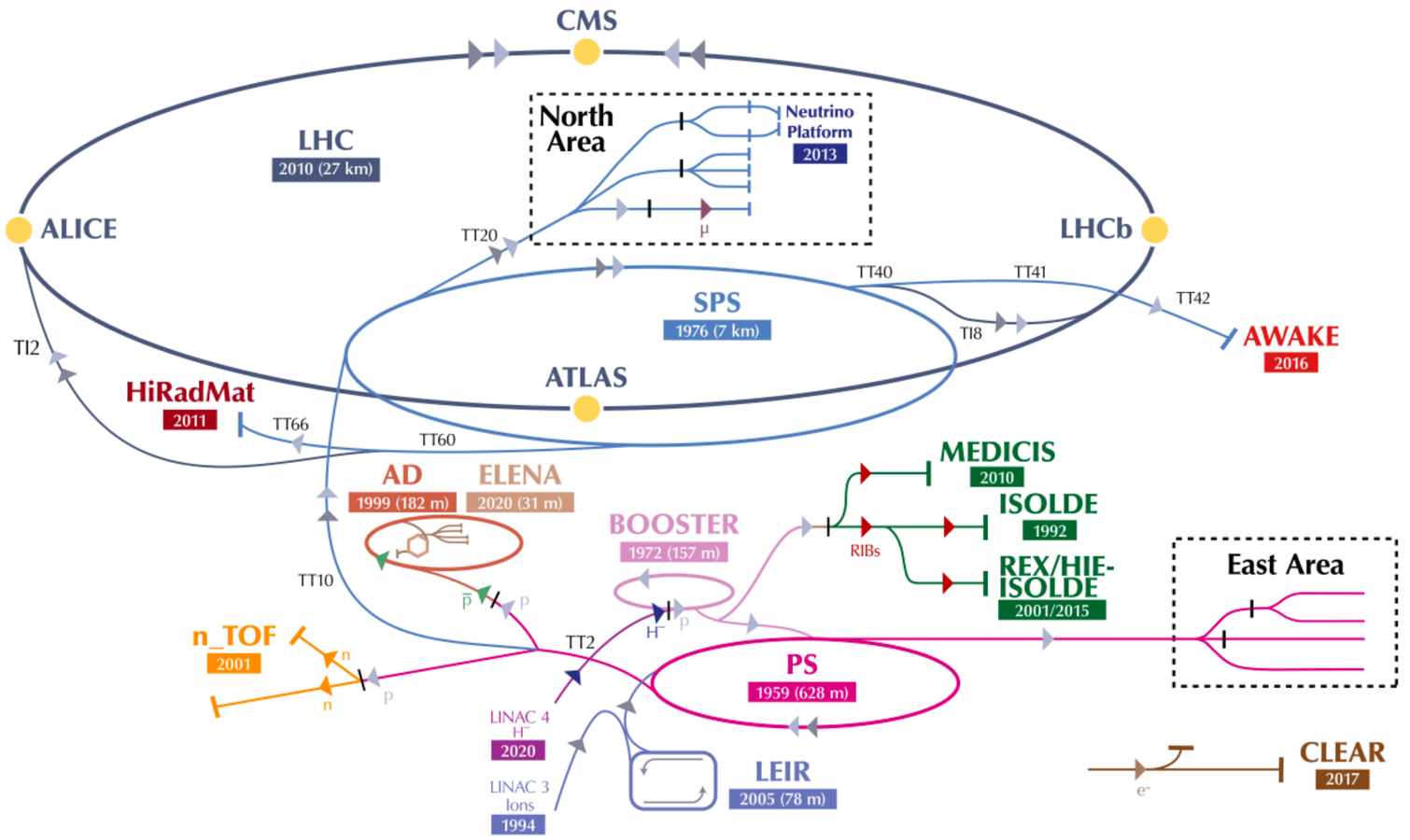
$$P_\gamma = \frac{1}{6\pi\epsilon_o}\frac{q^2a^2}{c^3}\gamma^4$$



For equal energy electrons and protons, which radiates more power?

What does this mean for accelerator design?

The CERN accelerator complex
Complexe des accélérateurs du CERN



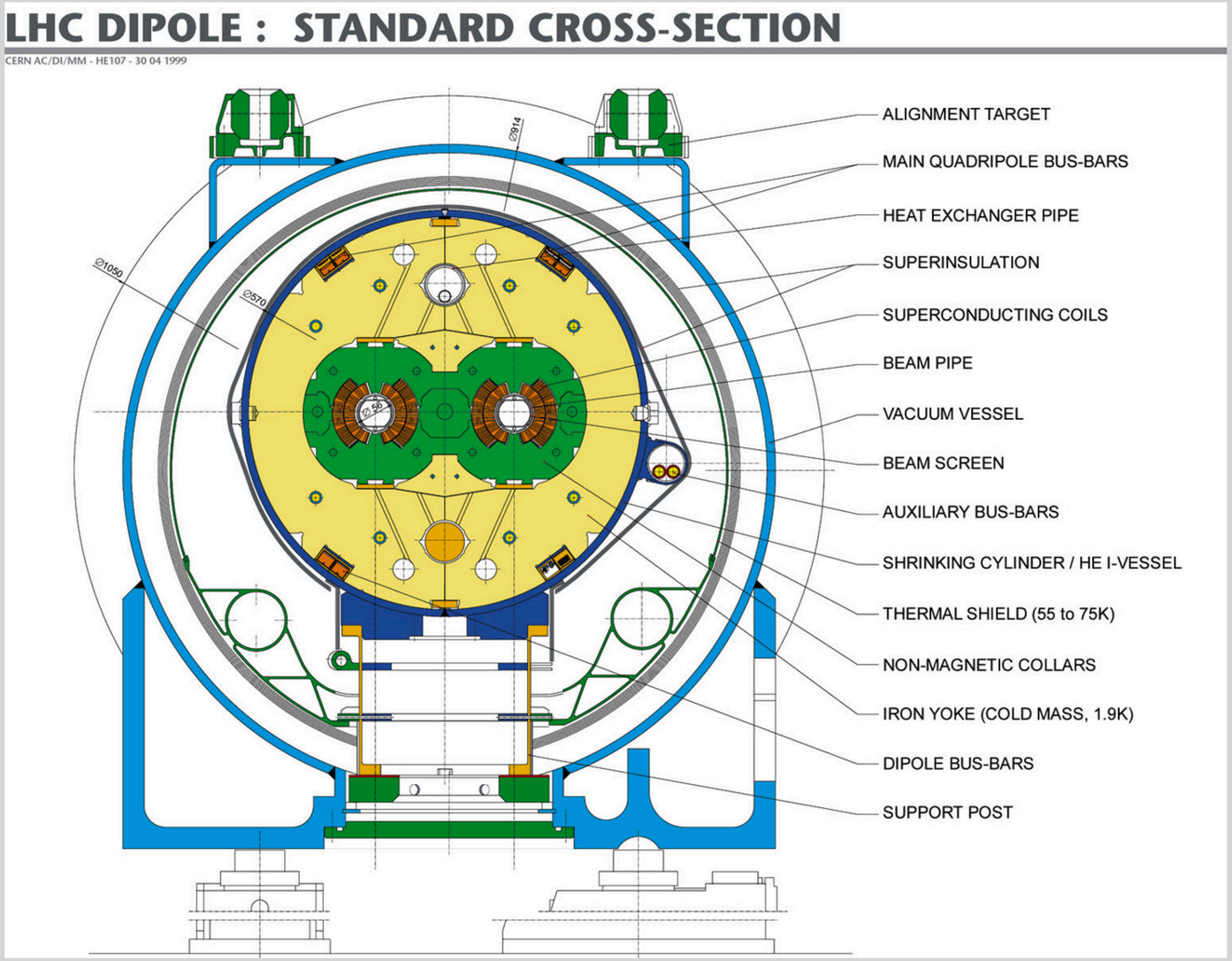
H⁻ (hydrogen anions) p (protons) ions RIBs (Radioactive Ion Beams) n (neutrons) p̄ (antiprotons) e⁻ (electrons) μ (muons)

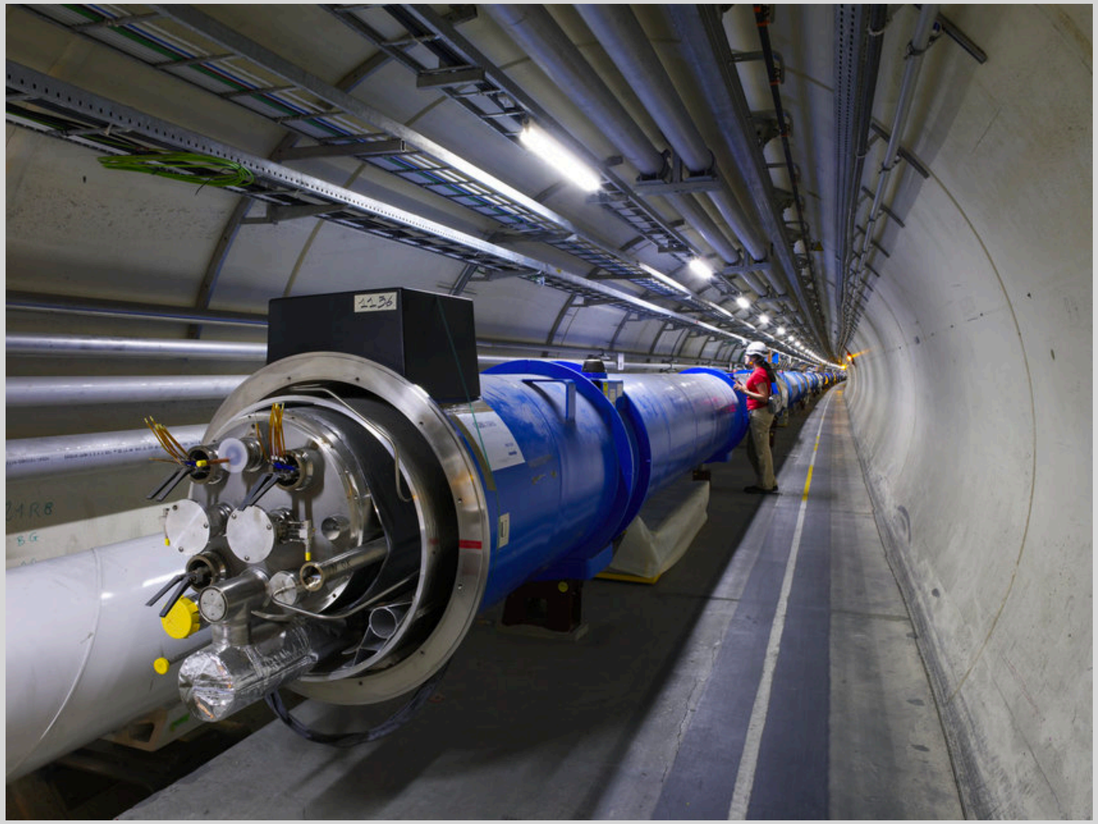
LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive EXperiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

January 2022

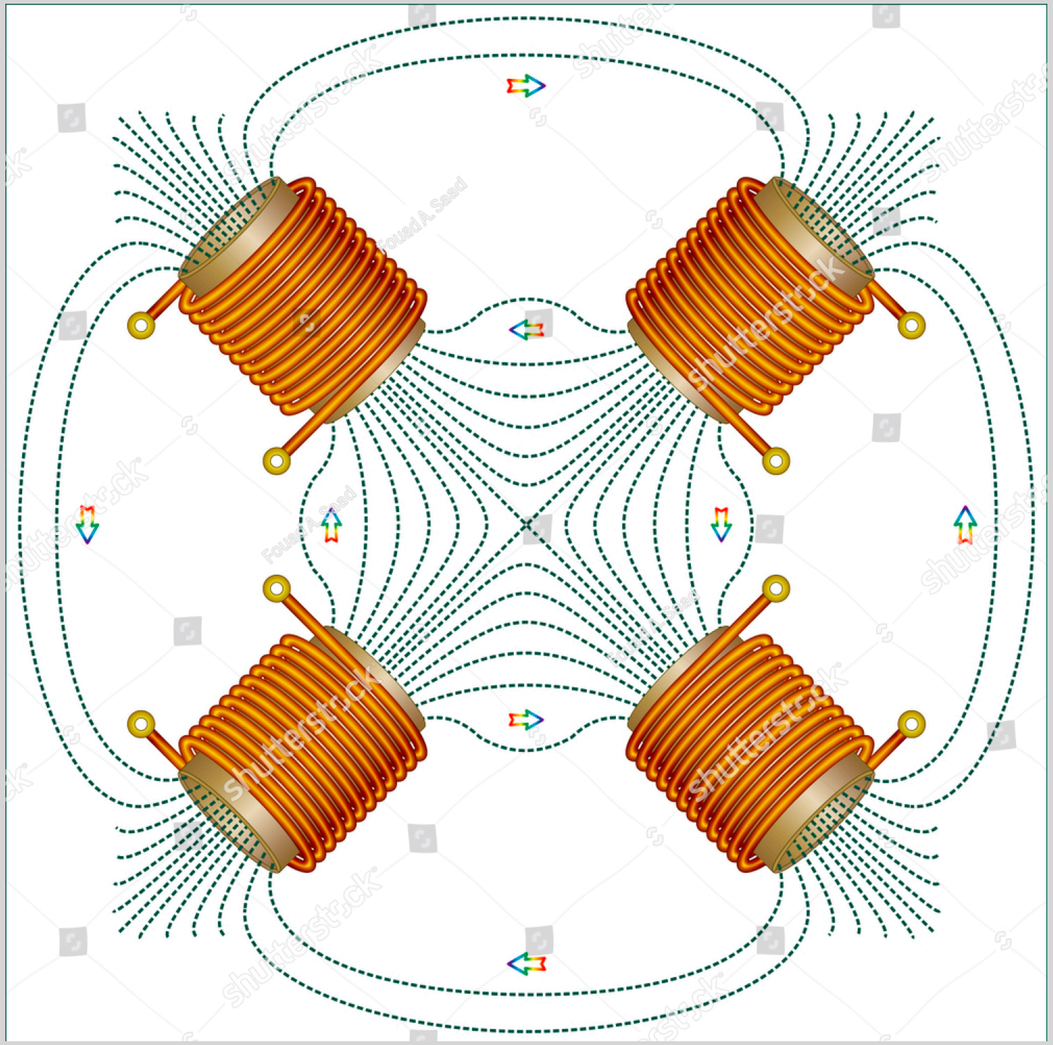
Magnets

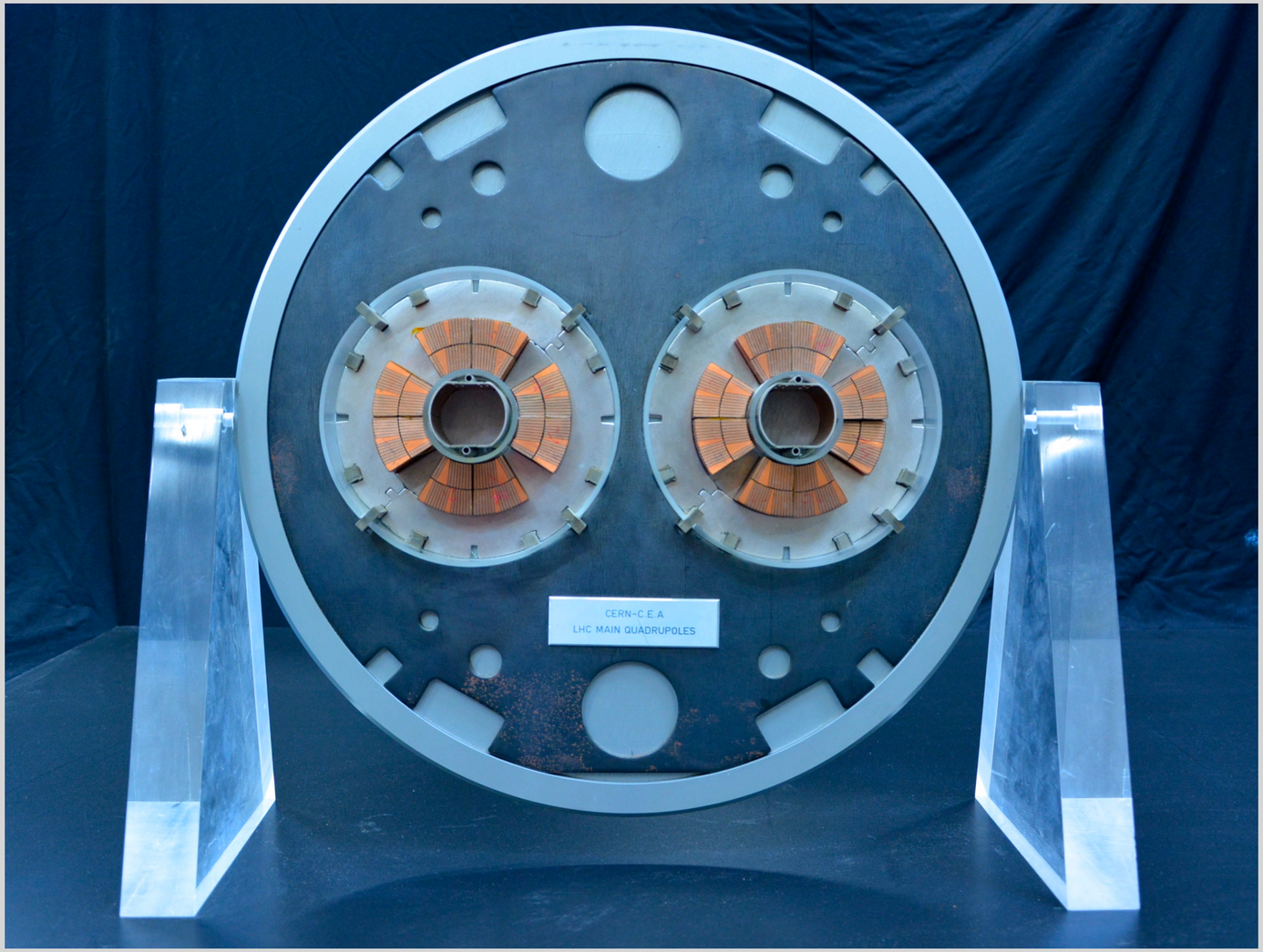
Dipoles


LHC DIPOLE : STANDARD CROSS-SECTION
CERN AC/DI/MM - HE107 - 30 04 1999
ALIGNMENT TARGET
MAIN QUADRIPOLE BUS-BARS
HEAT EXCHANGER PIPE
SUPERINSULATION
SUPERCONDUCTING COILS
BEAM PIPE
VACUUM VESSEL
BEAM SCREEN
AUXILIARY BUS-BARS
SHRINKING CYLINDER / HE I-VESSEL
THERMAL SHIELD (55 to 75K)
NON-MAGNETIC COLLARS
IRON YOKE (COLD MASS, 1.9K)
DIPOLE BUS-BARS
SUPPORT POST
Ø914
Ø1050
Ø570
Ø55



Quadrupoles



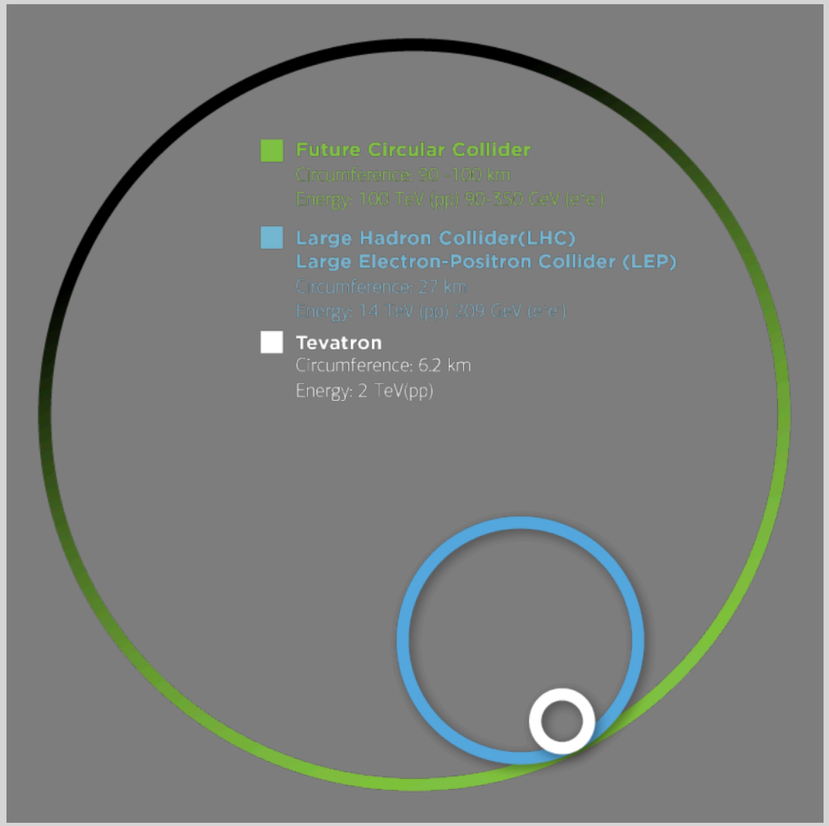


Long-Term CERN Plans

LHC / HL-LHC Plan

HL-LHC TECHNICAL EQUIPMENT:

HL-LHC CIVIL ENGINEERING:



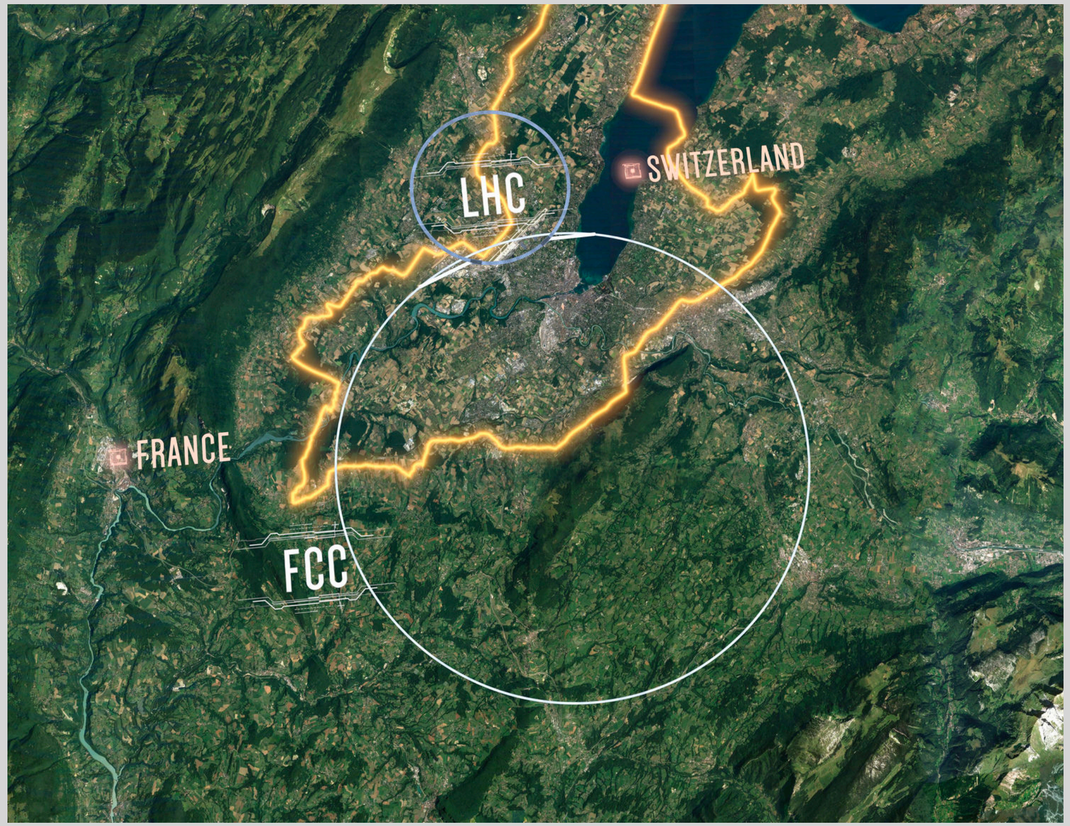


Table 1. FCC programme: schedule, construction and operating costs.

(a) Schedule of different scenarios within the FCC programme

		Start		Duration		
		Project	*Physics*	*Implementation*		*Operation*
				Preparation	Construction	
FCC-ee		2020	2039	8	10	15
FCC-hh	*with prior implementation of FCC-ee*	2020	2039, mid 2060's	9 (8+1)	20 (10+10)	40 (15+25)
	standalone	2020	mid 2040's	8	15	25
HE-LHC		2020	mid 2040's	8	8	20