

Outline

- Relativistic Kinematics
 - ▶ (4-momentum)² invariance, invariant mass
 - ▶ Hypothesis testing, production thresholds
 - ▶ Cross-sections, flux and luminosity, accelerators
 - ▶ Particle lifetime, decay length, width

- Classification of particles
 - ▶ Fermions and bosons
 - ▶ Leptons, hadrons, quarks
 - ▶ Mesons, baryons

- Quark Model
 - ▶ Meson and baryon structure
 - ▶ Isospin, strangeness

- Particle Interactions
 - ▶ Virtual particles
 - ▶ Strong and weak interactions
 - ▶ Parity, charge conjugation
 - ▶ Weak decays
 - ▶ Colour charge, QCD, gluons
 - ▶ Charmonium and upsilon systems

- Electroweak Interactions
 - ▶ Charged and neutral currents
 - ▶ W, Z, LEP e⁺e⁻
 - ▶ Higgs and top

- LHC Experiments

- Future - introduction to accelerator physics

Today

Lecture 4 (4 slides/page) - Fixed target and colliding beam experiments

- Perkins 3rd edition, pp. 28-32 (acceleration in linear vs. circular machines)
- Perkins 3rd edition, pp 32-33 (collider vs. fixed target machines and luminosity)
- Table of collider parameters - try to verify luminosity calculation for a few of these?
- Brief review of accelerator physics of colliders from Particle Data Group, K. Nakamura et al., JPG
- See also: Tigner and Chao, Handbook of Accelerator Physics and Engineering (copy in Library)
- USPAS - U.S. Particle Accelerator School
 - Course material - slides/lecture notes
 - Joint Accelerator Conference - proceedings for all major accelerator physics conferences

Previous
Lecture

• Lecture 3 (4 slides/page) - Particle decays and hypothesis testing

- Bubble Chamber web (CERN/G.T.Jones)
- Kinematics. from PDG, J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)

Further/Background Reading

TWiki > [General Web](#) > [UndergraduateTeaching](#) > [Y3Pp](#) (14 Jan 2013, NigelWatson)

Y3 Particle Physics

Material for the 2012-13 course.

Lectures start 7 January 2013 and are:

- Mondays at 1500, Watson Lecture Theatre C
- Thursdays 1200, Poynting Physics Small Lecture Theatre (S06)

References for further reading/background information will be given below each lecture.

The course [Reading List](#) is similar to previous PP courses.

- [Course Summary](#)
- [Reading List](#)
- [Useful \(not exhaustive\) collection of web pages](#)

Written lecture notes are not distributed but all transparencies/handouts are given below.

- [Lecture 1 \(4 slides/page\)](#) - general introduction to Particle Physics
- [Review of Quark Model](#), in *2008 Particle Data Group Review of Particle Physics*, C. Amster et al., published in [Physics Letters B667, 1 \(2008\)](#).
 - CERN Summer Studentships
 - [CERN Summer Student information](#) - deadline 27 Jan. 2013
 - [2012 Summer student pages - everything to see](#)
 - DESY Summer Studentships
 - [Poster](#)
 - [DESY Summer Student information](#) - application deadline 31 Jan. 2013
- [Lecture 2 \(4 slides/page\)](#) - Relativistic kinematics and four momenta
 - Griffiths, pages 89-103
 - Williams, page 159
 - [Handout on kinematics and units](#)
 - Units: see also Perkins (3rd edition), pg.25.
- [Lecture 3 \(4 slides/page\)](#) - Particle decays and hypothesis testing

**Per lecture reading in course texts – please look at it
Library reading list for course updated/expanded**

LEP Collider close to max. energy

Beam "lifetime" in e^+e^-

Luminosity vs. time (energy)

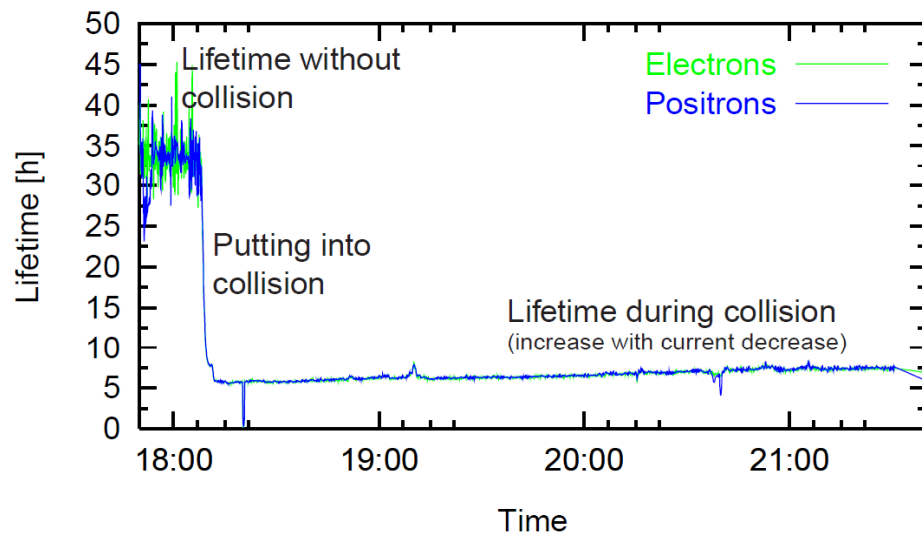


Figure 1: Evolution of beam lifetime in LEP.

R. Assmann et al, "Luminosity and Beam Measurements Used for Performance Optimisation in the LEP Collider", EPAC, Vienna, p. 265 (2000).

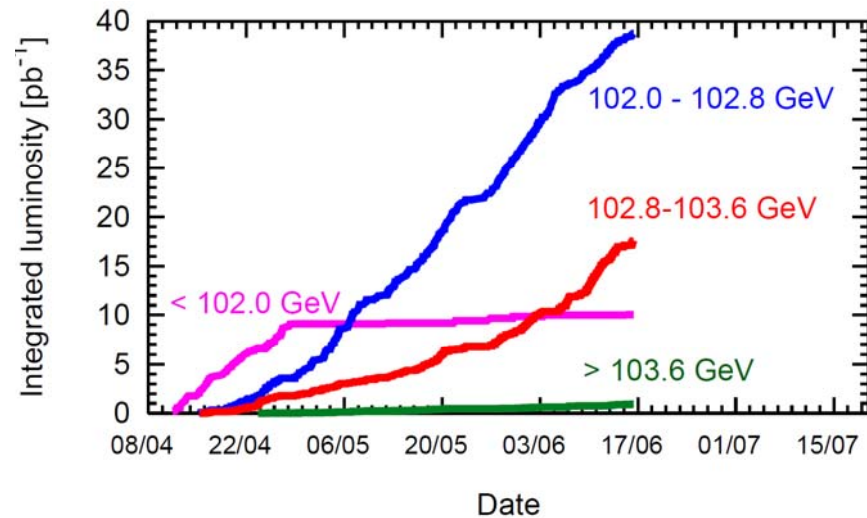


Figure 2: Luminosity production in 2000. The three angles correspond to 2, 1 and 0 klystrons overhead (right hand numbers, from top to bottom).

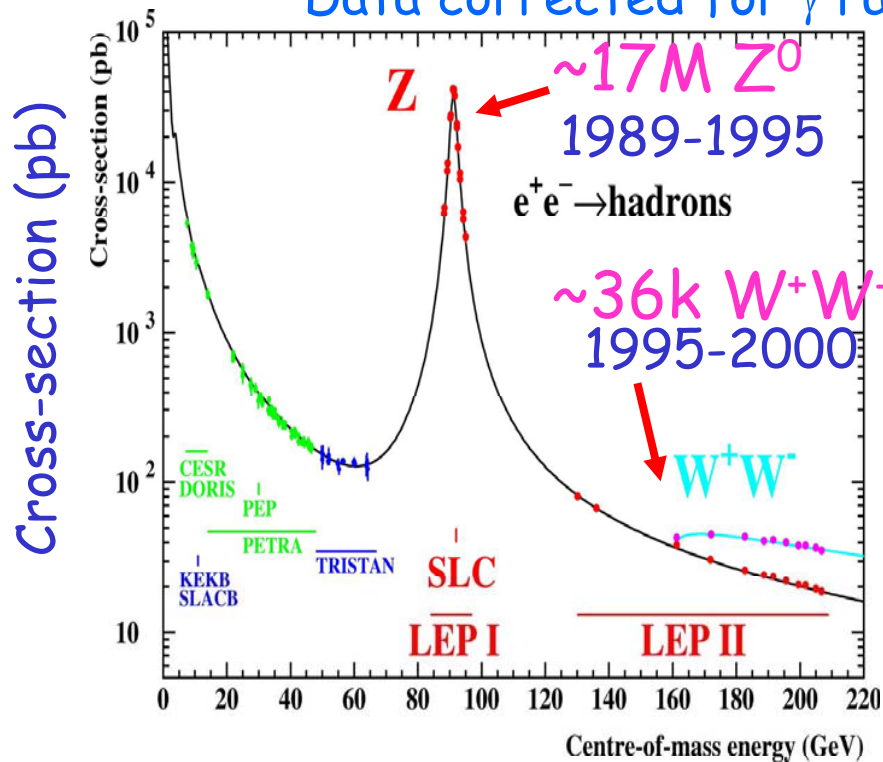
G. Arduini et al, "LEP Operation and Performance with 100 GeV Colliding Beams," EPAC, Vienna, p. 265 (2000).

Example: data rates

Physics cross-sections

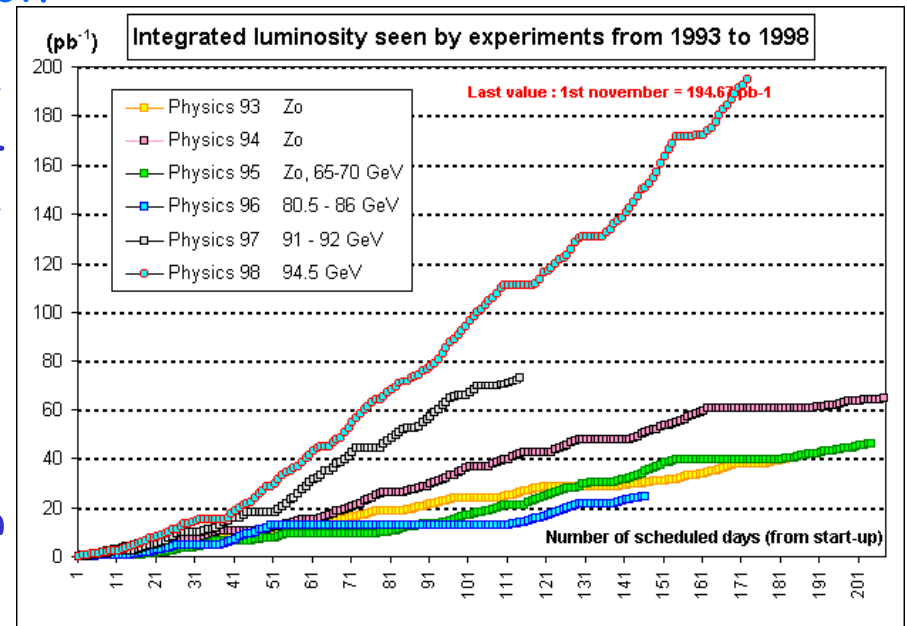
Integrated collider lumi.

Data corrected for γ radiation



Centre-of-mass energy (GeV)

Integrated lumi. (1/pb)



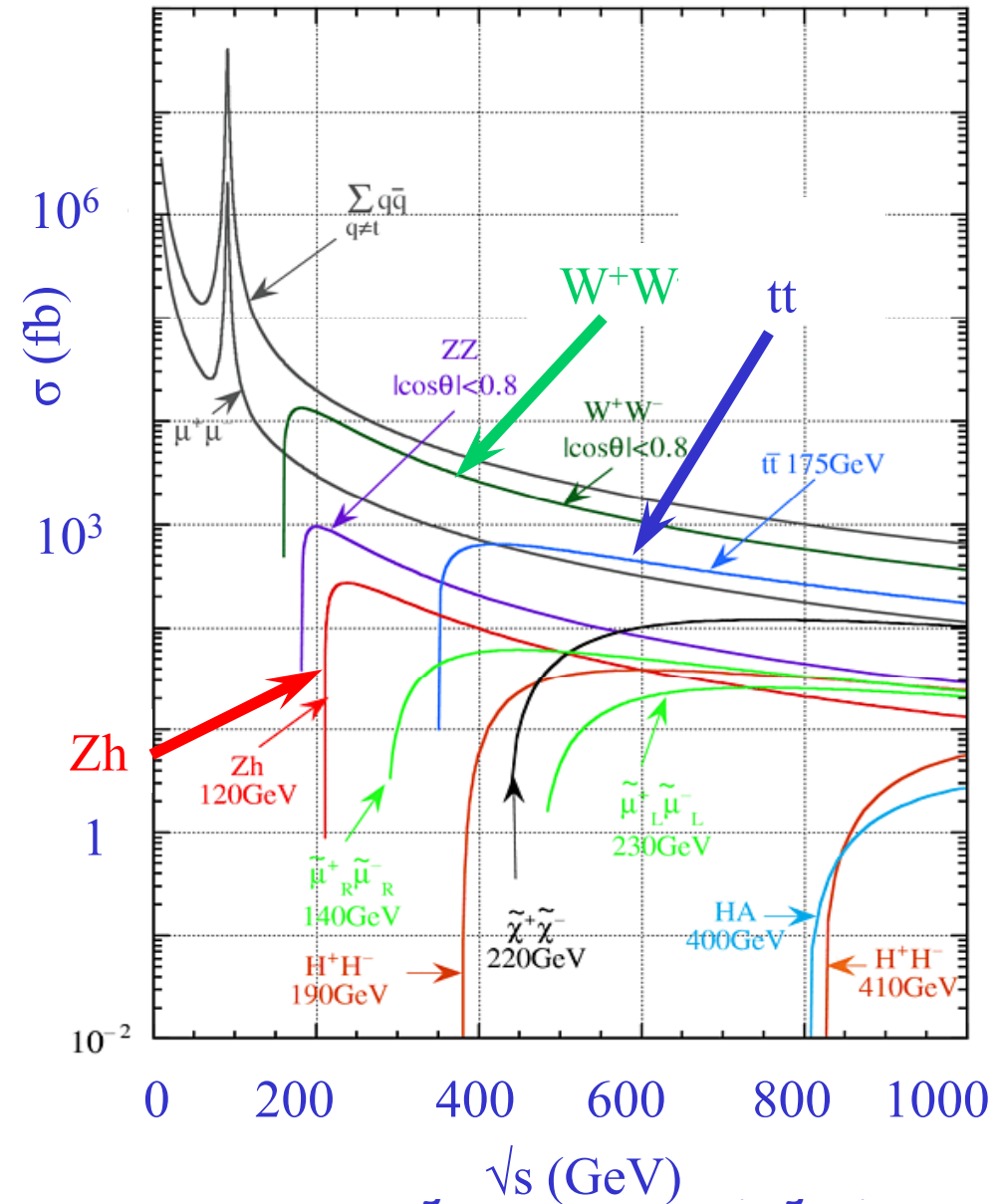
Days since start up

Example of machine parameters

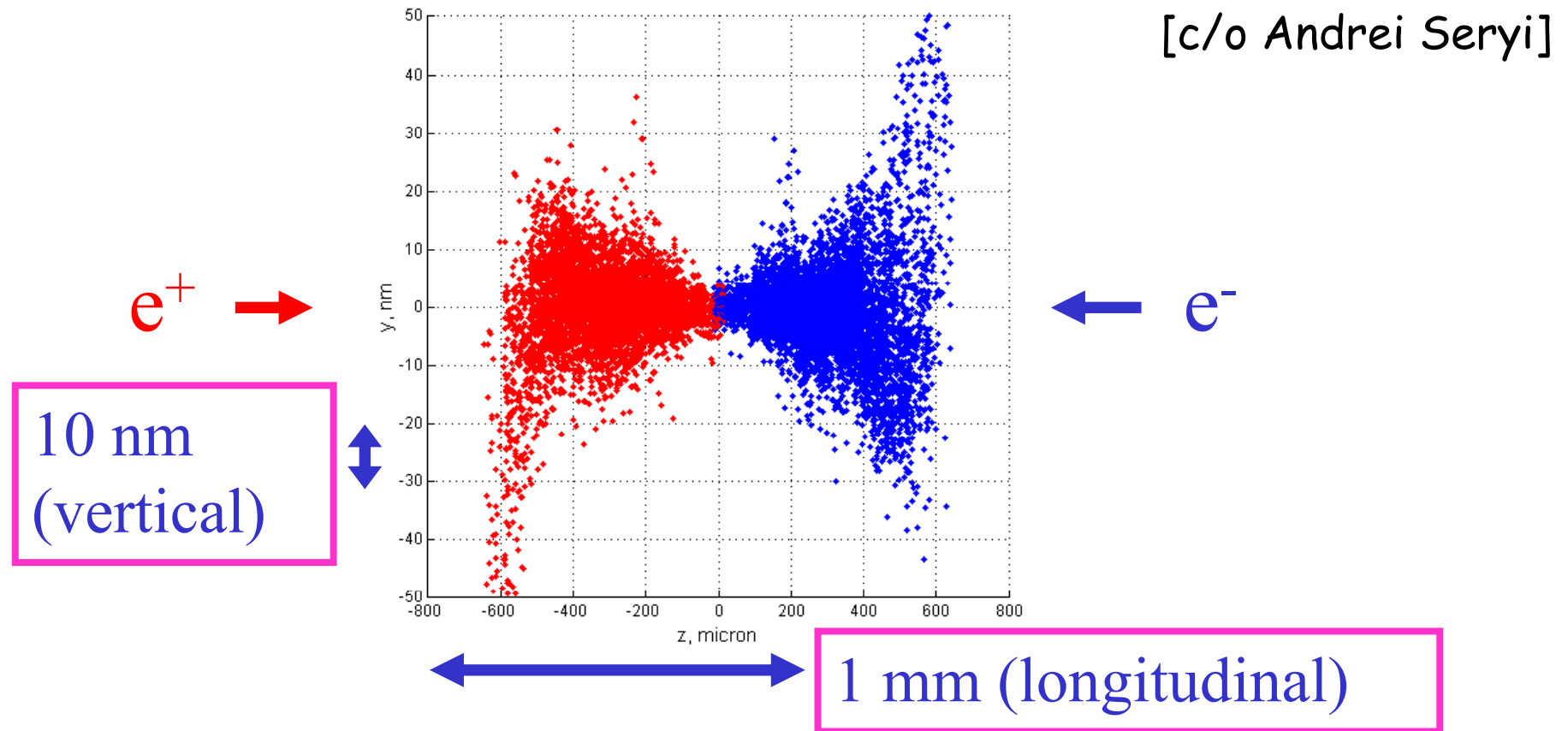
	CESR (Cornell)	CESR-C (Cornell)	LEP (CERN)	ILC (TBD)
Physics start date	1979	2002	1989	TBD
Physics end date	2002	2008	2000	—
Maximum beam energy (GeV)	6	6	100 - 104.6	250 (upgradeable to 500)
Luminosity ($10^{30} \text{ cm}^{-2}\text{s}^{-1}$)	1280 at 5.3 GeV/beam	76 at 2.08 GeV/beam	24 at Z^0 100 at > 90 GeV	2×10^4
Time between collisions (μs)	0.014 to 0.22	0.014 to 0.22	22	0.3^{\ddagger}
Full crossing angle ($\mu \text{ rad}$)	± 2000	± 3300	0	14000
Energy spread (units 10^{-3})	0.6 at 5.3 GeV/beam	0.82 at 2.08 GeV/beam	0.7→1.5	1
Bunch length (cm)	1.8	1.2	1.0	0.03
Beam radius (μm)	H : 460 V : 4	H : 340 V : 6.5	H : 200 → 300 V : 2.5 → 8	H : 0.639 V : 0.0057
Free space at interaction point (m)	± 2.2 (± 0.6 to REC quads)	± 2.2 (± 0.3 to PM quads)	± 3.5	± 3.5
Luminosity lifetime (hr)	2-3	2-3	20 at Z^0 10 at > 90 GeV	n/a
Turn-around time (min)	5 (topping up)	1.5 (topping up)	50	n/a
Injection energy (GeV)	1.8-6	1.5-6	22	n/a
Transverse emittance ($10^{-9}\pi \text{ rad}\cdot\text{m}$)	H : 210 V : 1	H : 120 V : 3.5	H : 20-45 V : 0.25 → 1	H : 0.02 V : 8×10^{-5} (at 250 GeV)
β^* , amplitude function at interaction point (m)	H : 1.0 V : 0.018	H : 0.94 V : 0.012	H : 1.5 V : 0.05	H : 0.02 V : 0.0004
Beam-beam tune shift per crossing (units 10^{-4})	H : 250 V : 620	e^- : 420 (H), 280 (V) e^+ : 410 (H), 270 (V)	830	n/a
RF frequency (MHz)	500	500	352.2	1300
Particles per bunch (units 10^{10})	1.15	4.7	45 in collision 60 in single beam	2
Bunches per ring per species	9 trains of 5 bunches	8 trains of 3 bunches	4 trains of 1 or 2	2625

Higher energy e^+e^- colliders

- In planning/R&D phase
- Physics motivations many
- Cross-sections small!
- Luminosity **the** issue!
- b/c-tagging with high purity/efficiency
 - ▶ e.g. Higgs branching ratios
- Precision Tracking
- Recoil mass measurements
- Jet energy resolution
- Multi jet final states, e.g.
 - ▶ $tt\bar{t}$
 - ▶ separation of WW/ZZ



Beam-Beam effects in future e^+e^- machines



- Mutual focussing, “pinch” enhancement
- Large disruption – single pass machine
- Beam-beam effects, amplify initial vertical offsets

▶ detect downstream, feedback, maintains lumi

Glasgow, 24-Jan-2008

Nigel Watson / Birmingham

Luminosity in future e^+e^- machine

■ High luminosity achieved by

[c/o Andrei Seryi]

▶ Many incident particles

▶ Small transverse cross-section at interaction point

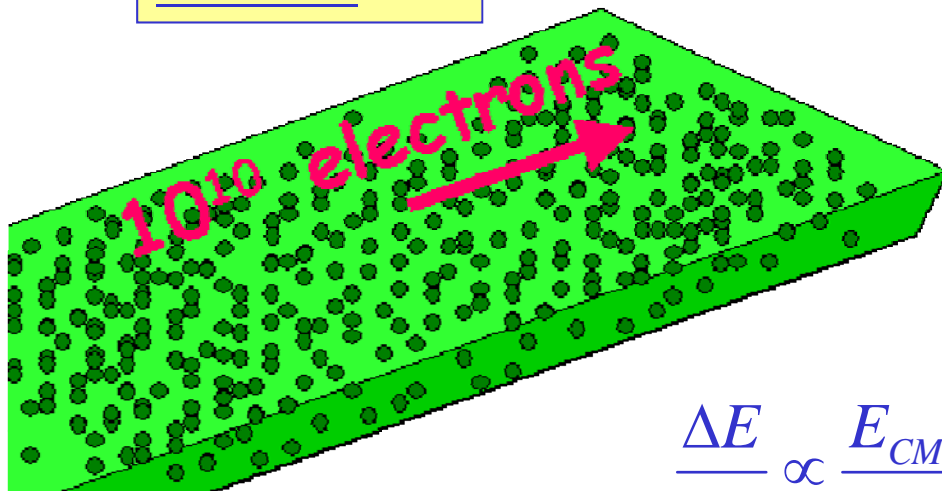
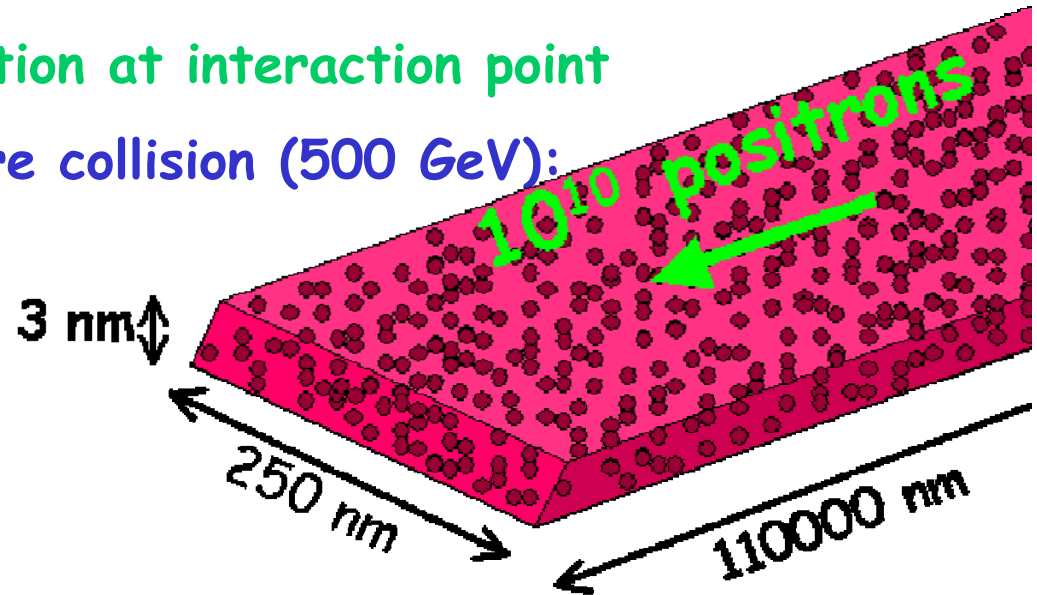
■ e.g., LC beam sizes just before collision (500 GeV):

250 * 3 * 110000 nm

(x y z)

↑

vertical size
is smallest



$$\frac{\Delta E}{E} \propto \frac{E_{CM}}{\sigma_z} \frac{N^2}{(\sigma_x + \sigma_y)^2}$$

$$L = \frac{f_{rep} n_b N^2}{4\pi \sigma_x \sigma_y} H_D$$