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, bary
- Quark Model
  - Meson and ba
  - Isospin, strar
- Particle Interactio
  - Virtual partic
  - Strong and w
  - Parity, charg
  - Weak decays
  - Colour charge, QCD, gluons
  - Charmonium and upsilon systems
- Electroweak Interactions
  - Charged and neutral currents
  - W, Z, LEP e
  - Higgs and th
- LHC Experiments
- Future – introduction to accelerator physics

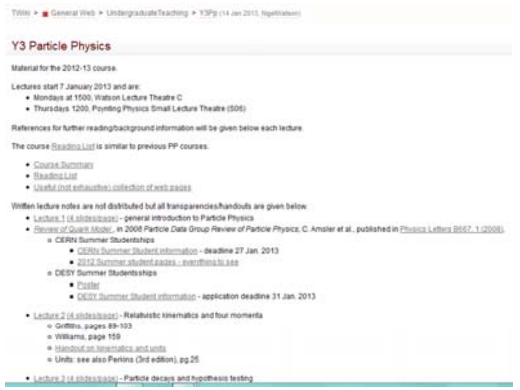
Today

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



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^-

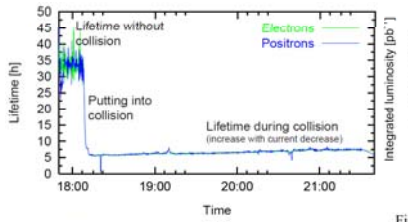


Figure 1: Evolution of beam lifetime in LEP.

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

Luminosity vs. time (energy)

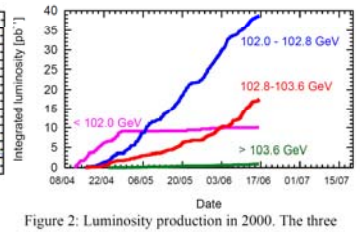


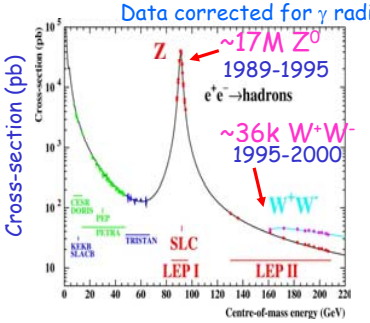
Figure 2: Luminosity production in 2000. The three anges correspond to 2, 1 and 0 klystrons overhead (right hand numbers, from top to bottom).

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

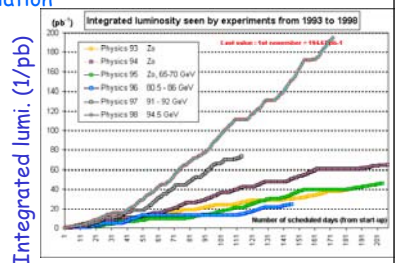
Example: data rates

Physics cross-sections

Data corrected for γ radiation



Integrated collider lumi.

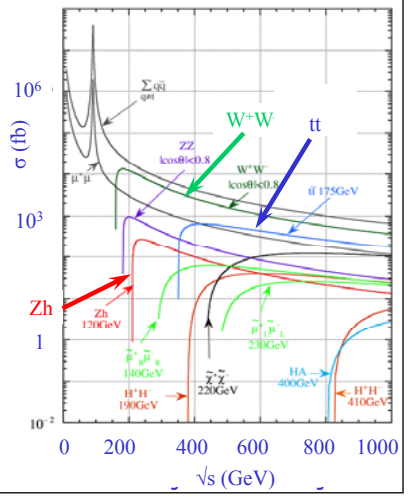


Example of machine parameters

	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} cm^{-2}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[1]
Full crossing angle (μ 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: 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} π rad-m)	H: 210 V: 1	H: 120 V: 3.5	H: 20-45 V: 0.25 → 1	H: 0.02 V: 8×10^{-3} (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^{-3})	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

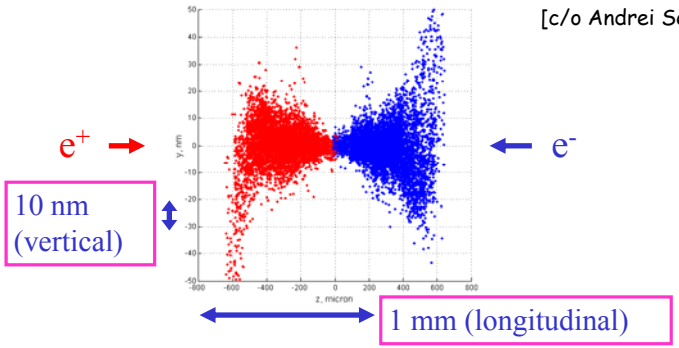
Higher energy e^+e^- colliders

- 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.
  - ttbar
  - separation of WW/ZZ



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

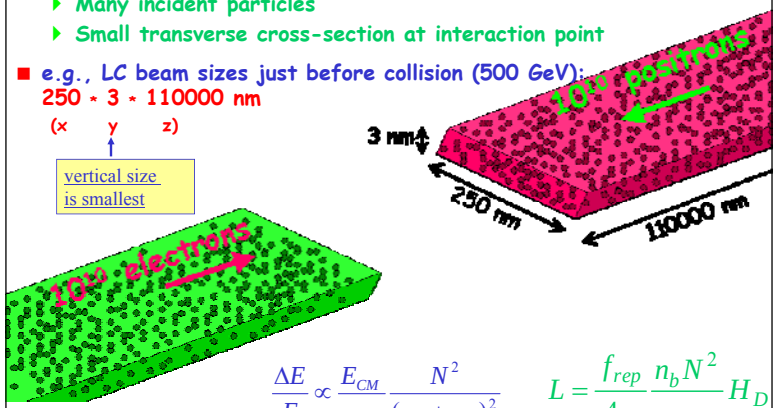
[c/o Andrei Seryi]



- Mutual focussing, "pinch" enhancement
- Large disruption – single pass machine
- Beam-beam effects, amplify initial vertical offsets
  - detect downstream, feedback, maintains lumi

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



$$\frac{\Delta E}{E} \propto \frac{E_{CM}}{\sigma_z} \frac{N^2}{(\sigma_x + \sigma_y)^2} \qquad L = \frac{f_{rep}}{4\pi} \frac{n_b N^2}{\sigma_x \sigma_y} H_D$$