Phenomenology at colliders (1)

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Plan

I. INTRODUCTION AND MOTIVATION

1. Why colliders ?
  - energy
  - parameters : luminosity
  - structure : orbit, acceleration, collimation, emittance

2. Detectors
  - structure, acceptance

3. The need for pdf's
  - the Drell-Yan process
  - jet production
  - top production

II. STRUCTURE FUNCTIONS AND PARTON DISTRIBUTION FUNCTIONS

1. Deep inelastic scattering and structure functions
2. Quark parton model
3. Scaling violation
4. QCD evolution and DGLAP equations

IiI. FACTORISATION THEOREMS; PDF PARAMETERISATIONS

1. Factorisation theorems
2. Drell-Yan production with CMS
3. Parton distribution function parameterisations
4. Parton distribution uncertainties
5. Some (of many) uncovered topics

I.1 Why colliders ?
Structure, parameters

Fixed target and collider experiments

Fixed target

beams: e, p, ions (+ radioactive beams) ; γ, ν, μ, π, K, hyperons

target: p, n (D_2), nuclei

Colliders

leptons	e^+e^- - future $\mu^+ \mu^-$ (?)	LEP, SLC, meson factories (s, c, b)
hadrons	pp ppbar ions	ISR SppS Tevatron RHIC LHC
l-h	ep	HERA

Centre of mass energy $\sqrt{s}$

FT $\sqrt{s} = 2\, m\, E_b$

coll. $\sqrt{s} = 2\, E_b$

LEP 2x50 ... 2x104 GeV

ISR 2x31 GeV SppS 2x350 Tev 2x1 TeV LHC 2x10-14 TeV

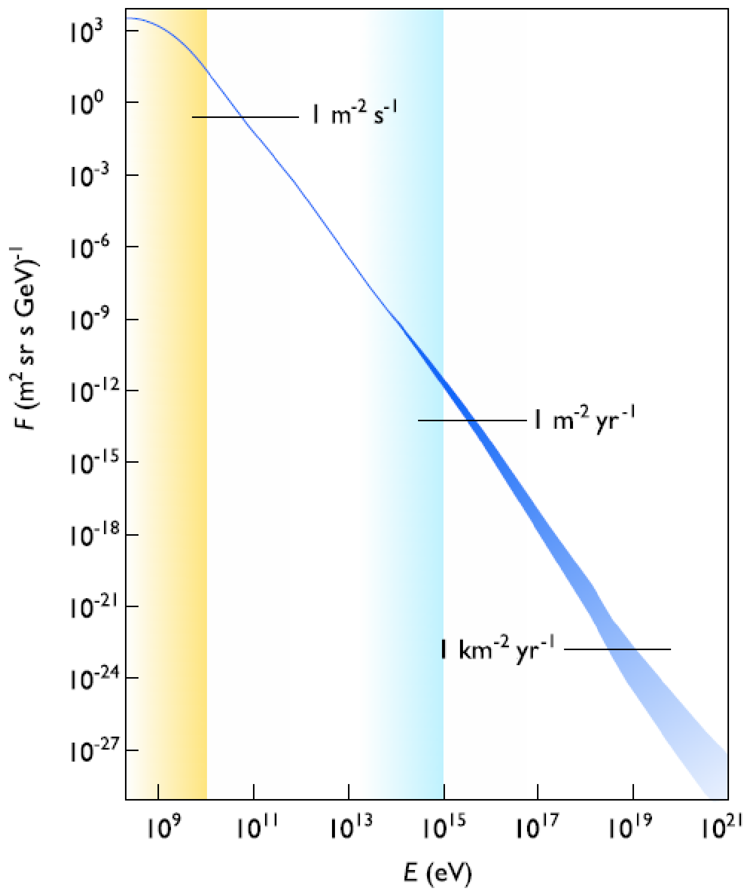
meson factories adjust to ϕ, Ψ, Υ

Universe as accelerator :

Cosmic ray spectrum

-> 10^{19} eV

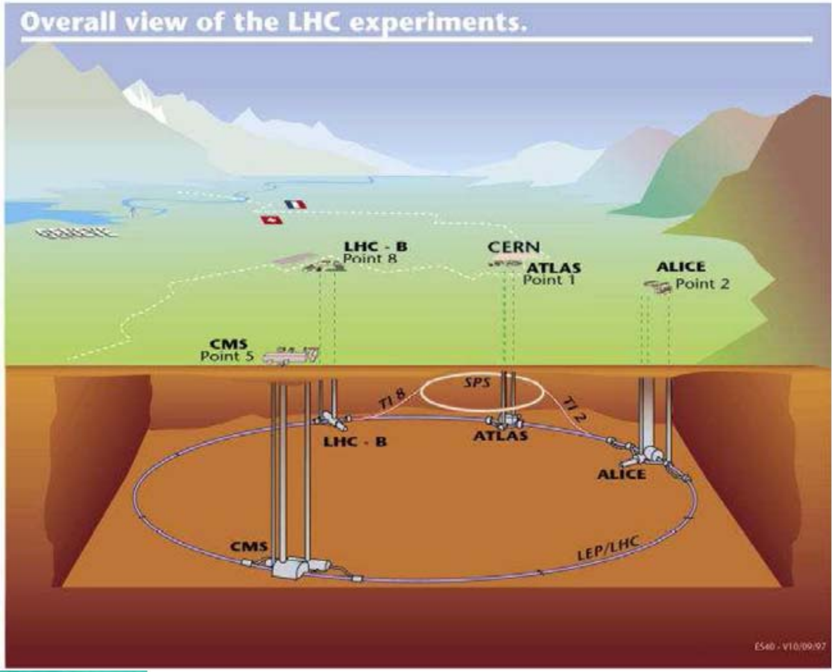
equivalent collider energy ?



Collider structure

« Circular » geometry

+ straight sections : injection, extraction, acceleration, experiments

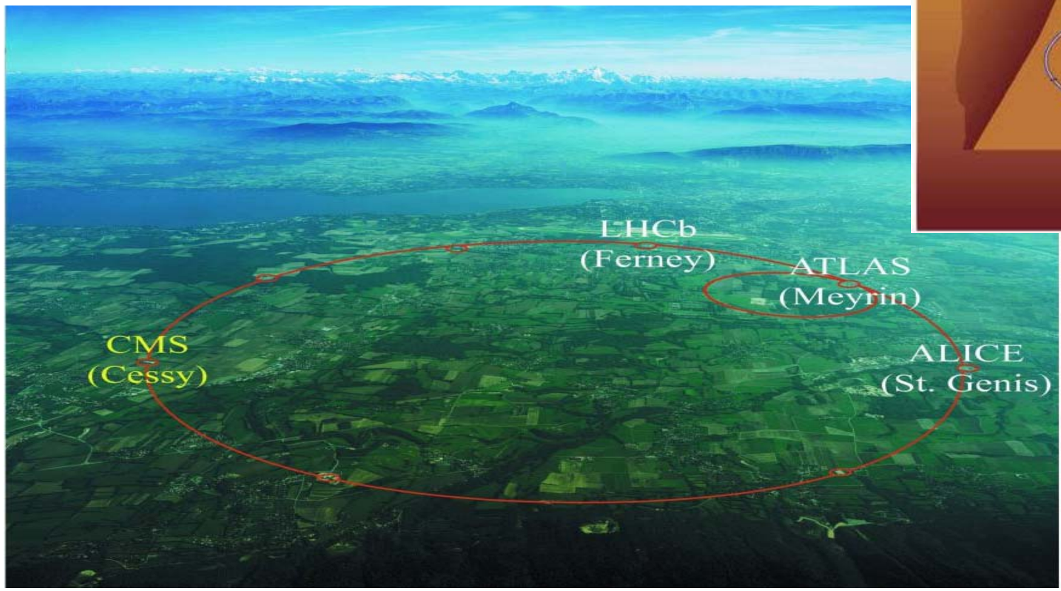


E = 300 B R

(B in GeV, B in Tesla, R in km)

LHC : R in circular sections about 3 km (LEP tunnel)

B = ??



Electron colliders

Limitation of electron circular colliders :

Bremsstrahlung emission (synchrotron radiation) ~ γ^4

cf. LEP at 104 GeV

-> linear colliders : SLD, ILC, CLIC

hudge accelerator gradient needed !

-> hadronic colliders

-> $\mu^+ \mu^-$ plans

Advantage of lepton colliders

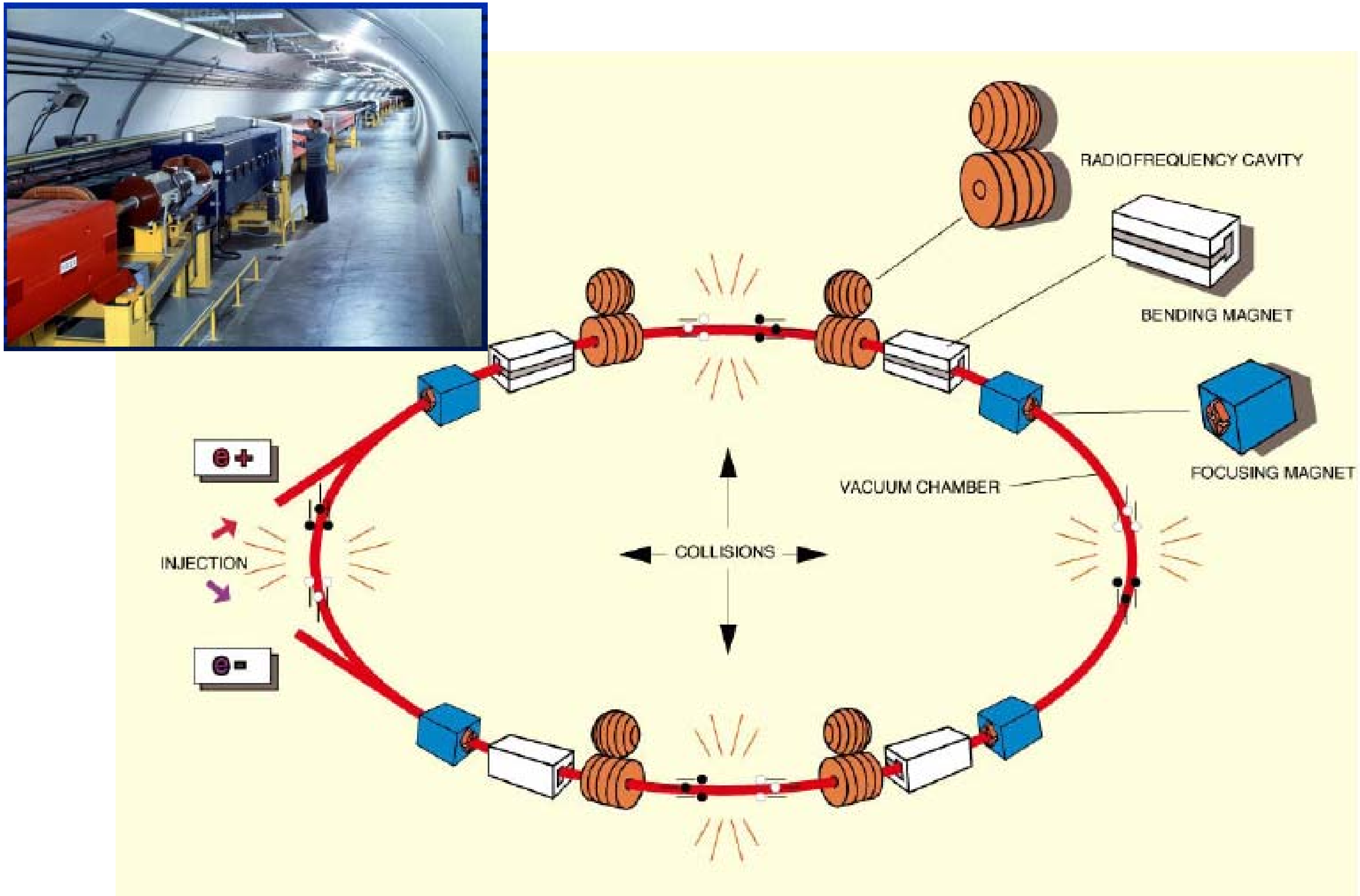
well defined centre of mass energy

hadron colliders : *<u>parton</u>* collisions

Bending : superconducting dipole magnets, B perp. to beam

Focusing : quadrupole magnets   1 focusing + 1 defocusing in the 2 perp. directions

Acceleration : superconducting radiofrequency cavities



Collider parameters

Luminosity

$dN = L\ \sigma\ dt$

$L = i_1\ i_2\ l_b\ /\ s.c\quad = 1.3\ 10^{27}\ i_1\ i_2\ l_b\ /\ s\quad [cm^{-2}\ s^{-1}]$

NB in colliders, beam are in *bunches*

record luminosity : Belle 2 $10^{34}\ cm^{-2}\ s^{-1}$

- what is the reach of 1 year running with $L = 10^{31}\ cm^{-2}\ s^{-1}$?

- for $\sigma(pp)$ about 100 mb:

how many superimposed interactions at LHC (time between bunches = 40 ns)

for $10^{34}\ cm^{-2}\ s^{-1}$

increase luminosity => bunches as compact as possible

strong focusing close to the interaction points (experiments)

Luminosity measurement

- beam detectors

- physics processes

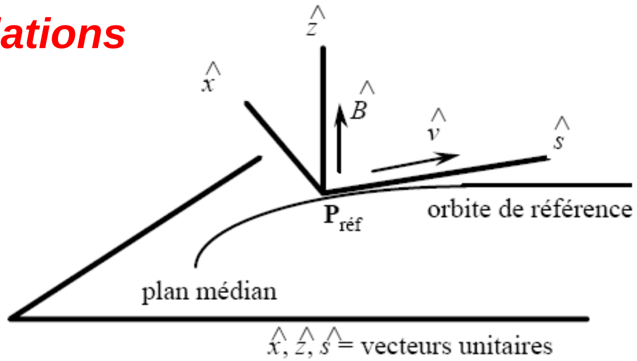
LEP Bhabha scattering : $e^+ + e^- \rightarrow e^+ + e^- + \gamma$

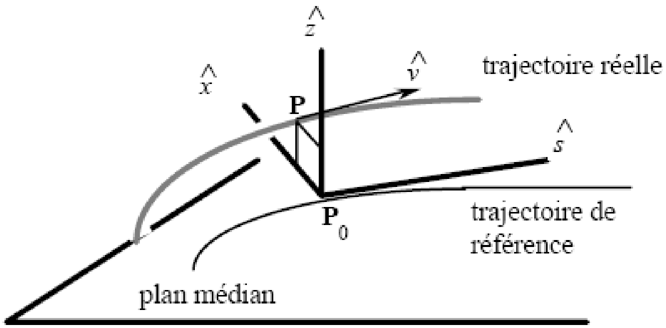
HERA Bethe-Heitler scattering : $e + p \rightarrow e + p + \gamma$

LHC Drell-Yan cross section at the Z peak

total inelastic cross section (use of forward calorimeters)

Oscillations





particles which are not *exactly* on « reference orbit » oscillate around it

- Δx — x = dir. perp. to beam in hor. plane i.e. along radius
- Δz — z = vert. dir.
- Δp — not injected with exactly same energy
  (no problem with ee: Brem. uniformises !)
- $\Delta \phi$ — not injected at exactly the same phase (at the same time)

Δx, Δz : « *betatronic oscillations* » = transverse oscillations

Δp : effect on acceptance in x

transverse oscillations

amplitude of these oscillations -> acceptance of vacuum chamber

$\Delta \phi$: « *synchrotron oscillations* » = longitudinal oscillations

(part. should remain inside bunch !)

Betatronic oscillations (Δx, Δz)

oscillation phase space is given by ellipse in the (x, x') spa

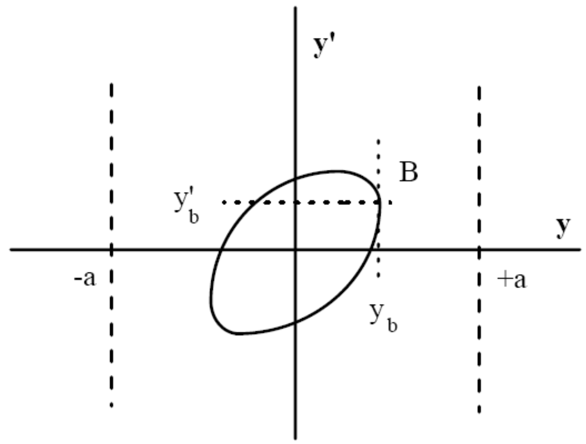
x = dir. perp. to beam in hor. plane

x' = gradient along the beam : dx / ds

(idem for z, vert. direction)

Dimension of this ellipse given by injection conditions :

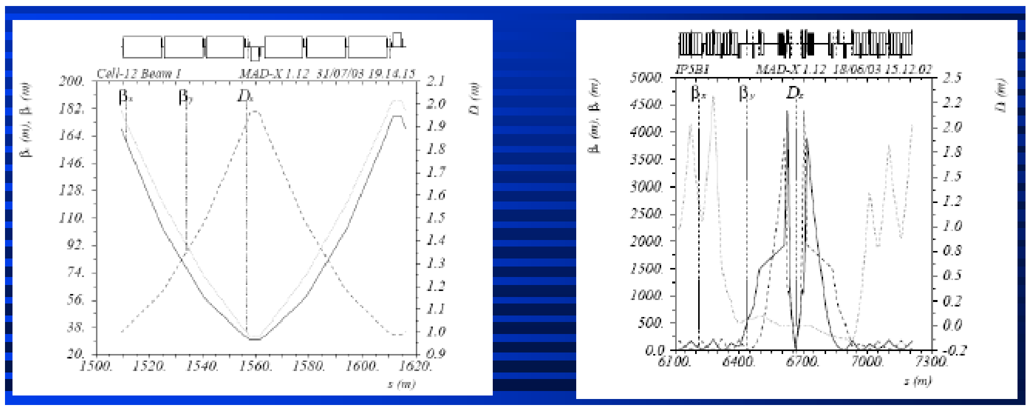
« *emittance* »



focus in x => large x' => large angle

this is described by « *beta function* »

focusing by « small beta insertions »



For total cross section measurements (forward elastic scattering) :

large dispersion of interaction angle incompatible with measurement at very small angle (TOTEM)

=> which beta function values ?

Problem : focusing in x ↔ defocusing in z

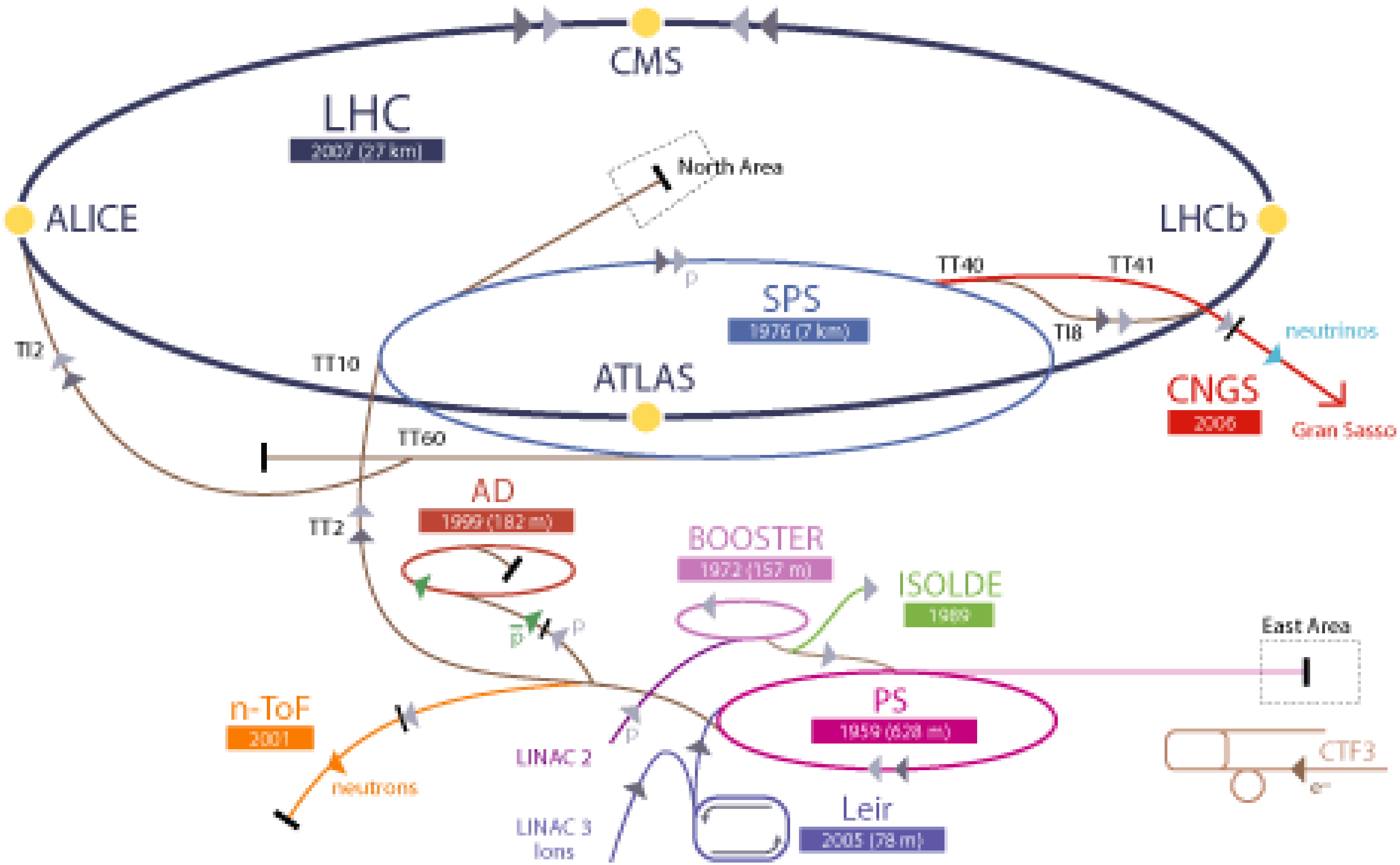
Solution : pairs of focusing and defocusing quadrupoles

(cf. optics)

(+ sextupoles, octopoles for other corrections)

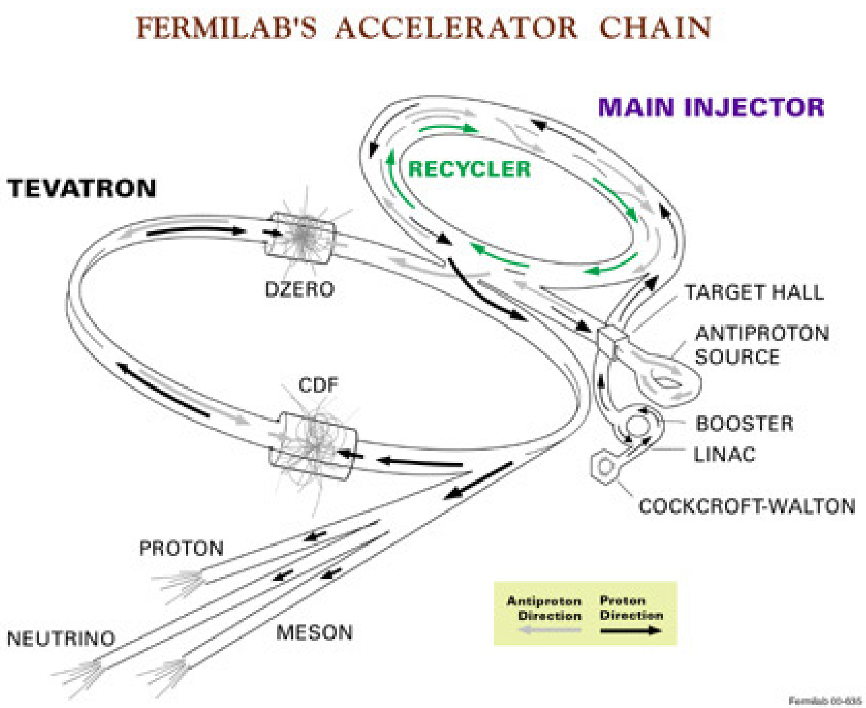
Tuning conditions => chain of injectors

CERN Accelerator Complex



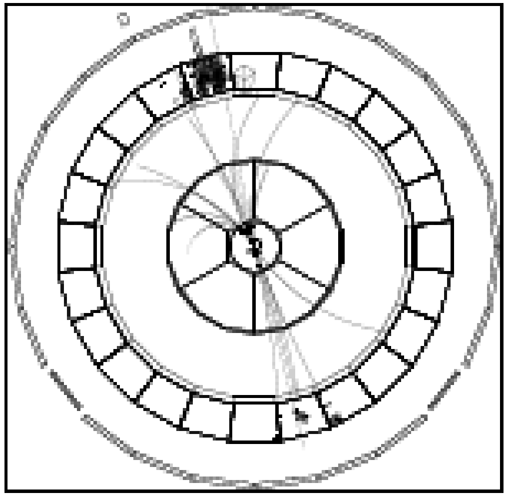
Tevatron

+ antiproton source and accumulation

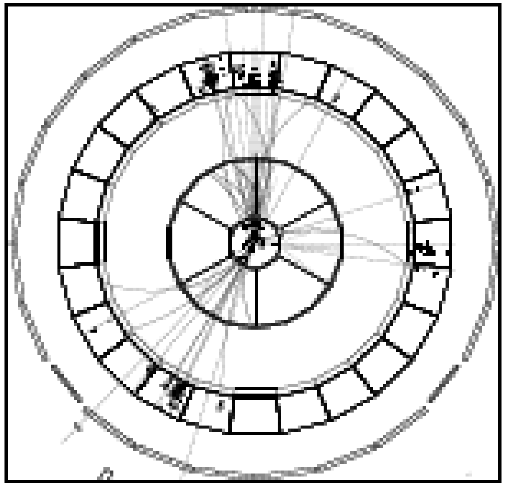


I.2 Collider detectors

e^+e^- interactions (LEP)

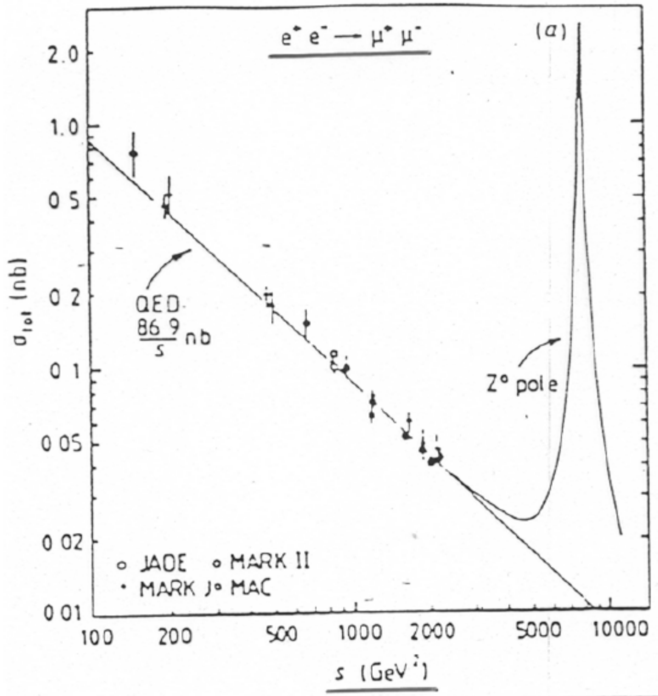


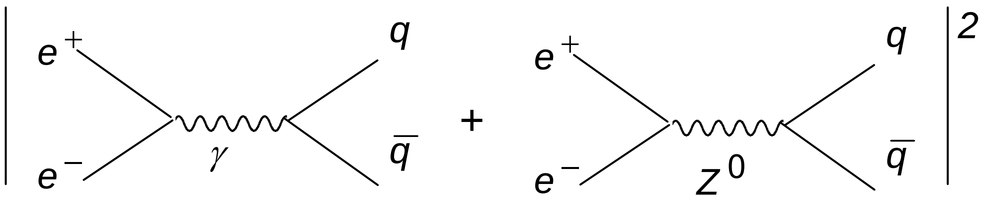
$e^+e^- \to Z^o \to q\bar{q}$



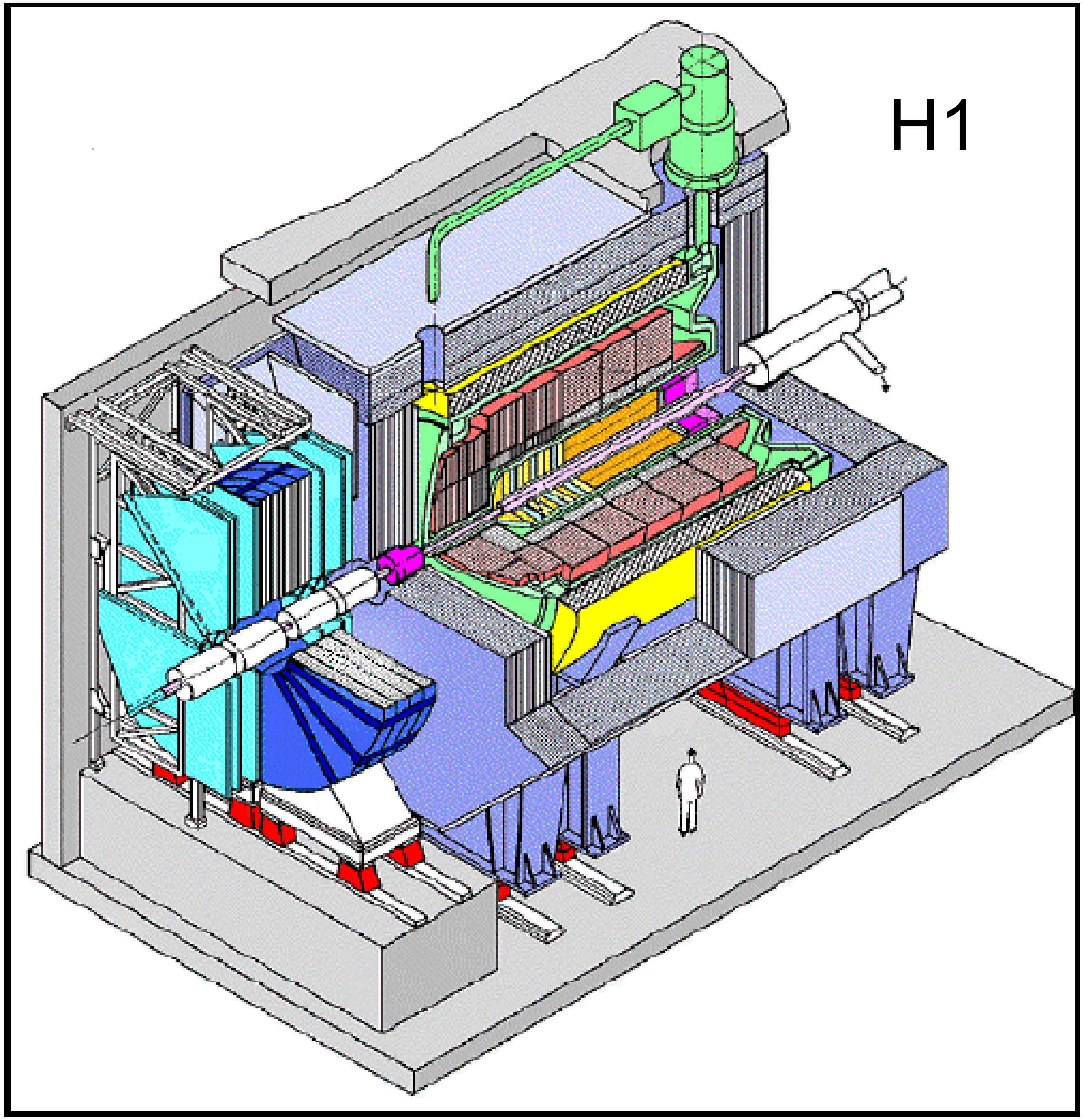
$e^+e^- \to Z^o \to q\bar{q}g$

symmetric, hermetic, (modest) particle identification
(tracks, electrons and photons, hadrons, muons)
very « clean » events, well centred





ep interactions (HERA)



hermetic

not symmetric

Other asymmetric detectors:

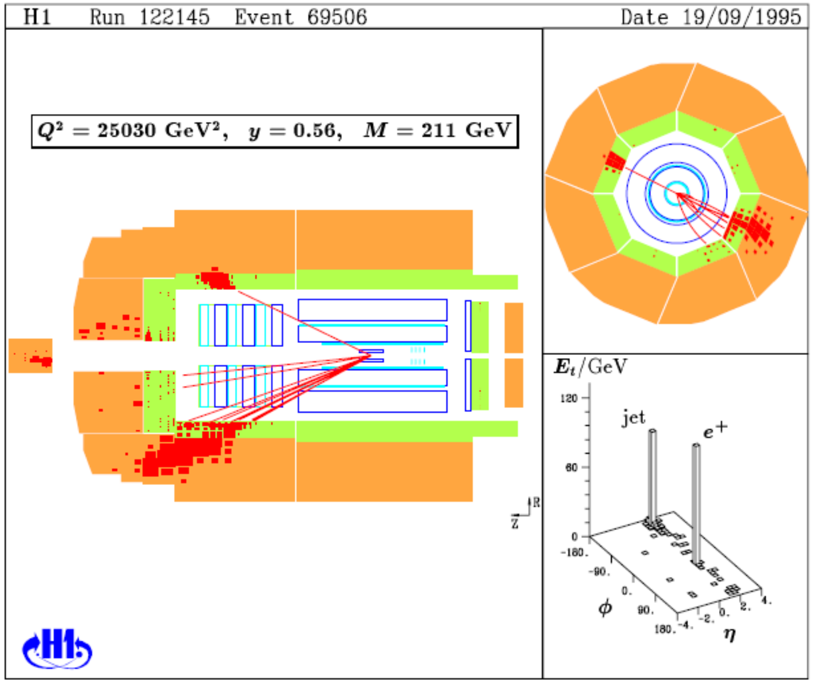
b factories (Belle)

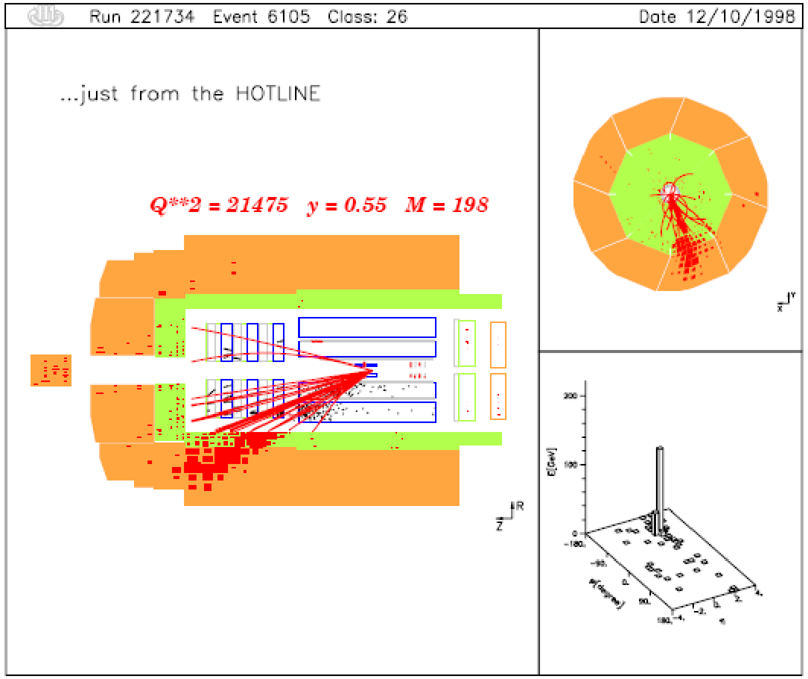
Υ boosted

→ one b boosted

→ enhance decay vertex
meast.

H1





neutral current event

$$e + p \rightarrow e + q\ jet + p\ jet$$

charged current event

$$e + p \rightarrow \nu_e + q\ jet + p\ jet$$

asymmetric events → asymmetric detector

(where is the ν ?)

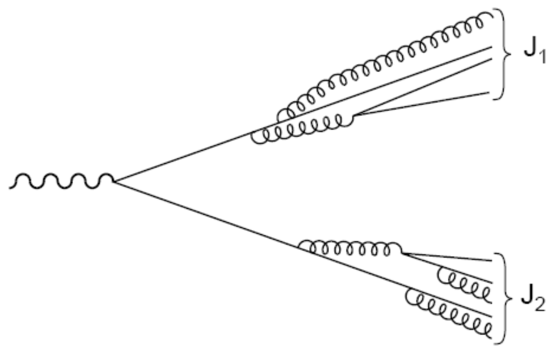
interaction on a quark in the proton, carrying $E_q = x\, E_p$

additional activity in the « forward » region = p remnant jet

$$W^2 \simeq Q^2 / x$$

Jet fragmentation

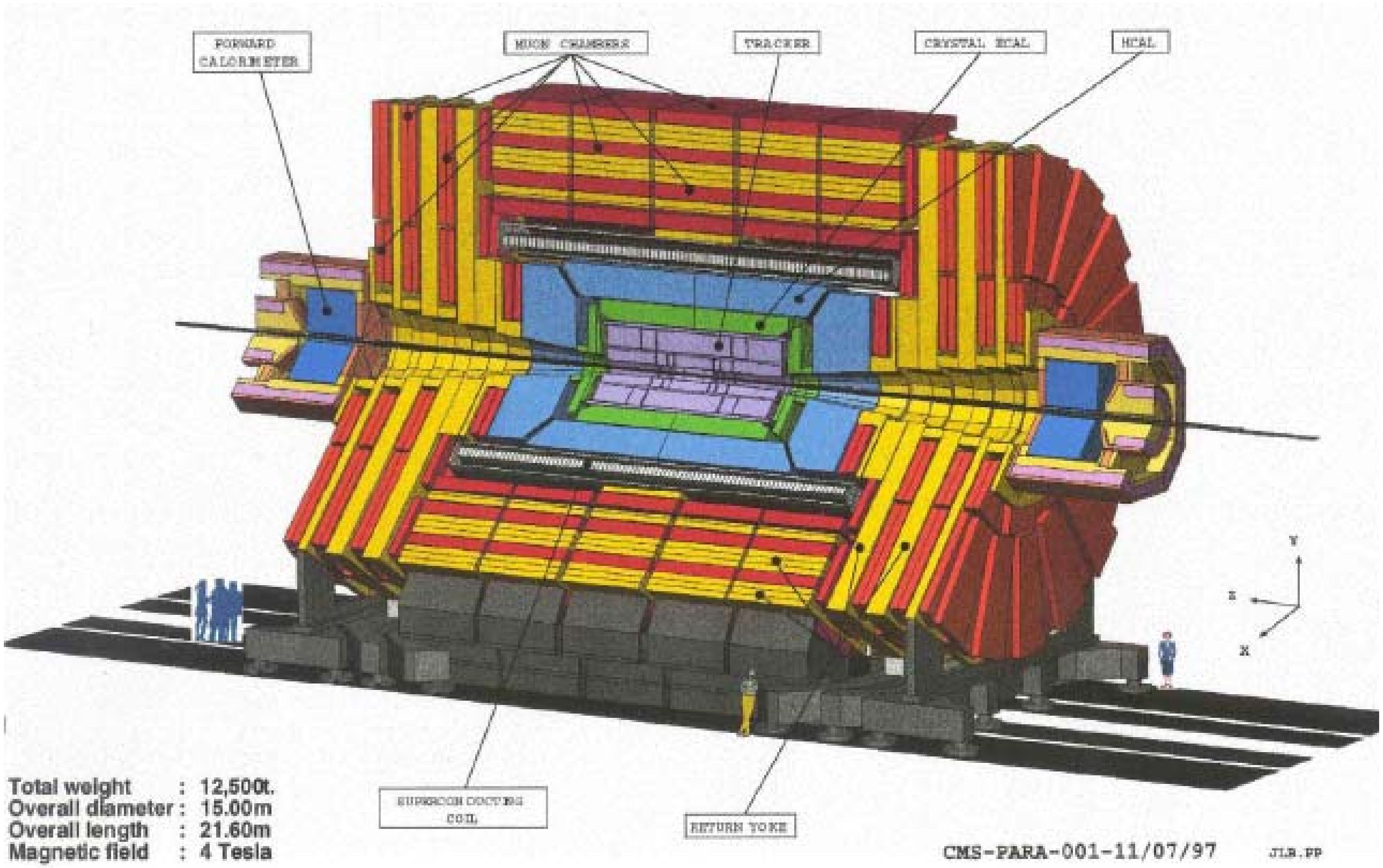
quarks and gluons are colour charged
=> must « hadronize »
gluon Bremsstrahlung



typical p_t of particles around jet (quark or gluon) axis
given by strong interaction scale ≈ 1 fm
exp (–B p_T) with B ≈ 300 MeV

(0.2 GeV fm = 1)

CMS

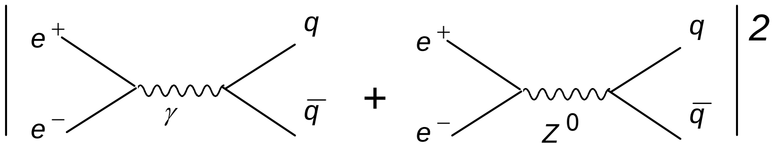


hermetic symmetric particle identification

I.3 Parton distribution functions motivations

Drell-Yan production

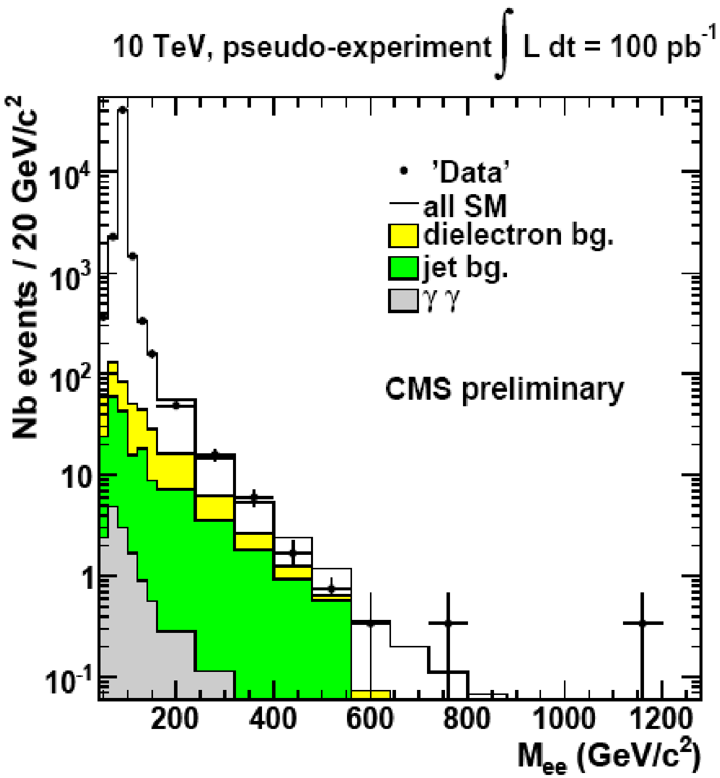
LEP $\quad e^+e^- \to \gamma / Z \to q\bar{q}$

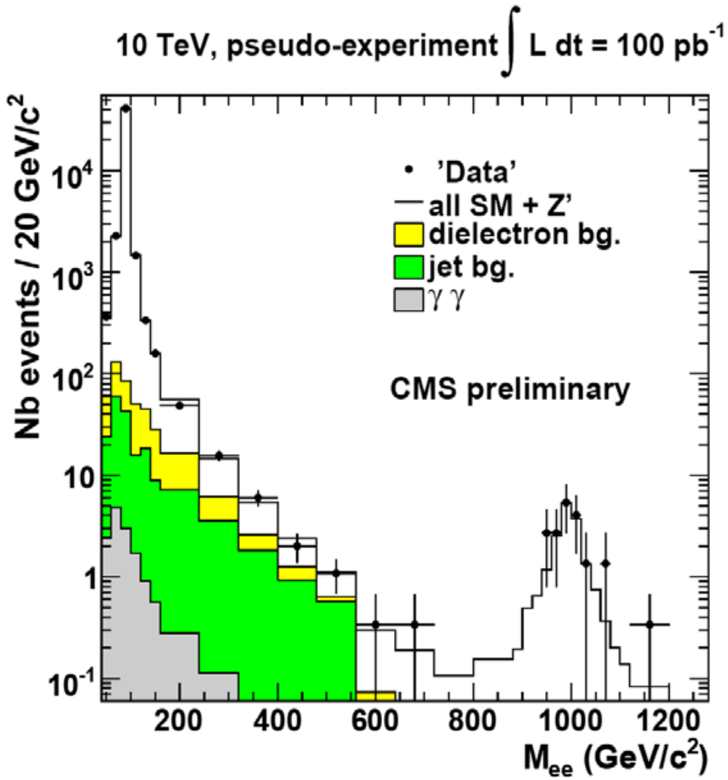


LHC $\quad q\bar{q} \to \gamma / Z \to e^+e^-$

+ Z' ???

(GUT, extradimensions)





Kinematics

quark with proton energy fraction x_1 antiquark with x_2

Let us compute

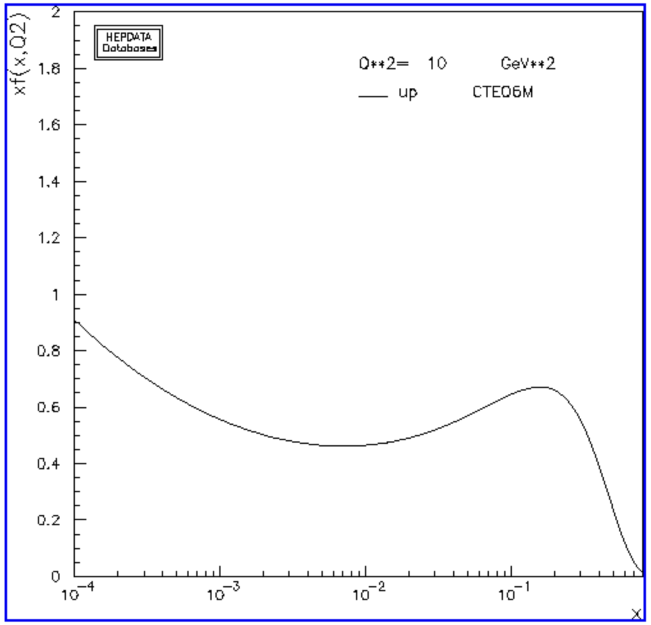
$M = \sqrt{(x_1 x_2)}\sqrt{s}$ ($\sqrt{s} = 2E_b$)

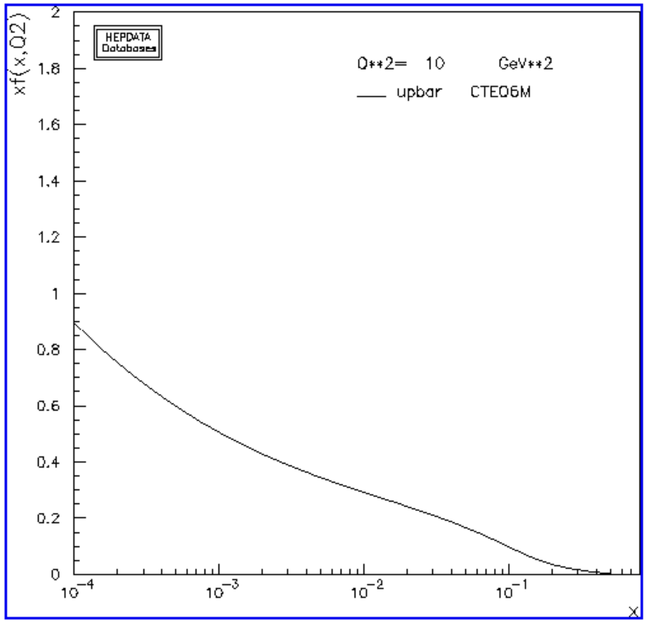
x_1 x_2 not fixed and no reason that $x_1 = x_2$

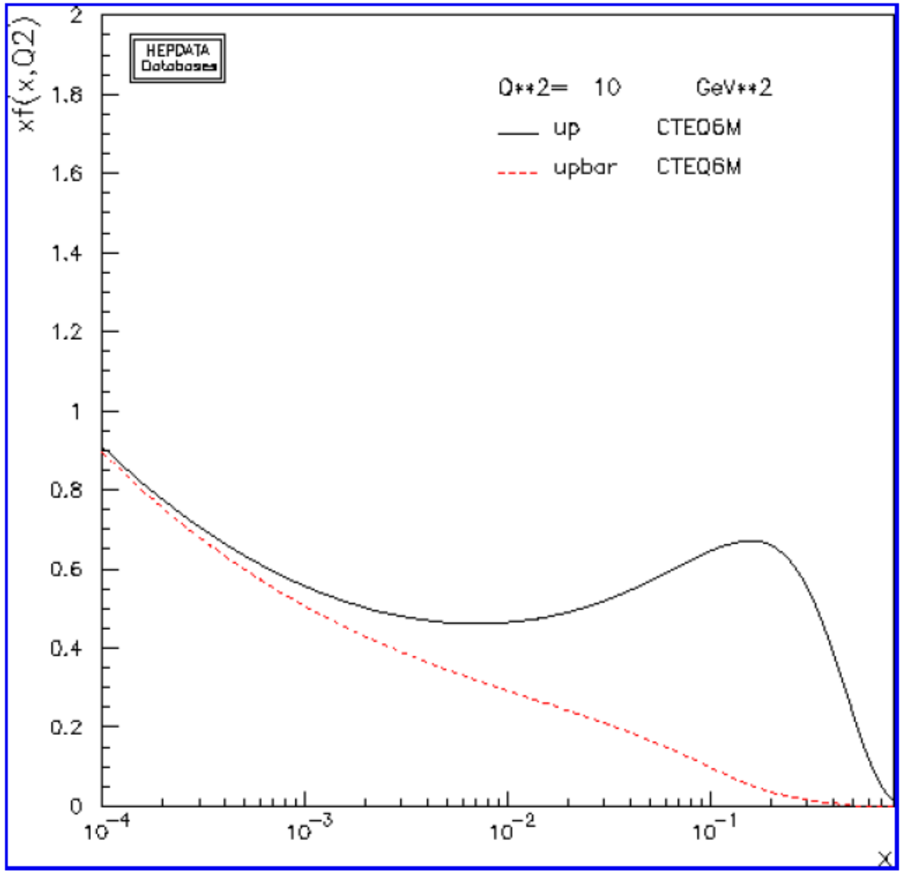
i.e. two interacting particles (quarks) have different energies ≠ e^+e^-

M = 100 GeV → *<x> = ?*

but mass distribution depends on quark distribution in proton – pdf's







Remember : $W^2 \simeq Q^2 / x$

=> **<u>smaller</u> *x* reachable at <u>larger</u> beam energy**