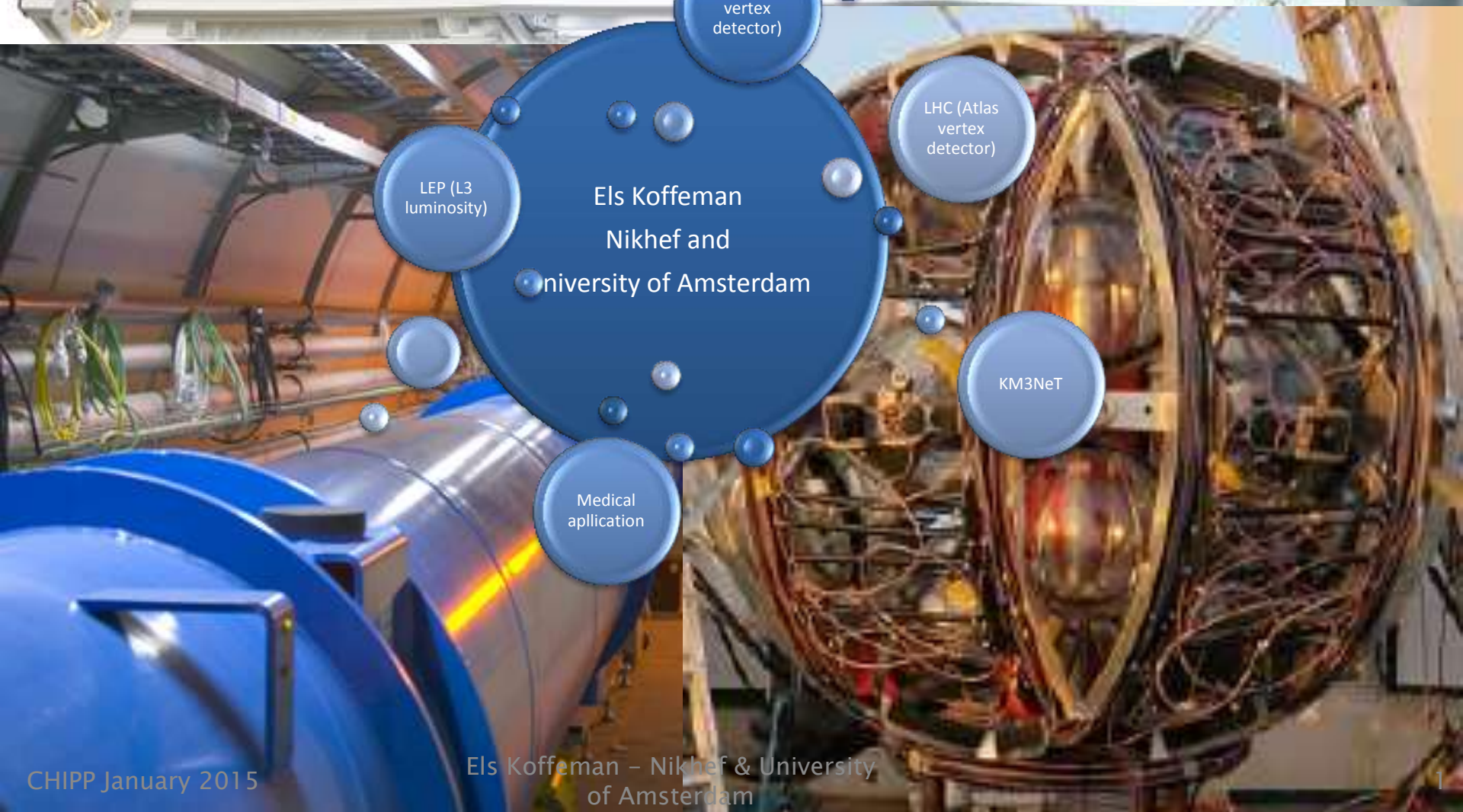HERA (ZEUS vertex detector)

LHC (Atlas vertex detector)

LEP (L3 luminosity)

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KM3NeT

Medical application

I: Observables
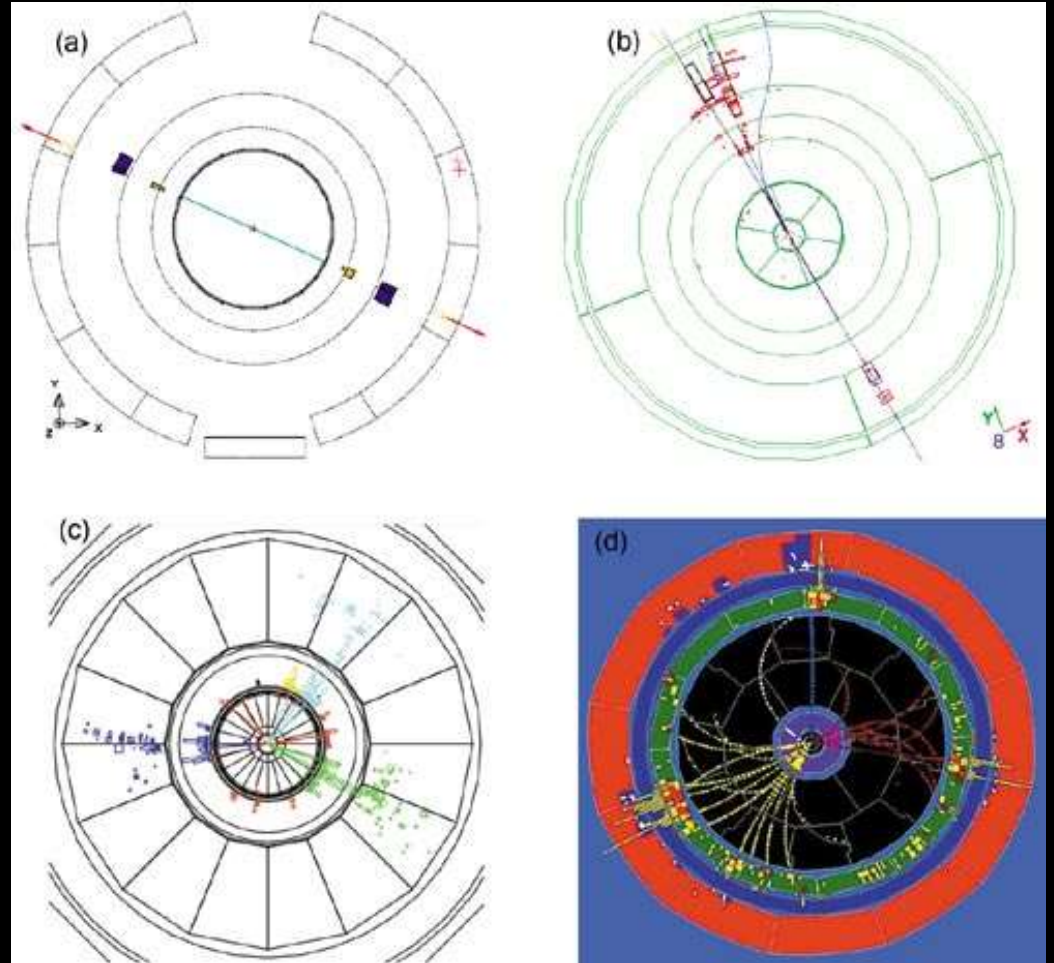# II: Particle Interactions
III: Position & Energy
IV: Medical applications

Els Koffeman
koffeman@nikhef.nl

Quiz & Prize

- Which event is Higgs candidate?
  - A en B
  - D
  - None
  - Need more info

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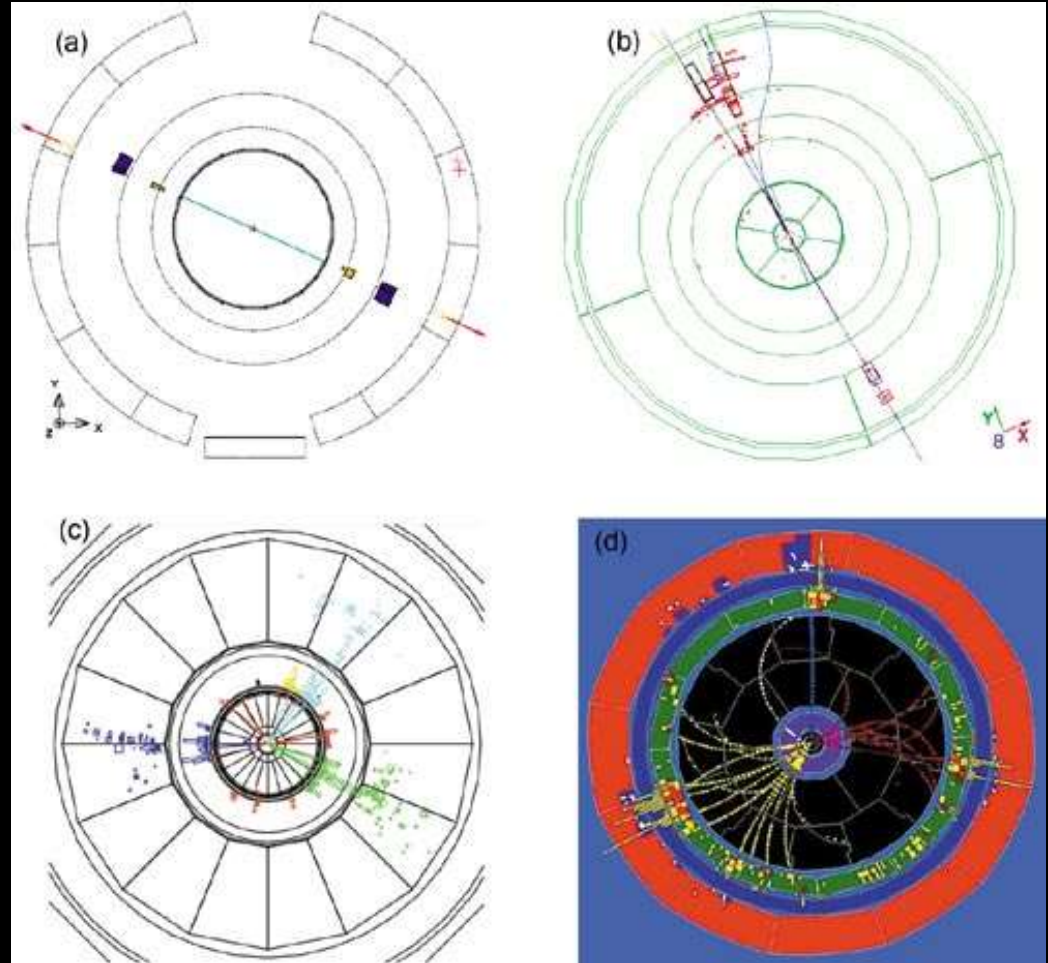
Quiz & Prize

- ## Which collider
  - HERA
  - LEP
  - LHC
  - Just a simulation

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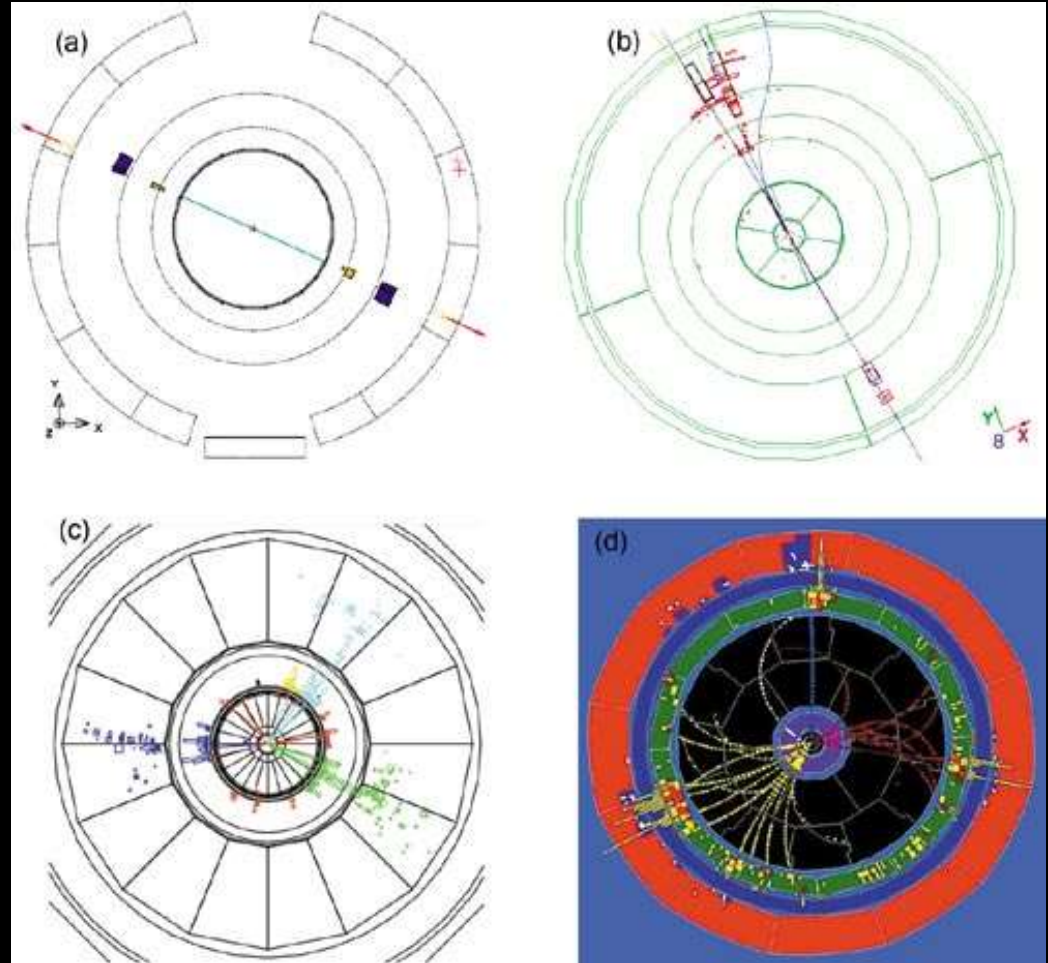
Quiz & Prize

- Which shows a Zboson decay into two tau particles ?
  - a
  - b
  - c
  - d

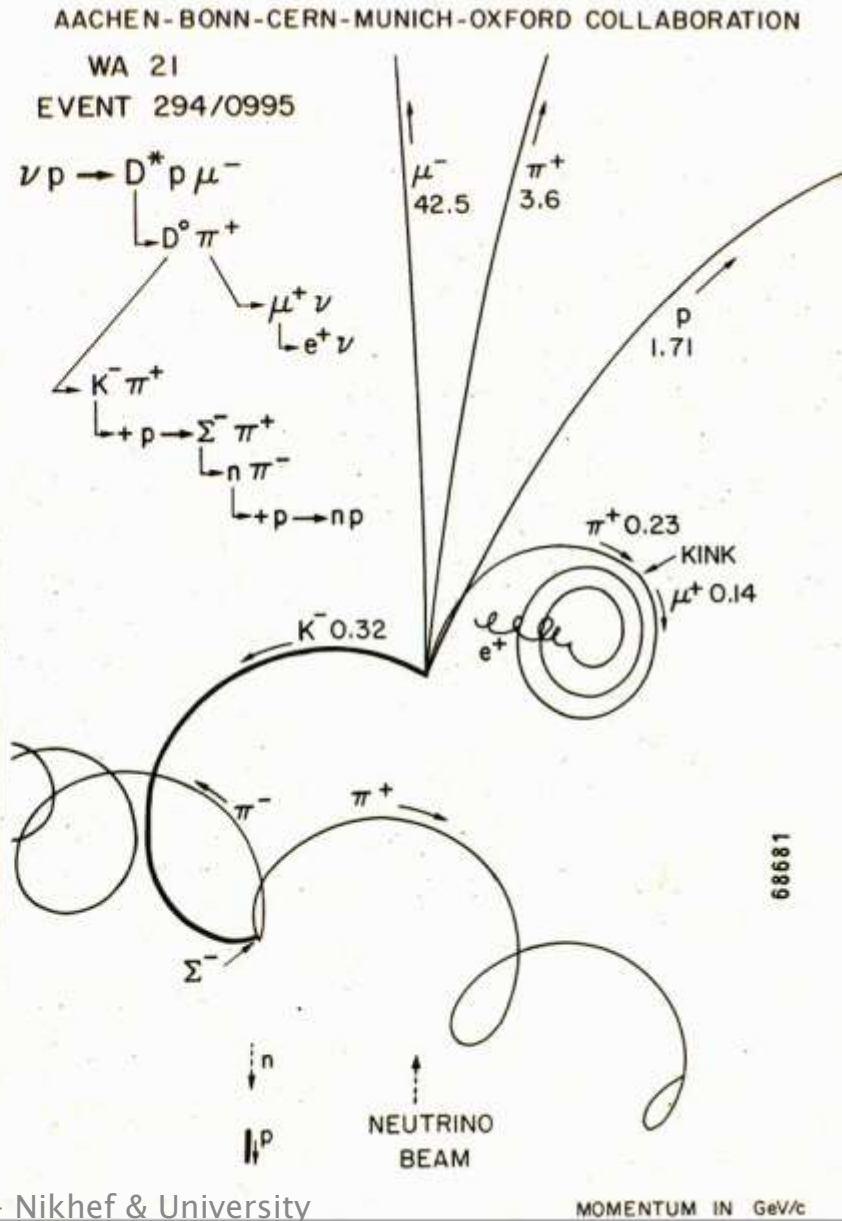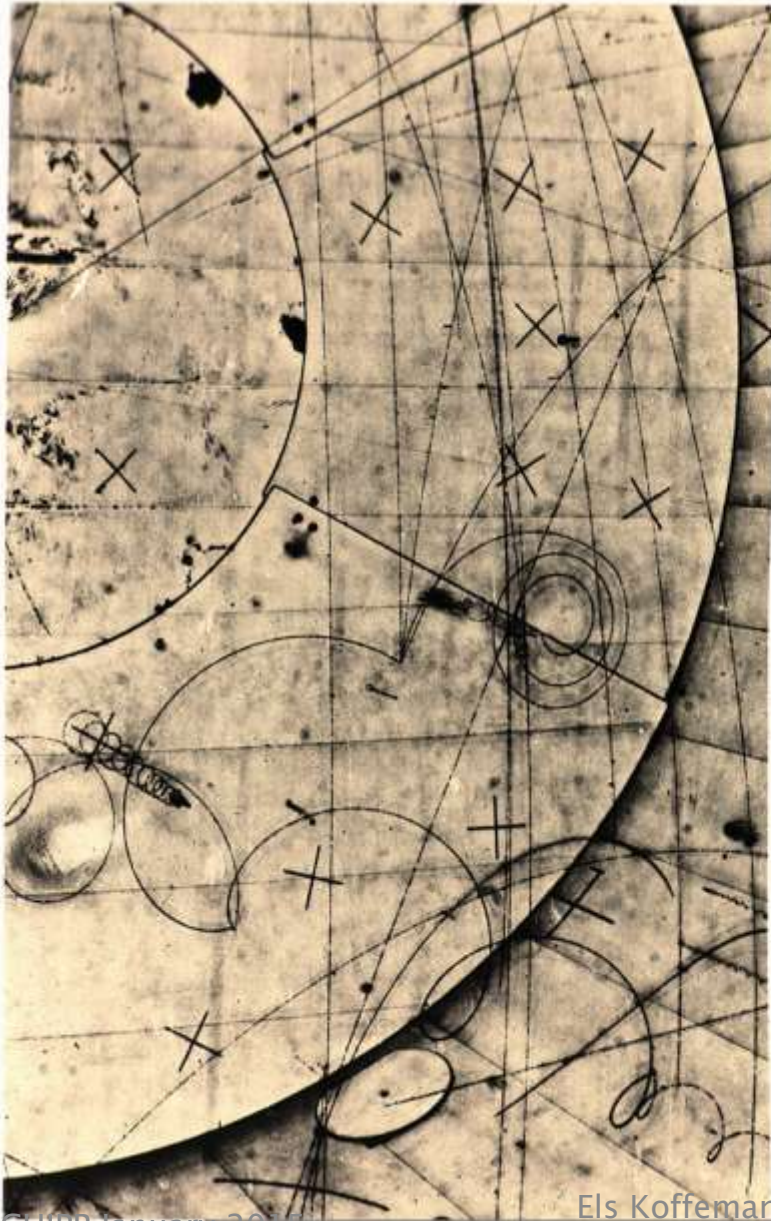Els Koffeman - Nikhef & University of Amsterdam

Quiz & Prize

- Tiebreaker
- What was the energy available at the LEP collider?
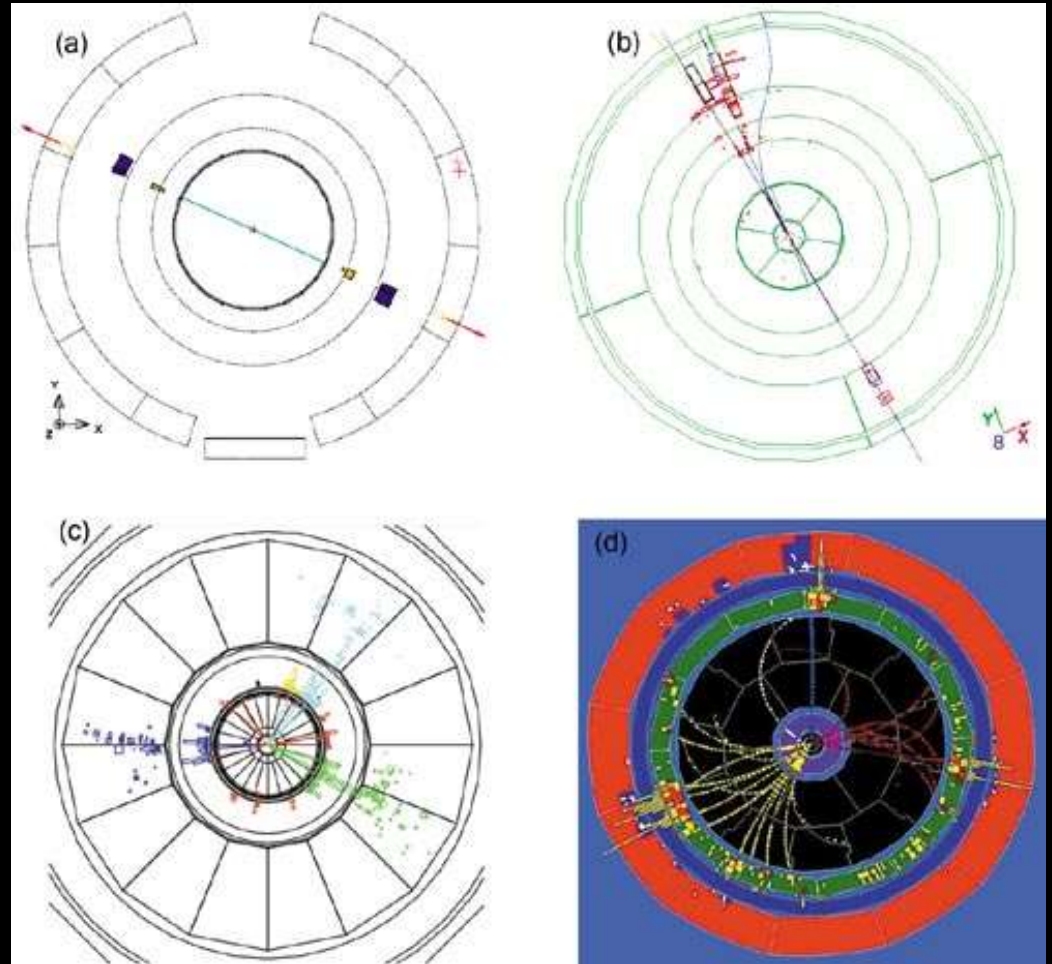
Literature & references

- Particle physics online database : www.pdg.lbl.gov
- Nuclear physics: International Atomic Energy Agency www.iaea.org
- Dan Green – The physics of particle detectors

D meson production in 1978
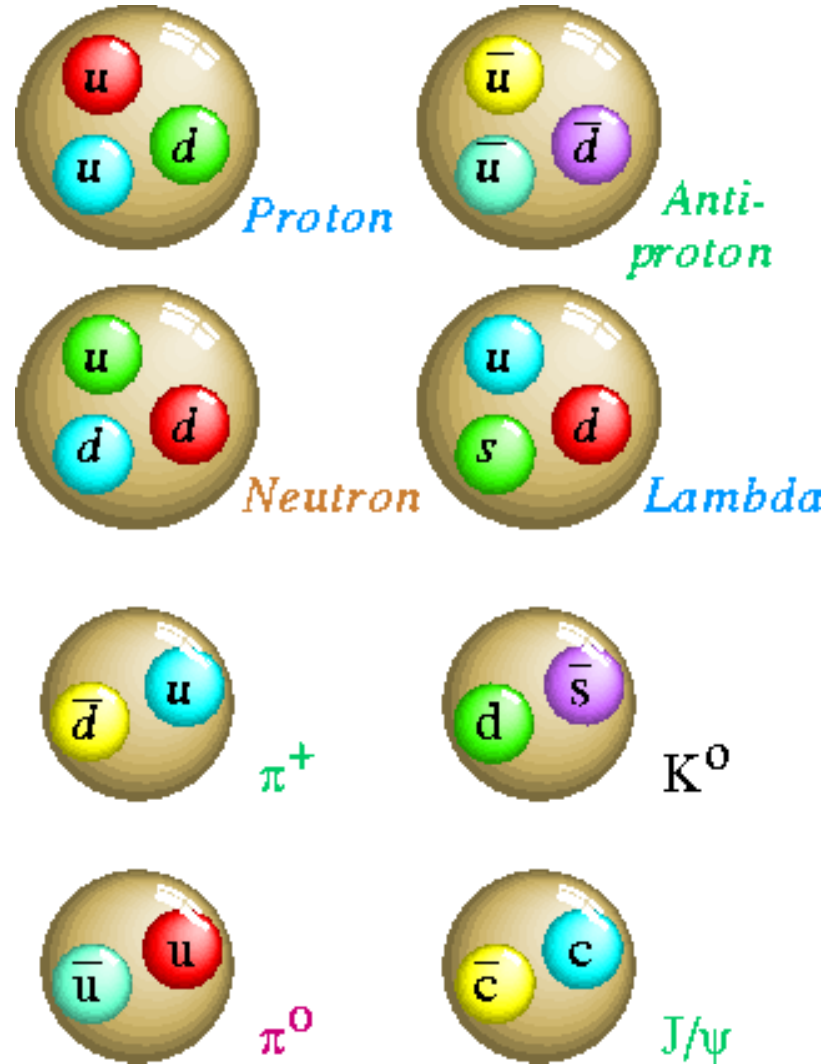

AACHEN-BONN-CERN-MUNICH-OXFORD COLLABORATION

WA 21
EVENT 294/0995

$\nu p \rightarrow D^* p \mu^-$
$\quad \quad \downarrow D^0 \pi^+$
$\quad \quad \quad \quad \downarrow \mu^+ \nu$
$\quad \quad \quad \quad \quad \downarrow e^+ \nu$
$\quad \quad \downarrow K^- \pi^+$
$\quad \quad \quad \downarrow + p \rightarrow \Sigma^- \pi^+$
$\quad \quad \quad \quad \downarrow n \pi^-$
$\quad \quad \quad \quad \downarrow + p \rightarrow n p$

μ^- 42.5

π^+ 3.6

p 1.71

π^+ 0.23
KINK
μ^+ 0.14

K^- 0.32

e^+

π^-

π^+

Σ^-

68681

n

p

NEUTRINO BEAM

MOMENTUM IN GeV/c

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8

Particle properties

- Charge
- Mass
- Flavour
- Colour
- Spin
- Coupling strength

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9

Kinematics

- Four momentum

$$p = (\frac{E}{c}, \vec{p})$$

- Relativistic particle

$$\vec{\beta} = \frac{\vec{v}}{c}$$

- Momentum

$$\vec{p} = \gamma m \vec{v}$$

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Accelerators and reactors

- Xray tube (1896)
- Cyclotron (1930)
- Synchrotron (1945)

Cyclotron

vacuum chamber, dees, magnetic field, ion source, electric field region, beam, target
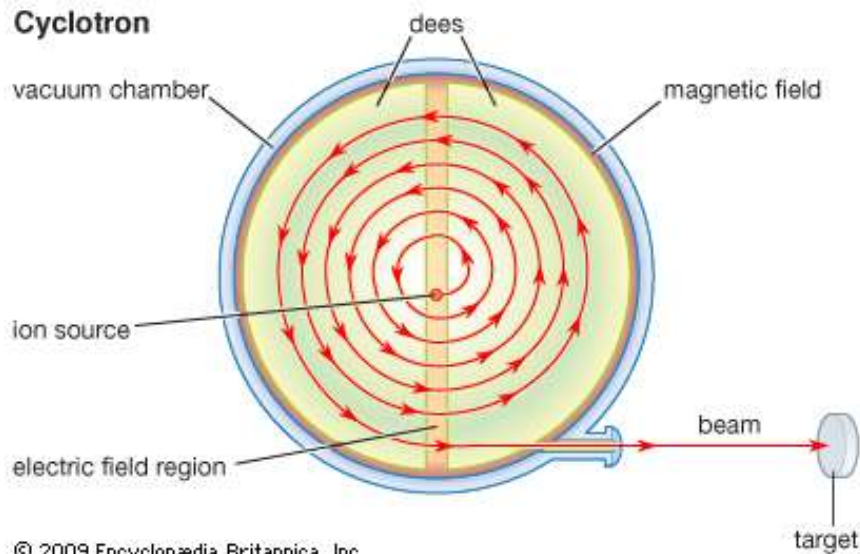
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Colliders

- Centre of mass energy collision

$$E_{\text{cm}} = \left[(E_1 + E_2)^2 - (p_1 + p_2)^2 \right]^{1/2} \, ,$$

$$= \left[m_1^2 + m_2^2 + 2E_1 E_2 (1 - \beta_1 \beta_2 \cos\theta) \right]^{1/2}$$

- Luminosity

$$\mathcal{L} = f \frac{n_1 n_2}{4\pi \sigma_x \sigma_y}$$

- Cross section

$$\sigma = \frac{N_{\text{events}}}{\text{Luminosity}}$$

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Invariant mass reconstruction

- Invariant mass of a set of particles

$$M^2 = \left(\sum E_i\right)^2 - \left(\sum p_i\right)^2 \cdot \left(\sum p_i\right)^2$$

- two particles 1 and 2

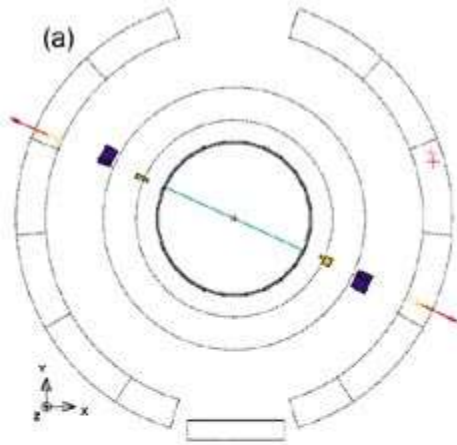$$M_{1,2} = \sqrt{(E_1 + E_2)^2 - p_1^2 - p_2^2 - 2 p_1 \cdot p_2 \cos\theta}$$

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Overview

	CESR (Cornell)	CESR-C (Cornell)	KEKB (KEK)	PEP-II (SLAC)	LEP (CERN)	ILC (TBD)
Physics start date	1979	2002	1999	1999	1989	TBD
Physics end date	2002	2008	—	2008	2000	—
Maximum beam energy (GeV)	6	6	$e^- \times e^+ :\ 8 \times 3.5$	e^-: 7–12 (9.0 nominal) e^+: 2.5–4 (3.1 nominal) (nominal E_{cm} = 10.5 GeV)	100 - 104.6	250 (upgradeable to 500)

	HERA (DESY)	TEVATRON* (Fermilab)	RHIC (Brookhaven)				LHC (CERN)	
Physics start date	1992	1987	2001	2000	2004	2002	2008	2009
Physics end date	2007	—	—				—	
Particles collided	ep	$p\bar{p}$	pp (pol.)	Au Au	Cu Cu	d Au	pp	Pb Pb
Maximum beam energy (TeV)	e: 0.030 p: 0.92	0.980	0.1 60% pol	0.1 TeV/n	0.1 TeV/n	0.1 TeV/n	7.0	2.76 TeV/n
Luminosity (10^{30} cm^{-2}s^{-1})	75	286	35 (pk) 20 (ave)	0.0030 (pk) 0.0012 (ave)	0.020 (pk) 0.0008 (ave)	0.23 (pk) 0.11 (ave)	1.0×10^4	1.0×10^{-3} $(5.4 \times 10^{-5})^\dagger$

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LEP: ee-colllider

- LEP

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LEP: ee-colllider

- Opal
- Delphi
- L3
- Aleph

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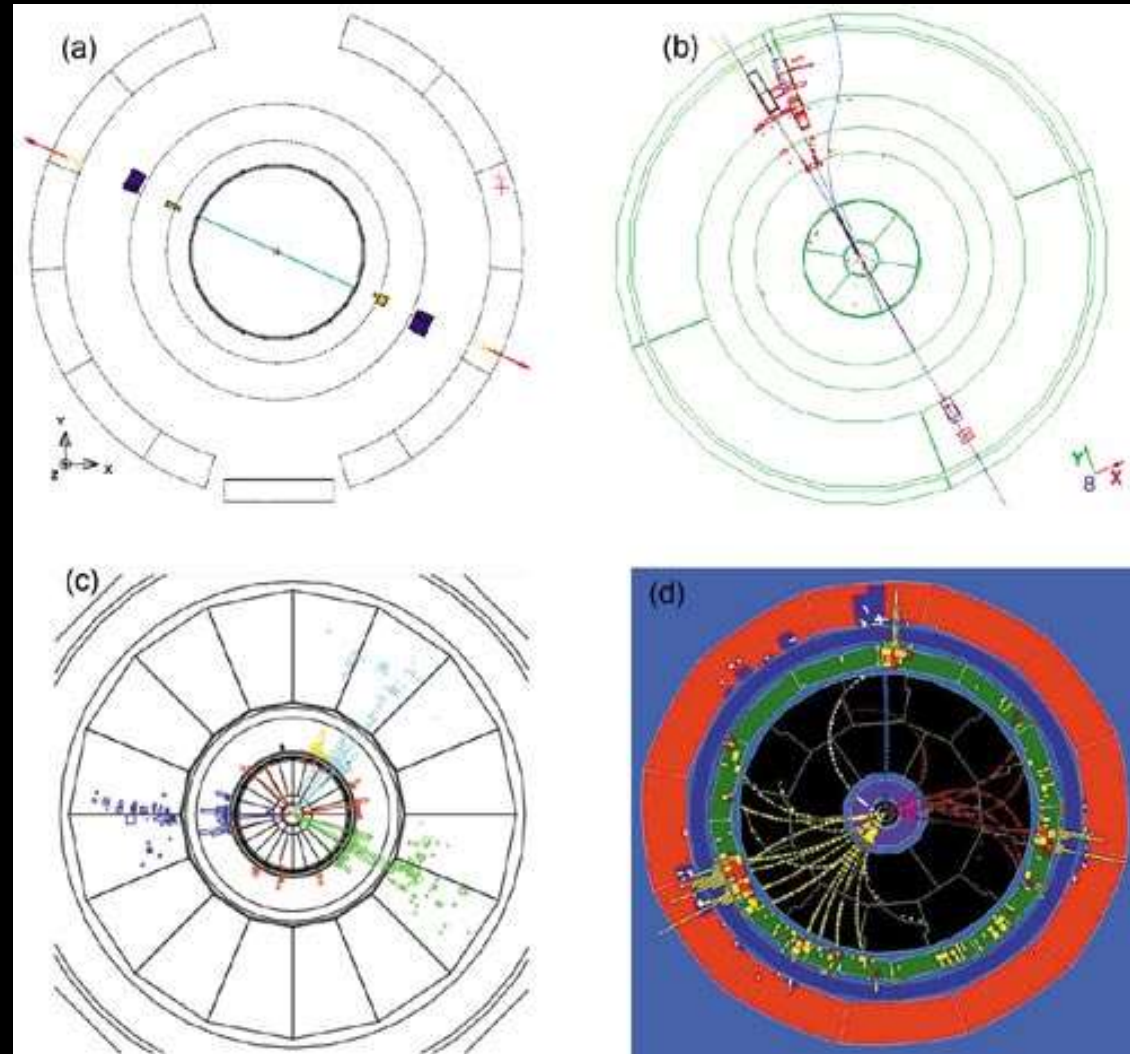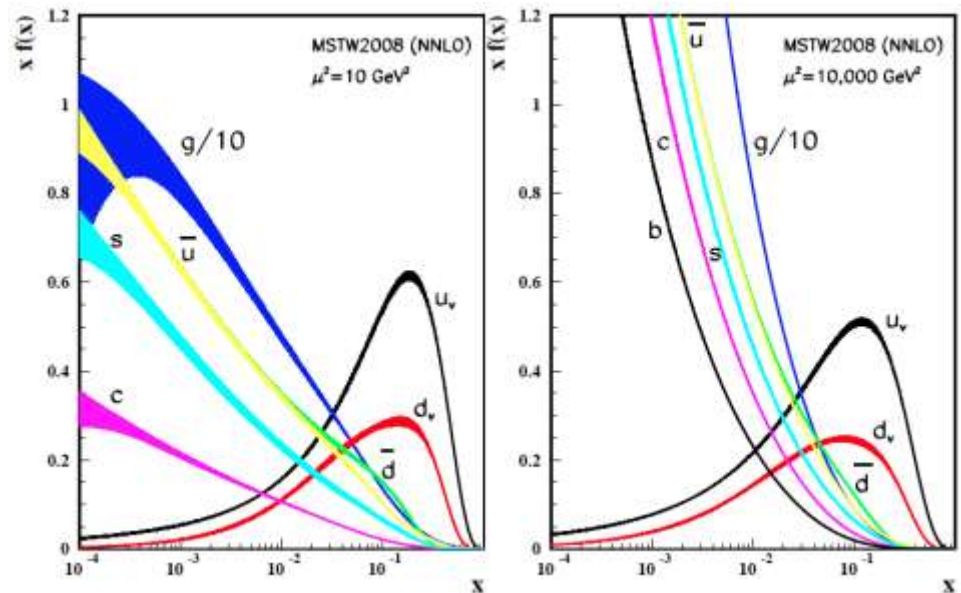
Tevatron: pp̄

- Energy 1.96 TeV
- Discovery of the top quark
- D0 and CDF

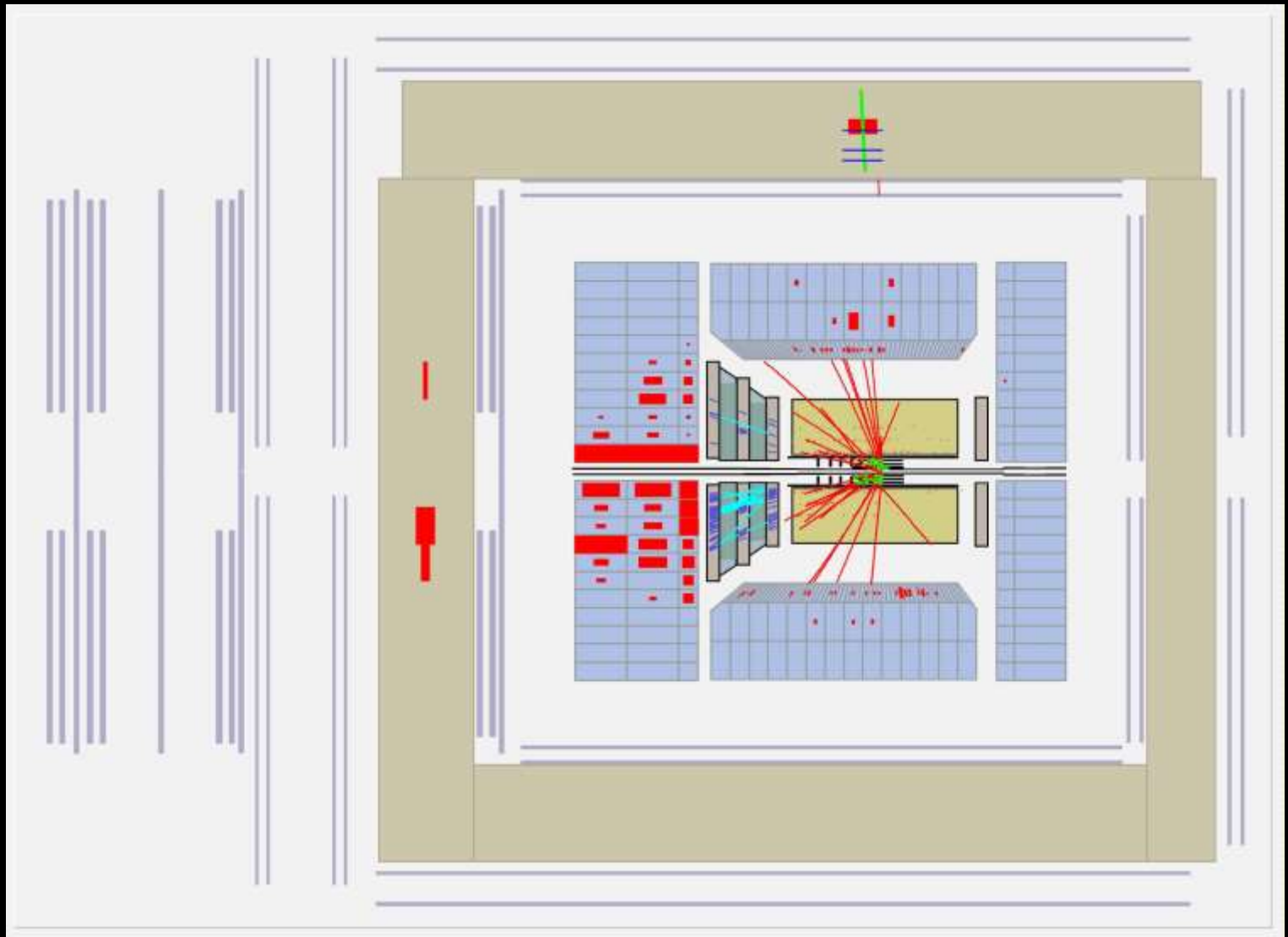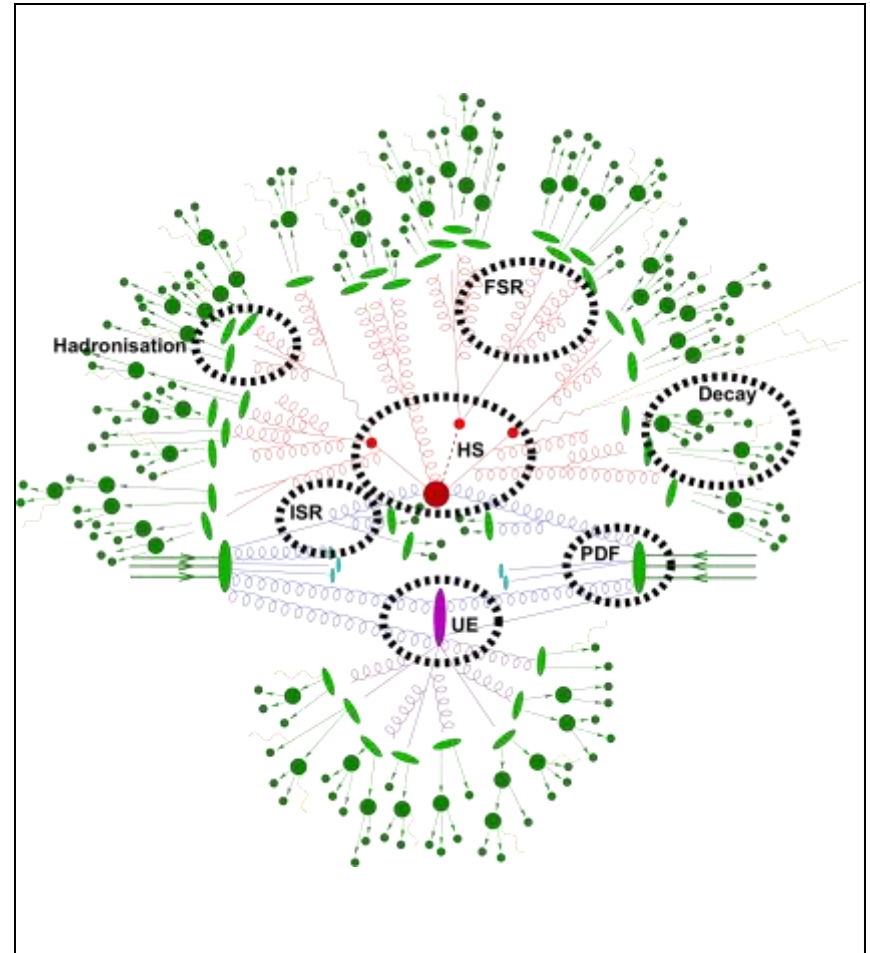Els Koffeman - Nikhef & University of Amsterdam
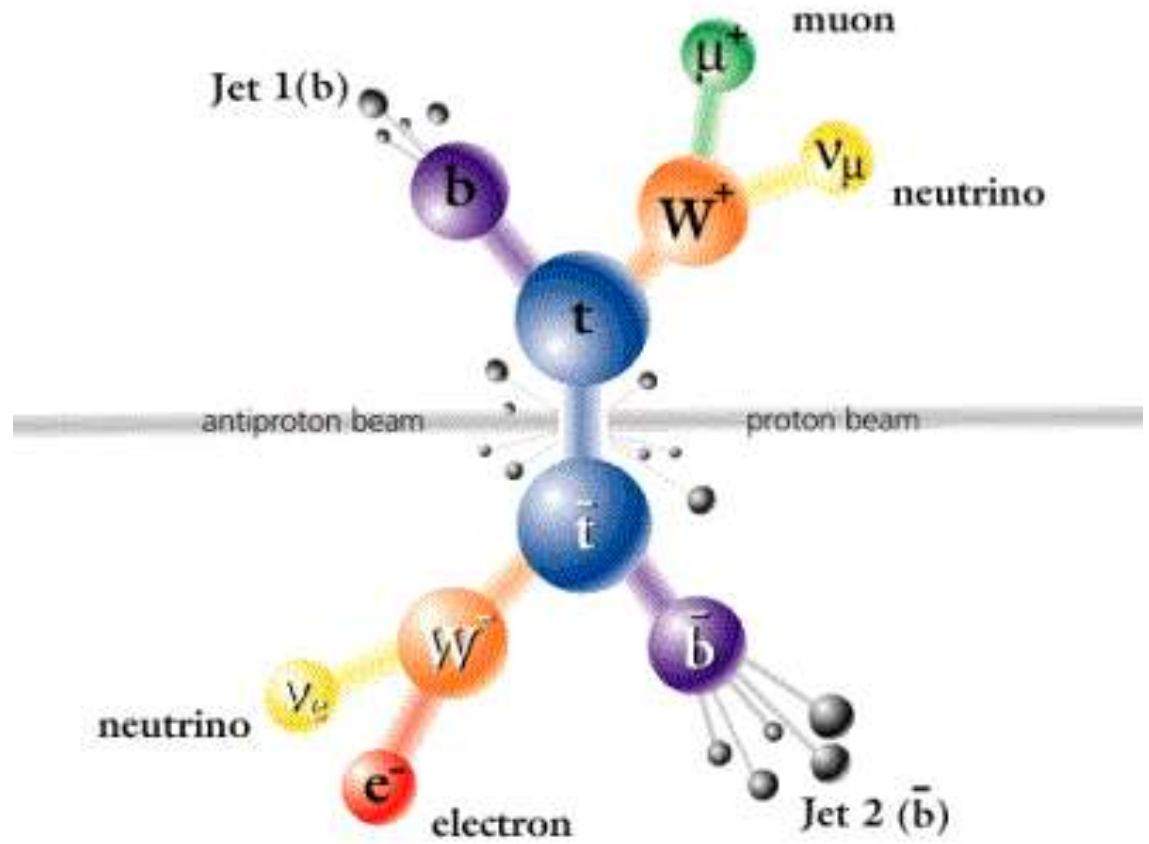
HERA : ep collider

- Deep inelastic scattering of electrons on protons probing proton structure

- Precise measurements of the parton distribution functions

- ZEUS and H1

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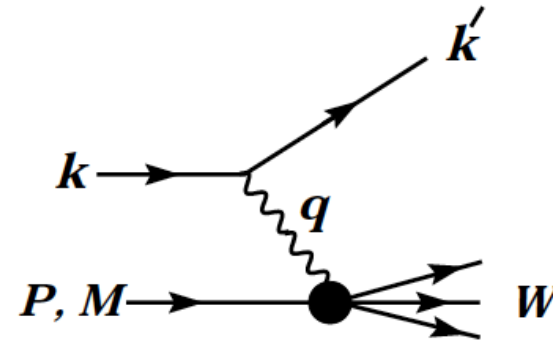
pp collider : LHC

- Goal 14 TeV collision
- x1 and x2 determine hard scatter

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Final state - hadronisation

- Production of a quark-pair

- Gluon radiation

- Fragmentation

- DETECTOR:

- Jets originating from the interaction point

- Some particles in the jet are unstable
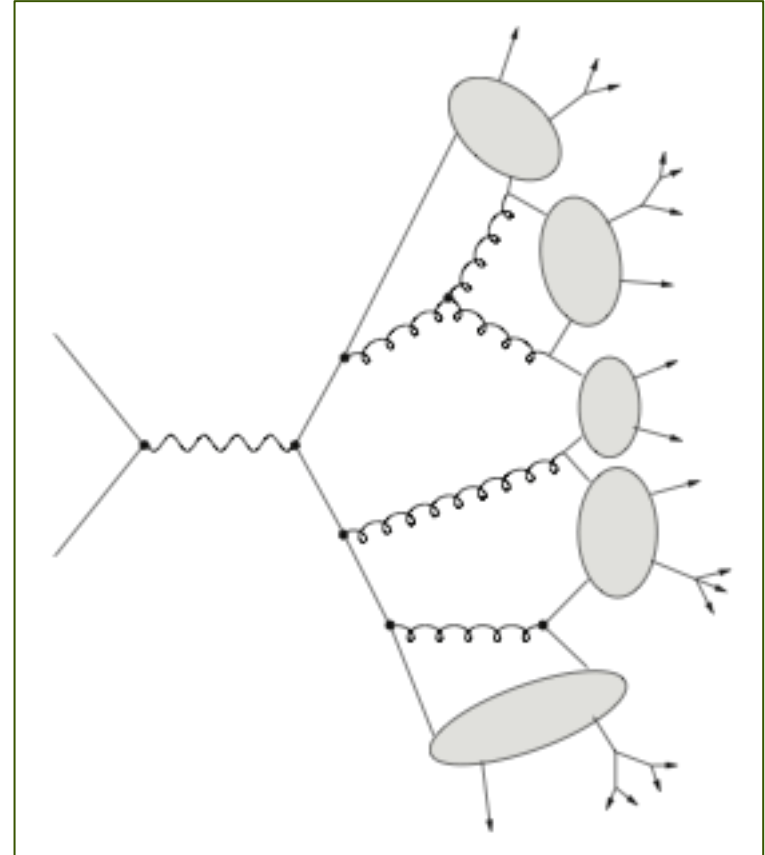
Els Koffeman - Nikhef & University of Amsterdam

Proton beams

1200 superconducting magnets with opposite B-fields. Occupy most of the space in the LHC tunnel

Els Koffeman – Nikhef & University of Amsterdam
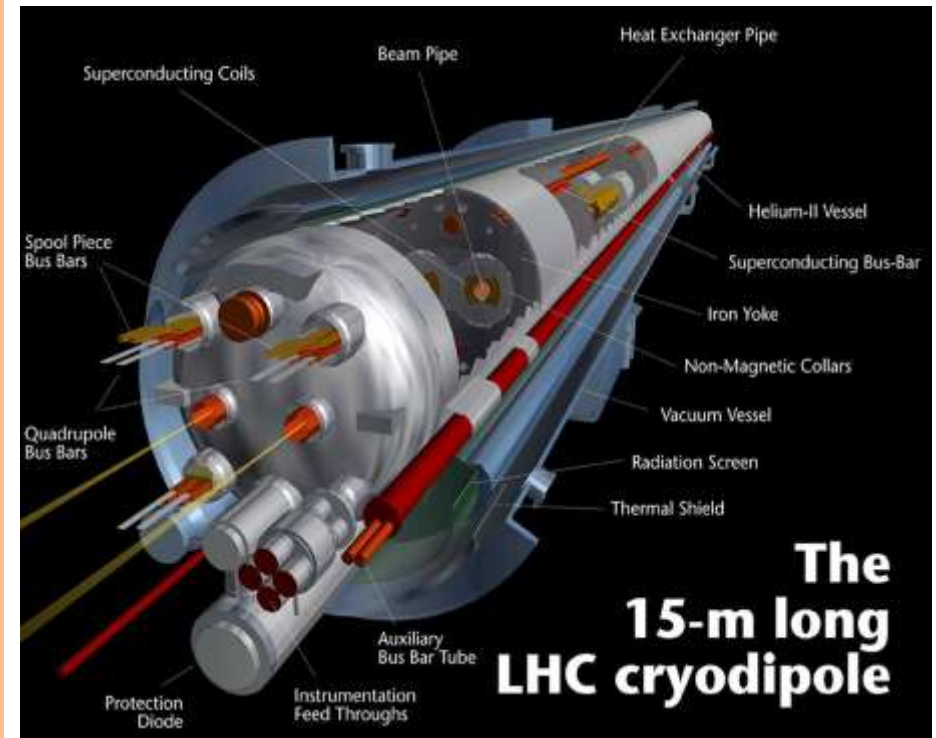
Proton beams

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Els Koffeman – Nikhef & University of Amsterdam
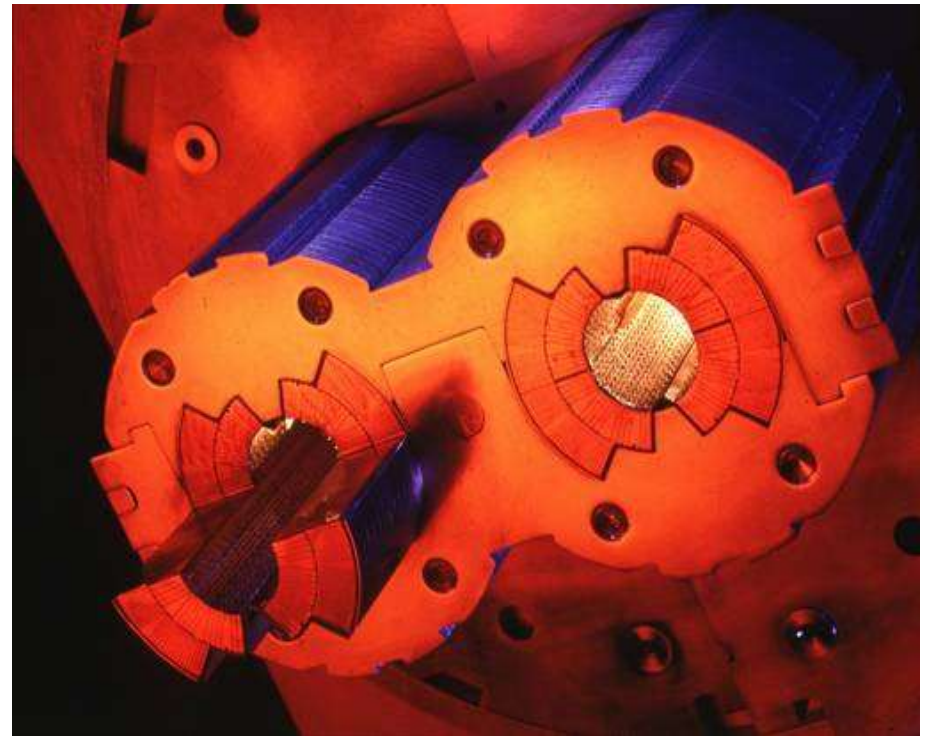
Observables particles

- Prompt stable particles : from the interaction point
  - photon, electron
  - muon
  - hadron (pion, proton, neutron,...)
  - (neutrino)
- Daughter particles from unstable prompt particles
  - Examples:
    - pions (from K_{short})
    - photons (pion decay)
- Collections of particles
  - Jet from hadronisation of a singleparton

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Less common observables

- ## Chemical reactions
  - photographic emulsion reducing silver grains

- ## Transition radiation
  - Medium emits x-rays when permittivity changes

- ## Acoustic wave
  - Cosmic air shower can create sonic boom

- ## Physical transitions
  - Boiling, melting, condensation, heat
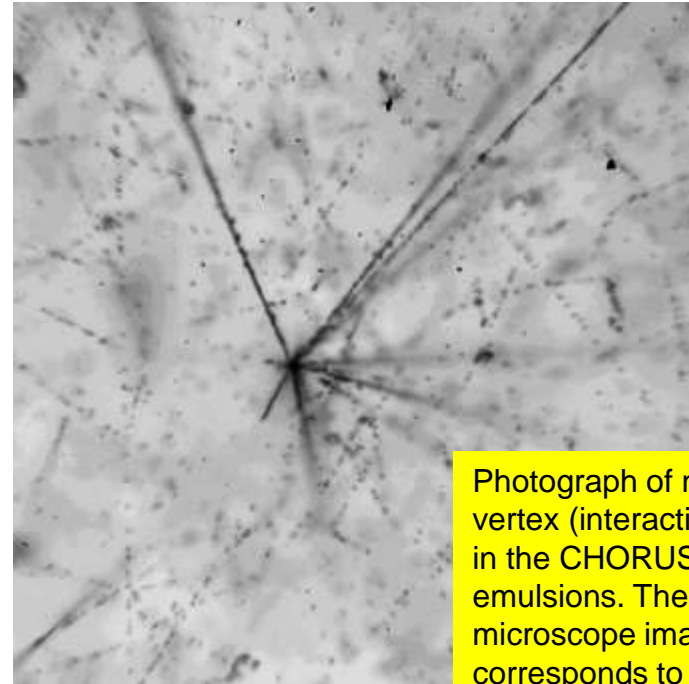
Photograph of neutrino vertex (interaction point) in the CHORUS emulsions. The image microscope image size corresponds to about 0.1mm x 0.1 mm
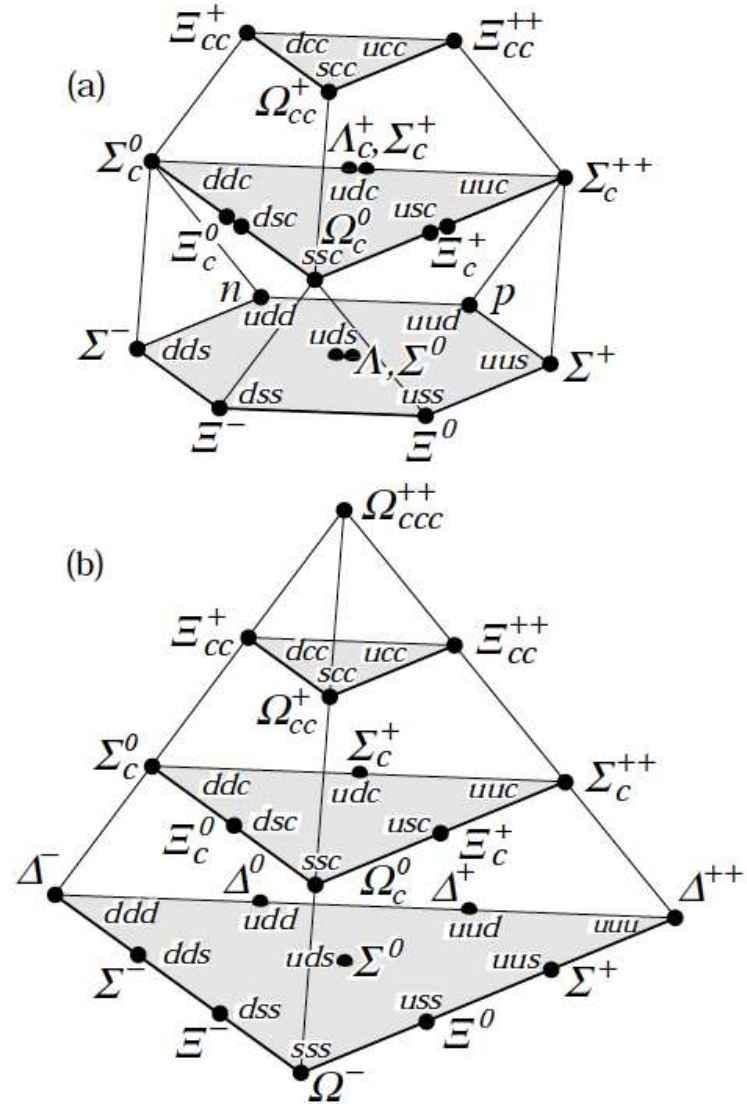
Mesons

- Combination of a quark + antiquark (colorless)

- Each meson has unique properties
  - Charge
  - Spin
  - Isospin

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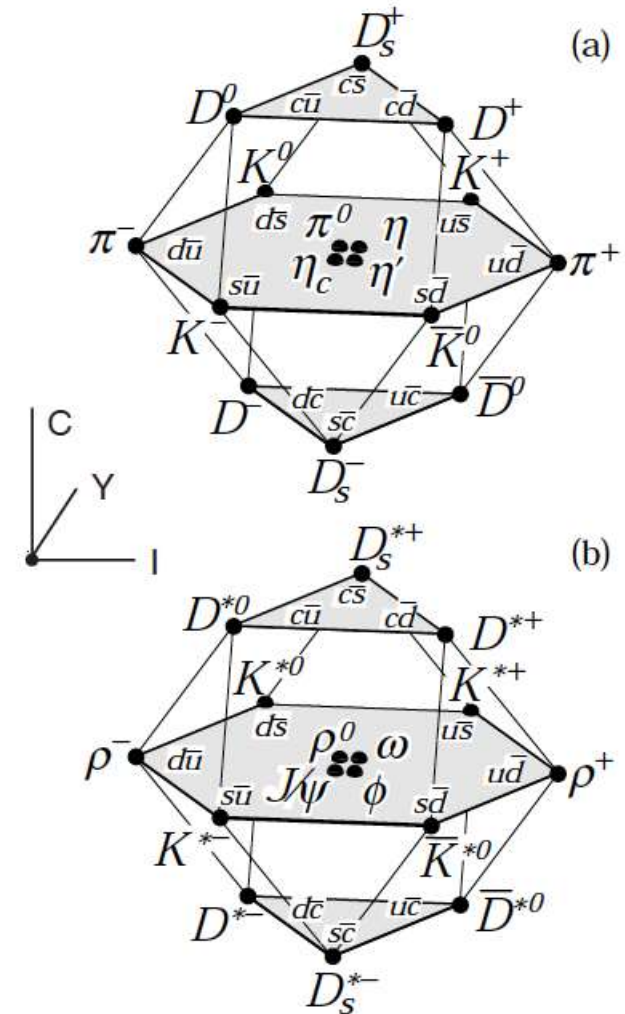
Baryons

- ## Three quark states
  - Colorless
  - Scalar en vectors

- ## Generally heavier than a proton

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Unstable particles

- Reconstruct invariant mass from decay products

$$M^2 = (\sum_i E_i)^2 - \left\| \sum_i p_i \right\|^2$$

Example PDG

$J/\psi(1S)$ $I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3096.916 \pm 0.011$ MeV
Full width $\Gamma = 93.2 \pm 2.1$ keV
$\Gamma_{ee} = 5.55 \pm 0.14 \pm 0.02$ keV

$J/\psi(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons	(87.7 ± 0.5) %		−
virtual $\gamma \rightarrow$ hadrons	(13.50 ± 0.30) %		−
$e^+ e^-$	(5.94 ± 0.06) %		1548
$\mu^+ \mu^-$	(5.93 ± 0.06) %		1545

Example

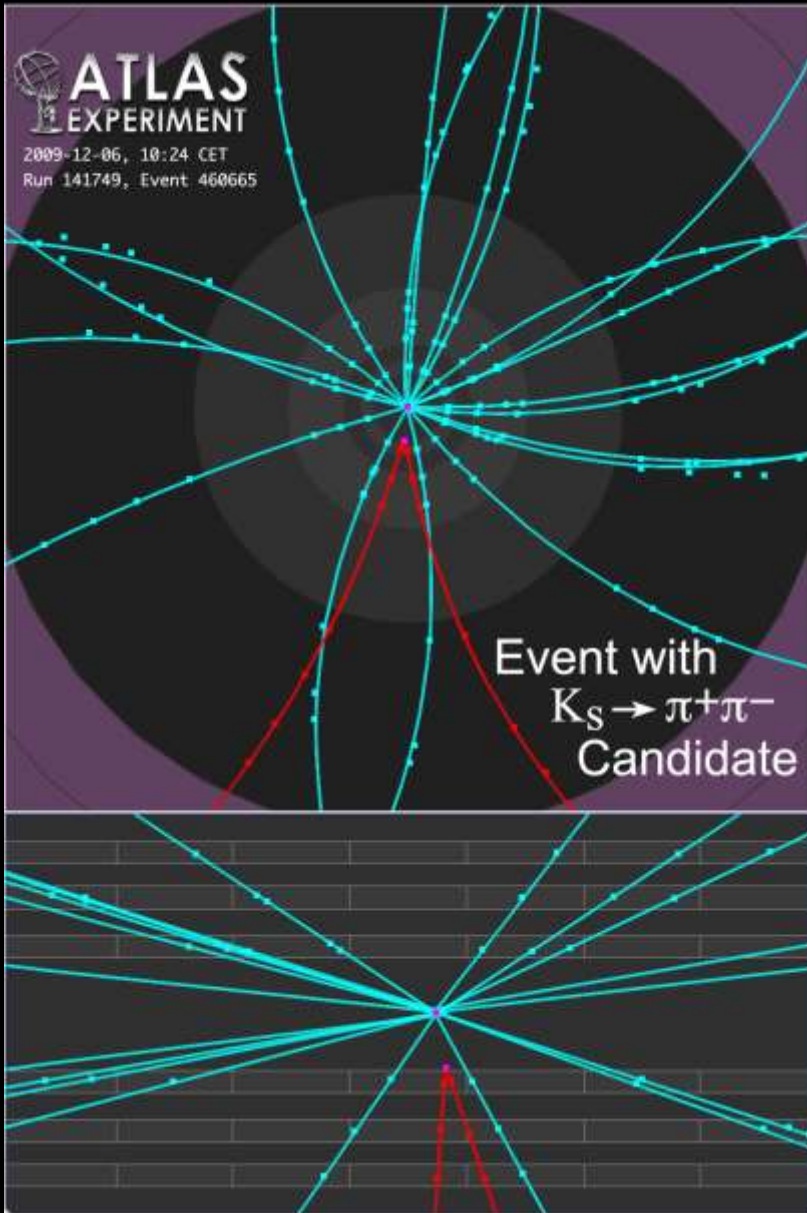K^0_S $I(J^P) = \frac{1}{2}(0^-)$

Mean life $\tau = (0.8953 \pm 0.0005) \times 10^{-10}$ s $(S = 1.1)$ Assuming CPT

Mean life $\tau = (0.8958 \pm 0.0005) \times 10^{-10}$ s   Not assuming CPT
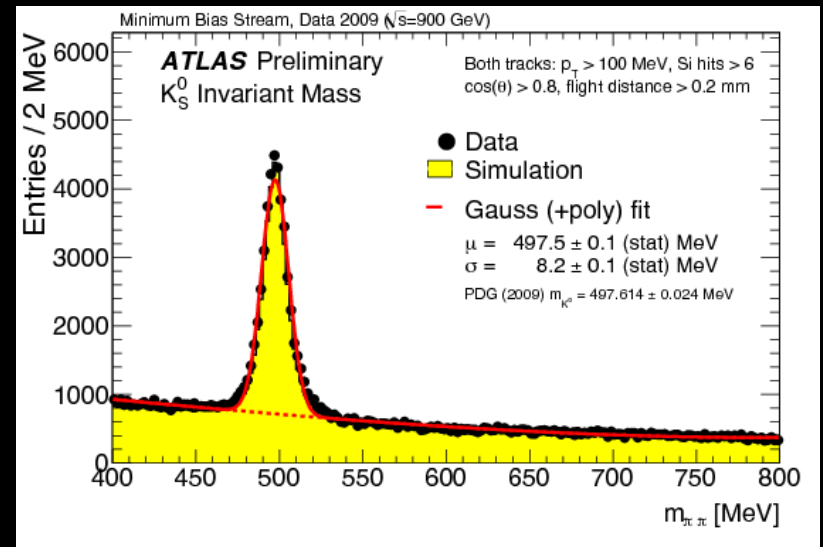
$c\tau = 2.6842$ cm   Assuming CPT

- ## Measure
  - Lifetime τ or distance = γcτ but it is an exponential decay $N(t) = N(0)\exp(-t/\tau)$

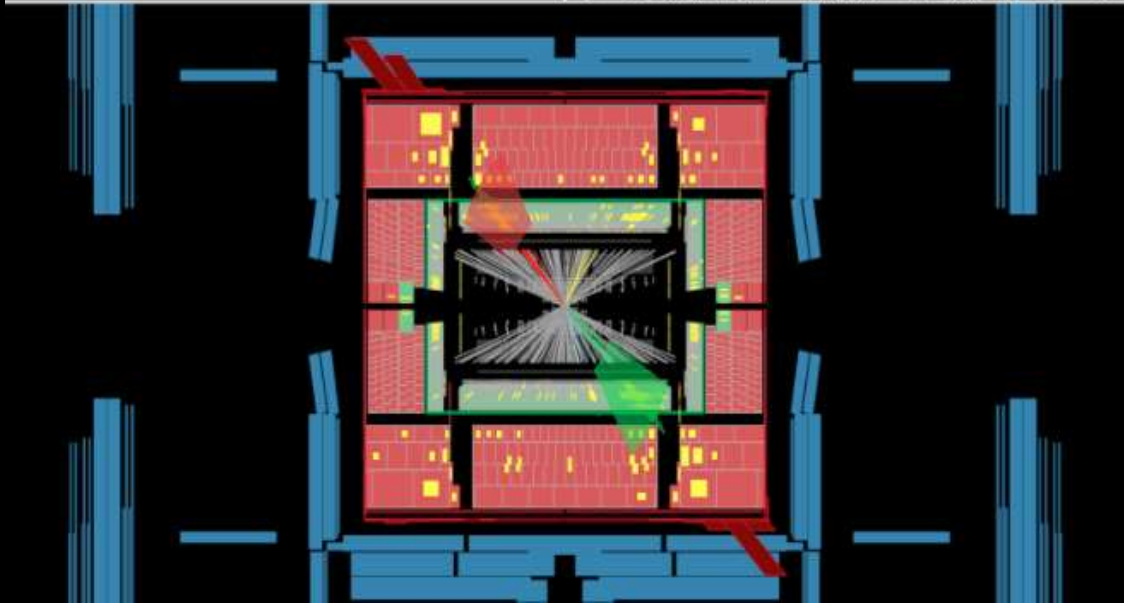| K^0_S DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes			
$\pi^0 \pi^0$	(30.69 ± 0.05) %		209
$\pi^+ \pi^-$	(69.20 ± 0.05) %		206
$\pi^+ \pi^- \pi^0$	$(3.5 {}^{+1.1}_{-0.9}) \times 10^{-7}$		133

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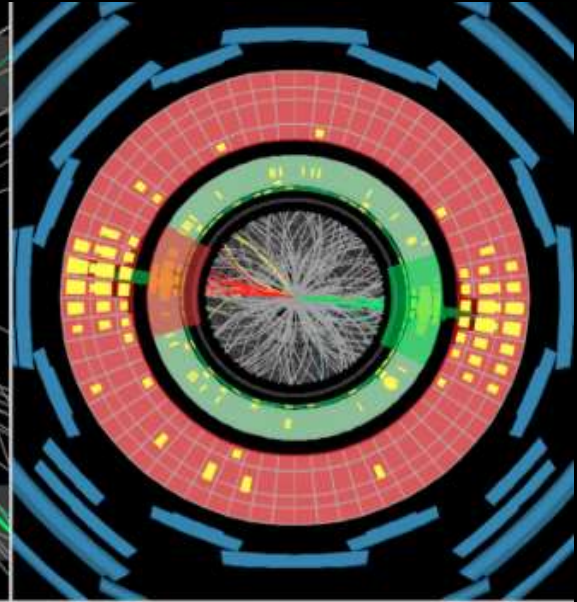
Run Number: 201269, Event Number: 80898559

Date: 2012-04-14 22:30:13 CEST

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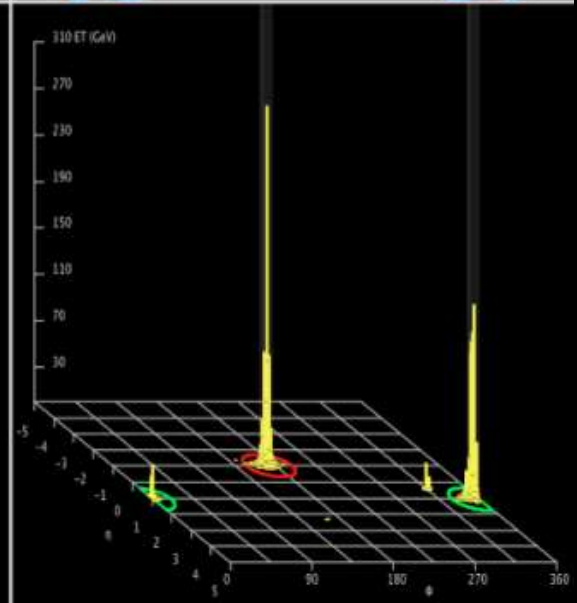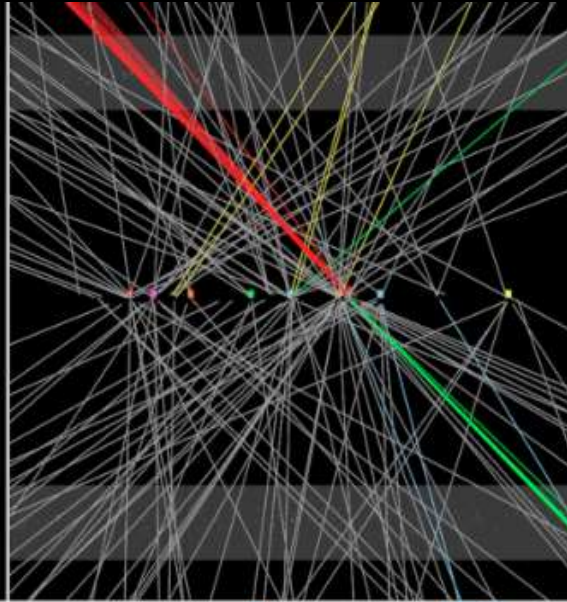
Luminosity

Luminosity driven by final focu magnets (quadrupoles) before the interaction point

Relative beam sizes around IP1 (Atlas) in collision

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Higgs -> 4 quark-jets

jet

jet

proton

proton

jet
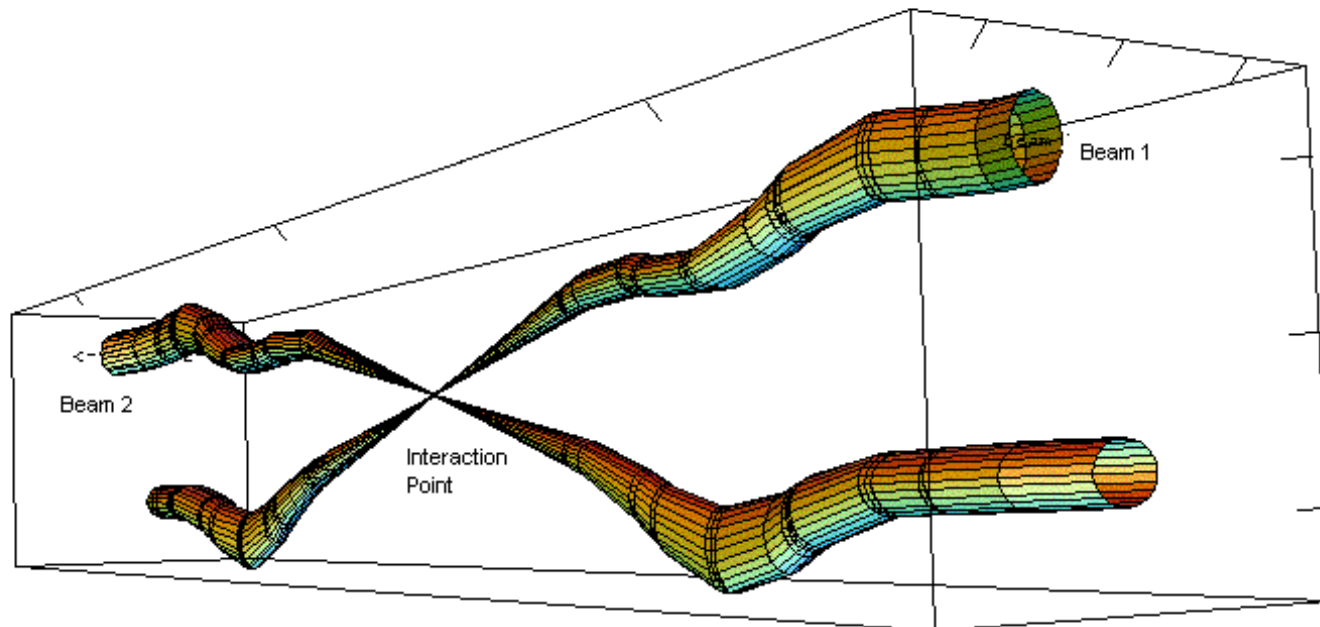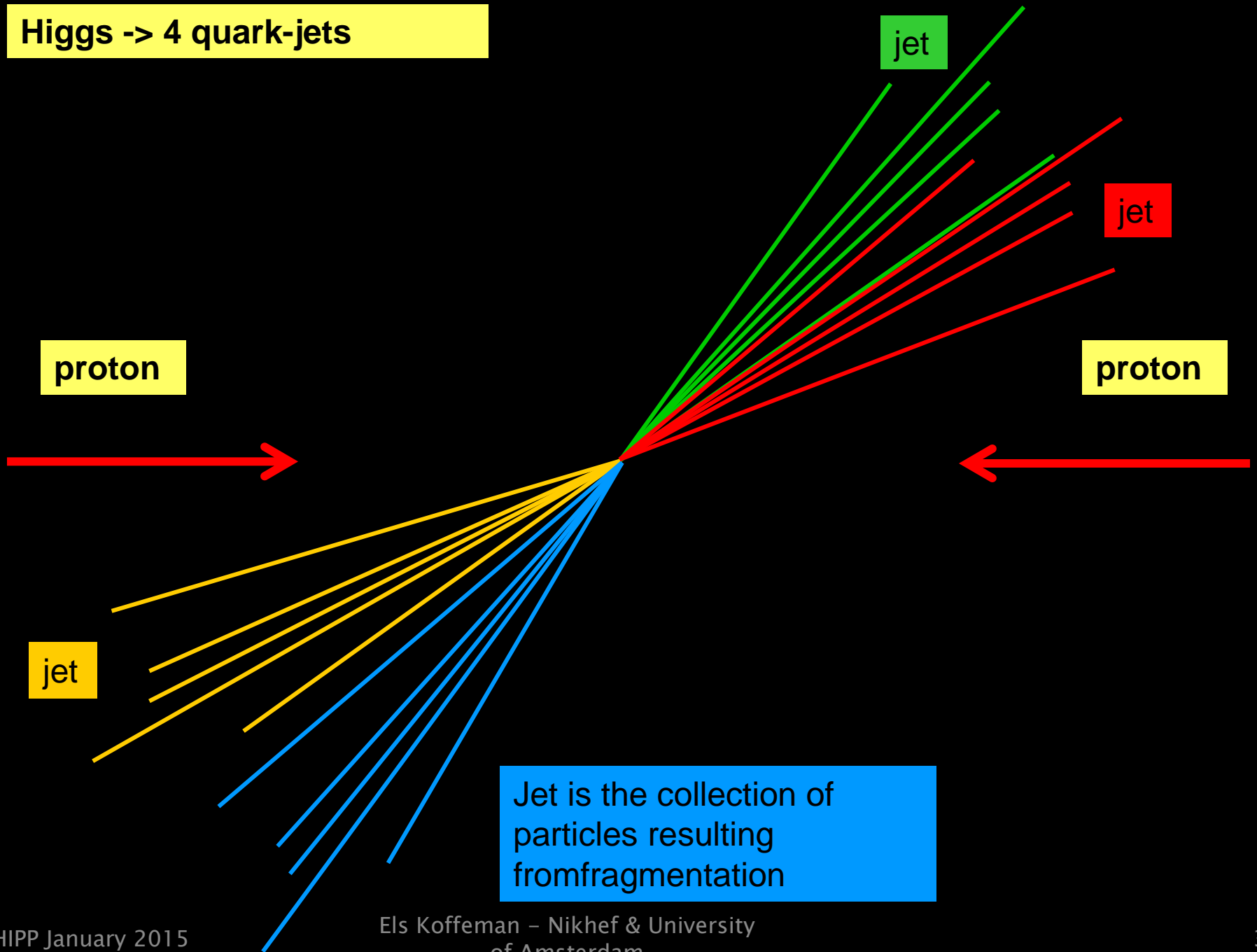
Jet is the collection of particles resulting fromfragmentation

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10 cm

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10 cm

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Connect the dots…..

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