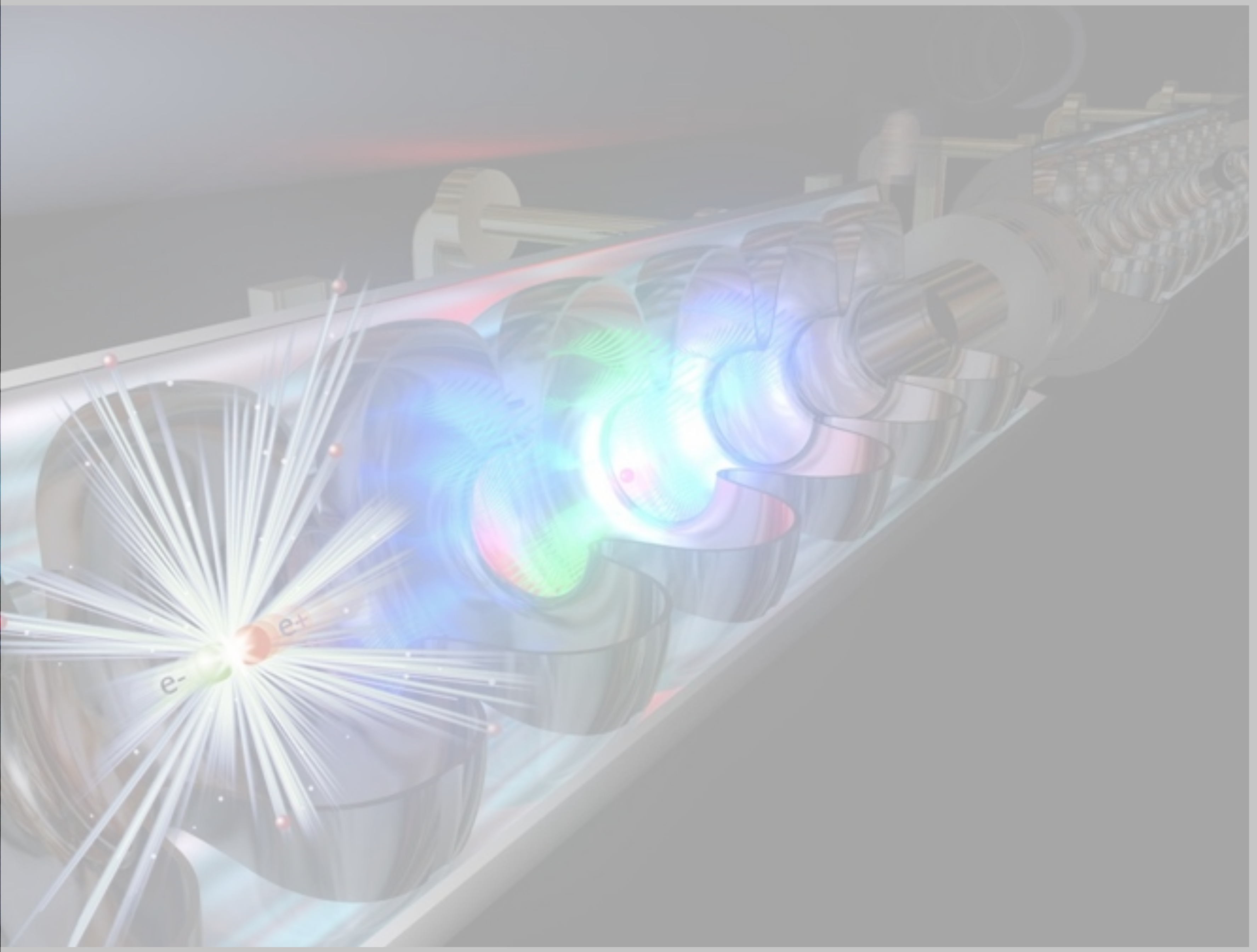
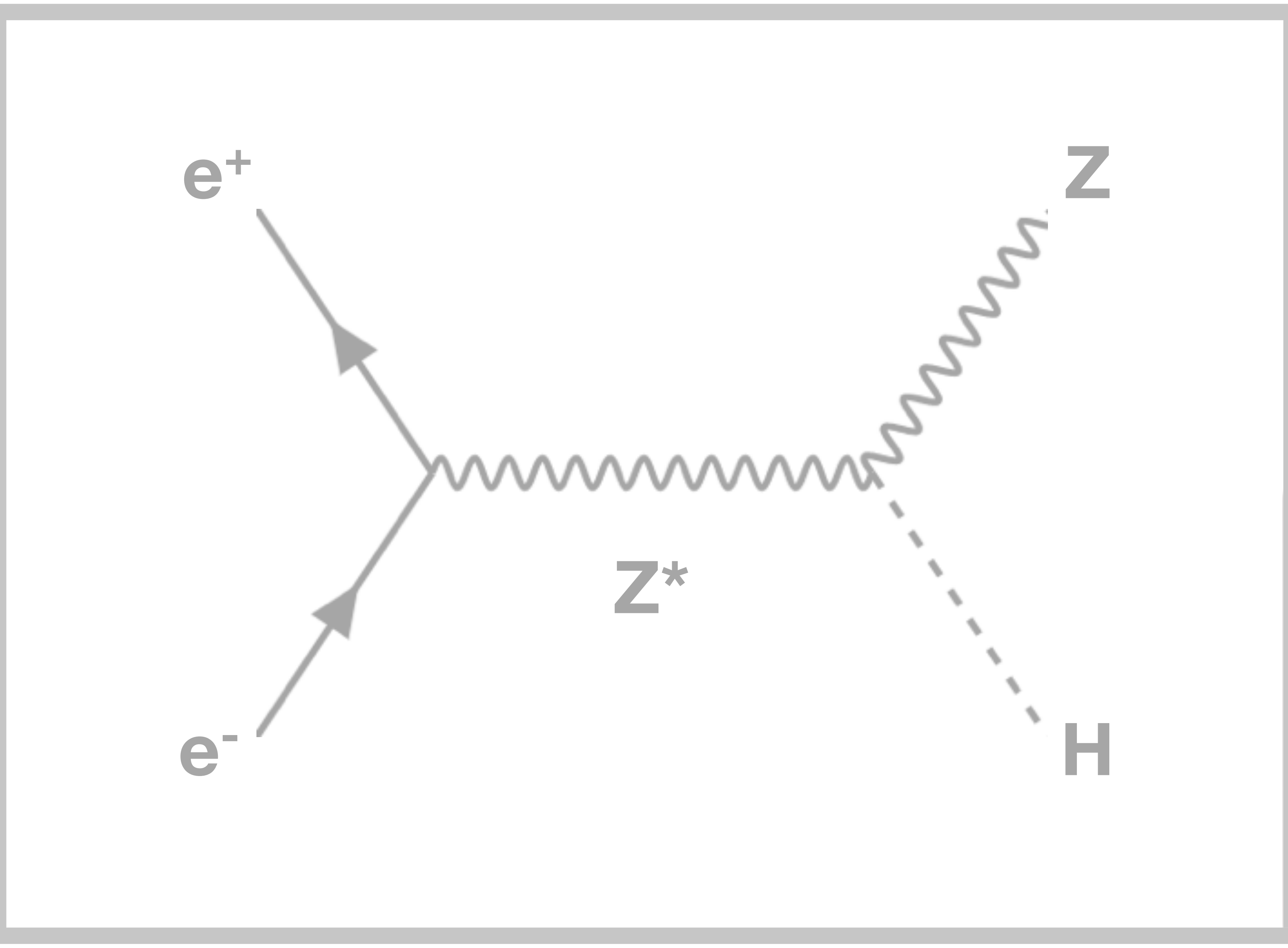
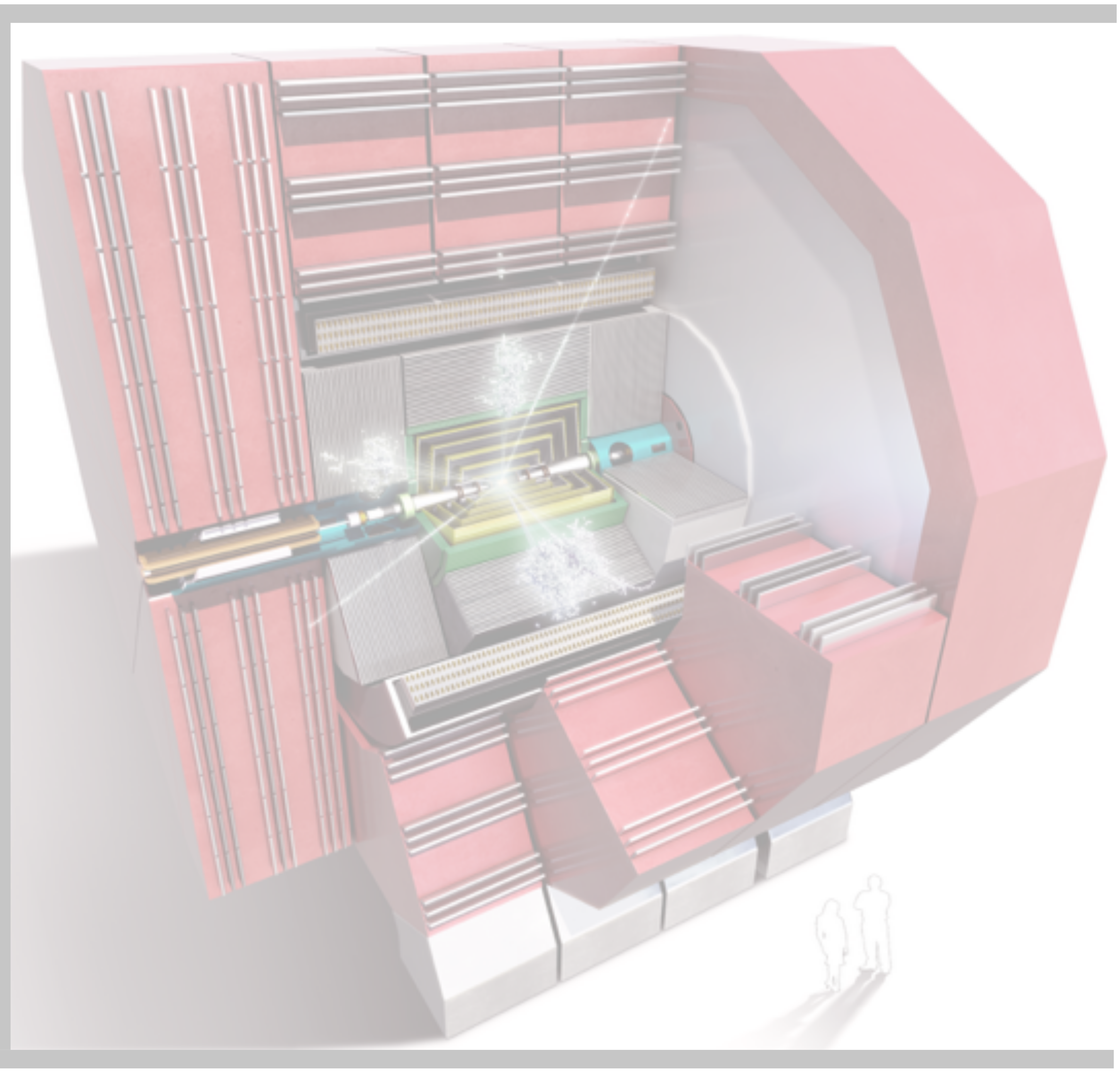
Introduction to Multi Purpose Detectors



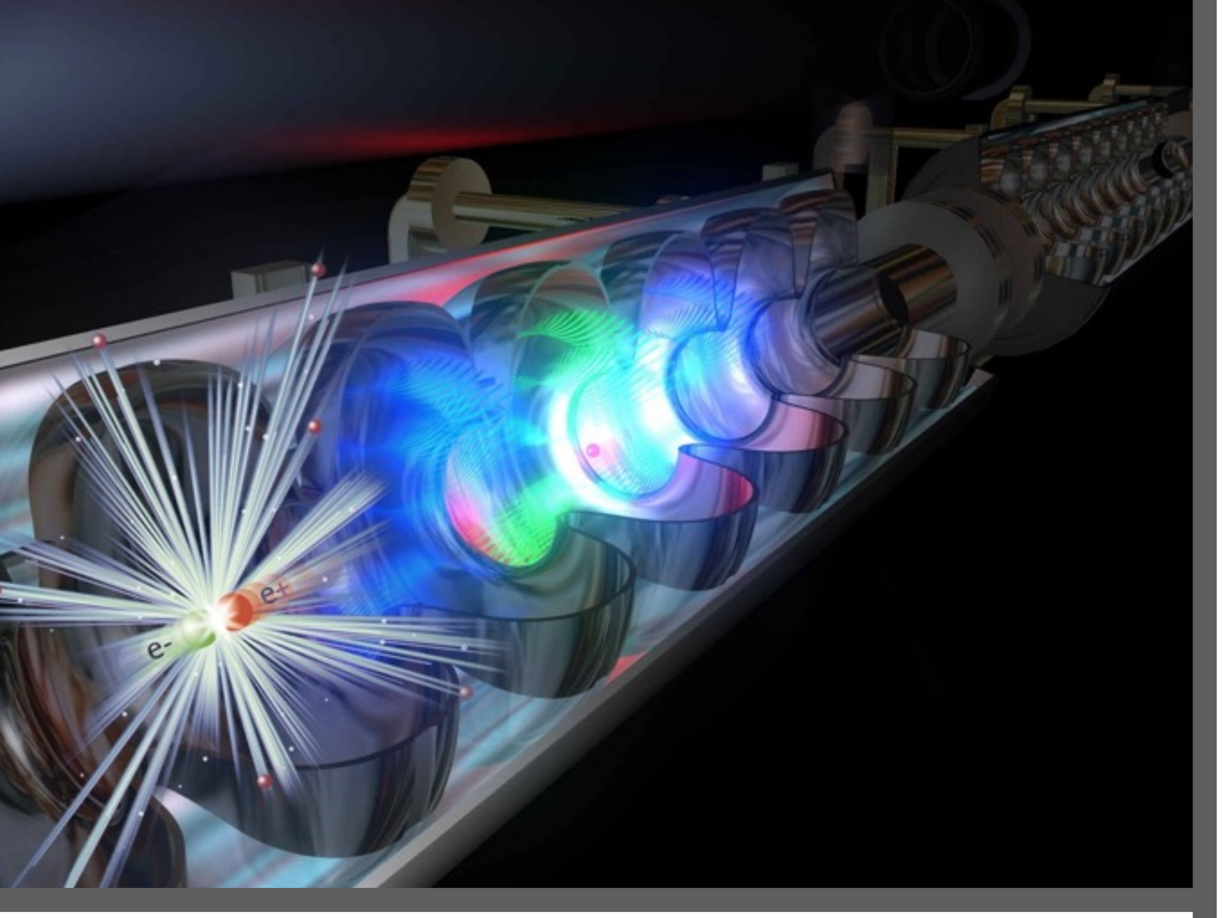


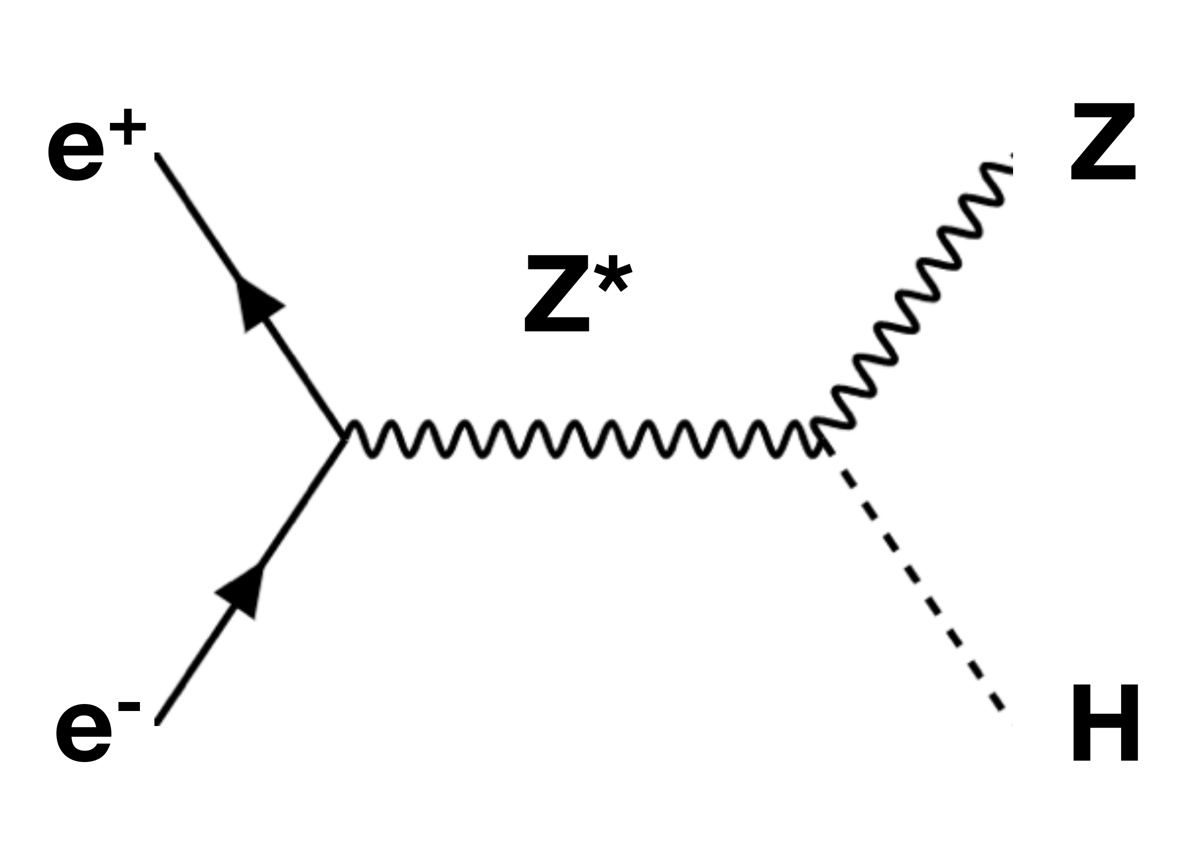


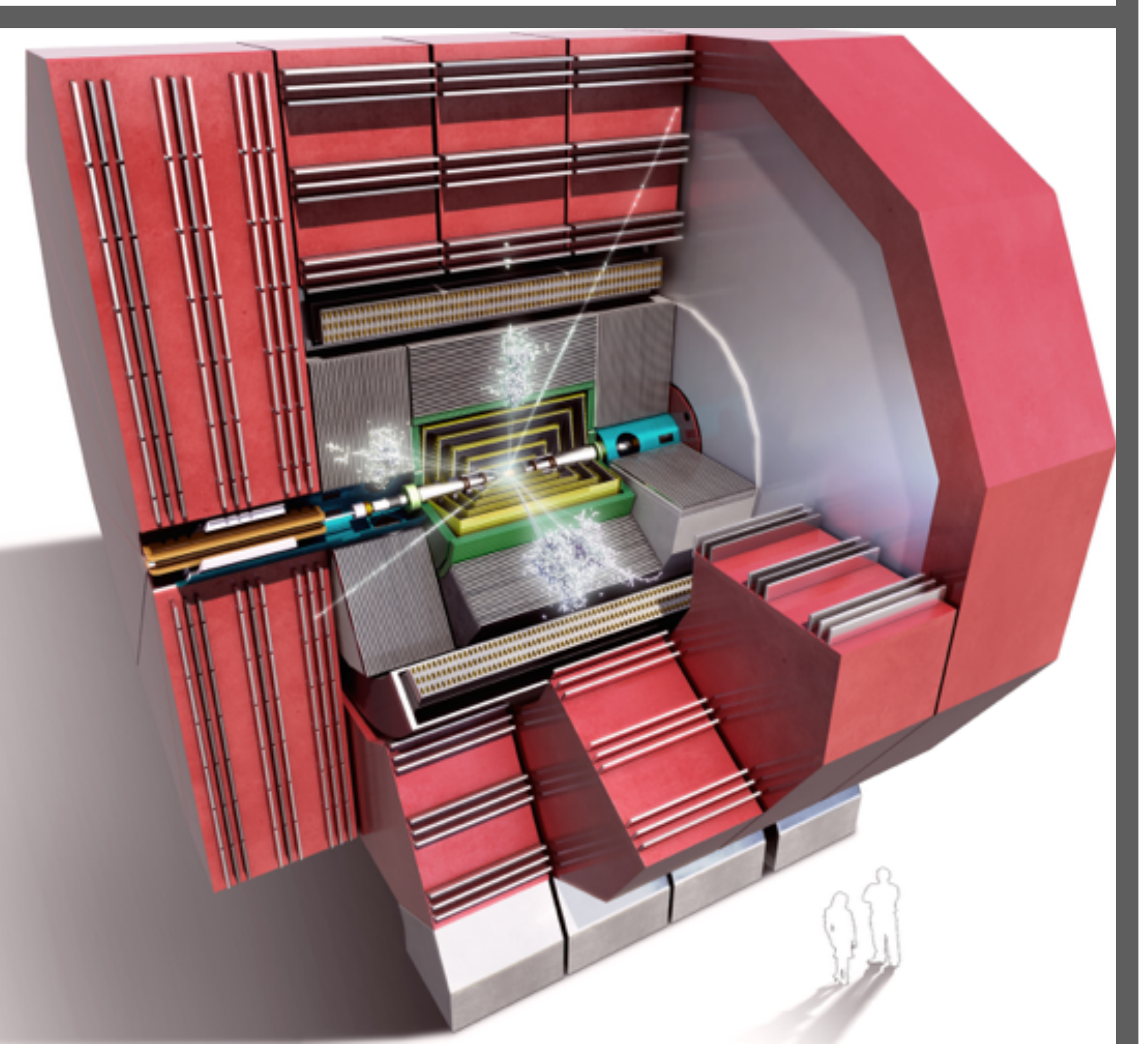
M. Gabriel

IMPRS Colloquium

2nd December 2016







Outline:

1. Accelerator Environment
2. Higgs Interaction
3. Multi Purpose Detectors
4. Summary & Conclusion

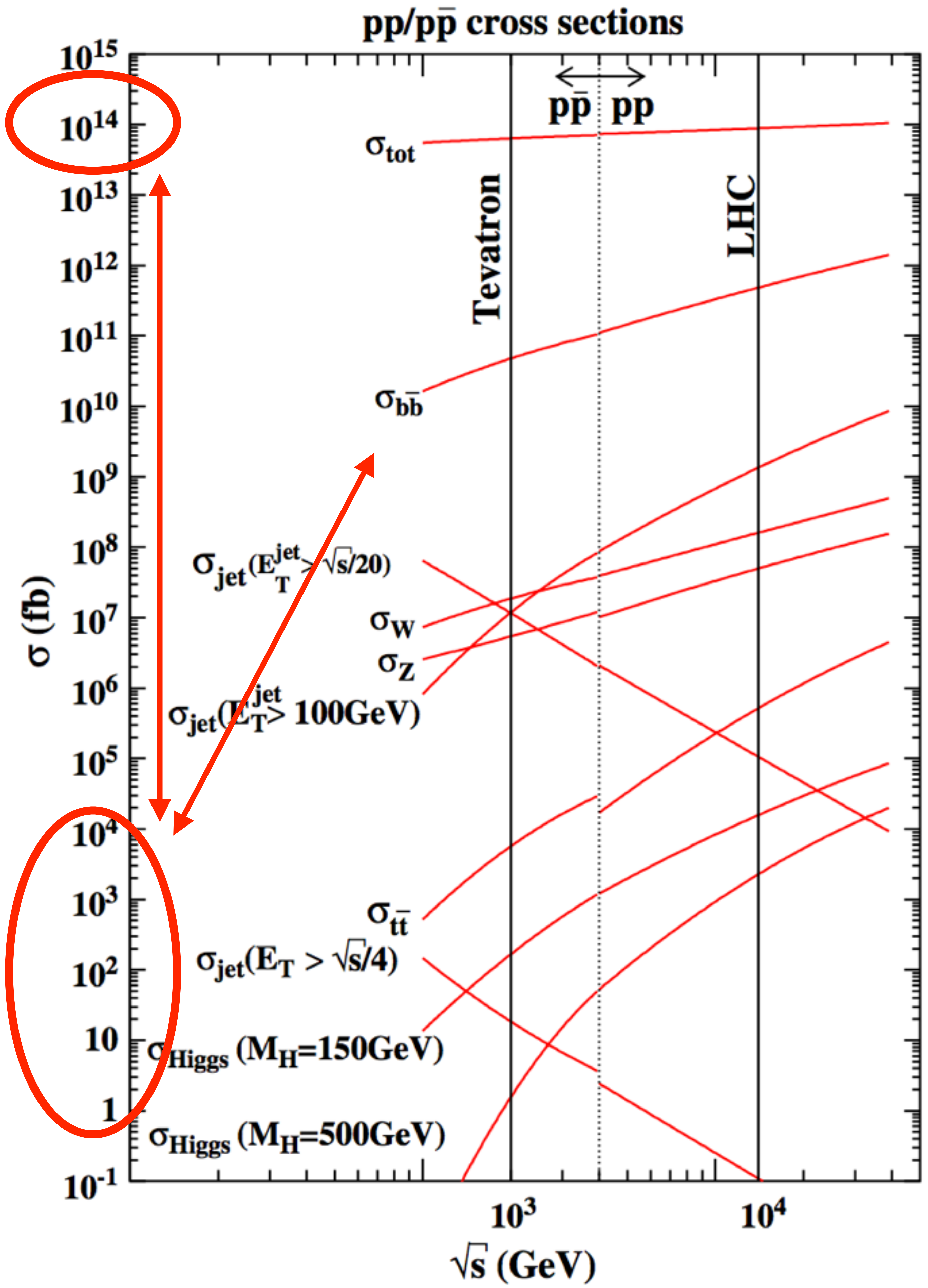
Accelerator Environment: Large Hadron Collider (pp-collider)

Machine parameters:
- 14 TeV center of mass energy
- ~ 10^{11} protons/bunch
- ~ 2000 bunches/ring

Collision parameters:
- 25 ns (40 MHz) between bunch collisions
- ~ 10^9 pp collisions/s & 20 - 30 pp-interactions/beam crossing

Physics impact:
- very high QCD background/low signal
- multiple collision/bunch crossing => disentangle hits, tracks & signals
- triggering is crucial aspect for filtering interesting events
- high event rate needs high read out rate and leads to huge amounts of data

More Information about data handling by Ludo:
Making use of experimental data: computing and analysis



Accelerator Environment: Compact Linear Collider (e+e-)

CLIC machine parameters:

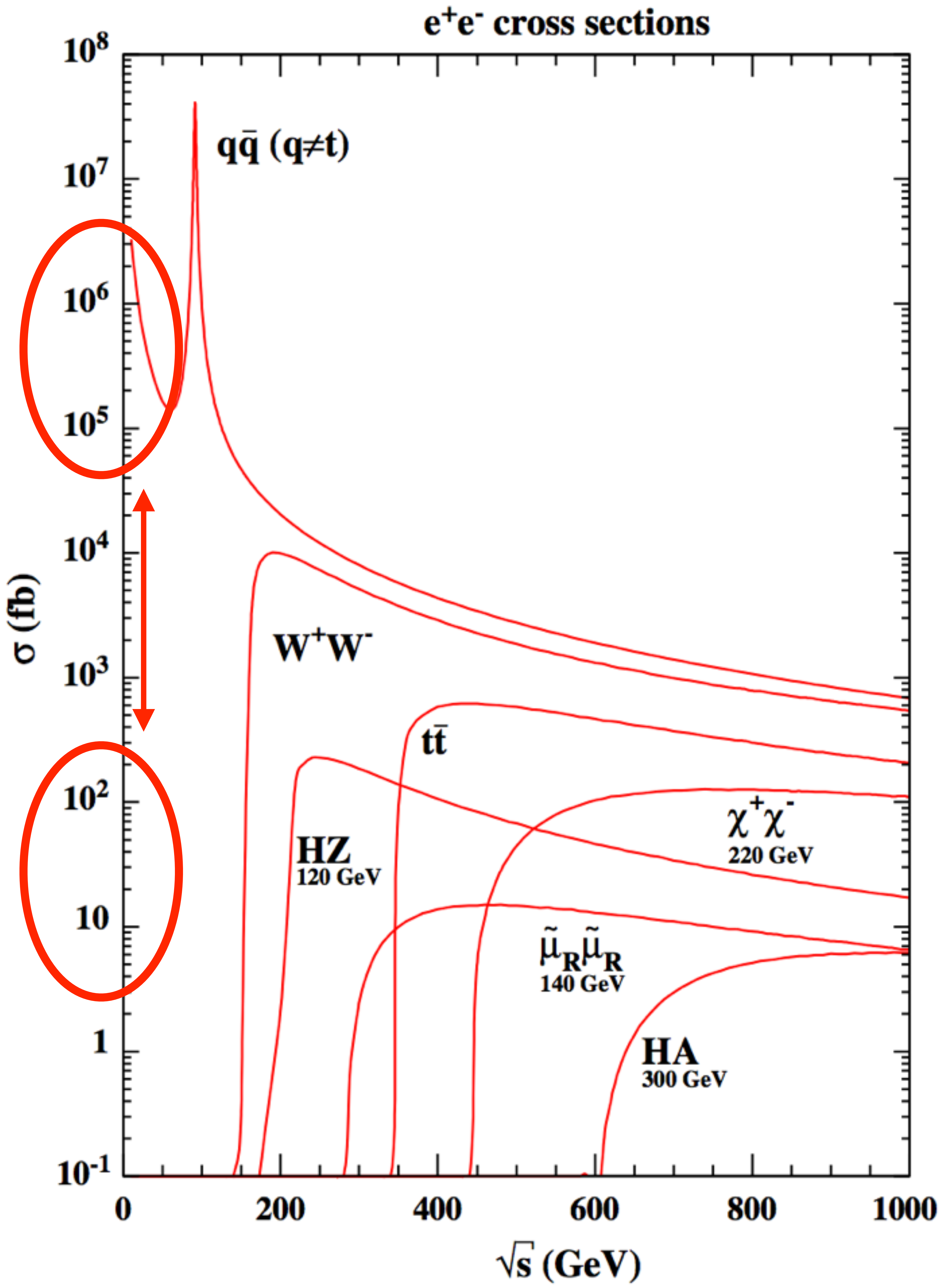
- staged build process - 380 GeV, 1000 TeV & 3 TeV center of mass energy
- ~ 10^9 electrons/bunch
- ~ 312 bunches/bunch train

Collision parameters:

- 0.5 ns (~ 2 GHz) between bunch collisions & 20 ms between bunch trains
- high luminosity requires narrow focusing at IP - nano meter beam sizes

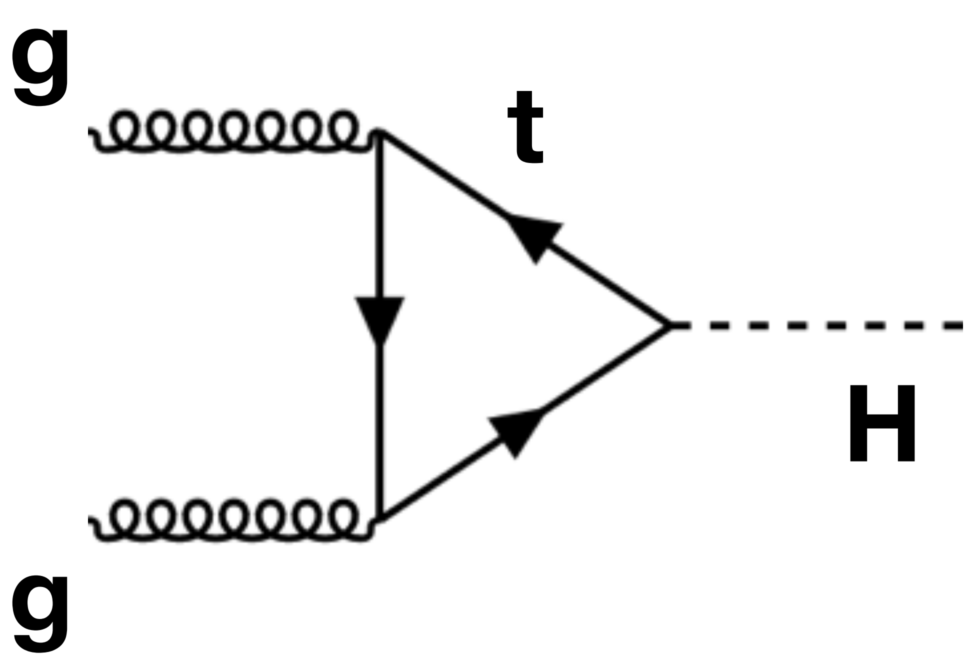
Physics impact:

- focusing leads to beam-beam-interaction (Beamstrahlung) - spread & long tail in electron energy distribution/photon emission
- e+e- background from photons
- $\gamma\,\gamma$->hadrons background - ~ 3.2 events/bx

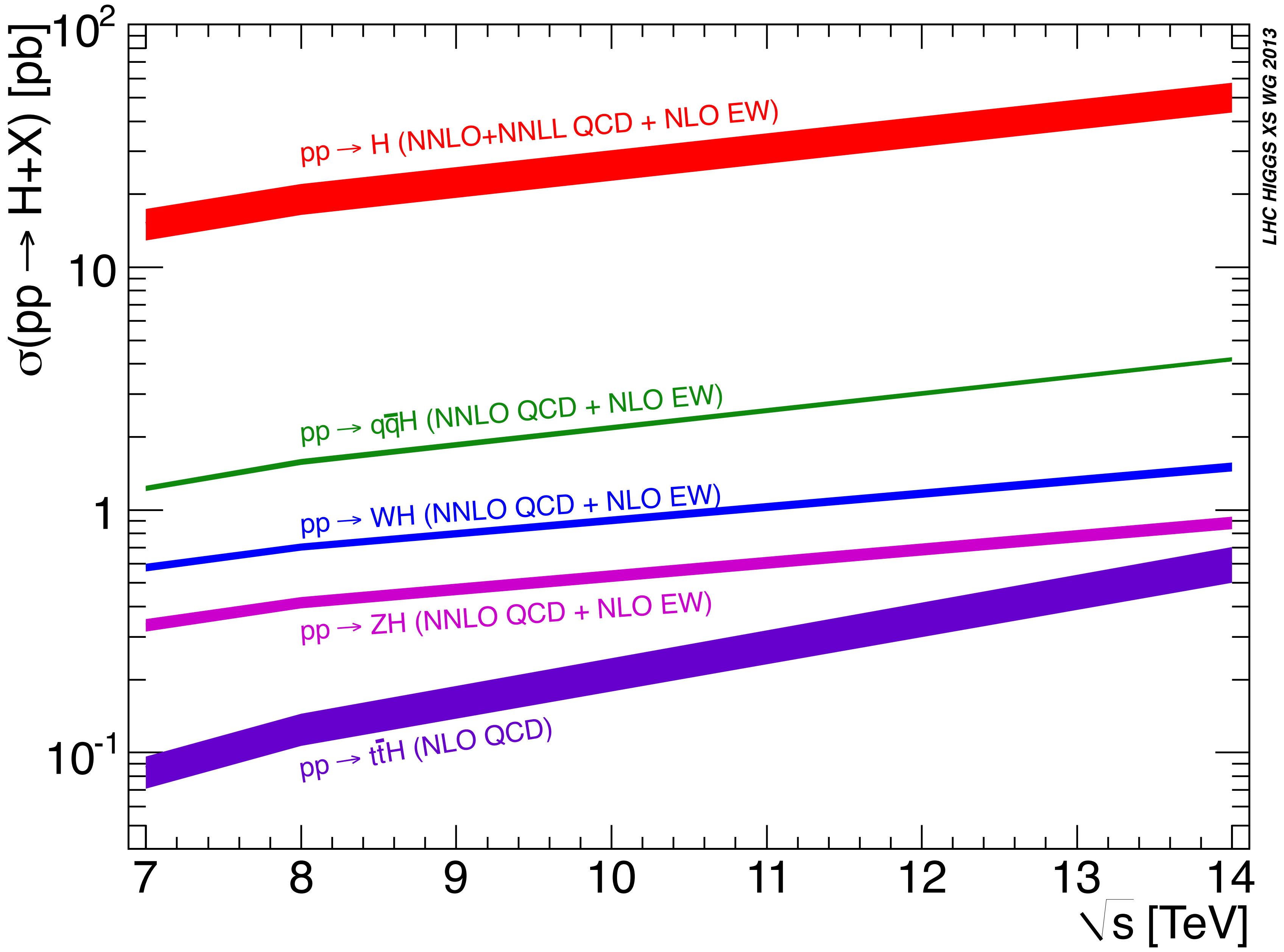


Example Measurement: Higgs Production

Gluon fusion

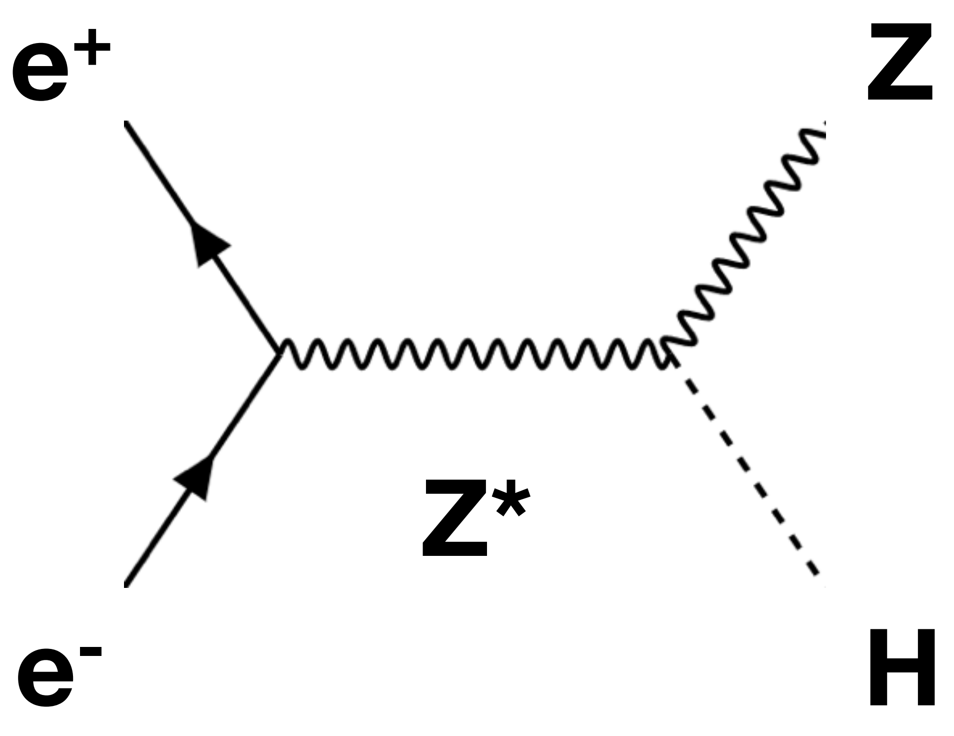


pp-colliders:
- gluon fusion dominant production at $\sqrt{s}$ = 14 TeV



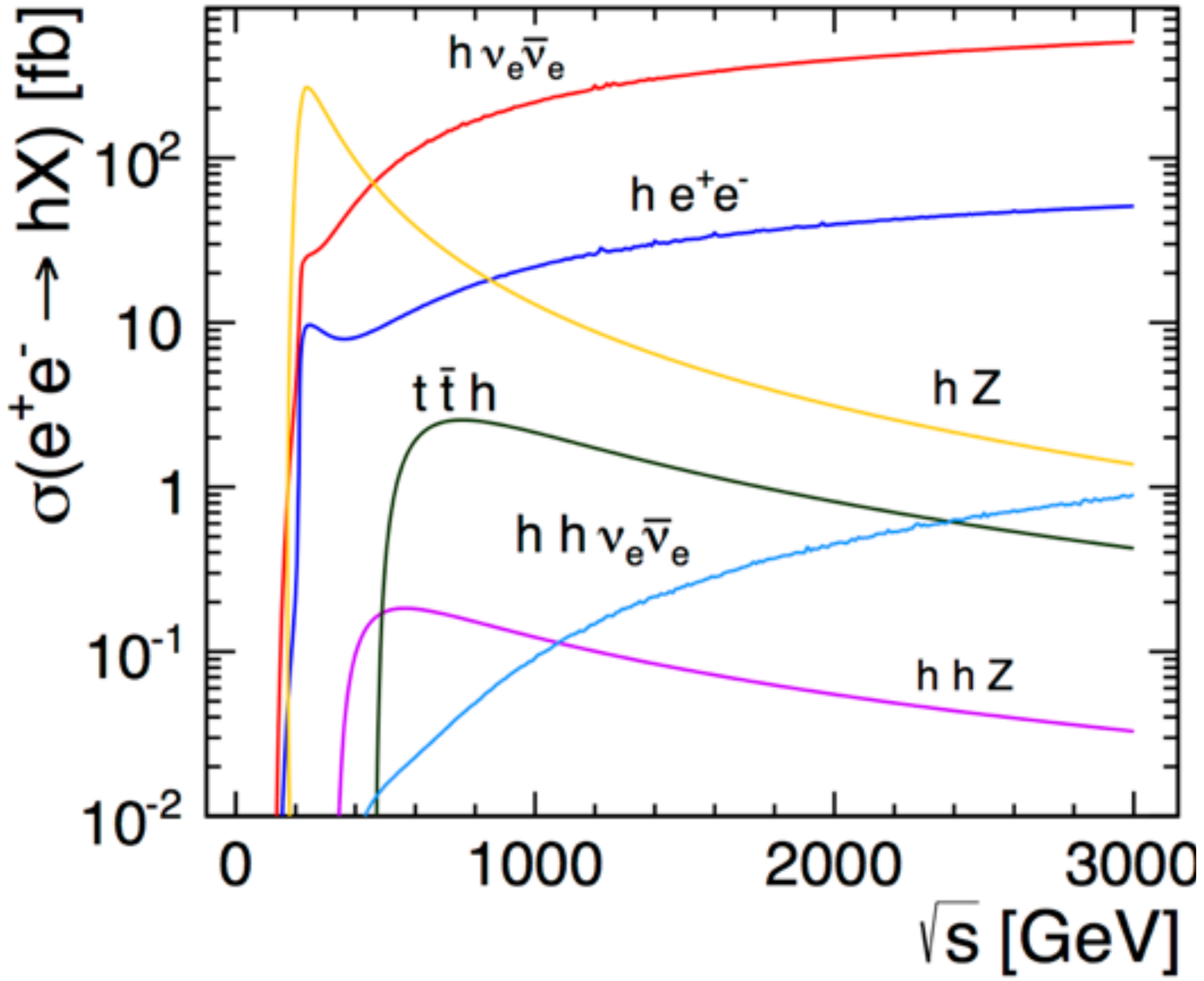
SM Higgs production cross section as a function of center of mass energy for pp collisions. Source: PDG 2015

Higgs Radiation



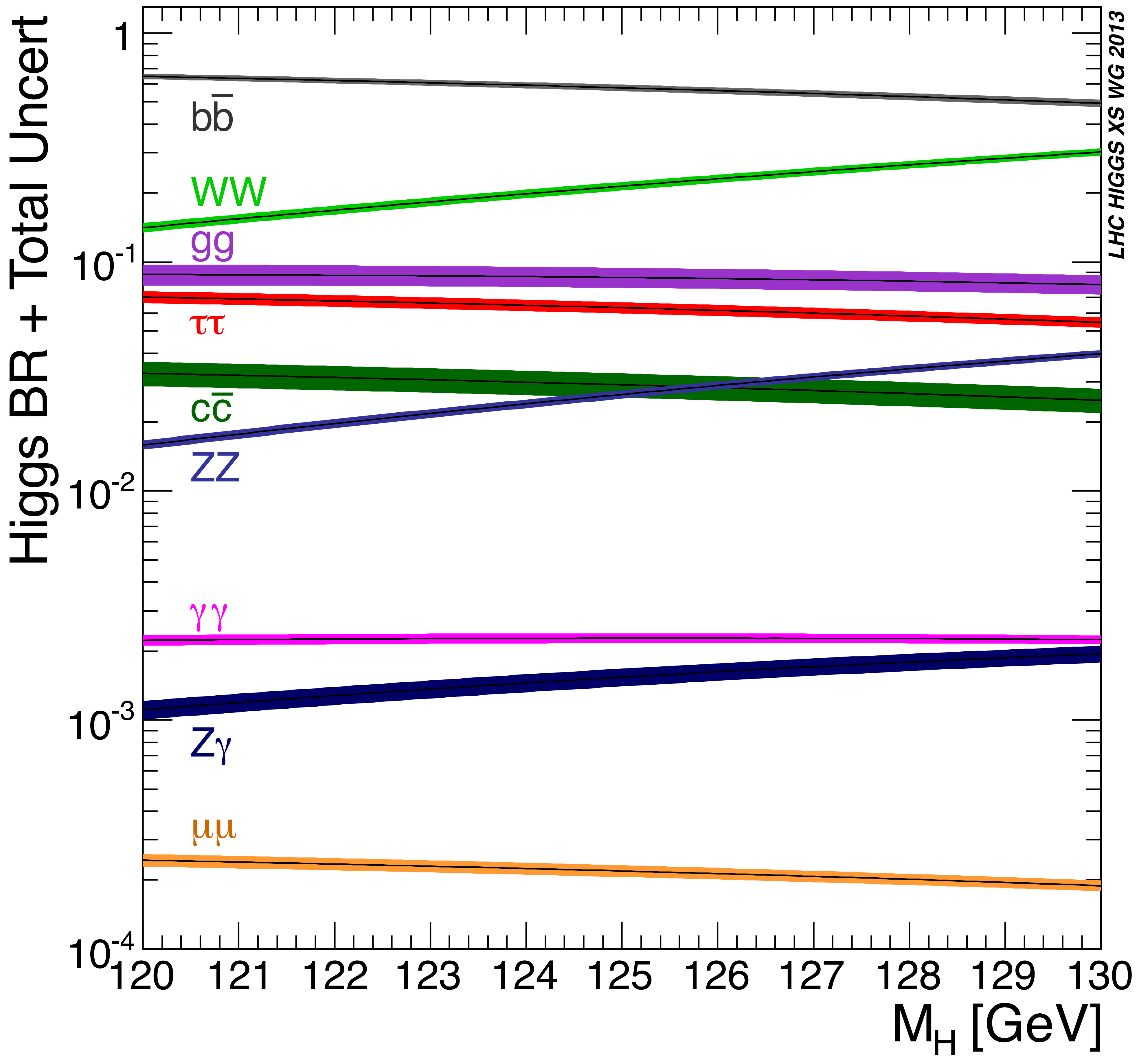
e^+e^- -colliders:
- Higgs radiation dominant $\sqrt{s}$ < ~ 350 GeV
- Vector boson fusion dominant $\sqrt{s}$ > ~ 350 GeV

Example production: e^+e^-->ZH



SM Higgs production cross section as a function of center of mass energy for e^+e^- collisions.

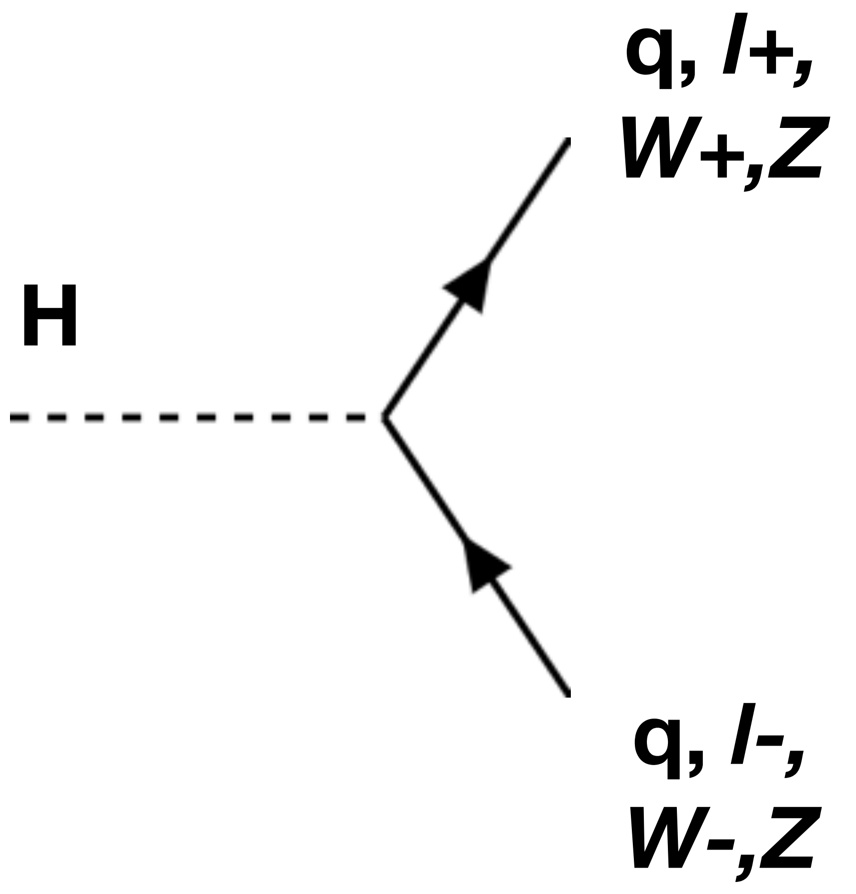
Example Measurement: Higgs & Z Decay



The branching ratios for the main decays of the SM Higgs boson near mH = 125GeV. Source: PDG 2015

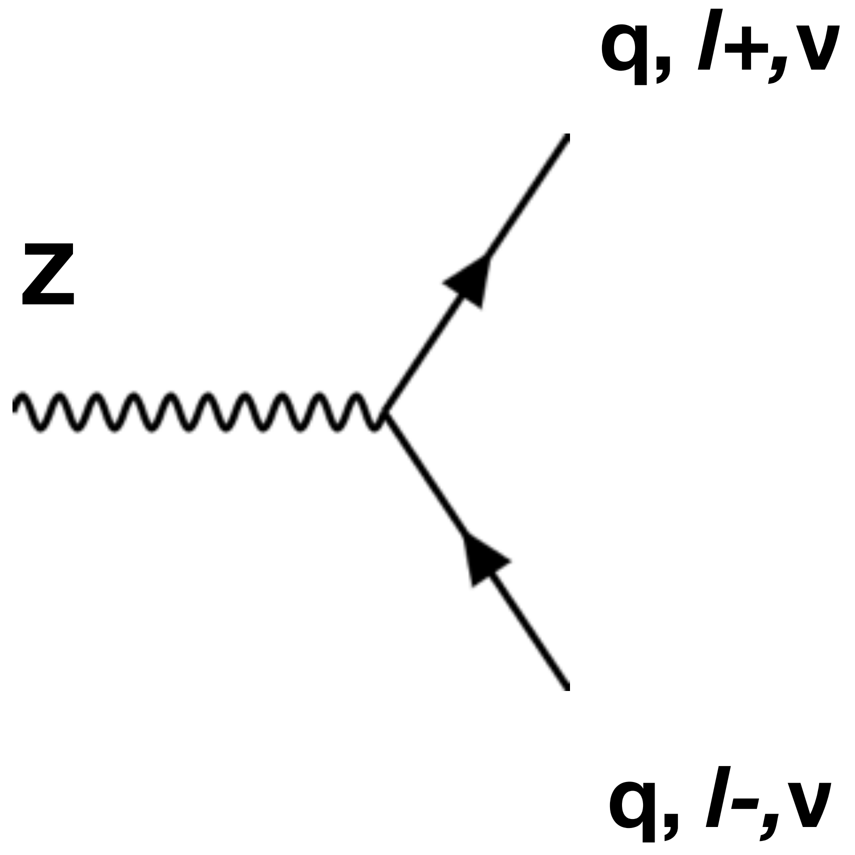
Higgs decay:

- many different decay modes
- background given by accelerator & physics
- H->bb in pp-collider totally background dominated - irreducible bkg
- decay mode under investigation drives detector design



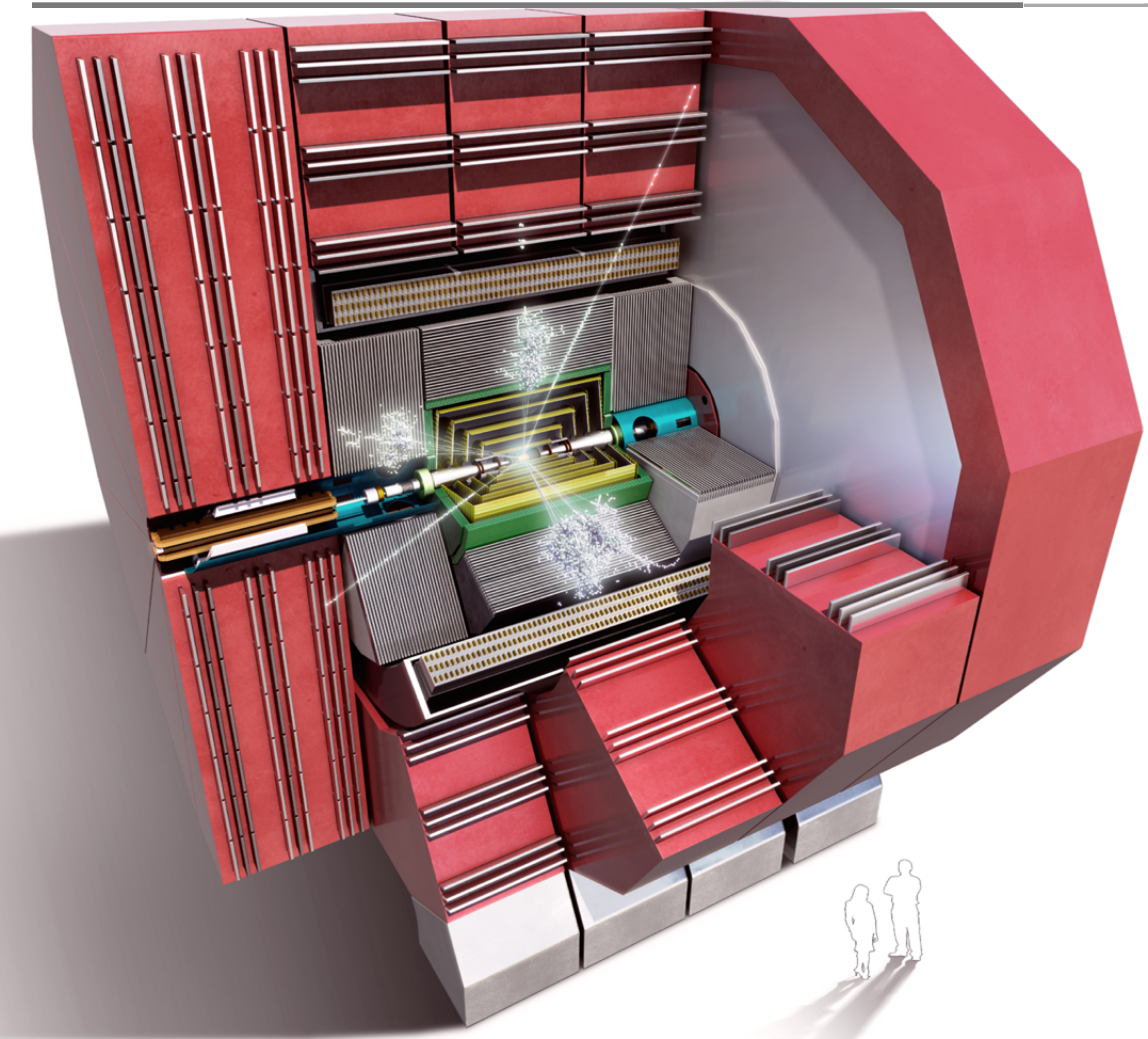
Z decay:

- ~ 70% into hadrons
- ~ 10% into leptons



Example decay:
$e^+e^- \to ZH \to bb + l^+l^-$

Modern Multipurpose Detectors

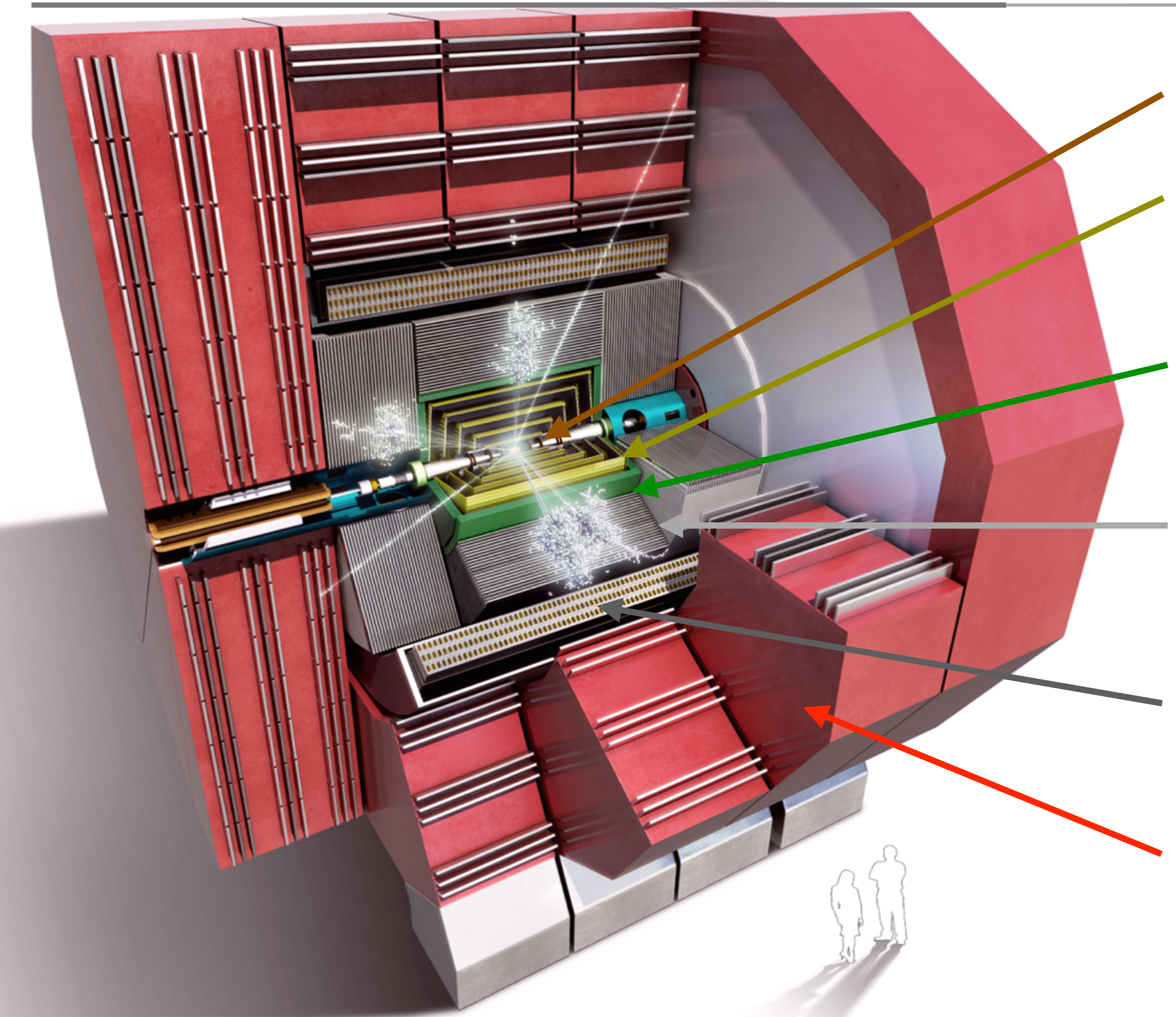


Modern multi propose detectors:

- broad spectrum of measurements
- ideally perform all measurement in the best way
- all build in the more or less the same way
  - onion shapped
  - strong magnetic field
  - 4π coverage
- some examples:
  - **A T**oroidal **L**HC **A**pparatu**S** (ATLAS)
  - **C**ompact **M**uon **S**olenoid (CMS)
  - **CLIC S**ilicon **D**etector (SID) - proposed CLIC detector

Focus on **SiD!**

CLIC Silicon Large Detector (SiD)



Vertex detector: r = 27 - 77 mm

Main tracker: r = 230 - 1200 mm

Electromagnetic calorimeter:
r = 1.3m - 1.43m

Hadronic calorimeter: r = 1.45 - 2.6m

Superconducting magnet:
r = 2.75 - 3.7 m

Return yoke & muon chambers:
r = 3.9 - 7 m

Particle Tracking: Momentum Measurement in B-Fields

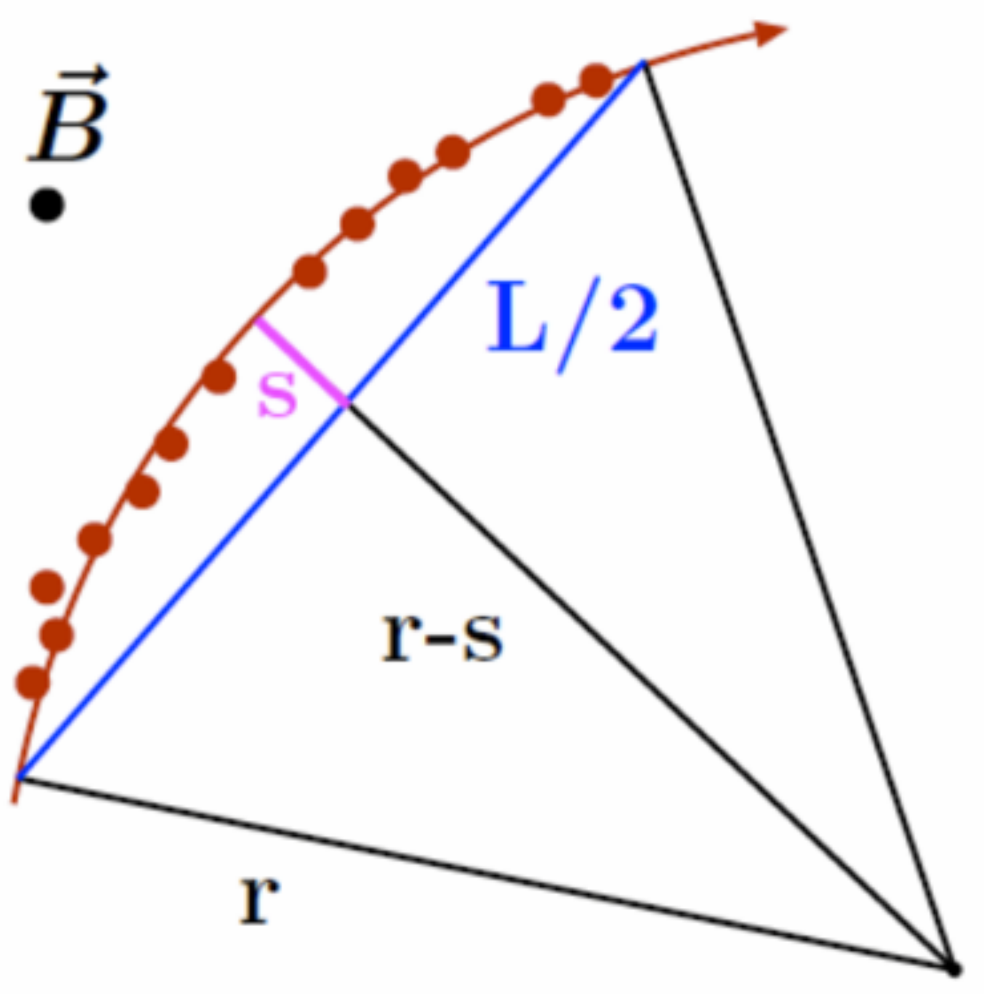
Charged particles are deflected in magnetic fields:

- radius of deflection measurements:

$$p_T[\mathrm{GeV/c}] = 0.3\ B[\mathrm{T}]\ R[\mathrm{m}]$$

- in reality only bent track segments:

$$s = \frac{0.3BL^2}{8p_T}$$



Errors on the momentum resolution:

- overall error on momentum:

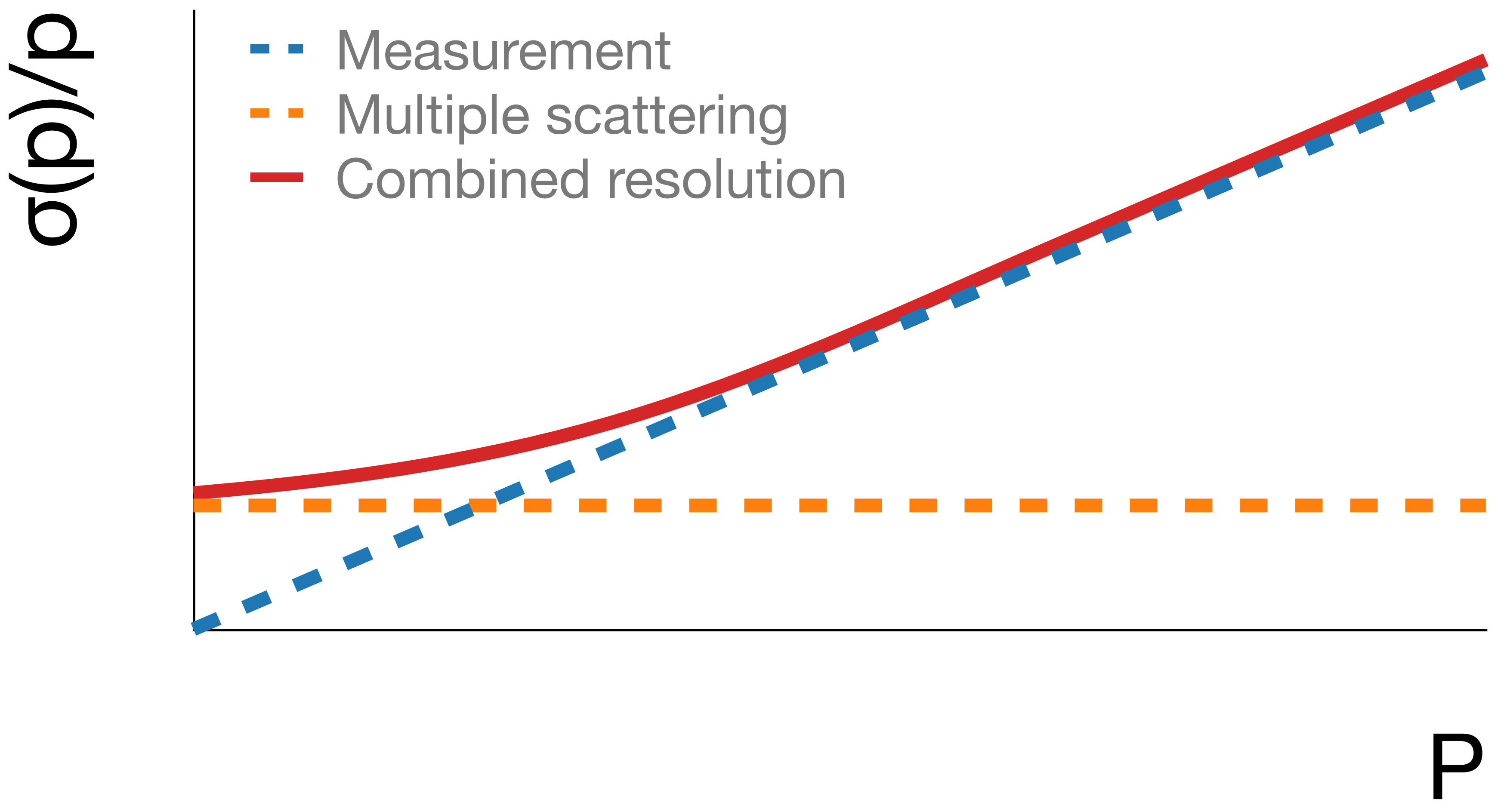
$$\left(\frac{\sigma_{p_T}}{p_T}\right)^2 = \left(\frac{\sigma_{ms}}{p}\right)^2 + \left(\frac{\sigma_{meas.}}{p_T}\right)^2$$

- measurement contribution:

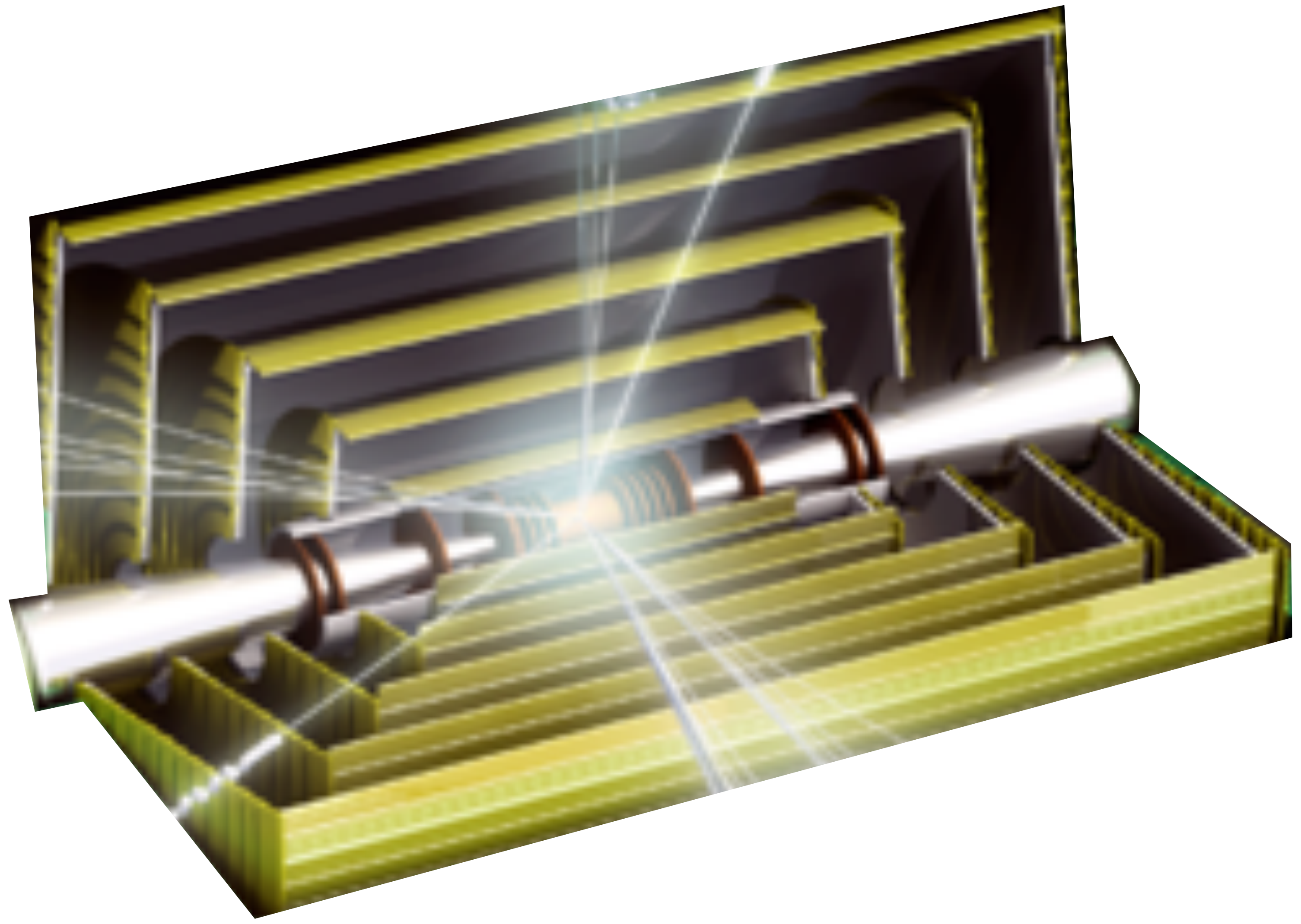
$$\frac{\sigma_{meas.}}{p_T} \propto \sqrt{\frac{720}{N+4}} \cdot \frac{\sigma_x p_T}{BL^2}$$

- multi scattering contribution:

$$\frac{\sigma_{ms}}{p} \propto \left(\frac{1}{B\sqrt{LX_0}}\right)$$



Particle Tracking: Detector Systems



Vertex detector:

- identification of secondary vertices - b and c-tagging
- highest resolution - close as possible to IP
- 3 or so layers of pixel

Main tracker:

- measure particle tracks
- 5 silicon strip layers

Detector concepts:

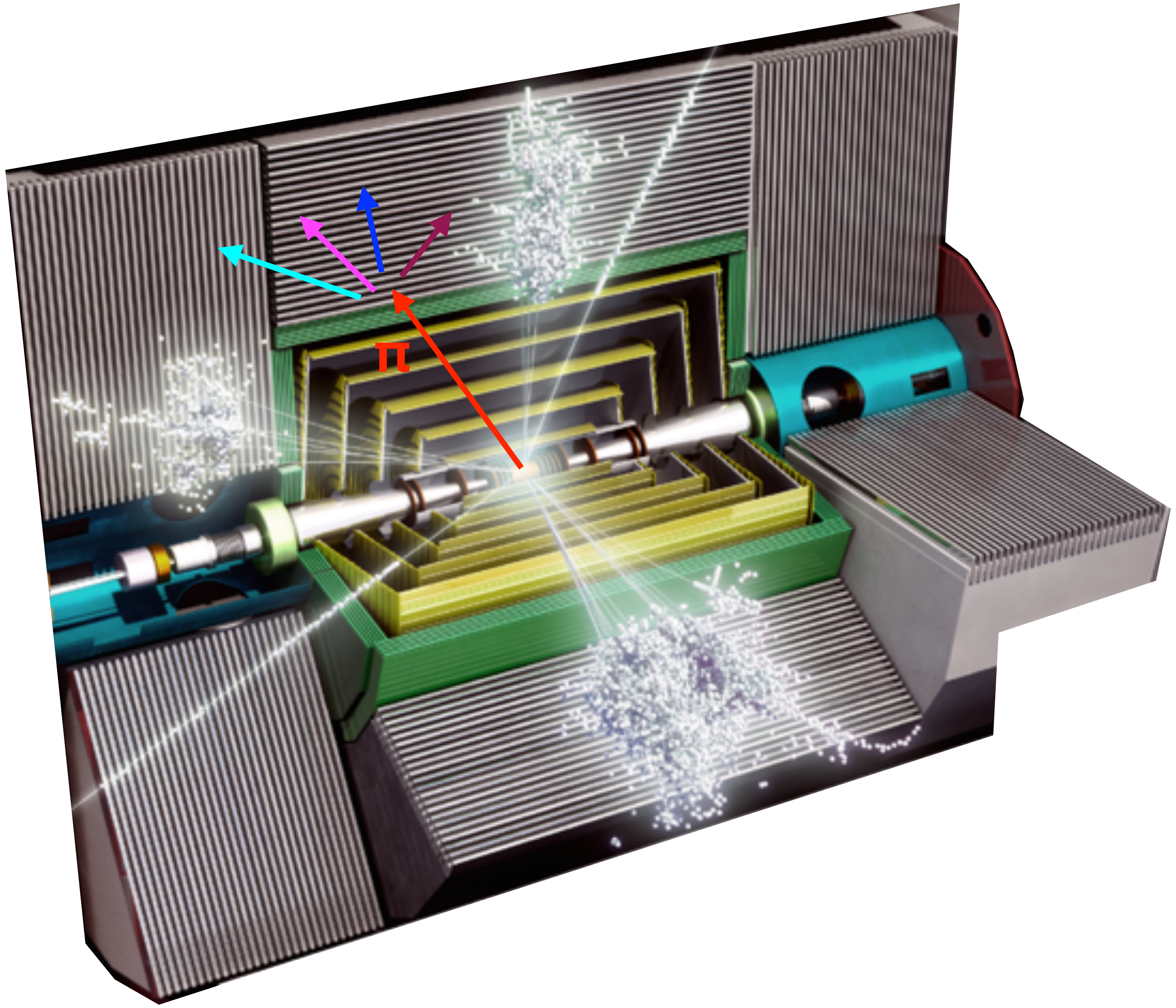
- measure position in space/track in magnetic field
- minimise influence on particles - low material budget requiered
- measurement of all charged particles (e,μ,τ, p, π)

Common technologies for tracking detectors:

- gas detectors - many space points but drift time/ pile up problem
  - drift tubes ~ 50 to 150 μm
  - Time Projection Chamber (TPC)
- silicon detectors - fast, very good spatial resolution but few space points expensive
  - silicon stripes ~ 20 - 30 μm
  - silicon pixel ~ 5-15 μm

More Information about tracking detectors by Julien:
ATLAS Inner Detector

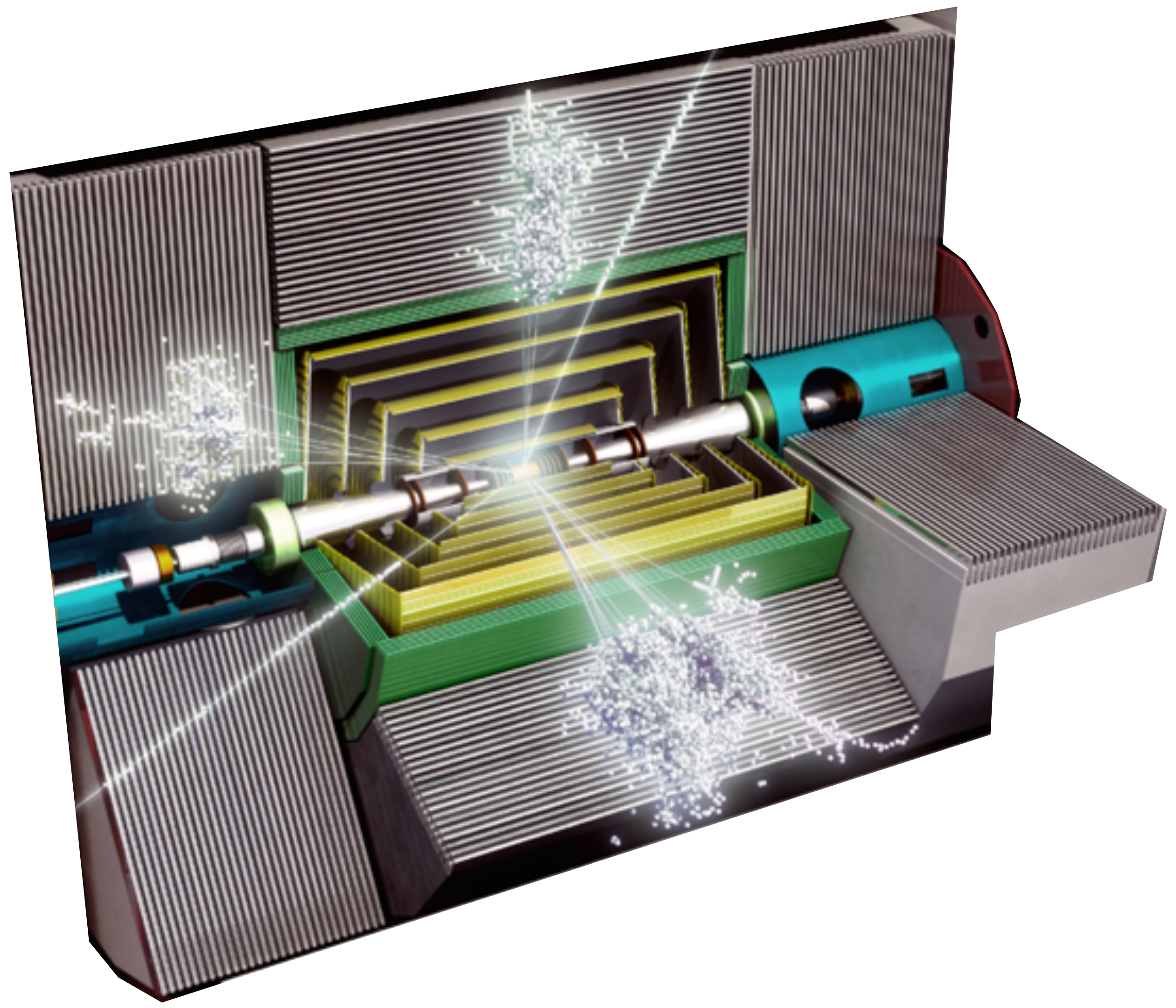
Calorimetry: Basic Idea

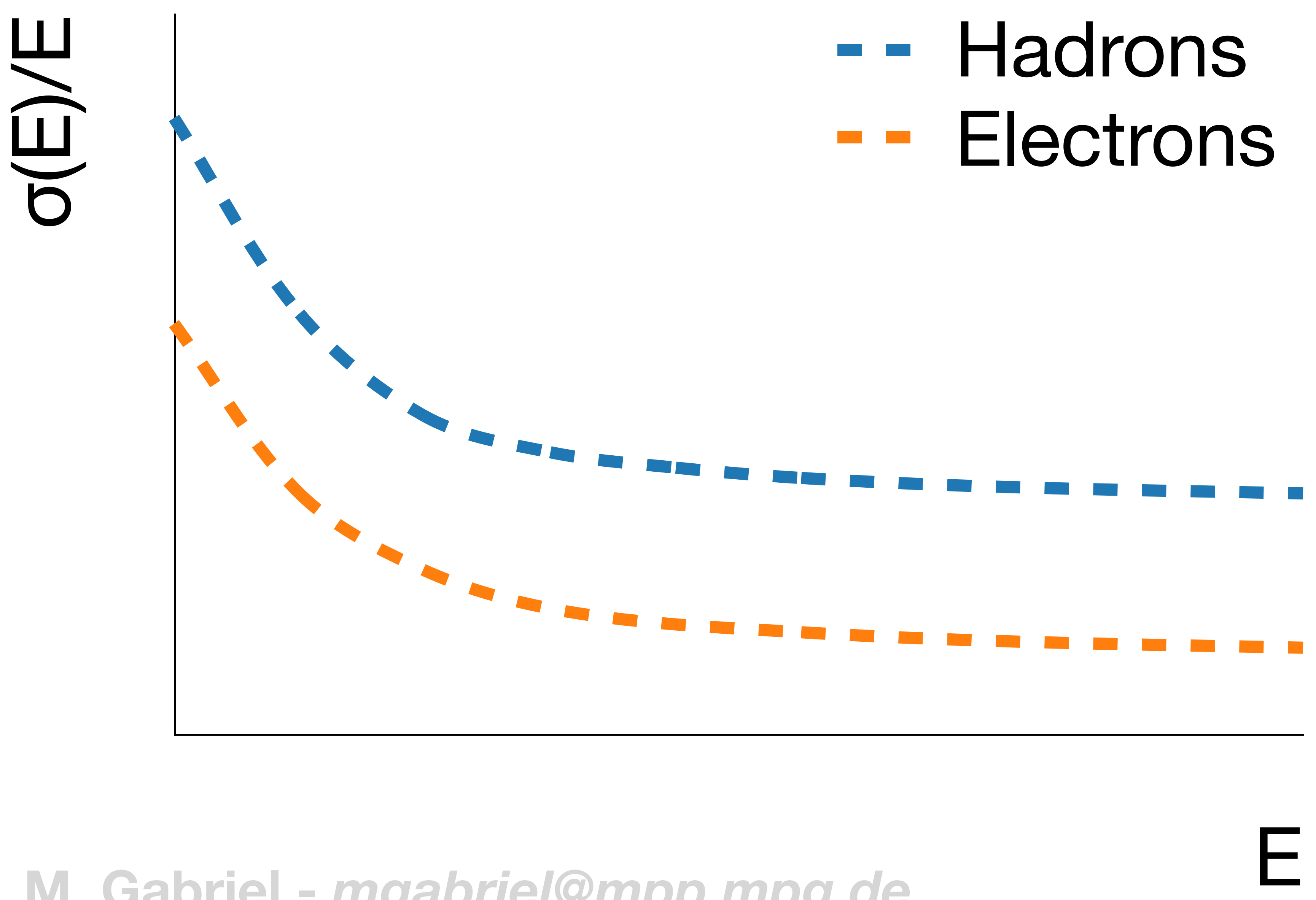


Detector concept:

- measure energy of elementary particles by total absorption - destructive measurement
- convert single high energy particle into multiple low energy particles - shower development
- convert particle energy to detector response
- measurement ~ constant over 4π
- measurement of all particles (except muons neutrinos) - total energy
- reconstruct missing energy & neutrinos by momentum conservation

Calorimetery: Detector Systems





Electromagnetic **C**alorimeter (**ECal**):

- measure photon and lepton energy - identify photons
- Radiation Length X_0: mean distance after which highly relativistic electron has lost all but 1/e of it's energy due to Bremsstrahlung
- relatively good energy resolution

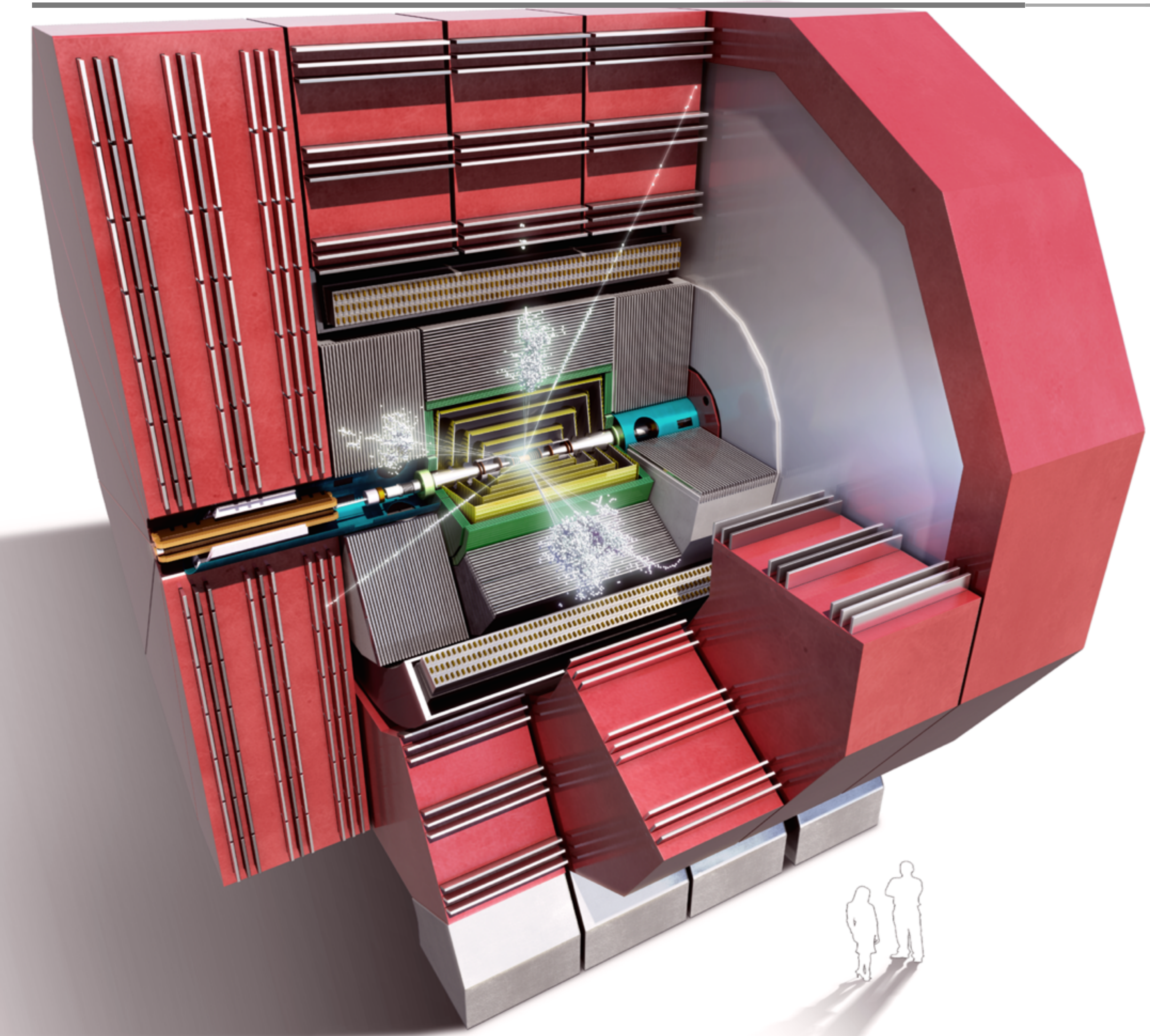
Hadronic **C**alorimeter (**HCal**):

- measure strongly interacting particles - identify neutral hadrons
- Nuclear Interaction Length λ_{int}: mean path length after which the probability of not having been in strong interaction is 1/e
- relatively bad energy resolution - weak spot in overall detector

More Information about calorimeters by Yasmine & Christian:

- Basic Concepts of Calorimetry
- Advanced Techniques in Calorimetry

Magnet & Muon System



Magnet system:

- has to accommodate tracker and calorimeters
- major cost driver for larger radii
- usually superconducting coils
  - SiD: 5 T solenoid
  - CMS: 4 T solenoid
  - ATLAS: 2 T super conducting solenoid + 0.5 T normal conducting toroidal

Iron return yoke:

- return magnetic field lines

Muon systems:

- interleaved inside the return yoke
- for example RPCs or big scintillators
- identification and measurement of muons
- detect shower leakage

Analysis Summary & Conclusion

Example measurement:

- Higgs production in Higgs radiation
- Higgs decay into bb-pair
- Z decay into two leptons e or μ

Vertex & main tracker:

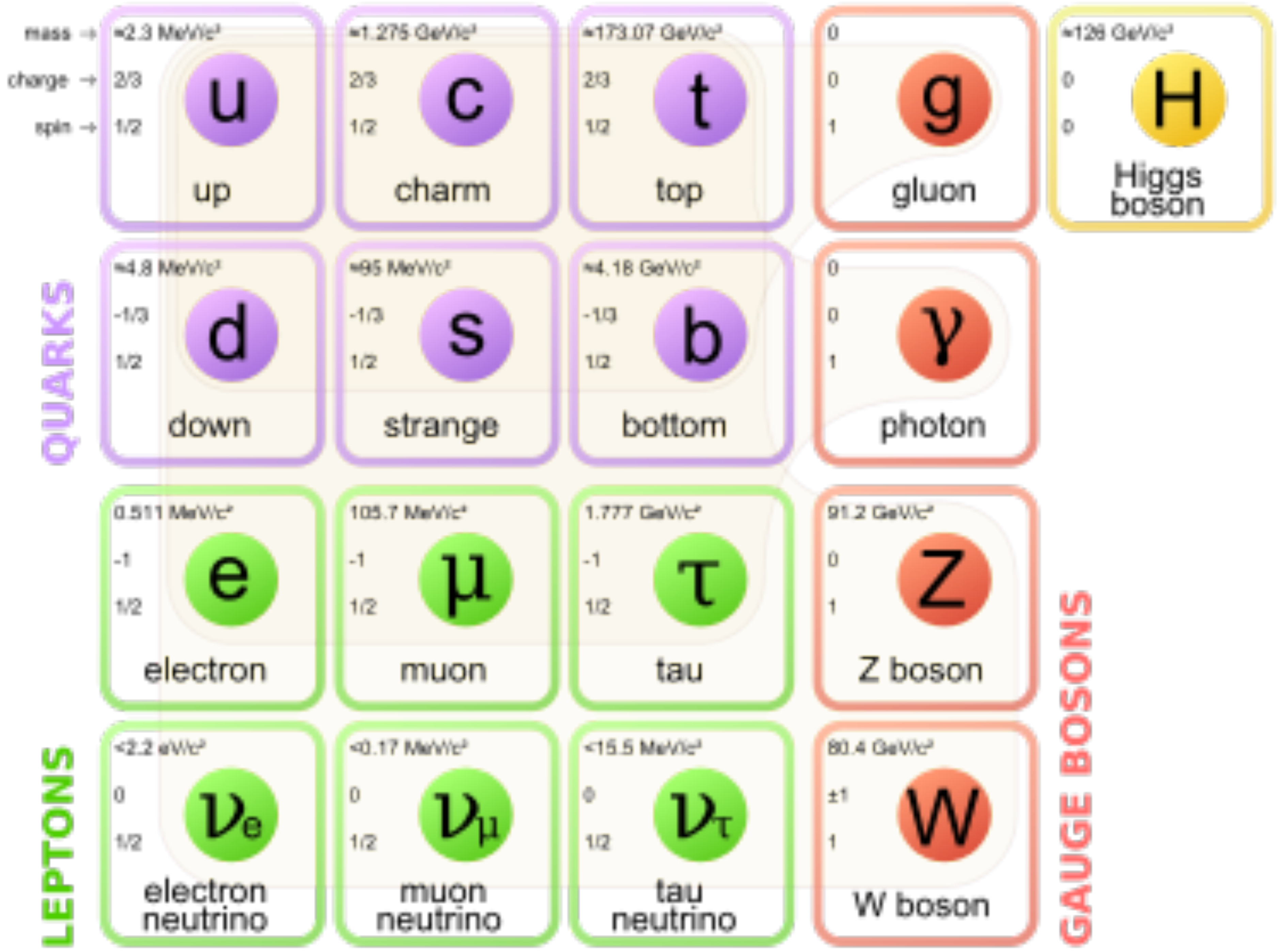
- measurement of particle tracks in magnetic field
- identification of b hadron by secondary vertices
- determination of lepton & charged hadron momentum

ECal & HCal:

- measurement of all particle energies (except muon)
- reconstruct missing energy
- measure bb-pair energy

Magnet and muon system:

- outer most part of the detector
- supply magnetic field
- identify muons



Source: wikipedia.org

All systems in a modern Multi Purpose Detector work together - all are needed for the full picture!

Backup