
# Short Recap Lecture 1
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## Collider Physics

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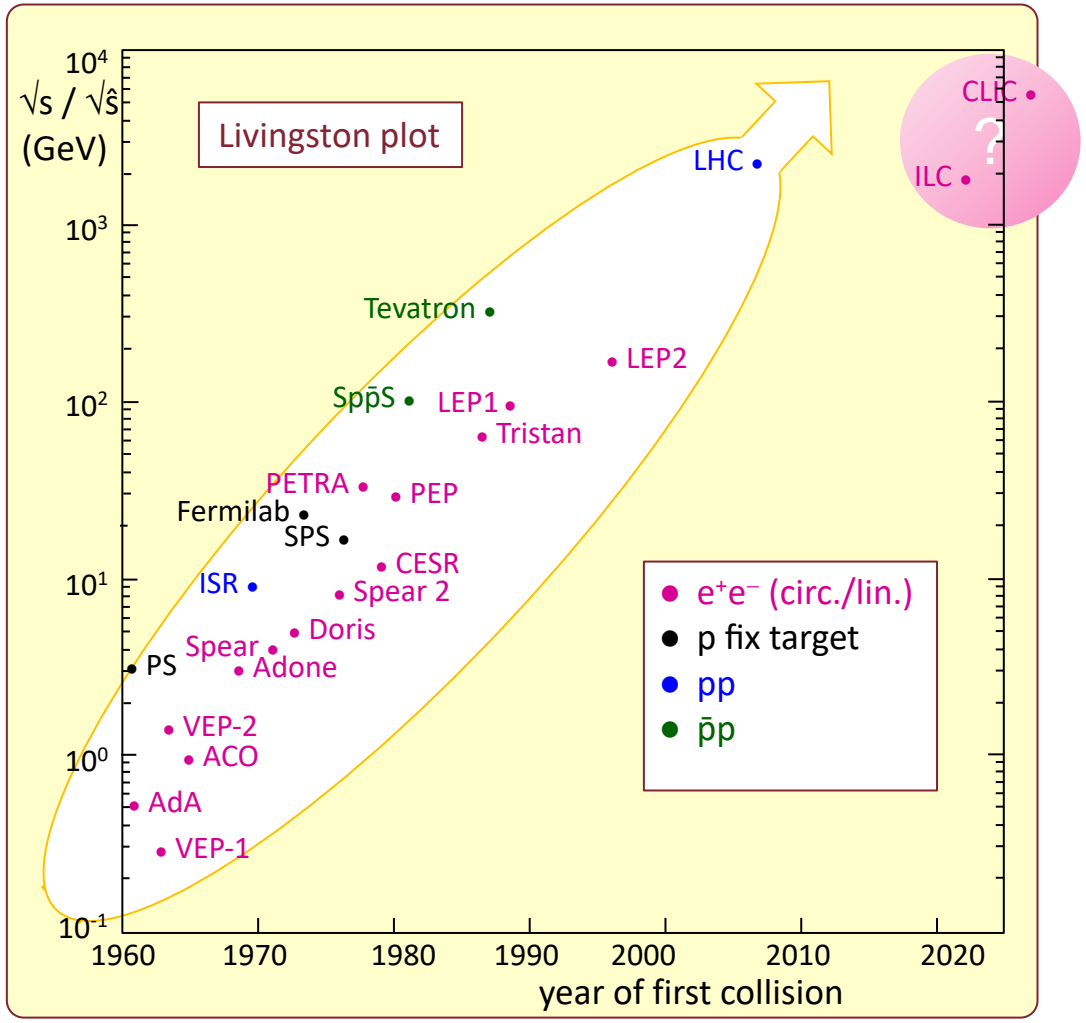
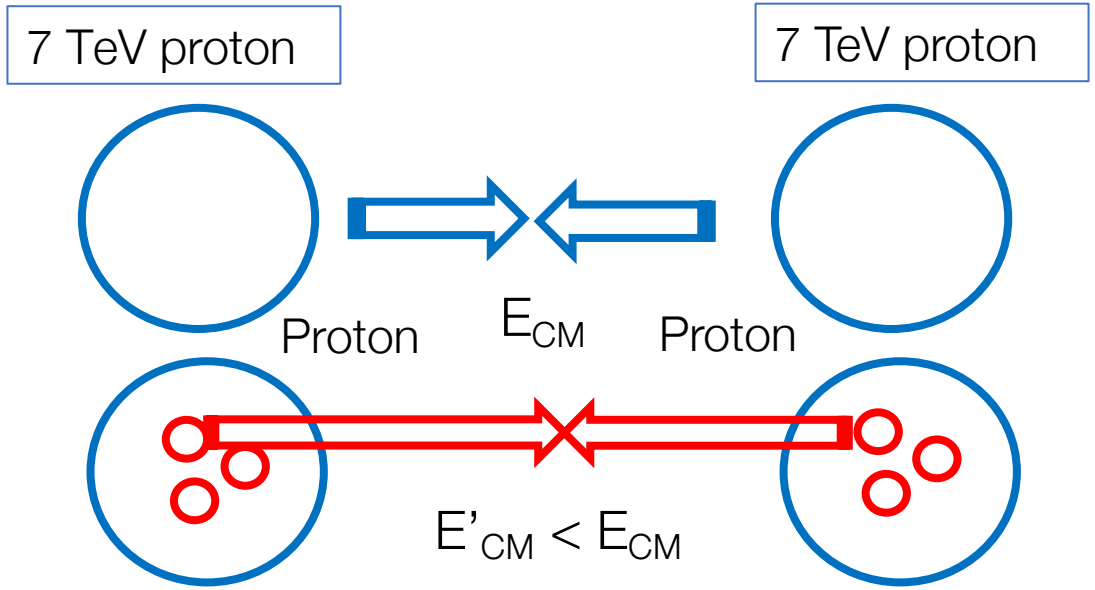
# Prologue: the Quest for High Energy

To study the intimate structure of matter we have to use probes with wave-lengths as small as possible →
Collide two beams against each other




The CM energy at component level is lower!
Quarks carry a fraction of the proton energy

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# Quantum Mechanics (in 1 Table...)

| | Equation | Derivatives | Comment |
|---|---|---|---|
| Schröedinger | $i\frac{\partial\psi(\boldsymbol{x},t)}{\partial t} = -\frac{1}{2m}\frac{\partial^2\psi(\boldsymbol{x},t)}{\partial x^2}$ | 1st order time, 2nd order space | Low energy approx., non relativistic invariant |
| Klein-Gordon | $\left(\partial^\mu\partial_\mu + m^2\right)\psi(\boldsymbol{x},t) = 0$ | 2nd order space & time | Negative energy solutions |
| Dirac | $i\frac{\partial}{\partial t}\psi = \left(-i\alpha_x\frac{\partial}{\partial x} - i\alpha_y\frac{\partial}{\partial y} - i\alpha_z\frac{\partial}{\partial z} + \beta m\right)\psi$<br>$\psi = \begin{pmatrix}\psi_1\\ \psi_2\\ \psi_3\\ \psi_4\end{pmatrix}$ $\hat{S}_z u_1(E,0.0,\pm p) =$<br>$+\,1/2\,u_1(E,0.0,\pm p)$<br>$\hat{S}_z u_2(E,0.0,\pm p) = -\,1/2\,u_2(E,0.0,\pm p)$<br>$\hat{S}_z v_1(E,0.0,\pm p) = +\,1/2\,v_1(E,0.0,\pm p)$<br>$\hat{S}_z v_2(E,0.0,\pm p) = -\,1/2\,v_2(E,0.0,\pm p)$ | 1st order space & time | Spin & anti-particles<br>Fermions, spin up, down<br>Antifermions, spin up, down |

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# 'Ultimate' point-like Constituents of Matter

Table 1 : Fundamental fermions and bosons in the standard model of the microcosm

| Fermions | | | | Bosons | |
|---|---|---|---|---|---|
| $\begin{pmatrix} u \\ d \end{pmatrix}$ | $\begin{pmatrix} c \\ s \end{pmatrix}$ | $\begin{pmatrix} t \\ b \end{pmatrix}$ | Quarks | Fundamental Interactions | Mediators |
| $\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}$ | $\begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}$ | $\begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$ | Leptons | Strong | 8 gluons |
| | | | | Electromagnetic | $\gamma$ |
| | | | | Weak | $W^+, W^-, Z^0$ |
| First family | Second family | Third family | | Gravitational | Graviton |
| | | | | Higgs Boson | $H^0$ |

| | First family | | | |
|---|---|---|---|---|
| | Symbol | Q | $L_e$ | B |
| Leptons | $\nu_e$ | 0 | 1 | – |
| | $e^-$ | −1 | 1 | – |
| Quarks | $u$ | +2/3 | – | +1/3 |
| | $d$ | −1/3 | – | +1/3 |

$Q$ is the electric charge in unit of the proton charge, $L_e$ is the electronic lepton number, $B$ the baryonic number.



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# The Standard Model

| Force Carrier | Photon | W & Z Boson | Gluons | Graviton |
|---|---|---|---|---|
| | EM | Weak | Strong | Gravitational |
| Quarks | ✅ | ✅ | ✅ | ✅ |
| Leptons | ✅ | ✅ | | ✅ |
| Neutrinos | | ✅ | | |

The ***hadrons*** may be baryons constituted by three quarks or mesons quark-antiquark pair

the total number of baryons and leptons must be conserved.

→ If an electron is produced, it must be created in association with a positron (its antiparticle, with electric charge and leptonic number of opposite sign) as expected from the Dirac theory.

Each of these three interactions is associated with a charge: electric charge, weak charge and strong charge.

*A particle is subject to an interaction if and only if it carries the corresponding charge*:

– Leptons and quarks carry weak charge.
– Quarks are electrically charged, so are some of the leptons (e. g., electrons).
– Strong (Colour) charge is only carried by quarks (not by leptons).

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