General Approach to Physics Limits of Ultimate Colliders

WEPAB017

Vladimir Shiltsev, FNAL, PO Box 500, Batavia, IL 60510 USA

shiltsev@fnal.gov

Abstract:

This paper presents an attempt to evaluate limits on energy, luminosity and social affordability of the ultimate future colliders - linear and circular, proton, electron positron and muon, based on traditional as well as on advanced accelerator technologies. .

Limits on *Energy* (1)

- Linear vs Circular

$$\Delta U_{SR} = \frac{90\,\mathrm{keV}\cdot E_e^4(\mathrm{GeV})}{R[\mathrm{m}]}$$

$$\Delta U_{SR} < E_e$$

$$E_e < 500\,\mathrm{GeV}\cdot\left(\frac{R}{10\,\mathrm{km}}\right)^{1/3}$$

for muons: $\times\left(\frac{m_\mu}{m_e}\right)^{4/3}$

$$E_\mu < 600\,\mathrm{TeV}\cdot\left(\frac{R}{10\,\mathrm{km}}\right)^{1/3}$$

for protons: $\times\left(\frac{m_p}{m_e}\right)^{4/3}$

$$E_p < 10\,\mathrm{PeV}\cdot\left(\frac{R}{10\,\mathrm{km}}\right)^{1/3}$$

- Particles don't survive acceleration

$$dN/dt = -N/\gamma\tau_0$$

$$\frac{N}{N_0} \approx \left(\frac{m_\mu c^2}{E}\right)^{\kappa}, \quad \kappa = (m_\mu c/\tau_0 G)$$

Physics–Uspe

  - Unstable particles

for muons $G \gg 3\ \mathrm{MeV\ m^{-1}}$

for τ-leptons $G \gg 0.3\ \mathrm{TeV\ m^{-1}}$

  - Lossy transport from cell to cell (loss in plasma material, c-t-c efficiency)

$$\left(1-\frac{\Delta N}{N}\right)^M \lesssim 1$$

$$M = \frac{E}{\Delta E_{cell}} = \frac{5\,\mathrm{TeV}}{5\,\mathrm{GeV}} = 10^3$$

$$M\cdot\frac{\Delta N}{N} \lesssim 1 \Rightarrow \frac{\Delta N}{N} < 10^{-3}$$

lab

Circumference 100 km, B<16 T, *E<50 TeV*

Circumference 40,000 km, B=1 T, *E<1.3 PeV*

Length 50 km, G<0.1 GV/m, *E<5 TeV*

Length 10 km, G<1 TV/m, *E<10 PeV*

Limits on E, L, C, P, size, etc

Probability ≈ Cost^2/(1+Cost^4)

! WARNING !

The *αβγ* cost model:

$$\mathrm{Cost(TPC)} = \alpha\, L^{1/2} + \beta\, E^{1/2} + \gamma\, P^{1/2}$$

a) **Is for a "green field" facility !**
b) **US-Accounting !**
c) **There is hidden correlation btw *E* and technology progress**
d) **Pay attention to units**(10 km for *L*, 1 TeV for *E*, 100 MW for *P*)
   - **α≈ 2B$/sqrt(L/10 km)**
   - **β≈ 10B$/sqrt(E/TeV)** for SC/NC RF
   - **β≈ 2B$ /sqrt(E/TeV)** for SC magnets
   - **β≈ 1B$ /sqrt(E/TeV)** for NC magnets
   - **γ≈ 2B$/sqrt(P/100 MW)**

USE AT YOUR OWN RISK!

COPYRIGHT © 2007 FOURTH CORNER EXCHANGE

Limits on luminosity:

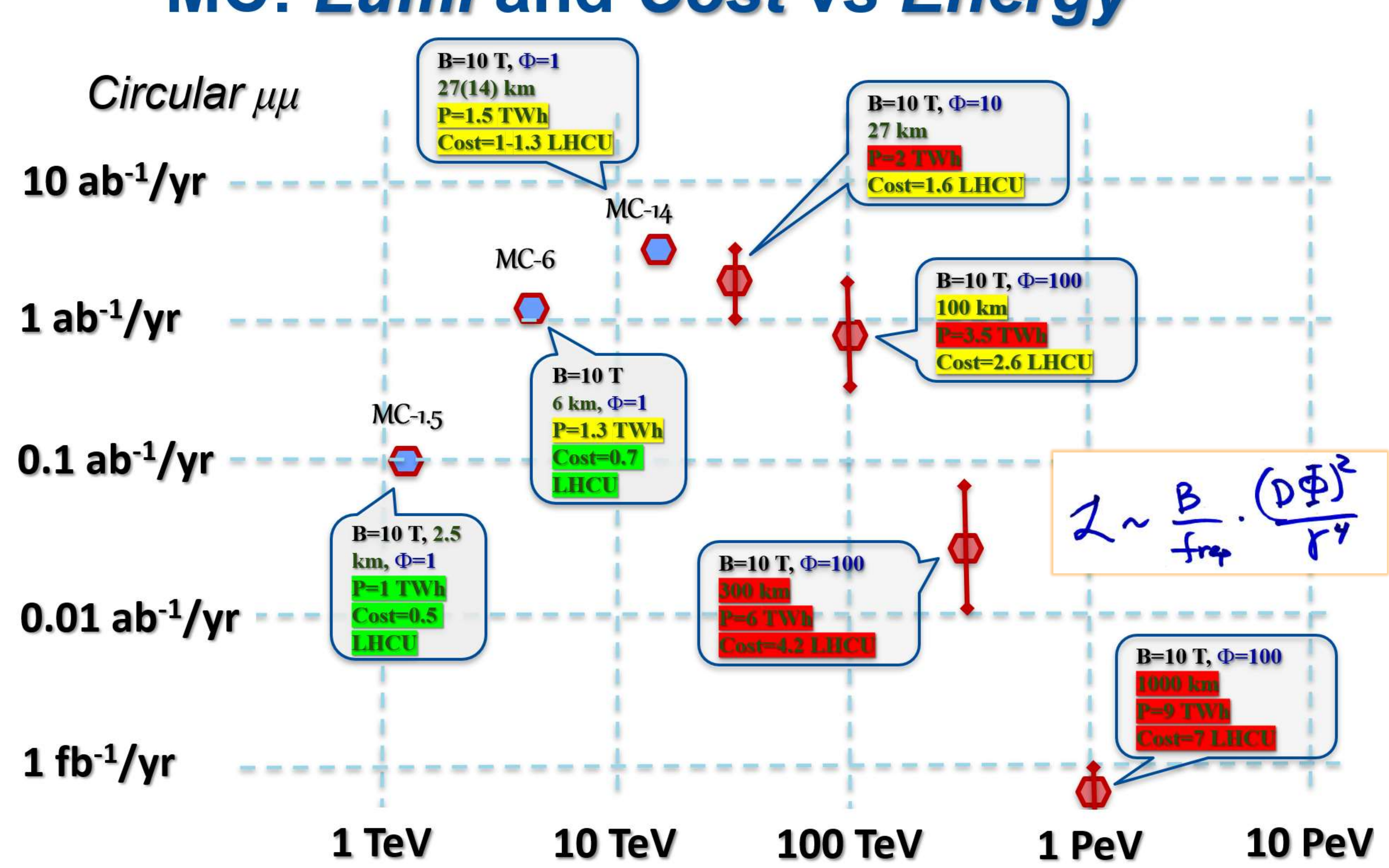
beam power

beam-beam limit… space-charge limit…beam loading…event pile-up…

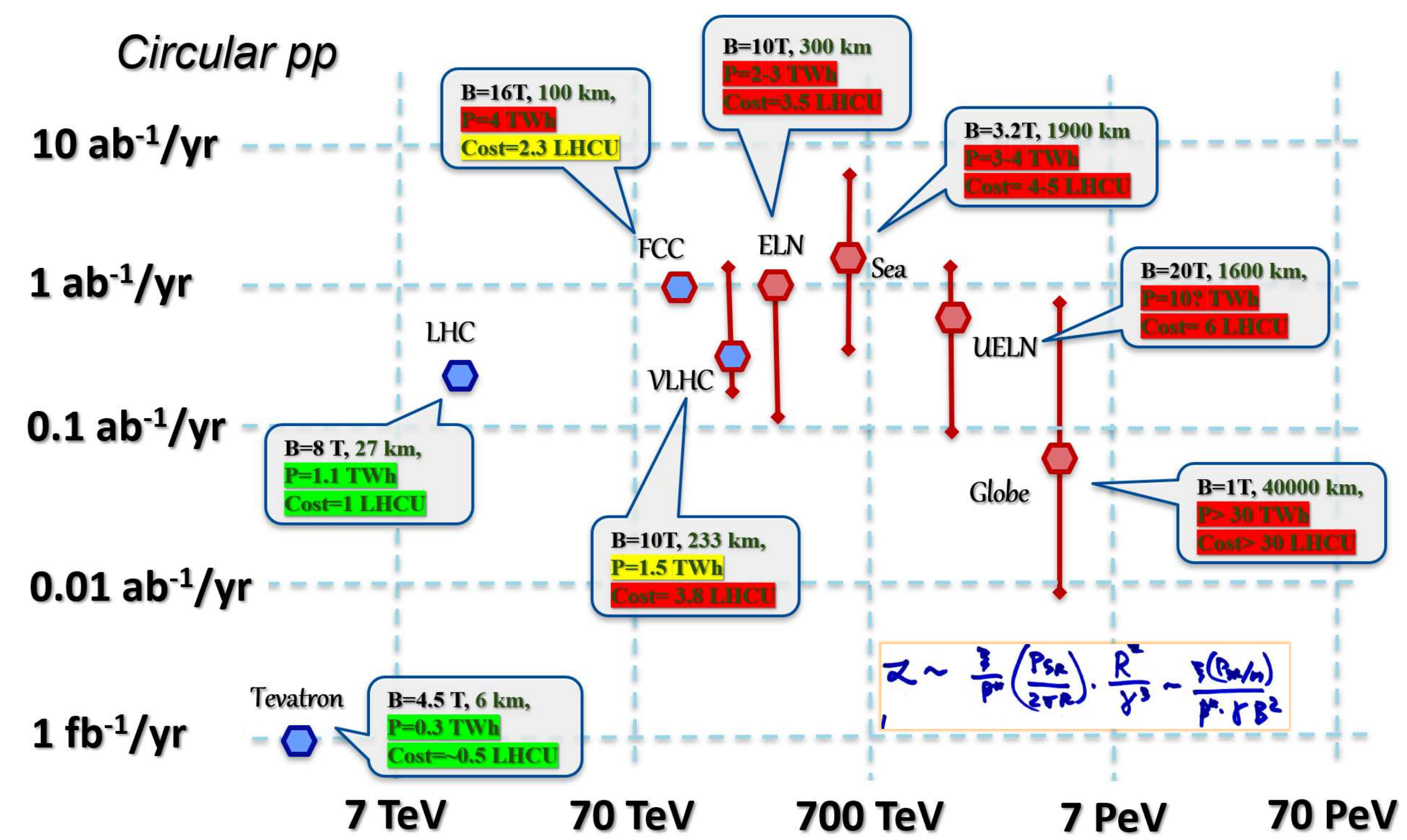
particle production…beamstrahlung…synchrotron radiation… SR/m…

IR rad damage…ν-radiation dose… instabilities…jitter/emittance growth

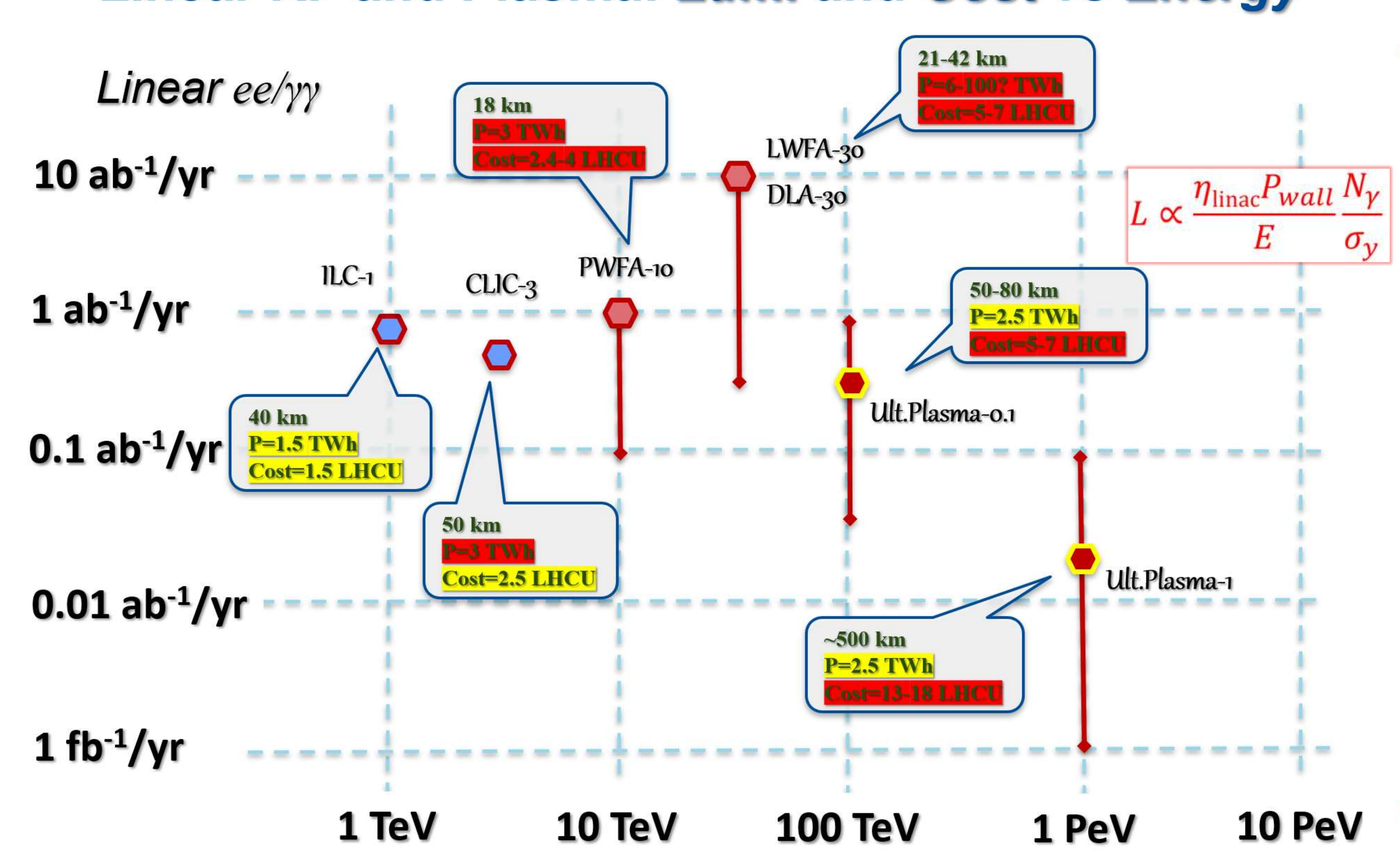
MC: *Lumi* and *Cost* vs *Energy*

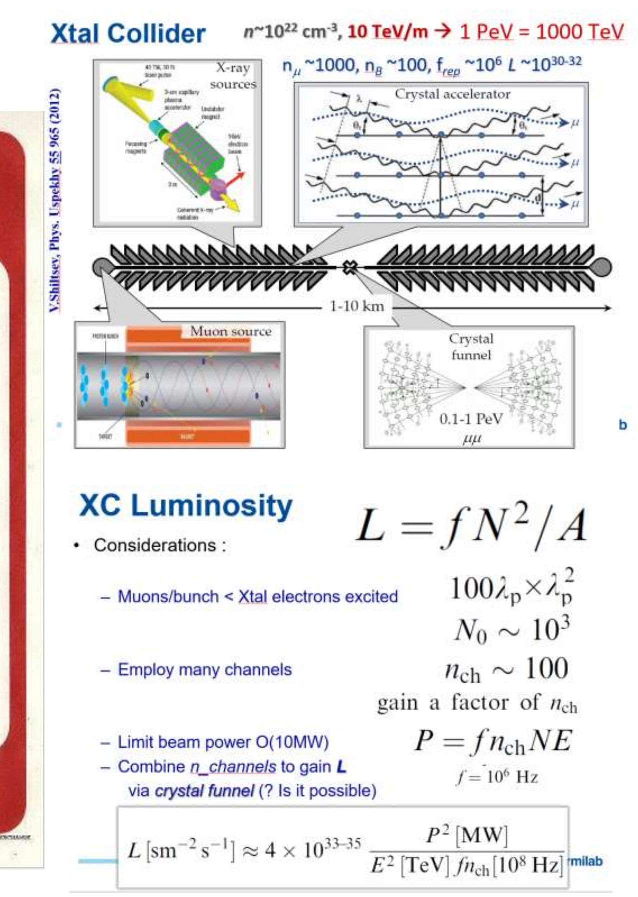


pp Colliders: *Lumi* and *Cost* vs *Energy*

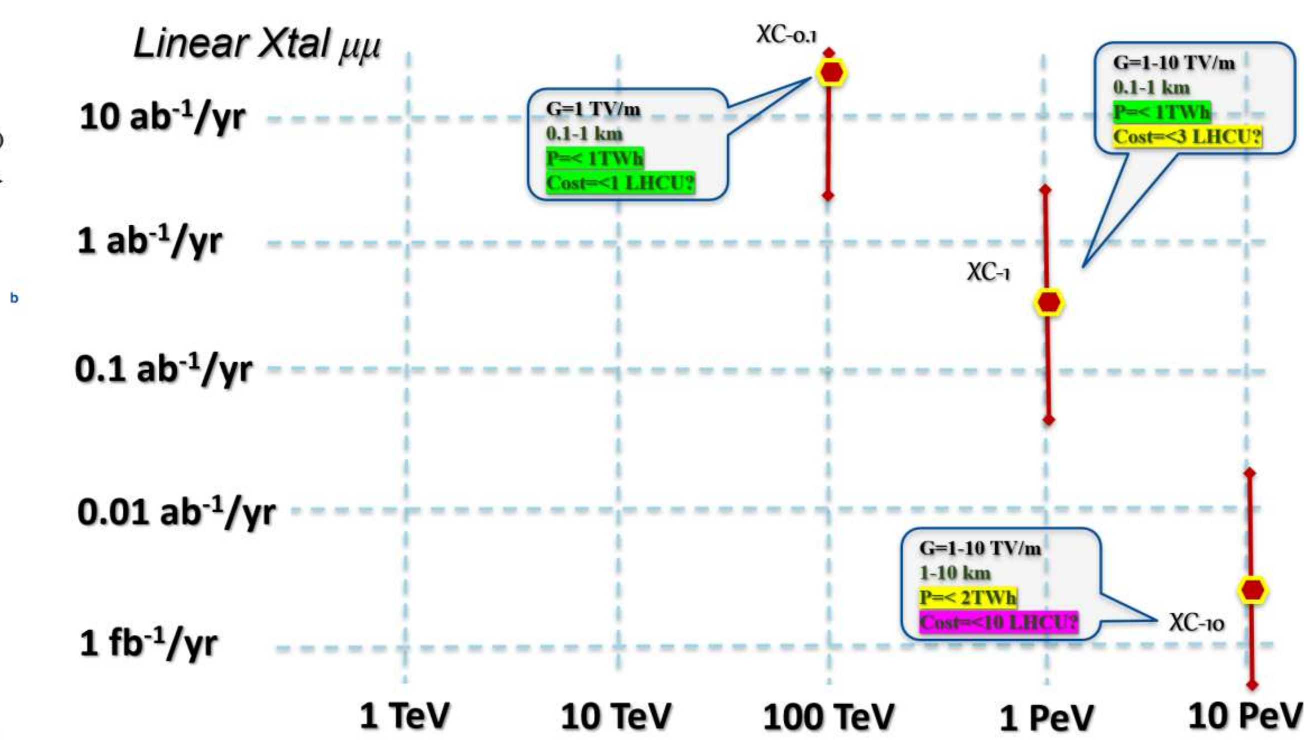


Linear RF and Plasma: *Lumi* and *Cost* vs *Energy*





Xtal Colliders: *Lumi* and *Cost* vs *Energy*



Main Conclusions:

- **For ultimate high energy colliders:**
  - **Major thrust is *Energy***
  - **Major concern/limit *is Cost***
  - **Main focus is *Luminosity* and *Power***
- **Cost:**
  - **Critically dependent on core acceleration technology**
  - **Existing injectors and infrastructure greatly help**
- **High *Energy* means low *Luminosity* :**
  - **Don't expect more than 0.1-1 ab^{-1}/yr at 30TeV-1 PeV**
  - **Assume *Power* limited to 1-3 TWh/yr**
- **For considered collider types:**
  - **Circular *pp* – limit is close or below 100 TeV (14 TeV cm)**
  - **Circular ee – limit is ~0.4-0.5 TeV**
  - **Circular *μμ* – limit is between 30 and 100 TeV**
  - **Linear RF *ee/γγ*, Plasma *ee/γγ* – limit is between 3 and 10 TeV**
  - **Exotic crystal *μμ* – promise of 0.1-1 PeV, low Luminosity**
- **Muons are particles of the future**