Colliders - “*Quo Vadis?*”

past 20 years, next 20 years and beyond

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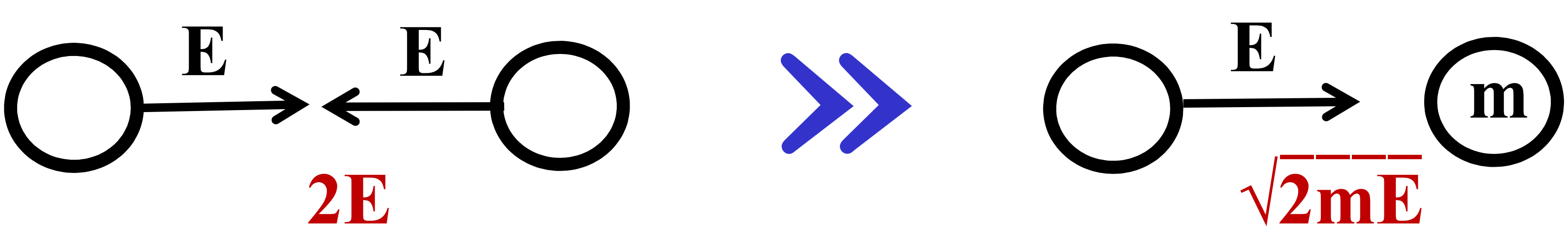
Colliders

Invented in 1956 (if not earlier)

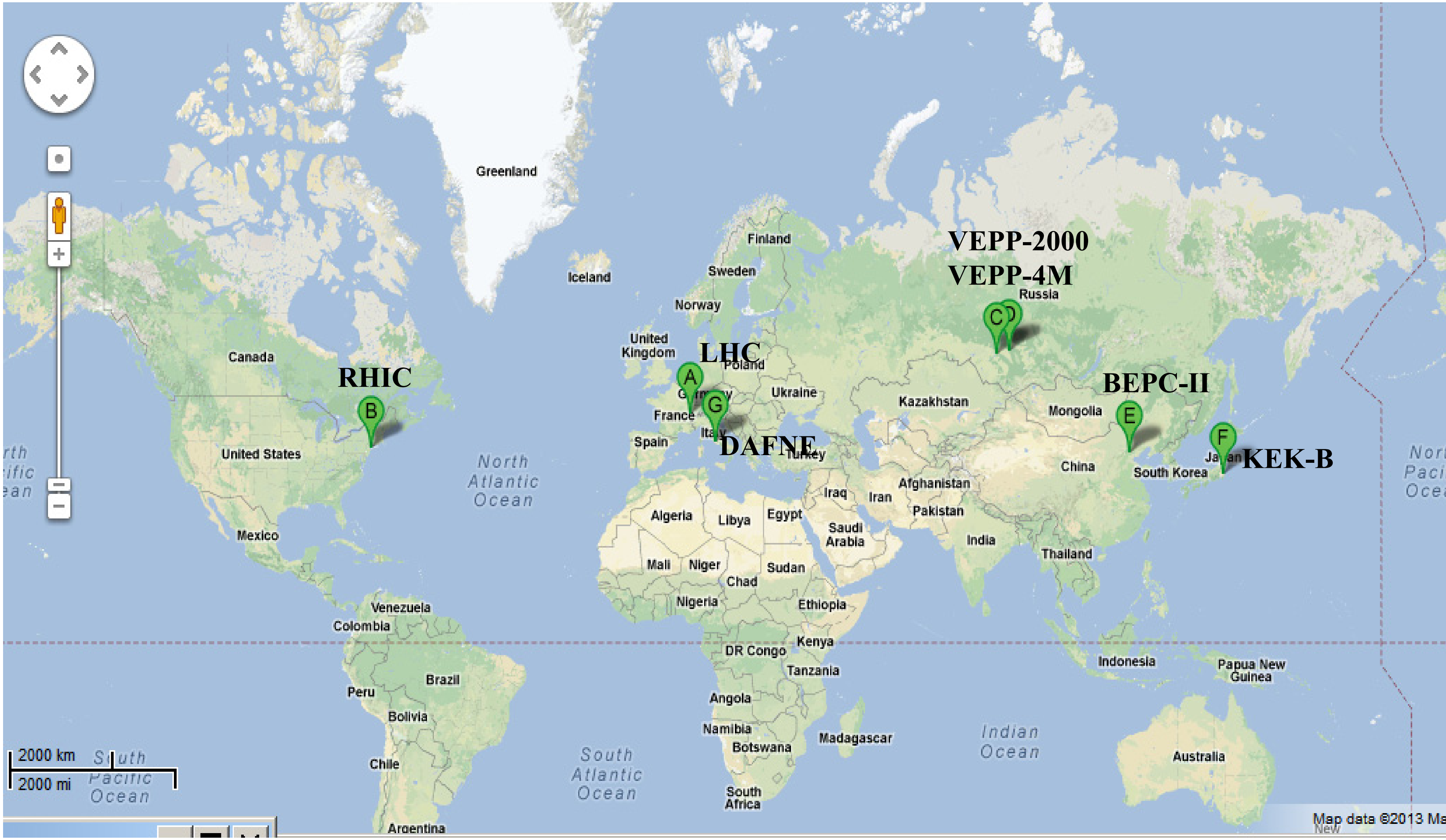
First collisions detected in 1964 (50 years!)

"…It is estimated that [since then] accelerator science has influenced almost 1/3 of physicists and physics studies and on average contributed to physics Nobel Prize-winning research every 2.9 years. " **Haussecker&Chao** ***Physics in Perspective*** **13** 146 (2011)

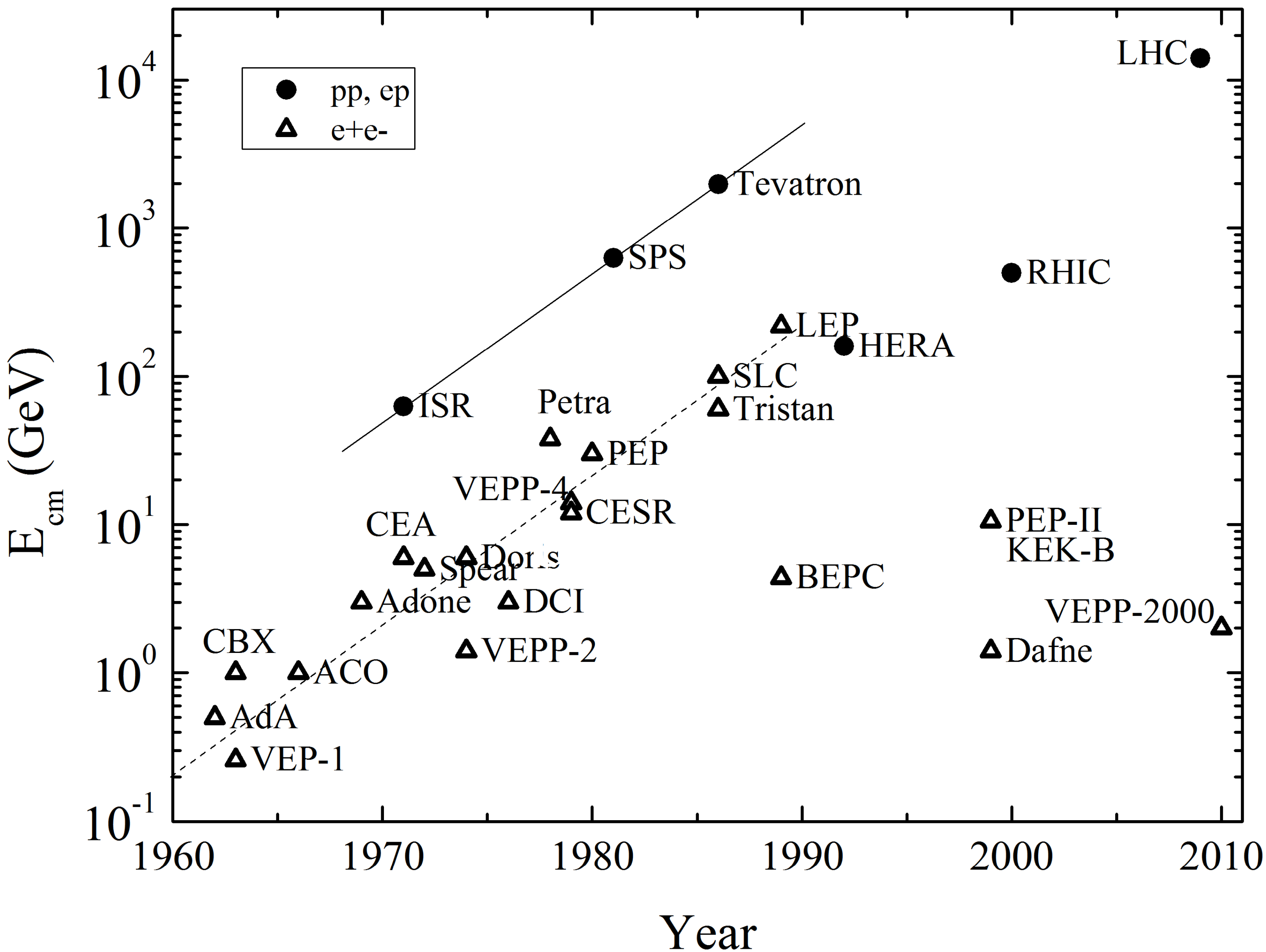
The (only) reason is **ENERGY**



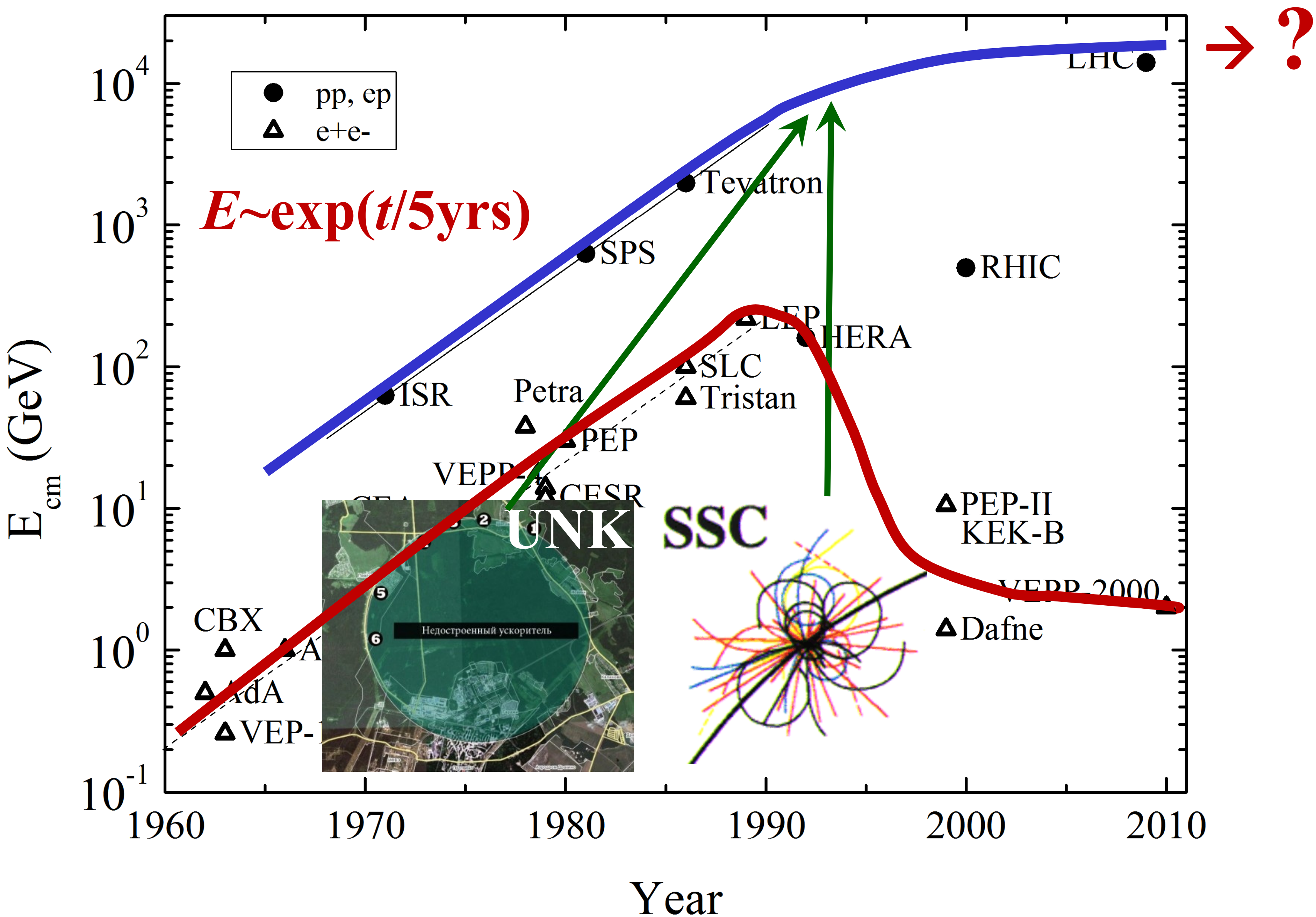
29 Built… 7 in Operation Now



Colliders: Glorious Past

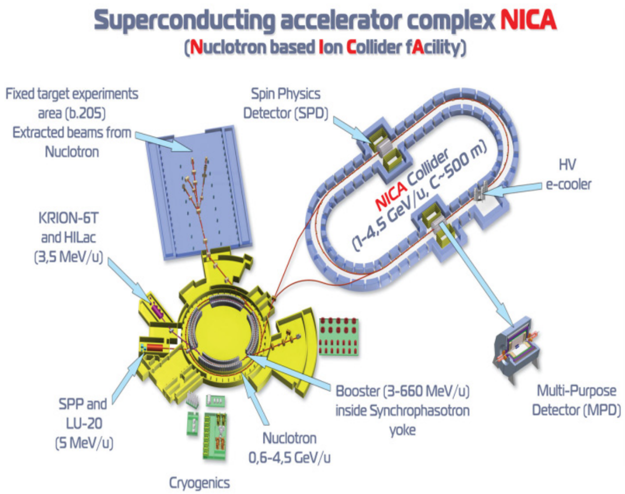


Colliders: Glorious Past

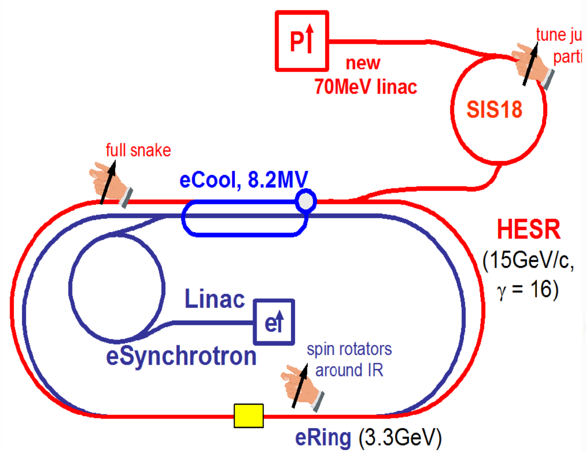


Colliders for Tomorrow (ca 2020)

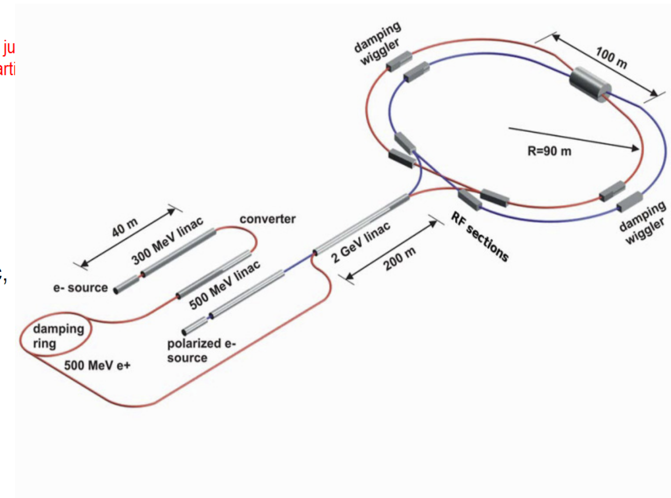
Dubna: 1-4.5 GeV/amu
ion-ion (p,..Au^{+79}) ~10^{27} cm^{-2} s^{-1}



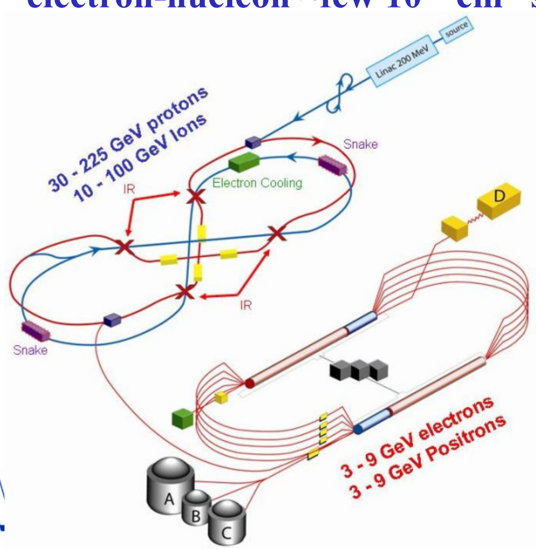
ENC at FAIR: ~15 GeV cm
electron-nucleon ~10^{32} -10^{33}cm^{-2}s^{-1}



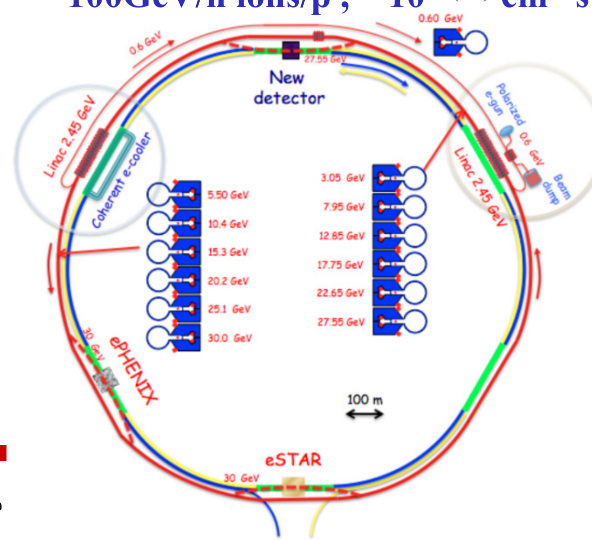
C-Tau factory in Novosibirsk:
2-5 GeV cm e+e- ~10^{35} cm^{-2}s^{-1}



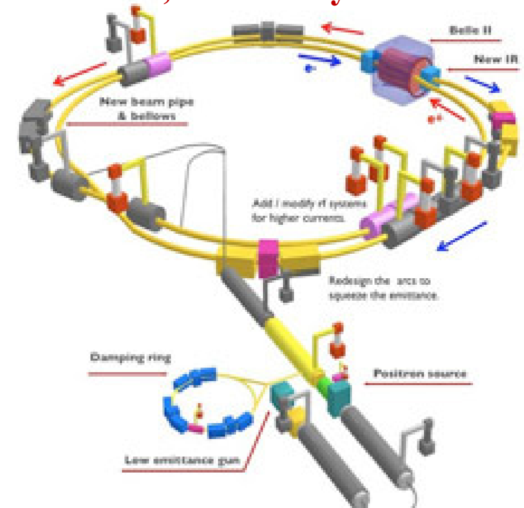
ELIC at JLab: ~50 GeV cm
electron-nucleon ~few 10^{34} cm^{-2}s^{-1}



eRHIC at BNL: ~20 GeV e-,
100GeV/n ions/p , ~$10^{32(34)}$ cm^{-2}s^{-1}



Super-KEKB Factory
4+7 GeV e+ e-, luminosity ~10^{36} cm^{-2}s^{-1}



Colliders for Tomorrow (ca 2030)

- LHC:
  - high-luminosity LHC (x5 design L)
  - LHeC
- Lepton Colliders
  - ILC
  - CLIC
  - $\mu+\mu-$ Collider
- Higgs Factory:
  - linac based *e+e-*
  - ring based *e+e- or* $\mu+\mu-$

Depend on:

LHC results

(Cost/Performance)

Feasibility

Let's Talk About

MONEY

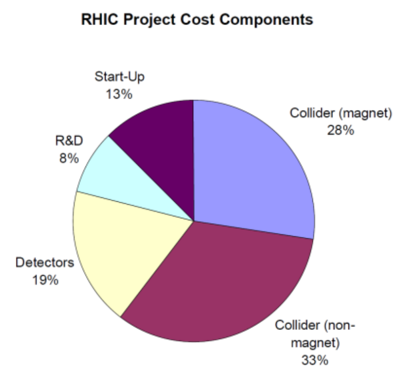
... scientifically, no emotions

Scale of Numbers

- **US HEP** budget is ~0.8 B$ / year
  - ➢Can(?) shoot for (25% x 0.8B$ x 10 yrs) = **2 B$**
  - ➢with int'l partners x 2 (?) = **4 B$**
- **World's** Particle Physics ~3 B$ / year
  - ➢can possibly afford "global" **8-12 B$ project**
  - ➢ will require **all of us** as **>1000 experts needed**
  - ➢ "one machine for all" = no domestic **for 2 out of 3**

"Known" Costs for 15 Machines

- **Actual**
  - RHIC, BFs, SNS, LHC
- **Under construction**
  - XFEL, FAIR, ESS
- **Future**
  - SSC, VLHC, NLC, PrX, ILC, CLIC, SPL, NuFACT



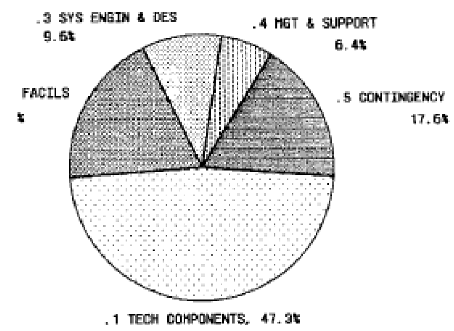
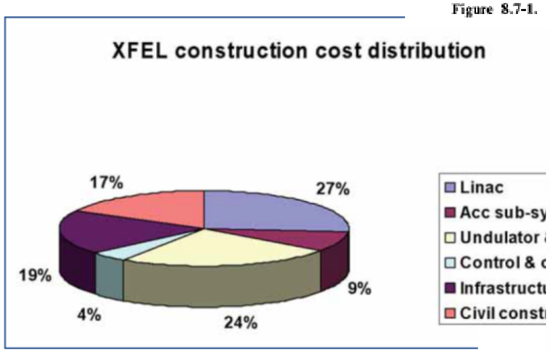
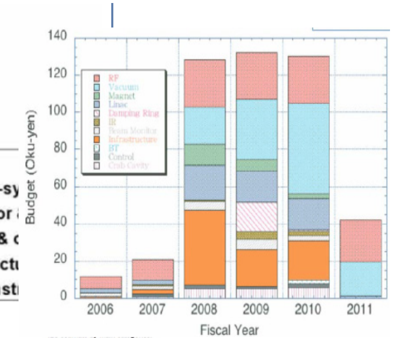
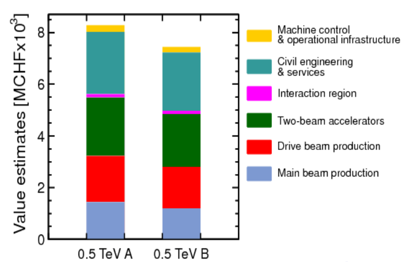
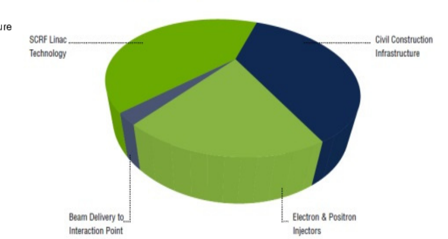


Figure 8.7-1. SSC cost estimate summary: Level 2 WBS categories.









It is possible to parameterize the cost for known technologies

Phenomenological Cost Model

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

"Total Project Cost in the US accounting"

"Tunnel Length" Civil Construction

"Energy" – Cost of Accelerator Components

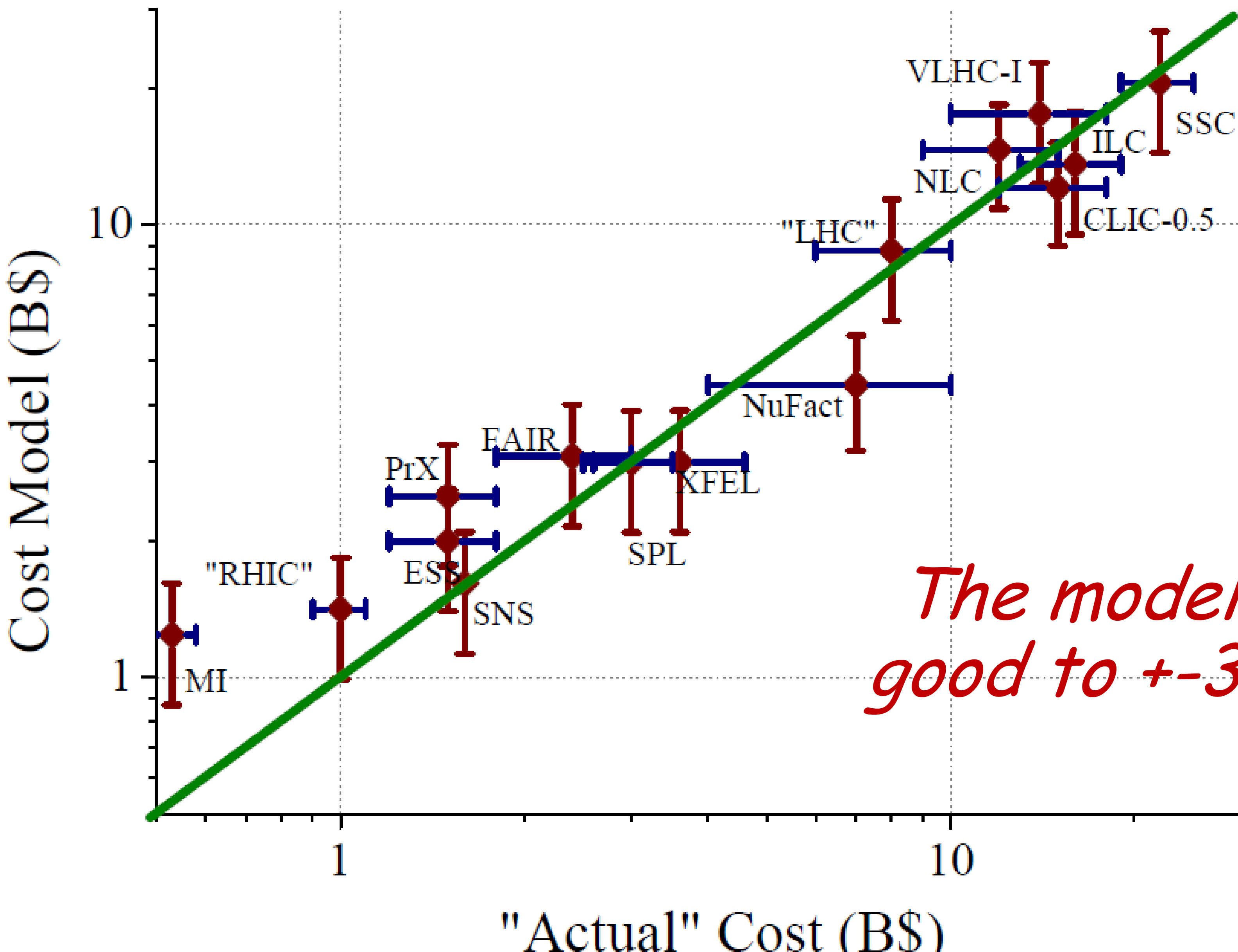
"Site Power" Infrastructure

where α,β,γ - technology dependent constants

- α≈ 2B$/sqrt(L/10 km)
- β≈ 10B$/sqrt(E/TeV) for RF
- β≈ 3B$/sqrt(E/ TeV) for SC magnets

  β≈ 1B$ /sqrt(E/TeV) for NC magnets
- γ≈ 2B$/sqrt(P/100 MW)

Total Cost vs Model (Log-Log)



The model is good to +-30%

The *αβγ*-Model Predictions

- **US alone** can afford
  - Proton Driver (Project X)
- **World's Big Project possibilities**
  - Higgs factory ("~ any type")
  - may be Muon Collider or ILC-0.5 TeV
- **What's Beyond our limits**
  - >0.5 TeV e+e- collider ("~ any type")
  - >30 TeV hadron ("~ any type")

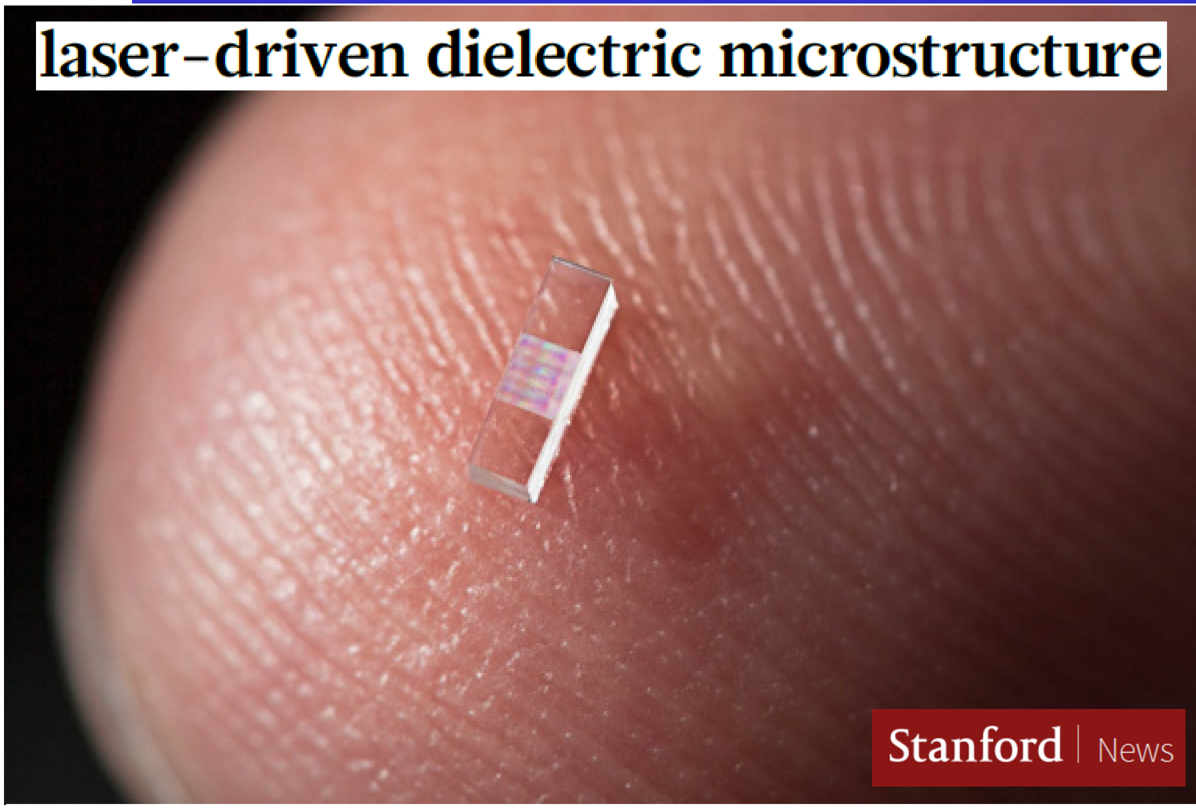
Far Future Colliders: "Phase-Space"

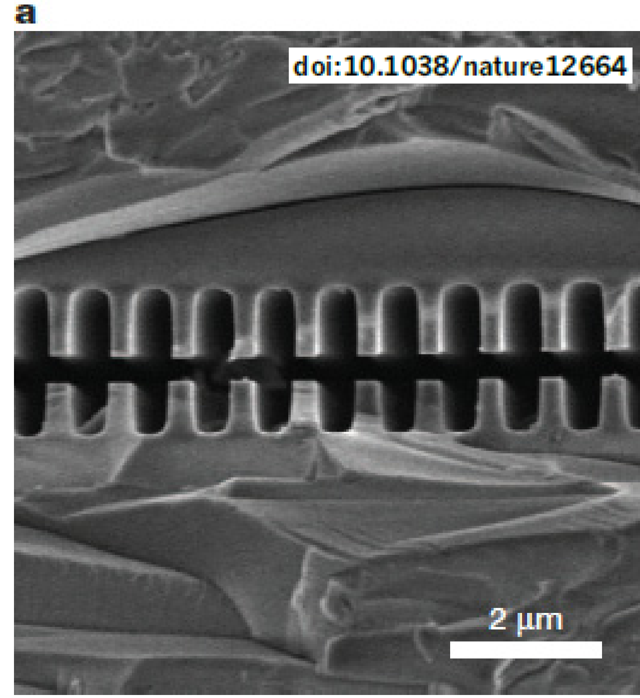
- "Interesting Physics"
  - 100-1000+ TeV (*10-100* × *LHC*)
  - decent luminosity
- "Live within our means":
  - < 10 B$
  - < 10 km
  - < 10 MW (beam power, ~100MW total)

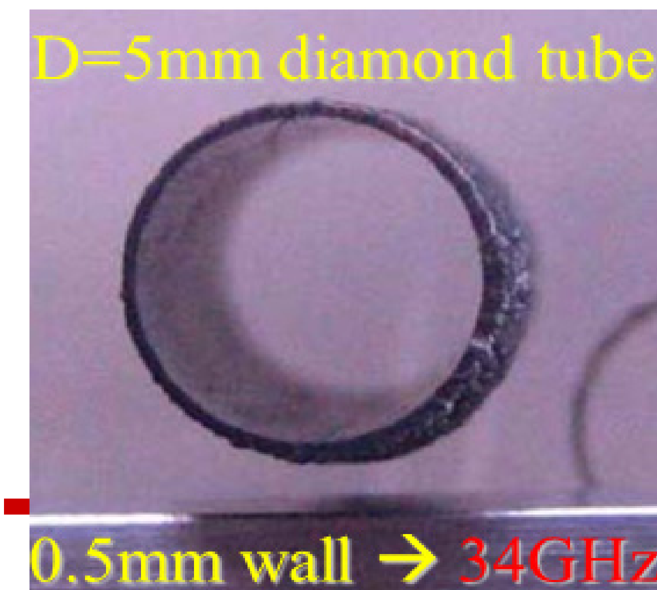
→**The technology should provide >10 GeV/m @ total component cost <1M$/m (~NC magnets now)**

~ 50 MeV per meter

Options: #1 Dielectric Structures







Now ~0.2 GeV/m (optical & X-band)

Can do(?) ~1 GeV/m (diamond @THz)

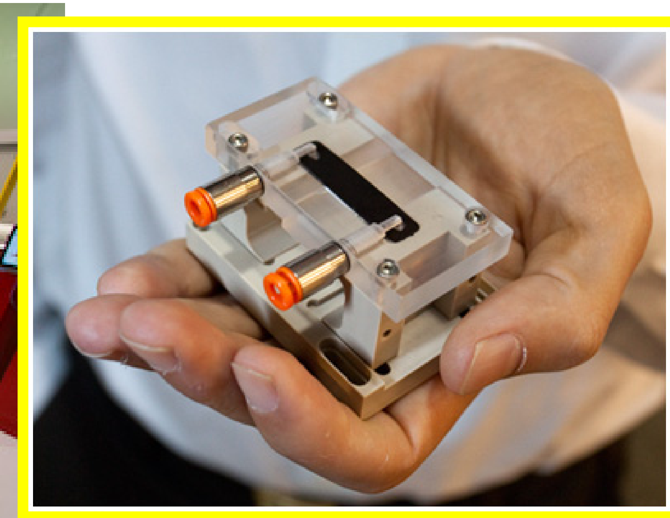
Cost/m – unknown

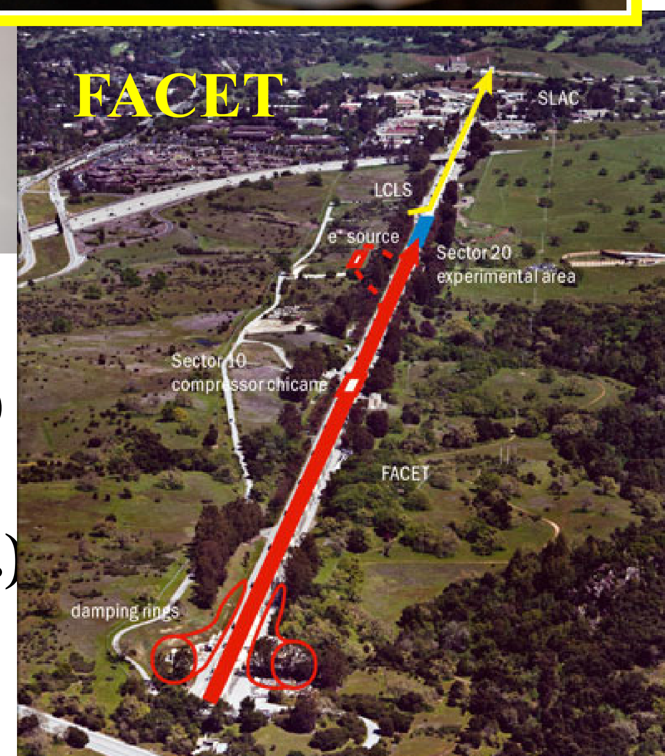
Power ~100MW/TeV (2011 est.)

Luminosity - unknown

… but at >1 TeV electrons radiate

Option #2: Plasma





Now ~10-30 GeV/m (laser & plasma)

Can do(?) ~10 GeV/m (average geometrical)

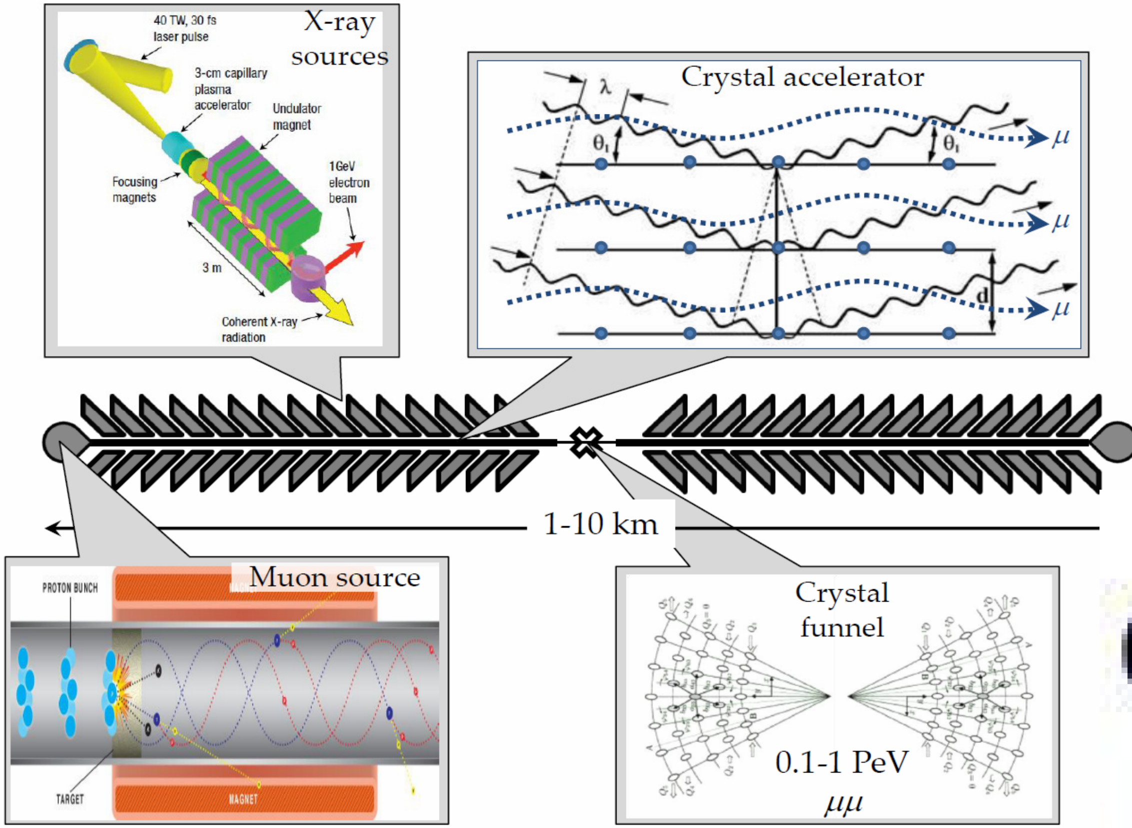
Cost/m ~15M$/10 GeV (now… need <1)

Power MW: 130 /TeV-140/(10TeV) (2011 est.)

Luminosity - unknown (many issues, dE/E)

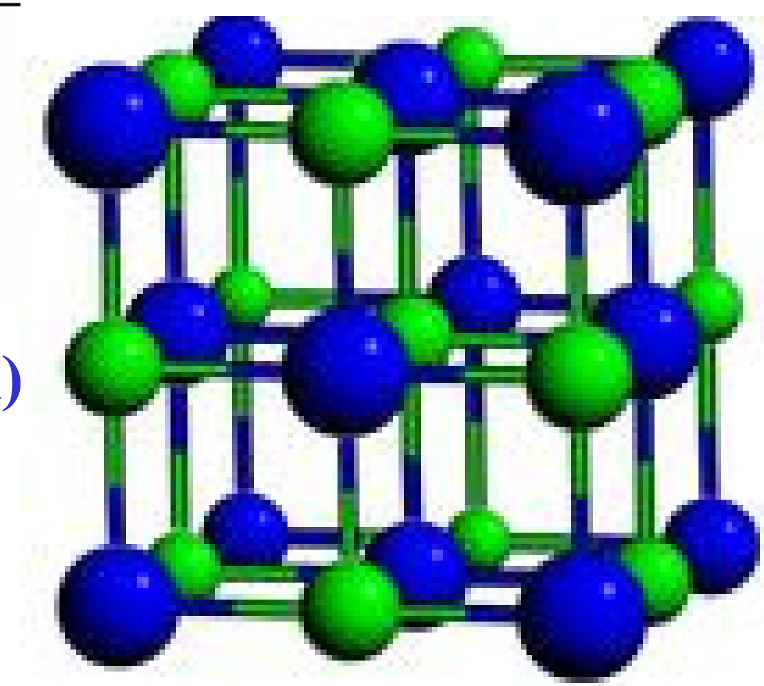
… but at >1 TeV electrons radiate

Option #3: Muons & Crystals



$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$

$\sim 10^{22}$ cm^{-3}, **10 TeV/m**, $\lambda_p \sim 1$A



Can do(??) ~100+ GeV/m (test at ASTA)

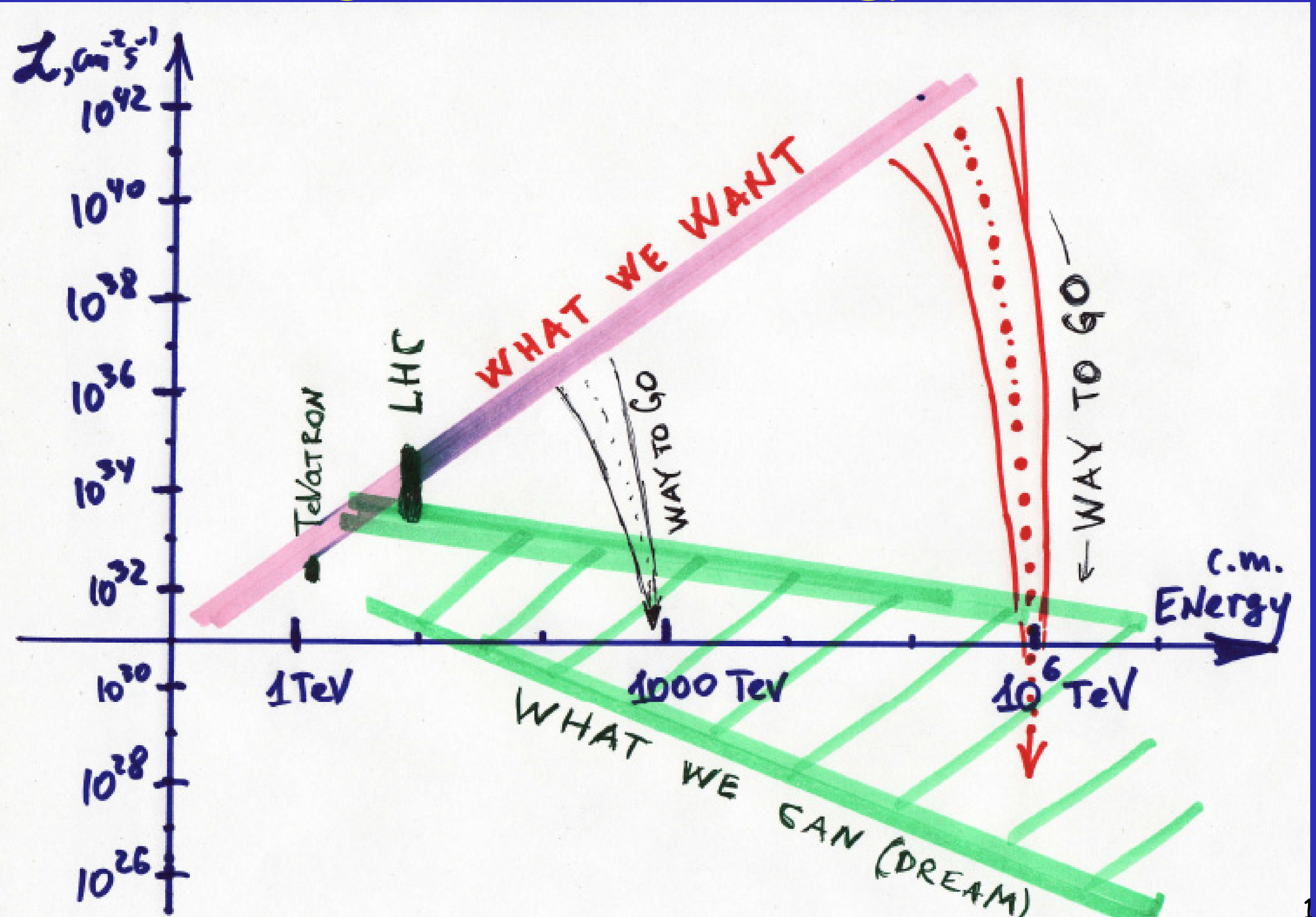
Cost/m unknown

Power MW: unknown

Luminosity - unknown (low)

… and - Muons do not radiate !!

Paradigm Shift : *Energy* vs *Lumi*



Summary

- Colliders=success: 29 built over 50 yrs, ~10 TeV c.m. achieved
- The progress has greatly slowed down due to increasing size, complexity and cost of the facilities. The prospects for the next 20 years depend on the LHC discoveries.
- Realities set constraints on the far-future colliders : <10B$, <10 km, <100MW.
- There is (at least one) conceivable possibility to reach 100-1000 TeV c.m. within these limits (in far future).
- At least three paradigm shifts are needed:
  - development of the new technology based on ultrahigh acceleration gradients ~0.1-10 TeV/m in, e.g., crystals;
  - acceleration of heavier particles, preferably, muons;
  - new approaches to physics research with luminosity limited to $\sim 10^{30\text{-}32}$ $cm^{-2}s^{-1}$.