Future energy frontier colliders in the US and critical accelerator technologies

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Fermilab All-Sci-Retreat, April 8, 2017

Future Energy Frontier in US

- ***Post LHC*** **- 40-500 TeV cme** *pp* **colliders:**
  - finish 87km SSC tunnel, 16 T magnets = 50 TeV cme
  - 233 km VLHC, 2 T superferric magnets = 40 TeV cme
  - 4.5T small SC, 270 km "Texas-tron"/1900 km "sea-tron" = 100/500TeV
- ***Post ILC*** **- 1-10 TeV cme** *e+e-* **colliders:**
  - 1 TeV ILC upgrade with "novel SRF technology"
  - 3 TeV CLIC-type NC RF
  - 1…3…10 TeV plasma beam/laser driven
- ***New Branch*** **- 3,6,…1000 TeV cme** $\mu+\mu-$ **colliders:**
  - "traditional" with 20T SC magnets (Fermilab site filler) 6 TeV cme
  - 16T SC +pulsed magnets in LHC/SPS/PS tunnels 14 TeV cme
  - Same with Low-Luminosity "no cooling scheme"
  - Far-far-future Crystal/CNT acceleration 100-1000 TeV cme, low-*L*
- **Accelerator R&D:**
  - What we do now
  - What we might need to do

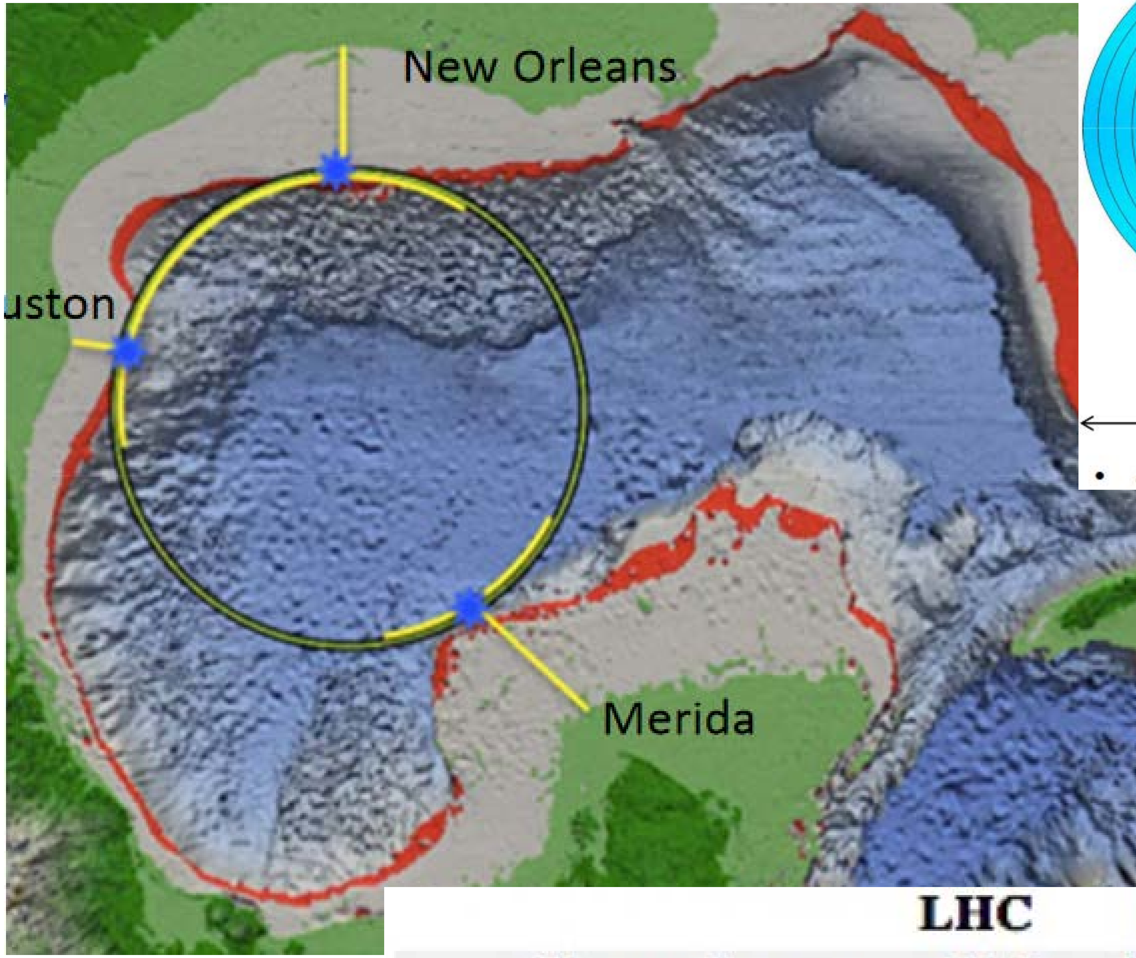
SSC

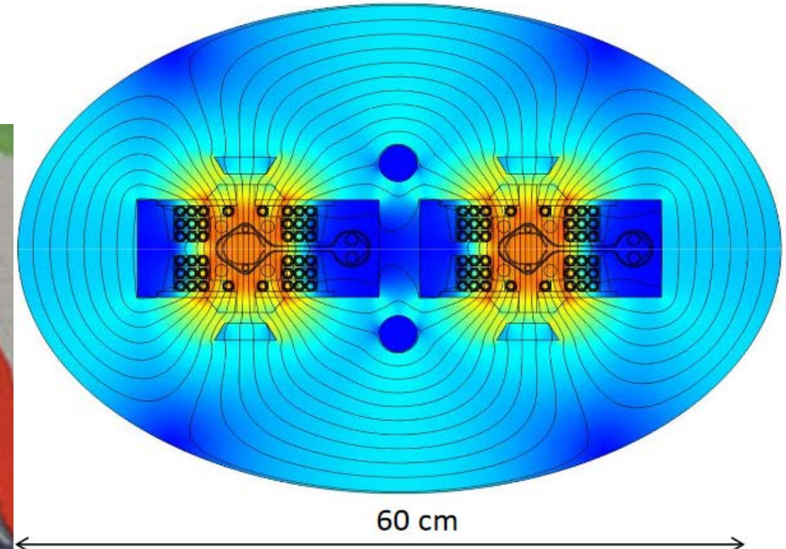
* 23 km out of 87 were bored
* 6.6 T dipoles prototyped

Recently:

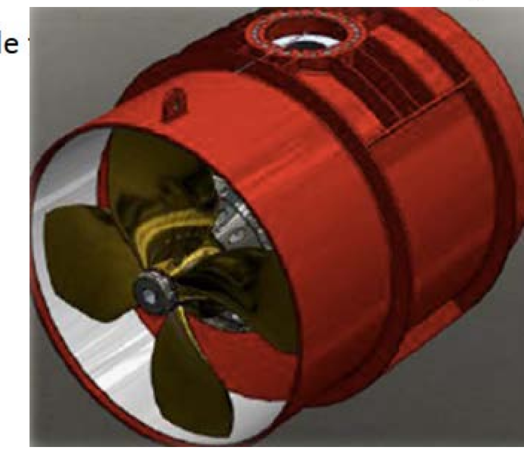
- Cheap tunnel → 270 km
- Cheap magnets 4.5T

1900 km submerged option





- 4.5 Tesla dipole



	LHC	100 TeV		500 TeV	
Circumference	26.7	100	270	1900	km
Collision energy	14	100	100	500	TeV
Dipole field	8.3	16	4.5	3.2	Tesla
Luminosity/I.P.	1.0	5	5	50	$10^{34}cm^{-2}s^{-1}$

VLHC-I:

20+20 TeV p-p
233 km

FNAL-TM-2149 (2001)

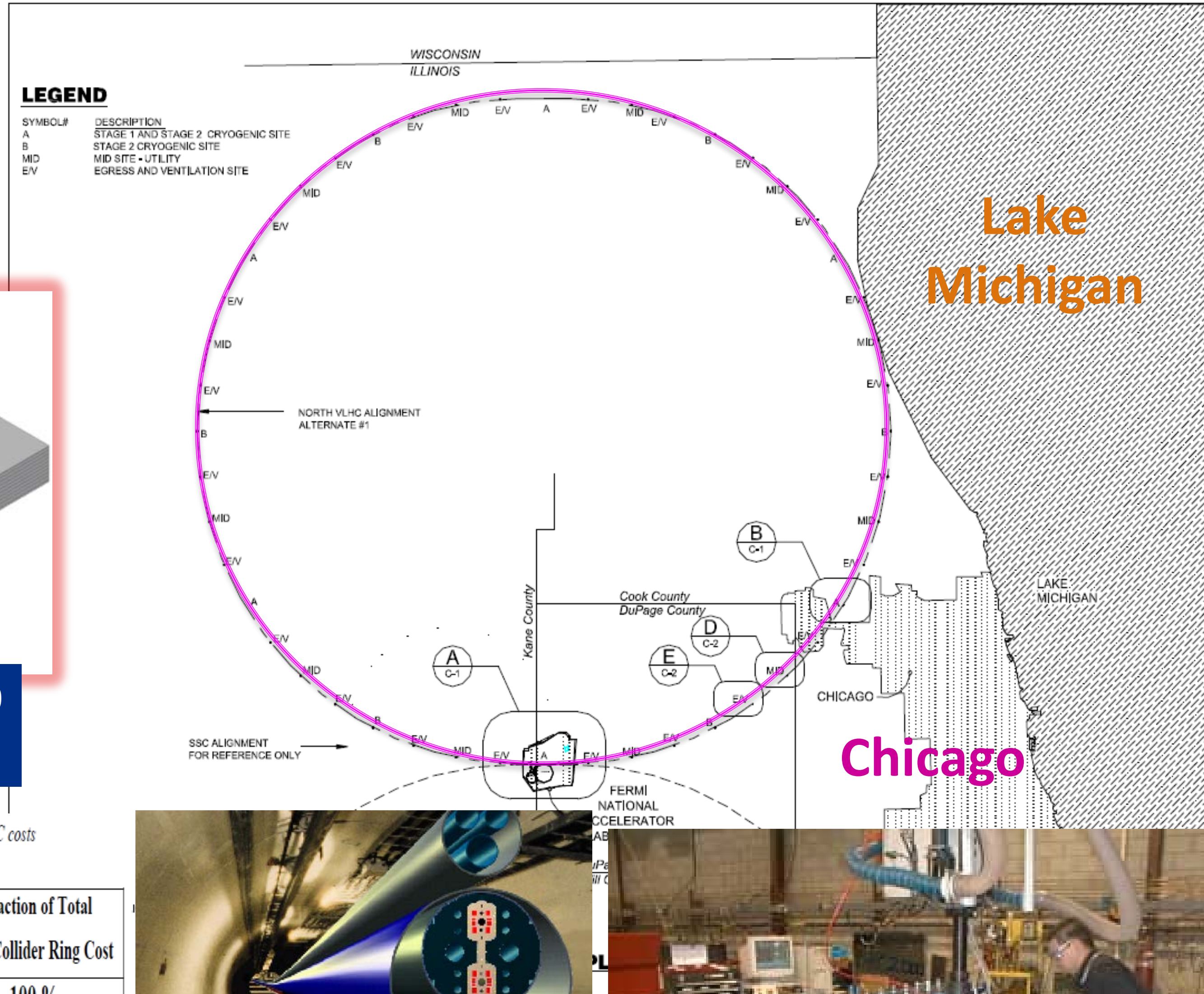
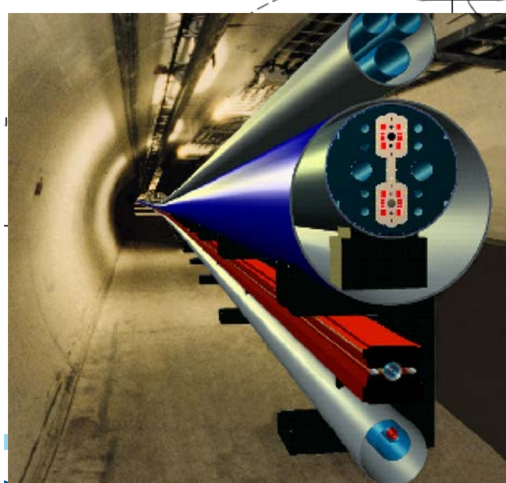


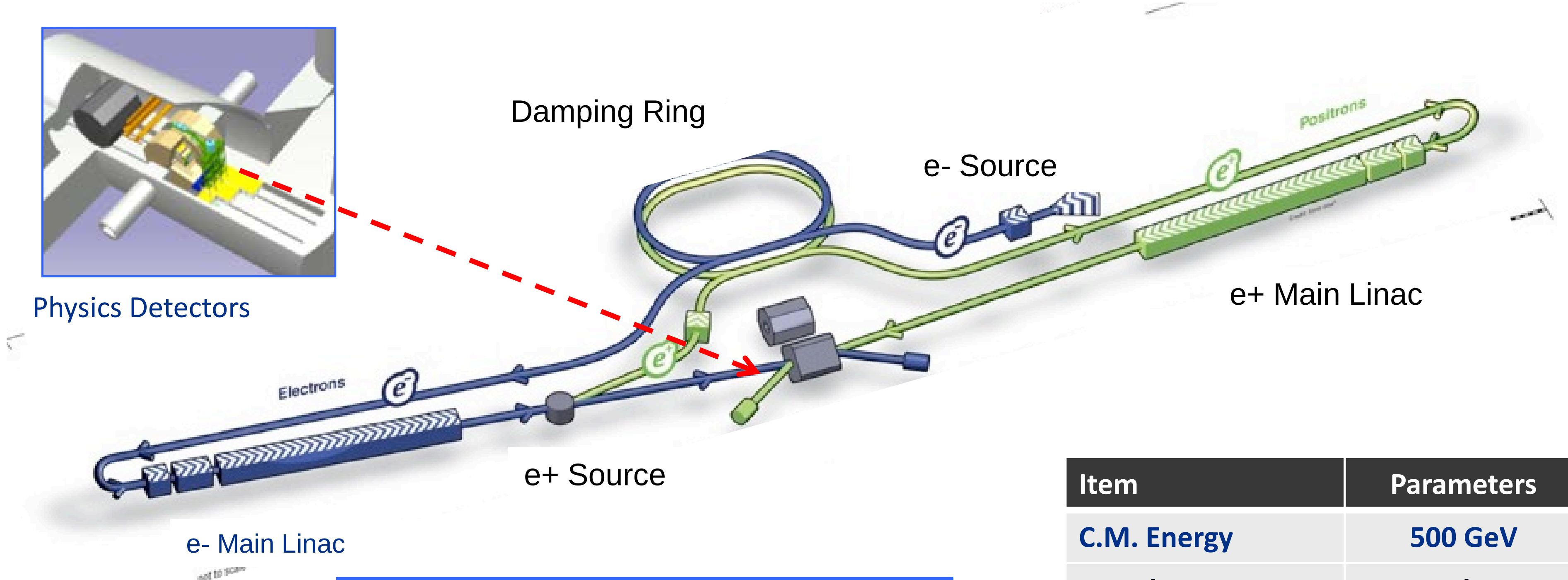
Table 9.3. A comparison by major system of the Stage-1 VLHC costs and the SSC baseline cost escalated to FY2001 dollars.

Collider System	Fraction of total Stage-1 VLHC Cost	Fraction of Total SSC Collider Ring Cost
Total Cost	100 %	100 %
Construction – Below Ground	51 %	15 %
Construction – Above Ground	8 %	5 %
All Magnets (except IR)	22 %	61 %
All Other Collider Systems	19 %	19 %
Total Cost in FY2001 M$	$4,138	$3,790

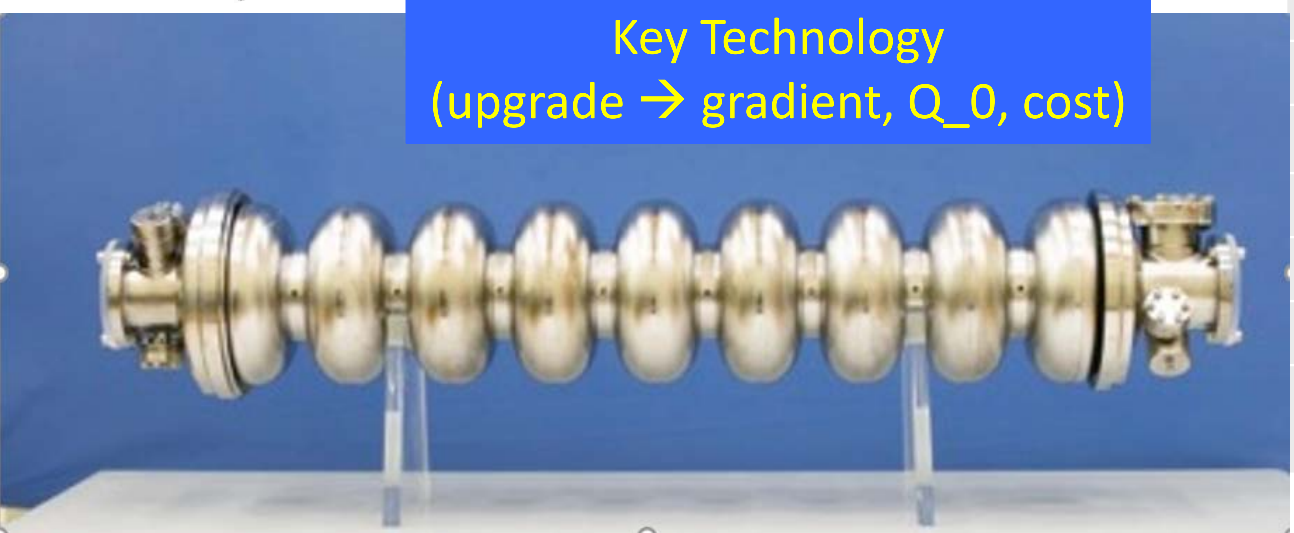


also 100 km ring P.Bhat , et al, arxiv 1306.2369

ILC: 0.5TeV, 230 MW → 1 TeV, ??



Key Technology
(upgrade → gradient, Q_0, cost)



Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA
Beam size (y) at FF	5.9 nm
SRF Cavity G. Q_0	31.5 MV/m Q_0 = 1x10^{10}

NC RF/Klystron based NLC 1 TeV e+e-, 30 km, 250MW

Snowmass 2001 CDR

Two beams concept CLIC: 3 TeV e+e-, ~60 km, 560 MW… then klystrons again

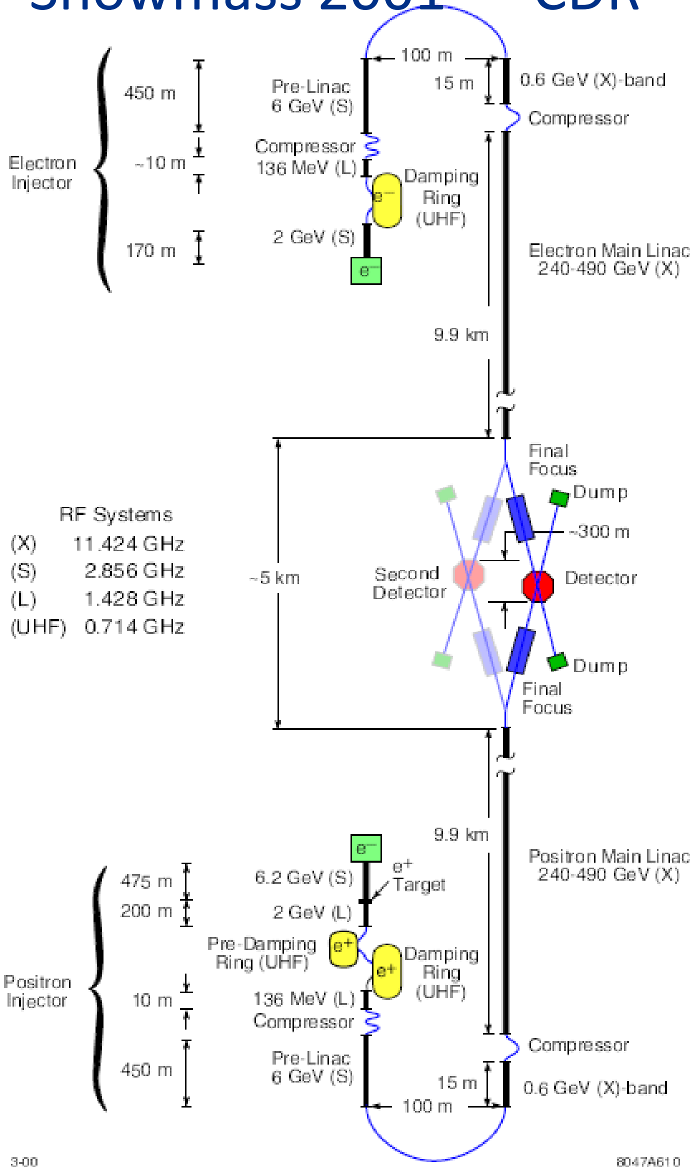
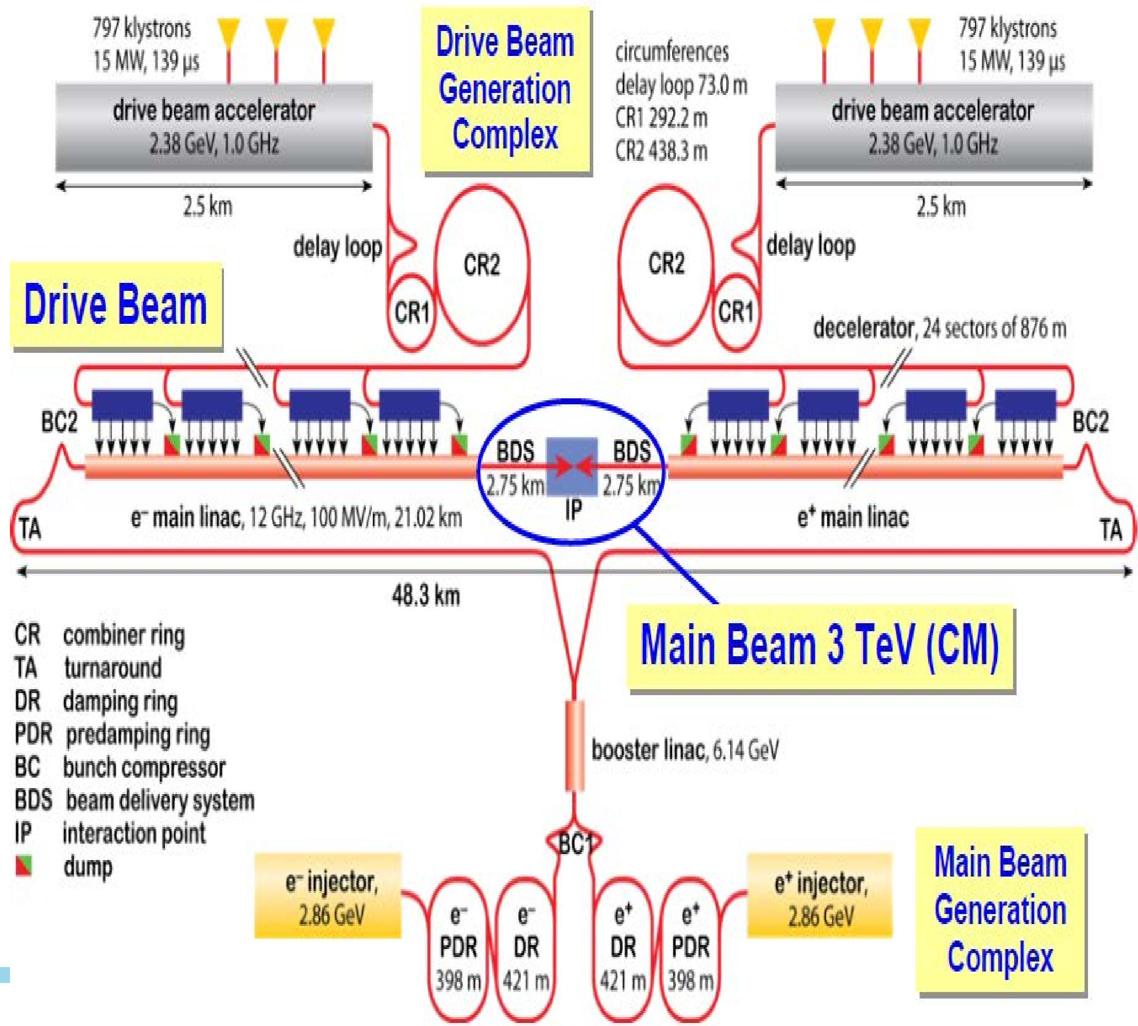
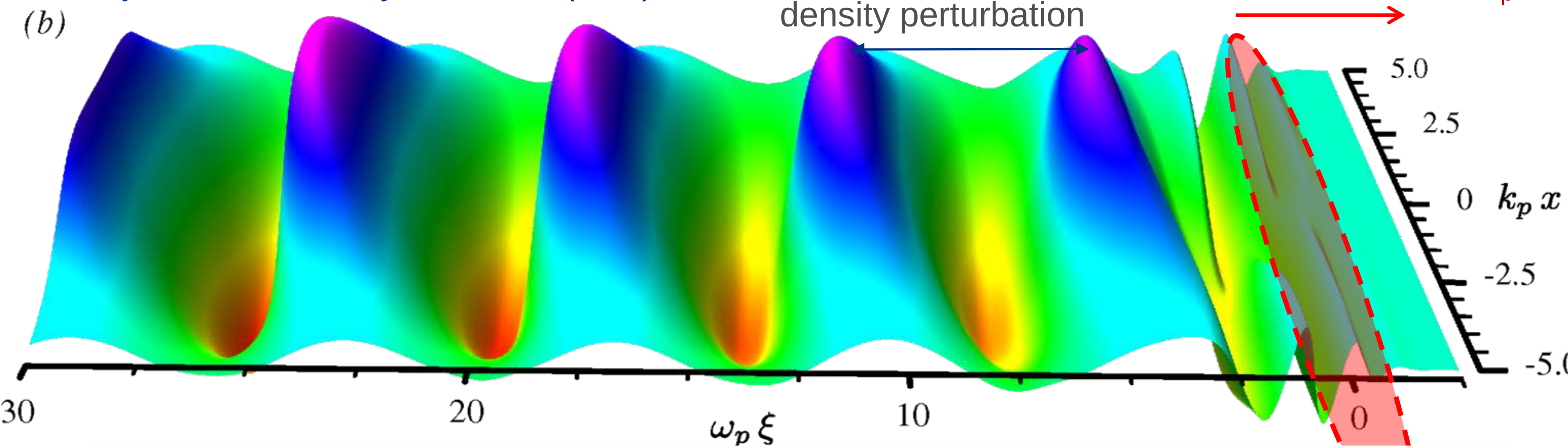


Figure 1: Schematic of the NLC.



Plasma Waves

Idea- Tajima & Dawson, Phys. Rev. Lett. (1979)



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

Option A:

Short intense e-/e+/p bunch

Few 10^{16}cm^{-3}, **6 GV/m** over 0.3m

Option B:

Short intense laser pulse

~10^{18}cm^{-3}, **50 GV/m** over 0.1m

"Plasma-Collider" studies: **staging kills ! <*E*>~2 GV/m,ε**

Design of a 6 TeV muon collider

20 T in dipoles

M-H. Wang[a], Y. Nosochkov[a], Y. Cai[a] and M. Palmer[b]

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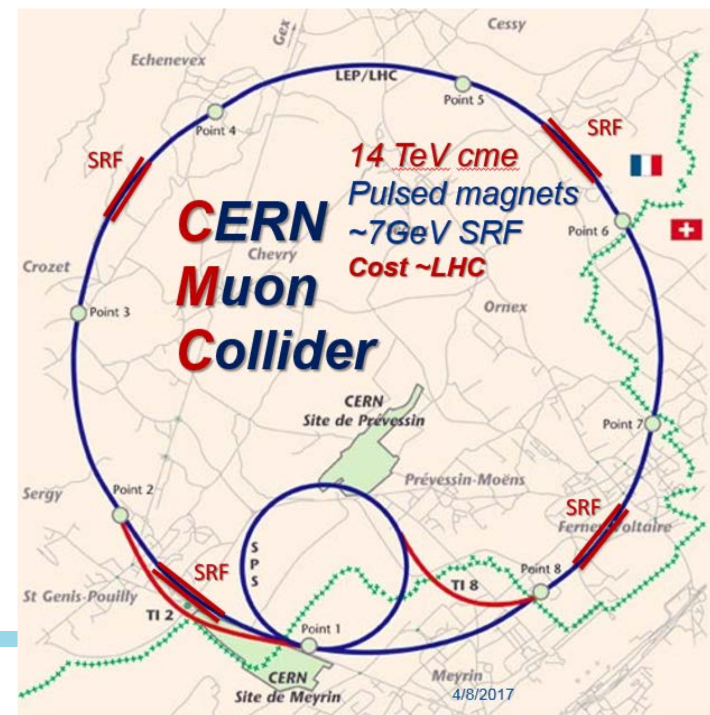
Table 2. Parameters of the 6 TeV muon collider design.

Parameter	**Unit**	**Value**
Beam energy	TeV	3.0
Number of IPs		2
Circumference	m	6302
β^*	cm	1
Tune x/y		38.23/40.14
Momentum compaction		−1.22E-3
Normalized emittance	mm·mrad	25
Momentum spread	%	0.1
Bunch length	cm	1
Muons/bunch	10^{12}	2
Repetition rate	Hz	15
Average luminosity	10^{34} cm^{-2}s^{-1}	7.1



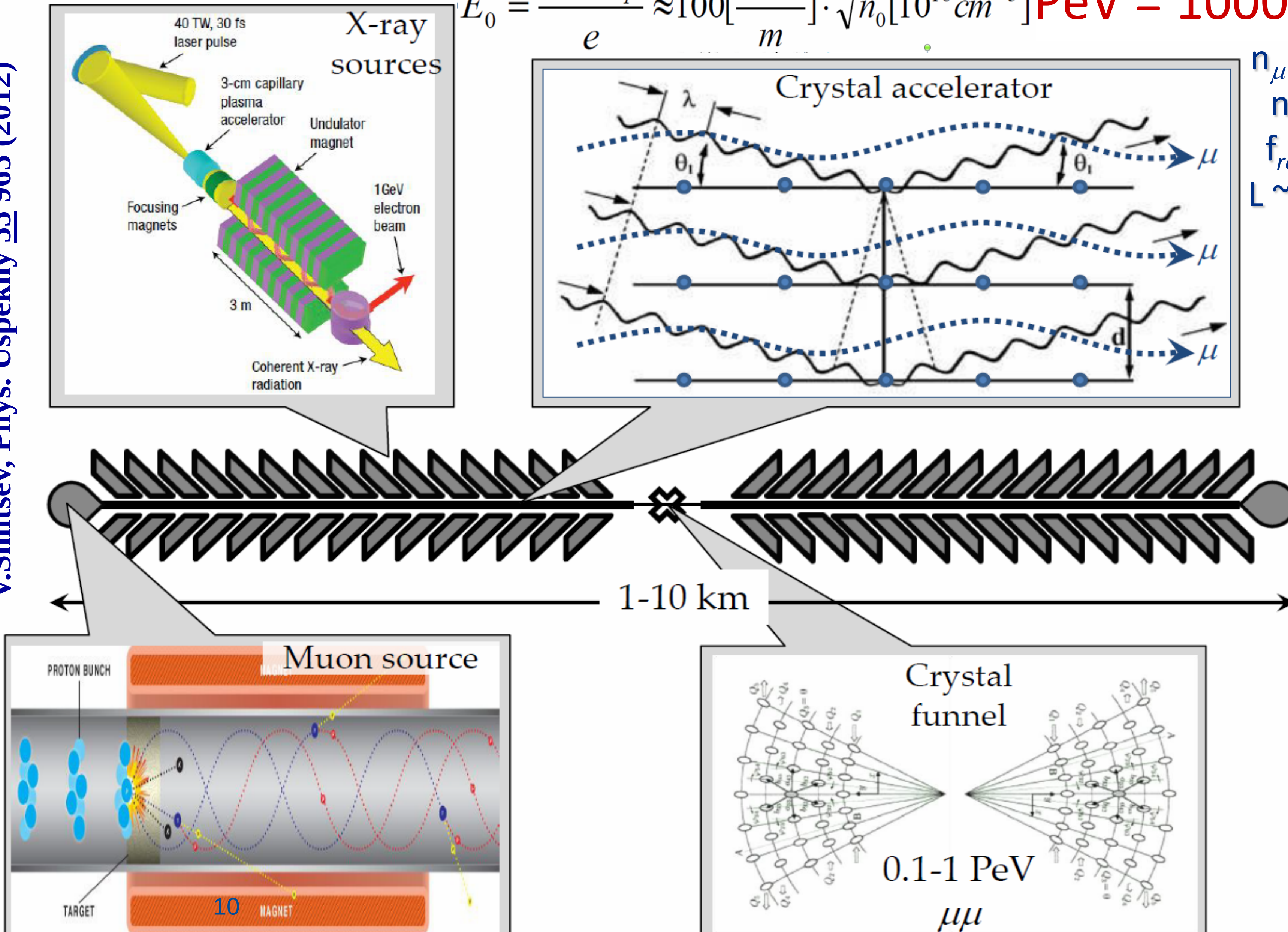
Futuristic: Crystals & Muons

n~10^{22} cm^{-3}, **10 TeV/m →**

$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$ PeV = 1000 TeV

n_μ ~1000
n_B ~100
f_{rep} ~10^6
L ~$10^{30\text{-}32}$

V.Shiltsev, Phys. Uspekhy 55 965 (2012)



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Accelerator R&D at FNAL/US

- Accelerator and Beam Physics
  - Experimental R&D at IOTA/FAST
  - Beam physics, theory, design, modeling
- Advanced Accelerator Concepts
  - Wakefield collider design/analysis, exp'ts
- Particle Sources and Targets
  - High-power targetry R&D
- High-Field Magnets and Materials
  - SC magnets (16 T) and materials (doped)
- RF Accelerator Technology
  - Cost-effective SRF R&D (G, Q, NbCu, Nb3Sn), NC RF R&D (300MeV/m)
- What we might need to explore:
  - Low field HTS magnets
  - Pulsed/fast cycling magnets
  - Muon sources
  - Acceleration in Xtals/CNTs
  - Graphene/borophene conductors