Bigger, brighter, more powerful…
Where Are We Going in the Field of High Energy Accelerators?

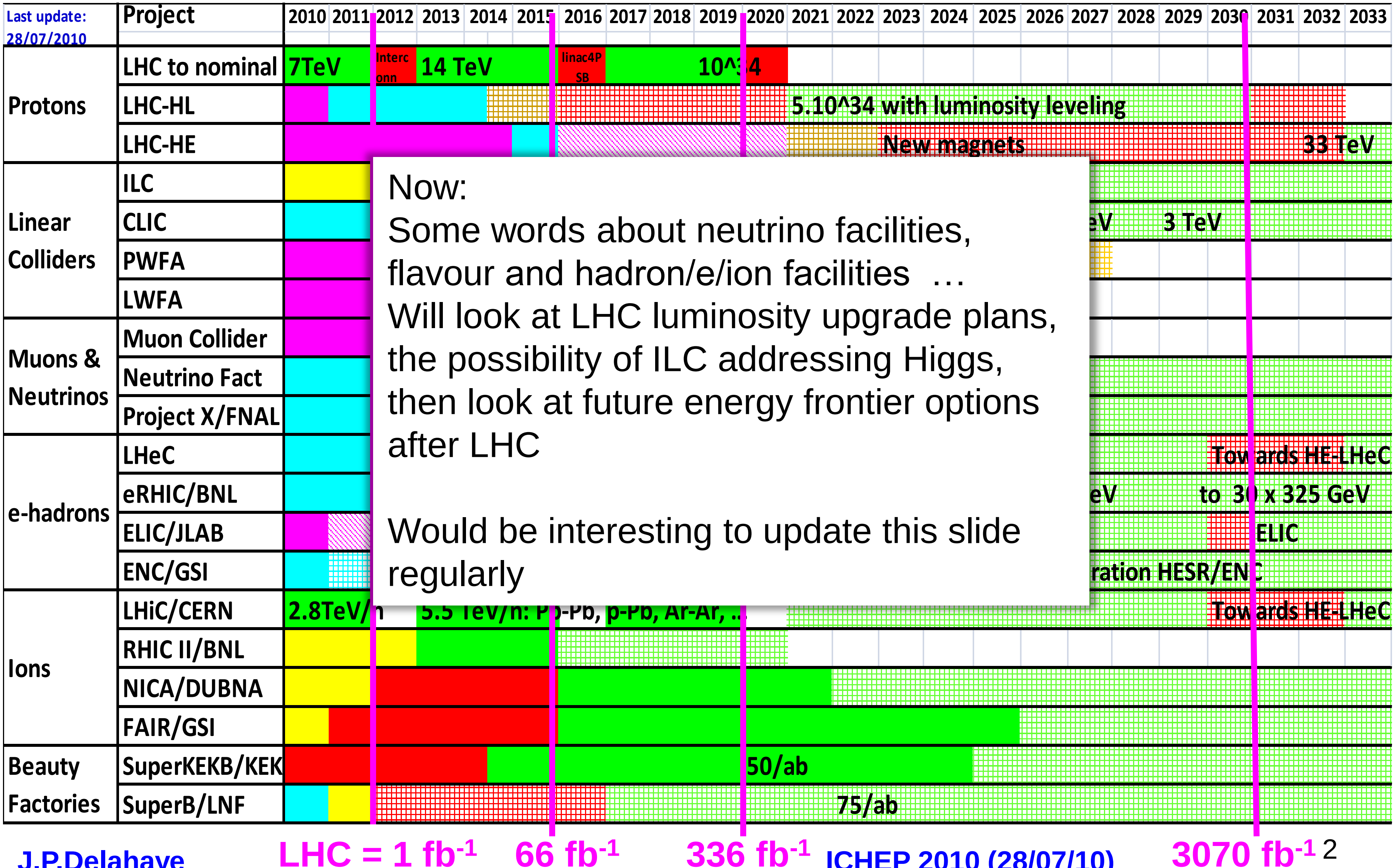
Outline:

- Overview
- A few examples of recent projects (neutrinos, flavour factories, antimatter, ions…)
- Future 'big boys': ILC/CLIC/LHC...
- What does this mean for controls?

Slides from numerous sources, have tried to leave names on them acknowledging the source

Tentative schedule new projects

Color code	approved	envisaged/proposed
R&D		
R&D to CDR		
Technical design to TDR		
Construction		
Operation		

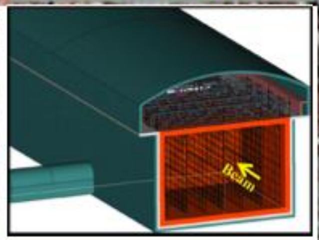


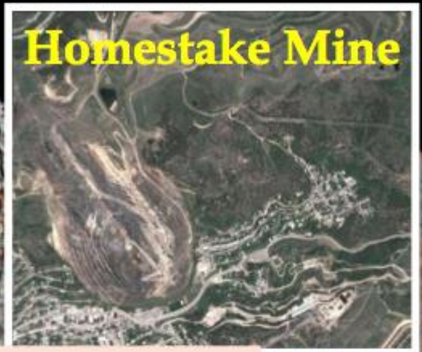
Now:
Some words about neutrino facilities, flavour and hadron/e/ion facilities …
Will look at LHC luminosity upgrade plans, the possibility of ILC addressing Higgs, then look at future energy frontier options after LHC

Would be interesting to update this slide regularly

Long-Baseline Neutrino Experiment

Far detector





Stage 1: >10kton Liq.Ar TPC, aiming to go to underground (1,600m)

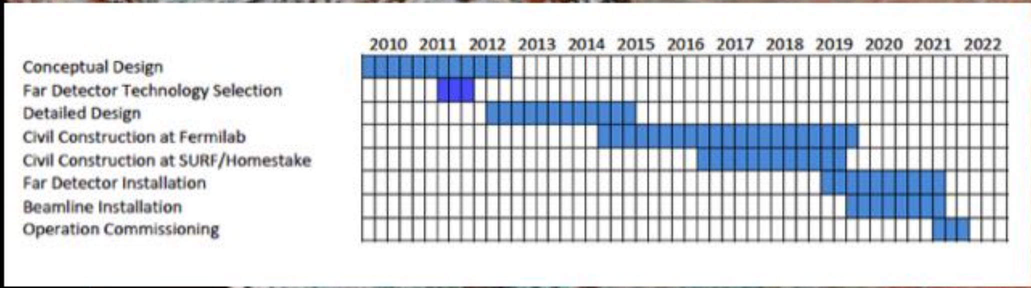
Stage 2: Additional 20-30kt

Wide-band, 3GeV ν_μ

L=1300km

1300 km

Fermilab



Review driven schedule.

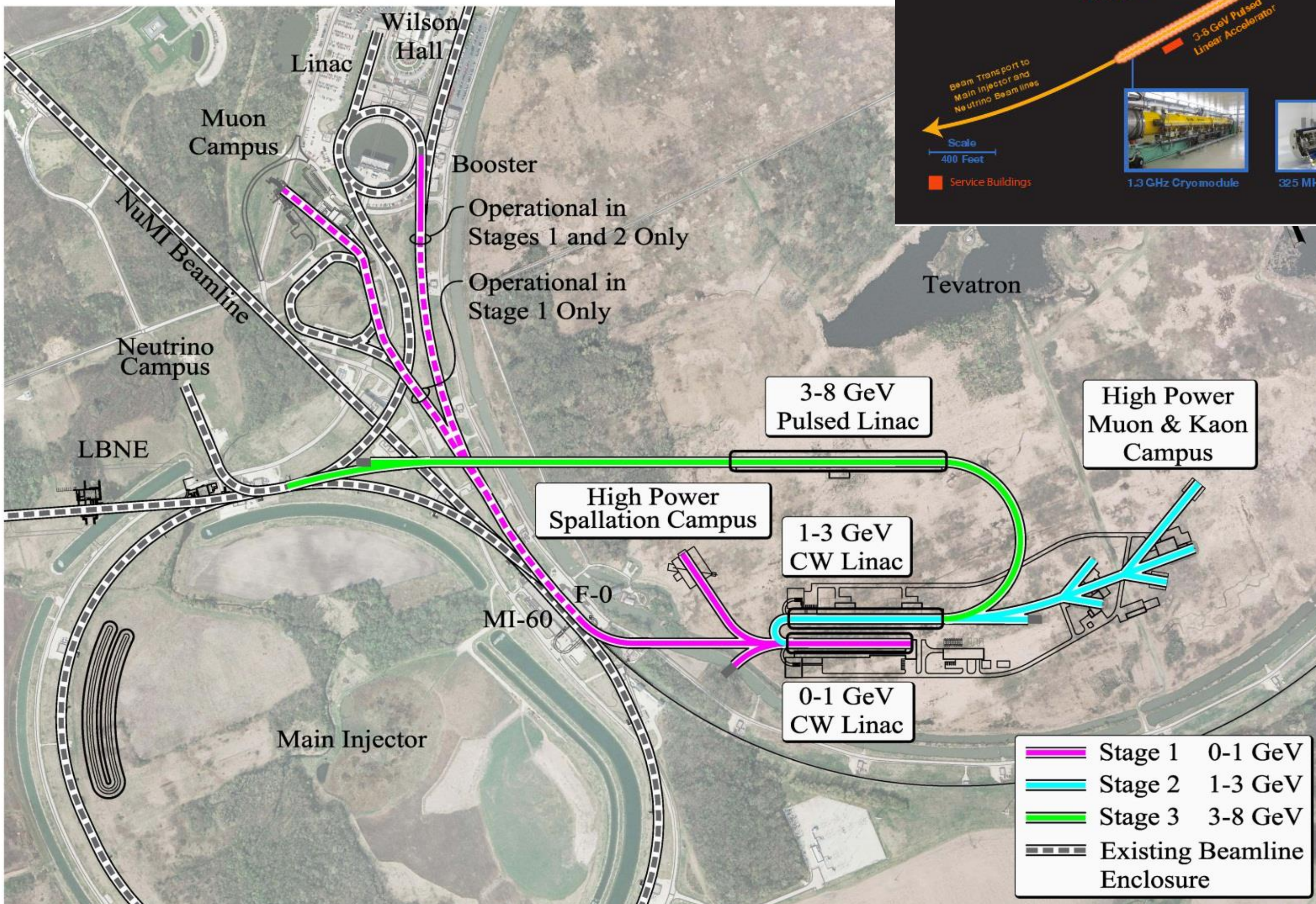
Start operation in ~2022.

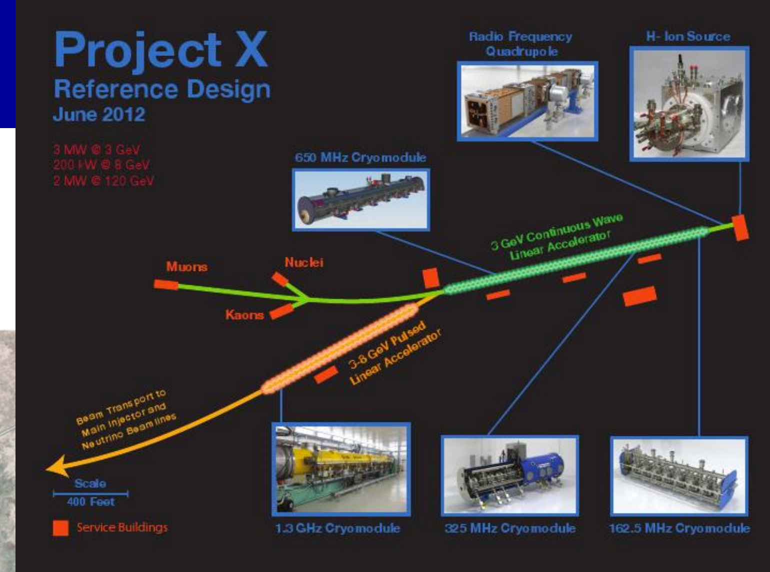
Beam and near complex

Stage 1: 700kW Main Injector beam

Upgradable to >2.3MW w/ Project X

Project-X


Wilson Hall
Linac
Muon Campus
Booster
Operational in Stages 1 and 2 Only
Operational in Stage 1 Only
NuMI Beamline
Neutrino Campus
Tevatron
LBNE
3-8 GeV Pulsed Linac
High Power Muon & Kaon Campus
High Power Spallation Campus
1-3 GeV CW Linac
F-0
MI-60
0-1 GeV CW Linac
Main Injector
Stage 1 0-1 GeV
Stage 2 1-3 GeV
Stage 3 3-8 GeV
Existing Beamline Enclosure

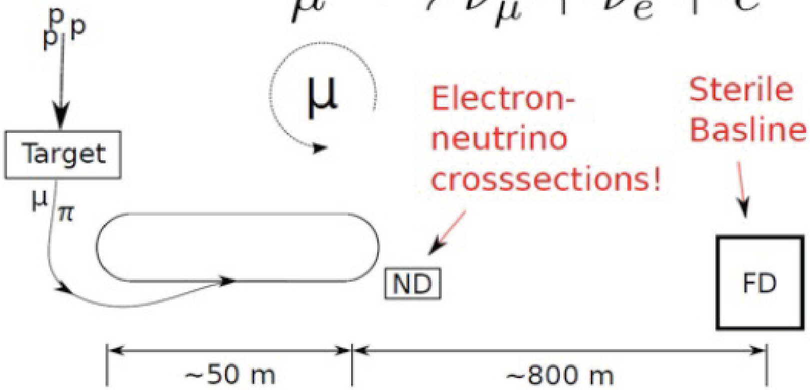

Project X
Reference Design
June 2012
3 MW @ 3 GeV
200 kW @ 8 GeV
2 MW @ 120 GeV
Radio Frequency Quadrupole
H- Ion Source
650 MHz Cryomodule
3 GeV Continuous Wave Linear Accelerator
Muons
Nuclei
Kaons
3-8 GeV Pulsed Linear Accelerator
Beam Transport to Main Injector and Neutrino Beam lines
Scale
400 Feet
Service Buildings
1.3 GHz Cryomodule
325 MHz Cryomodule
162.5 MHz Cryomodule

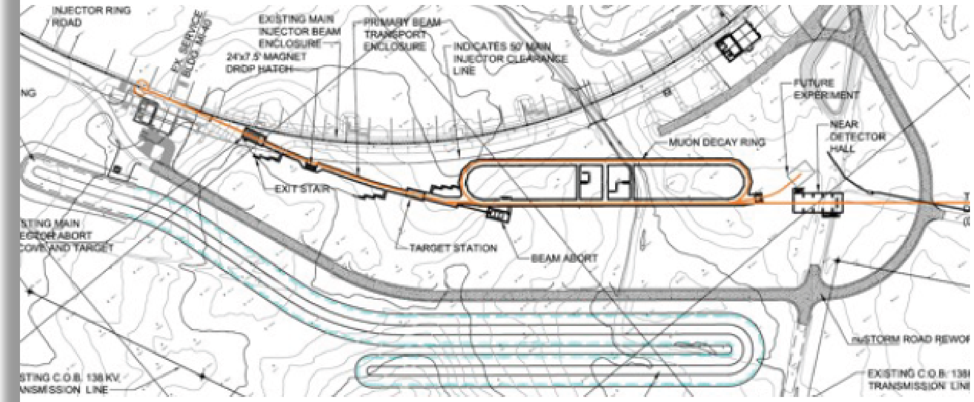
nu-STORM

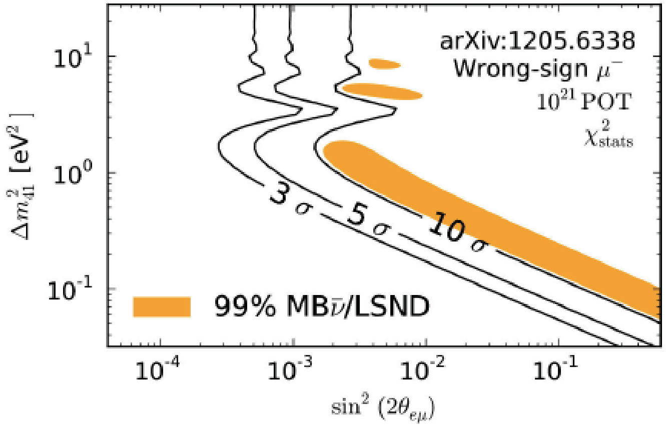
- Neutrinos from Stored Muons (old idea but never realised!)
- Strongly revived interest in the combination of
  - a clear resolution of the short-baseline neutrino anomalies with >>5σ C.L.
  - the precise measurements of the electron neutrino cross-sections needed for LBL experiments,
  - and the synergy with neutrino-factory technology.
- **FNAL PAC stage-1 approval in June 2013. To be reviewed by US HEPAP P5 in the future (≈300M$ project).**
- **LOI submitted at CERN in June 2013, under review.**

Well-understood neutrino source:

$$\mu^+ \rightarrow \bar{\nu}_\mu + \nu_e + e^+$$



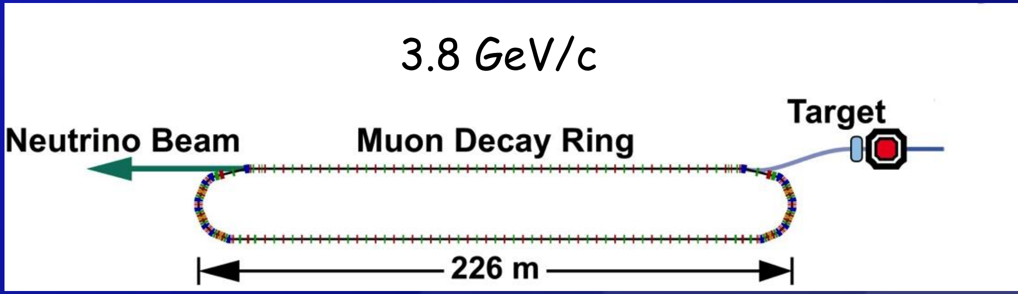




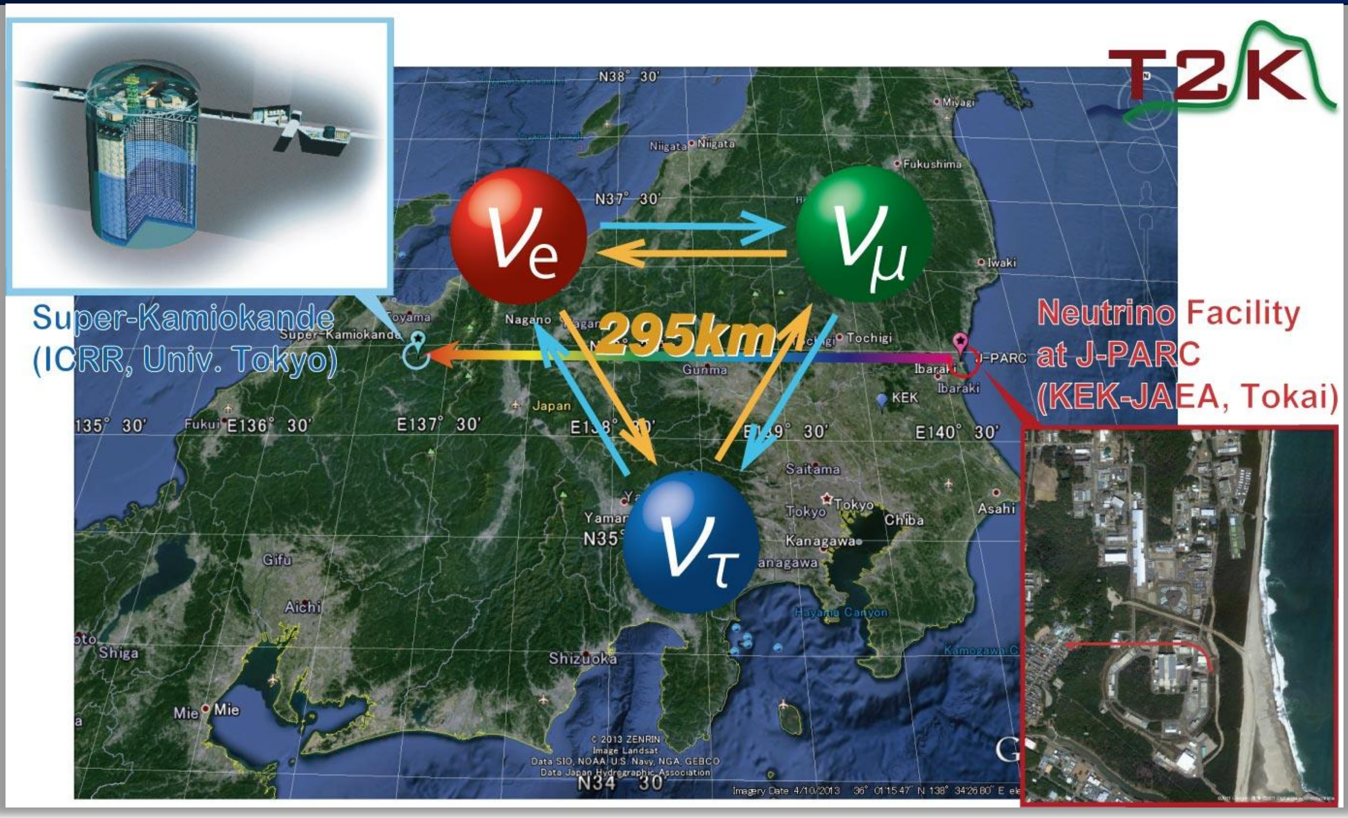
EPS-HEP 2013 A. Rubbia – Future neutrino programme 29

Baseline

- ~ 100 kW Target Station (designed for 400kW)
  - Assume 60-120 GeV proton
  - Carbon target
    - Inconel
  - Horn collection after target
- Collection/transport channel
  - Stochastic injection of π
- Decay ring
  - Large aperture FODO
    - Also considering RFFAG
  - Instrumentation
    - BCTs, mag-Spec in arc, polarimeter



J-PARC



At J-PARC, a proton beam is accelerated by a series of accelerators, which consists of

- A 400 MeV (currently operating at 180 MeV) linear accelerator (LINAC)
- A 3 GeV rapid cycling synchrotron (RCS)
- A 50 GeV (currently 30 GeV) main ring (MR)

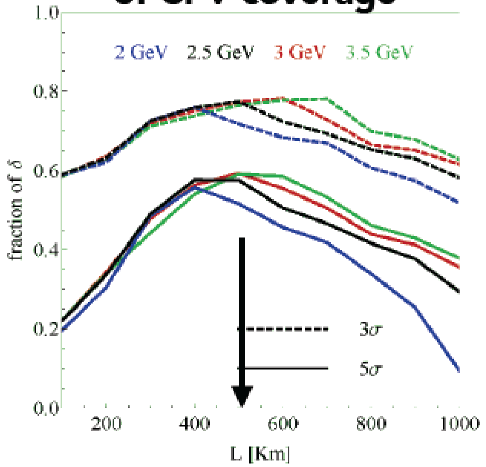
The applications of these beams include fundamental nuclear and particle physics, materials and life science, and nuclear technology.

Higher intensity plans exists, as well as detector upgrade plans …

The EUROSB concept

- The European Spallation Source (ESS), which is being built in Lund, will have a 5 MW 2.5 GeV superconducting linac
- First beams 2019, Full operation 2025
- **Idea: Double linac power to 10MW (+accumulator ring) to deliver in addition 5MW to a neutrino target to produce extremely intense beam with an average neutrino energy ≈300 MeV (Estimated additional cost for ν beam: 400M€)**
- A MEMPHYS 540kton Water Cerenkov detector at Garpenberg mine (L=540 km).

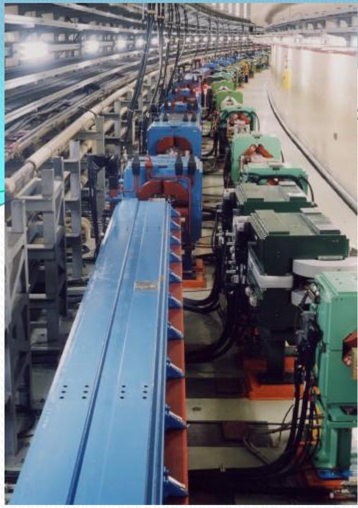
Preliminary estimate of CPV coverage



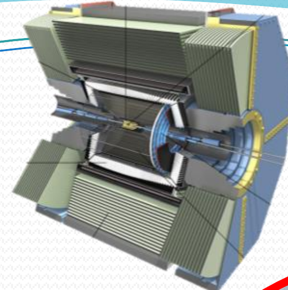
- Unique opportunity to develop MW-class very low-energy neutrino beam and understand operational issues (highly challenging!)
- Low energy beam poorly focused and cross-sections very low, so sensitivity limited by statistics (at present level of understanding of systematic errors)
- Synergy with LAGUNA/LBNO for the far site (CERN-Garpenberg≈1700km and Protvino-Garpenberg≈1300km) and detector

Flavour Factories

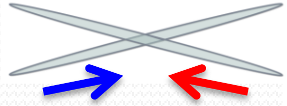
- Past:
  - PEP-II @ SLAC, USA
  - KEKB @ KEK, Japan
- Present:
  - DAΦNE @ INFN-LNF, Italy
  - Vepp2000 @ BINP, Russia
  - BEPCII @ IHEP, China
- Future:
  - SuperKEKB @ KEK
- Proposals:
  - Tau-Charm @ BINP, INFN, IHEP, TAC (Turkey)

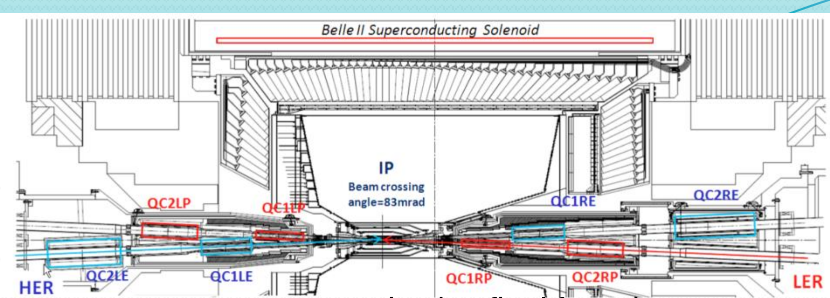


Upgrade to Belle II detector



Colliding bunches





New superconducting final focusing magnets near the IP

e^+ 3.6A

e^- 2.6A

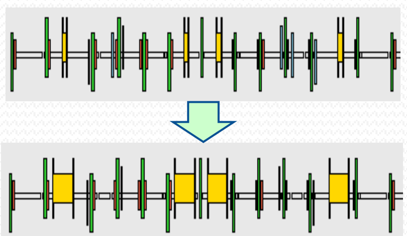
KEKB to SuperKEKB

- Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- Beam current double

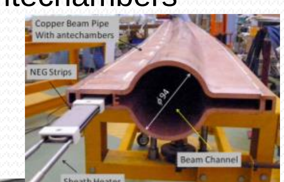
$$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

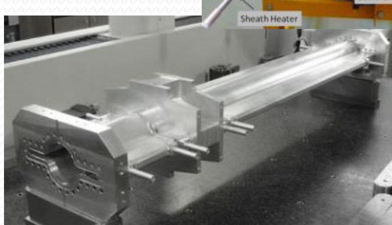
40 times higher luminosity
2.1x10³⁴ --> 8x10³⁵ cm⁻²s⁻¹

Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)



Replace beam pipes with TiN-coated beam pipes with antechambers





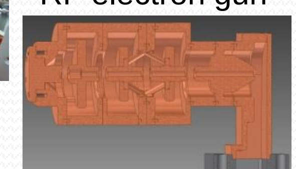
Reinforce RF systems for higher beam currents

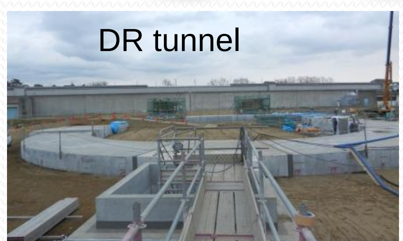
Improve monitors and control system

Injector Linac upgrade

Upgrade positron capture section

Low emittance RF electron gun





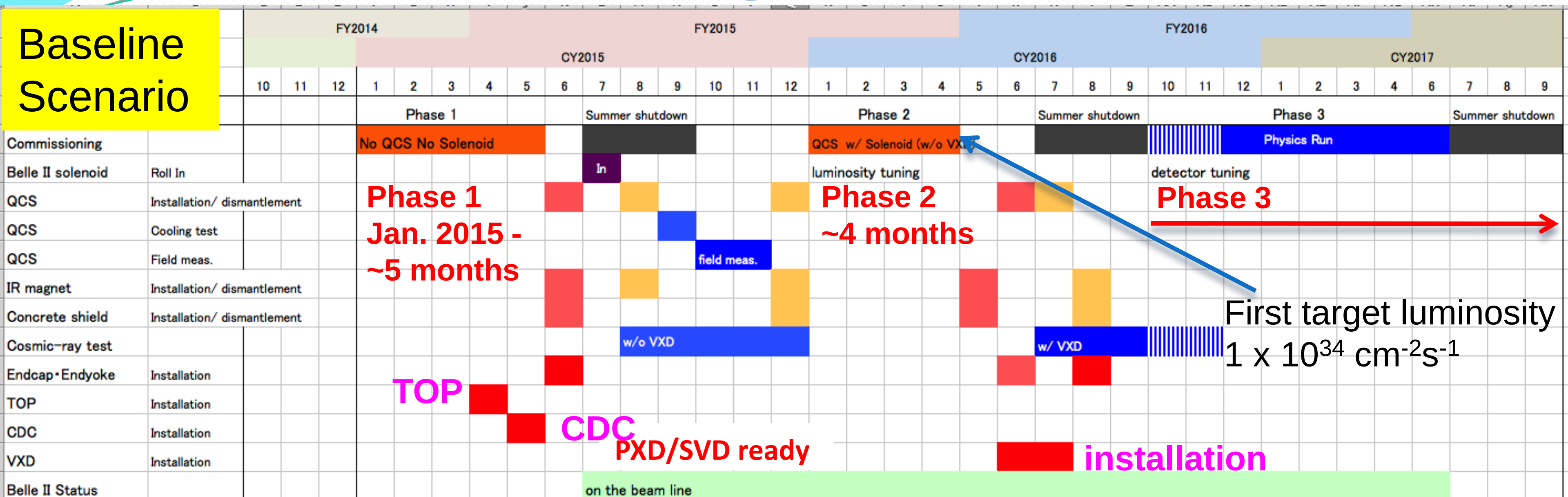
New e+ Damping Ring

Parameters of KEKB and SuperKEKB

parameters		KEKB(@record)		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Crossing angle (full)	φ	22		83		mrad
# of Bunches	N	1584		2500		
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.28	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Max. beam currents	I_b	2.0	1.4	3.6	2.6	A
Beam-beam param.	ξ_y	0.129	0.090	0.0881	0.0807	
Bunch Length	σ_z	6.0	6.0	6.0	5.0	mm
Horizontal Beam Size	σ_x^*	150	150	10	11	um
Vertical Beam Size	σ_y^*	0.94		0.048	0.062	um
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

Intra-beam scattering is included.

Commissioning Scenario



[Phase 1] **No QCS, No Belle II**

- Basic machine tuning, Low emittance tuning
- Vacuum scrubbing (0.5 ~ 1.0 A, >1 month)
- DR commissioning start (~Apr. -)

[Phase 2] **With QCS, With Belle II (without Vertex Detector)**

- Small x-y coupling tuning, Collision tuning
- βy^* will be gradually squeezed
- Background study

[Phase 3] **With Full Belle II**

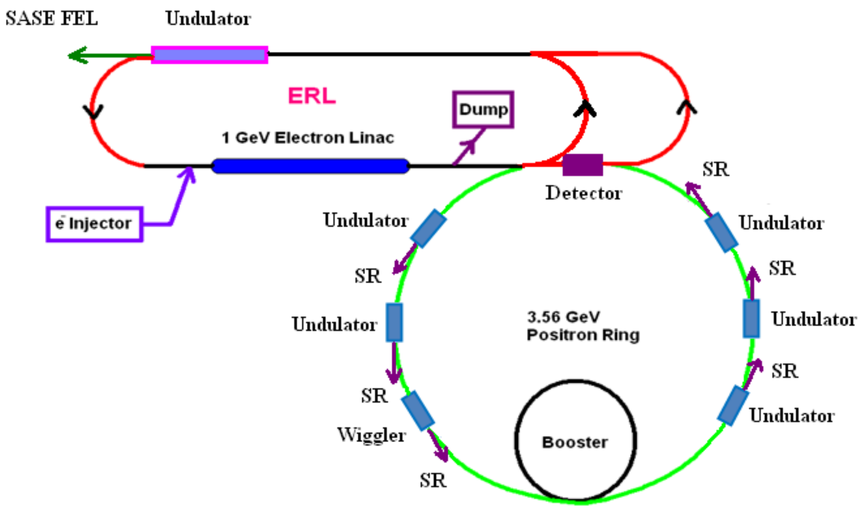
- Increase beam current with adding more RF
- Increase luminosity

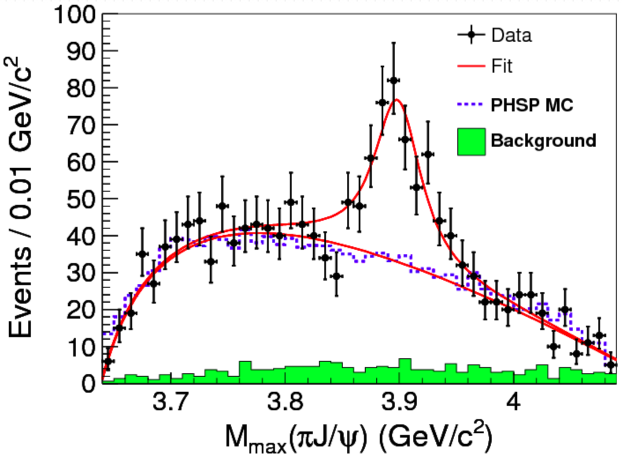
Super τ/charm proposals

	Italian Tau/Charm	BINP Tau/Charm	IHEP Tau/Charm	Turkish Charm
	2 rings	2 rings	2 rings	Linac+rin g
Luminosity ($cm^{-2}s^{-1}$)	1 x 10^{35}	1 x 10^{35}	1 x 10^{35}	1.4 x 10^{35}
Circumference (m)	340	360/800	990	250 (600?)
Beam energy (GeV)	1 → 2.3	0.5 → 2	3	1 + 3.56
Emittance H (nm)	5	3/10	10	16
Coupling (%)	0.25	0.5	0.5	0.3
IP β (x,y) (mm)	70, 0.6	200,0.6/20, 0.76	1000, 1	80, 5
bb V tune shift	0.64 → 0.08	0.095→0.17	0.06	0.12
Crab waist	YES	YES	YES	NO
Beam current (A)	1 → 1.7	1.8 → 1.7	2.7	0.48 + 4.8
N. of bunches	530	418	540	125

M. E. Biagini, INFN/LNF

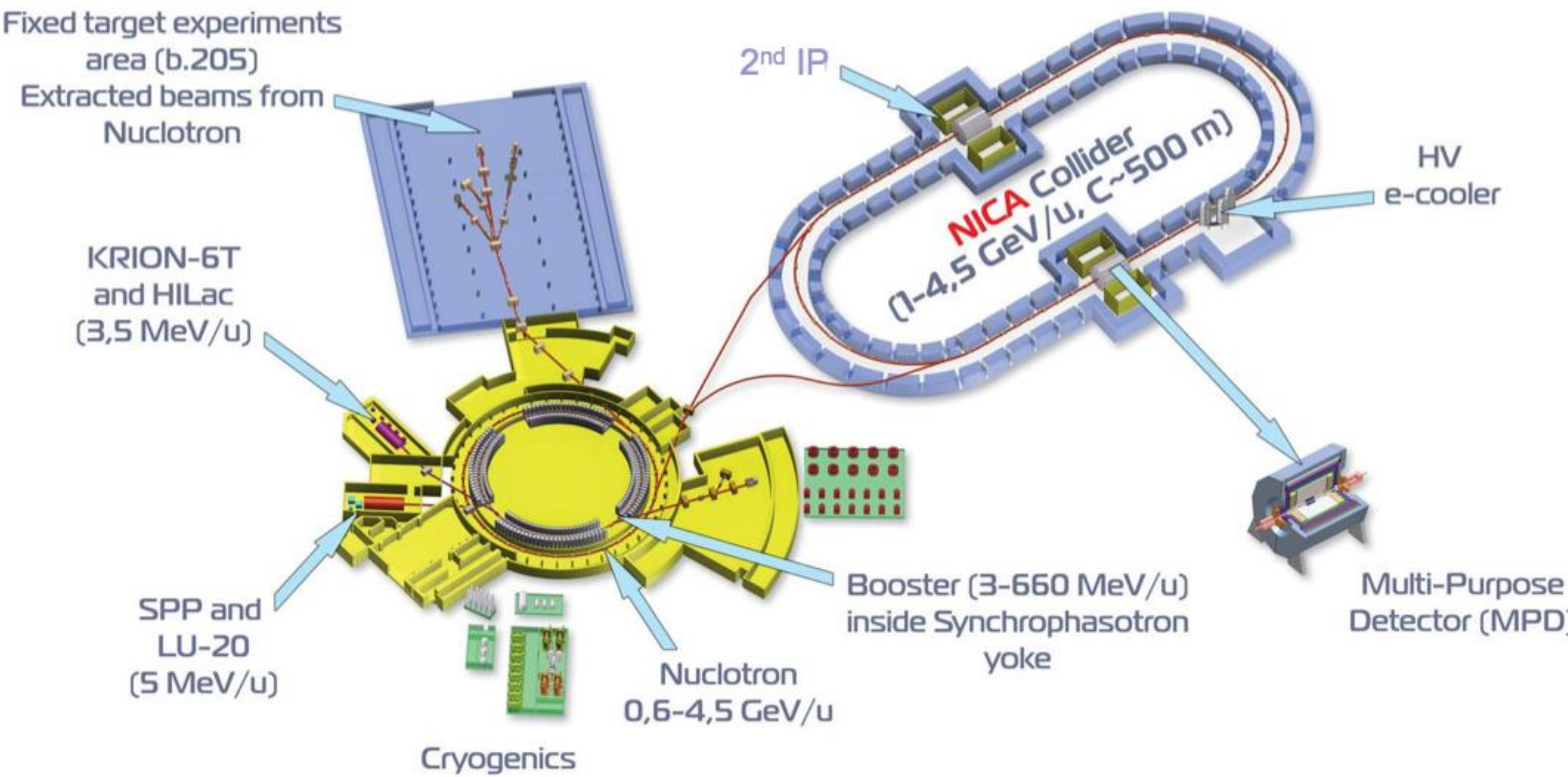
Example of possible future…



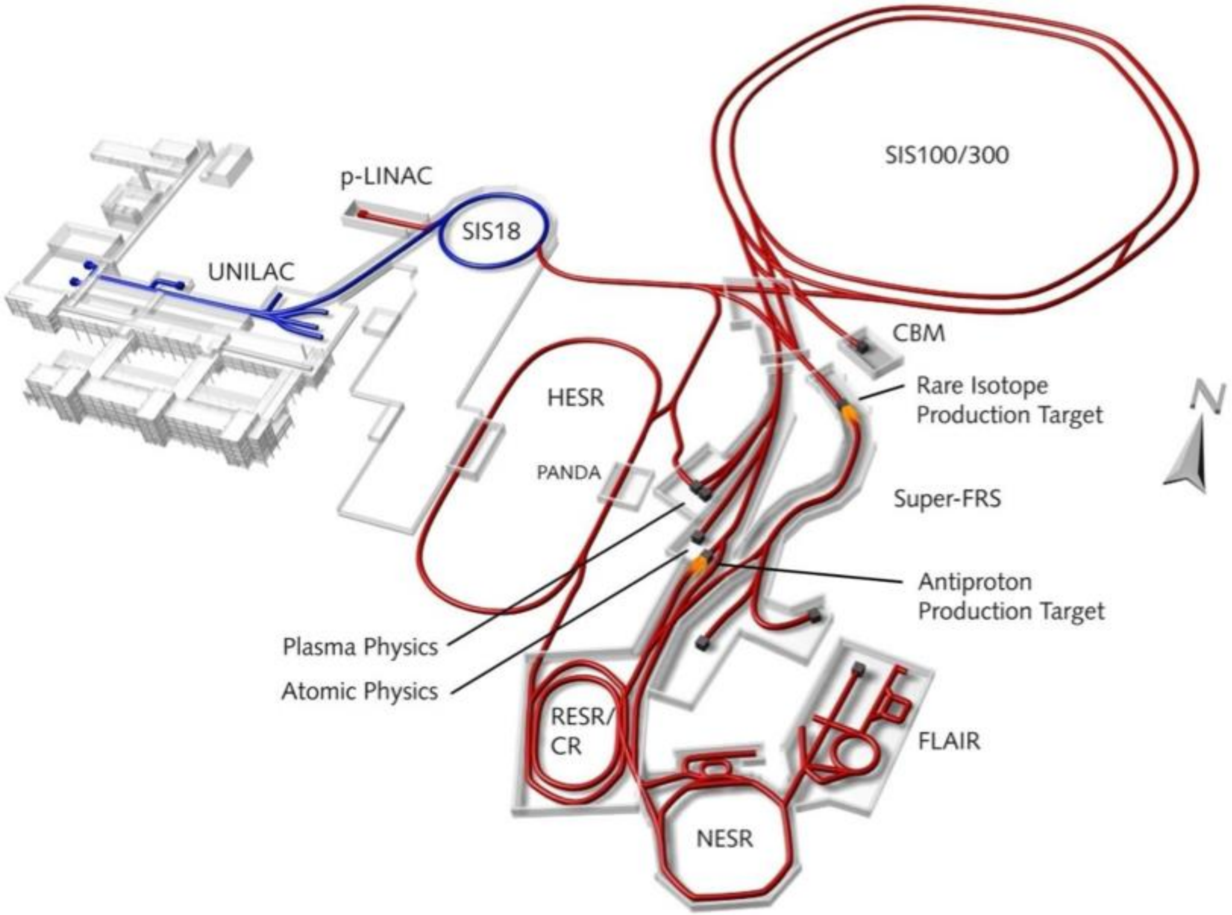


Superconducting accelerator complex NICA

(Nuclotron based Ion Collider fAcility)



Facility for Antiproton and Ion Research - FAIR



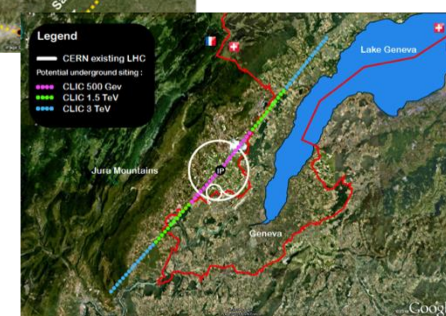
European Strategy Priorities

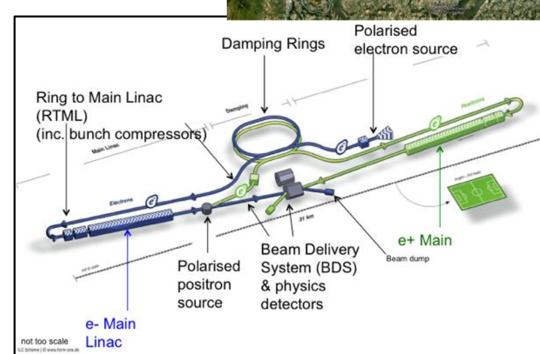
European Strategy priorities:

- LHC and LHC luminosity upgrades (until ~2030)
  - Higgs and Beyond the Standard Model physics in long term programme
- BSM – does it show up at LHC at 14 TeV, 2015 onwards ?
  - What are the best machines to access such physics directly post-LHC …. we don't know but we can prepare main options the next years towards next strategy update (~2018)
  - Two alternatives considered; higher energy hadrons (HE LHC or VHE LHC), or highest possible energy e+e- with CLIC
- ILC in Japan, a possibility for exploring the Higgs in detail, starting at 250 GeV
  - If implemented a comprehensive programme that can map out the Higgs sector in particular
- A European Neutrino program in a global context, high lighting
  lo
- S

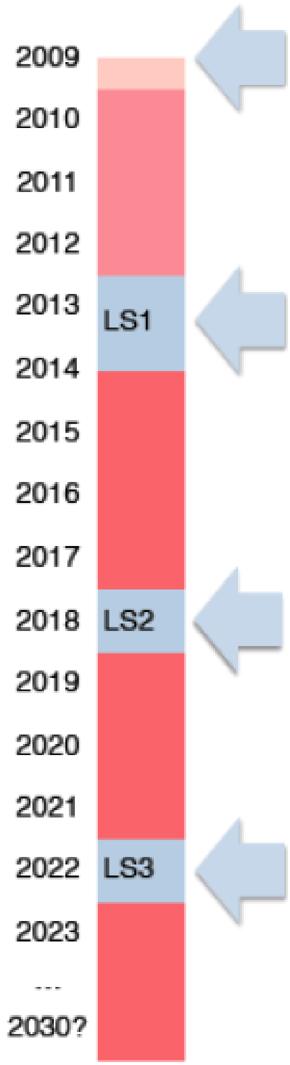
CERN MTP (= medium term plan) in June 2013:

- Highest Priority:
  full exploitation of LHC physics potential
- High Priority items:
  design studies and R&D at energy frontier
  possible participation in the ILC Project
  development of neutrino program
  unique fixed target physics program





“Exploitation of the full potential of the LHC"



✧ LHC startup, $\sqrt{s}$ = 900 GeV

$\sqrt{s}$=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns

Go to design energy, nominal luminosity

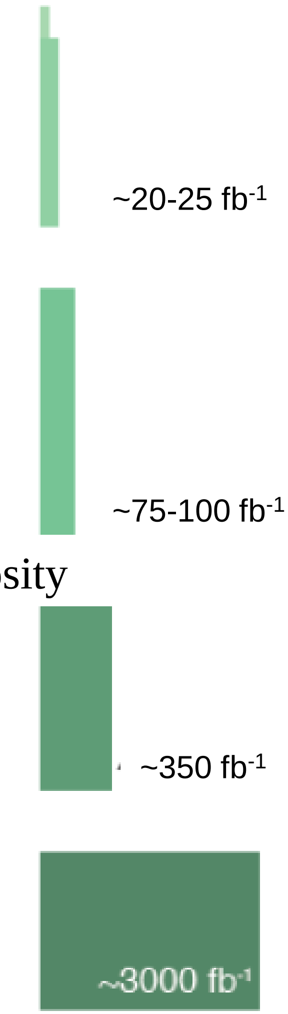
$\sqrt{s}$=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

Injector and LHC Phase-1 upgrade to ultimate design luminosity

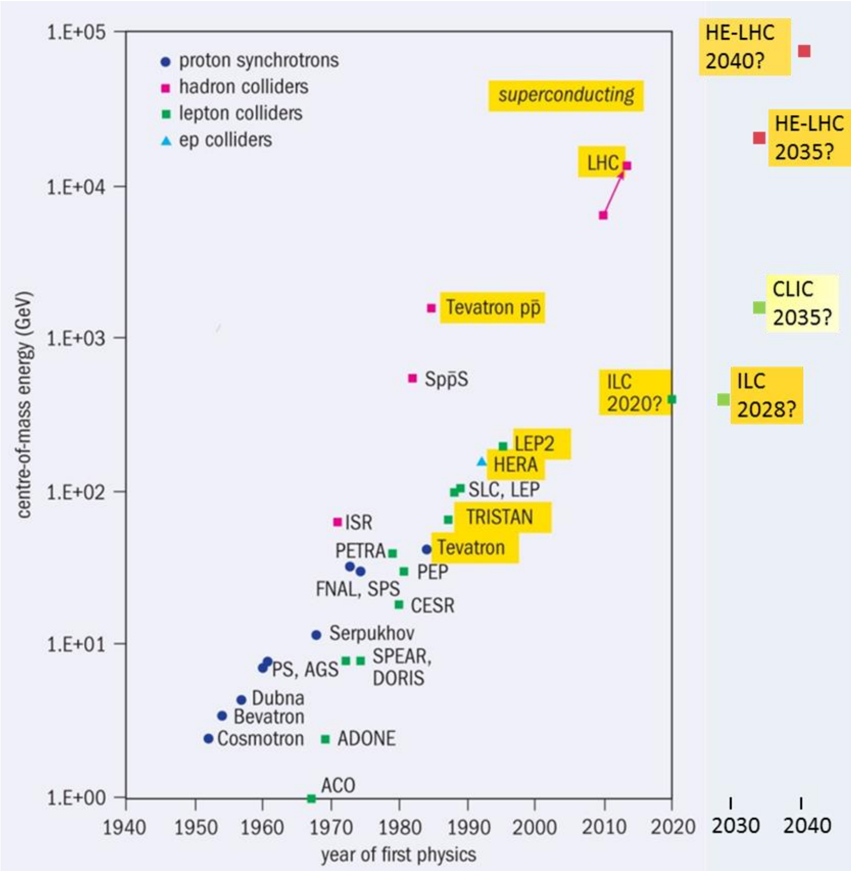
$\sqrt{s}$=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

HL-LHC Phase-2 upgrade, IR, crab cavities?

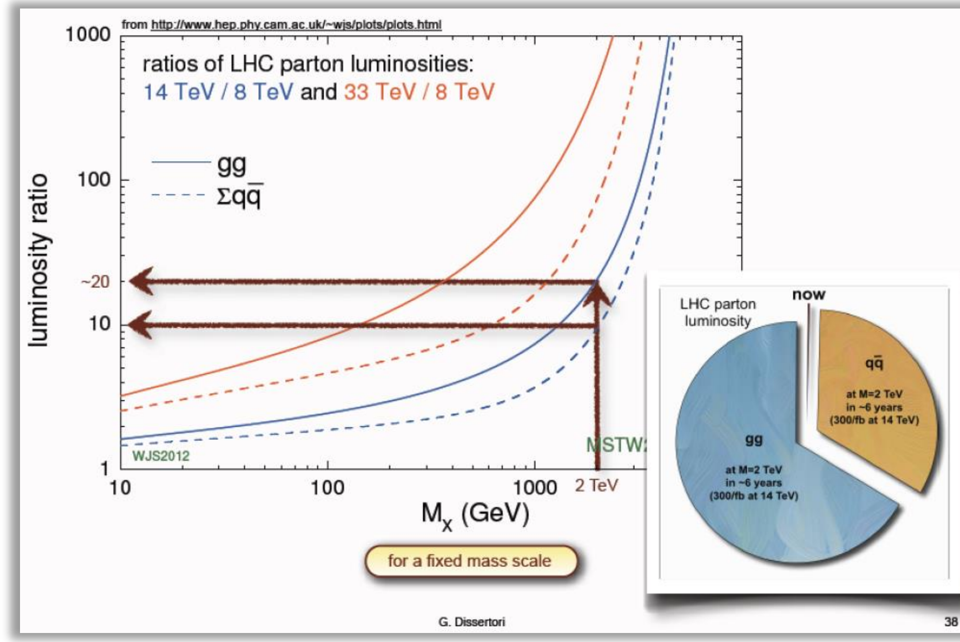
$\sqrt{s}$=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity leveling

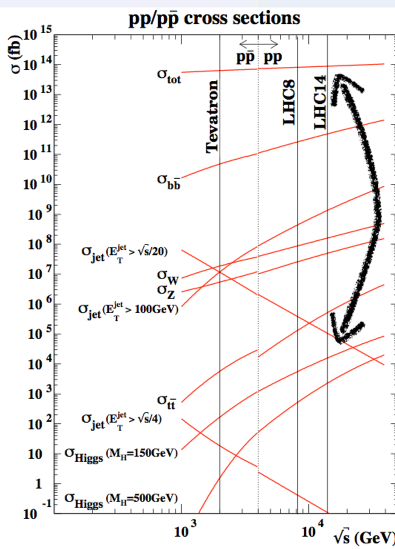


Energy frontier machines (hadrons or leptons)



L.Rossi

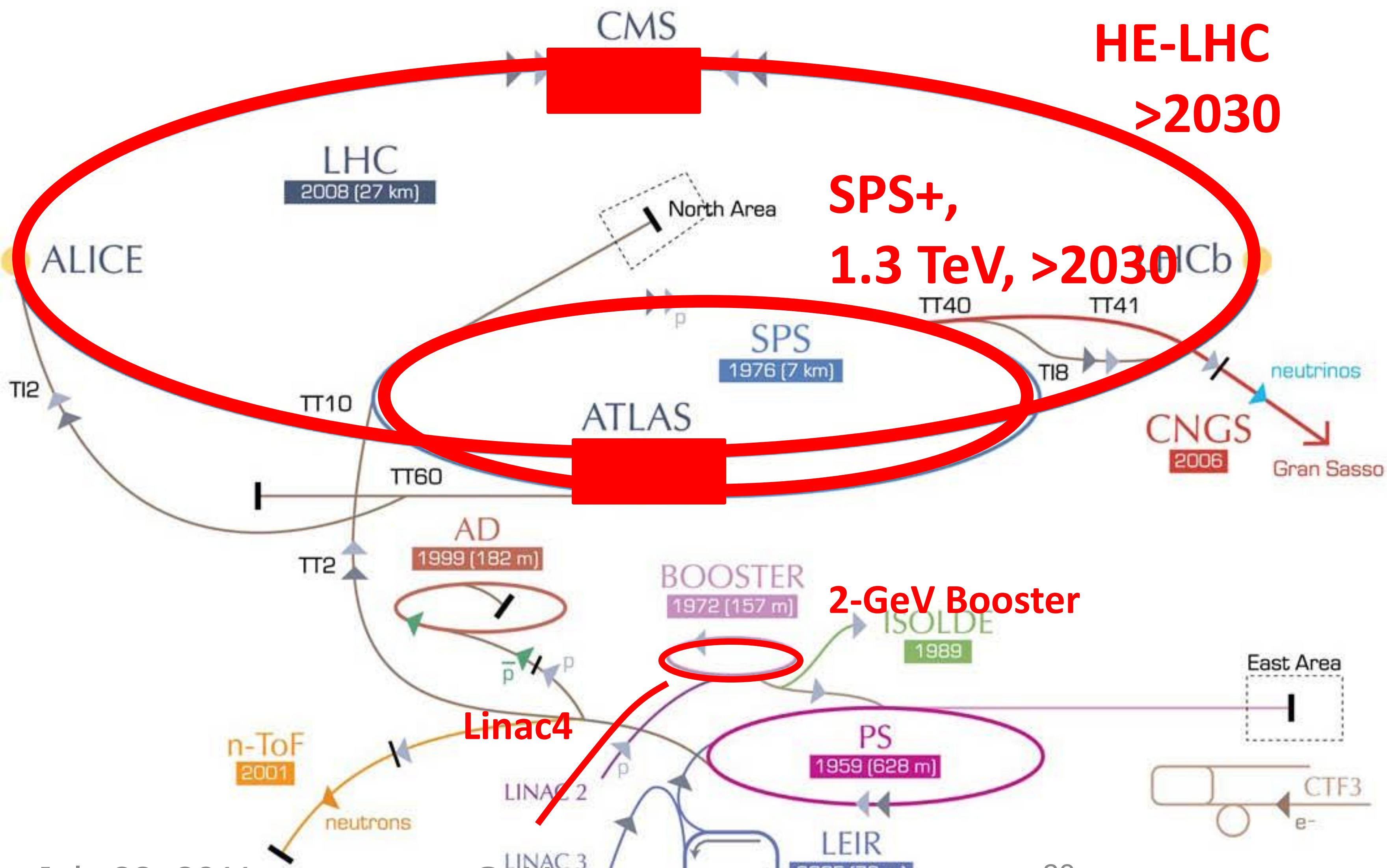




Process	VLHC	CLIC	
	200 TeV	3 TeV	5 TeV
squarks	15	1.5	2.5
sleptons		1.5	2.5
Z'	30	20	30
q^*	70	3	5
l^*		3	5
Extra two dimensions	65	20 – 33	30 – 55
$W_L W_L$	30σ	70σ	90σ
TGC (95%)	0.0003	0.00013	0.00008
Λ compos.	130	300	400

Need to look at physics models (hopefully guided by new LHC data), reach (E,Lum), costs, schedules – to determine the way forward

HE-LHC – LHC modifications

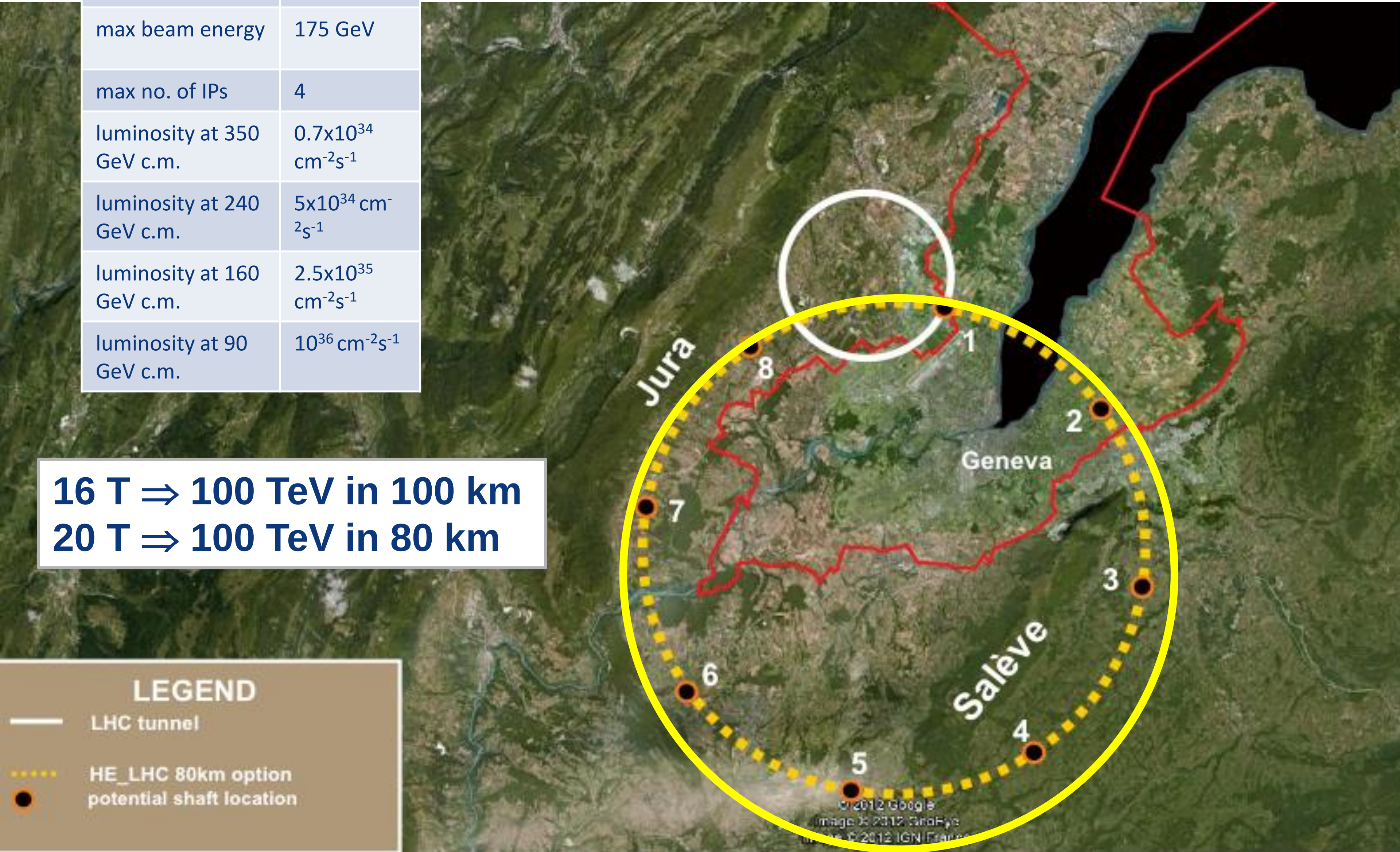


80-100 km tunnel in Geneva area – VHE-LHC

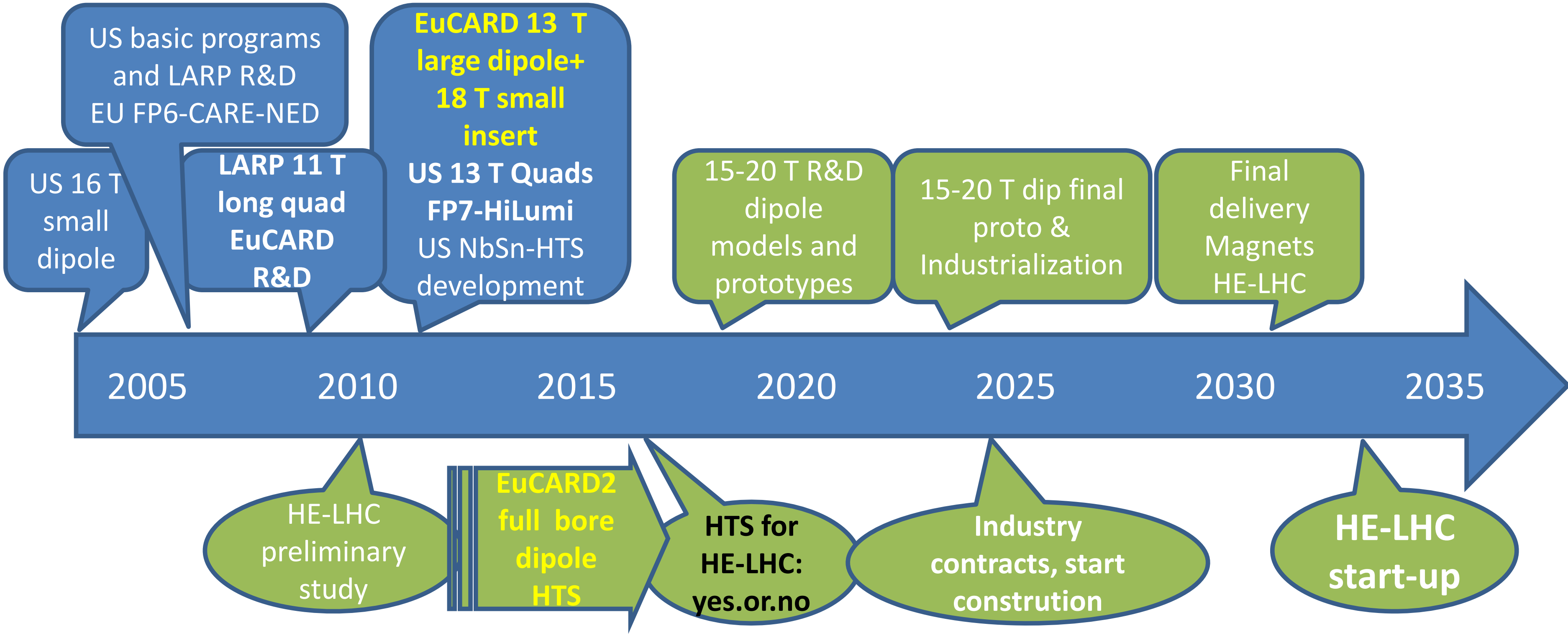
with possibility of e+-e- (TLEP) and p-e (VLHeC)

	TLEP
circumference	80 km
max beam energy	175 GeV
max no. of IPs	4
luminosity at 350 GeV c.m.	0.7×10^{34} $cm^{-2}s^{-1}$
luminosity at 240 GeV c.m.	5×10^{34} $cm^{-2}s^{-1}$
luminosity at 160 GeV c.m.	2.5×10^{35} $cm^{-2}s^{-1}$
luminosity at 90 GeV c.m.	10^{36} $cm^{-2}s^{-1}$

16 T ⇒ 100 TeV in 100 km
20 T ⇒ 100 TeV in 80 km



An intense R&D programme is required to continue rigorously now if HE-LHC should become a real option for following the HL-LHC in the 2030s

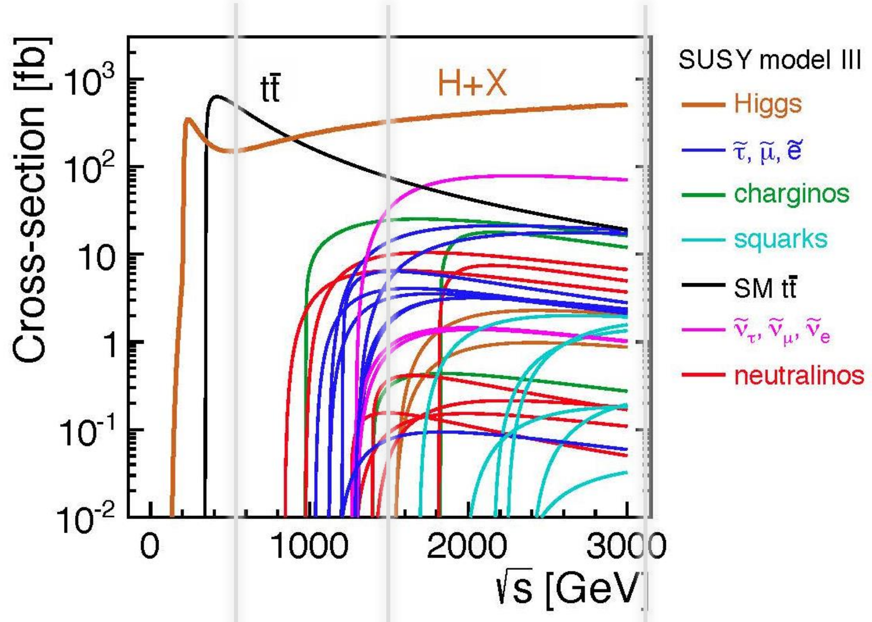


HL-LHC work as a test bed

From L. Rossi, CERN

Physics at Linear Colliders from 250 GeV to 3000 GeV

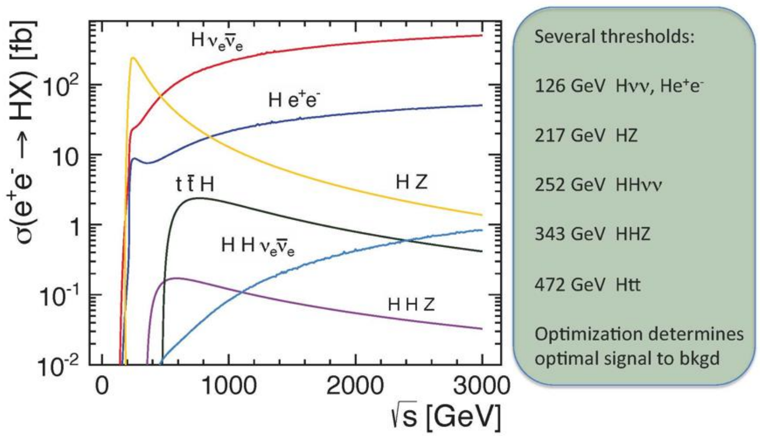
- **Physics case for the Linear Collider:**
  - **Higgs physics (SM and non-SM)**
  - **Top**
  - SUSY
  - Higgs strong interactions
  - New Z’ sector
  - Contact interactions
  - Extra dimensions
  - ….



Recently: Further work on completing picture of Higgs prospects at ~350 GeV, ~1.4 TeV, ~3 TeV, example for CLIC:

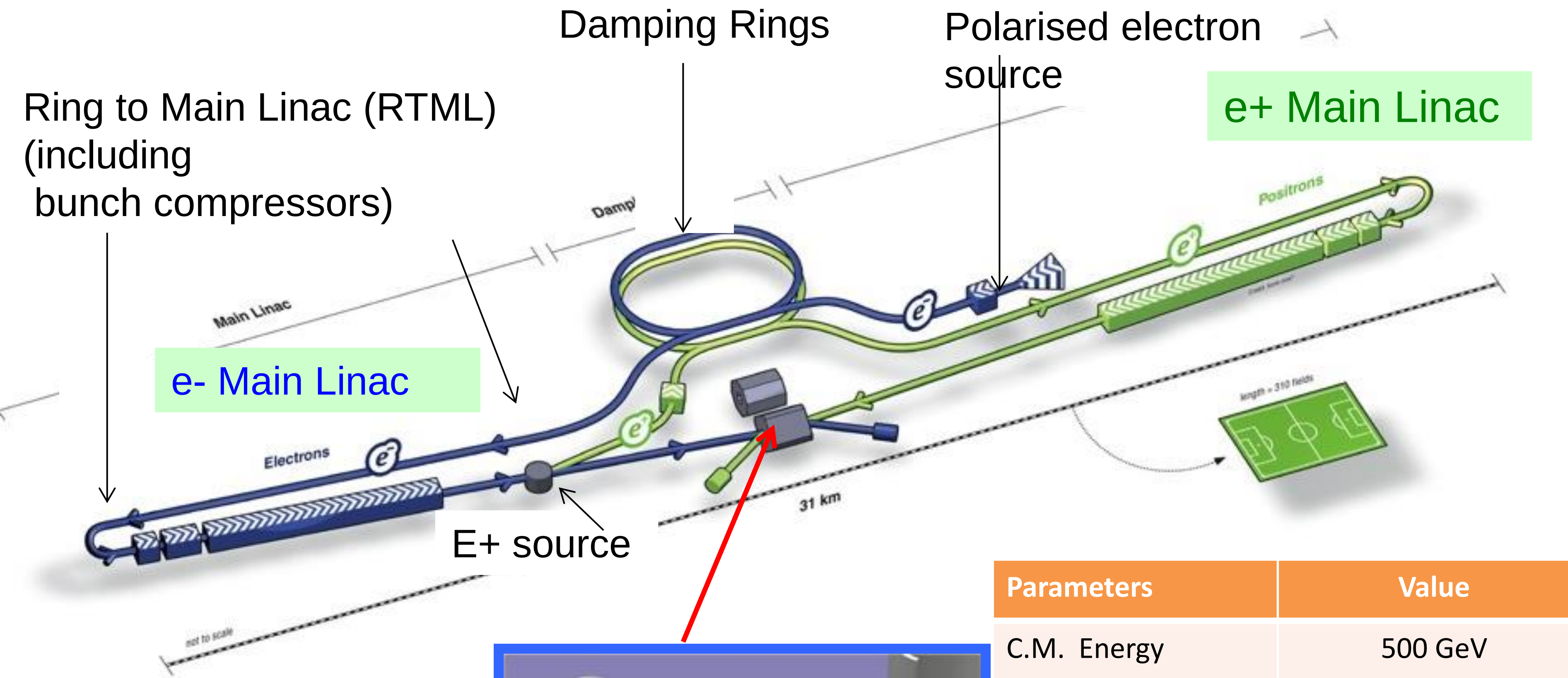
collision energy Polarization e⁻/e⁺	√s = 1.4 TeV unpolarized	√s = 1.4 TeV -80% / +30%	√s = 3.0 TeV unpolarized	√s = 3.0 TeV -80% / +30%
Δ σ(HHνν)	≈ 22%	≈ 18%	≈ 10%	≈ 7%
Δ λ_{HHH}	≈ 28%	≈ 22%	≈ 16%	≈ 11%
Numbers with polarized beams obtained by scaling signal and background cross sections, ignoring polarization-dependent changes to kinematic properties.				all cross section values: mH = 120 GeV

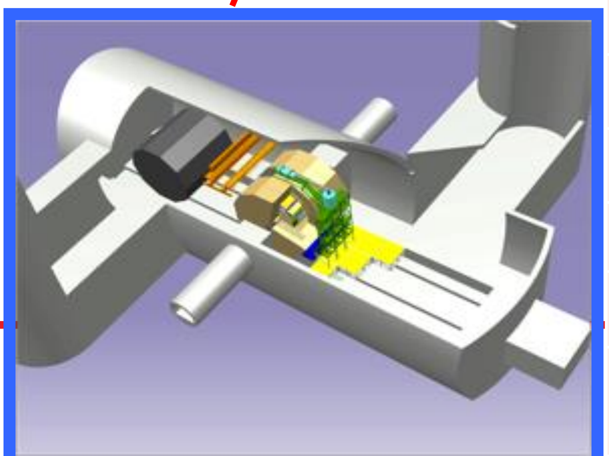
Higgs boson Production Cross-Sections



Lebrun et al., arXiv:1209.2543

ILC TDR Layout

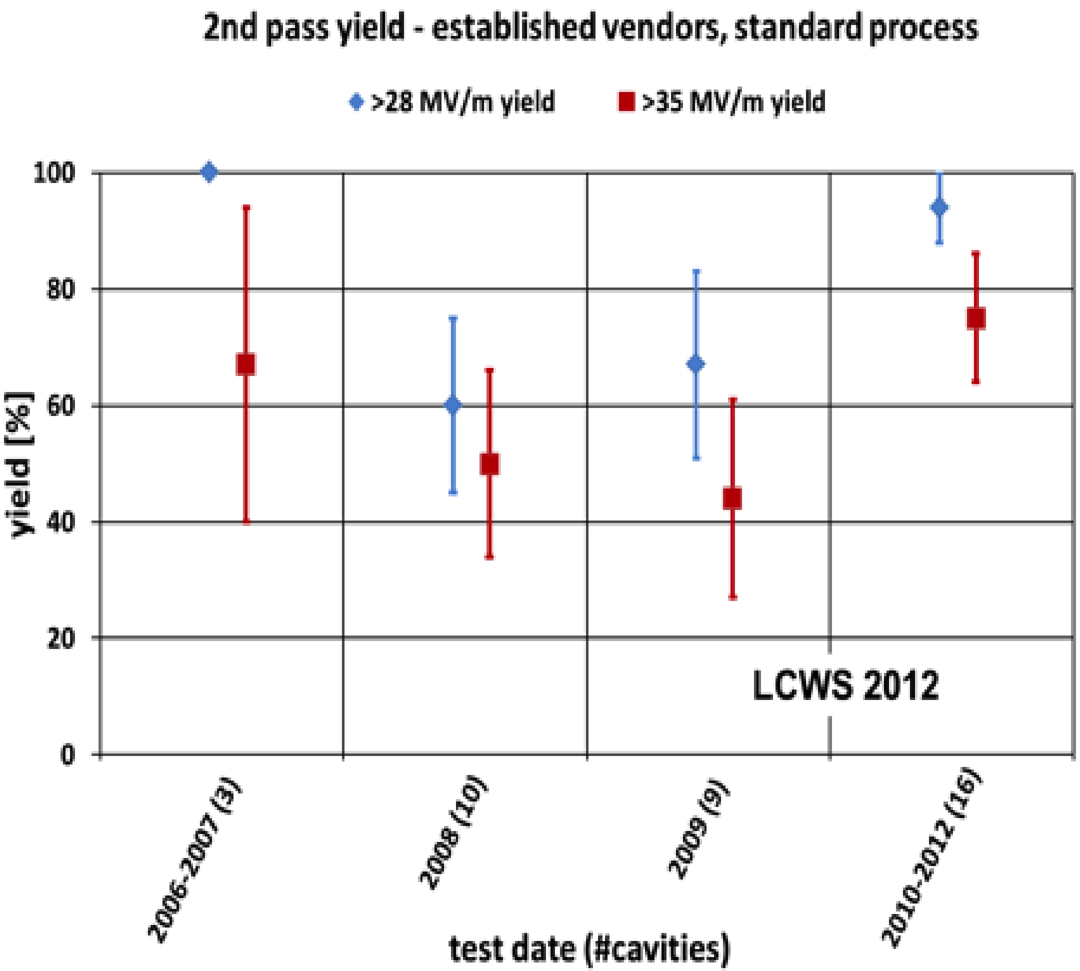




Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

ILC Scheme | © www.form-one.de

Progress in SCRF Cavity Gradient



Production yield:
94 % at > 28 MV/m,

Average gradient:
37.1 MV/m

reached (2012)

Accelerator System Tests

2009 ~

NML (FNAL)

- Under construction
- Up to 6 cryomodules
- Operation: end 2012
  - (3 CM)

FLASH (DESY)

- TDP focus
- 7 CM → 1.2 GeV beam
- photon user facility

Full systems integration testing

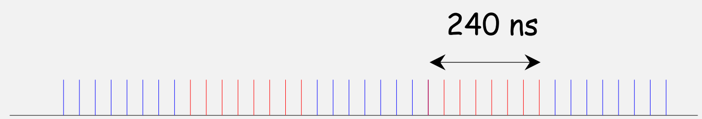
STF (KEK)

- “Quantum Beam” experiment 2011
- 1 CM with beam 2013
- (2 CM 2015)

CLIC Layout at 3 TeV

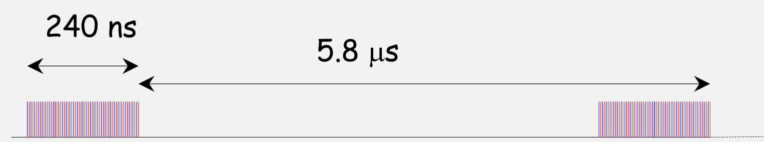
Drive Beam Generation

Drive beam time structure - initial

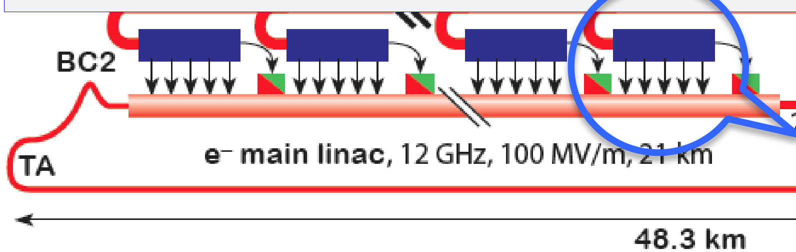


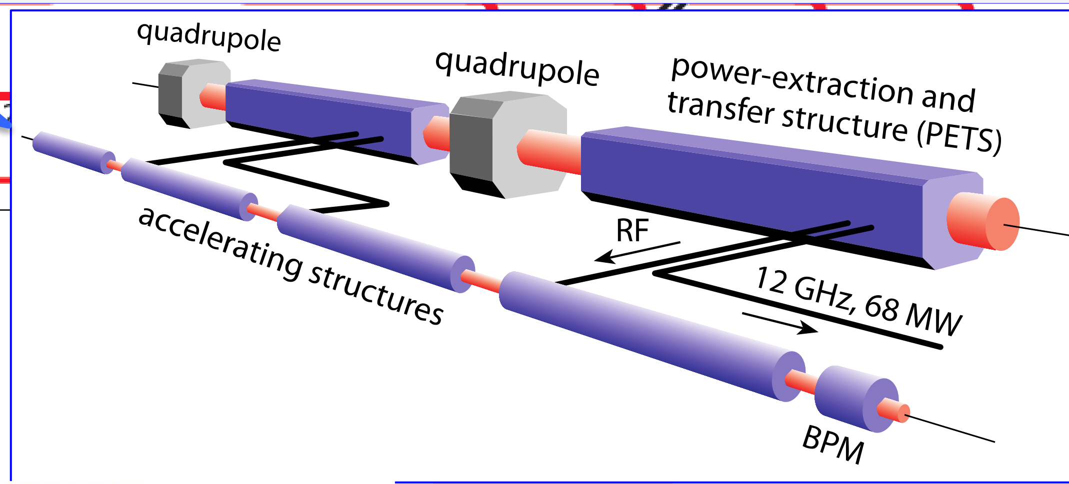
140 µs train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

Drive beam time structure - final



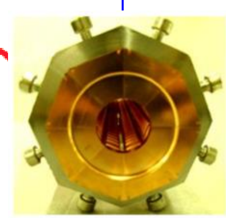
24 pulses – 101 A – 2.5 cm between bunches



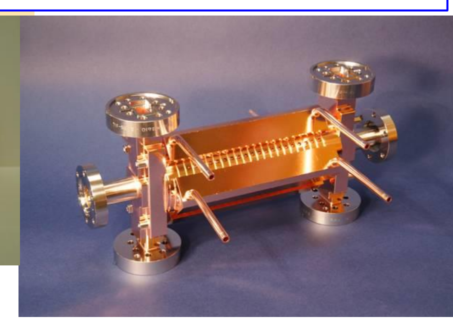


CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
(red/green square)	dump

e⁻ injector,
2.86 GeV

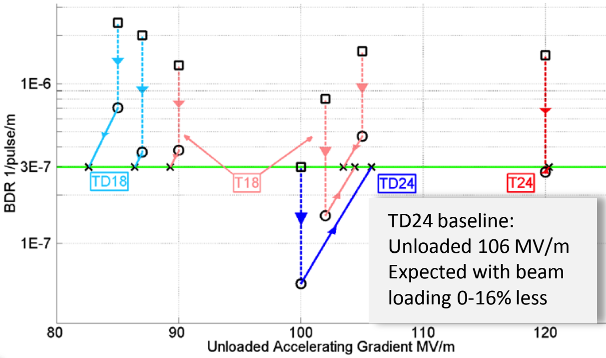




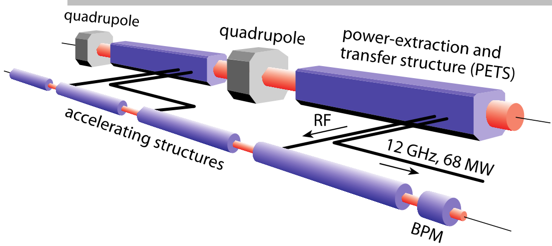


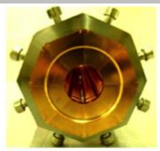
Main Beam Generation Complex

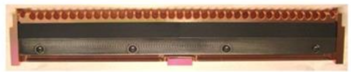
Conclusion of the accelerator CDR studies

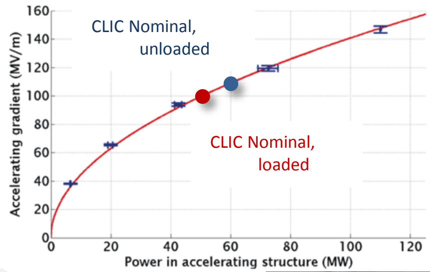


Main linac gradient	–	Ongoing test close to or on target
	–	Uncertainty from beam loading being tested
Drive beam scheme	–	Generation tested, used to accelerate test beam abov specifications, deceleration as expected
	–	Improvements on operation, reliability, losses, more deceleration studies underway

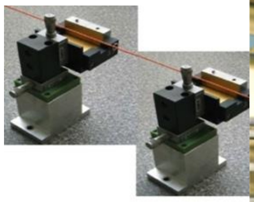


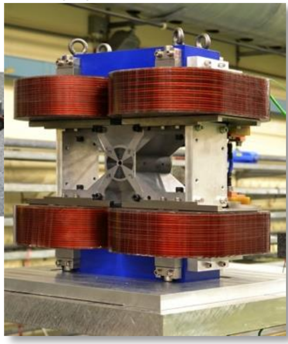






Luminosity	–	Damping ring like an ambitious light source, no show stopper
	–	Alignment system principle demonstrated
	–	Stabilisation system developed, benchmarked, better system in pipeline
	–	Simulations on or close to the target
Operation & Machine Protection	–	Start-up sequence and low energy operation defined
	–	Most critical failure studied and first reliability studies
Implementation	–	Consistent three stage implementation scenario defined
	–	Schedules, cost and power developed and presented
	–	Site and CE studies documented





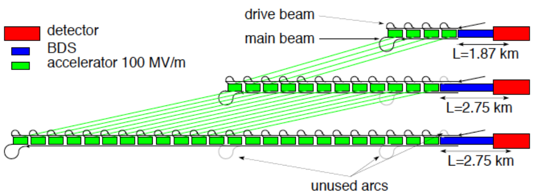
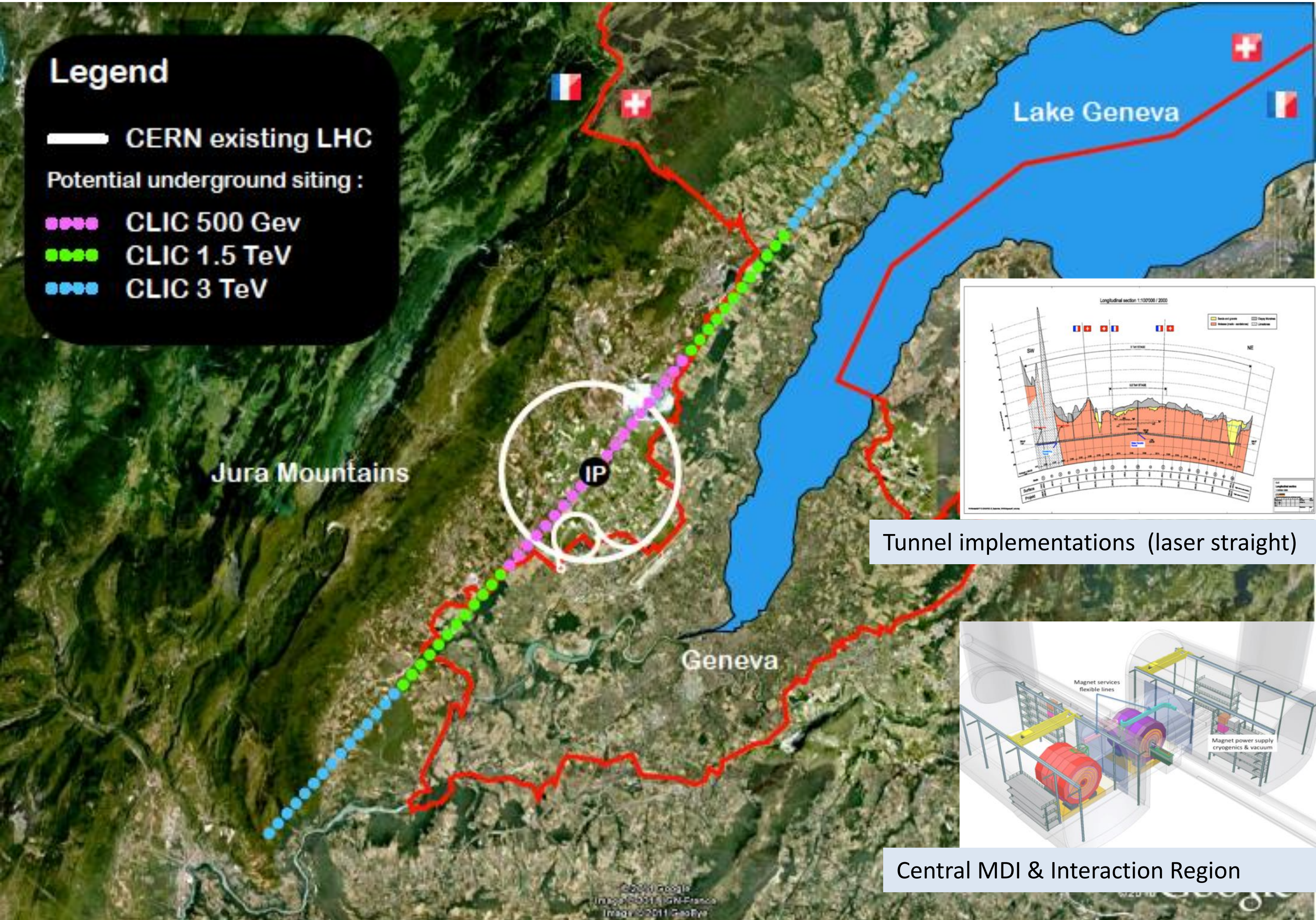


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

CLIC near CERN



Implications for Controls

- ...preparation of the round table discussion....
- Three tier design well establised everywhere...will persist
- Application layer....can not get much more complicated than at LHC; needs a lot of domain competence; underying technologies may evolve, the key is still to understand what you want and implement this. Security aspects, versioning and release tests will become more important (we are handling very fragile and expensive installations). Check limits of scalability.
- Middle tier and data storage will evolve together with industry standards. Scalability also an issue here.
- Front ends: A real development is needed here: Less expensive, radiation hard, cheap and reliable interconnectivity to data concentrators. Open source hardware and FE software, more modular with zillions of network attached devices.
- For the next years no real ‘big boy ‘construction projects in sight, but many other facilities, test stands and technology developments. Industry should act in this period as collaboration partner and not only as service provider for final installations.
- It seems all projects are based on a smaller and smaller core community at the host laboratories. Collaborations with industry vital (for both).