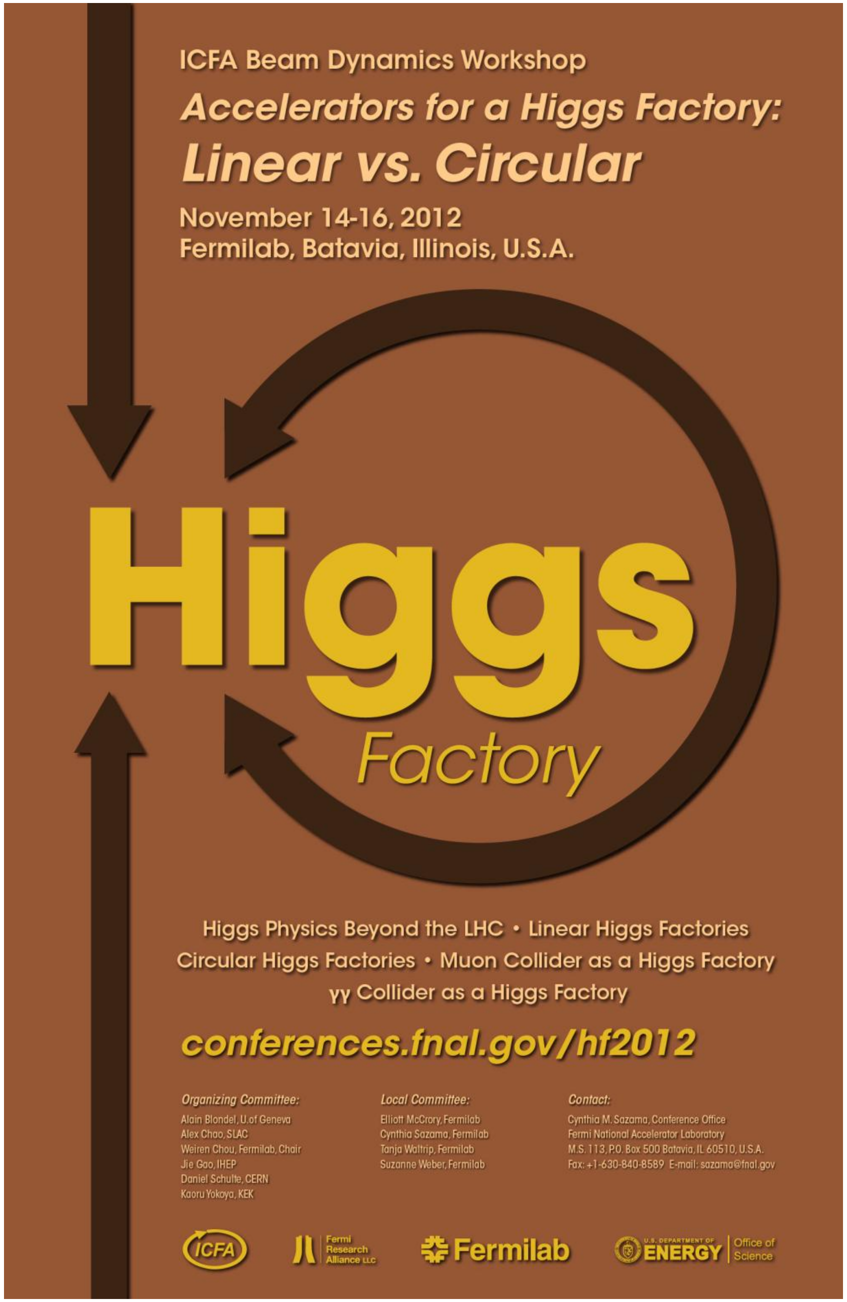
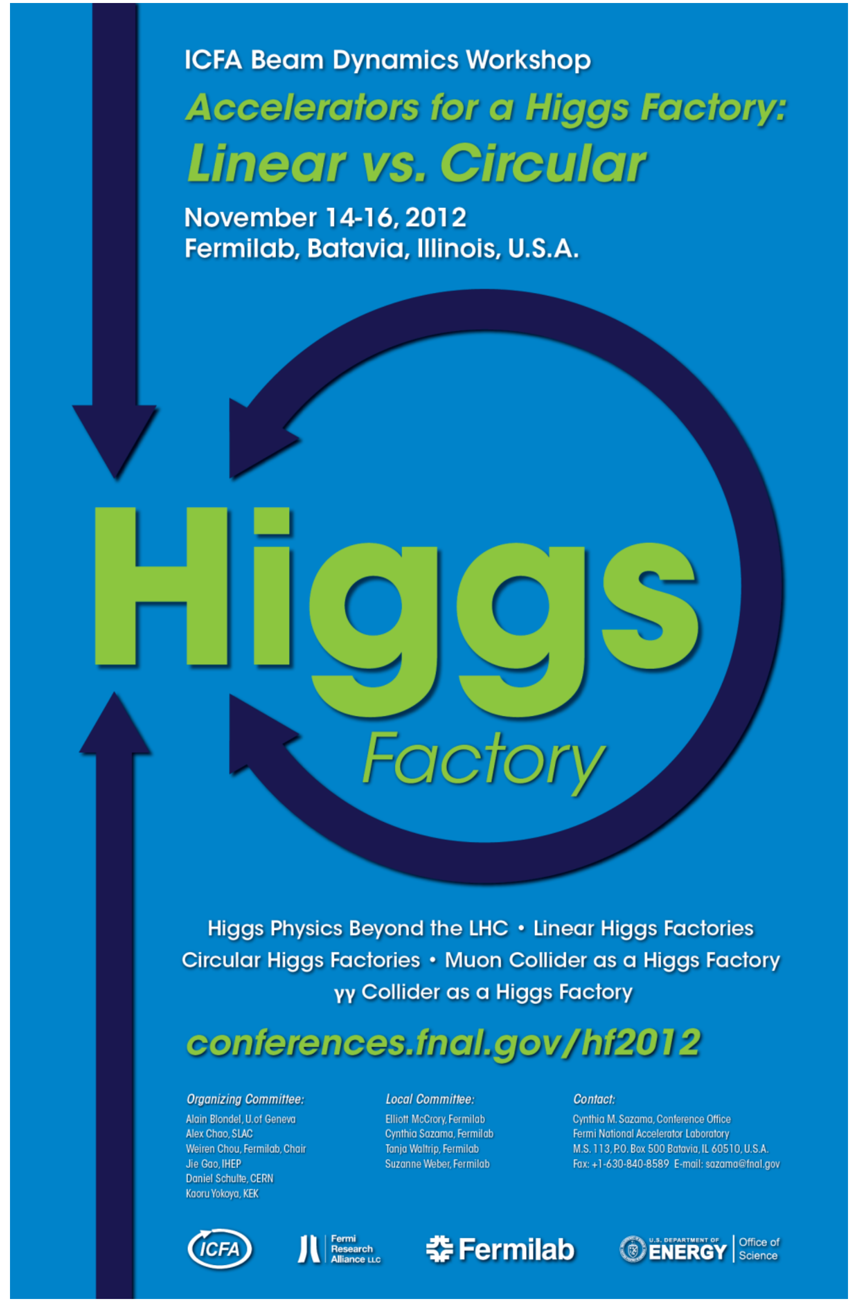
The 2012 Higgs Factory Workshop, A Summary

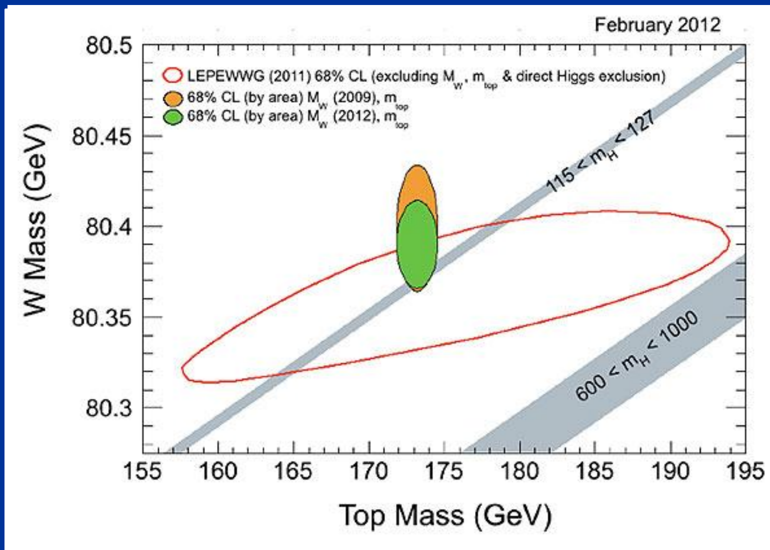
Edward Nissen



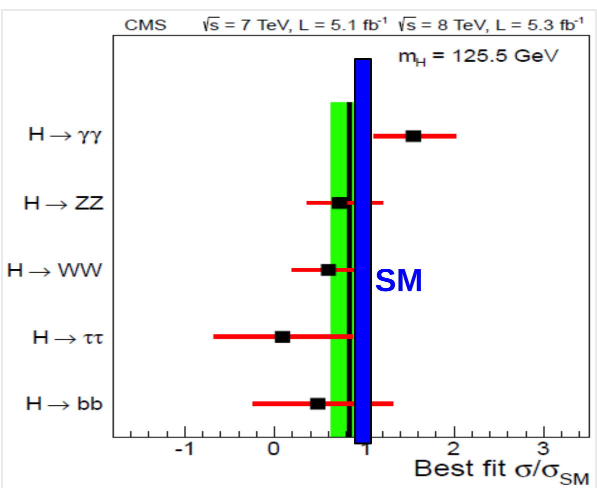


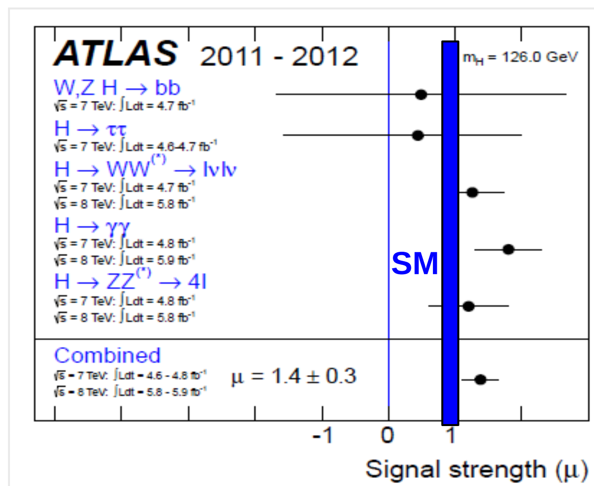
Adapted from summary talk by W. Chou

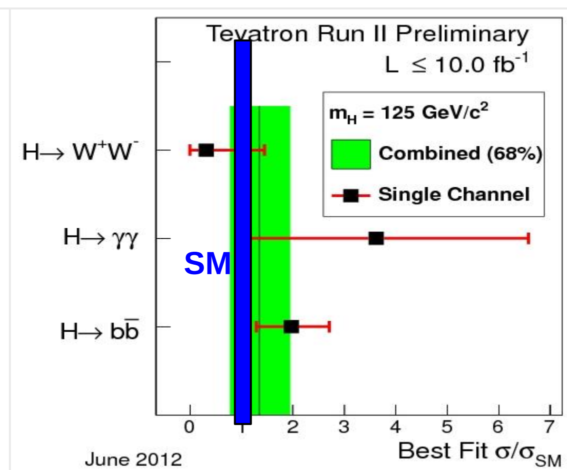
Higgs and the Standard Model



So far, consistent with the Standard Model







Higgs Factories

- Inexpensive
- Can produce Higgs particles at a rate of ~10,000 per year
  - Luminosity not the ideal measure of machine performance
  - Most comparisons will be done using Higgs production rates instead

Higgs Factories: Types

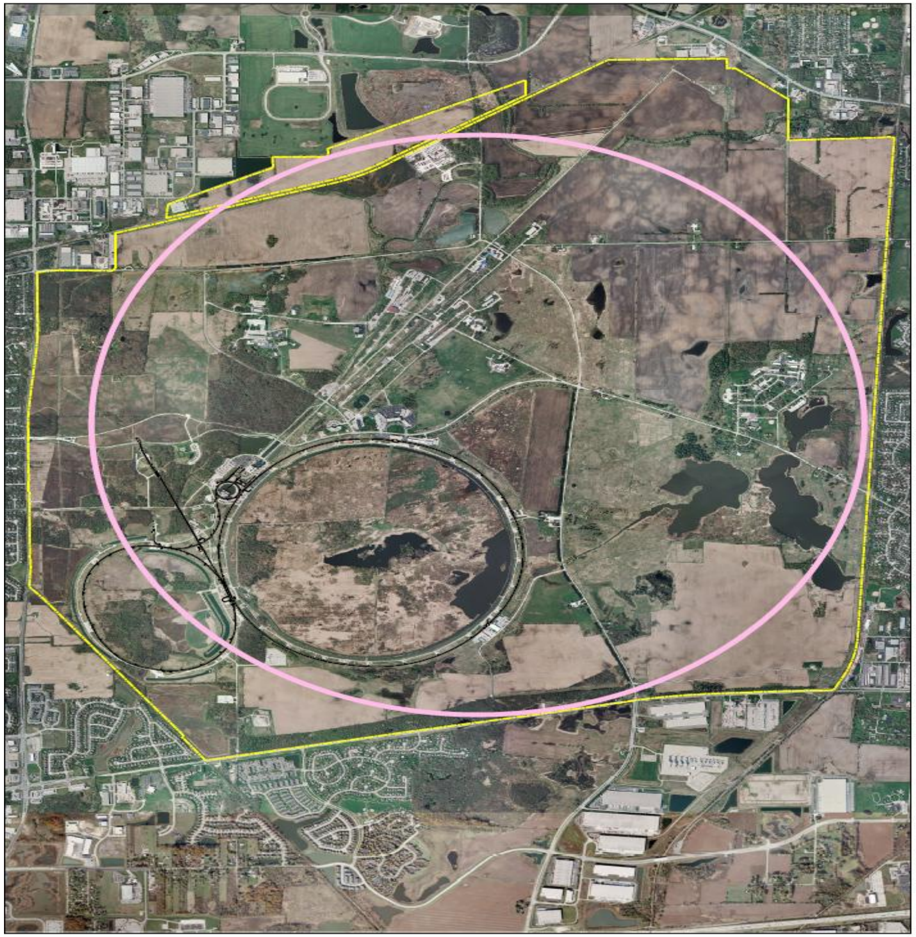
- Circular Collider
- Linear Collider
- Muon Collider
- $\gamma\gamma$ Collider

Circular Higgs Factory

- Advantages
  - Understood technology
  - Some designs can use existing tunnels
  - Can have more than one detector
  - Large tunnels can be reused for Hadron machines

- Disadvantages
  - Synchrotron Radiation
  - Beamstrahlung
  - Low Emittance lattices
  - Requires Positron source

Fermilab Site-Filler



Fermilab Site Filler rings
Circumference = 16 km

Higgs factory

- Beam Energy = 120 GeV
- SR power, both beams=100MW
- Initial luminosity=5×10^{33} cm^{-2} s^{-1}
- βx^*, βy^* = (20, 0.2) cm
- Beam-beam tune shifts =(0.067, 0.095)
- Beam current = 5 mA

Z Factory

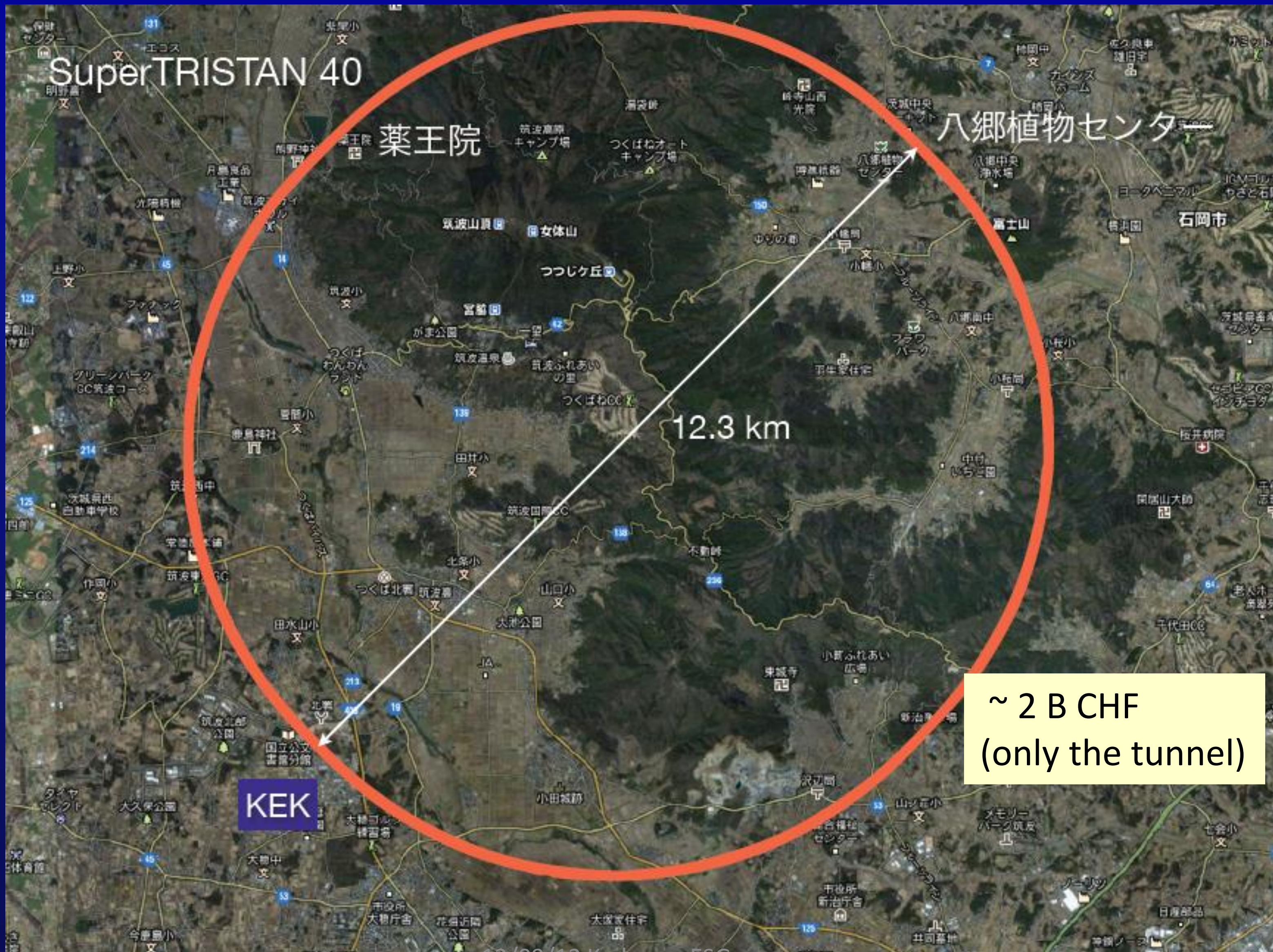
- Beam Energy = 46 GeV
- SR power, both beams= 60 MW
- Initial luminosity=3×10^{34} cm^{-2} s^{-1}
- Beam-beam tune shifts= (0.032, 0,045)
- Beam current = 134 mA

Beyond HE-LHC : new tunnels in Geneve area 47 km – 80 km

1) 42 TeV c.o.m. with 8.3 T (present LHC dipoles)
2) 80 TeV c.o.m. with 16 T (high field based on Nb3Sn)
3) 100 TeV c.o.m with 20 T (very high field based on HTS)

Figure 9. Two possible location, upon geological study, of the 80 km ring for a Super HE-LHC (option at left is strongly preferred)

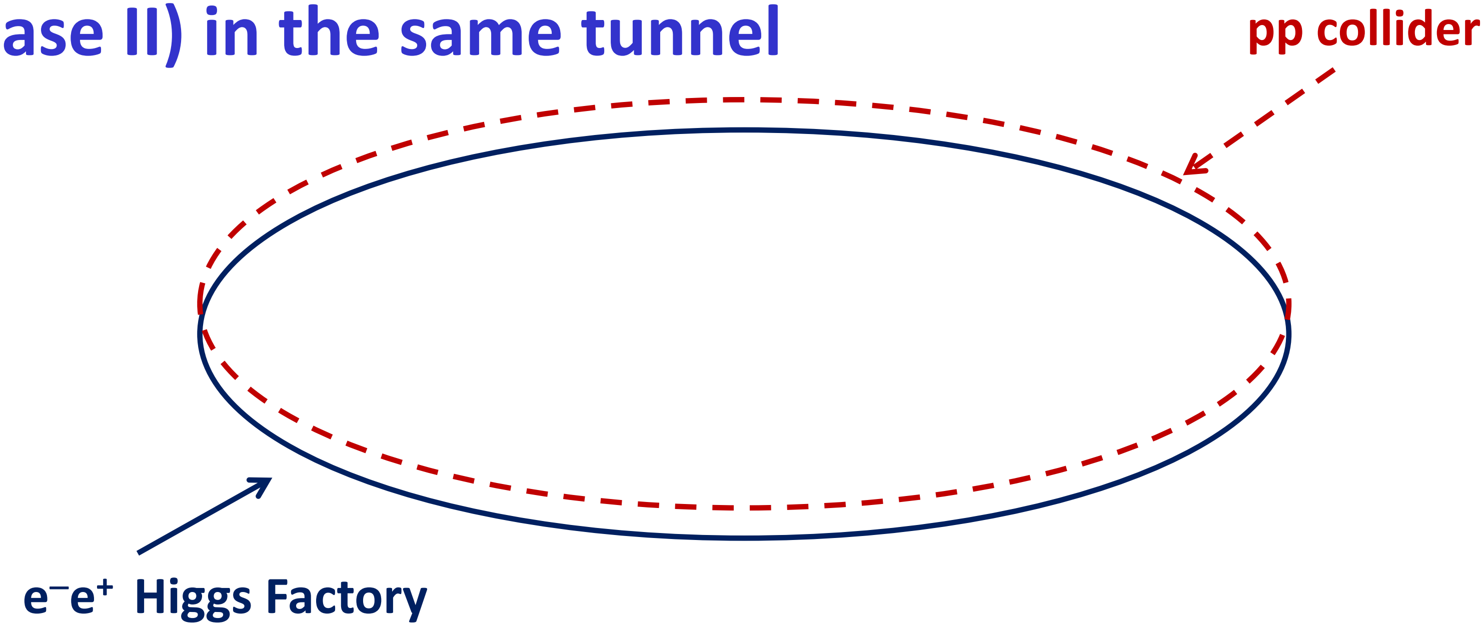
SuperTRISTAN



13 Feb. 2012 K. Oide (KEK)

What is a (CHF + SppC)

- Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel



Conclusion (Q. Qin)

- A CHF + SppC was proposed in IHEP for high precise probe of Higgs, and new discovery of physics as well.
- Main parameters and basic lattices are studied and further iterations are required.
- Budget and time schedule are not yet estimated.

LEP3/TLEP R&D items (F. Zimmermann)

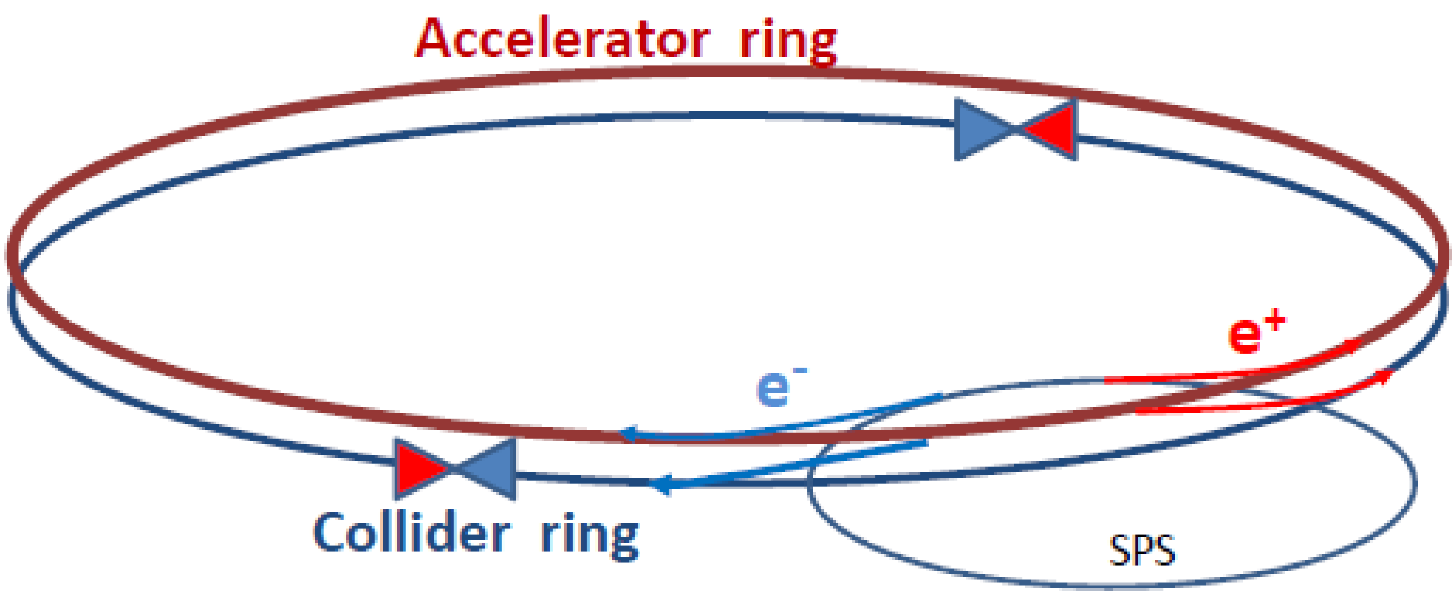
- choice of RF frequency: 1.3 GHz (ILC) or 700 MHz (ESS)? & RF coupler
- SR handling and radiation shielding (LEP experience)
- beam-beam interaction for large Q_s and significant hourglass effect
- IR design with large momentum acceptance
- integration in LHC tunnel (LEP3)
- Pretzel scheme for TERA-Z operation

How can one increase over LEP 2 (average) luminosity by a factor 500 without exploding the power bill?

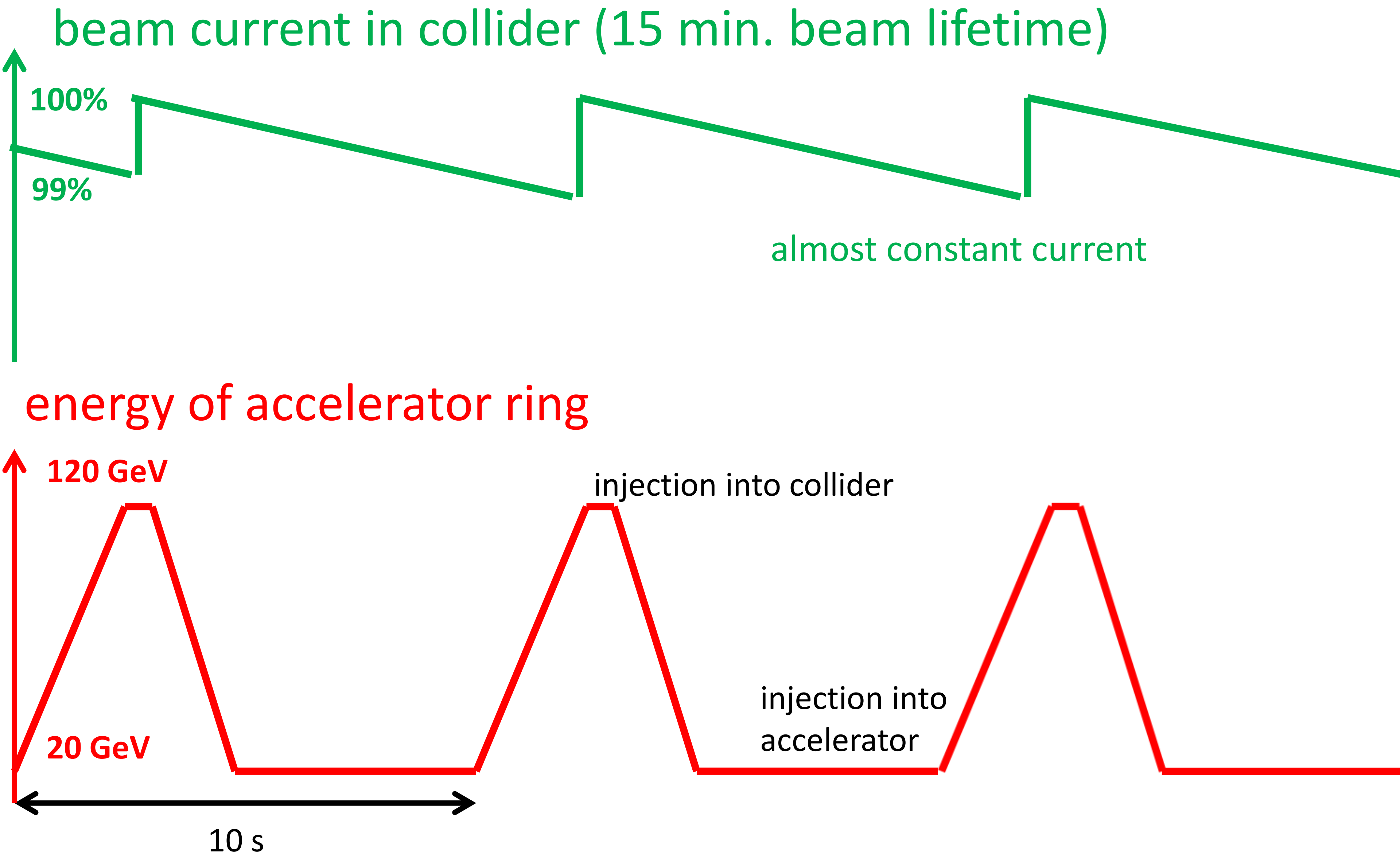
Answer is in the B-factory design: a very low vertical emittance ring with higher intrinsic luminosity

electrons and positrons have a much higher chance of interacting

- ➔ much shorter lifetime (few minutes)
  - ➔ feed beam consituously with a ancillary accelerator

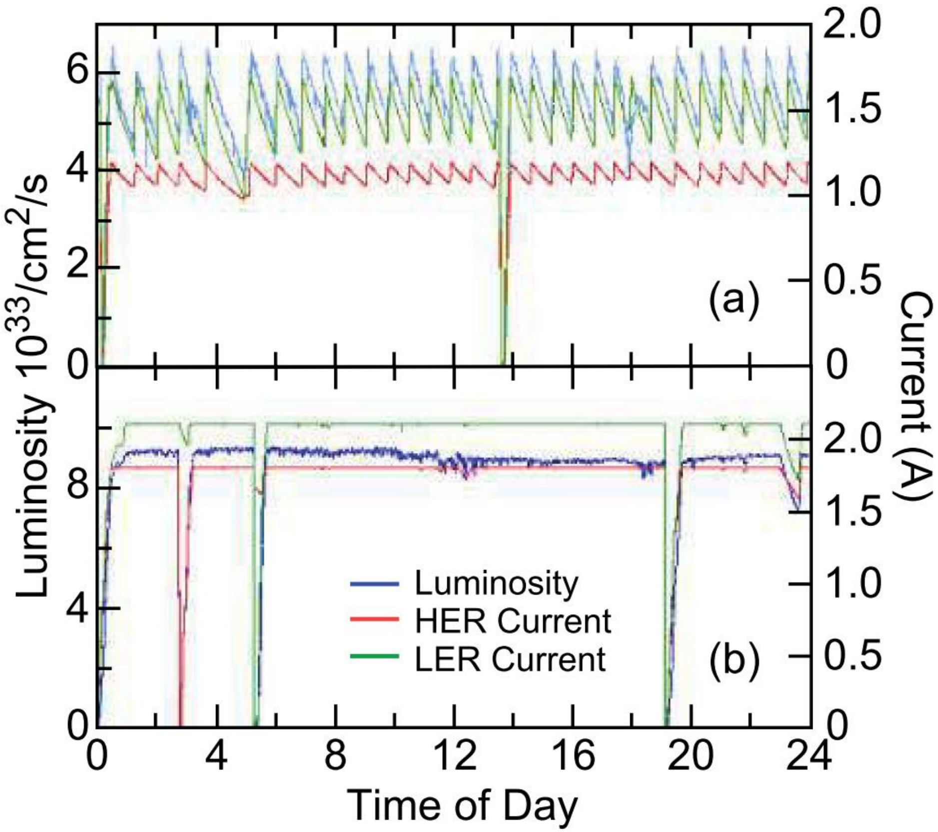


Top-up Injection: Schematic Cycle



PEP-II/BaBar Top-Up Injection (Accelerator)

Improved peak and average luminosity.



Before Top-Up Injection

After Top-Up Injection

PEP-II: Luminosity and beam currents for a 24-hour period (a) before and (b) after the implementation of trickle injection.

Conclusions (J. Seeman)

Top-up injection will work for a Circular Higgs Factory.

A full energy injector is needed.

A synchrotron injector will work the best but is more than is needed. (60 Hz)

A rapidly ramped storage ring is likely adequate. (4 sec)

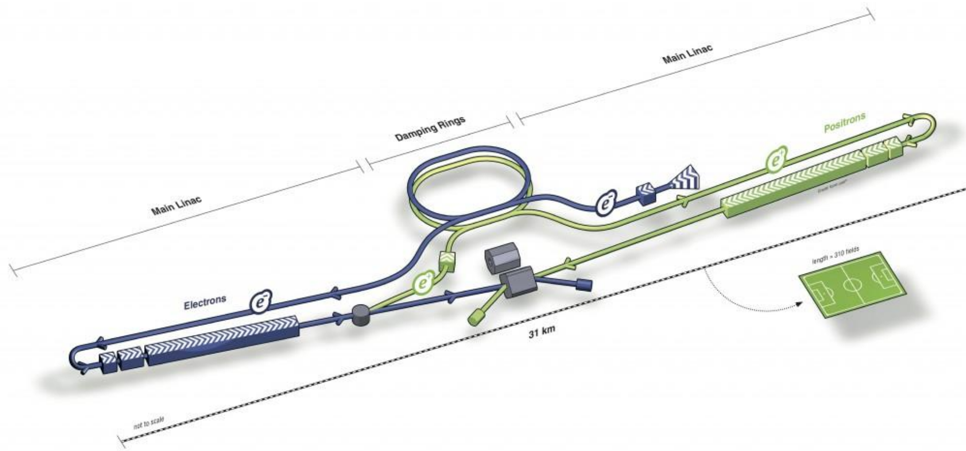
A slowly ramped storage ring injector doesn’t make the luminosity constant enough.

The detectors will need to mask out the buckets with damping injected bunches during data taking.

Linear Higgs Factory

- Advantages
  - Significant design work has already been performed on a global scale
  - Allows for high energy reach with Leptons
- Disadvantages
  - High Cost
  - Work remains on industrialization of major components
  - Requires positron production

ILC as a Higgs Factory



TESLA Cavity (DESY/FNAL)

Blade Tuner (FNAL)

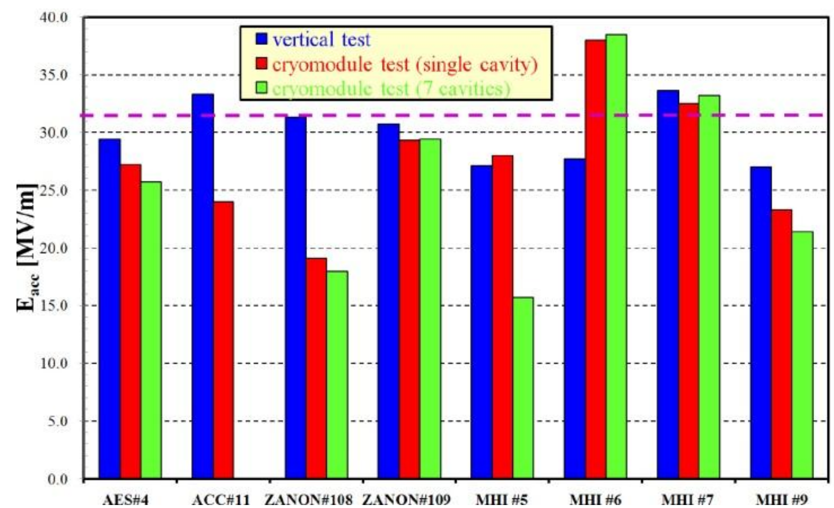
Saclay Tuner (DESY)

TTF-III Coupler (DESY/FNAL)

Tesla-like Cavity (KEK)

Slide-Jack Tuner (KEK)

STF-II Coupler (KEK)



JAHEP Statement (October 2012)

Proposal for Phased Execution of the ILC Project

The Japan Association of High Energy Physicists (JAHEP) accepted the recommendations of the Subcommittee on Future Projects of High Energy Physics[1] and adopted them as JAHEP's basic strategy for future projects, in March 2012. Later in July 2012 a new particle consistent with a Higgs Boson was discovered at LHC, while in December 2012 the Technical Design Report of the International Linear Collider (ILC) will be completed by the worldwide collaboration.

On the basis of these developments and following the subcommittee's recommendation on ILC, JAHEP proposes that ILC shall be constructed in Japan as a global project based on agreement and participation by the international community in the following scenario:

(1) Physics studies shall start with precision study of "Higgs Boson" and will evolve into studies on top quark, "dark matter" particles, and Higgs self-couplings, by upgrading the accelerator. A more specific scenario is as follows:

(A) A Higgs factory with a center-of-mass energy of approximately 250 GeV shall be constructed as a first phase.

(B) The machine shall be upgraded in stages up to a center-of-mass energy of ~500 GeV, which is the baseline energy of the overall project.

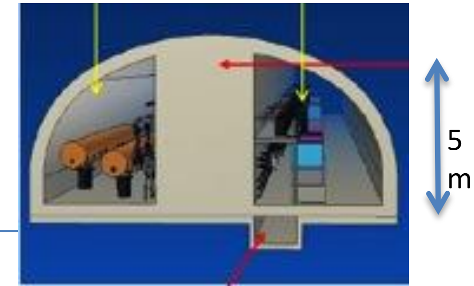
(C) Technical extendability to a 1 TeV region shall be secured.

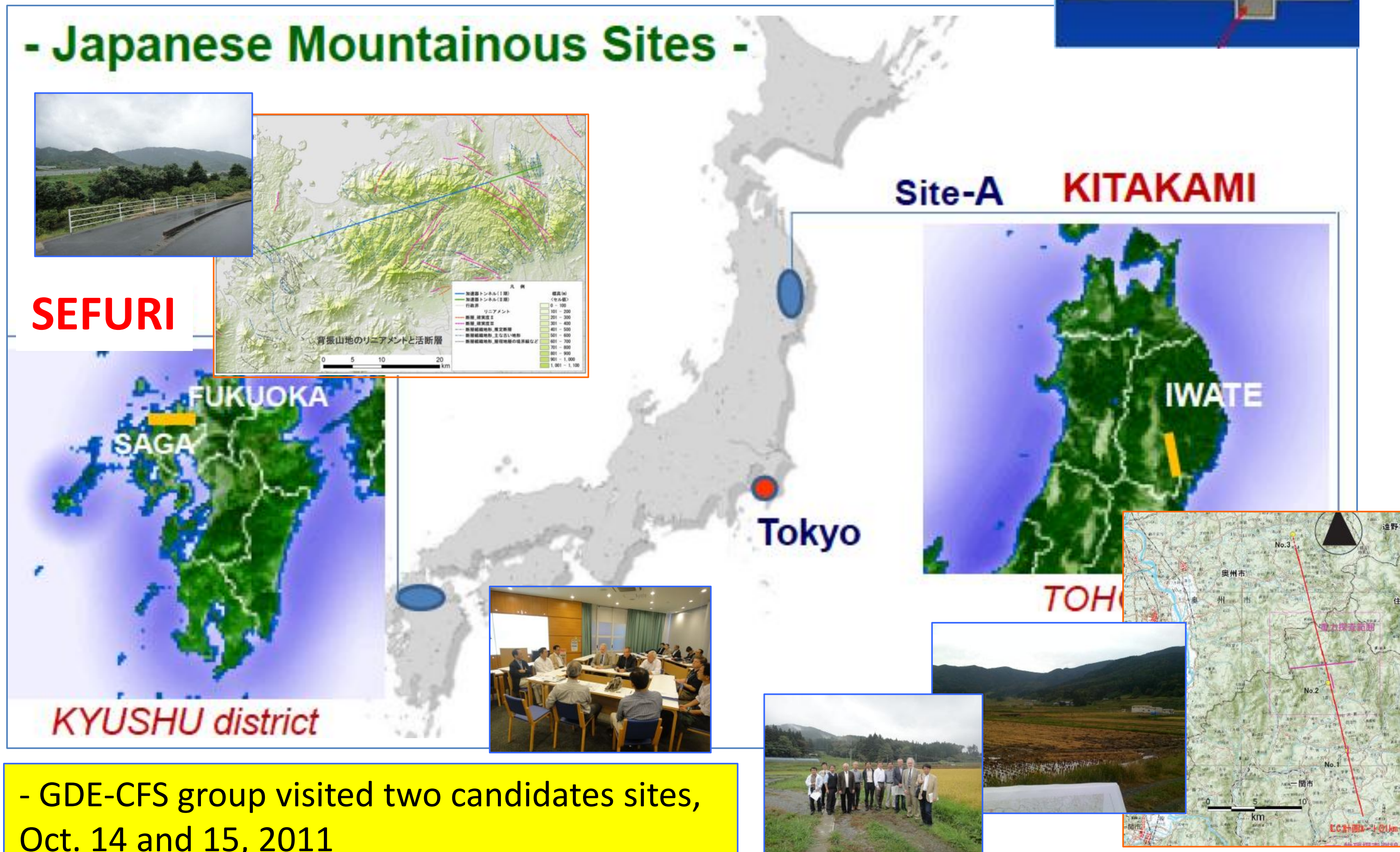
ILC = Global Project

(2) A guideline for shares of the construction costs is that Japan covers 50% of the expenses (construction) of the overall project of a 500 GeV machine. The actual shares, however, should be left to negotiations among the governments.

(a translation of the official JAHEP statement, Oct 2012)

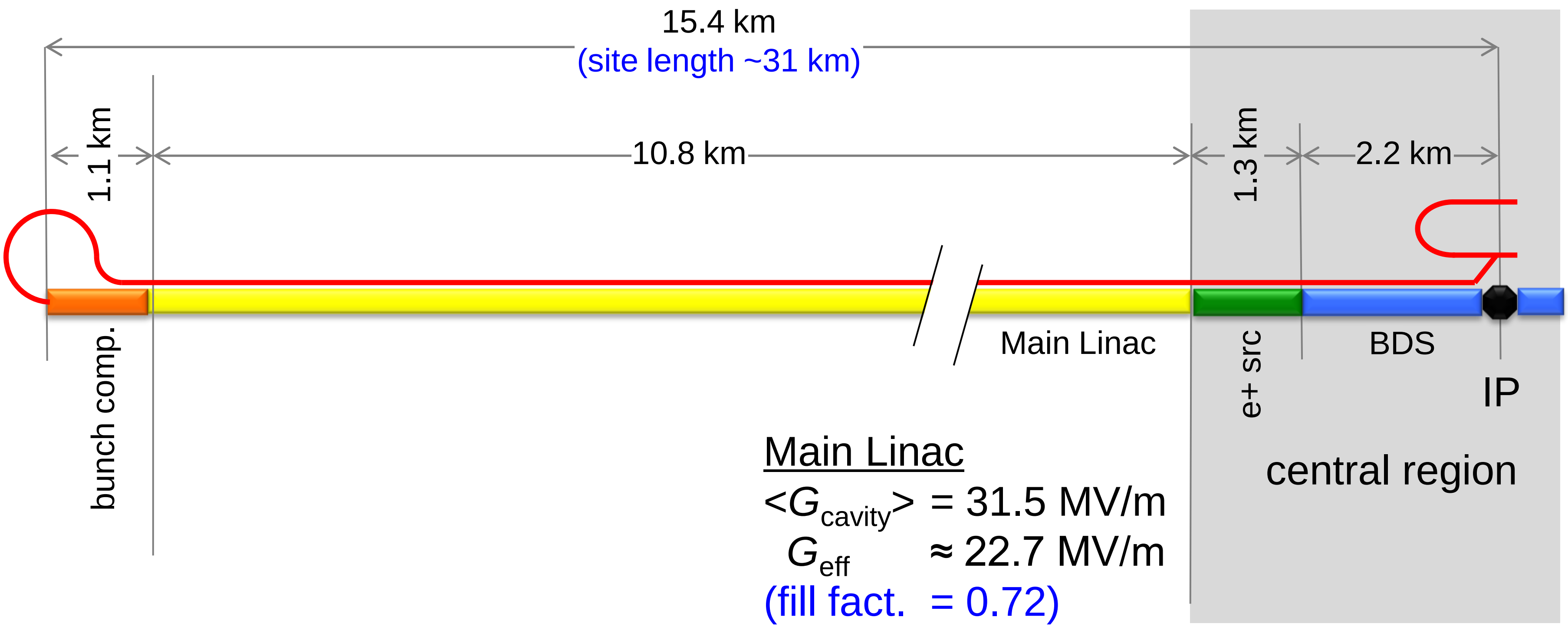
Two Candidate Sites in Japanese mountainous locations





- GDE-CFS group visited two candidates sites, Oct. 14 and 15, 2011

TDR 500 GeV Baseline



<u>Main Linac</u>

$\langle G_{cavity} \rangle = 31.5$ MV/m

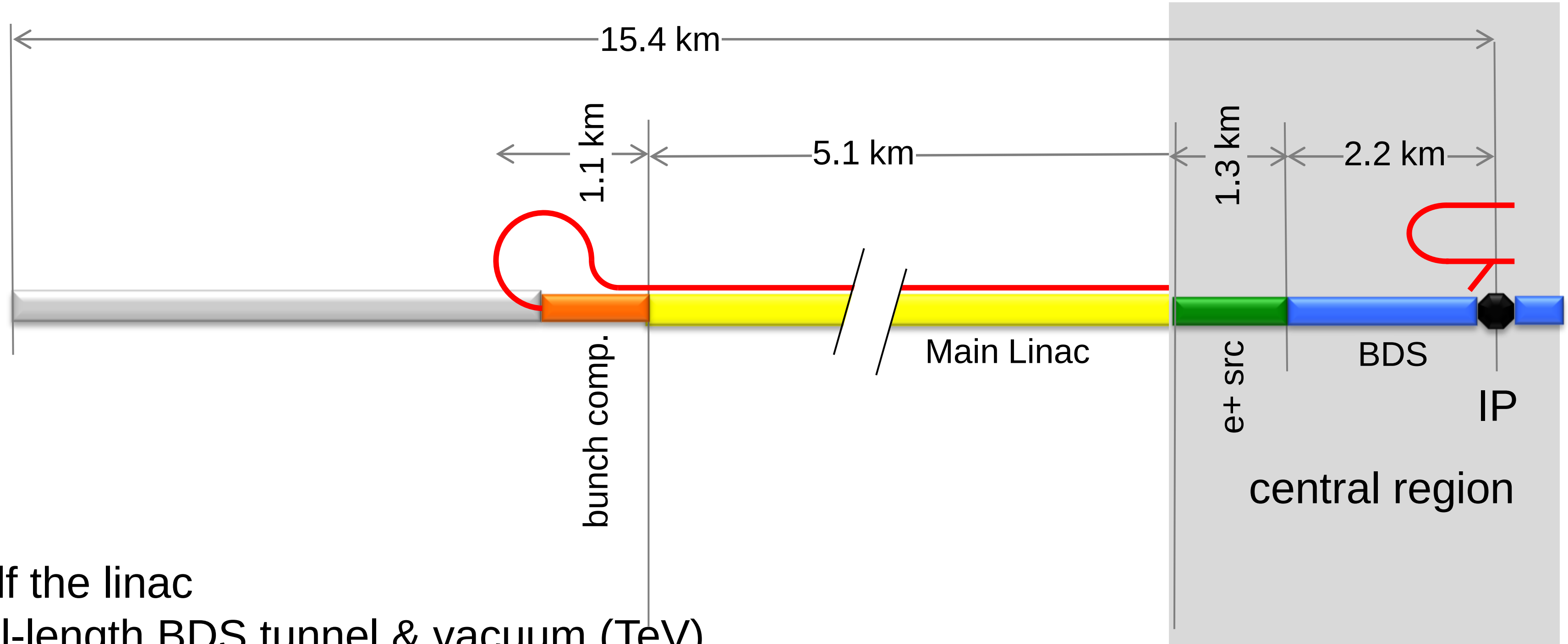
$G_{eff} \approx 22.7$ MV/m

(fill fact. = 0.72)

Cost: 100%

P_{AC}: 161 MW

250 GeV staged (scenario 1)

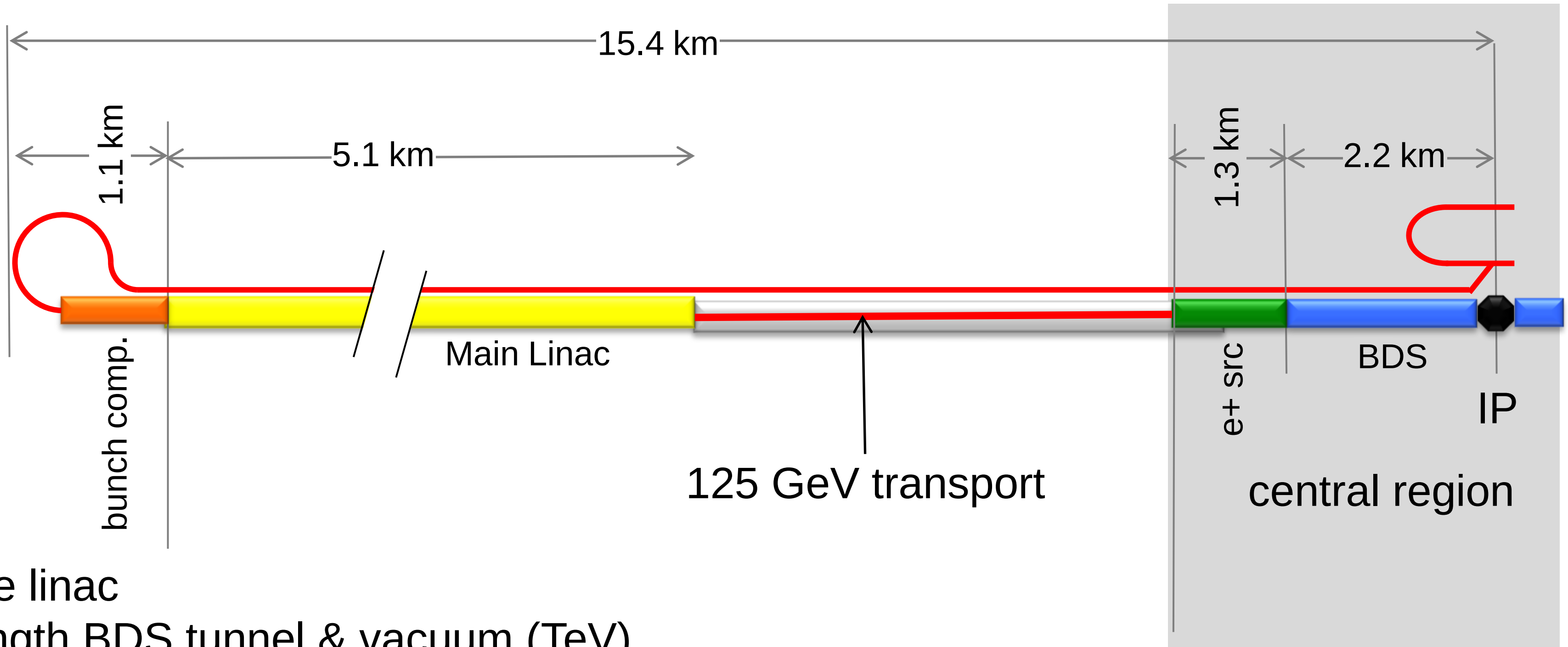


Half the linac
Full-length BDS tunnel & vacuum (TeV)
½ BDS magnets (instrumentation, CF etc)
½ RTML LTL

Extended tunnel/CFS already 500 GeV stage

10Hz mode e- linac

250 GeV staged (scenario 2)



Half the linac
Full-length BDS tunnel & vacuum (TeV)
½ BDS magnets (instrumentation, CF etc)
1 RTML LTL
5km 125 GeV transport line

quasi-adiabatic energy upgrade?

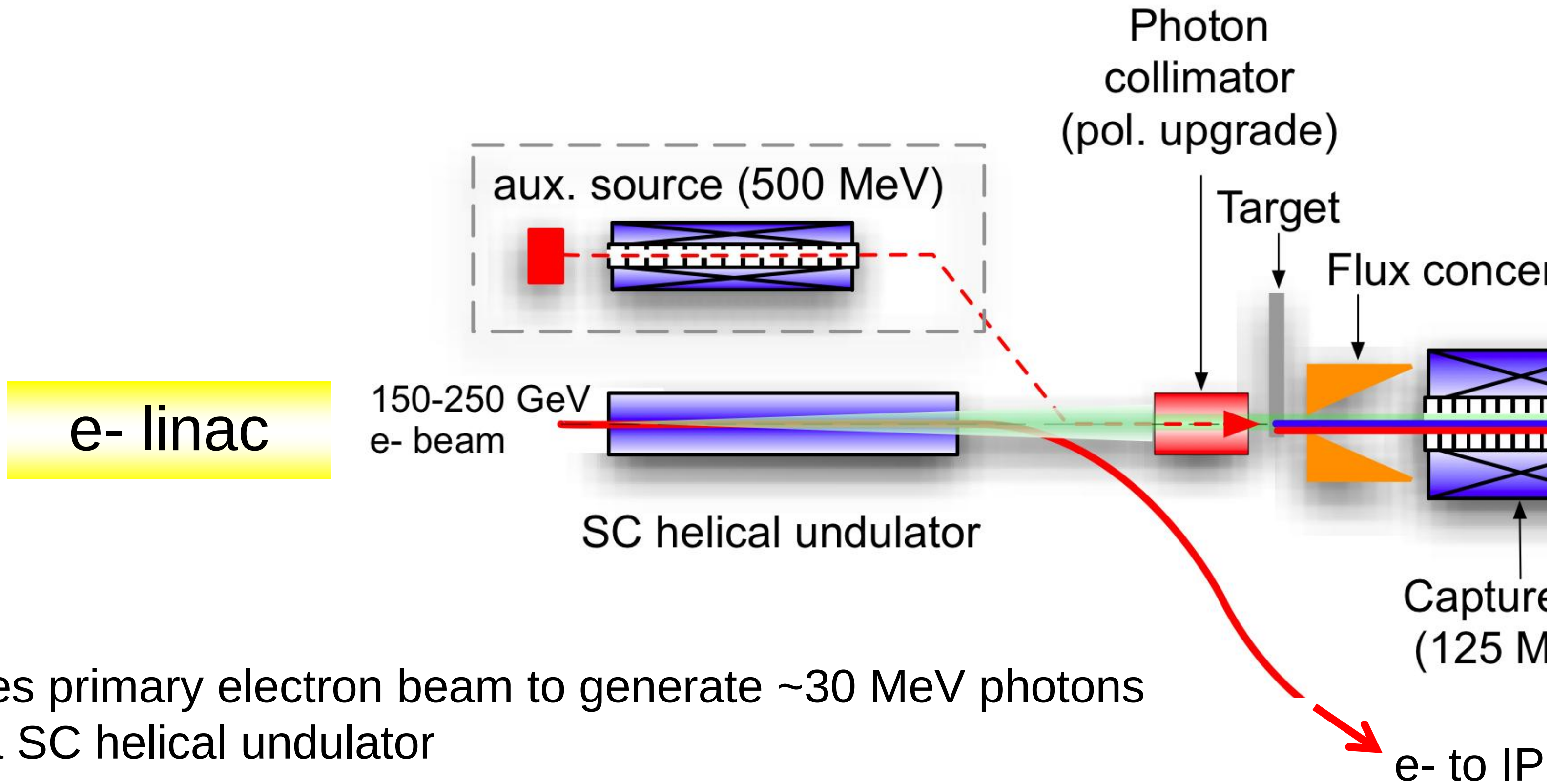
Extended tunnel/CFS already 500 GeV stage

10Hz mode e- linac

Summary (N. Walker)

- **ILC (500 GeV) machine already "contains" a light Higgs factory**
  - Luminosity: 7.5×10^{33} cm^{-2} s^{-1}
  - (Possible to upgrade by factor 2)
- **Standalone machine for LHF**
  - reduced cost by ~35% (P_{AC} ~ 100 MW)
  - reduces schedule by 12-18 months (perhaps a little more)
- **Only really makes sense as part of a first-stage machine**
  - scope of complete project still ~500 GeV
  - TeV upgrade remains optional

ILC Polarised-Positron Production

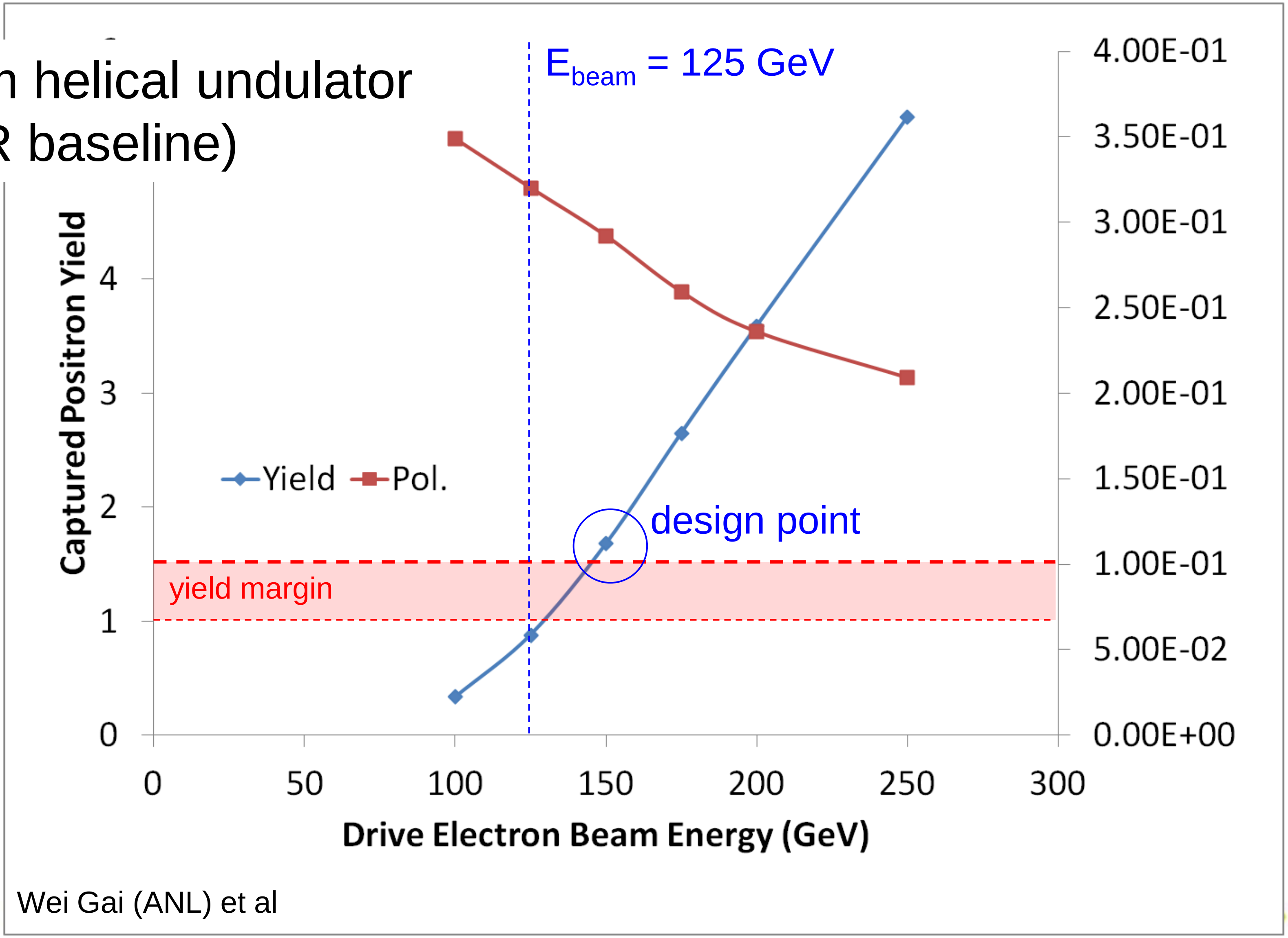


Uses primary electron beam to generate ~30 MeV photons in a SC helical undulator

Photons converted into e+e- pairs in “thin” titanium target

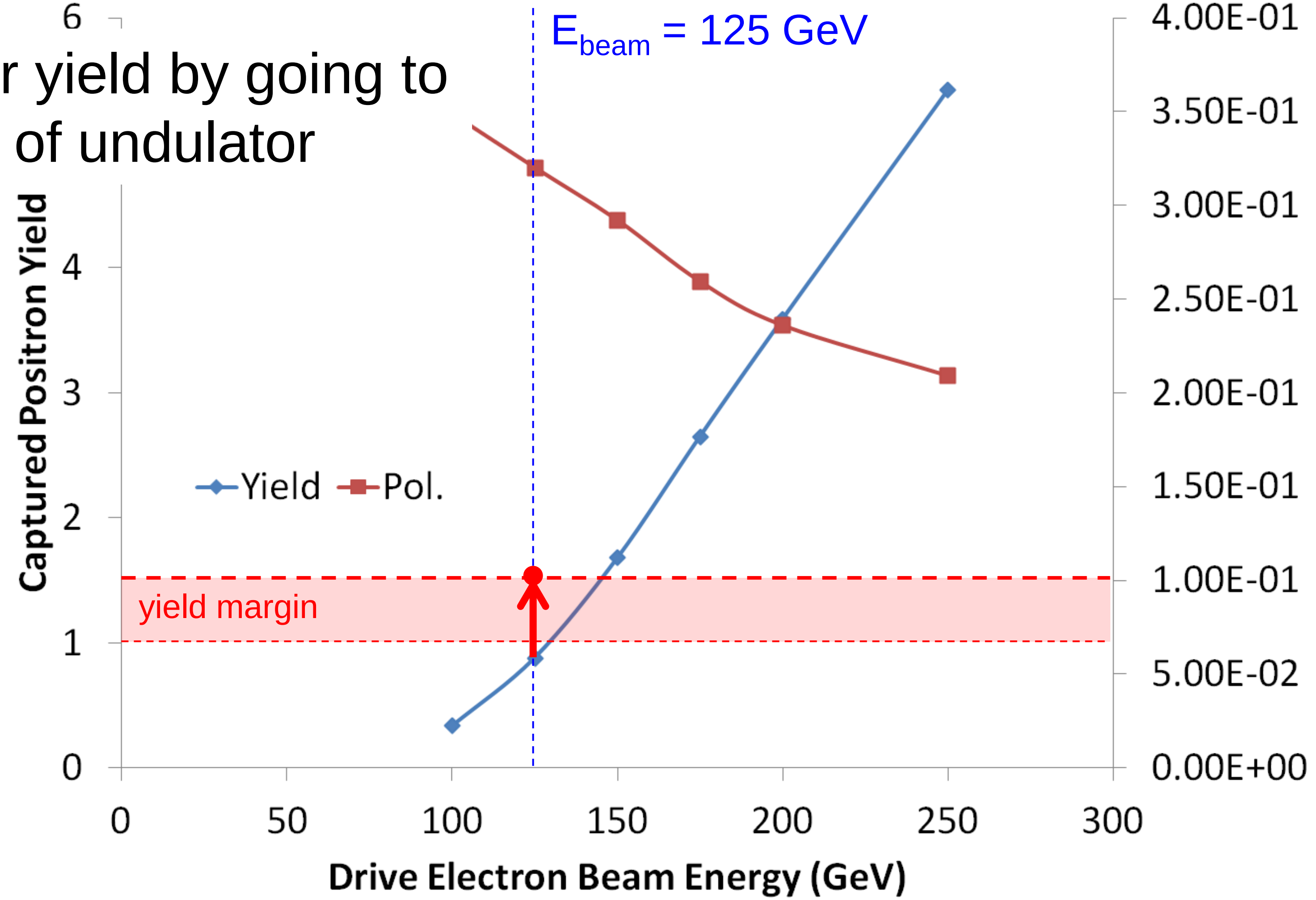
Positron production yield dependent on e- beam energy (and therefore E_{cm})

Positron Yield



Positron Yield for a LHF

Recover yield by going to ~250 m of undulator

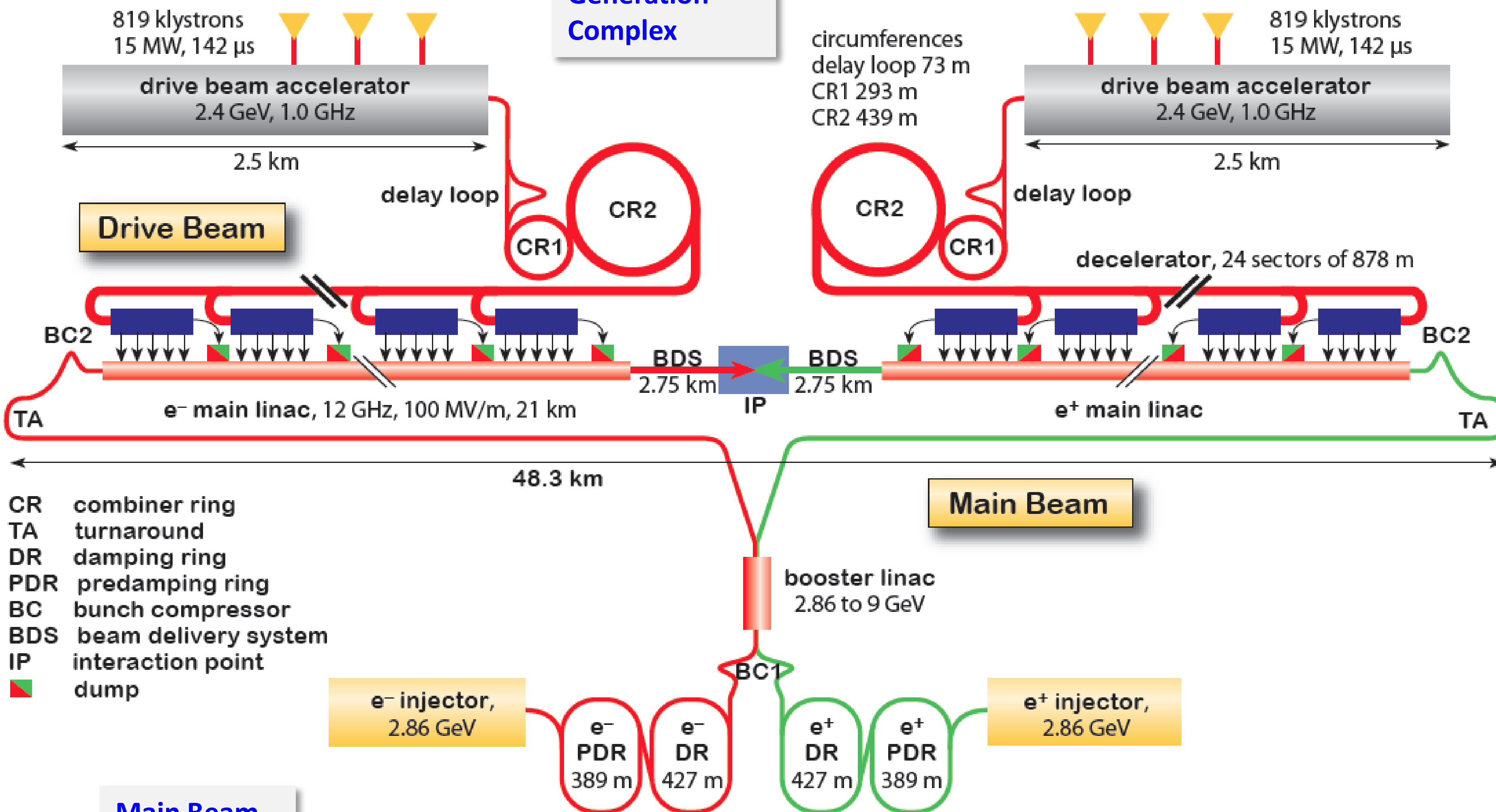


Wei Gai (ANL) et al

CLIC Layout at 3 TeV

Goal: Lepton energy frontier

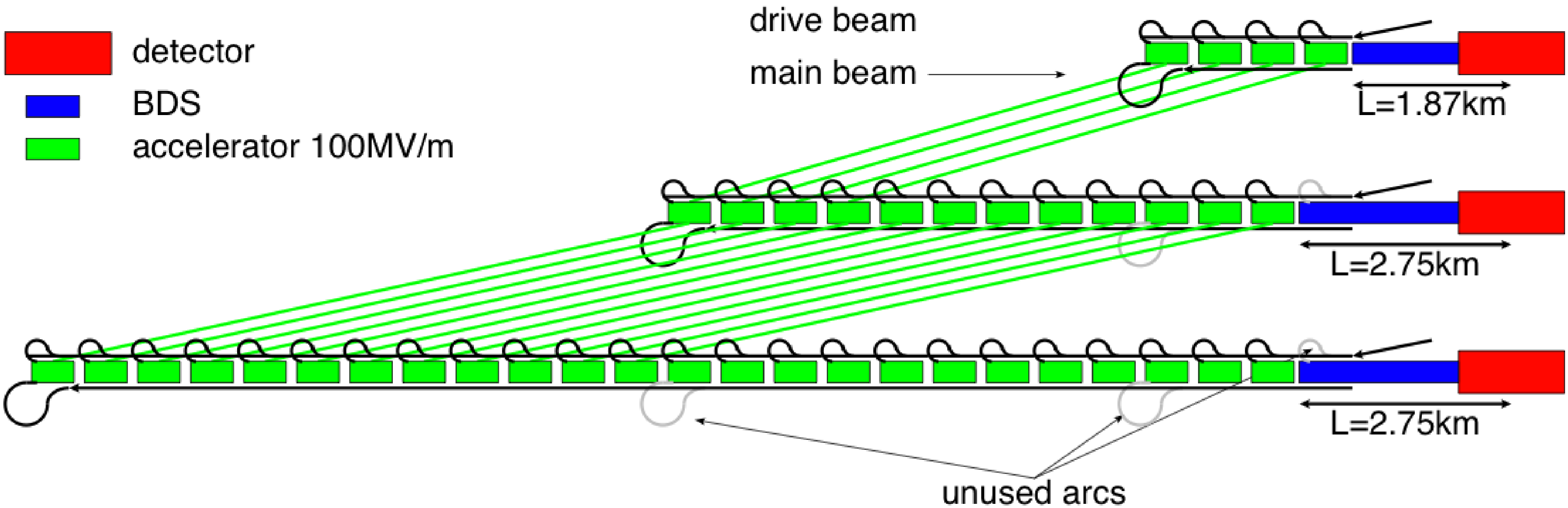
Drive Beam Generation Complex



Main Beam Generation Complex

D. Schulte, CLIC, HF 2012, November 2012

Staging Scenario B



4 sectors equal 500GeV

12 sectors equal 1.5TeV

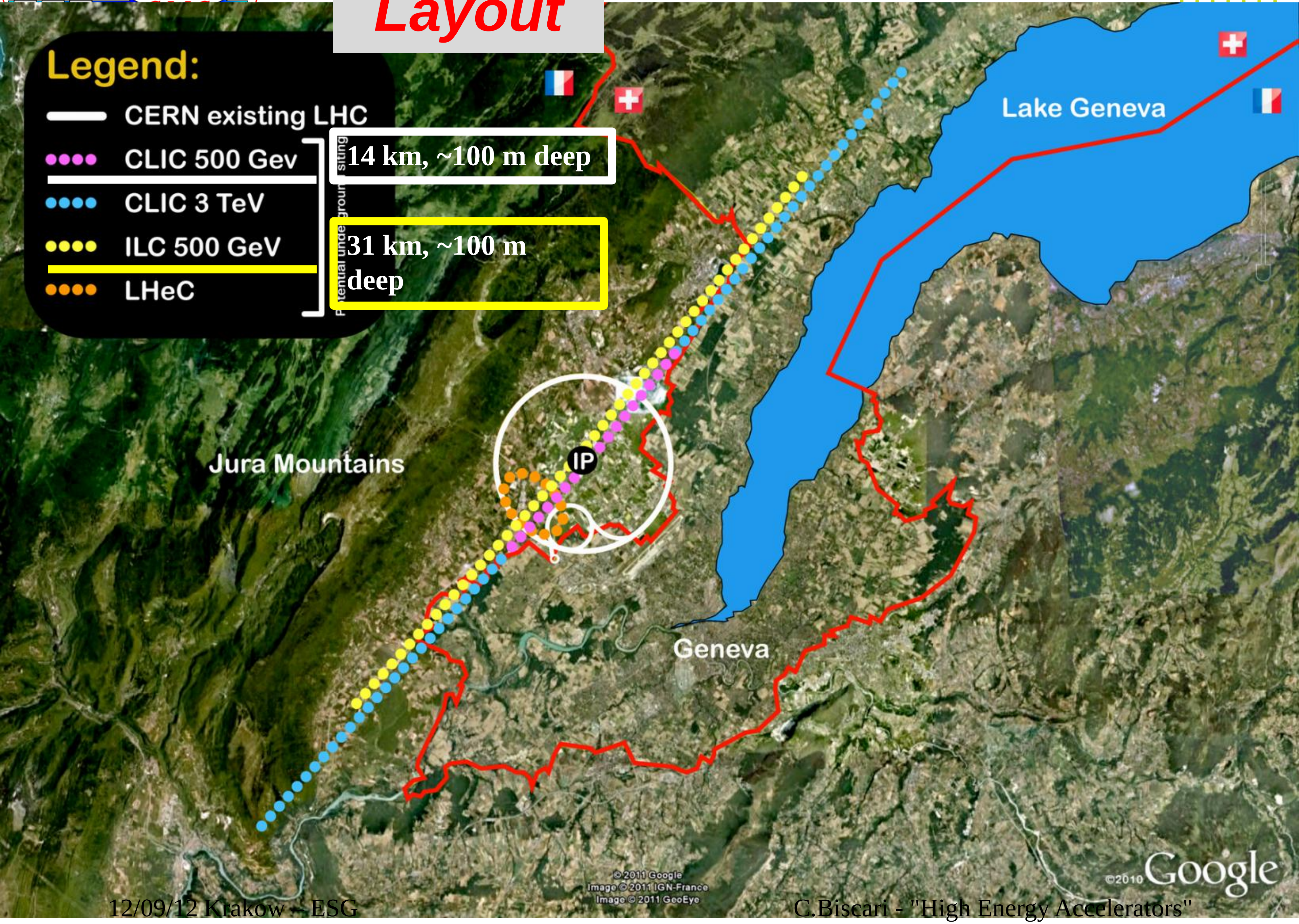
24 sectors equal 3TeV

Energy choices made with Physics Group

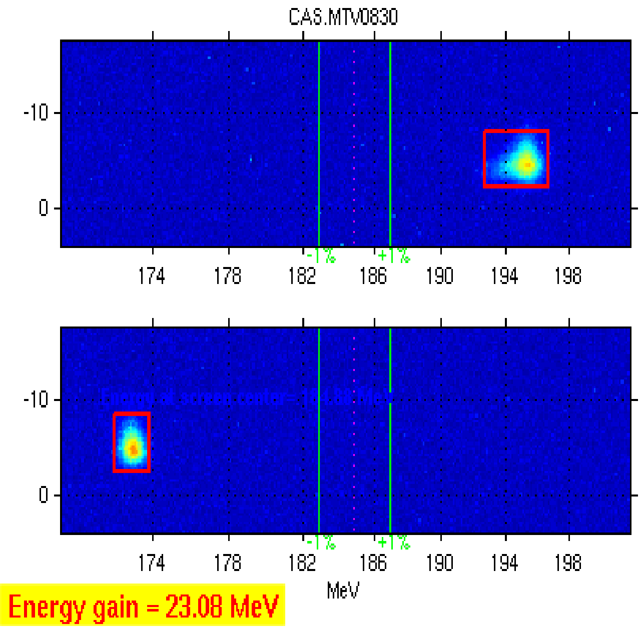
Need to be reviewed when more LHC results become available

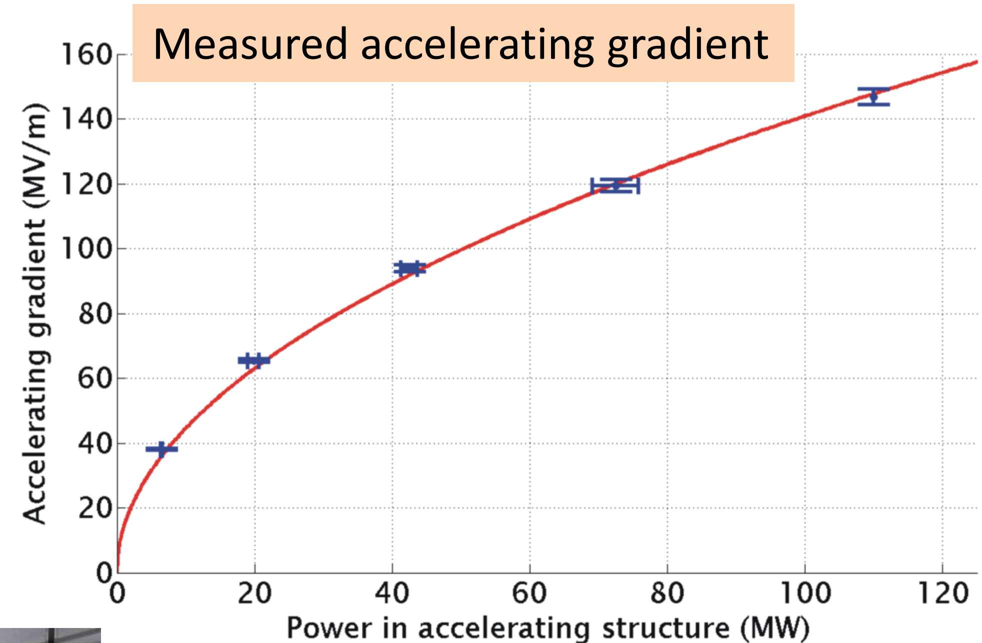
They are only an example

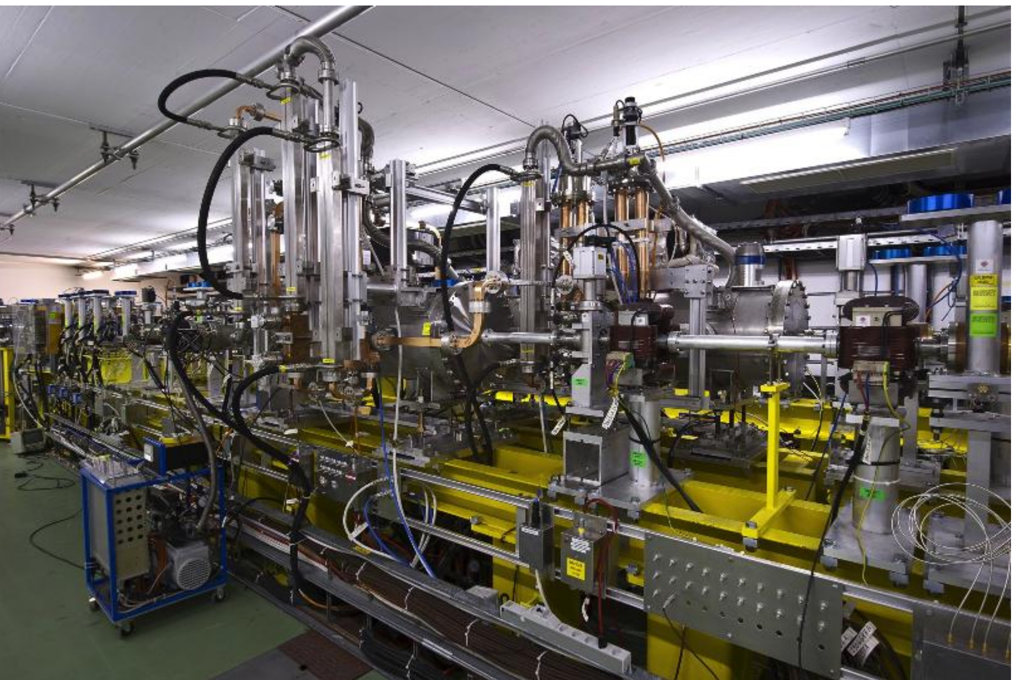
Layout


Legend:
CERN existing LHC
CLIC 500 Gev
CLIC 3 TeV
ILC 500 GeV
LHeC
Potential underground siting
14 km, ~100 m deep
31 km, ~100 m deep
Lake Geneva
Jura Mountains
IP
Geneva
©2011 Google
Image © 2011 IGN-France
Image © 2011 GeoEye
©2010 Google

TBTS: Two Beam Acceleration







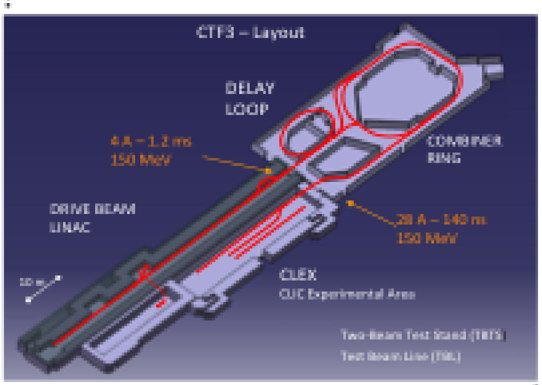
Maximum gradient 145 MV/m

Consistency between
- produced power
- drive beam current
- test beam acceleration

Timeline

2012-16 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



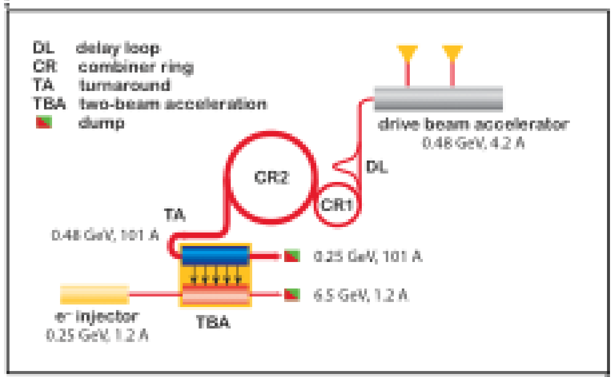
2016-17 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2017-22 Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



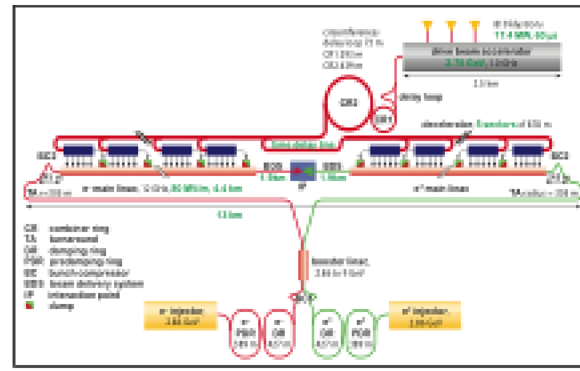
2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.

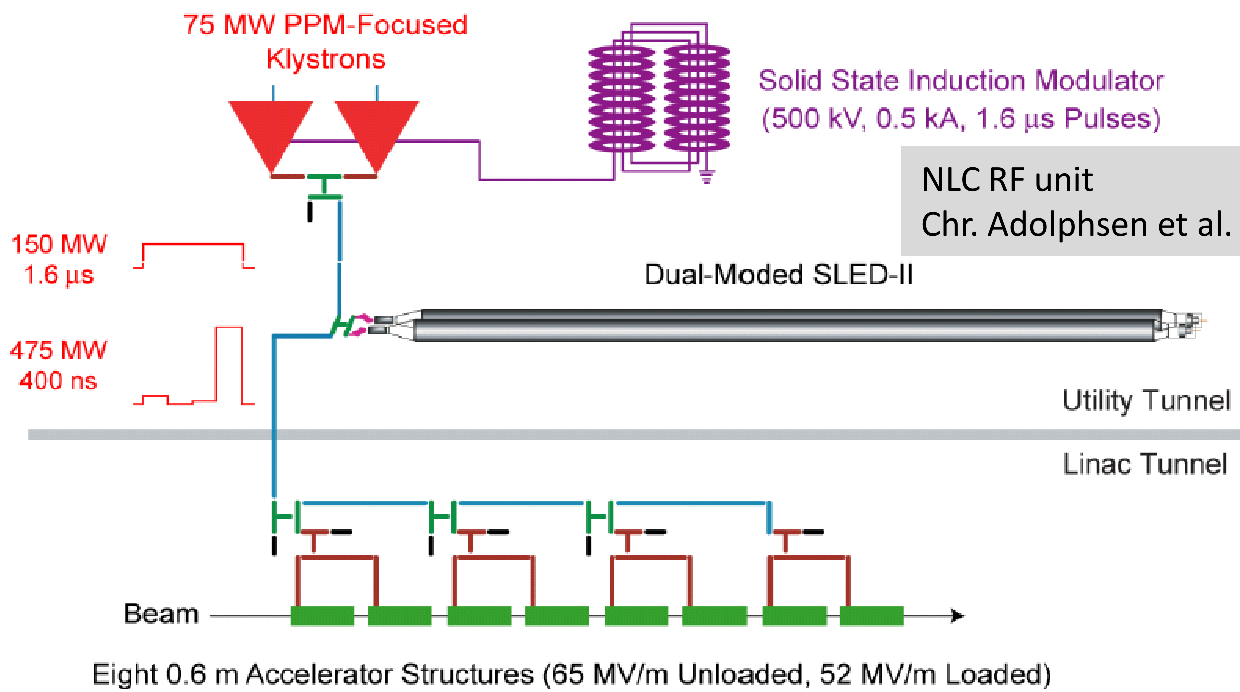


2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

Note on Klystron-based First Stage

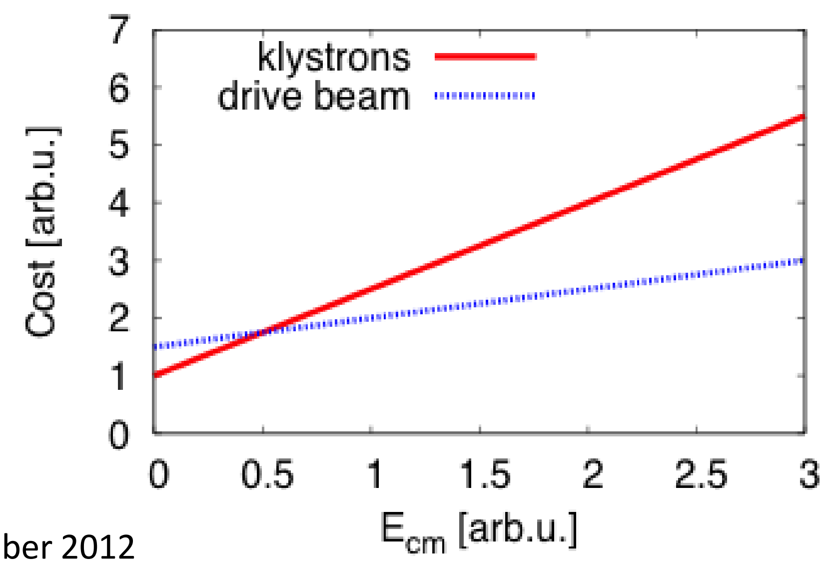
Klystrons-based design have been
Developed in the past: NLC and JLC-X



NLC RF unit
Chr. Adolphsen et al.

They aimed at
75MW power, 1.6μs pulse length
and 55% efficiency
-> reasonable limit of feasibility

Would need about 30,000 klystrons
for CLIC at 3TeV
-> much more expensive than drive
beam
But could be interesting at low
energies
-> is being explored for first stage



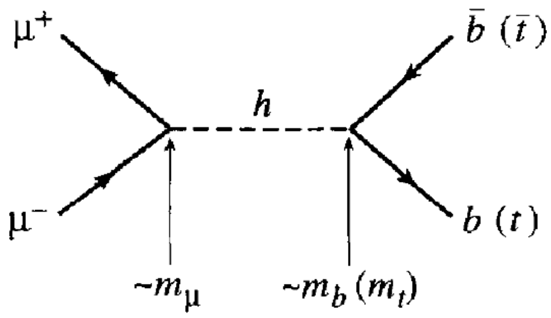
Muon Collider Higgs Factory

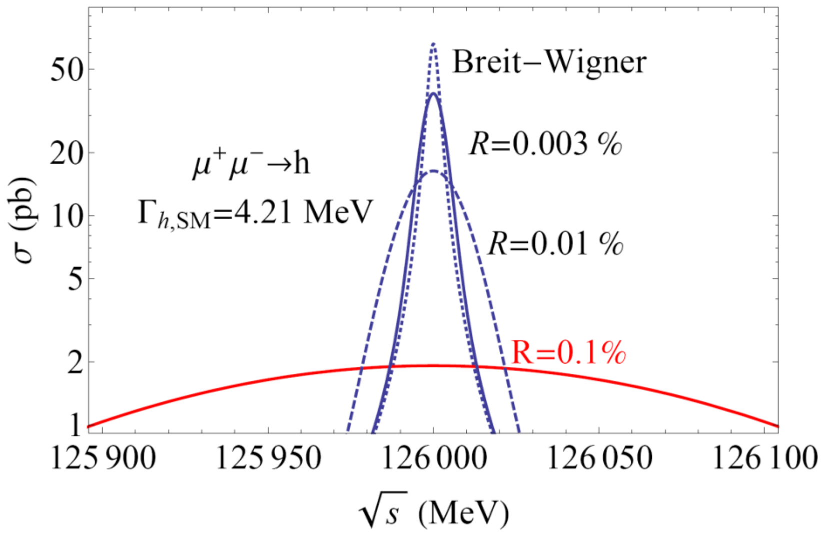
- Advantages
  - High Cross Section
  - Small size
  - No Synchrotron Radiation or Beamstrahlung
  - The future of the energy frontier for leptons

- Disadvantages
  - Unproven Technology
  - Cooling work needed
  - Constant decay of muons
  - Costs unknown

Muon Collider as a Higgs Factory

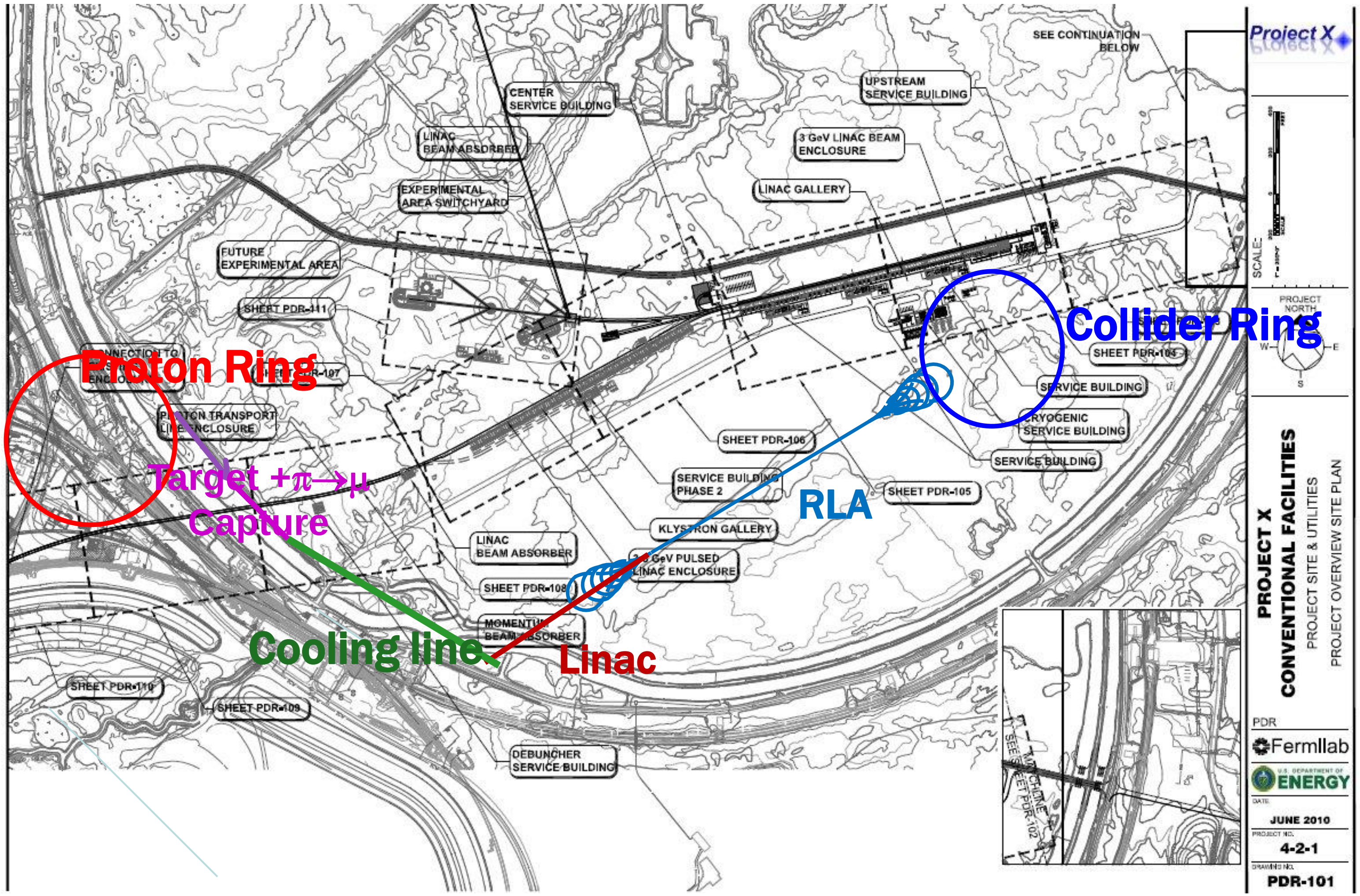
s-channel production of Higgs boson (Han and Liu)





- s-channel Higgs production cross section in a muon collider is 40,000 times larger than in an e^+e^- collider
- Muon collider can measure the decay width Γ directly without any theoretical assumption (a unique advantage) – if the muon beam energy resolution is sufficiently high
- But the required energy resolution is very demanding

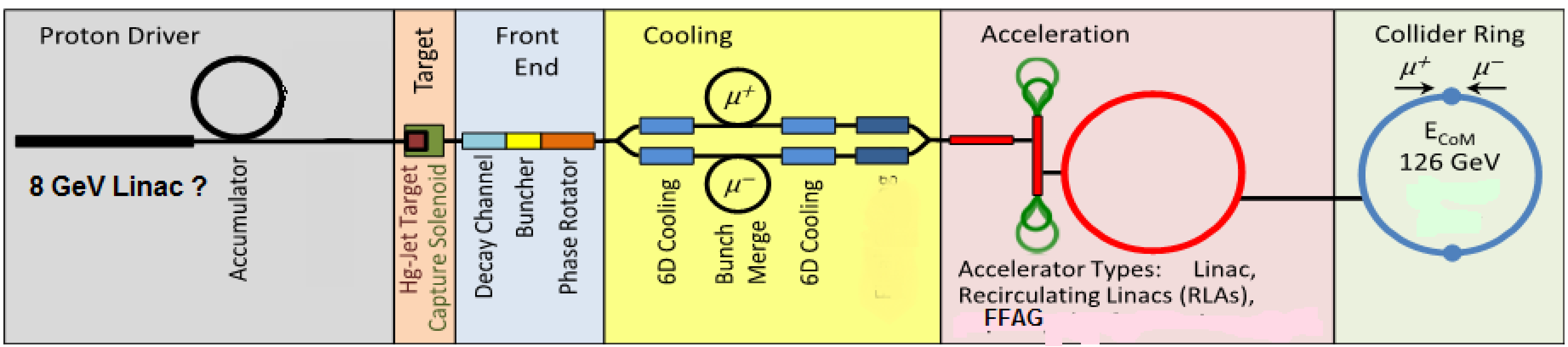
Scale of facility



126 GeV $\mu^+-\mu^-$ Collider

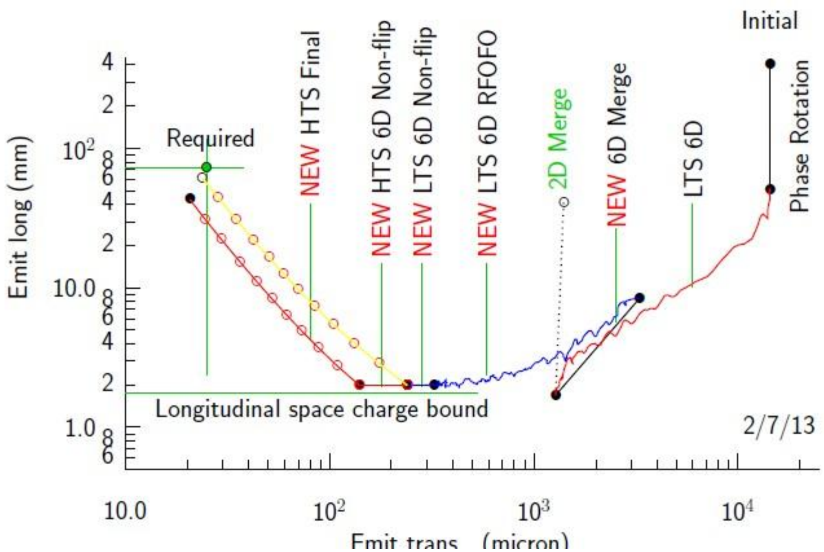
- **8 GeV, 4MW Proton Source**
  - 15 Hz, 4 bunches 5×10^{13}/bunch
- **π→μ collection, bunching, cooling**
- $\varepsilon_{\perp,N}$ =400 π mm-mrad, $\varepsilon_{\|,N}$= 2 π mm
  - 10^{12} μ/ bunch
- **Accelerate, Collider ring**
  - δE = 4 MeV, C=300m
  - Detector
  - monitor polarization precession
  - for energy measurement
    - $\delta E_{error} \rightarrow$ 0.1 MeV

Parameter	Symbol	Value
Collision Beam Energy	$E_{\mu+}, E_{\mu-}$	63GeV
Luminosity	L_0	10^{31}
Number of μ bunches	n_B	1
$\mu^{+/-}$/ bunch	N_μ	10^{12}
Transverse emittance	$\varepsilon_{t,N}$	0.0004m
Longitudinal emittance	ε_{LN}	0.002m
Energy spread	δE	4MeV
Collision β*	β^*	0.05 m
Beam size at collision	$\sigma_{x,y}$	0.02cm
Beam size (arcs)	$\sigma_{x,y}$	1.0cm
Beam size IR quad	σ_{max}	5.4cm
Storage turns	N_t	1000
Proton Beam Power	P_p	4 MW
Bunch frequency	F_p	60 Hz
Protons per bunch	N_p	5×10^{13}
Proton beam energy	E_p	8 GeV



Upgrade path (E and L)

- **More cooling**
  - $\varepsilon_{t,N} \rightarrow 0.0002$, $\beta^* \rightarrow 1$cm
- **Bunch recombination**
  - **60Hz → 15 ?**
  - L $\rightarrow 10^{32}$
- **More cooling**
  - **low emittance**
  - $\varepsilon_{t,N} \rightarrow 0.00003$, $\beta^* \rightarrow 0.3$cm
  - **L** $\rightarrow 10^{33}$
- **More Protons**
  - **4MW** → 8 → ?
  - 15Hz
  - **L** $\rightarrow 10^{34}$
- **more Acceleration**
  - →4 TeV or more …
  - **L** $\rightarrow 10^{35}$

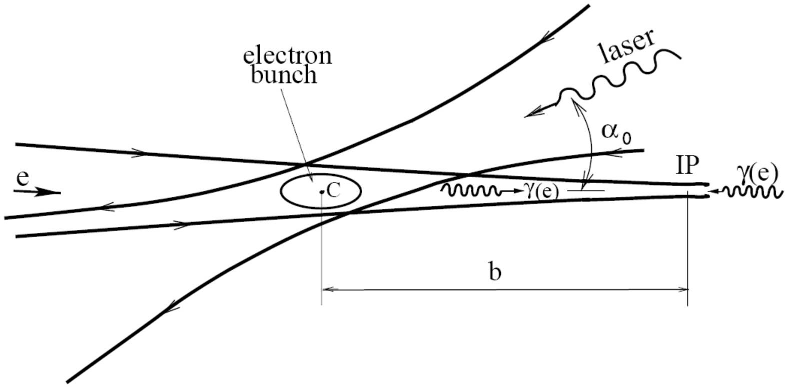


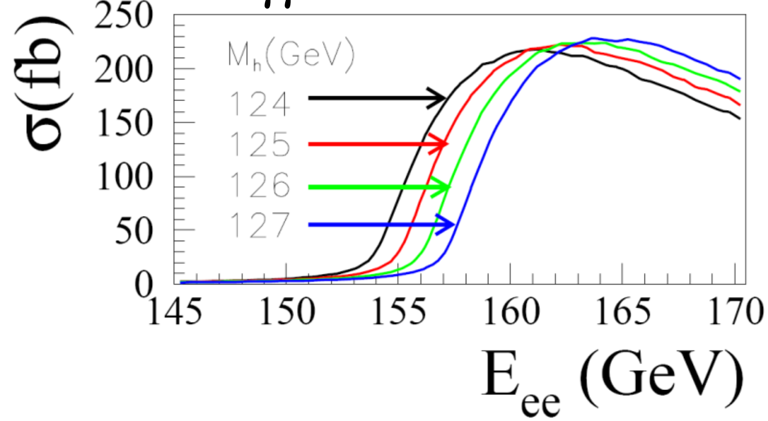
	Higgs[1]	Design	Design	Extrap[2]	
C of m Energy	0.126	1.5	3	6	TeV
Luminosity	0.002	1	4	12	10^{34} cm^{-2}sec^{-1}
Muons/bunch	2	2	2	2	10^{12}
Total muon Power	1.2	7.2	11.5	11.5	MW
Ring circumference	0.3	2.6	4.5	6	km
β^* at IP = σ_z	80	10	5	2.5	mm
rms momentum spread	0.004	0.1	0.1	0.1	%
Repetition Rate	30	15	12	6	Hz
Proton Driver power	4	4	3.2	1.6	MW
Muon Trans Emittance	300	25	25	25	μm
Muon Long Emittance	2	72	72	72	mm

$\gamma\gamma$ Collider Higgs Factory

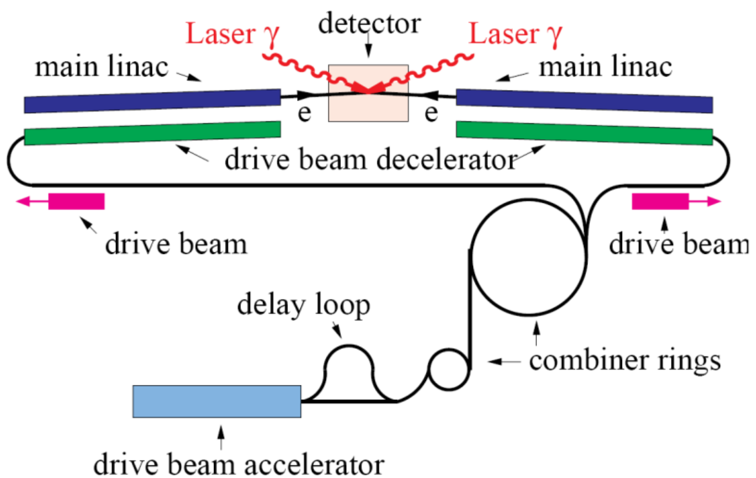
- Advantages
  - Lowest energy for Higgs Production, (160 GeV v. 240 GeV)
  - Can Provide CP violation information on the Higgs
  - Can be added to a normal linear collider
  - No Positrons required
- Disadvantages
  - Unproven Technology
  - Limited Physics reach
  - Requires very high power Laser

$\gamma\gamma$ Collider as a Higgs Factory





CLIC-based



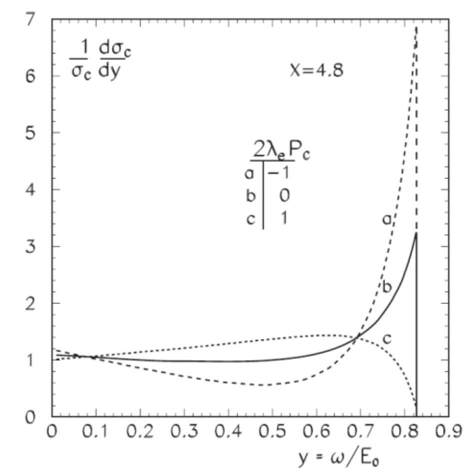


Figure 1.3.1: *Spectrum of the Compton scattered photons for different polarisations of the laser and electron beams.*

$$\omega_m = \frac{x}{x+1}E_0; \quad x \approx \frac{4E_0\omega_0}{m^2c^4} \simeq 15.3\left[\frac{E_0}{\text{TeV}}\right]\left[\frac{\omega_0}{eV}\right],$$

Issues for $\gamma\ \gamma$ colliders

- IR related
  - Beam crossing angle
  - Optics in the IR region
  - extraction line(e) and beam dump (γ)

- Lasers

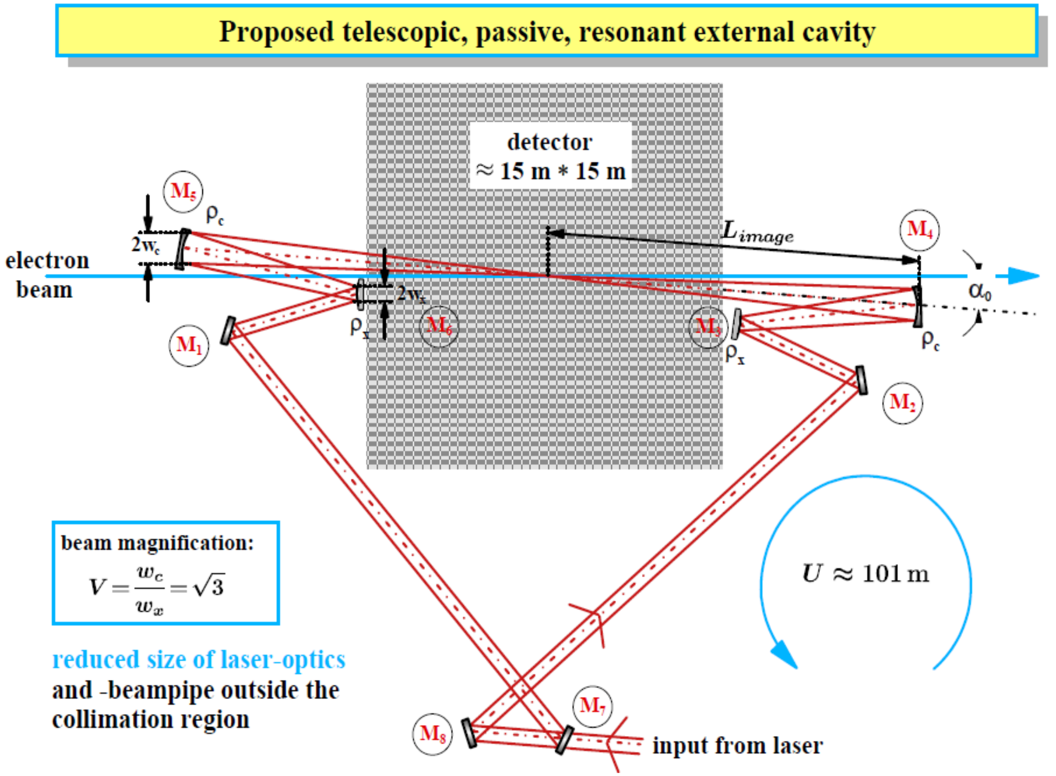
(T. Takahashi)

Pulse Stacking Cavity for ILC

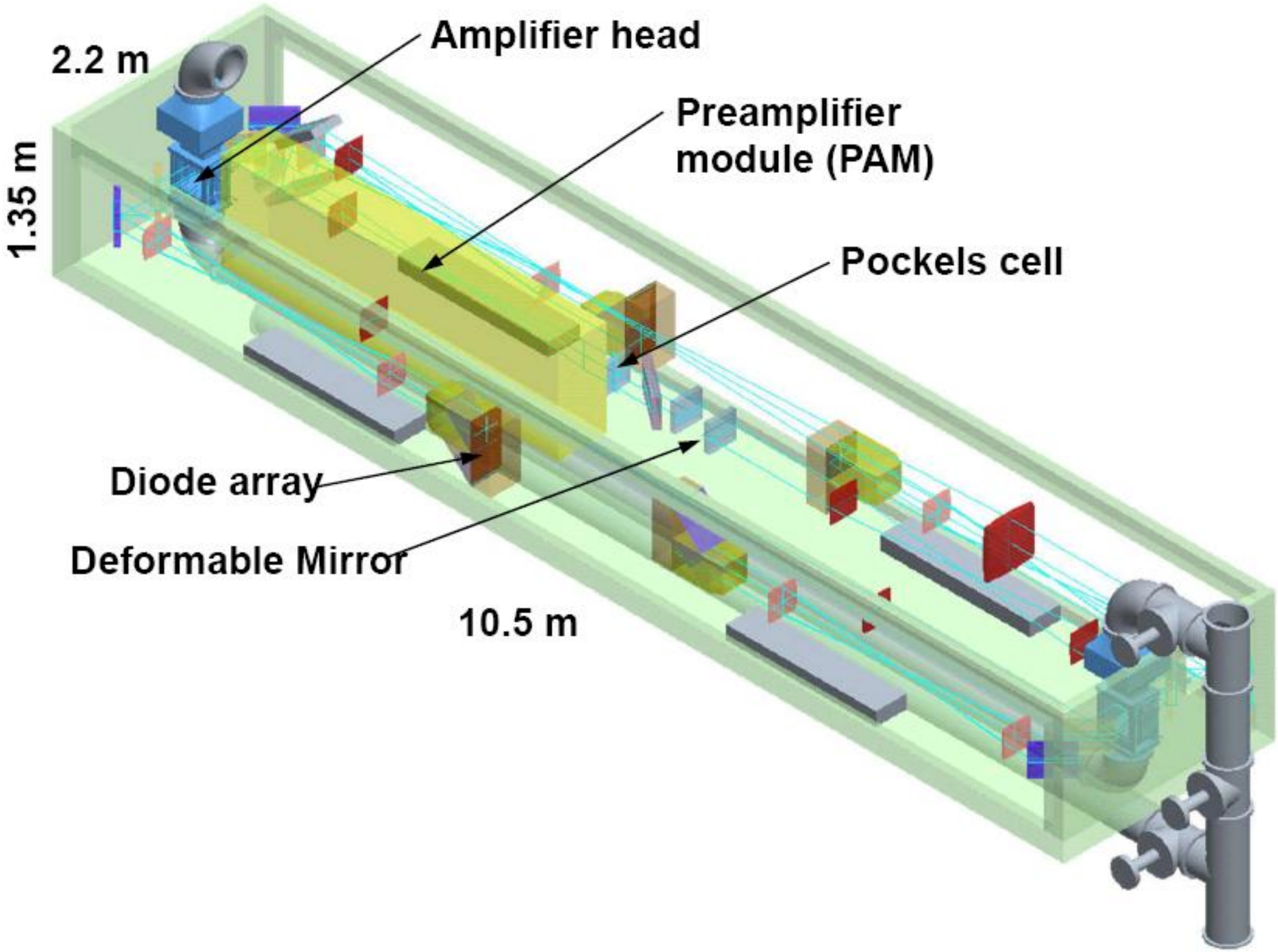
- total length ~100m
- power enhancement ~100

- L =nλ
- d L<< λ/enhancement

- mode locked pulsed laser
  100MHz 0.1J/pulse



The entire 1ω beamline can be packaged into a box which is 31 m^3 while providing 130 kW average power



modified design approach

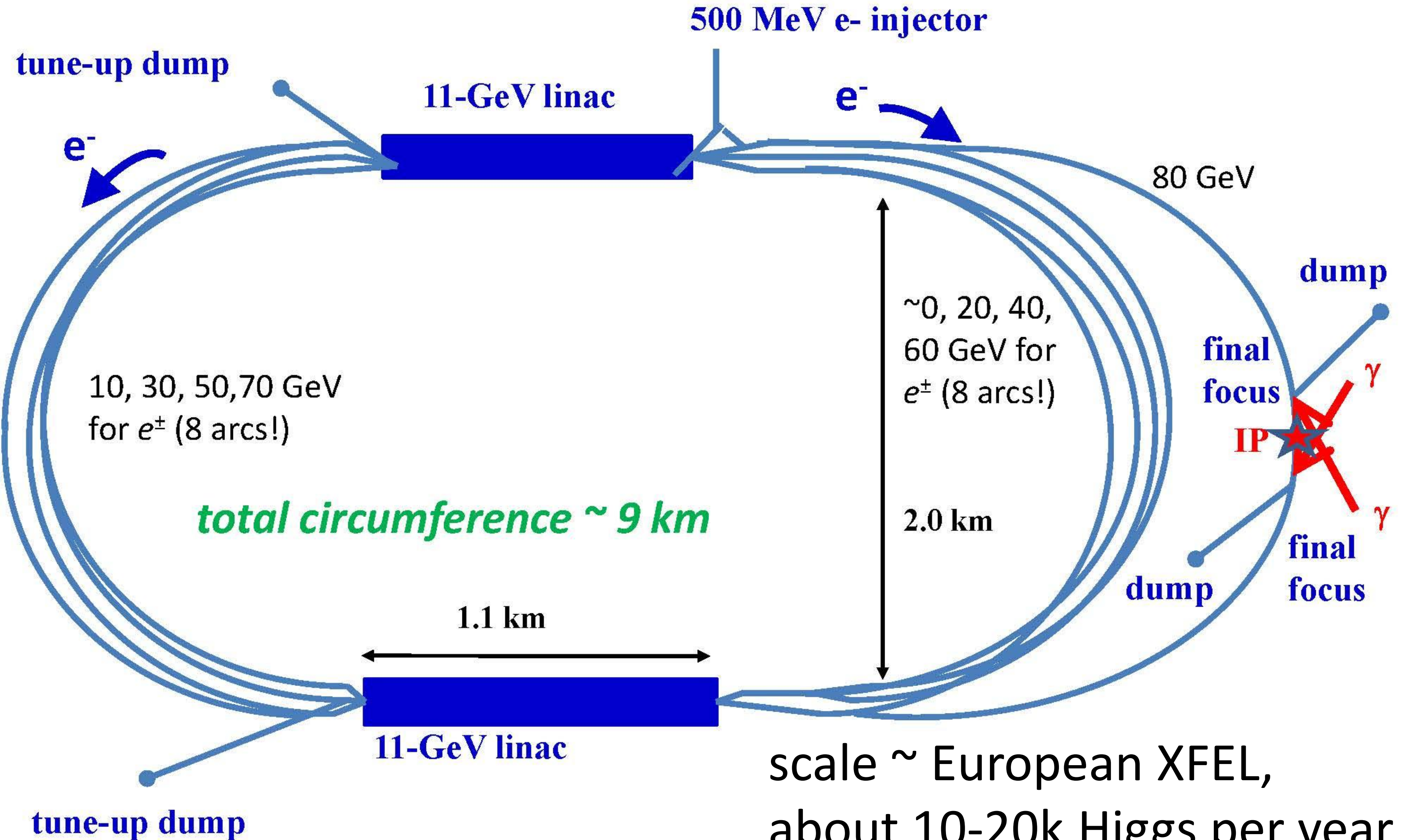
Yuhong Zhang
JLAB

thin laser target

- eliminates most useless and harmful soft γ photons from multiple Compton scattering
- **relaxed laser requirements (~factor 10)**

high luminosity achieved through an increase of bunch repetition rate and **higher e- beam current** (~factor 10) with multi-pass recirculating linac and **energy recovery**

SAPPHiRE: a Small γγ Higgs Factory

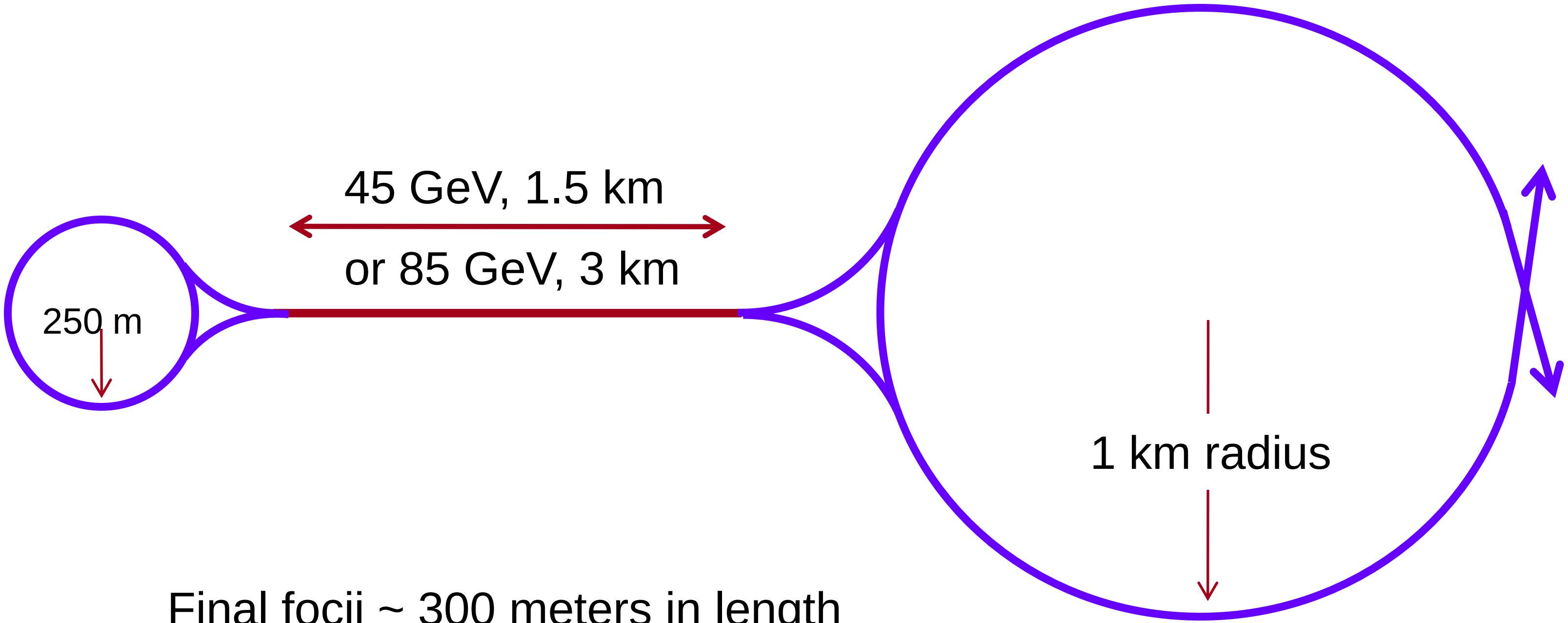


scale ~ European XFEL,
about 10-20k Higgs per year

SAPPHiRE: Small Accelerator for Photon-Photon Higgs production using Recirculating Electrons

SLC-ILC-Style (SILC) Higgs Factor (T. Raubenheimer)

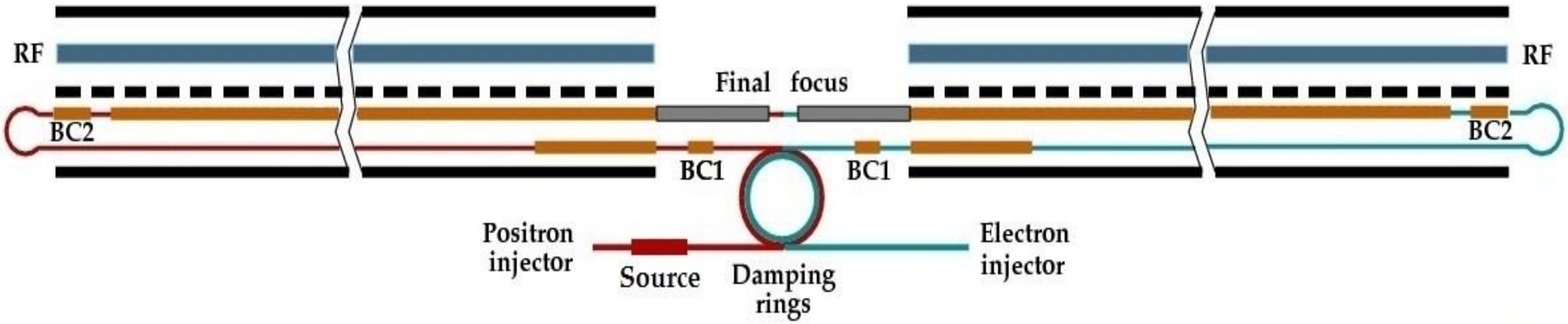
Some challenges with 2-pass design!

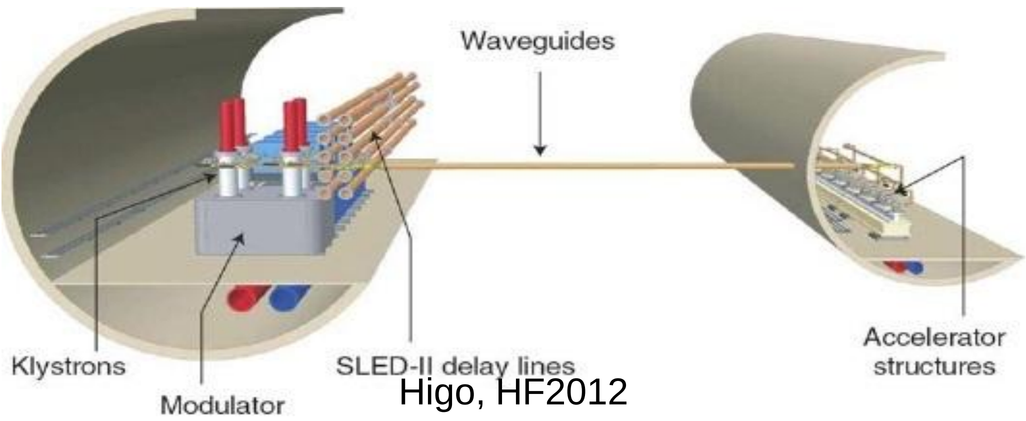


Final focii ~ 300 meters in length
Laser beam from fiber laser or FEL

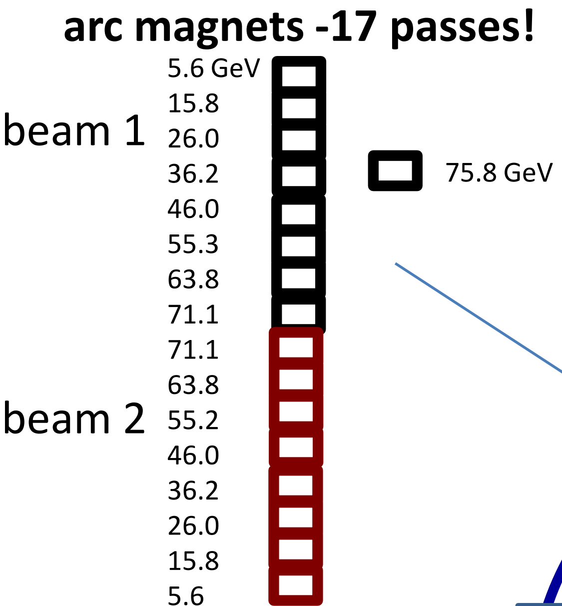
Upgrade with plasma afterburners (what cms energy is possible?)

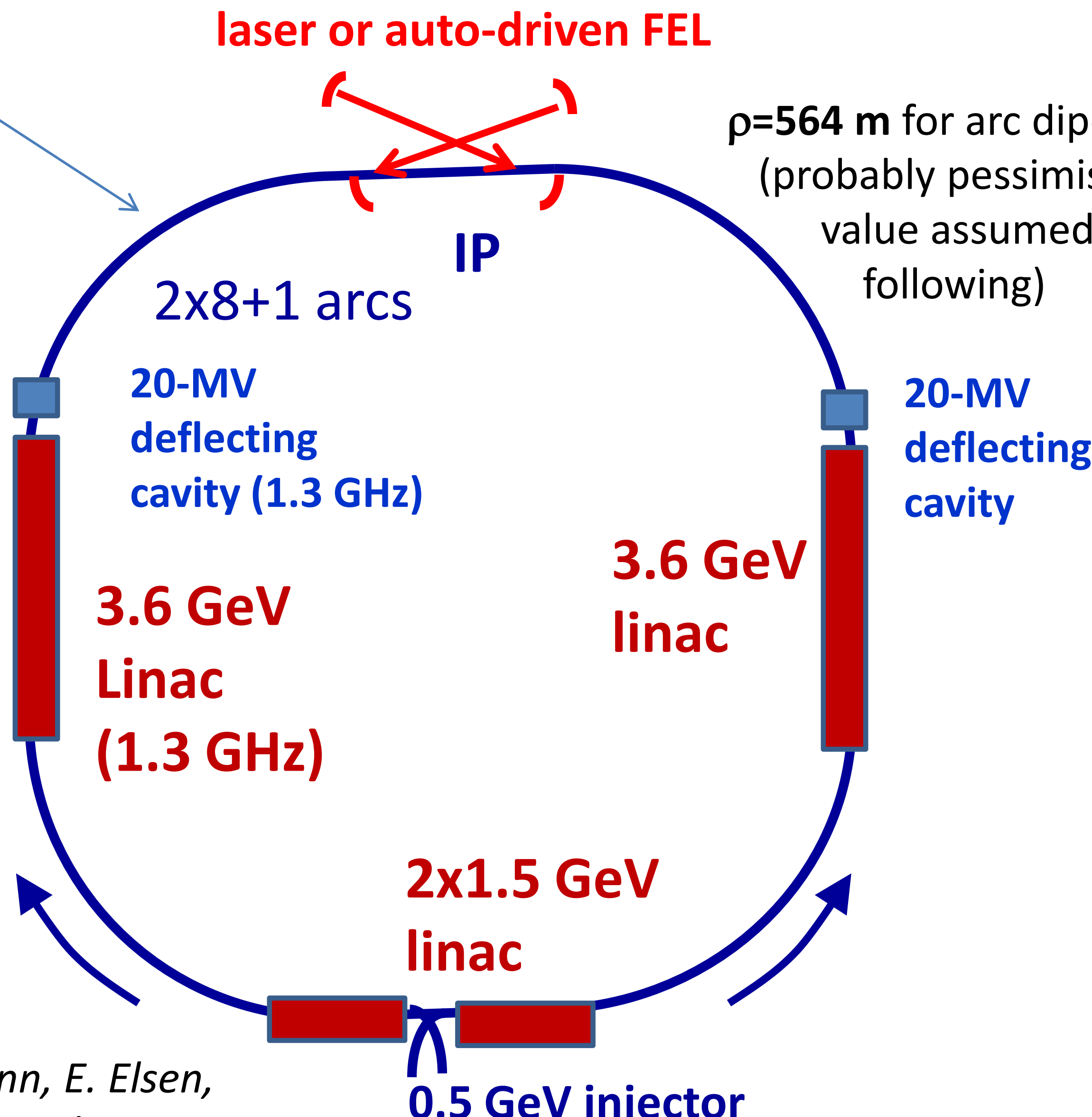
Schematic layout of the collider





HERA Tunnel Filler





ρ=564 m for arc dipoles
(probably pessimistic;
value assumed in the
following)

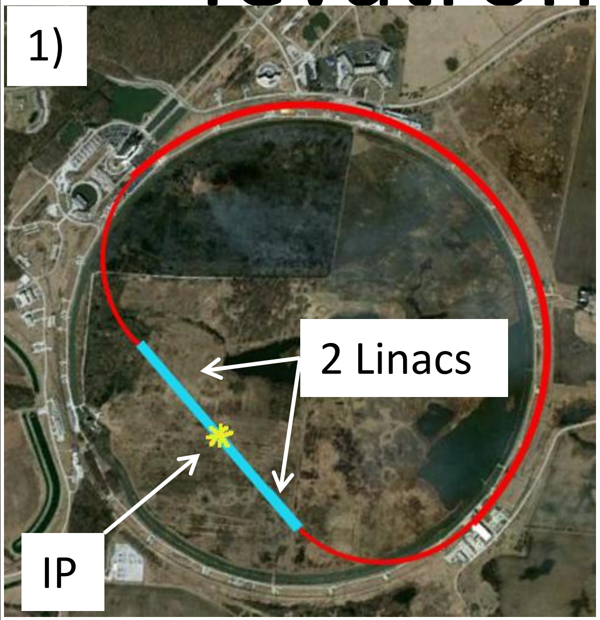
real-estate
linac
Gradient
~ 10 MV/m

total
SC RF =
10.2 GV

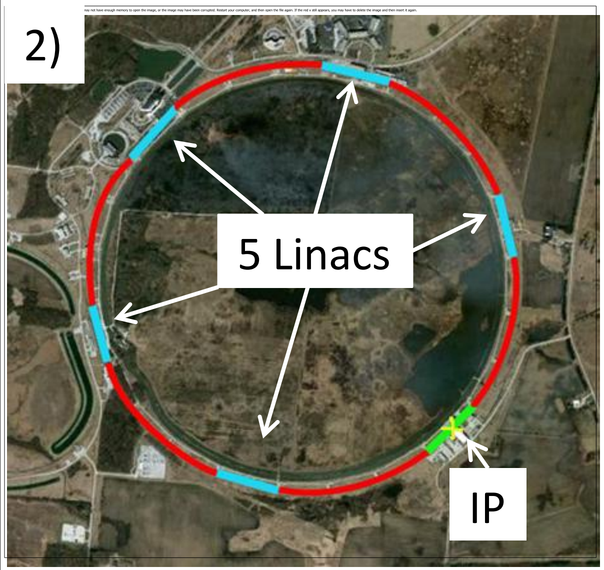
F. Zimmermann, R. Assmann, E. Elsen,
DESY Beschleuniger-Ideenmarkt, 18 Sept. 2012

Edward Nissen

Possible Configurations at FNAL Tevatron Tunnel Filler Options



Top Energy	80 GeV	80 GeV
Turns	4	5
Avg. Mag. ρ	661.9 m	701.1 m
Linacs (2)	10.68GeV	8.64GeV
δp/p	8.84×10^{-4}	8.95×10^{-4}
ϵ_{nx} Growth	2.8μm	2.85μm



Top Energy	80 GeV	80 GeV
Turns	3	4
Magnet ρ	644.75 m	706.65 m
Linacs (5)	5.59GeV	4.23GeV
δp/p	6.99×10^{-4}	7.2×10^{-4}
ϵ_{nx} Growth	1.7μm	1.8μm

- Both versions assume an effective accelerating gradient of 23.5 MeV/m
- Option 1: would require more civil construction, but would only require two sets of spreader /recombiner magnets, and only two linacs, for greater simplicity.
- Option 2: would require 10 sets of spreader /recombiner magnets and 5 linacs but would achieve better beam parameters

Summary

- Circular Colliders have the least technical risk, but aside from LEP3 would be very expensive
- Linear colliders are furthest along in the design process, and already have a global support network
- Muon Colliders offer room for growth, but are not mature enough for a near term facility
- $\gamma\gamma$ Colliders offer low cost but are still an unproven technology that may lack sufficient physics reach for a dedicated facility.