Higgs factories

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LHC on the March,
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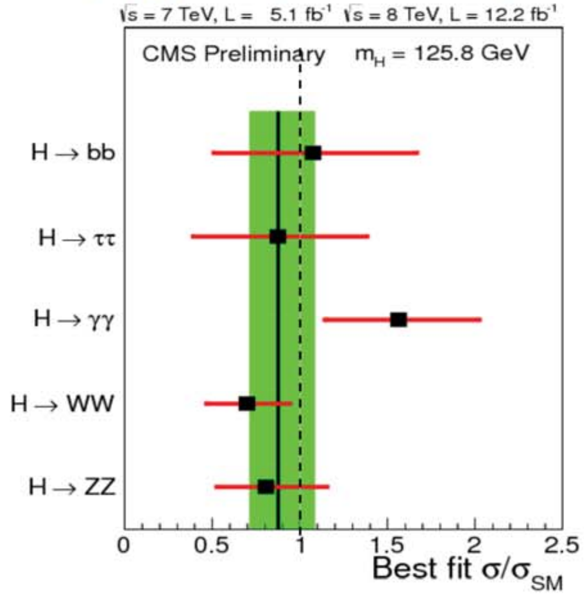
- Muon collider HF.
- Photon collider HF.
- Conclusion

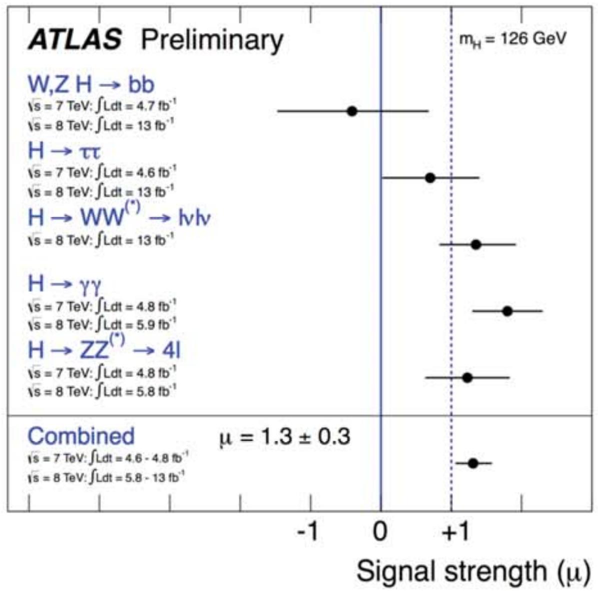
PS. the talk is based mostly on slides from HF2012, FNAL, Nov.14-16, 2012

The situation today

(P. Janot, HF2012)

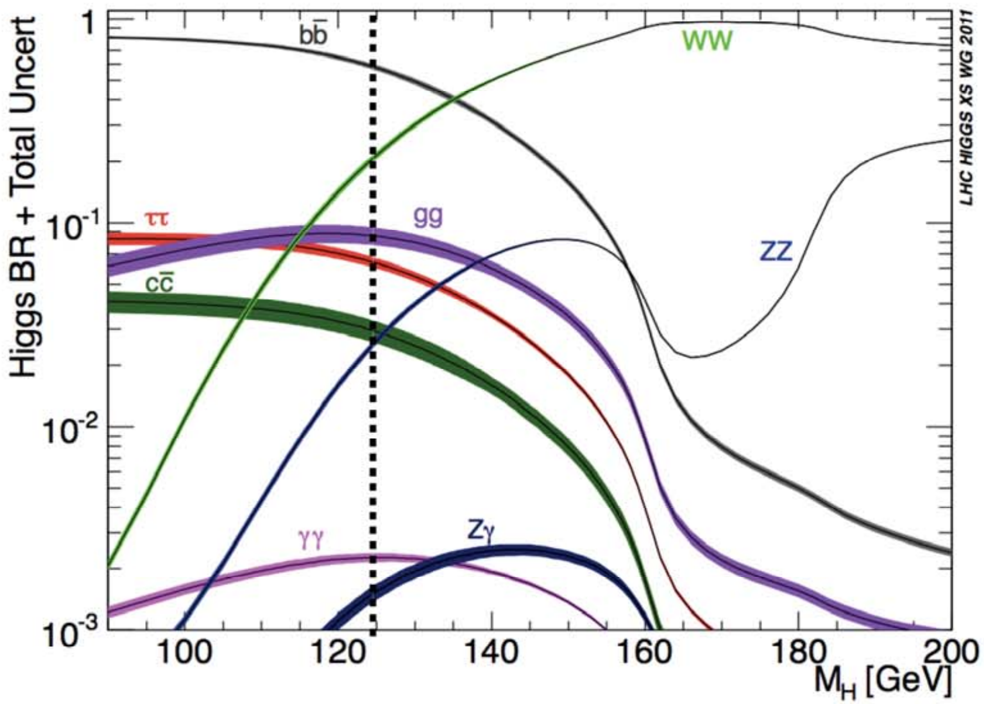
Decays to ZZ, γγ, WW, ττ and bb; Properties very much like those of a SM Higgs boson;





Situation today (cont)

- **We are here (or thereabout):**



m_H = 125 GeV

Decay	BR [%]	Unc. [%]
bb	57.9	3.
$\tau\tau$	6.4	6.
cc	2.8	12.
$\mu\mu$	0.022	6.
WW	21.6	4.
gg	8.2	10.
ZZ	2.6	4.
$\gamma\gamma$	0.27	5.
Zγ	0.16	9.
Γ_H [MeV]	4.0	4.

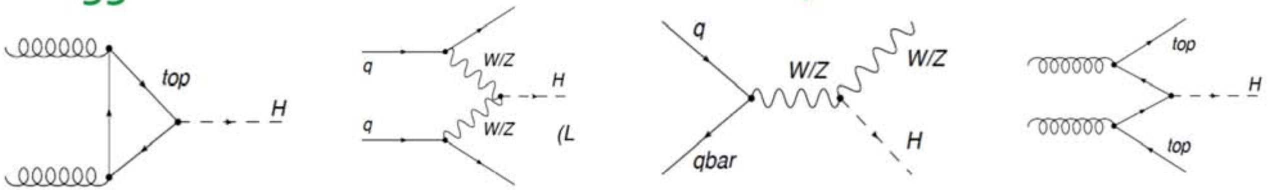
- **Note : The LHC is a Higgs Factory !**
  - Total cross section at 8 TeV : 22 pb
    - 1M Higgs already produced – more than most other Higgs factory projects.
    - 15 Higgs bosons / minute – and more to come.

(P. Janot, HF2012)

Situation in 2022

The approved LHC programme will be completed (P. Janot, HF2012)

- With 300 fb^{-1} @ 13 TeV, CMS and ATLAS will measure five production modes
  - $gg \to H$ VBF WH, ZH ttH

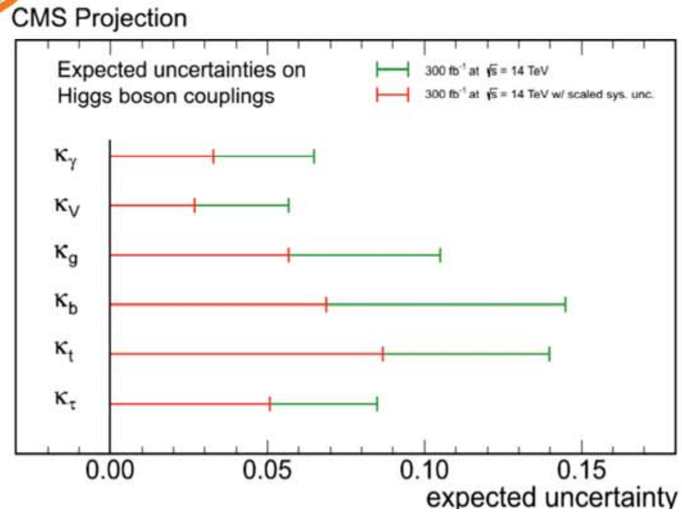


  - ... and six decay modes : $\gamma\gamma$, ZZ, WW, $\tau\tau$, bb, $\mu\mu$

Unknown, not measureable at LHC

- CMS projections with 300 fb^{-1}
  - Measure $\sigma(XX)$*BR(YY) = $\Gamma(XX) * \Gamma(YY) / \Gamma_{tot}(H)$
    - Assume no exotic decays
    - Assume reduce set of couplings
  - Infer the following coupling accuracy
    - 10-15% on fermionic couplings
    - 5-6% on bosonic couplings
    - 5-10% on couplings through loops

      Model dependent
  - Similar performance for ATLAS



Measurement needed after LHC

(P. Janot, HF2012)

We are entering the precision measurement era

- **Need to characterize the new state**
  - Measurement of Higgs branching ratios and related couplings
  - Measurement of the Higgs coupling to the top quark
  - Higgs quantum numbers determination
  - Higgs mass precision measurement
  - Higgs boson self couplings
  - Total Higgs decay width
- **Need to determine the (tree-level) structure of the theory**
  - Invisible Higgs decays, Exotic Higgs decays
  - Parameterization of deviations from SM through higher-order operators
- **Need to evaluate (new physics) loop-induced effects**
  - Interpretation of the $H \rightarrow \gamma\gamma$ and $H \rightarrow gg$ branching fractions
  - Precision electroweak measurements
  - Precision mass measurements (W, Z, top, …)

(In purple : known to be difficult at the LHC)
(In green : some precision reached with LHC)

Precision needed after LHC

(P. Janot, HF2012)

- **New physics affects the Higgs couplings**
  - **SUSY** $\frac{g_{hbb}}{g_{h_{SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{SM}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \mathrm{TeV}}{m_A}\right)^2$ **, for tanβ = 5**
  - **Composite Higgs** $\frac{g_{hff}}{g_{h_{SM}ff}} \simeq \frac{g_{hVV}}{g_{h_{SM}VV}} \simeq 1 - 3\% \left(\frac{1\ \mathrm{TeV}}{f}\right)^2$
  - **Top partners** $\frac{g_{hgg}}{g_{h_{SM}gg}} \simeq 1 + 2.9\% \left(\frac{1\ \mathrm{TeV}}{m_T}\right)^2, \quad \frac{g_{h\gamma\gamma}}{g_{h_{SM}\gamma\gamma}} \simeq 1 - 0.8\% \left(\frac{1\ \mathrm{TeV}}{m_T}\right)^2$
  - **Other models may give up to 5% deviations with respect to the Standard Model**

Low energy precision Higgs factory concepts

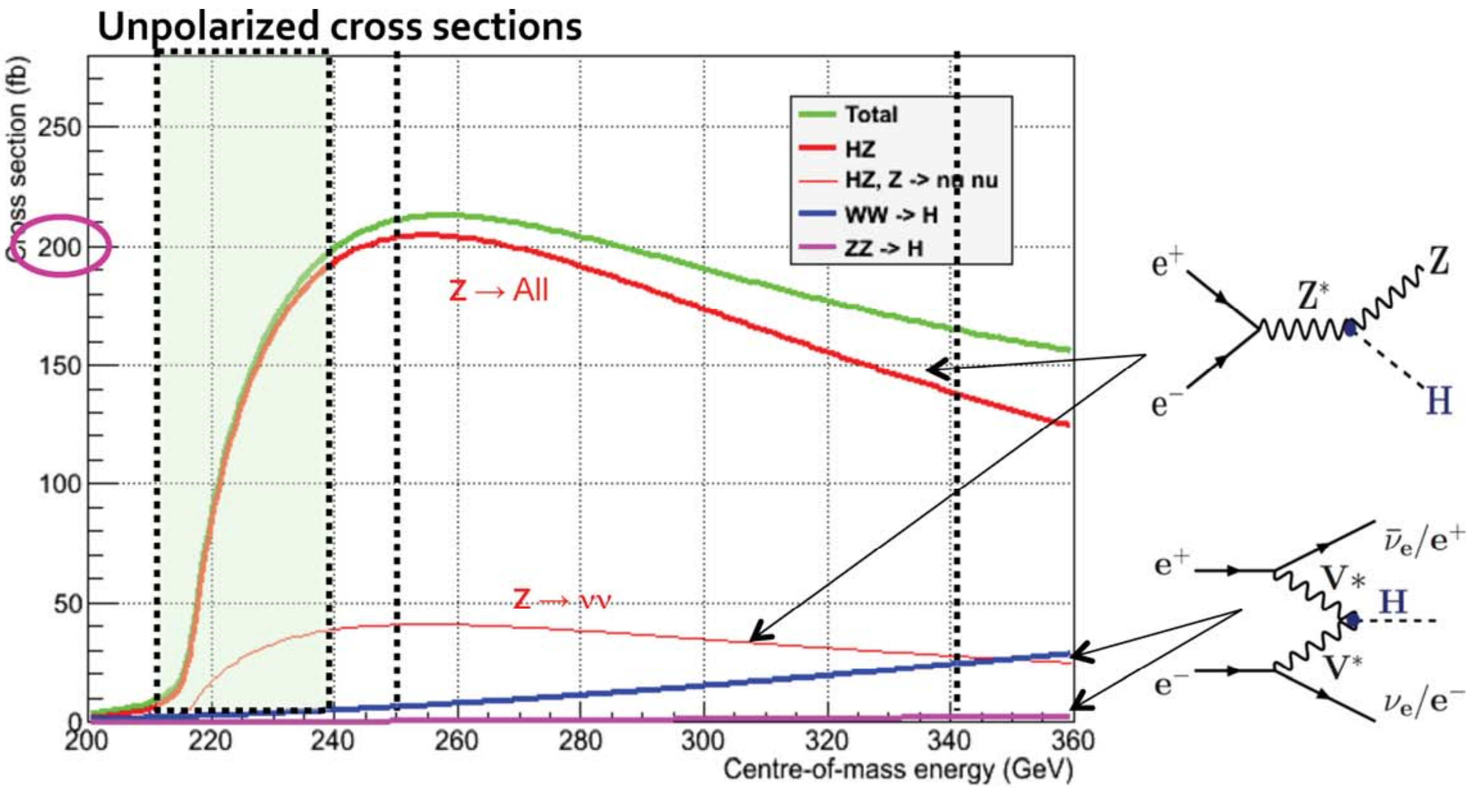
- $\sqrt{s} \leq 350$ GeV : Feasible by 2025 – 2035 ?
  - Goal : Precision measurements of the new state

Factory	Example	$\sqrt{s}$	Benefits from	Extendable
e^+e^- (Linear)	ILC	Phase 1 Up to 350 GeV	20 years of R&D	500 Gev (1 TeV?) GigaZ
e^+e^- (Circular)	LEP3	Up to 240 GeV LHC tunnel	ILC, LHeC, LHC b Factories	HL/HE-LHC, 33 TeV TeraZ
	TLEP	Up to 350 GeV New 80km tunnel	ILC, LHeC b Factories	VHE-LHC, 100 TeV TeraZ
$\mu^+\mu^-$ (Circular)	LEMC	125 GeV Up to 350 GeV	MICE R&D ν Factory	5-15 TeV
$\gamma\gamma$	CLICHE PLC SAPPHIRE	~125 GeV Up to 300 GeV	ILC, CLIC, LHeC	–

Higgs studies in e+e- collisions

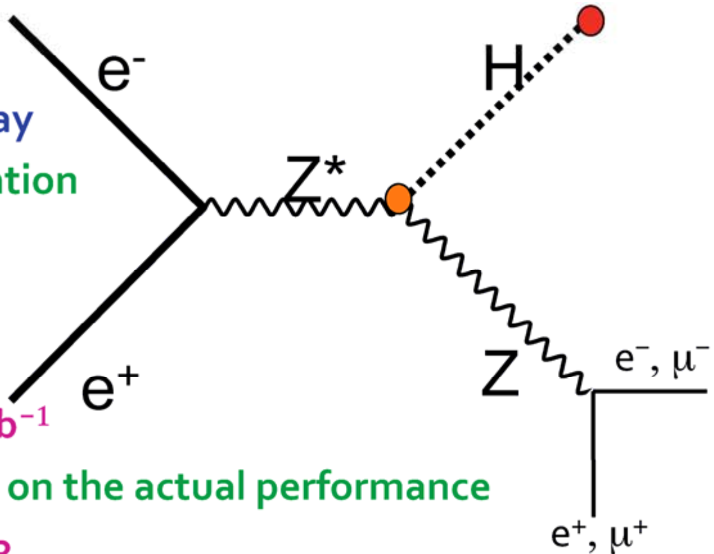
- Physics case not driven by the fact that the collider is linear or circular
  - Scan of the HZ threshold : √s = 210-240 GeV — Spin
  - Maximum of the HZ cross section : √s = 240-250 GeV — Mass, BRs, Width, Decays
  - Just below the tt threshold : √s ~ 340-350 GeV — Width, CP

Need 100's fb⁻¹



e+e-: Higgs measurement at $2E_0$=240 GeV

- With $e^+e^- \to ZH \to e^+e^-X$ and $\mu^+\mu^-X$ events
  - Measure HZ cross section in a model independent way
    - Find m_H peak from the leptons and E,p conservation
    - Determine spin with three-point threshold scan
      - 10 fb^{-1} / point suffice
    - Determine σ_{HZ} and g_{HZZ} coupling at 240 GeV
      - 3% (1.5%) precision on σ_{HZ} (g_{HZZ})with 250 fb^{-1}
    - Good tracker needed, but details mildly depend on the actual performance
      - Plots below with ILD@ILC and CMS@LEP3



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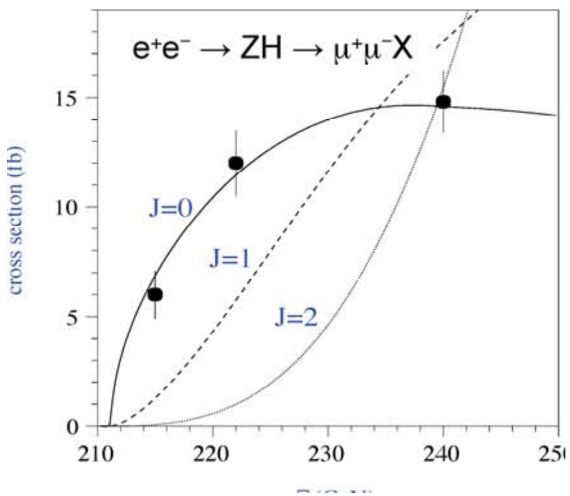
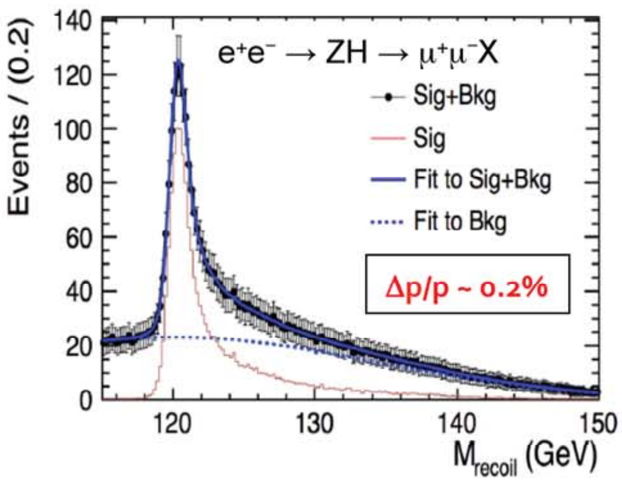
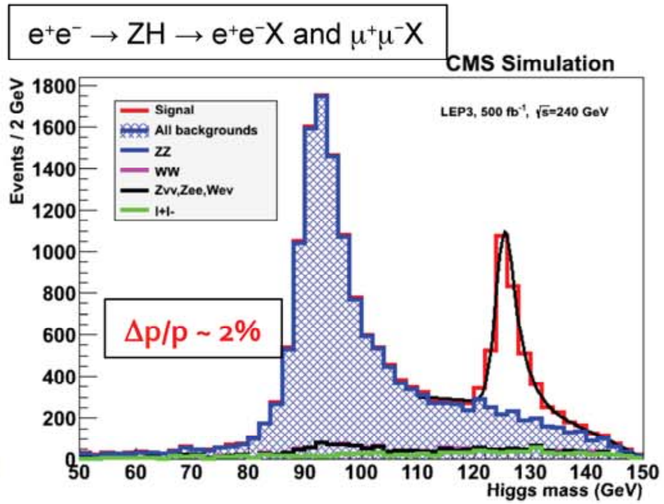
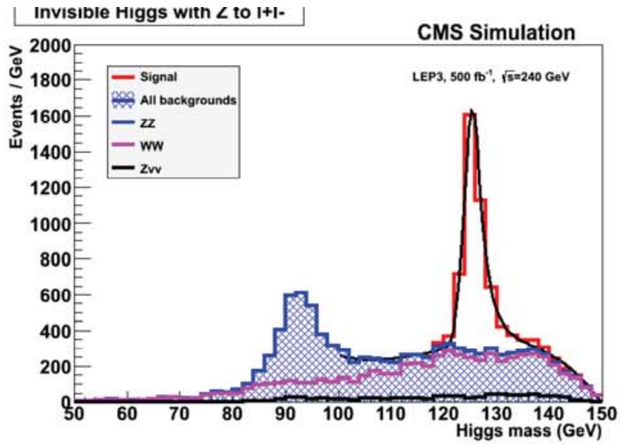






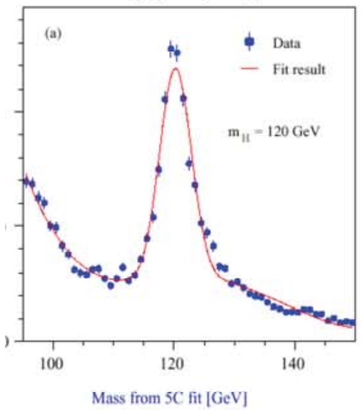
e+e-: Higgs measurement at $2E_0$=240 GeV (cont)

- **With ZH → e^+e^-X and $\mu^+\mu^-X$ events (cont'd)**
  - **Measure invisible decay branching ratio (X = nothing)**
    - **Precision on BR_{INV} ~ 1% with 250 fb^{-1}**
    - **Or exclude BR_{INV} > ~2% at 95% C.L.**

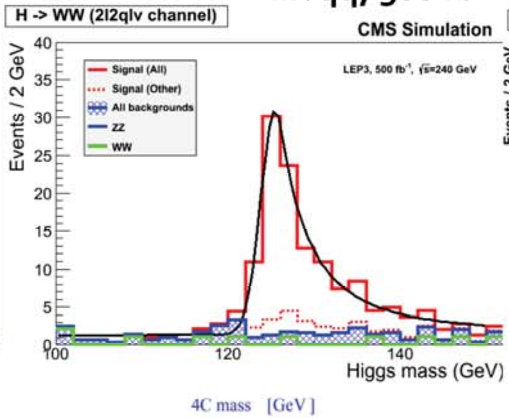


- **Measure other σ_{HZ}×BR(H→ ff,VV)**
  - **With exclusive selections of Z and H decays**
    - **Precision of 1.5% to 8% with 250 fb^{-1} for the copious decays (bb, WW, gg, ττ, cc)**
    - **Need more luminosity for rare decays (γγ, Zγ, μμ)**
      - ➡ **Particle flow, b and c tagging, lepton and photon capabilities needed**

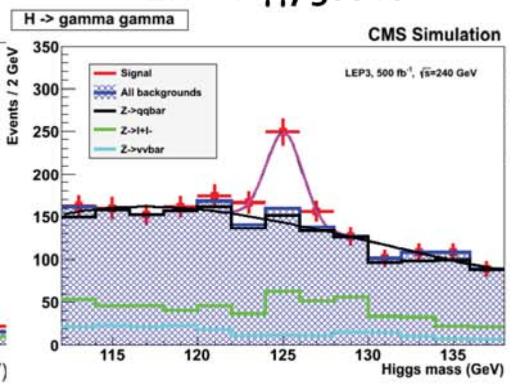
ZH→ qqbb, 250 fb^{-1}



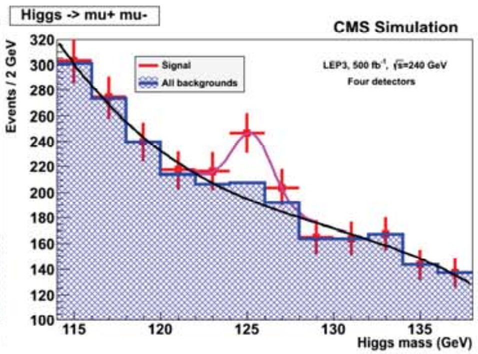
ZH→ llWW→ lllνqq, 500 fb^{-1}



ZH→ Xγγ, 500 fb^{-1}

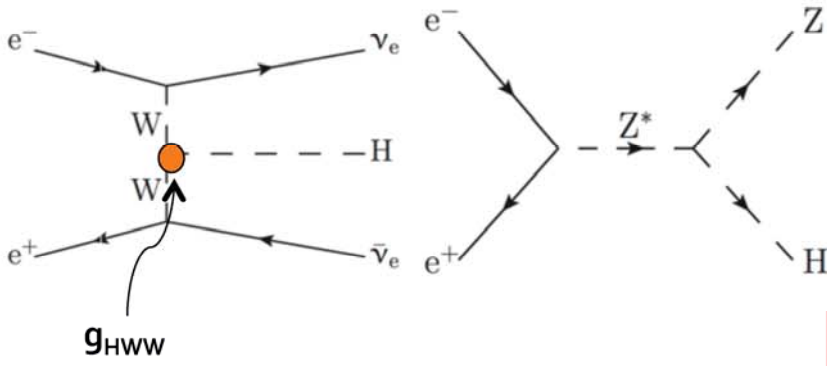


ZH→ Xμμ, 2 ab^{-1}

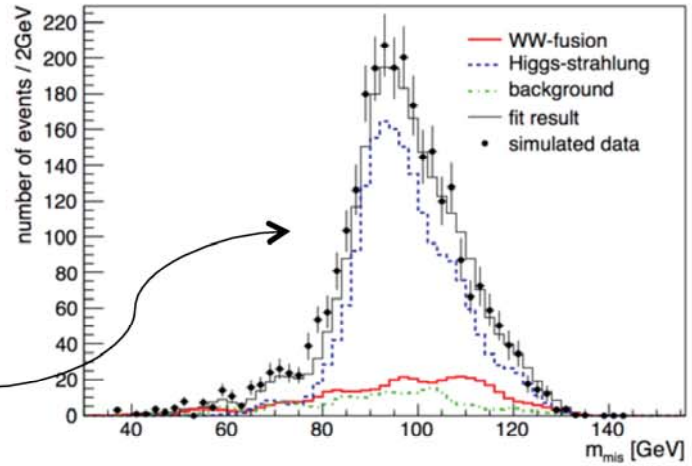


e+e-: Higgs measurement at $2E_0$=240 GeV (cont)

- **Higgs width from the $H\nu\nu$ final state**
  - From $\sigma_{WW\to H}$ and BR(H→ WW)
    - $\sigma_{WW\to H} \sim g^2_{HWW}$
    - BR(H→ WW) = $\Gamma_{H\to WW} / \Gamma_H \sim g^2_{HWW} / \Gamma_H$
      - ➨ $\Gamma_H \sim \sigma_{WW\to H}$ / BR(H→ WW)



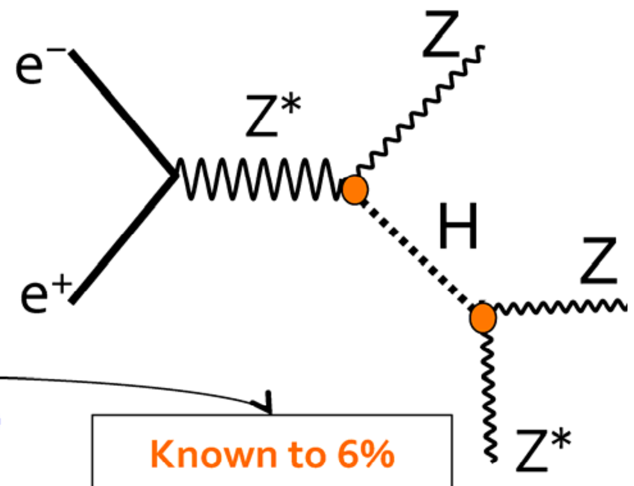
  - Contribution to $H\nu\nu$ from HZ ~ 40 pb
    - Known from ZH → e^+e^-X and $\mu^+\mu^-X$
  - Contribution from WW fusion ~ 6 pb
    - To be measured
  - Select $\nu\nu bb$ events from ZH and WW fusion
    - Needs adequate b tagging and particle flow
  - Fit the missing mass distribution for $N_{WW\to H\to bb}$
    - σ_{HZ} x BR(H→ bb) known to ~1.5% or better
    - $\sigma_{WW\to H} = N_{WW\to H\to bb}$ / BR(H→ bb)
      - ➨ Precision on $\sigma_{WW\to H}$ ~ 14% with 250 fb^{-1}
      - ➨ $\Gamma_H \sim \sigma_{WW\to H}$ / BR(H→ WW), measured up to 15% precision with 250 fb^{-1}



[12]

e+e-: Higgs measurement at $2E_0$=240 GeV (cont)

- **Higgs width from the ZZZ final state**
  - Number of ZZZ events ~ $\sigma_{HZ} \times BR(H \to ZZ)$
    - $\sigma_{HZ} \sim g^2_{HZZ}$
    - $BR(H \to ZZ) = \Gamma_{H \to ZZ}/\Gamma_H \sim g^2_{HZZ} / \Gamma_H$
      - ➨ Number of ZZZ events ~ g^4_{HZZ} / Γ_H



Known to 6% from l^+l^-X events with 250 fb-1

  - Select $l^+l^-\ l'^+l'^-$ X events (~ background and H →WW free)
    - Number of events in 250 fb^{-1} @ 240 GeV :
      - ➨ 250 $fb^{-1} \times$ 200 fb $\times BR(H \to ZZ) \times BR(Z \to ll)^2 \times 3$

        → About 40 events, of which ~25 selected

  - Hence measure the total width Γ_H with a precision of 21%
    - Reduced to 12% in combination with WW fusion measurement
      - ➨ Could be further reduced with other Z decays

        (Need full simulation and WW/ZZ simultaneous fit)

  - Note : Precision of a few % can be reached on Γ_H if one assumes no exotic Higgs decays

e+e-: Linear vs Circular at 2E= 240 GeV

- **A few performance benchmarks** (P. Janot, HF2012)

	ILC	LEP3	TLEP	
Lumi / IP / 5 yrs	250 fb^{-1}	500 fb^{-1}	2.5 ab^{-1}	???
# IP	1	2 - 4	2 - 4	
Lumi / 5 years	0.25 ab^{-1}	1 - 2 ab^{-1}	5 - 10 ab^{-1}	
Beam Polarization	80%, 30%	–	–	
$L_{0.01}$ (beamstrahlung)	86%	100%	100%	
Number of Higgs	70,000	400,000	2,000,000	
Cost/Higgs	100 k$	5 k$	3.5 k$	????

- **Measurement precision goes like 1 / √L**
- **Beam polarization increases the signal cross section by ~40% for the linear option**
  - **A precision of 2.5% at ILC corresponds to ~1.2% at LEP3 and ~0.4% at TLEP**
- **Beamstrahlung effects** ($L_{0.01}$, pileup, detector background) **negligible for circular option**
- **Disclaimer : Cost estimates can easily be wrong by a factor π**
  - **But numbers are encouraging enough to justify further study of the circular option**

e+e-: Linear vs Circular at 2E= 240 GeV

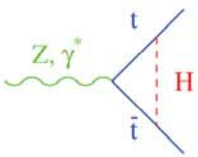
- **Precision on H(125) branching fractions, width, mass, … after 5 years**

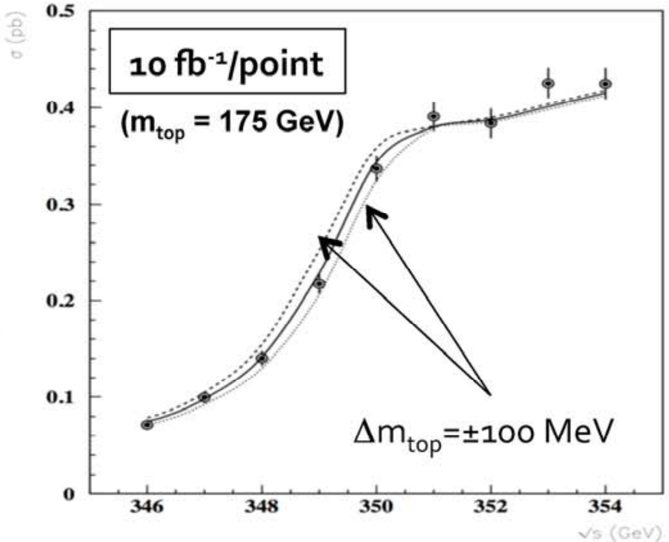
	ILC	LEP3 (4)	TLEP (4)
σ_{HZ}	2.5%	1.3%	0.4%
BR(H→bb)	2.7%	1.4%	0.5%
BR(H→cc)	7.3%	4% (*)	1.4%
BR(H→gg)	8.9%	4.5% (*)	1.5%
BR(H→WW*)	8.6%	3.0%	1.0%
BR(H→ττ)	7.0%	3.0%	0.9%
BR(H→ZZ*)	21%	7.1%	3.1%
BR(H→γγ)	30%	6.8%	3.0%
BR(H→μμ)	–	28%	13%
$\sigma_{WW\to H}$	12%	5% (*)	2.2%
Γ_H, Γ_{INV}	10% , < 1.5%	4% , < 0.7%	1.8% , < 0.3%
m_H	40 MeV	26 MeV	8 MeV

e+e-: Higgs measurement at $2E_0$=350 GeV

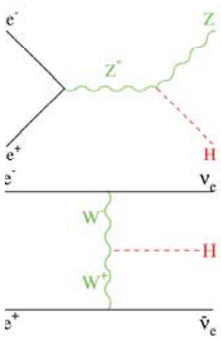
- Luminosity similar for ILC and TLEP
  - At each IP : 350 fb^{-1} over 5 years
    - With possibly 4 detectors at TLEP
  - Scan of the tt threshold
    - From the cross section
      - Top mass and width to 50 MeV or better
      - Probe the ttH coupling to 40%

        No beamstrahlung is a advantage
      - Study rare top decays

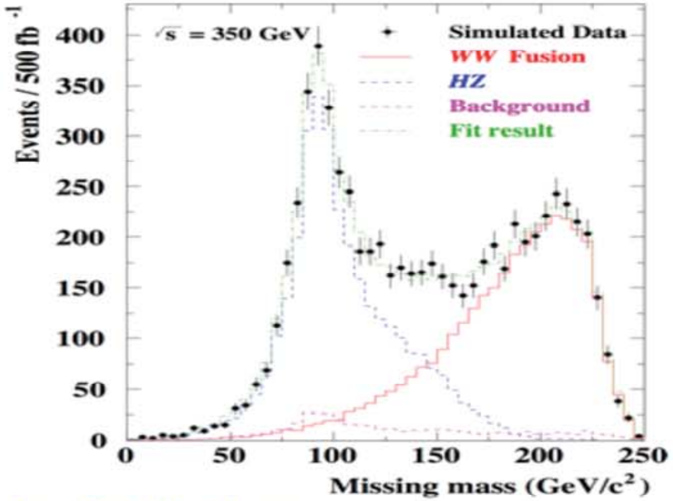




  - More study of the Hνν final state with H→bb
    - Contribution from HZ : ~ 25 fb
    - Contribution from WW→H : ~ 25 fb



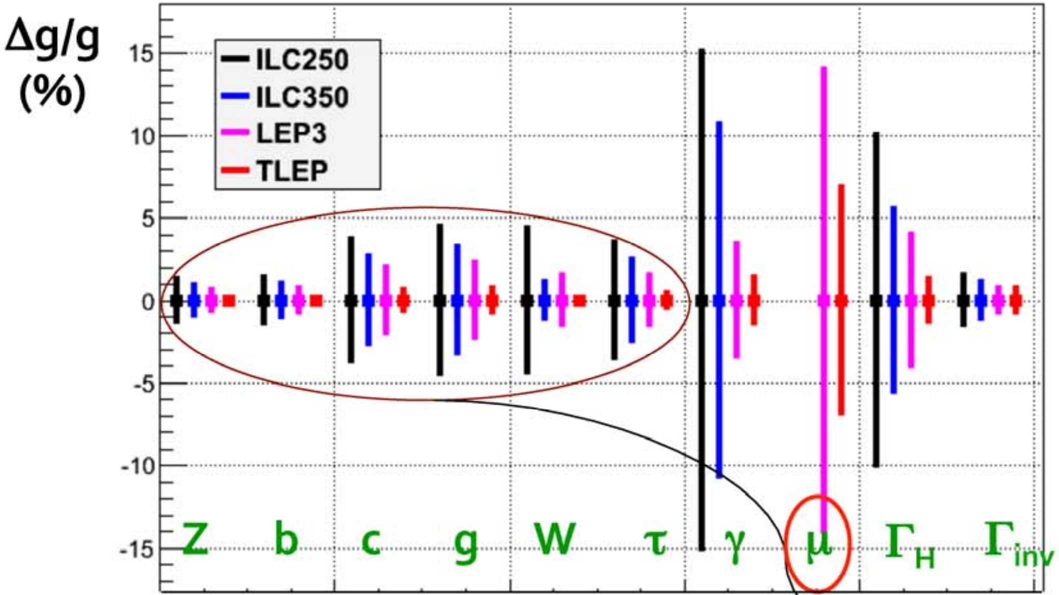
	ILC (250+350)	TLEP (240+350)
$\sigma_{WW\to H}$	11% → 4%	1.5% → 1.1%
Γ_H	10% → 5.5%	1.8% → 1.3%



      - Smaller improvement for other BR and σ
  - Measure CP mixture to ~5% from HZ yield and angular distributions

Low-energy e+e- Higgs factories: Summary

- **Precision on couplings and width** (if advertised luminosities are achieved)



Remember LHC, 300 fb^{-1} : [3]

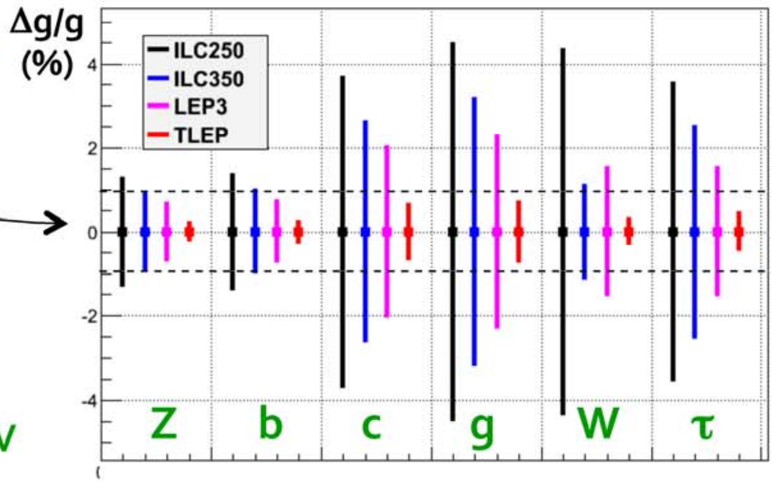
10-15% on fermionic couplings

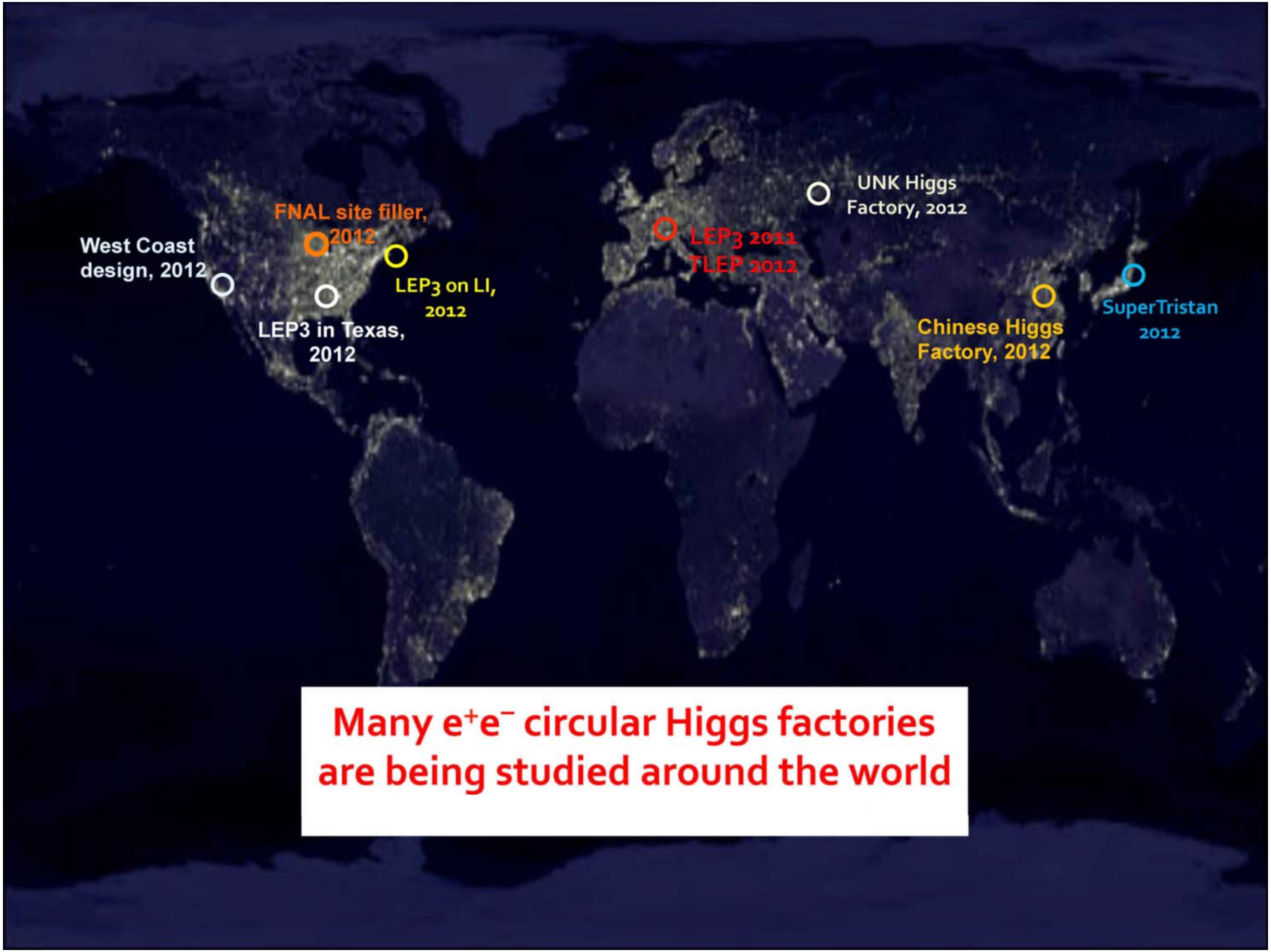
5-6% on bosonic couplings

5-10% on couplings through loops

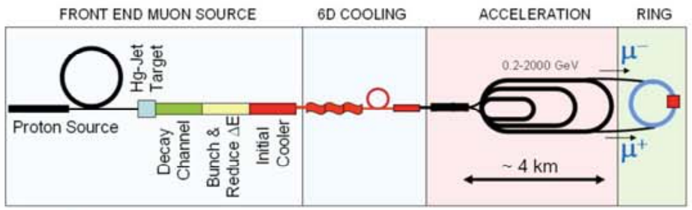
and possibly 2-10% on all couplings with 3 ab^{-1}

- ILC250/350 would be a good complement to LHC
- LEP3 could be an advantageous backup
  - Larger lumi, Several IP's, TeraZ, Cost
- TLEP would be a superior option
  - Precision adequate for testing NP beyond TeV
    - In Higgs decays and in EWRC




UNK Higgs
Factory, 2012
FNAL site filler,
2012
West Coast
design, 2012
LEP3 2011
TLEP 2012
LEP3 on LI,
2012
SuperTristan
2012
LEP3 in Texas,
2012
Chinese Higgs
Factory, 2012
Many e⁺e⁻ circular Higgs factories
are being studied around the world

Muon colliders vs e+e- colliders



- **Much work needed to realize a $\mu^+\mu^-$ collider**
  - Linear e^+e^- : R&D is essentially over
  - Circular e^+e^- : everything is "off-the-shelf"
  - A $\mu^+\mu^-$ collider needs all what it takes for a ν Factory, plus
    - Superb 6D muon cooling feasibility needs to be demonstrated (MICE and beyond)
    - The μμH coupling needs to be ascertained (e.g., with HL-LHC, LEP3, TLEP)
    - Ways to fight huge detector background from muon decays must be studied
      - ➨ Might take a decade or two … but once it is done …
- **Muons are leptons (~ like electrons) and heavy (~ like protons)**
  - A $\mu^+\mu^-$ collider can a priori do all what an e^+e^- collider can do
  - A $\mu^+\mu^-$ collider ring can be as small as a proton collider (negligible synchrotron radiation)
    - With LHC dipole magnets of 9 T, allowing for 2000 turns / muon

	Z Factory	Higgs Factory	Top Factory
√s (GeV)	91.2	240	350
Circumference (m)	160	410	600

A new ring for each new energy !

[14,15]

- Luminosity limited by the beam energy spread requirement
  - ➨ A few 10^{33} cm^{-2}s^{-1} for $\delta E/E$ = 1% with a 4 MW source (decreases with $\delta E/E$)

Muon colliders vs e+e- colliders (cont.1)

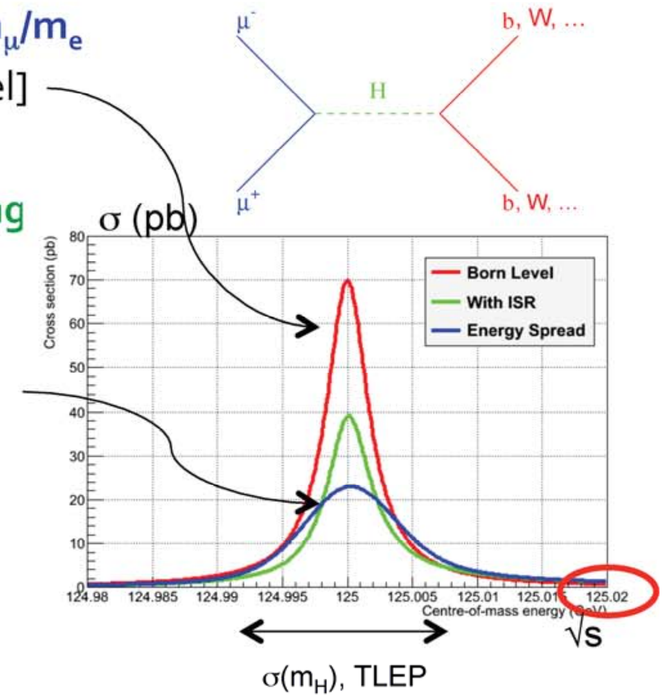
- A $\mu^+\mu^-$ collider can do things that an e^+e^- collider cannot do
  - Direct coupling to H expected to be larger by a factor m_μ/m_e

$$\sigma(\mu^+\mu^- \to H) \approx 40000 \times \sigma(e^+e^- \to H)$$ [σ_{peak} = 70 pb at tree level]

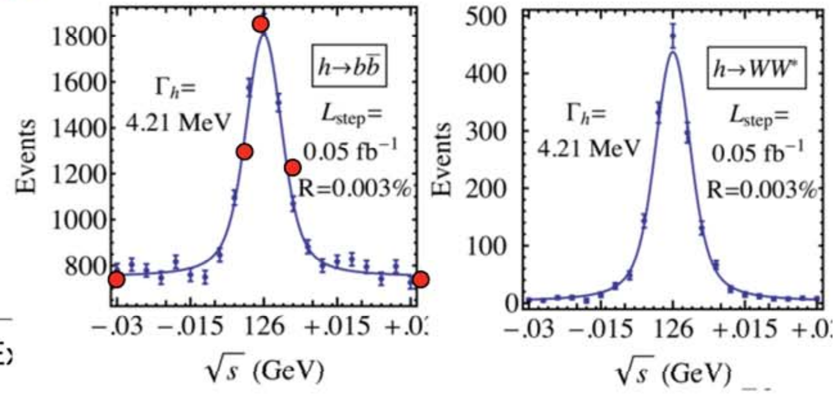
  - Beam energy spread $\delta E/E$ may be reduced to 3×10^{-5}
    - 6D Cooling, no beamstrahlung, ~no bremsstrahlung
    - For $\delta E/E$ = 0.003% (δE ~ 3.6 MeV, Γ_H ~ 4 MeV)
      - Corresponding luminosity ~ 10^{31} cm^{-2}s^{-1}

Expect 2300 Higgs events in 100 pb^{-1}/ year

  - Polarization, beam energy and energy spectrum
    - Can be measured with an exquisite precision
      - From the electrons of the muon decays
  - Then measure the lineshape of the Higgs at $\sqrt{s}$ ~ m_H
    - Five-point scan, 50 + 100 + 200 + 100 + 50 pb^{-1}
      - Precision from H→bb and WW :



m_H	σ_{Peak}	Γ_H
0.1 MeV	0.6 pb	0.2 MeV
10^{-6}	2.5%	5%



Patrick Janot HF2012 : Higgs beyond LHC
14 Nov 2012

Muon colliders vs e+e- colliders (cont.2)

- **Comparison with e^+e^-**
  - Precision on m_H is 100 times better
    - No real impact on underlying physics …
  - Precision on Γ_H (5%) is similar to ILC (6%) and LEP3 (4%), worse than TLEP (2%)
    - Can improve by increasing the power of the proton source (L goes like Power²)
  - σ_{Peak} is a whole new measurement : what does it bring ?
    - Maximally sensitive to Γ_H when $\delta E = \Gamma_H\sqrt{\pi/2}$
      - Effectively reduces error on Γ_H to 3%
      - And measure BR($H\to\mu\mu$) or Γ($H\to\mu\mu$) to 3%

        $g_{H\mu\mu}$ to 1.5% (cf 14% @ LEP3 and 6.5% at TLEP)

$$\sigma_{peak} \propto BR_{\mu\mu} BR_{bb} \left(1 + \frac{8}{\pi}\frac{\delta E^2}{\Gamma_H^2}\right)^{-\frac{1}{2}}$$

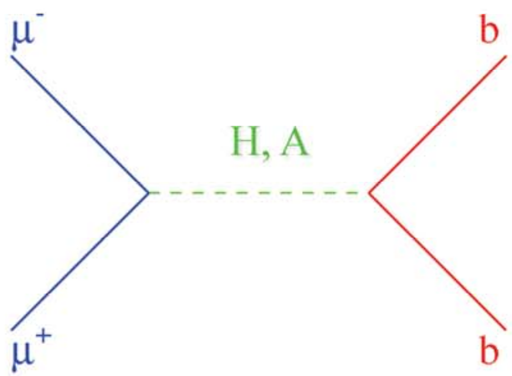
  - Other couplings better determined in e^+e^- collisions
  - Need significantly higher luminosity for $\mu^+\mu^-$ colliders to become unique Higgs factories

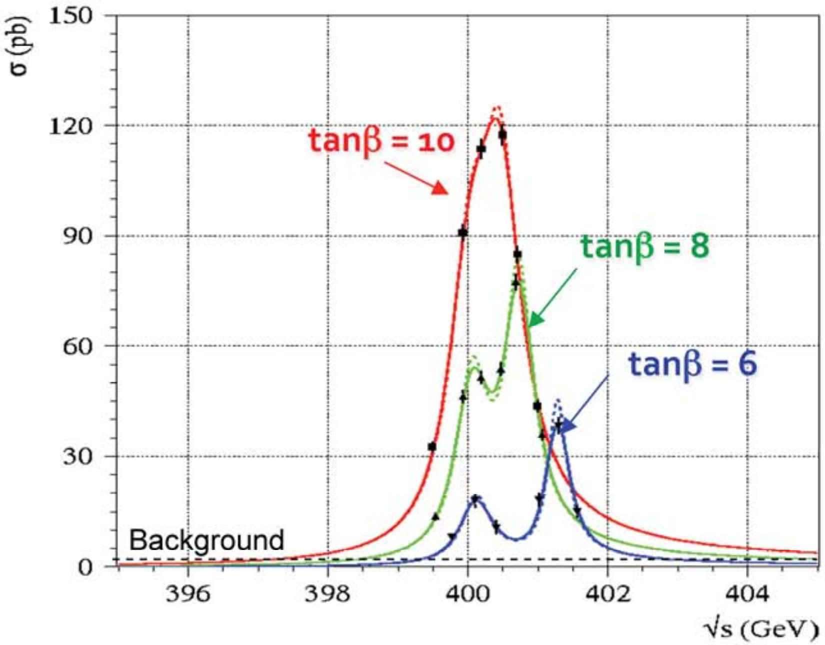
  - Note : CP Studies
    - Can see $\mu^+\mu^-\to A$ at least as well as $\mu^+\mu^-\to H$
      - Unlike e^+e^- colliders for which AZZ couplings is absent at tree level
    - Disentangling a A/H mixture is challenging
      - Need higher L, high muon beam polarization, and specific P_-/P_+ orientations

Muon colliders vs e+e- colliders (cont.3)

- **Probably better suited for the study of a richer Higgs sector ?** [14]
  - Ex: $m_A = 400\ GeV/c^2$, $m_h = 125\ GeV/c^2$, $m_{SUSY} = 1\ TeV/c^2$
    (~very difficult to see at LHC, need 1 TeV e^+e^-)
    - H,A widths ~ 500 MeV → $\delta E/E$ can be increased to 0.1% → $L = 5\times10^{32}\ cm^{-2}s^{-1}$
  - Larger potential for CP and CP violation studies

Error bars = 1 week of running

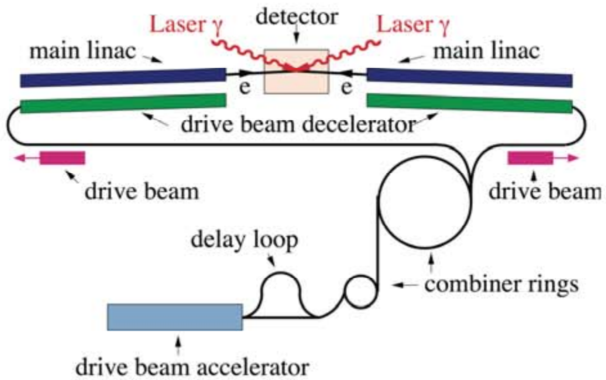




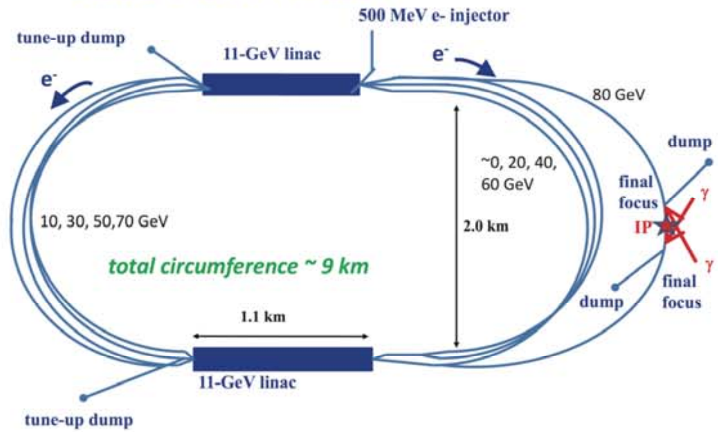
Higgs physics at a γγ collider

Usually photon collider is considered as a natural low cost addition to e+e- linear colliders ILC, CLIC (the second IP or the second stage), but there are suggestions of γγ colliders without e+e-:

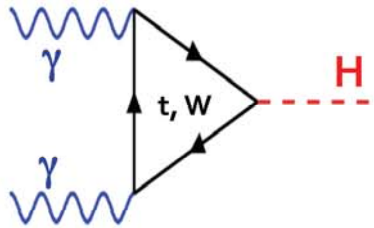
- **Need two polarized 80 GeV e^- beams and two polarized LASERs**
  - Can be a natural extension of a linear collider (here : CLICHE)

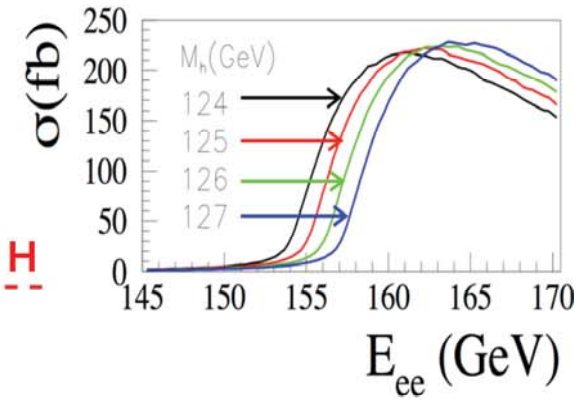


  ... or use two recirculating LINACs (here : SAPPHIRE)



  - Typical performance benchmarks with $P_e = 0.8$
    - γγ → H cross section ~ 200 fb
      - ➨ 3 times smaller if $P_e = 0.0$
    - ~20,000 Higgs bosons / year
      - ➨ Same as LEP3 (but one IP)
    - Fully polarized photons
      - ➨ Flexible polarizations



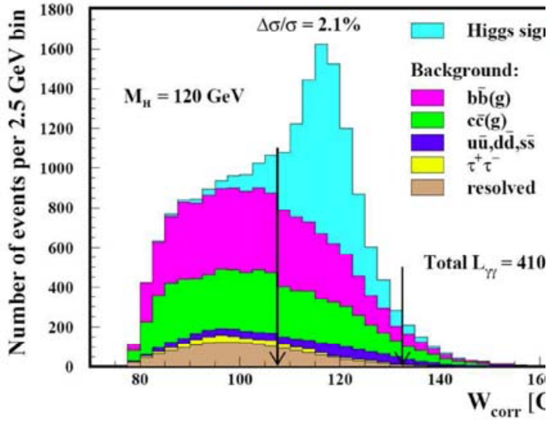


Higgs physics at a $\gamma\gamma$ collider (cont.2)

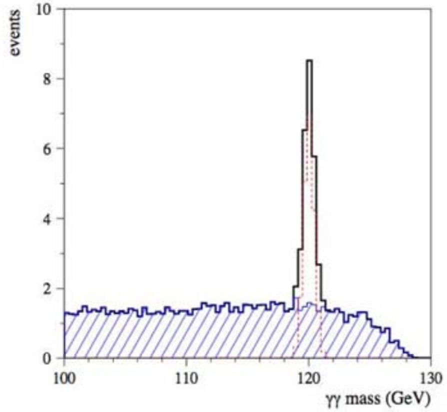
- **Precision after 5 years : First estimates**

$\sigma_{\gamma\gamma\to H} \times BR(H\to bb)$	1%
$\sigma_{\gamma\gamma\to H} \times BR(H\to WW^*)$	3%
$\sigma_{\gamma\gamma\to H} \times BR(H\to ZZ^*)$	5%
$\sigma_{\gamma\gamma\to H} \times BR(H\to \gamma\gamma)$	10%
$\sigma_{\gamma\gamma\to H} \times BR(H\to Z\gamma)$	16%
Γ_H	11%
m_H	50 MeV

Example : $\gamma\gamma\to H\to bb$



$\gamma\gamma\to H\to\gamma\gamma$



- Need inputs from e^+e^- collider, e.g., BR(H→bb), to get $\sigma_{\gamma\gamma\to H}$
  - Unique measurement of $g_{H\gamma\gamma}$ to 1%, sensitive to NP through loops
    - Cf 3.5% @ LEP3 and 1.5% @ TLEP
  - Other figures similar to / worse than LEP3 precision. No cc, gg measurement.

- Possibility of CP and CP violation studies with different input photon polarizations

Resume: $\gamma\gamma$ Higgs factory can't measure $H\to cc,\tau\tau,\mu\mu,gg$ and invisible decays, therefore can be considered only as a good add-on to e+e- linear colliders.

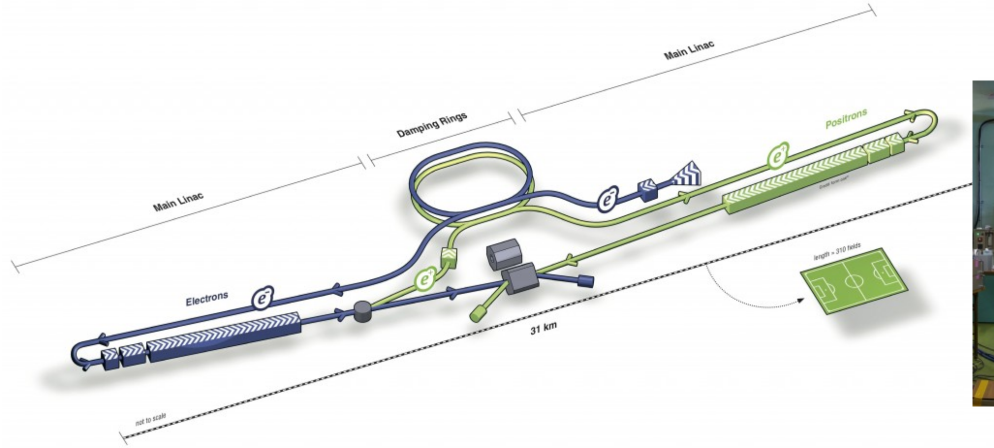
Higgs factory colliders

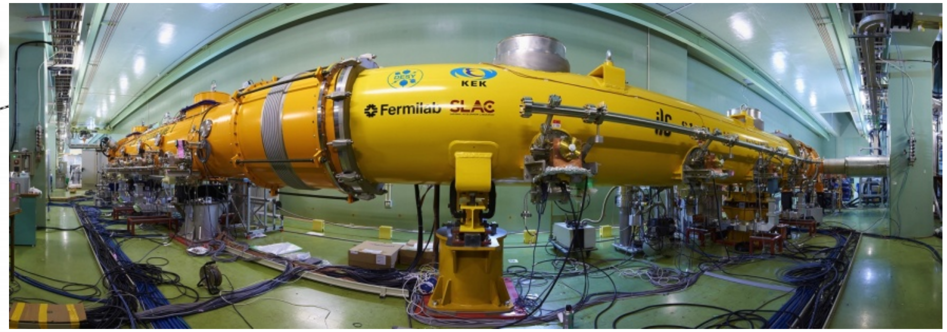
- Linear e+e- collider:
  - ILC
  - CLIC
  - X-band klystron based
- Circular e+e- collider:
  - LEP3
  - TLEP
  - SuperTRISTAN
  - Fermilab site-filler
  - China Higgs Factory (CHF)
  - SLAC/LBNL big ring
- Muon collider
  - Low luminosity
  - High luminosity
- $\gamma\gamma$ collider:
  - ILC-based
  - CLIC-based
  - Recirculating linac-based SAPPHiRE)
  - SLC-type

Linear e^+e^- Collider as a Higgs Factory

- Advantages:
  - Extensive design and prototyping work have been done
  - Big investment have been made. Key technologies are in hand.
  - There exist well-organized international collaborations led respectively by the ILC GDE and CLIC Collaboration (to be combined under the Linear Collider Director appointed by ICFA)
  - Important step towards high energy e+e- collisions
  - Polarized beams (e- 80%, e+ 30%)
  - A front runner (in terms of readiness)
- Challenges:
  - High cost
- Specific issues:
  - ILC
    - FFS
    - Positron source
    - Industrialization of SRF
    - For Higgs factory: Need 10 Hz for e+ production, or use unpolarized e+ beam as a backup scheme
  - CLIC
    - Accelerating structure
    - Industrialization of major components
    - From CDR to TDR

ILC as a Higgs Factory





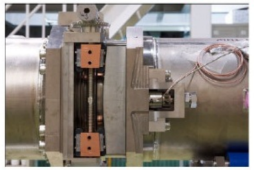
TESLA Cavity (DESY/FNAL)

Blade Tuner (FNAL)

Saclay Tuner (DESY)

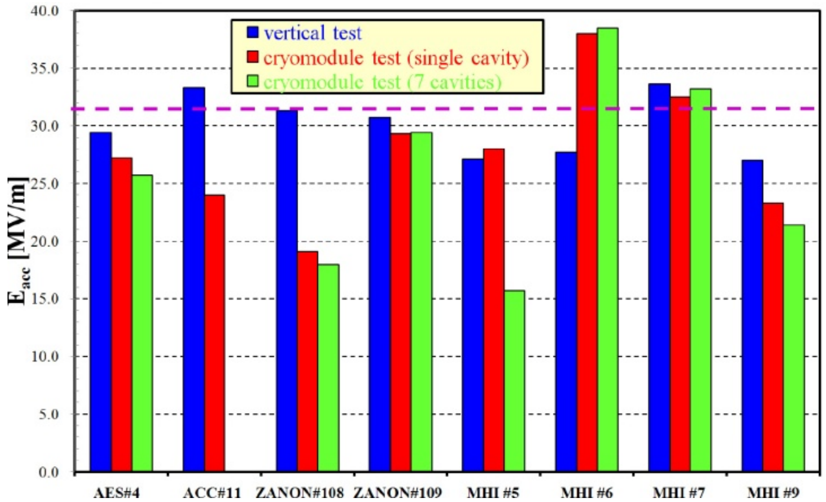
TTF-III Coupler (DESY/FNAL)

Tesla-like Cavity (KEK)

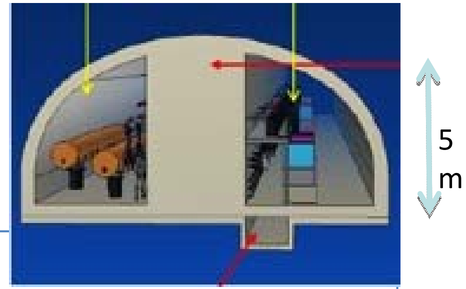


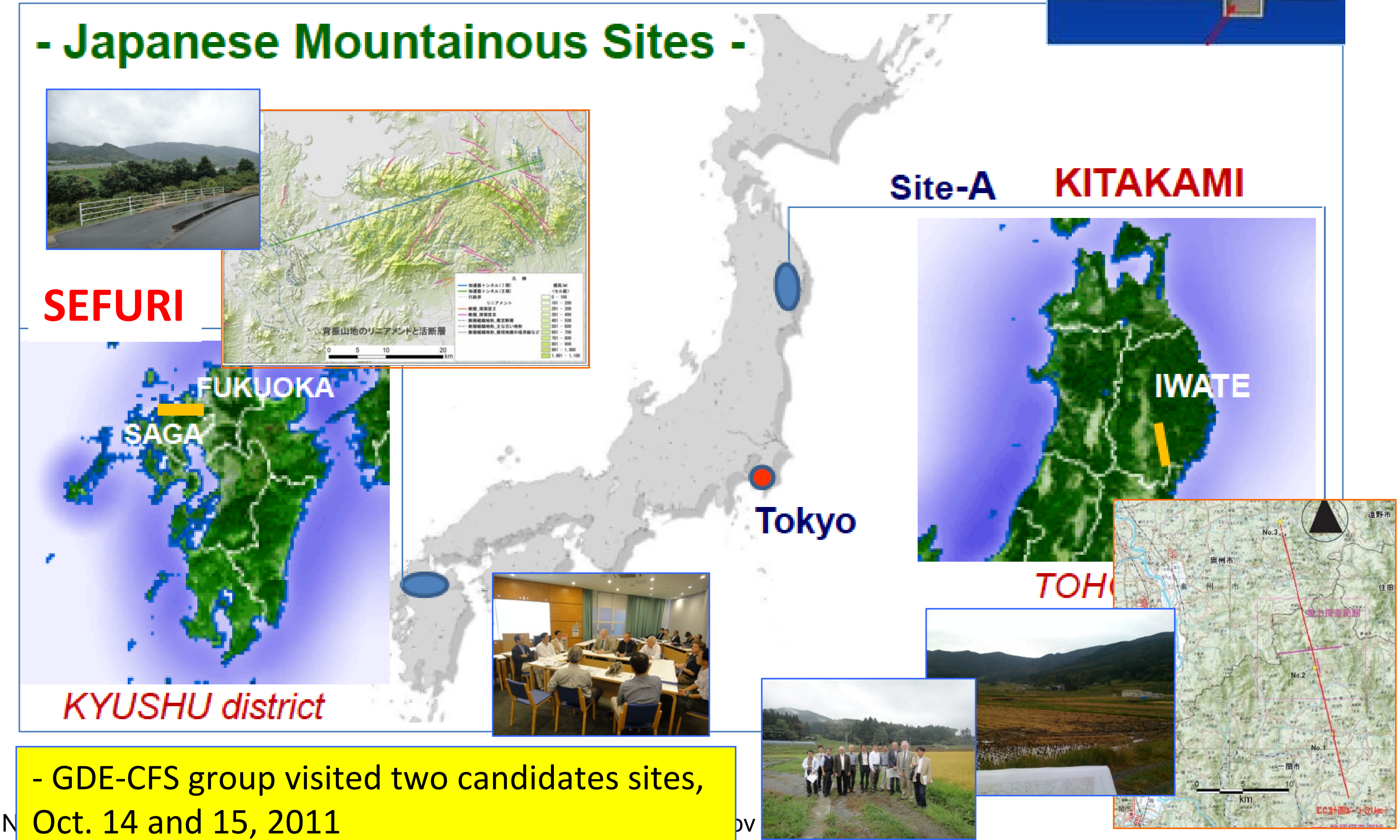
Slide-Jack Tuner (KEK)

STF-II Coupler (KEK)



Two Candidate Sites in Japanese mountainous locations





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

TDR Technical Volumes

2007

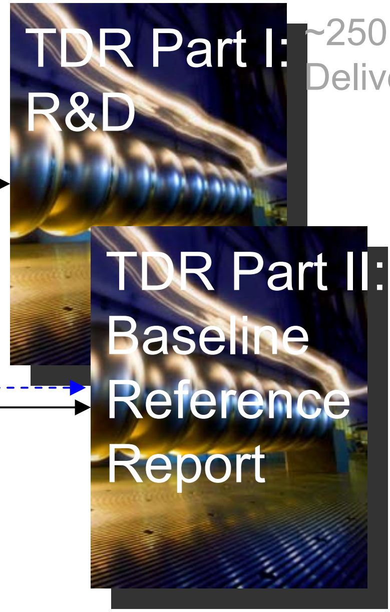
Reference Design Report

2011

ILC Technical Progress Report ("*interim report*")

AD&I

2013*



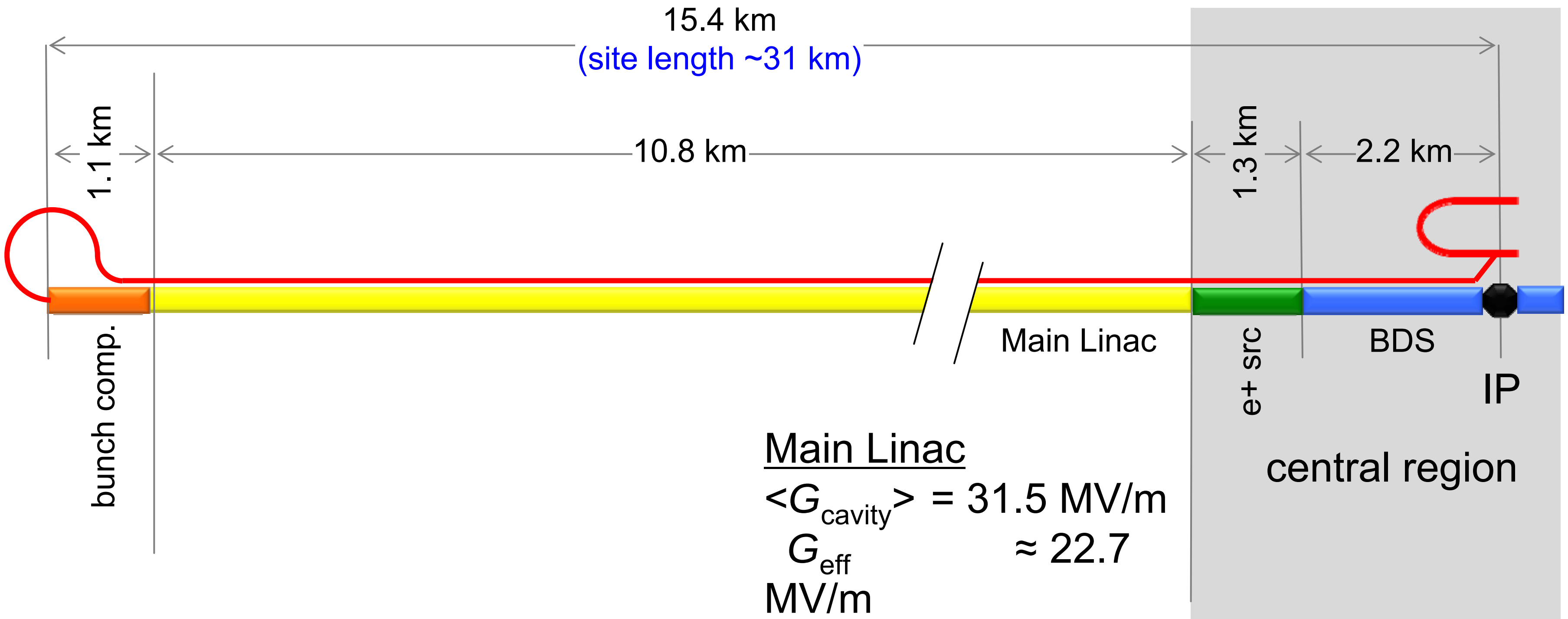
~250 pages
Deliverable 2

~300 pages
Deliverables 1,3 and 4

Technical Design Report

* end of 2012 – formal publication early 2013

TDR 500 GeV Baseline



<u>Main Linac</u>

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

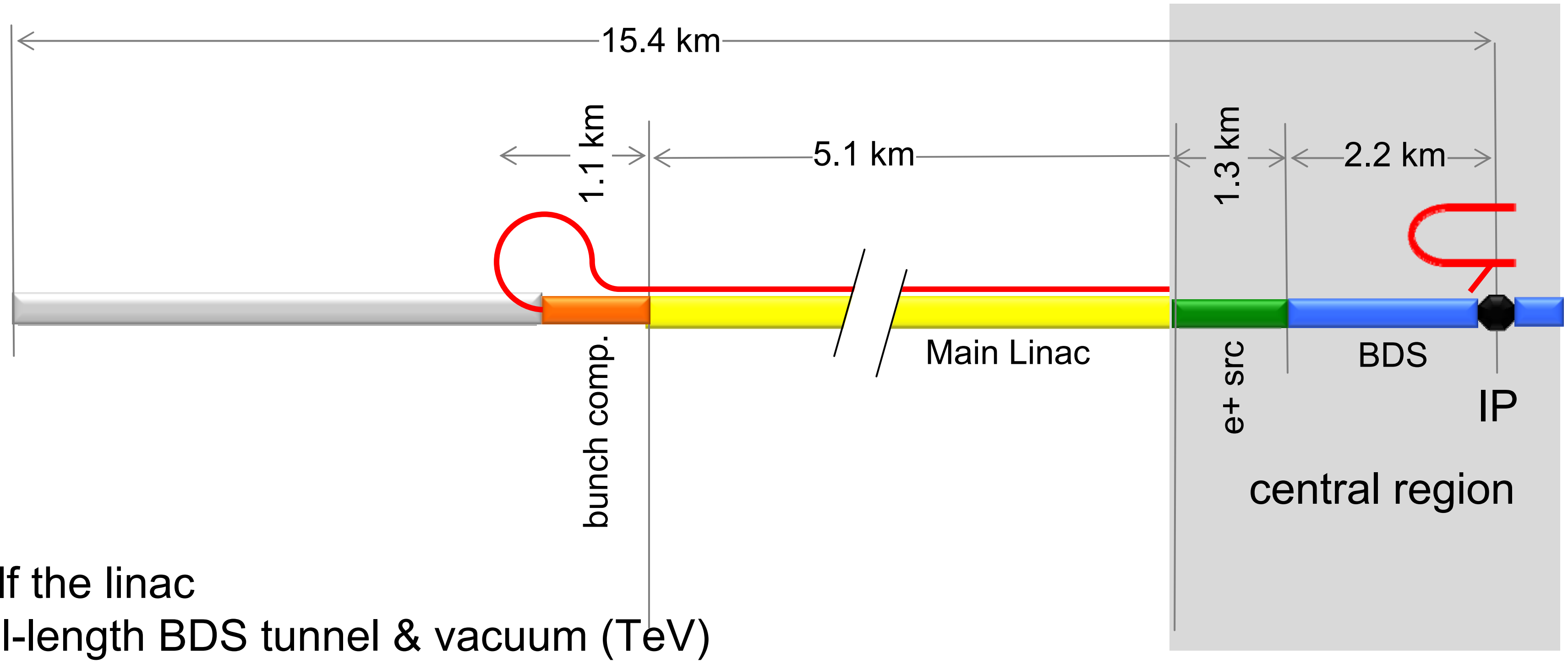
G_{eff} ≈ 22.7 MV/m

(fill fact. = 0.72)

Cost: 100%

P_{AC}: 161 MW

250 GeV staged (scenario 1)

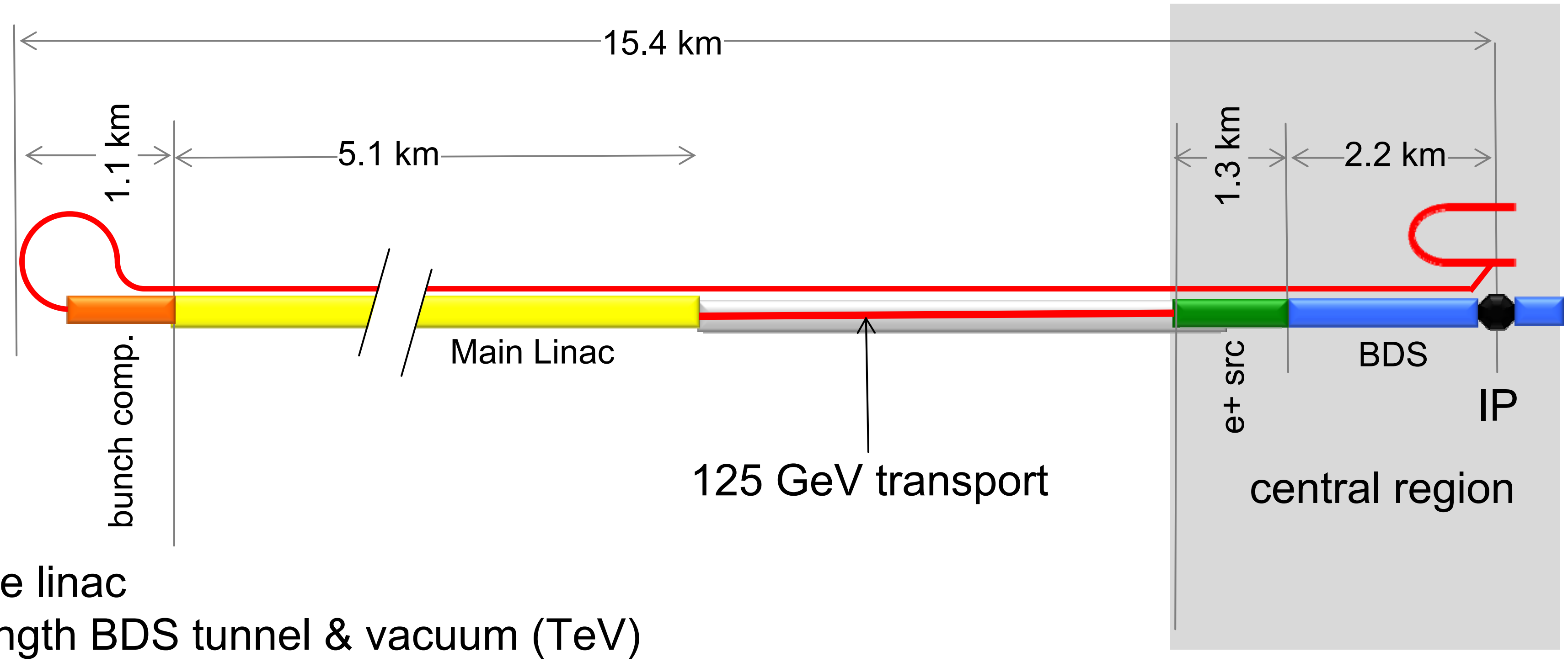


Half the linac
Full-length BDS tunnel & vacuum (TeV)
½ BDS magnets (instrumentation, CF etc)
½ RTML LTL

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)

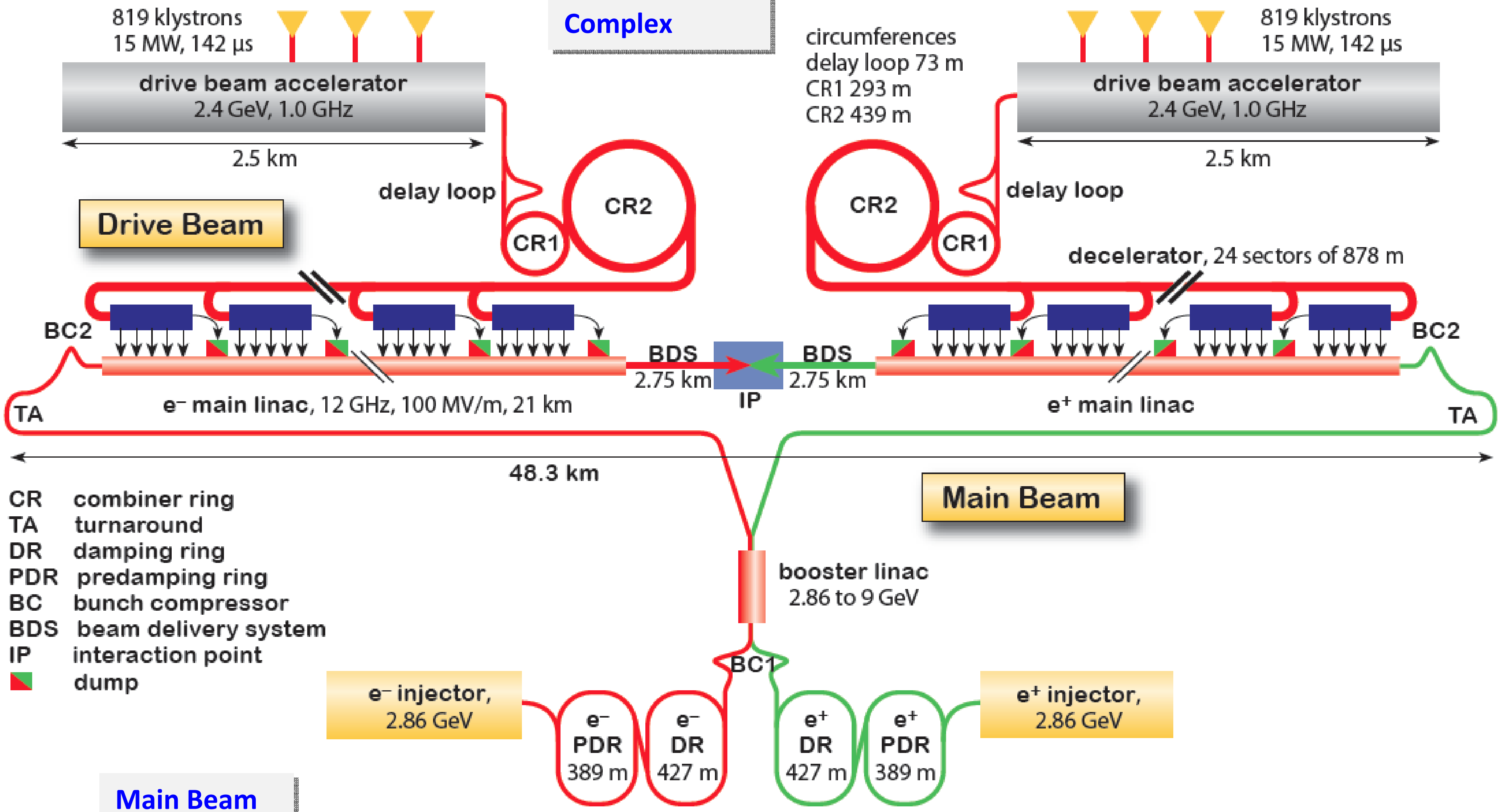
- ILC (500 GeV) machine already "contains" a light Higgs factory
  - Luminosity: 7.5×10^{33} cm^{-2} s^{-1}
  - (Possible to upgrade by factor 2)
- Standalone machine for LHF
  - reduced cost by ~35% (P_{AC} ~ 100 MW)
  - reduces schedule by 12-18 months (perhaps a little more)
- Only really makes sense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

CLIC Layout at 3 TeV

Goal: Lepton energy frontier

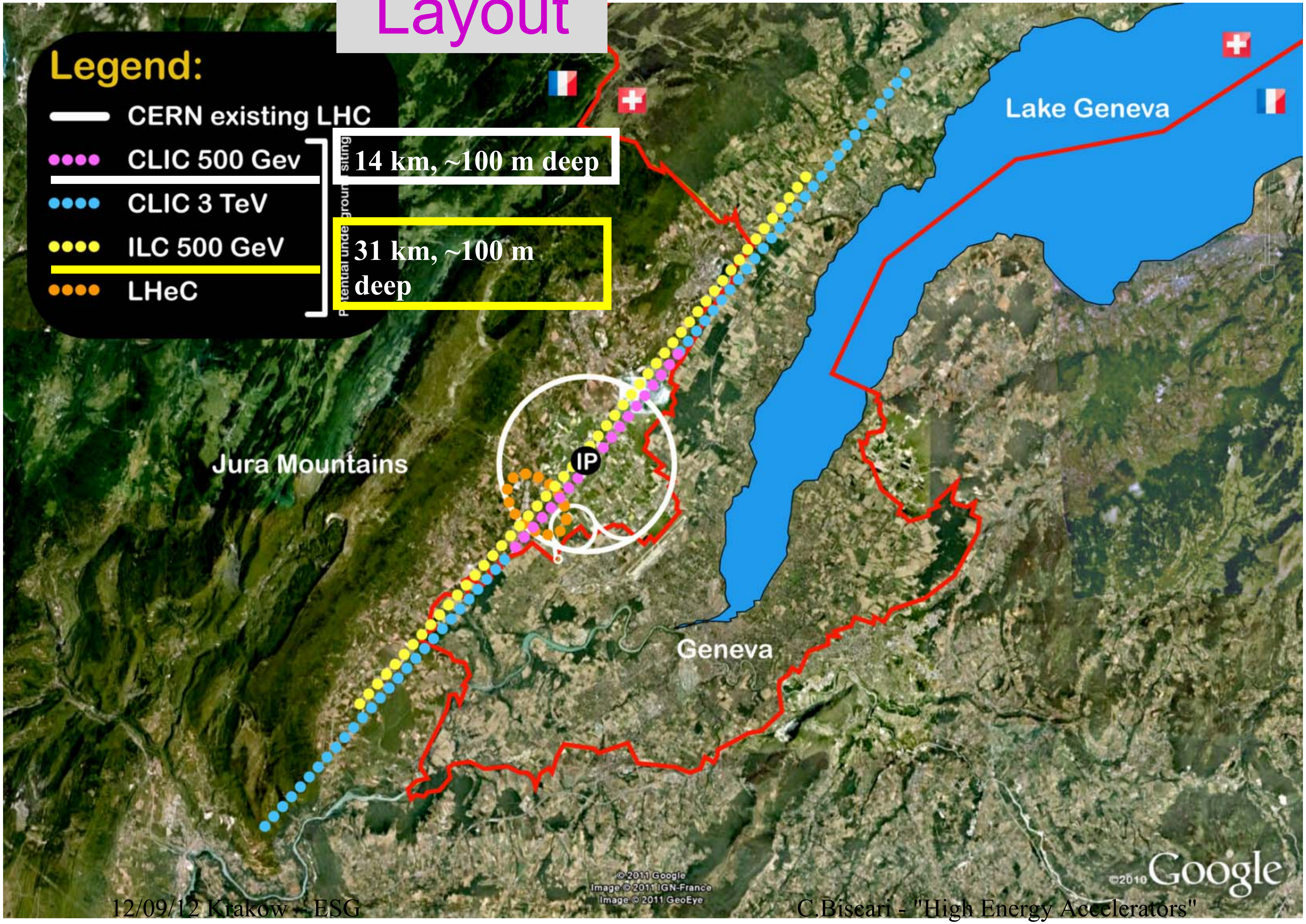
Drive Beam Generation Complex

D. Schulte, CLIC, HF 2012, November 2012

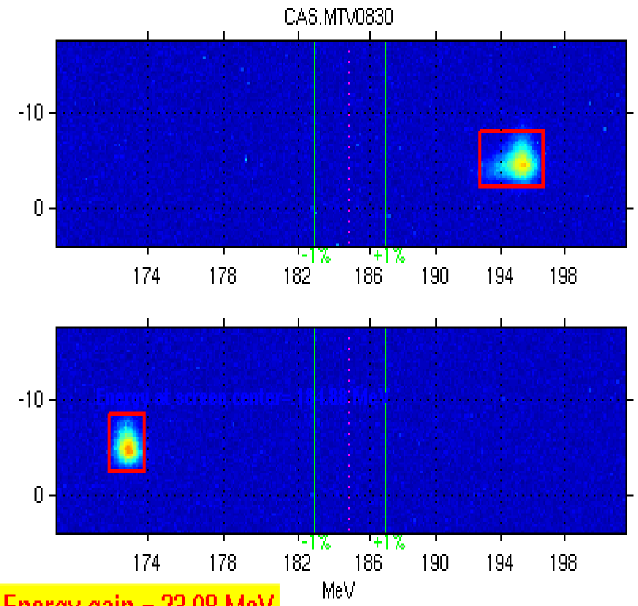


Main Beam Generation Complex

Layout

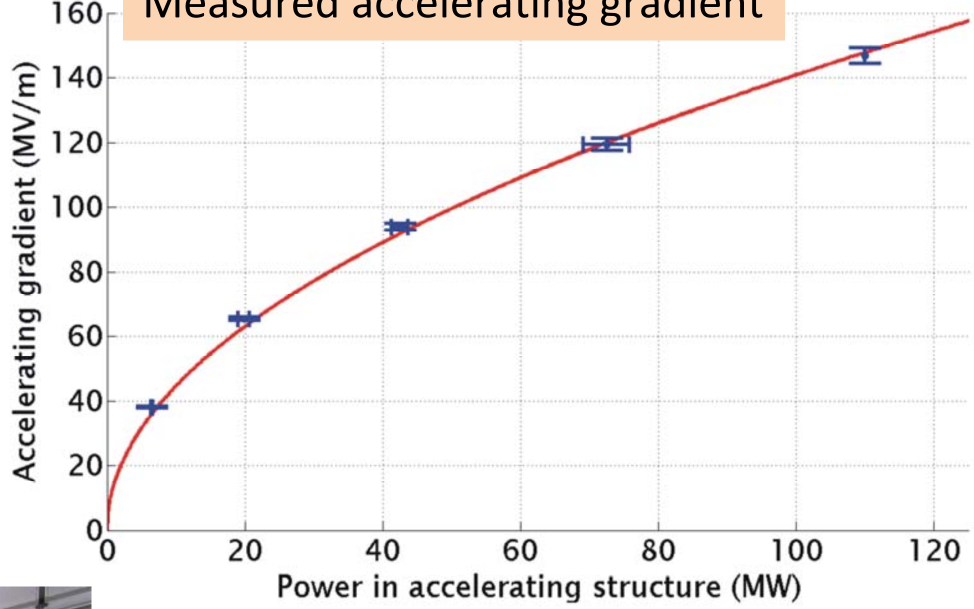

Legend:
CERN existing LHC
CLIC 500 Gev
CLIC 3 TeV
ILC 500 GeV
LHeC
14 km, ~100 m deep
31 km, ~100 m deep
Lake Geneva
Jura Mountains
IP
Geneva
© 2011 Google
Image © 2011 IGN-France
Image © 2011 GeoEye
©2010 Google

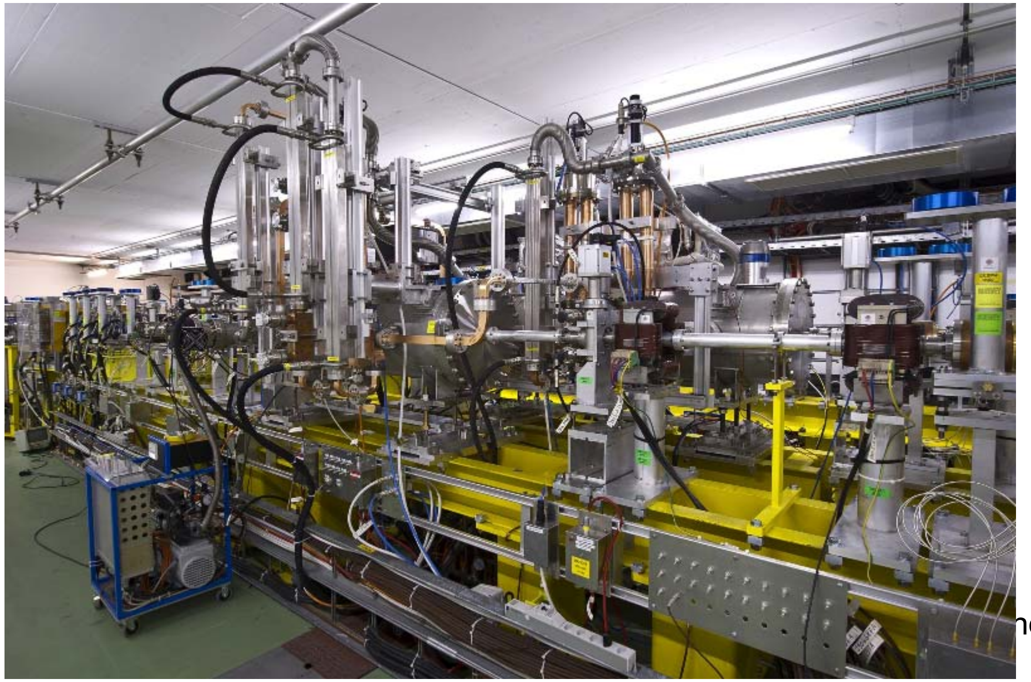
TBTS: Two Beam Acceleration



Energy gain = 23.08 MeV

Measured accelerating gradient





Maximum gradient 145 MV/m

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

The CLIC CDR documents

D. Schulte, CLIC, HF 2012, November 2012

Vol 1: The CLIC accelerator and site facilities (H.Schmickler)

- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- Complete, presented in SPC in March 2011, in print: https://edms.cern.ch/document/1234244/

Vol 2: Physics and detectors at CLIC (L.Linssen)

- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- Completed and printed, presented in SPC in December 2011 http://arxiv.org/pdf/1202.5940v1

Vol 3: “CLIC study summary” (S.Stapnes)

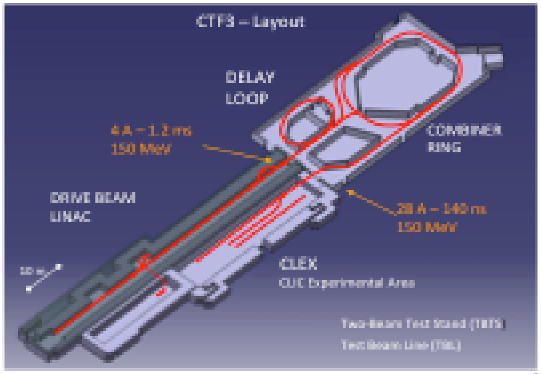
- Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)
- Completed and printed, submitted for the European Strategy Open Meeting in September http://arxiv.org/pdf/1209.2543v1

In addition a shorter overview document was submitted as input to the European Strategy update, available at: http://arxiv.org/pdf/1208.1402v1

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.



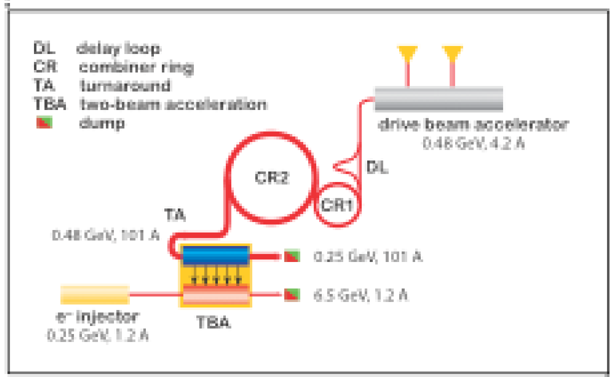
2016-17 Decisions

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.



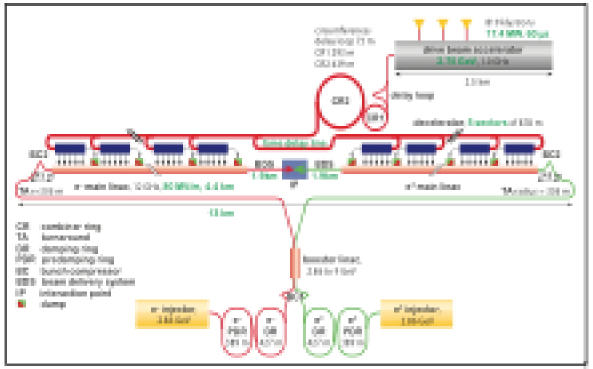
2022-23 Construction Start

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.

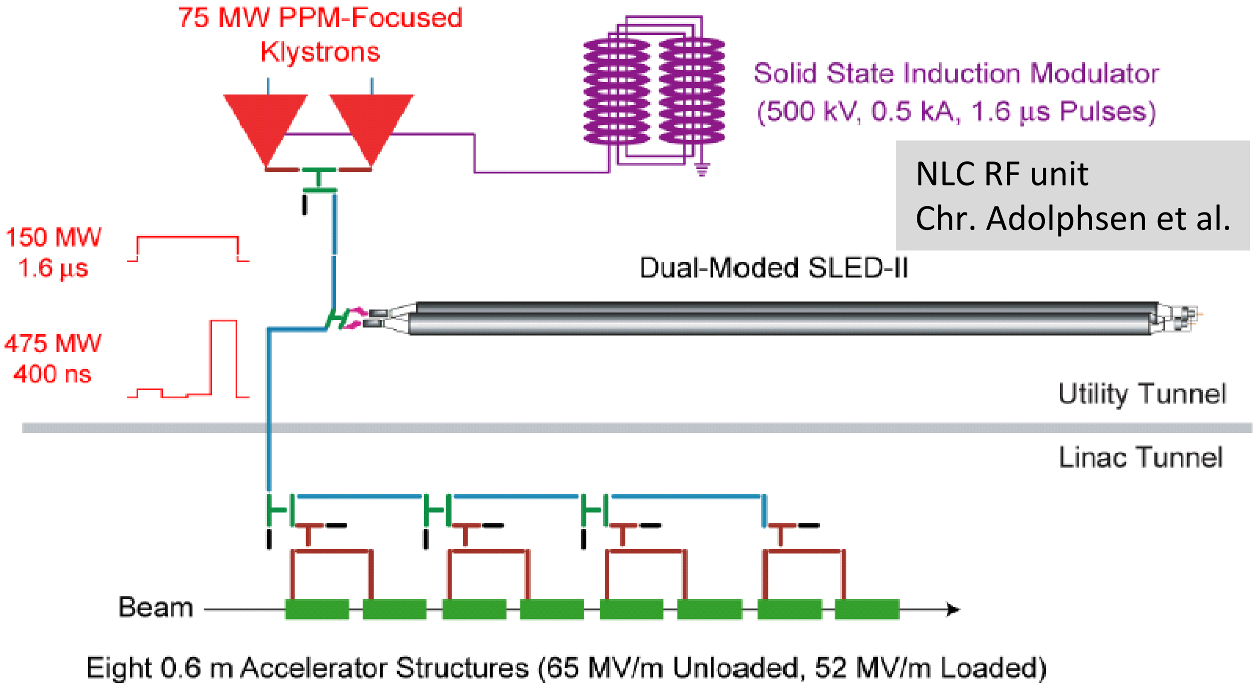


2030 Commissioning

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

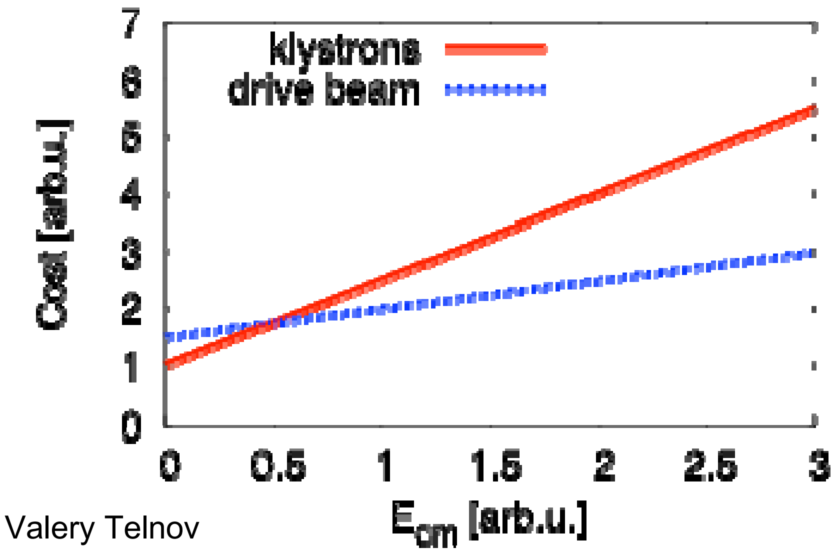
Note on Klystron-based First Stage

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



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



Circular e^+e^- Collider as a Higgs Factory

W. Chou, HF2012

"Happy families are all alike; every unhappy family is unhappy in its own way."

- Leo Tolstoy, Anna Karenina, Chapter 1, first line

Circular e+e- colliders are all alike.

The only difference is their size:

- 16 km (Fermilab site-filler)
- 27 km (LEP3)
- 40 km (SuperTRISTAN-40)
- 50 km (CHF-1)
- 70 km (CHF-2)
- 80 km (TLEP, SuperTRISTAN-80)
- 233 km (VLLC)

40

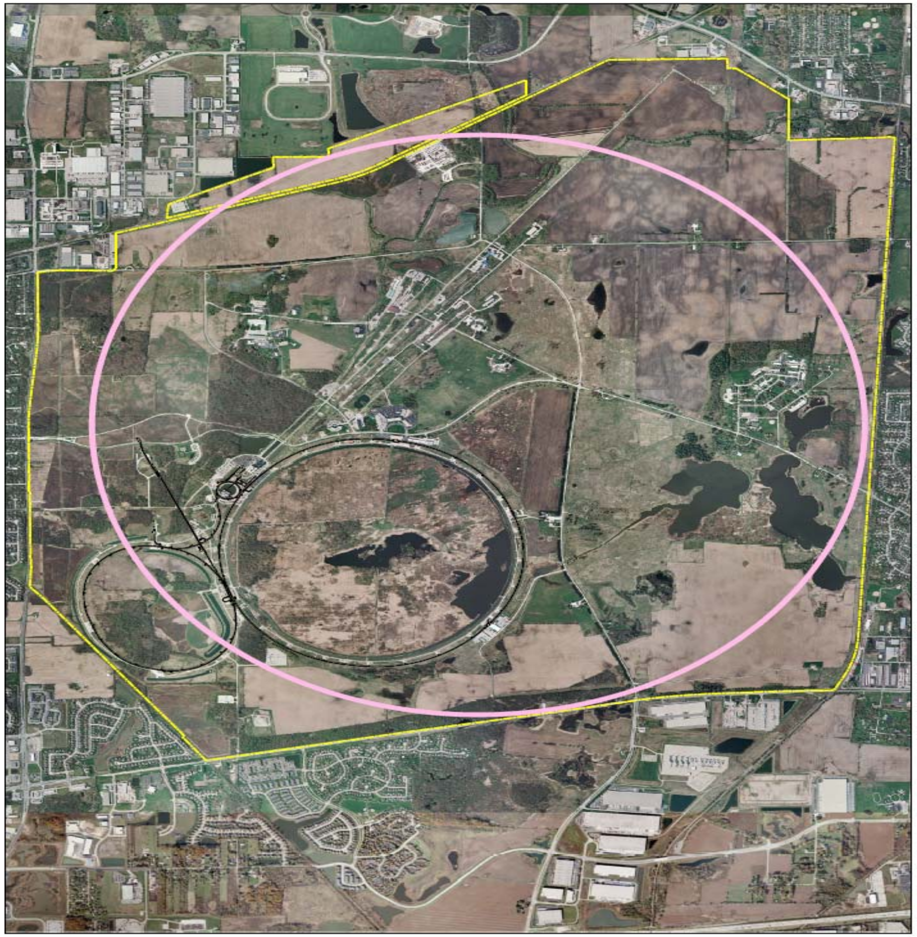
Circular e^+e^- Collider as a Higgs Factory

W. Chou, HF2012

- Advantages:
  - At 240 GeV, potentially a higher L to cost ratio than a linear one
  - Based on mature technology and rich experience
  - Some designs can use existing tunnel and site
  - More than one IP
  - Tunnel of a large ring can be reused as a pp collider in the future
- Challenges:
  - Beamstrahlung limiting beam life time requires lattice with large momentum acceptance
  - RF and vacuum problem from synchrotron radiation
  - A lattice with low emittance
  - Efficiency of converting wall power to synchrotron radiation power
  - Limited energy reach
  - No comprehensive study; design study report needed.

41

Fermilab Site-Filler



Fermilab Site Filler rings
Circumference = 16 km

Higgs factory

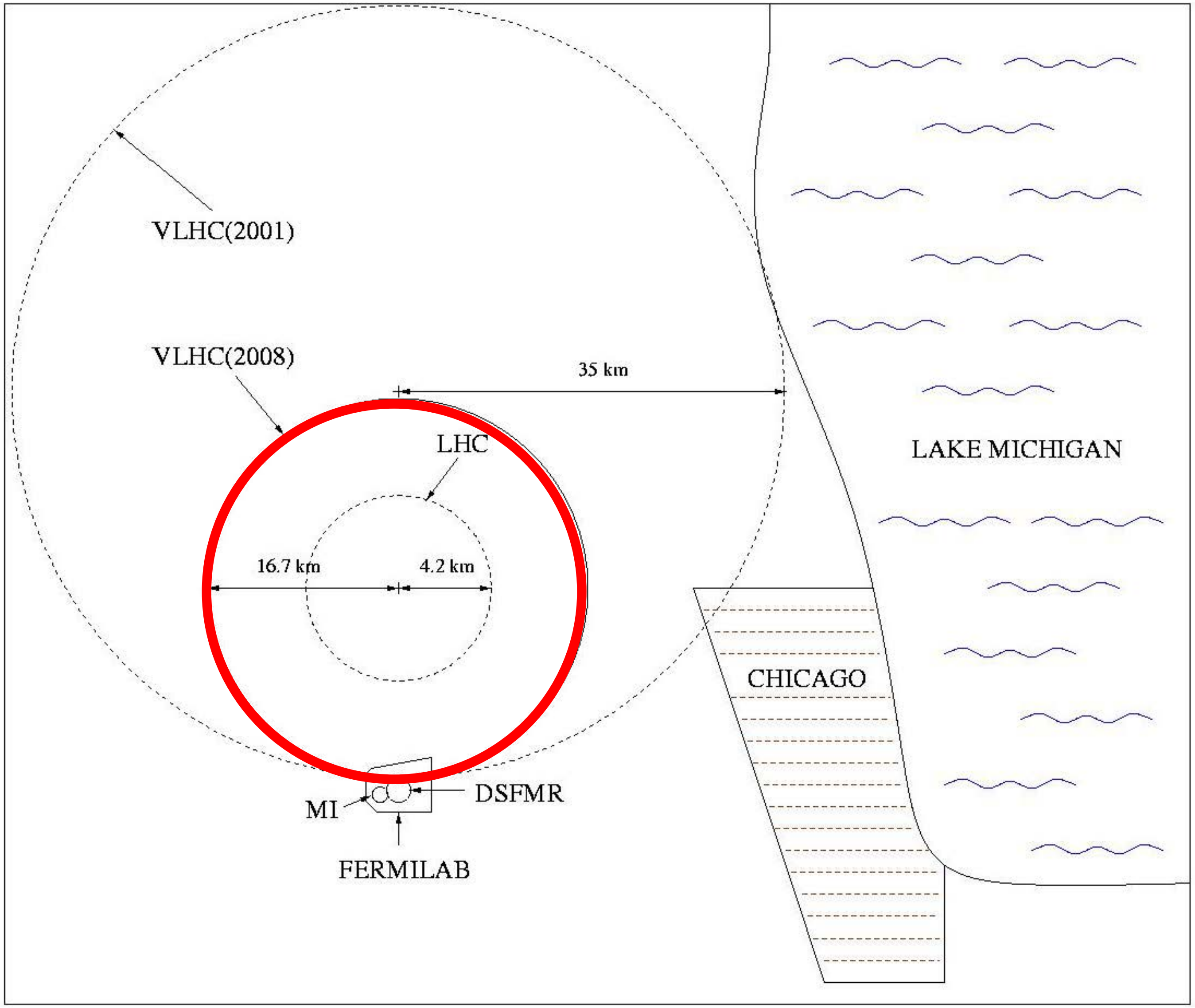
- Beam Energy = 120 GeV
- SR power, both beams=100MW
- Initial luminosity=5×10^{33} cm^{-2} s^{-1}
- βx*, βy* = (20, 0.2) cm
- Beam-beam tune shifts =(0.067, 0.095)
- Beam current = 5 mA

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

105 km tunnel near FNAL

H. Piekarz, "… and … **path to the future of high energy particle physics**," JINST 4, P08007 (2009)



(+ FNAL plan B from R. Talman)

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

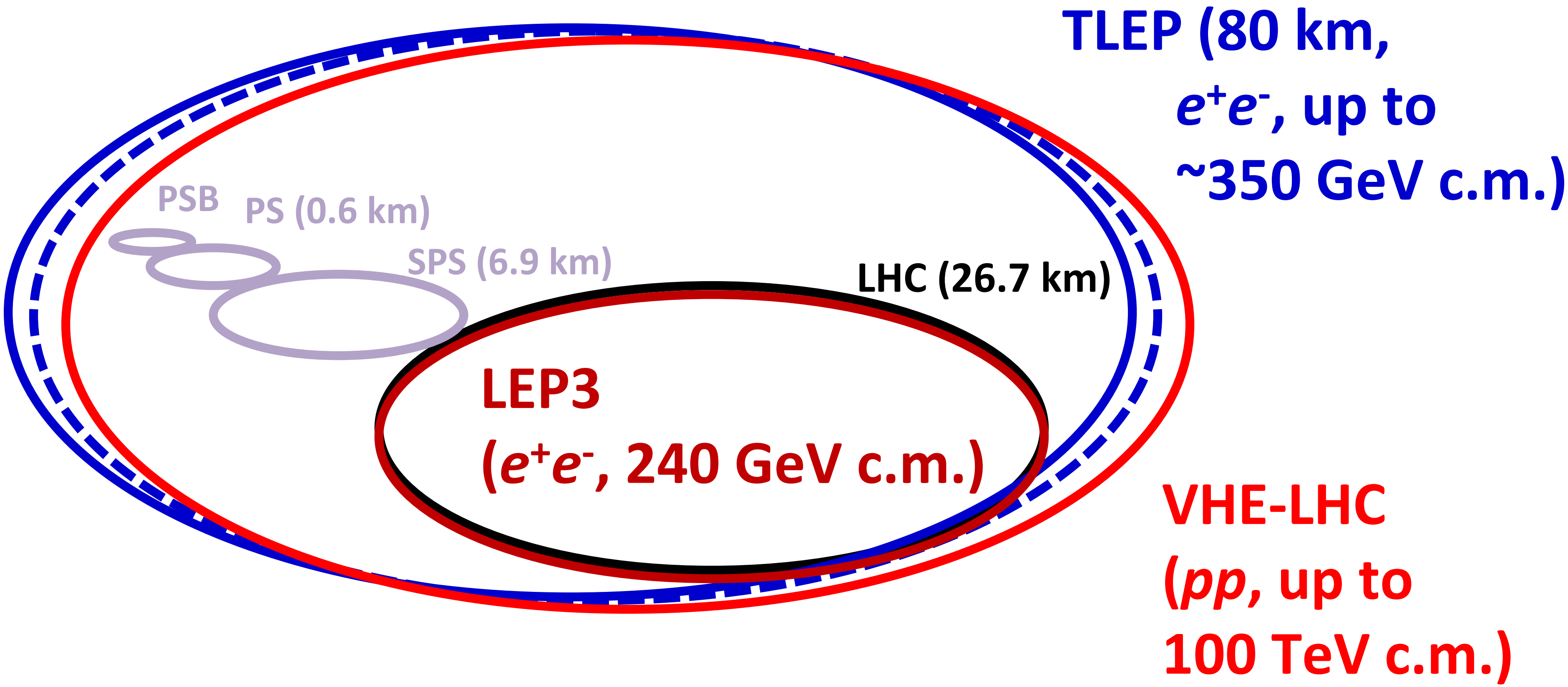
12/09/12 Krakow – ESG
C.Biscari - "High Energy Accelerators"

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)

circular Higgs factories at CERN & beyond

(F. Zimmermann)



also: ***e*^±^ (200 GeV) – *p* (7 & 50 TeV)** collisions

a long-term strategy for HEP!

two options

- installation in the LHC tunnel “LEP3”
  - \+ inexpensive (<0.1xLC)
  - \+ tunnel exists
  - \+ reusing ATLAS and CMS detectors
  - \+ reusing LHC cryoplants
  - \- interference with LHC and HL-LHC
- new larger tunnel “TLEP”
  - \+ higher energy reach, 5-10x higher luminosity
  - \+ decoupled from LHC/HL-LHC operation & construction
  - \+ tunnel can later serve for HE-LHC (factor 3 in energy from tunnel alone) with LHC remaining as injector
  - \- 4-5x more expensive (new tunnel, cryoplants, detectors)

LEP3, TLEP

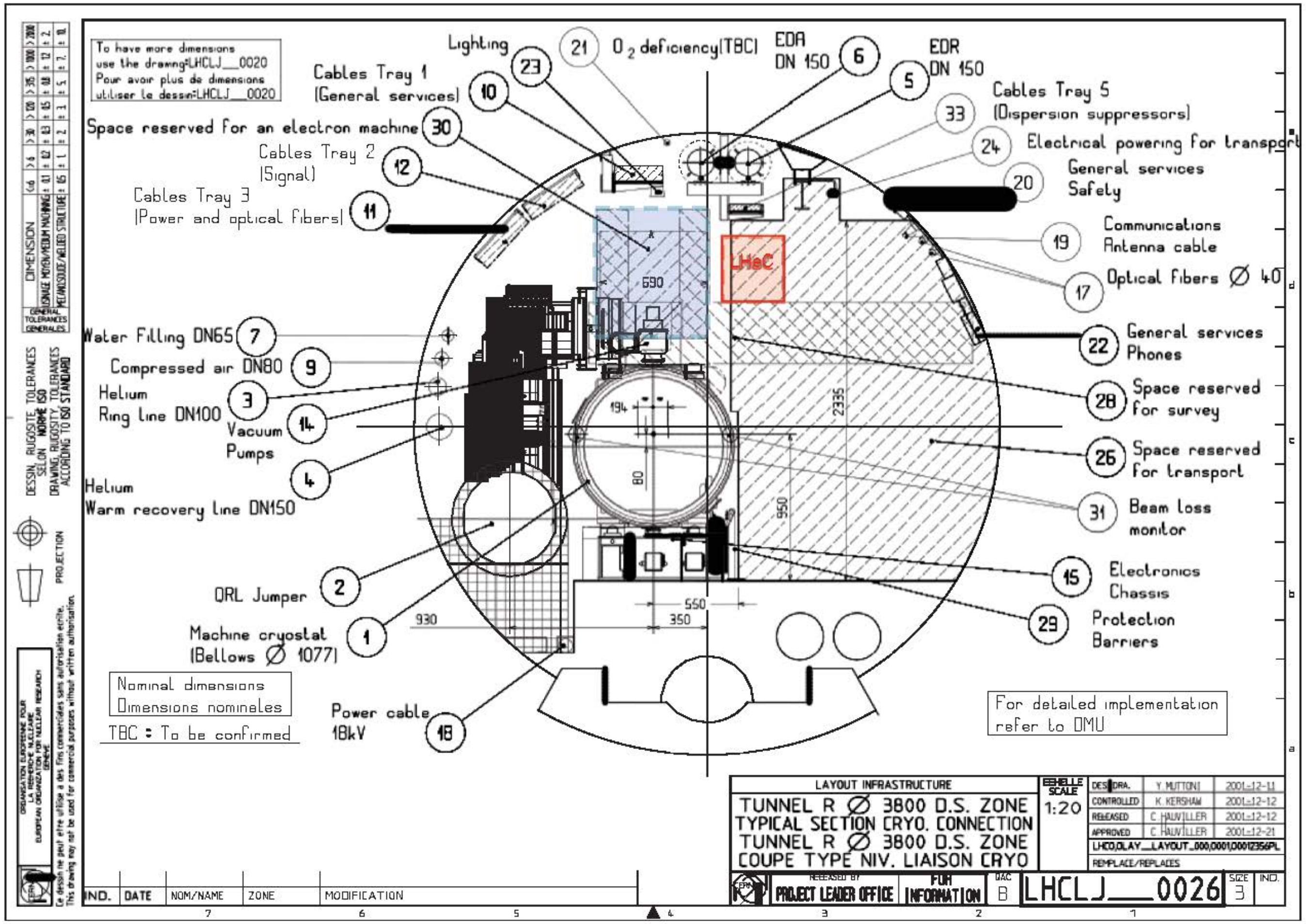
(e$^+$e$^-$ -> ZH. e$^+$e$^-$ → W$^+$W$^-$. e$^+$e$^-$ → Z.[e$^+$e$^-$→ $t\bar{t}$])

key parameters

	LEP3	TLEP
circumference	26.7 km	80 km
max beam energy	120 GeV	175 GeV
max no. of IPs	4	4
luminosity at 350 GeV c.m.	-	0.7×10^{34} cm^{-2}s^{-1}
luminosity at 240 GeV c.m.	10^{34} cm^{-2}s^{-1}	5×10^{34} cm^{-2}s^{-1}
luminosity at 160 GeV c.m.	5×10^{34} cm^{-2}s^{-1}	2.5×10^{35} cm^{-2}s^{-1}
luminosity at 90 GeV c.m.	2×10^{35} cm^{-2}s^{-1}	10^{36} cm^{-2}s^{-1}

at the *Z* pole repeating LEP physics programme in a few minutes…

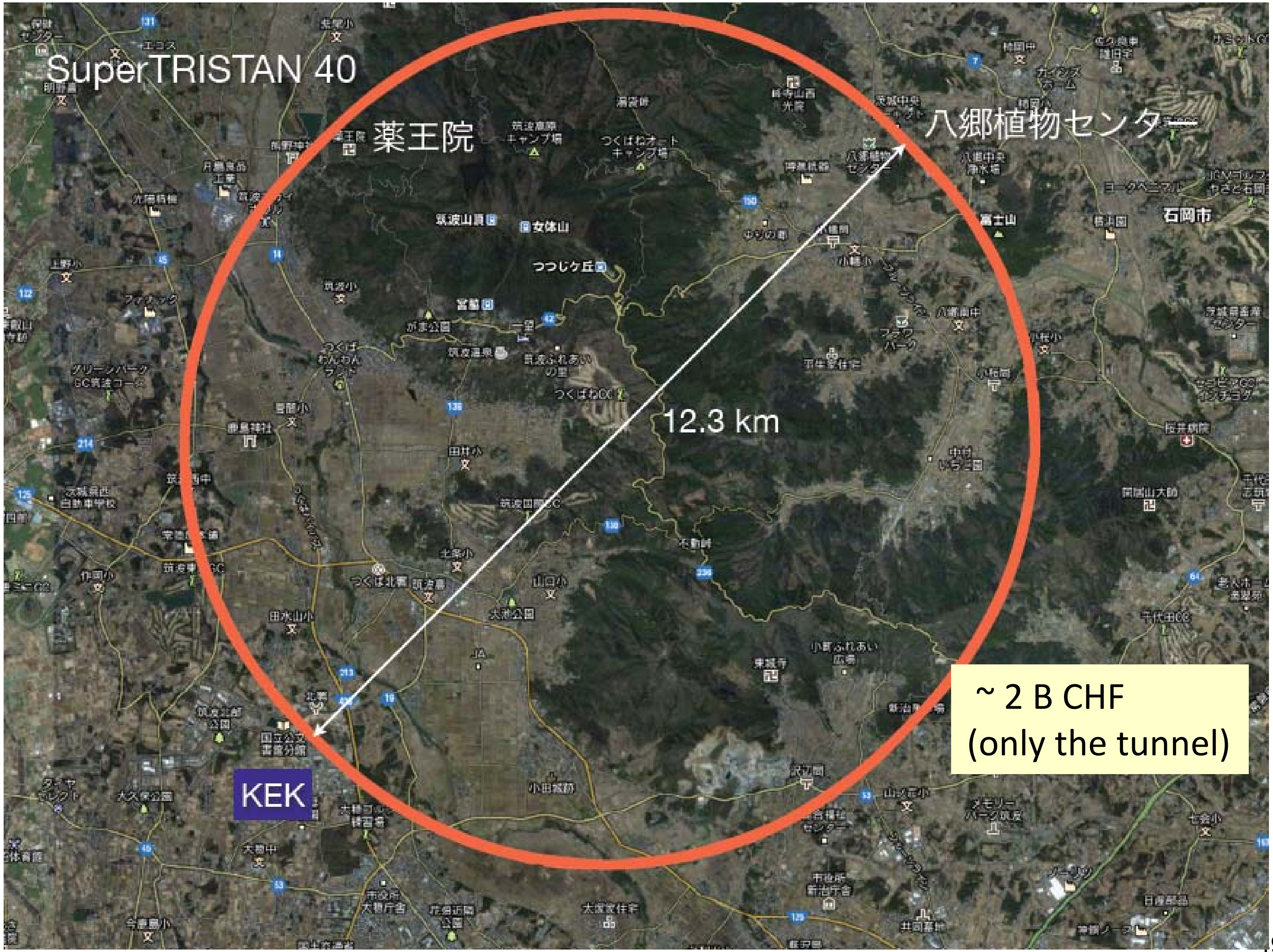
putting LEP3 into the LHC tunnel?



LHC tunnel cross section with space reserved for a future lepton machine like LEP3 [blue box above the LHC magnet] and with the presently proposed location of the LHeC ring [red]

LHC community is against LEP-3 in LHC tunnel, until LHC is there

SuperTRISTAN



80 km ring in KEK area
12.7 km
KEK
City Office
Makabe Branch
Mt Tsukuba
筑波山
Tsutsujigaoka
つつじヶ丘
Miyawaki
宮脇
Mt Fuji
富士山
Ishioka
City Office
Chiyoda Branch
市役所千代田庁舎
City Office
Niihari Branch
Toyosato
Hospital
筑波国際CC
筑波東急GC
サミットGC
千代田PA
Map data ©2012 Google, ZENRIN

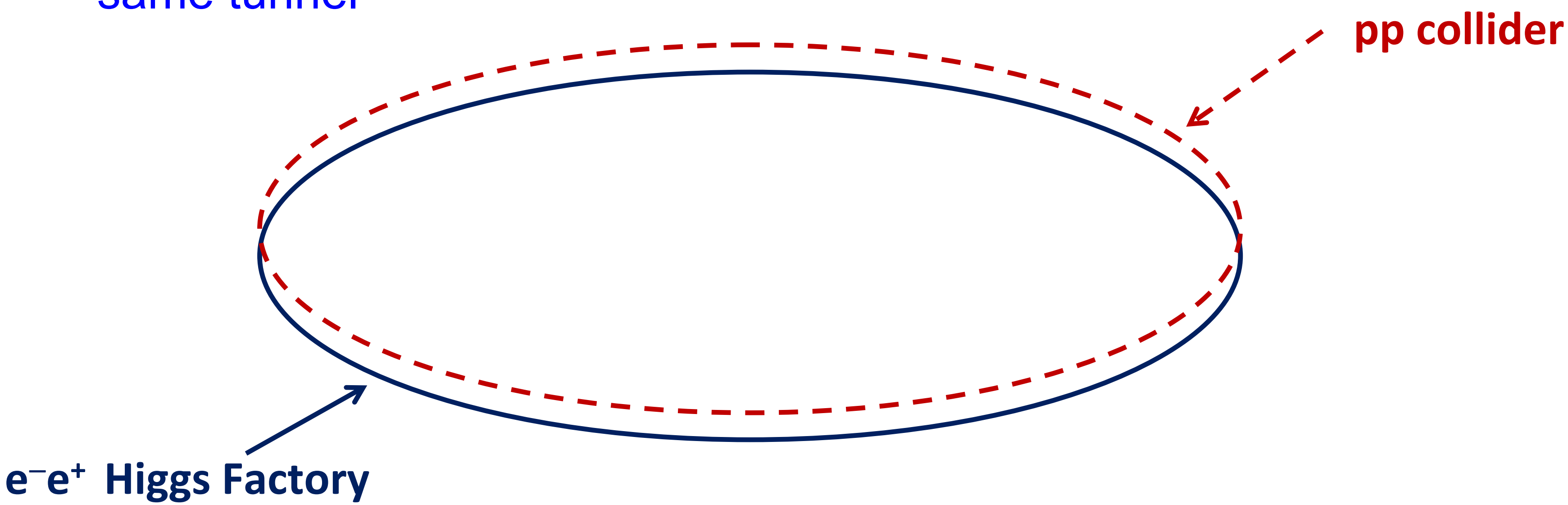
Parameters Example

K.Oide, HF2012

	TRISTAN	KEKB	LEP2	LEP3	TLEP-t	SuperTRISTAN		
						40	80	
Beam Energy	32	8 / 3.5	105	120	175	120	175	GeV
Circumference	3	3	27	27	80	40	80	km
Beam Current / beam	7	1400 1700	4	7.2	5.4	6.5	4.2	mA
Bunches / beam	2	1600	4	4	12	8	22	
β* x / y	2000 / 40	1200 / 6	1500 / 65	200 / 1	200 / 2	200 / 1	200 / 1	mm
Emittances x / y		18 / 0.1	48 / 0.25	25 / 0.1	20 / 0.1	40 / 0.04	12 / 0.012	nm
Bunch length	10	6	3	3	1.5	1.2	1.2	mm
Beam-beam parameters x,y	0.02 0.025	0.05 0.09	0.025 0.065	0.09 0.08	0.05 0.05	0.032 0.083	0.035 0.089	
Beamstrahlung loss / spread / equil. spread				0.04 0.15	0.05 0.24	0.02 0.07 0.43	0.02 0.08 0.39	%
synch. tune	0.1	0.02				0.23	0.27	
mom. compact.	140	20	18.5	9.0	1.0	2.7	1.6	10^{-3}
Radiation loss / turn	300	4 / 2	2750	6900	9300	3450	8080	MV
RF Voltage	400	10 / 5	3640	9000	12000	8300	16000	MV
RF frequency	508	509	352	700	700	1300	1300	MHz
Total SR Power	4.2	5.6 / 3.4	22	100	100	45	68	MW
Luminosity / IP	0.04	21	0.13	9.4	6.5	10	10	/nb/s

What is a (CHF + SppC)

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



- 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.

Requirement of the beam lifetime>30 min leads tothe restriction on the beam parameters:

$$\frac{N}{\sigma_x \sigma_z} < 0.1\eta \frac{\alpha}{3\gamma {r_e}^2}$$

η is the ring energy acceptance

This formula is the basis for the following discussions.

With account of $\xi_y = \frac{N r_e \beta_y}{2\pi\gamma\sigma_x\sigma_y} \approx \frac{N r_e \sigma_z}{2\pi\gamma\sigma_x\sigma_y}$ for $\beta_y \approx \sigma_z$

and SR power in rings $P = 2\delta E \frac{cNn_{\mathrm{b}}}{2\pi R} = \frac{4e^2\gamma^4 cNn_{\mathrm{b}}}{3RR_{\mathrm{b}}}$

The maximum luminosity of storage rings with account of beamstrahlung

$$\mathcal{L} \approx h \frac{(0.1\eta\alpha)^{2/3} PR}{32\pi^2\gamma^{13/3} r_e^3} \left(\frac{R_{\mathrm{b}}}{R}\right) \left(\frac{6\pi\xi_y r_e}{\varepsilon_y}\right)^{1/3}$$

In practical units

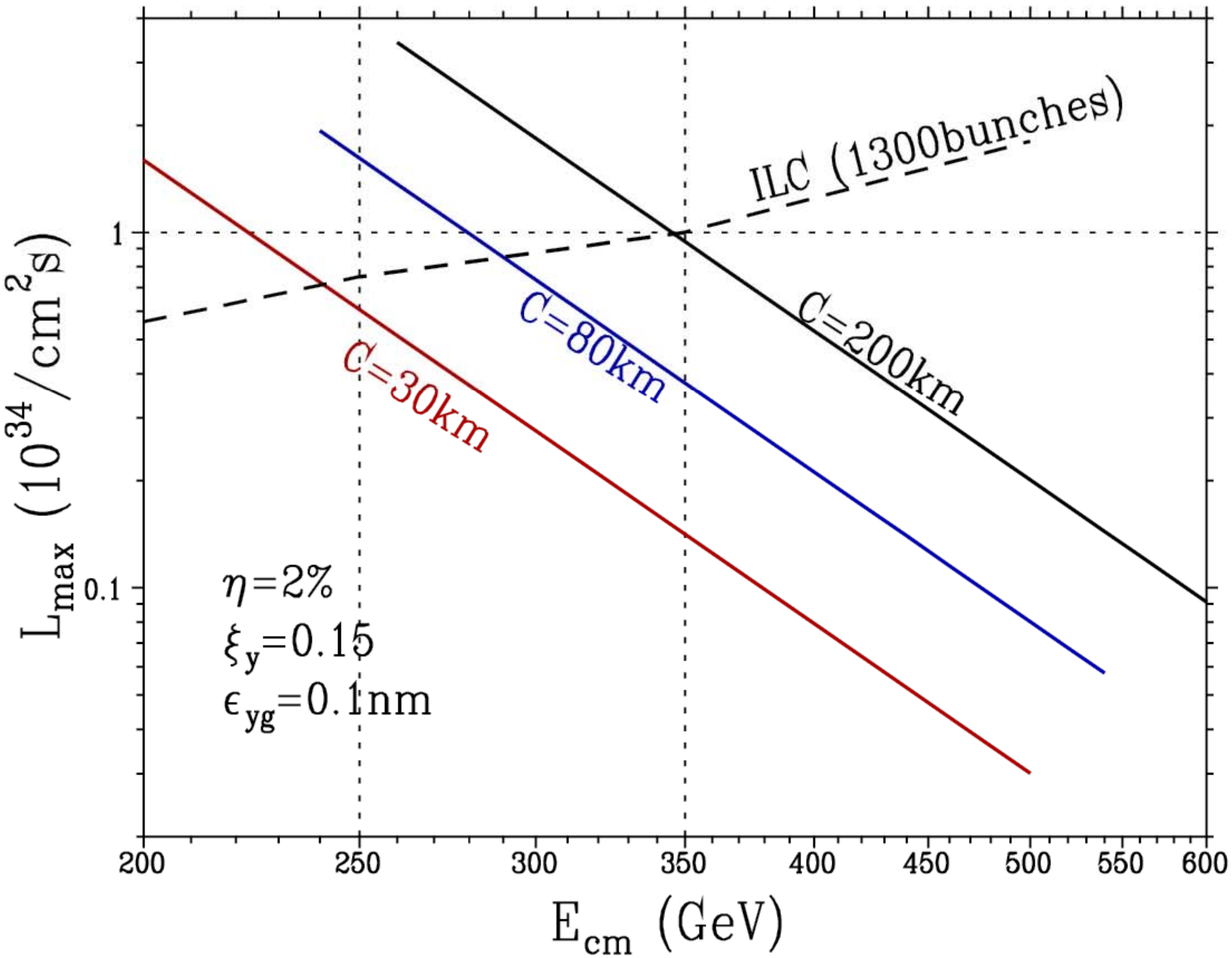
$$\frac{\mathcal{L}}{10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}} \approx \frac{100 h\eta^{2/3}\xi_y^{1/3}}{(E_0/100\,\mathrm{GeV})^{13/3}(\varepsilon_y/\,\mathrm{nm})^{\frac{1}{3}}}$$

Luminosity vs. Energy

K.Yokoya, using V.Telnov's formula

example with

- η=2%
- ξ_y=0.15
- ε_{gy}=0.1nm



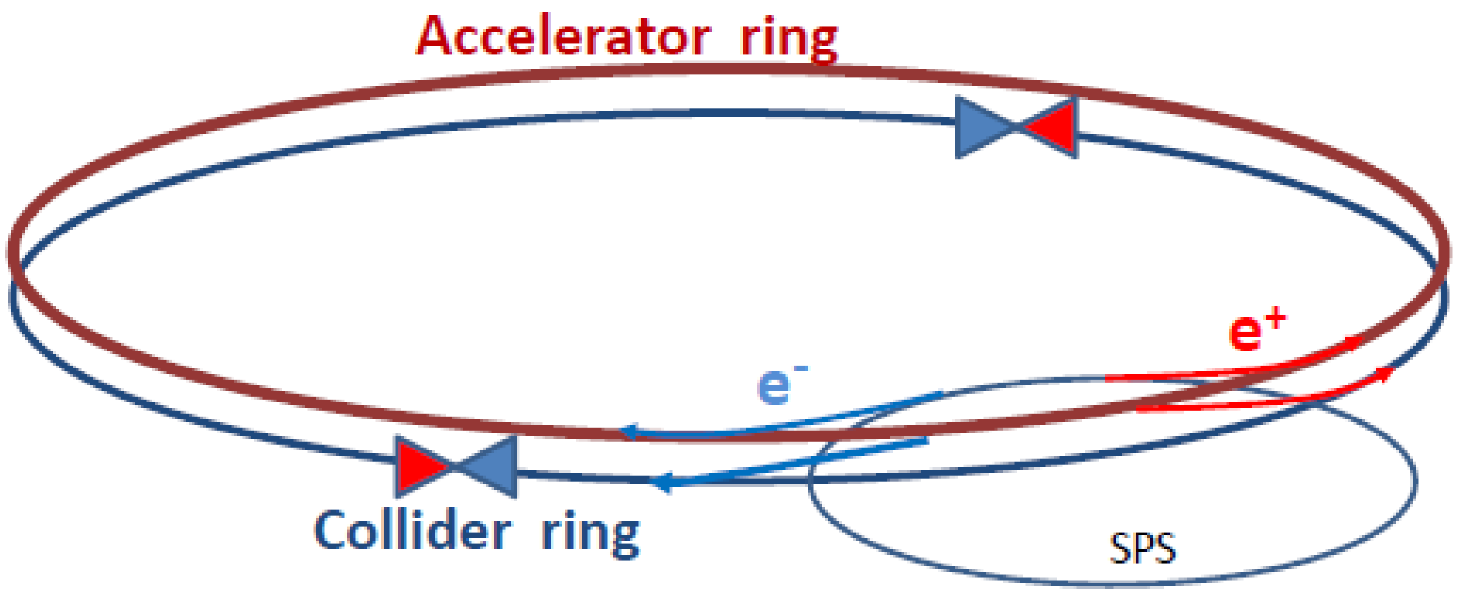
How can one increase over LEP 2 (average) luminosity by a factor 500 without exploding the power bill?

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

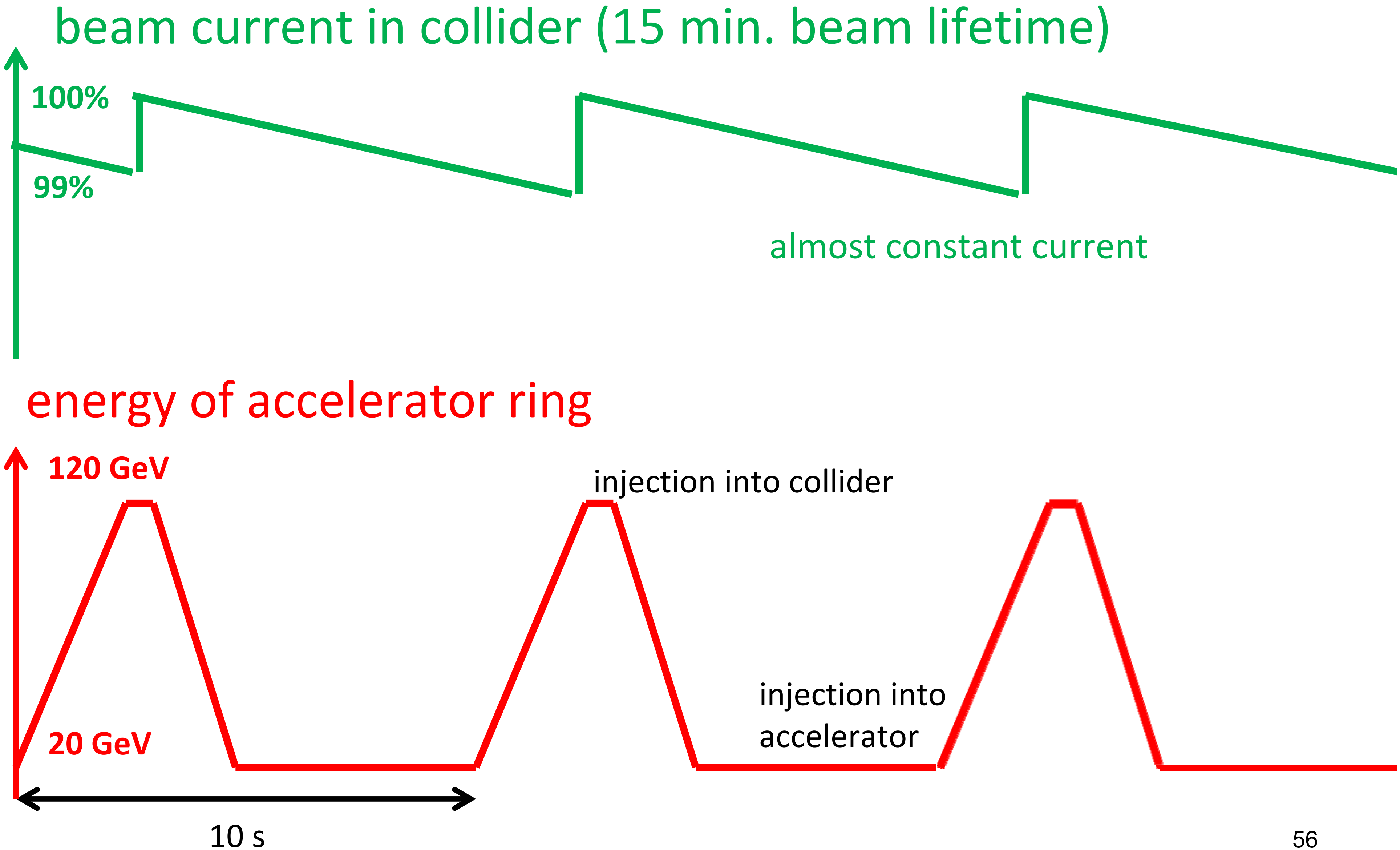
➔ much shorter lifetime (few minutes)

➔ feed beam consituously with a ancillary accelerator



No

Top-up Injection: Schematic Cycle



Muon Collider as a Higgs Factory

- Advantages:
  - Large cross section σ ($\mu+\mu- \rightarrow h$) = 41 pb in s-channel resonance will compensate low luminosity (to compare to e+e- → ZH at 0.2 pb)
  - Small size footprint
  - No synchrotron radiation problem
  - No beamstrahlung problem
  - Unique way for direct measurement of the Higgs line shape and total decay width Γ
  - Exquisite energy calibration
  - A path to very high energy lepton-lepton collisions
- Challenges:
  - Muon 4D and 6D cooling needs to be demonstrated
  - Need small c.o.m energy spread (0.003%)
  - RF in a strong magnetic field
  - Background from constant muon decay
  - Significant R&D required towards end-to-end design and firming up luminosity figures
  - Cost unknown (not much cheaper than a TeV muon collider)

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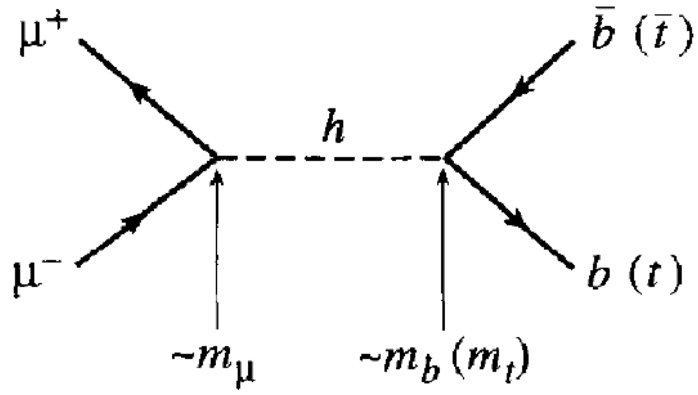
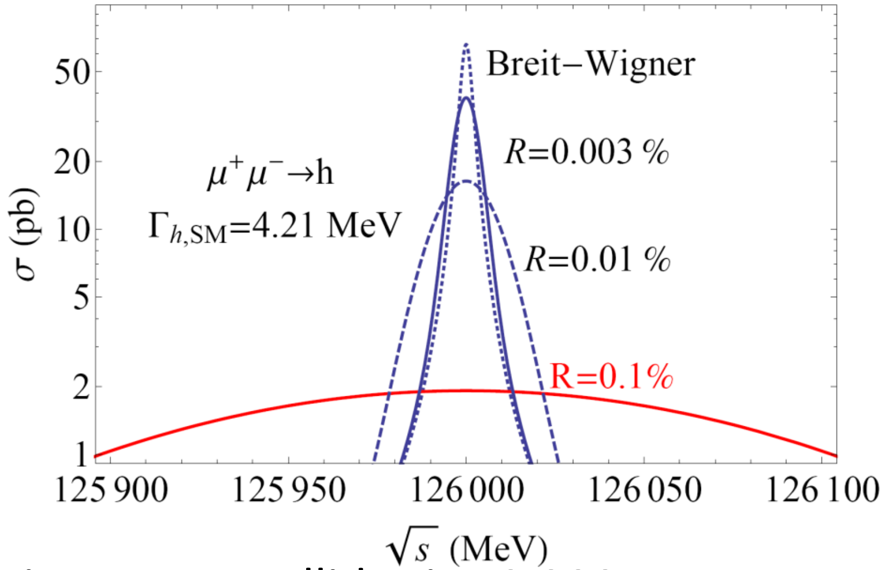
Muon Collider as a Higgs Factory

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

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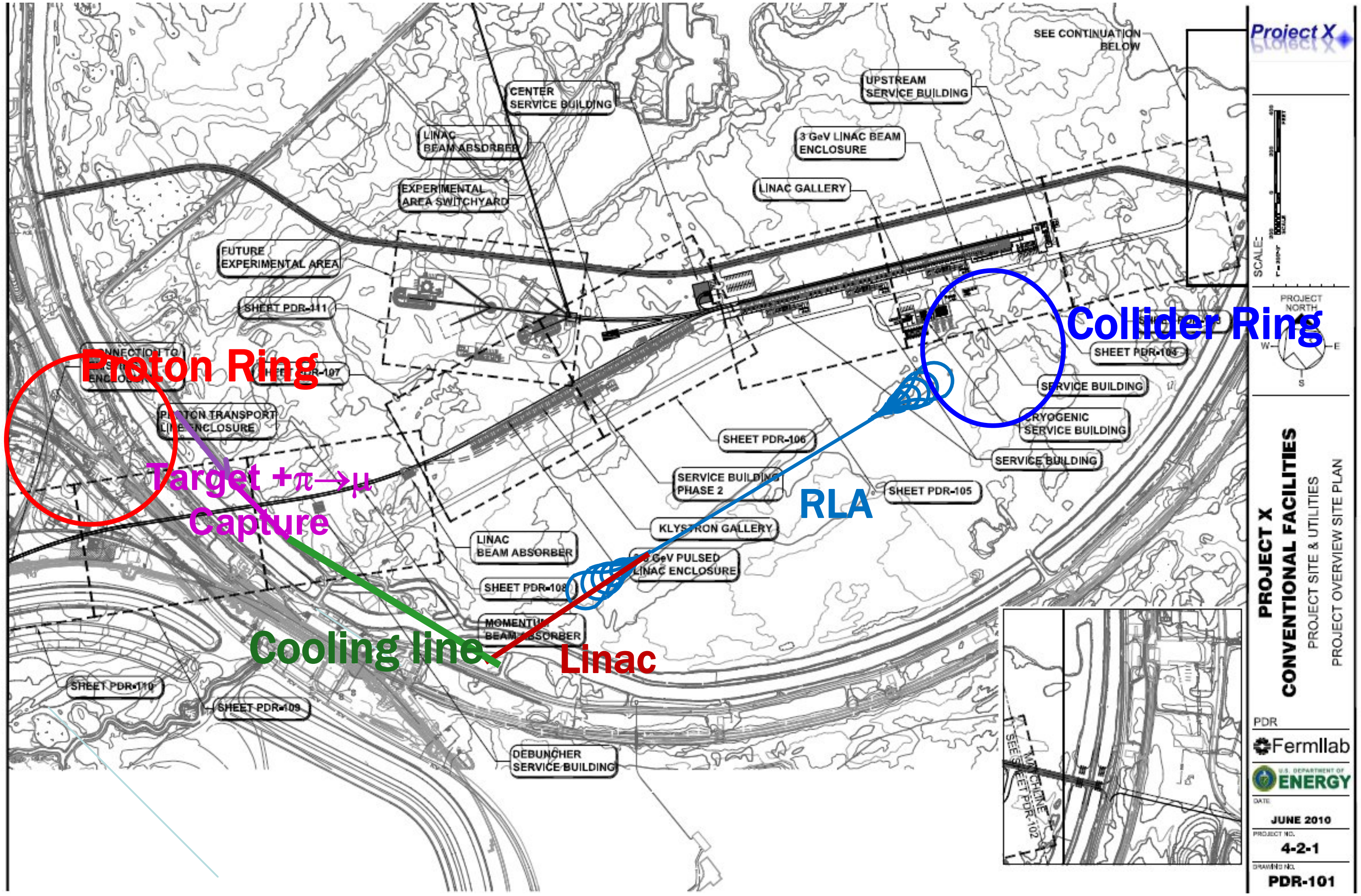
Scale of facility



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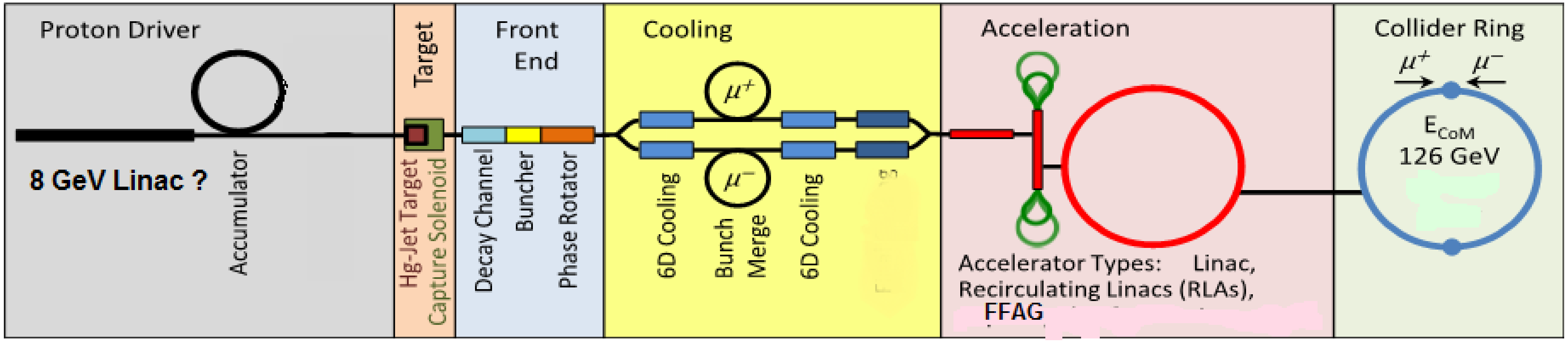
126 GeV μ^+-μ^- Collider

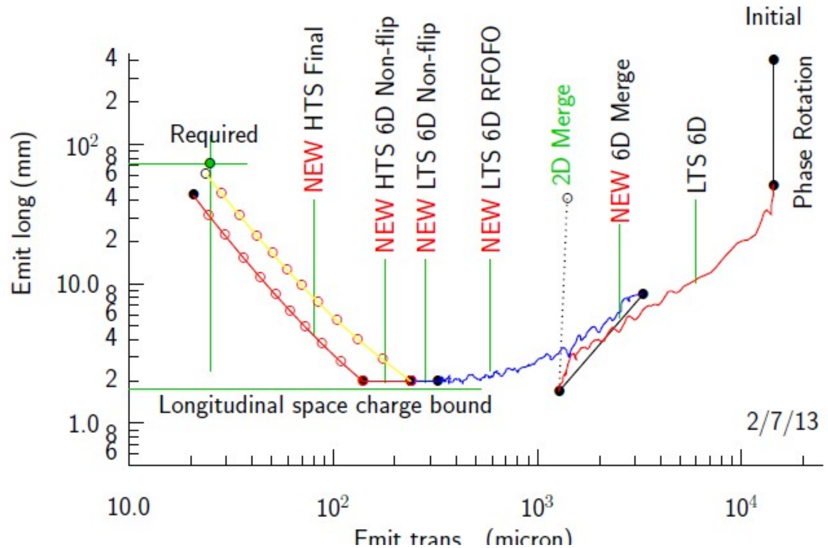
- 8 GeV, 4MW Proton Source
  - 15 Hz, 4 bunches 5×10^{13}/bunch
- $\pi\rightarrow\mu$ collection, bunching, cooling
- ➢ $\varepsilon_{\perp,N}$ =400 π mm-mrad, $\varepsilon_{\parallel,N}$= 2 π mm
- 10^{12} μ/ bunch
- Accelerate, Collider ring
  - δE = 4 MeV, C=300m
  - Detector
  - monitor polarization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

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

Polarization & Energy measurement

Raja and Tollestrup (1998) Phys. Rev. D 58 013005

- Electron energy (from decay) depends on polarization
  - polarization is ~25% → 10%

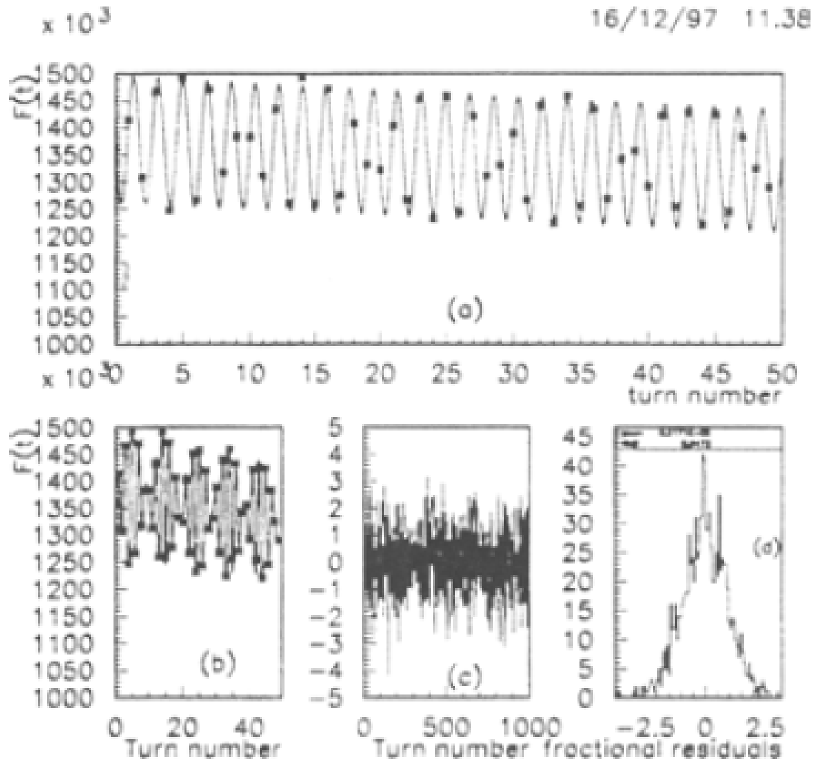
$$< E_{lab} >= \frac{7}{20} E_\mu (1 + \frac{\beta}{7} \hat{P})$$

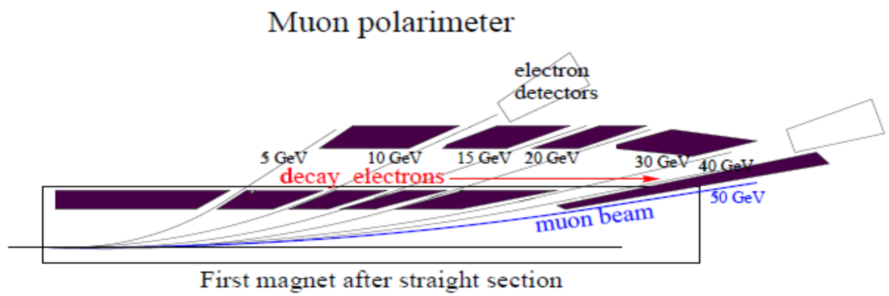
$$E(t) = N e^{(-\alpha t)} (\frac{7}{20} E_\mu (1 + \frac{\beta}{7} (\hat{P} cos\omega t + \phi)))$$

$$\omega = 2\pi\gamma \frac{g-2}{2} = \sim 0.7 * 2\pi$$

  - Measure ω from fluctuations in electron decay energies
- 10^6 decays/m

  <E_μ> depends on Frequency
  - **Frequencies can be measured very precisely**
  - E, δE to 0.1 MeV or better (?)
  - need only > ~5% polarization ?

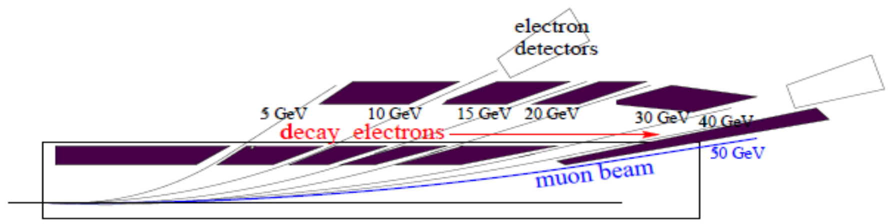




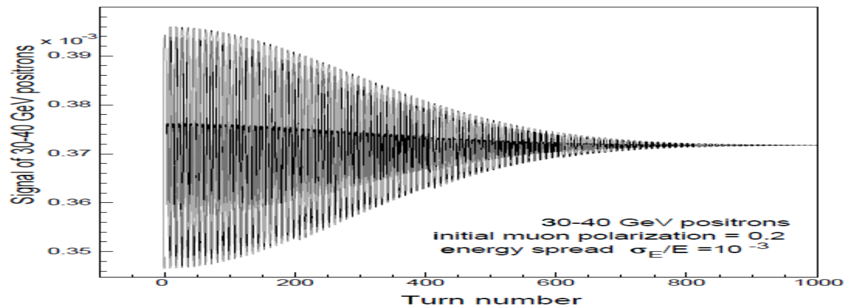
Polarization

- Because the absolute value of the polarization is not relevant, and only frequencies are involved, the systematic errors are very small (~5-100 keV) on both the beam energy and energy spread.
  - A. Blondel

Muon polarimeter



First magnet after straight section



Analyses of such spectra show that for a 50 GeV beam with $\sigma_E/E = 10^{-3}$ and 20% polarization, these parameters can be determined for *each muon fill* with a statistical precision of:

$\Delta E/E = 2 \times 10^{-6}$ ($\Delta E = 100$ keV) for the energy,
$\Delta \sigma_E/E = 2 \times 10^{-6}$ for the relative energy spread,
$\Delta P = 3 \times 10^{-4}$ for the polarization itself.

For a beam-energy spread of $\sigma_E/E = 3 \times 10^{-5}$ these numbers become:

$\Delta E/E = 10^{-7}$ ($\Delta E = 5$ keV) for the energy,
$\Delta \sigma_E/E = 5 \times 10^{-7}$ for the relative energy spread,
$\Delta P = 10^{-4}$ for the polarization itself.

The errors are smaller in this case since the polarization survives longer.

$\gamma\gamma$ Collider as a Higgs Factory

- Advantages:
  - Allow access to CP property of the Higgs
  - Lower beam energy (80 GeV per e- beam to generate 63 GeV γ beam)
  - High polarization in the colliding γ beams
  - No need for e+ beam
  - 160 GeV e- linac has a lower cost w.r.t. a 240 GeV linear e+e- collider
  - Can be added on a linear e+e- collider
- Challenges:
  - Physics not as comprehensive as a 240 GeV e+e- collider would be.
  - Background problem
  - IR design
  - No comprehensive study.; design study report needed.
- Specific issues:
  - ILC-based
    - Optical cavity
  - CLIC-based
    - Laser can piggy-back on the Livermore LIFE fusion project. (But the project schedule is unknown.)
  - Recirculating linac-based:
    - Polarized low emittance e- gun

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Original Paper on $\gamma\gamma$ Collider

Production of high-energy colliding $\gamma\gamma$ and γe beams with a high luminosity at VLÉPP accelerators

I. F. Ginzburg, G. L. Kotkin, V. G. Serbo, and V. I. Tel'nov
Institute of Nuclear Physics, Academy of Sciences of the USSR, Siberian Branch

(Submitted 10 March 1981; resubmitted 14 September 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **34**, No. 9, 514–518 (5 November 1981)

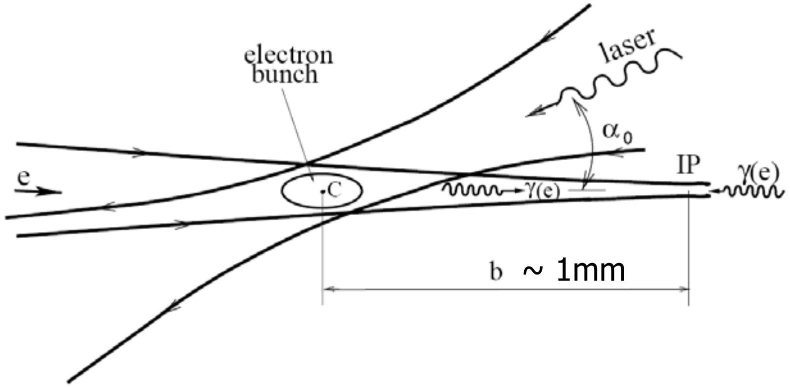
Colliding $\gamma\gamma$ and γe beams with an energy and luminosity of the same order of magnitude as for e^+e^- beams can be produced by scattering a laser light at the accelerators with colliding e^+e^- beams with an energy $\gtrsim 100$ GeV. Such accelerators are currently in the design stage.

PACS numbers: 29.25.Fb, 29.25.Bx

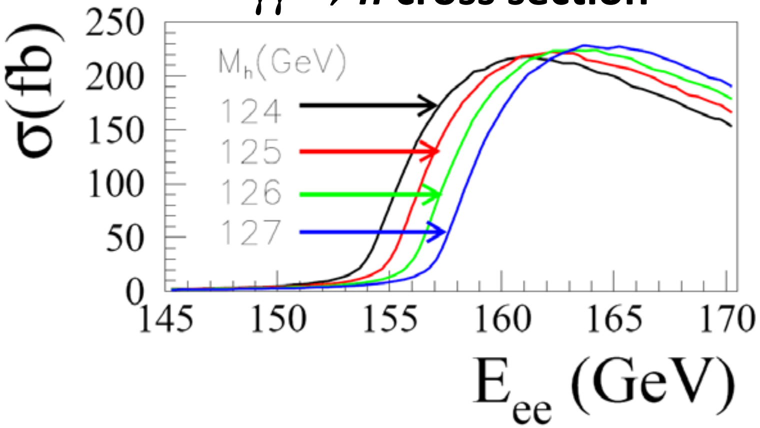
1. The reactions $\gamma\gamma \to$ hadrons and $\gamma e \to e +$ hadrons, which are studied at linear accelerators with e^+e^- beams in the collision of virtual photons, have recently attracted considerable interest.[1] In this letter we show that direct $\gamma\gamma$ and γe collisions with a high energy and luminosity can be used to study these reactions.

It is clear that colliding e^+e^- beams with an energy $E \gtrsim 100$ GeV can be produced only at linear accelerators.[2] Such accelerators are currently in the design state in Novosibirsk [(VLÉPP, $E = 100$–300 GeV (Ref. 2)] and in the U.S.A. [SLAC Linear Collider (SLC), $E = 50$ GeV (Ref. 3)]. The fundamentally new feature of these accelerators is that their $e^\pm$ beams are used only once [at a low repetition rate $\nu = 10$ Hz (Ref. 2) or 180 Hz (Ref. 3)]. If a large fraction of electrons are converted to photons, then the luminosity of $\gamma\gamma$ or γe collisions produced in this manner will be close to that of the e^+e^- collisions, $L_{ee} \sim 10^{32}$ cm^{-2} sec^{-1}. This simple concept is the basis of our study (see Ref. 4).

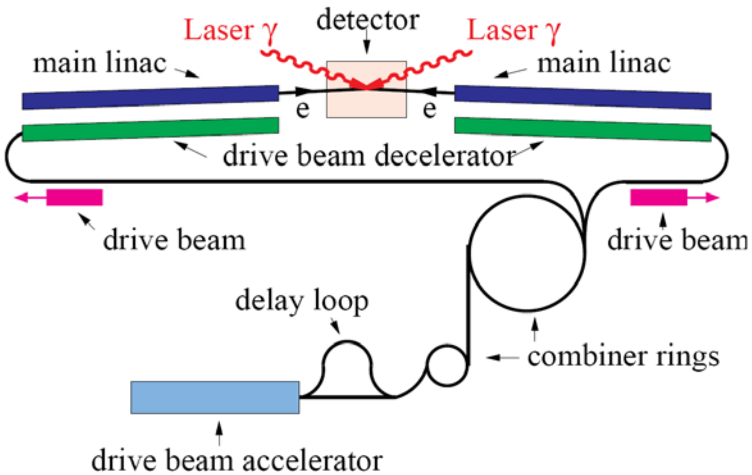
$\gamma\gamma$ Collider as a Higgs Factory



$\gamma\gamma \rightarrow h$ cross section



CLIC-based



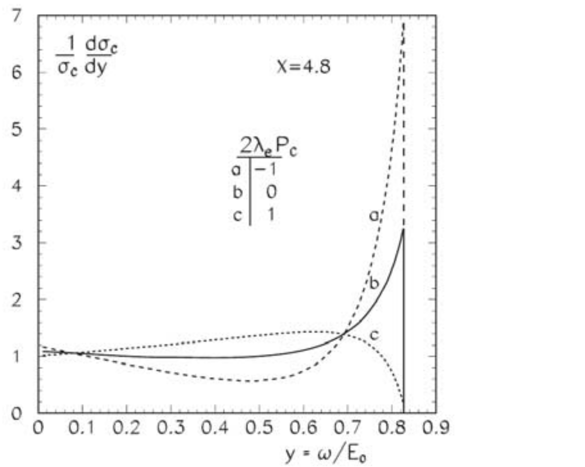


Figure 1.3.1: *Spectrum of the Compton scattered photons for different polarisations of the laser and electron beams.*

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

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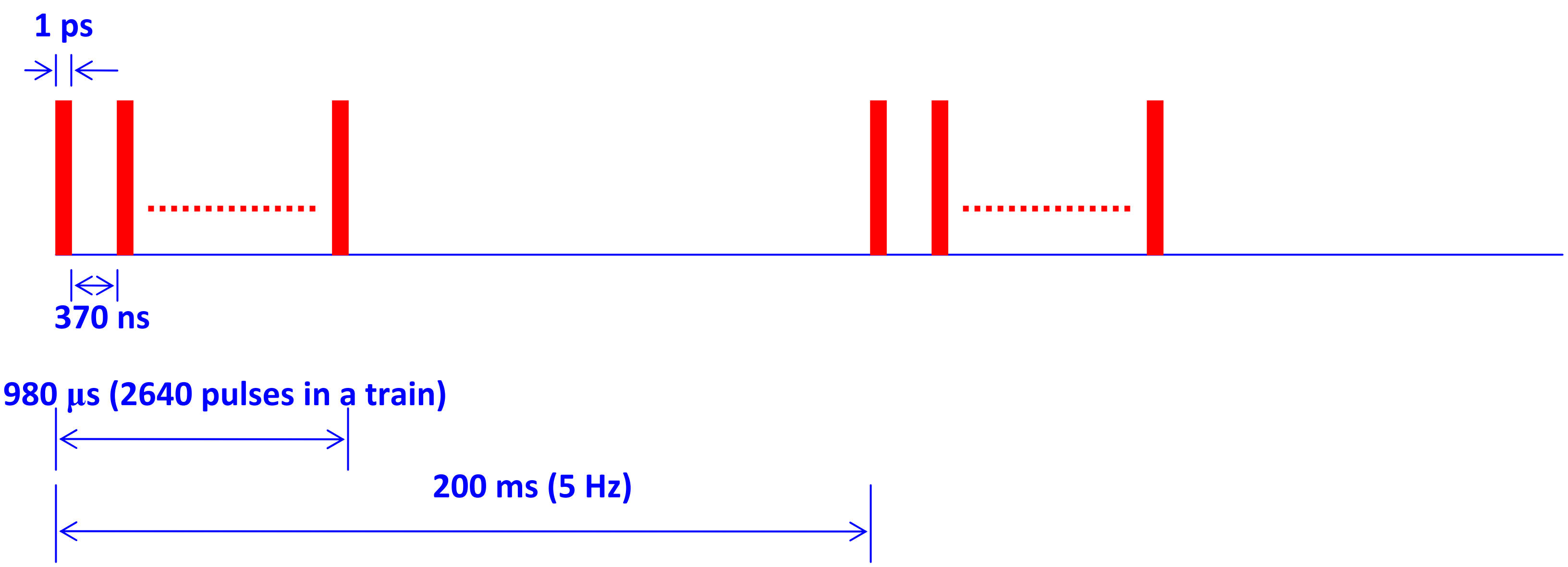
Issues for $\gamma\gamma$ colliders

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

- Lasers

ILC-based $\gamma\gamma$ Collider



Laser Requirements

Pulse width	Pulse energy	Pulse spacing	No. pulses in a train	Laser power in a train	Laser average power	Rep rate	Wavelength	Spot size	Crossing angle
1 ps	10 J /Q	370 ns	2640	25 MW /Q	150 kW /Q	5 Hz	1 µm	120 nm x 2.3 nm	25 mrad

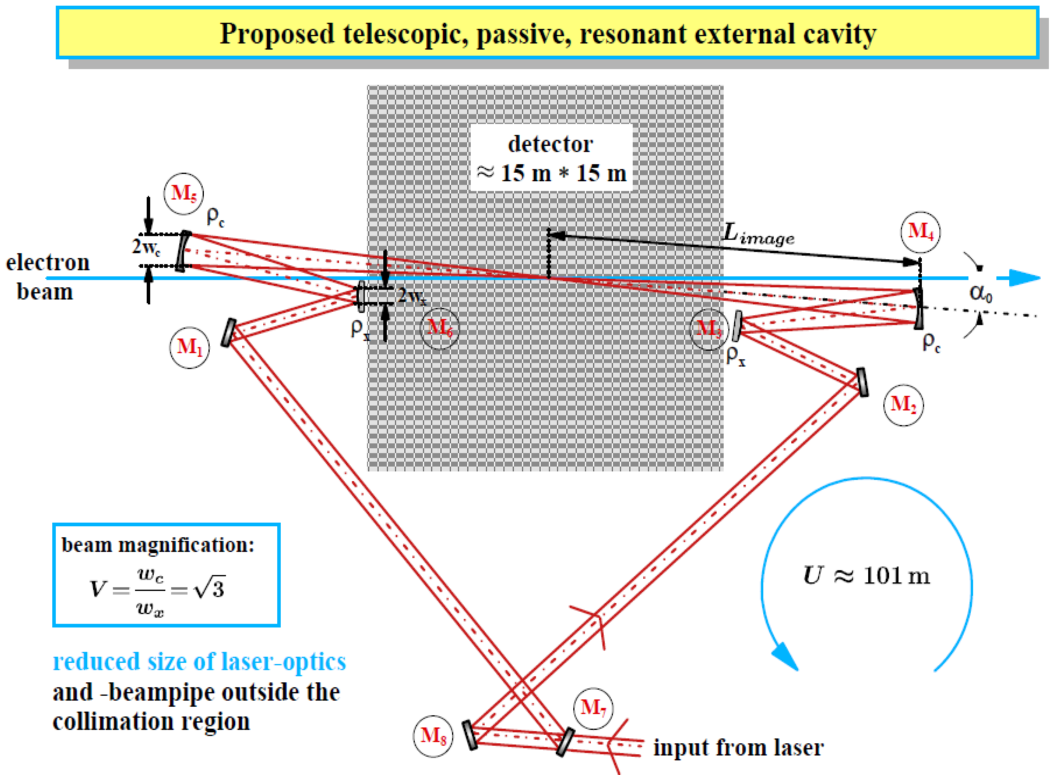
Need an optical cavity with Q ~ 300

Pulse Stacking Cavity for ILC

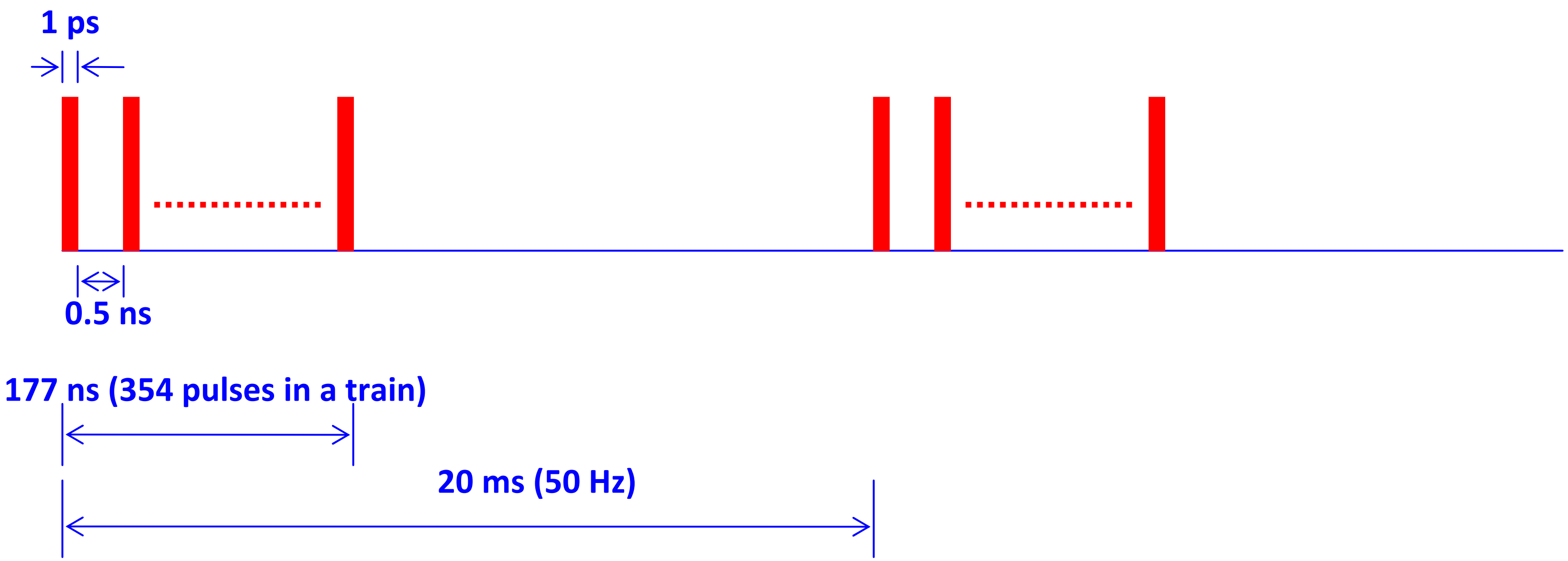
- total length ~100m
- power enhancement ~100

- L =nλ
- dL<< λ/enhancement

- mode locked pulsed laser 100MHz 0.1J/pulse



CLIC-based γγ Collider



Laser Requirements

Pulse width	Pulse energy	Pulse spacing	No. pulses in a train	Laser power in a train	Laser average power	Rep rate	Wavelength	Spot size	Crossing angle
1 ps	5 J	0.5 ns	354 (5 x 354 = 1770 J per train)	10 GW	88.5 kW	50 Hz	1 μm	120 nm x 2.3 nm	25 mrad

Livermore LIFE fusion project laser beam: 130 kW average power, 8100 J / pulse, 16 Hz (LIFE would have 384 such beams)

N

LIFE

Conclusion

- A baseline LIFE design and review is complete
  - Detailed designs and experimental benchmarking are underway
  - A subscale beamline is expected to be produced in the next few years
- Full scale beamlines (with associated cost reductions) are contingent on NIF ignition and the instantiation of the LIFE program
- LIFE laser 130 kW average power could be modified for CLIC based g-g pulsetrains
  - The LIFE pulsetrain is 8.1 kJ pulses at 16 Hz.
  - CLIC based pulsetrains are 3X LIFE repetition rate, but 4.6X lower energy
  - Minor modifications would be needed to accommodate the change of pulse format

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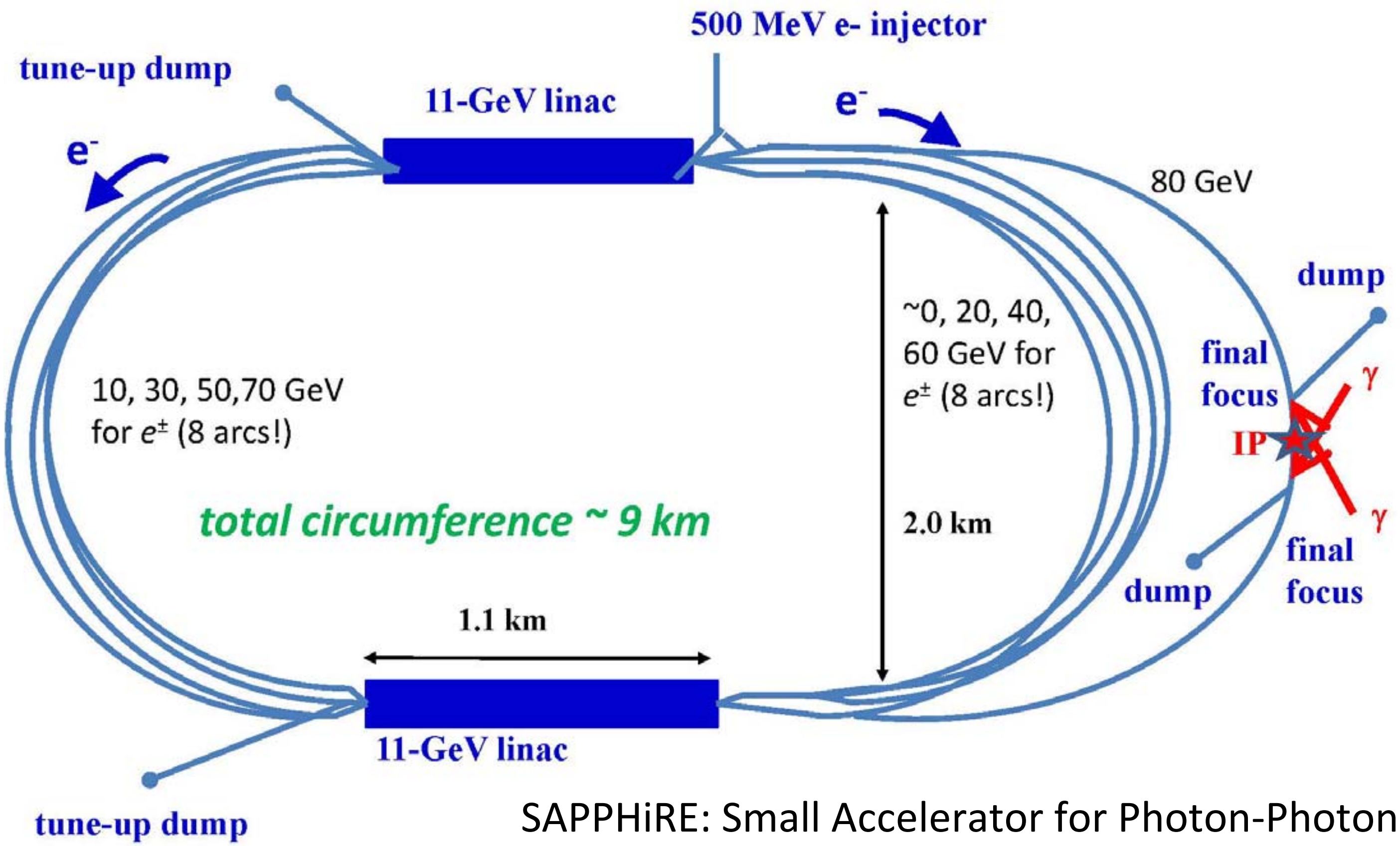
SAPPHiRE: a Small $\gamma\gamma$ Higgs Factory



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

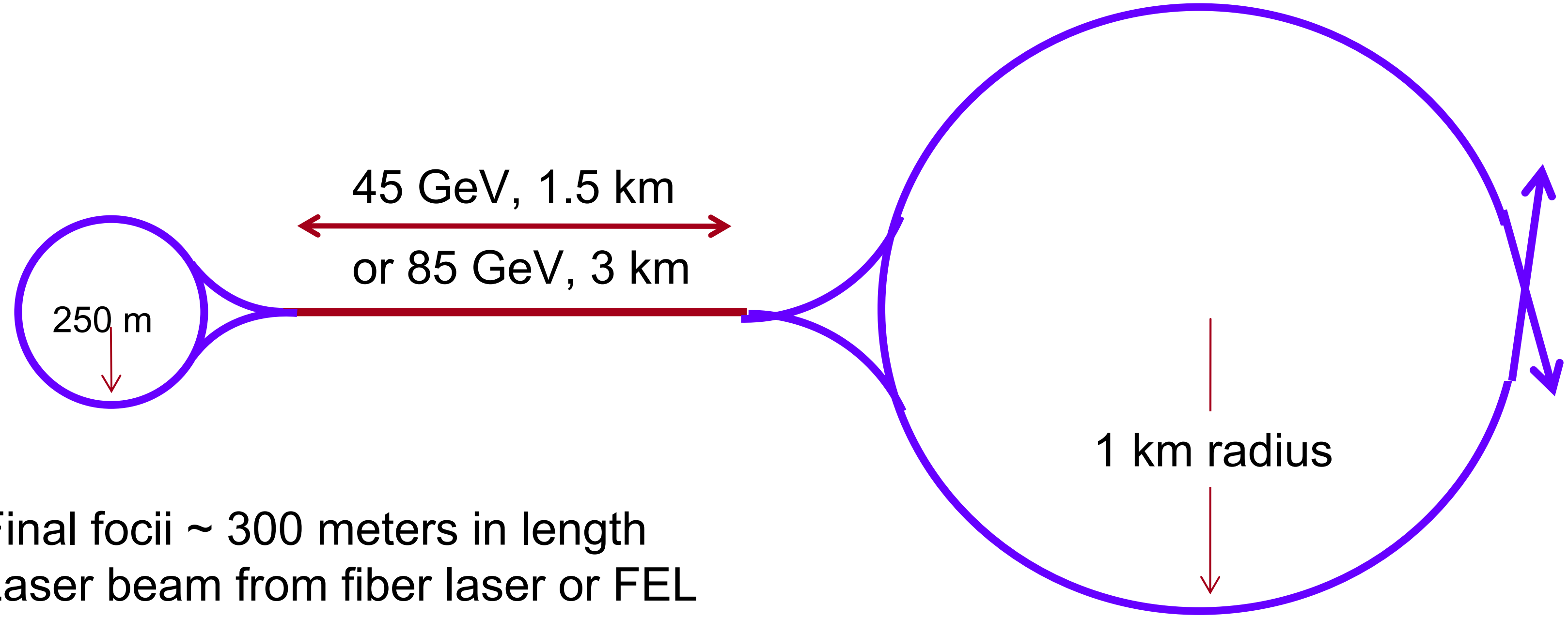
Problems:

- Photon collider needs polarized electron beams with low emittances, such RF photoguns do not exist yet (so, one needs damping rings).
- Gamma-gamma collider can not measure all Higgs properties, e+e- collisions are needed.

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
2 x 85 GeV is sufficient for $\gamma\gamma$ collider
Upgrade with plasma afterburners to reach 2 x 120 GeV. Then final ring should have R=3.5 km (to preserve emittance).

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What's Next? (after HF2012)

- The Organizing Committee will write a workshop report:
  - Higgs physics: What the LHC can do? What a Higgs factory can do for given energy and luminosity (e^+e^-, $\mu^+\mu^-$, $\gamma\gamma$)?
  - Performance, technology maturity and readiness, upgrade potential, and technical challenges requiring further R&D for each type of Higgs factory
  - Comparison tables
  - An Executive Summary
- Target readers:
  - Joint ICFA – Lab Directors meeting (February 21-22, 2013 at TRIUMF)
  - US Snowmass 2013 conference (July 29 – August 6, 2013 at Univ. of Minnesota)
  - European Strategy Updates meeting (January 21-22, 2013)
  - HEP roadmap study in Asia (Japan and China)
  - World HEP and accelerator communities (report to be published in the *ICFA Beam Dynamics Newsletter* no. 60, April 2013)
- Target date for completing the report:
  - January 15, 2013
- The organizing committee recommends these studies should continue. It also believes this workshop provides a good platform for the international community to get together for discussions of a future Higgs factory and should also continue. The next workshop will be about one year from now. The place and dates are yet to be decided. Stay tuned!

Conclusion

❖ A Higgs factory is needed for precision measurement of the Higgs properties. Most probable candidates:

Linear e+e- Collider (2E=240-350 GeV)
Ring e+e- Collider (2E=240-350 GeV, depending on R)
Muon collider (2E=126 GeV)
$\gamma\gamma$ collider, only as add-on to e+e-.

❖ The choice depends on LHC discoveries:

If new physics (like SUSY, etc) exists in 200-1000 GeV region, then ILC or CLIC.

If new physics exist in 1000-3000 GeV region, then CLIC.

If nothing, except H, is found, then a low energy e+e- Higgs factory, ring or LC. Ring Higgs factory with large R looks very attractive.

❖ Muon collider is always welcome (as potentially a highest energy collider)