Overview of Accelerators as Higgs Factories

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2012.10.24 LCWS12, Arlington, Texas

thanks to Mark Palmer (muon), Valery Telnov (ring, $\gamma\gamma$)

Possible Higgs Factories

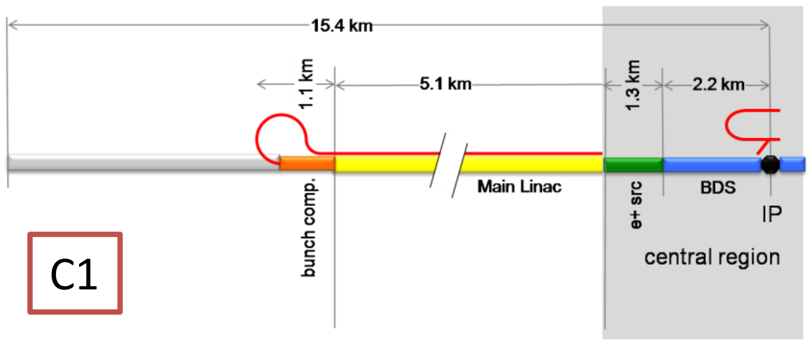
- e^+e^- LC
  - ILC
  - CLIC
  - NLC/GLC-type (klystron-based normal-conducting LC)
- e^+e^- Ring Colliders
  - Ring Colliders
    - LEP3, TLEP, SuperTRISTAN, FNAL site filler, ...
- $\mu^+\mu^-$ Collider
- γ-γ Collider
  - SC Linac-based
    - ILC-based
    - Recirculating linac
  - NC Linac-based
    - CLIC-based
    - NLC/GLC-type
    - SLC-type

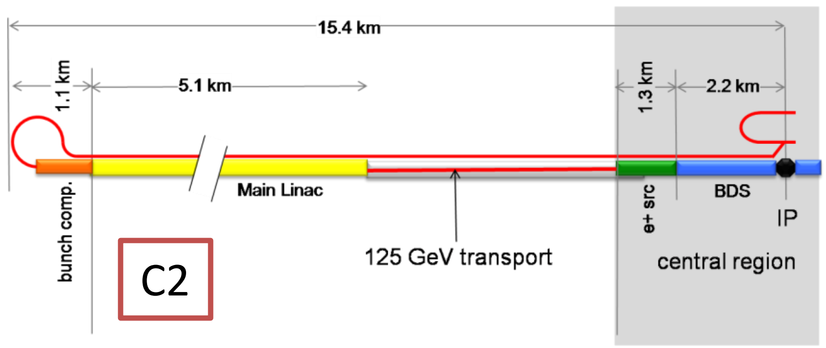
ILC Higgs Factory

- Yesterday’s 2 hour session
- Technology is obvious
  - (except positron)
- The only concerns are
  - cost
  - staging
- Staging scenario
  - A) 500GeV machine
  - B) just enough 250GeV machine
  - C) 250GeV machine in 500GeV tunnel

ILC Staging

- choices for the first stage
  A) 500GeV machine
  B) just enough 250GeV machine and tunnel
  C) 250GeV machine in 500GeV tunnel
    C1) Fill downstream of 500GeV tunnel
      must move turnaround in upgrade, but installation done in parallel
    C2) Fill upstream of 500GeV tunnel





Summary

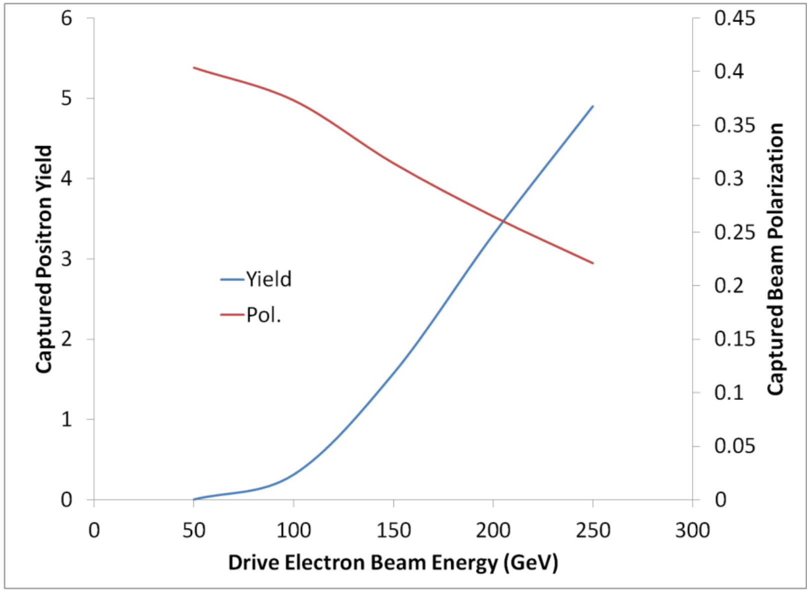
Nick Walker, Yesterday

		TPC	MW
B	Minimal Higgs Machine	67%	120
C1	Full tunnel scenario 1	73%	120
C2	Full tunnel scenario 2	75%	125
	Remove 10-Hz op.	-3%	-25

Warning!
Approximate Scaling Only!
Highly likely to change

ILC Positron

- Production yield low at E_e < 150GeV
- 10Hz scheme in the baseline design
  - 150/125GeV alternating operation of electron linac
  - technically no problem
  - but not elegant
  - construction of extra 25GeV linac plus additional DR RF (cost ~3%)
  - higher power consumption



ILC Positron -- Solutions

- Asymmetric collider?
  - 150x105 GeV instead of 125x125 GeV
    - Physics study needed
- Conventional source?
  - Consistent design exists
  - No positron polarization
- The elegant solution is shorter-pitch undulator but the technology is still far
  - Nb3Sn
  - RF undulator ?

BUT acccording to yesterday's session (Wei & Wanming)

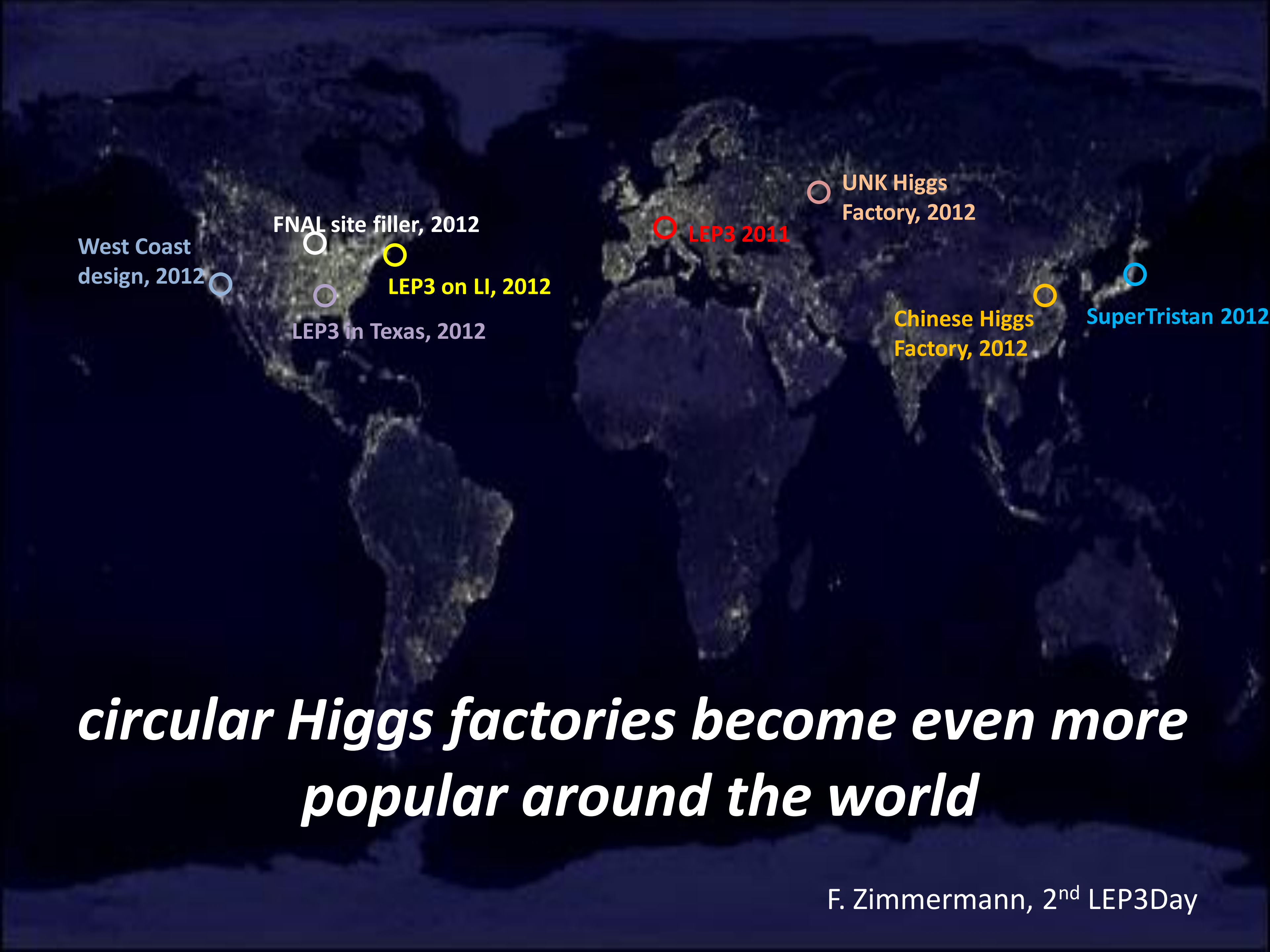
- Use longer undulator (+100m) using the space reserved for polarization collimator
- positron yield ~ 1.5 at E_e = 125 GeV
- Energy loss 3.6GeV (← 3GeV in baseline)
- PEDD on target 1.5 times higher than in baseline but still lower than in RDR
  - Owing to the bunch number reduction 2625→1312
  - So, cannot double the number of bunches, presumably.

CLIC

- technology obvious (same as 500GeV)
- Not large differences from ILC in the beam parameters
- maturity of technology is an issue for early start
- staging
  - start at E_{cm}=350 ?   (← physics)
  - Possible use of X-band klystron in the first stage (D.Schulte, this WS)
    - technology mature.
    - choice of cavities
    - cheaper?

e^+e^- Ring Colliders

- Lots of proposals since LEP3 proposal
- Except for the local issues
  - Can be accommodated in existing tunnel? (LHC)
  - If new tunnel, does it fit with future plans of the lab? (LHeC, HELHC, VLHC, etc)
- Problems are common to all the proposals
- The only parameters are
  - Ring size
  - site power limitation



circular Higgs factories become even more popular around the world

F. Zimmermann, 2nd LEP3Day

Proposed Ring Colliders

- Several authors suggested possibilities of e+e- ring colliders for Ecm>200GeV.
  A) T.Sen, J.Norem, Phys.Rev.ST-AB 5(2002)031001
     C=233km tunnel for VLHC
  B) A.Blondel and F.Zimmermann, CERN-OPEN-2011-047, Jan.2012 (Version 2.9). arXiv:1112.2518. Also IPAC12 TUPPR078.
     LEP3, DLEP.
     LEP3Day June 18. 2nd LEP3Day Oct.23 (**yesterday!**)
  C) K.Oide, "SuperTRISTAN: A possibility of ring collider for Higgs factory", KEK meeting on 13 Feb 2012.
     SuperTRISTAN
  D) G.Lyons, arXiv:1112.1105 [physics.acc-ph], Feb.2012.
     PhD thesis. Nanobeam version of A)
     IPAC12 TUPPR008
  E) D.Summers, et.al. “Rapid Recycling Magnets - Tests & Simulations”, Muon Accelerator Program 2012 Winter Meeting, 4-8 Mar.2012.
     SLAC. Small ring version of D)
     See also IPAC12 TUPPR008
- There seems to be more: China, etc.

Ring Collider Proposed Parameters

Name		LEP2 for comparison	LEP3	TLEPt	SuperTRI STAN	CW250	Summers
Circumference	km	26.7	26.7	80	60	233	15.00
Beam energy	GeV	104.5	120	175	200	250	120
Bunch population	10^10	57.5	100	75	249.2	48.5	48.5
Number of bunches/beam		4	4	12	1	41	3
Number of IP		4	2	2	1	1	1
Bunch collision frequency	kHz	44.91	44.91	44.97	5.00	52.75	65.10
geo.emit(x)	nm	48	25	20	3.2	3.6	3.6
geo.emit(y)	nm	0.25	0.1	0.1	0.017	0.00022	0.00099
betax	mm	1500	200	200	30	20	20
betay	mm	50	1	1	0.32	0.6	0.6
sigx	micron	268	71	63	9.8	8.5	8.5
sigy	micron	3.536	0.32	0.32	0.0738	0.0244	0.0244
sigz	mm	16.1	2.3	2.5	1.4	6.67	6.67
half.cross.angle	mrad	0	0	0	35	17	34
bending radius	km	3.096	2.62	9	7.65	29	1.9
radiation loss/turn	GeV	3.408	6.99	9.3	18.5	11.9	9.7
Damping partition		1.1	1.5	1	2	2	2
radiation power (2beams)	MW	22	100	100	74	98	98
Tune shift/IP (x)		0.025	0.09	0.05	0.017	0.0007	0.0014
Tune shift/IP (y)		0.065	0.08	0.05	0.155	0.23	0.2
Equilibrium energy spread	%	0.22	0.23	0.22	0.196	0.126	0.236
Luminosity per IP	10^34	0.0125	1.07	0.65	5.2	7.6	4.4

Data taken from the papers in red in the prewvious page

(yellow) Not given in the reference. Computed from other values

(blue) Not given in the reference. Assumed.

Common Features of e^+e^- Ring Colliders

- High luminosity ~10^{34} $cm^{-2}s^{-1}$ causes short beam life time due to radiative Bharbha scattering
  - ➢ Top-up injection needed
  - ➢ one more ring
- Bunch collision frequency (5-50kHz) much lower than in B factories (10-100MHz)
  - – because synch.rad.power must be reduced
    → reduce total current , keeping luminosity
    → increase bunch charge & decrease # of bunches
  - – hence, LC-like collision frequency and bunch charge
    → beamstrahlung similar to LC

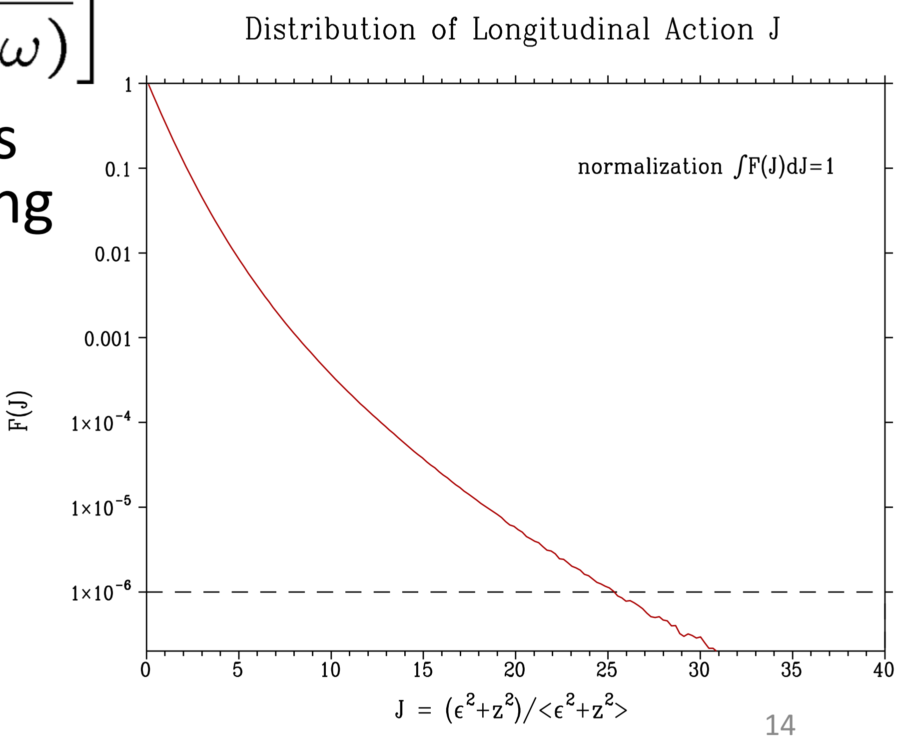
Limitation of e⁺e⁻ Ring Colliders

- Beamstrahlung at high-energy tail causes significant energy loss of electrons/positron

$$\Upsilon_{max} \approx \frac{2Nr_e^2\gamma}{\alpha\sigma_z(\sigma_x+\sigma_y)}$$

$$\frac{dW}{d\omega} \propto \exp\left[-\frac{2\omega}{3\Upsilon(E_e-\omega)}\right]$$

- Particles with large energy loss cannot circulate around the ring (momentum band-width)
- Affects the beam life time
- Hence, ring colliders are much more fragile than LCs against beamstrahlung

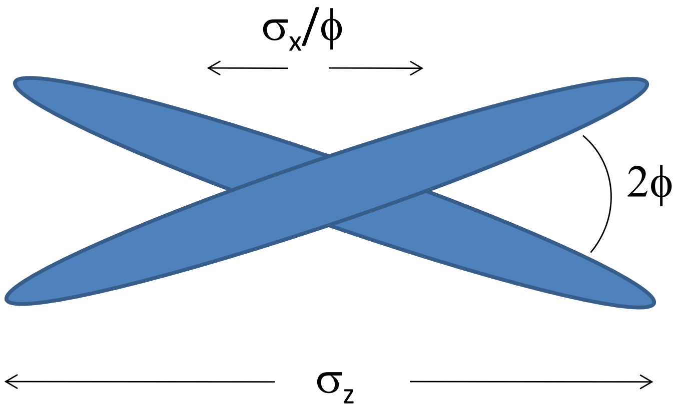


Nanobeam Scheme (or Crab Waist)

- large crossing angle >> σ_x/σ_z

  (no crab cavity compensation)

- merits
  - effectively short bunch without using high RF voltage
  - this makes smaller beta possible
- proposed in C)D)E)
- But does not help in solving the beamstrahlung issue



Luminosity Scaling of e^+e^- Ring Colliders

V. Telnov, arXiv:1203.6563v, 29 March 2012

- For given Upsilon, the momentum band width must be

$$\eta \equiv [\Delta p/p]_{max} \gtrsim 15\Upsilon$$

- Then, the luminosity at beamstrahlung limit and tune-shift limit is given by

$$\mathcal{L} \propto \frac{\rho P_{SR}}{E^{13/3}} \left(\frac{\xi_y \eta^2}{\varepsilon_{g,y}} \right)^{1/3}$$

P_{SR} : syn.rad.power

ρ : bending radius

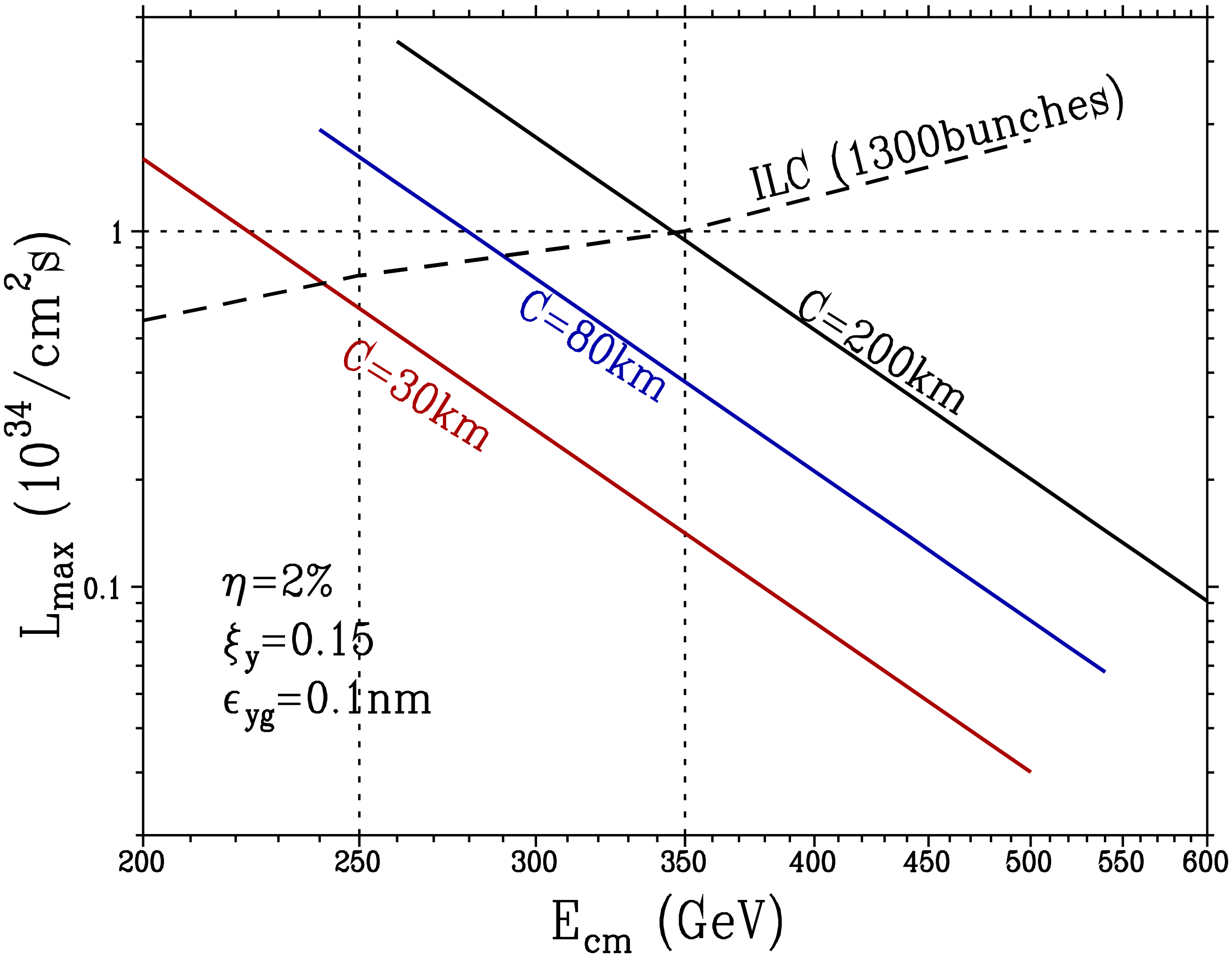
ξ_y : tune-shift

$\varepsilon_{g,y}$: geometric emit.

Luminosity vs. Energy

example with

- η=2%
- ξ_y=0.15
- ε_{gy}=0.1nm



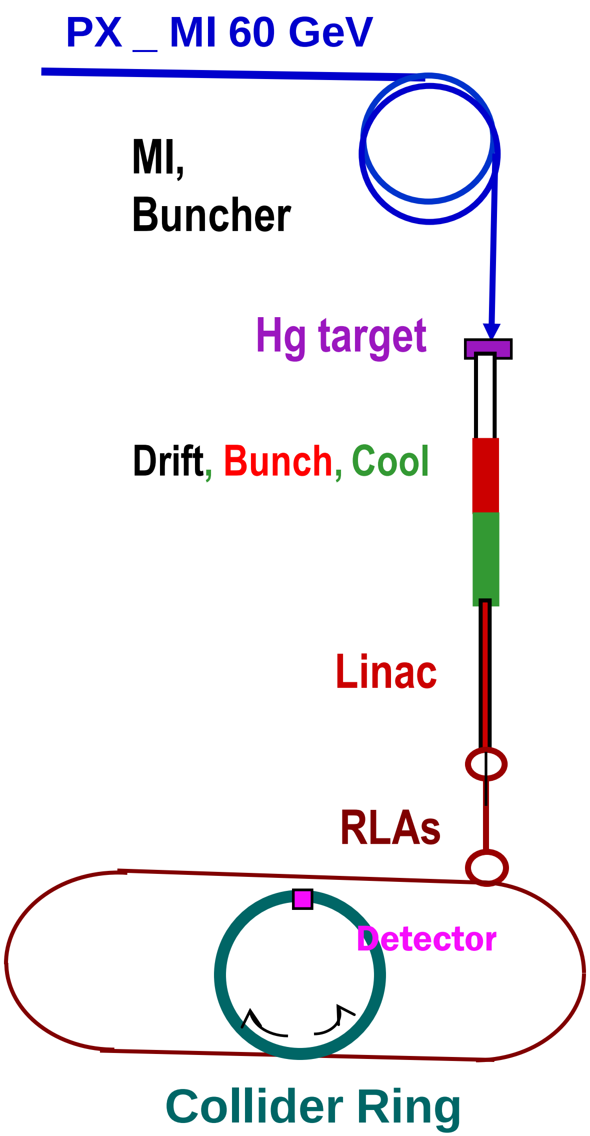
R&D Items of Ring Colliders

- Momentum band-width
  - bucket height must be > η (OK with a bit higher V_{RF})
  - arc is OK (light sources accept > 4%)
  - FFS is not easy
    - chromaticity $L^*\eta/\beta_y^*$ larger than existing covery
    - synchrotron oscillation should be included (very rapid)
    - 2% is perhaps feasible (non-educated guess)
- Vertical emittance
  - light sources can reach ε_{gy} ~ 1pm at low energy
  - but colliders at high energy?
  - still far above the fundamental limit due to radiation opening angle ($1/\gamma$)
  - but ref D)E) assume too small emittance
- Synchrotron radiation power O(100MW)
  - 4x LEP2

Muon Collider

- s-channel Higgs production
  - σ~40pb, Γ~4MeV
  - L~10^{31} sufficient if beam energy spread is small enough
- Possibility of $\mu^+\mu^- \rightarrow Z$ suggested since the very beginning of muon collider study

Higgs MC Parameters

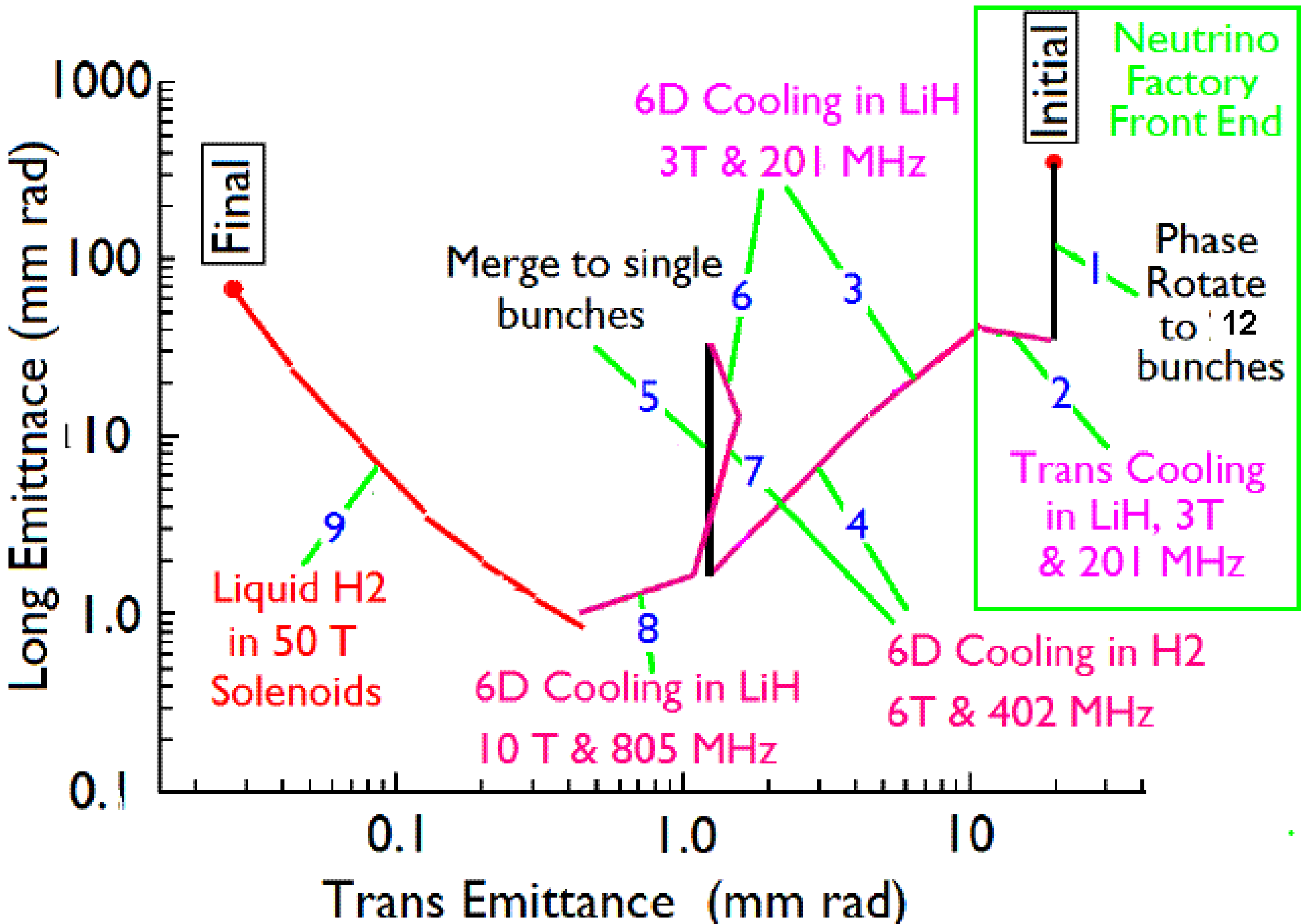


D.Neufer, Nufact July 2012

Parameter	Symbol	Value
Proton Beam Power	P_p	2 MW
Bunch frequency	F_p	15 Hz
Protons per bunch	N_p	10^{13}
Proton beam energy	E_p	60 GeV
Number of μ bunches	n_B	1
$\mu^{+/-}$/ bunch	N_μ	2×10^{12}
Transverse emittance	$\varepsilon_{t,N}$	0.0005m
Energy spread	δE	2MeV
Collision β^*	β^*	0.05 m
Collision β_{max}	β^*	1000m
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
Collision Beam Energy	$E_{\mu+},E_{\mu\_}$	62.5GeV (125GeV total)
Storage turns	N_t	1000
Luminosity	L_0	10^{31}

Required Cooling

- The last step (transverse cooling in very high field) for TeV collider is not needed.
- Longitudinal emittance is more important for Higgs



Muon Collider as a Higgs Factory

- Most key facilities for TeV collider are needed for Higgs factory except the last cooling
  - Proton driver of several MW
  - Target at several MW
  - Ionization cooling
    - ~10^6 in 6D emittance, 10^3 in ε_L to ~1mm.rad
  - collider ring issues (muon decay, etc)
- Will require tens of years of R&D
- Cost is not cheap

Gamma-Gamma Colliders

Common features

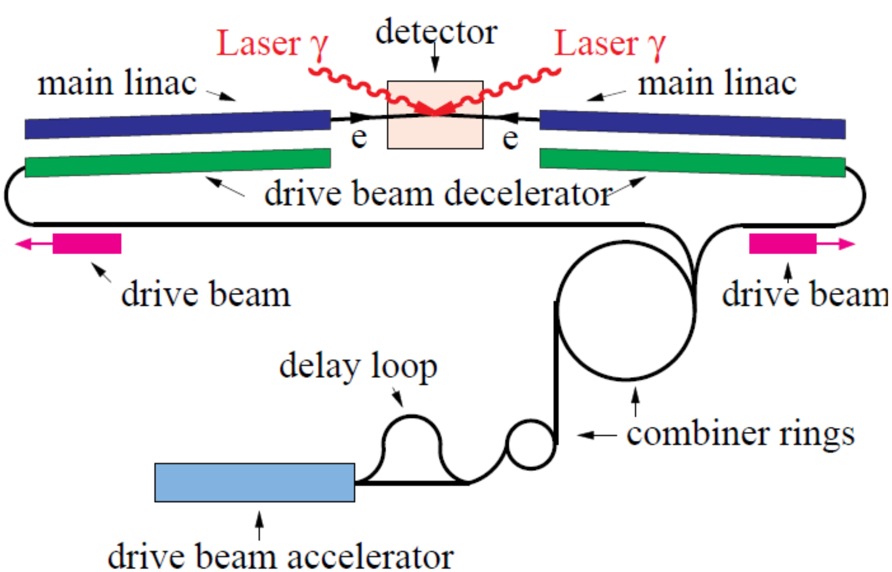
- convert e^- into γ just before IP by laser-Compton scattering
- positron is not needed
- maximum photon energy

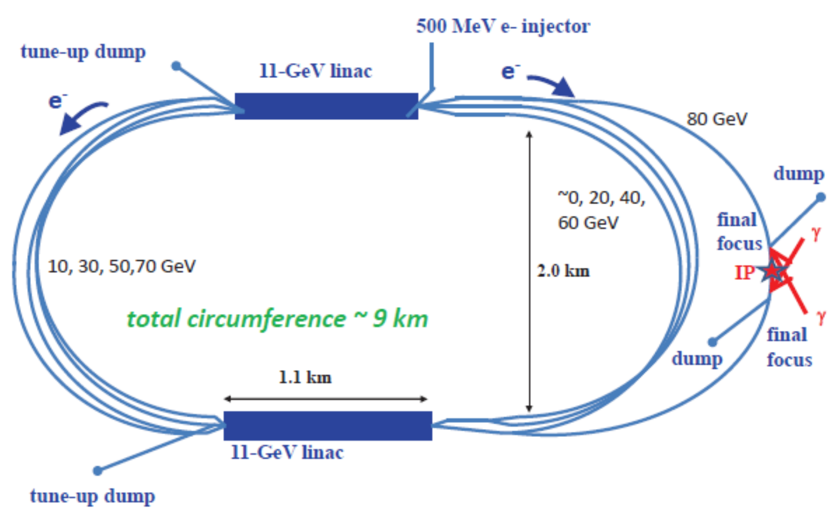
$$\omega = \frac{x}{1 + x + \xi^2} E_e, \qquad x \equiv \frac{4 E_e \omega_L}{m^2}$$

- Optimum laser wavelength $\lambda = \lambda_0$
  λ_0 = 1μm * (E_e /250GeV) corresponding to x=4.83
  - pair creation starts if $\lambda < \lambda_0$
  - photon energy lower if $\lambda > \lambda_0$
- required laser flush energy to convert most of the electrons is a few (5-10) Joules
  (weakly depends on electron bunch length)

Lowest energy Higgs factory

- 80GeV e- on 80GeV e- converted by laser with x=4.83 gives 66GeV on 66 GeV γ-γ collider
  (lowest energy to produce H except muon collider)
- "precursor" to e^+e^- linear collider
  (H. Sugawara, 2009)
- CLICHE (2003)
- SAPPHiRE (2012)





Laser Technology for γ-γ

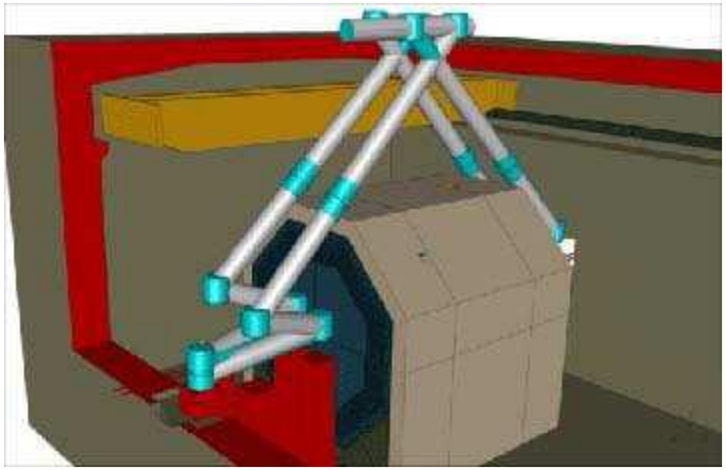
- Classified into two categories according to the required pulse configuration
  - NC linac based (CLIC, CLICHE, NLC/GLC-type, SLC-type)
    - bunch distance O(ns)
    - pulse length O(μs)
    - repetition rate O(100Hz)
  - SC linac based (ILC, SAPPHiRE)
    - bunch distance O(0.1-1 μs)
    - pulse length O(ms)
    - repetition rate O(10Hz)
- In both cases
  - Required laser flush energy several Joules
    → Use of FEL is presumably unrealistic
  - Laser bunch length a few ps
    - laser peak power ~1TW

NC Linac Based γ-γ

- Beam train is too short for the accumulation by optical cavities
- Required laser energy per e^- beam pulse = a few kJ
- Diode-pumped laser will be ready in the near future (e.g. LIFE project for laser fusion)
  - Need a technology to divide a pulse into several hundred bunches → can be done
  - ICFA-ICUIL white paper http://www-bd.fnal.gov/icfabd/WhitePaper_final.pdf (Beam Dynamics News Letter 56)
- Cost ? $100M?
- V.Telnov proposed FEL-pumped solid state laser in LCWS2010 (CERN)

SC Linac Based γ-γ

- Can use enhancement by optical cavity
  - SAPPHiRE : too large bunch distance (1.5km) but can still use optical cavity
- Laser
  - average power of drive laser = 100W to 1kW
  - Not too far
- Optical cavity
  - required Q = O(1000)
    - ✓ available
  - path length =O(100m)
    - ✓ O(1m) available
  - stored energy = O(10J)
    - ✓ only O(1mJ) available
  - Need intensive R&D
    - first stability control
    - then, high power
    - proposed at ATF but need strong push



Gamma-Gamma General Status

- γ-γ technology is still premature
  - need > 5 years of R&D
- Cannot start with γ-γ at the lowest energy if early start is planned
  - need 100% confidence at the time of project approval
- From technology view point it is reasonable to start with e^+e^- at ZH and, if needed, convert to γ-γ later
  - importance of γ-γ must be evaluated before the construction of e+e- (possible constraints in IR, e.g., the crossing angle)

(personal) Conclusions

- ILC/CLIC Higgs factory are obvious if 500GeV is feasible
  - cost and staging issues
  - CLIC has maturity problem for early start
- e^+e^- Ring Colliders
  - Technology not trivial
    - Good exercise of accelerator physics (till an LC starts)
  - LEP3 (27km, 240GeV) & TLEP (80km, 350GeV) are just at the border of feasibility
  - Can be a choice if higher energy with e^+e^- is not needed at all
- γ-γ Colliders
  - technology immature
  - good target as a second stage of linear colliders
- Those who are not satisfied with personal conclusions, go to FNAL ➔

HF2012
Accelerators for Higgs Factory

- Nov.14-16 FNAL
- concentrate on accelerators
- http://conferences.fnal.gov/hf2012
- Program

Nov.14	AM	Introduction and physics
(Wed)	PM	e+e- Linear Colliders
Nov.15	AM	e+e- Ring Colliders
(Thu)	PM	
Nov.15	AM	e+e- Ring Colliders and muon collider
(Fri)	PM	γ-γ colliders and summary