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European Coordination for Accelerator Research and Development

**PUBLICATION**

# SAPPHiRE and LHeC

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07 December 2012

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EuCARD-PRE-2012-006

# SAPPHiRE & LHeC

Frank Zimmermann

HF2012, FNAL, 16 November 2012

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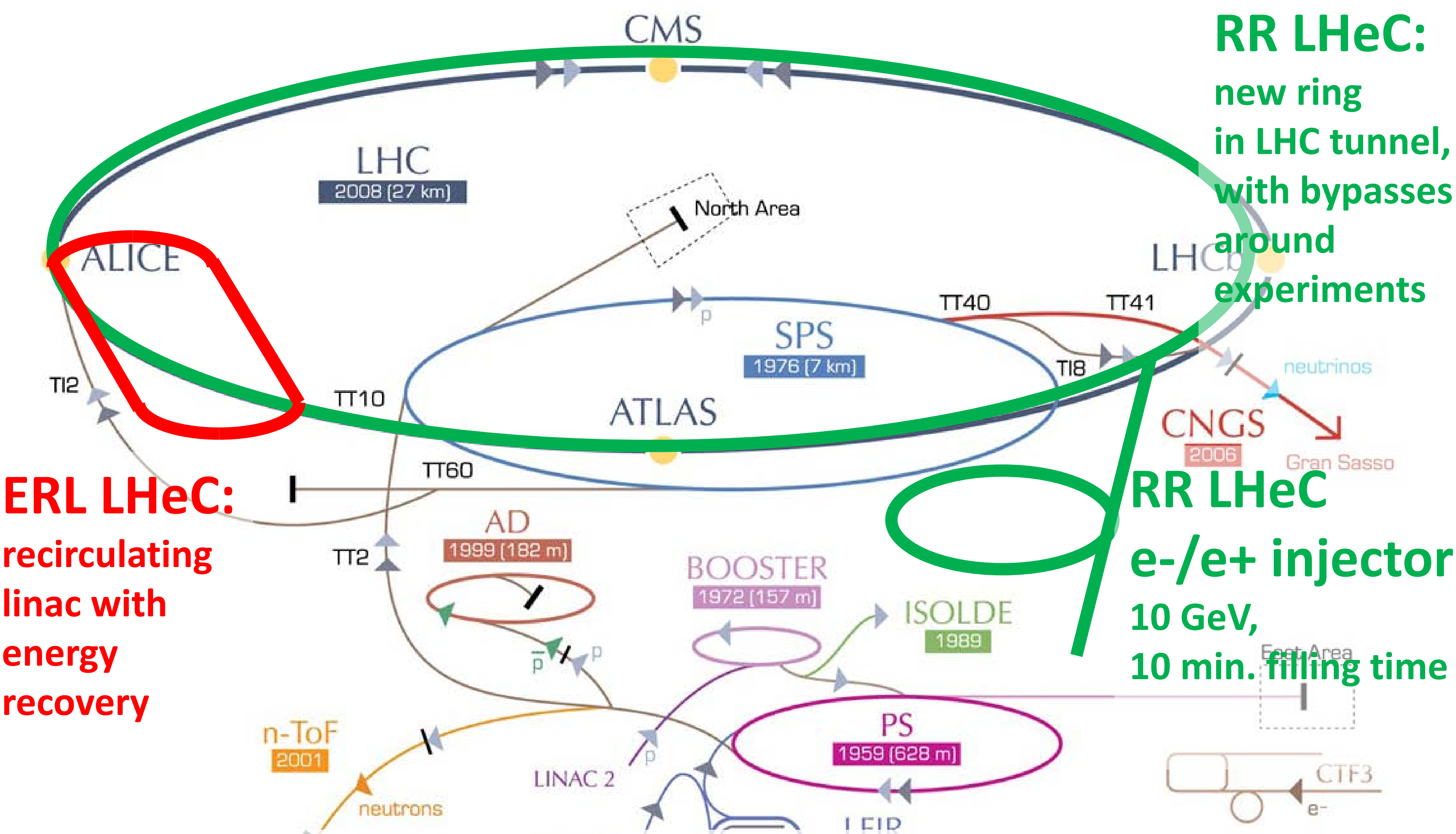
work supported by the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579

cern.ch/accnet

LHeC

# Large Hadron electron Collider (LHeC)




**At 2012 CERN-ECFA-NuPECC LHeC workshop ERL-LHeC was selected as baseline (*RR LHeC issues: HL-LHC schedule, tunnel work, interference*)**

# LHeC Conceptual Design Report

DRAFT 1.0
Geneva, September 3, 2011
CERN report
ECFA report
NuPECC report
LHeC-Note-2011-003 GEN

LHeC

## A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group

THIS IS THE VERSION FOR REFEREEING, NOT FOR DISTRIBUTION

**LHeC CDR published in J. Phys. G: Nucl. Part. Phys. 39 075001 (2012)**

http://cern.ch/lhec

LHeC

## LHeC Study Group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About 150 Experimentalists and Theorists from 50 Institutes
Tentative list

Thanks to all and to CERN, ECFA, NuPECC

**~600 pages**

# LHeC Higgs physics

- precision coupling measurements
  ($Hb\bar{b}$, $H\gamma\gamma$, $H4l$,…)
- reduction of theoretical QCD-related uncertainties in *pp* Higgs physics
- potential to find new physics at the cleanly accessible *WWH* (and *ZZH*) vertices

# *L-R* LHeC road map to ≥$10^{33}$ $cm^{-2}s^{-1}$

***luminosity of LR collider:***

(round beams)

$H_D$~1.3

D. Schulte
LHeC2010

$$L = \frac{1}{4\pi e}\frac{N_{b,p}}{\varepsilon_p}\frac{1}{\beta^*_p} I_e H_{hg} H_D$$

**highest proton beam brightness "permitted" (ultimate LHC values)**

**$\gamma\varepsilon$=3.75 µm**

**$N_b=1.7\text{x}10^{11}$**

**bunch spacing 25 or 50 ns**

**smallest conceivable proton β* function:**
- **reduced *l** (23 m → 10 m)**
- **squeeze only one *p* beam**
- **new magnet technology $Nb_3Sn$**

**$\beta^*_p$=0.1 m**

**average $e^-$ current limited by energy recovery efficiency**

**$I_e$=6.4 mA**

**maximize geometric overlap factor**
- **head-on collision**
- **small e- emittance**

**$\theta_c$=0**

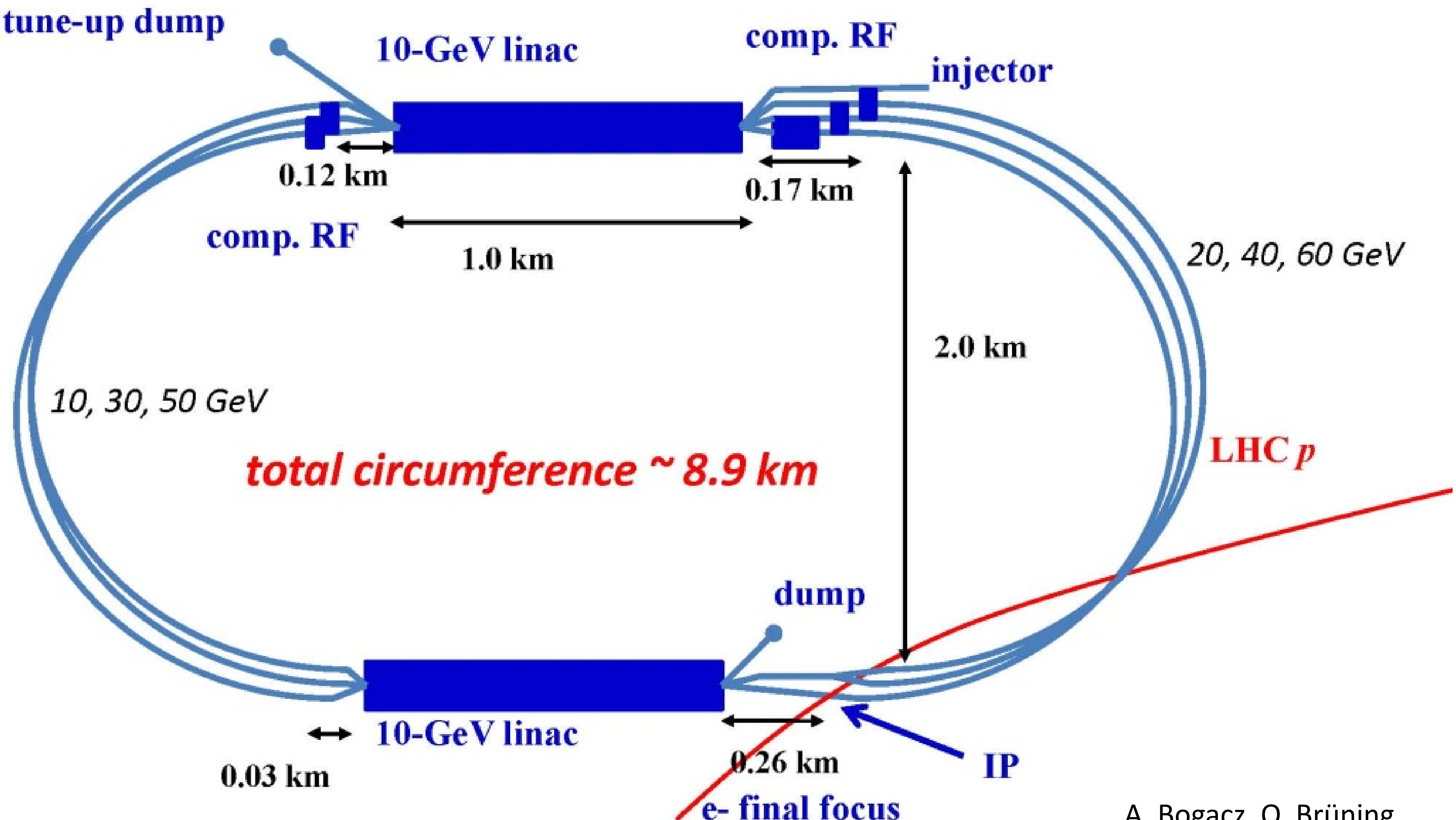
**$H_{hg}$≥0.9**

| parameter [unit] | LHeC | |
|---|---|---|
| **species** | ***$e^{\pm}$*** | ***p, $^{208}Pb^{82+}$*** |
| beam energy (/nucleon) [GeV] | 60 | 7000, 2760 |
| bunch spacing [ns] | 25, 100 | 25, 100 |
| bunch intensity (nucleon) [$10^{10}$] | 0.1 (0.2), 0.4 | 17 (22), 2.5 |
| beam current [mA] | 6.4 (12.8) | 860 (1110), 6 |
| rms bunch length [mm] | 0.6 | 75.5 |
| polarization [%] | 90 ($e^+$ none) | none, none |
| normalized rms emittance [μm] | 50 | 3.75 (2.0), 1.5 |
| geometric rms emittance [nm] | 0.43 | 0.50 (0.31) |
| IP beta function $\beta^*_{x,y}$ [m] | 0.12 (0.032) | 0.1 (0.05) |
| **IP rms spot size [μm]** | **7.2 (3.7)** | **7.2 (3.7)** |
| synchrotron tune | - | 0.0019 |
| hadron beam-beam parameter | 0.0001 (0.0002) | |
| lepton disruption parameter *D* | 6 (30) | |
| hourglass reduction factor $H_{hg}$ | 0.91 (0.67) | |
| pinch enhancement factor $H_D$ | 1.35 (0.3 for $e^+$ ) | |
| **luminosity/ nucleon [$10^{33}$ $cm^{-2}s^{-1}$]** | **1 (10), 0.2** | |

LHeC baseline (& pushed) parameters

# LHeC ERL layout

two 10-GeV SC linacs, 3-pass up, 3-pass down; 6.4 mA, 60 GeV $e^-$'s collide w. LHC protons/ions



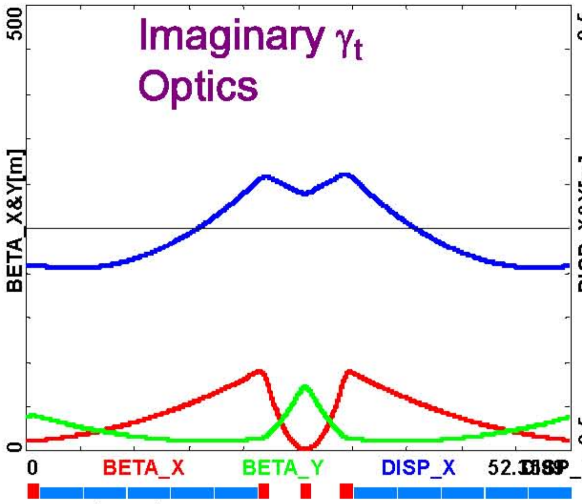

(C=1/3 LHC allows for ion clearing gaps)

A. Bogacz, O. Brüning,
M. Klein, D. Schulte,
F. Zimmermann, et al

# LHeC: 3 passes, flexible momentum compaction arc lattice building block: 52 m long cell with 2 (10) dipoles & 4 quadrupoles

LHeC flexible momentum compaction cell; tuned for small beam size (low energy) or low $\Delta\varepsilon$ (high energy)

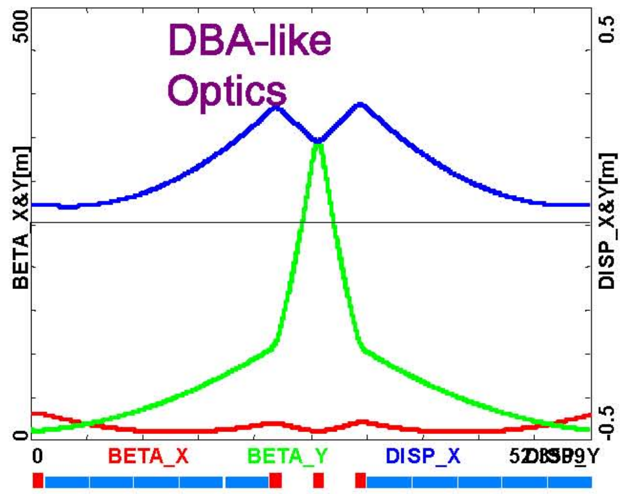
**Arc 1 , Arc2**




$$\langle H \rangle = 8.8 \times 10^{-3}\ m$$

**limit chamber size**
**(>12 σ at 25 mm diameter)**

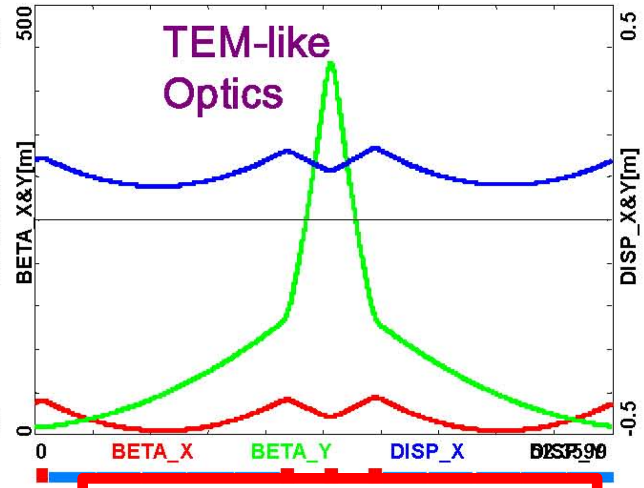
**Arc 3, Arc 4**




$$\langle H \rangle = 2.2 \times 10^{-3}\ m$$

Alex Bogacz

**Arc5, Arc 6**



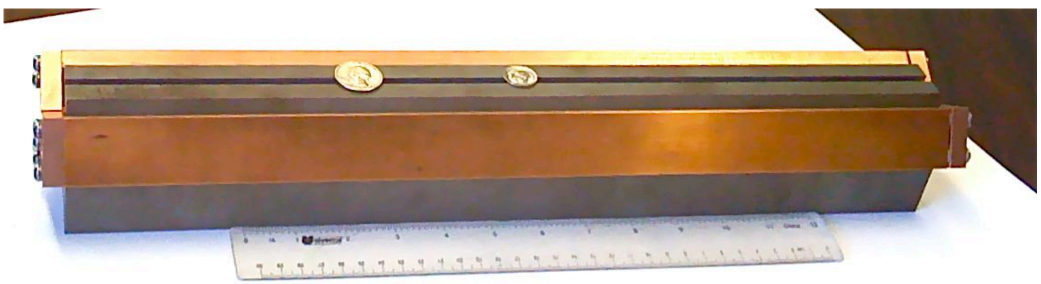

$$\langle H \rangle = 1.2 \times 10^{-3}\ m$$

factor of 18 smaller than FODO

**limit emittance growth**

# prototype arc magnets

eRHIC dipole model (BNL)



**5 mm gap**
max. field 0.43 T (30 GeV)

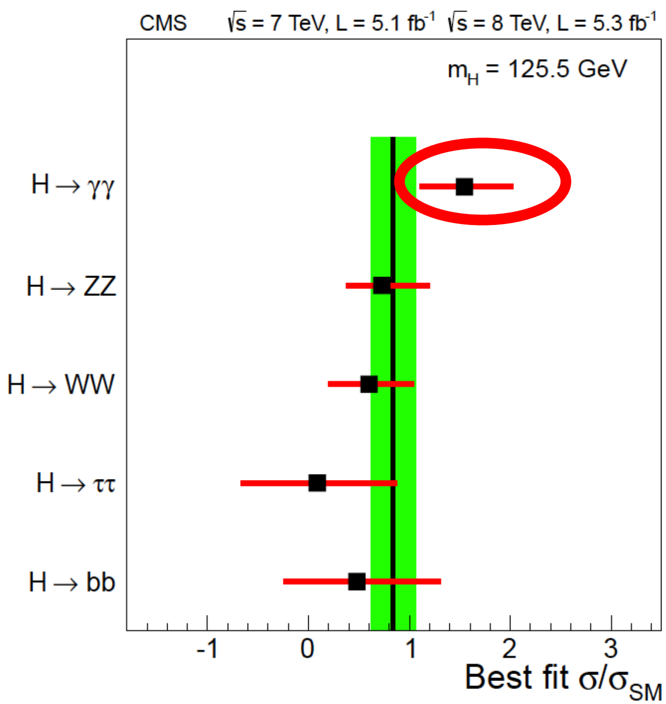
LHeC dipole models (BINP & CERN)

25 mm gap
max. field 0.264 T (60 GeV)

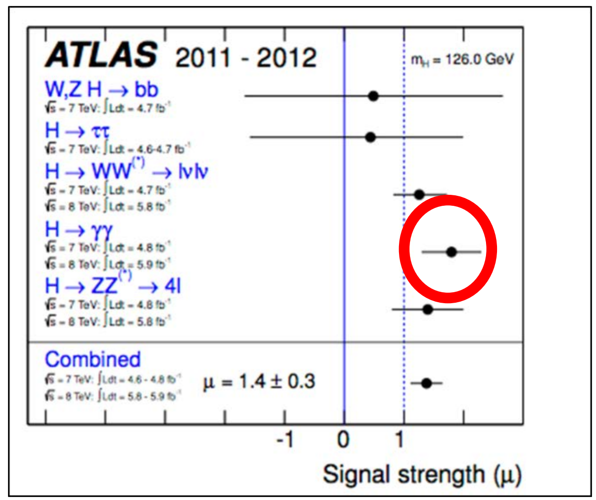

SAPPHiRE

# X(125) seems to strongly couple to $\gamma\gamma$

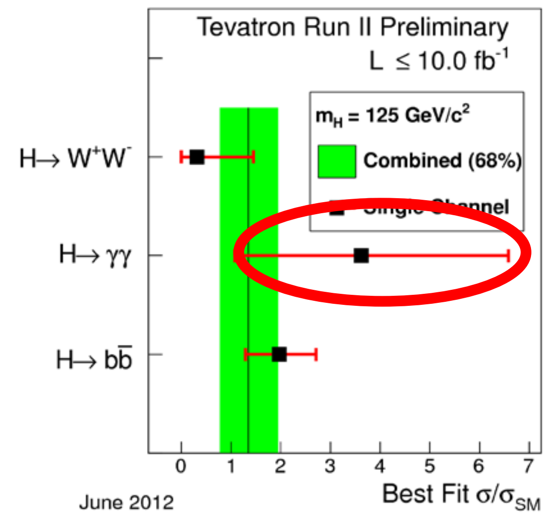
LHC CMS result



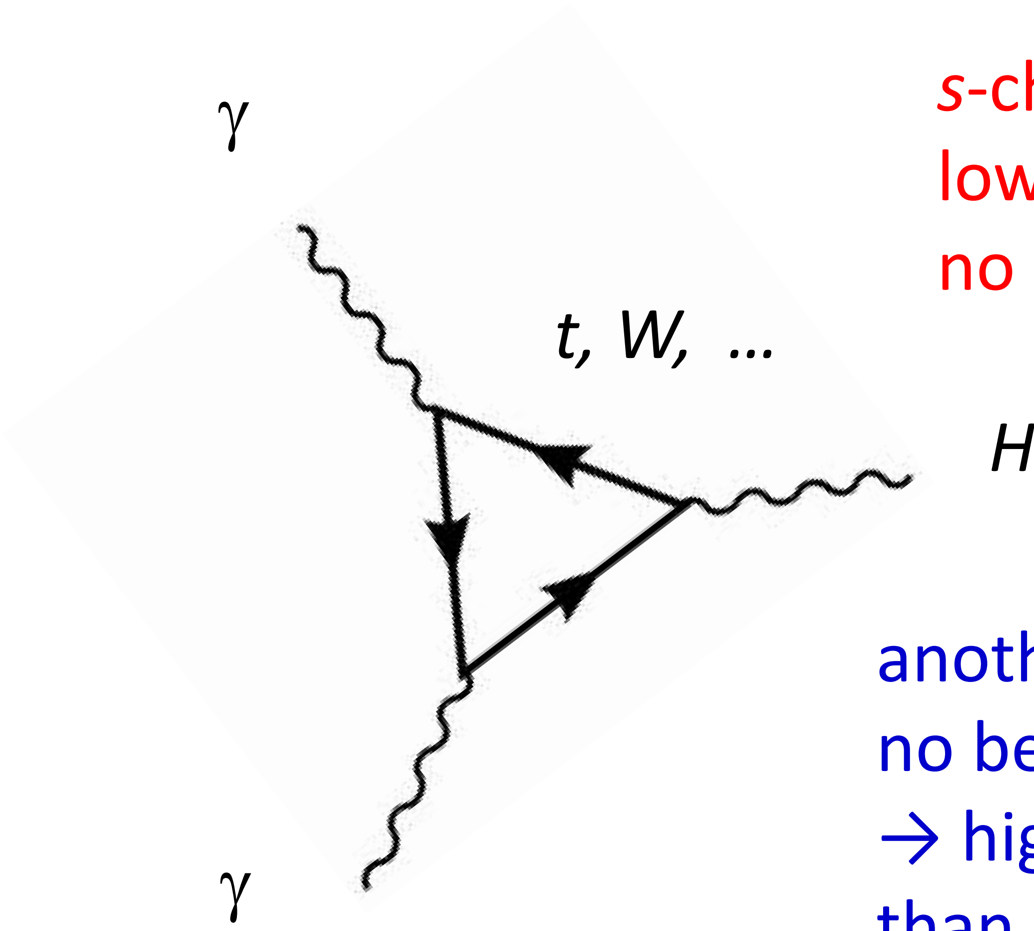

LHC ATLAS result




TeV Run-II result



# a new type of collider?




*s*-channel production;
lower energy;
no $e^+$ source

another advantage:
no beamstrahlung
→ higher energy reach
than $e^+e^-$ colliders

$\gamma\gamma$ collider Higgs factory

# LHC – *the first photon collider!*

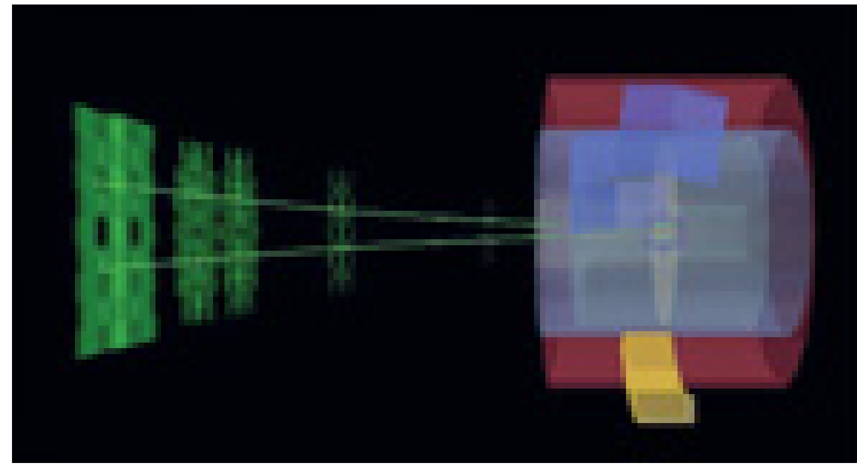
**CERN COURIER**

Nov 6, 2012

**Using the LHC as a photon collider**

ALICE

The protons and nuclei accelerated by the LHC are surrounded by strong electric and magnetic fields. These fields can be treated as an equivalent flux of photons, making the LHC the world's most powerful collider not only for protons and lead ions but also for photon-photon and photon-hadron collisions (*CERN Courier* October 2007). This is particularly so for beams of multiply charged heavy-ions, where the number of photons is enhanced by almost four orders of magnitude compared with the singly charged protons (the photon flux is proportional to the square of the ion charge).



**ultra-peripheral photon-photon interaction in *Pb-Pb* collisions at ALICE**

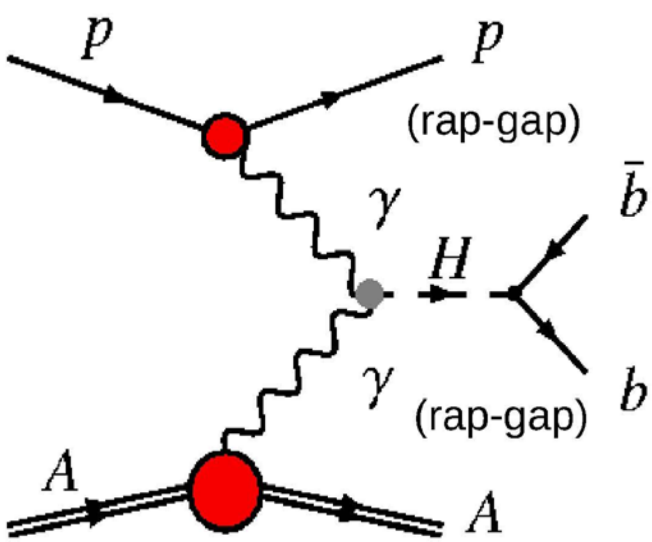
CERN Courier, November 2012

*thanks to John Jowett*

# Higgs γ γ production in p-A collisions

DdE&J.P.Lansberg PRD81 (2010)014004

- Exclusive electromagnetic Higgs production:




**in LHC *p-Pb* γ–γ collisions**

- Photons emitted by p & A.
- Proton & nucleus survive interaction (proton dissociation also considered)
- Two rapidity gaps (p & A sides).

- Excellent scientific motivations:
  - H-bbar decay (dominant for preferred low-mass Higgs) considered "impossible" at the LHC (except boosted H)
  - Direct measurement of H-b Yukawa coupling possible
  - Independent measurement of H-γγ coupling (besides H-γγ decay)

*thanks to John Jowett*

# Expected Higgs counts/year

DdE&J.P.Lansberg PRD81 (2010)014004

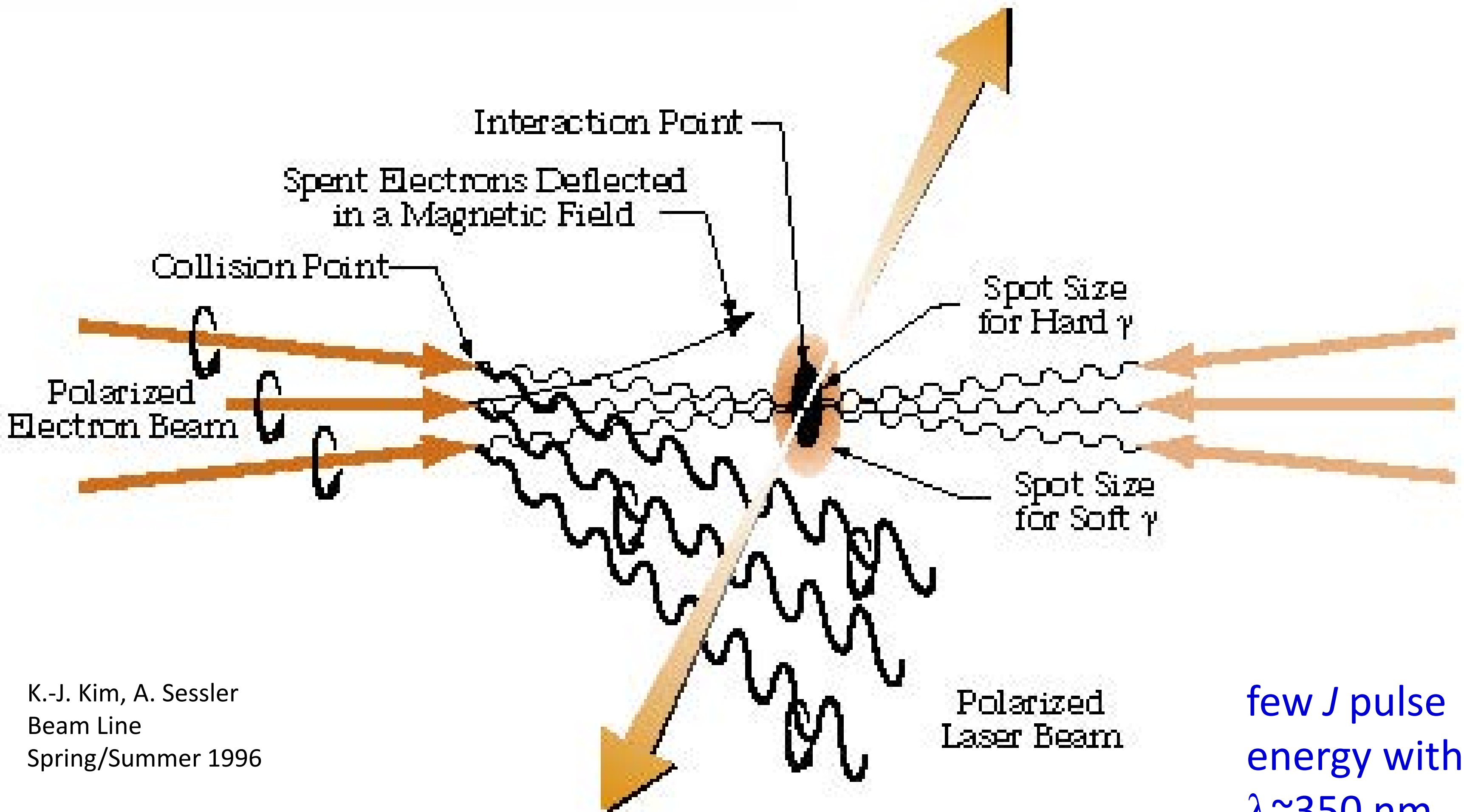
- Higgs event rates: **in LHC *p-Pb* γ–γ collisions**
  - Negligible for nominal heavy-ion lumis ($10^{29}$) & runtimes (1 month).
  - But, for p-Pb, $10^{31}$ cm$^{-2}$s$^{-1}$ & $\Delta t=10^7$ s: 25 H→bbar/year
  - pPb @ 8.8 TeV: highest Higgs rates with lowest event pileup.

| System | nominal runs | | | | upgraded $p$A scenario | | | |
|---|---|---|---|---|---|---|---|---|
| | $\mathcal{L}_{AB}$ (cm$^{-2}$s$^{-1}$) | $\Delta t$ (s) | $\langle N_{\rm pileup}\rangle$ | $N_{\rm Higgs}$ total $(H\to b\bar{b})$ | $\mathcal{L}_{AB}$ (cm$^{-2}$s$^{-1}$) | $\Delta t$ (s) | $\langle N_{\rm pileup}\rangle$ | $N_{\rm Higgs}$ total $(H\to b\bar{b})$ |
| $pp$ (14 TeV) | $10^{34}$ | $10^7$ | 25 | 77. (55.) | $10^{34}$ | $10^7$ | 25 | 77. (55.) |
| $p$O (9.9 TeV) | $2.7\cdot10^{30}$ | $10^6$ | 0.20 | 0.022 (0.016) | $1.6\cdot10^{32}$ | $10^7$ | 3.9 | 13. (10.) |
| $p$Ar (9.4 TeV) | $1.5\cdot10^{30}$ | $10^6$ | 0.18 | 0.045 (0.032) | $1\cdot10^{32}$ | $10^7$ | 3.6 | 30. (22.) |
| $p$Pb (8.8 TeV) | $1.5\cdot10^{29}$ | $10^6$ | 0.05 | 0.050 (0.035) | $1\cdot10^{31}$ | $10^7$ | 1 | 34. (25.) |
| PbPb (5.5 TeV) | $5\cdot10^{26}$ | $10^6$ | $5\cdot10^{-4}$ | 0.009 (0.007) | $5\cdot10^{26}$ | $10^7$ | $5\cdot10^{-4}$ | 0.15 (0.1) |



**~34 events / yr with lots of effort**

# $\gamma\gamma$ collider based on $e^-$




K.-J. Kim, A. Sessler
Beam Line
Spring/Summer 1996

few *J* pulse energy with λ~350 nm

*combining photon science & particle physics!*

# which beam & photon energy / wavelength?

$$E_{\gamma,max} = \frac{x}{1+x} E_{beam}$$

$$x = \frac{4E_e\omega_L}{m_e^2}\cos^2\frac{\theta}{2}$$

example $x \approx 4.3$

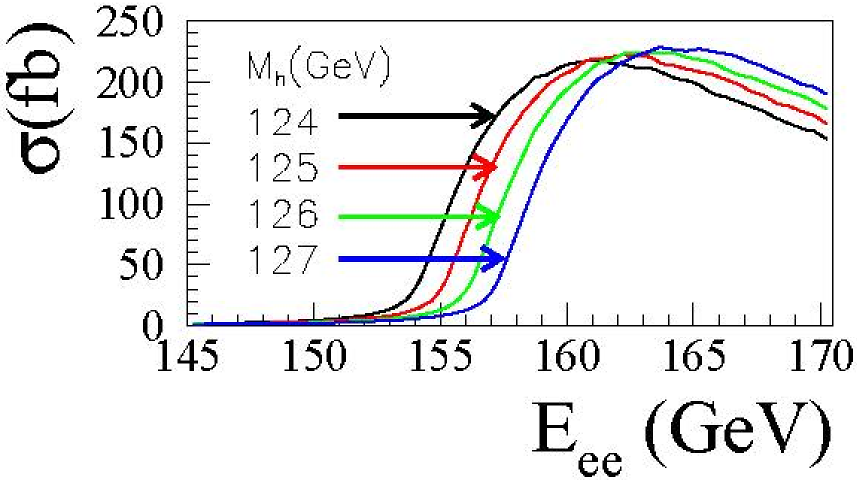
(for $x$>4.83 coherent pair production occurs)

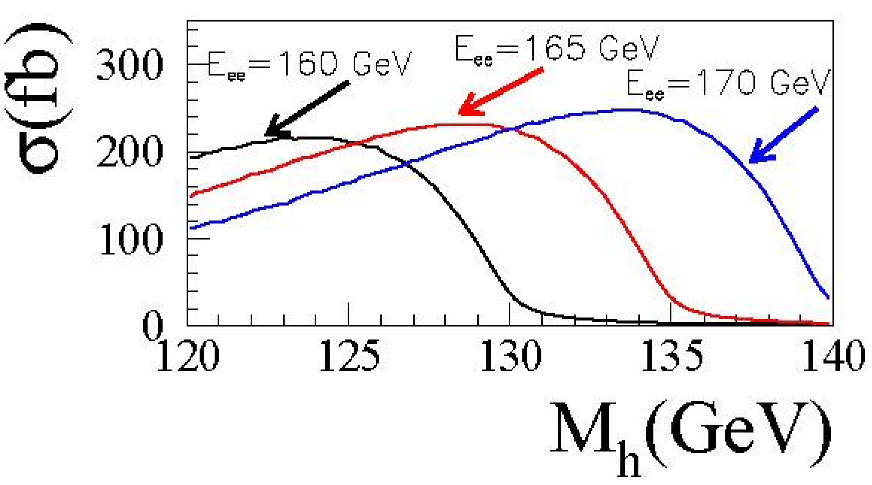
with $E_{beam} \approx 80$ GeV: $E_{\gamma,max} \approx 66$ GeV

$E_{CM,max} \approx 132$ GeV

$E_{photon}$ ~3.53 eV , λ~351 nm

# Higgs $\gamma\gamma$ production cross section



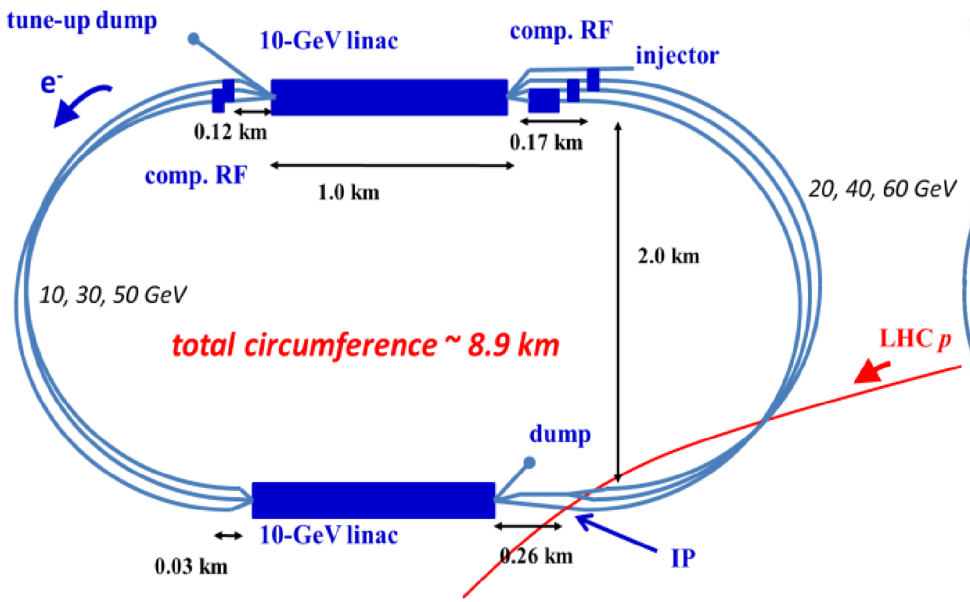

*Left: The cross sections for* $\gamma\gamma \rightarrow$ h *for different values of* $M_h$ *as functions of* $E_{CM}$($e^-e^-$).

*Right: The cross section for* $\gamma\gamma \rightarrow$ h *as a function of* $M_h$ *for three different values of* $E_{CM}$($e^-e^-$).

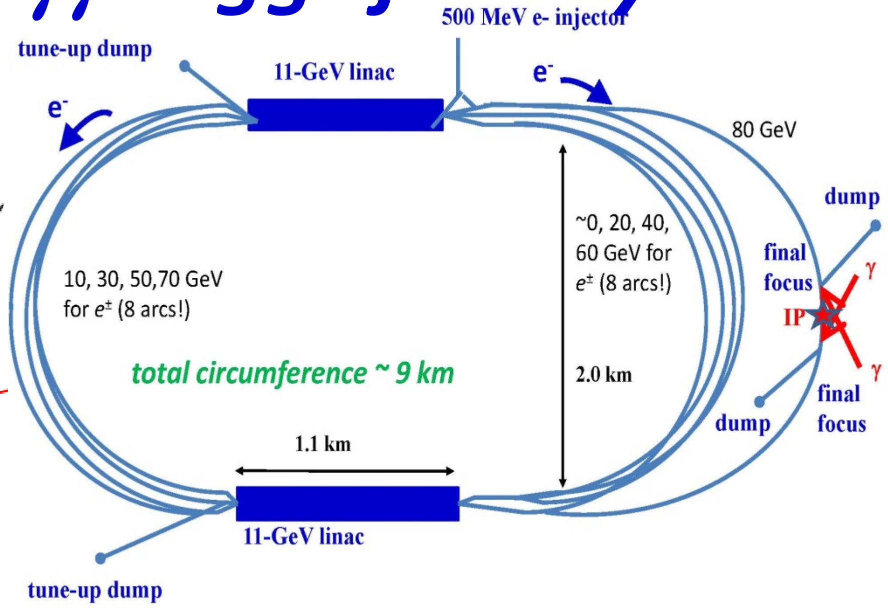
*Assumptions: electrons have 80% longitudinal polarization and lasers are circularly polarized, so that produced photons are highly circularly polarized at their maximum energy.*

# Reconfiguring *LHeC* → *SAPPHiRE*

## *LHeC-ERL*

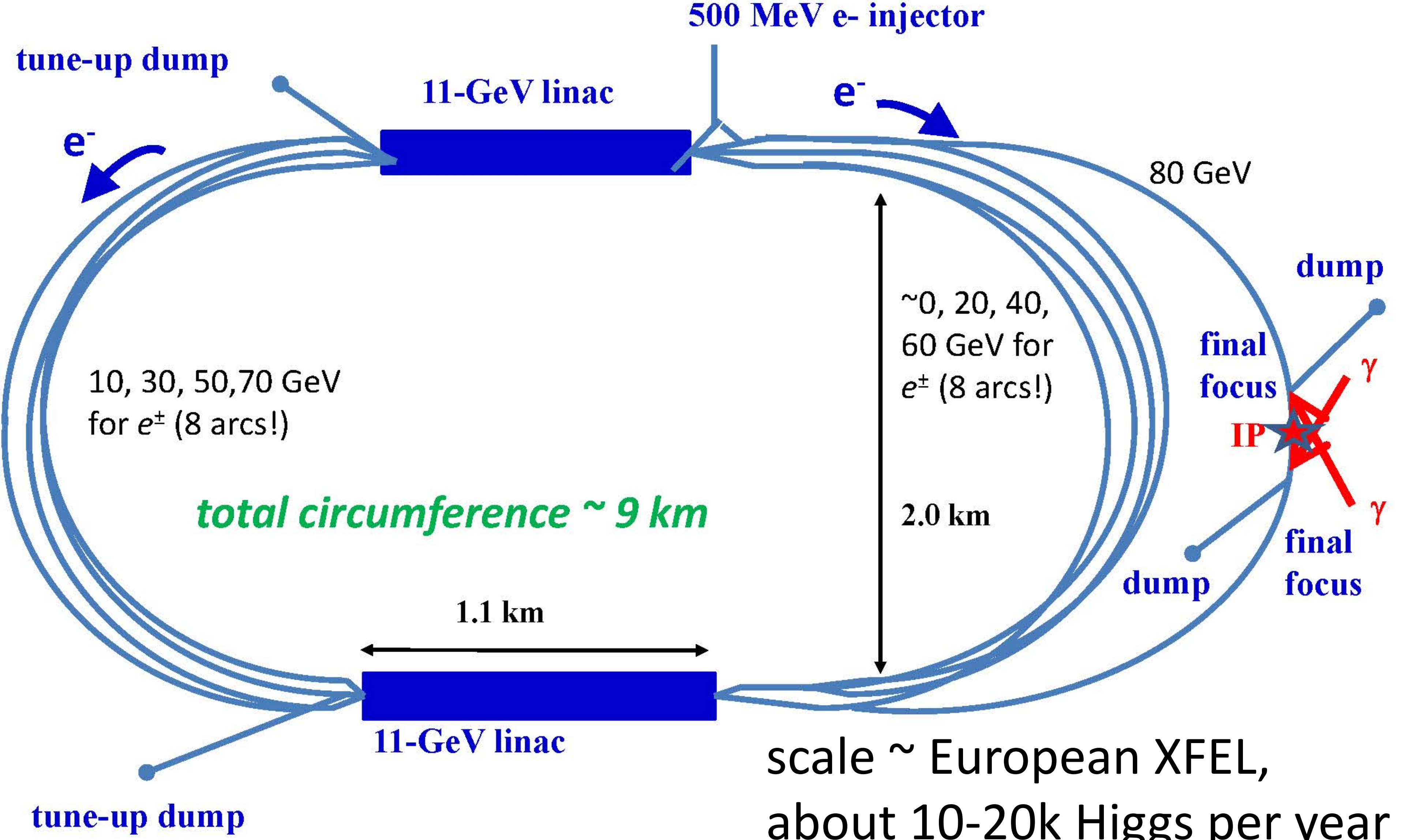



## *SAPPHiRE**
## *γγ Higgs factory*




*Small Accelerator for Photon-Photon Higgs production using Recirculating Electrons

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



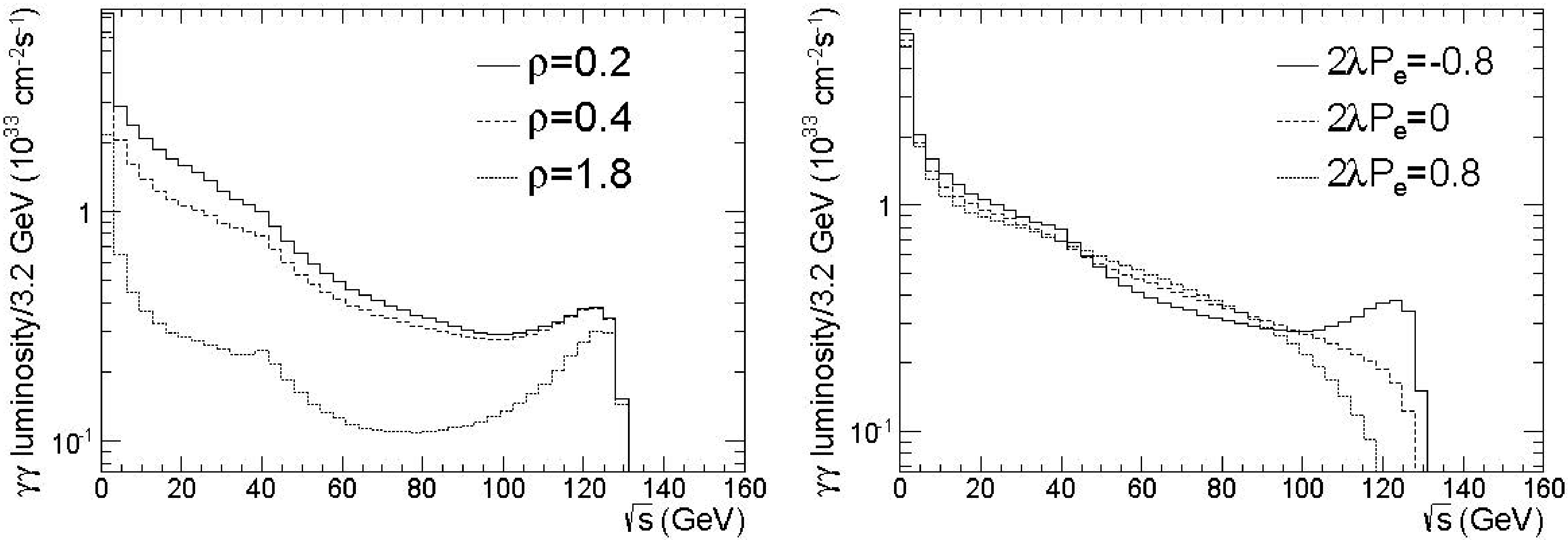

scale ~ European XFEL, about 10-20k Higgs per year

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

| SAPPHiRE | symbol | value |
|---|---|---|
| total electric power | $P$ | 100 MW |
| beam energy | $E$ | 80 GeV |
| beam polarization | $P_e$ | 0.80 |
| bunch population | $N_b$ | $10^{10}$ |
| repetition rate | $f_{rep}$ | 200 kHz |
| bunch length | $\sigma_z$ | 30 $\mu$m |
| crossing angle | $\theta_c$ | ≥20 mrad |
| normalized horizontal/vert. emittance | $\gamma\varepsilon_{x,y}$ | 5,0.5 $\mu$m |
| horizontal IP beta function | $\beta_x^*$ | 5 mm |
| vertical IP beta function | $\beta_y^*$ | 0.1 mm |
| horizontal rms IP spot size | $\sigma_x^*$ | 400 nm |
| vertical rms IP spot size | $\sigma_y^*$ | 18 nm |
| horizontal rms CP spot size | $\sigma_x^{CP}$ | 400 nm |
| vertical rms CP spot size | $\sigma_y^{CP}$ | 440 nm |
| $e^-e^-$ geometric luminosity | $L_{ee}$ | $2 \times 10^{34}$ cm$^{-2}$s$^{-1}$ |

# *SAPPHiRE* $\gamma\gamma$ luminosity

M. Zanetti




luminosity spectra for SAPPHiRE as functions of $E_{CM}(\gamma\gamma)$, computed using Guinea-Pig for **three possible normalized distances** $\rho \equiv l_{CP\text{-}IP}/(\gamma\sigma_y{}^*)$ (left) and **different polarizations of in-coming particles** (right)

# Energy loss on multiple passes

The energy loss per arc is $\Delta E_{arc}\ [\mathrm{GeV}] = 8.846 \times 10^{-5} \frac{(E\ [GeV])^4}{2\rho[\mathrm{m}]}$

For **ρ=764 m** (LHeC design) the energy loss in the various arcs is summarized in the following table. *e*⁻ lose about 4 GeV in energy, which can be compensated by increasing the voltage of the two linacs from 10 GV to 10.5 GV. We take 11 GV per linac to be conservative.

| beam energy [ GeV] | $\Delta E_{arc}$ [GeV] | $\Delta\sigma_E$ [MeV] |
|---|---|---|
| 10 | 0.0006 | 0.038 |
| 20 | 0.009 | 0.43 |
| 30 | 0.05 | 1.7 |
| 40 | 0.15 | 5.0 |
| 50 | 0.36 | 10 |
| 60 | 0.75 | 20 |
| 70 | 1.39 | 35 |
| 80 | 1.19 | 27 |
| **total** | **3.89** | **57 (0.071%)** |

# Emittance growth

The emittance growth is $\Delta\varepsilon_N = \frac{2\pi}{3}\frac{C_q r_e}{\rho^2}\gamma^6\langle H\rangle$

with $C_q$=3.8319x10$^{-13}$ m, and ρ the bending radius.

For LHeC RLA design with $l_{bend}$=10 m, and ρ=764 m, <H>=1.2x10$^{-3}$ m [Bogacz et al]. At 60 GeV the emittance growth of LHeC optics is 13 micron, too high for our purpose, and extrapolation to 80 GeV is unfavourable with 6th power of energy. From L. Teng we also have **scaling law $< H > \propto l_{bend}^3/\rho^2$** , which suggests that **by reducing the cell length and dipole length by a factor of 4 we can bring the horiz. norm. emittance growth at 80 GeV down to 1 micron**.

**$\Delta\varepsilon_{N,x}\leq 1$ μm:**
**reduced LHeC cell length**
**52 → 13 m**
**will do**

Valery Telnov thinks this scaling is too optimistic reference

TM-1269
0102.000

Fermilab

Minimizing the Emittance in Designing the Lattice of an Electron Storage Ring

L.C. Teng

June 1984

# flat polarized electron source

- target $\varepsilon_x/\varepsilon_y$ ~ 10
- flat-beam gun based on flat-beam transformer concept of Derbenev et al.
- starting with $\gamma\varepsilon$~4-5 μm at 0.5 nC, injector test facility at **Fermilab A0 line achieved emittances of 40 μm horizontally and 0.4 μm vertically, with $\varepsilon_x/\varepsilon_y$~100**
- for SAPPHiRE **we only need $\varepsilon_x/\varepsilon_y$~10, but at three times larger bunch charge (1.6 nC) and smaller initial $\gamma\varepsilon$~1.5 μm**
- these parameters are within the present state of the art (e.g. the LCLS photoinjector routinely achieves 1.2 μm emittance at 1 nC charge)
- however, **we need a polarized beam**...

Valery Telnov stressed this difficulty

***can we get ~ 1-nC polarized $e^-$ bunches with ~1 $\mu$m emittance?***

ongoing R&D efforts:

**low-emittance DC guns**
(MIT-Bates, Cornell, SACLA?, JAEA, KEK…)

[E. Tsentalovich, I. Bazarov, et al]

**polarized SRF guns** (FZD, BNL,…)

[J. Teichert, J. Kewisch, et al]

# Cornell DC gun

*The answer is a **qualified 'yes'.** Presently we have demonstrated 90% emittances of **0.5mm-mrad at 80pC/bunch and 0.2mm-mrad at 20pC/bunch for 2ps rms bunches** with the gun voltage and photocathode we are using. The scaling with charge is bunch_charge^(1/2) meaning that **numbers around 2-3 mm-mrad should be doable from our gun today [for 1-2 nC charge].***
*We are working on **further improving our gun and laser shaping, expecting to halve the emittance even when using the same photocathodes** we have today. Better photocathodes automatically translate into smaller emittances and many pursue this venue as well*

Ivan Bazarov, 7 Nov 12

# SACLA pulsed "DC" gun

*I think **our gun almost meets your requirement** except for the repetition rate*

Hitoshi Tanaka, 7 Nov 12

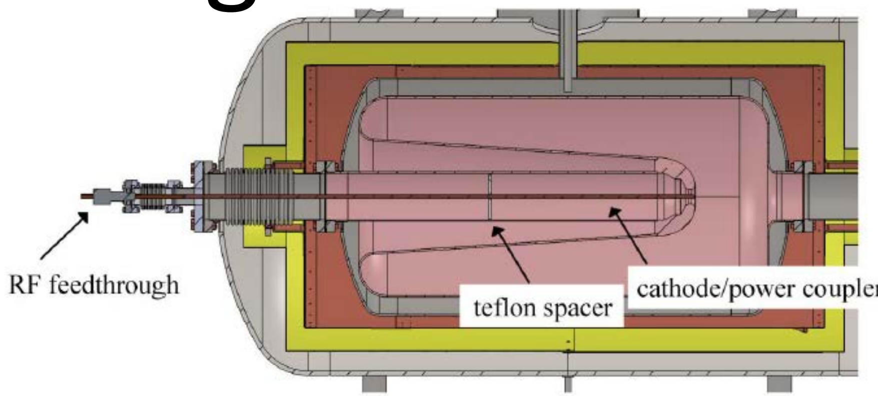
# Rossendorf polarized SRF gun

*Für **2013** wollen wir die 2. Version der SRF-Gun in Betrieb nehmen. Das neue Cavity erreichte im Test am Jlab ein Peakfeld von 43 MV/m. Mit diesen Werten sollten wir **1 nC Ladung mit 500 kHz Reprate im CW** (0.5 mA average current) erreichen. Die Emittanz könnte etwa **2 µm** sein. Auf **1 µm** könnte man etwa kommen, wenn wir **vom Gausslaser zum Flat-top** übergehen (analog zu PITZ/XFEL gun).*
*Mit der Inbetriebnahme der 2. Gun, wird dann auch das Kathodentransfersystem ausgetauscht, und wir denken dann auch die **GaAs-Kathoden** zu testen. Ergebnisse dann **im Jahr 2014**.*

Jochen Teichert, 12 Nov 12

# BNL QWT polarized SRF gun

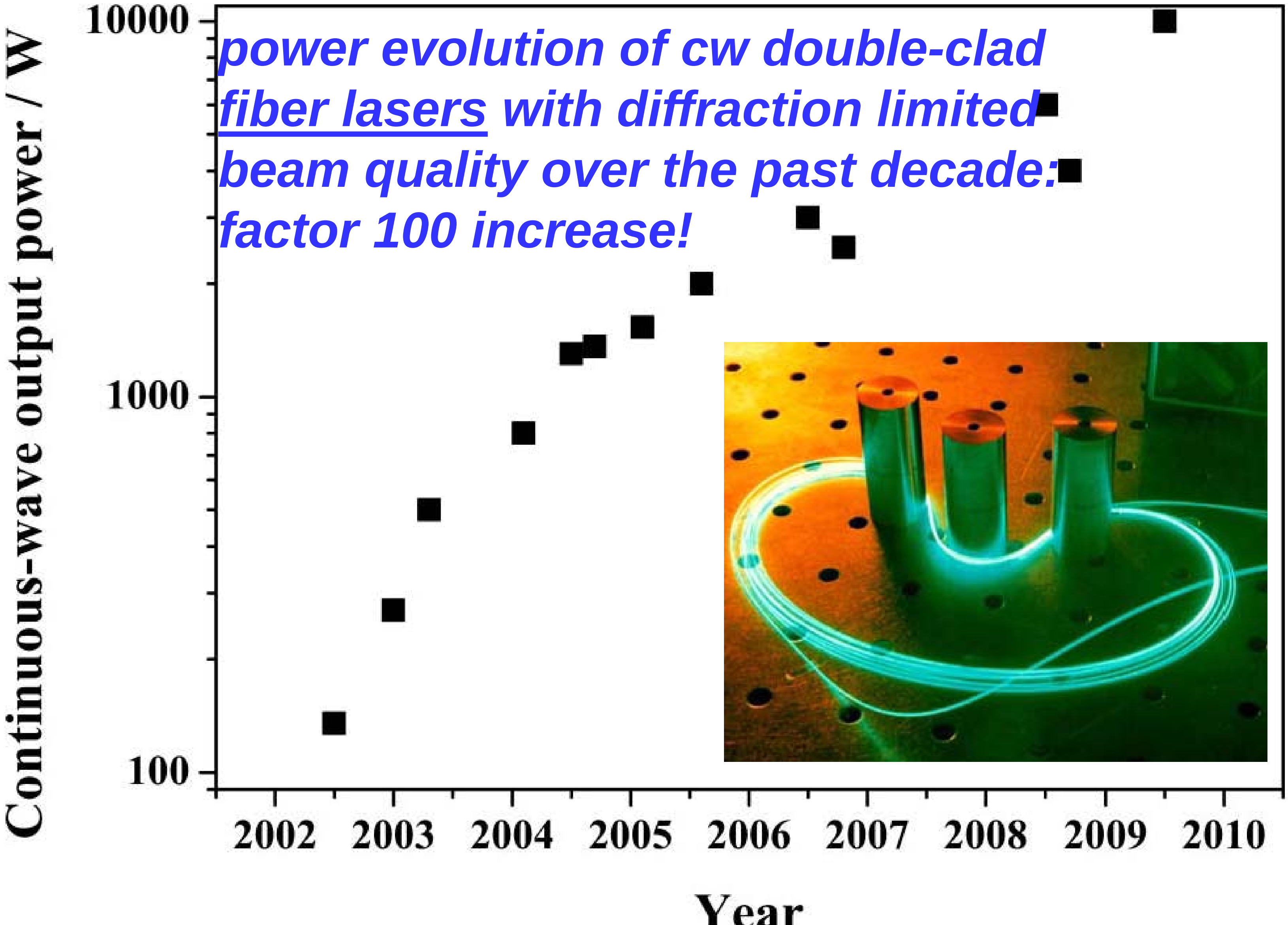
***simulations of 5 µm emittance***
***at 10 nC** with 112 MHz gun*




Tor Raubenheimer, 14 Nov 2012

# *laser progress: example fiber lasers*

***power evolution of cw double-clad <u>fiber lasers</u> with diffraction limited beam quality over the past decade: factor 100 increase!***

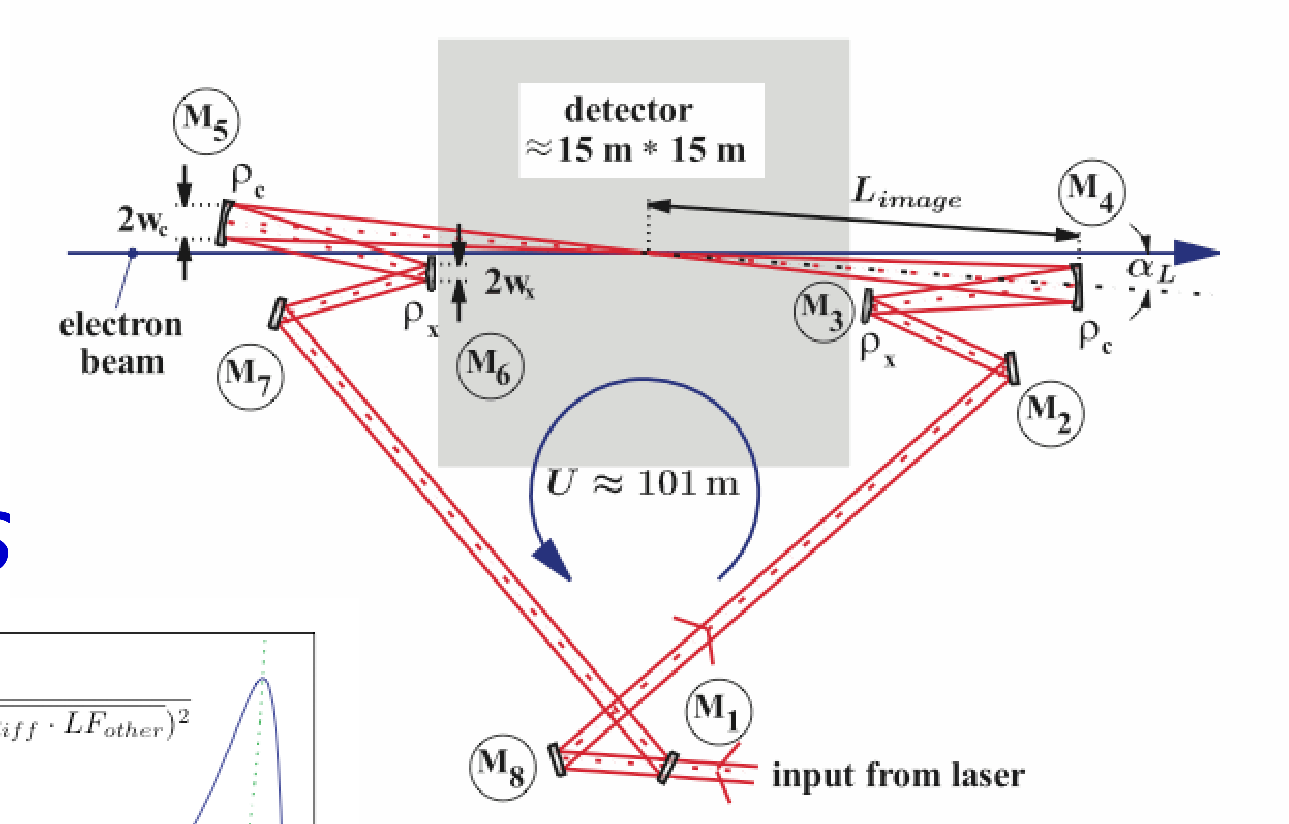


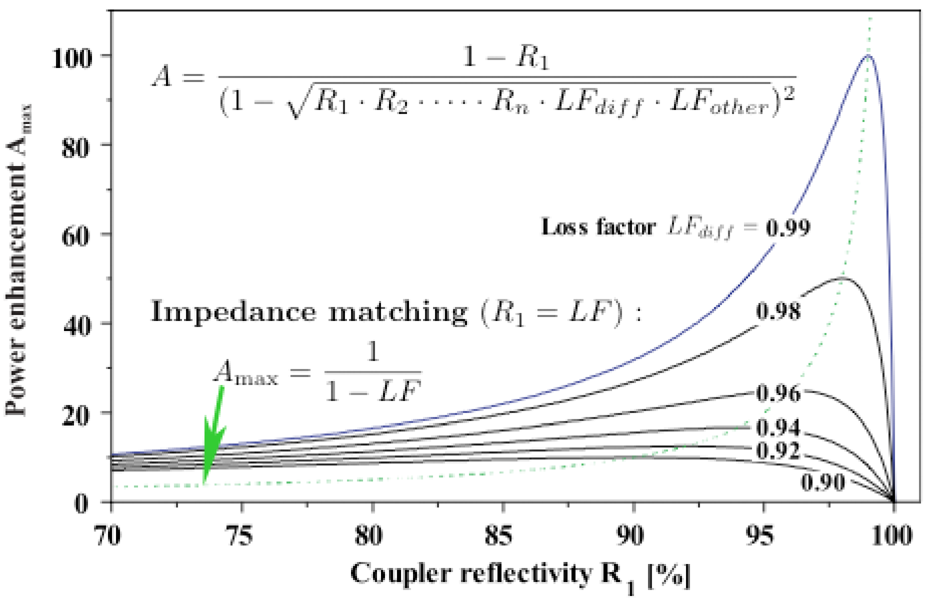

**Source: Fiber lasers and amplifiers: an ultrafast performance evolution,** Jens Limpert, Thomas Schreiber, and Andreas Tünnermann, Applied Optics, Vol. 49, No. 25 (2010)

# passive optical cavity

→

*relaxed laser parameters*

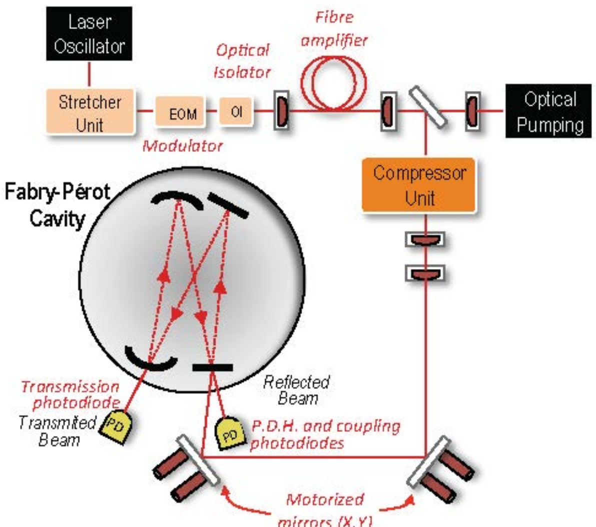



K. Moenig et al, DESY Zeuthen

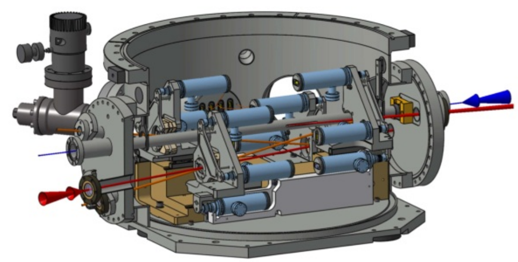
# LAL ***MightyLaser*** experiment at **KEK-ATF**

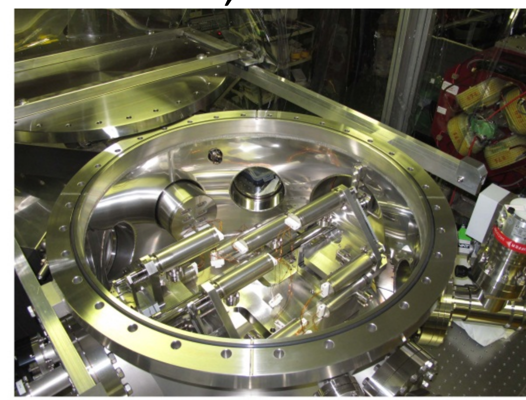
## non-planar high finesse four mirror Fabry-Perot cavity; first Compton collisions observed in October 2010



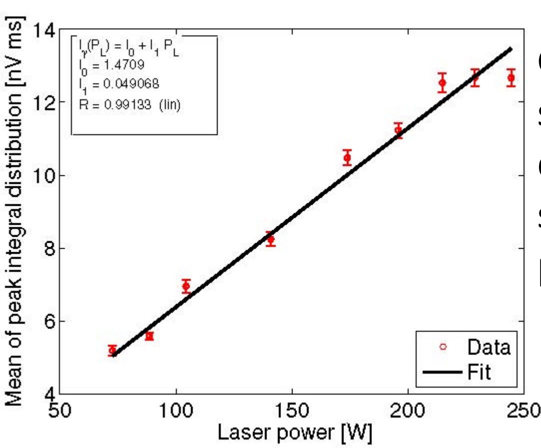

Optical system used for laser power amplification and to inject laser into FPC

I. Chaikovska, N. Delerue, A. Variola, F. Zomer et al

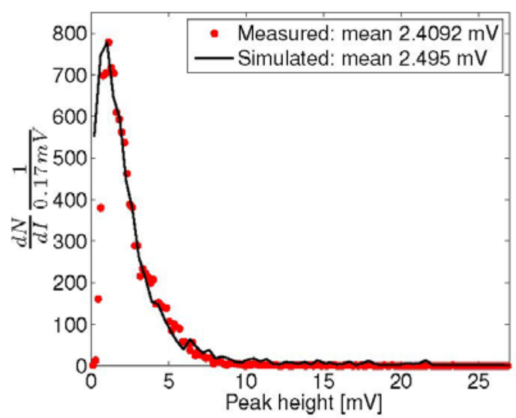




Vacuum vessel for Fabry-Perot cavity installed at ATF




Gamma ray spectrum for different FPC stored laser power

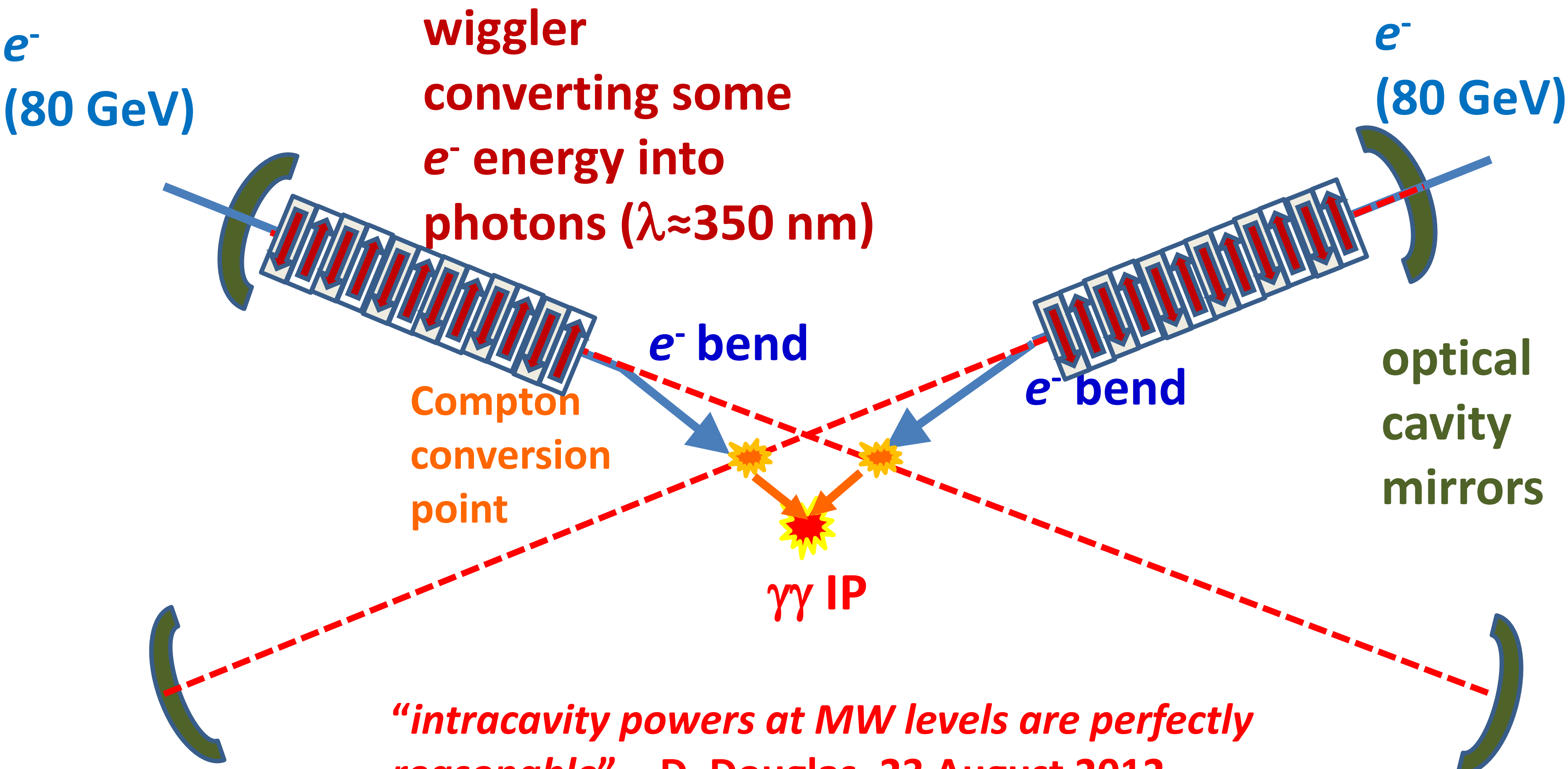



Comparison of measured and simulated gamma-ray energy spectra from Compton scattering

***Plan: improve laser and FPC mirrors & gain several orders***

I. Chaikovska, PhD thesis to be published

# self-generated FEL $\gamma$ beams (instead of laser)?




***"intracavity powers at MW levels are perfectly reasonable"*** **– D. Douglas, 23 August 2012**

example:

$\lambda_u$=200 cm, $B$=0.625 T, $L_u$=100 m, $U_{0,SR}$=0.16 GeV, 0.1%$P_{beam}$≈25 kW

*scheme developed with Z. Huang*

# modified design approach

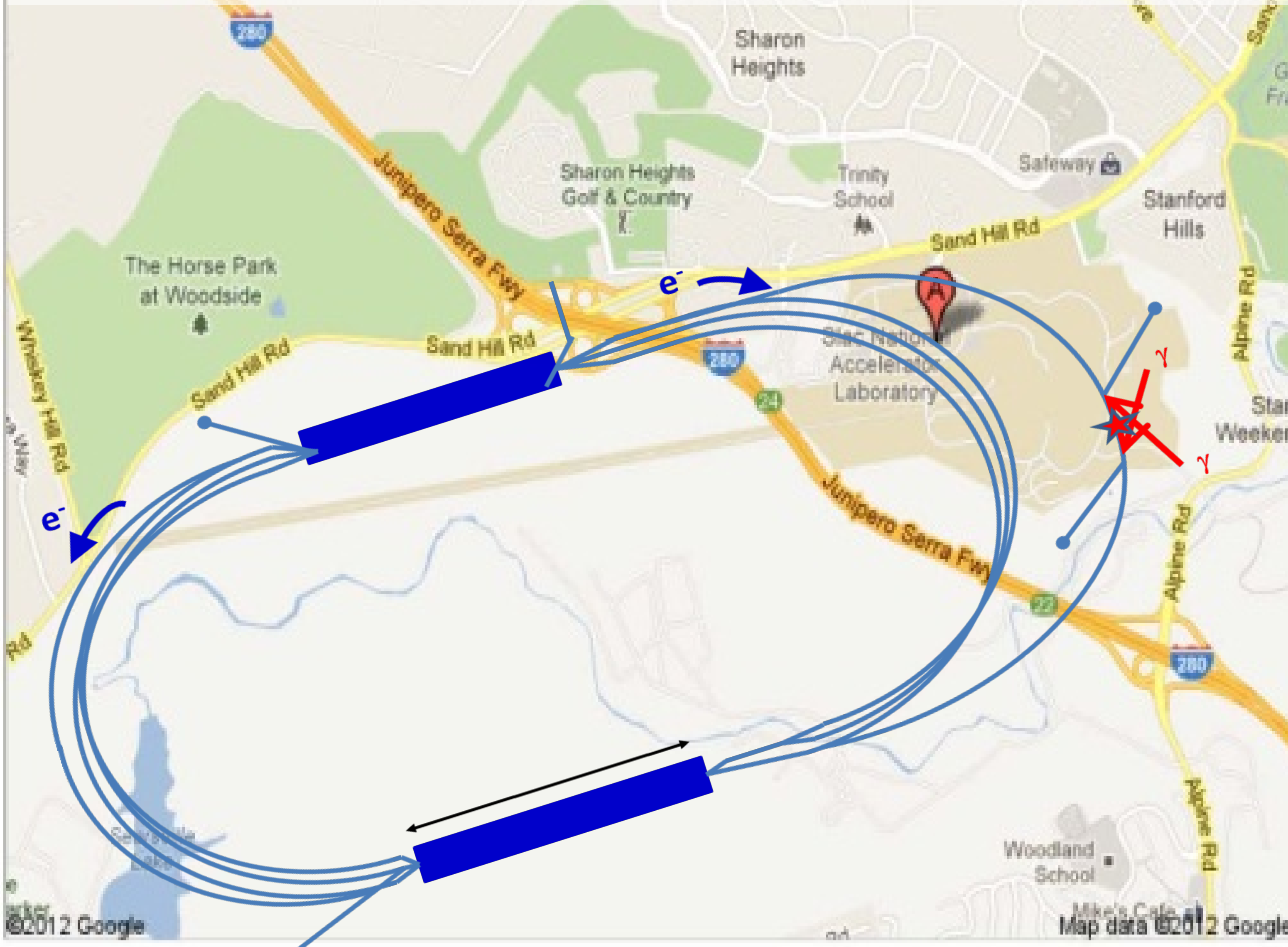
Yuhong Zhang
JLAB

**thin laser target**

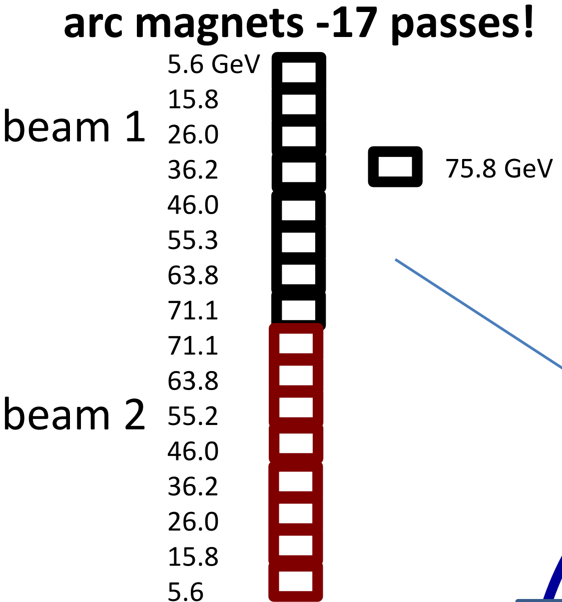
- eliminates most useless and harmful soft γ photons from multiple Compton scattering
- **relaxed laser requirements (~factor 10)**

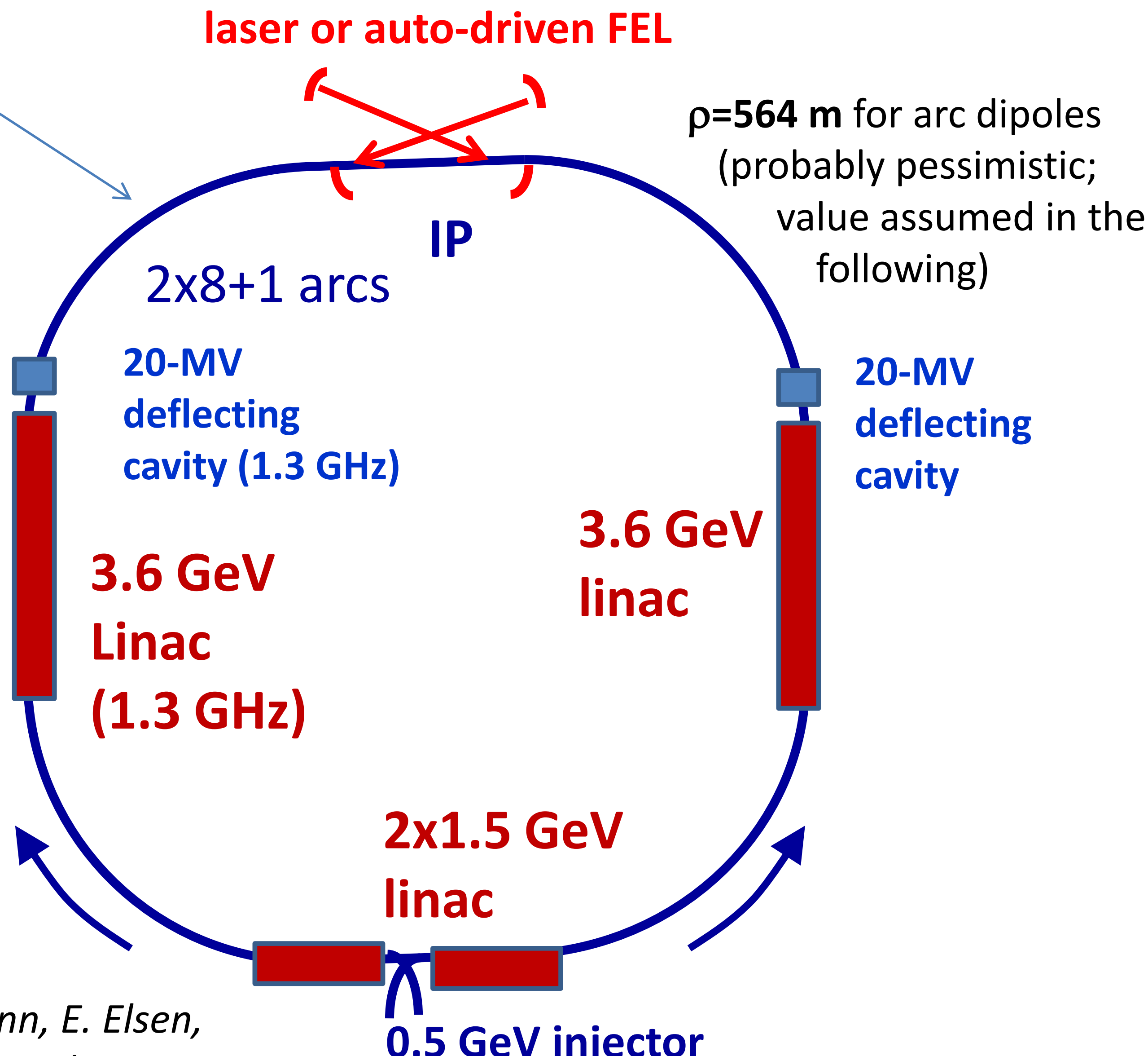
high luminosity achieved through an increase of bunch repetition rate and **higher e- beam current** (~factor 10) with multi-pass recirculating linac and **energy recovery**

# SAPPHiRE “fits” on the SLAC site



# HERA Tunnel Filler




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

Town Hall meeting Dec 19 2011

# Possible Configurations at JLAB

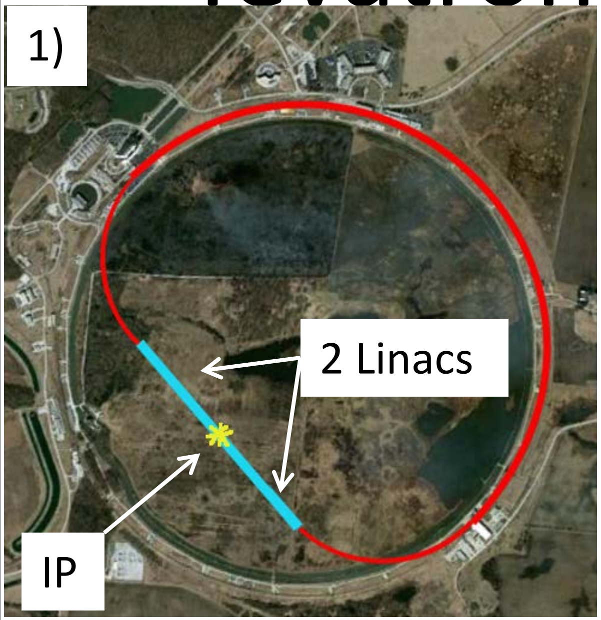


85 GeV Electron energy
$\gamma$ c.o.m. 141 GeV

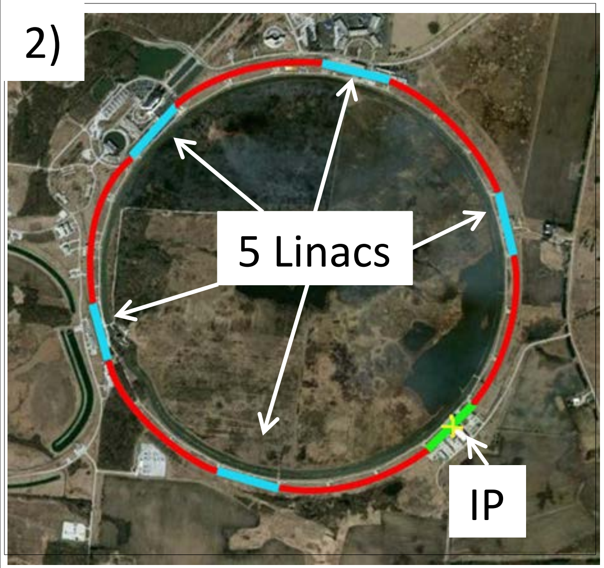
103 GeV Electron energy
$\gamma$ c.o.m. 170 GeV

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 | $8.84\times10^{-4}$ | $8.95\times10^{-4}$ |
| $\epsilon_{nx}$ 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 | $6.99\times10^{-4}$ | $7.2\times10^{-4}$ |
| $\epsilon_{nx}$ 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

# LHeC R&D items

- SC IR final “half quadrupole”
- IR beam pipe
- RF cryostat incl. cavity & coupler
- dedicated LHeC ERL test facility
- proto collaboration for detector

# SAPPHiRE R&D items

- $\gamma\gamma$ interaction region
- large high-finesse optical cavity
- high repetition rate laser
- FEL in unusual regime
- separation scheme for beams circulating in opposite directions
- polarized low-emittance $e^-$ gun
- detector

# Conclusions

SAPPHiRE +LHeC are exciting & popular projects

**SAPPHiRE and/or LHeC** may be some of the **cheapest possible options to further study the Higgs** (cost ~1BEuro scale); feasible, **but, esp. SAPPHiRE, not easy**

**JLAB thin-target approach** is interesting option

**LHeC is necessarily based at CERN**

**SAPPHiRE matches infrastructure, expertise & sites of many HEP or former or future HEP laboratories** (DESY, SLAC, KEK, FNAL, JLAB,...)


flying into Chicago on Tuesday night
lots of lights - ideal place for a $\gamma\gamma$ collider?!
thank you for your attention!

## **References for LHeC and SAPPHiRE**:


[1] S. A. Bogacz, J. Ellis, L. Lusito, D. Schulte, T. Takahashi, M. Velasco, M. Zanetti, F. Zimmermann, 'SAPPHiRE: a Small Gamma-Gamma Higgs Factory,' arXiv:1208.2827

[2] D. Asner et al., 'Higgs physics with a gamma gamma collider based on CLIC I,' Eur. Phys. J. C 28 (2003) 27 [hep-ex/0111056].

[3] J. Abelleira Fernandez et al, 'A Large Hadron Electron Collider at CERN - Report on the Physics and Design Concepts for Machine and Detector,' Journal of Physics G: Nuclear and Particle Physics 39 Number 7 (2012) arXiv:1206.2913 [physics.acc-ph].

[4] Yuhong Zhang, 'Design Concept of a $\gamma$–$\gamma$ Collider-Based Higgs Factory Driven by Energy Recovery Linacs,' JLAB Technote JLAB-TN-12-053, 31 October 2012

[5] E. Nissen, 'Optimization of Recirculating Linacs for a Higgs Factory,' prepared for HF2012

[6] J. Limpert, T. Schreiber, A. Tünnermann, 'Fiber lasers and amplifiers: an ultrafast performance evolution,' Applied Optics, Vol. 49, No. 25 (2010)

*back-up slides*

| (recirculating) SC linac parameters | eRHIC (BNL) | **LHeC** |
|---|---|---|
| #linacs | 2 | **2** |
| length/linac [km] | 0.2 | 1.0 |
| energy gain / linac [GeV] | 2.45 | **10.0** |
| #acceleration passes | 6 | **3** |
| maximum final energy [GeV] | 30 | 60 |
| real estate gradient [MV/m] | 12.45 | 10.0 |
| energy gain / cavity [MeV] | 20.4 | **20.8** |
| cells / cavity ; cavities / linac | 5 ; 120 | 5 ; 480 |
| RF frequency [MHz] | 703.8 | **721 (or 1300)** |
| cavity length [m] | 1.065 | 1.04 |
| R/Q [linac Ω] | 506 | 570 |
| $Q_0$ [$10^{10}$] | 4.0 | **2.5** |
| power loss / cavity [W] | 23.7 | 32 |
| electrical cryopower per linac [MW] | 2 | **10** |

# linac features

LHeC linac 5x longer with 4x the energy gain

(cavity filling factor 0.50 vs 0.64)

eRHIC linac: no focusing

LHeC linac: ~100 quadrupoles

increase multi-pass BBU threshold

LHeC linac quadrupole options:

- electromagnets with indiv. powering
- clustered electromagnets
- permanent magnets

$Q_0$: a key parameter !

# LHeC electrical power budget

| parameter | electrical power [MW] |
|---|---|
| total main linac cryopower | **21** |
| RF microphonics control | **24** |
| extra RF for SR losses | **23** |
| extra-RF cryopower | 2 |
| $e^-$ injector | 6 |
| arc magnets | 3 |
| **total** | **78** |

design constraint: total el. power <100 MW