Future Accelerators

Preface

Heuer

Large Hadron Collider

Future ee

FCC

China

Contribution to the Christmas Meeting of HEP at the Liverpool University

Max Klein 17.12.2013

Long ago …

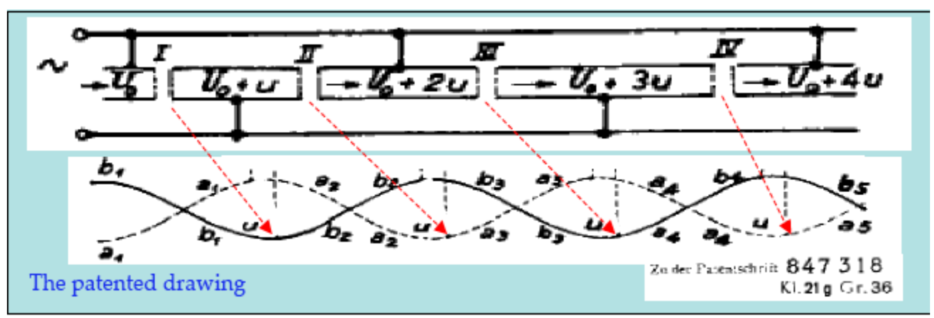
Braun cathode ray tube (1897)

Karl Ferdinand Braun

"What we require is an apparatus to give us a potential of the order of 10 million volts which can be safely accomodated in a reasonably sized room and operated at a few kilowatts of power.
We require too an exausted (*evacuated*) tube capable of withstanding this voltage…….I see no reason why such requirements can not be made practical."

Rutherford 1930

1920



R.Wideroe's sketch in: "*The Infancy of Particle Accelerators*", DESY-Report 94-039.

What I will not talk about*)

Accelerators running in the world

CATEGORY OF ACCELERATORS	NUMBER IN USE (*)	
High Energy acc. (E >1GeV)	~120	
Synchrotron radiation sources	>100	
Medical radioisotope production	~200	
Radiotherapy accelerators	> 7500	9000
Research acc. included biomedical research	~1000	
Acc. for industrial processing and research	~1500	
Ion implanters, surface modification	>7000	
TOTAL	> 17500	

(*) W. Maciszewski and W. Scharf: Int. J. of Radiation Oncology, 2004

- About half are used for bio-medical applications

…Neither will I cover fixed target beams, neutrinos especially …

*) very many thanks to Steve Myers (ISR, LEP, LHC + the future) and success with the doctors

Famous statements I heard ..

Lev Landau (2nd ear..)
The advantage of accelerators over cosmic rays is that we control the initial conditions.

Abdus Salam (Panel on the Future of HEP, ICHEP 1980, Madison, USA)
If we do not invest in new technologies and a new generation of accelerator physicists particle physics will die in 2-3 decades when its accelerators won't be realistic anymore

Leon Lederman (same panel)
Someone at CERN recently taught the accelerator physicists that there was nothing new to be expected between the Fermi and the Planck scale, how stupid..

Carlo Rubbia (DG, 1990, ICHEP Singapore)
Following LEP there will be pp collisions in the LEP tunnel by 1996 and ep by 1998

Famous statements may mean..

Lev Landau (2nd ear..)
- Accelerators are still worth developing as the cosmos is a bad replacement

Abdus Salam (Panel on the Future of HEP, ICHEP 1980, Madison, USA)
- We have invested in new technologies and a new generation of accelerator physicists but the next generation of accelerators looks extremely challenging

Leon Lederman (same panel)
- We still fear there is nothing between Higgs and a scale of 10^{11} or 10^{16} GeV but "we want to view particle physics as driven by experiment" B. Richter (Nov.2011)

Carlo Rubbia (DG, 1990, ICHEP Singapore)
- Modern time schedules may be less optimistic than Carlo's, yet are still wrong

Huge success of the HEP Community

4.7.2012 greeting Melbourne from CERN

"The Higgs: So simple and yet so unnatural" G.Altarelli,arXiv:1308.0545

The LHC has only just begun..

F.Bordry LHCC 11/2013

HL-LHC Upgrade Ingredients

- Geometric reduction factor ➔ $\beta^* \geq 10$ cm & Crab Cavities
- Triplet aperture ➔ New large aperture triplet magnets
- Bunch intensity ➔ $N_b = 2.2\ 10^{11}$ (limited in LHC by e-cloud)
  ➔ injector complex upgrade prerequisite for HL-LHC!!!
- Event pile-up in detectors ➔ luminosity leveling
- Beam Losses and Radiation ➔ shielding, Cryo upgrade & relocation of electronics and PC
- Collective effects and impedance ➔ Collimator Upgrade
- Electron cloud effect ➔ beam scrubbing & feedback

Higgs with HL-LHC

LHC 300 fb^{-1} at 14 TeV:

- Mass: <100 MeV (statistical)
- Coupling κ rel. precision*
  - Z, W, b, τ 10-15%
  - t, μ 3-2 σ observation
  - $\gamma\gamma$ and gg 5-11%

HL-LHC 3000 fb^{-1} at 14 TeV:

- Mass: << 50 MeV (statistical)
- Couplings κ rel. precision*
  - Z, W, b, τ, t, μ 2-10%
  - $\gamma\gamma$ and gg 2-5%

**Assuming sizeable (1/2) reduction of theory errors*

- "QCD scale" go to Higher order QCD computation ?
- gg "PDF" from LHC data ?

Mass Measurement:

Several exp./theory challenges to reach 50 MeV (e/γ/μ calibration E-scale, Interference, FSR, ..)

F.Cerutti, "Properties of the New Boson" EPS13 Stockholm

Higgs physics at the LHC is a long term challenge [di-H, CP, M, VV damping..]

The Question of the next Decade(s)

What is really this Higgs boson that might have been discovered at ~ 125GeV?

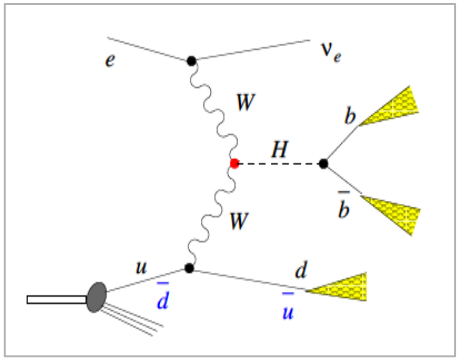
" Higgs = emergency tire of the SM"

Altarelli @ Blois'10

[picture courtesy to Andreas Weiler]

..There is NO decision nor serious long term strategy possible before LHC resumes, 2017

10^{34} Luminosity can boost LH(e)C to a precision H facility



Polarised electrons
Maximum lumi
Forward tracking
High resolution
No pile-up
Direction asymmetry
… STUDY MORE !

LHeC Higgs		CC (e^-p)	NC (e^-p)	CC (e^+p)
Polarisation		-0.8	-0.8	0
Luminosity [ab^{-1}]		1	1	0.1
Cross Section [fb]		196	25	58
Decay	BrFraction	N^H_{CC} e^-p	N^H_{NC} e^-p	N^H_{CC} e^+p
$H \to b\bar{b}$	0.577	113 100	13 900	3 350
$H \to c\bar{c}$	0.029	5 700	700	170
$H \to \tau^+\tau^-$	0.063	12 350	1 600	370
$H \to \mu\mu$	0.00022	50	5	–
$H \to 4l$	0.00013	30	3	–
$H \to 2l2\nu$	0.0106	2 080	250	60
$H \to gg$	0.086	16 850	2 050	500
$H \to WW$	0.215	42 100	5 150	1 250
$H \to ZZ$	0.0264	5 200	600	150
$H \to \gamma\gamma$	0.00228	450	60	15
$H \to Z\gamma$	0.00154	300	40	10

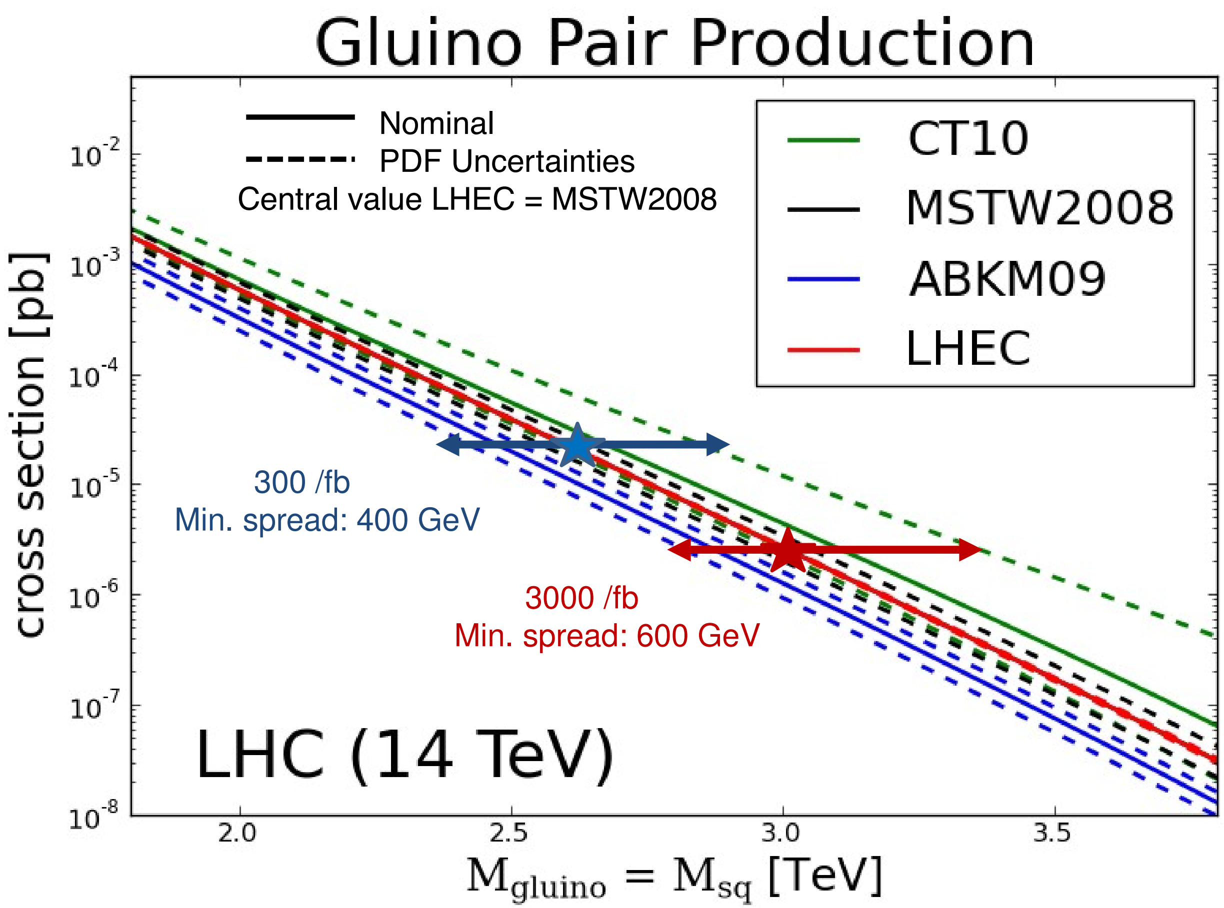
H-bbar coupling to 0.7% precision with $1ab^{-1}$, at an S/B of 1 – studies of τ, c, .. to come

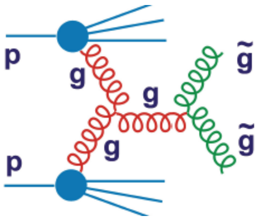
The LHeC WW → H cross section is as large as the ILC Z*→ZH cross section (300fb)…

→ 50pb@LHC, hiLumi + ep [H + PDFs] +QCD@h.o. : LHC - a high precision H factory

U.Klein Talk at EPS 7/2013, B.Mellado, Talk at LPCC 3/2013, CDR..

HL-LHC - Searches

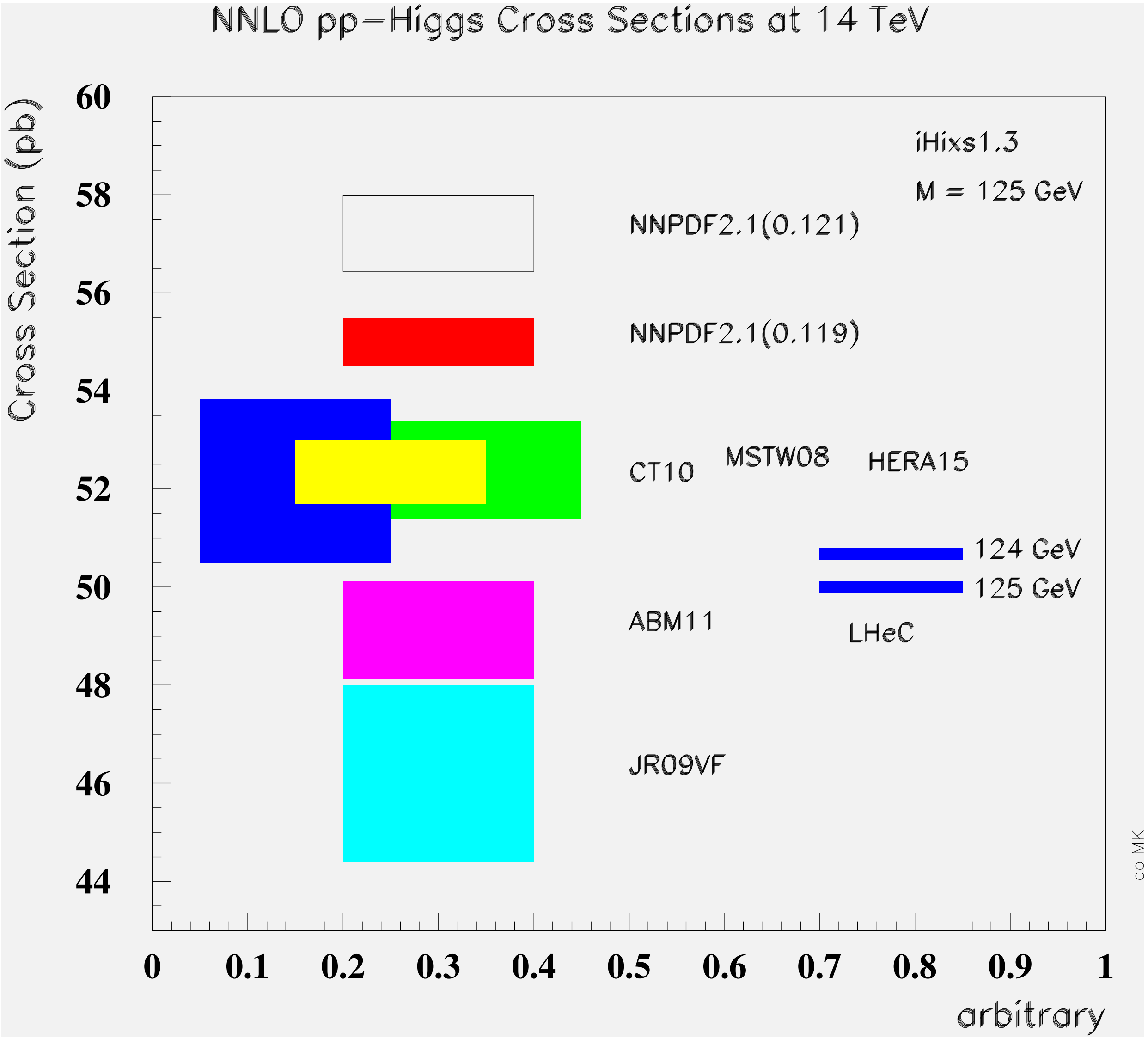




High precision PDFs are needed for the HL-LHC searches in order to probe into the range opened by the luminosity increase and to interprete possibly intriguing effects based on external information.

LHeC BSM poster at EPS13 M.D'Onofrio et al. see also arXiv:1211:5102 Relation LHeC-LHC
Simulated PDFs from LHeC are on LHAPDF (Partons from LHeC, MK, V.Radescu LHeC-Note-2013-002 PHY)

Precision for Higgs at the LHC



O.Brüning and M.Klein arXiv:1305.2090, MPLA 2013

LHeC:

Exp uncertainty of predicted H cross section is 0.25% (sys+sta), using LHeC only.

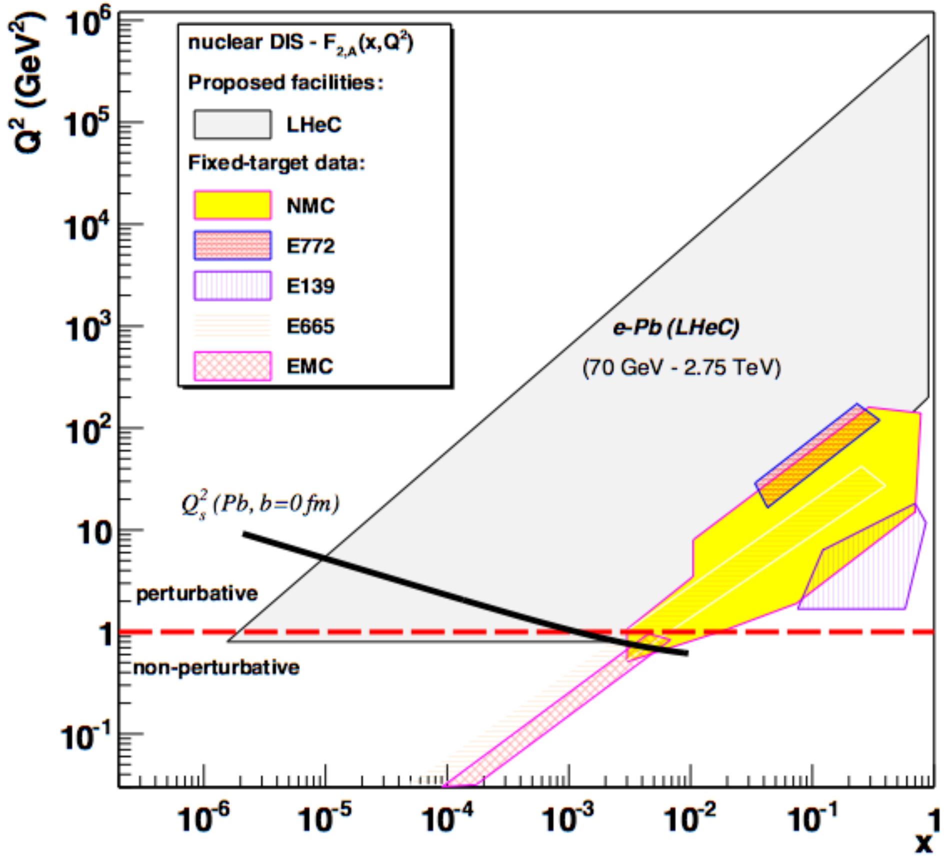
Leads to H mass sensitivity.

Strong coupling underlying parameter (0.005 → 10%). LHeC: 0.0002 !

Needs N^{3}LO

HQ treatment important ...

LHeC as Electron Ion Collider



LHeC is part of NuPECCs long range plan since 2010
$L_{eN} \sim 10^{32}$ cm^{-2} s^{-1}

Extension of kinematic range in lA by FOUR orders of magnitude will change QCD view on nuclear structure and parton dynamics

May lead to genuine surprises…

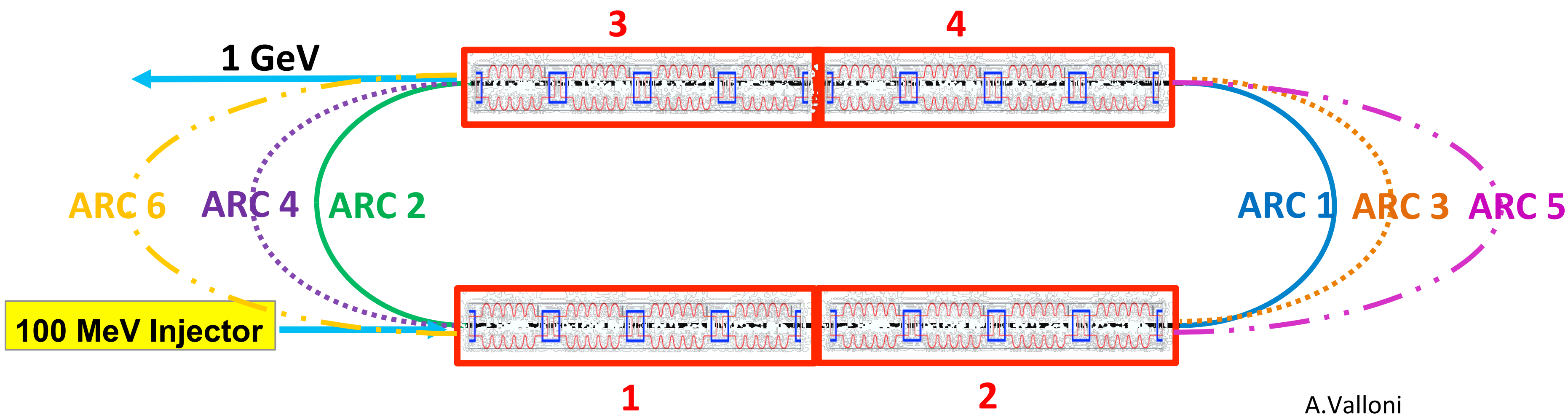
- No saturation of xg (x,Q^2) ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?

Expect saturation of rise at
$$Q^2_s \approx xg\ \alpha_s \approx c\ x^{-\lambda} A^{1/3}$$

Precision QCD study of parton dynamics in nuclei
Investigation of high density matter and QGP
Gluon saturation at low x, in DIS region.

[next LHeC workshop, January 20/21.2014 at Chavannes, near CERN, new IAC (H.Schopper)]

Current CERN ERL Test Facility Design (Final Stage)



[(75 MeV*2)*2]*3 + 100 MeV = 1000 MeV

Daresbury workshop: January 2013: **802 MHz**, basic parameters reviewed

Strong international interest in collaborating:
AsTEC, IHEP Beijing, BINP Novosibirsk, BNL, Cornell, Jefferson Lab, U Mainz..

First steps endorsed recently: Development of 2 cavity cryo modules by 2016 and design of the testfacility by 2014 (CDR) and 2016 ("TDR")

Next decades

Rolf Heuer at
Aix Les Bains
1. 10. 2013

Road beyond Standard Model

LHC results vital to guide the way at the energy frontier

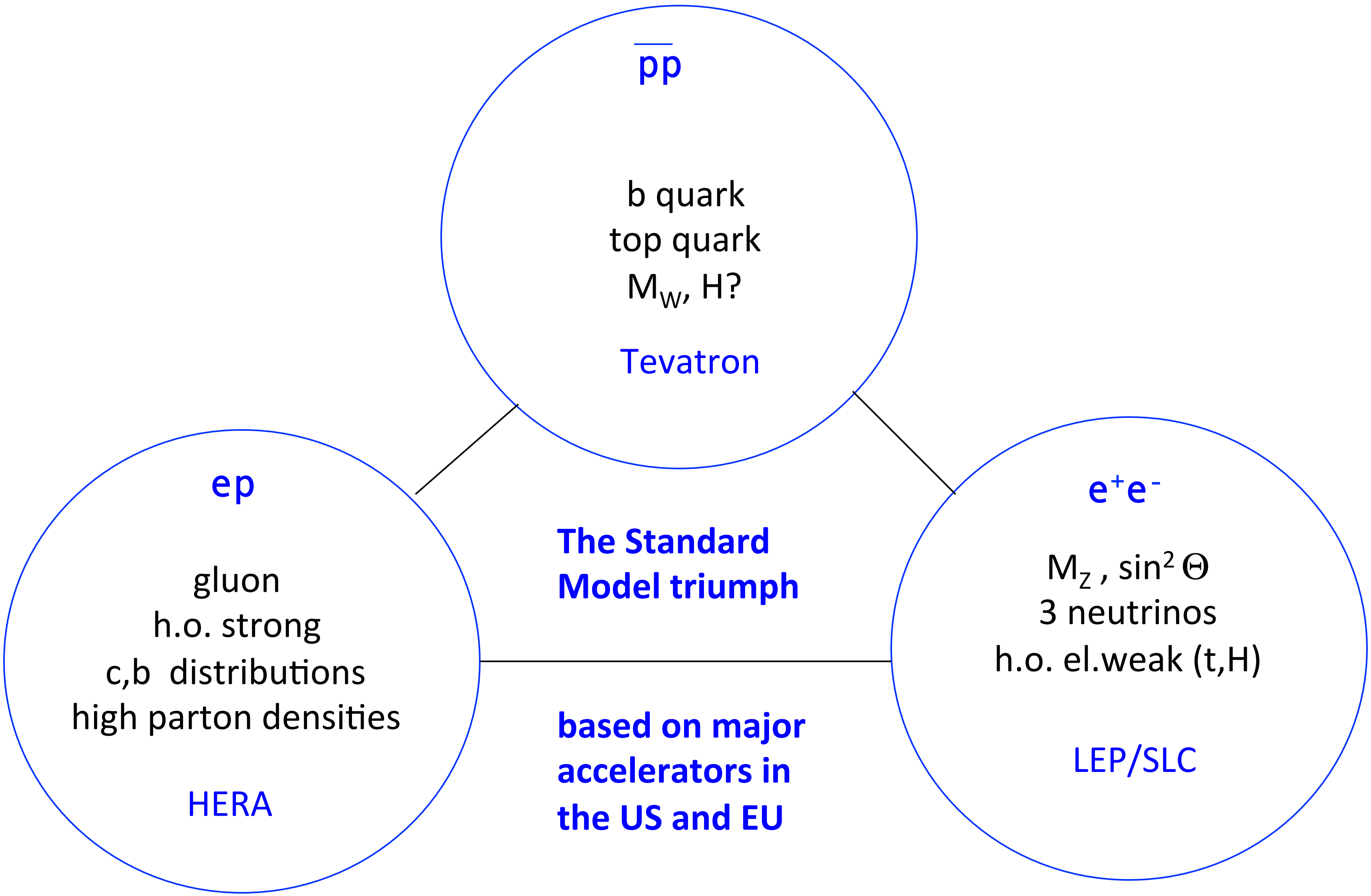
At the energy frontier through synergy of

hadron - hadron colliders (LHC, (V)HE-LHC?)

lepton - hadron colliders (LHeC ??)

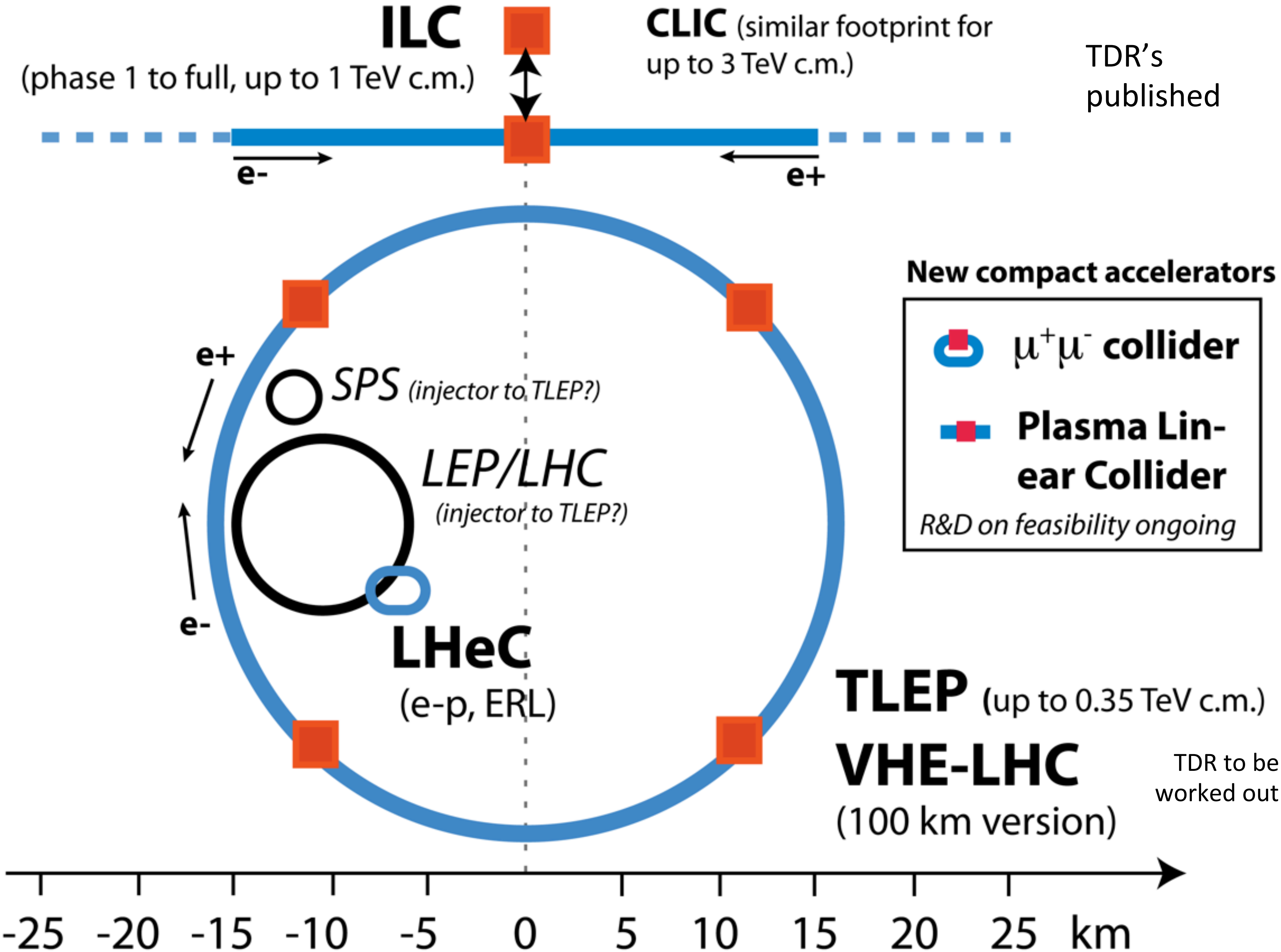
lepton - lepton colliders (LC (**ILC** or CLIC) ?)

Exploration of the Fermi Scale [1985-2015]



With size of investments and efforts, HEP eventually dependent on global economics

Lepton collider options beyond LHC



R.Aßmann, EPS13

FEC- future electron-positron colliders

LINEAR COLLIDER COLLABORATION

Juan Fuster's

My summary of the summary

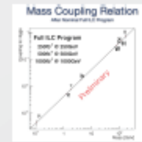
Sense títol, 2009 El Roto, Andrés Rábago García

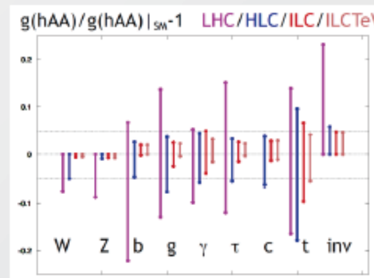
An "expert" has advised me that only the biggest and most aggressive will survive

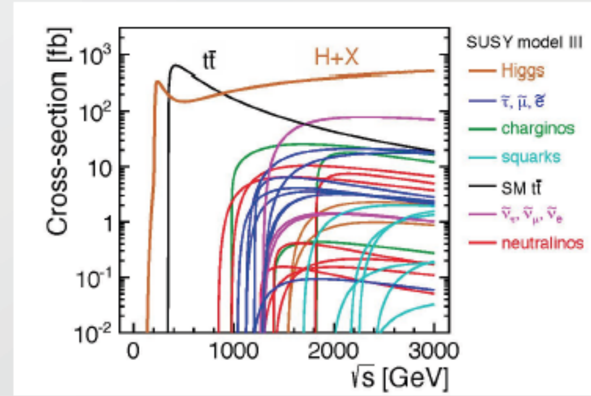
Plenary ECFA talk by Juan Fuster, November 2013 at CERN, on the Linear Collider

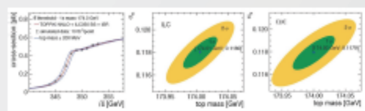
Physics at Linear Colliders from 250 GeV to 3000 GeV

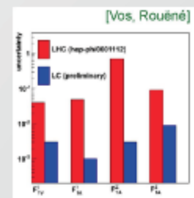
- **Physics case for the Linear Collider:**
  - Higgs physics (SM and non-SM)
  - Top
  - SUSY
  - Higgs strong interactions
  - New Z' sector
  - Contact interactions
  - Extra dimensions
  - ….
- **ILC and CLIC physics case is very similar,** (energy range, technical readiness are the issue)

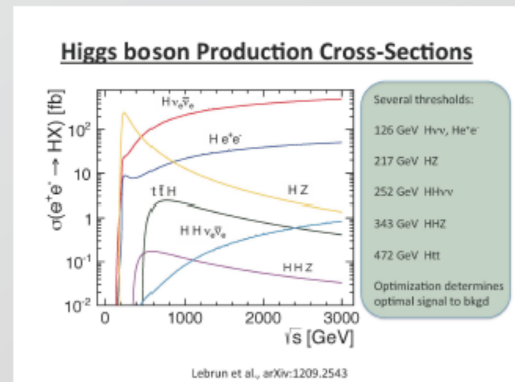










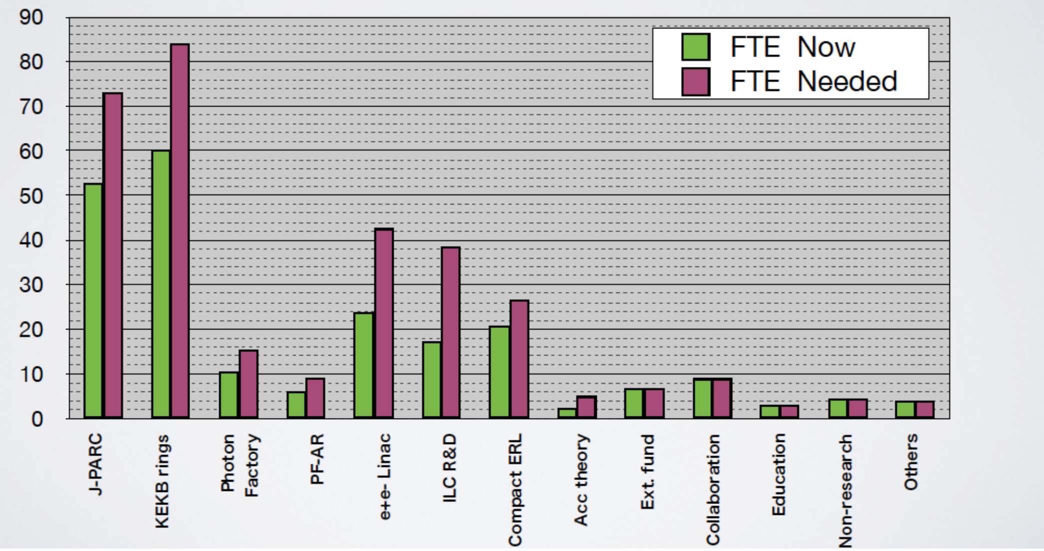


J. Brau et al.	The Physics Case for an e+e- Linear Collider, arXiv:1210.0202
L. Linssen et al **P. Lebrun et al**	CLIC CDR, arXiv:1202.5940,1209.2543
H. Baer et al.	ILC Technical Design Report, Volume 2, Physics at the International Linear Collider, 2013

Concerns*)

Physics reach vs LHC and HL-LHC, compare with SppS and LEP?
Technical parameters:
6nm spot, e^+ from 150m undulators (no experience),
10k cavities at high gradient and their uniformity
Human resources:

・KEK has only about 300 accelerator scientists and engineers, which are 30% of staffs required for the ILC construction, even if all other projects are sacrificed.
・No concrete plan has been proposed to gather from abroad.



*) From K.Oide: input to Japanese Science Council 20. July 2013

Concerns*)

・Although more than 1,000 people are needed at the construction, only about 200 are necessary for the operation.
・It is hard to train specialists only through such a temporal employment.
・It works only when there exists a big lab such as CERN or Fermilab as a buffer, but nothing comparable exists in Japan.

Labs	Main projects	People in accelerators
CERN	LHC SPS/PS/Linac/CTF	~1,200
FNAL	Main Injector Project-X R&D	~600
DESY	PETRA-III / DORIS Euro XFEL	~600
SLAC	LCLS R&D	~800
BNL	RHIC NSLS/NSLS-II	~900
KEK	J-PARC KEKB Linac PF PF-AR STF ATF ERL	~300 (Acc Lab: 220)

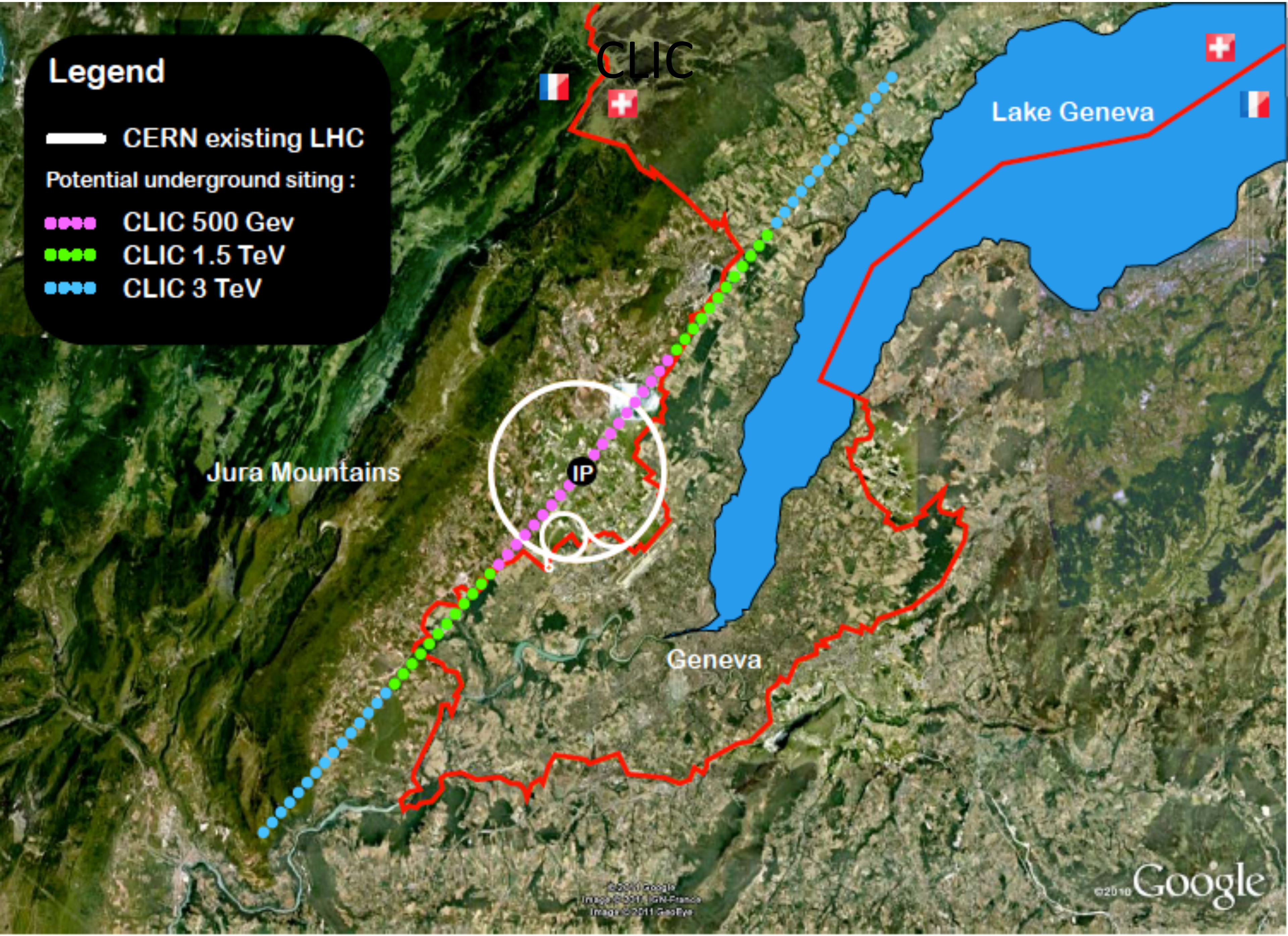
*) From K.Oide: input to Japanese Science Council 20. July 2013

・You have to pay attention on a tendency of some people at the US who ask counter contributions from Japan to the US, if US collaborates in the Japan hosted ILC, which is recognized as a Japanese domestic project by them.

The ILC in Japan can only come as a global enterprise, and it would be after the LHC.
At DESY since ~1993 the LC was promised to begin in 10 years hence, for H AND SUSY.
It is in my view crucial for HEP and the ILC community that a decision was taken soon.

← MK not KO

CLIC


Legend
CERN existing LHC
Potential underground siting :
CLIC 500 Gev
CLIC 1.5 TeV
CLIC 3 TeV
Lake Geneva
Jura Mountains
IP
Geneva

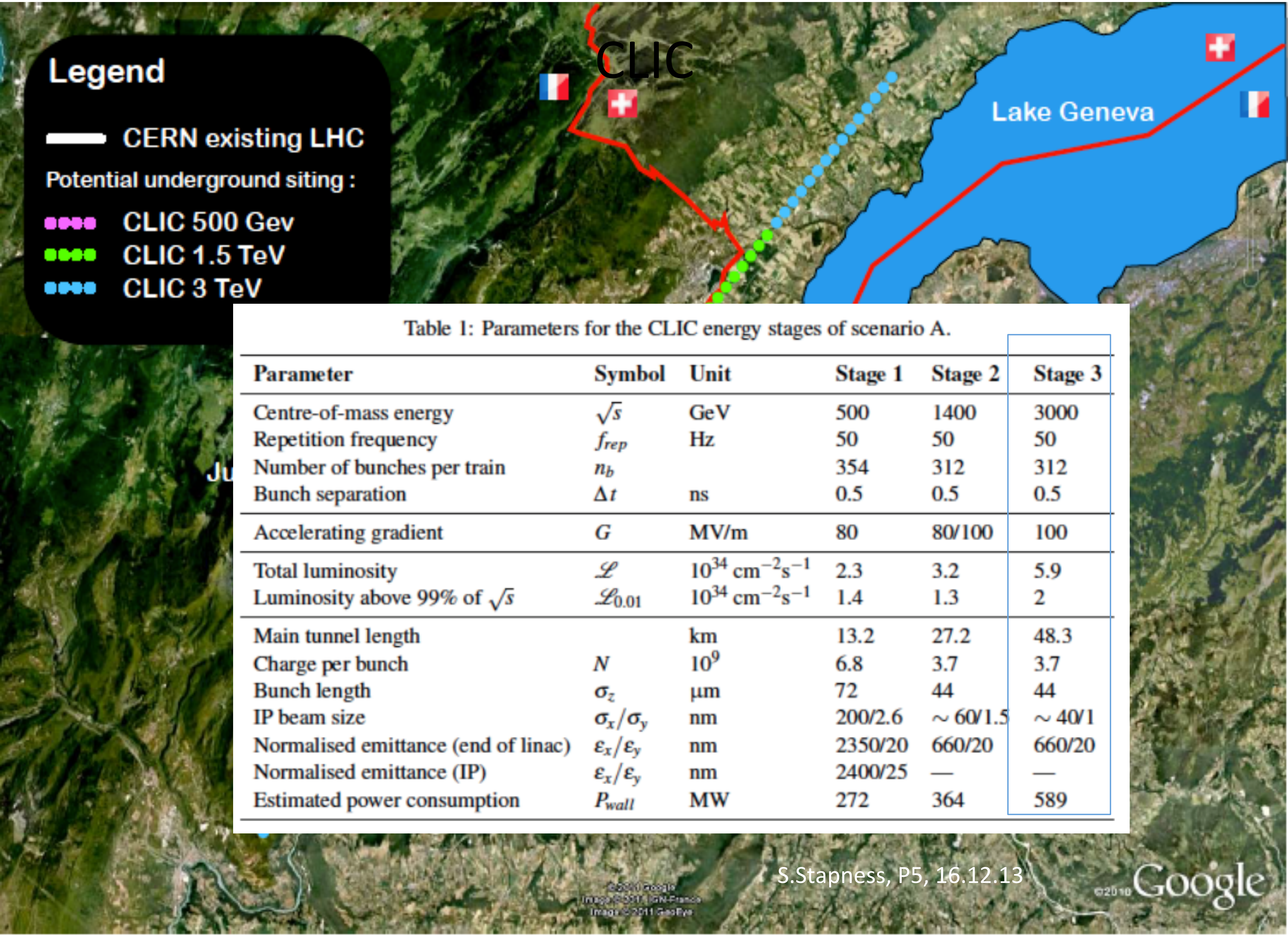
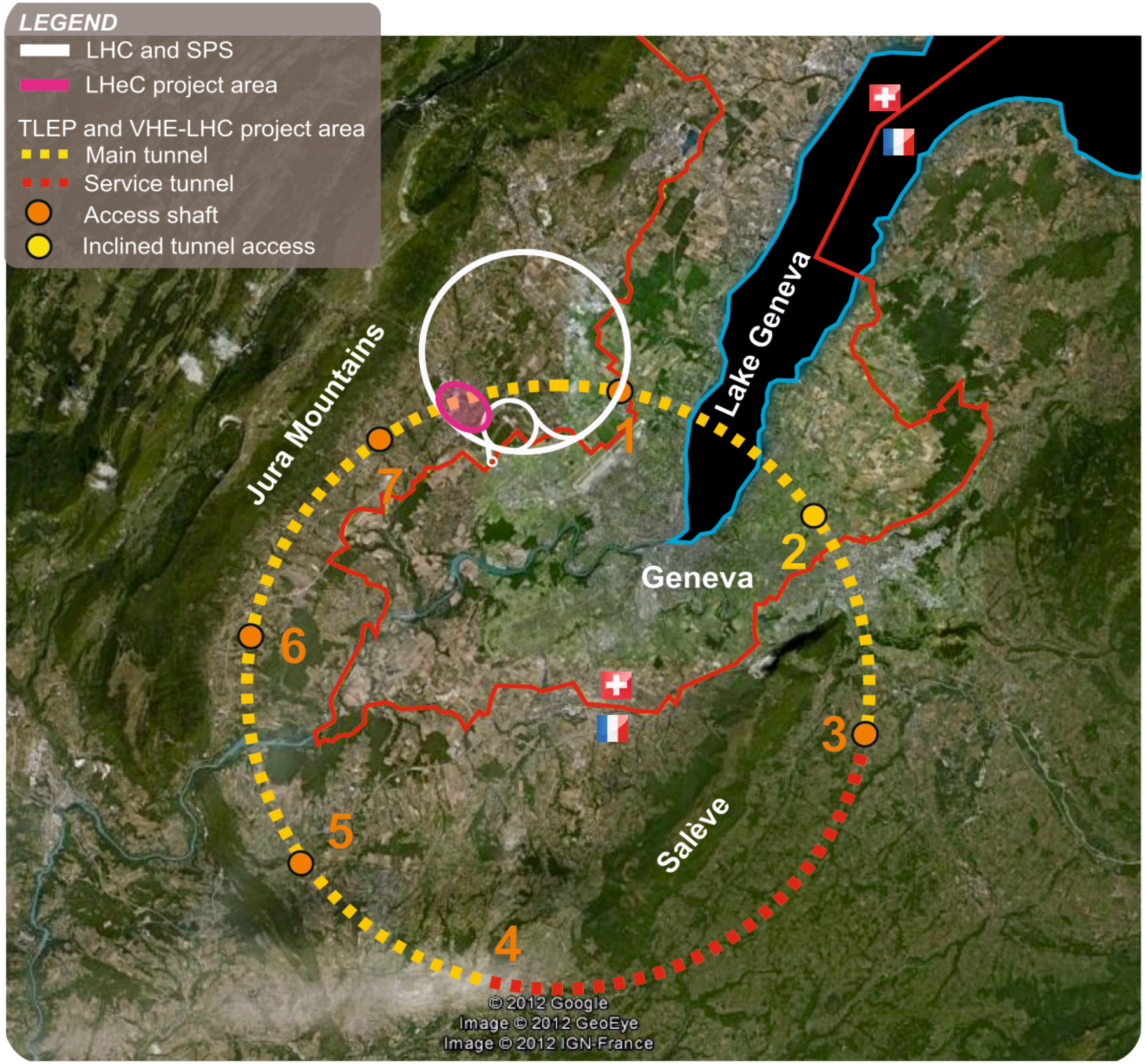


Table 1: Parameters for the CLIC energy stages of scenario A.

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		354	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	80	80/100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	2.3	3.2	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	1.4	1.3	2
Main tunnel length		km	13.2	27.2	48.3
Charge per bunch	N	10^9	6.8	3.7	3.7
Bunch length	σ_z	μm	72	44	44
IP beam size	σ_x/σ_y	nm	200/2.6	$\sim$ 60/1.5	$\sim$ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	2350/20	660/20	660/20
Normalised emittance (IP)	$\varepsilon_x/\varepsilon_y$	nm	2400/25	—	—
Estimated power consumption	P_{wall}	MW	272	364	589

S.Stapness, P5, 16.12.13

Future Rings at CERN*)



FCC

FHC

FHeC

FLC (or FEC)

*) "Civil Engineering Feasibility Studies for Future Ring Colliders at CERN", Contributed by O.Brüning, M.Klein, S.Myers, **J.Osborne**, L.Rossi, C.Waaijer, F.Zimmerman to **IPAC13 Shanghai**

Team preparing FCC Kick-Off & Study

Future Circular Colliders - Conceptual Design Study
Study coordination, host state relations, global cost estimate
M. Benedikt, F. Zimmermann

Hadron injectors
B. Goddard

VL Hadron collider
D. Schulte

Infrastructure, cost estimates
P. Lebrun

e+ e- collider
J. Wenninger

High Field Magnets
L. Bottura

Supercon-ducting RF
E. Jensen

Cryogenics
L. Tavian

Specific Technologies (MP, Coll, Vac, BI, BT, PO)
JM. Jimenez

Physics and experiments

Hadron physic Experiments, infrastructure
A. Ball, F. Gianotti, M. Mangano

e+ e- exper., physics
A. Blondel J.Ellis, P.Janot

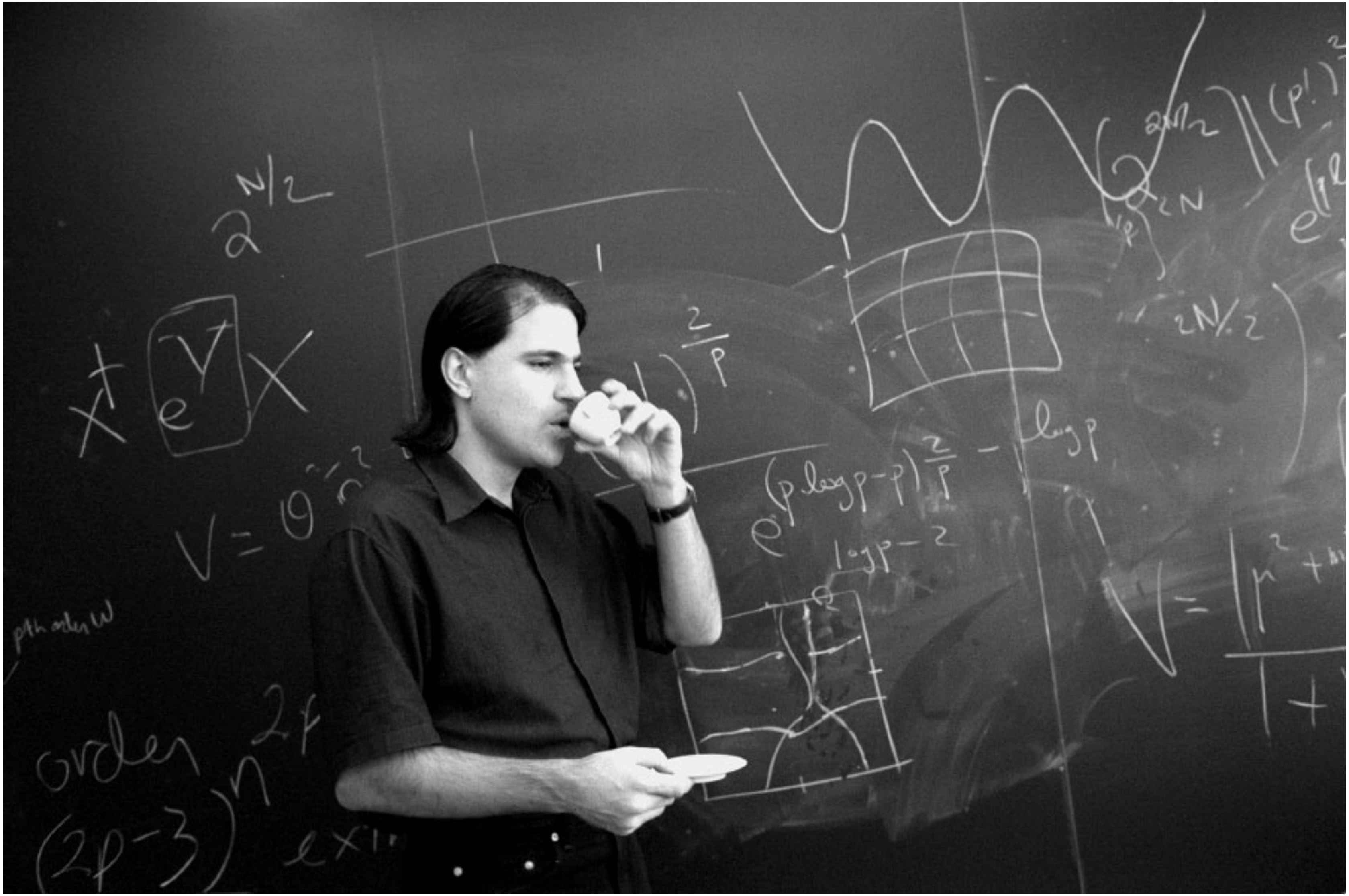
e- p physics +
M. Klein

e- p option
Integration aspects **O. Brüning**

Operation aspects,
energy efficiency, OP & mainten., safety, environment.
P. Collier

Planning (Implementation roadmap, financial planning, reporting)
F. Sonnemann

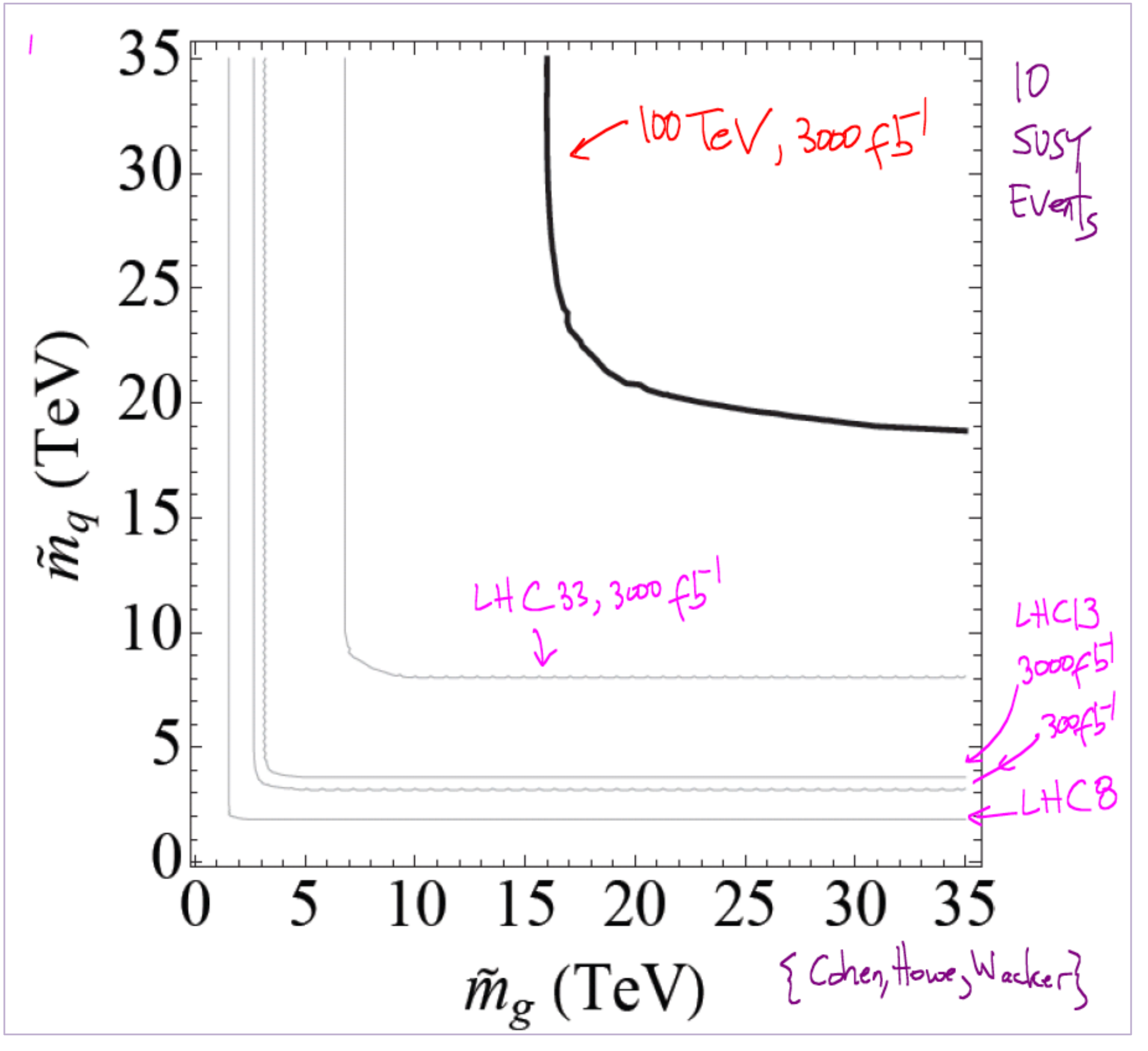
No New Big Accelerator without Big Theory*)



Nima Arkani-Hamed

*) and coffee..

SUSY still on ?



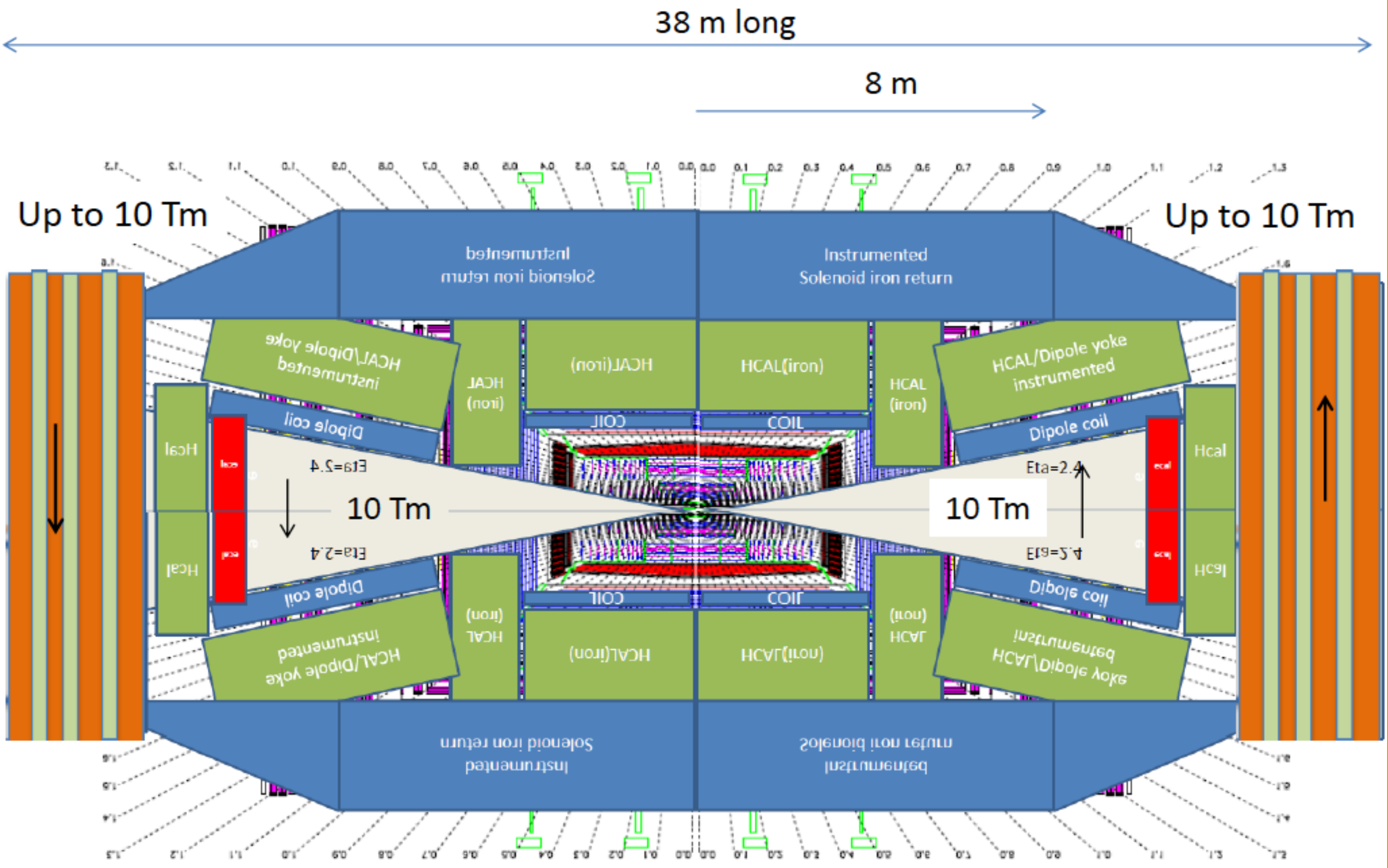
Nima
at Beijing
16.12.13

Main Parameters for FHC *(VHE-LHC)*

- Energy **100 TeV c.m.**
- Dipole field **15 T** (baseline) [20 T option]
- Circumference ~ 100 km
- #IPs 2+2
- Beam-beam tune shift 0.01 (total for 2 IPs)
- Bunch spacing 25 ns [5 ns option]
- Bunch population (25 ns) 10^{11} – $1\text{x}10^{11}$ (beam current 0.5-1 A)
- Normalized rms emittance 2.2 μm
- Luminosity $5\text{x}10^{34}$ $cm^{-2}s^{-1}$
- β^* 1.1 m [2 m conservative option]
- Synchroton radiation arc 26 W/m/ap. [arc fill factor 78%]
- Stored beam energy 8.3 GJ/beam
- Longit. emit damping time 0.5 h
- Straight section length 1400-2000 m (8 or 12)
- Option: Polarized proton beams (with Siberian snakes)

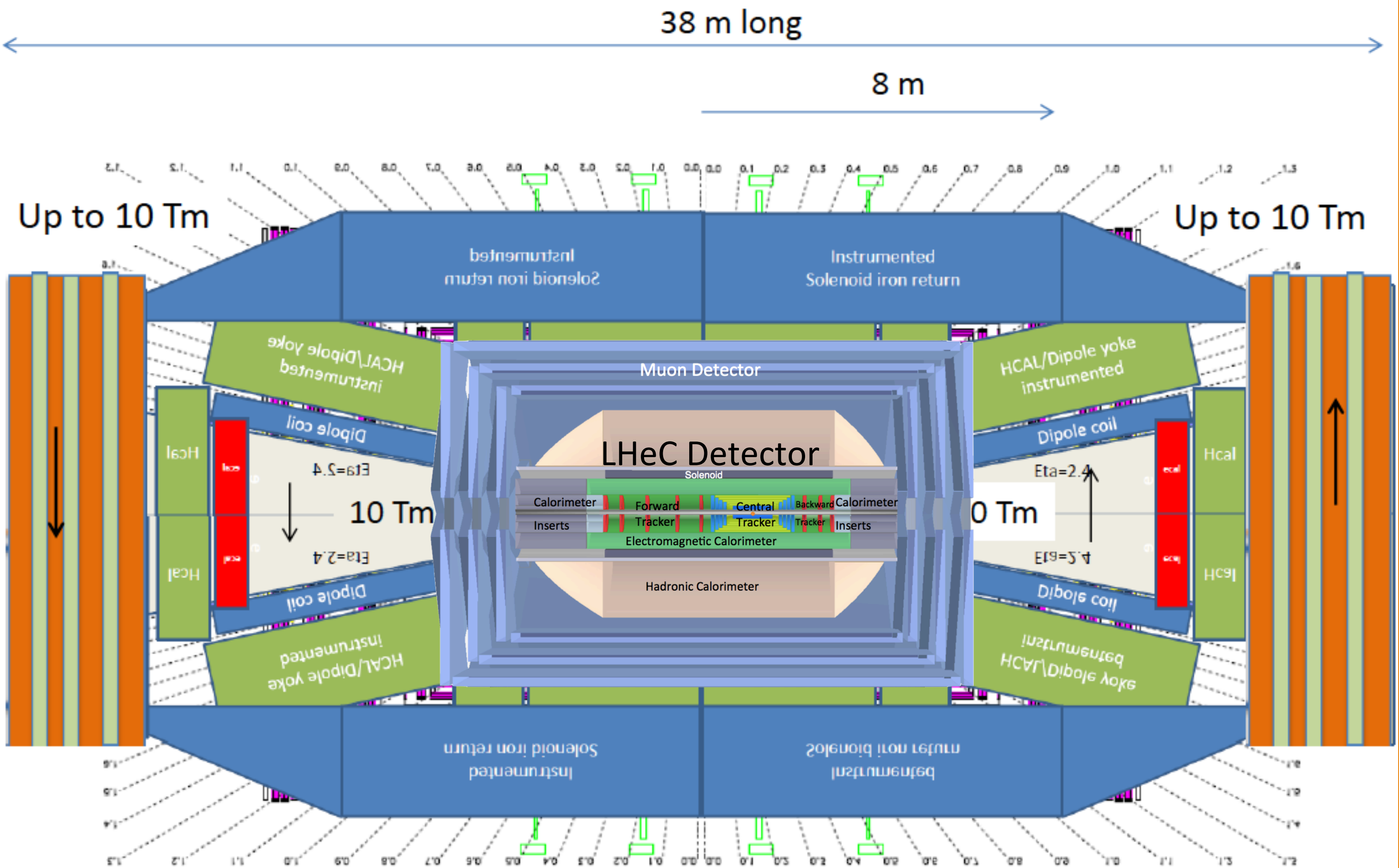
preliminary

A Detector sketch for the FHC



From D.Fournier with F.Gianotti, L.Pontecorvo, H.TenKate Nov13 FHC Meeting at CERN

A Detector sketch for the FHC



From D.Fournier with F.Gianotti, L.Pontecorvo, H.TenKate Nov13 FHC Meeting at CERN

Main Parameters for FLC *(TLEP)*

- Energy c.m. **91 (Z), 160 (W) , 240 (H), 350 ($t\bar{t}$) GeV**
  (energy upgrade 500-ZHH/ttH)
- Circumference ~ 100 km
- Total SR power **≤ 100 MW**
- #IPs 4
- Beam-beam tune shift / IP scaled from LEP
- Beam current 7 mA (TLEP-t) to 1400 mA (TLEP-Z)
- Horiz. geom. emittance 2-20 nm
- Vert. geom. Emittance 2-60 pm
- Luminosity / IP 6×10^{35} $cm^{-2}s^{-1}$ at 91 GeV c.m.
  5×10^{34} $cm^{-2}s^{-1}$ at 240 GeV c.m.
  1×10^{34} $cm^{-2}s^{-1}$ at 350 GeV c.m.
- Top-up injection to cope with short lifetime from rad. Bhabha scattering & beamstrahlung
- Polarization at *Z* pole and *WW* threshold
- β_y^* 1 mm ~ σ_z

preliminary

F.Zimmermann at Beijing 16.12.13

Tentative Parameters for FHeC (RR)

collider parameters	$e^{\pm}$ scenarios			protons
species	$e^{\pm}$	$e^{\pm}$	$e^{\pm}$	p
beam energy [GeV]	**60**	**120**	**250**	**50000**
bunch spacing [μs]	0.125	2	33	0.125 to 33
bunch intensity [10^{11}]	3.8	3.7	3.3	3.0
beam current [mA]	477	29.8	1.6	384 (max)
rms bunch length [cm]	0.25	0.21	0.18	2
rms emittance [nm]	6.0, 3.0	7.5, 3.75	4, 2	0.06, 0.03
$\beta_{x,y}$*[mm]	5.0, 2.5	4.0, 2.0	9.3, 4.5	500, 250
$\sigma_{x,y}$* [μm]	5.5, 2.7			
b-b parameter ξ	**0.13**	0.050	0.056	0.017
hourglass reduction	**0.42**	**0.36**	0.68	
CM energy [TeV]	3.5	4.9	7.1	
luminosity[10^{34}cm^{-2}s^{-1}]	**21**	**1.2**	**0.07**	

F.Zimmermann at Beijing 16.12.13

FCC at Geneva

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Fabiola Gianotti
Brennan Goddard
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title

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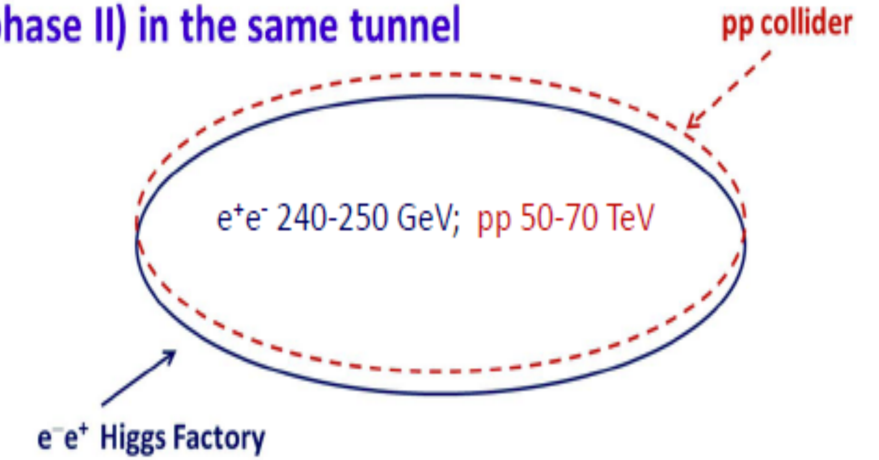
…. Guide to program of IPAC13 Shanghai May 2013

Yifang Wang
Beijing 16.12.13

CEPC+SppC

- We are looking for a machine after BEPCII
- A circular Higgs factory fits our strategic needs in terms of timing, science goal, technological & economical scale, manpower reality, etc.
- Its life can be extended to a pp collider: great for the future

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



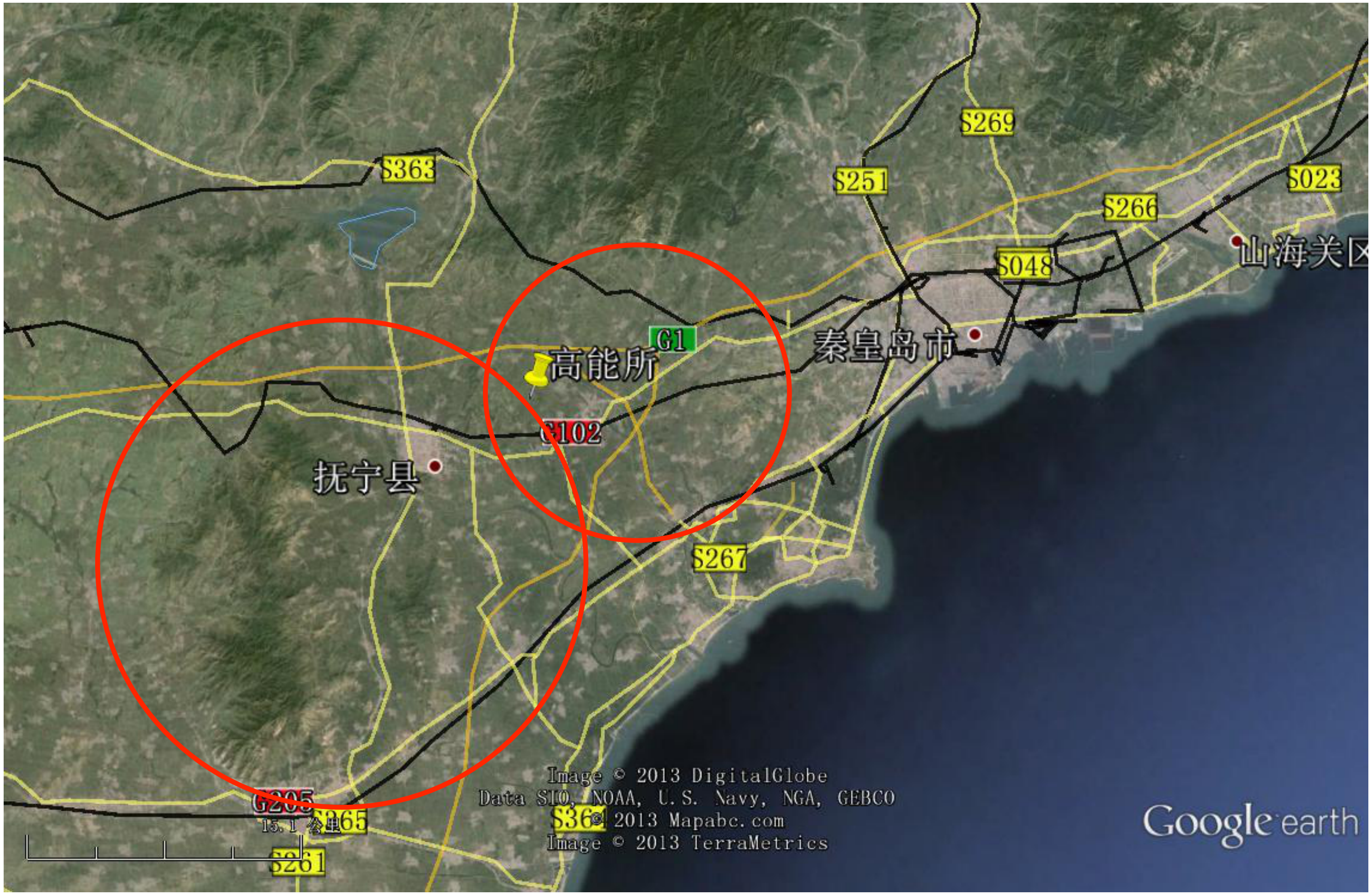
- Circular Higgs factory is complementary to ILC
  - Push-pull option
  - Low energy vs high energy

We hope to collaborate with anyone who is willing to host this machine. Even if the machine is not built in China, the process will help us to build the HEP in China

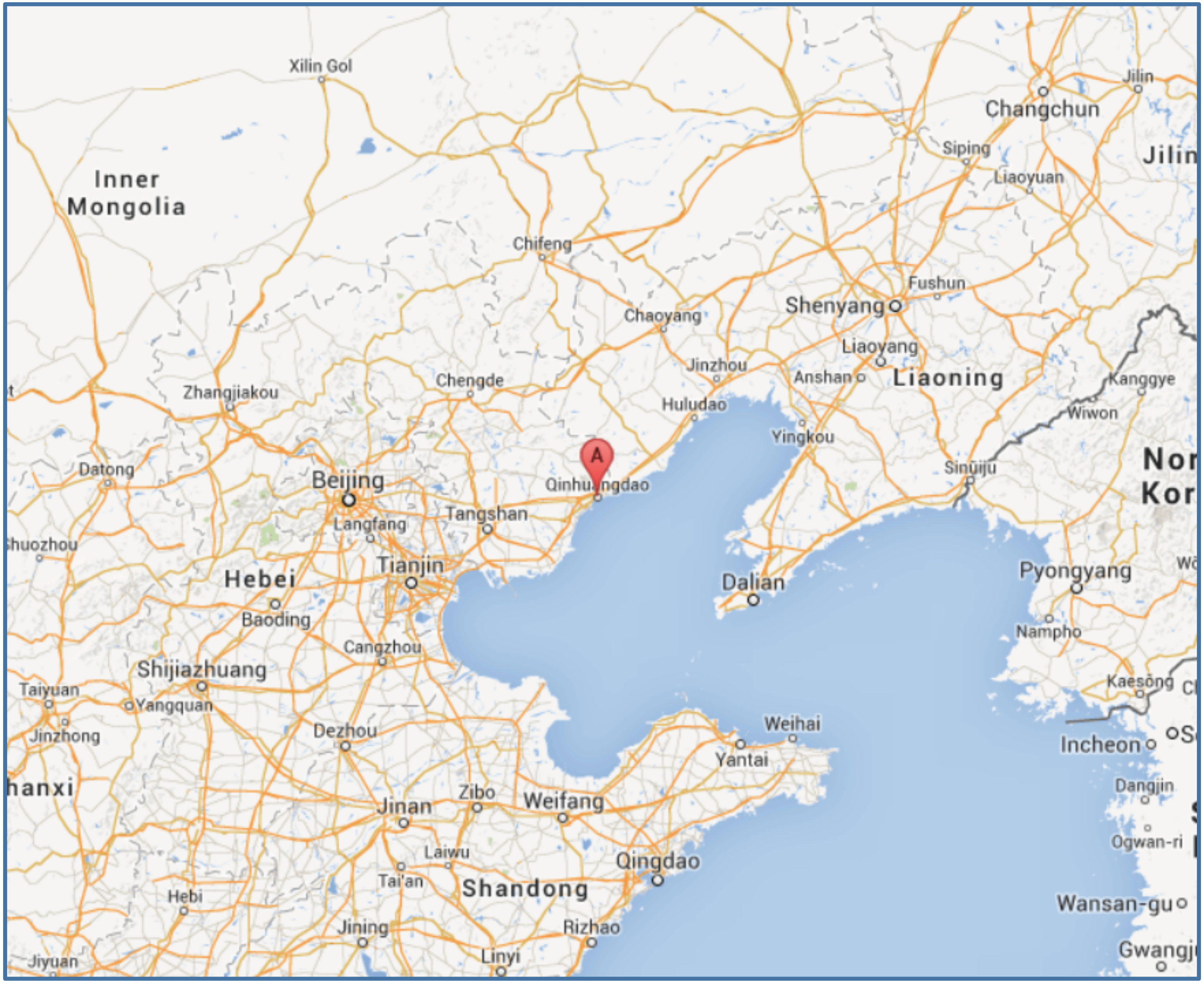
Yifang Wang
Beijing 16.12.13

CEPC+SppC

– For example, Qin-Huang-Dao



Qin-Huang-Dao



Yifang Wang
Beijing 16.12.13

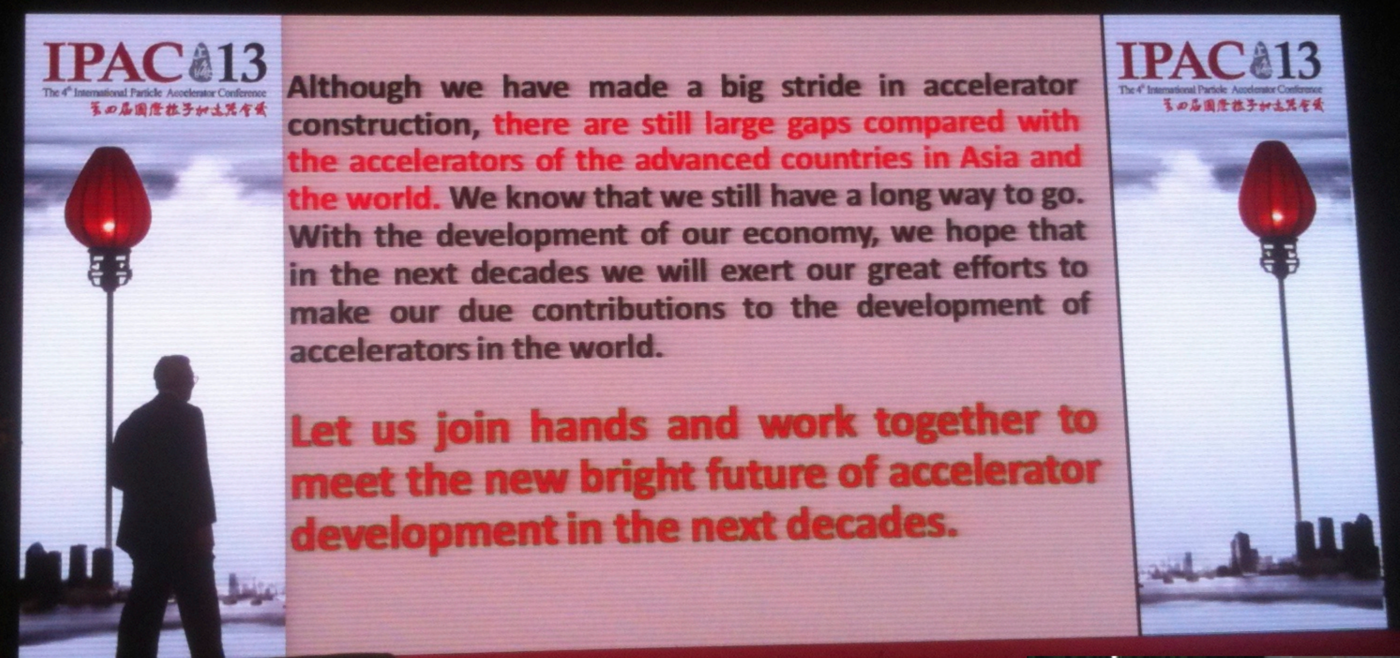
CEPC+SppC

- When(dream):
  - CPEC
    - Pre-study, R&D and preparation work
      - Pre-study: 2013-15
      - R&D: 2015-2020
      - Engineering Design: 2015-2020
    - Construction: 2021-2027
    - Data taking: 2028-2035
  - SPPC
    - Pre-study, R&D and preparation work
      - Pre-study: 2013-2020
      - R&D: 2020-2030
      - Engineering Design: 2030-2035
    - Construction: 2035-2042
    - Data taking: 2042 -

Kick-off @ Sep 2013

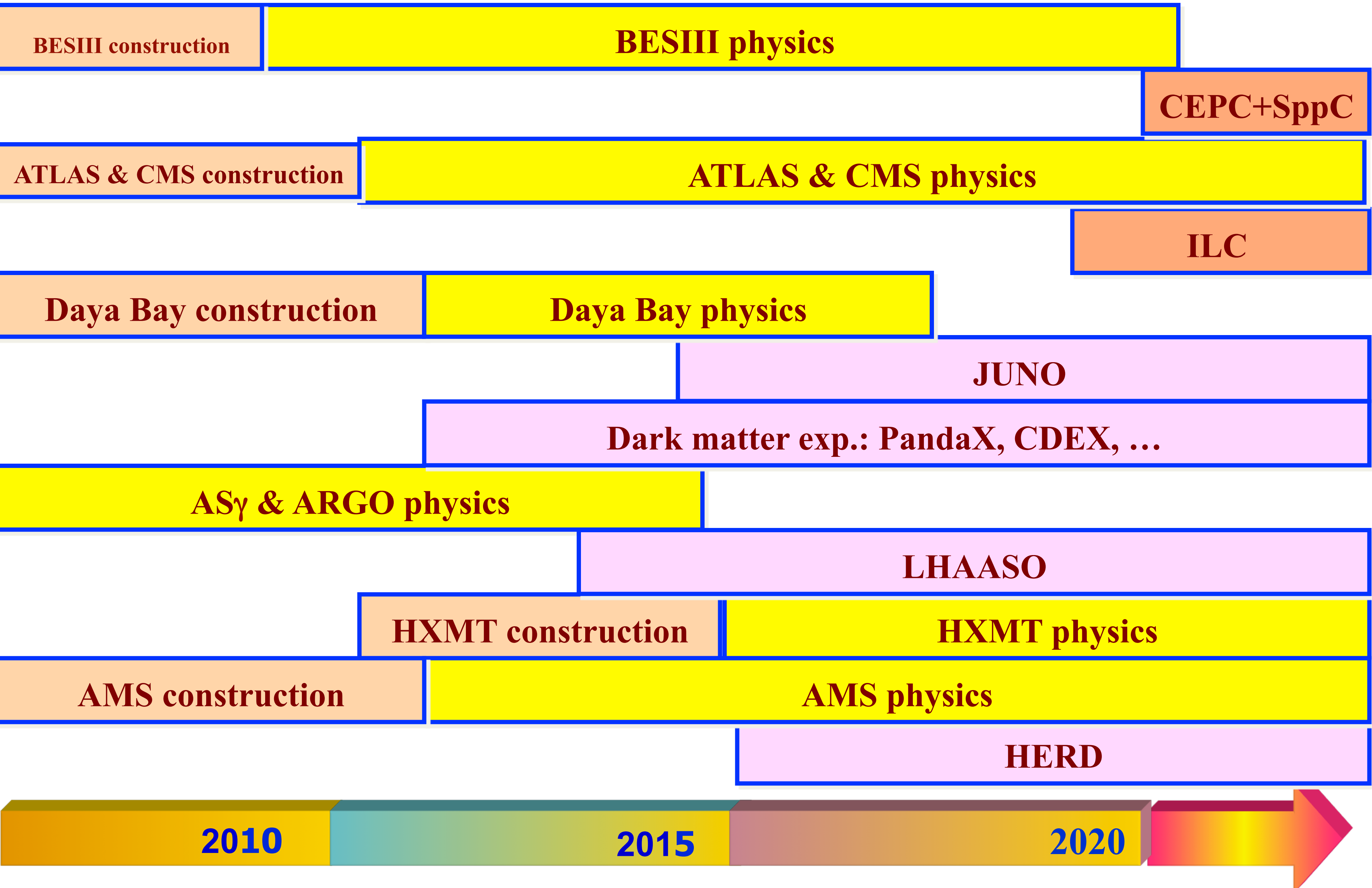
cf detector talk yesterday by Manqui Ruan at Beijing workshop

China



Shouxian Fang

Particle Physics in China： a Possible Future



Remarks

The future collider is the LHC at high luminosity.

It may be complemented by the LHeC for Higgs precision, search range & QCD.

The future planning of e^+e^- (Higgs) machines runs a bit wild, where is ICFA

An 80- 100km tunnel is being considered at CERN as a base for a new pp collider, with an ep complement based on the 60 GeV ERL linac, or the e ring, and an e+e- circular Higgs facility "as an intermediate step" (RH).
Kick off meeting February 12-14 at Geneva, 2014. This needs overriding reasons.

Technically, for pp the goal are high field SC magnets and for ee and ep are high quality SC RF cavities [cf backup]

Apparently a focus of HEP moves from the US to Asia, and CERN has to struggle.

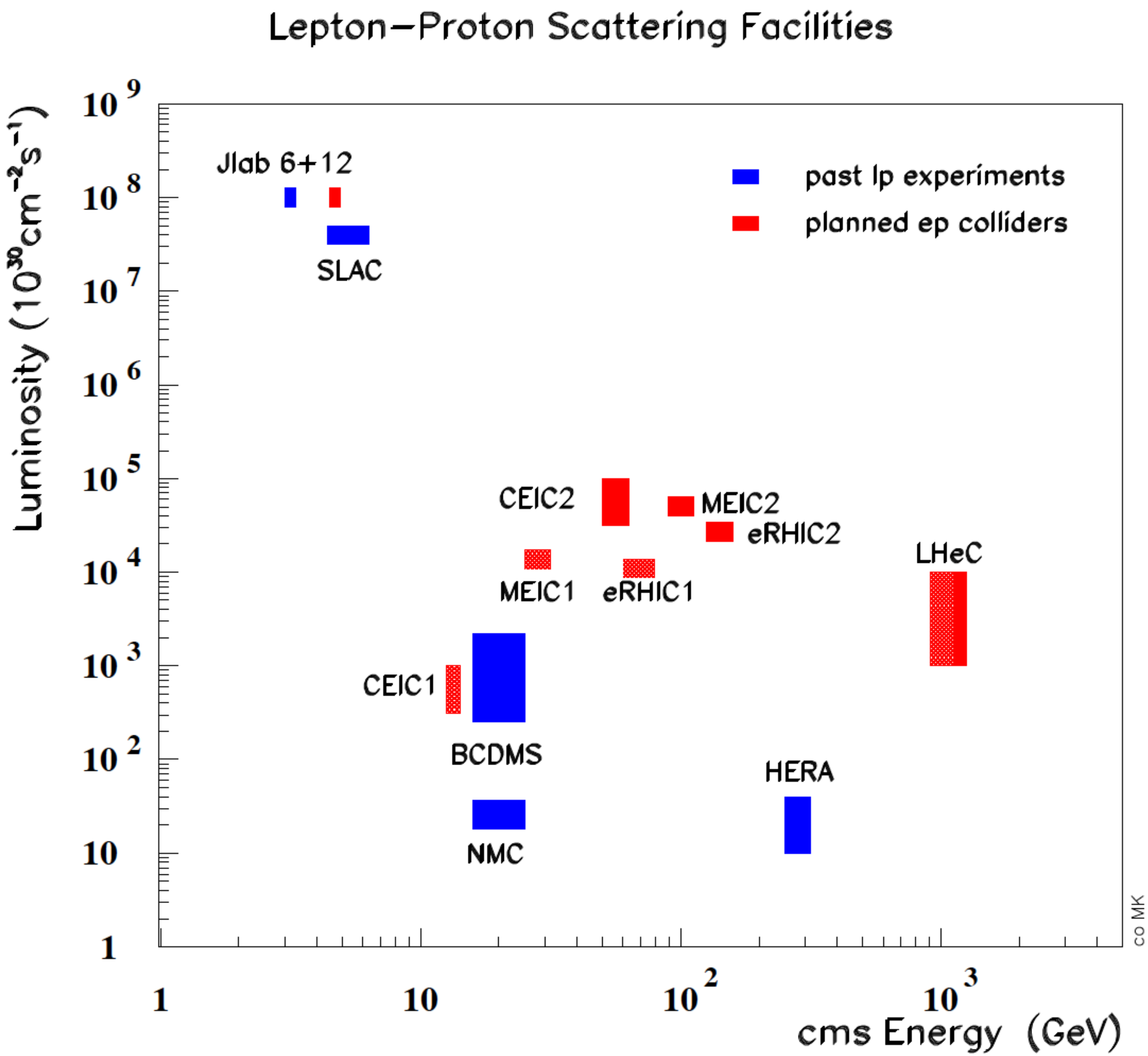
Merry Christmas and Many Christmases to enjoy

Victor Weisskopf

Predicting is difficult especially when it concerns the future.

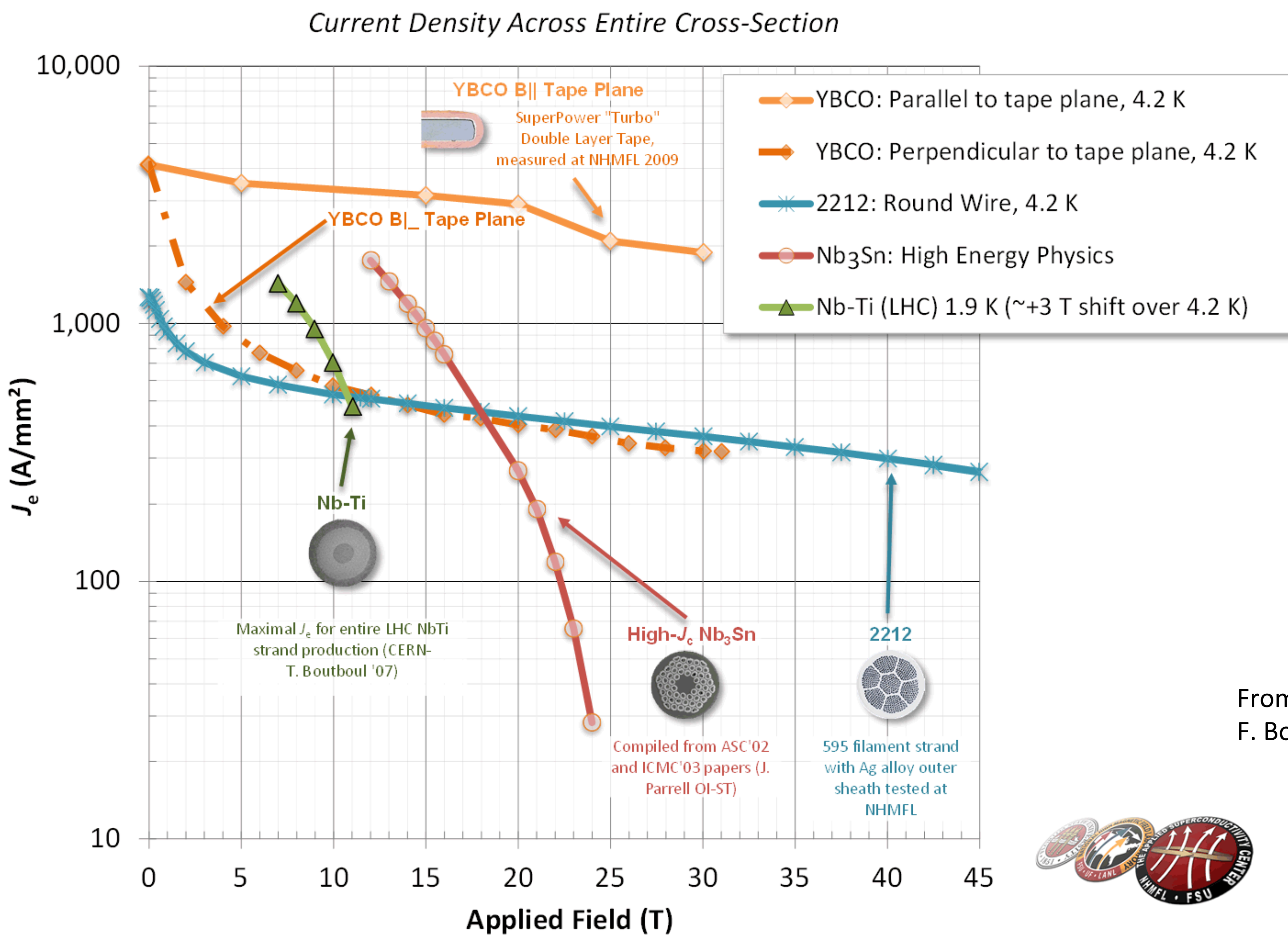
I heard this from VW at Leipzig in a seminar on the MIT bag model, 1975

backup



Energy frontier deep inelastic scattering: Higgs, top, searches, PDFs low x, nuclear matter. These and further physics topics require maximum beam energy and high luminosity.

Development of SuperConductorMagnets

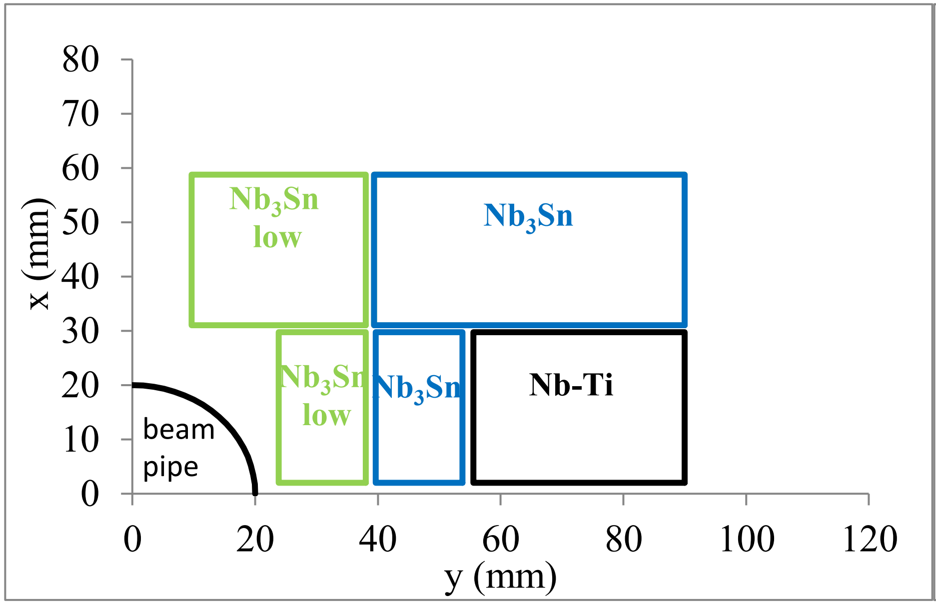


From a talk by
F. Bordry at EPS13

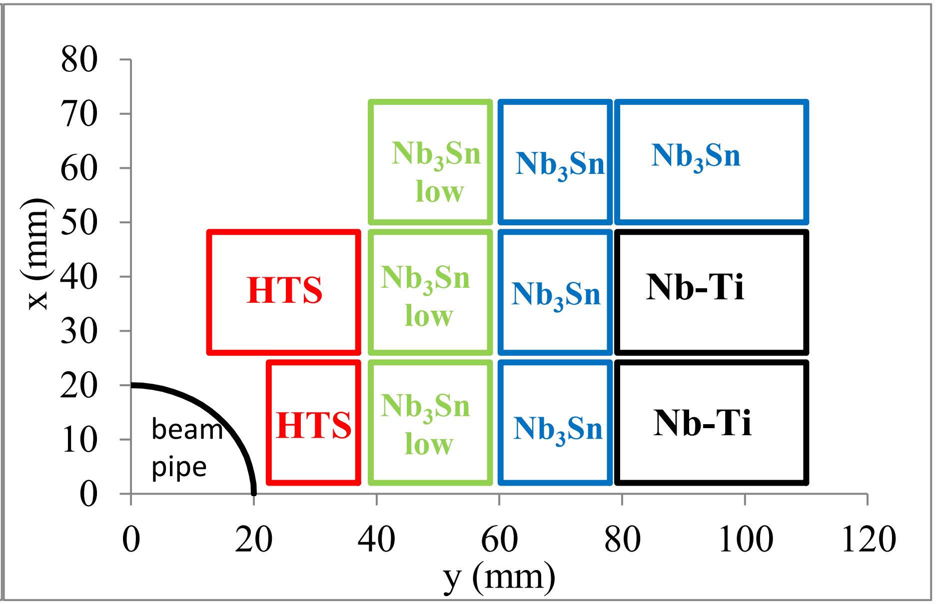
Nb_3Sn to reach 15 T → 100 TeV cms energy in pp in a 100 km tunnel. HTS - current ??

Cost-Optimized Magnets for FHC

15-T dipole



20-T dipole



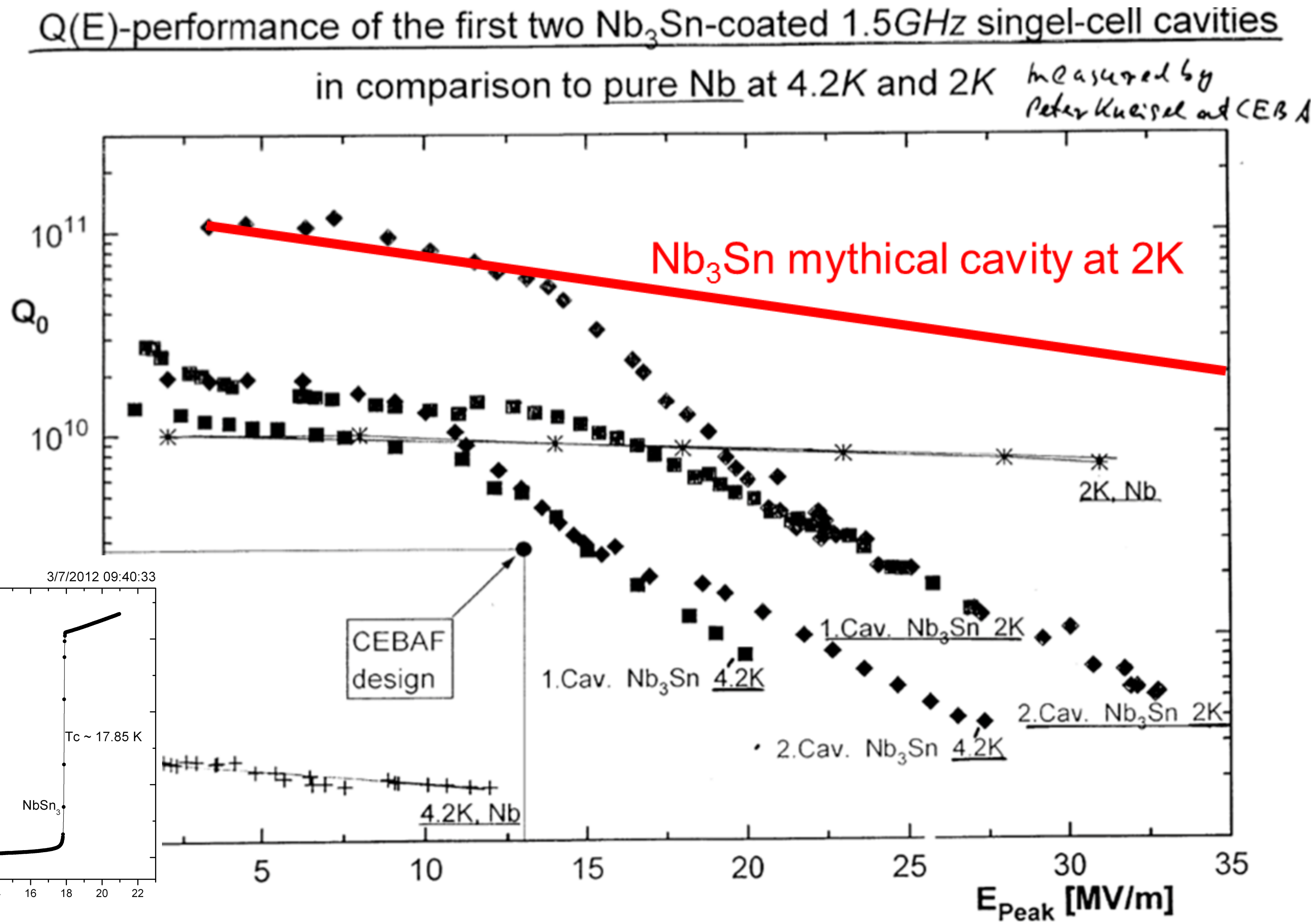
15 T dipoles + 100 km circumference

→ 100 TeV *pp*

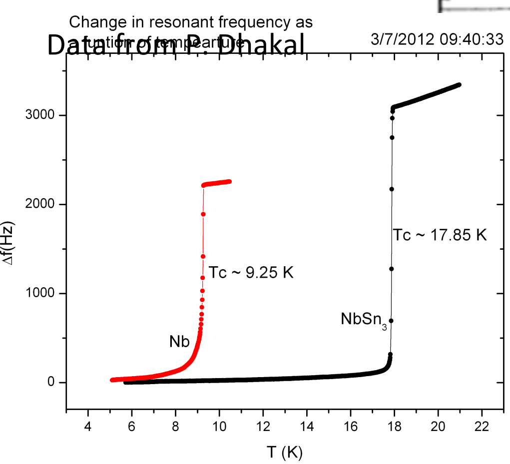
E. Todesco, L. Rossi, P. McIntyre

potential of Nb_3Sn for SRF cavities

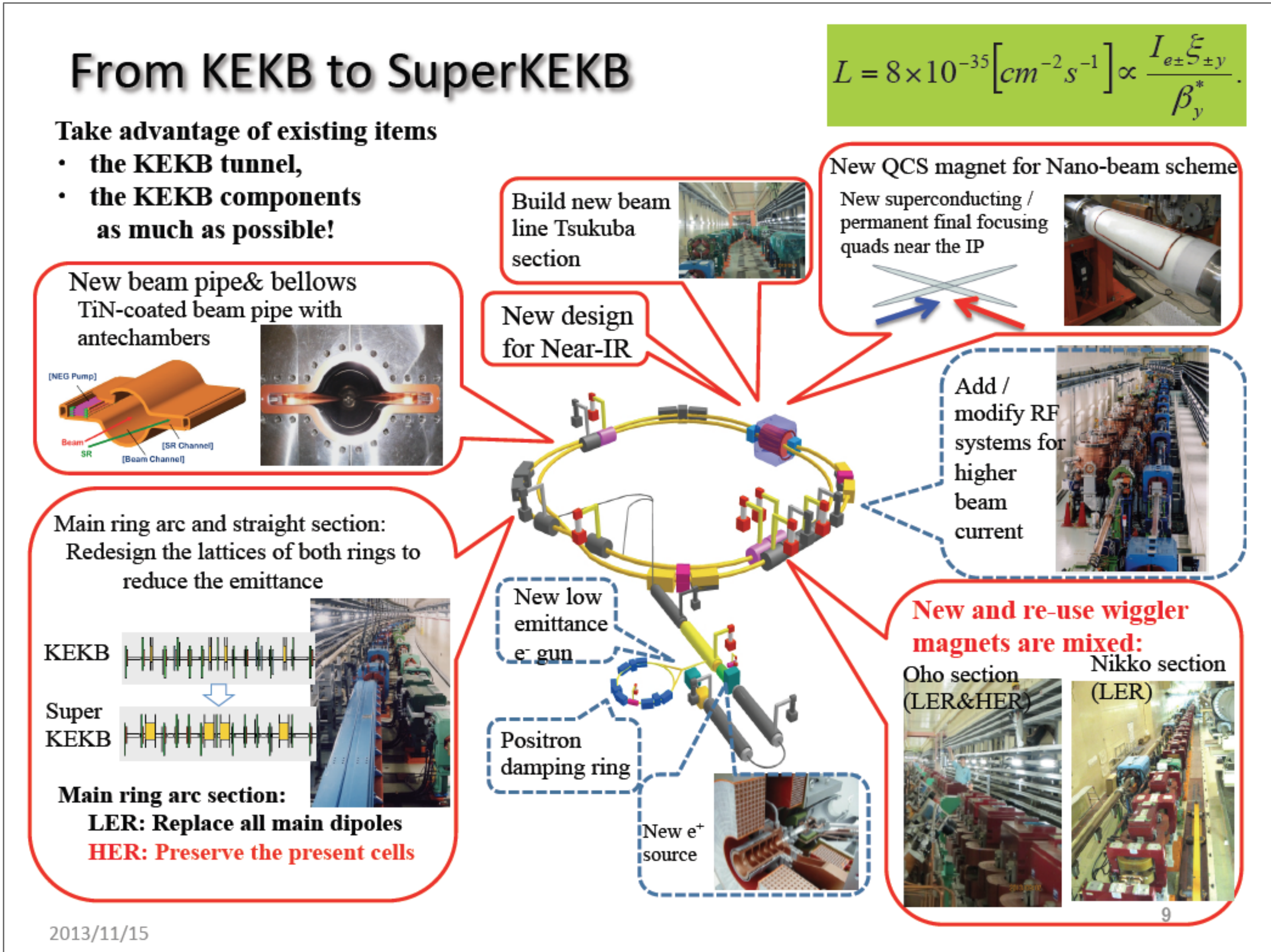
R&D progressing at JLAB & Cornell



Data from P. Dhakal



Robert Rimmer, JLAB



C.Schwanda at ECFA 11/13