ICHEP2012
Melbourne

36th International Conference on High Energy Physics

4 – 11 July 2012
Melbourne Convention and Exhibition Centre

Closing Talk
Future Machines
Outlook

R.-D. Heuer, CERN

Melbourne, July 11, 2012

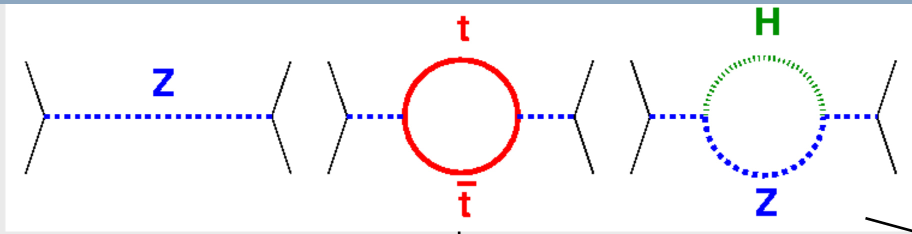
Past few decades

"Discovery" of Standard Model

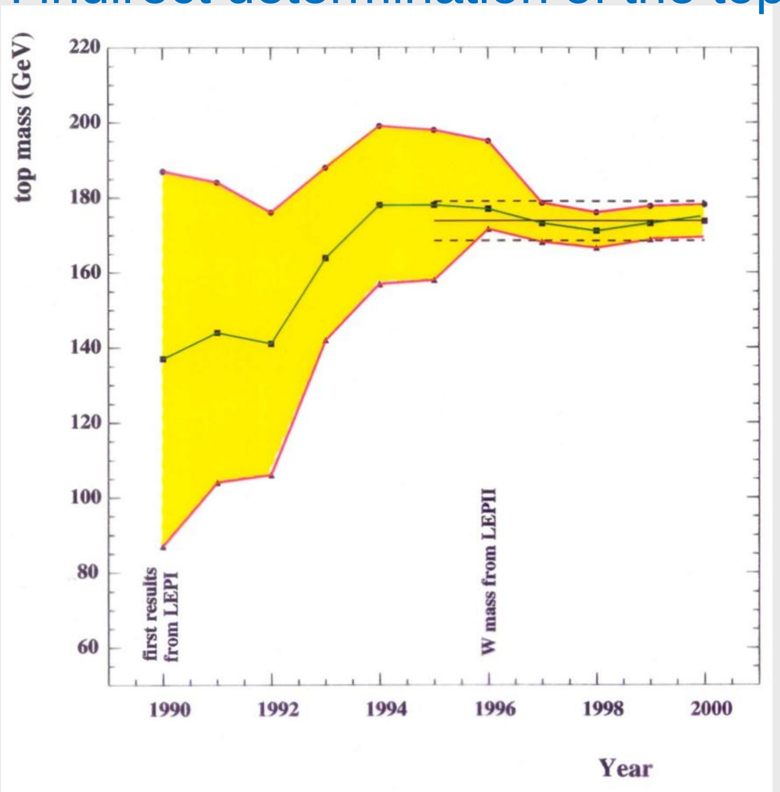
through ***precision measurements*** *at the*

- ***Intensity frontier*** *(e.g. neutrino facilities, b-factories, rare decay experiments. . .)*
- ***Energy frontier*** *(through the interplay of hadron, lepton and lepton-hadron colliders)*

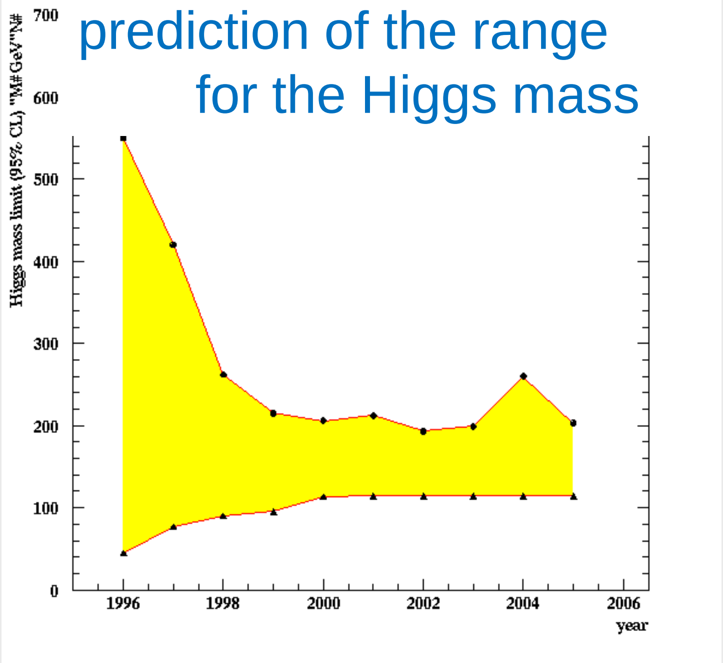
Test of the SM at the Level of Quantum Fluctuations



LEP: indirect determination of the top mass



prediction of the range for the Higgs mass



possible due to

- precision measurements
- known higher order electroweak corrections

$$\propto \left(\frac{M_t}{M_W}\right)^2, \ln\left(\frac{M_h}{M_W}\right)$$

‘Today’

Exciting Times

- ***At the intensity frontier, results from neutrino experiments at reactors open new prospects***
- ***At the energy frontier, the LHC brings us into unexplored territory***

What's new

landmark conference ICHEP2012

- At the intensity frontier:

Large mixing angle

θ_{13} around 9 °

Daya Bay and RENO:

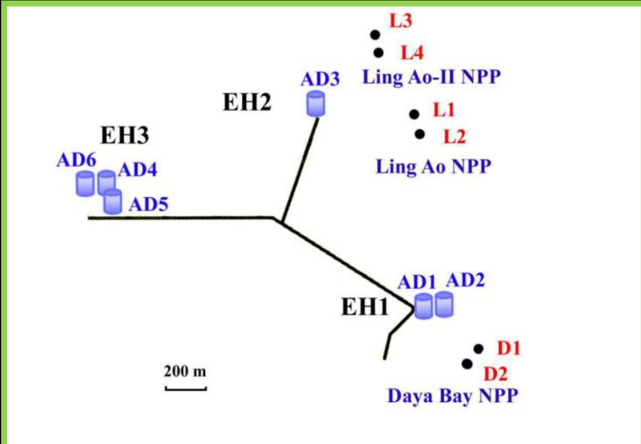
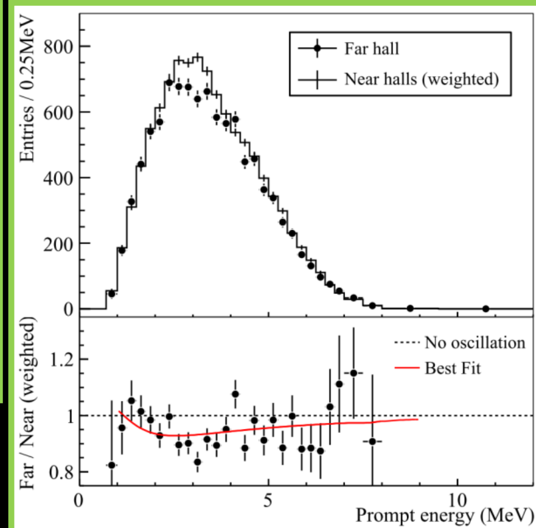
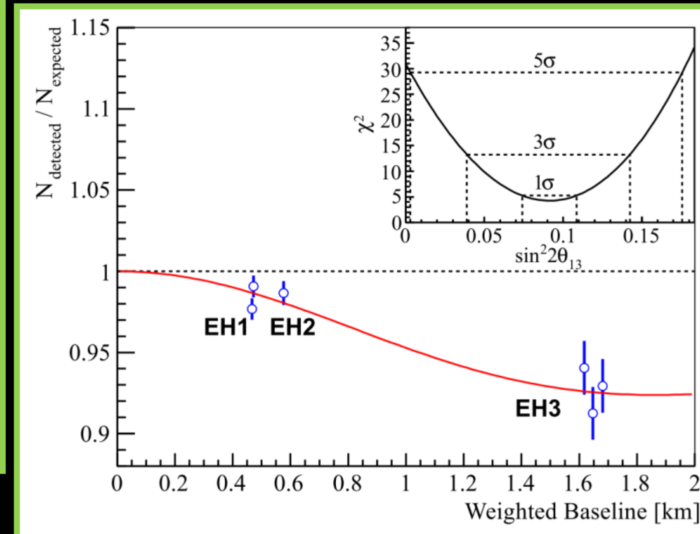
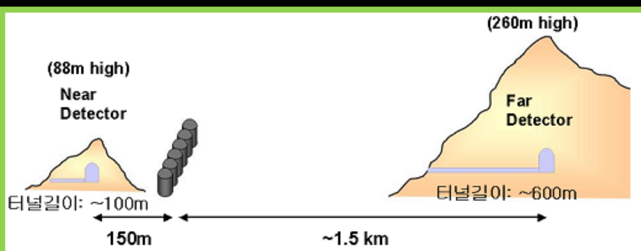
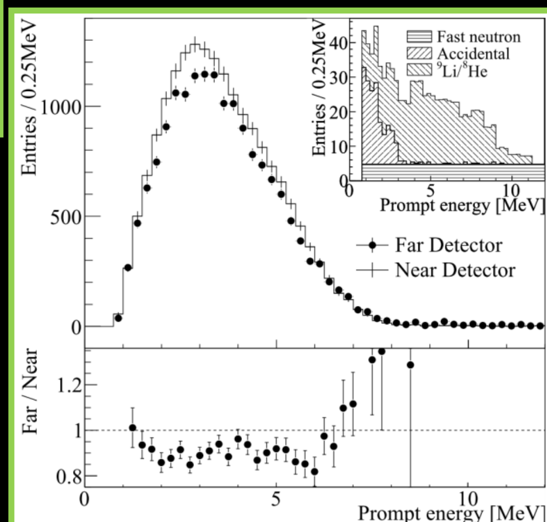


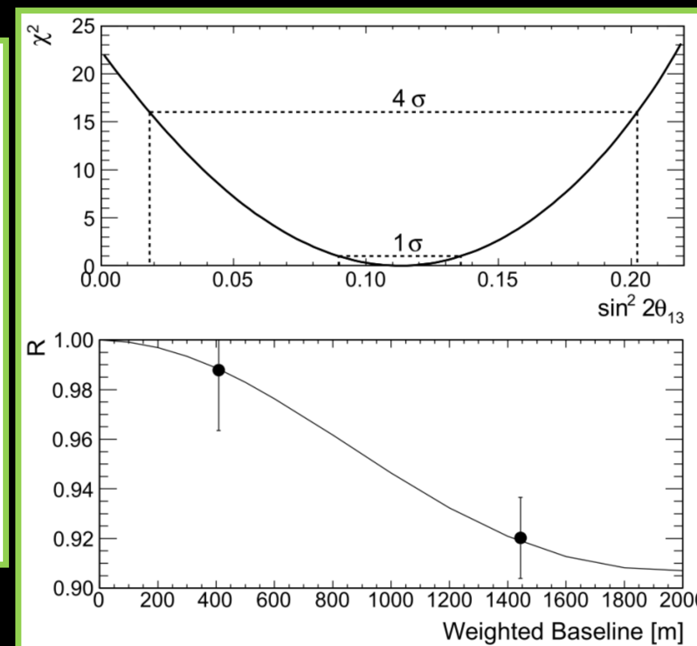
FIG. 1. Layout of the Daya Bay experiment. The dots represent reactors, labeled as D1, D2, L1, L2, L3 and L4. Six ADs, AD1–AD6, are installed in three EHs.











	$\sin^2 2\theta_{13}$		
	Value	Statistical	Systematic
D-Chooz	0.086	0.041	0.030
Daya Bay	0.092	0.016	0.005
RENO	0.113	0.013	0.019
Mean	***0.098***	***0.013***	

	$\sin^2 \theta_{13}$	
Mean	***0.025***	***0.003***

What's new

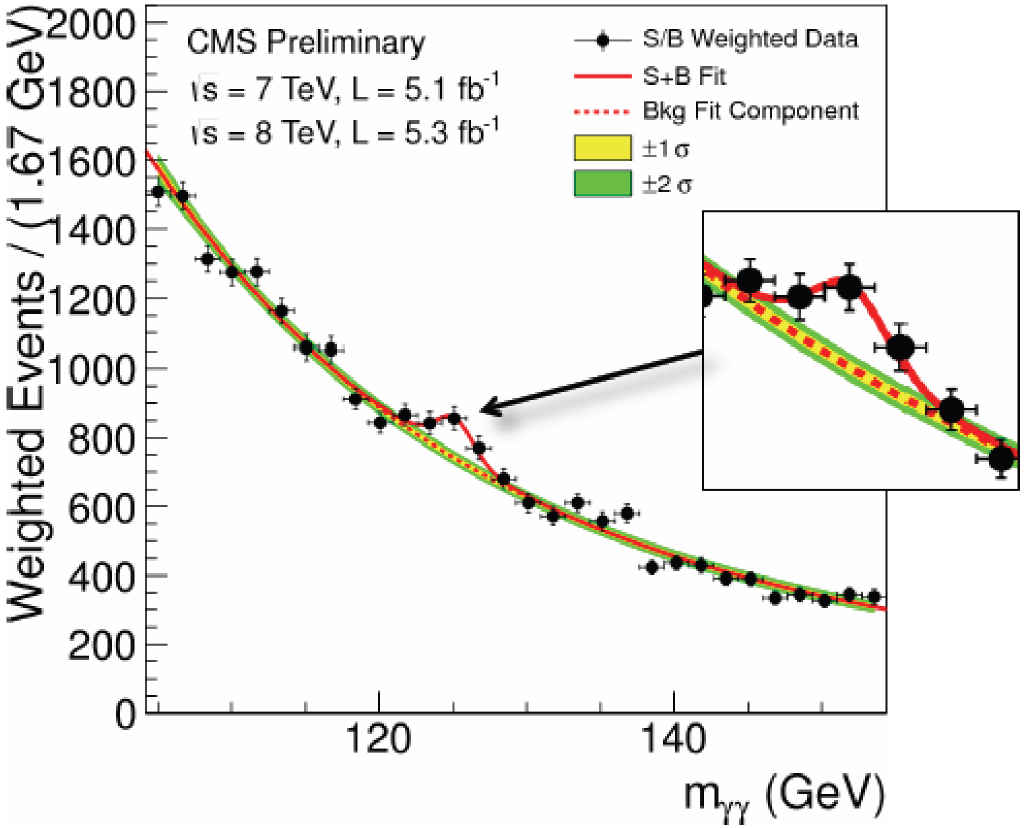
landmark conference ICHEP2012

- At the energy frontier:

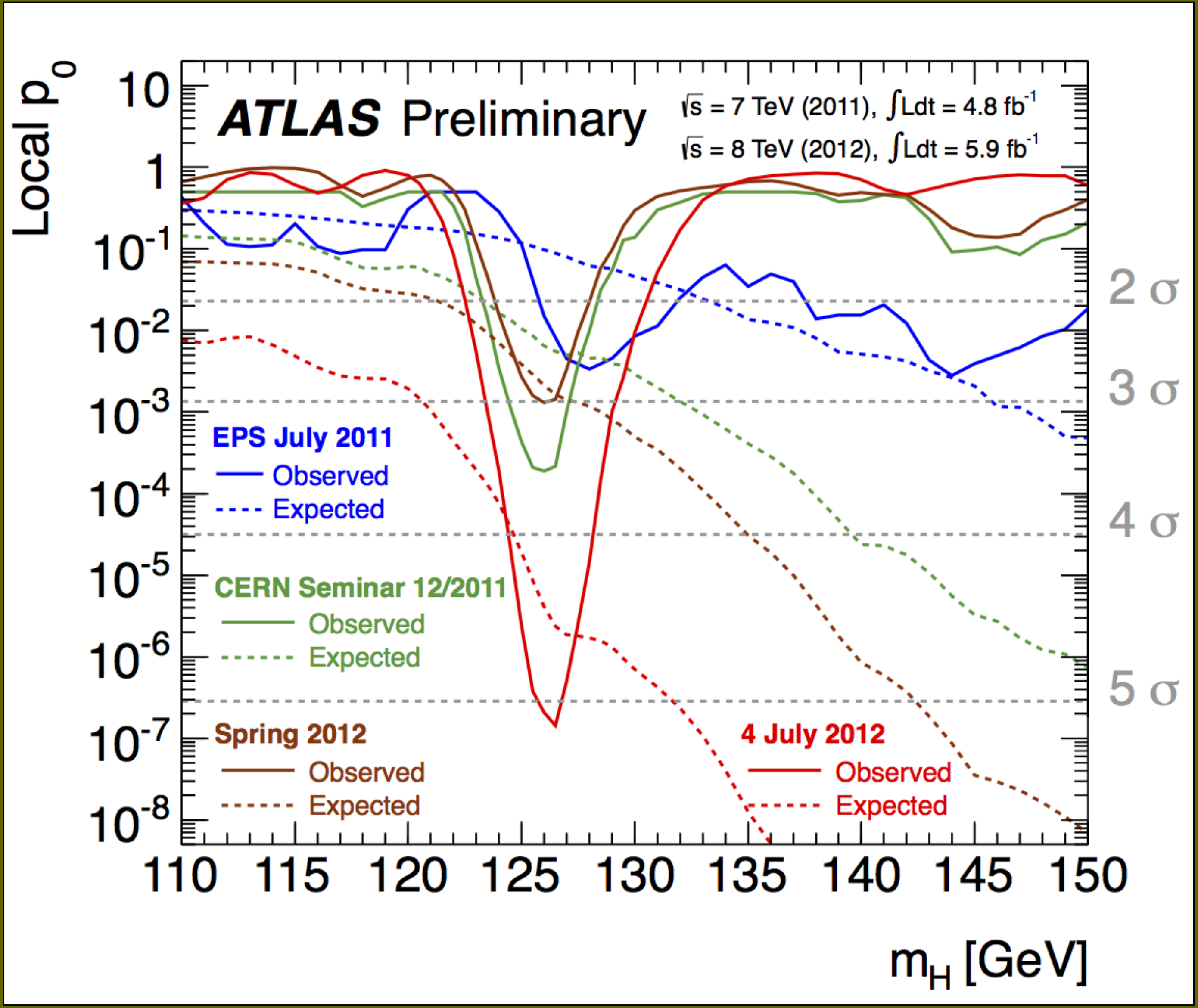
New particle at 125/126 GeV consistent with Higgs Boson

S/B Weighted Mass Distribution

- Sum of mass distributions for each event class, weighted by S/B
  - B is integral of background model over a constant signal fraction interval

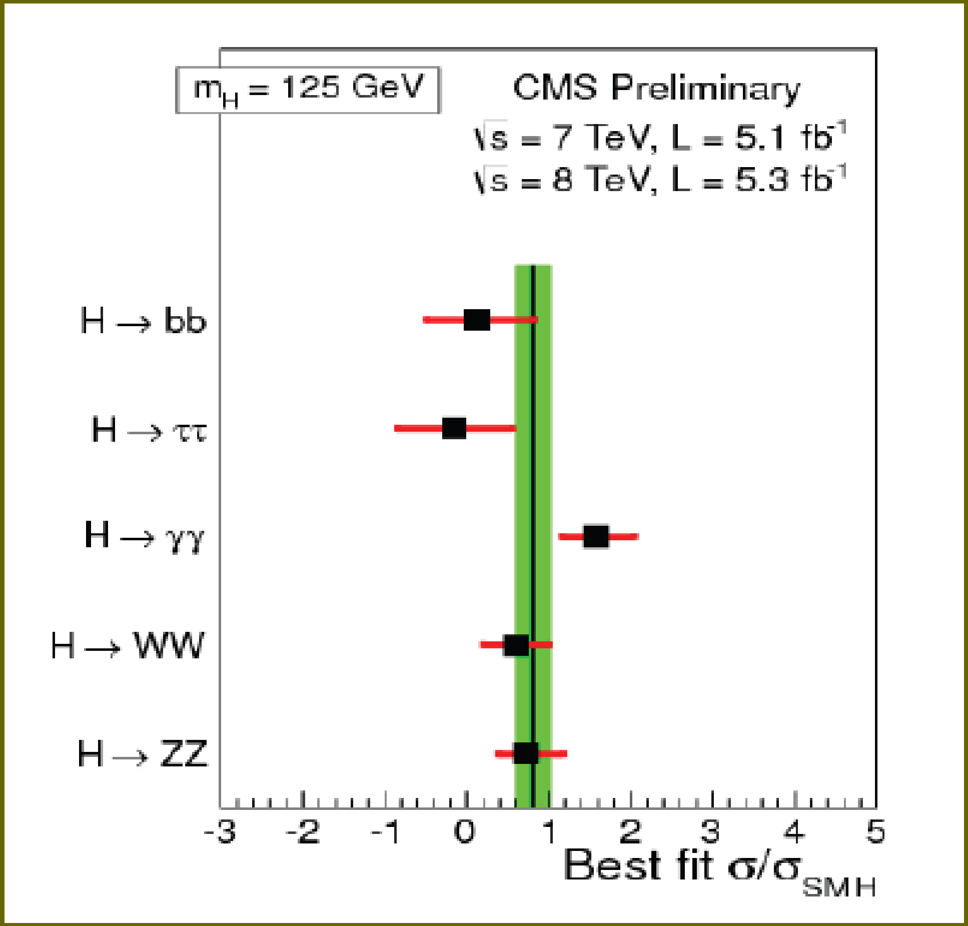


Evolution of the excess with time



Energy-scale systematics not included

… but that's only the beginning !
What's next ?



Measure the properties of the new particle with high precision

Next decades

Road beyond the Standard Model

- At the intensity frontier:

"Super" b-factories, rare decay experiments,

. . . ., and

Neutrino Facilities

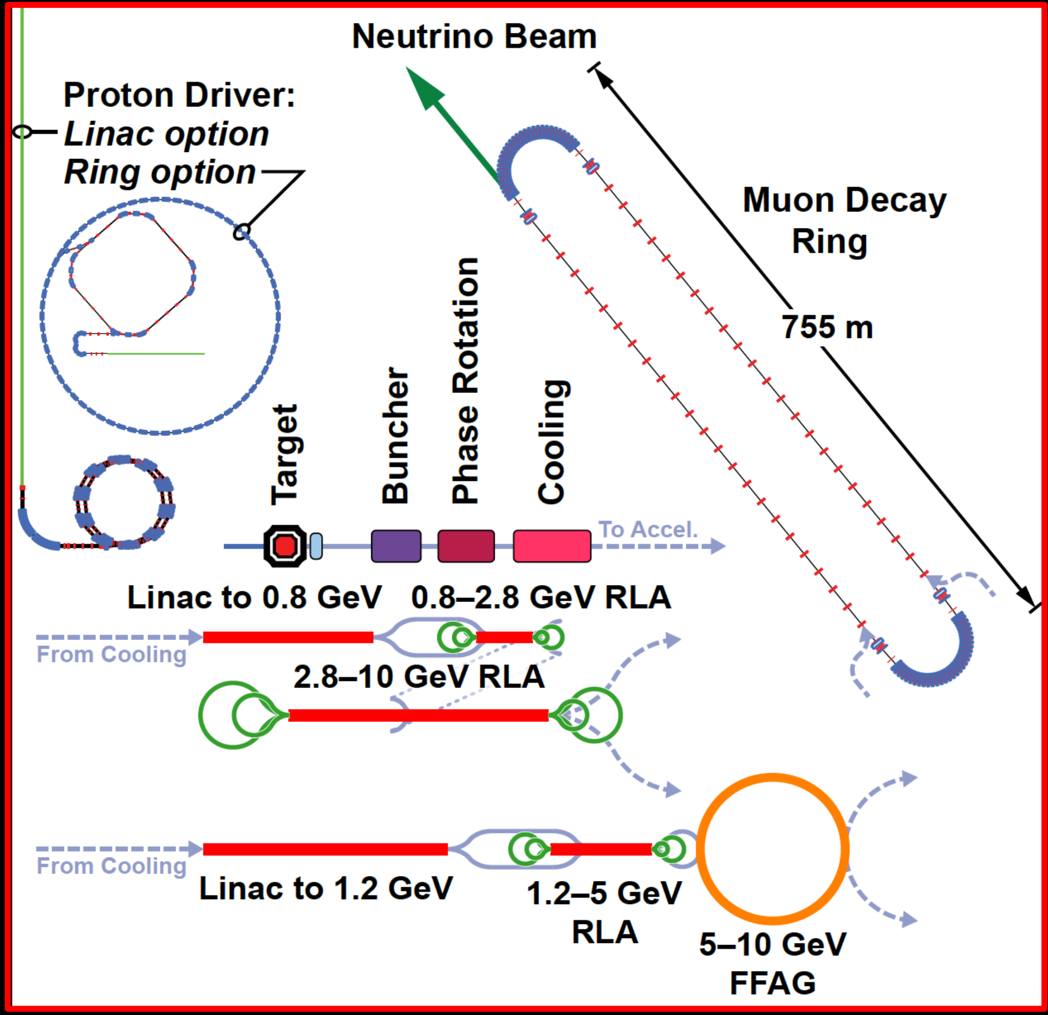
Options:

- **Conventional super-beams:**
  - Wide-band, long baseline: e.g. LBNE, LBNO
    - $<E_\mu>$ ~ 2—3 GeV; matched to LAr or magn.Fe calorimeter;
    - Long-baseline allows observation of first and second maximum
    - Near detector exploited to reduce systematic errors
  - Narrow-band, short baseline: e.g. T2HK, SPL
    - $<E_\mu>$ ~ 0.5 GeV; matched to $H_2 0$ Cherenkov;
    - Short-baseline allows observation of first maximum
    - Near detector exploited to reduce systematic errors
- **Beta-beam, short baseline:**
  - $<E_\mu>$ ~ 0.5 GeV; matched to $H_2 0$ Cherenkov;
  - Short-baseline allows observation of first maximum
  - Requires short-baseline super-beam to deliver competitive performance

K.Long

Neutrino Factory:

- Optimise discovery potential for CP and MH:
  - Requirements:
    - Large ν_e ($\bar{\nu}_e$) flux
      - Detailed study of sub-leading effects
- Unique:
  - (Large) high-energy ν_e ($\bar{\nu}_e$) flux
    - Optimise event rate at fixed *L/E*
    - Optimise MH sensitivity
    - Optimise CP sensitivity



K.Long

Scenario of a staged programme:

- Large value of θ_{13}, makes it likely that the next generation long-baseline experiments will determine the neutrino mass hierarchy;
  - However, sensitivity to CP violation will be limited;
- In the first instance, a combination of long-baseline (wide-band beam) experiments (e.g. LBNE/LBNO) and short baseline experiments (e.g. T2HK) may offer an attractive way forward:
  - In such an approach:
    - CP reach is limited by systematic effects;
    - Hints of CP violation would require follow up by the Neutrino Factory.
- The Neutrino Factory seems the facility of choice;
  - Consensus (?):
    - Will be required to:
      - Complete the Standard Neutrino Model and to test whether it is a good description of nature
- But, stored muon beams have not yet been shown to be capable of serving a world-class neutrino programme:
  - Require to push through R&D and complete IDS-NF, considering an incremental implementation in parallel; and
  - Establish a first, realistic, scientifically first-rate neutrino experiment based on a stored muon beam

K.Long

Next decades

Road beyond Standard Model

- At the energy frontier:

through synergy of

hadron - had ... ders

... hadron colliders

lepton - lepton colliders

LHC results will guide the way at the energy frontier


LHC

The predictable future: LHC Time-line

2009 — Start of LHC

Run 1: 7 and 8 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up luminosity to nominal (10^{34} … 00 fb^{-1}

2018 — Injector and LHC Phase-I upgrad…

Run 3: Ramp up l… fb^{-1} / year accumu…

~2022 — Phase-I… …ng magnets and CRAB ca… …with levelling

Run 4: C… → 3000 fb^{-1}

2030

Study of the properties of the Higgs Boson
or
other ew symmetry breaking mechanism
and
Physics beyond the Standard Model

The predictable future: Strategy

1) Continuously throughout the years (mainly during shutdowns):

Performance-Improving Consolidation

i.e. replace (aging) components by better performing ones

2) Depending on Physics Requirements:

High Luminosity LHC (~2022)

i.e. upgrade to deliver a total of some 3/ab

Key message

There is a program at the energy frontier with the LHC for at least 20 years:

8 TeV
14 TeV design luminosity
14 TeV high luminosity (HL-LHC)

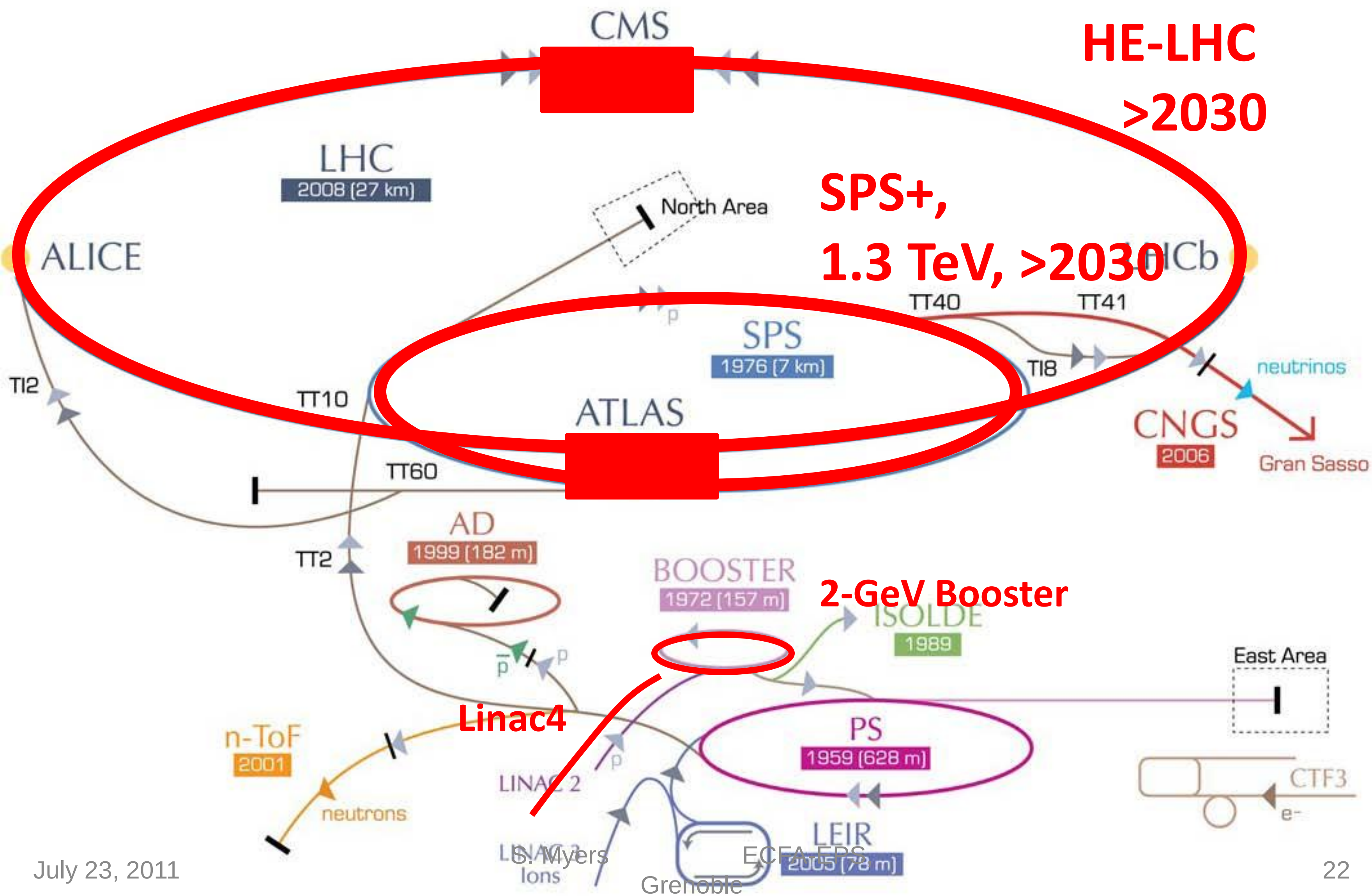

beyond LHC ?

High Energy Hadron – Hadron Collider

HE - LHC

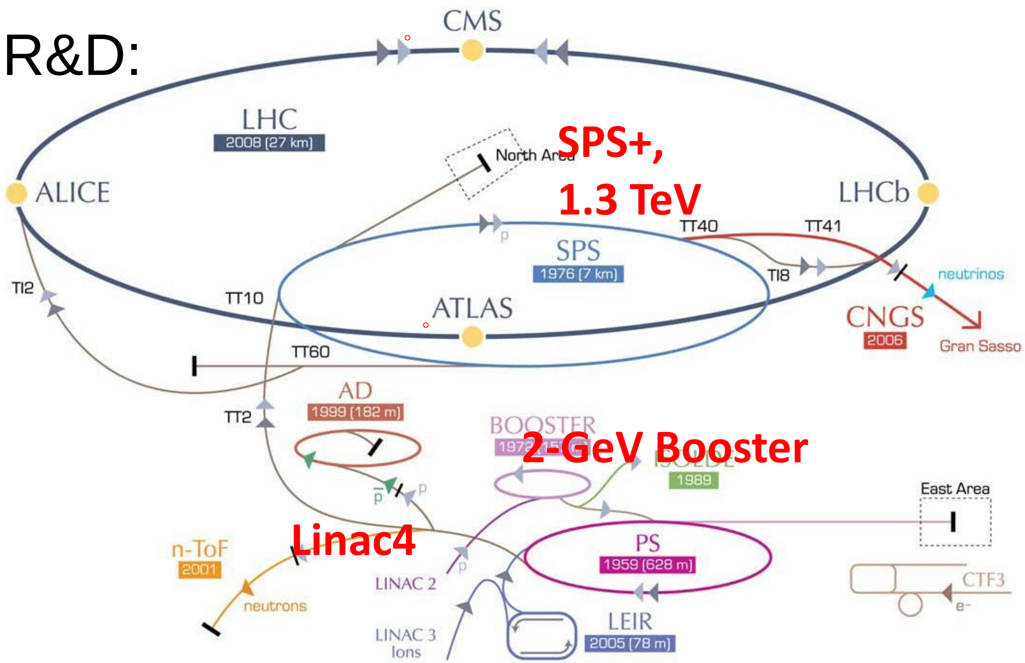
Study of New Physics Phenomena

HE-LHC – LHC modifications



Very Long-Term Objectives: High-Energy LHC

HE-LHC – main Issues and R&D:



- High-field 20T dipole magnets based on Nb_3Sn, Nb_3Al, and HTS
- High-gradient quadrupole magnets for arc and IR
- Fast cycling SC magnets for ~1.3 TeV injector
- Emittance control in regime of strong SR damping and IBS
- Cryogenic handling of SR heat load (first analysis; looks manageable)
- Dynamic vacuum

S. Myers, L. Rossi

High Energy-LHC (HE-LHC)

CERN working group since April 2010

EuCARD AccNet workshop HE-LHC'10 ,
14-16 October 2010, Proc. CERN-2011-003

<u>key topics</u>

beam energy 16.5 TeV; 20-T magnets

cryogenics: **synchrotron-radiation heat**

radiation damping & emittance control

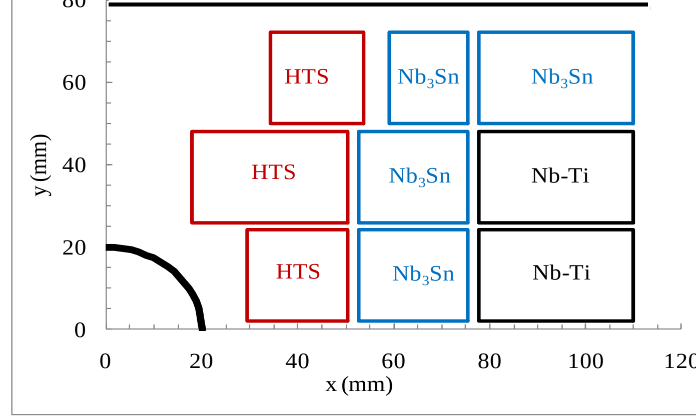
vacuum system: synchrotron radiation

new injector: energy > 1 TeV

parameters

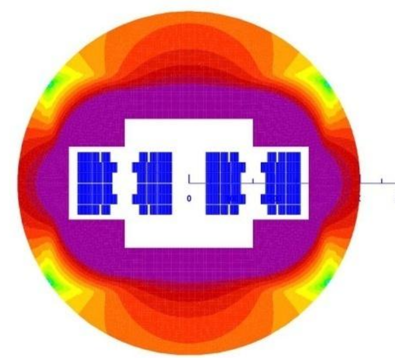
	LHC	HE-LHC
beam energy [TeV]	7	16.5
dipole field [T]	8.33	20
dipole coil aperture [mm]	56	40
#bunches	2808	1404
IP beta function [m]	0.55	1 (x), 0.43 (y)
number of IPs	3	2
beam current [A]	0.584	0.328
SR power per ring [kW]	3.6	65.7
arc SR heat load dW/ds [W/m/ap]	0.21	2.8
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0
events per crossing	19	76

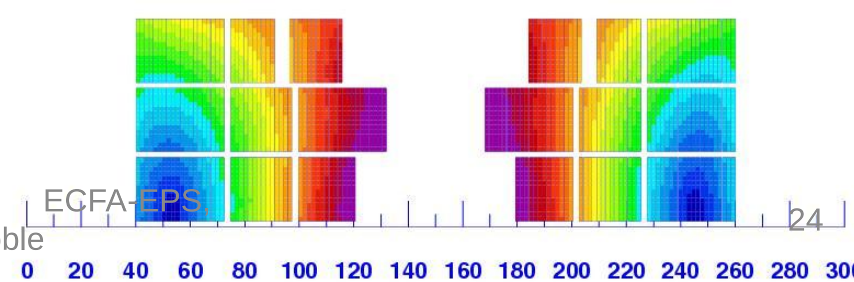
	Turns	%
Nb-Ti	40	28%
Nb_3Sn	58	41%
HTS	45	31%



E. Todesco

hybrid magnet





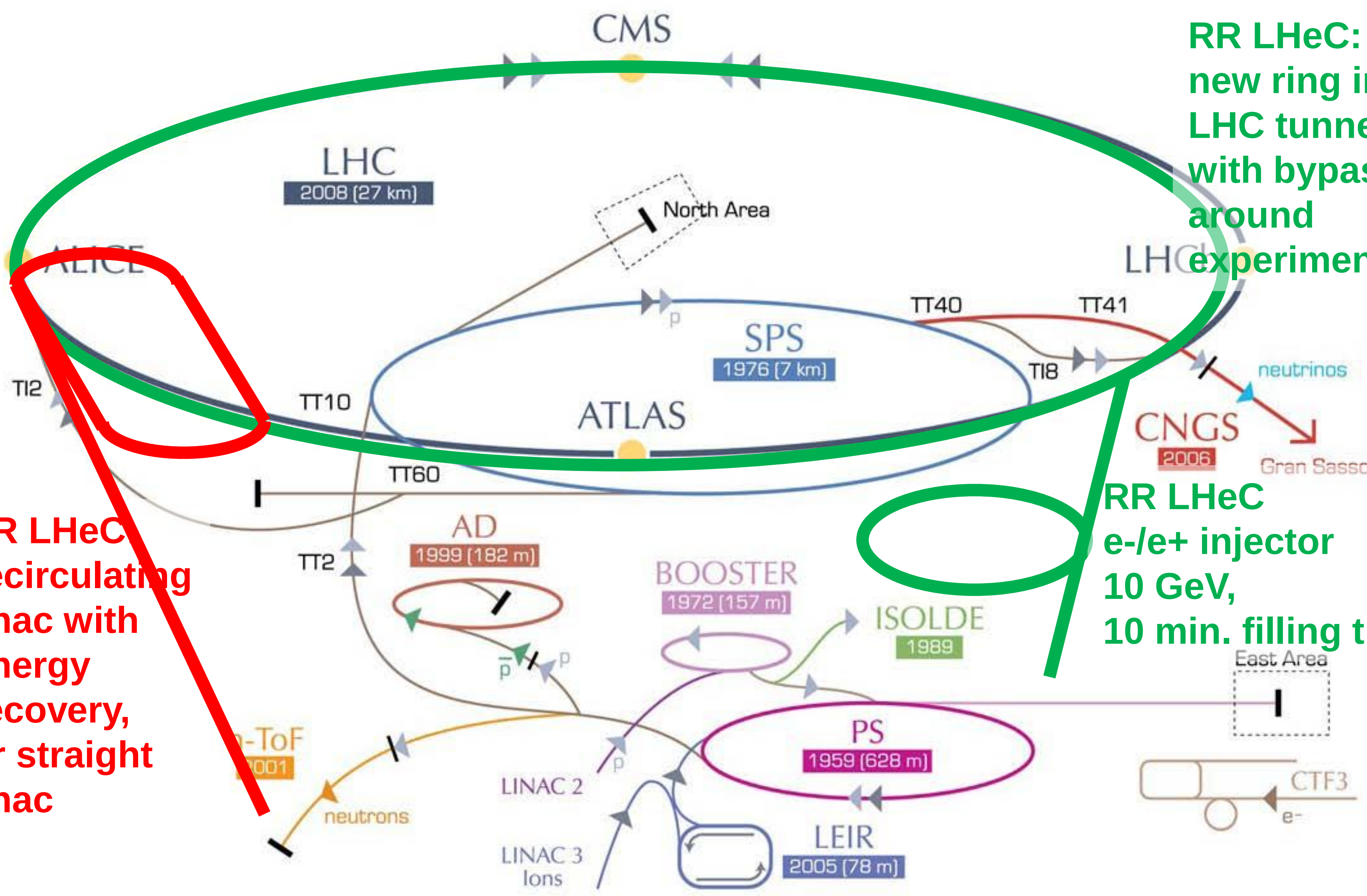
Lepton – Hadron Collider

LHeC

QCD, Leptoquarks,

Higgs properties?

LHeC options: RR and LR



RR LHeC: new ring in LHC tunnel, with bypasses around experiments

RR LHeC e-/e+ injector 10 GeV, 10 min. filling time

LR LHeC: recirculating linac with energy recovery, or straight linac

Summary

- **LHeC**, in ep(A) collisions synchronous with pp running, could deliver fundamentally new insights on the structure of the proton (and nucleus) with high precision.
- At LHeC, a light Higgs boson and its CP eigenstates could be uniquely accessed via WW and ZZ fusion - complementary to LHC experiments.
- Sensitivity to H → bb is estimated by an initial simulation study: LHeC has the potential to measure H → bb coupling to ~4% accuracy with 60 GeV electron beam. Other production and decay channels have to be explored still using dedicated LHeC detector simulation, instead of the PGS used so far.
- With the isolation of the H→bb signal at the LHeC, a window of opportunity opens for the exploration of the CP properties of the HVV vertex: LHeC offers a number of advantages
  - Clear separation of HWW and HZZ couplings
  - Very good signal to background ratio
  - Identification of backward forward directions (and full azimuthal coverage)
- Detector design is crucial for an efficient H→ bbar signal selection and CC/NC multi-jet background rejection. **Prospects have just started to be explored.**

Lepton – Lepton Colliders

Linear e^+e^- Colliders: ILC / CLIC

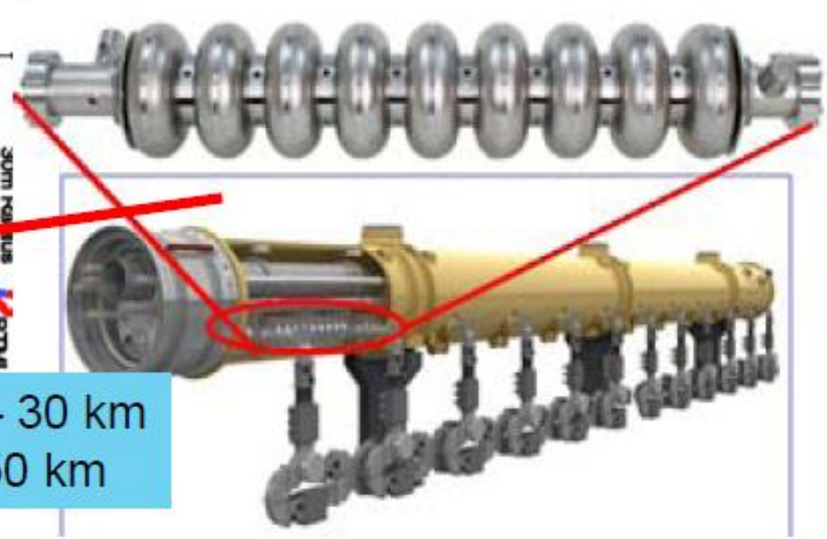
Both projects are global endeavours

Wide range of Physics Topics, e.g.

- Higgs couplings, in particular **self coupling**
- precision studies of Z, W, and **Top**
- new physics phenomena

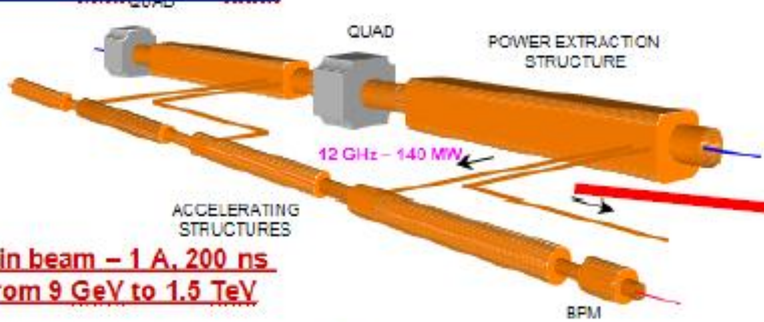
Linear Collider layouts

http://www.linearcollider.org/cms   http://clic-study.web.cern.ch/CLIC-Study/

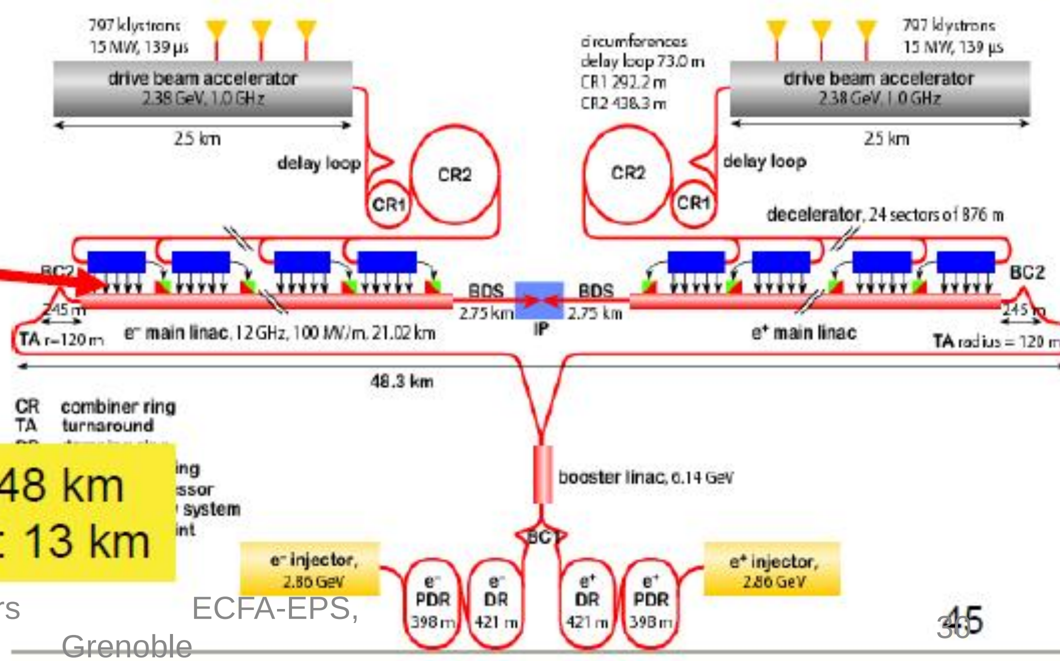


ILC 0.5 TeV – 30 km
ILC 1 TeV – 50 km

Drive beam - 95 A, 300 ns from 2.4 GeV to 240 MeV



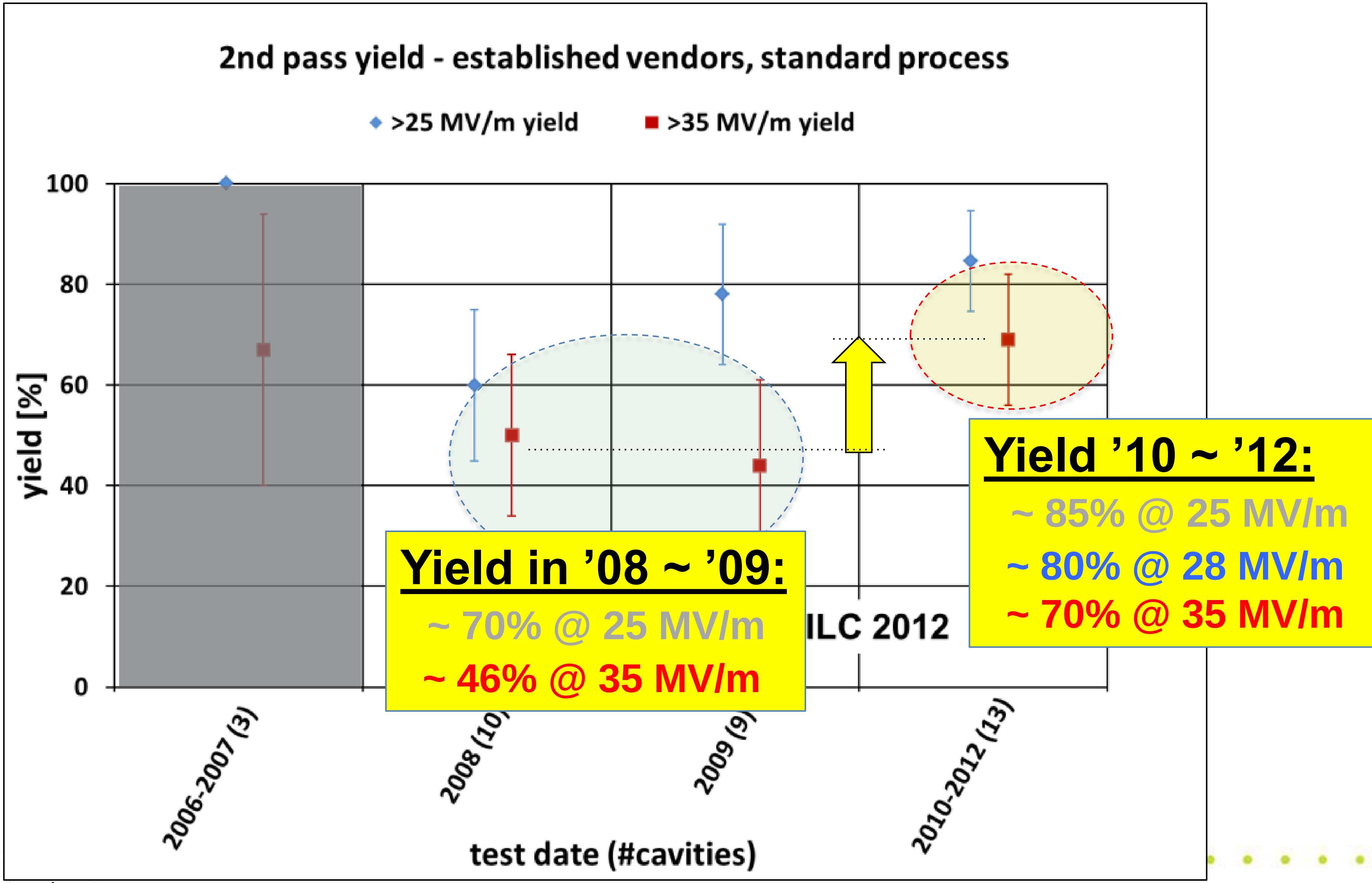
Main beam – 1 A, 200 ns from 9 GeV to 1.5 TeV



CLIC 3 TeV: 48 km
CLIC 0.5 TeV: 13 km

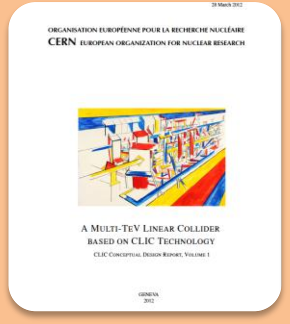
Yearly Progress in Cavity Gradient Yield

as of April 24, 2012



Conclusion of CLIC CDR studies

Main linac gradient	– Ongoing test close to or on target – Uncertainty from beam loading
Drive beam scheme	– Generation tested, used to accelerate test beam, deceleration as expected – Improvements on operation, reliability, losses, more deceleration (more PETS) to come
Luminosity	– Damping ring like an ambitious light source, no show stopper – Alignment system principle demonstrated – Stabilisation system developed, benchmarked, better system in pipeline – Simulations seem on or close to the target
Operation Machine Protection	– Start-up sequence defined – Most critical failure studied – First reliability studies – Low energy operation developed

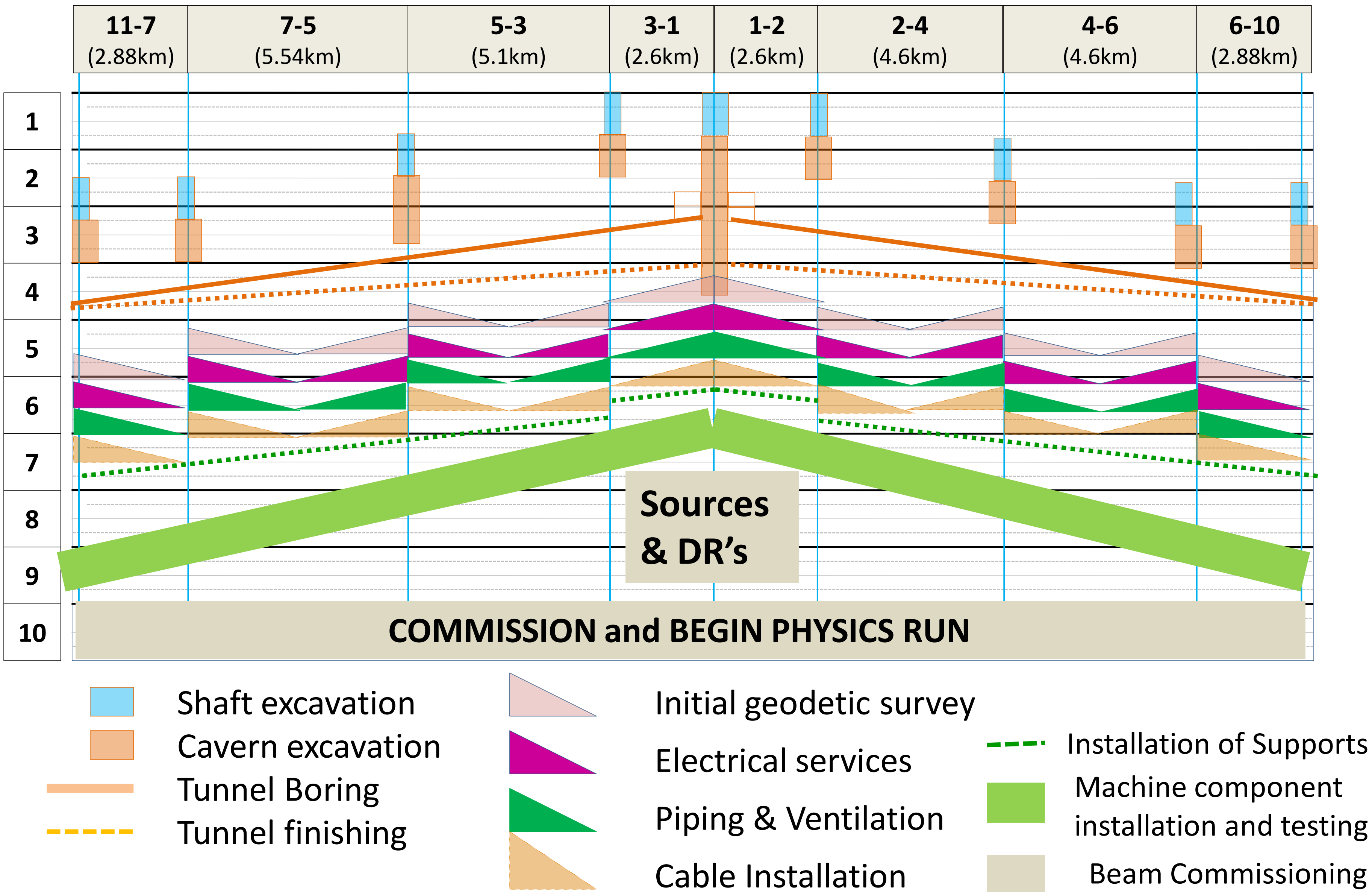


Vol 1: The CLIC accelerator and site facilities (H.Schmickler)

- 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, final editing ongoing, presented in the SPC In March 2012 (Daniel Schulte)

http://project-clic-cdr.web.cern.ch/project-CLIC-CDR/

An Example ILC Construction Schedule



Key message

High Priority Items for Linear Collider Projects

ILC and CLIC projects → LC project

Construction Cost

Power Consumption

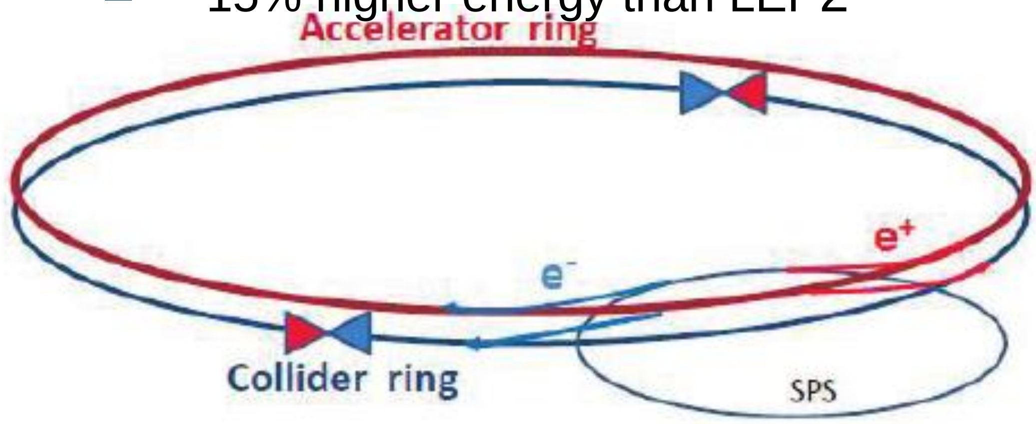
Value Engineering

Very recently brought up: LEP3 circular Higgs factory ($e^+e^- \rightarrow Z^* \rightarrow Z+H$)

- Initial thoughts – <u>very</u> preliminary:

  EuCARD: http://indico.cern.ch/conferenceDisplay.py?confId=19

  – ~ 15% higher energy than LEP2



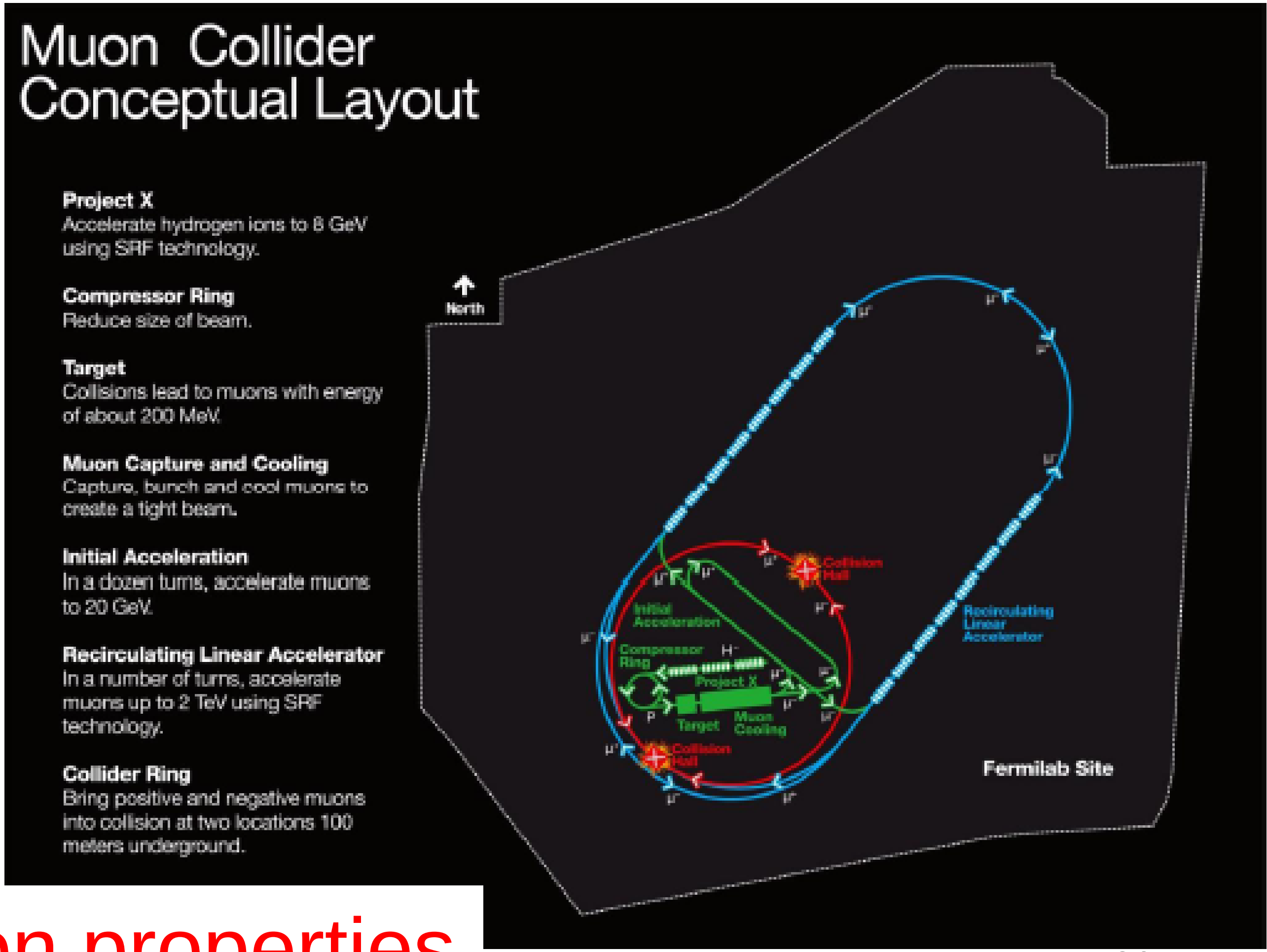
- Installation in the LHC tunnel "LEP3"

	LEP2	LHeC	LEP3
b. energy E_b [GeV]	104.5	60	120
circumf. [km]	26.7	26.7	26.7
beam current [mA]	4	100	7.2
#bunches/beam	4	2808	4
#$e-$/beam [10^{12}]	2.3	56	4.0
horiz. emit. [nm]	48	5	25
vert. emit. [nm]	0.25	2.5	0.10
bending rad. [km]	3.1	2.6	2.6
part. number J_ϵ	1.1	1.5	1.5
mom. c. α_c [10^{-5}]	18.5	8.1	8.1
SR p./beam [MW]	11	44	50
β^*_x [m]	1.5	0.18	0.2
β^*_y [cm]	5	10	0.1
σ^*_x [μm]	270	30	71
σ^*_y [μm]	3.5	16	0.32
hourglass F_{hg}	0.98	0.99	0.67
E^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99
$V_{RF,tot}$ [GV]	3.64	0.5	12.0
$\delta_{max,RF}$ [%]	0.77	0.66	4.2
ξ_x/IP	0.025	N/A	0.09
ξ_y/IP	0.065	N/A	0.08
f_s [kHz]	1.6	0.65	3.91
E_{acc} [MV/m]	7.5	11.9	20
eff. RF length [m]	485	42	606
f_{RF} [MHz]	352	721	1300
δ^{SR}_{rms} [%]	0.22	0.12	0.23
$\sigma^{SR}_{z,rms}$ [cm]	1.61	0.69	0.23
L/IP[10^{32}cm^{-2}s^{-1}]	1.25	N/A	107
number of IPs	4	1	2
beam lifetime [min]	360	N/A	16
Υ_{BS} [10^{-4}]	0.2	0.05	10
n_γ/collision	0.08	0.16	0.60
ΔE^{BS}/col. [MeV]	0.1	0.02	33
ΔE^{BS}_{rms}/col. [MeV]	0.3	0.07	48

Alain Blondel, Frank Zimmermann et al.

Lepton Colliders: Muon Collider

- Compact facility accelerating muons with recirculating linacs



<u>Major Challenges</u>

1. Muon generation
2. Cooling of muons
3. Cost-efficient acceleration
4. Collider ring and backgrounds from decays

– Higgs Boson properties

and beyond ???

High Gradient Acceleration

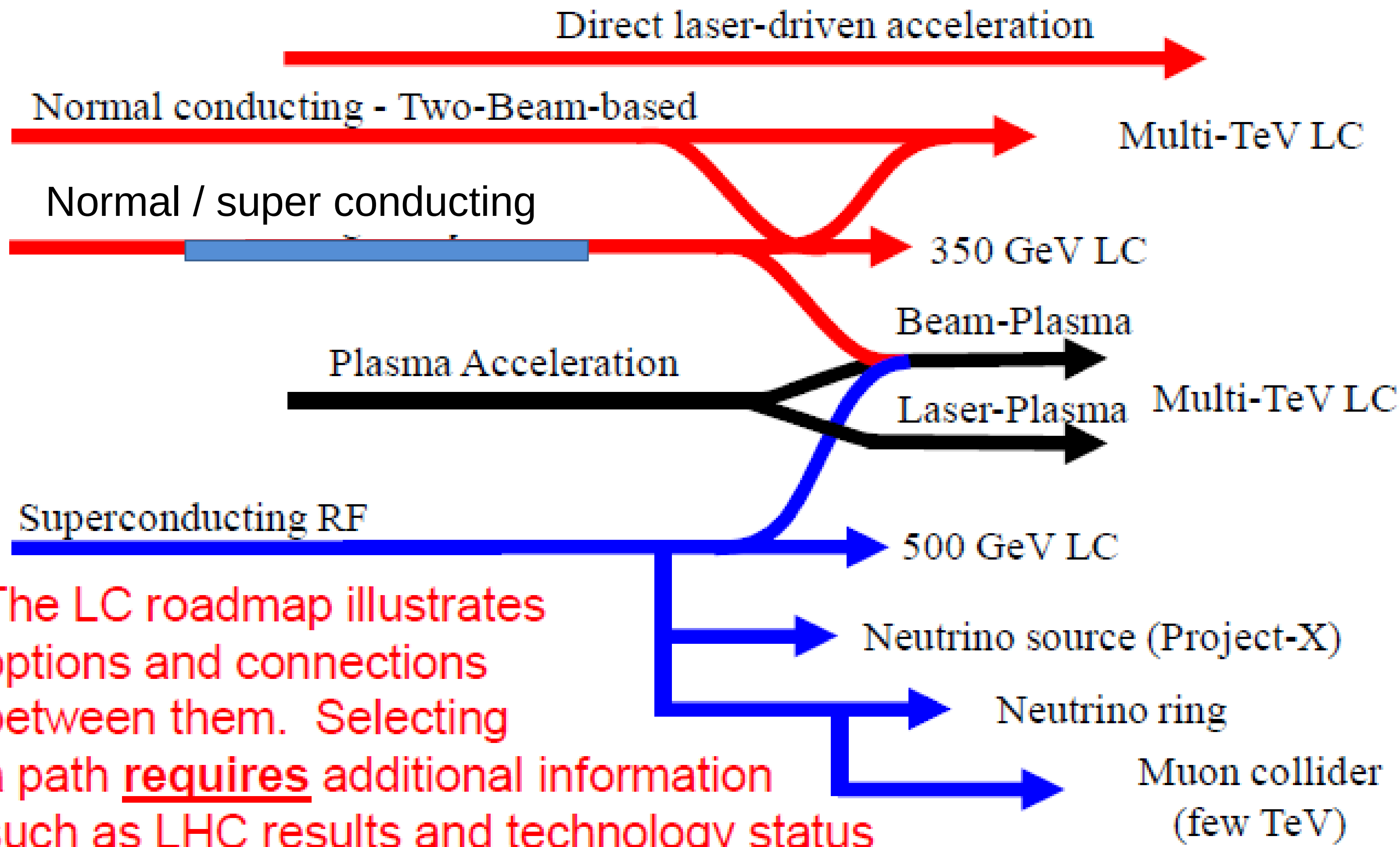
- High gradient acceleration requires high peak power and structures that can sustain high fields
  - Beams and lasers can be generated with high peak power
  - Dielectrics and plasmas can withstand high fields

- Many paths towards high gradient acceleration
  - RF source driven superconducting structure 40 MV/m
  - RF source driven metallic structure MV/m
  - Beam-driven metallic stru
  - Laser-driven die ures
  - Beam ctric structures
    } ~1 GV/m
  - La ven plasmas
  - Beam-driven plasmas
    } ~10 GV/m

R&D on new technologies mandatory

From: T.Raubenheimer, EPS 2011

Example Roadmap for Multi-TeV Lepton Colliders



The LC roadmap illustrates options and connections between them. Selecting a path **requires** additional information such as LHC results and technology status

….→….not to be taken as time axis….→….

From: T.Raubenheimer, EPS 2011

Key message

All projects need continuing accelerator and detector R&D;

All projects need continuing attention concerning a convincing physics case;
close collaboration exp-theo mandatory

so that the right decision can be made when the time comes to identify the next energy frontier accelerator (collider).
Today, we need to keep our choices open.

Choices ?

- Rich variety of projects under study
  at the energy frontier
  and the intensity frontier
- Global – Regional – National Projects

→ Need global collaboration and stability over long time scales

→ mandatory to have accelerator laboratories in all regions

Choices ?

→ Need to present and discuss all these projects in an international context before making choices

→ Need to present physics case(s) always taking into account latest results at existing facilities

→ Need to present (additional) benefits to society from the very beginning of the project

→ Need to have excellent communication and outreach accompanying all projects

The Economist July 7th 2012 (Editorial)

. . . . The laws of physics, though, are eternal and universal. Elucidating them is one of the triumphs of mankind. And this week has seen just such a triumphant elucidation.

.

For non-physicists, the importance of finding the Higgs belongs to the realm of understanding rather than utility. It adds to the sum of human knowledge–

.

(10bn) That is still a relatively small amount, though, to pay for knowing how things really work, and no form of science reaches deeper into reality than particle physics. As J.B.S. Haldane, a polymathic British scientist, once put it, the universe may be not only queerer than we suppose, but queerer than we can suppose. Yet given the chance, particle physicists will give it a run for its money. ■

from Choices ? *to* Choice !

- Roadmap (Japan) just published
- Roadmap discussion (US) next year
- Update of the European Strategy for Particle Physics in 2012/13 ≡ Strategy of Europe in a global context

  - Several Meetings with **international participation**

    → bottom-up process: community input requested

      1st open meeting September 2012, Cracow

  - Finalization: May/June 2013

- Started with the ICFA Seminar 3-6 October 2011 at CERN

  Use as 1st step to harmonize globally Particle Physics Strategy

CERN today….into the future

- **CLIC conceptual design report by 2012**
- **Participation in all LC activiti…**
- **LHeC conceptu… …sign report early 2012**
- **R&D … high-field magnets (towards HE-LHC)**
- **Generic R&D (high-power SPL, Plasma Acc)**
- **Participation in Neutrino-Projects studied**

Position CERN as Laboratory at the energy frontier

CERN: opening the door…

- **Membership for Non-European countries**
- **New Associate Membership defined**
- **CERN participation in global projects independent of location**

Excellent results at this

landmark conference ICHEP2012

It's the right time for the next steps

Past decades saw precision studies of 5 % of our Universe → Discovery of the Standard Model

The LHC is delivering data

We are just at the beginning of exploring 95 % of the Universe

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exciting prospects