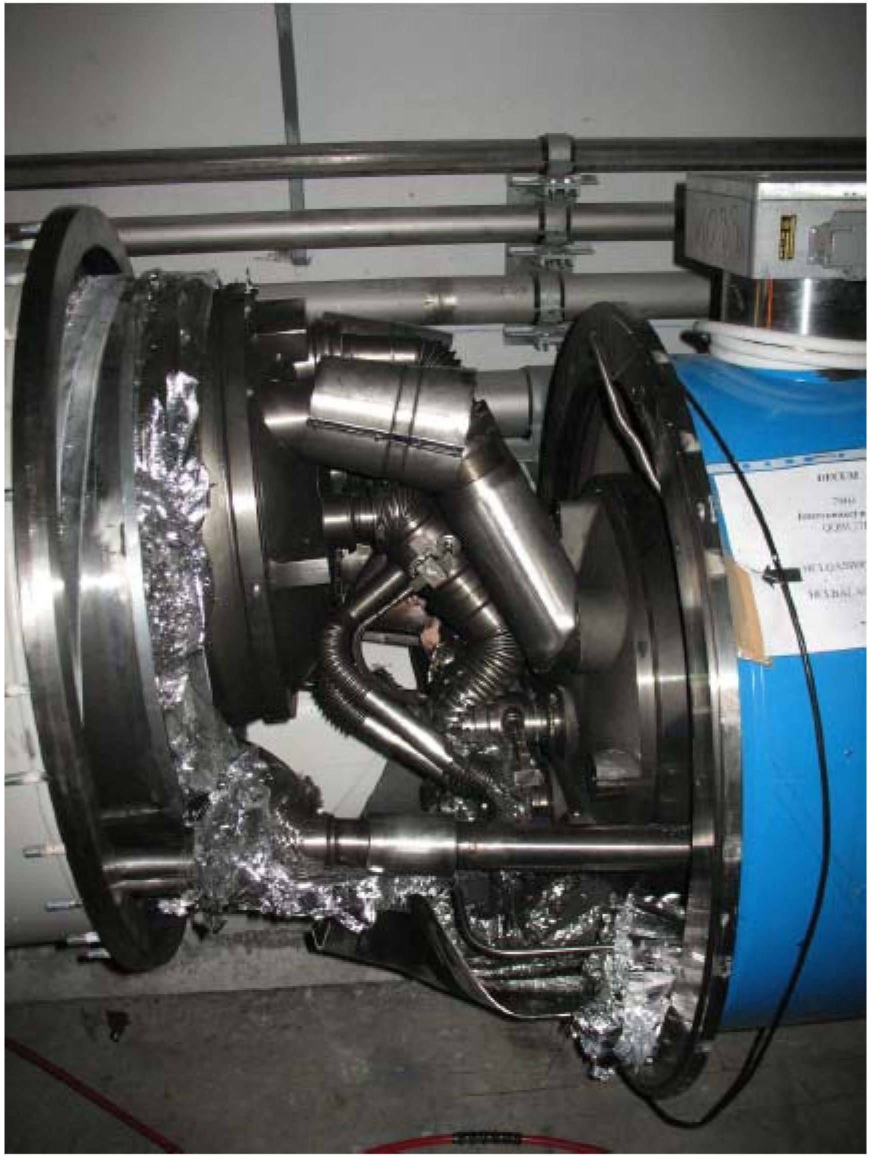
CERN Overview

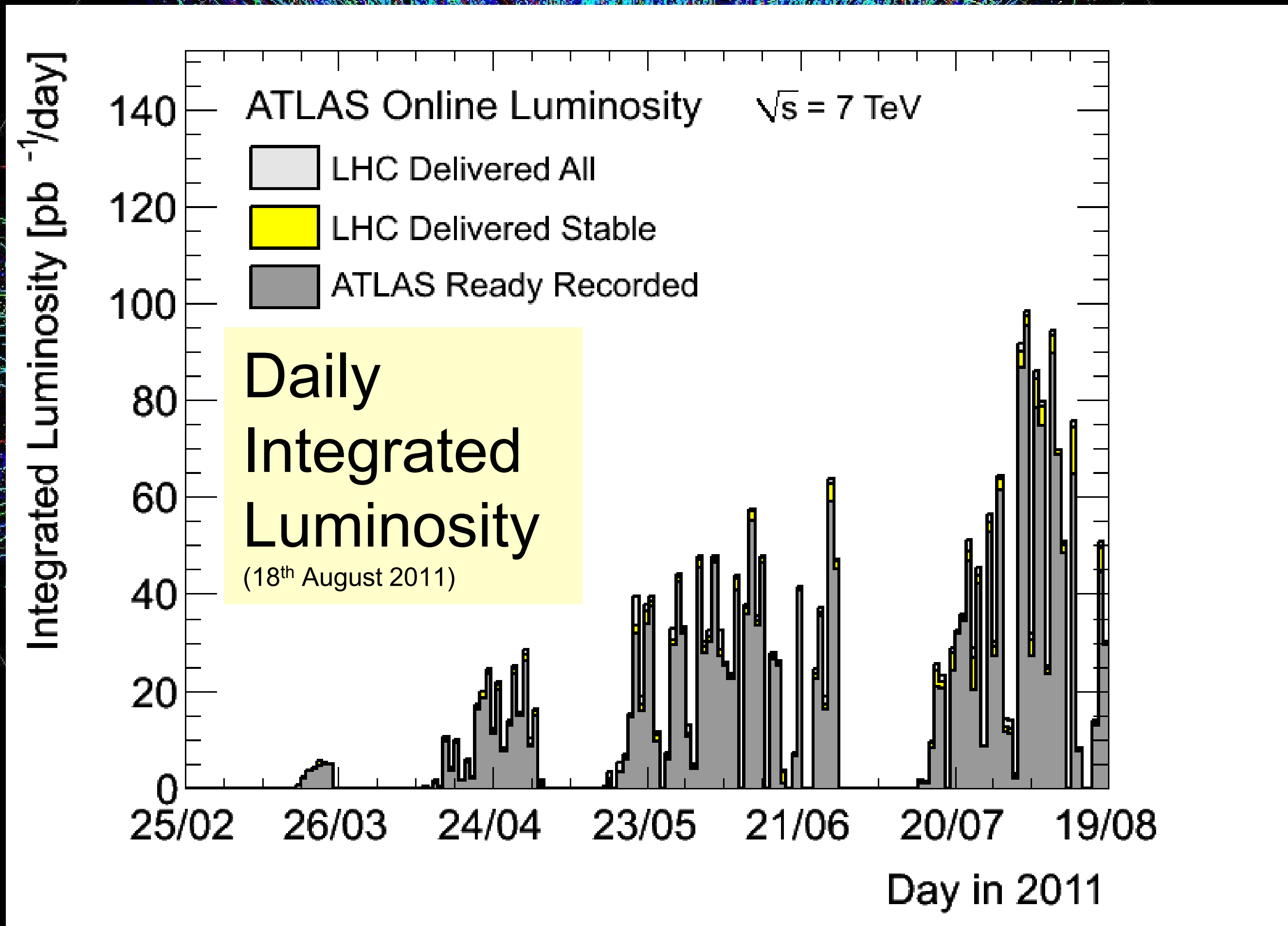
Rüdiger Schmidt, KfB Tagung, 31 August 2011

Thanks to G.Arduini, R.Assmann, O.Brüning, F.Zimmermann, L.Rossi, S.Myers, R.Garoby, F.Bordry, J.Blanco

LHC Status 2008

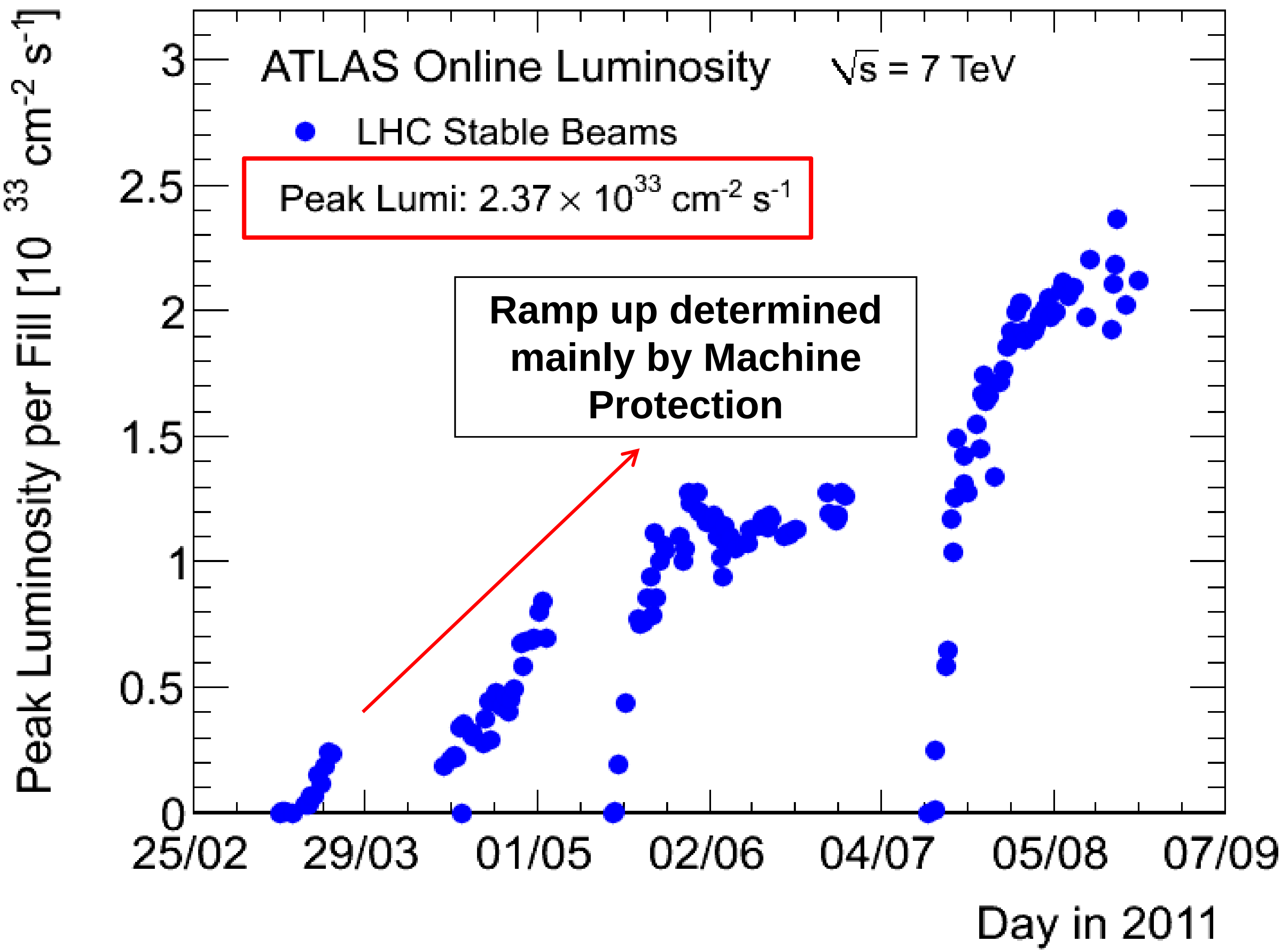


LHC Status 2011

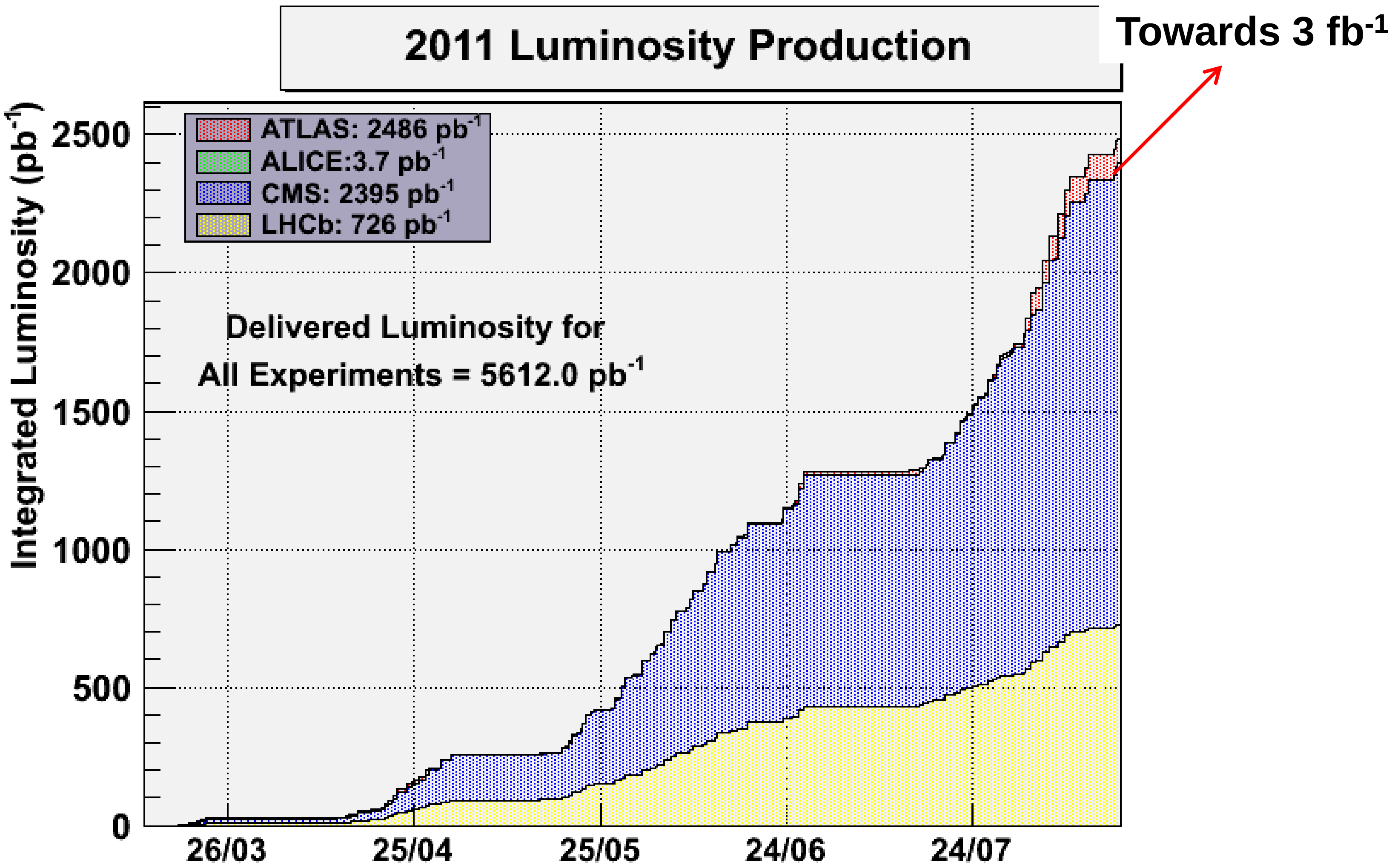


ALICE event

LHC Luminosity during 2011



LHC Luminosity Production

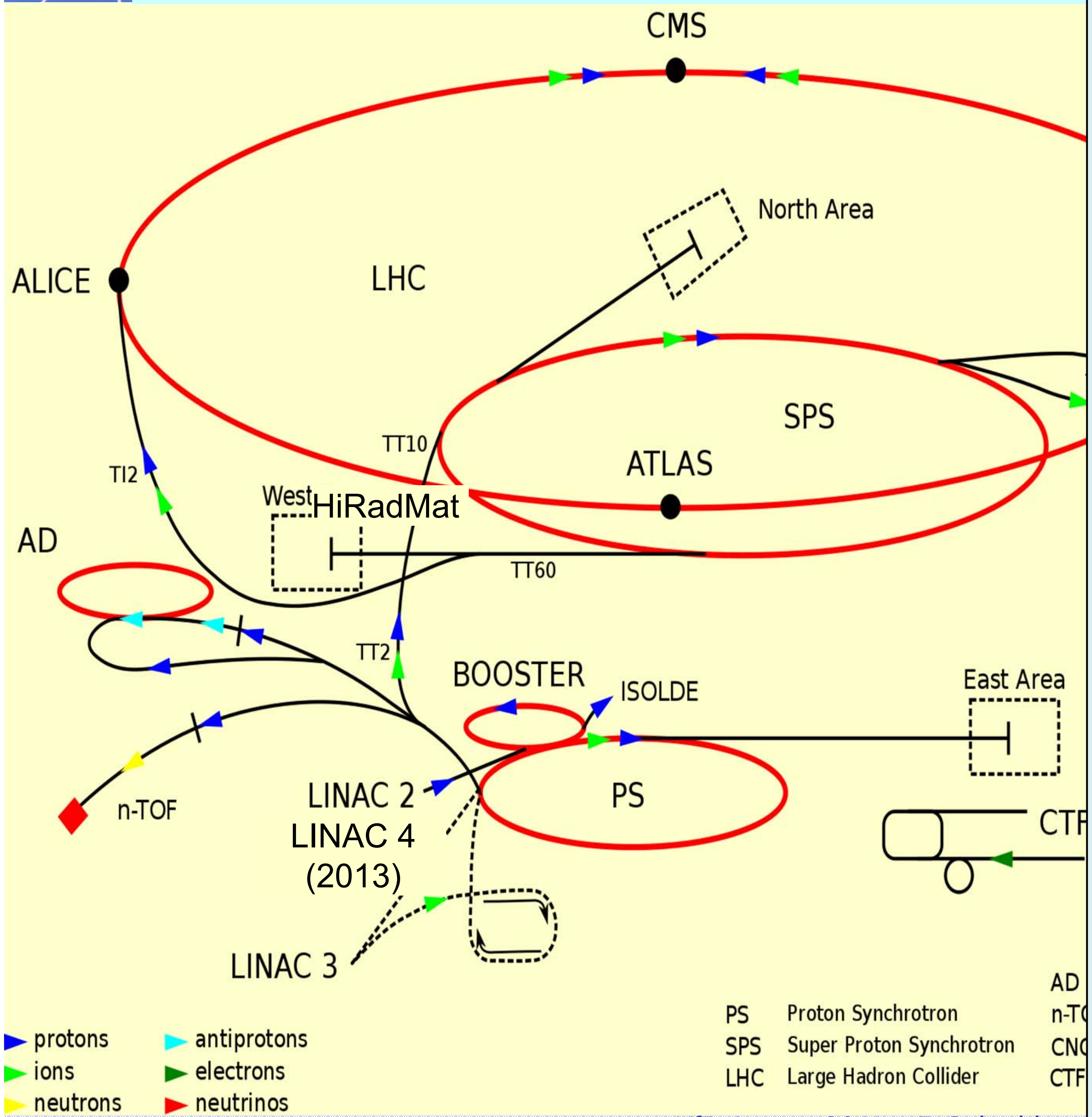


LHC Future

- The full exploitation of the LHC has the highest priority in the CERN Medium Term Plan.

- The LHC and LHC Injector upgrade programmes are aimed at achieving an integrated luminosity of more than 200 fb^{-1} per year (today about 3 fb^{-1} per year)

CERN ACCELRATOR



LHC Proton and Ion collider

Achieving nominal parameter

Upgrade towards higher luminosity: **HL – LHC**

Upgrade towards higher energy: **HE – LHC**

LHC injector complex

HiRadMat at SPS

LHeC proton electron collider

- Electron ring in the LHC tunnel
- Energy recovery recirculating Linac

CLIC / CTF3

Novel Acceleration Techniques

Elena (pbar at low energy)

ISOLDE and REX ISOLDE (radioactive beams)

LHC Parameters

	Achieved in 2011 record fill	Nominal
Energy [TeV]	3.5	7
Number of bunches	1380	2808
Protons per bunch	$1.25*10^{11}$	$1.15*10^{11}$
Nominal Emittance [μm]	2	3.75
Beta function at IP [m]	1.5	0.5
Distance between bunches [ns]	50	25
Luminosity [$cm^{-2}s^{-1}$]	**$2.3*10^{33}$**	$1*10^{34}$
Energy stored in one beam [MJ]	103	364

LHC challenges

- Going from 50ns bunch spacing to 25ns bunch spacing
  - Electron clouds
  - Heating of HOM heating of accelerator components (injection kickers, cryogenics, collimators.. depends on total intensity and bunch length)
  - Single Event Effects (SEE, depend on total intensity and luminosity)
  - Vacuum instabilities at very high bunch intensities. Proton losses causing heating and desorption?
  - Beam instabilities
  - UFOs (not serious for the moment, at 3.5TeV/beam but…)
  - Machine Protection and collimation: energy stored in beams increases
- Increasing the energy from 3.5 TeV to 6.5…7.0 TeV after the long shutdown 1 (2013-2014) for consolidation of splices
  - UFOs (beam loss monitors with lower thresholds)
  - Performance of the magnet system (quenches)
  - Reliability of equipment

LHC High Luminosity

Luminosity Upgrade Scenario

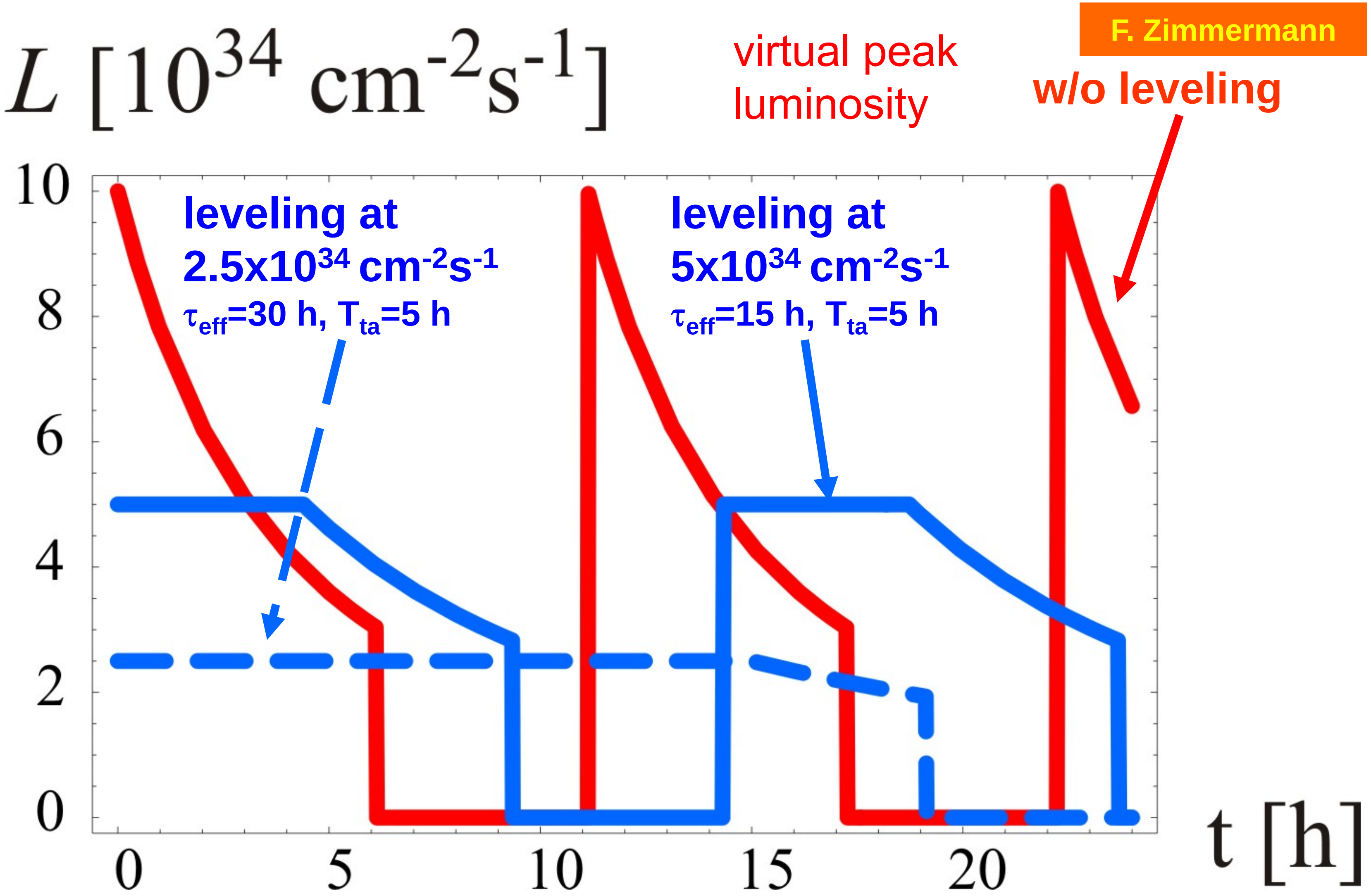
- For LHC very high luminosity, the luminosity lifetime becomes comparable with the turn round time

  => Low efficiency

- Preliminary estimates show: integrated luminosity is greater with a **peak luminosity of 5x10^{34} cm^{-2} s^{-1} and longer luminosity lifetime** (by luminosity leveling) than with a luminosity 10^{35} cm^{-2} s^{-1} and a luminosity lifetime of a few hours
- Luminosity Leveling by changing Beta*, crossing angle, crab cavities, bunch length, off steering, …

- **Goal 200-300 fb^{-1} per year (today about 3 fb^{-1}/y)**

Luminosity leveling



High Luminosity LHC Performance goal

- Leveled peak luminosity: $L = 5\ 10^{34}\ cm^{-2}\ sec^{-1}$
- Virtual peak luminosity: $L \geq 10\ 10^{34}\ cm^{-2}\ sec^{-1}$
- Integrated luminosity: 200 fb^{-1} to 300 fb^{-1} per year

- Implies bunch populations as high as **$3.5x10^{11}$** p for 50 ns beam or more than $2x10^{11}$ p for 25 ns beam

- The nominal bunch population is **$1.15x10^{11}$** p!!

Principles of action

- **To increase performance**
  - **Brightness ↗**

⇒ Increase injection energy in the PSB from 50 to 160 MeV, Linac4 (160 MeV H^-) replacing Linac2 (50 MeV H^+)

⇒ Increase injection energy in the PS from 1.4 to 2 GeV, increasing the field in the PSB magnets, replacing power supply and changing transfer equipment

⇒ Upgrade the PSB, PS and SPS to make them capable to accelerate and manipulate a higher brightness beam (feedbacks, cures against electron clouds, hardware modifications to reduce impedance…)

⇒ Study intensity limits in the LHC

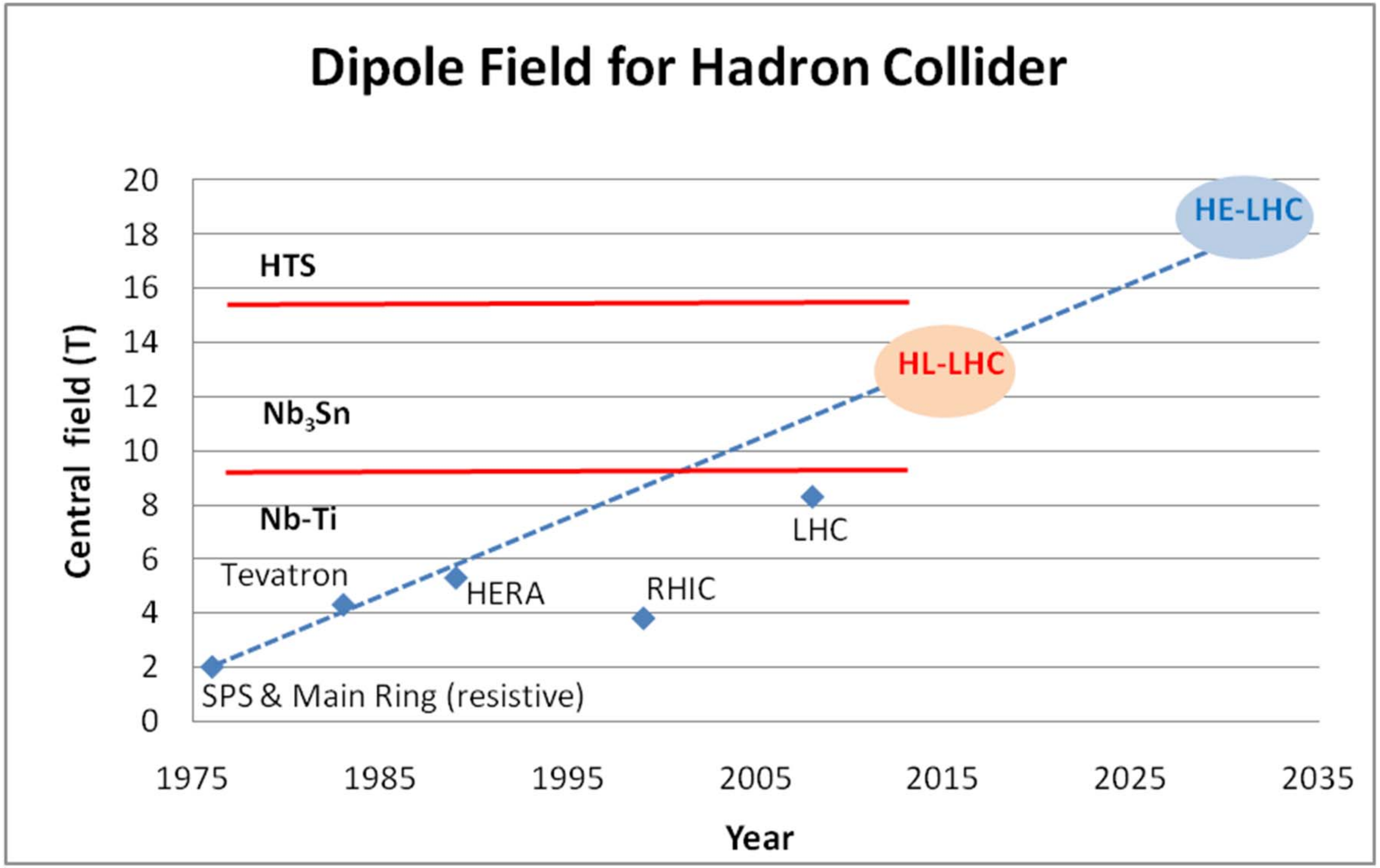
Beam dynamics issues

Main expected intensity limitations….

- Impedance effects in PS, SPS, LHC leading to:
  - Transverse and longitudinal beam instabilities and emittance blow-up
  - heating (and outgassing) due to resistive wall and trapped modes
- Electron cloud effects in PS, SPS and LHC leading to:
  - Vacuum pressure rise
  - Heat load in the LHC beam screens
  - Coherent instabilities and incoherent emittance blow-up leading to poor beam and luminosity lifetimes
- Space charge effects in PS and SPS at injection leading to:
  - Beam losses
  - Emittance blow-up

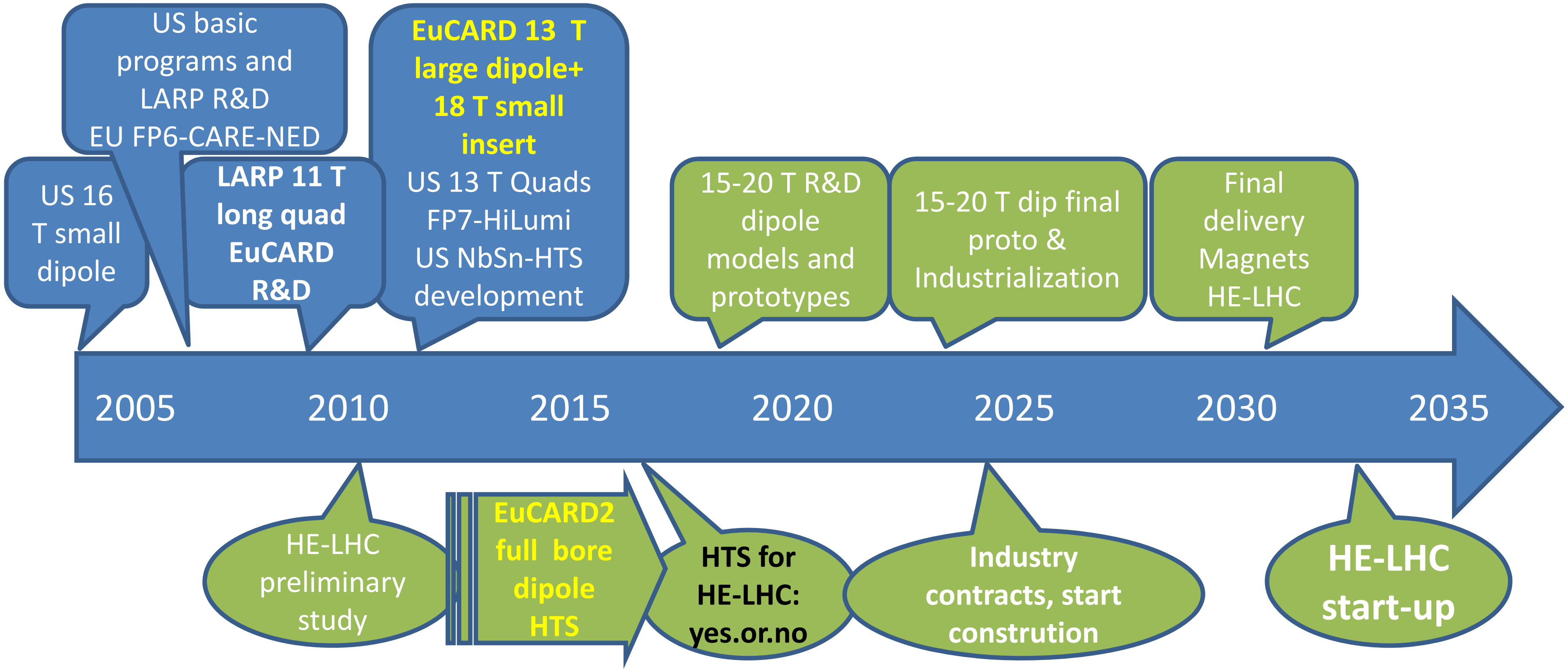
LHC High Energy

Is there a further exploitation of the LHC tunnel and infrastructure?



We need to go faster than for LHC.
But LHC « suffered » from LEP and LEP II endeavour

What is the possible for HE-LHC?

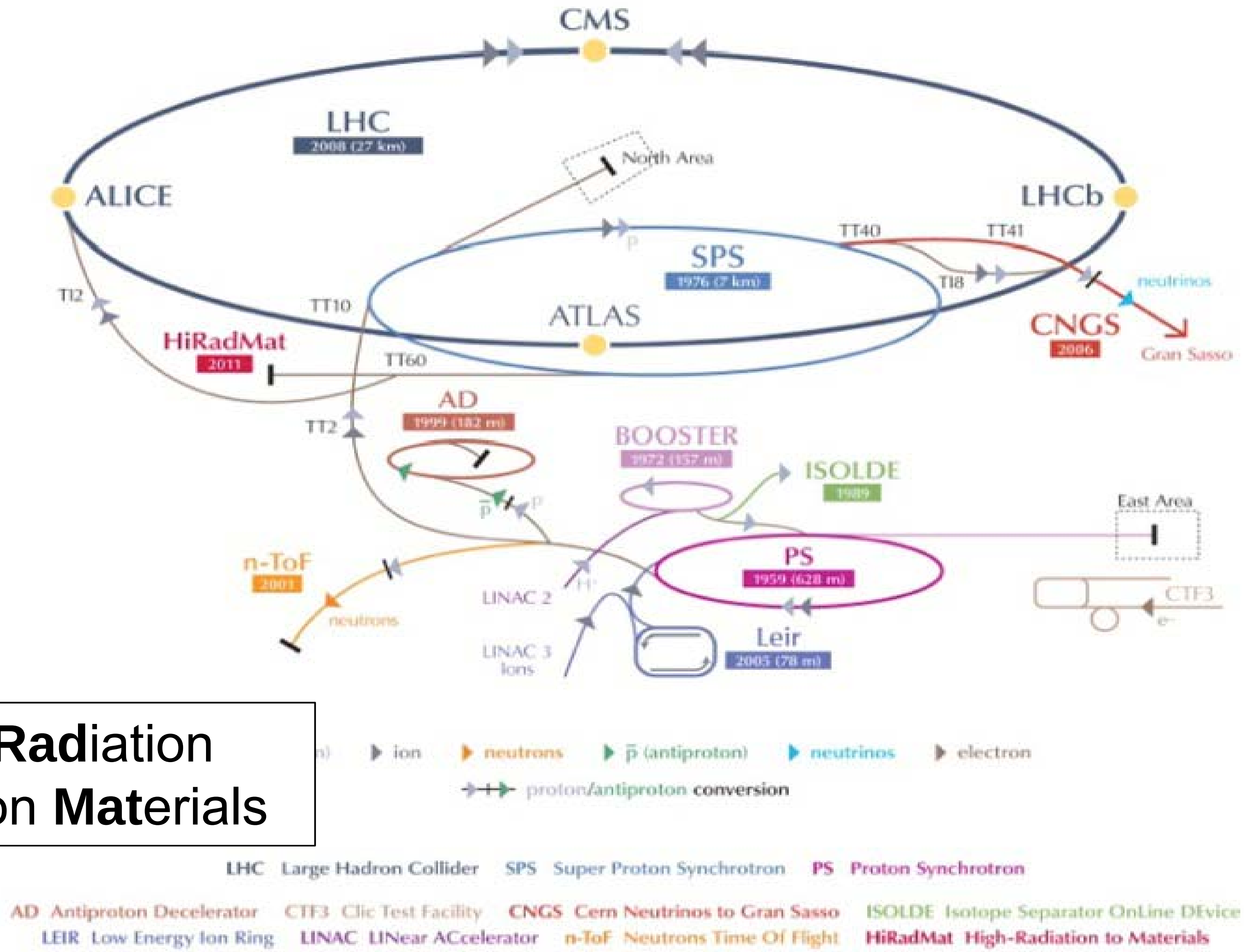


Conclusion

- HL-LHC project is starting, forming large international collaborations
- HL-LHC has a flexible 10 year plan: however the development of the main hardware is –almost – traced
- HL-LHC builds on the strength and expertise of:
  - CERN injectors (that will deliver the needed beam)
  - LHC operation and MD (for understanding the real limitation)
  - HL-LHC needs long preparation, since it will use new hardware beyond state-of-the-art and as such, in addition to the physics goal**, it may pave the way toward a high energy LHC**

- HE-LHC may be the ultimate upgrade of the LHC: **26-33 TeV c.o.m**
  - Relies on the Very High Field Magnet Development: 16-20 T!
  - Injection, Beam Dump, Vacuum and Cryogenics, together with Collimation, are also a big challenge. Beam handling technology must be improved by a factor 1.5 to 2.

A new facility: HiRadMat

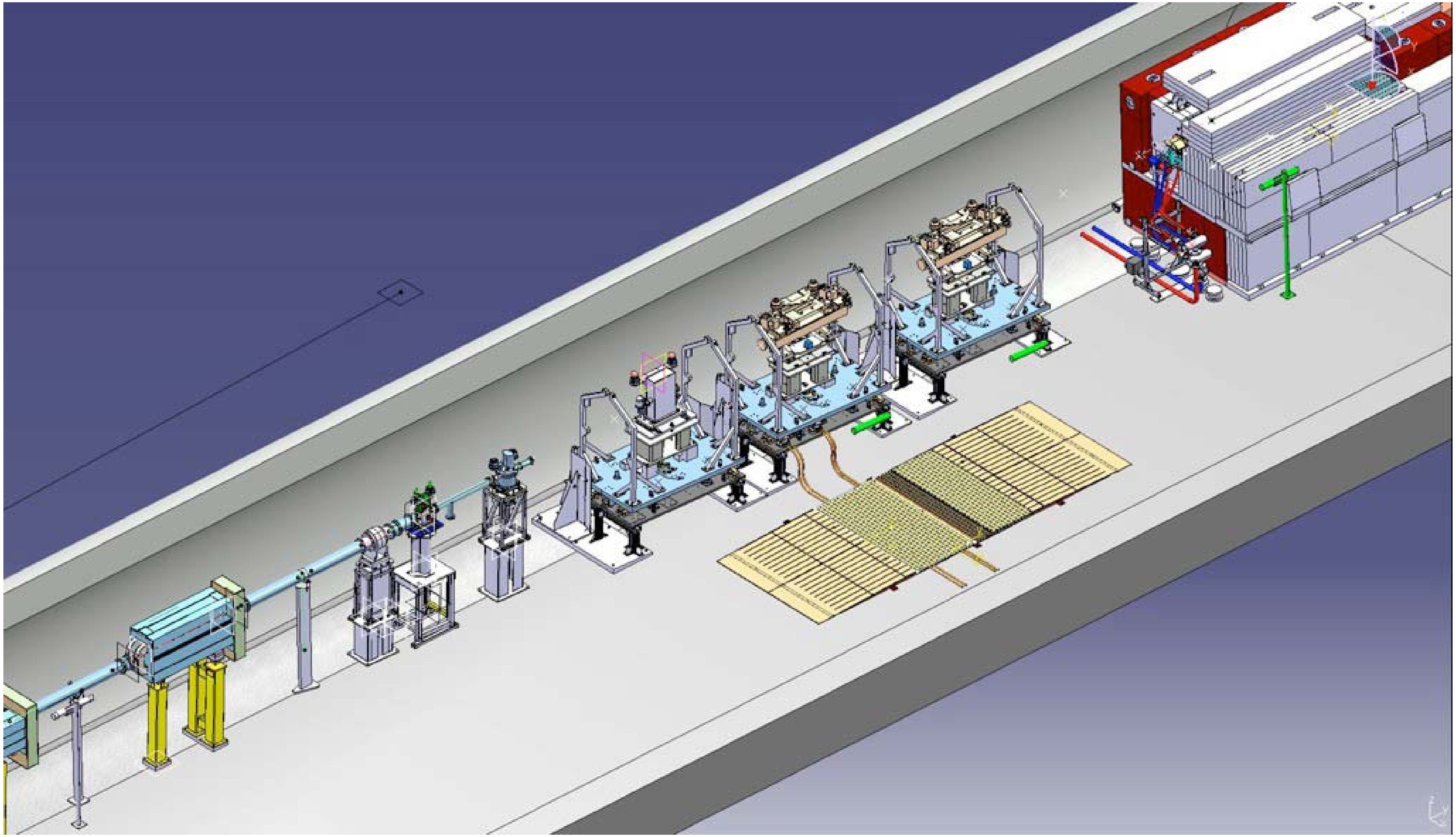


High **Rad**iation impact on **Mat**erials

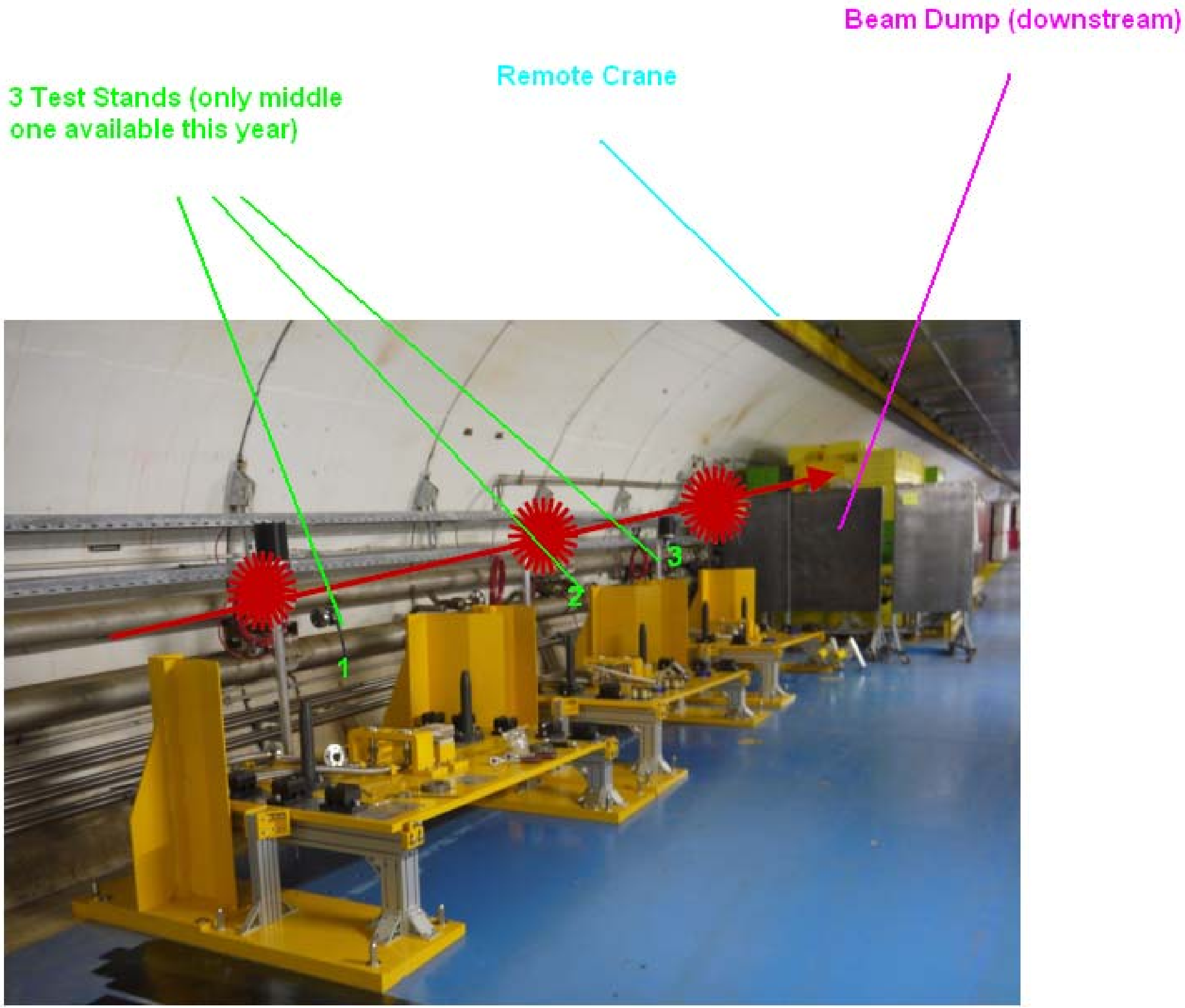
HiRadMat

- HiRadMat is a facility designed to **study the impact of intense pulsed beams on materials**
  - Thermal management (heating)
  - Material damage even below the melting point
  - Material vaporization (extreme conditions)
  - Radiation damage to materials
  - Thermal shock
  - Beam induced pressure waves
- It will serve as test bed, important for the design validation of LHC near beam components before installation in the ring
- Targeted users: LHC collimators and beam absorbers, R&D on materials, high-power targetry, test of vacuum components (beam windows, coating), others?
- **It is a user facility, open to non CERN users**

Target area of HiRadMat



Target area of HiRadMat



Parameters for HiRadMat

	Protons	Heavy ions ($Pb82^+$)
Beam Energy	440 [GeV]	173 [GeV/u], 36.1 [TeV/ions]
Pulse energy	up to 3.4 [MJ]	up to 21 [kJ]
Bunch intensity	3×10^9 to 1.7×10^{11} [protons]	3×10^7 to 7×10^7 [ions]
Number of bunches	1 to 288	52
Max intensity	4.9×10^{11} [protons]	3.64×10^9 [protons]
Bunch length	11.24 [cm]	11.24 [cm]
Bunch spacing	25, 50, 75 or 150 [ns]	100 [ns]
Pulse length	7.2 [µs]	5.2 [µs]
Cycle length	18 [s]	13.2 [s]
Beam spot at the experiment	**down to rms = 0.1 mm**	variable around 1 [mm^2]

LHeC

Colliding
Protons
Electrons

LHeC: Motivation

LHeC

- Exploring the interaction of matter in three channels:

  -hadronic interaction: pp or pp-bar collisions (e.g. SppS, Tev)
  -leptonic interactions: e+e- collisions (e.g. SLC, LEP)
  -hadronic-leptonic interactions (e.g. HERA)

  In the past the exploration of all three channels have provided vital insight for the construction of the Standard Model

- e-p collisions for the TeV Scale:
  -TeV CM collision energies using the LHC require lepton beam energies between 60 GeV and 140 GeV
  -Efficient exploitation requires a luminosity of: $L \approx 10^{33}\ cm^{-2}\ s^{-1}$

LHeC Proposal endorsed by ECFA (30.11.2007)

As an add-on to the LHC, the LHeC delivers in excess of 1 TeV to the electron-quark cms system. It accesses high parton densities 'beyond' what is expected to be the unitarity limit. Its physics is thus fundamental and deserves to be further worked out, also with respect to the findings at the LHC and the final results of the Tevatron and of HERA.

First considerations of a ring-ring and a linac-ring accelerator layout lead to an unprecedented combination of energy and luminosity in lepton-hadron physics, exploiting the latest developments in accelerator and detector technology.

It is thus proposed to hold two workshops (2008 and 2009), under the auspices of ECFA and CERN, with the goal of having a Conceptual Design Report on the accelerator, the experiment and the physics. A Technical Design report will then follow if appropriate.

Unanimously supported by rECFA and ECFA plenary in November 2007

Design Considerations

LHC hadron beams: **E_p=7 TeV;**

CM collision energy: $E^2_{CM} = 4\ E_e * E_{p,A}$ ➔ **50 to 150 GeV**

Integrated e±p : O(100) fb^{-1} ≈ 100 * L(HERA) → **synchronous ep and pp operation**

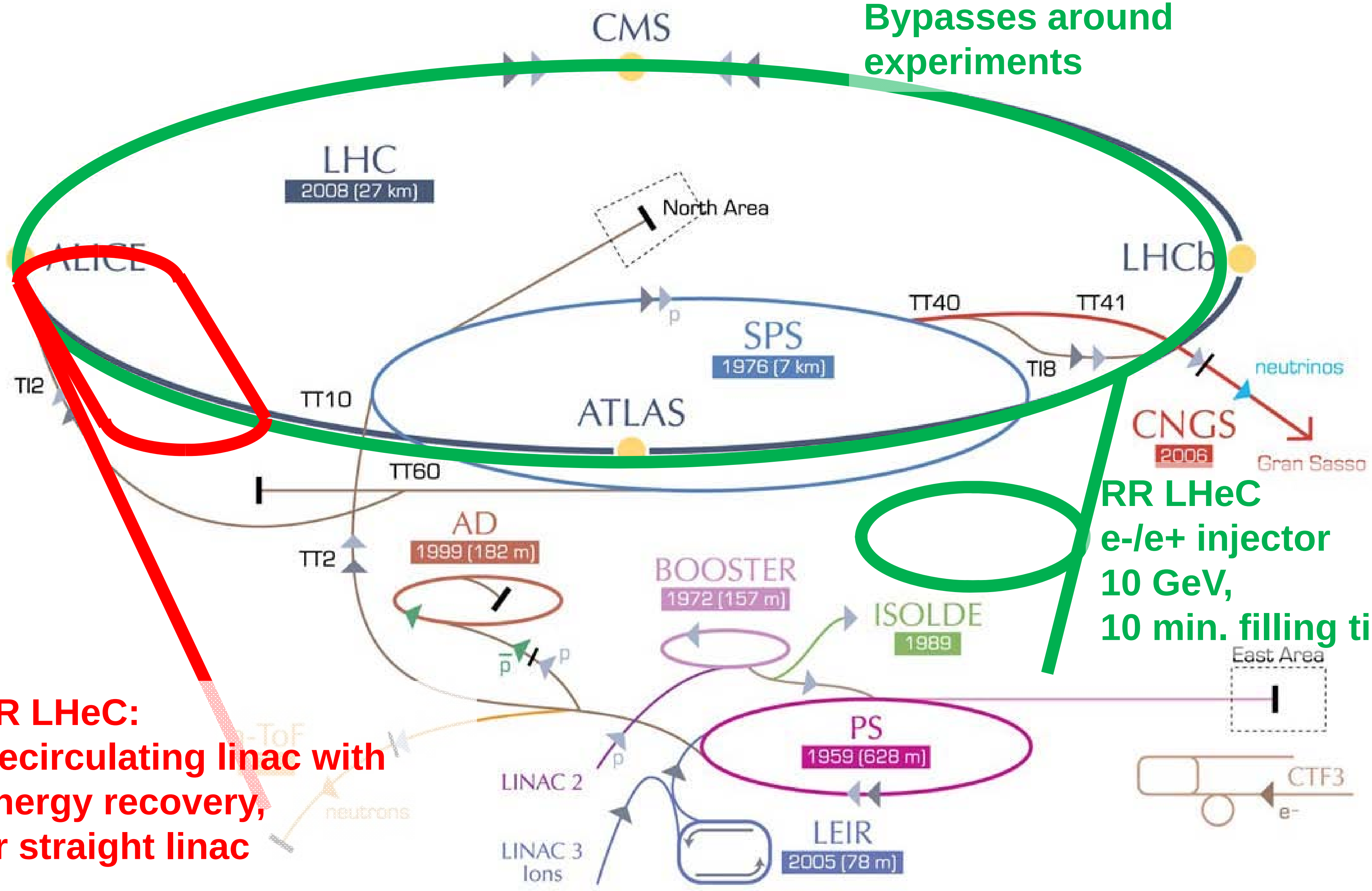
Luminosity O (10^{33}) $cm^{-2}s^{-1}$ with 100 MW power consumption ➔ Beam Power < 70 MW

Start of LHeC operation together with HL-LHC in 2023 (installation in LS3 in 2022)

- **e Ring in the LHC tunnel (Ring-Ring - RR)**
- **Superconducting ERL (Linac-Ring - LR)**

LHeC options: RR and LR

RR LHeC:
new ring in LHC tunnel,
Bypasses around
experiments

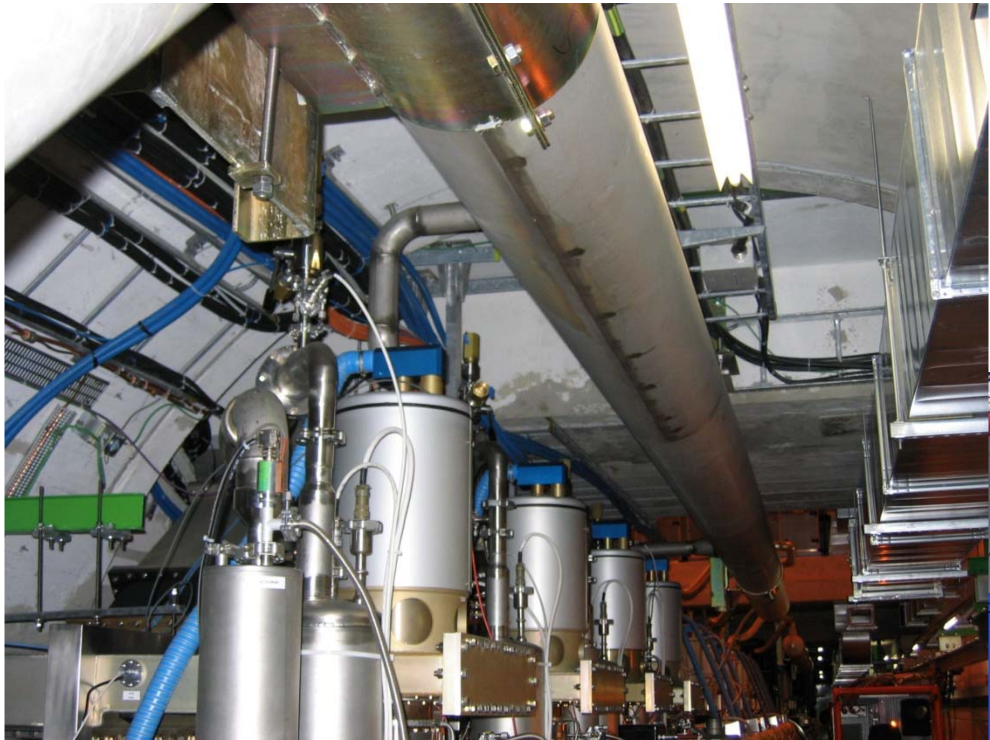


RR LHeC
e-/e+ injector
10 GeV,
10 min. filling time

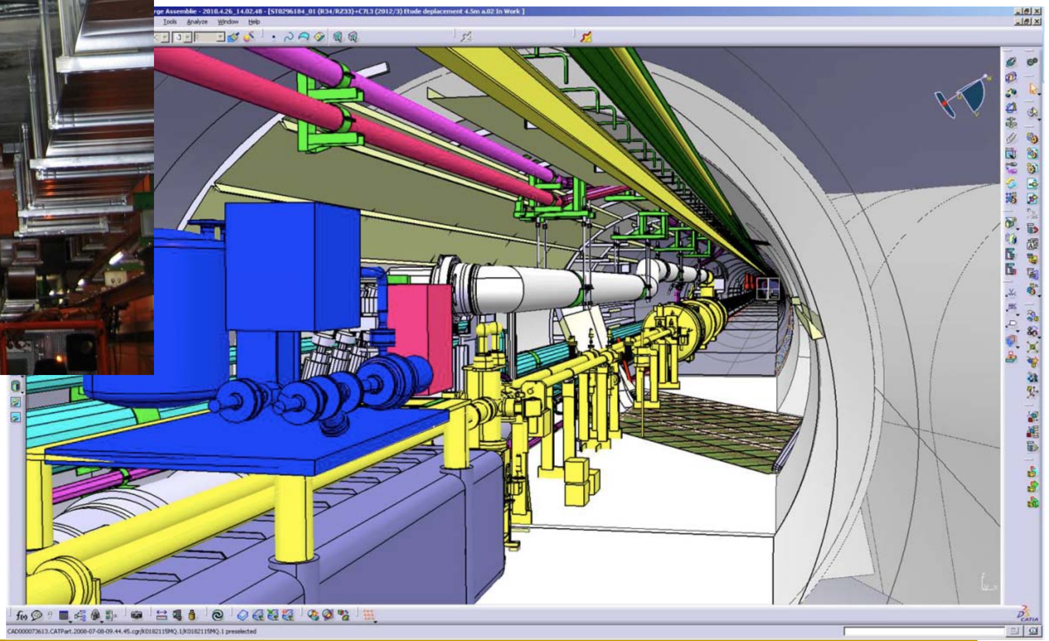
LR LHeC:
Recirculating linac with
energy recovery,
or straight linac

LHeC: Ring-Ring Option

Challenge 2: Integration in the LHC tunnel



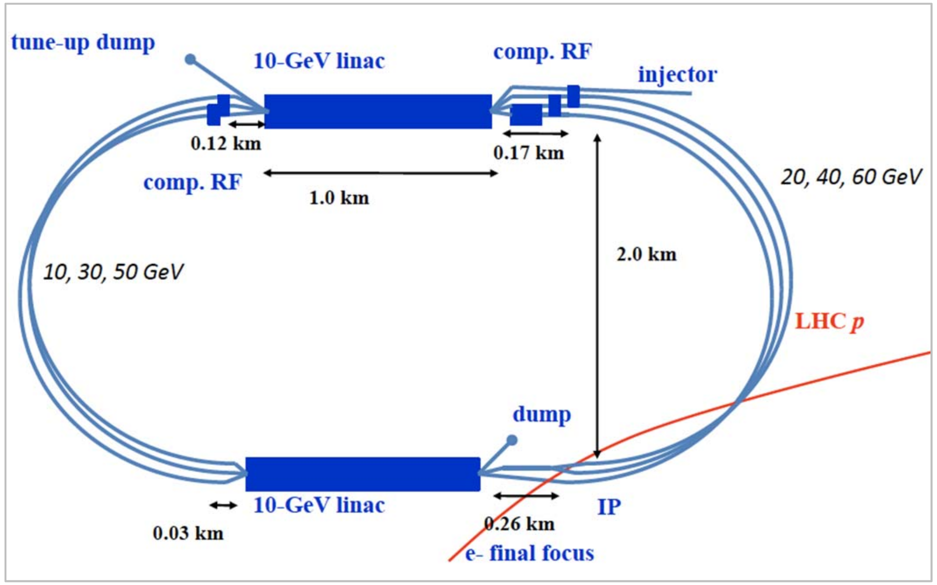
RF Installation in IR4



Cryo link in IR3

LHeC: Baseline Linac-Ring Option

- Challenge 1: Super Conducting Linac with Energy Recovery & high current (> 6mA)



Two 1 km long SC linacs in CW operation ($Q \approx 10^{10}$)

➔ requires Cryogenic system comparable to LHC system!

- Challenge 2: Relatively large return arcs
  - ➔ ca. 9 km underground tunnel installation
  - ➔ total of 19 km bending arcs
  - ➔ same magnet design as for RR option: > 4500 magnets

Design Parameters

electron beam	RR	LR	LR*
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	17	10	0.4[illegible]
polarization [%]	40	90	[illegible]
bunch population [10^9]	26	[illegible]	[illegible]
e- bunch length [mm]	10	[illegible]	[illegible]
bunch interval [ns]	[illegible]	[illegible]	[illegible]
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	[illegible]	[illegible]	[illegible]
rms IP beam size σ	[illegible]	[illegible]	[illegible]
e- IP beta fun[illegible]	[illegible]	[illegible]	[illegible]
full cros[illegible]	[illegible]	[illegible]	[illegible]
ge[illegible]	[illegible]	[illegible]	[illegible]
repe[illegible]	[illegible]	[illegible]	[illegible]
beam [illegible]	[illegible]	[illegible]	5
ER effic[illegible]	[illegible]	[illegible]4%	N/A
average cu[illegible]	[illegible]	6.6	5.4
tot. wall plu[illegible]	100	100	100

prot[illegible]	[illegible]R	LR
[illegible]	[illegible]	1.7
[illegible]	[illegible]	3.75
[illegible]	[illegible]	7
[illegible]	[illegible]	1
[illegible]	[illegible]	[illegible]5

Final parameter set to be developed as we gain experience with LHC operation (beam-beam, spacing etc)

The goal here is to demonstrate that realistic sets exist for both LHeC versions

[illegible]conservative

[illegible]gn also for deuterons (new) and lead (exists)

RR= Ring – Ring
LR =Linac –Ring

Ring uses 1° as baseline : L/2
Linac: clearing gap: L*2/3

*) pulsed, but high energy ERL not impossible

LHeC Planning and Timeline

- We assume the LHC will reach end of its lifetime with the end of the HL-LHC project:

  -Goal of integrated luminosity of 3000 fb^{-1} with 200 fb^{-1} to 300 fb^{-1} production per year ➔ ca. 10 years of HL-LHC operation

  -Current planning based on HL-LHC start in 2022

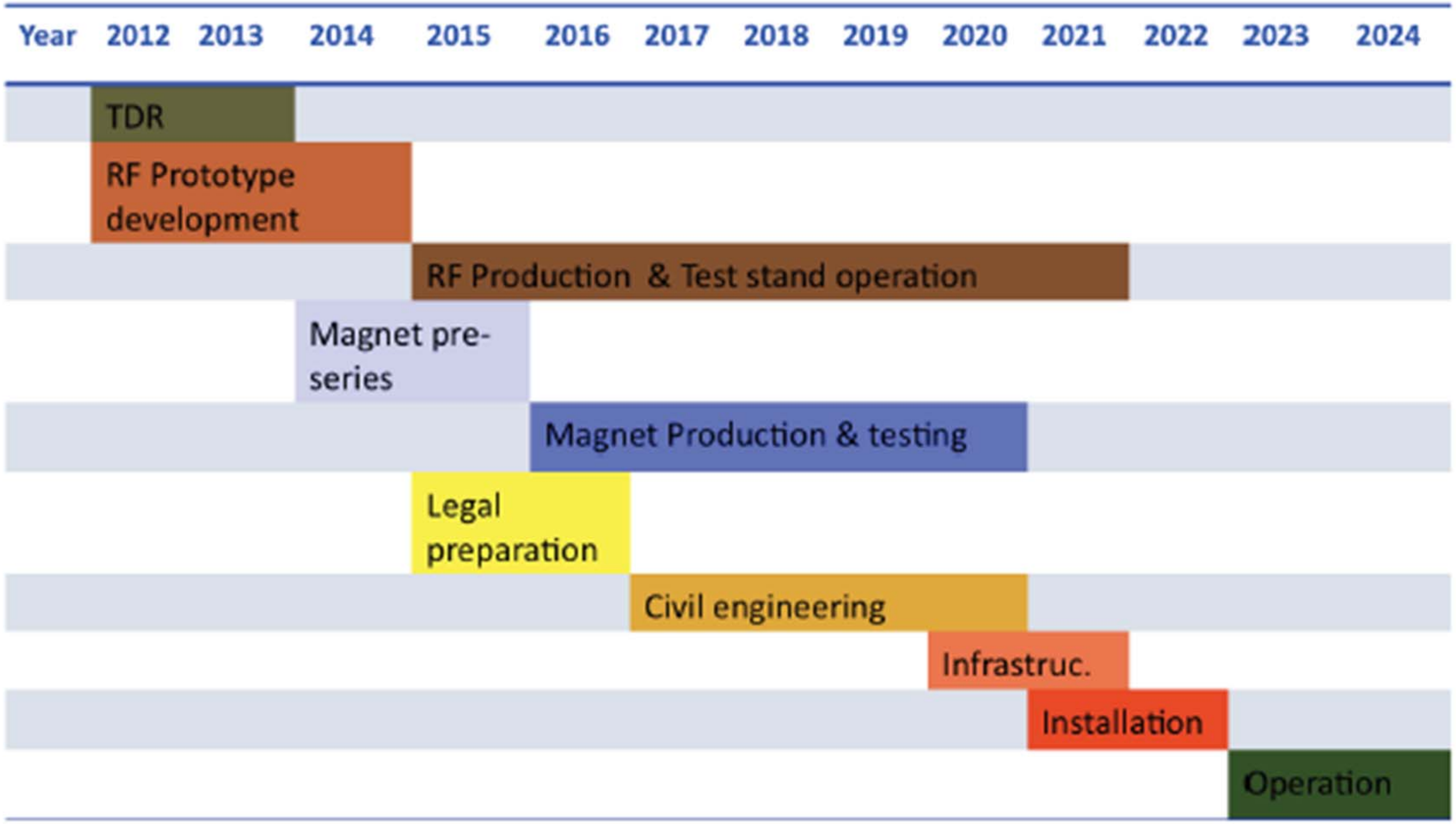
  ➔ end of LHC lifetime by 2032 to 2035

- LHeC operation:

  -Luminosity goal based on ca. 10 year exploitation time (100 fb^{-1})

  -LHeC operation beyond or after HL-LHC operation will imply significant operational cost overhead for LHC consolidation

LHeC Tentative Time Schedule



LS3 --- HL LHC

We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)

LHeC Planning and Timeline

LHeC

R&D activities:

- Superconducting RF with high Q-value
- Normal conducting compact magnet design
- Superconducting IR magnet design
- Test facility for Energy recovery operations and – or
- compact injector complex
- High intensity polarized positron sources

LHeC - Participating Institutes: A very rich collaboration

LHeC

CERN

SLAC
NATIONAL ACCELERATOR LABORATORY

The Cockcroft Institute
of Accelerator Science and Technology

NTNU
Norwegian University of
Science and Technology

Jefferson Lab
Thomas Jefferson National Accelerator Facility

CLIC

ANKARA ÜNİVERSİTESİ
ANKARA ÜNİVERSİTESİ 1946

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN
Istituto Nazionale
di Fisica Nucleare
Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

ECFA

EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

UNIVERSITY OF
LIVERPOOL

BROOKHAVEN
NATIONAL LABORATORY

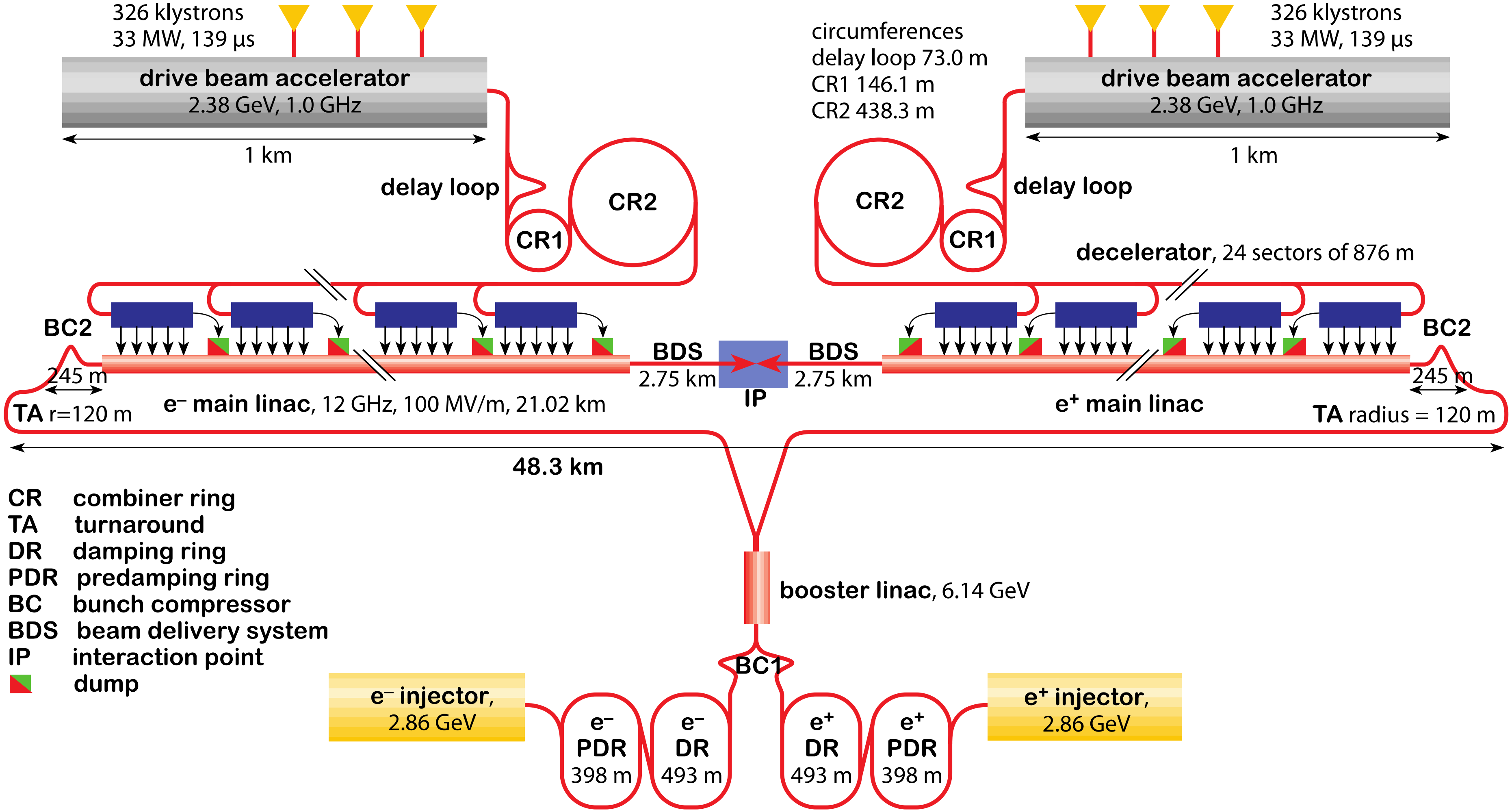
СИБИРСКОЕ ОТДЕЛЕНИЕ РАН
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И.Будкера
630090 Новосибирск

KEK

CLIC

Colliding
Electrons
Positrons

The CLIC Layout



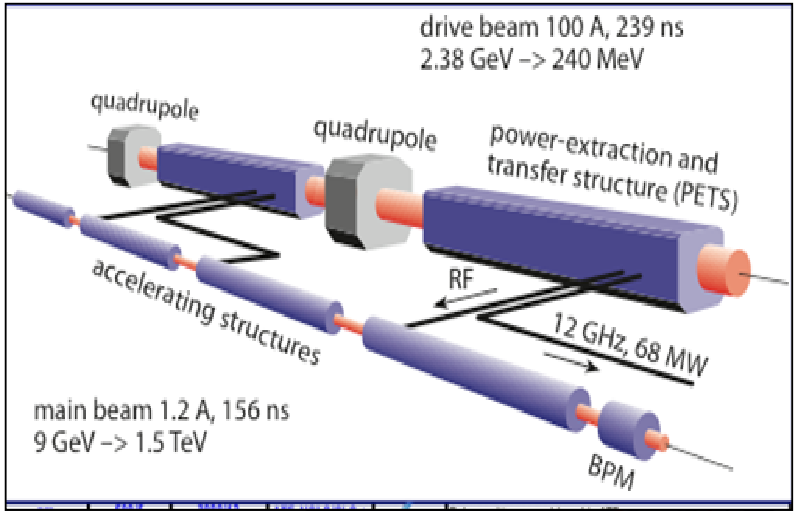
CLIC main parameters

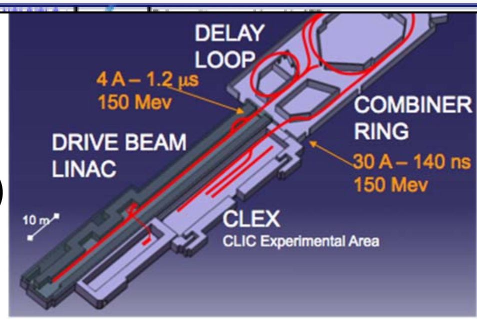
Centre-of-mass energy	500 GeV	3 TeV
Total (Peak 1%) luminosity	$2.3(1.4)\cdot 10^{34}$	$5.9(2.0)\cdot 10^{34}$
Total site length (km)	13.0	48.3
Loaded accel. gradient (MV/m)	80	100
Main linac RF frequency (GHz)	12	
Beam power/beam (MW)	4.9	14
Bunch charge (10^9 e+/-)	6.8	3.72
Bunch separation (ns)	0.5	
Beam pulse duration (ns)	177	156
Repetition rate (Hz)	50	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	4.8/25	0.66/20
Hor./vert. IP beam size (nm)	202 / 2.3	40 / 1
Hadronic events/crossing at IP	0.19	2.7
Coherent pairs at IP	100	$3.8\ 10^8$
Wall plug to beam transfer eff	4.1%	5.0%
Total power consumption (MW)	240	560

Feasibility studies and the Conceptual Design Report

Feasibility issues (some examples in following slides):

- Drive beam generation
- Beam driven RF power generation
- Accelerating Structures
- Two Beam Acceleration
- Ultra low emittances and beam sizes
- Alignment
- Vertical stabilization
- Operation and Machine Protection System





CDRs:

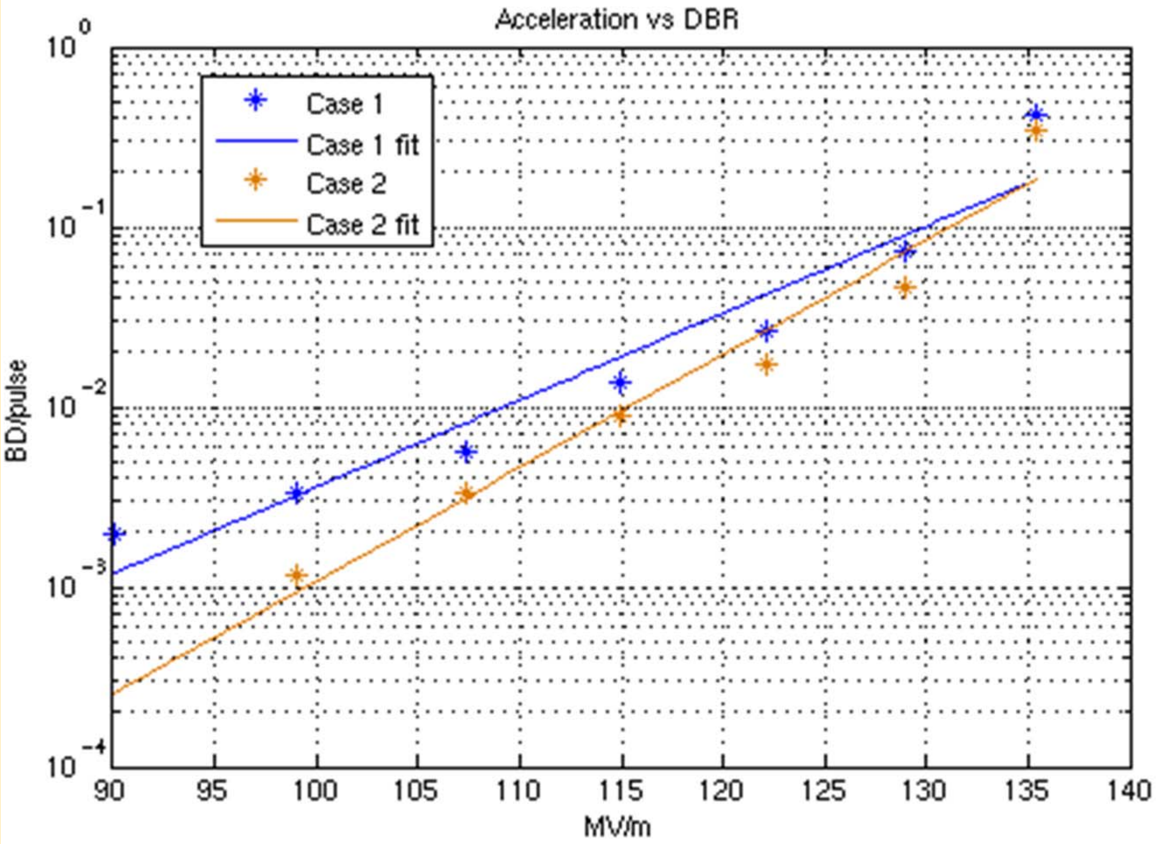
- Vol 1: The CLIC accelerator and site facilities (H.Schmickler)
  - CLIC concept with exploration over multi- … energy range up to 3 TeV
  - Feasibility study of CLIC parameters … at 3 TeV (most demanding)
  - Consider also 500 GeV, and in… …gy ranges
- Vol 2: The CLIC physics and d… …n)
- Vol 3: CLIC study summ…
  - Summary and … European Strategy process, including possible implementation stages for a CLIC mac… …osting and cost-drives
  - Pr… … and work plan of post CDR phase (2012-16)
- Timesca…
  - By e… …011: Vol 1 and 2 completed
  - Spring/mid 2012: Vol 3 ready for the European Strategy Open Meeting

Being prepared

Two Beam Test Stand (TBST) results 2011

- Well established two beam acceleration experiments
- Calibration converging, structure correctly tuned
- Interesting breakdown studies started

Very preliminary, RF parts in early conditioning phase
Blue: all components, Orange: limited to structures



2011 : CTF3 TBTS running for full after winter shut-down. Gradients of 110 – 130 MV/m are routinely reached (20% above CLIC target).

Summary

- CDR underway and good progress on feasibility issues
- Increased focus on ensuring the machine can be adapted to running a several energies and be implemented in stages to provide physics as quickly and efficiently as possible
- Plans 2011-2016 formulated towards implementation plan – resources situation reasonable thanks to collaborative efforts
- CLIC organization adapted to new phase, being implemented now

- Collaboration with other institutes for topics on CLIC, and for topics of common interest for CLIC and ILC
  - Example: sc damping wiggler with KIT (incl. beam dynamics)

Combined ILC/CLIC working groups

	CLIC	ILC
Physics & Detectors	L.Linssen, D.Schlatter	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)	L.Gatignon D.Schulte, R.Tomas Garcia	B.Parker, A.Seriy
Civil Engineering & Conventional Facilities	C.Hauviller, J.Osborne.	J.Osborne, V.Kuchler
Positron Generation	L.Rinolfi	J.Clarke
Damping Rings	Y.Papaphilipou	M.Palmer
Beam Dynamics	D.Schulte	A.Latina, K.Kubo, N.Walker
Cost & Schedule	P.Lebrun, K.Foraz, G.Riddone	J.Carwardine, P.Garbincius, T.Shidara

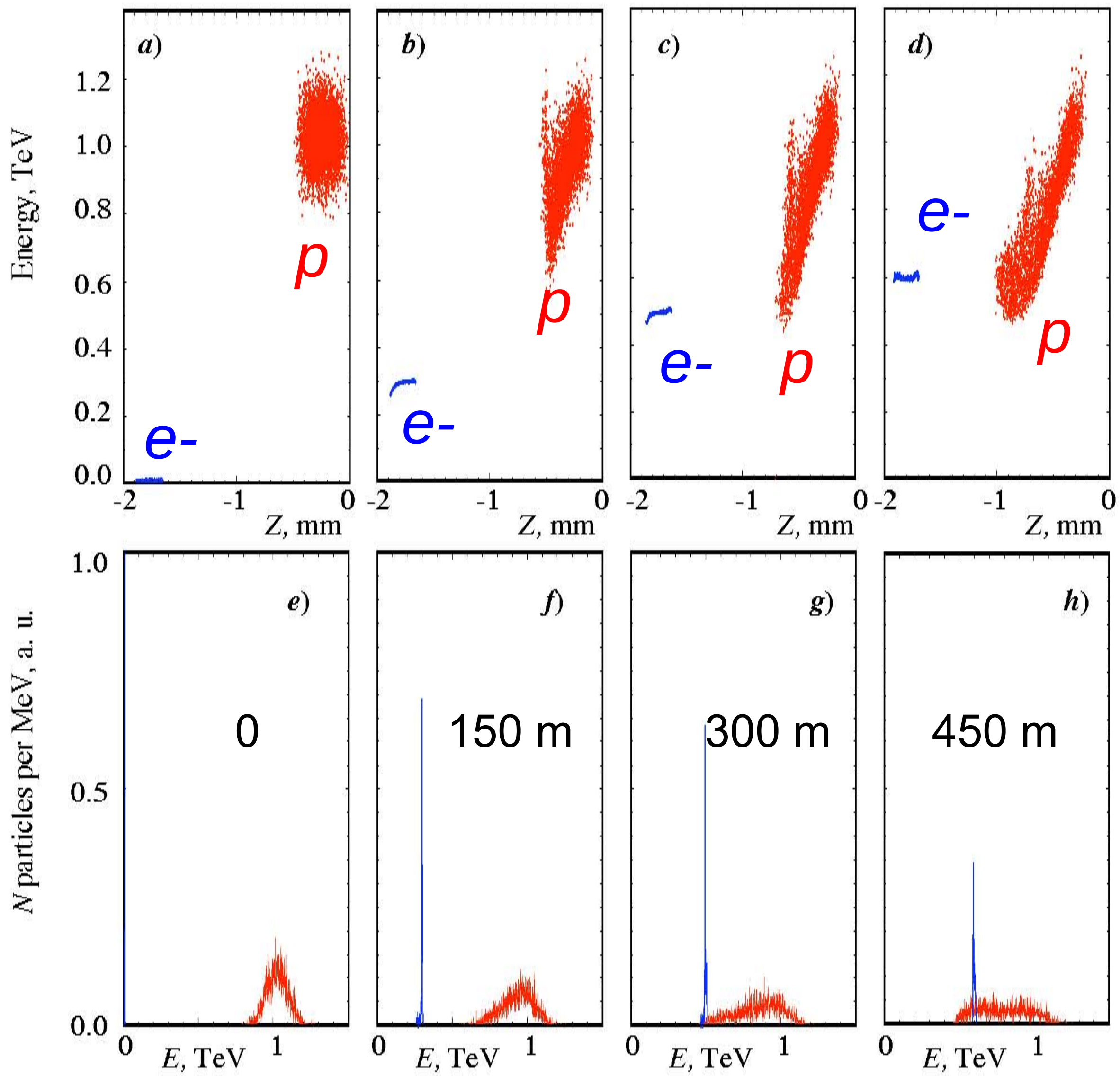
+ General issues groups for accelerator, chairs M. Harrison (ILC)/P. Lebrun (CLIC)

New acceleration techniques

advanced concepts “made in Germany”:

TeV protons as plasma driver to accelerate electrons to TeV-scale energy

A.Caldwell, K.Lotov,A.Pukhov, F.Simon; MPI-P München, U. Düsseldorf, & Novosibirsk



first contacts

Snapshots of the combined longitudinal phase space of the driver and the witness beam (energy vs coordinate), frames (a)-(d) and corresponding energy spectra, frames (e)-(h). The snapshots are taken at acceleration distances Z = 0, 150, 300, 450 m. The electrons are shown as blue points, while the protons are depicted as red points.

arXiv:0807.4599v1, July ‘08

Proposals for collaborations

1. Impedances and wakefields
   – TUDa (O. Boine-Frankenheim), Uni ROSTOCK (U.v.Rienen), CERN
2. Ion effects and instabilities
   – Uni ROSTOCK (U.v.Rienen), CERN
3. Electron clouds
   – TUDa (O. Boine-Frankenheim), Uni ROSTOCK (U.v.Rienen), CERN
4. Beam impact on beam absorbers and collimators
   – GSI, Uni Heidelberg, CERN
5. Fast Beam Loss Monitoring
   – Universität Postdam, DESY Zeuthen, DESY
6. Electron Positron sources
   – TU Dresden (J. Teichert), U Mainz, CERN
7. Polarisation
   – U Mainz (K. Aulenbacher), CERN
8. High brilliance high current electron sources
   – U Mainz, CERN
9. Power efficient accelerators (ERLs)
   – U Mainz, TUDa, KIT, HZB, CERN
10. Dämpfungsringe und supraleitende Dämpfungswiggler (SR)
    – KIT, CERN
11. Plasmabeschleunigung (experiment and theory, protons short bunches, others)
    – Uni Düsseldorf, Uni Hamburg, MPI Munich, TU Darmstadt, CERN …

Conclusions

Clear interest of CERN to participate, for various projects

Clear interest of CERN to participate, for acceleleration to high energy

Suggest to extend scope to „LHC performance and upgrades“

LHeC is a very interesting project, where does it fit? ERL?

EP-1	EP-3	EP-4	EP-5
Elsen, Eckard	Müller, Günther	Grüner, Florian	Boine-Frankenheim
Superconduct. RF	ILC/CLIC	PWA	LHC collective Effects
Eichhorn, Ralph Foster, Brian Jakoby, Weiland Khahn, Shaukat Müller, Günther Quadt, Arnulf Ratzinger, Ulrich Rienen, Ursula van Weiland, Thomas	Bernhard, Axel Hillert, Wolfgang Müller, Günther Teichert,J., Aulenbacher K.	Caldwell, Allen Karsch, Stefan Osterhoff, Jens Pukhov, Alexander Quadt, Arnulf Weiland, Thomas Willi, Oswald	Boine-Frankenheim Rienen, Ursula van Weiland, Thomas

HK-6	HK-8	HK-9	HK-10	HK-11	HK-12	HK-13
Oliver Kester UFRA	Boine-Frankenheim	Jankowiak, Andreas	Roth, Markus	Hillert, Wolfgang	Klingbeil	Klingbeil
Ionsources	Kollektive Effekte	ERL	Laser-Ion-Beschleunigung	ENC@FAIR	SynchBeams	BunchTransfer
Karsch, Stefan Weiland, Thomas	Boine-Frankenheim Karsch, Stefan Munteanu, Irina Ratzinger, Ulrich Rienen, Ursula van Weiland, Thomas	Aulenbacher, Kurt Eichhorn, Ralph	Boine-Frankenheim Ratzinger, Ulrich Roth, Markus Willi, Oswald	Aulenbacher, Kurt Hillert, Wolfgang	Adamy, Jürgen Glesner, Manfred Hofmann, Klaus Jakoby Klingbeil, Harald Weiland, Thomas Zipf, Peter	Fricke Glesner, Manfred Hofmann, Klaus Klingbeil, Harald

Müller, Günther TBC
Hillert, Wolfgang TB

Not clear about differences between „Kollektive Effekte“ und „LHC collective effects“

Conclusion

- Most future CERN accelerator research is based on the experience with LHC
  - CLIC/ILC project needs will be better defined with LHC results
- Research in many areas in accelerator physics and technology is required
- New concepts will be addressed
- Lot of work ahead of us… limited resources everywhere – share experience and resources
- CERN offers a lot of expertise, is willing to learn from others and to collaborate
- We are looking forward to it…. in particular to collaborate with the numerous experts in our field in Germany