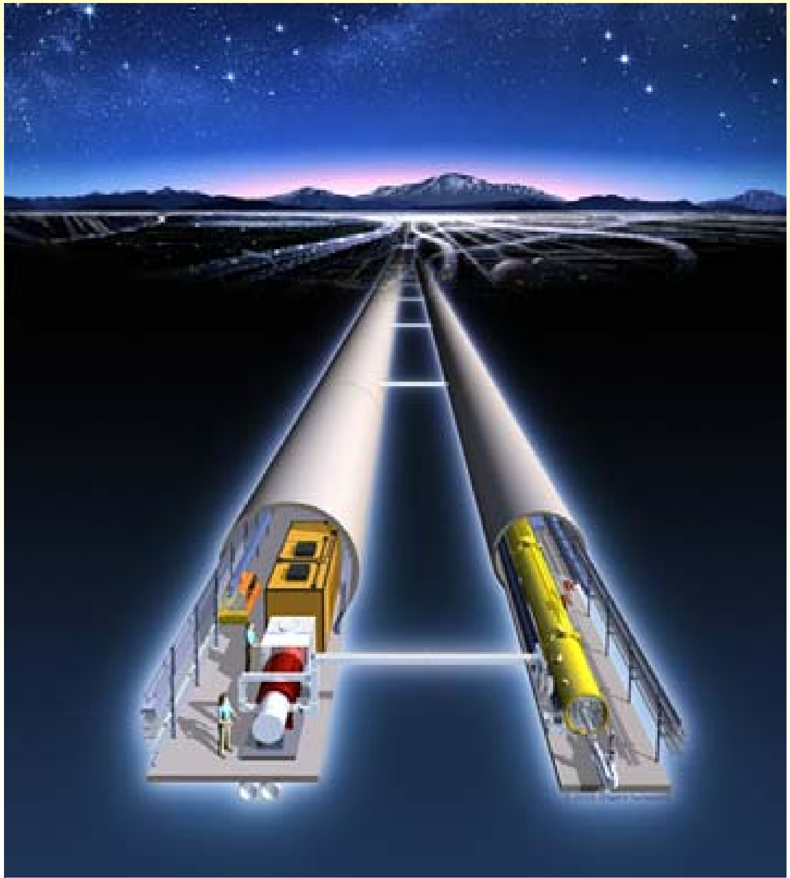
Congressino della Sezione di Roma 2009 Roma , 4 maggio 2009

Fisica ai possibili collider futuri



- i progetti in discussione (novita` recenti)
- scale dei tempi (?)
- "scenari" di fisica

Barbara Mele

INFN Istituto Nazionale di Fisica Nucleare Sezione di Roma

Future Collider Overview Series

part of the LHC4FC Institute at CERN, TH

10 February 2009

10:00 Lyn Evans: LHC accelerator status and upgrade plans

17 February 2009

10:00 Klaus Desch: Physics case for the ILC

11:00 Brian Foster: Technology progress report of the ILC

18 February 2009

10:00 Emmanuelle Perez: Physics opportunities with the LHeC

11:00 Max Klein: Machining the LHCeC option

19 February 2009

10:00 Marco Battaglia: Physics case for CLIC

11:00 Jean-Pierre Delahaye: Technology path to CLIC

20 February 2009

14:00 Michelangelo Mangano: Physics opportunities with the sLHC

24 February 2009

10:00 Roberto Palmer: Muon collider technology status

26 February 2009

10:00 Aurelio Juste: Tevatron update and status

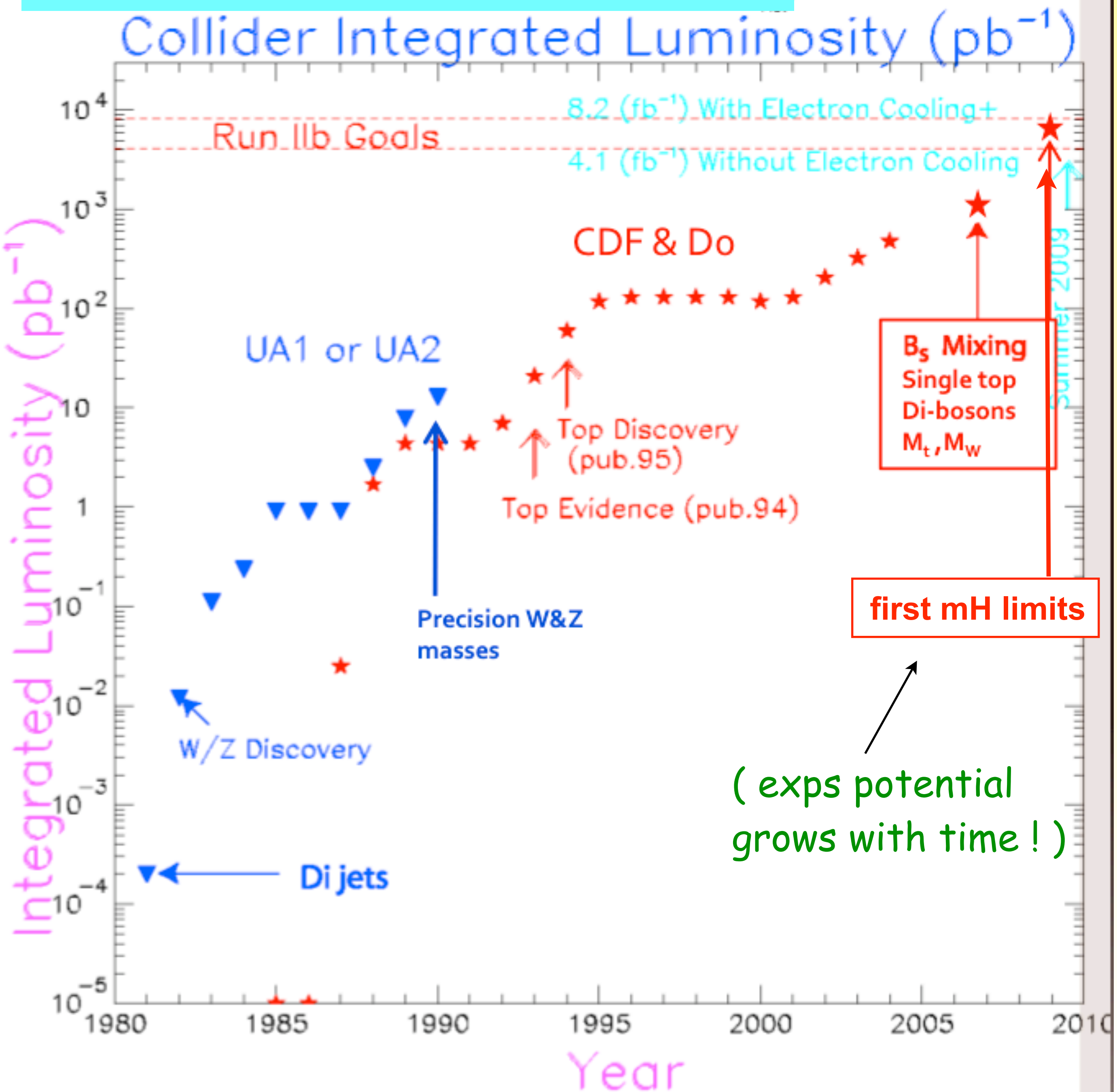
main source for this talk (for slides, too!)

http://sites.google.com/site/lhc2fcwg4/

Foreword (a provocative one!)

- decision about any big project *(by now)* waits for first results from LHC, but....
- it could take quite a few years to establish the LHC Physics Scenario *needed* to make such a decision .....
    - ***cf. LEP project approved in 1981 (before direct observation of W and Z bosons at the SPS...)***
- **how long will LHC take to deliver such results ?**

SPS & Tevatron Discoveries vs time

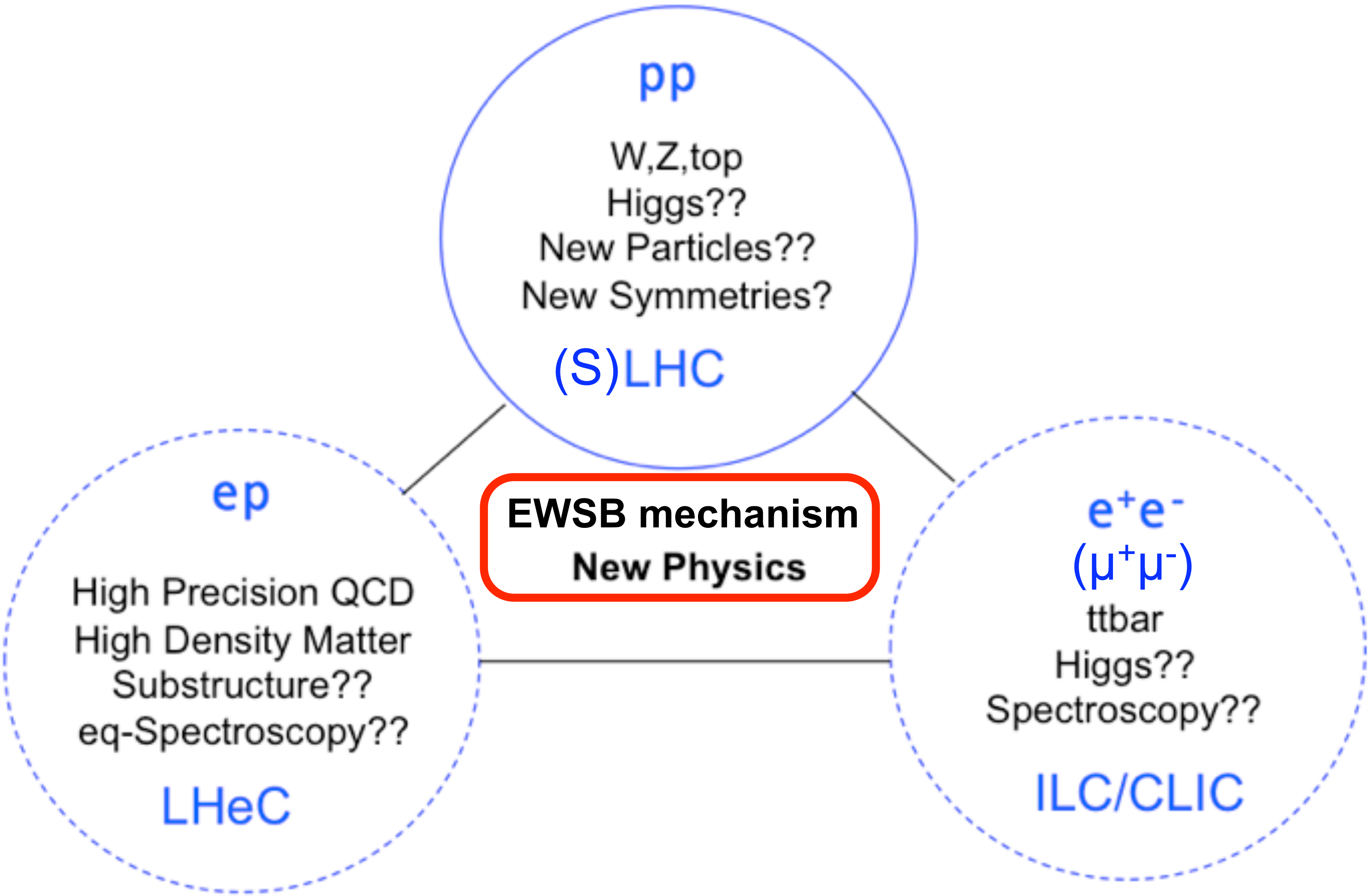


for SPS and Tevatron discoveries, we had quite accurate TH expectations !

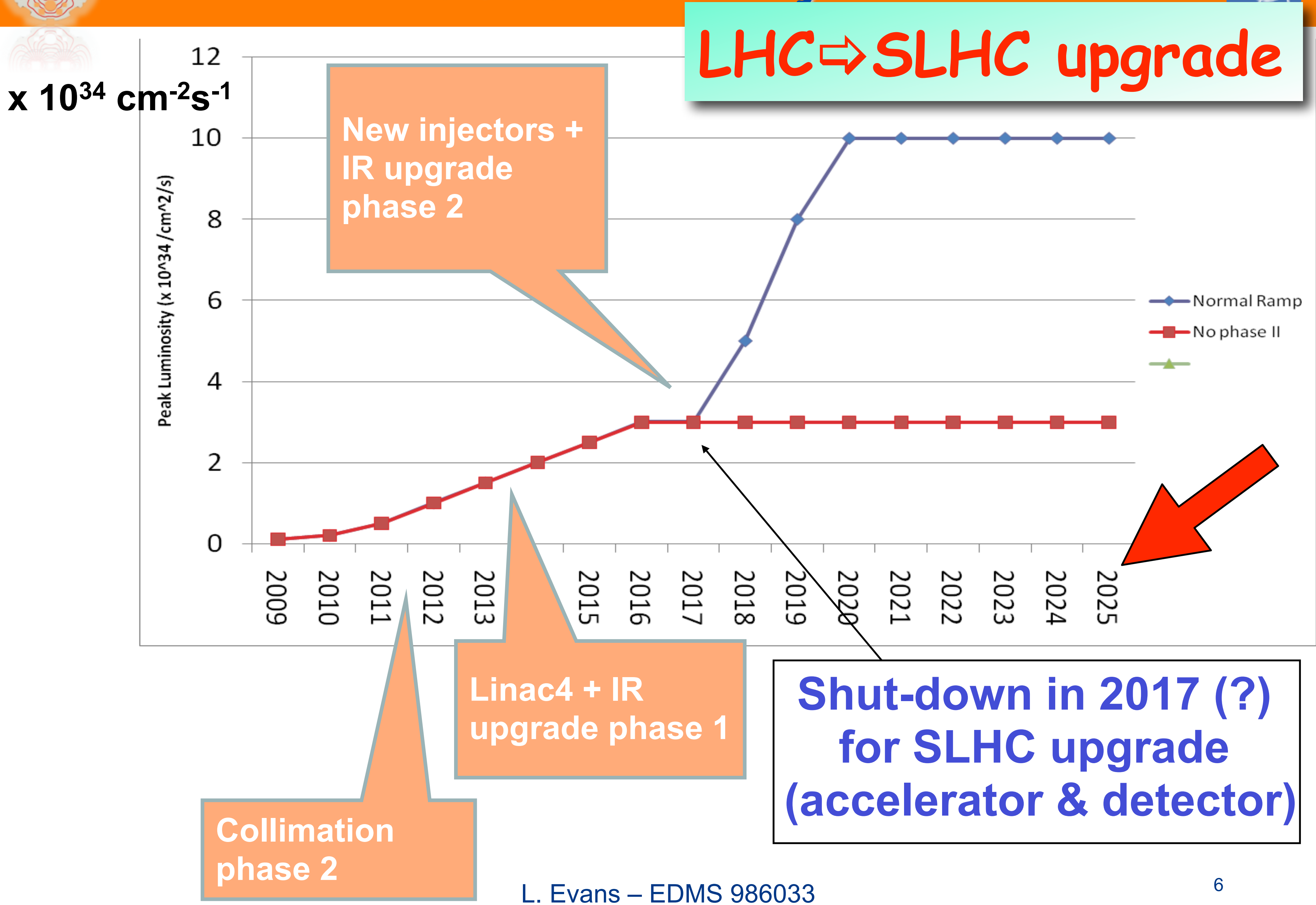
at LHC, less clear-cut TH expectations (how much ∫L is needed ???)

could delay the detection
→ of a NP signal
→ of a new Collider project approval ....

The TeV Scale [2010-2035..]



Peak luminosity…



Physics Opportunities at the LHeC

Emmanuelle Perez (CERN)

LHeC: A Large Hadron electron Collider at the LHC

5-140 GeV $e^{\pm}$ on 1-7 TeV p,A

Possible "upgrade" of the LHC :

add-on of an electron beam to study :

Deep-inelastic scattering ep and eA at

- unprecedented energy
- with an integrated luminosity of O(10 fb^{-1})

http://www.lhec.org.uk

Towards the CDR by 2010

Following a suggestion of Council, ECFA + CERN in 11/07 set the task to work out a CDR within 2 years on the physics, machine and detector for a TeV energy ep/eA collider based on the LHC beams.

Scientific Advisory Committee (12/08)

Guido Altarelli (Rome)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
Joel Feltesse (Saclay)
Lev Lipatov (St.Petersburg)
Roland Garoby (CERN)
Rolf Heuer (DESY)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Karlheinz Meier (Heidelberg, ECFA)
Richard Milner (Bates)
Steven Myers, (CERN)
Guenter Rosner (Glasgow, NuPECC)
Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Steering Group

Oliver Bruening	(CERN)
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Stefano Forte	(Milano)
Max Klein - chair	(Liverpool)
Paul Newman	(Birmingham)
Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

DIS05, 06, 07, 08: Future of DIS and LHeC (Proceedings)

EPAC08 Genoa: 3 Papers on Accelerator

First ECFA-CERN Workshop on the LHeC Divonne 1.-3.9.08

Opening: J.Ellis, Kh.Meier, G.Rosner, J.Engelen, G.Altarelli

DIS09: April 25, Madrid: Pre-Meeting on the LHeC

PAC09 Vancouver, May 2009

September 7/8, 2009: 2nd ECFA-CERN Workshop

November 2009: Report to ECFA

May 2010: Delivery of CDR (~200 pages on Physics, Det,, ACC)

WG Convenors →

Accelerator Design [RR and LR]

Oliver Bruening (CERN),

John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd

Bernhard Holzer (DESY),

Uwe Schneeekloth (DESY),

Pierre van Mechelen (Antwerpen)

Detector Design

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)

New Physics at Large Scales

Emmanuelle Perez (CERN),

Georg Weiglein (Durham)

Precision QCD and Electroweak

Olaf Behnke (DESY),

Paolo Gambino (Torino),

Thomas Gehrmann (Zuerich)

Claire Gwenlan (UCL)

Physics at High Parton Densities

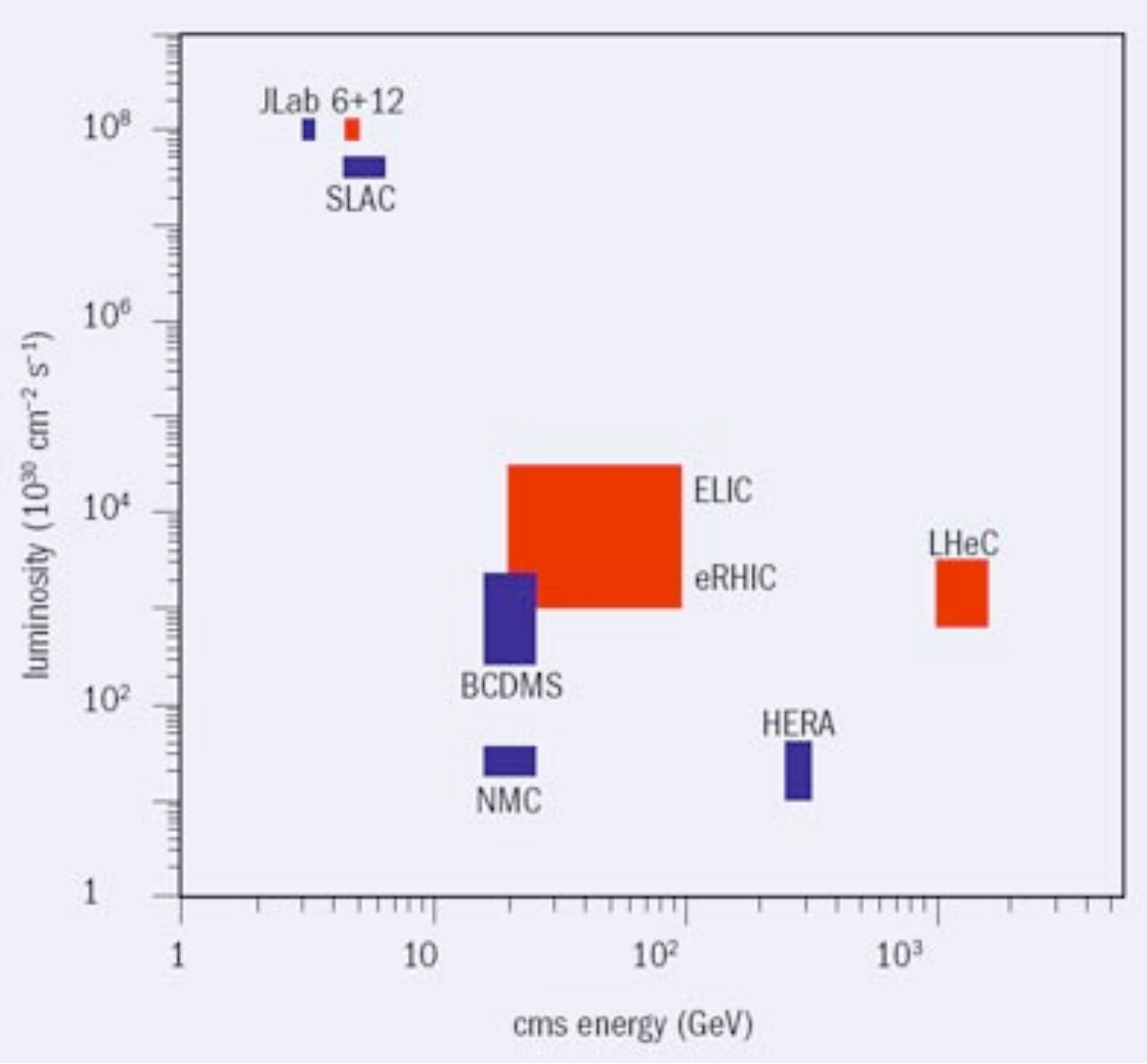
Nestor Armesto (CERN),

Brian Cole (Columbia),

Paul Newman (B'ham),

Anna Stasto (MSU)

$L \sim 10^{33}\ cm^{-2}s^{-1}$ and $\sqrt{S} \sim 1.4$ TeV



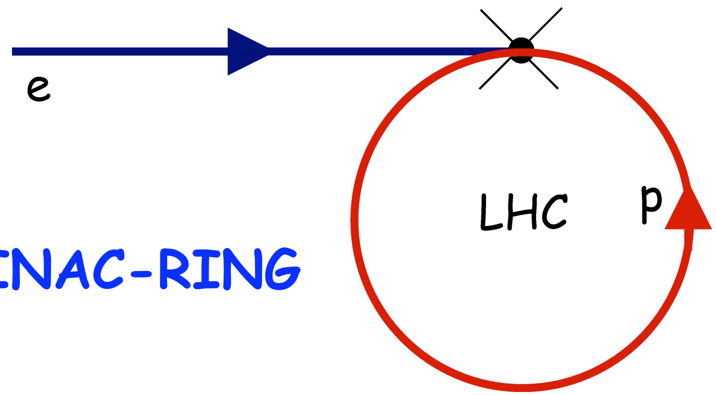
LHeC is not the first proposal for higher energy DIS, but it is the first with the potential for significantly higher luminosity than HERA …

… achievable with a new electron accelerator at the LHC …

[Willeke et al, JINST 1 (2006) P10001]

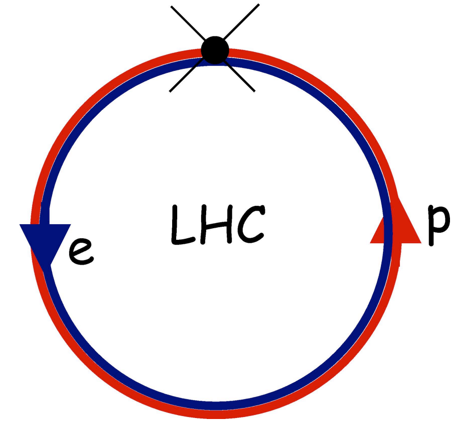
How could ep be done with LHC ?

(... whilst allowing simultaneous ep and pp running ...!!!!)



LINAC-RING

- Previously considered as `QCD explorer' (also THERA)
- Reconsideration (Chattopadhyay, Zimmermann et al.) recently
- **Main advantages**: low interference with LHC, $E_e \rightarrow$ 140 GeV, LC relation

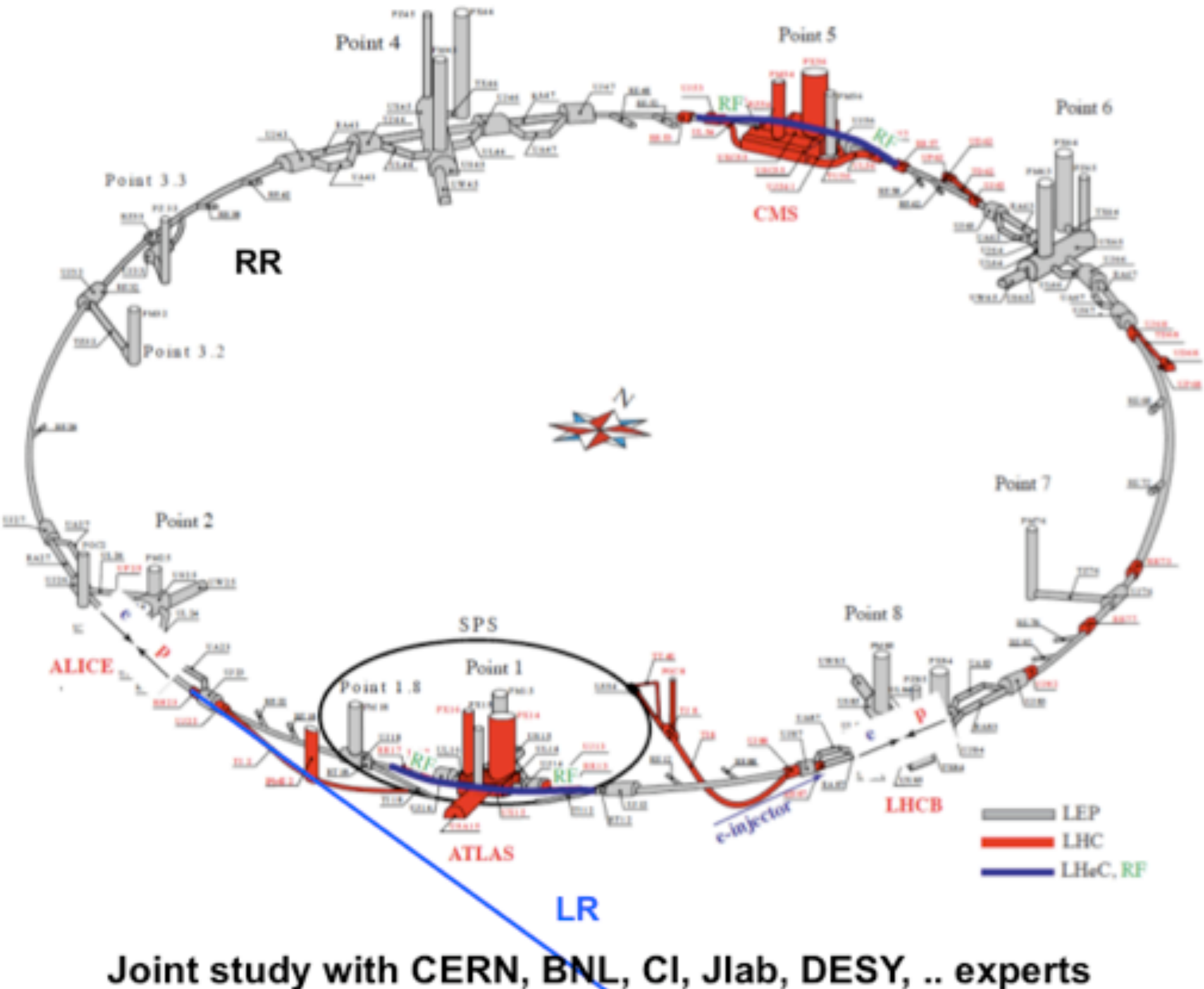


RING-RING

- First considered (as LEPxLHC) in 1984 ECFA workshop
- Recent detailed re-evaluation with new e ring (Willeke)
- **Main advantages**: high peak lumi obtainable.
- synchrotron limits e^- beam energy (70GeV)

Machine Considerations and Studies

high $E_{e,p,A}$, $e^{\pm}$ polarised, high Luminosity



Joint study with CERN, BNL, CI, Jlab, DESY, .. experts

generalities

simultaneous ep and pp

power limit set to 100MW

IR at 2 or 8

p/A:

SLHC - high intensity p
(LPA/50ns or ESP/25ns)

Ions: via PS2
new source for deuterons

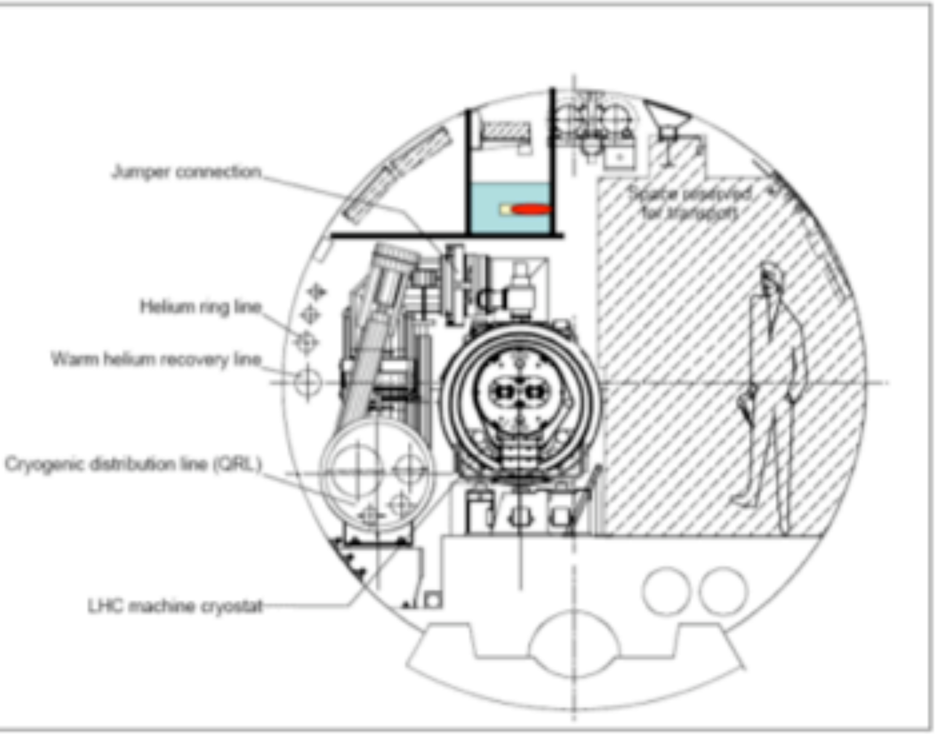
e Ring:

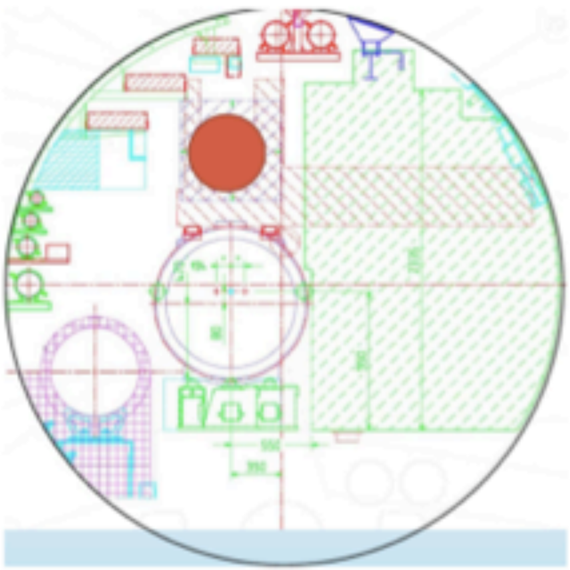
bypasses: 1 and 5
[use also for rf]

injector: SPL, or dedicated

e LINAC:

limited to ~6km (Rhone)
for IP2, longer for IP8
CLIC/ILC tunnel.?





e Ring Further Considerations

Mount e on top of p - feasible at first sight
needs further, detailed study of pathway

Installation: 1-2 years during LHC shutdowns.
LEP installation was ~1 year into empty tunnel.
Radiation load of LHC pp will be studied.

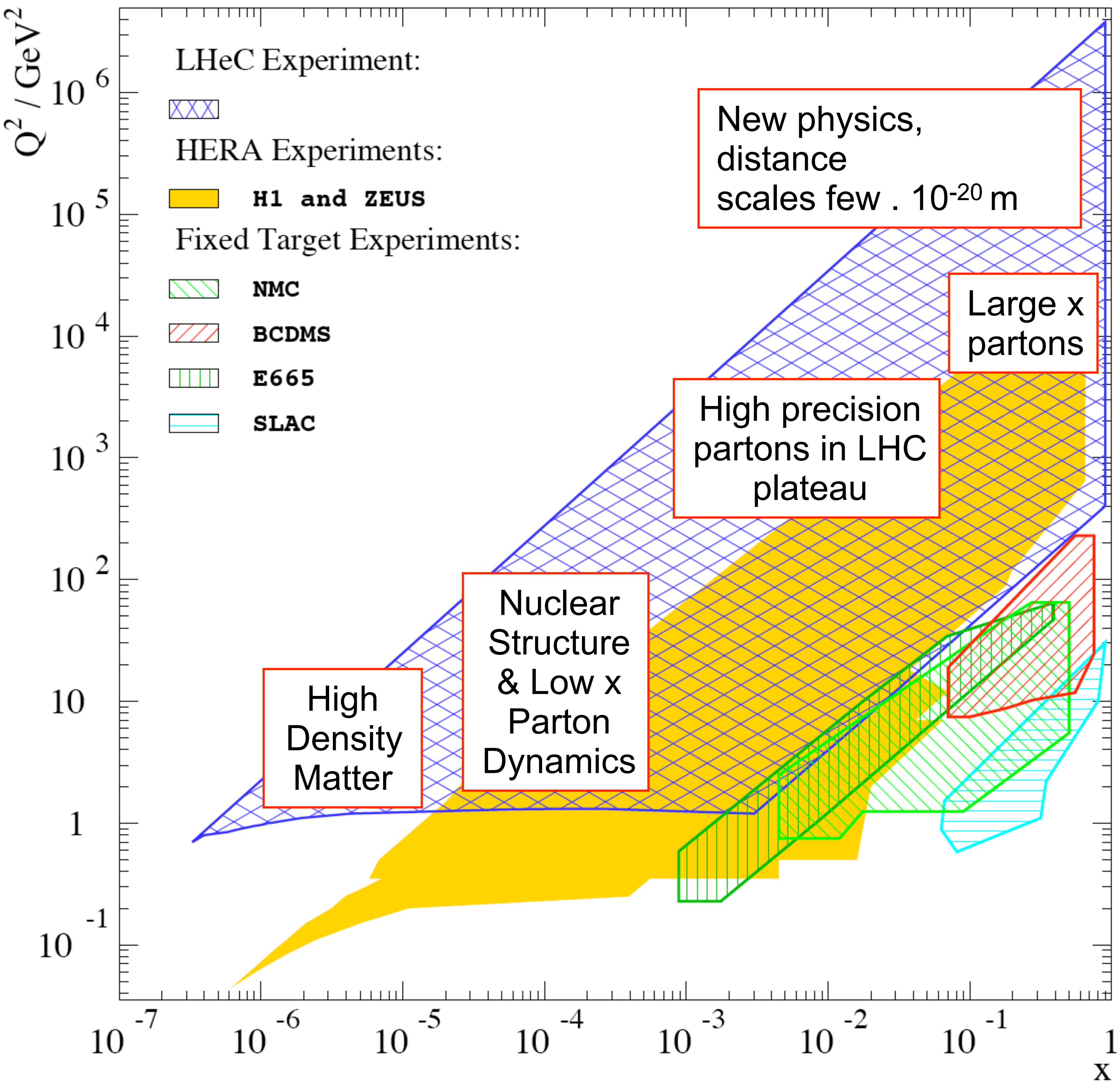
Injection:
LEP2 was 4 10^{11} e in 4 bunches
LHeC is 1.4 10^{10} in 2800 bunches
may inject at less than 20 GeV.

Power for 70 (50) GeV E_e fits into bypasses:

SC system at 1.9º K (1 GHz)
r.f. coupler to cavity: 500 kW CW - R+D
9 MV/cavity.
100(28) cavities for 900(250)MV
cavity: beam line of 150 (42) m
klystrons 100 (28) at 500kW
plus 90 m racks ..
gallery of 540 (150) m length required.

T.Linnecar

Kinematics & Motivation



$\sqrt{s} = 1.4$ TeV

- High mass (M_{eq}, Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs
- Low x frontier [x below 10^{-6} at $Q^2 \sim 1$ GeV^2]
  → novel QCD …

New Physics at the LHeC

Wide range of basic physics

Maximum $W < 1.4$ TeV
for $E_e = 140$ GeV, $E_p = 7$ TeV

- **Lepto-Quark Production and Decay (s and t-channel effects)**
- **Squarks and Gluinos**
- **ZZ, WZ, WW elastic and inelastic collisions**
- **Technicolor**
- **Novel Higgs Production Mechanisms**

could help in H->bb!

- **Composite electrons**
- **Lepton-Flavor Violation**
- **QCD at High Density in ep and eA collisions**
- **Odderon**

Broad physics goals (to be discussed at the Workshop)

- Proton structure and QCD physics in the domain of x and Q^2 of LHC experiments
- Small-x physics in eP and eA collisions
- Probing the $e^{\pm}$-quark system at ~TeV energy
  eg leptoquarks, excited e*'s, mirror e, SUSY with no R-parity......
- Searching for new EW currents
  eg RH W's, effective eeqq contact interactions...

G. Altarelli

J.Bartels: Theory on low x

The LHeC is a PeV equivalent fixed target ep scattering experiment.

At ~50 000 times higher Q^2 than the SLAC MIT experiment it needs an only few times longer LINAC (or a ring).

Its physics potential is extremely rich. Both a LINAC and a ring look feasible.

The CDR is at midterm:

ECFA 11/07

NuPECC 9/08

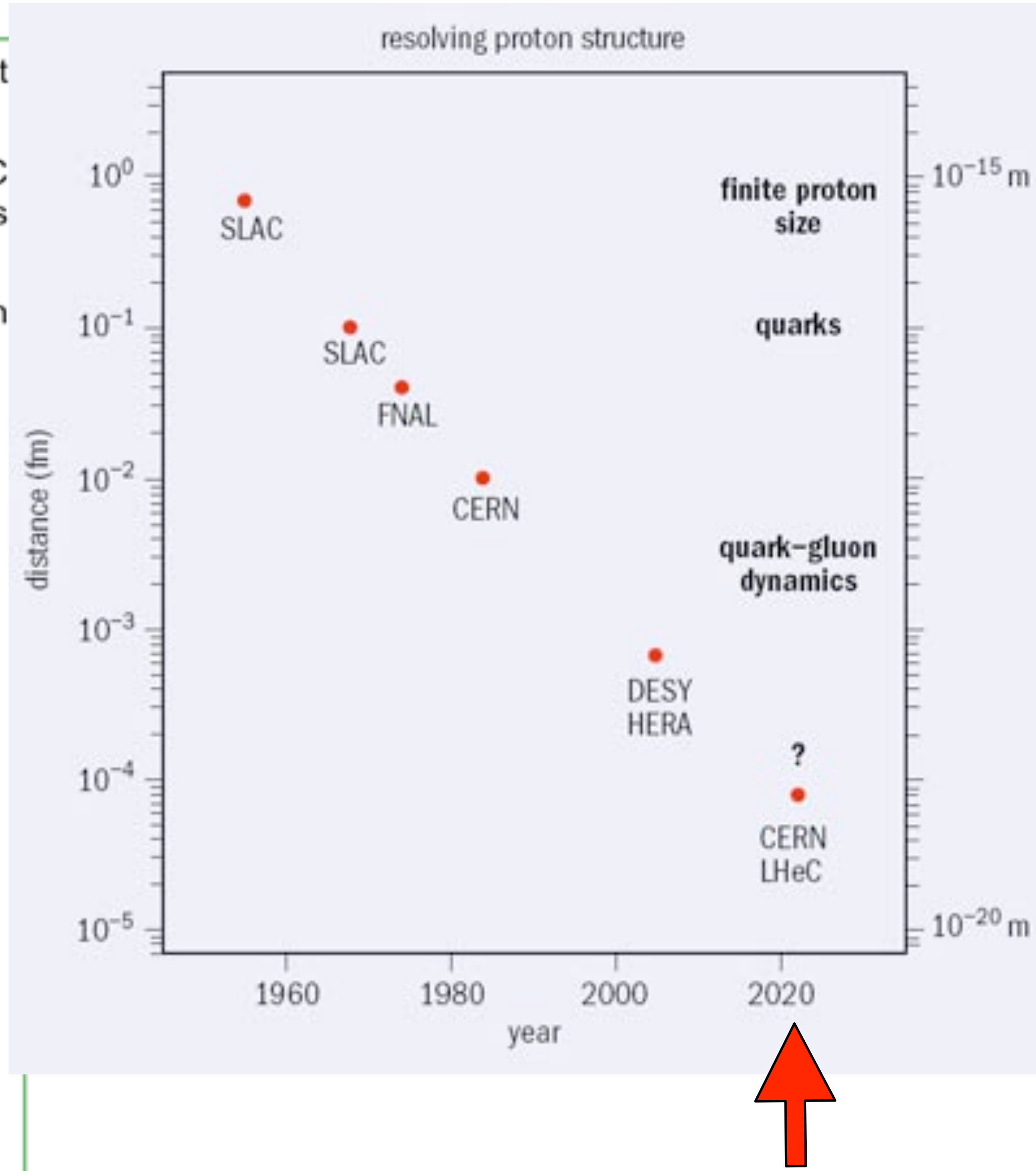
ICFA 10/08

ECFA 11/08

Final report to ECFA: 11/09.

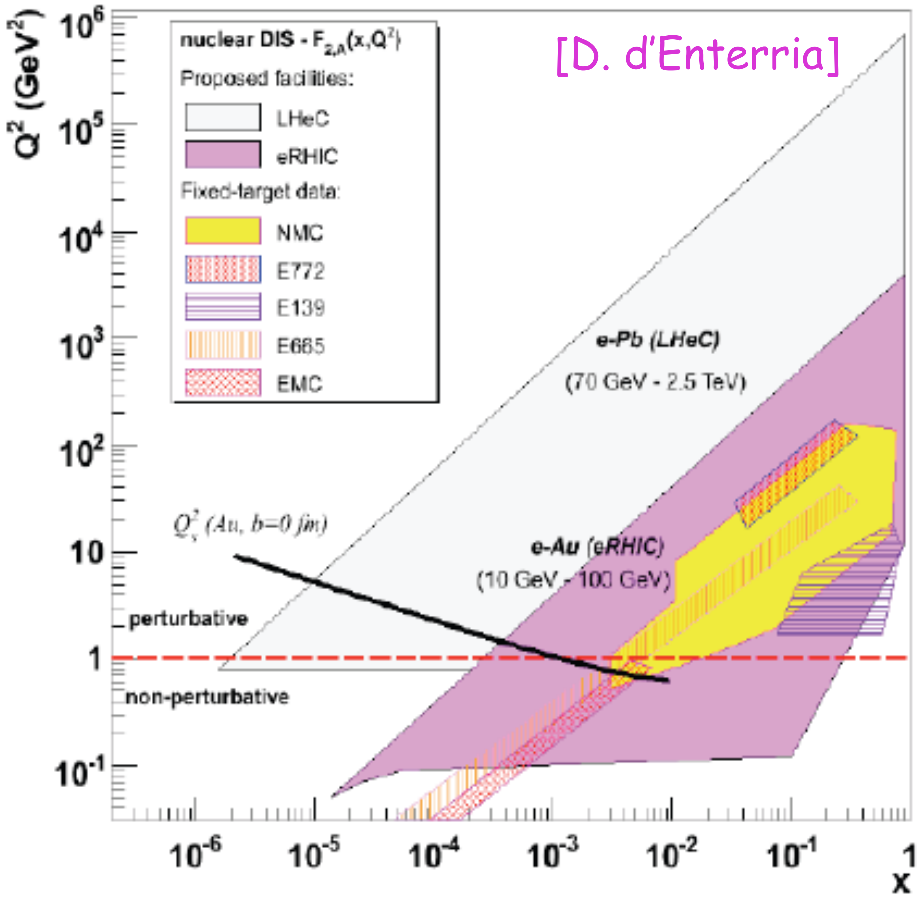
Written CDR 5/10

The CDR is a contribution to the discussion on the future of HEP which awaits LHC data. The LHeC may be built, with your support.



http://www.lhec.org.uk

With AA at LHC, LHeC is also an eA collider



- Very limited x and Q^2 range so far (unknown for x <~ 10^{-2}, gluon very poorly constrained)

- LHeC extends kinematic range by 3-4 orders of magnitude

  opportunity to extract and understand nuclear parton densities in detail …

→ ~$A^{1/3}$ enhanced gluon density → additional sat^n sensitivity
→ initial state in AA quark-gluon plasma studies @ LHC / RHIC
→ relations between diffraction and shadowing

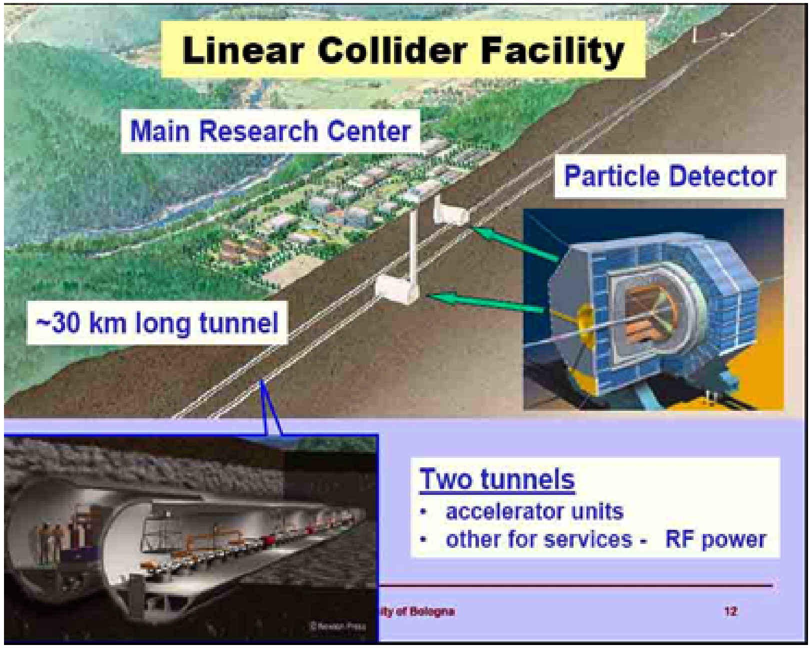
meas. of both eA and ep at high densities to test the Gribov-Glauber relationship of nuclear shadowing to diff.

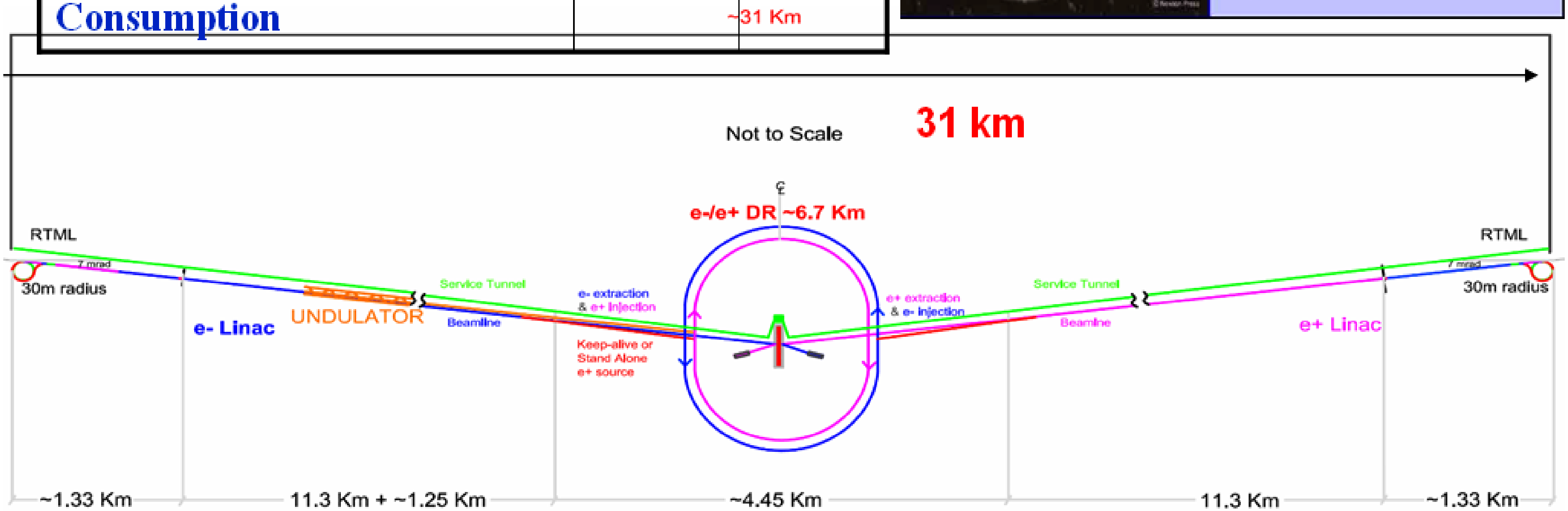
→ Neutron structure & singlet PDF evolution from deuterons

Very rich physics programme !

ILC (E$_{cm}$ up to ~ 500 GeV)

Max. Center-of-mass energy	500	GeV
Peak Luminosity	~2x10^{34}	cm^{-2}s^{-1}
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Total AC Power Consumption	~230	MW





. . . in 90's DESY, SLAC, KEK involved in different projects

in 2002, ICFA ⇨ ILCSC

Technology decision in 2004 : use superconducting RF (~TESLA)

⇨ the International Linear Collider ILC

the baseline (2008):

- $e^+ e^-$ LC operating from M_Z to 500 GeV, tunable energy !
- beam energy stability and precision: 10^{-3} or better
- e^- polarization (at least 80%)
- at least 500 fb^{-1} in the first 4 years
- upgradable to ~ 1 TeV , 1 ab^{-1} / 3-4 years

options :

A lot of flexibility !

- e^+ polarization >50%
- GigaZ (high luminosity running at M_Z and $2M_W$)
- e-e-, $\gamma\gamma$, eγ collisions

⇨ Global Design Effort (GDE) started (2005)

high-precision physics (and more) at ILC !

- *can determine properties of New Discoveries at LHC*

  (cross sections, BR's, couplings, Quantum numbers).

- *can measure radiative EW precision pattern of Standard Model observables with higher precision*

  ⇒ *extends new-physics potential **(deep into multi-TeV region)** even in case no new particle observed at LHC.*

- *can detect what is "invisible" or "unexpected" at LHC.*

LHC: interaction rate of 10^9 events$/s$

$\Rightarrow$ can trigger on only 1 event in 10^7

ILC: untriggered operation (10⁵ annihil.s/sec)

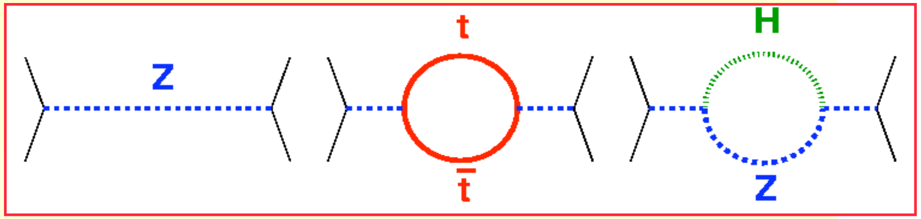
$\Rightarrow$ can find signals of unexpected new physics (direct production $+$ large indirect reach) that manifests itself in events that are not selected by the LHC trigger strategies

m_{top} prediction from HO corrections (proved !!!)

Indirect Determinations :

m(top) = 173^{+13}_{-10} GeV

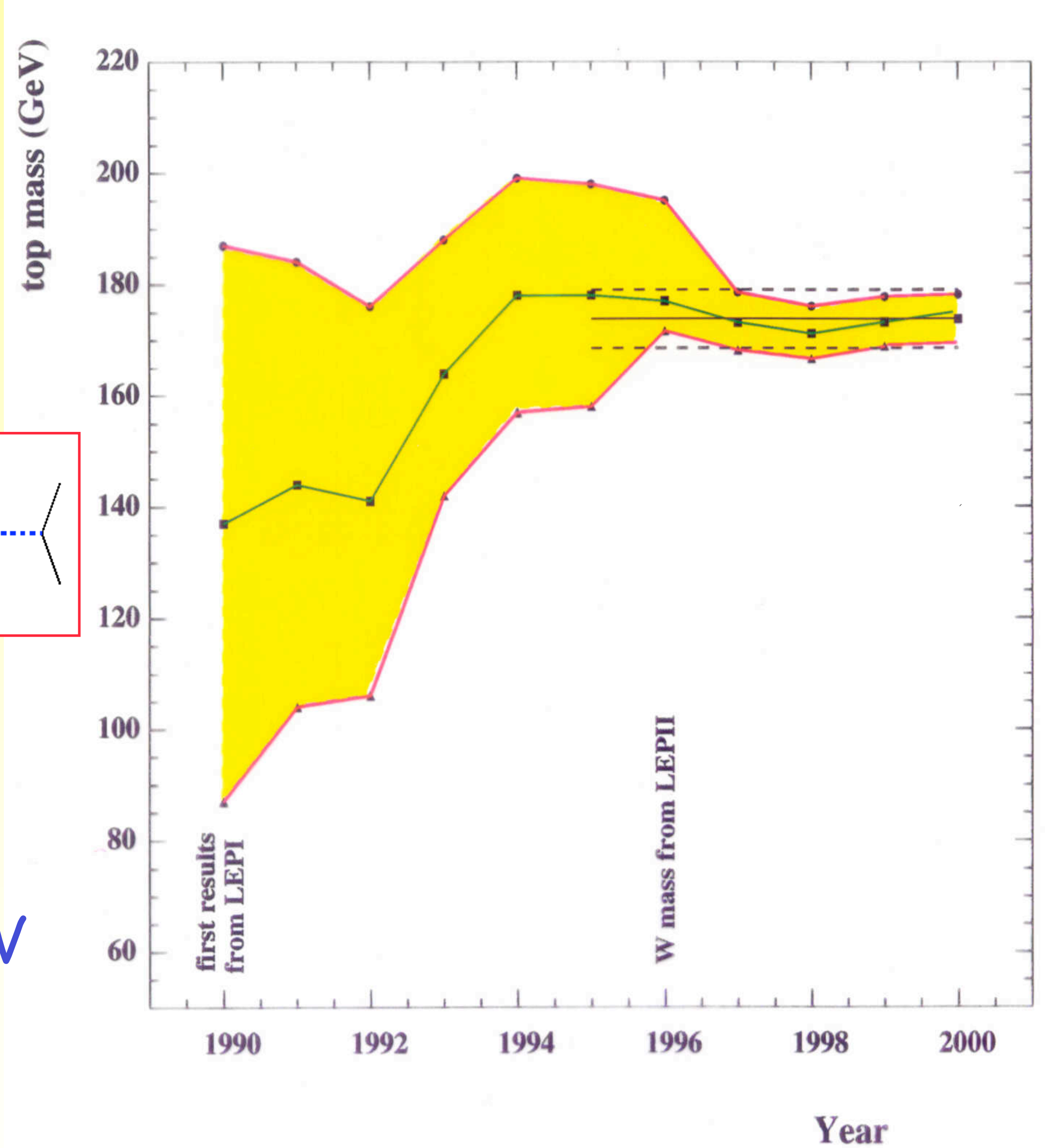
(only Z-pole data, 2008)



Direct Determinations :

m(top) = 173.1 ± 1.3 GeV

(CDF/D0, 2009)

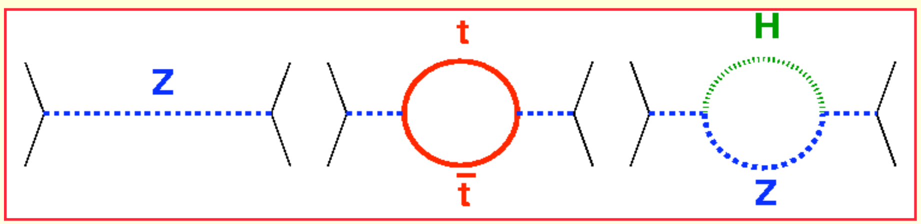


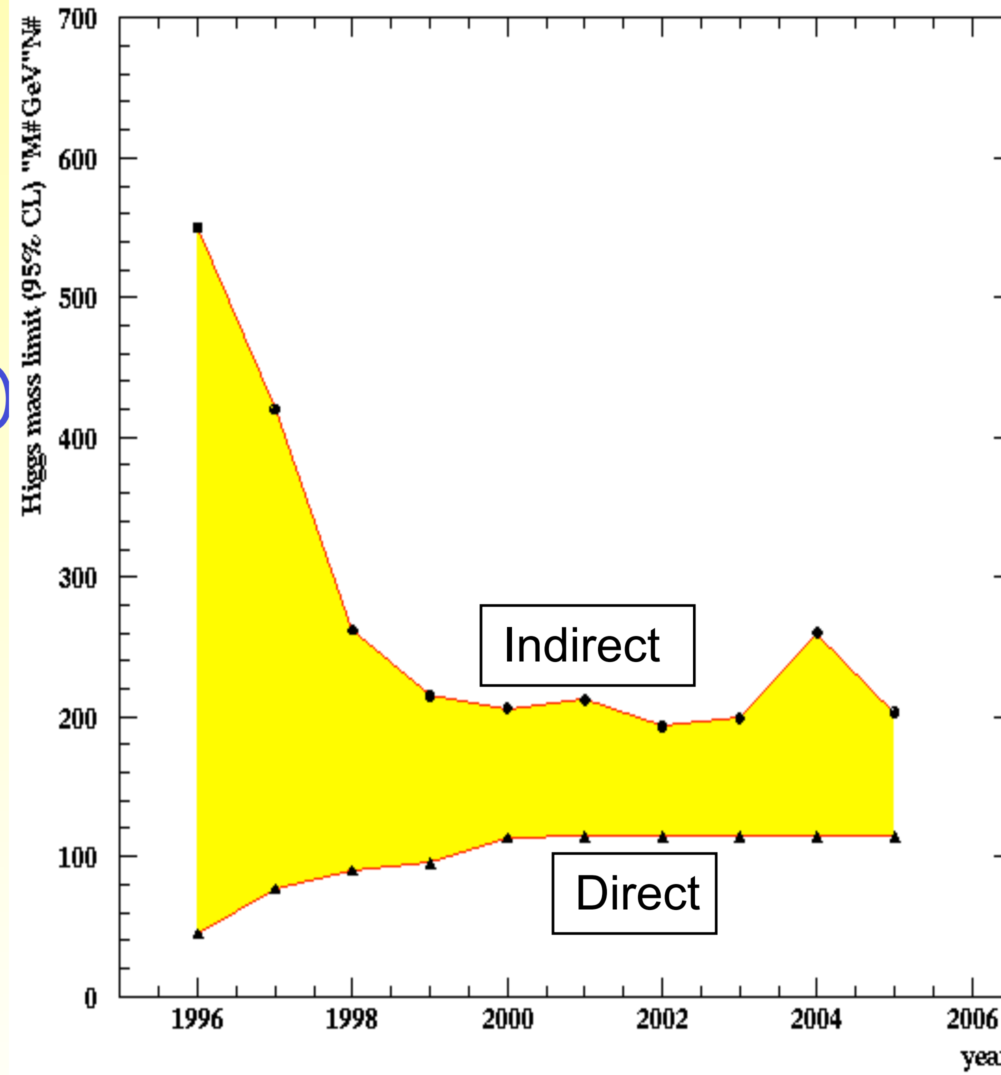
m_{Higgs} prediction from HO corrections (???)

Indirect constraints (ew fit):

m_{Higgs} < **154** GeV
(assuming no direct bound)

(→**185** GeV, incl. direct LEP bound)



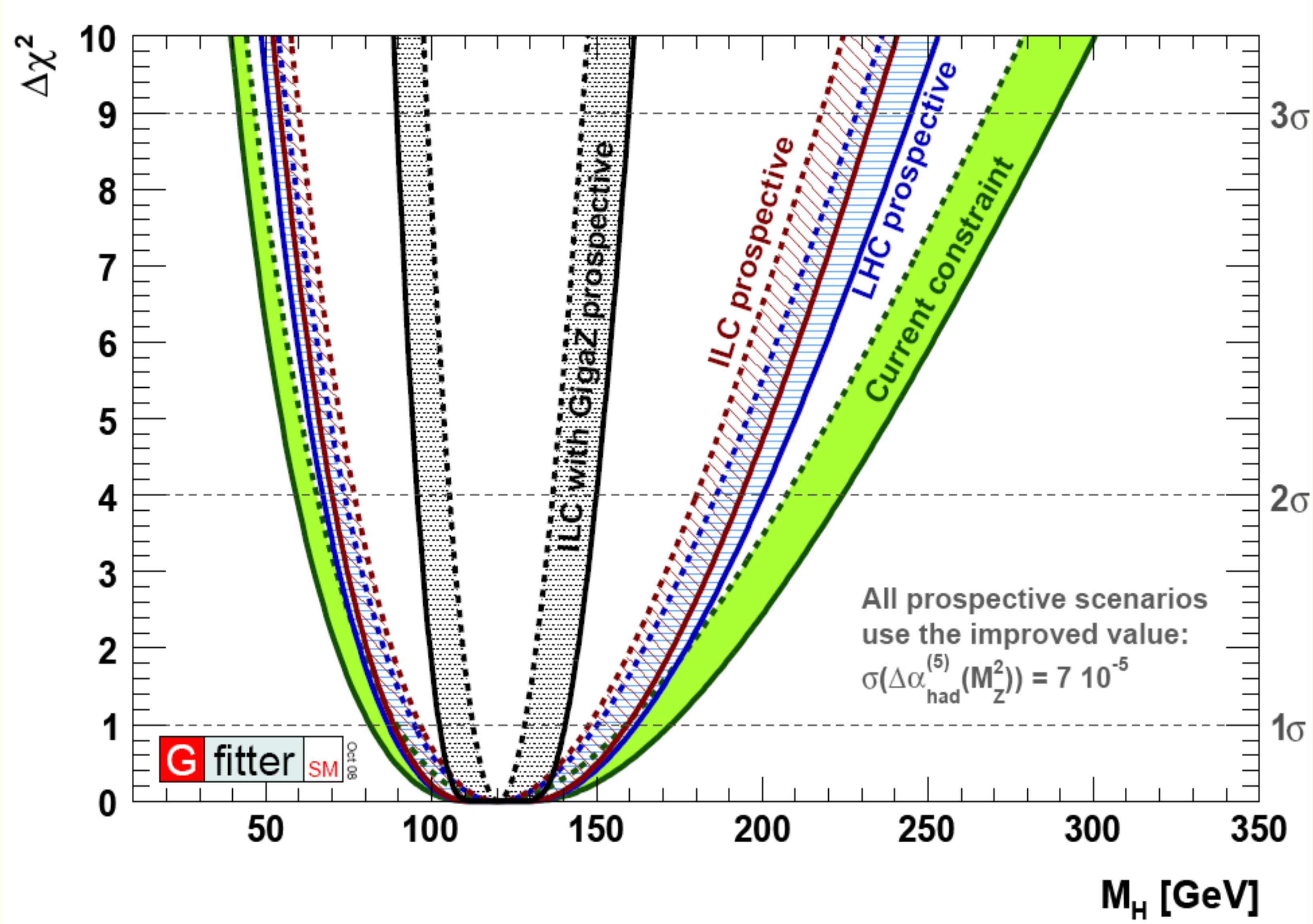


Direct limits :

m_{Higgs} > **114.4** GeV (LEP2)

New Tevatron limit: m_{Higgs} < **160** GeV and > **170** GeV

Electro-weak fit with Giga-Z



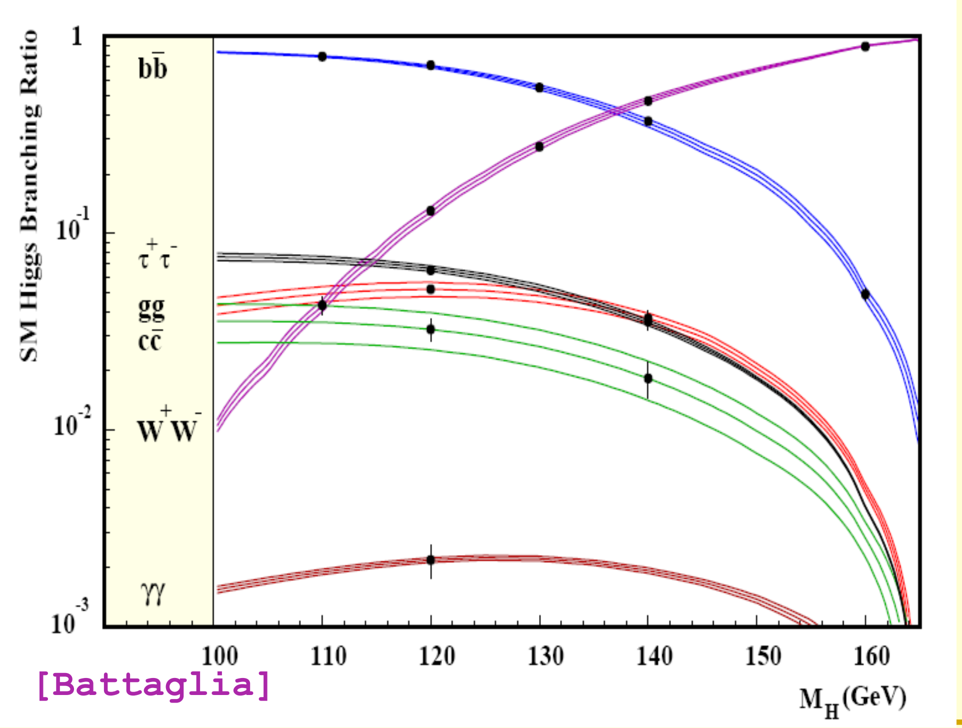
[Flächer, Goebel, Haller, Höcker, Mönig, Stelzer 08]

K. Desch, 17/02/2009

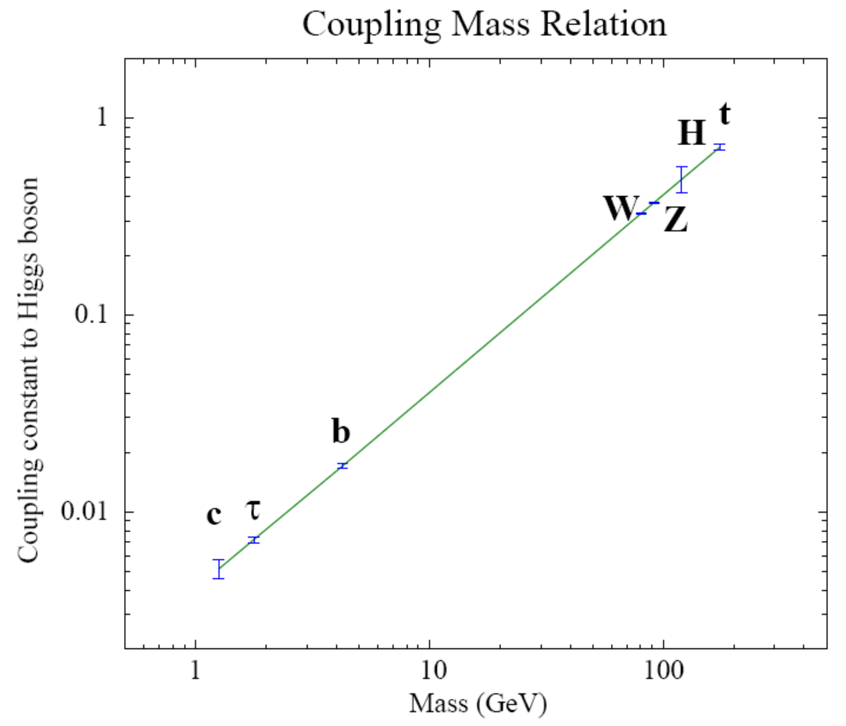
Higgs physics – the light Higgs case (m <160 GeV)

precise measurements of

- couplings to bosons, up- and down-type fermions
- mass, total width
- quantum numbers J^{PC} (incl. sensitivity to CP violation)
- (not so precise but only) measurement of λ_{HHH}



[Battaglia]

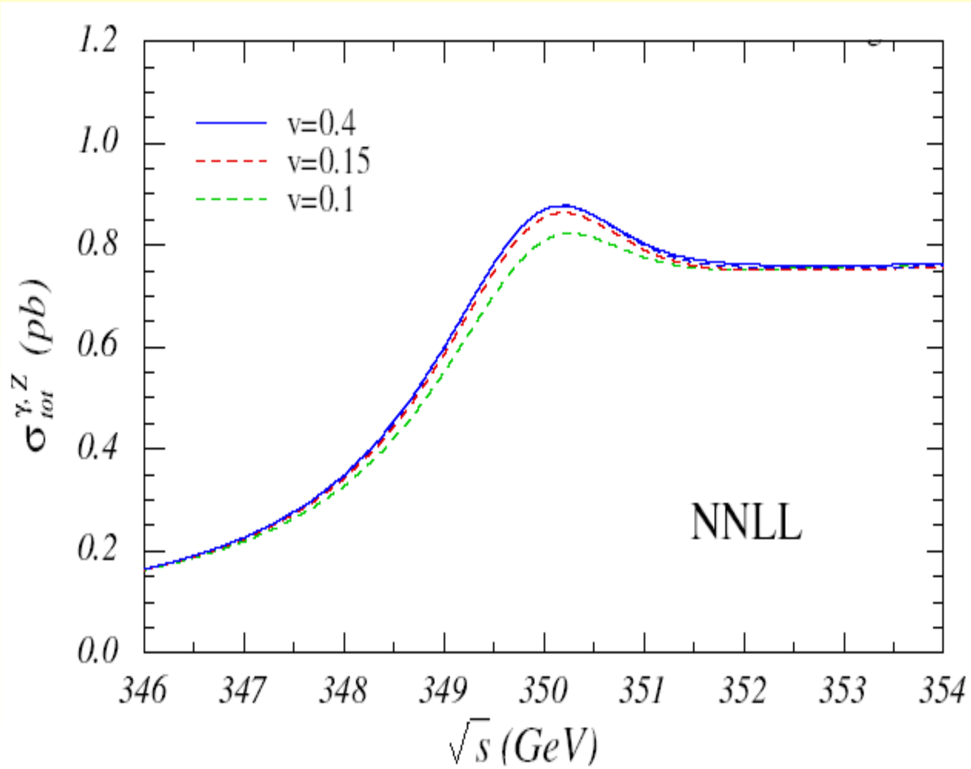


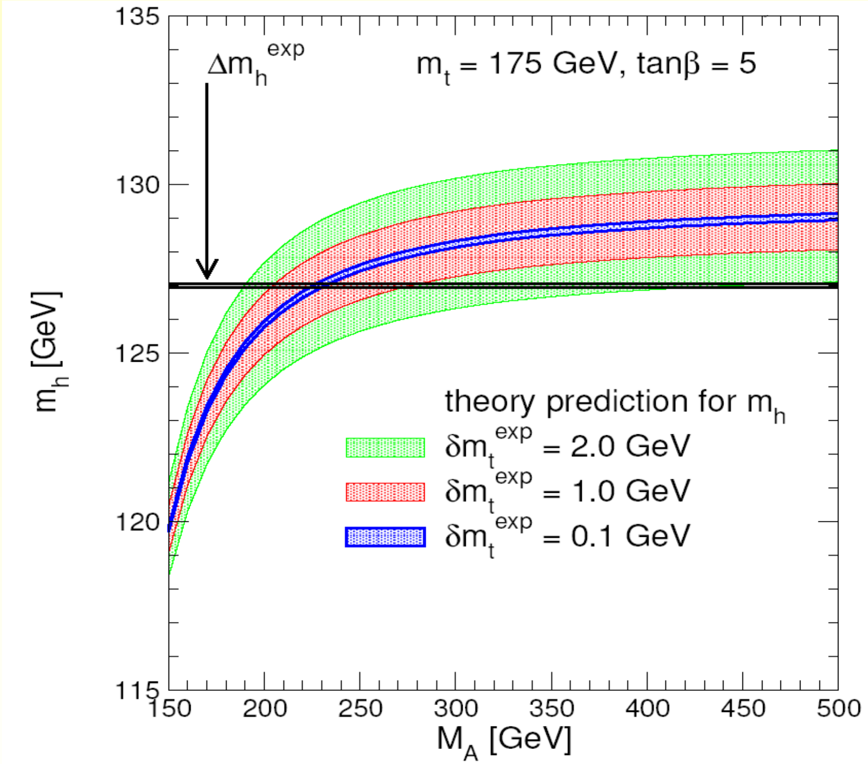
top quark physics (it is there for sure !)

• threshold scan provides excellent mass measurement
Theory (NNLL) controls $m_t(\overline{MS})$ to 100 MeV

• precise m_{top} **vital** for

- improved SM fits
- MSSM (m_h prediction)
- DM-density in mSugra
- . . . .

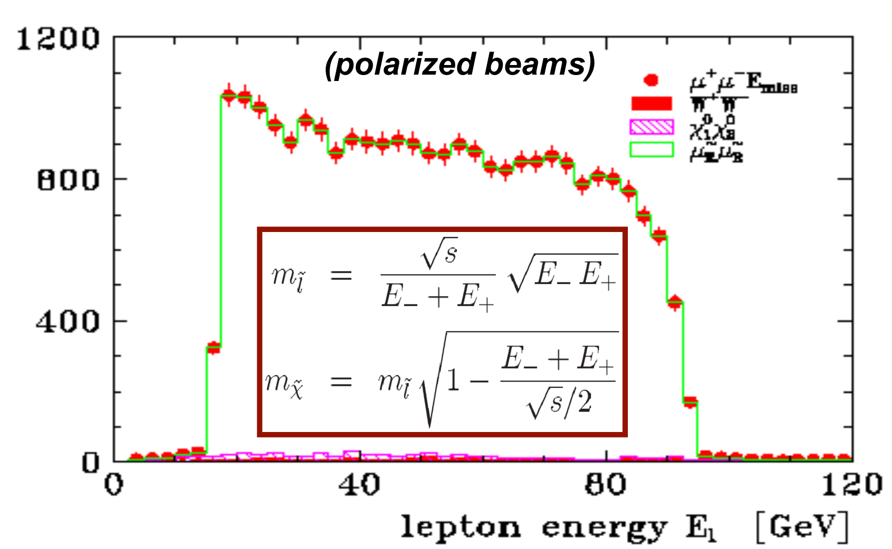




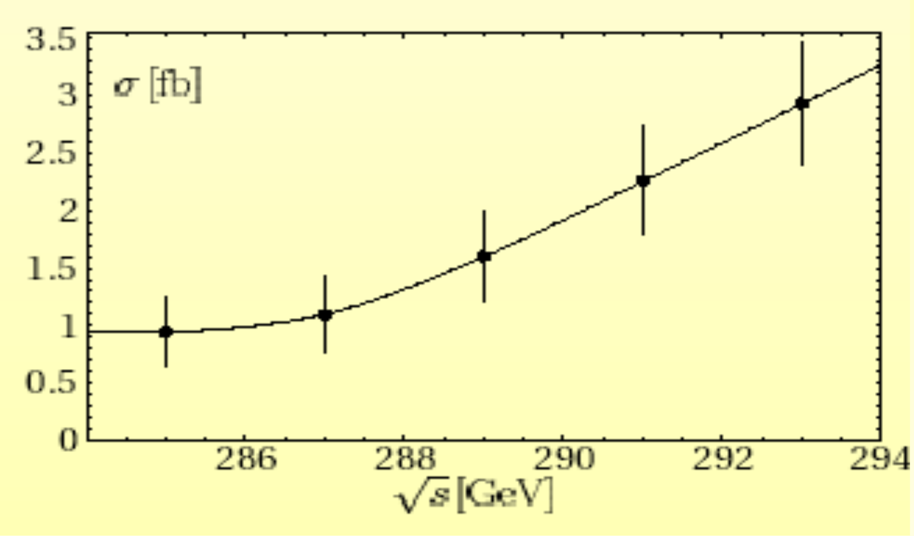
Supersymmetry

Two methods to obtain absolute sparticle masses:

a) in the continuum:



b) at the kinematic threshold:



many more observables than just masses:

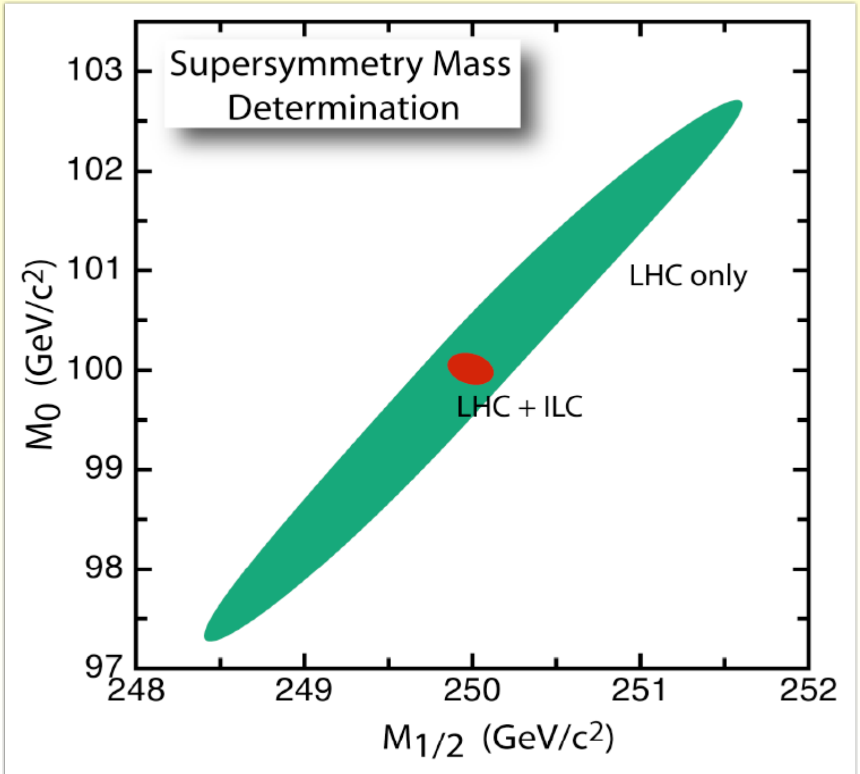
mass precision $^0/_{00}$ - $^0/_0$

- angular distributions, FB-asymmetries
- cross sections
- LR-asymmetries
- ratios of branching ratios

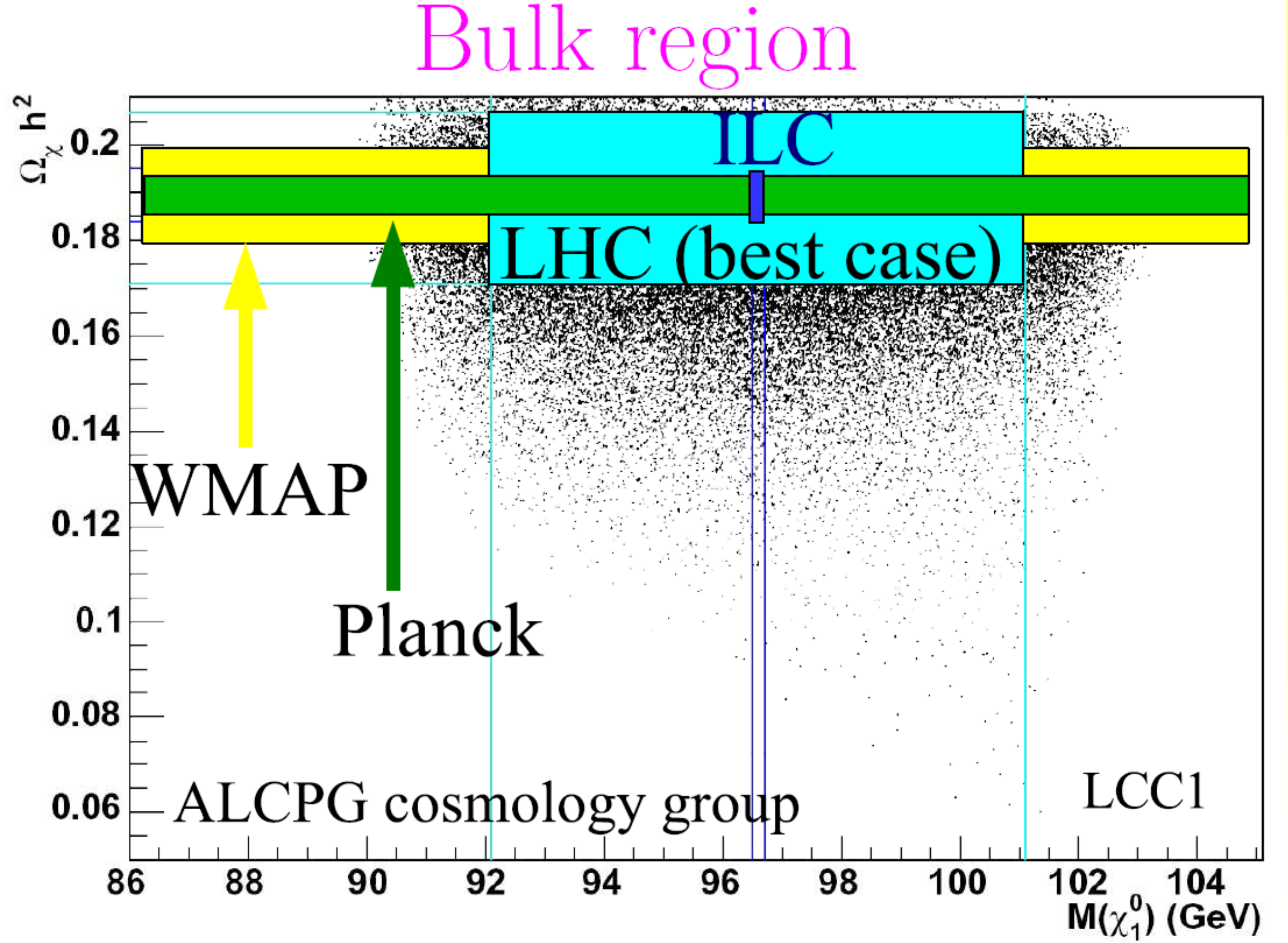
→ possibility to determine SUSY parameters without many model assumptions

SUSY : ILC + LHC

- **LHC able to measure the parameters at the level %**
- **ILC will improve by a factor 10**
- **LHC+ILC reduces the model dependence**
- **MSSM can be probed at both colliders with sensitivities to different regions of the parameter space**



Dark Matter : is it the Susy LSP ?



Effective 4-fermion contact interactions

$$\mathcal{L}_{CI} = \sum_{i,j=\mathrm{L,R}} \eta_{ij} \frac{g^2}{\Lambda_{ij}^2} (\overline{\mathrm{u}}_{F,i}\gamma^\mu \mathrm{u}_{F,i})(\overline{u}_{f,j}\gamma^\mu u_{f,j})$$

		LHC Λ [TeV]				LC Λ [TeV]			
model		LL	RR	LR	RL	LL	RR	LR	RL
eeqq:	Λ_+	20.1	20.2	22.1	21.8	64	24	92	22
	Λ_-	33.8	33.7	29.2	29.7	63	35	92	24
ee$\mu\mu$:	Λ_+					90	88	72	72
	Λ_-					90	88	72	72
eeee:	Λ_+					44.9	43.4	52.4	52.4
	Λ_-					43.5	42.1	50.7	50.7

Table 7.1: The 95% sensitivity reaches for a basic choice of contact interactions expected for the LHC [9] ($L_{int} = 100\ fb^{-1}$ at 14 TeV and δL=5%) and the LC [11, 13] ($L_{int} = 1\ ab^{-1}$ at 0.5 TeV and P_{e^-}=0.8, P_{e^+}=0.6).

hep-ph/0410364

Global Effort on Design / R&D

(none can afford this project alone !)

(2006)

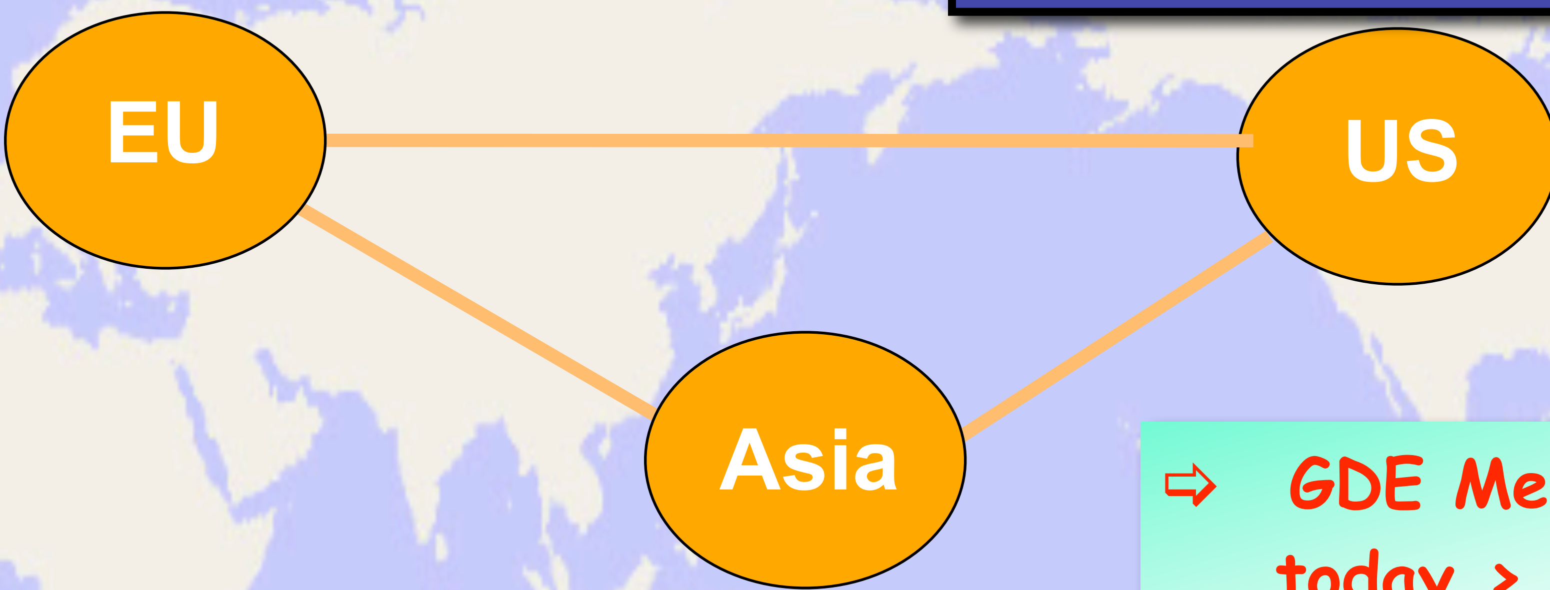
Present GDE Membership

Americas 22

Europe 24

Asia 18

About 30 FTEs



⇨ GDE Members today > 500 !

Joint Design, Implementation, Operations, Management

Host Country Provides Conventional Facilities

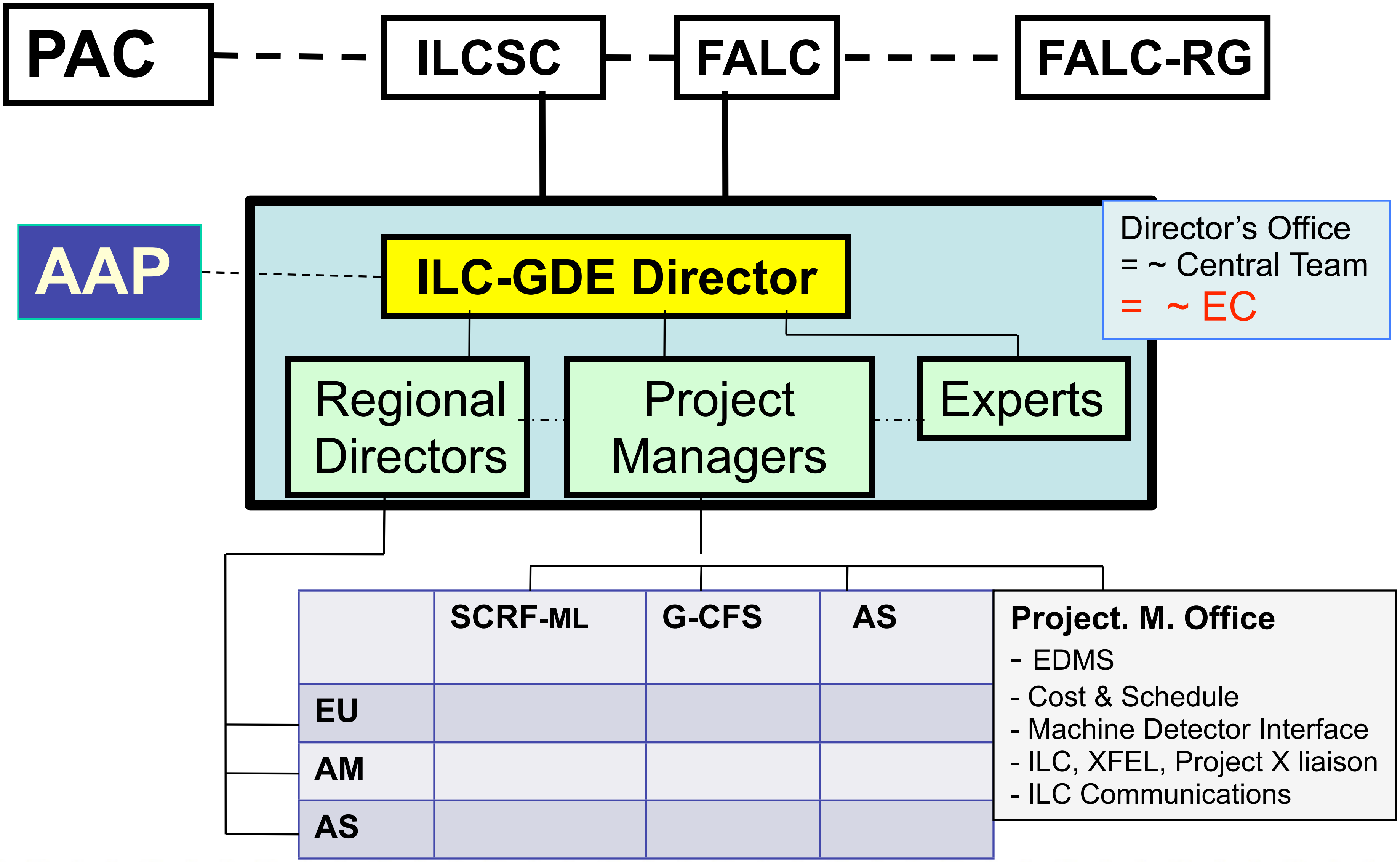
BLACK DECEMBER 2007

- Without warning, severe budget cuts in the USA and the UK
  - In UK, we preserved support for key scientists and their teams, but lost broader program (40 FTE to ~ 15 FTE)
  - In US, budget reduced FY08 to $15M, essentially already spent last December. The US program has effectively been on hold for 9 months.
- Global Program has impressively moved on in the face of these devastating problems
  - The core of our program is focused on large R&D facilities; Global collaboration increased toward prioritized goals

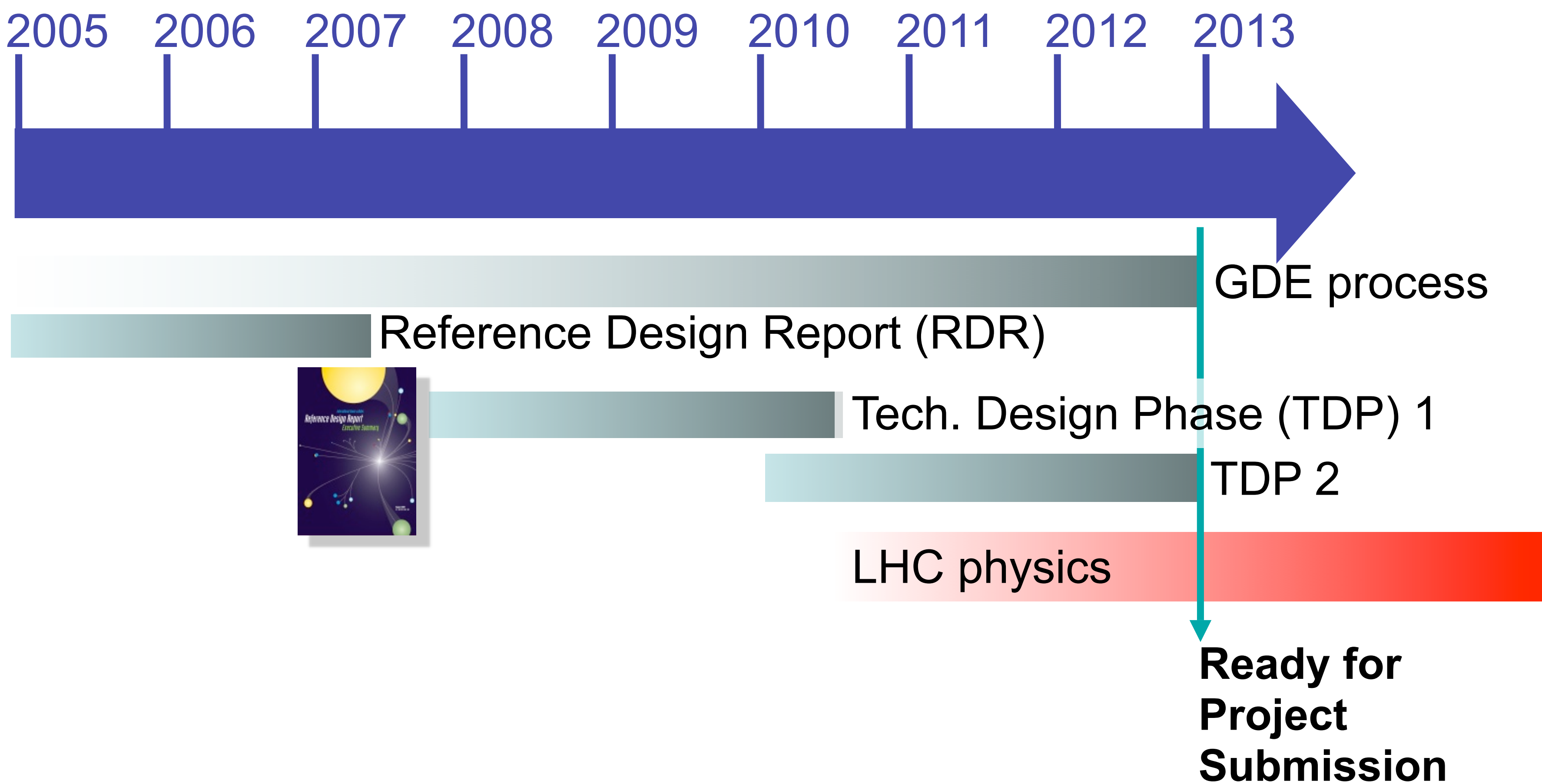
Global Design Effort Mission

- Produce a design for the ILC that includes a *detailed design concept, performance assessments, reliable international costing, an industrialization plan, siting analysis, as well as detector concepts and scope*.
- Coordinate worldwide prioritized proposal driven R & D efforts (to *demonstrate and improve the performance, reduce the costs, attain the required reliability*, etc.)
- B. Barish is GDE Director, assisted by 3 regional directors: BF (Europe); K. Yokoya (Asia); M. Harrison (Americas). 3 PMs – Marc Ross (Americas); N. Walker (Europe); A.Yamamoto (Asia). GDE (> 30% FTE)- currently 480 GDE members worldwide.

ILC-GDE Organization Chart



GDE ILC Timeline

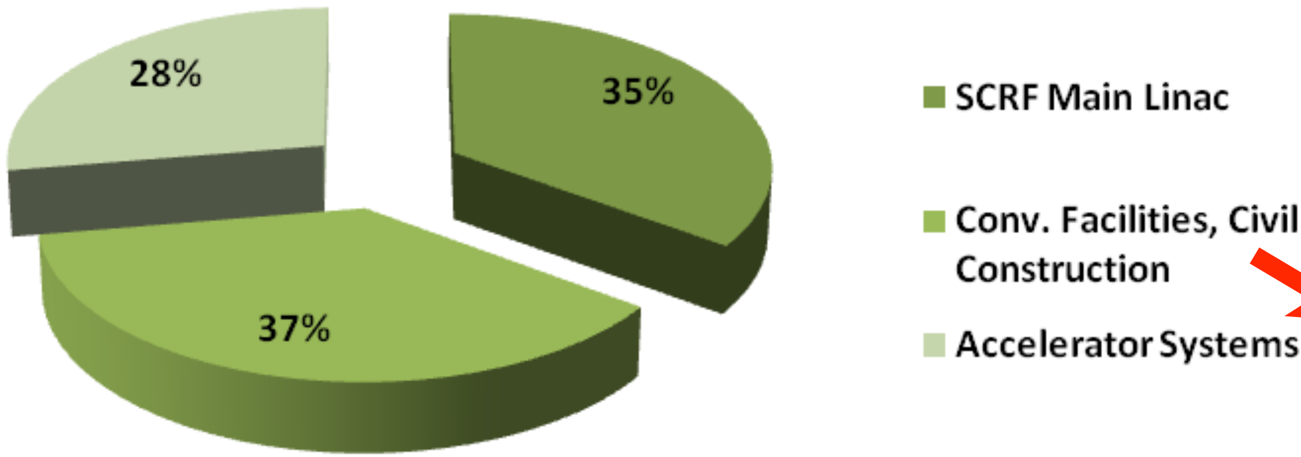


Summary and Outlook

- The RDR describes a machine that could be built tomorrow – but it is expensive.
- Significant R&D is under way to produce savings while maintaining the physics specifications – much has already been achieved.
- Collaboration with CLIC is close and growing. We will build the best machine whenever - and wherever – political will and funding becomes available.
- It is our job to be ready, and to oil the wheels, whenever exciting results at LHC give us the lubrication.

RDR cost estimate

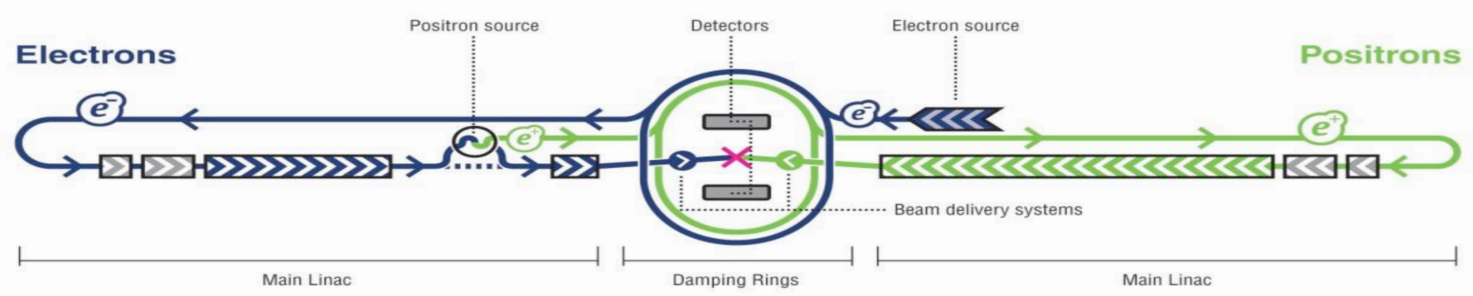
- Estimated cost (2007) ~6.7 Billion ILCU*
  - **4.87 BILCU shared**
  - **1.78 BILCU site-specific**



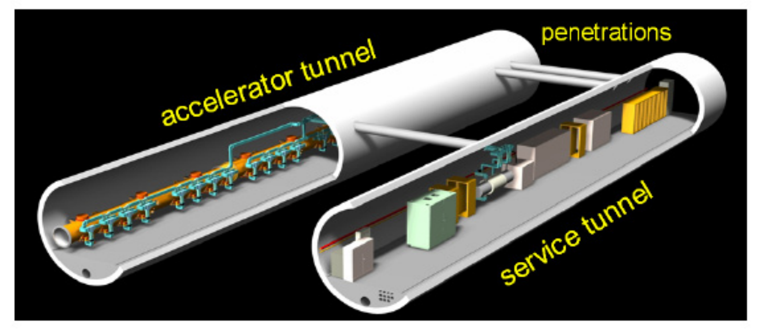
CFS identified as a major cost driver with high-potential for cost-saving

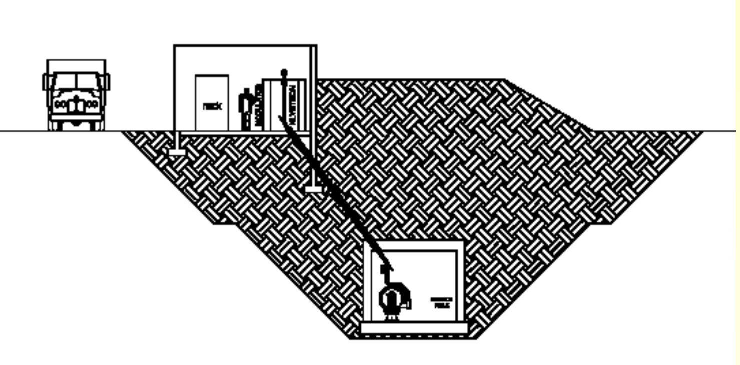
CFS requirements driven by machine design & layout

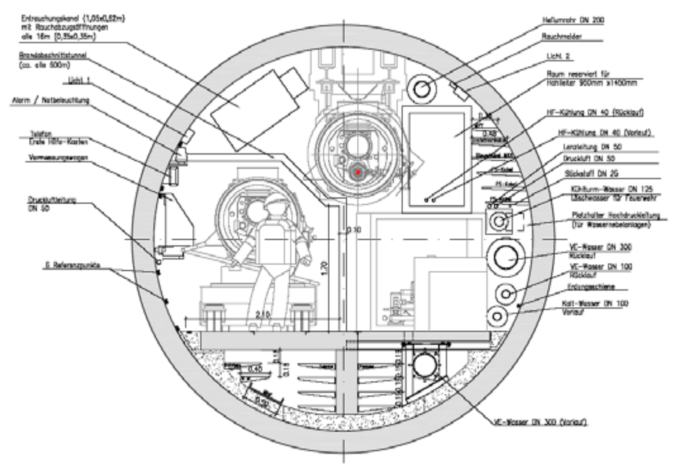
- 10,000 person-years "implicit" labour



Main Linac & Support Tunnel

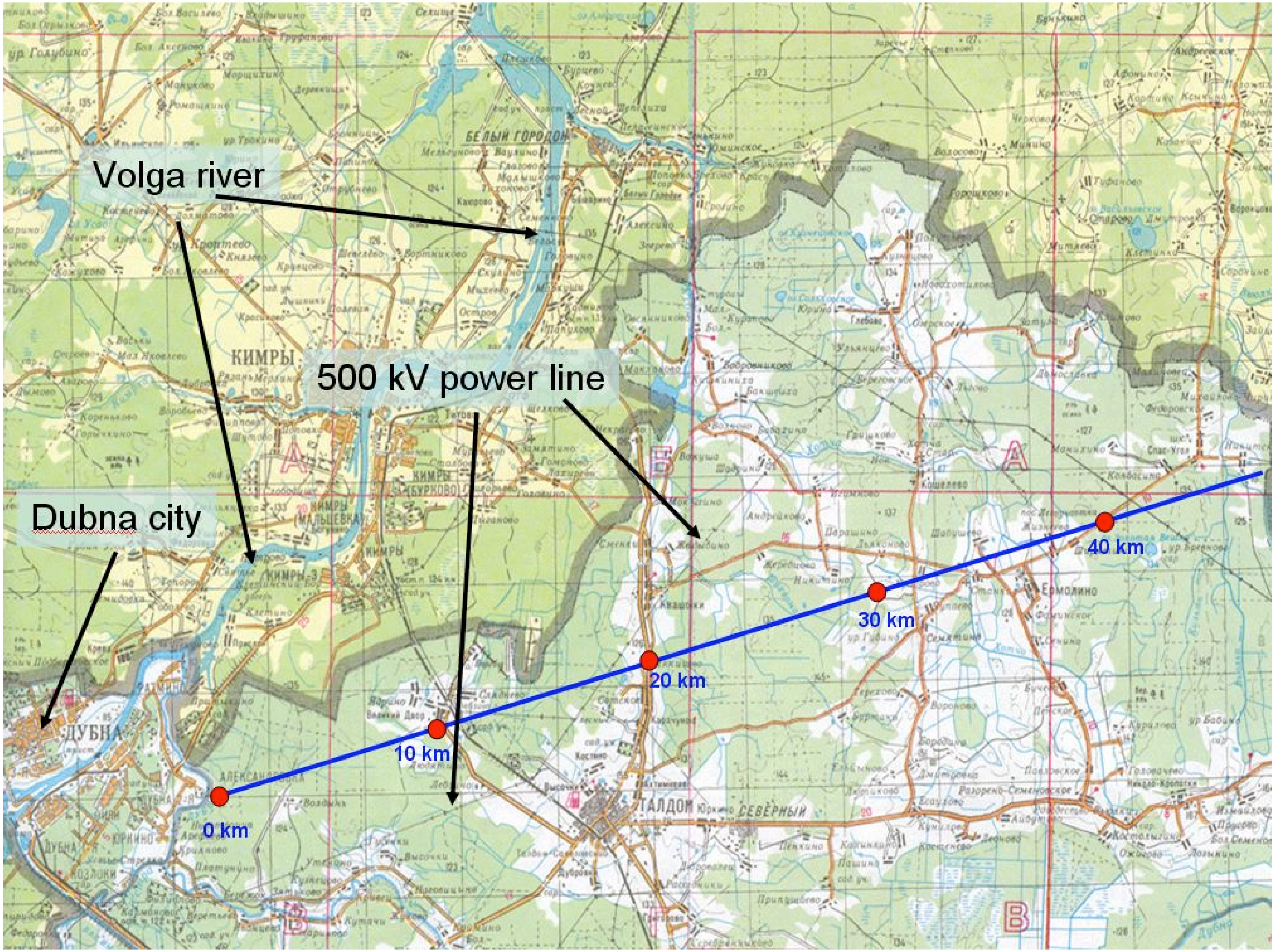






- RDR (two-tunnel)
  - **Access to equipment during ops**
    - Reliability/availability
- Shallow sites
  - **Cut and cover like solutions**
  - **"service tunnel" on the surface**
- Single tunnel
  - **European XFEL-like solution**
    - availability / reliability

CF&S – Shallow site



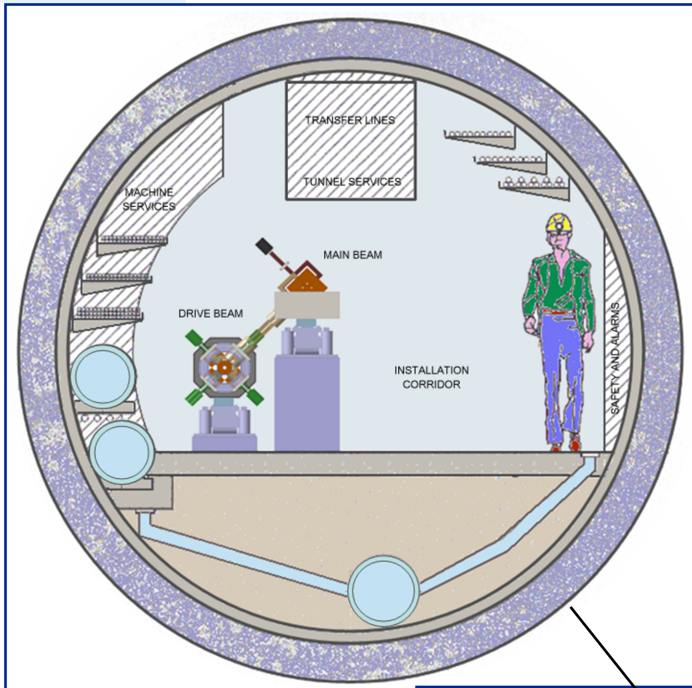
CLIC – basic features

(E_{cm} up to ~ 3 TeV)

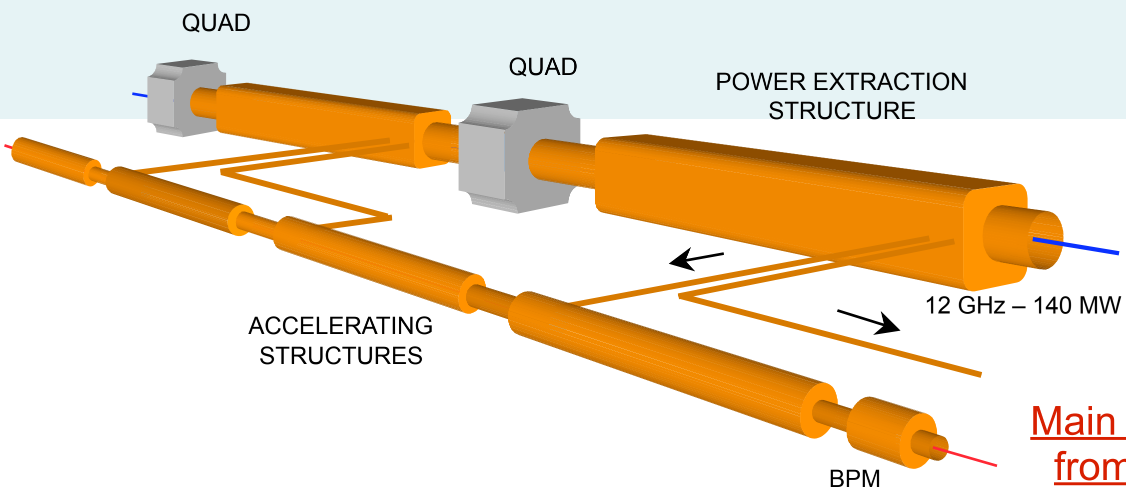
- **High acceleration gradient: > 100 MV/m**
  - "Compact" collider : total length < 50 km at 3 TeV
  - Normal conducting acceleration structures at high frequency

- **Novel Two-Beam Acceleration Scheme**
  - Cost effective, reliable, efficient
  - Simple tunnel, no active elements
  - Modular, easy energy upgrade in stages

CLIC TUNNEL CROSS-SECTION



4.5 m diameter



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

Main CLIC Parameters

Center-of-mass energy	3 TeV
Peak Luminosity	$7 \cdot 10^{34}$ cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)	$2 \cdot 10^{34}$ cm^{-2} s^{-1}
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	41.7 km
Bunch charge	$4 \cdot 10^{9}$
Beam pulse length	200 ns
Average current in pulse	1 A
Hor./vert. normalized emittance	660 / 20 nm rad
Hor./vert. IP beam size bef. pinch	53 / ~1 nm
Total site length	48.25 km
Total power consumption	390 MW

CLIC major activities and milestones up to 2010

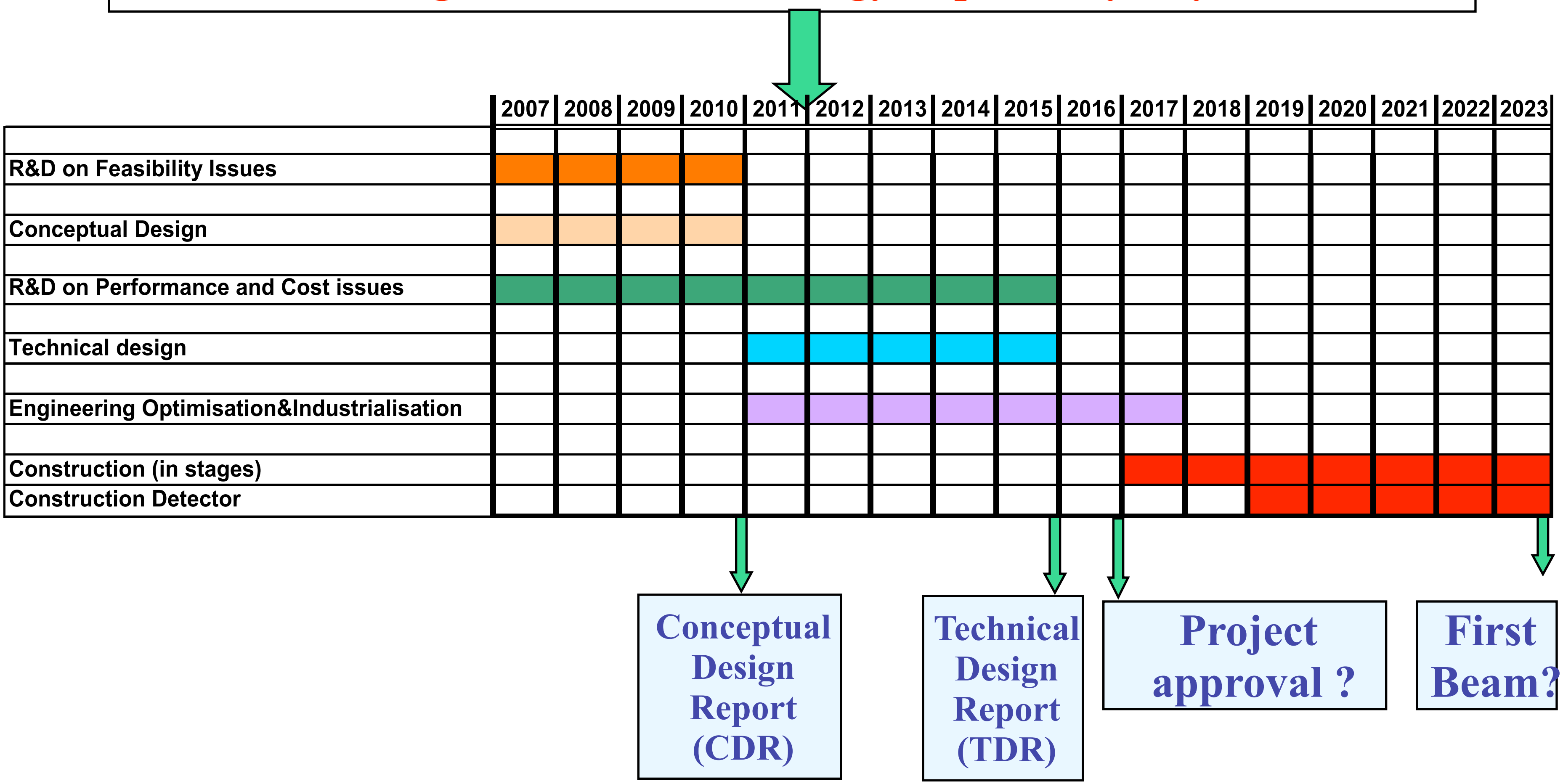
- **Demonstrate feasibility of CLIC technology**
  - **Address all feasibility issues**

- **Conceptual Design Report to be published in 2010 including :**
  - **Physics, Accelerator and Detectors**
  - **R&D on critical issues and results of feasibility study,**
  - **Preliminary performance and cost estimation**

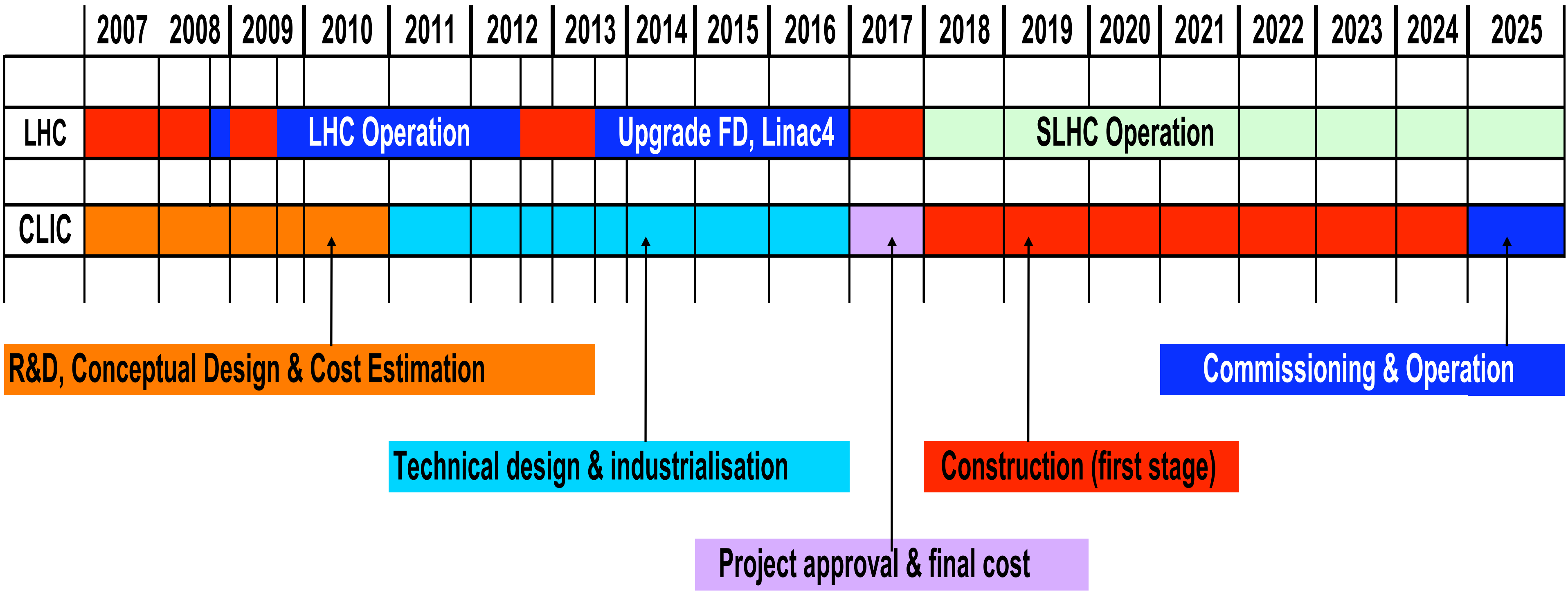
Tentative long-term CLIC scenario

Shortest, Success Oriented, Technically Limited Schedule

Technology evaluation and Physics assessment based on LHC results for a possible decision on Linear Collider with staged construction starting with the lowest energy required by Physics



Tentative LHC/CLIC schedules



A necessary and beneficial CLIC /ILC Collaboration

http://clic-study.web.cern.ch/CLIC-Study/CLIC_ILC_Collab_Mtg/Index.htm

- **Focusing on subjects with strong synergy between CLIC & ILC**
  - **making the best use of the available resources**
  - **adopting systems as similar as possible**
  - **identifying and understanding the differences due to technology and energy (technical, cost….)**
- **developing common knowledge of both designs and technologies on status, advantages, issues and prospects for the best use of future HEP**
- **preparing together by the Linear Collider Community made up of CLIC & ILC experts:**
  - **the future evaluation of the two technologies**
  - **proposal(s) best adapted to the (future) HEP requirements**

CLIC / ILC Collaboration

27 October 2008

CLIC / ILC Joint Statements

27 October 2008

Purpose of these statements:

The CLIC and ILC Collaborations agree to work together, within the framework of the CLIC / ILC Collaboration, to outline comparative statements to be used in presenting their respective projects. The Collaboration members agree to limit statements made about each other's projects to specifically agreed upon statements such as those listed below:

- **Project design**

The CLIC and ILC projects both plan to release design documents in the coming years. The CLIC Conceptual Design Report is to be published in 2010. If the CLIC technology is demonstrated to be feasible, a CLIC Technical Design will then be launched for publication in a CLIC TDR by 2015. The ILC TDR will be published in 2012. The design reports are intended to summarize the R&D and project planning at that time and will serve as indicators of project readiness. Both TDRs are intended to be submitted to governments and associated funding agencies in order to seek project approval.

- **Test facilities and system tests**

The CLIC and ILC projects both have test facilities either in operation or under construction for the purpose of demonstrating the performance of key technical components or to allow system engineering and industrialization. For each project, R&D priorities and schedules have been defined and it is anticipated that milestones and progress will be reviewed and reported on by members of the community. The XFEL project, with the same technical basis as the ILC, although at a lower accelerating gradient, and 7% of the energy of one of the ILC linacs, is a large-scale system test and demonstration of the industrialization of the ILC linac technology. The CERN- based CTF3 project is a demonstration of the CLIC two beam technology, although at a lower beam power.

- **Technology maturity and risk**

The collaborations agree that the ILC technology is presently more mature and less risky than that of CLIC. There are plans to demonstrate, by 2010, the feasibility of CLIC technology and to reduce the associated risk in the future. The ILC collaboration will focus on consolidation of the technology for global mass-production. Both collaborations consider it essential to continue to develop both technologies for the foreseeable future.

- **Costing**

Project planners from the CLIC and ILC projects are developing common methodologies and tools with the intention of enabling the development of similarly-structured project planning and costing documents for each of the two projects. The two collaborations agree to make no public statements about the comparative cost numbers of the two machines until these project planning and costing documents are complete.

Barry C. Barish

Barry C. Barish
ILC-GDE Director

J-P. Delahaye
CLIC Study Leader

- Working Groups with joint leadership

- Accelerator Tech Areas
- Physics / Detectors
- Costing

- First progress reported last fall

LOI Follow-on: Study extrapolation to multi-TeV

Nature Editorial

- (November 27, 2008)

Friendly rivalry

The spirit of collaboration in the race to define the LHC's successor sets an example for large projects.

The future for high-energy physics is decidedly mixed. On the one hand, physicists are eagerly awaiting the insights into the Universe promised by the Large Hadron Collider (LHC) at CERN, the European particle-physics laboratory near Geneva. But as governments shift their priorities to societal problems, such as climate change, energy, health and the environment, the field as a whole must also face up to the fact that it will be increasingly difficult

"Given this financial uncertainty, it is important that the high-energy physics community does all it can to reduce any internal divisions and to strengthen its external coherence. That is why a new collaboration over what should come after the LHC is to be greeted with enthusiasm."

"The potential for destructive rivalry was real. Yet late last month, leaders of the two efforts formally agreed to collaborate as much as is practicable."

"The two rivals are closer than they have ever been, and yet research and development on the two underlying accelerator technologies will continue apace with a healthy spirit of competition."

"The result is that the ILC and CLIC are setting an example that other large scientific endeavours would do well to emulate."

On staging

Staged approach to LC seems politically more realistic and physically sensible

Various „natural" stages (ordered in $\sqrt{s}$) for an e^+e^- collider:

91.2 GeV -- Giga-Z

~ 250 GeV -- maximum of HZ cross section

344 GeV -- ttbar threshold

2 m(LSP,LKP,...) + X -- model independent WIMP measurements

2 m(NLSP) + X -- SUSY spectroscopy (part I)

~ 800 GeV -- maximum of ttH cross section, HH coupling

m (Z´)

2 m (squarks) + X

3 TeV

Different stages (and when to reach them) will (hopefully) be known from LHC data

Z and W factory

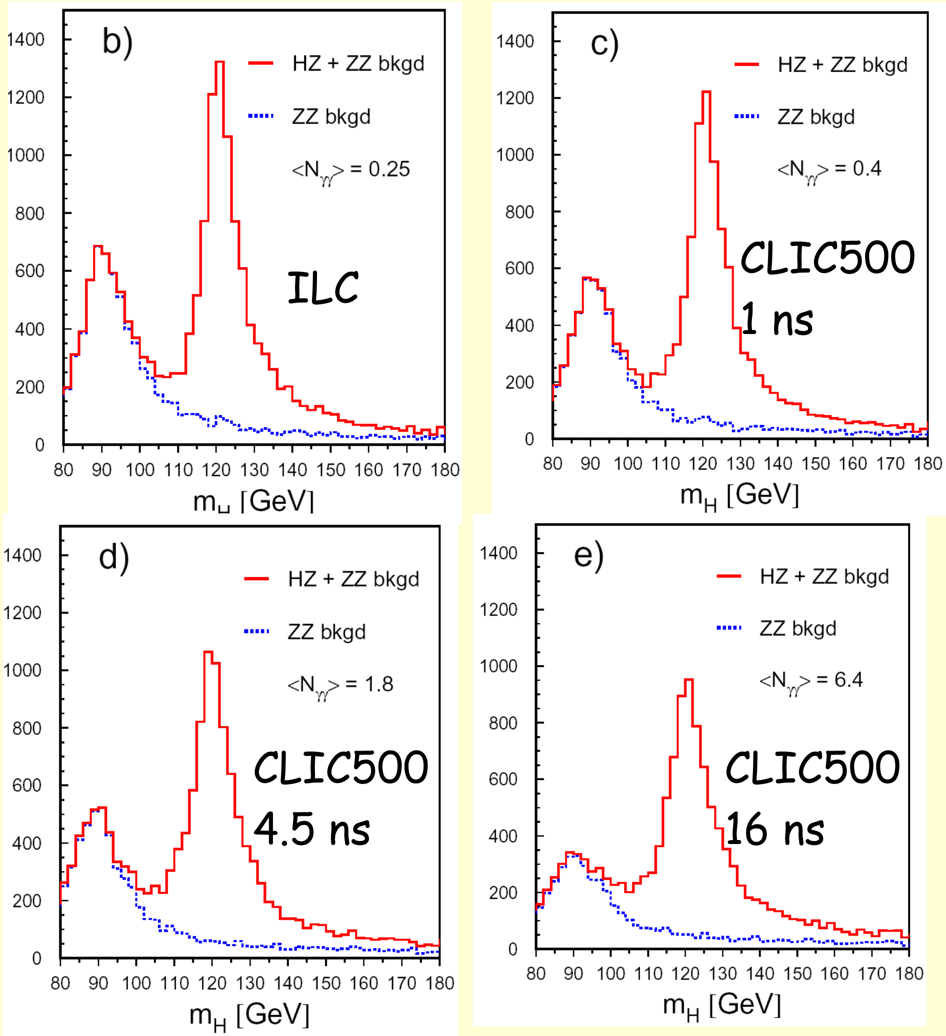
- Electron to positron collisions at 90 GeV (Z) with two linacs made each by one CLIC section with an overall length of about 2.3 km
- Electron to positron collisions at 160 GeV (W) with two linacs made each by two CLIC sections with an overall length of about 4 km
- Linac at reduced gradient of 58 MV/m (nom. 80 MV/m @ 500 GeV)
- Luminosity (L1%) of 2 10^{33} cm^{-2} s^{-1} at Z and 6.5 10^{33} cm^{-2} s^{-1} at W
  - Simple energy scaling from 500 GeV design
- Luminosity improvement by linac filling with 5 consecutive pulses with power source dimensioned for 500 GeV operation
  - Possible cost savings by half of power source complex powering both linacs alternatively (To be studied)
- Luminosity (L1%) of 1.10^{34} cm^{-2} s^{-1} at Z and 2.10^{34} cm^{-2} s^{-1} at W
- Complete injector complex of electrons and positrons required with possible polarisation of electrons but not of positrons

LC 500 GeV Main parameters

Center-of-mass energy	ILC	CLIC Conserv.	CLIC Nominal
Total (Peak 1%) luminosity	$2.0(1.5)\cdot10^{34}$	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	33.5	80	
Main linac RF frequency GHz	1.3 (SC)	12 (NC)	
Bunch charge10^9	20	6.8	
Bunch separation ns	176	0.5	
Beam pulse duration (ns)	1000	177	
Beam power/linac (MWatts)	10.2	4.9	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	10/40	3 / 40	2.4 / 25
Hor/Vert FF focusing (mm)	20/0.4	10/0.4	8/0.1
Hor./vert. IP beam size (nm)	640/5.7	248 / 5.7	202/ 2.3
Soft Hadronic event at IP	0.12	0.07	0.19
Coherent pairs/crossing at IP	10?	10	100
BDS length (km)	2.23 (1 TeV)	1.87	
Total site length (km)	31	13.0	
Wall plug to beam transfer eff.	9.4%	7.5%	
Total power consumption MW	216	129.4	

Does LC Technology matter?

Higgs recoil mass



many LC precision measurements

depend on machine precisions

more than on detector precision

- threshold scans
- polarized cross sections

Needs careful consideration!

Average energy loss (beamstrahlung)

2.4% / 7% / 29%
ILC500/CLIC500/CLIC300

Muon Colliders

R. B. Palmer (BNL)

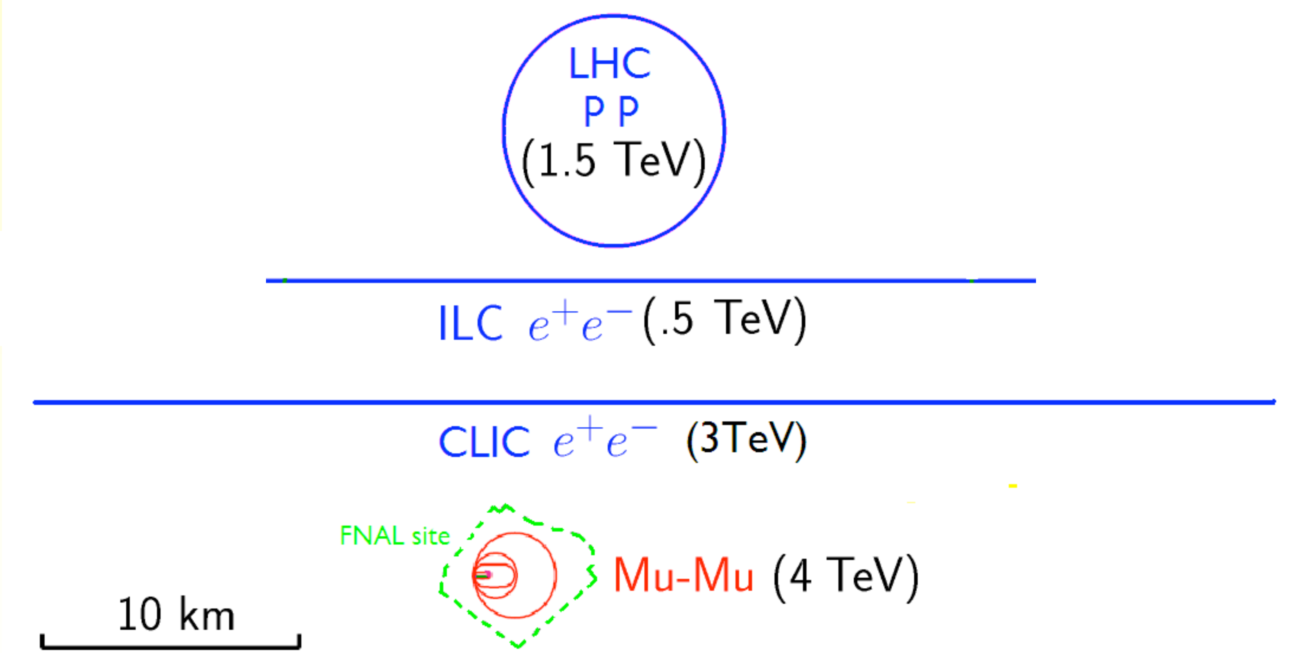
CERN LHC2FC

Feb 24 2009

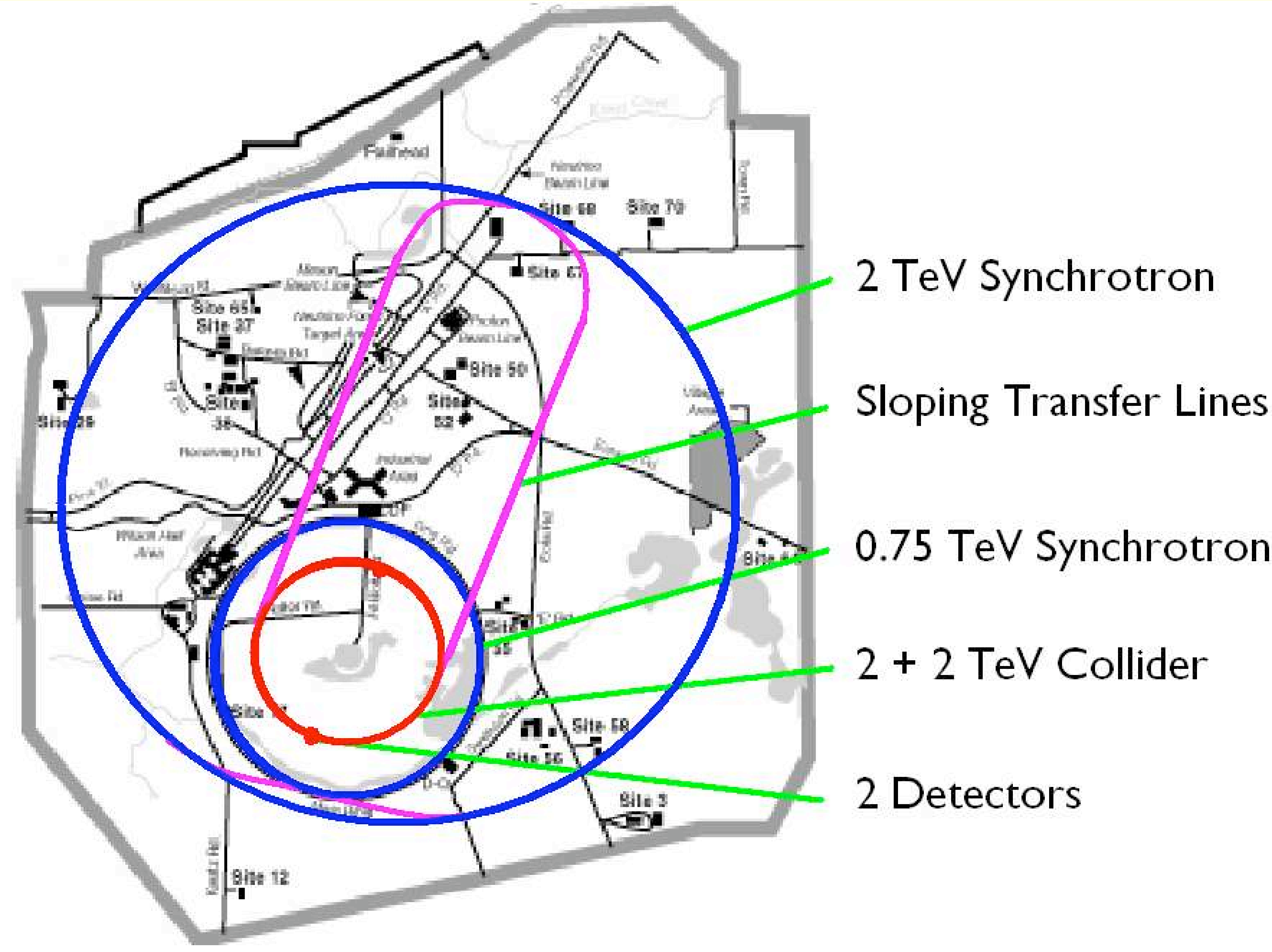
- Why ?
- The "easy" Parts
  - Driver
  - Target & capture
  - Acceleration
  - Collider ring
- The hard part: Muon Cooling
  - rf breakdown problem
  - Magnetic insulation
  - High pressure gas
- R&D Proposed Program
- Conclusion

Why a Muon Collider?

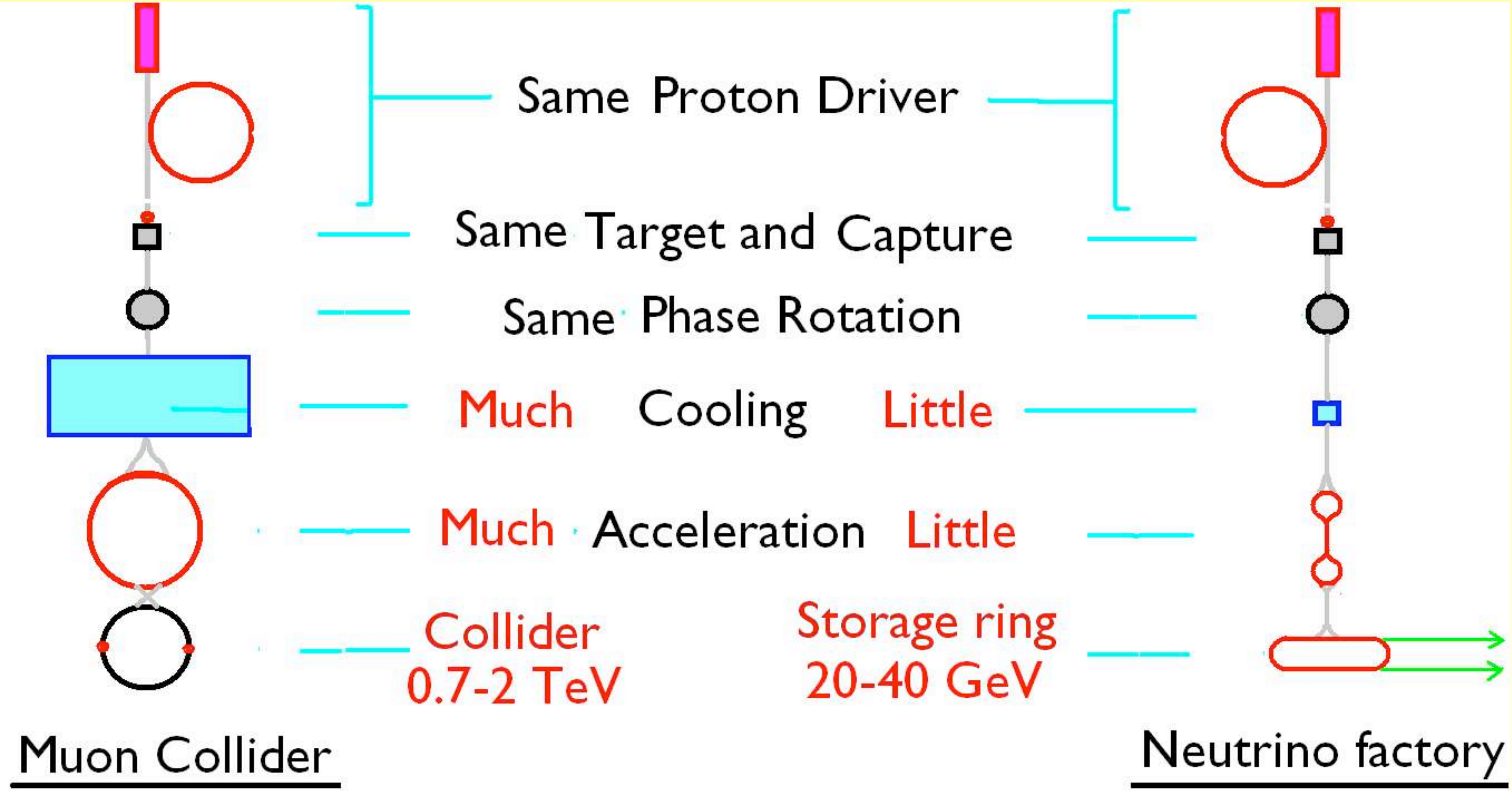
- Point like interactions as in linear e^+e^-
- Negligible synchrotron radiation:
  Acceleration in rings Small footprint Less rf Hopefully cheaper
- Collider is a Ring
  $\approx$ 1000 crossings per bunch Larger spot Easier tolerances 2 Detectors
- Negligible Beamstrahlung Narrow energy spread
- 40,000 greater S channel Higgs Enabling study of widths ***(+ CLIC potential...)***



Layout of 4 TeV Collider using pulsed synchrotrons



Schematics of Collider and Neutrino Factory



- Much of the R&D is common and has been pursued by the same US collaboration
- Significant European role only in Neutrino Factory
- Recent FNAL involvement specifically in Collider

Collider Parameters

C of m Energy	1.5	4	TeV
Luminosity	1	3 (6)	10^{34} cm^{2}sec^{-1}
Beam-beam Tune Shift	0.1	0.1	
Muons/bunch	2	2	10^{12}
Ring $<$bending field$>$	5.2	10.4	T
Ring circumference	3	4	km
Beta at IP $= \sigma_z$	10	10	mm
rms momentum spread	0.1	0.12	%
Muon Beam Power	7.5	9 (18)	MW
Required depth for ν rad	13	135 (270)	m
Repetition Rate	12	6 (12)	Hz
Proton Driver power	4	1.8 (3.6)	MW
Muon Trans Emittance	25	25	pi mm mrad
Muon Long Emittance	72,000	72,000	pi mm mrad

- Emittance and bunch intensity requirement same for both examples
- Luminosities ($\Delta E < 1\%$) are comparable to CLIC's
- Depth for ν radiation for off site dose $<$ 1 mrem/year (1/10 US Federal limit)

Current Organizations

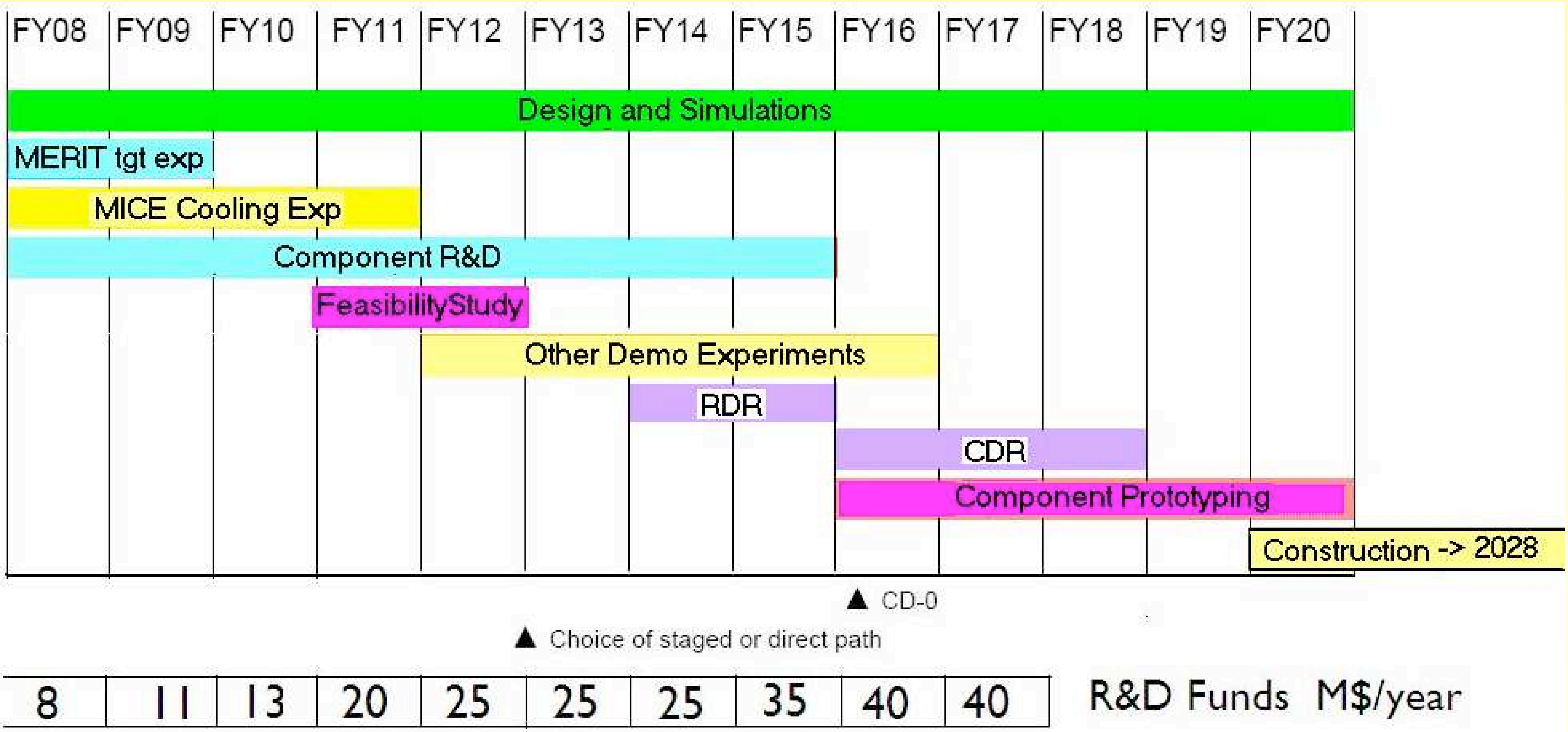
- Neutrino Factory and Muon Collider Collaboration (NFMCC)
  - US Labs and Universities (Founded in 1997)
  - 2 spokespersons (Bross, Kirk) and Project manager (Zisman)
  - Funded primarily by DoE
- Muon Collider Task Force
  - Set up by FNAL Director in 2007
  - Coordinated with NFMCC
- Total current effort $\approx$ 8 M$/year

R&D Needed to establish "feasibility"

- Demonstrate mercury jet target (essentially done by MERIT)
- Demonstrate ionization cooling (should be done by MICE)
- Solve rf Breakdown problem
- Achieve, as nearly as possible, an end to end simulation
- Get a first estimate of cost

Desired time to establish "feasibility" : 2012

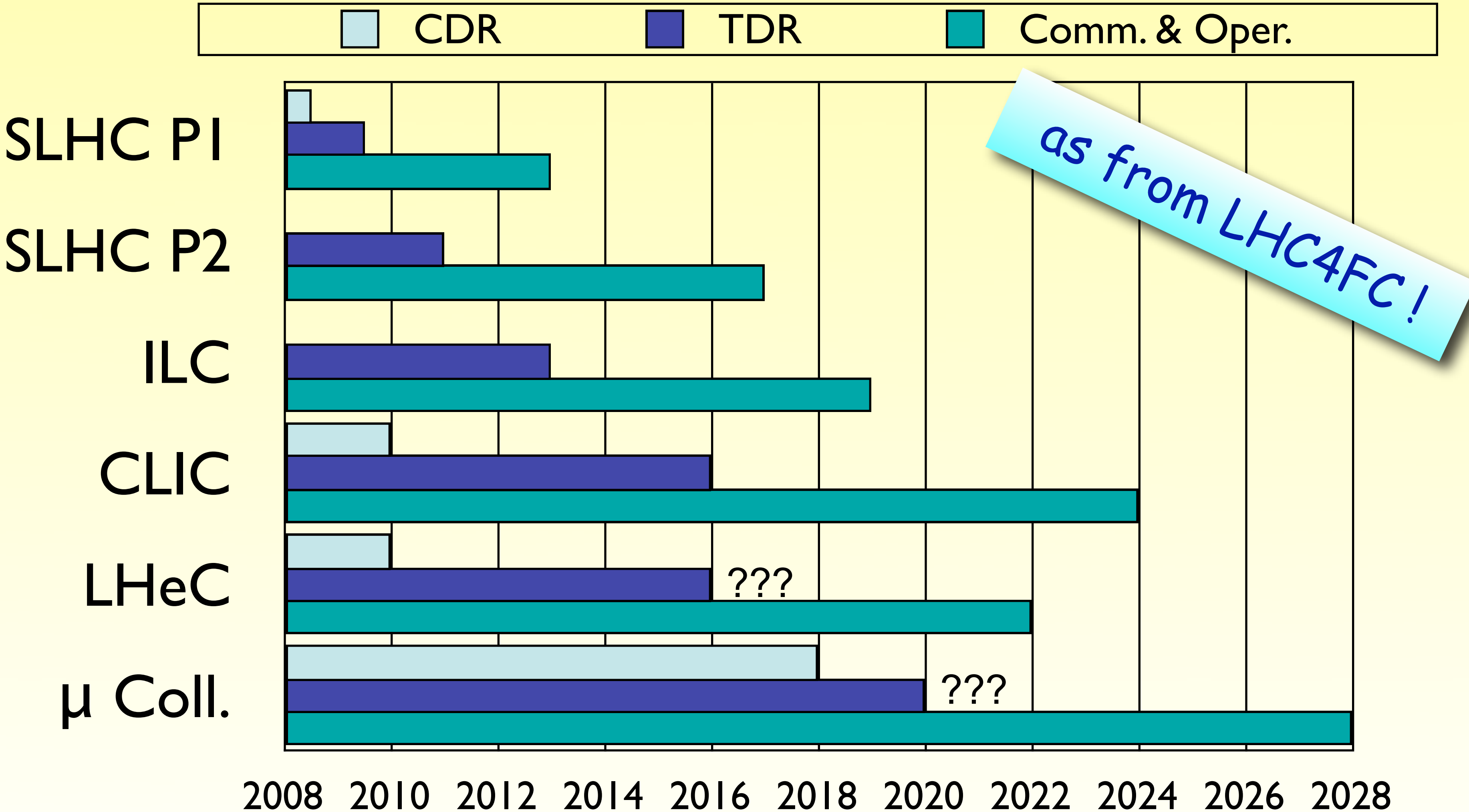
Time Line and Funding Needs (as presented to P5)



- Funding request includes that for Neutrino Factory R&D
- Funding increase ($\approx 3\times$) needed if Muon Collider is to be credible option by 2012

Summary of single tentative schedules

(Shortest, Success Oriented, Technically Limited)



LHC science will need to 'validate' the science case

(time scale ?)