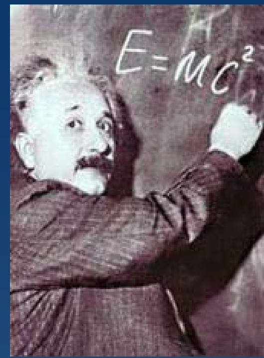
CERN
and the Future of Particle Physics

The Energy Frontier

R-D Heuer
La Thuile
March 4, 2011

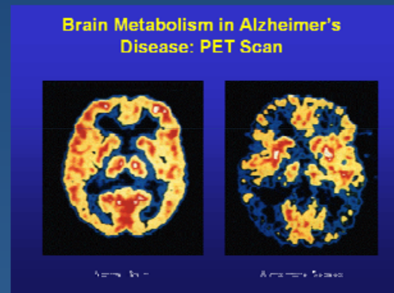
Innovation
CERN
uniting people
Education
Research

The Mission of CERN

- Push back the frontiers of knowledge

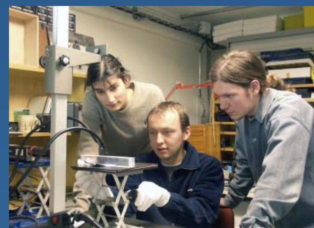
  E.g. the secrets of the Big Bang …what was the matter like within the first moments of the Universe's existence?

- Develop new technologies for accelerators and detectors

  Information technology - the Web and the GRID

  Medicine - diagnosis and therapy

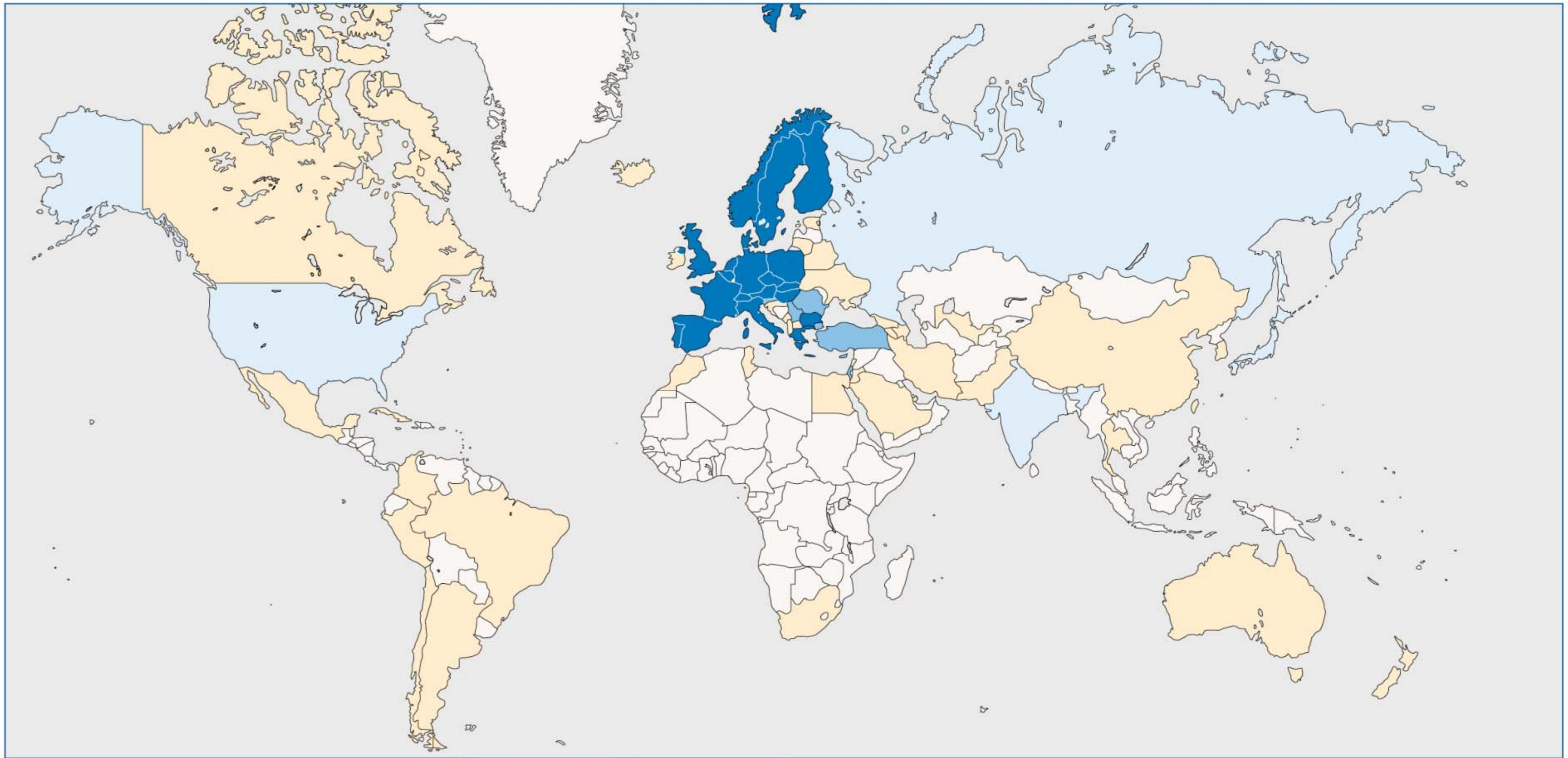



- Train scientists and engineers of tomorrow

- Unite people from different countries and cultures

CERN in Numbers

Distribution of all CERN Users by Nation of Institute on 6 January 2011



Member states 6361

Austria	79
Belgium	130
Bulgaria	47
Czech Republic	187
Denmark	73
Finland	84
France	854
Germany	1221
Greece	109
Hungary	55
Italy	1428
Netherlands	171
Norway	82
Poland	193
Portugal	134
Slovak Republic	61
Spain	329
Sweden	72
Switzerland	351
United Kingdom	701

Prospective Members

Candidate for Accession
Romania

Membership applicants
Cyprus, Israel, Serbia, Slovenia, Turkey

Observer states 2935

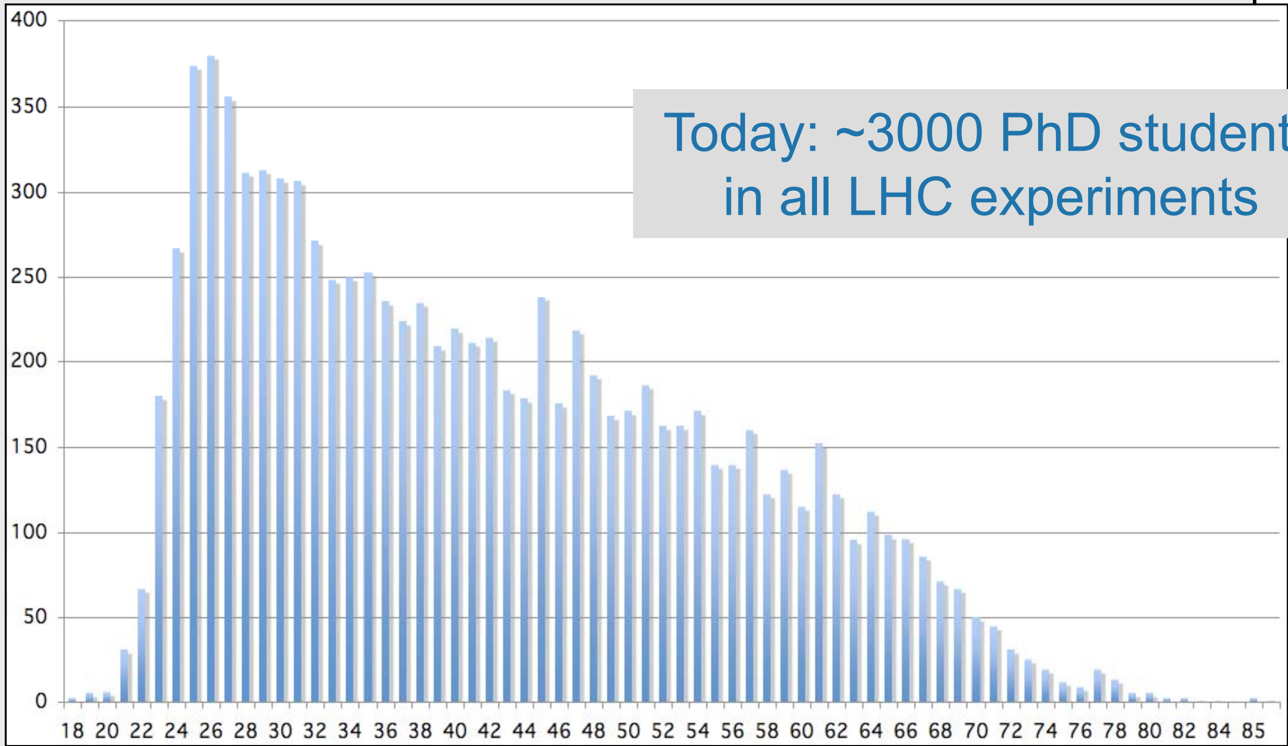
India	91
Israel	60
Japan	204
Russian Federation	829
Turkey	67
USA	1684

Other states 828

Albania	2
Argentina	11
Armenia	12
Australia	19
Azerbaijan	1
Belarus	20
Brazil	79
Canada	150
Chile	3
China	84
China (Taipei)	50
Colombia	9
Croatia	16
Cuba	4
Cyprus	8
Egypt	5
Estonia	11
Georgia	8
Iceland	3
Iran	17
Ireland	14
Korea (Rep of)	74
Lebanon	1
Lithuania	12
Malta	1
Mexico	32
Montenegro	1
Morocco	5
New Zealand	8
Pakistan	16
Peru	2
Qatar	1
Romania	62
Saudi Arabia	2
Serbia	22
Slovenia	29
South Africa	11
Thailand	1
The F.Y.R.O.M	2
Tunisia	1
Ukraine	18
Uzbekistan	1

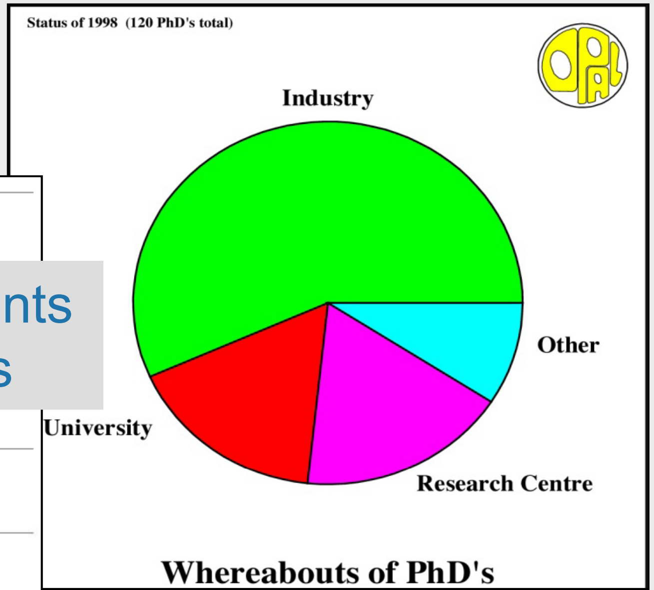
Age Distribution of Scientists
- and where they go afterwards

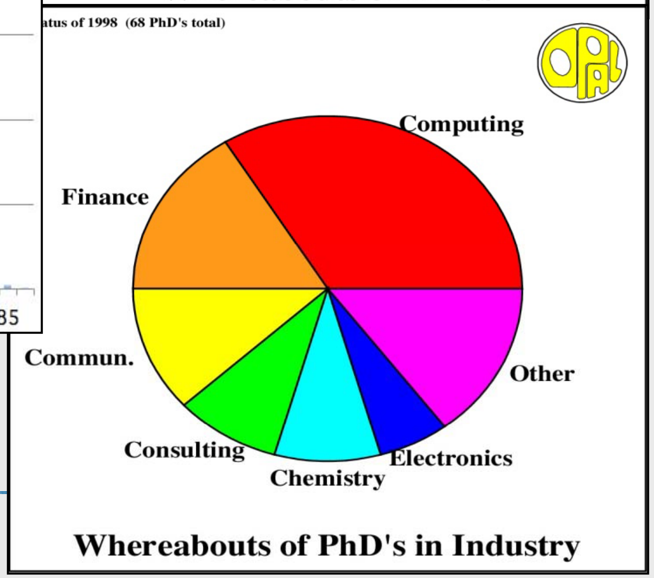
Survey in March 2009



Today: ~3000 PhD students in all LHC experiments

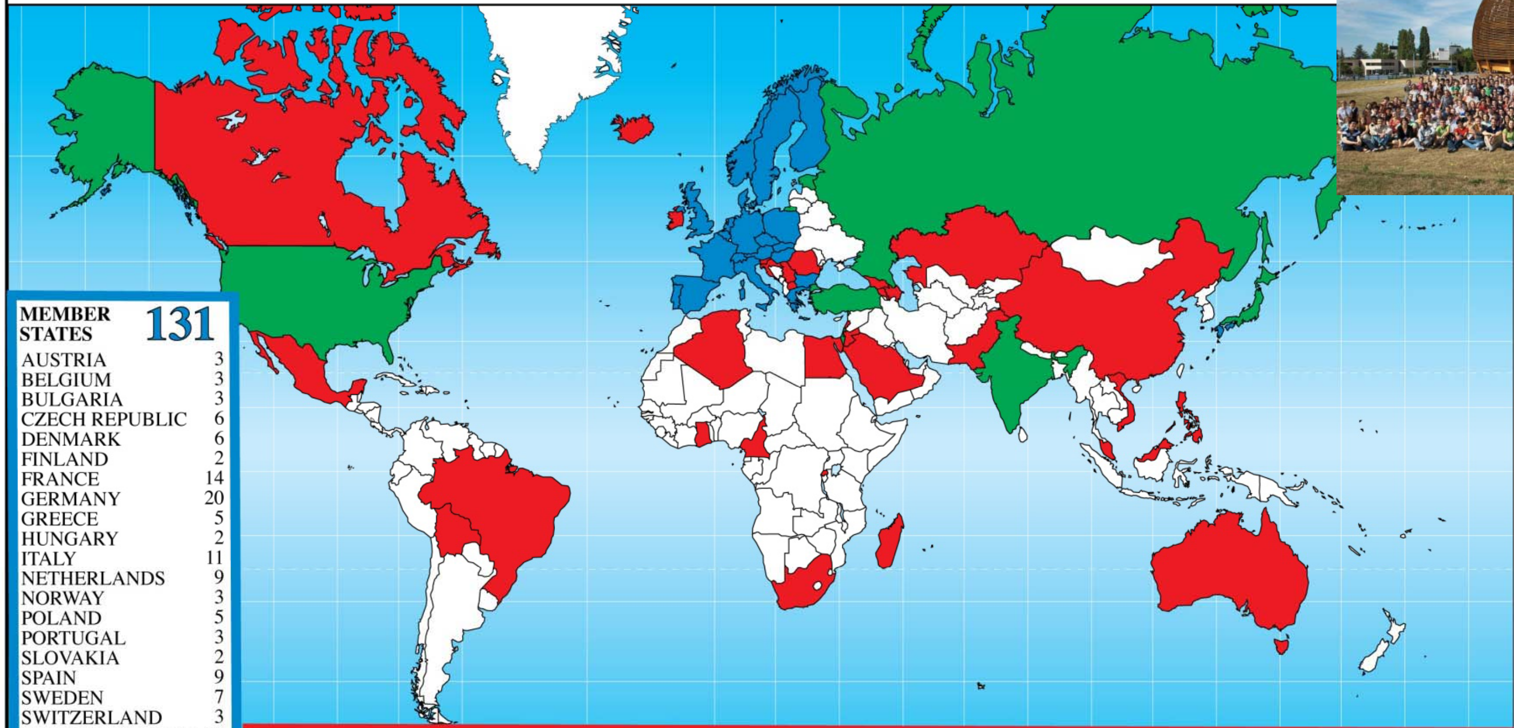
They do not all stay: where do they go?





Summer Students @ CERN

Distribution of Summer Students 2010



MEMBER STATES 131

AUSTRIA	3
BELGIUM	3
BULGARIA	3
CZECH REPUBLIC	6
DENMARK	6
FINLAND	2
FRANCE	14
GERMANY	20
GREECE	5
HUNGARY	2
ITALY	11
NETHERLANDS	9
NORWAY	3
POLAND	5
PORTUGAL	3
SLOVAKIA	2
SPAIN	9
SWEDEN	7
SWITZERLAND	3
UNITED KINGDOM	15

OBSERVER STATES 53

INDIA	8
ISRAEL	4
JAPAN	5
RUSSIA	9
TURKEY	10
USA	17

NON-MEMBER STATES 66

ALGERIA	2
ARMENIA	2
AUSTRALIA	2
AZERBAIJAN	1
BOLIVIA	1
BOSNIA & HERZEGOVINA	2
BRAZIL	2
CAMEROON	1
CANADA	5
CHINA	2
CROATIA	4
EGYPT	1
ESTONIA	2
GHANA	1
GIBRALTAR	1
ICELAND	1
IRELAND	1
JORDAN	1
KAZAKHSTAN	1
LEBANON	1
MADAGASCAR	2
MALAYSIA	1
MALTA	3
MEXICO	2
PAKISTAN	6
PHILIPPINES	1
ROMANIA	1
RWANDA	1
SAUDI ARABIA	2
SERBIA	1
SINGAPORE	1
SLOVENIA	1
SOUTH AFRICA	1
SOUTH KOREA	1
THAILAND	2
F.Y.R.O.M.	2
VIETNAM	4

Past few decades

"Discovery" of Standard Model

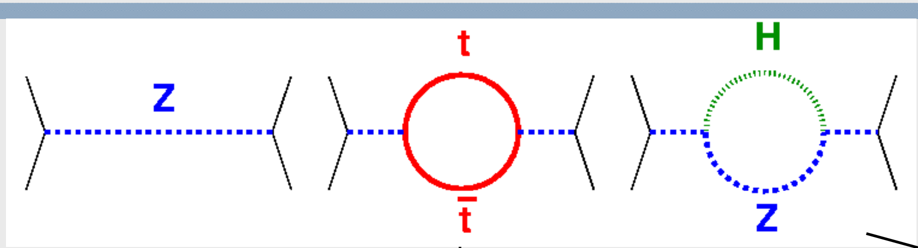
through synergy of

hadron - hadron colliders (e.g. Tevatron)

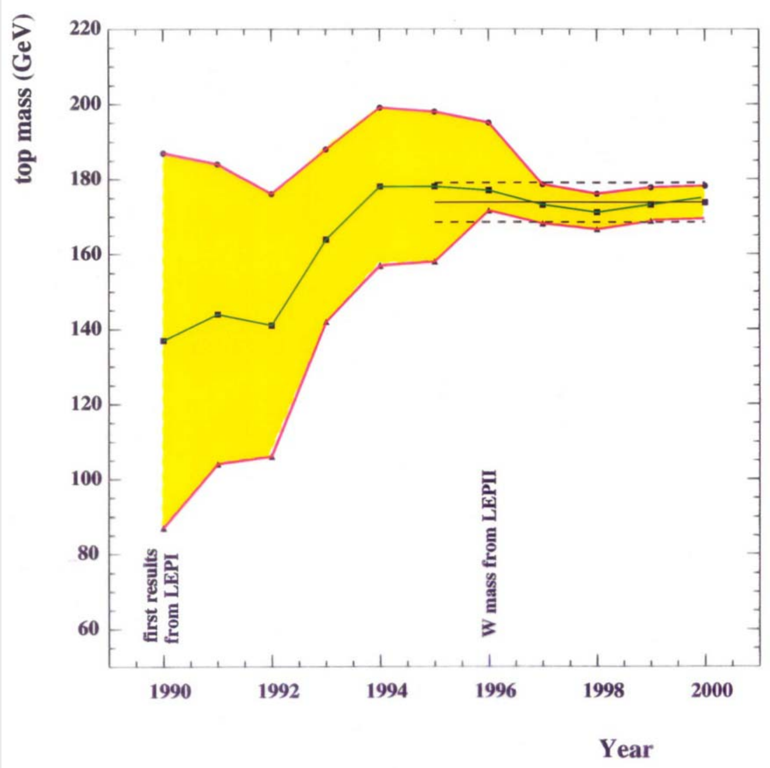
lepton - hadron colliders (HERA)

lepton - lepton colliders (e.g. LEP, SLC)

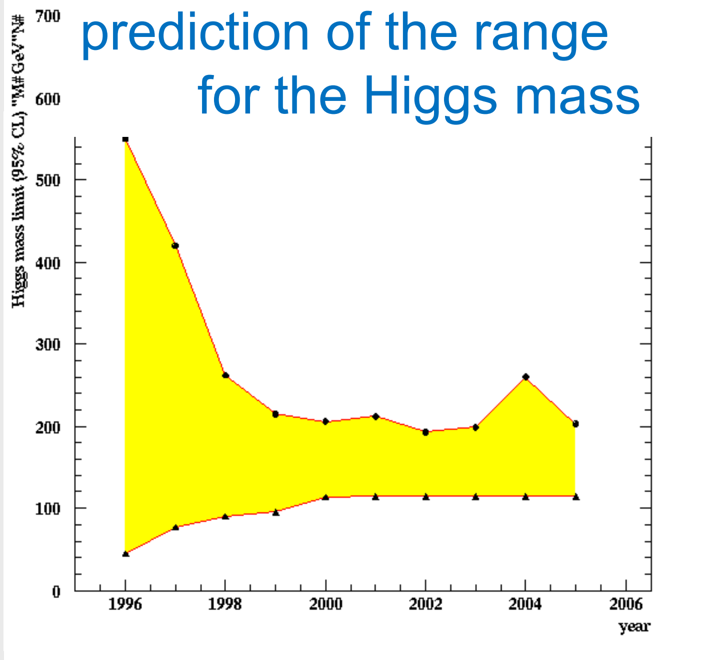
Test of the SM at the Level of Quantum Fluctuations



indirect determination of the top mass



prediction of the range for the Higgs mass



possible due to

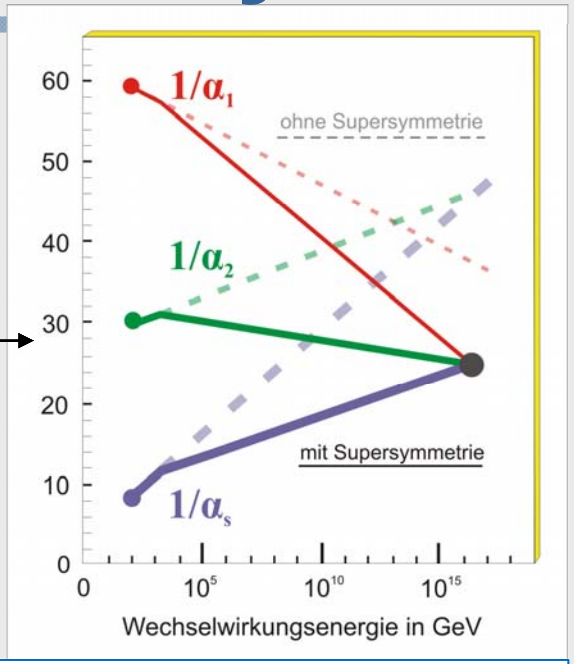
- precision measurements
- known higher order electroweak corrections

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

Key Questions of Particle Physics

origin of mass/matter or
origin of electroweak symmetry breaking

unification of forces



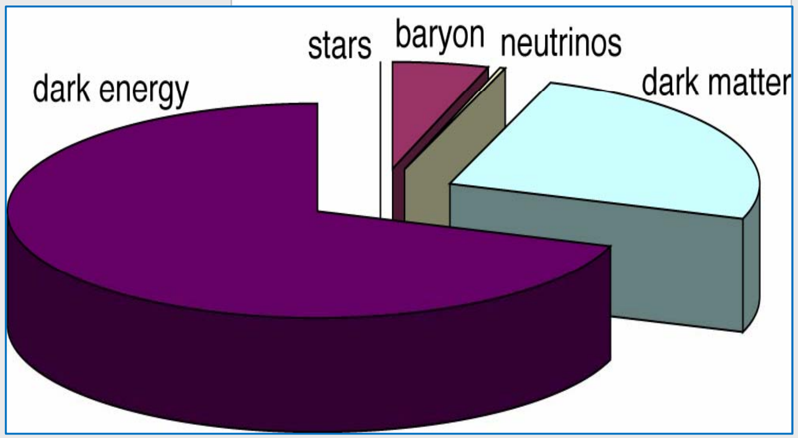
fundamental symmetry of forces and matter

unification of quantum physics and general relativity

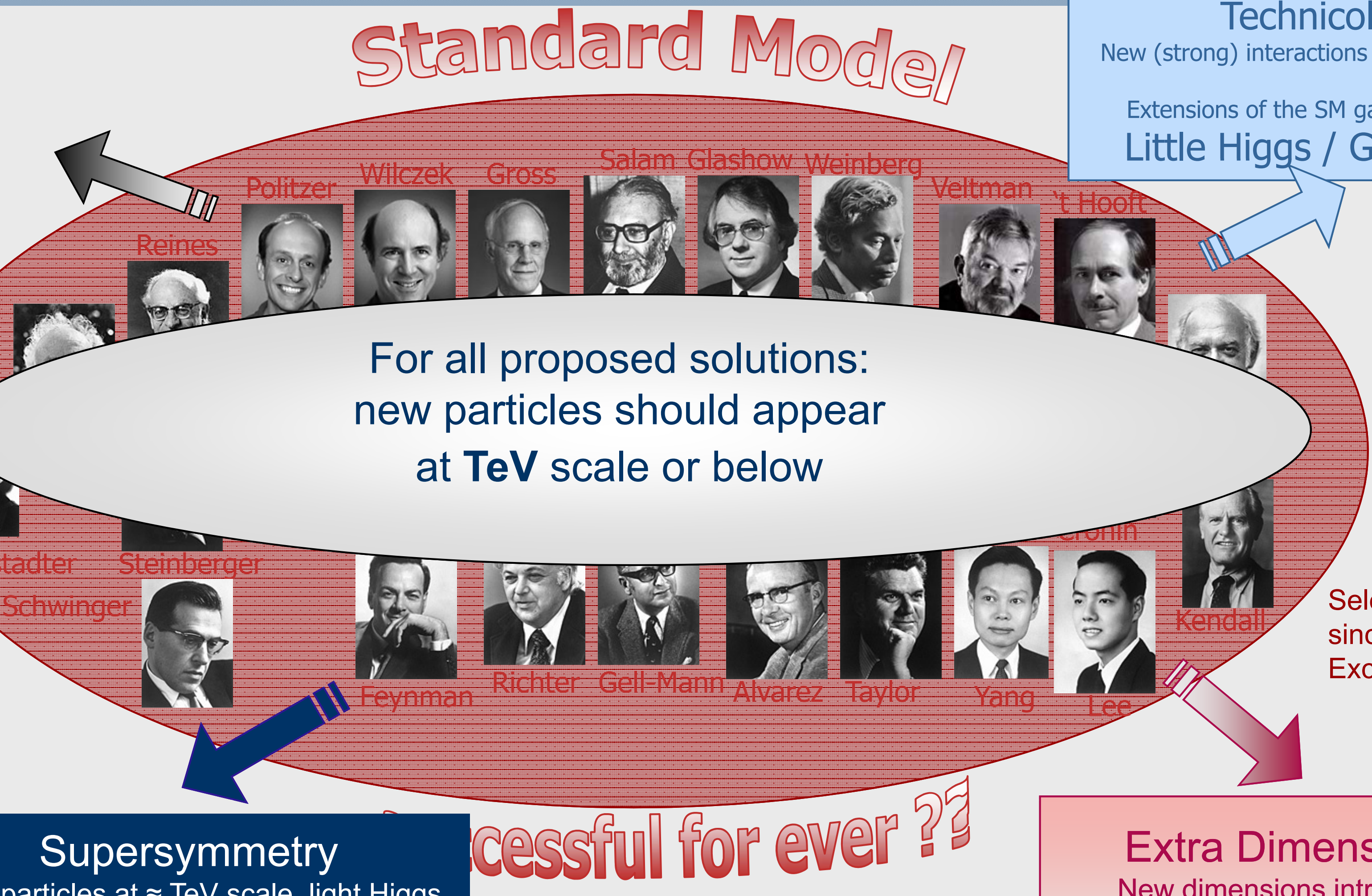
number of space/time dimensions

what is dark matter

what is dark energy



Solutions?



Technicolor
New (strong) interactions produce EWSB

Extensions of the SM gauge group :
Little Higgs / GUTs / …

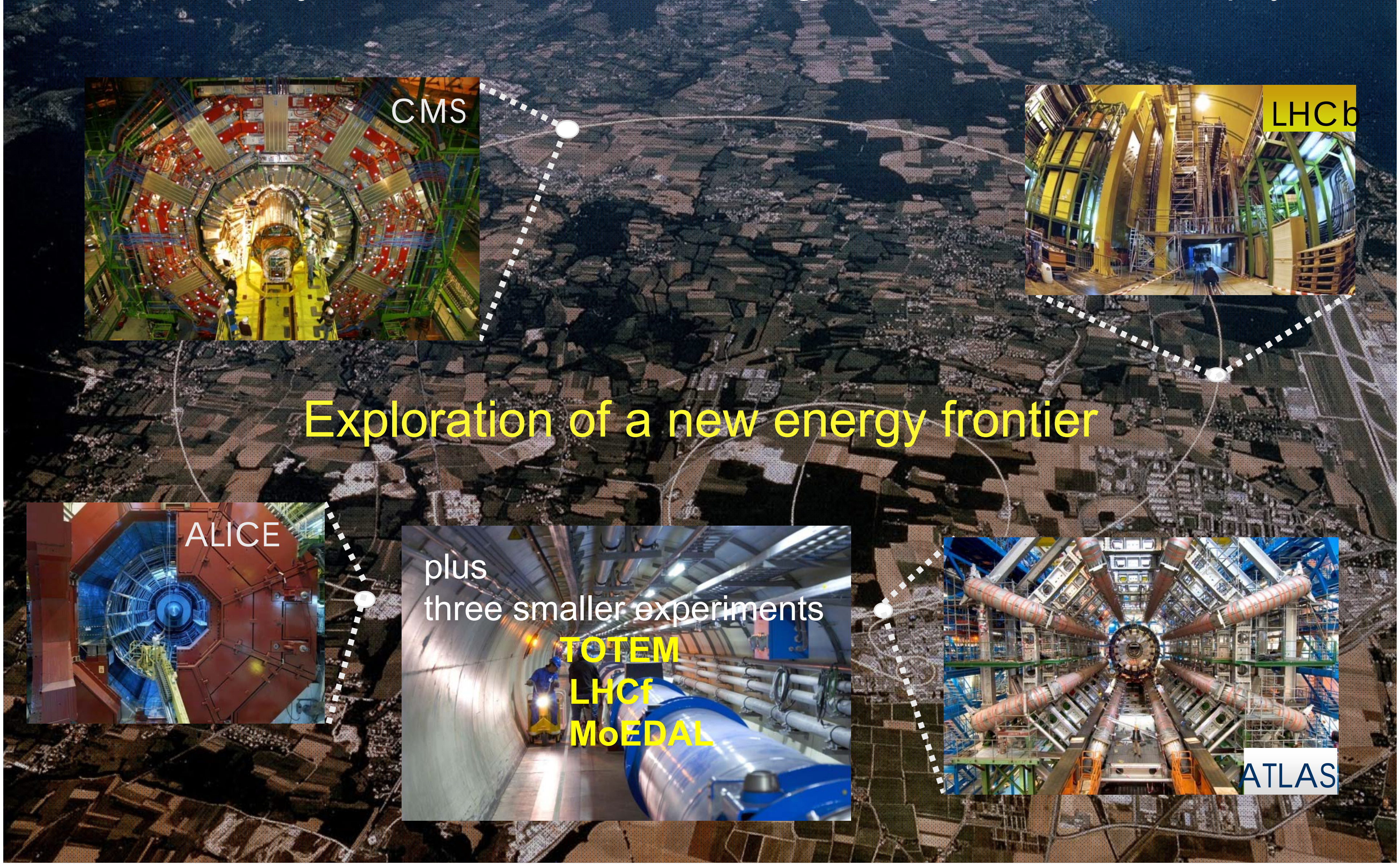
Selected NP
since 1957
Except P. Higgs

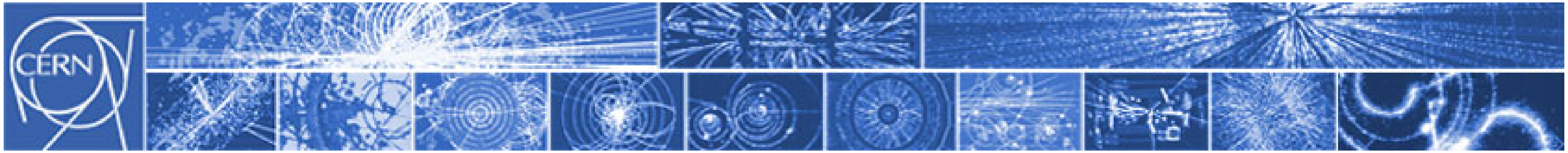
Supersymmetry
New particles at ≈ TeV scale, light Higgs
Unification of forces
Higgs mass stabilized
No new interactions

Extra Dimensions
New dimensions introduced
$m_{Gravity} \approx m_{elw}$ ➲ Hierarchy problem solved
New particles at ≈ TeV scale

Enter a New Era in Fundamental Science

Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is the most exciting turning point in particle physics.





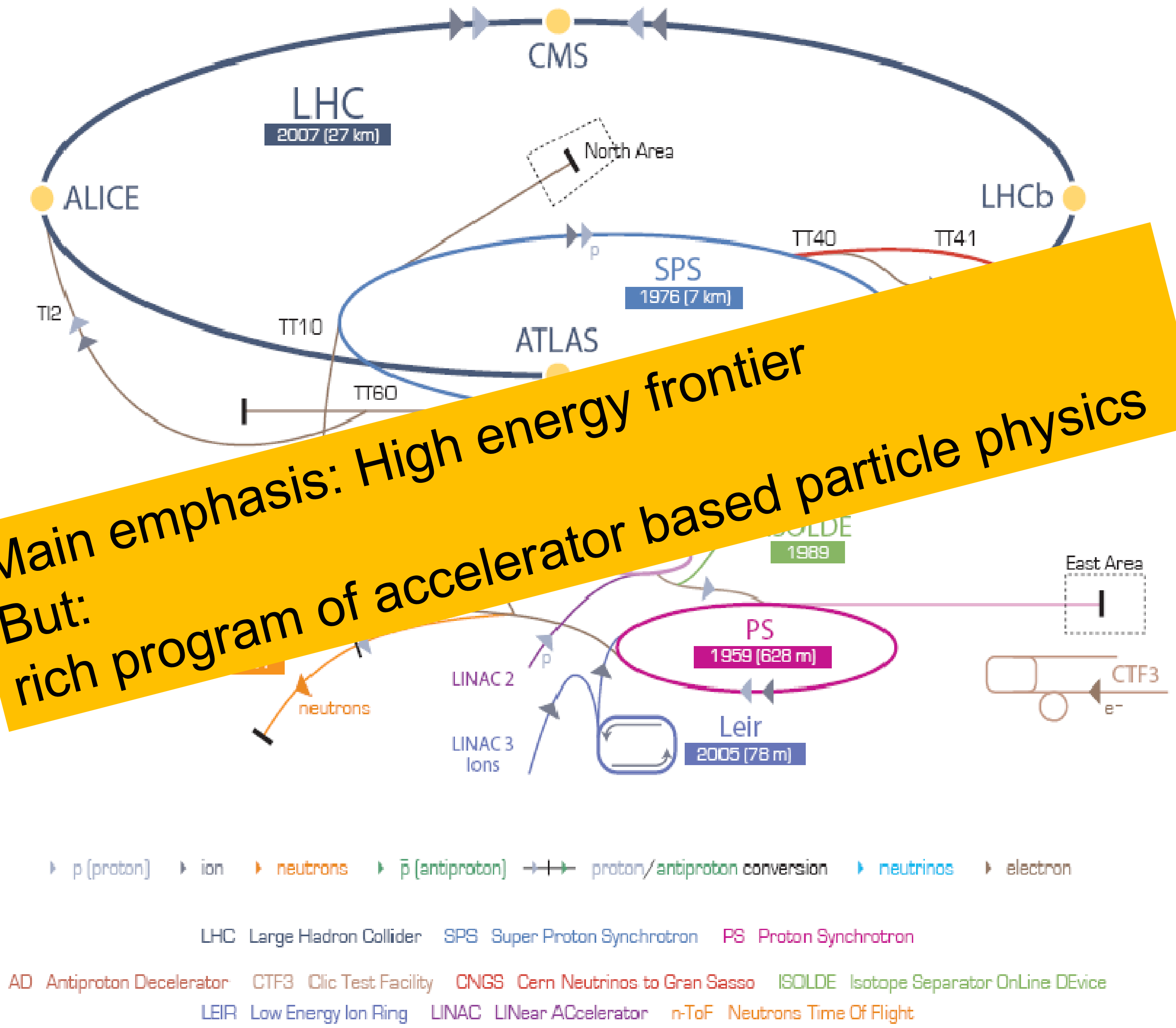
CERN: Scientific Strategy

- Full exploitation of LHC physics potential
  - Reliable operation (including consolidation and LINAC 4)
  - Remove bottlenecks to benefit from nominal luminosity for both machine and detectors
  - Focused R&D and prototyping for High-Luminosity LHC
  - Re-establish standards for technical and general infrastructure
- Preparation for the long-term future (>2015)
  - Energy frontier
    - **CLIC/ILC** collaboration and R&D (for detectors and machine)
    - Generic R&D for **High-Energy LHC** (i.e. high field magnets)
  - R&D for high-power proton sources (HP-SPL) e.g for v-physics
- World-class fixed-target physics program (incl. v-projects)

Main emphasis: High energy frontier

But:

rich program of accelerator based particle physics



Fixed Target Physics

Antiproton Physics

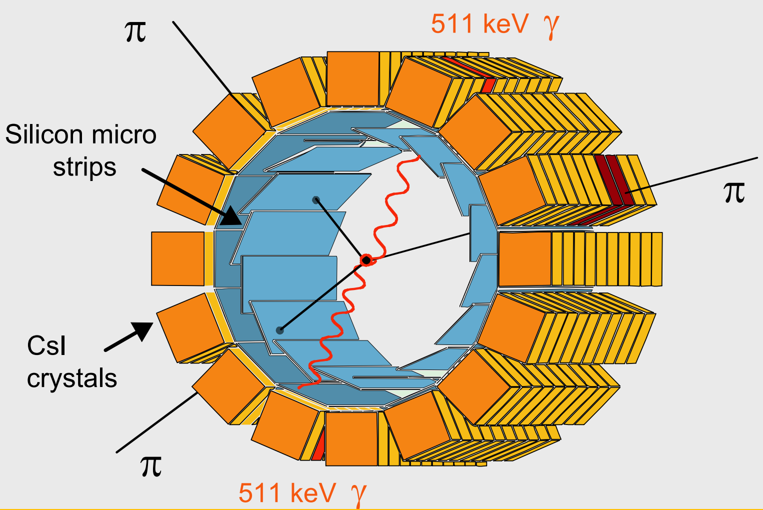
Cold antiprotons
("manufacturing anti-matter")

1. PS $p \rightarrow pp$ 10^{-6}/collision
2. AD deceleration + cooling
   stochastic + electron
3. Extraction @ ~ 0.1*c*
4. Produce thousands of *anti-H*

Anti-H annihilations detected

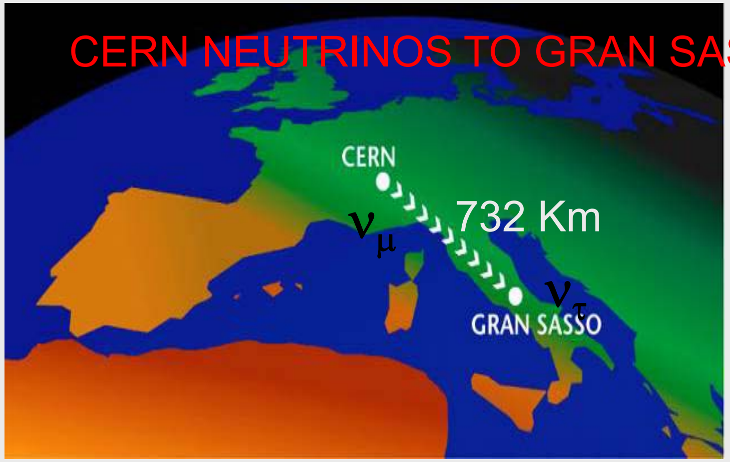
ATHENA (→ ALPHA)

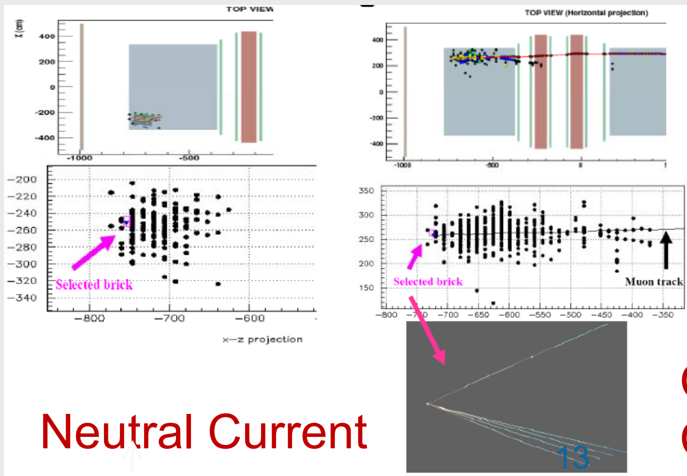
anti-H (pe^+) + matter → $\pi^+\pi^-$ + $\gamma\gamma$



**ALPHA and ASACUSA:
First storage of Antihydrogen atoms**

Neutrino Physics



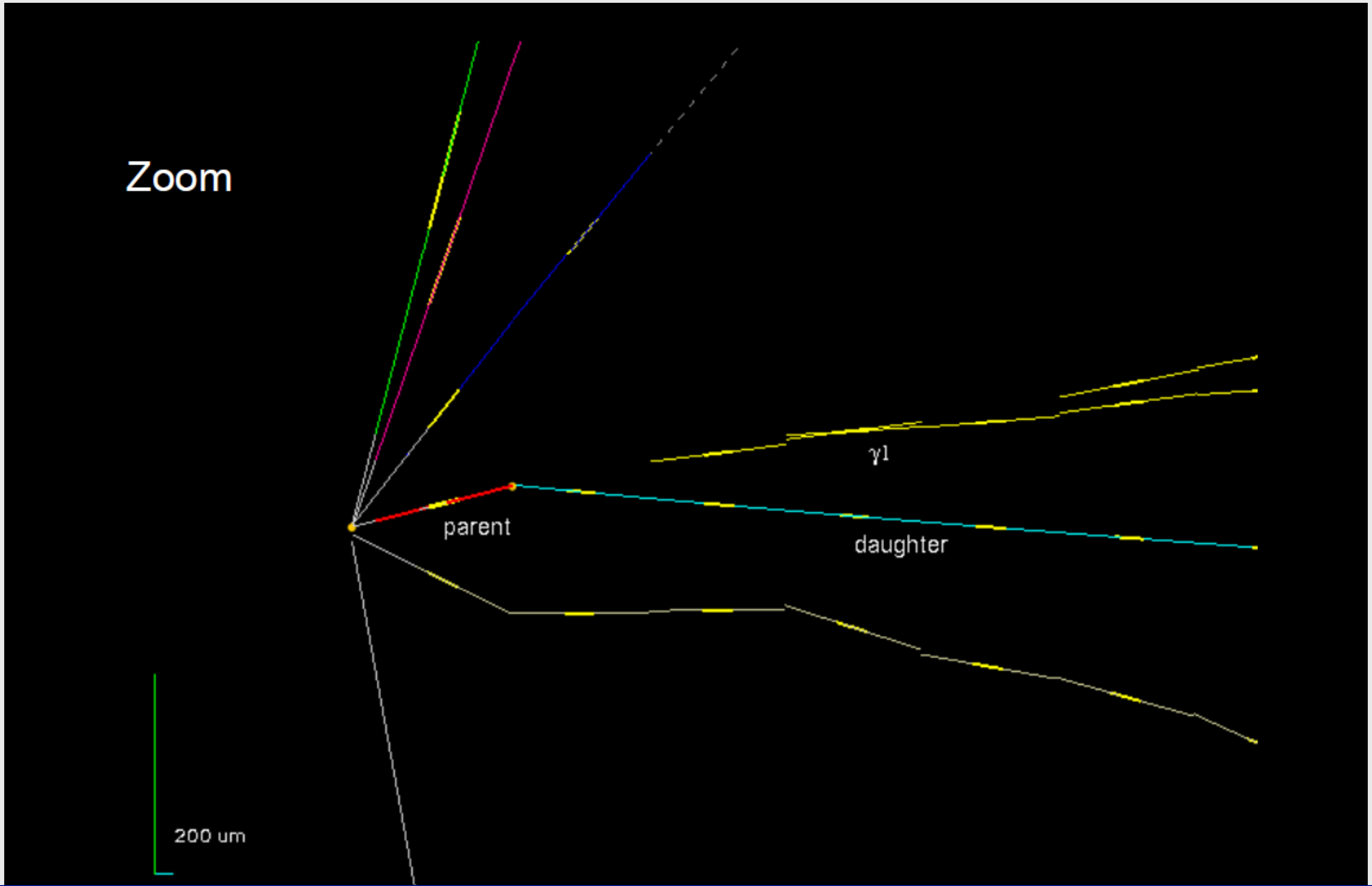


OPERA

Charge Current

CNGS - OPERA

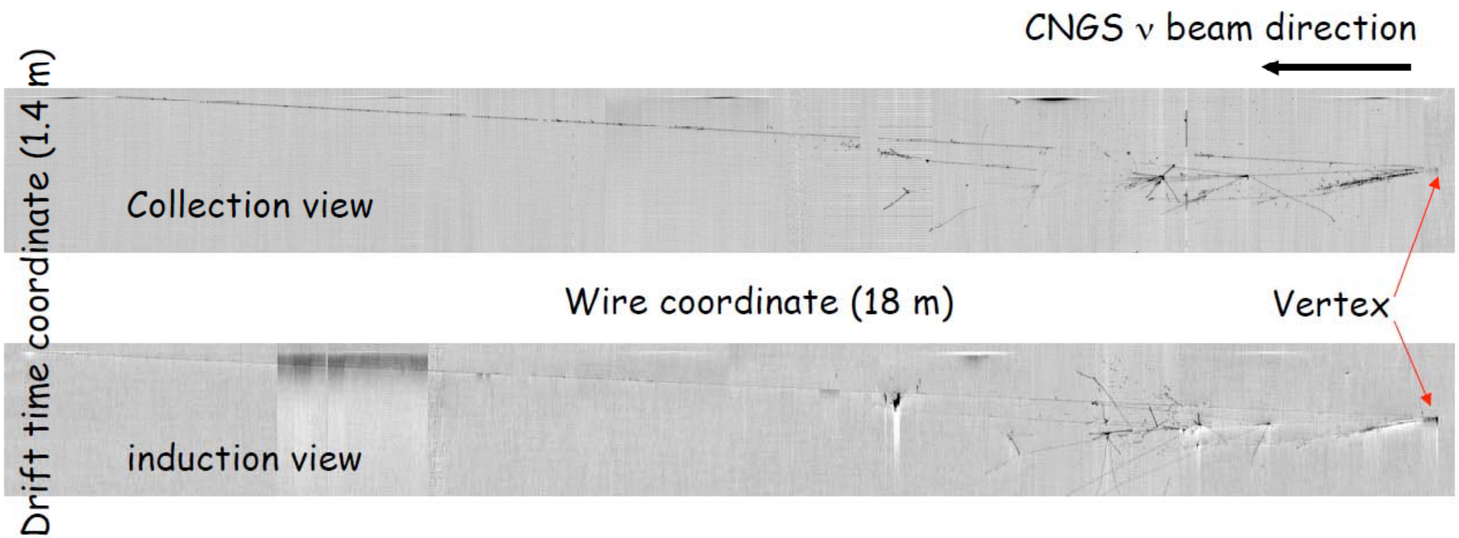
First υ_τ Candidate



Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC)
(as seen by the electronic detectors)

CNGS - ICARUS

The first CNGS neutrino interaction in ICARUS T600



- Leading muon (crossing horizontally the whole cryostat)
- Two charged particle tracks undergoing hadronic interactions
- Two γ converting at 14 and 16 cm from vertex (π^0?)
- Vertex not fully visible in collection view, due to locally wrong wire biasing

ALPHA

HBAR PRODUCTION RUNS

2010 breakthrough: 38 Hbar atoms trapped

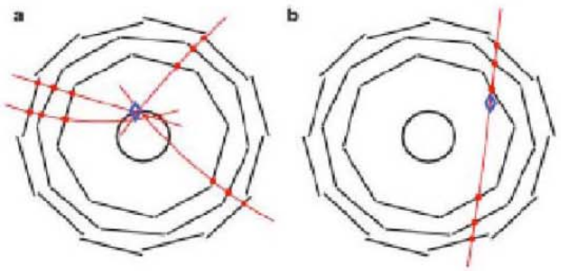
e^+ evaporative cooling, bias electric voltages to sweep pbar BG out

Distributions of
released antihydrogen atoms
and antiprotons

published in

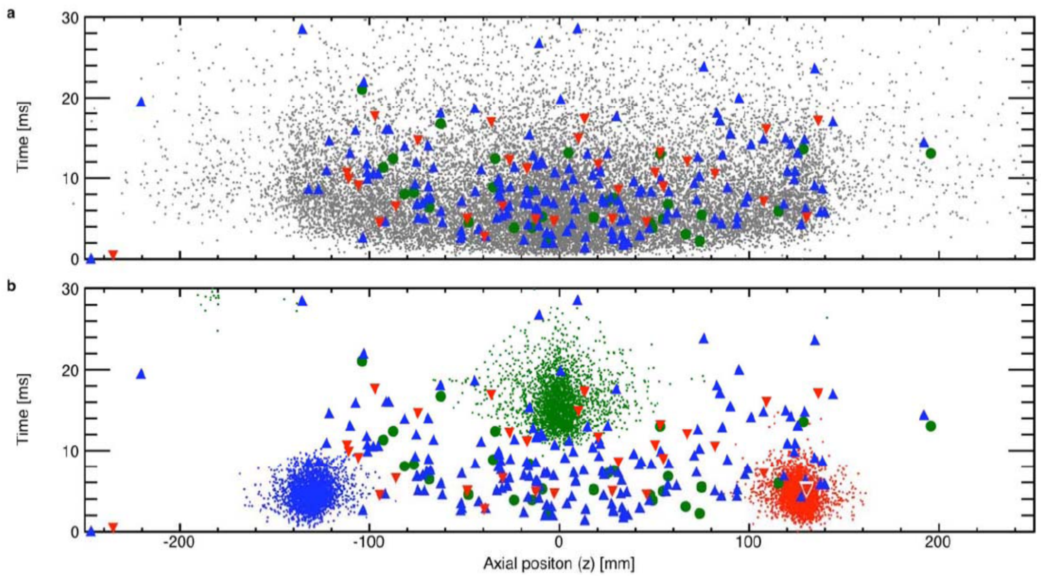
nature

GB Andresen *et al.* *Nature* **000**, 1-4 (2010)



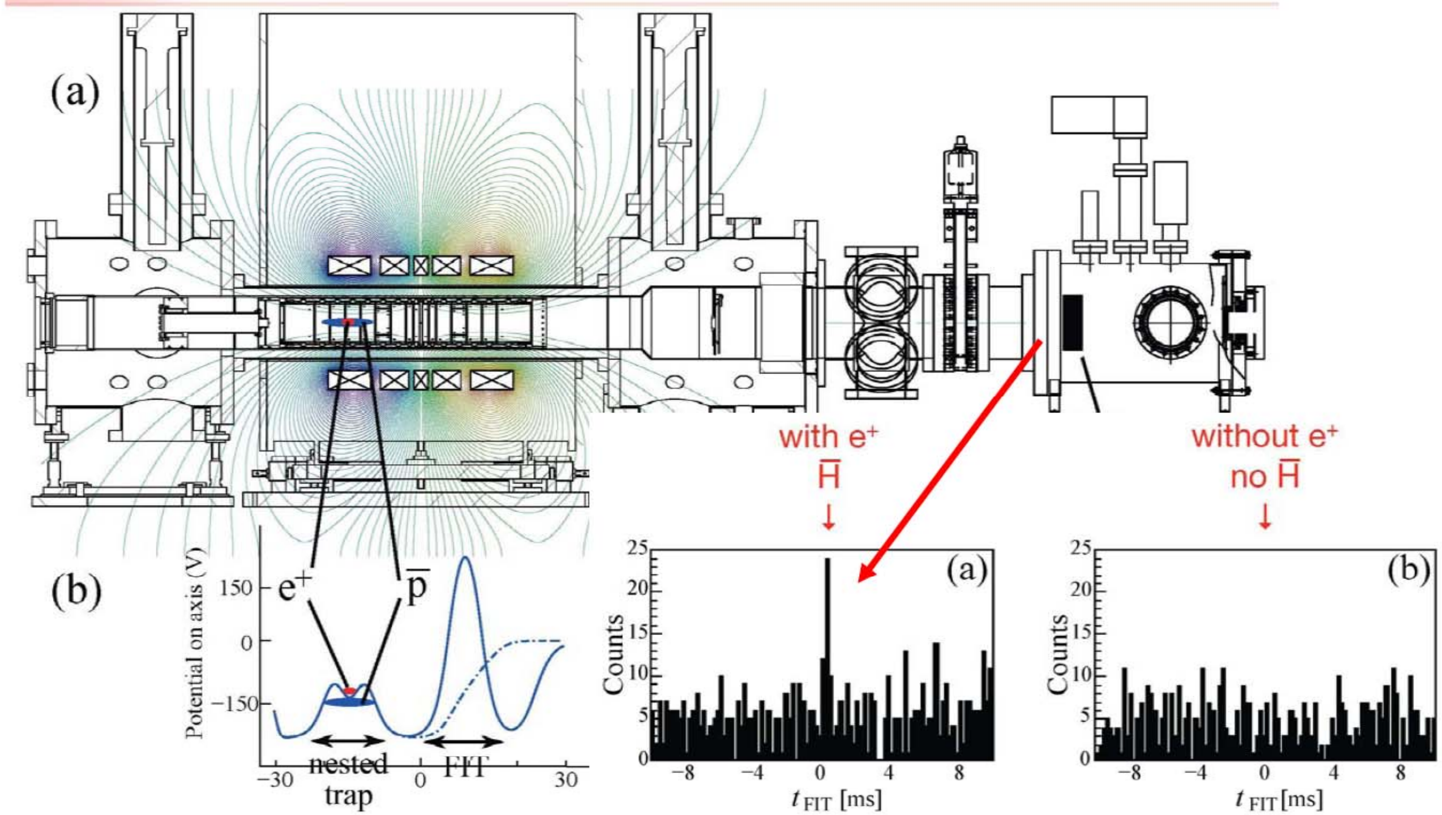
Late 2010 progress: Hbar trapping efficiency x 8

1 Hbar trapped / run, 252 Hbar in total, up to 1000 s lifetime



ASACUSA

ANTI-HYDROGEN TRAPPING



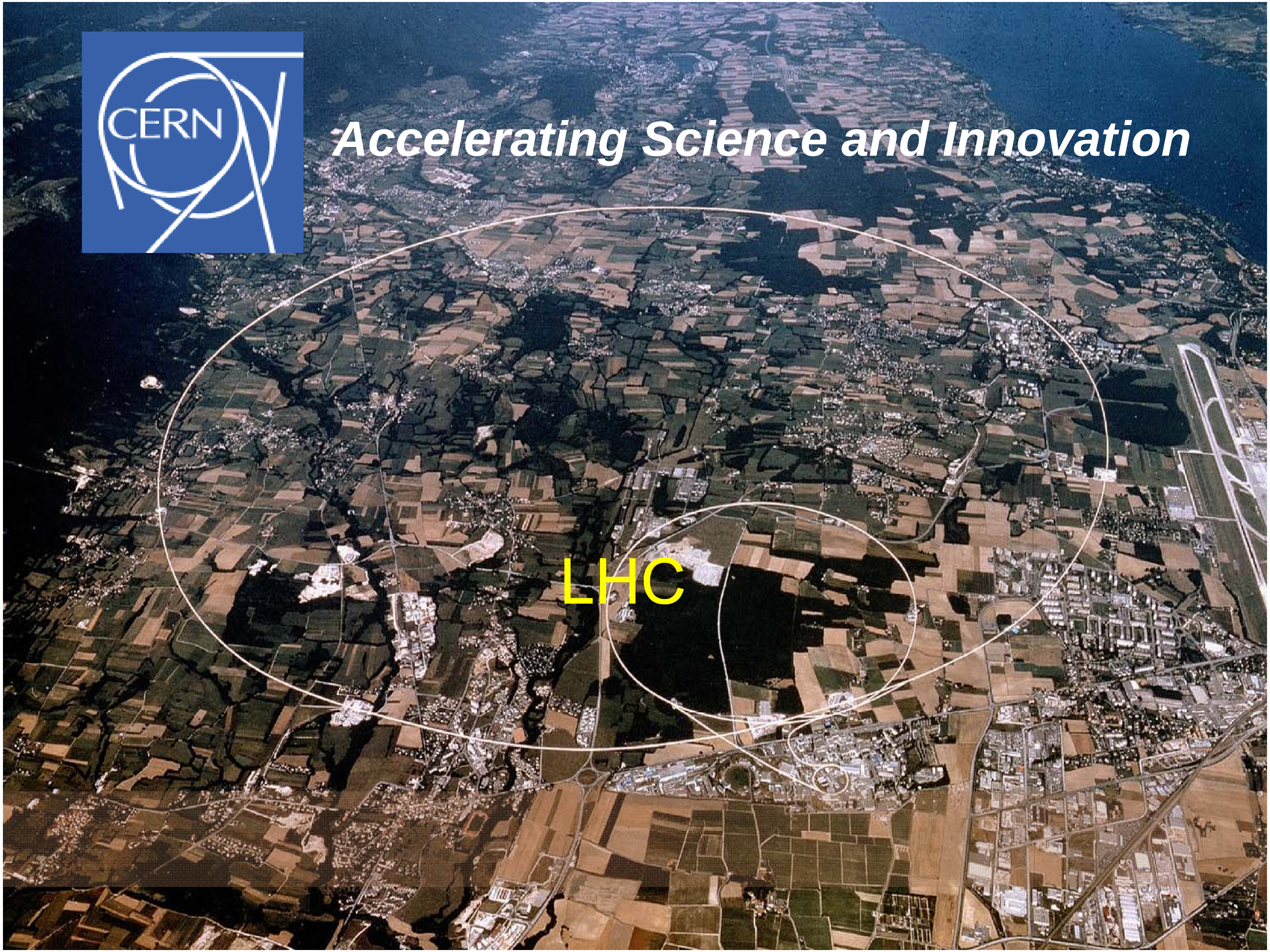
2010 breakthrough: Hbar formation demonstrated

~70 Hbar detected/run (~1% of produced)

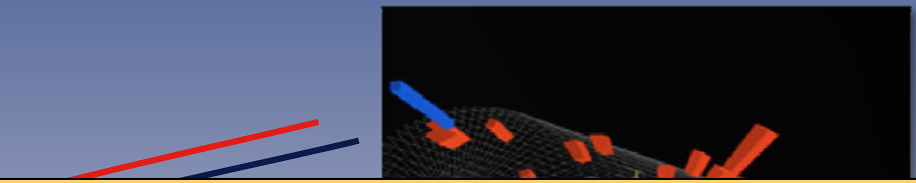
C. Vallée RB 195 Report from SPSC 100 7

The CLOUD Experiment

- Experiment using cloud chamber to study possible link between cosmic-rays and cloud formation.
  - Studies suggest that cosmic-rays may have an influence on the amount of cloud cover through the formation of new aerosols (tiny particles suspended in the air that seed cloud droplets).
- Understanding the underlying microphysics in controlled laboratory conditions is a key to unraveling the connection between cosmic-rays, clouds and climate.
- First time high-energy physics accelerator used to study atmospheric and climate science.


CERN
Accelerating Science and Innovation
LHC

First Collisions at LHC on 23 November 2009 at E_{CM} = 900 GeV



<u>Chronology of a fantastic escalation of events:</u>

2009

- 20 November: first beams circulating in the LHC
- 23 November: first collisions at $\sqrt{s}$ = 900 GeV
- 8, 14, 16 December: few hours of collisions at $\sqrt{s}$ = 2.36 TeV (the world record !)
- 16 December- 26 February: technical stop

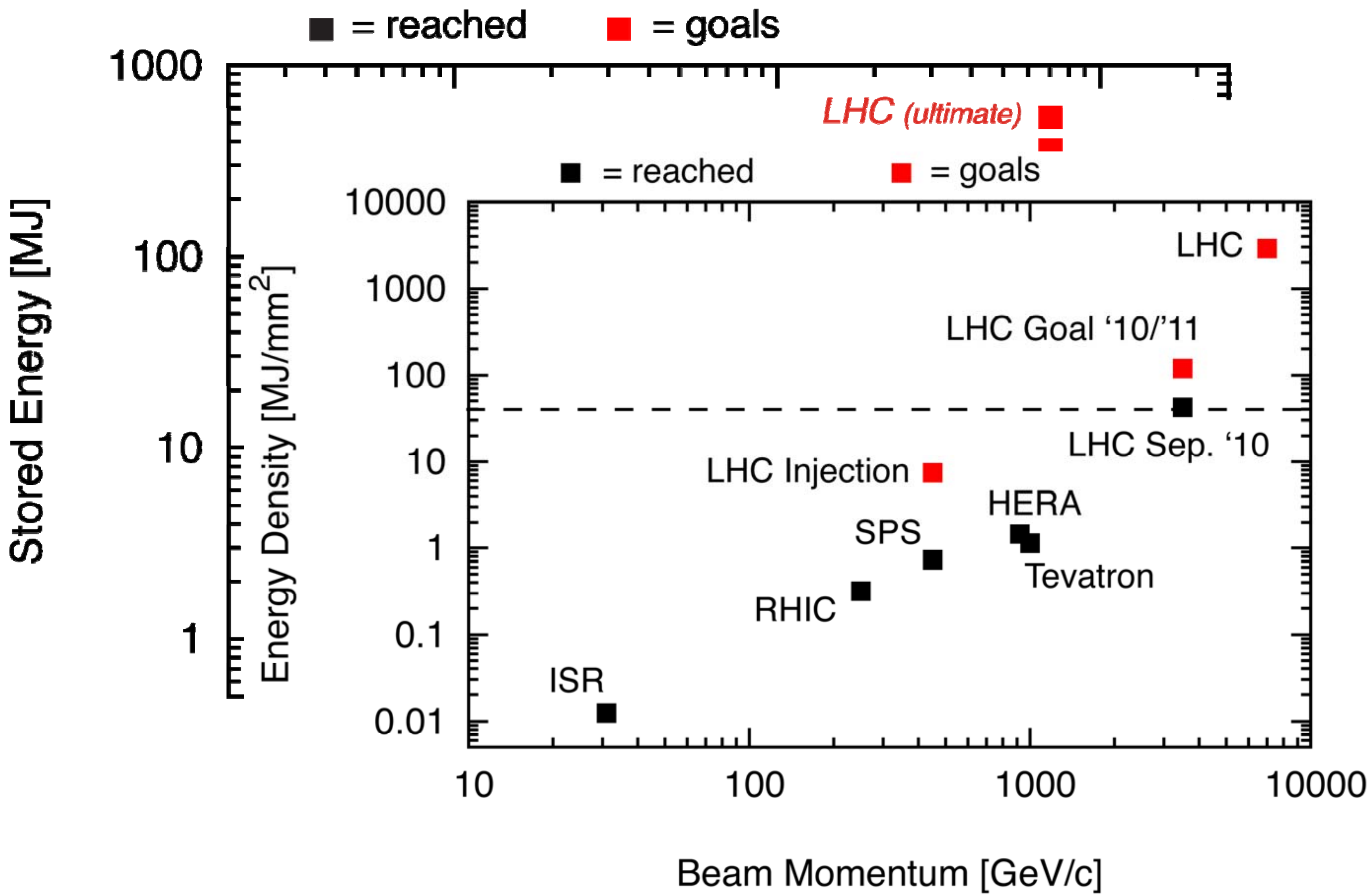
2010

- 27 February : machine operation started again
- 19 March : first (single) beams ramped up to 3.5 TeV
- 30 March : first collisions at 3.5+3.5 TeV

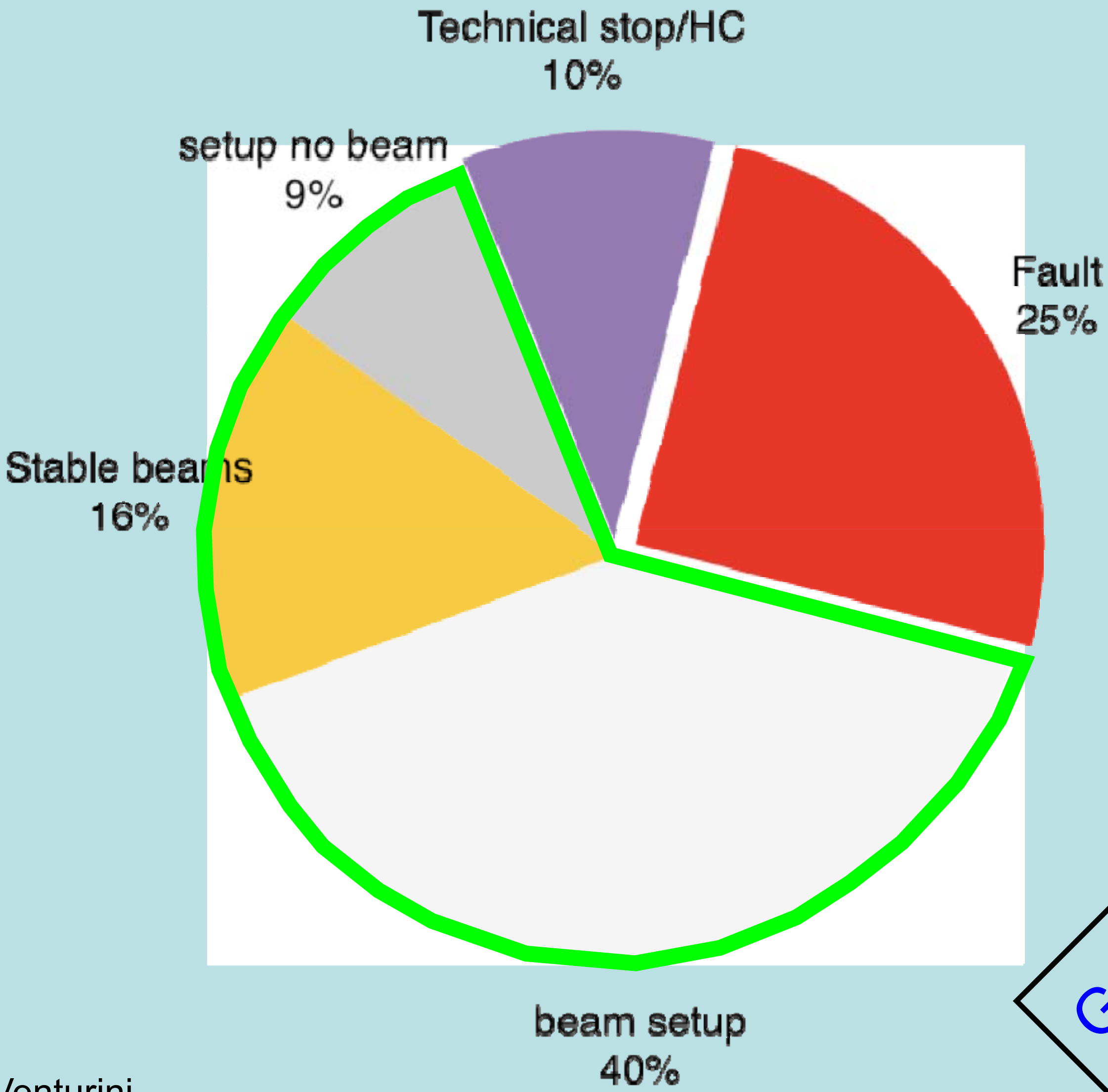
- immediate data taking by all experiments with high efficiency
- end July: first results presented at the international High Energy Conference
- since then, more than tenfold statistics increase

… after more than a year of repairs and improvements

Stored Energy in the LHC



Overall LHC efficiency in 2010



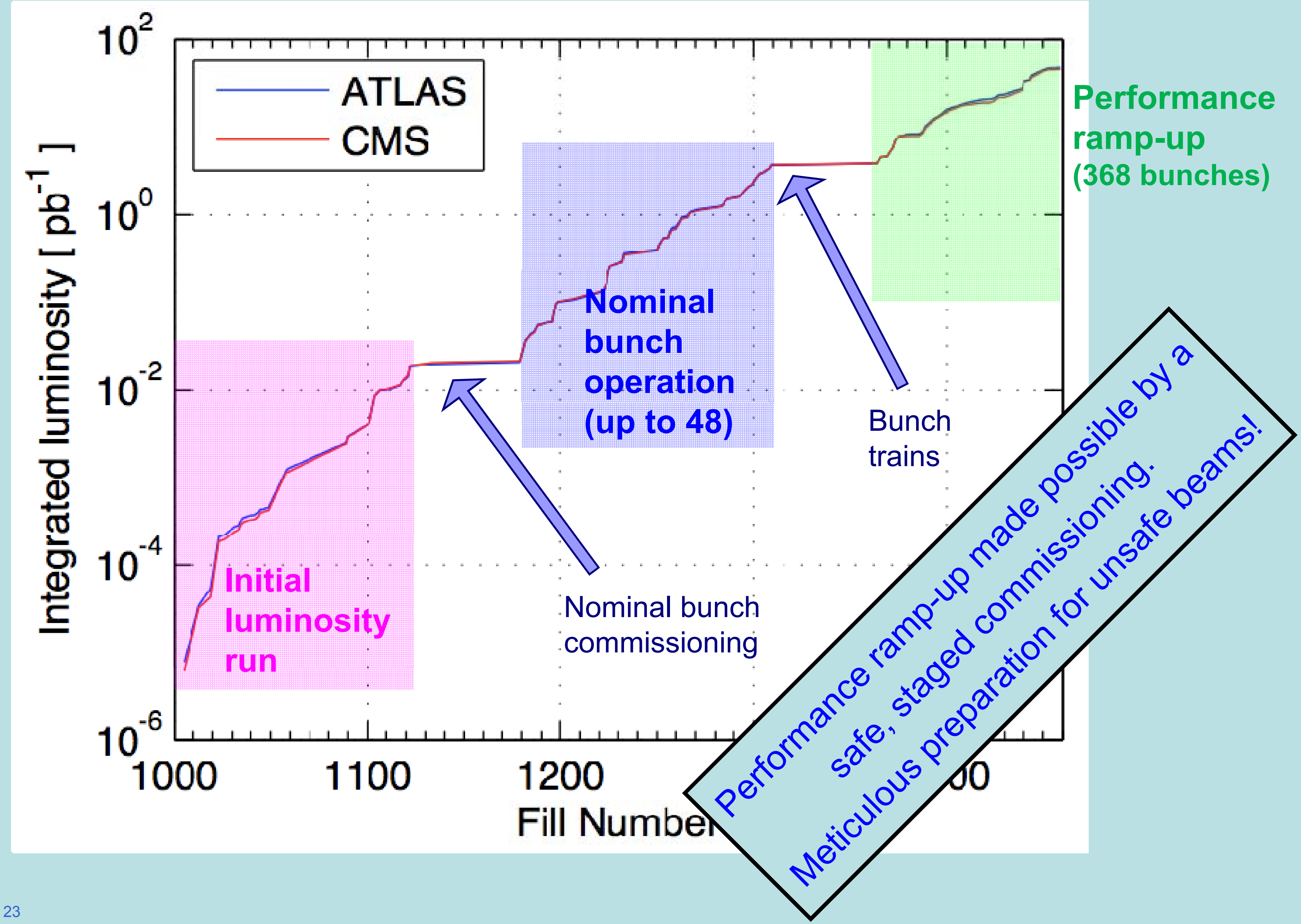
65% availability!

Great achievement for the first year of operation!

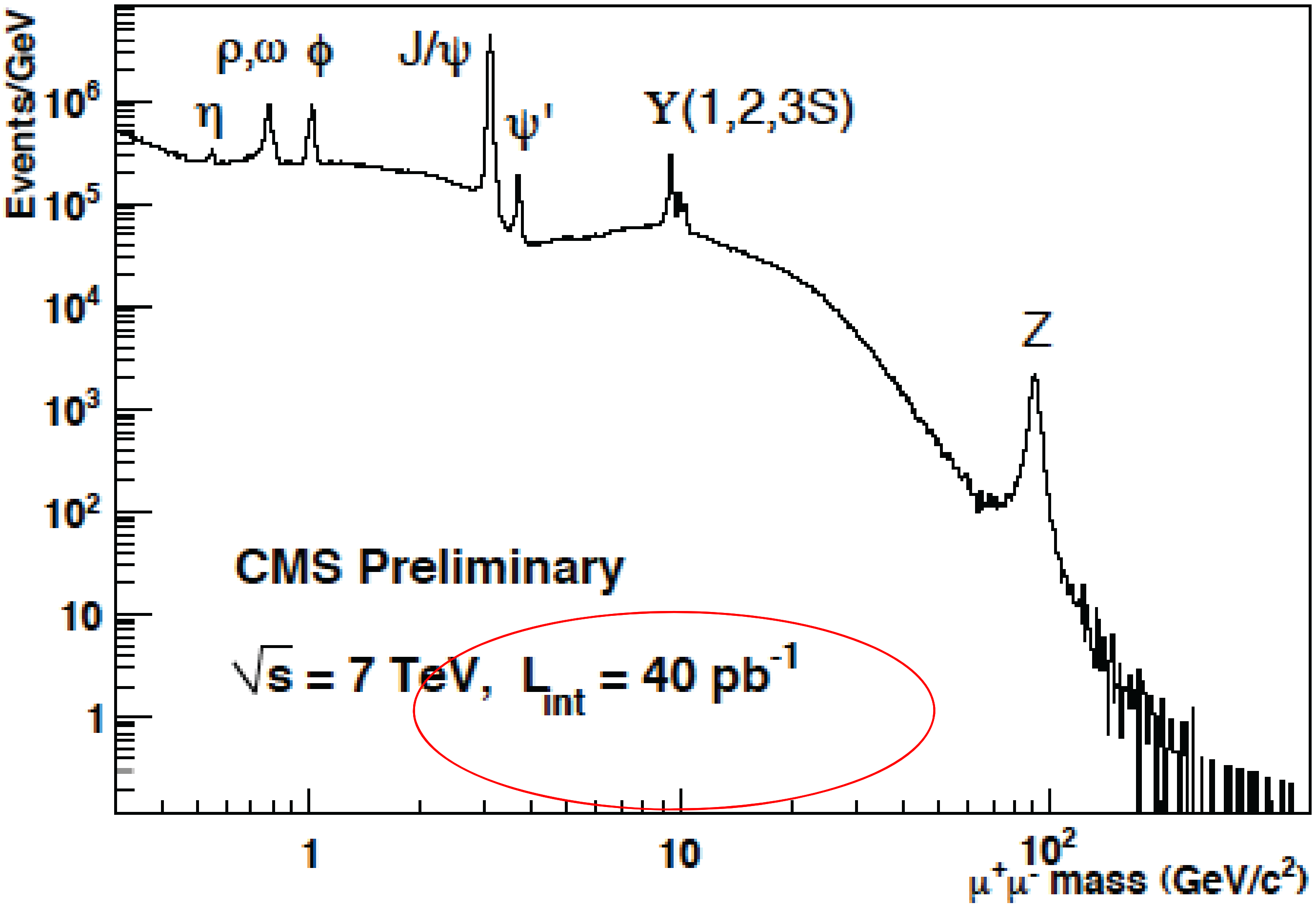
W. Venturini

Luminosity: 3 running periods

2010



Re-discovered the Standard Model at 7TeV



LHC Strategy

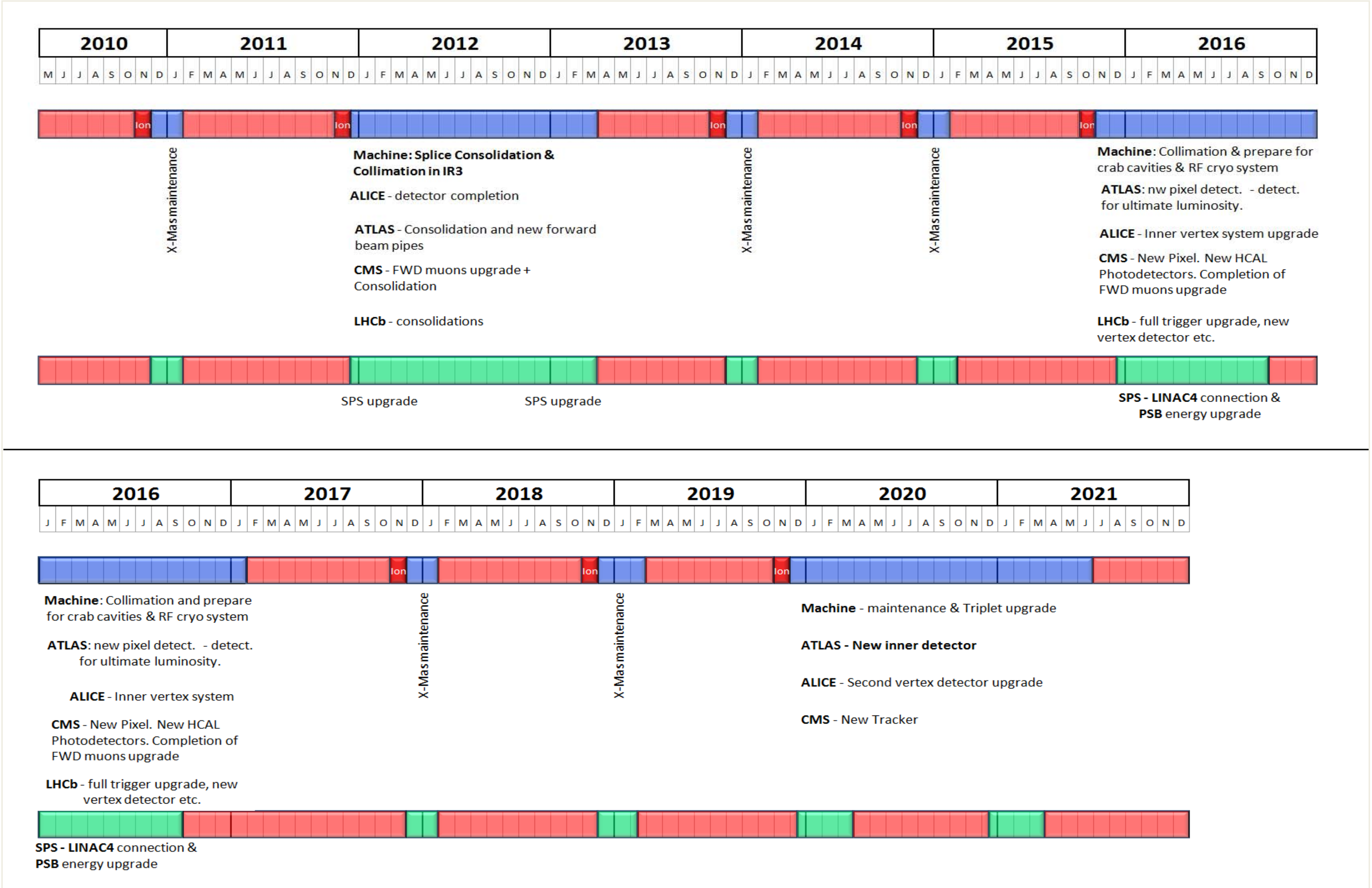
Full exploitation of the LHC physics potential
→ maximize integrated luminosity useful for physics

- LHC operation until around 2030, aim at $\int L dt \approx 3000$/fb

- Between 2010 and ~2020: ~design luminosity (~$10^{34}/cm^2/s$)
  connection of LINAC4 around 2016/17
  detector modifications to optimize data collection

- High Luminosity LHC (HL-LHC) from ~2020 to ~2030
  luminosity around $5 \times 10^{34}/cm^2/s$, luminosity leveling
  new Inner Triplet around 2020/21 (combine both phases)
  detector upgrades around 2020/21 → R&D NOW

The 10 year technical Plan before Chamonix

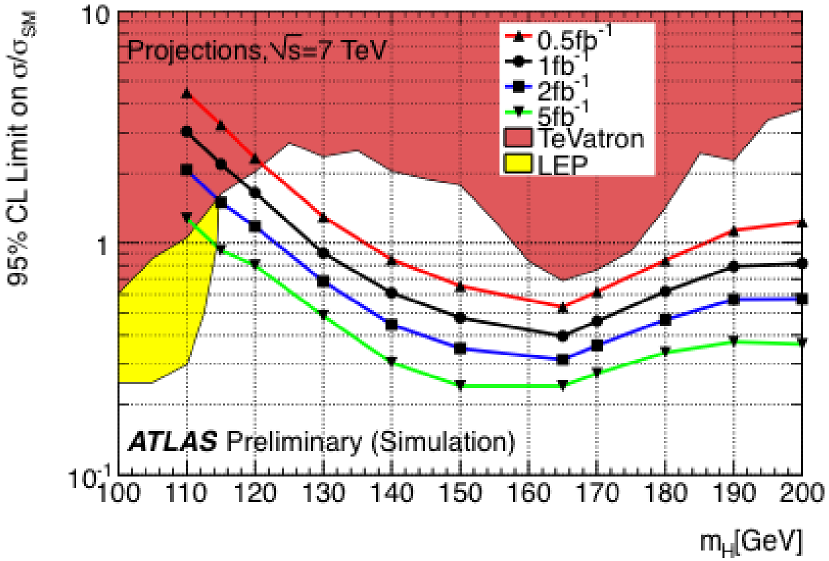


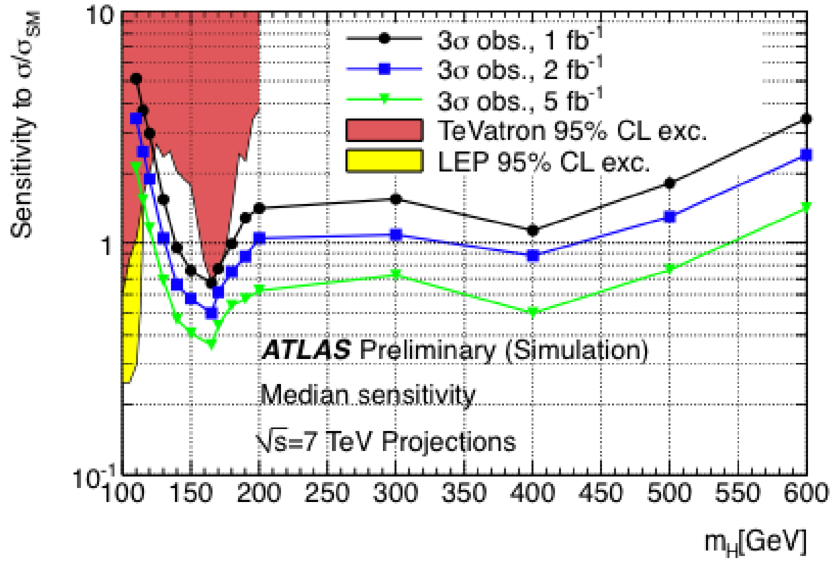
LHC potential performance range

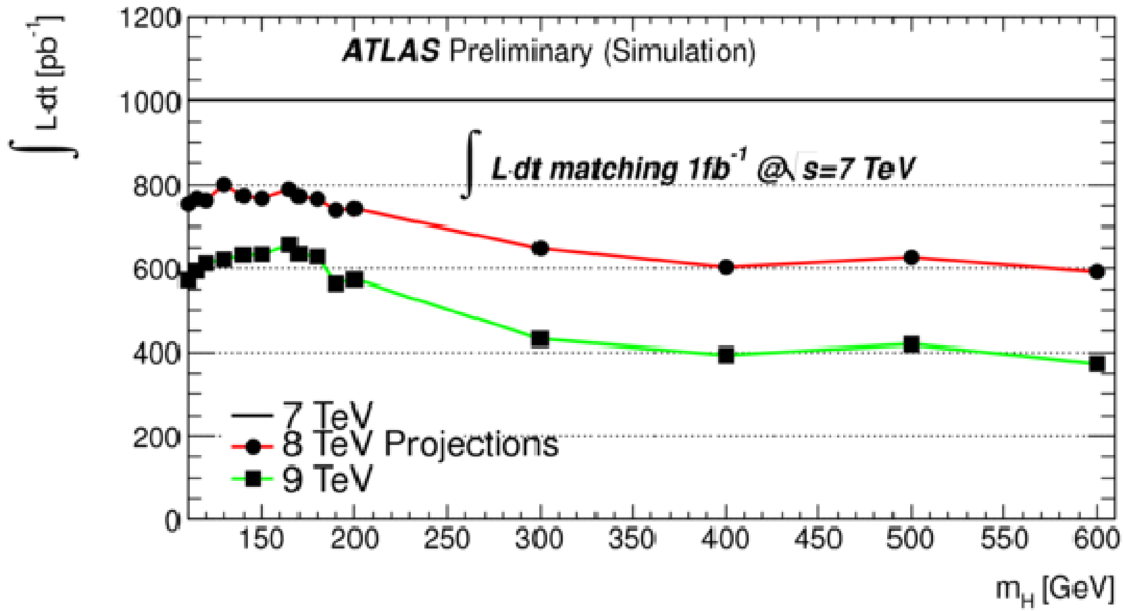
Goal: 1 fb^{-1}

- **Energy: 3.5 TeV to 4 TeV**
  To be discussed at the Chamonix workshop in Jan. 2011.
- **Bunch intensity**
  Baseline 1.2×10^{11} protons, higher possible from injectors.
- **Number of bunches**
  450 to 930 bunches (75 ns spacing): potential **factor 2**.
- **Colliding beam sizes**
  Maintain excellent beams from injectors: **50% smaller** than nominal
  Possible to "squeeze" beams further: another **50% gain**!
- **Peak luminosities in the range of 6 to 16 x 10^{32} $cm^{-2}s^{-1}$ could be possible.**
  At least 3 times more than what we have seen in 2010!
- **Integrated luminosity between 1 and 3 fb^{-1} would appear feasible.**

Higgs sensitivities







Higgs 2011/2012

- Accelerator Chain performed very well in 2010

- Detectors performed very well in 2010

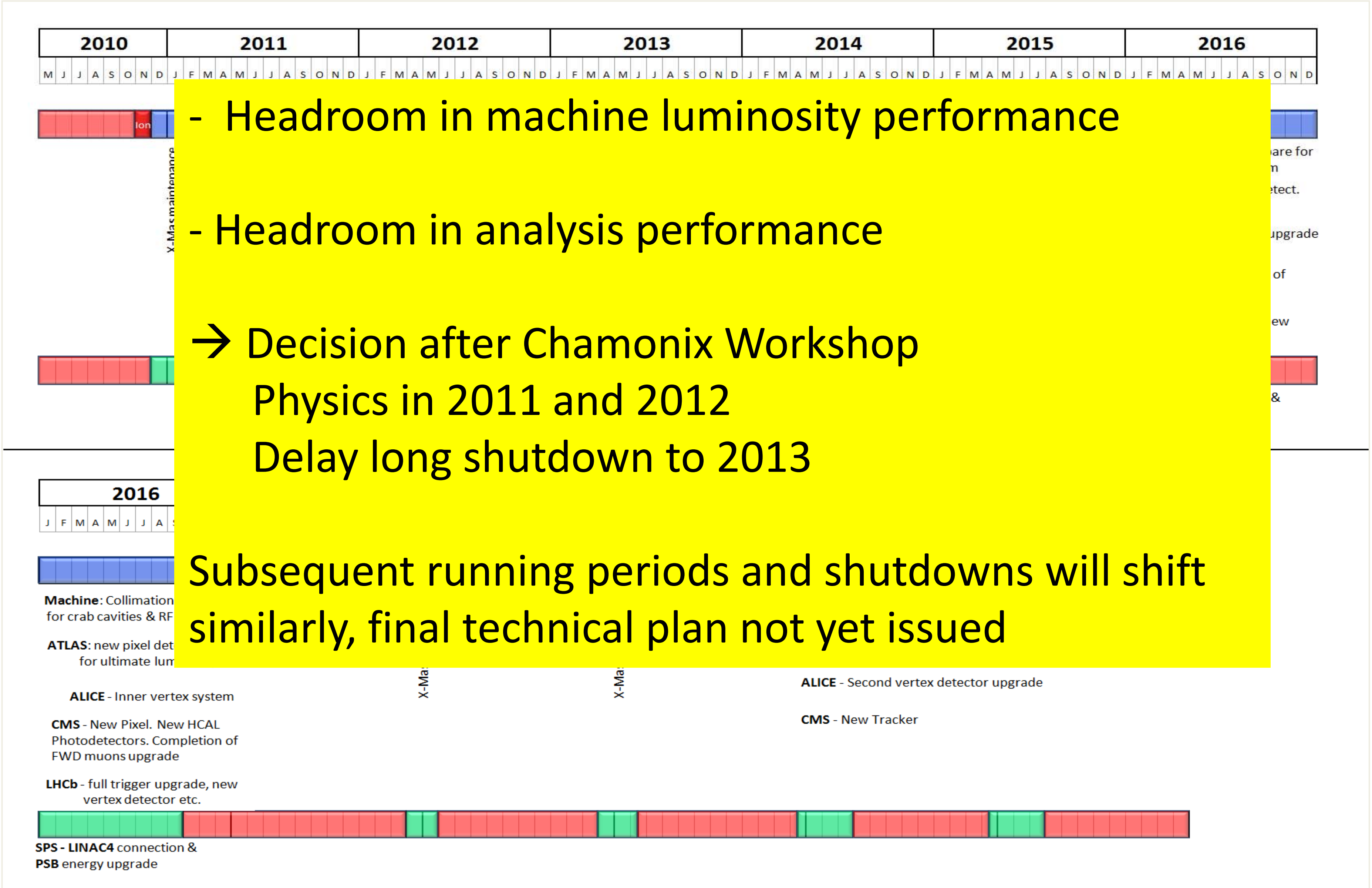
- Headroom in accelerator performance

- Headroom in analysis performance

- Excellent prospects for Higgs-Boson Discovery or Exclusion in 2011/2012

Exciting Prospects: LHC running in 2011 and 2012 at $\sqrt{s}$ = 7 TeV (2011)

The 10 year technical Plan



- Headroom in machine luminosity performance

- Headroom in analysis performance

→ Decision after Chamonix Workshop
Physics in 2011 and 2012
Delay long shutdown to 2013

Subsequent running periods and shutdowns will shift similarly, final technical plan not yet issued


beyond LHC ?

2010-2013: Decisive Years

- Experimental data will take the floor to drive the field to the next steps:

- LHC results
- Θ_{13} (T2K, DChooz, etc..)
- υ masses (Cuore, Gerda, Nemo…)
- Dark Matter searches
- …….

Key Messages

- Need to clear the cloud of TeV-scale physics to obtain clear views
- LHC and HL-LHC with prospects towards 2030
- **Synergy of colliders**
- **LHC results decisive**

Next decades (?)

Road beyond Standard Model

through synergy of

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

lepton - hadron colliders (LHeC??)

lepton - lepton colliders (LC?)

Linear e^+e^- Colliders

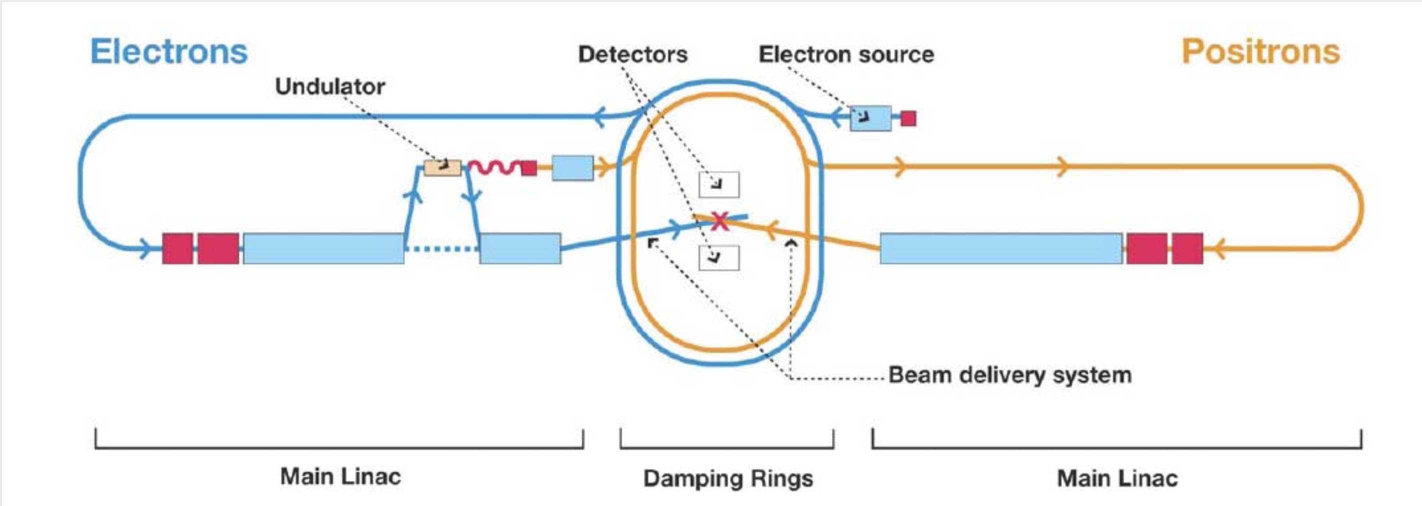
- The machine which will complement and extend the LHC best, and is closest to be realized, is a Linear e^+e^- Collider with a collision energy of at least 500 GeV.

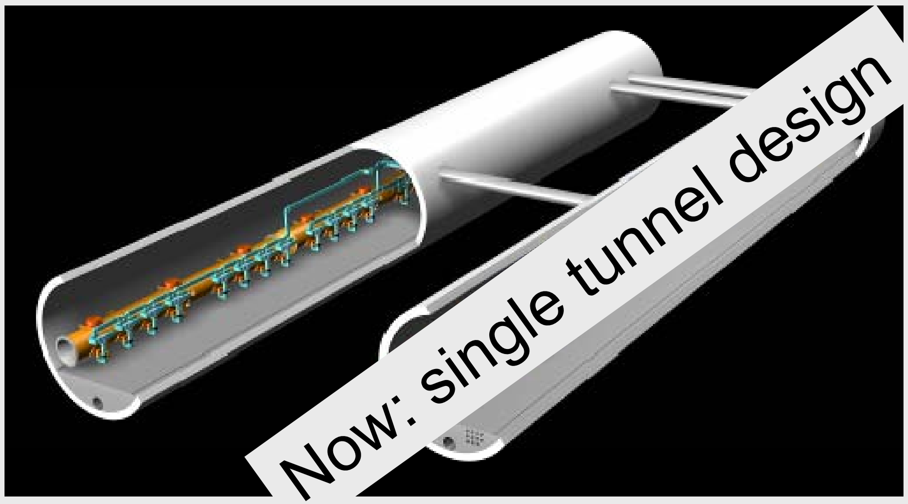
PROJECTS:

⇒ TeV Colliders (CMS energy up to 1 TeV) → Technology ~ready
ILC with superconducting cavities

⇒ Multi-TeV Collider (CMS energies in multi-TeV range) → R&D
CLIC → Two Beam Acceleration

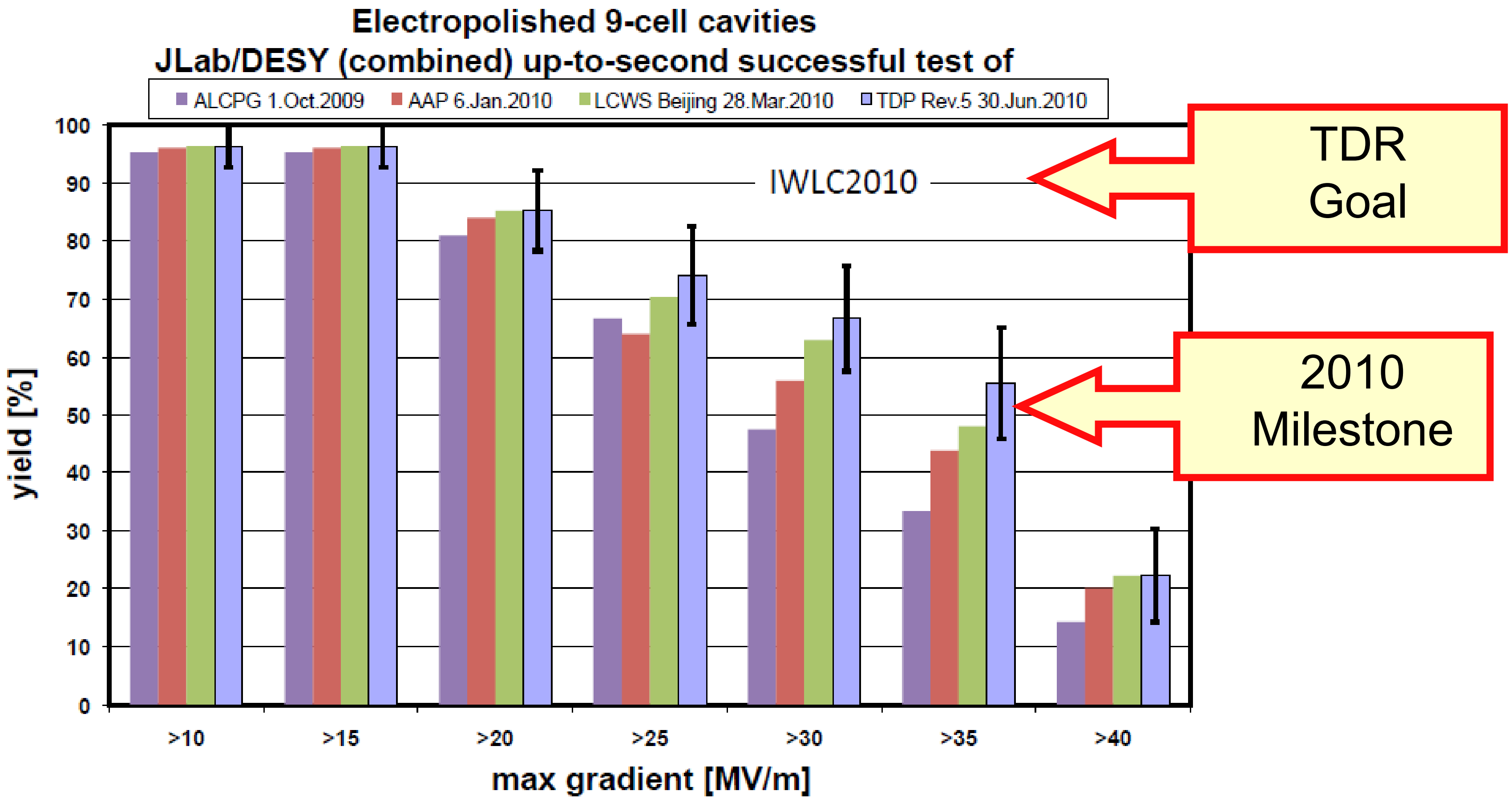
The International Linear Collider



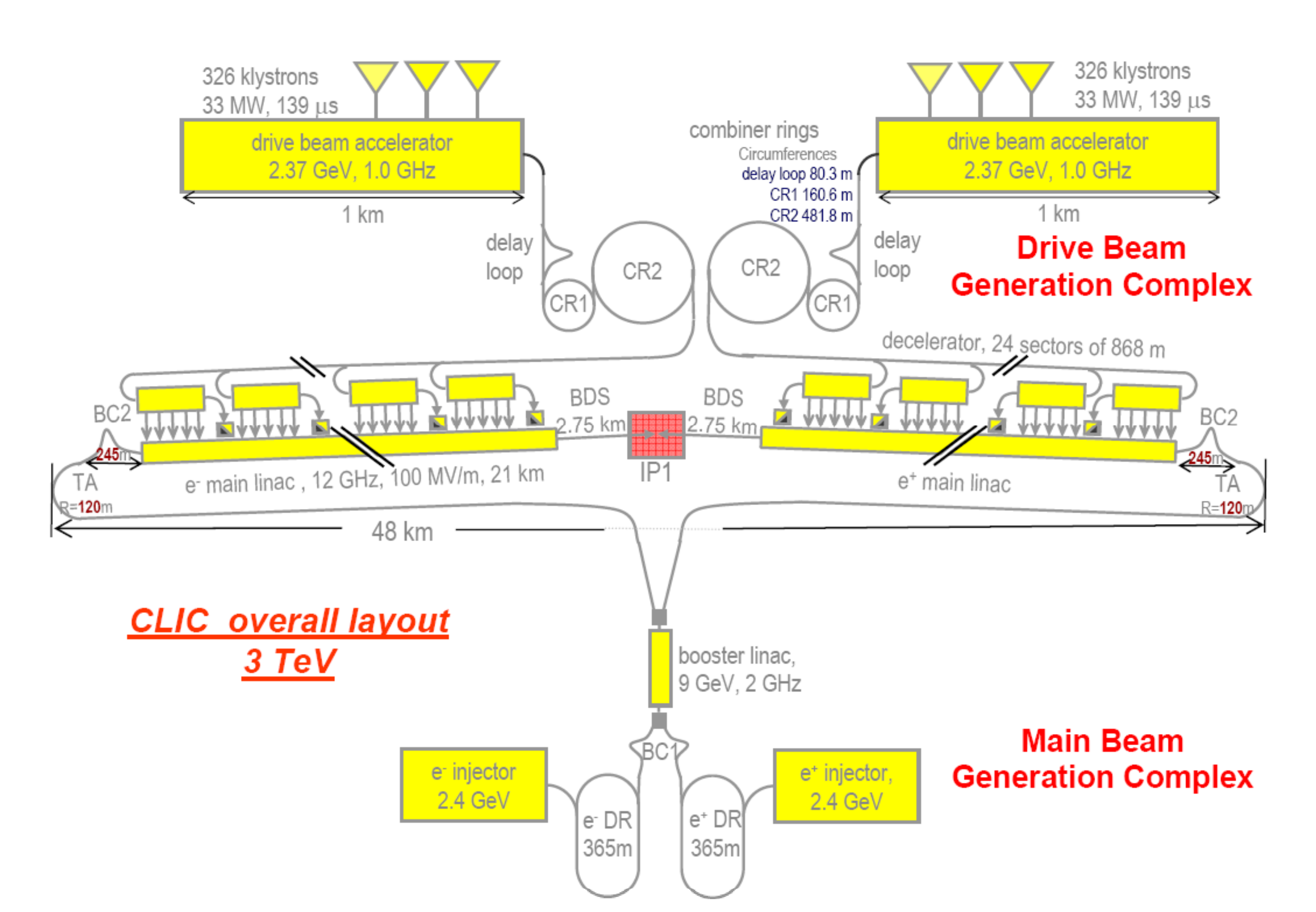


Energy	250 Gev x 250 GeV
# of RF Units	560
# of Cryomodules	1680
# of 9-cell Cavities	14560
Accelerating Gradient	31.5 MeV/m
Peak luminosity	2 10^{34} $cm^{-2}s^{-1}$
Rep. Rate	5 Hz
IP	σ_x 350 – 620 nm; σ_y 3.5 – 9.0 nm
Total Power	~230 MW
2 Detectors Push-pull	

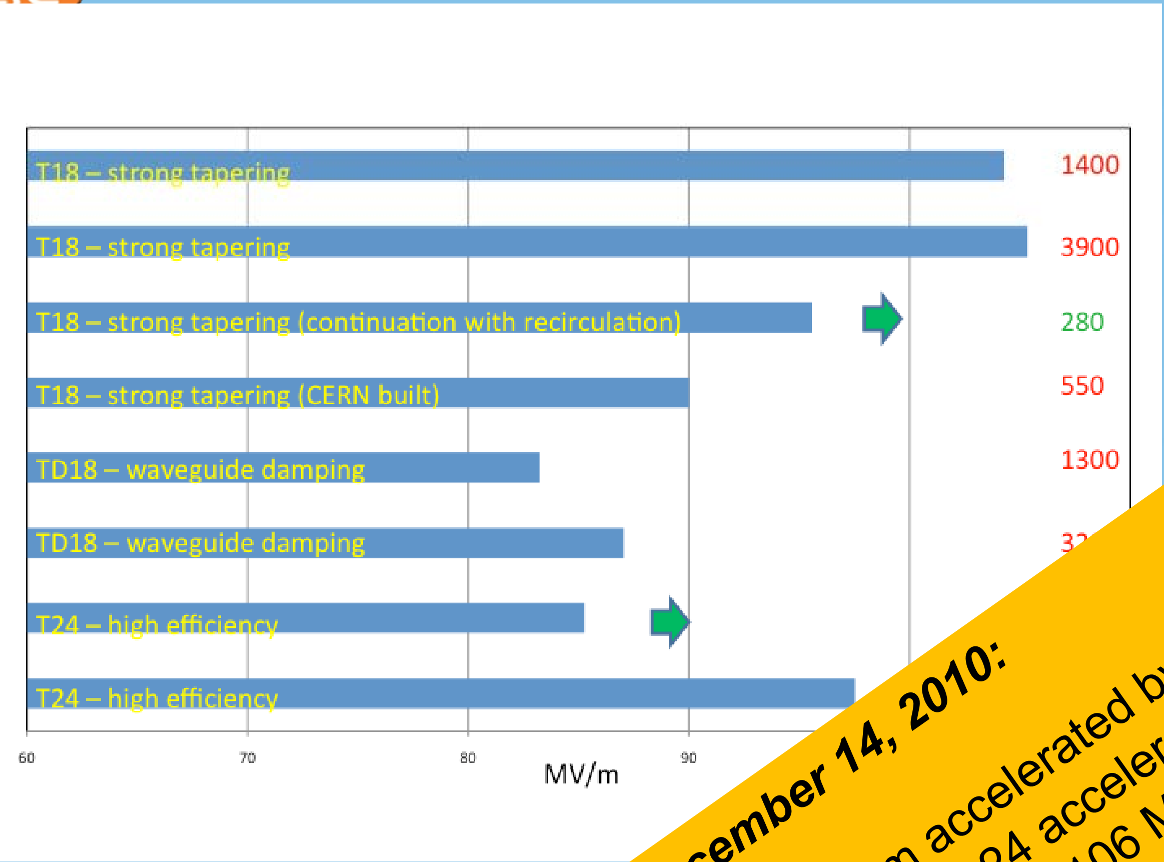
Cavity Gradient Milestone Achieved

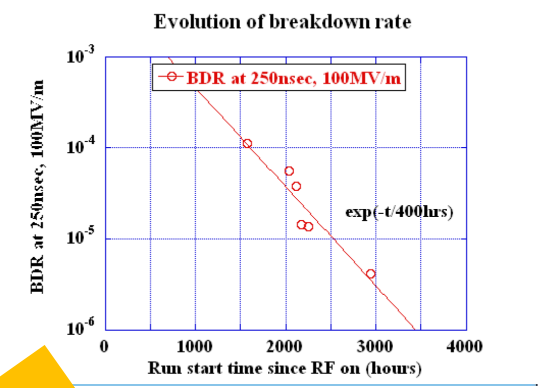


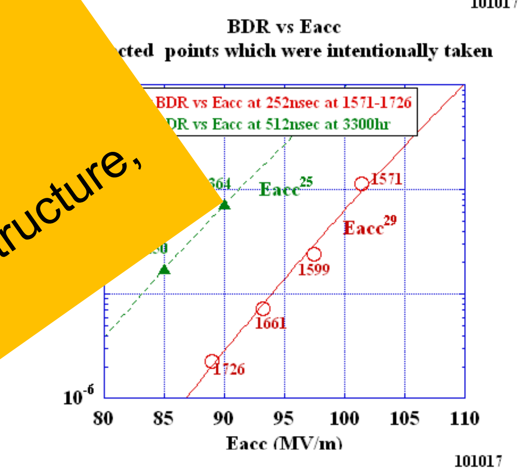
CLIC Overall Lay-out

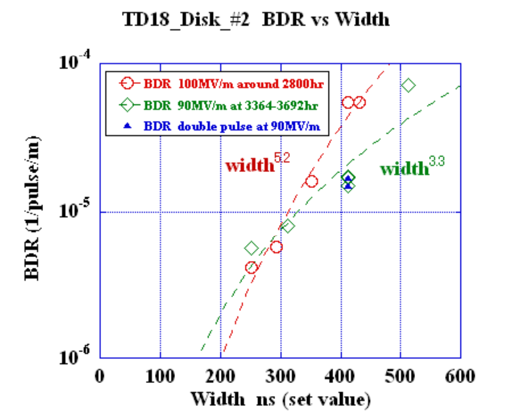


Gradient at CLIC $4*10^{-7}$ BDR and 180 ns pulse length









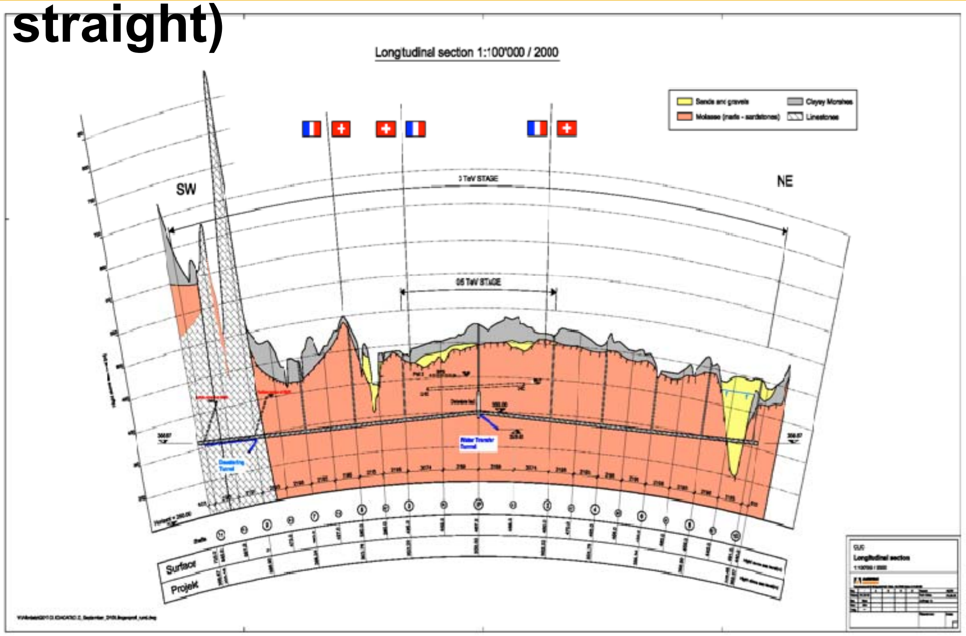
T18 and TD18 built and tested at SLAC and KEK

- real prototypes with improved design are T24 and TD24
- measurements in plot on the right for TD18 at KEK

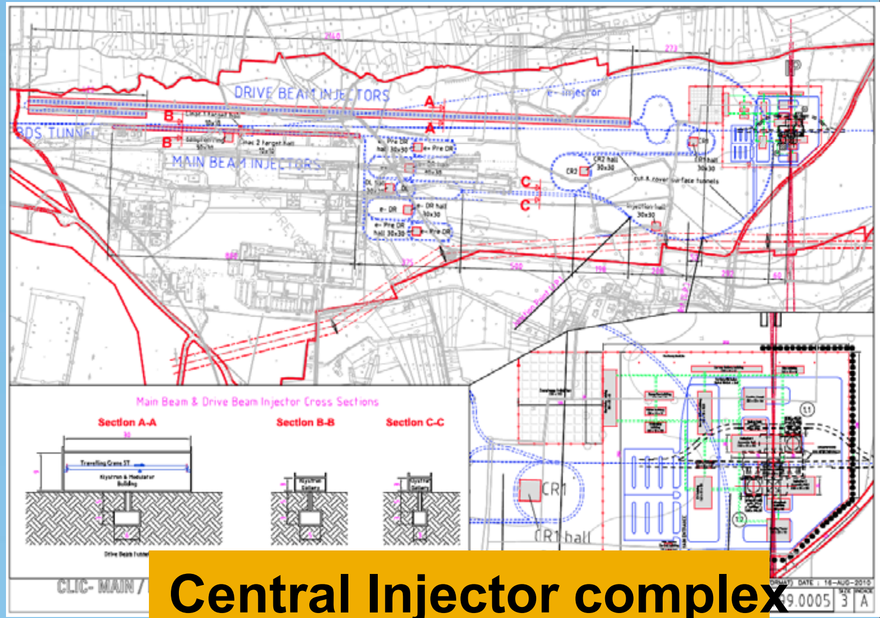
December 14, 2010:

Probe beam accelerated by 23 MV in a TD24 accelerating structure, corresponding to 106 MV/m.

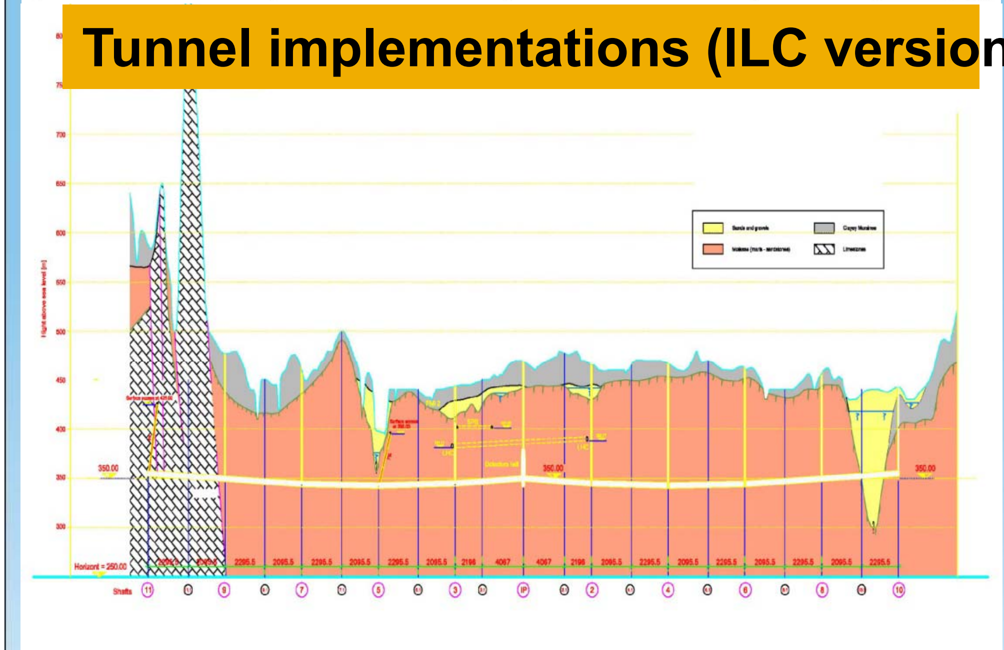
Tunnel implementations (laser straight)



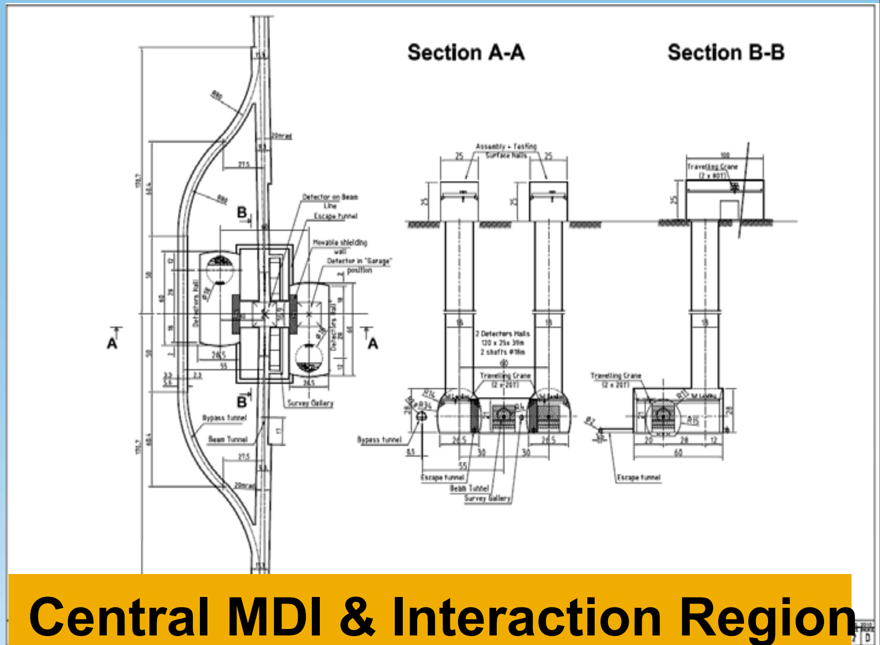
Central Injector complex



Tunnel implementations (ILC version)



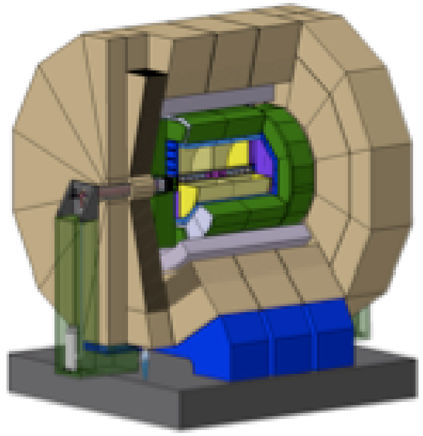
Central MDI & Interaction Region



Validated ILC concept

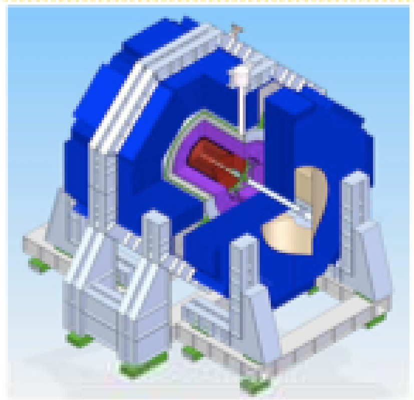
ILD: International Large Detector

"Large" : tracker radius 1.8m
B-field : 3.5 T
Tracker : TPC + Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



SiD: Silicon Detector

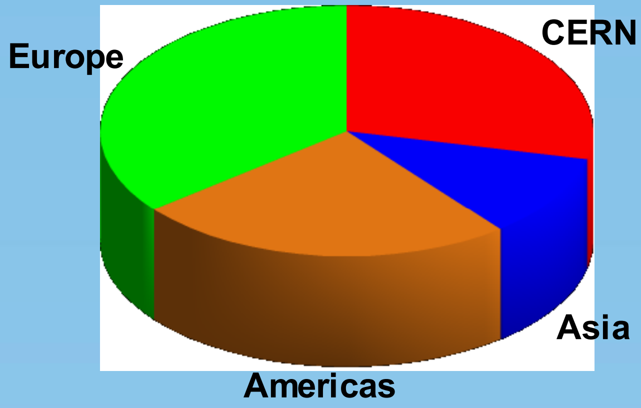
"Small" : tracker radius 1.2m
B-field : 5 T
Tracker : Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



CLIC detector concepts will be based on SiD and ILD.
Modified to meet CLIC requirements

Linear Collider Detector project @ CERN

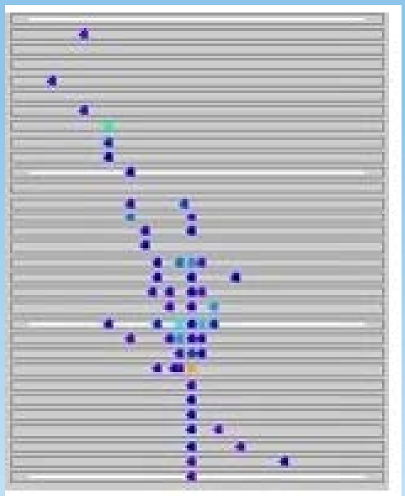
LCD: addressing physics and detectors at CLIC and ILC



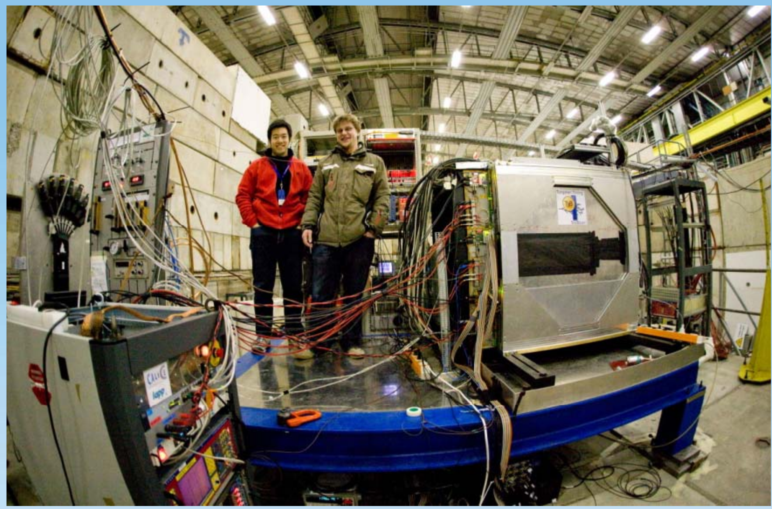
Affiliation of CLIC CDR editors

Current focus:
Preparation of conceptual design report for CLIC detectors => developed into a truly international effort in 2010

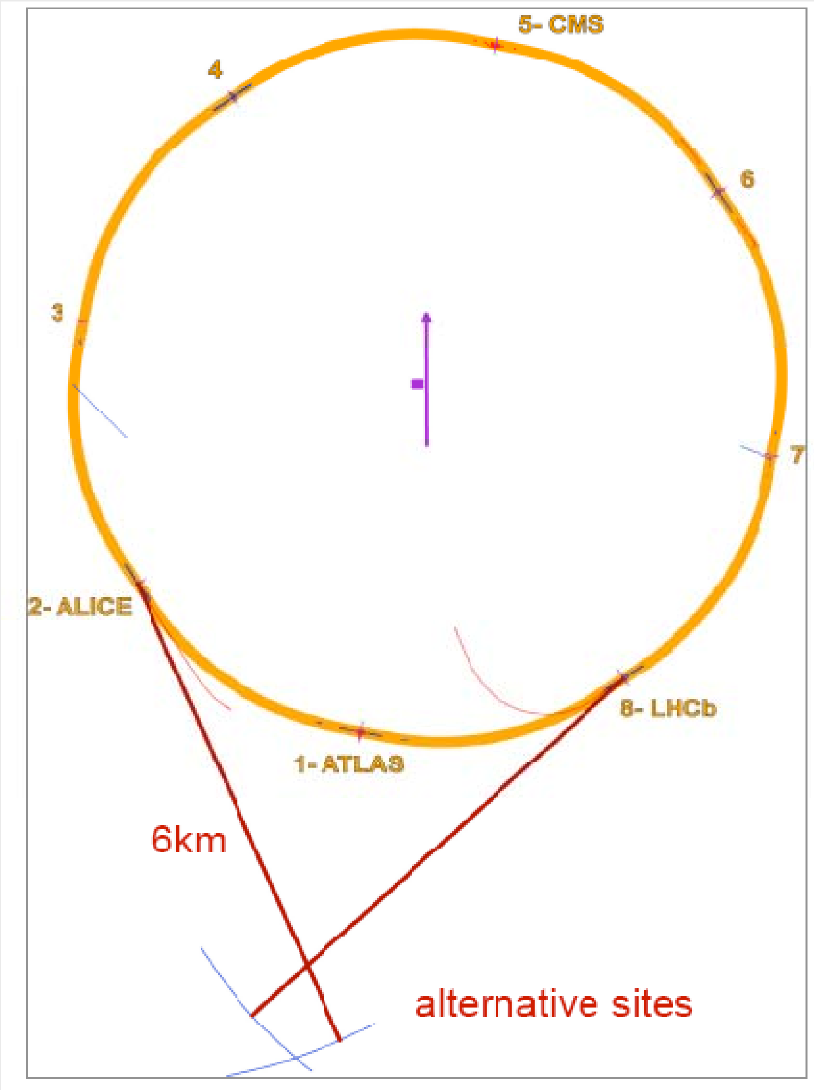
Experimental issues for a CLIC experiment now well understood, and detector geometries for the CLIC benchmark studies were fixed



Beam test with a tungsten-based HCAL for linear collider, CALICE collaboration



Large Hadron electron Collider: possible layouts



40 - 140 GeV
on
1 - 7 TeV

ring-ring solution:
$L \leq 10^{33}$

linac-ring solution:
L few 10^{31} (?)

Would be the successor of HERA at higher cms

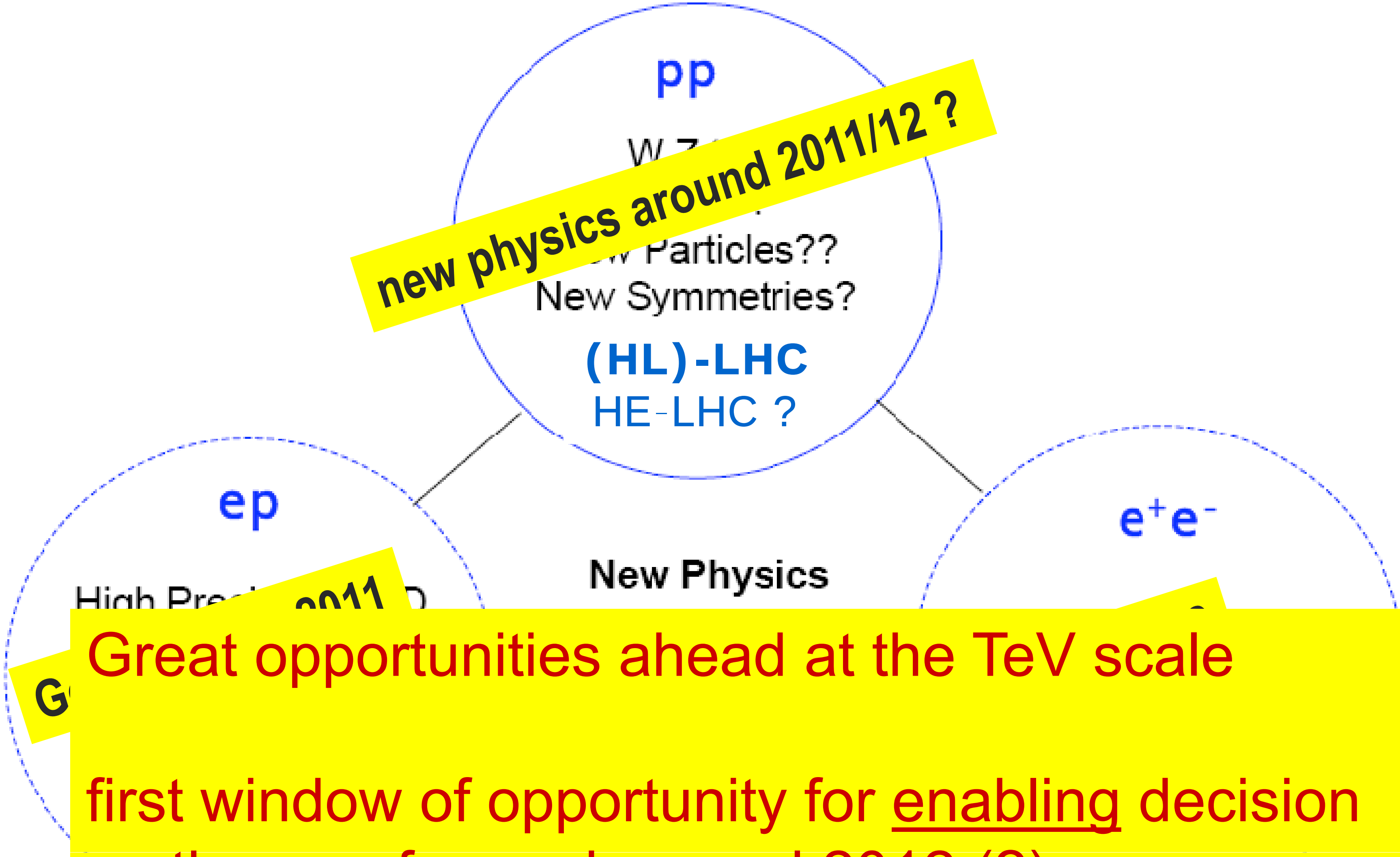
Key Messages

- Need to clear the cloud of TeV-scale physics to obtain clear views
- LHC and HL-LHC with prospects towards 2030
- **Synergy of colliders**
- **LHC results decisive**

- ILC could be constructed now
- CLIC more R&D needed
- Converge towards one LC project

- Detector R&D mandatory for all projects

The TeV Scale (far) beyond 2010



Great opportunities ahead at the TeV scale

first window of opportunity for <u>enabling</u> decision on the way forward around 2012 (?)

Results from LHC will guide the way

Expect

- period for decision enabling on next steps earliest 2012 (at least) concerning energy frontier
- (similar situation concerning neutrino sector Θ_{13})

We are NOW in a new exciting era of accelerator planning-design-construction-running

and need

- intensified efforts on R&D and technical design work to enable these decisions
- global collaboration and stability on long time scales (don't forget: first workshop on LHC was 1984)

→ more coordination and more collaboration required

Opening the door…

- Council opened the door to greater integration in particle physics when it recently unanimously adopted the recommendations to examine the role of CERN in the light of increasing globalization in particle physics.
  - *Particle physics is becoming increasingly integrated at the global level.*
  - *Council's decision contributes to creating the conditions that will enable CERN to play a full role in any future facility wherever in the world it might be.*

- The key points agreed by Council include:
  - *All states shall be eligible for Membership, irrespective of their geographical location;*
  - *A new Associate Membership status is to be introduced to allow non-Member States to establish or intensify their institutional links with CERN;*
  - *Participation of CERN in global projects wherever sited.*

- **Romania** is in accession to Membership
- Applications for Membership from **Cyprus, Israel, Serbia, Slovenia and Turkey** have already been received by the CERN Council.

We need to define the most appropriate organizational form for global projects NOW and need to be open and inventive (scientists, funding agencies, politicians. . .)

Mandatory to have accelerator laboratories in all regions as partners in accelerator development / construction / commissiong / exploitation

Planning and execution of HEP projects today need global partnership for *global, regional and national* projects

in other words: for the whole program

Use the exciting times ahead to establish such a partnership

Particle Physics can and should play its role as spearhead in innovations as in the past

now and in future