CERN

История и вклад в физику

CERN

Conseil Europèenne pour la Recherche Nuclèaire

Впервые идея создания общеевропейского центра физики частиц была публично высказана Луи де Бройлем в 1949 г.

“ … a laboratory or institution where it would be possible to do scientific work, but somehow beyond the framework of the different participating states.

… this body could be endowed with more resources than national laboratories and could, consequently, undertake tasks… beyond their scope…”

Collaboration could be easier due to the “true nature of science”

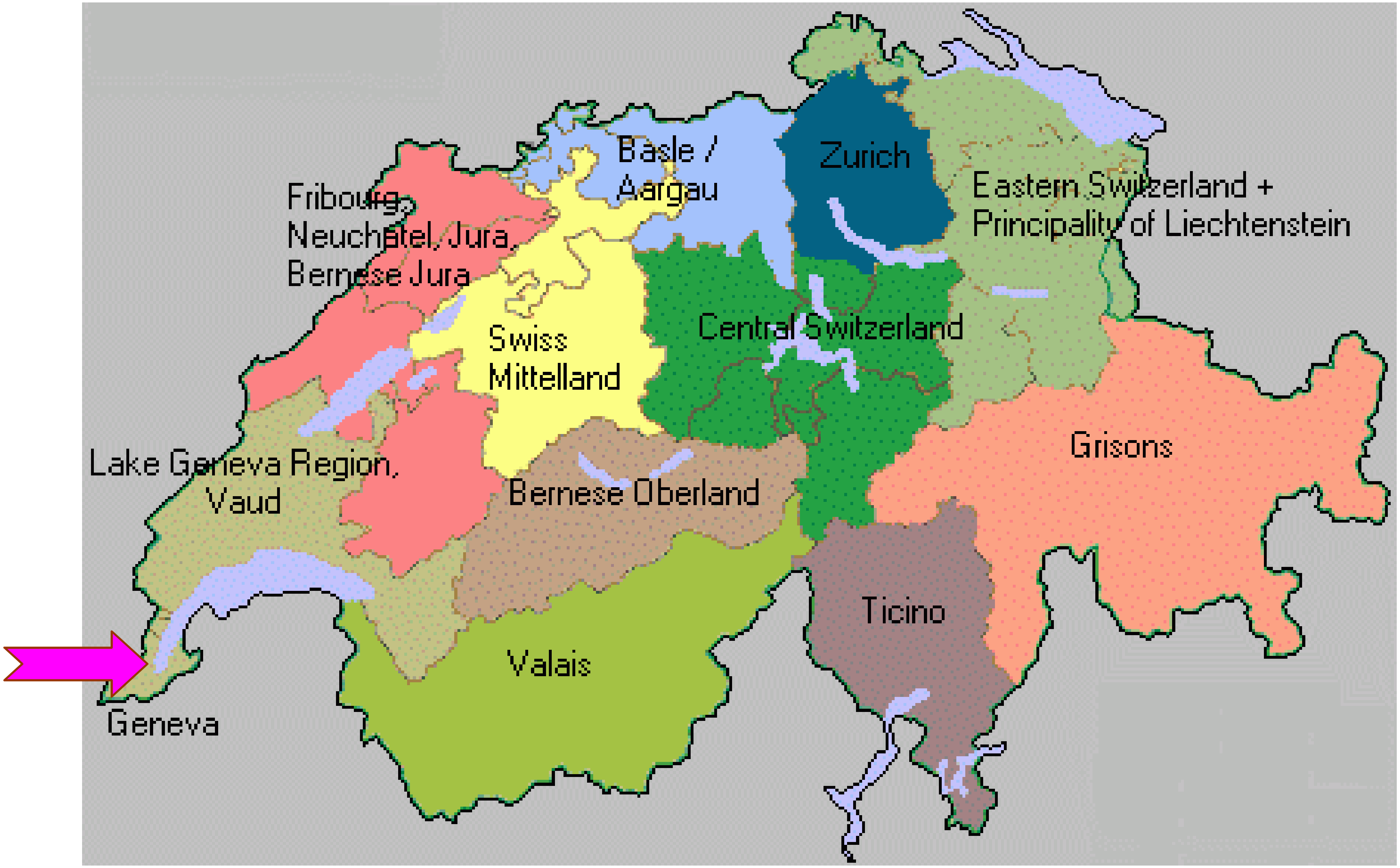
This kind of cooperation would serve also other disciplines

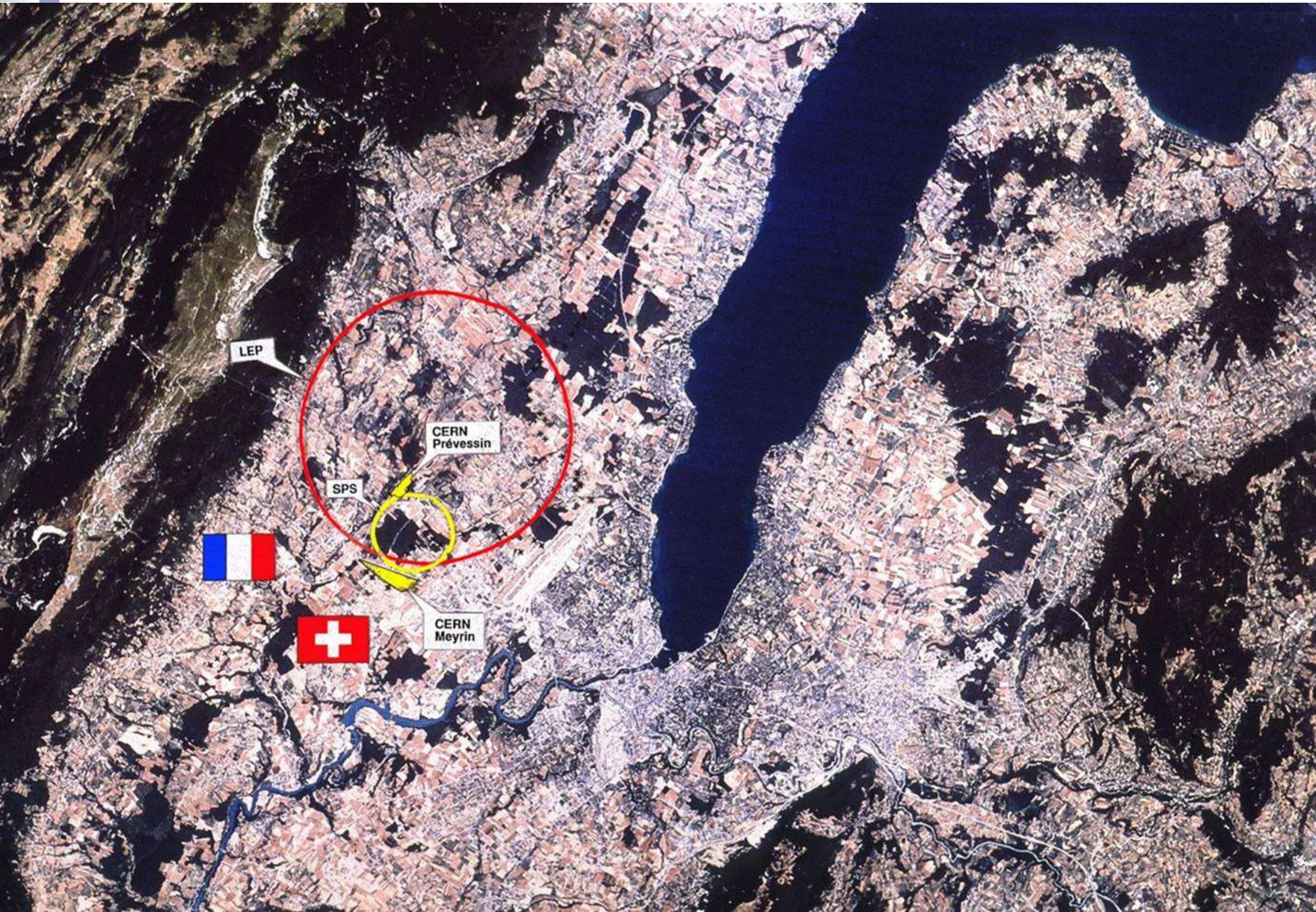
1. Австрия (1959)
2. Бельгия (1953)
3. Болгария (1999)
4. Чехия (1993)
5. Дания (1953)
6. Финляндия (1991)
7. Франция (1953)
8. Германия (1953)
9. Греция (1953)
10. Венгрия (1992)
11. Италия (1953)
12. Голландия (1953)
13. Норвегия (1953)
14. Польша (1991)
15. Португалия (1986)
16. Словакия (1993)
17. Испания (1961)
18. Швеция (1953)
19. Швейцария (1953)
20. Англия (1953)

История формирования CERN

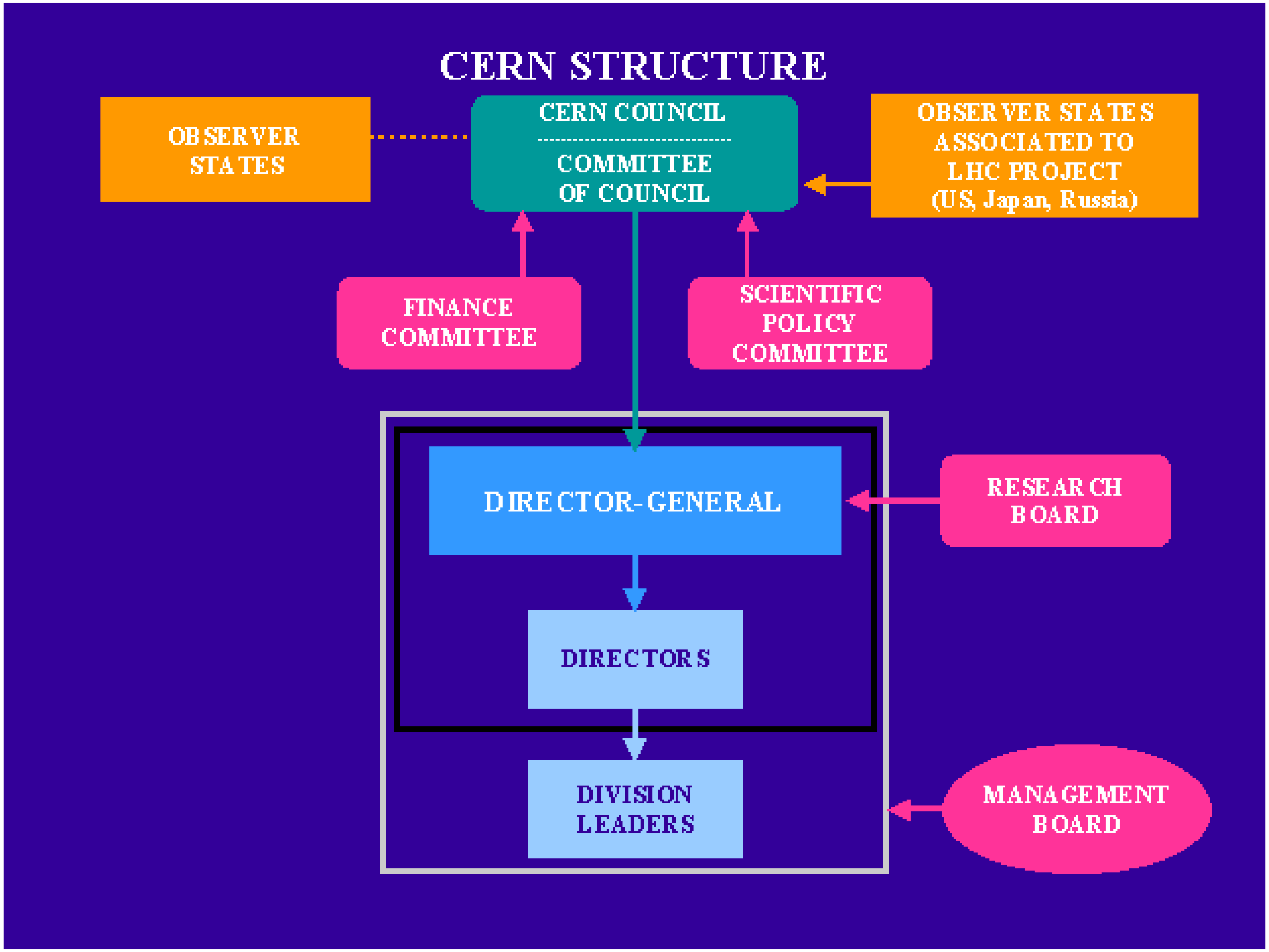
1. Англия (1953)
2. Бельгия (1953)
3. Германия (1953)
4. Греция (1953)
5. Голландия (1953)
6. Дания (1953)
7. Италия (1953)
8. Норвегия (1953)
9. Франция (1953)
10. Швеция (1953)
11. Швейцария (1953)

1. Австрия (1959)
2. Испания (1961)
3. Португалия (1986)
4. Финляндия (1991)
5. Польша (1991)
6. Венгрия (1992)
7. Словакия (1993)
8. Чехия (1993)
9. Болгария (1999)

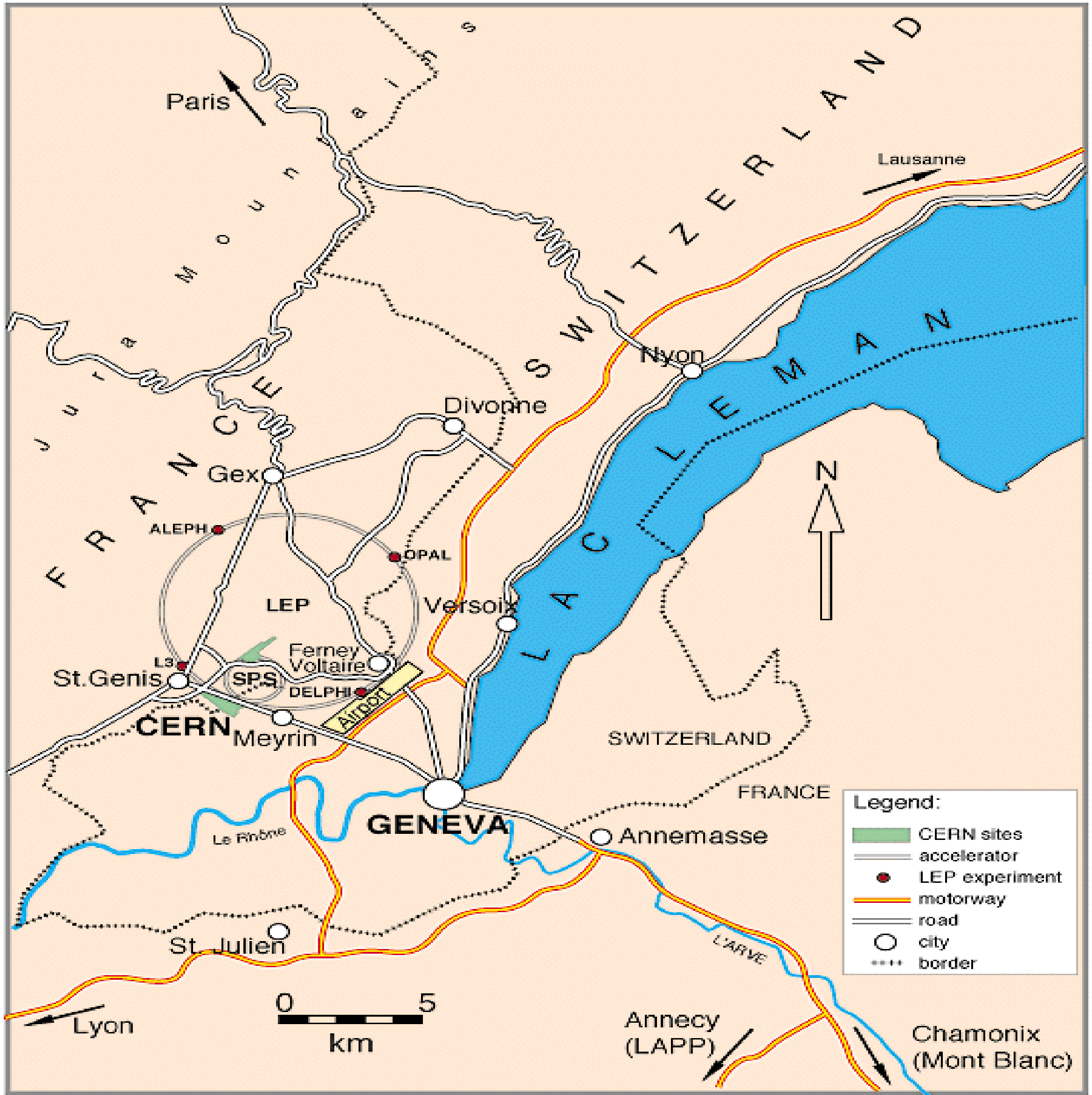

Basle /
Aargau
Zurich
Fribourg,
Neuchâtel, Jura,
Bernese Jura
Eastern Switzerland +
Principality of Liechtenstein
Swiss
Mittelland
Central Switzerland
Grisons
Lake Geneva Region,
Vaud
Bernese Oberland
Ticino
Valais
Geneva


LEP
CERN
Prévessin
SPS
CERN
Meyrin

Организационная структура CERN

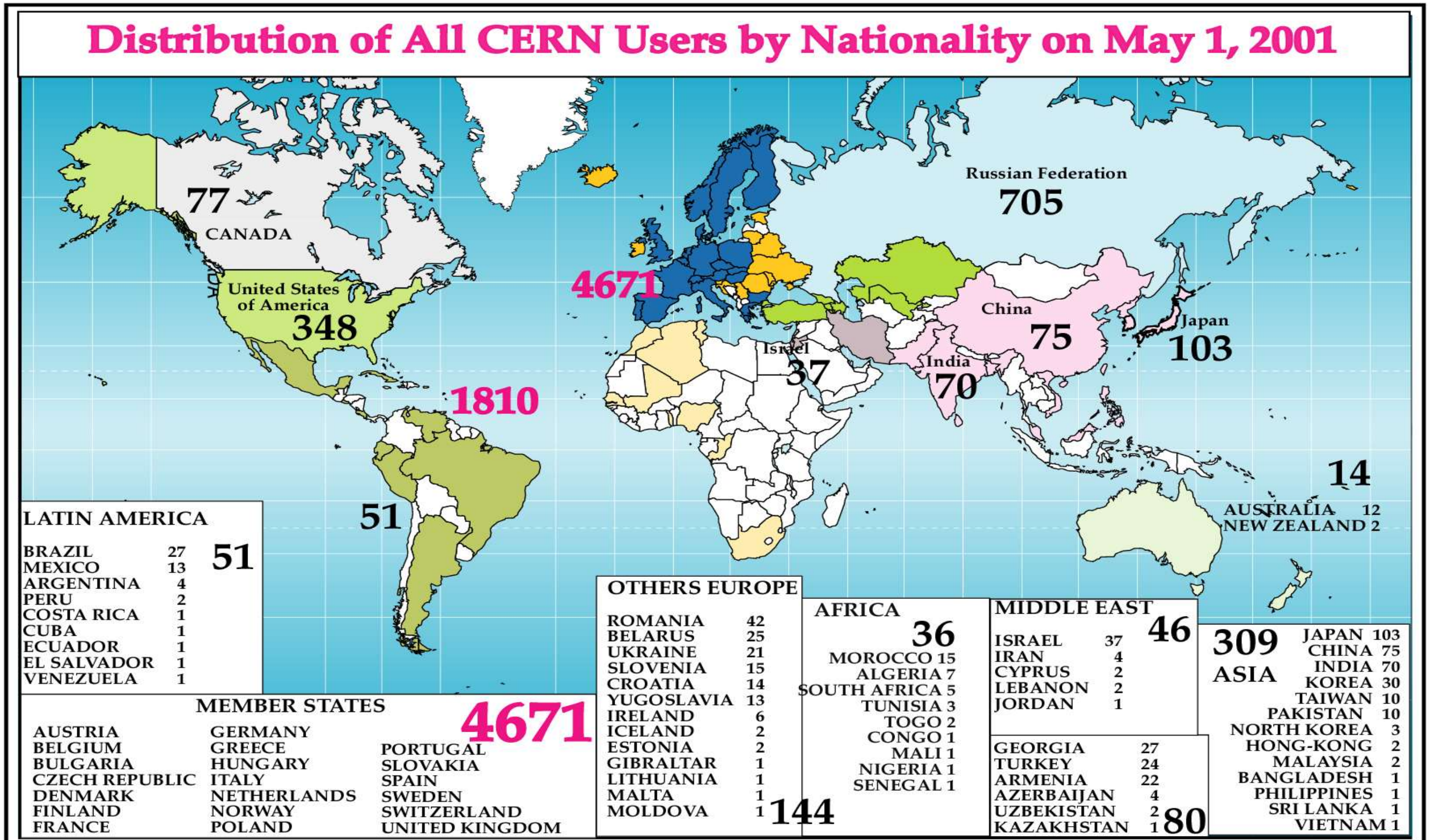


CERN – маленький город



CERN - маленький город

Зарегистрированные участники научных программ CERN.



Поля/силы в Природе

- **Известны 4 типа полей/сил:**

1. **Гравитационное**
2. **Электромагнитное (ЭМ → КЭД)**
3. **Слабое**
4. **Сильное**

Естественное стремление науки – понять природу и построить теорию единообразно описывающую все поля.

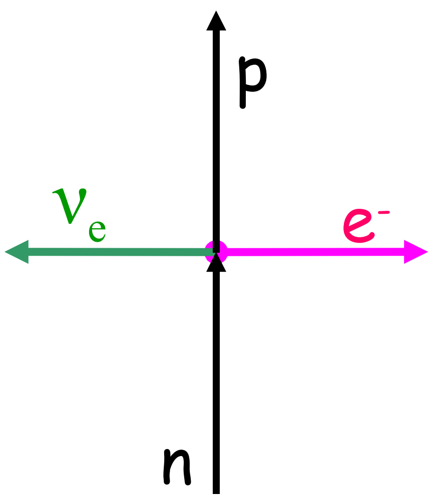
Основные характеристики полей/сил

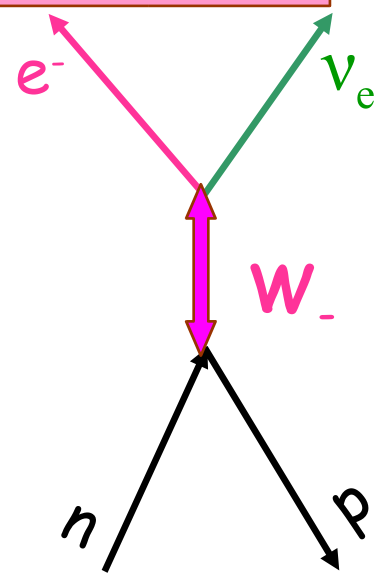
Характеристики взаимодействия	Гравитация	Слабое	ЭМ	Сильное
Порядок константы взаимодействия	10^{-38}	10^{-6}	10^{-3}	1
Радиус	∞	10^{-16}	∞	10^{-13}
$M_{\text{переносчика}}$ Gev	0	W,Z ~ 100	0	П ~ 0,1
Универсальность	All	All	All	Hadrons

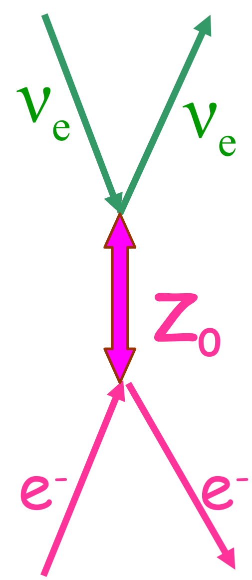
Диаграммы взаимодействий

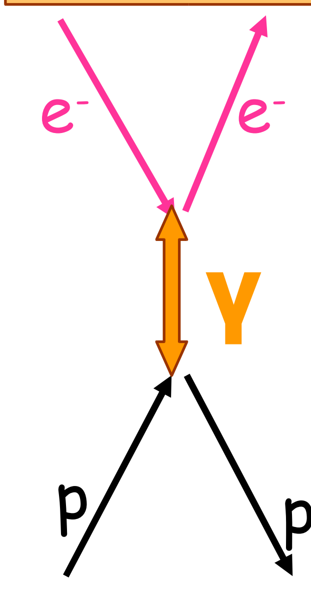
Слабое взаимодействие

Четырехфермионное вз-ие Ферми	Заряженный ток	Нейтральный ток	Эл.-Магн.
$n \rightarrow p + e^- + \nu_e$	$n \rightarrow p + e^- + \nu_e$	$\nu_e + e^- \rightarrow \nu_e + e^-$	$p + e^- \rightarrow p + e^-$









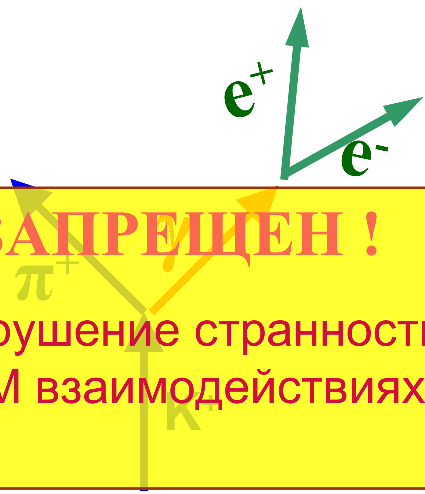
История становления теории (электро)слабых взаимодействий.

- Самое «молодое» из известных 4 типов взаимодействия – слабое (распад ядер- Беккерель 1896г.)
- Первая теор.модель – четырехфермионное взаимодействие (Э.Ферми). Точечное взаимодействие. Хорошо описывало первые экс.данные, НО:
  - – почему в отличии от ЭМ и сильного – точечное?
  - – как описывать иные кроме β распадов нейтрона и протона процессы ?
- Если допустить обменную природу сл.вз-ия, то наряду с заряженным переносчиком (W±) должен существовать и нейтральный (Z_0). Кроме того эти переносчики должны быть «тяжелыми» (~ 100 GeV)
- НО проанализировав имеющиеся экс.данные обнаружили, что процессы за счет нейтрального тока никогда не наблюдались !

История становления теории (электро)слабых взаимодействий.

- Для прямого поиска W и Z нужны ускорители с E_{cm}>100 GeV, которых в это время ещё не существовало (~1970г.)
- Поэтому единственная возможность состояла в поисках «косвенных» проявлений – поисков процессов, идущих за счет слабых токов (НСТ). Основная эксп. проблема – универсальность ЭМ и слабых вз-ий вследствие чего – подавляющий фон от ЭМ процессов, константа взаимодействия которых на 3 порядка больше.
- Одна из возможностей – поиск НСТ в процессах распадов, запрещенных за счет ЭМ взаимодействия. К этому времени были обнаружены «странные» частицы (К-мезоны), которые рождались только парами, что является веским признаком проявления ещё одного квантового числа (странности; S-strange), присущего этим частицам.
- Это квантовое число строго сохранялось для ЭМ и сильных вз-ий, но могло нарушаться в слабых.

Поиски распада $K^+ \to \pi^+ + e^+ + e^-$

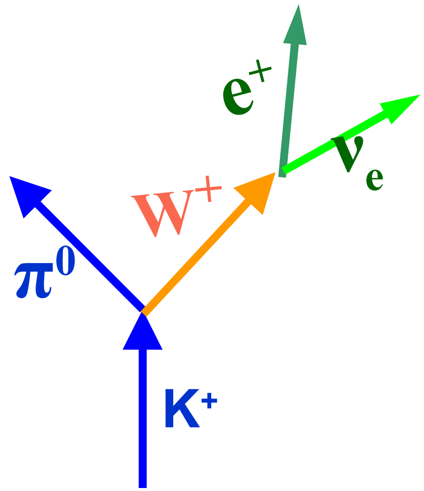


ЗАПРЕЩЕН !

(Нарушение странности в ЭМ взаимодействиях)

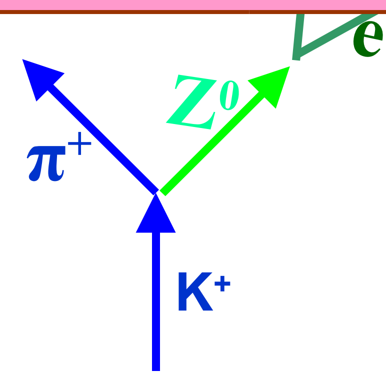
Эл.Магн.

$K_{e3} \sim 4,8\ \%$



Слаб. Заряж. ток

Не обнаружен на уровне 10^{-5} !?

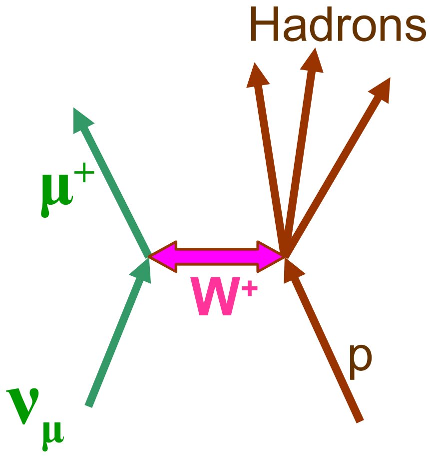


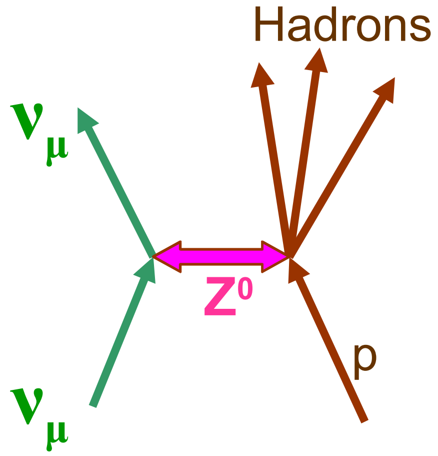
Слаб. Нейтр.ток

История становления теории (электро)слабых взаимодействий.

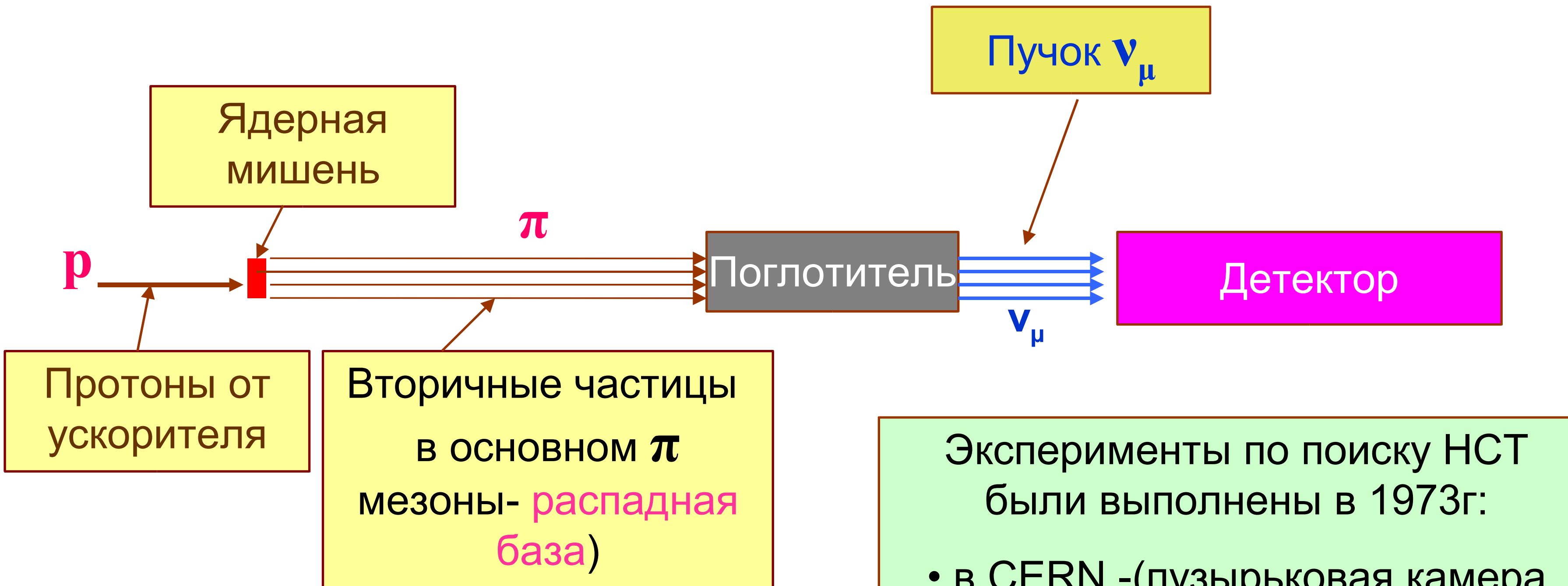
- Оставалась последняя надежда – поиск процессов НСТ во взаимодействии частиц обладающих только слабым взаимодействием (нейтрино ν)

Взаимодействие нейтрино с веществом (адронами)





Как получают нейтрино на ускорителях



$$p + A \rightarrow \pi + X$$

$$\pi \rightarrow \mu + \nu_\mu$$

Эксперименты по поиску НСТ были выполнены в 1973г:

- в CERN -(пузырьковая камера GARGAMEL) и
- FNAL – (нейтринный детектор)

Схема нейтринного детектора

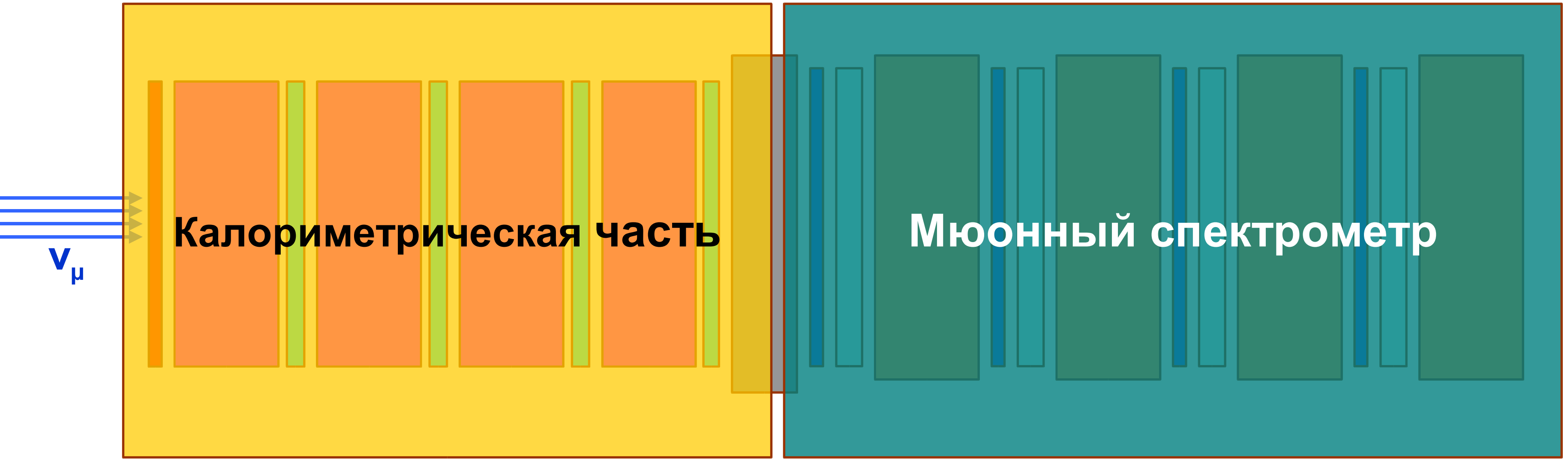


Схема нейтринного детектора

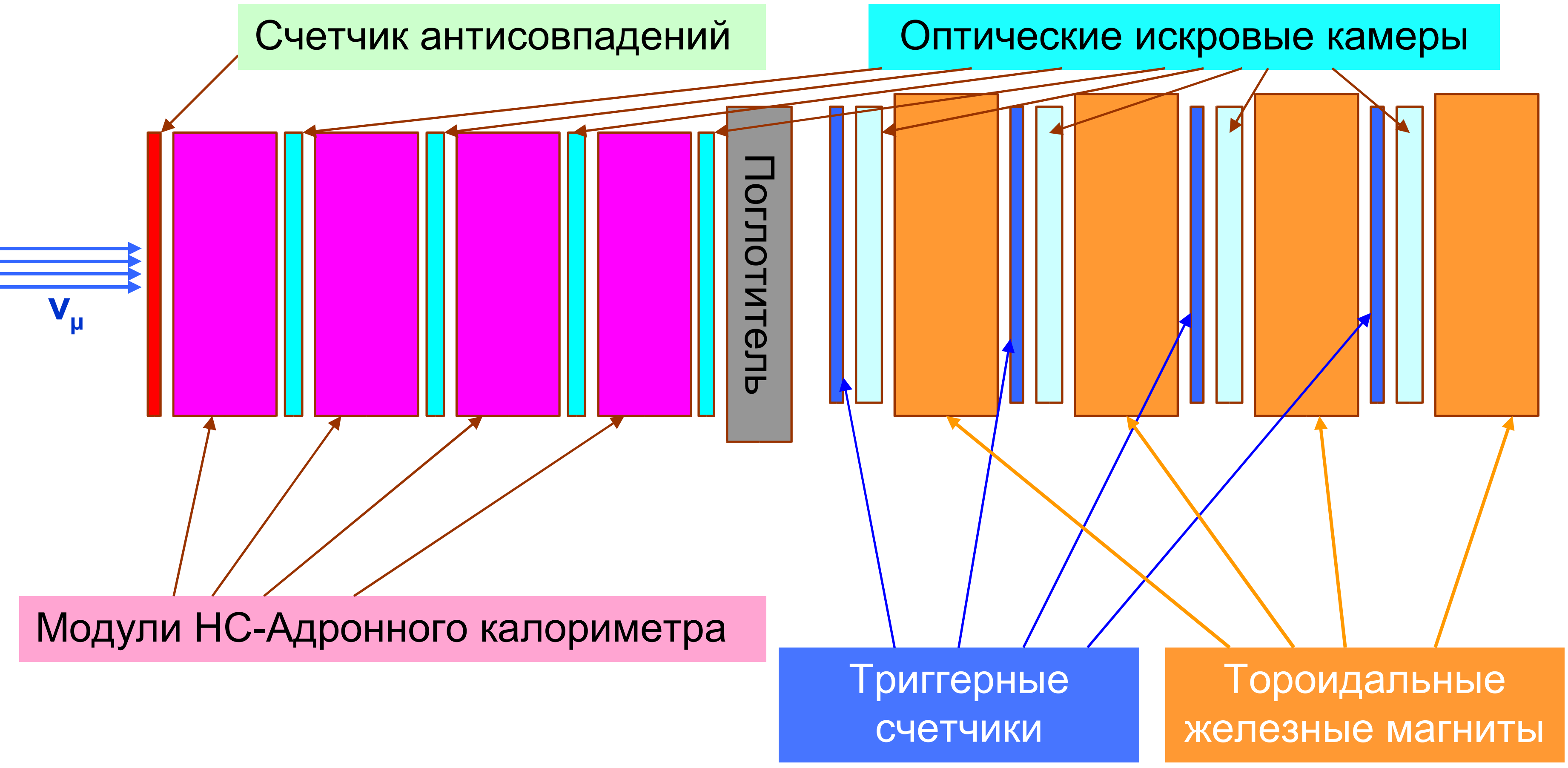
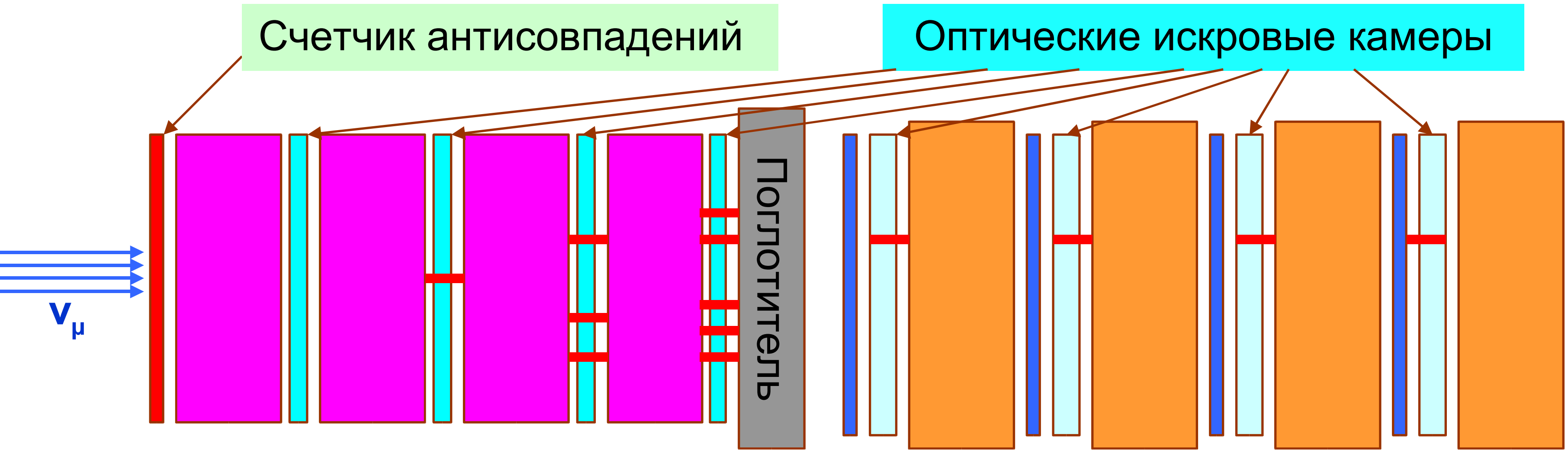
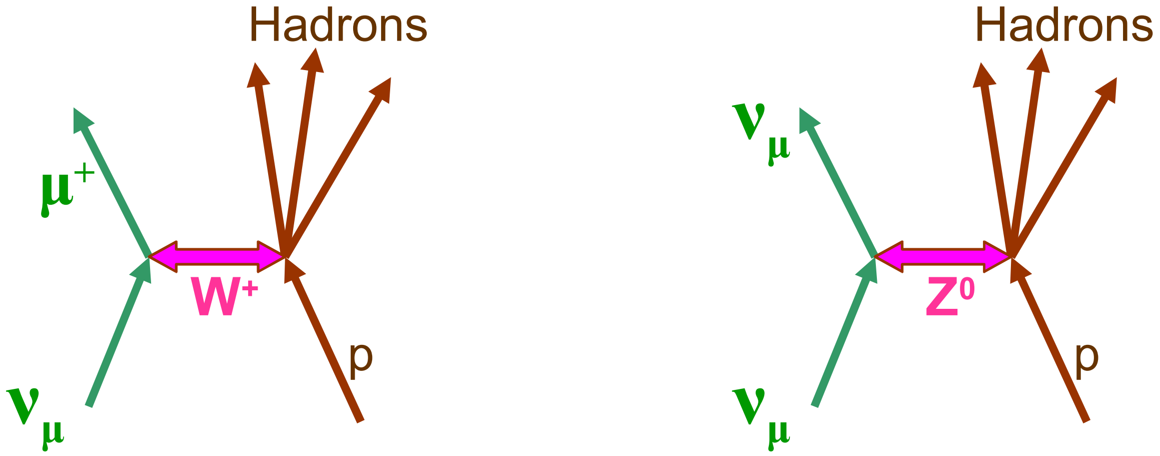


Схема нейтринного детектора





Результаты экспериментов 1973 г в CERN и FNAL

CERN - Gargamel (CF_3Br)

- Было получено:

в пучке ν_μ - $80*10^3$ фото

в пучке $\bar{\nu}_\mu$ - $200*10^3$ фото

Среди них было найдено

428 соб с μ в конечном состоянии

И 102 соб без μ в конечном состоянии

FNAL – нейтринный спектрометр

Зарегистрировано 991 одно событие взаимодействия нейтрино из них:

771 соб. с μ в конечном состоянии и

220 соб. без μ в конечном состоянии

В 1979 г. S.Weiberg, A.Salam и S.L.Glashow была присуждена Нобелевская премия по физике

«за их вклад в теорию единого слабого и электромагнитного взаимодействия между элементарными частицами, включая предсказание слабых нейтральных токов»

Экспериментальное наблюдение промежуточных векторных бозонов - W^+, W^- и Z^0

- К моменту открытия НСТ наиболее мощными ускорителями на земле были (строились)

Центр	Имя	Год запуска	Частицы	Энергия (E), GeV	Энергия CM (E), GeV
CERN	SpS	1976	Протоны	400	28
FNAL	Tevatron	1985	Протоны	1000	45

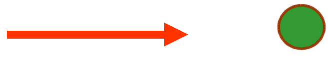
Максимально достижимая энергия в СЦМ для обоих из них (28 и 45 GeV) была недостаточна для поиска W и Z. Строительство протон-протонных коллайдеров планировалось на 80-е годы.

Поэтому в 1976г. Carlo RUBBIA, P.McIntyre и D.Cline предложили реконструировать ускоритель CERN в протон-антипротонные коллайдеры !!

Идея была заимствована из уже имеющегося опыта создания e^+e^- встречных пучков.

Фиксированная мишень

M



$m;P_{in};E_{in}$

$$E_{cm}= \sqrt{(m^2+2E_{in}M+M^2)}$$

$$m \sim M \ll E_{in}$$

$$E_{cm}= \sqrt{(2E_{in}m)}$$

Встречные пучки

m_1,E_1,P_1 m_2,E_2,P_2

$$E_{cm}=E_1+E_2=2E$$

Установки для поиска W^+, W^- и Z^0
(UA1 и UA2; CERN)

$$P + \bar{P} \rightarrow W^{\pm} + X$$

$$\hookrightarrow e^{\pm} + \nu_e$$

$$P + \bar{P} \rightarrow Z^0 + X$$

$$\hookrightarrow e^+ + e^-$$

$$\mu^+ + \mu^-$$

Основные принципы отбора событий (триггер):

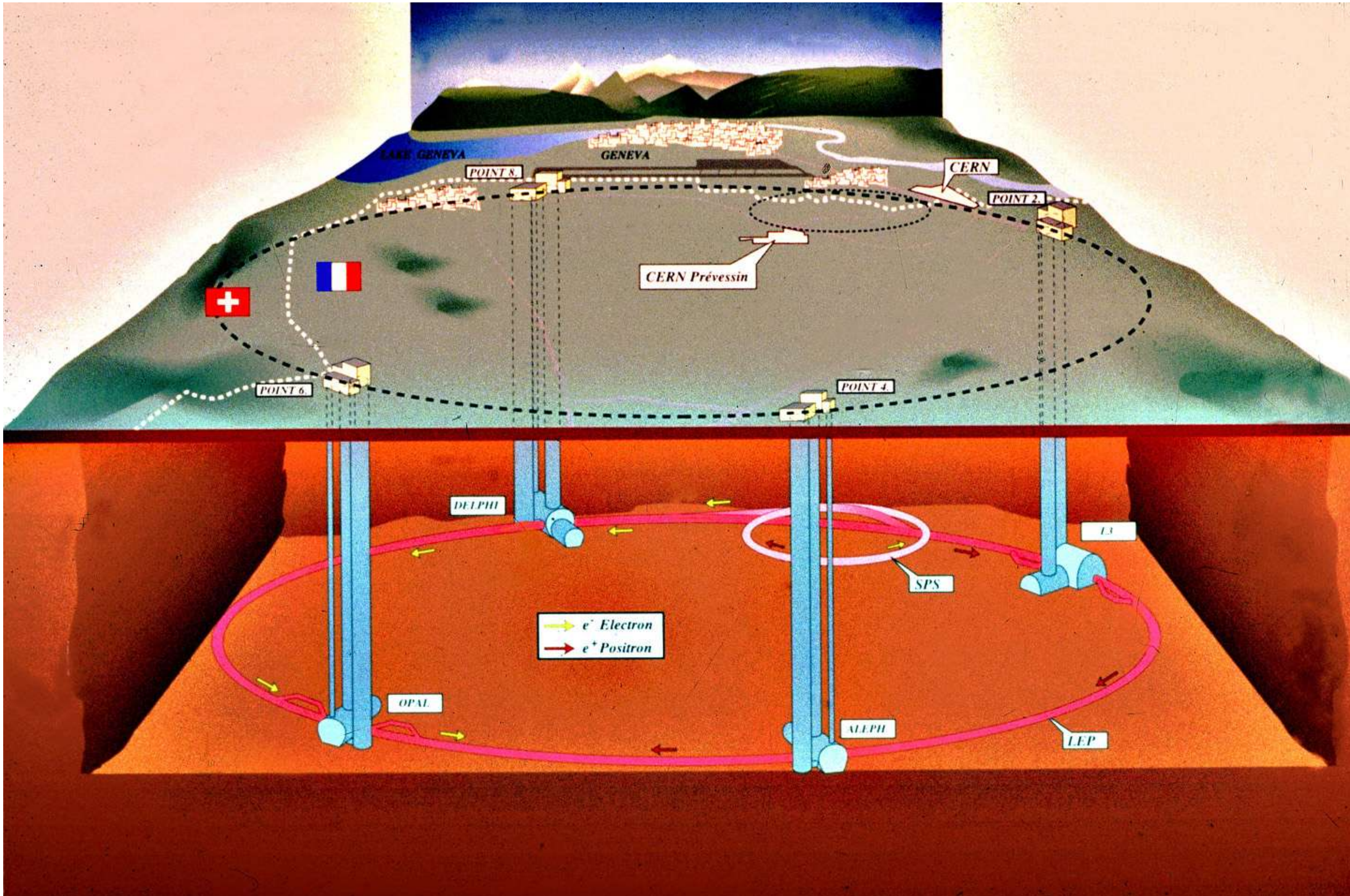
• большой поперечный импульс

• большая недостающая энергия

От обнаружения к детальному изучению

- Строительство LEP и его установок
- 10^6 Z^0 – бозонов
- Определение числа поколений в природе

Large Electron Positron collider



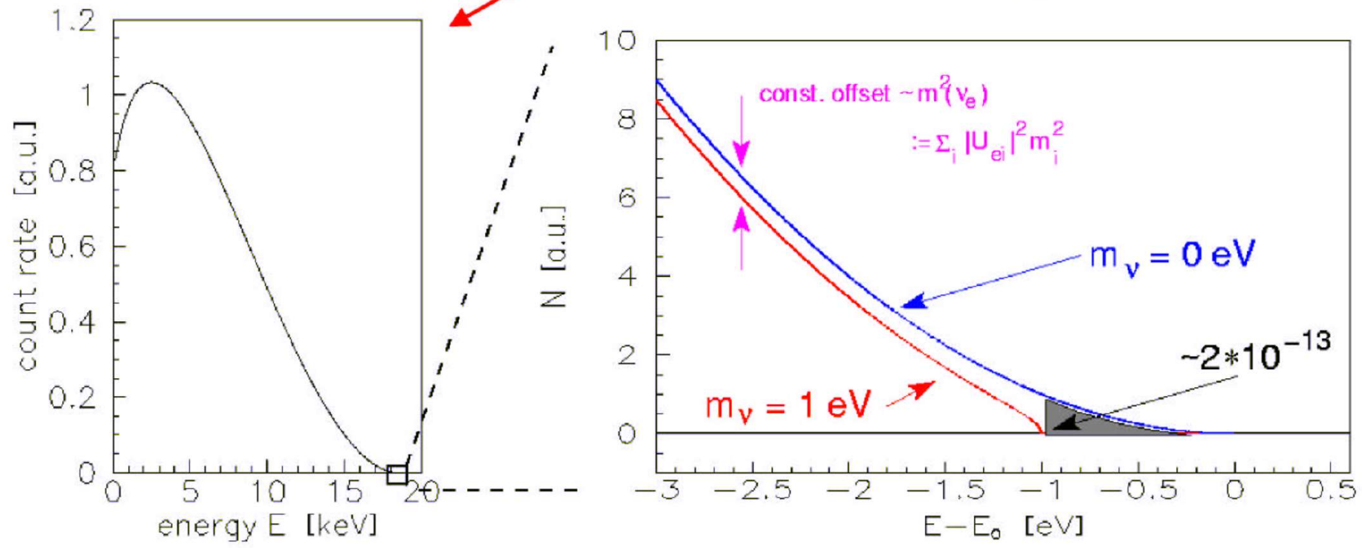
Direct measurement of $m(\nu_e)$

Tritium β decay: $^3H \rightarrow {}^3He^+ + e^- + \bar{\nu}_e$

super−allowed

$E_0 = 18.6$ keV

$t_{1/2} = 12.3$ a

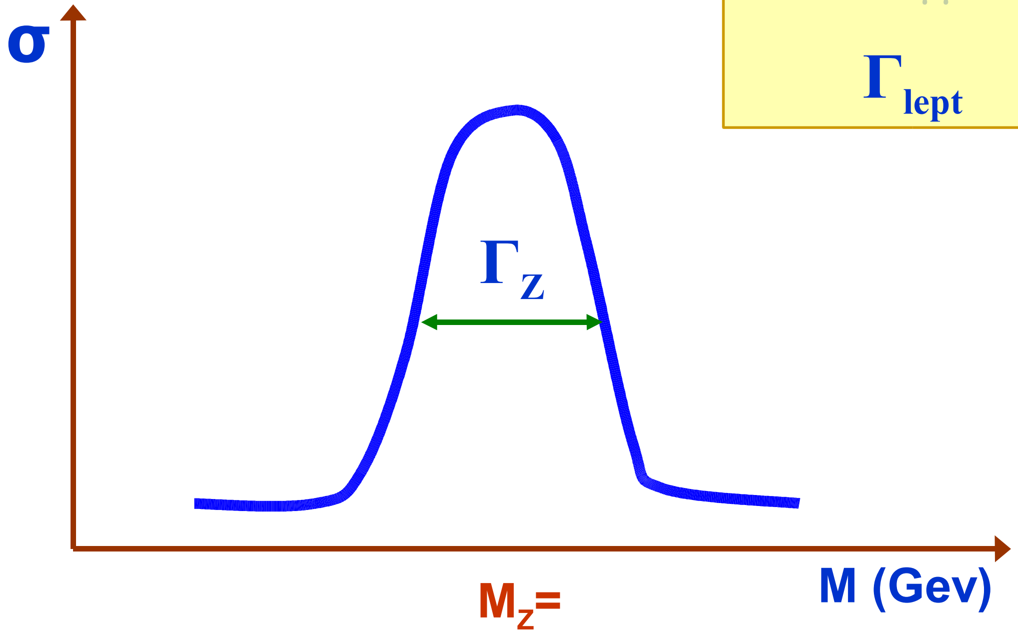


Need **very high energy resolution &**
very high luminosity &
very low background
} ⇒ **MAC−E−Filter**

Понятие «невидимой ширины» (Invisible width)

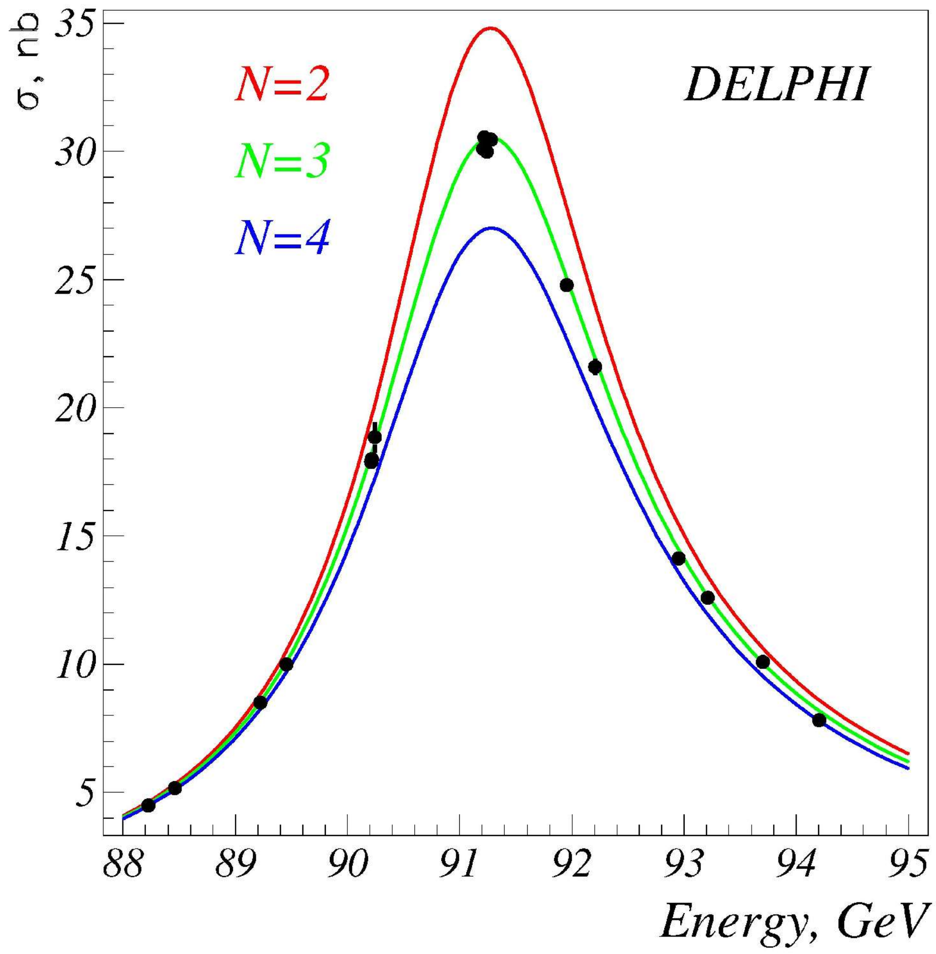
$$\Gamma_{tot} = \Gamma_{had} + \Gamma_{ee} + \Gamma_{\mu\mu} + \Gamma_{\tau\tau} + \Gamma_{\nu\nu} + \Gamma_{\nu\nu} + \Gamma_{\nu\nu}$$

Γ_{lept} $\quad$ Γ_{inv}



$$N_\nu = \Gamma_{inv}/\Gamma_{\nu\nu}$$

$$\Gamma_{inv} = \Gamma_{tot} - \Gamma_{had} - \Gamma_{lept}$$


σ, nb
35
30
25
20
15
10
5
N=2
N=3
N=4
DELPHI
88
89
90
91
92
93
94
95
Energy, GeV

Status Report on the CERN Programme

Robert Aym

8th ICFA Seminar

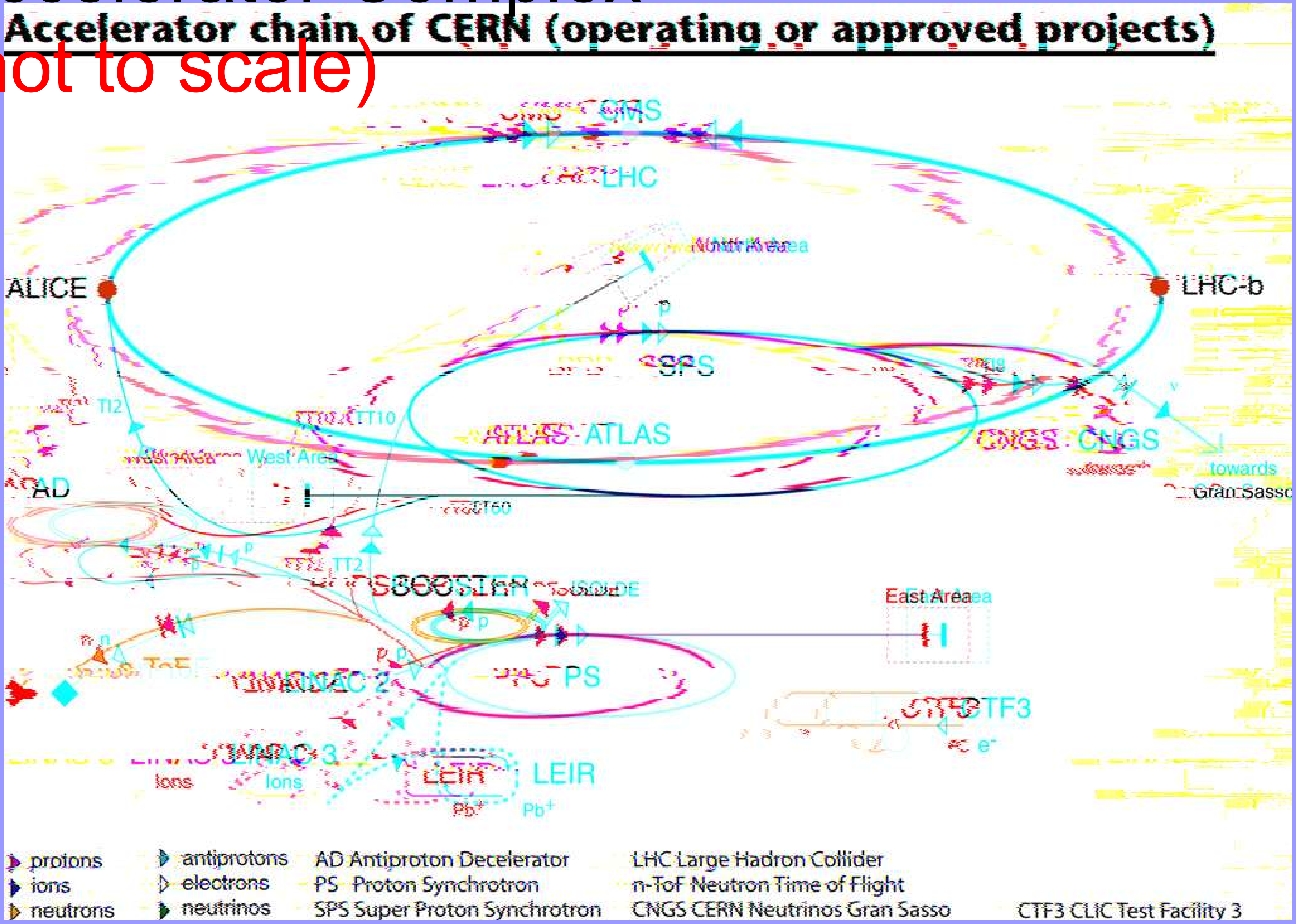
28 September - 1st October 2005

Daegu - Korea

Outline

- The Infrastructure
- The LHC Program
  - Status LHC
  - Status LHC experiments
- ‘Fixed target’ Program
- Accelerator R&D, in particular the **C**ompact **LI**near **C**ollider
- Future
  - International Linear Collider; CLIC
  - Neutrino superbeam, betabeam, factory
  - PAF, POFPA and the Strategy Group

CERN: the World's Most Complete Accelerator Complex (not to scale)



The Large Hadron Collider

The Large Hadron Collider: 14 TeV pp collisions at 10^{34} $cm^{-2}s^{-1}$

New energy domain (x10), new luminosity domain (x100)

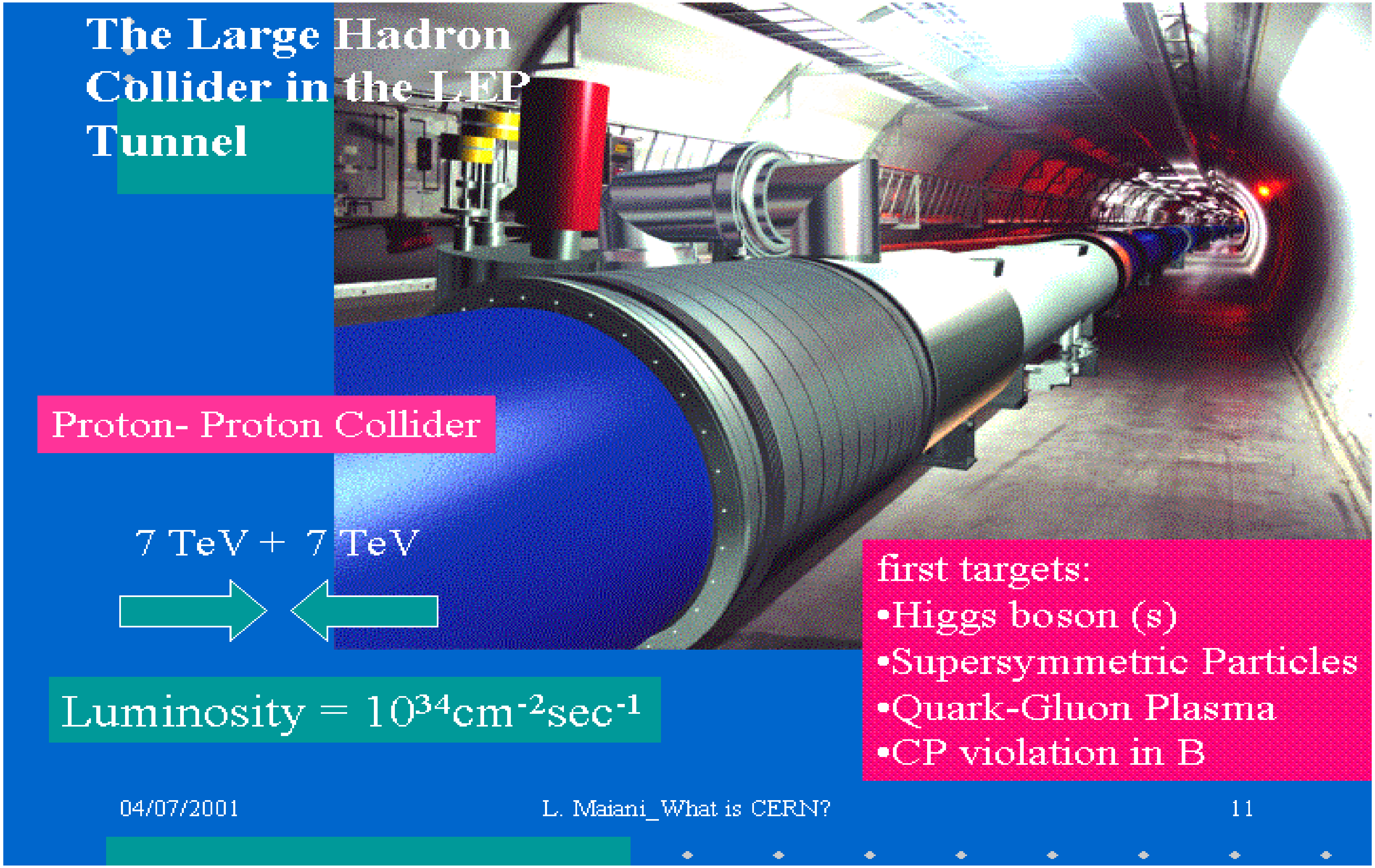
Will have to cross threshold of electroweak symmetry breaking; unitarity of WW scattering requires $M_{Higgs} < 850$ GeV

Many possibilities: Standard Higgs – SUSY (many possibilities...)
-Large Extra Dimensions (quantum gravity)

-and many more results on CP violation, Quark Gluon Plasma, QCD, ..., surprises...

The LHC results will determine the future course of High Energy Physics

Project Large Hadron Collider

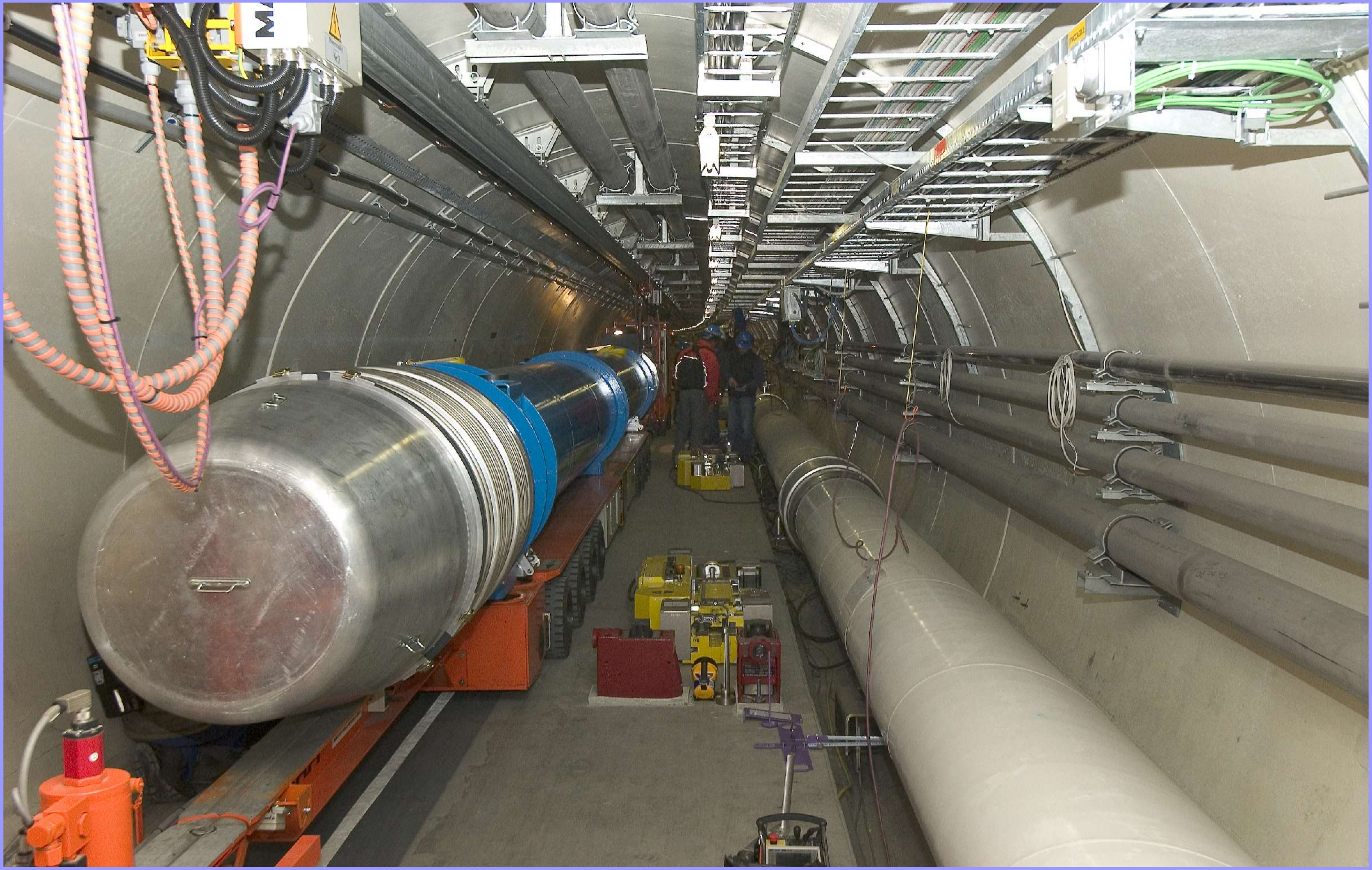


The LHC (Project Leader Lyndon Evans)

First cryodipole lowered on 7 March 2005

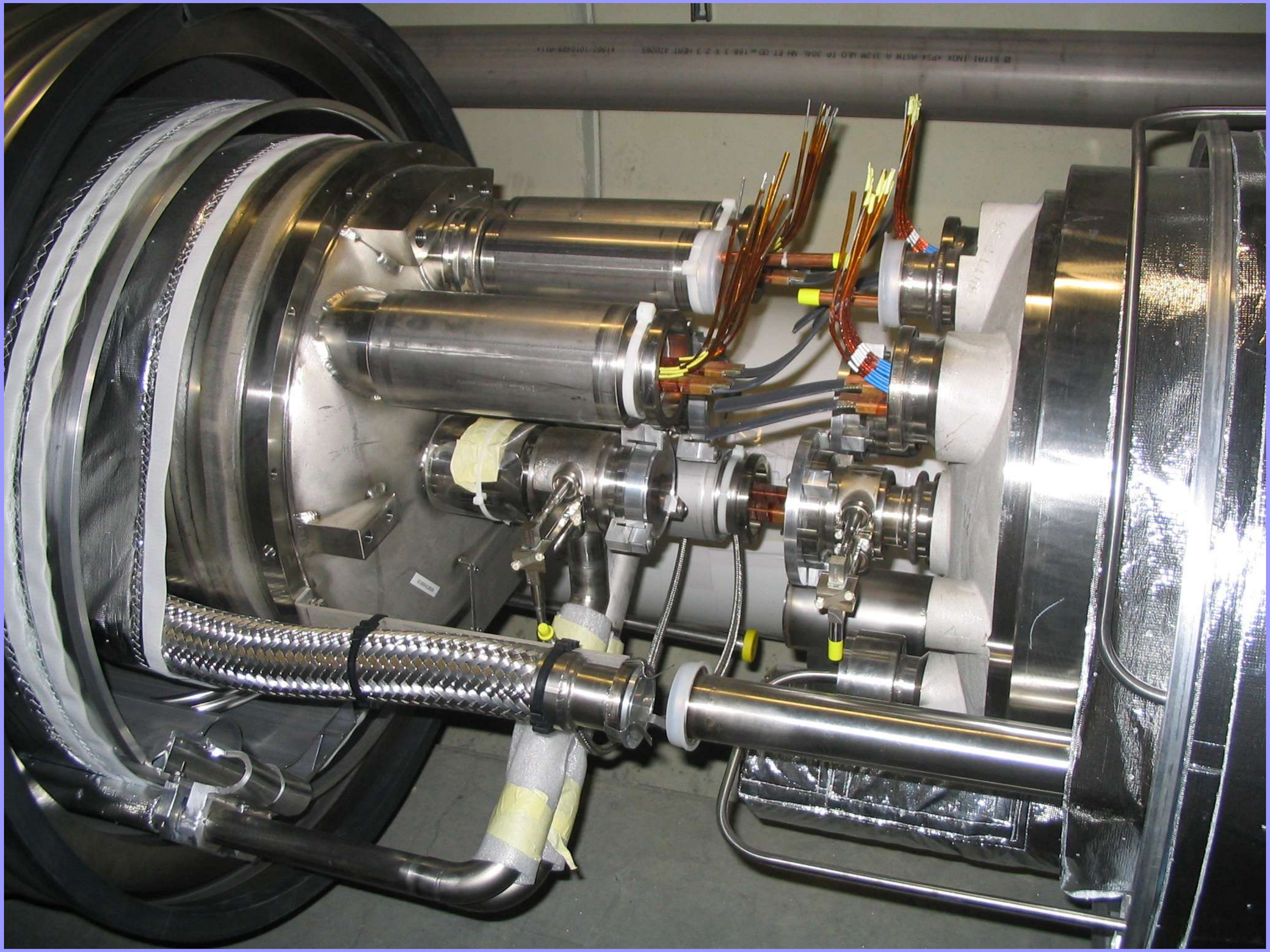
Transport in the tunnel with an optical guided vehicle

Arrival on installation location



Transfer on jacks

Preparation of interconnect

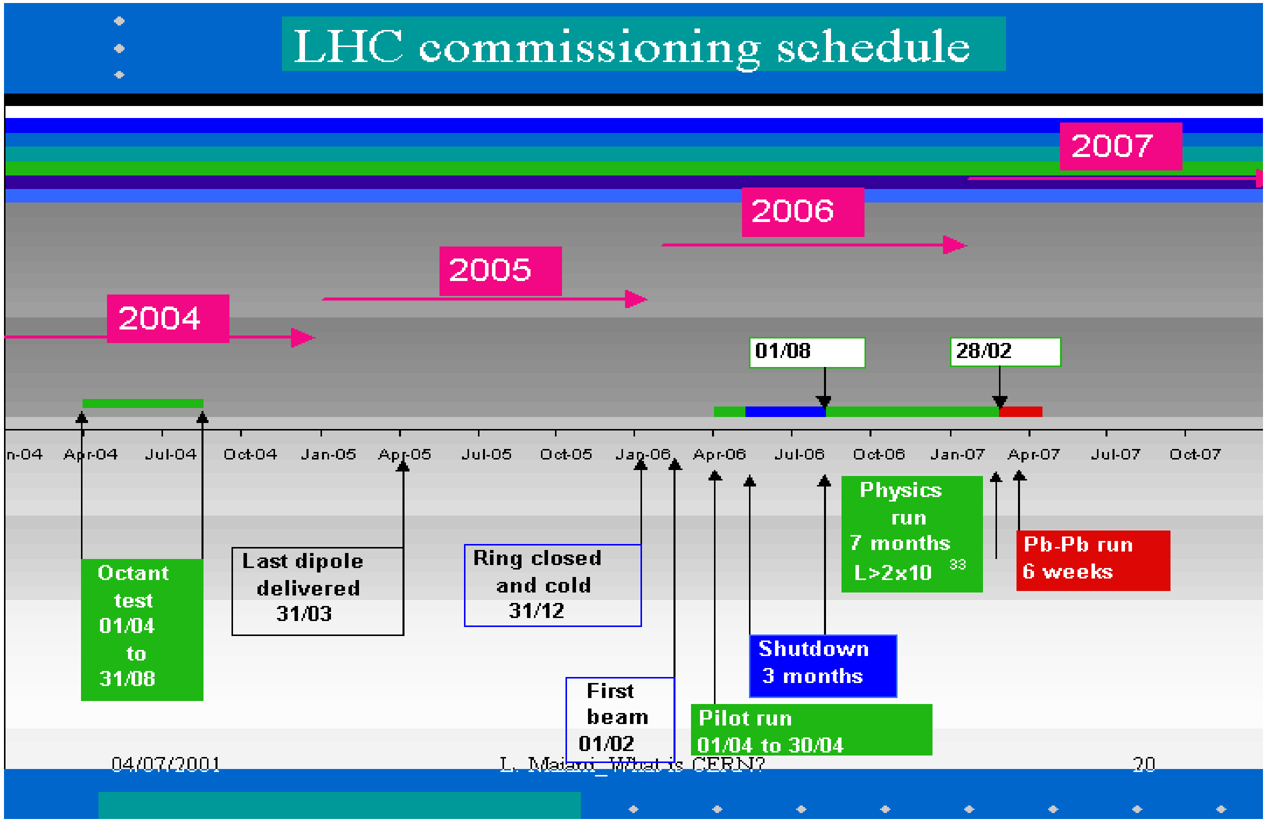


LHC installation & commissioning

- Main objectives:
  - terminate installation in February 2007
  - first collisions in summer 2007

- The industrial production of standard components is compatible with this objective.
- ....
- ....

Schedule from DG report 04/07/2001



The Detectors

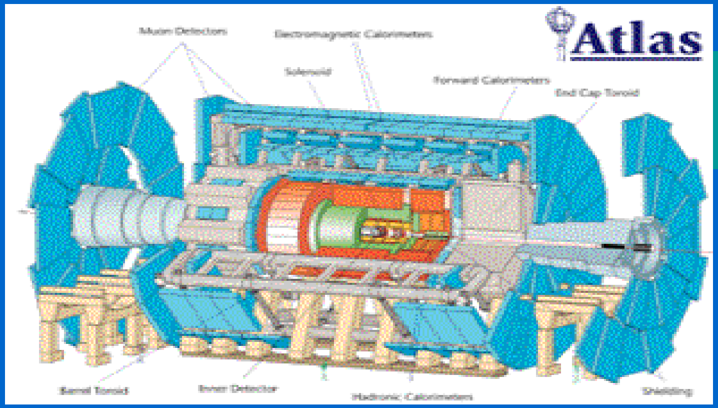
Event rate 20 - 25 per bunch crossing (every 25 ns)
--> 10^9 events / s --> 10^{11} - 10^{12} tracks /s

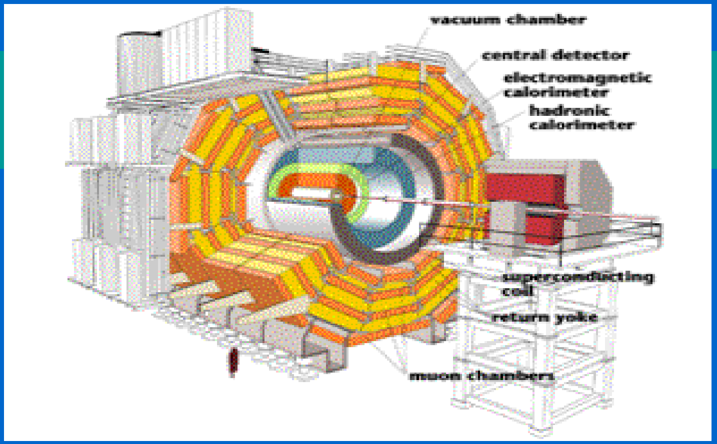
Very remarkable: experiments will, in this environment:

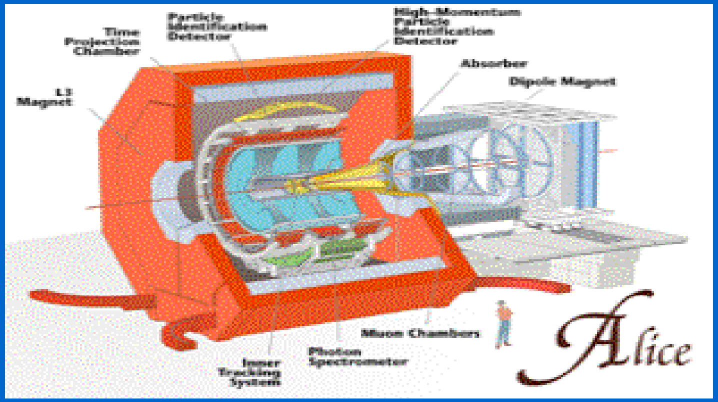
- reconstruct secondary vertices from B mesons, only mm's away from the primary vertex.
- reconstruct individual photons with sufficient energy and angular resolution for (light) Higgs detection

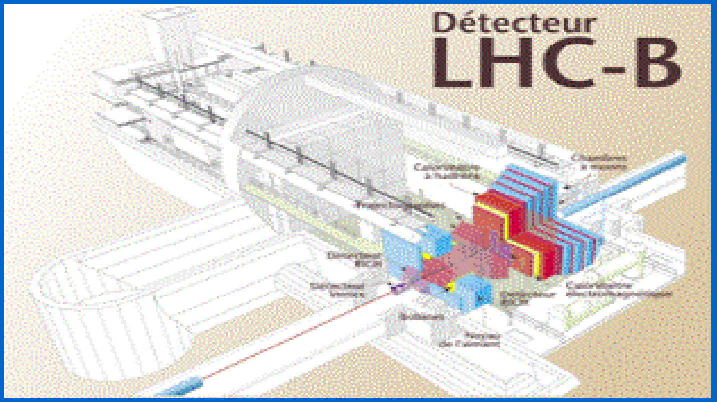
in addition to many more capabilities: they are 'general purpose - 4π' detectors, featuring tracking, magnetic momentum analysis, calorimetry, muon spectrometry, in an almost **hermetic** setup

Установки LHC

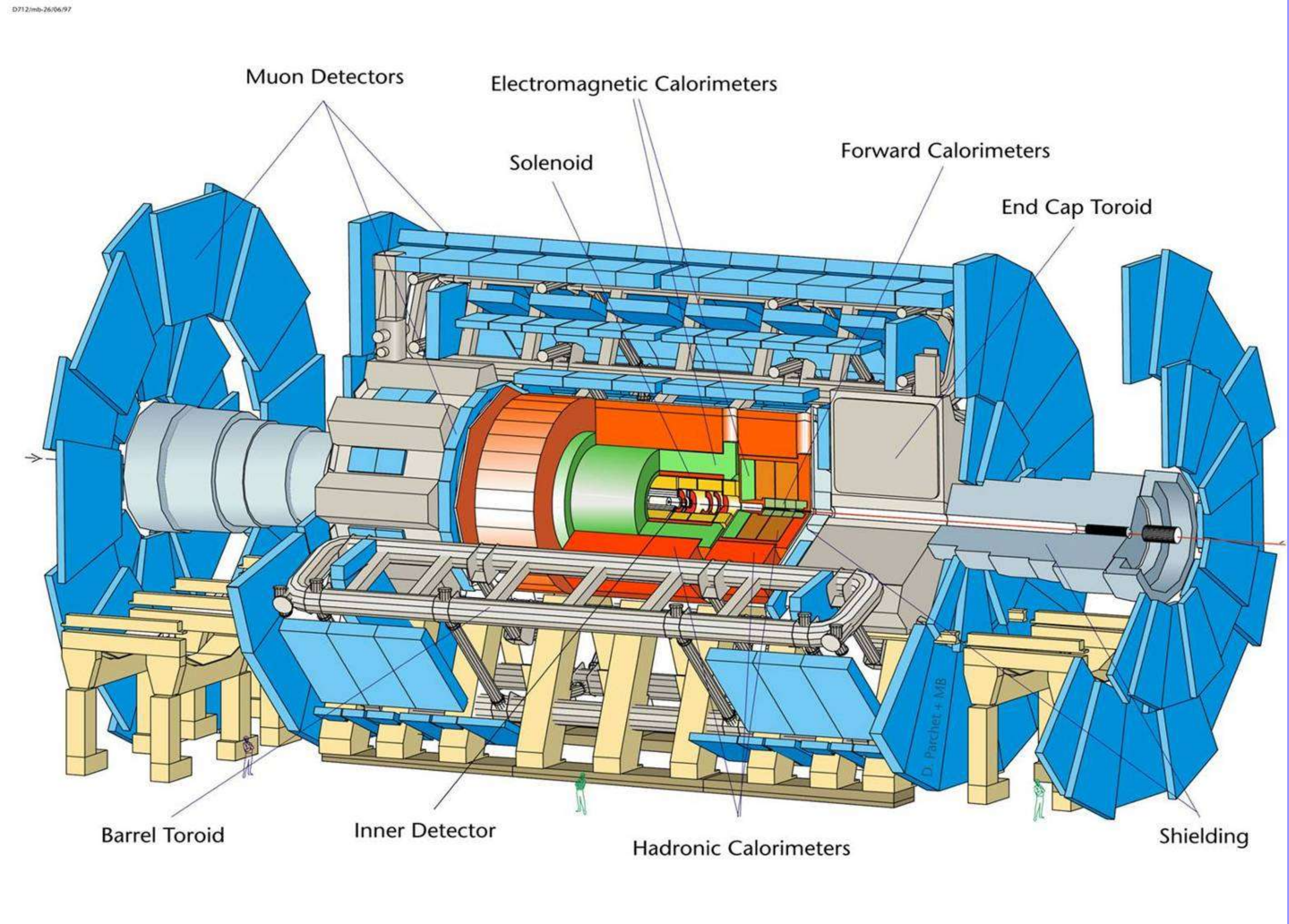








ATLAS (spokesperson Peter Jenni)



Barrel Toroid construction status

All surface construction and testing work in Hall 180 has been completed

The mechanical installation of the last coil is shown on the next slide

Currently the warm structure is being completed, as well as the so-called cryo-ring connecting in series the 8 coils (vacuum, cryogenics, conductor)

The first cool-down is scheduled for the end of the year, followed by an excitation test beginning of 2006

LHC 2001


Point 1 - PX14 shaft - July 18, 2000 - CERN ST-CE
ATLAS shaft and service cavern
04/07/2001
L. Maiani_What is CERN?
16

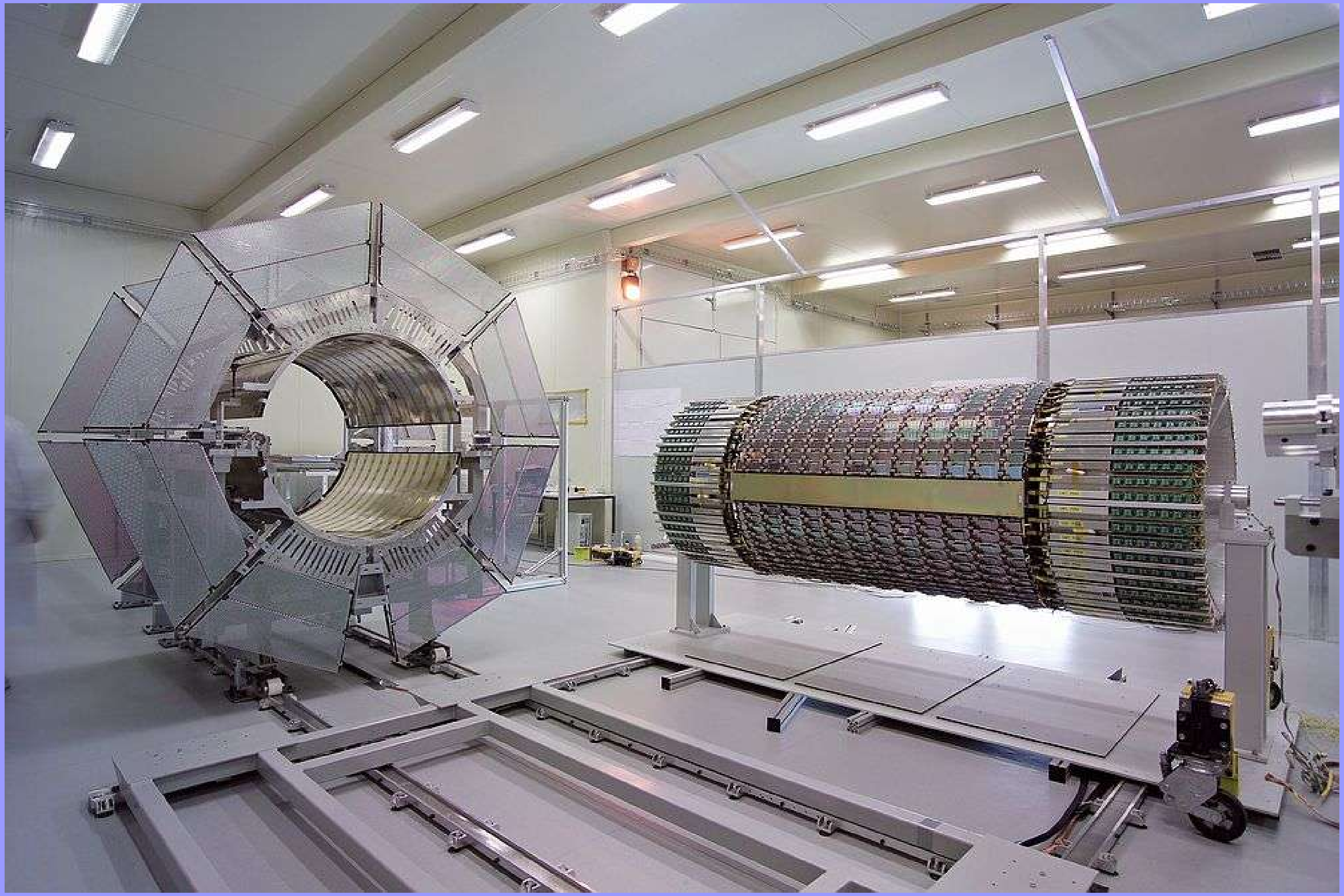
ATLAS Updates

9th September 2005

http://cern.ch/jenni/ATLAS.Council.9Sep05.ppt

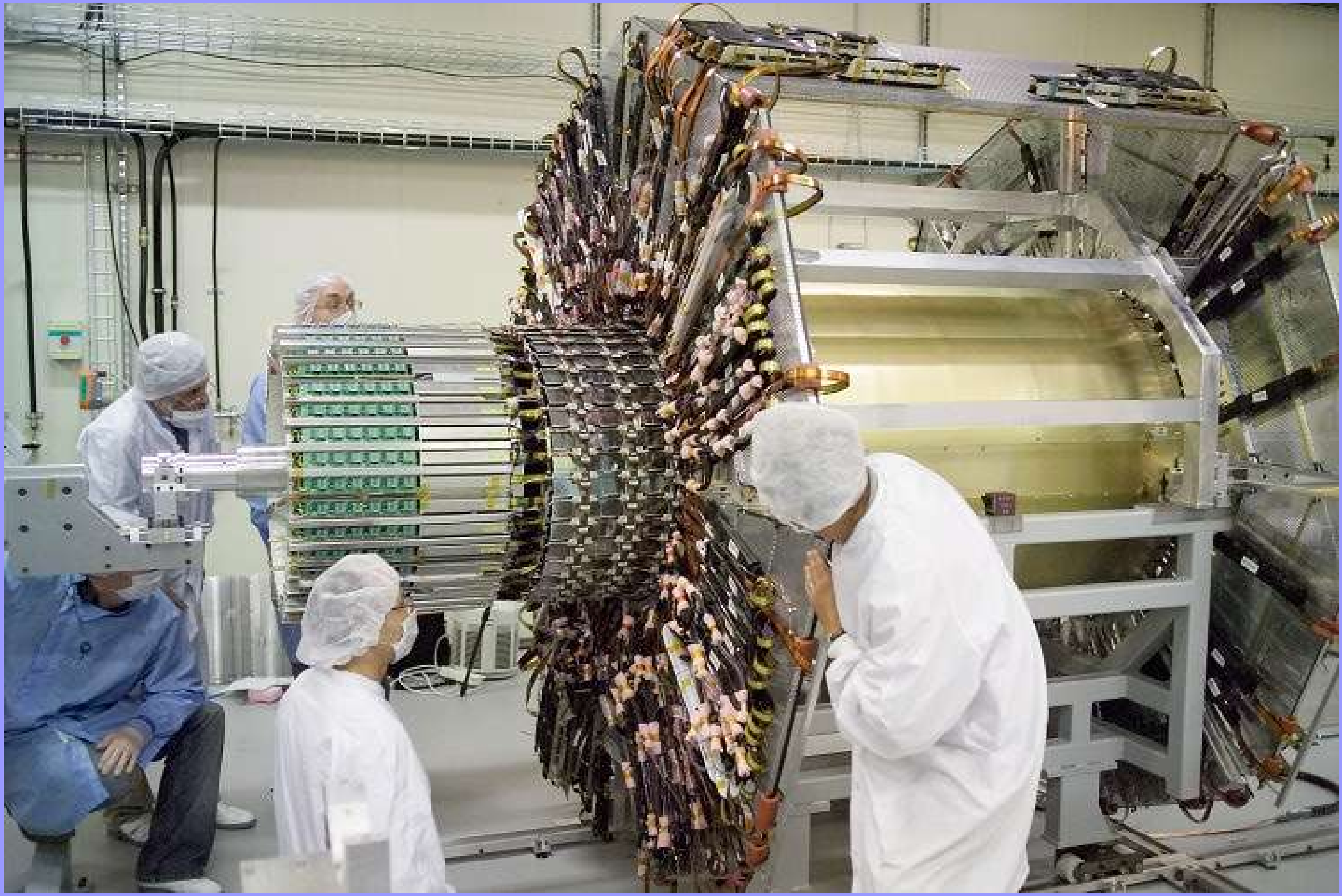
Silicon Tracker (SCT)

All four barrel cylinders are complete and at CERN, the integration into the cylindrical support structure has started



Outermost ATLAS SCT barrel cylinder before insertion into the support structure

Insertion of the 3rd cylinder (out of the four) into the barrel SCT



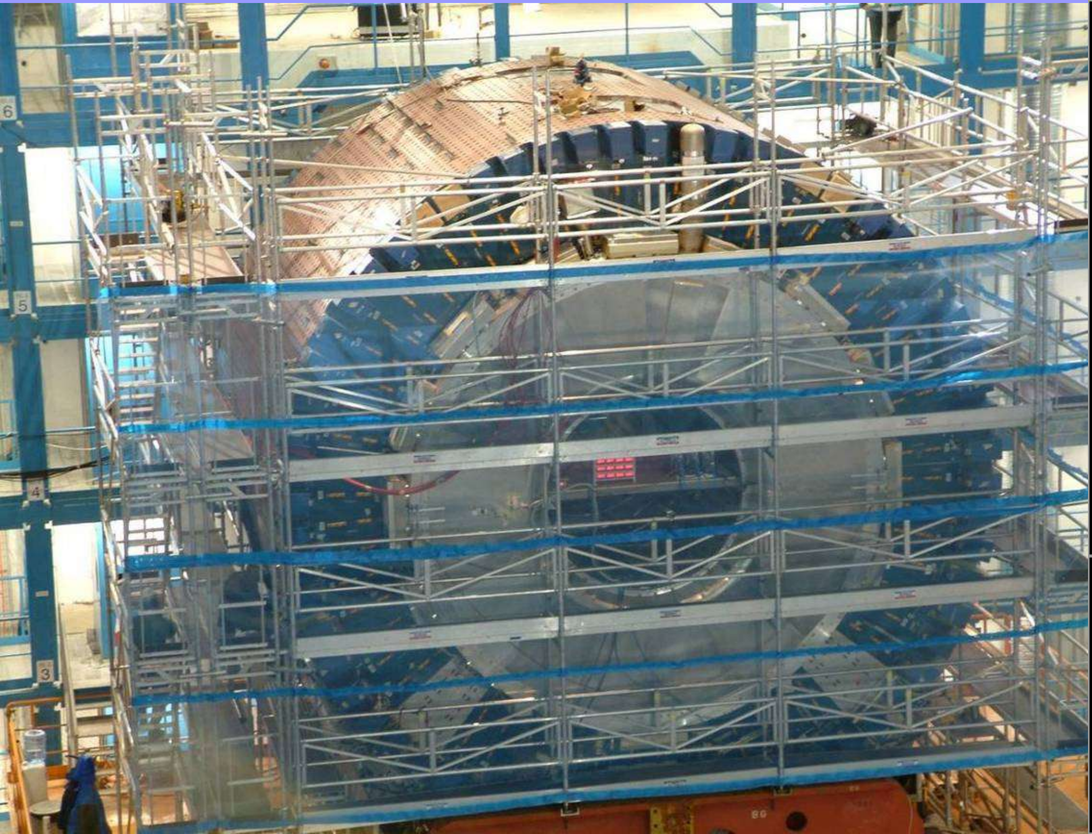
ATLAS Barrel Calorimeter

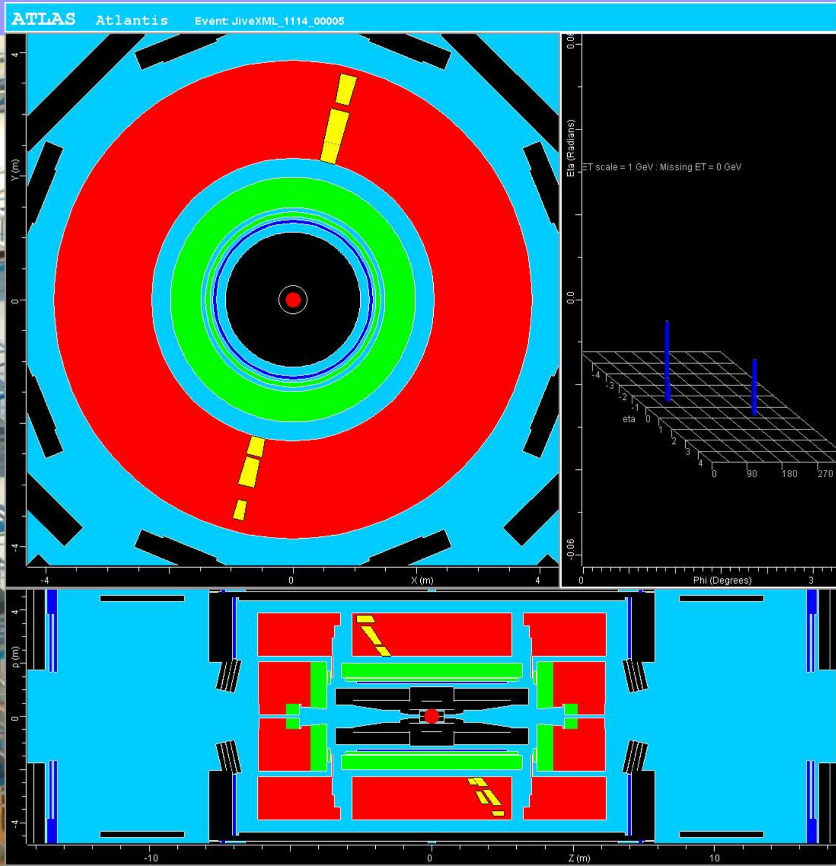
The mechanical installation of the LAr and Tile Barrel Calorimeters in the pit has been completed end of 2004 on the support trucks below the access shaft on the C-side

The installation of electronics and services is ongoing, including also services for the ID

The Barrel Calorimeter is scheduled to move into the completed Barrel Toroid end of October

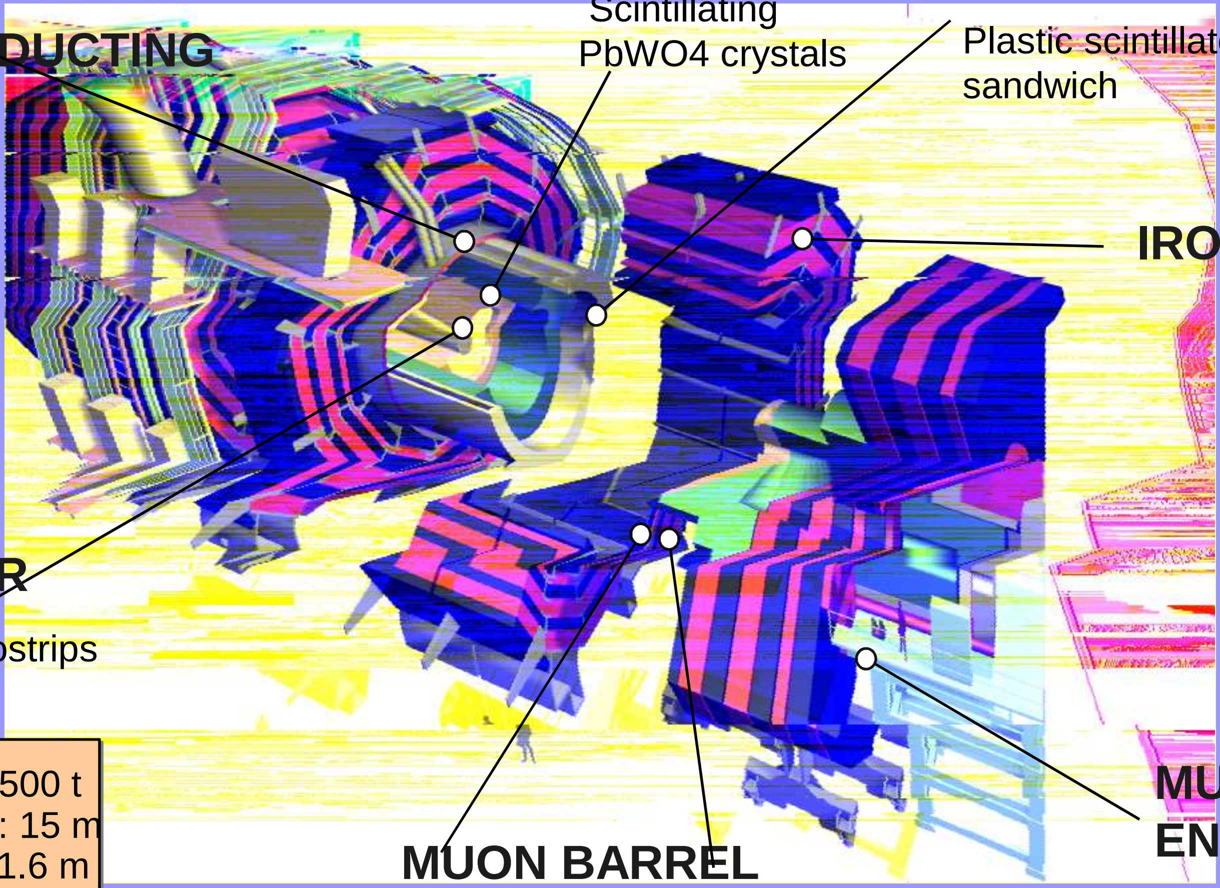
In the meantime first cosmic ray events have been registered in part of the Tile Calorimeter as shown in the event display below





The CMS Detector

(Spokesperson Michel Della Negra)



Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

Progress in SX5: Coil

Swivelling of coil carried out on 25 Aug
Coil insertion in w/s 12 Sep, swivelling of inner vac tank: ~ 20 Sept

Coil cool-down and start of electrical tests : Jan 06 - delay of ~ 6 weeks

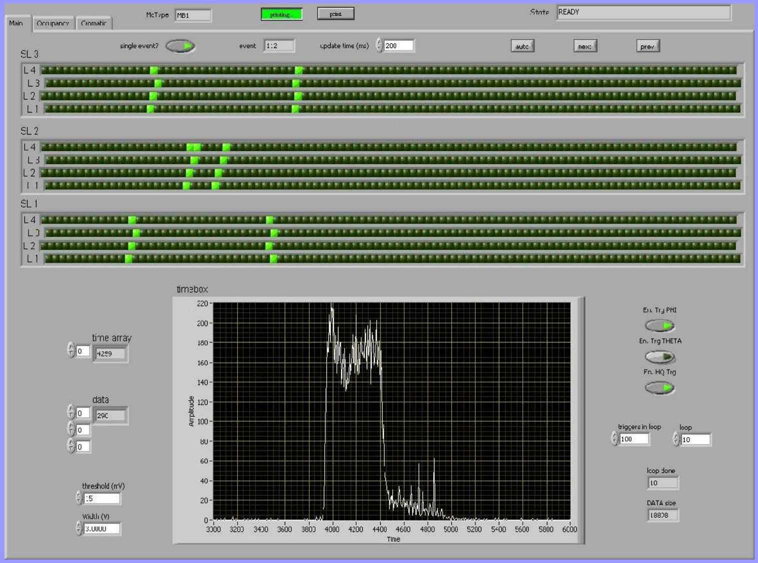
Progress in SX5: Barrel Yoke Wheels

YB+2: 40 DT/RPC chambers installed and commissioned.
YB+1: 40 DT/RPC chambers will have been installed by the end of this week.
~80 ch installed out of 210 that can be installed on the surface in SX5

Bulk cabling in October-December
Slice test of DT/RB, standalone, then with DAQ, *by end 2005*

Display of 2 cosmic μ

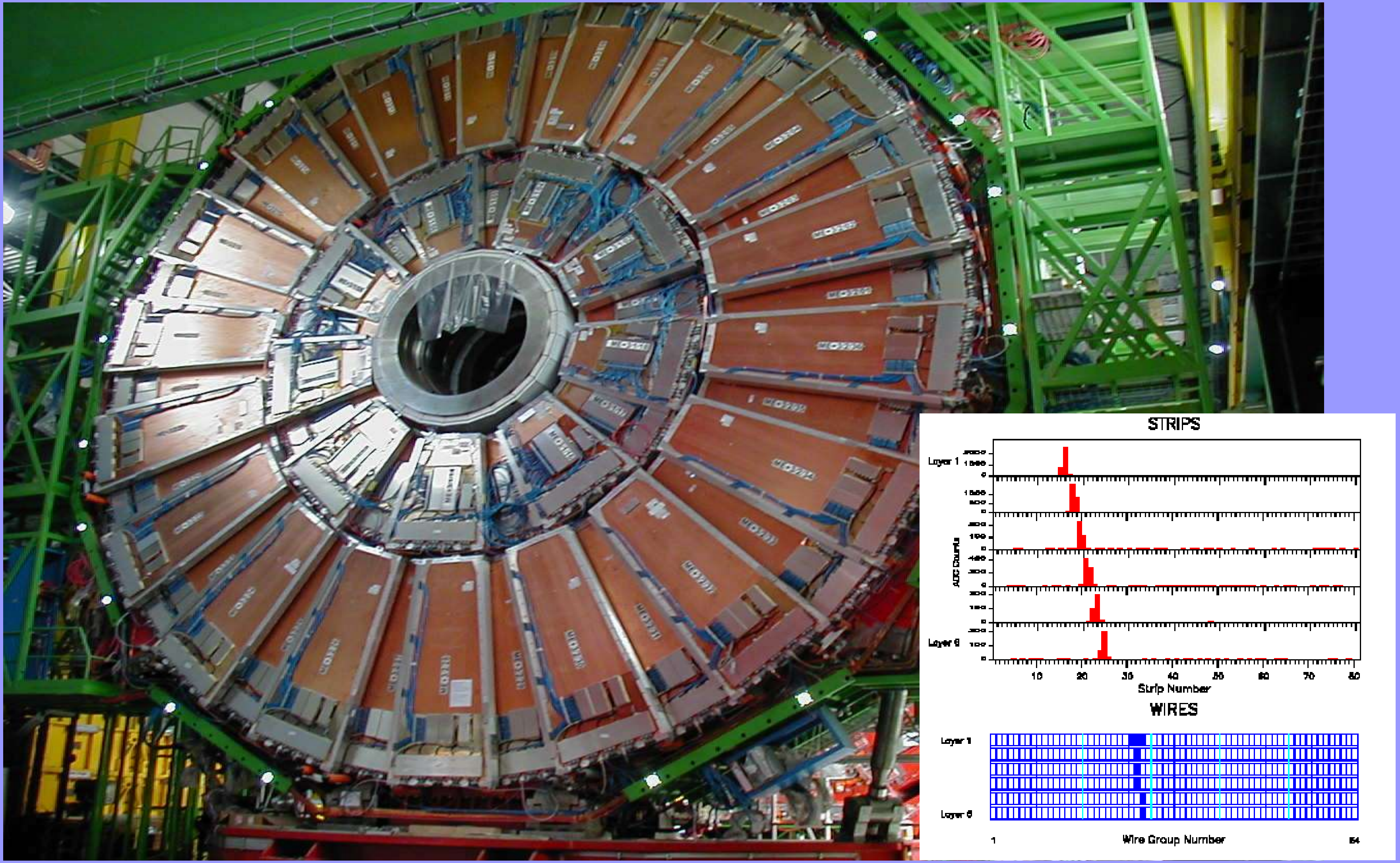
r–ϕ
Z
r–ϕ



Endcap Muons: CSCs at SX5

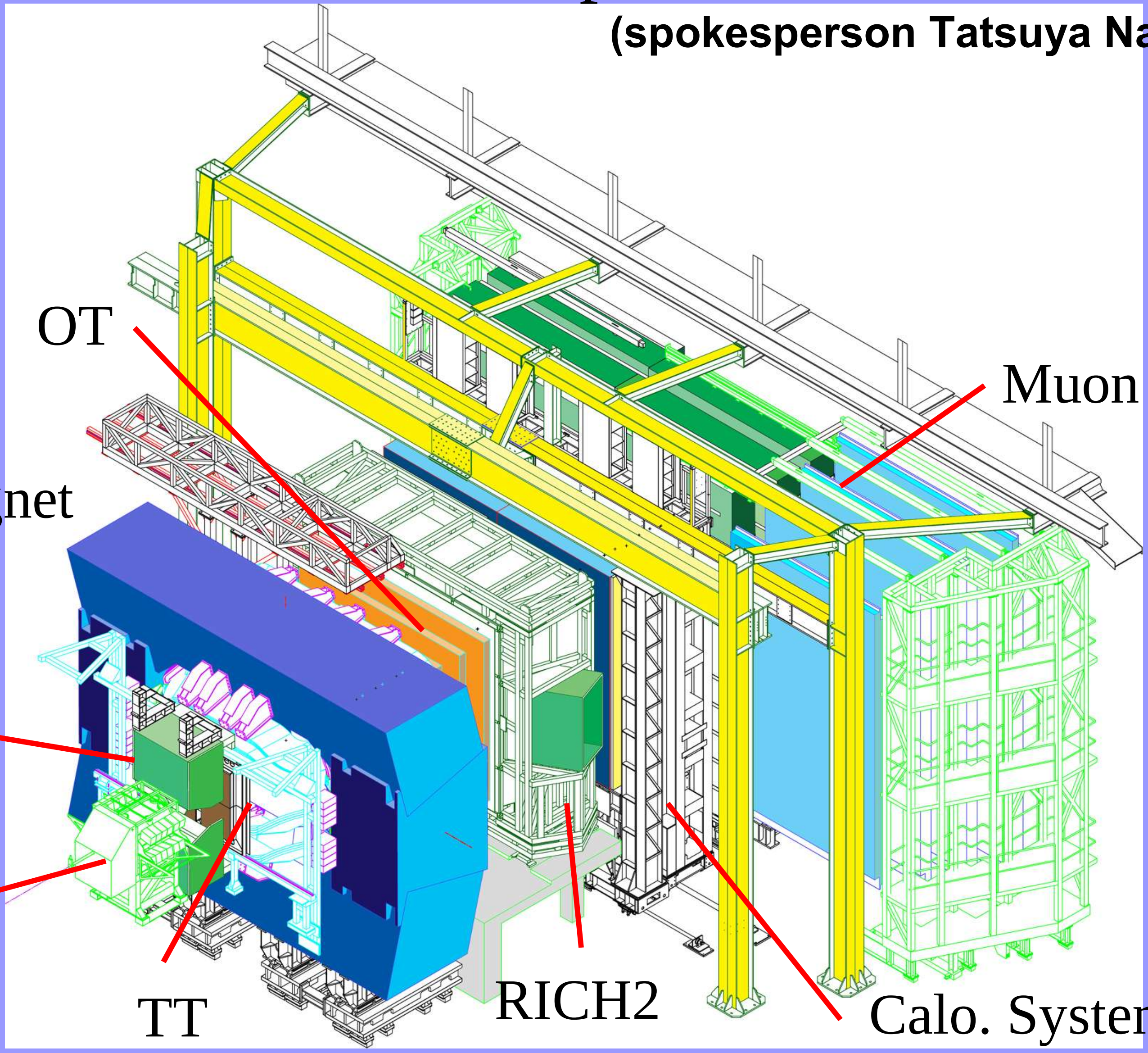
CSCs installed: 60% (out of 396)

CSCs commissioned (cosmics): 40%



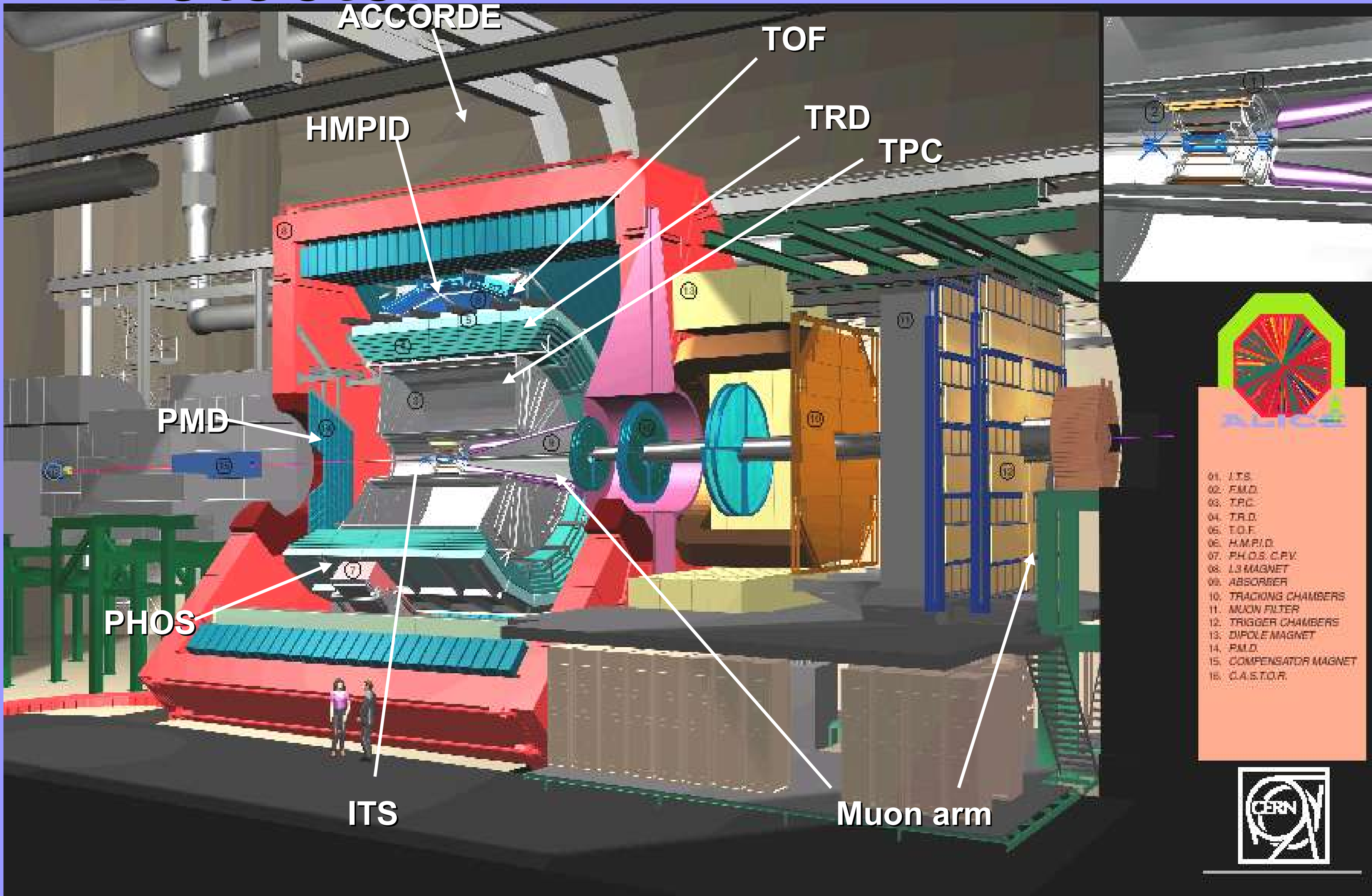
LHCb Spectrometer

(spokesperson Tatsuya Nakada)



ALICE Detector

(Spokesperson Juergen Schukraft)



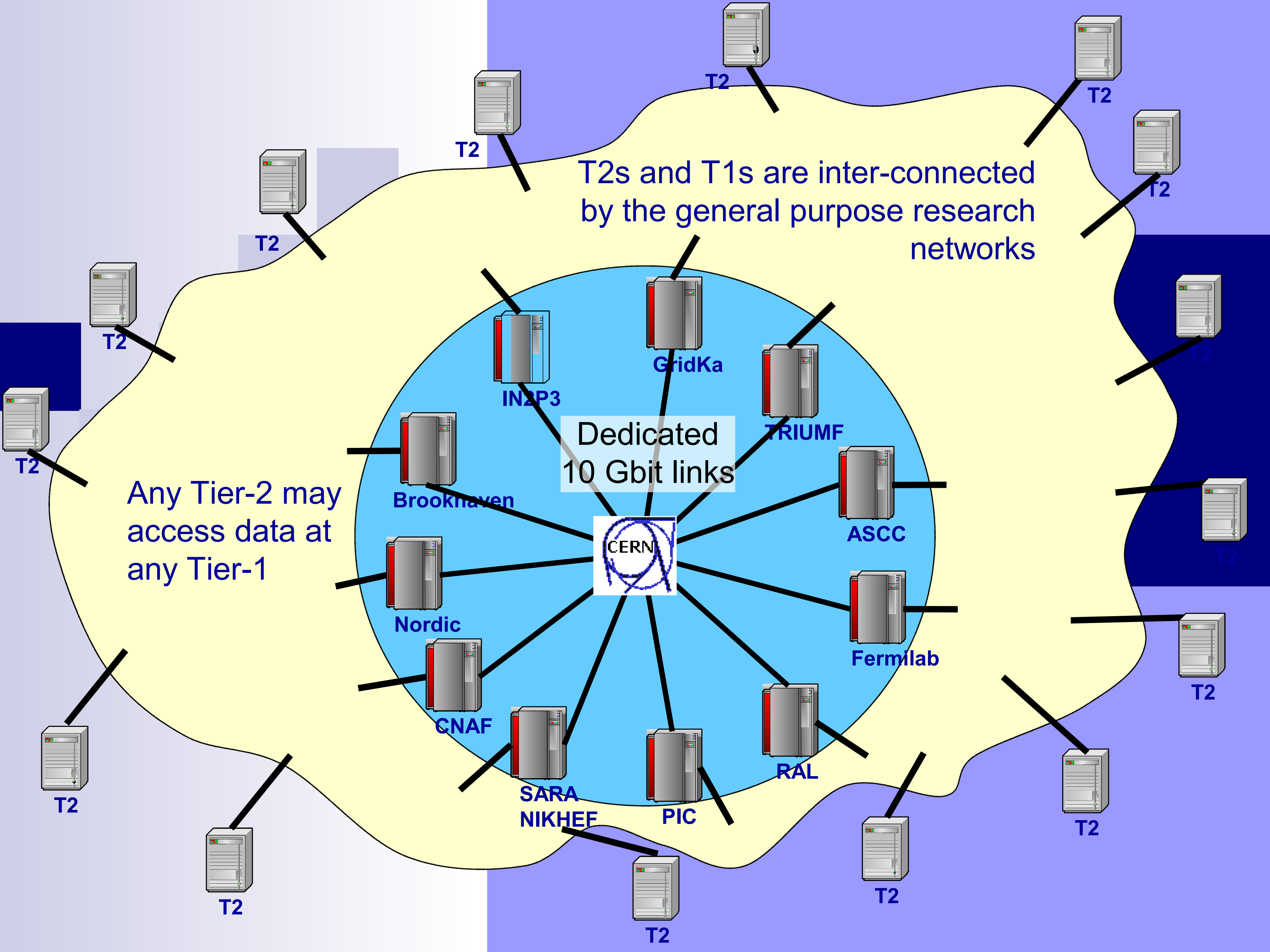
LHC Computing Grid: G

oject leader Les Robertson)

is about storing 15 PB (imagine!) of new data per year; processing them and making the information available to thousands of physicists all around the world!

Model: 'Tiered' architecture; 100,000 processors; multi-PB disk, tape capacity

Leading 'computing centers' involved


T2s and T1s are inter-connected by the general purpose research networks
Any Tier-2 may access data at any Tier-1
Dedicated 10 Gbit links
CERN
GridKa
IN2P3
TRIUMF
Brookhaven
ASCC
Nordic
Fermilab
CNAF
SARA NIKHEF
PIC
RAL
T2
T2
T2
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T2
T2

LCG

- The "Baseline Services" for the LCG services at startup have been agreed. These are the basic services that must be provided at CERN, Tier-1 and Tier-2 centres, and have to be in operation for Service Challenge 4 in April 2006.

- A detailed plan for Service Challenge 3 has been agreed with Tier-1 sites and the experiments. Service Challenge 3 is being prepared now and is scheduled to open as a stable service including 9 Tier-1 centres and several Tier-2s in September 2005.

- The deployment plan for the new CASTOR mass storage management system at CERN has been agreed with the experiments, with the aim of completing the migration of LHC to this system by the end of February 2006.

- The draft TDR for the initial LHC computing services is complete.
  The final version will be published on 20 June.

The LCG project is taking an active part in the preparation of the proposal for the second phase of the EGEE project (April 2006-March 2008). This will be an evolution of the current project, with the major emphasis remaining grid operations.

Conclusions Status LHC Project

The LHC project (machine; detectors; LCG) is well underway for physics in 2007

Detector construction is generally proceeding well, although not without concerns in some cases; an enormous integration/installation effort is ongoing – schedules are tight but are also taken very seriously; this is not the moment to reduce manpower (on the contrary)

LCG (like machine and detectors at a technological level that defines the new ‘state of the art’) needs the already reported ‘missing’ manpower in order to fully develop the functionality required; the required performance necessitates investments that cannot quite be covered by the budget available in the MTP.

Outline

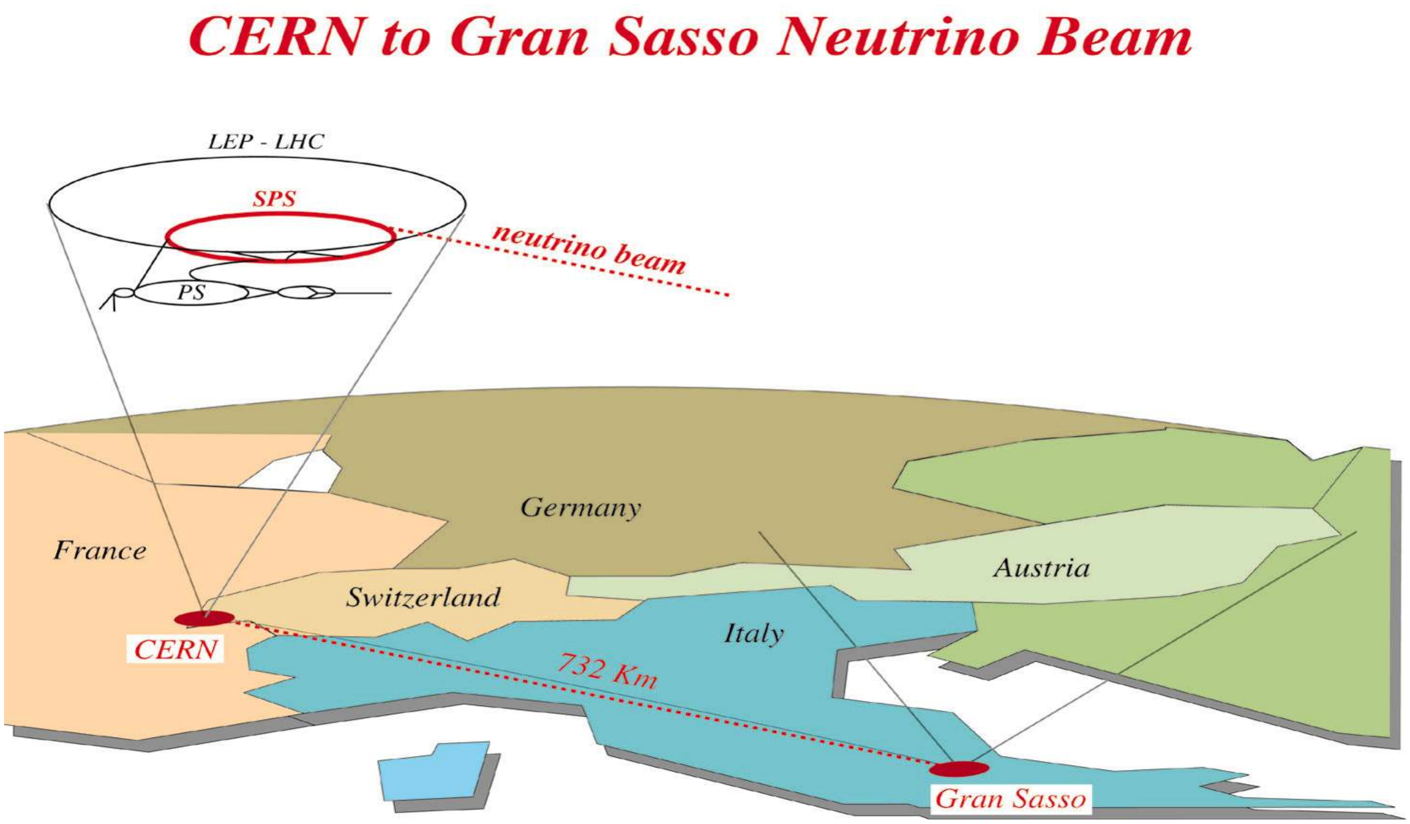
- The Infrastructure
- The LHC Program
  - Status LHC
  - Status LHC experiments
- ‘Fixed target’ Program
- Accelerator R&D, in particular the **C**ompact **LI**near **C**ollider
- Future
  - International Linear Collider; CLIC
  - Neutrino superbeam, betabeam, factory
  - PAF, POFPA and the Strategy Group

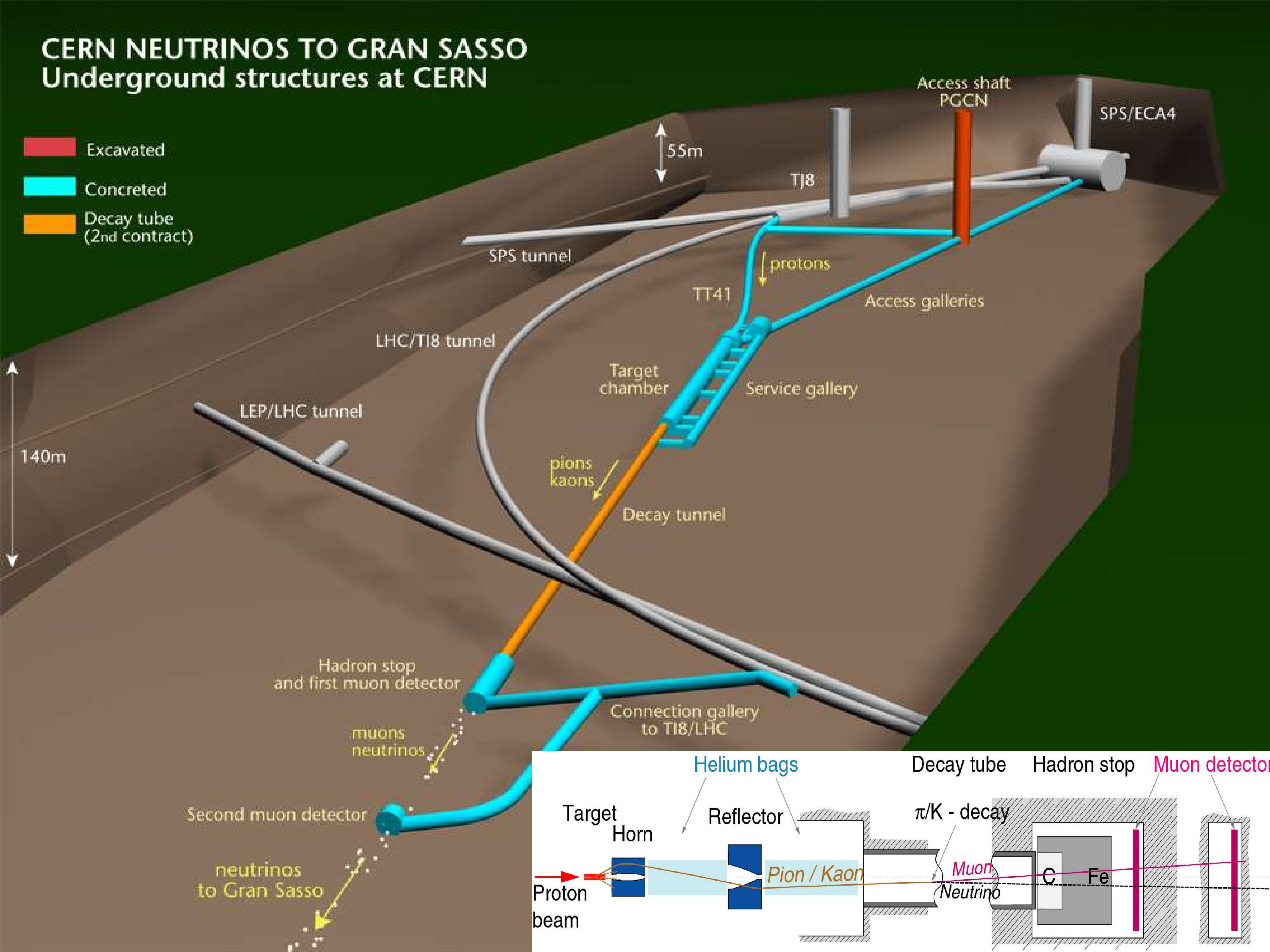
CNGS

CERN Neutrinos to Gran Sasso

Study Tau-neutrino appearance in Mu-neutrino beam through detection of charged Tau lepton.

Relatively high E neutrino beam

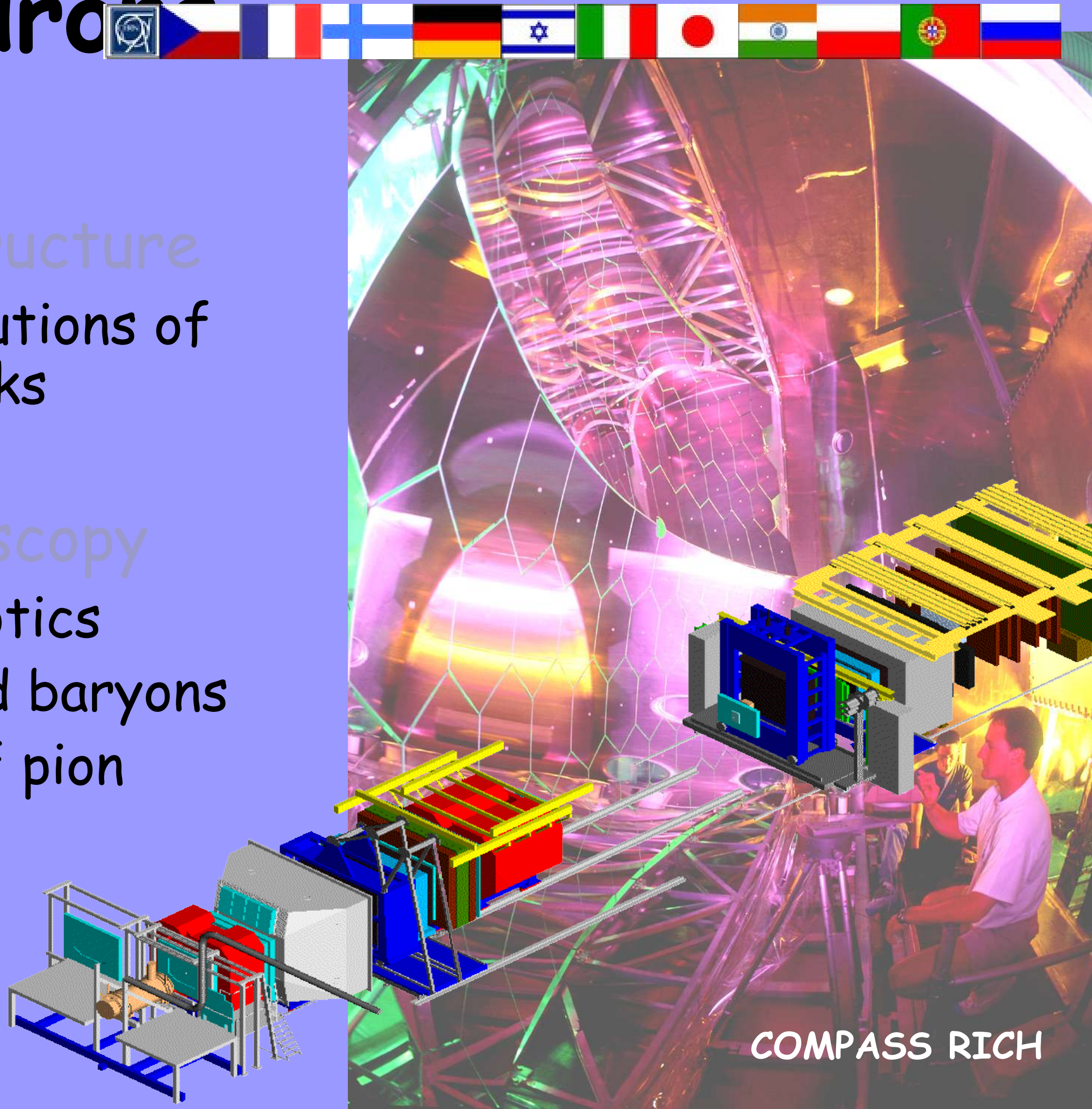

CERN to Gran Sasso Neutrino Beam
LEP - LHC
SPS
neutrino beam
PS
Germany
France
Austria
Switzerland
Italy
CERN
732 Km
Gran Sasso


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
Excavated
Concreted
Decay tube
(2nd contract)
55m
Access shaft
PGCN
SPS/ECA4
TJ8
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
LEP/LHC tunnel
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos
to Gran Sasso
Helium bags
Decay tube
Hadron stop
Muon detector
Target
Horn
Reflector
π/K - decay
Proton
beam
Pion / Kaon
Muon
Neutrino
C
Fe

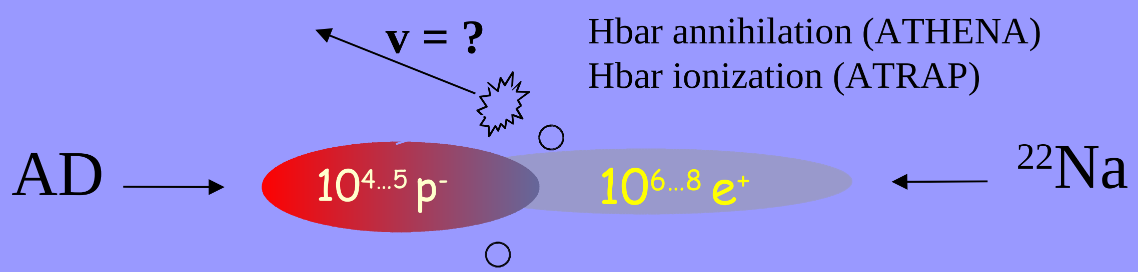
COMPASS: QCD structure of hadrons

Physics

- nucleon spin-structure
  - helicity distributions of gluons and quarks
  - transversity
- hadron spectroscopy
  - glue-balls & exotics
  - double-charmed baryons
  - polarisability of pion and kaons



AD: Antihydrogen Production (ATHENA, ATRAP)



Results (2002-2004) :

- Nested Penning traps:

  - **large number** of antihydrogen formed (> 1 mio)!!
  - formation process: high or low n-states ?
  - kinetic energy of Hbar (200 meV? 0.4 meV) ?

- Excited positronium collisions:

  - **very small** number of antihydrogen formed (< 100)
  - Hbar in high-n states
  - potentially smaller kinetic energy (< 0.4 meV)?

Long term perspectives:

1) **Hyperfine Structure** $\Delta E/E \sim 10^{-9} - 10^{-10}$

2) **1S-2S energy difference** $\Delta E/E \sim 10^{-12} - 10^{-16}$

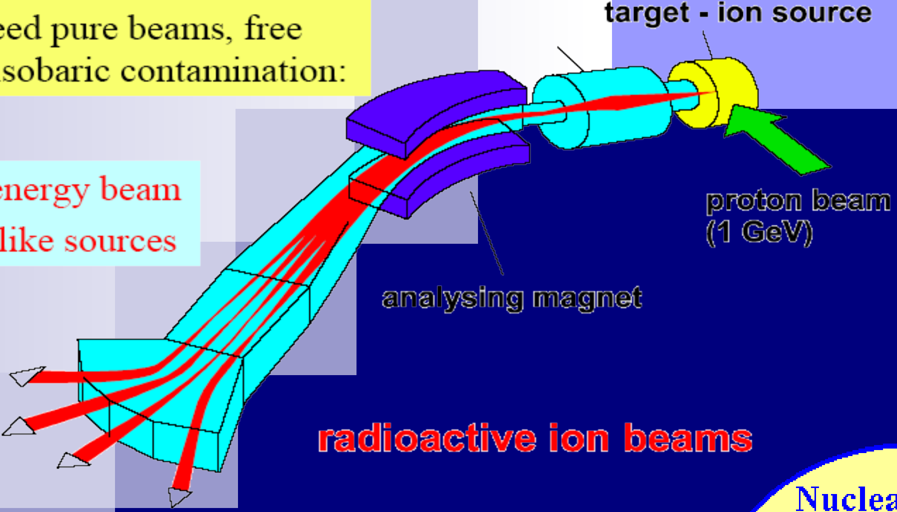
3) **Gravitation** $\Delta G/G \sim 10^{-3} - 10^{-7}$

ISOLDE: producing radioactive nuclei

ISOLDE
CERN

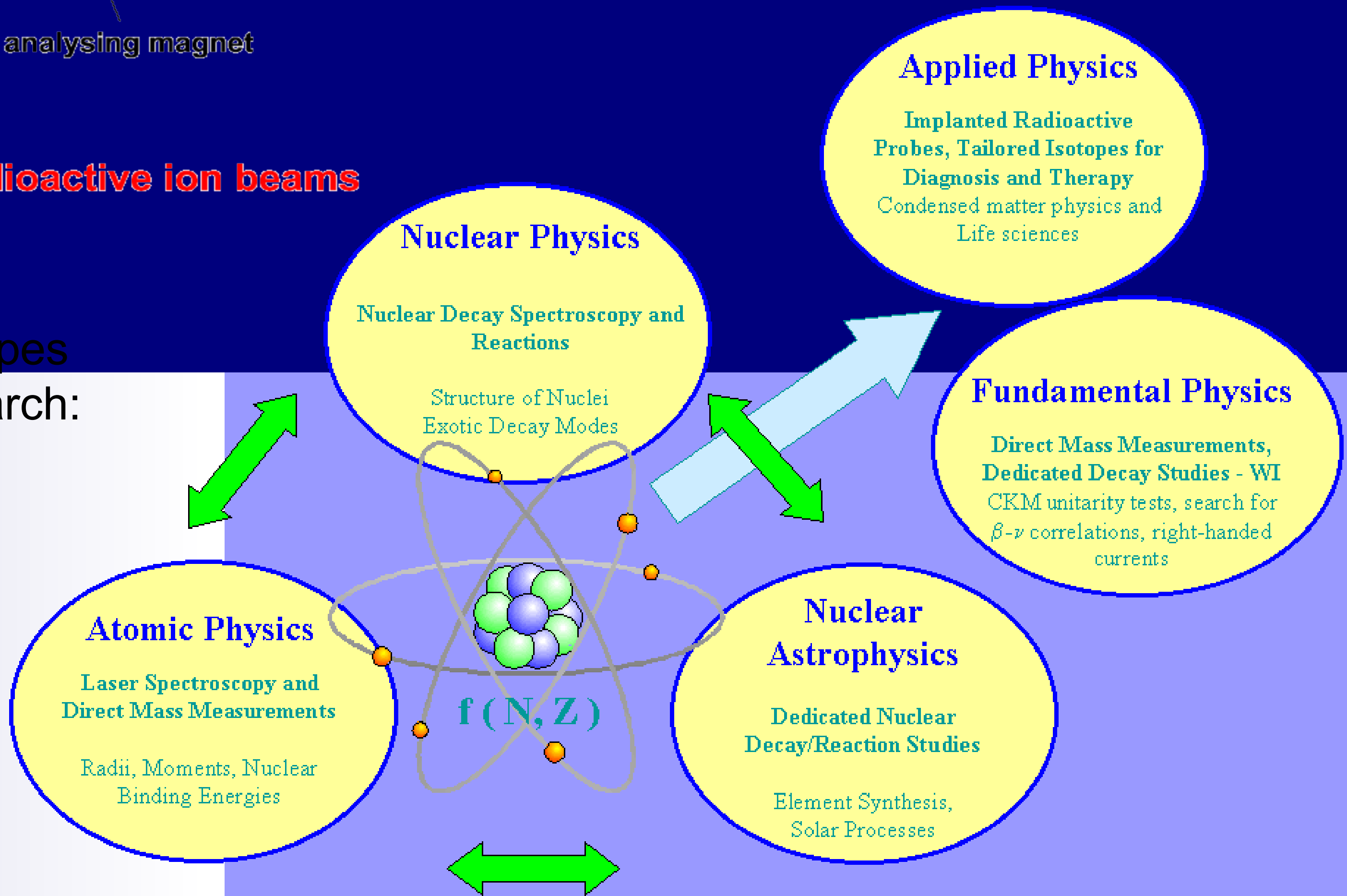
We need pure beams, free from isobaric contamination:

Low energy beam
Point like sources



Intense proton beams from PS-Booster

800 different isotopes available for research:



~450 users
(100 institutes)

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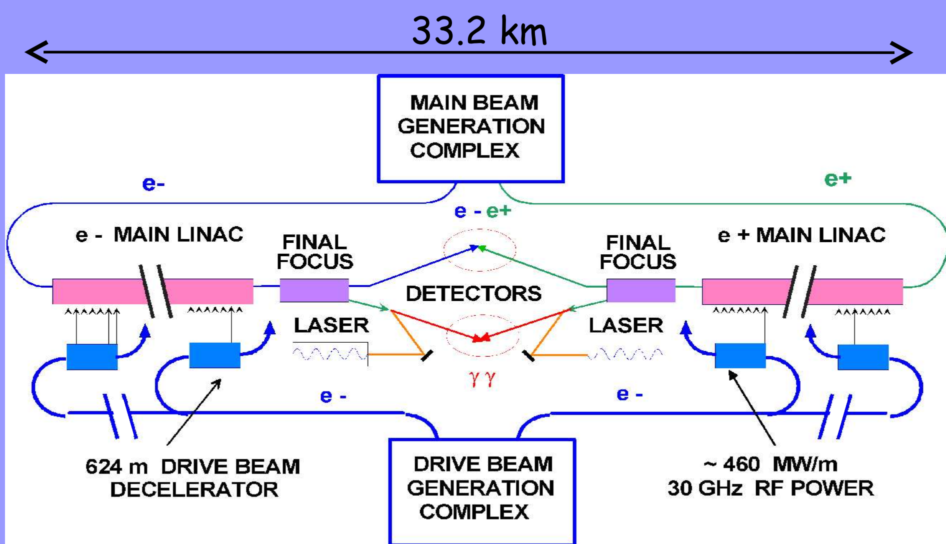
  - PAF, POFPA and the Strategy Group

Linear electron-positron Colliders

The CLIC concept (1986..!)

High current, low energy drive beam
RF power extracted and fed into accelerated beam ('warm structures')
Accelerated R&D programme with the aim to prove feasibility by 2010

Basic features of the CLIC scheme



Overall layout for a center of mass energy of 3 TeV/c

- **High acceleration gradient (150 MV/m)**
- **"Compact" collider-overall length 33 km**
  - **Normal conducting accelerating structures**
  - **High acceleration frequency (30 GHz)**
- **Two-Beam Acceleration Scheme**
  - **RF power generation at high frequency**
  - **Cost-effective & efficient (~ 10% overall)**

A multi-MW proton driver

Why? LHC luminosity upgrade? Eurisol? ν Superbeam? Beta-beam? Neutrino factory?

How? SPL? RCS?

When? Decision on Linac4 in 2006 is a possible/probable first step; major next steps > 2010, after CLIC feasibility/ILC decision

Physics with Megawatt

- Long-range programme in ν physics:
  superbeam, β beam, ν factory
- Complementary programme in μ physics:
  rare μ decays, μ properties, μ colliders?
- Next-generation facility for nuclear physics
  also tests of SM, nuclear astrophysics
- Synergy with CERN programme:
  LHC, CNGS ν, ISOLDE, heavy ions, β beam

Interesting project – and CERN would be a good place for it

From Medium Term Plan, CERN/2615

Legend: Approved (green bar) Under Consideration (black bar)

	2004	2005	2006	2007	2008	2009	2010
LHC Experiments							
Other LHC Experiments (e.g. MOEDAL, LHCf)							
Non-…							
R&D (Detector & Accelerator)							

- Will determine the future course of high energy physics
- Detector completion/upgrade/in particular for luminosity upgrade (→ 10^{35}) (~2014); requires R&D, machine and detectors

- Very limited neutrino programme (in scope)
- New initiatives include $K^+ \to \pi^+ \nu\nu$; why not $K^0 \to \pi^0 \nu\nu$..?
- New initiatives may include a long term neutrino programme
- CERN working groups Proton Accelerators for the Future (PAF) and Physics Opportunities at Future Proton Accelerators (POFPA) 2006 (or maybe 2007) onwards

EURISOL Design Study (including beta beams)

- Accelerator R&D includes EU funded networks, joint projects, design studies
- Linear colliders: Eurotev ('generic') and CLIC (CERN and partners collaboration', feasibility proof by 2009)

No fully-fledged Neutrino Factory Design Study yet (2008 if EU support)

LHC Programme is priority number one, collisions Summer 2007
LHC Programme most prominent and productive physics programme at CERN; scientific lifetime 15 years or more

Important decisions in 2010 (CERN budget should allow for new initiatives!); ‘big’ decisions to be taken in a global context, taking into account LHC results; CLIC feasibility; ILC progress;...
There is an independent (not budget wise...) case for ‘neutrino physics’

CERN Council will form a Strategy Group, helped by a Preparatory Group in order to formulate a strategy for Europe

Special Strategy Group meeting in Spring 2006 in (near) Berlin; followed by special Council meeting in July 2006 in Lisbon.