CERN, Avril 2008

La physique des particules élémentaires, le LHC, l'expérience CMS, le Modèle Standard

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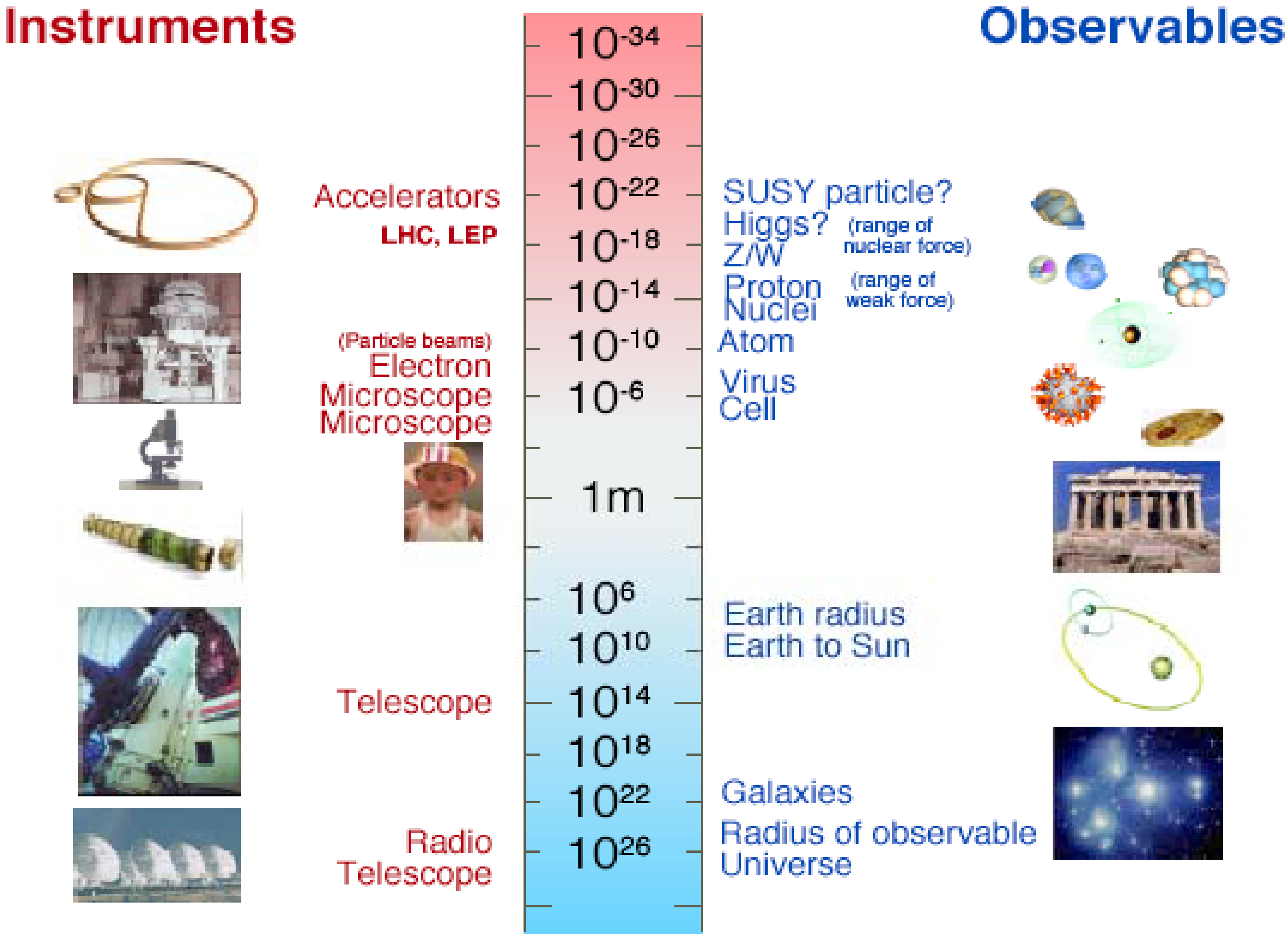
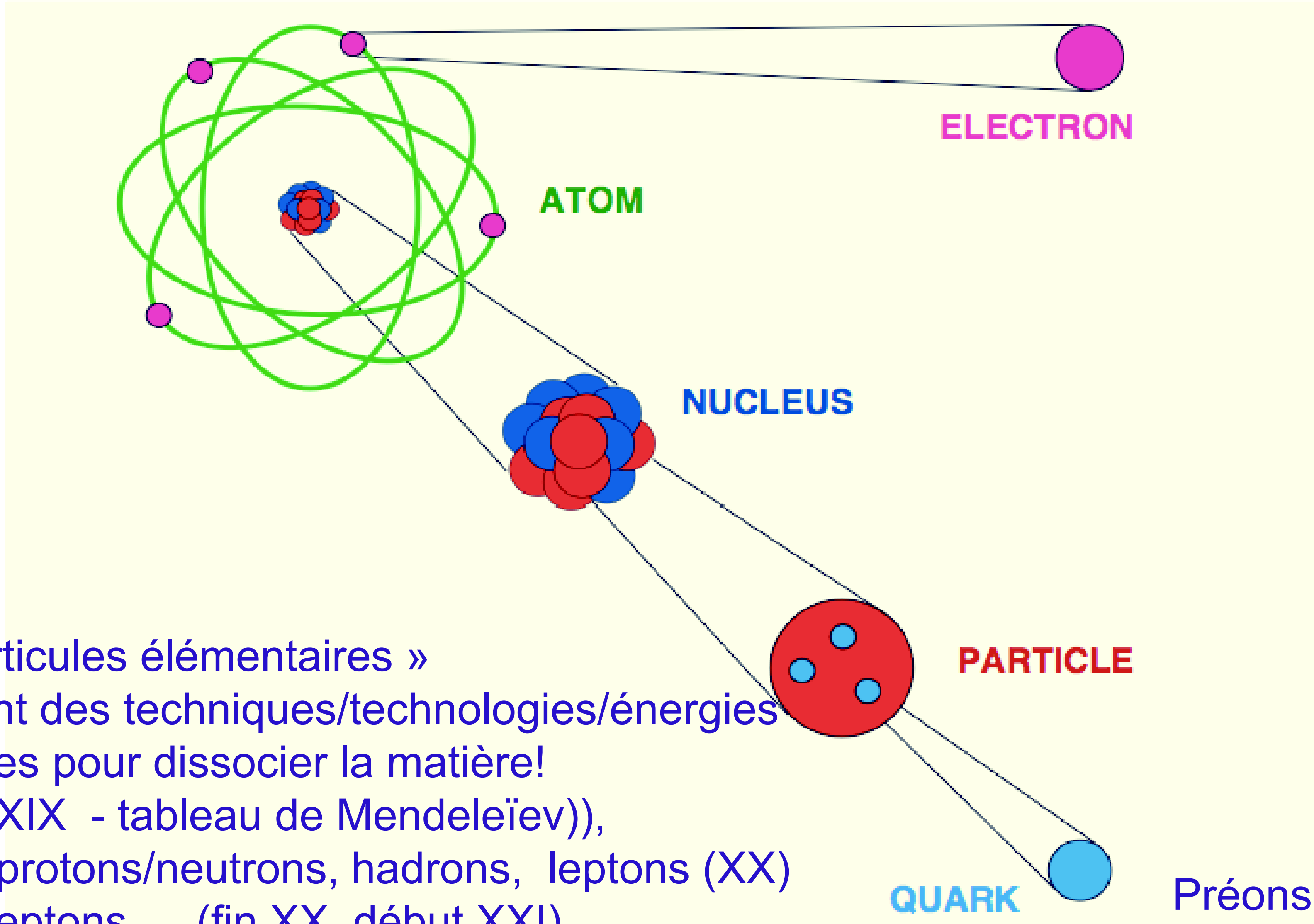
La taille des objets



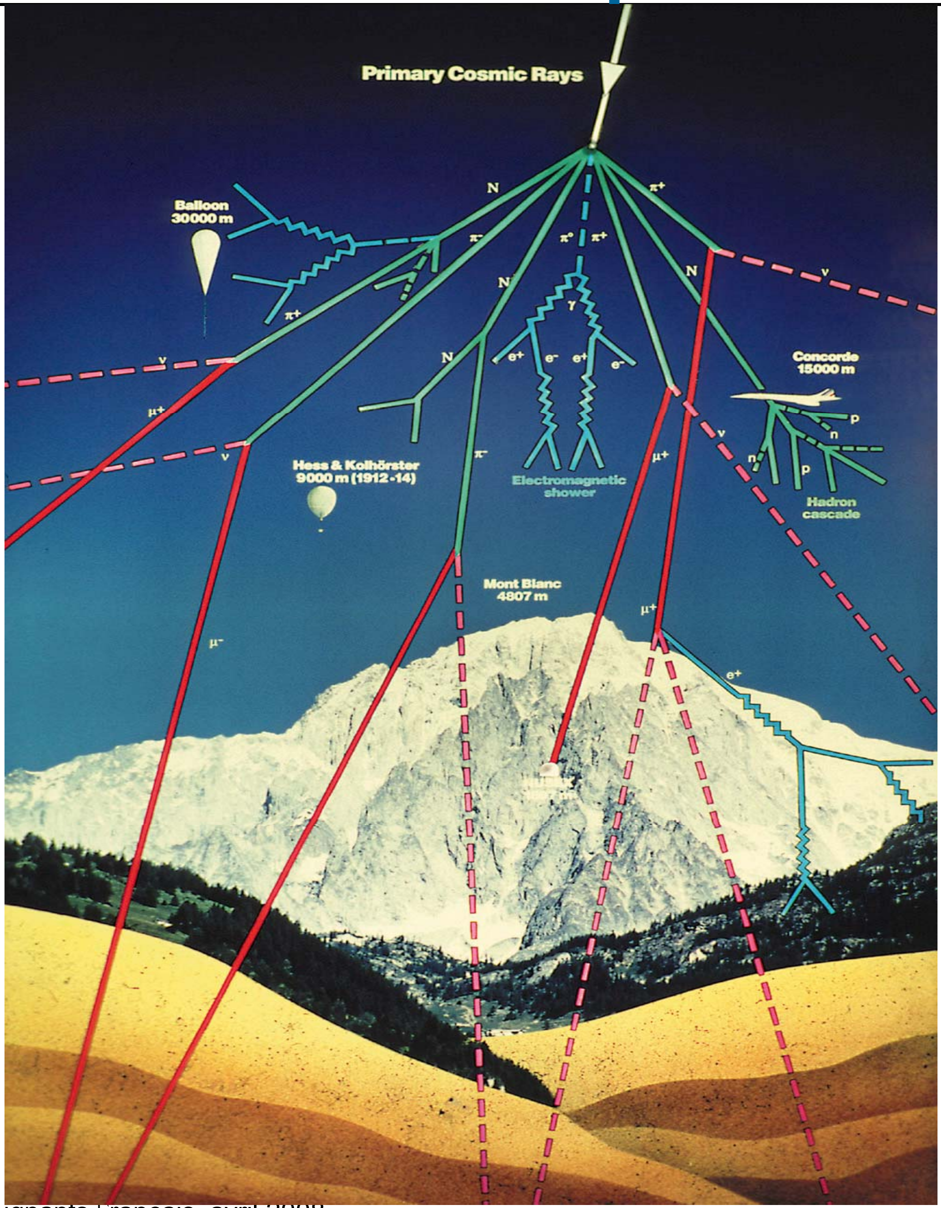
Les constituants de la matière



Les « particules élémentaires »
dépendent des techniques/technologies/énergies
disponibles pour dissocier la matière!
Atomes (XIX - tableau de Mendeleïev)),
Noyaux -protons/neutrons, hadrons, leptons (XX)
Quarks, leptons…..(fin XX, début XXI)

Préons?
Strings/cordes?

Rayons cosmiques: début de la physique des particules

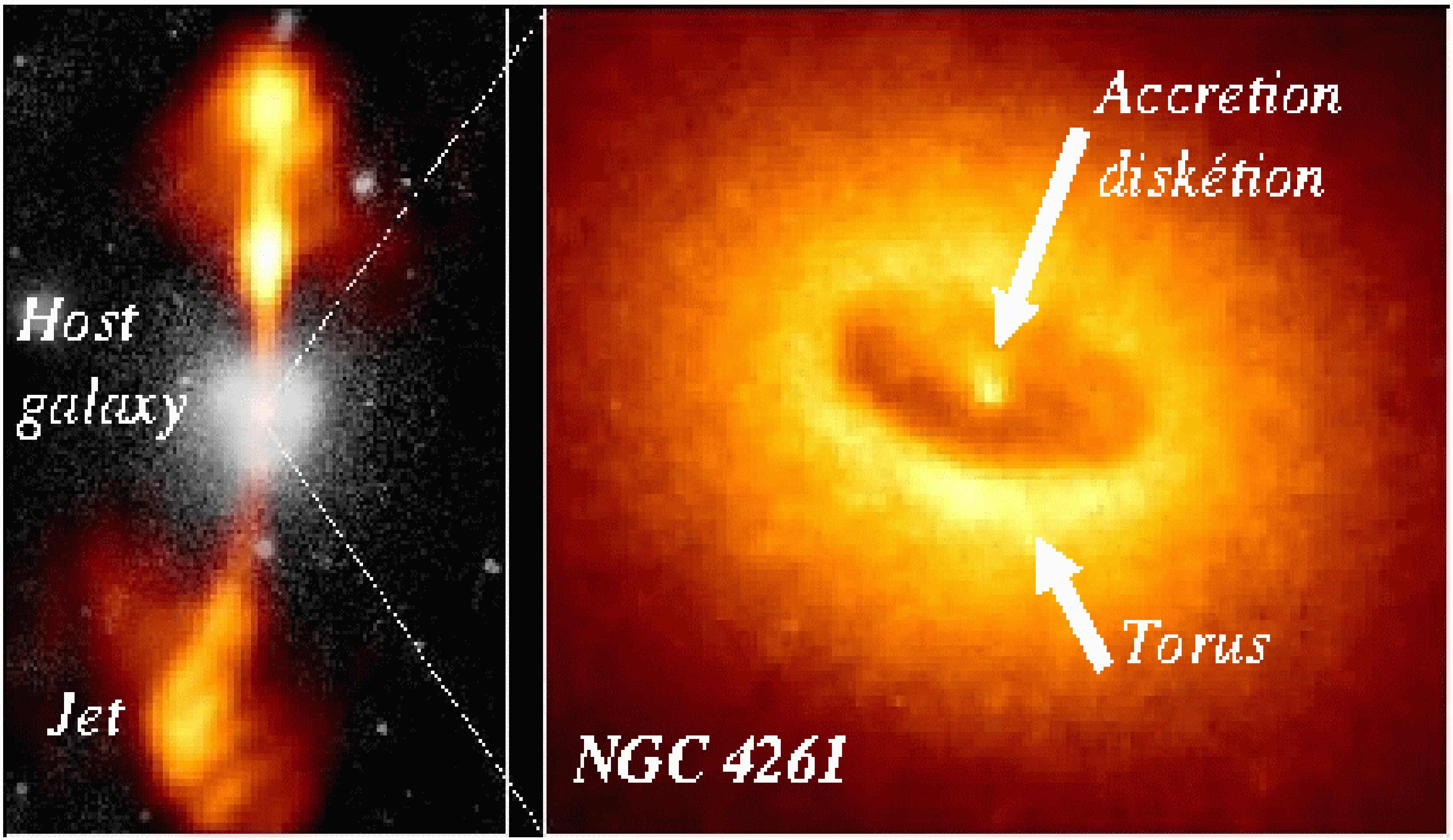


Premières observations:
Hess, début du XX siècle
chambres a ionisation
dans des ballons

Développement accéléré
dans les années ~1940-50:
muon,
mésons: pions, kaons…
hypérons: lambda, sigma…
dans des émulsions,
chambres de Wilson….

Etudes systématiques a
l'aide d'accélérateurs et de
chambres a bulles
puis de détecteurs et
spectromètres électroniques

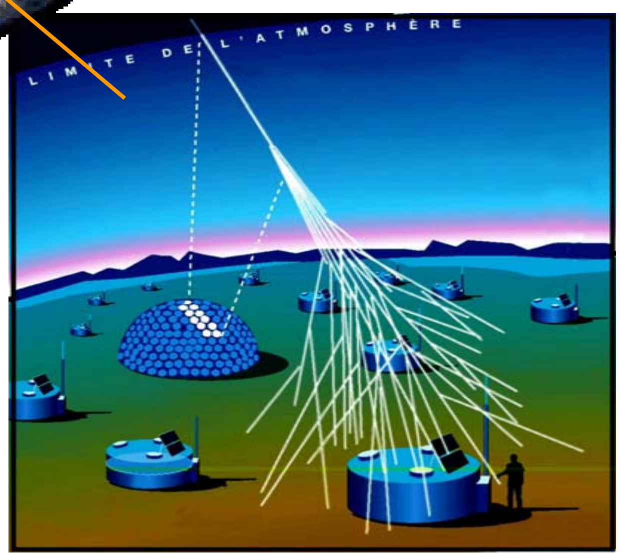
Possible sources of cosmic rays: Active Galactic Nuclei, Quasars, Jets…..

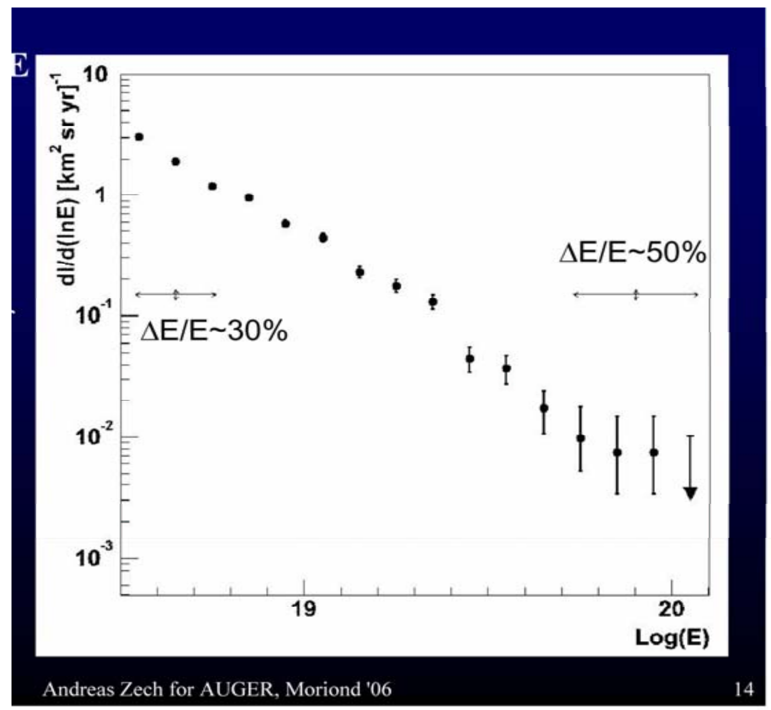


Le spectre des rayons cosmiques, l'observatoir Pierre Auger

Understand, identify the nature
of extreme high energy particles

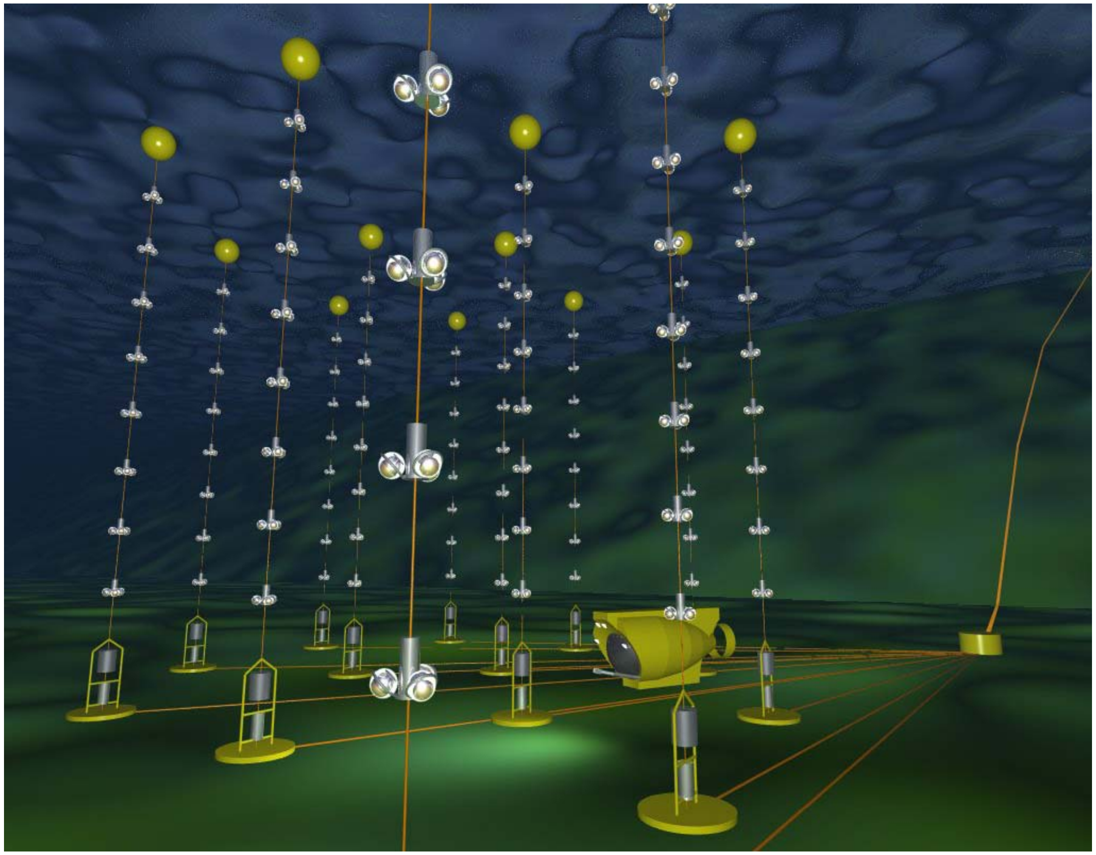
First results:
Energy spectrum above $10^{18.5}$ eV





Area 3000 km2
NEAR COMPLETION

L’expérience sous-marine ANTARES /Toulon



Expériences du même genre:
Lake Baïkal
Amanda & Ice-cube dans la glace de l'Antarctique, NESTOR (Péloponèse)….

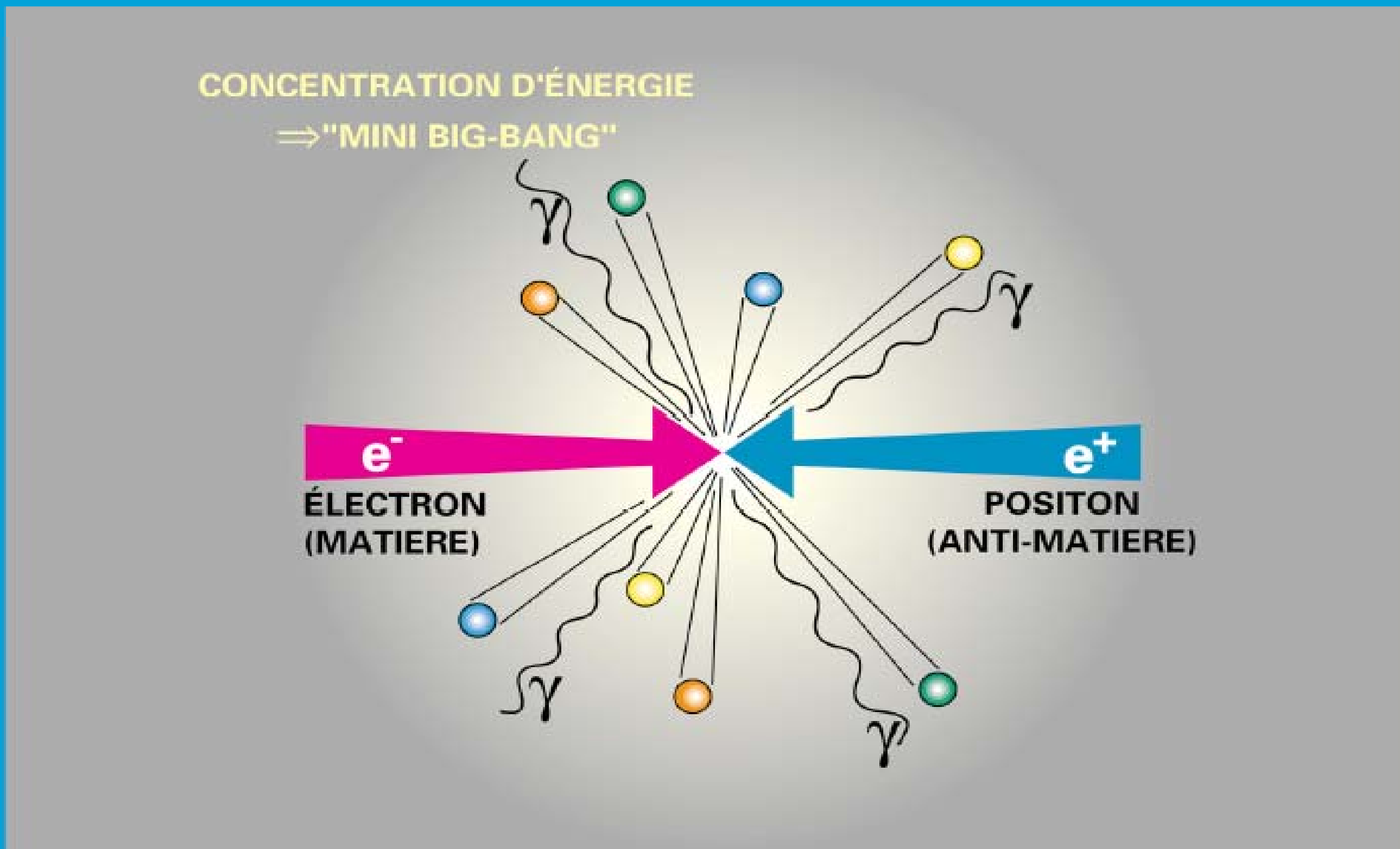
Les accélérateurs, collisions de particules - création de nouvelles…… mini Big Bang

I N 2 P 3

Institut National de Physique Nucléaire et de Physique des Particules

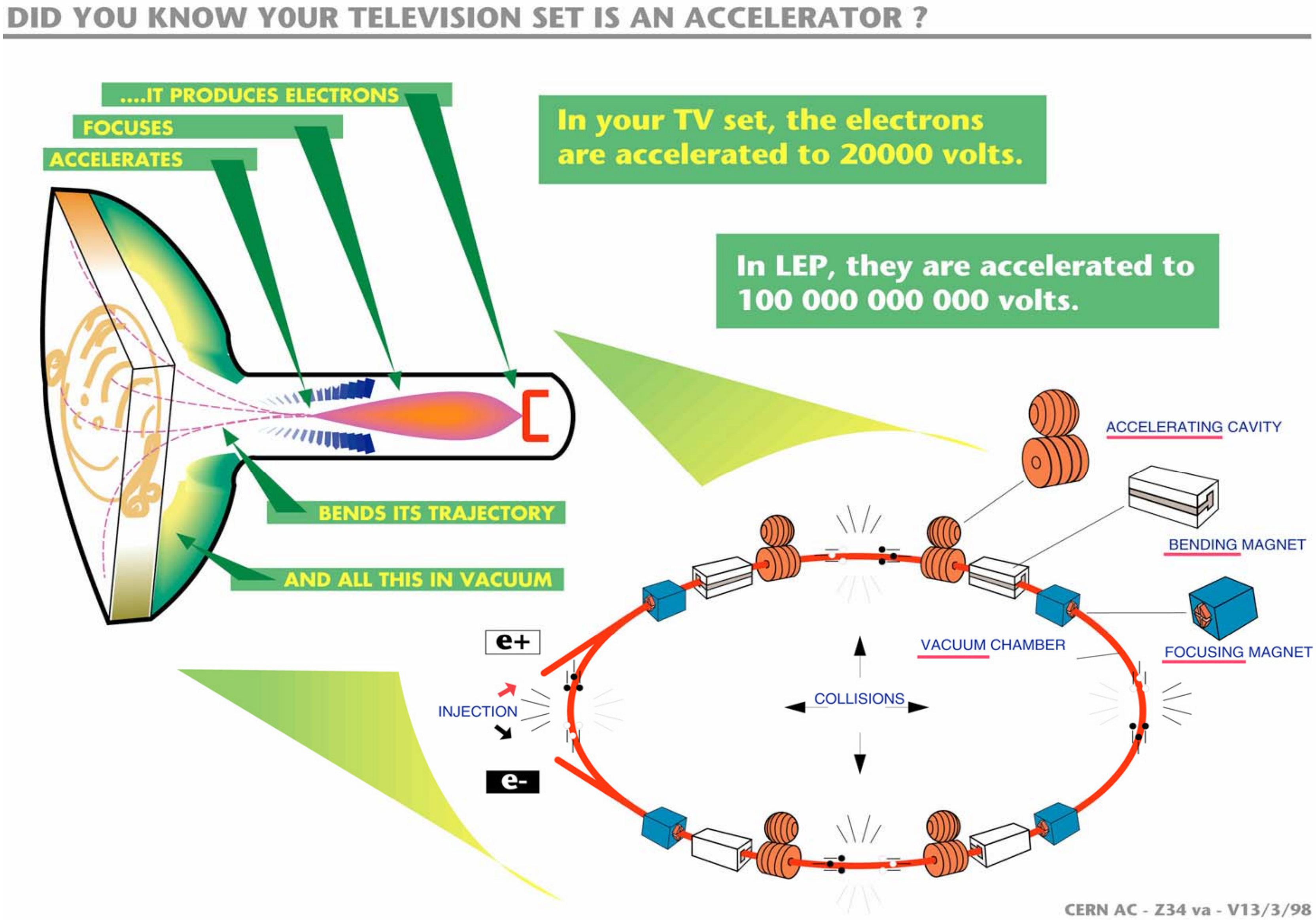
$E=mc^2$: annihilation →

création de particules connues, nouvelles



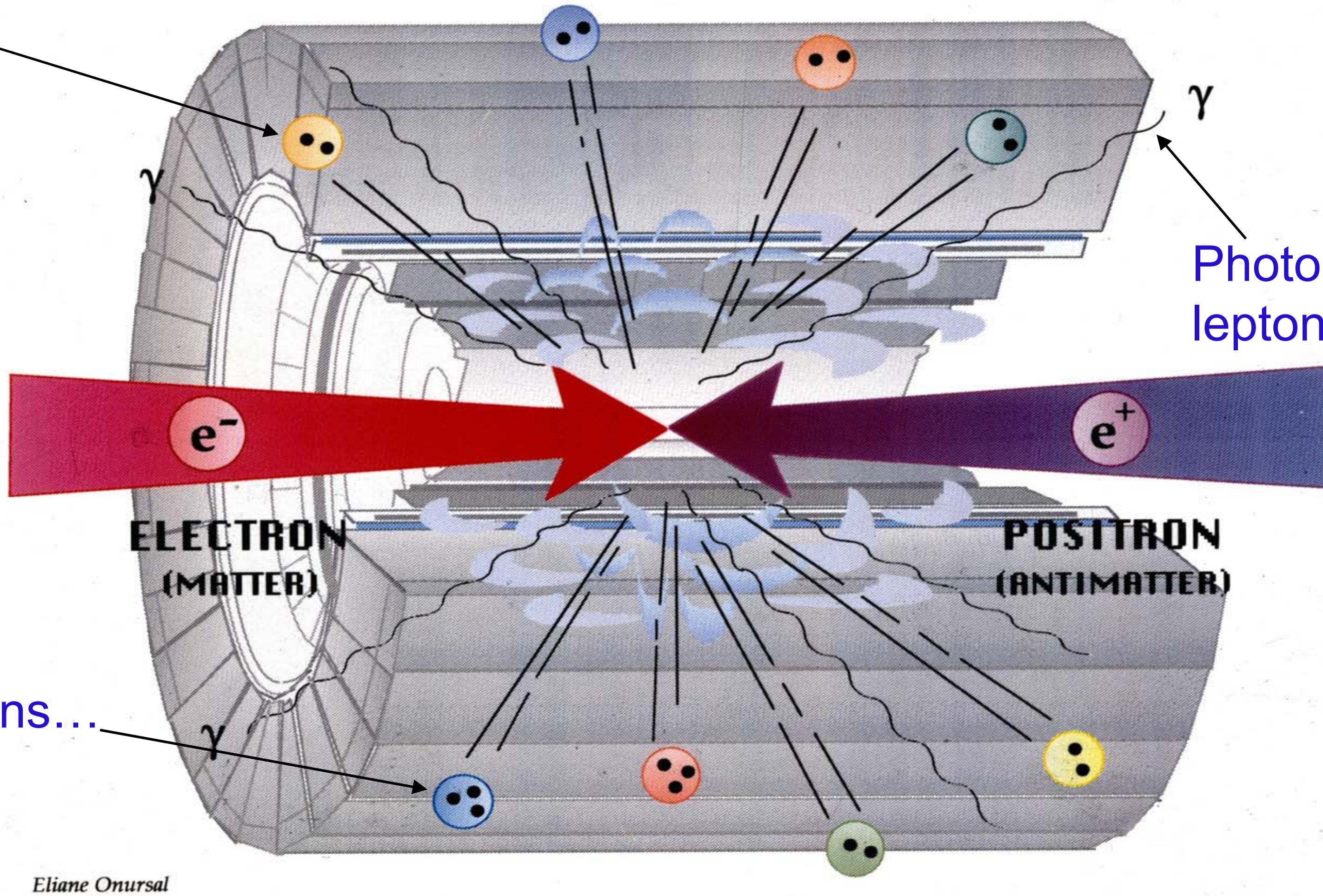
T7

Qu'est ce qu'un accélérateur?



Qu'est ce qu'un détecteur de particules?

Mésons: pions, kaons..

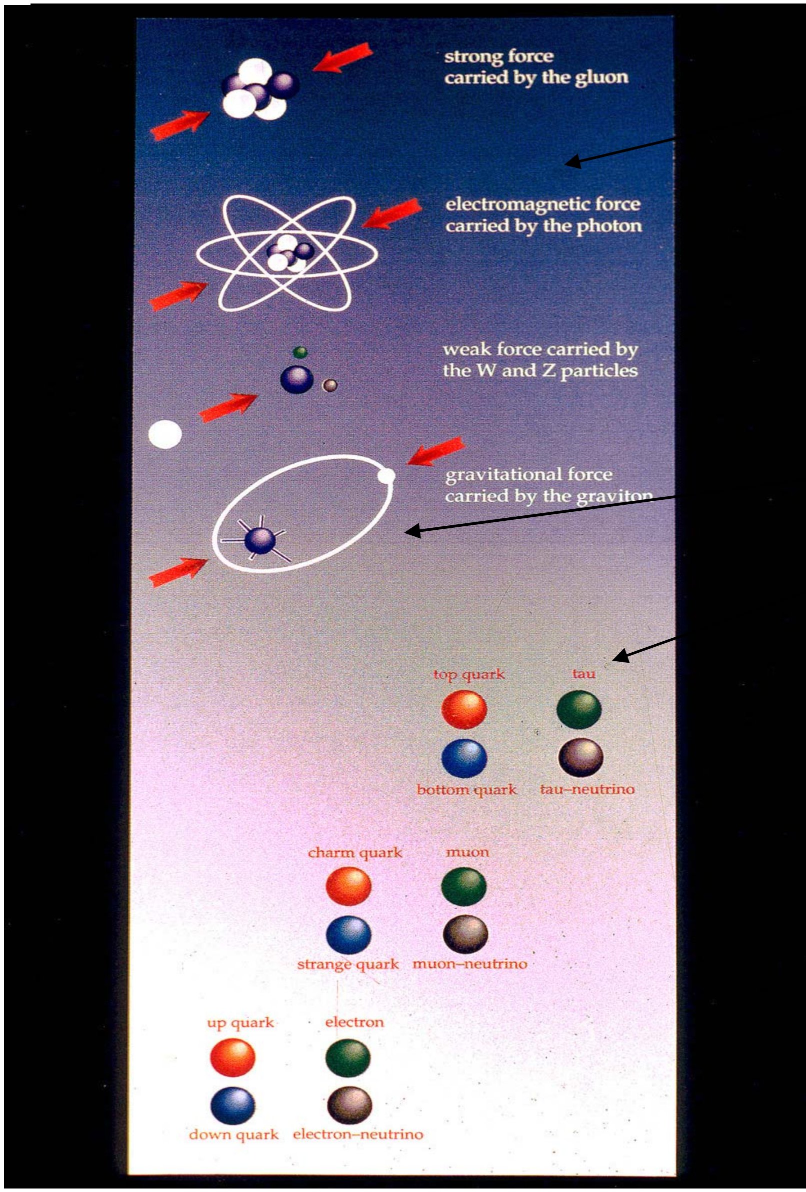


Photons, leptons…….

Nucléons,hypérons…

Les techniques prédominantes ces trentes dernières années sont des « spectromètres électroniques » associés a des accélérateurs-collisionneurs

Les particules élémentaires et les forces fondamentales

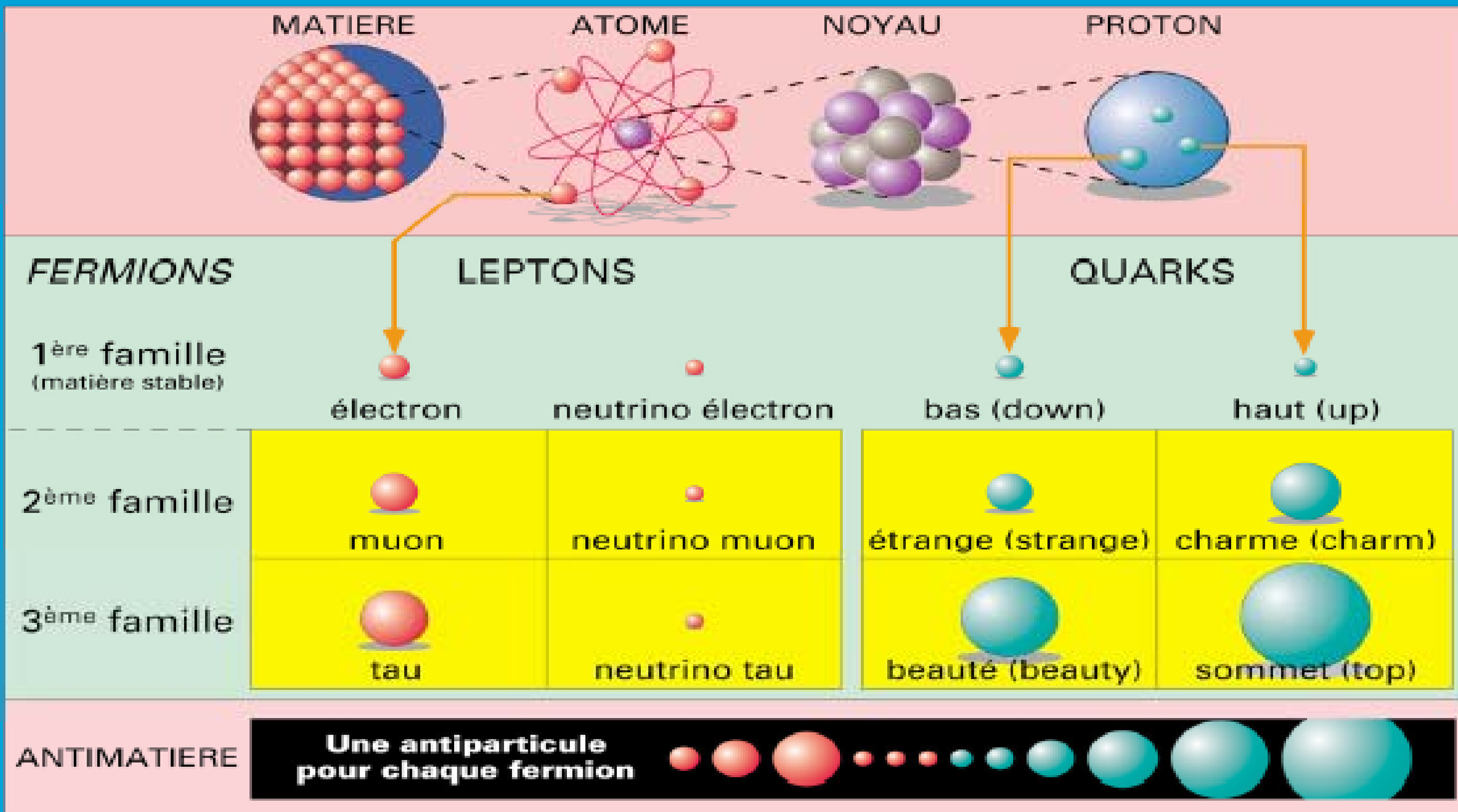


Situation dans les années ~1940 a 70
Unification électro-faible ~70 ~ 90/2000
Modèle WSGW,
Expériences UA1/2, neutrinos, PETRA
LEP, Tevatron

Gravitation….strings/cordes?

développement dans les années ~1970 a 2000
Gell-Mann, Zweig, eight-fold way,
modèle des quarks « mathématiques »,
Systématique des hadrons - multiplets de SU(3)
Diffusion profondément inélastique
Modèle des partons/quarks,
Quark c (GIM) 1974 et le lepton τ (74/76)
Quark b (76 - 77), nombres de neutrinos/LEP
Quark top ~1995 - au Tevatron

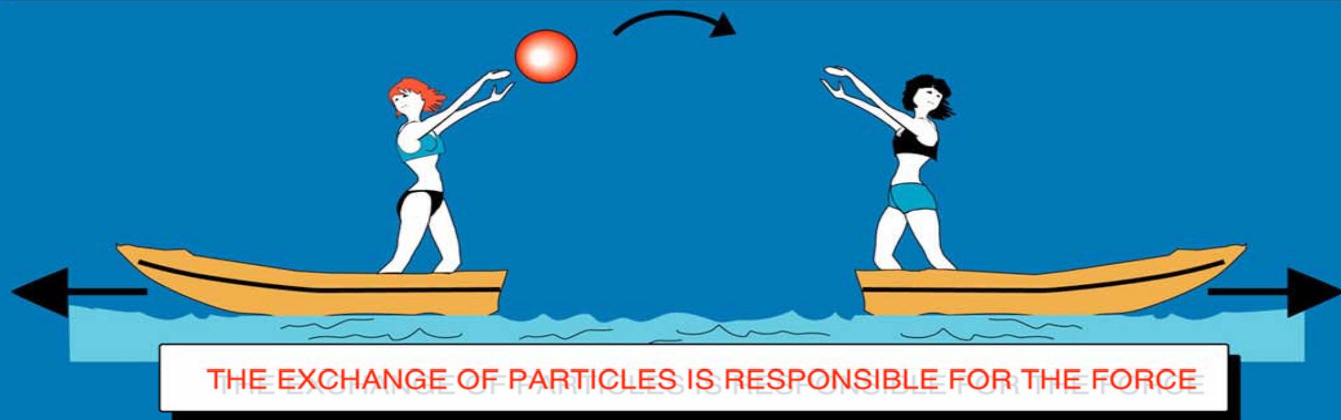
Les constituants élémentaires de la matière



Les interactions fondamentales/propriétés principales

The forces in Nature

TYPE	INTENSITY OF FORCES (DECREASING ORDER)	BINDING PARTICLE (FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1	GLUONS (NO MASS)	ATOMIC NUCLEUS
ELECTRO -MAGNETIC FORCE	~ 10^{-3}	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	~ 10^{-5}	BOSONS Z^{o} , W+ , W- (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	~ 10^{-38}	GRAVITONS (?)	HEAVENLY BODIES



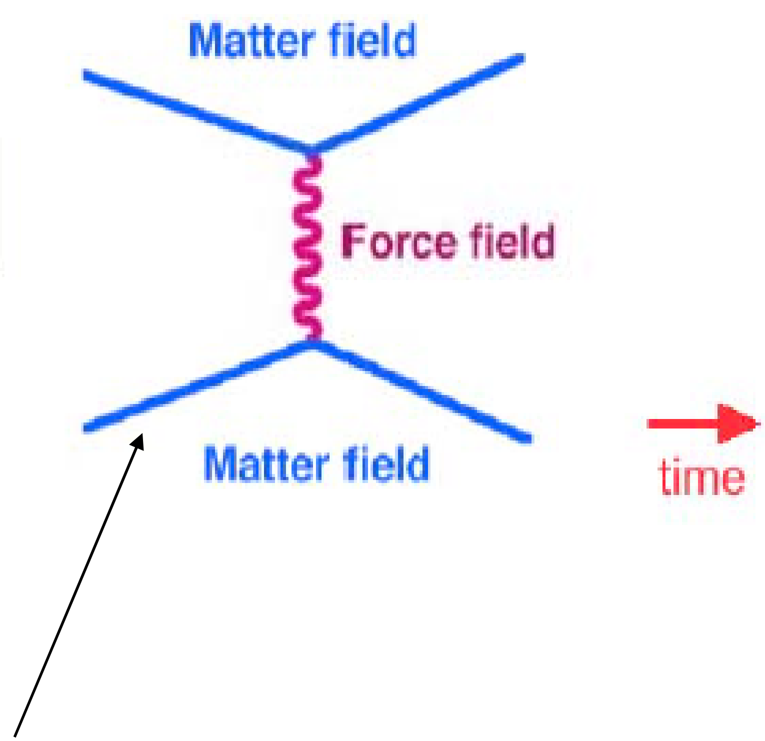
CERN AC _Z04_ V25/8/1992

Comment les forces se transmetent-elles en théorie des champs?

Forces are transmitted by the exchange of (force) particles between (matter) particles

Explains the differences between forces
To verify : look for force particles

« diagramme de Feynman »



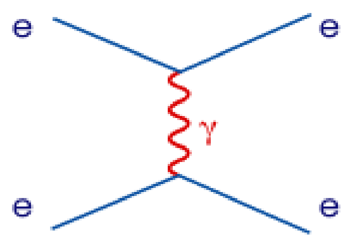
$$\text{Range of a Force} \ \alpha \ \frac{1}{\text{mass of exchange particle}}$$

Observe 4 forces
There are 4 different types of force fields

Interaction entre particules de matière par échange de quantas du champs de force

Fundamental interactions - Feynman diagrams

Electromagnetic interaction : electrons exchanging a photon.



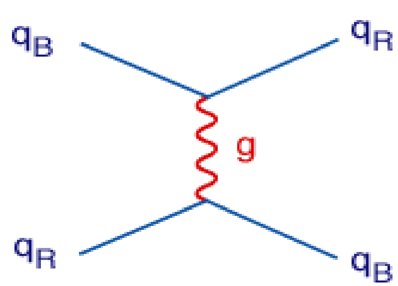
$R_{force} \sim 1/M_{\text{field quantum}}$

couplage e - par la charge électrique
le photon est le quantum du champs

Weak interactions : quark and lepton exchanging a W or a Z.

couplage par la charge faible g
g ~ e;
théorie électrofaible unifiée GWSW
trois quantas: W^+, W^-, Z

Strong interaction : quarks exchanging a gluon and colour.



couplage par la charge « forte » de couleur -
8 quantas: les gluons,
la QCD

Features of Fundamental Forces

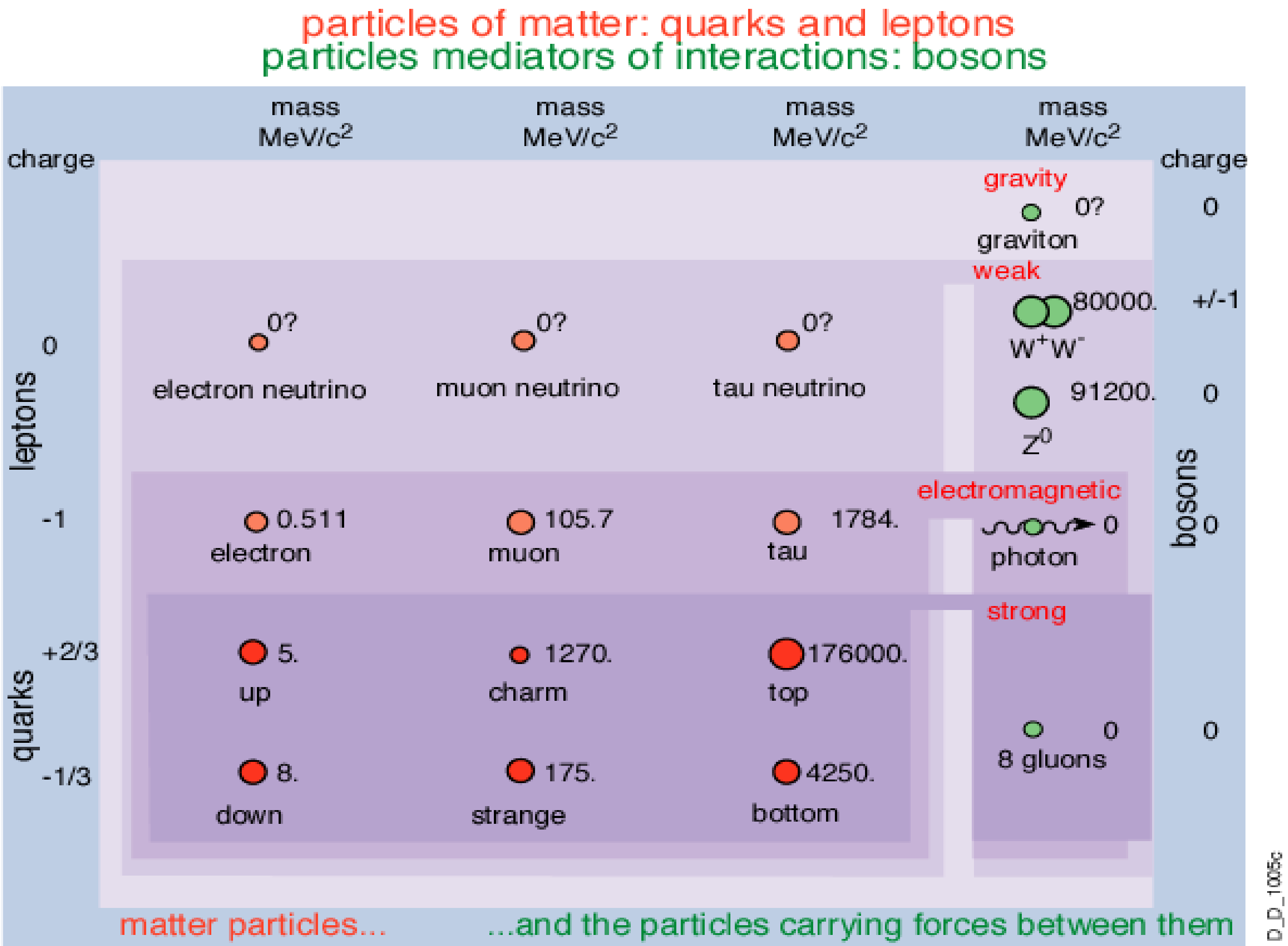
What characterizes a force ? Strength, range and source charge of the field.

Interaction	Exchanged quantum *(source ch)*	Range (m)	Relative Strength	Examples in nature
Strong	gluon *colour*	10^{-15}	1	proton (quarks)
Electromagnetic	photon *electric*		$<10^{-2}$	atoms
Weak	W, Z *hypercharge*	$<10^{-17}$	10^{-5}	radioactivity
Gravity	graviton ? *mass*		10^{-38}	solar system

Ratio of electrical to gravitational force between two protons is ~ 10^{38} !!

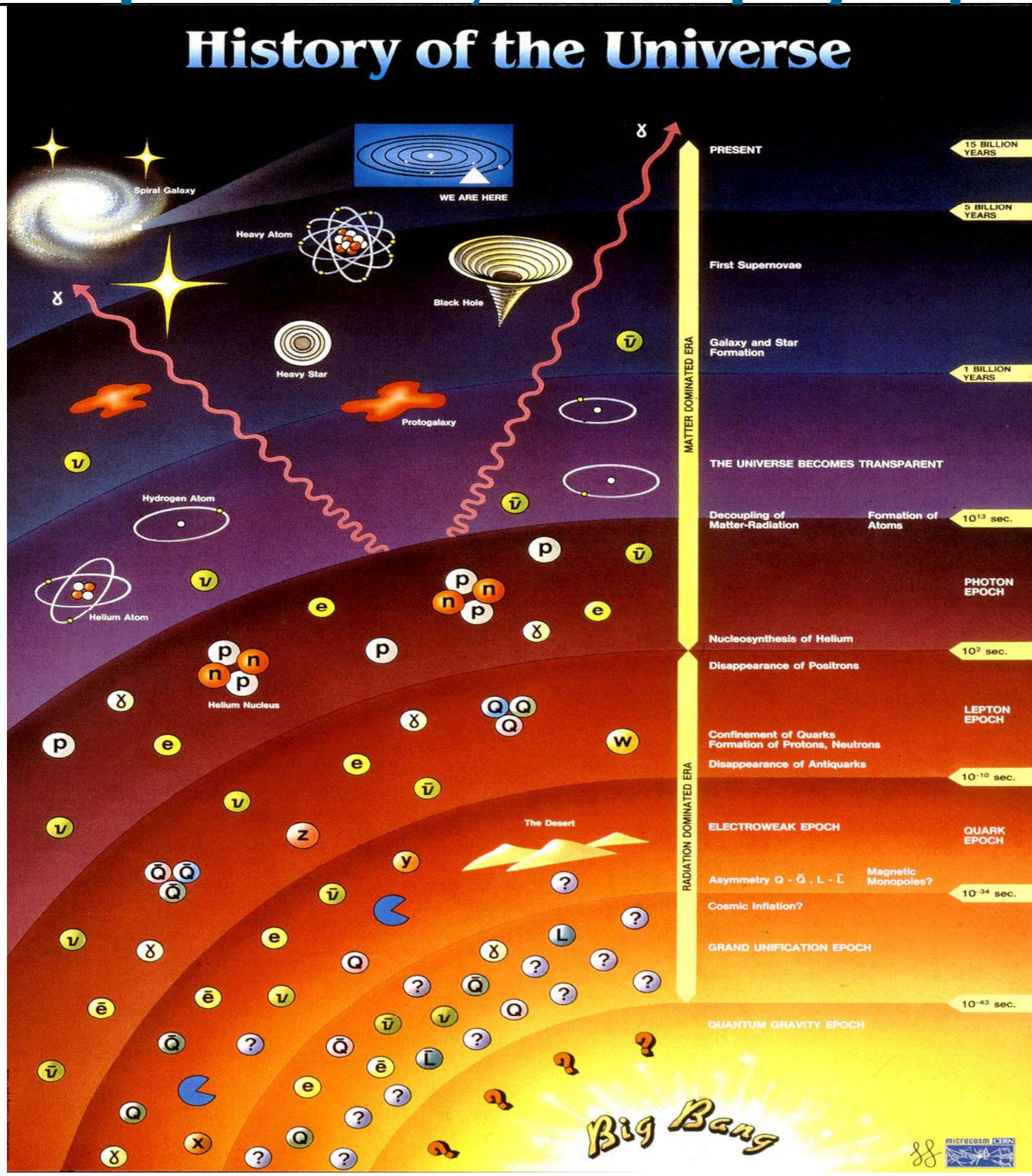
Can such different forces have the same origin ??

Les particules élémentaires situation fin du XX siècle

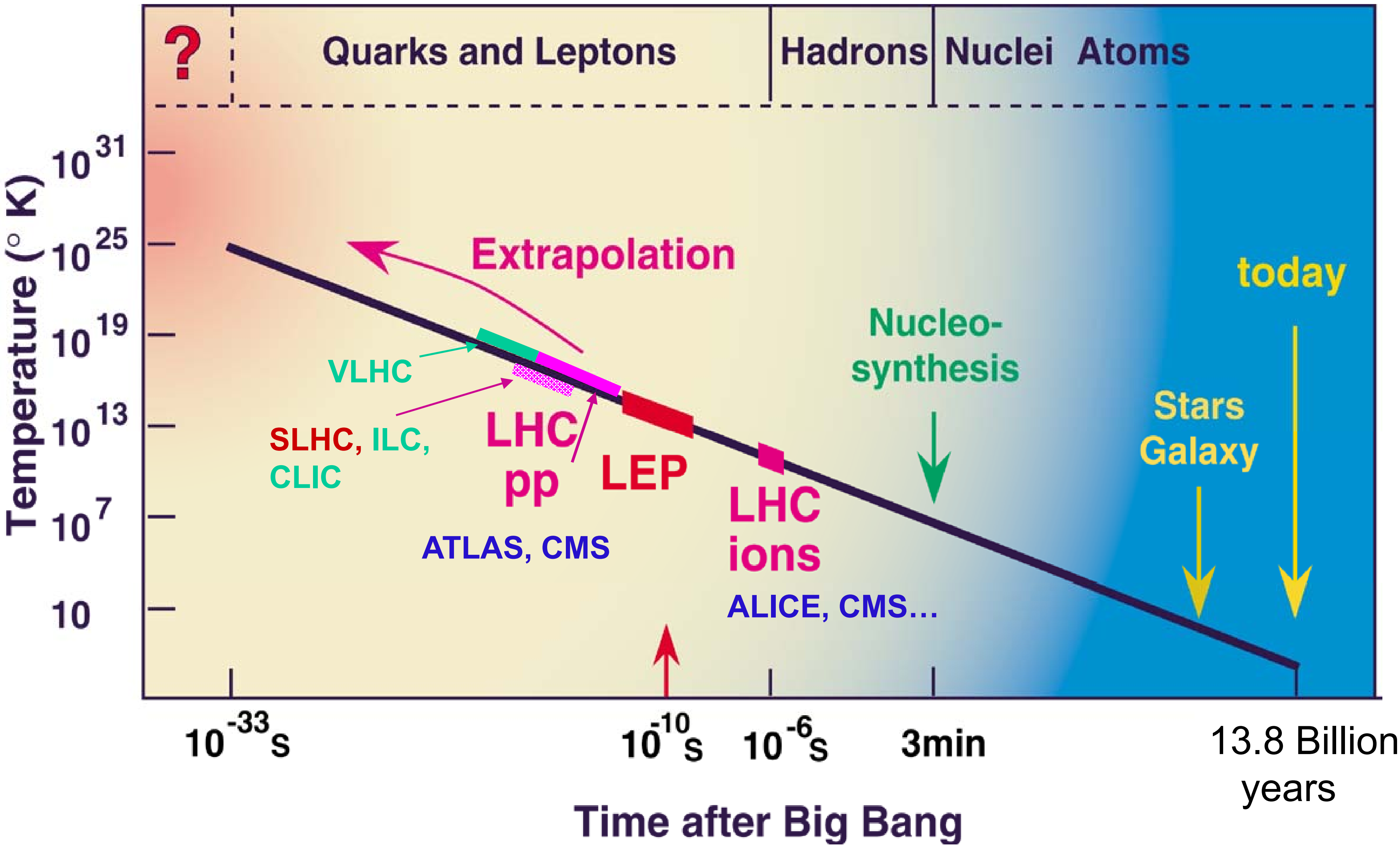


in the Standard Model we expect one more (hypothetical) particle endowing bosons, quarks and leptons with mass : the Higgs boson

L’Histoire de l’Univers, la physique des particules, l’astrophysique



Connecting particle physics, the LHC and the Universe: towards the origin - the Big Bang



Vers le Modèle Standard: l'unification électro-faible

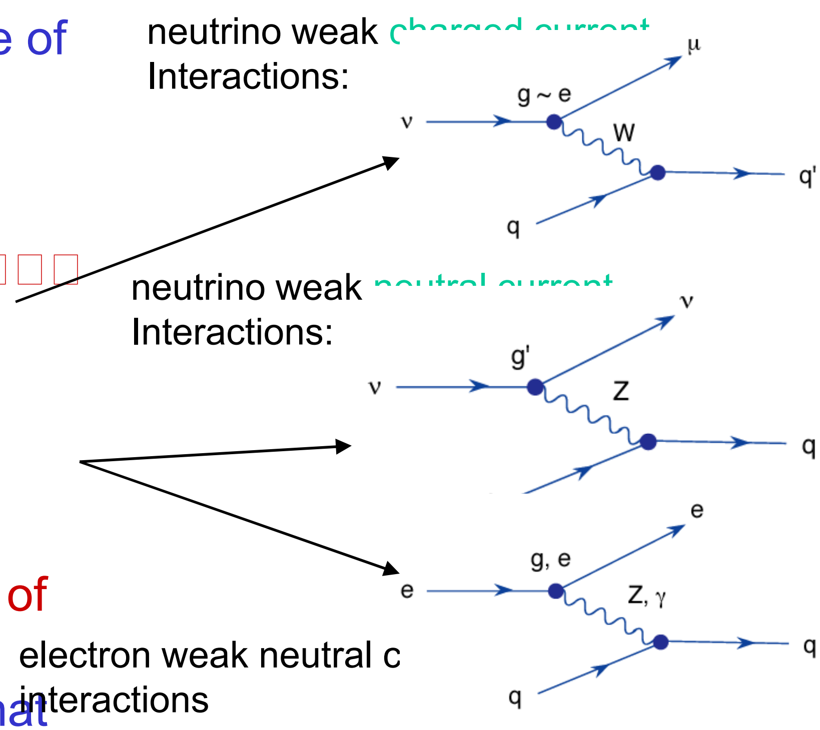
In 1966/67 S. Weinberg, A. Salam, J. Ward, S.L. Glashow… proposed a theory providing a unified description of electromagnetic and weak interactions with a Higgs mechanism to give mass to the weak quanta;
the short range of weak interactions ($< 10^{-15}$cm) implied large masses for the W^+ and W^- force carriers as $R_{force} \sim 1/M_{\text{field quantum}}$

- This unified scheme however implied the existence of four field quanta:

γ - which [illegible],

W^+ and W^- - for charged weak interactions ("weak charged currents"),

Z^0 - a sort of "heavy photon" - implying the existence of "neutral current" weak interactions
i.e. of a new type of weak interactions, unknown at that time!



Expectations for W, Z

- In 1973 discovery of neutral-current neutrino interactions at CERN (in Gargamelle):

- In 1970 the GIM mechanism was invented, the charm quark introduced and found in 1974 as J/ψ - the most "tangible" evidence for existence of quarks, then the Y system with b-quarks in ~1977;

- in 1973 QCD was introduced as the theory of colored quarks and gluons

- in 1979 Weinberg, Salam and Glashow got the Nobel Prize for the electro-weak unification and the prediction of the existence of the Z

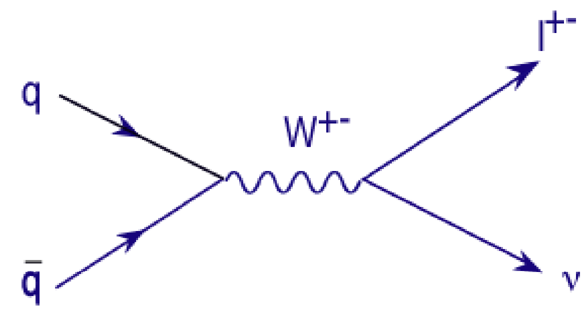
➡ ……things were getting very serious!

W, Z production, required collider cm energy

Main W and Z production processes at a proton – antiproton collider:

$$u + \bar{d} \rightarrow W^{+} \qquad \bar{u} + d \rightarrow W^{-}$$

$$u + \bar{u} \rightarrow Z \qquad d + \bar{d} \rightarrow Z$$



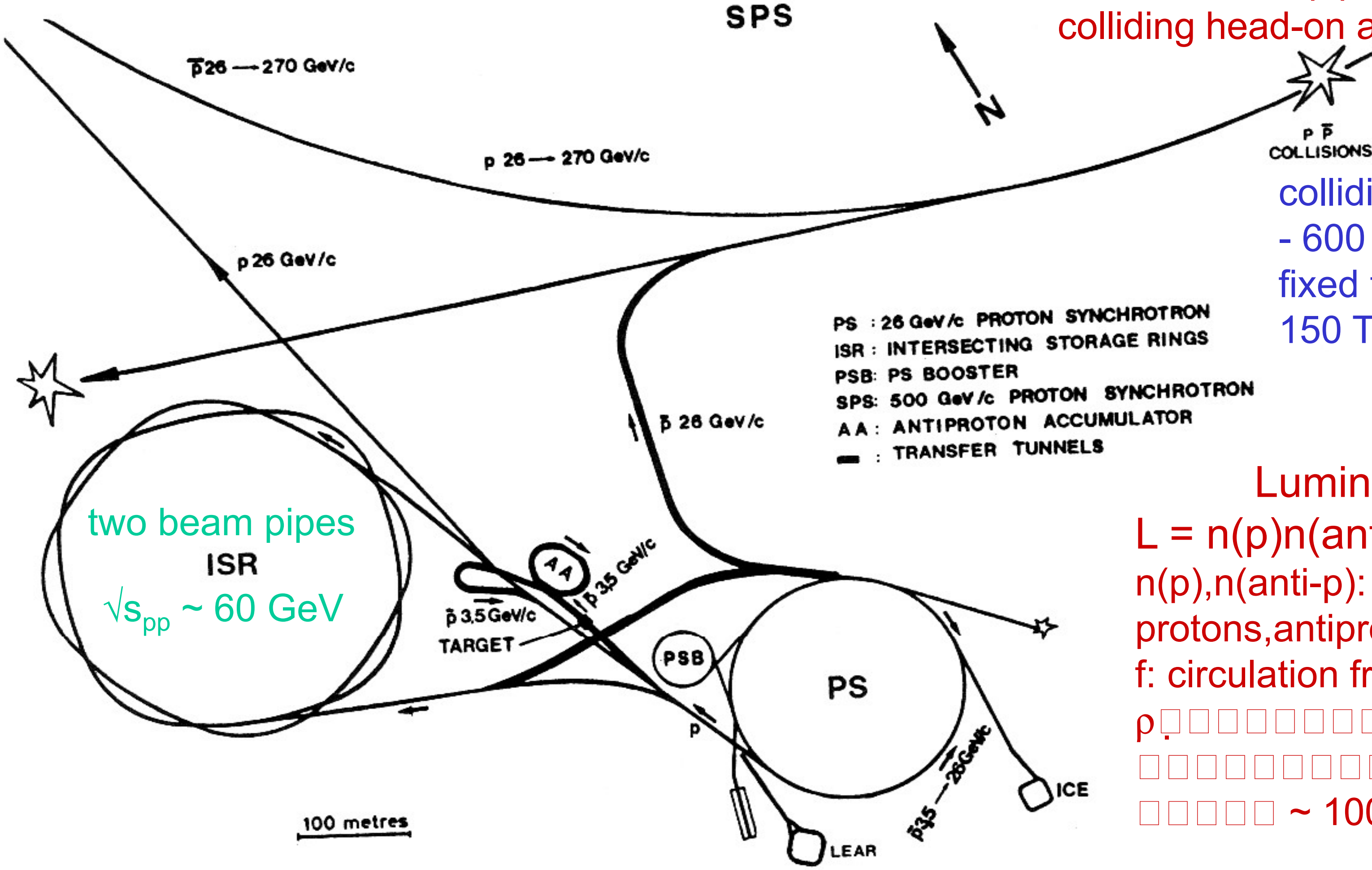
- Energy requirements:
  proton (antiproton) momentum at high energies is carried by gluons (~ 50%) and valence quarks (antiquarks) (~ 50%) thus:

quark momentum ~ (1/6) proton momentum

➡ collider energy ≈ 6 x boson mass ≈ 500 – 600 GeV

The CERN antiproton-proton collider complex

protons and antiprotons counter-rotating
in same beam pipe - as in an e+e- machine!
colliding head-on at $\sqrt{s}$ ~ 500 - 600 GeV



colliding head-on at $\sqrt{s}$ ~ 500 - 600 GeV is equivalent to a fixed target experiment at ~ 150 TeV beam energy

Luminosity:

$L = n(p)n(\text{anti-}p)f/(4\pi\rho^2)$

n(p),n(anti-p): numbers of protons,antiprotons per bunch

f: circulation frequency

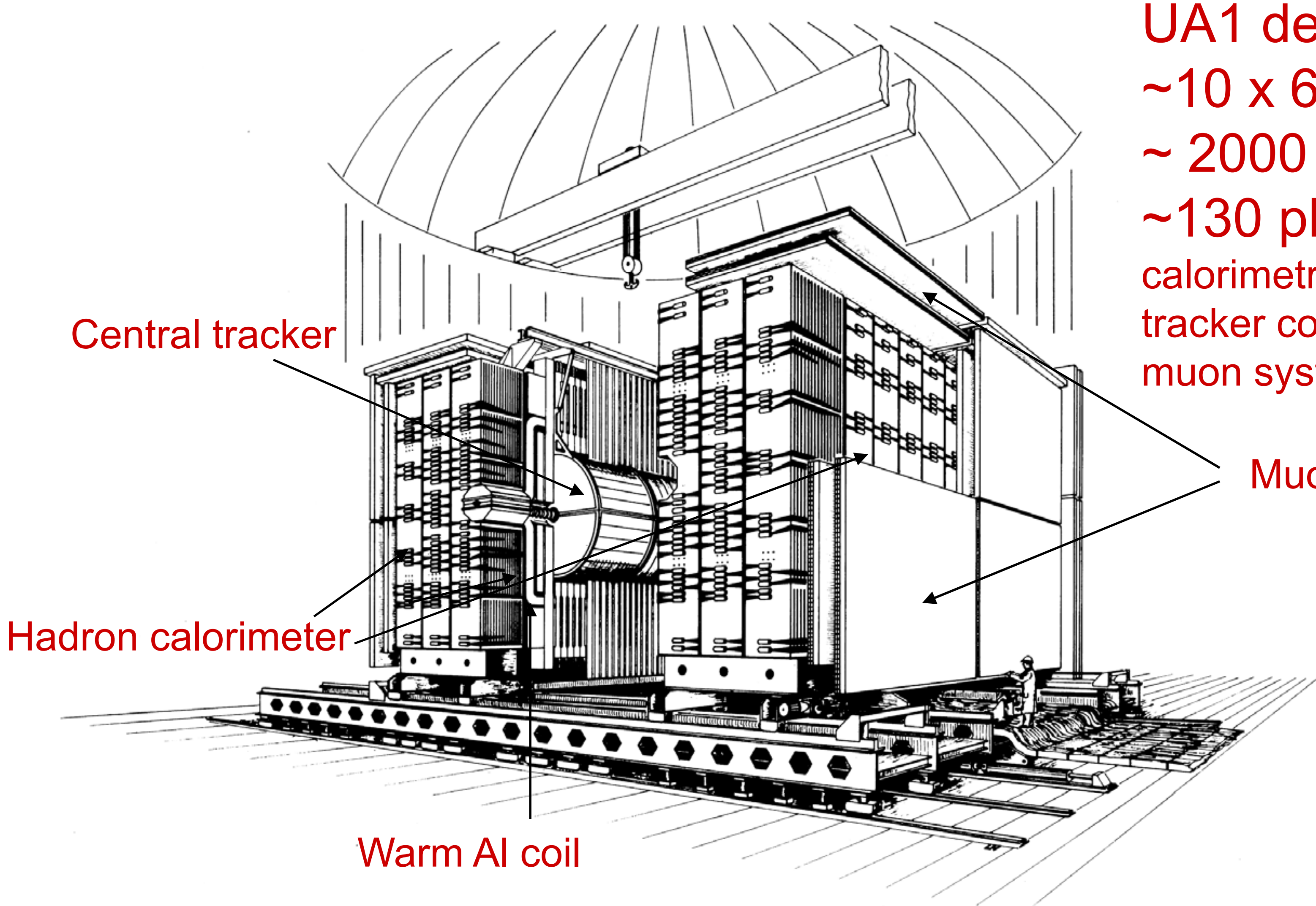
ρ

~ 100 μm

The transformation of the SPS into a collider was accomplished by the summer of 1981

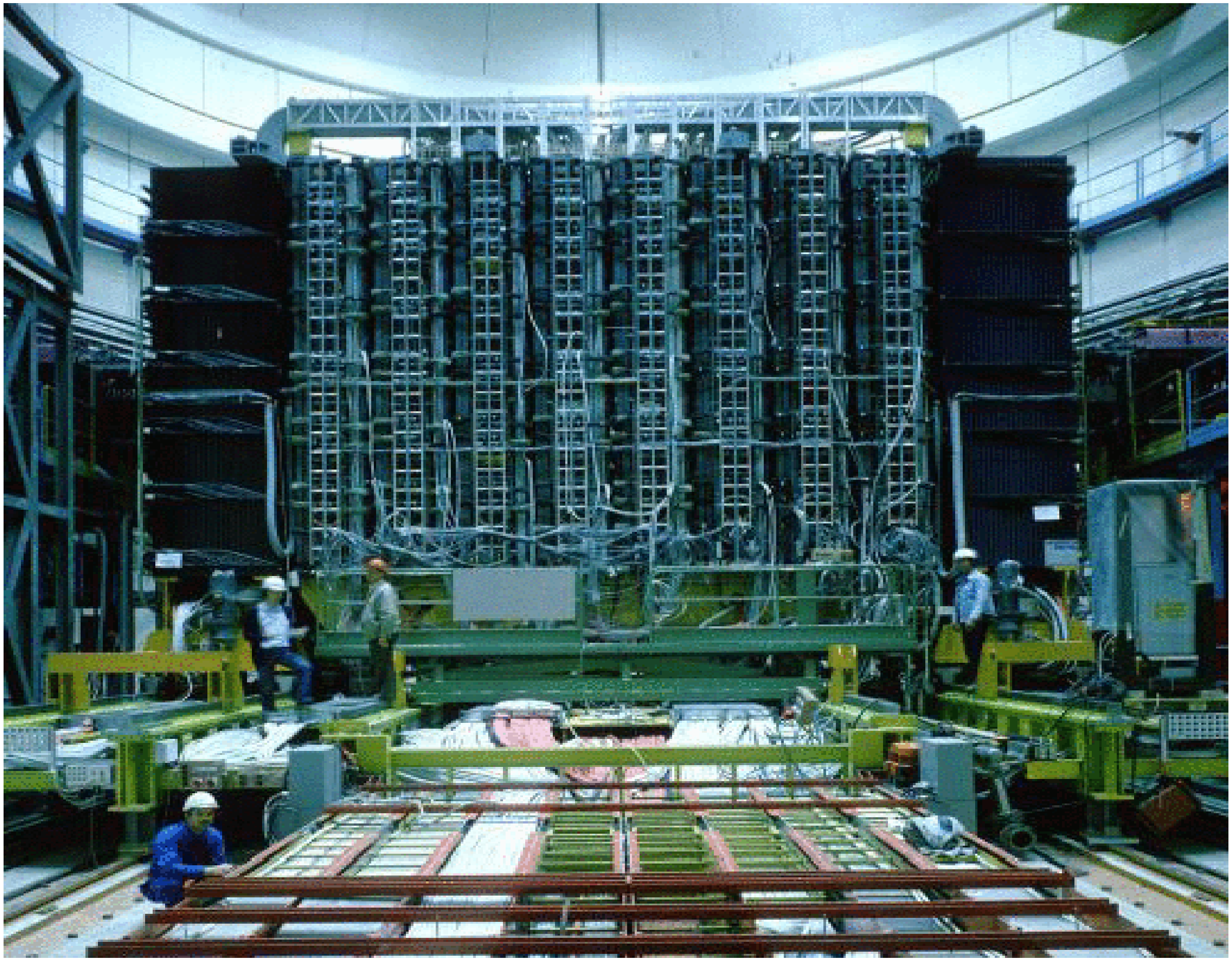
- in <~ 3 years

Le détecteur UA1 (Underground Area 1)



UA1 detector:
~10 x 6 x 6 m^3,
~ 2000 tons
~130 physicists
calorimetric coverage $|\eta| < 5.0$
tracker coverage $|\eta| < 3.0$
muon system coverage $|\eta| < 2.3$

Le détecteur UA1 en construction (1979/81)

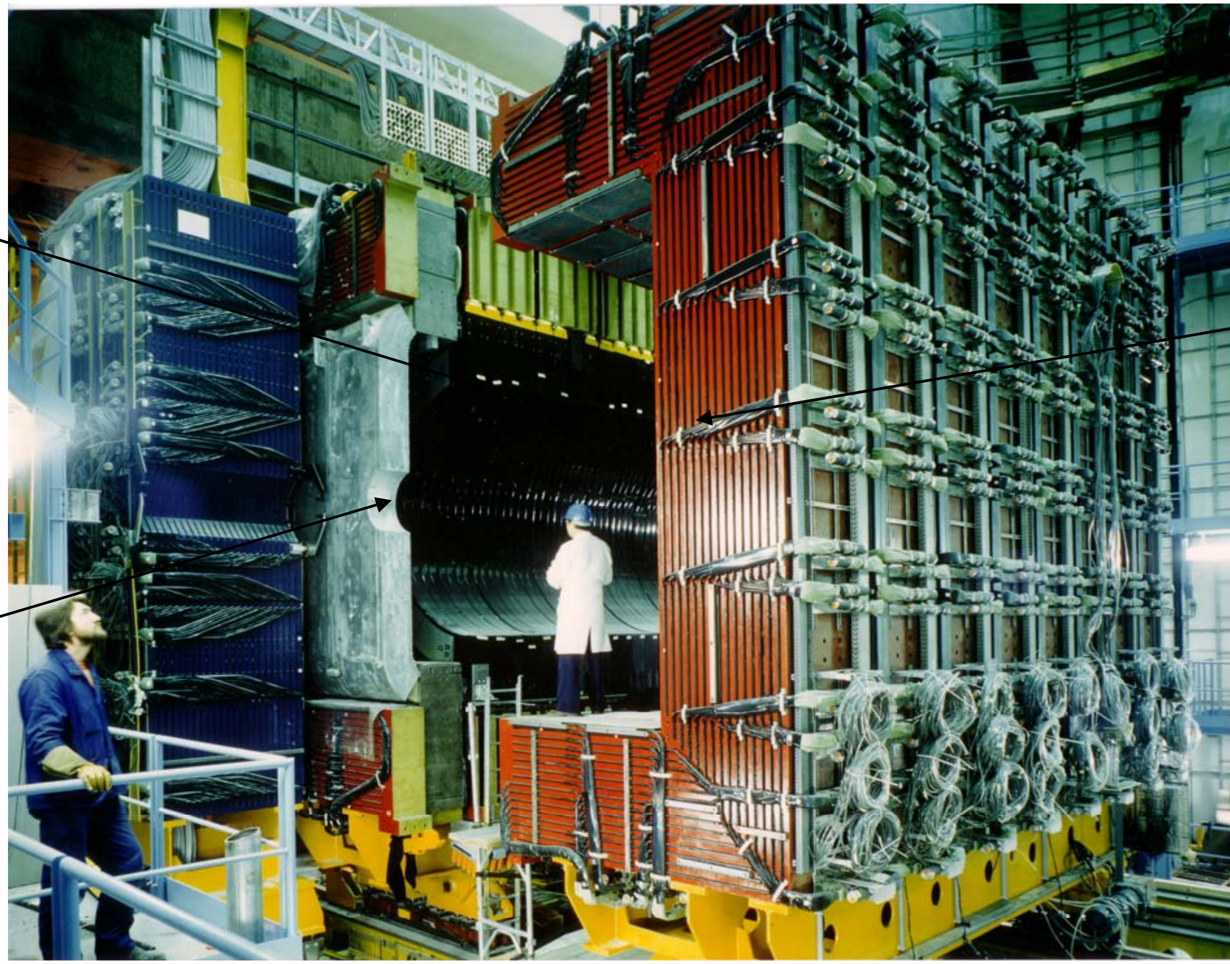


Le détecteur UA1 en construction (1979/81)

ECAL
(2x24 gondolas)
Scint.-Pb sandwich
1.2mmPb/1.5mmSci
$\Delta\phi\Delta\eta$= 180° x 0.14
$27X_0$ deep, four segments in depth

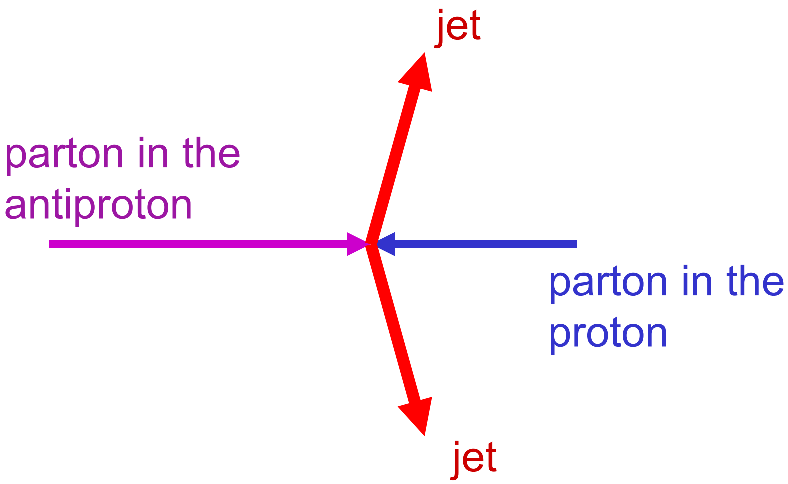
+ 2x32 radial sectors in end-caps
acceptance $|\eta| < 3.0$

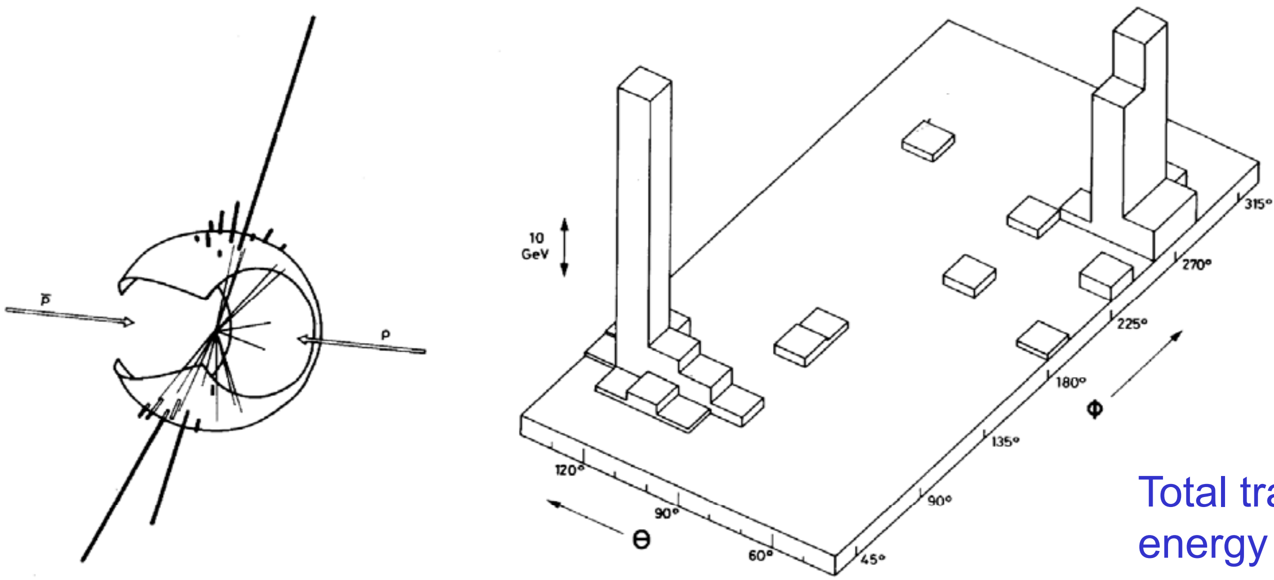
warm Al coil,
7kG horizontal field,
$80m^3$ field volume



HCAL
5cm iron/1cm Scint.
3.5 λ_{int} deep

First observations: QCD Jets in the antiproton-proton collider





(a) (b)

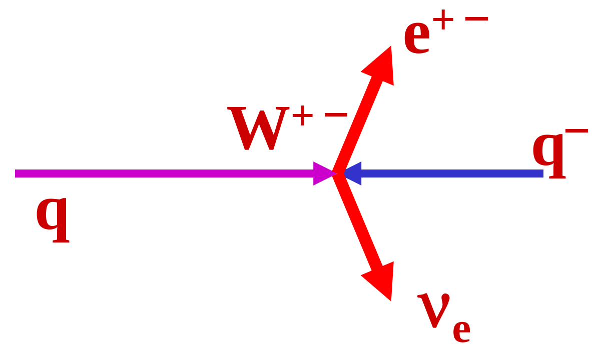
UA2

Total transverse energy ~ 140 GeV

W discovery, first W $\rightarrow$ eν events, run of 1982

Search for leptonic decays:

$W^{+-} \rightarrow e^{+-} + \nu_e$ $W^{+-} \rightarrow \mu^{+-} + \nu_\mu$



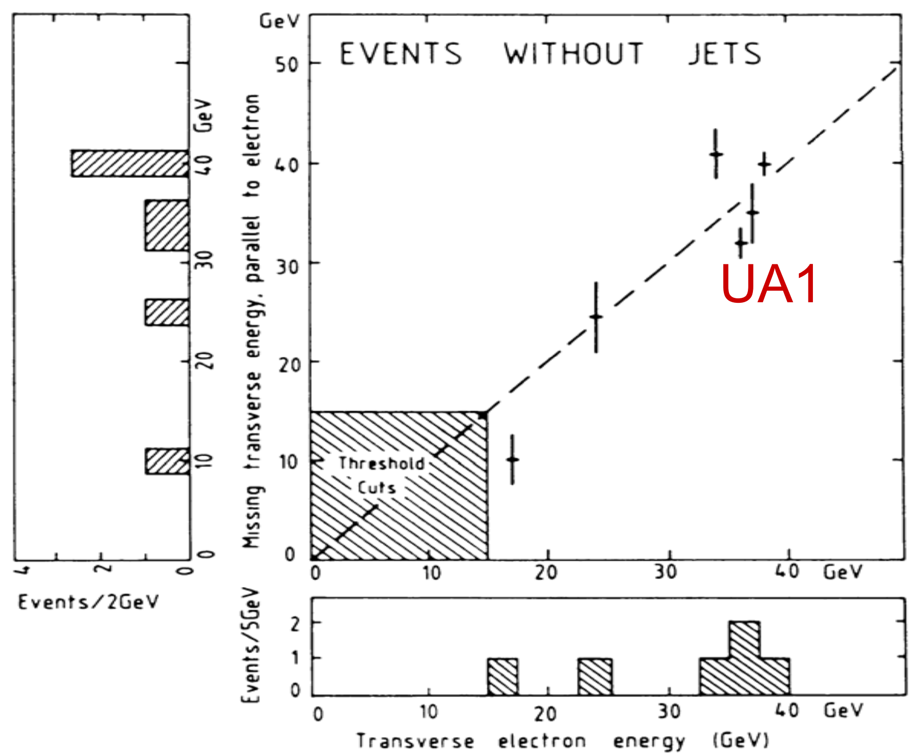
- UA1 W $\rightarrow$ eν initial selection cuts:

E_t^{miss} > 15 GeV (resolution in UA1 ~ 6 GeV),
E_t^{ECAL} > 15 GeV (cluster in 1 or 2 gondolas),
single hard track (p_t > 7 GeV) pointing to ECAL cluster,
no jet back-to back to e^{+-} candidate,

➡ 6 events selected (5 W$\rightarrow$ eν + 1 W$\rightarrow$ $\tau\nu$)

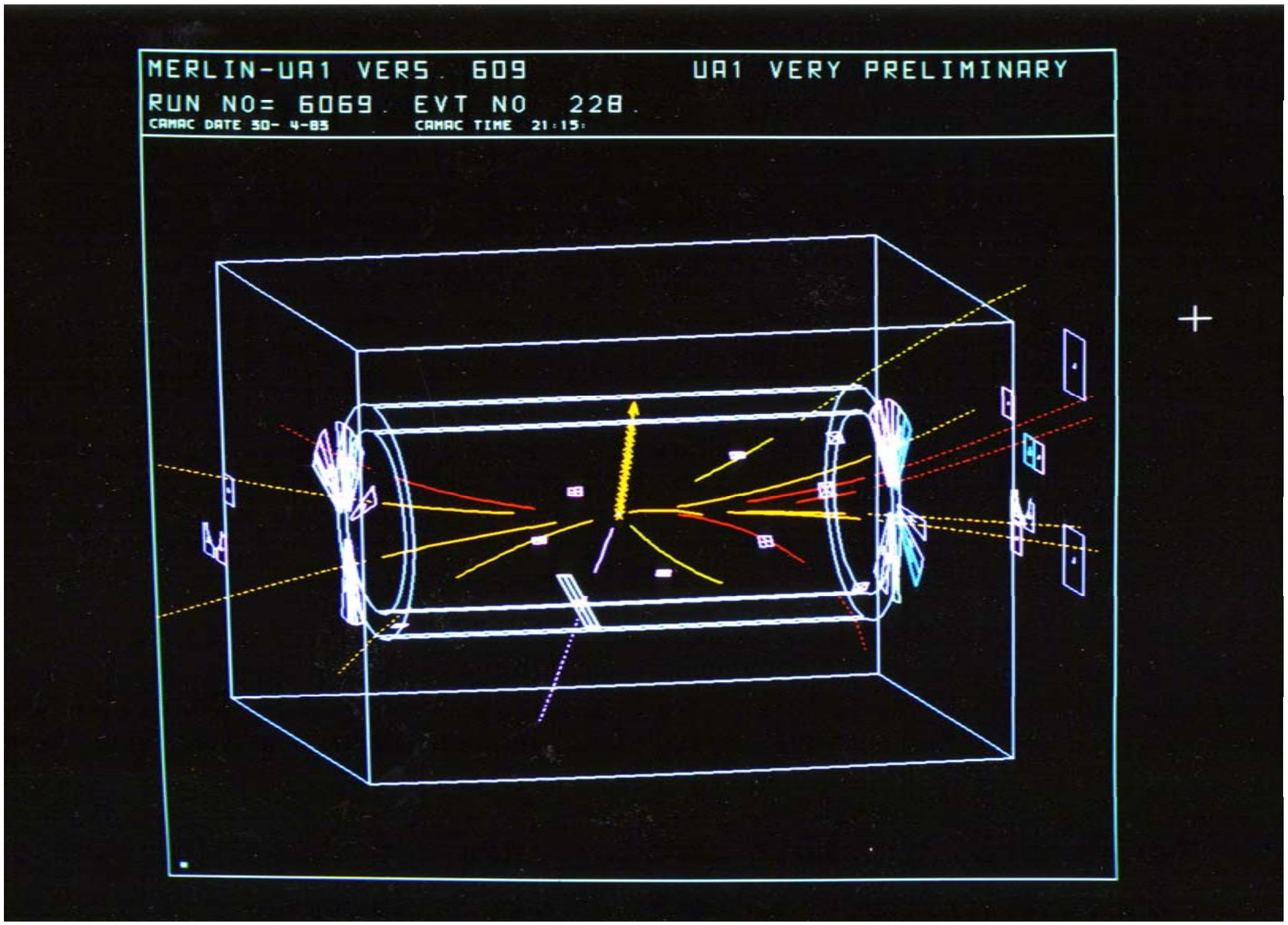
➡ m_W = 81 ± 5 GeV (UA1)

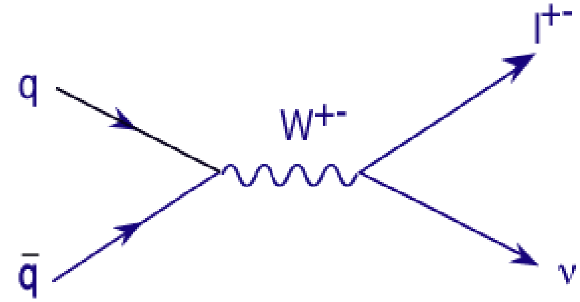
Correlation between missing transverse energy and e^{+-} transverse energy for the first W events

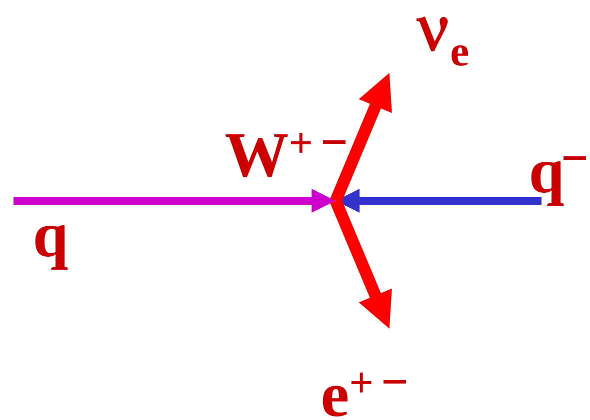


D. Denegri; CERN, Enseignants Francais, avril 2008

Among the first W → eν events in UA1

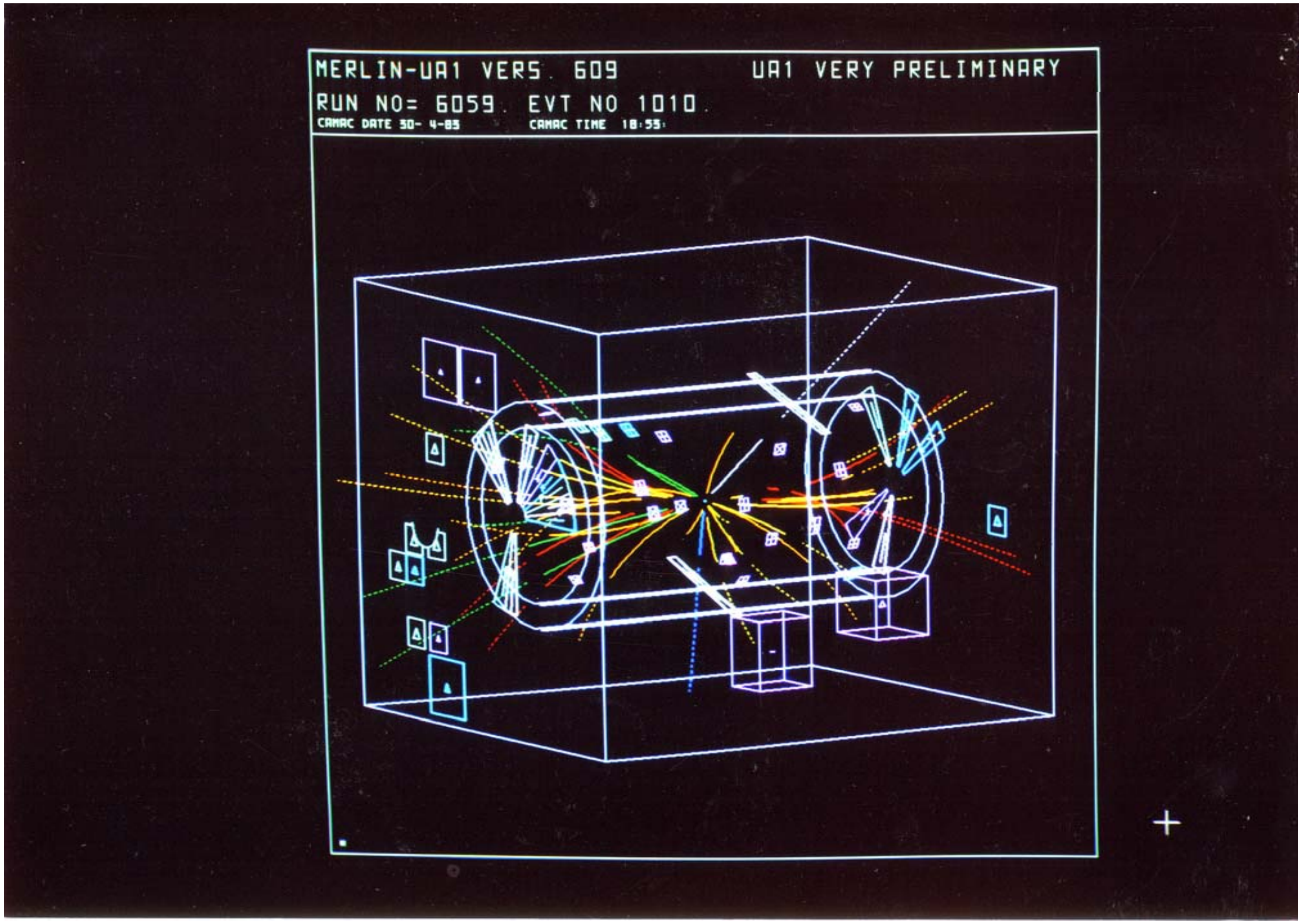


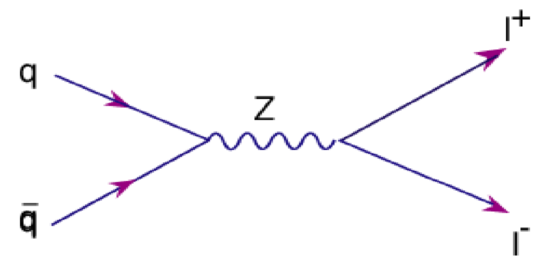


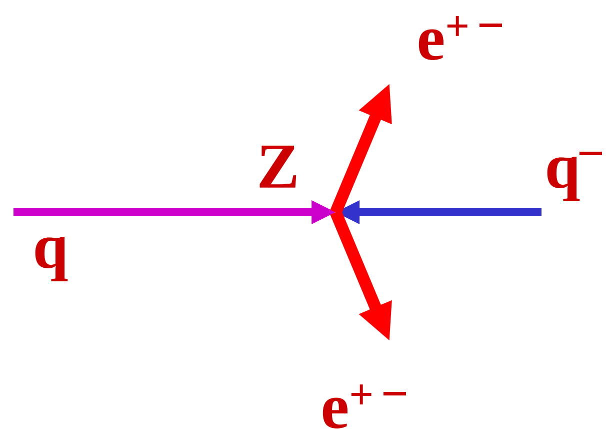


One of the very first W to eν events seen in UA1, as visible on the interactive graphic display (Megatek). There was a color coding for tracks and energy deposits in calorimetric cells. The high momentum electron track is pointing almost downwards towards a large energy deposit in a “gondola” (oblong white rectangle). The missing transverse energy vector is the heavy arrow pointing upwards.

Among the first Z → e^+e^- events in UA1 (May 1983)







One of the first Z to e^+e^- events seen in UA1, as visible on the Megatek. The high momentum e^+ and e^- tracks are straight and pointing to large energy deposits in two “gondolas” in white. Smaller momentum tracks and energy deposits are also color coded.

Le Z au LEP (la forme de Breit-Wigner) 1990/95 et le comptage des espèces/types de neutrinos

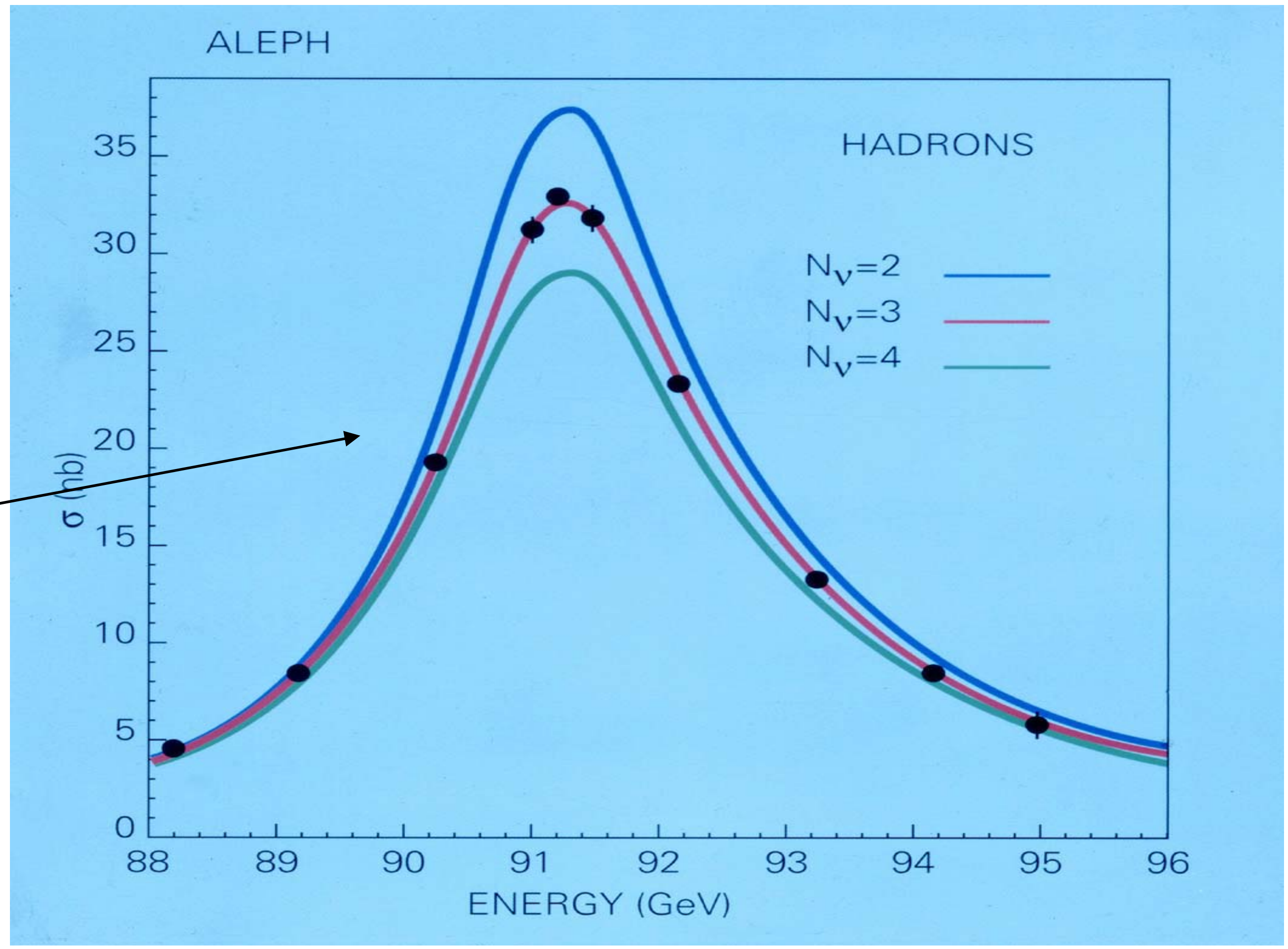
LEP: Large Electron positron collider

UA1/2: $Z \rightarrow e^+e^-$

LEP: $e^+e^- \rightarrow Z$

LEP data on Z
few years later!!

Altogether ~ 80 million Z's produced at LEP and ~ 17.000 W's



Three neutrino species!

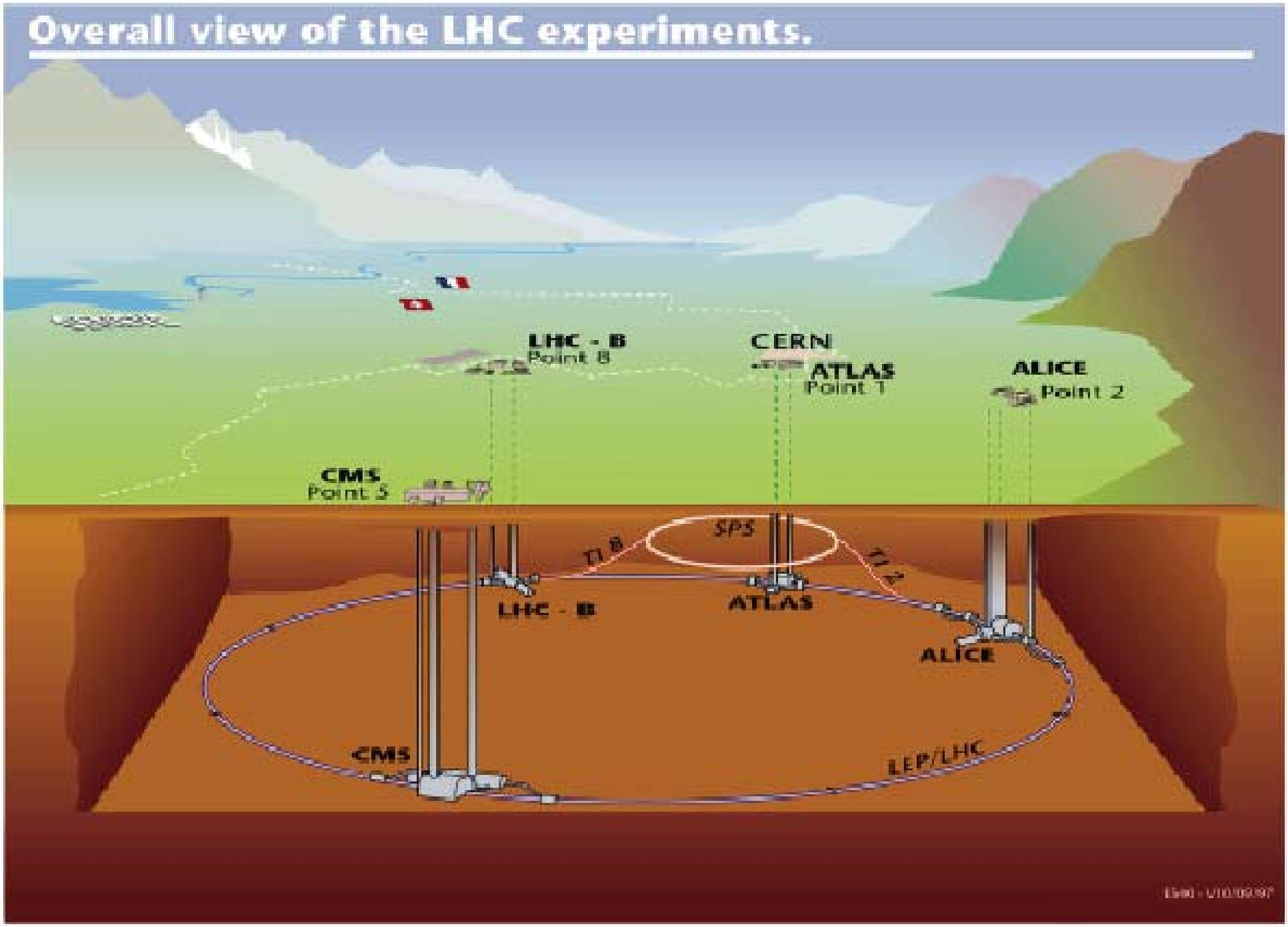
Le projet LHC, le détecteur CMS

Le Modèle Standard au LHC:
le quark top, le boson de Higgs,

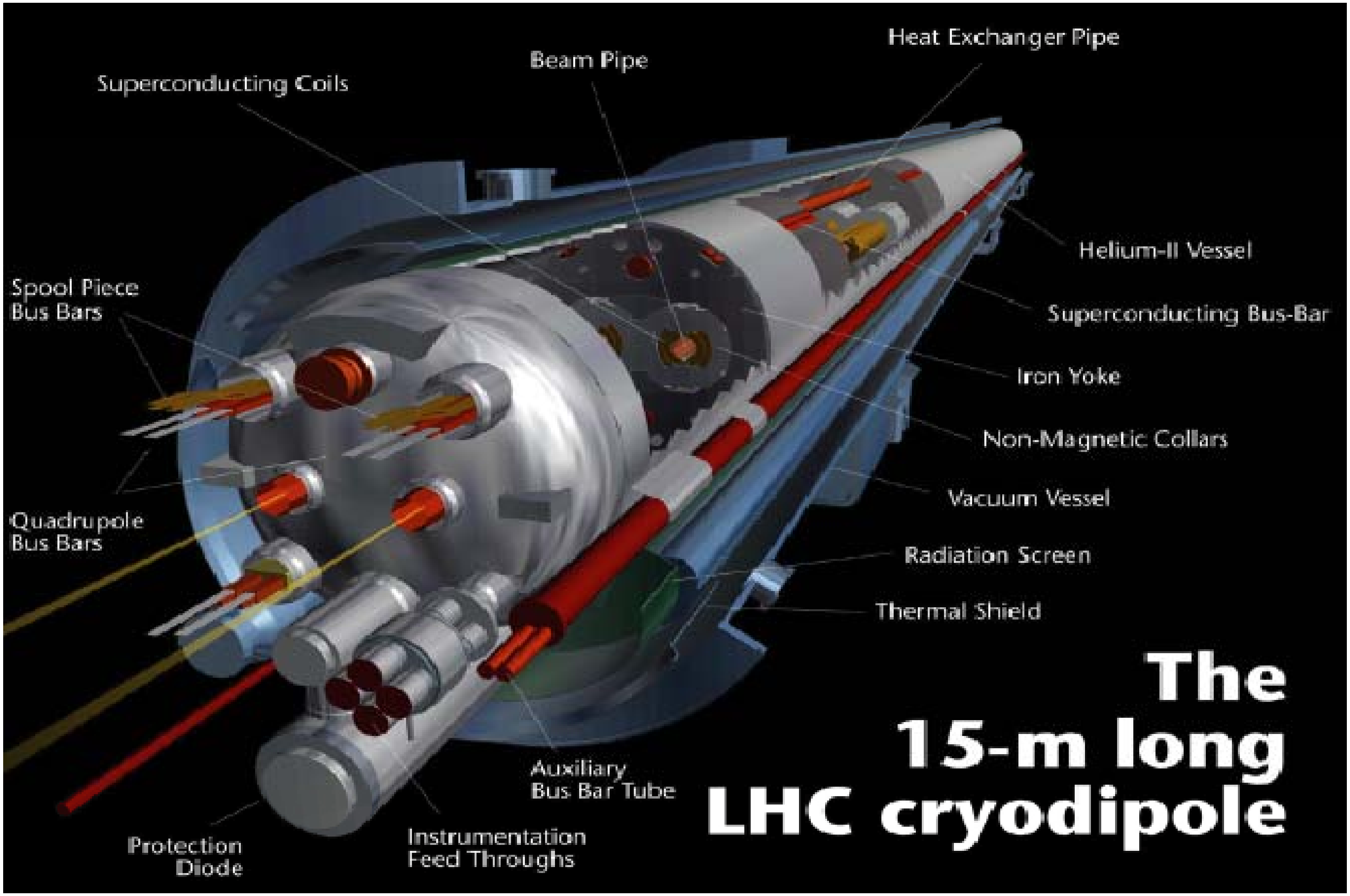
la supersymmetrie
les mini trous noirs….

Le site du LHC (Large Hadron Collider)

Le LHC et les expériences

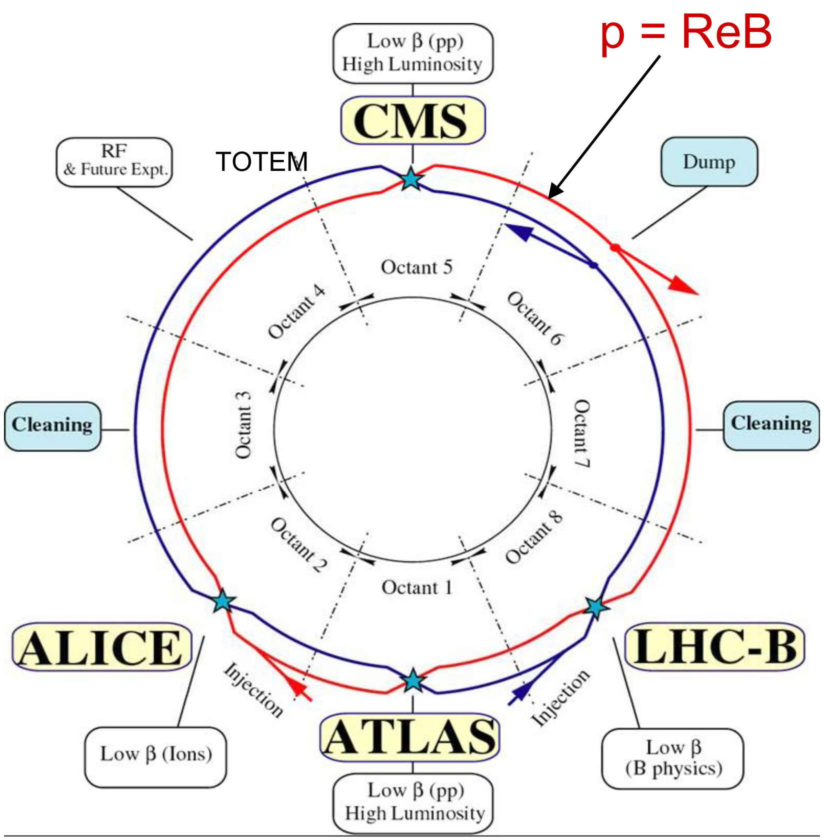


Les dipoles (aimants de courbure des faisceaux) du LHC - éléments clée de la machine



The Large Hadron Collider (LHC)

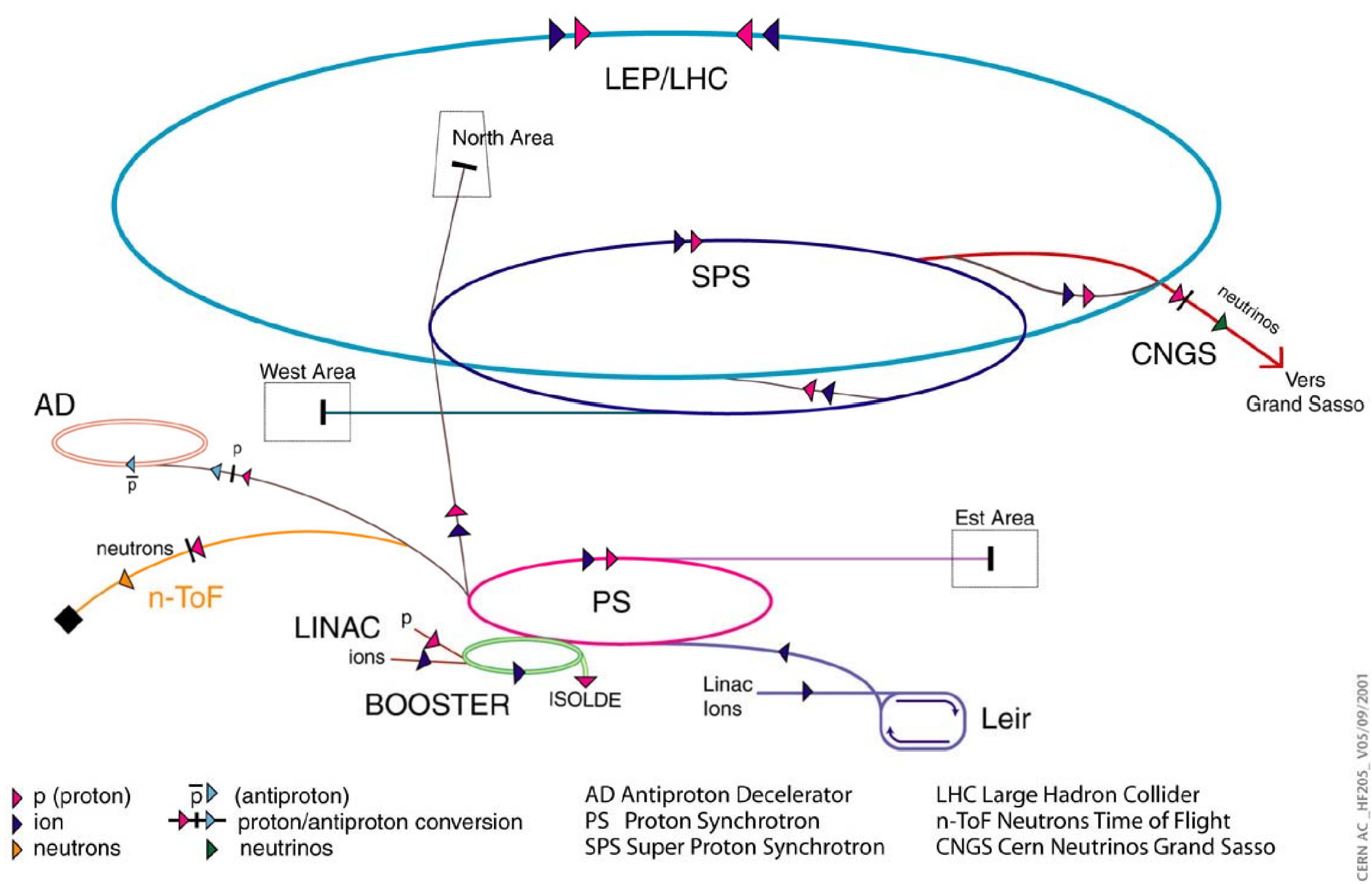
~ 65% of the 27 km long circumference covered twice with B = 8.3T 1232 2-in-1 superconducting dipoles of 14.3m length operated at 1.9 ^{o}K, 500 2-in-1 quadrupoles with 215T/m, altogether 1200 tons of superconducting cable and 40.000 tons of material at 1.9 ^{o}K superfluid He temperature!.



LEP	e^+e^-	200 GeV	10^{32} cm^{-2} s^{-1}
Tevatron	p-p	2000 GeV	$3*10^{32}$ cm^{-2} s^{-1}
LHC	pp	14.000 GeV	10^{34} cm^{-2} s^{-1}

Les accélérateurs du CERN et le LHC

Accelerator chain of CERN (operating or approved projects)



Les grandes questions de la physique des particules - fin du XX s.

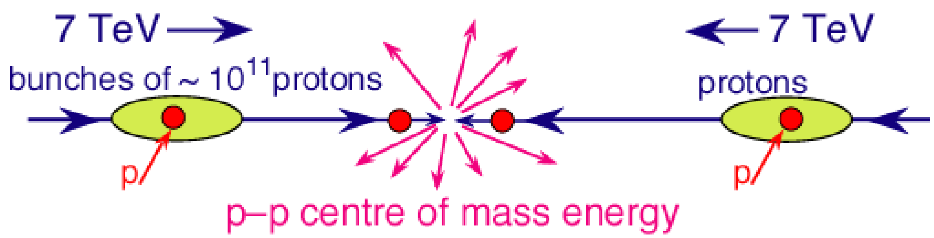
- What is the origin of mass? Why has the Z boson a mass of 91 GeV while the related photon is massless?
  Higgs mechanism: Tevatron, LHC
- Is there TeV scale Supersymmetry leading to grand unification of forces at $\sim 10^{16}$ GeV?
  Tevatron, LHC
- Is there a fundamental particle responsible for the dark matter of the Universe?
  WIMP searches, LHC (SUSY Dark Matter)
- Do present day elementary particles have a substructure?
  HERA,Tevatron, LHC
- What is the origin of the matter-antimatter asymmetry in the Universe?
  CP/B: BABAR, BELLE, Tevatron, LHC
- Extra dimensions/TeV scale quantum gravity?
  LHC
- Is there a new state of matter, the quark - gluon plasma?
  RHIC, LHC (ALICE,CMS...)

. . .

The LHC experiments can answer or bring significant light on these questions

Les collisions proton-proton - pas aussi simples que les collisions e+e- dans le LEP!

1) proton – proton collisions:

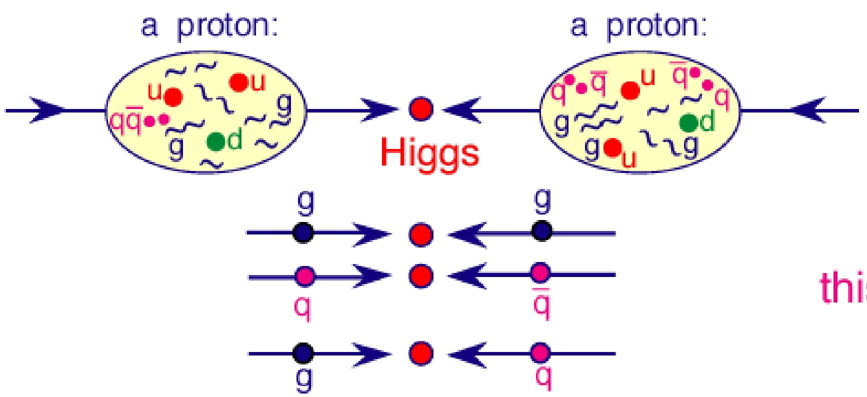


CERN anti-proton – proton collider : 0.6 TeV

Fermilab anti-proton – proton collider : 2.0 TeV (1TeV = 1000 GeV = 10^{12} eV)

LHC proton – proton collider : 14 TeV

2) constituant – constituant (quarks, gluons) collisions:



this is the interesting part!

constituant-constituant center of mass energy $\lesssim$ 1 TeV

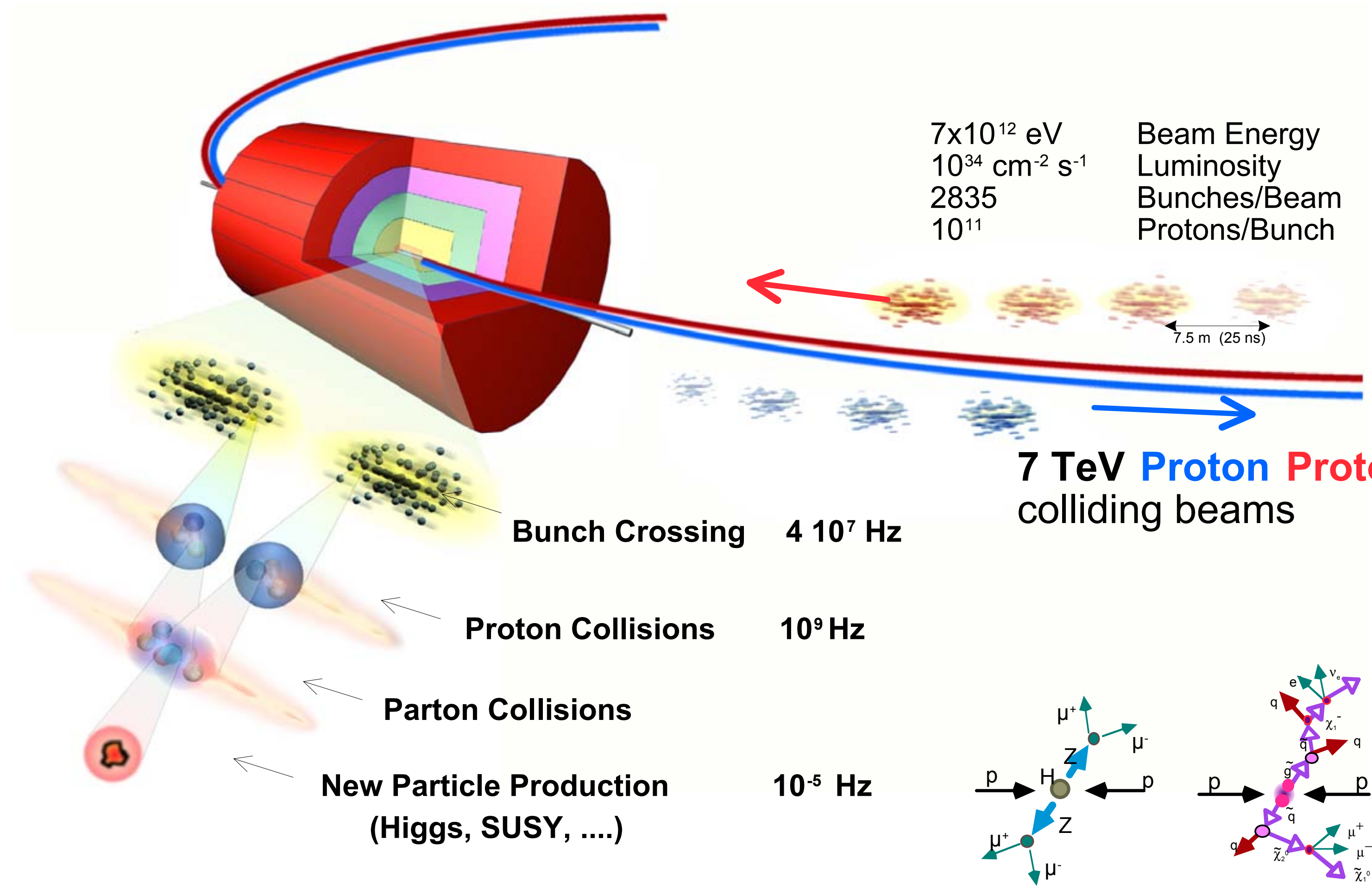
but: $m_{Higgs} \lesssim 1$ TeV

→ LHC is the adequate machine

D.D 703c.2

Le LHC, organisation des faisceaux, fréquence des collisions…..

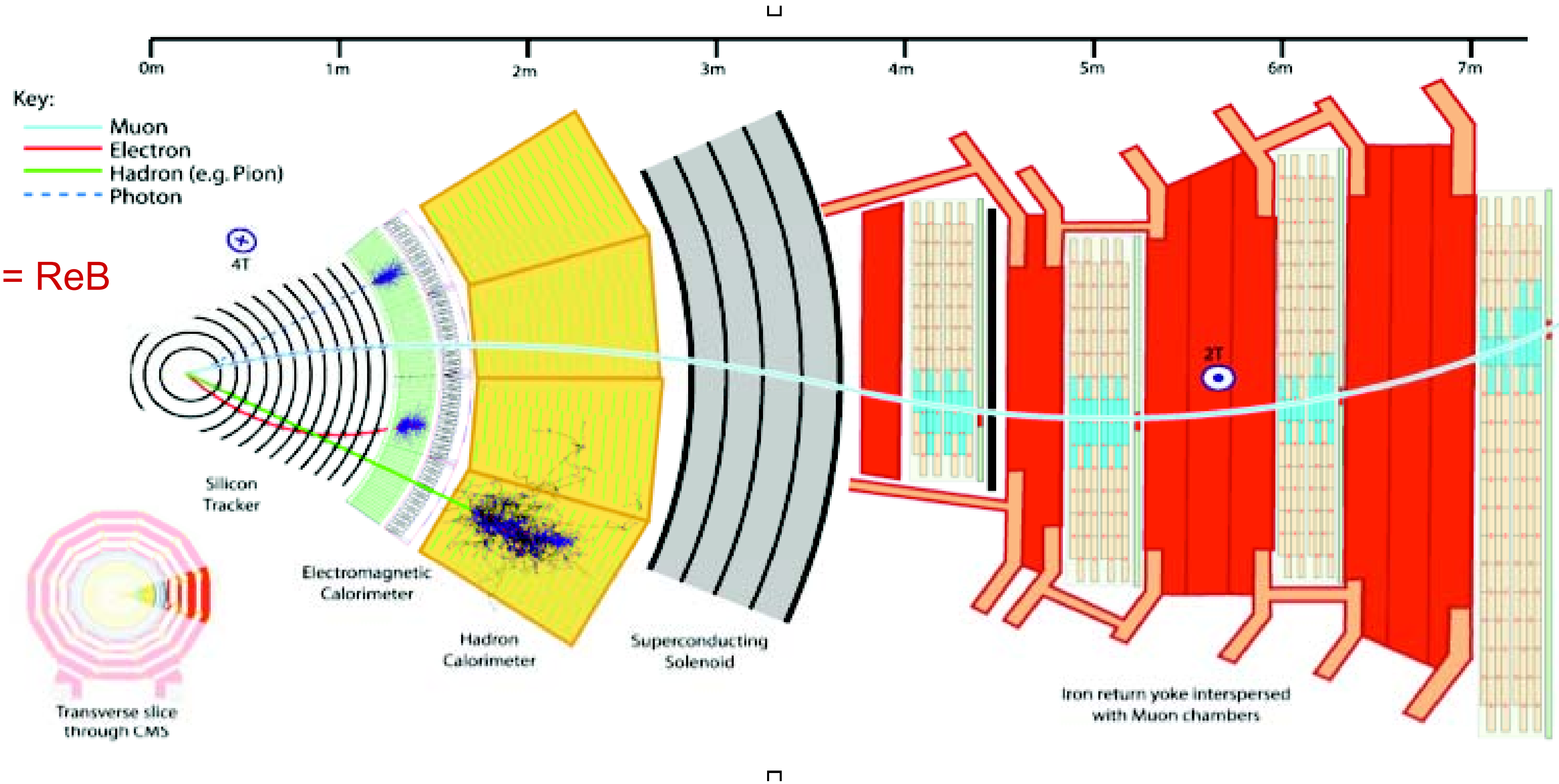
nécessite d'un système de déclenchement et présélection en ligne des événements



Selection of 1 event in 10,000,000,000,000

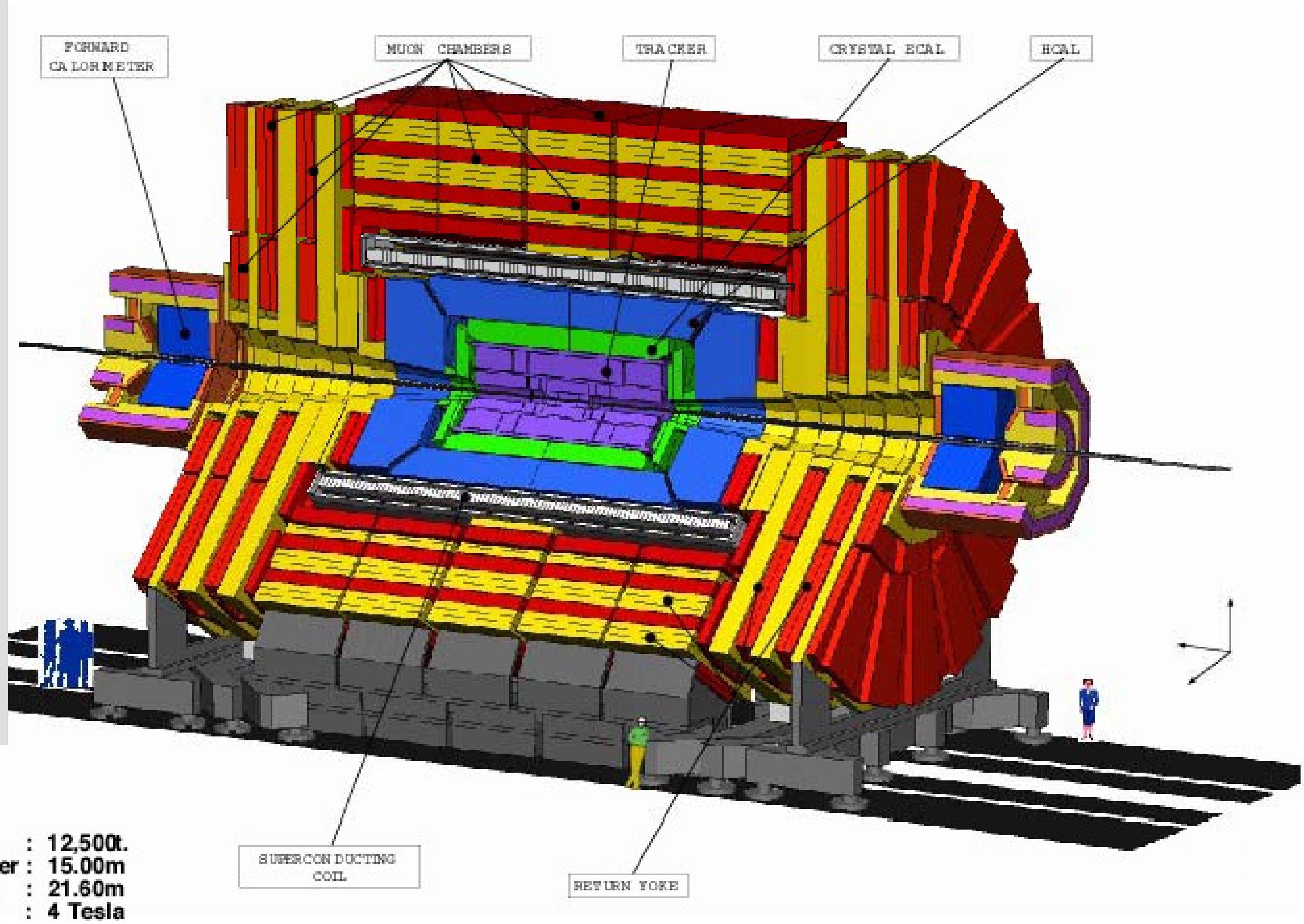
Particle interactions in the detectors

p = ReB



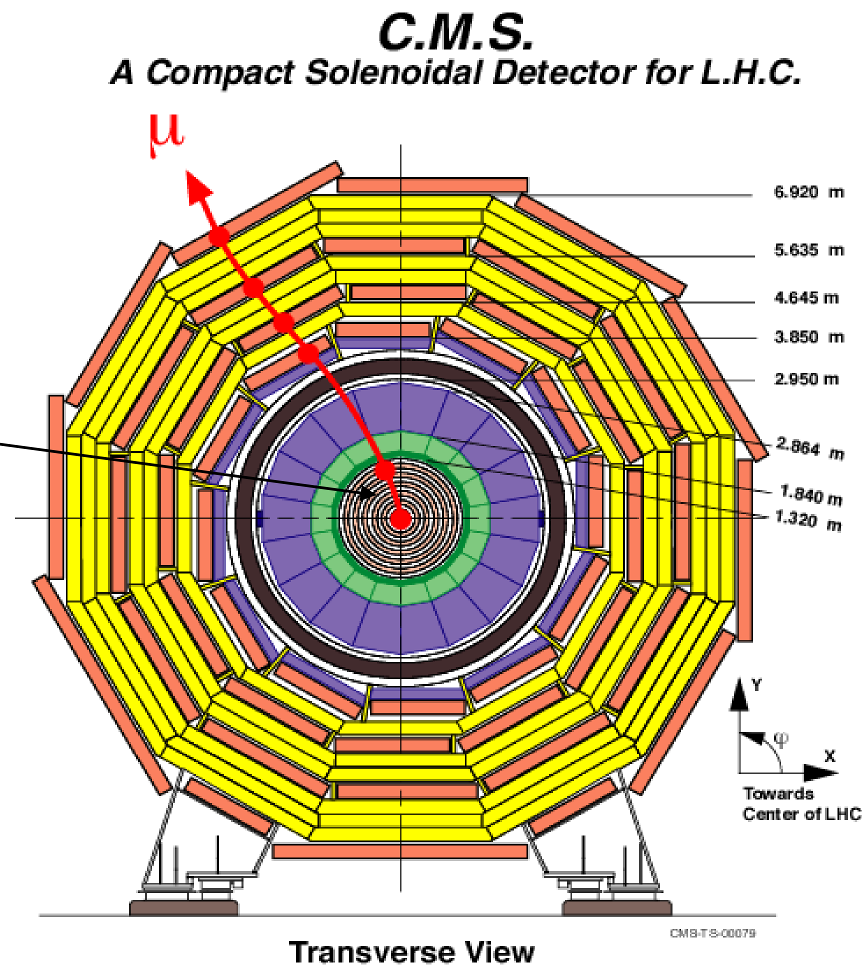
Le détecteur CMS (Compact Muon Solenoid)

CMS in brief:
- 4 T solenoid
- μ chambers in iron yoke
- HCAL: copper & scintillator
- ECAL: ~ 80×10^3 $PbWO_4$ crystals
- All Si-strip tracker $220\ m^2$, 10^7 channels
- Si-pixel detector, $2\ m^2$ 70×10^6 channels



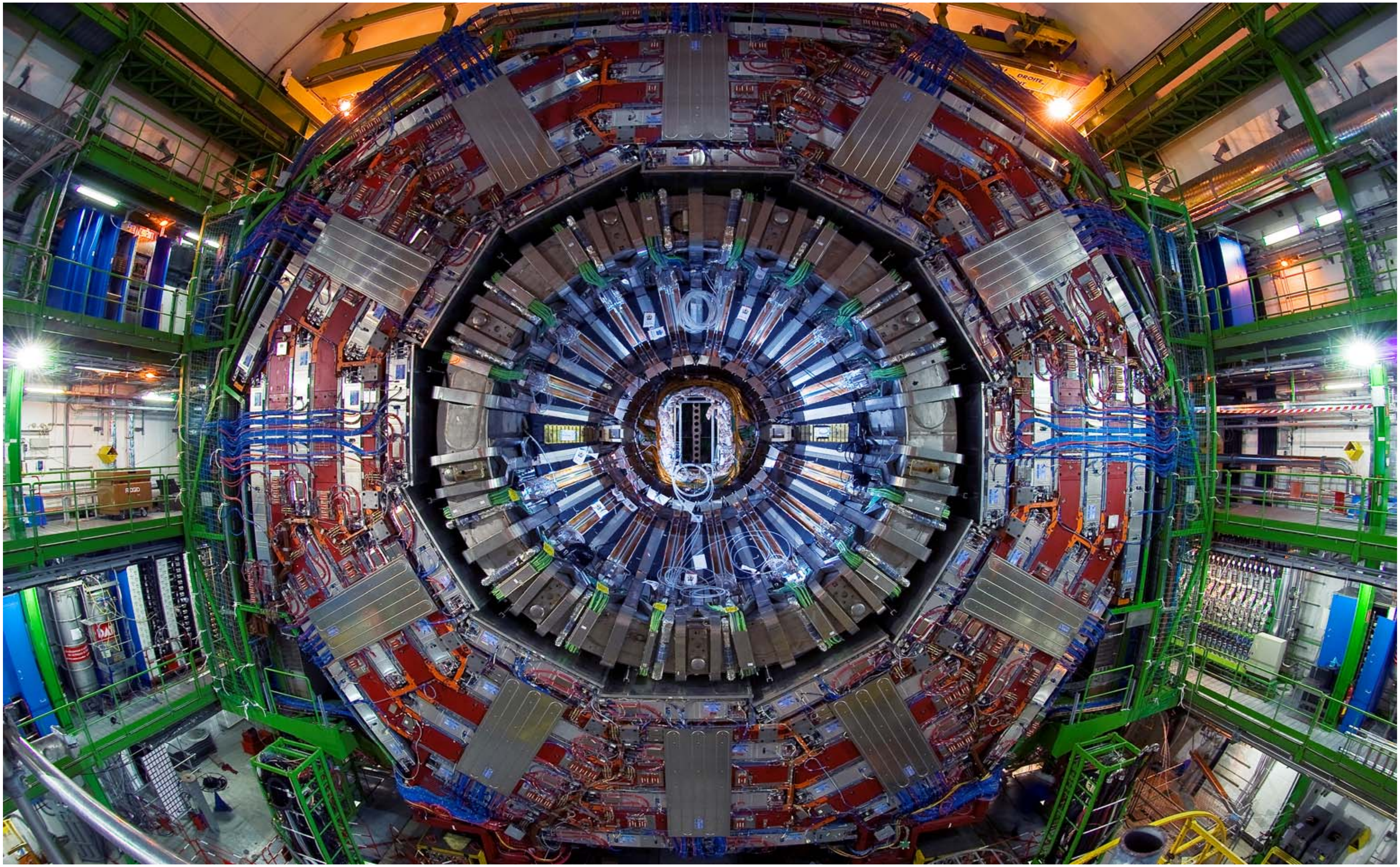
Total weight	:	12,500t.
Overall diameter	:	15.00m
Overall length	:	21.60m
Magnetic field	:	4 Tesla

p = ReB

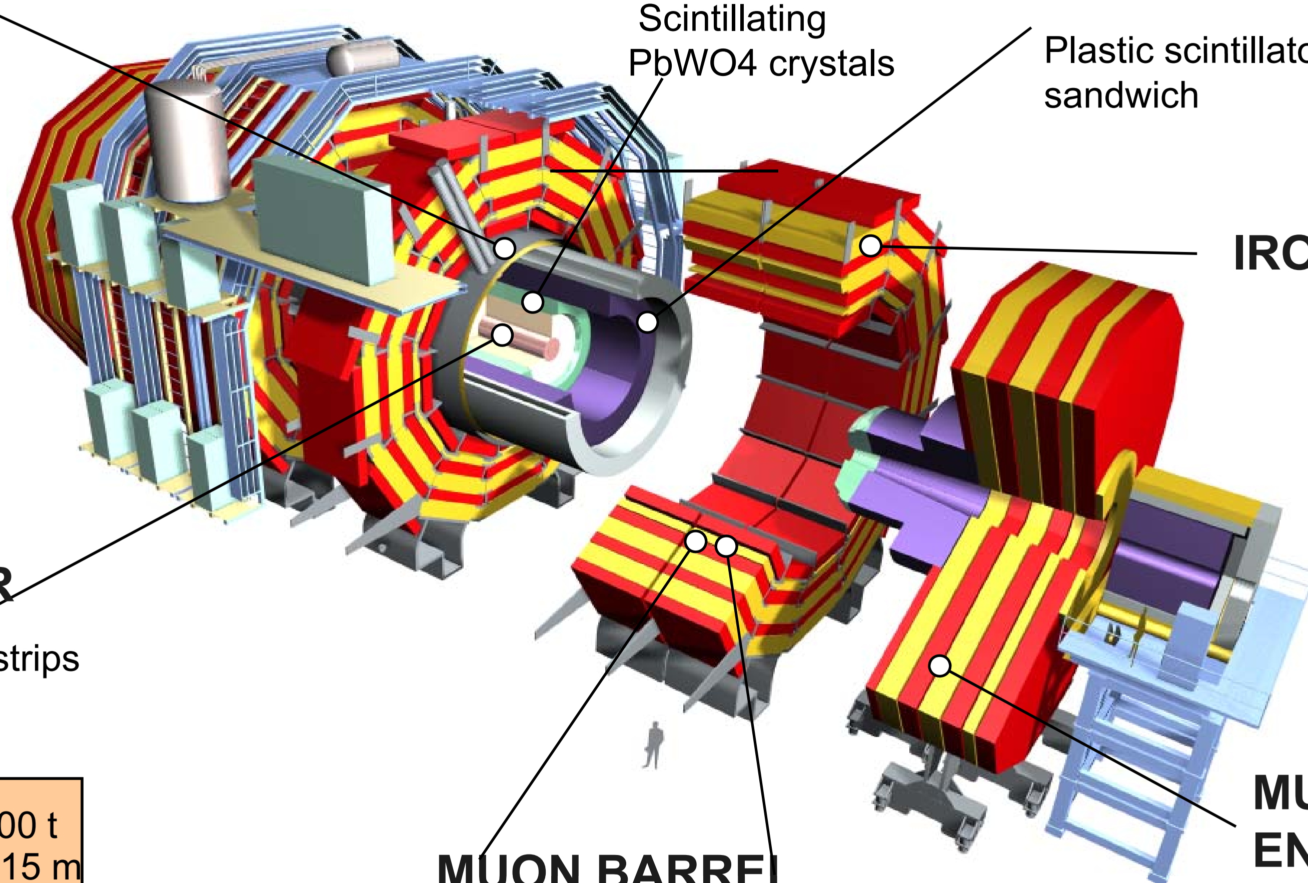


C.M.S.
A Compact Solenoidal Detector for L.H.C.
μ
6.920 m
5.635 m
4.645 m
3.850 m
2.950 m
2.864 m
1.840 m
1.320 m
Y
φ
X
Towards
Center of LHC
CMS-TS-00079
Transverse View

CMS - situation en janvier 2008 - insertion du détecteur de traces



The CMS detector - major components



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

Cross section of various SM processes

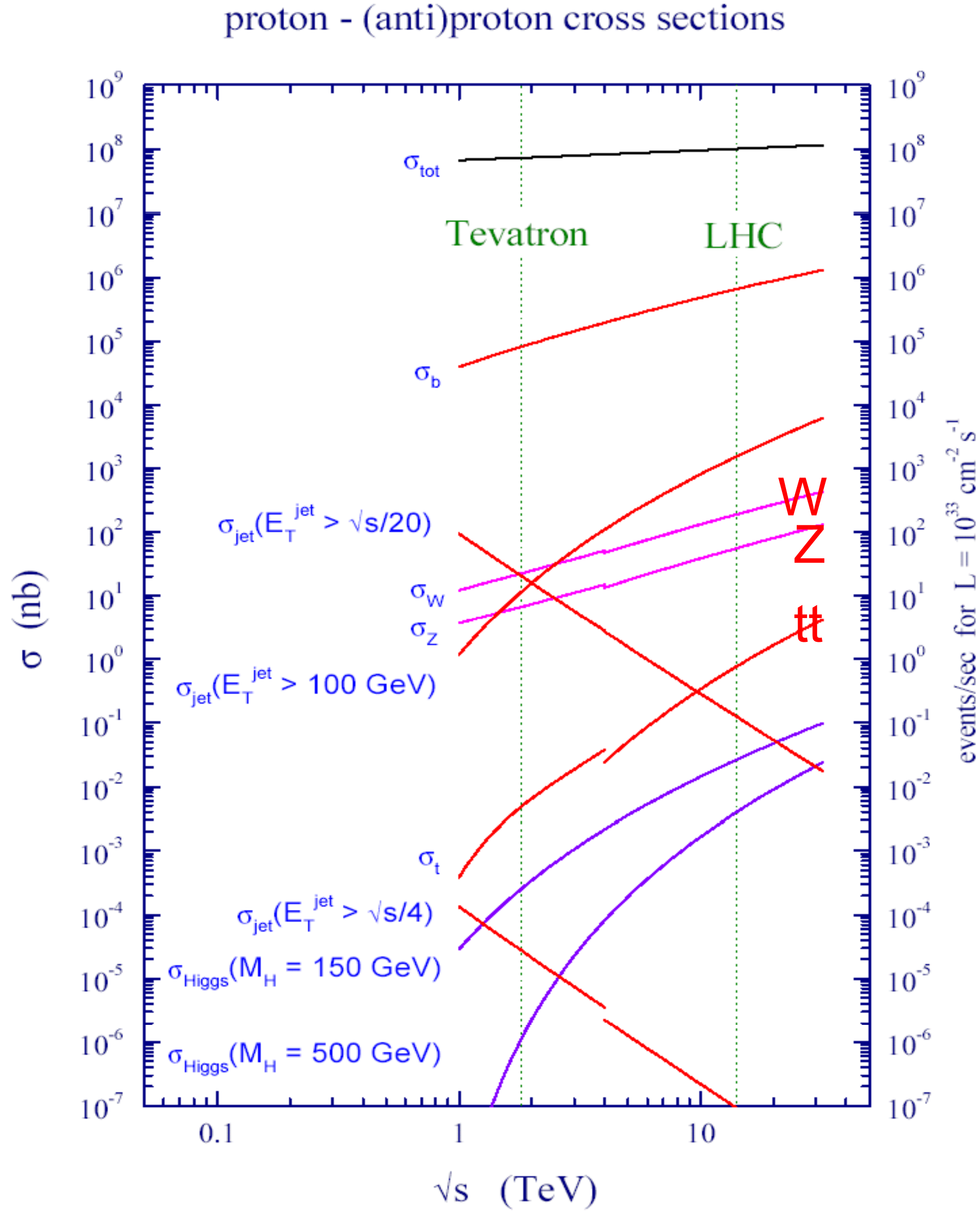
In the LHC low luminosity phase of $10^{33} cm^{-2} s^{-1}$ approximately

10^8 pp interactions
10^6 bb events
200 W-bosons
50 Z-bosons
1 tt-pair

will be produced per second and

1 light Higgs per few minutes!

The problem is to detect and trigger on the events in presence of large bkgds!



Le quark top

The top is a rather exceptionnal object:

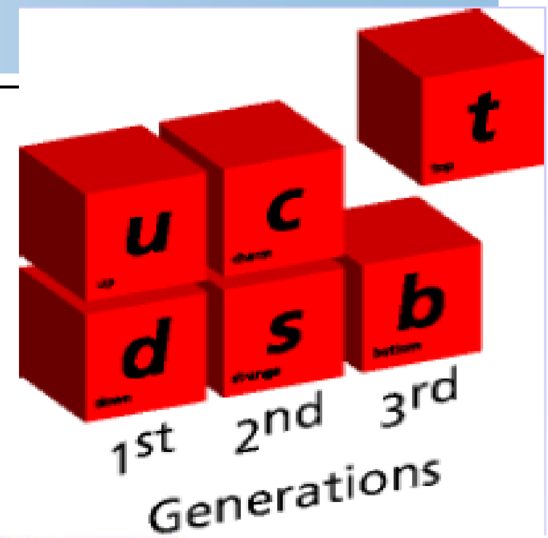
- by far the heaviest fermion

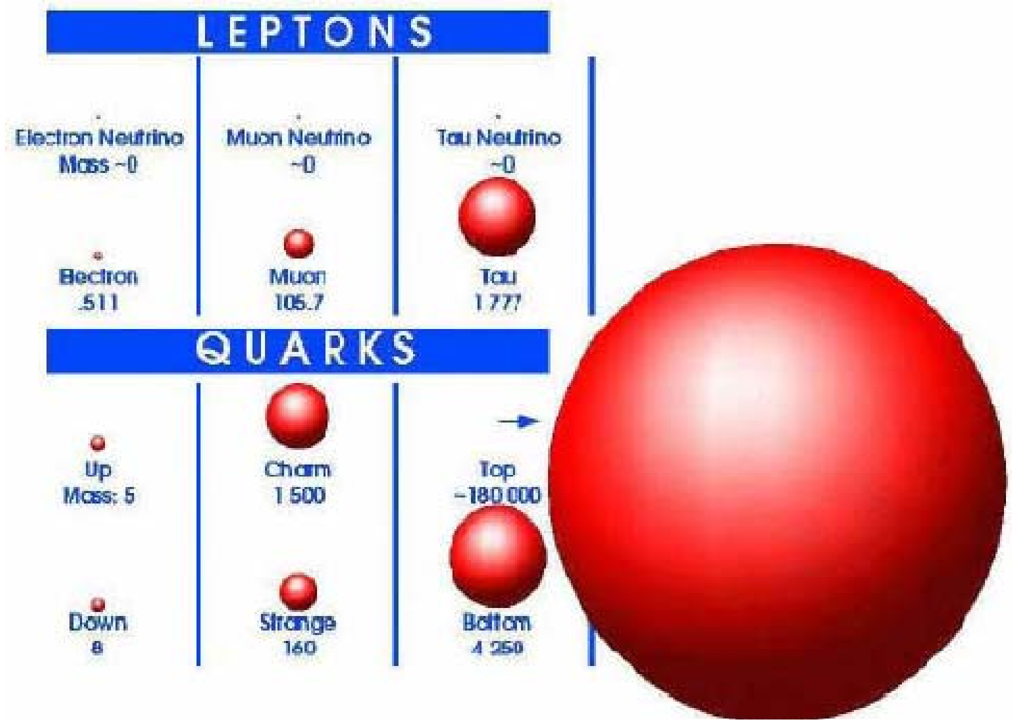
- discovered 1995 at the Tevatron
  O(100) events observed in Run I

- still littleknown about it (mass)
  would like to measure all other
  properties, spin, BR's....

- top has a very short lifetime
  the <u>only</u> quark that decays before
  forming hadrons

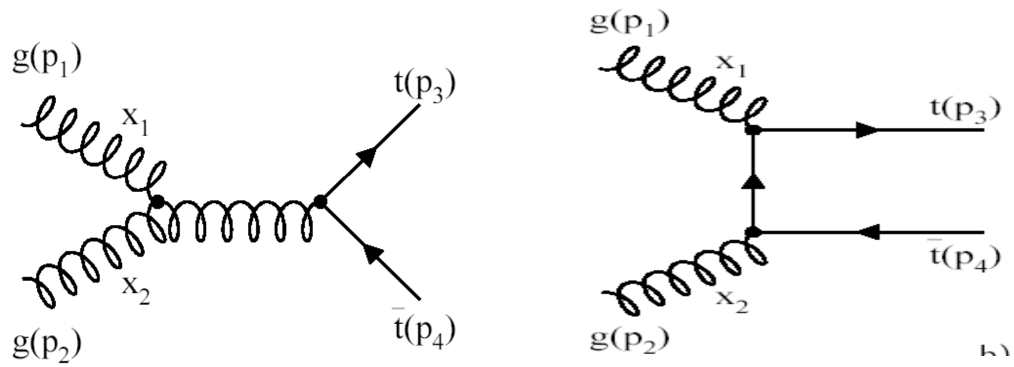
- can determine spin, polarisation from
  its decay products





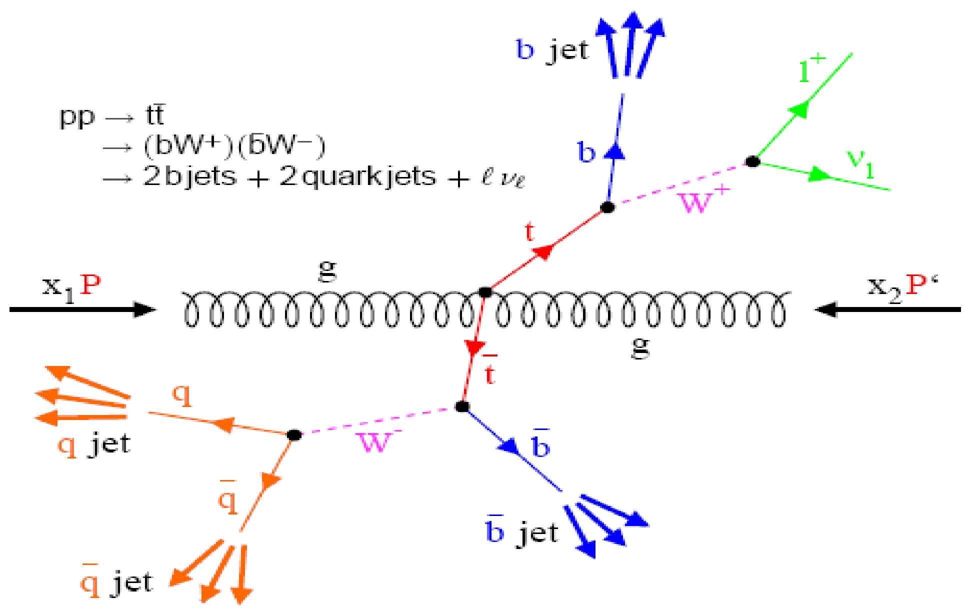
Production et désintegration du quark top au LHC, canal semi-leptonique

Top production at LHC
gluon-gluon fusion dominates:



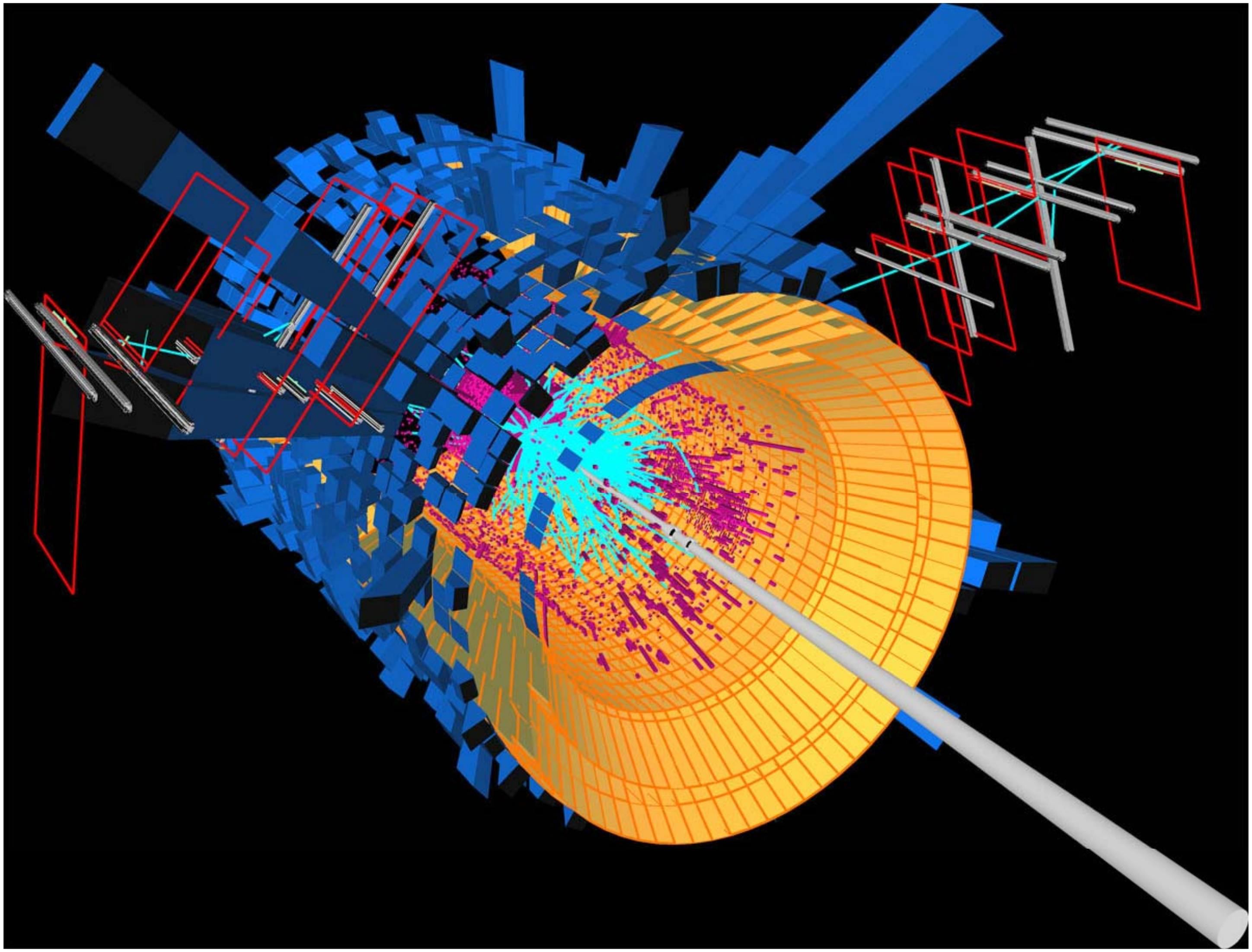
Top decays:
$t \rightarrow bW \rightarrow bl\nu$
$t \rightarrow bW \rightarrow bqq$

semi-leptonic $tt \rightarrow bWbW \rightarrow bl\nu bqq$



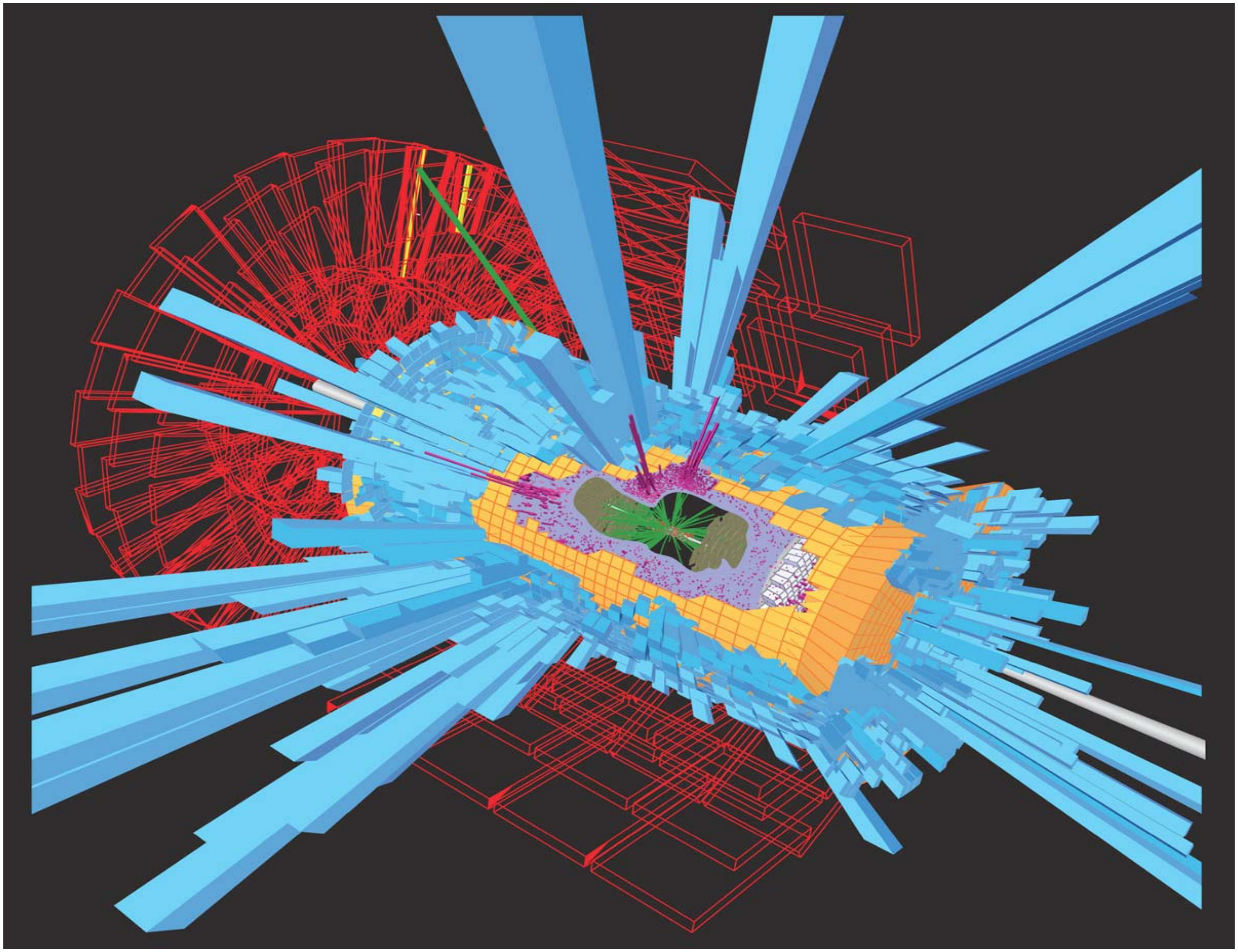
Collision telle quelle est vue
dans le referentiel du laboratoir
ie centre de masse de la collision
proton-proton dans CMS

A semileptonic t-tbar event display in CMS



Simulation de production de pair tt-bar dans CMS

IGUANA simulation of a tt-bar event in CMS

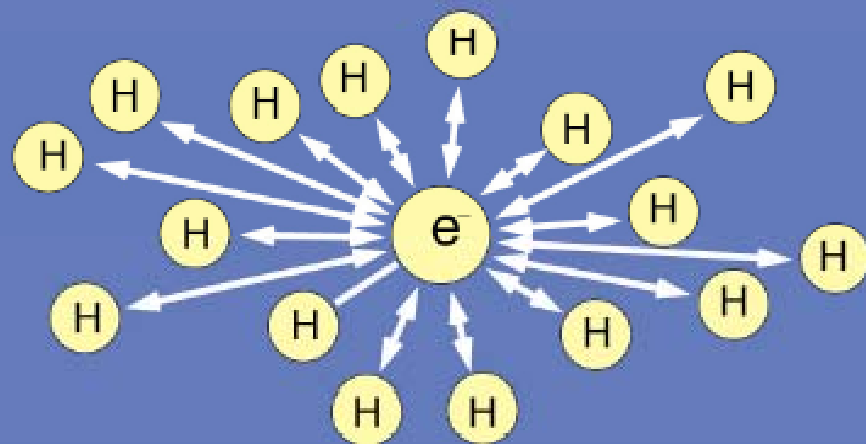


IN2P3

Masse et phénomène de Higgs

Qu'est-ce que le vide ?

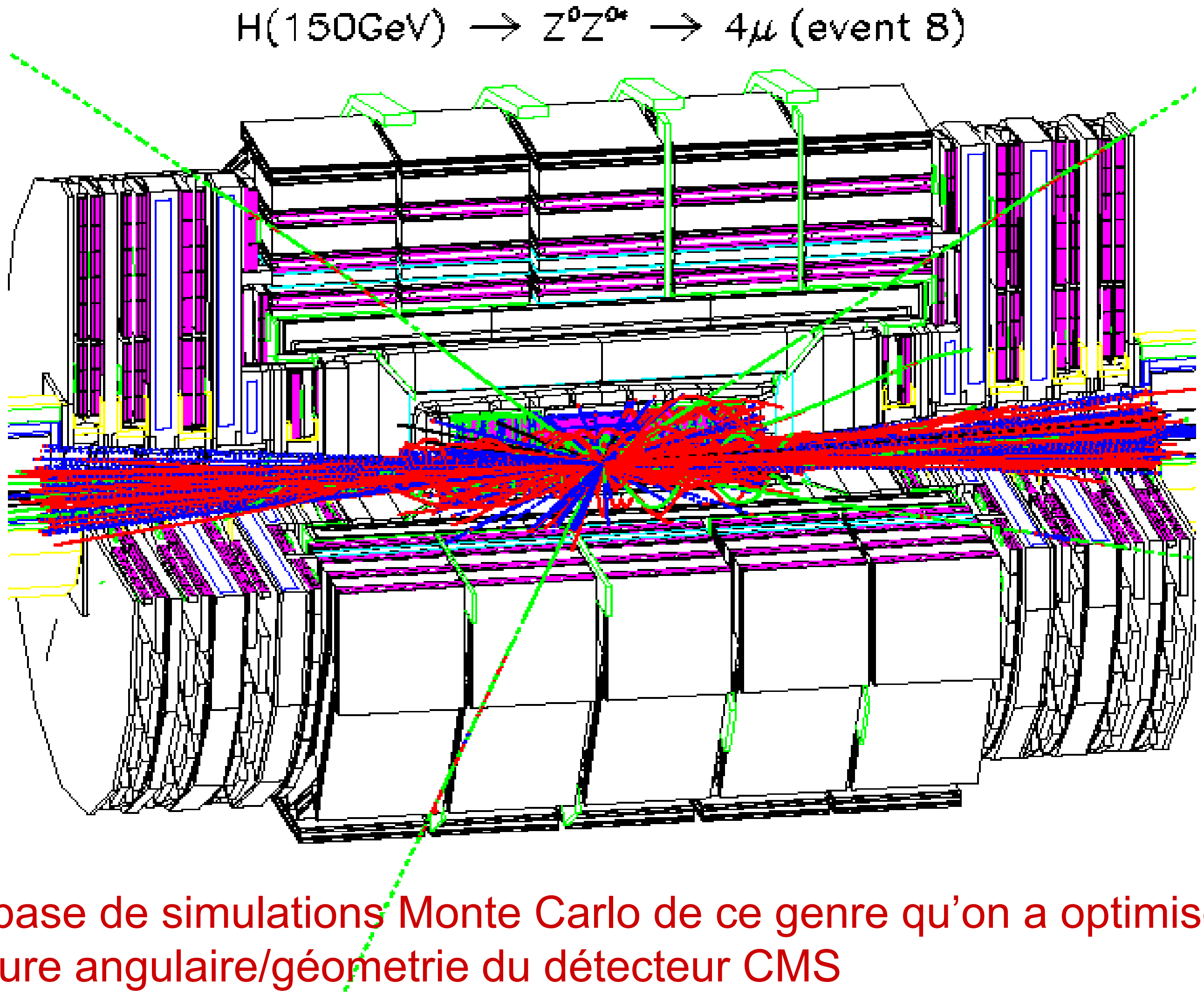
- Présence de particules virtuelles (indétectables directement)
  fugitives
- Présence de "particules de Higgs"...



...responsables de l'inertie des particules
mais on n'a encore jamais vu le Higgs...

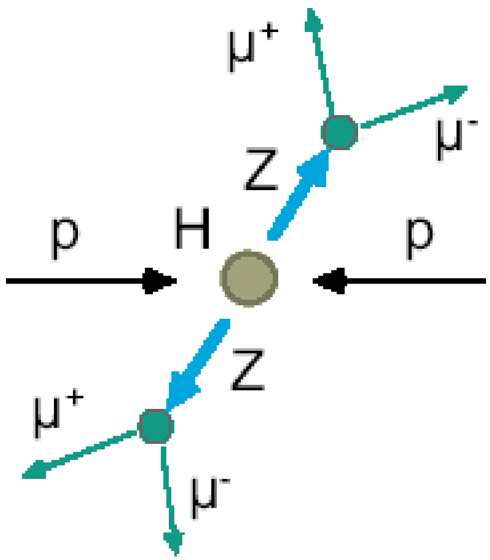
T13

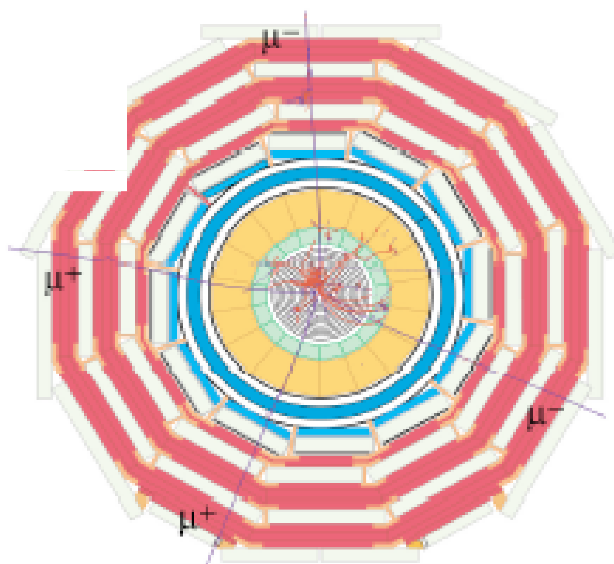
Simulation d'un événement avec production d'un boson de Higgs dans CMS, suivi d'une désintégration en ZZ donnant 4 muons



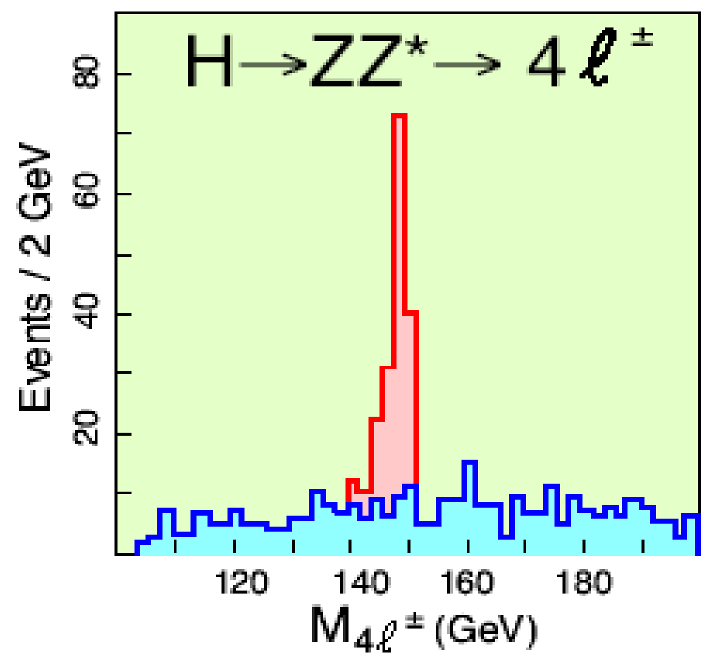
C'est sur la base de simulations Monte Carlo de ce genre qu'on a optimisé la conception et la couverture angulaire/géometrie du détecteur CMS

Production et detection du Higgs dans CMS, mode H → ZZ → 4 leptons





M_{Higgs} = 150 GeV



Supersymmetry

Boson-fermion symmetry, introduced to cure some of the problems of the SM (hierarchy, stabilizes Higgs mass........)

additional particles expected:

fermions → boson super-partners

bosons → fermion super- partners

SUSY is a broken symmetry, but:

$| m^2_{part} - m^2_{spart} | \lesssim 1 \text{ TeV}^2$

if of relevance at e-w scale

Various scenarios are possible, SUGRA, GMSB, R-parity violation.......
SUSY could also be realized not at the ew scale but only at a much higher one, but
there are hints from the gauge couplings unification for the TeV scale ie within the LHC reach

The Minimal Supersymmetric Model particle spectrum:

Squarks ($\tilde{q}$), gluinos ($\tilde{g}$), sleptons ($\tilde{\ell}$)

neutralinos $\tilde{\chi}^0_i$ (i= 1,4), charginos $\tilde{\chi}^\pm_i$ (i= 1,2)

Higgs sector: h^0, H^0, A^0, $H^\pm$

Production and decay:

Sparticles are pair produced (if R-parity conserved); Lightest sparticle (LSP) is stable and weakly interacting

This LSP, if it is the lightest neutralino $\tilde{\chi}^0_1$,it is an excellent cold dark matter candidate

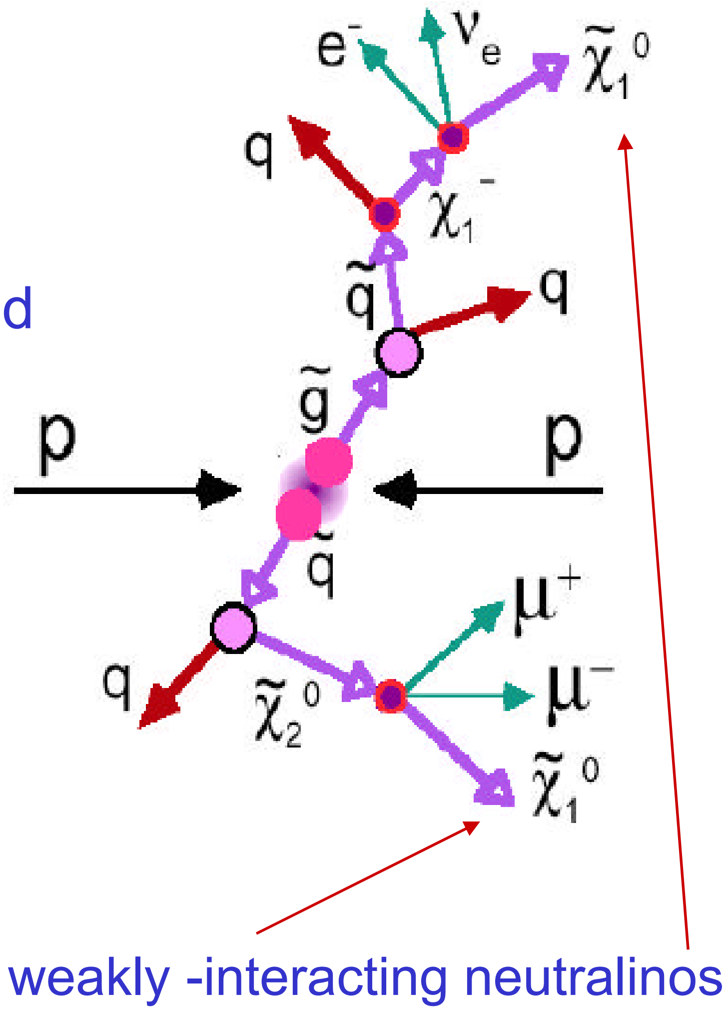
SUSY - generic sparticle searches

General characteristics of R-parity conserving SUSY:

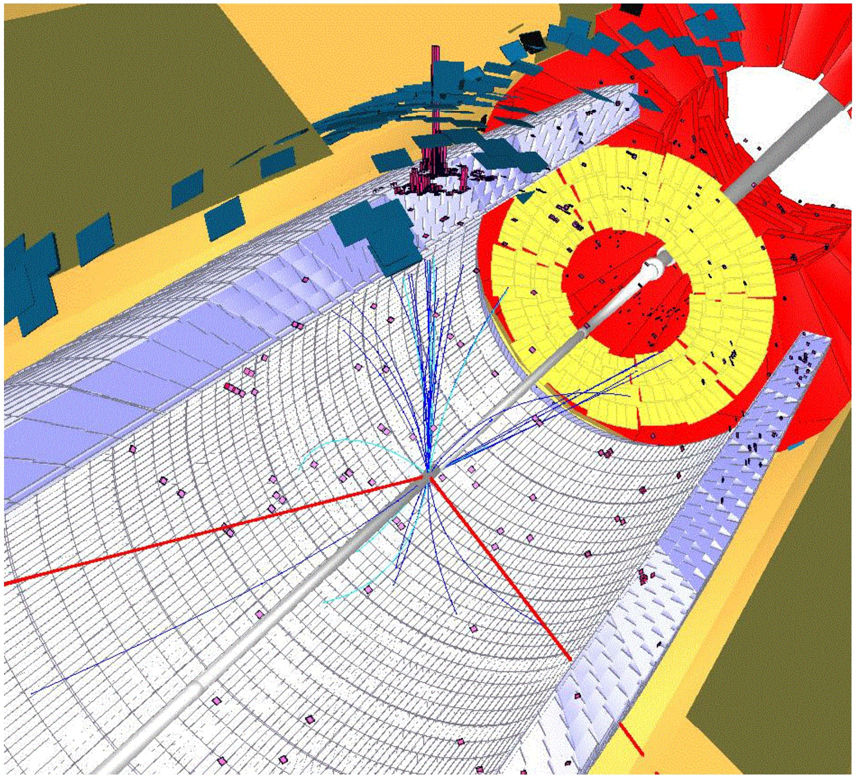
- sparticles pair produced and LSP stable
  ➡ large amount of missing transverse energy

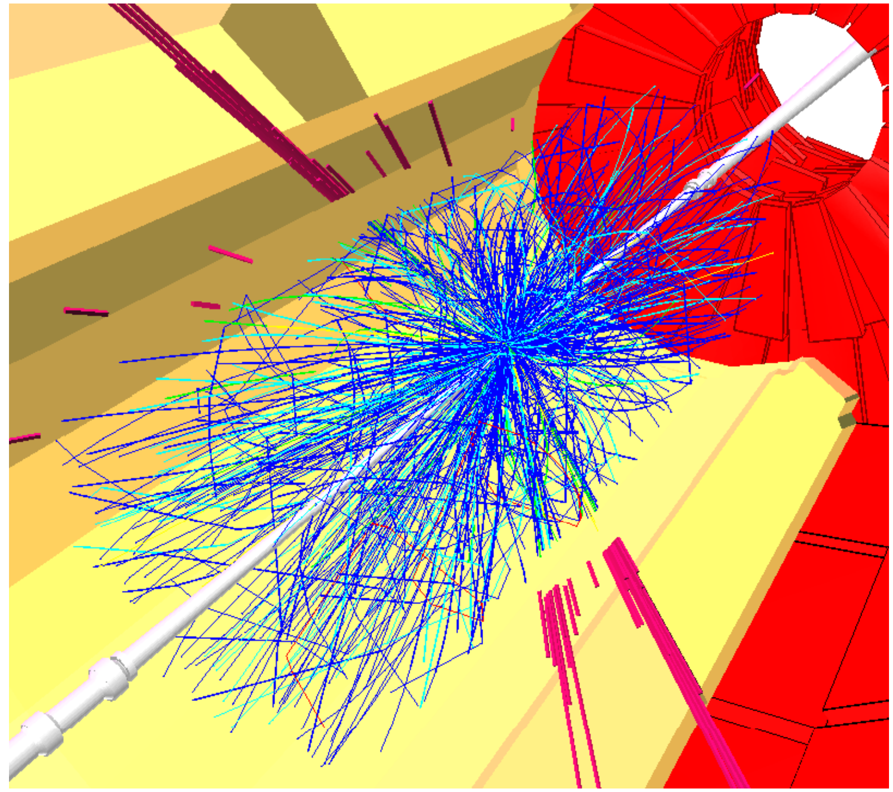
- coloured sparticles are copiously produced and cascade down to the LSP with emission of many hard jets and often leptons

➡ Generic SUSY signatures are E_T^{miss} + multi-jets (and multi-leptons)



SUSY events simulations in CMS



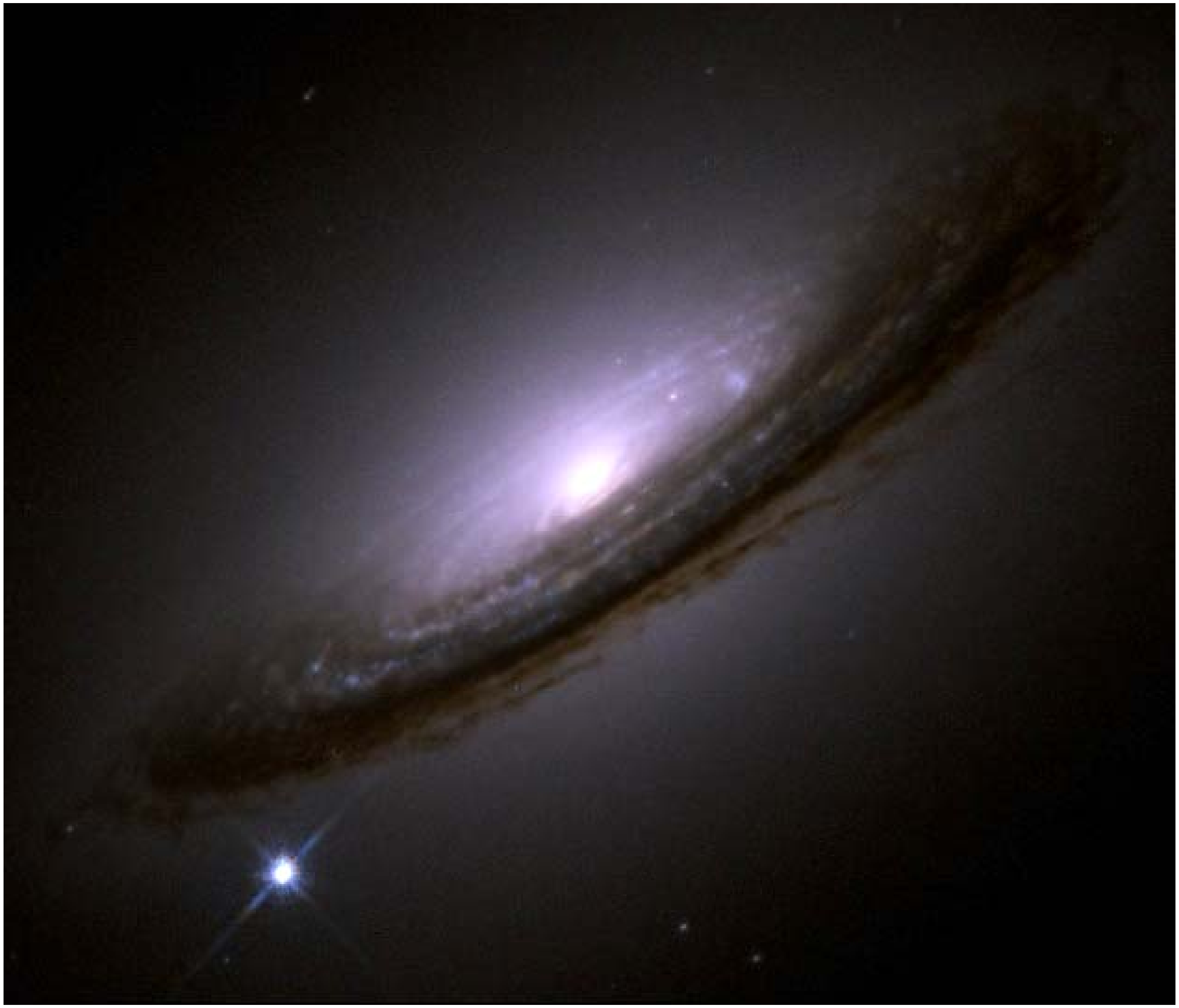


SUSY events (LM4 point: leptons, missing E_T)

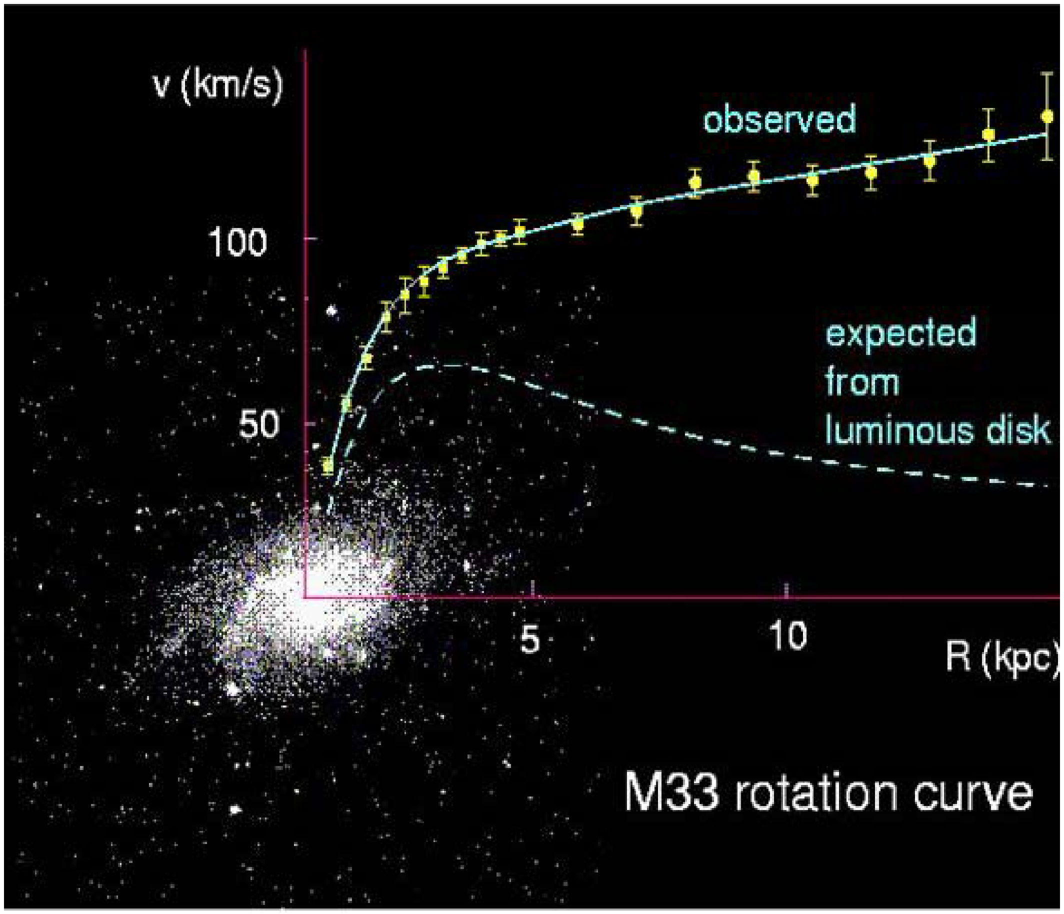
SUSY events (HM1 point at $10^{34} cm^{-2} s^{-1}$)

Y. Osborne

Galaxie avec une Supernova type SNIa



Matière noir dans les galaxies



Mystérieuses courbes de rotation

Pour la plupart des galaxies spirales, l'étude des vitesses de rotation des étoiles suggère l'existence de matière noire autour de la galaxie

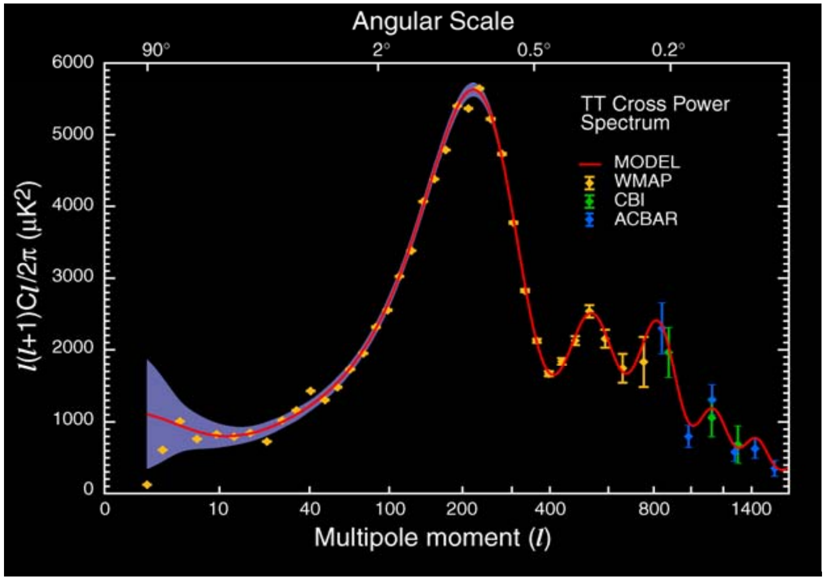
A l'échelle galactique:

M(total) ~ 10 x M(matière lumineuse)

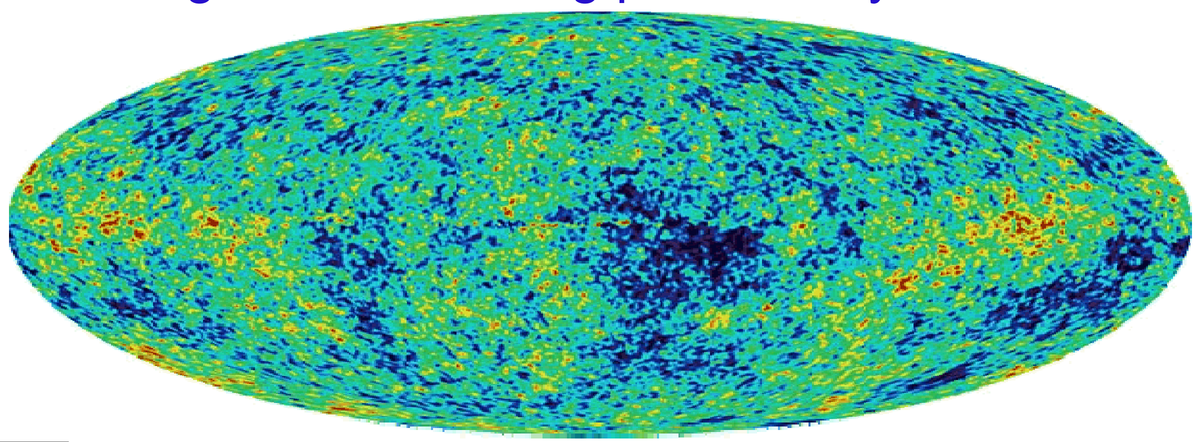
…

58

WMAP and CMB anisotropies
Dark Matter/SUSY/LHC



WMAP measurement of cosmic background anisotropies - evidence for density inhomogeneities seeding present day structures



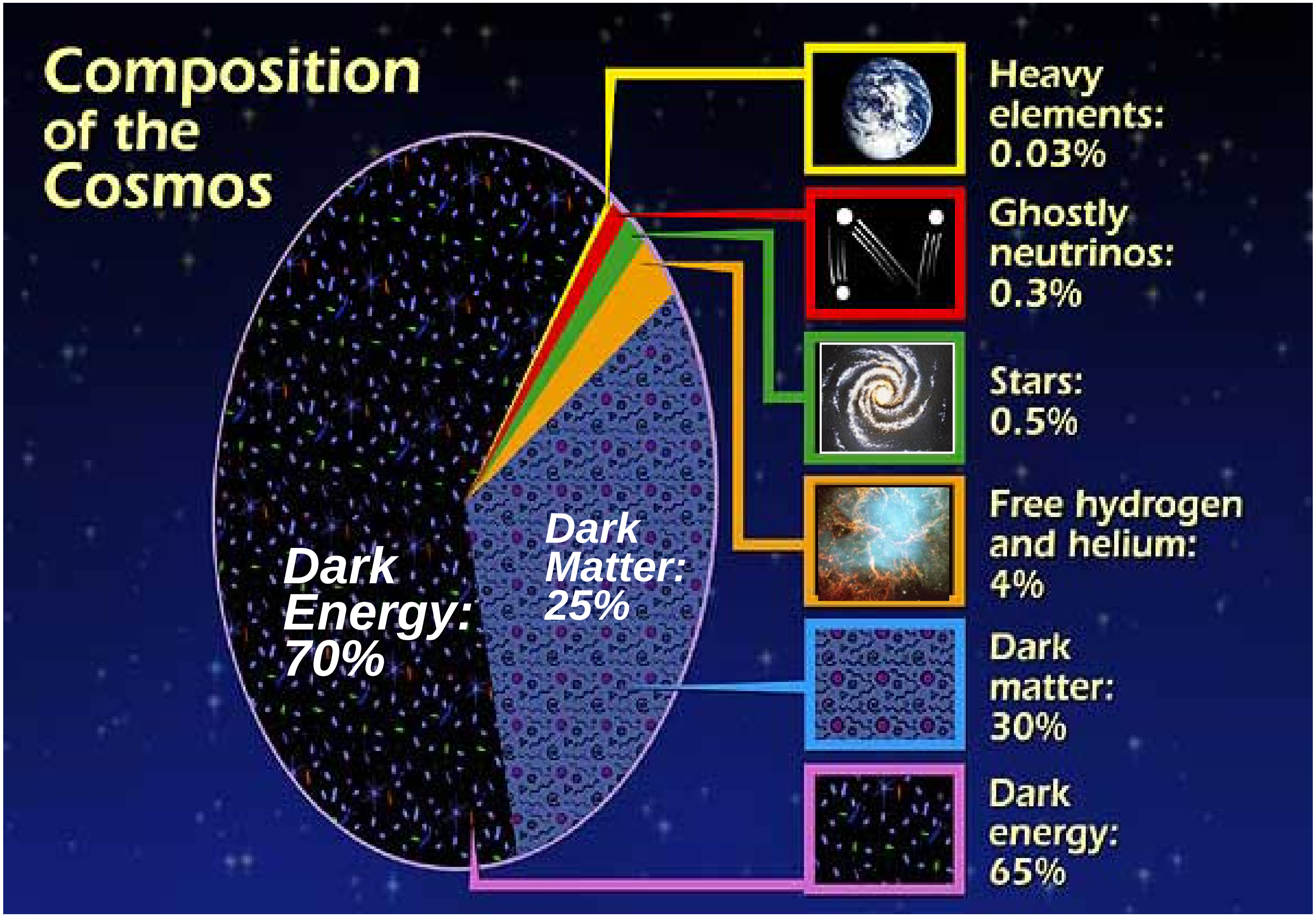
in terms of the critical density:

Baryon density : $\Omega_b = 0.044 \pm 0.004$
Dark Matter : $\Omega_m = 0.23 \pm 0.04$
Dark Energy : $\Omega_\Lambda = 0.73 \pm 0.04$

Connection with SUSY and LHC

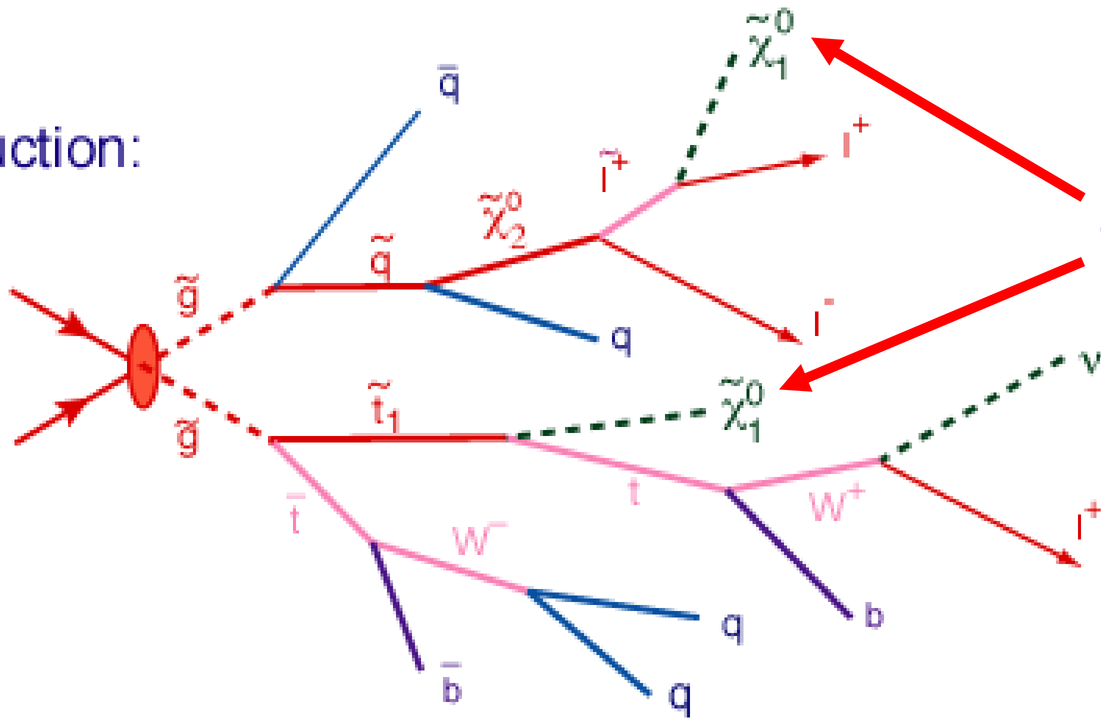
Data from WMAP significantly constrain the Dark Matter content of the Universe, the LSP (Lightest Supersymmetric Particle) is a plausible particle-physics candidate for DM

Matter/Energy in the Universe



Supersymmetric particle and neutralino Dark Matter (?) production at the LHC

- Production:



escaping weakly -interacting neutralinos

- More generally $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, $\tilde{q}\tilde{q}$ production leads to:

  lepton(s) + E_T^{miss} + jets final states

- Backgrounds: W + jets, Z+jets, $t\bar{t}$, Wtb, WW, WZ...

If Planck scale in TeV range possibility for quantum mini black holes at LHC!!

- Schwarzschild radius

4-dim., $M_{gravity} = M_{Planck}$ $\quad R_S \sim \frac{2}{M_{Pl}^2} \frac{M_{BH}}{c^2}$

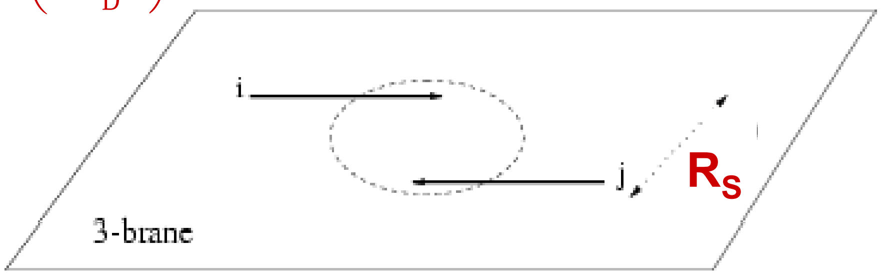
$R_s \rightarrow << 10^{-35}$ m

4 + n-dim., $M_{gravity} = M_D \sim$ TeV $\quad R_S \sim \frac{1}{M_D} \left(\frac{M_{BH}}{M_D} \right)^{\frac{1}{n+1}}$

$R_s \rightarrow \sim 10^{-19}$ m

⬇

Since M_D is low, tiny black holes of M_{BH} ~ TeV can be produced if partons ij with $\sqrt{s_{ij}} = M_{BH}$ pass at a distance smaller than R_S



- Large partonic cross-section : $\sigma(ij \rightarrow BH) \sim \pi R_S^2$
- $\sigma(pp \rightarrow BH)$ is in the range of 1 nb – 1 fb

e.g. For M_D ~1 TeV and n = 3, produce 1 event/second at the LHC!!

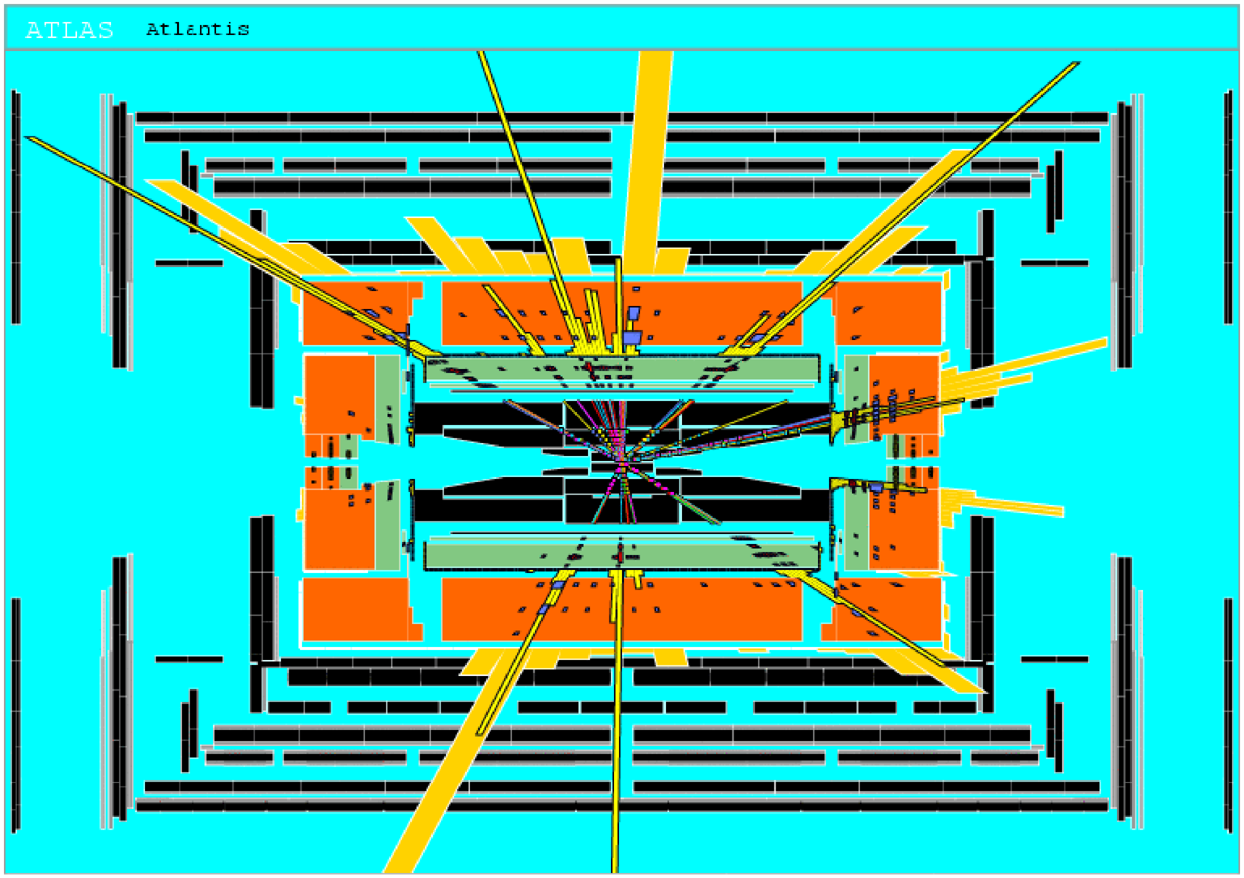
- Black holes decay immediately by Hawking radiation (democratic evaporation)

expected signature (quite spectacular …)

Production of quantum mini-black holes

If the Planck scale in ~TeV region: can expect Black Hole production

Simulation of a black hole event with M_{BH} ~ 8 TeV in ATLAS



M_D ~ 1 TeV
n=6

~ Spherical events
Many high energy jets
leptons, photons etc.

BH's will decay within 10^{-27} secs or so

Detectors, electronics (and rest of the world) are safe!!

Physics at LHC - overview

pp Collisions:

i) Hard collisions

- Standard Model Higgs search, full mass range up to m_H ~1 TeV
- SUSY Higgs searches, full MSSM(h^0, H^0 , A^0 , $H^\pm$) parameter space, searches beyond MSSM
- Squark, gluino searches up to ~ 2.5 TeV; sleptons,neutralinos...GMSB modes, SUSY Dark Matter
- New gauge bosons, generic W', Z' up to ~ 4.5 TeV
- Alternative e-w symmetry breaking mechanims, for ex. ρ_{TC},$V^\pm_{BESS}$, V_{DHT} , non-resonant strongly interacting W, Z sector up to ~ 2 TeV
- Extra dimensions studies (KK recurrencies, R-S gravitons, radion....)
- Detailed studies of top (mass, spin, decay modes, couplings)
- Tests of QCD with top, W, Z production, jets, direct γ; compositness
- Tests of ew gauge couplings - triple gauge boson vertices; LNFV τ decays down to BR ~10^{-8}

ii) CP violation in the B sector, rare B modes, B^0_S oscillations.....

iii) Soft physics: σ_{tot}, σ_{el} , $d\sigma/dt$, diffractive physics, double Pomeron,...

Heavy Ion Collisions: from O-O to Pb-Pb; p-A collisions

Search for quark - gluon plasma, soft and in particular hard probes:

- energy flows, quarkonium suppression, jet quenching, hard photons, dimuons, Z production......

Spares

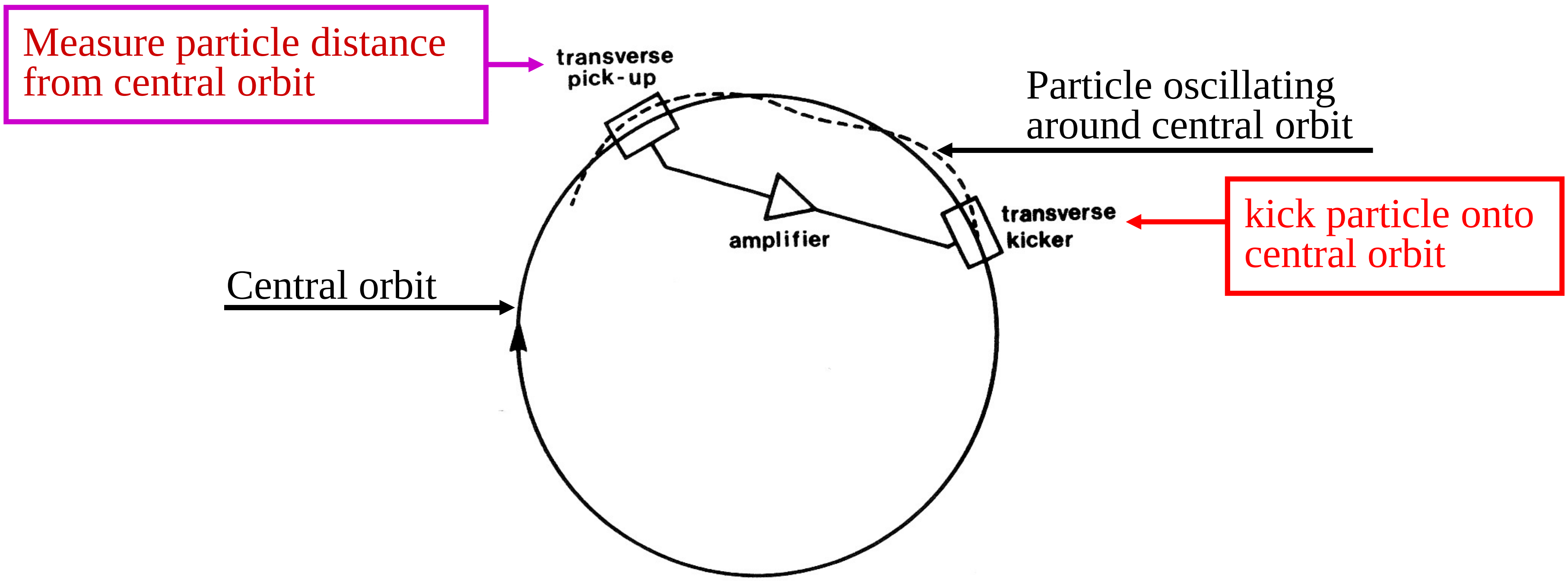
Evidence for the Big Bang

I. What is the evidence for the Big Bang?

1. The universe is expanding
2. The observed abundance of helium (~25%) and other light elements (D, ^3He and ^7Li) are too great to have been synthesized inside stars
3. There is a uniform cosmic microwave background radiation (CBR) characterized by a black body spectrum of approximately 3 K

Stochastic cooling (S. van der Meer)

Principle of operation: for ex. cooling in the horizontal plane:

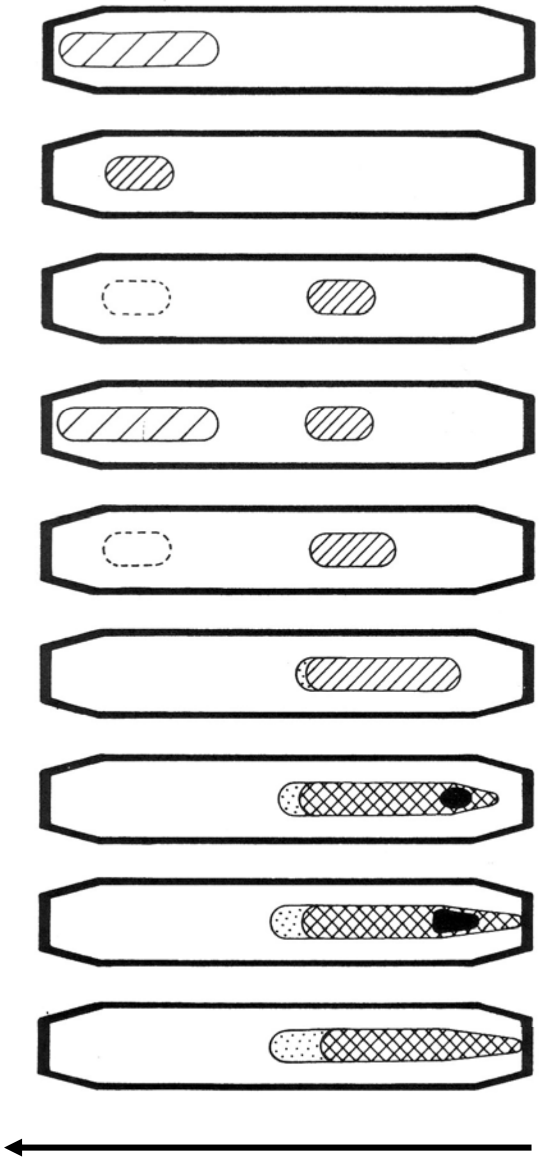


In practice, the pick-up system measures the average distance from central orbit of a group of particles

Independent pick-up – kicker systems to cool:
- horizontal motion
- vertical motion
- longitudinal motion (decrease of $\Delta p/p$)

Antiproton Accumulator - operation

AA vacuum chamber



The first pulse of 7×10^6 $\bar{p}$ has been injected

Precooling reduces momentum spread

First pulse is moved to the stack region where cooling continues

Injection of 2^{nd} $\bar{p}$ pulse 2.4 s later

After precooling 2^{nd} pulse is also stacked

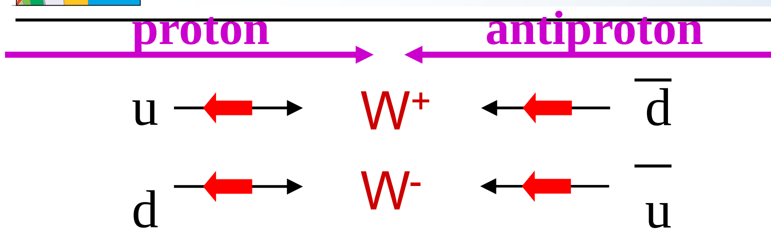
After 15 pulses the stack contains 10^8 $\bar{p}$

After one hour a dense core has formed inside the stack

After one day the core contains enough $\bar{p}$'s for transfer to the SPS

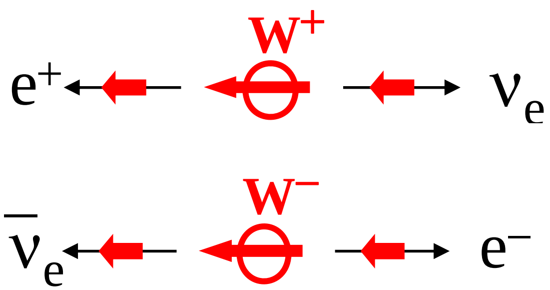
The remaining $\bar{p}$'s are used for next day accumulation

W confirmation, V-A asymmetry in UA1, run of 1983



The almost complete $W^{\pm}$ polarization along antiproton direction was a consequence of V–A coupling - key feature of the W (parity non-conservation!) - and of the collider cm energy ~ 500 - 600 GeV guarantying valence quark fusion into W (x_q, x_{anti-q} ~ $m_W / \sqrt{s}$ ~ 0.2), combined with V-A in decay results in leptonic ang. asymmetry!

In the W rest frame:



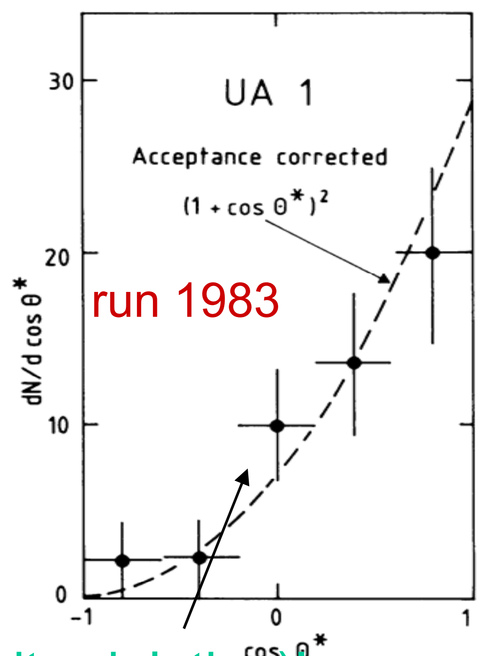
Electron (positron) angular distribution:

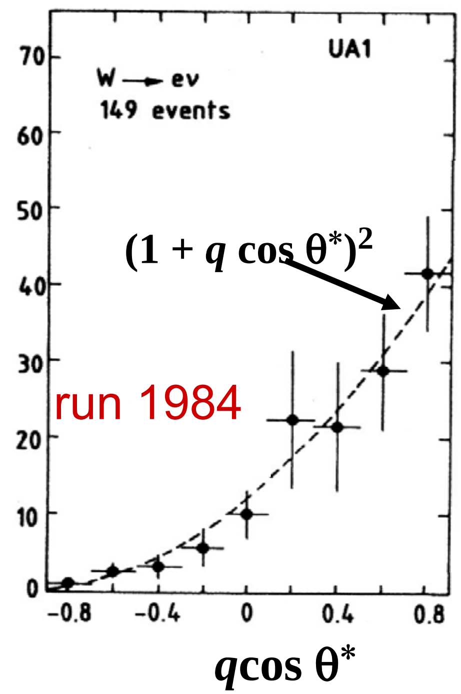
$$\frac{dn}{d\cos\theta^*} \propto \left(1 + q\cos\theta^*\right)^2$$

q = +1 for positrons; q = -1 for electrons

θ^* = 0 along antiproton direction

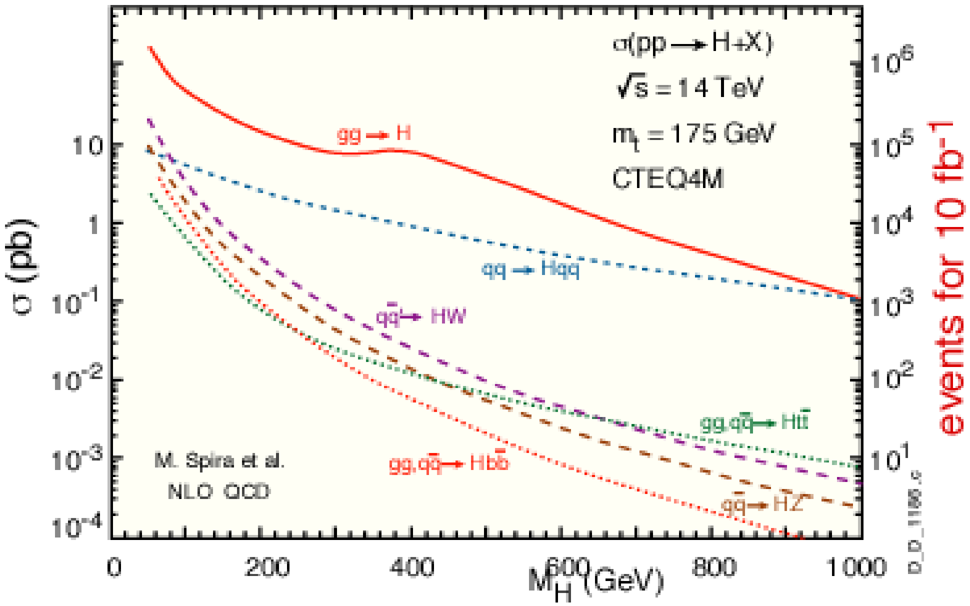
magnetic field of UA1 crucial for this!

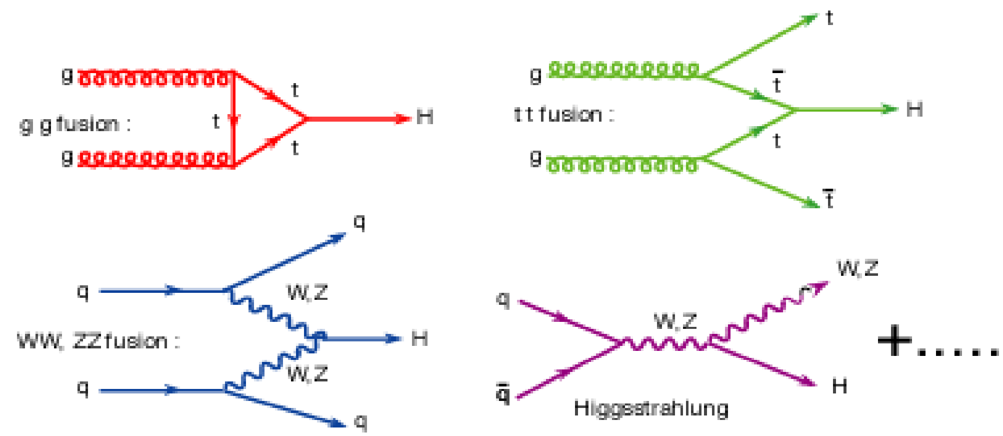




➡ it is really THE W (spin =1, max. parity violation)!

Production du boson de Higgs au LHC et modes de désintégration les plus appropriés





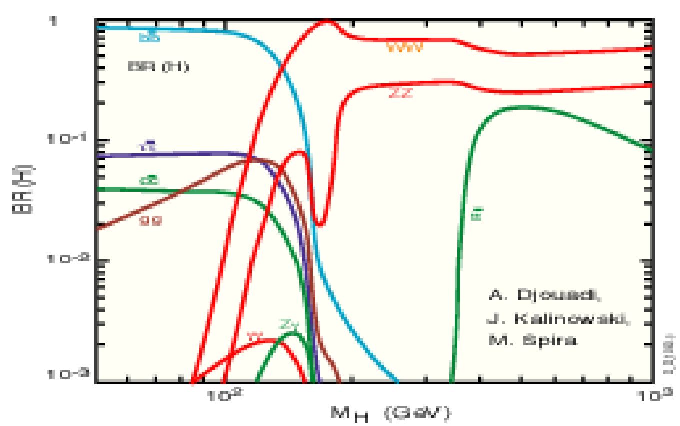
production rates are ~ significant
(ex. 200 GeV H_{SM} produced at 0.02 Hz at 10^{33} $cm^{-2}s^{-1}$!)

but best modes have low BR:

$BR(H \to ZZ \to 4l^{\pm}) = 1.4 \cdot 10^{-3}$

$BR(H \to ZZ \to 4\mu^{\pm}) = 3 \cdot 10^{-4}$

region of interest: m_H ~100 - 250 GeV

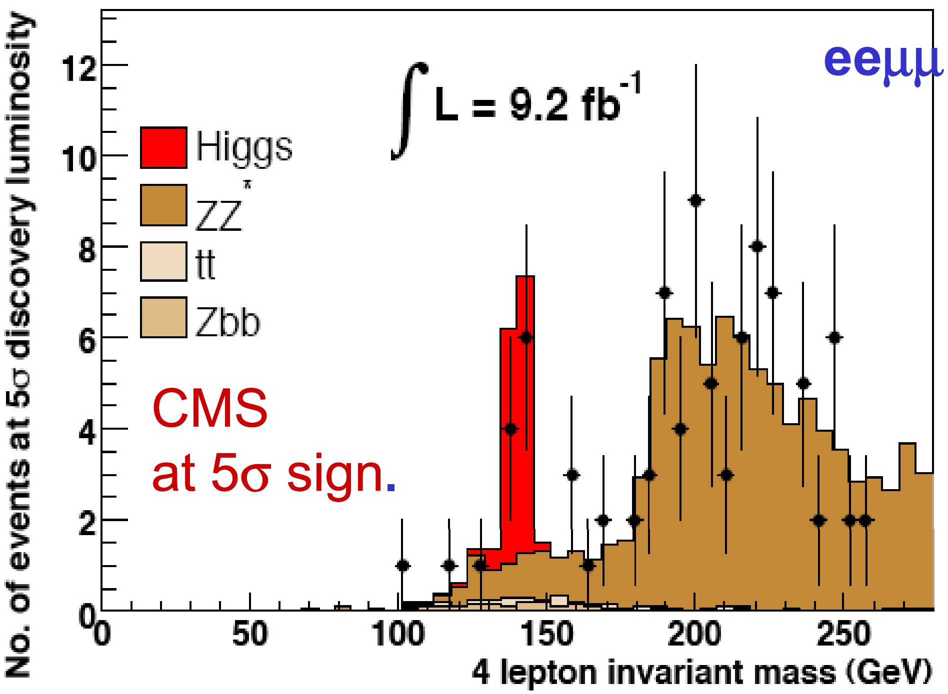


SM Higgs Branching Ratios

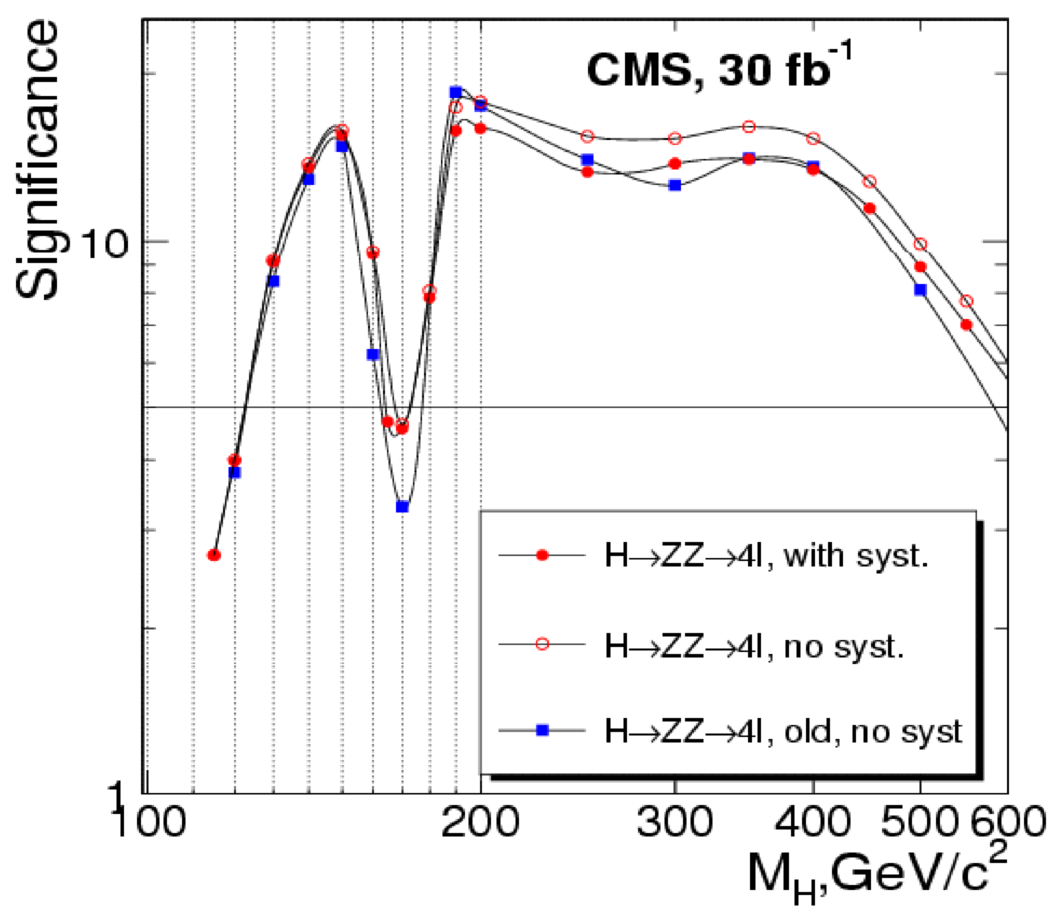
useful decay modes are
$H \to bb$, $\gamma\gamma$, $ZZ (\to 4l^{\pm})$, $WW (\to l\nu l\nu)$, $\tau\tau$

H → ZZ → 4 leptons, 10 - 30 fb^{-1} phase

In ZZ final states observation possible with ~10 fb^{-1}



Higgs signal significance vs mass



SUSY dark matter and present constraints

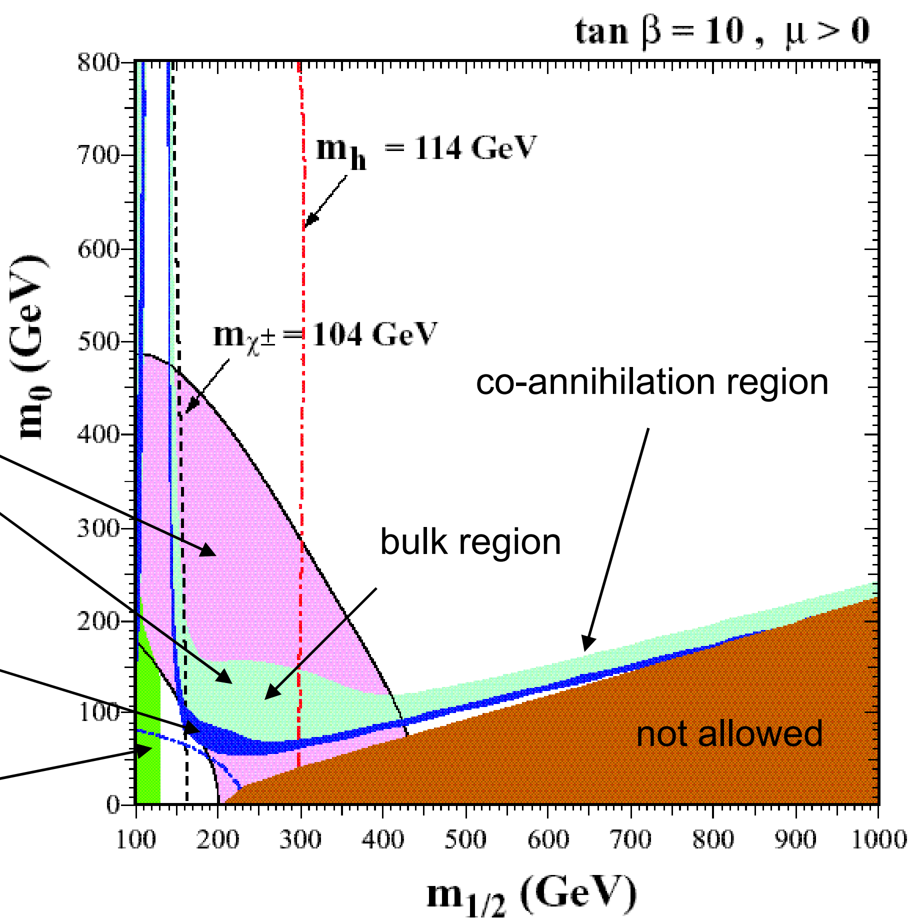
J. Ellis,K.A.Olive,Y.Santoso,V.C.Spanos,hep-ph/0303043

favored by g_μ-2
at 2σ level

older cosmological constraint
$0.1 < \Omega\chi h^2 < 0.3$

newer cosmological constraint
$0.094 < \Omega\chi h^2 < 0.129$

excluded by $b \to s\gamma$

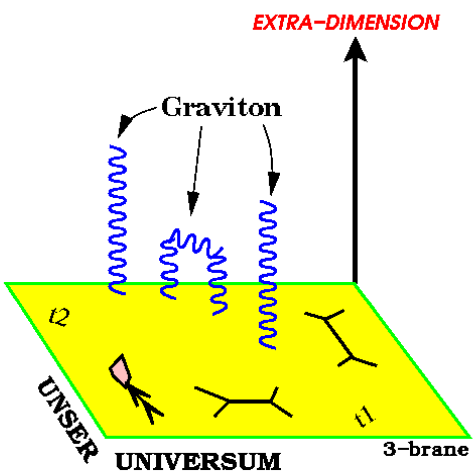


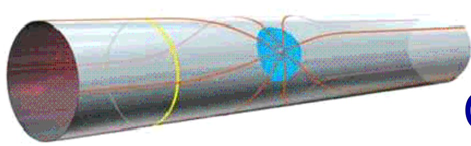
Large Extra Dimensions/ possibility for mini Black Holes

ADD: Arkani –Ahmed, Dimopolous,Dvali

Problem: $m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\ \text{GeV}$ ⟷ $M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\ \text{GeV}$

Idea from String Theory (assumes 11 space-time dimensions). Assume the world we see is in 4 dimensions, but that gravity can expand in 4+δ dimensions. Extra dimensions have size R (μm to fm), then gravity could grow at a much faster rate at short distances, thus Planck scale much (





Curled up…

$$V(r) \sim \frac{m_1 m_2}{M_{Pl}^2} \frac{1}{r}$$

$$V(r) \sim \frac{m_1 m_2}{M_D^{\delta+2}} \frac{1}{r^{\delta+1}}, \quad (r \ll R)$$

$$V(r) \sim \frac{m_1 m_2}{M_D^{\delta+2} R^{\delta}} \frac{1}{r}, \quad (r \gg R)$$