# Future perspective in Elementary Particle Energy

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# $\Box$ Predictions of the m<sub>top</sub> from higher order corrections

op mass (GeV

Extremely precise higher order corrections for the electromagnetism: Lamb shift, G-2 of muon and electron and so on

Most likely also the same with higher order renormalizable corrections of electro-weak interactions





Indirect Determinations of the top mass

#### Will the same be true for the Higgs ?



Prediction of the range for the Higgs mass

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# The so called "no fail" theorem for LHC ?

- Some of the most relevant questions for the future of Elementary particles are related to the completion of the Standard model and of its extensions.
- Central to the Standard Model is the experimental observation of the Higgs boson, for which a very strong evidence for a relatively low mass comes from the remarkable findings of LEP and of SLAC.
- In the case of an elementary Higgs, while fermion masses are "protected", the Higgs mass becomes quadratically divergent due to higher order fermion corrections. This would shift its physical mass near to the presumed limit of validity of quantum mechanics.
- Therefore in order to "protect" the mass of the Higgs, we need an extremely
  precise graph cancellation in order to compensate for the divergence of the
  known fermions.
- SUSY is indeed capable of ensuring such a symmetric cancellation, with a SUSY partner yet to be discovered for each and every ordinary particle.
- A low Higgs mass tells us that the mass range of the SUSY partners must be not too far away.
- If SUSY does not exist, something else, like for instance "Technicolor" must exist !!!! ( so theorists think they know)
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# The case of superconductivity

- In the old Lindau-Ginzberg theory the phenomenon of superconductivity was due to the presence of a neutral scalar particle.
- In reality the phenomenon of superconductivity is generated dynamically by the presence of the so called Cooper pairs, i.e. the dynamic creation of a scalar by electron pairs.
- In the case of the Higgs particle similar alternatives are conceivable.
  - If Higgs is elementary, the super-symmetric cancellation is highly probable.
  - If Higgs is the complex resultant for instance of fermions or other combinations there no reason to justify the presence of such huge cancellation.
- Even if a Higgs particle is detected, there is no need of "nofail theorem" unless one can prove that Higgs is elementary. LHCatSplit, Oct 4, 2008

# Running coupling constants

 Running coupling constants are modified above SUSY threshold, and the three main interactions converge to a common Grand Unified Theory at about 10<sup>16</sup> GeV but provided that SUSY is there at a not too high masses



- A discovery of a "low mass" *elementary* Higgs may become an important hint to the existence of an extremely rich realm of new physics, *a real blessing for LHC*.
- A doubling of the number of elementary particles, is a result of gigantic magnitude.

### LHC as sources of SUSY

The experimental signature of a SUSY type particle is generally very characteristic and it deeply affects the number and the kinematical configuration of large  $p_{\perp}$  events.



2 leptons  $p_{1}$ >15 GeV+  $E_{1}$  miss> 100 GeV



# WMAP results

Parameter	Value
Baryon Density	$\Omega_{\rm b} h^2 = 0.024 \pm 0.001$
Matter Density	$\Omega_{\rm m}h^2=0.14\pm0.02$
Hubble Constant	$h=0.72\pm0.05$
Baryon Density/Critical Density	$\Omega_{\rm b} = 0.044 \pm 0.004$
Matter Density/Critical Density	$\Omega_{\rm m} = 0.27 \pm 0.04$
Age of the Universe	$t_{o} = 13.7 \pm 0.2$



### Cosmic concordance

- One of the most exciting cosmological results is the now solid experimental evidence of a cosmic concordance,  $\Omega_o = 1.02 \pm 0.02$  of a mixture of about 2:1 between dark energy and matter.
- These results are to be compared with the also firmly established Big Bang Nucleo Synthesis,  $\Omega_{BBN} = 0.044 \pm 0.004$ , i.e. ordinary hadronic matter is only a few % of  $\Omega_o$ .
- There is therefore strong, direct cosmological support for a sofar unknown non hadronic matter  $\Omega_M - \Omega_{BNN} \approx 0.226 \pm 0.06$
- The experimental detection of a such new form of dark matter is an extremely exciting programme.
- Ordinary matter is the source of all inanimate and living things we know of and it had an immense evolutionary role over the 13.7 billion years from the big bang: what about the source of the otherwise dominant dark matter ?

### Weak lensing observations of cluster merger

QuickTime<sup>™</sup> and a TIFF (Uncompressed) decompressor are needed to see this picture.

- Shown in green contours in both panels are the weak lensing  $\Box$ reconstruction with the outer contour level at  $\Box \kappa = 0.16$  and increasing in steps of 0.07. The white contours show the errors on the positions of the  $\kappa$  peaks and correspond to 68:3%, 95:5%, and 99:7% confidence levels. The white o show the location of the centers of the masses of the plasma clouds.
- The gravitational potential does not trace the plasma distribution, the dominant baryonic mass component, and thus proves that the majority of the matter in the system is unseen.

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Clowe, Bradac et al.

# SUSY as the source of non-baryonic matter?

- The relation between dark matter and SUSY matter is far from being immediate: however the fact that such SUSY particles may also eventually account for the non baryonic dark matter is therefore either *a big coincidence or a big hint*.
- However in order to be also the origin of dark mass, the lowest lying neutral SUSY particle must be able to survive the 13.7 billion years of the Universe The lifetime of an otherwise fully "permitted" SUSY particle decay is typically ≈10<sup>-18</sup> sec !
- We need to postulate some strictly conserved quantum number (R-symmetry) capable of an almost absolute conservation, with a forbidness factor well in excess of  $4 \times 10^{-17} / 10^{-18} = 4 \times 10^{35}$ !!!

# Dark Matter Candidates ?

- Despite the impressive amount of astrophysical evidence, the exact nature of Dark Matter is still unknown.
- All present evidence *is now limited to gravitational effects*. The main question is that if other types of interactions may be also connected to DM. A key question is the presence of a *electroweak coupling to ordinary matter*.
- Elementary particle physics provides a number of possible candidates in the form of long lived, Weakly Interacting Massive Particles (WIMPs).
- "Popular" bets are, at the moment, the lightest SUSY particle (the Neutralino) and the Axion.

•Kaluza-Klein DM inUED •Kaluza-Klein DM in RS •Axion

•Axino Gravitino Photino SM Neutrino Sterile Neutrino Sneutrino •Light DM Little Higgs DM •Wimpzillas •Q-balls Mirror Matter Champs (charged DM) •D-matter Cryptons Self-interacting Superweakly interacting Braneworls DM Heavy neutrino NEUTRALINO Messenger States in GMSB Branons Chaplygin Gas Split SUSY •Primordial Black Holes

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# Predictions of relic Susy/WIMP



Typical recoil threshold for elastic nuclear recoils > 30 keV

# **Discrimination Methods**

Nuclear Recoils (Neutrons, WIMPs) Electron Recoils (gammas, betas)



# Competition

More than 20 experiments running or in construction



#### Model Independent Annual Modulation Result DAMA/Nal (7 years) + DAMA/LIBRA (4 years) Total exposure: 300555 kg×day = 0.82 ton×yr experimental single-hit residuals rate vs time and energy





Acos[ω(t-t<sub>0</sub>)] ; continuous lines:  $t_0 = 152.5 \text{ d}$ , T = 1.00 y

2-4 keV

A=(0.0215±0.0026) cpd/kg/keV  $\chi^2$ /dof = 51.9/66 **8.3 \sigma C.L.** 

Absence of modulation? No  $\chi^2$ /dof=117.7/67  $\Rightarrow$  P(A=0) = 1.3×10<sup>-4</sup>

#### 2-5 keV

A=(0.0176±0.0020) cpd/kg/keV  $\chi^2$ /dof = 39.6/66 **8.8 \sigma C.L.** 

Absence of modulation? No  $\chi^2$ /dof=116.1/67  $\Rightarrow$  P(A=0) = 1.9×10<sup>-4</sup>

#### 2-6 keV

A=(0.0129±0.0016) cpd/kg/keV  $\chi^2$ /dof = 54.3/66 **8.2 \sigma C.L.** 

Absence of modulation? No  $\chi^2$ /dof=116.4/67  $\Rightarrow$  P(A=0) = 1.8×10<sup>-4</sup>

The data favor the presence of a modulated behavior with proper features at 8.2 °C.L.

# Evidence of $\Omega_{\Lambda} \neq 0$ : Dark Energy ?



#### Regression velocity of Type 1A SN



energy characterized by

negative pressure

# A few comments about Dark Energy.

- Several increasingly accurate Astronomical observations have strengthened the evidence that today's Universe is dominated by an exotic nearly homogeneous energy density with negative pressure. The empty space still contains lots of invisible energy.
- The simplest candidate is a cosmological term in Einstein's field equations. Independently of the nature of this energy, the constant  $\Lambda \neq 0$  is not larger than the critical cosmological density  $\Omega_0 \approx 1$ , and thus incredibly small by particle physics standards. This is a profound mystery, since we expect that all sorts of vacuum energies contribute to the effective cosmological constant.
- Since the vacuum energy density is constant in time, while the matter energy density decreases as the Universe expands, why are the two comparable at about the present time, tiny in the early Universe and very large in the distant future?
- The problem of the value of  $\Lambda$  is one of the greatest questions of the Universe, all along from its introduction in 1917 by Einstein: it has now become widely clear that we are facing a deep mystery and *that the problem will presumably stay with us for along time.*

# Gravitational waves: coming and how soon?

- In spite of the large investments in LIGO and VIRGO, no gravitational event has been so far detected.
- Some better hope with the Advanced LIGO and VIRGO, enhancing sensitivity between 3 and 10 times present status.



- Third generation cryogenic interferometers, to improve x 100 times the present sensitivity to the frequencies 1-10 Hz. In Europe the Einstein Telescope (ET), while similar initiatives are growing in US and Japan.
- A completely different frequency range (0.0001-0.1 Hz) will be the LISA space project supported by ESA and NASA. It will comprise three satellites flying five million kilometres apart, in an equilateral triangle.

# Neutrinos

- Are neutrino a simple carbon copy repetition of guarks? Masses were once taken as zeros "by ignorance" Oscillations are an extension of KM-C mixing Matter oscillations are due to neutral currents But this is't all ! Important discoveries are ahead:  $\rightarrow$  CP violation in the lepton sector  $\rightarrow$  Majorana or Dirac v's;v-less  $\beta$ -decay,v-masses Sterile neutrino and other "surprises" Right handed neutrinos and see-saw mechanisms from Nature 455.156 Very large and expensive experiments both without and with
  - new long baseline accelerators ( $\beta$  and  $v_{\mu}$  beams) are required.
- Of course the astronomical importance of neutrinos from space is immense so is their role in the cosmic evolution.

### New accelerators for neutrinos

- Crucial but very difficult experiments are needed in order to complete the phenomenology of the neutrino sector.
- Such a wide programme demands new accelerated neutrino beams with well identified initial species, long decay distances and novel detection technologies.
- Cosmological arguments have suggested that in order to ensure dominance of matter over anti-matter the CP violation of the guark sector must be extended also to the leptonic sector.
- To this effect, all the three neutrino mixing angles must have non zero values, including the presently unknown  $\theta_{13}$ , for which the CHOOZ experiment has given the limit  $\sin^2(2 \theta_{13}) < 0.14$  (0.18).
- Provided  $\theta_{13} \neq 0$ , the leptonic CP violating phase  $\delta$  becomes accessible with sufficient statistics and in absence of backgrounds.
- Conventional horns and high energy proton beams in MWatt region may be capable of pushing the sensitivity up to  $sin^2(2 \theta_{13}) > 0.02$ , the limit due to the tiny natural  $v_e$  contamination of the horn driven  $v_u$  beam.
- Entirely new methods are required if  $\sin^2(2 \theta_{13})$  would turn out to have an even smaller value. LHCatSplit, Oct 4, 2008

# Double Chooz in France, Daya Bay in China and so on



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1.2 1

0.8

0.4

0.6

0.2

# Future options

- Starting either from an initial high purity  $v_{\mu}$  or  $v_{e}$  source, the key physical process is the observation of tiny  $\mathcal{O} (\approx 10^{-3})$  oscillation mixing between  $v_{\mu} \leftrightarrow v_{e}$  related to  $\theta_{13}$ .
- Two advanced methods both based on cooling technologies are being considered:
- 1) Muon beams, following a method by Skrinsky
  - → 4 MW Proton driver: production target
  - $\rightarrow$  Target, capture channel: Create  $\pi$ , decay to  $\mu$
  - $\rightarrow$  Cooling:Reduce transverse emittance (1.7  $\mu$ /p)
  - Muon acceleration: ~130 MeV to 20-50 GeV
  - Decay ring(s): Store for ~500 turn;Long straights
- 2) Beta-beams: Zucchelli has proposed a neutrino beam from the β-decay of a short lived nucleus followed by acceleration and decay in a dedicated high energy storage ring. It was originally based on He-6 and Ne-19(?), produced by many MW



A novel method based on ion cooling of Li-8 and B-8 is here described LHCatSplit, Oct 4, 2008



#### Muon Ionisation Cooling Experiment (MICE at RAL)



# Ionization cooling of slow ( $\beta \approx 0.1$ ) ions

- Stochastic cooling and electron cooling are both well established cooling techniques.
- The unique features of the slow moving, highly ionising and massive ions suggest the development of a novel cooling method based on the non-Liouvillian nature of the dE/dx losses.
- The basic configuration consists of
  - → an appropriate (small) storage ring,
  - a thin target "foil" which induces energy losses and
  - $\rightarrow$  an accelerating RF cavity.
- An initially injected ion beam after being captured by ionisation stripping of the thin target into its highest ionisation state is permanently stored in the ring. An accelerating cavity of an appropriate voltage and sufficient longitudinal amplitude replaces continuously the energy losses of the stored beam maintaining the equilibrium (orbit) configuration.



#### Beta beams: A = 8: the Li/Be/B triplet



Isospin triplet with A = 8 (Li-8, Be-8, B-8), decaying to the fundamental level of Be-8. In absence of Coulomb corrections, the three states would have identical nucleons configurations because of charge independence. The actual experimental values of the beta decaying doublet Li-8 with = 0.84 s and B-8 with  $\tau_{1/2} = 0.77$  s are respectively  $Q^* = 16.005$  MeV and  $Q^* = 16.957$  MeV.

# The storage ring

- Singly ionized Li-7 injected at 27 MeV are fully ionized by stripping in the gas jet target.
- The circulating beam has a period of  $P_{S}$ =0.136 µs, corresponding to a revolution frequency  $f_{S}$ = 7.35 Mhz.
- At the RF cavities the lattice should be with zero dispersion but at the gas target it should be dispersive.
- The gas target energy loss is U<sub>o</sub> = 300 keV and it is wedge shaped. The wedge is adding a linear function to the energy loss, U<sub>o</sub>+U'x with U x = 700 keV/m to damp long. motion.
- Produced secondary particles are collected in the thin reaction stopper foils and brought as neutrals to rest..
- Channelled to an ion source, they are ionised again and accelerated to high energies with conventional methods.



#### **Detection rates**

- The detector distance is 730 km, corresponding to the Soudan from LNAL or LNGS from CERN.
- We have considered a LAr detector of 50 kton (35'000 m3) if  $sin^2(2 \theta_{13}) > 2.7 \times 10^{-3}$ , doubled to 100 kton for an ultimate experimental sensitivity as small as  $\approx 6 \times 10^{-4}$ . Rates before cuts refer to a 5 years exposure with 200 d/y.



# Signals and background in LAr

- The signal is a large e-like signal to which a small  $\mu$  -like signal is superposed.
- The background is rejected selecting the events leading to a muon capture (70% of all cases). The pion background is rejected on the following criteria:
  - 1) The neutral current signal with a pion faking the muon has a rate of the order of 1/60 of the CC current rate.
  - 2) The total visible energy deposited along the track as well as the range are accurately measured in LAr. For a given energy, the range of a muon is longer than the one of a pion. Calculations using the FLUKA simulation indicate that a separation better than 1/200 is possible with a few percent loss of the muon track.
  - 3) About 70% of the negative muons and all pions will undergo nuclear capture at the end of the range but with very different characteristics. Discrimination of the local energy (blob) offers a good identification between  $\pi$  and  $\mu$  -(a factor 50 in the  $\pi \leftrightarrow \mu$  star identification).

QuickTime™ and a decompressor are needed to see this picture.

Total background events ≈ 0.5 events for 100 kton LAr and 5 years of running

### High Energy Colliders: ILC ( $E_{cm}$ up to ~ 500 GeV)



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### High Energy Colliders: CLIC ( $E_{cm}$ up to ~ 3TeV)



### Main CLIC parameters

Center-of-mass energy	3 TeV
Peak Luminosity	7.10 <sup>34</sup> cm <sup>-2</sup> s <sup>-1</sup>
Peak luminosity (in 1% of energy)	2·10 <sup>34</sup> cm <sup>-2</sup> s <sup>-1</sup>
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	41.7 km
Bunch charge	4·10 <sup>9</sup>
Beam pulse length	200 ns
Average current in pulse	1 A
Hor./vert. normalized emittance	660 / 20 nm rad
Hor./vert. IP beam size bef. pinch	53 / ~1 nm
Total site length	48.25 km
Total power consumption	390 MW

# Proton decay

- Proton (nucleon) decay should occur but at an insignificant rate at the Planck mass.
- Grand Unified gauge Theories predict a much larger decay rates, but still smaller than the present limits of about 10<sup>34</sup> y.
- Running coupling constants might converge according to LEP extrapolations and SUSY to a necessary common value: it would predict Higgs dominance converging to the heaviest quark and lepton, hence dominance of exotic channels, like K+v<sub> $\tau$ </sub>, K+ $\mu$ , etc.
- An adequate sensitivity improvement would require detectors of extremely large sensitive mass and of remarkable quality in order to identify the signal over the many other backgrounds.
- The detector should be combined with a long baseline accelerator experiment to study CP-violation in the neutrino oscillation.

#### Proton decay: sensitivity WITH LAr vs exposure



 $6 \times 10^{34}$  nucleons (100 kton)  $\Rightarrow$  $\tau_p$  /Br > 2 10<sup>34</sup> years  $\times$  T(yr)  $\times \epsilon$  @ 90 CL  $p \rightarrow K^+ v_e$  $P_{= 425 MeV}$  MC

65 cm

#### "Single" event detection capability





#### $p \rightarrow \pi^{o} + e^{+}$ in LAr

#### 210 cm



# Conclusions

- Frank Wilczek (Physics, 2004) has said that "only the LHC stands a real chance of breaking the existing paradigm" and Nature has named it "the unstoppable collider".
- I have been for decades one of the most strenuous supporters of the LHC. However I believe that we cannot predict where and if the next major discoveries/surprises may come from. Ultimately the LHC and the other experiments are fighting together, like did David and Goliath.
- The discovery of SUSY may be a real "bonanza" for the present (and future) colliders but its relation to the now credible dark matter is by no mean obvious or granted.
- Likewise the neutrino sector may reserve for us incredible new discoveries. Proton decay will never be observable with accelerators. Gravitational waves are about to be discovered in the laboratory and in space.
- Events from the sky and underground have an immense role to play in the future. Now that LHC is on the verge of operation, European physics and CERN have the obligation of concentrating some of the efforts and funding <u>also</u> on a broader range of other activities in the framework of a wider collaborative effort with the rest of the world.

Thank you !

# Exploiting the reverse kinematics

- Reactions are Li-7(d,p) Li-8 and Li-6(He3,n) B-8.
- In the region of few MeV d and He-3, the cross section for the reaction Li-7(d,p) Li-8 is about 100 mb with (a max at 200 mb), while for the reaction Li-6(He3,n) B-8 it is about a fraction 10 lower.
- The products of a D or He-3 beam are emitted over a large angles and very small kinetic energies, (B-8 at 2 MeV is ≈ 0.5 mg/cm<sup>2</sup>) The power requires a very thin moving Li target in liquid form.
- Therefore choose the "mirror" system, namely a beam of Li-7 or Li-6 hitting a gaseous target either of D or of He-3.
- The emission angles are in a narrow angular cone around about 10° and 12° respectively, with a convenient and relatively concentrated outgoing energy spectrum.



# An $\beta$ -beam configuration based on B-8 and Li-8 decays.

- With B-8, two main factors are reducing the required proton equivalent energy of the accelerator with respect to the Zucchelli/CERN proposal, namely
  - the higher average CM neutrino energy of 7.0 MeV rather than 1.7 MeV

 $\rightarrow$  Z/A = 5/8 = 0.625 rather than 2/6 = 0.333 for He-6, incrementing  $\gamma$  by 1.87.

- For a given magnetic rigidity or proton equivalent momentum, the choice of B-8 produces neutrinos with an average energy 4.11 x 1.87 = 7.7 times larger !
- As a consequence, for instance the existing Main Energy Injector at FNAL with 120 GeV protons may be modified in order to produce fully stripped B-8 beta neutrinos with an end point of 2.5 GeV, perfectly suited for L = 730 km and the Sudan mine. The relativistic factor is  $\gamma_{B-8}$ = 80 for the nominal magnetic rigidity.
- We assume that the improved accelerator complex, now being currently improved to accelerate up to a 2 MWatt proton beam, may be also able to accelerate the same circulating current also for B-8, corresponding to 2 ÷ 3 x 10<sup>13</sup> ions/s.
- Similar modifications may be at hand at CERN in order to produce a sufficiently large B-8 circulating current and a proton equivalent energy in the interval 100 ÷ 200 GeV in order to send neutrinos to LNGS laboratory.
- The high energy ion beam extracted from the main accelerator is accumulated on a storage ring with one long straight section pointing to the neutrino detector, comprehending 1/3 of the circumference.