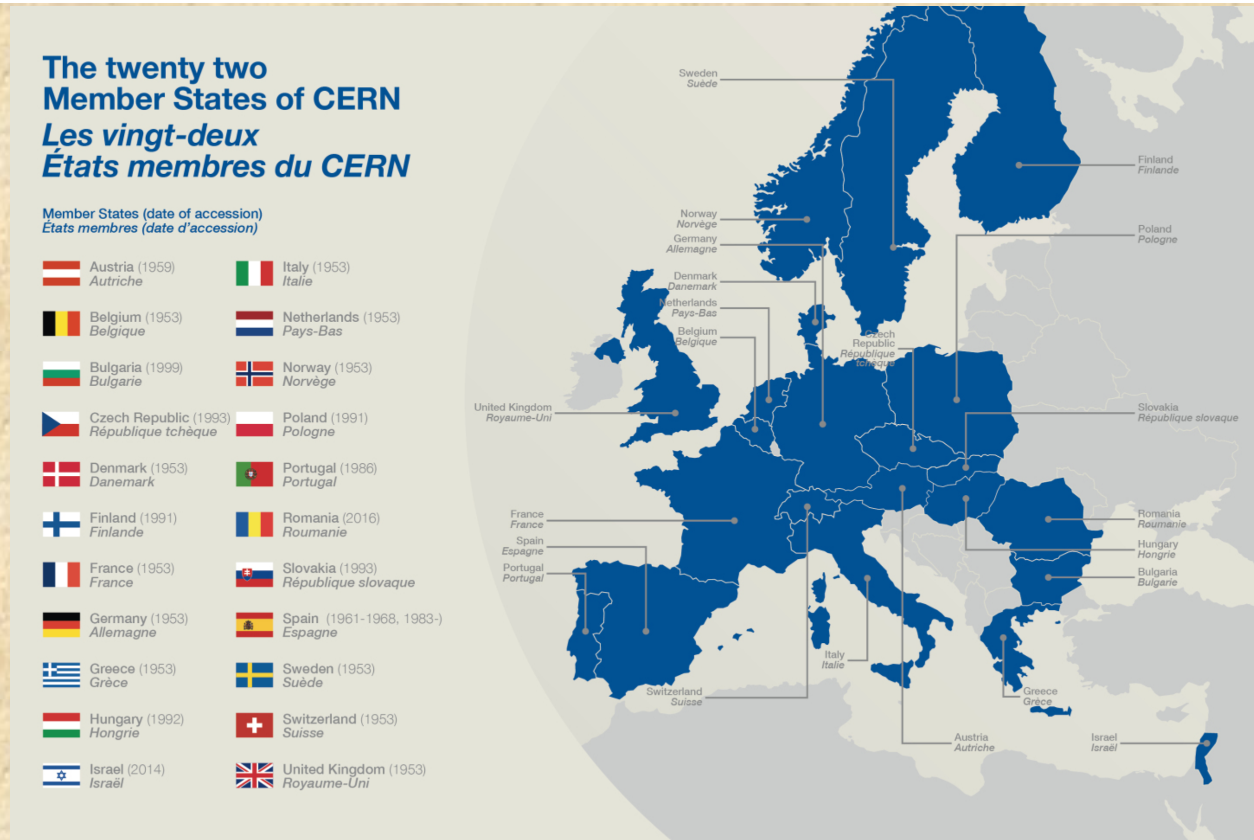
Welcome, Bien Venu, Hola, Herzlich Willkommen,
Seja Muito Bem Vindo

The CERN Accelerator School


Hotel Do Mar,
Sesimbra, Portugal

The CERN Accelerator School




*Since 1983 organisation of lecture series on particle accelerators and colliders of all kinds*

*… in all 22 CERN member states.*

* *Introductory level lectures*
* *Advanced level courses*
* *Lectures on special topics*

*… and our Special Topic is*

*High Gradient Wakefield Acceleration*

# Time Table of the School

## Coffee & Cookies

## Tea & Cookies

| Time | Mo, 11.03.2019 | Tu, 12.03.2019 | Wed, 13.03.2019 | Thu, 14.03.2019 | Fri, 15.03.2019 | Sat, 16.03.2019 | Sun, 17.03.2 | Mo, 18.03.2019 | Tu, 19.03.2019 | Wed, 20.03.2019 | Thu, 21.03.2019 | Fri.22.03.2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09:00h | | Welcome & Opening<br>*B. Holzer* | Introduction to plasma physics II<br>*P. Gibbon* | Plasma sources I<br>*J. Osterhoff* | Plasma sources II<br>*J. Osterhoff* | Plasma wake generation (non-linear)<br>*L. Silva* | | Blow out regime<br>*L. Silva* | Particle beam diagnostics<br>*B. Marchetti* | electron sources from plasma I<br>*B. Cros* | staging (incl. Synchr. & tolerances)<br>*C. Lindstrom* | |
| 10:00h | A | Conventional Acc. & their limits I<br>*M. Ferrario* | Laser beam physics<br>*L. Corner* | Plasma wake generation (linear)<br>*Z. Najmudin* | Modelling and simulation I<br>*J.L. Vay* | Modelling and simulation II<br>*J.L. Vay* | E<br>x | laser driver propag. in plasmas<br>*S. Mangles* | Plasma diagnostics<br>*J. Osterhoff* | Dielectrical Acc Structures (Theory)<br>*N. Schoenenberger* | positron acc. in plasmas<br>*S. Corde* | D<br>E<br>P |
| 11:00h | R | Coffee | Coffee | Coffee | Coffee | Coffee | c | Coffee | Coffee | Coffee | Coffee | A |
| 11:30h | R<br>I<br>V | Conventional Acc. & their limits II<br>*M. Ferrario* | laser diagnostics<br>*L. Corner* | Acceleration of e- in a plasma II<br>*A. Thomas* | Injection extraction and matching I<br>*M. Ferrario* | Modelling and simulation III<br>*J.L. Vay* | u<br>r | Beam driven (experiment)<br>*E. Gschwendtner* | Beam driver propogation (beams)<br>*R. Assmann* | electron sources from plasma II<br>*B. Cros* | case study<br>*A. Walker* | R<br>T<br>U |
| 12:30h | **Lunch** | Lunch | Lunch | Lunch | Lunch | Lunch | s | Lunch | Lunch | Lunch | Lunch | R |
| 14:30h | | Introduction & hist. overview<br>*V. Malka* | Laser driven wakefields I<br>*S. Karsch* | | Injection extraction and matching II<br>*M. Ferrario* | Mod & simul hands on II<br>*J. Vieira, R. Fonsecca* | i<br>o | Laser driven (experiment)<br>*S. Mangles* | Beam driven systems (PWFA) I<br>*P. Muggli* | Dielectrical Acc Structures (Exp)<br>*N. Schoenenberger* | Radiation generation<br>*F. Albert* | E |
| 15:30h | D<br>A<br>Y | Introduction to plasma physics I<br>*P. Gibbon* | Acceleration of e- in a plasma I<br>*A. Thomas* | Free | Applications<br>*Z. Najmudin* | Mod & simul hands on III<br>*J. Vieira, R. Fonsecca* | n | case study<br>*A. Walker* | Beam driven systems (PWFA) II<br>*P. Muggli* | Discussion 2<br>*B. Holzer* | case study presentations<br>*A. Walker* | D<br>A<br>Y |
| 16:30h | | Tea | Tea | Afternoon | Tea | Tea | | Tea | Tea | Tea | Tea | |
| 17:00h | | Introduction to laser physics I<br>*L. Corner* | Laser driven wakefields II<br>*S. Karsch* | | Discussion 1<br>*B. Holzer* | Seminar I<br>*IST* | | Seminar: Acceleration of protons & ions<br>*L. Willingale* | case study<br>*A. Walker* | case study<br>*A. Walker* | case study presentations<br>*A. Walker* | |
| 18:00h | | 1 slide / 1 minute<br>*B. Holzer* | case study Introduction<br>*A. Walker* | | Mod & simul hands on I<br>*J. Vieira, R. Fonsecca* | case study<br>*A. Walker* | | case study<br>*A. Walker* | Departure Gala Dinner:<br>*19:00h* | case study<br>*A. Walker* | Coherent X-rays and applications<br>*M. Fajardo* | |
| | | | | | | | | | | | | |
| 20:00h | **Dinner** | Dinner | Dinner | Dinner | Dinner | Dinner | Dinner | Dinner | Gala_Dinner | Dinner | Dinner | |

# Time Table of the School

## Case Studies … *It is YOUR turn !!!*

***Organiser: Andreas Walker***

***Details …***

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| 11:00h | R | Coffee | Coffee | Coffee | Coffee | Coffee | c | Coffee | Coffee | Coffee | Coffee | A |
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| 12:30h | A | Lunch | Lunch | Lunch | Lunch | Lunch | s | Lunch | Lunch | Lunch | Lunch | R |
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| 16:30h | | Tea | Tea | Afternoon | Tea | Tea | | Tea | Tea | Tea | Tea | |
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| 18:00h | | 1 slide / 1 minute<br>*B. Holzer* | case study Introduction<br>*A. Walker* | | Mod & simul hands on I<br>*J. Vieira, R. Fonsecca* | case study<br>*A. Walker* | | case study<br>*A. Walker* | Departure Gala Dinner:<br>*19:00h* | case study<br>*A. Walker* | Coherent X-rays and applications<br>*M. Fajardo* | |
| | | | | | | | | | | | | |
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# Welcome Drink Today

## 19:00h

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| 20:00h | | Dinner | Dinner | Dinner | Dinner | Dinner | Dinner | Dinner | Gala_Dinner | Dinner | Dinner | |

# The famous CAS Questionnaire

## - Students-Feedback-Sheet -

**PLASMA WAKE ACCELERATION**
**CERN, Geneva, Switzerland**
**23-29 November, 2014**

***YOUR IMPRESSIONS OF THE PROGRAMME***

Please mark each lecture with a number 1 to 5 in each of the three columns labelled "Level, Content and Presentation". The meaning of the numbers is as shown below. Please take the time to complete this sheet and leave it in the box provided in the Secretariat or mail it to Mrs. B. Strasser, CERN, CERN Accelerator School, DG Department, CH-1211 Geneva 23. Your answers are confidential.

| LEVEL | CONTENT | PRESENTATION |
|---|---|---|
| 1 – Much too low | 1 – Completely uninteresting | 1 – Very poor |
| 2 – Low | 2 – Uninteresting | 2 – Poor |
| 3 – Just right | 3 – Of some interest | 3 – Fair |
| 4 – Too high | 4 – Interesting | 4 – Good |
| 5 – Much too high | 5 – Very interesting | 5 – Very good |

| TITLE | LEVEL | CONTENT | PRESENTATION |
|---|---|---|---|
| Introduction & Historical Overview | | | |
| Accelerator Physics & Limitations I, II | | | |
| Introduction to Plasma Physics I, II | | | |
| Introduction to Laser Physics & High Power Lasers | | | |
| Plasma Wake Generation (Linear) | | | |
| Acceleration of e- in a Plasma | | | |
| Plasma Wake Generation (Non-Linear) | | | |
| Blow Out Regime | | | |
| Laser Driven Systems | | | |
| Beam Driven Systems | | | |
| Plasma Injection Schemes | | | |
| Injection Extraction & Matching | | | |
| Modelling and Simulations I, II | | | |
| Beam Driven Propagation (Beams) | | | |
| Beam Driven Propagation (Lasers) | | | |
| Bream Driven Plasma Acceleration (Experiment) | | | |
| Plasma Diagnostics | | | |
| Particle Beam Diagnostics I, II | | | |
| Radiation Generation | | | |
| Plasma Sources | | | |
| Laser Driven (Experiment) | | | |
| Applications | | | |

*** it is important**

*** there are different scalings for level**
**"3" = perfect**

*** and content / presentation**
**"5" = perfect**

**Example:**
**If you want to say**
***"super dooper great topic***
***& everything perfect"***
***you write 3/5/5***

# Online Evaluation Form:


**Access to web-form is granted to participants using the email addresses indicated in their Indico registrations**

**Step 1**:

email with the link has been sent to all participants

If you did not receive the email, contact Anastasiya.Safronava@cern.ch

**Step 2**:

to login use the same email account; it will certainly work for CERN and for Google accounts, but not only

If you can not login, contact Anastasiya.Safronava@cern.ch

Solutions: provide your Google account if you have one, or a temporary CERN account will be created for you

# One Slide, One Minute

## *for the fun of it*

***Thanx to all volonteers !!***

***It will be super relaxed …. And will last indeed ONE MINUTE per presentation !!***

***The chair person will try his best to stay on time.***

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| 16:30h | | Tea | Tea | Aft |
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| 18:00h | | 1 slide / 1 minute<br>*B. Holzer* | case study Introduction<br>*A. Walker* | |
| | | | | |
| 20:00h | | Dinner | Dinner | Dinner |

*We owe our sponsors*
*a debt of gratitude*

***For their financial and moral contribution to our student grants.***

***ARIES***
***EuroNNac***
***ICFA***

***CERN***
***DESY***
***IST / Golp***
***Ecole Polytechnique***
***et al.***

The CERN Accelerator School


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Only in the year 2014 CAS organized the previous course on "Plasma Wake Acceleration", which found large interest in the community. Since this field is very rapidly evolving CAS is proposing again a course on "High Gradient Wakefield Acceleration" in spring 2019. This course will cover some fundamentals of Wakefield acceleration, the main classes of laser beam, electron beam and proton beam induced plasmas, plus several technology items related to the subject. The course will be accessible for newcomers in the field, but it will also provide up-to-date information for more advanced students.

**Contact:** CERN Accelerator School
CH – 1211 Geneva 23
**cas.web.cern.ch**
**Accelerator.school@cern.ch**

## *Last Remark:*

*in case of any questions / comments / problems ...*

*talk to / call*

*Bernhard Holzer* *0041-75411-1056*
*Delphine Rivoiron* *0041-75411-4977*
*Maria Filippova*

*And finally:*

*A great Thank You to the Speakers for a tremendous effort that they did preparing their lectures*

*And to YOU, the students for the tremendous effort that lies in front of you !!*

***So far so good.***

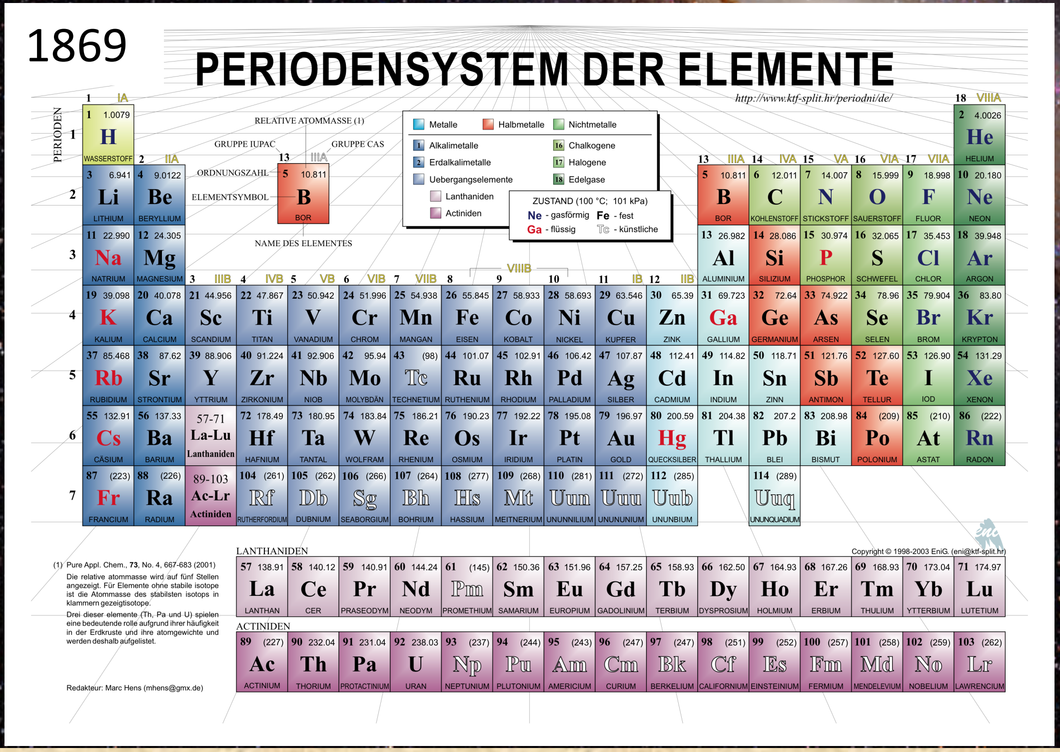
***And WHY all that ????***

# Future Accelerators

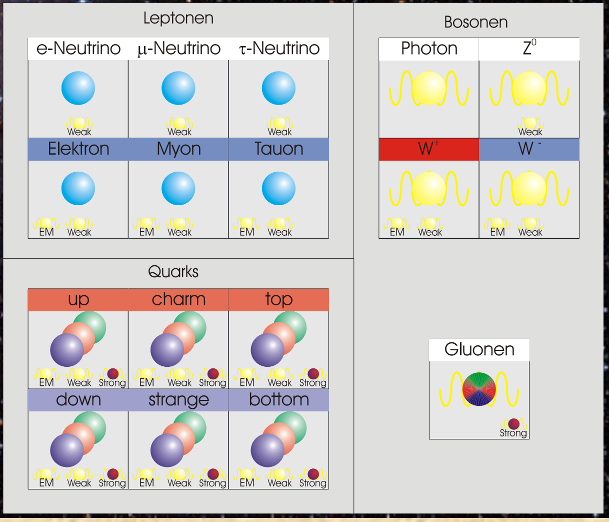
Bernhard Holzer,
CERN, ABP & CAS

## A Short Introduction ... LOL

***In the end and after all ... : We try to explain the structure of the "hadronischen matter" in the Universe.***
***In short words: What is going on up there ???***



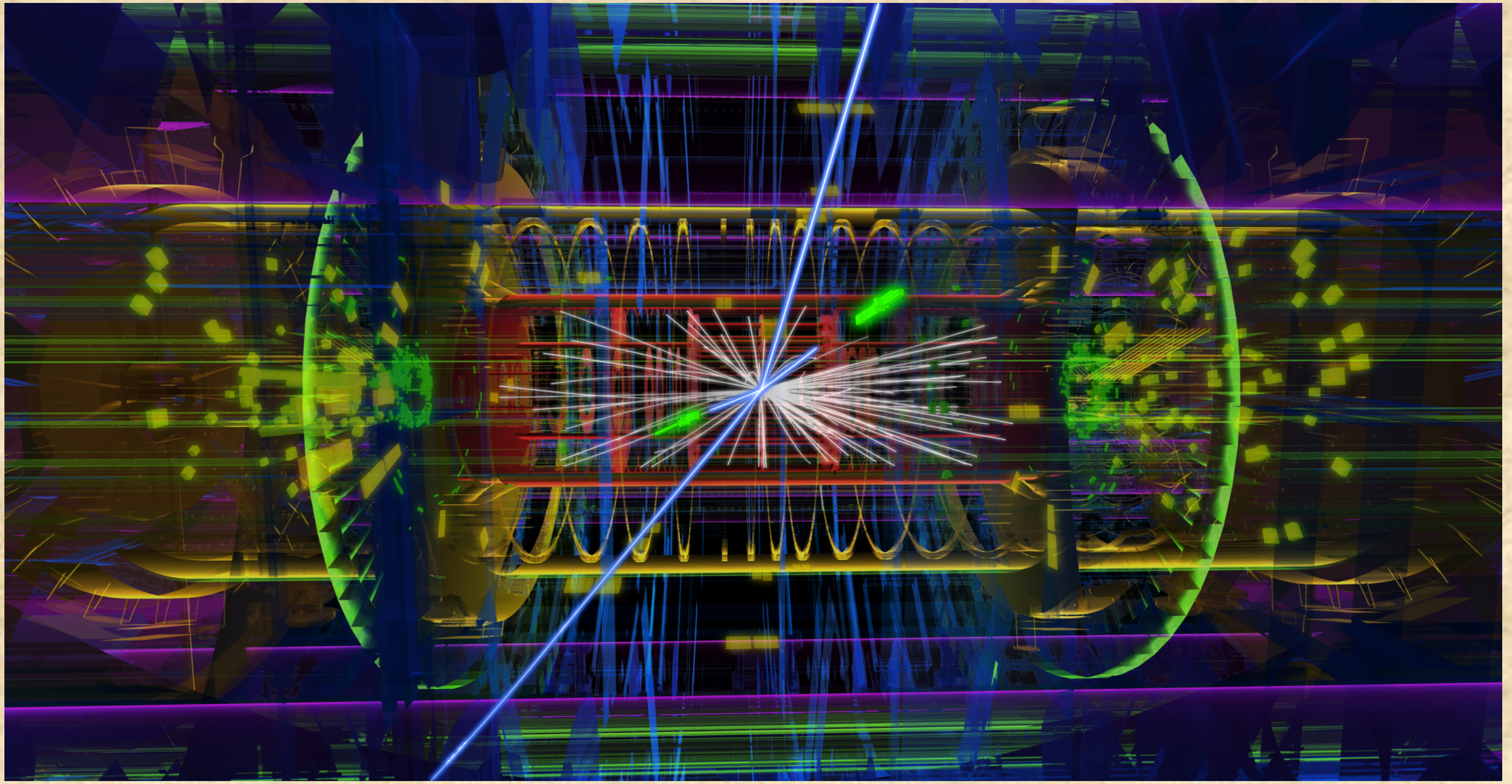

$E=mc^2$ , $\lambda=h/p$



## *1.) Where are we ?*

**** Standard Model of HEP***
**** Higgs discovery***

## ... and why all that ??
## High Light of the HEP-Year 2012 / 13 naturally the HIGGS



*ATLAS event display: Higgs => two electrons & two muons*

$$E = m_0c^2 = (m_{e1} + m_{e2} + m_{\mu 1} + m_{\mu 2})*c^2 = 125.4\ GeV$$

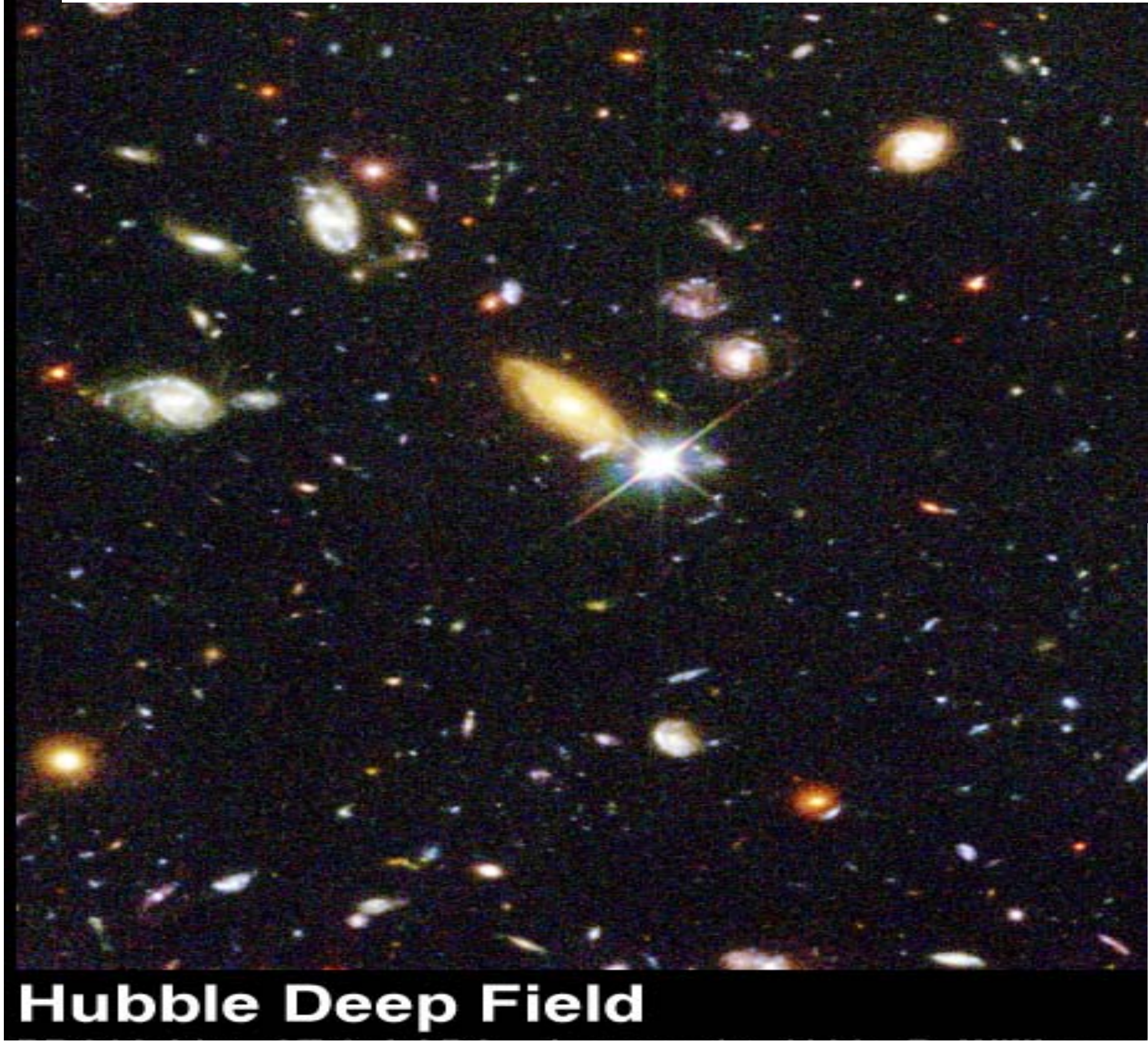
*2.) Where do we go ?*

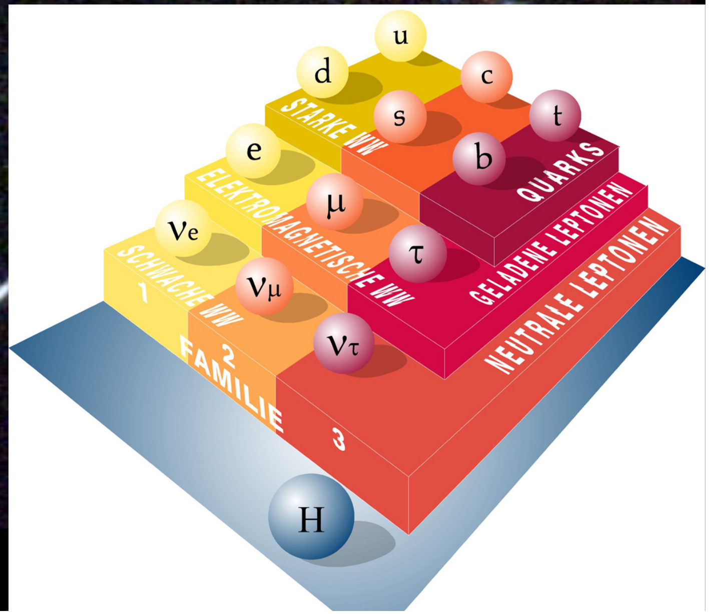
- ***Physics beyond the Standard Model***
- ***Dark Matter / Dark Energy***

## *What's next ???*

*Dark Matter & Dark Energy*

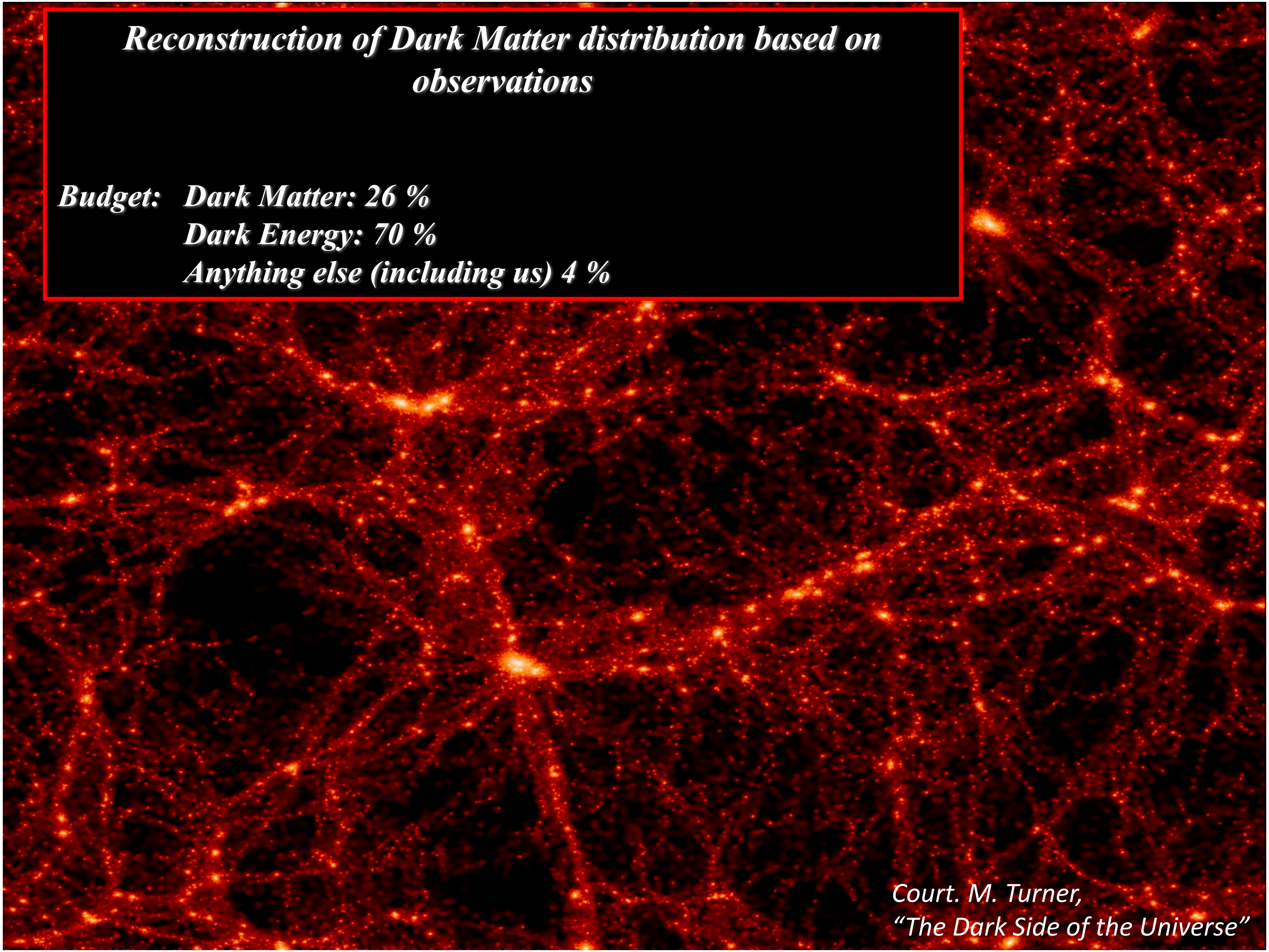
*Physics beyond the Standard Model*



***Reconstruction of Dark Matter distribution based on observations***

***Budget:*** ***Dark Matter: 26 %***
***Dark Energy: 70 %***
***Anything else (including us) 4 %***



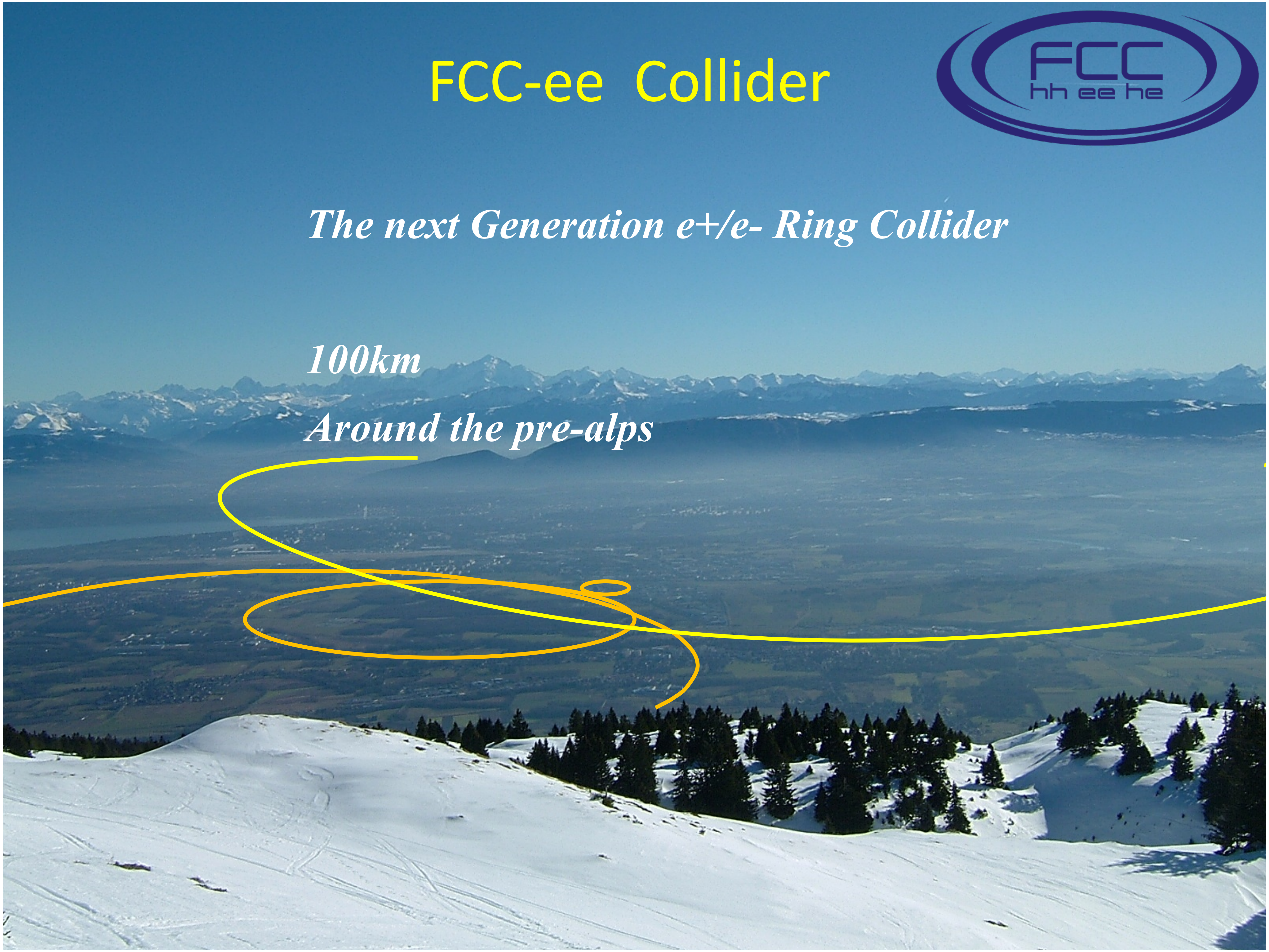
*Court. M. Turner,*
*"The Dark Side of the Universe"*

# *Considered Future High Energy Frontier Colliders*

***Circular colliders:***
***FCC (Future Circular Collider … Euro-Circol)***
***FCC-hh: 100 TeV proton-proton cm energy***
***FCC-ee: Potential intermediate step 90-350 GeV lepton collider***

***Linear colliders***
***ILC (International Linear Collider): $e^+e^-$, 500 GeV cms energy, Japan considers hosting project***
***CLIC (Compact Linear Collider): $e^+e^-$, 380GeV - 3TeV cms energy, CERN hosts collaboration***

***High Gradient Wake Acceleration Techniques***
***Plasma Acceleration***
***Particle driven***
***Laser driven***
***Dielectrical Structures***


FCC-ee Collider
FCC hh ee he
The next Generation e+/e- Ring Collider
100km
Around the pre-alps

## *4.) Push for higher energy: FCC*

**** increasing the ring size***

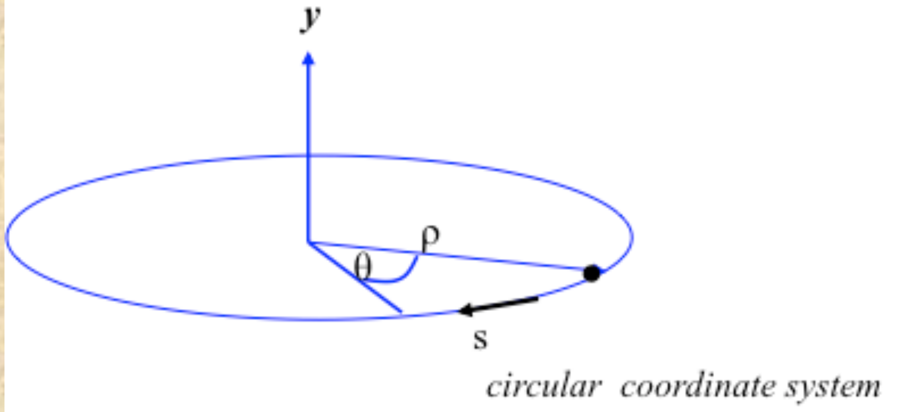
**** limited by Synchrotron Radiation***

**** and RF Power***

*studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines.*

# Maximum Beam Energy in a Storage Ring:

***For a given magnet technology it is the size of the machine that defines the maximum particle momentum ... and so the energy***




*Condition for an ideal circular orbit:*

*Lorentz force* $$F_L = e\,v\,B$$

*centrifugal force* $$F_{centr} = \frac{\gamma\, m_0\, v^2}{\rho}$$

$$\frac{\gamma\, m_0\, v^2}{\rho} = e\,v\,B$$

$$\frac{p}{e} = B\,\rho$$

*B ρ = "beam rigidity"*

***The maximum particle momentum is given by the field strength B and the storage ring size 2πρ***

## *Synchrotron Radiation*

ca 400 000 v. Chr.: Mankind discovers the Fire

# Synchrotron Radiation

***In a circular accelerator*** ***charged particles loose energy*** ***via emission of intense light.***

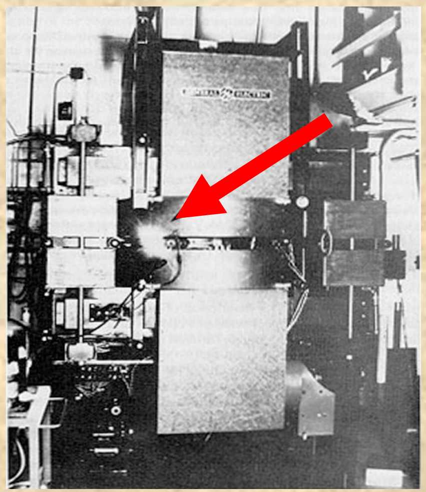
$$P_s = \frac{2}{3}\alpha\hbar c^2 \frac{\gamma^4}{\rho^2}$$ *radiation power*

$$\Delta E = \frac{4}{3}\pi\alpha\hbar c \frac{\gamma^4}{\rho}$$ *energy loss*

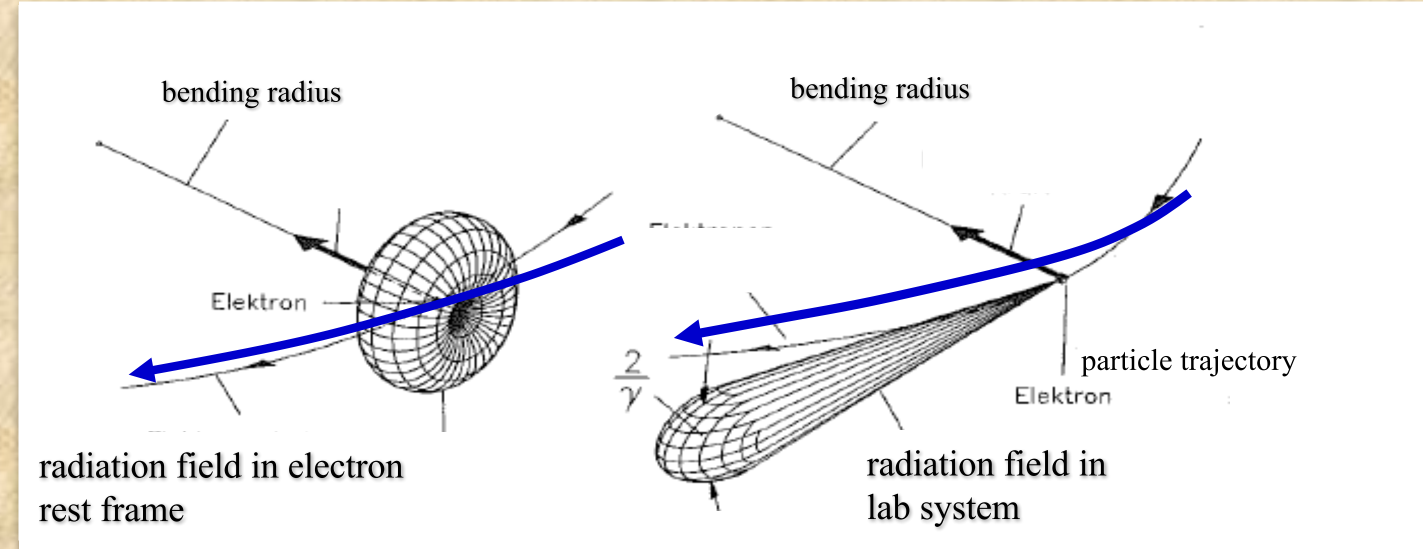
$$\omega_c = \frac{3}{2}\frac{c\gamma^3}{\rho}$$ *critical frequency*

$$\alpha \approx \frac{1}{137}$$

$$\hbar c \approx 197\ MeV\ fm$$



***1946 observed for the first time in the General Electric Synchrotron***



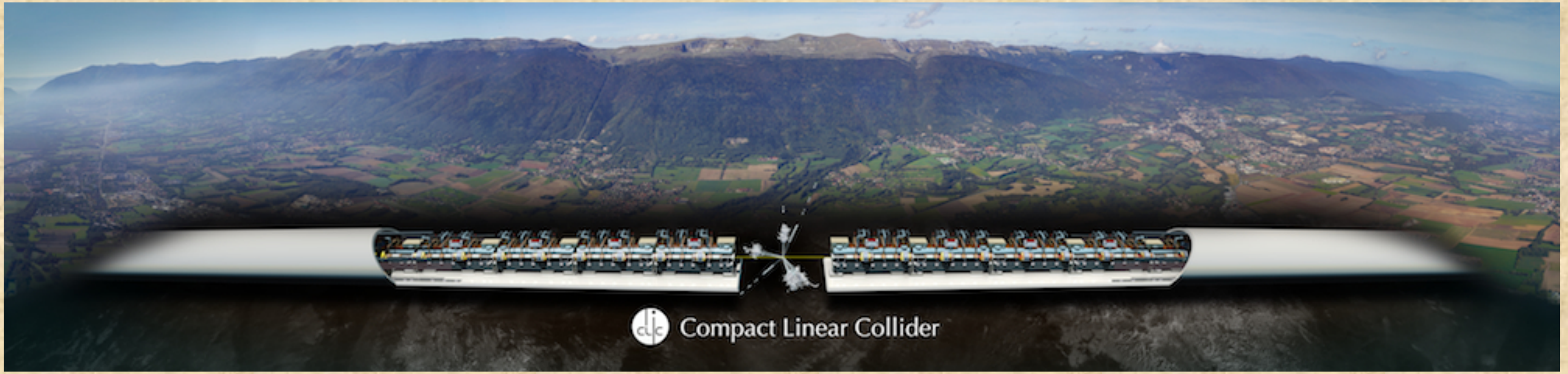

*court. K. Wille*

***5.) Push for higher lepton energy***

- ***go linear***
- ***higher acceleration gradients***

# *CLIC ... a future Linear e+/ e- Accelerator*

*„C“-LIC ... = CERN ... or „compact“*




*50 km*

| Description [units] | 500 GeV | | 3 TeV |
|---|---|---|---|
| Total (peak 1%) luminosity | 2.3 (1.4)$\times 10^{34}$ | | 5.9 (2.0)$\times 10^{34}$ |
| Total site length [km] | 13.0 | | 48.4 |
| Loaded accel. gradient [MV/m] | 80 | | 100 |
| Main Linac RF frequency [GHz] | | 12 | |
| Beam power/beam [MW] | 4.9 | | 14 |
| Bunch charge [$10^9$ $e^+/e^-$] | 6.8 | | 3.72 |
| Bunch separation [ns] | | 0.5 | |
| Bunch length [$\mu$m] | 72 | | 44 |
| Beam pulse duration [ns] | 177 | | 156 |
| Repetition rate [Hz] | | 50 | |
| Hor./vert. norm. emitt. [$10^{-6}/10^{-9}$m] | 2.4/25 | | 0.66/20 |
| Hor./vert. IP beam size [nm] | 202/2.3 | | 40/1 |

*CLIC parameter list*

# *CLIC: Normal conducting RF system*

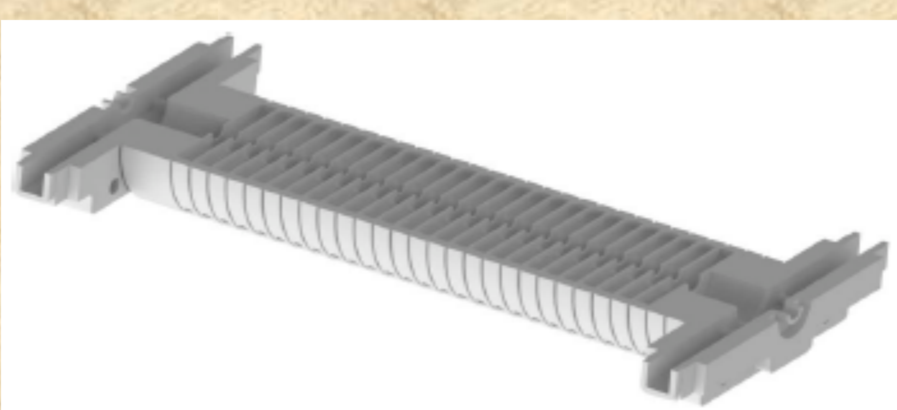
## *challenge: running at the break down limit*

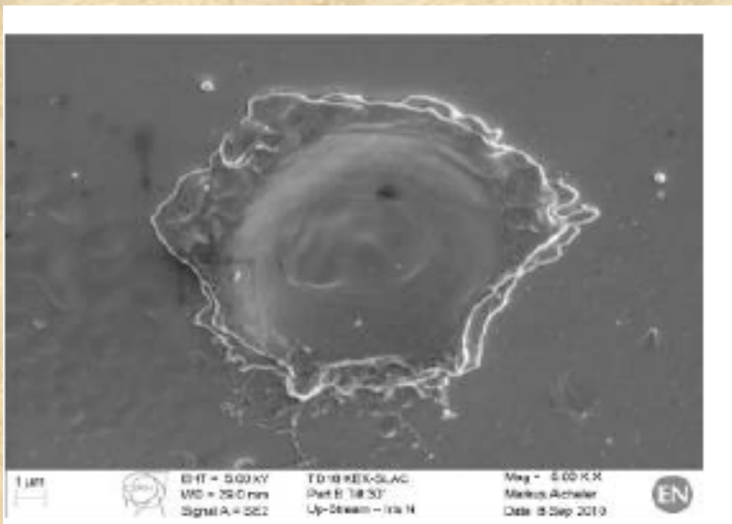
***Accereration Gradient 100MV/m studied & optimised since years***

***" how far can we go and how much can we optimise such a future accelerator before we reach technical limits and how can we push these limits ? "***

***they have impact on***

- ***=> the accelerator performance (luminosity)***
- ***=> beam quality***
- ***=> and the accelerating structure itself***

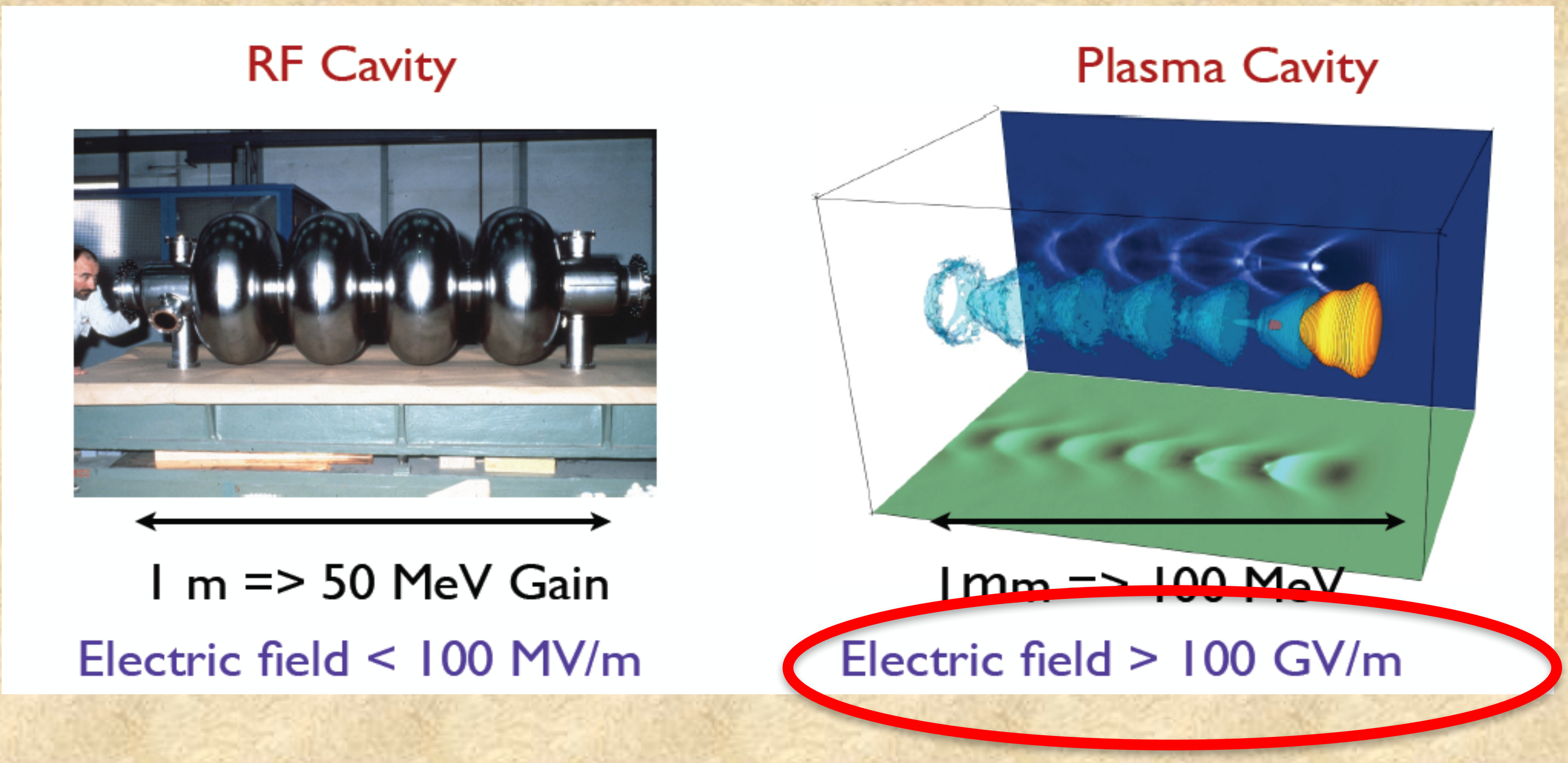




***6.) Push for higher energy***

**** higher acceleration gradients***
**** new acceleration techniques***

# *Plasma Wake Acceleration:*
# *Push for highest acceleration gradient*



# *Study of High Gradient Acceleration Techniques*

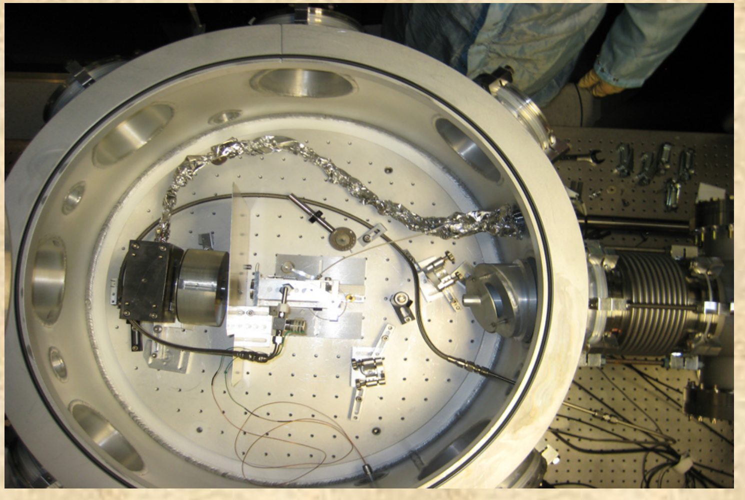
***P**lasma **W**ake **A**cceleration*

*particle beam driven / LASER driven*

*Incoming laser pulse (or pulse of particles) creates a travelling plasma wave in a low-pressure gas*

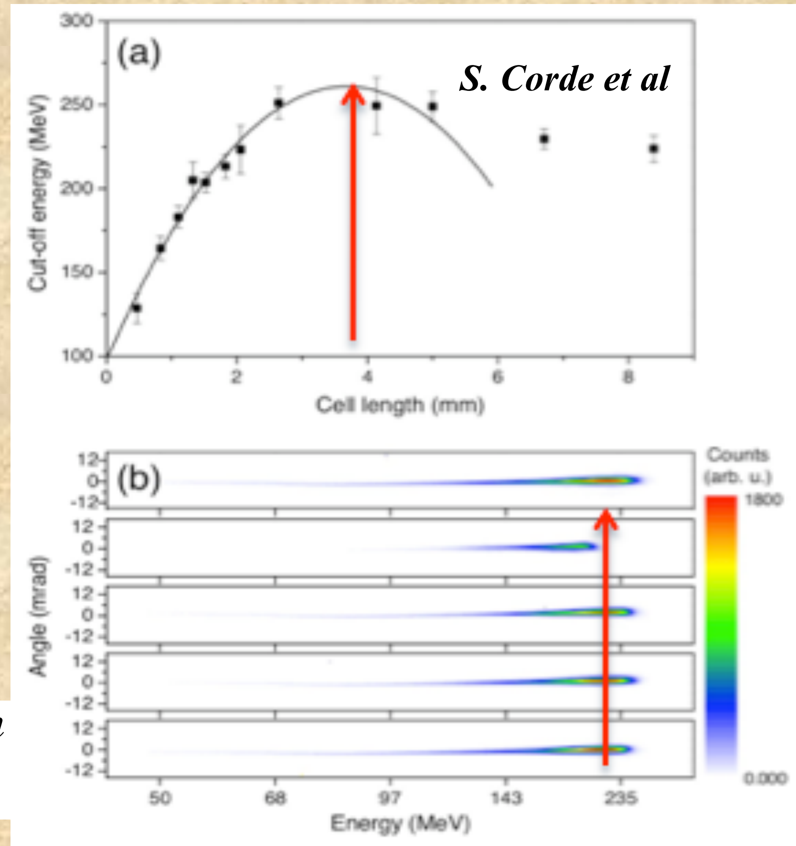
*Plasma wake field gradient accelerates electrons that 'surf' on the plasma wave*

*Field Gradients up to 100 GeV /m observed*



*Plasma cell Univ. Texas, Austin*
*$E_e$ =2 GeV*

$$\Delta E / \Delta s = 200\, MeV / 4\, mm$$
$$= 50\, GeV / m$$



## *Open questions in particle physics*

***Dark matter & Energy***

***… on which energy scale to look for it ?***

***Physics beyond the standard model***

***... Lepton or Proton colliders ?***

***Beam dynamics aspects***

***... Circular or linear ?***

***Technical aspects***

***... Traditional, sc / nc or PWA ?***