Overview of new science projects

Ken Peach

John Adams Institute for Accelerator Science

7th June 2006


MAGNET TECHNOLOGIES + + + + + +

+ PRECISION MACHINING + VACUUM TECHNOLOGIES + CRYOGENICS +
MANUFACTURING TECHNOLOGIES + MATERIAL DEVELOPMENT

Trends, Development and Collaboration Possibilities

7th and 8th of June 2006 at Geneva (CERN)

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Outline

1. **Introduction**
   - What is particle physics?
   - Why do we need technology "at the edge"?
2. **The LHC**
   - Present status
   - Implications of future upgrades
3. **The Linear Collider**
   - What it is and why is it needed
   - Present status and possible future
4. **Neutrino Facilities**
   - What are they and why are they nee
   - Present status and possible future
5. **Other projects**
   - Some examples
6. **Summary and Conclusions**

All
need
magnets
somewhere

Introduction

What is particle physics?

Why do we need technology “at the edge”?

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What is particle physics?

The particle physics “Mission Statement”

1) Identify the most fundamental constituents of the Universe
2) Describe how they interact and inter-relate

and if possible

3) Explain why 1) and 2) above are as they are, and cannot be otherwise

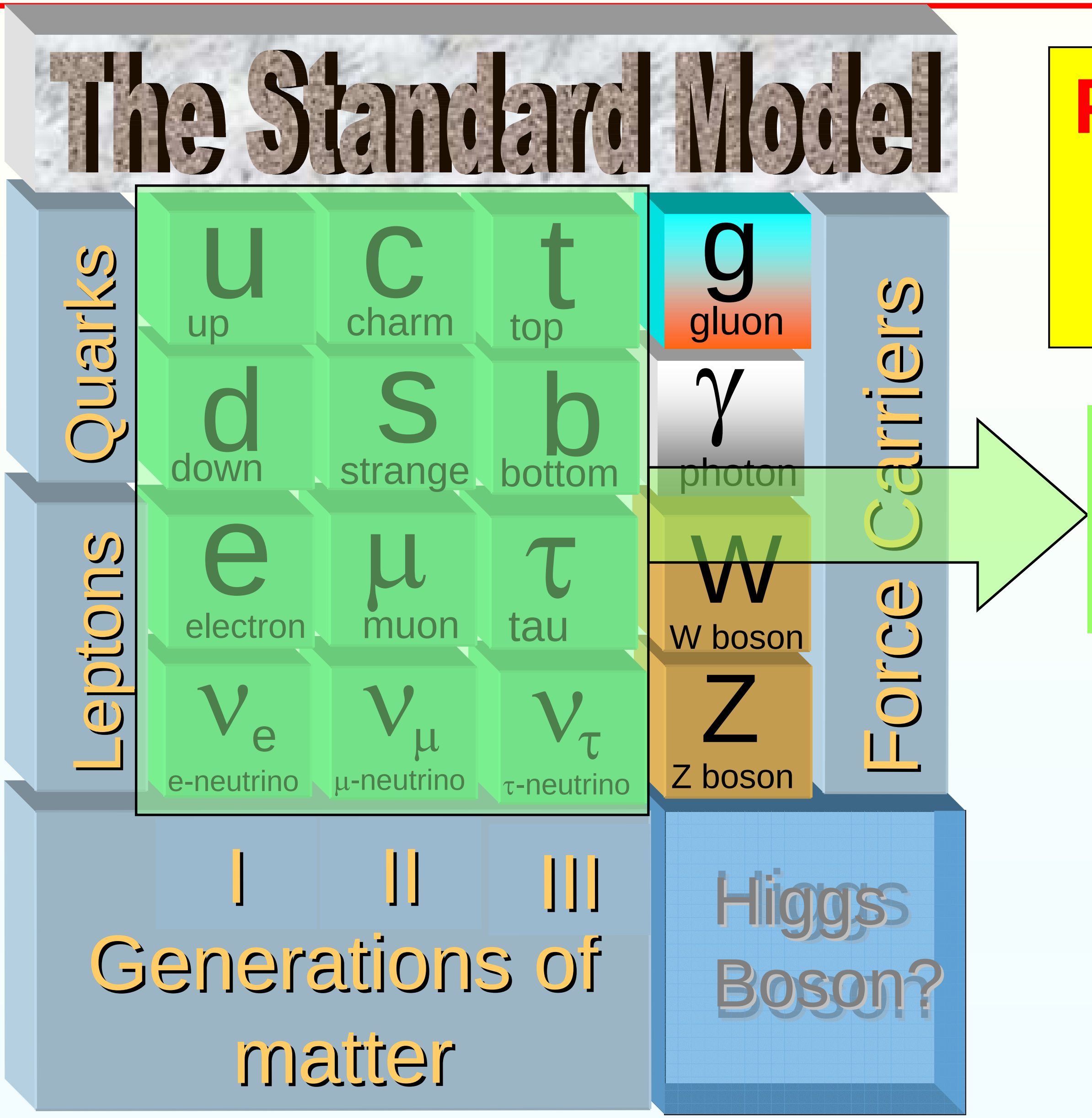
Then, we have “understood” how the Universe works at its deepest (simplest?) level

in the first billionths of a second after the Big Bang

But we are left with the task of explaining how the rich complexity that developed in the ensuing 13.7 billion years came about…

Which is a much more complex task!

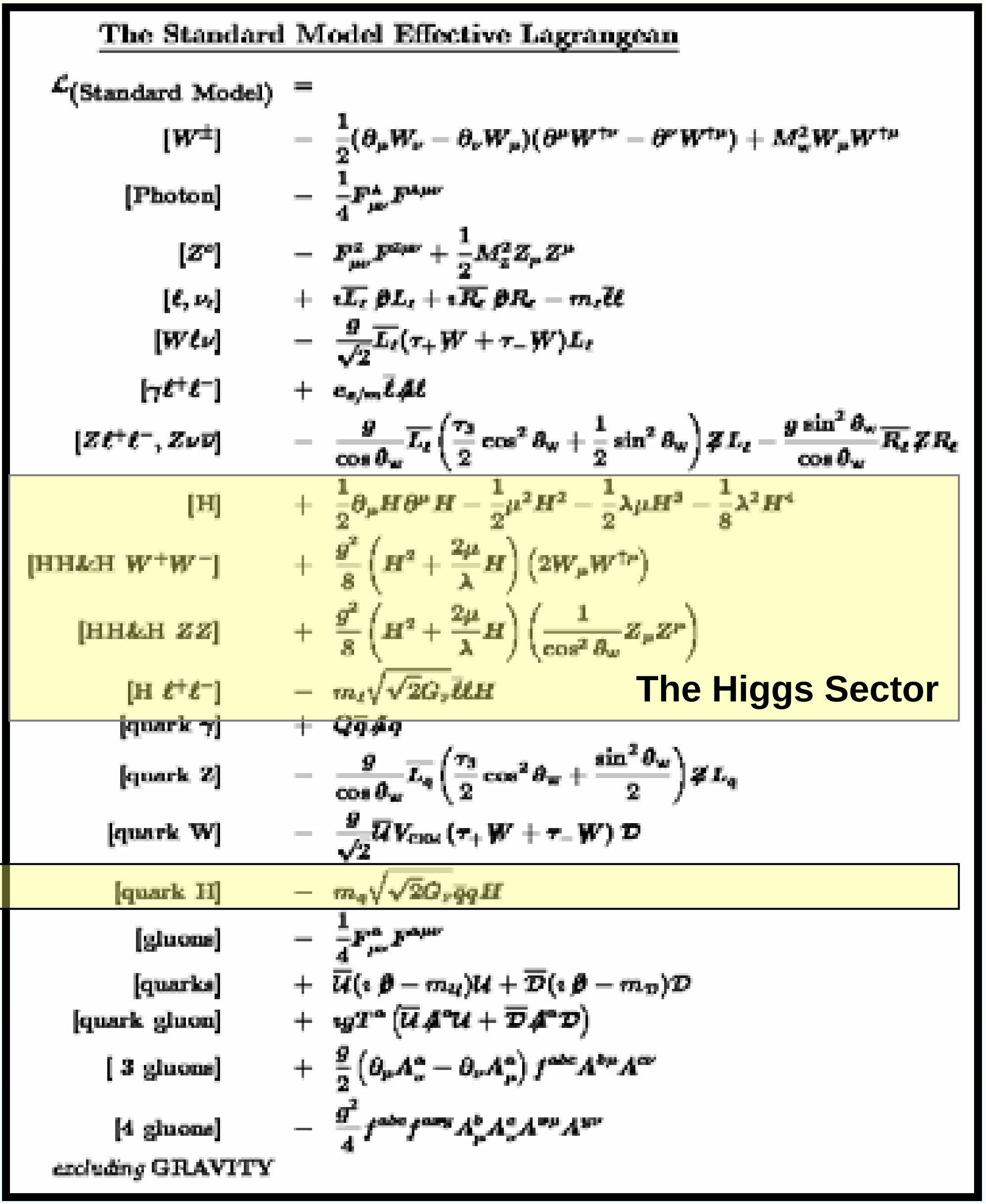
The experimentalist’s view



Particles and Forces

Each with its own ‘antiparticle’

The Standard Model (again)



The Standard Model Effective Lagrangean

$$
\begin{aligned}
\mathcal{L}_{\text{(Standard Model)}} &= \\
[W^{\pm}] \quad & - \frac{1}{2}(\partial_\mu W_\nu - \partial_\nu W_\mu)(\partial^\mu W^{\dagger\nu} - \partial^\nu W^{\dagger\mu}) + M_w^2 W_\mu W^{\dagger\mu} \\
[\text{Photon}] \quad & - \frac{1}{4} F^{A}_{\mu\nu} F^{A\mu\nu} \\
[Z^0] \quad & - F^{Z}_{\mu\nu} F^{Z\mu\nu} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu \\
[\ell, \nu_\ell] \quad & + i\overline{L_\ell}\, \not\partial L_\ell + i\overline{R_\ell}\, \not\partial R_\ell - m_\ell \bar{\ell}\ell \\
[W\ell\nu] \quad & - \frac{g}{\sqrt{2}} \overline{L_\ell}(\tau_+ \not W + \tau_- \not W) L_\ell \\
[\gamma\ell^+\ell^-] \quad & + e_{s/m} \bar{\ell} \not A \ell \\
[Z\ell^+\ell^-, Z\nu\bar{\nu}] \quad & - \frac{g}{\cos\theta_w} \overline{L_\ell} \left(\frac{\tau_3}{2}\cos^2\theta_w + \frac{1}{2}\sin^2\theta_w\right) \not Z L_\ell - \frac{g\sin^2\theta_w}{\cos\theta_w} \overline{R_\ell} \not Z R_\ell \\
[\text{H}] \quad & + \frac{1}{2}\partial_\mu H \partial^\mu H - \frac{1}{2}\mu^2 H^2 - \frac{1}{2}\lambda\mu H^3 - \frac{1}{8}\lambda^2 H^4 \\
[\text{HH\&H } W^+W^-] \quad & + \frac{g^2}{8}\left(H^2 + \frac{2\mu}{\lambda} H\right)\left(2W_\mu W^{\dagger\mu}\right) \\
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[\text{gluons}] \quad & - \frac{1}{4} F^{a}_{\mu\nu} F^{a\mu\nu} \\
[\text{quarks}] \quad & + \overline{\mathcal{U}}(i\not\partial - m_{\mathcal{U}})\mathcal{U} + \overline{\mathcal{D}}(i\not\partial - m_{\mathcal{D}})\mathcal{D} \\
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[\text{4 gluons}] \quad & - \frac{g^2}{4} f^{abe} f^{cde} A^b_\mu A^c_\nu A^{d\mu} A^{e\nu}
\end{aligned}
$$

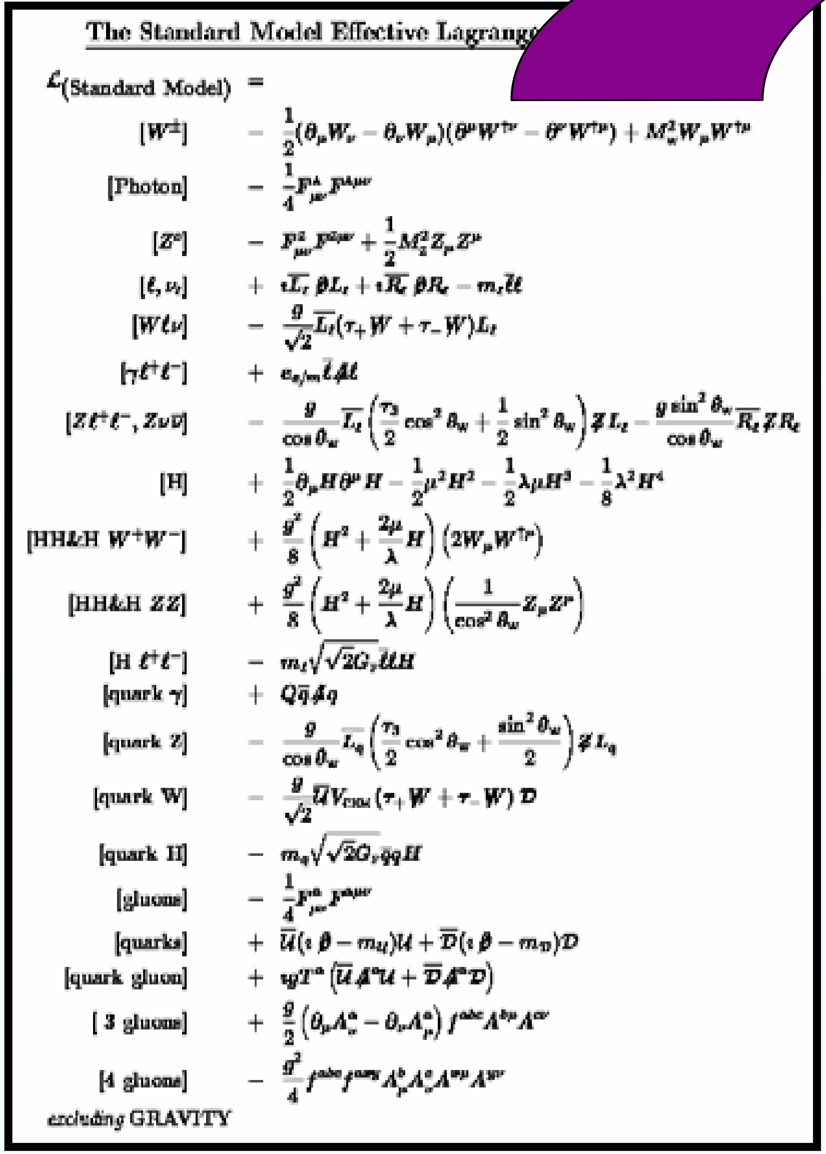
excluding GRAVITY

The Higgs Sector

The Parameters

- 6 quark masses
  - m_u, m_c, m_t
  - m_d, m_s, m_b
- 3 lepton masses
  - m_e, m_μ, m_τ
- 2 vector boson masses
  - M_W, M_Z
    - $(m_\gamma, m_g = 0)$
- 1 Higgs mass
  - M_h
- 3 coupling constants
  - G_F, α, α_s
- 3 quark mixing angles
  - $\theta_{12}, \theta_{23}, \theta_{13}$
- 1 quark phase
  - δ

How good is the Standard Model?



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$[Z^o]$	$-$	$F^Z_{\mu\nu} F^{Z\mu\nu} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu$
$[\ell, \nu_\ell]$	$+$	$i\overline{L_\ell}\,\partial\!\!\!/ L_\ell + i\overline{R_\ell}\,\partial\!\!\!/ R_\ell - m_\ell \bar{\ell}\ell$
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$[Z\ell^+\ell^-, Z\nu\bar{\nu}]$	$-$	$\frac{g}{\cos\theta_w} \overline{L_\ell} \left(\frac{\tau_3}{2}\cos^2\theta_w + \frac{1}{2}\sin^2\theta_w\right) Z\!\!\!/ L_\ell - \frac{g\sin^2\theta_w}{\cos\theta_w} \overline{R_\ell} Z\!\!\!/ R_\ell$
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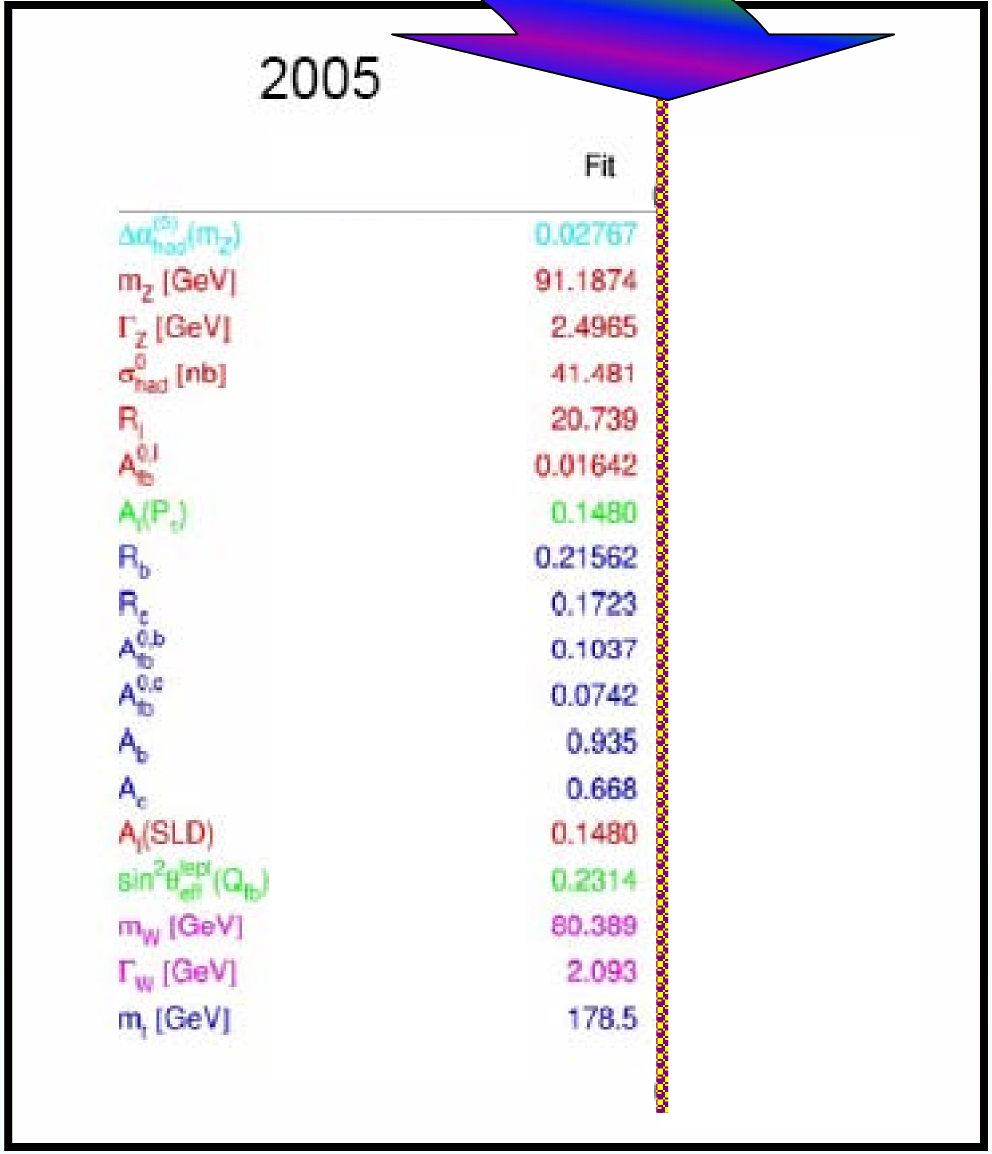
excluding GRAVITY



2005

	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02767
m_Z [GeV]	91.1874
Γ_Z [GeV]	2.4965
σ_{had}^0 [nb]	41.481
R_l	20.739
$A_{fb}^{0,l}$	0.01642
$A_l(P_\tau)$	0.1480
R_b	0.21562
R_c	0.1723
$A_{fb}^{0,b}$	0.1037
$A_{fb}^{0,c}$	0.0742
A_b	0.935
A_c	0.668
A_l(SLD)	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2314
m_W [GeV]	80.389
Γ_W [GeV]	2.093
m_t [GeV]	178.5

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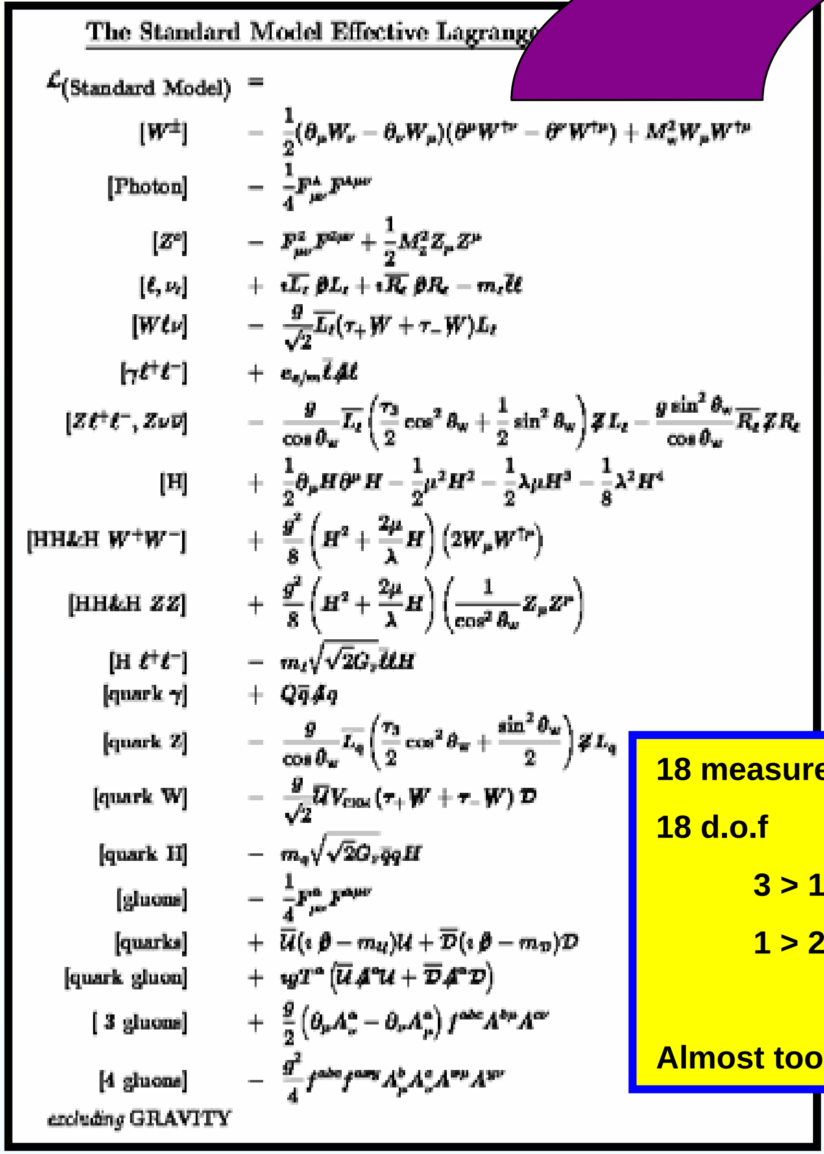

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excluding GRAVITY

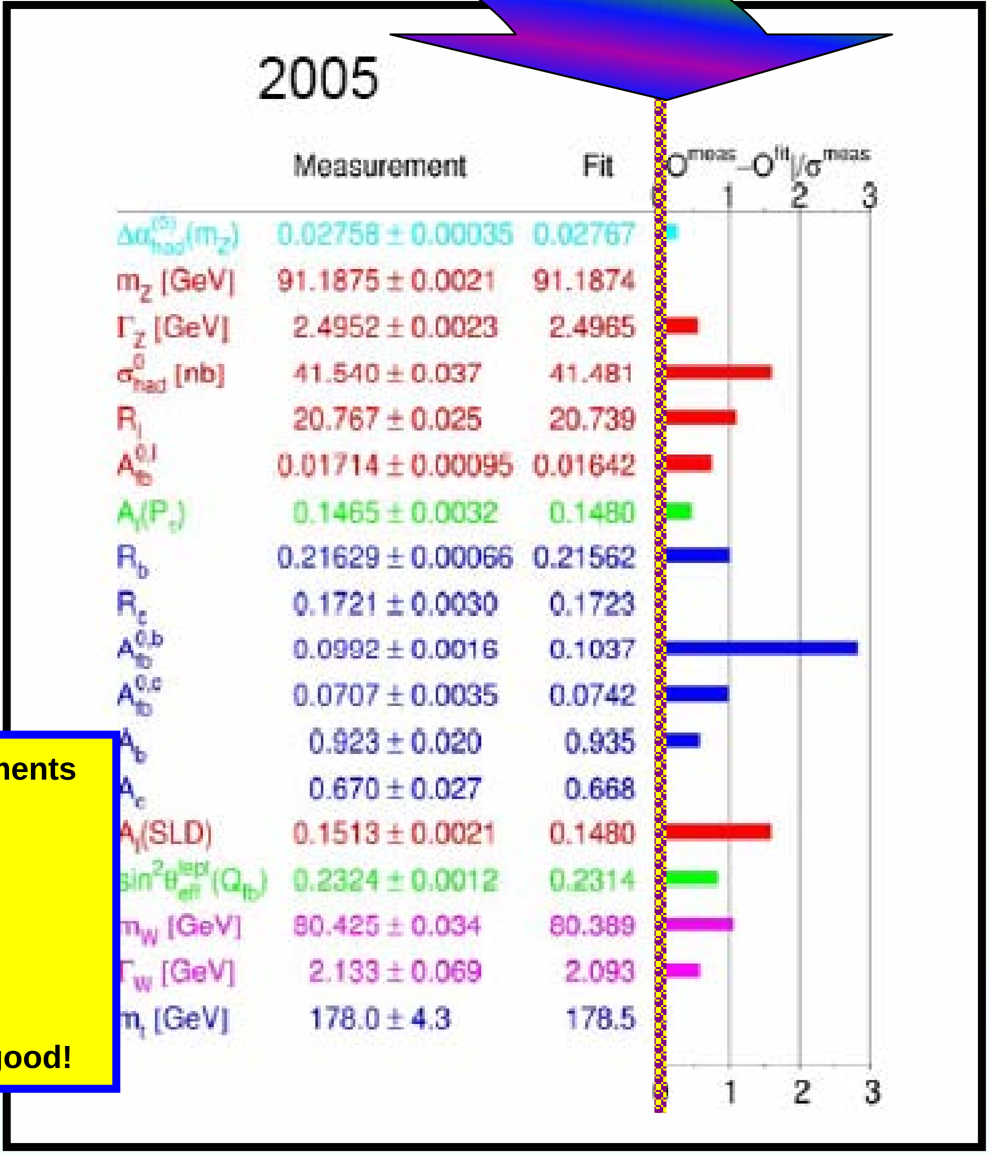
18 measurements

18 d.o.f

$3 > 1\sigma$

$1 > 2\sigma$

Almost too good!



2005

	Measurement	Fit
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m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ^0_{had} [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21562
R_c	0.1721 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037
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A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.389
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What remains to be done?

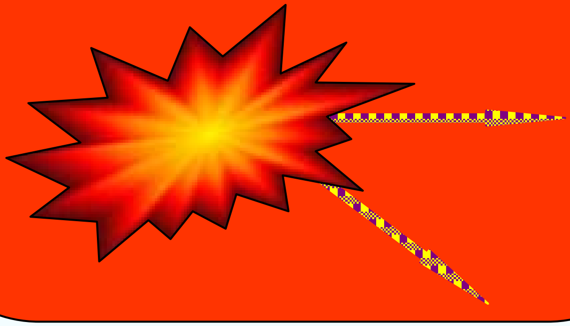
- **The Standard Model is a very good *description* of the universe at the particle scale (~$2M_W$)**
  - **But does not *explain* many things**
    - **Why so many particles?**
    - **Why so many forces?**
    - **What is mass?**
      - **Why do particles have the masses they have?**
    - **How do neutrinos get mass?**
      - **Are neutrinos different? How do they fit in?**
    - **What is Dark Matter? Dark Energy?**
    - **Why is matter different from antimatter?**
      - **(Where did all the antimatter go?)**
    - **Where does gravity fit in?**

Why do we need technology "at the edge"?

2 routes to new knowledge about the fundamental structure of the matter

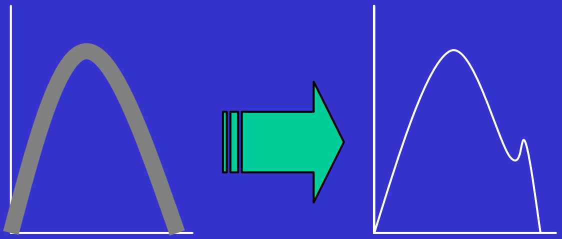
High Energy Frontier

New phenomena
(new particles)
created when the
"usable" energy > mc^2 [×2]



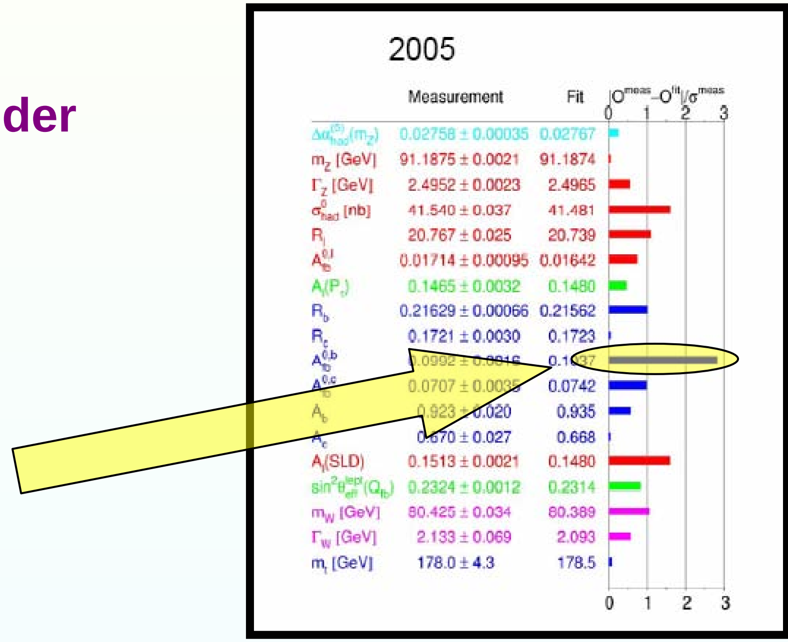
High Precision Frontier

Known phenomena studied with high precision *may* show inconsistencies with theory



What do we need to make progress?

- **To reach higher energy**
    - **To go beyond the LEP/Tevatron energy scale**
        - **~100-500GeV**
            - **The Large Hadron Collider**
            - **The Linear Electron-Positron Collider**
- **To reach higher precision**
    - **10 × statistics would make this effect (if real) 8σ**
        - **Particle “factories”**
            - **Strange, Charm, Tau, Bottom,…**
- **New types of accelerator**
    - **Neutrino factories**
    - **Beta beams**
    - **Muon colliders …**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The LHC

Present status

Implications of future upgrades

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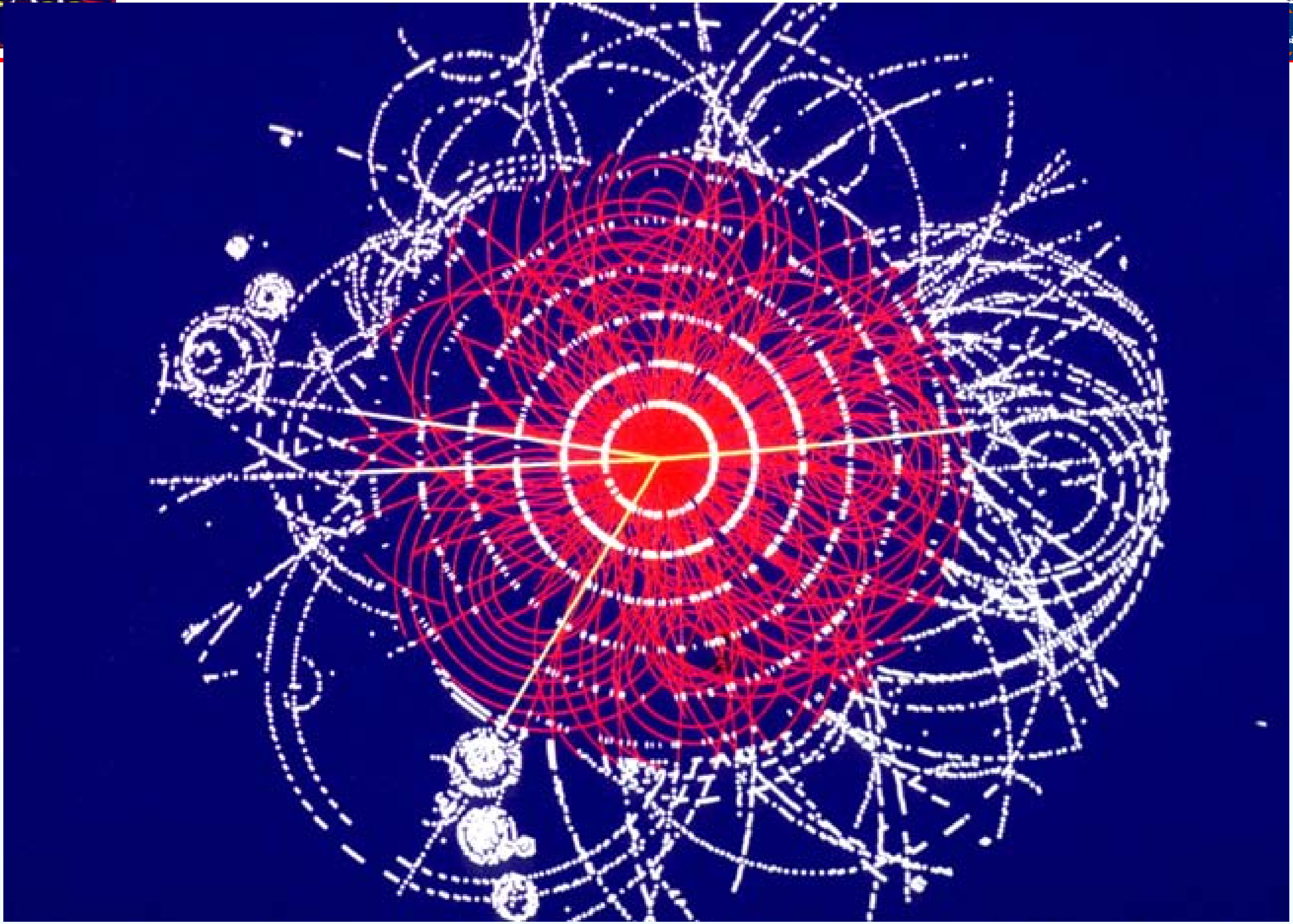
What is the LHC?



Possible LHC upgrades

Luminosity

Data Doubling Time

- ~ a few years
- LHC will need a Luminosity Upgrade after ~7-8 years of operation
  - ~2015
- ~10x Luminosity ≡ 30% increase in Energy

Energy

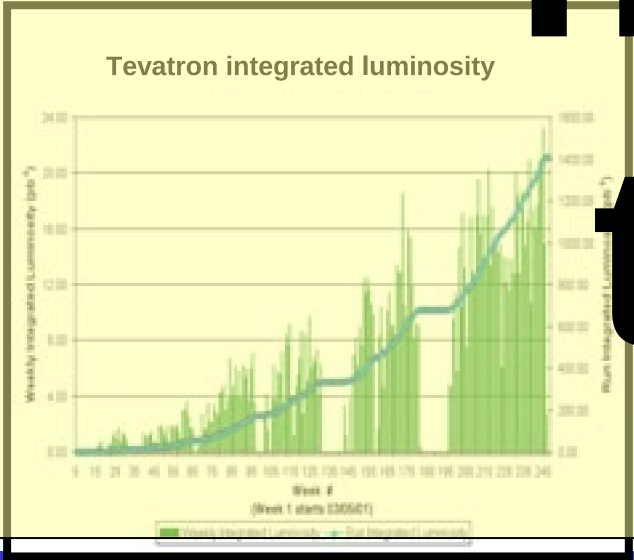
If the physics at the LHC indicates that there would be a big discovery potential for an LHC with ~2x the energy

- Build a new machine with twice the energy on top of the LHC
- Need new magnets (at least 2x the magnetic field)

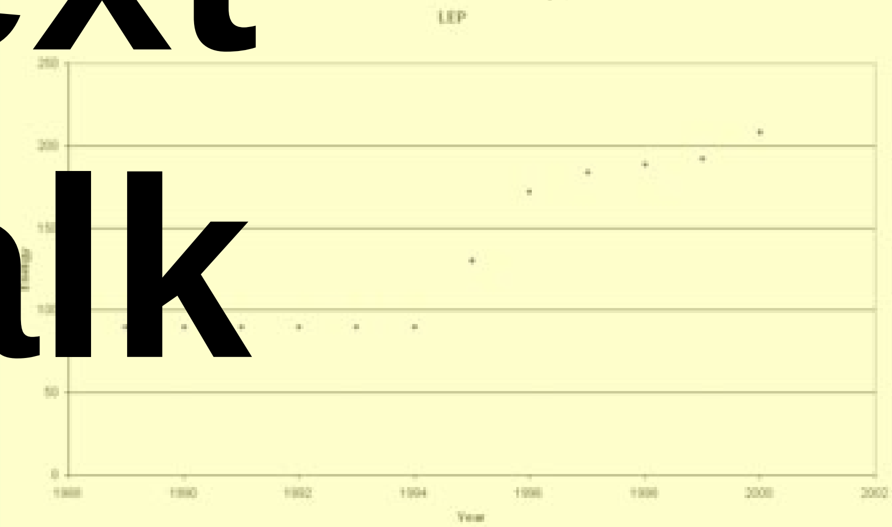
See next talk

From History

TEVATRON Luminosity

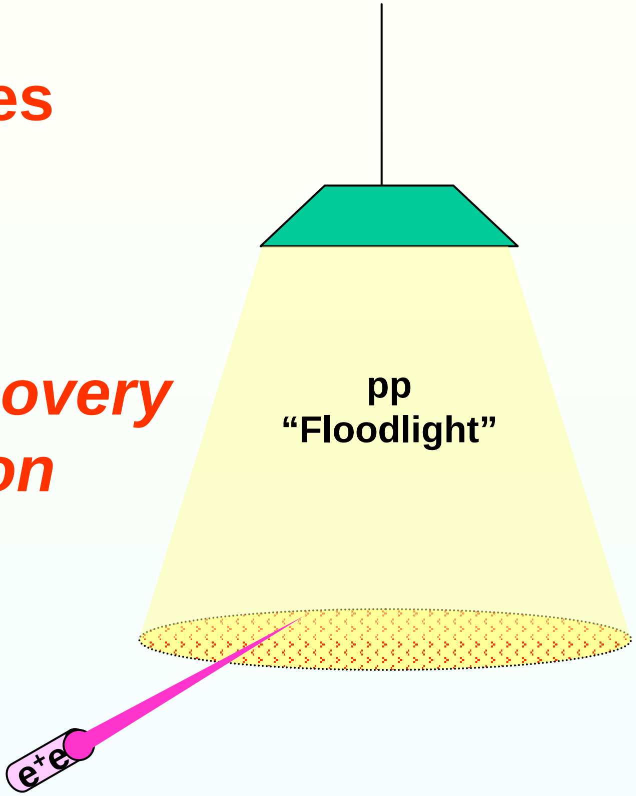


LEP Energy



After the LHC?

- **What next?**
  - **Need to study the new discoveries**
    - **Precision measurements**
- **History shows that**
  - **Proton colliders are good at *discovery***
  - **e^+e^- colliders are good at *precision measurement***
- **Need higher energy than LEP**
  - **But synchrotrons at the limit**
    - **Synchrotron radiation**
      - **$\propto E^4$ at fixed radius**
        - **i.e. 2 × Energy = 16 × Power or 16 × Radius!**
  - **Back to the Linac!!!!**



The Linear Collider

What it is and why is it needed
Present status and possible future

http://www.adams-institute.ac.uk

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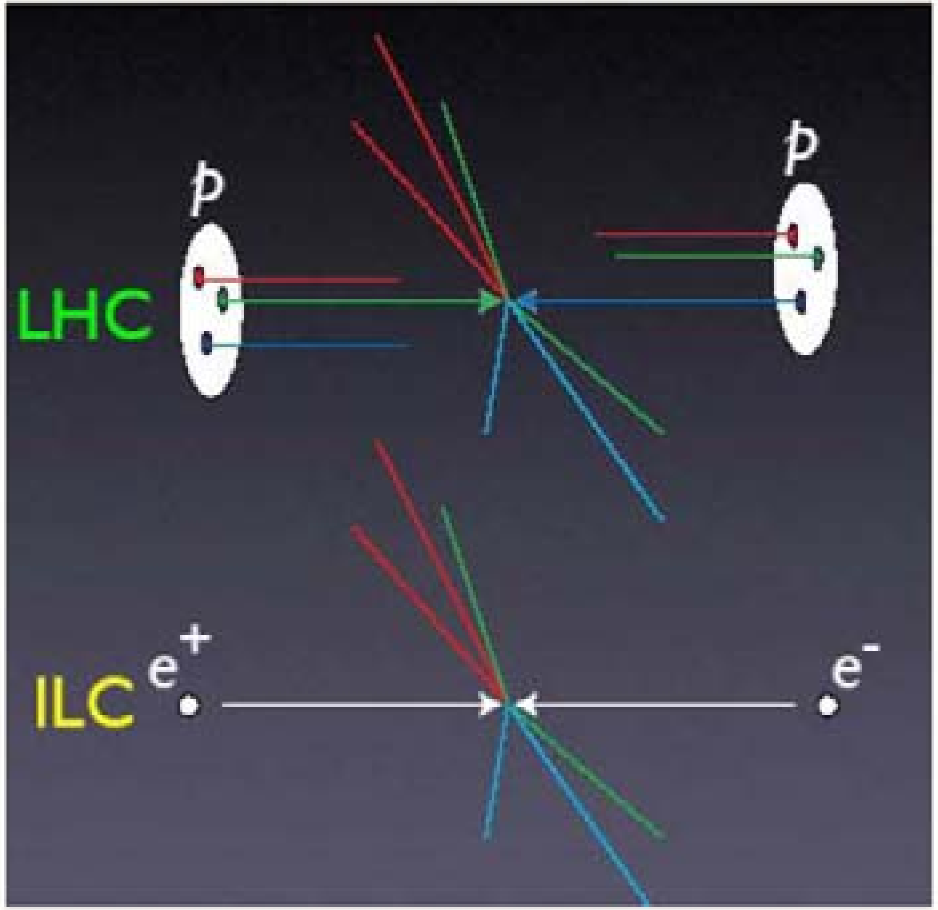
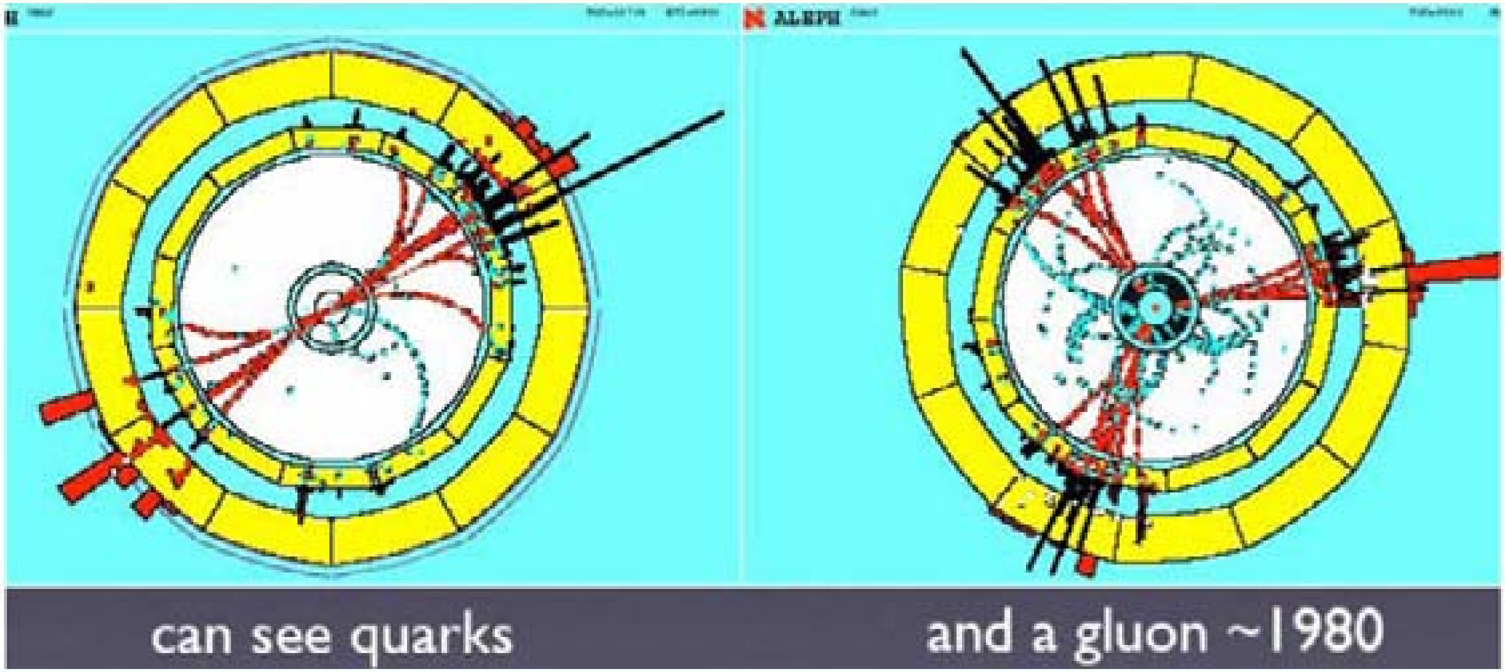
Why an e+e- collider?

- elementary particles
- well-defined
  - energy,
  - angular momentum
- uses full COM energy
- produces particles democratically
- can mostly fully reconstruct events



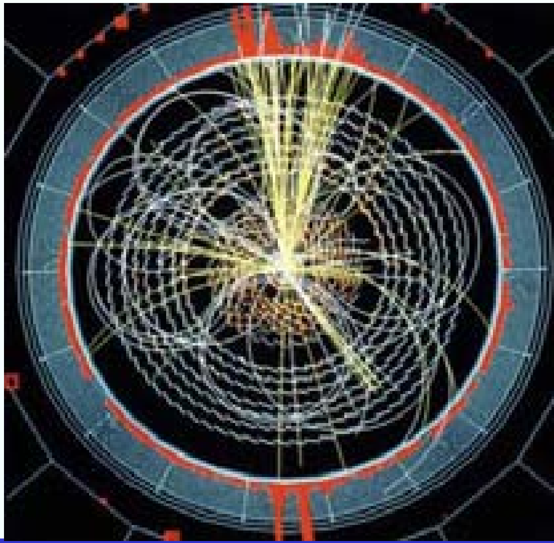
After Barry Barish

Why an e+e- collider?



← LEP

LHC →



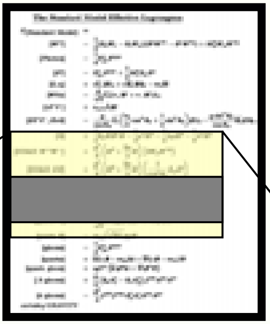
After Barry Barish

The Linear Collider

- **Why?**
  - More energy
    - LEP – up to 200 GeV
    - LC – up to 1000 GeV
      - Study the Higgs particle

Similar precision on new discoveries + spectroscopy of new states

Identify the underlying theory



$$\begin{array}{rcl}
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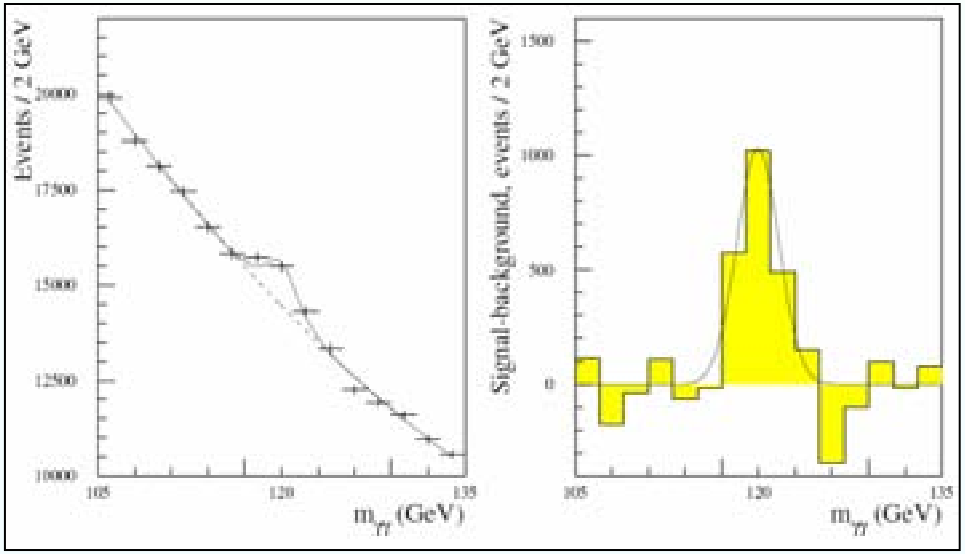
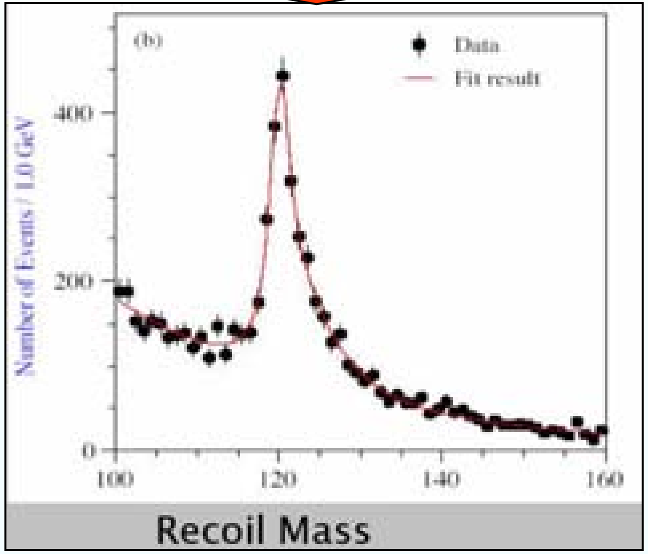
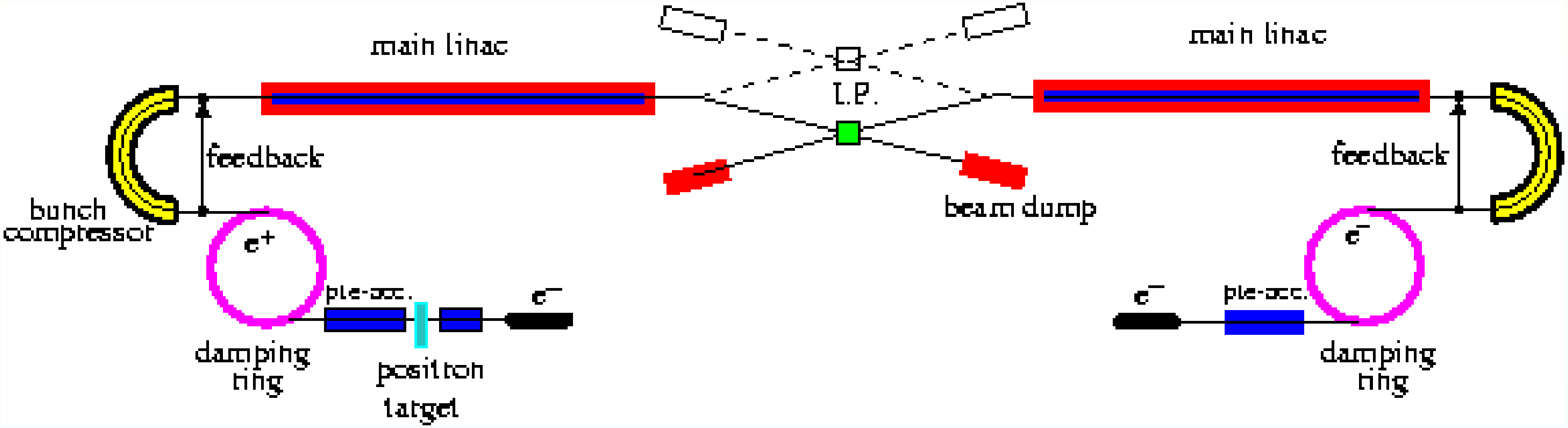
[\mathrm{H}\ \ell^+\ell^-] & - & m_\ell\sqrt{\sqrt{2}G_F}\bar{\ell}\ell H \\
[\mathrm{quark}\ \mathrm{H}] & - & m_q\sqrt{\sqrt{2}G_F}\bar{q}q H
\end{array}$$



c.f. LHC

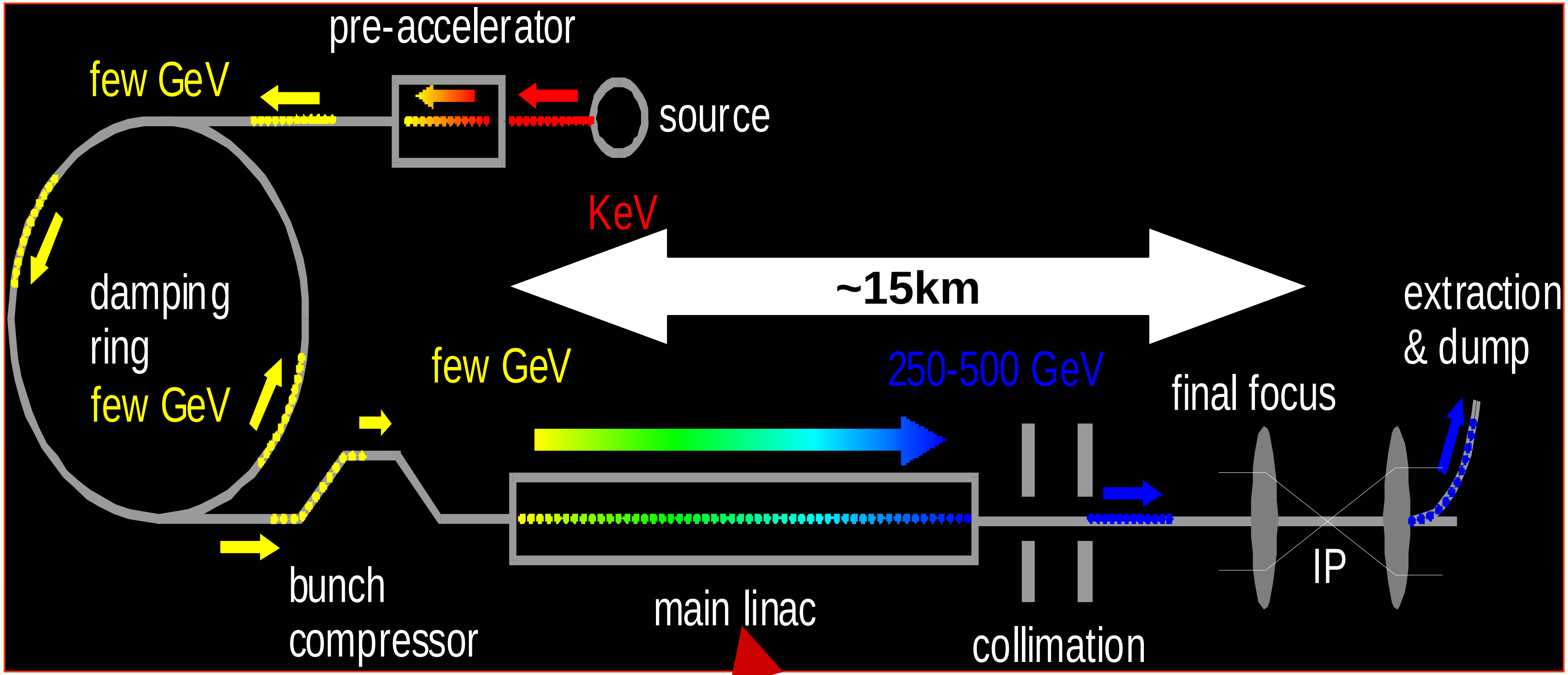


A Linear Collider



After Rainer Wanzenberg

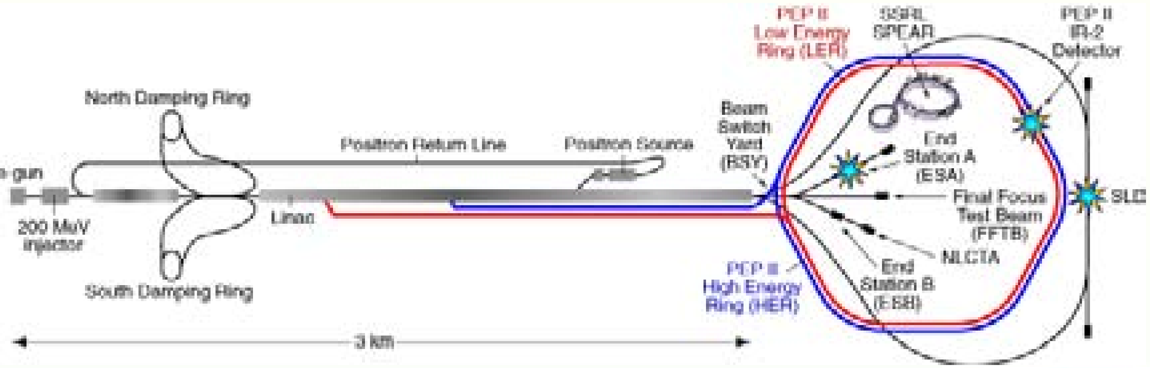
The International Linear Collider



Superconducting RF Main Linac

After Barry Barish

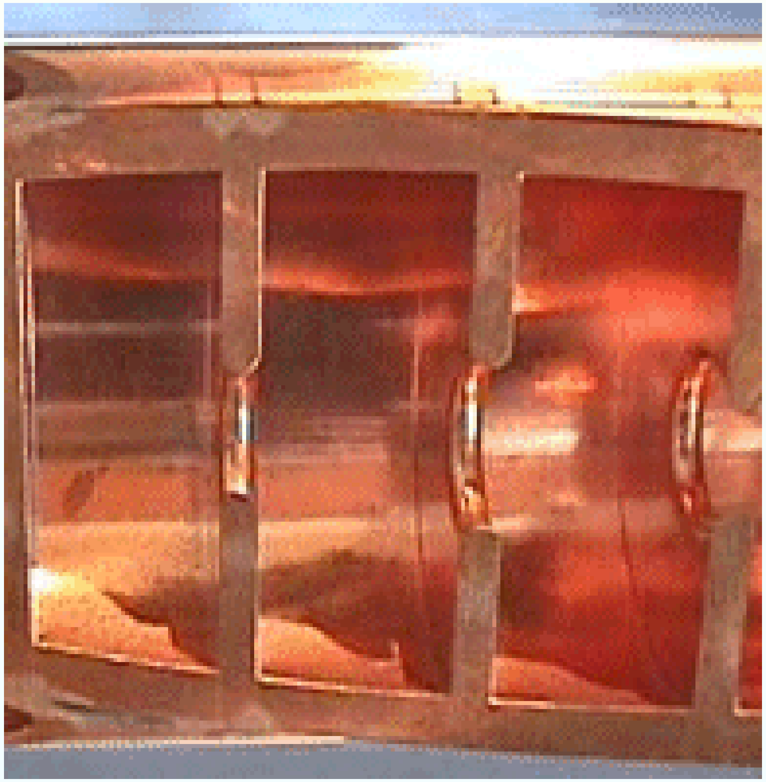
SLAC – The Stanford Linear Accelerator (Centre)

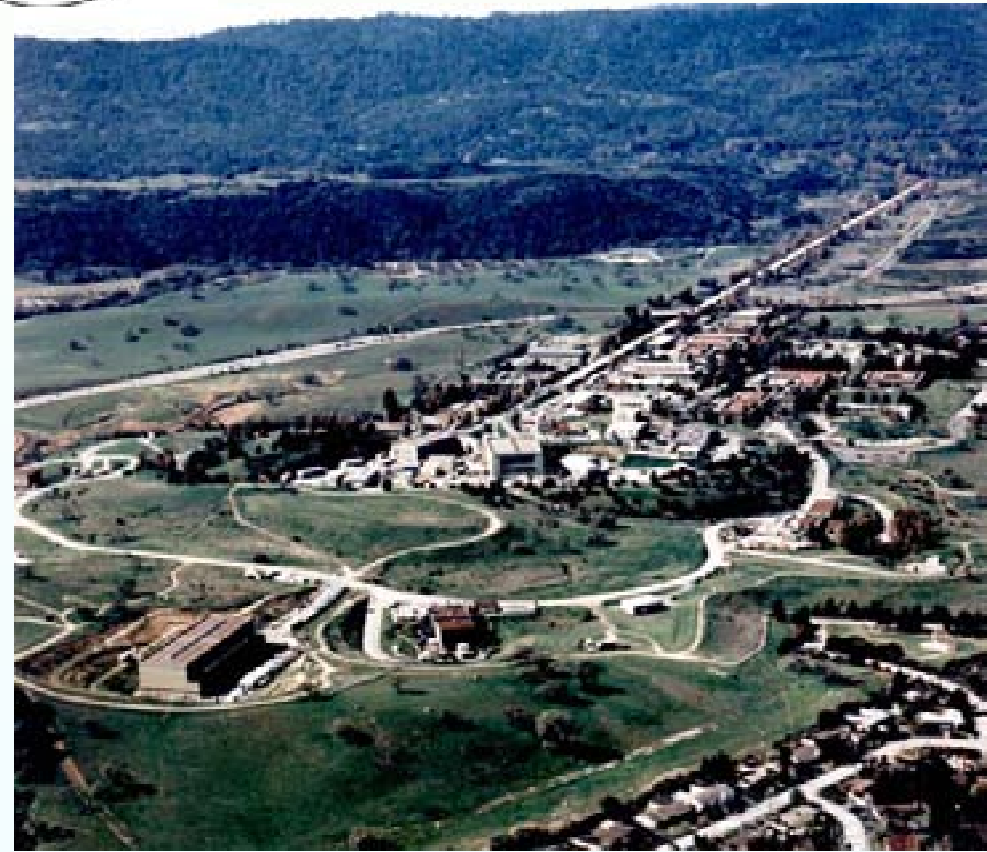


50 GeV electrons and positrons

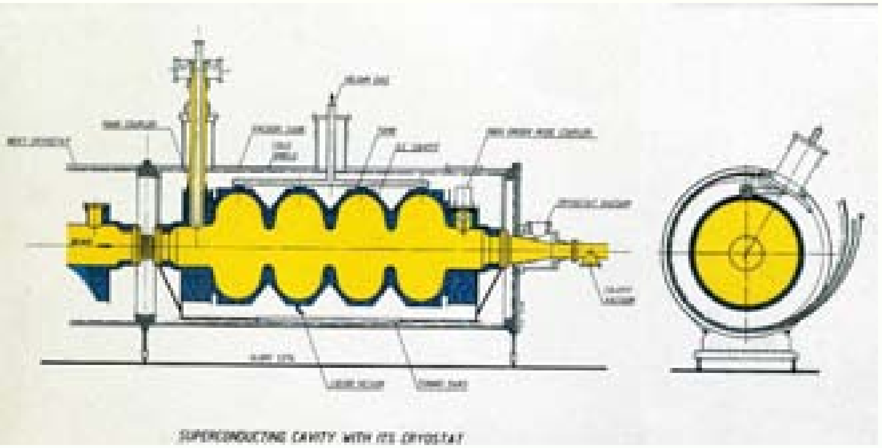
2.8GHz RF

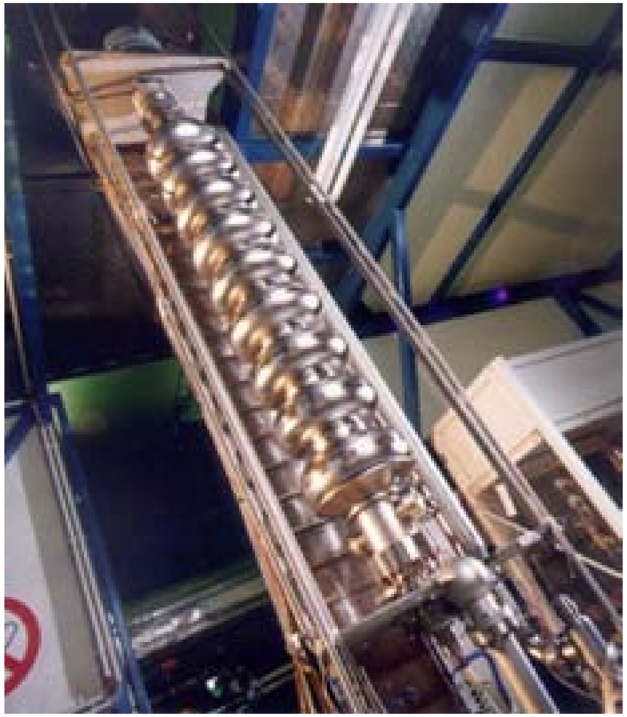
17MeV/m



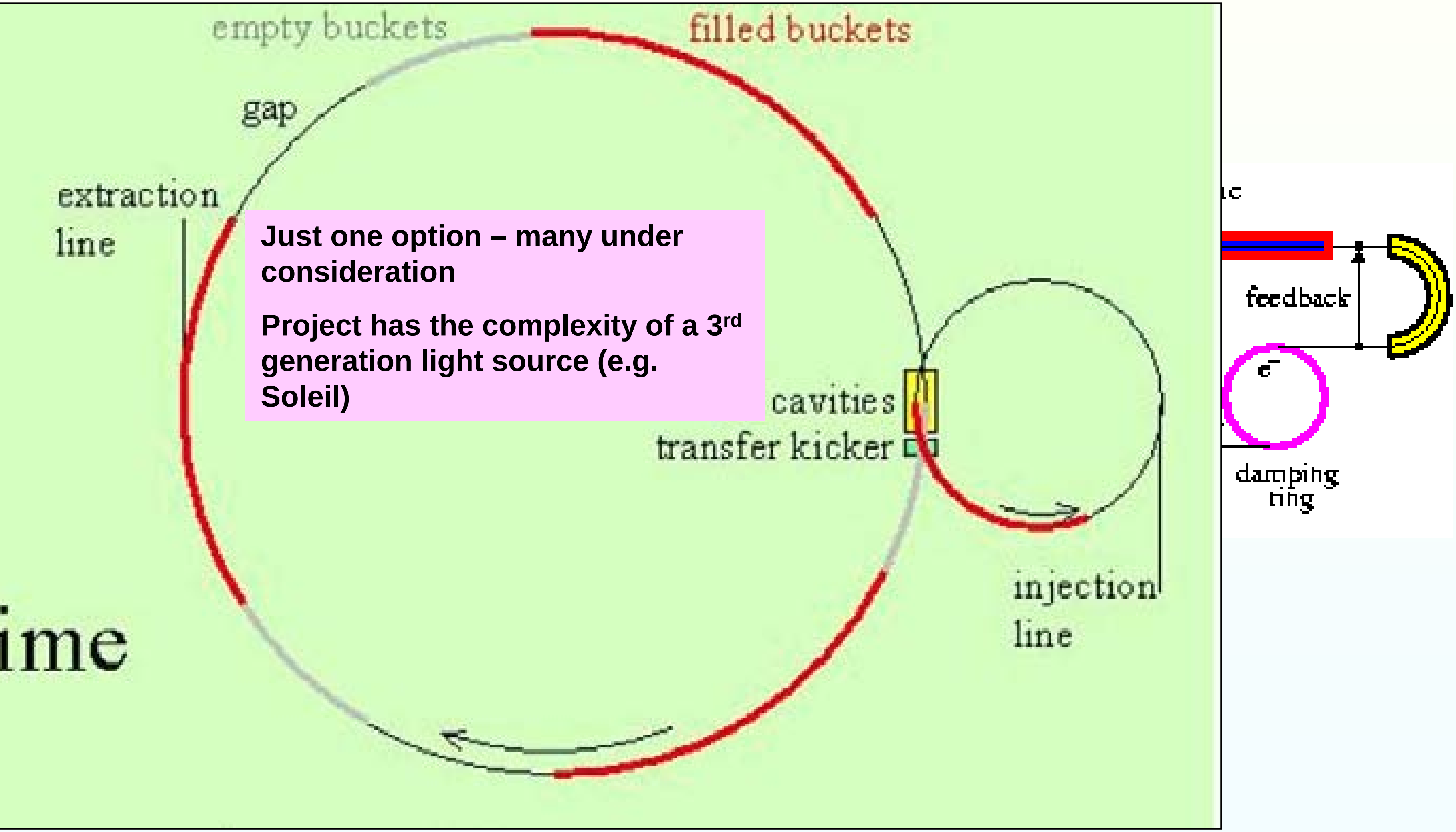


The heart of the Linear Collider





A Linear Collider – Damping Rings

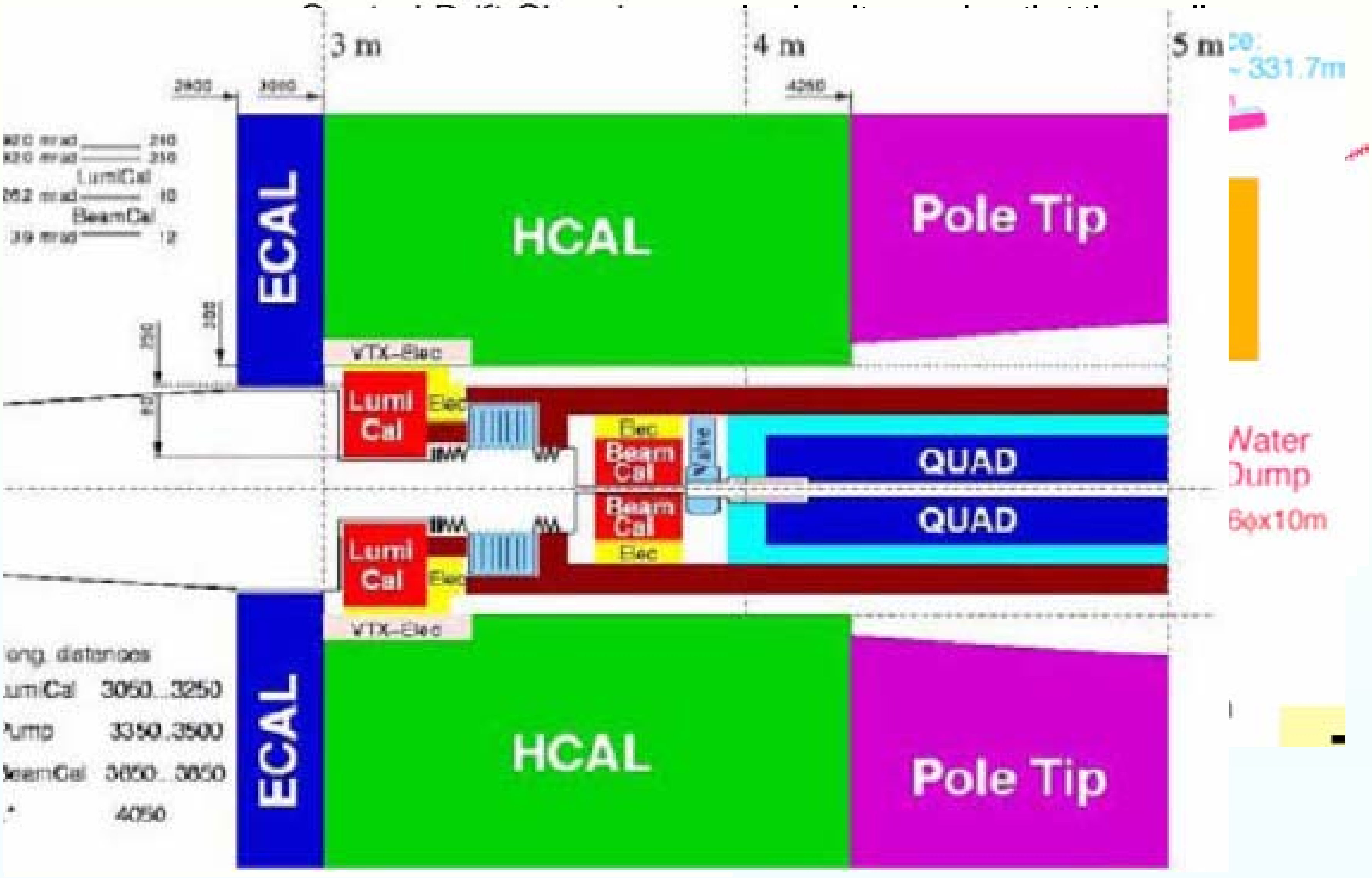


Just one option – many under consideration

Project has the complexity of a 3rd generation light source (e.g. Soleil)

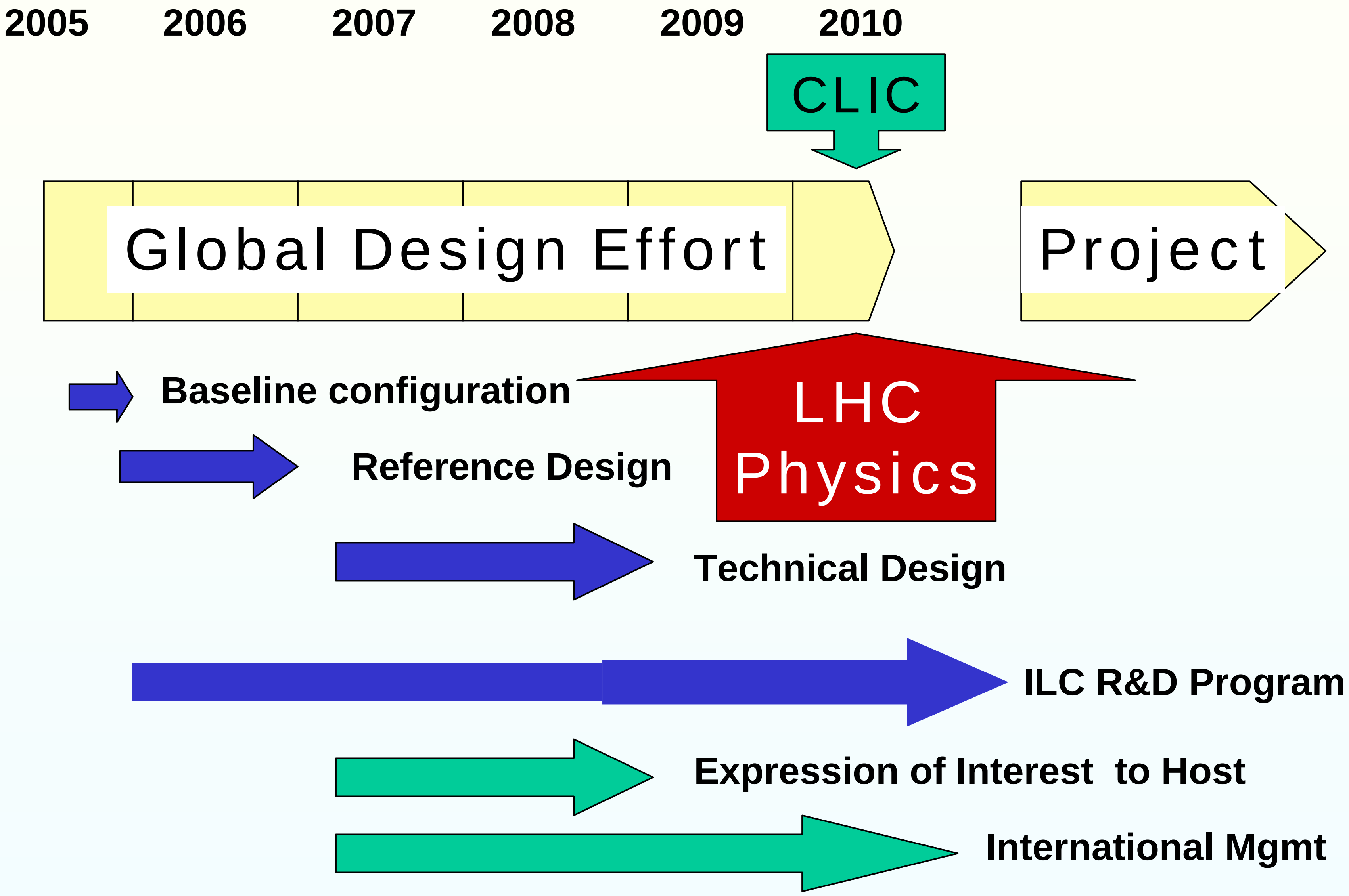
After Rainer Wanzenberg

An issue – Beam Delivery System



After Rainer Wanzenberg

The GDE Plan and Schedule



2005 2006 2007 2008 2009 2010

CLIC

Global Design Effort

Project

LHC Physics

Baseline configuration

Reference Design

Technical Design

ILC R&D Program

Expression of Interest to Host

International Mgmt

After Barry Barish

The Limits

- **The Superconducting RF Technology used in the ILC has a maximum accelerating gradient of around 50MV/m**
  - **1 TeV = 20 Km of acceleration**
    - **+ ~10 Km of Beam delivery System, diagnostics etc**
  - **3 TeV ➔ 60 Km of acceleration**
    - **Is there a better technology?**
      - **i.e. with a higher accelerating gradient**
        - » **Target ~150MeV/m**

CLIC – Compact Linear Collider

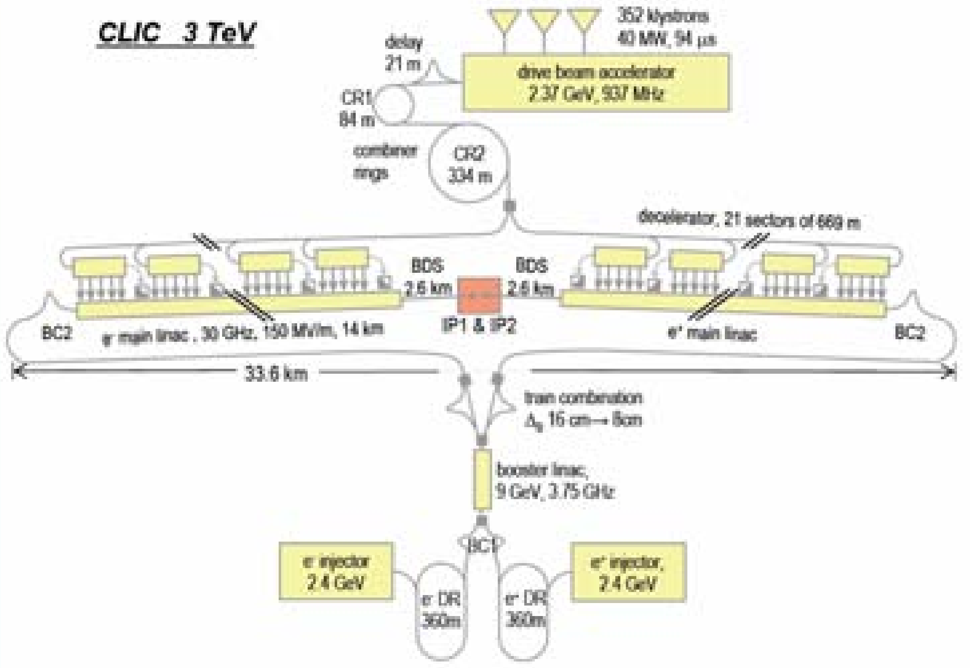
- **CLIC aim:**
  - **develop technology for e-/e+ collider with E_{CMS}= 1 - 5 TeV**

- **Physics motivation:**
  - **"Physics at the CLIC Multi-TeV Linear Collider :**
  - **report of the CLIC Physics Working Group,"**
    - **CERN report 2004-5**

- **Present aim:**
  - **Demonstrate all key feasibility issues by 2010**

After Robert Aymar

BASIC FEATURES OF CLIC



Overall layout of
CLIC for E_{CMS}= 3 TeV

High gradient 150 MV/m

- "Compact" collider - overall length < 34 km
- Normal conducting accelerating structures
- High acceleration frequency (30 GHz)

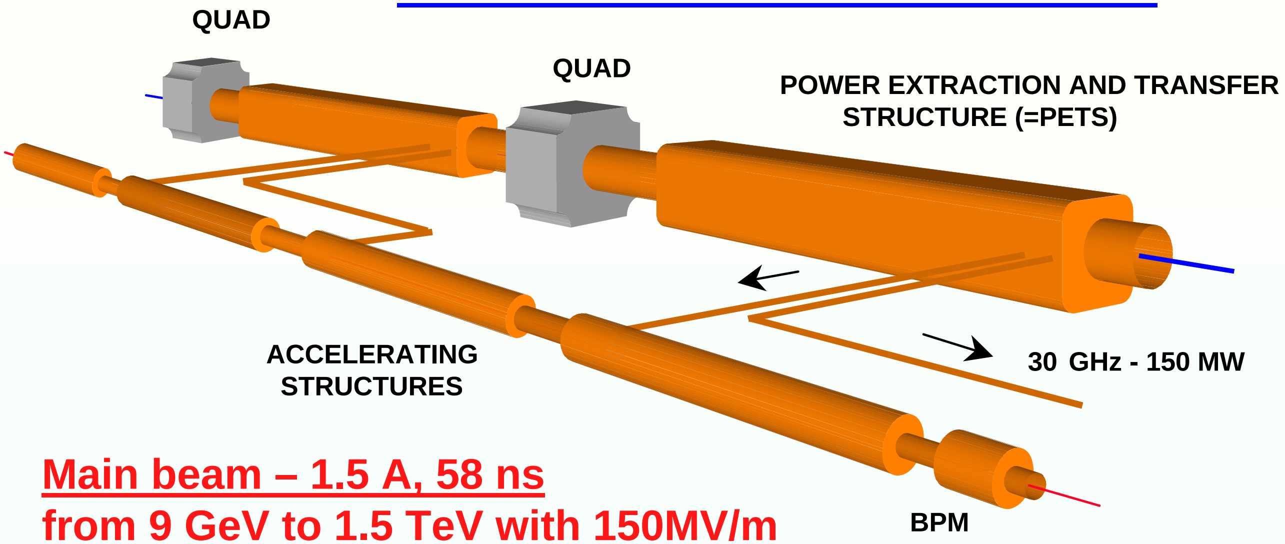
Two-Beam Acceleration Scheme

- Capable to reach high frequency
- Cost-effective & efficient (~ 10% overall)
- Simple tunnel, no active elements
- "Modular" design, can be built in stages

After Robert Aymar

CLIC TWO-BEAM SCHEME

Drive beam - 180 A, 70 ns
from 2.4 GeV to 240 MeV with -9MV/m

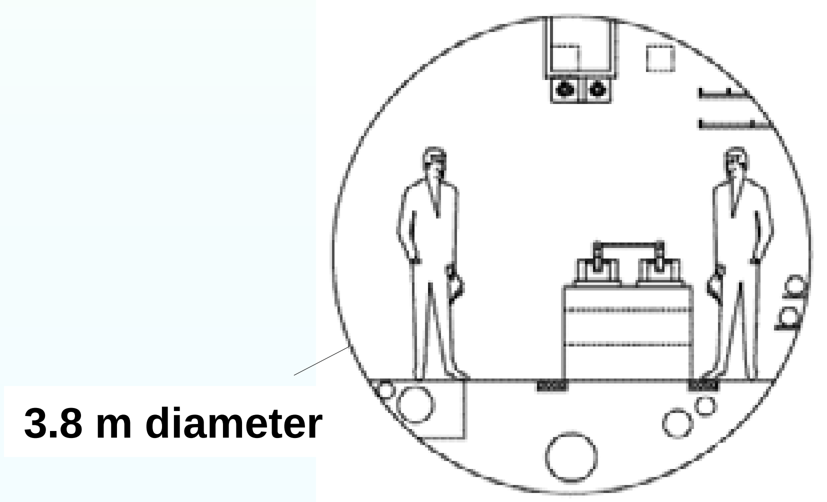


Main beam – 1.5 A, 58 ns
from 9 GeV to 1.5 TeV with 150MV/m

CLIC MODULE

(6000 modules at 3 TeV)

CLIC TUNNEL CROSS-SECTION



After Robert Aymar

New accelerating structure concept HDS

- **Damping waveguides + slotted iris**

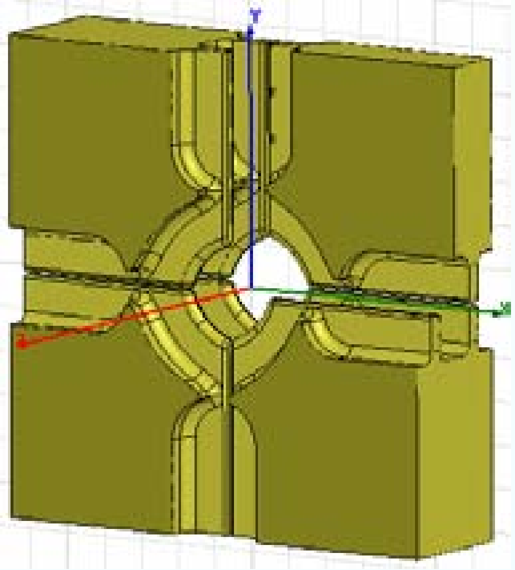
  → improved HOM damping and vacuum
- **Geometry optimized**

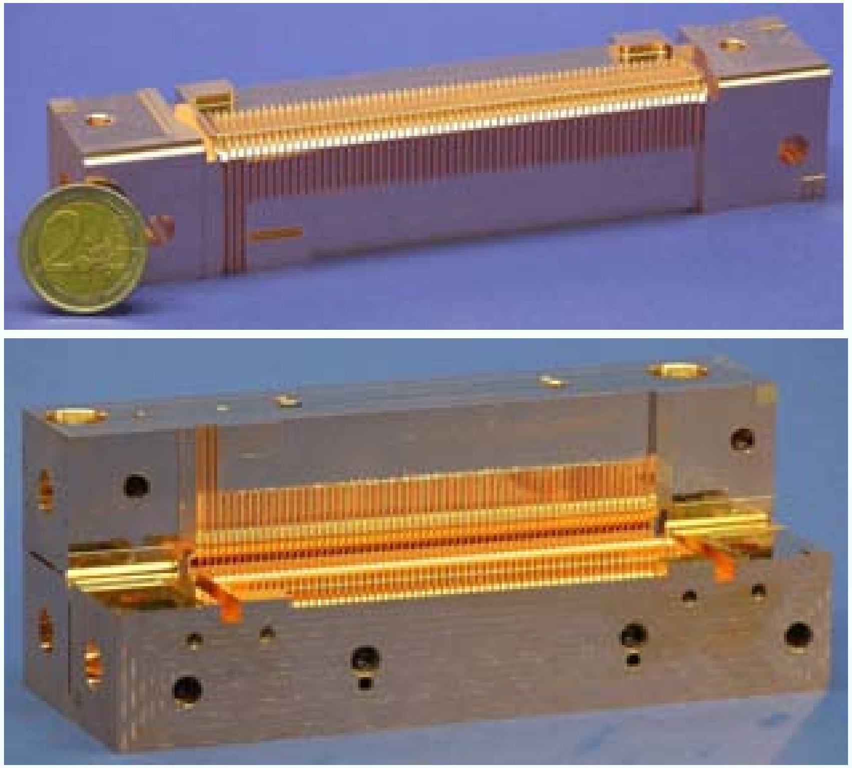
  → reduced E_{SURF}/E_{ACC} and pulsed heating
- **Assembly without brazing**

  → reduced cost for mass production

  → cold worked Cu-Zr with improved mechanical strength
- **Molybdenum iris tips**

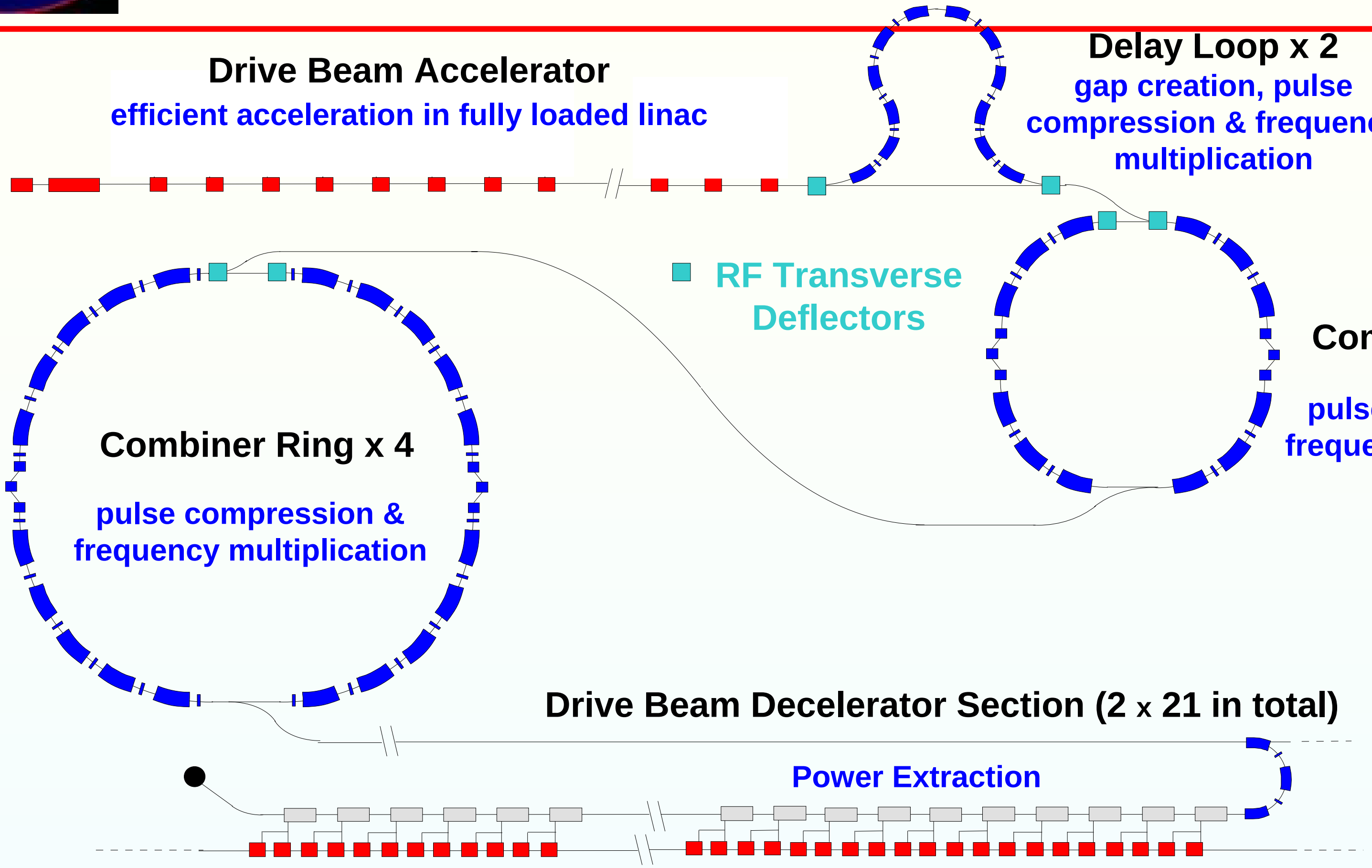
  → higher E_{ACC}





CLIC RF power source layout

After Robert Aymar



Drive Beam Accelerator

efficient acceleration in fully loaded linac

Delay Loop x 2

gap creation, pulse compression & frequency multiplication

RF Transverse Deflectors

Combiner Ring x 4

pulse compression & frequency multiplication

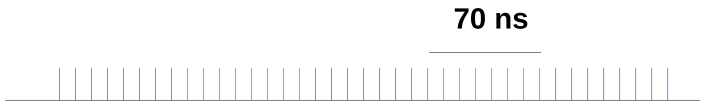
Combiner Ring x 4

pulse compression & frequency multiplication

Drive Beam Decelerator Section (2 x 21 in total)

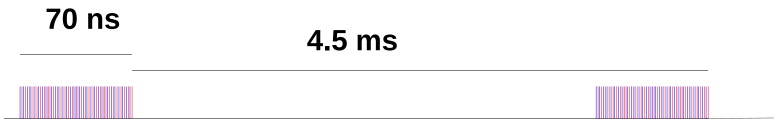
Power Extraction

Drive beam time structure - initial



100 ms train length - 32 x 21 x 2 sub-pulses - 5.7 A
2.5 GeV - 64 cm between bunches

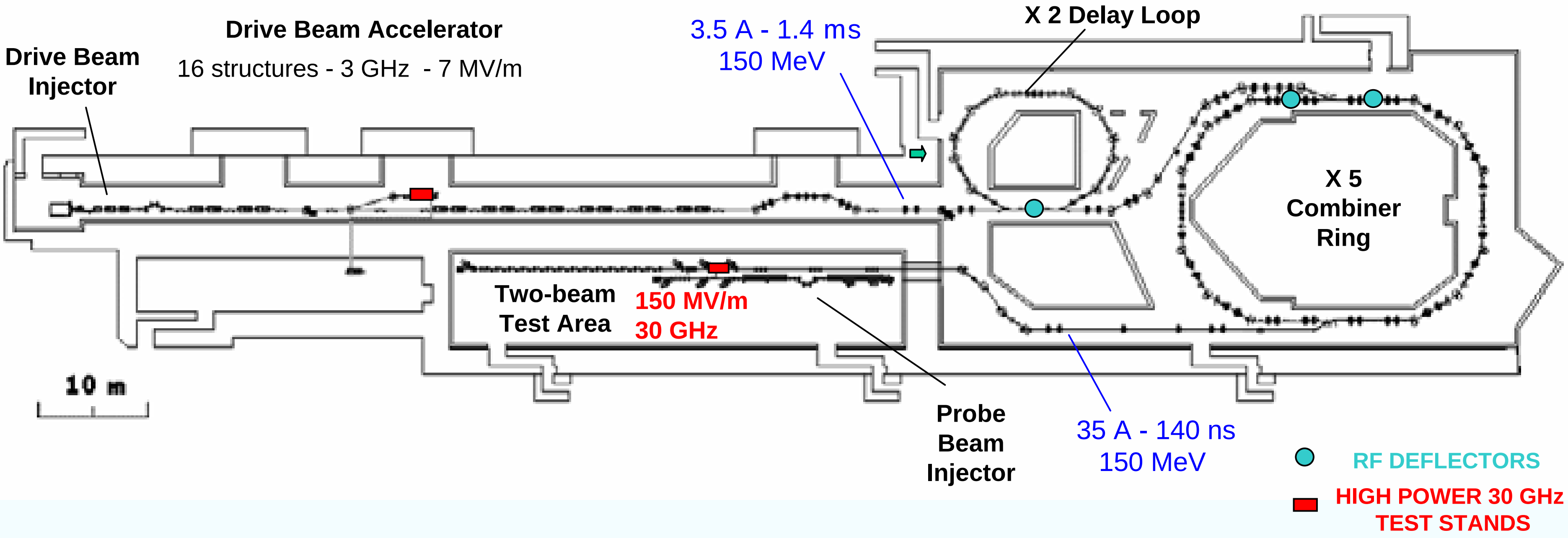
Drive beam time structure - final



2 x 21 pulses – 180 A - 2 cm between bunches

CTF3 Motivations and Goals

- Build a small-scale version of the CLIC RF power source, in order to demonstrate:
  - full beam loading accelerator operation
  - electron beam pulse compression and frequency multiplication using RF deflectors
- Provide the 30 GHz RF power to test the CLIC accelerating structures and components at and beyond the nominal gradient and pulse length (150 MV/m for 70 ns) .
- Tool to demonstrate CLIC feasibility issues identified by ILC-TRC



Neutrino Facilities

What are they and why are they needed
Present status and possible future

http://www.adams-institute.ac.uk

Ken.Peach@adams-institute.ac.uk

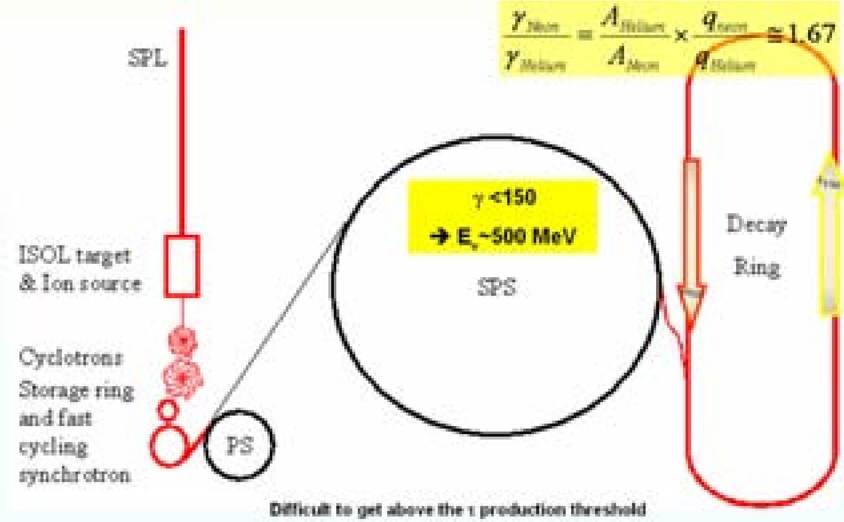
Neutrino Facilities: What are they and why are they needed

Recent discoveries in neutrino physics ("neutrino oscillations") require new neutrino facilities

- **Beams of precisely known composition ($\nu_{e}, \nu_{\mu}, \nu_{\tau}$), energy (spectrum) and flux**

β beams

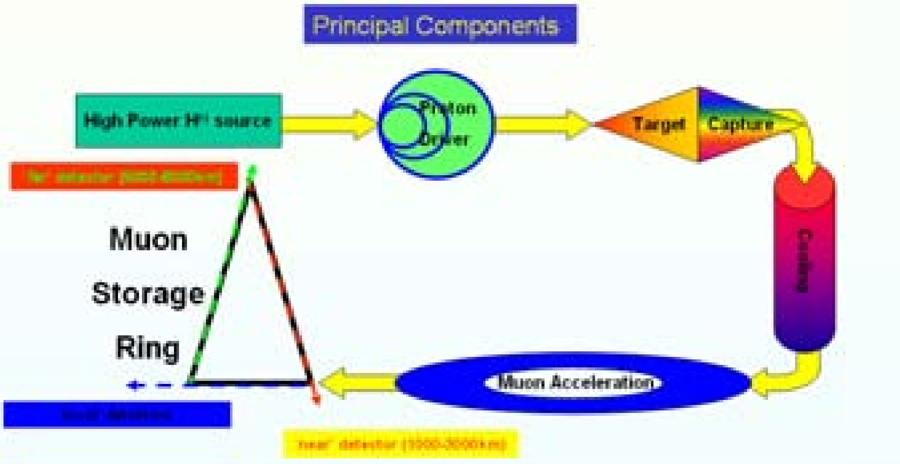
Pure electron (anti)neutrino beams from decay of stored radioactive nuclei



Difficult to get above the τ production threshold

Neutrino Factories

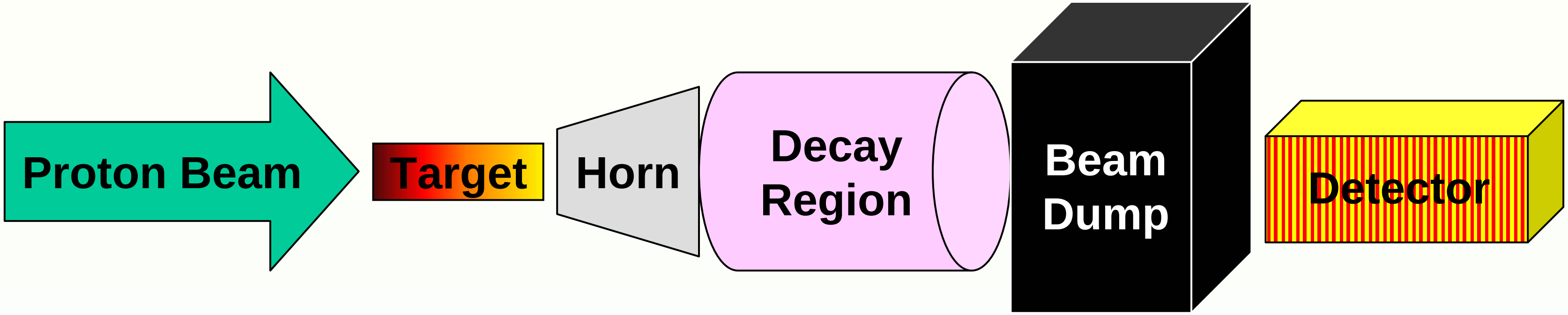
Pure electron neutrino & muon antineutrino beams (or vice versa) from decay of stored muons



Both need new physics input (q13) and the development of new technologies

Both are "1B€" projects (accelerator, storage ring, detectors)

Conventional Neutrino Beams



- **Main components**
  - Proton Beam
    - Energy, Intensity, frequency
  - Target
  - Horn (focussing)
  - Decay Region
  - Beam Dump
  - Detector

Note

For any (class of) experiment

$N_{ev} \propto P \times M \; (\times E_\nu)$

P: Beam Power; M: Target Mass; E_ν: Neutrino Energy

Example of a Neutrino Beam

West Area Neutrino Facility at CERN SPS

Why Change?

CHORUS, NOMAD

Wide Band Beam

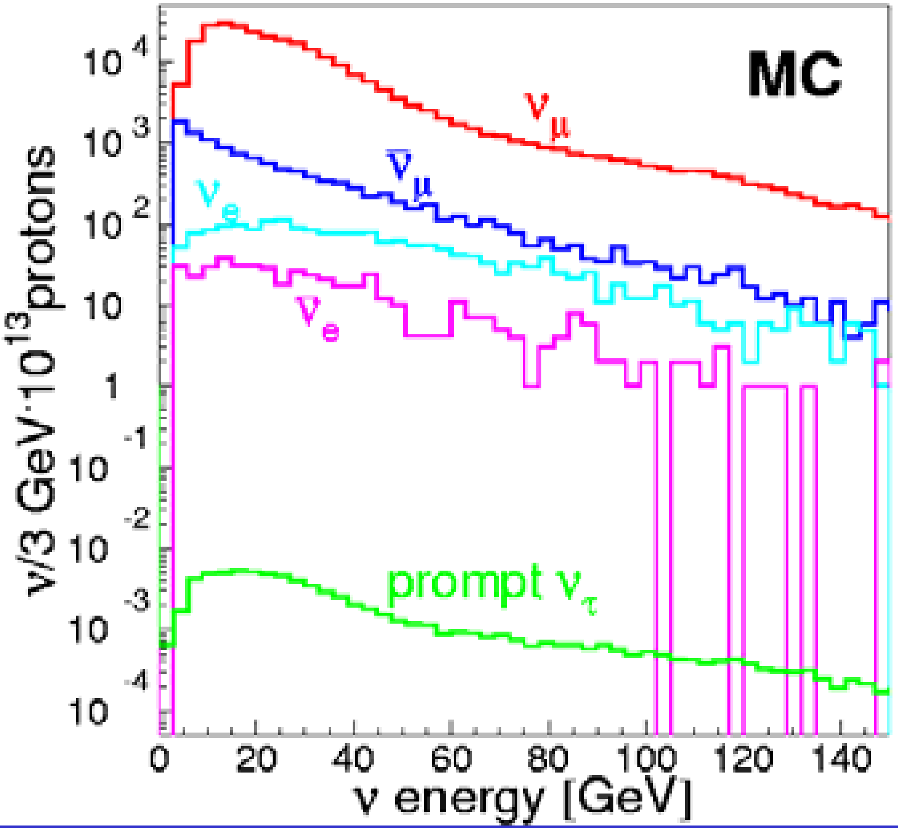
- **5.06×10^{19} POTs (1994-1997)**
- **$<E\nu_\mu>$ ~ 27 GeV**
- **$<L>$ ~ 0.6 km**

  $<L>/<E>$ ~ 2×10^{-2} km/GeV

  $\rightarrow \Delta m^2 > 1$ eV^2

- **Prompt ν_τ : negligible**

$\sim 10^{12}$ neutrinos



J Panman, Neutrino 2004

… because Neutrino Physics has changed!!!

- **1950’s and early 60’s**
  - Nature (and existence) of the neutrino
    - (Reines & Cowan, Lederman, Schwartz and Steinberger)
- **Late 1960s, 1970s, 1980s**
  - Structure of the nucleon
    - F_2, xF_3 etc
  - Structure of the weak current
    - Neutral currents, $sin_2\theta_w$ etc
- **Now, and future**
  - Nature of the neutrino
    - Neutrino Mass and Neutrino Oscillations
    - Standard Model assumption of massless neutrinos is *wr*
      - Note: difficult to add neutrino mass to SM *a la Higgs*
      - Lack of Charge → additional mass-like (Majorana) terms
- **New Physics at last!!!!**

New facilities allow old physics to be done much better

What to Measure?

Neutrinos

ν_e disappearance

$\nu_e \rightarrow \nu_\mu$ appearance

$\nu_e \rightarrow \nu_\tau$ appearance

ν_μ disappearance

$\nu_\mu \rightarrow \nu_e$ appearance

$\nu_\mu \rightarrow \nu_\tau$ appearance

… and the corresponding antineutrino interactions

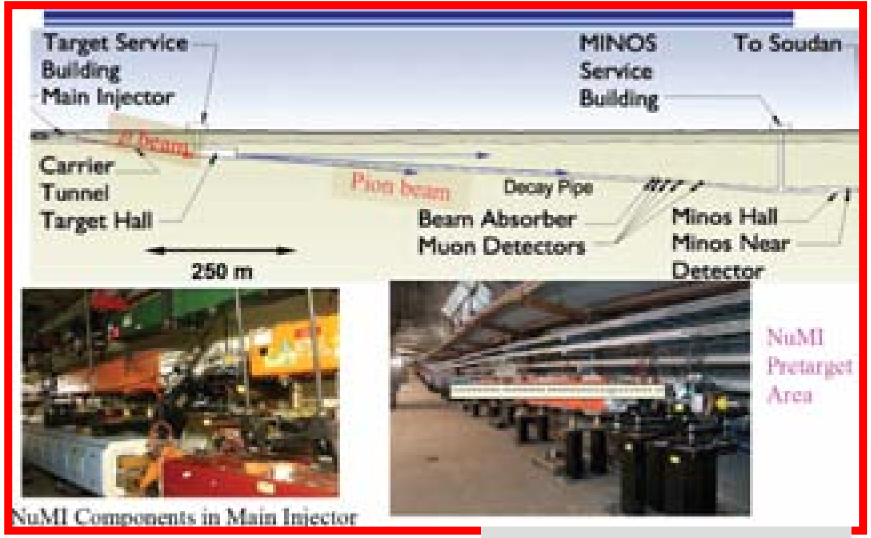
Note: the beam requirements for these experiments are:

high intensity	known flux
known spectrum	known composition (preferably no background)

Recent & Running Experiments (2)

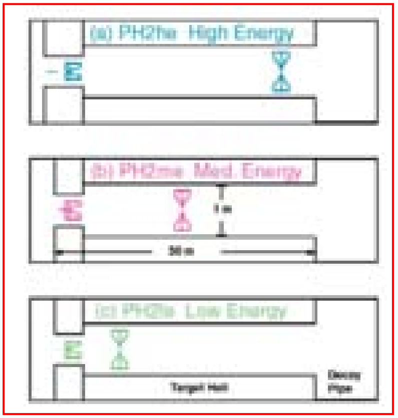
NuMI / MINOS

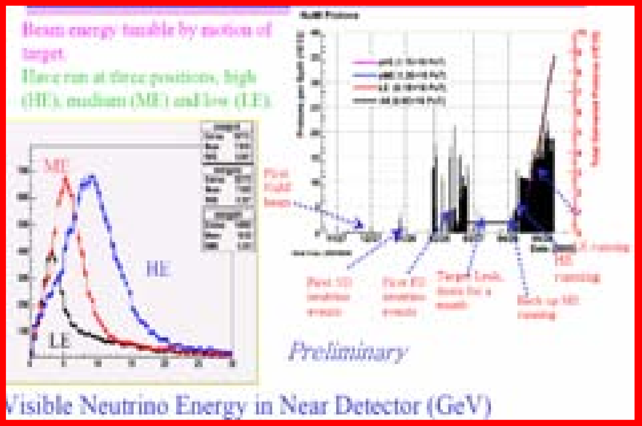
- 120 GeV protons from the MAIN INJECTOR in a single turn (8.7µs)
- 1.9 s cycle time
- *i.e.* ν beam `on' for 8.7µs every 1.9 s
- 2.5x10^{13} protons/pulse
- 0.3 MW on target !
- Initial intensity
  - 2.5x10^{20} protons/year



NuMI Components in Main Injector

R Plunkett, NuFACT05

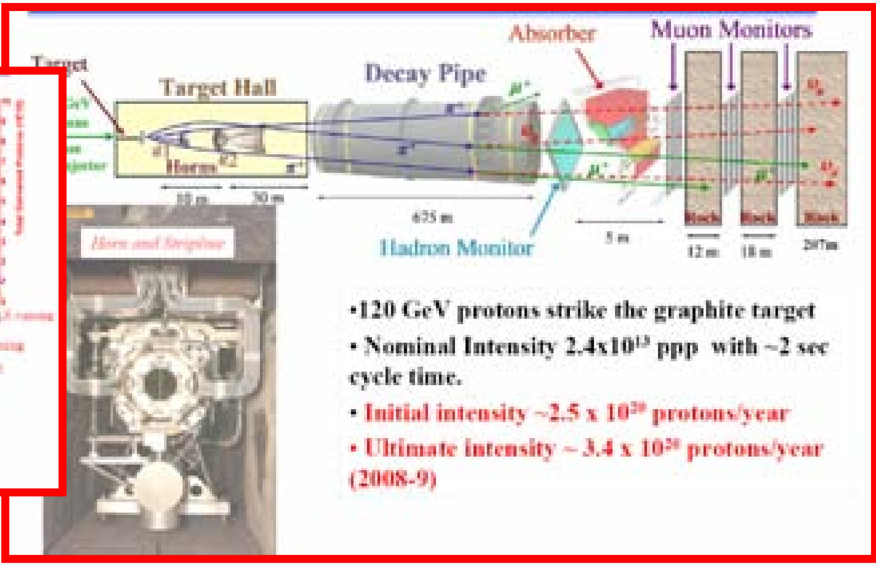




Beam energy tunable by motion of target.

Have run at three positions, high (HE), medium (ME) and low (LE).

Visible Neutrino Energy in Near Detector (GeV)



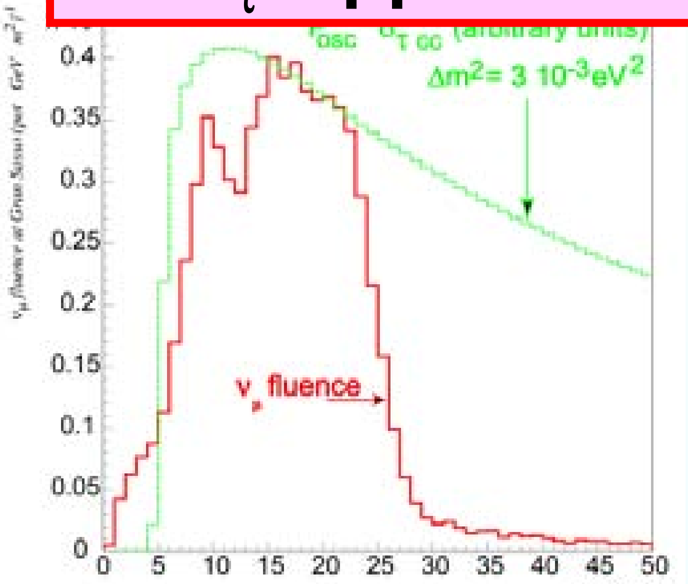
- 120 GeV protons strike the graphite target
- Nominal Intensity 2.4x10^{13} ppp with ~2 sec cycle time.
- Initial intensity ~2.5 x 10^{20} protons/year
- Ultimate intensity ~ 3.4 x 10^{20} protons/year (2008-9)

M Thomson, Neutrino 2004

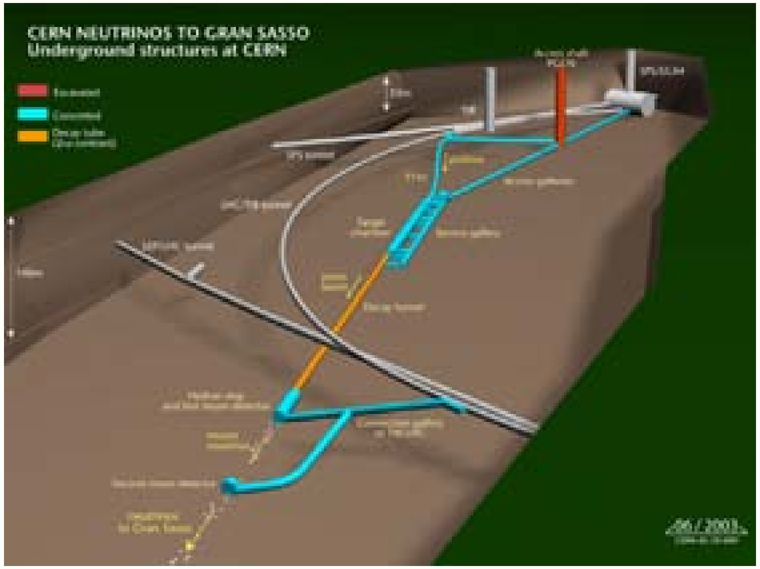
CNGS

732 Km

ν_τ appearance!!



P Migliozzi, NuFACT05

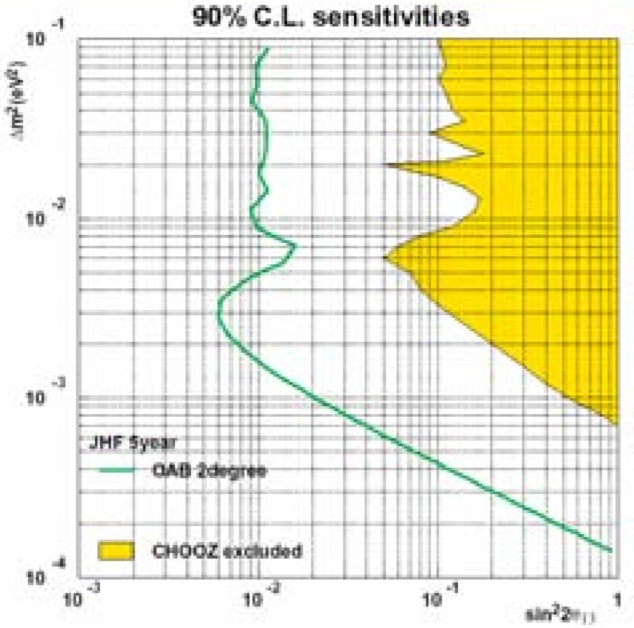


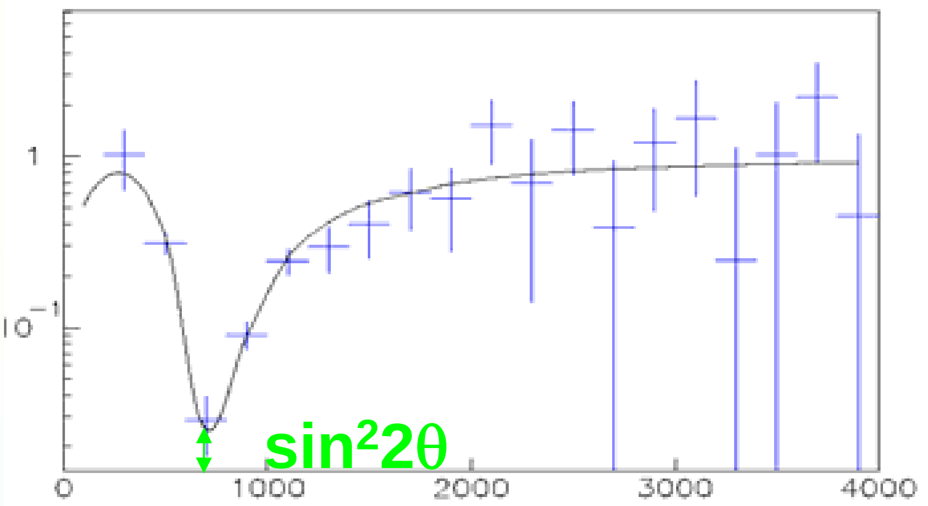
Due to start data taking this year

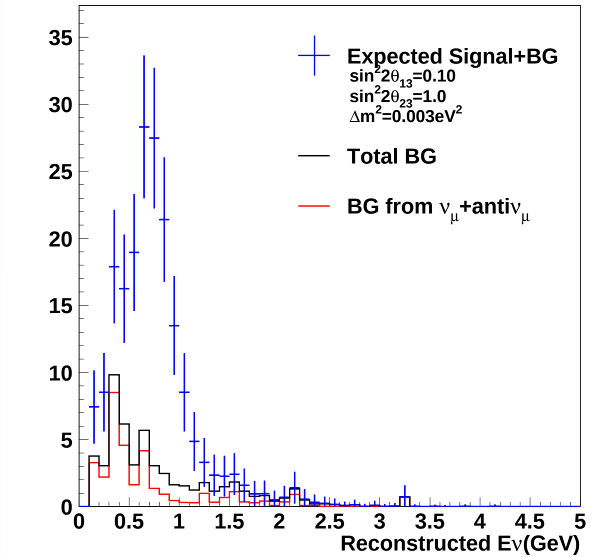
Proposals for new “Off-axis” neurino beam experiments

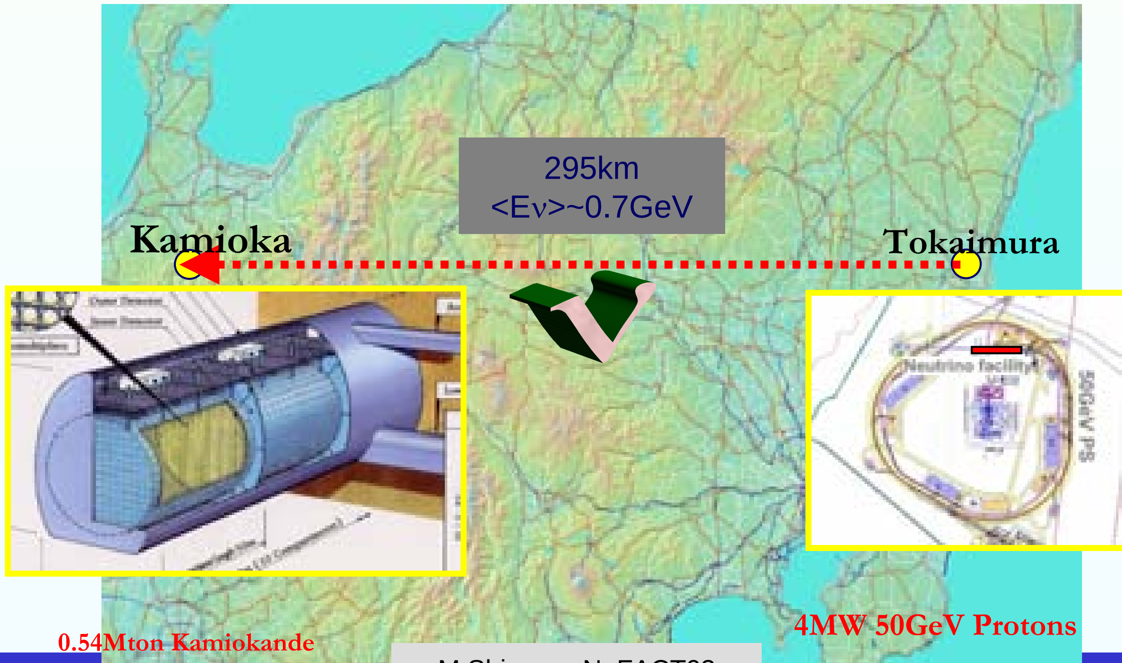
- T2K (Tokai [J-PARC] to SuperKamiokande)
  - Under construction
- NOνA (Fermilab to “somewhere near MINOS”)
  - Under consideration

T2K



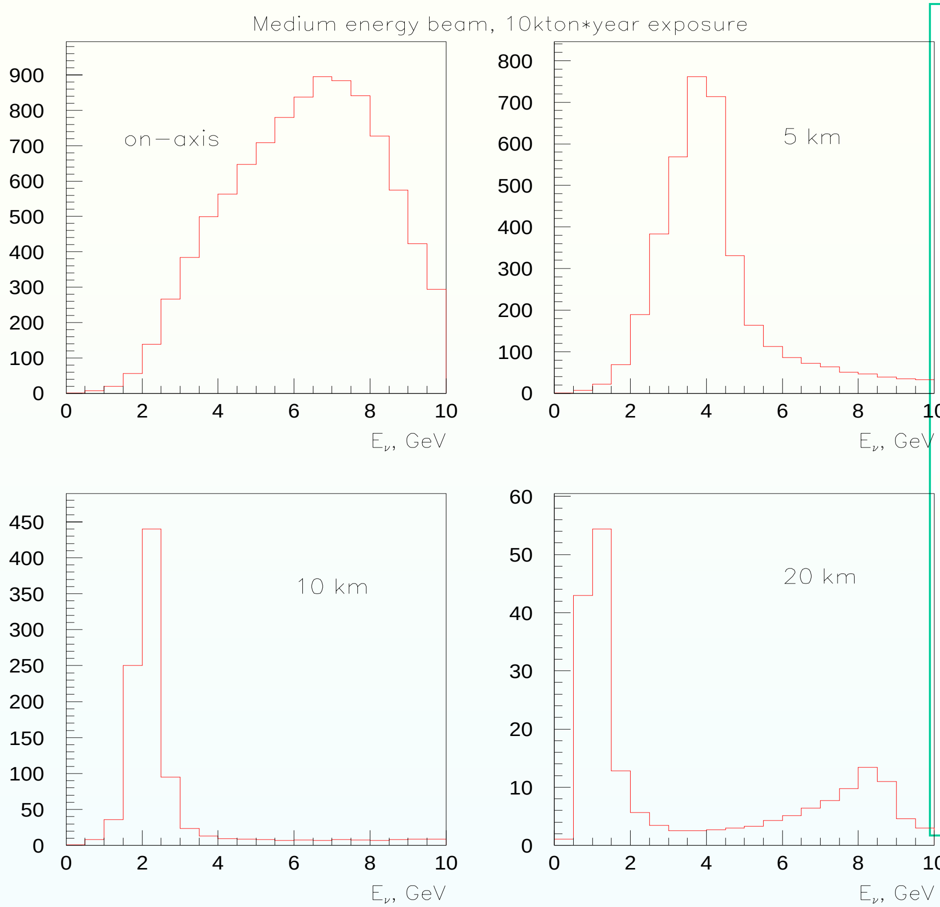


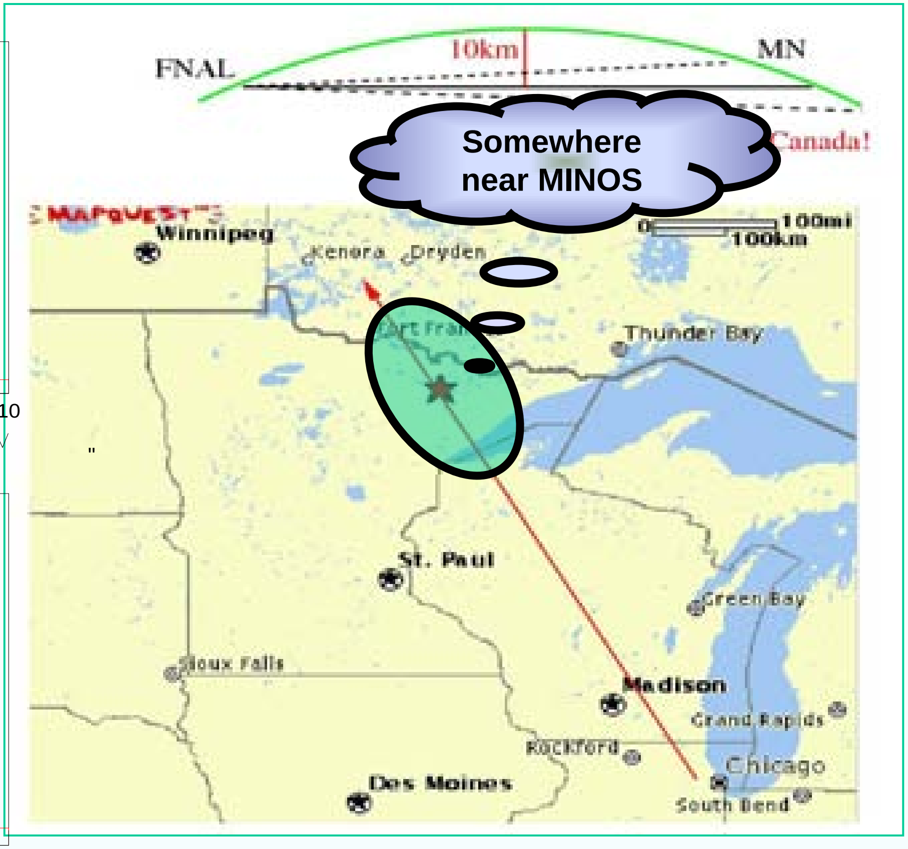




M ShizowaNuFACT03

NuMI Off Axis





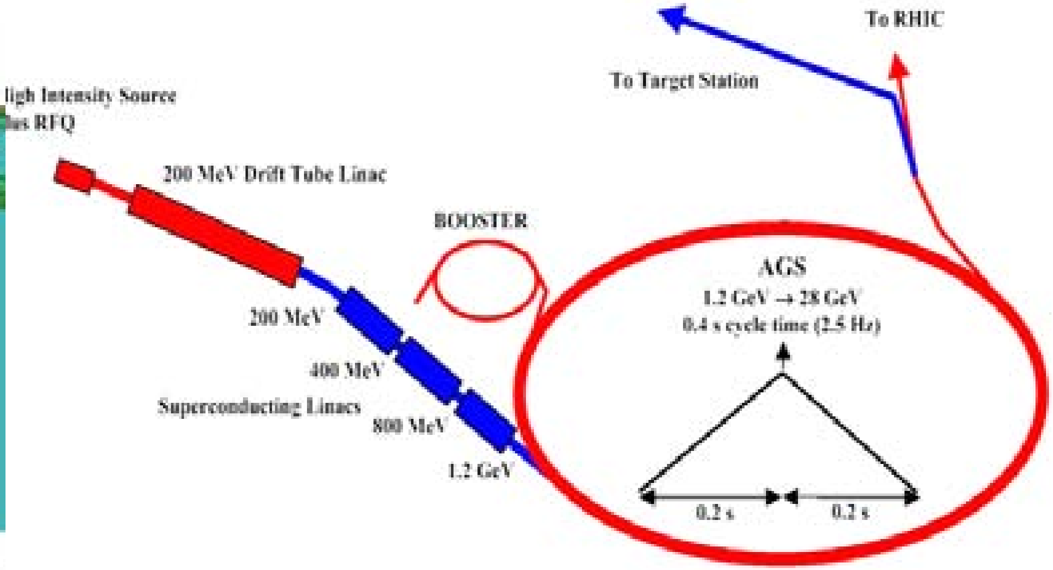
- ~ 2 GeV energy :
  - Below τ threshold
  - Relatively high rates per proton, especially for antineutrinos
- Matter effects to differentiate mass hierarchies
- Baselines 700 – 1000 km

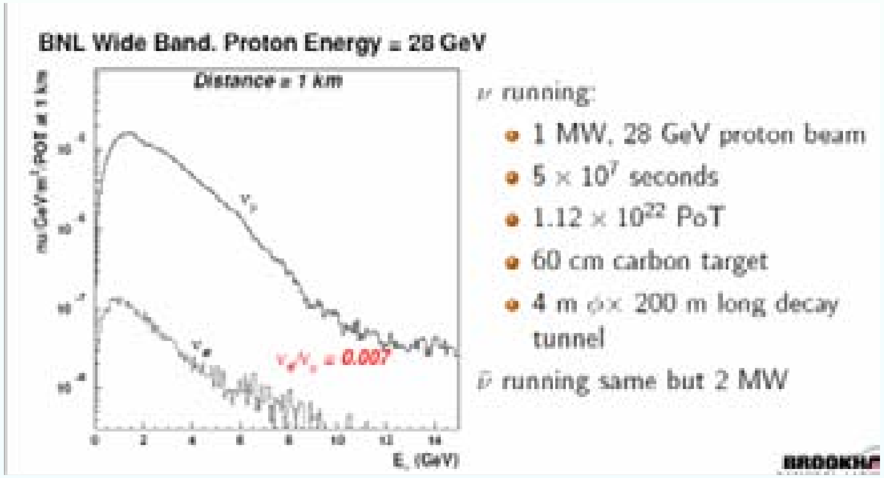
Michael, NuFACT03

BNL to H??

Example Baseline: 2540 km

Homestake & Henderson equivalent. Assume UNO class far detector.

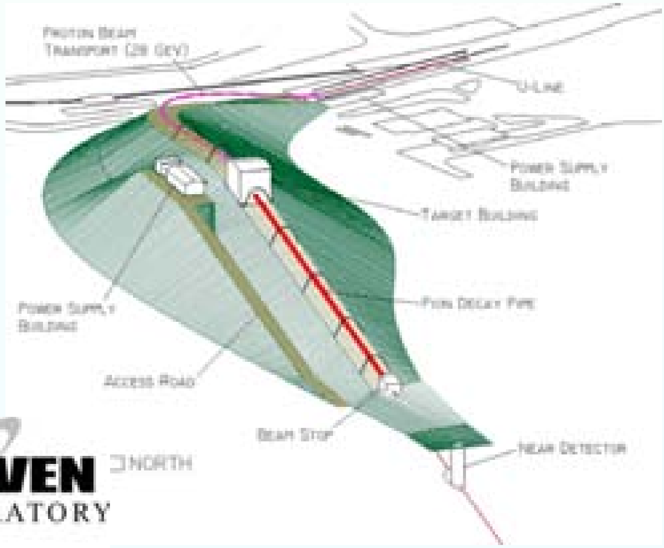




ν running:

- 1 MW, 28 GeV proton beam
- 5×10^7 seconds
- 1.12×10^{22} PoT
- 60 cm carbon target
- 4 m $\phi \times$ 200 m long decay tunnel

$\bar{\nu}$ running same but 2 MW

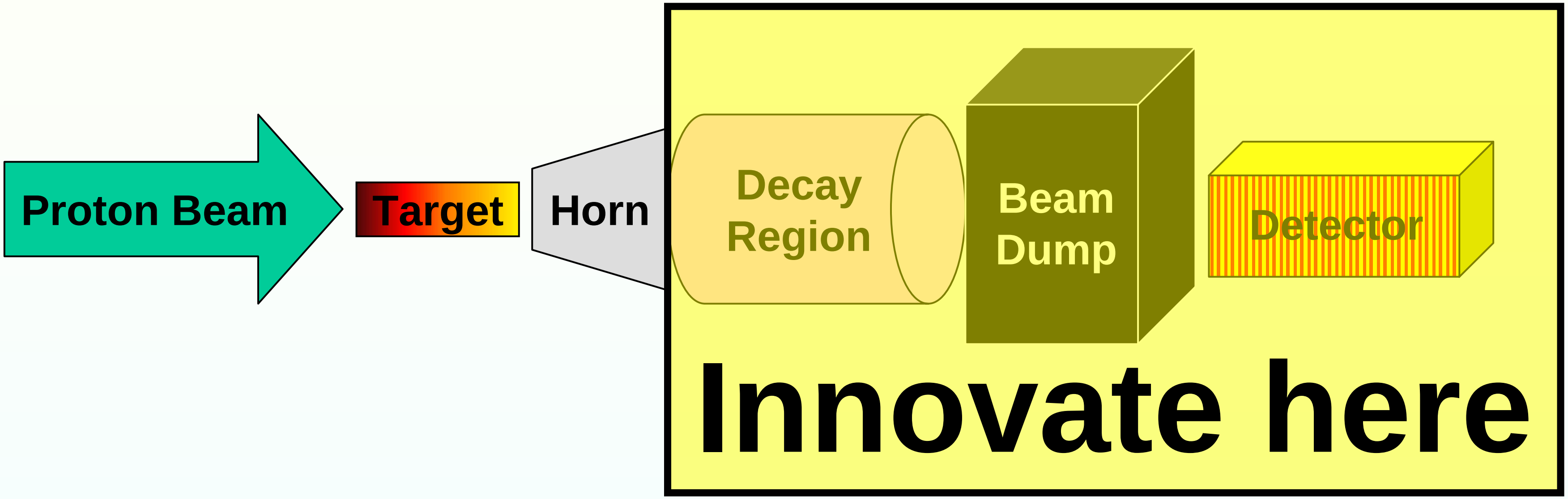


BROOKHAVEN
NATIONAL LABORATORY

B Viren, NuFACT05c

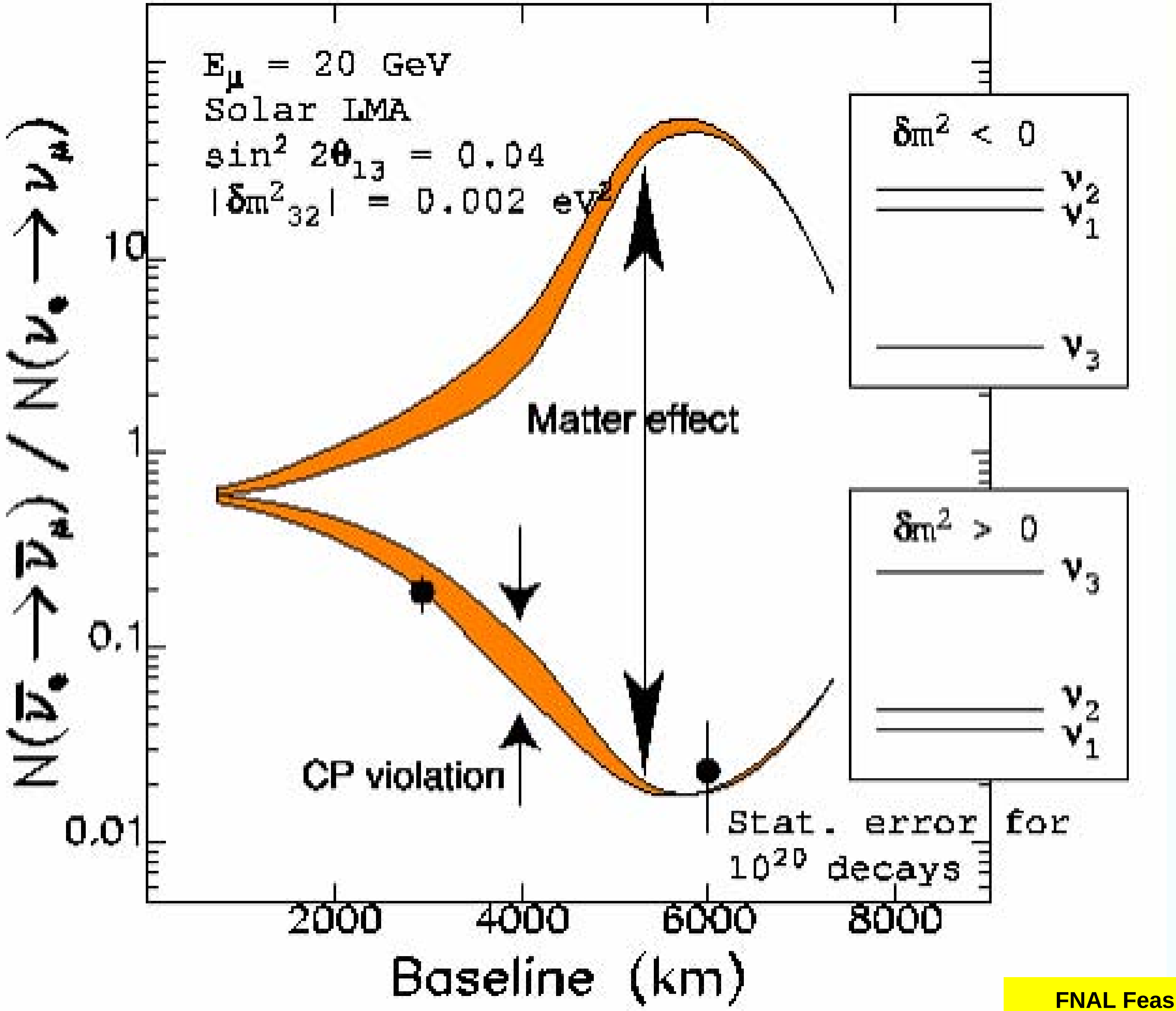
New kinds of Neutrino Beam

Neutrinos NOT from π decay!



- **Generate the neutrino beams from unstable particles in storage rings with long straight sections**

CP-violation



FNAL Feasibality Study 1

β-beam ($\nu_e \rightarrow \nu_\mu$ appearance)

- **Need E_{ν_e} > 100 MeV**
  - Conventional (high energy) neutrino beams
    - Come from K decays
    - small fraction of beam
- **New idea (Zucchelli)**
  - β beams
    - Pure electron (anti) neutrino beams

    from

    accelerated radioactive ions

Possible β^+ emitters (ν_e)

Isotope	Z	A	A/Z	$T_{1/2}$	$Q_{\beta\ (gs>gs)}$	$Q_{\beta\ eff.}$	$E_{\beta\ av.}$	$E_{\nu\ av.}$	<E_LAB> (MeV)
				s	MeV	MeV	MeV	MeV	(@450 GeV/p)
8B	5	8	1.6	0.77	17.0	13.9	6.55	7.37	4145
10C	6	10	1.7	19.3	2.6	1.9	0.81	1.08	585
14O	8	14	1.8	70.6	4.1	1.8	0.78	1.05	538
15O	8	15	1.9	122.2	1.7	1.7	0.74	1.00	479
18Ne	10	18	1.8	1.67	3.4	3.4	1.50	1.86	930
19Ne	10	19	1.9	17.34	2.2	2.2	0.96	1.25	594
21Na	11	21	1.9	22.49	2.5	2.5	1.10	1.41	662
33Ar	18	33	1.8	0.173	10.6	8.2	3.97	4.19	2058
34Ar	18	34	1.9	0.845	5.0	5.0	2.29	2.67	1270
35Ar	18	35	1.9	1.775	4.9	4.9	2.27	2.65	1227
37K	19	37	1.9	1.226	5.1	5.1	2.35	2.72	1259
80Rb	37	80	2.2	34	4.7	4.5	2.04	2.48	1031

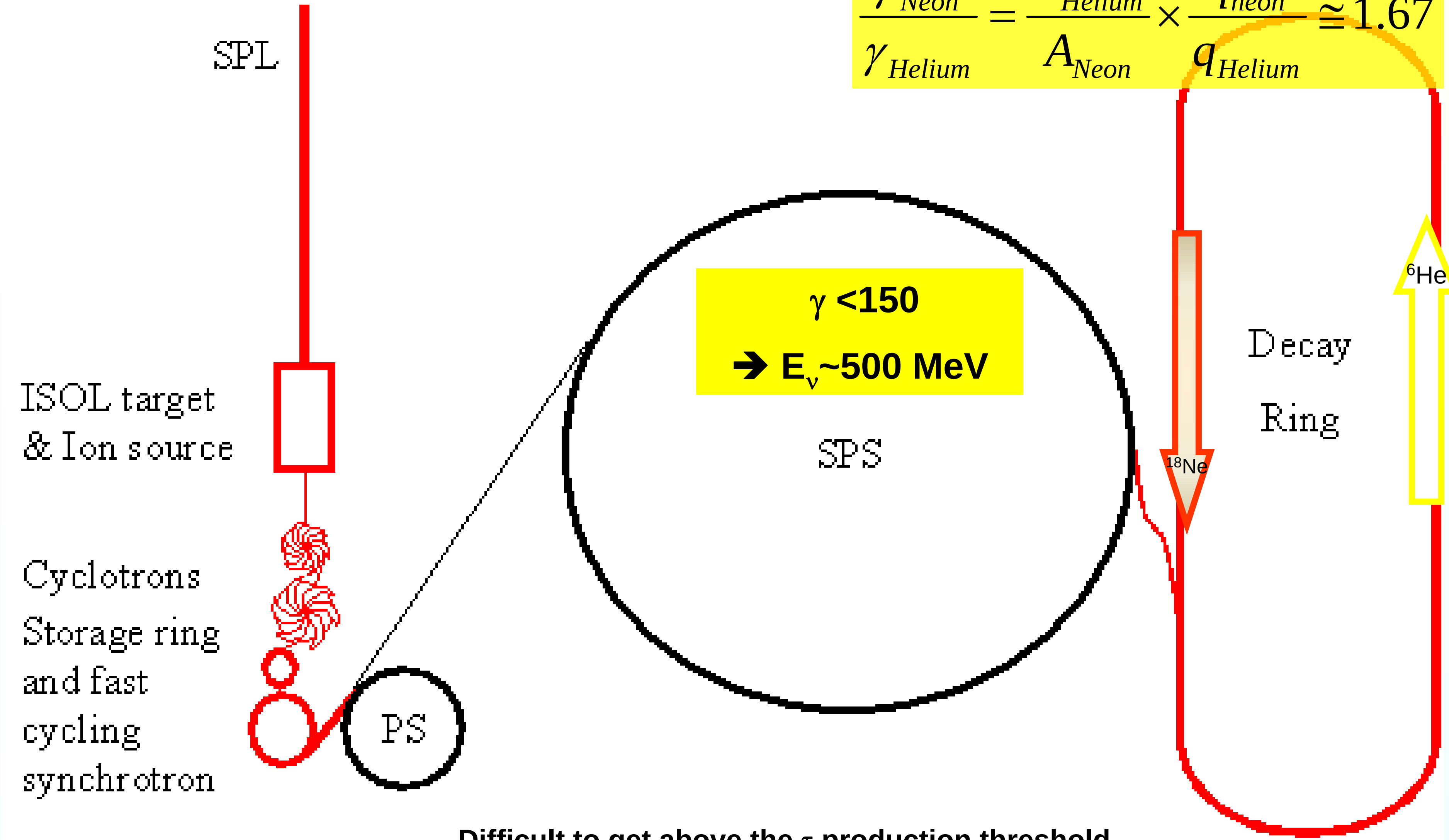
Possible β^- emitters ($\overline{\nu}_e$)

Isotope	Z	A	A/Z	$T_{1/2}$	$Q_{\beta\ (gs>gs)}$	$Q_{\beta\ eff.}$	$E_{\beta\ av.}$	$E_{\nu\ av.}$	<E_LAB> (MeV)
				s	MeV	MeV	MeV	MeV	(@ 450 GeV/p)
6He	2	6	3.0	0.807	3.5	3.5	1.57	1.94	582
8He	2	8	4.0	0.119	10.7	9.1	4.35	4.80	1079
8Li	3	8	2.7	0.838	16.0	13.0	6.24	6.72	2268
9Li	3	9	3.0	0.178	13.6	11.9	5.73	6.20	1860
11Be	4	11	2.8	13.81	11.5	9.8	4.65	5.11	1671
15C	6	15	2.5	2.449	9.8	6.4	2.87	3.55	1279
16C	6	16	2.7	0.747	8.0	4.5	2.05	2.46	830
16N	7	16	2.3	7.13	10.4	5.9	4.59	1.33	525
17N	7	17	2.4	4.173	8.7	3.8	1.71	2.10	779
18N	7	18	2.6	0.624	13.9	8.0	5.33	2.67	933
23Ne	10	23	2.3	37.24	4.4	4.2	1.90	2.31	904
25Ne	10	25	2.5	0.602	7.3	6.9	3.18	3.73	1344
25Na	11	25	2.3	59.1	3.8	3.4	1.51	1.90	750
26Na	11	26	2.4	1.072	9.3	7.2	3.34	3.81	1450

Bouchez, NuFACT03

β-beam

$$\frac{\gamma_{Neon}}{\gamma_{Helium}} = \frac{A_{Helium}}{A_{Neon}} \times \frac{q_{neon}}{q_{Helium}} \cong 1.67$$



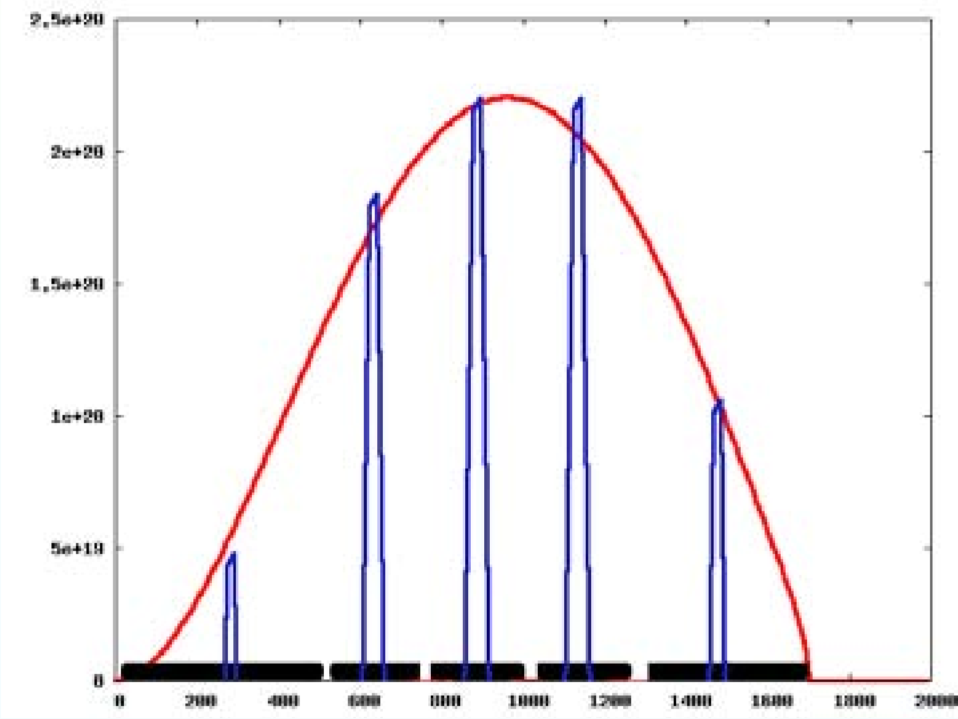
γ <150

→ E_ν~500 MeV

Difficult to get above the τ production threshold

Electron-capture beta-beam

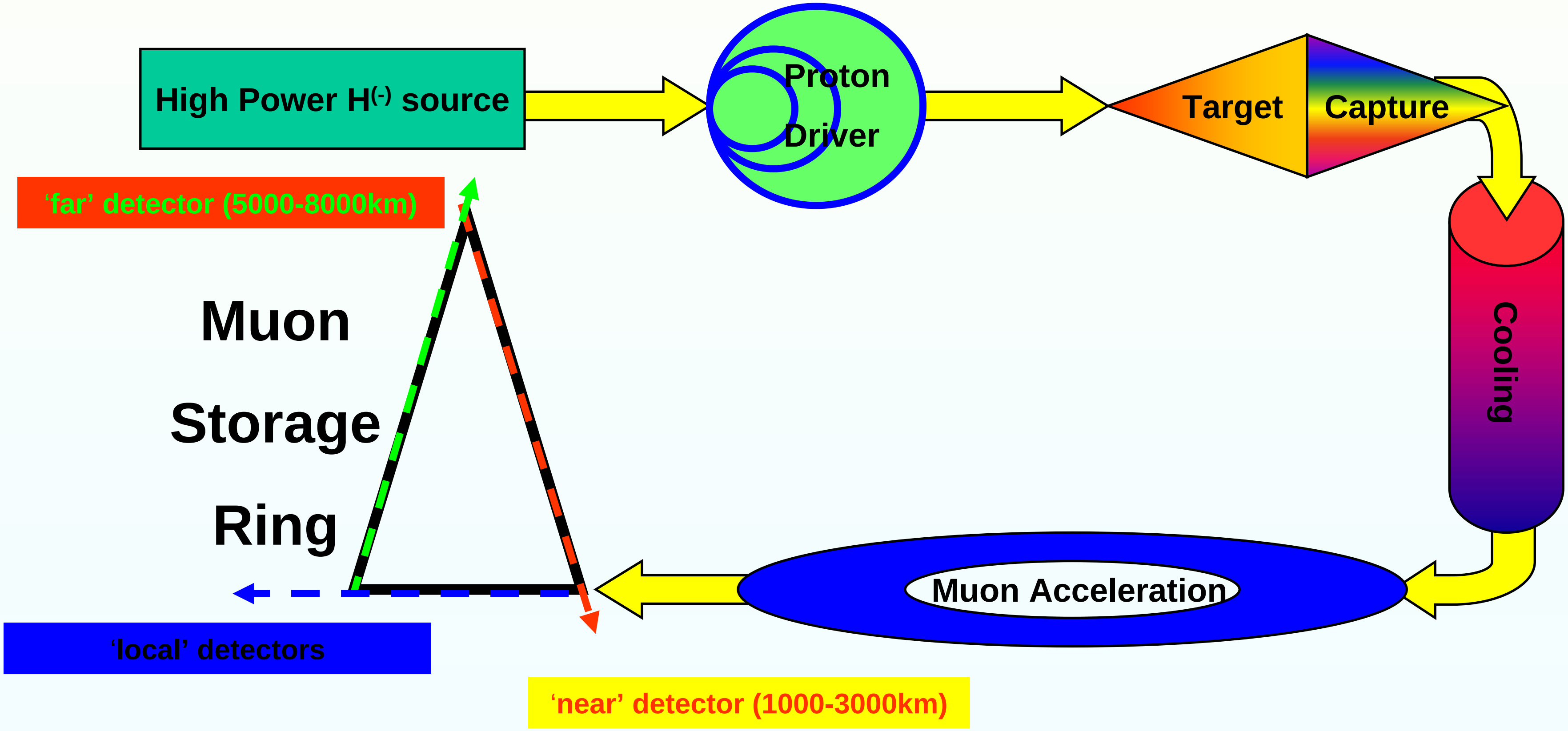
- **Concept:** J. Burguet-Castell (Valencia)
  J. Sato (TUM)
  - $N + e^- \rightarrow N' + \nu$ … two body decay
- **Most favourable isotope?**
  - ^{150}Dy: half-life = 7.2 mins; E_ν = 1.4 MeV; BR ~100%
- **Energy spectrum:**
  - Removes migrations between energy bins
- **Powerful in combination with beta-beam**



A Neutrino Factory is …

⑤ ♋■ ♋♍♍♏●♏❒♋⧫□❒ ♍□❍□●♏⌧ ♎♏⬧♓♑■♏♎ ⧫□ □❒□♎◆♍♏ ✇📂📁📄📂 ❍◆□■ ♎♏♍♋⍓⬧ □♏❒ ⍓♏♋❒ ♎♓❒♏♍⧫♏♎ ♋⧫ ♋ ♎♏⧫♏♍⧫□❒ ⧫♒□◆⬧♋■♎⬧ □♐ &❍ ♋⬥♋⍓

Principal Components



High Power H$^{(-)}$ source

Proton Driver

Target

Capture

Cooling

Muon Acceleration

Muon Storage Ring

'far' detector (5000-8000km)

'local' detectors

'near' detector (1000-3000km)

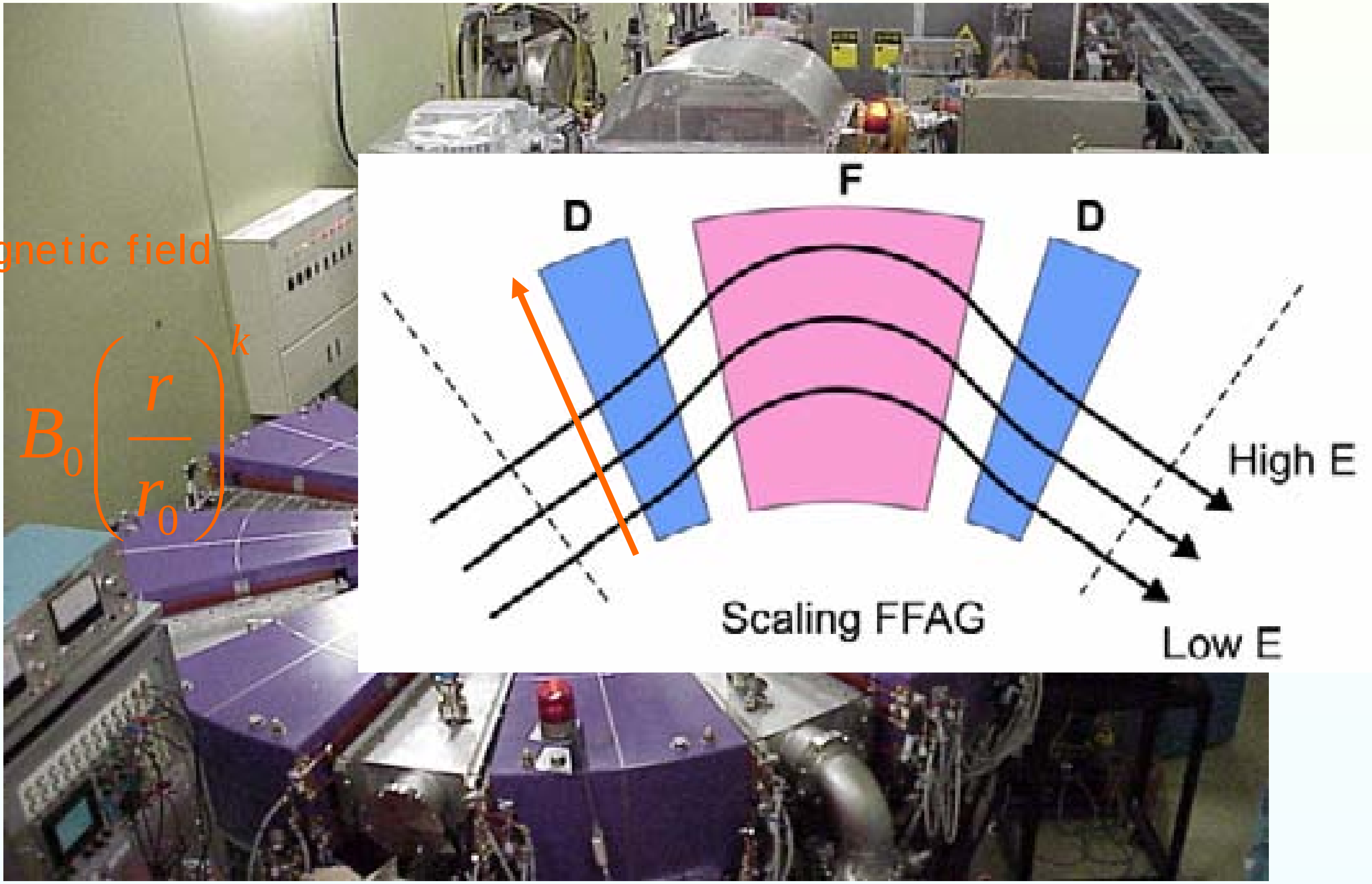
Neutrino Factory Challenges

- **Parameters**
  - Need to know that θ_{13} is not zero
    - Other parameters well known to fix (E_μ,L)
- **Technology**
  - Proton driver
    - RCS or LINAC?
  - Proton energy?
    - HARP, E910, MIPP
  - Target
    - MW beam power
      - Mercury, solid, liquid-cooled, pellet, …
  - Pion/muon collection and/or cooling
    - Magnetic Horns or Solenoids?
    - Phase Rotators, FFAG’s, cooling?
  - RF and acceleration
    - RLA’s or FFAG’s?
  - Muon Storage Ring
    - Racetrack, triangular or bow-tie
    - Conventional or FFAG?

- **Other uses of high power protons & muons?**

What is an FFAG?

Fixed Field Alternating Gradient accelerator

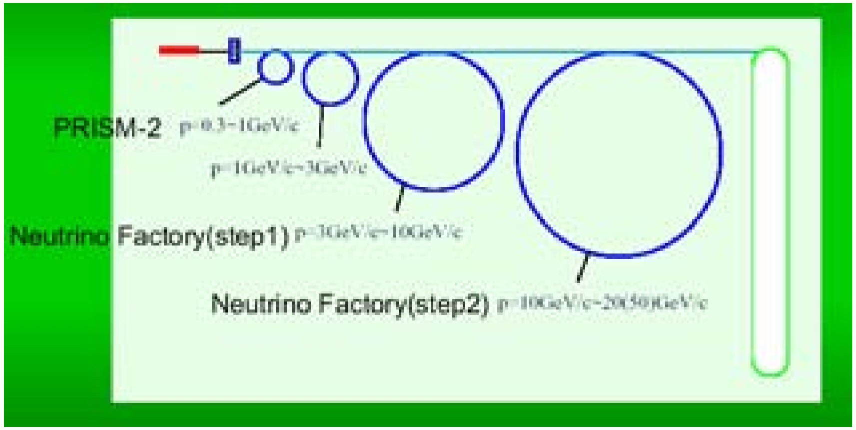


Magnetic field

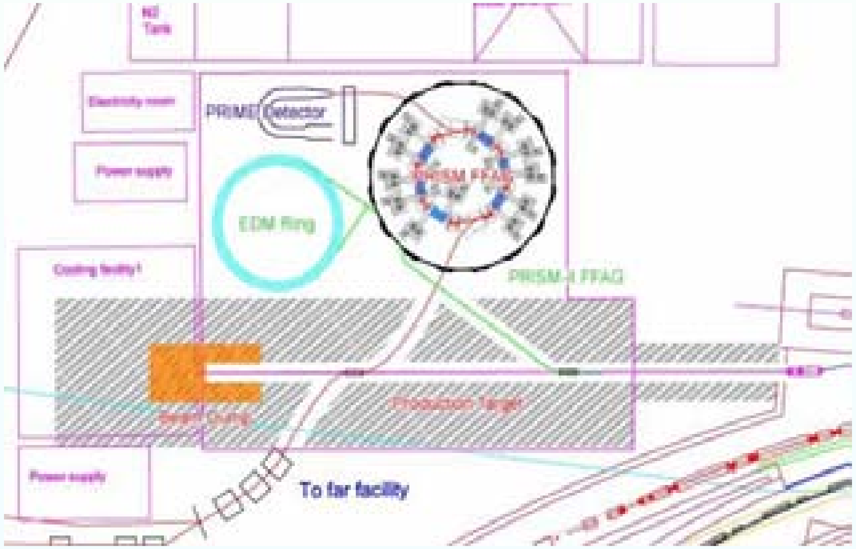
$$B = B_0 \left(\frac{r}{r_0} \right)^k$$

Rob Edgecock/CCLRC

The FFAG model

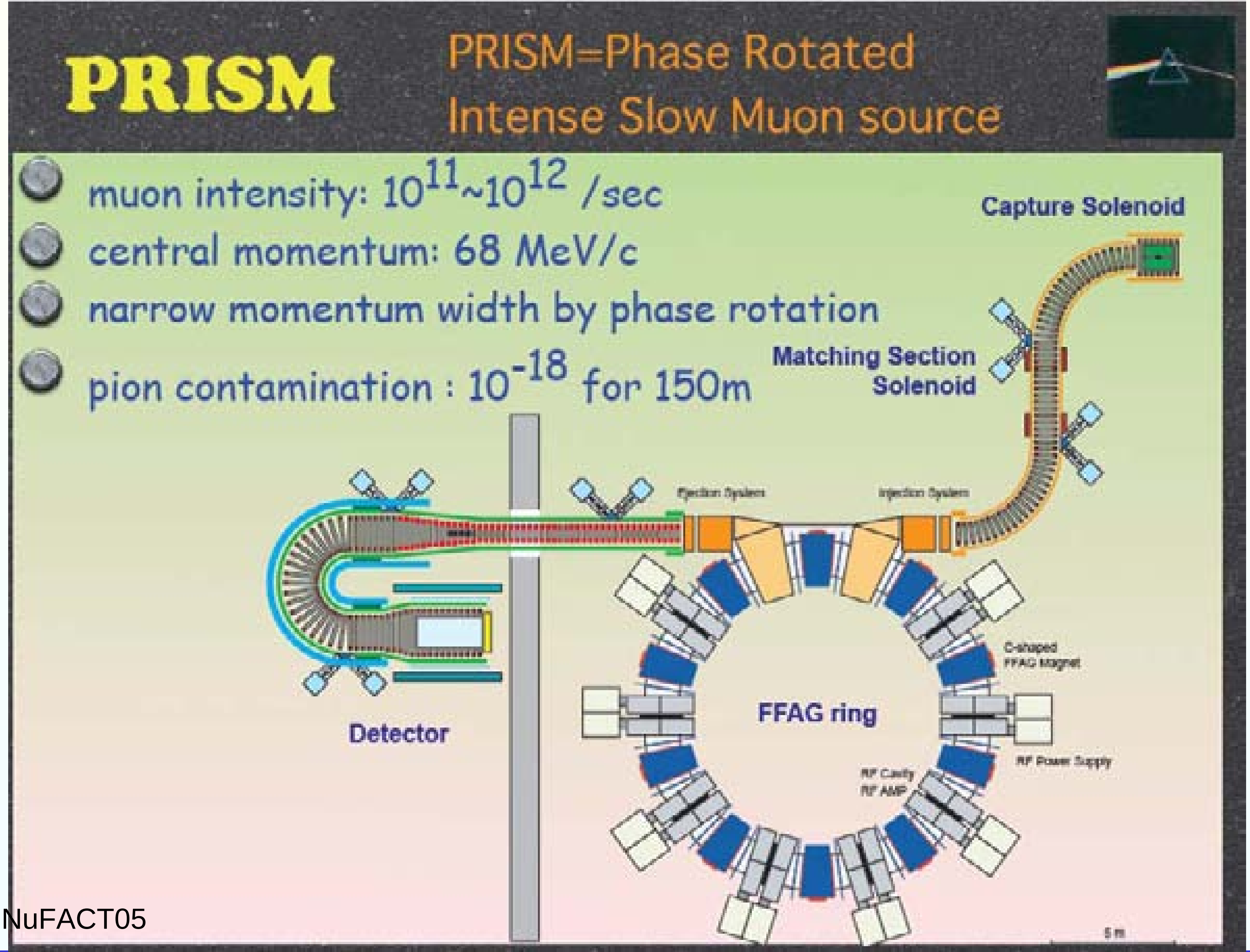


- **High Power Proton Driver**
  - **Muon g-2**
- **Muon Factory (PRISM)**
  - **Muon LFV**
- **Muon Factory-II (PRISM-II)**
  - **Muon EDM**
- **Neutrino Factory**
  - **Based on 1 MW proton beam**
- **Neutrino Factory-II**
  - **Based on 4.4 MW proton beam**



After Y Kuno

PRISM



PRISM

PRISM=Phase Rotated Intense Slow Muon source

- muon intensity: 10^{11}~10^{12} /sec
- central momentum: 68 MeV/c
- narrow momentum width by phase rotation
- pion contamination : 10^{-18} for 150m

Kuno, NuFACT05

Other Key Challenges

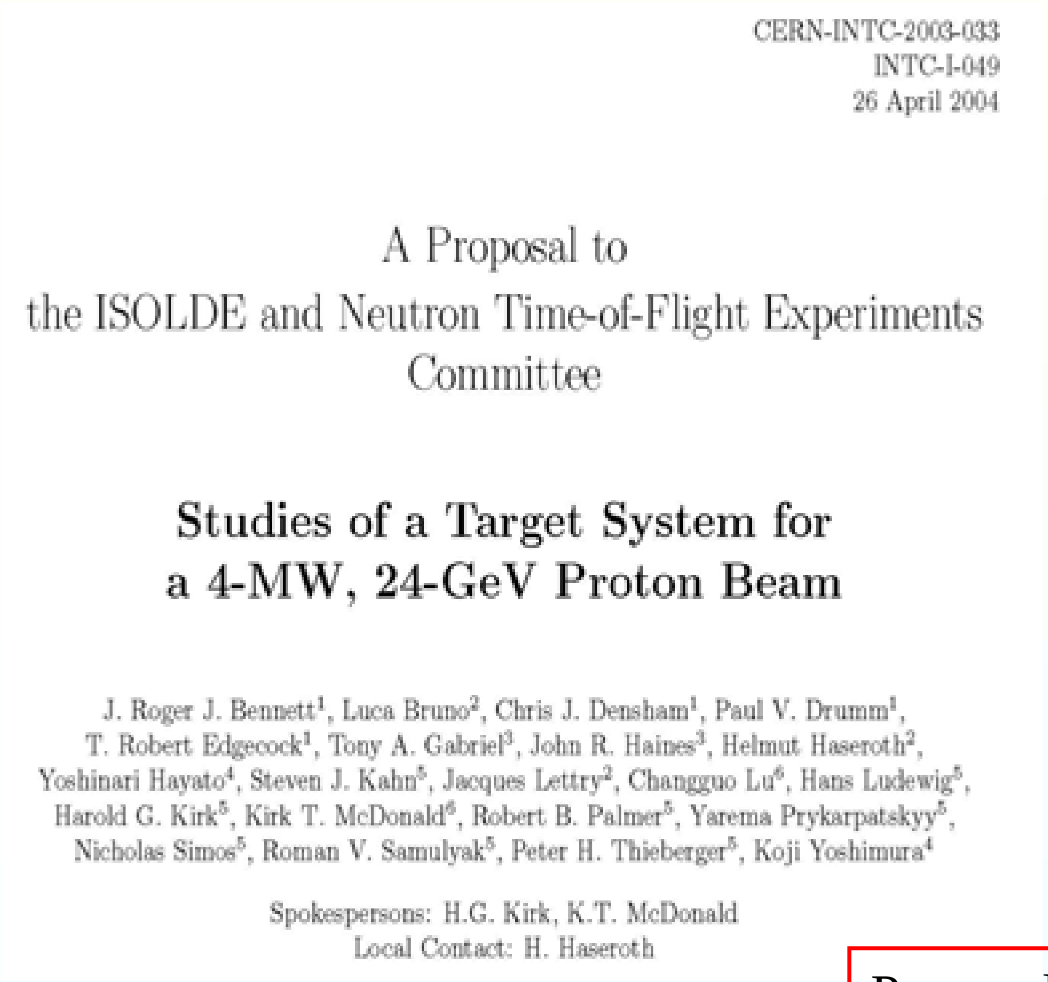
Targets

- ~ same power as SNS targets
  - Open
  - Small
  - Environmental protection?

Muon Cooling

- Certainly needed for a muon collider
- Almost certainly needed for a neutrino factory
  - (combined FFAG/cooling or ring-coolers?)

nTOF11 (MERIT)



CERN-INTC-2003-033
INTC-I-049
26 April 2004

A Proposal to
the ISOLDE and Neutron Time-of-Flight Experiments
Committee

Studies of a Target System for
a 4-MW, 24-GeV Proton Beam

J. Roger J. Bennett[1], Luca Bruno[2], Chris J. Densham[1], Paul V. Drumm[1],
T. Robert Edgecock[1], Tony A. Gabriel[3], John R. Haines[3], Helmut Haseroth[2],
Yoshinari Hayato[4], Steven J. Kahn[5], Jacques Lettry[2], Changguo Lu[6], Hans Ludewig[5],
Harold G. Kirk[5], Kirk T. McDonald[6], Robert B. Palmer[5], Yarema Prykarpatskyy[5],
Nicholas Simos[5], Roman V. Samulyak[5], Peter H. Thieberger[5], Koji Yoshimura[4]

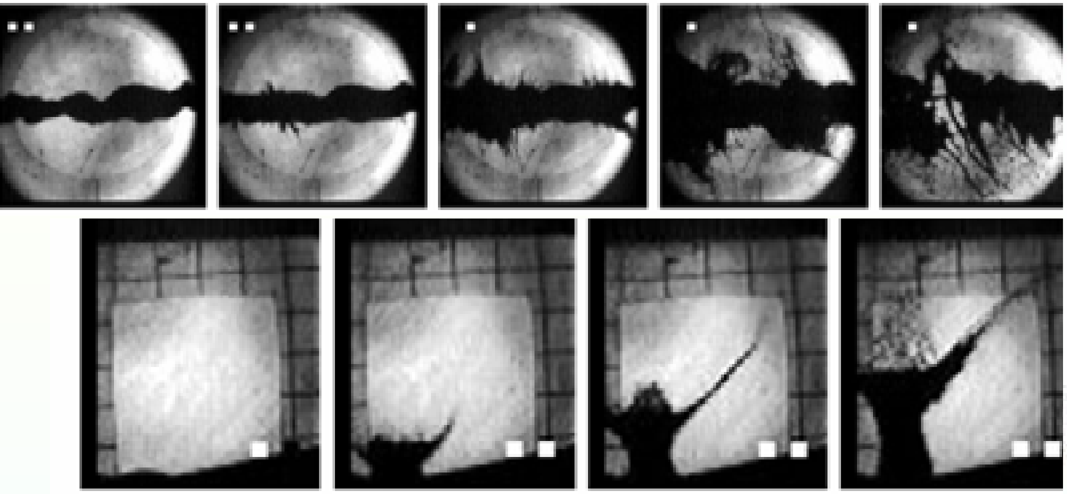
Spokespersons: H.G. Kirk, K.T. McDonald
Local Contact: H. Haseroth

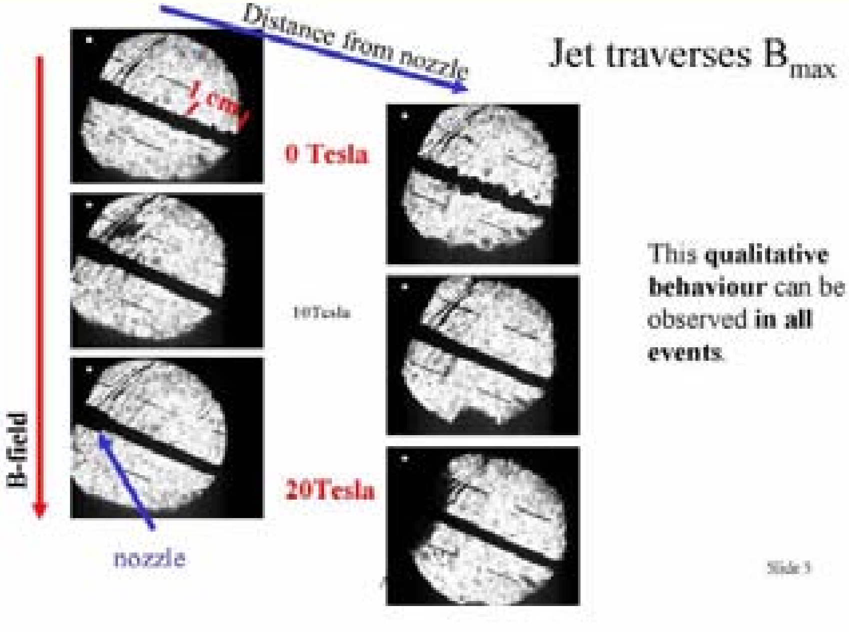
Participating Institutions

1) RAL
2) CERN
3) KEK
4) BNL
5) ORNL
6) Princeton University

Proposal submitted April 26, 2004

nTOF11 (MERIT)

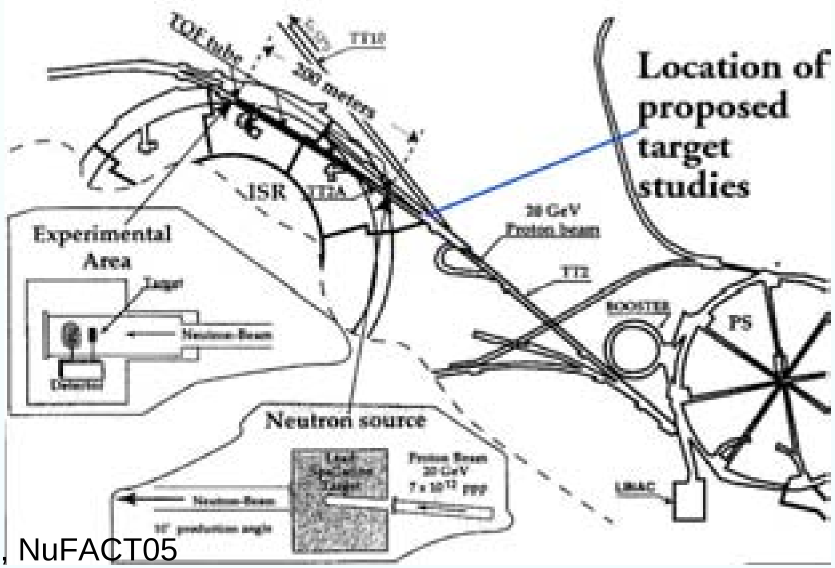




Jet traverses B_{max}

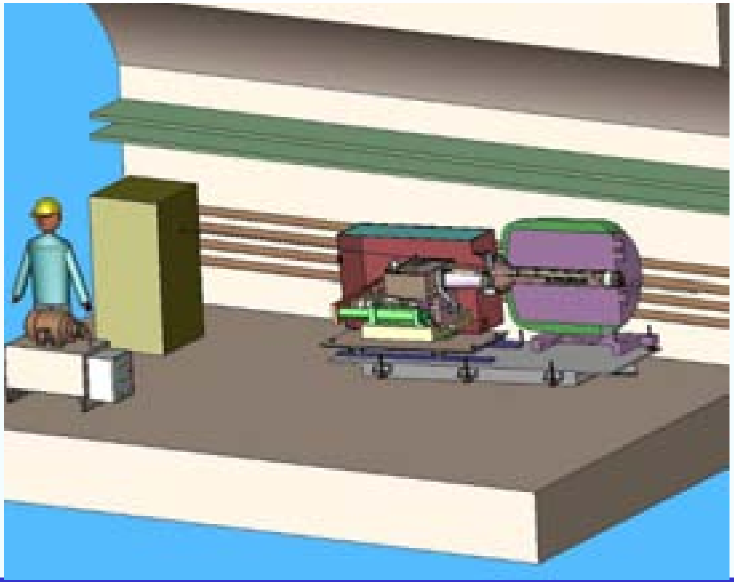
This qualitative behaviour can be observed in all events.

Slide 5



Location of proposed target studies

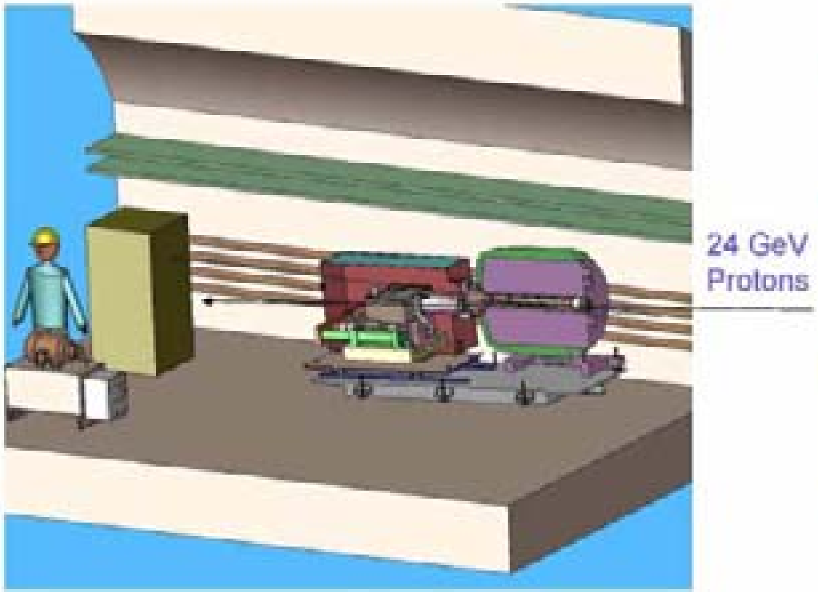
Kirk, NuFACT05

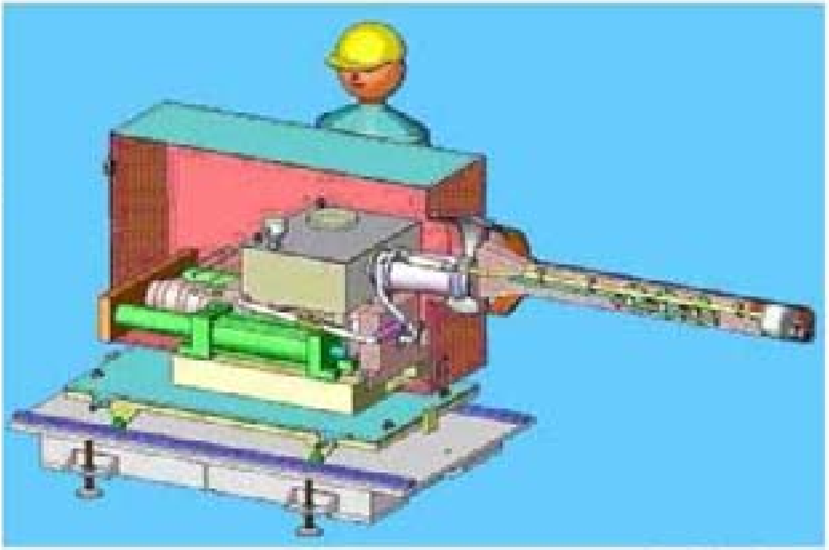


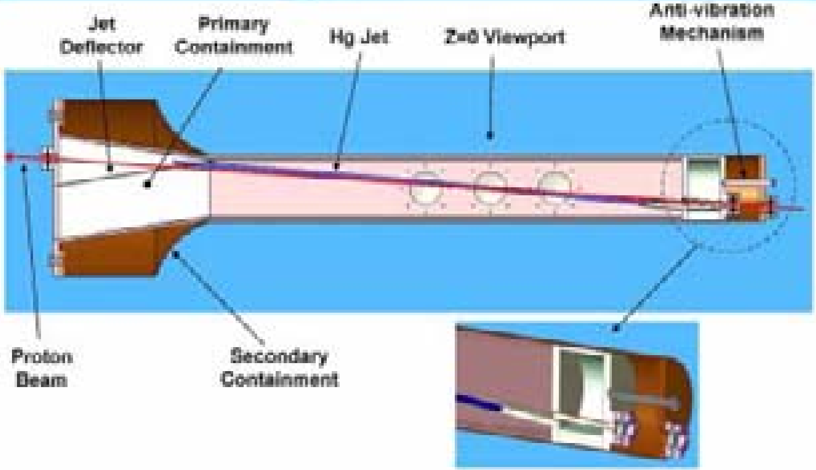
Jet Design

(V. Graves/P. Spampinato, ORNL)

"Syringe" pump system delivers 1.6 l/s of mercury in a 20-m/s jet for 10-20 s.



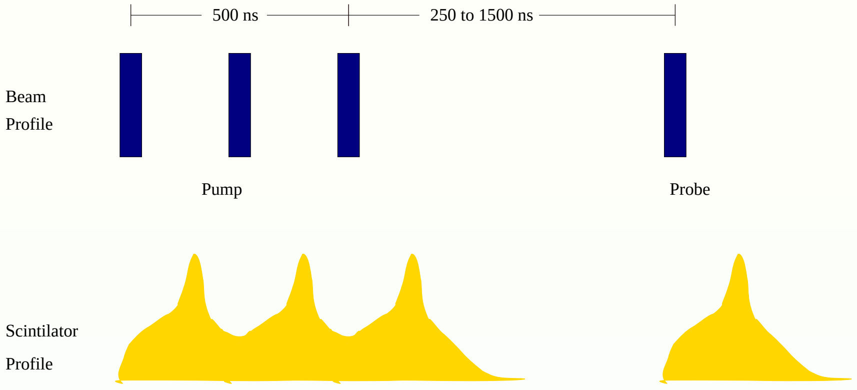




McDonald, NuFACT05

Programme

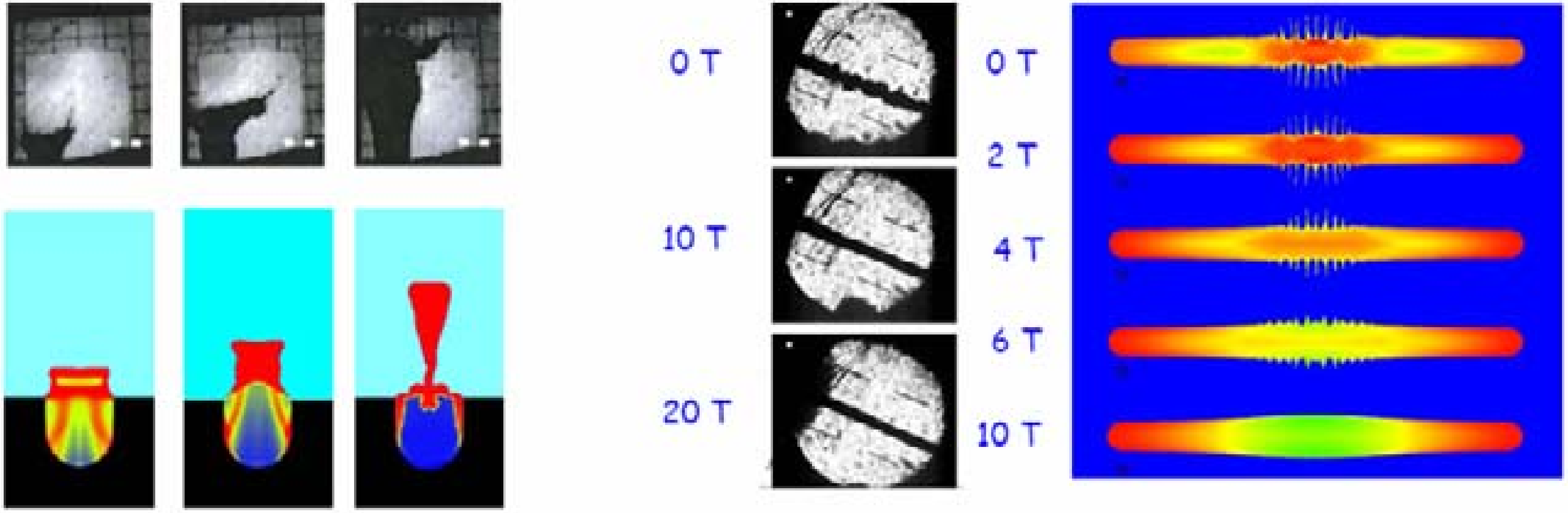
- 24 GeV Proton beam
- Up to 28 x 10^{12} Protons (TP) per 2μs spill
- Proton beam spot with r $\leq$ 1.5 mm rms
- 1cm diameter Hg Jet
- Hg Jet/Proton beam off solenoid axis
  - Hg Jet 100 mrad
  - Proton beam 67 mrad
- Test 50 Hz operations
  - 20 m/s Hg Jet
  - 2 spills separated by 20 ms



- Ship Pulsed Solenoid to MIT July 2005
- Test Solenoid to 15 T peak field August 2005
- Test Cryogenic valve box September 2005
- Integration of Solenoid/Hg Jet system Summer 2006

Simulation

- simulations (Samulyak) of Hg-jet target reaching high levels of sophistication

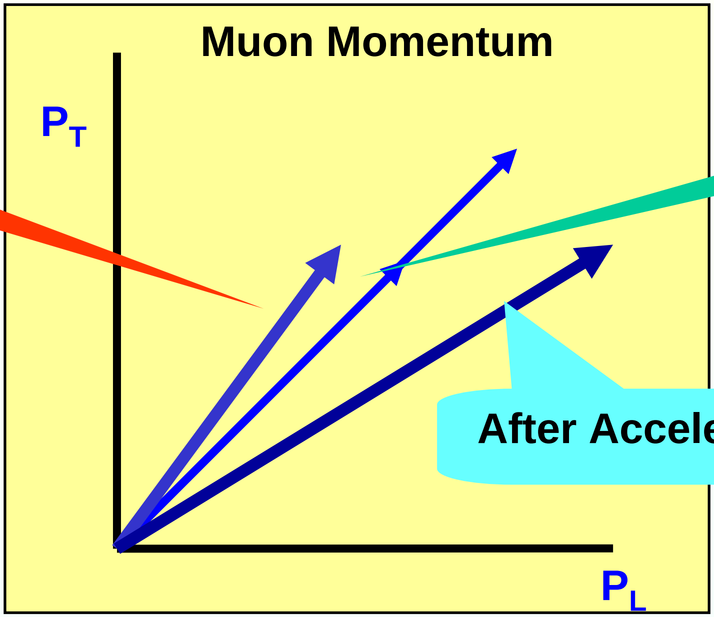


Zisman, NuFACT05

Ionization Cooling

After Multiple Scattering

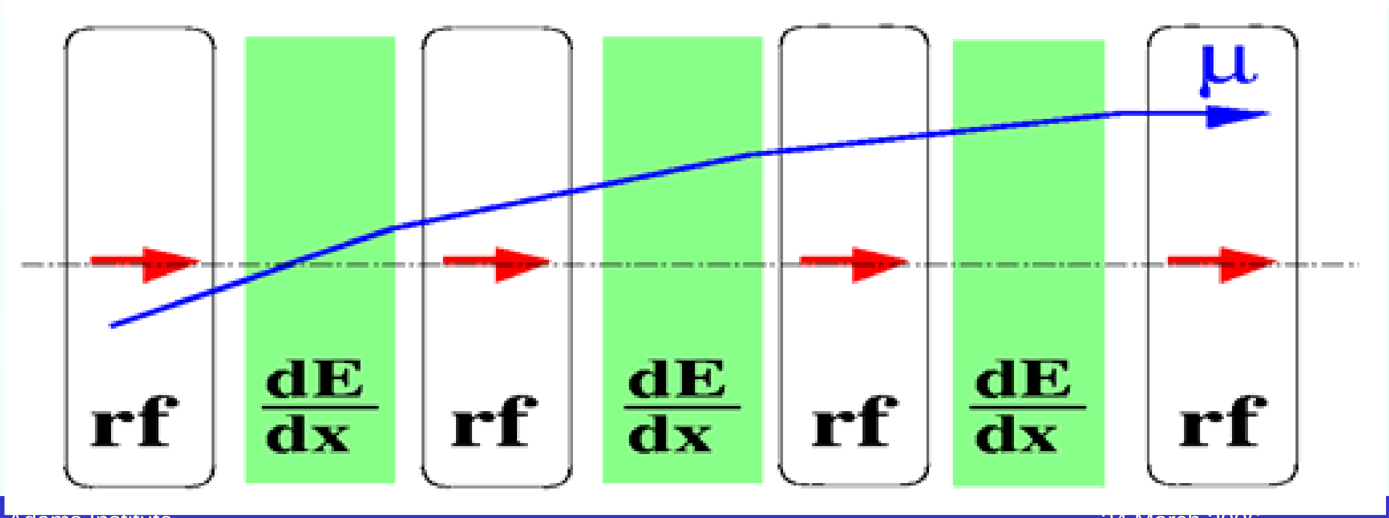
$$\frac{d\varepsilon_n}{ds} = \frac{\beta_\perp}{\beta^3 m_\mu c^2 X_0 E_\mu}\frac{dE_\mu}{ds}$$



After Acceleration

After ionisation energy loss

$$\frac{d\varepsilon_n}{ds} = -\frac{\varepsilon_n}{\beta^2 E_\mu}\frac{dE_\mu}{ds}$$

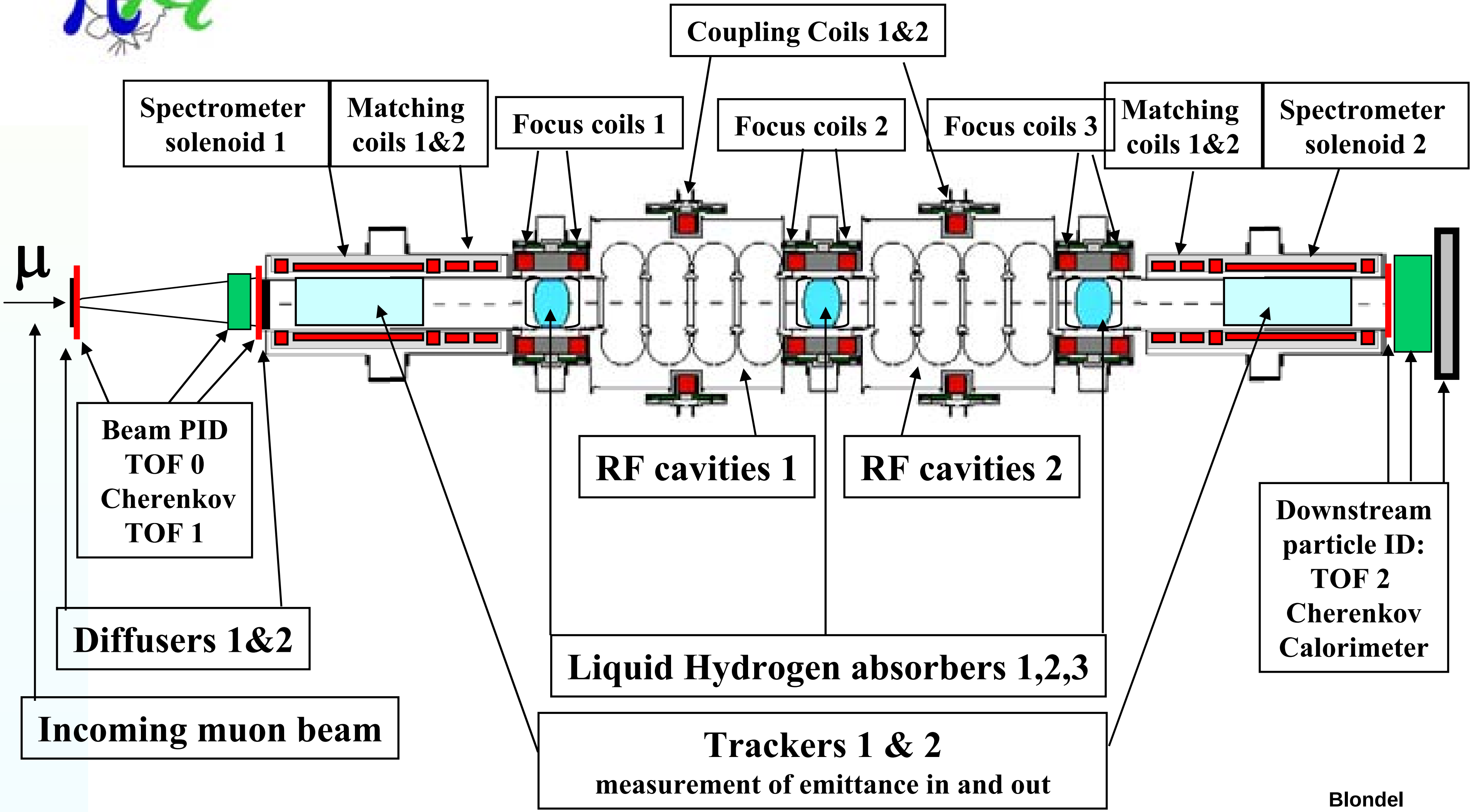


10% cooling of 200 MeV/c muons requires ~ 20 MV of RF

single particle measurements =>

measurement precision can be as good as $\Delta (\varepsilon_{out} / \varepsilon_{in}) = 10^{-3}$

never done before either….


μ

Coupling Coils 1&2

Spectrometer solenoid 1

Matching coils 1&2

Focus coils 1

Focus coils 2

Focus coils 3

Matching coils 1&2

Spectrometer solenoid 2

Beam PID
TOF 0
Cherenkov
TOF 1

RF cavities 1

RF cavities 2

Downstream particle ID:
TOF 2
Cherenkov
Calorimeter

Diffusers 1&2

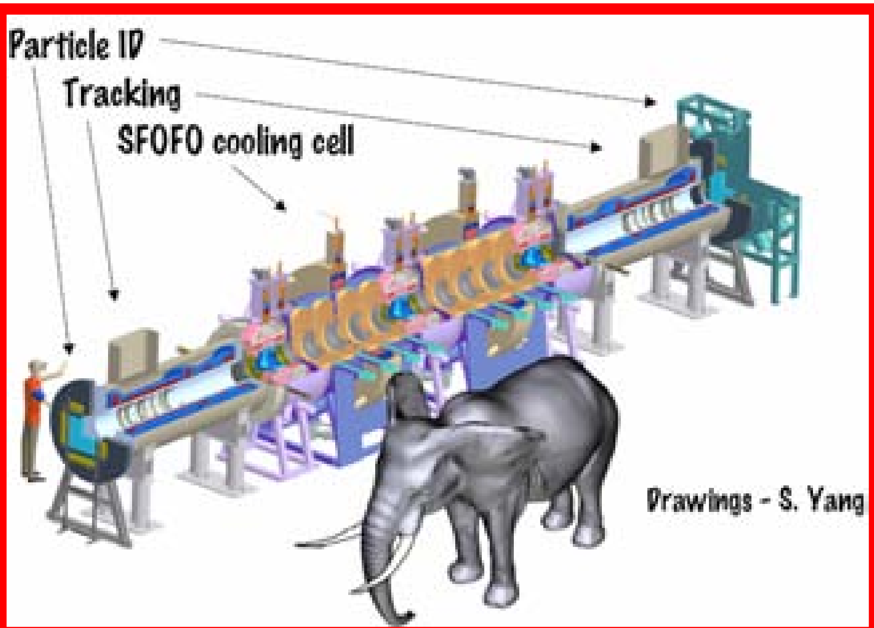
Liquid Hydrogen absorbers 1,2,3

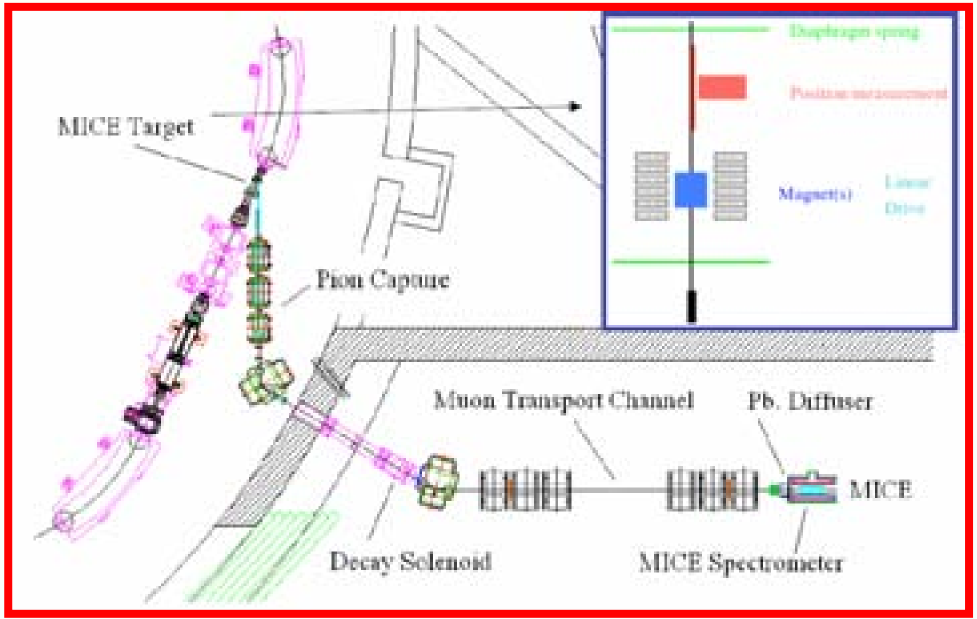
Incoming muon beam

Trackers 1 & 2
measurement of emittance in and out

Blondel

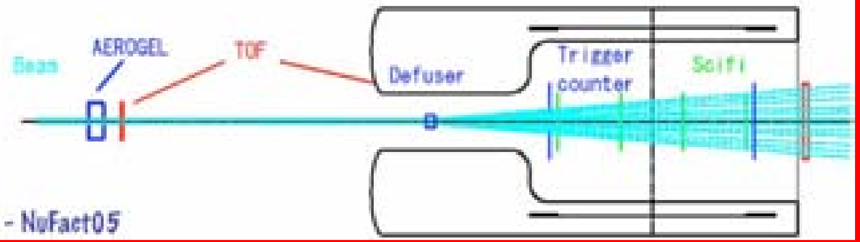
MICE



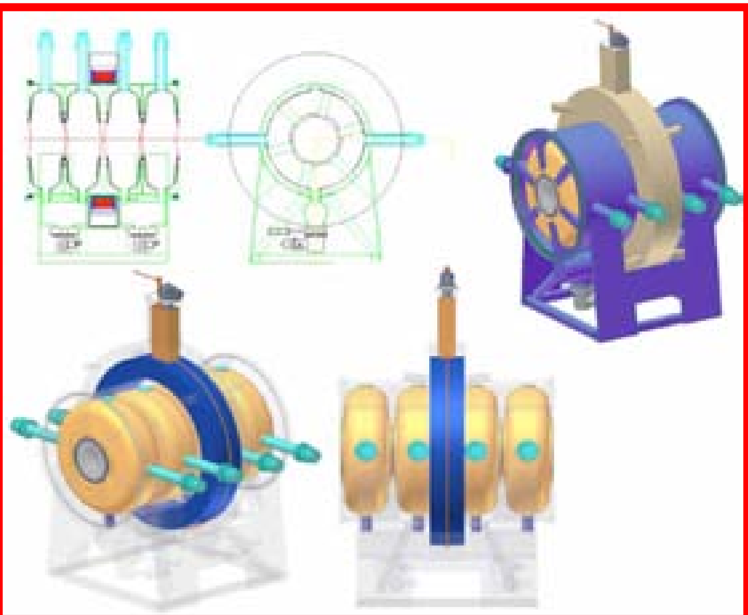


- First part completed June 2 at KEK T2 beamline
- Data taken for
  - TOF calibration
  - Aerogel Cerenkov performance
  - Beam survey
  - DAQ test
- Ready to test tracker prototype

Super JACEE



Y. Torun - NuFact05



Other projects

Some examples

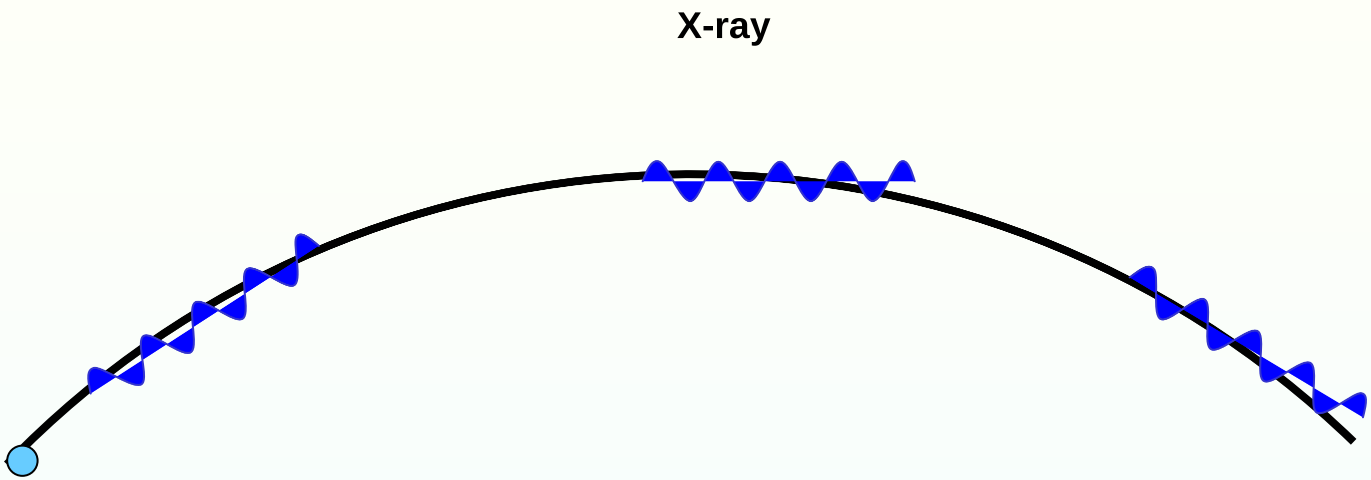
1. SR & Free Electron Lasers
2. Hadron Therapy

Synchrotron Radiation and Free Electron Lasers

http://www.adams-institute.ac.uk

Ken.Peach@adams-institute.ac.uk

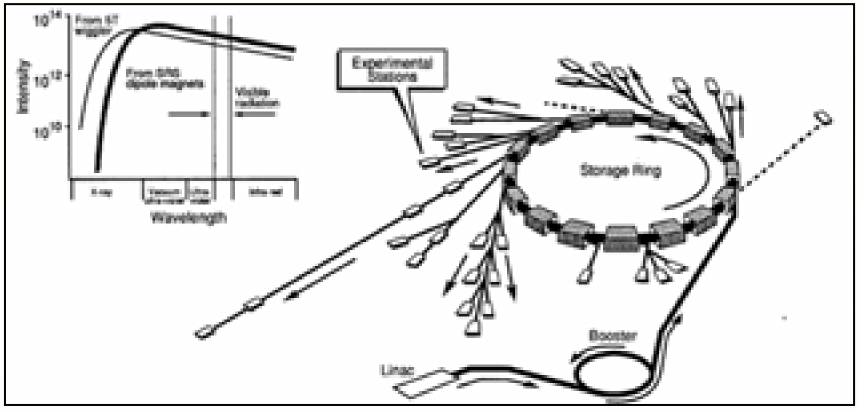
What is Synchrotron Radiation?



Motion of a charged particle (an electron) in a magnetic field

When ultra-relativistic, emits x-rays tangential to the motion

SRS @ Daresbury



Vlu#Mrkq#Zdonhu/

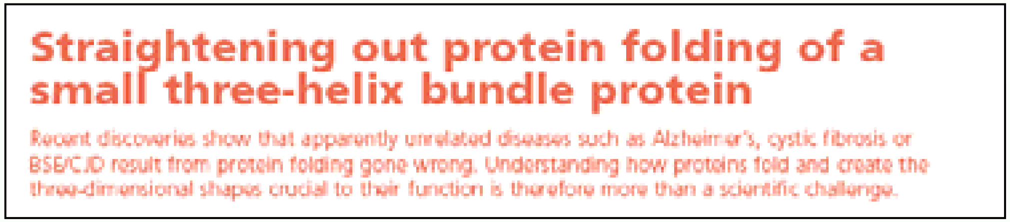
Qreho#Sul}h#
lq#Fkhplvwu|/#4<<:

Širu#hoxflgdwlrq#
ri#wkh#
hq}|pdwlf#phfkdqlvp#
xqghuo|lqj
wkh#v|qwkhvlv#ri#
dghqrvlqh#wulskrvskdwh
+DWS,õ

Examples of use of Synchrotron Radiation

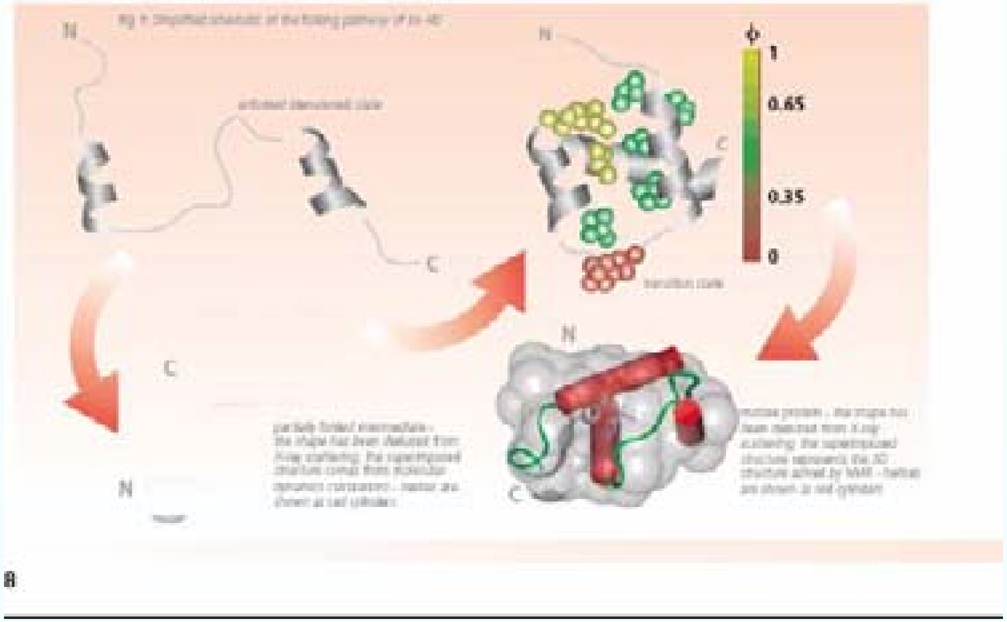
Characterisation of the metallurgical properties of a 7th cBC Corinthian-type Greek bronze helmet

'First Aias son of Telamon, bulwark of the Achaians, brake a battalion of the Trojans and brought his comrades salvation, smiting a warrior that was chiefest among the Thracians, Eussoros' son Akamas the goodly and great. Him first he smote upon his thick-crested helmet ridge and drave into his forehead, so that the point of bronze pierced into the bone, and darkness shrouded his eyes'. **Homer, Iliad VI 5-11.** (translation by Andrew Lang, Walter Leaf and Ernest Myers, Macmillan 1912).



Straightening out protein folding of a small three-helix bundle protein

Recent discoveries show that apparently unrelated diseases such as Alzheimer's, cystic fibrosis or BSE/CJD result from protein folding gone wrong. Understanding how proteins fold and create the three-dimensional shapes crucial to their function is therefore more than a scientific challenge.



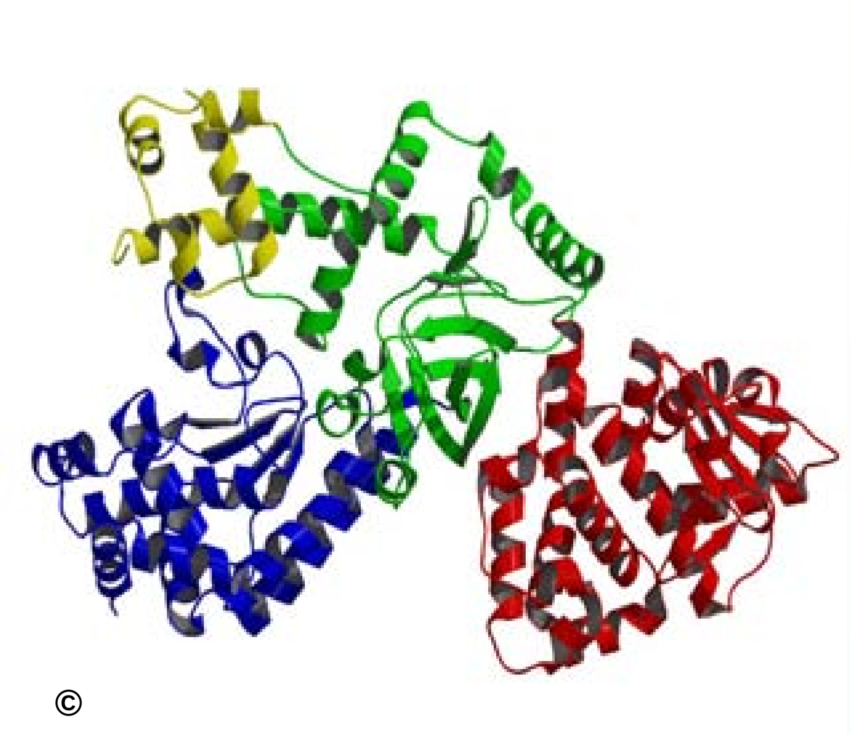
CCLRC/SRD annual report

Some Synchrotron Radiation Science

Structure of Anthrax

Diffraction pattern from pea lectin


© CCLRC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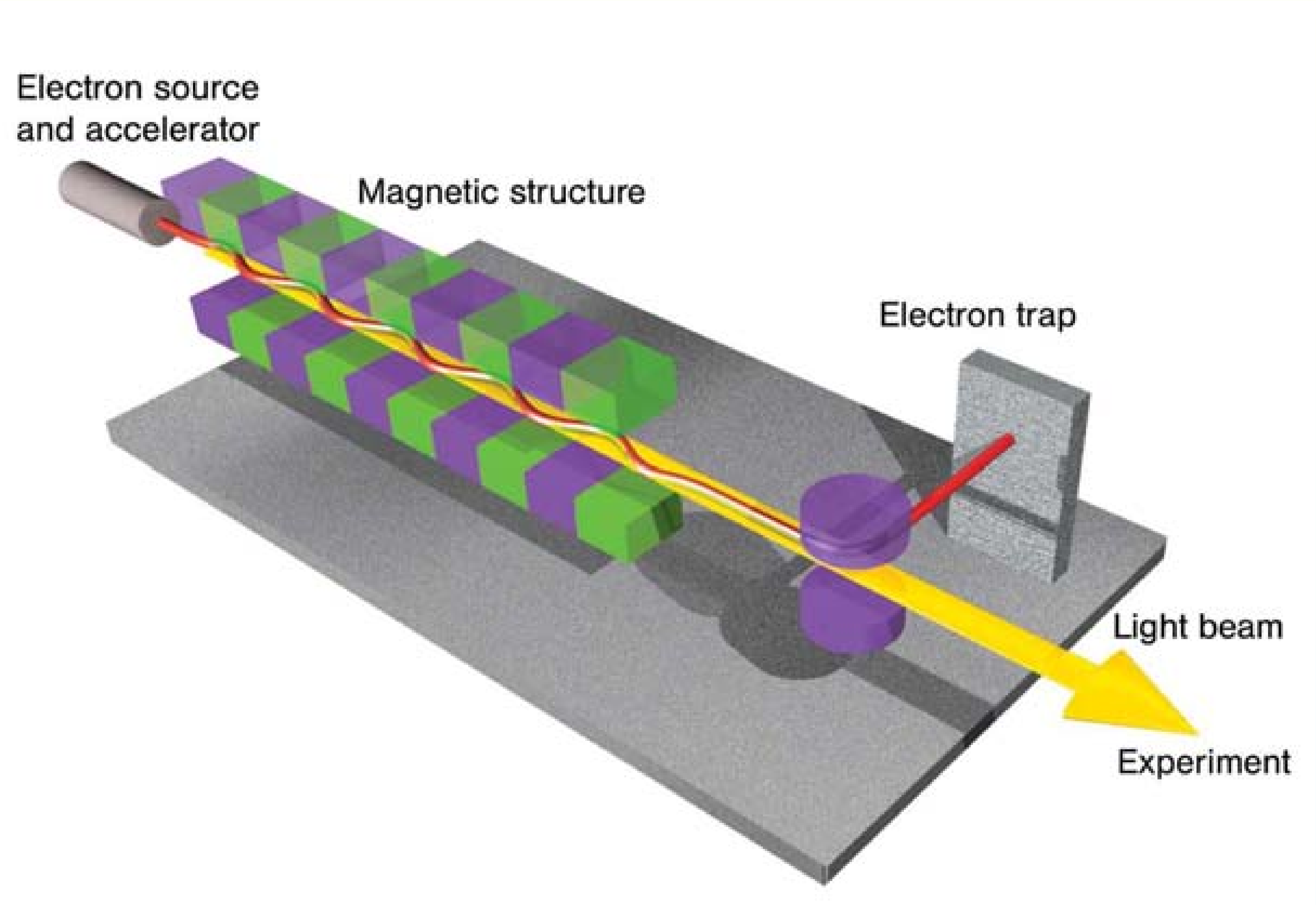
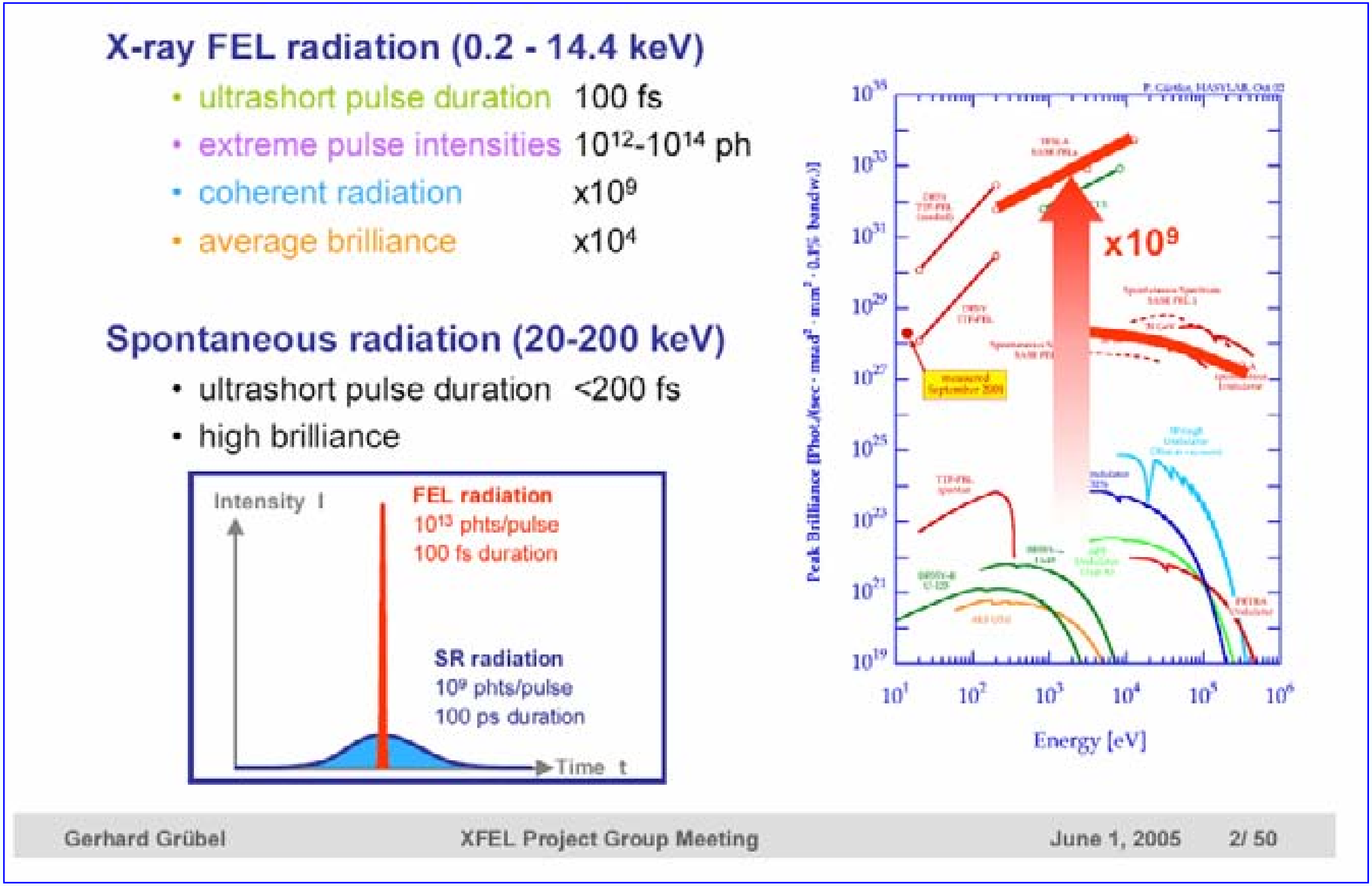
Diamond @ RAL

The X-ray Free Electron Laser



The X-ray Free Electron Laser



X-ray FEL radiation (0.2 - 14.4 keV)

- ultrashort pulse duration 100 fs
- extreme pulse intensities 10^{12}-10^{14} ph
- coherent radiation x10^9
- average brilliance x10^4

Spontaneous radiation (20-200 keV)

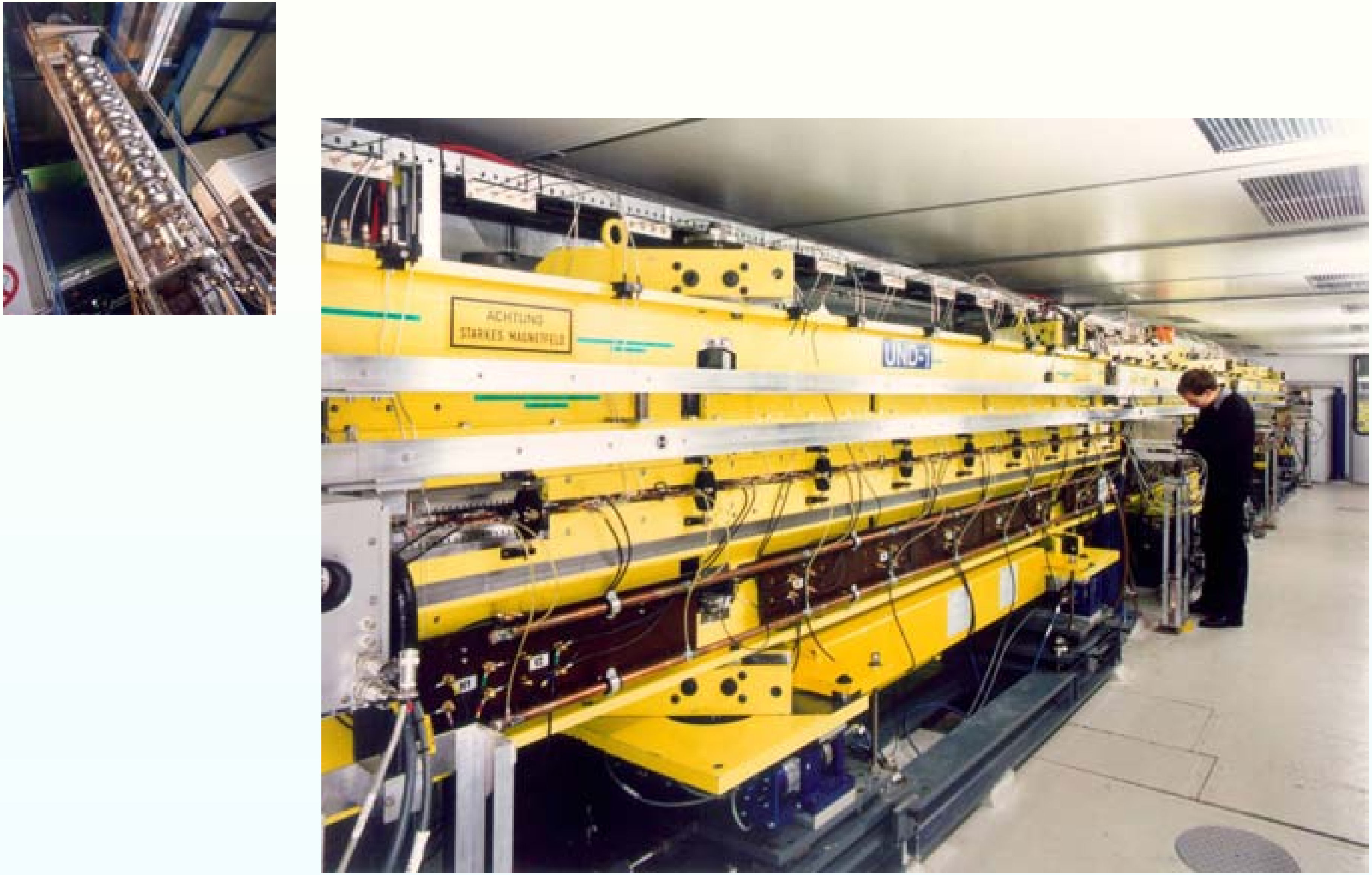
- ultrashort pulse duration <200 fs
- high brilliance

FEL radiation
10^{13} phts/pulse
100 fs duration

SR radiation
10^9 phts/pulse
100 ps duration

Gerhard Grübel XFEL Project Group Meeting June 1, 2005 2/ 50

The X-FEL



Hadron Therapy

http://www.adams-institute.ac.uk

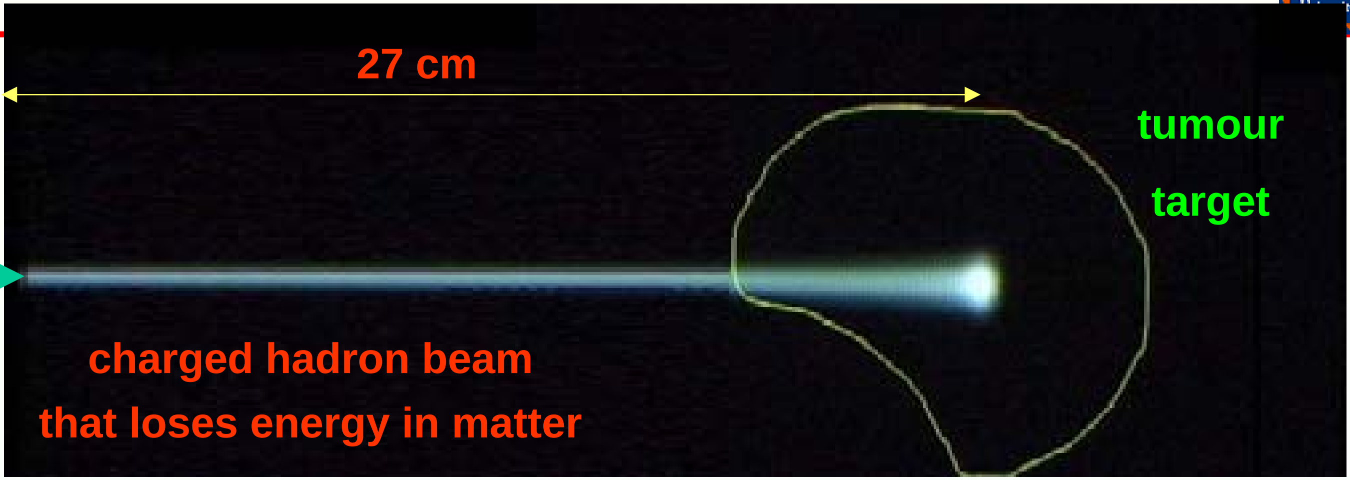
Ken.Peach@adams-institute.ac.uk

Hadrontherapy accelerators: the rationale

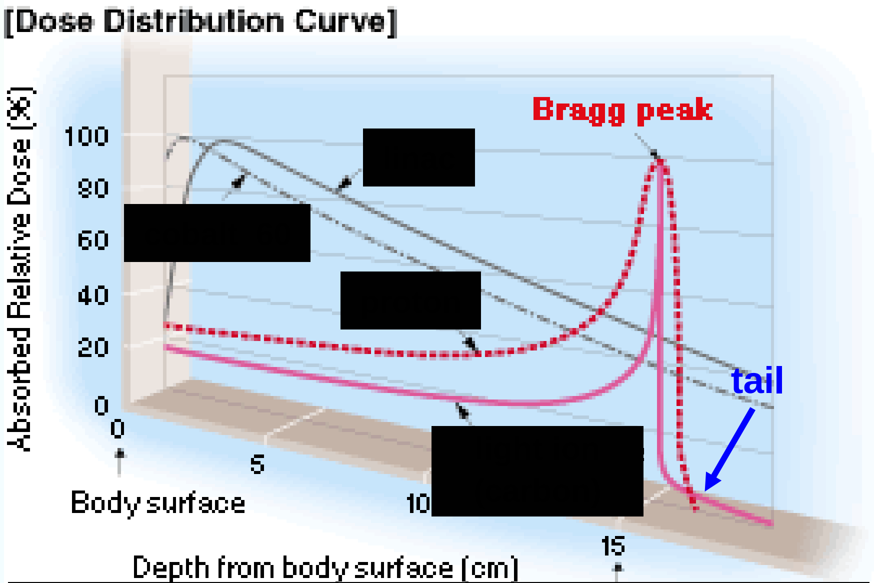
200 MeV - 1 nA protons

4800 MeV – 0.1 nA carbon ions

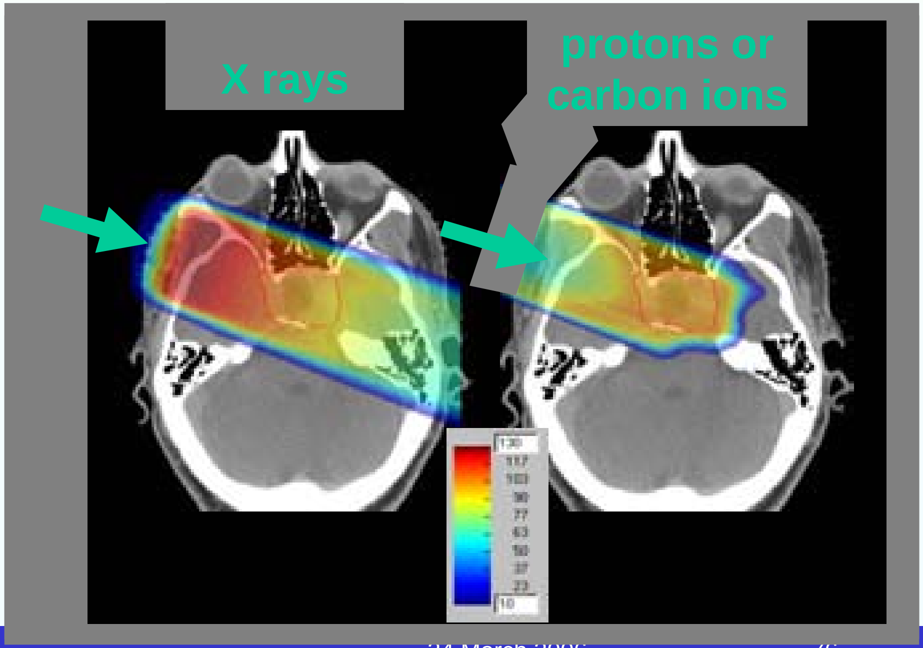
which can control radioresistant tumours



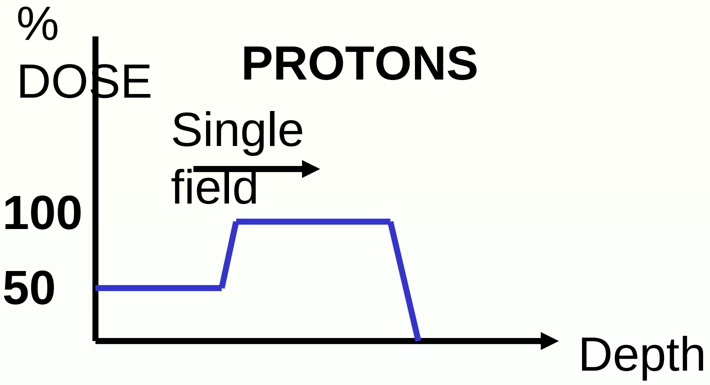
Amaldi

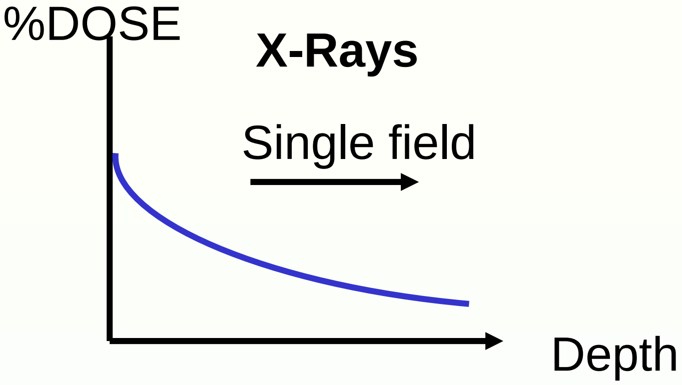


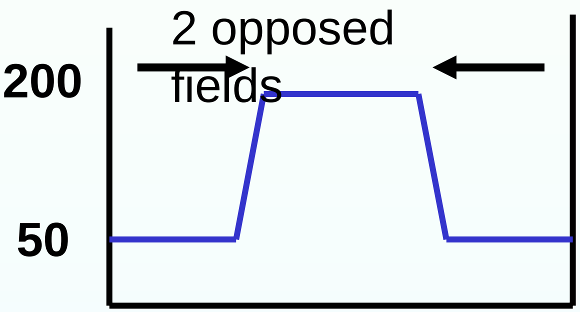
http://global.mitsubishielectric.com/bu/particlebeam/index_b.html

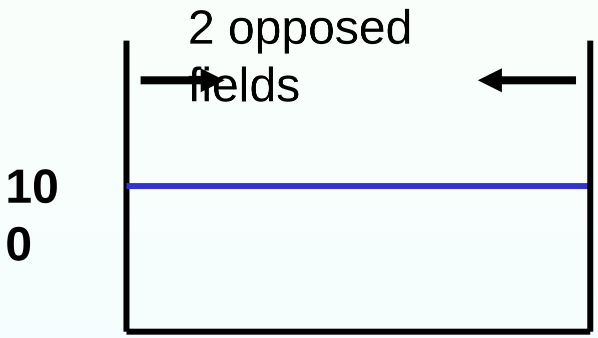


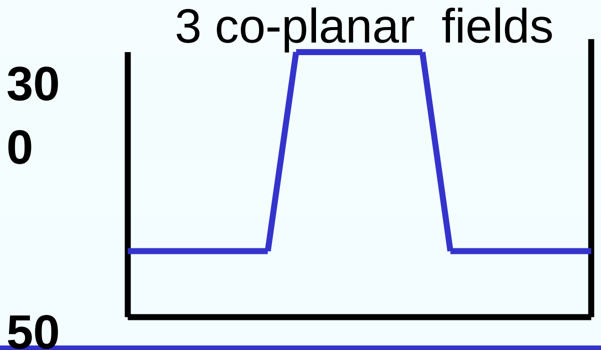
How does it work?

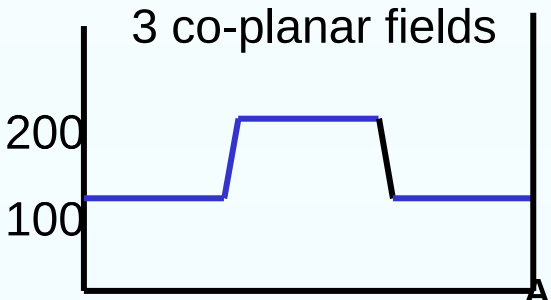






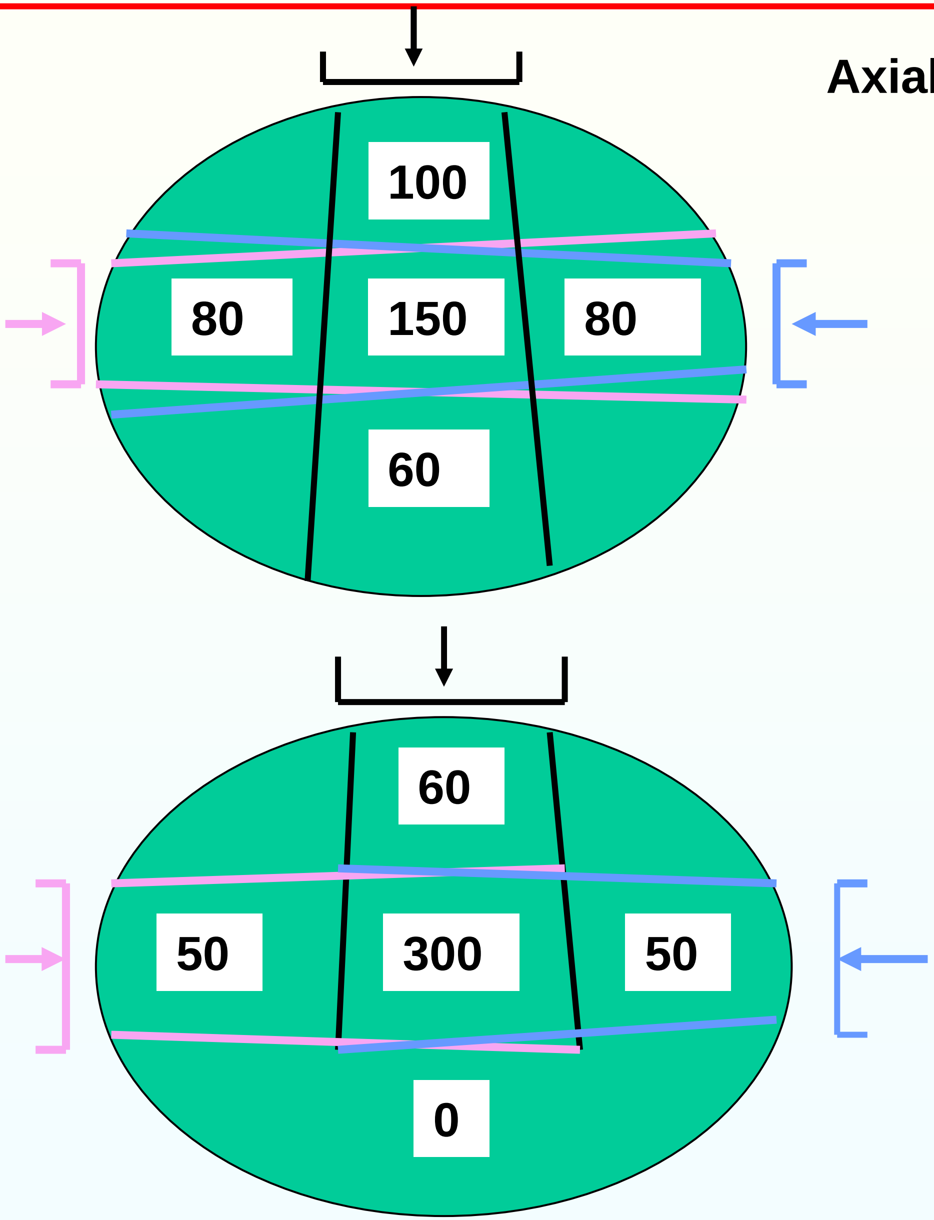






After Bleddyn Jones

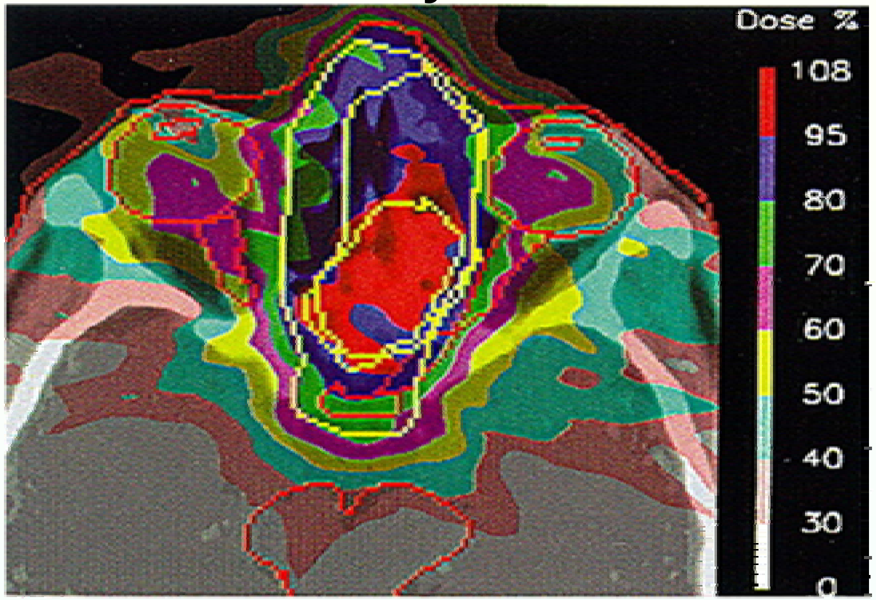
3 Field techniques



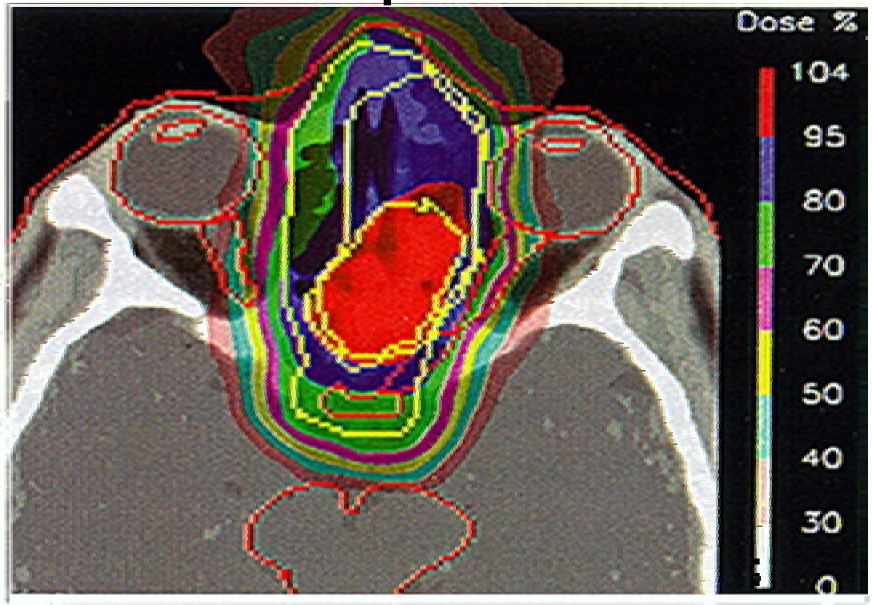
After Bleddyn Jones

Carbon ions are qualitatively different from X-rays

9 X ray beams



1 proton beam



Carbon ions deposit in a cell 24 times more energy than a proton

producing not reparable multiple close-by double strand breaks

so that they can control radioresistant tumours

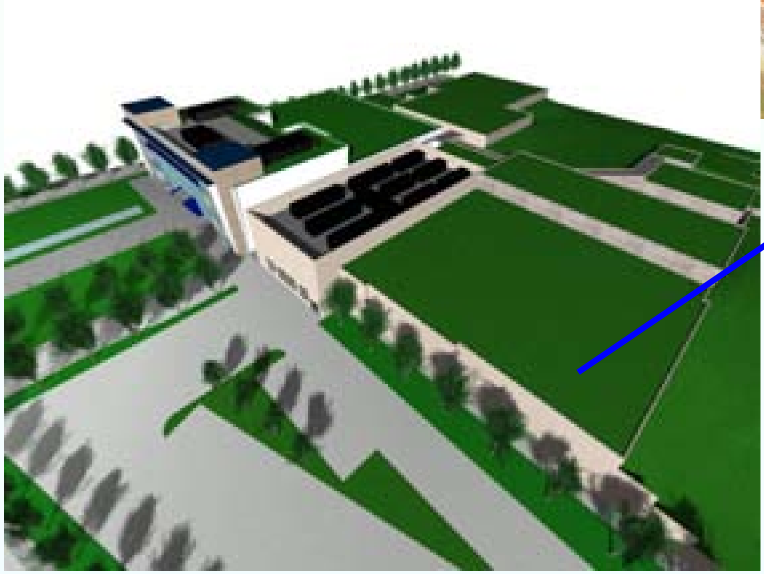
At HIMAC (Japan) the doses are delivered in only 5-10 fractions

In Heidelberg and in Pave Europe moves towards the frontier of “dual” centres

Amaldi

The CNAO Italian national centre designed by TERA

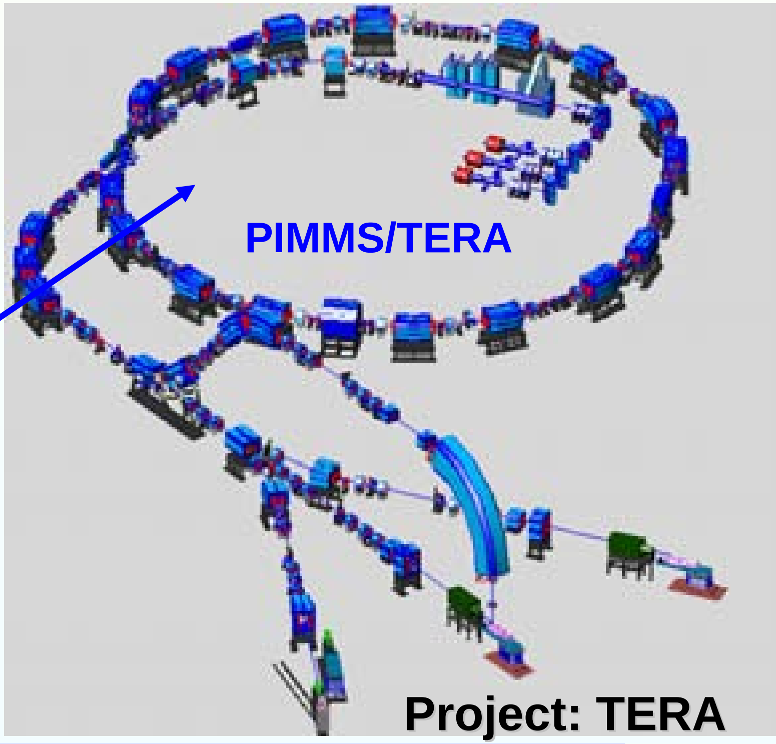
Project: Calvi –TEKNE



Main source of 90 MEuro:
Italian Health Ministry

CNAO Foundation constructs and manages

INFN is co-responsible for the construction



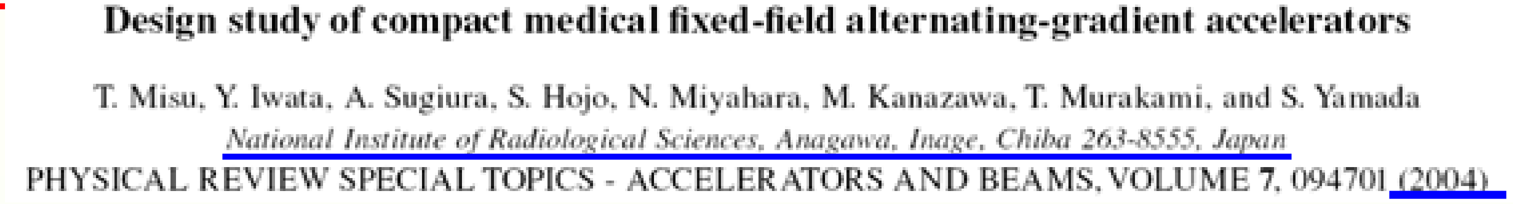
PIMMS/TERA

Project: TERA

A company is negotiating with CNAO a license for PIMMS/TERA

Amaldi

FFAG design for carbon ion therapy



Design study of compact medical fixed-field alternating-gradient accelerators

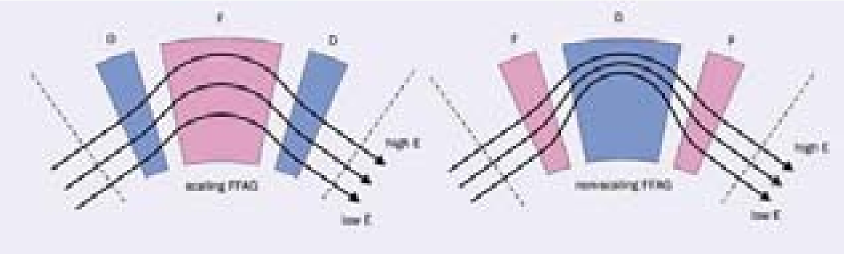
T. Misu, Y. Iwata, A. Sugiura, S. Hojo, N. Miyahara, M. Kanazawa, T. Murakami, and S. Yamada

National Institute of Radiological Sciences, Anagawa, Inage, Chiba 263-8555, Japan

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME 7, 094701 (2004)

carbon ions 4800 MeV

FIG. 7. Overall view of the triple-cascade radial-sector FFAG system.



E. Keil, A.M. Sessler

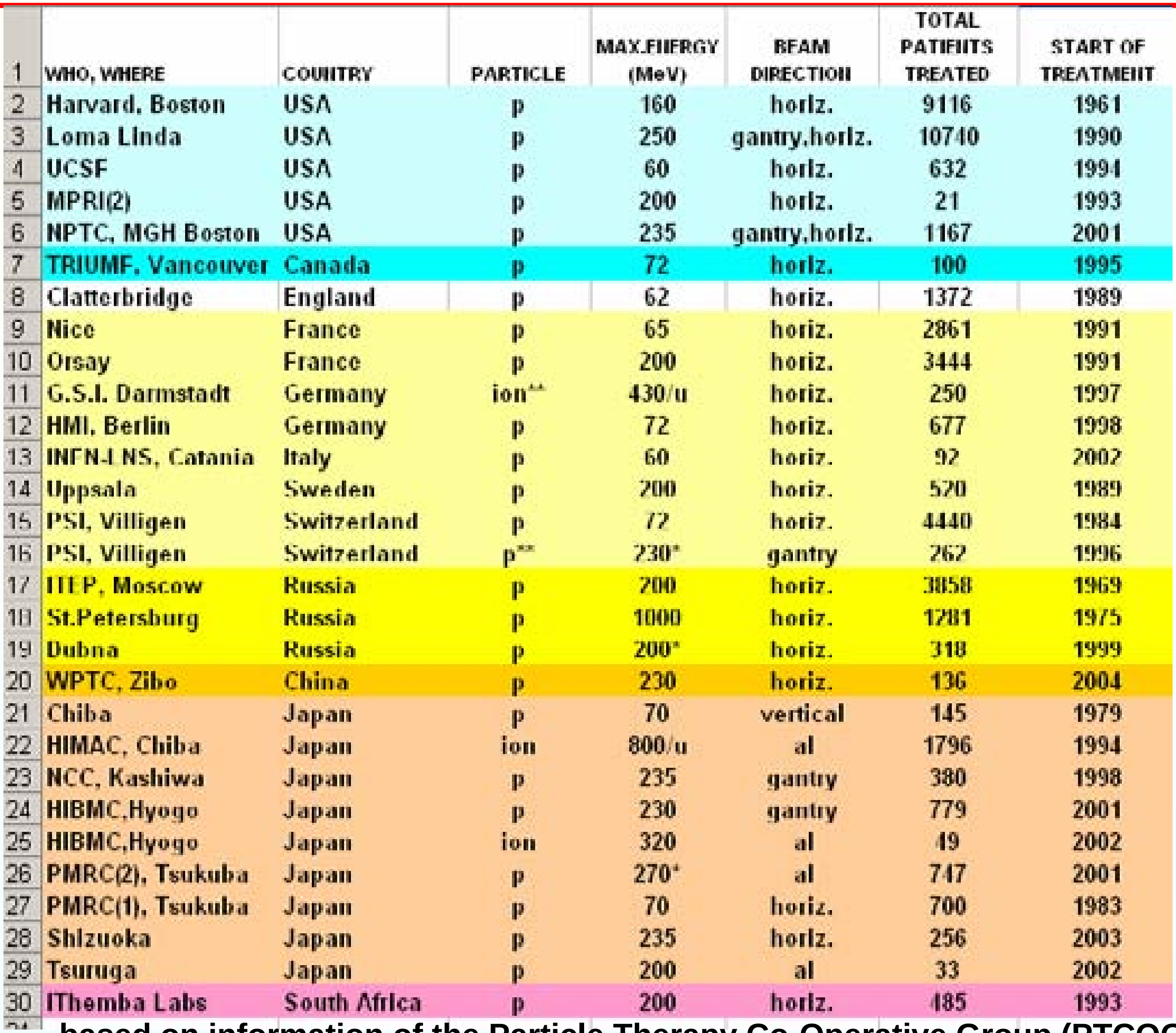
et al.

Non-scaling design

has smaller radius

Amaldi

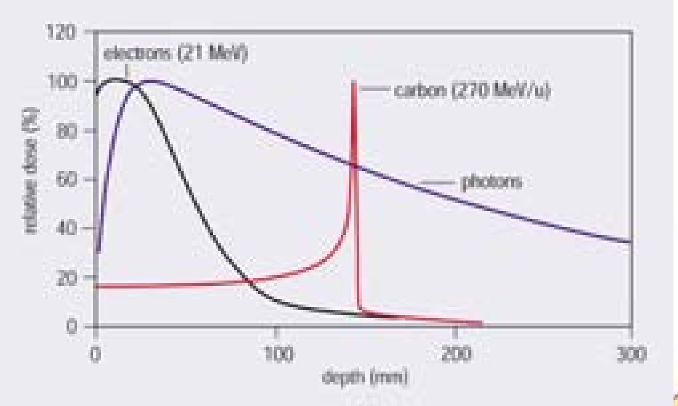
Many centres world-wide

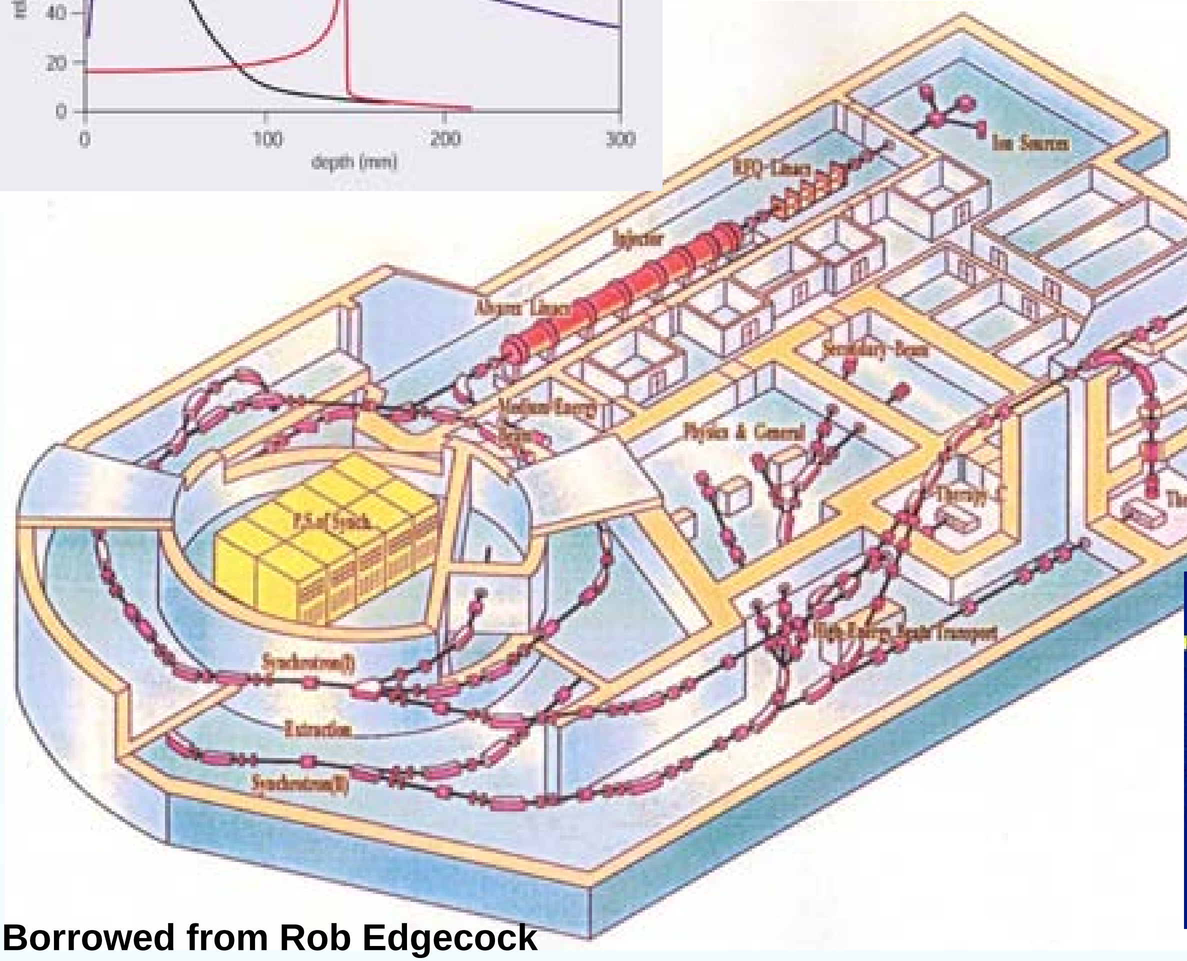


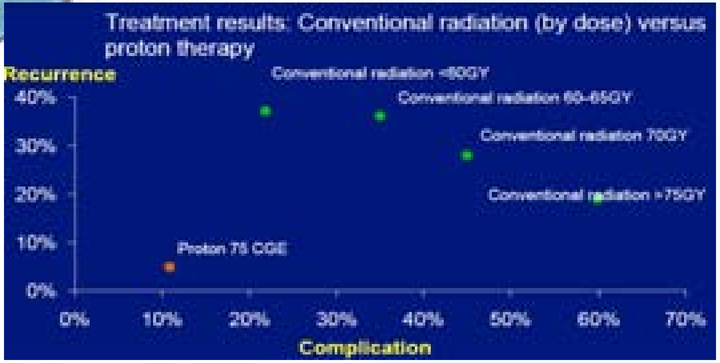
1	WHO, WHERE	COUNTRY	PARTICLE	MAX.ENERGY (MeV)	BEAM DIRECTION	TOTAL PATIENTS TREATED	START OF TREATMENT
2	Harvard, Boston	USA	p	160	horiz.	9116	1961
3	Loma Linda	USA	p	250	gantry,horiz.	10740	1990
4	UCSF	USA	p	60	horiz.	632	1994
5	MPRI(2)	USA	p	200	horiz.	21	1993
6	NPTC, MGH Boston	USA	p	235	gantry,horiz.	1167	2001
7	TRIUMF, Vancouver	Canada	p	72	horiz.	100	1995
8	Clatterbridge	England	p	62	horiz.	1372	1989
9	Nice	France	p	65	horiz.	2861	1991
10	Orsay	France	p	200	horiz.	3444	1991
11	G.S.I. Darmstadt	Germany	ion**	430/u	horiz.	250	1997
12	HMI, Berlin	Germany	p	72	horiz.	677	1998
13	INFN-LNS, Catania	Italy	p	60	horiz.	92	2002
14	Uppsala	Sweden	p	200	horiz.	520	1989
15	PSI, Villigen	Switzerland	p	72	horiz.	4440	1984
16	PSI, Villigen	Switzerland	p**	230*	gantry	262	1996
17	ITEP, Moscow	Russia	p	200	horiz.	3858	1969
18	St.Petersburg	Russia	p	1000	horiz.	1281	1975
19	Dubna	Russia	p	200*	horiz.	318	1999
20	WPTC, Zibo	China	p	230	horiz.	136	2004
21	Chiba	Japan	p	70	vertical	145	1979
22	HIMAC, Chiba	Japan	ion	800/u	al	1796	1994
23	NCC, Kashiwa	Japan	p	235	gantry	380	1998
24	HIBMC,Hyogo	Japan	p	230	gantry	779	2001
25	HIBMC,Hyogo	Japan	ion	320	al	19	2002
26	PMRC(2), Tsukuba	Japan	p	270*	al	747	2001
27	PMRC(1), Tsukuba	Japan	p	70	horiz.	700	1983
28	Shizuoka	Japan	p	235	horiz.	256	2003
29	Tsuruga	Japan	p	200	al	33	2002
30	iThemba Labs	South Africa	p	200	horiz.	485	1993

based on information of the Particle Therapy Co-Operative Group (PTCOG)

Hadron Therapy in Chiba (Japan)







Treatment results: Conventional radiation (by dose) versus proton therapy

Vwdqgdug#iurp#Orpd#Olqgd

Borrowed from Rob Edgecock

Medical applications of accelerators

- **Oncology**
  - Protons, heavy ions, electrons

- **Preparation of radio-nuclides**

- **Requires precision control of**
  - Energy
  - Dose
  - Position
    - **Just like the linear collider (energy, luminosity)**

Summary

Summary

- There are several global frontier particle physics projects needing new and challenging accelerators over the next 10-20 years
- There will be many other uses of the technologies developed to make them feasible and affordable
  - In other branches of science
  - In industry
  - In medicine
- There will also be national and regional accelerator projects doing frontier research …
- There are plenty of challenges and opportunities for innovation