Congratulations on OCPA2010

July 29 - August 7, 2010

IHEP · Beijing

中国科学院

国家自然科学基金委员会
National Natural Science Foundation of China

NSRRC

国家同步辐射实验室

World Scientific
Connecting Great Minds

SINAP

清华大学
Tsinghua University

北京大学
PEKING UNIVERSITY

- This is the sixth OCPA Accelerator School in its series.
- The first School was held in Hsinchu, Taiwan, August 3-12, 1998
- The second in Yellow Mountain, Anhui, July 18-27, 2000
- The third in Singapore, July 25 to August 3, 2002. The 2004 school was canceled due to SARS .
- The fourth School was held in Yangzhou, Jiangsu, July 27-August 5, 2006 ,
- The fifth in Nantou, Taiwan, September 1-10, 2008.
- The purpose of this school is to provide the students a basic training on modern accelerators.
- The themes of OCPA2010 are spallation neutron sources and particle therapy accelerator facilities.
- The lectures involve basic accelerator physics, technology systems and applications.
- The curriculum for the school is designed as basic topics (10 courses), topics on spallation neutron sources (4 courses), topics on hadron therapy (6 courses), technical topics (11 courses), and seminars (5 courses).
- Professors form U.S., Mainland and Taiwan are invited to give the lectures.

OCPA1998

(August 3-14, 1998, SSRC, Hsinchu)

要 求

- 认真听课
- 参加考试
- 完成作业
- 善始善终

祝各位同学取得好成绩

为今后工作准备好身手

Program of the Sixth OCPA Accelerator School

TIME	July 29	July 30	July 31	August 1	August 2	August 3	August 4	August 5	August 6	August 7
08:00-09:00	G1: Intro. to Accelerators	G3-Long. Dynamics	G5-Impedance	G7-Hadron synchrotrons	EXCURSION	G8-Injection & extraction	S1-New light sources	H5-IMP carbon therapy	T10-Cryogenics & SC	S4-Targets & spectrometers
09:00-10:00	G1: Intro to Accelerators	G3-Long. Dynamics	G5-Impedance	G7-Hadron synchrotrons		G8-Injection & extraction	S2-Advanced acceleration	H6-Taiwan proton therapy	T10-Cryogenics & SC	S5-Management engineering
Break						Break				
10:15-11:15	G1: Intro. to Accelerators	G3-Long. Dynamics	G6-Hadron linacs	G7-Hadron synchrotrons		G9-Beam transport	H1-Hadron therapy	T7-RF for hadron linac	G10-Cyclotron	S5-Management engineering
11:15-12:15	G2-Transverse Dynamics	G4-Lattice	G6-Hadron linacs	N2-Spall. Neu. sources		G9-Beam transport	H1-Hadron therapy	T7-RF for hadron linac	G10-Cyclotron	Closing
Lunch						Lunch				
14:00-15:00	G2-Transverse Dynamics	G4-Lattice	G6-Hadron linac	N3-Design CSNS linac		N4-Design CSNS RCS	H2-Accel. for hadron therapy	T8-RF for hadron rings	T11-Radiation protection	DEPARTURE
15:00-16:00	G2-Transverse Dynamics	G4-Lattice	N1-High power accel.	N3-Design CSNS linac		N4-Design CSNS RCS	H2-Accel. for hadron therapy	T8-RF for hadron rings	Exam	
Break						Break				
16:15-17:15	T2-Magnet	T1-Ion source	T5-Vacuum	T3-Power supply		T6-Beam Diagnostics	H3-Beam delivery	T9-Control		
17:15-18:15	T2-Magnet	T1-Ion source	T5-Vacuum	T4-Pulsed PS		T6-Beam Diagnostics	H3-Beam delivery	T9-Control		
Super						Super				
20:00-21:00	S3-Accel. applications	Office hours and discussion	Office hours and discussion	Banquet		Office hours and discussion	H4-APTF design	Office hours and discussion	Office hours and discussion	
21:00-22:00	S3-Accel. applications	Homework	Homework			Homework	Homework	Homework	Homework	

G1-A

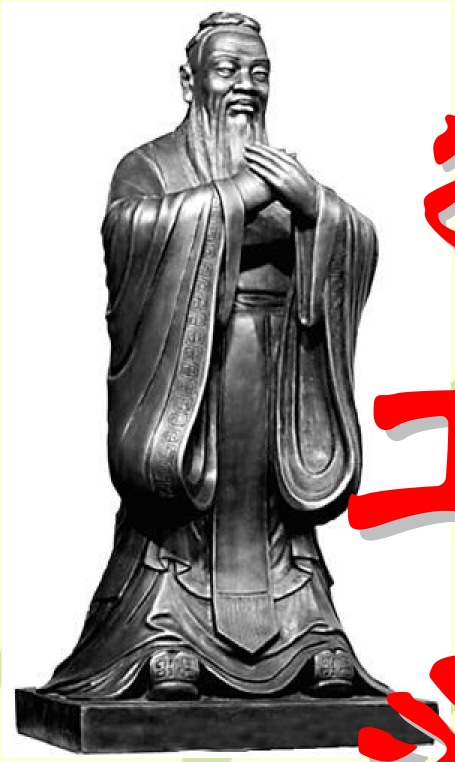
An Introduction to Particle Accelerators

Historical Evolution, Innovative Ideas and Prospective in Accelerator Developments

C.Zhang

6th OCPA Accelerator School

July29 - August 7, 2010 • Beijing



孔子
(公元前551-479)

子曰：

工欲善其事
必先利其器

《论语·魏灵公》

Sharp tools make good work

Preface

The human's curiosity on the universe has always been the driven force behind the development of telescopes and microscopes. As a type of powerful microscope, particle accelerators play an important role in discovery on the micro-world, which provide a major stimulus for research into the constituents and nature of matter. Traced to its three roots, the history of accelerators is a continuous upgrade towards higher energy, better performance and wider application. Innovative ideas, new methods, and new technologies emerge in endlessly…

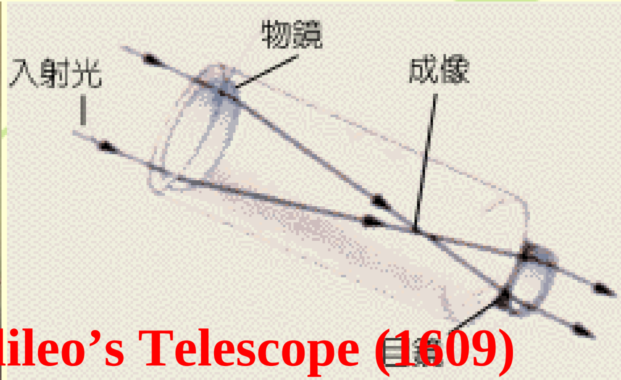
Outline

- From telescope to microscope
- Historical evolution of accelerators
- Frontiers of modern accelerators
- Future science and accelerators
- Summary

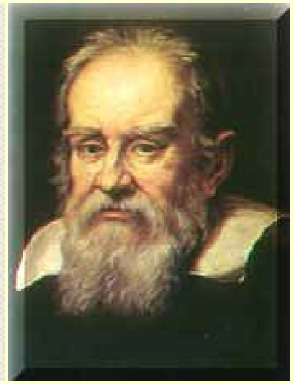
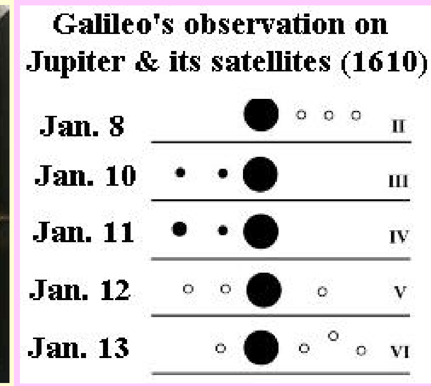
(1) *From telescope to microscope*

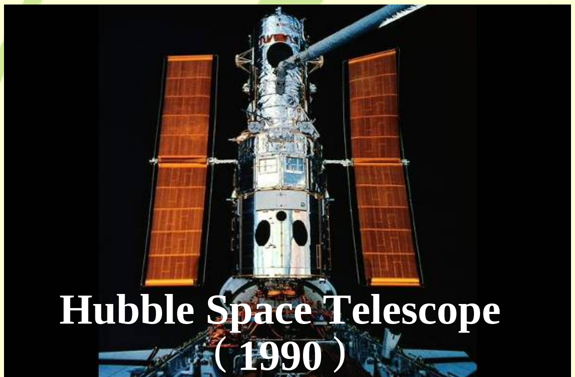
- **400 years of telescopes and microscopes**
- **The Glashow snake and universe**
- **Fundamental particles and interaction**
- **Methods to investigate the micro-world**

1.1 400 Years of Telescope

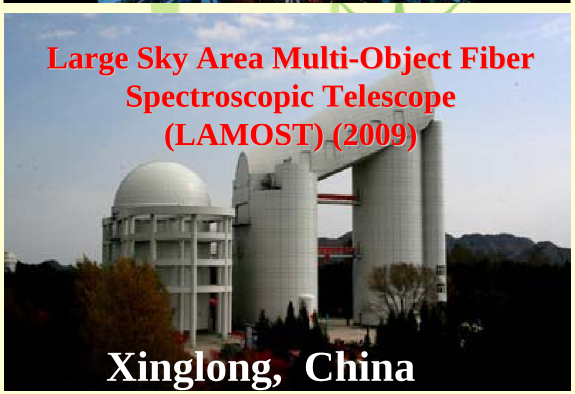



Galileo's Telescope (1609)

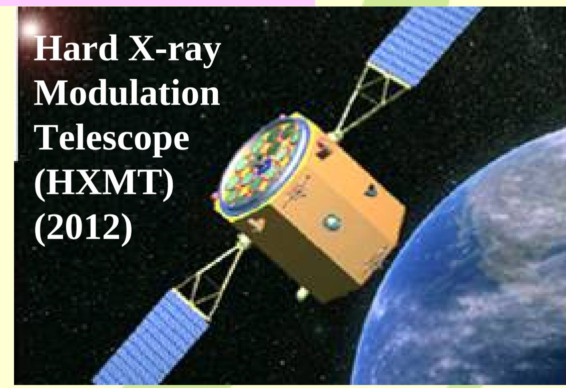



Hubble Space Telescope (1990)



Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) (2009)

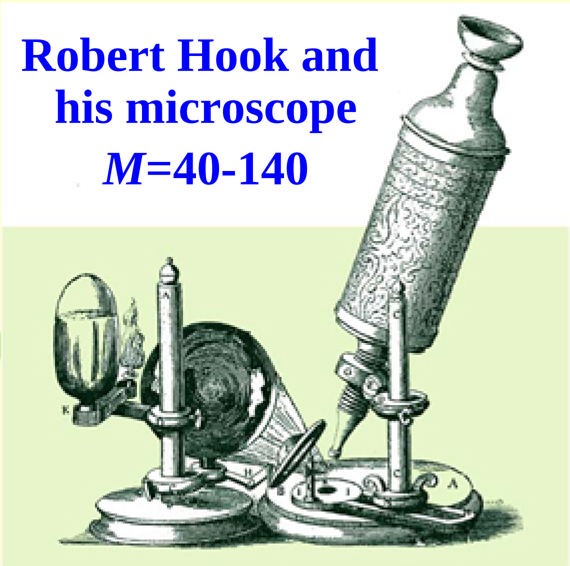
Xinglong, China



Hard X-ray Modulation Telescope (HXMT) (2012)

500 m Aperture Spherical radio Telescope（FAST）2013

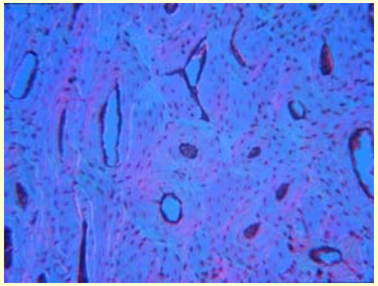
400 Years of Microscopes

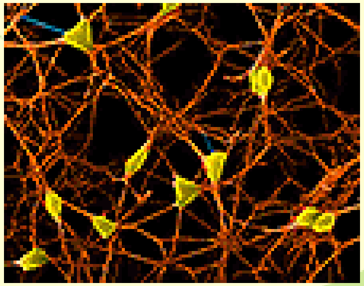


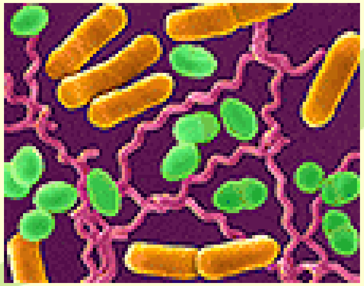
Robert Hook and his microscope
M=40-140

Early Microscope (Cuff, 1740)

Electron microscope (1933)

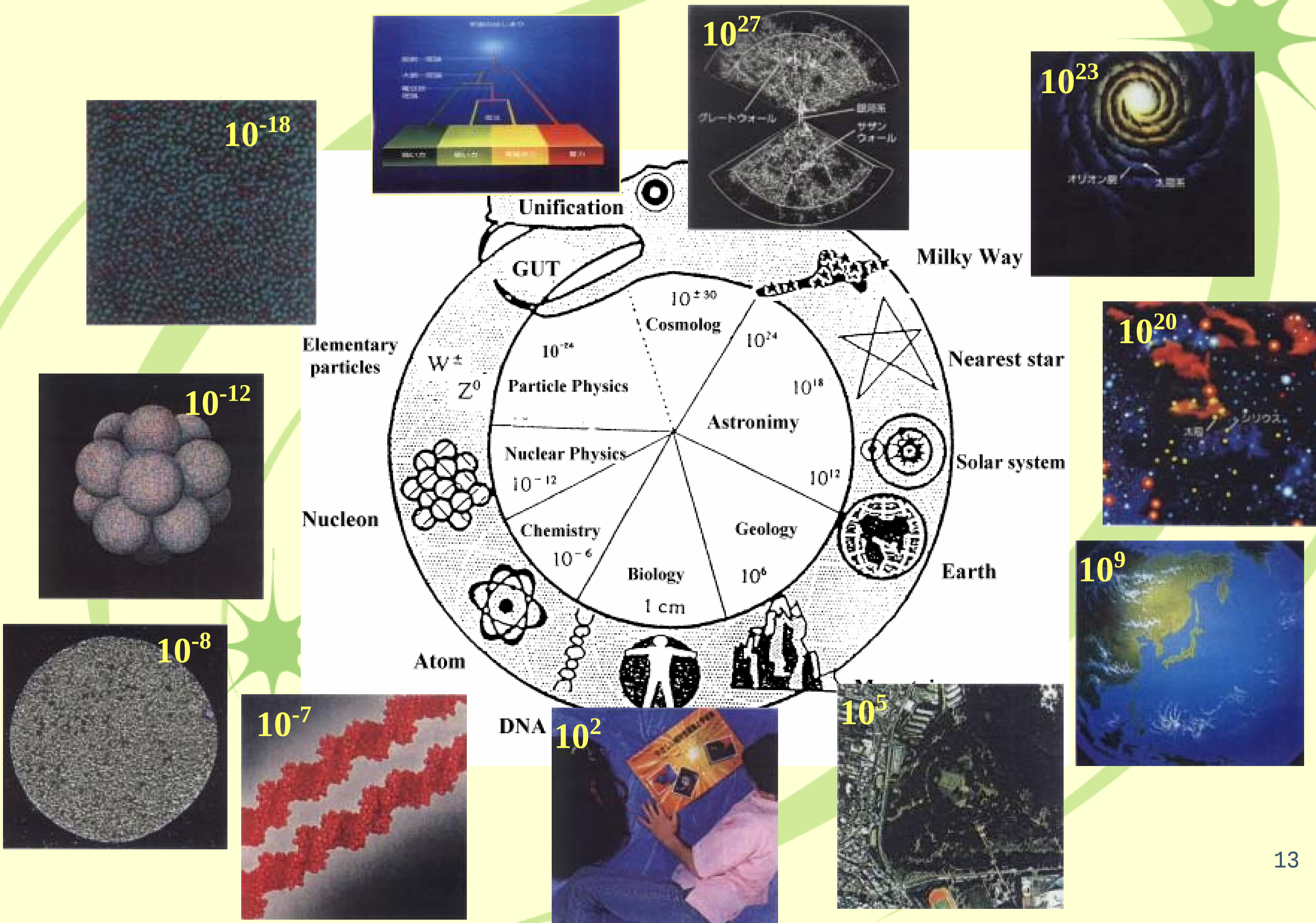


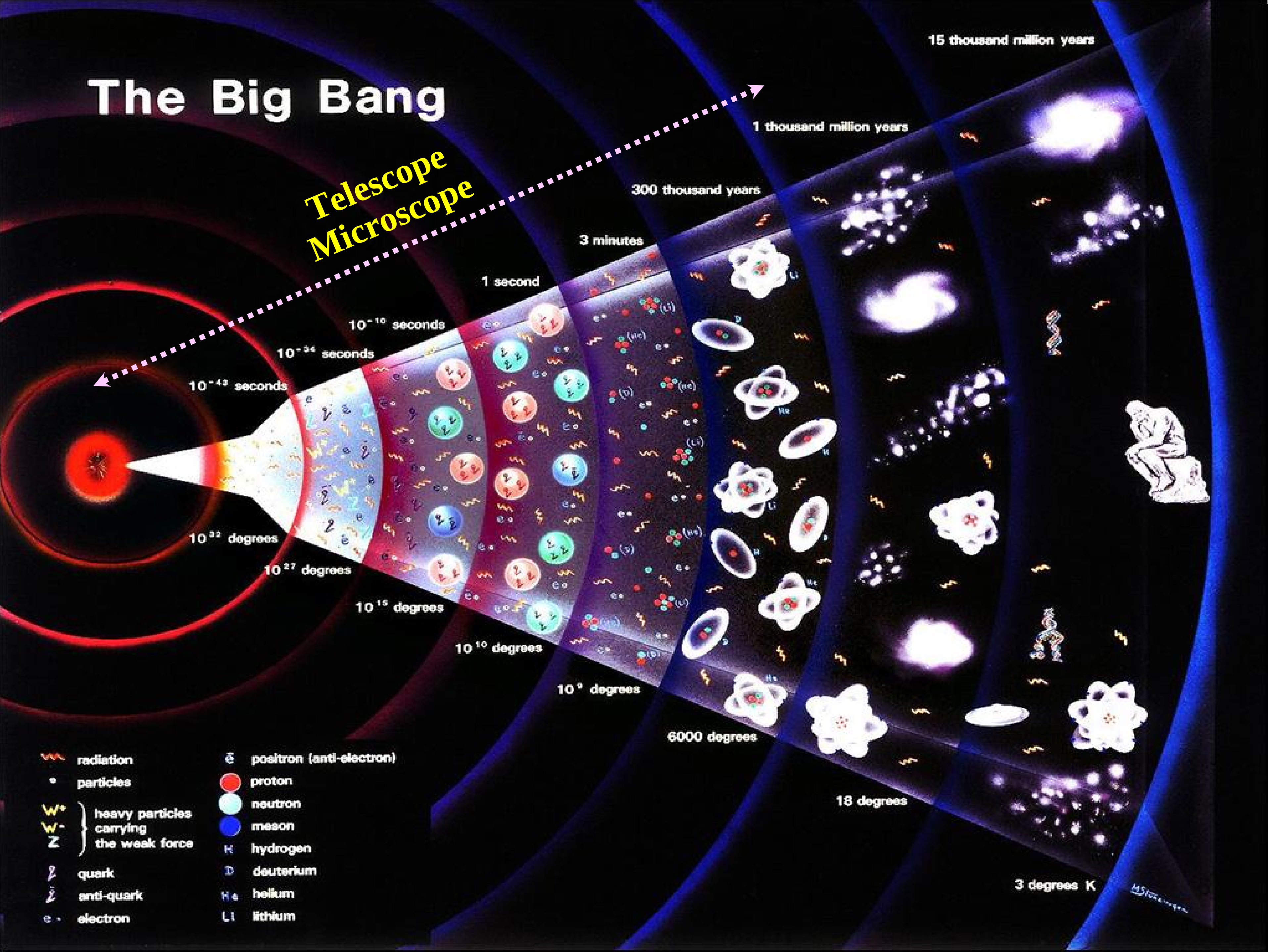




Sweep Electron Microscope (1965)

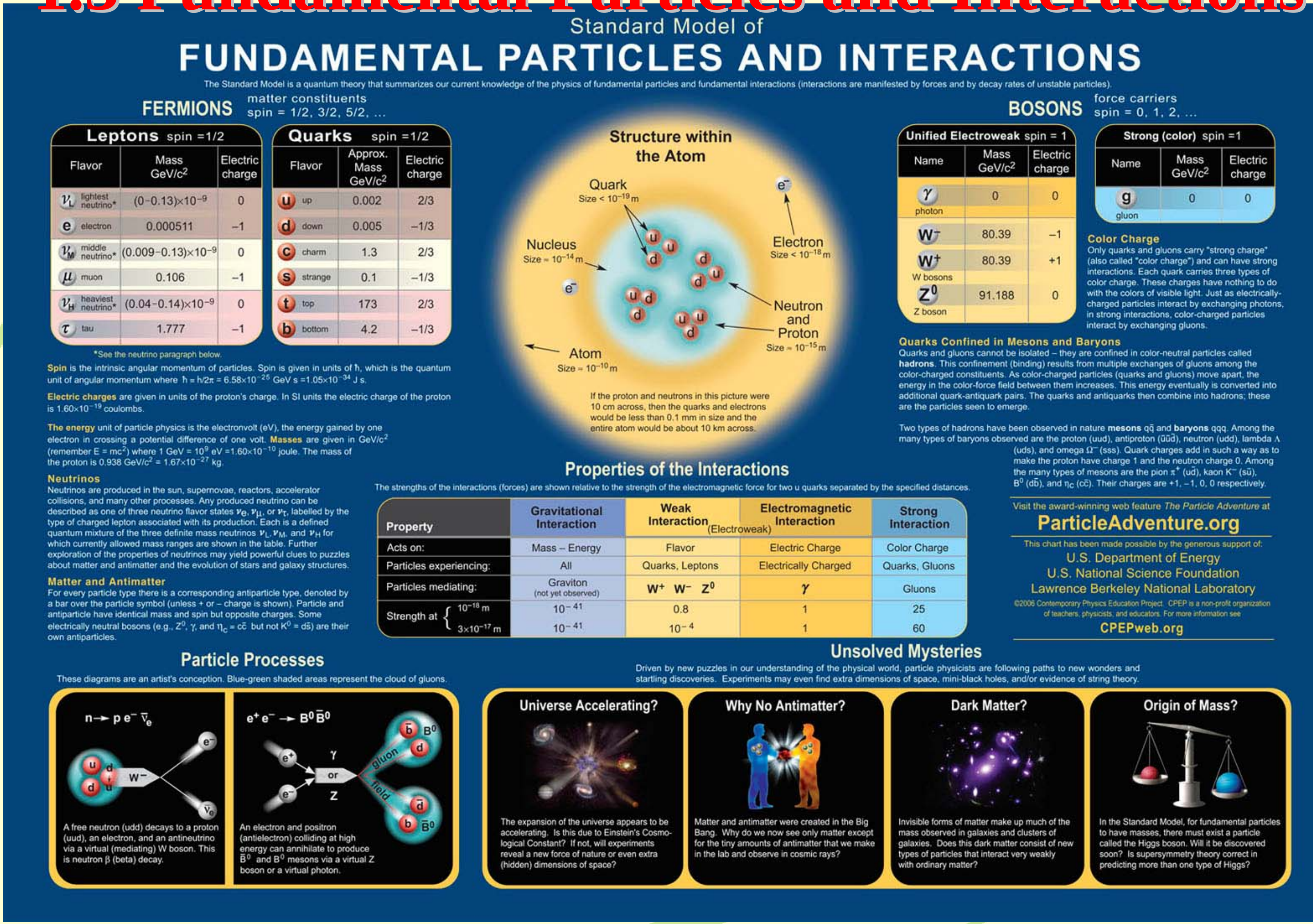
1.2 The Glashow Snake and Universe





The Big Bang
Telescope
Microscope
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
10^{32} degrees
10^{27} degrees
10^{15} degrees
10^{10} degrees
10^{9} degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium

1.3 Fundamental Particles and Interactions



1.4 Methods to investigate the micro-world

$$\lambda^{-1} = \frac{E\beta}{hc}$$

Cristal
~ 1 cm

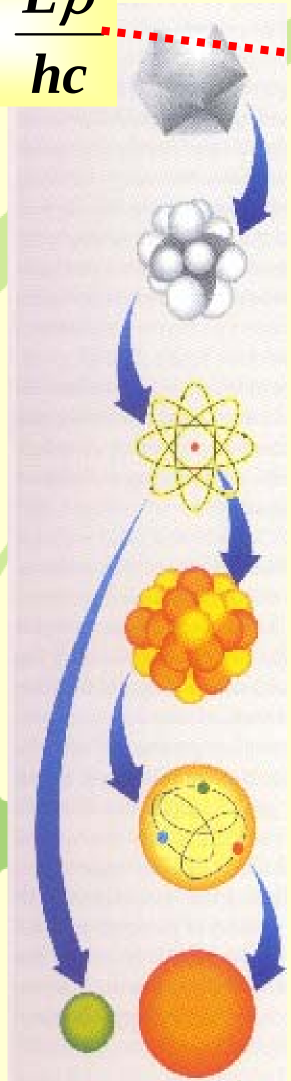
Molecule
~ 10^{-7} cm

Atom
~ 10^{-8} cm

Nucleus
~ 10^{-12} cm

Proton
~ 10^{-13} cm

Lepton, Quark
< 10^{-16} cm

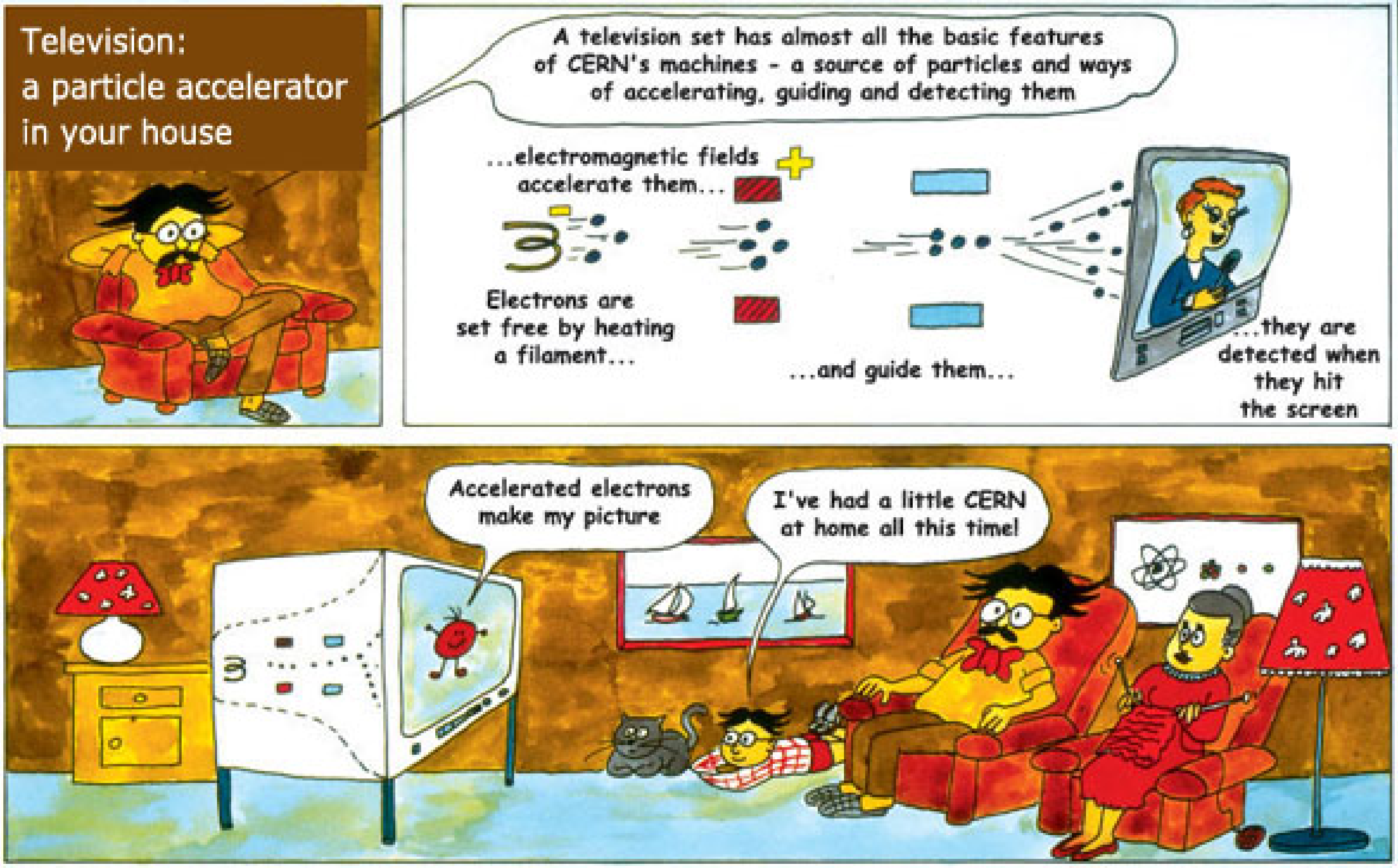


Observed Substance	Size (cm)	Beam Energy $E=hc/\lambda\beta$	Method
Cell/Bacteria = *Aggregate of molelule*	10^{-3}~10^{-5}	*0.1~10eV*	Optical microscope
Molecule = *Aggregate of atoms* ex) Water = H_2O	~10^{-7}	*~1keV*	Electron microscope
Atom = *Nucleus + Electrons*	~10^{-8}	*~ 10keV*	Synchrotron radiation
Nucleus ex) Oxygen = **8p+8n**	~10^{-12}	*>100MeV*	Low-energy electron or proton accelerators
Hadron = *Aggregate of quarks* ex) **p=u+u+d, $J/\psi=c+\underline{c}$**	~10^{-13}	*>1 GeV*	High-energy proton accelerators
Quark, Lepton … (u,d) (s,c) (b,t) $(e,\nu_e)\,(\mu,\nu_\mu)\,(\tau,\nu_\tau)$	<10^{-16}	*>1000 GeV*	High-energy electron or proton colliders
……	……	……	……

(2) *Historical evolution of accelerators*

- **A particle accelerator at your home**
- **Historical roots of accelerators**
- **Main development**
- **Evolution of acceleration principle**
- **Step up to modern accelerators**

2.1 A particle accelerator at your home

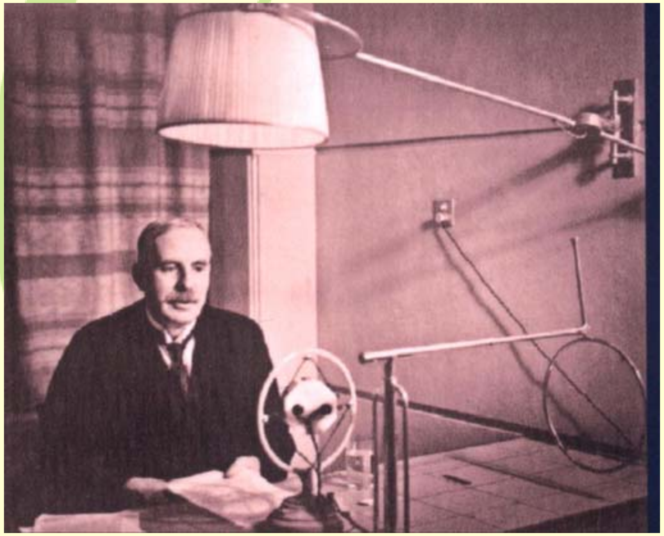


2.2 *Historical Roots*

The birth of an era

1919 Rutherford induced a nuclear reaction with natural alphas.

1928 Gamov predicted tunnelling and 500 keV might be suffice to split atom.



I have long hoped for a source of positive particles more energetic than those emitted from natural radioactive substances.

Ernest Rutherford, 1928

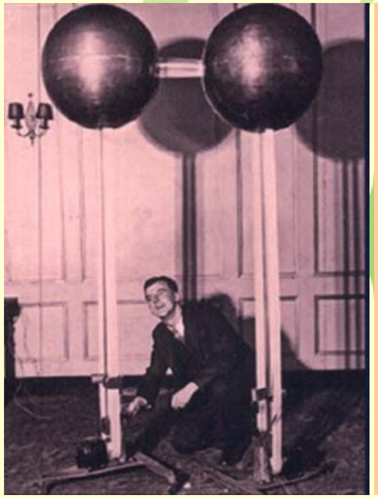
2.2 *Historical Root 1*

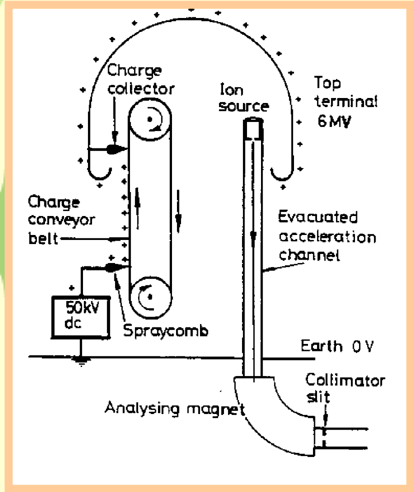
High-voltage acceleration

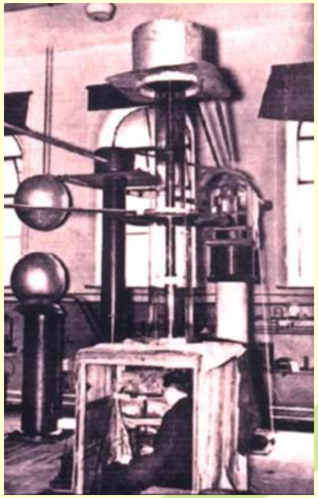
1928 Cockcroft & Walton started designing an 800 keV generator encouraged by Rutherford.

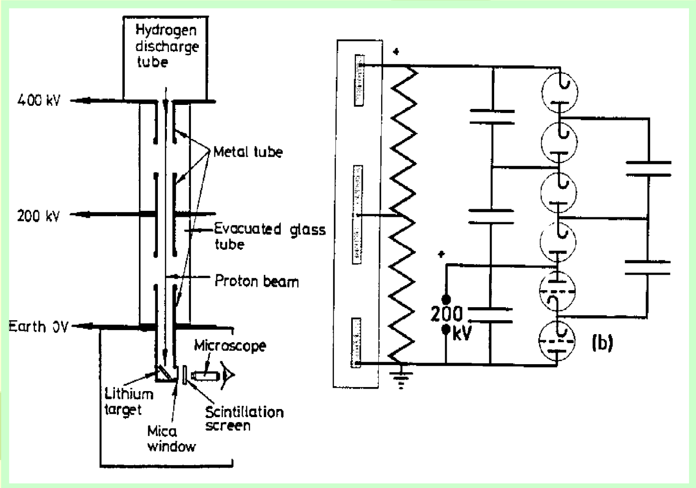
1931 Van de Graff invented electrostatic generator.

1932 The rectifier generator reached 700 kV and Cockcroft & Walton split lithium atom with 400 keV proton.



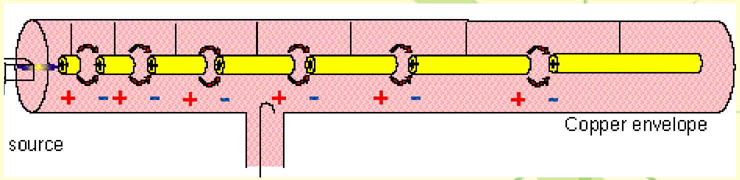






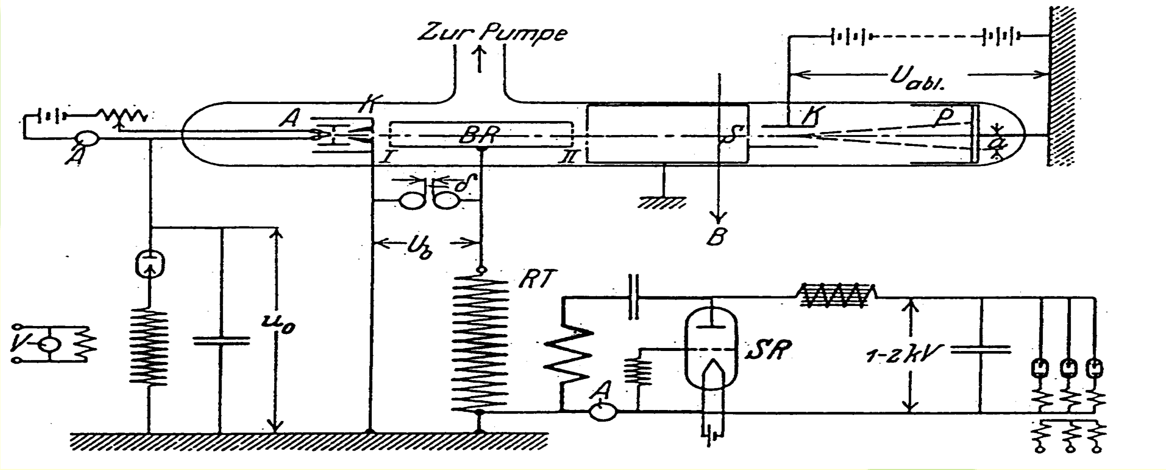
Historical Root 2

Resonant acceleration



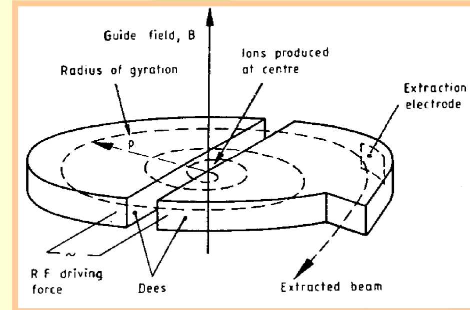
1924 Gustav Ising proposed time-varying fields across drift tube.

1928 Rolf Wideroe demonstrated Ising's principle with 1 MHz, 25 kV oscillator to make 50 keV potassium ions.



Historical Root 2 **(cont.)**

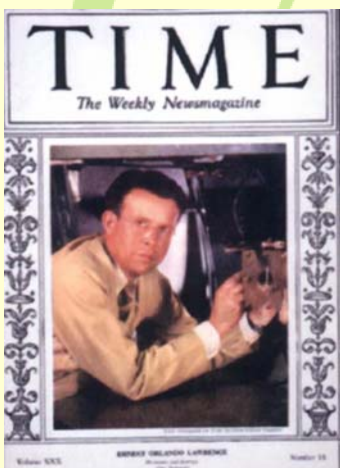
Resonant acceleration

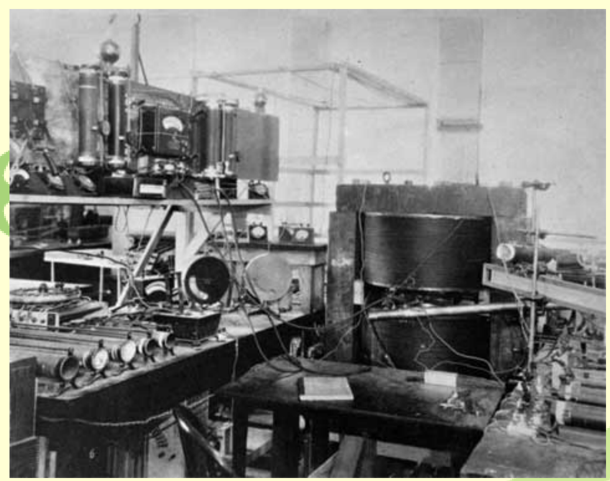


1929 Lawrence, inspired by Wideroe and Ising, conceived the cyclotron.

1931 Livingston demonstrated the cyclotron by accelerating protons to 80 keV;

1932 Lawrence's cyclotron produced 1.25 MeV protons and split the atom just few weeks after Cockcroft & Walton.





Historical Root 3

Betatron acceleration

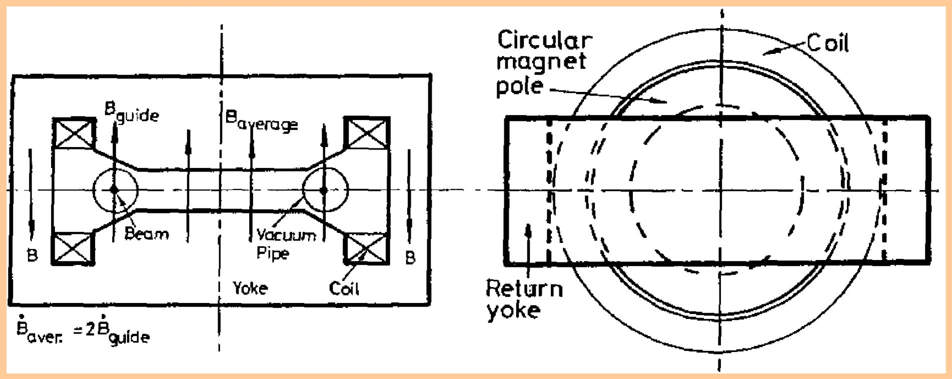
$$\frac{dB_0(t)}{dt} = \frac{1}{2}\frac{d\overline{B}(t)}{dt}$$

1923 Wideroe, a young Norwegian student, drew in his laboratory notebook the design of the betatron with 2-1 rule. Two years later he added the condition for radial stability but not publish.

1927 Wideroe made a model betatron, but it did not work. Discouraged he changed course and built a linear accelerator.

1940 Kerst re-invents the betatron and built the first working machine for 2.2 MeV electron.

1950 Kerst built the world's largest betatron of 300 MeV.

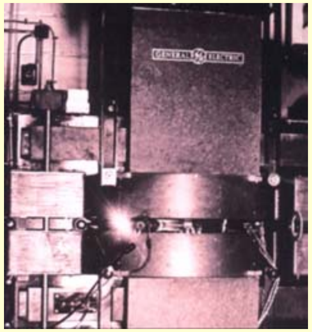


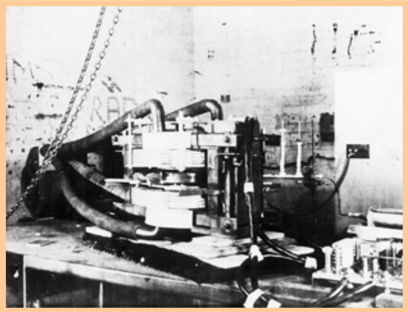
1.3 *Main Development*

1944 V.Veksler & E.Mcmillan discovers principle of phase stability and invent the synchrotron.

1944 Veksler proposes an idea of microtron.

1945 Energy loss due to synchrotron radiation is measured in an betatron;

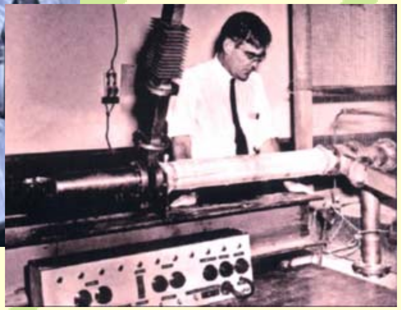




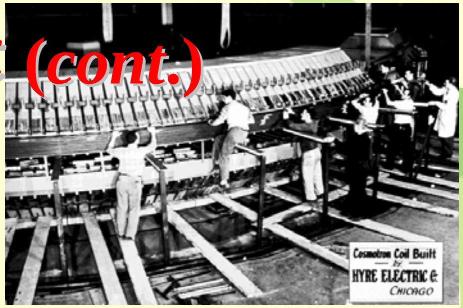
1946 F.Goward & D.Barnes make a synchrotron works.

1946 First proton linear accelerator of 32 MeV is built at Berklay.

1946 First electron linear accelerators are studied at Stanford and MIT.



Main Development (cont.)



1952 BNL builds 3 GeV Cosmitron.

1952 E.Courant, M.Livingston & H.Snyder propose the principle of strong focusing.

1959 CERN builds 28 GeV CPS; BNL builds 33 GeV AGS (1960);

1960's Several SR facilities are set up on rings initially for HEP;

1962 First single-ring e^+-e^- collider AdA of 2×250 MeV is built at Frascati.

1.3 *Main Development* (cont.)

1970 V. Teplyakov and I.Kapchinski invent radio frequency quadrupole linac (RFQ);

1971 J.Maday invented first free electron laser;

1972 First double-ring proton collider ISR 2×28 GeV is built at CERN;

Since 70's A number of e^+e^- colliders constructed;

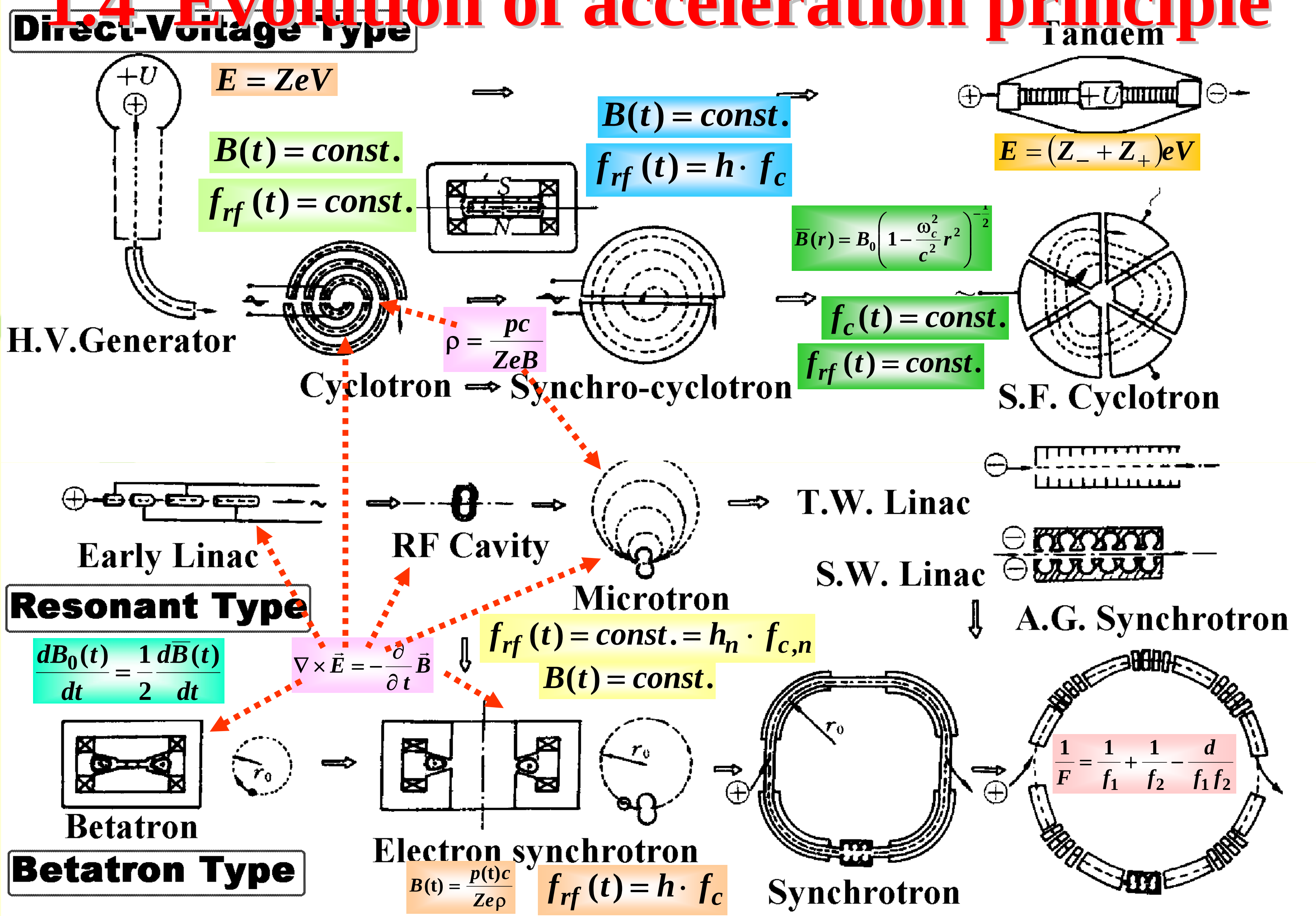
Since 80's A number of SR facilities and spallation neutron sources constructed;

1989 First linear collider SLC of 2 × 50 GeV is built at SLAC

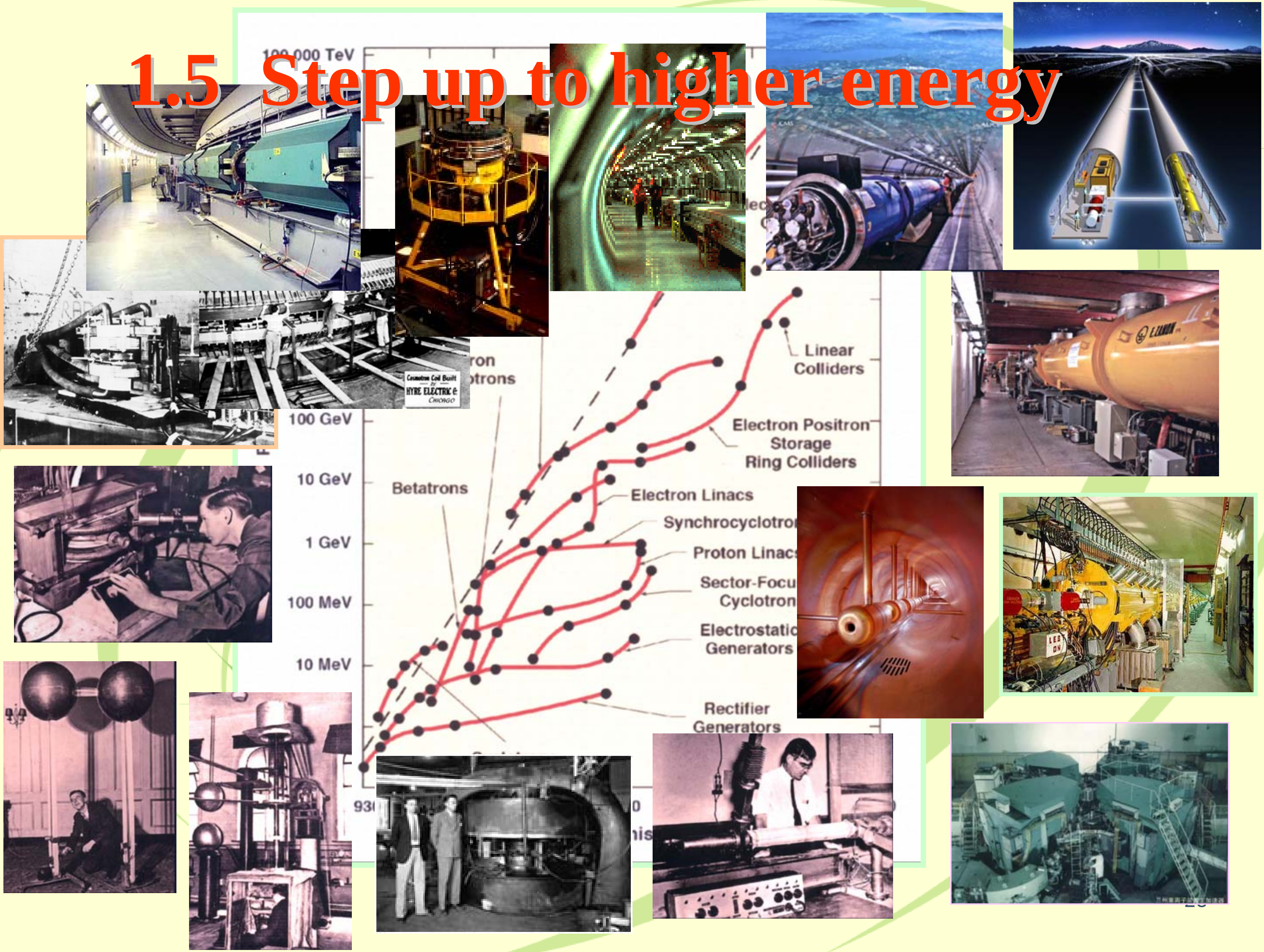
2008 First beam from LHC;

…… ……

1.4 Evolution of acceleration principle



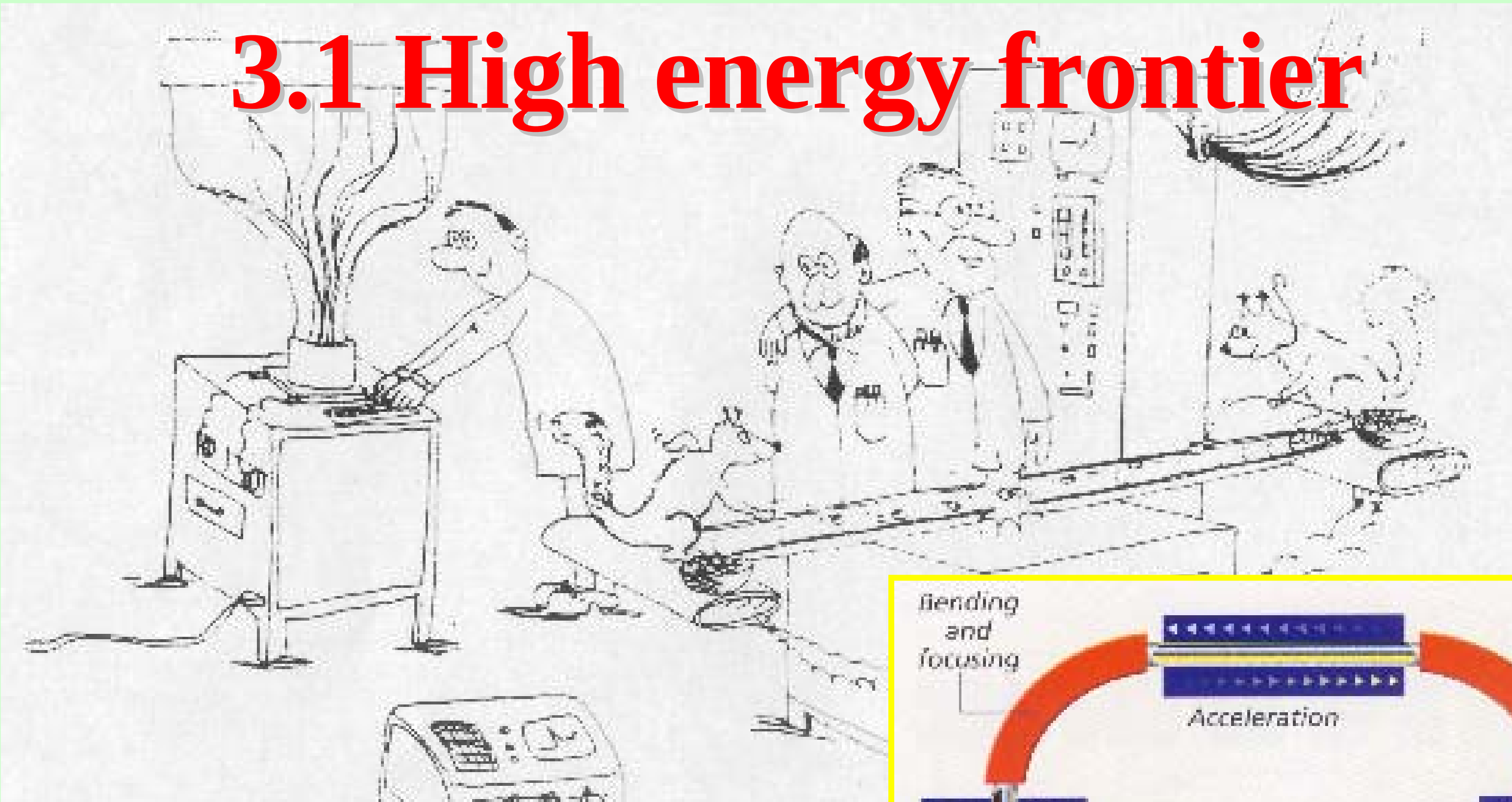
1.5 Step up to higher energy



(3) *Frontiers of modern accelerators*

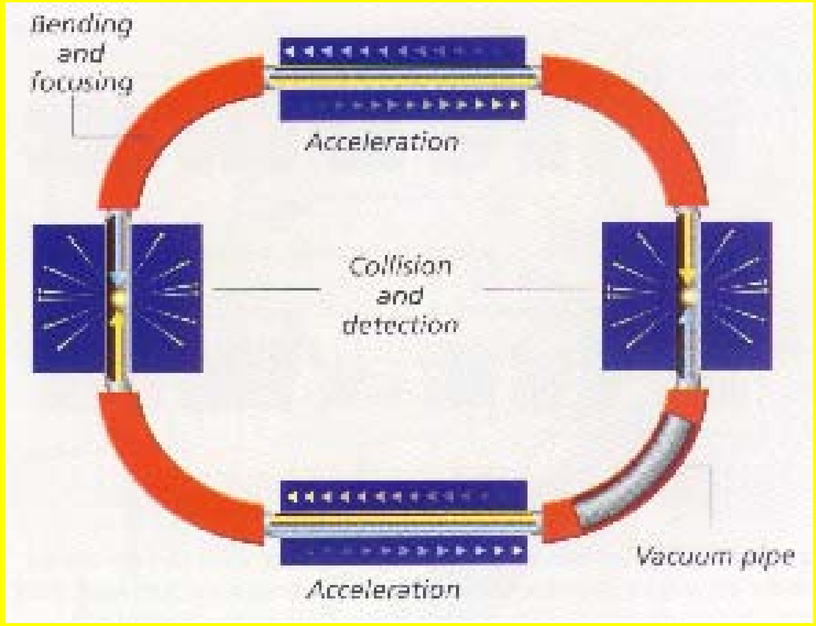
- **High energy frontier**
- **High luminosity frontier**
- **Multidisciplinary platforms**
- **Application of accelerators**
- **Novel acceleration methods**

3.1 High energy frontier



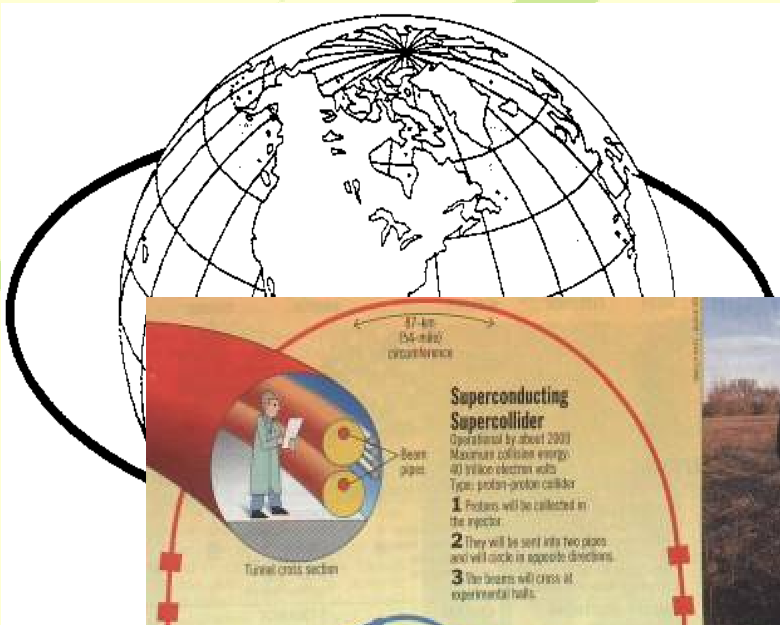
Fixed target: $E_{cm} \approx (2EE_0)^{1/2}$

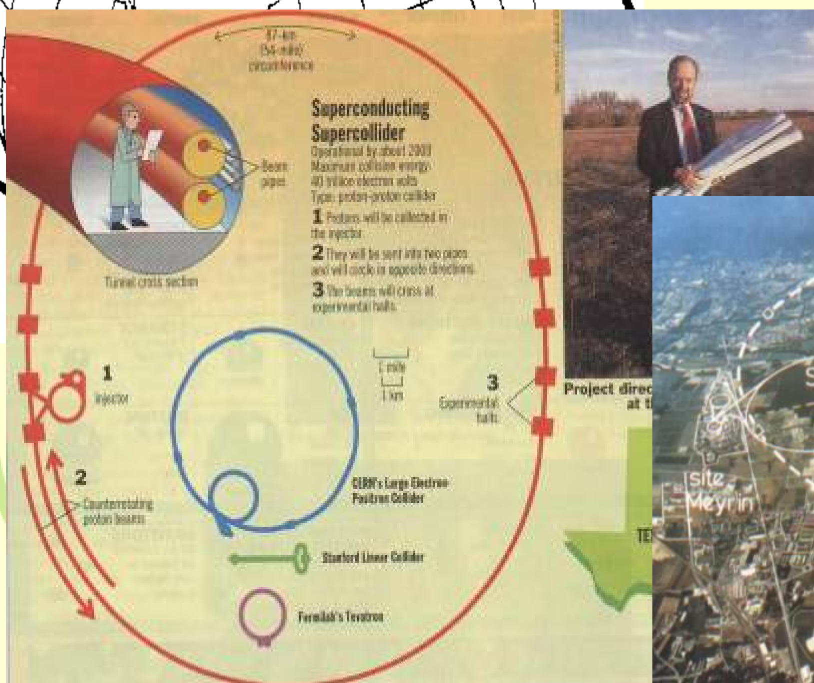
Collider: $E_{\mathrm{cm}} = 2E$

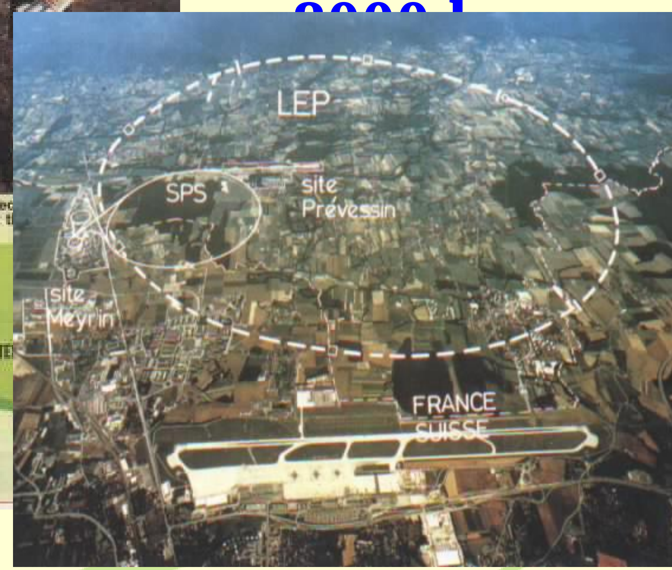


Fermi's Dream (1954)

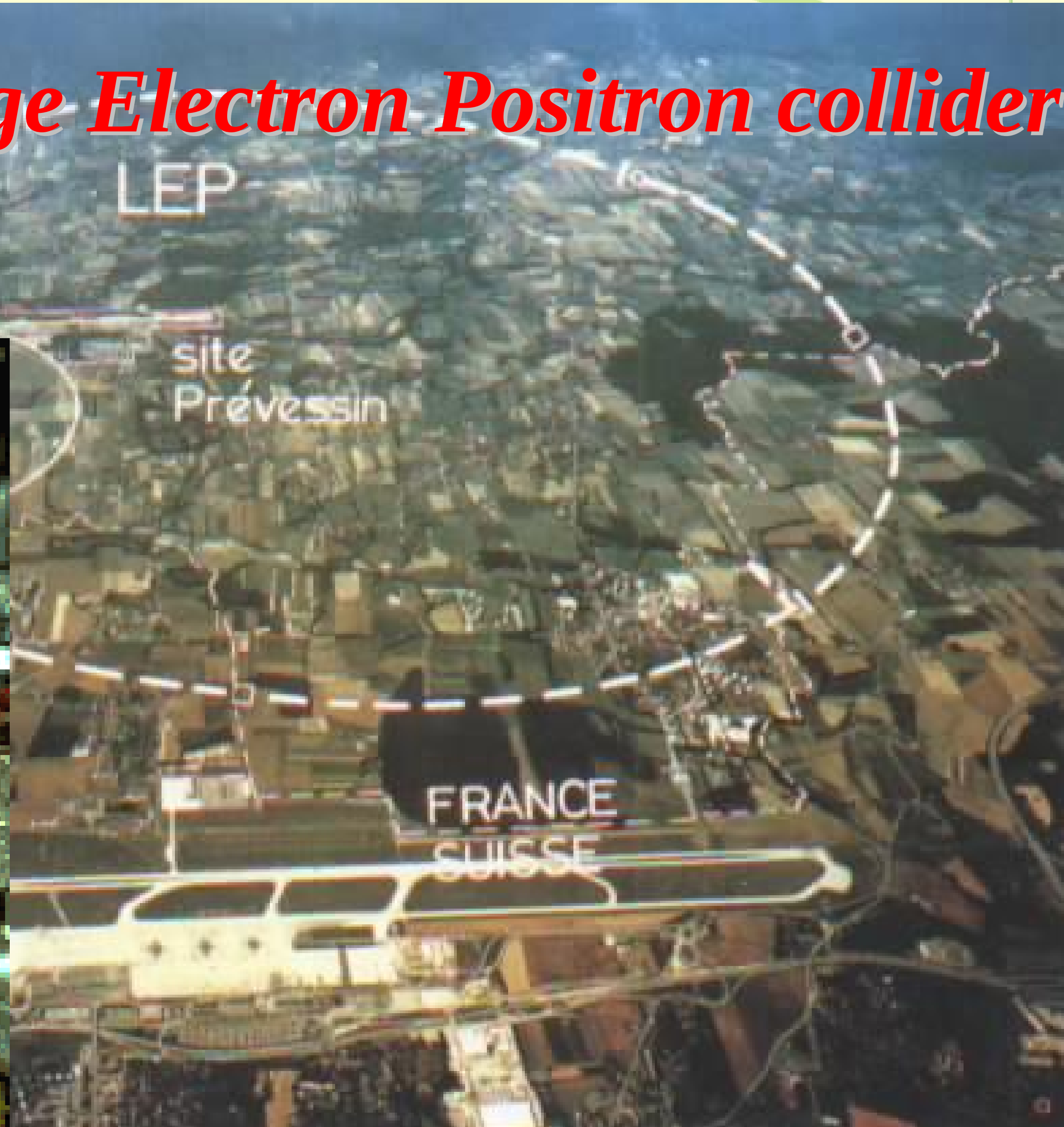
	Fermi's Dream	SSC	(LHC)
E_{beam}	5000 TeV	20	(7.0)
$E_{C.M.}$	3 TeV	40	(14)
ax	2 T	6.6	(8.3)
	2000 k	13	(4.3)
		8 ?	（5）
		9 ?	（10）

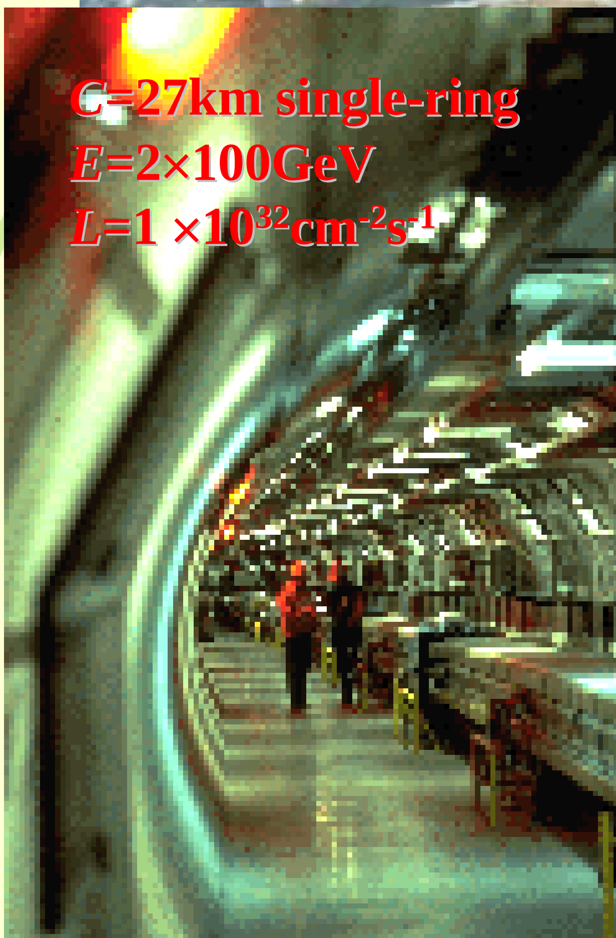






LEP: *Large Electron Positron collider*



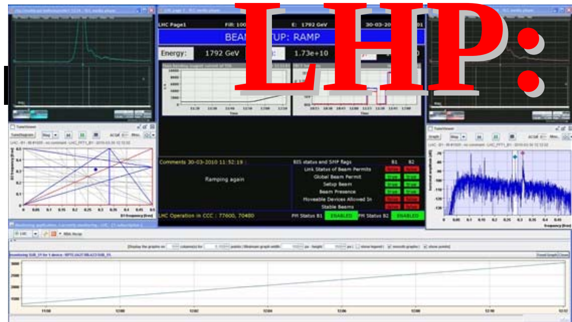


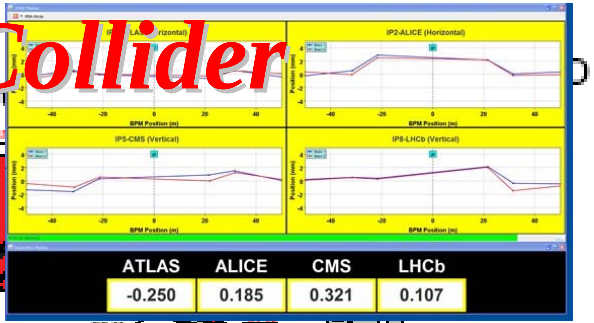
C=27km single-ring

E=2×100GeV

L=1 ×$10^{32}$$cm^{-2}s^{-1}$

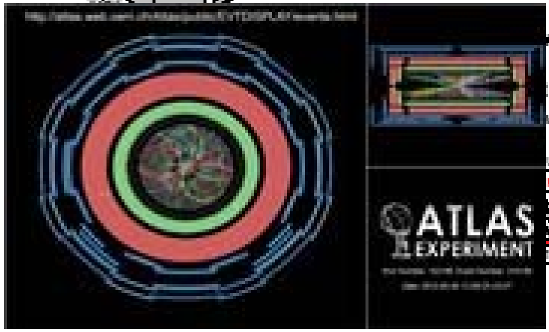
LHP: *Large Hadron Collider*

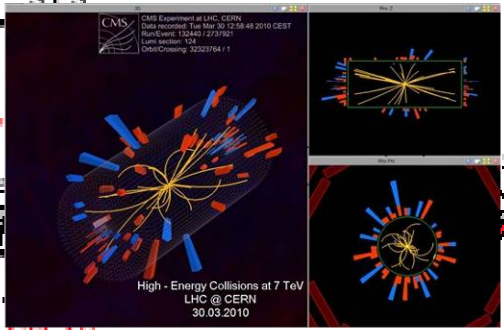




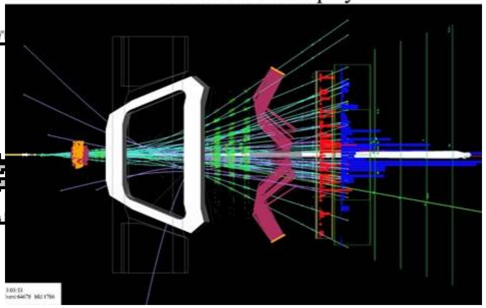




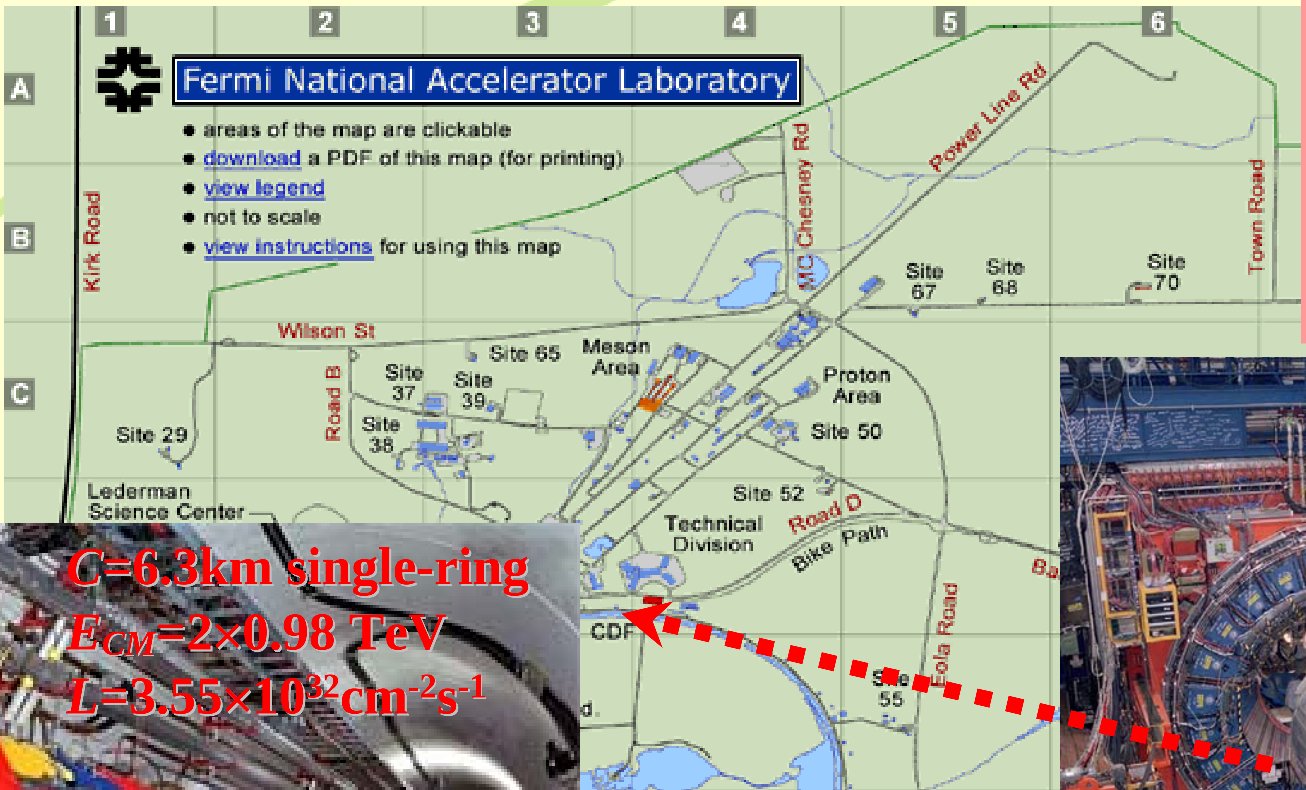



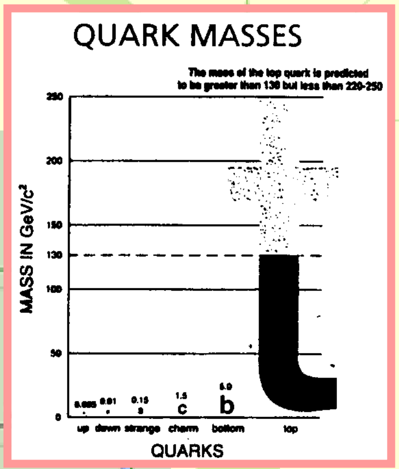


LHCb Event Display



Tevatron at FNAL

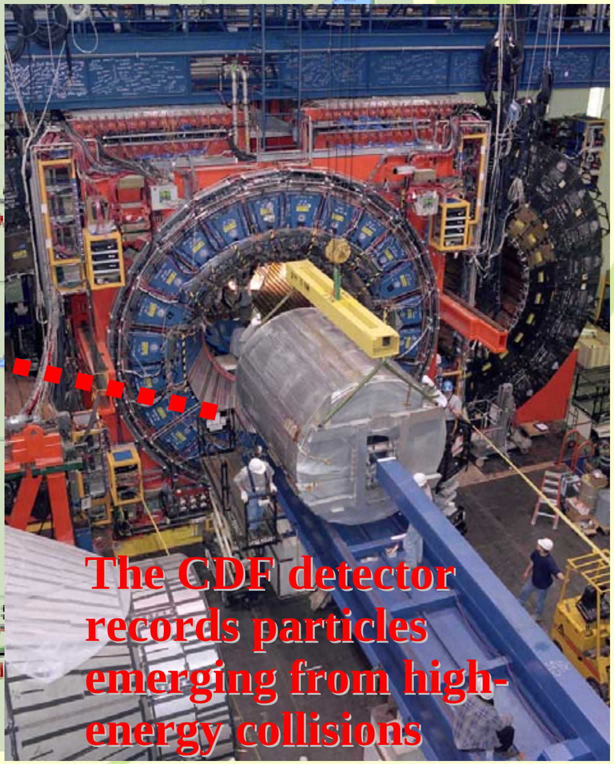




C=6.3km single-ring

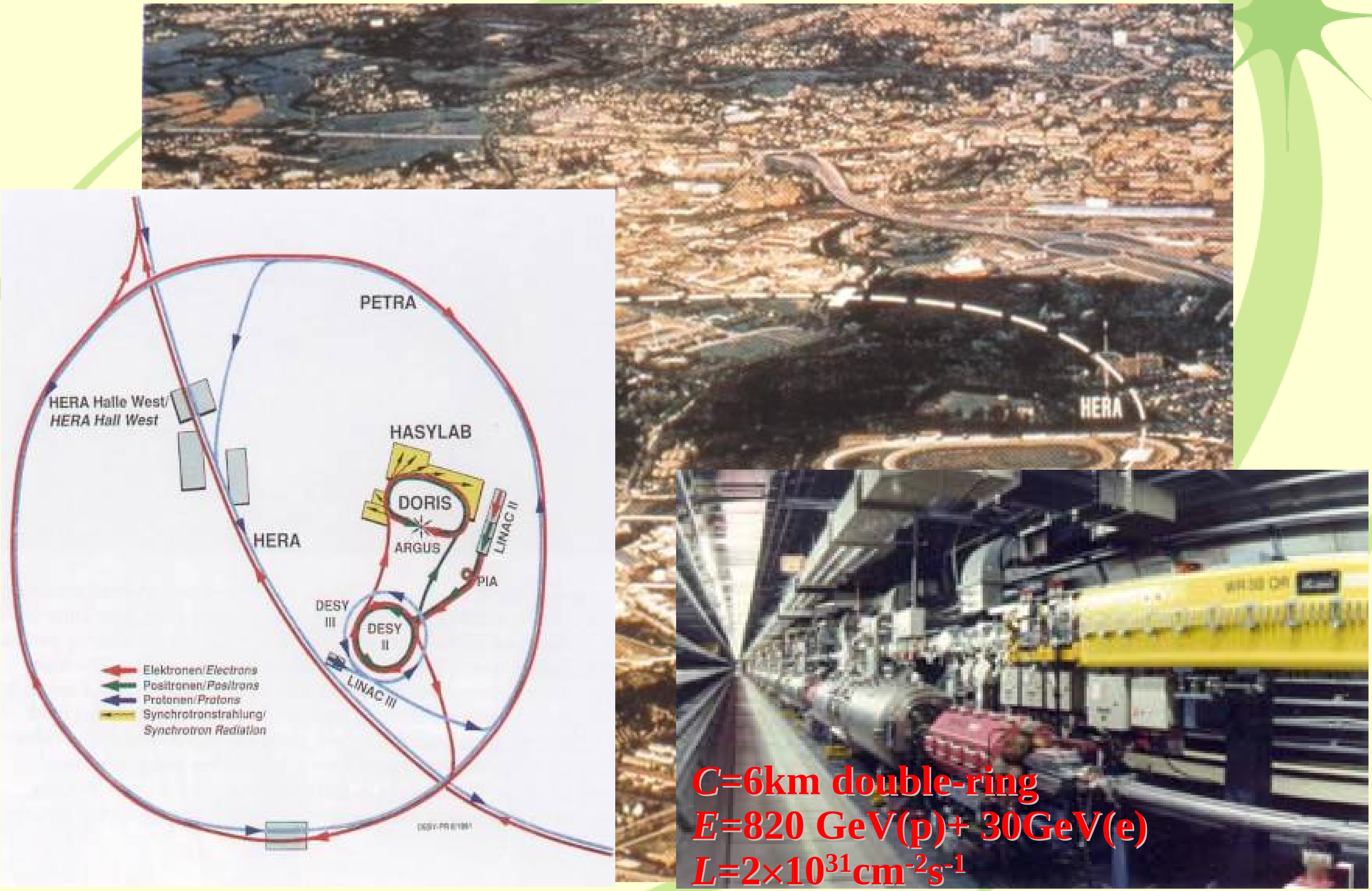
$E_{CM}=2\times0.98$ TeV

$L=3.55\times10^{32}\text{cm}^{-2}\text{s}^{-1}$



The CDF detector records particles emerging from high-energy collisions

DESY and HERA

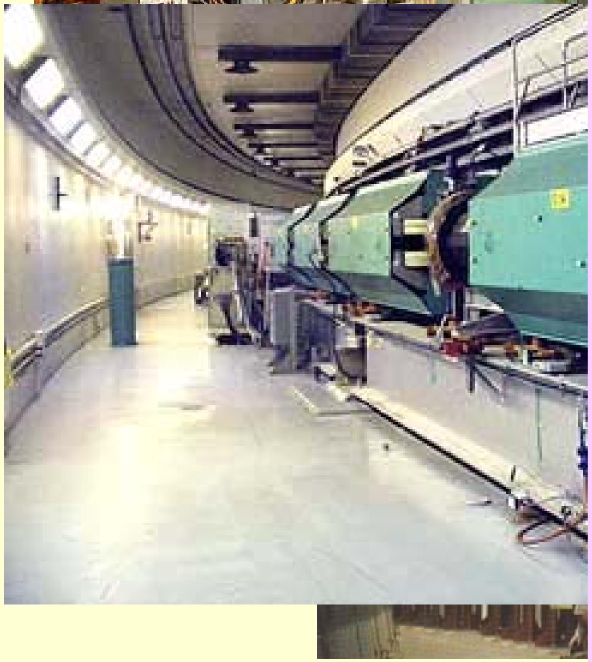


C=6km double-ring

E=820 GeV(p)+ 30GeV(e)

$L=2\times10^{31}cm^{-2}s^{-1}$

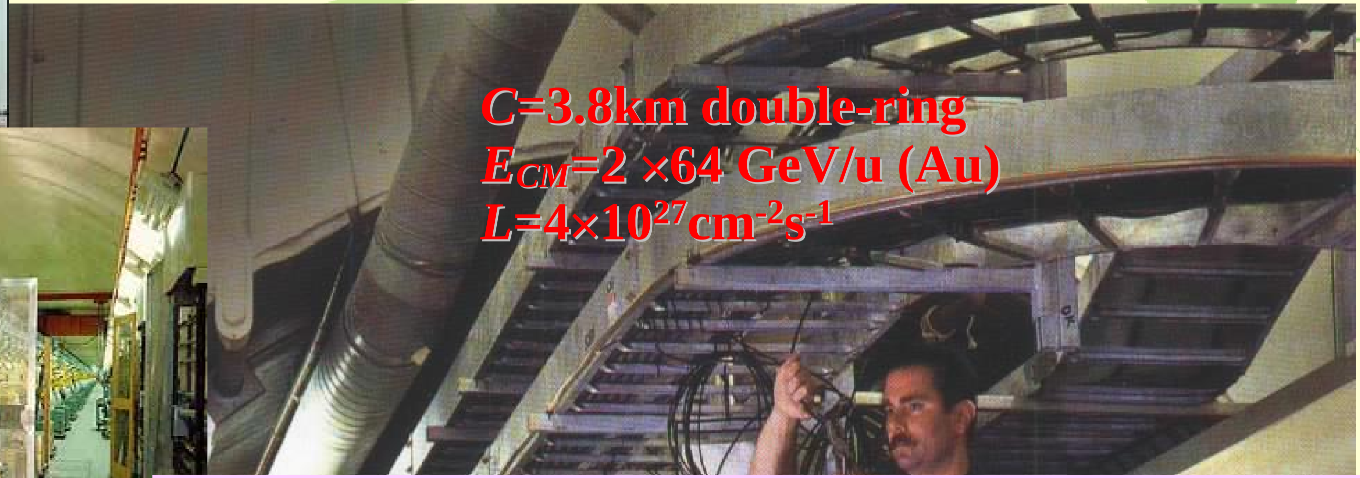
RHIC of BNL

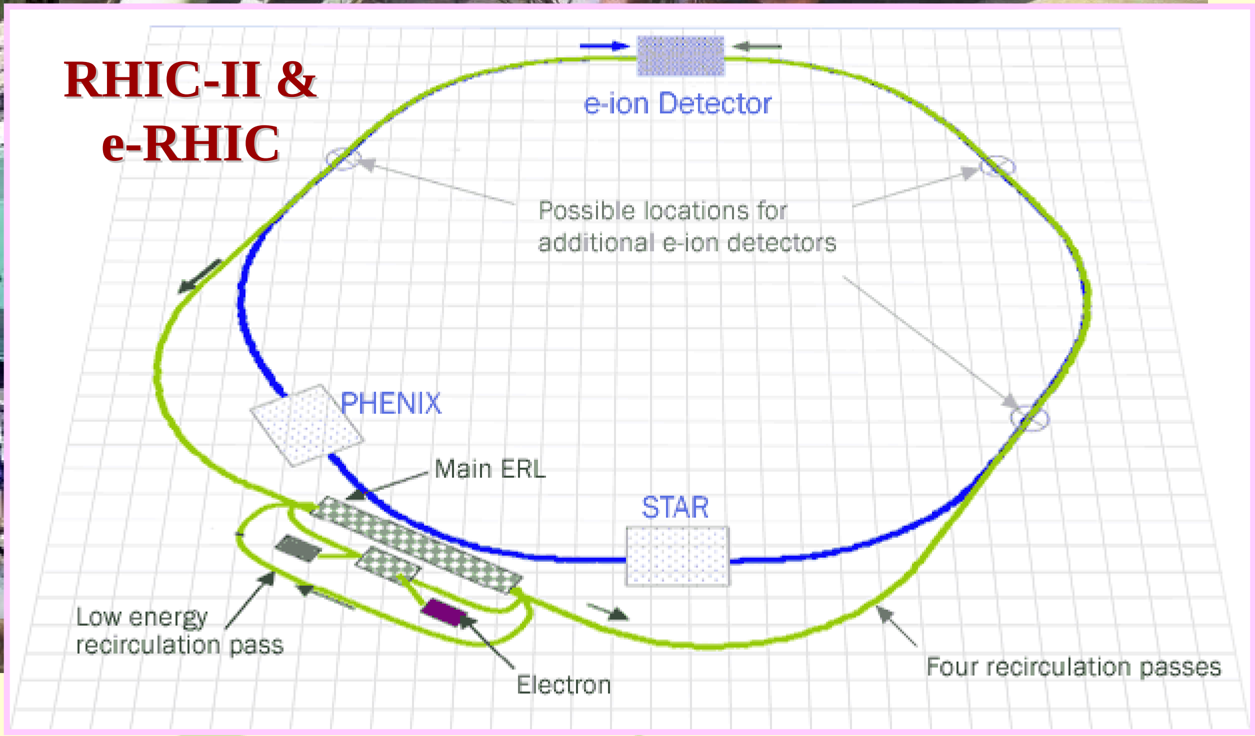


C=3.8km double-ring

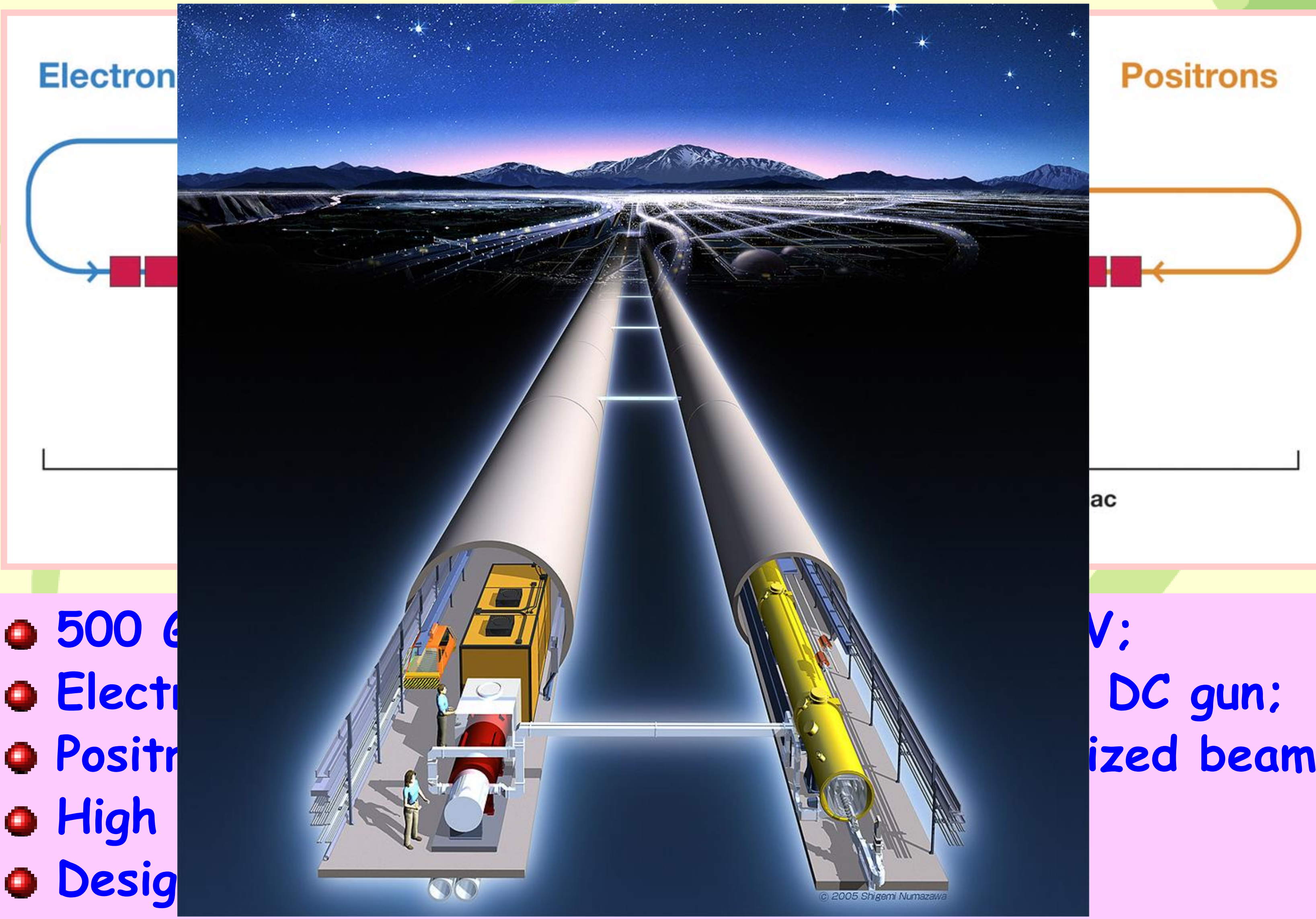
E_{CM}=2 ×64 GeV/u (Au)

$L=4\times10^{27}cm^{-2}s^{-1}$



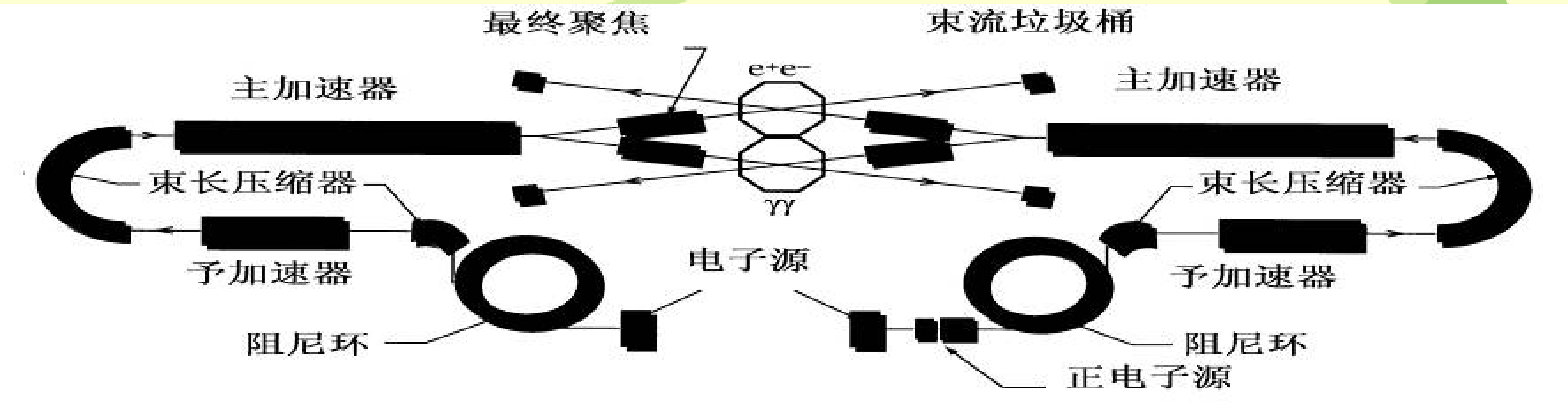


International Linear collider

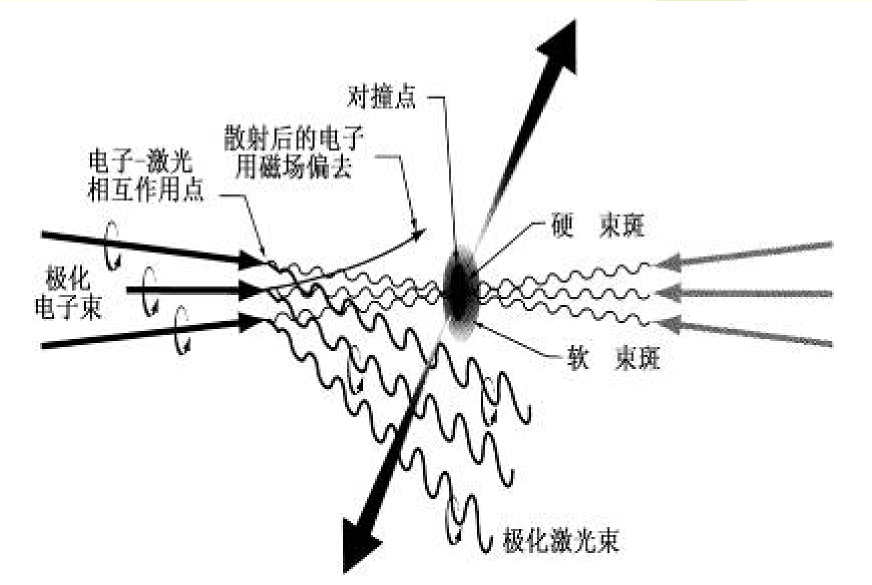


- 500 G V;
- Electr DC gun;
- Positr ized beams;
- High
- Desig

γ–γ Collider



Beam Energy *E*	250 GeV
Particle per bunch	0.65×10^{10}
Overall Length	~10 km
Repitation	180Hz
Bunch Length	0.1 mm
Beam Size at IP	71nm×9nm
Polarization	All and adjustable
Distance if X-e IP and γ–γ IP	5 mm
e^+e^- Luminosity	$\sim1\times10^{34}cm^{-2}s^{-1}$
γ–γ Luminosity	$\sim1\times10^{33}cm^{-2}s^{-1}$



μ^+ - μ^- Colliders

Exotic Same as electron, $m^{\pm}$ is lepton, but unstable $t_{m0} \approx$ 2ms

Reasonable m_m=105 MeV, $\frac{m_\mu}{m_e} = 206.8$

$P_{SR} \propto \frac{1}{\rho}\left(\frac{E}{E_0}\right)^4, \quad \frac{P_{SR,\mu}}{P_{SR,e}} \approx 10^{-9}$, which is negligible

$\Rightarrow$ $m^{\pm}$ storage ring $\Rightarrow$ smaller and more effective

$t_m = g t_{m\,0}$, E=2TeV, g=20000, t_m =40ms, $N = t_m / T_{rev} \approx$ 1500

$$\sigma\left(\mu^+, \mu^- \to Higgs\right) \propto m^2 \Rightarrow \frac{\sigma_{\mu^\pm}}{\sigma_{e^\pm}} \approx 40000$$

hadrons, m,n,K…$\Rightarrow$ Chance for new physics discovery

Challengeable $t_{m\,0} \approx$ 2ms, t_m =40ms @2TeV

$\Rightarrow$ $V_{RF} \propto dE/dt$, difficulty, cost…

very fast cooling $\Rightarrow$ *Ionzation cooling*

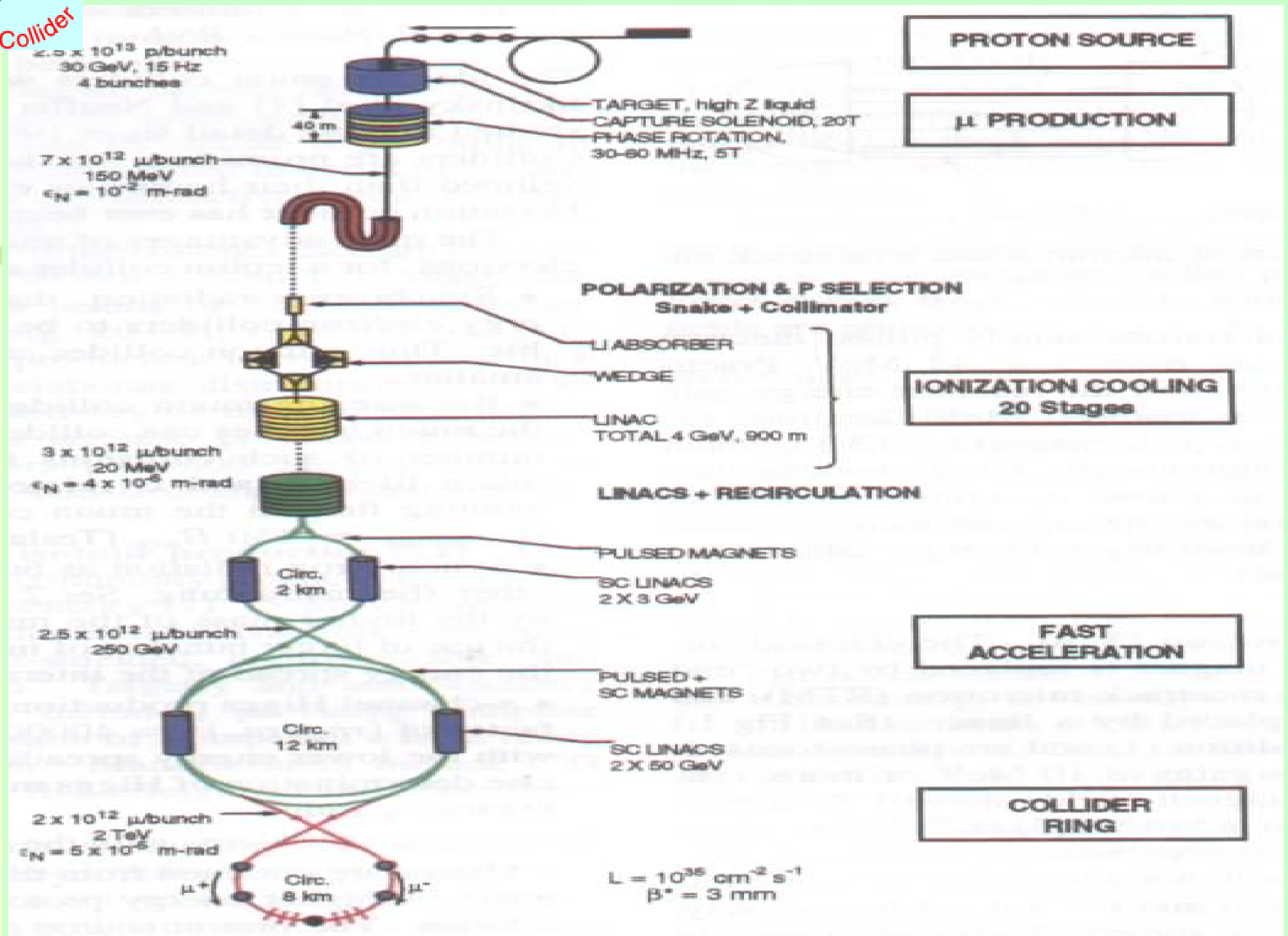
$m^{\pm}$ Decay $\Rightarrow$ Background, shielding issues……

neutrino pollution $D \propto E^3 \Rightarrow$ very serious @E=2TeV

……

Being studied P.Chen (SLAC), Y.Cho(ANL) K.Y.Ng, Z.Qian (FNAL), Y.Zhao, H.Wang, H.Ma (BNL), Q.S.Shu (CEBAF), D.Li (LBL) ……

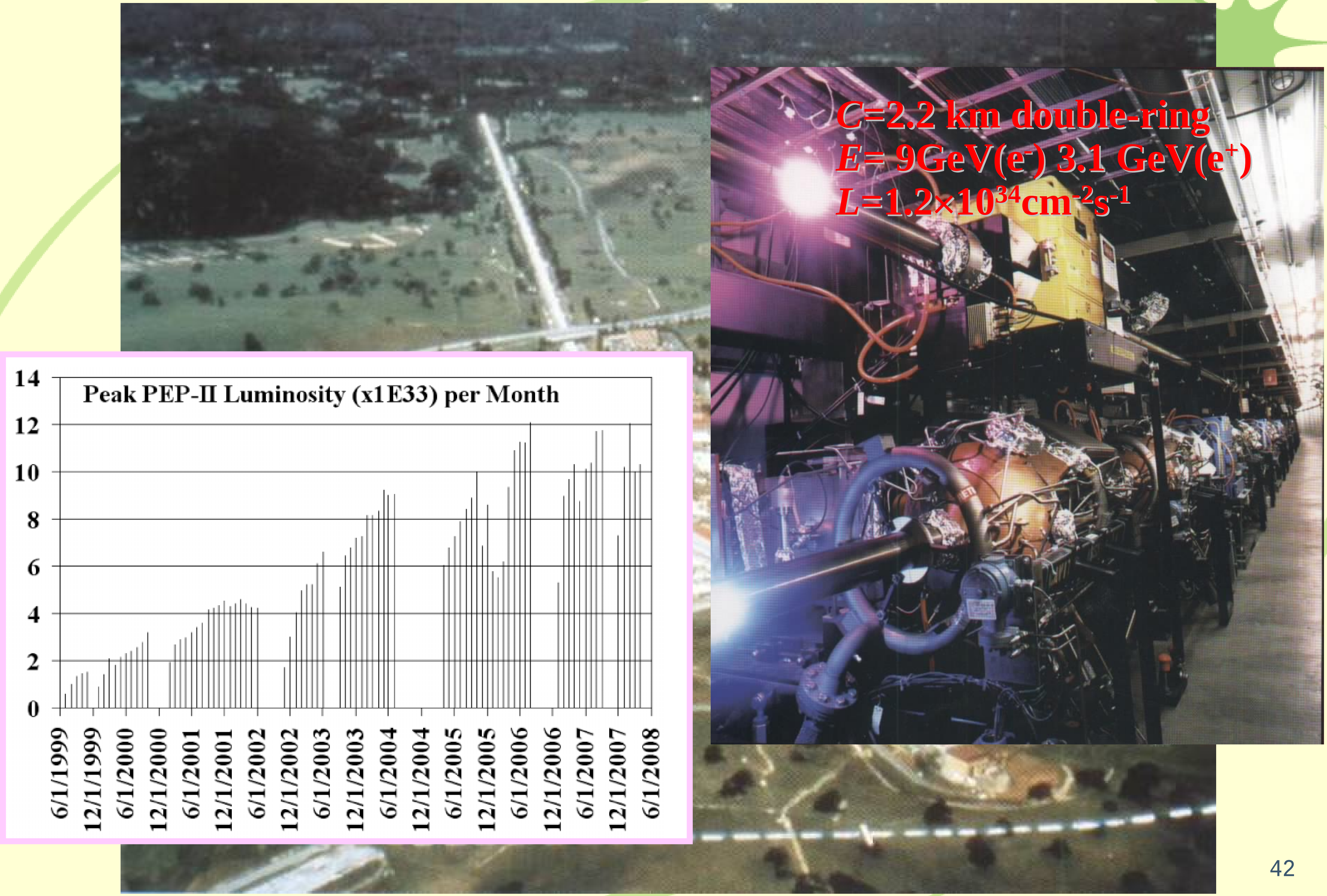
A schematic diagram of E=2×2TeV μ⁺-μ⁻ Collider



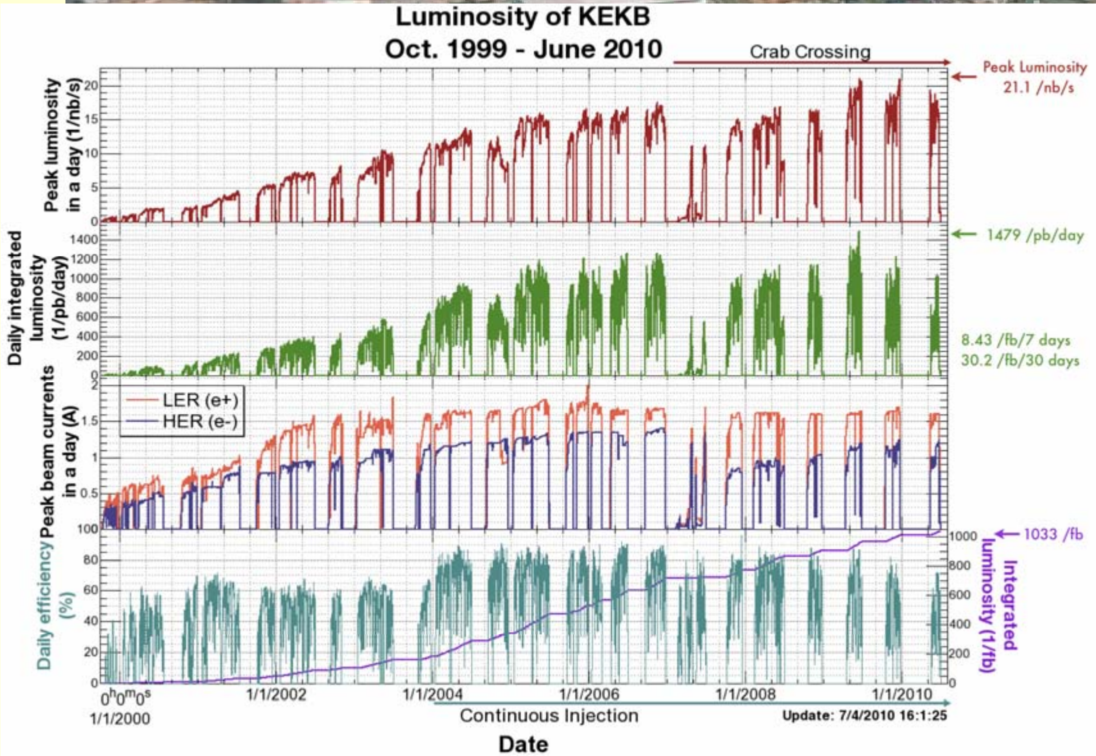
3.2 High luminosity frontier

- **After discovery made with pioneer accelerators, more detail and accurate investigation need to be made in order to extend the discovery with higher statistics, which needs higher luminosity machines;**
- **Higher luminosity calls for higher performance colliders with higher current, better final focusing, and usually double-ring structure…**
- **Challenge to accelerator physics and technology: beam instabilities and impedance, injection, interaction region, vacuum, accurate bunch monitoring …**

PEPII at SLAC



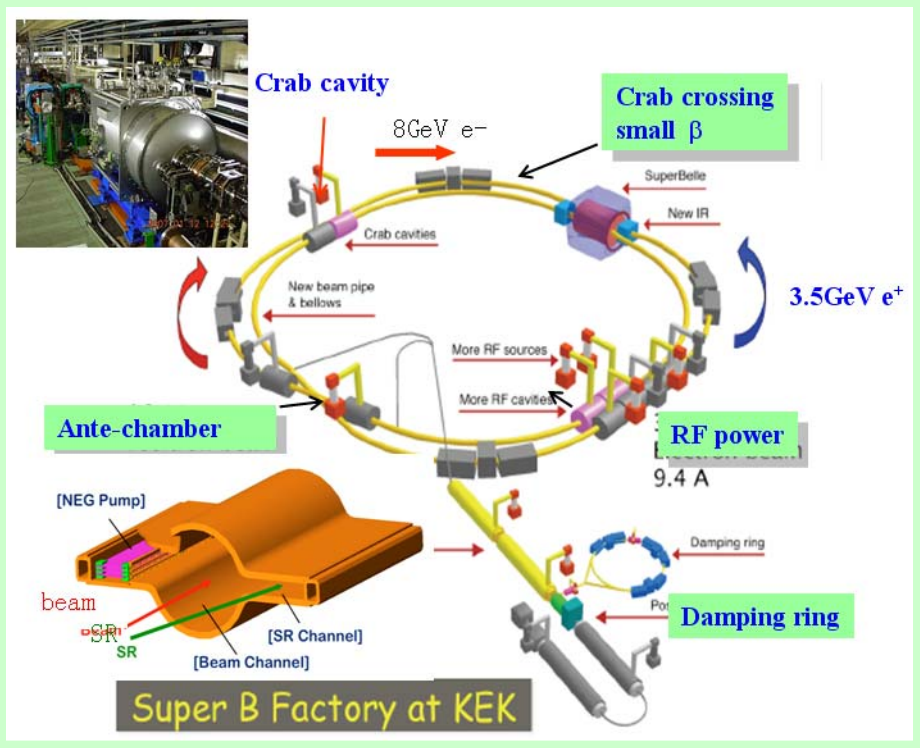
KEK and KEKB


Luminosity of KEKB
Oct. 1999 - June 2010
Crab Crossing
Peak Luminosity 21.1 /nb/s
Peak luminosity in a day (1/nb/s)
Daily integrated luminosity (1/pb/day)
1479 /pb/day
8.43 /fb/7 days
30.2 /fb/30 days
Peak beam currents in a day (A)
LER (e+)
HER (e-)
Daily efficiency (%)
Integrated luminosity (1/fb)
1033 /fb
1/1/2000
1/1/2002
1/1/2004
1/1/2006
1/1/2008
1/1/2010
Continuous Injection
Update: 7/4/2010 16:1:25
Date

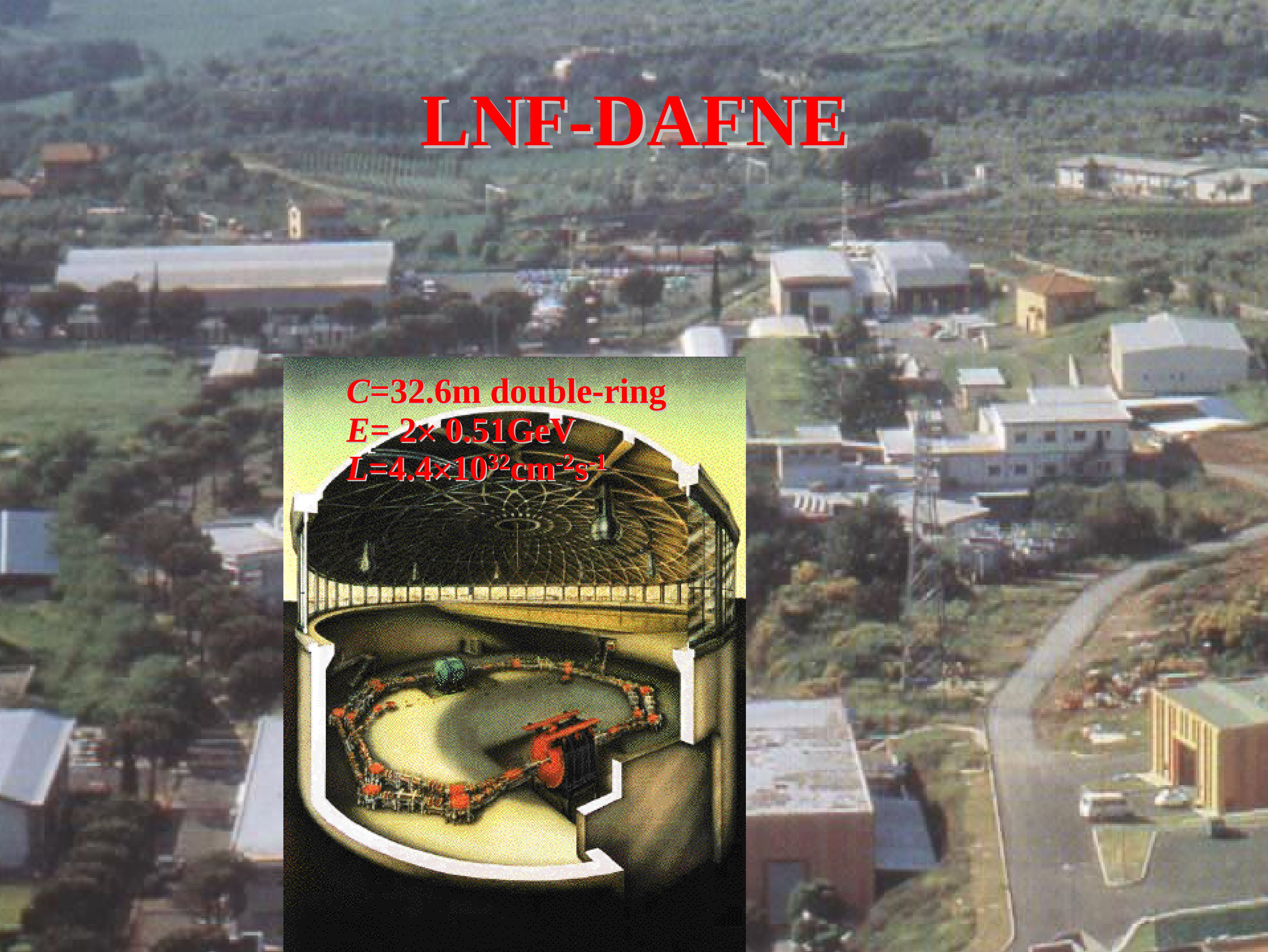

C=3 km double-ring
E= 8GeV(e^-) 3.5 GeV(e^+)
$L=2\times10^{34}cm^{-2}s^{-1}$

Super B-Factories

		Base Line		Low Emittance		High Current		τ-charm	
		HER	LER	HER	LER	HER	LER	HER	LER
Tune shift x		0.0021	0.0033	0.0017	0.0025	0.0044	0.0067	0.0052	0.0080
Tune shift y		0.097	0.097	0.0891	0.0892	0.0684	0.0687	0.0909	0.0910
Total RF Wall Plug Power	MW	16.38		12.37		28.83		2.81	



LNF-DAFNE

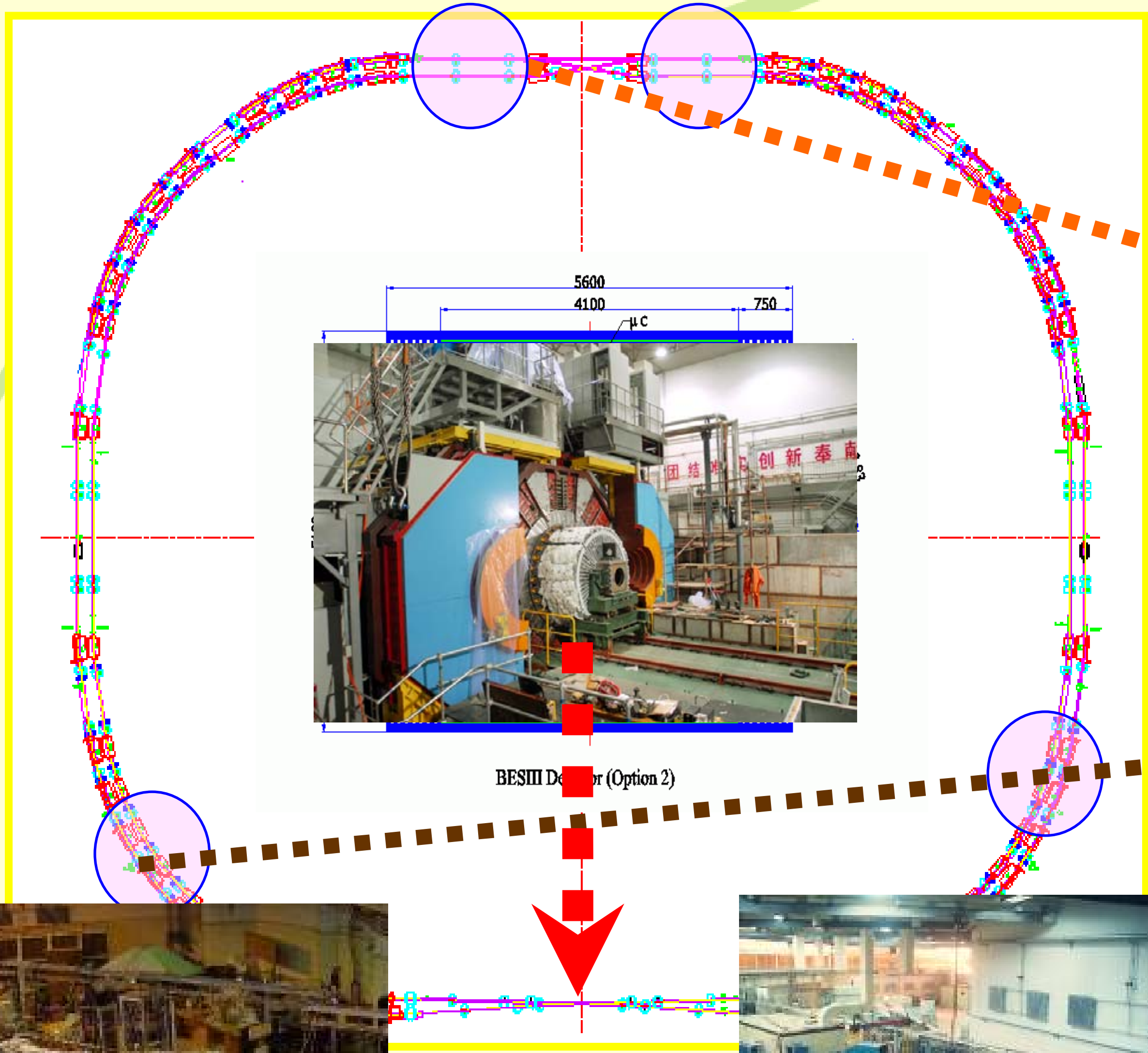


C=32.6m double-ring

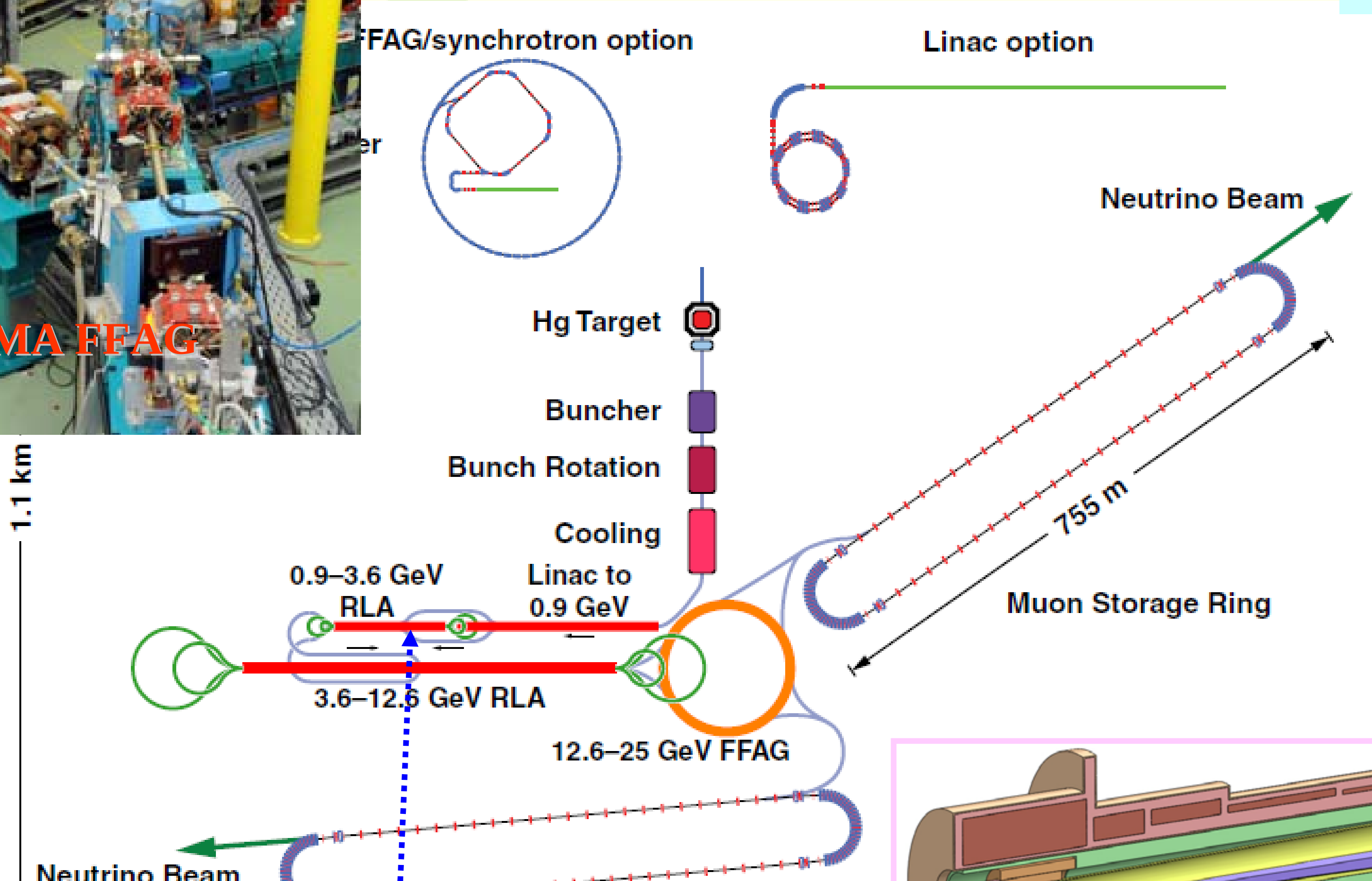
E= 2× 0.51GeV

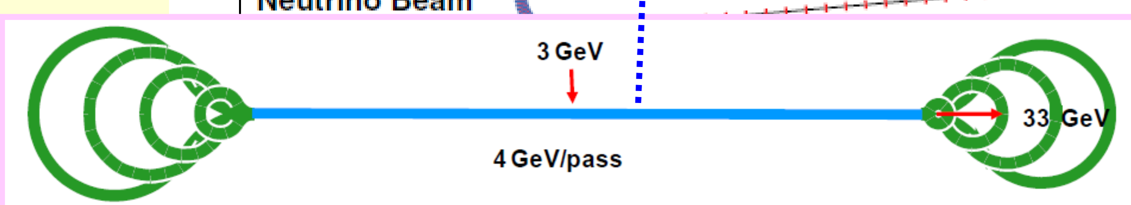
L=4.4×10^{32}cm^{-2}s^{-1}

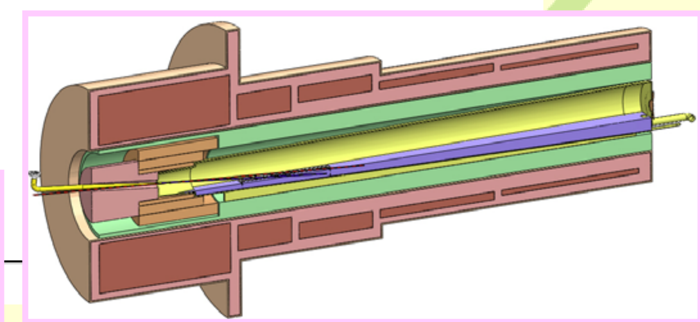
BEPCII: a double-ring e^--e^+ collider for charm-τ physics



Neutrino Factory







3.3 Multidisciplinary platforms

- Synchrotron radiation sources
- Free electron lasers
- Energy Recovery Linac
- Spallation neutron sources

3.3.1 Synchrotron Radiation Sources

- ***Energy loss per tern*：**

$$U_0(\mathrm{keV}) = 88.5\frac{E(\mathrm{GeV})^4}{\rho(\mathrm{m})}$$

BEPC：*E*=2.8GeV, r=10.345m，U_0=526keV

- ***Critical energy*：**

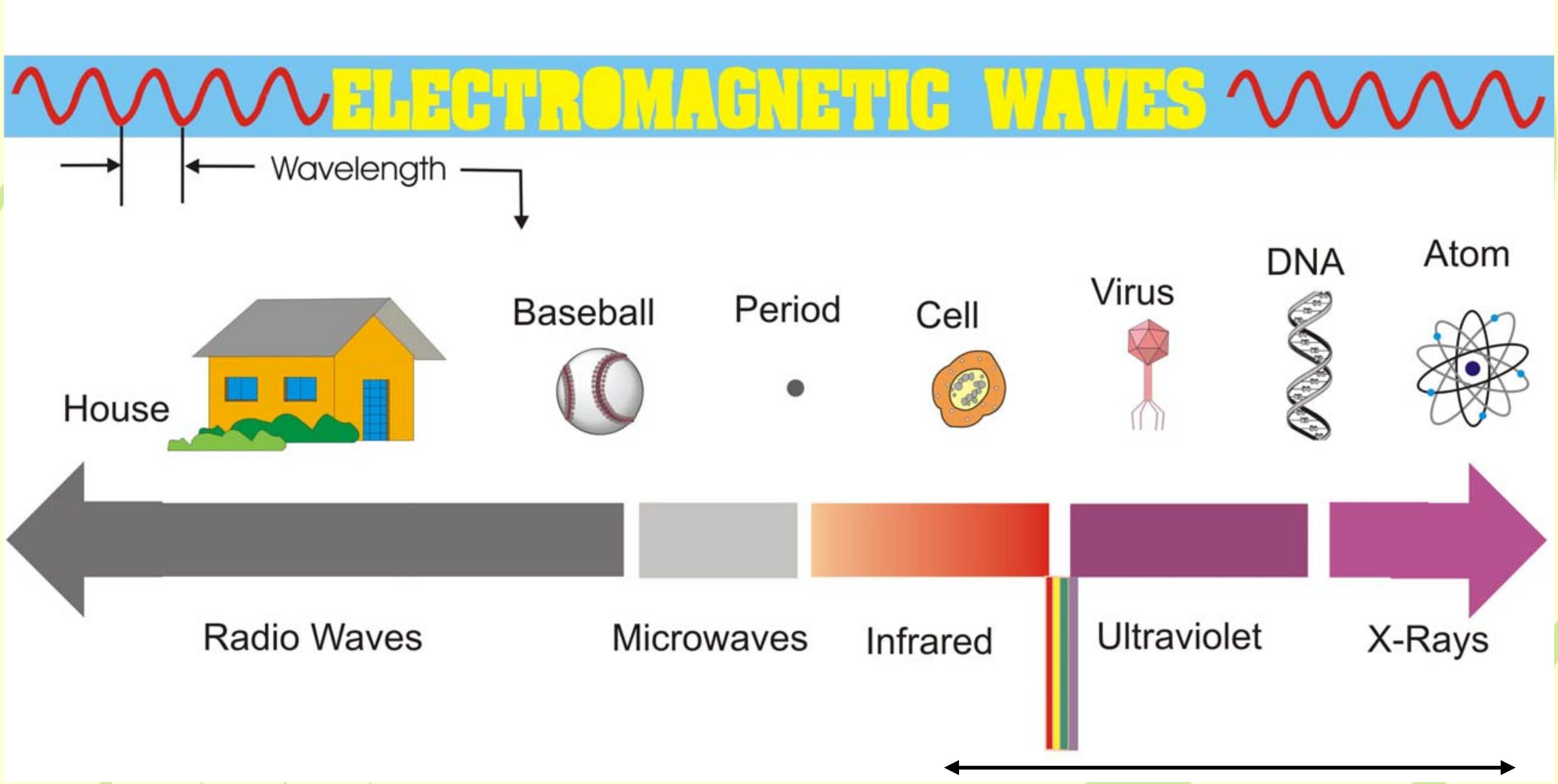
$$u_c(\mathrm{keV}) = 0.665E^3(\mathrm{GeV})B(\mathrm{T})$$

- ***Radiation damping***
  - ***z:* Higher the *E* more the U_0**
  - ***x* & *y*：$\Delta x', \Delta y' \neq 0$， $(\Delta x', \Delta y')_{RF}=0$**
- ***The Damping time***

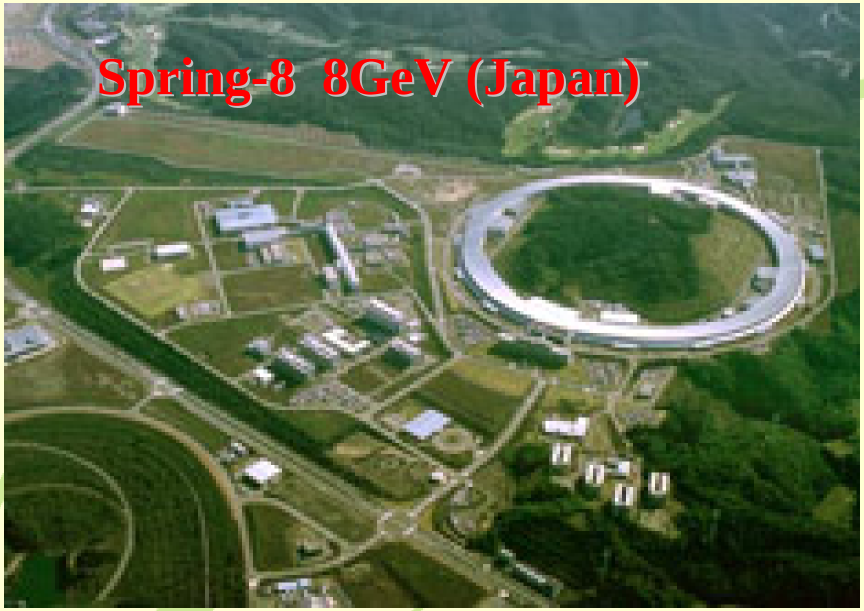
$$\tau_{x,y,e}(\mathrm{ms}) = \frac{C(\mathrm{m})\rho(\mathrm{m})}{13.2J_{x,y,e}E^3(\mathrm{GeV})}$$

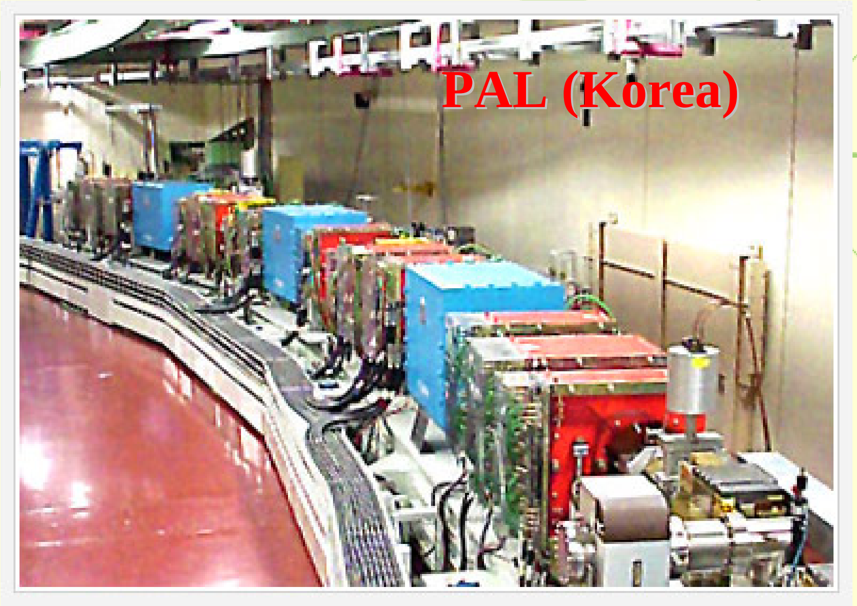
Electromagnetic Radiation

How it relates to the world we know



Synchrotron radiation is used for experiments typically over this region


Spring-8 8GeV (Japan)


PAL (Korea)


SSRF 3.5GeV (China)


SSRC 1.5GeV (Taiwan)


Indus-2 2.5GeV (India)

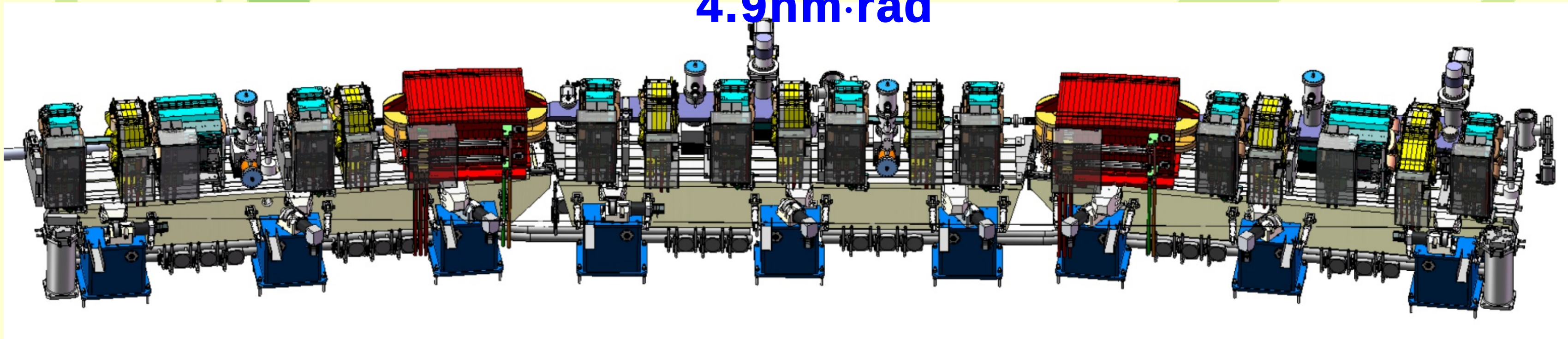
SIAM 1GeV (Thailand)
TOSHIBA

SSLS 0.5GeV (Singapore)

SESAME 2.5GeV (Jordan)

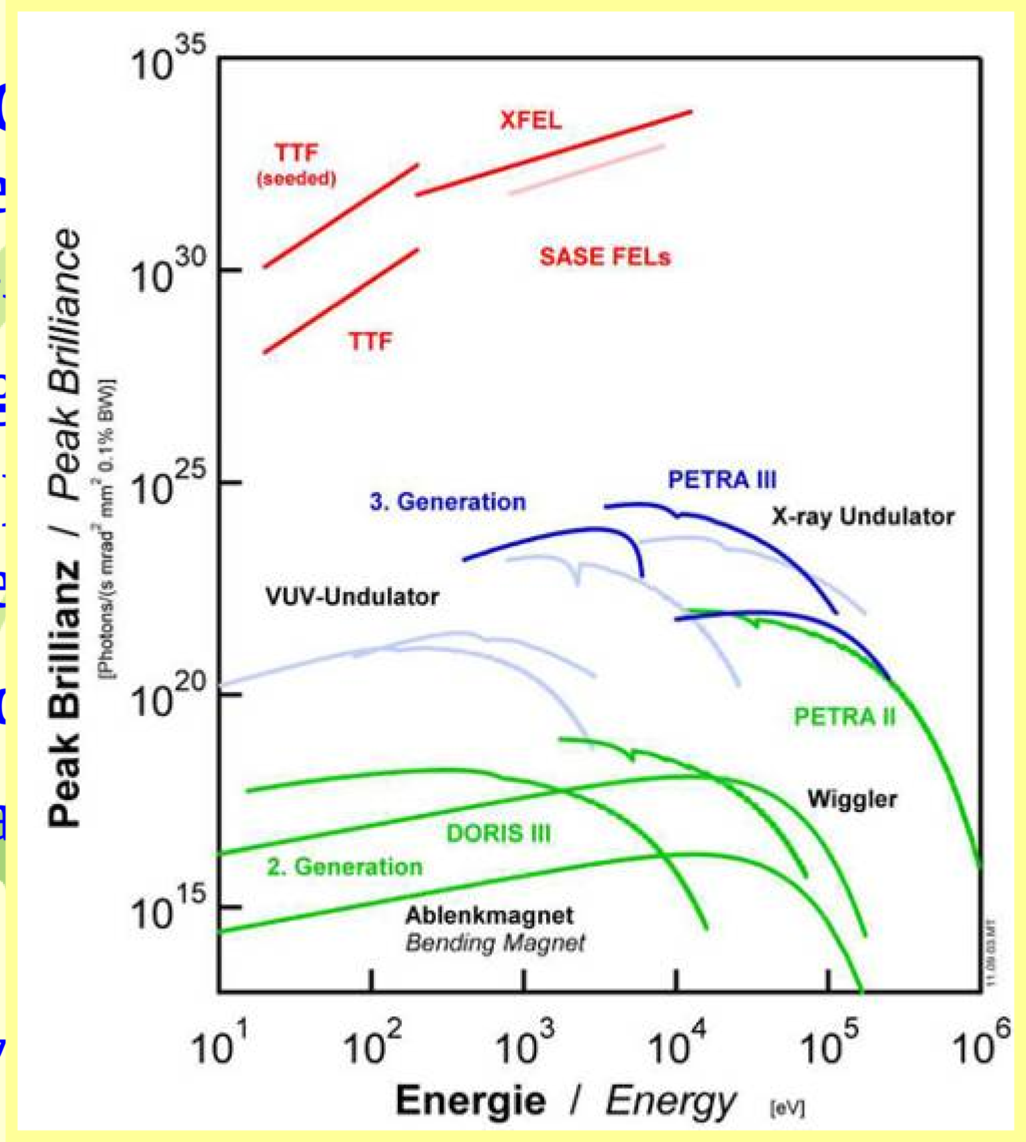
TPS

3GeV, 1.6–4.9nm·rad



3.3.2 Free Electron Lasers (FEL)

- FEL (… rons of accele…
- The " … e electrons ➔ hig … e …
- Two … ne IR and UV re … rd X ray).
- Worl … on.
- China
- From … GHG.
- Many

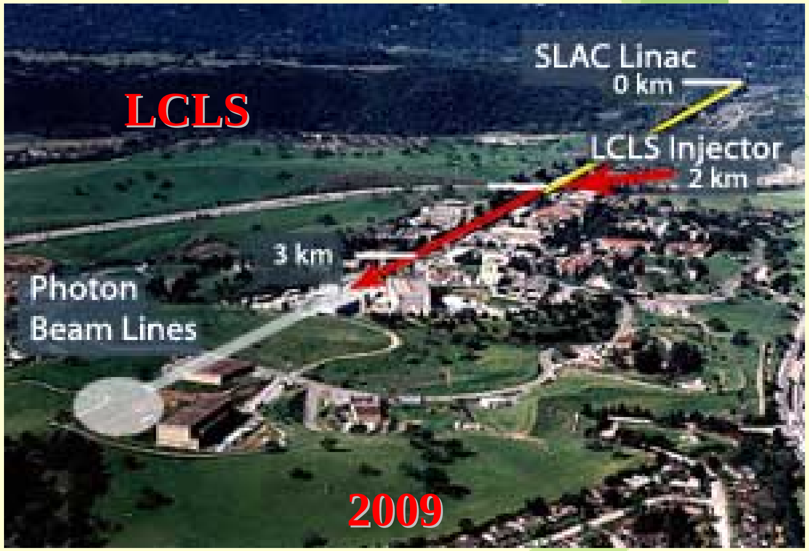


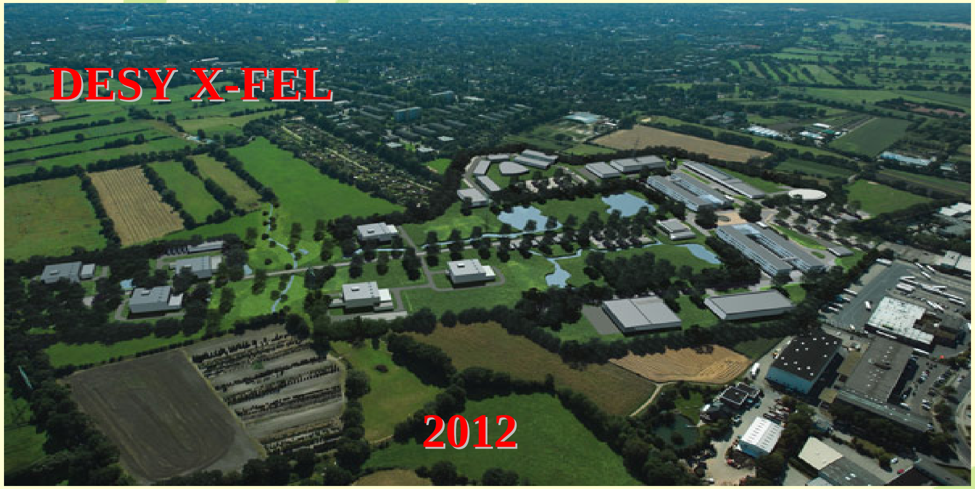
XFELs coming soon

X-Ray Free-Electron Laser Projected Parameters

	LCLS (US)	DESY XFEL (Europe)	SCSS (Japan)
Pulse duration	<230 fs	100 fs	80 fs
Wavelength	1–64 Å	1–15 Å	1–50 Å
Repetition rate	120 Hz	10 Hz	60 Hz
Electron bunches per pulse	1	≤3000	1
Electron beam energy	4–14 GeV	≤20 GeV	≤8 GeV
Photons per pulse ($\times 10^{12}$)	1.2 (at 1.5 Å)	1.2 (at 1 Å)	0.76 (at 1 Å)
Linac length	1 km	2 km	350 m
Estimated cost*	$379 million	$1 billion	$330 million
Estimated start date	2009	2012	2010

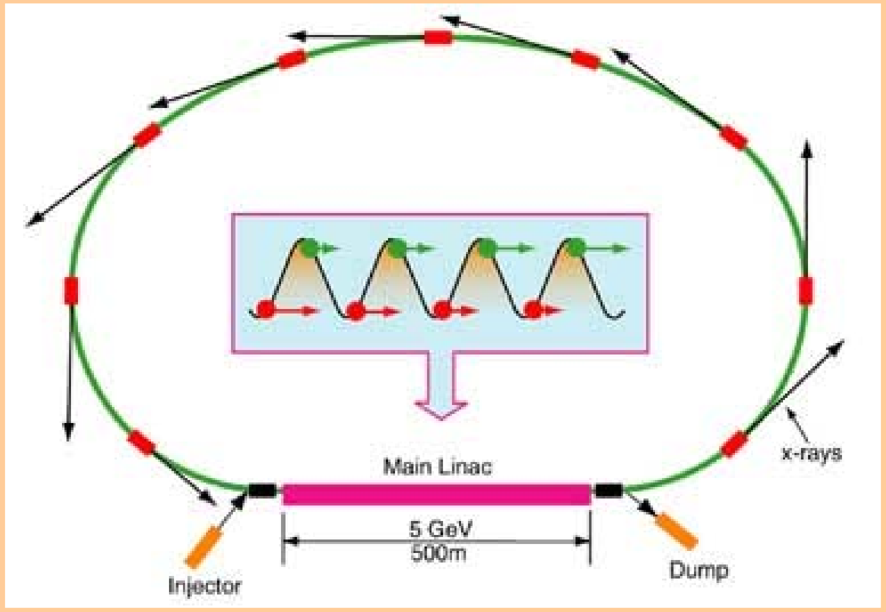
*Estimates include varying amounts of instrumentation and different methods of accounting.

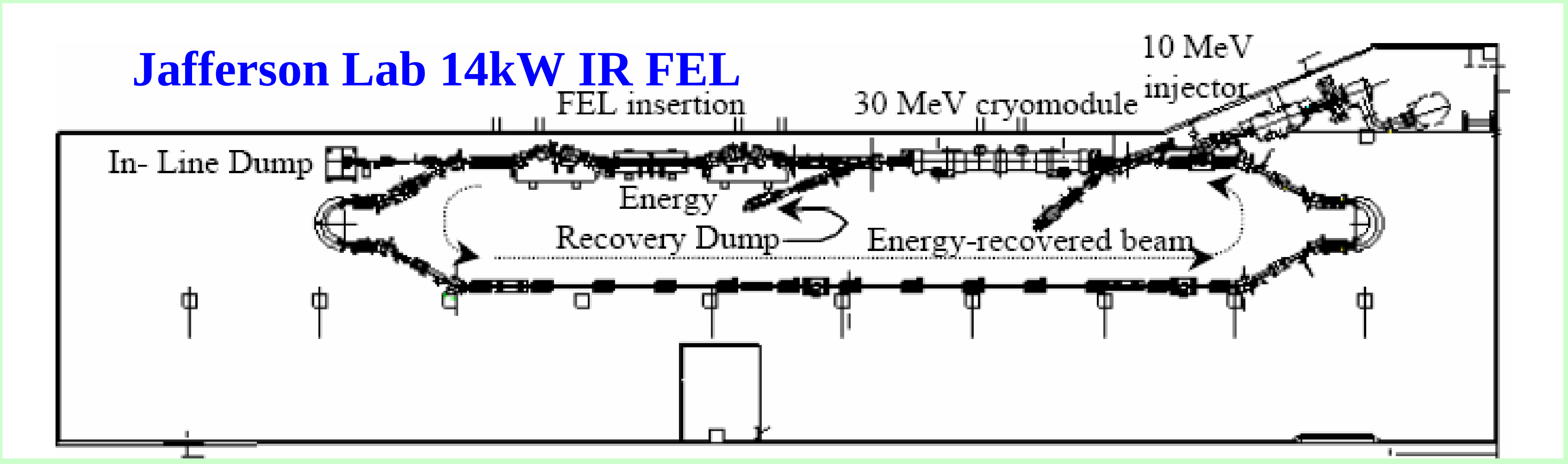




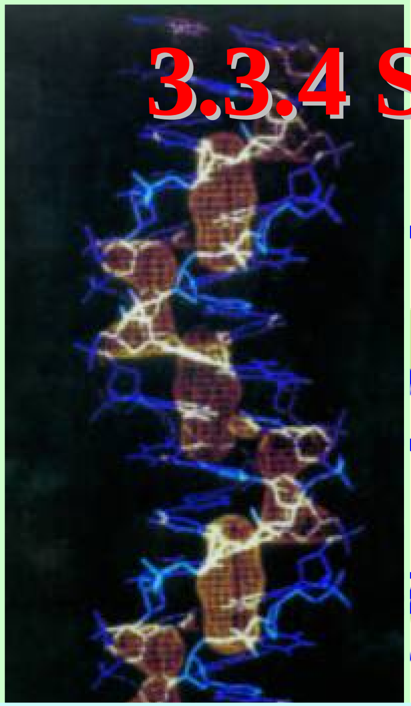
3.3.3 Energy Recovery LINAC (ERL)

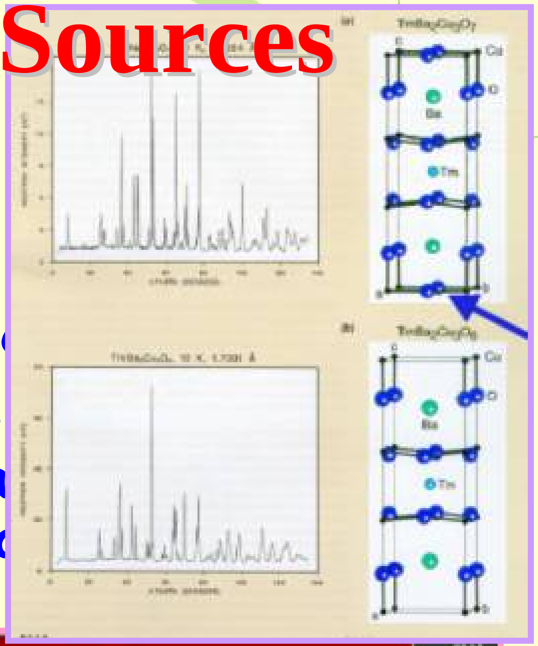
- Very high average brilliance ➨ ~10^{23} ph./mm^2/mrad^2/0.1%/s ;
- Many beamlines ➨ more users;
- Femto-second pulse with high repetition ➨ molecular dynamics…
- Coherence ➨ Imaging of non-crystalline materials …





3.3.4 Spallation Neutron Sources





ons show unique properties:

ro magnetic moment in spite of

ngth of the order of interatomi

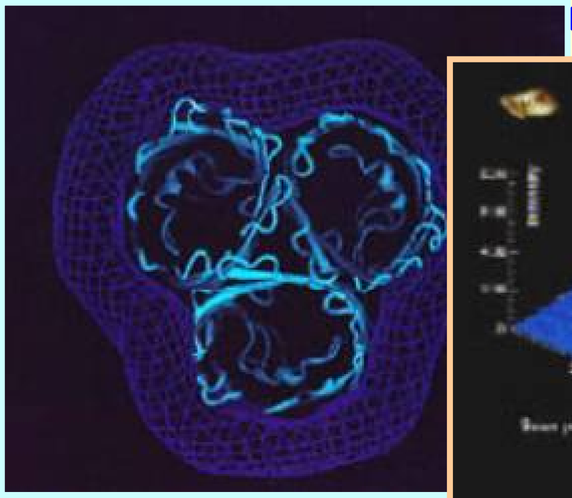
able to collective excitations in

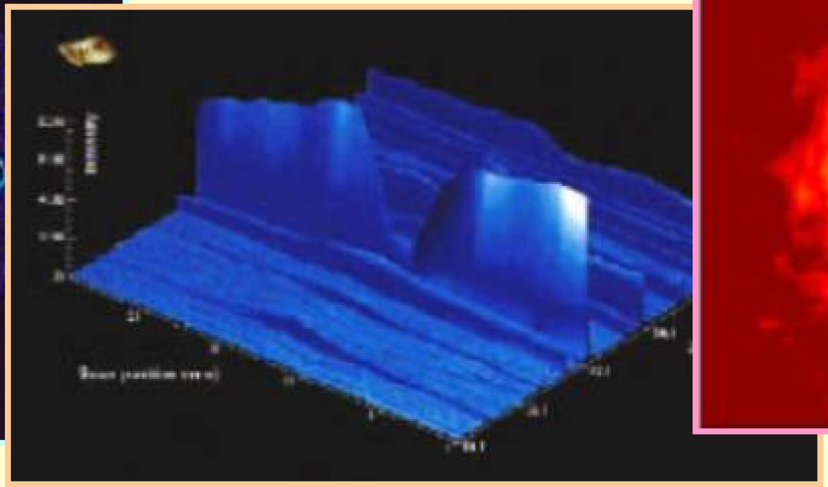
t to reactor source, SNS is a

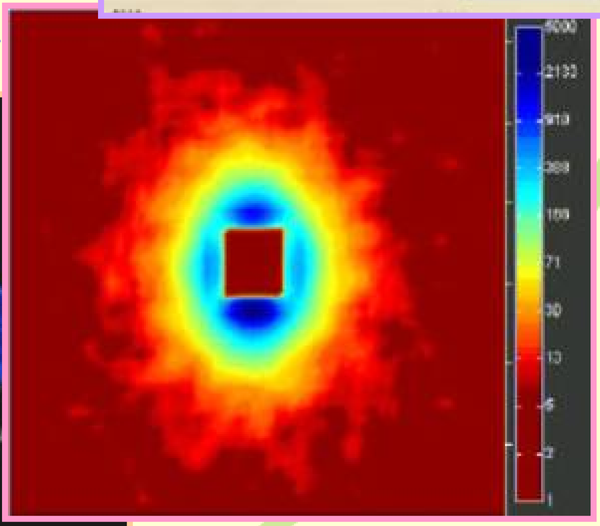
h resolution, low background

energy.

entary with synchrot



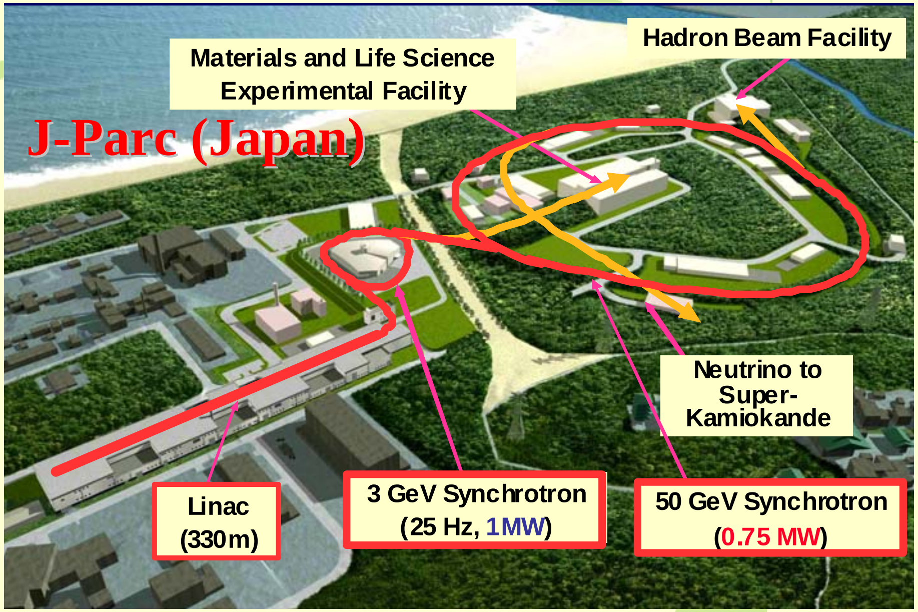




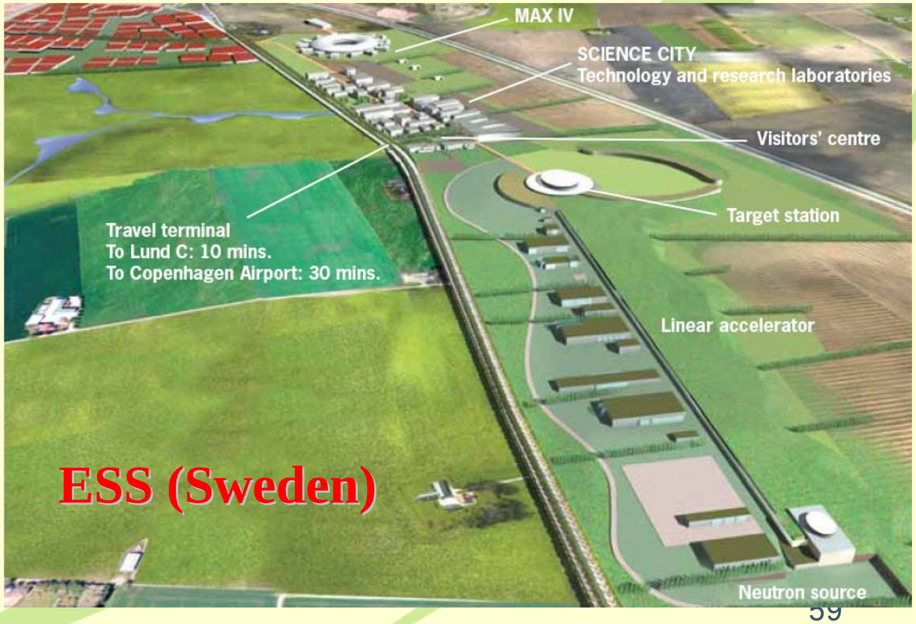
Existing and planned spallation neutron sources

Name	Status	Beam Energy (GeV)	Ave.Beam Power (MW)	Repetition rate (Hz)	Proton per pulse (10^{13})	Pulse length (μs)
IPNS ANL	Operat. 1981	0.05 linac 0.5 RCS	0.0075	30	0.3	0.1
ISIS RAL	Operat. 1981	0.07 linac 0.8 RCS	0.16	50	2.5	0.45
SINQ PSI	Operat. 1981	0.59 Cyclotron	≤0.9	CW	-	-
LANCE LANL	Operat. 1981	0.8 linac	0.08	20	3	0.27
LANCE II LANL	Plan	0.8 linac	1.0	30	-	1200
SNS US	Operation	1.0 linac A.R.	1 → 5	60	10	0.55
J-Parc	Operation	0.4 linac 3.0RCS	1.0	25	8.3	<1
ESS Europe	Plan	1.33 linac A.R.	5.0	50	47	1
CSNS China	Plan	0.08 linac 1.6 RCS	0.12 →0.5	25	2	0.4


SNS (US)
Front-End Building
Klystron Building
Central Helium Liquefaction Building
Linac Tunnel
Ring
Radio-Frequency Facility
Target
Future Target Building
Support Buildings
Central Laboratory and Office Complex
Center for Nanophase Materials Sciences
Joint Institute for Neutron Sciences


J-Parc (Japan)
Materials and Life Science Experimental Facility
Hadron Beam Facility
Neutrino to Super-Kamiokande
Linac (330m)
3 GeV Synchrotron (25 Hz, 1MW)
50 GeV Synchrotron (0.75 MW)


PEFP (Korea)

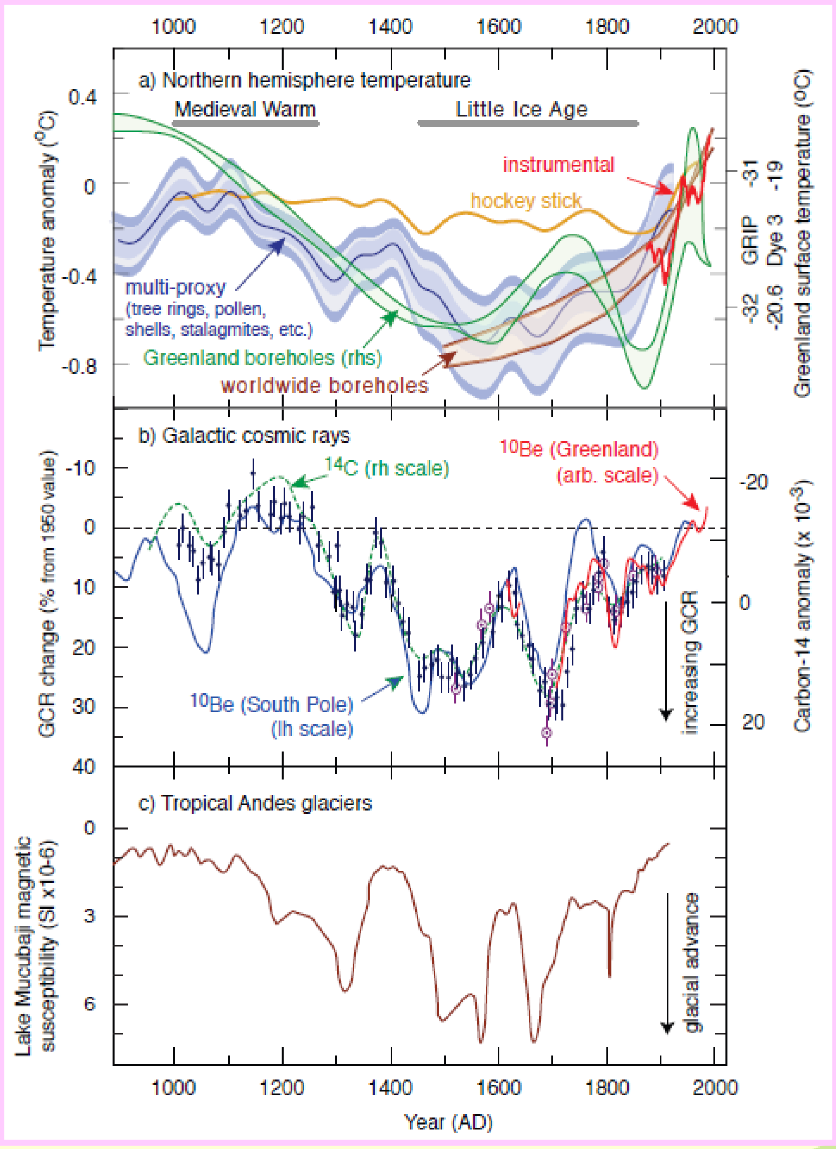

MAX IV
SCIENCE CITY
Technology and research laboratories
Visitors' centre
Target station
Travel terminal
To Lund C: 10 mins.
To Copenhagen Airport: 30 mins.
Linear accelerator
ESS (Sweden)
Neutron source

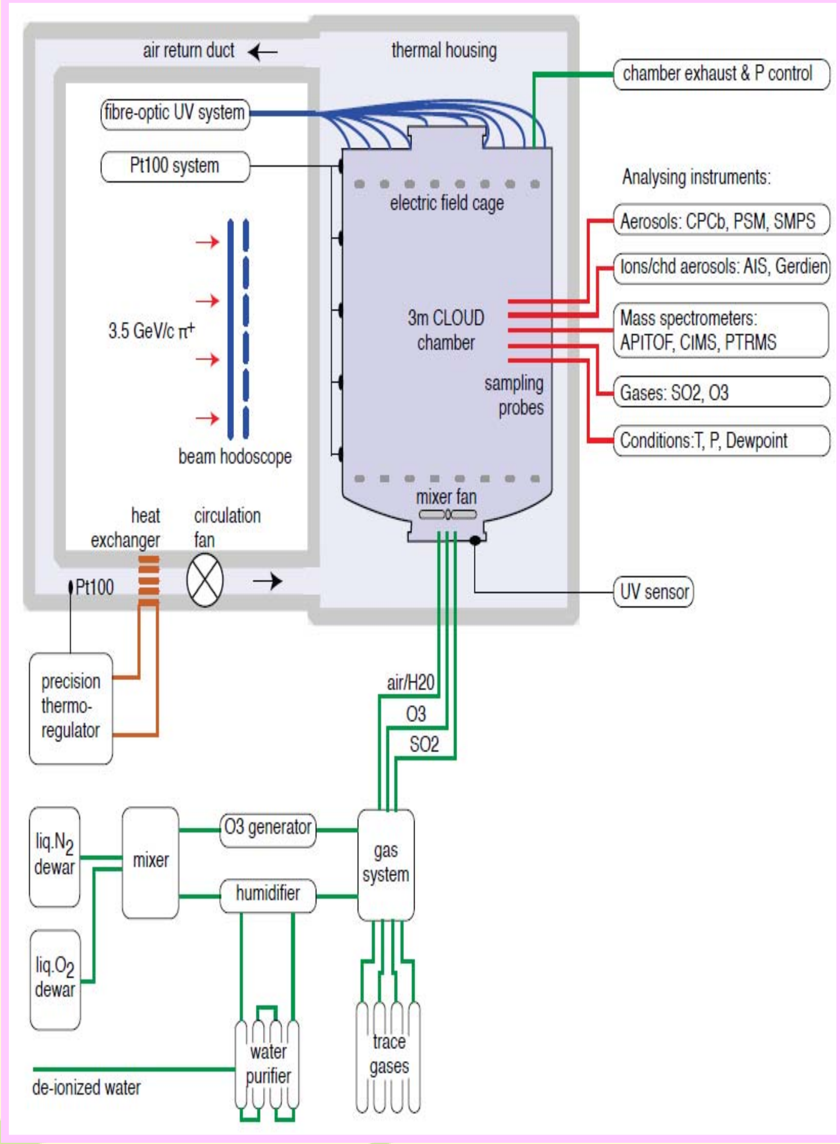
3.4 Application of accelerators

Although accelerators were developed for particle physics, many thousands of them are put to practical uses in other branches of scientific research as well as in industry, agriculture, medicine and many other fields of our society.

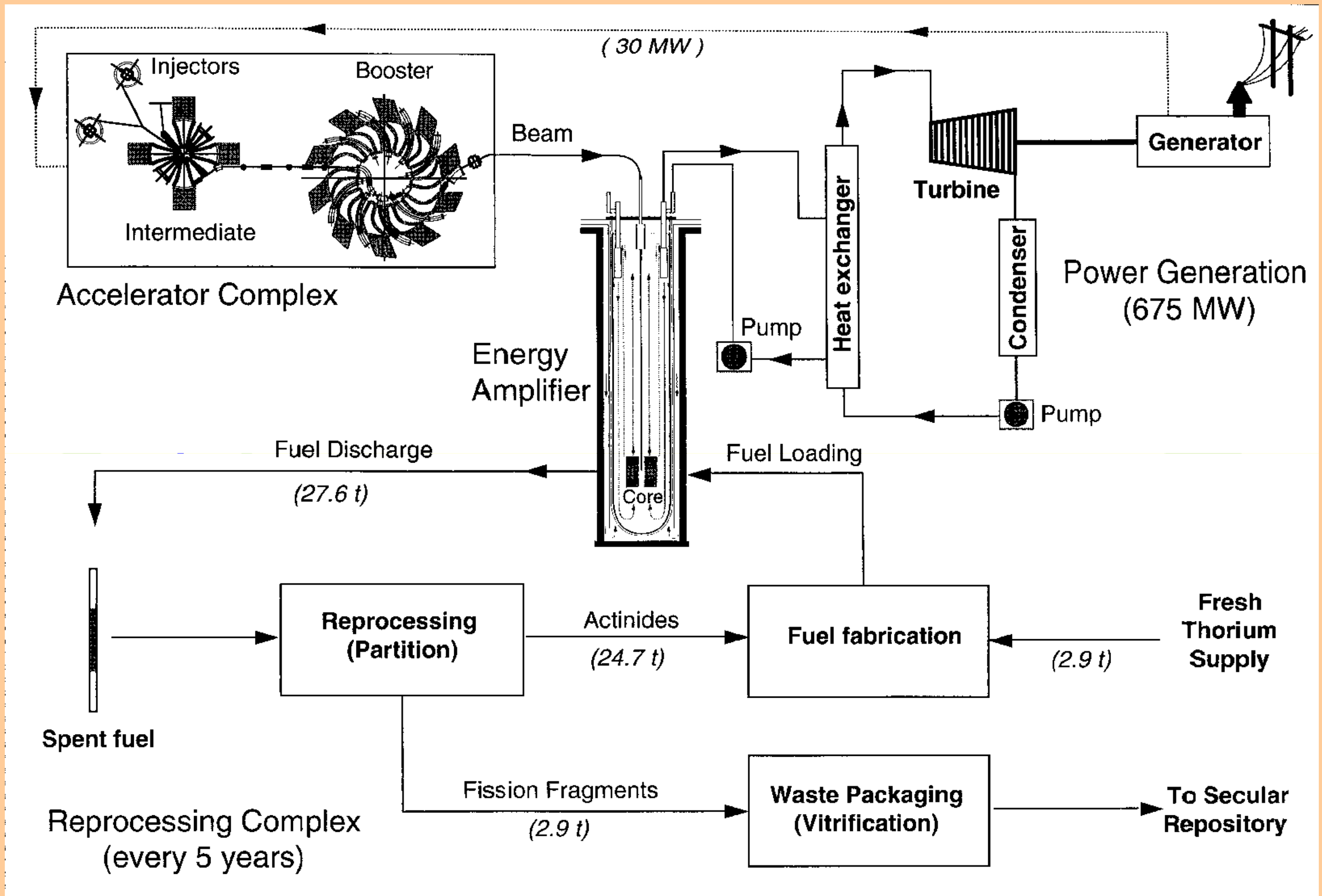
- **Accelerator Driven Sub-critical reactor**
- **Nuclear waste transmutation**
- **Medical accelerators**
- **Irradiation**
- **Non-destructive inspection**

Messages from IPAC'10

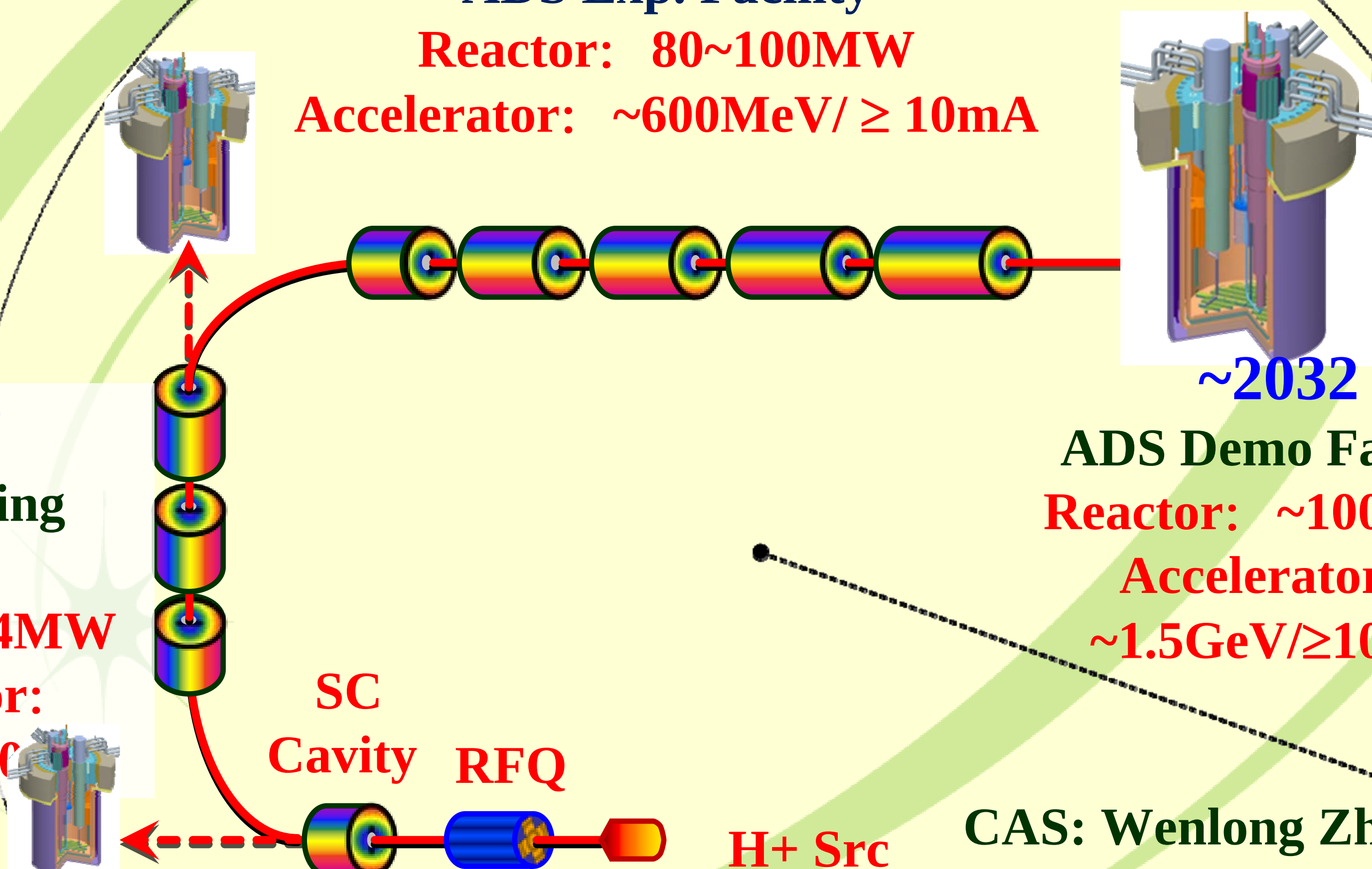




3.4.1 Accelerator Driven Sub-critical reactor (ADS)



China's Roadmap for ADS



~2022
ADS Exp. Facility
Reactor: 80~100MW
Accelerator: ~600MeV/ ≥ 10mA

~2017
ADS Testing Setup
Reactor: ~4MW
Accelerator:
40MeV/ ≥ 10

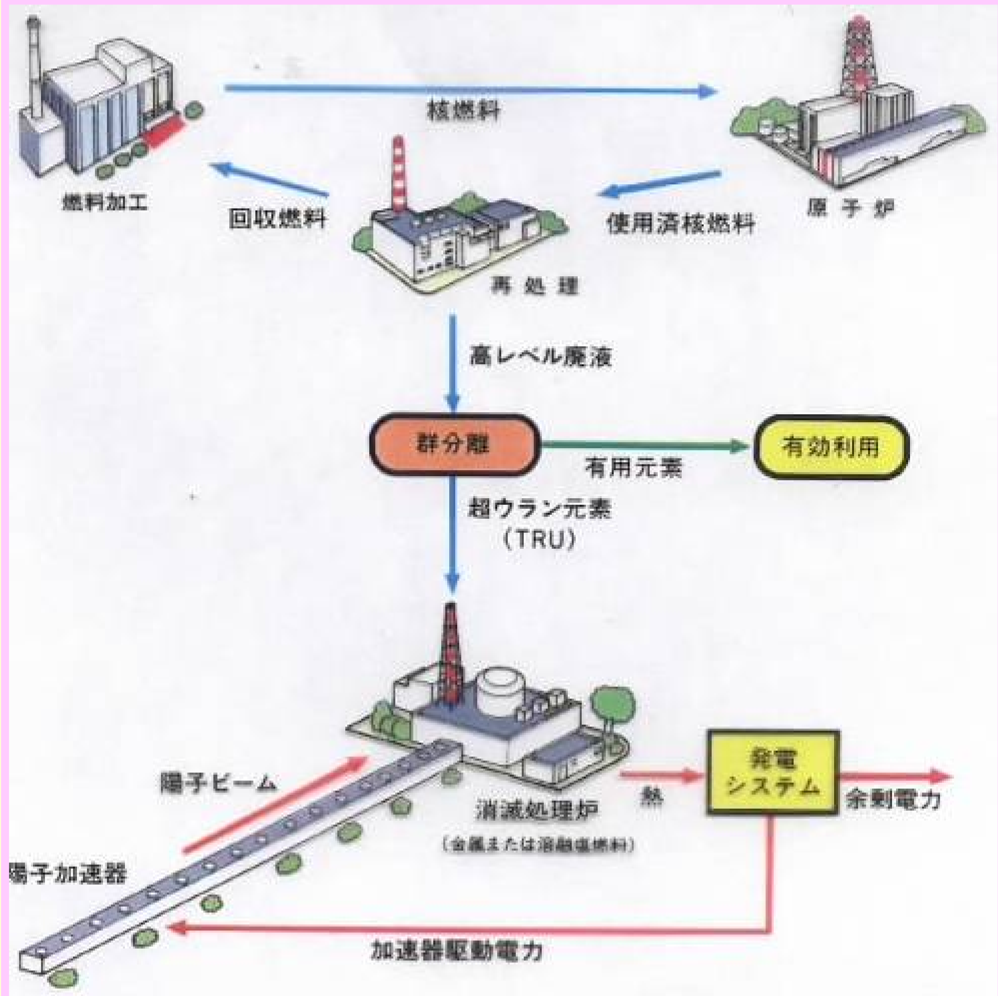
~2032
ADS Demo Facility
Reactor: ~1000MW
Accelerator:
~1.5GeV/≥10mA

CAS: Wenlong Zhan

July 7, 2010

3.4.2 Nuclear waste transmutation

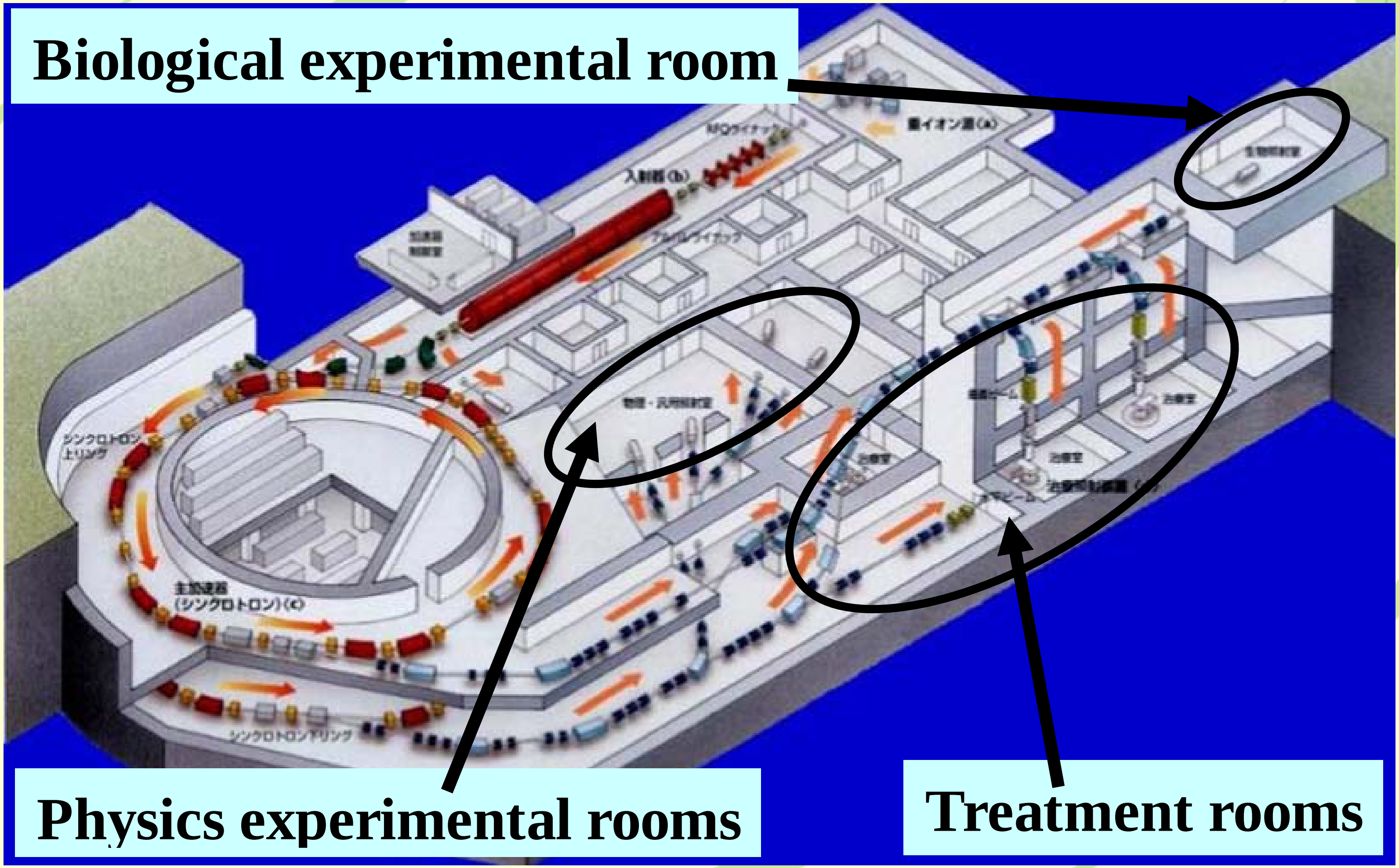
The concept of energy amplifier is extended to the transmutation of long-lived nuclear waste. The idea is to mix nuclear plutonium waste with the thorium fuel so that it also undergoes fission and breaks up into harmless elements.



3.4.3 Medical accelerators

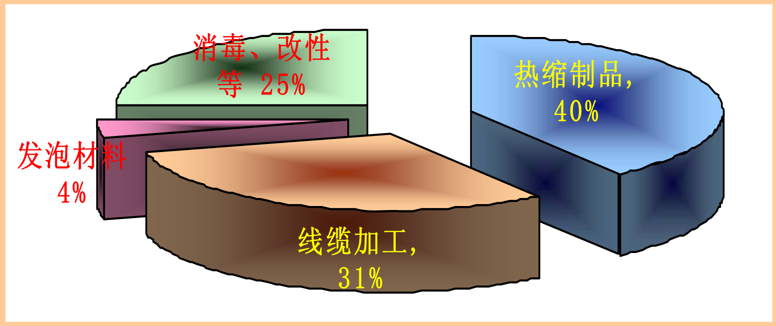
HIMAC

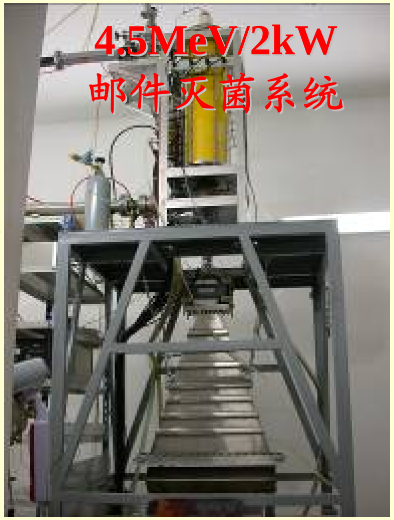
Heavy Ion Medical Accelerator in Chiba



3.4.4 Irradiation

据不完全统计，我国已建成的功率在5kW及其以上的工业用电子辐照加速器有100多台，总功率已超过6MW，仅2005年以来的4年里，新增建的加速器辐照生产线约20条。

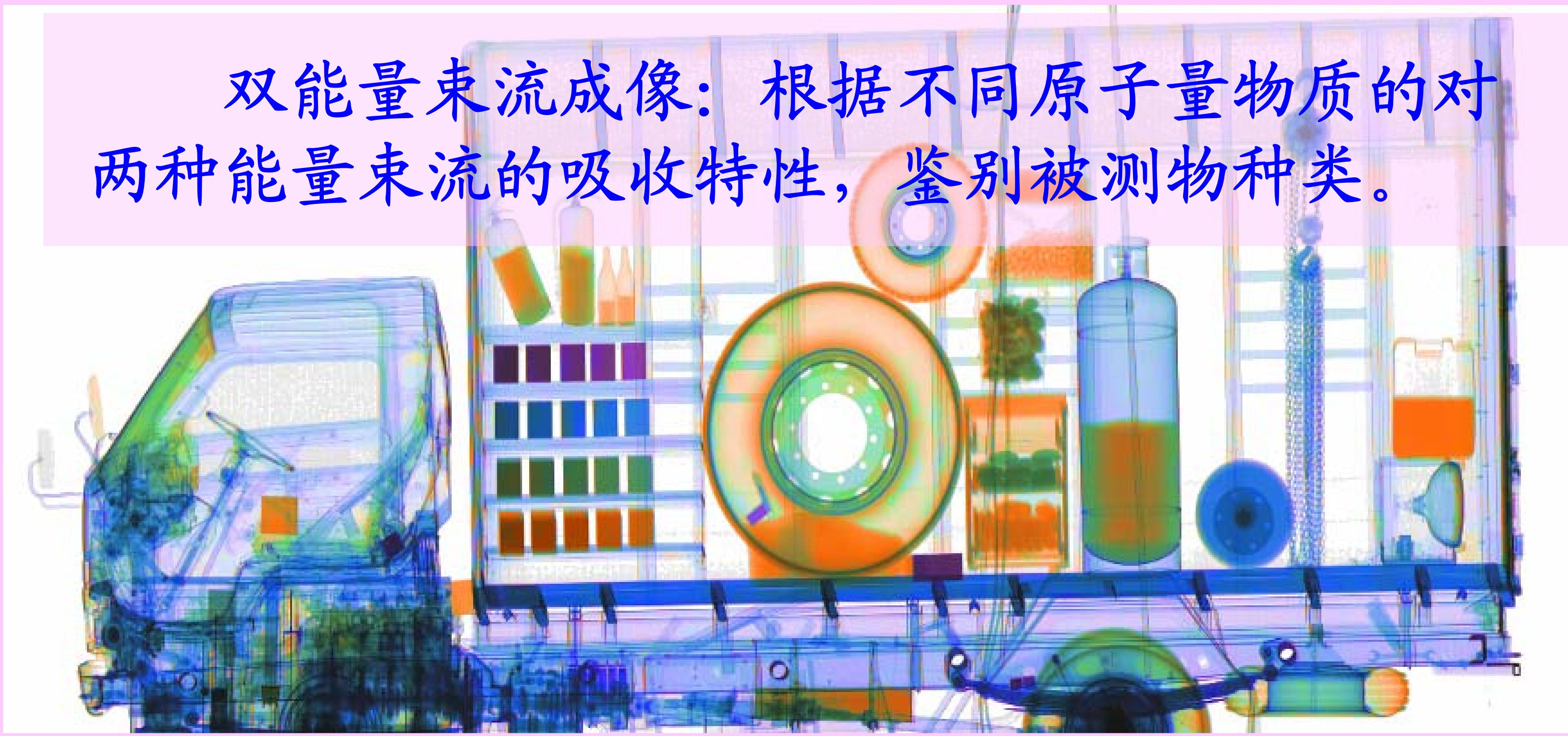




3.4.5 Non-destructive inspection

e.g. Container inspection facilities

双能量束流成像：根据不同原子量物质的对两种能量束流的吸收特性，鉴别被测物种类。



3.5 New methods and Technologies

The novel acceleration methods proposed so far can be classified into two catalogs;

- To transfer energy from photons to particle beams; laser accelerators of different kinds, such as beat-wave accelerators, grating accelerator, inverse Cherenkov effect accelerator, inverse FEL accelerators and others. The maximum electric field in laser can be as high as key issue 10^5~10^9 MV/m, while the key issue is how to obtain the E_z component at the beam direction.
- To transfer energy from one beam to another beam:
  - A high-speed moving beam directly drives the accelerated beam: smoke-ring accelerator, linear beam accelerator, etc.
  - Wake field accelerators (WFA): laser WFA, plasma WFA, dielectric WFA, coupled wake tube accelerator and two beam accelerator.

Various wake field acceleration approaches

WF Device	Max. Drad.	Advantages	Disadvantages	Experimental Status
LWFA Laser WFA	multi-GV/m	High-gradient	Requires powerful short pulse laser. Poor efficiency.	Preliminary experiments underway; electrons are captured and accelerated
PWFA Plasma WFA	≈ GV/m	High-gradient	Requires difficult drive beam, alignments. Same focus problem as LWFA	Acceleration of injected beam at 5-7MeV/m using few nC drive beam
Iris loaded WFA	50MV/m	Simple and well understood	Low gradient, requires good beam-beam alignment.	Similar to PWFA
DWFA Dielectric WFA	100MV/m	Very simple; Deflection modes damped	Requires difficult drive beam, good beam-beam alignment.	Similar to PWFA
CWTA Coupled Wake Tube	500MV/m	Stepped up gradients; beam-beam effects small. Simple extension of acceleration possible.	Requires efficient coupling of RF power,. Drive beam less difficult than DWFA	Experiment under construction

Laser plasma accelerators produced "Dream beam" followed up by worldwide experiments

ICL/RAL, UK

"Monoenergetic beams of relativistic electrons from intense laser-plasma interactions"

S. P. D. Mangles et al., NATURE, 431, 535, 2004.

LBNL, US

"High-quality electron beams from a laser wakefield accelerator using plasma-channel guiding"

C. G. R. Geddes et al., NATURE, 431, 538, 2004.

LOA, France

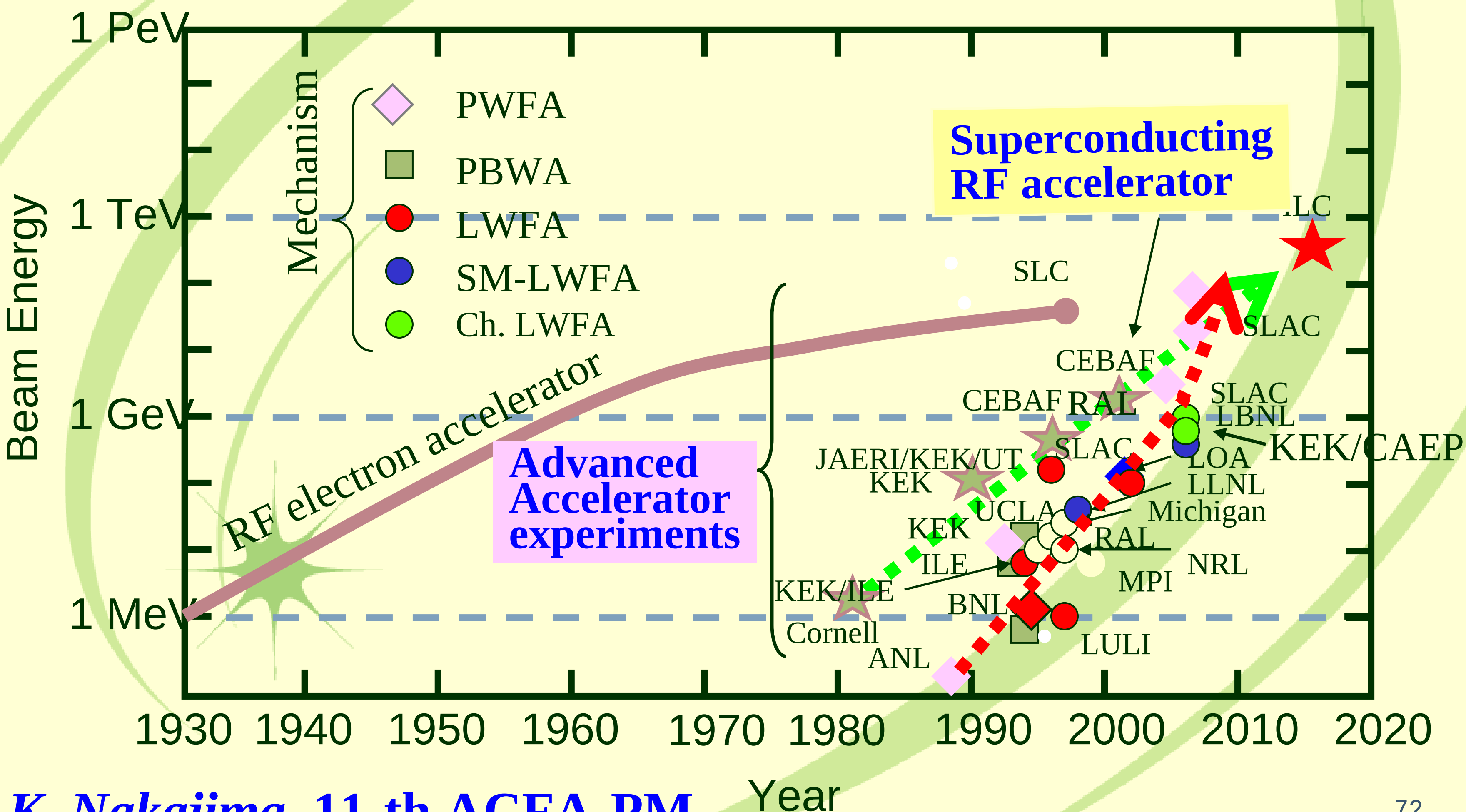
"A laser-plasma accelerator producing monoenergetic electron beams"

J. Faure et al., NATURE, 431, 541, 2004.

Thomas Katsouleas, NATURE, 431, 515, 2004

History of Accelerators - Livingston chart

Advanced Accelerators gear up to TeV



***K. Nakajima*, 11-th ACFA-PM**

International collaboration on High-energy Laser-plasma Acceleration at CAEP, China

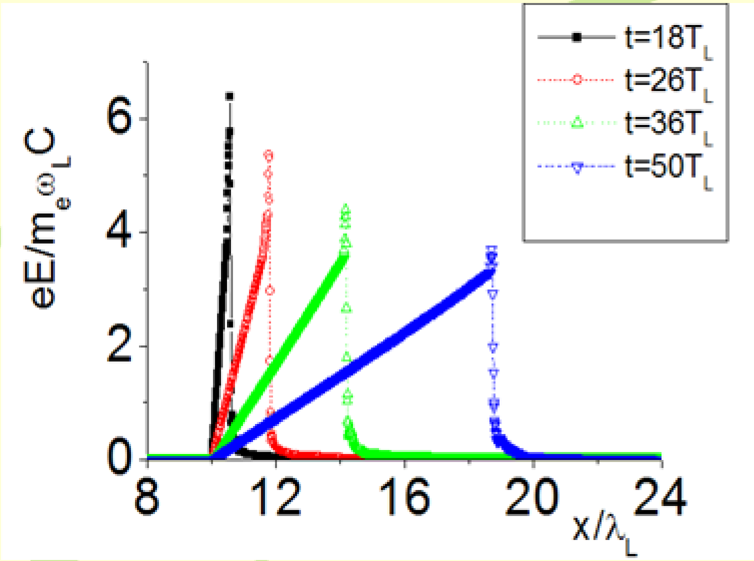
Phase-I:

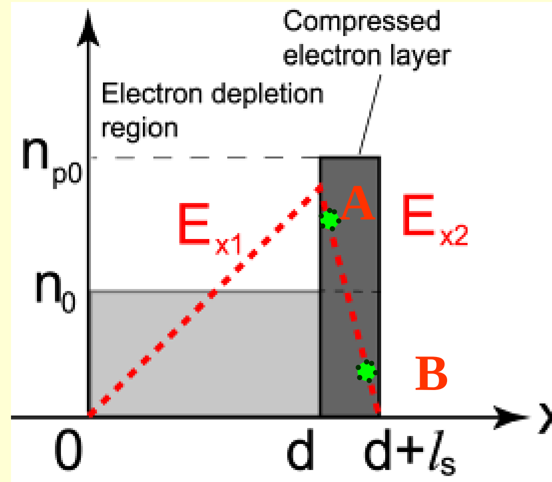
1 GeV monoenergetic electron acceleration with 10 mm size gas jet and a long focusing optics

Phase-II:

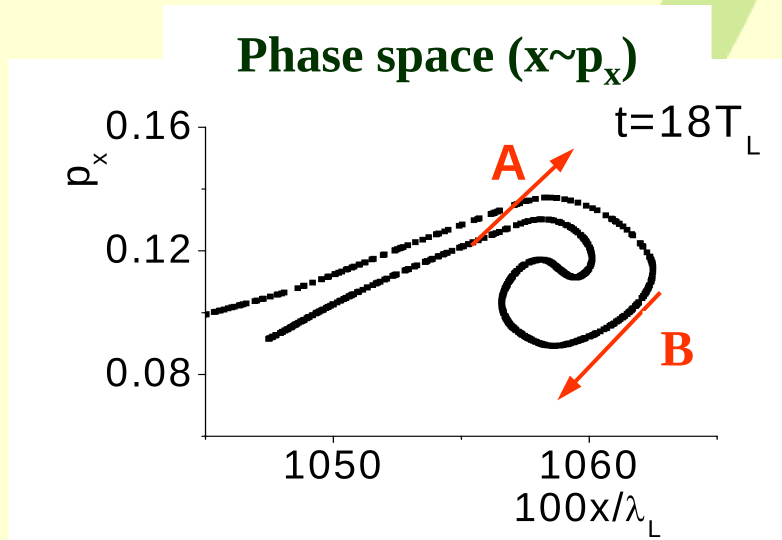
Multi-GeV monoenergetic electron acceleration with a long-range discharge plasma channel

北京大学激光加速质子的研究





提出新的激光加速机制—稳相加速

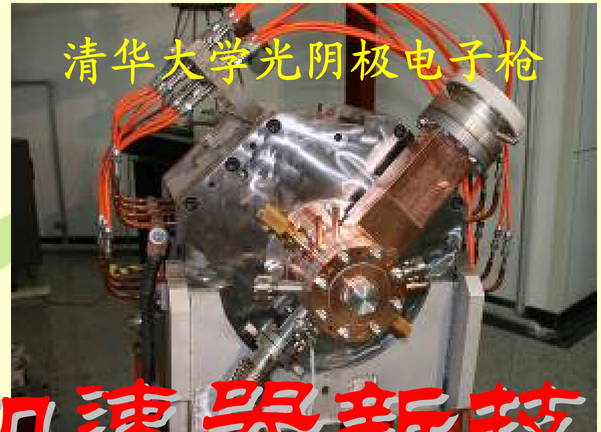


在相稳定加速区内用圆偏振激光脉冲产生单能强流质子束

PRL 100, 135003 (2008) PHYSICAL REVIEW LETTERS week ending 4 APRIL 2008

加速器新技术


近物所超导ECR源


清华大学光阴极电子枪

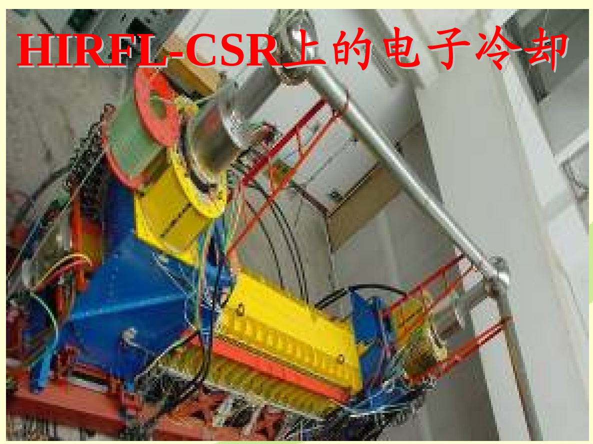

高能所正电子源

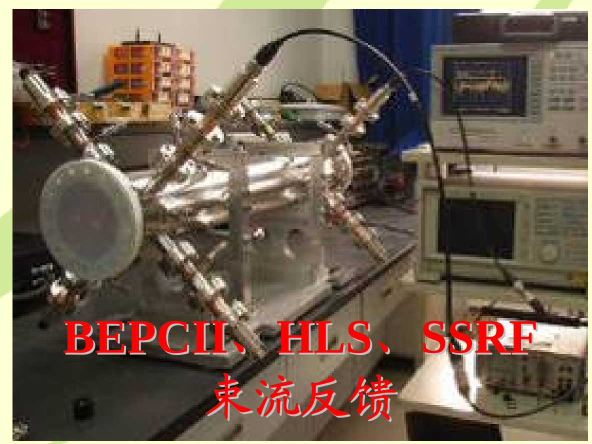

北大光阴极注入器


北大超导加速器


SSRF和BEPCII超导腔


原子能院1/4波长
超导谐振腔


HIRFL-CSR上的电子冷却


BEPCII、HLS、SSRF
束流反馈


北京大学国产实用型多Cell
射频超导腔发展
我国第一只纯铌超导腔
QWR腔
北京大学射频超导课题组成立
1988
1994
2000
2002
2005
2006
2007
2008
2009
2×3.5cell
2×9cell

76

(4) *Future science and accelerators*

- **Higher beam energy**
- **Higher beam intensity**
- **Higher time resolution**
- **Higher spatial resolution**

North Sea
NORWAY
London
Oslo
SWEDEN
FINLAND
DENMARK
Copenhagen
Stockholm
Helsinki
Berlin
POLAND
Warsaw
St. Petersburg
Minsk
BELARUS
Rostov
Moscow
ROMANIA
Kiev
Gorkiy
Perm
Bucharest
Volga
Kazan
Sverdlovsk
BULGARIA
UKRAINE
Ufa
Chelyabinsk
Krasnojarsk
Istanbul
Saratov
Kuybyshev
Omsk
Novosibirsk
Irkutsk
Black Sea
Volgograd
Krasnodar
Ankara
TURKEY
GEORGIA
ARMENIA
AZERBAIJAN
Caspian Sea
Astana
Qaraghandy
Aral Sea
KAZAKHSTAN
SYRIA
UZBEKISTAN
TURKMENISTAN
Tashkent
Bishkek
Alma Ata
Lake Balkhash
Urumqi
KYRGYZSTAN
Baghdad
IRAQ
Tehran
Esfahan
Ashgabat
Dushanbe
TAJIKISTAN
Basra
KUWAIT
IRAN
Shiraz
AFGHANISTAN
Kabul
Islamabad
Riyadh
BAHRAIN
QATAR
Multan
Indus
New Delhi
SAUDI ARABIA
UAE
PAKISTAN
Jaipur
Agra
NEPAL
Kathmandu
BHUTAN
Muscat
Ganges
Sanaa
YEMEN
OMAN
Arabian Sea
Allahabad
BANGLADESH
Ahmadabad
Dhaka
Surat
Kolkata (Calcutta)
(Bombay) Mumbai
Nagpur
Pune
MYANMAR
Bay of Bengal
INDIA
Chennai (Madras)
Cochin
SRI LANKA
Colombo
I N D I A N
O C E A N
Barents Sea
Kara Sea
Laptev Sea
Lena
Aldan
Ob'
Yenisey
Angara
RUSSIA
Lake Baykal
Sea of Okhotsk
Amur
P A C I F I C
O C E A N
Sapporo
Sendai
Sea of Japan
Qiqihar
Jixi
Harbin
Jilin
Tokyo
JAPAN
NORTH KOREA
Ulaanbaatar
MONGOLIA
Benxi
Fuxin
Pyongyang
Beijing
Seoul
SOUTH KOREA
Baotou
Taian
Yellow Sea
Yinchuan
Taiyuan
Xining
Kaifeng
Lanzhou
Xian
Hefei
Shanghai
Ningbo
East China Sea
CHINA
Yangtze
Mianyang
Chengdu
Yueyang
Fuzhou
Wenzhou
Zigong
Xiamen
TAIWAN
Dukou
Guiyang
Shantou
Nanning
Hong Kong
Hanoi
South China Sea
LAOS
Vientiane
Manila
PHILIPPINES
Rangoon
Mekong
THAILAND
VIETNAM
Bangkok
CAMBODIA
Davao
Phnom Penh
Ho Chi Minh City
BRUNEI
MALAYSIA
Kuala Lumpur
SINGAPORE
INDONESIA
Tropic of Cancer

1000 times higher energy

Acceleration Technology

1 PeV=10^{15} eV

Laser-plasma LC

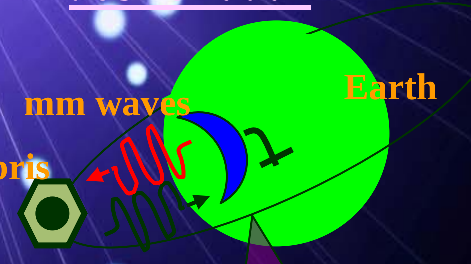
"New paradigm"

Leptogenesis

SUSY breaking

Earth-based space debris radar

Two-beam LC



Extra dimension
Dark matter
Supersymmetry

Ultra-High Voltage STEM with Superconducting RF cavity

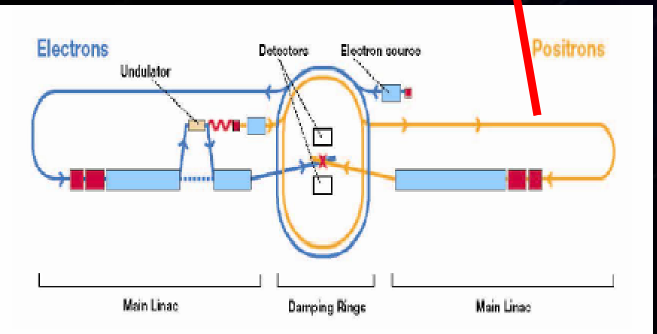
ILC

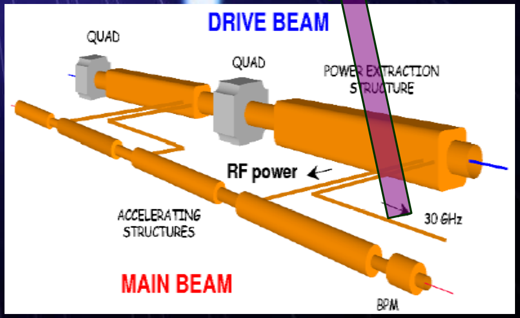
1 TeV=10^{12} eV

"Standard model"

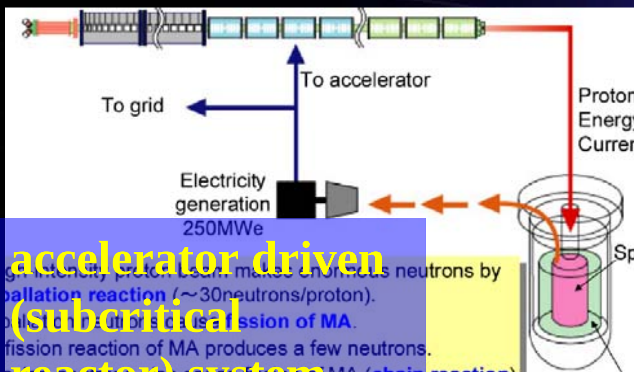
Higgs
Quarks
Leptons

T. Suzuki @ACFA08

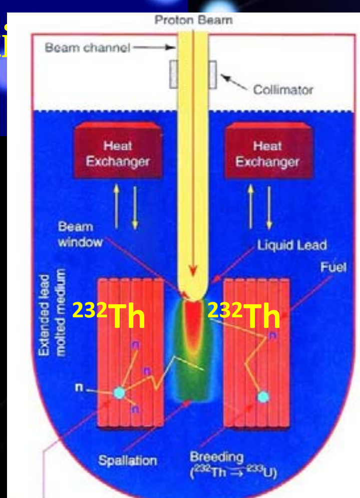




1000 times more powerful beam



accelerator driven (subcritical reactor) system and nuclear waste transmutati system



100 MW Beam Power

Inertial Fusion

Nuclear waste processing

Brighter neutron source

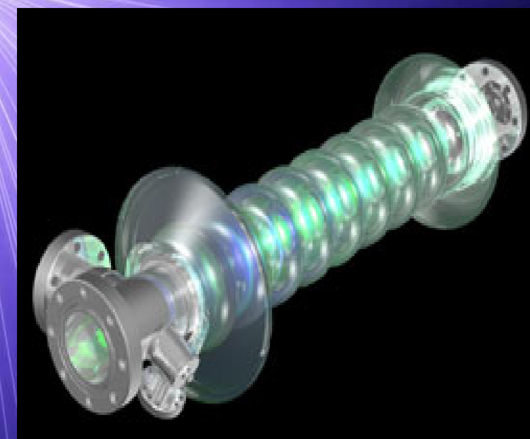
Muon Collider

Neutrino Factory

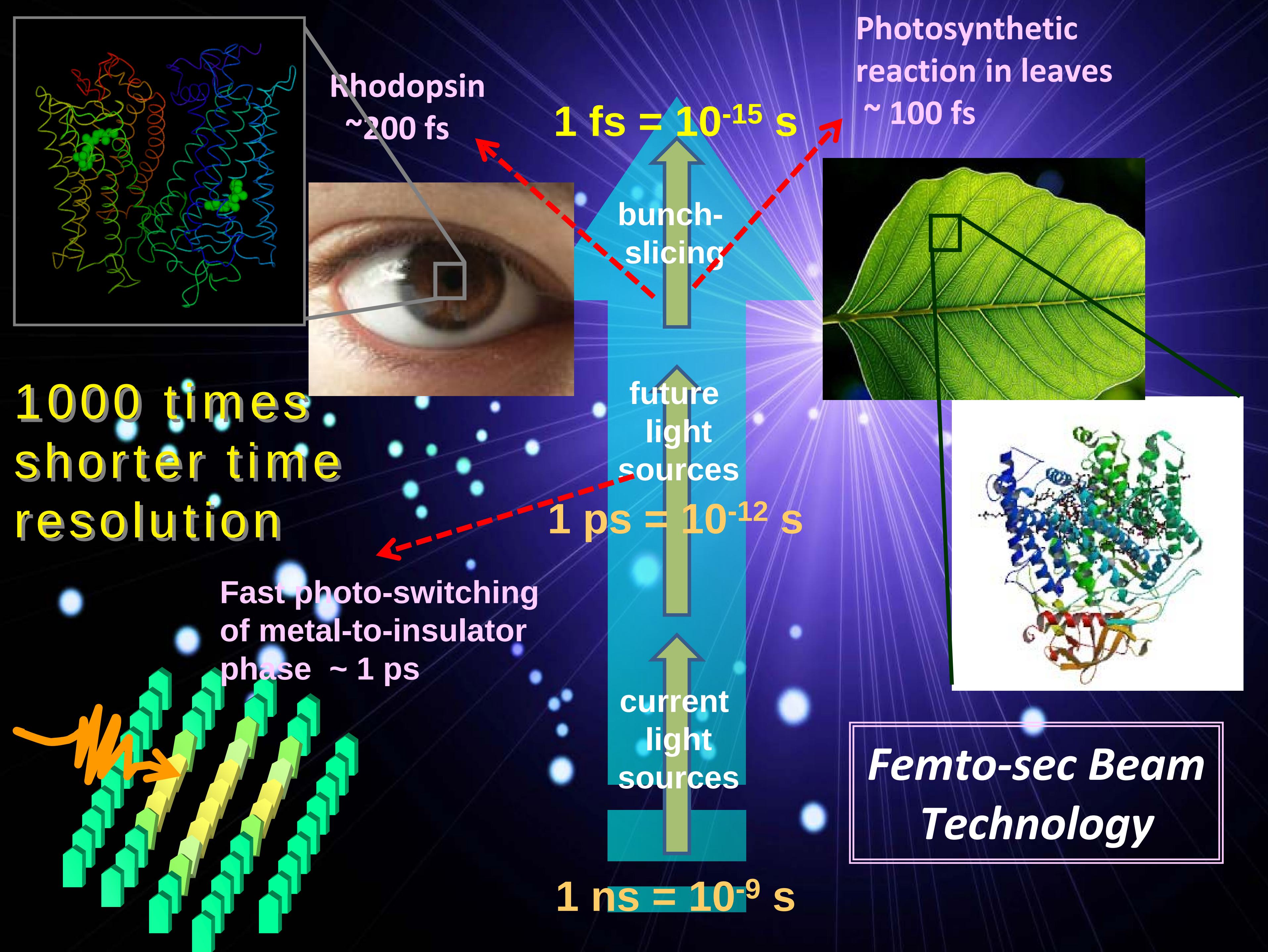
Linear Collider

100 kW Beam Power

Muon-collider Neutrino Factory



Super-conducting Accelerator Technology


Rhodopsin
~200 fs
1 fs = 10-15 s
Photosynthetic
reaction in leaves
~ 100 fs
bunch-
slicing
future
light
sources
1000 times
shorter time
resolution
1 ps = 10-12 s
Fast photo-switching
of metal-to-insulator
phase ~ 1 ps
current
light
sources
Femto-sec Beam
Technology
1 ns = 10-9 s

1000 times higher spatial resolution

1 pm

future light sources

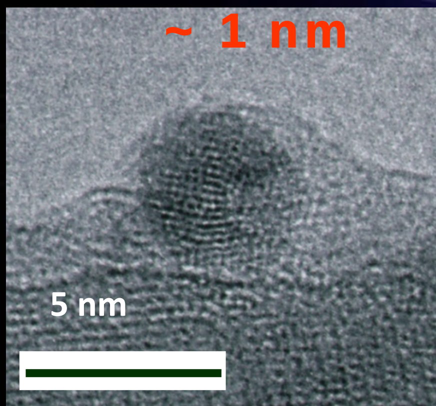
1 nm

10 nm

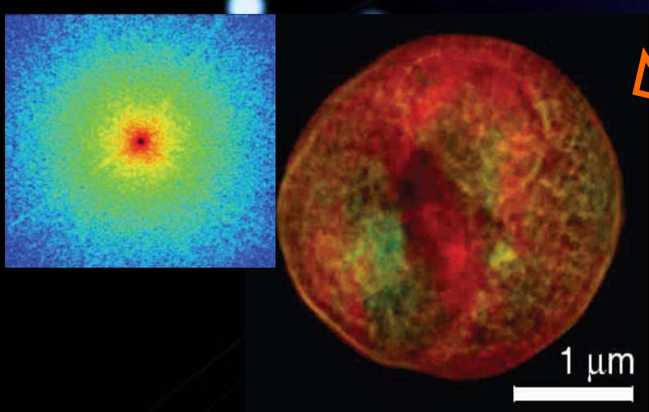
current light sources

~100 nm

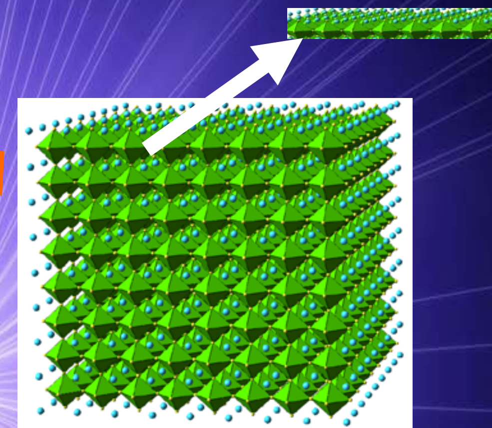
catalytic chemistry ~ 1 nm



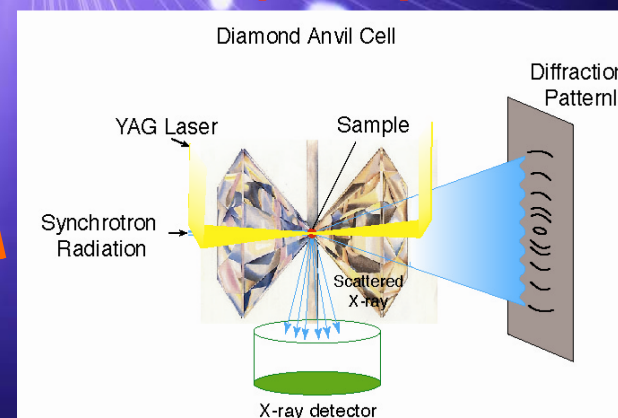
cellular structure and function ~ (1-10) nm



Nano-crystal ~ 1 nm



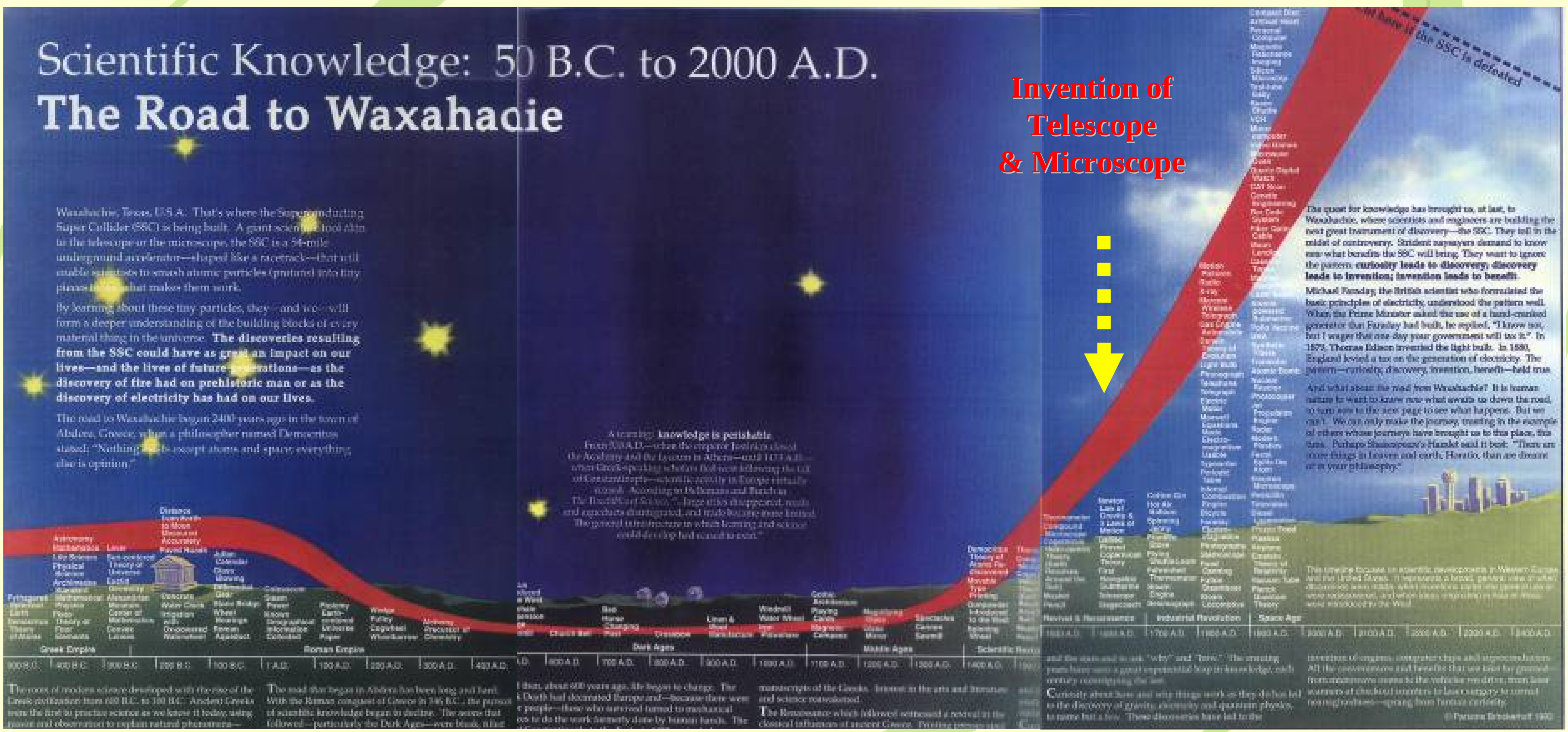
extreme condition ~ (1-10) nm



Nano beam Technology

Future science calls for innovative ideas for new generation of accelerators

Scientific Knowledge from 500 B.C. to 2000 A.D.



Summary

- As an powerful tool for acceleration of charged particle beams, particle accelerators have been rapidly developed since it was invented in 1930's aiming at the researches on the micro-world;
- Traced to its three roots, the history of accelerators is a continuous upgrade for higher energy and better performance;
- The higher energy and higher luminosity are two frontiers of the accelerators for high energy physics;
- Synchrotron radiation sources, free electron lasers and spallation neutron sources and etc. are in vigorously growing;

Summary (cont.)

- Variety of low energy accelerators are widely applied in all aspects of our society;
- New methods, and new technologies emerge in endlessly and will present a entirely new appearance of accelerators;
- Future science calls for innovative ideas for new generation of accelerators.
- As "microscope" for micro-world, the accelerators will be further developed in 21st century in the world as well as in Asia.

Question

To line up the following types of accelerators with the characters listed in the right side:

Synchrotron	B=const., $f_{rf}=h \cdot f_c$
Betatron	B=const., f_{rf}=const.
Cyclotron	$B = \frac{pc}{Ze\rho}$, $\frac{dB_0(t)}{dt} = \frac{1}{2}\frac{d\bar{B}(t)}{dt}$
Synchro-cyclotron	$B = \frac{pc}{Ze\rho}$, $f_{rf}=h \cdot f_c$