ACCELERATOR SCIENCE

A A A S

February 13, 2009

SCIENCE OF ACCELERATORS

&

SCIENCE WITH ACCELERATORS

SCIENCES NOW USING ACCELERATORS

(some examples momentarily)

Accelerator
Art
Biology
Chemistry
Crystallography
Dendrology
Engineering
Environment
Geology
Medicine
Metallurgy
Nano
Nuclear
Ornithology
Particle
Pharmaceutical
Planetology
Rheology
Surface
Zoology

etc. etc.

DON'T FORGET INDUSTRY

?HOW MANY SCIENTISTS USING ACCELERTORS?

World Wide

~ 35,000 – estimate including all sciences as best we can

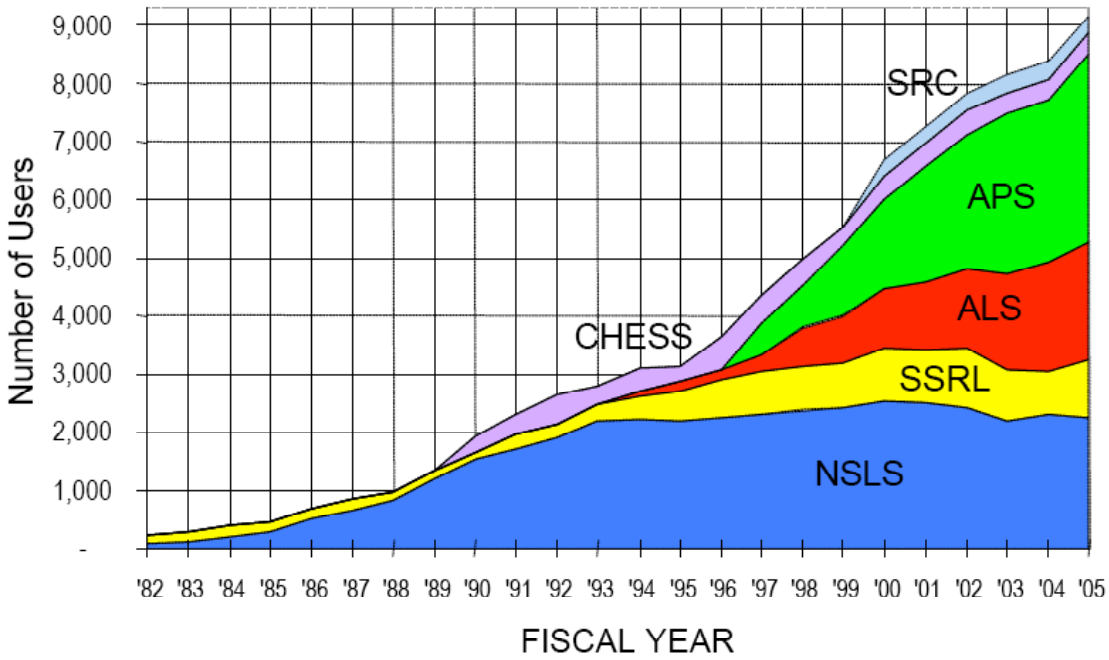
US Alone

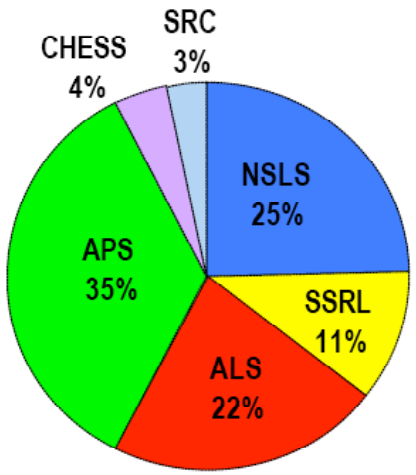
~ 12,000 – including all sciences

Biggest US Group – "Materials" (includes most of list above)

~ 9,000 + and growing fast

The 6 Federally Funded U.S. Light Sources Hosted 9,159 Users in FY 2005





The size and demographics of the user community have changed dramatically since the 1980s when only a few hundred intrepid users visited the synchrotron light sources each year. Here, "user" is a researcher who proposes and conducts peer-reviewed experiments at a scientific facility or conducts experiments at the facility remotely. A user does not include individuals who only send samples to be analyzed, pay to have services performed, or visit the facility for tours or educational purposes. Users also do not include researchers who collaborate on the proposal or subsequent research paper but do not conduct experiments at the facility. For annual totals, an individual is counted as 1 user at a particular facility no matter how often or how long the researcher conducts experiments at the facility during the year.

courtesy Pat Dehmer

?HOW MANY ACCELERATORS ARE THERE?

World Wide Scientific(research accelerators)

~ 120 = SR+n ⇑ + particle and nuclear ⇓ + beam science ⇓

about half of them are "major" i.e. have a significant number of outside users

World Wide Medical + Industrial

~ 30,000 (*courtesy R. Hamm, R&M Technical Enterprises)*

roughly evenly divided – Europe, Asia, America - Europe slightly dominant in numbers

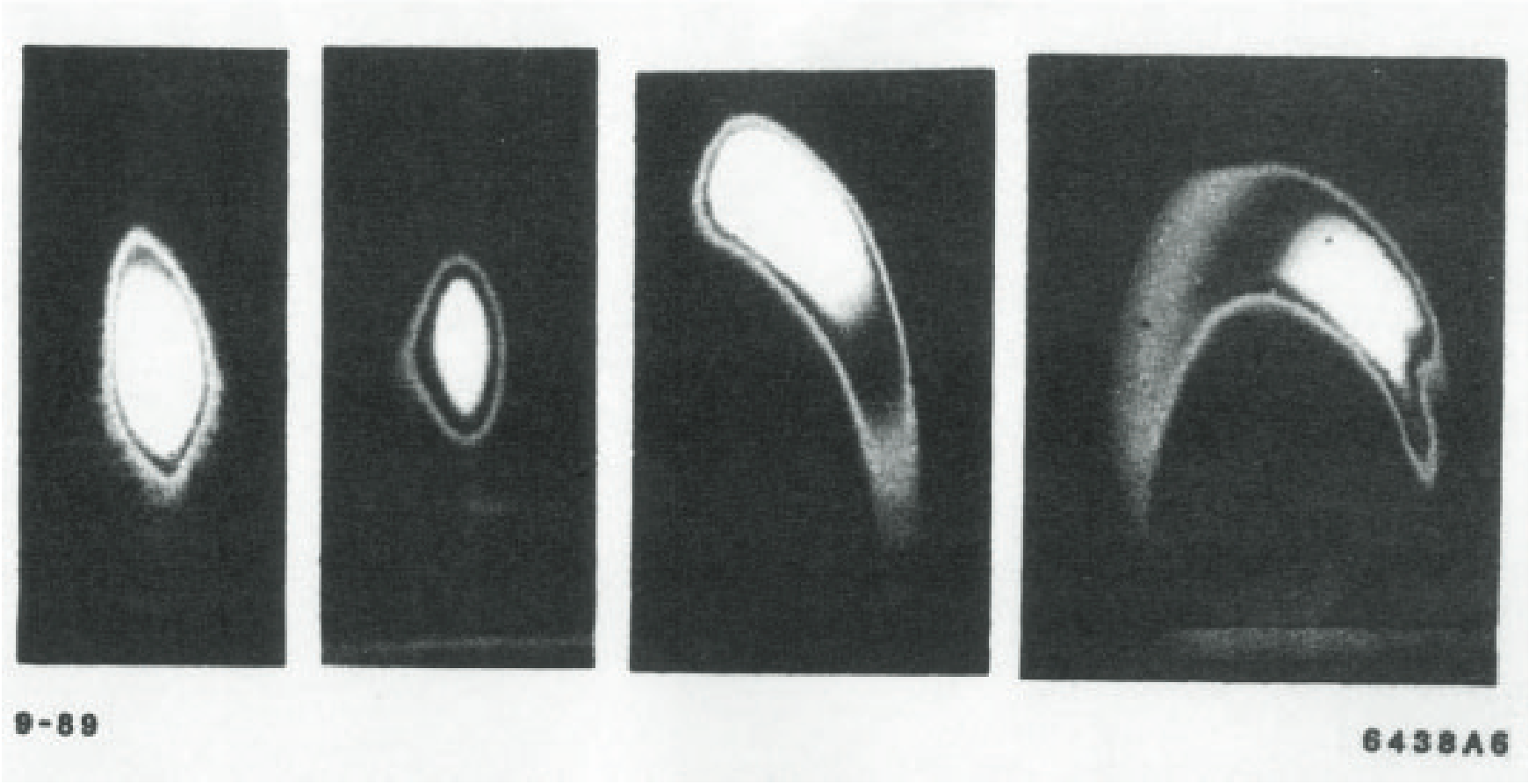
SCIENCE OF ACCELERATORS THEMSELVES

The Science of Particle Beams, their Manipulation and Use

PARTICLE BEAMS ARE MANY BODY SYSTEMS WITH NON-ISOTROPIC, NON-THERMAL DISTRIBUTIONS. THEY EXHIBIT MANY COLLECTIVE INSTABILITIES AND SELF-ORGANIZING PHENOMENA WHEN INTERACTING WITH ELECTROMAGNETIC FIELDS AND PLASMAS.

How to understand and master them is the name of the game

an example



BBU in the SLC

PROGRESS IN THE SCIENCES USING ACCELERATORS IS PACED BY THE PROGRESS IN THE SCIENCE OF ACCELERATORS

Some measures of progress

Quantity	Few years ago we got	Challenges for Today
Energy	GeV	TeV
$\Delta E / m$	10's MV	25,000MV
$\bar{I}$	mA	A
$\hat{I}$	10'sA	kA
τ	ns	≤ fs
ρ	10^{15}/cc	10^{22}/cc
ε_n	$10\,\mu m$	$<0.1\,\mu m$

(not all simultaneously)

Each step takes us further from equilibrium and thus more challenging of achievement

Denizens of this science work on theory and practice of:

- Sources- e to U polarized and unpolarized
  - AMO phys&chem., UHV, materials prep…
- Confinement systems – bends, lenses, separators…
  - nonlinear mechanics, magnets, sc materials, plasma..
- Accelerating systems – microwave cavities, lasers,…
  - nonlinear mechanics, rf superconductivity, EM theory..
- Radiation Phenomena, SR, CSR + back influence on beam
  - EM theory, nonlinear mechanics…
- Instrumentation – optical, electrical, electronic, thermal…
  - many physics and engineering arts
- System analysis – control systems, process control…
  - control theory, IT implementation…

MANY POTENTIAL ACCELERATOR IMPROVEMENTS ENVISIONED BUT STILL OUT OF REACH

Lots of R&D to be done

Where will it be done?

Who will do it?

How will the next frontier accelerators be
Conceived ?
Implemented ?
Operated ?

PARADIGM of the Recent Past (US)

(begging pardon for oversimplification)

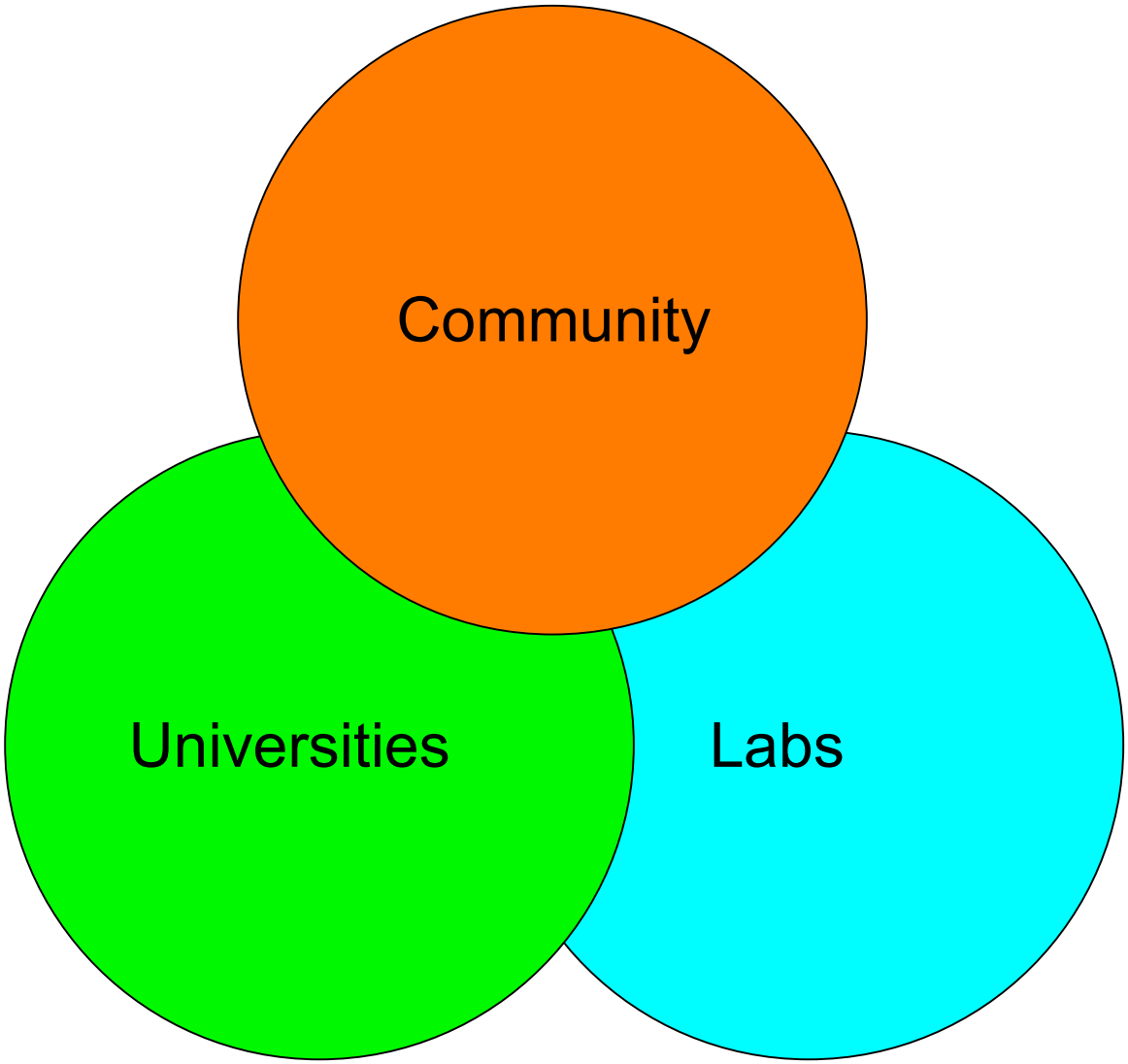
- Users (largely high energy and nuclear) invented and implemented new approaches, i.e. user need driven
- Students at the user university and/or lab formed the next generation of user/accelerator builder
- Evolution of the sciences and needs drove specialization leading to recognition of "accelerator scientist" as a career path – stewardship remains with HEP&NUC
- A very few remaining universities with accelerators offered students opportunities for full accelerator education: user; builder; r&d performer; operator

These students went on to leadership roles in accelerator work around the world in research labs and industry

TODAY'S SITUATION

(*conflating r&d and education/training)*

Accelerator Education/R&D *grass roots* "ORG CHART"



DECOMPOSING TODAY'S SITUATION:

Accelerator Labs ~ 11 major user serving Labs in US

- on the job training employees for accelerator expertise
- student projects supervised by lab personnel
- student projects supervised by university faculty in play with lab personnel

Universities

- ~ 14 universities have PhD programs in accelerators, most having connections with a major, off campus Lab
- 2 universities have user serving accelerator labs on campus, (3 more relatively close to campus) offering the fully rounded accelerator science education
- ~24 universities take accelerator education seriously enough to participate in the "community" program offering academic credit to students

Community Program (shares expertise among the above)

- Material support from the 11 accelerator labs and DOE/NSF
- US Particle Accelerator School (USPAS) 1987 - present
  - 2, two week sessions annually
  - faculty from Labs and universities (US and abroad)
  - intensive with homework, labs and exams
  - ~130 students per session (multiple repeats)
  - originally for sponsoring institutions, now 60% are university grad students and post docs worldwide
- Community R&D as well
  - international e.g. sharing personnel and tech dev't.
  - intra US – ditto
  - not as big as the education collaboration but growing

RESULTANT

- *Worldwide* there are about 200 – 250 PhD students in accelerator science
  - about 1/3 in the US
- How many stay in the field? Don't know but anecdotally at my univ 1/3 to 1/2 leave the research accelerator buiness
- How many research accelerator scientists are there?
  - in US ~ 1200 (self affirmed)
- Some of our students go abroad as well as leaving the field so that we do not have enough to fill US needs
  $\Rightarrow$intense competition for workforce $\Rightarrow$ limits on what we can do to meet the world scientific competition

CULTURE CHALLENGE

- MUCH GENERIC ACCELERATOR R&D WAS CARRIED OUT IN ASSOCIATION WITH OPERATION OF ACCELERATORS FOR PARTICLE AND NUCLEAR PHYSICS – INCLUDED STUDENTS IN ALL PHASES

- US INVESTMENT IN ACCELERATOR OPERATIONS FOR PARTICLE PHYSICS GOING DOWN TAKING GENERIC R&D WITH IT – BUT INCREASED WORKFORCE NEEDED

- NEED A CONSCIOUS US EFFORT TO MAINTAIN OWN INTERNAL LEADERSHIP as well as LEADERSHIP ON THE WORLD STAGE – AGENCIES, LABS AND UNIVERSITIES TOGETHER WILL BE KEY IN THIS

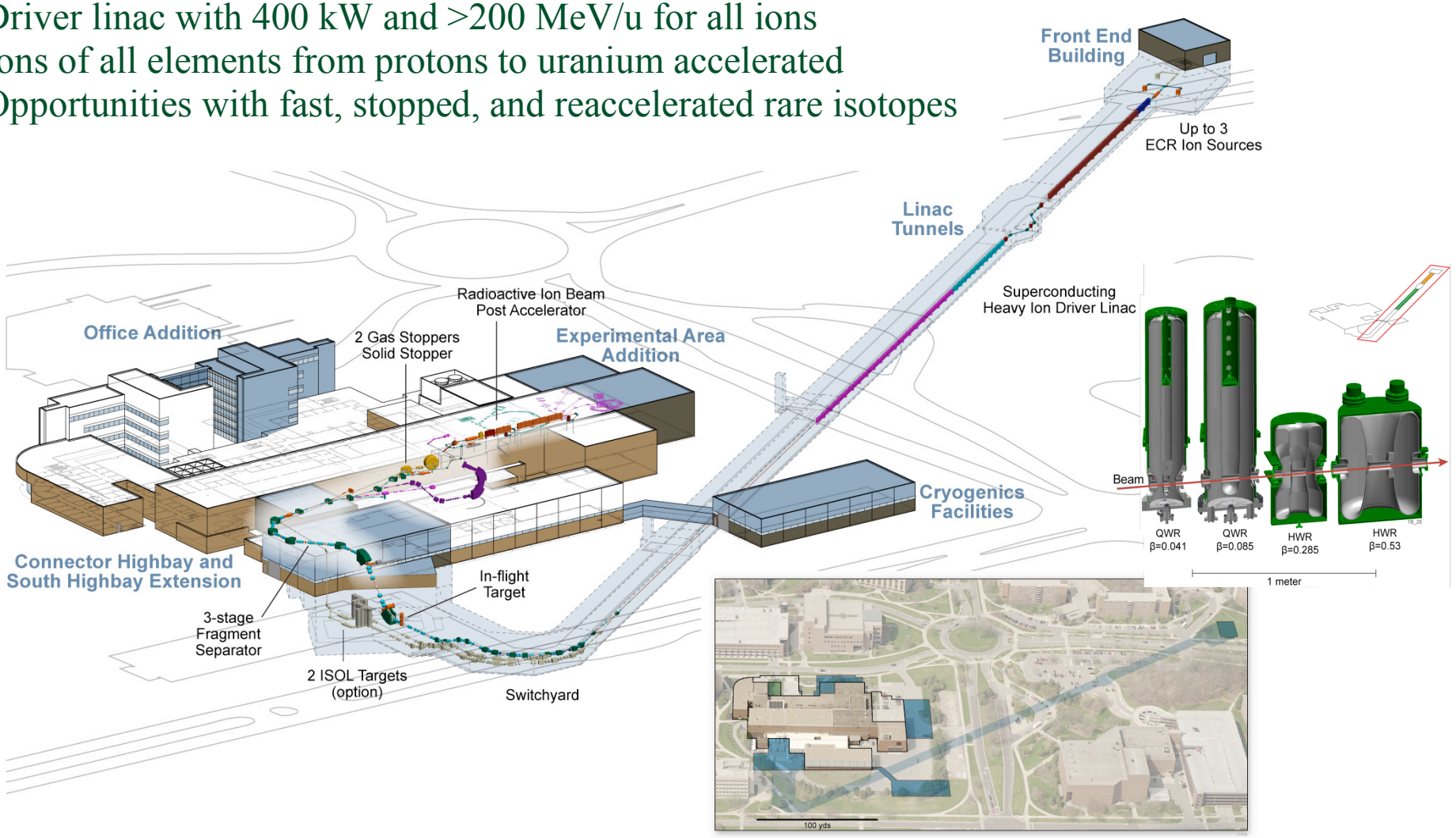
SOME EXAMPLES OF SCIENCE WITH ACCELERATORS

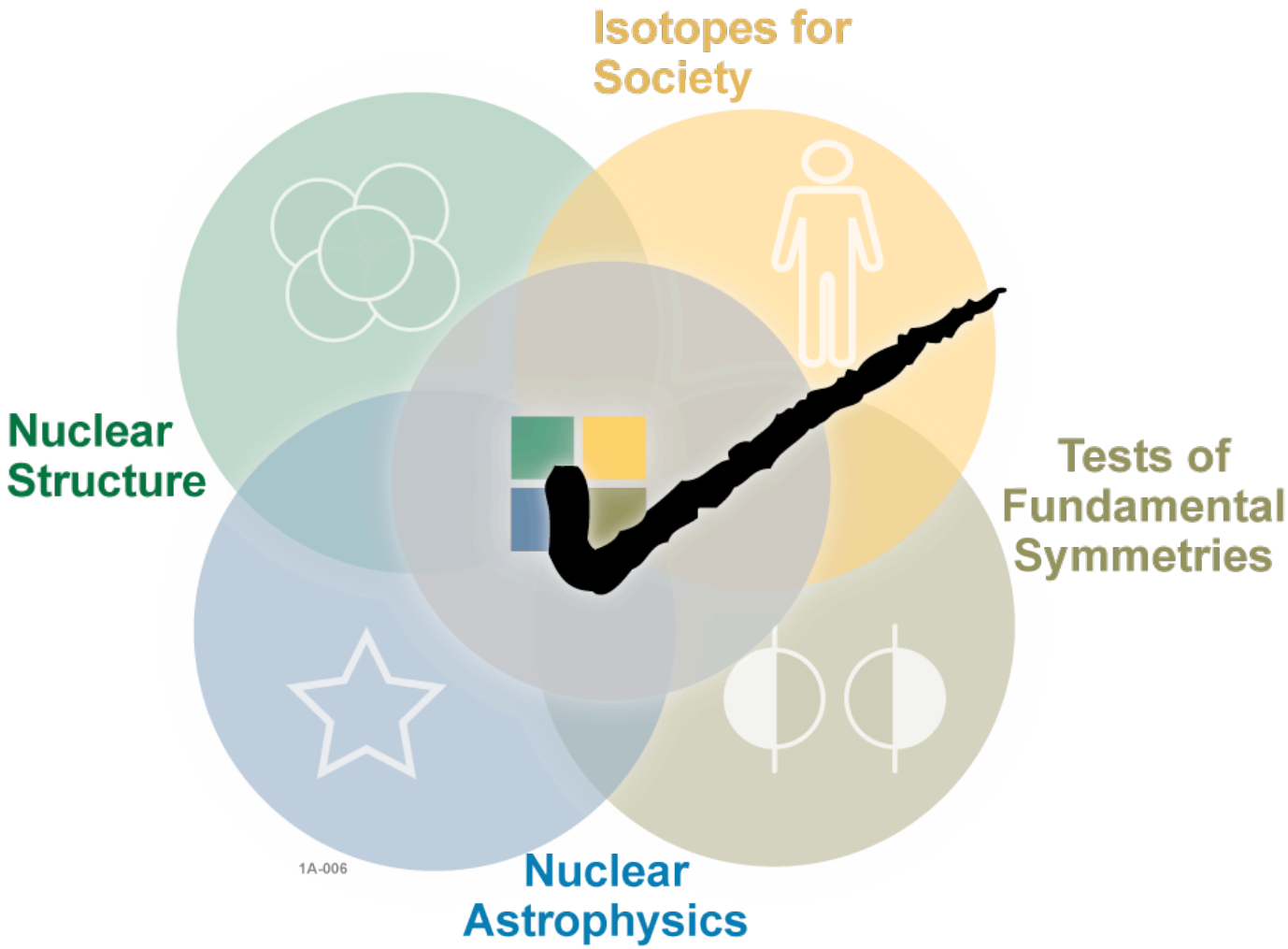
NOW AND COMING UP

NUCLEAR AND PARTICLE SCIENCE

FRIB at MSU – to come

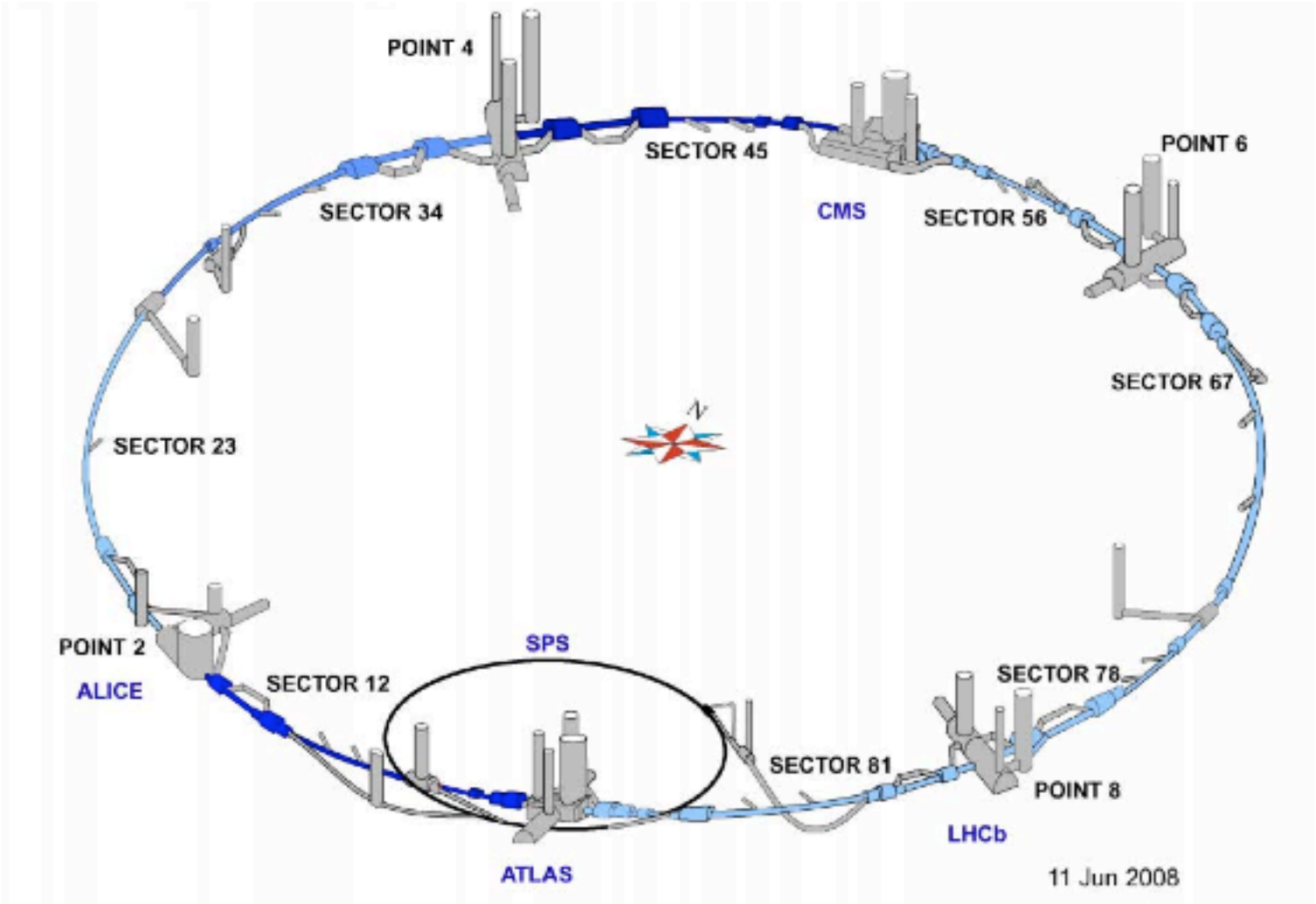
- Driver linac with 400 kW and >200 MeV/u for all ions
- Ions of all elements from protons to uranium accelerated
- Opportunities with fast, stopped, and reaccelerated rare isotopes





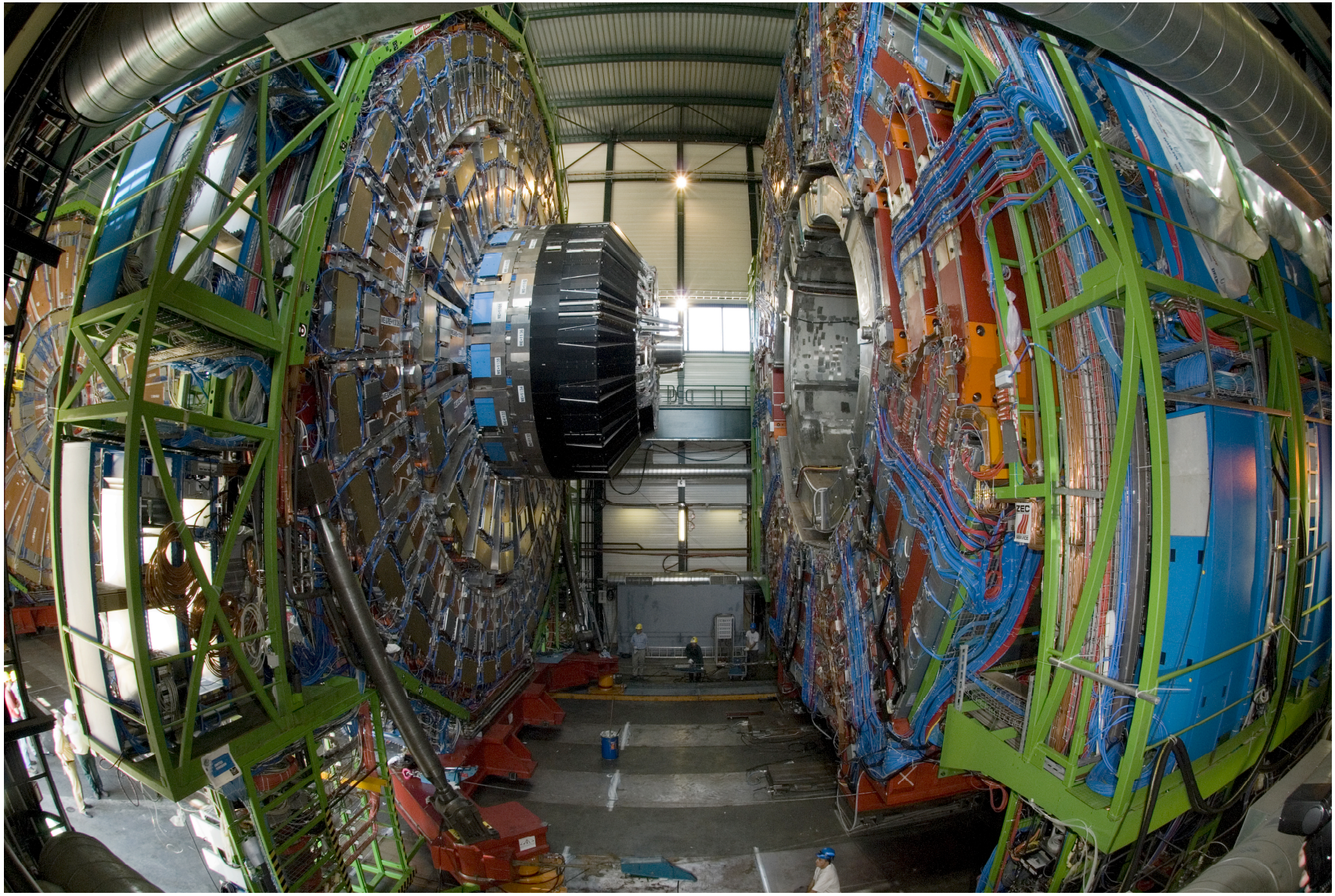
UNDERSTANDING THE UNIVERSE: Nuclei determine the chemical history of the Universe and drive stellar explosions. Connection of models of novae, supernovae, X-ray bursts etc. to observations require rare isotopes.

LHC – p p collider - in process of running in

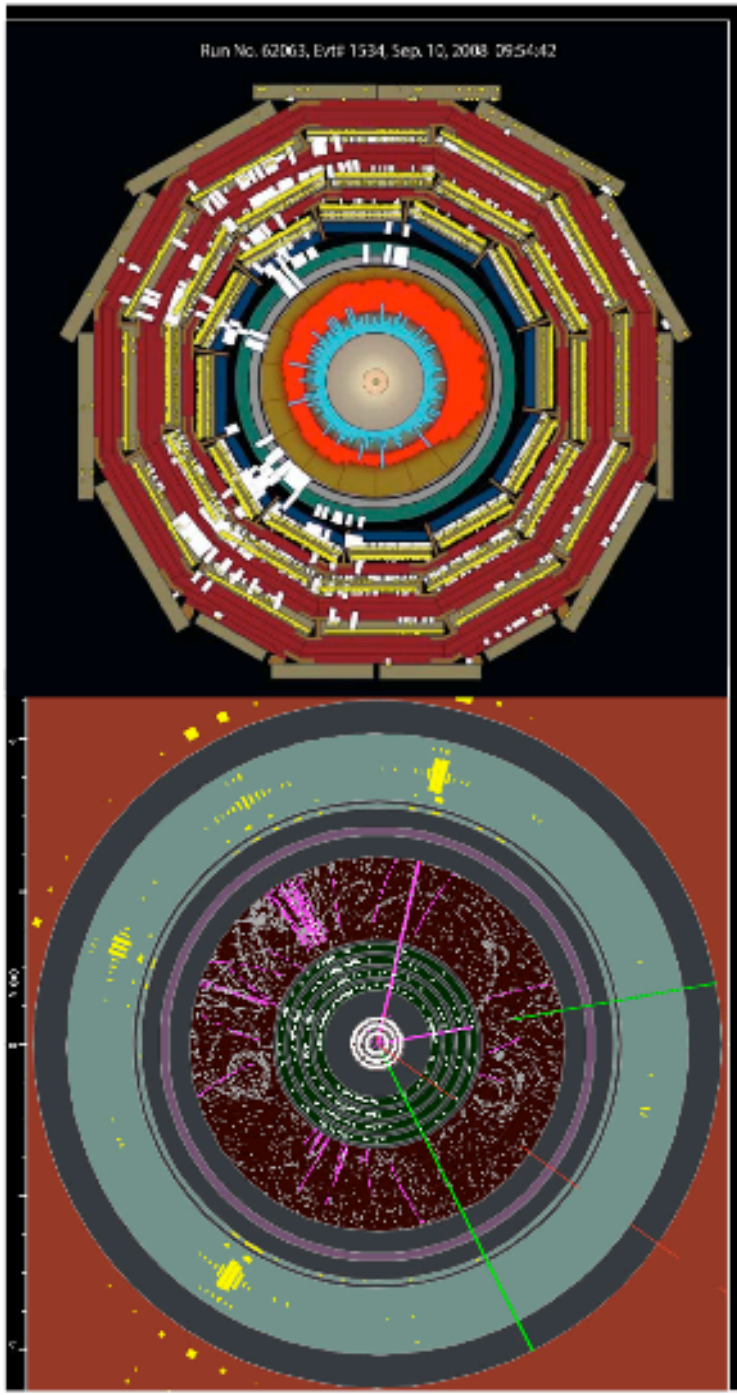


Artist's cutaway of the LHC – 27 km circumference, 14 TeV

CMS Detector



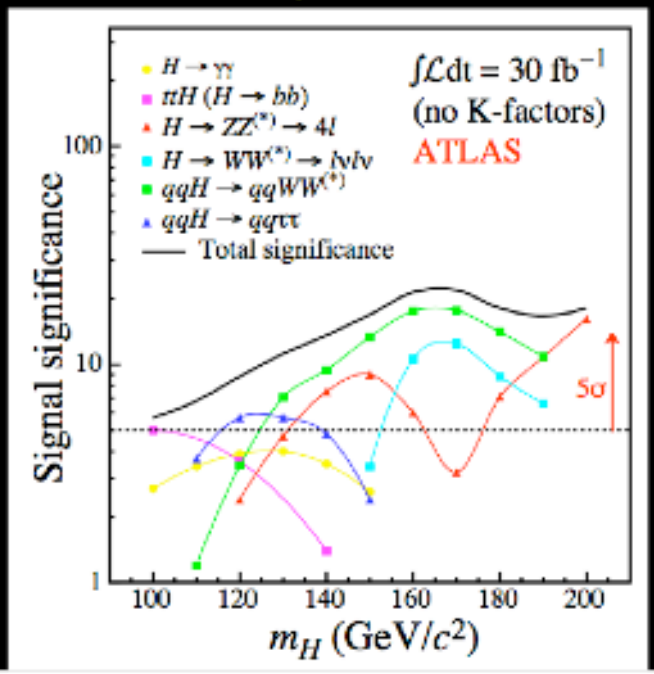
notice persons at bottom for scale



LHC Physics

Beam splash events observed
September 10, 2008
CMS (top) ATLAS (bottom)

TeV energy scale possibilities:
- Higgs (needed for weak force)
- Supersymmetry
- Extra dimensions
- Dark matter candidates
- Or, the unexpected



THESE AND MANY OTHER NEW FRONTIERS REMAIN TO BE OPENED UP USING ACCELERATORS.

OUR CHALLENGE IS TO KEEP THE IDEAS AND SKILLS FLOWING TO LEAD US ON TO THESE FRONTIERS AND BEYOND

thank you