Future Facilities
for Nuclear Astrophysics

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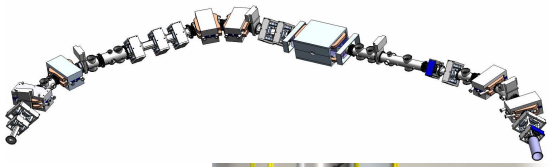
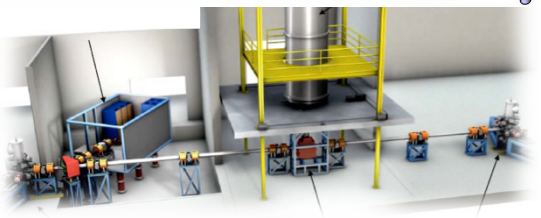
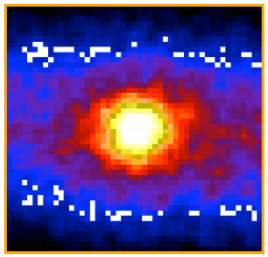
University of Notre Dame

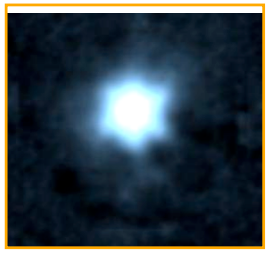
- Scientific questions and goals
- St. George
- DIANA
- NIF

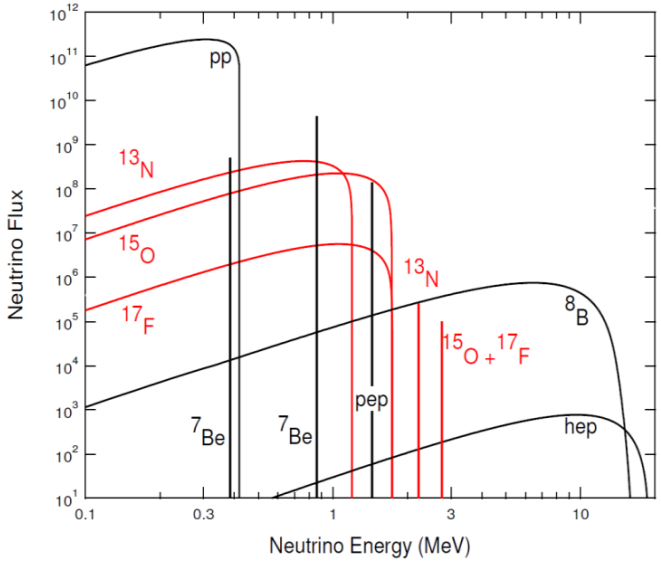




Scientific Motivation

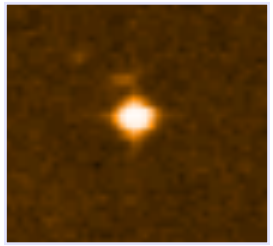


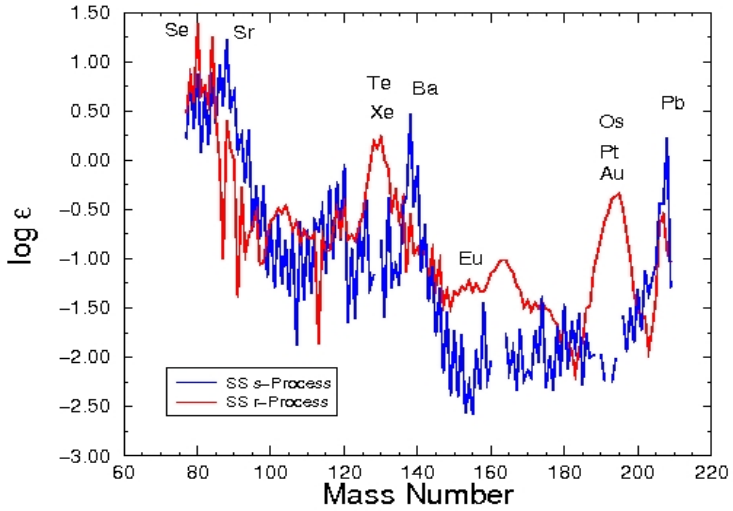




Low energy reactions with stable beams at threshold energies!

Stellar Neutrino Sources
in the sun & massive stars

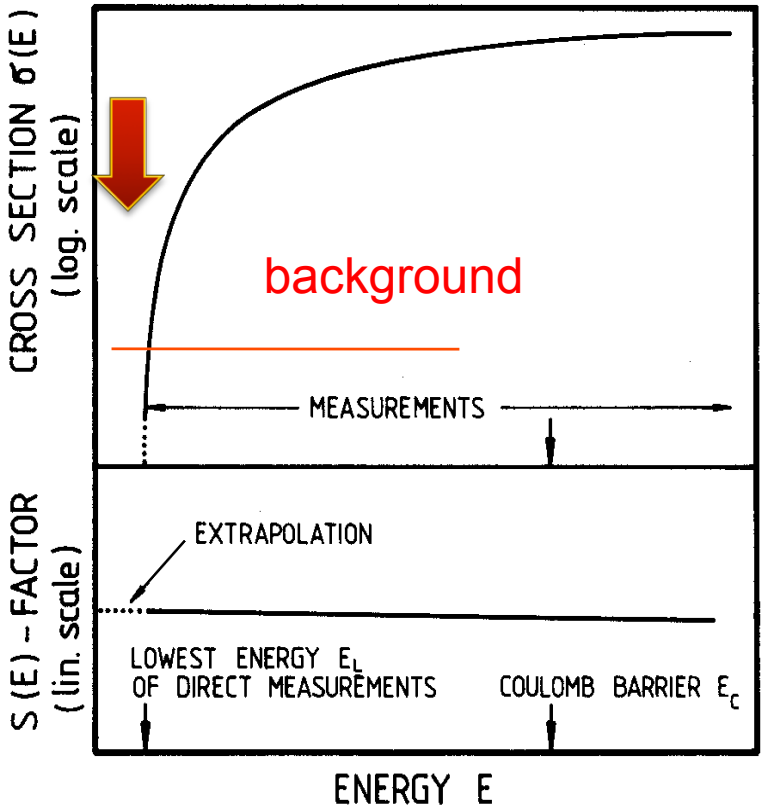


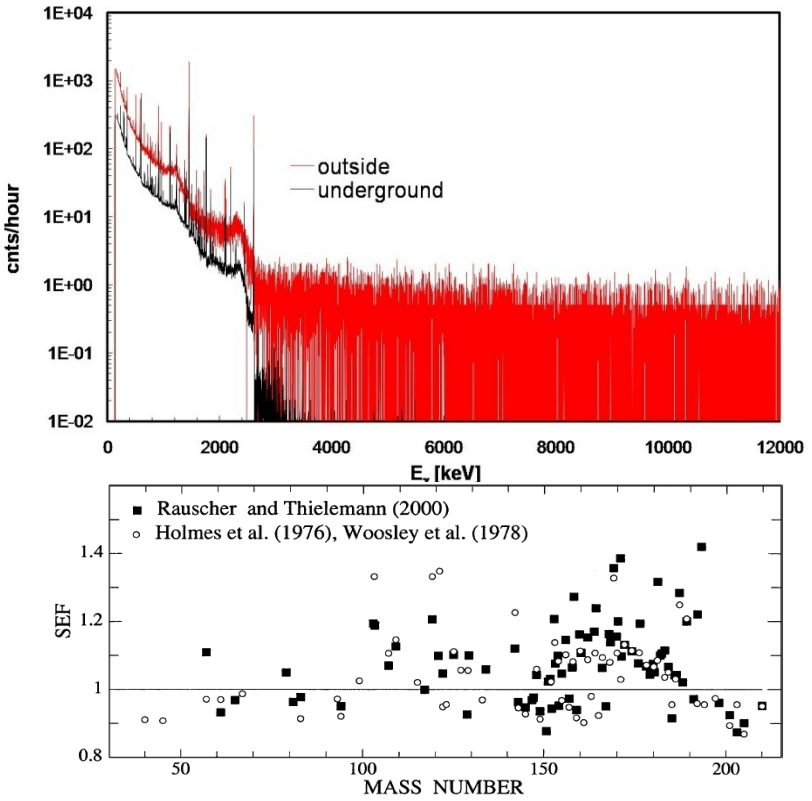


Origin of the Elements
in early & present Universe

Reducing background by using
inverse kinematics or underground techniques

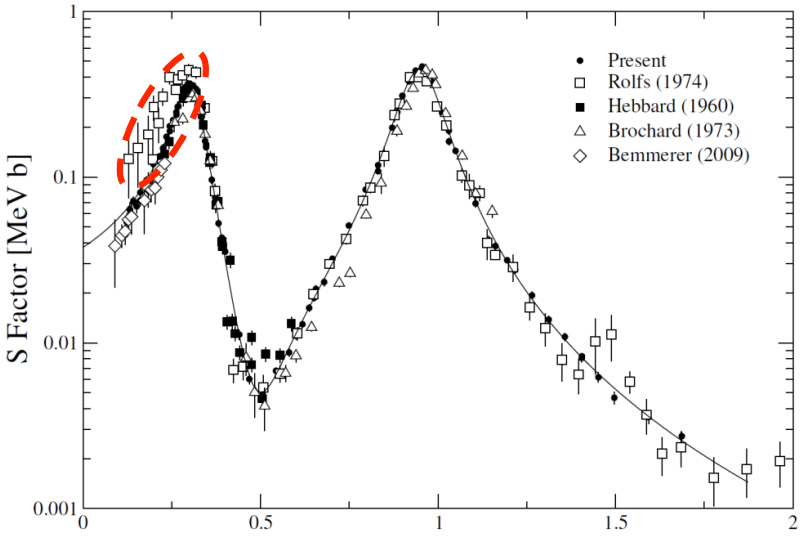
Studying thermal excitations
in hot dynamic plasma experiments

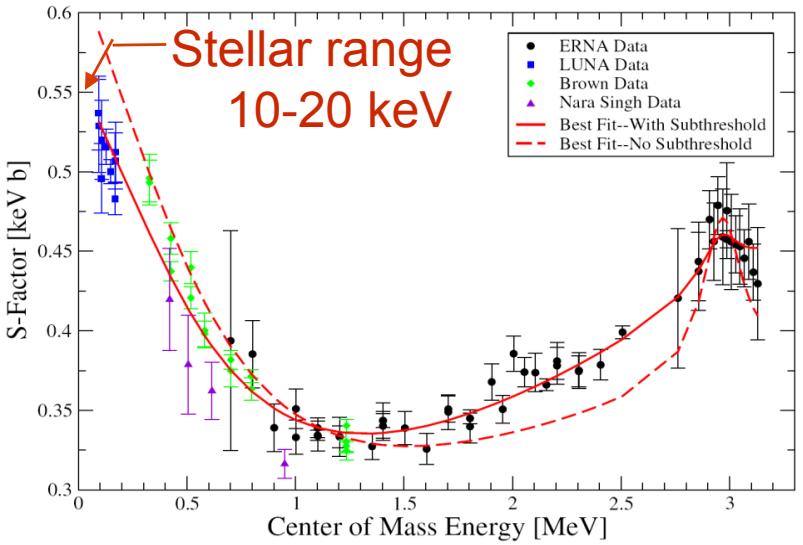




Solar Neutrino Sources

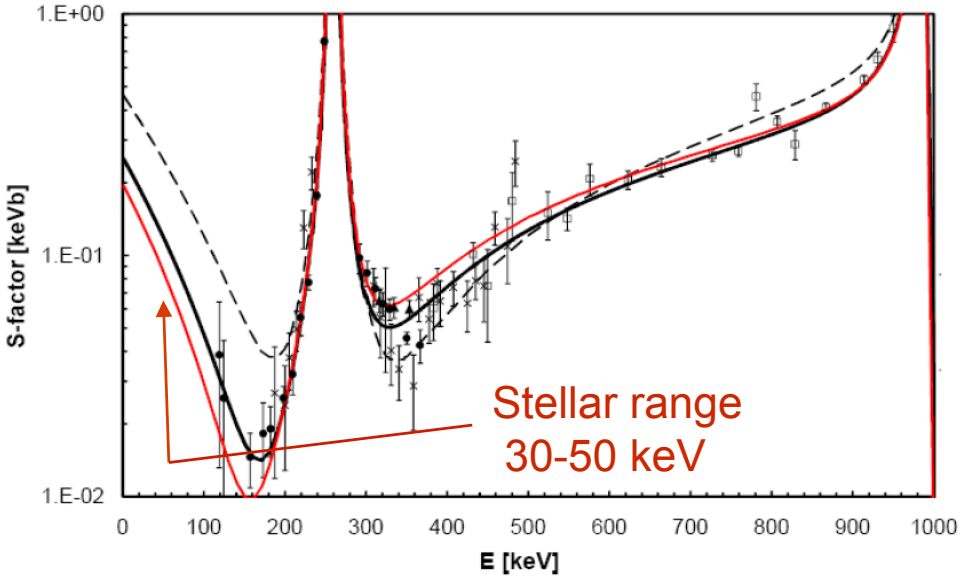
$^{3}He(\alpha,\gamma)^{7}Be$ (pp) and $^{14}N(p,\gamma)^{15}O$ (CNO)



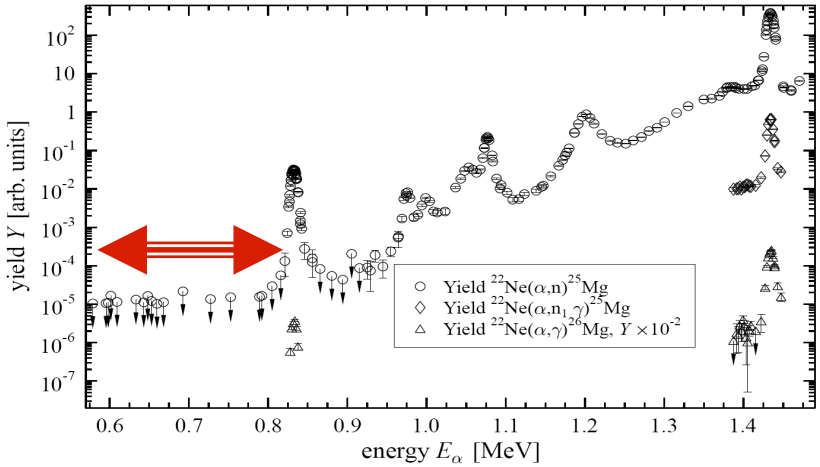


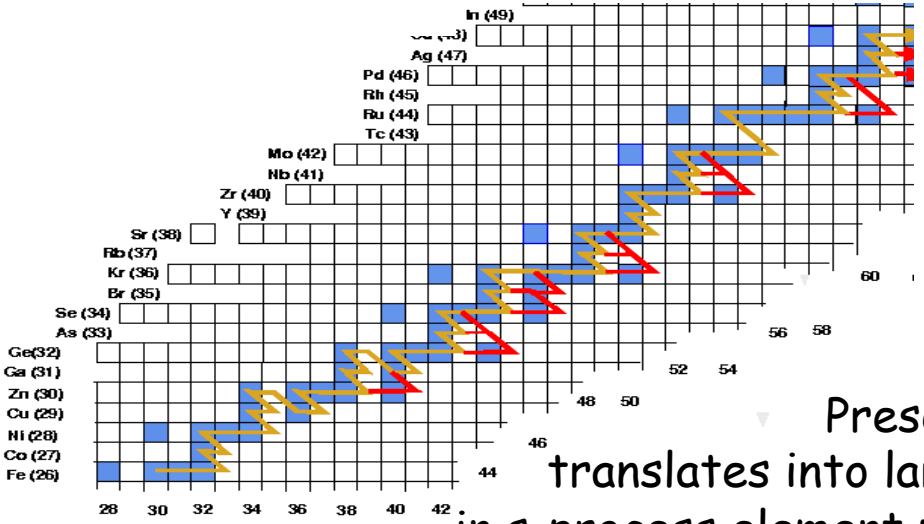
LUNA experiments are close to stellar energy range, theory based extrapolations suffer from model uncertainties.

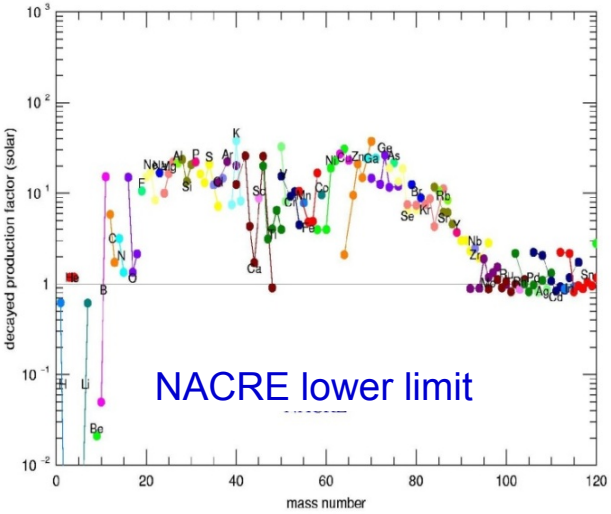
LUNA Measurements indicated already substantial deviations from earlier results and

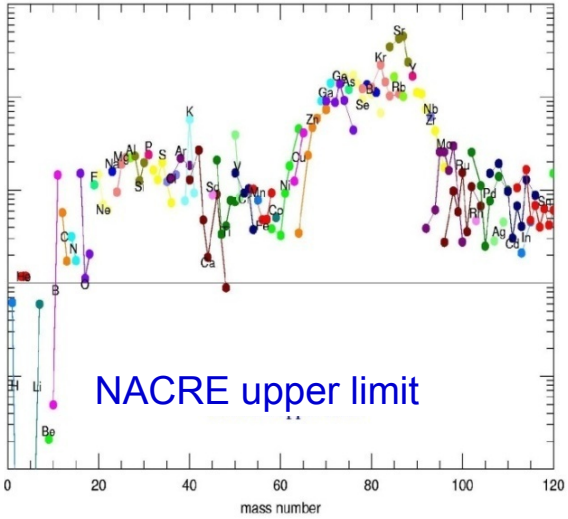


The ^{22}Ne(a,n) neutron source









Present uncertainty translates into large uncertainty in s-process element production with broad consequences for explosive scenarios of nucleosynthesis such as p-process and r-process

Inverse Kinematics with Recoil Separators

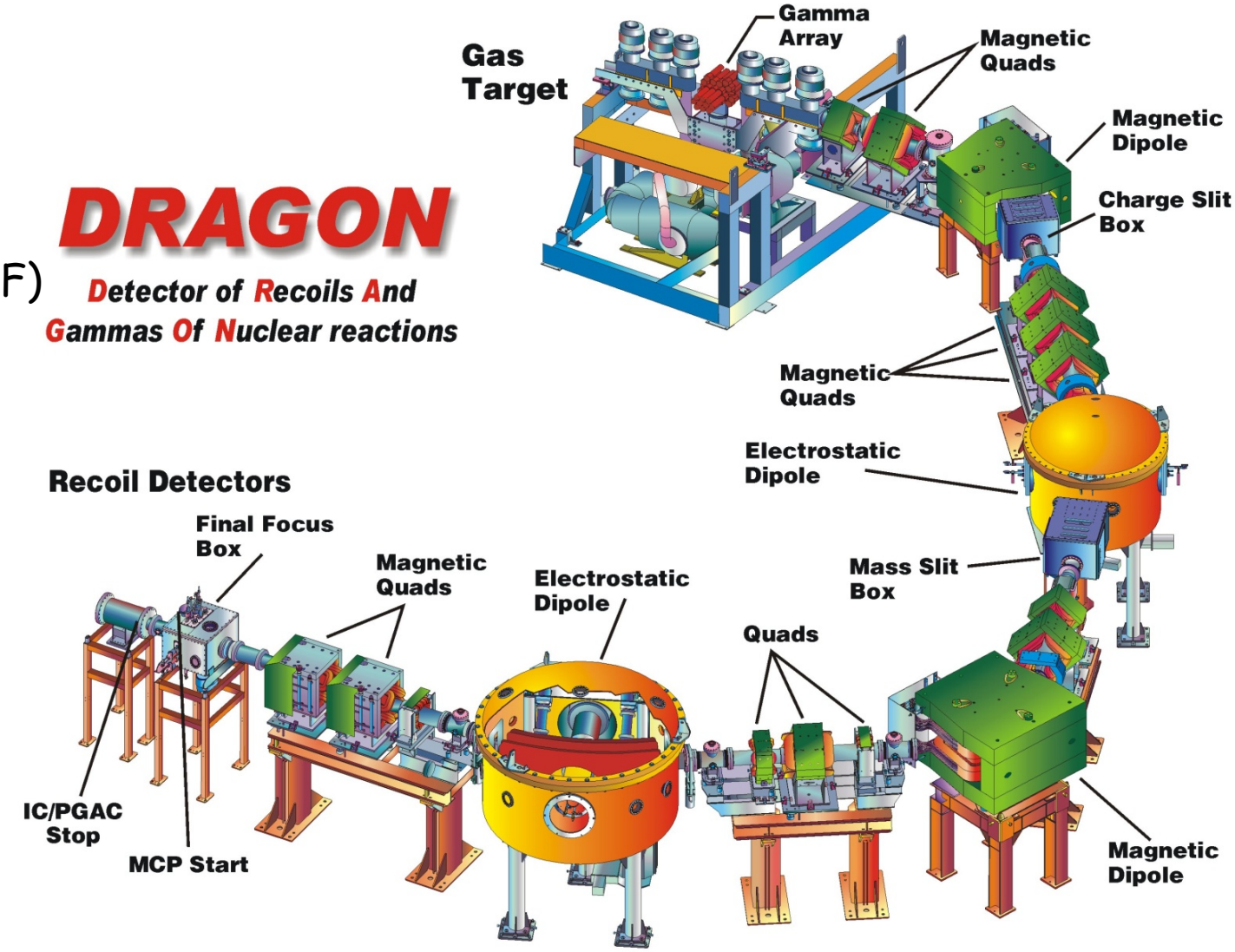
Number of successful measurements using inverse kinematics

with DRAGON (TRIUMF) and ERNA (Bochum)

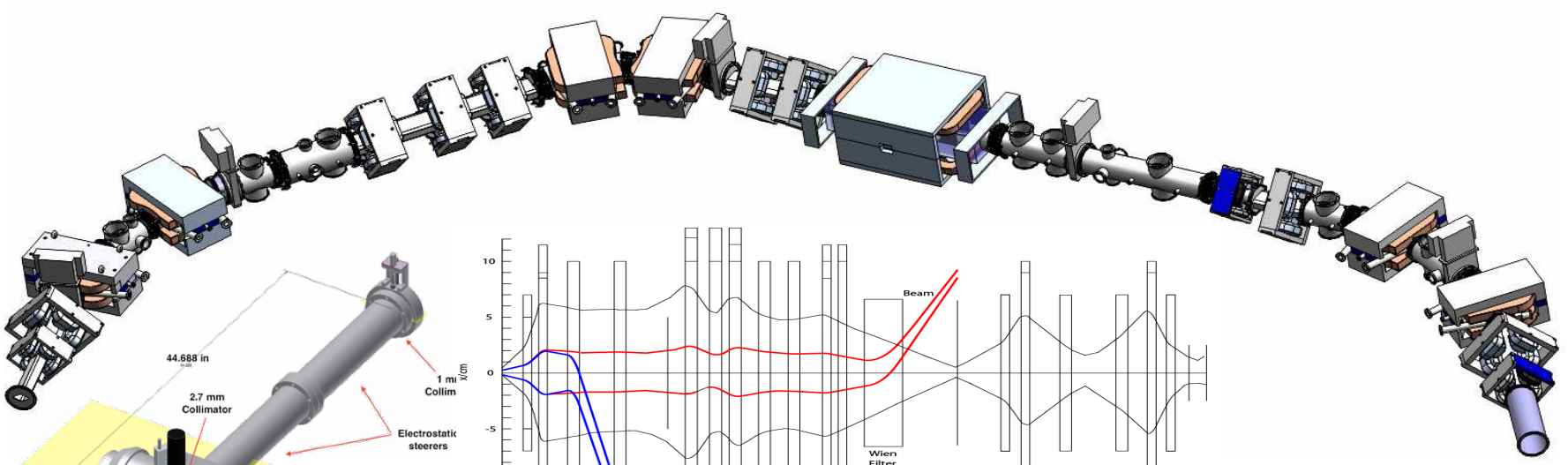
$^{3}He(\alpha,\gamma)^{7}Be$
$^{12}C(\alpha,\gamma)^{16}O$
$^{17}O(\alpha,\gamma)^{21}Ne$

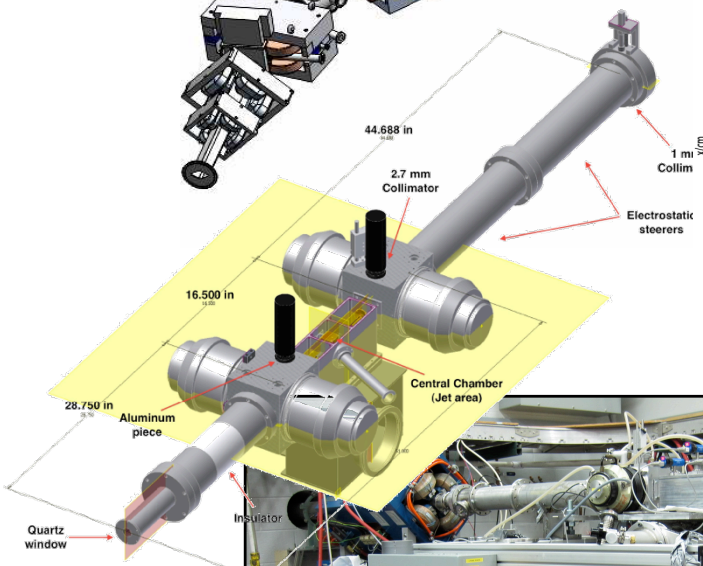
DRAGON

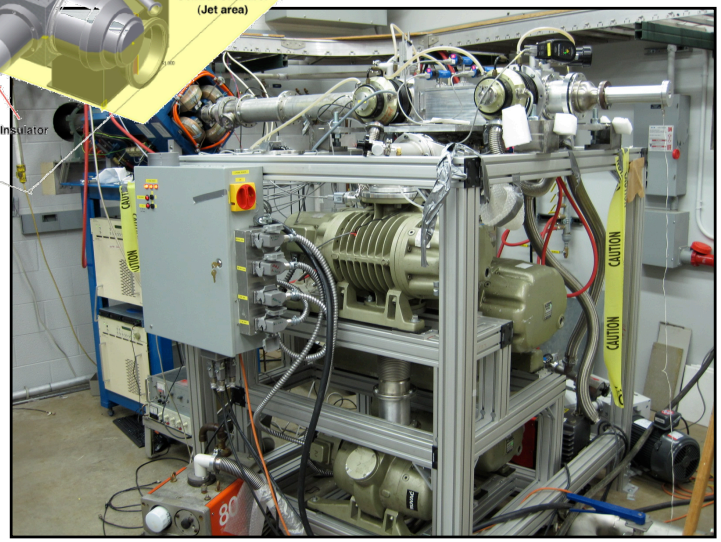
***D**etector of **R**ecoils **A**nd **G**ammas **O**f **N**uclear reactions*



New initiatives from St. George to …



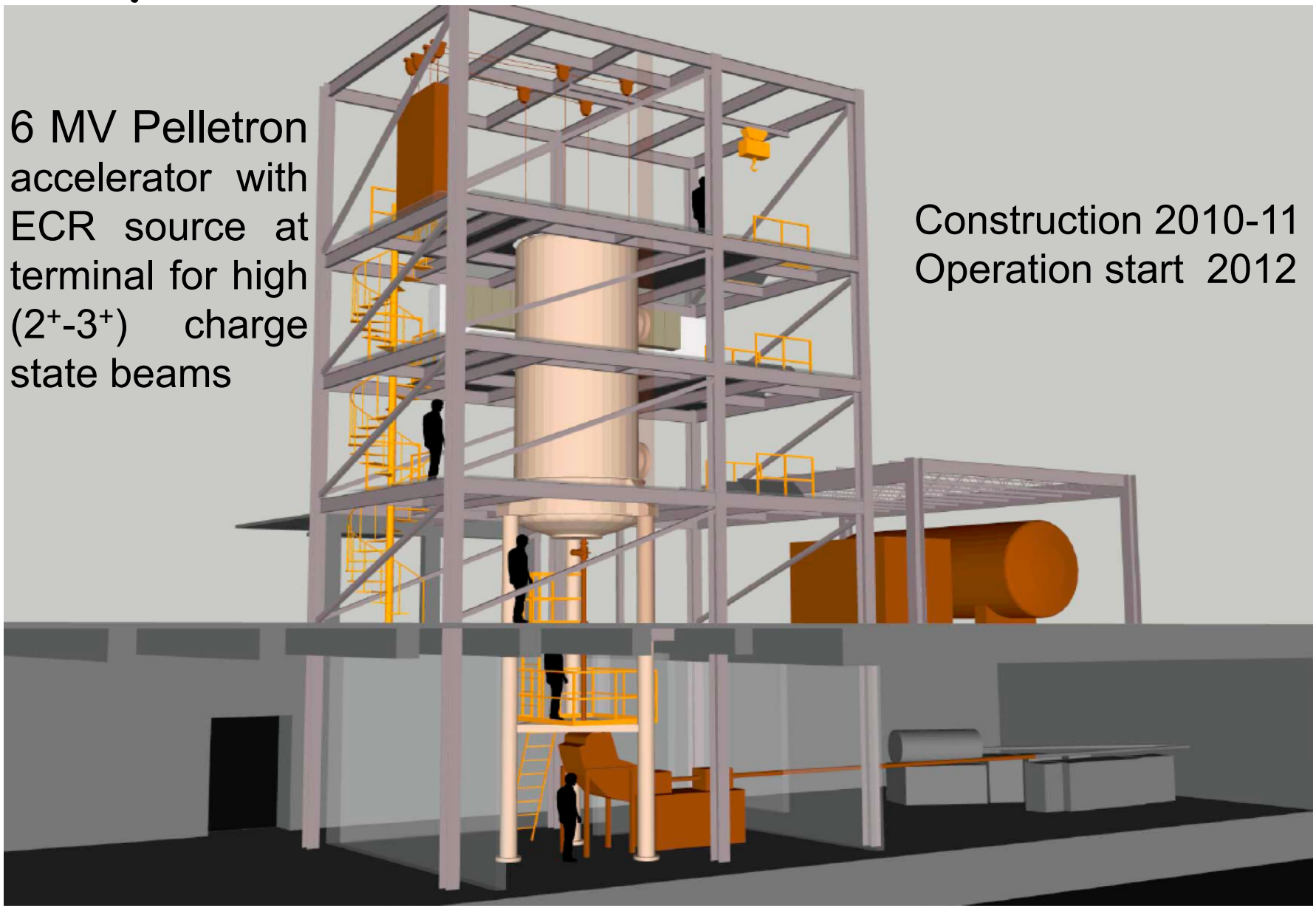




ERNA II or
DIOCLETIAN

Couder et al.
NIC_XI_136

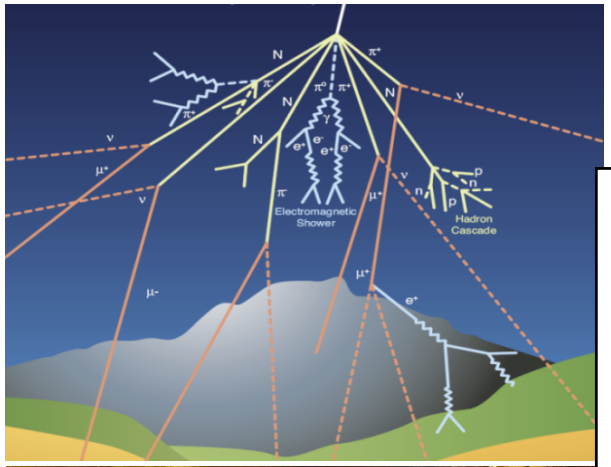
Heavy ion accelerator at Notre Dame



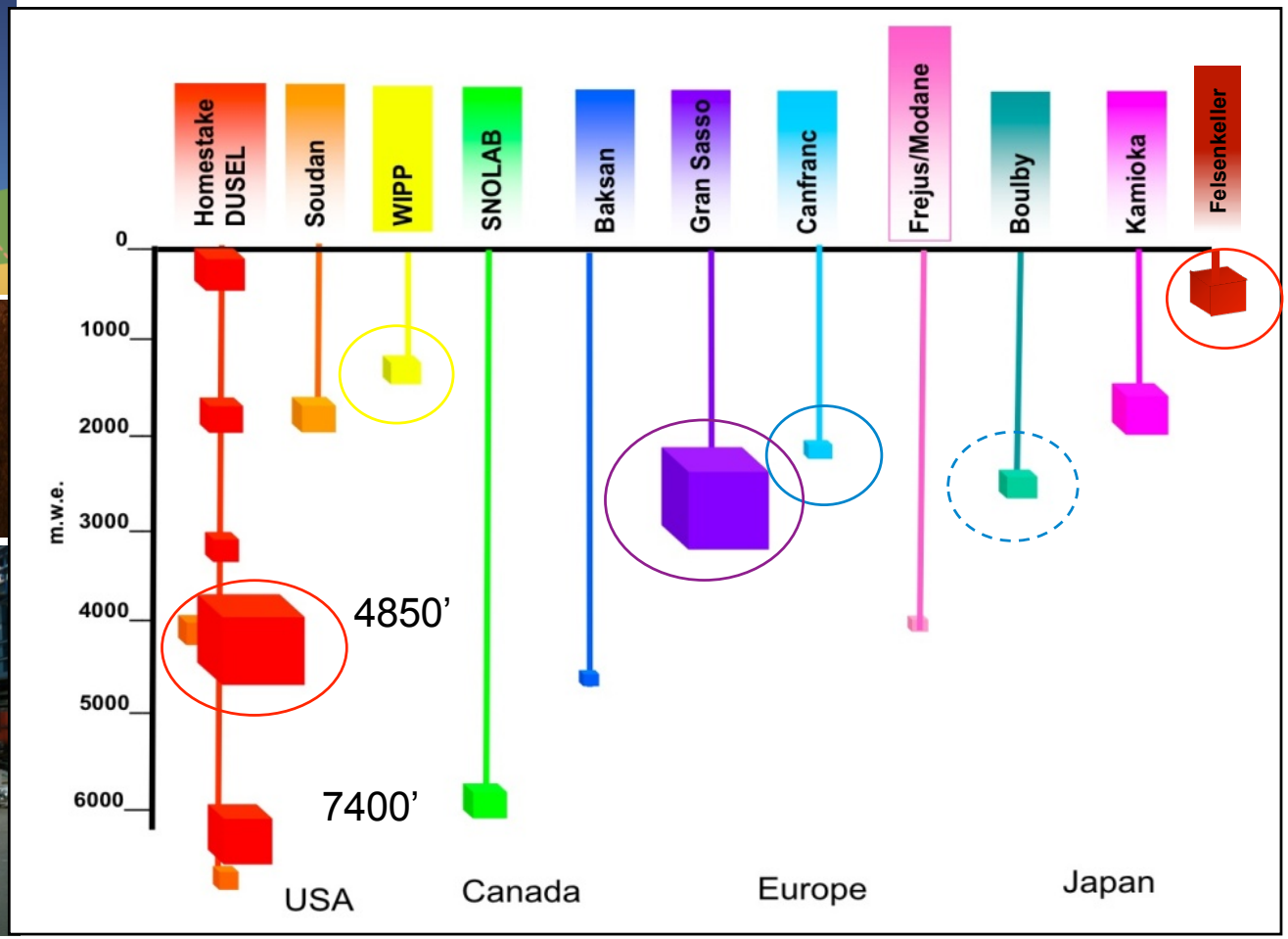
6 MV Pelletron accelerator with ECR source at terminal for high (2^+-3^+) charge state beams

Construction 2010-11
Operation start 2012

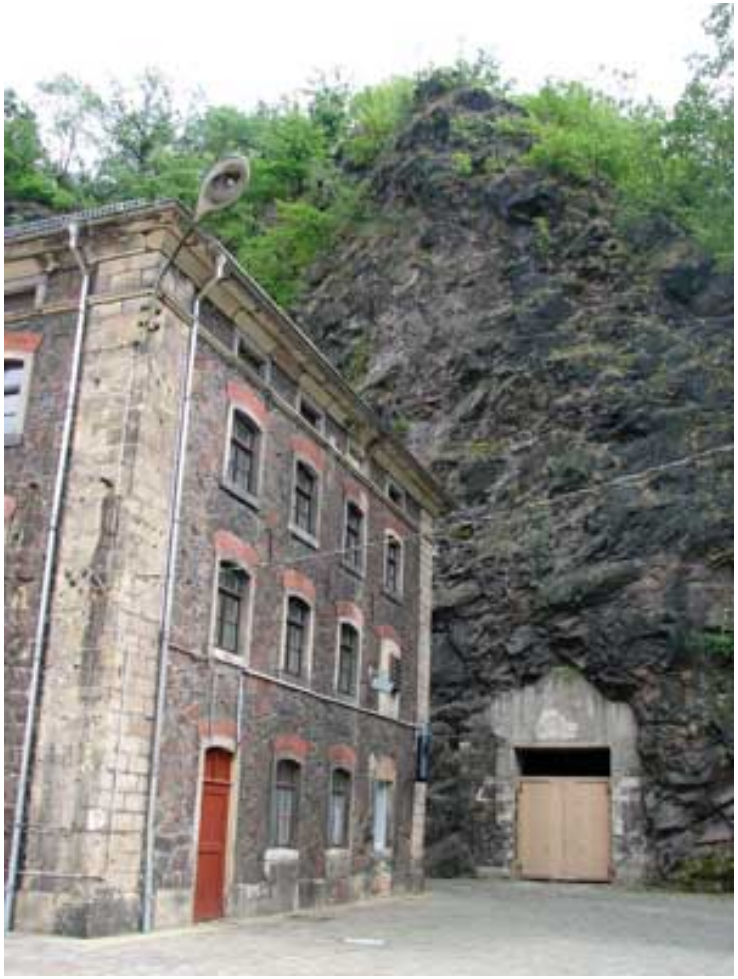
The International Situation



in the underground accelerator business



The latest sites for underground accelerator proposals



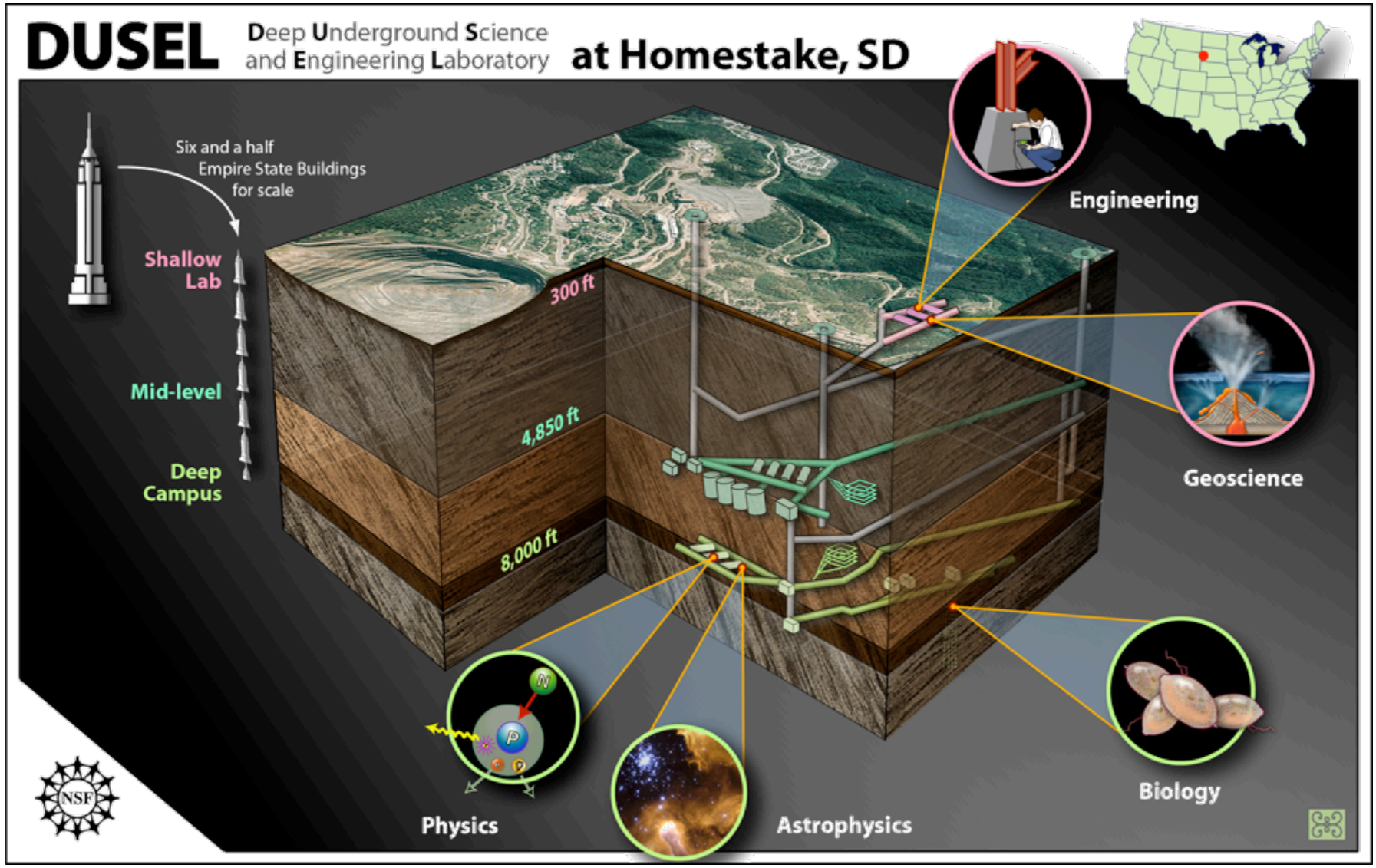
The Dresden Bierkeller

D. Bemmerer et al. NIC_XI_237

The Canfranc Railway Tunnel

L. Fraile et al. NIC_XI_093

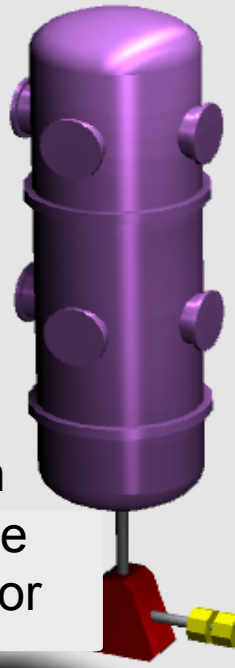
Deep Underground Science and Engineering Laboratory



Accelerator Vision

A. Lemut et al. NIC_XI_254

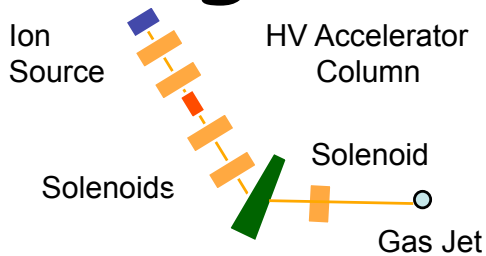
Beam optics design



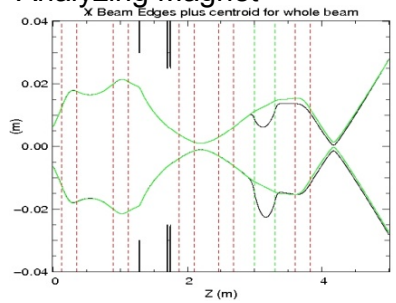
Dynamitron or Pelletron design with ECR source and modified accelerator tube!

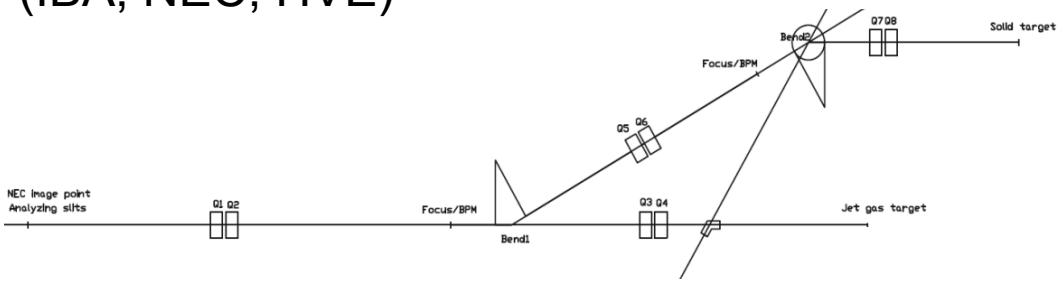
(IBA, NEC, HVE)

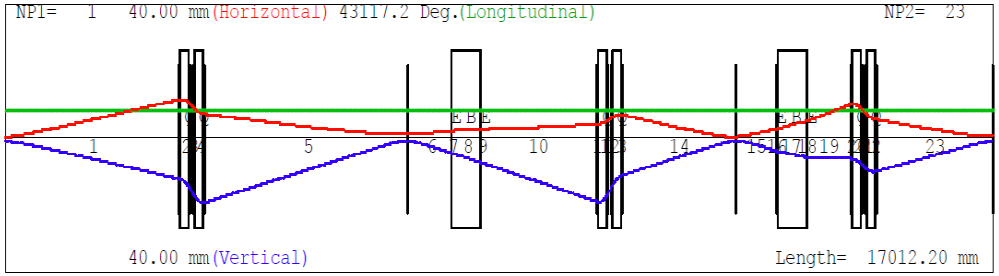
LBNL design
mA currents



Analyzing Magnet



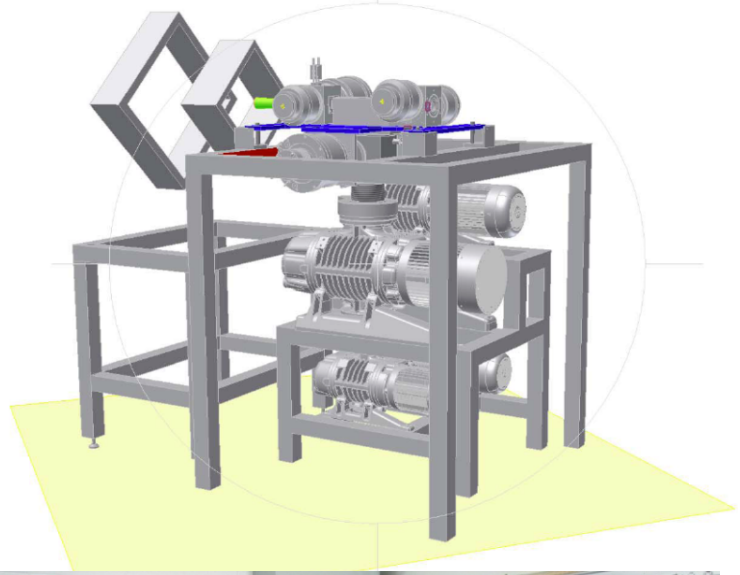


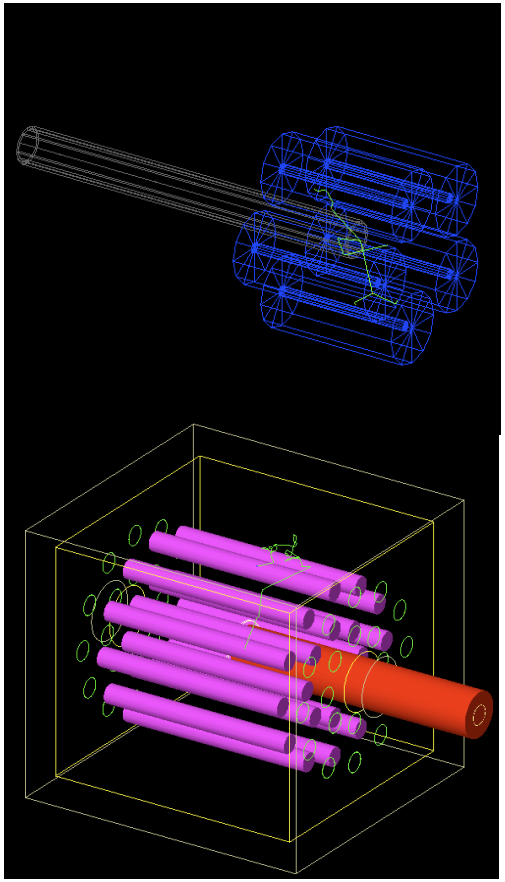


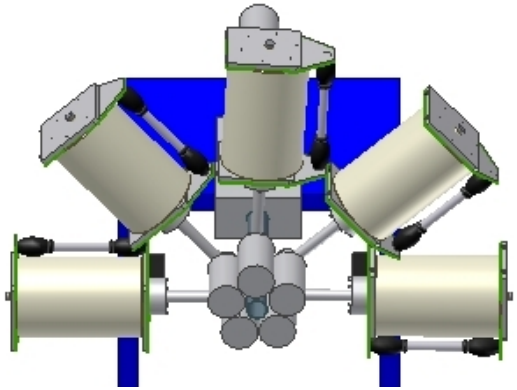
A. Lemut et al.
NIC_XI_254

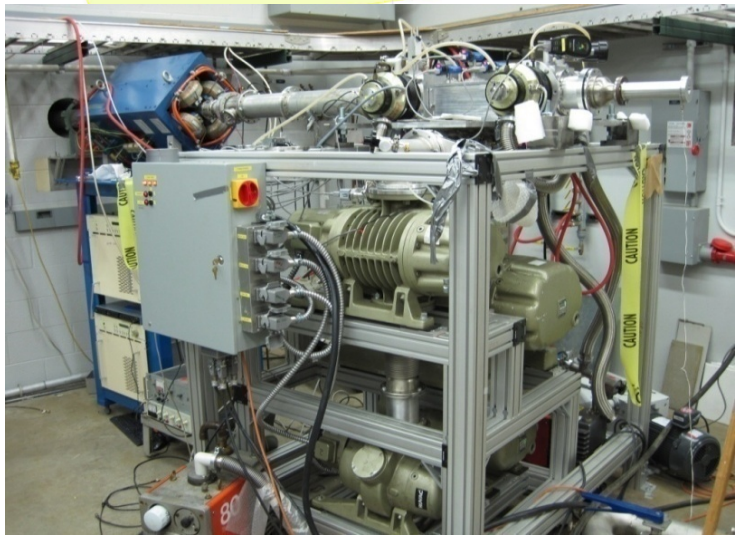
Equipment Development by university consortium, CSM, ND, UNC, WMU

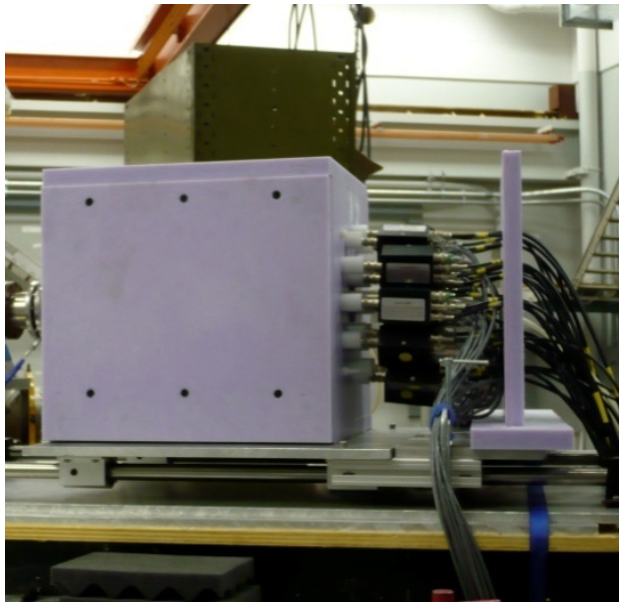
- Target systems
- Detector arrays
- Shielding



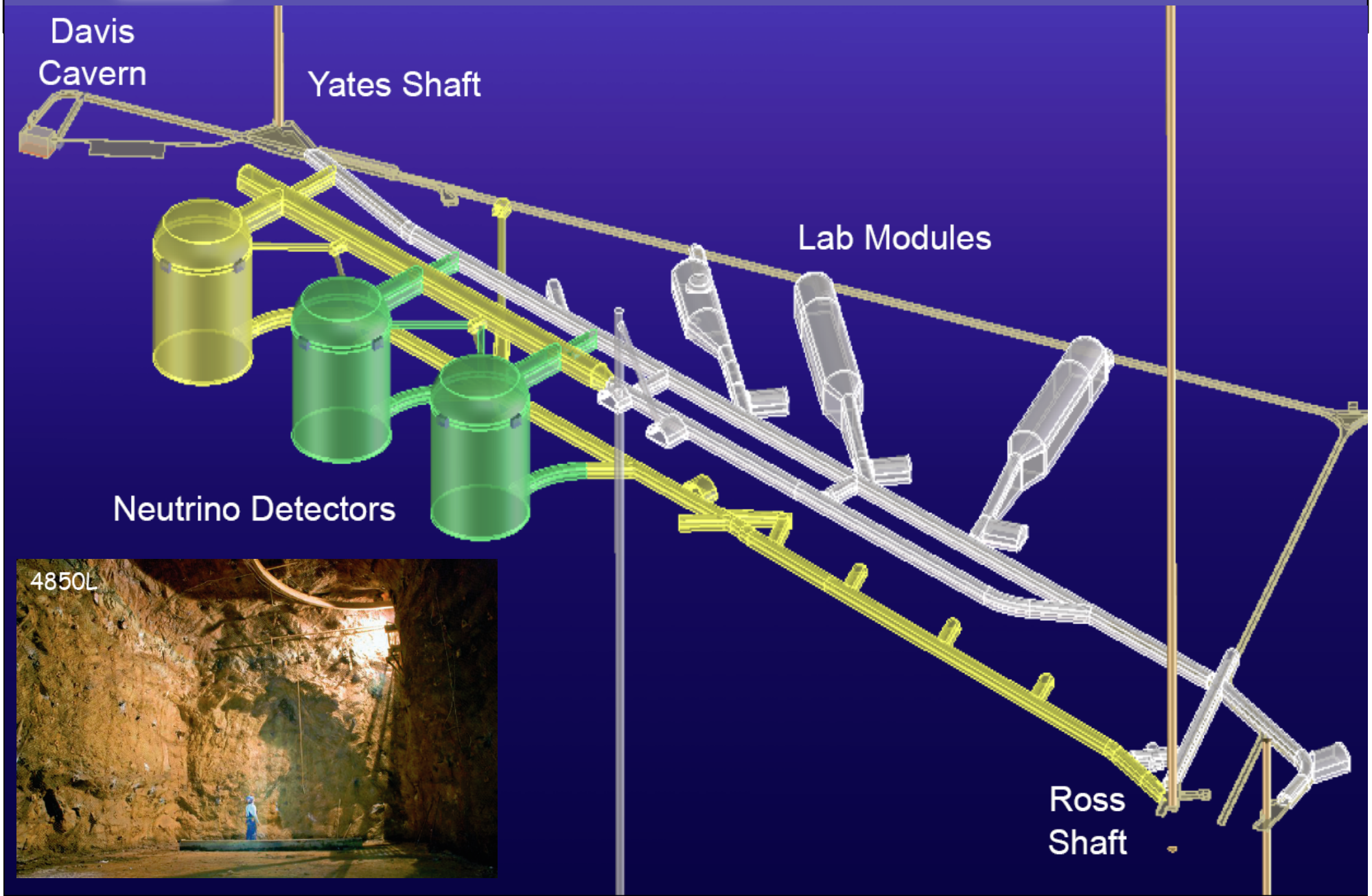




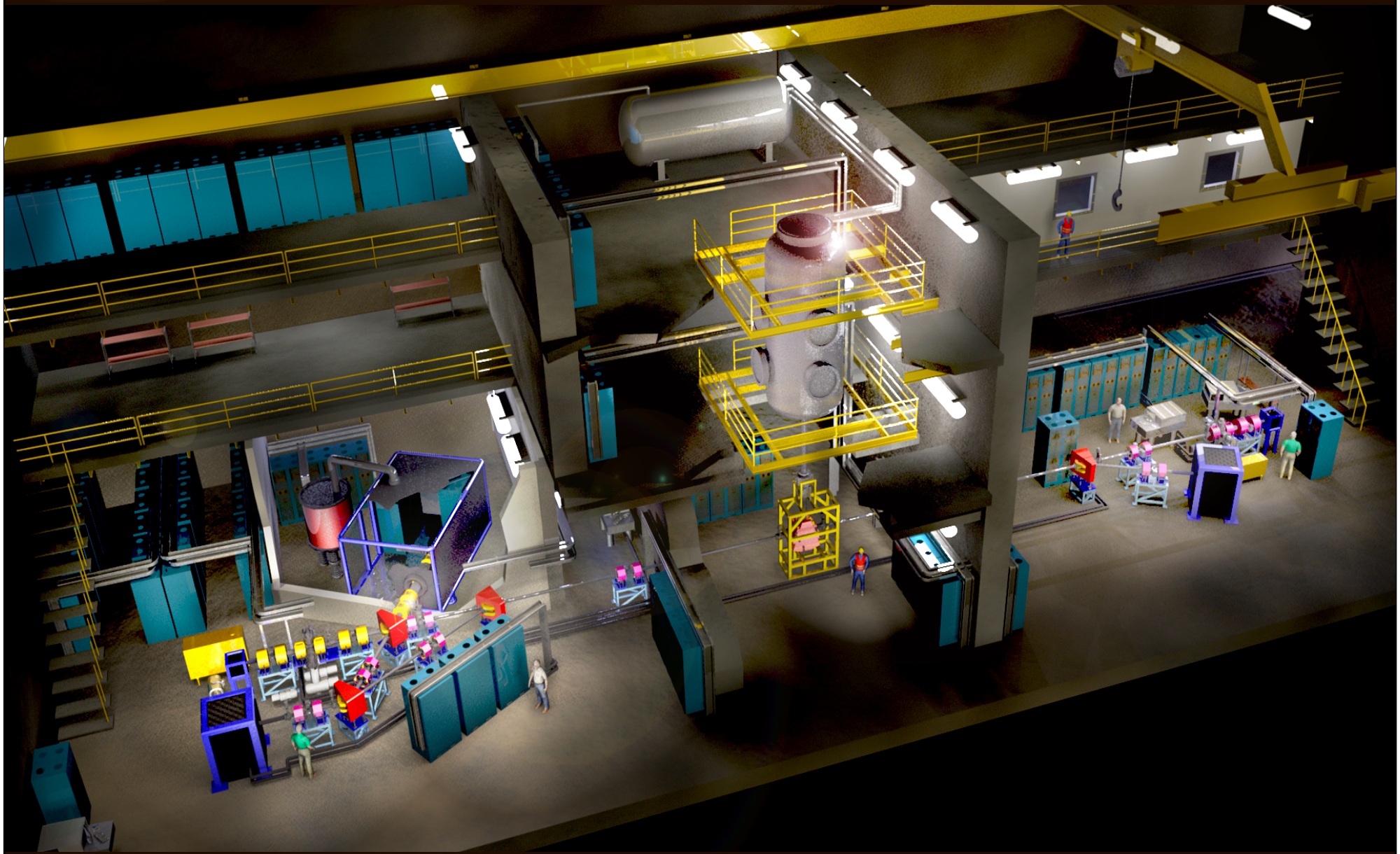




Location & Floor Plan



Design & Shielding

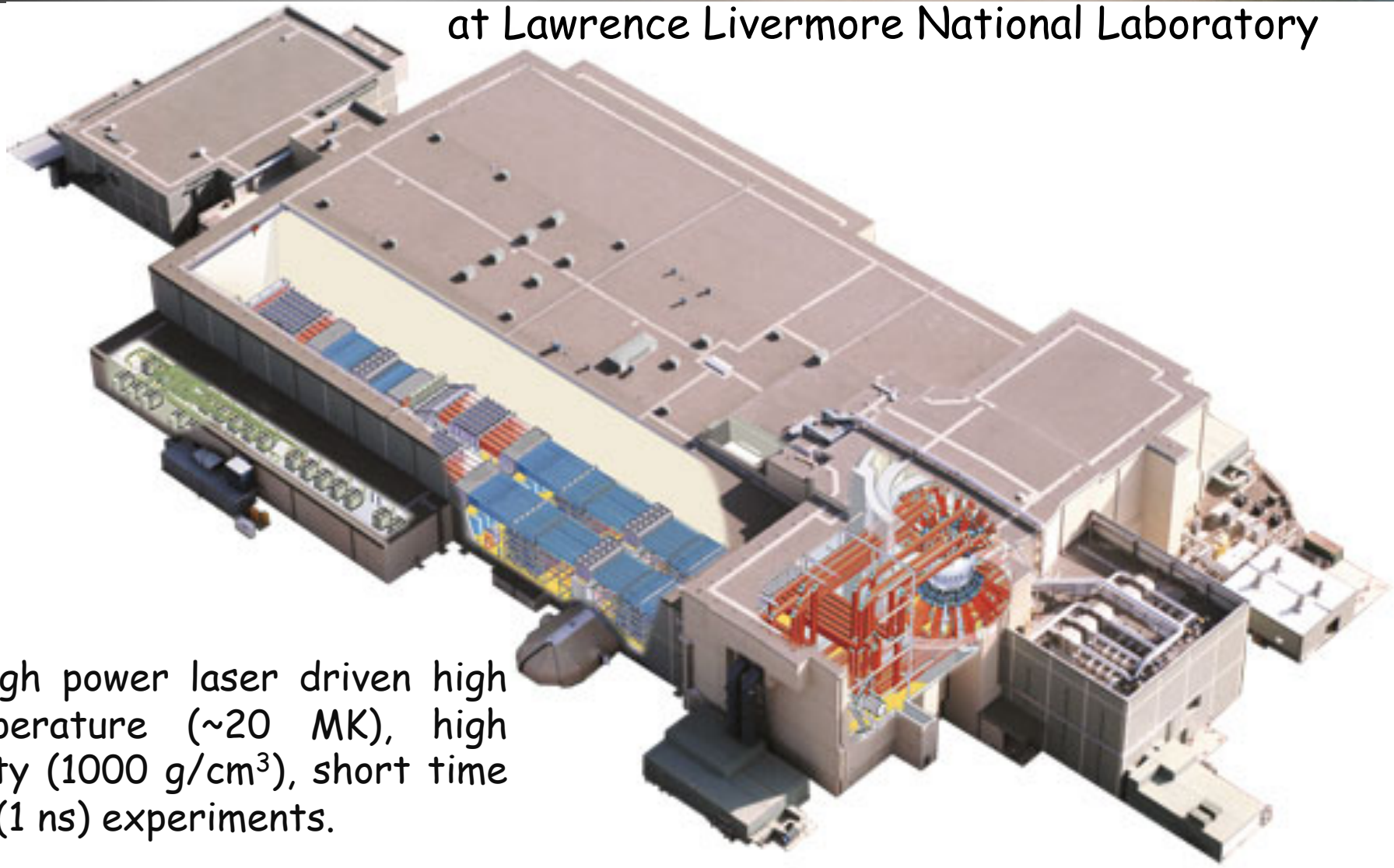


New Directions at NIF

192 high power laser driven high temperature (~20 MK), high density (1000 g/cm^3), short time scale (1 ns) experiments. In 2010, NIF has started experiments on hydrogen fueled capsules. Goals: applications, nuclear astrophysics, atomic physics, extreme matter physics.

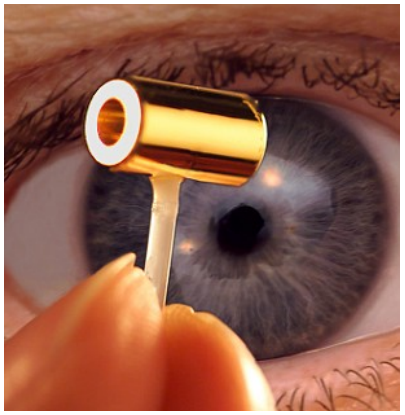
NIF
National Ignition Facility & Photon Science
Bringing Star Power to Earth

at Lawrence Livermore National Laboratory

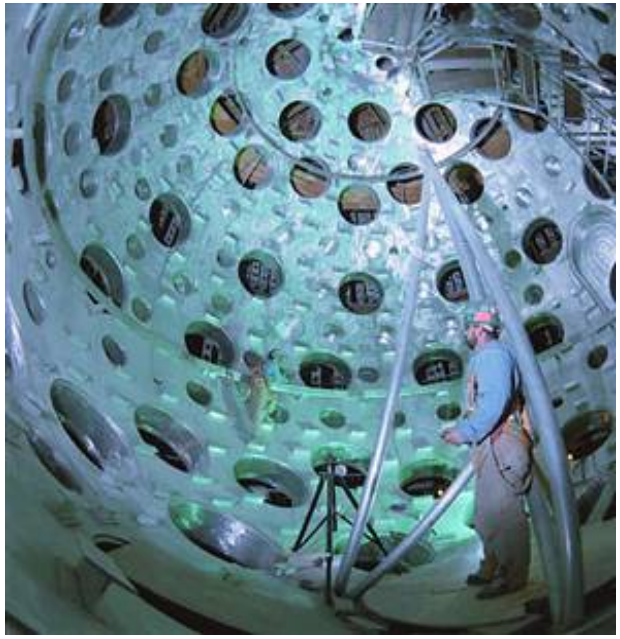


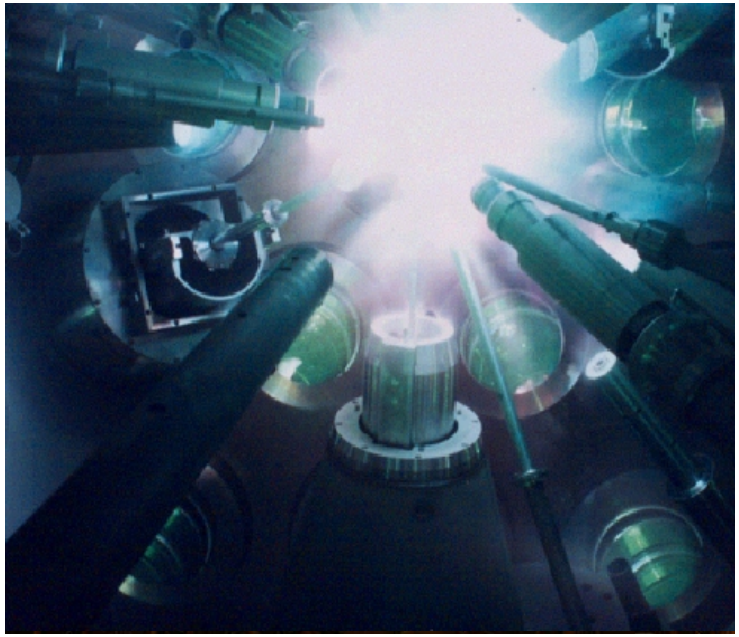
192 high power laser driven high temperature (~20 MK), high density (1000 g/cm^3), short time scale (1 ns) experiments.

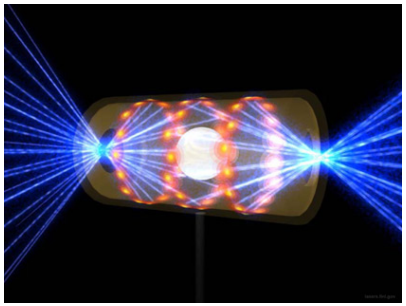
NIF principle



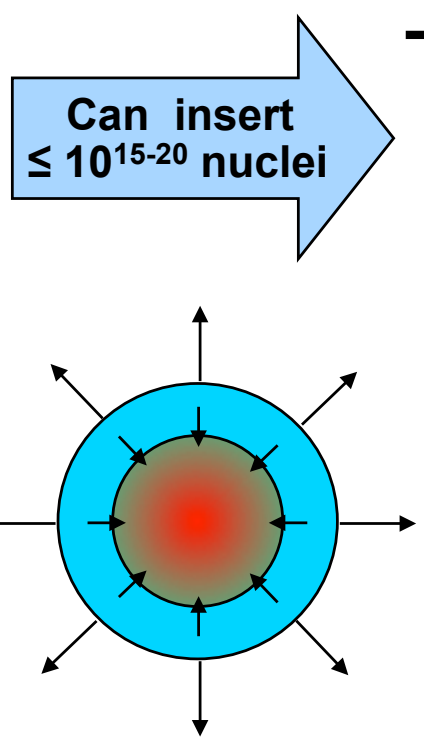
1 shot per day



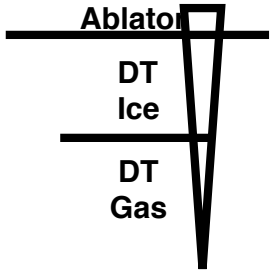




Neutron environment at NIF

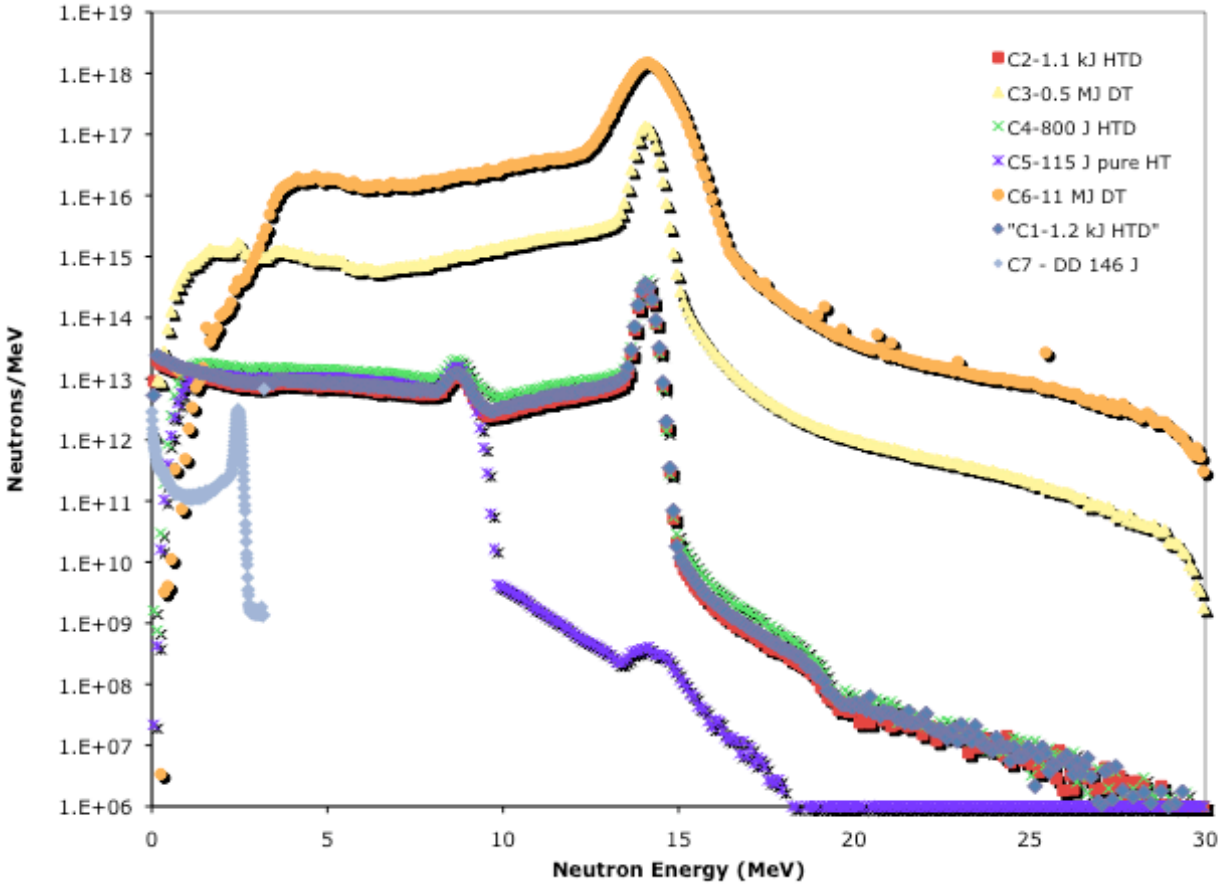


Can insert
≤ $10^{15\text{-}20}$ nuclei



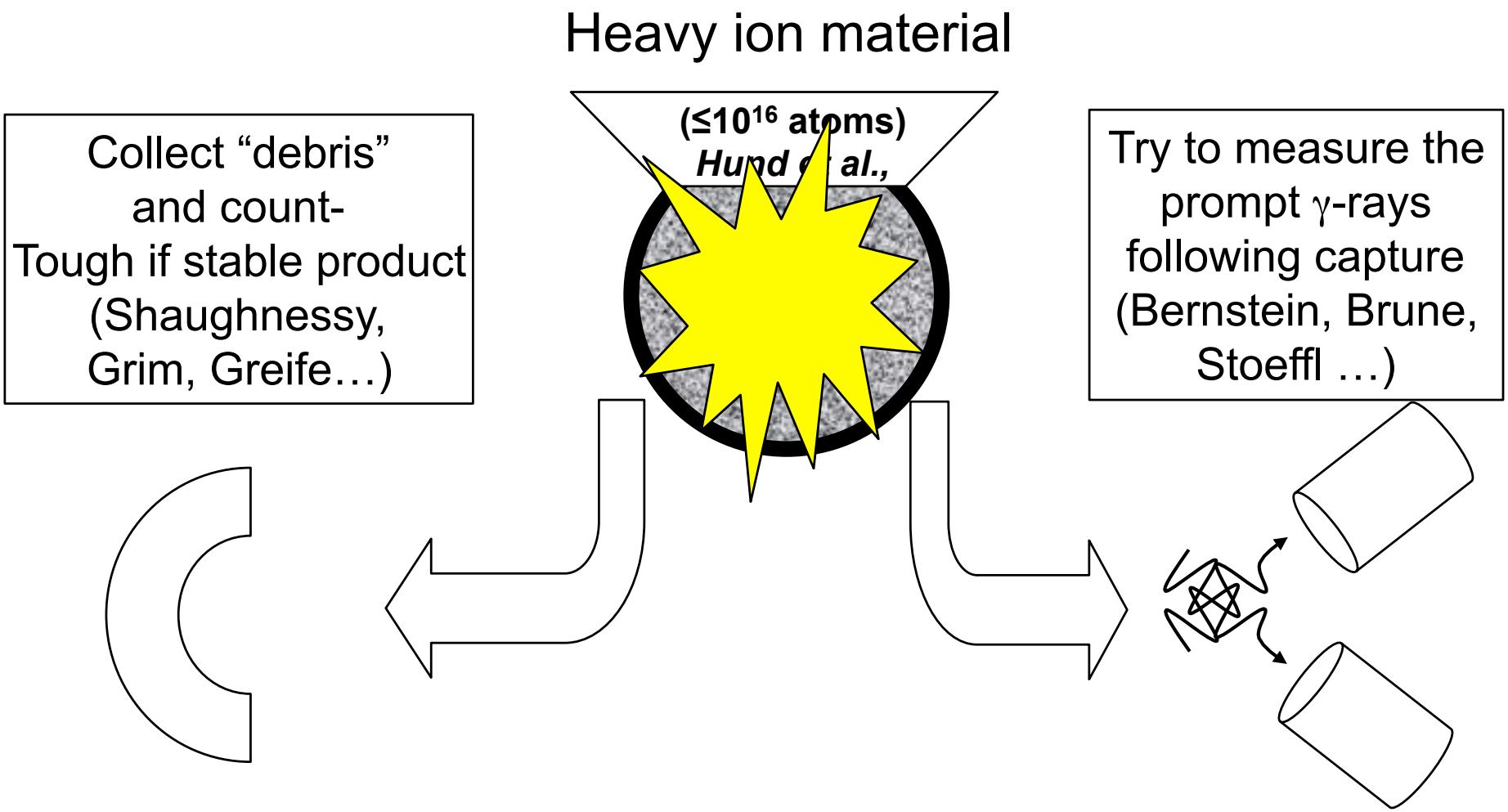
$r_{initial}$ =1 mm
r_{final} =30 μm

10^{11} – 10^{18}
neutrons

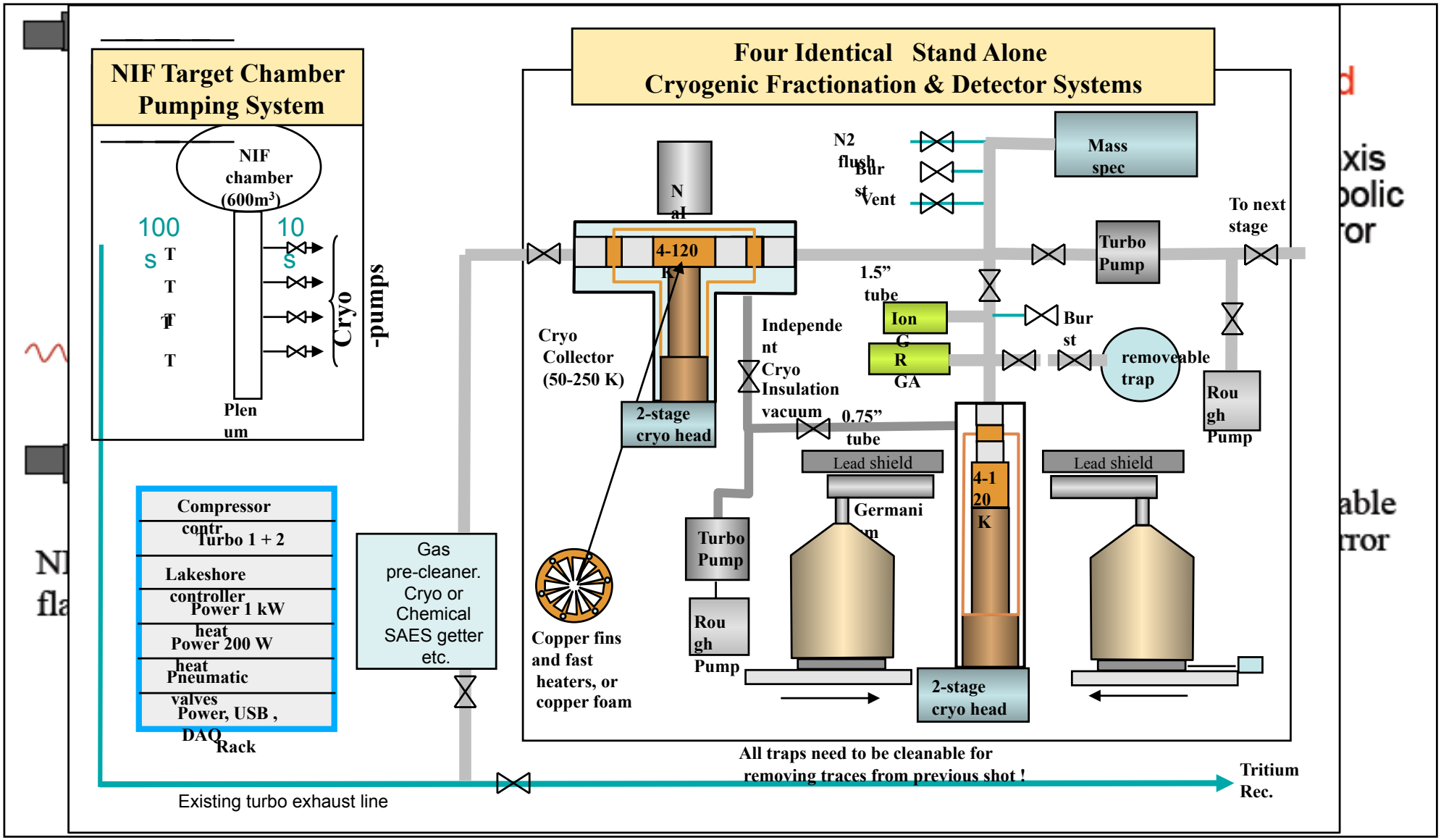


Up to 300 shots/year with ≈15% dedicated for basic science (Ride-along also possible)

Neutron capture or other (charged particle) reaction studies



Challenges


NIF Target Chamber Pumping System
NIF chamber (600m³)
100 s
10 s
T
Cryo -pumps
Plen um
Four Identical Stand Alone Cryogenic Fractionation & Detector Systems
N2 flush
Bur st
Vent
Mass spec
To next stage
Turbo Pump
1.5" tube
Ion G
R GA
Bur st
removeable trap
Rou gh Pump
4-120 K
Cryo Collector (50-250 K)
Independent Cryo Insulation vacuum
2-stage cryo head
0.75" tube
Lead shield
Germani m
4-1 20 K
Lead shield
Turbo Pump
Rou gh Pump
Copper fins and fast heaters, or copper foam
2-stage cryo head
Compressor contr
Turbo 1 + 2
Lakeshore controller
Power 1 kW heat
Power 200 W heat
Pneumatic valves
Power, USB , DAQ
Rack
Gas pre-cleaner. Cryo or Chemical SAES getter etc.
All traps need to be cleanable for removing traces from previous shot !
Tritium Rec.
Existing turbo exhaust line

Summary

- New initiatives worldwide for nuclear astrophysics facilities
- Strong effort in radioactive beams physics from FAIR to FRIB
- Strong effort in neutron beam physics from LANSCE to FRANZ
- Multiple efforts in underground physics worldwide
- Alternative accelerator based techniques
- Alternative new techniques & challenges at laser ignition labs from OMEGA to NIF