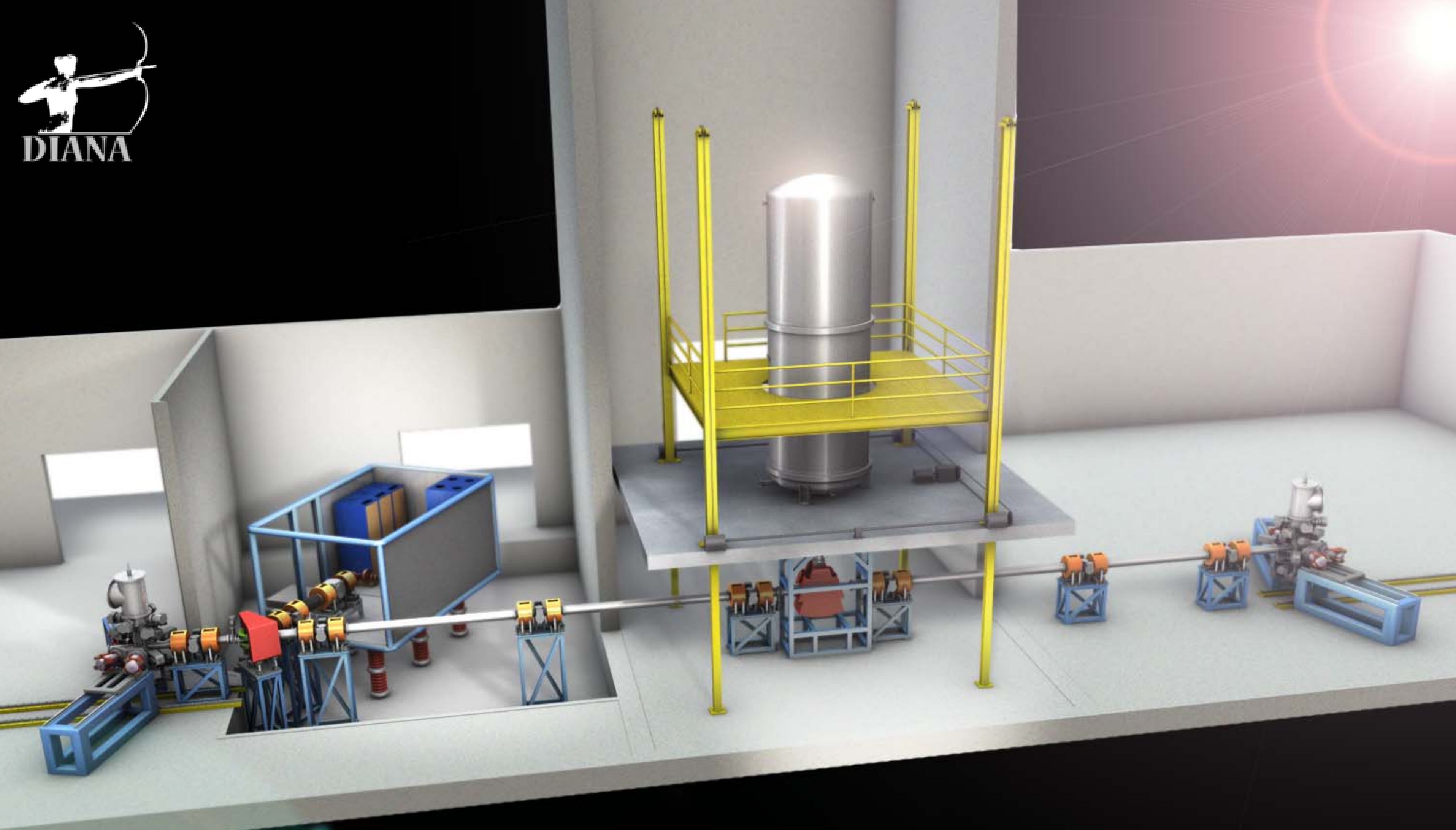


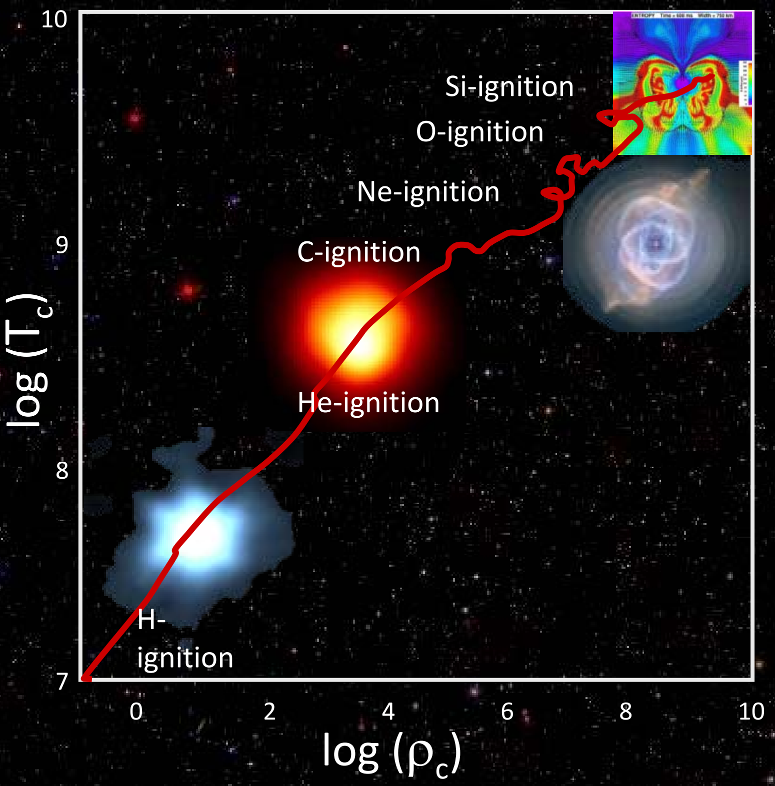
DIANA

A NOVEL NUCLEAR ASTROPHYSICS UNDERGROUND ACCELERATOR

M. Leitner
Lawrence Berkeley National Laboratory

HIAT'09
Venice, Italy, June 2009

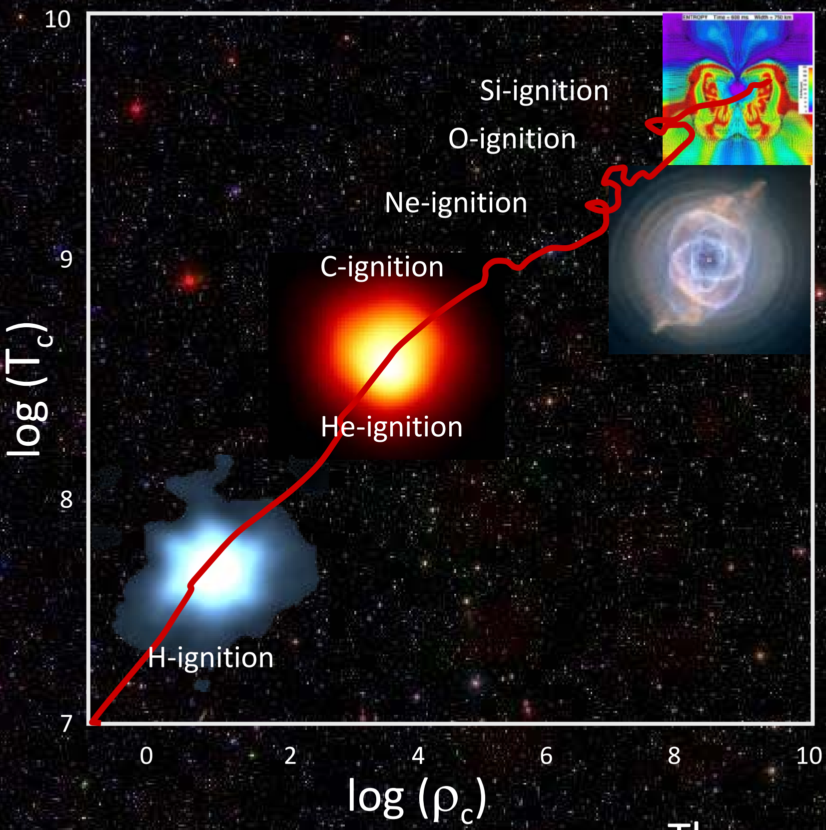
DIANA will address three fundamental scientific questions



- Solar neutrino sources and the metallicity of the sun
- Carbon-based nucleosynthesis
- Neutron sources for the production of trans Fe elements

Each phase of stellar evolution consists of different nuclear fuel cycles characterized by energy generation, time scale, nucleosynthesis cycles and outputs, which are determined by the nuclear reaction cross sections

DIANA will address three fundamental scientific questions



Hydrogen Burning

$^{3}He(\alpha,\gamma)^{7}Be$
$^{2}H(\alpha,\gamma)^{6}Li$
$^{3}He(^{3}He,2p)^{4}He$
$^{7}Be(p,\gamma)^{8}B$

$^{12}C(p,\gamma)^{13}N$
$^{14}N(p,\gamma)^{15}O$
$^{15}N(p,\gamma),(p,\alpha)^{16}O,^{12}C$

$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$
$^{18}O(p,\gamma),(p,\alpha)^{19}F,^{15}N$
$^{19}F(p,\gamma),(p,\alpha)^{20}Ne,^{16}O$

Helium Burning

$^{12}C(\alpha,\gamma)^{16}O$
$^{16}O(\alpha,\gamma)^{20}Ne$
$^{20}Ne(\alpha,\gamma)^{24}Mg$

$^{18}O(\alpha,\gamma)^{22}Ne$
$^{22}Ne(\alpha,\gamma)^{26}Mg$
$^{24}Mg(\alpha,\gamma)^{28}Si$

$^{13}C(\alpha,n)^{16}O$
$^{22}Ne(\alpha,n)^{25}Mg$
$^{25}Mg(\alpha,n)^{28}Si$
$^{26}Mg(\alpha,n)^{29}Si$

The versatility of the facility will also allow to address

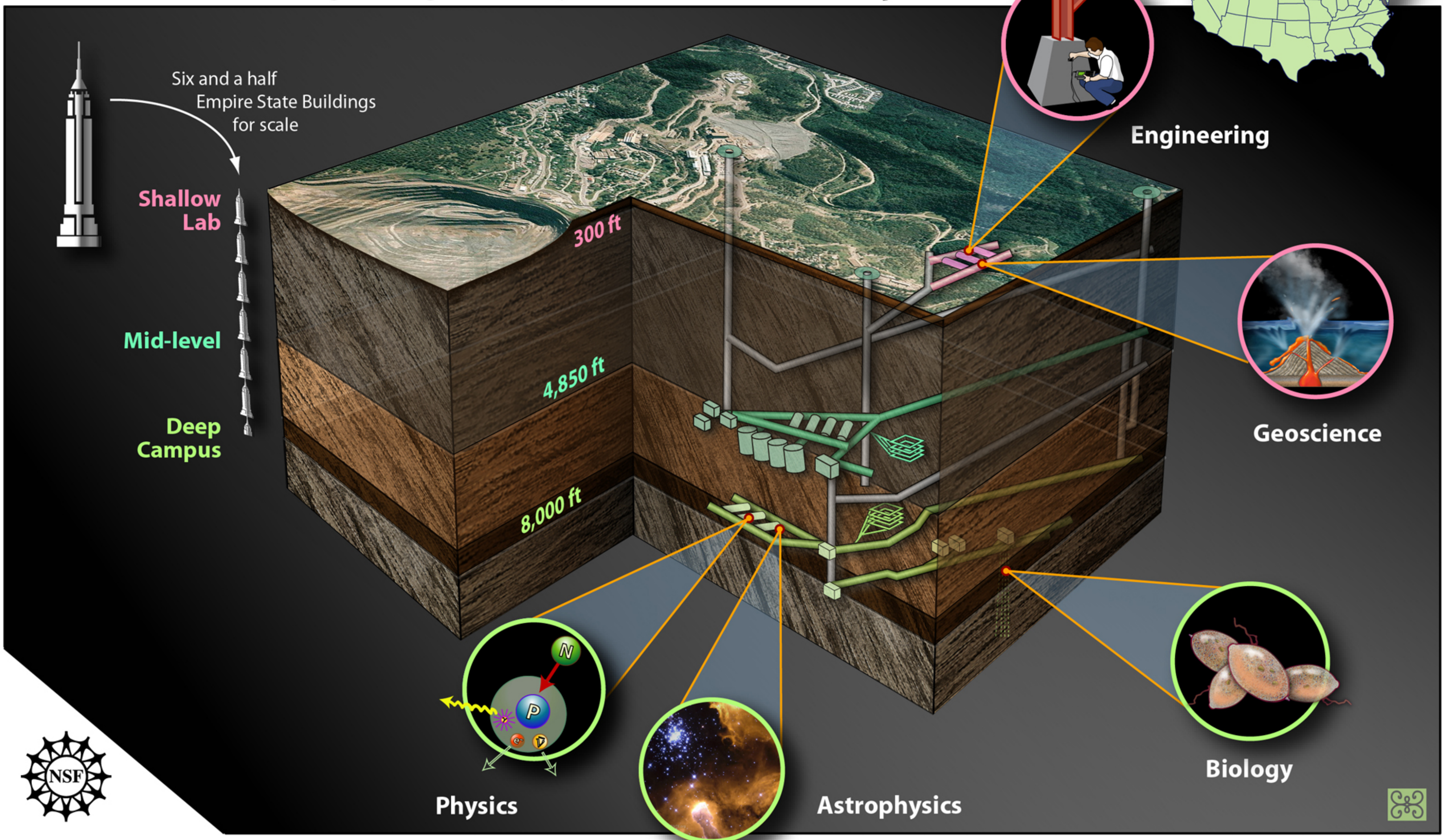
Heavy Ion Burning

$^{12}C+^{12}C$
$^{12}C+^{16}O$
$^{16}O+^{16}O$

$^{17}O(\alpha,n)^{20}Ne$
$^{28}Si(\alpha,\gamma)^{32}S$
...
..
.

Flexibility and wide energy range will make it a unique facility world wide and enable a long experimental program (10+ years)

DUSEL Deep Underground Science and Engineering Laboratory at Homestake, SD



PICTURE OF THE DUSEL HOMESTAKE SITE

All hardware has to be brought through the existing main shafts.

PICTURES OF THE DUSEL HOMESTAKE SITE

All hardware has to be brought through the existing main shafts.

DIANA S-4 PROJECT

Project Director
Michael Wiescher
Institute for Structure and Nuclear Astrophysics
University of Notre Dame

Project Management
Matthaeus Leitner
Engineering Division
Lawrence Berkeley National Laboratory

TARGET STATION DESIGN

Principal Investigator
Michael Wiescher
Institute for Structure and Nuclear Astrophysics
University of Notre Dame

Gas Jet Development
Target Station Physics Design
Magnet Optics and Design
Neutron Detectors

1 Post Doc
1 Staff Scientist

DIAGNOSTICS DEVELOPMENT

Principal Investigator
Christian Iliadis
Nuclear Astrophysics Group
University of North Carolina

Detector Development

1 Post Doc

ACCELERATOR AND FACILITY DESIGN

Principal Investigator
Daniela Leitner
Nuclear Science Division
Lawrence Berkeley National Laboratory

Low-Energy Accelerator Design
High-Energy Accelerator Design
Ion Optics
Facility Integration
Target Station Mechanical Design
Project Management

1 Post Doc
0.2 FTE Staff Scientist
0.8 FTE Mechanical Engineer
0.5 FTE Electrical Engineer
0.1 FTE Project Management
0.05 FTE Cost Estimator

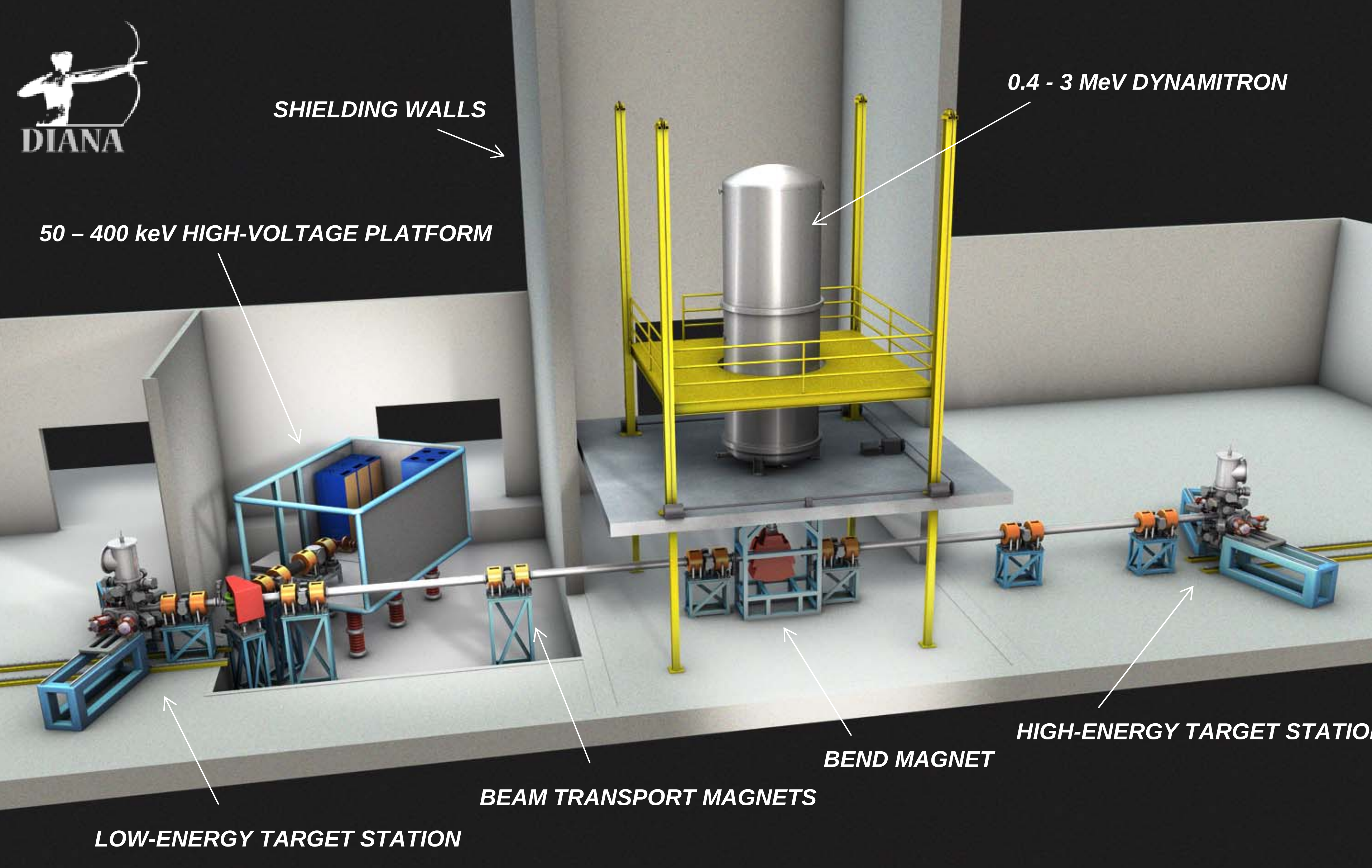
SHIELDING DEVELOPMENT

Principal Investigator
Michael Famiano
Physics Department
Western Michigan University

Shielding Development

0.15 Scientist

Dakota Ion Accelerators for Nuclear Astrophysics is a collaboration between the following institutions:



Dakota Ion Accelerators for Nuclear Astrophysics is a collaboration between the following institutions

UNIVERSITY OF NOTRE DAME

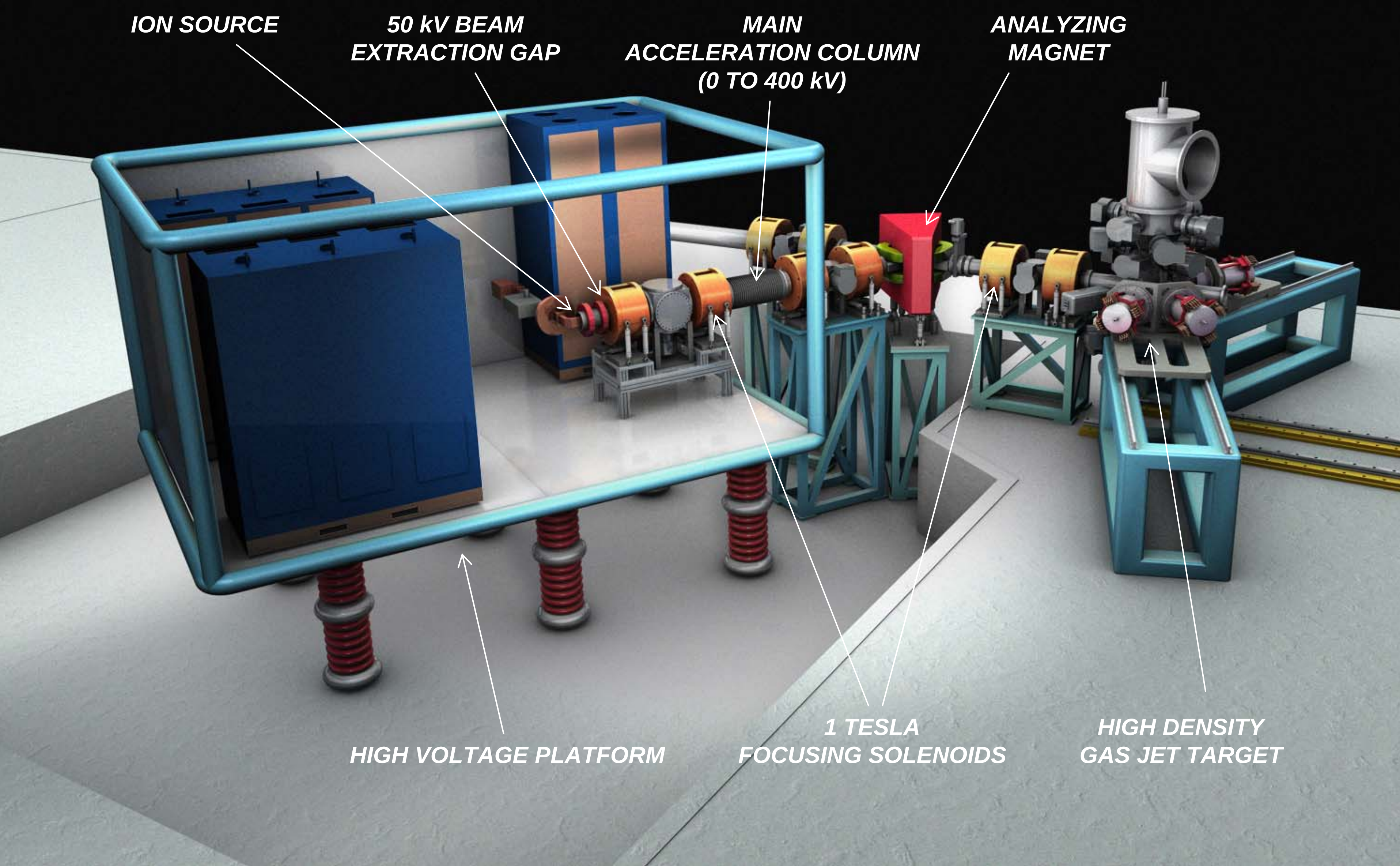
THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

BERKELEY LAB

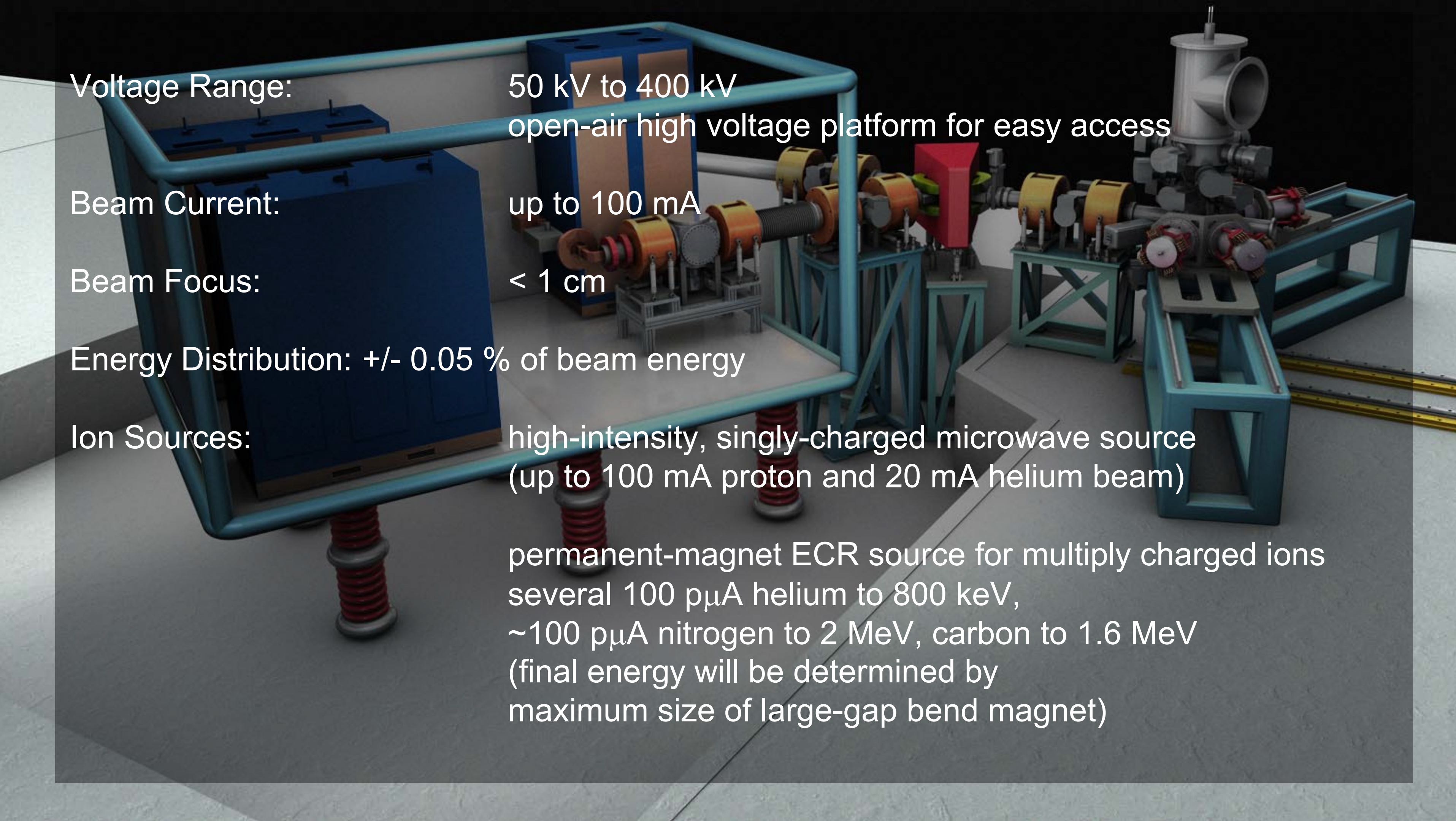
ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

LOW ENERGY ACCELERATOR AND TARGET STATION

DIANA



LOW ENERGY ACCELERATOR AND TARGET STATION



Voltage Range: 50 kV to 400 kV
open-air high voltage platform for easy access

Beam Current: up to 100 mA

Beam Focus: < 1 cm

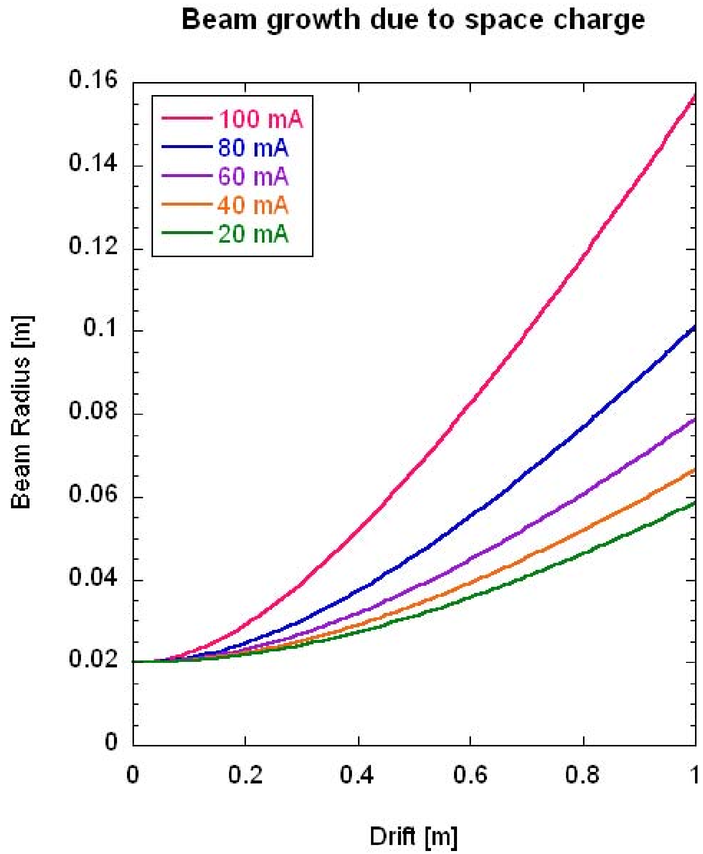
Energy Distribution: +/- 0.05 % of beam energy

Ion Sources: high-intensity, singly-charged microwave source
(up to 100 mA proton and 20 mA helium beam)

permanent-magnet ECR source for multiply charged ions
several 100 pμA helium to 800 keV,
~100 pμA nitrogen to 2 MeV, carbon to 1.6 MeV
(final energy will be determined by
maximum size of large-gap bend magnet)

SPACE CHARGE NEUTRALIZATION

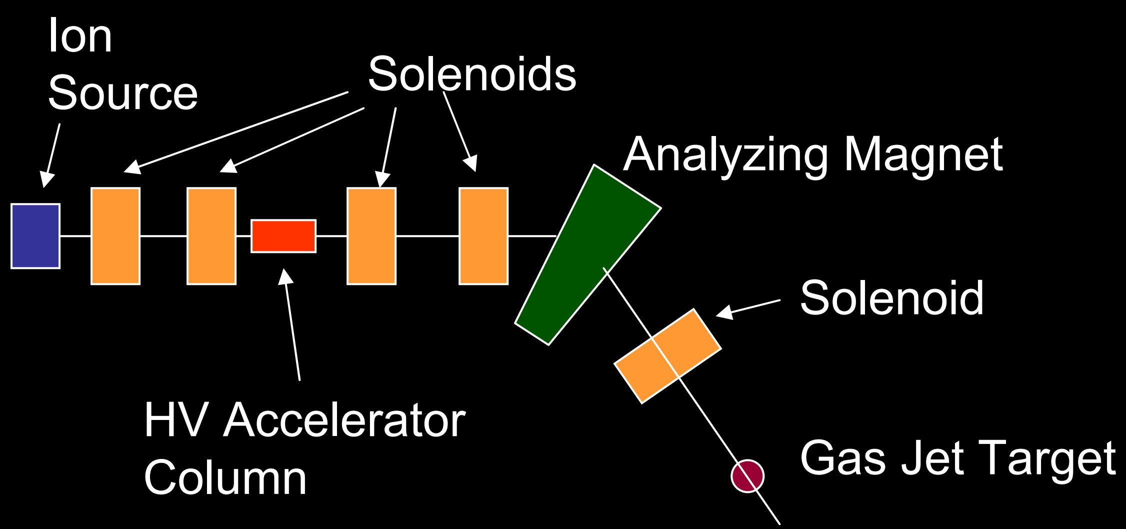
- Without some degree of neutralization a 100mA beam can't be transported at 50kV
- Space charge can introduce an unacceptable energy spread
- Electrons introduced through ionization of background gas by passing beam reduce beam potential - near full neutralization has been observed at higher pressures



- Diana transport calculations are based on 30 mA beam current assuming 70% neutralization
- Space charge neutralization in bend magnets are not well understood
- VENUS beam line at LBL could be used to test neutralization schemes

D. Todd,LBNL

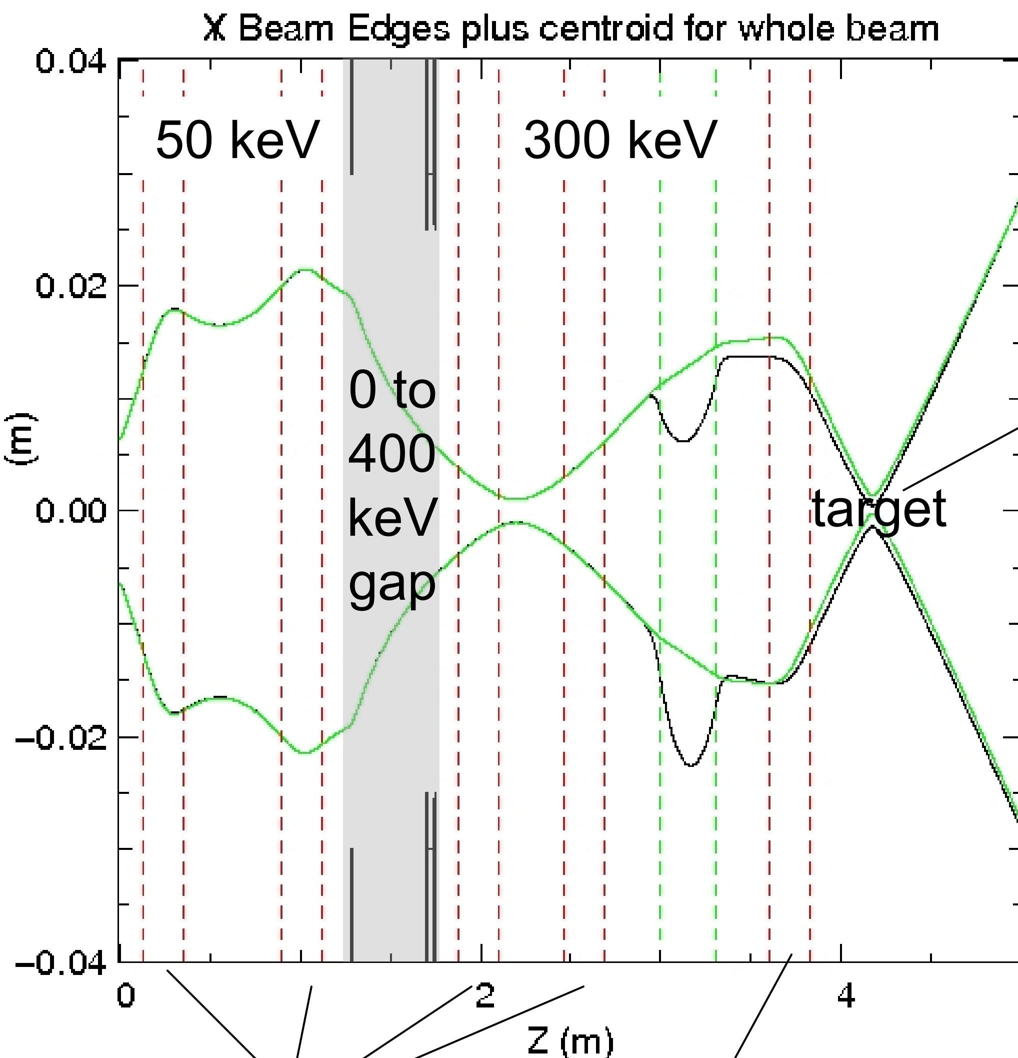
COMPACT LOW ENERGY ACCELERATOR LAYOUT FOR HIGH SPACE-CHARGE BEAM TRANSPORT



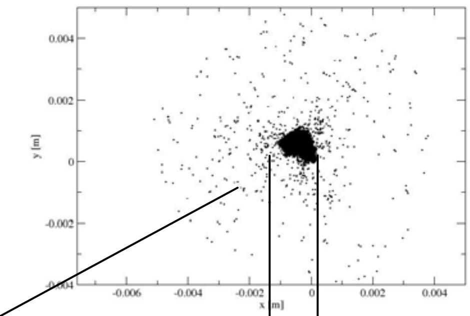
- Distance from extraction to gas jet: 6.62 m
- Solenoids of VENUS design (32 cm length, 26 cm radius)
- Acceleration gap based on high current injector at GSI, Darmstadt

WARP BEAM ENVELOPE FOR 300 keV

ion source and beam extraction



solenoids

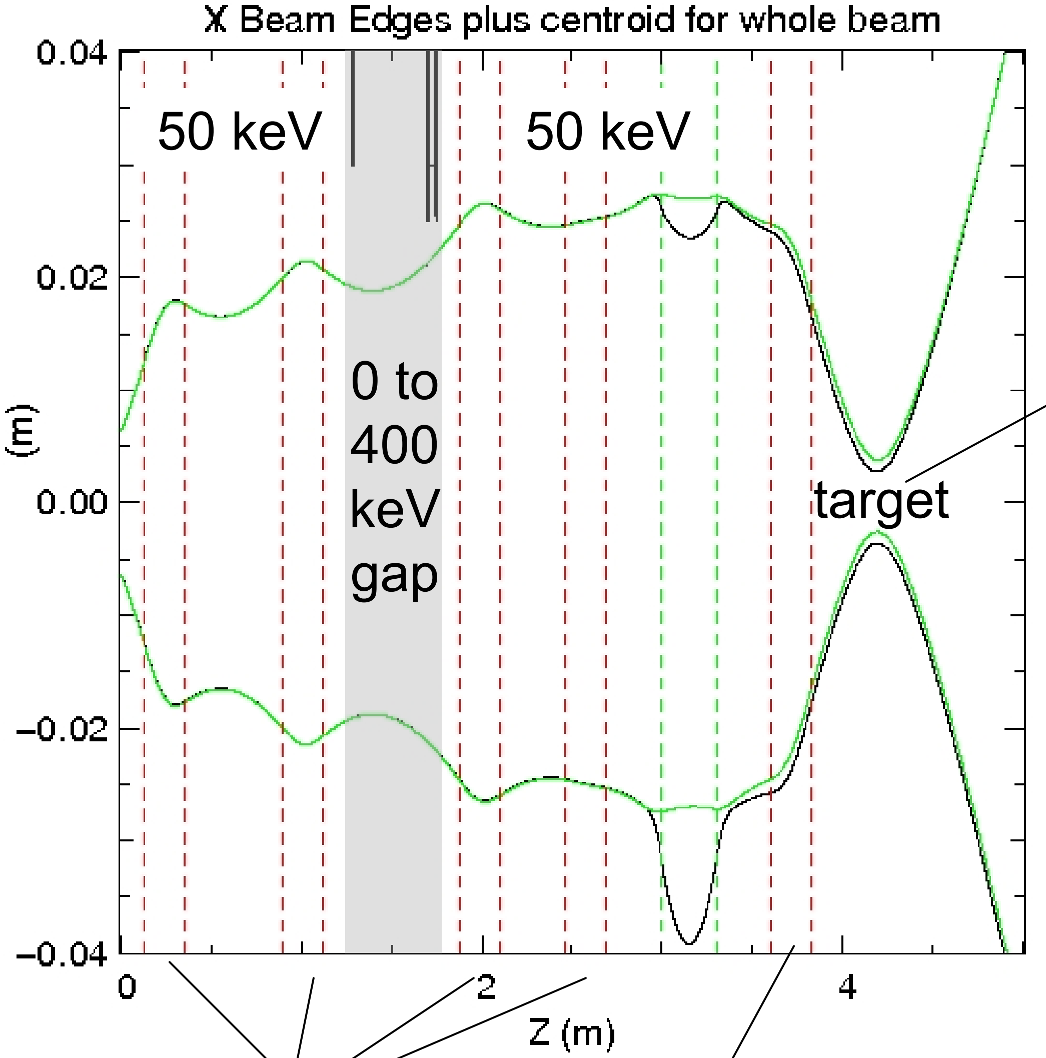


2 mm

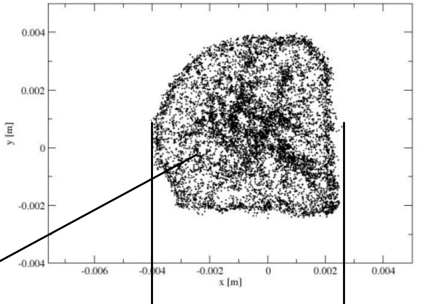
needs interfacing with the gas jet target geometry

WARP BEAM ENVELOPE FOR 50 keV

ion source and beam extraction



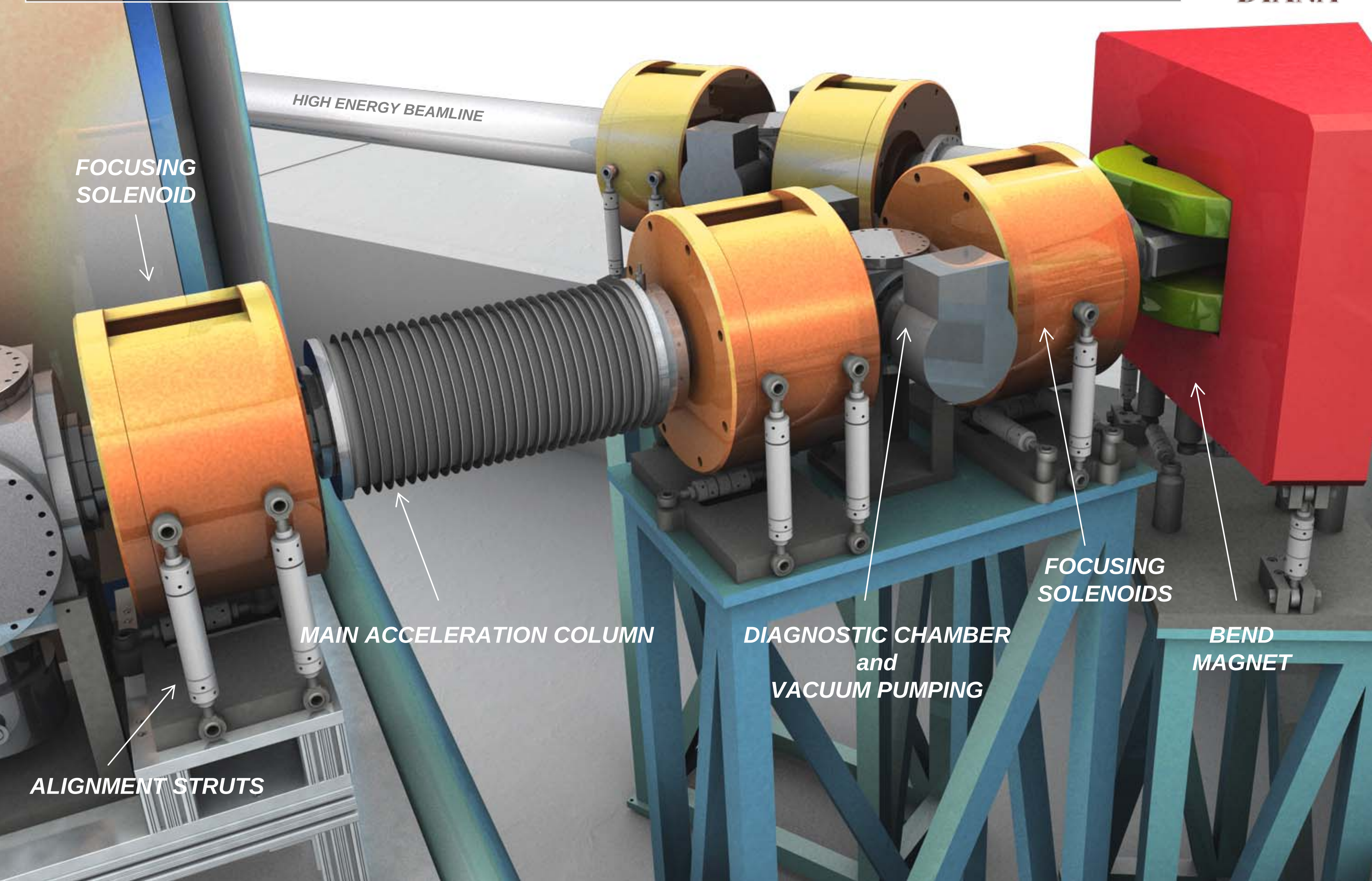
solenoids



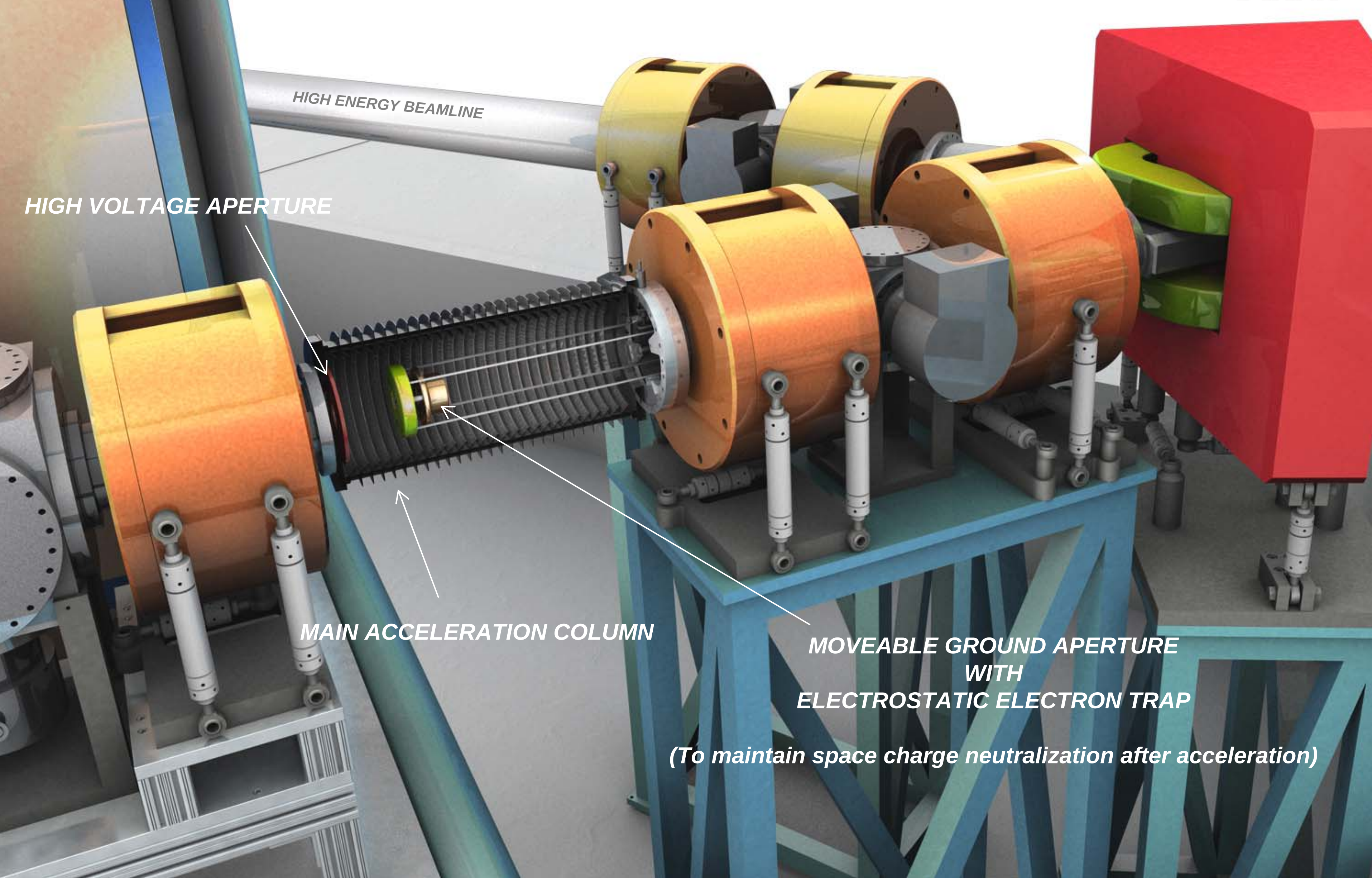
6 mm

needs interfacing with the gas jet target geometry

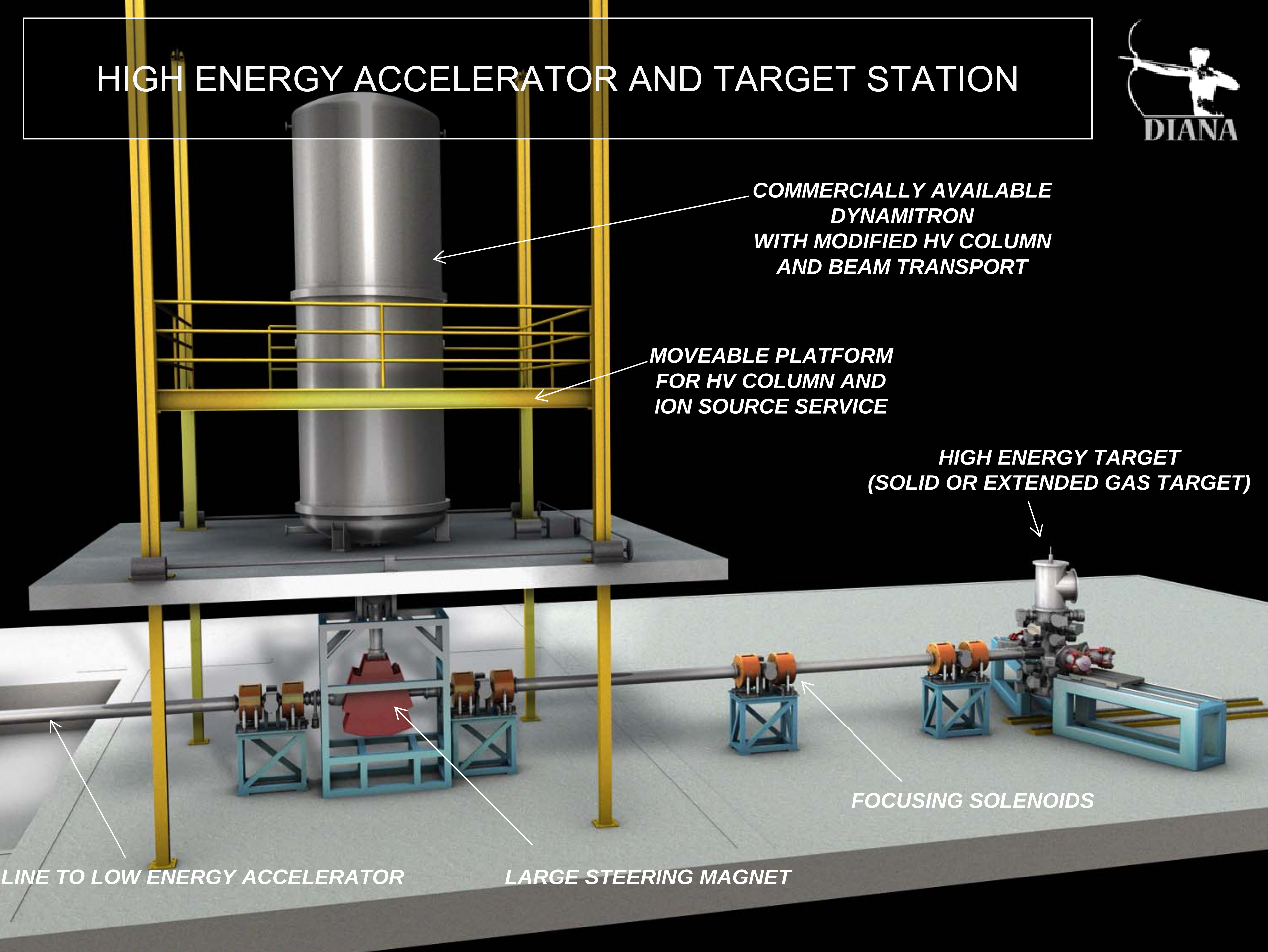
ADJUSTABLE ACCELERATION GAP WILL BE A MAIN FEATURE OF DIANA LOW ENERGY ACCELERATOR



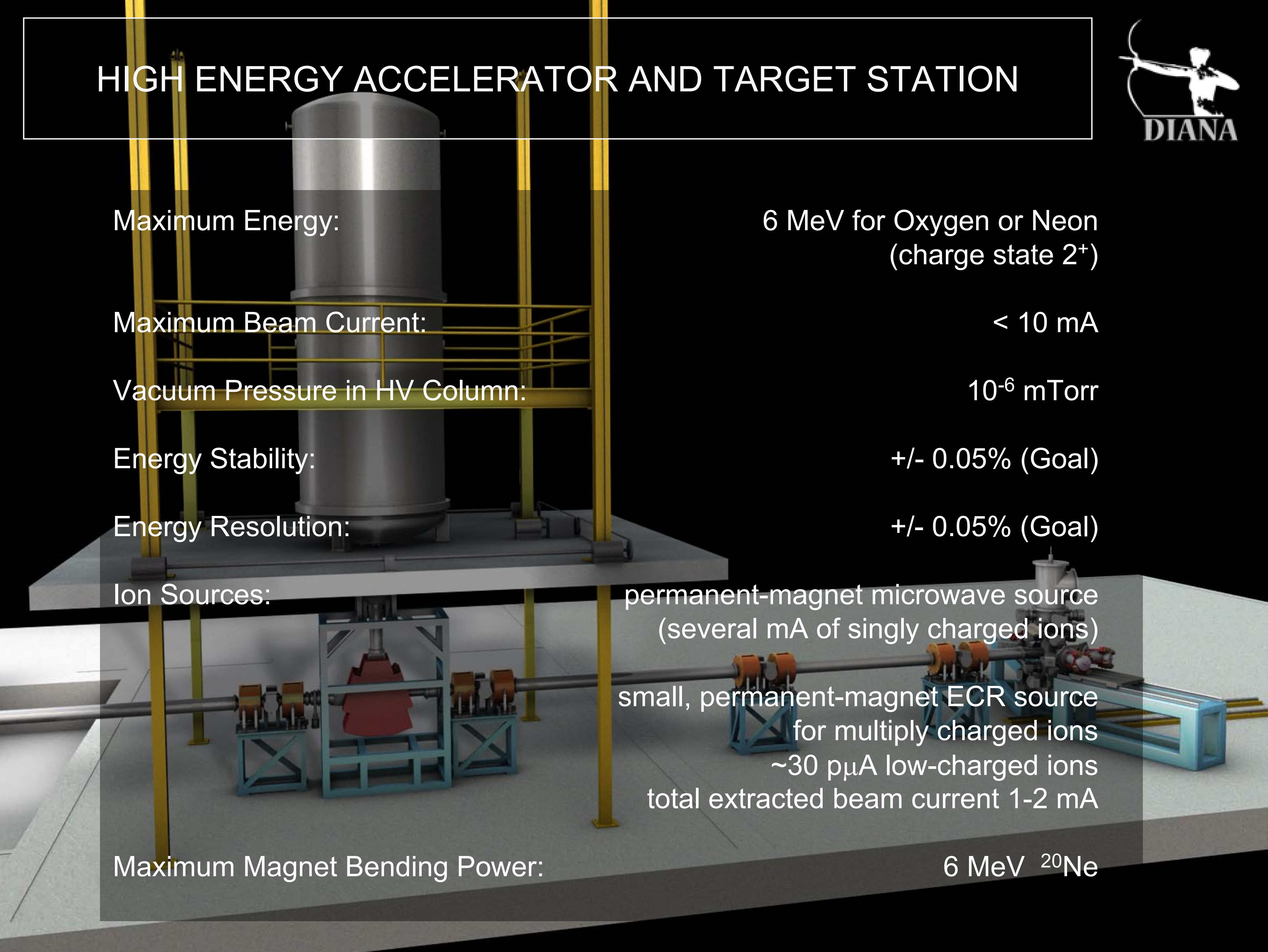
ADJUSTABLE ACCELERATION GAP WILL BE A MAIN FEATURE OF DIANA LOW ENERGY ACCELERATOR



HIGH ENERGY ACCELERATOR AND TARGET STATION



HIGH ENERGY ACCELERATOR AND TARGET STATION



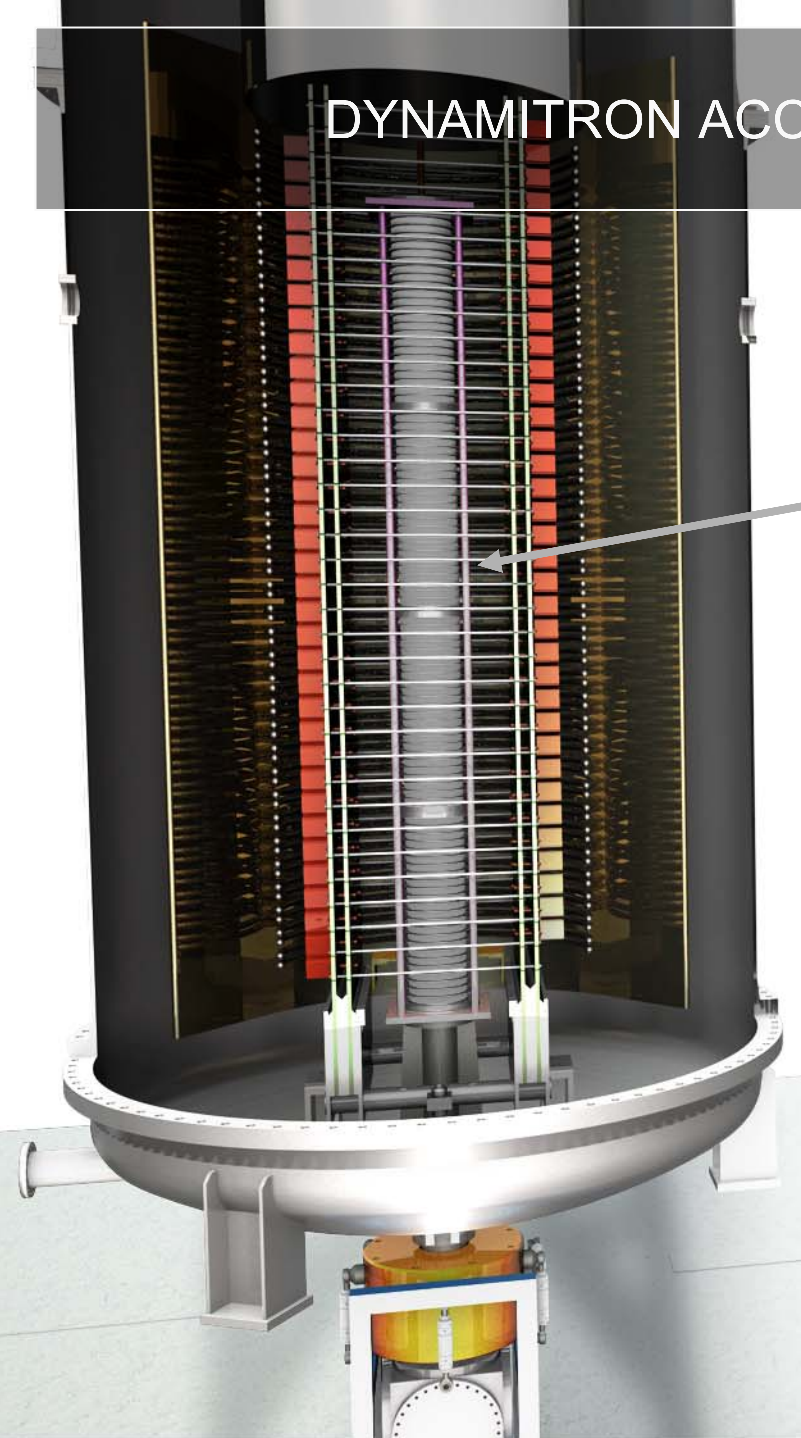
Maximum Energy:	6 MeV for Oxygen or Neon (charge state 2^+)
Maximum Beam Current:	< 10 mA
Vacuum Pressure in HV Column:	10^{-6} mTorr
Energy Stability:	+/- 0.05% (Goal)
Energy Resolution:	+/- 0.05% (Goal)
Ion Sources:	permanent-magnet microwave source (several mA of singly charged ions) small, permanent-magnet ECR source for multiply charged ions ~30 pμA low-charged ions total extracted beam current 1-2 mA
Maximum Magnet Bending Power:	6 MeV ^{20}Ne

DYNAMITRON ACCELERATION COLUMN

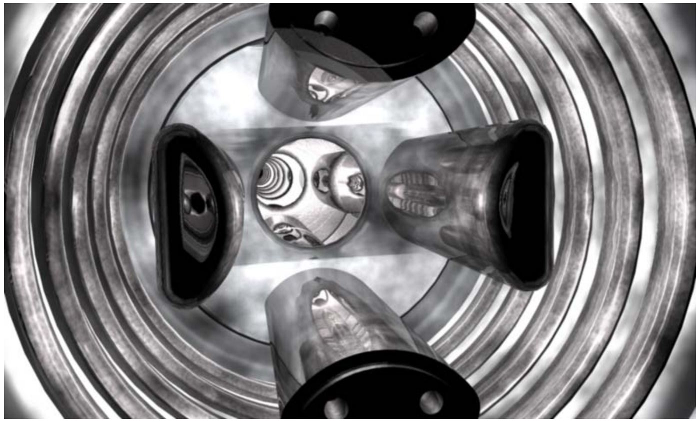
Moveable Service Platform, Dynamitron Tank, and HV Platform

Photos courtesy IBA Industrial
www.iba.be/industrial/dyna-files/dyna.php

DYNAMITRON ACCELERATION COLUMN

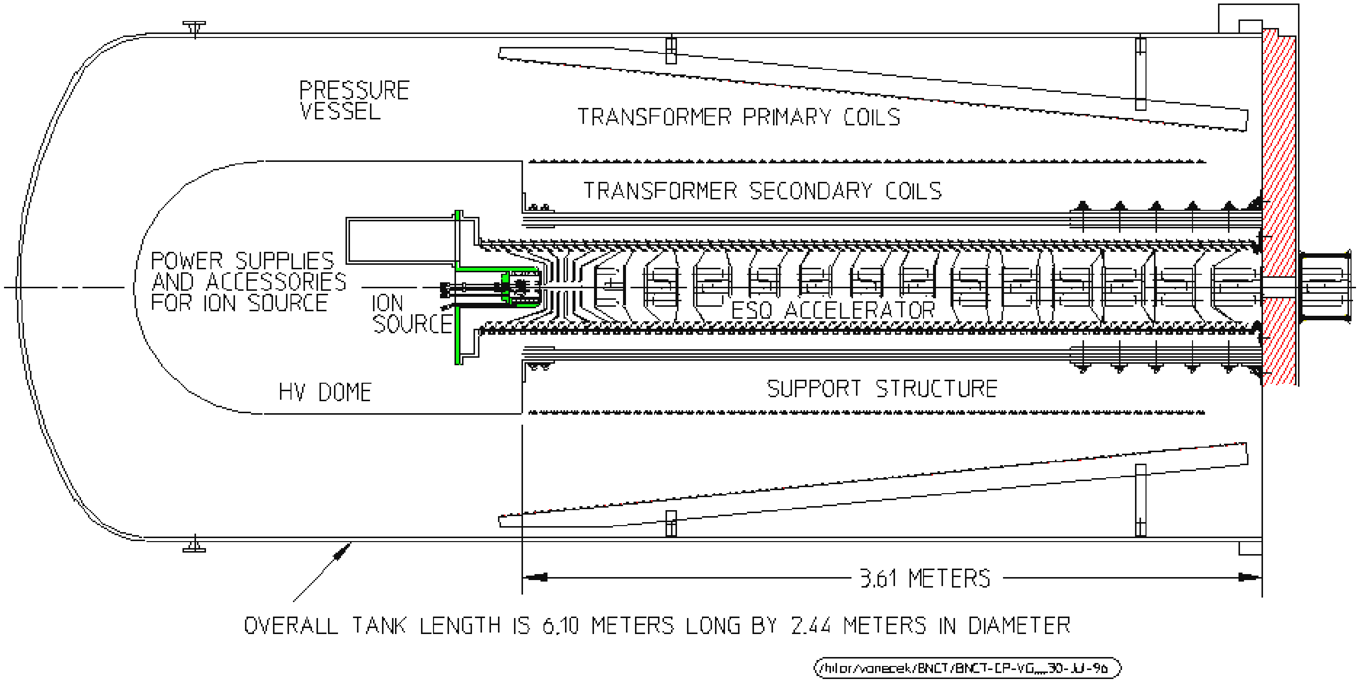


High Voltage Column (~Ø 6 inch) with ESQ Electrodes



LBNL Heavy Ion Fusion Program
HCX Electrostatic Quadrupole

HIGH CURRENT DYNAMITRON DEVELOPMENT HAS BEEN CONDUCTED AT LBNL



SCHEMATIC DIAGRAM OF THE ESQ ACCELERATOR FOR BNCT

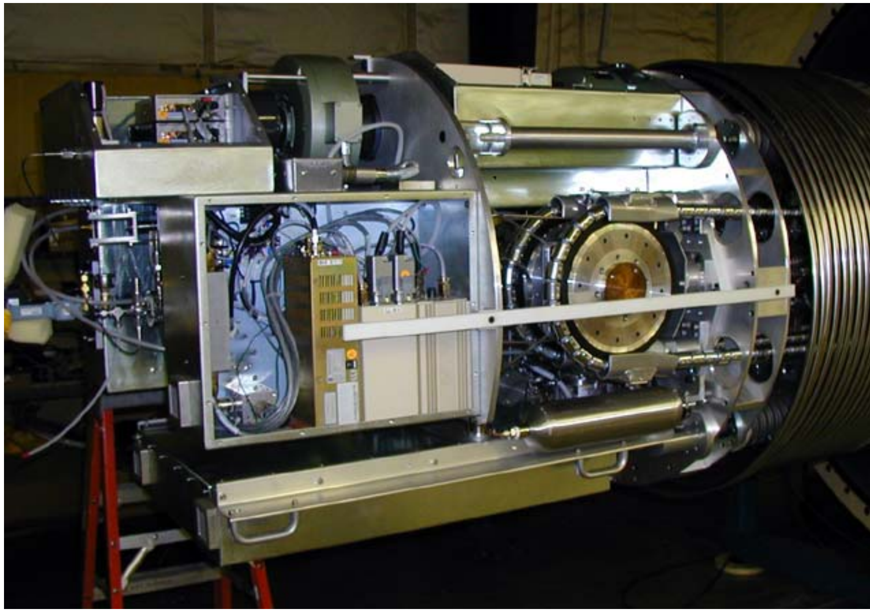
Electrostatic **Q**uadrupole (ESQ)

- **E**lectro **S**tatic **Q**uadrupole (ESQ) accelerators provide strong focusing for high currents and allow energy as well as current variability
- ESQs suppress secondary electrons to minimize electrical breakdowns

designed for BNCT application (50mA protons at 2.5MeV), J. Kwan et al. LBNL

ECR SOURCE ON DYNAMITRON PLATFORM WILL BE MOST CHALLENGING DEVELOPMENT ITEM

DIANA



Picture of a NEC Pelletron Platform

PANTECHNIK Permanent Magnet ECR Source
for singly and multiply charged ions

Examples:
5.5 MeV van de Graaf of the Hahn Meitner Institure in Berlin
10 GHz Nanogun on a 3 MeV NEC Pelletron

Challenges:
Vacuum Pumping, Extraction, Mass Analysis

SUMMARY

- DIANA will be a unique astrophysics accelerator:
    - Broad range of energies
    - Significantly higher beam currents than currently achievable
    - Target stations can be operated with overlapping beam energies

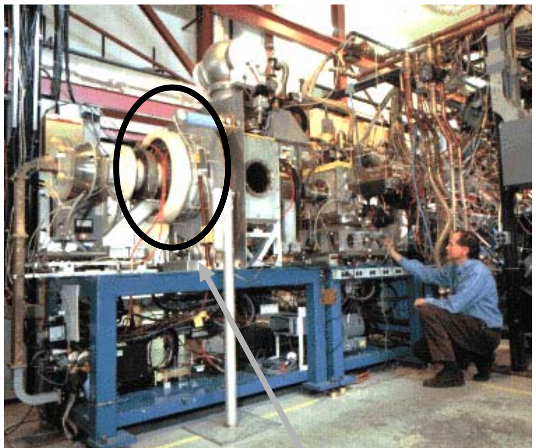
- Low energy beamline challenges:
    - Space charge neutralization
    - Compact beam transport with moveable acceleration gap
    - Fabrication of high voltage column
    - Focal spot size and target integration

- High energy beamline challenges:
    - Ion source vacuum pumping
    - Extraction system performance at higher vacuum pressure
    - ESQ beam transport
    - Beam transport for a wide energy range


DIANA
THANK YOU

HIGH CURRENT MICROWAVE SOURCES
LEDA in Los Alamos, SIHLI at CAE in France , > 100 mA H^+

Low-Energy Demonstrator Accelerator (LEDA):



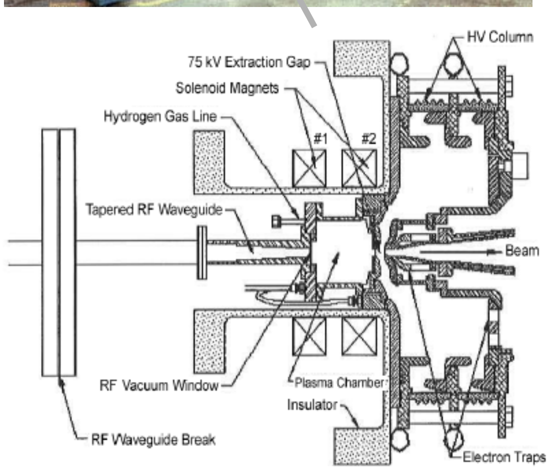
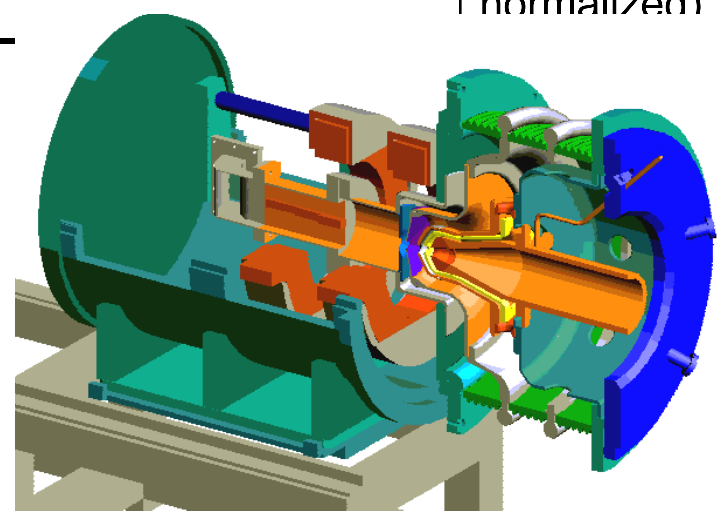


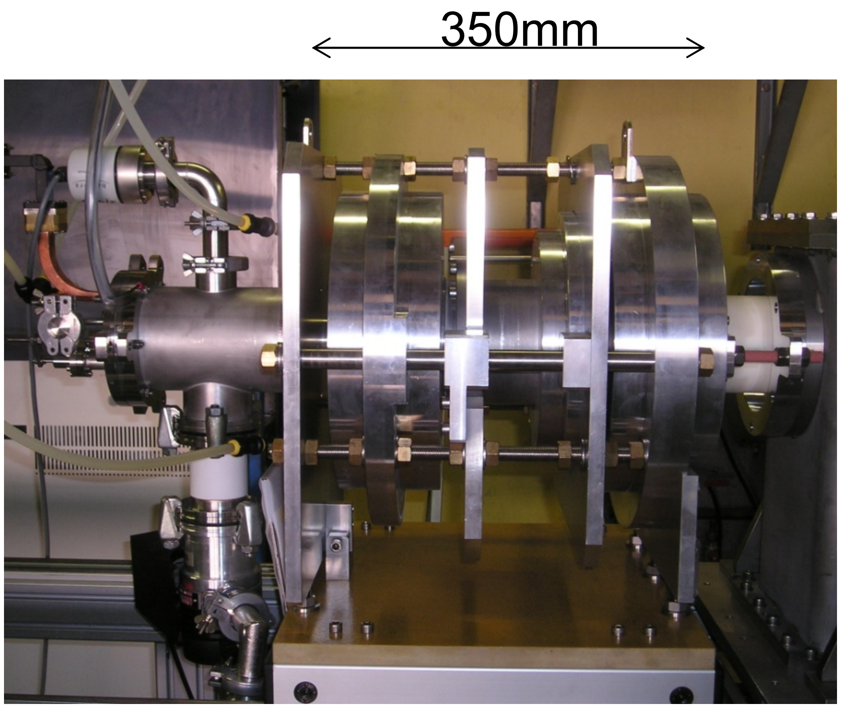
Figure 1. LEDA microwave proton source.

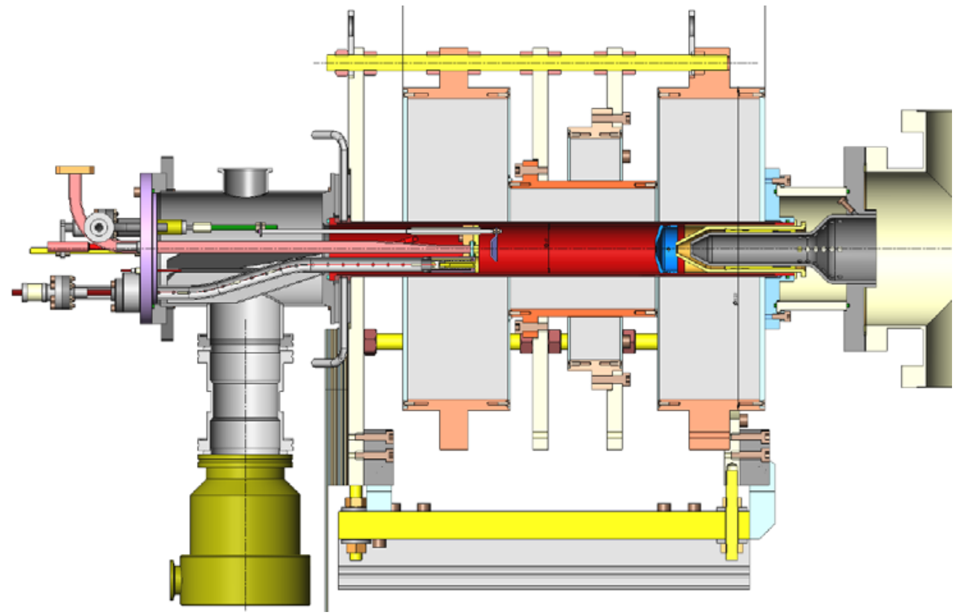
Proton beam current (mA)	117
Proton fraction(%)	90
Beam injection energy (keV)	75
Discharge power (W) 2.45 GHZ	600 to 800
Beam noise (%)	±1
Ion source emittance (πmm-mrad)	0.13 (rms, normalized)



*J. Sherman, et. al. *RSI*, vol. 69, 1003, 1998

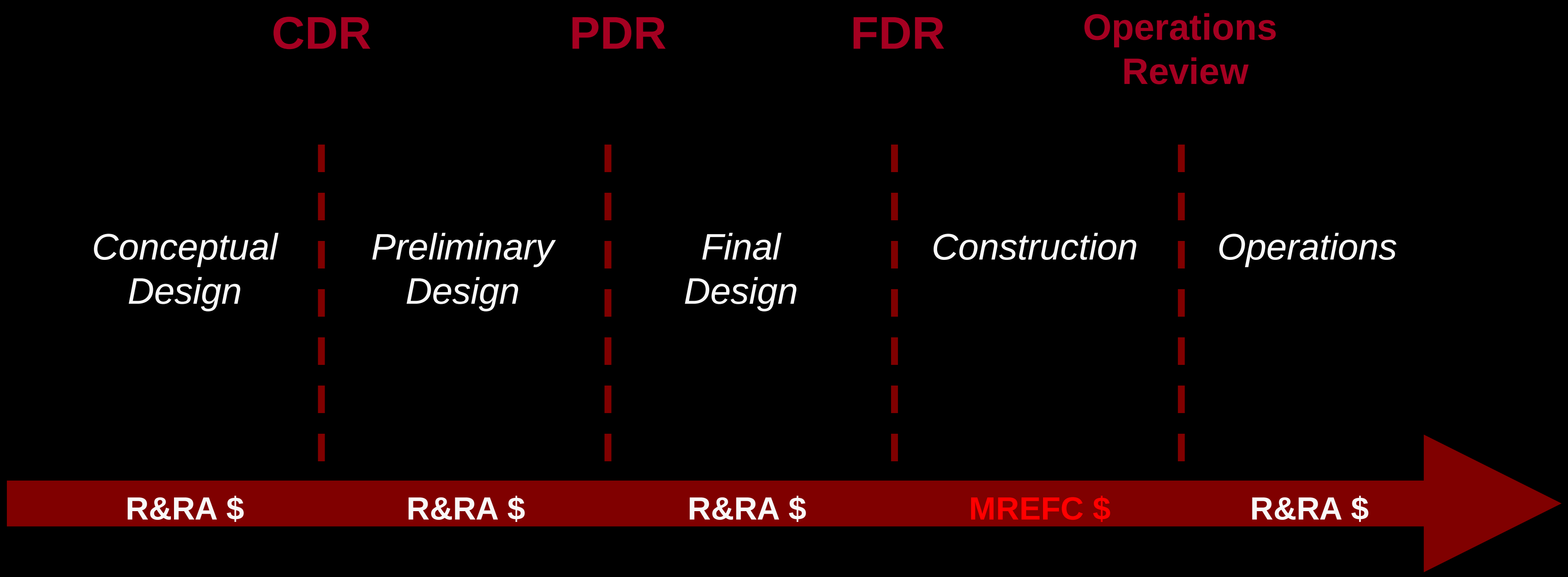
R. Gobin et al.Rev. Sci. Instrum. 75, 1414 (2004)





Oak Ridge High Voltage Platform

NATIONAL SCIENCE FOUNDATION
MAJOR RESEARCH EQUIPMENT FUNDING CYCLE



DOE Translation ("Critical Decisions"):

CD 0
Approve mission need

CD 1
Approve alternate selection and cost range

CD 2
Approve performance baseline

CD 3
Approve construction start

CD 4
Approve operations start