Summary of WANDA session

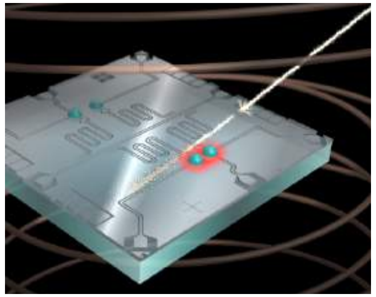
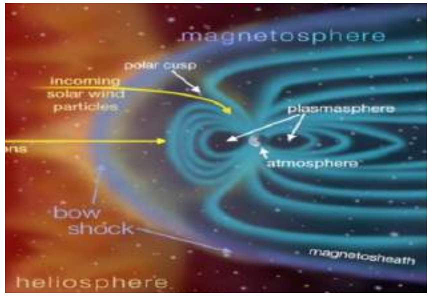
Nuclear Data for High Energy Ion Interactions and Secondary Particle Production

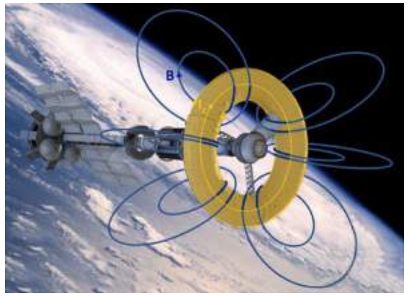
Ken LaBel
SSAI (NASA) and KBR Wyle (JHU/APL)

Ramona Vogt
LLNL and UC Davis

Michael Smith
ORNL Physics Division

Session Description

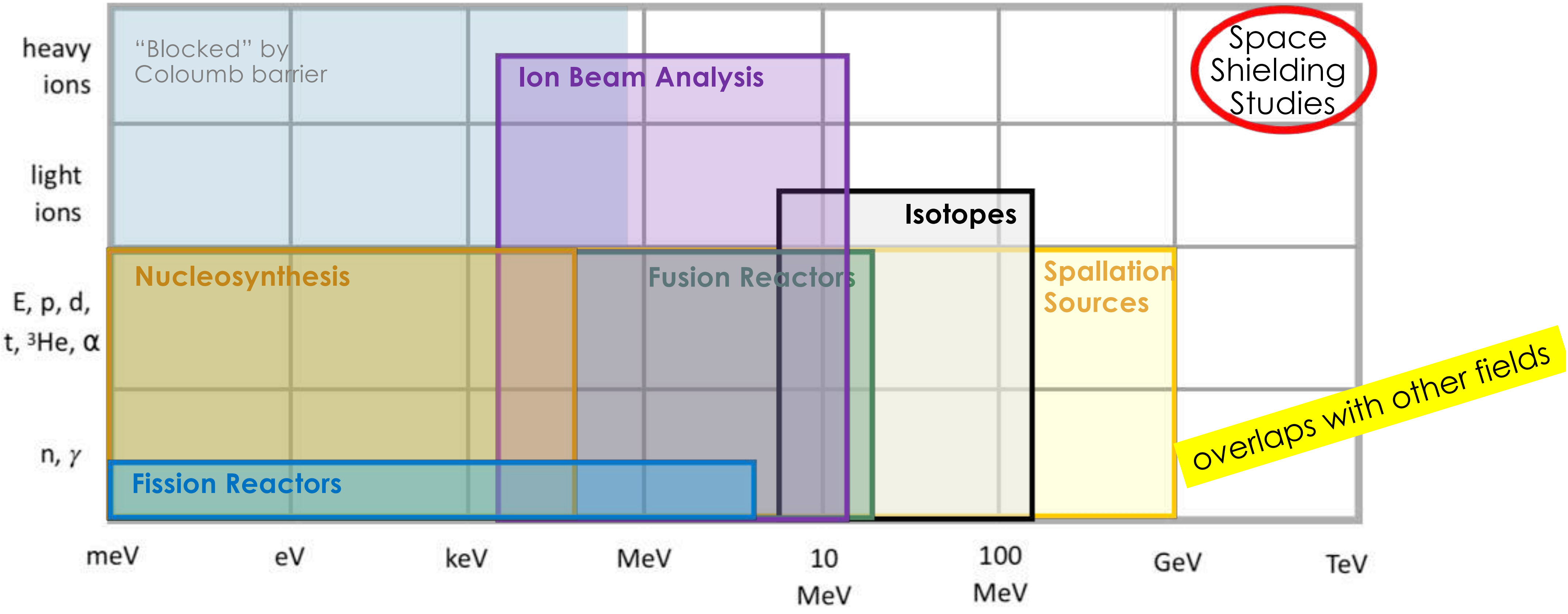




- Wide energy and species range of GCRs
- Interaction of GCRs with spacecraft materials creates a large complex cascade of secondaries
- These secondaries can harm humans and electronic systems
- How can we improve the nuclear data pipeline to understand these effects and enable safe space exploration?

Energy Range and Particle Types

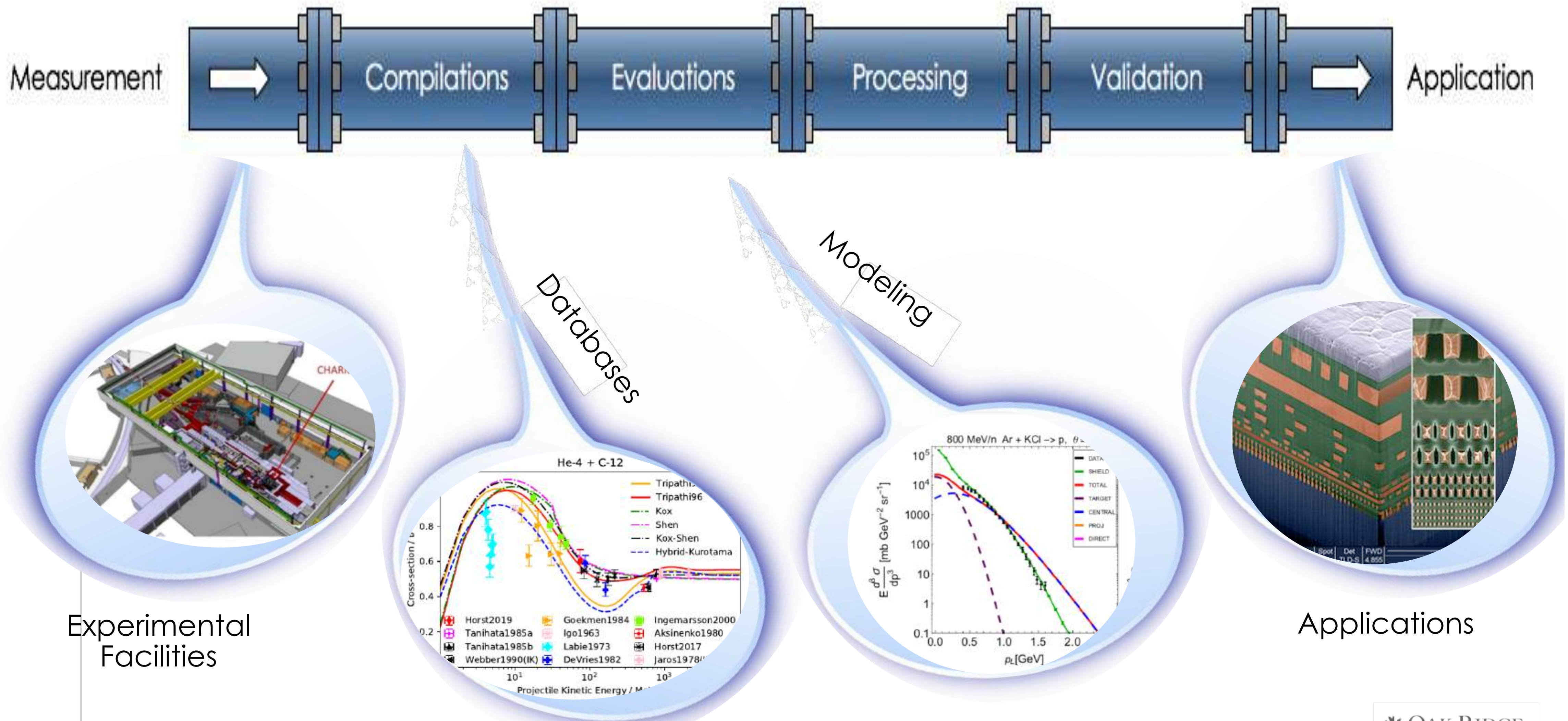
Dave Brown



- Wide range of energies and particle species for space applications

Focus Areas

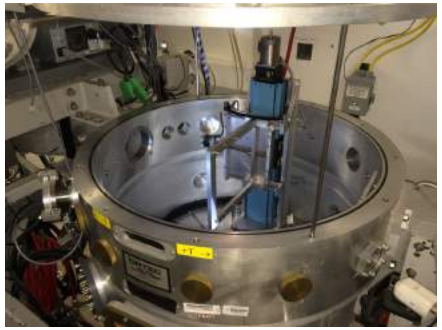
Nuclear Data Pipeline



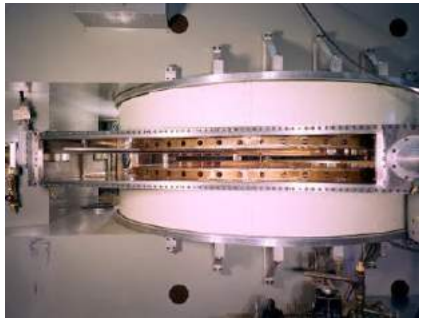
Ken LaBel Ramona Vogt Michael Smith

Experimental Facilities

Ken LaBel



TAMU REF



LBNL BASE

BNL NSRL

BNL SEUTF

MSU FSEE

Association for Research at University Nuclear Accelerators

ARUNA

- Numerous facilities used for measurements

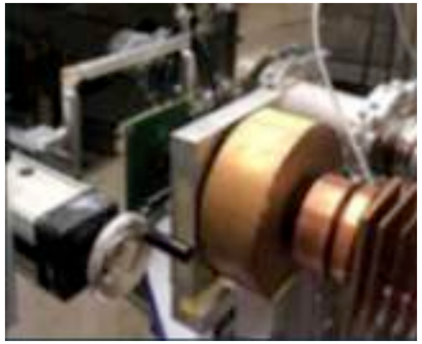
Experimental Facilities

Anastasia Pesce

UCL (Belgium)

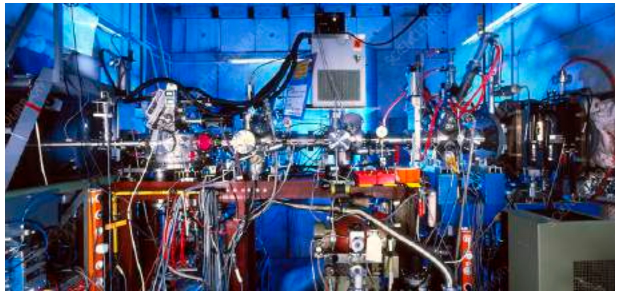
GANIL (France)

CERN (Switzerland)



PSI (Switzerland)

RADEF (Finland)



GSI (Germany)

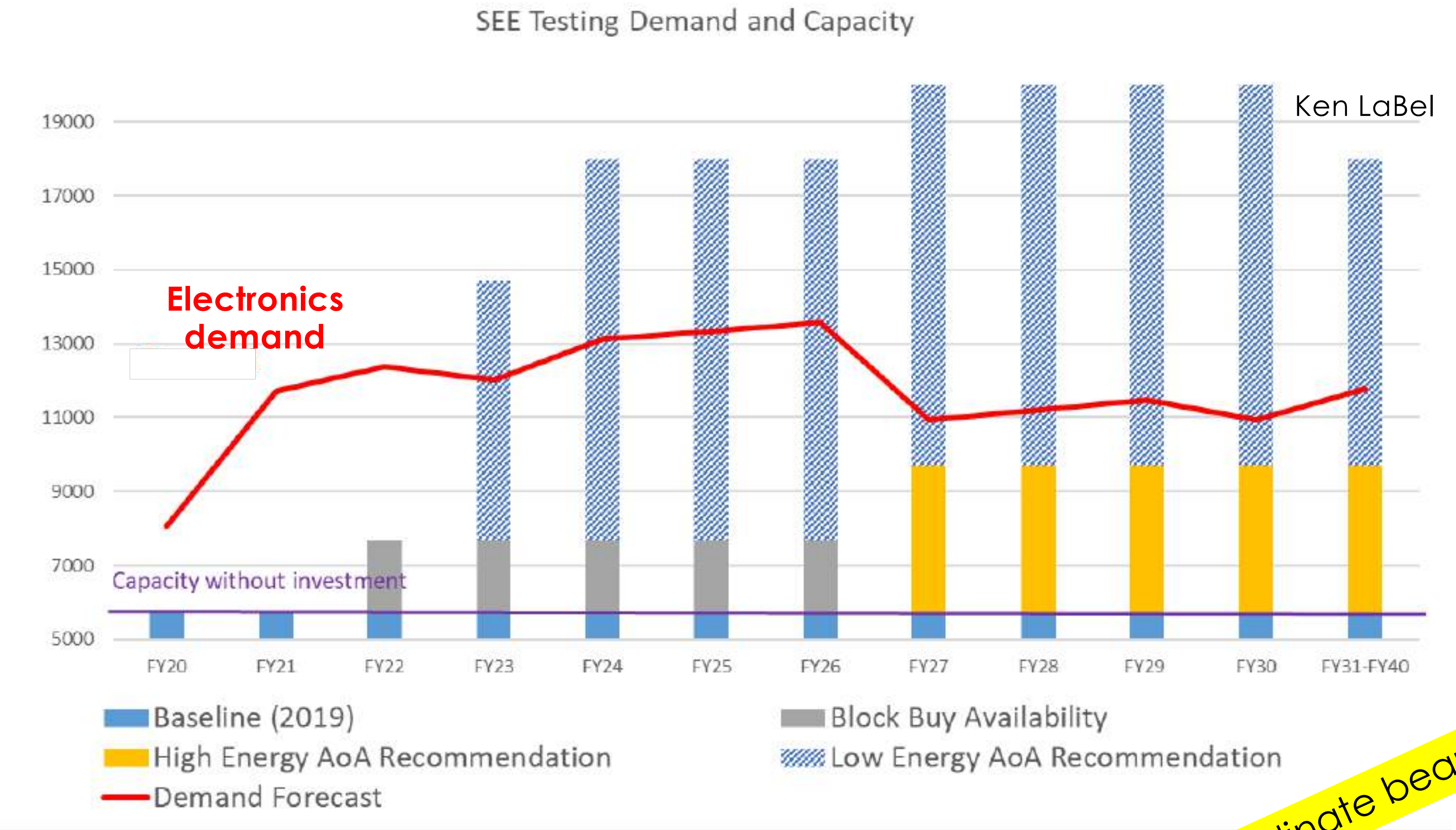
HPTC (Netherlands)

KVI (Netherlands)

LNS (Italy)

- Numerous facilities used for measurements

Experimental Facilities

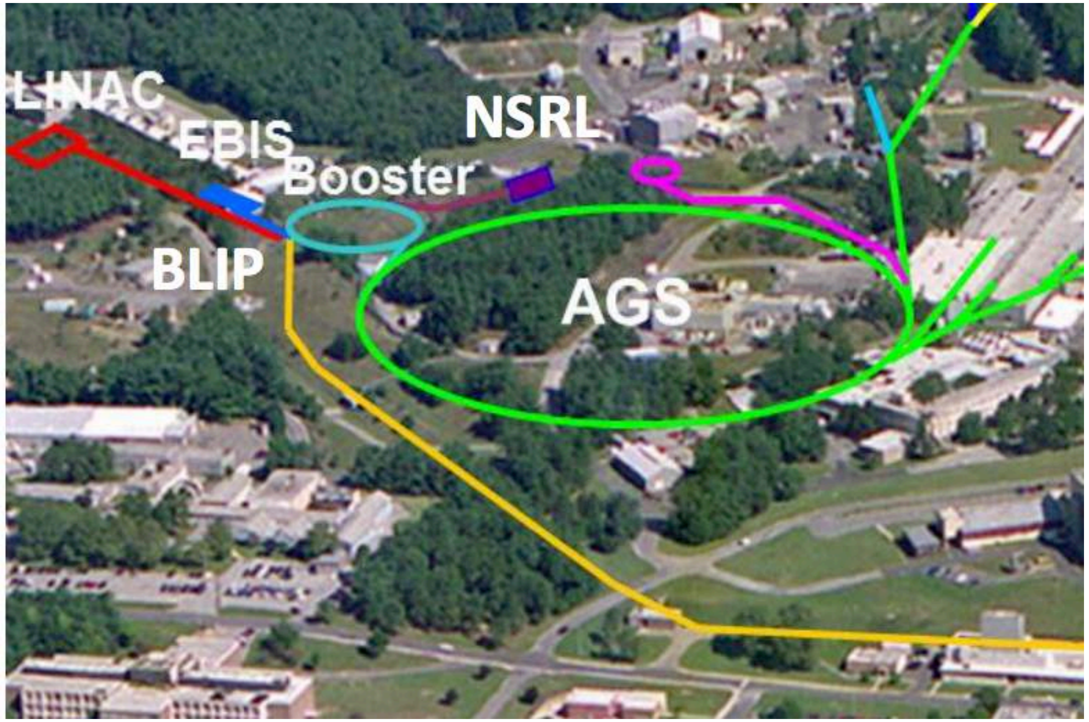


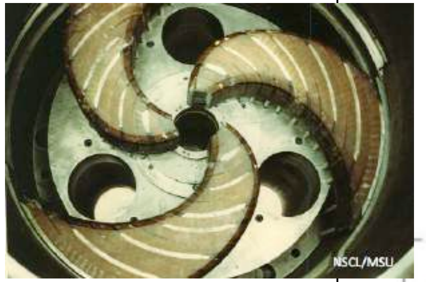
coordinate beam requests ☺

- Beam demand significantly outstrips availability

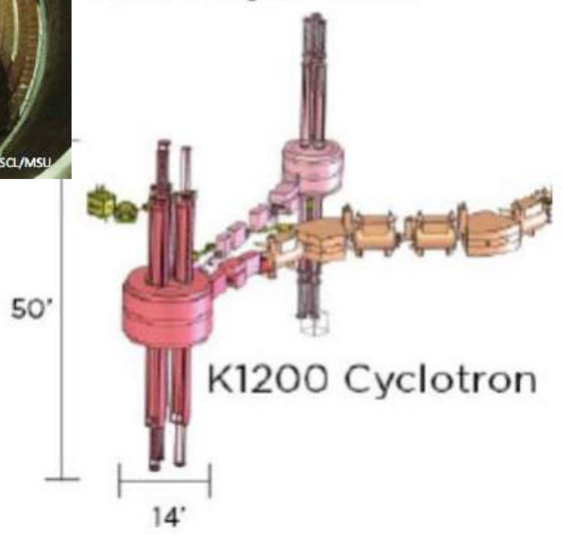
Experimental Facilities

BNL AGS





MSU NSCL



also …

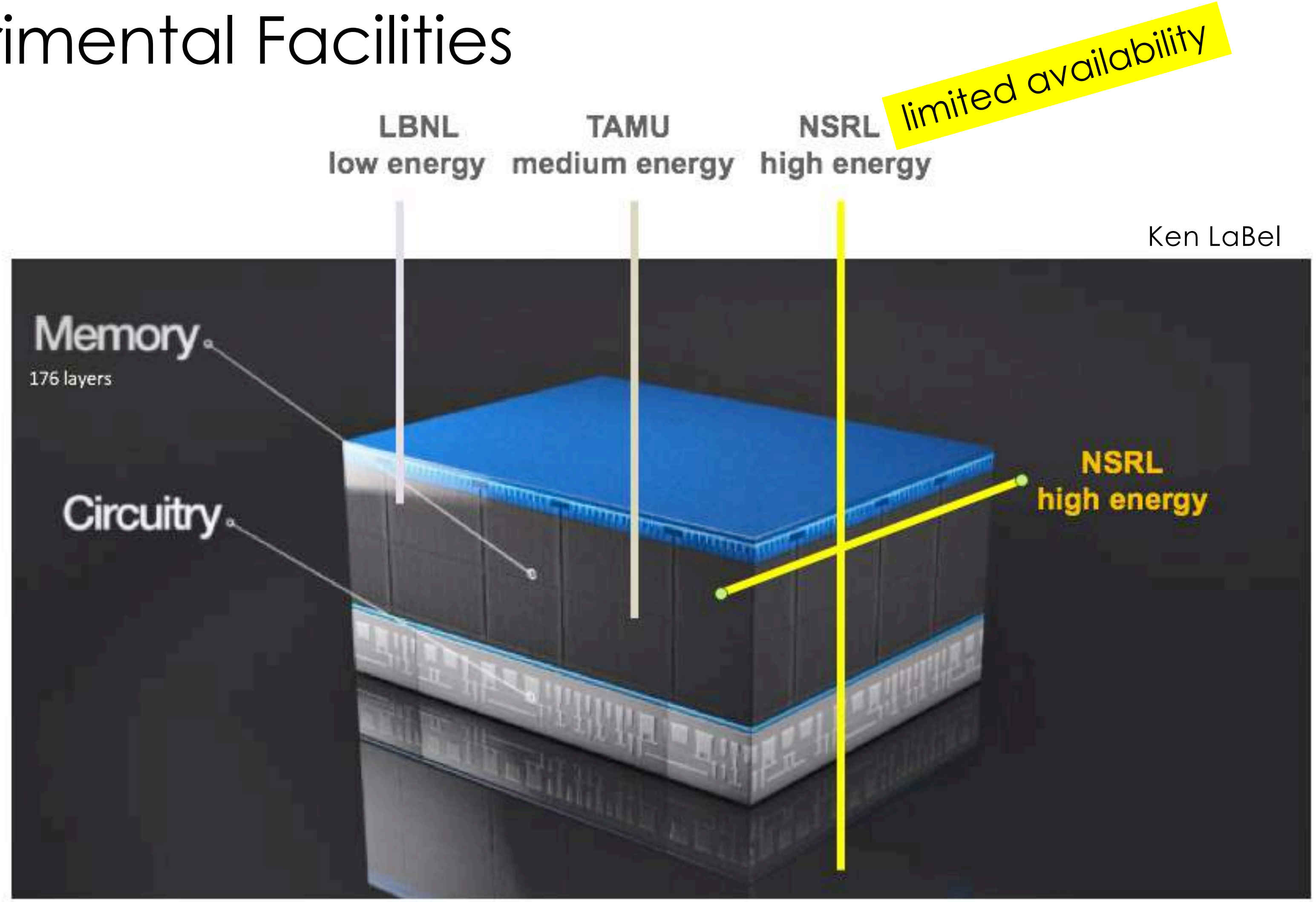
dormant SC360 cyclotron
Provision Knoxville TN

coordinate re-use

- Reusing accelerators could meet ***some*** user needs

Ken LaBel Ramona Vogt Michael Smith
Oak Ridge National Laboratory

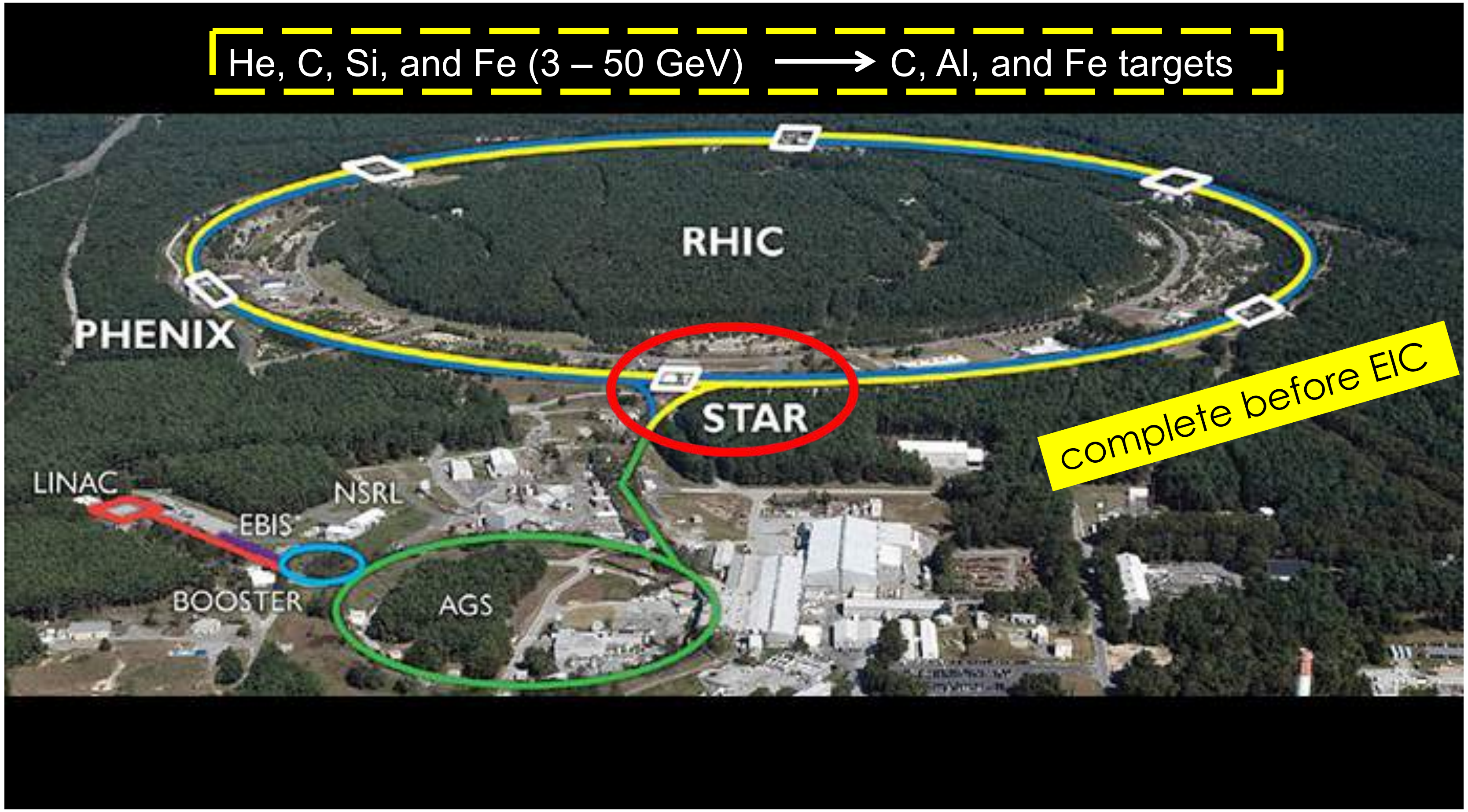
Experimental Facilities

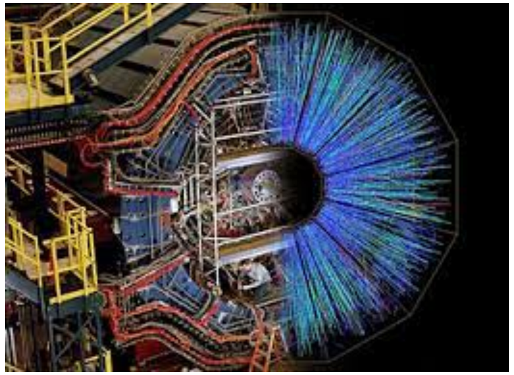


- Higher beam energies needed to reach sensitive volumes

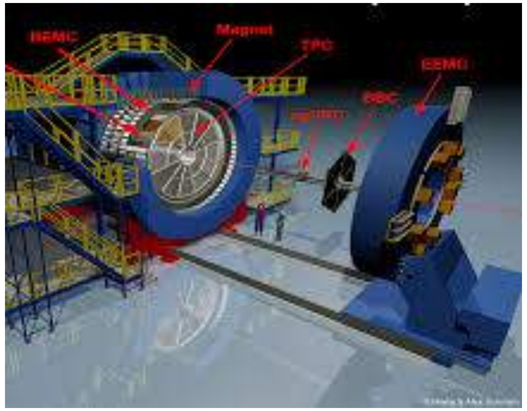
Experimental Facilities

Daniel Cebra





STAR



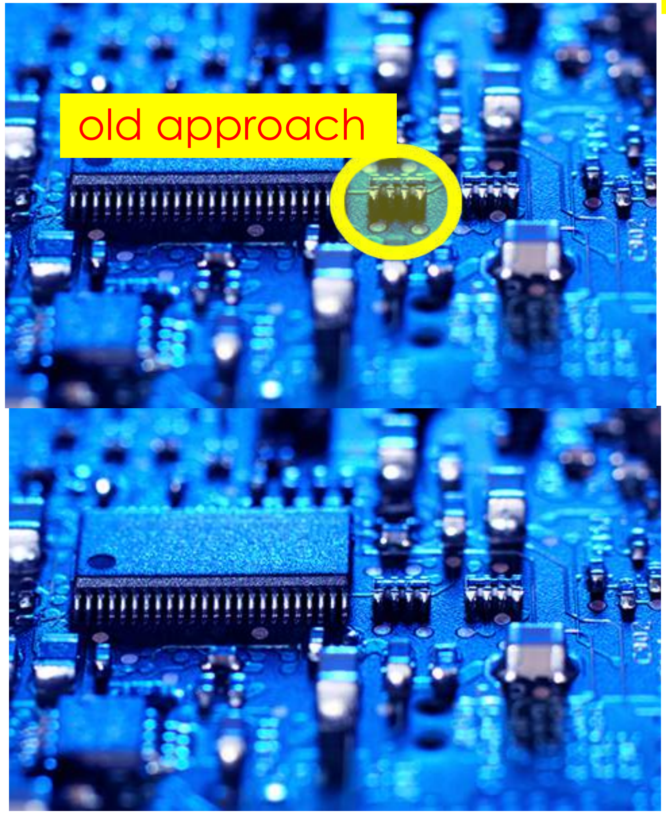
- **Unique, time-limited opportunity** to obtain critical **high-energy data**

Experimental Facilities

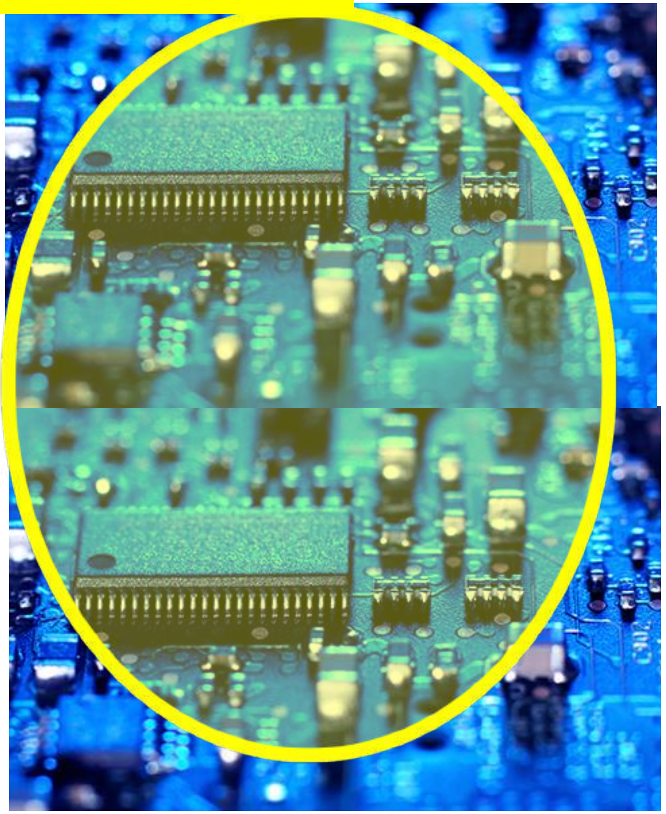
growing trend

batch mode

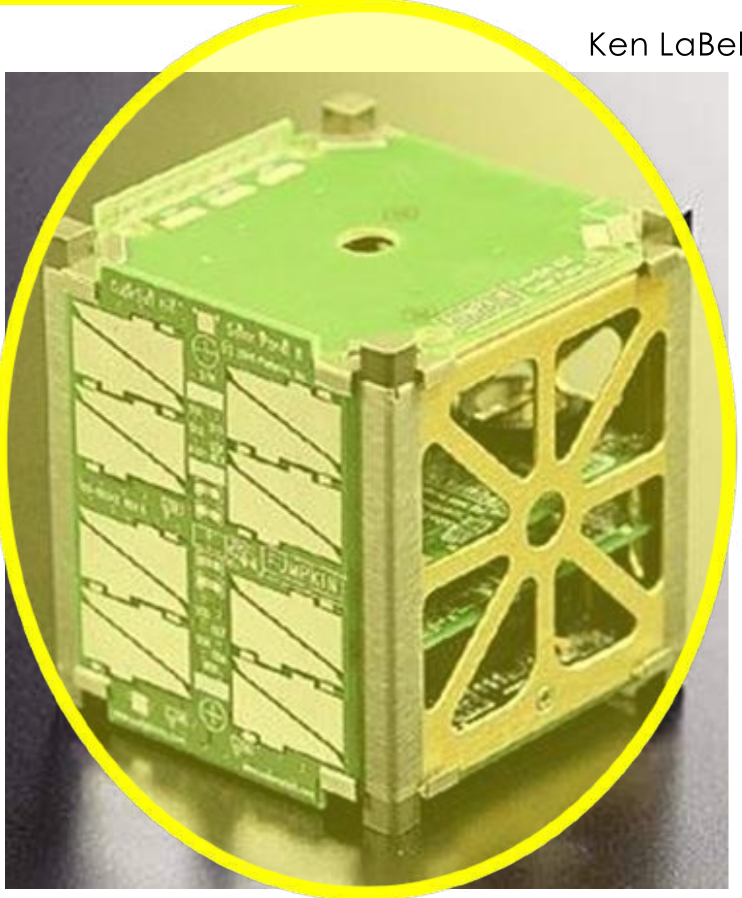
Ken LaBel



1 chip



1 circuit



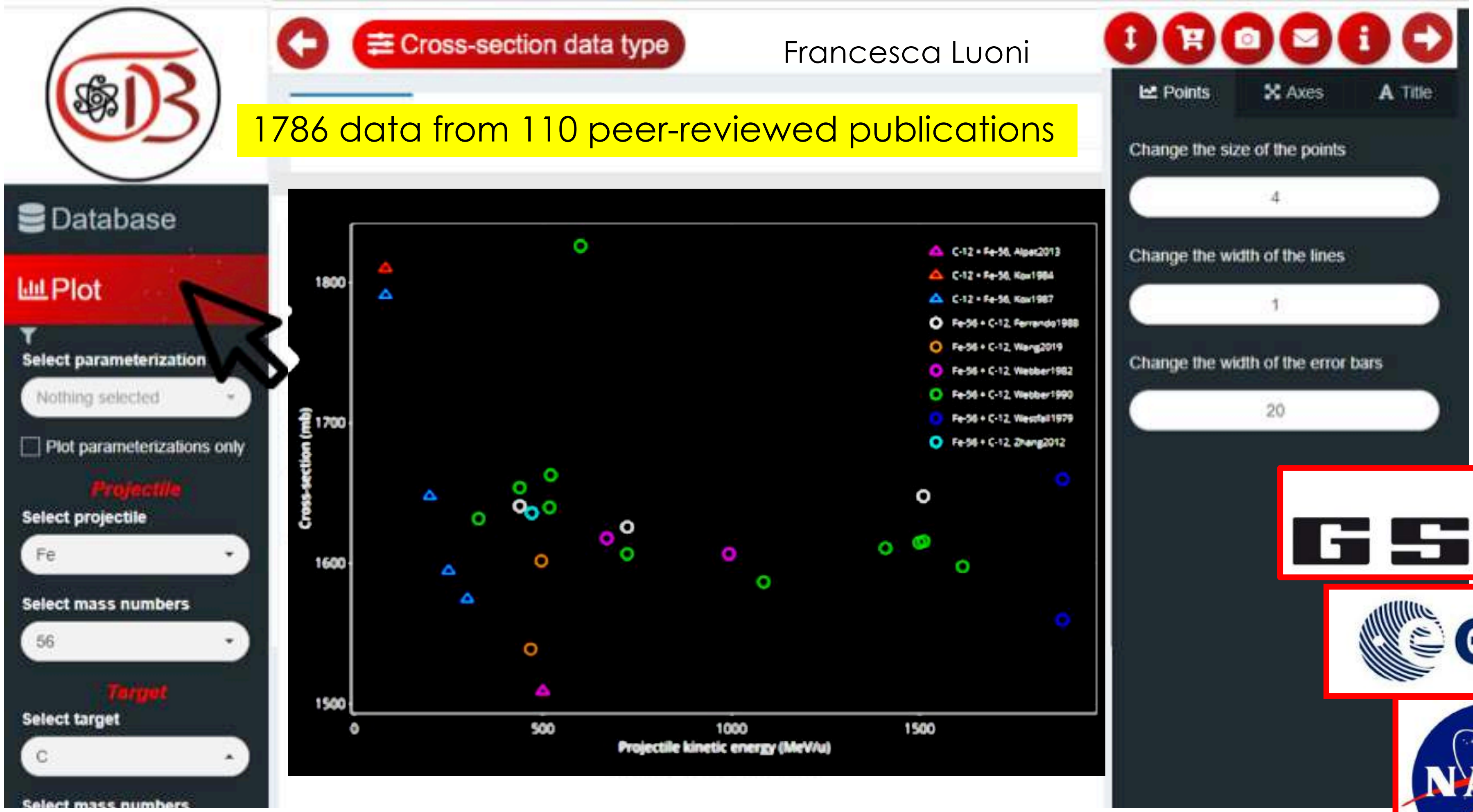
1 system

- Larger beam size capability needed to irradiate larger circuits/systems

Compilations, Databases, Dissemination

Francesca Luoni

1786 data from 110 peer-reviewed publications



- User-generated compilation of reaction data

Ken LaBel Ramona Vogt Michael Smith

Compilations, Databases, Dissemination

John Norbury

Cross section measurement database

Galactic Cosmic Rays (GCR)

- Protons $\rightarrow$ Fe nuclei $\sim$ 100 MeV/n – 50 GeV/n
- Peaks: H, He, C, O, Si, Fe   Z = 1, 2, 6, 8, 14, 26

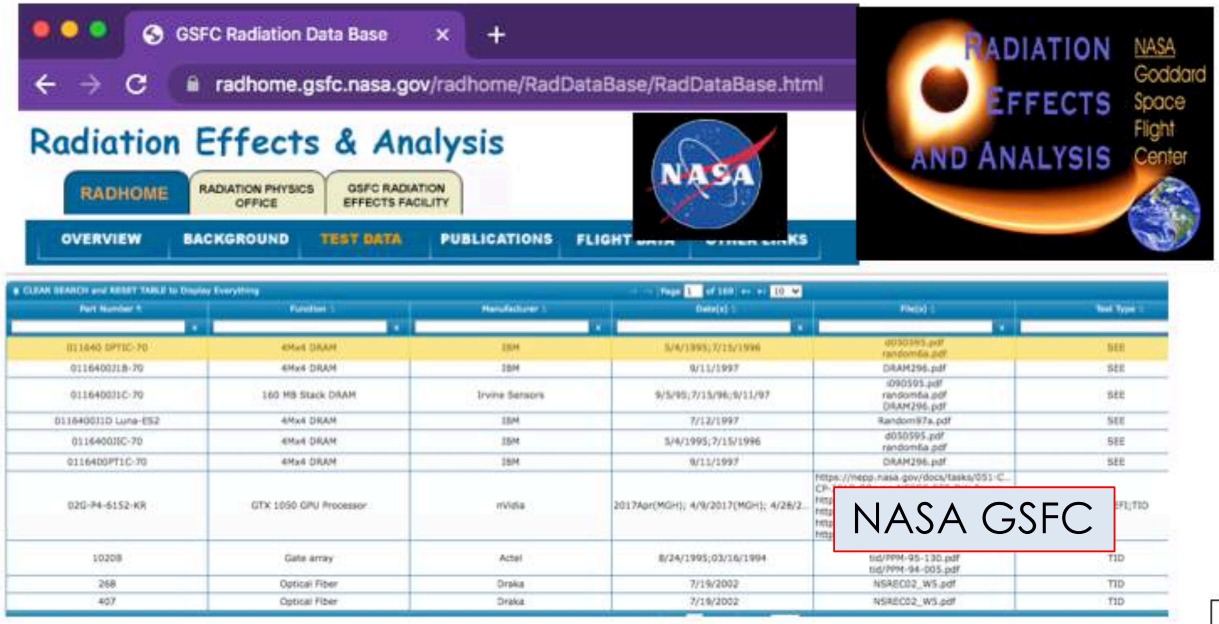
- NUCDAT (50,000 entries)

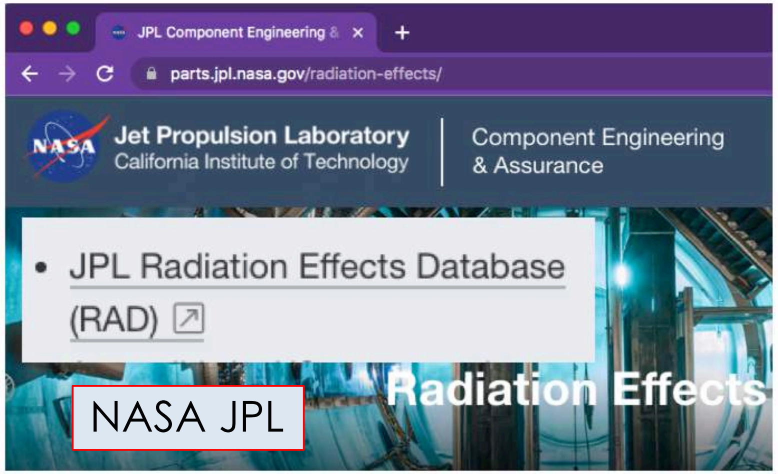
Norbury et al., Radiation Measurements 47, 315, 2012.
Health Physics 103, 640, 2013.
Journal of Physics (conf. ser.) 381, 012117, 2013.
Frontiers in Physics 8:565954, 2020.

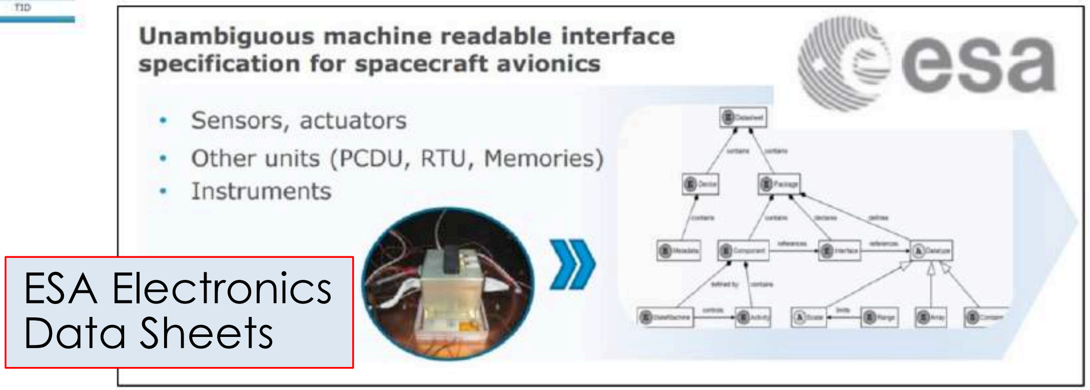
will be included in GSI-ESA-NASA database

- others have private data collections

Compilations, Databases, Dissemination







proprietary

security

formats

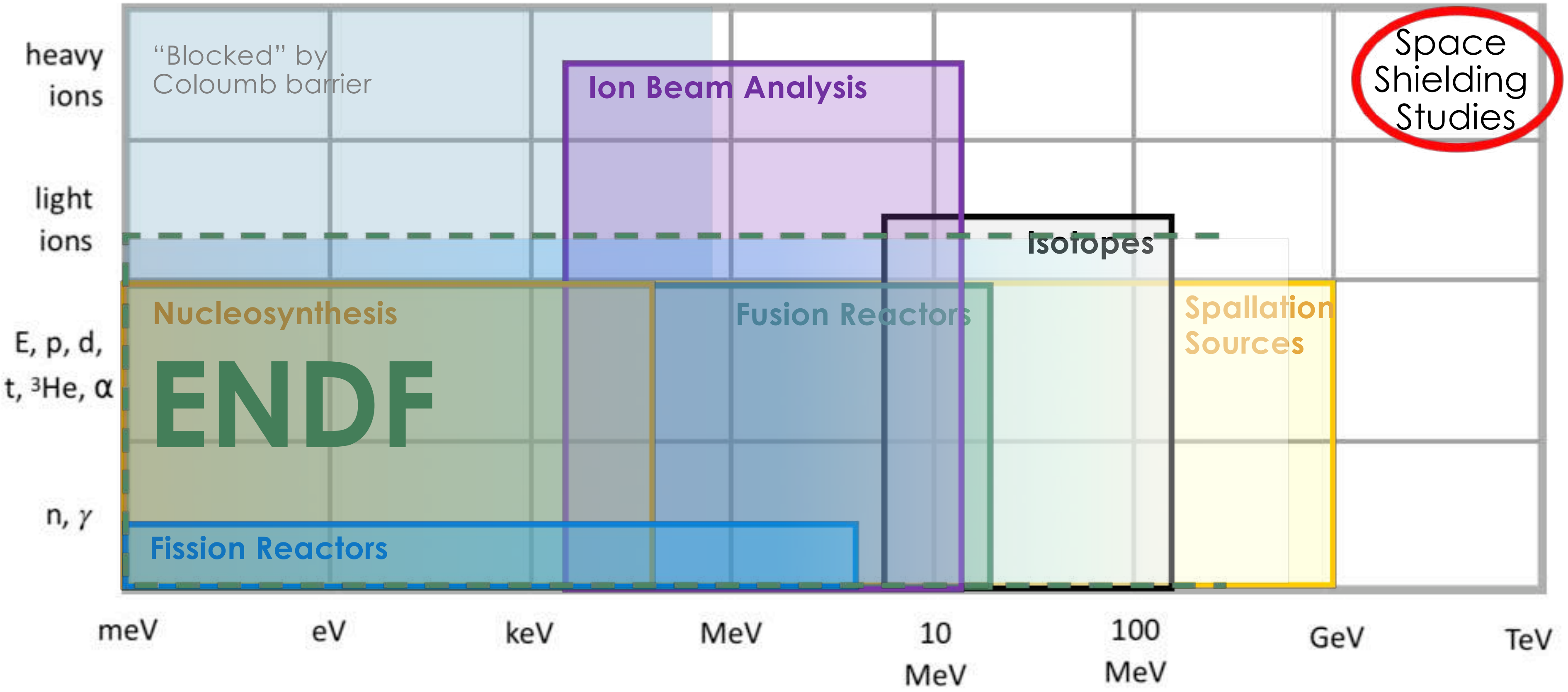
different systems

operating funds

- Data sharing has been challenging for Space Electronics community

Compilations, Databases, Dissemination

Dave Brown



- EXFOR & ENDF reaction data do not cover range of energies / species

Ken LaBel Ramona Vogt Michael Smith

Compilations, Databases, Dissemination

Table 4: Accelerator Shielding Experiments in SINBAD (in bold are recent compilations)

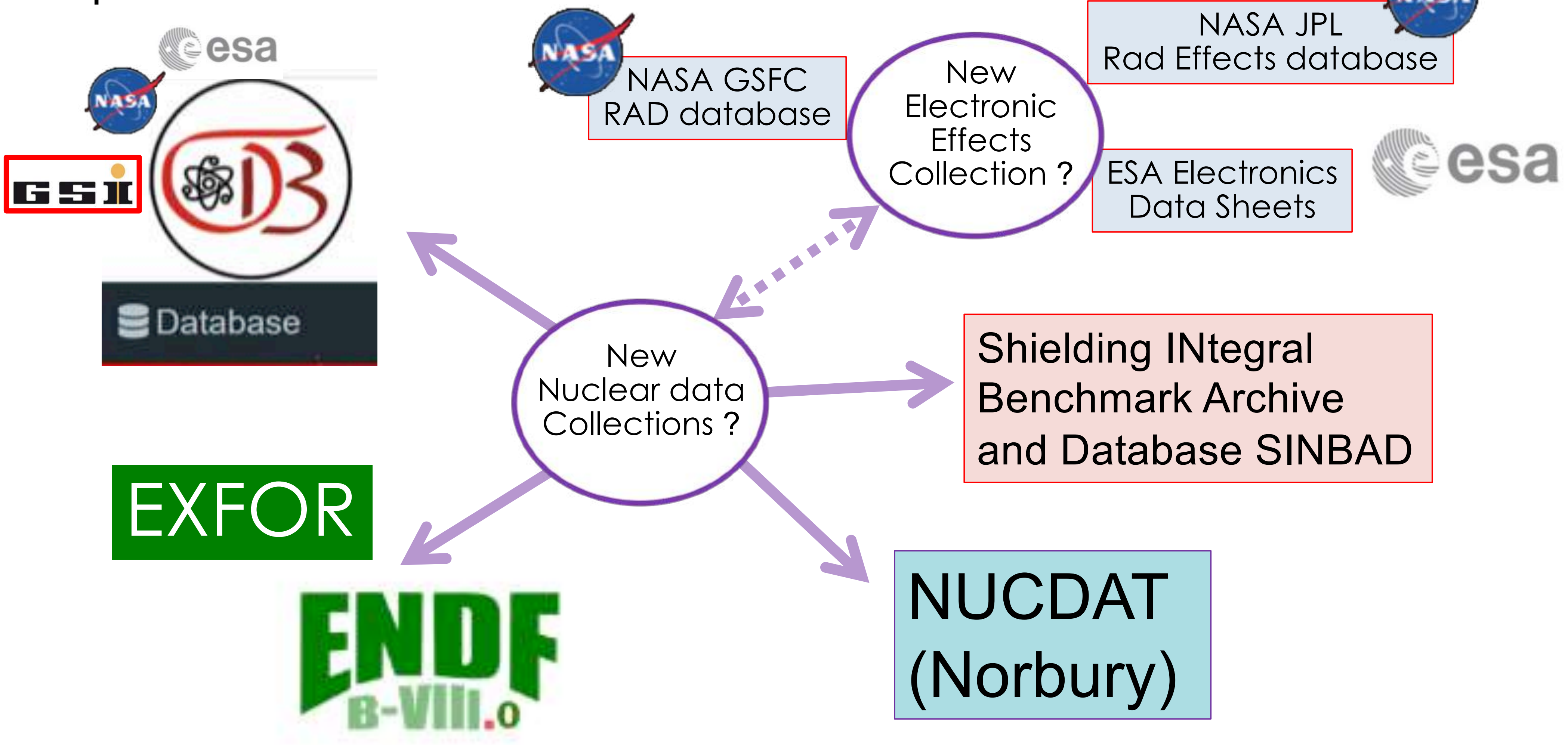
Title	**Shielding material**	**Projectile**	**Measured quantity**	**Computer code input**
Transmission Through Shielding Materials of n & γ Generated by 52 MeV p	C (< 64.5 cm thick), Fe (< 57.9 cm), H_2O (< 101 cm), concrete (< 115 cm)	52 MeV protons on C target	NE213 scintillation	No
Transmission Through Shielding Materials of n & γ Generated by 65 MeV p	concrete, iron, lead and graphite (10 to 100 cm thick)	65 MeV protons on Cu target	NE213 scintillation	No
TIARA 40 and 65 MeV Neutron Transmission Through Iron, Concrete and Polyethylene	Fe (130 cm), concrete (< 200 cm), polyethylene (up to 180 cm)	43 and 68 MeV protons on Li7 target	BC501A, Bonner ball, fission counters, TLD, SSNTD	No
ROESTI I and III	Fe and Pb (100 cm thick)	200 GeV/c positive hadrons (2/3 p,1/3 π^+)	In, S, Al, C foils, RPL	Yes
ROESTI II	Fe (100 cm thick)	24 GeV/c protons	In, S, Al, C foils, RPL	Yes
RIKEN Quasi-monoenergetic Neutron Field (70-210 MeV)	air	70 – 210 MeV protons on ^{7}Li	NE213 (TOF)	No
HIMAC He, C, Ne, Ar, Fe, Xe and Si ions on C, Al, Cu and Pb targets	C, Al, Cu and Pb targets	100-800 MeV/ nuc. He, C, Ne, Ar, Fe, Xe & Si ions	NE213 & NE102A scintillators	Yes
HIMAC/NIRS High	Fe (up to 100 cm)	400 MeV/nucleon	Neutron	Yes

OECD
NEA
Nuclear Energy Agency

SINBAD Integral Shielding database

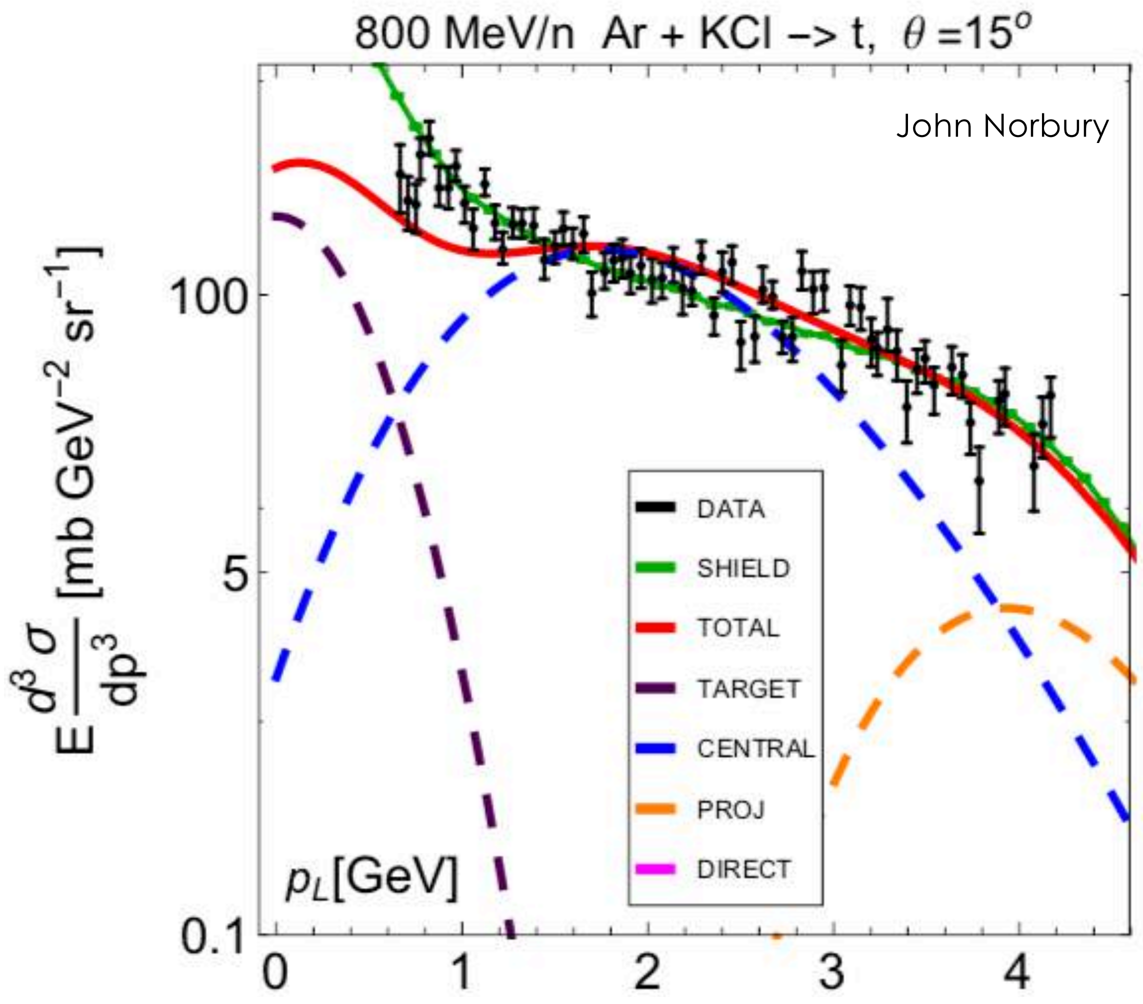
- SINBAD database can help space shielding and transport studies

Compilations, Databases, Dissemination



- Nuclear Data community could help these data efforts cooperate / coordinate / cross-link / evolve

Nuclear Reaction Modeling



DDFRG double differential fragmentation model (Norbury)

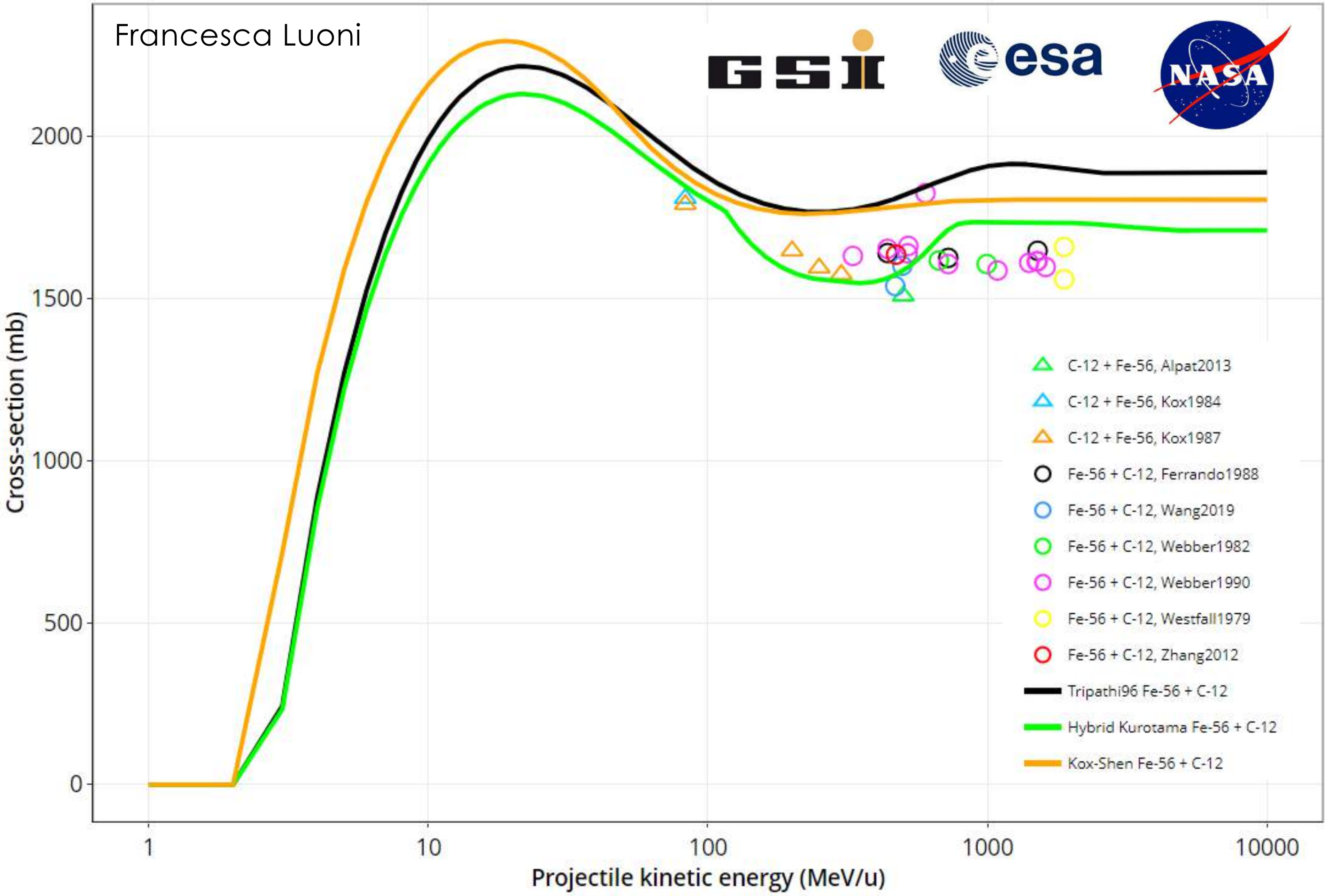
Thermal / Coalescence model for light ion production

$$E_A \frac{d^3\sigma_A}{dp_A^3} = C_A N_4^A \Big\{ w_{\mathcal{P}} \exp[(m_p - \gamma_{\mathcal{P}L}\sqrt{p_{pL}^2 + m_p^2} + \gamma_{\mathcal{P}L}\,\beta_{\mathcal{P}L}\,p_{pL}\cos\theta_{pL})/\Theta_{\mathcal{P}}]$$
$$+ w_{\mathcal{C}} \exp[(m_p - \gamma_{\mathcal{C}L}\sqrt{p_{pL}^2 + m_p^2} + \gamma_{\mathcal{C}L}\,\beta_{\mathcal{C}L}\,p_{pL}\cos\theta_{pL})/\Theta_{\mathcal{C}}]$$
$$+ w_{\mathcal{T}} \exp[(m_p - \gamma_{\mathcal{T}L}\sqrt{p_{pL}^2 + m_p^2} + \gamma_{\mathcal{T}L}\,\beta_{\mathcal{T}L}\,p_{pL}\cos\theta_{pL})/\Theta_{\mathcal{T}}]$$
$$+ w_{\mathcal{D}} w_{\mathcal{D}}^{(p)} \exp[(m_p - \gamma_{\mathcal{P}L}\sqrt{p_{pL}^2 + m_p^2} + \gamma_{\mathcal{P}L}\,\beta_{\mathcal{P}L}\,p_{pL}\cos\theta_{pL})/\Theta_{\mathcal{D}}]\Big\}^A$$

$$N_4 = \frac{\sigma_p}{4\pi m_p}\Big[\Theta_{\mathcal{P}}\, e^{\frac{m_p}{\Theta_{\mathcal{P}}}} K_1\!\left(\frac{m_p}{\Theta_{\mathcal{P}}}\right) + \Theta_{\mathcal{C}}\, e^{\frac{m_p}{\Theta_{\mathcal{C}}}} K_1\!\left(\frac{m_p}{\Theta_{\mathcal{C}}}\right)$$
$$+ \Theta_{\mathcal{T}}\, e^{\frac{m_p}{\Theta_{\mathcal{T}}}} K_1\!\left(\frac{m_p}{\Theta_{\mathcal{T}}}\right) + w_{\mathcal{D}}^{(p)}\,\Theta_{\mathcal{D}}\, e^{\frac{m_p}{\Theta_{\mathcal{D}}}} K_1\!\left(\frac{m_p}{\Theta_{\mathcal{D}}}\right)\Big]^{-1}$$

- Some successes with phenomenological reaction models

Nuclear Reaction Modeling



- Semi-empirical parameterizations are also valuable

Nuclear Instruments and Methods in Physics Research B 117 (1996) 347–349

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NIM B Beam Interactions with Materials & Atoms

Accurate universal parameterization of absorption cross sections

R.K. Tripathi [a,b,*], Francis A. Cucinotta [c], John W. Wilson [c]

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PHYSICAL REVIEW C VOLUME 35, NUMBER 5 MAY 1987

Trends of total reaction cross sections for heavy ion collisions in the intermediate energy range

S. Kox,[a] A. Gamp,*[a],[b] C. Perrin,[a] J. Arvieux,†[a] R. Bertholet,[c] J. F. Bruandet,[a] M. Buenerd,[a] R. Cherkaoui,‡[a] A. J. Cole,[a] Y. El-Masri,[a],[d] N. Longequeue,[a] J. Menet,[a] F. Merchez,[a] and J. B. Viano[a]

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Nuclear Instruments and Methods in Physics Research B 155 (1999) 349–356

NIM B Beam Interactions with Materials & Atoms

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Accurate universal parameterization of absorption cross sections III – light systems

R.K. Tripathi [a,b,*], F.A. Cucinotta [c], J.W. Wilson [a]

Nuclear Instruments and Methods in Physics Research B 334 (2014) 34–39

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

ELSEVIER

Current status of the "Hybrid Kurotama model" for total reaction cross sections

L. Sihver [a,*], A. Kohama [b], K. Iida [c], K. Oyamatsu [d], S. Hashimoto [e], H. Iwase [f], K. Niita [g]

PHYSICAL REVIEW C 89, 067602 (2014)

Improved parametrization of the transparency parameter in Kox and Shen models of total reaction cross sections

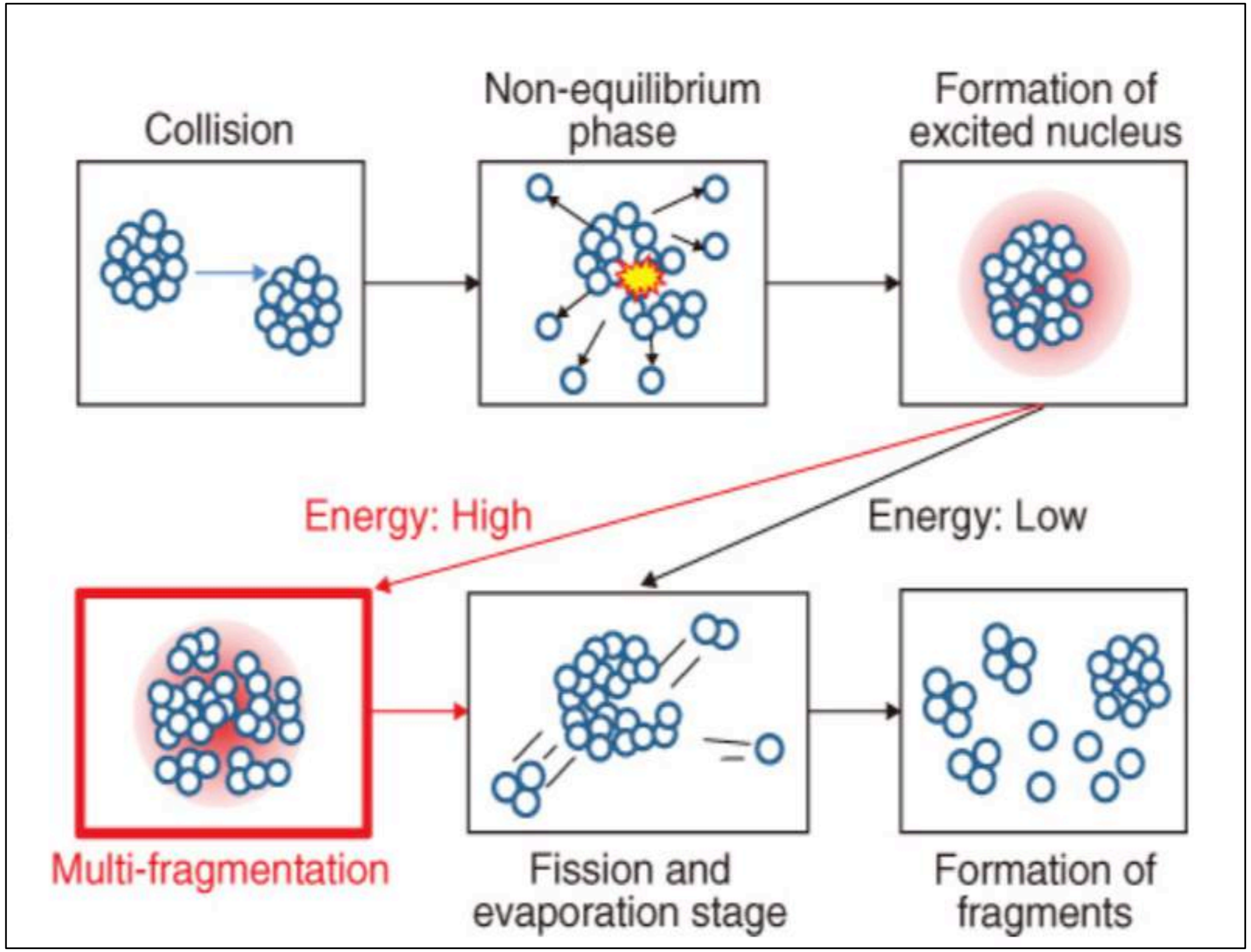
L. Sihver,[1,*] M. Lantz,[2,3] and A. Kohama[3]

TOTAL REACTION CROSS SECTION FOR HEAVY-ION COLLISIONS AND ITS RELATION TO THE NEUTRON EXCESS DEGREE OF FREEDOM

SHEN Wen-qing, WANG Bing, FENG Jun, ZHAN Wen-long, ZHU Yong-tai and FENG En-pu

Nuclear Reaction Modeling

Dave Brown

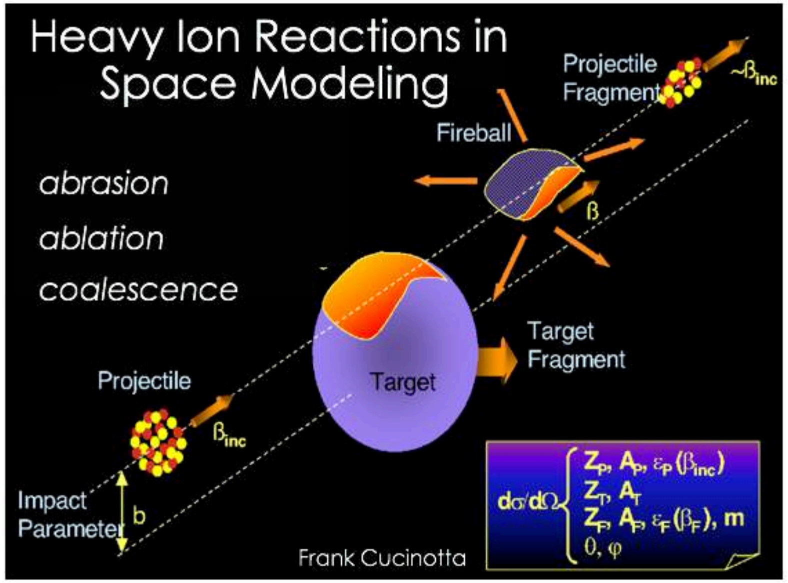


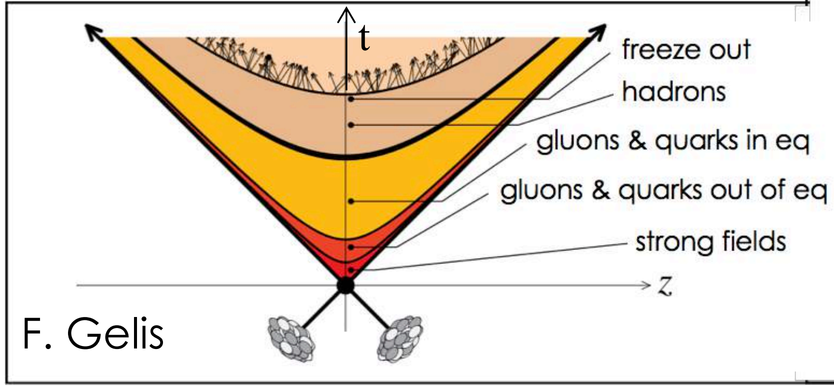
need higher energy data

- Tuning of models to data needed from 100 MeV/u – 1GeV/u

Ken LaBel Ramona Vogt Michael Smith

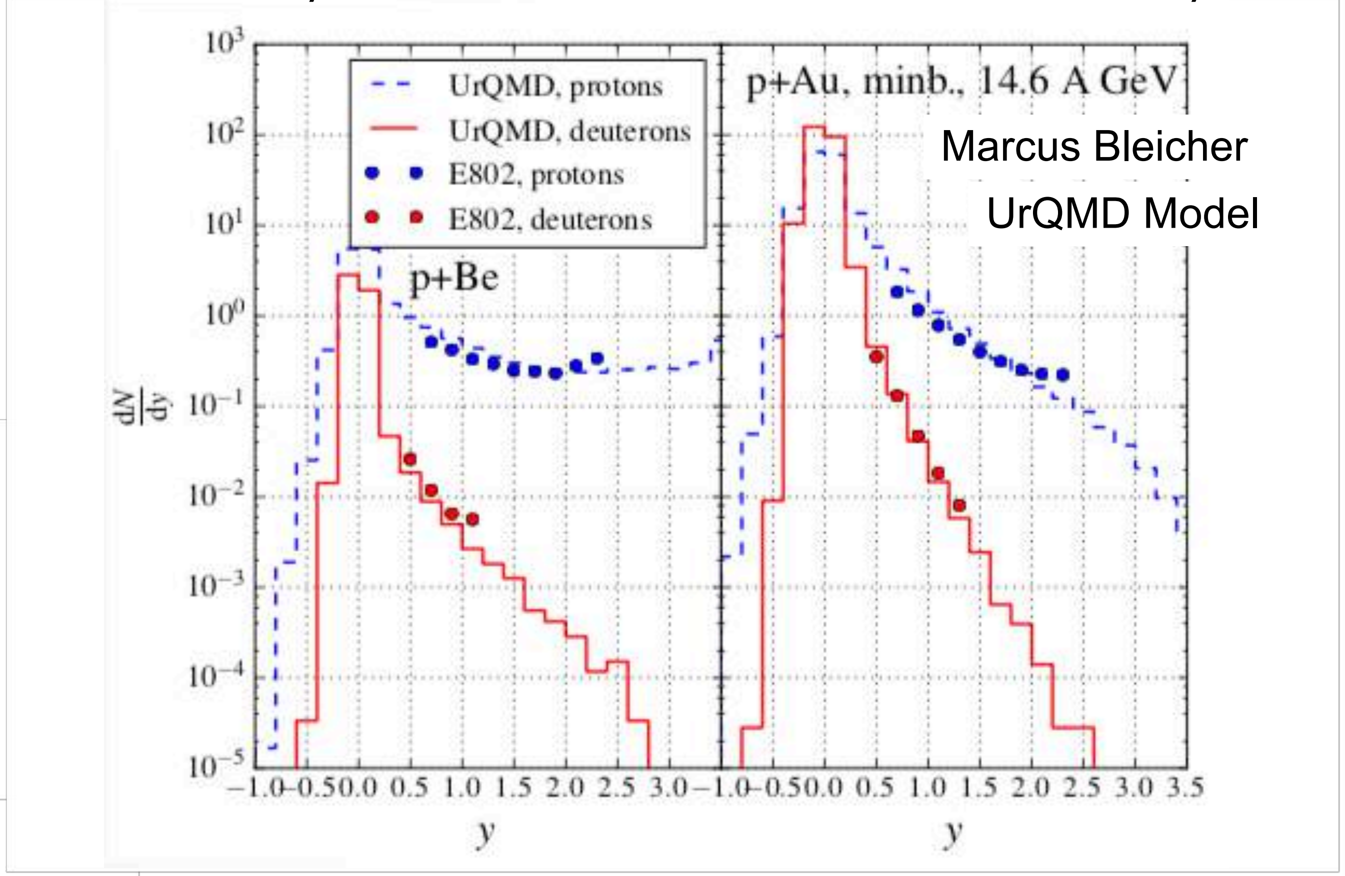
Nuclear Reaction Modeling





F. Gelis

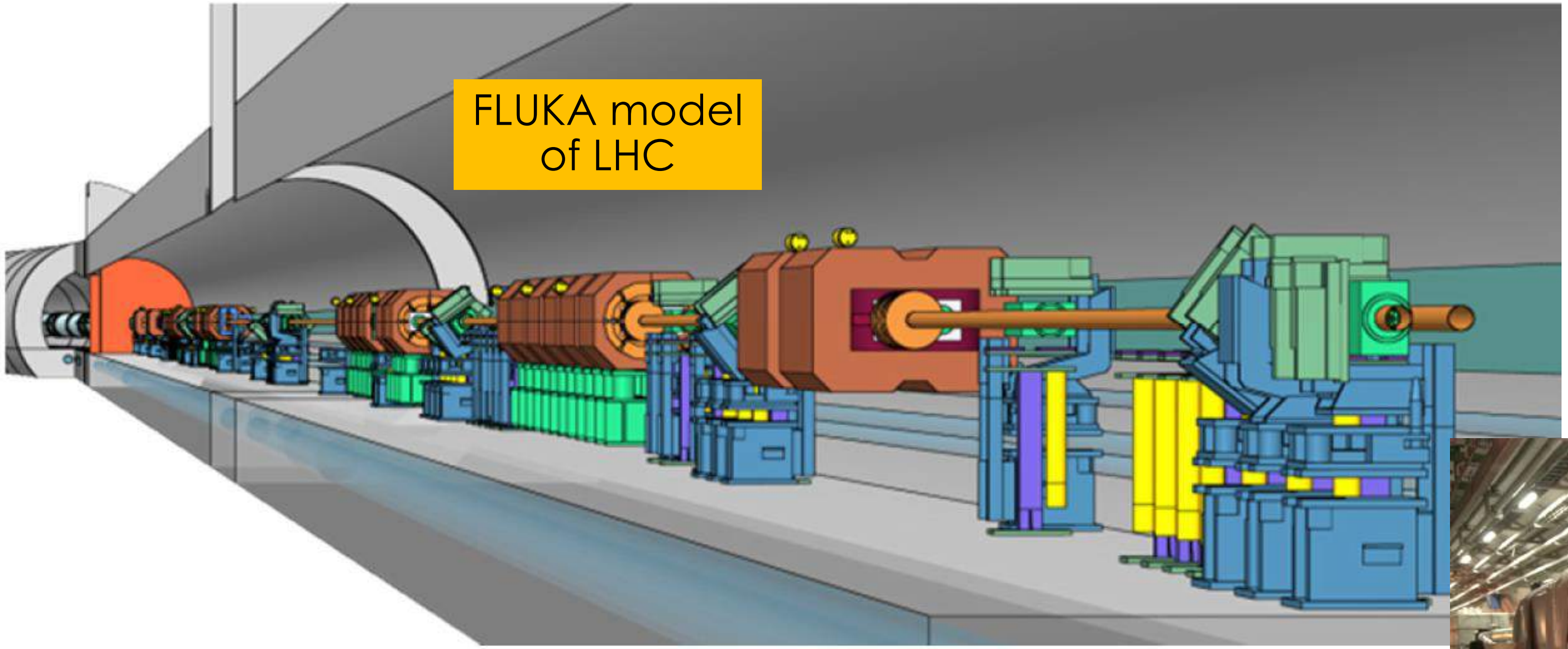
Heavy Ion Reactions in RHI community



- Current reaction models in space community could benefit from > 20 yrs of theory advances in R H I community

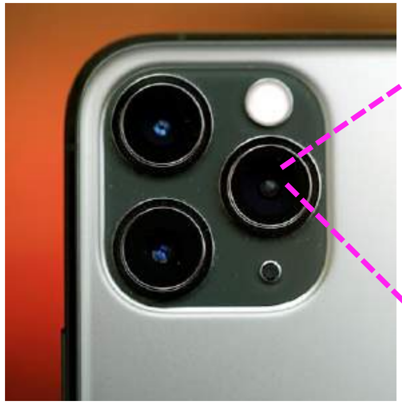
Nuclear Reaction Modeling

R. Garcia-Alia

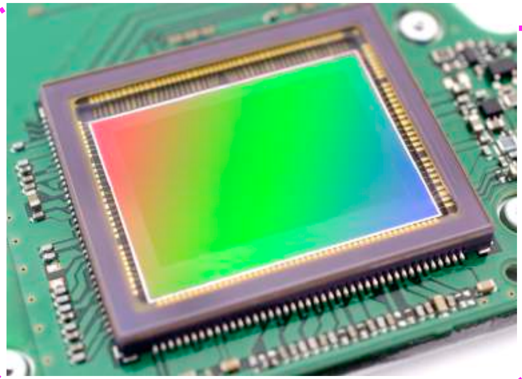


- Opportunity to provide modeling support for shielding applications

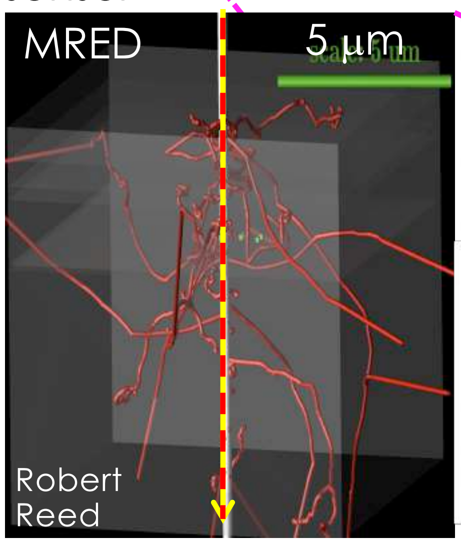
Applications - Electronics

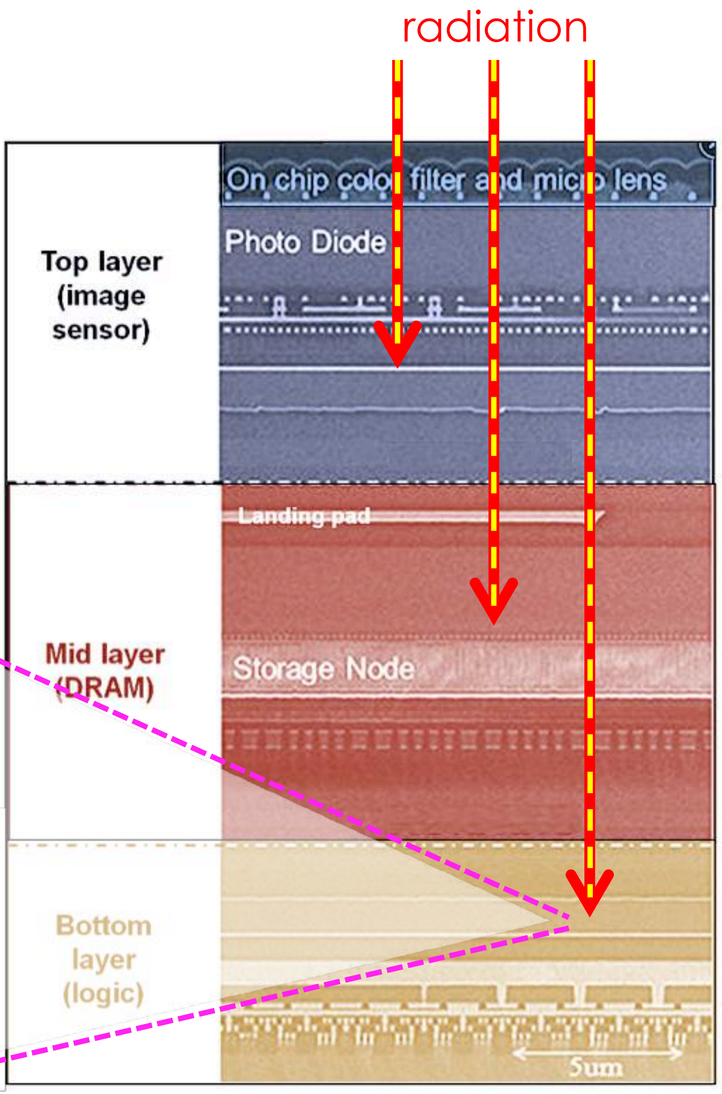


phone camera



CMOS image sensor





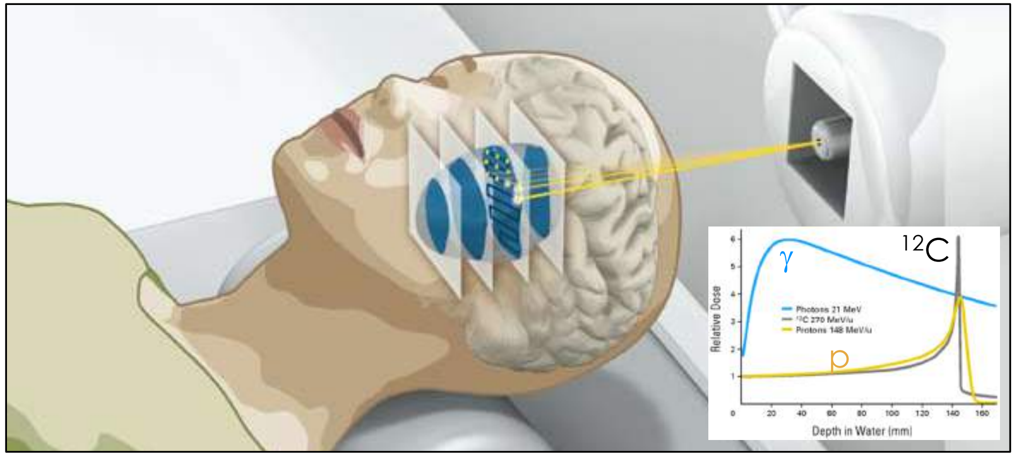
predict species, angles, energies

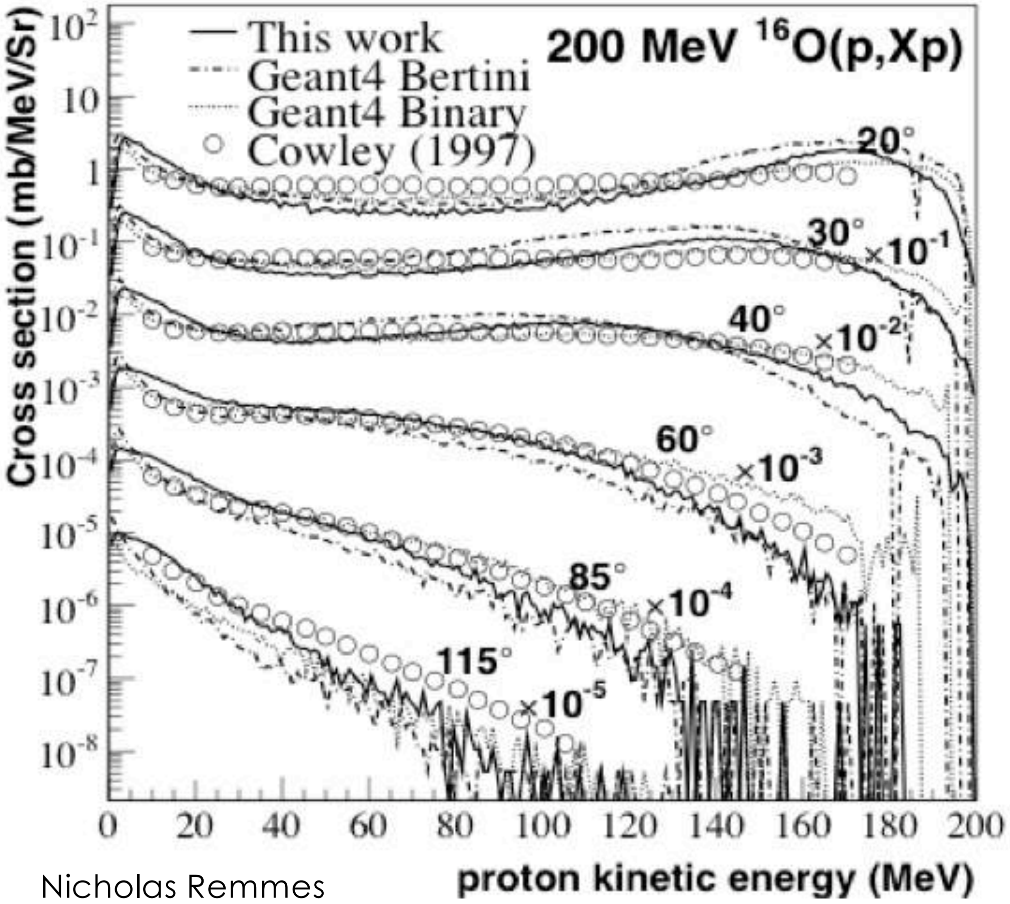
high-energy testing needed
for deep sub-micron electronics

measure for all relevant materials

- Production of secondaries in electronic circuits need improved models

Applications - Medical





Nicholas Remmes

Future:
shrink spatial resolution by $10^2 – 10^3$
go to ~GeV heavier ions
include improved physics models

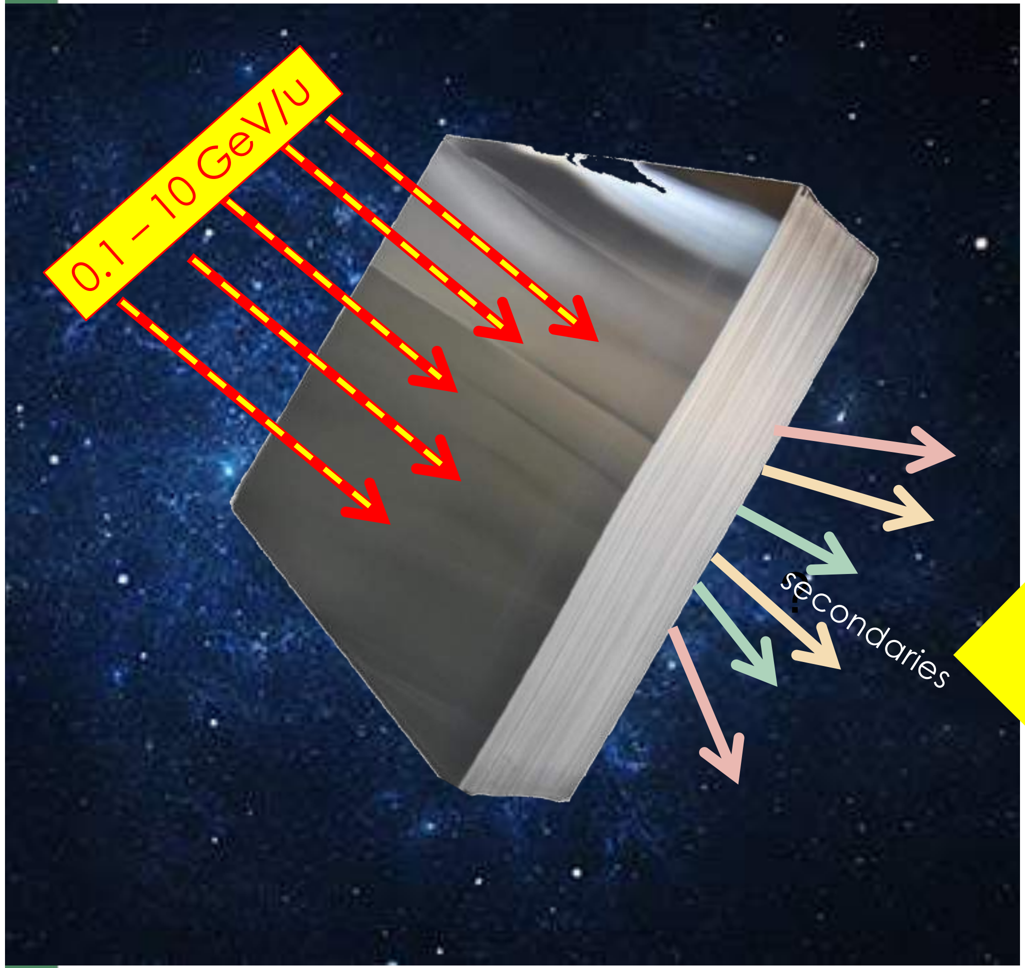
Approach: **port to GPUs**

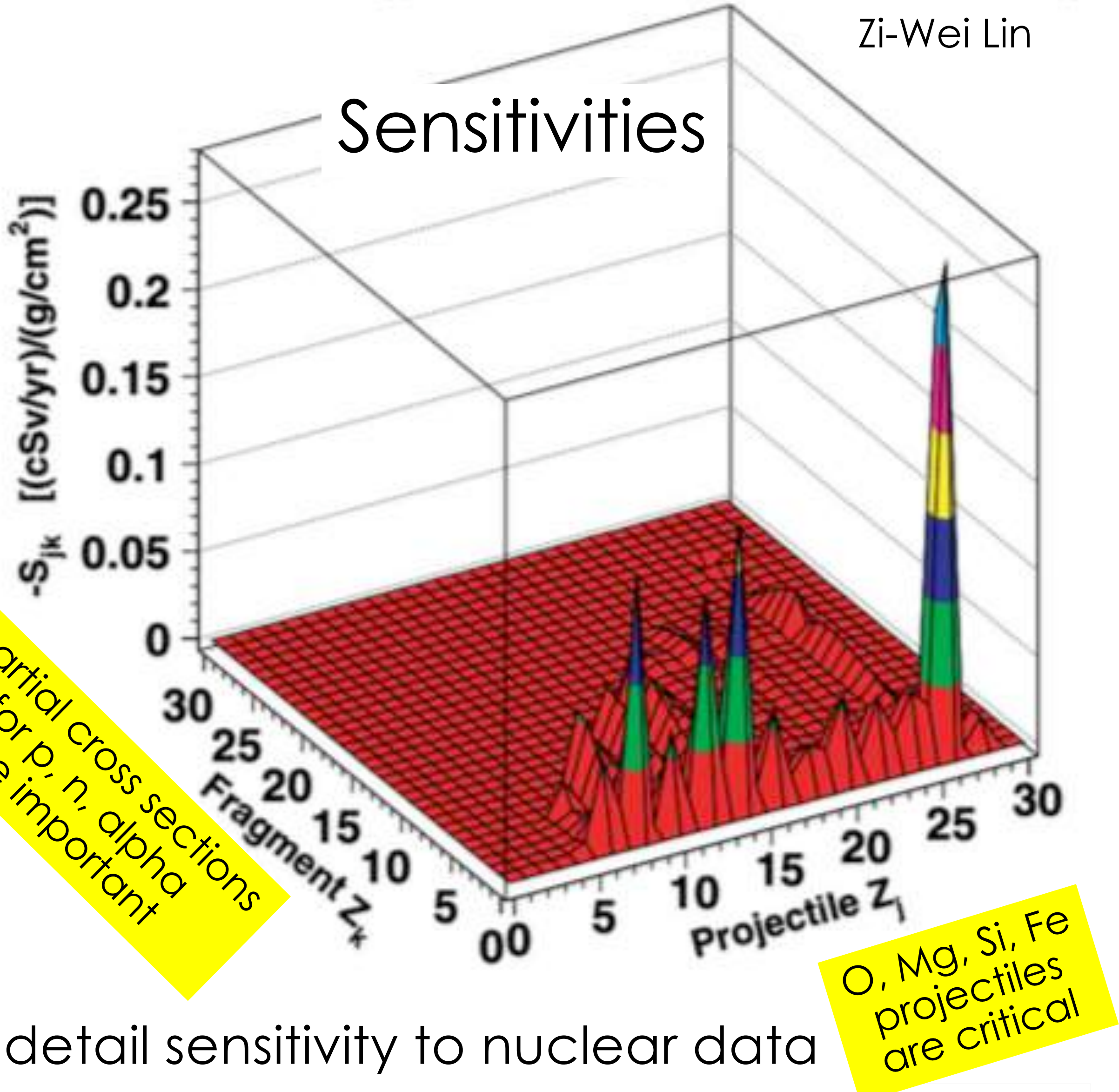
currently 200x faster than GEANT4

custom kernel for intranuclear cascade + particle evaporation + non-elastic Barashenkov and Glauber-Gribov cross sections

- Cancer therapy community developing HPC simulations that can benefit space human effects research

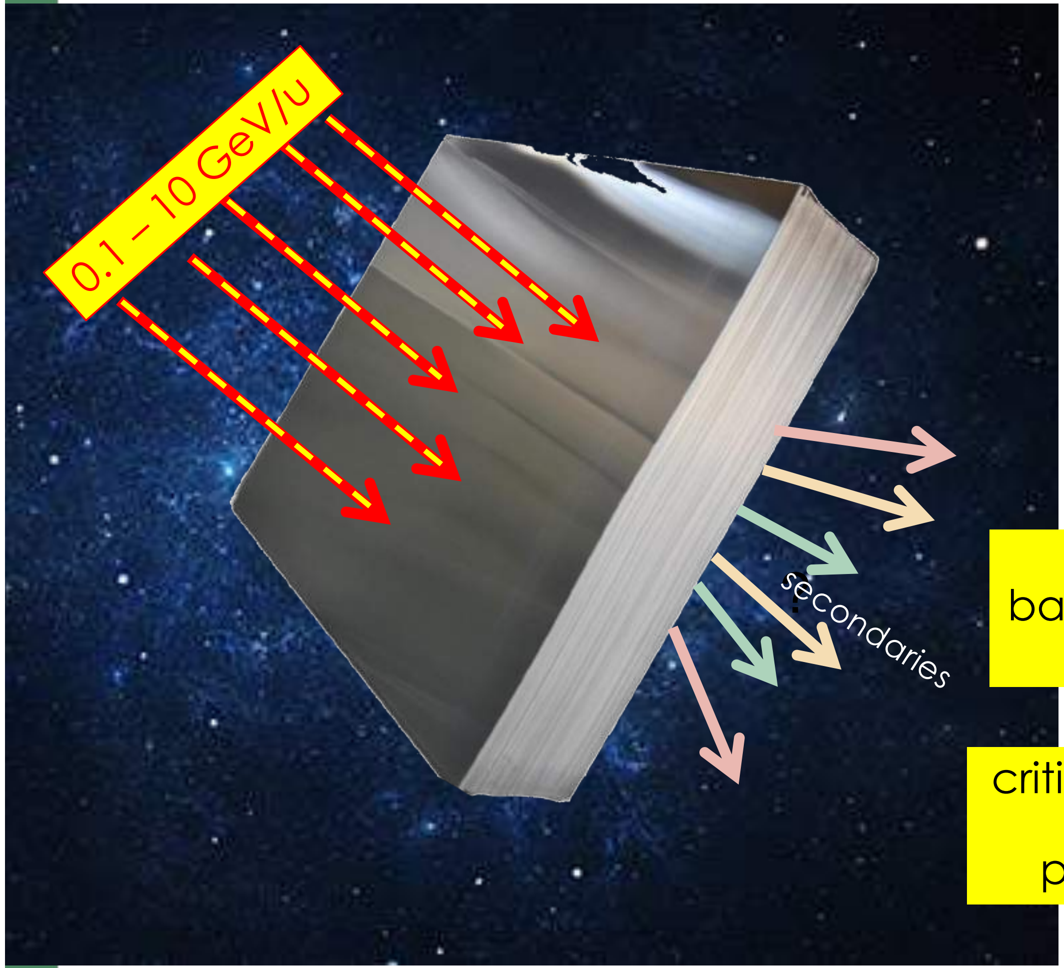
Applications - Modeling





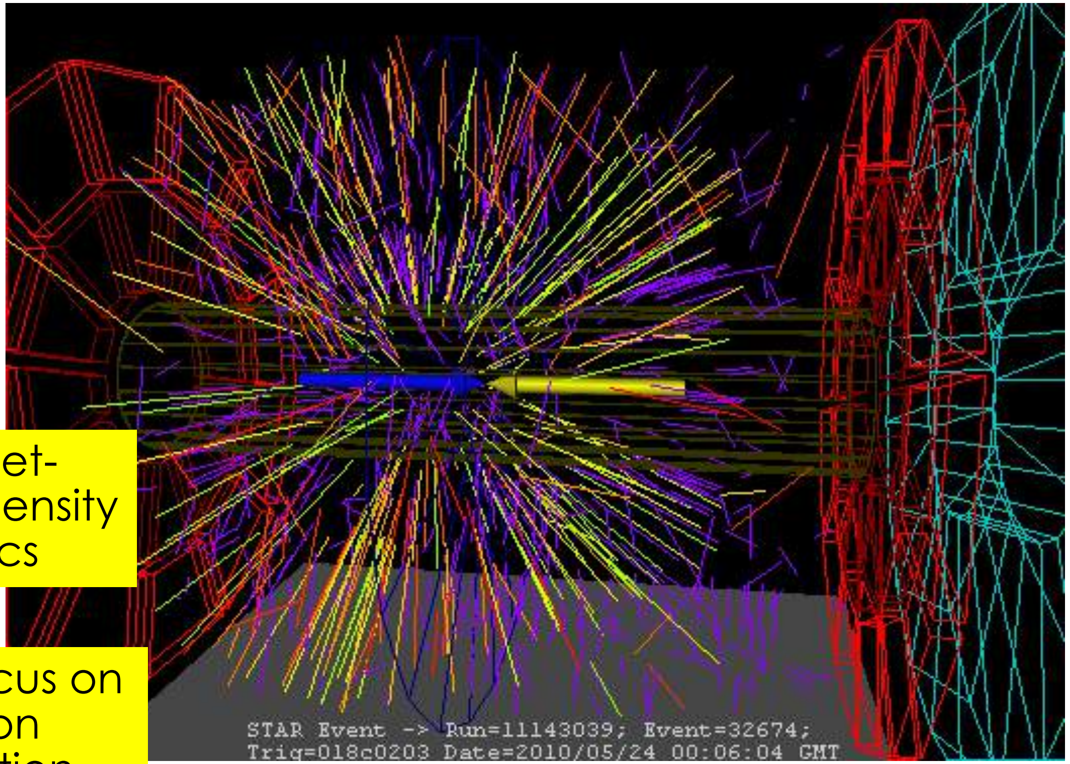
- Space radiation transport studies detail sensitivity to nuclear data

Applications - Modeling



high net-baryon density physics

critical focus on light ion production

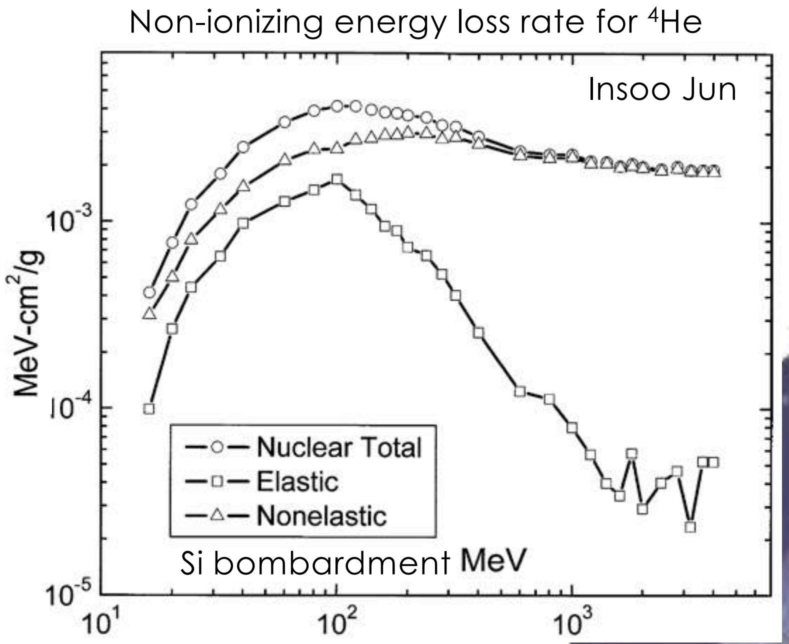


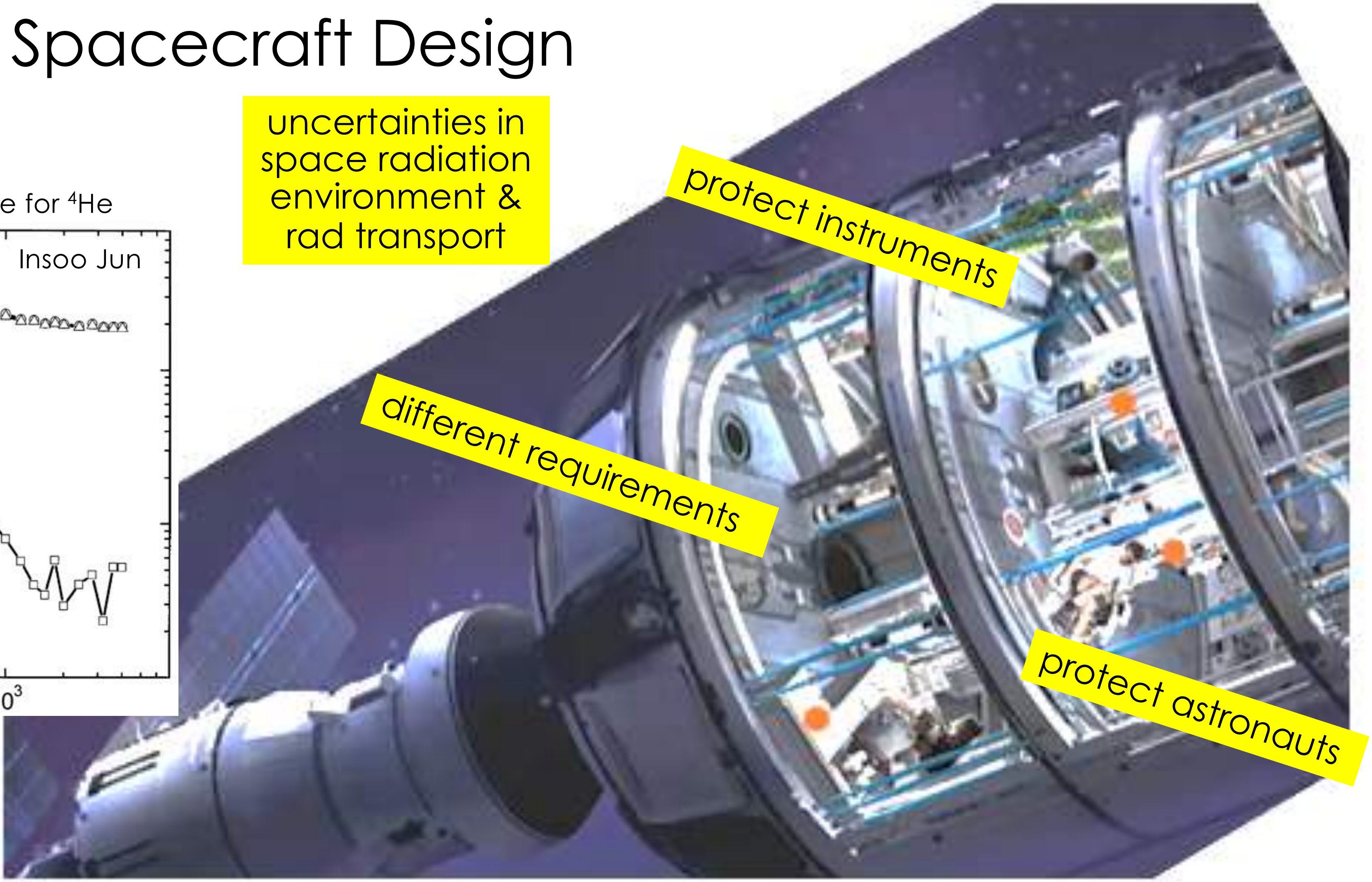
- Space transport studies should explore synergies with RHI collisions

Ken LaBel Ramona Vogt Michael Smith

Applications – Spacecraft Design

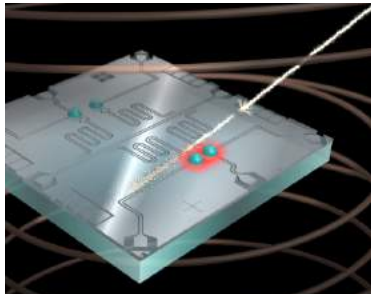
uncertainties in space radiation environment & rad transport

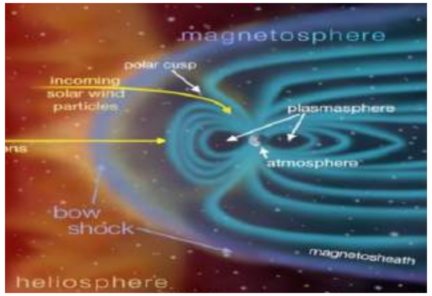


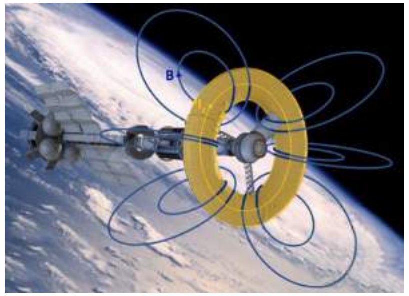


- Spacecraft design needs accurate and reliable **rad transport tools** with relevant nuclear data for ***all*** particle interactions

Final Comments







- **Electronics Effects** and **Human Effects** communities could benefit from **enhanced collaboration with nuclear physics** (and with each other)
- Numerous ties between the **Relativistic Heavy Ion community** and the **Space communities** should be **fostered and exploited** [reaction theory, RHIC measurements, transport simulations/light particle production]
- Coordinate **beam time requests** and **accelerator re-use** to best meet high demand for more experiments
- **Space community** could benefit tremendously from **expertise** in **Nuclear Data community** (databases, visualization, sensitivity tools, dissemination, archiving, model integration, ML approaches …)