Design and Status of the Super Separator Spectrometer for the GANIL SPIRAL2 Project

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Abstract: S^3 Design and Status

The Super Separator Spectrometer (S^3) is a device designed for experiments with the very high intensity stable heavy ion beams of the superconducting linear accelerator of the SPIRAL2 Project at GANIL. S^3 is designed to combine high acceptance, a high degree of primary beam rejection, and high mass resolving power to enable new opportunities in several physics domains, e.g. super-heavy and very-heavy nuclei, spectroscopy at and beyond the drip-line, isomers and ground state properties, multi-nucleon transfer and deep-inelastic reactions. The spectrometer comprises 8 large aperture multipole triplets (7 superconducting and 1 open-sided room temperature), 3 magnetic dipoles, and 1 electrostatic dipole arranged as a momentum achromat followed by a mass separator. A summary of the beam-optical simulations and the status of the main spectrometer components will be presented with special emphasis on the design of the superconducting multipole triplets.

Outline of this talk

- The GANIL SPIRAL2 Project
  - Overview talk this afternoon by E. Petit
- Physics with heavy ion beams at SPIRAL2
- Requirements/goals for the new spectrometer
- Optics configuration
- Technical components
- The superconducting multipole triplets
- The electric dipole

Scientific Program

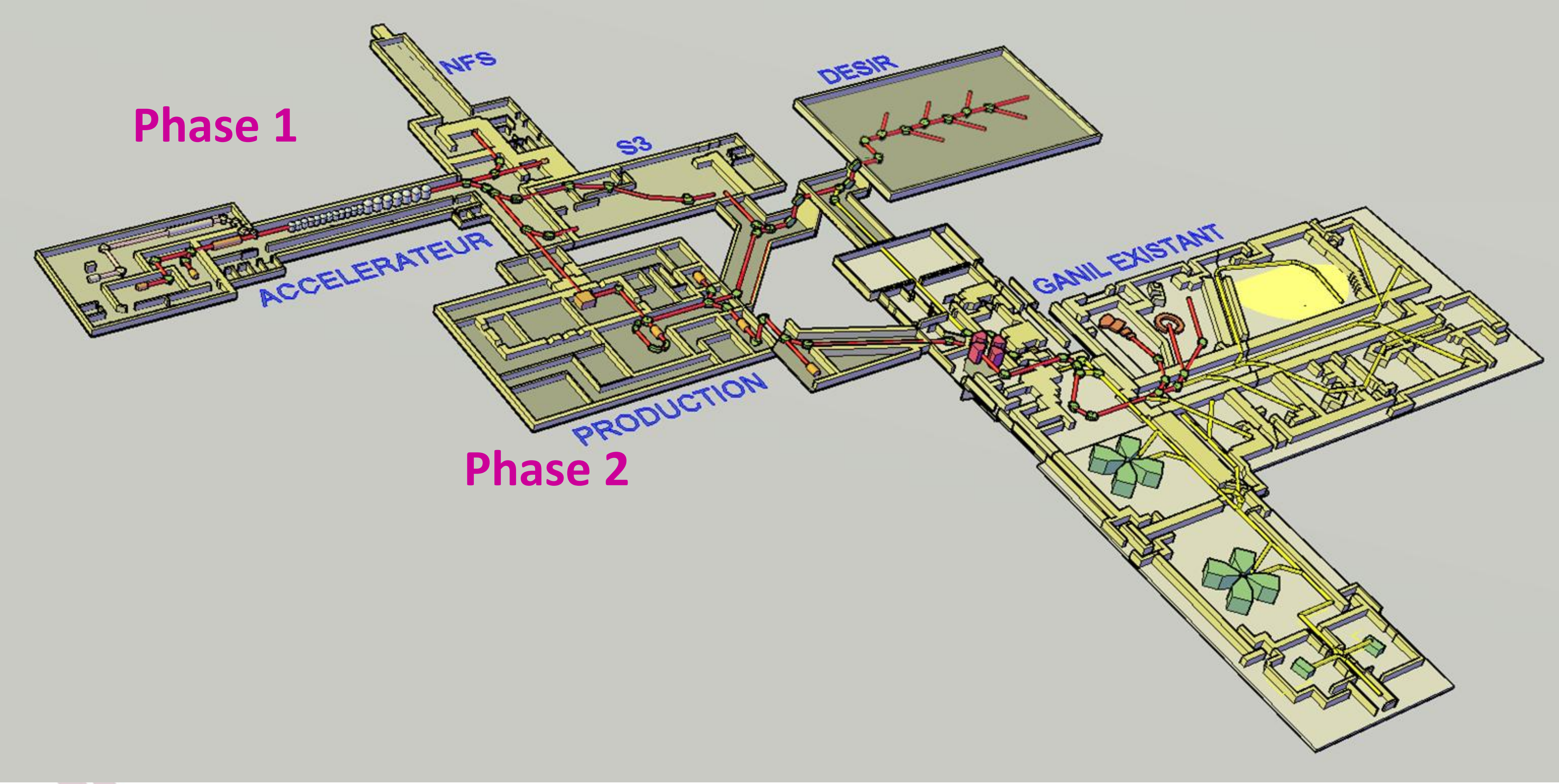
In order to define the spectrometer specifications, we selected several specific experiments, as a model for the physics at S3, and simulate their kinematical characteristics:

1. Direct kinematics fusion reaction: $^{48}Ca + ^{248}Cm \rightarrow ^{292}116 + 4n$
2. Inverse kinematics fusion reaction: $^{208}Pb + ^{48}Ca \rightarrow ^{254}No + 2n$
3. Fusion of symmetric systems: $^{58}Ni + ^{46}Ti \rightarrow ^{100}Sn + 4n$
4. Inverse kinematics fusion reaction (light system): $^{58}Ni + ^{12}C \rightarrow ^{68}Se + 2n$
5. Multi-nucleon transfer reaction (study of Neutron Rich Nuclei):
    - Light nuclei: $^{12}C + ^{13}C \rightarrow ^{11}Be + 2p$
    - Medium nuclei: $^{68}Se + ^{238}U \rightarrow ^{80}Zn + X$
    - Heavy nuclei: $^{238}U + ^{248}Cm \rightarrow ^{262}No + X$

SPIRAL2 under construction

Phase 1: High intensity stable beams in 2014 + Experimental rooms (S^3 + NFS)

Phase 2: High intensity Radioactive Ion Beams (RIB)



Benchmark reactions

SHE / VHE - Fusion-evaporation in direct kinematics

SHE / VHE **^{48}Ca+^{248}Cm → ^{292}116 + 4n**	Synthesis and delayed spectroscopy
	Chemistry
	Ground state properties (half-lives, masses, spectroscopy)

	E [MeV/n]	<Bρ> [Tm]	<Eρ> [MV]	<Q>	<V >[cm/ns]	Δθ (±2σ)[mrad]	dQ	dp/p[%]
Beam parameters ^{48}Ca	4.92	0.88	27	+17	3.0	± 8		±0.2
Recoil parameters ^{292}116	0.131	0.58	3	+25	0.5	± 40	± 2	±2.3

The ^{100}Sn factory

N = Z **^{58}Ni + ^{46}Ti → ^{100}Sn + 4n**	Ground state properties (half-lives, masses, spectroscopy)

	E [MeV/n]	<Bρ> [Tm]	<Eρ> [MV]	<Q>	<V >[cm/ns]	Δθ (±2σ) [mrad]	dp/p(±2σ)[%]
Beam parameters ^{58}Ni	2.94	0.660	15.6	21.68	2.37	±8.6	±0.2
Recoil parameters ^{100}Sn	0.882	0.559	7.27	24.17	1.30	±50	±7.4

Summary of Technical Challenges

High Beam intensity

➔High power target : 10pμA (= 6.10^{14}pps) or more

➔Rejection of the beam : $>10^{13}$

Low Energy (fusion-evaporation residues)

➔Large angular acceptance : +/- 50 mrad X and Y

➔Large Charge state acceptance : Bρ acceptance: +/- 10%

Many reaction channels (evaporation channels)

➔M/q selection : 1/350 resolution

➔Identification when possible

Transfer/Deep inelastic Reactions (non 0°)

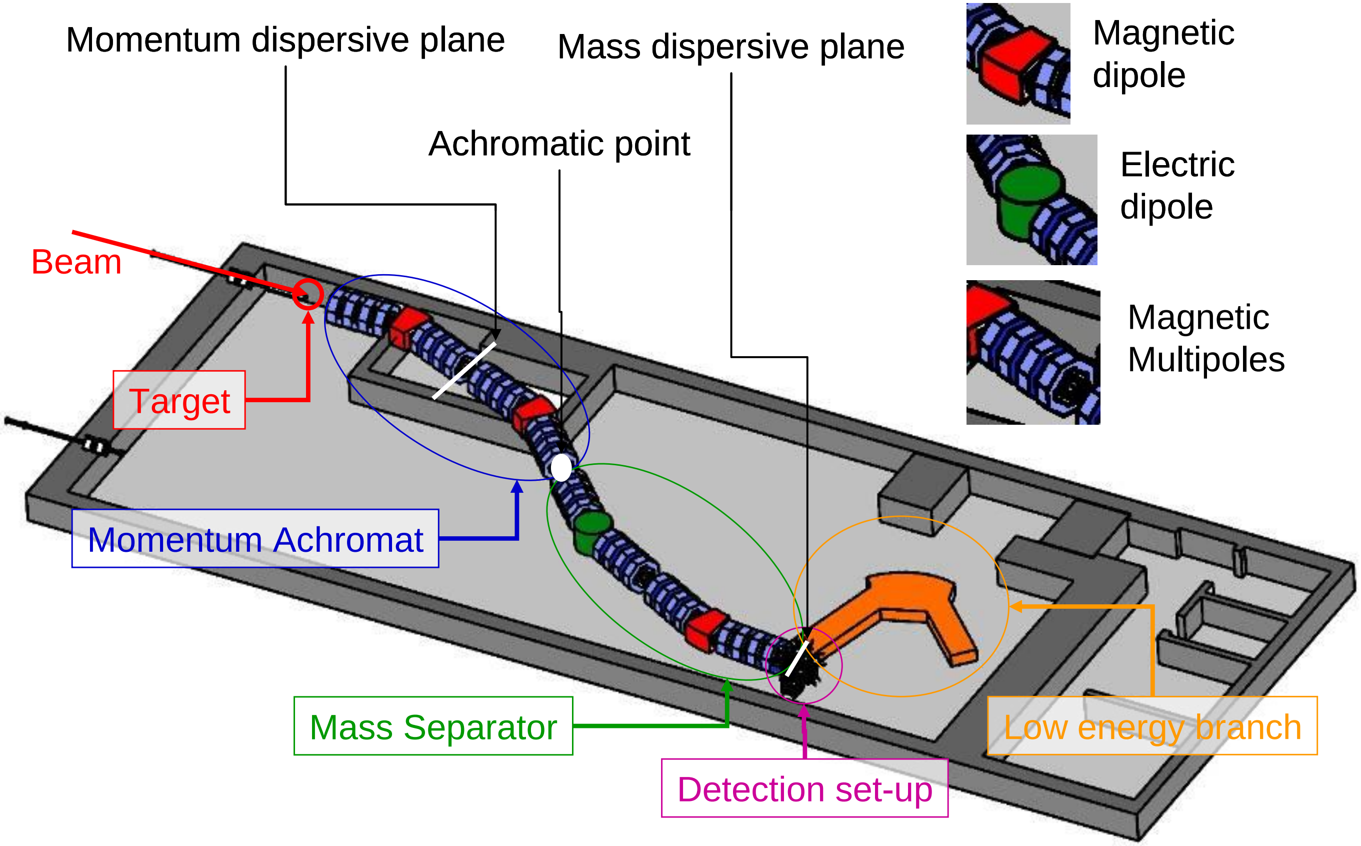
➔Beam Sweeper for incident beam at 10°

➔ Specific Target chamber and beam dump

Irfu
cea
saclay

S3 conceptual layout: Momentum Achromat, Mass Separator (MAMS)

Proposed Solution: Two-stage selection (Bρ and m/q) that will achieve very good rejection of both the beam and adjacent mass channels of reaction products



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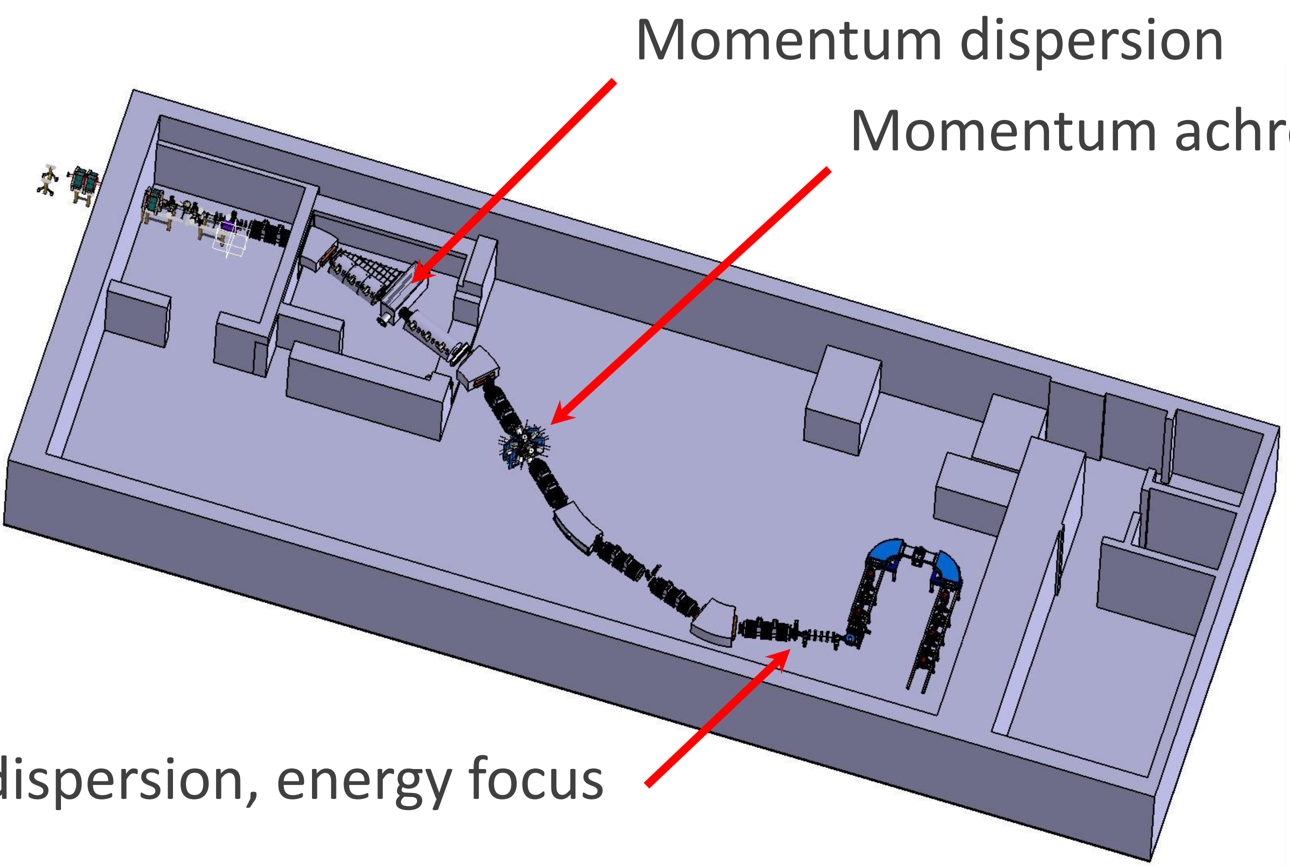


Histogram at mass focal Plane

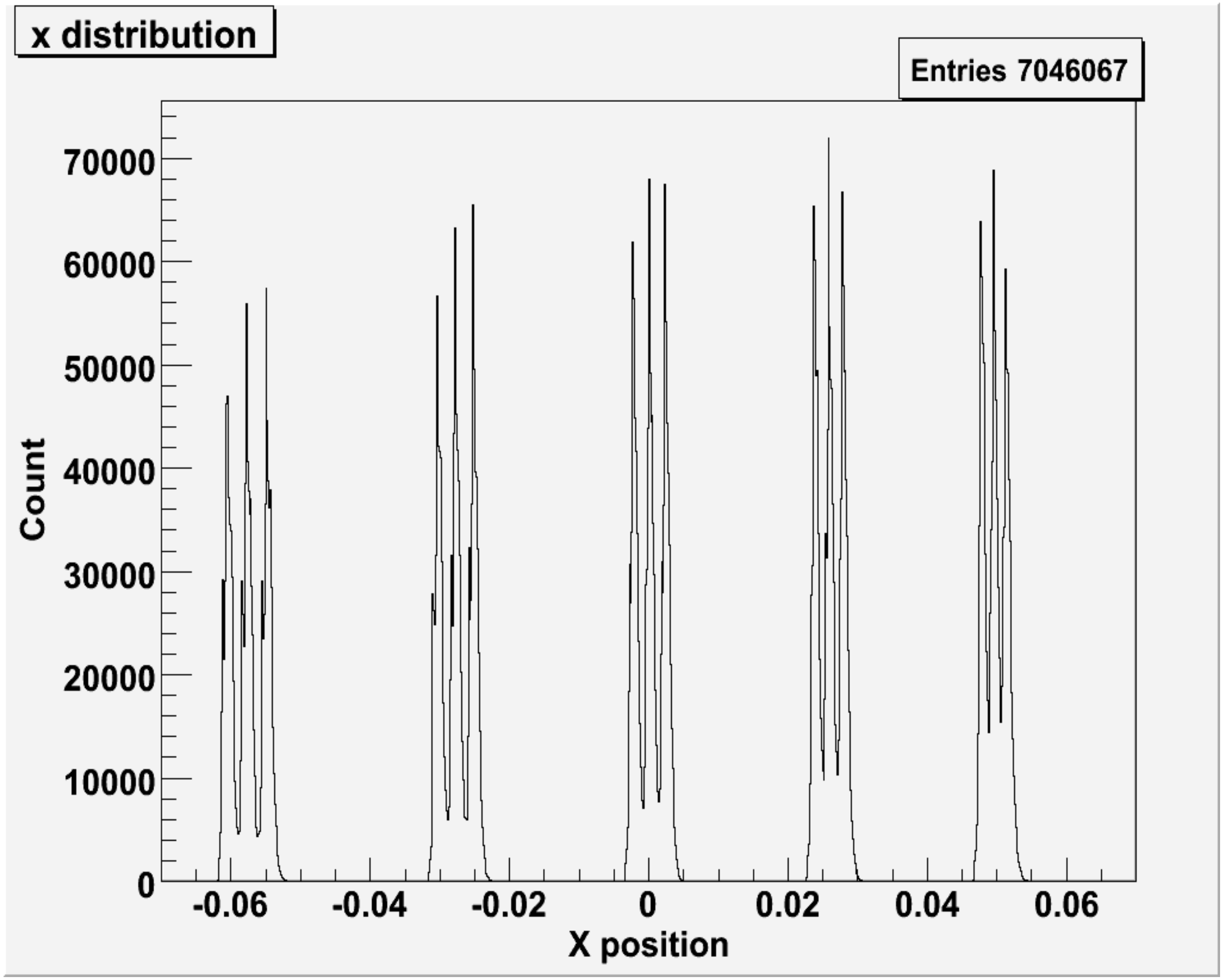
$^{48}Ca + ^{248}Cm \rightarrow ^{292}116 + 4n$

$\delta Q=\pm 2$, $\delta m=\pm 1$, $\Delta B\rho = 4.6\%$

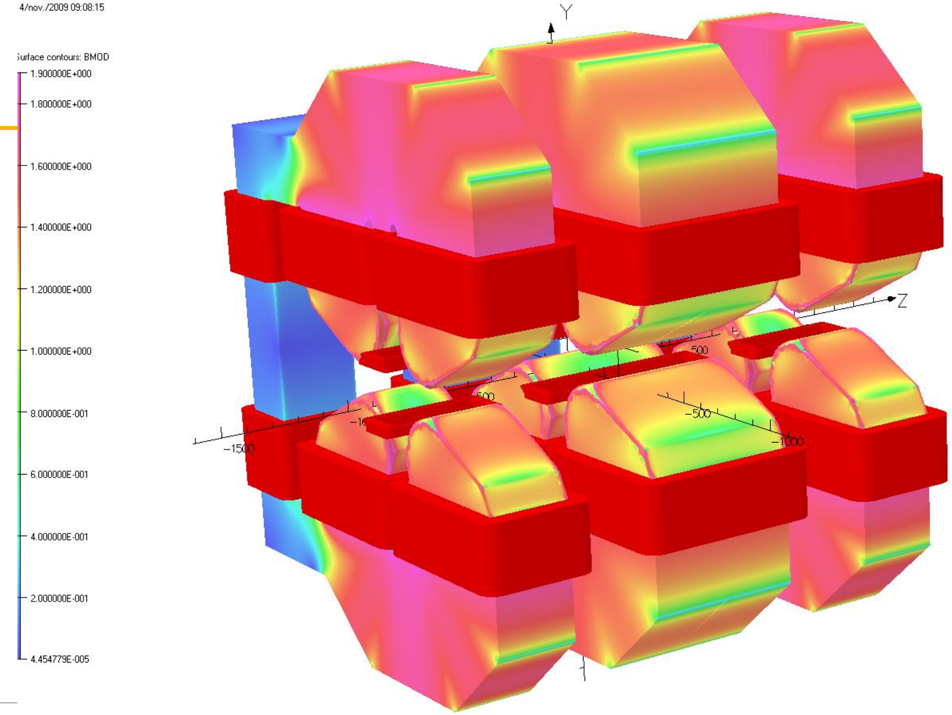
Overall transmission of fusion reactions ~50-60% for direct and symmetric kinematics

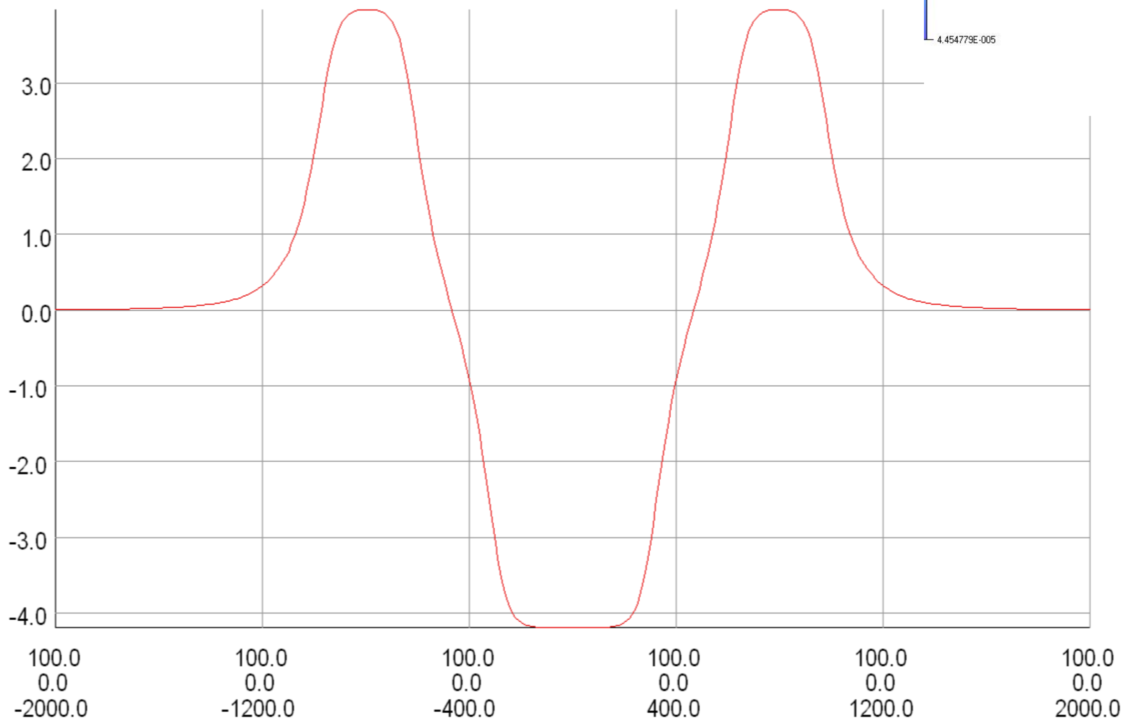
m/q resolution ~300-400 for 5 charge states

Optics team from GANIL, Saclay, Bucknell Argonne & Strasbourg



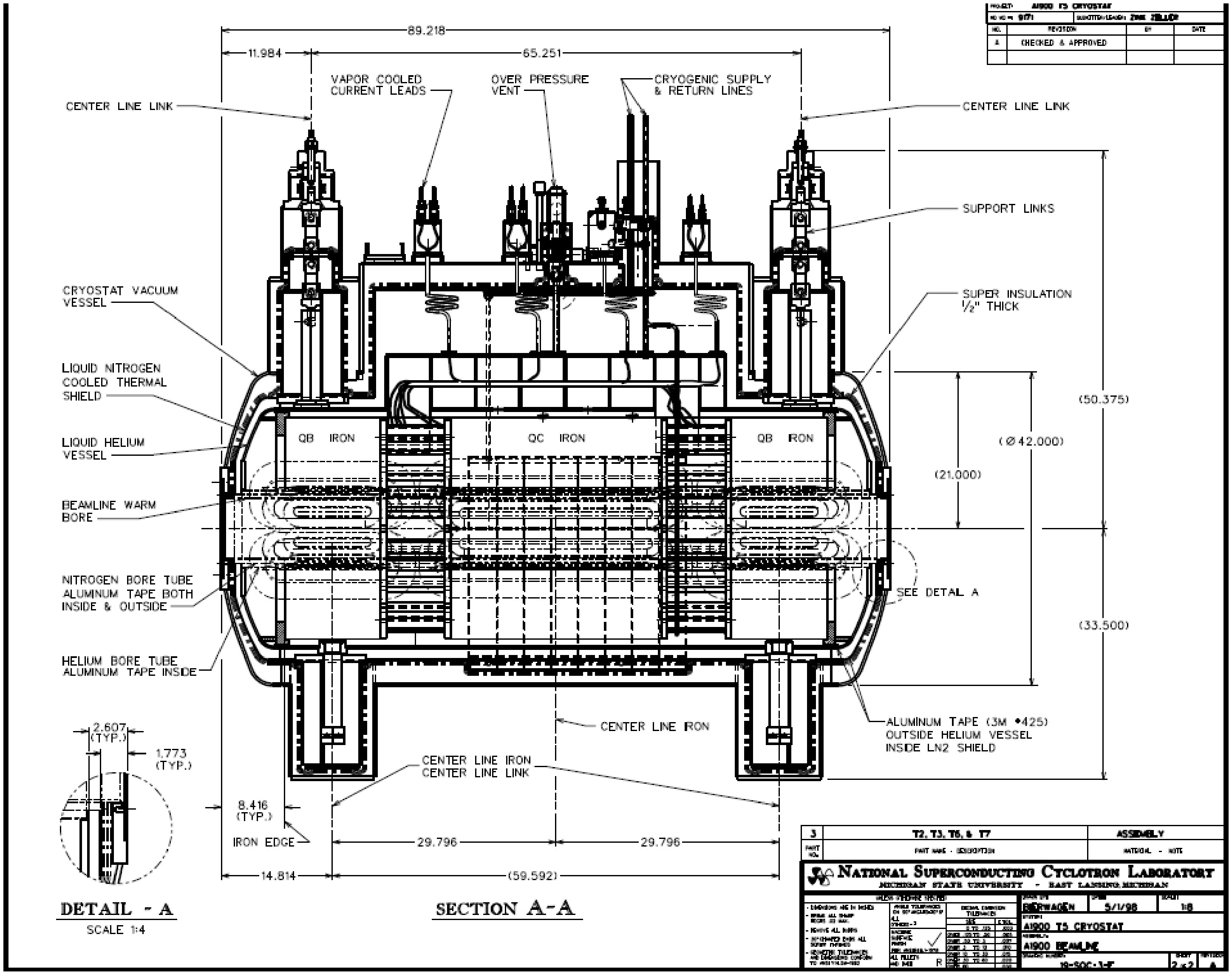
Plot showing position of mass lines, 5 charge states, 3 masses





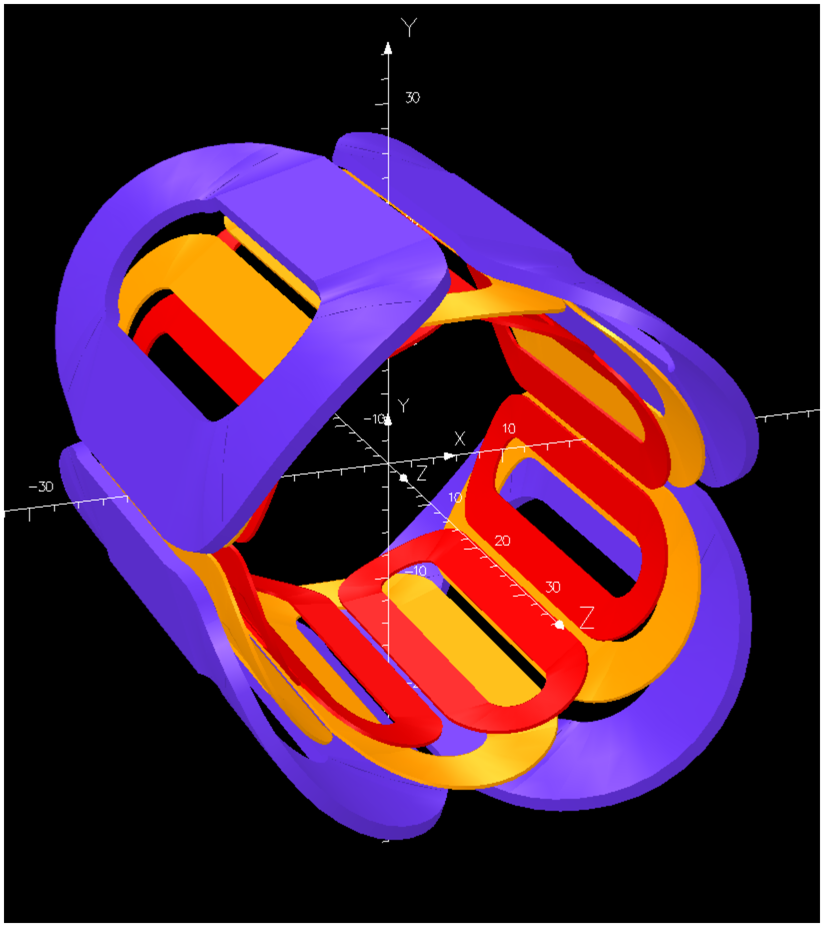
Open-sided RT magnets with sextupoles

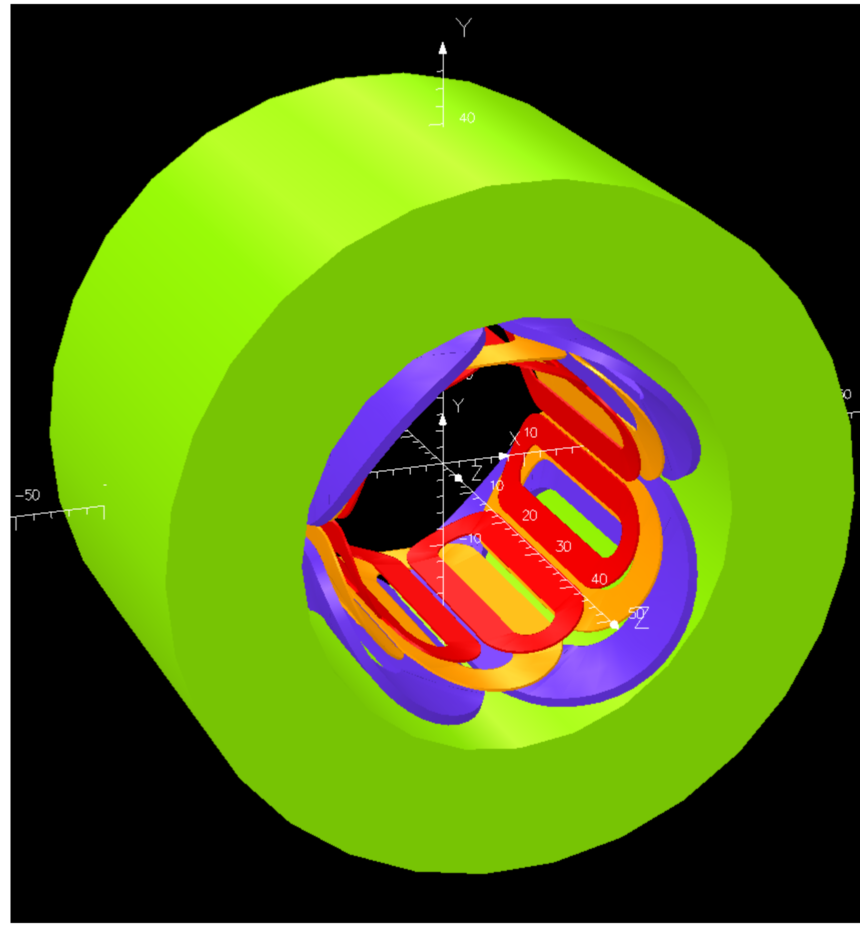
MSU/NSCL SC Cold-iron Triplet for fragment separator



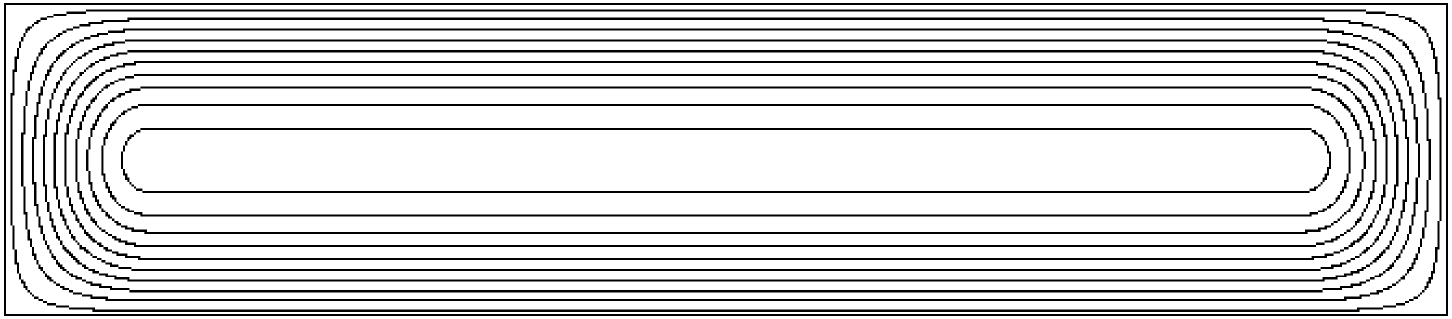
Argonne concept of SC multipoles

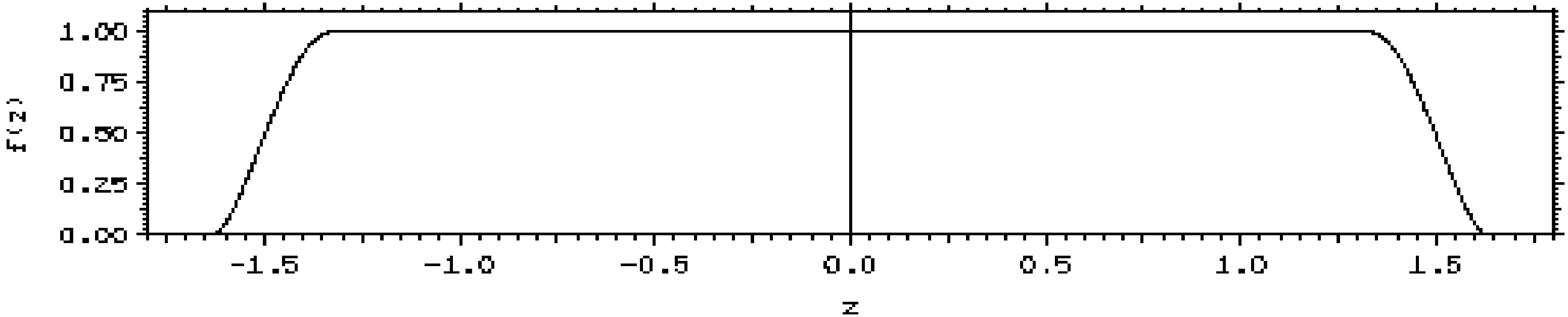
- High quality and cost-effective multipole designs using SC magnets are being developed





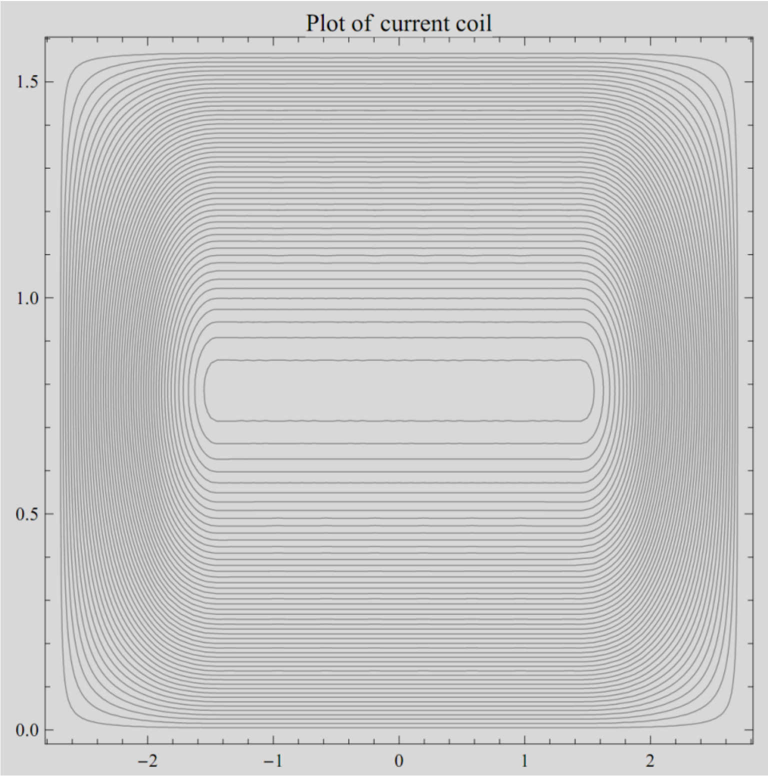
Winding with Pure sin$m\phi$ Symmetry and its Shape Function - nearly perfect multipole fields



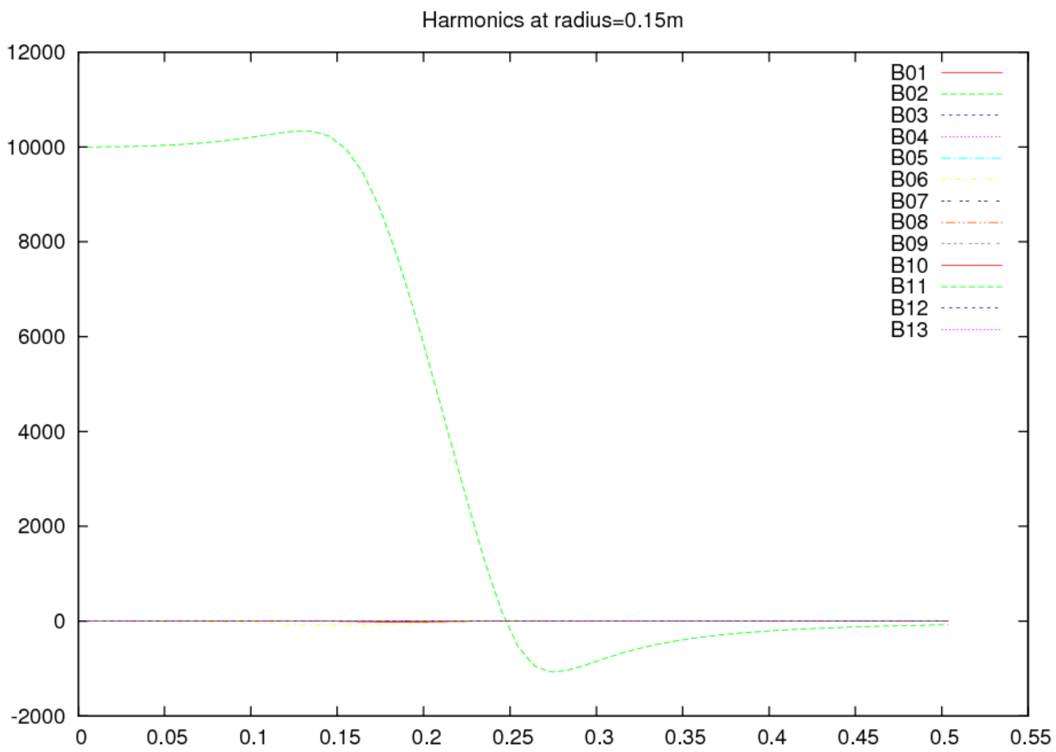


Peter Walstrom, NIM A519 (2004) 216

Harmonics for Quadrupole Magnet using Walstrom-type coils

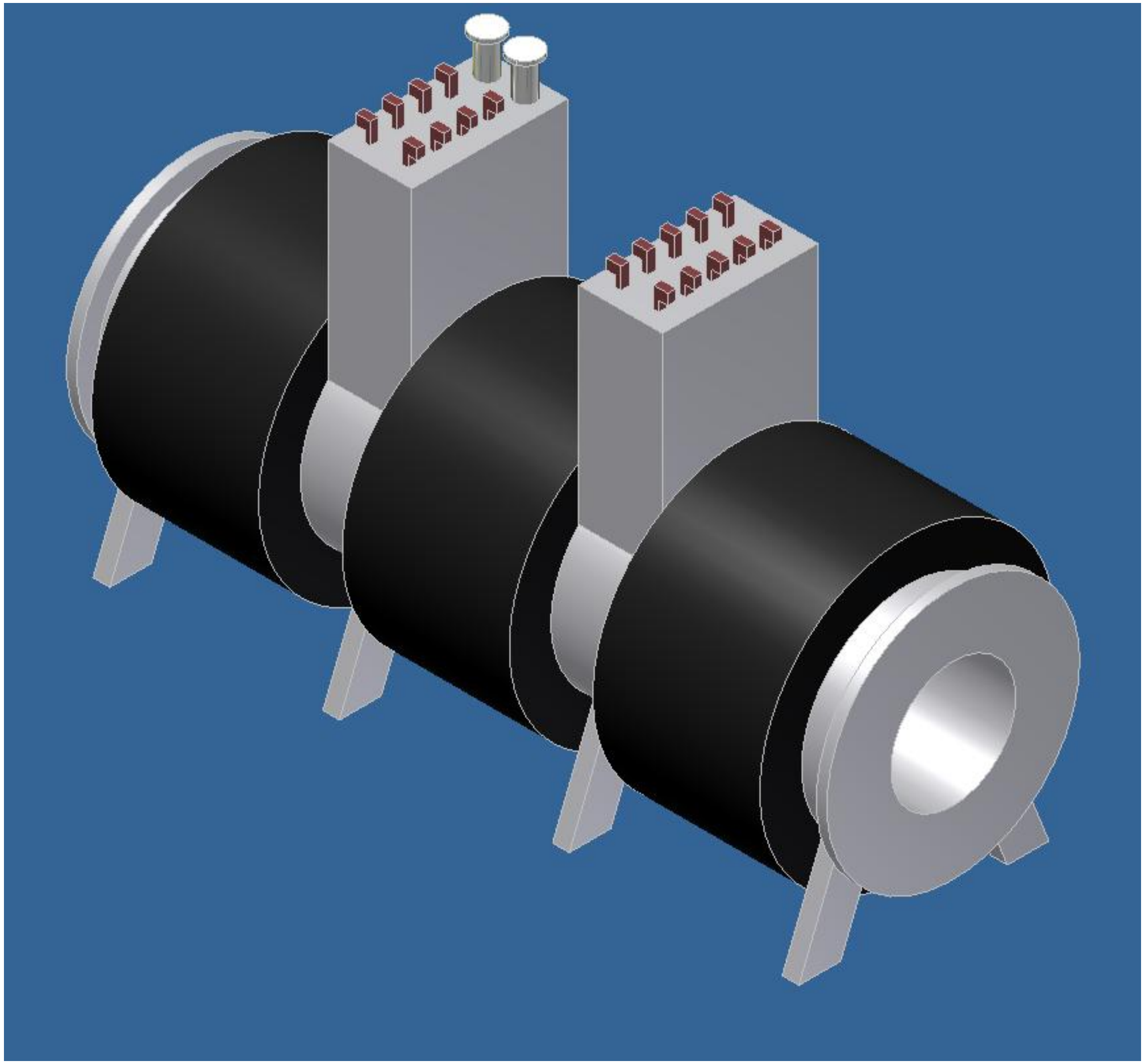


All allowed harmonics are near zero



Air-core 3D fields calculated within COSY ∞ by S. Manikonda

Preliminary model of a SC multipole triplet for S^3



Overall layout and concept of SMT

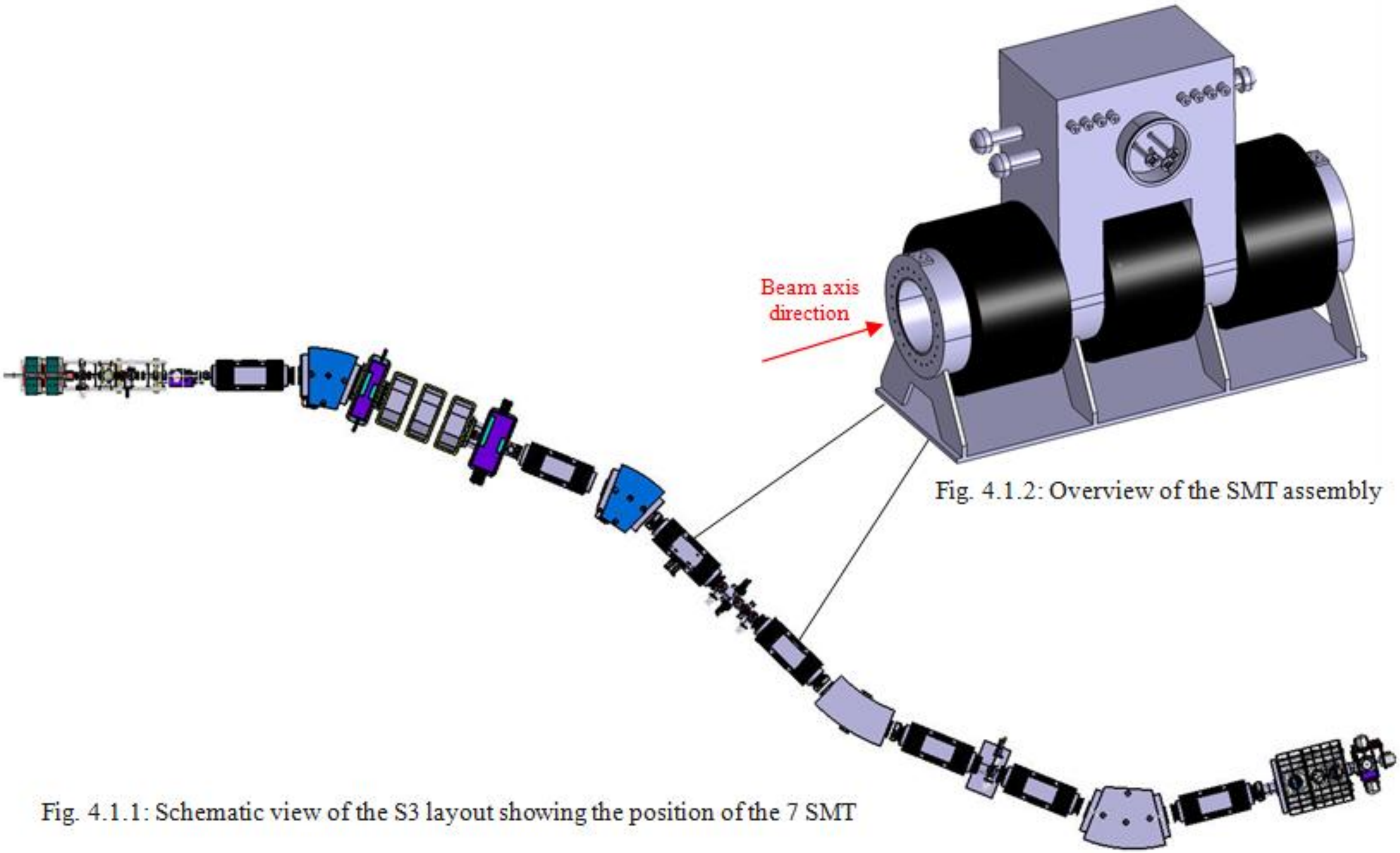


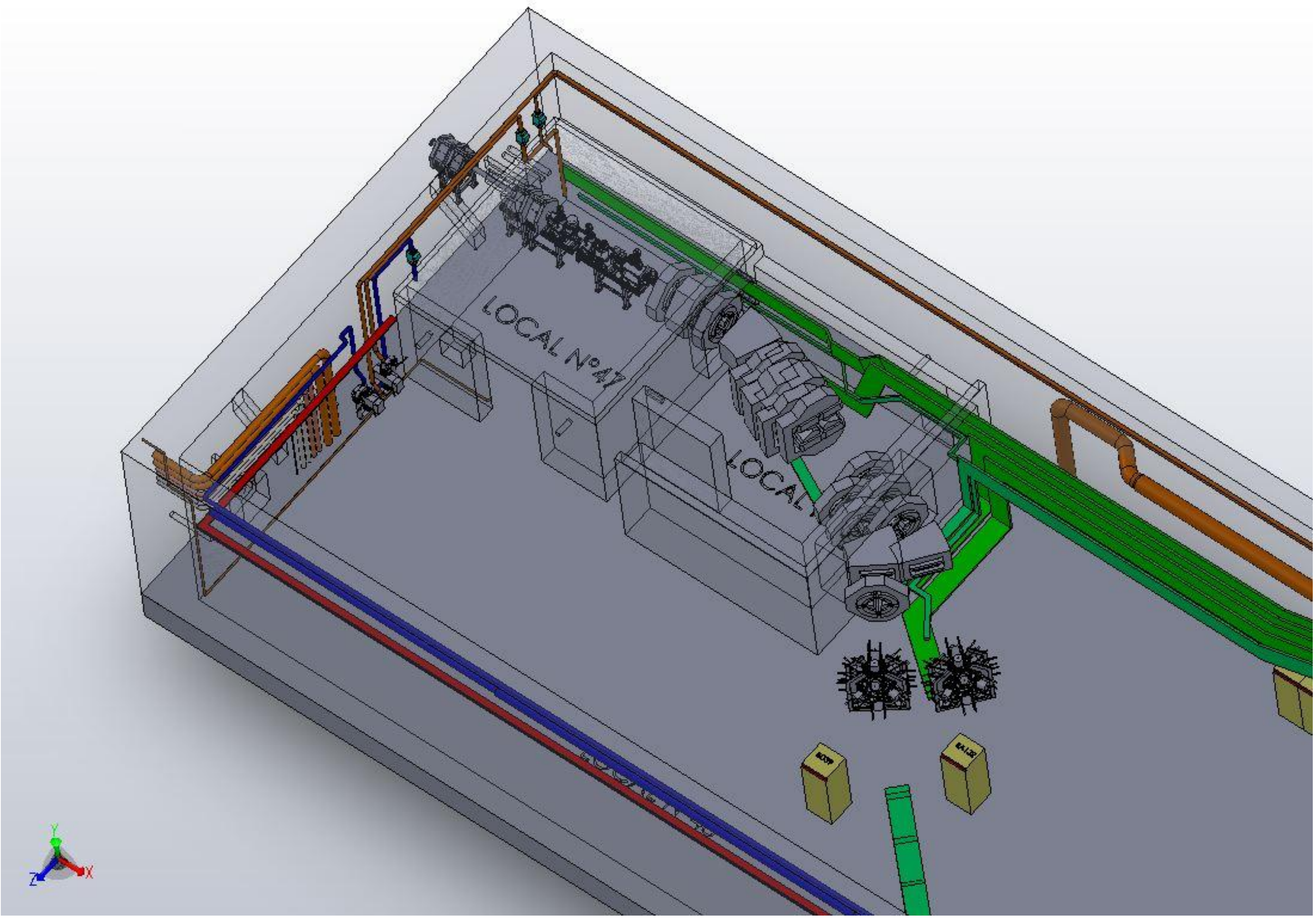
Fig. 4.1.2: Overview of the SMT assembly

Fig. 4.1.1: Schematic view of the S3 layout showing the position of the 7 SMT

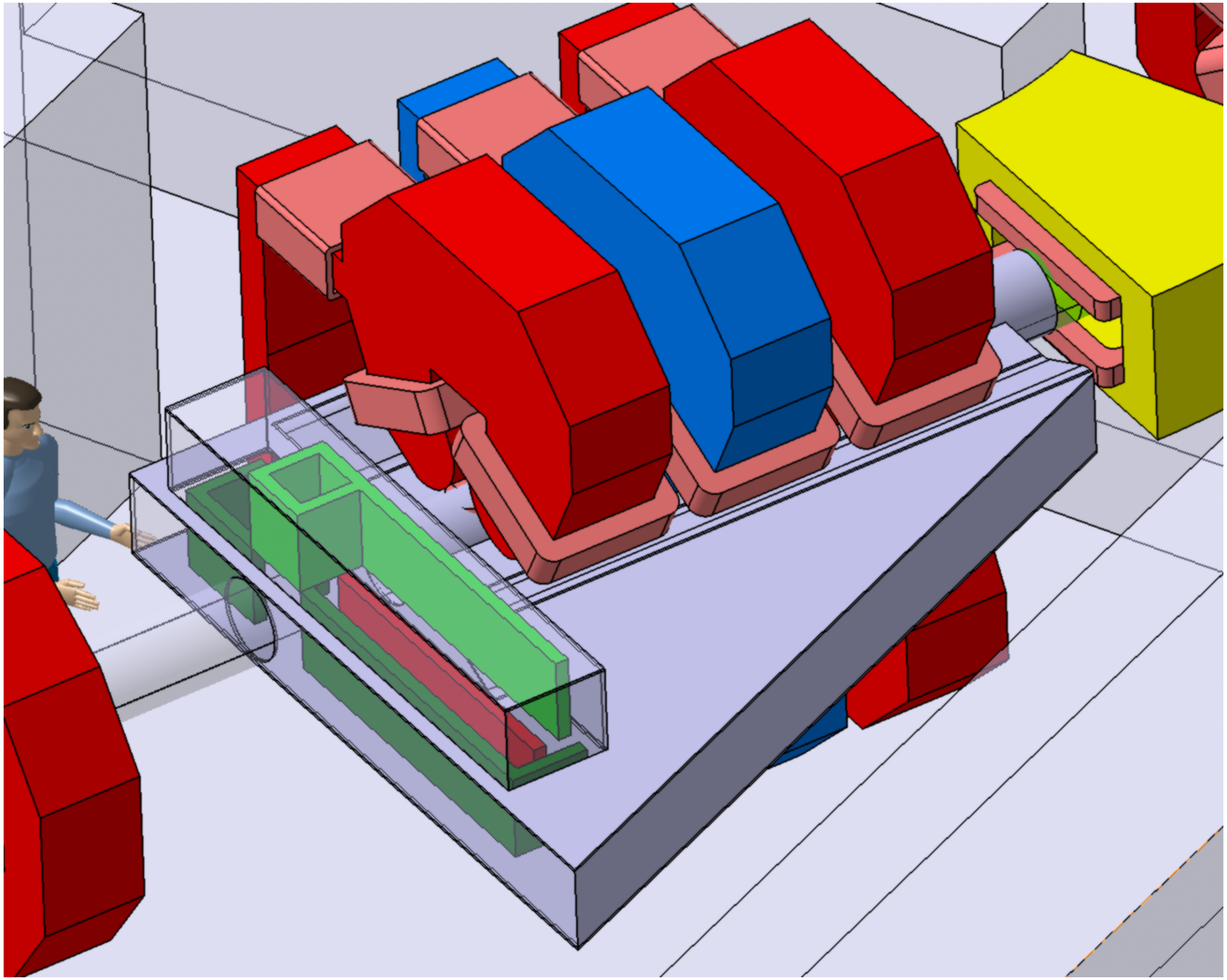
Summary of multiplet requirements for S3

- 8 triplets are required (quadruplet design changed to triplets to add space at target and focal planes while still fitting in the room)
- Can use 7 "closed" style with 1 "open-sided" for beam dump region
- SC multiplets: cost-effective, excellent field quality, shorter overall system
- Each "closed" singlet can have quadrupole, sextupole, & octupole coils, with 30-cm warm bore diameter & 40-cm effective length
- Fields required at 15-cm radius for 2 T-m rigidity (higher rigidity is easy):
  - Quadrupole: ~1.0 T
  - Sextupole: ~0.4 T
  - Octupole: ~0.2 T
- Cryogenics:
  - Warm iron used to speed up cool down
  - Small centralized cryo-system, ~100 W helium refrigeration with a small cold box (in the S3 vault)
  - Liquid helium bath for magnet coils
  - LN2-cooled shields
  - HTS and N2 gas-cooled leads
  - Operating current 200-400 amps (3 lead pairs per singlet)

Detailed beam dump concept being developed currently at Saclay

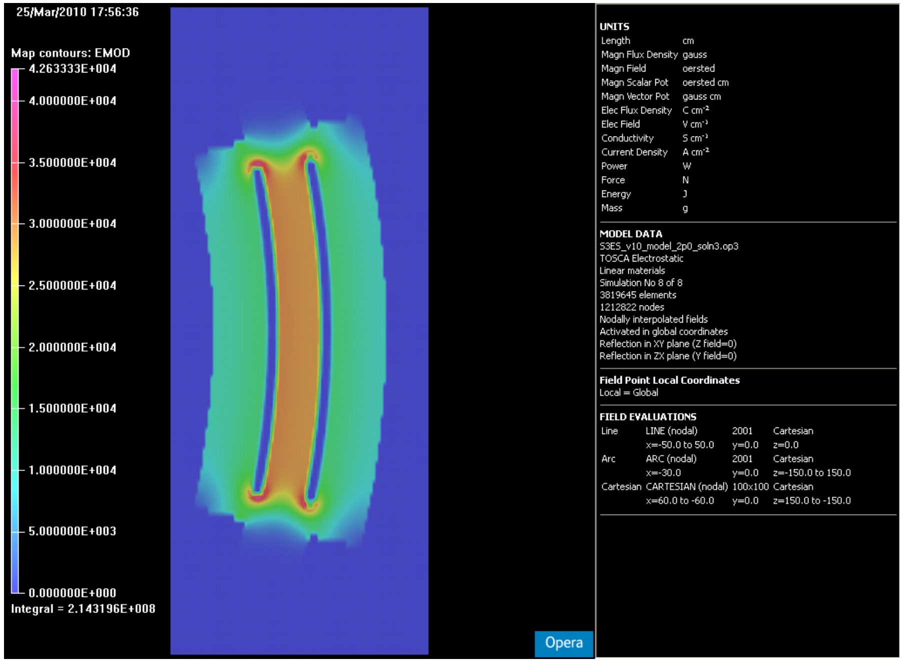


Beam Dump sketch

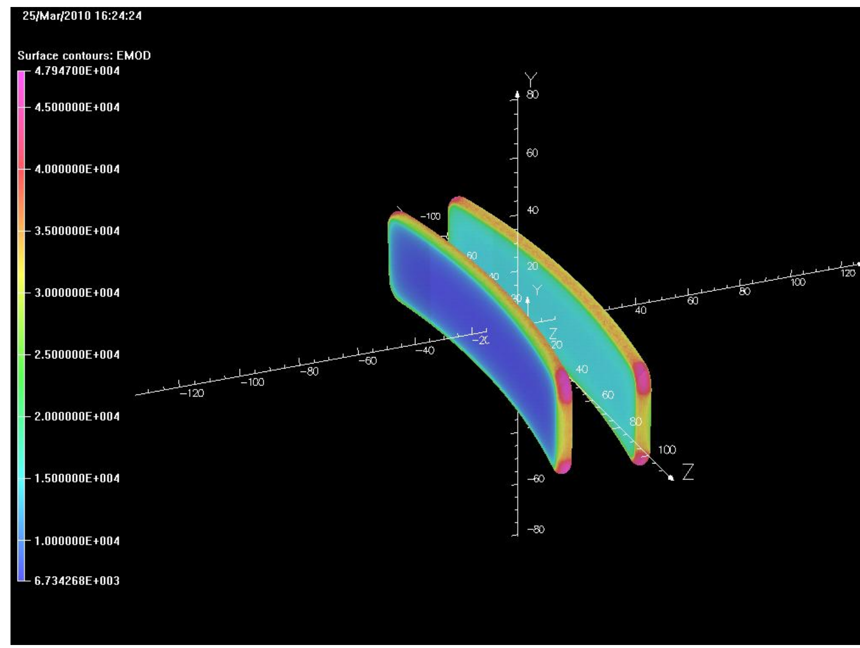


Safety related studies by Irfu/SENAC

E-dipole: +/- 300 kV, 20-cm gap



Preliminary Opera 3D model



Argonne/IPN-Orsay collaboration

Summary

- The S^3 separator is being designed and is to be built and used at SPIRAL2 by a large international collaboration: SPIRAL2 phase 1 research by 2015
- This instrument will use the intense stable heavy ion beams of SPIRAL2 phase 1
  - Important physics goals include studies of N~Z nuclei around ^{100}Sn, as well as, nuclear structure, chemistry, and synthesis studies of very- and super-heavy elements
- There are active collaborations proceeding with R&D and studies of all S^3 major subsystems – e.g. optics, magnets, E-dipole, targets, detectors, low energy branch
- Advanced optical simulations with a variety of magnet types are in progress
  - Simulations already show that SC multipoles with up to octupole corrections are required in the mass separator section
- RT and SC magnet design studies are in progress (mostly for “open-sided”)
- Safety studies are continuing and include detailed studies of the target and beam dump areas
- The electric dipole of S^3 is a limiting element for some beams and reactions
  - The ILL/LOHENGRIN E-dipole may be the best “model” for the S3 E-dipole