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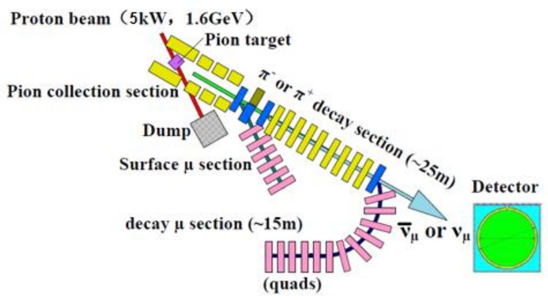
Chinese Academy of Sciences



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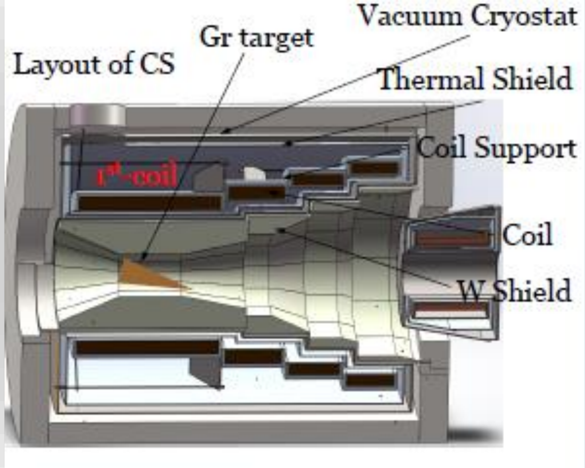
Introduction to Experimental Muon Source (EMuS) at China Spallation Neutron Source

+

Shielding Design for EMuS

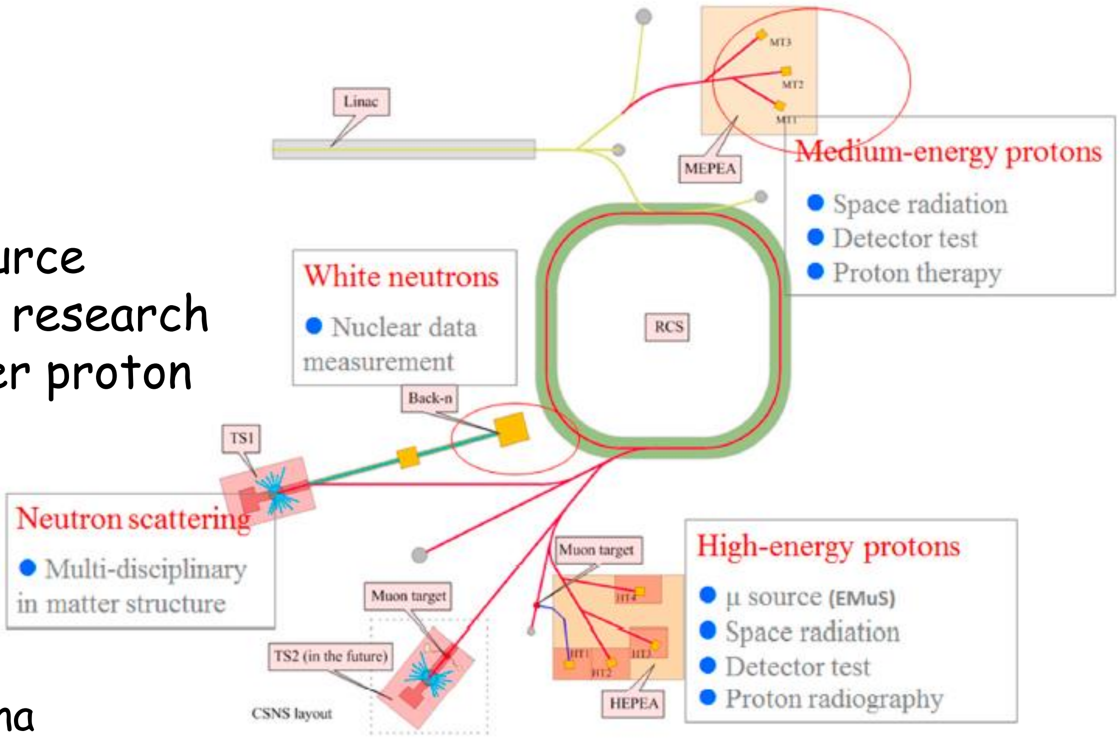
Nitin Yadav
IHEP



Slides credit: Nikos & G. Zhao, IHEP

EMuS at CSNS

- China Spallation Neutron Source (CSNS) is a multidisciplinary research facility based on a high-power proton accelerator.



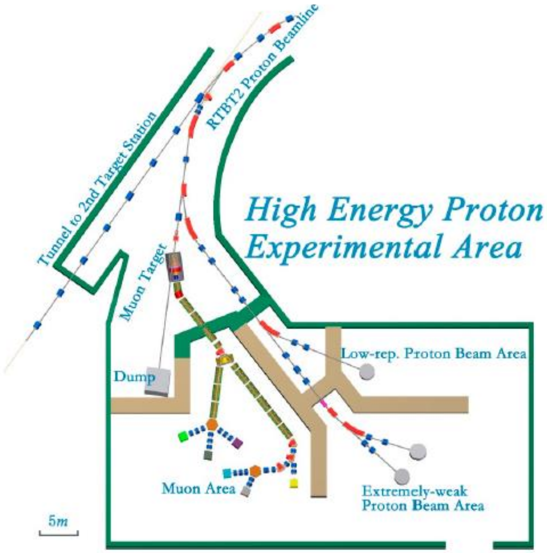
Medium-energy protons
- ● Space radiation
- ● Detector test
- ● Proton therapy

White neutrons
- ● Nuclear data measurement

Neutron scattering
- ● Multi-disciplinary in matter structure

High-energy protons
- ● μ source (EMuS)
- ● Space radiation
- ● Detector test
- ● Proton radiography

- Largest scientific facility in China
- Phase-I: 100-kW accelerator, one target station, 3 neutron instruments
- Upgrading: 500 kW, 20 neutron instruments (second target station)
- Besides neutron scattering, other applications have also great potential

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LINAC
RCS
TS1
HEPA
EMuS
TS2

Aims for EMuS, the first muon source in China

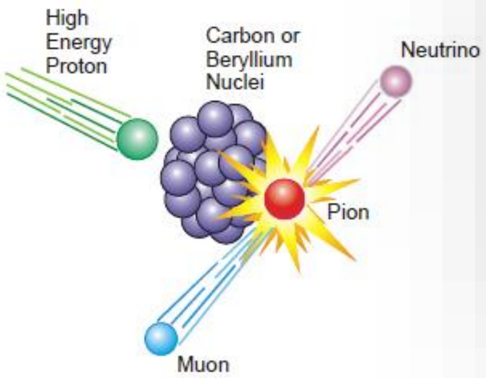
The high intensity muon source project EMuS is foreseen at CSNS and is being optimized for both muon and neutrino experiments

1. It is primarily intended for muon science and primarily for μSR techniques in matter physics and chemistry and also for BSM physics…

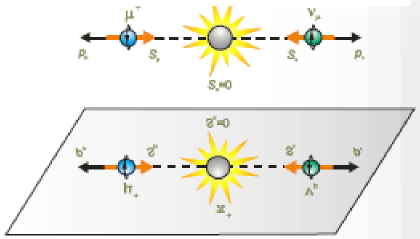
μSR muons

$$\pi^+ \to \mu^+ + \nu_u$$

$$\pi^- \to \mu^- + \overline{\nu}_\mu$$

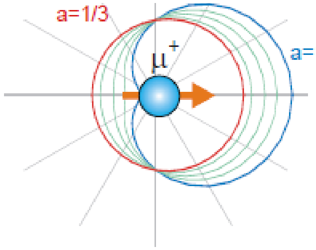


100 % polarisation due to DAR π



Parity-violating collinear decay of a pion π^+ at rest into a muon μ^+ and a muonic neutrino ν_μ.

Asymmetrical decay due to week interaction



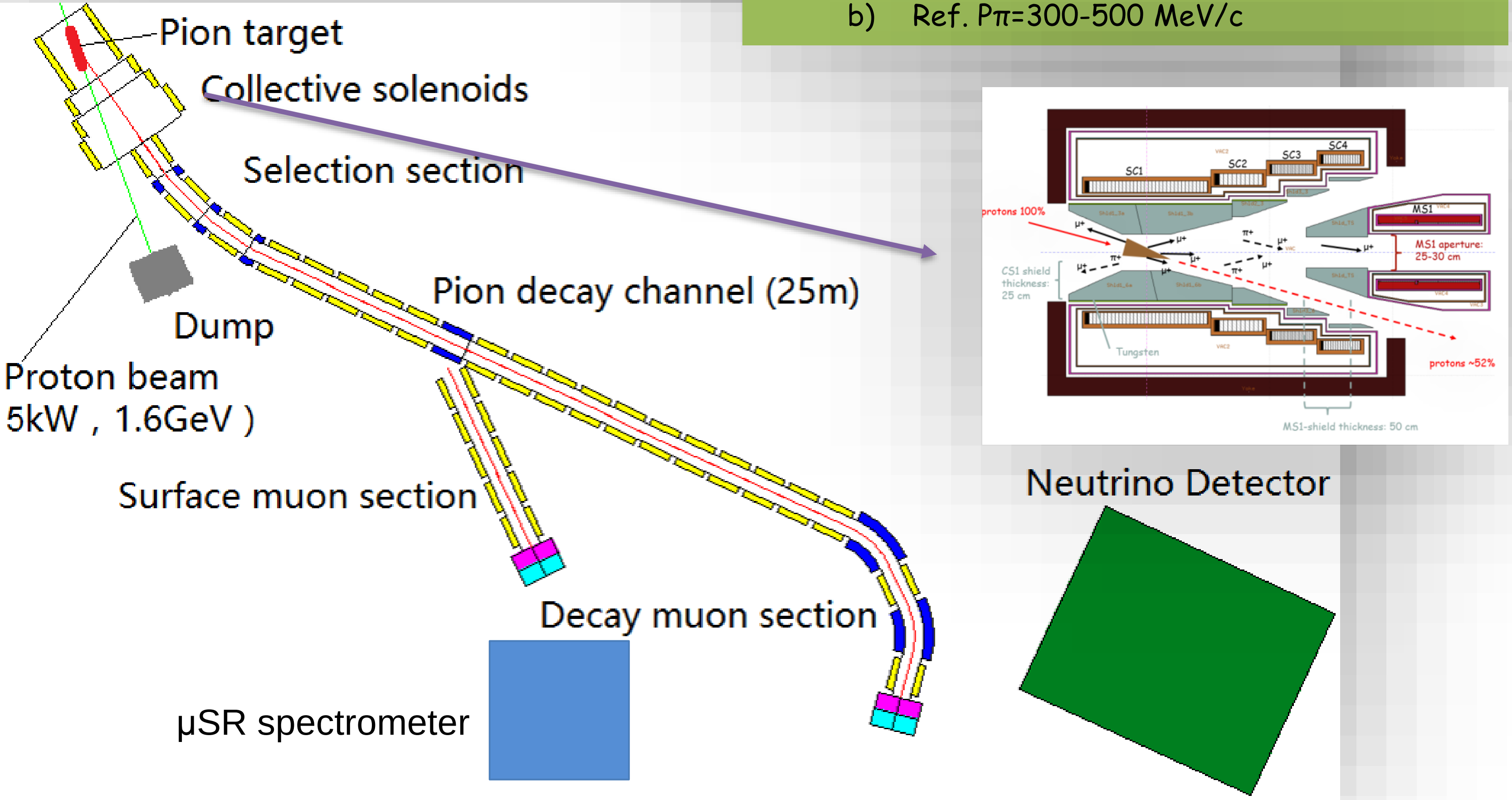
Angular distribution of the positrons from the muon decay: $W(E,\theta) = 1 + a(E)\cos(\theta)$. When all positron energies E are sampled with equal probability the asymmetry parameter has the value $a = 1/3$ (red curve).

Schematics of EMuS at CSNS

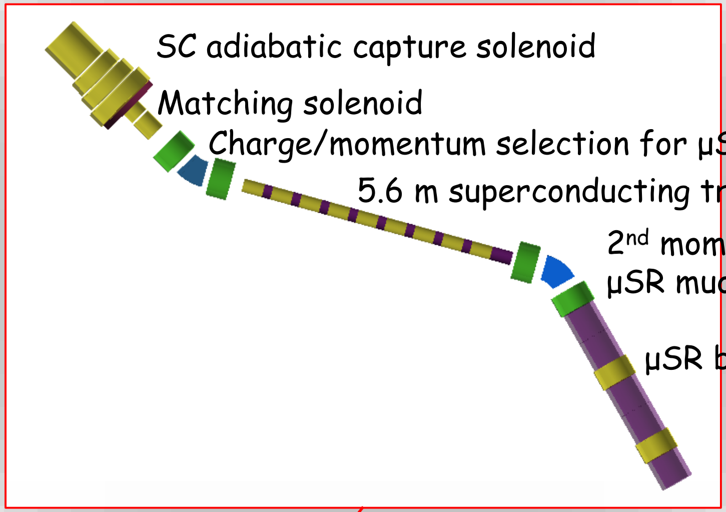
Parameters	CSNS-I	CSNS-II
Beam power (kW)	100	500
RCS Energy (GeV)	1.6	1.6
Beam current (μA)	62.5	312.5
Repetition rate (Hz)	25	25
Linac Energy [MeV]	80	250
EMuS power (kW)	5	25

Beam operation modes (independent):

1. Surface muon mode (baseline)
   a) Momentum spread: <±5%
   b) Ref. Pμ=29 MeV/c
2. Decay muon mode
   a) Momentum spread: <± 10%
   b) Ref. Pμ = Pmax depending on capture field
3. Neutrino mode (optional)
   a) Wide energy spectra
   b) Ref. Pπ=300-500 MeV/c



μSR mode schematics



SC adiabatic capture solenoid

Matching solenoid

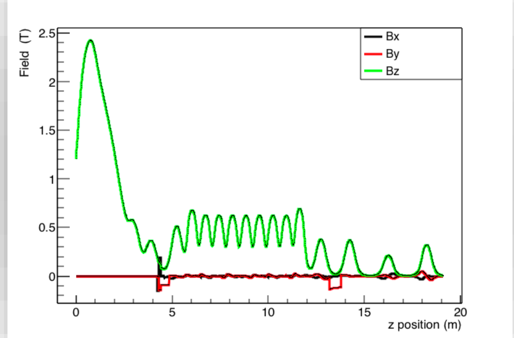
Charge/momentum selection for μSR muons

5.6 m superconducting transport solenoid

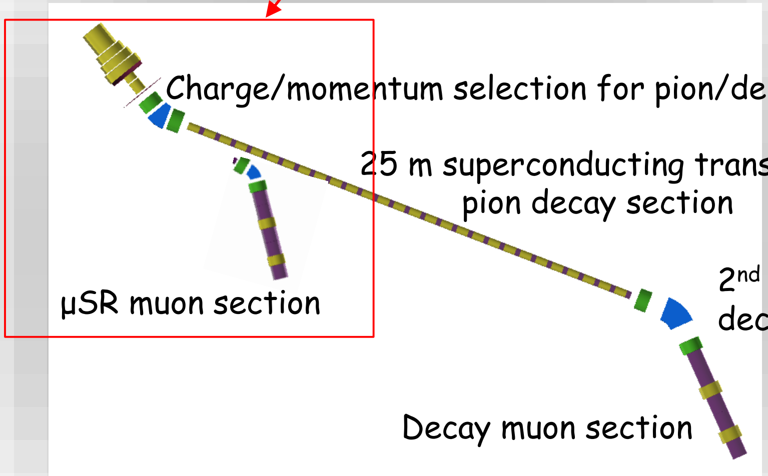
2nd momentum selection,
μSR muons separation

μSR beamline to detector

Adiabatic capture and transport field for μSR



decay muon/pion mode schematics



Charge/momentum selection for pion/decay muons

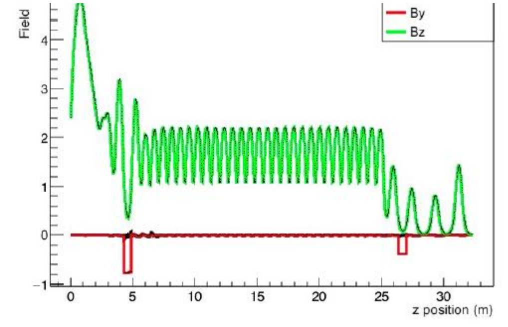
25 m superconducting transport solenoid
pion decay section

2nd selection,
decay muons

μSR muon section

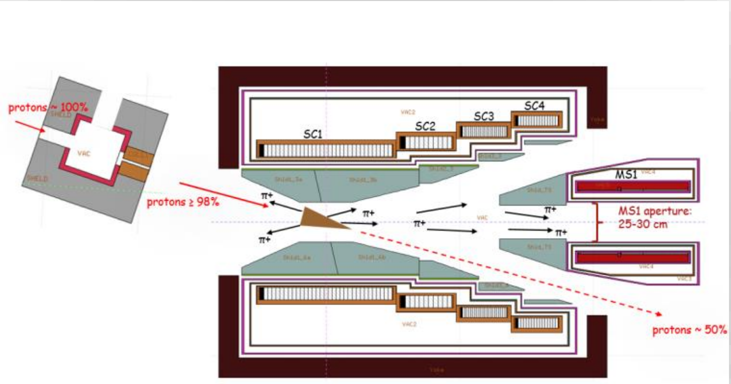
Decay muon section

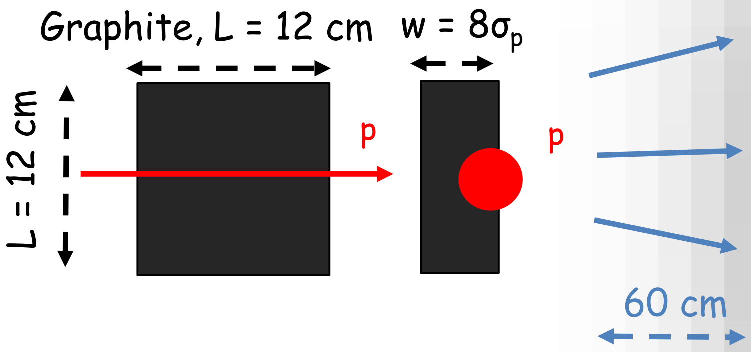
Adiabatic capture and transport field for pions and decay muons

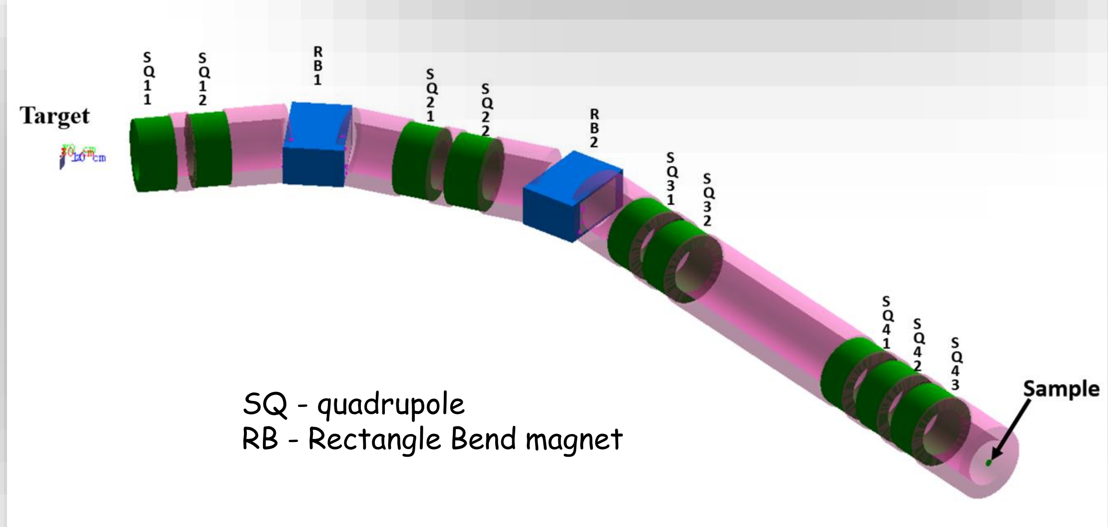


“Baby” scheme – phase I

- Sideway μSR collection at 90^0 at a distance of 60cm from target’s center with respect to the primary proton beam
- Quadrupole system low acceptance collector
- No SC solenoid







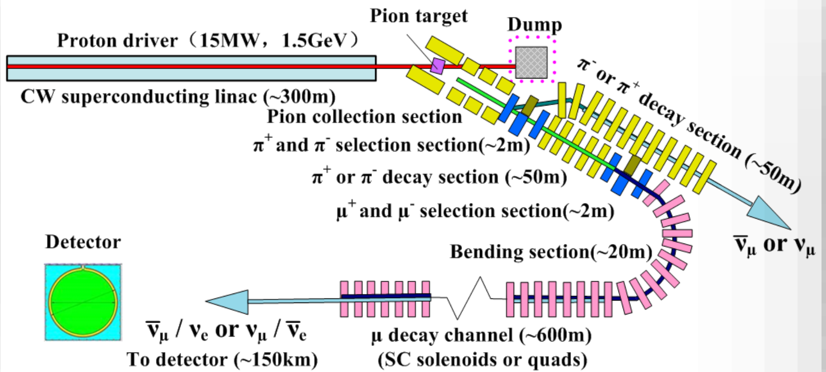
SQ - quadrupole
RB - Rectangle Bend magnet

~10^6 μSR / s with 94% polarization

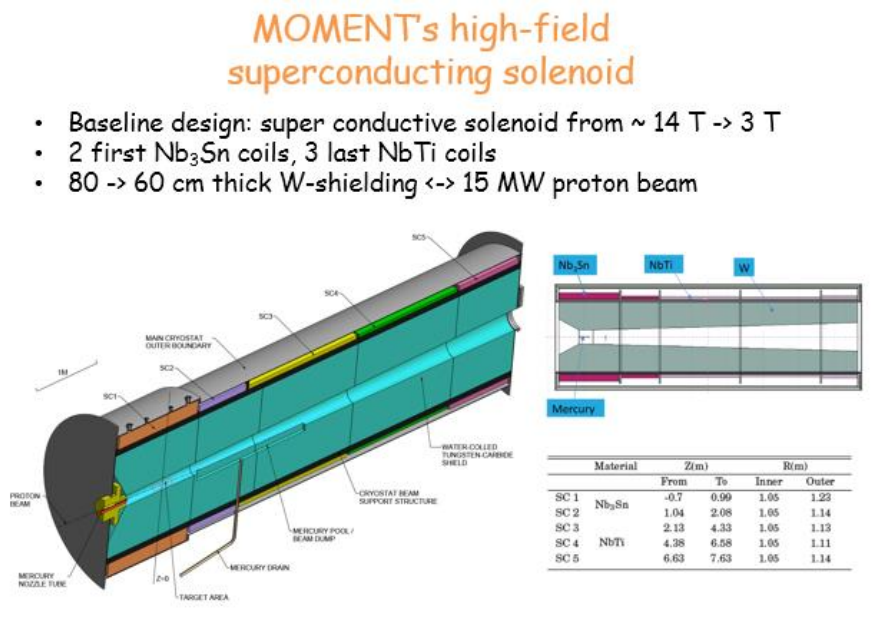
2. The neutrino beam is an option under investigation. Motivation of the neutrino beam is the lack of recent cross sections measurements at lower energies

3. EMuS could act as a high power targetry and accelerator R&D platform for MOMENT, a future muon-decay medium-baseline neutrino beam facility in China

MOMENT



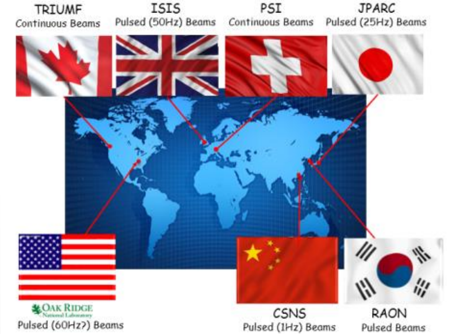
Novel waterfall granular target



MOMENT's high-field superconducting solenoid

- Baseline design: super conductive solenoid from ~ 14 T -> 3 T
- 2 first Nb_3Sn coils, 3 last NbTi coils
- 80 -> 60 cm thick W-shielding <-> 15 MW proton beam

	Material	Z(m)		R(m)	
		From	To	Inner	Outer
SC 1	Nb_3Sn	-0.7	0.99	1.05	1.23
SC 2		1.04	2.08	1.05	1.14
SC 3	NbTi	2.13	4.33	1.05	1.13
SC 4		4.38	6.58	1.05	1.11
SC 5		6.63	7.63	1.05	1.14



EMuS performance and comparisons

	ISIS	J-PARC /MUSE	TRIUMF	PSI	CSNS-I /EMuS	J-PARC /COMET	FNAL /Mu2e
Proton_E (GeV)	0.8	3	0.5	0.59	1.6	8	8
Current (μA)	200	315	150	2000	2.5	0.4	1
Repetition (Hz)	50	25	CW	CW	2.5	0.8×10^6	0.6×10^6
Beam power (kW)	160	900	75	1300	5	3.2	8
Bunches per pulse	2	2	-	-	1	1	1
C target thickness (mm)	5	20	10	40	300 Conical	700 Cylindrical	160 Cylindrical
Collection	Side	Side	Side	Side	in solenoid, forward	in solenoid, backward	in solenoid, backward
Acceptance (msr)	30	40	35	-	300		
Surface beam (μ+/s)	$6'10^5$	$3'10^7$	$1'10^6$	$1'10^8$	$4'10^7$		
Decay beam (μ^+/s or μ^-/s)	10^{4-5}	10^{6-7}	$1'10^5$	$1'10^7$	$\sim1'10^9$	$\sim1.2\times10^9$	$\sim1\times10^{10}$
Science	μSR Nucl. Phys.	μSR Part. Phys	μSR	μSR Part. Phys	μSR Part. Phys	Part. Phys.	Part. Phys.
First operation	1985-	2009-	1985-	1991-	2022-	2019-	2020-

Superconducting Coils.

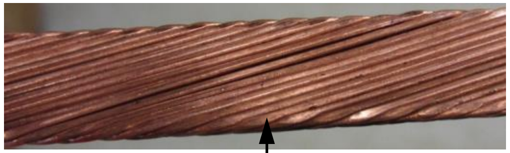
Typical conductor

- Option 1：Conductor ——Aluminum stabilized Rutherford cable

Aluminum

Rutherford cable

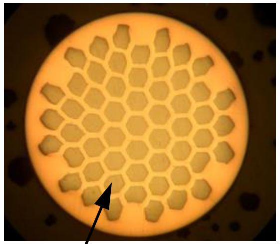
Cross section of Rutherford cable



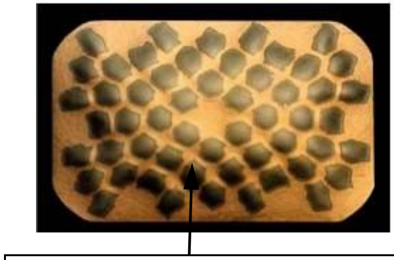
Rutherford cable

➢ Option 2： Conductor ——Nb-Ti / Copper Matrix Monolith Wire or Wire in channel

Monolith Wire

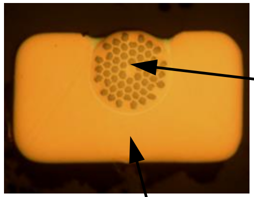


Cross section: Round



Cross section: Rectangle

Wire in channel



Monolith Wire

Copper stabilized

Radiation issues for the solenoids

- Damage to the superconductor's Aluminium stabilizer and Copper Matrix
  - How the radiation affects the electrical conductivity of the component metals of the superconductor cable?
- Maximum local radiation dose to the superconductor insulator over the lifetime of the experiment
  - What is the limit for the most radiation-sensitive material?
- Local heat load allowed anywhere within the superconducting coils
  - What is the heat load limit to prevent the SC from quenching?

Damage to the superconductor's stabilizer

- ❑ Residual Resistivity Ratio (RRR)
  - ❖the ratio of the electrical resistance at room temperature of a conductor to that at 4.5 K.

- ❑ RRR is an important parameter for the superconducting magnet design
  - ❖affects the magnet performance during operation in superconducting mode and irreversible transition to the normal state (quench)

- ❑ A given sample's RRR will
  - ❖decrease in various neutron environment
  - ❖recover while warming to room temperature (order of days)

- ❑ RRR limits
  - ❖ aluminum: initial RRR > 500; limit > 100; 100% recovery ability
  - ❖ copper: initial RRR > 100; limit > 50; ~90% recovery ability

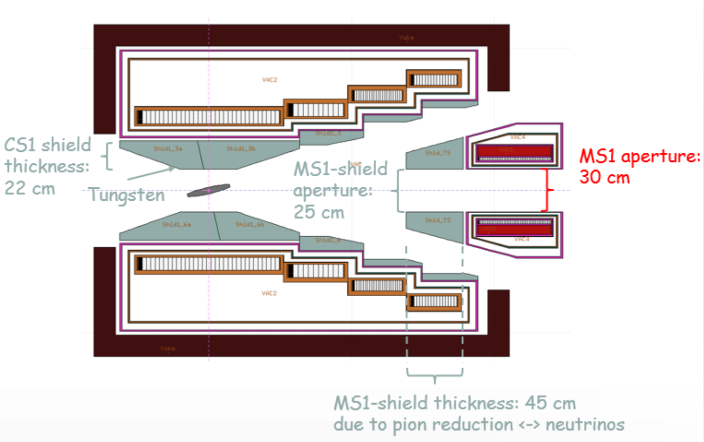
Damage to the epoxy

- ☐ Epoxy acts as an insulation which winds up the coils.
- ☐ In particular, the epoxy used to bond the insulation to the superconducting cable can tolerate a maximum of 7 MGy dose before it experiences a 10% degradation in its shear modulus .
- ☐ Hard to recover/locate the quench.

…its time to call the shield…

Radiation issues

- Low power densities on coils < 1 mW/cm^3
- neutron flux < 2x10^{21} n/m^2/y
- Resistivity increase for Al at NbTi wire can be solved by thermal cycling to room temperature
- Radiation degradation of the insulator for NbTi-Al wire can be solved by optimizing the W-shielding



CS1 shield thickness: 22 cm

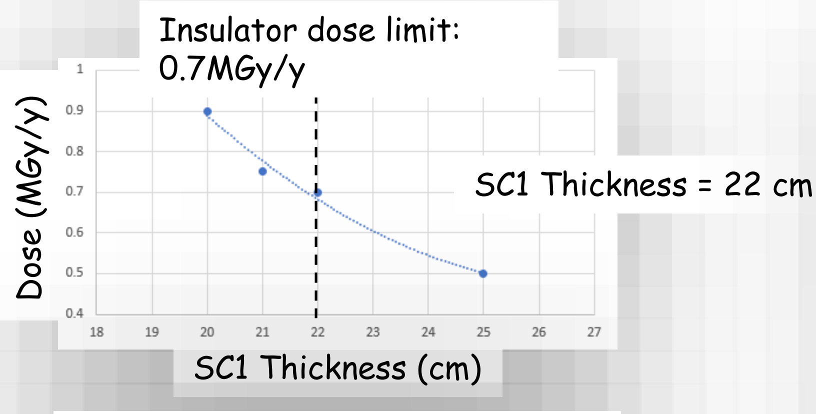
Tungsten

MS1-shield aperture: 25 cm

MS1 aperture: 30 cm

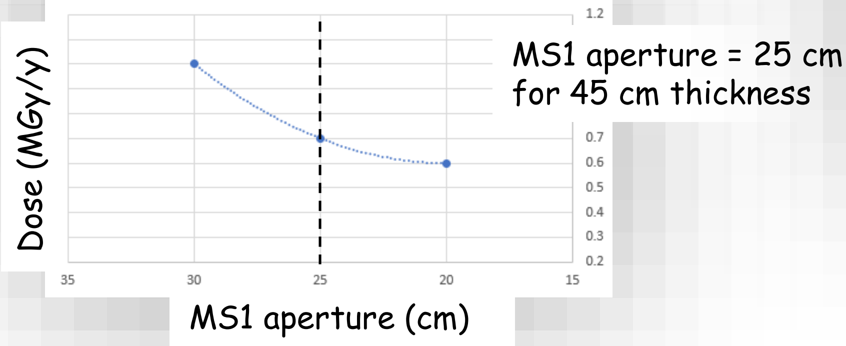
MS1-shield thickness: 45 cm due to pion reduction <-> neutrinos

Shielding optimization for insulator:

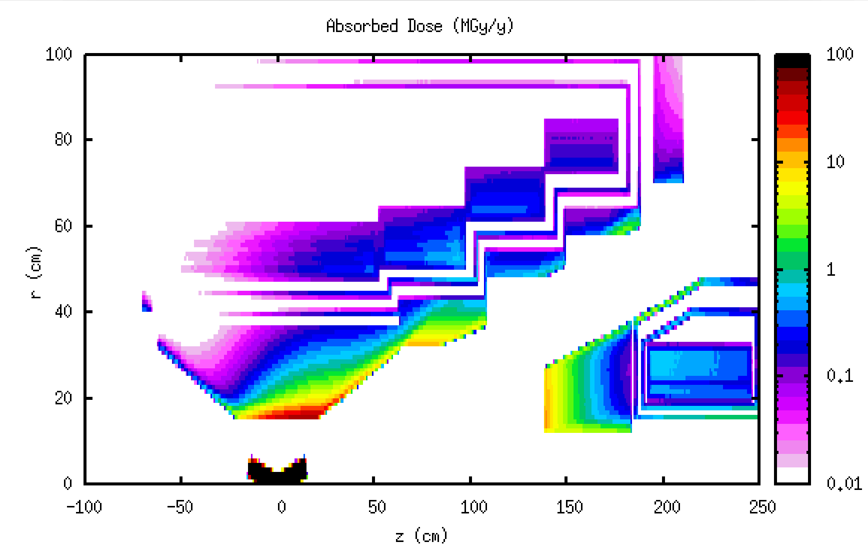


Insulator dose limit: 0.7MGy/y

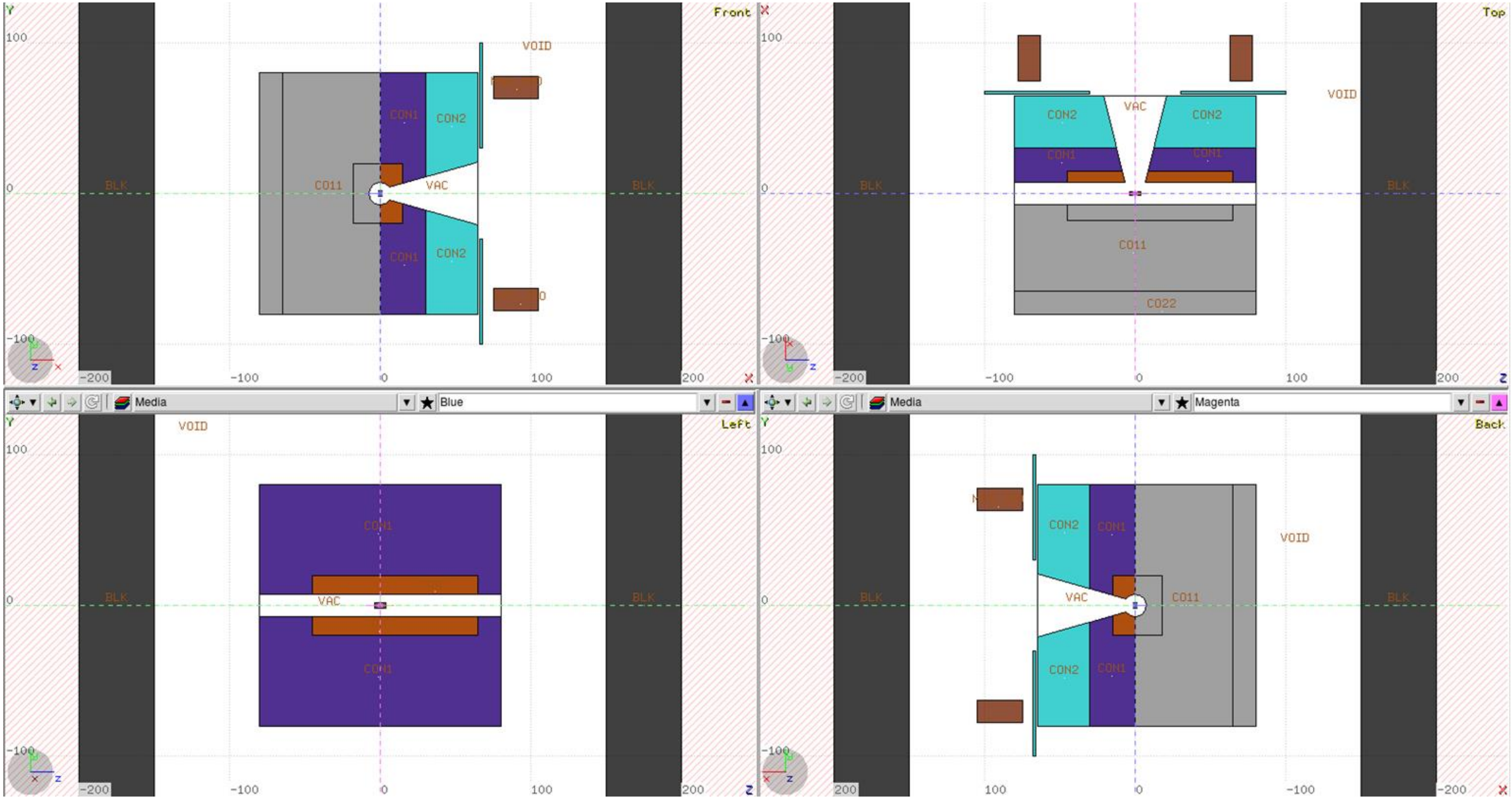
SC1 Thickness = 22 cm



MS1 aperture = 25 cm for 45 cm thickness

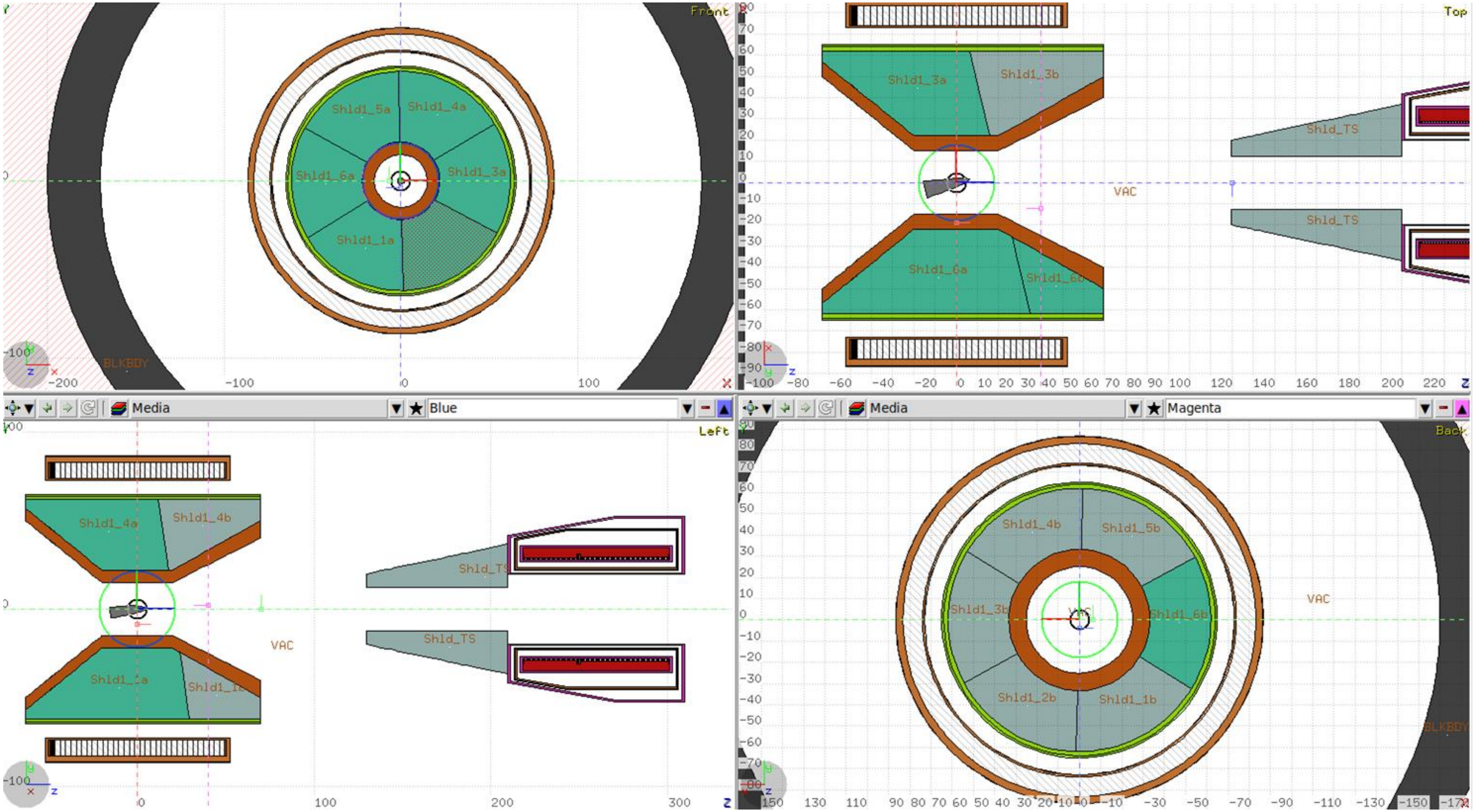


Hybrid shielding solution for Baby scheme: 30 years of running, 7MGy limit.
1. Al –Gd , Iron, Tungsten (2cm)
2. Al-Gd, Barite, Iron



Hybrid shielding solution for SC1 Baseline scheme: 30 years of running, 7MGy limit.

- Al –Gd , Steel 316, Tungsten and B4C layer
-~50 cm radius.



Summary and outlook I:

- EMuS is going to provide the first intense muon beam source at CSNS in China.
- Planned to achieve data by 2023.
- EMuS can be operated in different modes-
  - Surface muons
  - Decay Muons
  - Neutrinos
- EMuS can be used for uSR studies, neutrino cross section studies, cLFV studies…

Summary and outlook II:

- Shielding is important to protect the SC coils.
    - Hybrid shielding as potential solution for SC1 coils and Baby Scheme magnet coils.
    - Optimization studies are in progress.

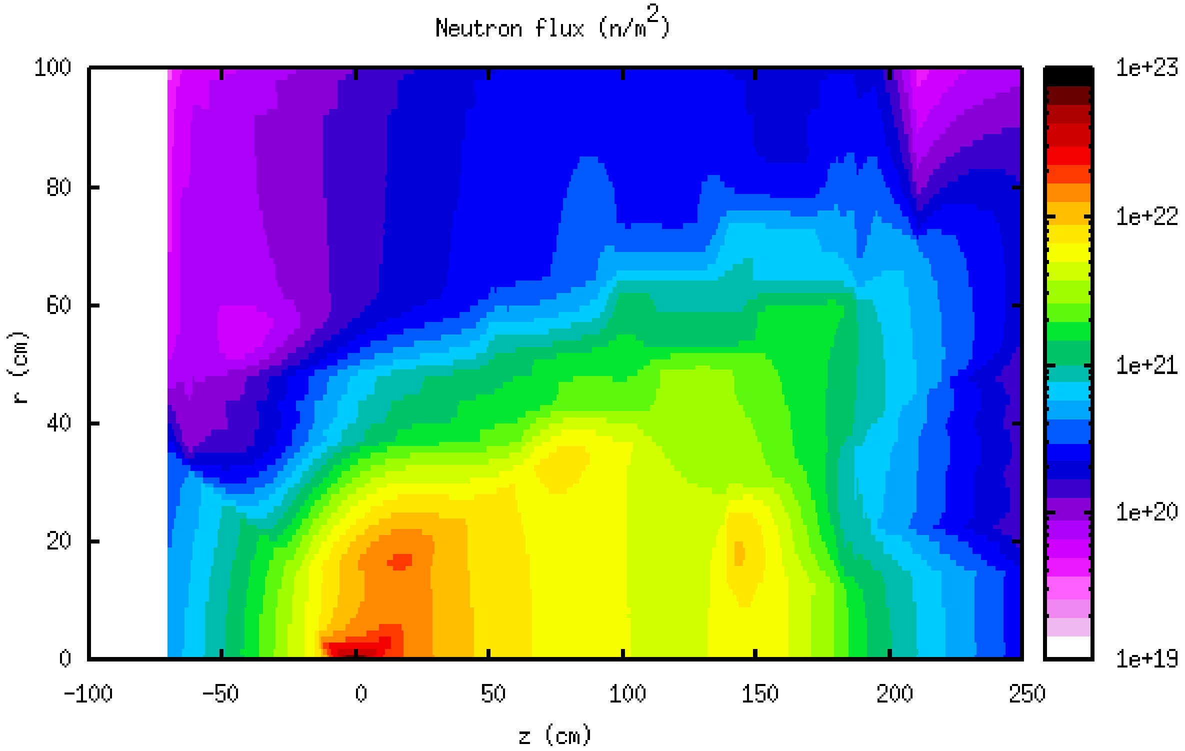
Thanking you!

Suggestions and comments will be highly appreciated.

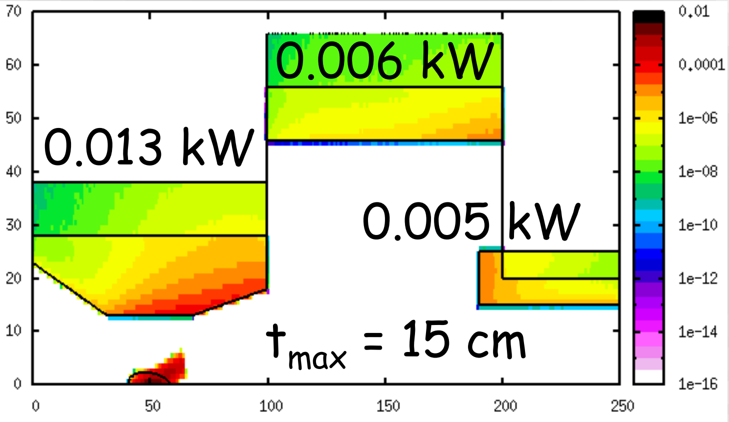
…shield will keep protecting the coils..

Extra

Neutron flux for the tungsten shields



Energy density deposition on target system (kW/cm^3) vs shield thickness



not to scale