Optimizing the Neutrino Factory Capture Section

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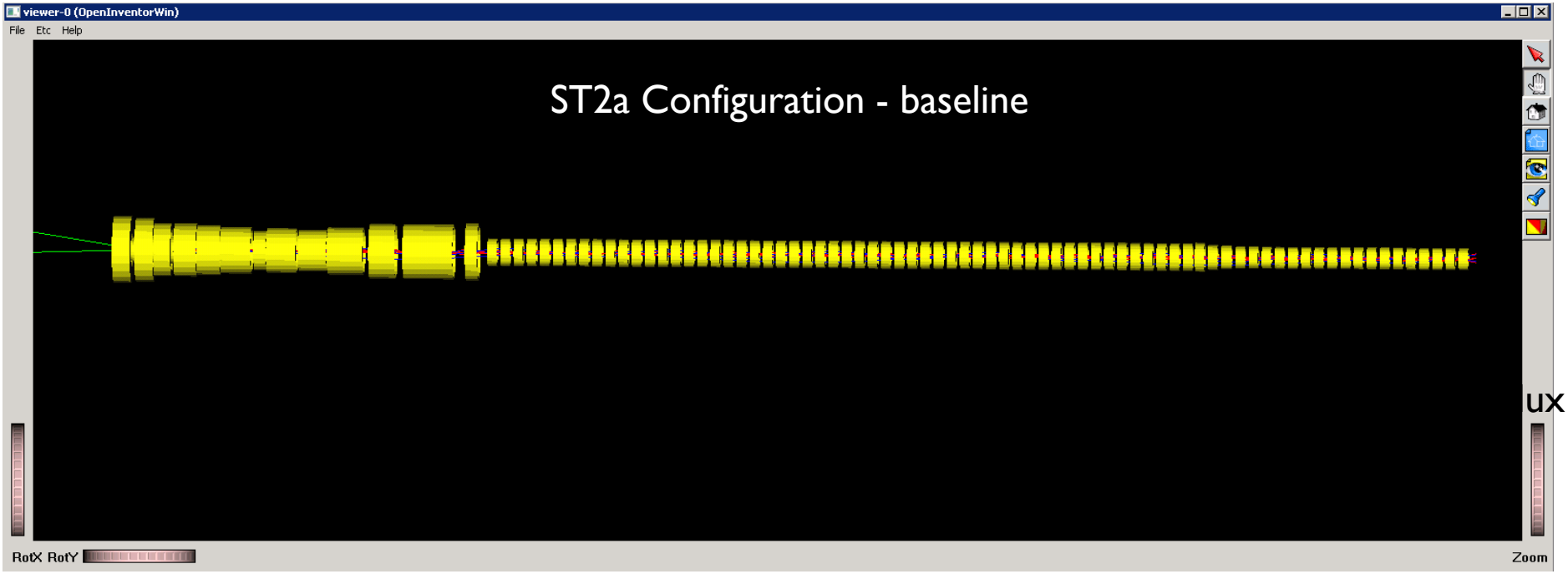
Optimization studies

- Fresh look at the NF solenoid target capture system
- Simulations using G4BeamLine and FLUKA
- Method:
  - Studies included alternative solenoid configurations
  - B-field tapering shape and inner shielding configurations
- Compare results by looking at the muon flux at z=50m
  - Muon selection (acceptance) cuts applied, i.e. select only muons that can be further transported in the Front-End

Alternative Solenoid Setups in G4BL

- Magnets showed in yellow, picture from G4BL-viewer



- First solenoid starts at z=-1.3m
- Muon flux at z=50m measured as reference for comparison

Alternative Solenoid Setups in G4BL

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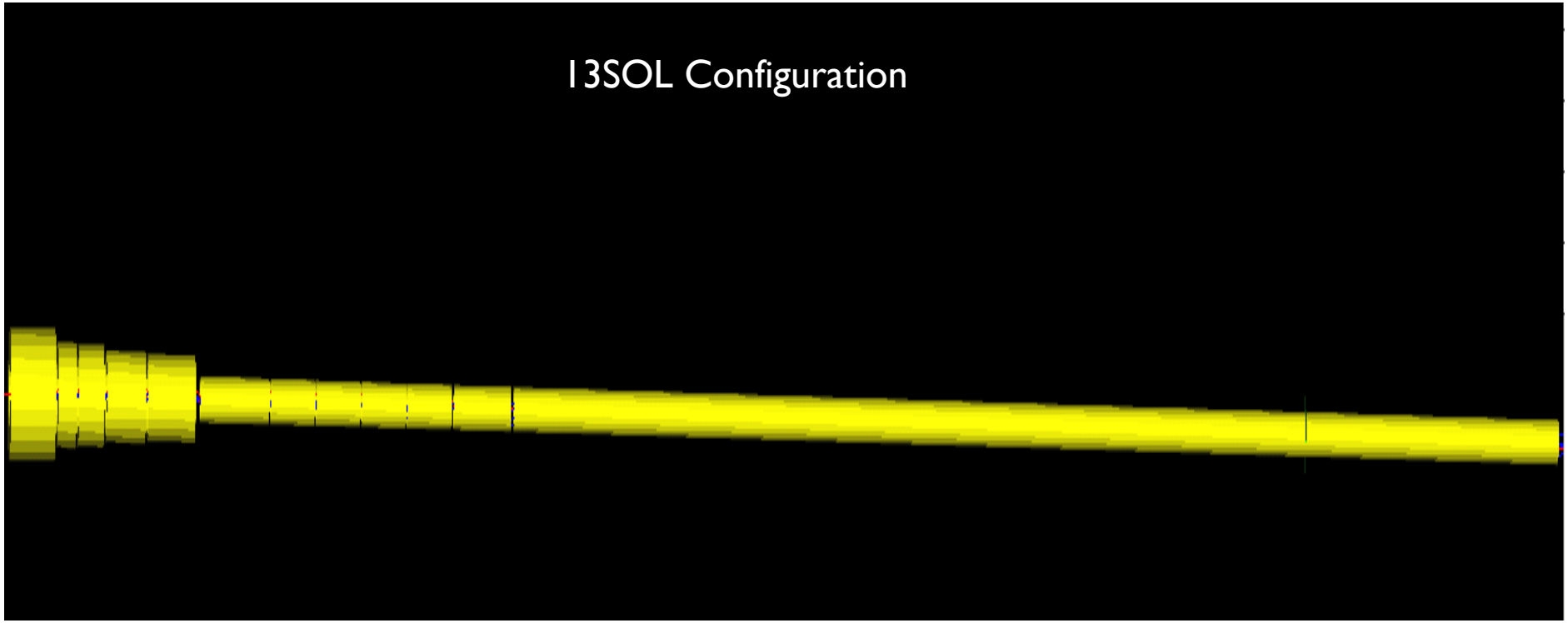

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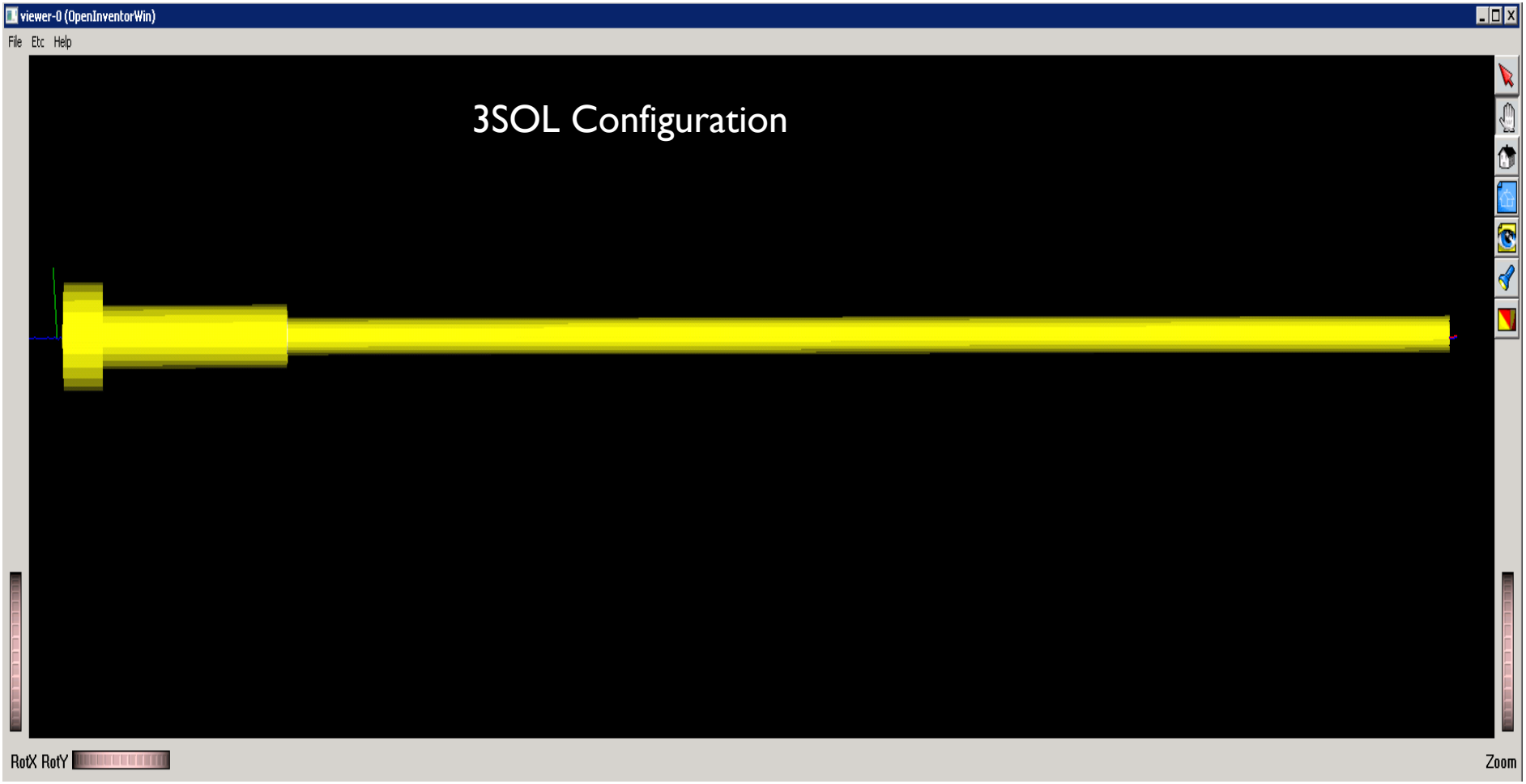
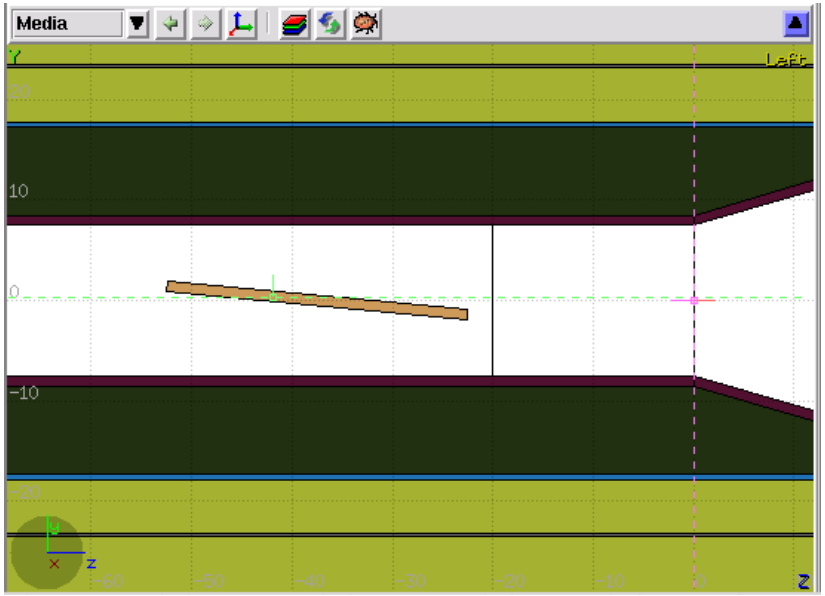


Beam and Target

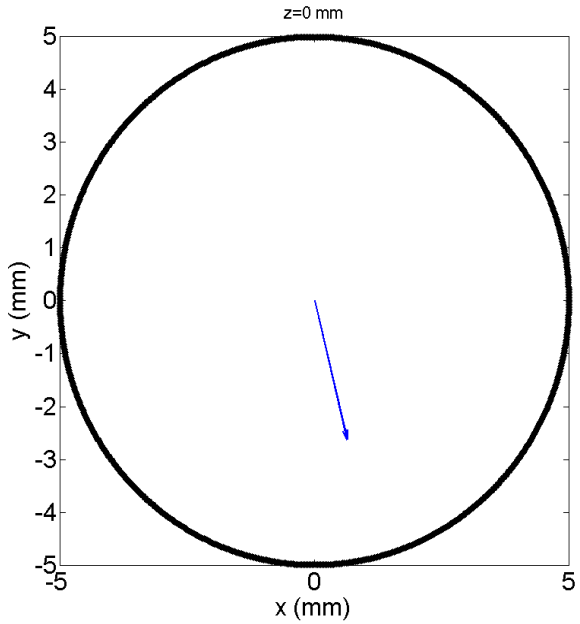
- 8 GeV Kinetic Beam Energy
- 1e5 POT
- σ= 1.5 mm

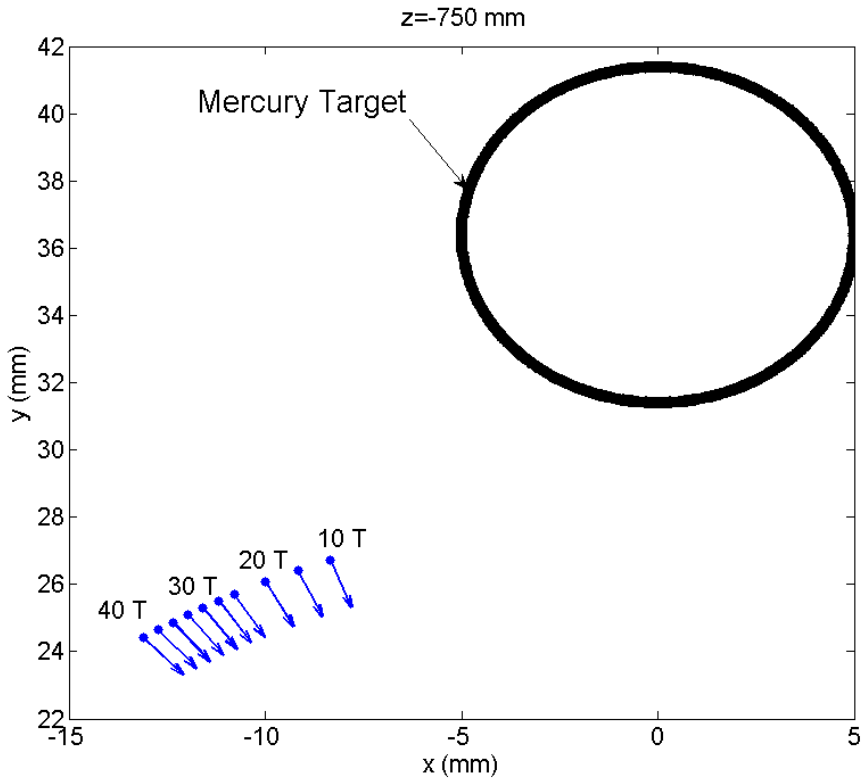


- Mercury target
- Radius=5 mm
- Length=30 cm
- Tilted 96.68mrad with respect to the z-axis
- Beam constraint:
  - Proton beam - target axis angle at z=-37.5cm : θ_{BT}=30mrad

Beam Entry Direction

- Beam entry position, at -75 cm, varies with magnetic field strength. Calculated from the center of target, at (0,0,-37.5) with **fixed angles**:
- θ_{BT}=30 mrad
- ϕ=144º





Acceptance Cuts

- Used full front-end made by Pavel Snopok in G4BL (Thanks Pavel !!)

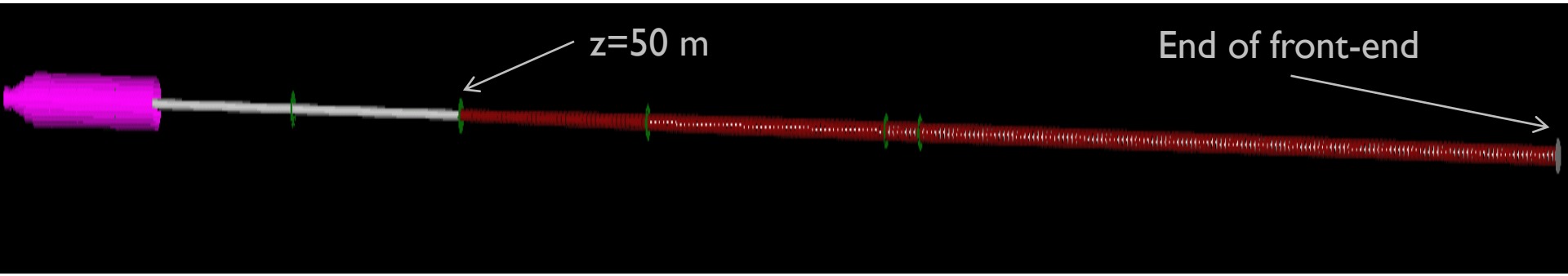
- Useful muons defined as the ones arriving at the end of the front-end satisfying the cuts of ecal9f routine:

Momentum	Transverse acceptance	Longitudinal acceptance cuts
[MeV/c]	*[m rad]*	*[m rad]*
$100<p_z<300$	$A_T<0.150$	$A_L<0.030$

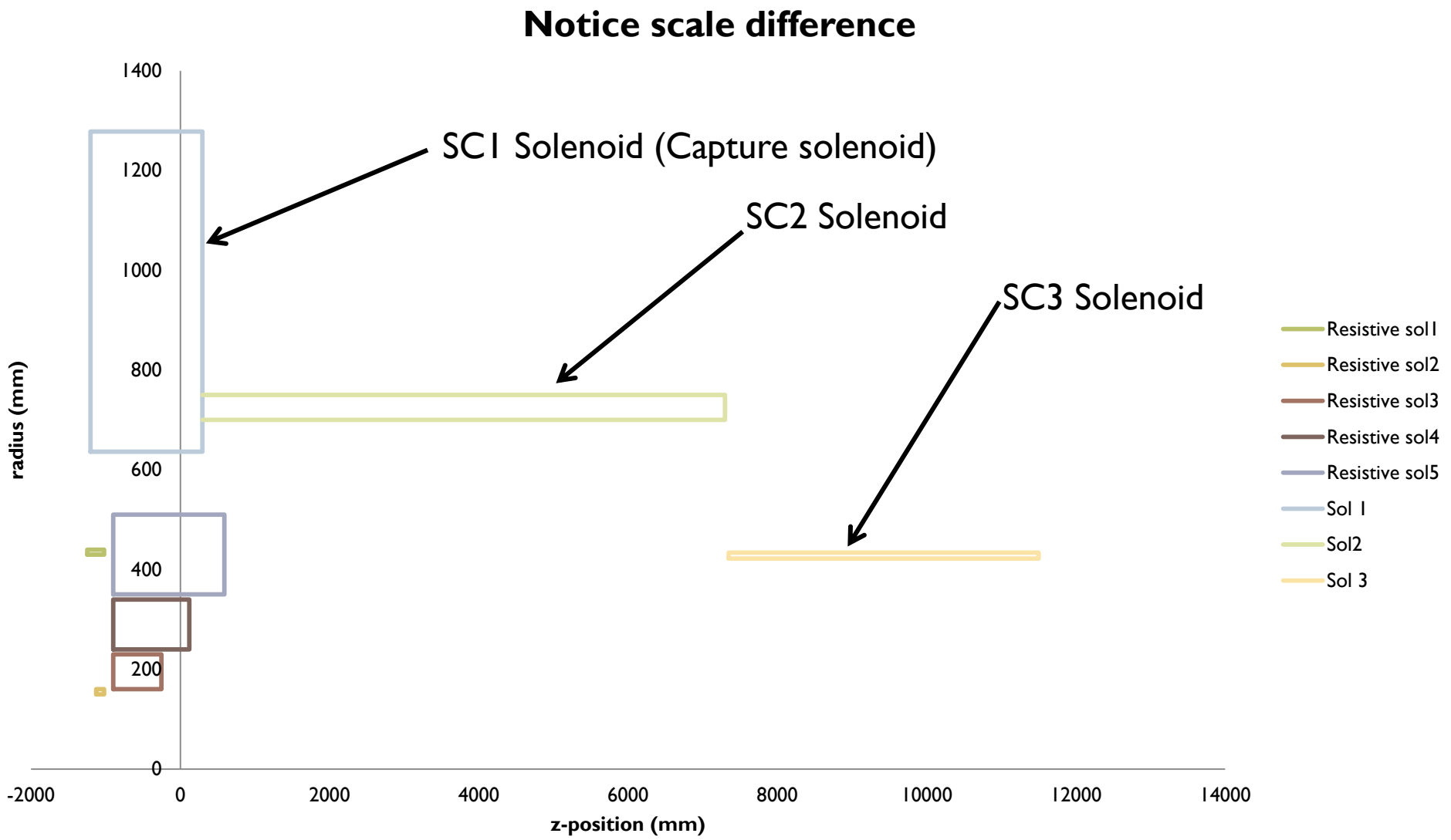
Acceptance Cuts

- Tracing back the useful muons to z=50 m
  - Use particle ID to find the survivors, define the time, momentum cuts.

Momentum	Transverse momentum	Time	Radius (mm)
[MeV/c]	*[MeV/c]*	*[ns]*	*[mm]*
100<pz<300	p_T<50	160<t<240	r<200



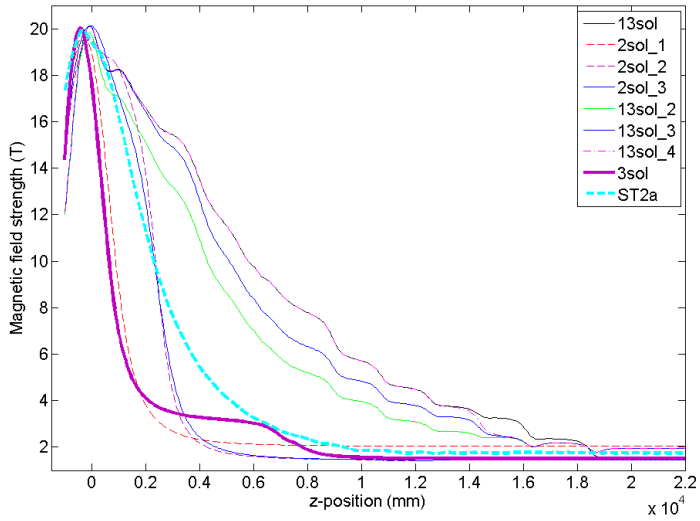
3 sol setup, without shielding

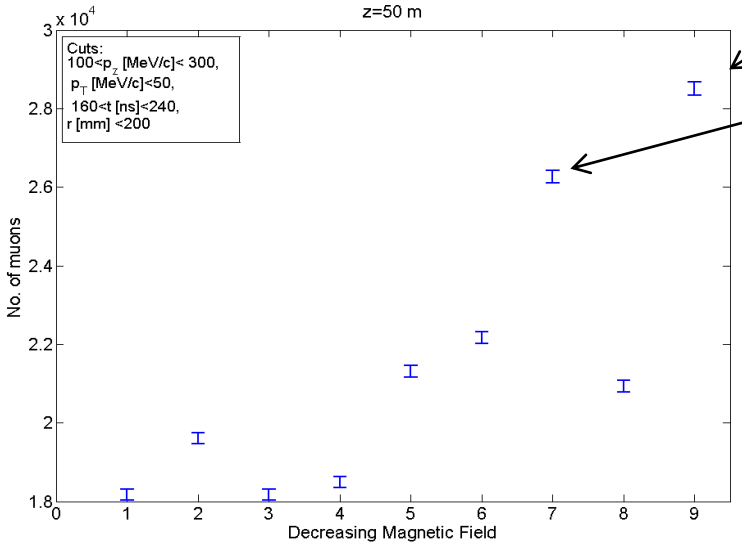


Magnetic field tapering

- The 3SOL configuration gives ~9% higher # of muons after the acceptance cuts wrt ST2a baseline

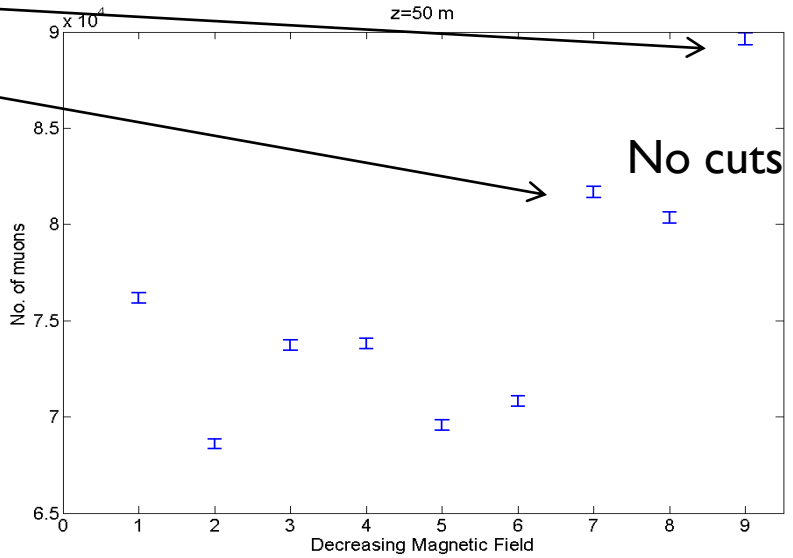
No. of muons at z=50 m			
	ST2a	3 sol	Ratio
w/cuts	26262	28513	1.09
No cuts	81682	89624	1.10





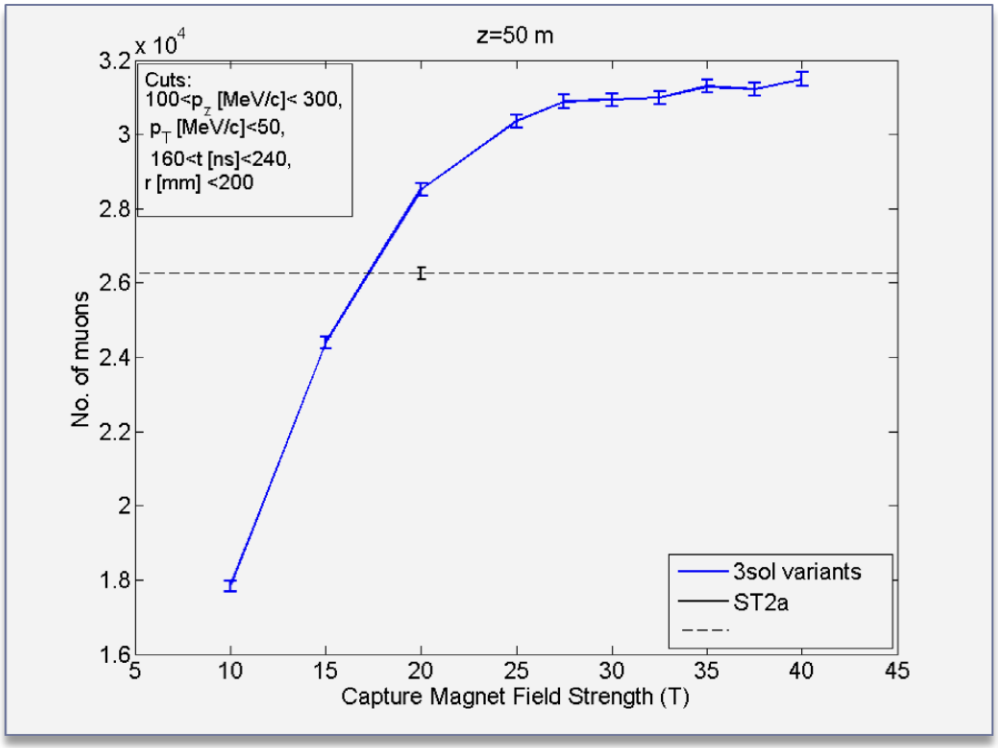
3sol

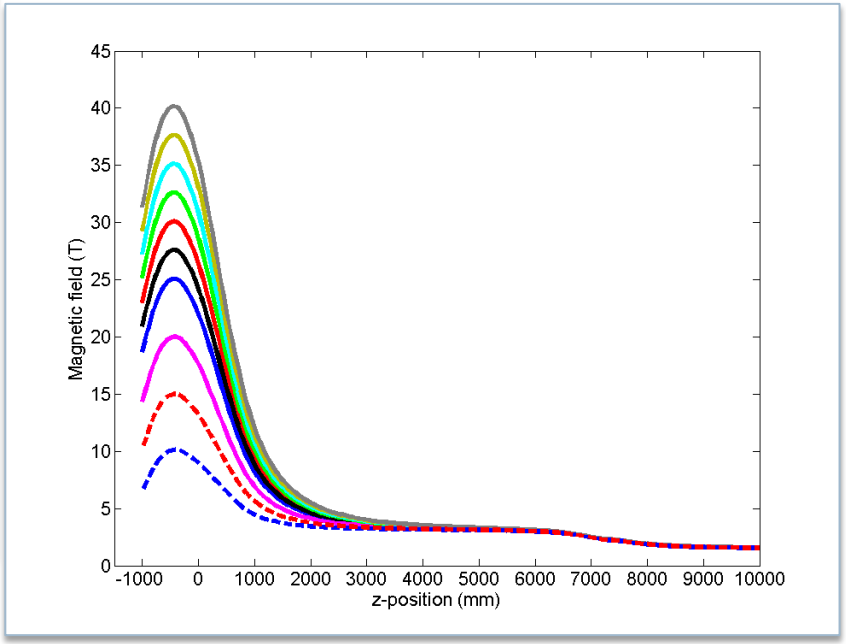
ST2a



3SOL Layout - Varying SC1

- Magnetic field strength varied from 10-40 T
- 20 T seems to be a good compromise





Conclusions – I

- Using simple layout configuration:
  - Rapidly decreasing magnetic field tapering as in the 3SOL case is a good alternative to the adiabatically tapered magnetic field
  - The lower current in SC2 may allow this solenoid, expected to receive the peak of the radiation from the target, to have a larger radius thus less exposed to radiation
  - The capture magnet producing a 20 T field seems to be a good compromise

- Next : Studies with inner shielding
  - Variation of SC1, SC2, SC3 field strengths independently

Inner Shielding layout

- Assuming adiabatic tapering:
  - The magnetic flux at the center of SC1 ($\Phi_1=\pi B_1 R_1^2$) and at the end of the capture/tapering section ($\Phi_2=\pi B_2 R_2^2$) must be conserved.
  - This results: $R_2^2= (B_1/B_2)*R_1^2$

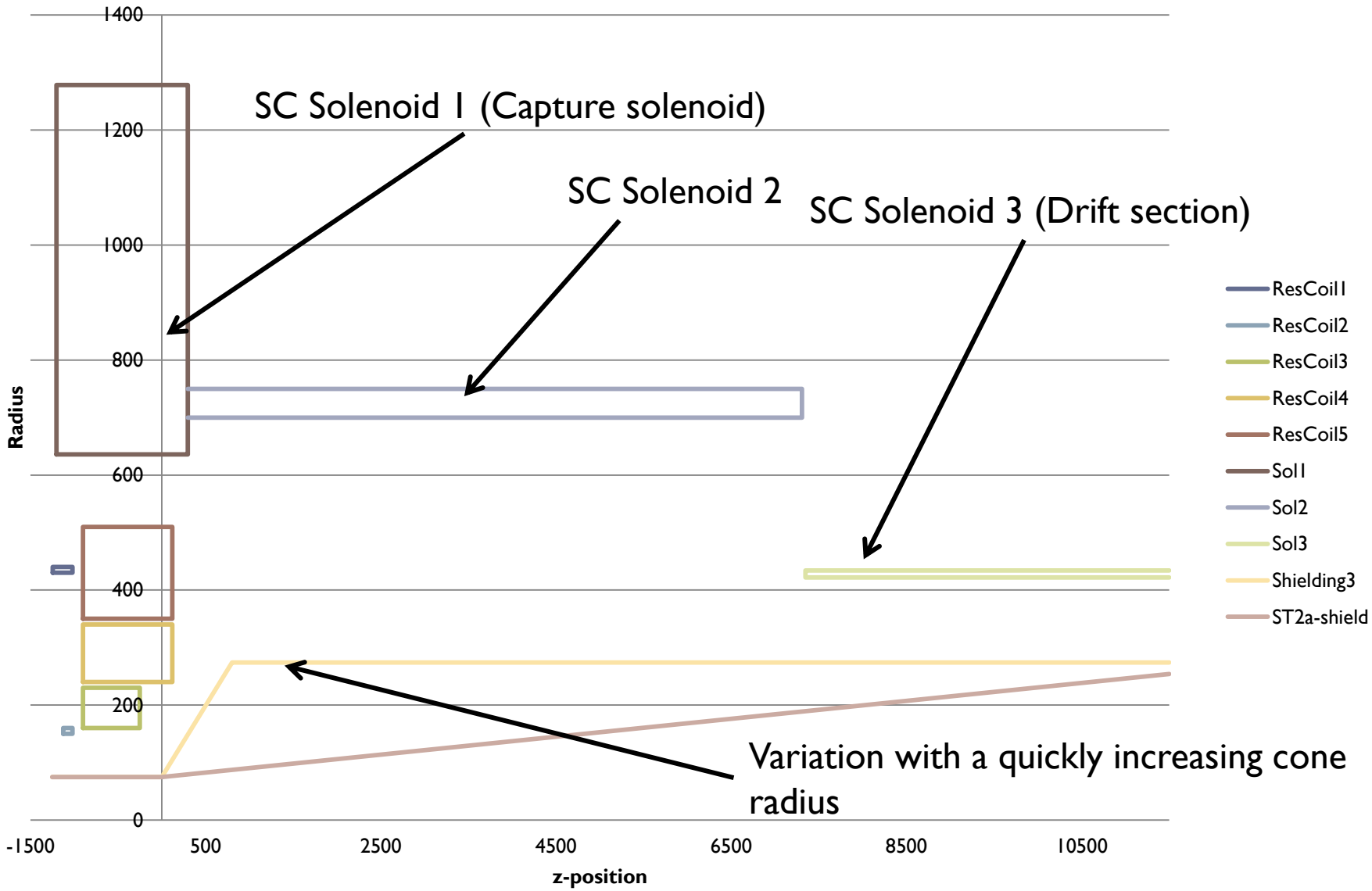
- ST2a:

  R_1= 7.5cm, R_2=25.4cm; when B_1=20T, B_2=1.75T

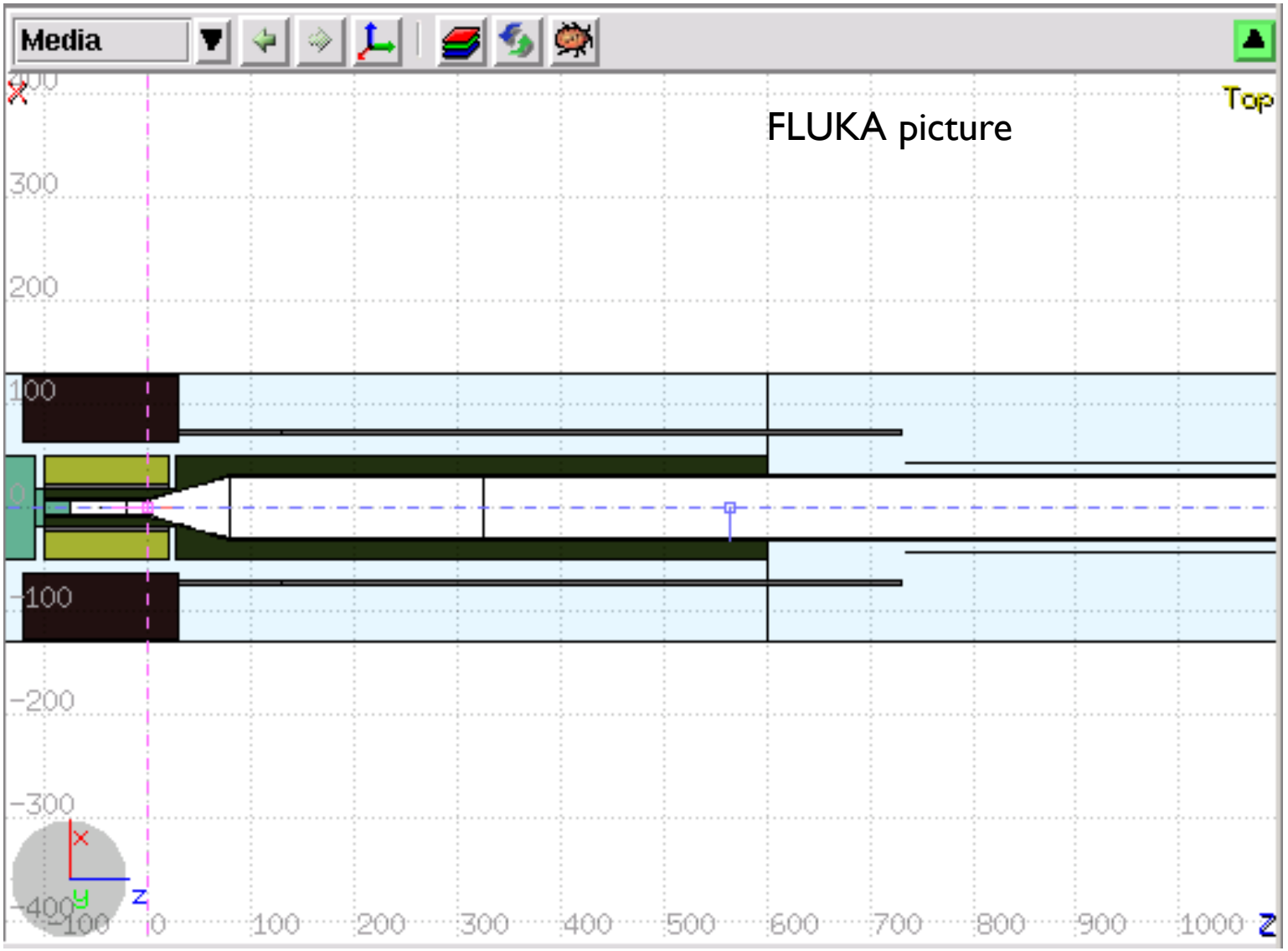
- 3SOL:

  R_1= 7.5cm, R_2=27.4cm; when B_1=20T, B_2=1.5T

3SOL configuration – inner shielding



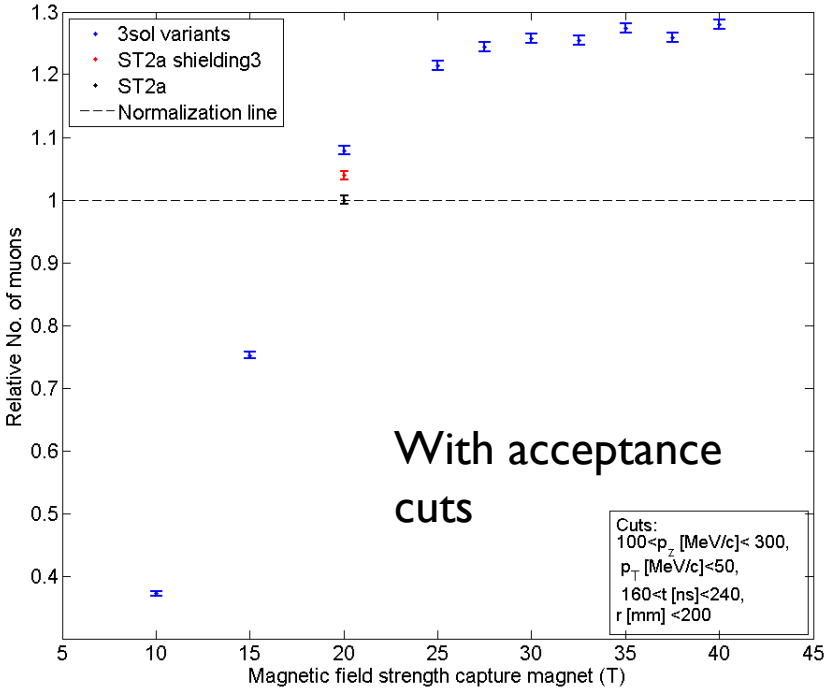
3SOL configuration – inner shielding

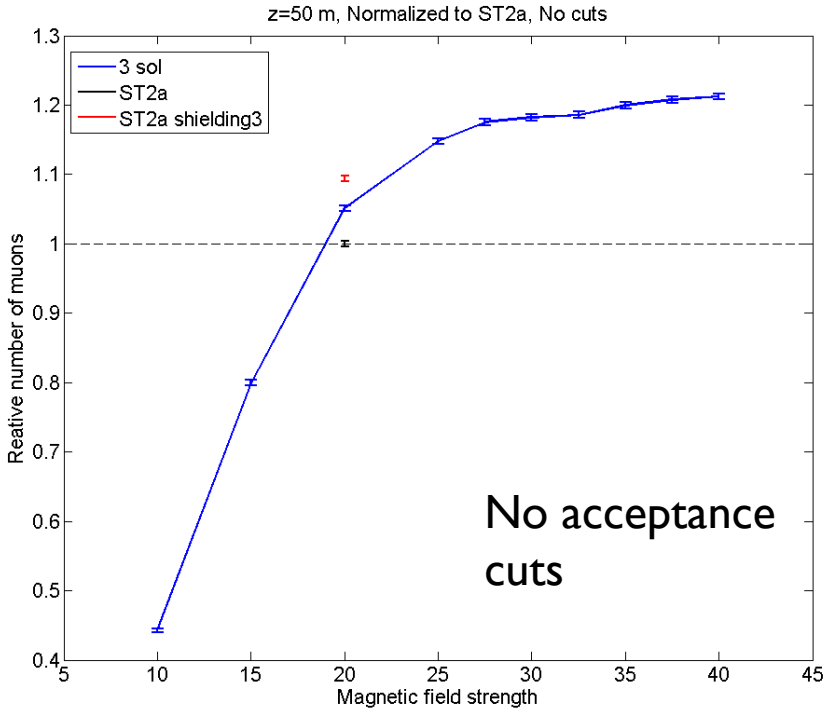


3SOL – Acceptance Sensitivity SC1

SC1=varies
SC2=constant
SC3=constant

- Want the highest field possible without loosing touch with reality, assume ~20 T
- **ST2a_modified has 3sol shielding**

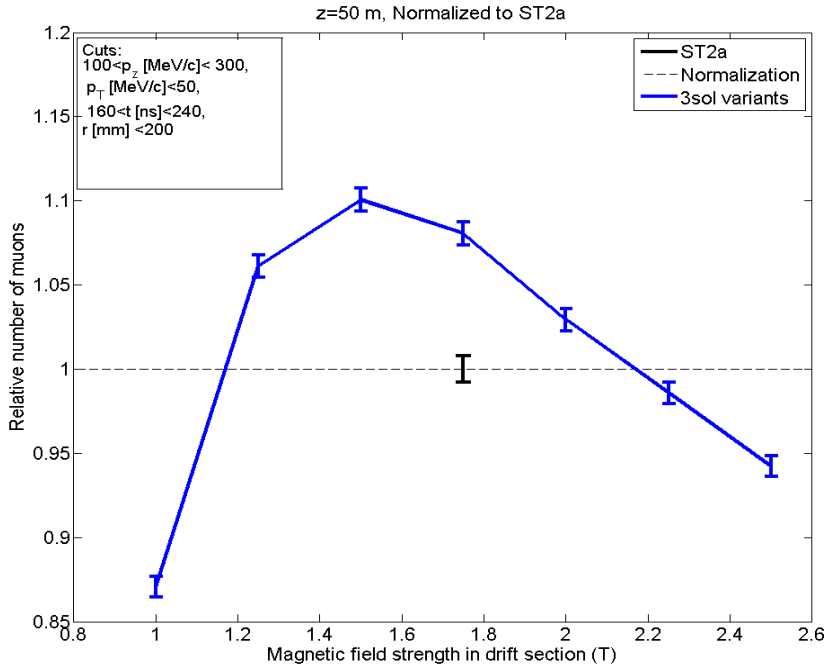


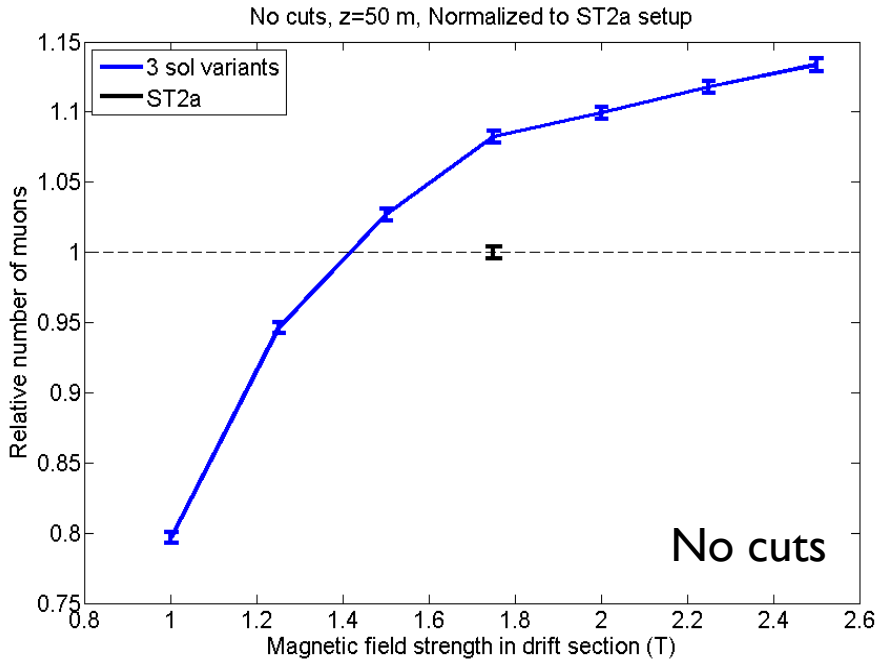


3SOL – Acceptance Sensitivity SC3

SC1=constant
SC2=constant
SC3=varies

- The 1.5 T field in the drift section gives the highest muon flux, when applying acceptance cuts
- Without any cuts, the higher the magnetic field strength the better

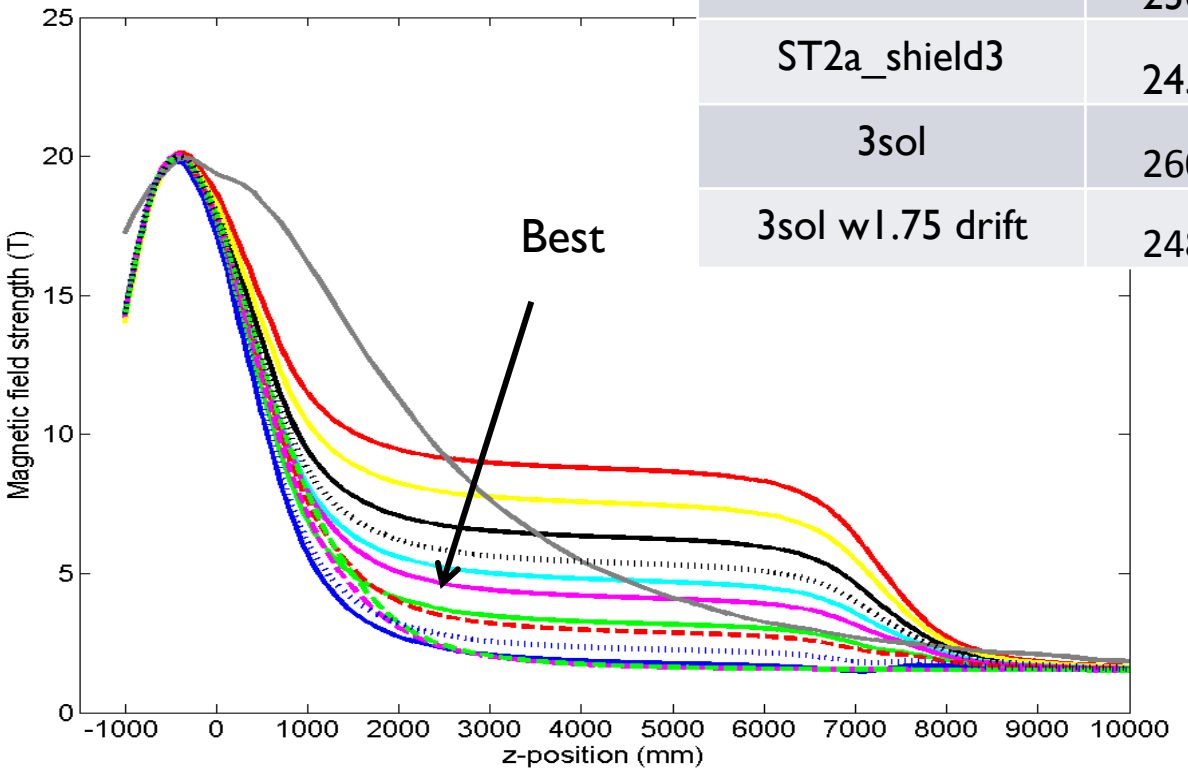




3SOL – Acceptance Sensitivity SC2

SC1=constant
SC2=varies
SC3=constant

Setup	Muons w/cuts	Relative w/cuts	Relative no cuts
ST2a	23671	1.00	1.00
ST2a_shield3	24591	1.04	1.09
3sol	26049	1.10	1.05
3sol w1.75 drift	24801	1.05	1.09



3SOL – Acceptance Sensitivity SC2

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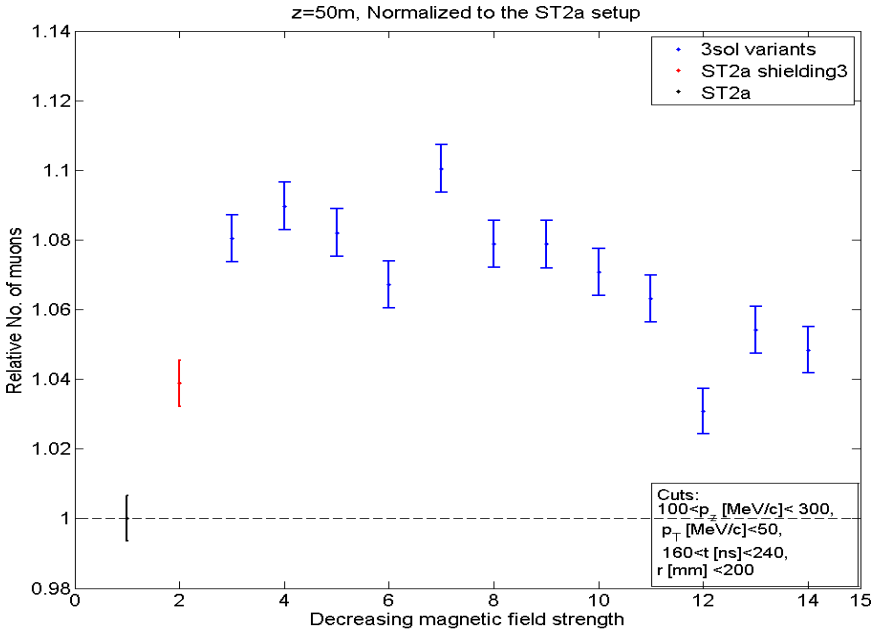
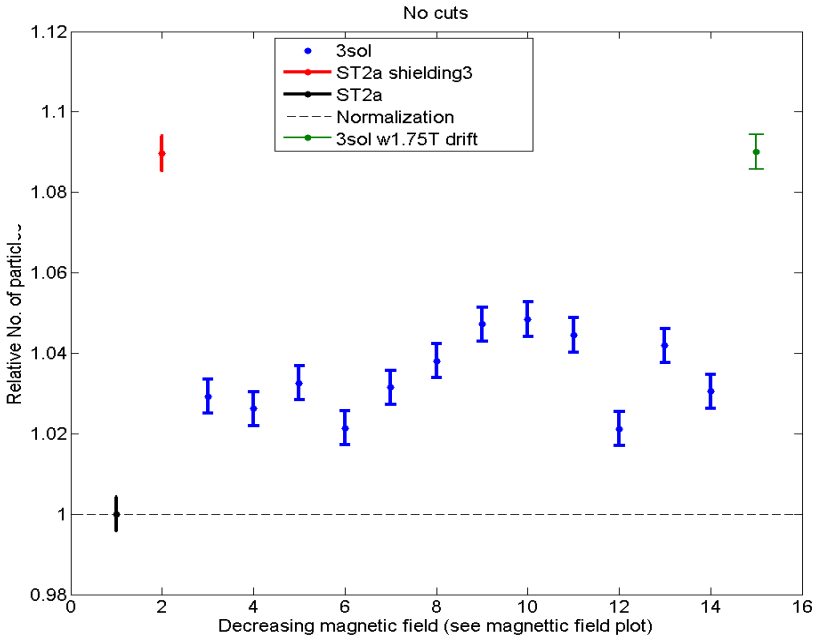
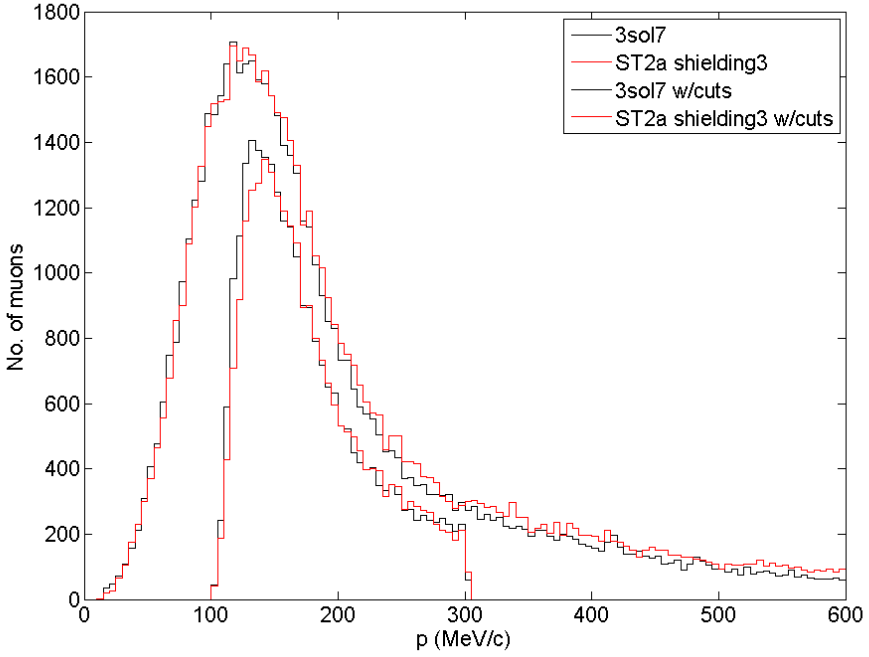
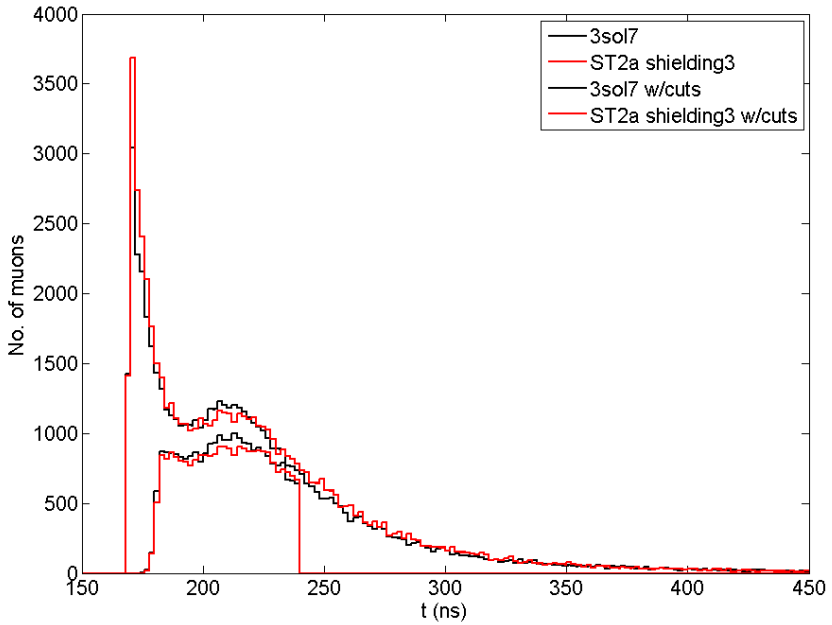




3SOL Sensitivity to acceptance cuts

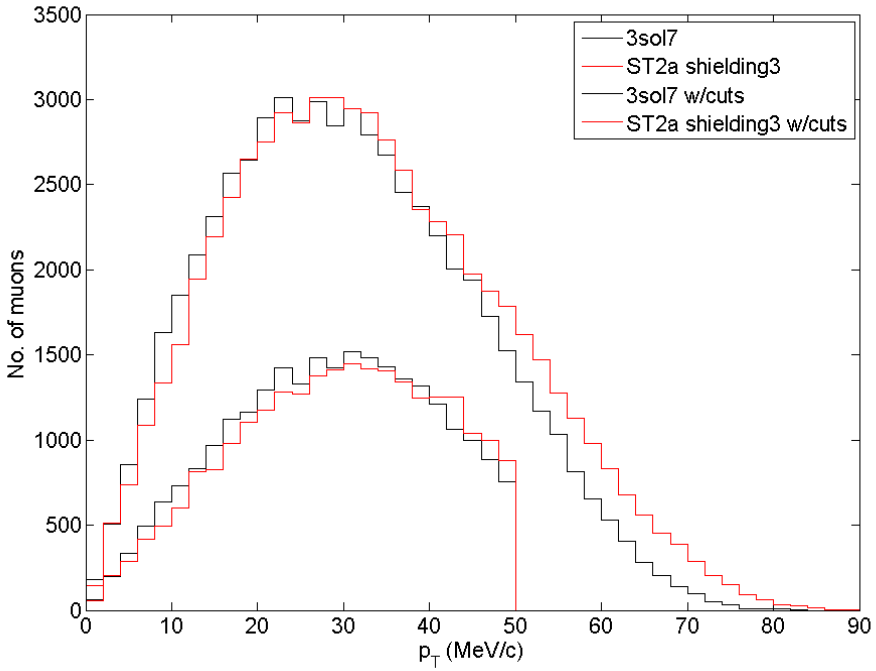
- 3sol captures more particles with the right time, position and momentum
- ST2a_modified captures more of the faster particles, but they are not accepted

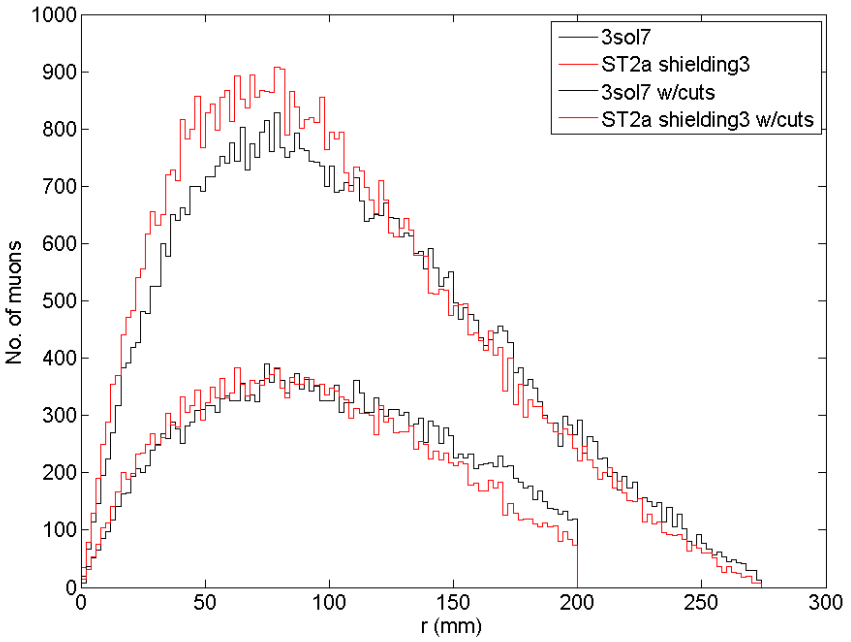




3SOL Sensitivity to acceptance cuts

- 3sol has a slightly higher mean radius <r> and a slightly lower mean transverse momentum<p_T>, resulting overall in a slightly higher yield of captured muons

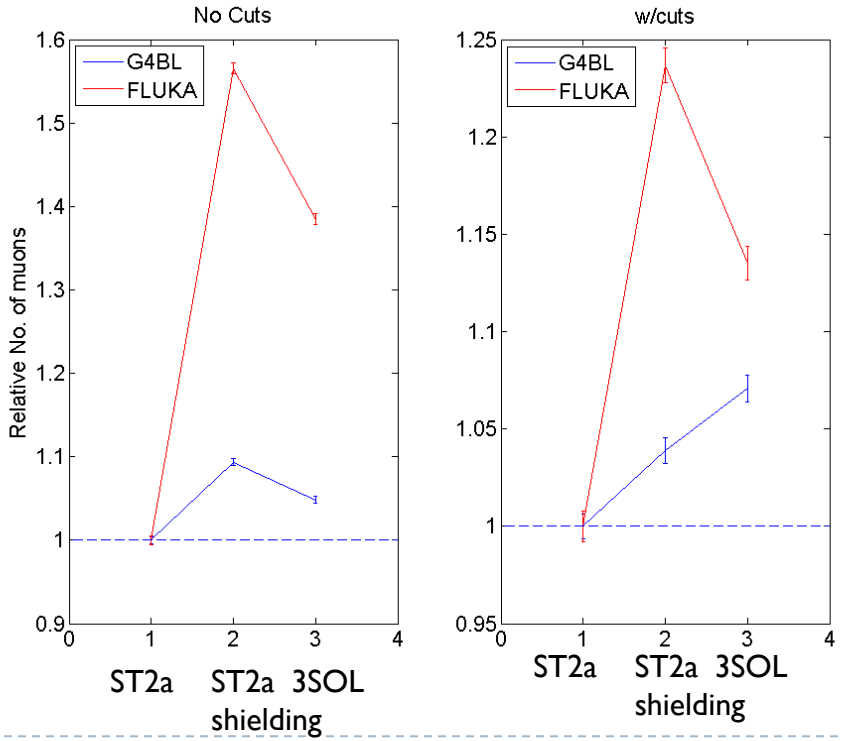




Muon flux: FLUKA vs G4BL

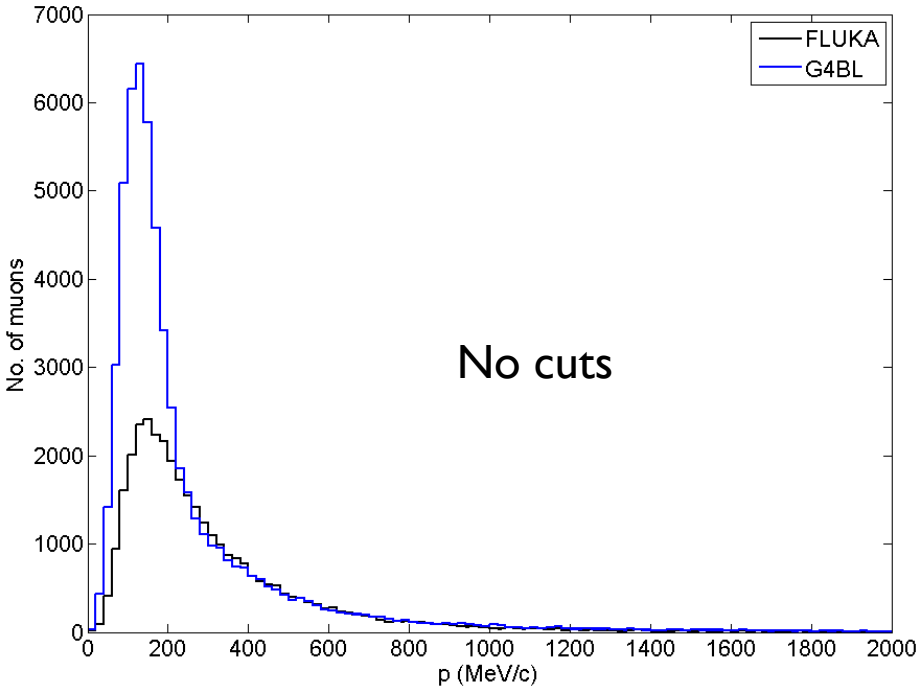
- Identical setups made for G4BL and Fluka
- The table and the plot shows the relative muon flux, normalized to the ST2a-setup
- FLUKA results are more sensitive to change of shielding

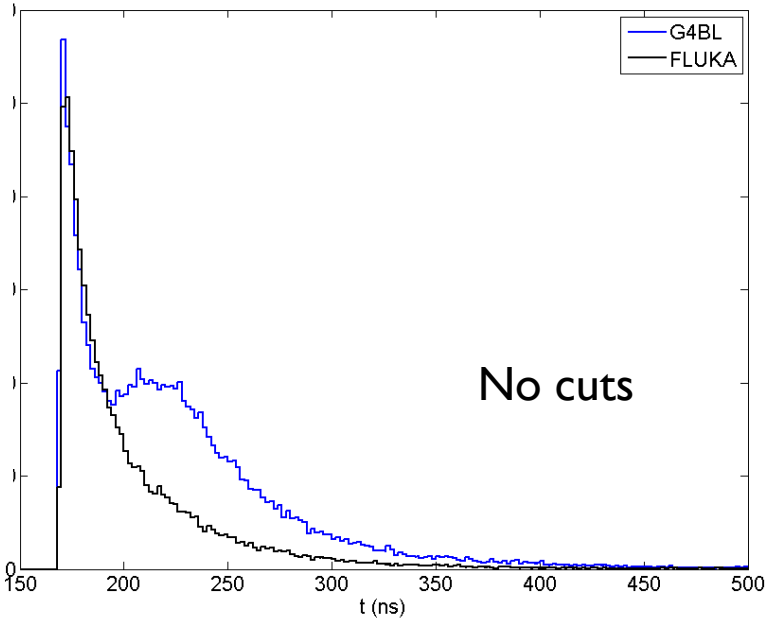
Relative No. of muons wrt ST2a				
Setup	No cuts		w/cuts	
	G4BL	FLUKA	G4BL	FLUKA
ST2a_shielding3	1.09	1.57	1.04	1.24
3SOL	1.05	1.38	1.10	1.14



ST2a: FLUKA vs G4BL

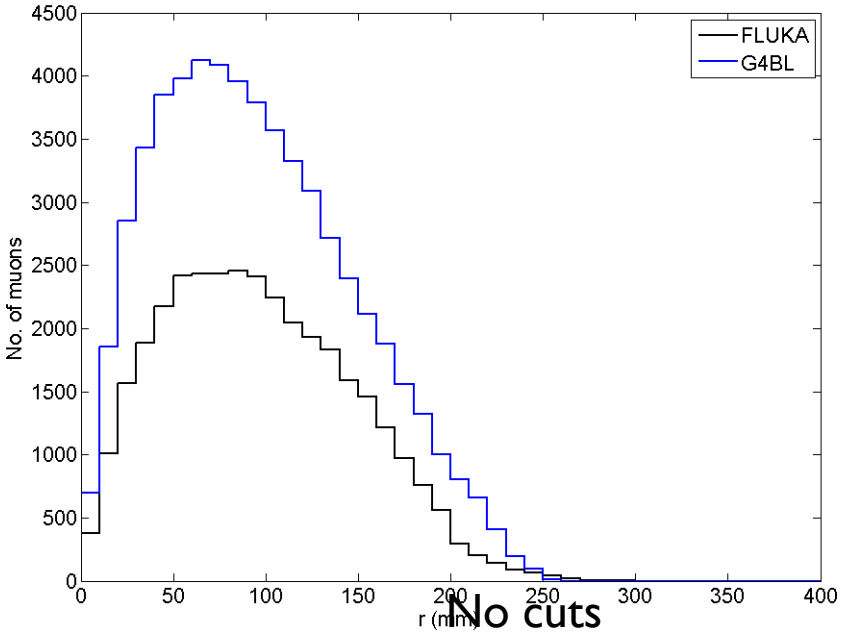
- G4BL produces softer momentum spectrum, resulting in a different time distribution wrt FLUKA

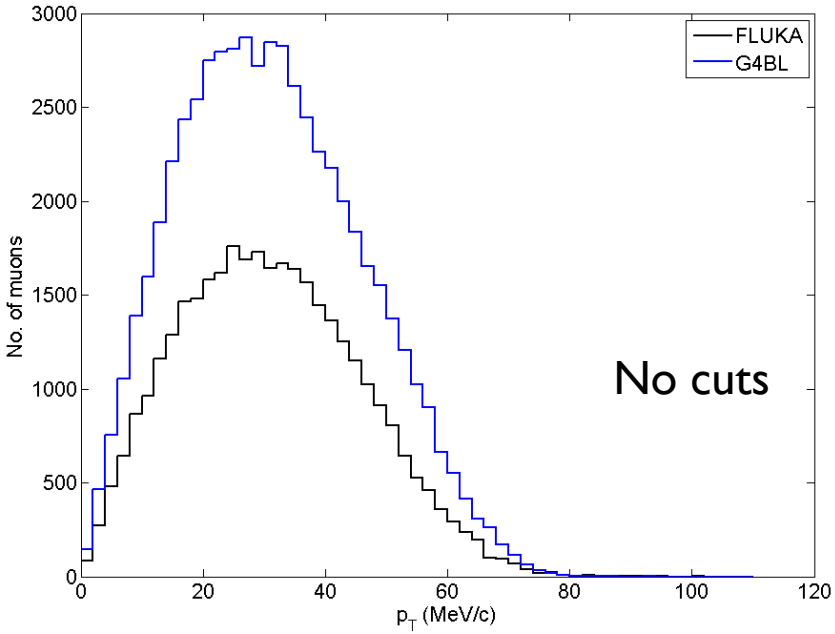




ST2a: FLUKA vs G4BL

- P_T and r distributions are similar, but G4BL gives a higher muon flux





Conclusions - II

- Using the muon acceptance cuts, the 3SOL setup gives higher yield of muons compared to ST2a
  - 10% difference using G4BL
  - 14% difference using FLUKA
- Before applying the acceptance cuts, the difference is much higher:
  - **+5%** in G4BL for 3SOL, and **38%** for 3SOL in FLUKA compared to ST2a
- FLUKA is more sensitive to the shielding layout
- Next steps:
  - study the energy deposition using FLUKA
  - Investigate further the particle production difference between G4BL and FLUKA