Dark Current Studies in ILC Main Linac (update)

N.Solyak, A.Sukhanov, I.Tropin, Y.Eidelman

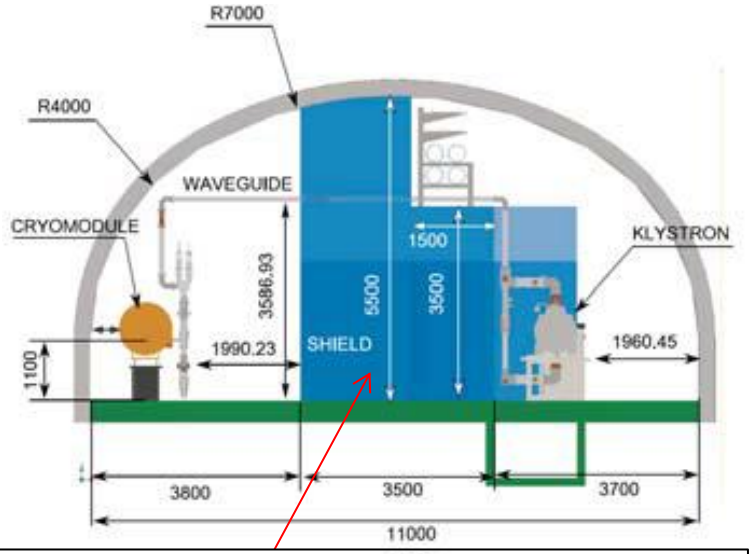
FNAL, Sept.10, 2015

Motivation

- Halo particle and Dark current electrons in ML produce radiation, which affect:
  - Beamline components and cables inside of CM
  - electronics outside of CM in ML tunnel
  - personnel and electronics in service tunnel

- Extensive studies needed to investigate halo & dark current radiation.
  - Reduce thickness and cost of the radiation shield
  - Radiation doses for ML components

Cross section of Kamaboko tunnel



Recent studies of dark current:

- TESLA. V.Balandin et.al, TESLA report,2003
- Solyak et. al.,Dark current midell for ILC ML, EPAC2008,
- T.Sanami, KEK, ALCW2014 Belgrad,.
- LCLS-II, M.Santana, DOE review Dec.2014
- JLAB 12GeV upgrade

Thickness of wall (1.5-3.5m) separating service and operational facility is determined by max beam losses in tunnel

Field Emission

- uniform distribution of emitters over the cavity surface
- Fowler-Nordheim model

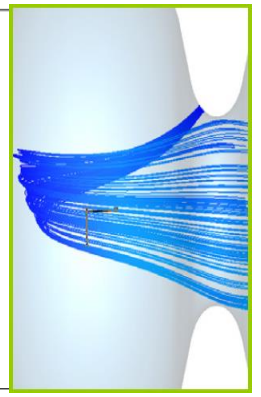
$$W_{FN} = N_{FN}(\beta_{FN}E)^2 \exp(-B_{FN}\varphi^{3/2}/\beta_{FN}E)$$

$\beta_{FN}=100$
$B_{FN}=6.83 \cdot 10^3$, $\varphi=4.2$ eV,
E in MV/m, I in Amp;

- Norm factor is determined from the nominal DC value (50nA) exiting cavity
  - Norm = 4.79e12 e-/s (taking into account RF duty factor 10Hz*1ms=0.01)

E=31.5 MV/m

Particle tracking in cavity (SLANS-2D)



100 trajectories with weight > 0.01

R,m

100k emitters random in phase and location with weight > 0.01
green - lost in cavity, red - exit to the right, blue - exit to the left

Reject particles with weigh <1% and energy < 0.5 MeV (parameters)

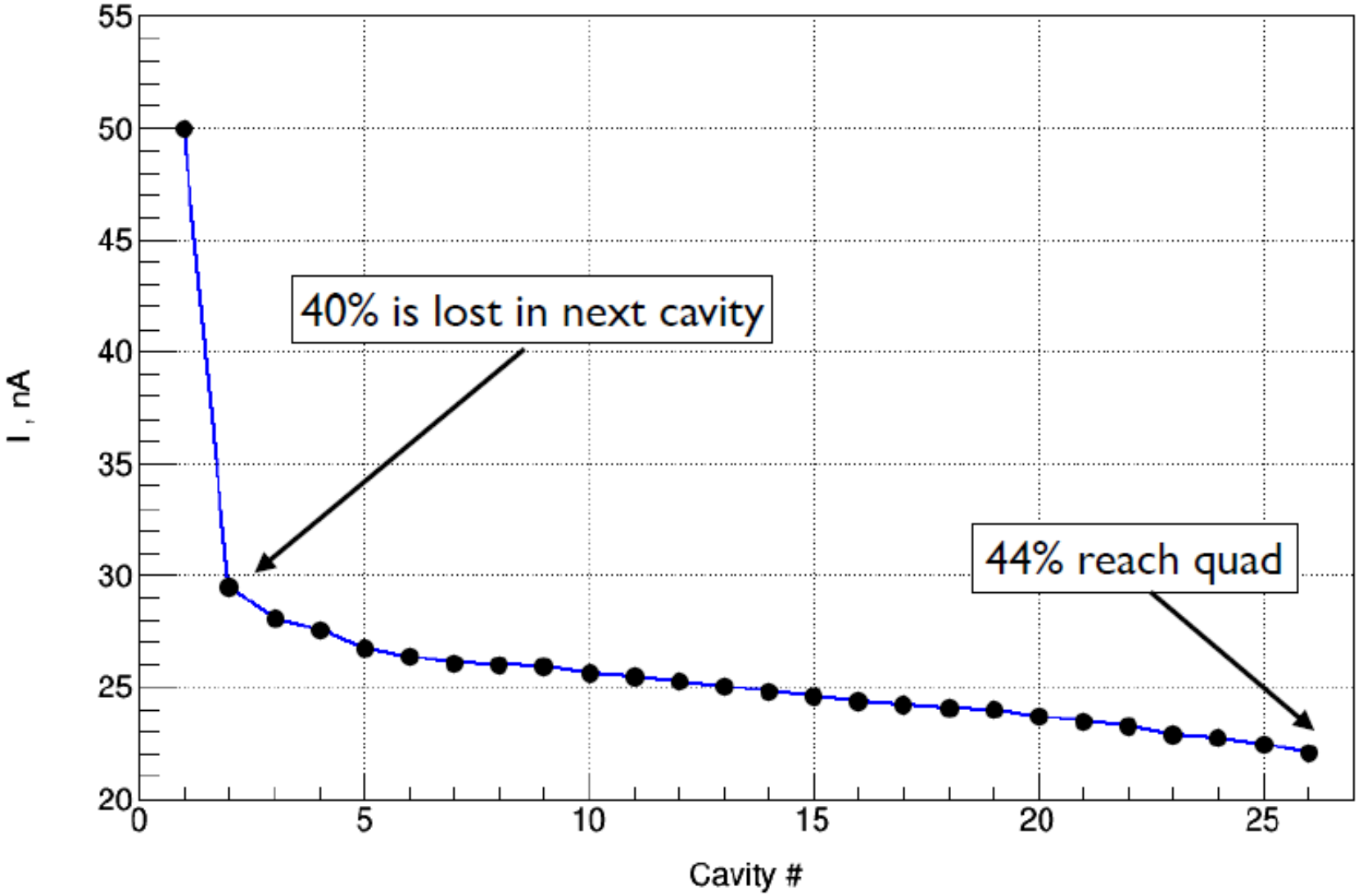
Particle Tracking in Cavity RF Field

- 92% of emitted particles are absorbed in the same cavity
- 4% of particles are captured into acceleration, exit cavity in the direction of the main beam into the next cavity
  - continue tracking of these particles through cavities down stream until they are lost or reach next quadrupole
- 4% of particles exit cavity up stream, in the direction opposite to the main beam, and enter previous cavity
  - continue tracking of these particles through cavities up stream until they are lost or reach previous quadrupole

- Add emission and tracking for all 26 cavities between quads

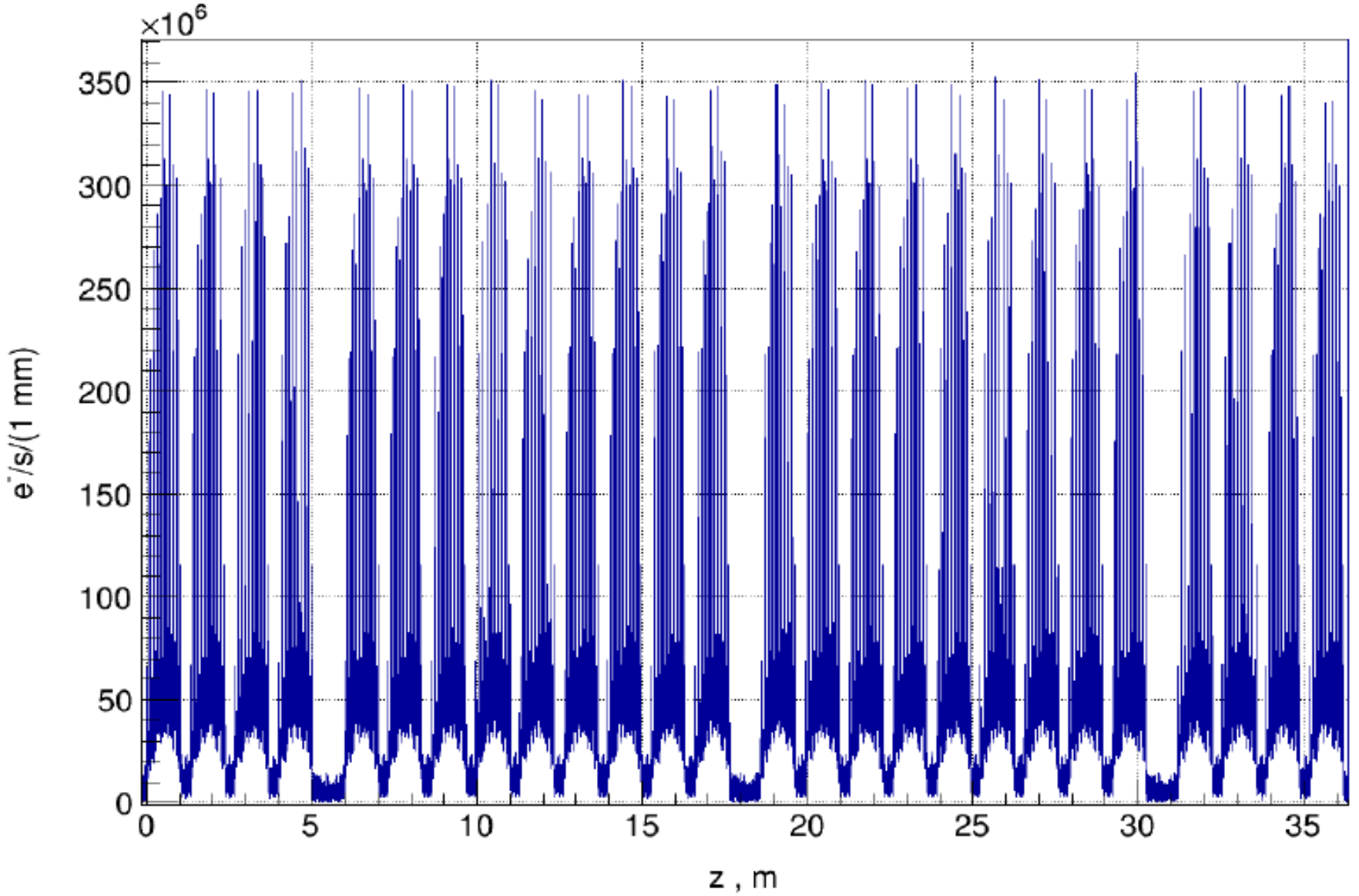
DC from Single Cavity

- Distribution of peak DC from single cavity along the string of 26 cavities



Tracking in 26 Cavities

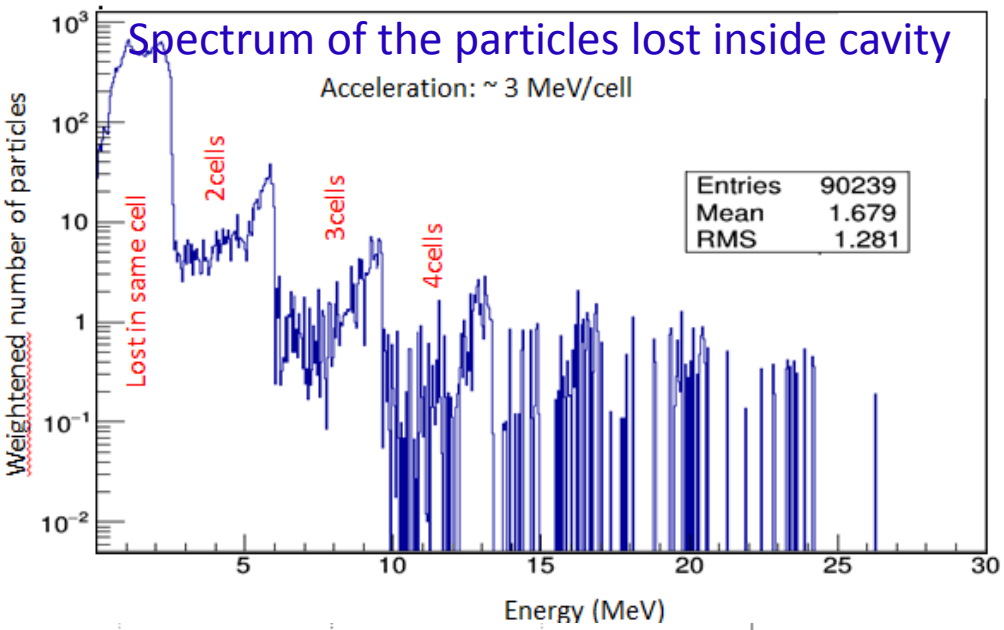
- Losses from emission in all 26 cavities (50 nA/cavity)

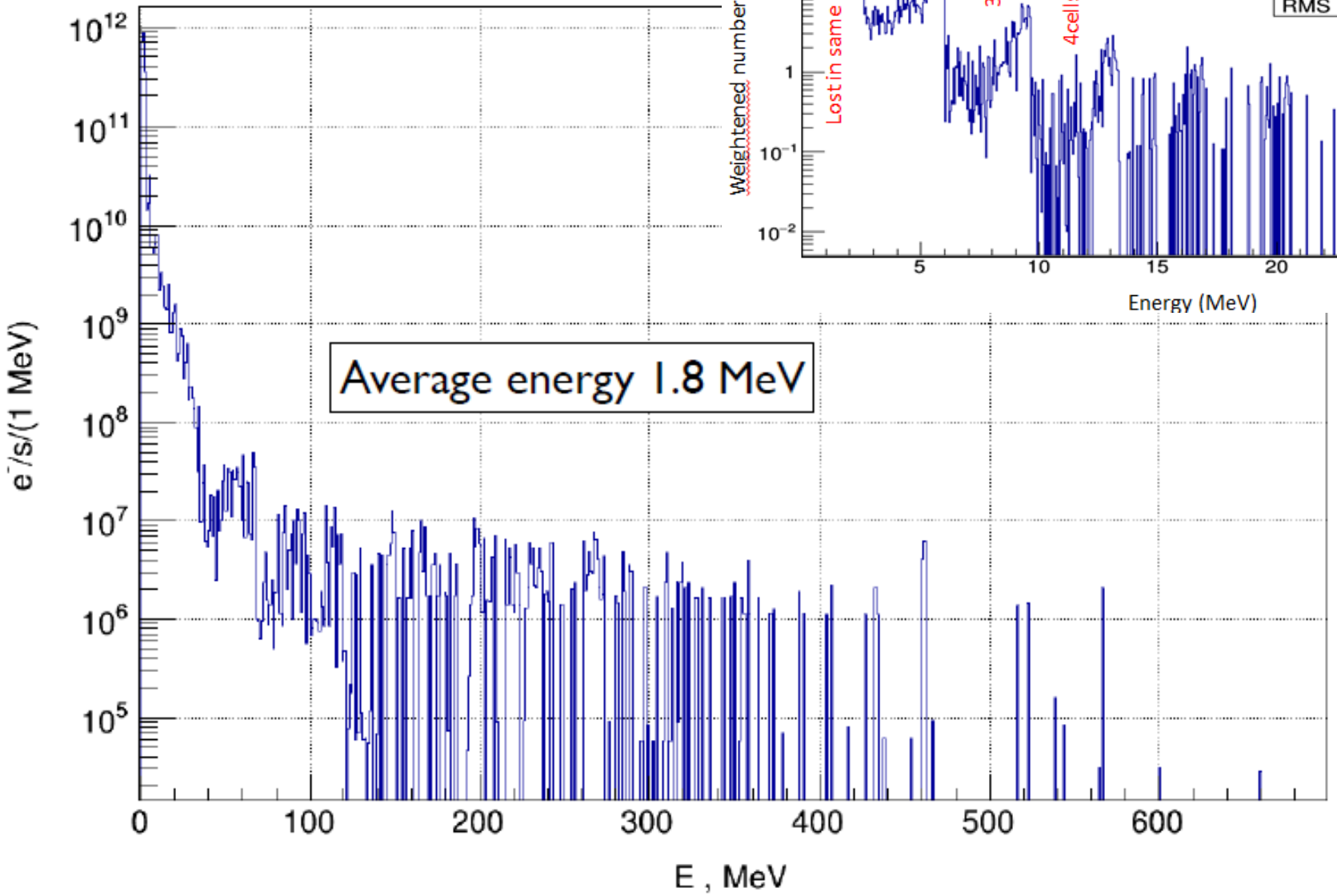


Energy spectrum of lost partocles

Tracking in 26 Cavities

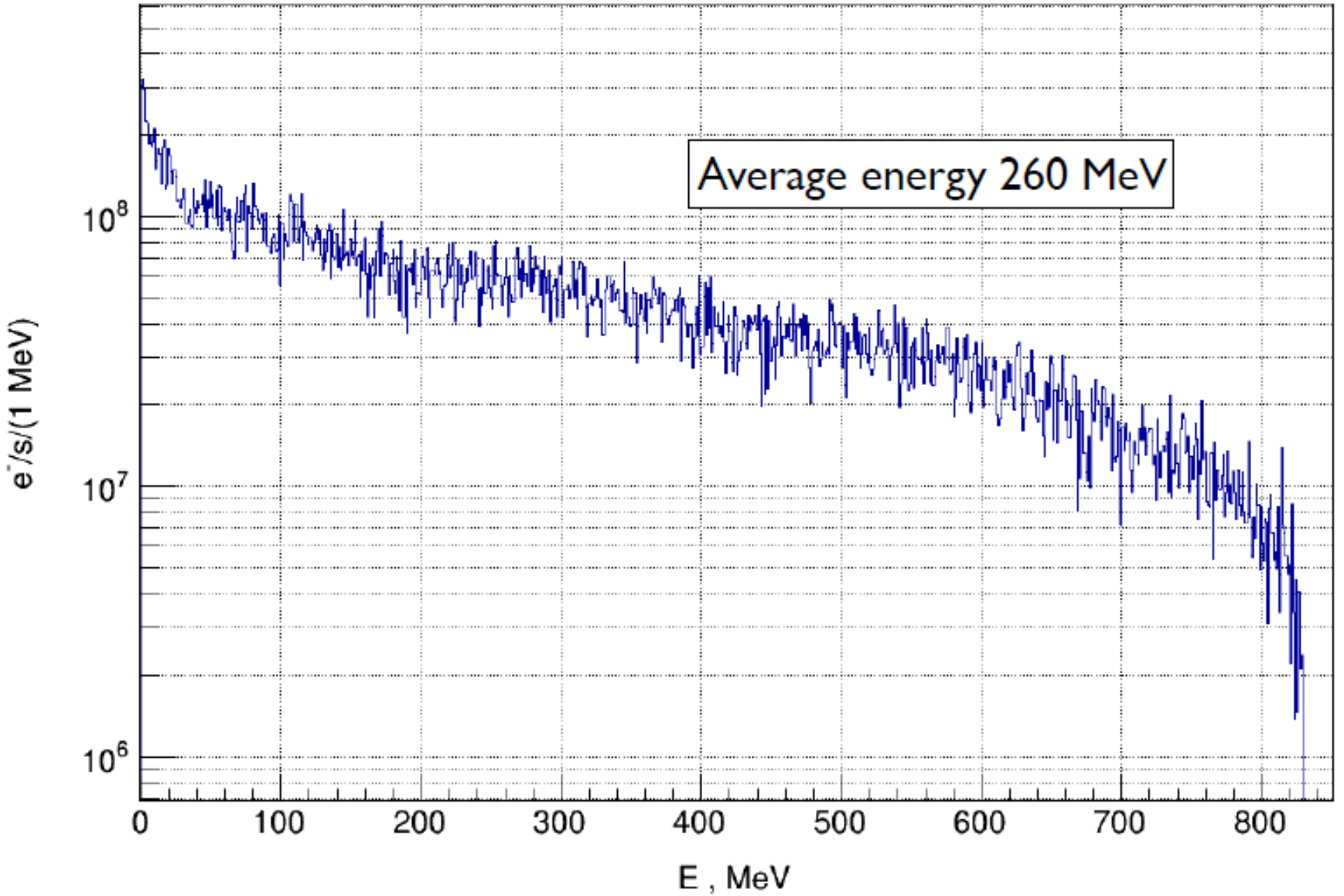
- Energy spectrum of lost particles



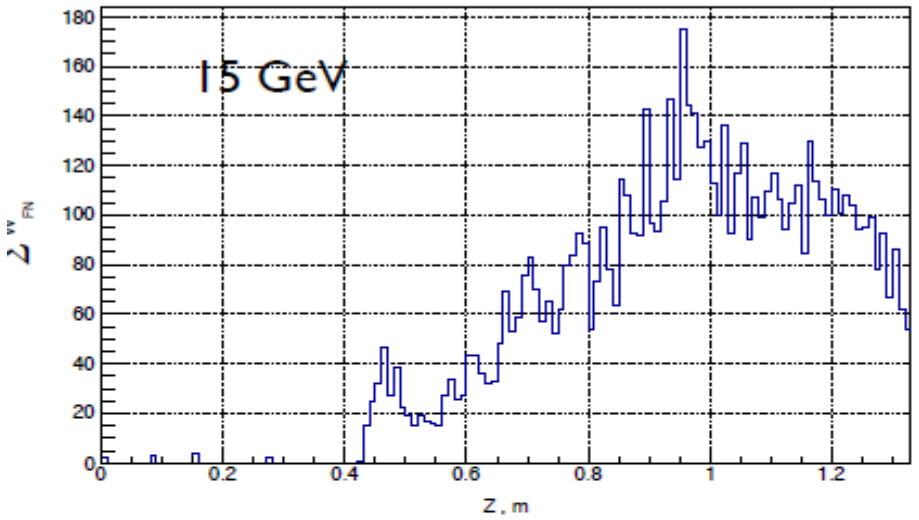


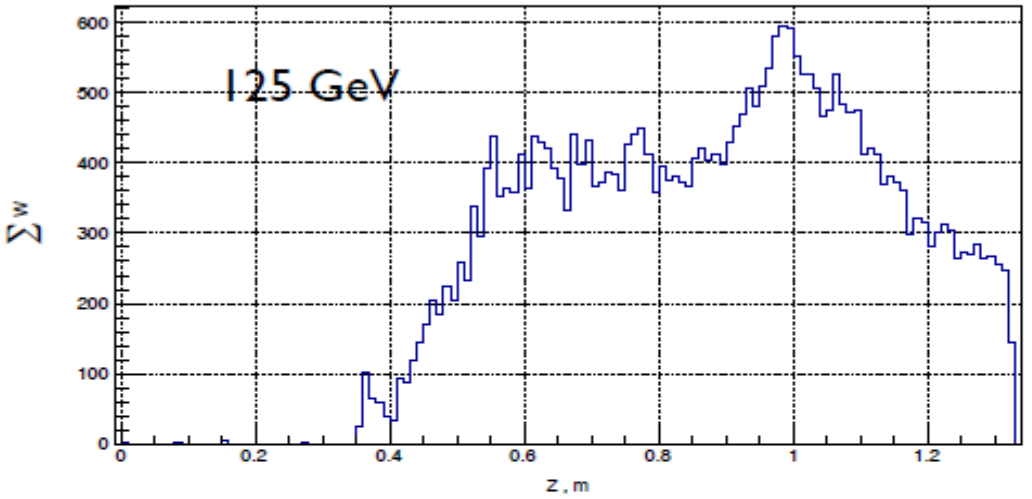
Tracking in 26 Cavities

- Energy spectrum of particles entering quad section



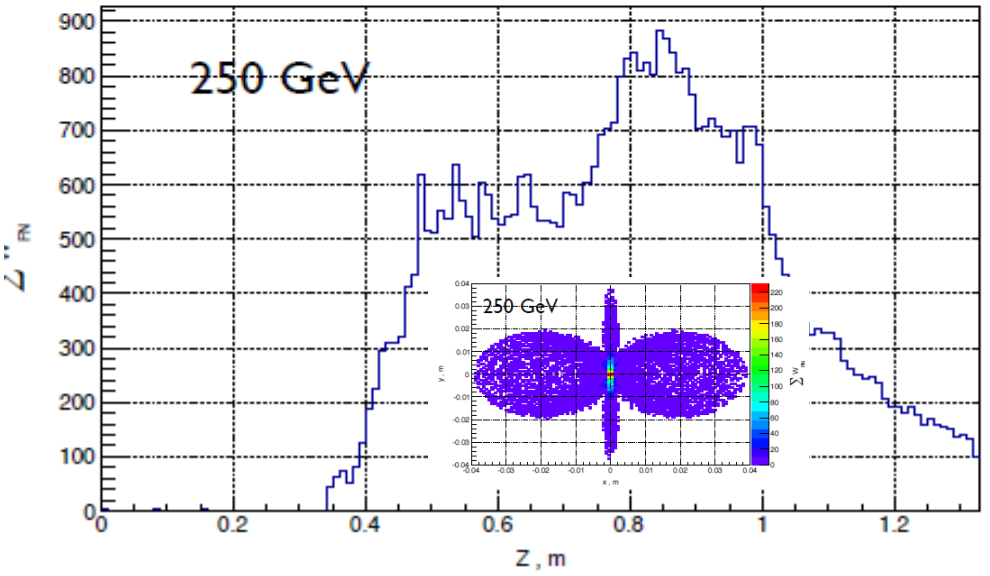
Losses in quad: Z distribution





Distribution of particles in Q

	Quad 15 GeV		Quad 125 GeV		Quad 250 GeV	
	N	Sum of FN weights	N	Sum of FN weights	N	Sum of FN weights
Lost in quad	22842	7163.8 (13.2)	116461	34438.1 (63.6%)	162104	45802 (86.4%)
Exit to the right	177758	46972.2 (86.8%)	84139	19697.8 (36.4%)	38494	8332 (15.4%)



Estimation of the prompt equivalent dose induced by dark current produced in section of the ILC ML

LCWS2014 Oct/8/2014 9:00-9:30

Japanese law (T.Sanami slide)

- Limit for personal
  - Radiation worker : 100 mSv / 5 years, 50 mSv / year 20 mSv/year
- Ambient dose limit
  - Radiation controlled area (accessible) : less than 1 mSv/week ~25 μSv/h
  - Boundary at radiation controlled area : less than 1.3 mSv / 3 month ~2.6 μSv/h
  - Site boundary : 250 μSv/ 3 month ~0.1 μSv/h
    - Operation hours should be taken into account
- Activity in tunnel air, Activity in released air, Activity in drain water
  - Defined for each nuclide and chemical form

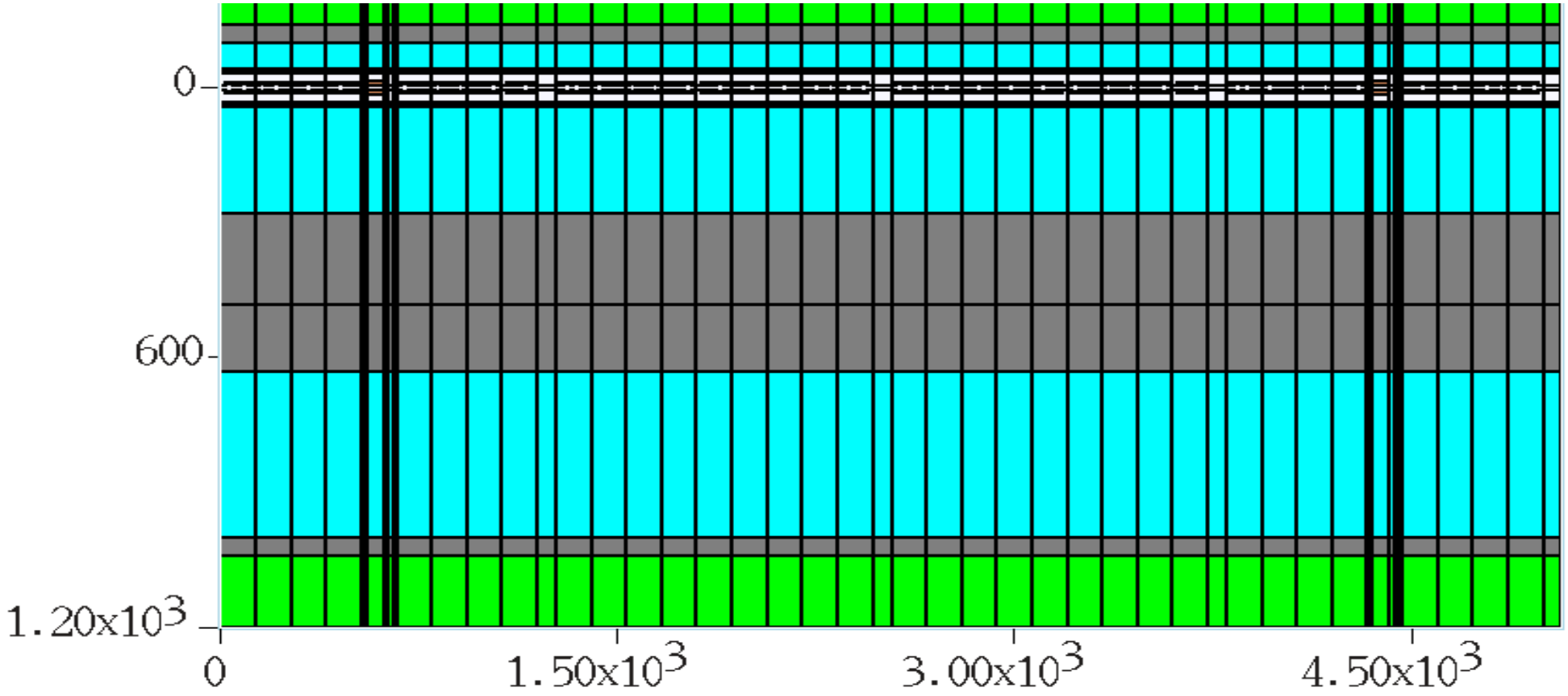
Two stage simulation

- Field emission simulation and tracking dark current electrons in cavities up to walls or entrance to quadrupoles done separately. Each particles information (coordinates, momentum etc.) saved to file.
- MARS simulation: continue trajectories written to the file, and calculate doses induced by dark current electrons.

MARS model

- Based on ROOT TGeo library.
- Built by means of the beam line builder implemented for MARS.
  - Extendable
  - For magnets: analytic approximation of magnetic fields is used inside aperture, 2D field maps – outside apertures (provided by Vladimir Kashikhin)
  - Can be exported to GDML format readable by Geant4 and Fluka.
- Representation of cryomodule and tunnel is converted from MARS "extended geometry" model developed in Japan (Sanami-san).
- Cavity model re-implemented to correspond to the model used in dark current simulations performed by Alexander Sukhanov. There is no field in cavities in current model.

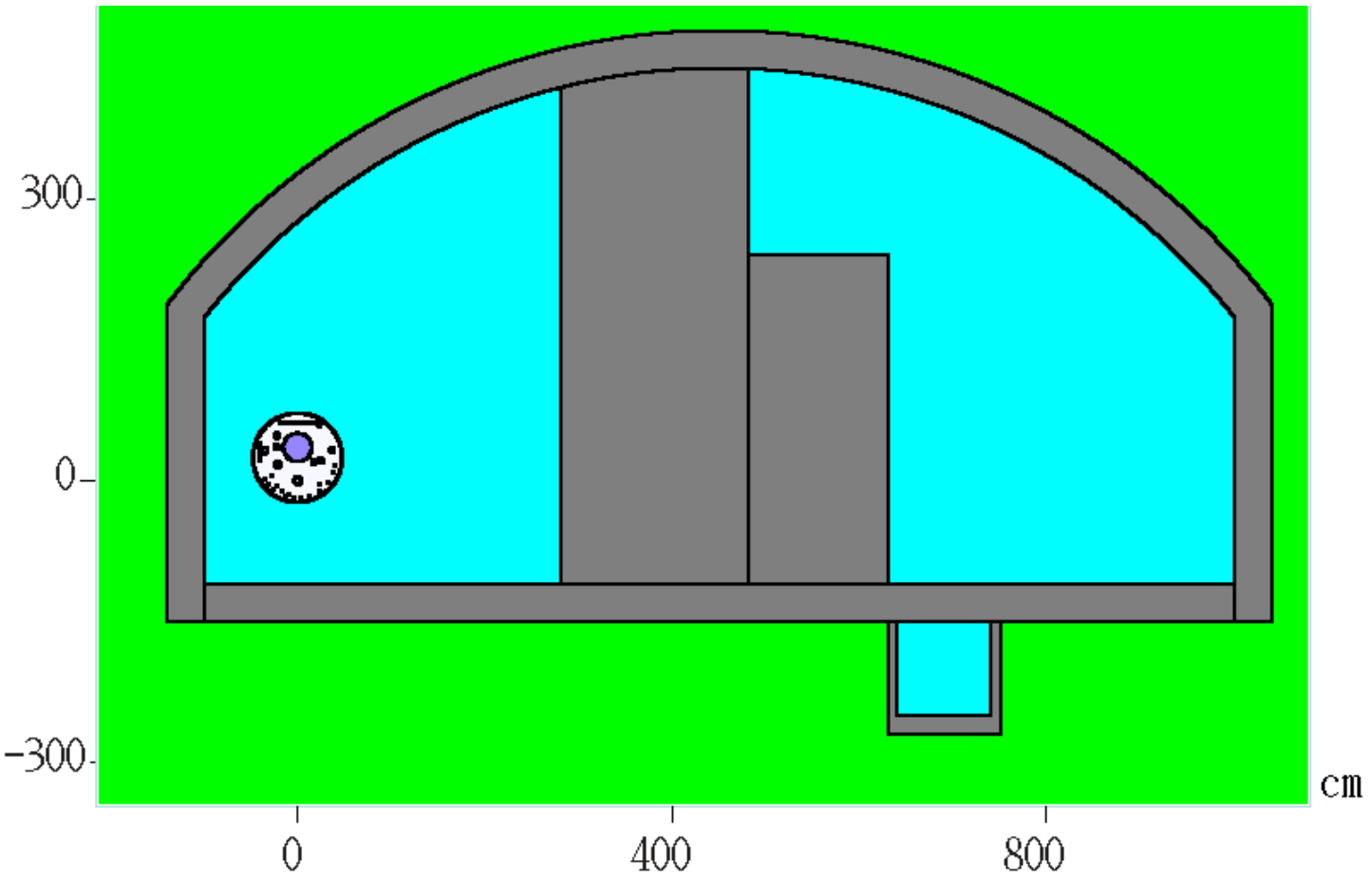
MARS model based on ROOT Tgeo package: Top view (geometry based on T.Sanami input)



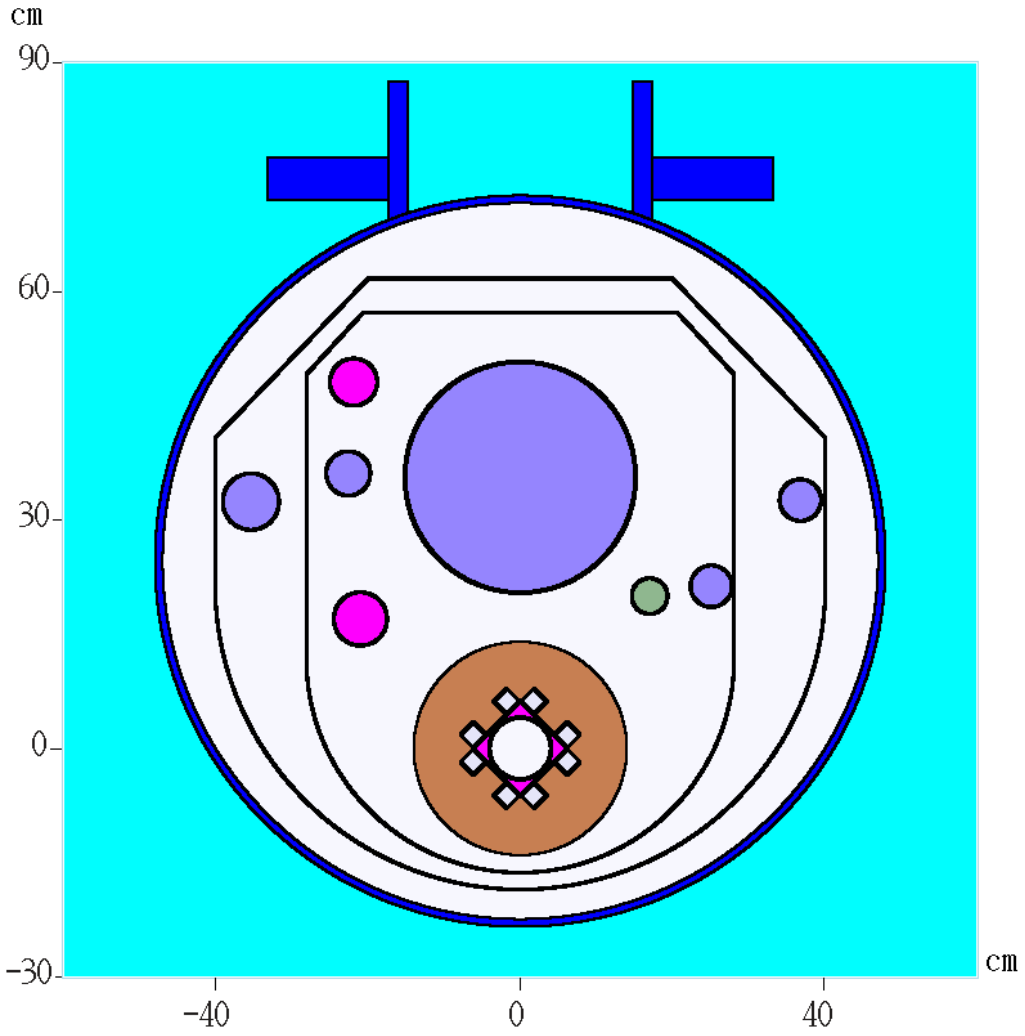
Length – 50,6m: 4 crymodules, 34 cavities, 2 quadrupoles

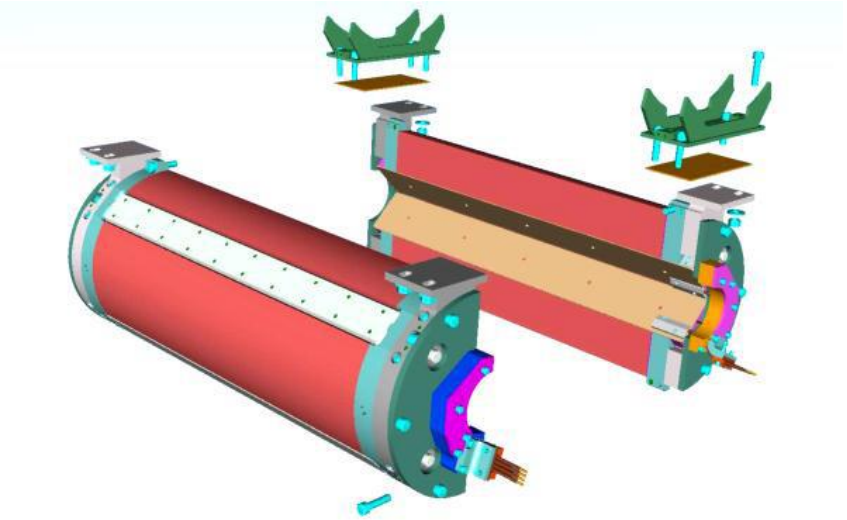
Geometry can be easily can be extended to full length of linac

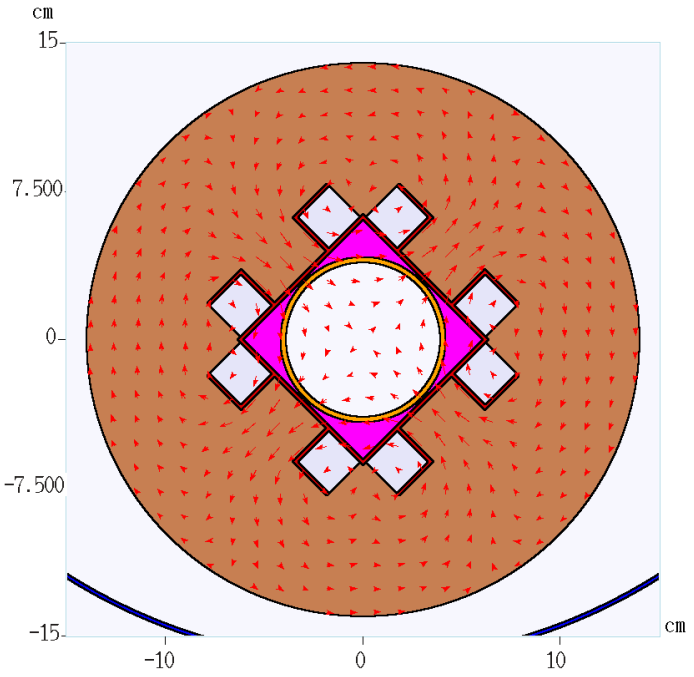
MARS model: Front View



ILC Cryomodule model

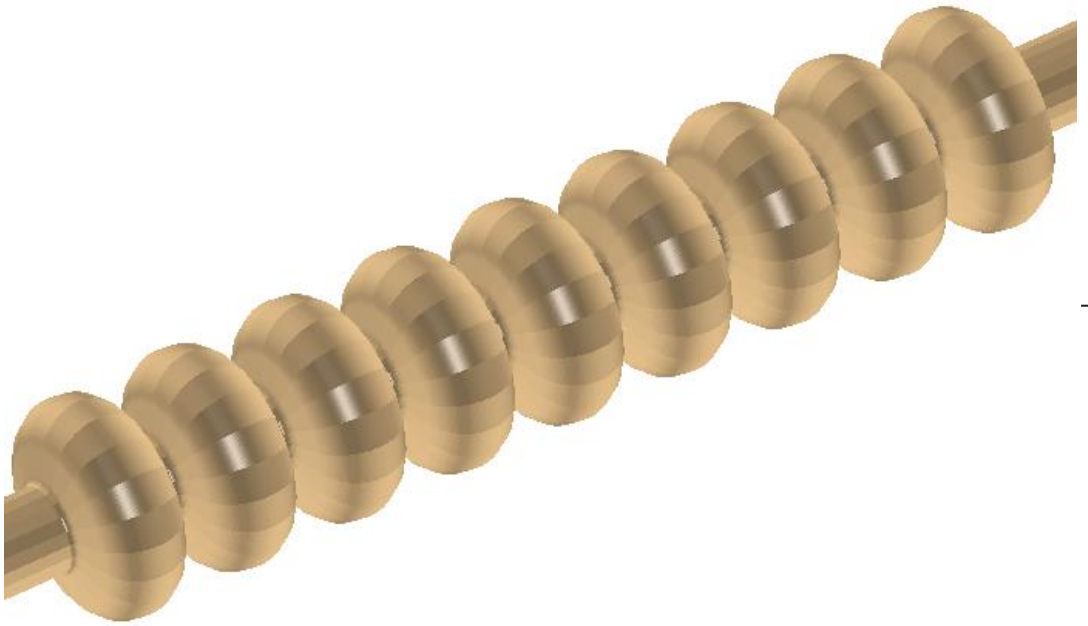


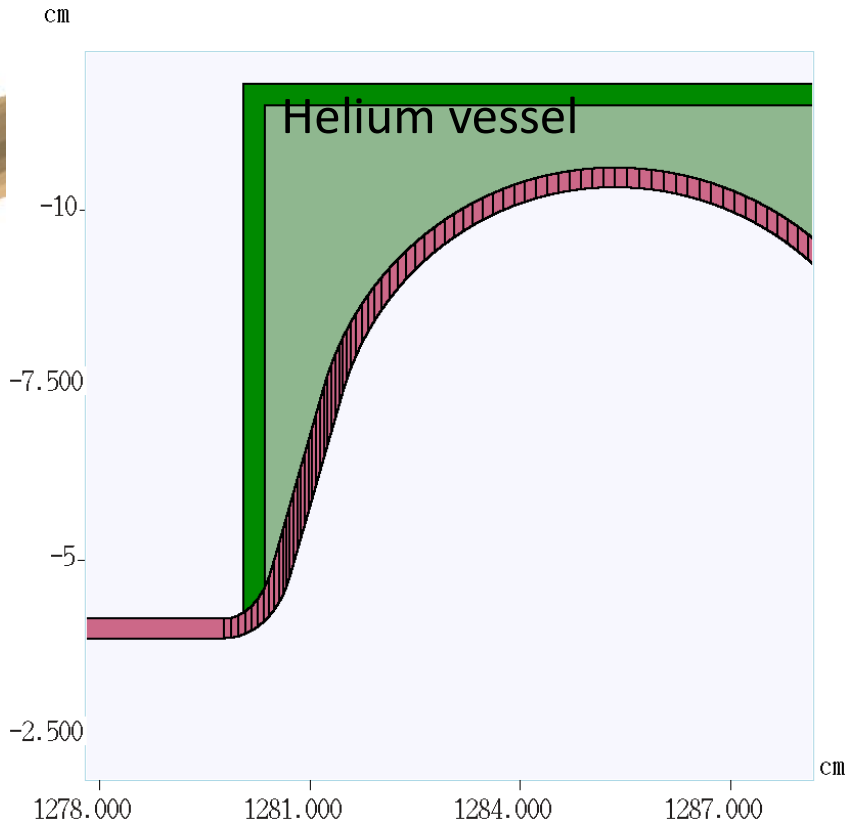




Splittable ILC magnet (V.Kashikhin)

Cavity model



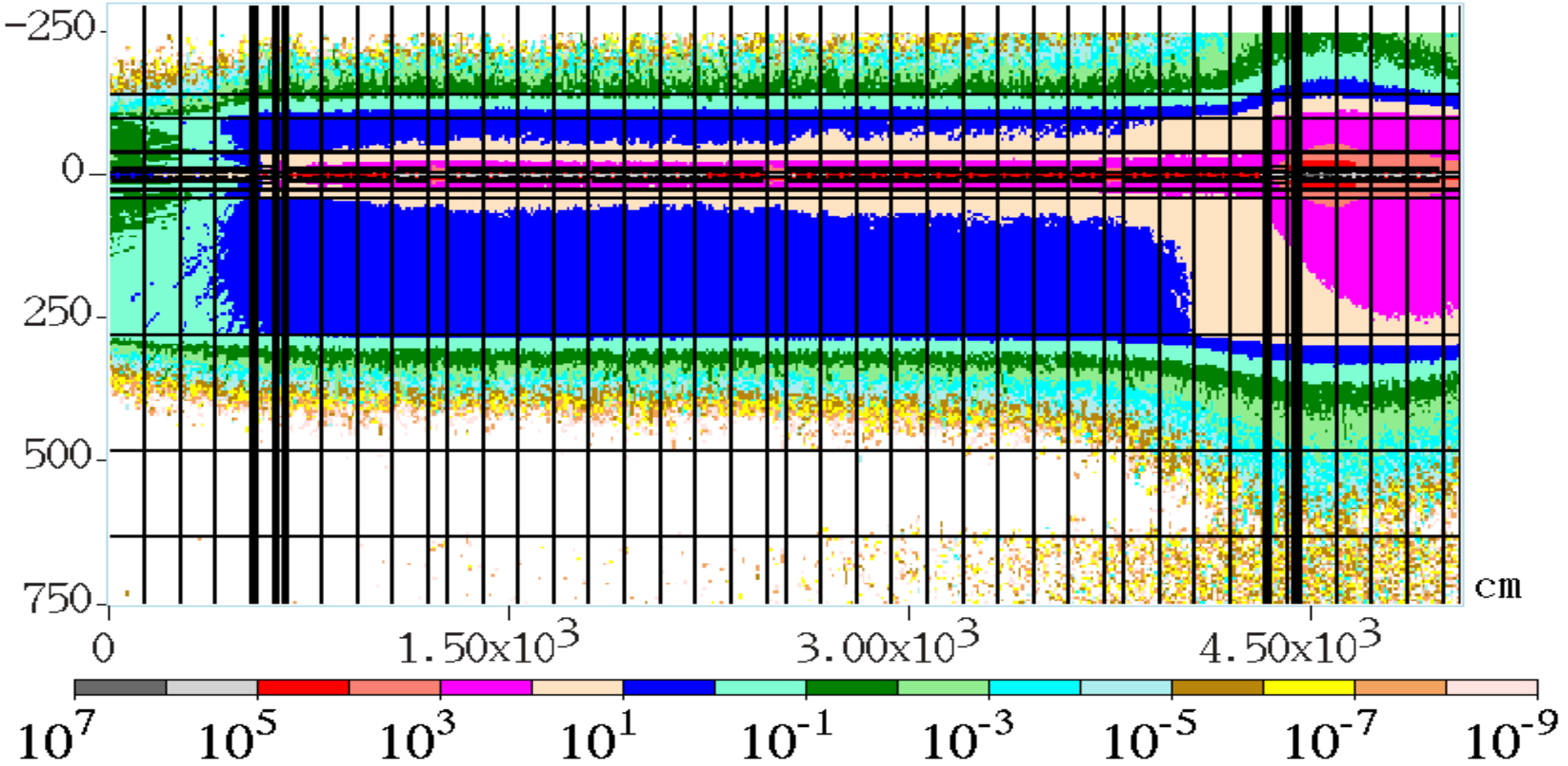


ROOT OpenGL viewer

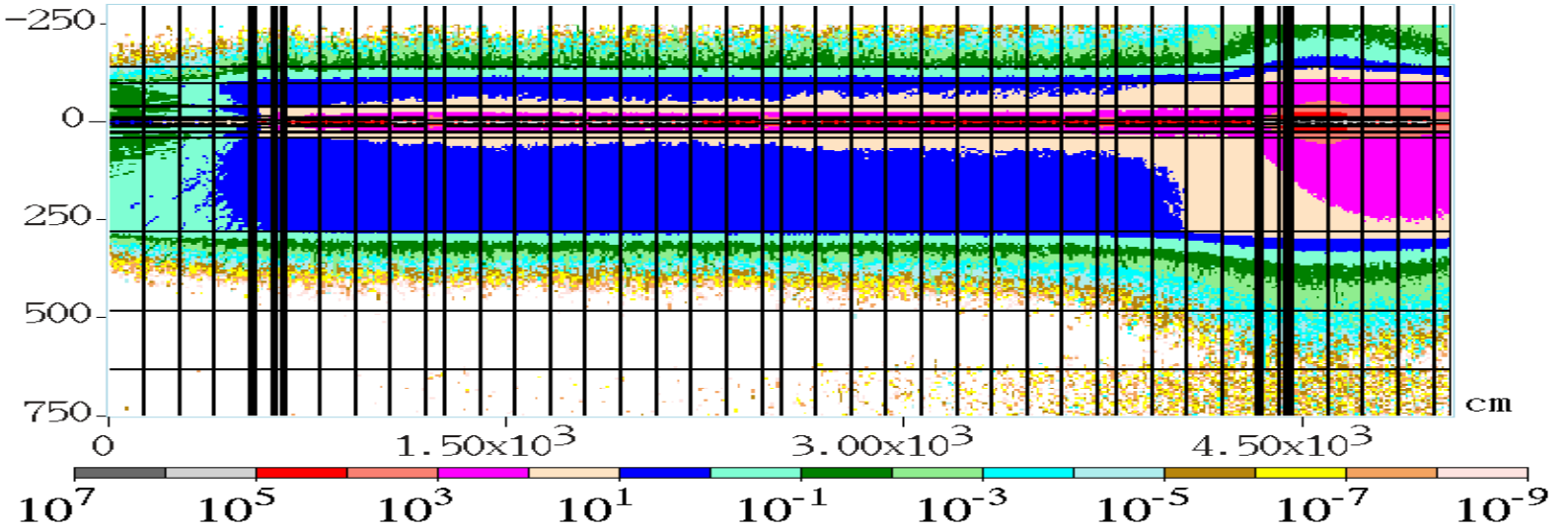
MARS viewer

Total prompt dose, mSv/hr

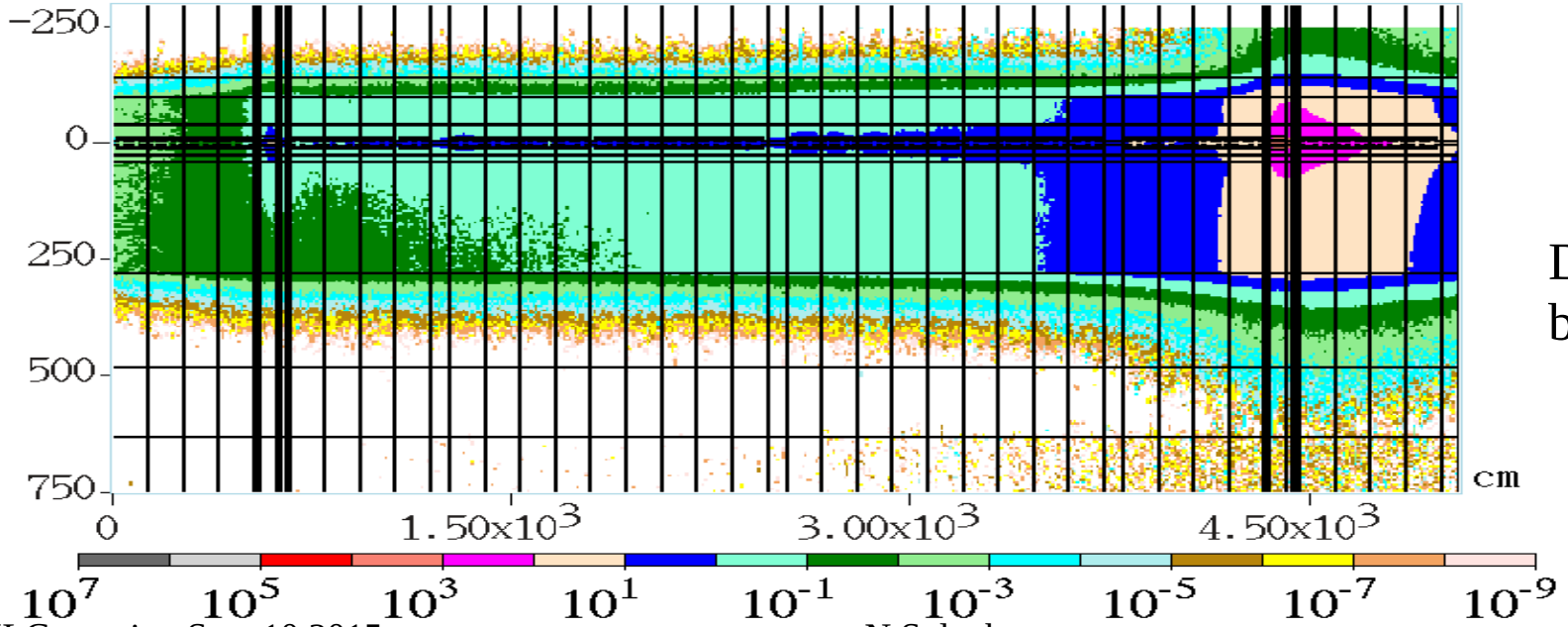
End of ML (250GeV)



Total dose and dose induced by neutrons mSv/hr

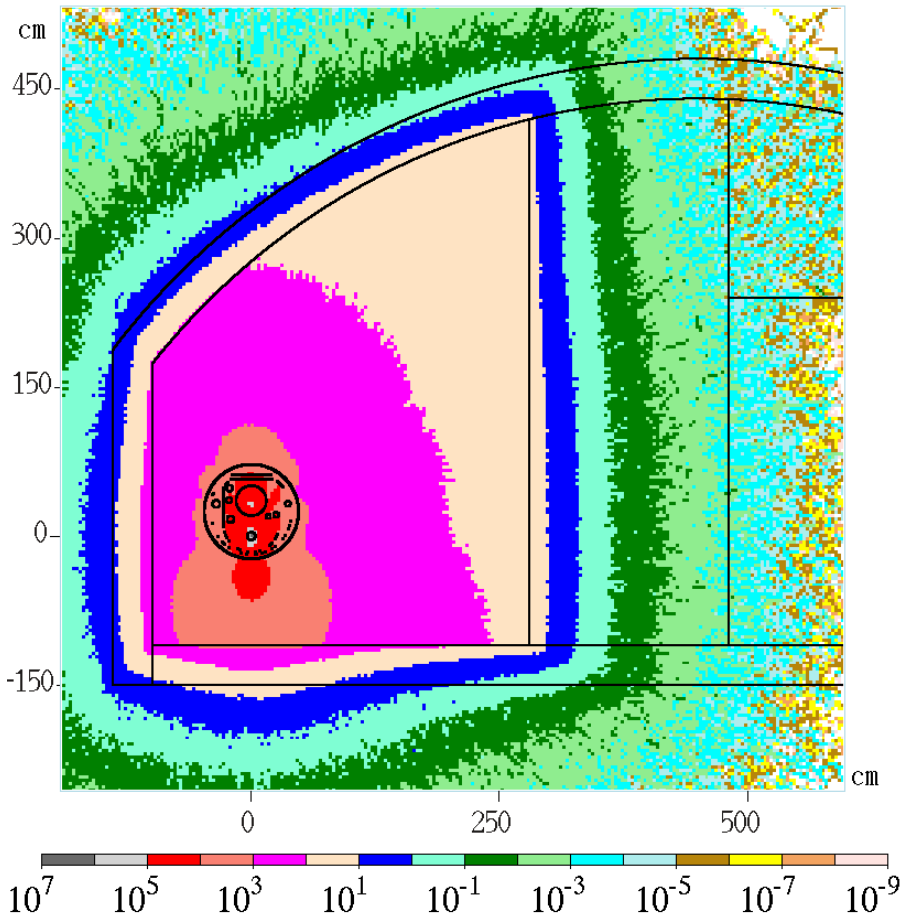


Total dose

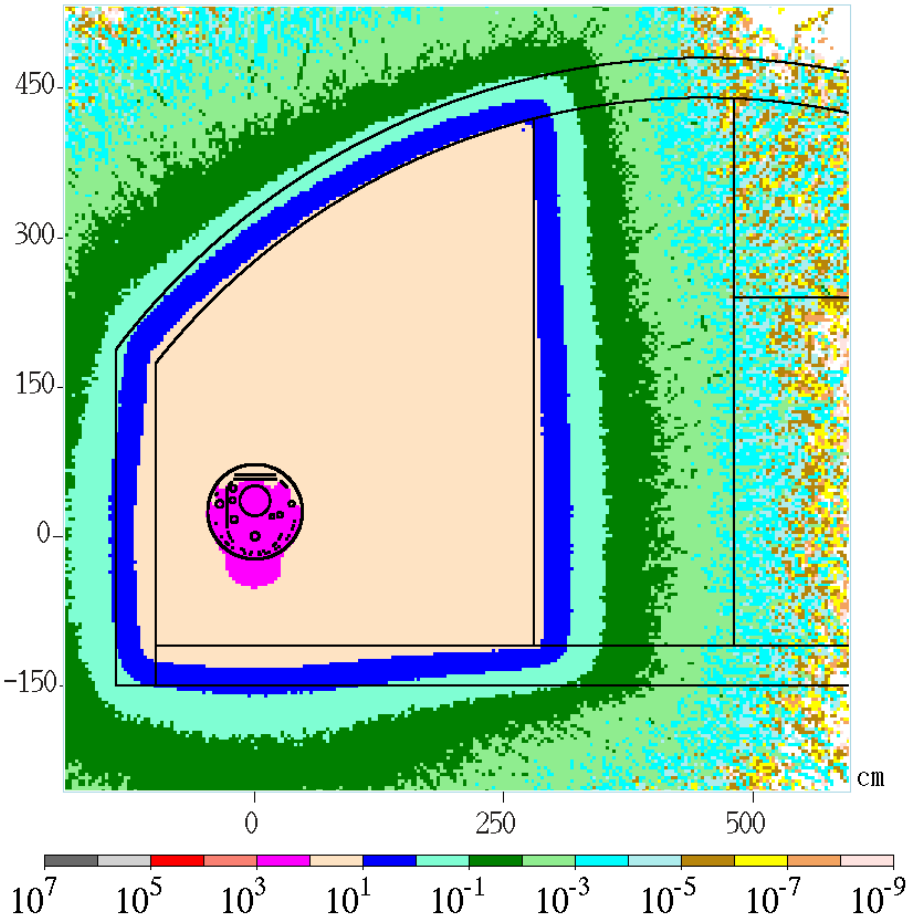


Dose induceg by neutrons

Dose after quadrupole (250 GeV), mSv/hr

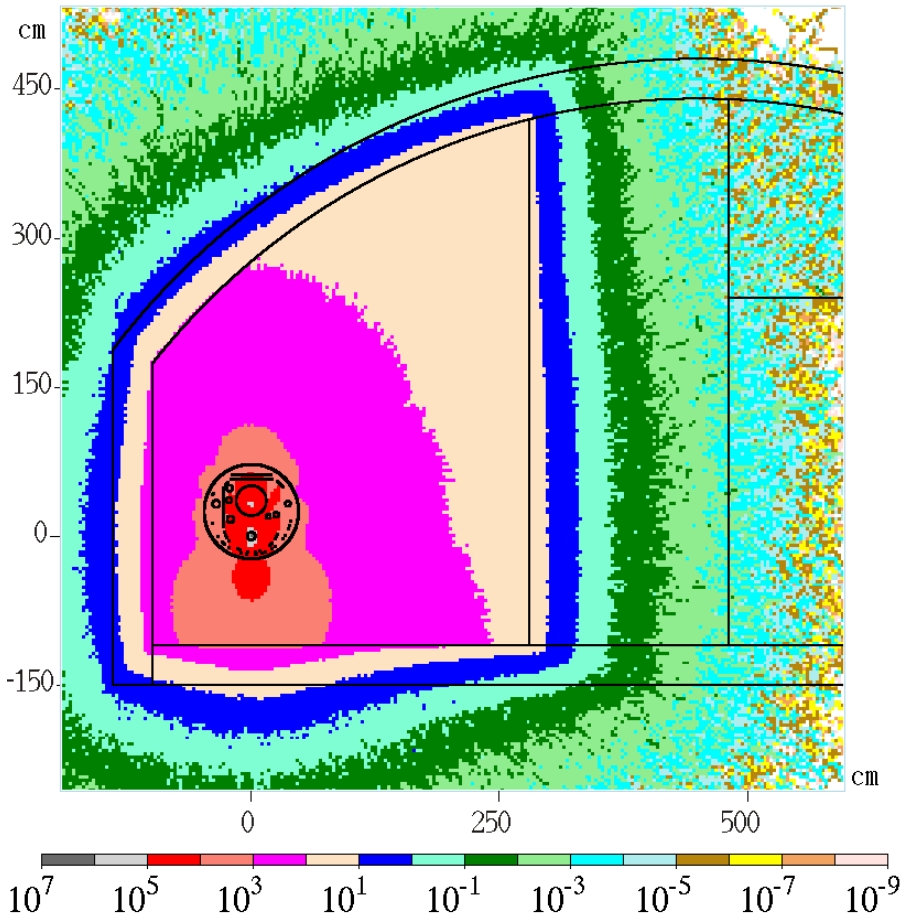


Total dose

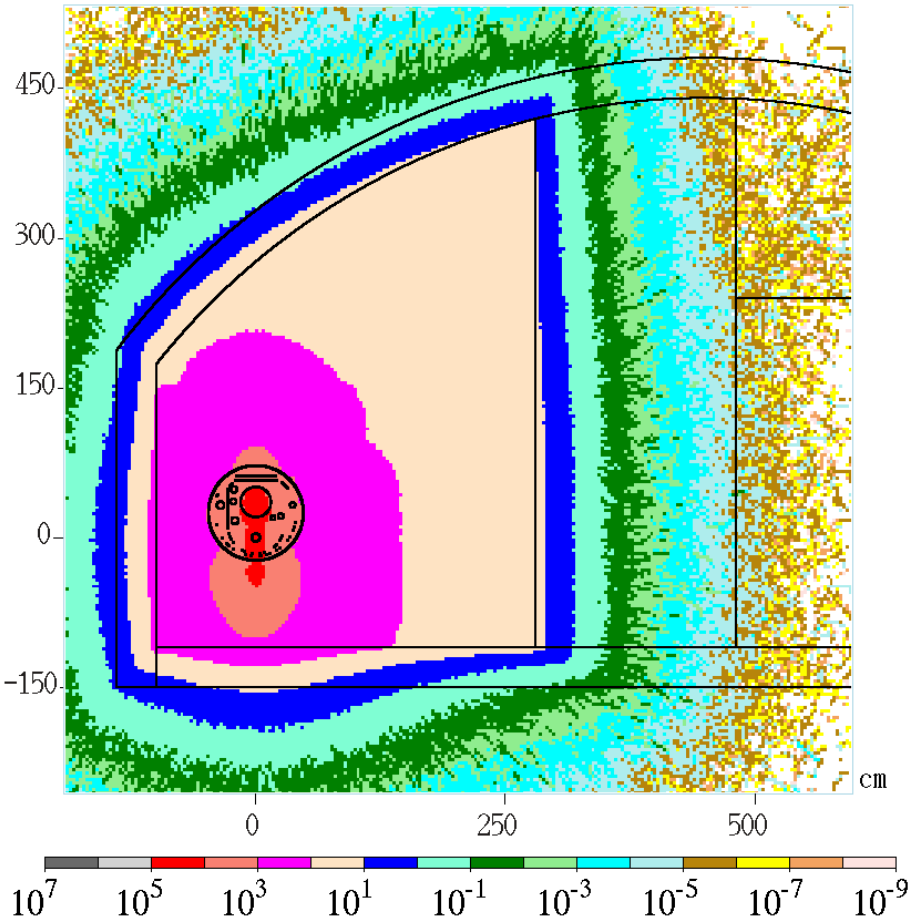


Dose induced by neutrons

Dose after quadrupole (250GeV), mSv/h

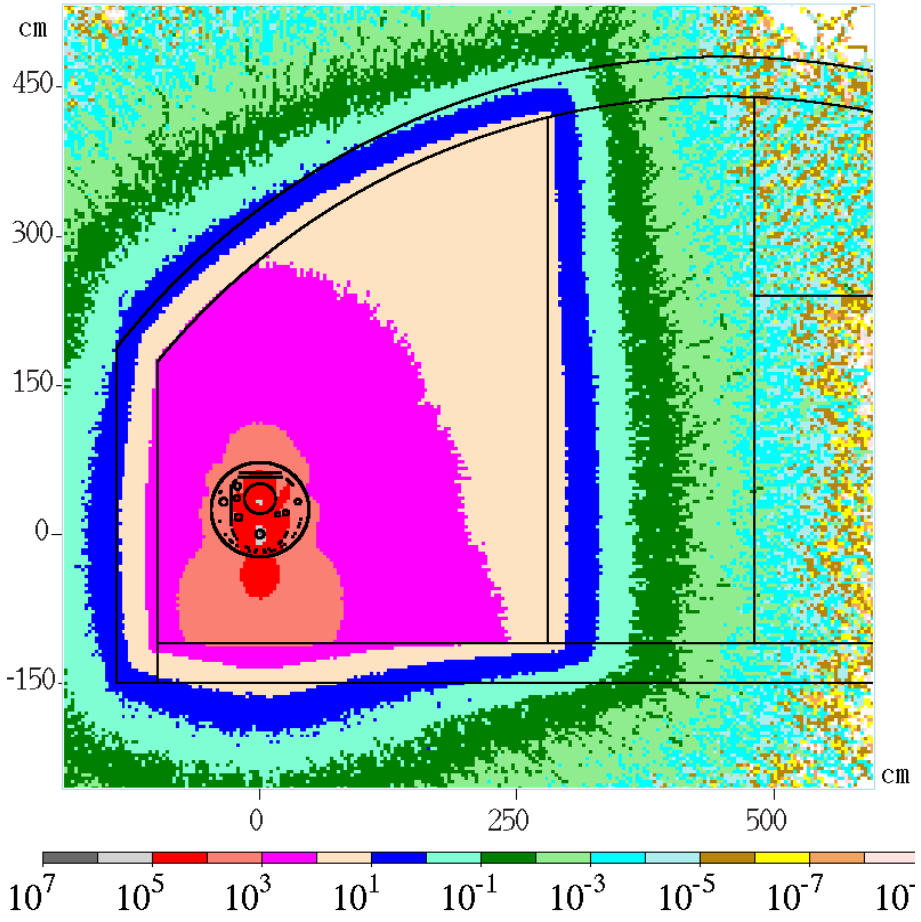


Total dose

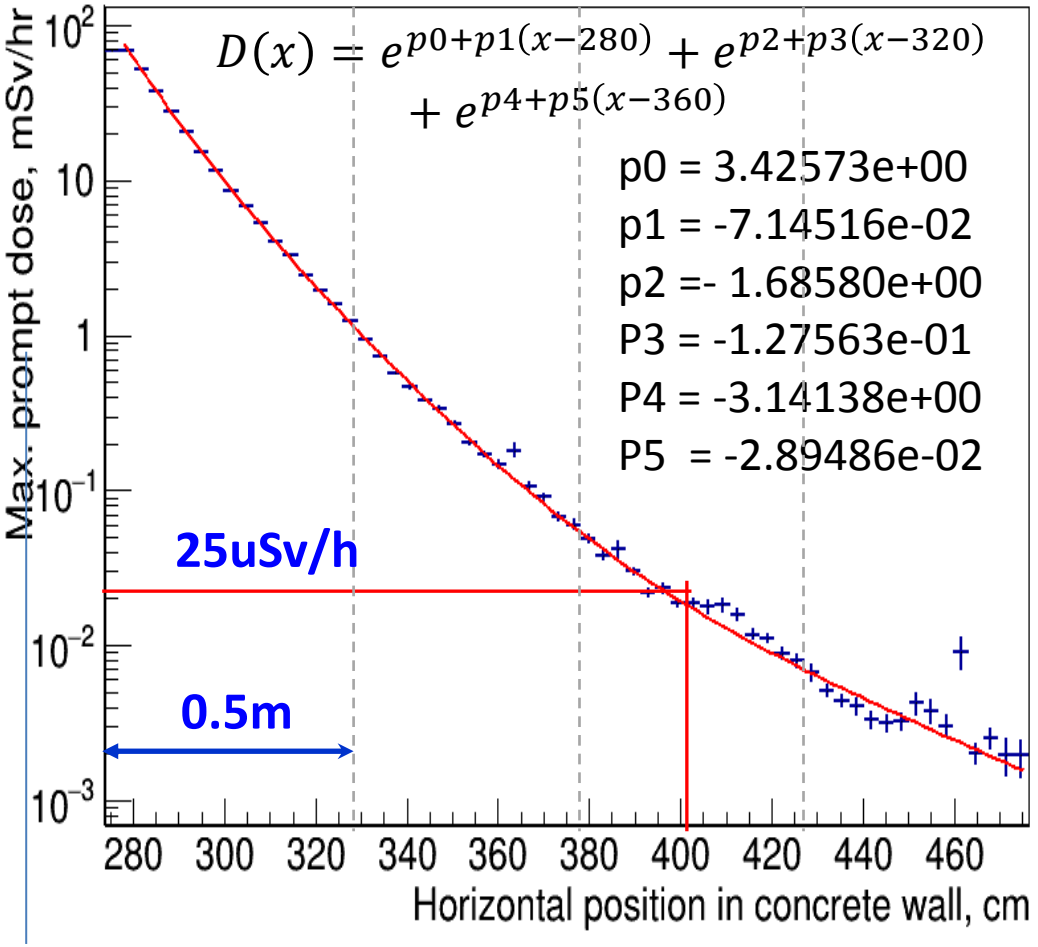


Contibution of photons

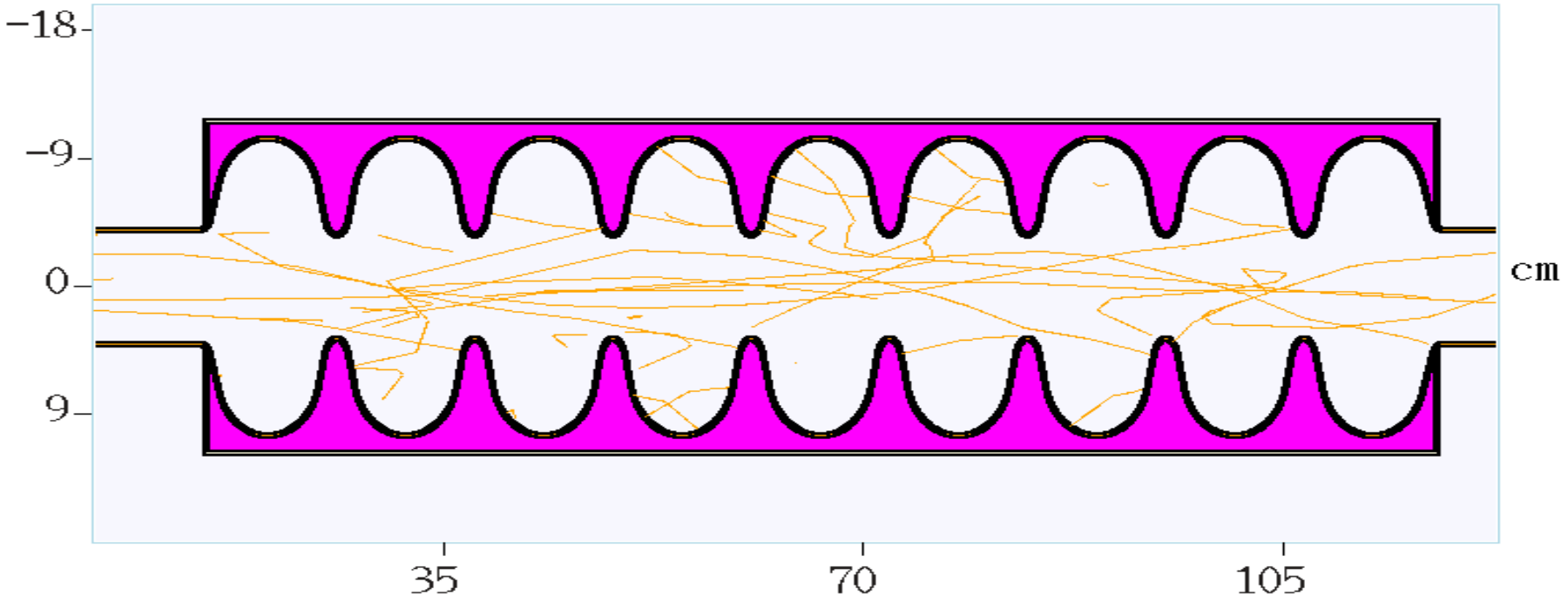
Concrete wall thickness



Fit for attenuation curve for prompt dose, mSv/hr



New possibility: tracking secondary particles in cavity field in MARS:



Tracking code and rf field maps is incorporated in MARS

Conclusion and Further studies

Based on preliminary results the concrete wall thickness between tunnels can be reduced from 3.5m to 1.5m.

Next steps:

Study possible dark current growing along the Linac

- Define saturation length for each quad settings (from 5GeV to 250 GeV) - *in progress*
- MARS simulation for worst cases.

Estimate effect of re-acceleration of secondary electrons in cavities.