High Electron Beam Dose Modification using Transverse Magnetic Fields

Ion Chamber Response Modification under Strong Magnetic Field Conditions

Sion Koren, Radiation Oncology

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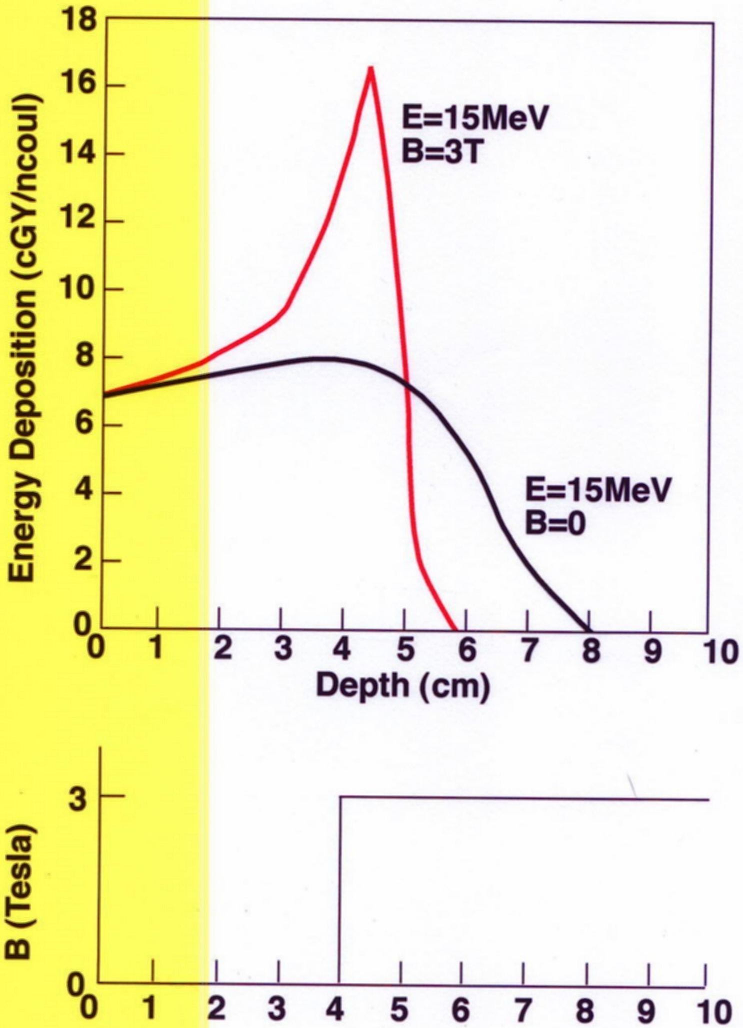
Preface

- Manipulation on charged particle beam for RT benefit.
- Suggested 1950, but has not been implemented (yet?) Bostick W H 1950 Possible Techniques in Direct-Electron-Beam Tumor Therapy *Physical Review* **77**(4) 564-565
- Usage of B fields
  - Transverse B field inn depth as step function



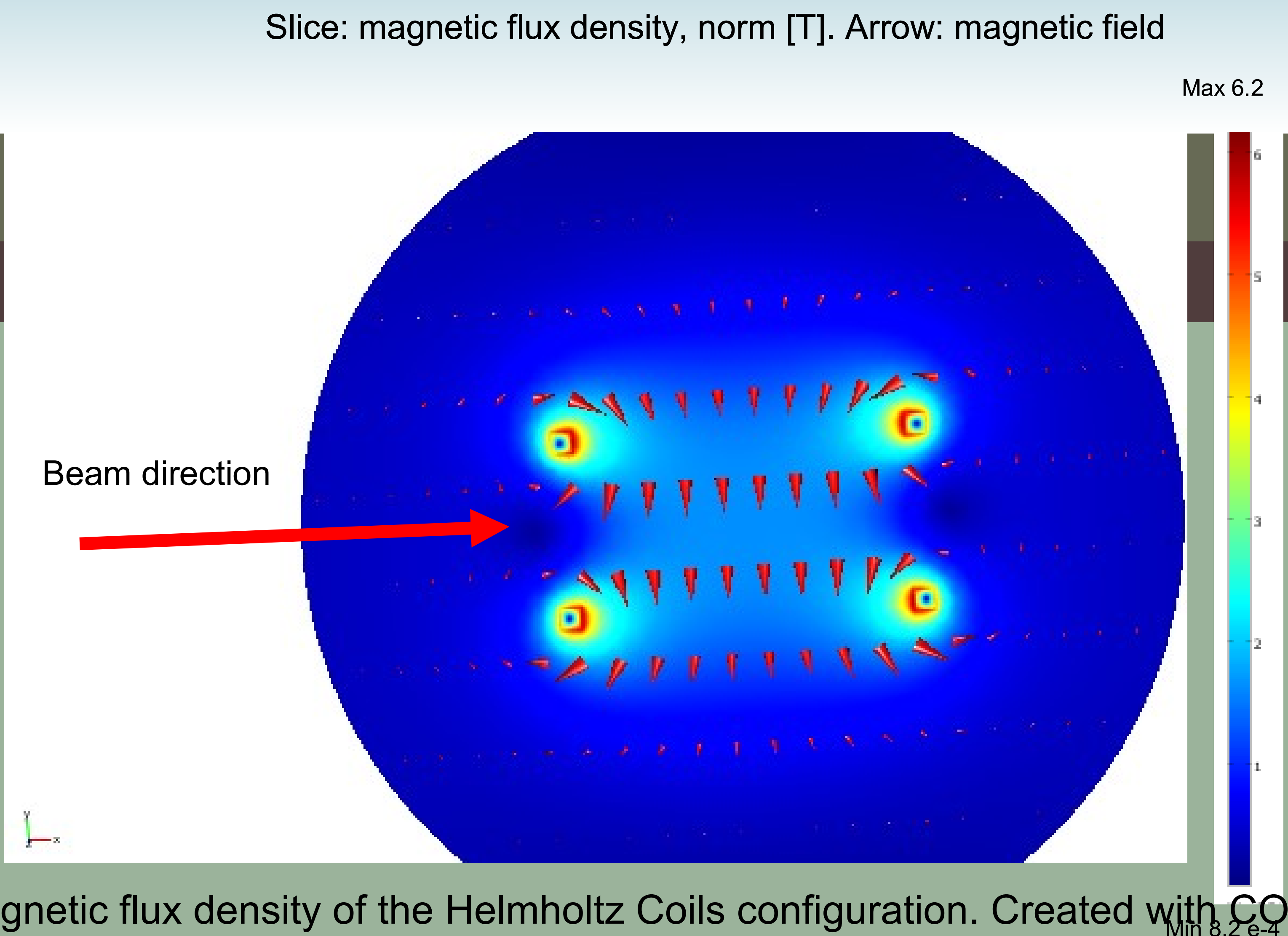
[3]Lee M C and Ma C M 2000 Monte Carlo characterization of clinical electron beams in transverse magnetic fields *Phys Med Biol*. 2947-2967

[4]Nardi E, Barnea G And Ma C M Electron beam therapy with coil-generated magnetic fields *Medical Physics* **31**(6) 1494-1503

Motivation

- Examine the feasibility of applying transverse B fields from a Helmholtz configuration.
  - Generating the flux map densities for X y and Z directions.
  - Transport in this B field

Generating B field maps- Comsol



Magnetic flux density of the Helmholtz Coils configuration. Created with COMSOL Multyphysics®.

Exporting from Comsol

- 3 matrices for the field flux density, for each direction.
- Check data sequence for future map reading

Magfld.f

```
*----------------------------------------------------------------------*
*                                                                      *
*     Copyright (C) 1988-2005      by Alberto Fasso` & Alfredo Ferrari *
*     All Rights Reserved.                                             *
*                                                                      *
*                                                                      *
*     Created  in 1988    by     Alberto Fasso`, CERN - TIS            *
*                                                                      *
*     Last change on 11-dec-92     by    Alfredo Ferrari               *
*                                                                      *
*     Input variables:                                                 *
*            x,y,z = current position                                  *
*            nreg  = current region                                    *
*     Output variables:                                                *
*            btx,bty,btz = cosines of the magn. field vector           *
*            B = magnetic field intensity (Tesla)                      *
*            idisc = set to 1 if the particle has to be discarded      *
*                                                                      *
*----------------------------------------------------------------------*
```

Initial array readings

```
$ CREATE MAGFLD.FOR
*COPY MAGFLD
*
*===magfld=============================================================*
*
      SUBROUTINE MAGFLD ( X, Y, Z, BTX, BTY, BTZ, B, NREG, IDISC )

      INCLUDE '(DBLPRC)'
      INCLUDE '(DIMPAR)'
      INCLUDE '(IOUNIT)'
!      COMMON XXX,YYY,ZZZ,XXX1,YYY1,ZZZ1
      integer i, j ,k, ii, jj, kk
      dimension XXX1(61,61,61)
      dimension YYY1(61,61,61)
      dimension ZZZ1(61,61,61)
             LOGICAL LFIRST
*
!       real double precision  temp1, temp2, temp3
       SAVE LFIRST,  XXX1,  YYY1 , ZZZ1
       DATA LFIRST / .TRUE. /


*   |  First call initializations:
      IF ( LFIRST ) THEN
*   |  *** The following 3 cards are mandatory ***
          LFIRST = .FALSE.
*   |  *** User initialization ***
*  read here your field values once
*  and save their array adding its name on the SAVE statement above

       write(LUNOUT,*) 'Initializing X...'
*       CALL OAUXFI('XXX',LUNRDB,'OLD',IERR)
       open(unit=40,file='../XXX',status='old')
       do i=1,61
          do j=1,61
             do k=1,61
*                read (XXX,105)XXX1(i,j,k)
                 read(40,*) XXX1(i,j,k)   !  , XXX1(i,j,2),XXX1(i,j,3),!
*      &    XXX1(i,j,4), XXX1(i,j,5)
*105         FORMAT (F10.5)
        enddo
          enddo
*          read(40,*)
           enddo
        close(40)
*       CLOSE(LUNRDB)

       write(LUNOUT,*) 'Initializing Y...'
*       CALL OAUXFI('YYY',LUNRDB,'OLD',IERR)
```

Define arrays

Save LFIRST in order to read the arrays only @ the beginning of transport

Output Indication

Have your arrays in your running directory

Free format reading

Close the file

Output file print

```
      enddo
        close(42)
*       CLOSE(LUNRDB)

      write(LUNOUT,*) 'B initialized!'
      ENDIF

*----------------------------------------------------------------------*
*                                                                      *
*     Copyright (C) 1988-2005      by Alberto Fasso` & Alfredo Ferrari *
*     All Rights Reserved.                                             *
*                                                                      *
```

LFIRST ENDIF

Transporting according to B field arrays

```
*------------------------------------------------------------------------*
      if (X<-60.0.or.X>0-30.0.or.abs(Y)<-15.0.or.abs(Z)<-15.0)then
      B=0.0
      return

      else


         ii=61
         jj=61
         kk=61
      do k=1,61
      if(X>-60.5+k/TWOTWO.and.X<-60.5+(k/TWOTWO+0.5)) then
!        if(X>-61.0+k.and.X<-61.0+(k+1.0)) then

         kk=k
         exit
      endif
      enddo
      do j=1,61
      if(Y>-15.5+j/TWOTWO.and.Y<-15.5+(j/TWOTWO+0.5)) then
         jj=j
         exit
      endif
      enddo
```

Transport position Outside our array

Finding particle's X position in 5 mm mesh inside the array

Once it's found, moving for the Y direction etc.

Transporting according to B field arrays (cont.)

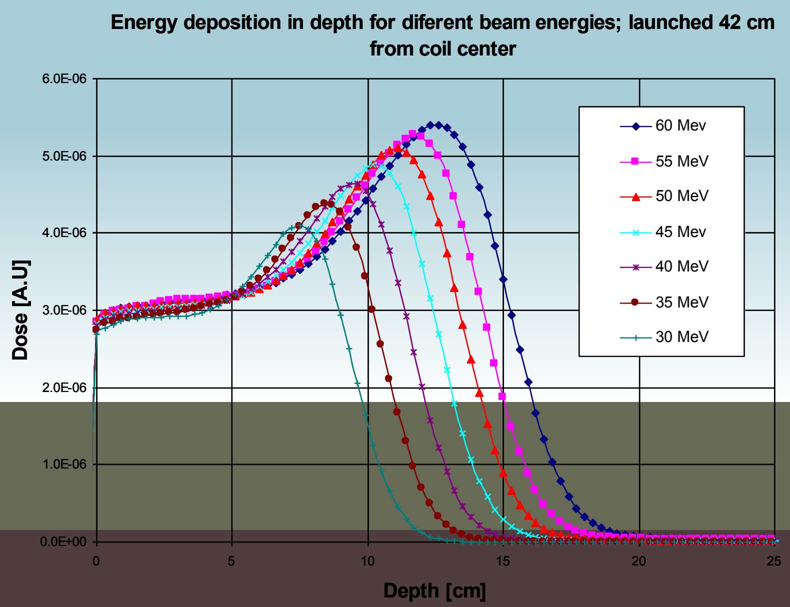
```
!       write(LUNOUT,*) ii,jj,kk
      BTX=XXX1(kk,jj,ii)
      BTY=YYY1(kk,jj,ii)
      BTZ=ZZZ1(kk,jj,ii)
!       write(LUNOUT,*) ii,jj,kk , BTX, BTY , BTZ
      B=SQRT(BTX**2+BTY**2+BTZ**2)
      BINLEN=ONEONE/B
*SQRT(BTX**2+BTY**2+BTZ**2)
      BTX=-ONEONE*BTX*BINLEN
      BTY=BTY*BINLEN
      BTZ=BTZ*BINLEN
!       temp1=BTX
!       temp2=BTY
!       temp3=BTZ
!          BTX=temp2
!           BTY=temp3
!            BTZ=temp1
      RETURN

      endif



      WRITE (LUNOUT,*)
*     &       ' Magfld called in zone ',NREG,' where there should'
      WRITE (LUNOUT,*)
*     &       ' be no magnetic field. Something is wrong'
      IDISC = 1
      RETURN
*=== End of subroutine magfld ==========================================*
      END
```

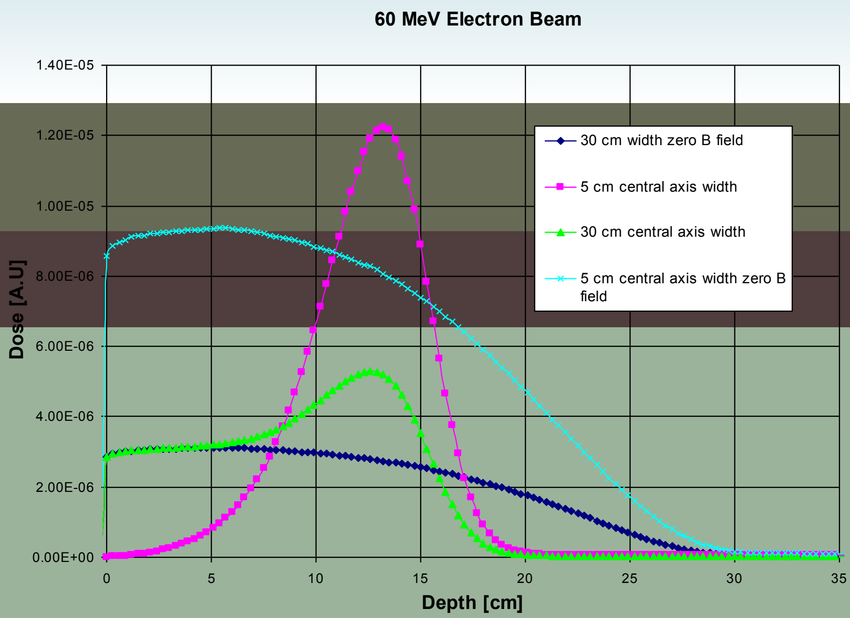
Setting corresponding field values

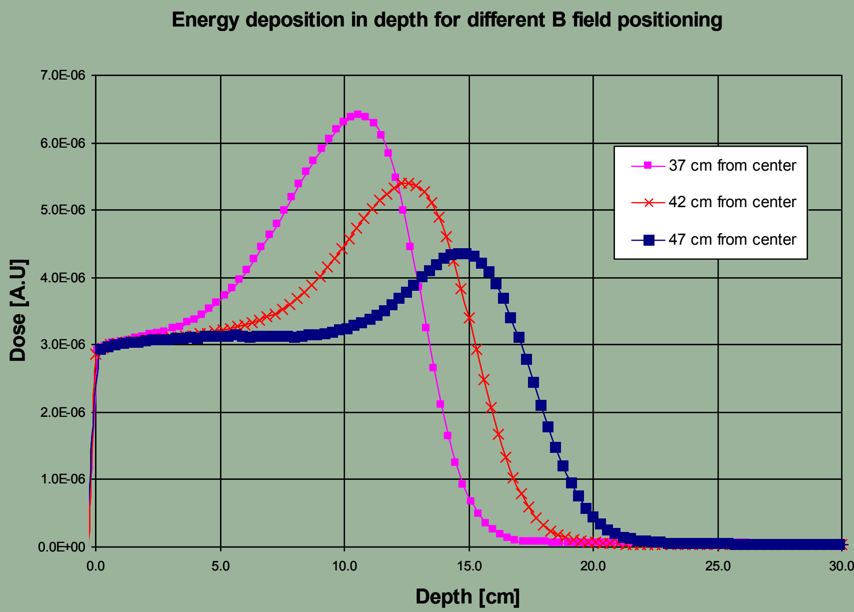
Field magnitude

Normalization: very very very important

Results





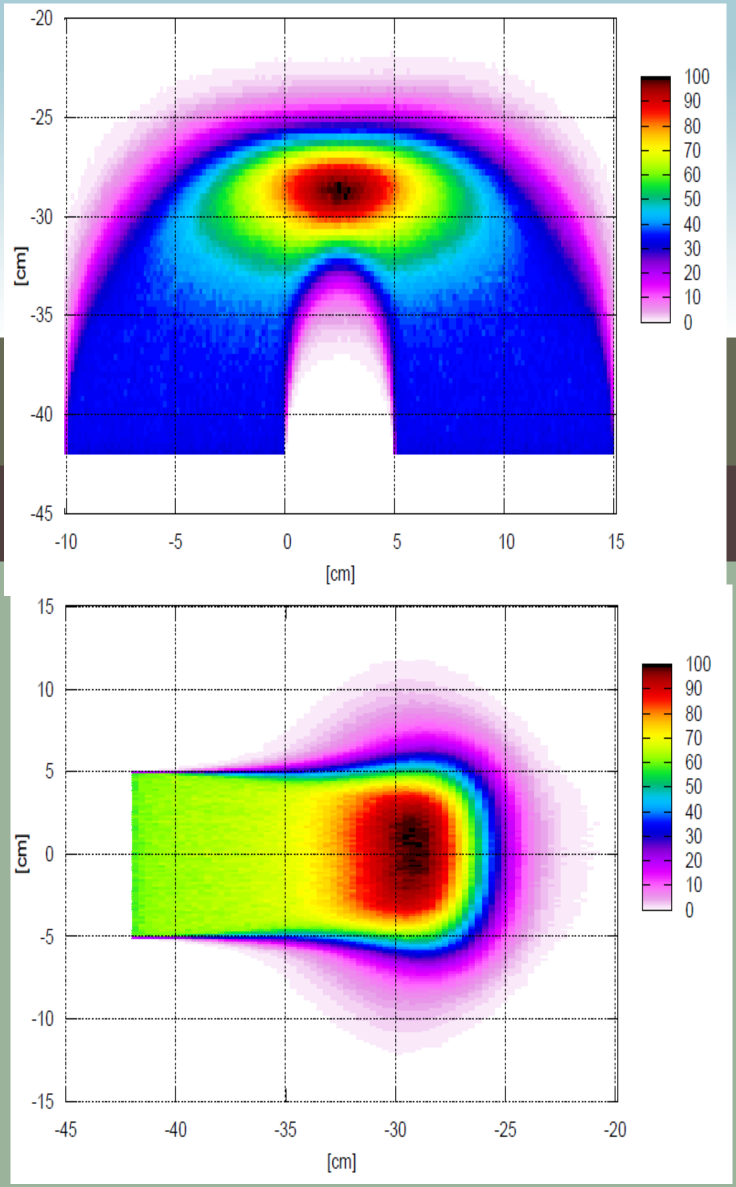


Energy deposition in depth curves for a 60 MeV electron two fields beam. One field is delivered with opposite current direction in coils, regarding the other.

Top: Energy deposition in depth for different electron beam energies, applied 25 cm from the center axis of the coils. Bottom: Energy deposition in depth for 60 MeV electron beam applied at different distances from the center axis of the coils.

Results

Normalized energy deposition distribution.



Normalized energy distributions for a 60 MeV electron two fields beam. One field is delivered with opposite current direction in coils, regarding the other. Top: X-Y plane. Bottom: X-Z plane

Ion Chamber Response Modification under Strong Magnetic Field Conditions

S Koren, R Price , A Guemnie Tafo , I Veltchev,
E Fourkal and C-M Ma

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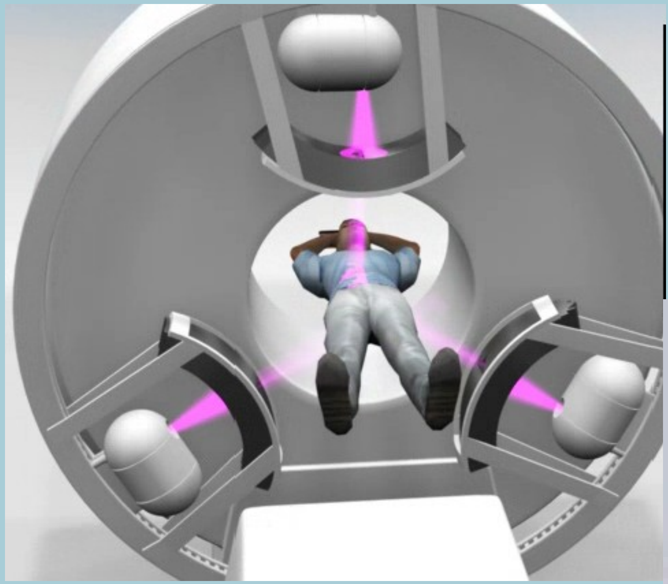
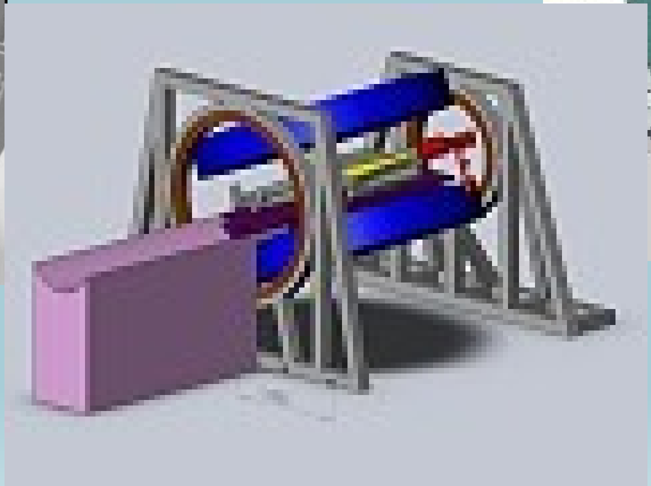
PREFACE

- Among the recently IGRT developments, the Linac-MRI coupled systems for soft tissues IGRT, was introduced.
- A requirement to perform dosimetry under magnetic field conditions has arisen.
- Can the ion chamber be used for dosimetry in the presence of a magnetic field?
- Response of a Farmer type chamber in 1.5T B field (measurements and MC simulations)

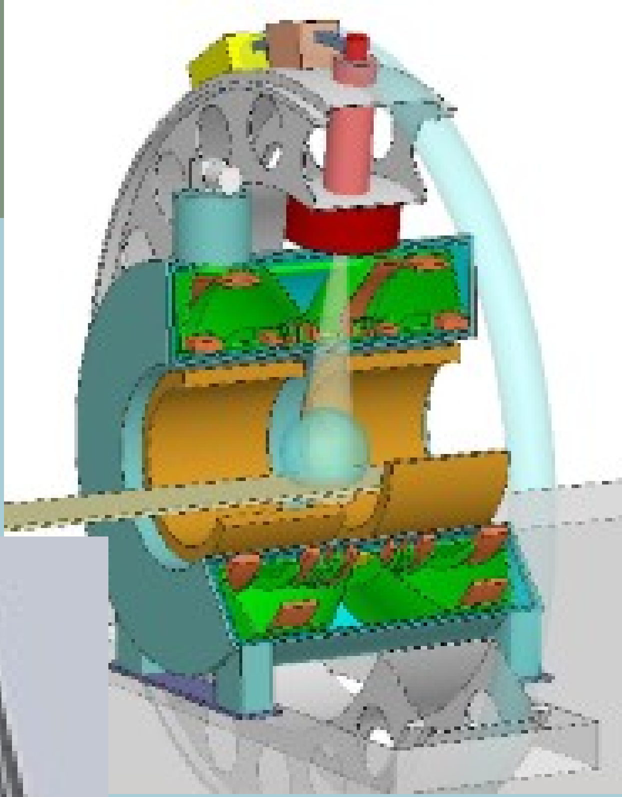
MRI LINAC



ViewRay inc. (Cleveland):
-0.2 T MRI
-3 Cobalt sources with 3 MLCs



Univ. of Alberta:
-0.2 T MRI
-6MV Accelerator



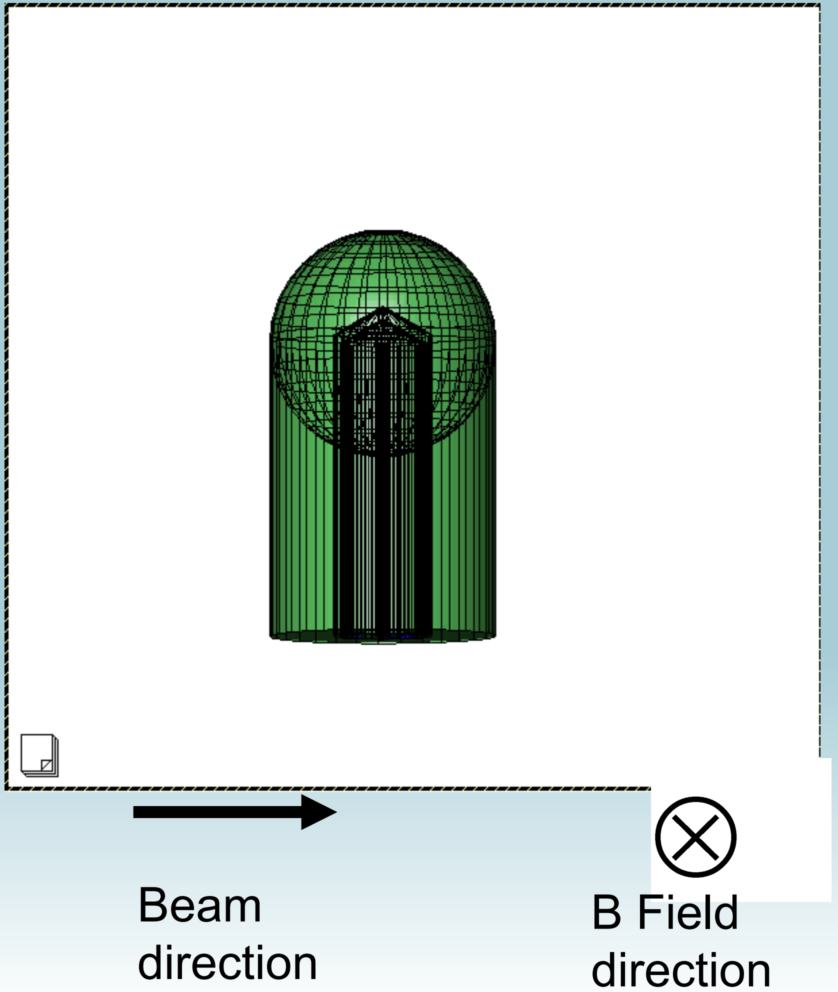
-Utrecht Univ. UMC
-Cylindrical 1.5T closed-bore MRI
-6MV accelerator

Dose modification

$$P_{\perp} = 3.00 \cdot B \cdot r$$

MeV/c Tesla cm

- In the presence of the B field, electrons will spiral about B field lines, following a helical track.
- The gyration radius is described in vacuum as a function of the perpendicular momentum of the electron with respect to the B field lines, and the B field magnitude.



Dose modification - magnitude and direction

- Number of electrons entering the chamber's cavity.
- The track length of electrons inside the cavity.
- Difference between transverse and longitudinal field direction with respect to beam propagation.
- The cylindrical shape of the chamber will introduce an additional spatial alignment dependency, with respect to the B field direction.

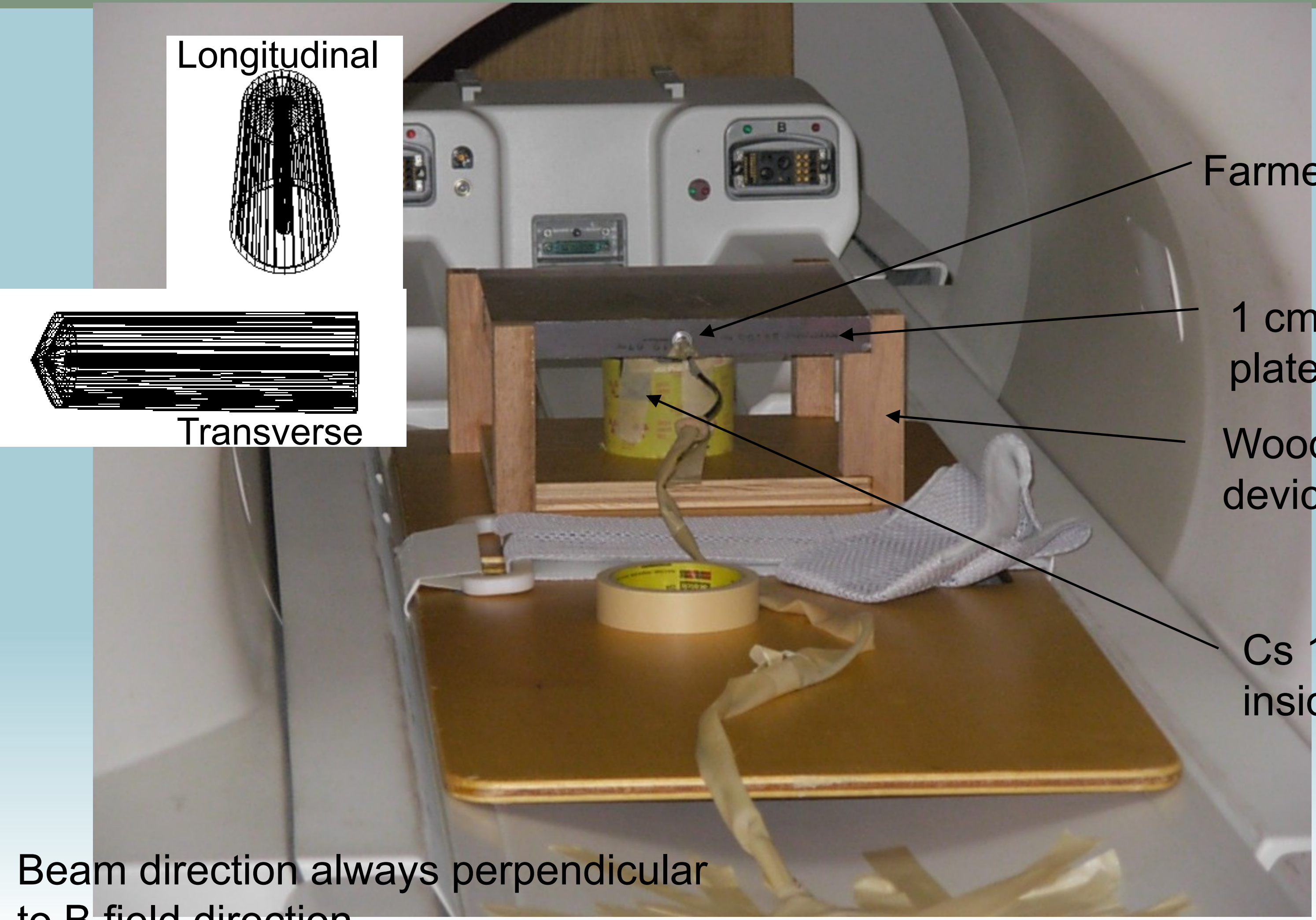
Meijsing I, Raaymakers B W, Raaijmakers A J E, Kok J G M, Hogeweg L, Liu B and Lagendijk J J W Dosimetry for the MRI accelerator: the impact of a magnetic field on the response of a Farmer NE2571 ionization chamber Phys. Med. Biol. 54 2993-3002 (2009).

Measurements Setup

- Ion Chamber: PTW 0.6 cc Farmer type chamber.
- Magnetic field: GE MRI 1.5 T bore
- Radiation Source: Cs-137 11.17 mCi (662 keV gamma emitter)
- A wooden frame was designed to allow varying field direction measurements (transverse and longitudinal with respect to chamber central axis) while keeping the source to chamber axis distance constant and on the same pivot.

Measurements Setup (cont.)

MRI Bore 1.5
Tesla B field

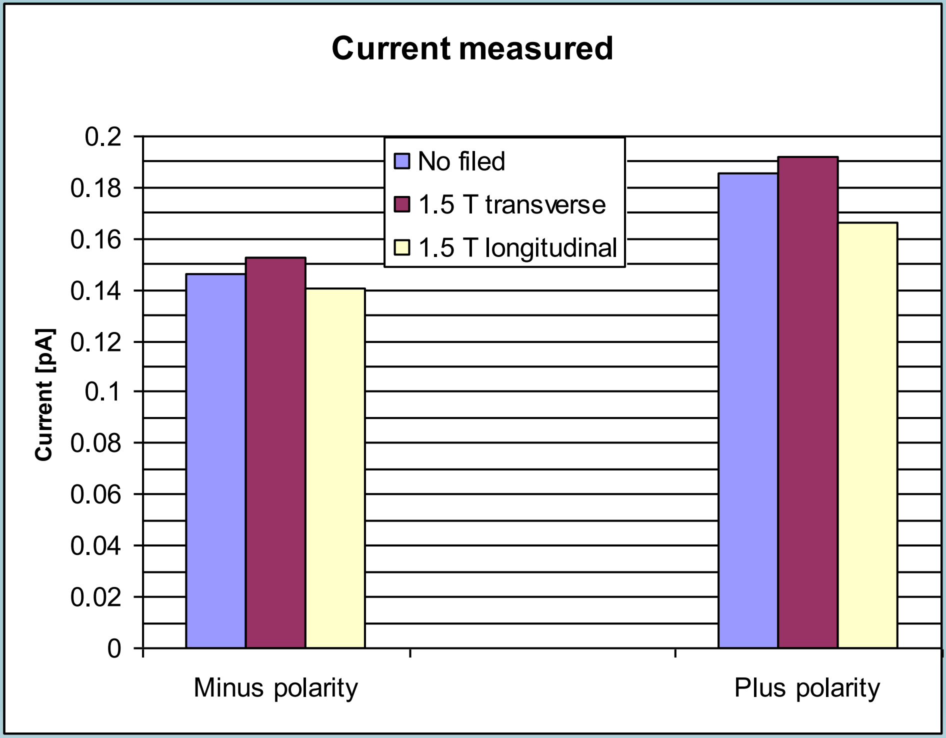


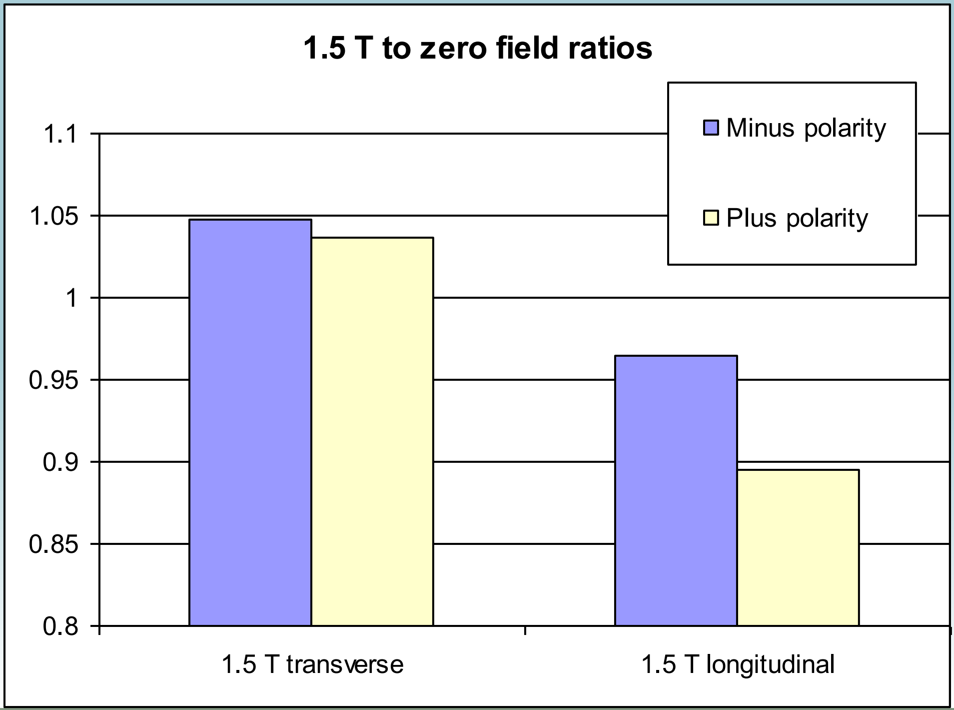
Beam direction always perpendicular to B field direction.

Measurements

- Chamber current was measured for transverse and longitudinal B field directions:
  - Taking into account different polarities.
  - Measuring the dependency for different applied voltage.

Results: chamber response

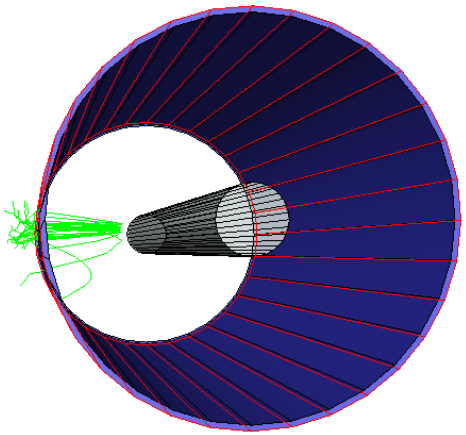




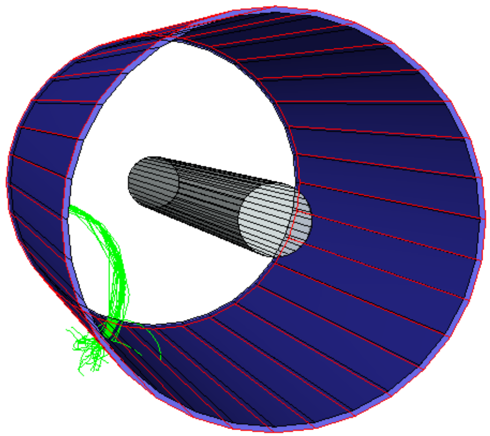
Electron tracks: Longitudinal vs. Transverse

350 keV electrons perpendicularly from the outer electrode.

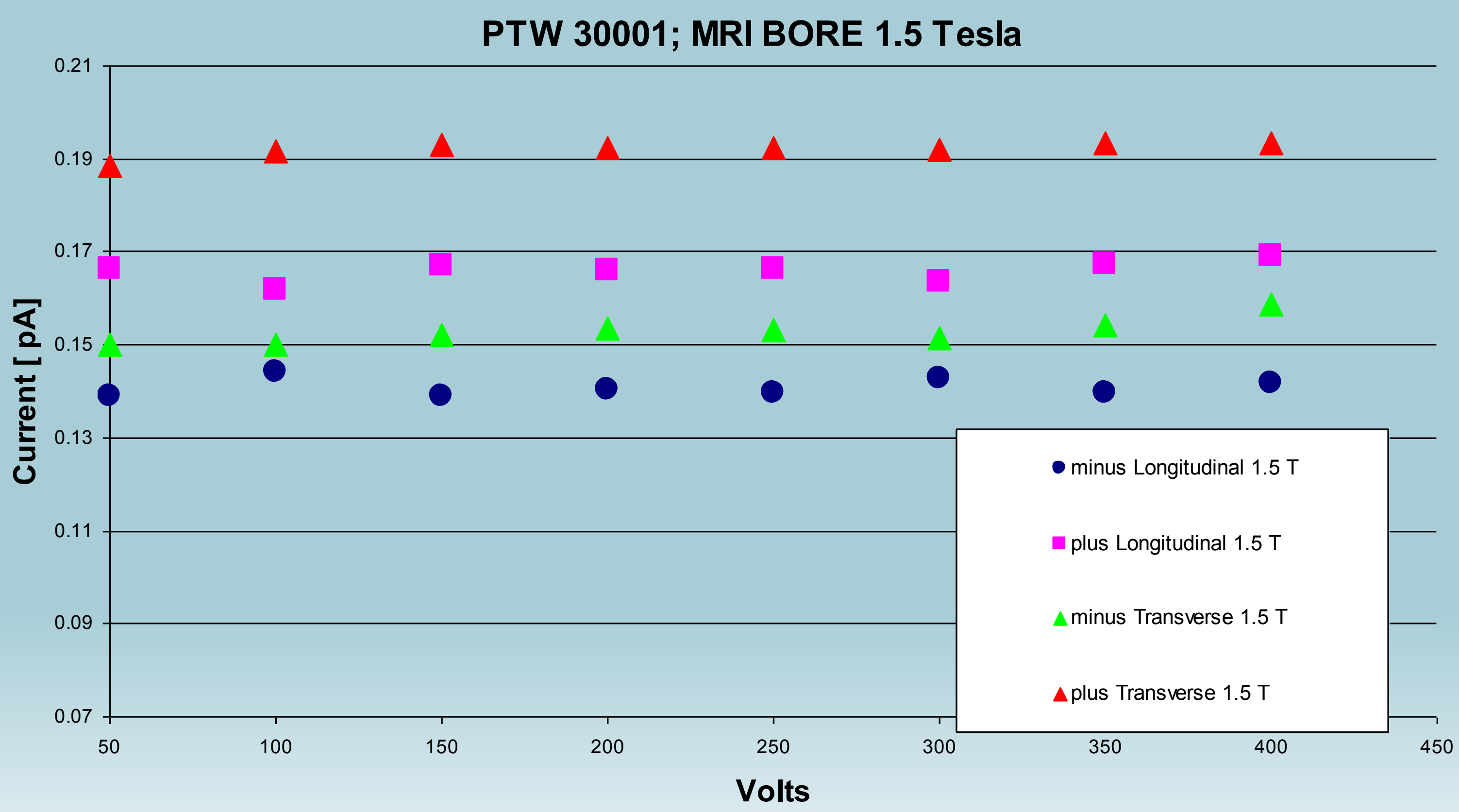
Transverse field



Longitudinal field



Chamber reading vs. the applied voltage



Monte Carlo simulation: FLUKA

- Transport in magnetic fields:

  MGNFIELD card/ magfld.f user routine

- Scoring:
  - Energy deposition inside cavity
  - Average electron track length in cavity
  - Fluence of electrons entering the cavity

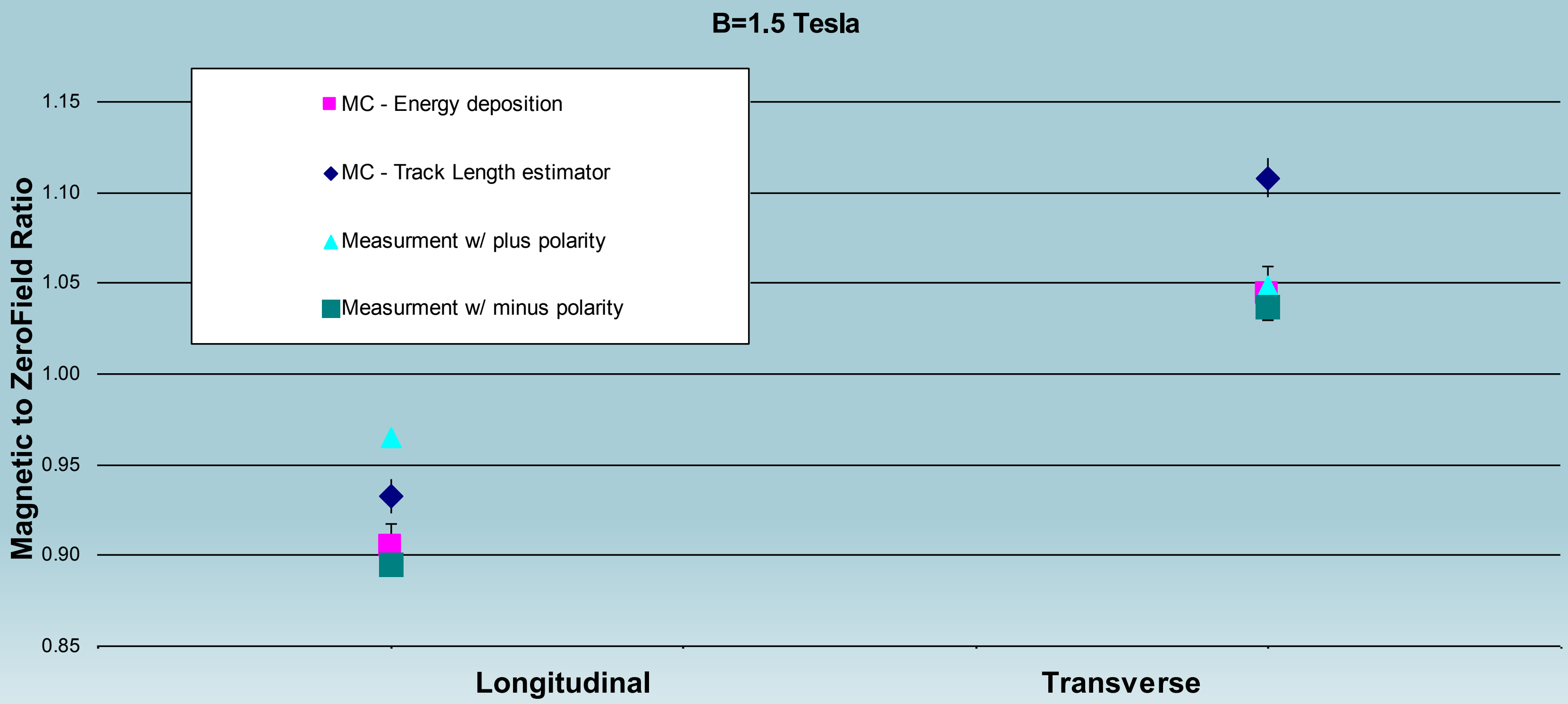
THE SIMULATION SETUP

- Cs-137 662 keV (Modeling a 6 MV and Co-60 source, can be done using Fluka user routines).
- Transport can be simulated in a single scattering electron step ("MULSOPT" card - time consuming)
- Cutoffs set to Fluka lower limit – 1 keV.
- Simulation was performed using FLAIR- Fluka advanced interface.
- Trajectory plotting held with Simple-Geo (PipsiCAD macro)

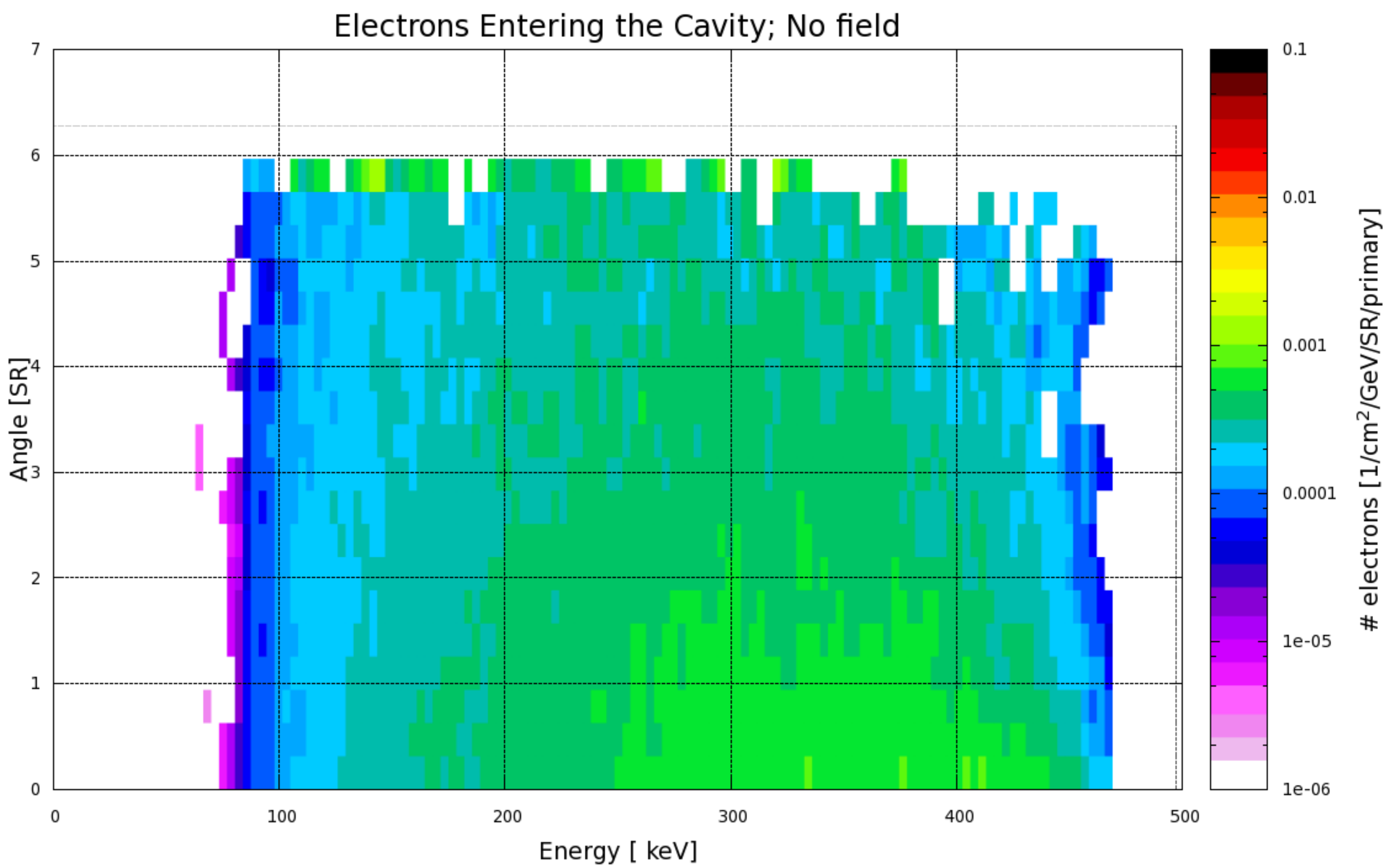
Theis C., B.K.H., Brugger M., Forkel-Wirth D., Roesler S., Vincke H. Interactive three dimensional visualization and creation of geometries for Monte Carlo calculations. Nuclear Instruments and Methods in Physics Research A 562, pp. 827-829 (2006).

Vlachoudis V. "FLAIR: A Powerful But User Friendly Graphical Interface For FLUKA" Proc. Int. Conf. on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York (2009).

MC Results: magnetic to zero field ratios



Cs137; Electron Entering the Cavity



Summary: B Field to Zero Field Ratios

	Monte Carlo	Cesium 137 (662 keV)
Transverse	Energy deposition in cavity (USRBIN card)	1.04
	Average track length	1.11
Longitudinal	Energy deposition in cavity (USRBIN card)	0.91
	Average track length	0.93

Measurements	Cesium 137 (662 keV)
transverse	1.04
longitudinal	0.93

Discussion; FLUKA input

MULSOPT card: control MCS

Discussion; Scoring

- What would be the proper way to score energy deposition in ion chamber dosimetry simulation?
  - USRTRACK USRBIN etc.
- Particle splitting
- How to record particle entering-exiting areas (even several times for the same history)

Conclusions

- The magnetic field modifies the charge measured in an ion chamber.
- The electric field is a small perturbation to ion collection and does not play a role in B field measurements.
- Polarity is more significant in the B field, and is more significant for longitudinal chamber alignment.
- Correction factors can be obtained for any source and magnetic field parameter.
- The Fluka MC code system is capable of simulating IC response in B fields.
- A spherical chamber shape will reduce geometrical shape dependencies, but a correction according to the field magnitude and beam to field directions, may still be needed.
- Liquid filled ion chambers can overcome average track length modification.
- Smaller cavity chambers are expected to elicit a decreased modification response due to the presence of the magnetic field.

THANKS

- Sion Koren

Sion.Koren@fccc.edu

ENERGY LOSS STRAGGLING

In "ETRAN" energy loss in track segments are sampled from the straggling distribution of the Landau modified by Blunck and Leisgang. This is done for the basic segment (i.e. m=1).

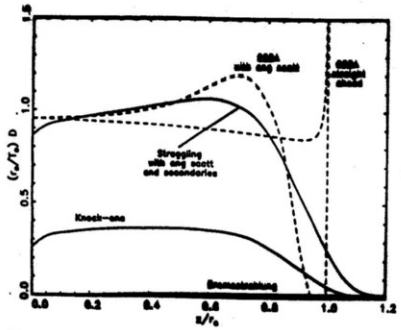


Figure 7.9. Absorbed-energy distribution for a broad beam of 20-MeV electrons incident perpendicularly on a thick slab of water. Results are given in terms of the dimensionless quantity $(r_o/T_o)D$, where $D(z)$ is the dose absorbed per unit depth at depth z, r_o is the incident electron's mean range and T_o its kinetic energy, and are plotted as a function of the scaled depth z/r_o. Results are shown for three transport-model choices: (a) primary electrons only, in the continuous-slowing-down approximation (csda) and with no angular deflections (straight ahead); (b) primary electrons only, csda and with angular deflections; and (c) energy-loss straggling with angular deflections and the transport and subsequent energy deposition by secondary electrons and bremsstrahlung photons. In cases (a) and (b), all bremsstrahlung was assumed to escape the target; for case (c), the contribution to the depth-dose is shown also separately for the knock-on electron (> 1 keV) and the bremsstrahlung components.