MODEL-BASED DOSE CALCULATION ALGORITHMS IN BRACHYTHERAPY

2017 AAPM SUMMER SCHOOL
CLINICAL BRACHYTHERAPY PHYSICS

In conjunction with the American Brachytherapy Society

CONFLICT OF INTEREST STATEMENT

- Luc Beaulieu was involved in initial validation of ACE through a research contract from Elekta.

- Ron Sloboda: research equipment and software have been provided by Elekta Brachytherapy and Varian Medical Systems

- Mark J Rivard and Firas Mourtada have no conflict to declare for this session

✓ Specific commercial algorithm, equipment, instruments, and materials are described to fully describe the necessary processes and procedures. Such identification does not imply recommendation or endorsement by the presenters nor imply that the identified algorithm, material or equipment is the best available.

✓ Opinions expressed are solely those of the speaker and are not meant to supersede official societal guidance.

MODEL-BASED DOSE CALCULATION: AN INTRODUCTION

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LEARNING OBJECITVES

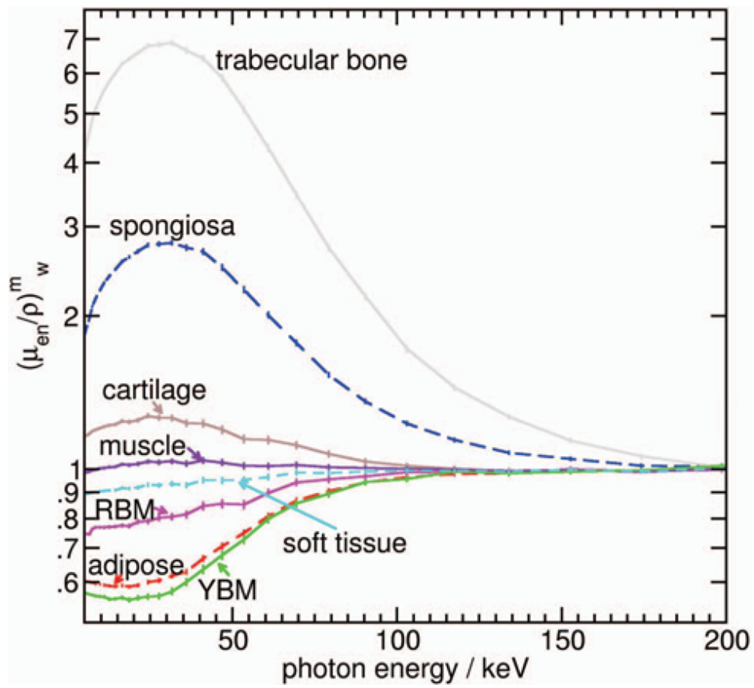
- Recast the dose calculation problem in term of transport physics
- Identify the assumptions needed to solve the transport equation

KEY REFERENCES

- Rivard MJ, Venselaar JLM, Beaulieu L. **The evolution of brachytherapy treatment planning**. Med Phys 2009;36:2136–53.
- Papagiannis P, Pantelis E, Karaiskos P. **Current state of the art brachytherapy treatment planning dosimetry algorithms**. Br J Radiol 2014;87(1041):20140163.
- **Monte Carlo Techniques in Radiation Therapy**. Joao Seco and Frank Verhaegen, CRC press, Taylor & Francis, 2016
- **Comprehensive Brachytherapy: physical and clinical aspect**. JLM Venselaar, D Baltas, AS Meigooni and P.J. Hoskin. CRC Press, Taylor & Francis, 2013.
- Beaulieu L, Carlsson Tedgren A, Carrier J-F, Davis SD, Mourtada F, Rivard MJ, et al. **Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation**. Med Phys 2012;39(10):6208–36.

LOOKING BACK AT TG43

- Very fast and extremely accurate
  - Based on model-based MC calculation and experimental measurements



- But, assumes:
  - Perfect source superposition
  - Full scatter conditions (infinite medium)
  - Medium = homogeneous water

Sensitivity of Anatomic Sites to Dosimetric Limitations of Current Planning Systems

anatomic site	photon energy	absorbed dose	attenuation	shielding	scattering	beta/kerma dose
prostate	high					
	low	XXX	XXX	XXX		
breast	high				XXX	
	low	XXX	XXX	XXX		
GYN	high			XXX		
	low	XXX	XXX			
skin	high			XXX	XXX	
	low	XXX		XXX	XXX	
lung	high				XXX	XXX
	low	XXX	XXX		XXX	
penis	high				XXX	
	low	XXX			XXX	
eye	high			XXX	XXX	XXX
	low	XXX	XXX	XXX	XXX	

Rivard, Venselaar, Beaulieu, Vision 20/20, *Med Phys* 36, 2136-2153 (2009)

HOW IMPORTANT IN THE CLINIC?

Site / Application	Importance
Shielded Applicators	Huge
Eye plaque	-10% to -30% (TG-129)
Breast Brachy	-5% to -40%
Prostate Brachy	-2% to -15% on D_{90}
GYN	Depends on applicators

TAKING A STEP BACK

ENERGY FLUENCE TO DOSE

- In TG-43, dose is related to energy fluence through S_K.

- At brachytherapy energy:
  - Secondary e^- range is small
    - << photon mean free path
    - << voxel calculation size
  - Radiative Kerma is negligible

$$D = K^{coll} \approx K$$

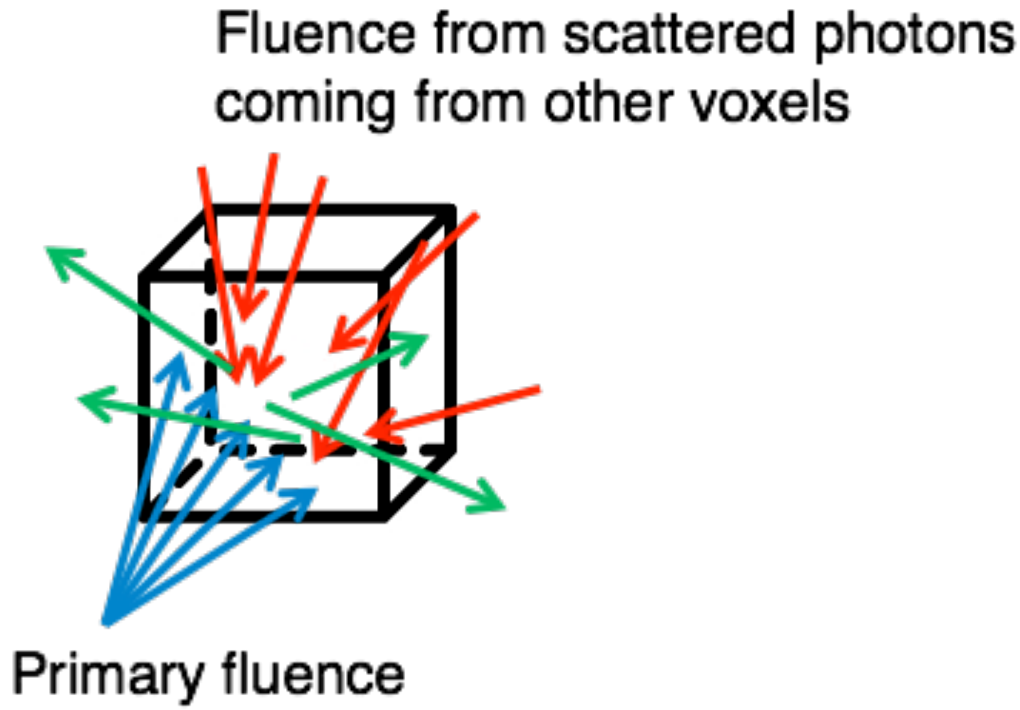
ENERGY FLUENCE TO DOSE

- If the energy fluence is known at all points in the geometry, than the dose rate can be easily computed across that geometry:

$$\dot{D}(\vec{r}) = \dot{K}(\vec{r}) = \int \dot{\Phi}(E,\vec{r},t)E\left({}^{\mu_{en}(E)}\!\big/\!_{\rho}\right)dE$$

WHICH FLUENCE?

Energy balance is held by interacting photons:
- absorbed in the voxel
- scattered outside is



- This can be put in equation

Adapted from Papaganis, ESTRO Adv Brachytherapy Physics Course

LINEAR BOLTZMANN TRANSPORT EQUATION

$$\hat{\Omega}\cdot\nabla\Phi_{\Omega,E}\left(\mathbf{r},E,\hat{\Omega}\right)=Q_{\mathrm{sc}}\left(\mathbf{r},E,\hat{\Omega}\right)+\frac{Q_{\mathrm{prim}}\left(E,\hat{\Omega}\right)}{4\pi}\delta\left(\mathbf{r}-\mathbf{r}_{\mathrm{p}}\right)-\sigma_{\mathrm{t}}(\mathbf{r},E)\Phi_{\Omega,E}\left(\mathbf{r},E,\hat{\Omega}\right) \quad (3)$$

$$\Phi_{\Omega,\mathrm{E}}=\Phi^{\mathrm{prim}}_{\Omega,\mathrm{E}}+\Phi^{\mathrm{sc}}_{\Omega,\mathrm{E}}$$

$$\hat{\Omega}\cdot\nabla\,\Phi^{\mathrm{prim}}_{\Omega,E}=\frac{Q_{\mathrm{prim}}\left(E,\hat{\Omega}\right)}{4\pi}\delta\left(\mathbf{r}-\mathbf{r}_{p}\right)-\sigma_{t}(\mathbf{r},E)\,\Phi^{\mathrm{prim}}_{\Omega,E} \quad (5)$$

✔ Trivial!

$$\hat{\Omega}\cdot\nabla\,\Phi^{\mathrm{sc}}_{\Omega,\mathrm{E}}=Q_{\mathrm{sc}}-\sigma_{t}(\mathbf{r},E)\,\Phi^{\mathrm{sc}}_{\Omega,\mathrm{E}} \quad (6)$$

✖ No analytical solution

Papagiannis et al. Br J Radiol 87 (2014) 20140163.

WHEN ALL ELSE FAILS…

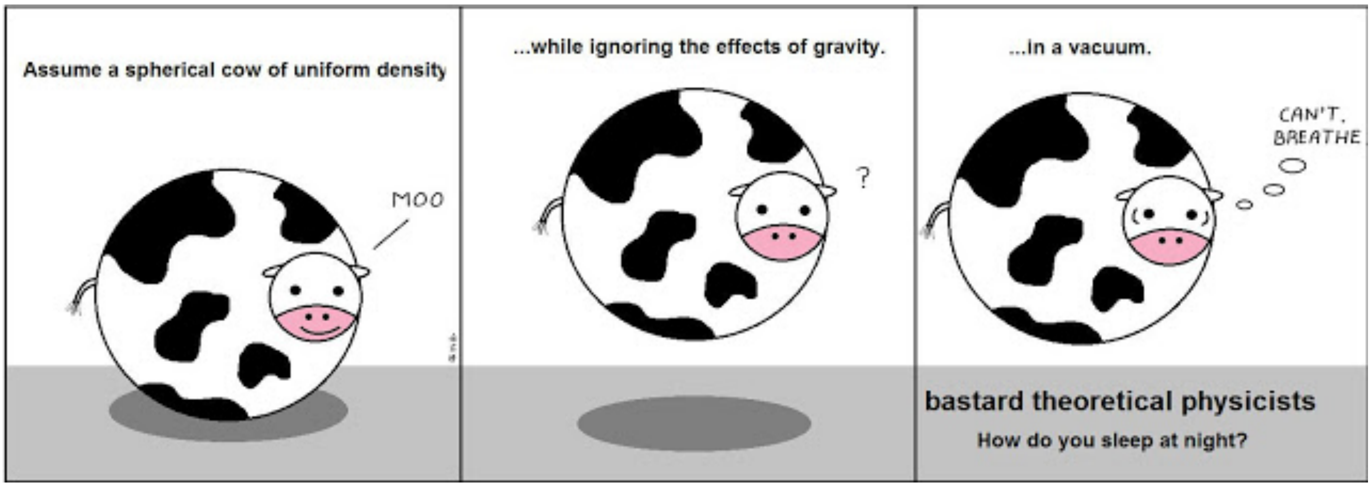


Image from: http://abstrusegoose-com/406

SOLVING THE SCATTER "CHALLENGES"

- Stochastic method
  -> Monte Carlo

- Deterministic methods
  -> Grid-Based Boltzmann Solver

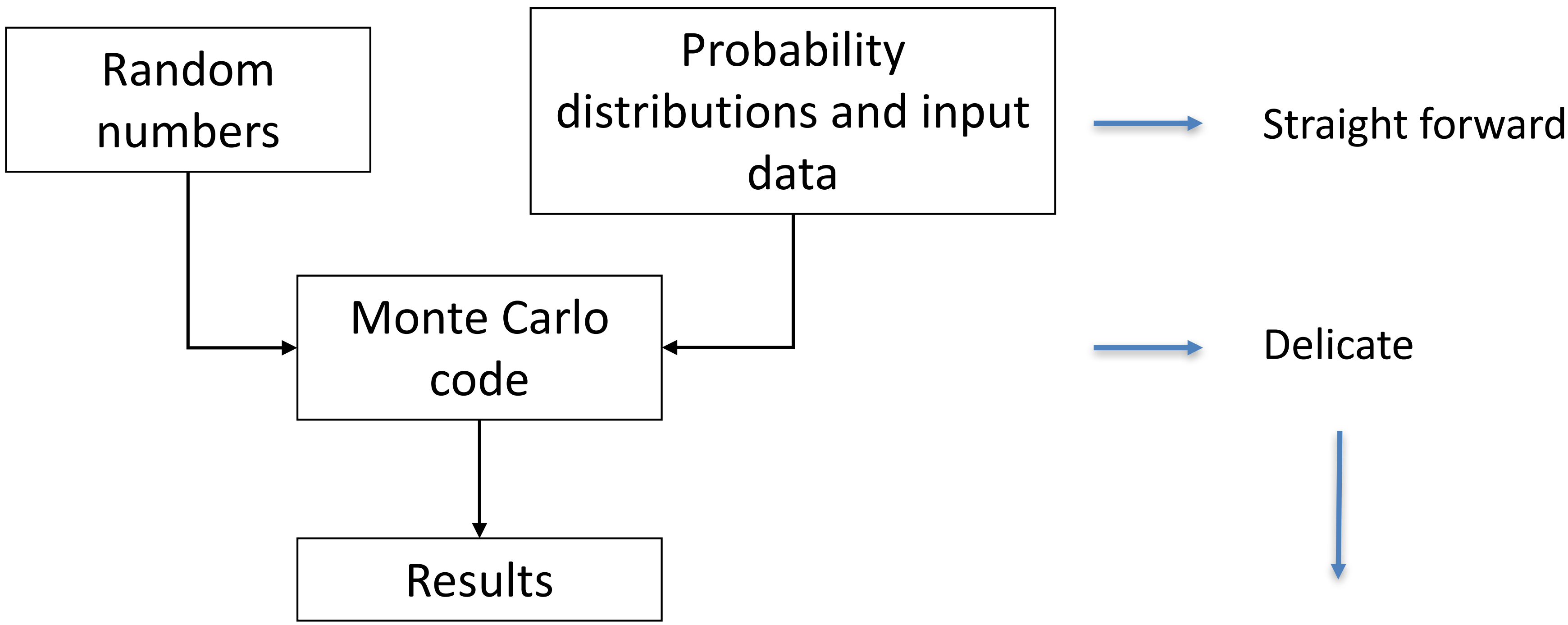
- A mix of both:
  -> Collapsed-Cone convolution

MONTE CARLO

- Intrinsically reproduce the stochastic nature of photon-matter interaction
  - photons deviates only when interacting
  - physics of interactions are known
    - type of interaction
    - residual energy following the interaction
    - direction and distance to the next interaction

-> dictated by cross sections or probability distributions

MONTE CARLO

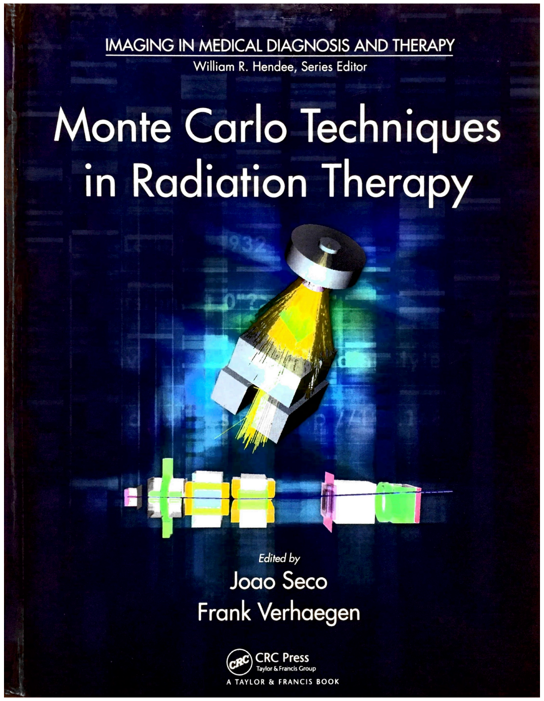


$$\varepsilon = \frac{1}{\sigma^2 T}$$

Efficiency of a MC code is given through the number of histories generated (of calculation time T) and the variance of the quantity of interest

adapted from Papagiannis – ESTRO Adv Phys. Course 2016; Section 2.2.2.1 of 2017 Summer School Book

MONTE CARLO



- General purpose codes
  - MCNP, EGS, ENGnrc, Geant4, Penelope
- Brachytherapy specific
  - PTRAN, MCTP, MCPI, Brachydose, ALGEBRA, egs_brachy
    - reduced physics sets and Dose=Kerma
    - path-length estimators
    - phase space
    - …

CONCLUSION

- TG-43 is very efficient when used in the condition for which it was created…
  - …<u>but not always the case in brachytherapy</u>

- The dose calculation "problem" can be recast intuitively and lead to the Boltzmann transport equation
  - analytical solution only for primary fluence
  - needs numerical methods for full dose calc

- Monte Carlo has been our gold standard for many decades
  - rely on strength (accuracy) of known probability distribution
  - computing power (large numbers!)

THEORY OF MBDCA: GBBS & CCC

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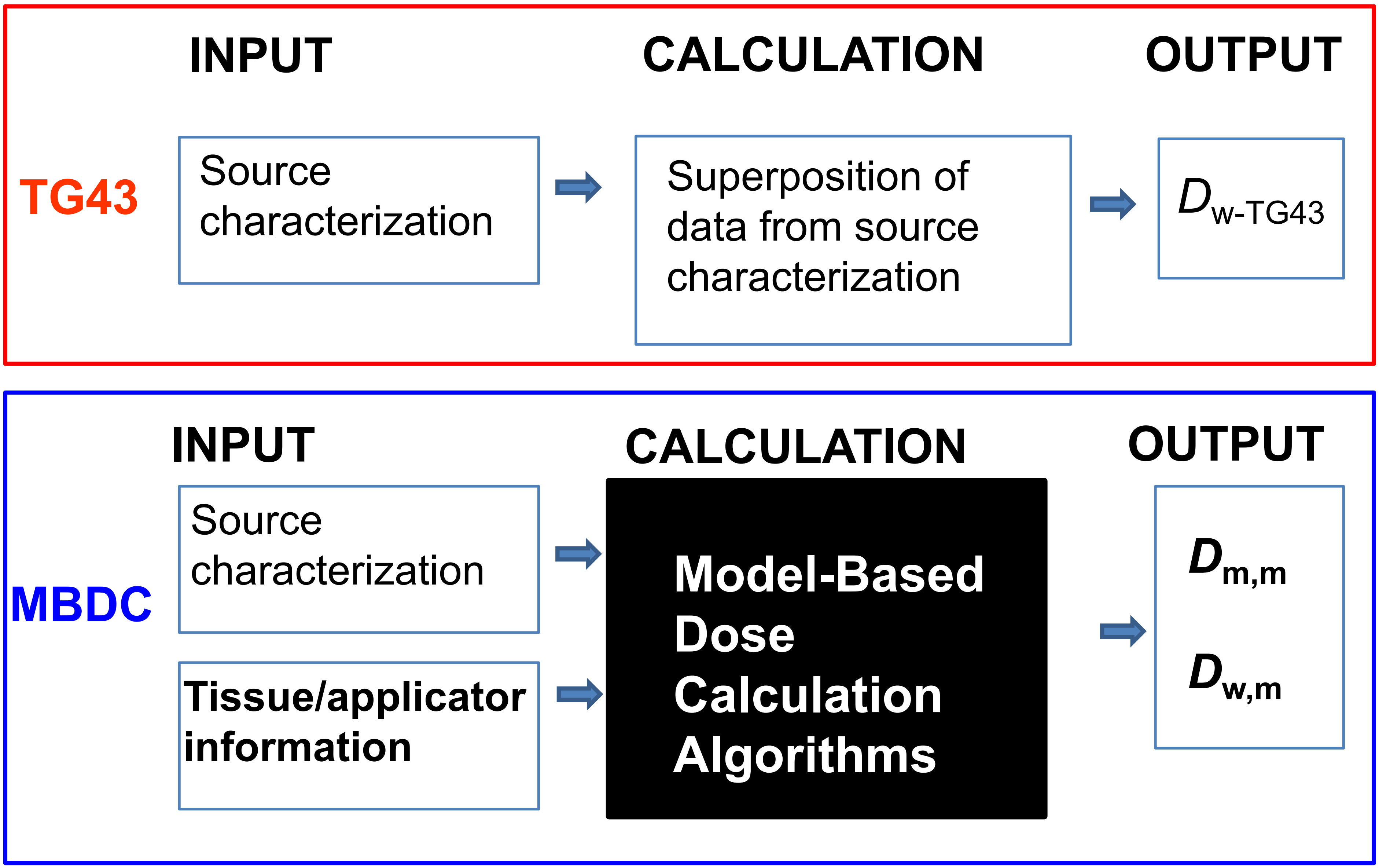
LEARNING OBJECTIVES

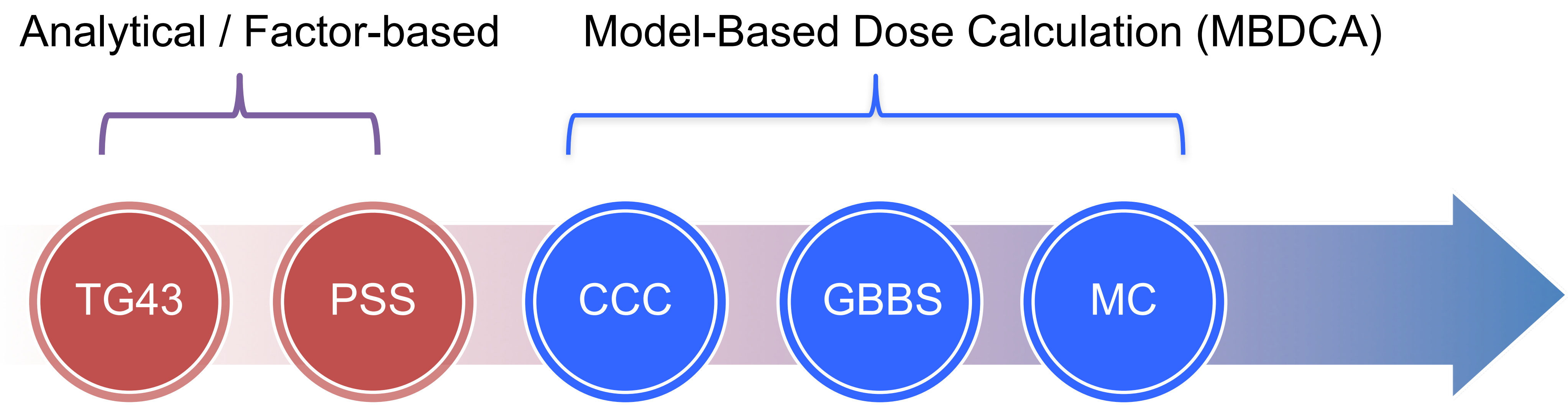
- Review basic principles of Grid-based Boltzmann Solver (GBBS)
- Review basic principles of Collapsed Cone Convolution (CCC)

Factor-based vs Model-based

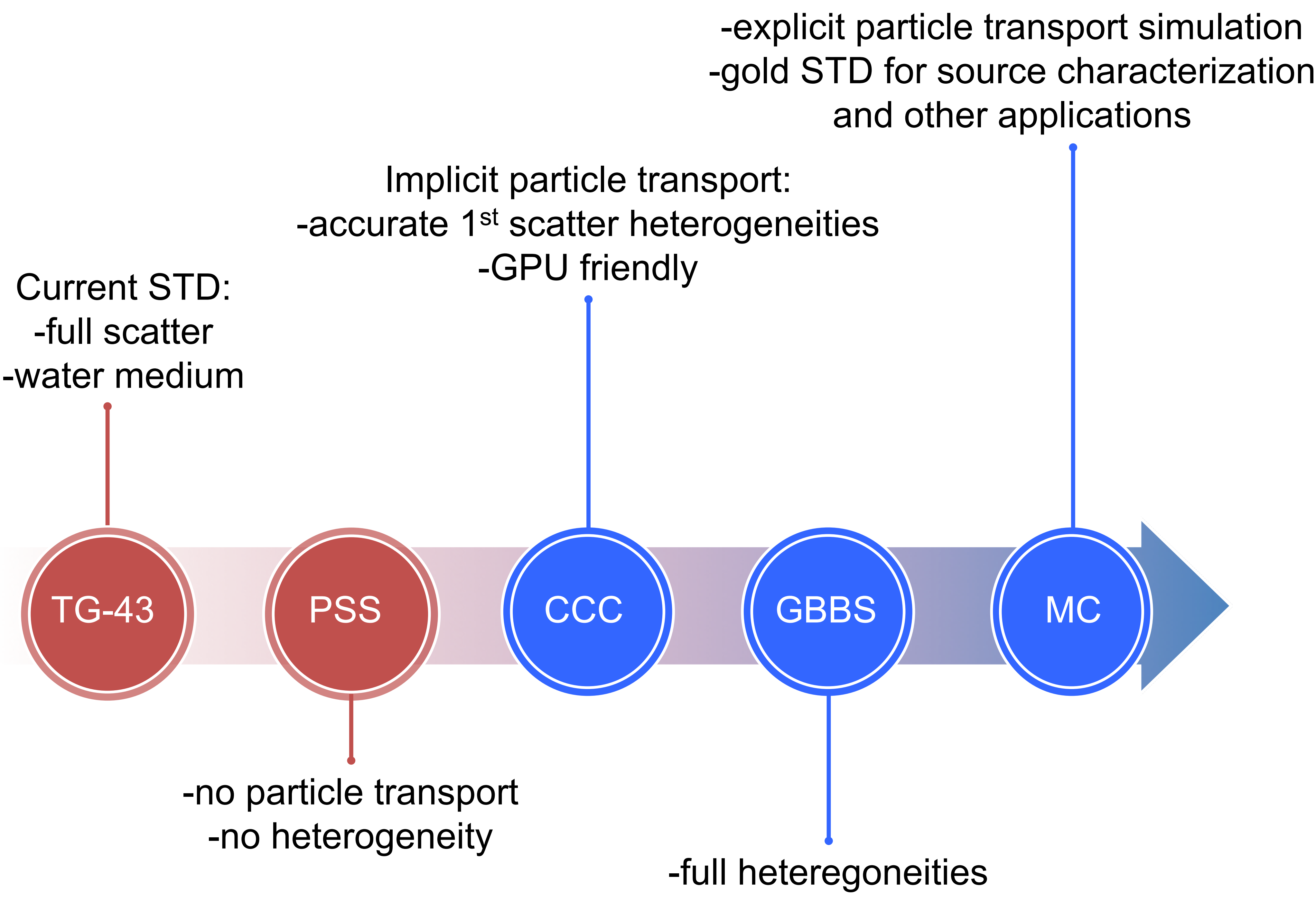


from Åsa Carlsson-Tedgren

Brachytherapy Dose Calculation Methods



Rivard, Beaulieu, and Mourtada, Vision 20/20, Med Phys 2010



from Luc Beaulieu

GBBS Basics

- Deterministic methods solve LBTE "explicitly" average particle behavior converges using LBTE differential form in the limit of very fine phase-space mesh spacing.
- Based on all phase-space discretization, such methods are referred to as the grid-based Boltzmann equation solvers (GBBS).
- In general, the method-of-characteristics, spherical harmonics, and discrete ordinates are all classified as deterministic.

(Shapiro *et al* 1976, Nigg *et al* 1991, Borgers 1998, Daskalov *et al* 2000, 2002, Gifford *et al* 2006, 2008, Vassiliev *et al* 2008, Gifford *et al* 2010, Mikell and Mourtada 2010, Han *et al* 2011)

Basic Operators of GBBS

- Solve LBTE by discretizing spatial (via finite difference or element meshes), angular (via discrete ordinates, spherical harmonics, etc.), and energy variables (via the multigroup method),
  - Results in a linear system of equations that are iteratively solved.

Grid-Based Boltzmann Solver (GBBS)

- Deterministic approach solving the linear Boltzmann transport equation

$$\hat{\Omega}\cdot\vec{\nabla}\psi^{\gamma} + \sigma_t^{\gamma}\psi^{\gamma} = Q^{\gamma(ext)} + Q^{\gamma(scat)}$$

Streaming operator | Collision operator | Sources

$$\hat{\Omega}\cdot\vec{\nabla}\psi^{e} + \sigma_t^{e}\psi^{e} - \frac{\partial}{\partial E}s_R\psi^{e} = Q^{e(ext)} + Q^{scat}$$

Streaming operator | Collision operator | CSDA operator | Sources

Grid-Based Boltzmann Solver (GBBS)

$$\hat{\Omega}\cdot\vec{\nabla}\Psi(\vec{r},E,\hat{\Omega})+\sigma_t(\vec{r},E)\Psi(\vec{r},E,\hat{\Omega})=Q^{scat}(\vec{r},E,\hat{\Omega})+Q^{ex}(\vec{r},E,\hat{\Omega})$$

– Position:	$\vec{r}=(x,y,z)$	Mesh position discretization (finite elements)
– Energy:	E	Energy bins (cross section)
– Direction:	$\hat{\Omega}=(\theta,\phi)$	Angular discretization

« multi-group discrete ordinates»

2D: Daskalov et al, Med Phys 29 (2002)
3D: Gifford et al, Phys Med Biol 53 (2006)

from Luc Beaulieu

Grid-Based Boltzmann Solver (GBBS)

- Varian BV-Acuros® implementation:
  - CPE assumption : Primary dose analytical (ray-tracing with scaling)
    - $D_{prim} = K_{coll}$
    - First scatter from primary:
      Scerma = Dprim•((μ-$μ_{en}$)/u_{en})
    - Share this step with CCC

  - 3D scatter integration through GBBS

  - Source modeling done in Atilla® (Transpire Inc)

from Luc Beaulieu

Major differences between deterministic and Monte Carlo solvers include

- Nonstochastic. Solution errors arise from systematic sources rather than statistical;
- Provide full solution for entire space rather than for specific regions (or tally location) done in MC
- More efficient than MC once derived for similar problems solved previously, i.e. similar brachytherapy sources and patient volumes.

GBBS Physics

- Impact of the number of energy groups on both accuracy and speed of convergence is a factor (Daskalov *et al* 2000, 2002, Gifford *et al* 2006, 2008).
- Cross sections produced by CEPXS are typically used and suitable for Ir-192 source energy (Lorence *et al* 1989).
- CEPXS includes all photon interactions (except Rayleigh scatter),

  effect of which is insignificant for dose distributions at energies produced by brachytherapy sources such as ^{192}Ir

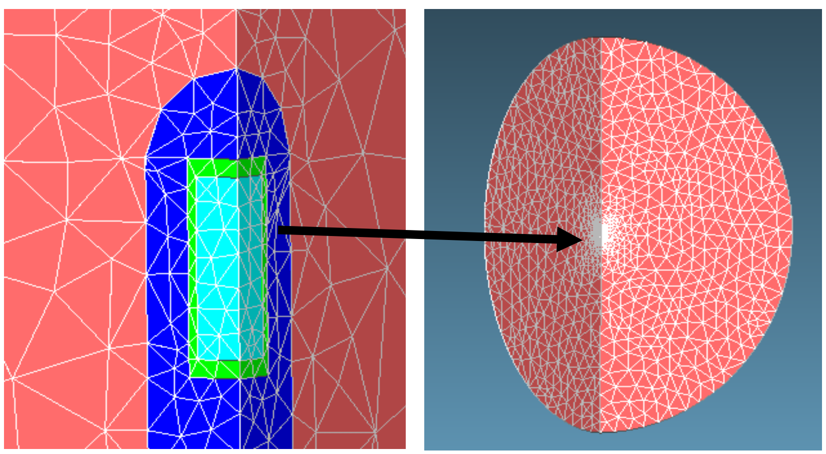
History of GBBS

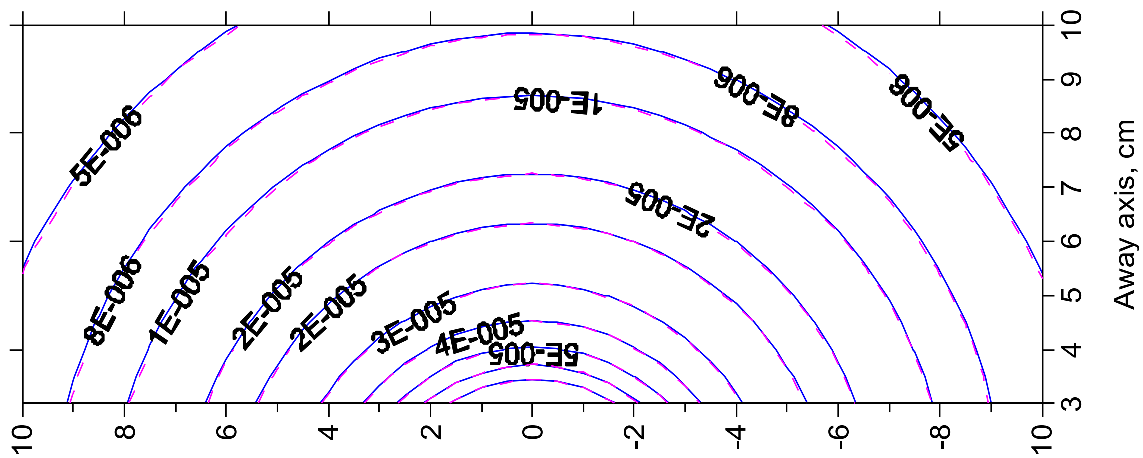
- 3D Attila® radiation transport code (LANL, Los Alamos, New Mexico) was first evaluated in 2004 for the dosimetry of a pulsed dose rate (PDR) ^{192}Ir source in water (Mourtada *et al* 2004, Gifford *et al* 2006, 2008)

- Based on the Attila work, a clinical GBBS platform, called Acuros was developed (Transpire Inc, Gig Harbort, WA) and licensed for use by Varian BrachyVision TPS.

^{192}Ir and ^{137}Cs Attila Benchmarks*

- F. Mourtada, T. Wareing, J. Horton, J. McGhee, D. Barnett, G. Failla, R. Mohan, 'A Deterministic Dose Calculation Method with Analytic Ray Tracing for Brachytherapy Dose Calculations', *AAPM*, Pittsburgh, PA, 2004.

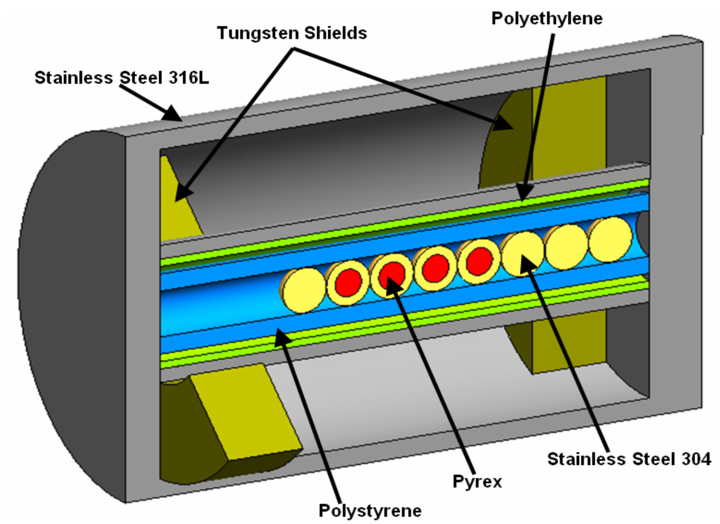


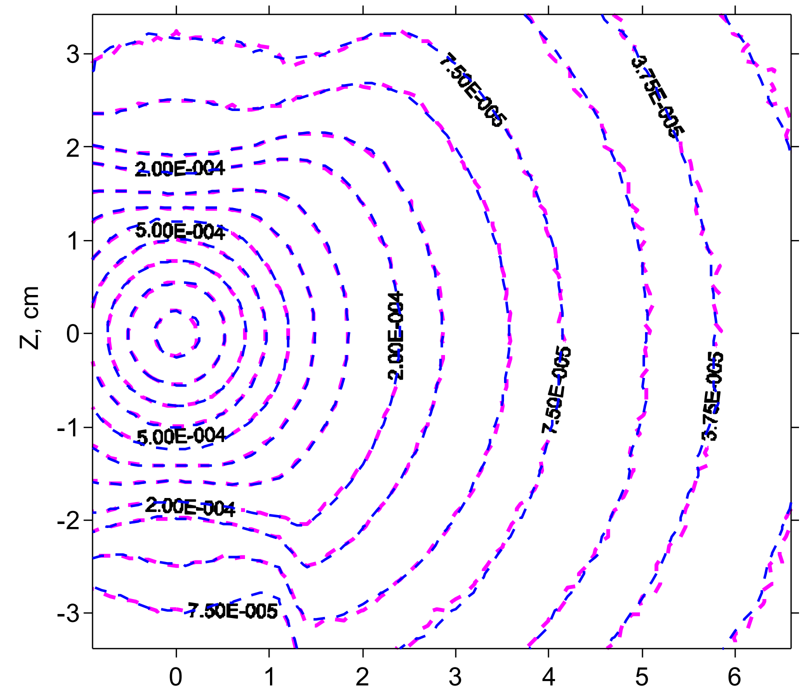


Attila (blue), MCNPX (pink)

^{137}Cs Attila Benchmarks

•F. Mourtada, T. Wareing, J. Horton, J. McGhee, D. Barnett, K. Gifford, G. Failla, R. Mohan, 'A Deterministic Dose Calculation Method Applied to the Dosimetry of Shielded Intracavitary Brachytherapy Applicators', *AAPM*, Pittsburgh, PA, 2004.

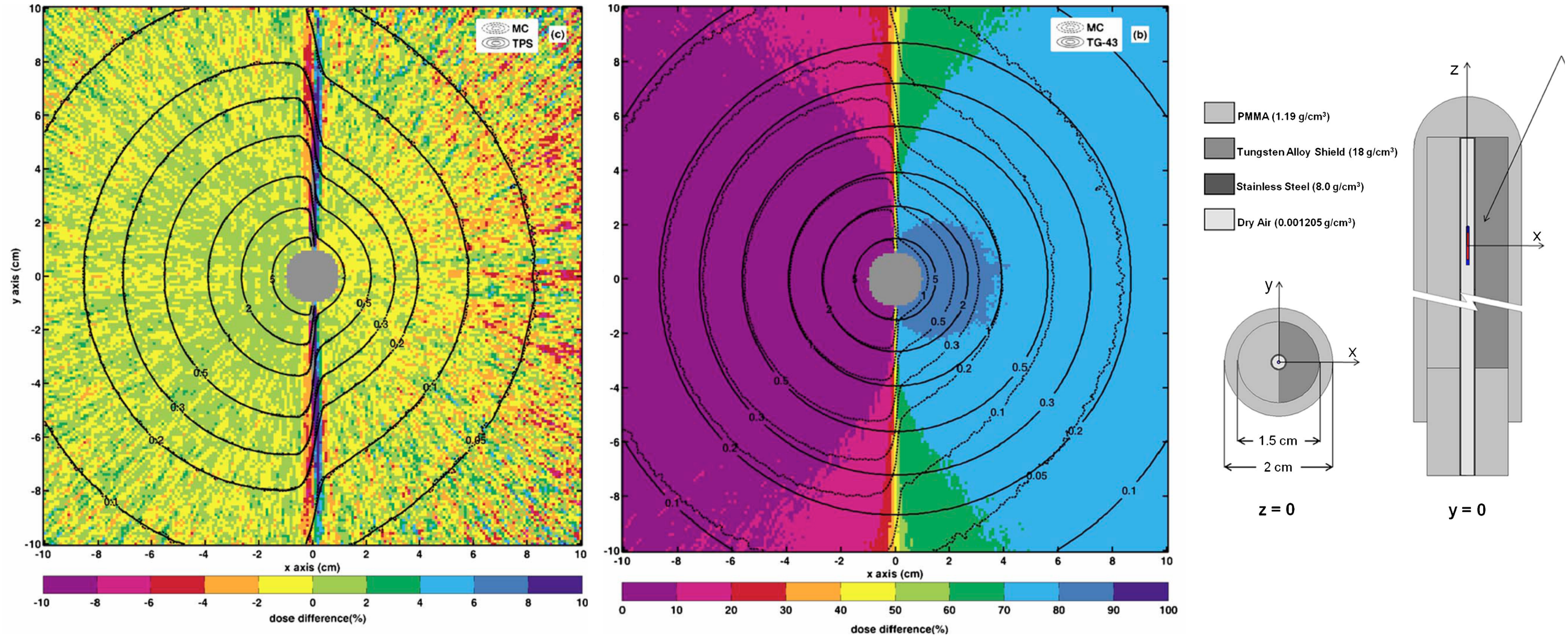




Attila (blue), MCNPX (pink)

AAPM 2004

Shielded GYN Cylinder



- Speed: 40 sec to 12 min depending on complexity

Figure from : L. Petrokokkinos *et. al.* Med. Phys. **38**, 1981-1992 (2011).

More references on the algorithm, see e.g.: K. A. Gifford et. al. Med. Phys. **35**, 2279-2285 (2008)

Deterministic Methods Ray-effect

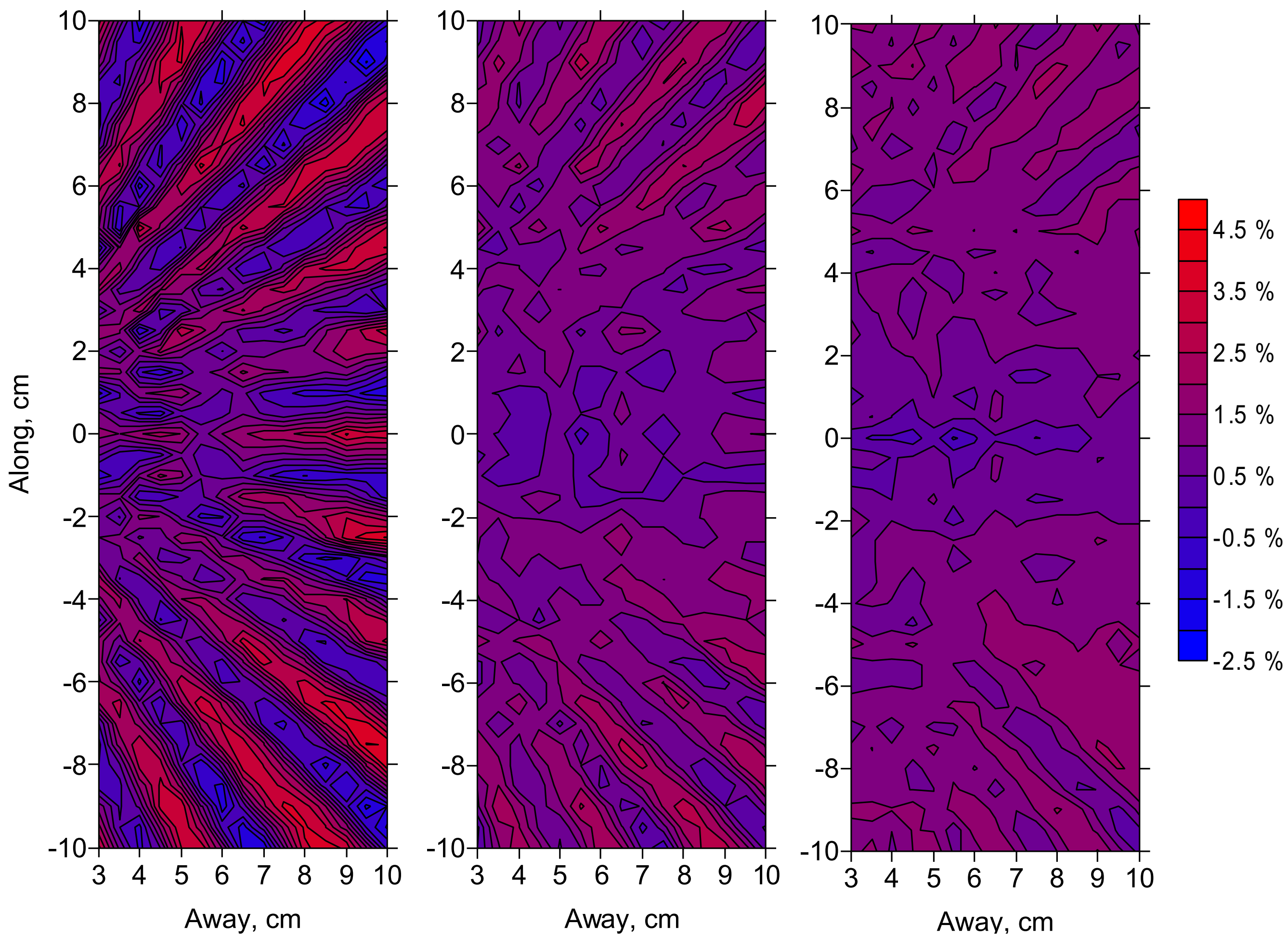


Figure from: Venselaar, Baltas, Meigooni, Hoskin (Eds), Comprehensive Brachytehrapy: physical and clinical aspects. CRC Press, Taylor & Francis, © 2013

Advanced Collapsed Cone Engine: ACE

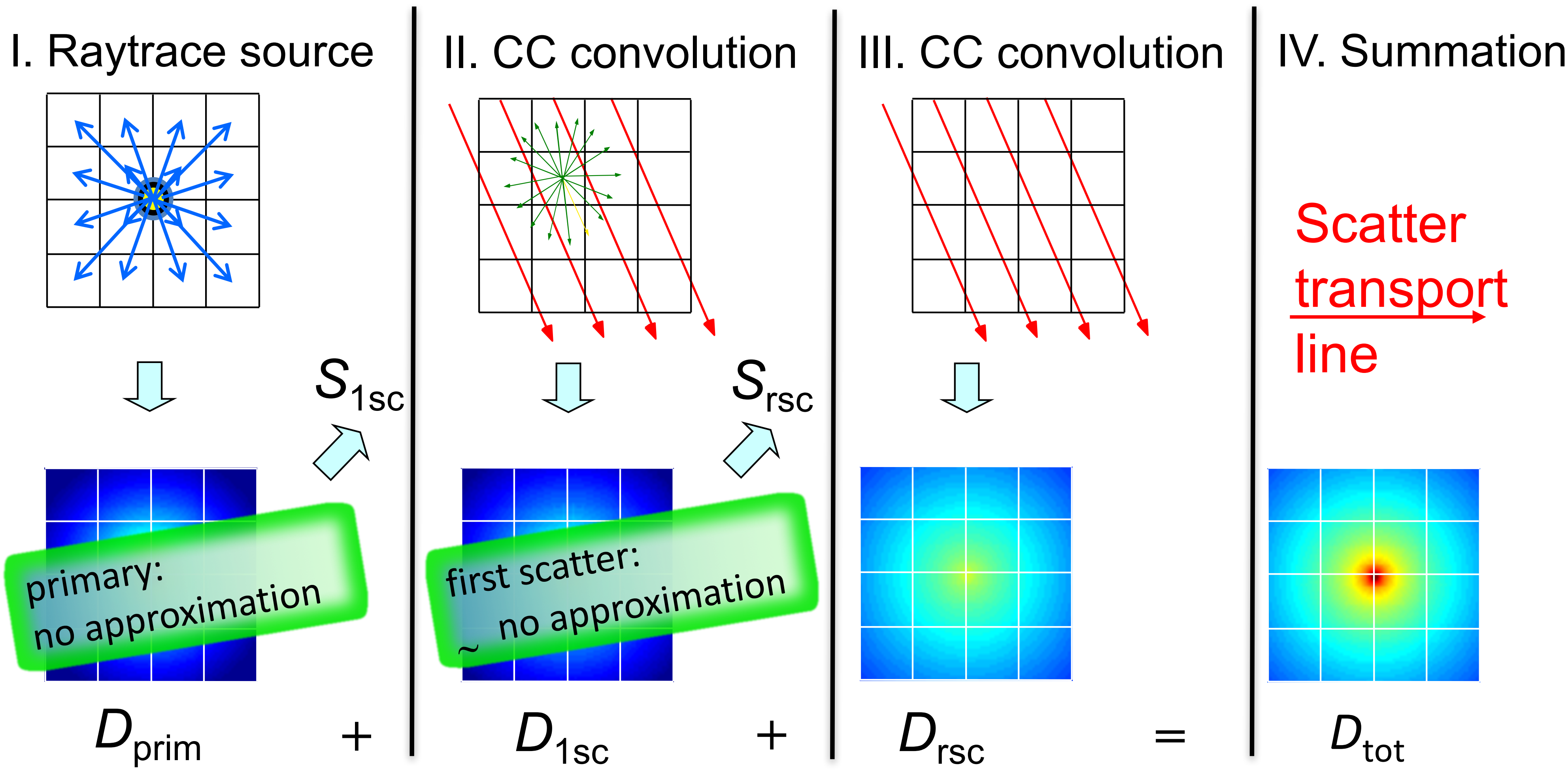
- Implementation only for ^{192}Ir
  1. CPE assumption : D_{prim} ➔ K_{coll}
     - Primary dose analytical (from fluence)
     - Ray-tracing with scaling (heterogeneities!)
     - Some correction factors (volume, anisotropy, …)

  2. First scatter from primary : $S_{1c} = \left(\dfrac{\mu - \mu_{en}}{\mu_{en}} \right) D_{prim}$

  1. Multiple scatter components from D_{1sc}.
     - Exponential parametrization of MC point kernels

Russell & Ahnesjö 1996 PMB 41; Carlsson & Ahnesjö 2000 Med Phys 27;
Carlsson & Ahnesjö 2000 PMB 45; Carlsson & Ahnesjö. 2003 Med Phys 30;
Russell et al 2005 Med Phys 32; Carlsson Tedgren & Ahnesjö 2008 Med Phys 35.

Outline of ACE



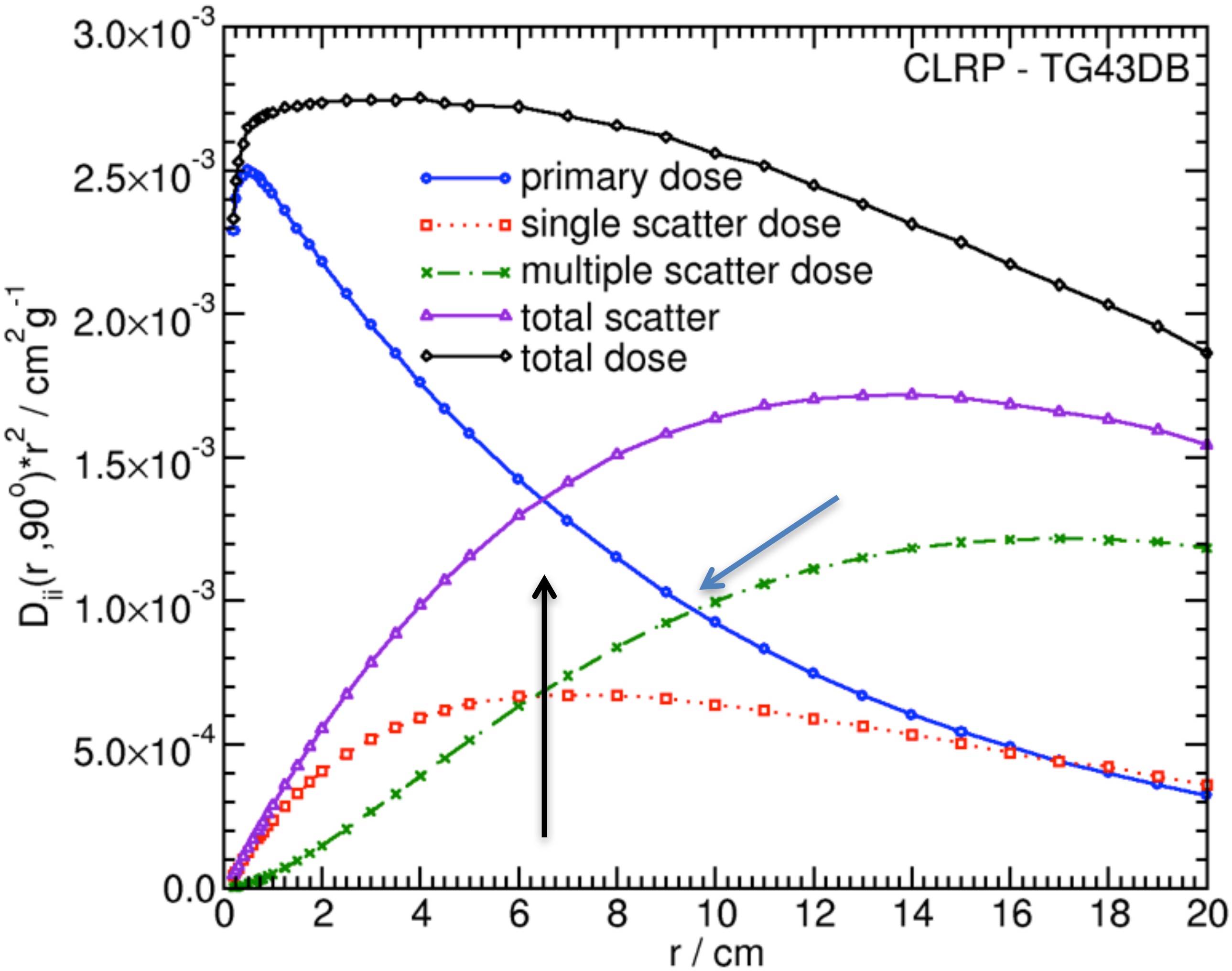
(Åsa K. Carlsson & Anders Ahnesjö, 2000)

Speed-up Techniques

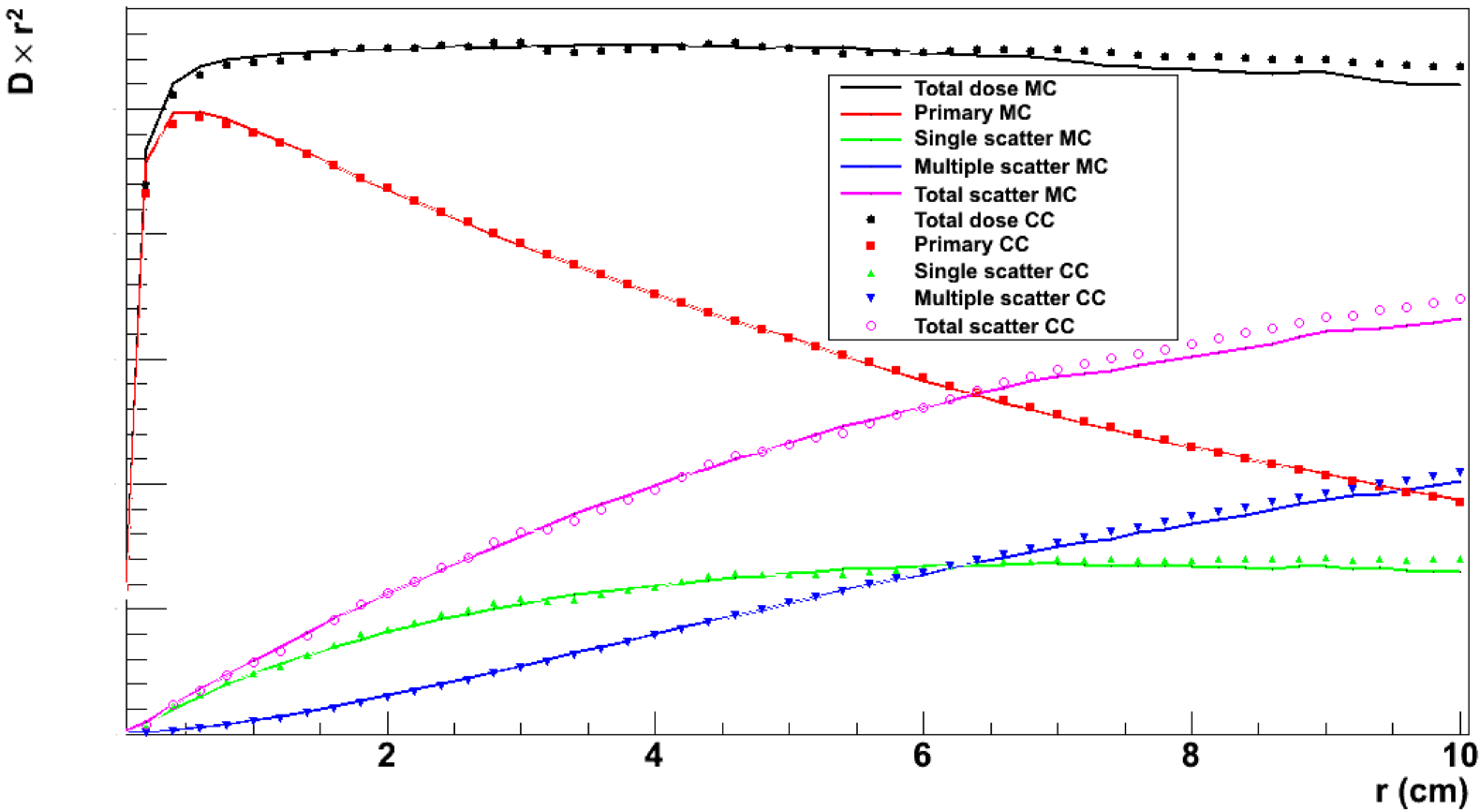
- GPU implementation (ray-tracing)
- Adaptive tessellations
- Adaptive voxel sizes

A small reminder…

- Primary dose dominates total dose for $r \leq 6$ cm



Full Backscatter



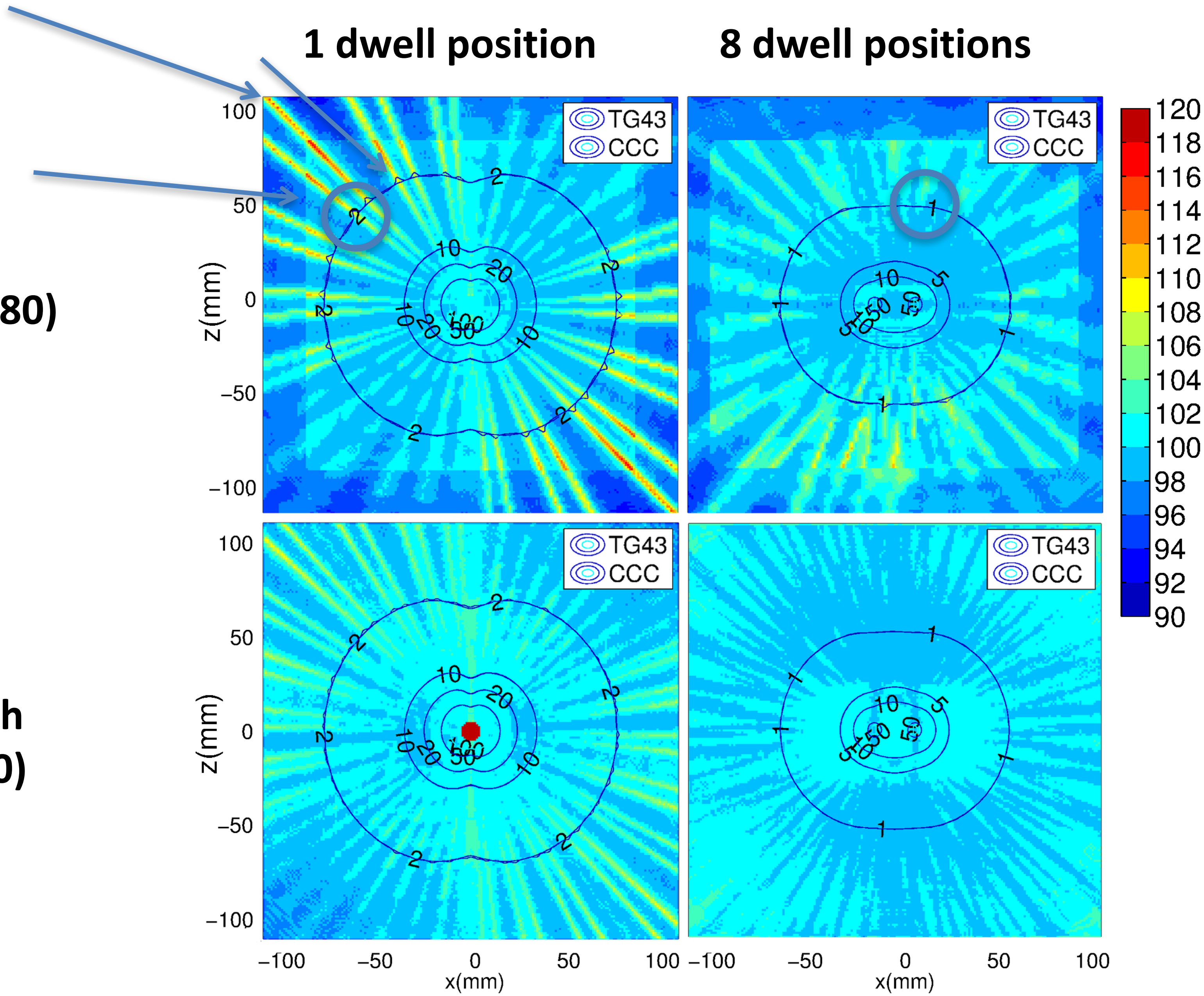
from Luc Beaulieu

1 dwell position

8 dwell positions

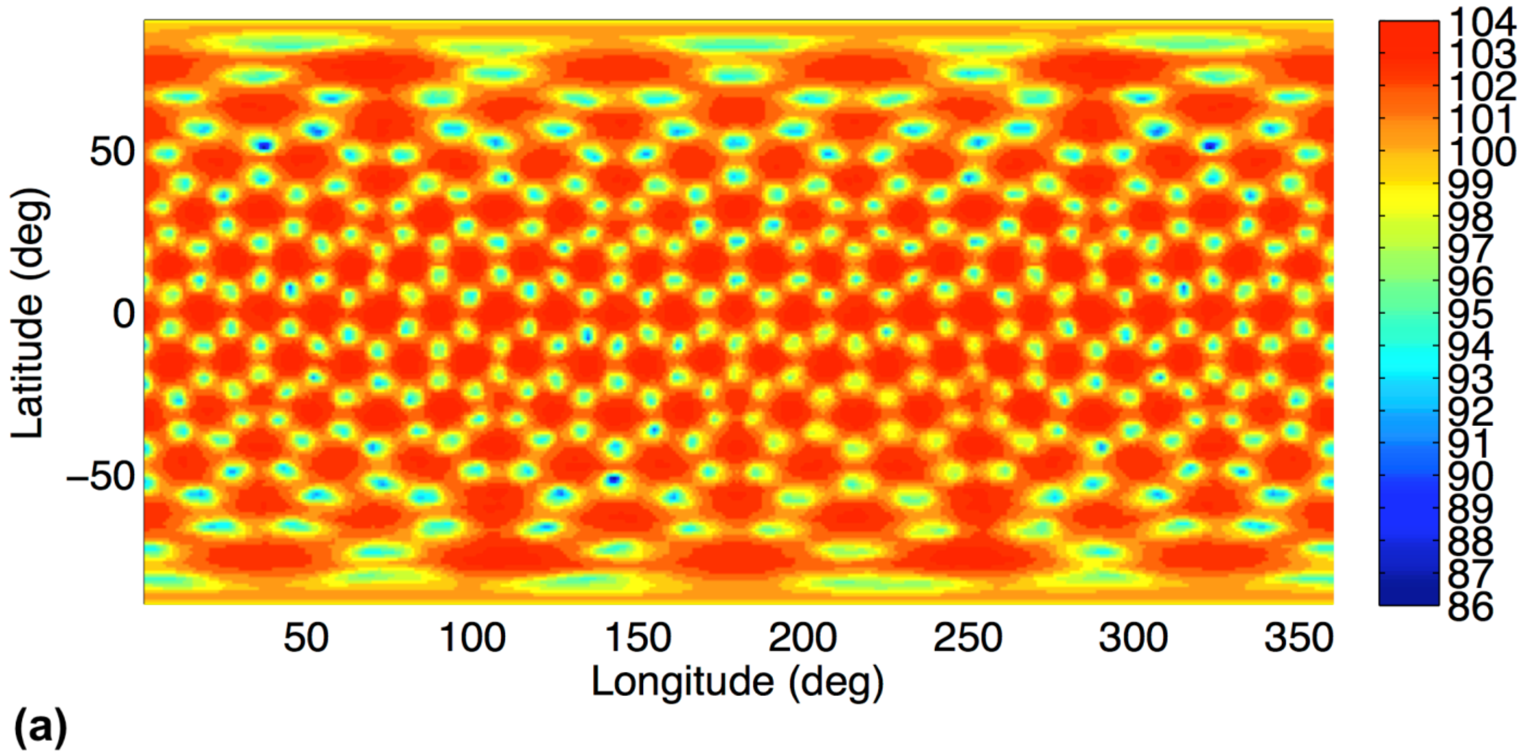
STD (320/180)

Super High (1620/180)



Ma et al, *Brachytherapy* 2016

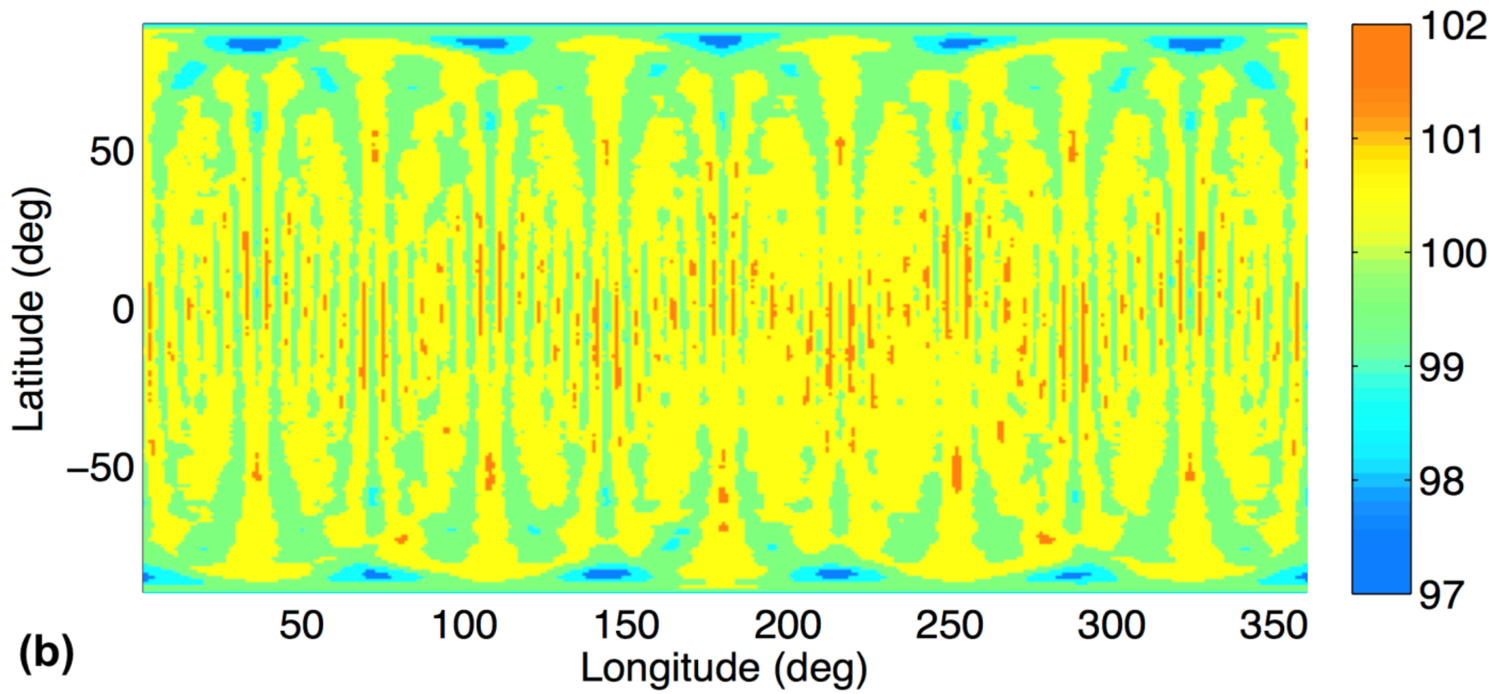
ACE "world map"



Single dwell position in full backscatter condition, std resolution.
<u>Map is a ratio: ACE/TG-43</u>

Ma et al, *Brachytherapy* 2016

ACE “world map”



17 dwell positions in full backscatter condition.

<u>Map is a ratio: ACE/TG-43</u>

Ma et al, *Brachytherapy* 2016

ACE Ray Effects

- **Single source** dosimetry is a most difficult case
  - Large dose gradient
  - Effect of tessellation readily visible
  - First scatter needs large numbers of angle (> 1000)
    - No ray-effect for *r* < 5 cm from a source (think primary!)

- For cases with **multiple dwell positions**
  - Ray-effect decreases quickly with dwell #
  - Limited need for high resolution beyond a few dwell.

Conclusions

- Model-based dose calculation algorithms GBBS and CCC have been developed recently and available only for Ir-192 brachytherapy.

- New users should realize the method limitations in terms of the ray effect;
  but should appreciate the advantages of calculation speed and high accuracy for clinical scenarios.

- Change in dose calculation standard is not new (e.g. lung EBRT)
  - Transition period
  - Revisiting dose-outcomes, dose prescription

MODEL-BASED DOSE CALCULATION: CLINICAL IMPLEMENTATION

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LEARNING OBJECITVES

- Show the performance of commercially available MDBCA
  - Relative to TG-43
  - For heterogeneous geometries
- Illustrate potential limitations

KEY REFERENCES

- Sloboda et al. **A Brief Look at Model-Based Dose Calculation Principles, Practicalities, and Promise.** Journal of Contemporary Brachytherapy 9 (2017) 79–88.
- Ma, Yunzhi, Frédéric Lacroix, Marie-Claude Lavallée, and Luc Beaulieu. **"Validation of the Oncentra Brachy Advanced Collapsed Cone Engine for a Commercial (192)Ir Source Using Heterogeneous Geometries**" *Brachytherapy* 14 (2015): 939–52.
- Papagiannis P, Pantelis E, Karaiskos P. **Current state of the art brachytherapy treatment planning dosimetry algorithms**. Br J Radiol 87(2014):20140163.
- Veelen, B V, Y Ma, and L. Beaulieu. 2014. **ACE—Advanced Collapsed Cone Engine. Elekta White Paper**.
- Zourari et al. **Dosimetric Accuracy of a Deterministic Radiation Transport Based (192)Ir Brachytherapy Treatment Planning System. Part III. Comparison to Monte Carlo Simulation in Voxelized Anatomical Computational Models**. Medical Physics 40 (2013) 011712.
- Petrokokkinos et al. **Dosimetric Accuracy of a Deterministic Radiation Transport Based 192-Ir Brachytherapy Treatment Planning System. Part II: Monte Carlo and Experimental Verification of a Multiple Source Dwell Position Plan Employing a Shielded Applicator**. Medical Physics 38 (2011) 1981–92.
- Zourari et al. **Dosimetric Accuracy of a Deterministic Radiation Transport Based 192Ir Brachytherapy Treatment Planning System. Part I: Single Sources and Bounded Homogeneous Geometries.** Medical Physics 37 (2010). 649–61.

MODEL-BASED DOSE CALCULATION ALGORITHMS

- Implementation **for ^{192}Ir (…and ^{60}Co)**
  1. CPE assumption : D_{prim} ➔ K_{coll}
     - Primary dose analytical (from fluence)
     - Ray-tracing with scaling (heterogeneities!)

  2. First scatter from primary : $S_{1c} = \left(\frac{\mu - \mu_{en}}{\mu_{en}} \right) D_{prim}$

➢ Scatter dose engine – differences in commercial implementation

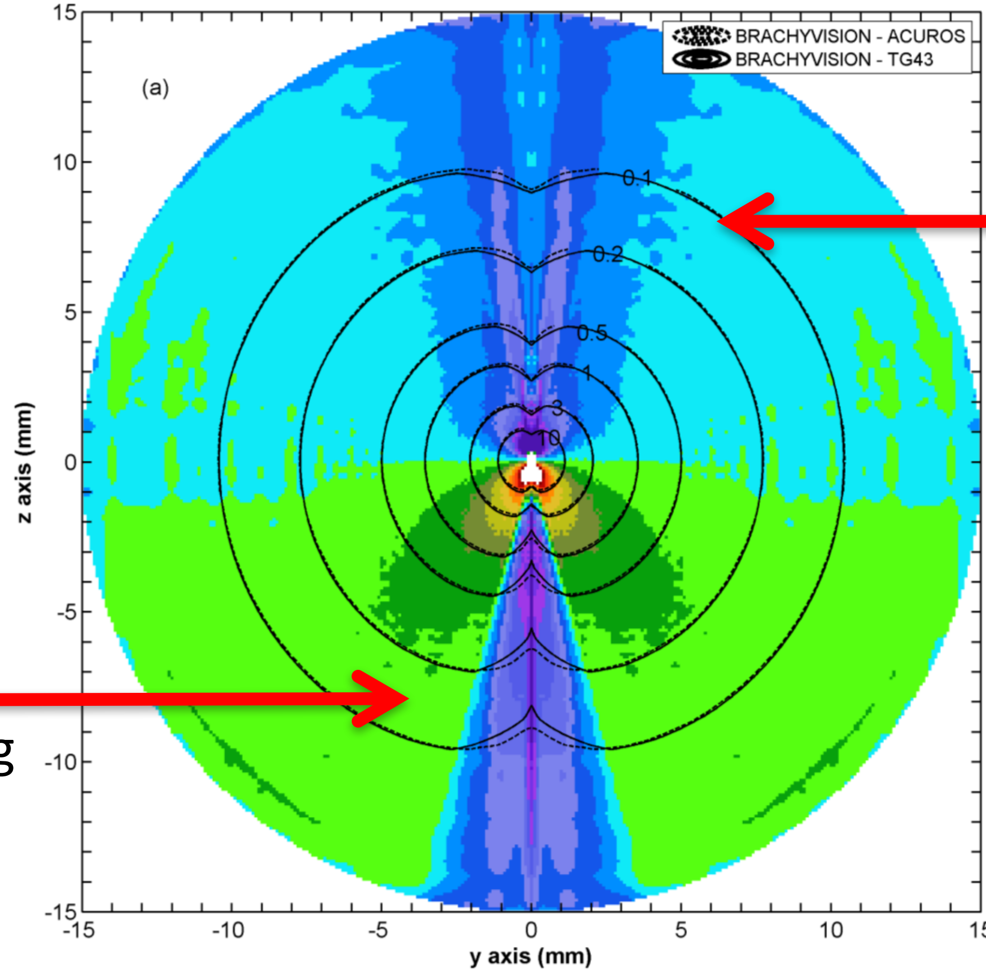
HOW WELL DO THEY PERFORMED?

- First: relative to TG43 in TG-43 conditions
  - one or multiple source positions
  - in water
  - with full scatter condition

- Second: their advanced features
  - Heterogeneities
  - Shielding

Beaulieu et al, *Med Phys* 39, 6209-6236 (2012)

Acuros vs TG43: TG-43 conditions

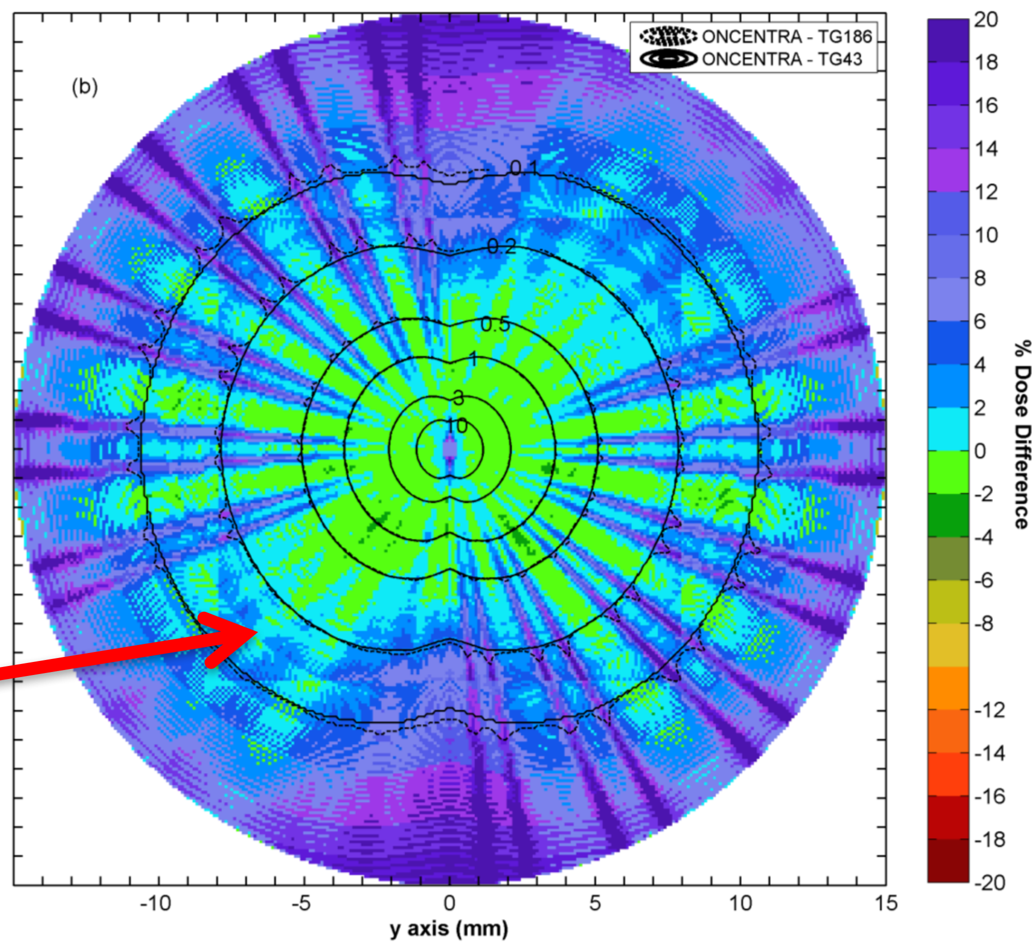


TG43
2D anisotropy
function

Difference in
source modeling

Papagiannis P, Pantelis E, Karaiskos P. **Current state of the art brachytherapy treatment planning dosimetry algorithms**. Br J Radiol 2014;87(1041):20140163.

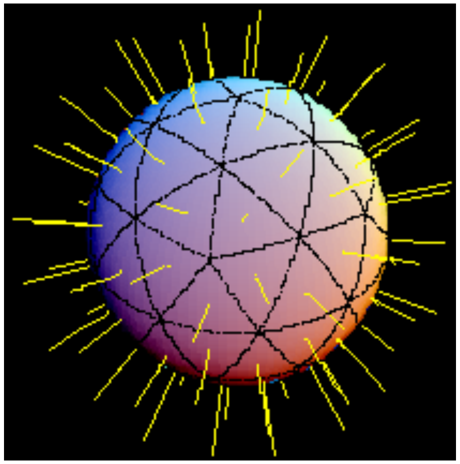
ACE vs TG43: TG-43 conditions



CCC settings

Papagiannis P, Pantelis E, Karaiskos P. **Current state of the art brachytherapy treatment planning dosimetry algorithms**. Br J Radiol 87(1041):20140163 (2014).

Tessellations

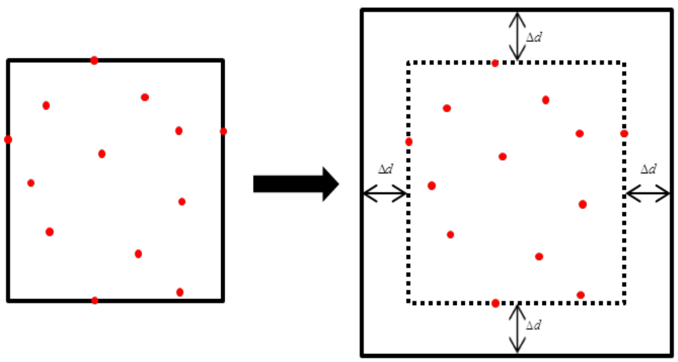


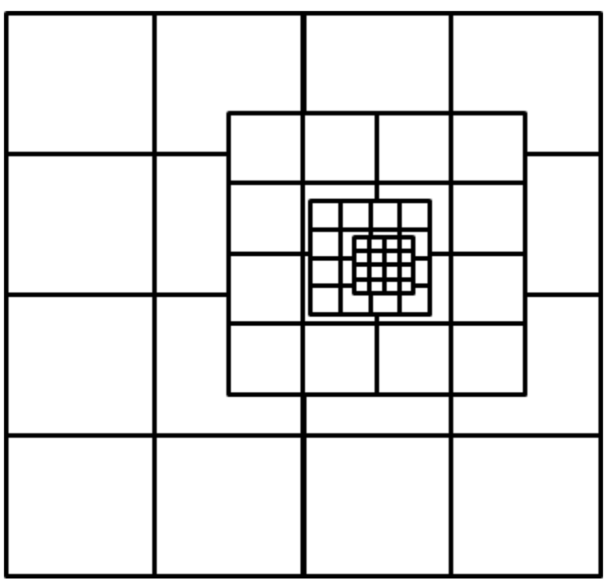
Accuracy level	0-50 dwell positions	51-150 dwell positions	151-300 dwell positions	>300 dwell positions
	Number of transport directions for first and residual scatter dose calculations.			
Standard	320 and 180	240 and 128	200 and 80	180 and 72
High	720 and 240	500 and 200	320 and 180	240 and 128

<u>Super High Mode 1620/320 (single dwell)</u>

* ACE white paper, Elekta: Bob van Veelen and Luc Beaulieu

Adaptive Voxel Sizes



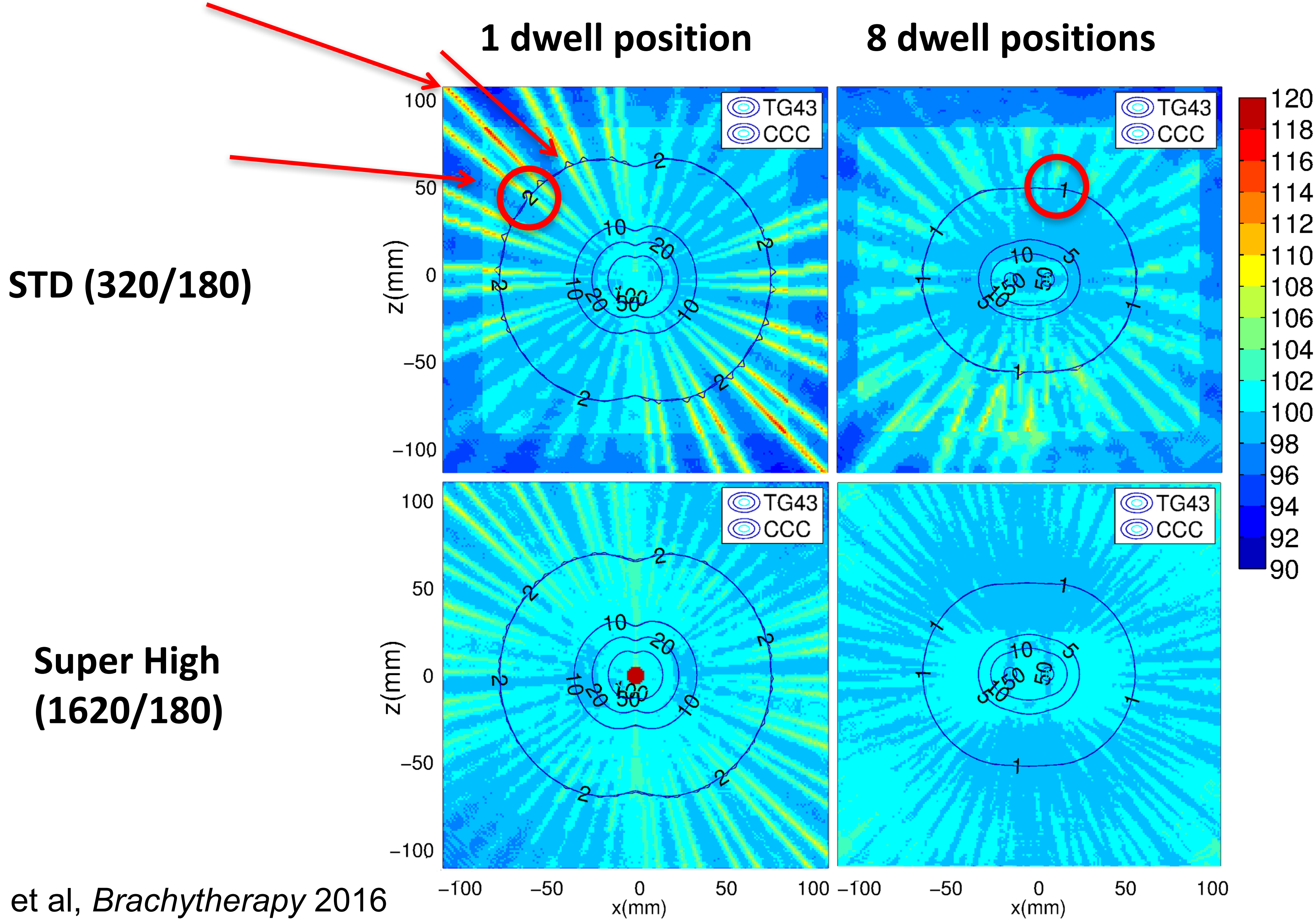


1, 2, 5, and 10 mm voxels

STD: 1, 8, 20, and 50 cm
High: 8, 20, 35, and 50 cm

* ACE white paper, Elekta: Bob van Veelen and Luc Beaulieu

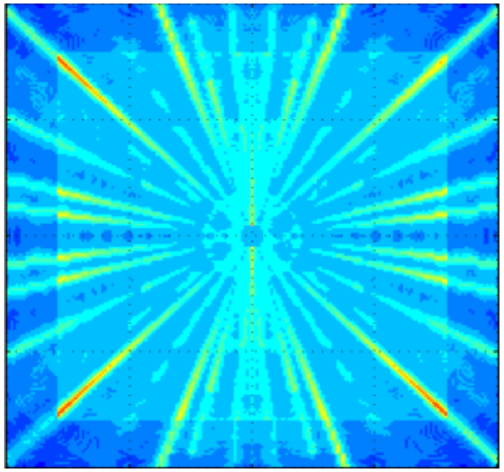
ACE vs TG43: TG-43 Conditions



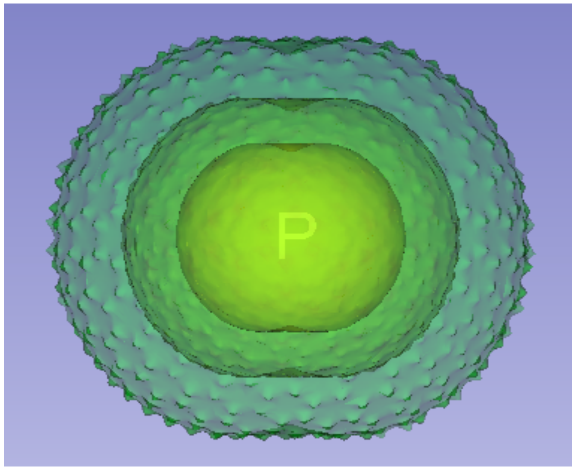
Ma et al, *Brachytherapy* 2016

ACE(CCC): The Ray Effect

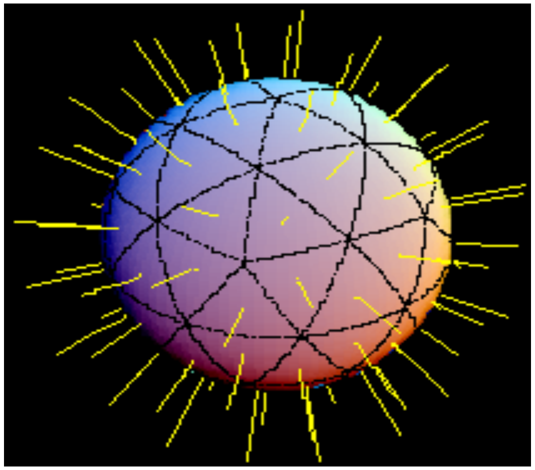
Single dwell in water



Ratio map



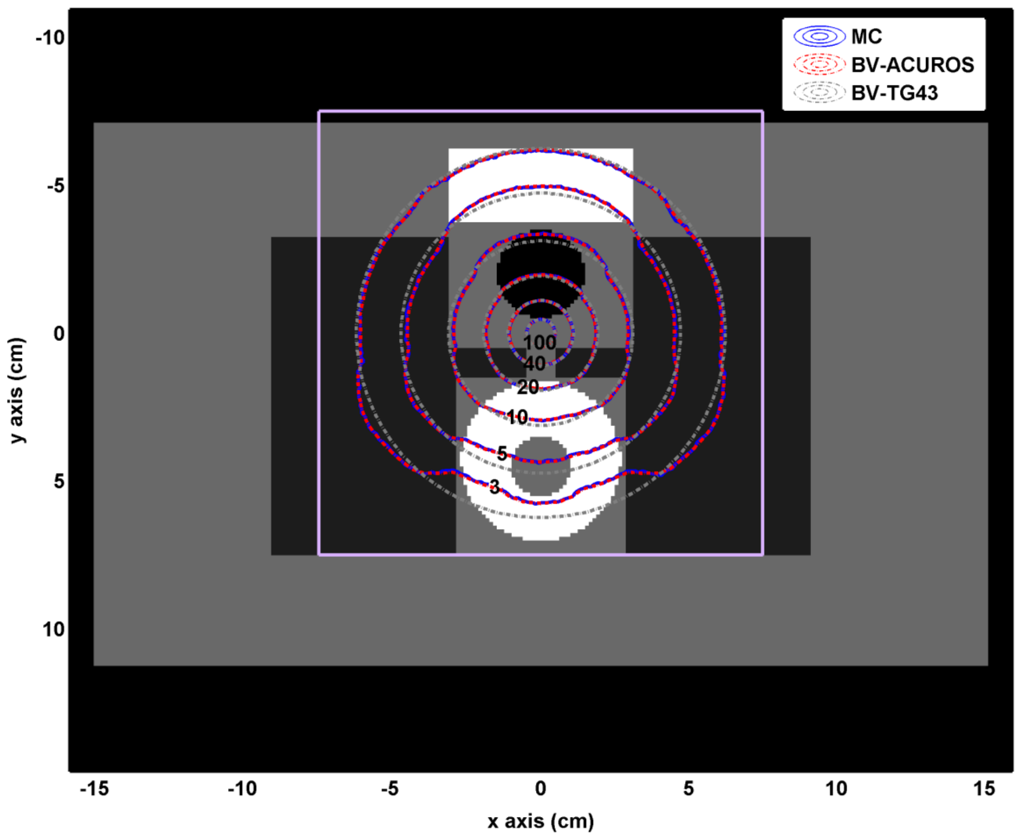
Isodose surface



Ma et al, *Brachytherapy* 2016

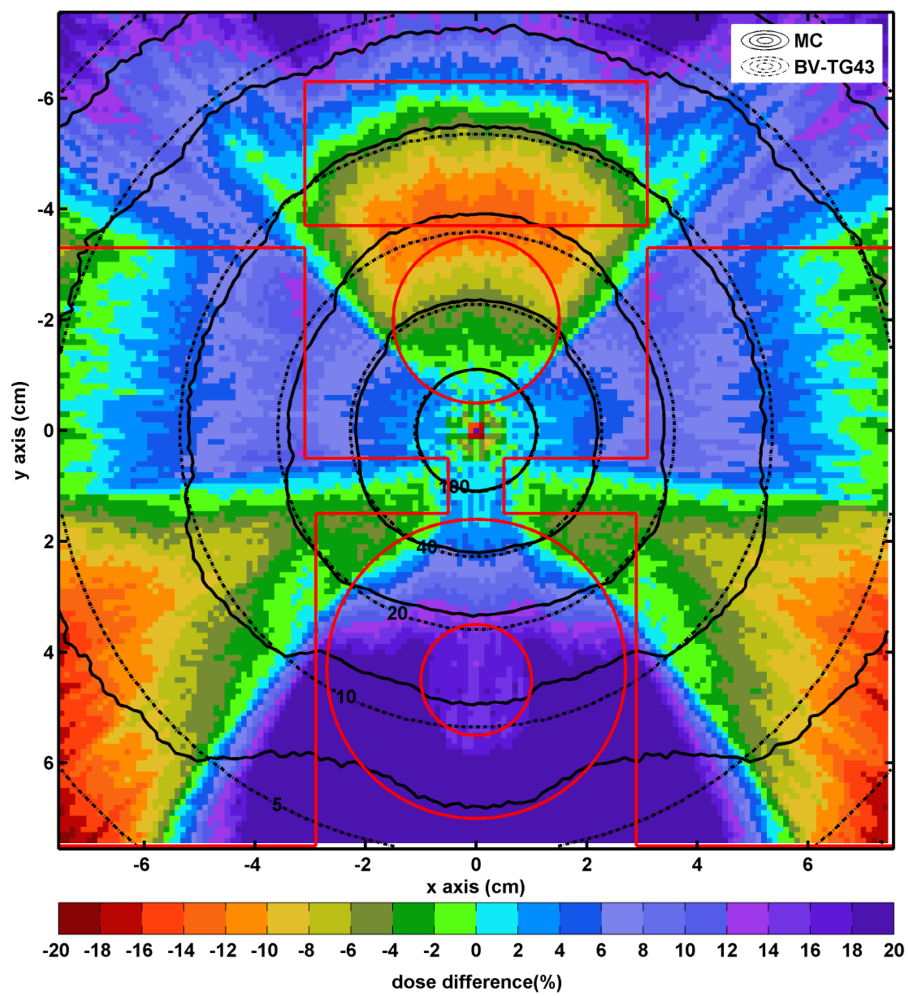
Heterogeneous Geometry

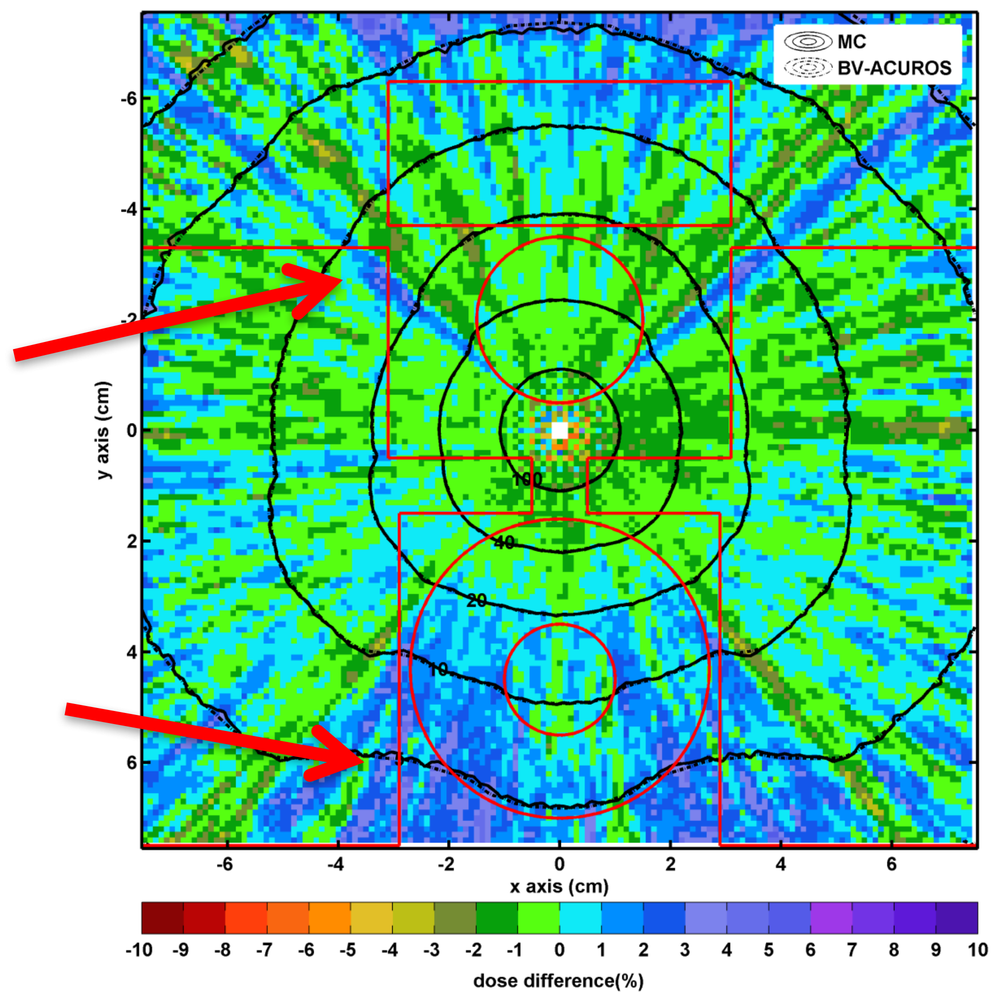
Single catheter esophagus phantom: Papagiannis et al., BJR 2014



HETEROGENEOUS GEOMETRY: ACUROS

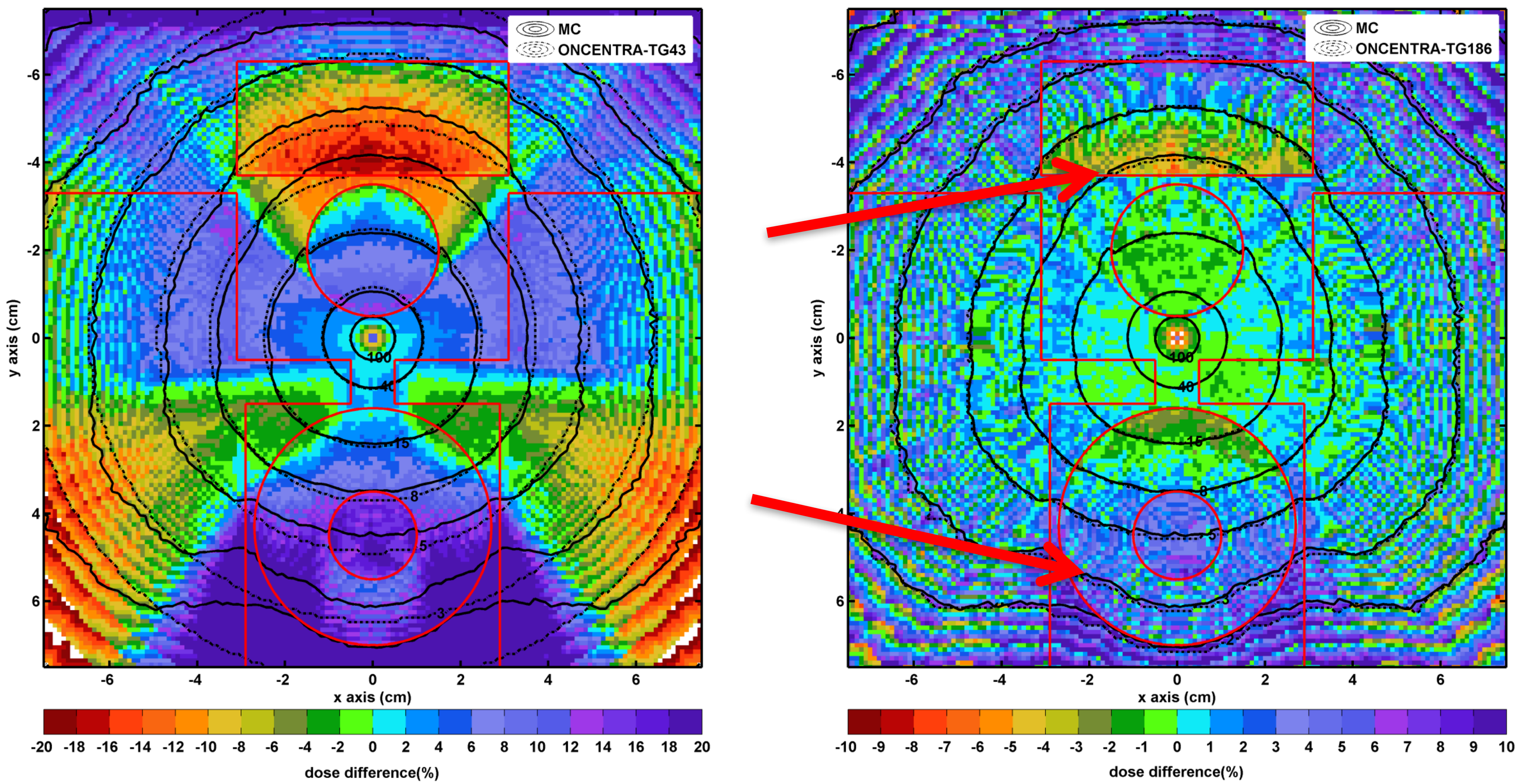
Single catheter esophagus phantom: Papagiannis et al., BJR 2014



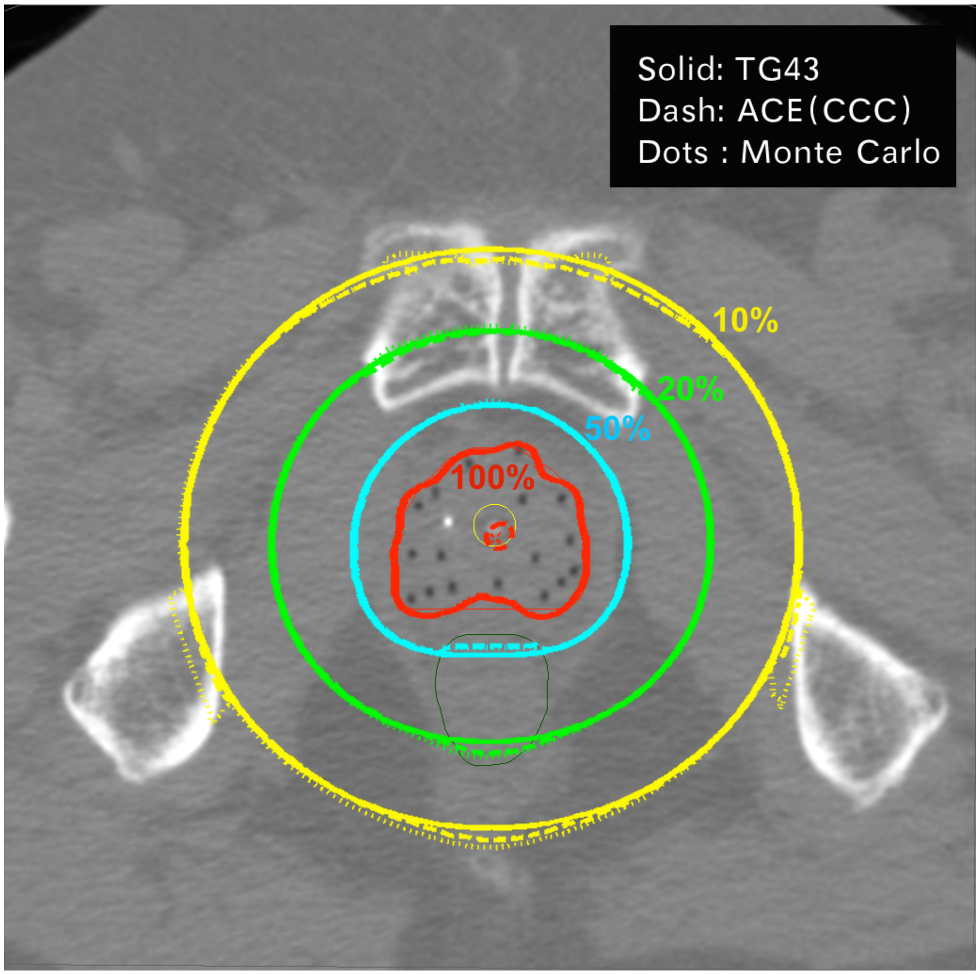


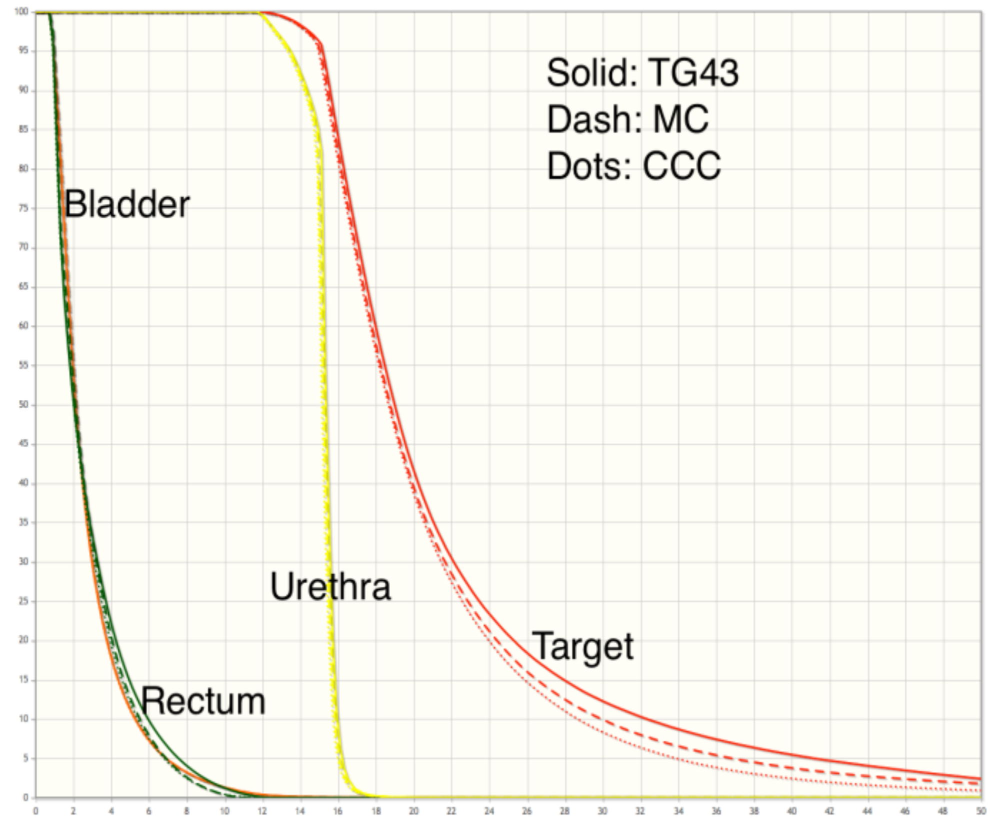
HETEROGENEOUS GEOMETRY: ACE

Single catheter esophagus phantom: Papagiannis et al., BJR 2014



HDR Prostate Implants

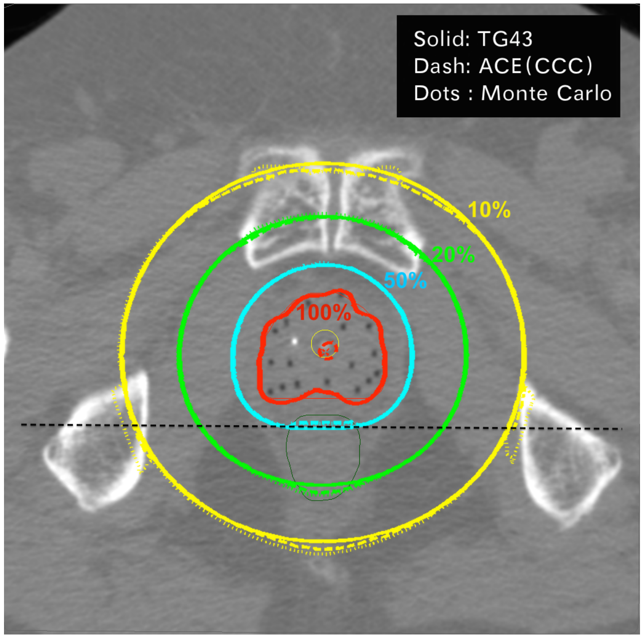


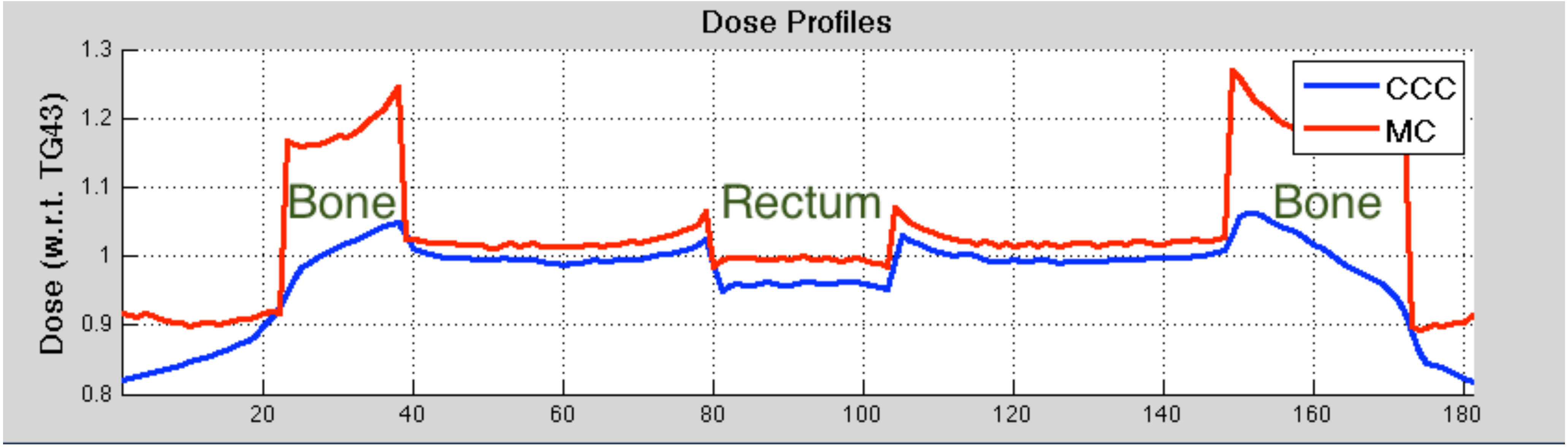


17 catheters; rectum set to air!

Ma et al, *Brachytherapy* 2016

HDR Prostate Implants



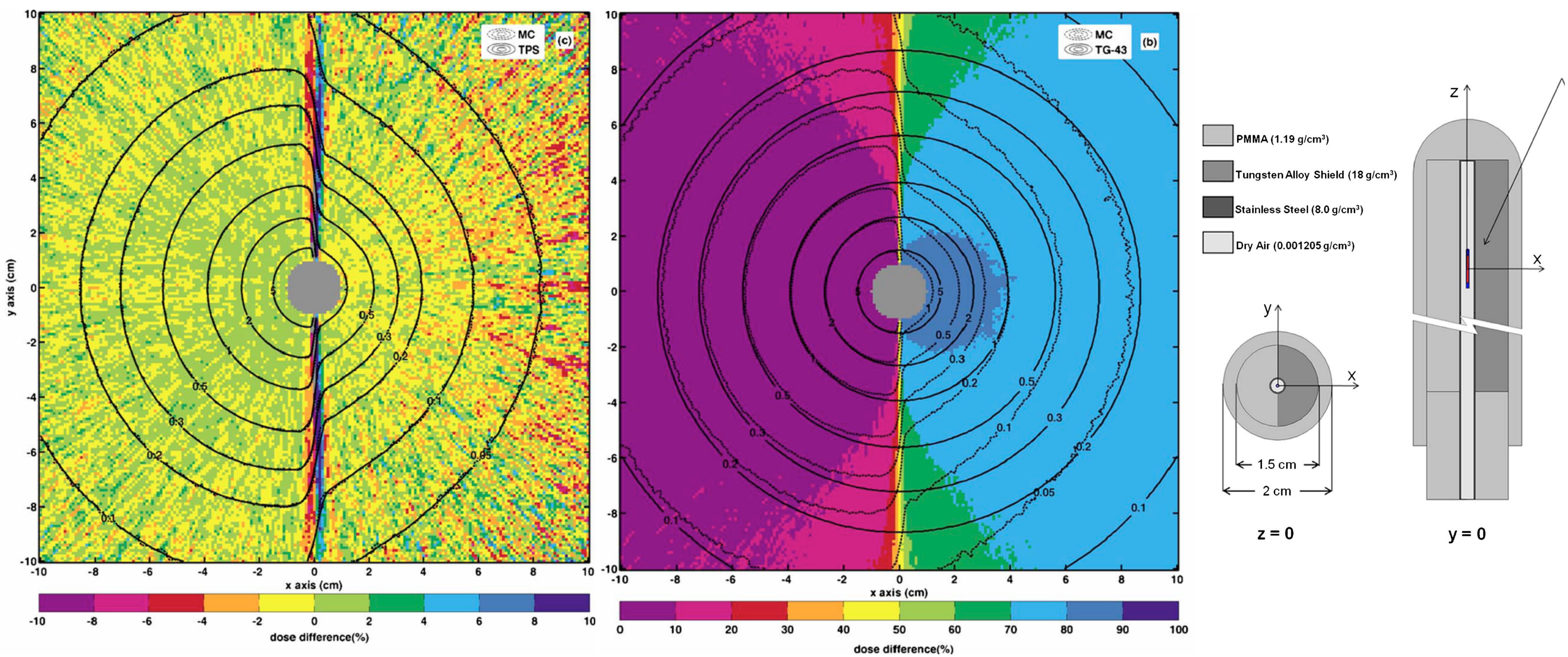


- Remaining issue with the multiple scatter point-kernels

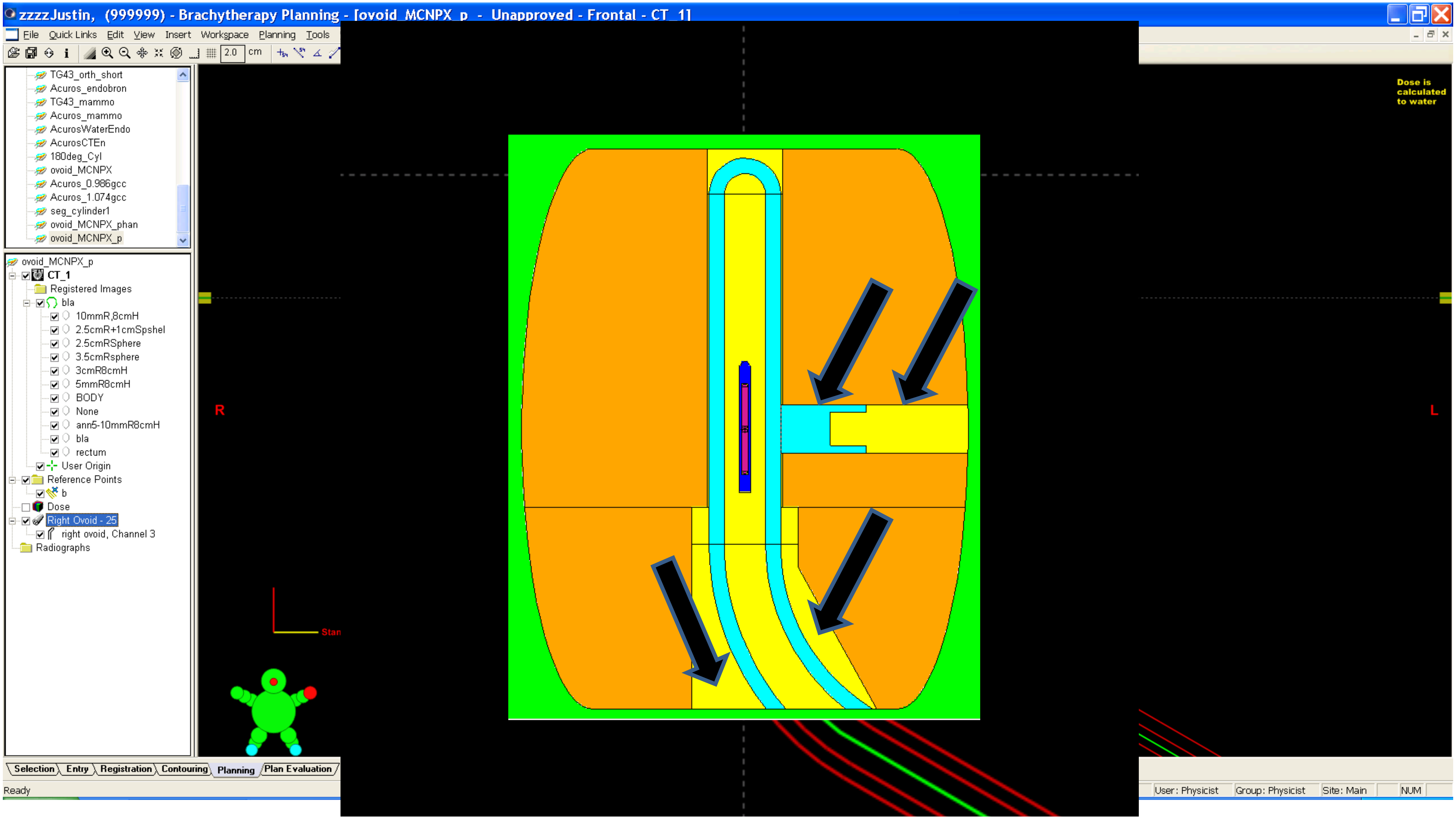
Ma et al, *Brachytherapy* 2016

Shielded Geometry

Petrokokkinos *et al*., Med Phys 38, 1981-1992 (2011)

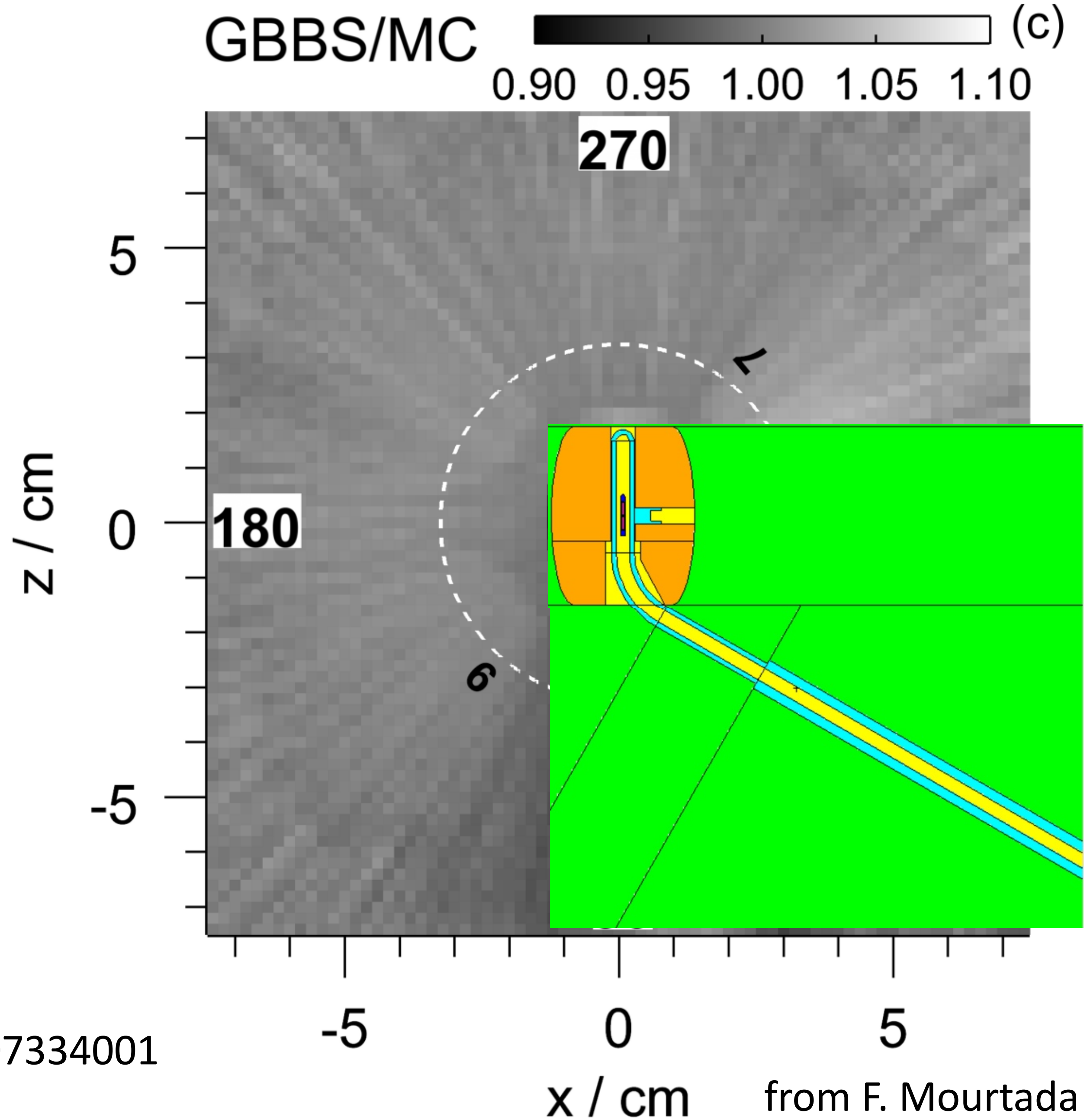


Results – CT/MR Ovoid Geometry



from F. Mourtada

Results - CT/MR Ovoid Dosimetry

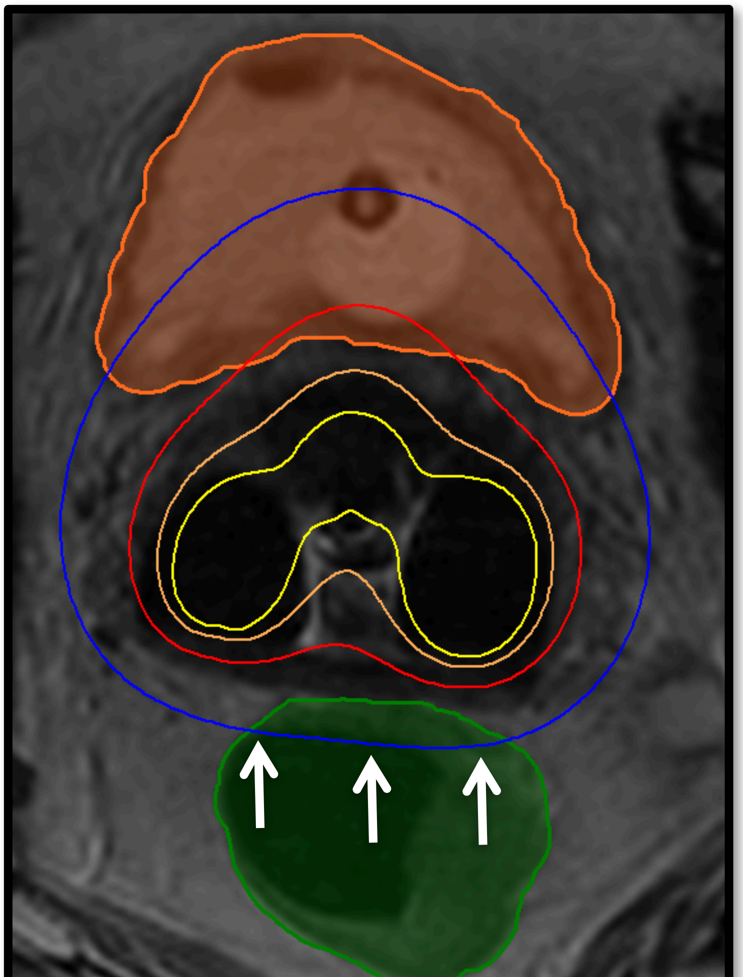


part #: AL07334001

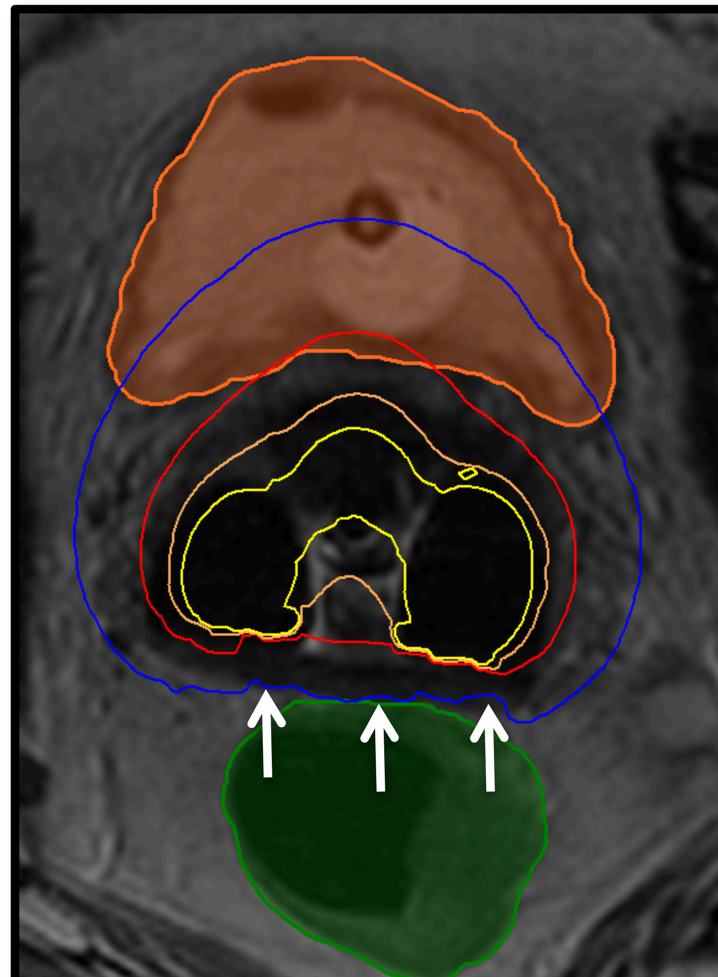
from F. Mourtada

Dose Distribution at Ovoids

TG43 (no shields)



TG186 (shields modeled)



200%
150%
100%
50%

Output of OncentraBrachy 4.5 with ACE - courtesy of F. Mourtada

Summary

- Both commercial implementations compare favorably to MC for heterogeneous geometry
  - have limitations related to discretization and scatter components

  - correct geometry and materials critical.

  - calculation time
    - a few seconds (single dwell in water) to…
    - a few minutes (complex multi-catheters implant in heterogeneous geometry)

    - could perform dose optimization (^{192}Ir HDR/PDR)…

      D'Amours et al., IJROBP 81, 1582–1589 (2011).

MBDCA: COMMISSIONING PROCESS

Ron S. Sloboda, Ph.D., FCCPM
Senior Physicist, Cross Cancer Institute
Professor, University of Alberta
Edmonton, AB, Canada

2017 AAPM SUMMER SCHOOL
CLINICAL BRACHYTHERAPY PHYSICS
In conjunction with the American Brachytherapy Society

LEARNING OBJECTIVES

- overview of MBDCA commissioning process
- list 5 main steps involved in Level 2 commissioning
- identify 3 dose comparison metrics useful for MBDCA commissioning

Preparation

- Perform regular TPS commissioning
  - TG-40 & TG-56 give general guidance
  - TG-59 gives specific guidance for HDR brachy
  - TG-64 gives specific guidance for permanent prostate brachy
- Familiarize yourself with the MBDCA
  - training courses
  - user manuals & technical documents
  - peer-reviewed literature

Commissioning Framework

MBDCA commissioning schema from TG-186

Level	Source Positions	Phantom(s)	Reference Dose Distribution
1	single	H_2O full scatter	TG-43
2	single, multiple	virtual geometries mimicking clinical scenarios	MC derived from same geometry

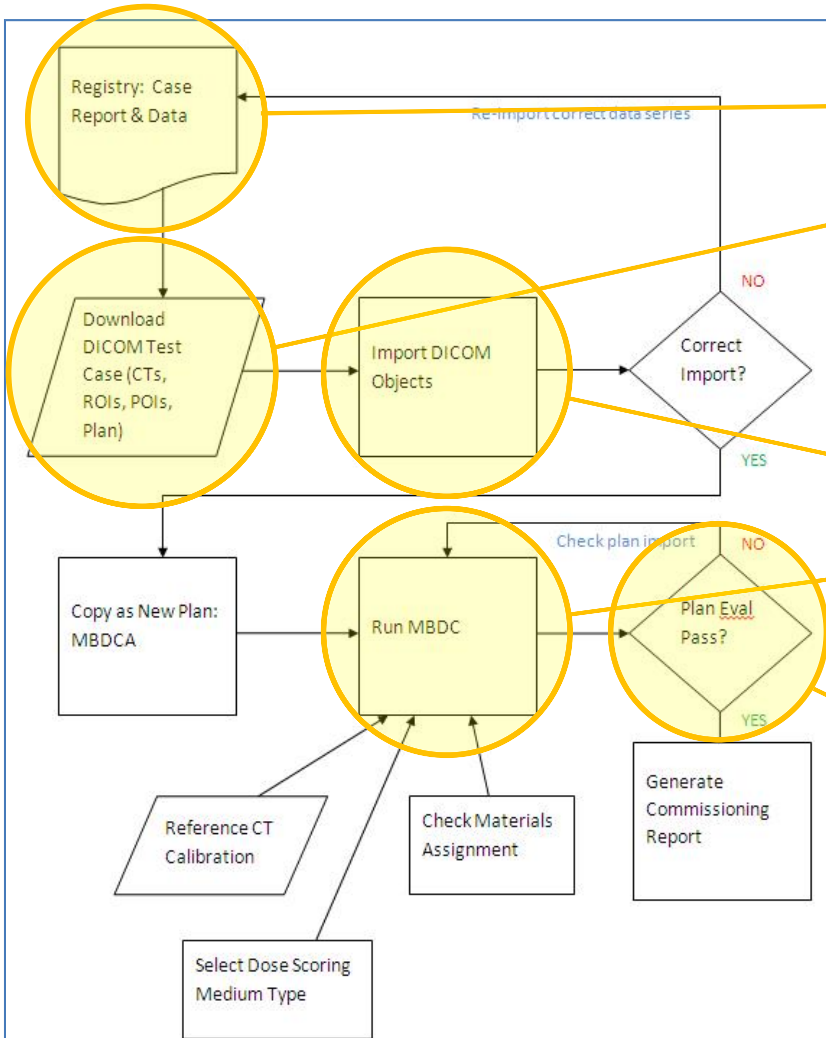
Commissioning Framework

Implemented for HDR ^{192}Ir brachytherapy by:

- defining a generic, virtual source[1]
- creating initial test plans 'Cases 1-4' and associated reference dose distributions[1,2]
- adding commissioning data to the Registry
- drafting commissioning guidance documents

[1] Ballester *et al*, Med Phys 2015; 42:3048-3062
[2] Ma *et al*, submitted to Med Phys

Commissioning Workflow



Abridged flowchart for MBDC software commissioning (adapted from TG-186).

1. access the Registry

2. download (a) a test plan and *(b)* MC reference dose distribution (DICOM)

3. import DICOM objects

4. calculate dose locally using the plan and MBDCA

5. compare & evaluate MBDCA and reference dose distributions

Guidance Documents

1. Access the Registry

http://rpc.mdanderson.org/RPC/home.htm

Brachy Sources → Source Registry → Model-based dose calcs

Model-Based Dose Calculations

Source Registry	Application for Registry	Registry Policy
Prerequisites	Dosimetry Datasets	Model-Based Dose Calcs
AAPM Publications	3rd Party Checks	Disclaimer

Reference dataset (DICOM archive) generated with MC simulation. Users may import these archives into TPS for benchmarking.

- Reference Data

TPS-specific seed DICOM archive. Users may start TPS calculation simply by importing these archives. CT images, RP and RS files are contained.

- Elekta Database
- Varian Database

Google web forum for sharing user ideas and experience.

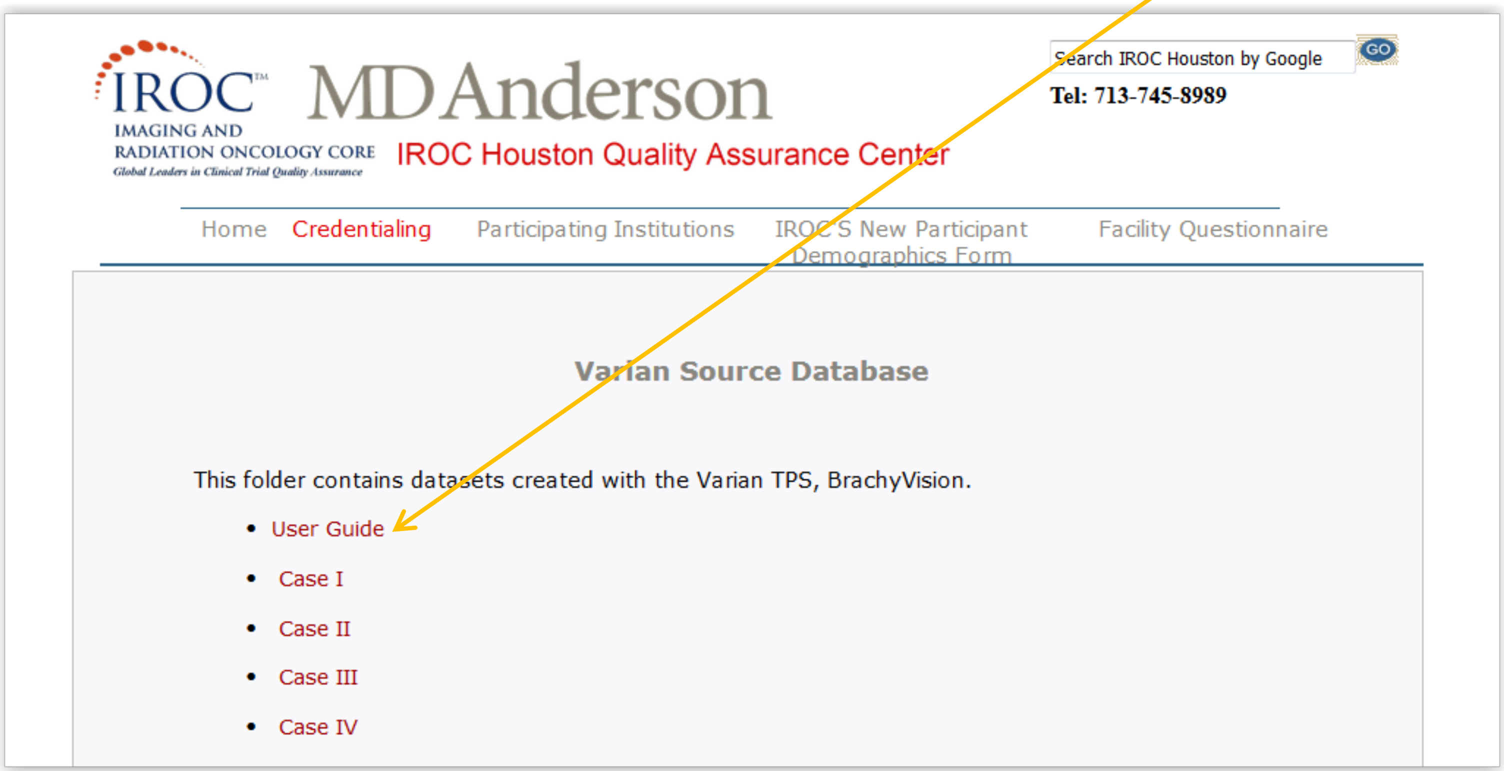
- MBDCA-BT Forum

Disclaimer for source-model definition files.

- Disclaimer

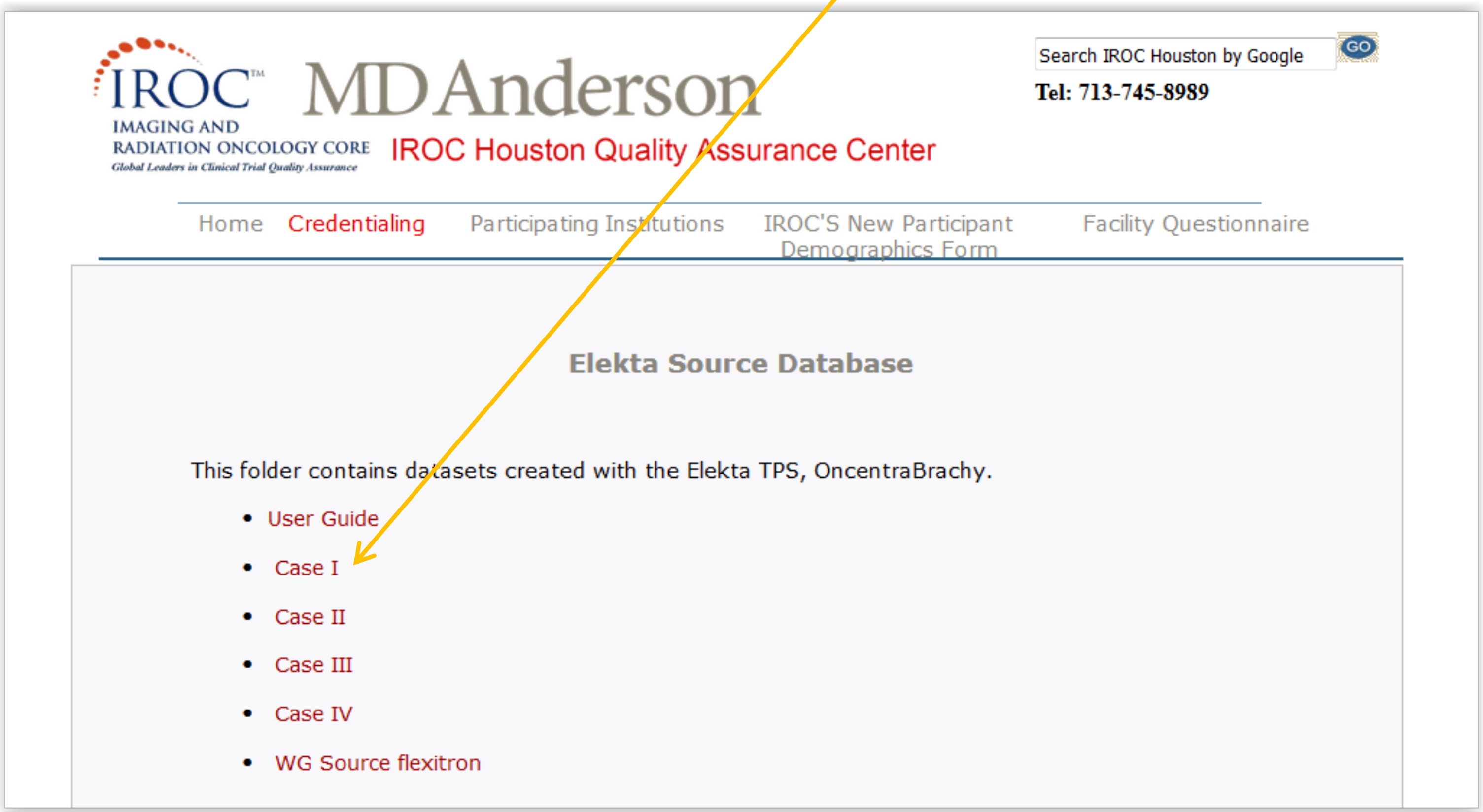
Guidance Documents

Open a TPS database to access the User Guide



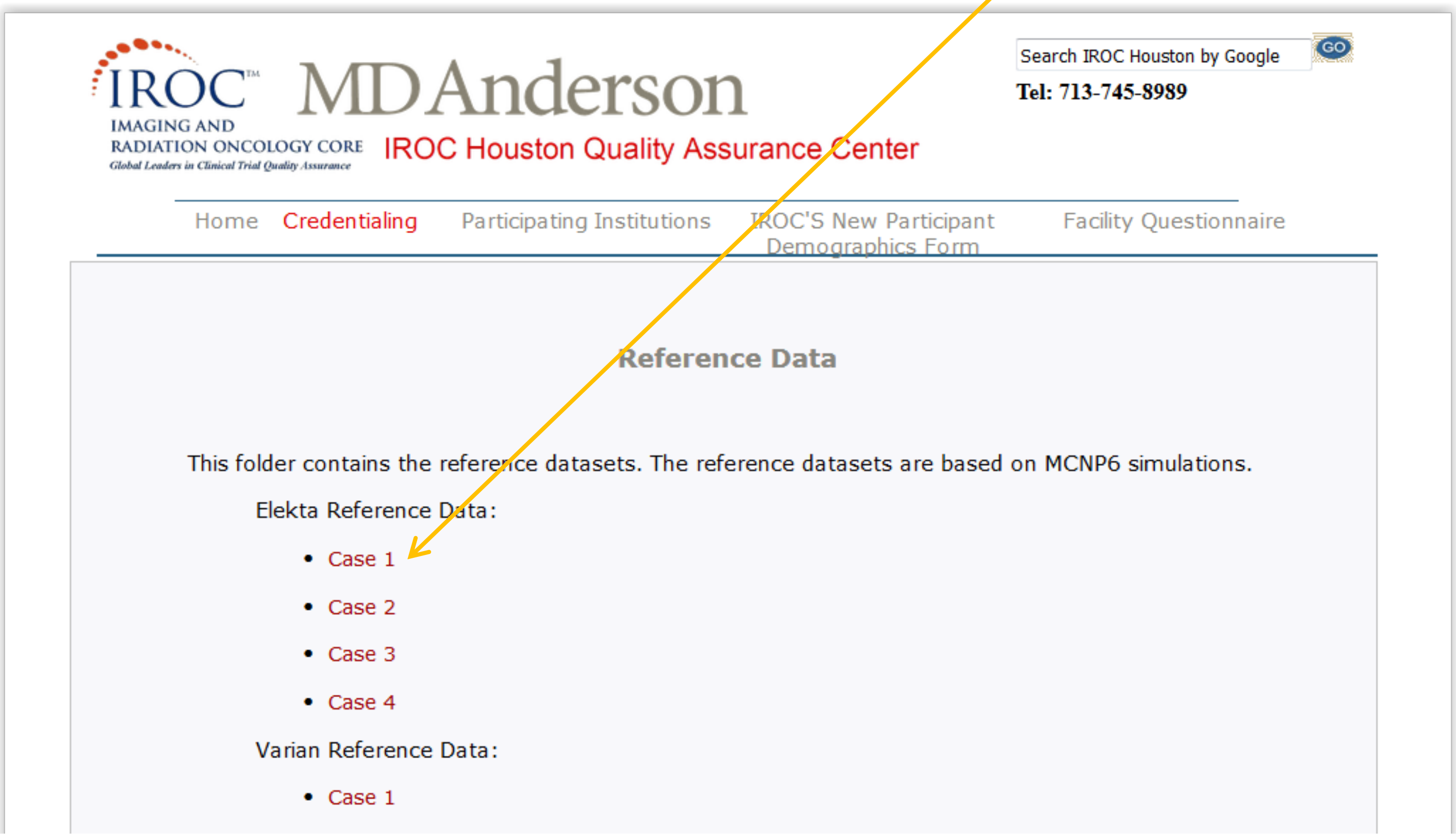
Main Steps

2. *(a) Download* a zipped test plan



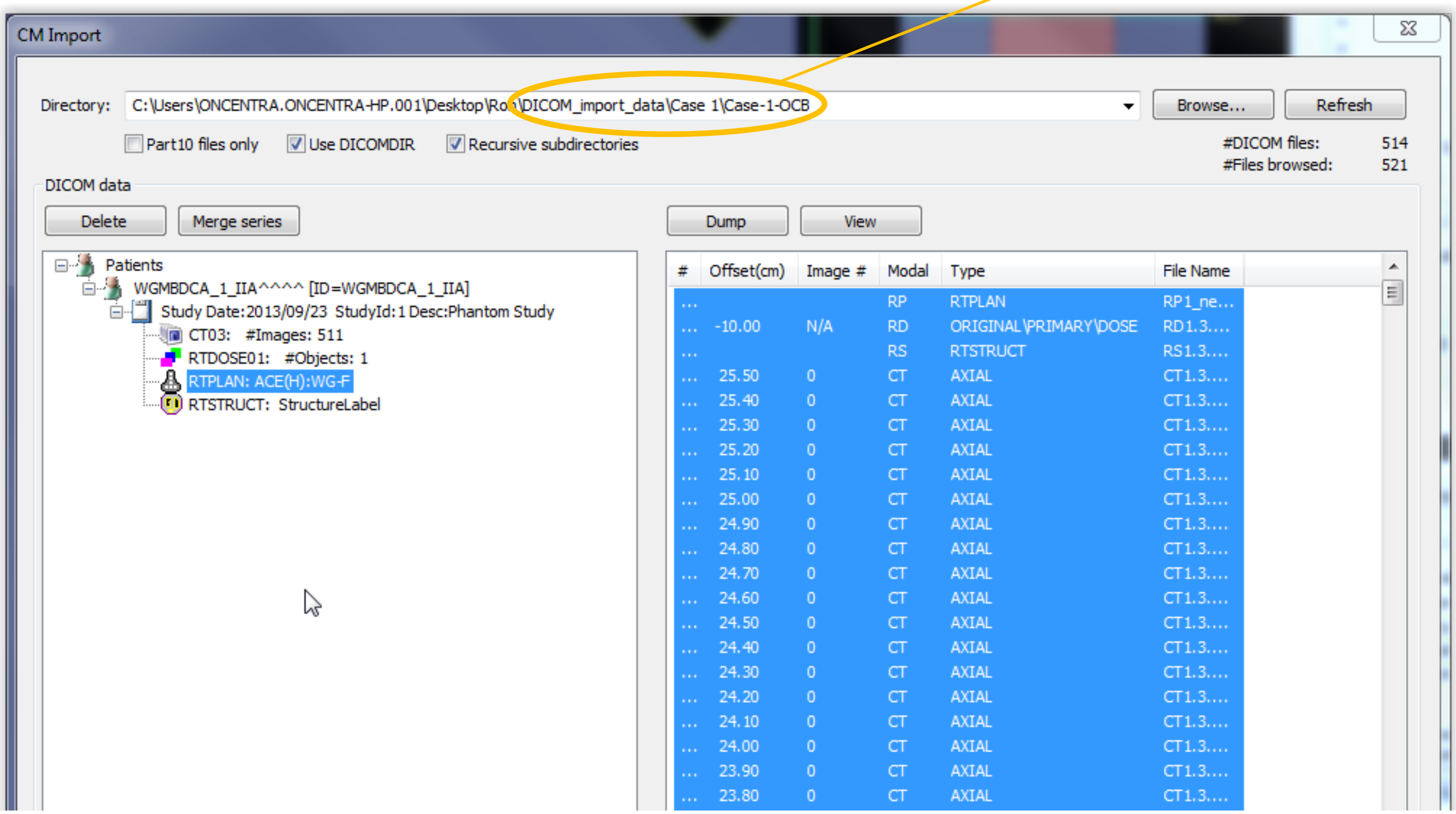
Main Steps

2.(b) Download a zipped ref. dose distribution



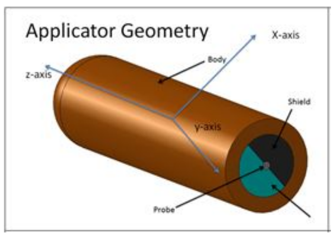
Main Steps

3. *Import* DICOM objects for the test plan and reference dose distribution

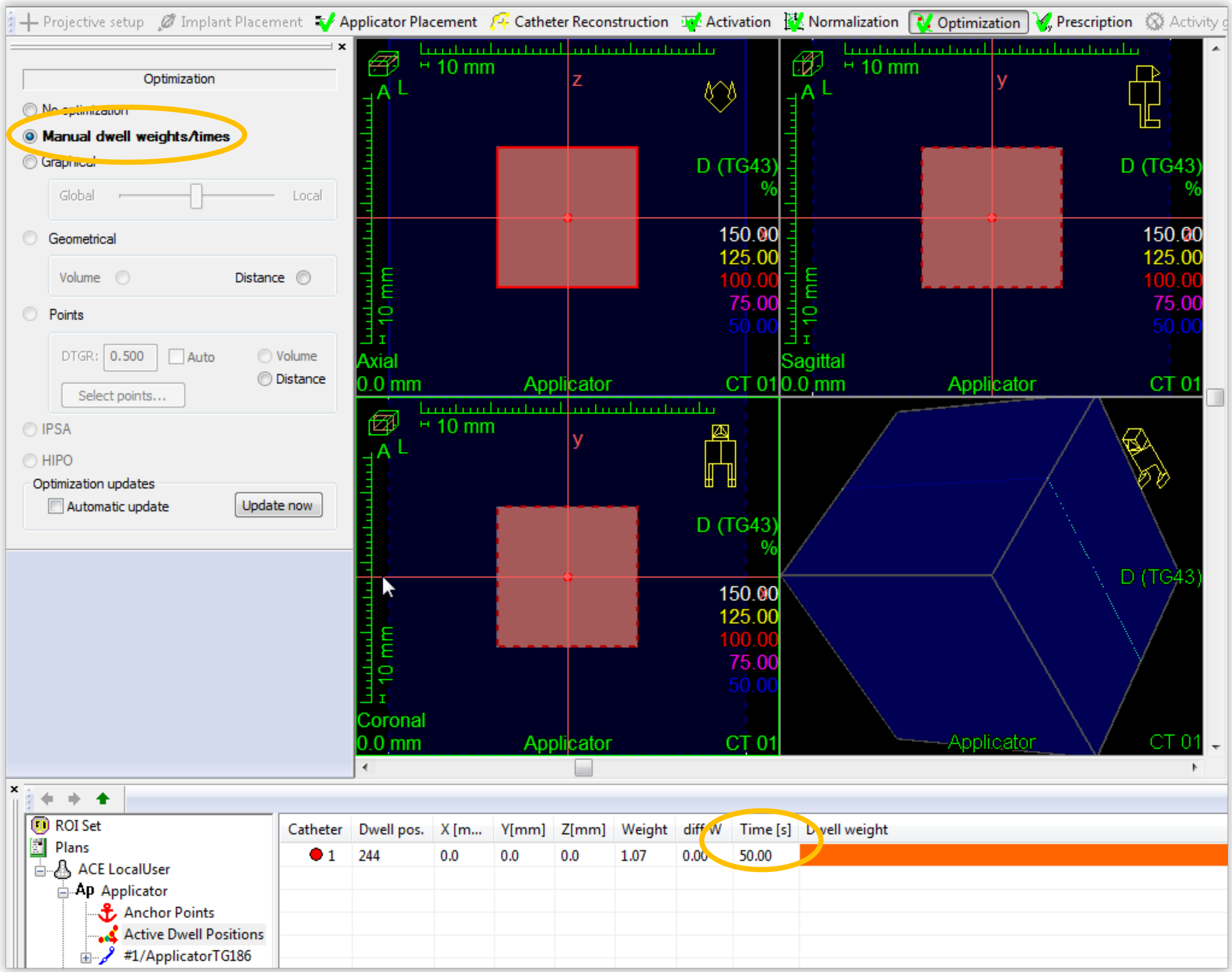


Main Steps

Set up for local dose calculation

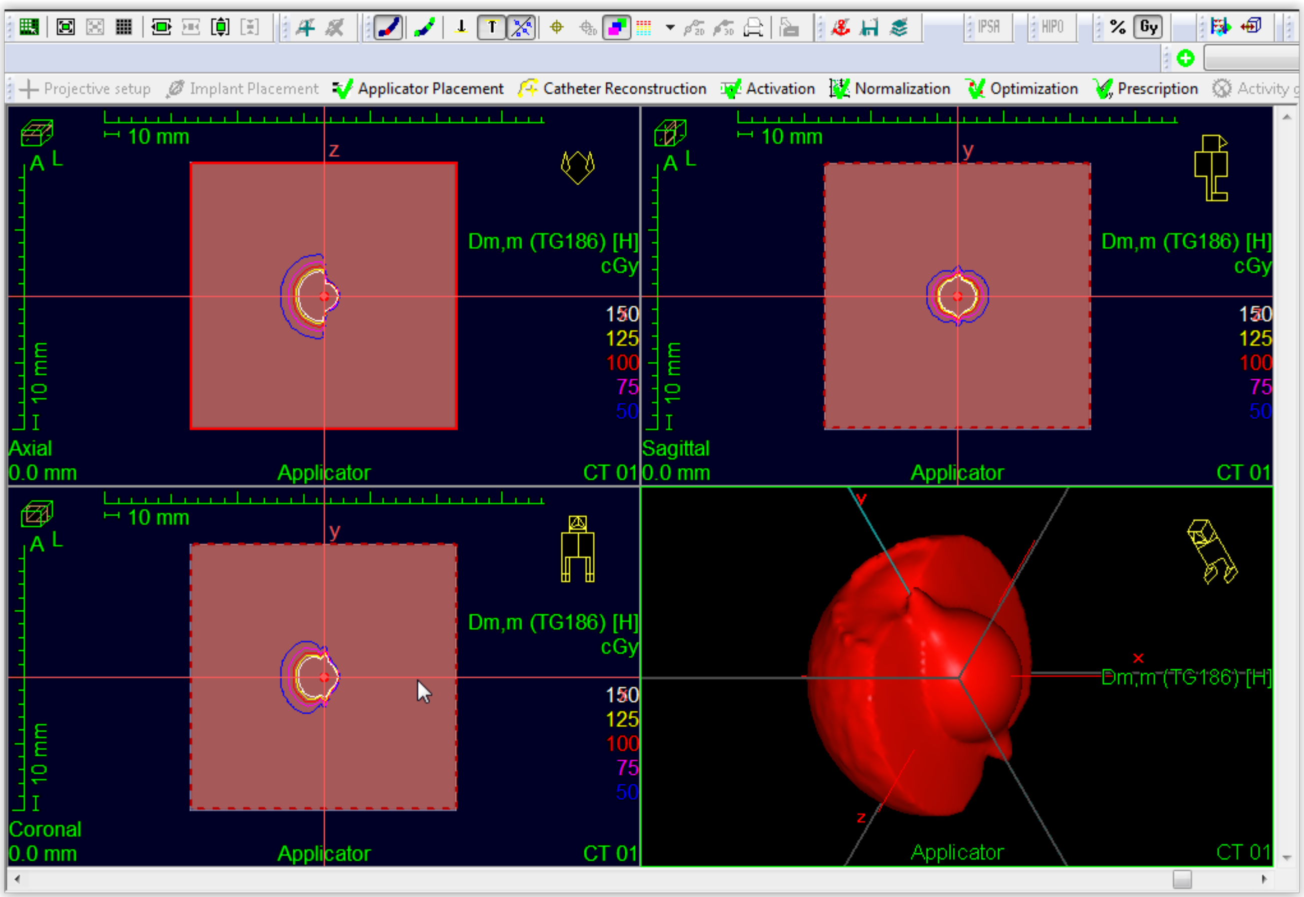


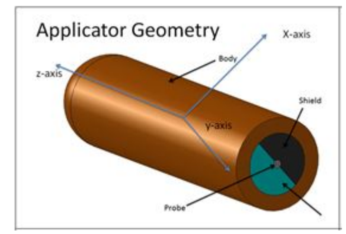
Case 4



Main Steps

4. *Calculate* dose locally using the MBDCA

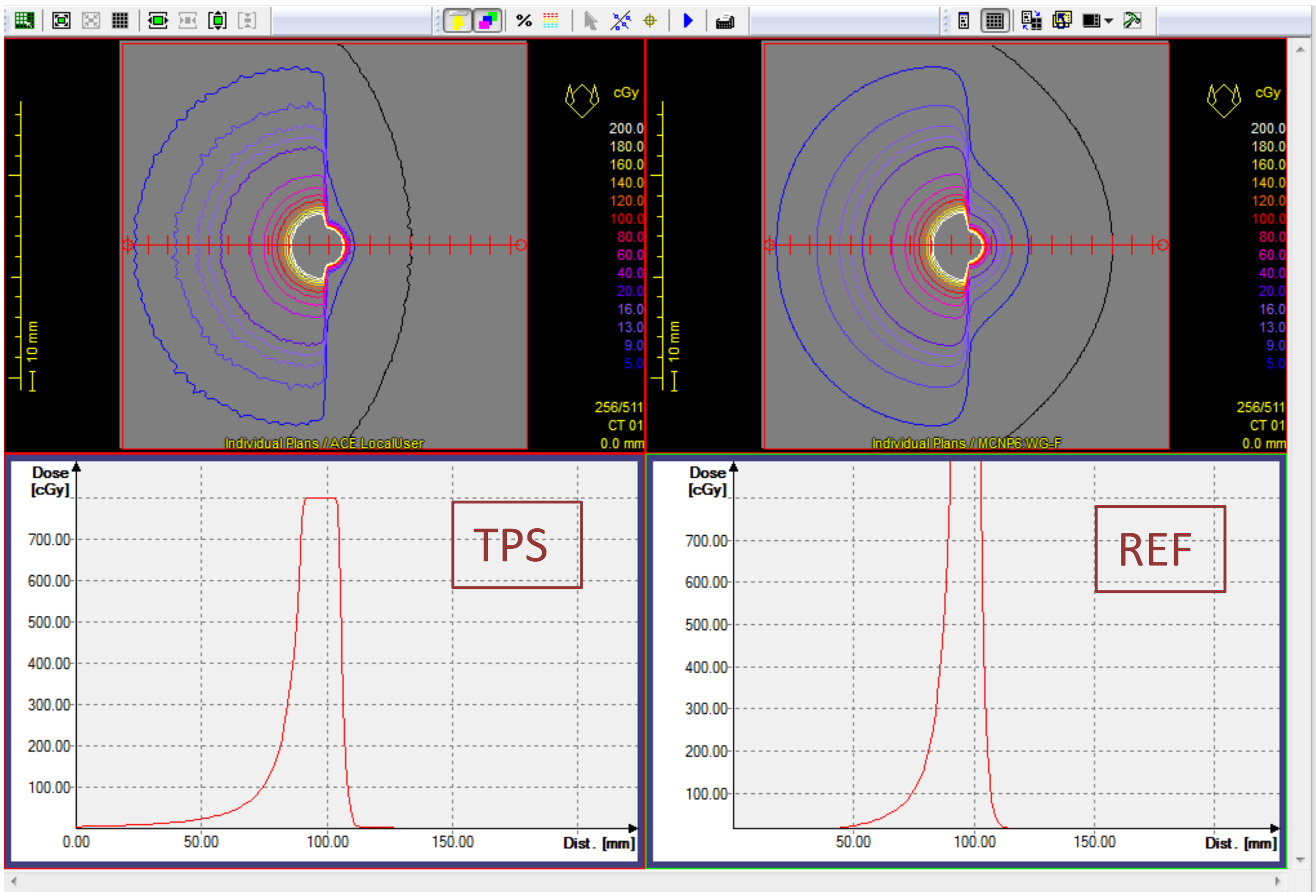


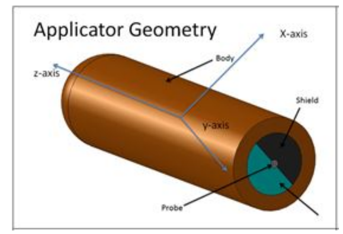


Case 4

Main Steps

5. Compare & evaluate TPS and Ref. doses



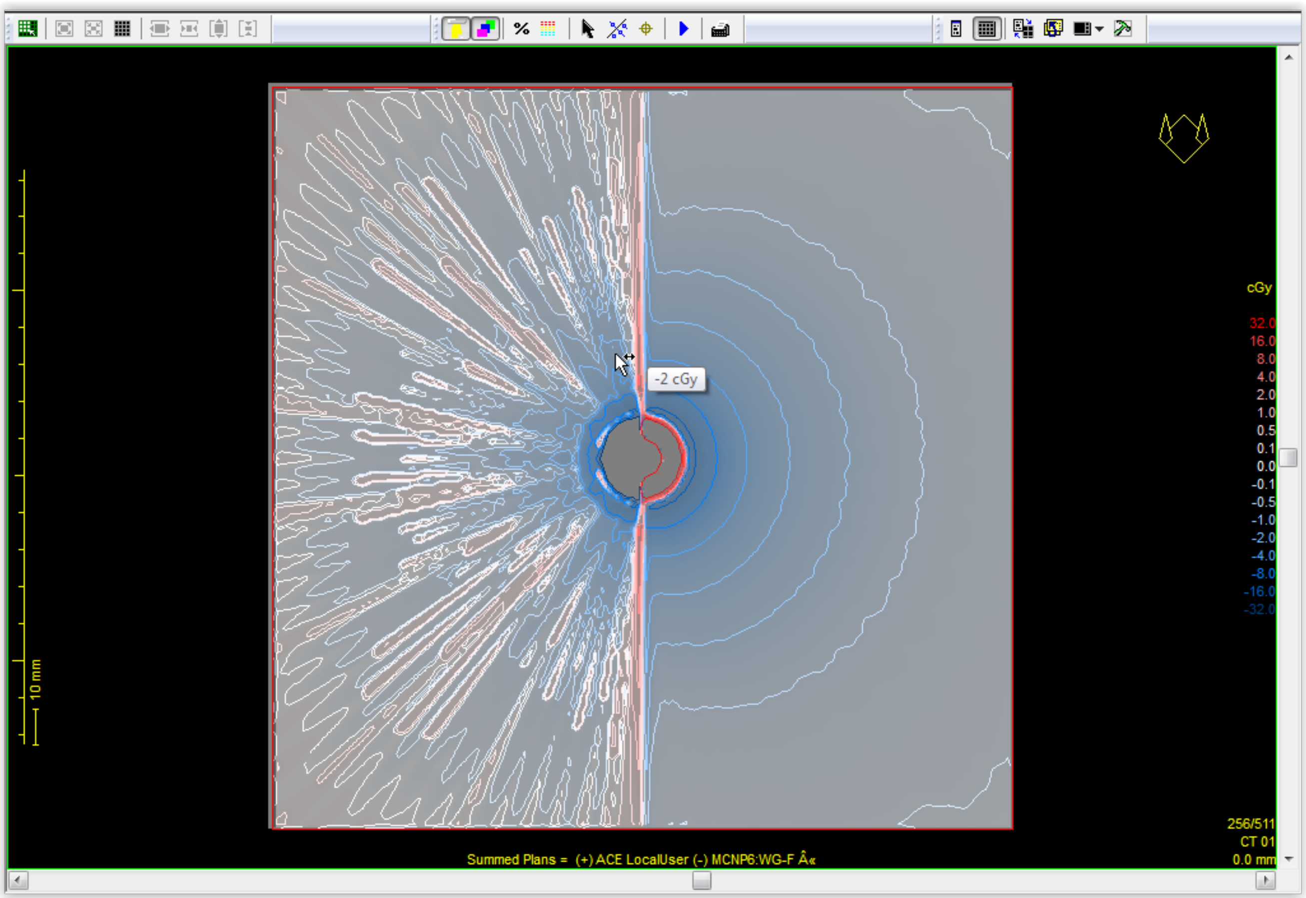


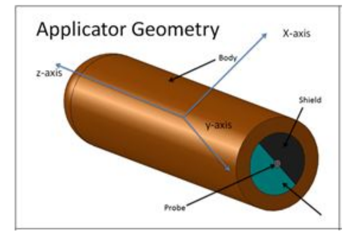
Case 4

OCB dose profiles

Main Steps

OcB dose difference map, point dose query





Case 4

Summary

- Prepare by performing regular TPS commissioning first and familiarizing with MBDCA implementation
- Access the Registry to obtain a TPS-specific User Guide (Elekta, Varian) for Level 2 commissioning
- Download a treatment plan and reference dose distribution for each test plan 'Case 1-4'
- Locally calculate a MBDCA dose distribution for each test plan and compare with reference dose distribution using available TPS tools

Acknowledgements

- AAPM WG-DCAB
  Luc Beaulieu, chair
- AAPM WG-BSR
  Mark Rivard, chair
- IROC Houston QAC
- Elekta Brachytherapy
- Varian Brachytherapy

Summary of TG-186 Recommendations and Ensuing Practical Issues for Model-Based Dose Calculation Algorithms for Brachytherapy

Mark J. Rivard, Ph.D., FAAPM

Department of Radiation Oncology

2017 AAPM SUMMER SCHOOL
CLINICAL BRACHYTHERAPY PHYSICS

In conjunction with the American Brachytherapy Society

Learning Objectives

- understand the TG-186 recommendations
- learn strategies to implement in your clinic
- acknowledge independent plan check limitations
- identify methods for plan comparisons
- frame tolerance levels for MBDCAs

AAPM/ESTRO/ABS/ABG TG-186 Report

Charge:

Provide guidance to MBDCA early adopters for BT dose calculations to ensure practice uniformity.

Outline:

1. Introduction
2. MBDCA Review
3. Dose Specification Medium Selection
4. CT Imaging and Patient Modeling
    4.B. Recommendations
5. MBDCA Commissioning
6. Other Issues and Limitations
7. Conclusions

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

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7. Conclusions

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

TG-186 Report: Recommendation #1

1a. Physicist responsibility for MBDCA dosimetry.

1b. Dose calcs should be based on accurate and spatially-resolved applicator & source models.

1c. These models should include correct material assignments to avoid dose-delivery errors prior to clinical implementation of the MBDCA.

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

TG-186 Report: Recommendation #2

2a. Patient CT grids (~ 1 mm)^3 are spatially inadequate for accurate modeling where source and applicator libraries are preferred.

2b. LE source dosimetry is sensitive to geometric simplification. MBDCA vendors should use analytic modeling schemes or recursively specify meshes with < 10 μm spatial resolution.

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

TG-186 Report: Recommendation #3

3a. Manufacturers of sources & applicators should disclose the geometries, material assignments, and manufacturing tolerances to physicists and MBDCA vendors to permit accurate dose modeling.

3b. MBDCA vendors should incorporate sources and applicators into their TPS or allow the physicist to with a simple method.

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

TG-186 Report: Recommendation #4

4a. Sources and applicators incorporated into a MBDCA TPS should be independently verified.

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

TG-186 Report: Recommendation #5

5a. Vendors of TPS applicator libraries should permit physicist verification of source or applicator characterization.

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

TG-186 Report: Recommendation #6

6a. Physicist should compare MBDCA-generated single-source dose distributions in water to directly calculated TG-43 benchmarks

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

TG-186 Report: Summary

Commissioning MBDCA TPSs requires diligence.

The AAPM, ESTRO, ABS, and ABG recommend that TG-43 based prescriptions remain in effect until sufficient clinical data become available to issue societal recommendations on dose prescriptions,

Beaulieu et al., Med. Phys. 39, 6208-6236 (2012)

MBDCA Usage: SS17 Poll

MBDCA Usage: SS17 Poll

1. Please raise your hand for the denominator.

2. Who currently uses MBDCA-based TPS?

3. Who is interested and has an identifiable hurdle?

4. Who thinks MBDCAs can improve cancer care?

5. Commissioning MBDCA TPSs requires diligence.

MBDCA Independent Checks

Independent checks recommended: AAPM, ACR, etc

- TG-43 independent check simple water geometry

What to do for complicated patient geometry?

- consider TG-43 hybrid approach for checking
- fixed source, applicator, tissue geometry

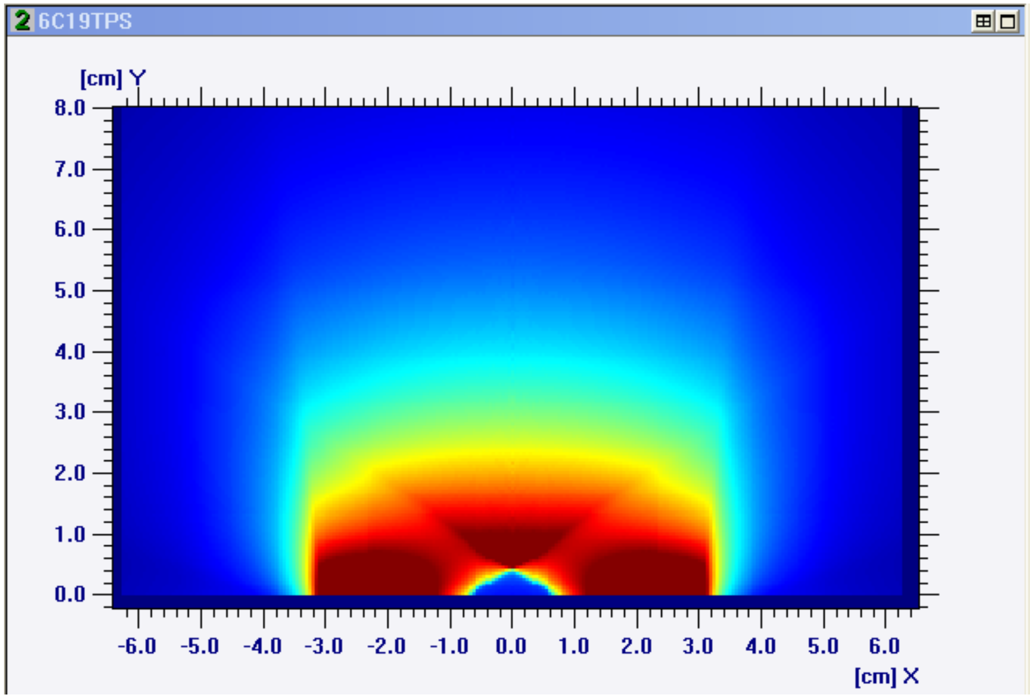
Attributes of checking tool dependent on energy:

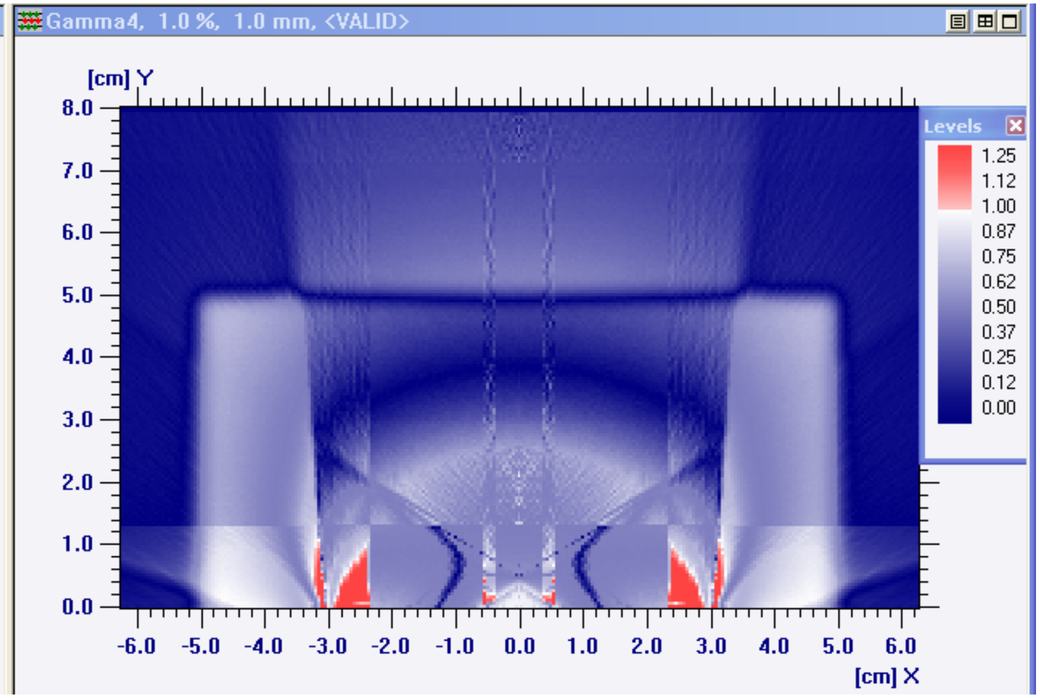
- high-E sources require geometric accuracy.
- low-E sources require detailed compositions.

To be continued …

Need New TPS Evaluation Criteria for BT

AccuBoost Pinnacle^3 vs. MCNP5



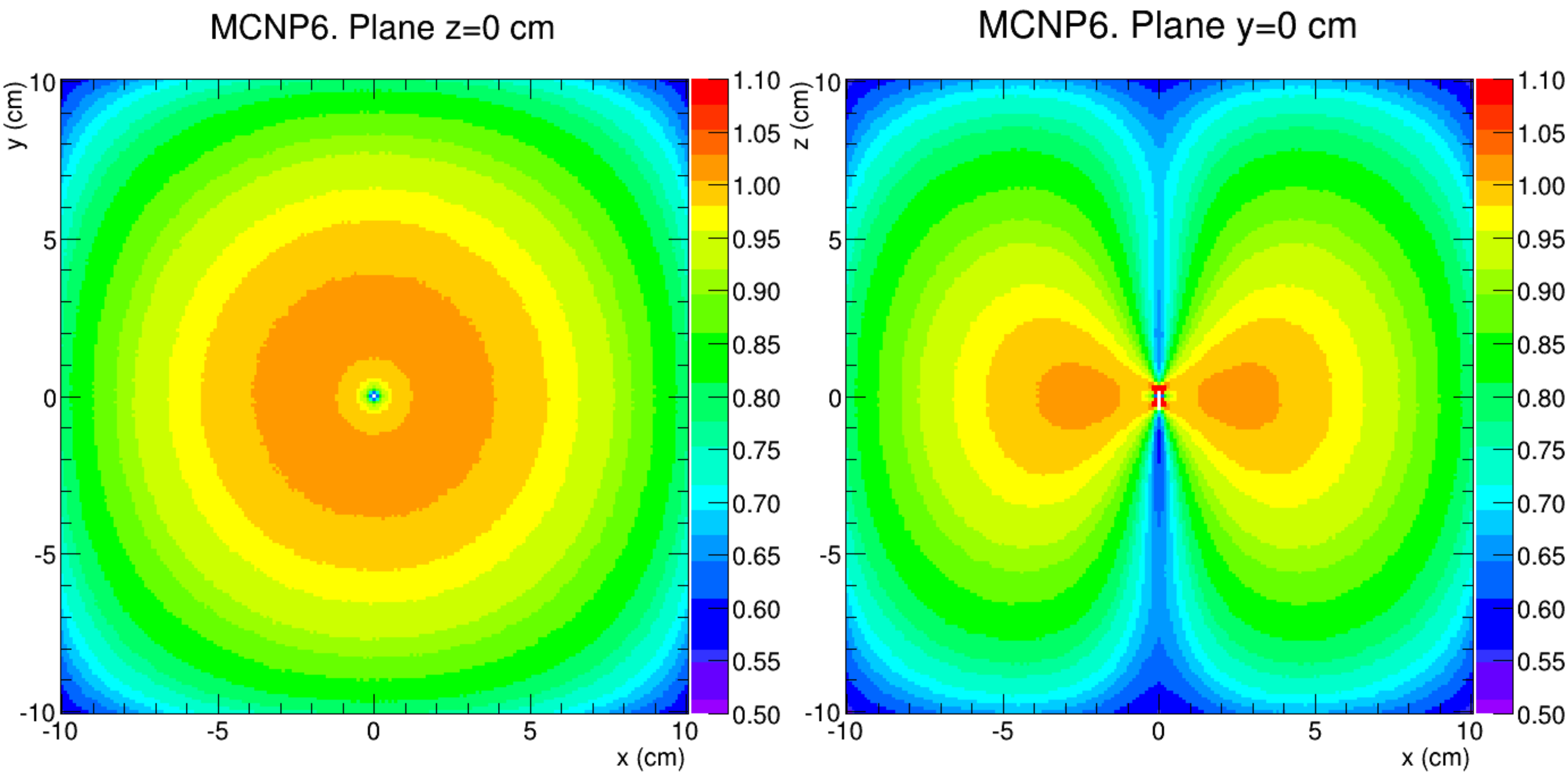


consider gamma-index analysis
distance-to-agreement (meaning?)

Yang et al., Med. Phys. 38, 1519-1525 (2011) Yang & Rivard, Med. Phys. 37, 5665-5671 (2010)

Need New TPS Evaluation Criteria for BT

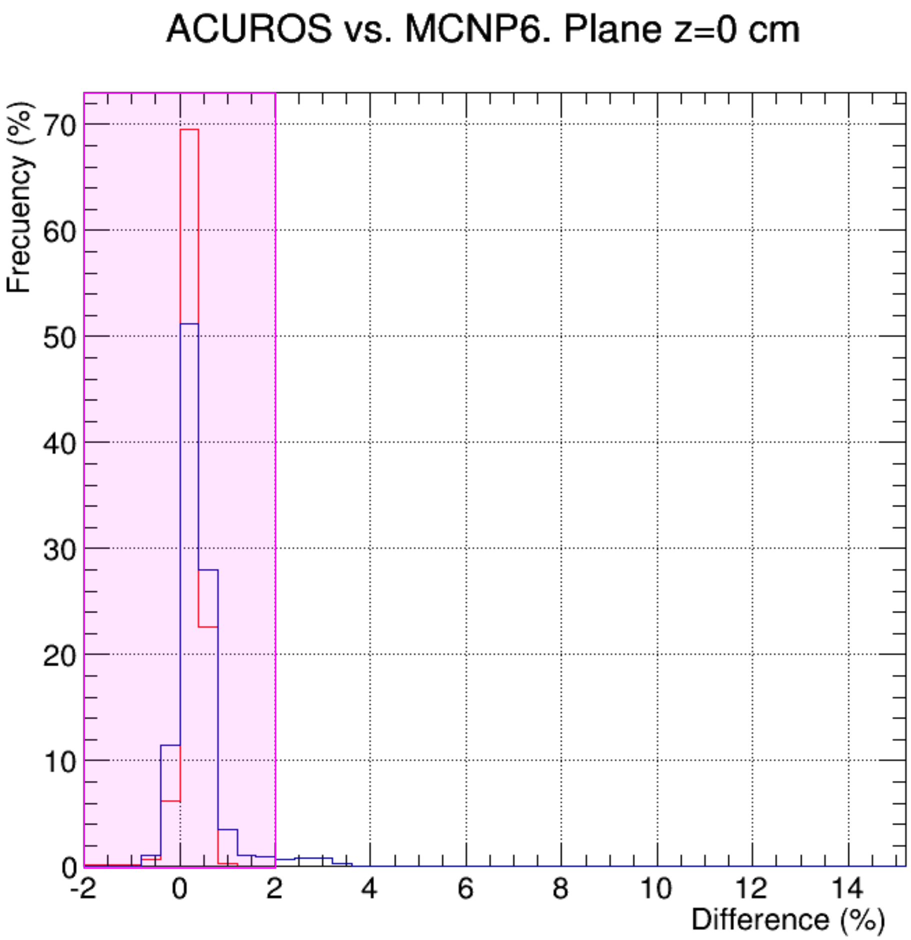
HDR ^{192}Ir source centered in cube (20 cm)^3



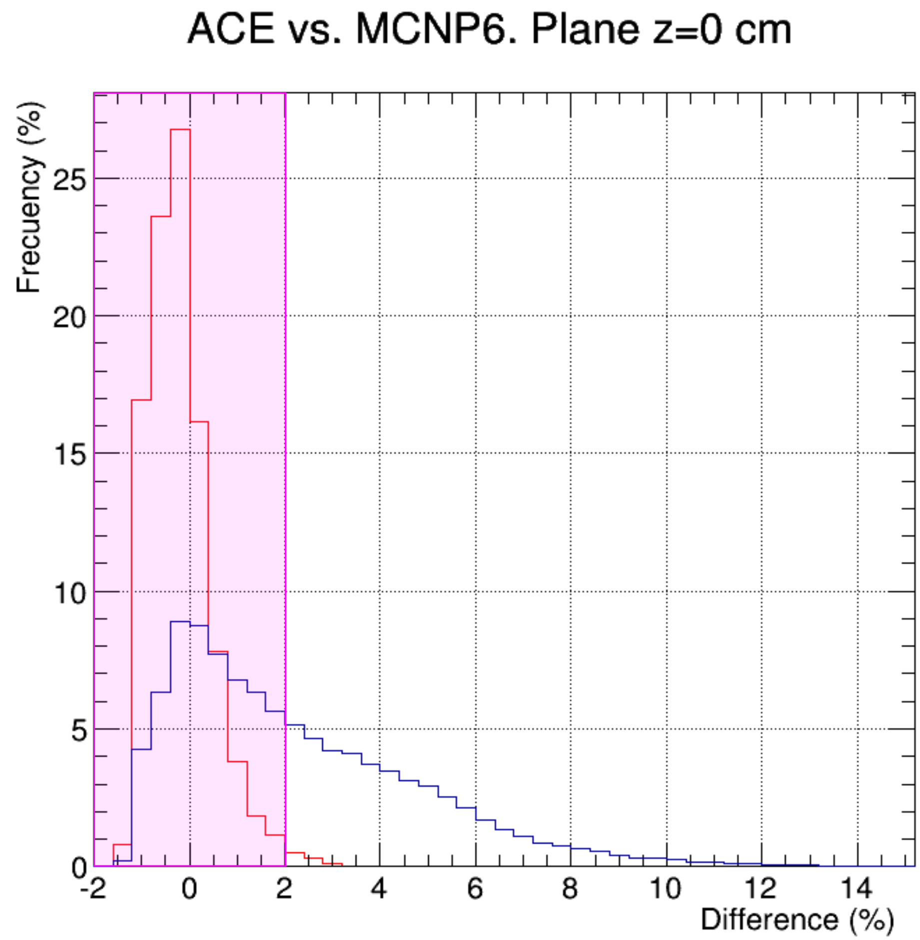
Ballester et al., Med. Phys. 42, 3048-3062 (2015)

Need New TPS Evaluation Criteria for BT

ACUROS and ACE vs. MCNP6: HDR ^{192}Ir source centered in cube (20 cm)^3



mostly inside 2% local agreement



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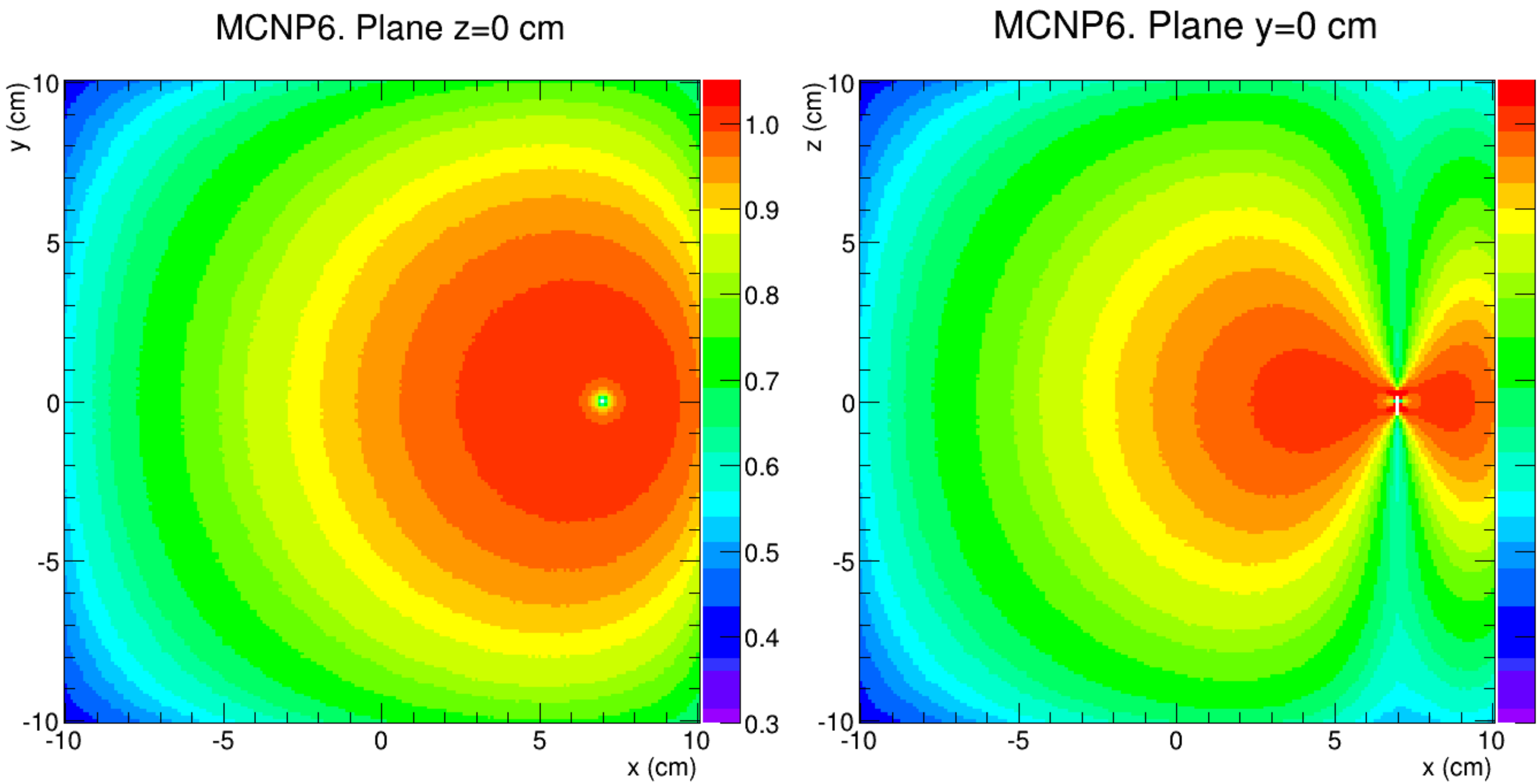
Ballester et al., Med. Phys. 42, 3048-3062 (2015)

Need New TPS Evaluation Criteria for BT

HDR ^{192}Ir source offset 3 cm from cube face



Ballester et al., Med. Phys. 42, 3048-3062 (2015)

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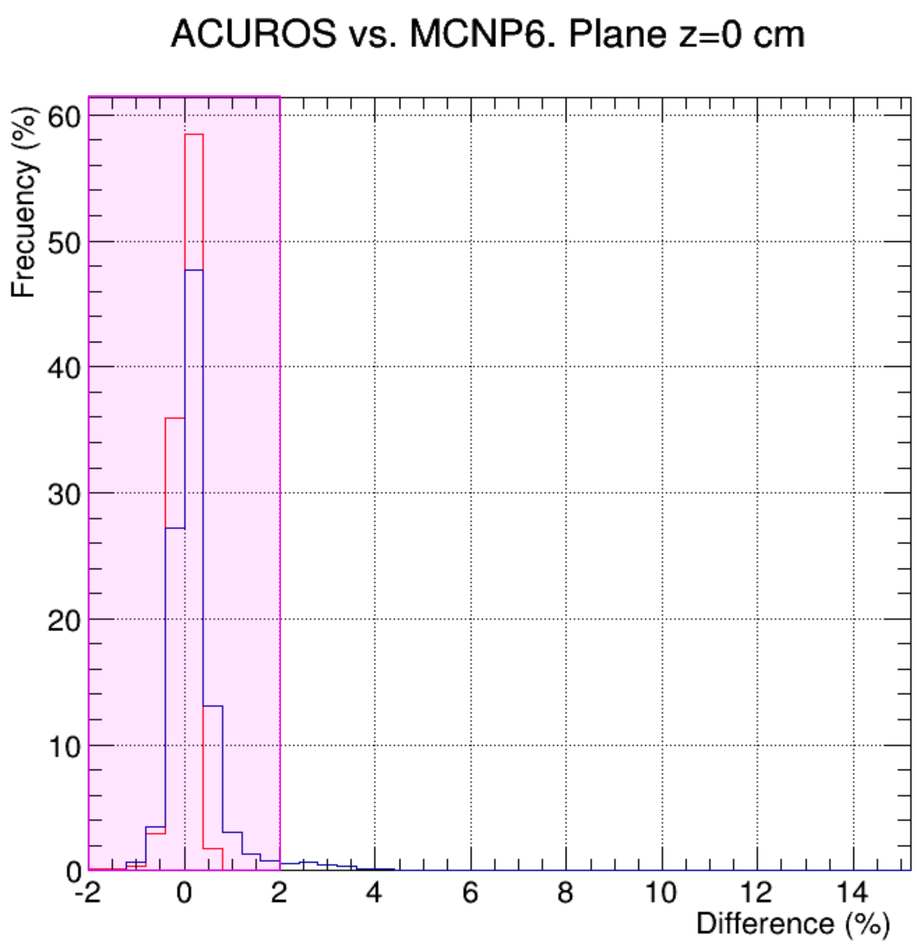
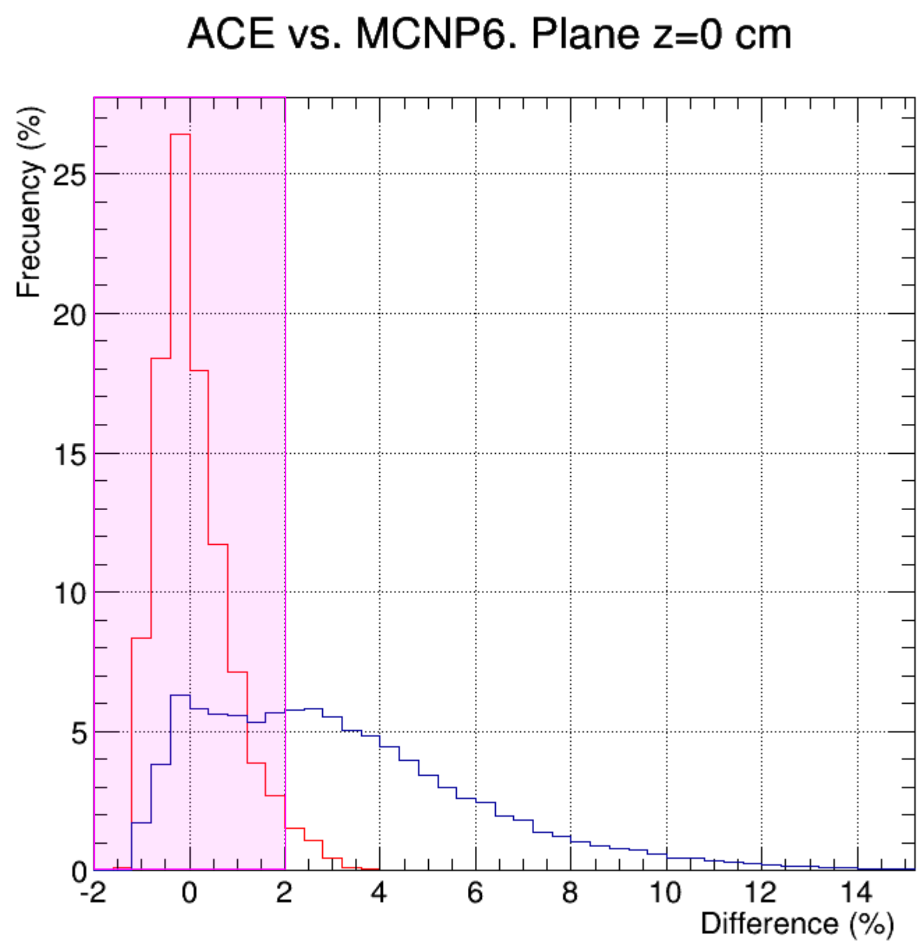




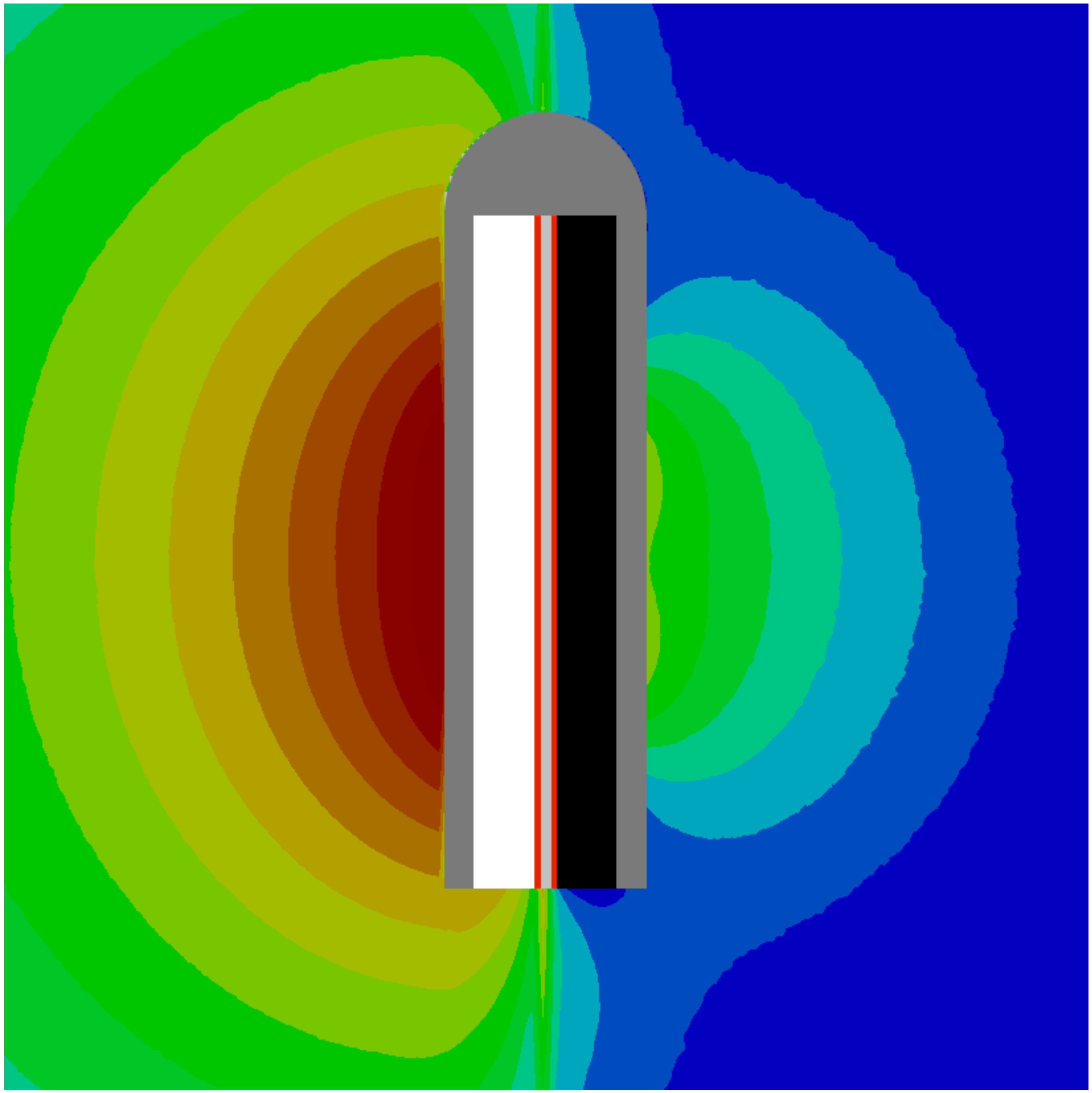
mostly inside 2% local agreement

somewhat inside 2% local agreement

Ballester et al., Med. Phys. 42, 3048-3062 (2015)

Need New TPS Evaluation Criteria for BT

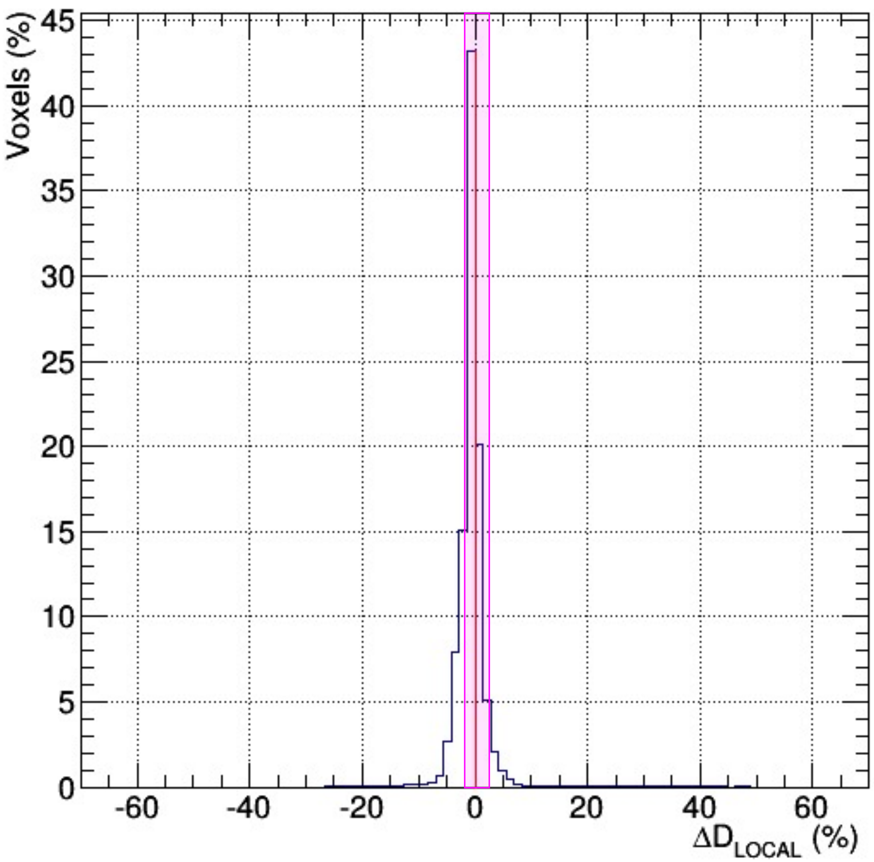
HDR ^{192}Ir source (1 dwell) inside shielded cylinder

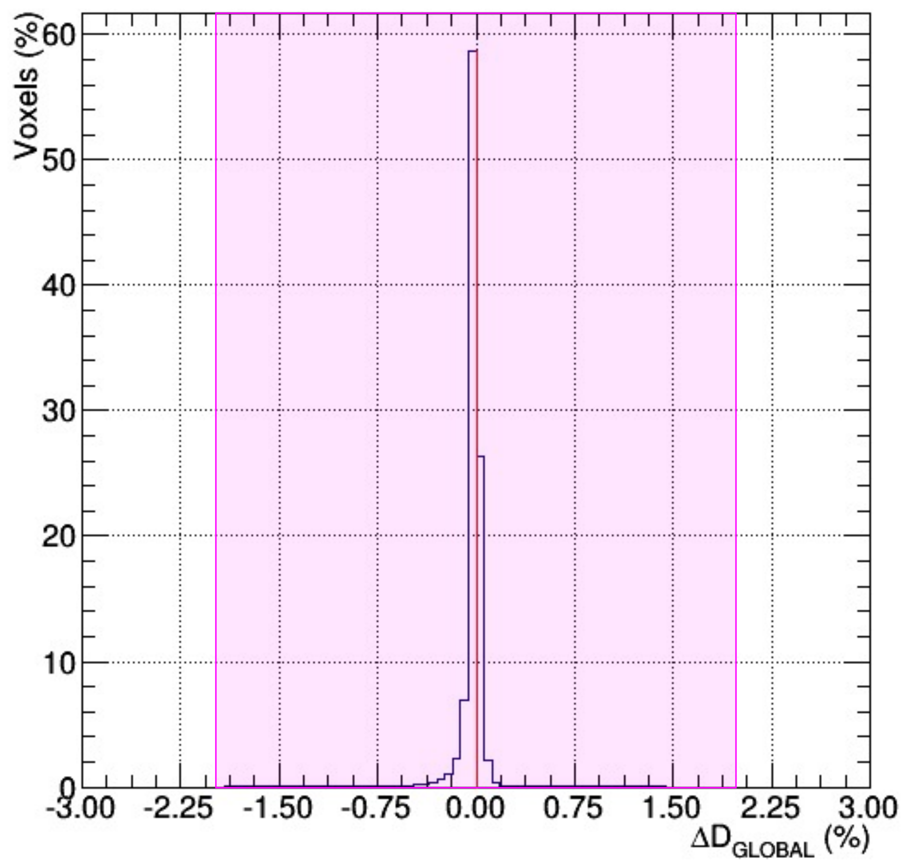


courtesy of Yunzhi Ma

Need New TPS Evaluation Criteria for BT

ACUROS vs. MCNP6: HDR ^{192}Ir source (1 dwell) inside shielded cylinder





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Ma et al., Med. Phys. (accepted for publication)

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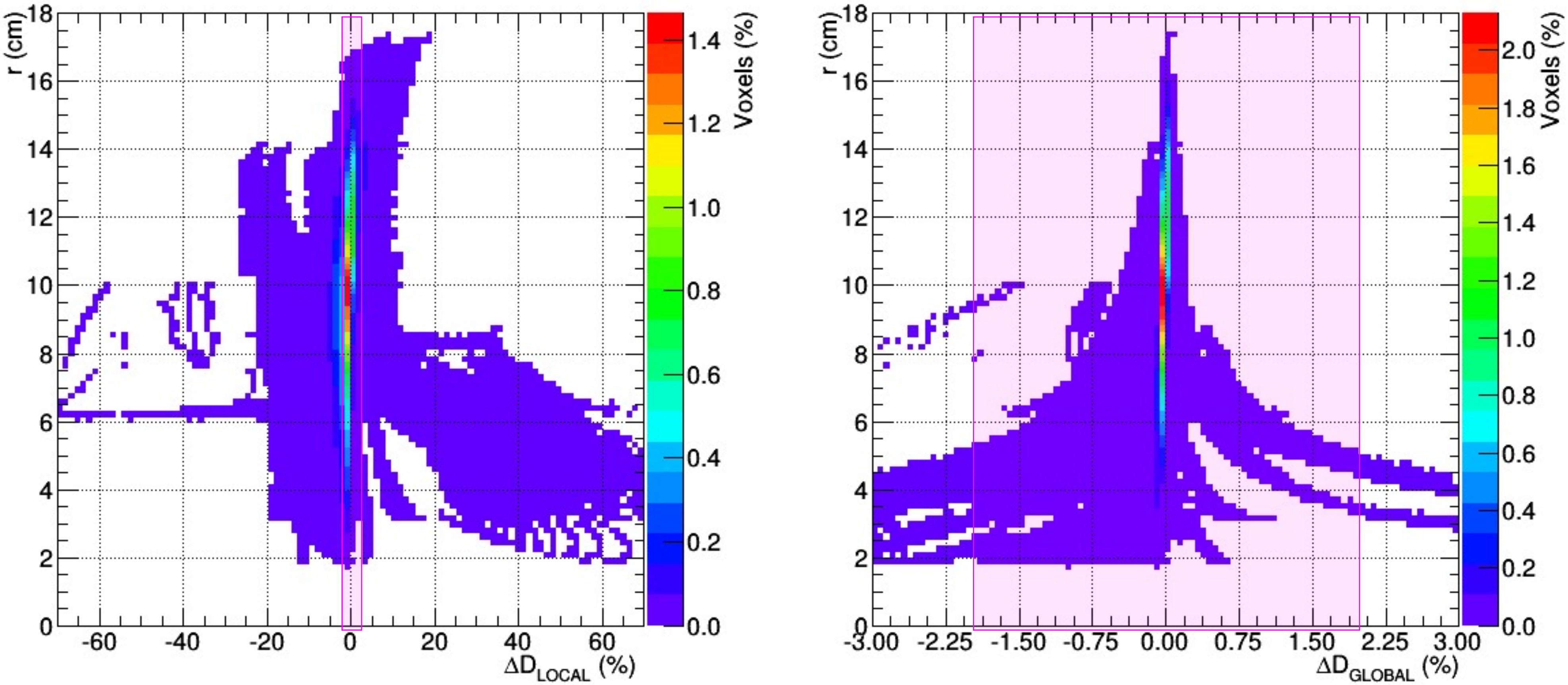

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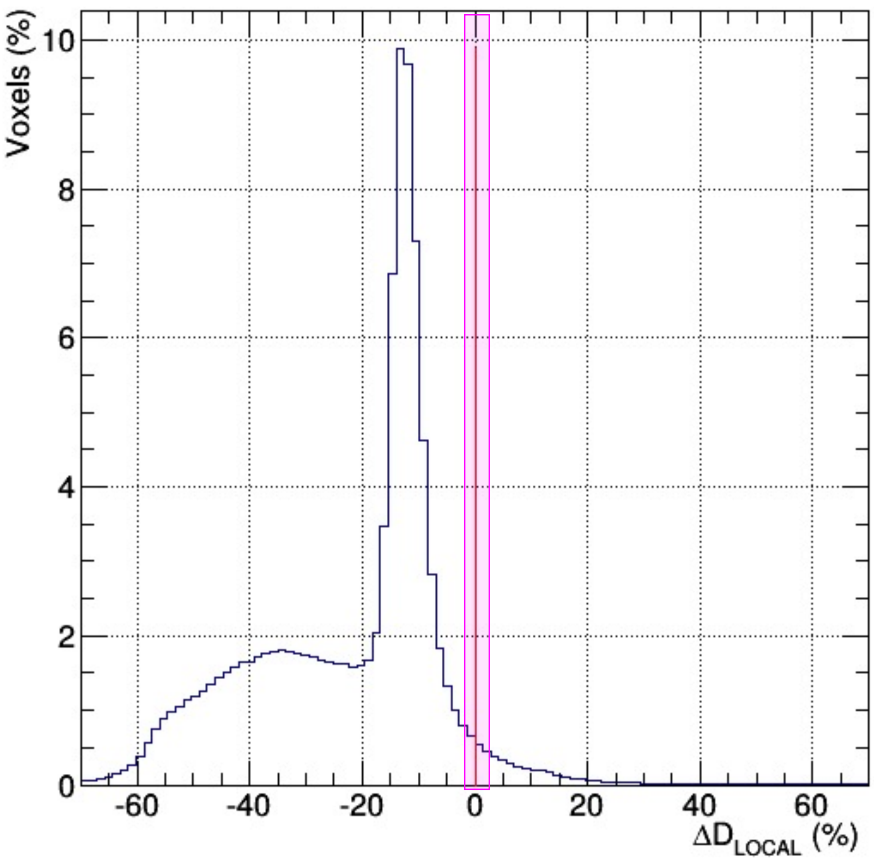

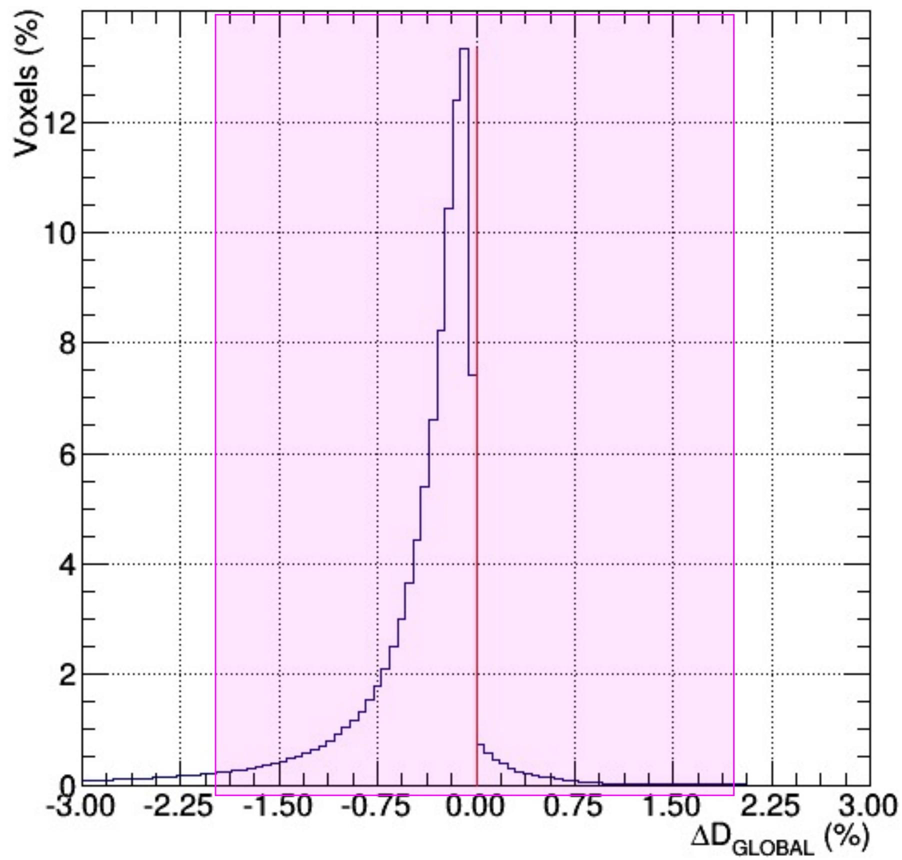

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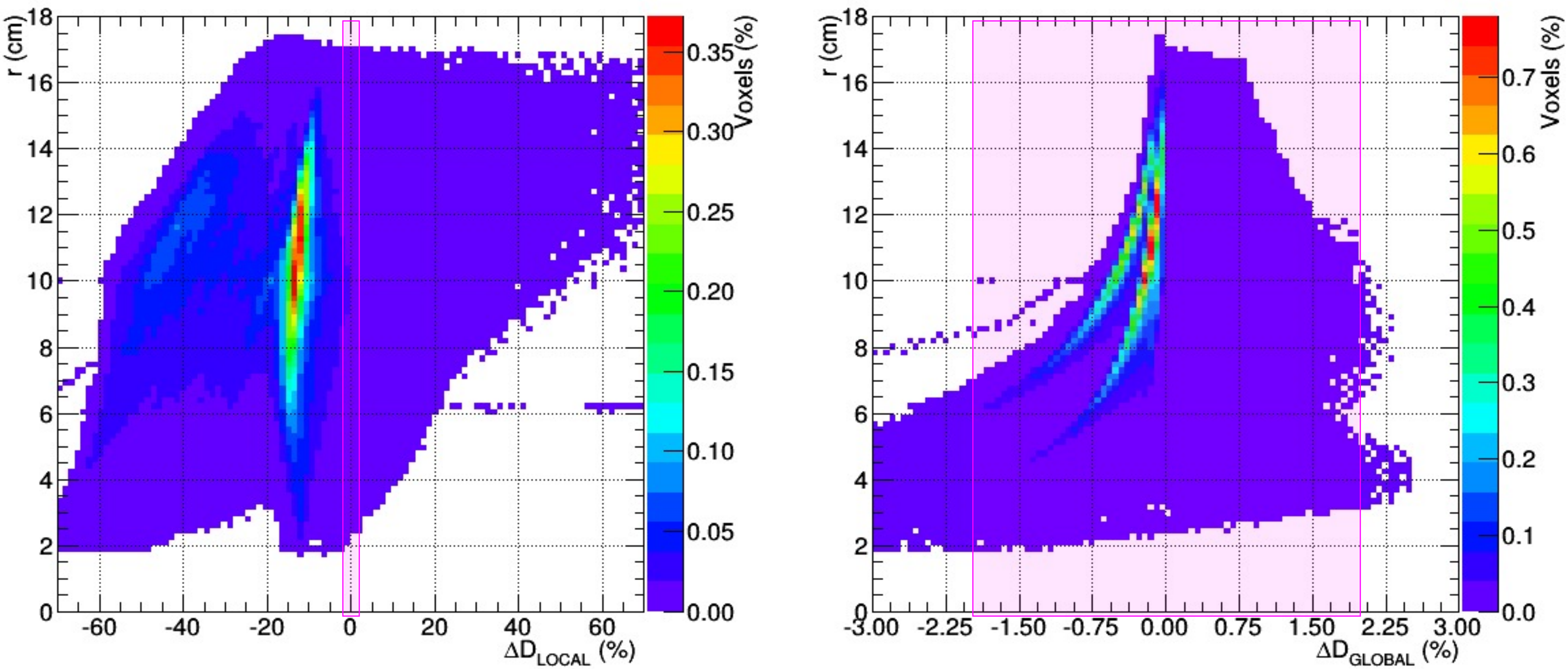

mostly **outside** 2% local agreement

Ma et al., Med. Phys. (accepted for publication)

Summary

- TG-186 has 6 recommendations to MBDCA early-adopters
- These recommendations are generally qualitative
- No commercial system yet in place for independent check
- New evaluation criteria (tools!) needed for plan comparisons
- Standard 2% agreement not valid for source commissioning
- Exciting develops underway with test cases & standardization

Acknowledgements

MBDCA WG members

- F. Ballester
- Luc Beaulieu, Chair
- Å. Carlsson Tedgren
- A. Haworth
- B. Libby
- J. R. Lowenstein
- Y. Ma
- F. Mourtada
- P. Papagiannis
- M. J. Rivard
- F.-A. Siebert Vice Chair
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