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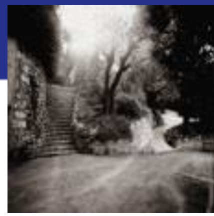
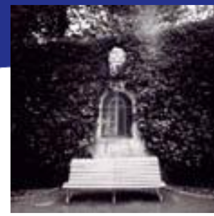





Modern clinical applications of Monte Carlo simulations for in-vivo patient-specific QA

Tony Popescu, *PhD FCCPM*

Senior Medical Physicist, British Columbia Cancer Agency
Adjunct Professor, University of British Columbia
Vancouver, Canada

MCMA, Naples, Italy, 17 October 2017

A truly ‘patient-specific’ QA protocol should be relevant to the actual patient treatment and be capable of providing *in vivo* dosimetry.

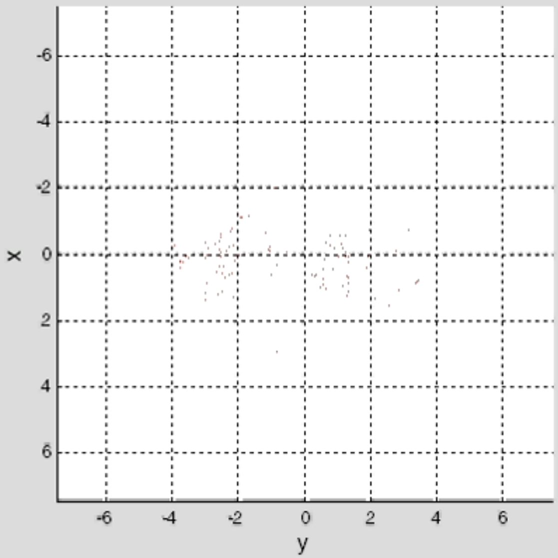
The major current commercially-available QA solutions (e.g. ArcCHECK, MapCheck, EPIdose (Sun Nuclear, USA); Delta4 (ScandiDos, Sweden); or MatriXX (IBA Dosimetry, Germany)), are valuable within the pre-treatment paradigm, but would not be able to catch an egregious error during treatment, such as patient miss-positioning, missing MLC, etc

In contrast, *transmission* EPID dosimetry and patient 3D dose calculation using real-time linac log information, in conjunction with CBCT imaging to assess changes in patient anatomy, could provide adaptive patient dose accumulation over the entire course of treatment

After scoring an output 4D phase space in DOSXYZnrc, the EPID MC dose can be obtained in a single simulation. Since the MU index is stored for each particle, specific control-point information can also be extracted.

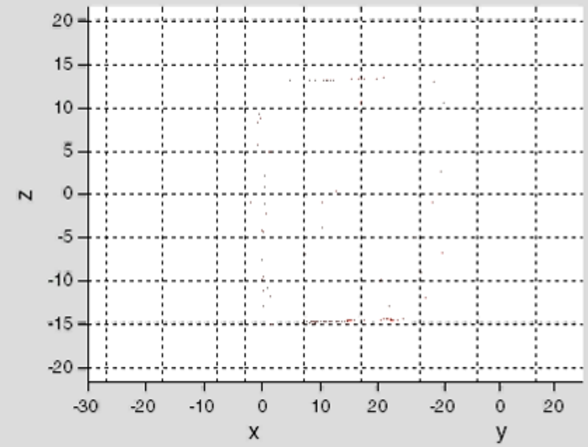
Example: VMAT plan with jaw tracking

MU index:
- ● 0.0 ~ 0.5
- ● 0.5 ~ 1.0



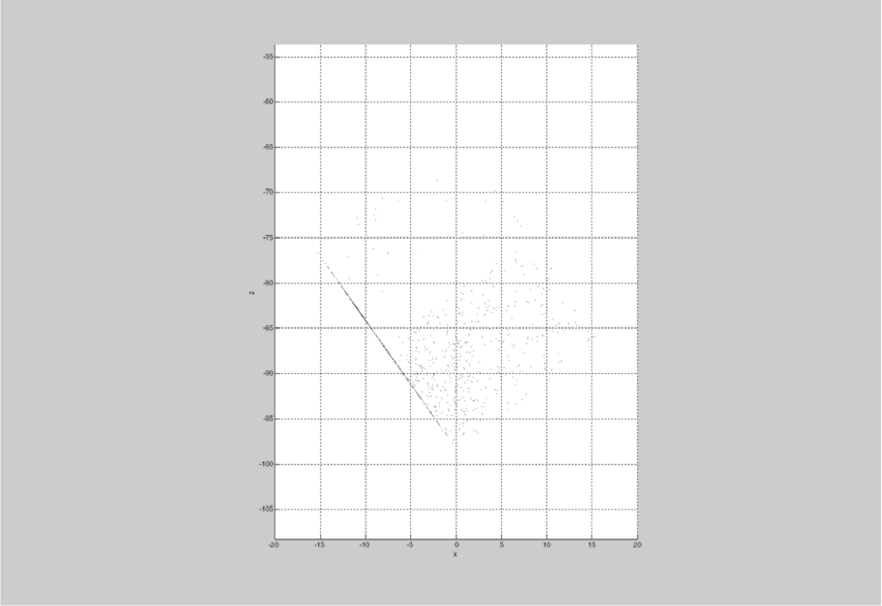
‘Entrance detector’ 4D phase space

4D exit phase space in DOSXYZnrc coordinates

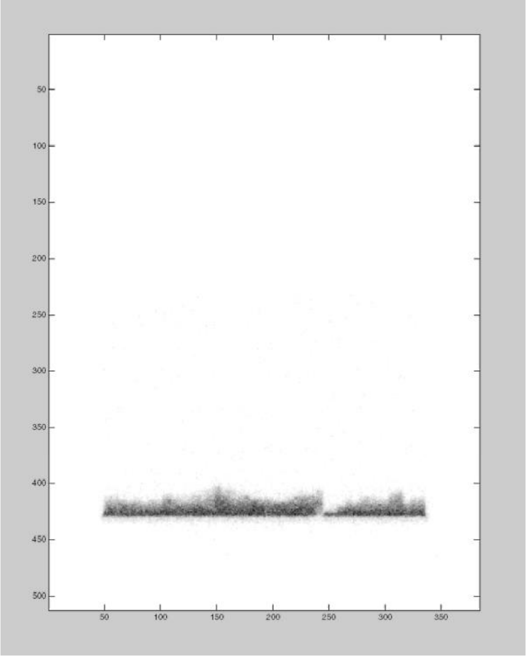


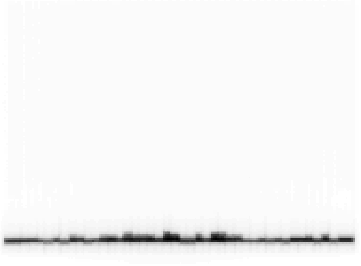
‘Exit detector’ 4D phase space

DOSXYZnrc isource=20 simulation



MC simulation of cumulative EPID dose



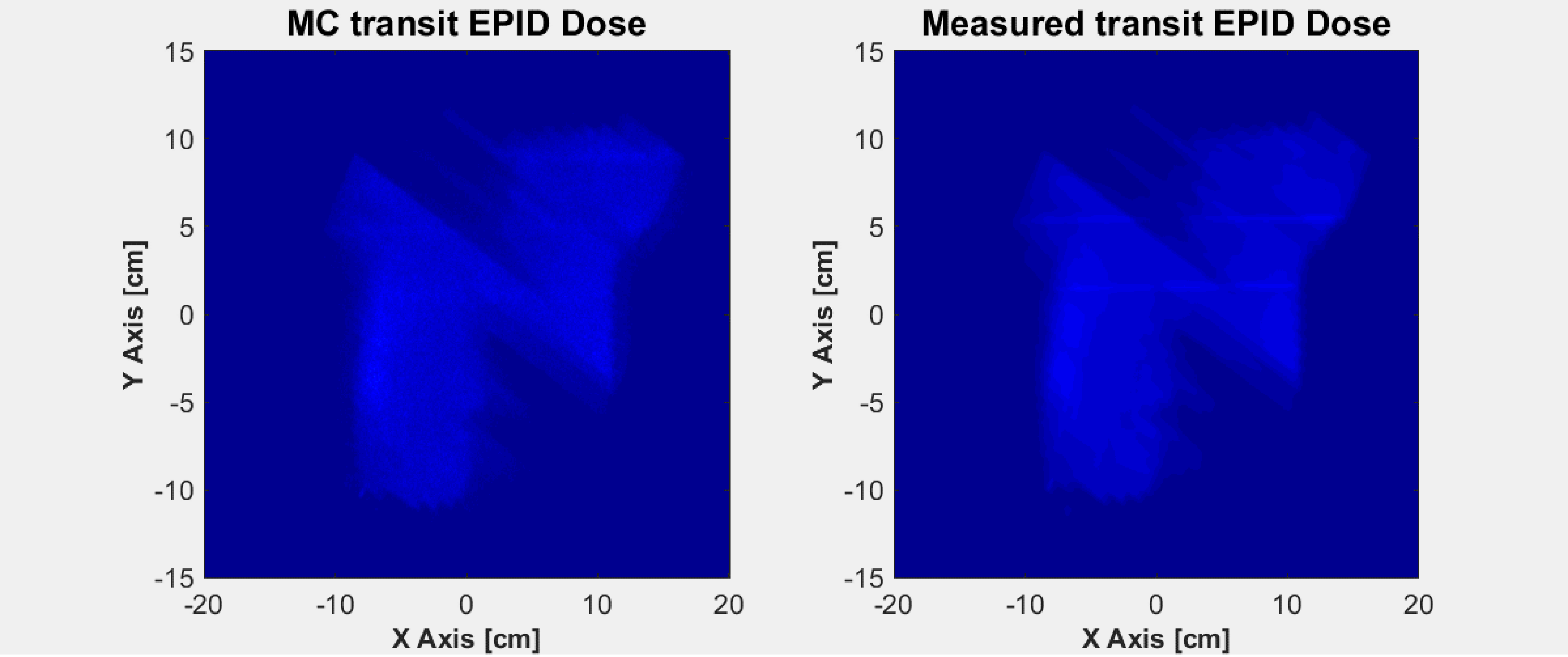


Actual cumulative EPID image, acquired in CineMode

Advantages of “time-stamping” particles:

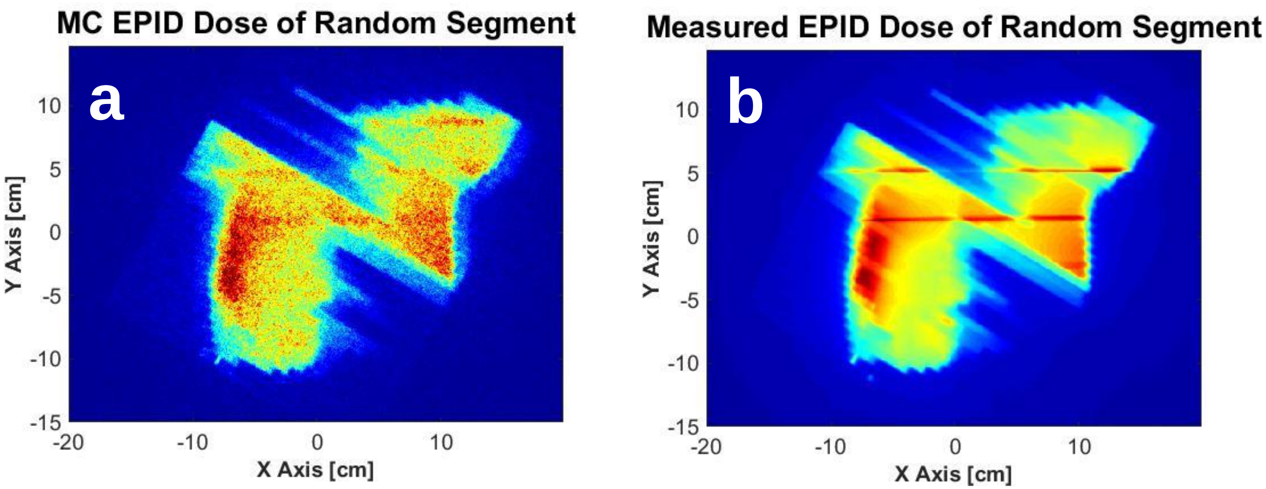
- Efficiency
  - Only one simulation required
  - Similar simulation time as conventional MC
- 4D dose data: [filename].edepdat
  - Contains all required dose information
  - No need for pre-defined interval of interest

Results ---- MC *vs*. Measurement



Results ---- MC *vs*. Measurement

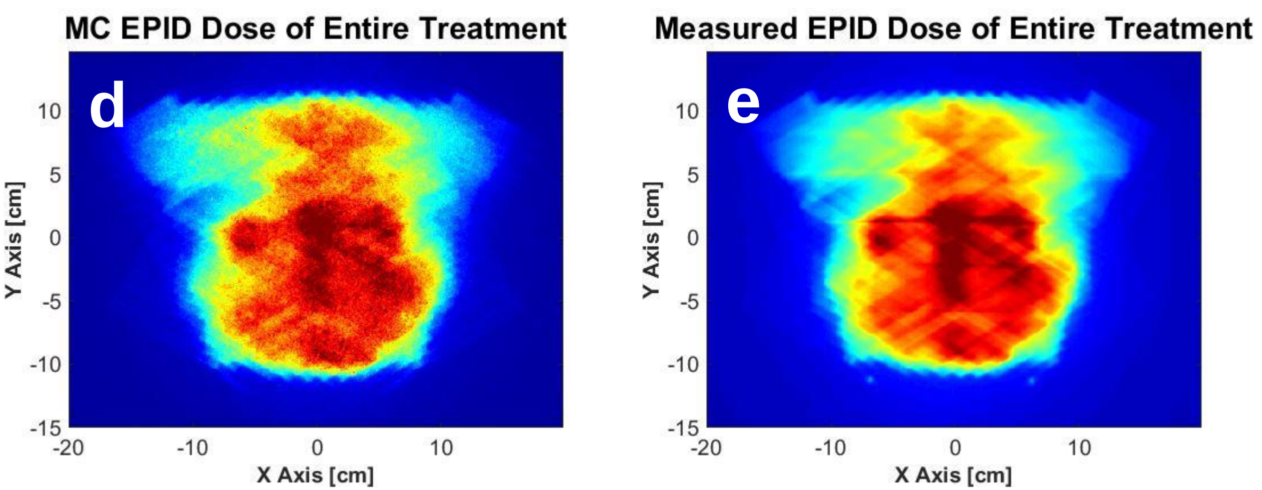
Dose for a single control point



3D Gamma pass rates:

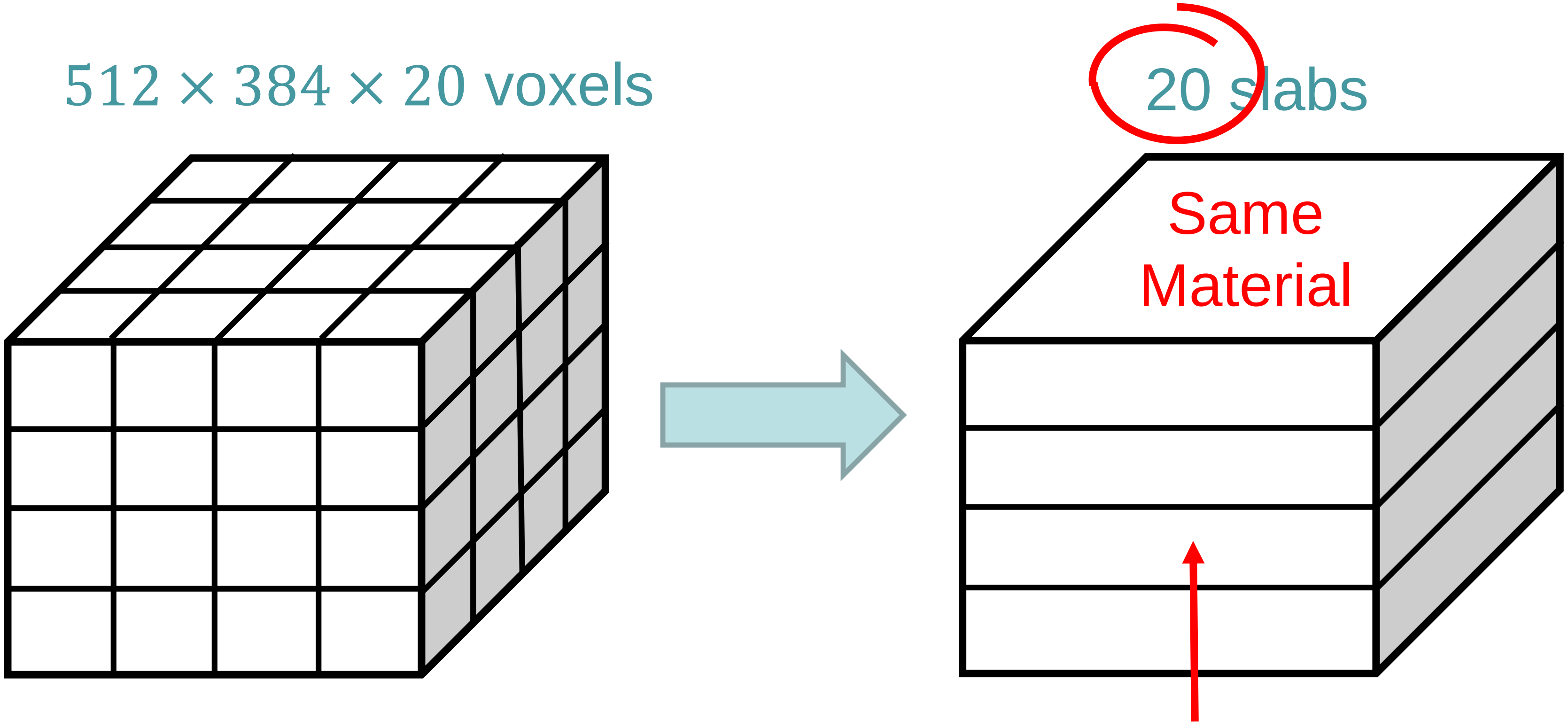
98.5%

Cumulative dose



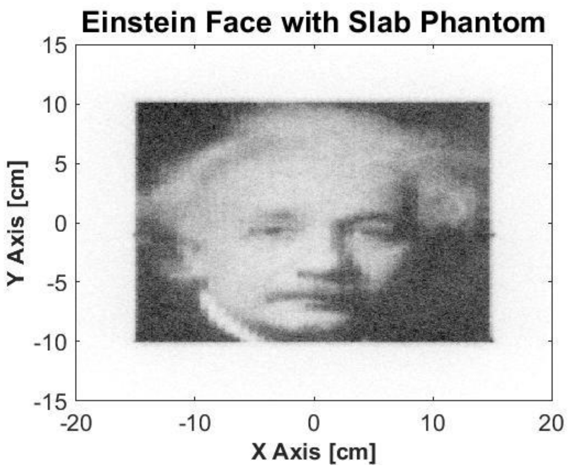
96.0%

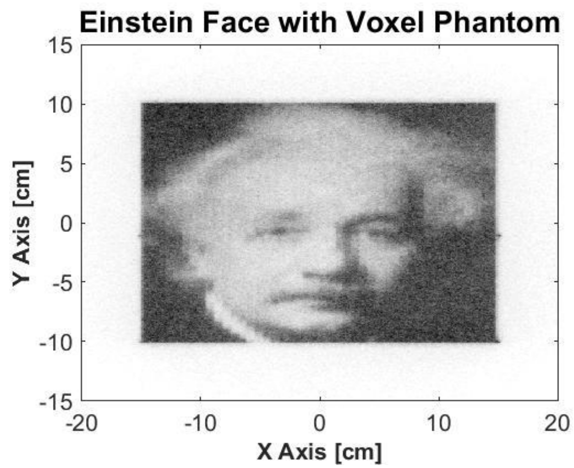
Faster simulation using slab phantom

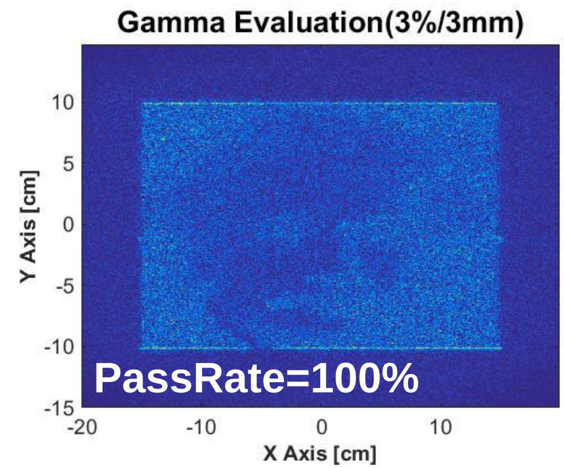


- Record 3D coordinates of energy deposition events
- Voxelization after simulation

Slab Phantom *vs.* Voxel Phantom

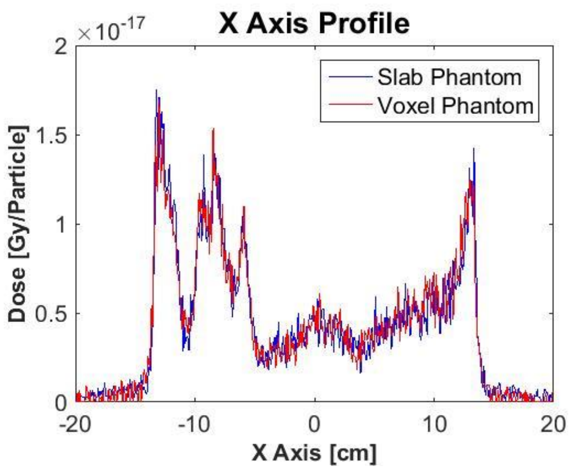


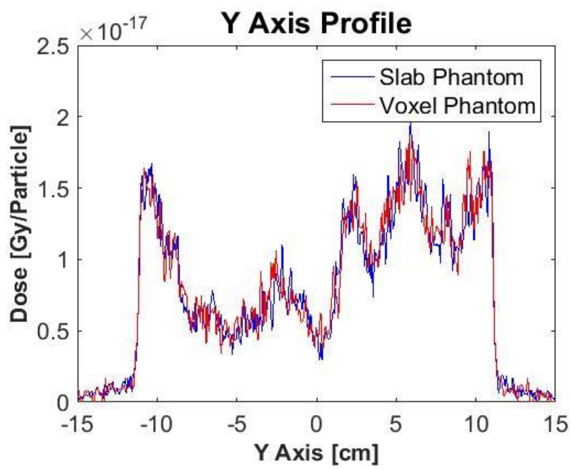




3

30
mins





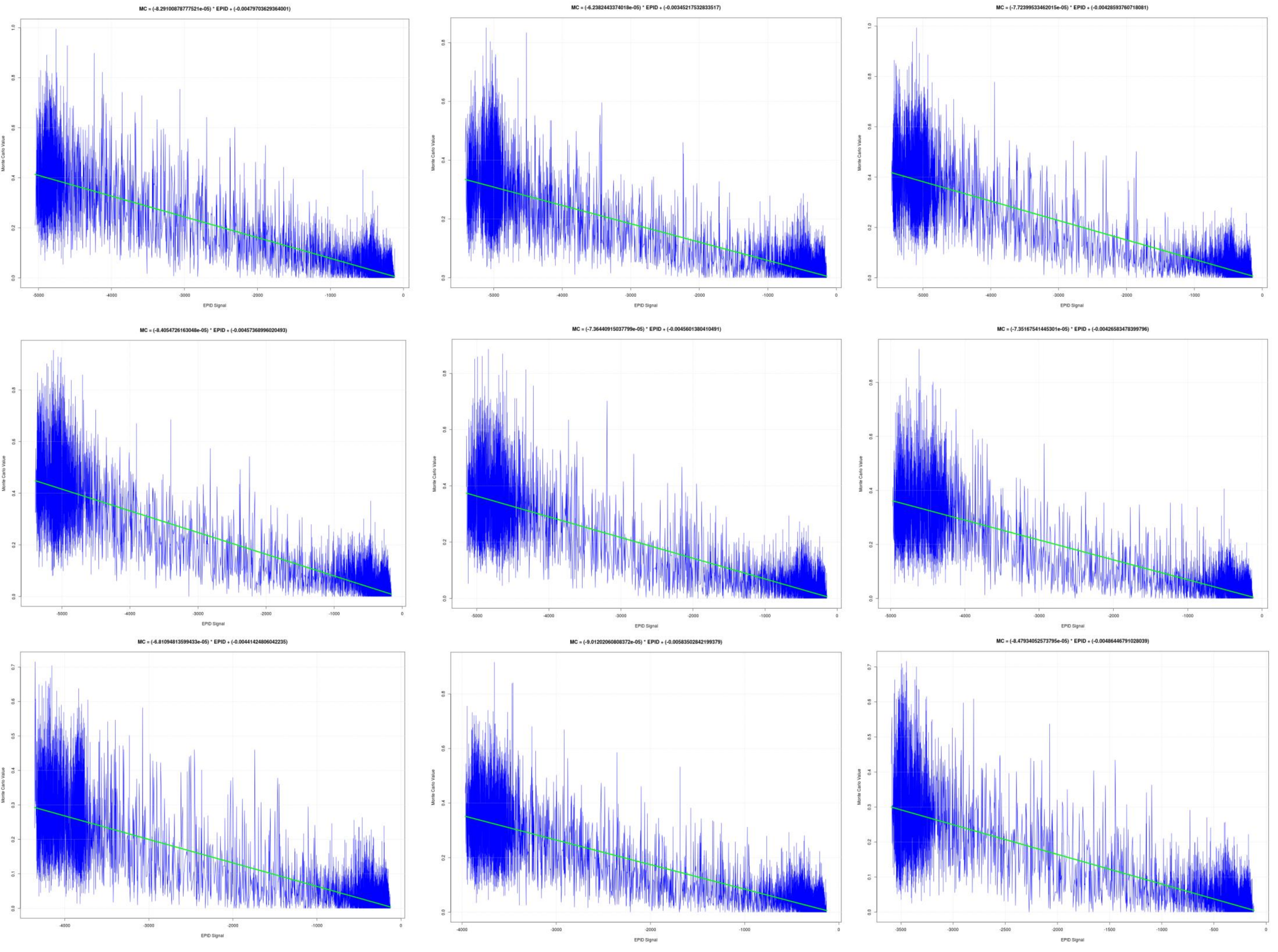
```
EPID_VMAT_prostate_phsp_out                                       #!GUI1.0
0
/home/tpopescu/EGS_HOME/dosxyznrc/Varian_iX_EPID_slab.egsphant
0.521, 0.01, 0
0, 0, 0,
2, 20, 2, 0, 0, 0, 0, 0, 0
0, -47.64, 0, 90, 270.0, 240, 100.0, 0.0
0, -47.64, 0, 90, 270.0, 240, 100.0, 1.0
2, 2, 0, 120, 0, 0, 0, 0
0,/home/tpopescu/EGS_HOME/dosxyznrc/VMAT_prostate_out.IAEAphsp,0
5000000000, 0, 999, 87, 911, 100.0, 0, 0, 3, 1, 1, 0, 0, 0, 1, 0
 #########################
 :Start MC Transport Parameter:

 Global ECUT= 0.521
 Global PCUT= 0.01
 Global SMAX= 5
 ESTEPE= 0.25
 XIMAX= 0.5
 Boundary crossing algorithm= PRESTA-I
 Skin depth for BCA= 0
 Electron-step algorithm= PRESTA-II
 Spin effects= On
 Brems angular sampling= Simple
 Brems cross sections= BH
 Bound Compton scattering= Off
 Compton cross sections= default
 Pair angular sampling= Simple
 Pair cross sections= BH
 Photoelectron angular sampling= Off
 Rayleigh scattering= Off
 Atomic relaxations= Off
 Electron impact ionization= Off
 Photon cross sections= xcom
 Photon cross-sections output= Off

 :Stop MC Transport Parameter:
 #########################
```

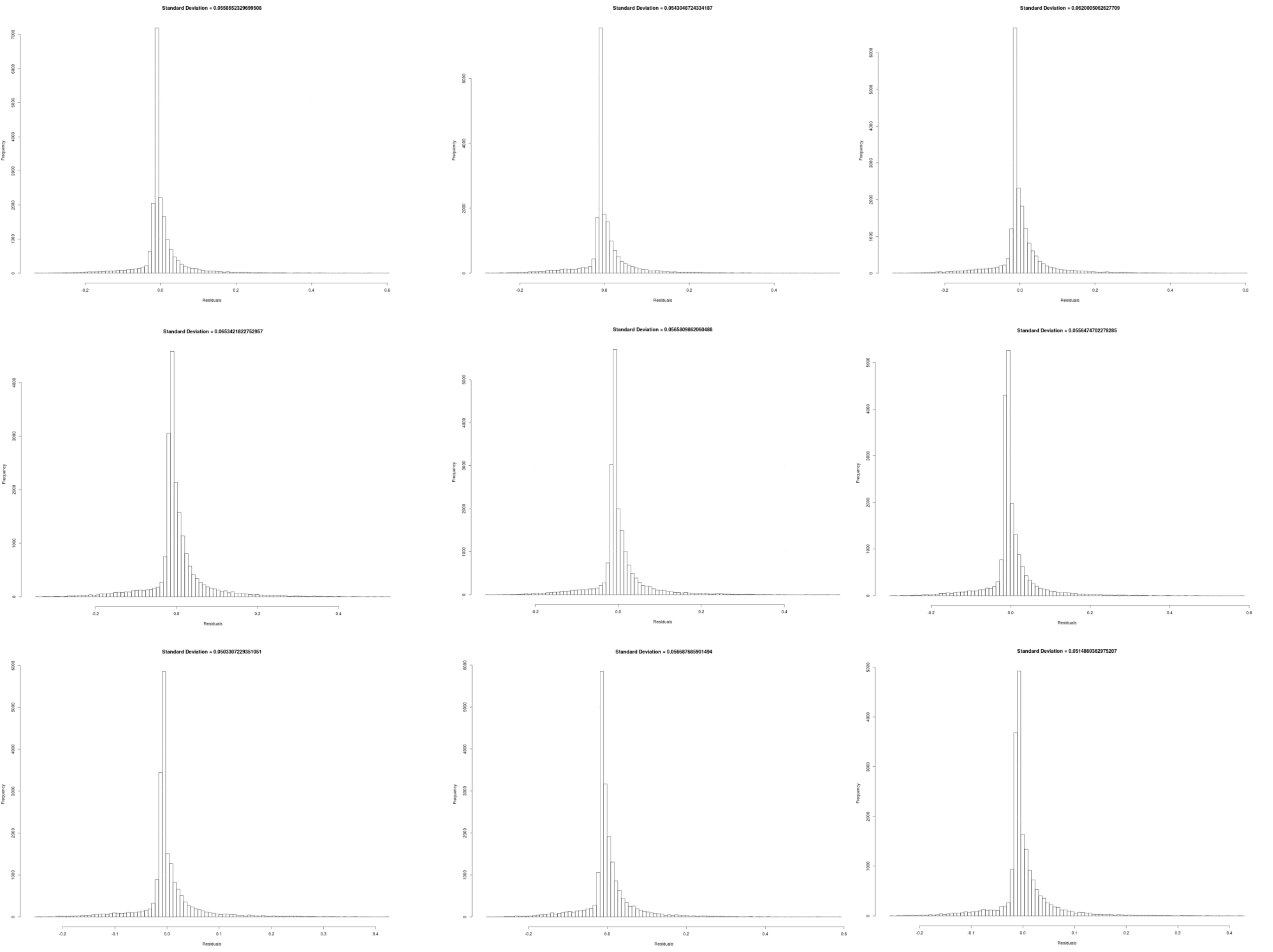
Images for a VMAT prostate patient, acquired during treatment (left) and MC simulated with 1.5×10^9 histories (right):

Cumulative images

Images for a VMAT prostate patient, acquired during treatment (left) and MC simulated with 1.5×10^9 histories (right):

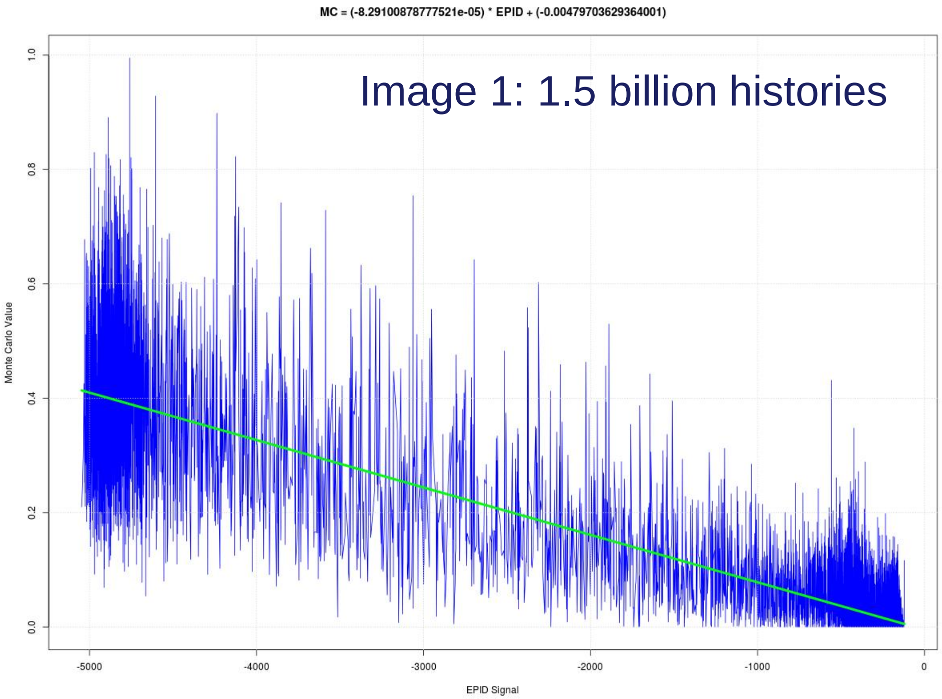
Cine-mode images

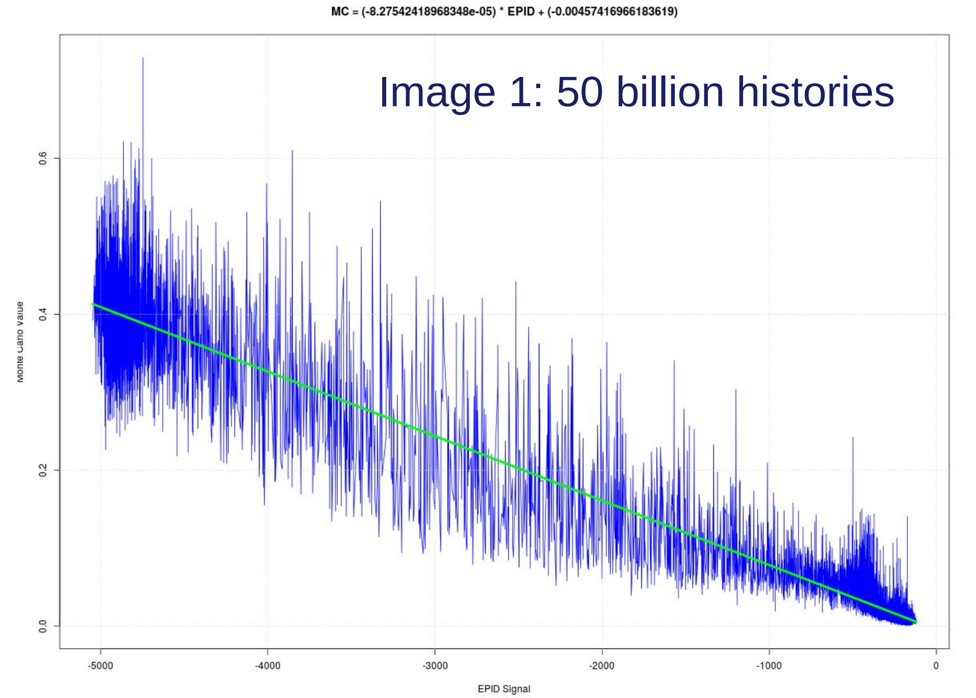

MC = (-8.29100878777521e-05) * EPID + (-0.00479703629364001)
MC = (-6.2382443374018e-05) * EPID + (-0.00345217532833517)
MC = (-7.72399533462015e-05) * EPID + (-0.00428593760718081)
MC = (-8.4054726163048e-05) * EPID + (-0.00457368996020493)
MC = (-7.36440915037799e-05) * EPID + (-0.0045601380410491)
MC = (-7.35167541445301e-05) * EPID + (-0.00426583478399796)
MC = (-6.81094813599433e-05) * EPID + (-0.00441424806042235)
MC = (-9.01202060808372e-05) * EPID + (-0.00583502842199379)
MC = (-8.47934052573795e-05) * EPID + (-0.00486446791028039)
Monte Carlo Value
EPID Signal

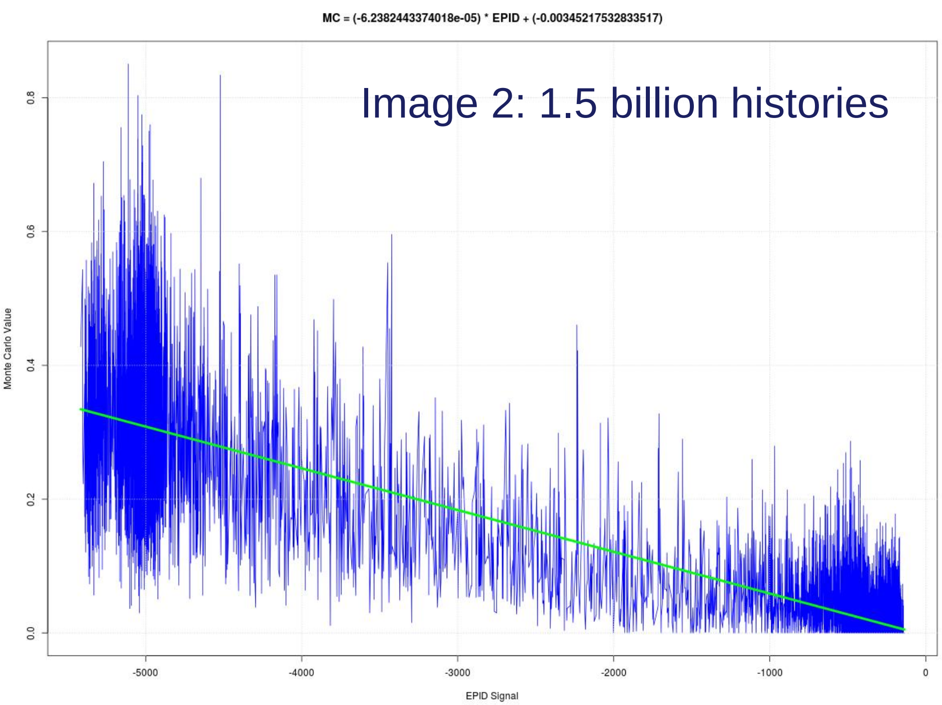

Standard Deviation = 0.0558552329699508
Standard Deviation = 0.0543048724334187
Standard Deviation = 0.0620005062627709
Standard Deviation = 0.0653421822752957
Standard Deviation = 0.0565809862060488
Standard Deviation = 0.0556474702278285
Standard Deviation = 0.0503307229351051
Standard Deviation = 0.056687685901494
Standard Deviation = 0.0514860362975207
Frequency
Residuals

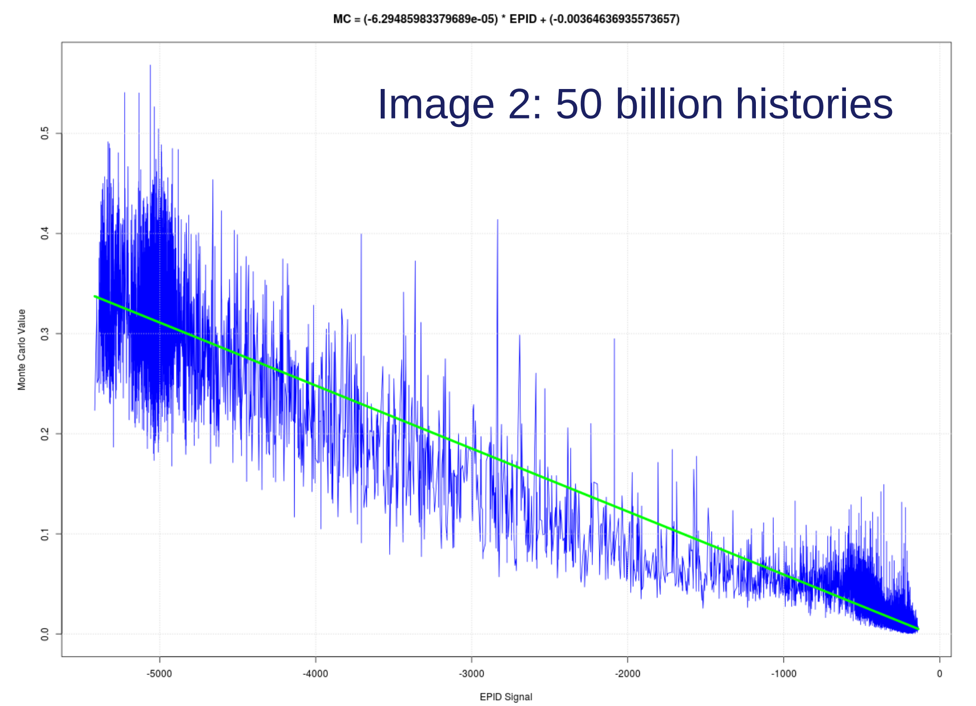
Linear fit and statistics of the residuals

EPID File Name	MC File Name	Correlation Coefficient	Slope	Intercept	Min Residuals	Max Residuals	StDev of Residuals
epid_01.Rdata	mc_01.Rdata	-0.90587	-0.000082910	-0.004797	-0.333545	0.605131	0.0559
epid_02.Rdata	mc_02.Rdata	-0.89565	-0.000062382	-0.003452	-0.281118	0.555170	0.0543
epid_03.Rdata	mc_03.Rdata	-0.91569	-0.000077240	-0.004286	-0.338864	0.604519	0.0620
epid_04.Rdata	mc_04.Rdata	-0.91957	-0.000084055	-0.004574	-0.347858	0.527754	0.0653
epid_05.Rdata	mc_05.Rdata	-0.90643	-0.000073644	-0.004560	-0.319605	0.534049	0.0566
epid_06.Rdata	mc_06.Rdata	-0.90372	-0.000073517	-0.004266	-0.304656	0.587691	0.0556
epid_07.Rdata	mc_07.Rdata	-0.88405	-0.000068109	-0.004414	-0.254017	0.425657	0.0503
epid_08.Rdata	mc_08.Rdata	-0.89793	-0.000090120	-0.005835	-0.306793	0.592821	0.0567
epid_09.Rdata	mc_09.Rdata	-0.89324	-0.000084793	-0.004864	-0.258157	0.428704	0.0515

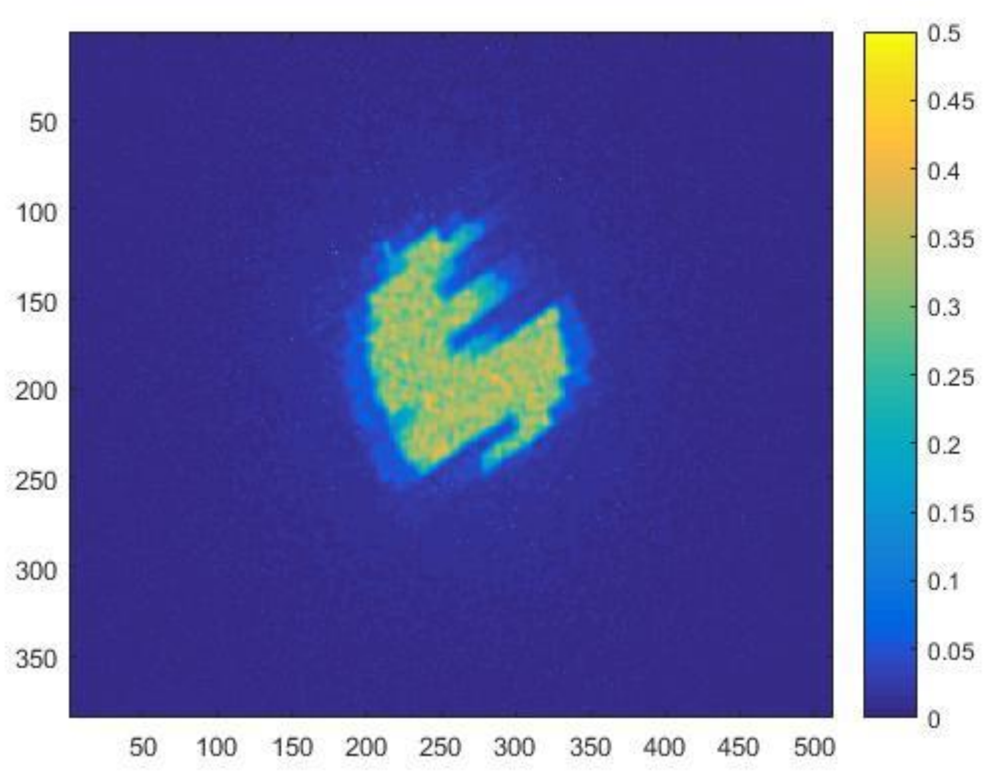

MC = (-8.29100878777521e-05) * EPID + (-0.00479703629364001)
Image 1: 1.5 billion histories
Monte Carlo Value
EPID Signal
0.0
0.2
0.4
0.6
0.8
1.0
-5000
-4000
-3000
-2000
-1000
0


MC = (-8.27542418968348e-05) * EPID + (-0.00457416966183619)
Image 1: 50 billion histories
Monte Carlo Value
EPID Signal
0.0
0.2
0.4
0.6
-5000
-4000
-3000
-2000
-1000
0

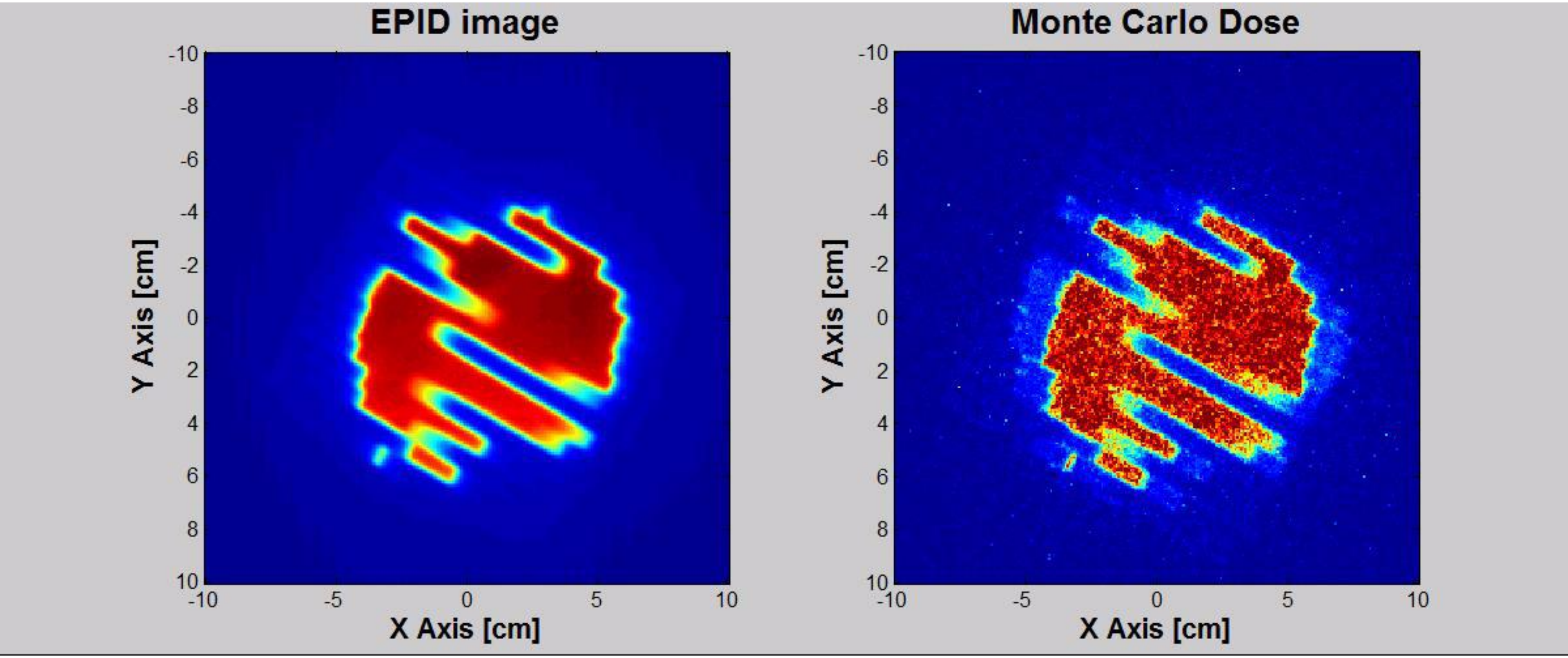

MC = (-6.2382443374018e-05) * EPID + (-0.00345217532833517)
Image 2: 1.5 billion histories
Monte Carlo Value
EPID Signal
0.0
0.2
0.4
0.6
0.8
-5000
-4000
-3000
-2000
-1000
0


MC = (-6.29485983379689e-05) * EPID + (-0.00364636935573657)
Image 2: 50 billion histories
Monte Carlo Value
EPID Signal
0.0
0.1
0.2
0.3
0.4
0.5
-5000
-4000
-3000
-2000
-1000
0

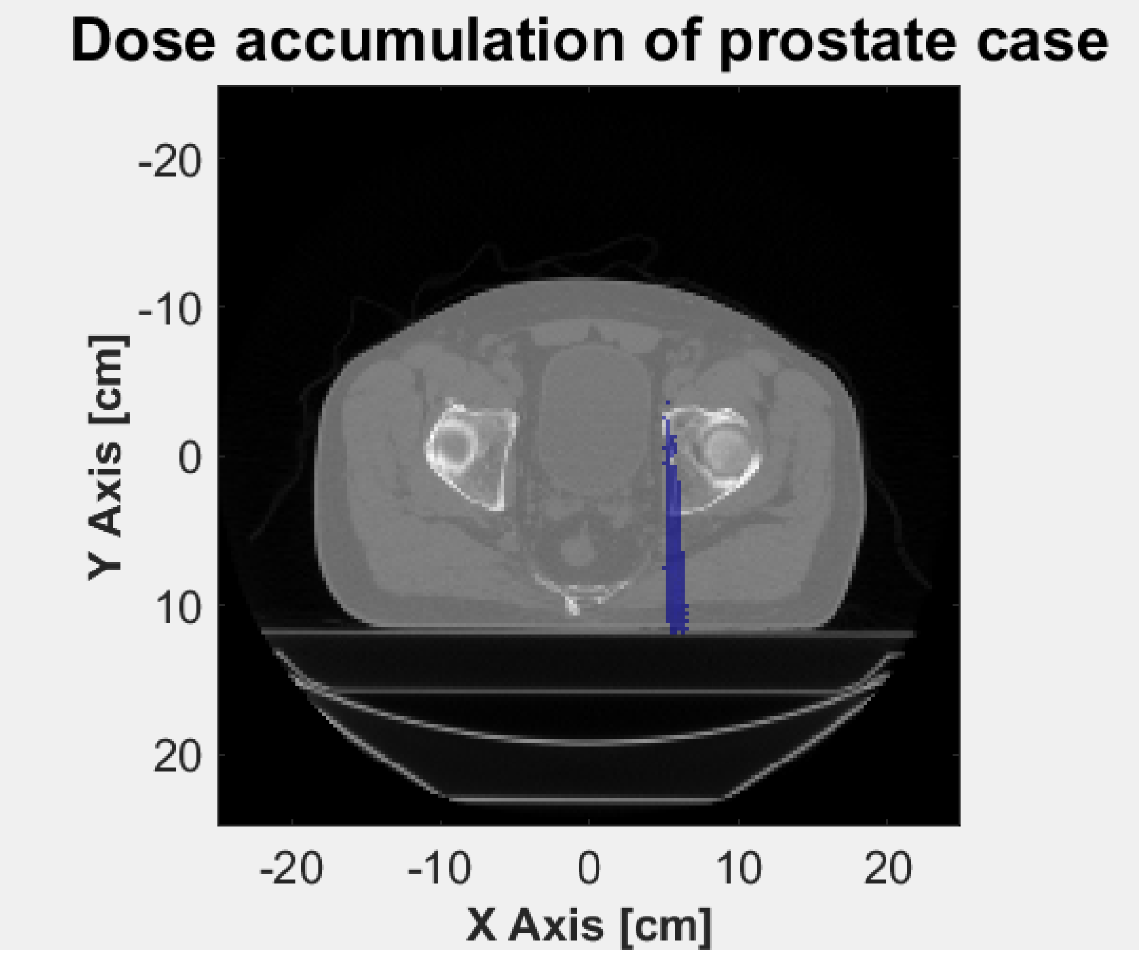
After applying a Savitzky-Golay denoising filter:



Images for the same patient, simulated with 5×10^{10} histories:



4D MC simulation with BEAMnrc/DOSXYZnrc



A simple and robust trajectory-based stereotactic radiosurgery treatment

Byron Wilson[a)]
Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada
Medical Physics, BC Cancer Agency, Vancouver, British Columbia V5Z 4E6, Canada

Karl Otto
Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada

Ermias Gete
Medical Physics, BC Cancer Agency, Vancouver, British Columbia V5Z 4E6, Canada

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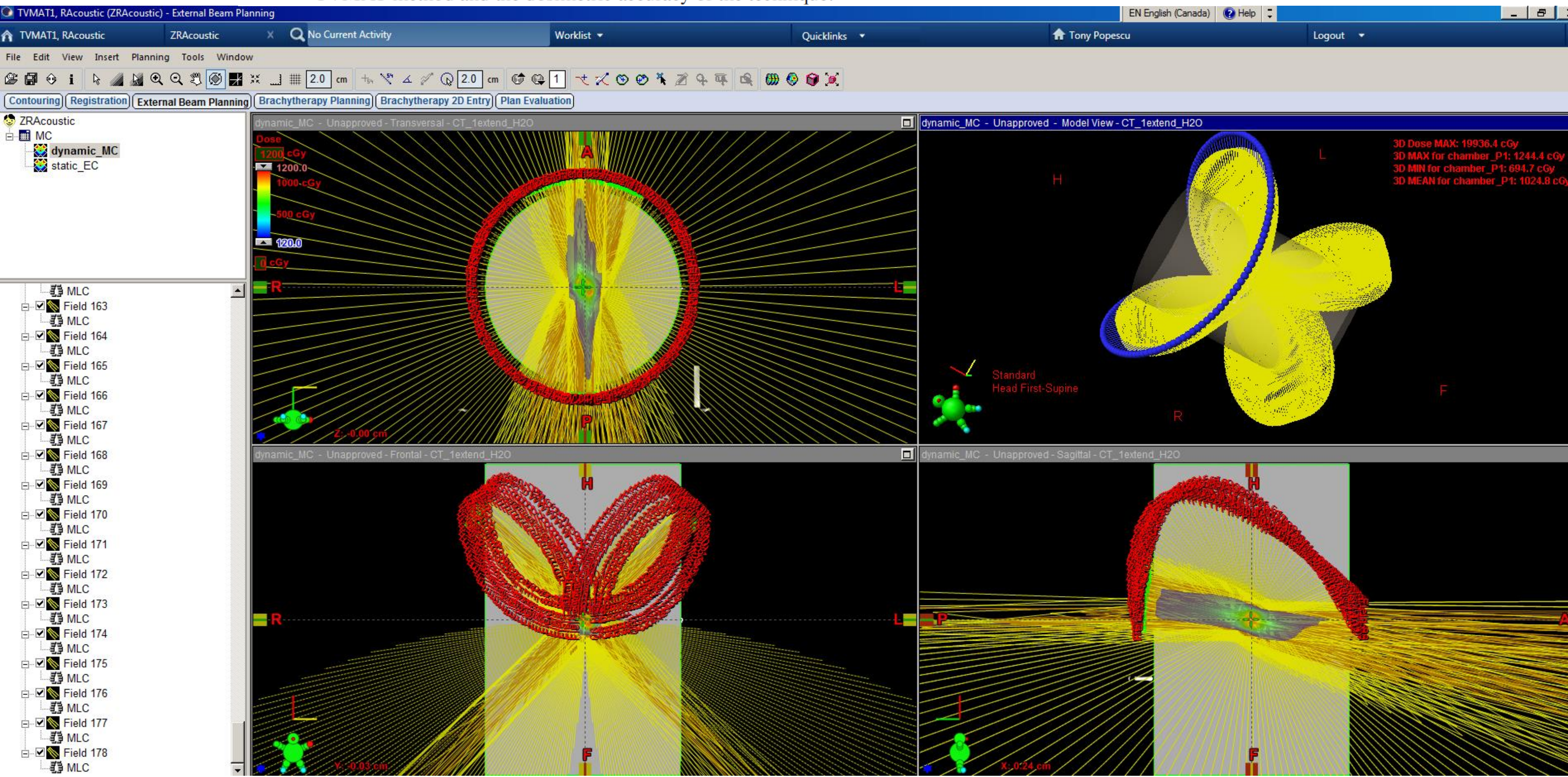
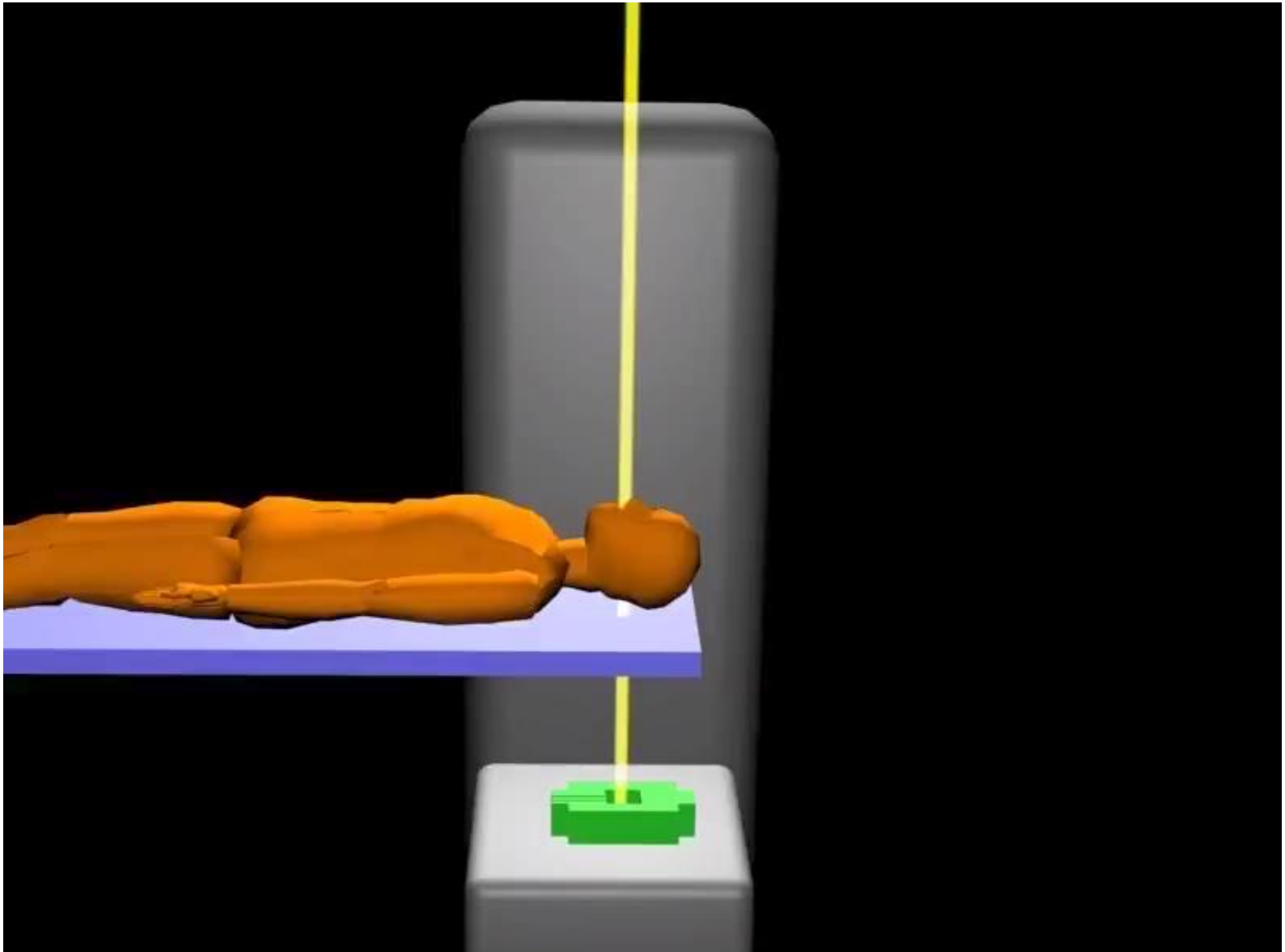
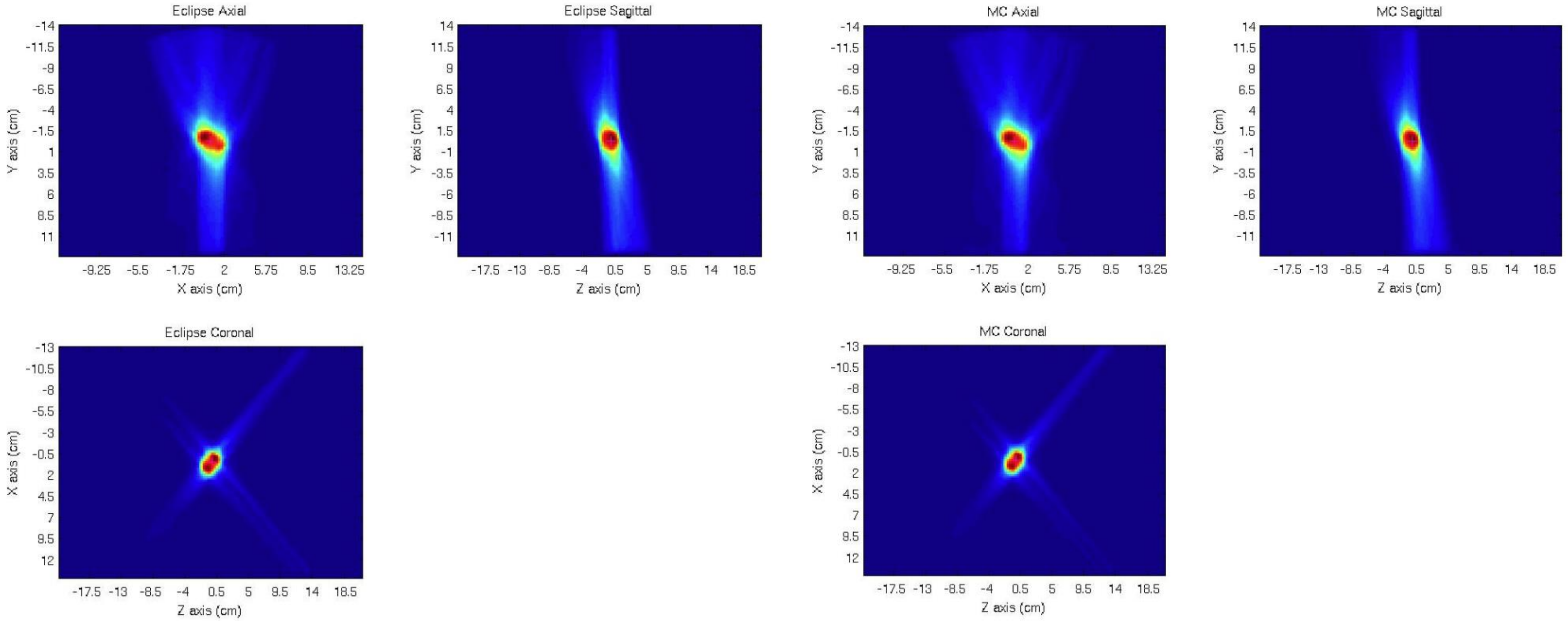
Introduction: We present a Trajectory-based Volumetric Modulated Arc Therapy (TVMAT) technique for Stereotactic Radiosurgery (SRS) that takes advantage of a modern linacs ability to modulate dose rate and move the couch dynamically. In addition, we investigate the quality of the developed TVMAT method and the dosimetric accuracy of the technique.







First few control points in the DOSXYXnrc Source 20 egsinp file:

```
0.000, -28.300, -87.887, 90, 91.00, 240, 100.0, 0.0000
0.000, -28.300, -87.887, 88, 90.04, 151, 100.0, 0.0056
0.000, -28.300, -87.887, 86, 90.14, 152, 100.0, 0.0113
0.000, -28.300, -87.887, 84, 90.32, 153, 100.0, 0.0169
0.000, -28.300, -87.887, 82, 90.58, 154, 100.0, 0.0226
0.000, -28.300, -87.887, 80, 90.91, 155, 100.0, 0.0282
0.000, -28.300, -87.887, 78, 91.31, 156, 100.0, 0.0339
0.000, -28.300, -87.887, 76, 91.80, 157, 100.0, 0.0395
0.000, -28.300, -87.887, 74, 92.36, 158, 100.0, 0.0452
0.000, -28.300, -87.887, 72, 93.01, 160, 100.0, 0.0508
0.000, -28.300, -87.887, 70, 93.74, 161, 100.0, 0.0565
0.000, -28.300, -87.887, 68, 94.56, 162, 100.0, 0.0621
0.000, -28.300, -87.887, 66, 95.47, 163, 100.0, 0.0678
0.000, -28.300, -87.887, 64, 96.48, 165, 100.0, 0.0734
0.000, -28.300, -87.887, 62, 97.59, 166, 100.0, 0.0791
0.000, -28.300, -87.887, 61, 98.80, 168, 100.0, 0.0847
```

3D Gamma: 97.1%

Conclusions:

- We developed a fast, all-in-one, DOSXYZnrc simulation technique for cine-mode EPID images, for the purpose of comparisons with the actual images acquired while the patient is being treated.

- In addition, the patient dose could be simulated and accumulated over the entire course of treatment (ideally, in an adaptive manner, using daily CBCT data), resulting in an authentic ‘patient-specific QA’.

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International collaborators:

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Jarkko Ojala

Local collaborators:

Julio Lobo

Shiqin Su

Iulian Badragan

Parmveer Atwal

Alanah Bergman

Tony Teke

John Lucido

Ernest Tsang

Vitali Moiseenko

Byron Wilson

Ermias Gete

Karl Otto

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Thank you !

Photo of Mt. Baker (an active volcano), as seen from Vancouver Island