SBRT portal dosimetry based on Monte Carlo simulation

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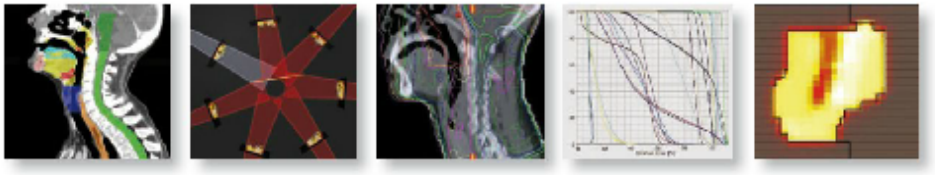
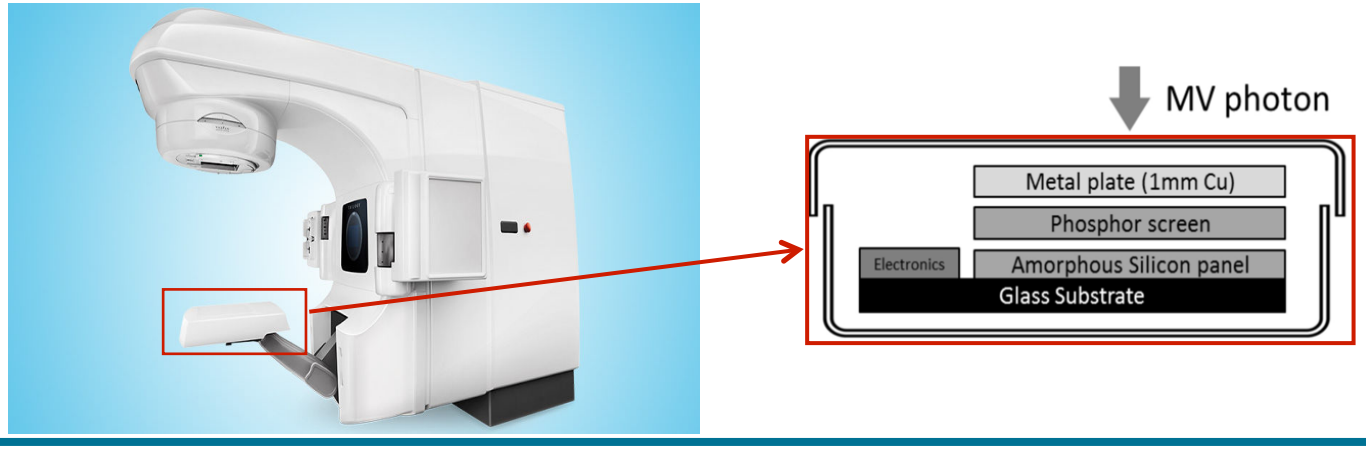
Context and rationale

- **Complexity of SBRT treatments** (hypofractionation schemes and small radiation fields, involving dynamic delivery techniques).



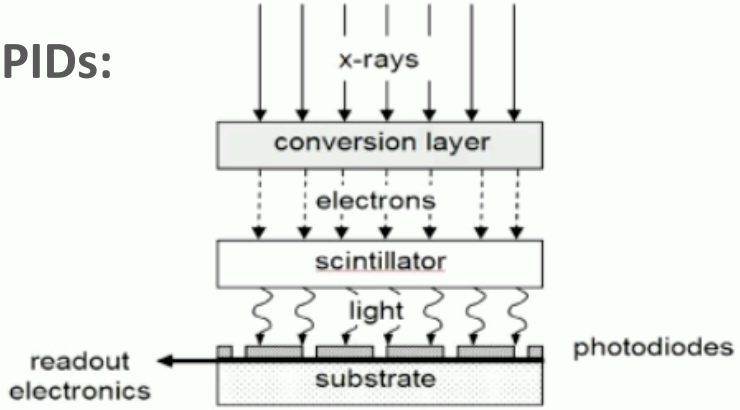
Robust pre-treatment and *in vivo* quality assurance → **EPID**-based dosimetry methods

- **Portal dosimetry with electronic portal imaging device – EPID**

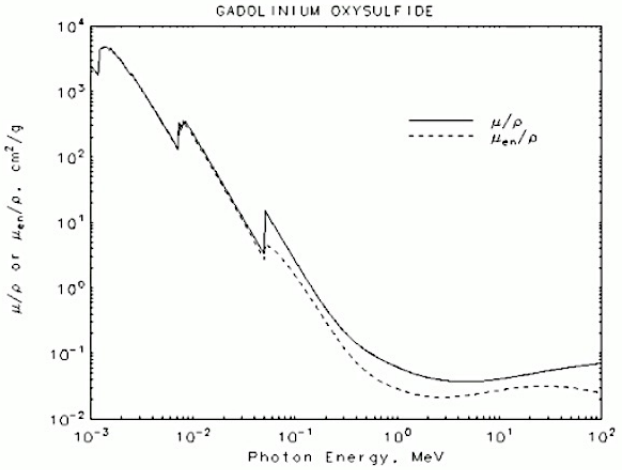


Context and rationale

- **Technology of amorphous silicon (a-Si) EPIDs:**
  - an overlaying x-ray converter − Cu ~ 1 mm;
  - phosphor scintillator (Gd_2O_2S:Tb);
  - large area photodiode array ~ 40 x 40 cm^2;
  - an electronic acquisition system and host computer.



- **EPID response as a dosimeter:**
  - EPID scatter kernel is different from water;
  - EPID response highly E-dependent.

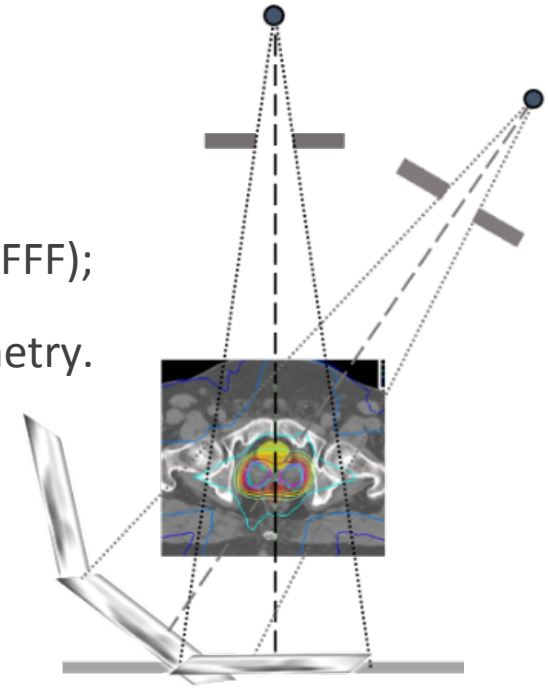


P. Greer, 2016 AAPM Annual Meeting and NIST

Context and rationale

- **Challenges of EPID for SBRT QA:**

- high dose rates –> EPID response saturation;
- small field dosimetry;
- commercial solutions not fully support some EPID models (FFF);
- **continuous EPID images** required for **3D EPID**-based dosimetry.



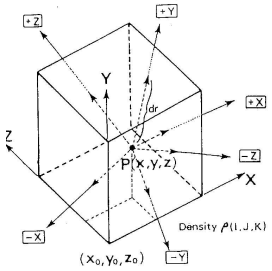
EPID-based dosimetry models (transit or non-transit) - Prediction model based on **empirical models:**

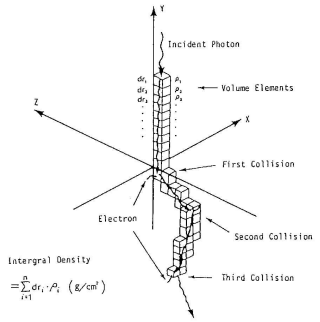
- Calibration of EPID signal to absorbed dose in water, including correction factors;

Context and rationale

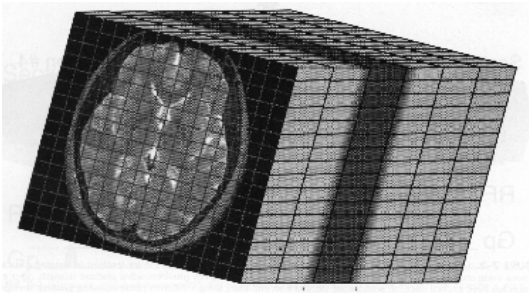
Monte Carlo simulation:

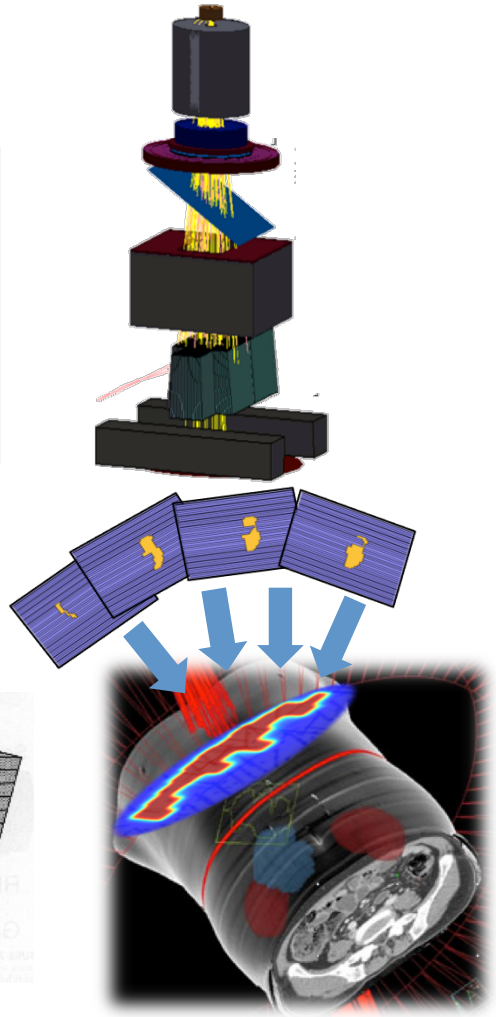
- **Direct prediction of EPID response.**
- **Explicit** particle transport throughout the detailed **geometry of linac** and **EPID and/or patient models**.
- Scattered and transmitted radiation through the beam modifiers – contribution of **complex apertures.**



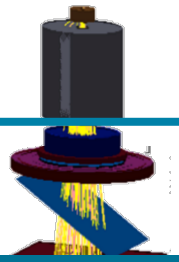


Transport of a photon in a three-dimensional patient.



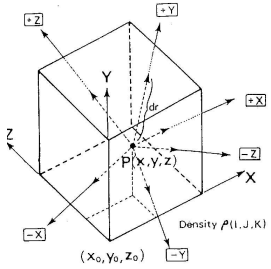


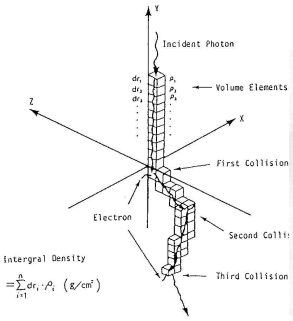
Context and rationale

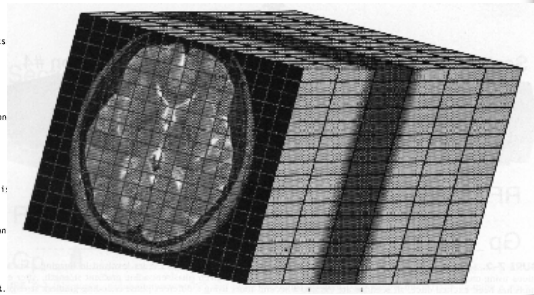


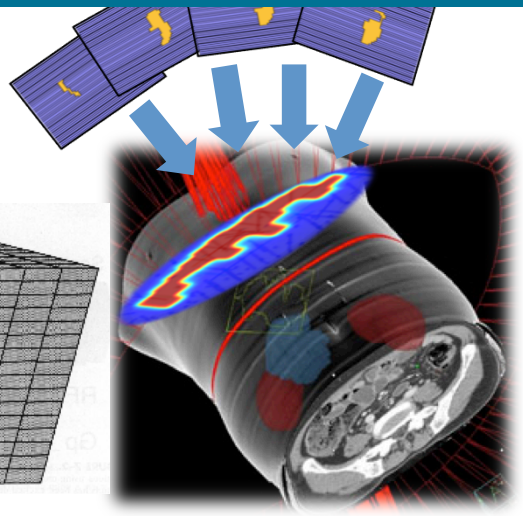
Purpose

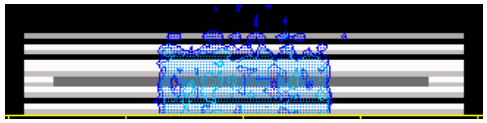
Detailed MC model of the linac in combination with EPID to accurately predict the absorbed dose to the detector for SBRT dosimetry applications.



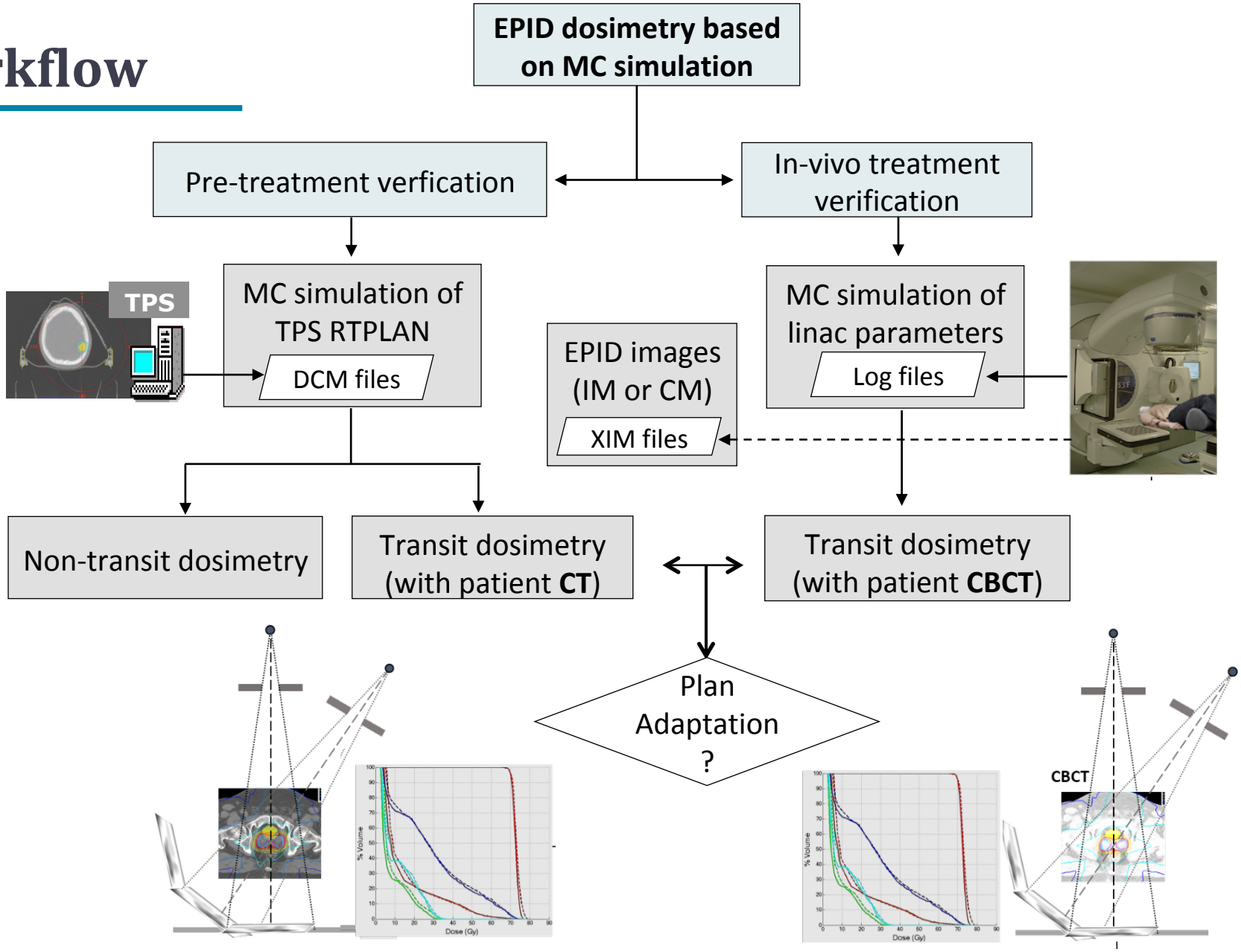








Workflow

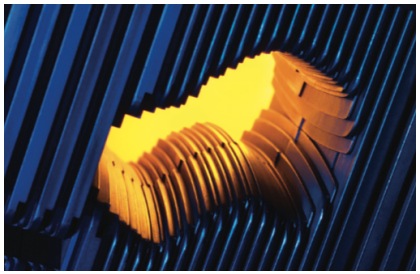

EPID dosimetry based on MC simulation
Pre-treatment verfication
In-vivo treatment verification
TPS
MC simulation of TPS RTPLAN
DCM files
MC simulation of linac parameters
Log files
EPID images (IM or CM)
XIM files
Non-transit dosimetry
Transit dosimetry (with patient CT)
Transit dosimetry (with patient CBCT)
Plan Adaptation ?
% Volume
Dose (Gy)
CBCT

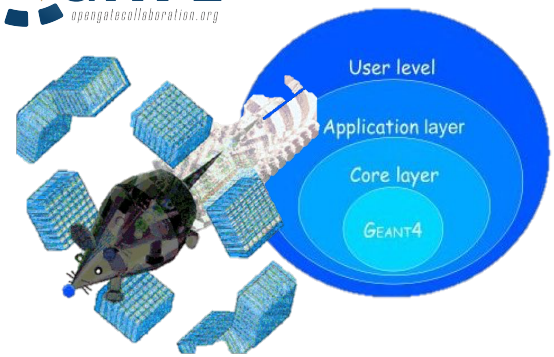
Material and methods

Monte Carlo simulation

- MC model of Varian **TrueBeam™ STx** linac with **aS1000 EPID**.
- Previous validation of part of linac head with **HD120™ MLC** (agreement ±2%).

from Varian Medical Systems website





GATE (v8.0) / Geant4 (v10.3.3)
Livermore physics list;
Range cuts ~ E : PCUT ≥ 1 KeV ; ECUT ≥ 10 KeV;
Variable N particles -> σ (MC) < 1 % ;
Simulations distributed on: 25 quad-core CPUs of 3.2 GHz Intel Core I5.

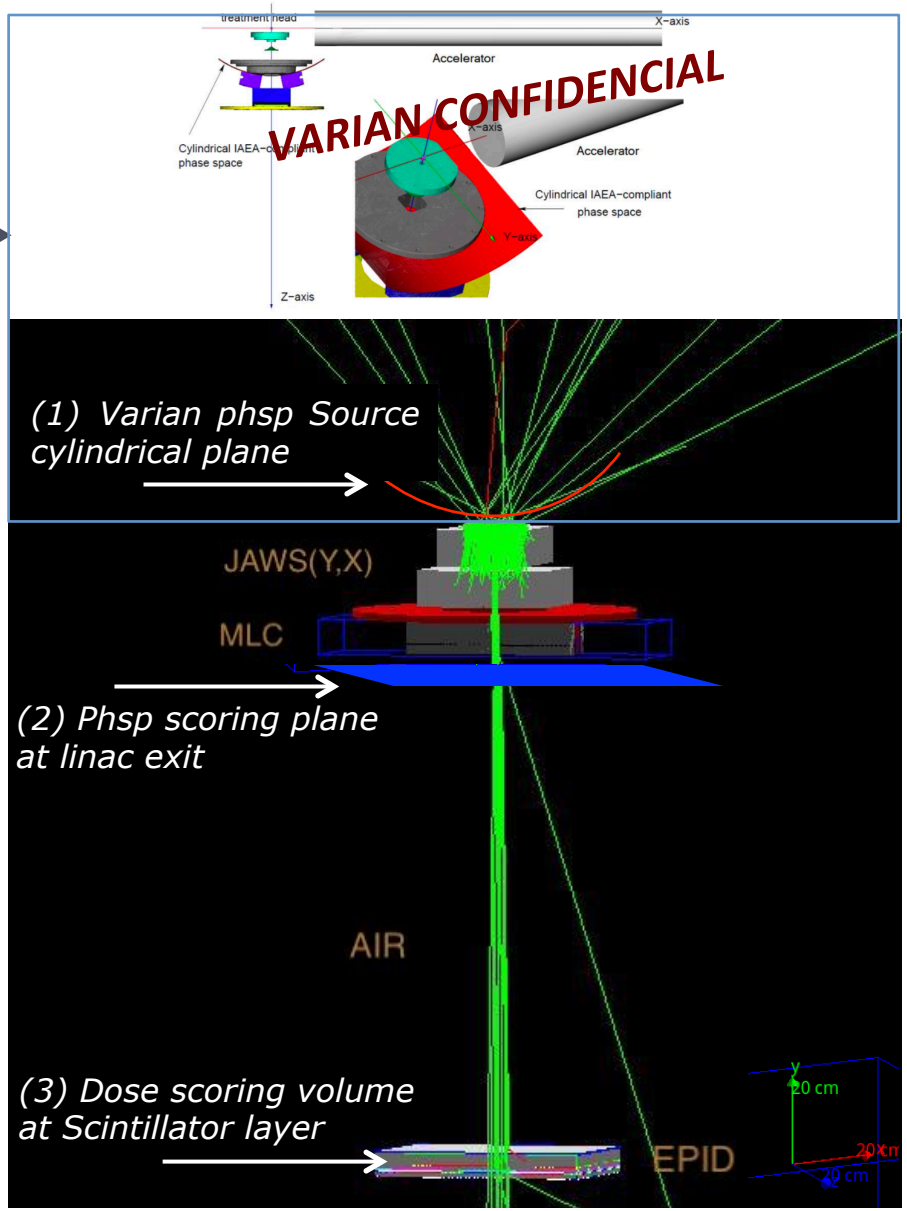
EPID: Active area of 40 x 30 cm^2 ; Resolution: 1024x768 pixels with size 0.39 x 0.39 mm^2.

Simulation scheme: non-transit

1. Upper part linac head geometry simulated in **Geant4** to obtain **Varian phsp source files** (IAEA format).
(Constantin et al. 2011 Med Phys,38) - 6 MV WFF
Belosi et al. Med. Phys. 41(5), 2014) - 6 & 10 MV FFF

2. **Treatment-dependent part** of linac head to obtain **phsp files at linac head exit.**

3. EPID transport simulation and **absorbed dose calculation in scintillator layer** (Gd_2O_2S:Tb).

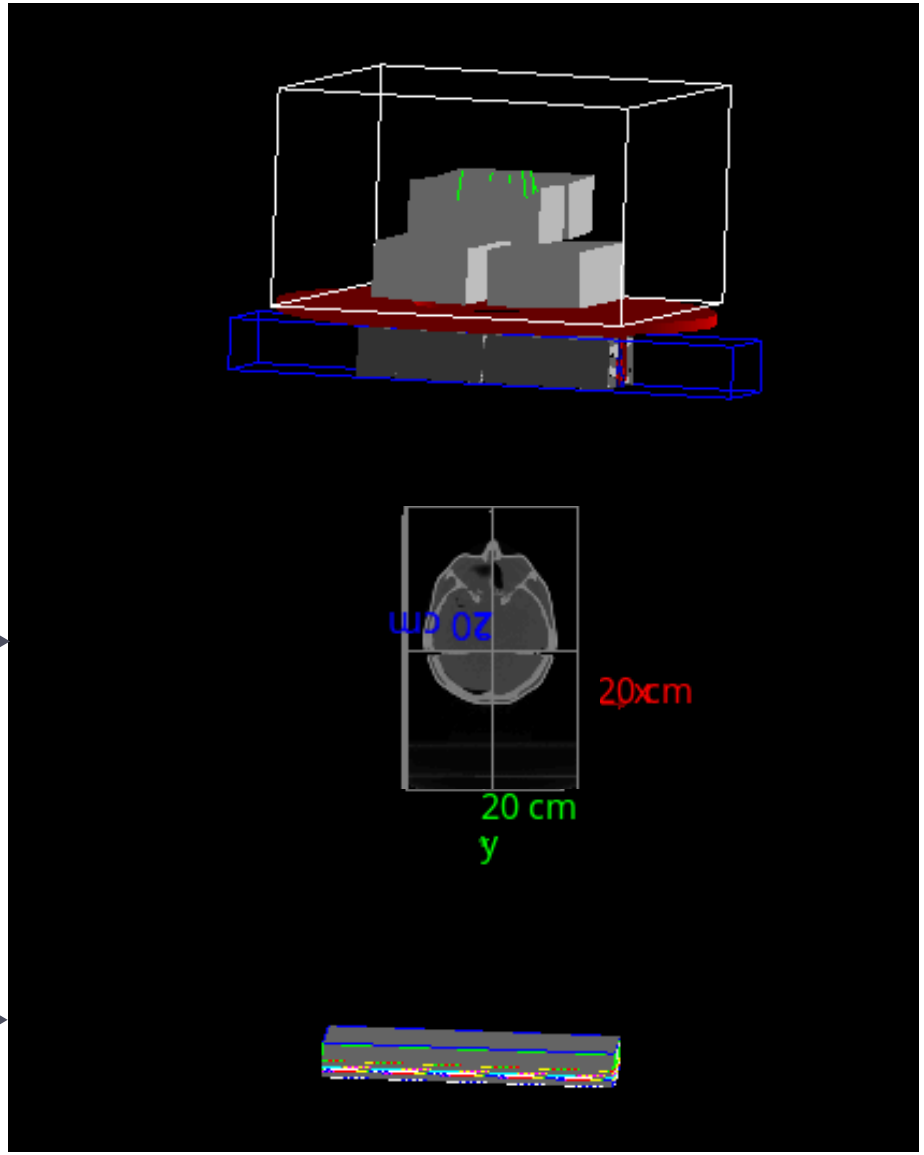


Simulation scheme: transit

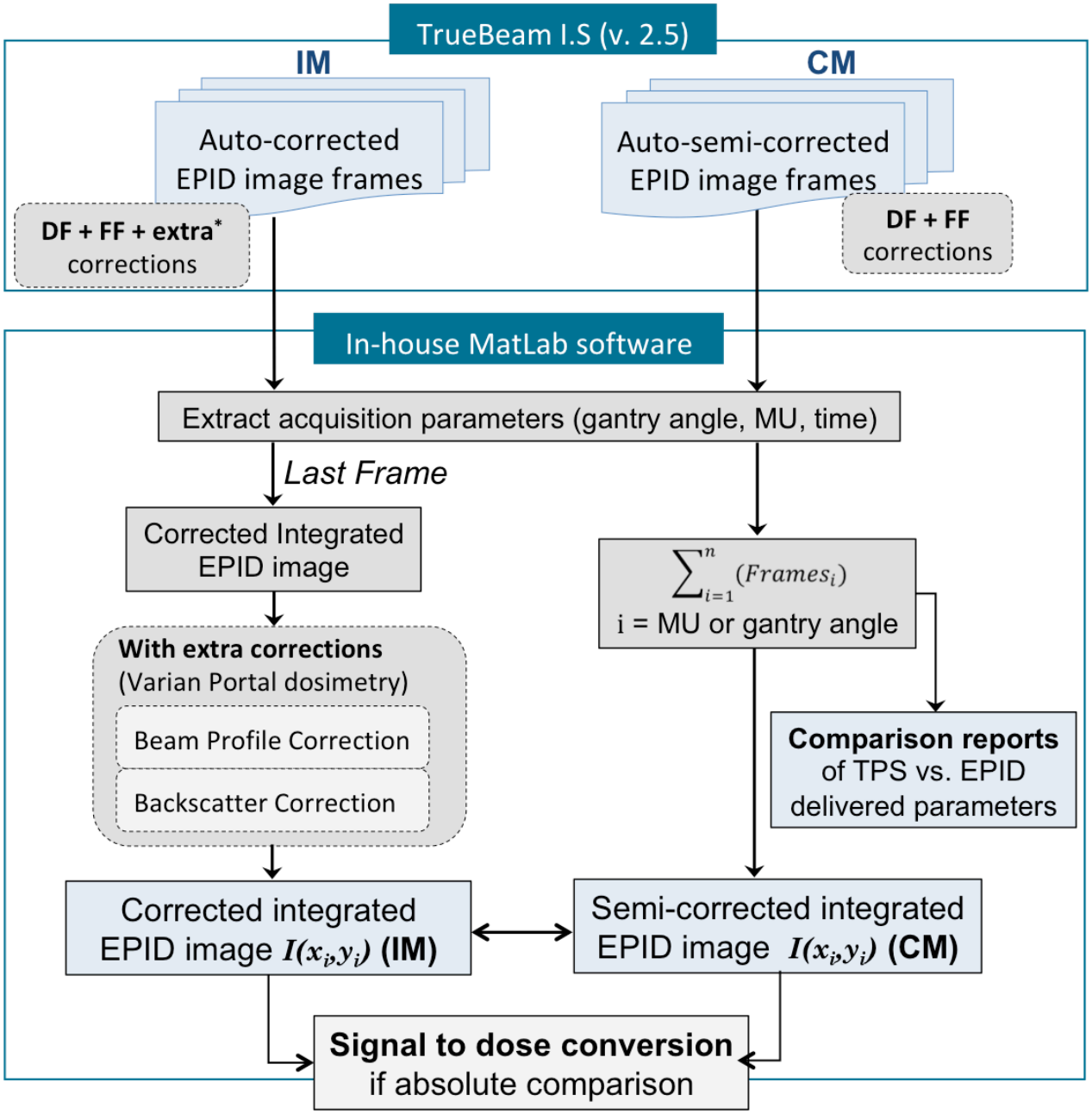
1. **Treatment-dependent part** of linac head geometry simulated in **GATE** to obtain **phsp files at linac head exit**.

2. **Patient/phantom** transport simulation and **absorbed dose calculation**.

2. **EPID** transport simulation and **absorbed dose calculation in scintillator layer** (Gd_2O_2S:Tb).



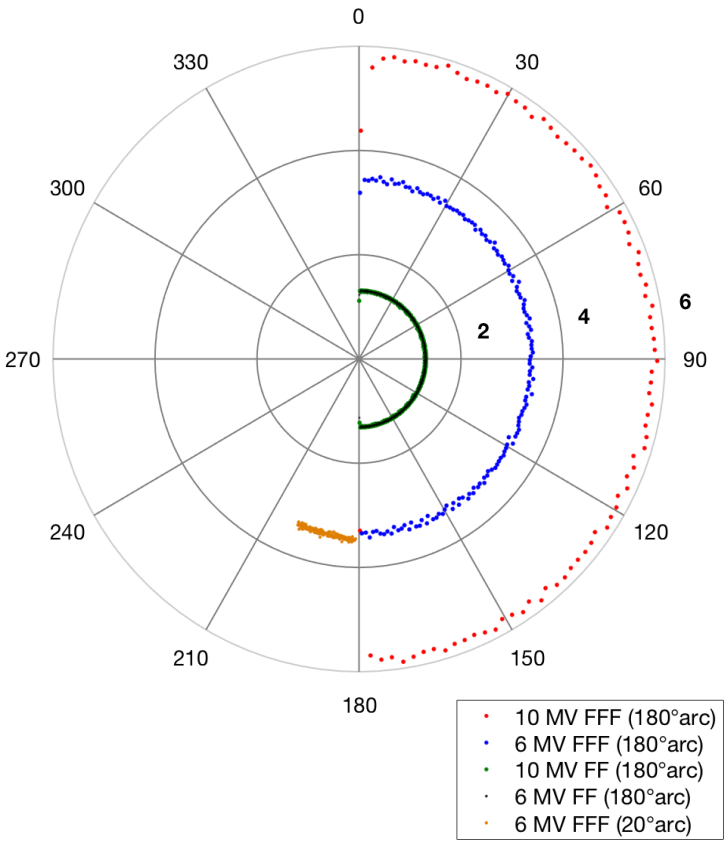
EPID image acquisition and processing



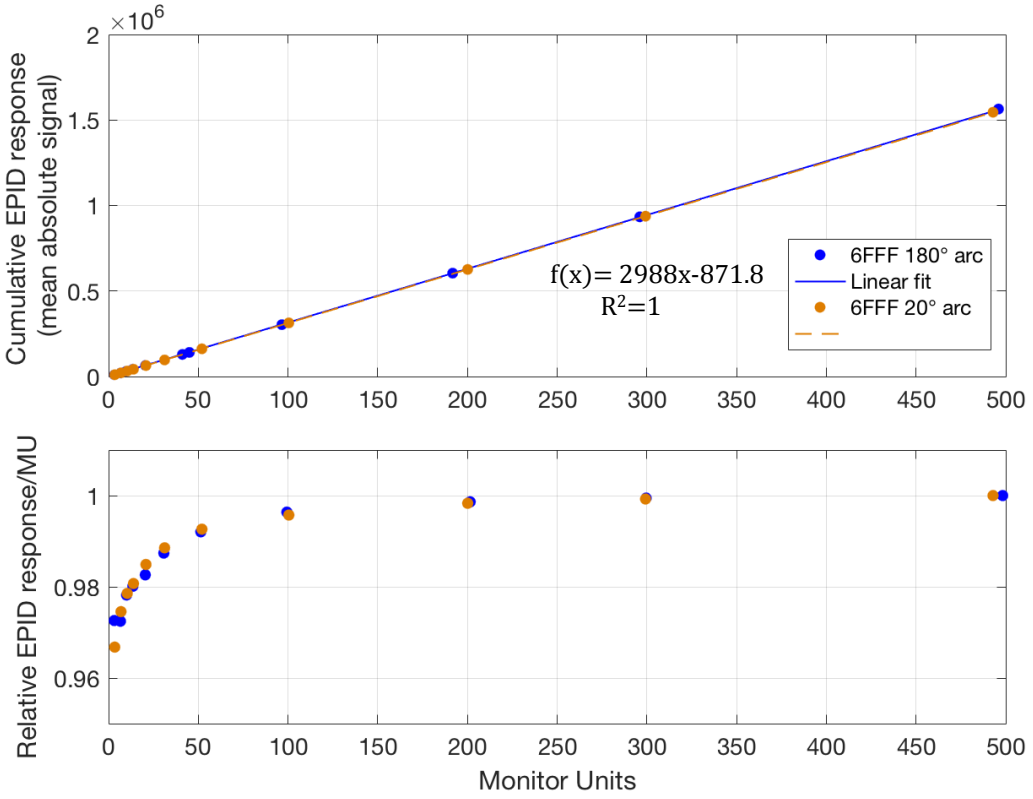
EPID image processing

Signal to dose conversion in CM

Angular distributions of MU/EPID Frame



180°arc vs. 20° arc for 6 MV FFF



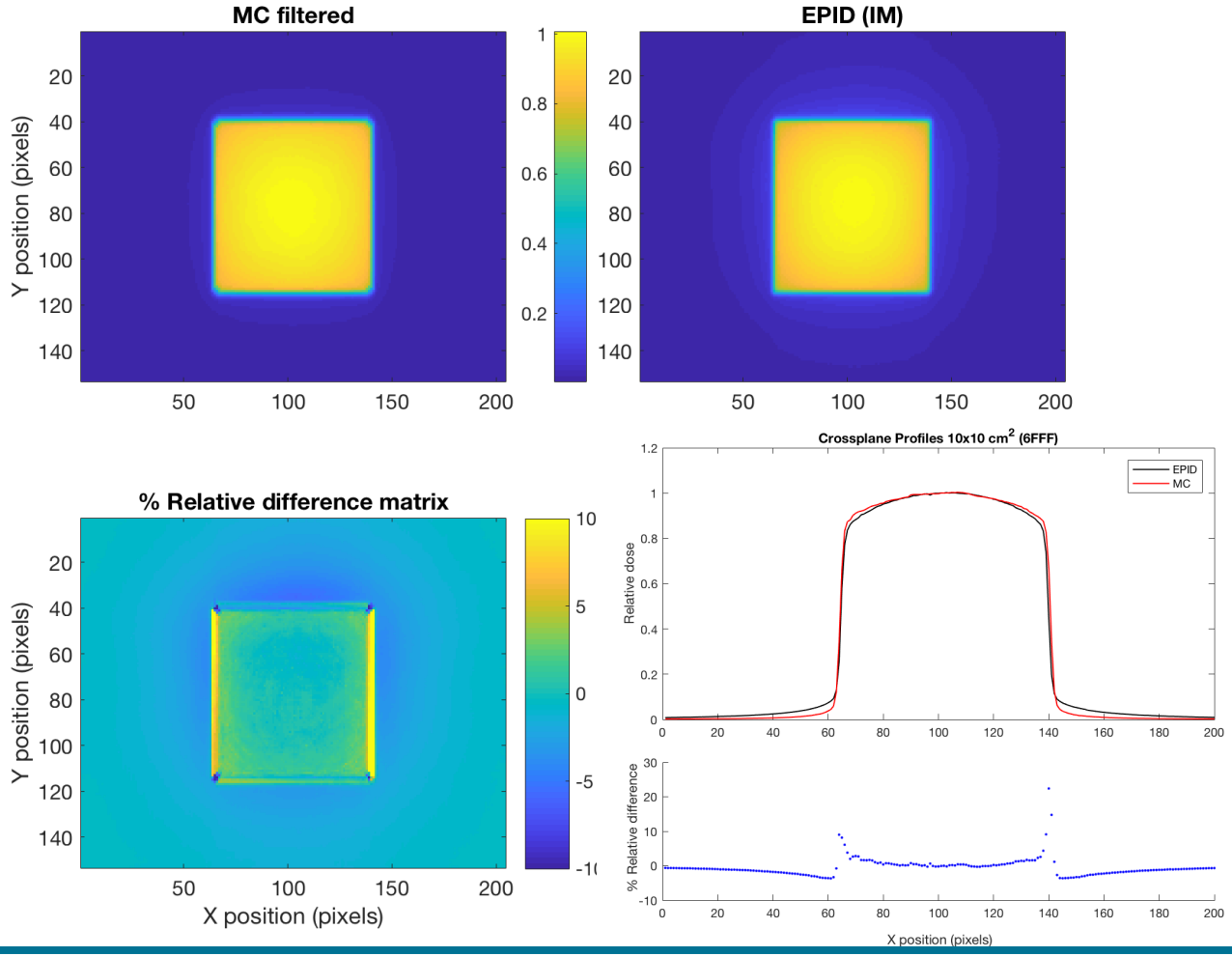
Study of influence of variable dose rate in response linearity with dynamic arc fields

Linearity deviations of CM with **arc fields**: **3.7%** (2.4MU) and **0.9%** [50-500 MU]

Results

EPID MC simulation of simple fields

MC vs. EPID integrated image for 10 x 10 cm^2



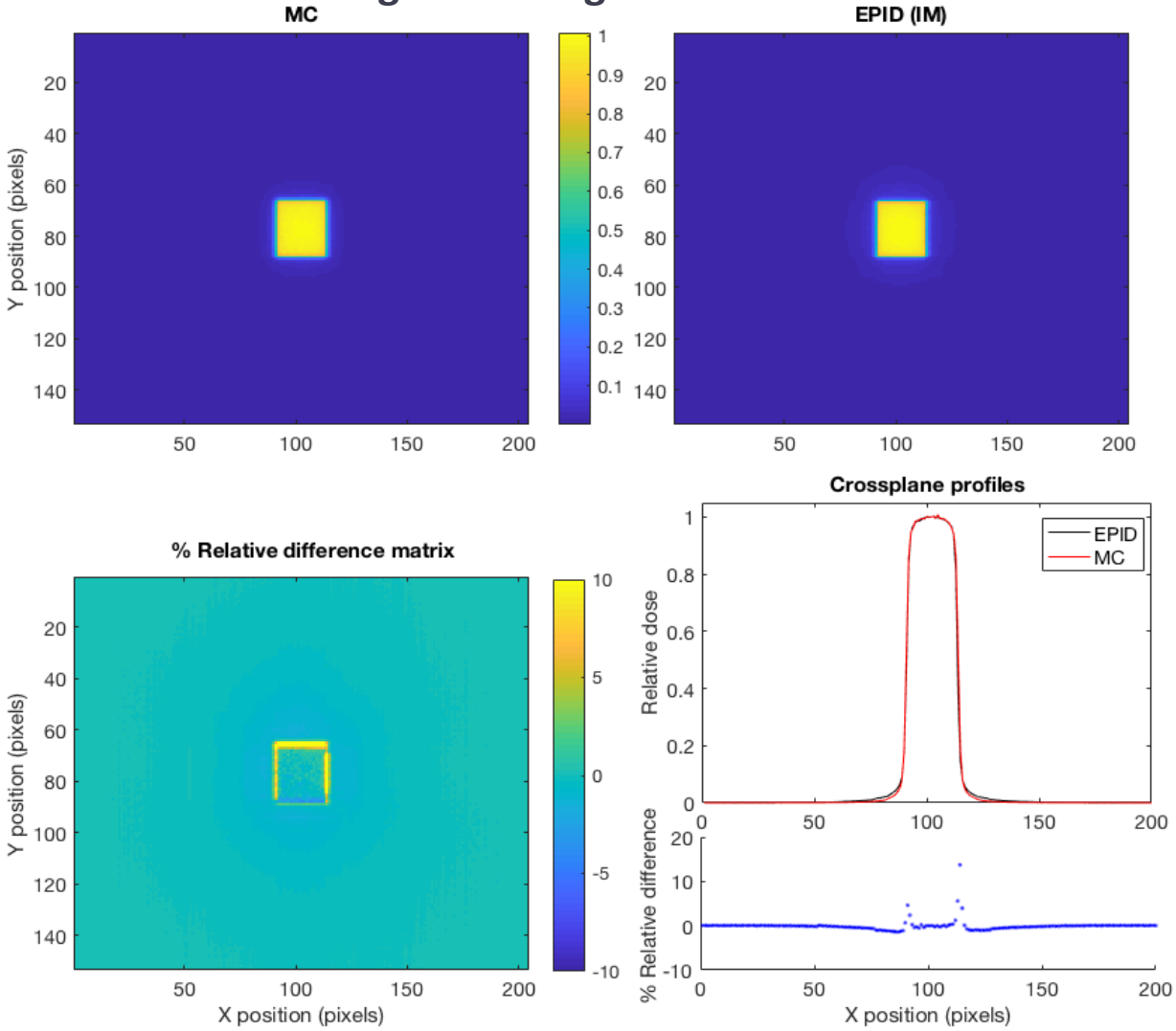
N particles= 4.4x10^9
Voxel size:
1.96x1.96x0.52 mm^3
t ~ 42h [11 cores]
σ_{MC} < 1 %

Agreement ± 1-2% / 3.5% tails (transmission)
Penumbra region [3-14%]

Results

EPID MC simulation of simple fields

MC vs. EPID integrated image for 3 x 3 cm^2



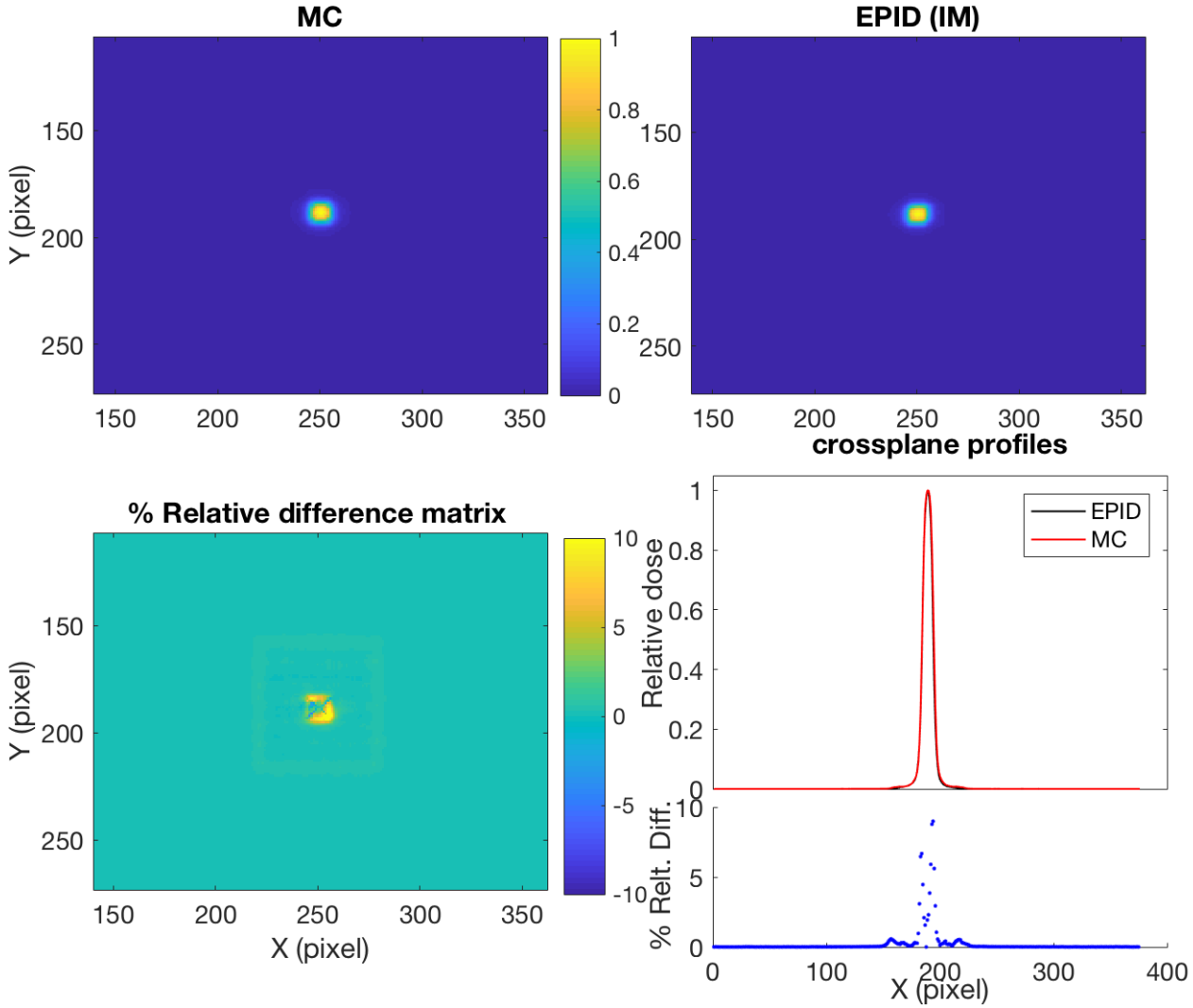
N particles= 4.4x10^9 ;
Voxel size:
1.96x1.96x0.52 mm^3
t ~ 20h [11 cores]
σ_{MC} < 0.5 % (1.5% outfield)

Agreement ± 1% / 1.5% tails (transmisson)

Results

EPID MC simulation of simple fields

MC vs. EPID integrated image for 0.5 x 0.5 cm^2



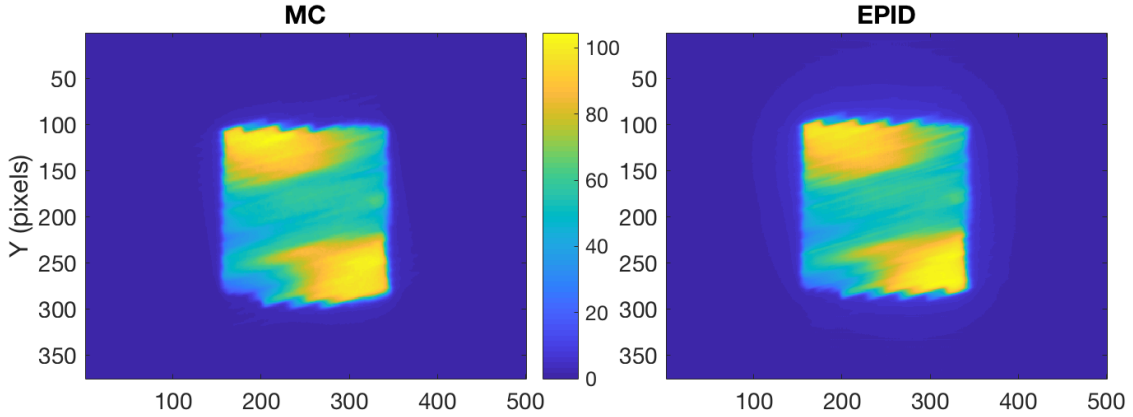
N particles= 5.5x10^9 ;
Voxel size: 0.8x0.8x0.52mm^3
t ~61h [5 cores]
σ_{MC} < 0.5 % (1.5% outfield)

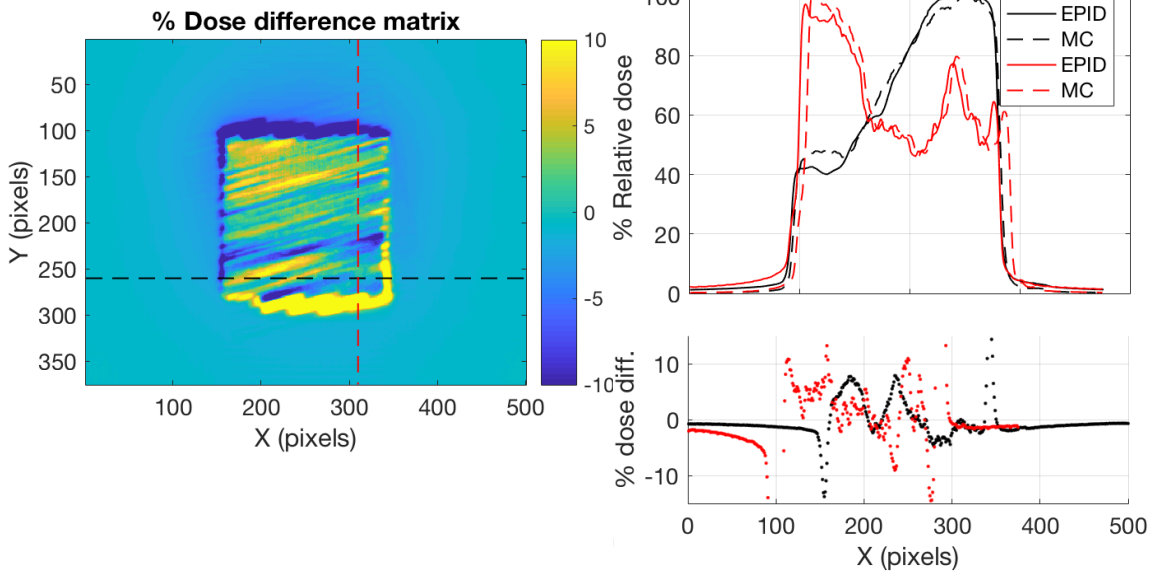
Agreement ± 1%
Few points [2-8%] at penumbra and outfield.

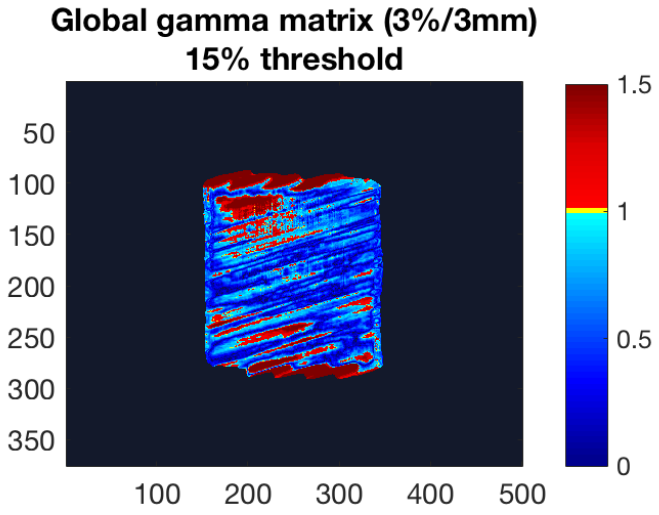
Results

Non-transit MC dosimetry SBRT VMAT treatment

Accumulated MC vs. EPID cine







γ < 1 = 78%

N particles/CP= 10^8
Total simulation time: ~23h
(178 CPs [75 cores])

Voxel size: 0.8x0.8.x0.52 mm^3
σ_{MC} < 1 %

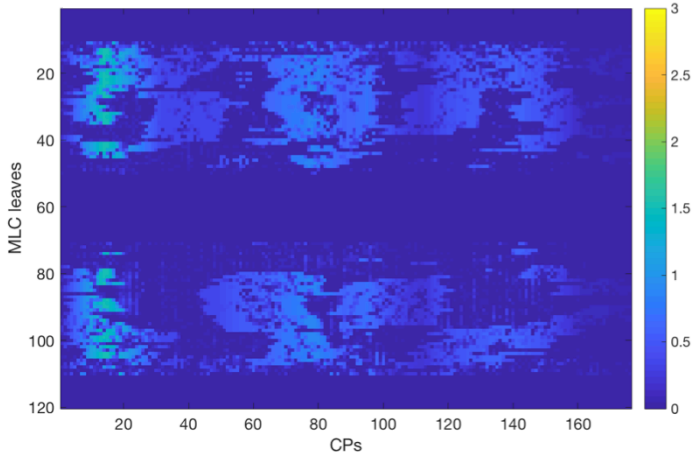
Results

Non-transit MC dosimetry SBRT VMAT treatment

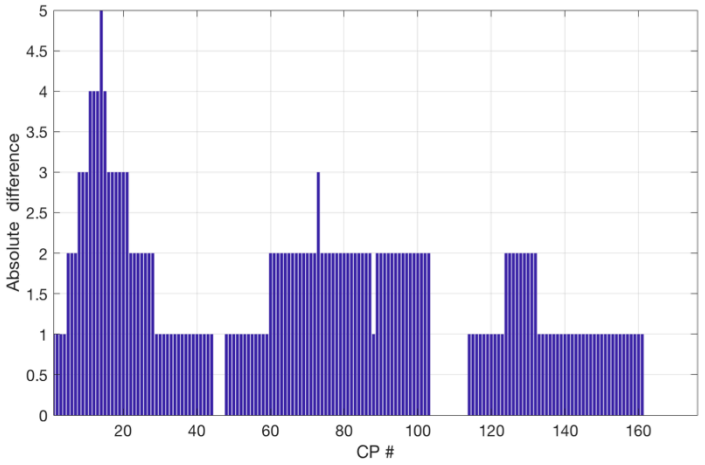
Simulated from TPS vs. delivered (EPID) parameters - also useful for linac QA.

- Could reveal important discrepancies in treatment delivery.

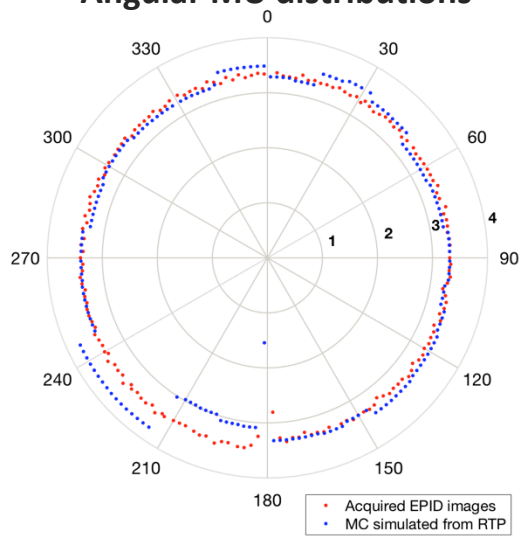
Difference sinogram: MLC positions difference (cm)



Gantry angle differences (°)



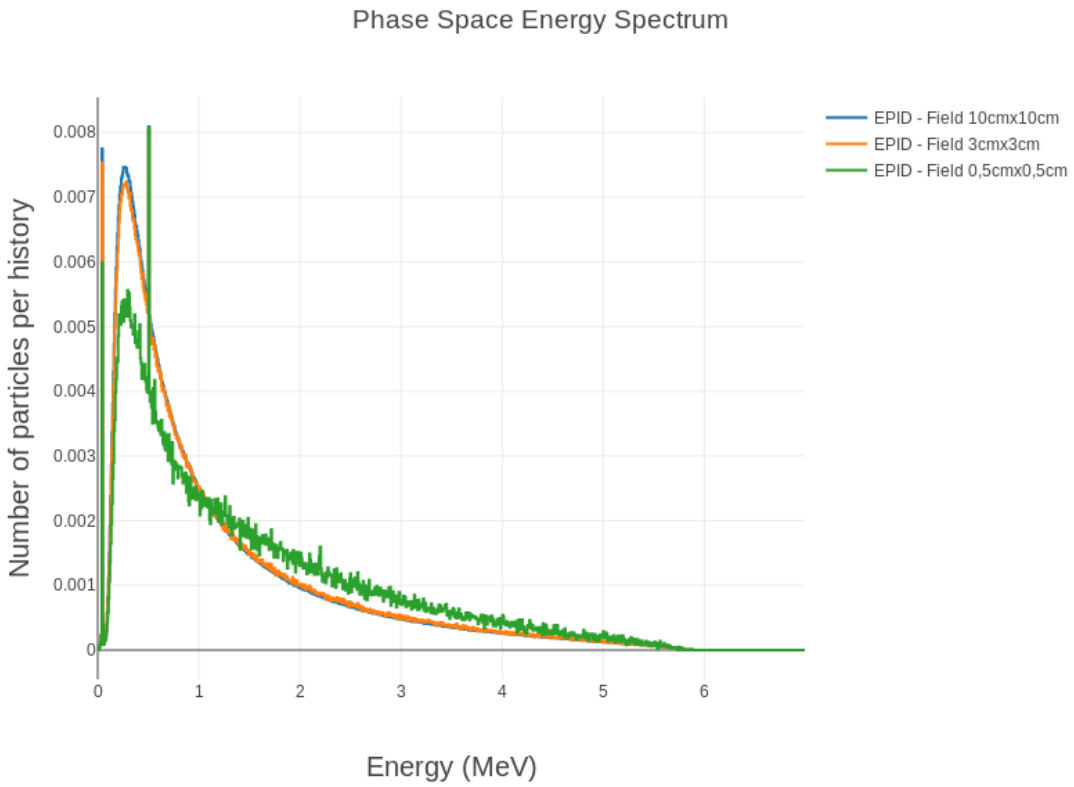
Angular MU distributions



Simulation of actual delivery parameters (EPID or log files) - work in progress

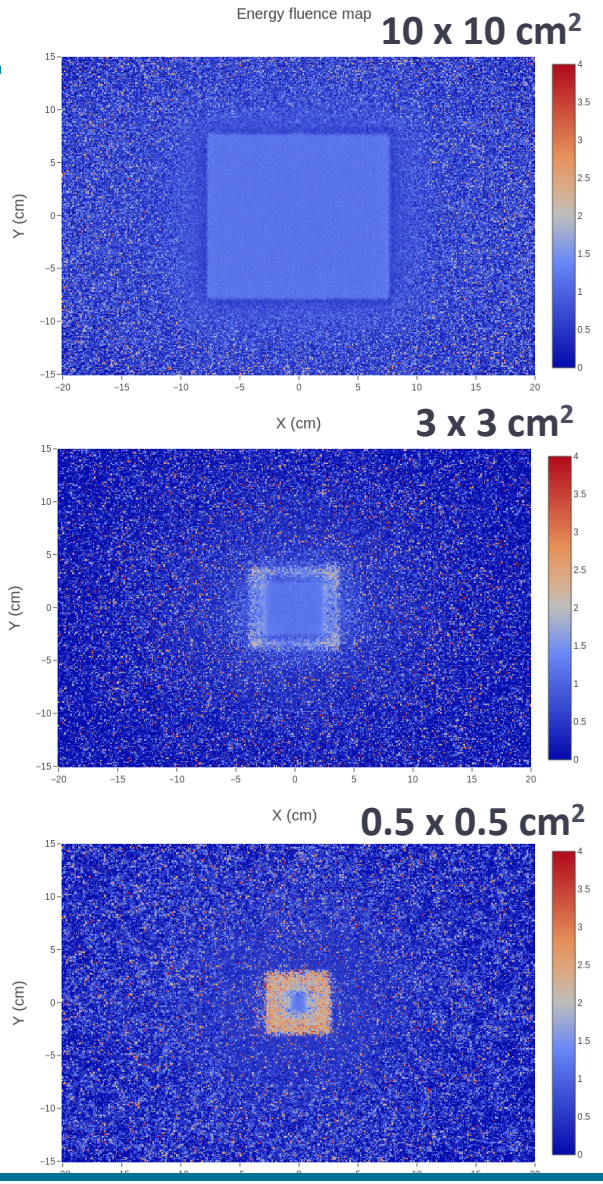
Results

Spectral and spatial energy distribution variations in stereotactic conditions.



Potentially consider different correction factors could improve conversion of acquired EPID images

Spatial particle energy distribution



Conclusions and perspectives

- MC simulation of EPID dose images has showed the **suitability of the MC model** in **predicting EPID response for non-transit dosimetry** with integrated images **for simple fields** and also **VMAT SBRT treatment** with continuous EPID imaging.

- This model **is ready to be extended for transit dosimetry** (ongoing work), and for further **SBRT EPID *in vivo* dosimetry** → considering log files and/or EPID files parameters and patient CBCT.

Thank you for your attention