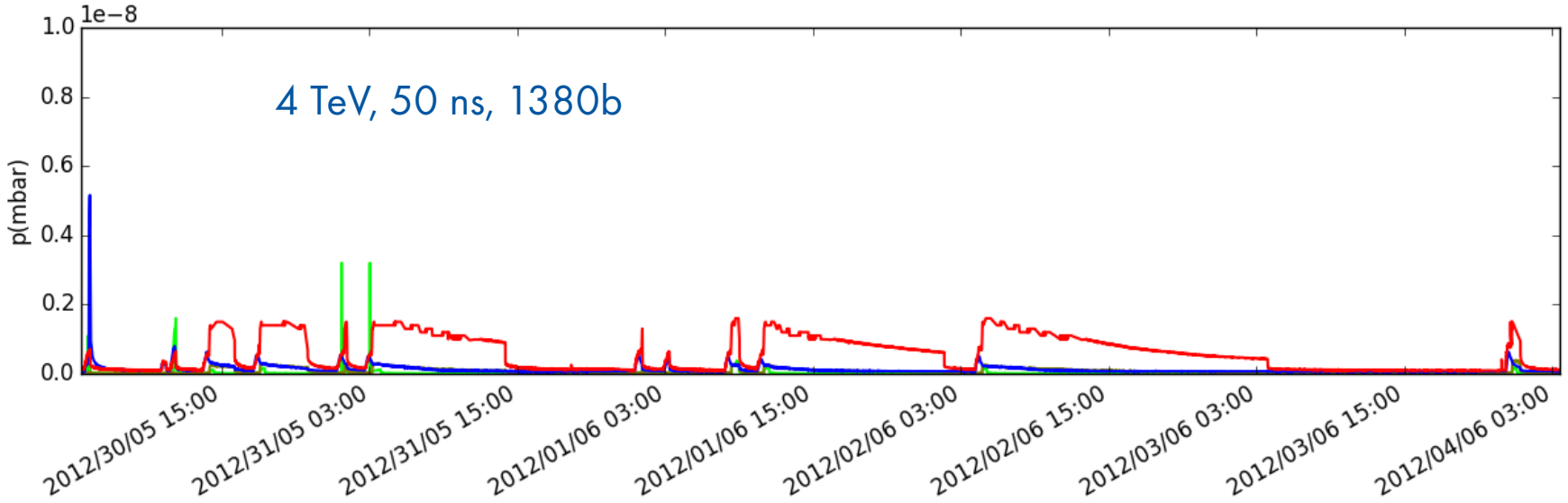
Simulation of Dynamic Pressure in LHC

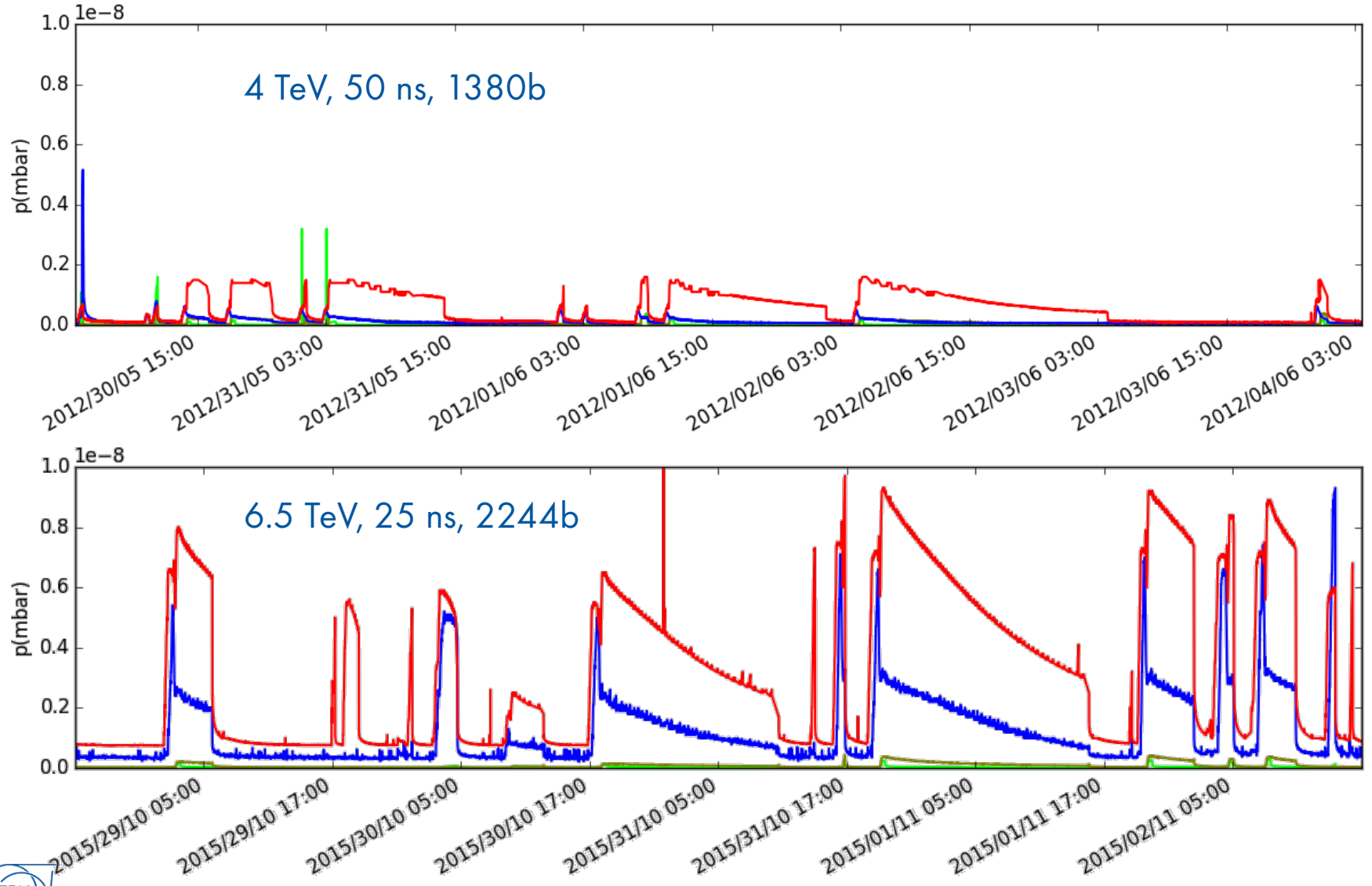
Jan Sopousek, TE-VSC-BVO

VSC Seminar 9/7/2016

Motivation


1e−8
1.0
0.8
0.6
0.4
0.2
0.0
p(mbar)
4 TeV, 50 ns, 1380b
2012/30/05 15:00
2012/31/05 03:00
2012/31/05 15:00
2012/01/06 03:00
2012/01/06 15:00
2012/02/06 03:00
2012/02/06 15:00
2012/03/06 03:00
2012/03/06 15:00
2012/04/06 03:00

Motivation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p(mbar)
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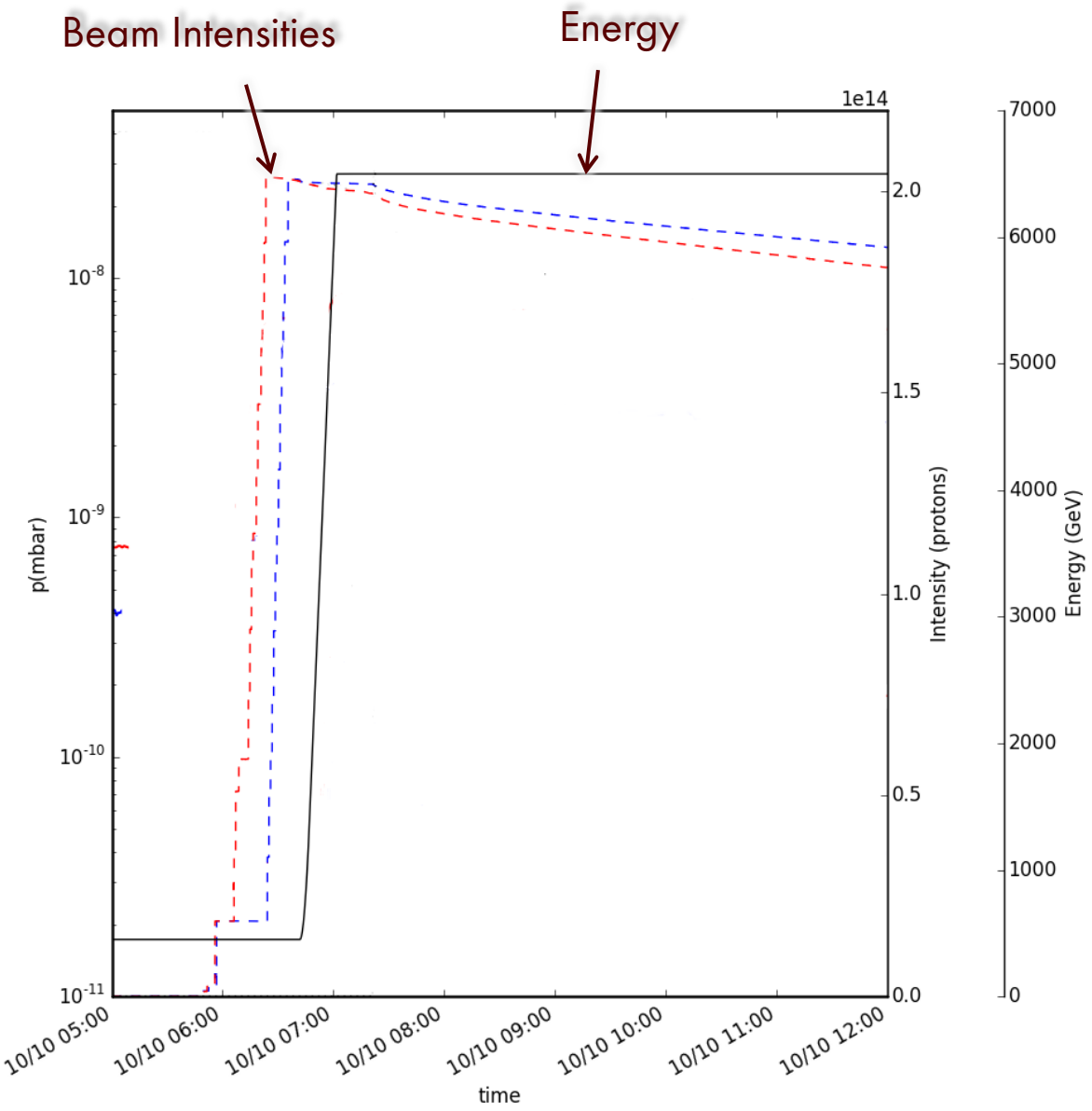
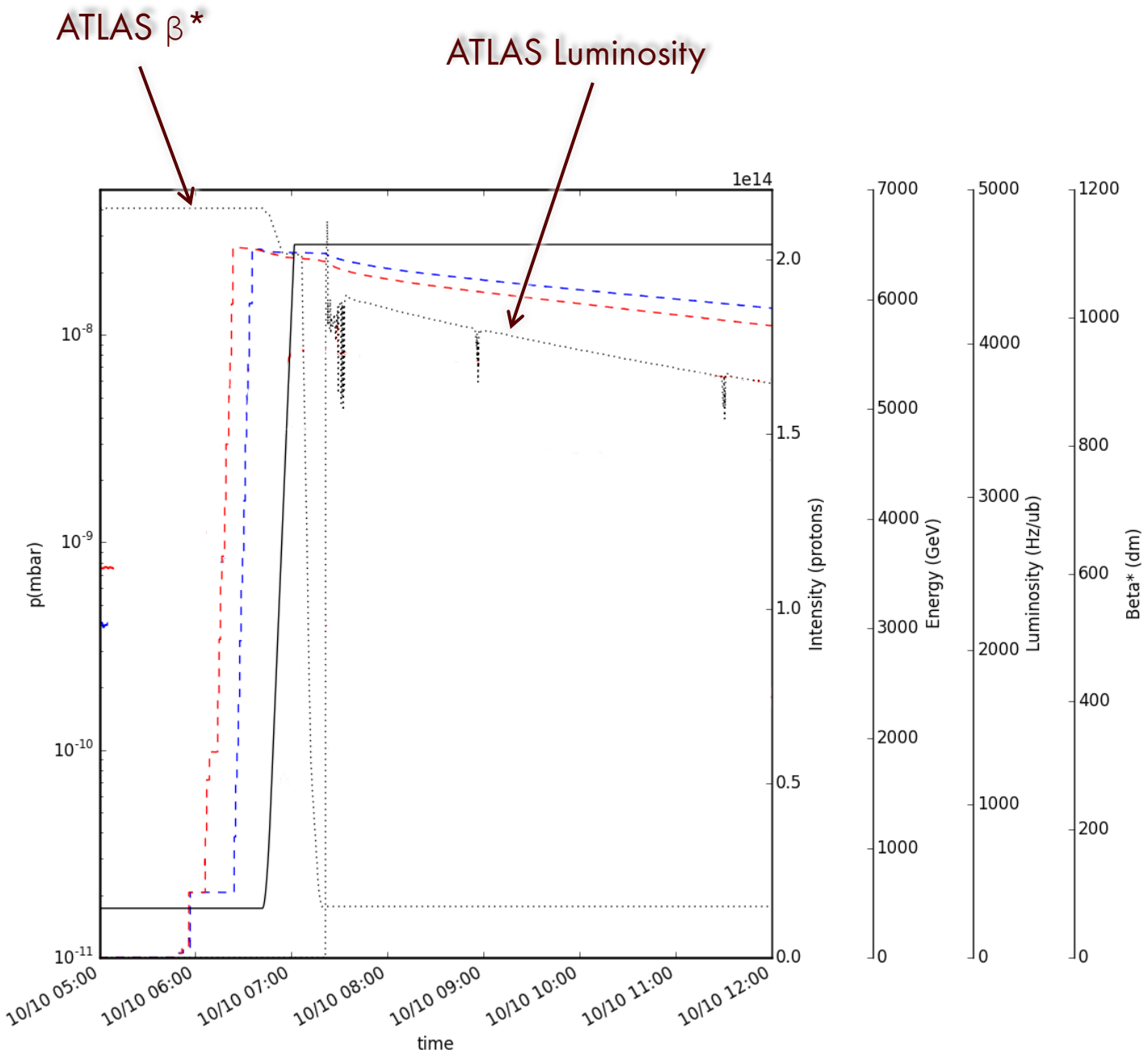
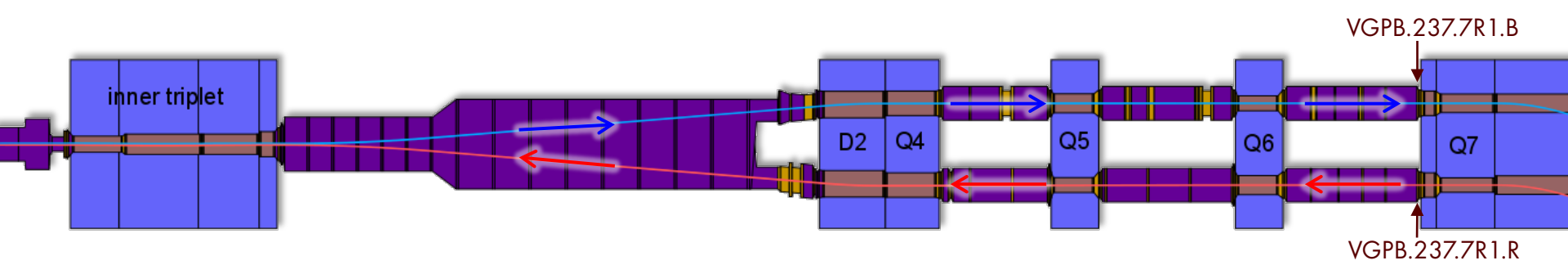
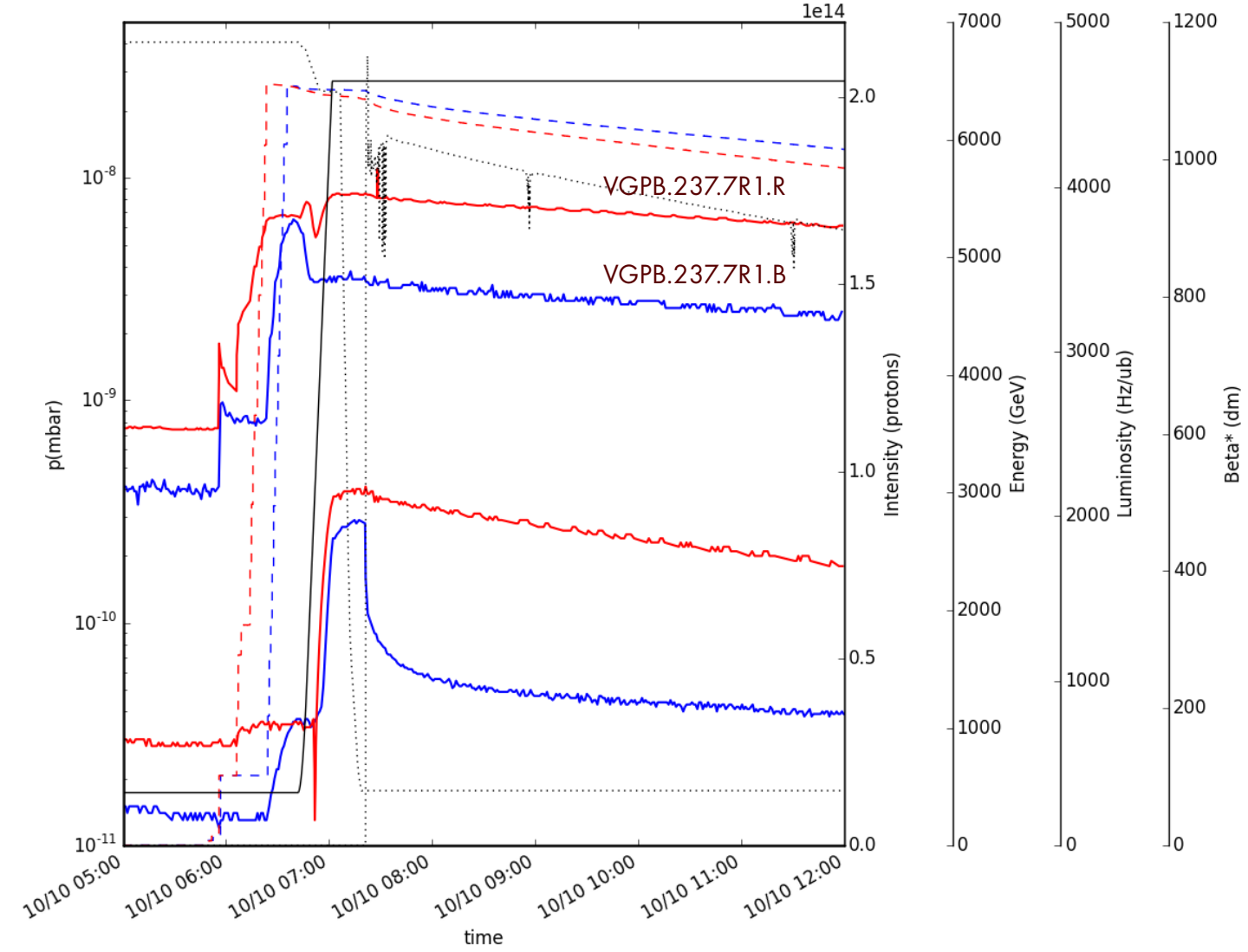
2012/01/06 15:00
2012/02/06 03:00
2012/02/06 15:00
2012/03/06 03:00
2012/03/06 15:00
2012/04/06 03:00
1e−8
1.0
0.8
0.6
0.4
0.2
0.0
p(mbar)
6.5 TeV, 25 ns, 2244b
2015/29/10 05:00
2015/29/10 17:00
2015/30/10 05:00
2015/30/10 17:00
2015/31/10 05:00
2015/31/10 17:00
2015/01/11 05:00
2015/01/11 17:00
2015/02/11 05:00

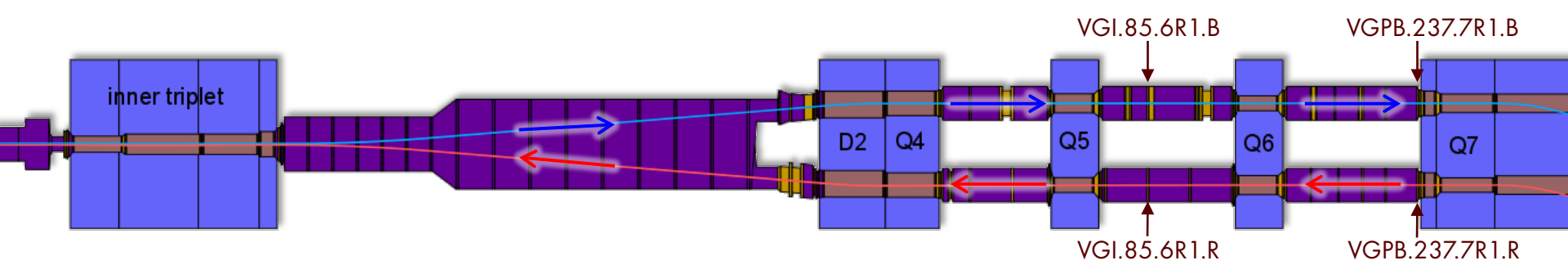
Pressure evolution during one fill

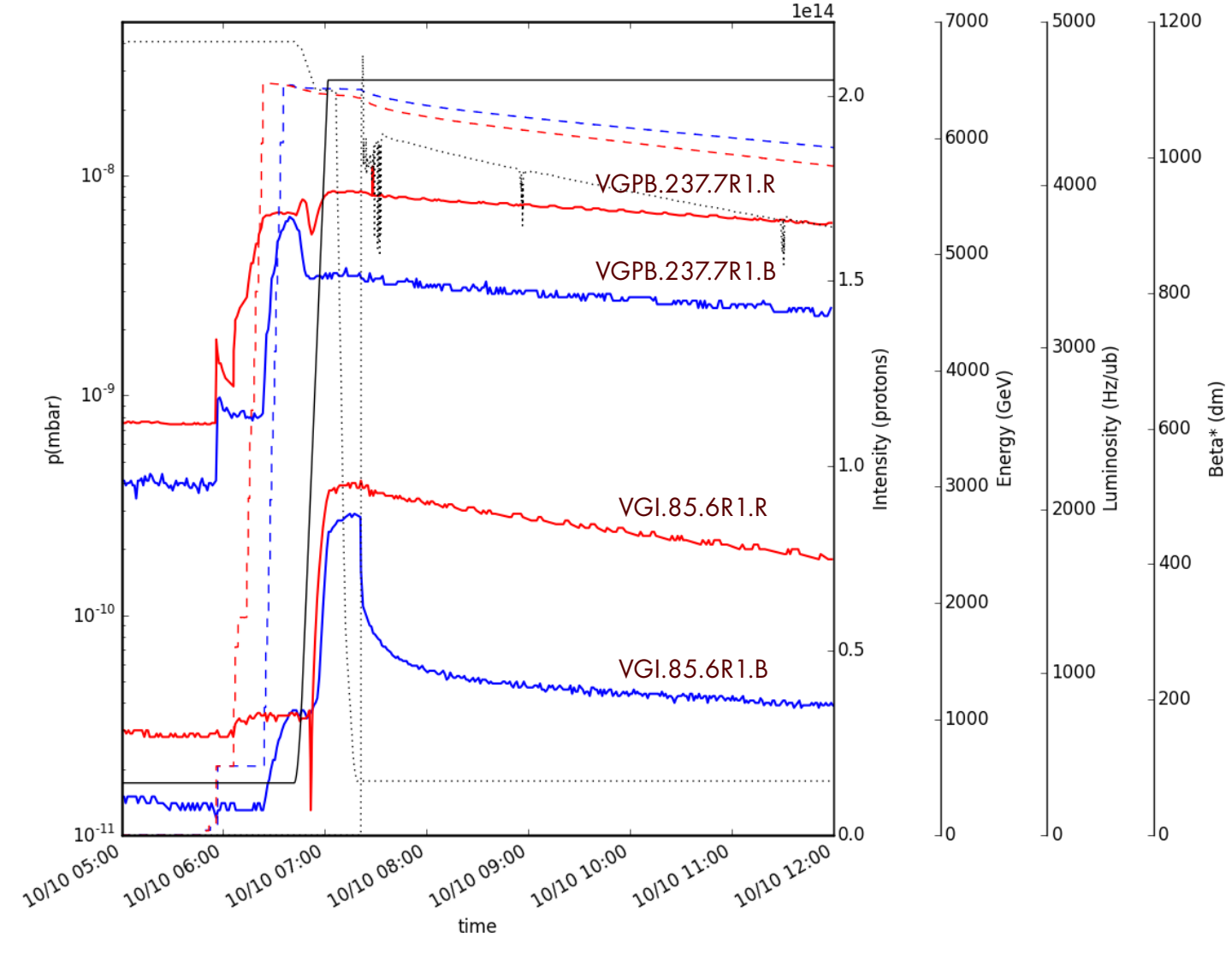


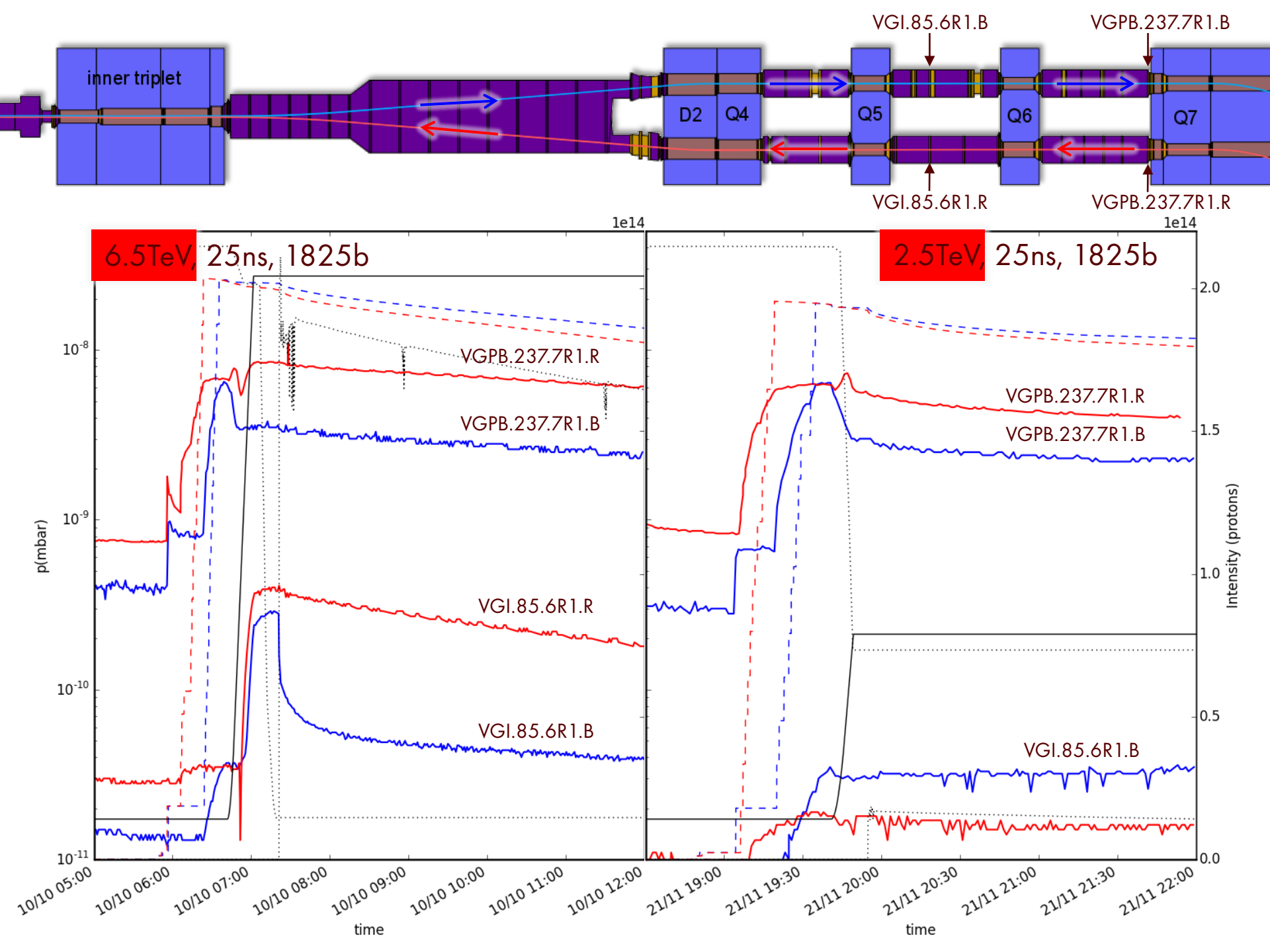

ATLAS β*
ATLAS Luminosity
1e14
p(mbar)
Intensity (protons)
Energy (GeV)
Luminosity (Hz/ub)
Beta* (dm)
time
10/10 05:00
10/10 06:00
10/10 07:00
10/10 08:00
10/10 09:00
10/10 10:00
10/10 11:00
10/10 12:00

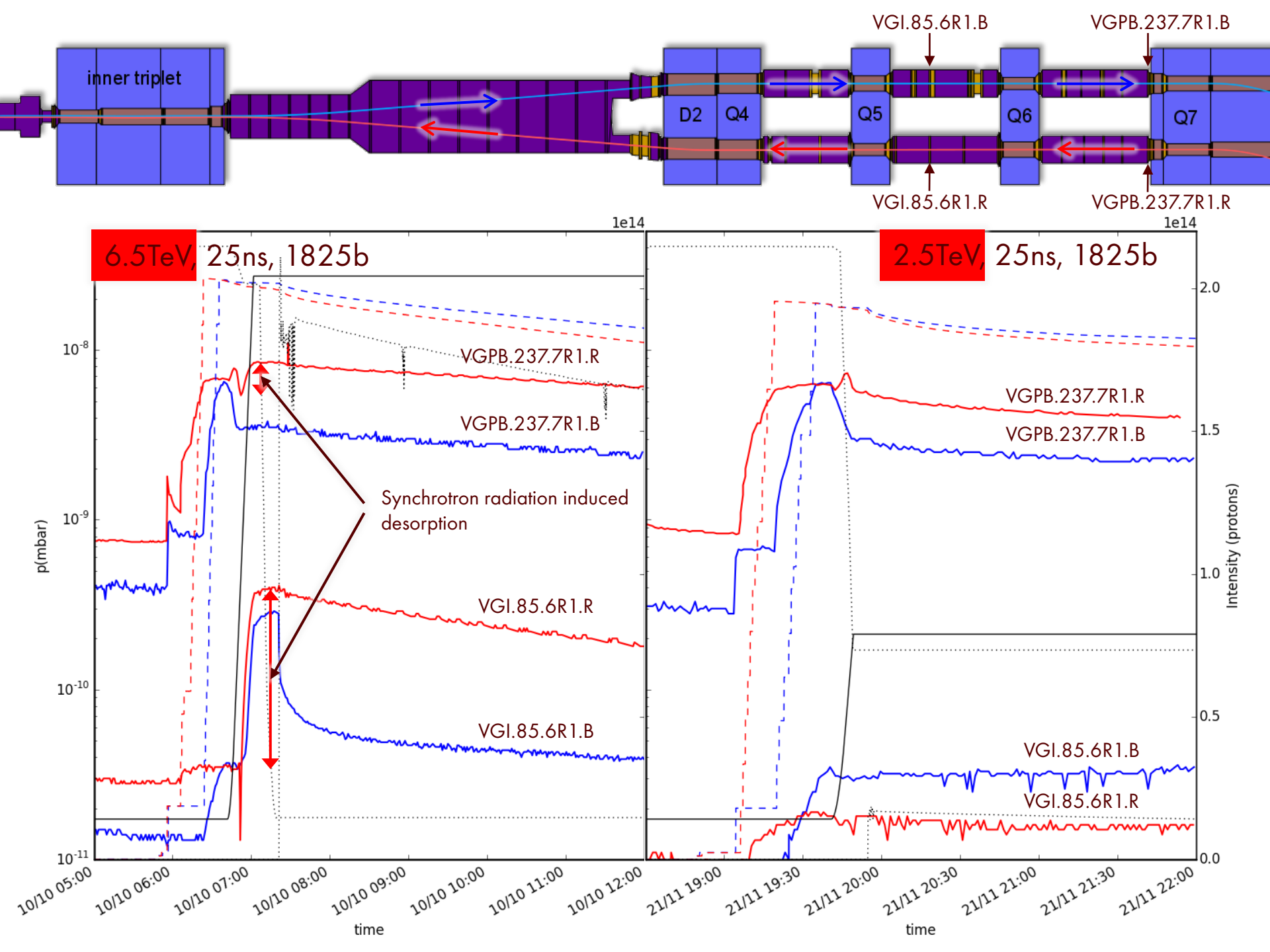

VGPB.237.7R1.B
inner triplet
D2
Q4
Q5
Q6
Q7
VGPB.237.7R1.R


1e14
VGPB.237.7R1.R
VGPB.237.7R1.B
p(mbar)
Intensity (protons)
Energy (GeV)
Luminosity (Hz/ub)
Beta* (dm)
time
10/10 05:00
10/10 06:00
10/10 07:00
10/10 08:00
10/10 09:00
10/10 10:00
10/10 11:00
10/10 12:00


VGI.85.6R1.B
VGPB.237.7R1.B
inner triplet
D2
Q4
Q5
Q6
Q7
VGI.85.6R1.R
VGPB.237.7R1.R


1e14
p(mbar)
10^{-8}
10^{-9}
10^{-10}
10^{-11}
VGPB.237.7R1.R
VGPB.237.7R1.B
VGI.85.6R1.R
VGI.85.6R1.B
Intensity (protons)
2.0
1.5
1.0
0.5
0.0
Energy (GeV)
7000
6000
5000
4000
3000
2000
1000
0
Luminosity (Hz/ub)
5000
4000
3000
2000
1000
0
Beta* (dm)
1200
1000
800
600
400
200
0
10/10 05:00
10/10 06:00
10/10 07:00
10/10 08:00
10/10 09:00
10/10 10:00
10/10 11:00
10/10 12:00
time


VGI.85.6R1.B
VGPB.237.7R1.B
inner triplet
D2
Q4
Q5
Q6
Q7
VGI.85.6R1.R
VGPB.237.7R1.R
6.5TeV, 25ns, 1825b
2.5TeV, 25ns, 1825b
1e14
1e14
p(mbar)
Intensity (protons)
VGPB.237.7R1.R
VGPB.237.7R1.B
VGI.85.6R1.R
VGI.85.6R1.B
time
time


inner triplet
D2
Q4
Q5
Q6
Q7
VGI.85.6R1.B
VGPB.237.7R1.B
VGI.85.6R1.R
VGPB.237.7R1.R
6.5TeV, 25ns, 1825b
2.5TeV, 25ns, 1825b
1e14
p(mbar)
Intensity (protons)
time
Synchrotron radiation induced desorption
10/10 05:00
10/10 06:00
10/10 07:00
10/10 08:00
10/10 09:00
10/10 10:00
10/10 11:00
10/10 12:00
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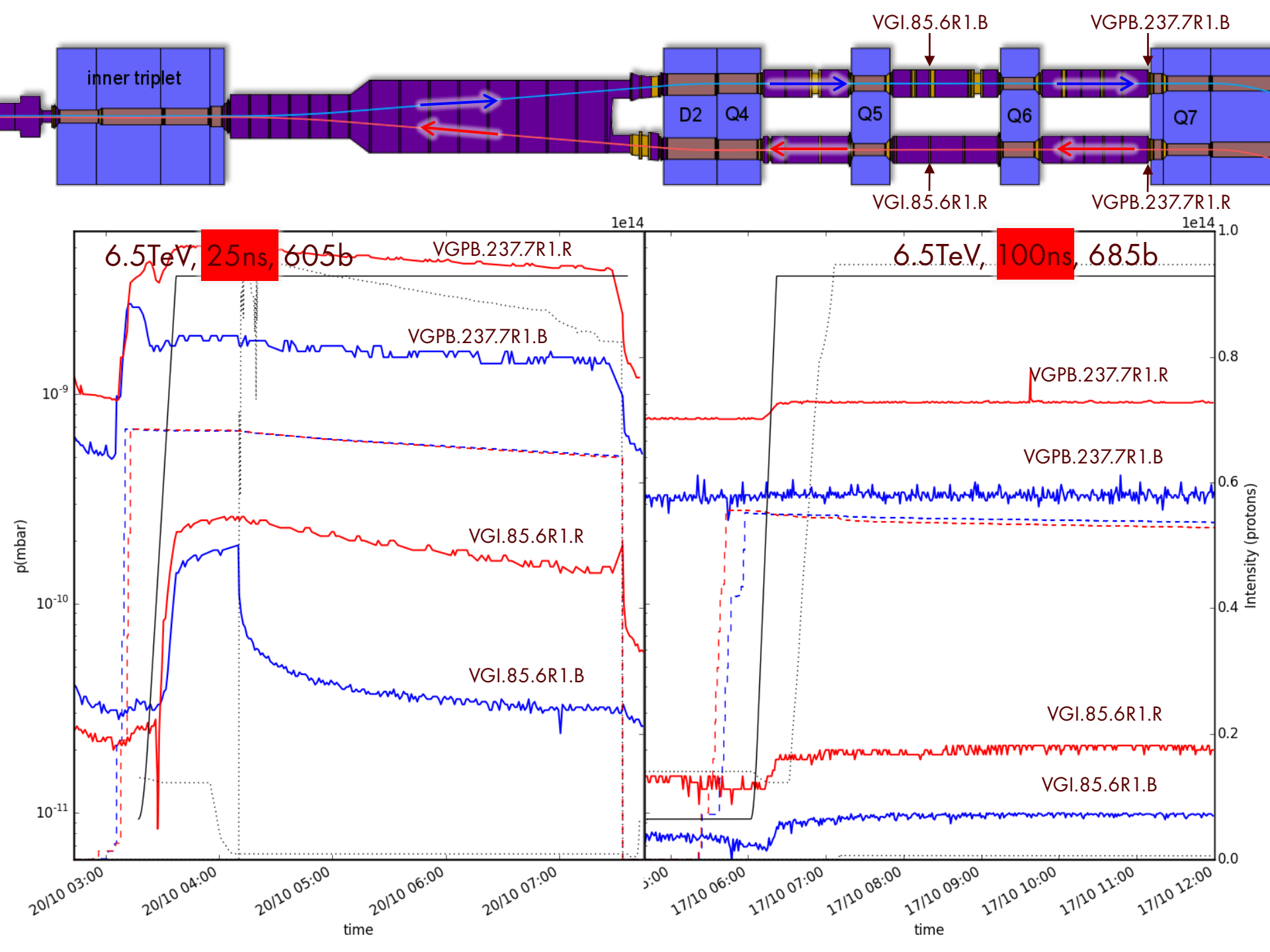
21/11 20:30
21/11 21:00
21/11 21:30
21/11 22:00


inner triplet
D2
Q4
Q5
Q6
Q7
VGI.85.6R1.B
VGPB.237.7R1.B
VGI.85.6R1.R
VGPB.237.7R1.R
6.5TeV, 25ns, 605b
6.5TeV, 100ns, 685b
1e14
1e14
VGPB.237.7R1.R
VGPB.237.7R1.B
VGI.85.6R1.R
VGI.85.6R1.B
p(mbar)
Intensity (protons)
time
time
20/10 03:00
20/10 04:00
20/10 05:00
20/10 06:00
20/10 07:00
17/10 06:00
17/10 07:00
17/10 08:00
17/10 09:00
17/10 10:00
17/10 11:00
17/10 12:00

Contents

- Overview of simulation
- Geometry of LHC and materials
- Synchrotron radiation
- Electron cloud effect
- Dynamical vacuum

Overview of simulation

- Geometry of LHC and materials
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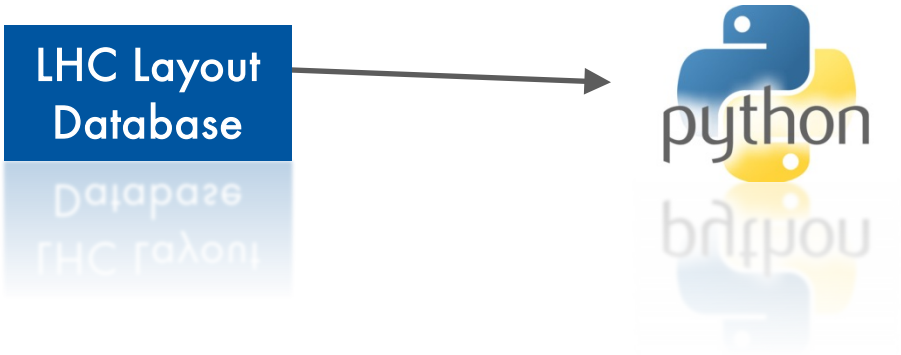
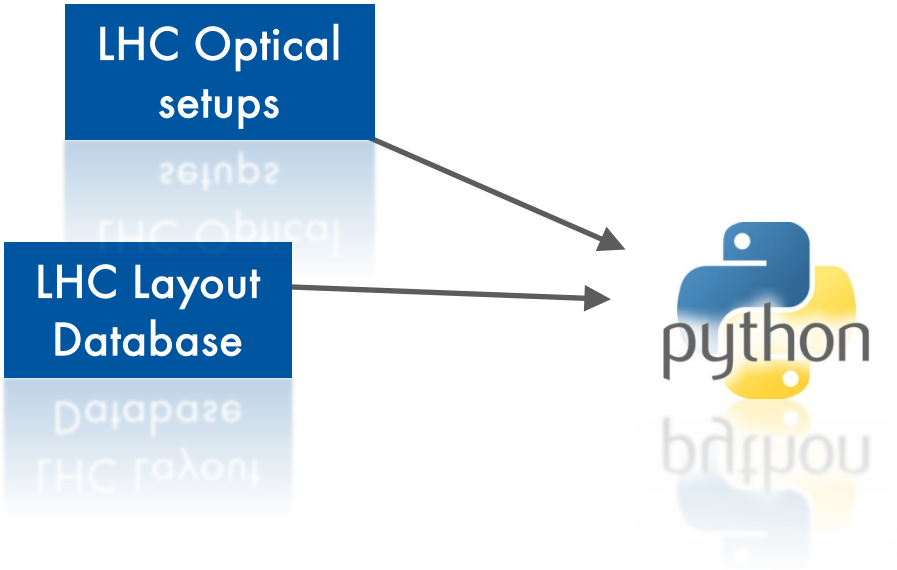
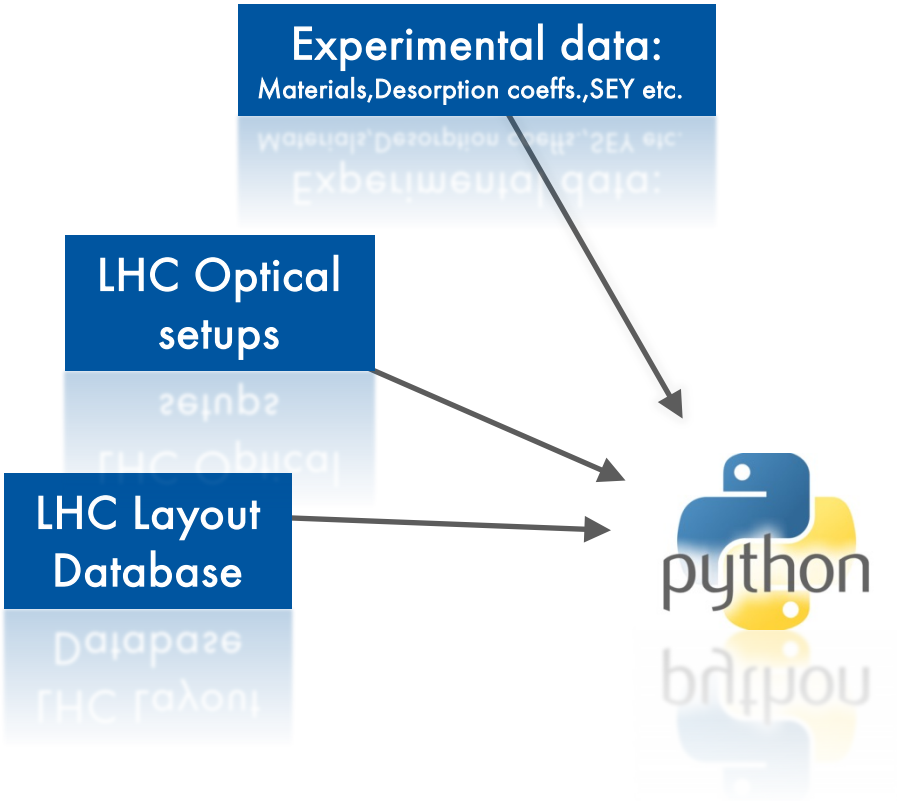
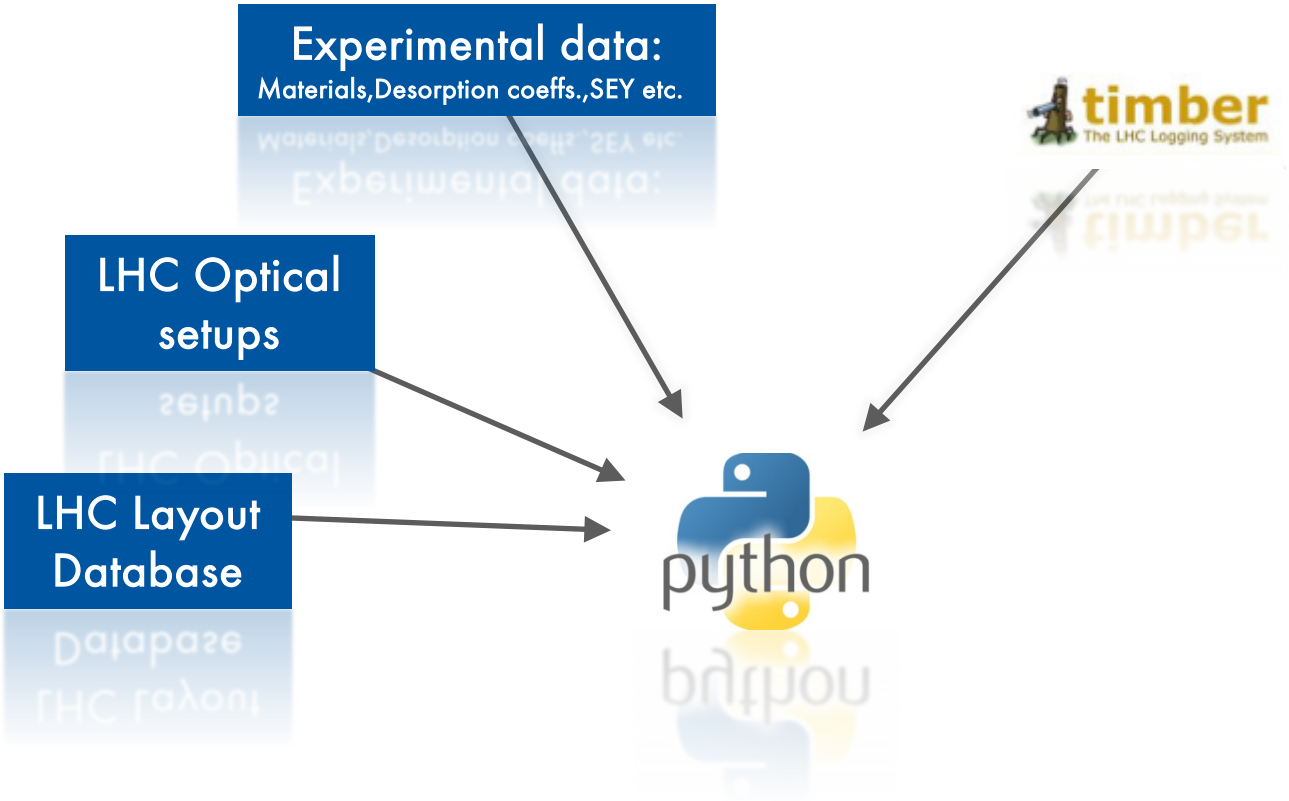
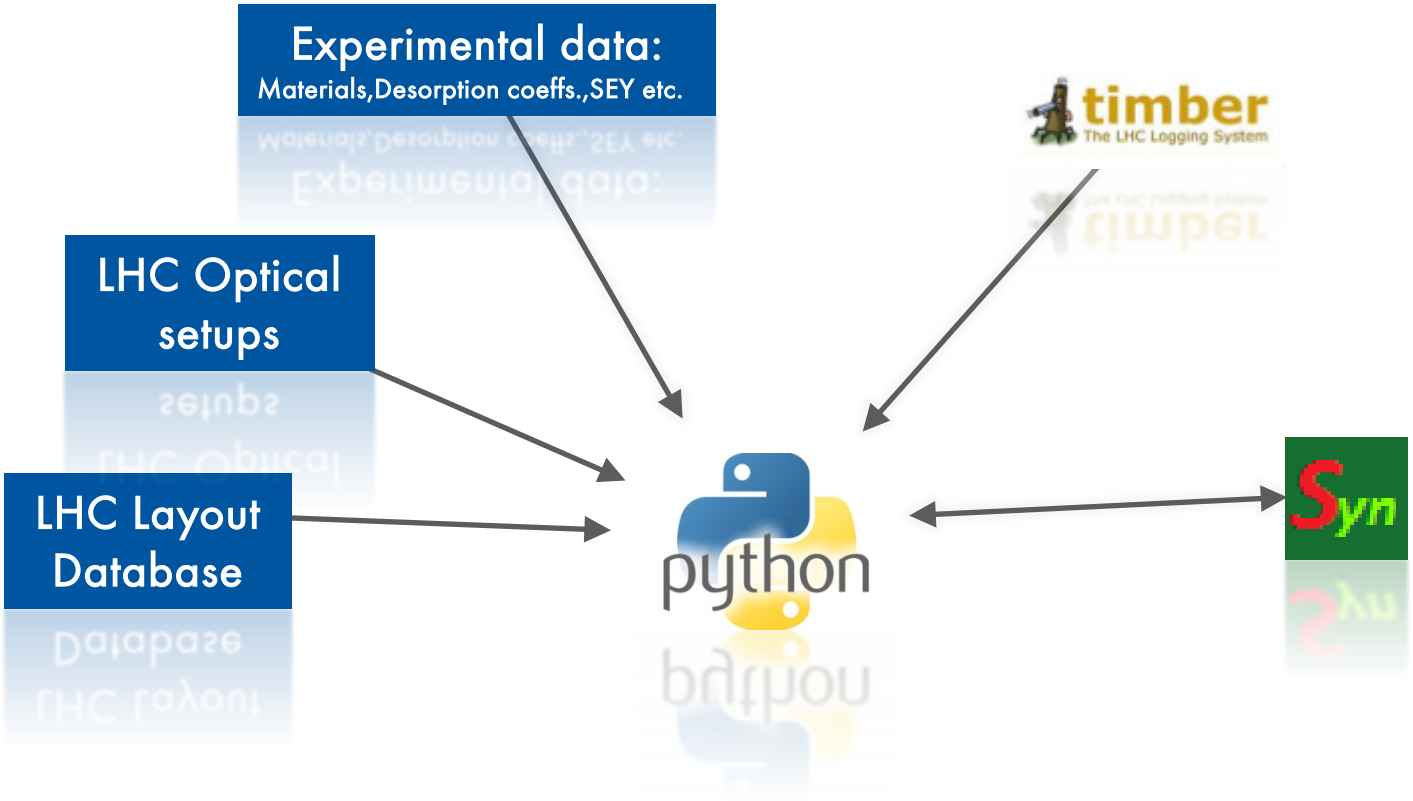
python


LHC Layout Database
python


LHC Optical setups
LHC Layout Database
python


Experimental data:
Materials,Desorption coeffs.,SEY etc.
LHC Optical setups
LHC Layout Database
python


Experimental data:
Materials,Desorption coeffs.,SEY etc.
timber
The LHC Logging System
LHC Optical setups
LHC Layout Database
python


Experimental data:
Materials,Desorption coeffs.,SEY etc.
timber
The LHC Logging System
LHC Optical setups
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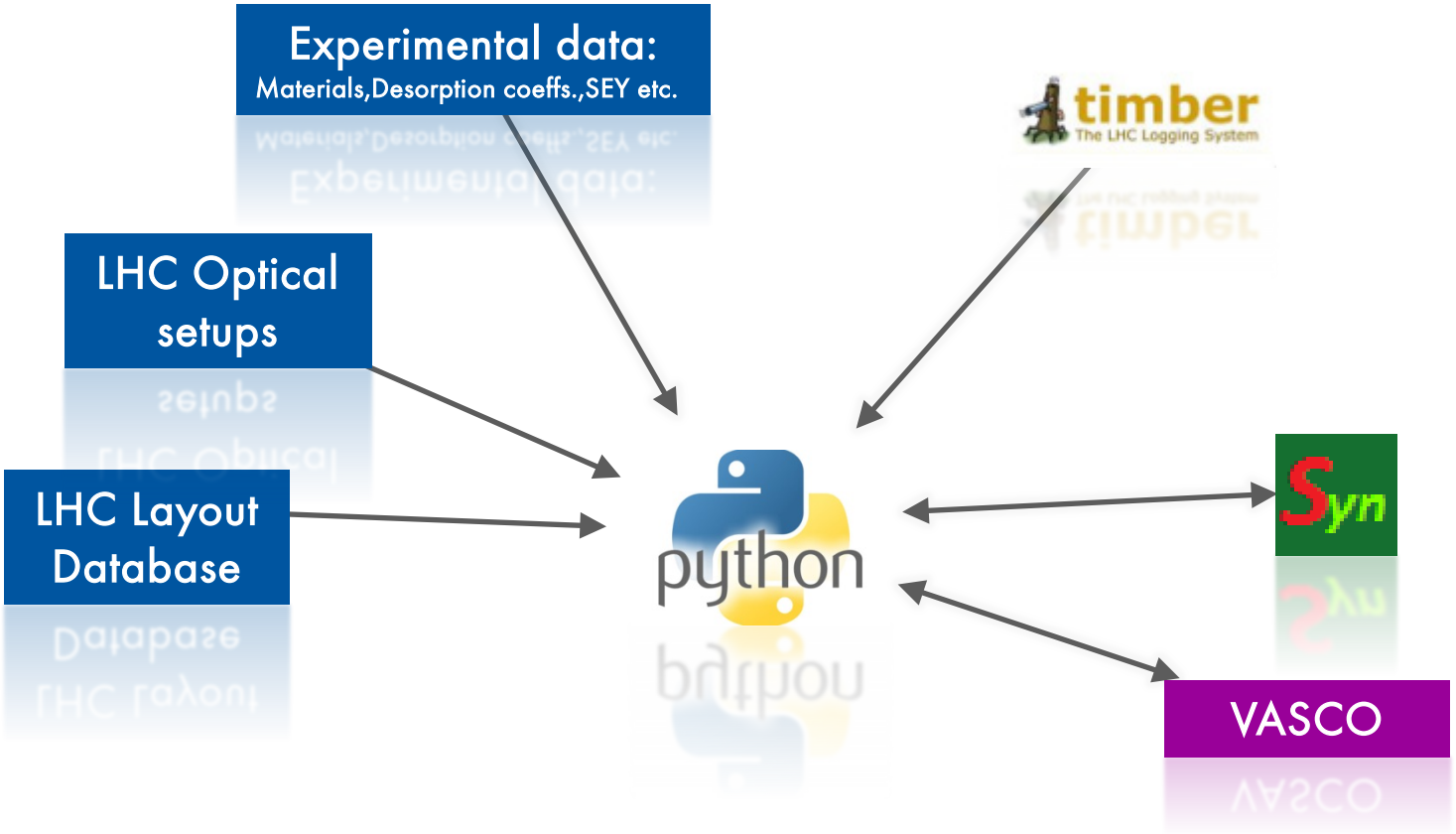
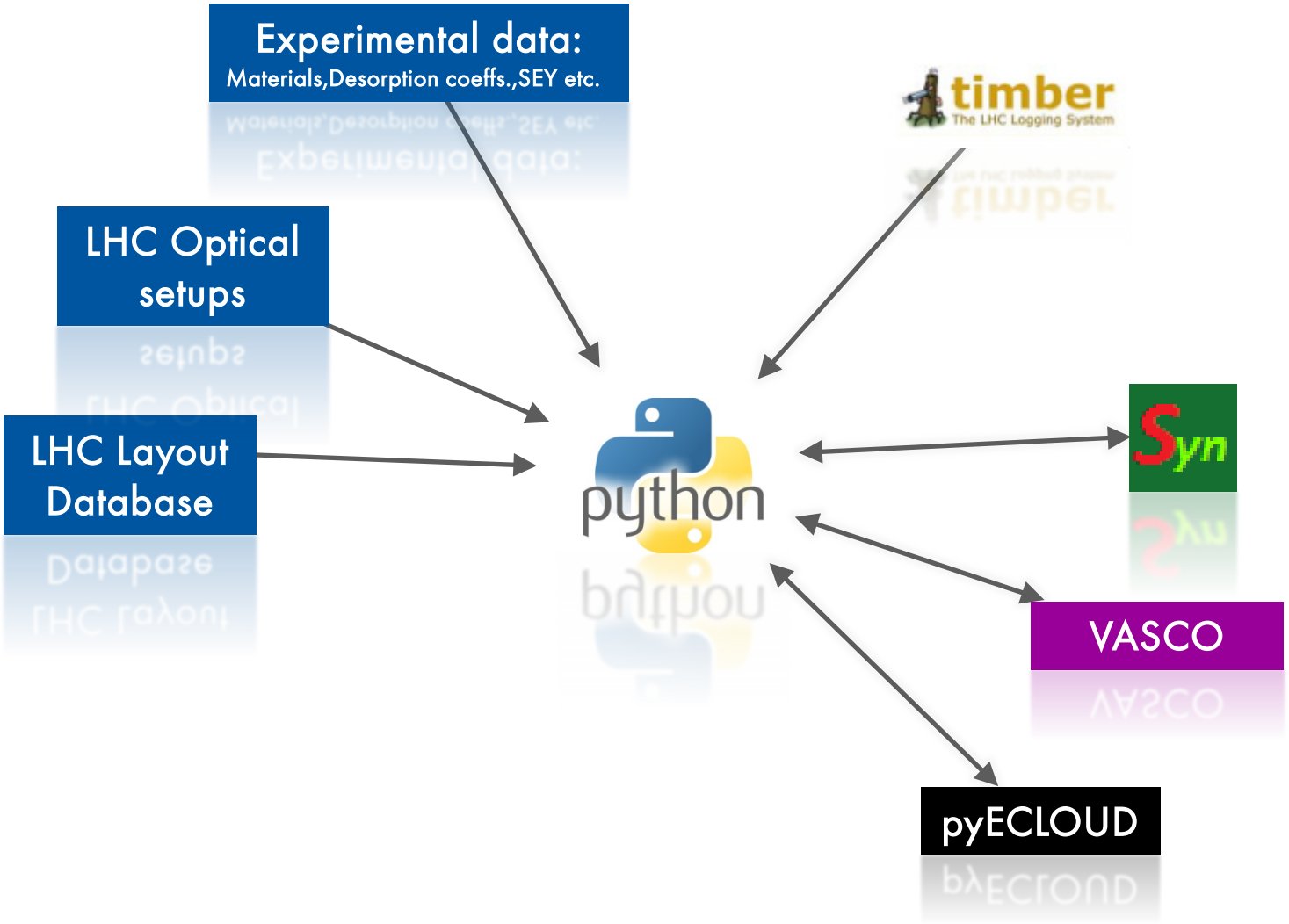
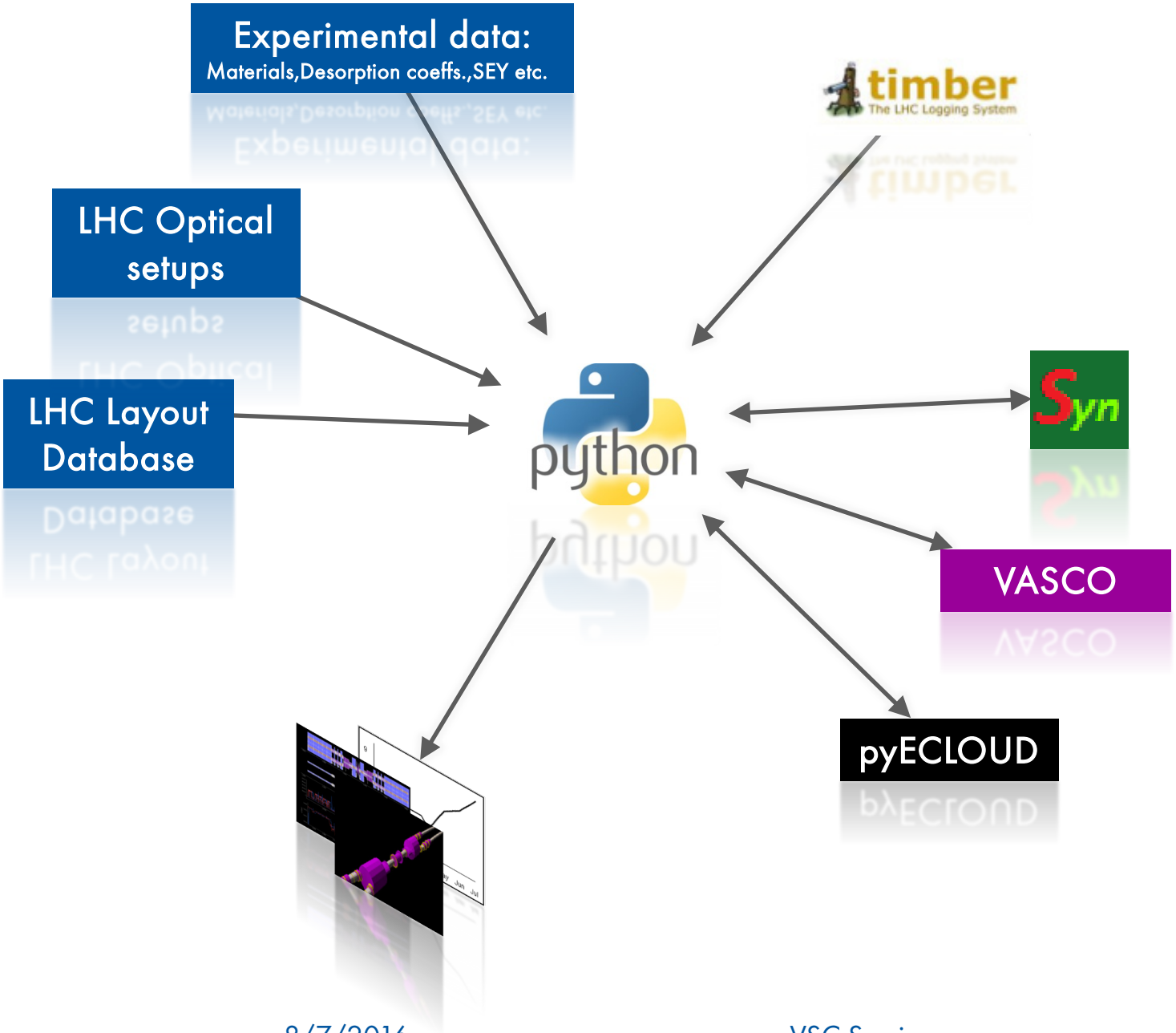
python
Syn


Experimental data:
Materials,Desorption coeffs.,SEY etc.
timber
The LHC Logging System
LHC Optical setups
LHC Layout Database
python
Syn
VASCO


Experimental data:
Materials,Desorption coeffs.,SEY etc.
timber
The LHC Logging System
LHC Optical setups
LHC Layout Database
python
Syn
VASCO
pyECLOUD


Experimental data:
Materials,Desorption coeffs.,SEY etc.
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The LHC Logging System
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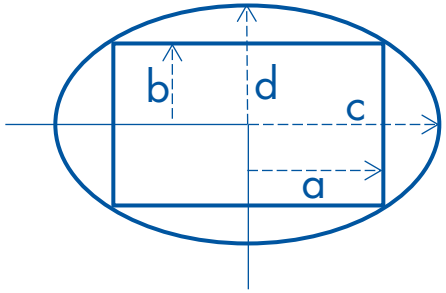
python
Syn
VASCO
pyECLOUD

- Overview of simulation
- **Geometry of LHC and materials**
- Synchrotron radiation
- Electron cloud effect
- Dynamical vacuum

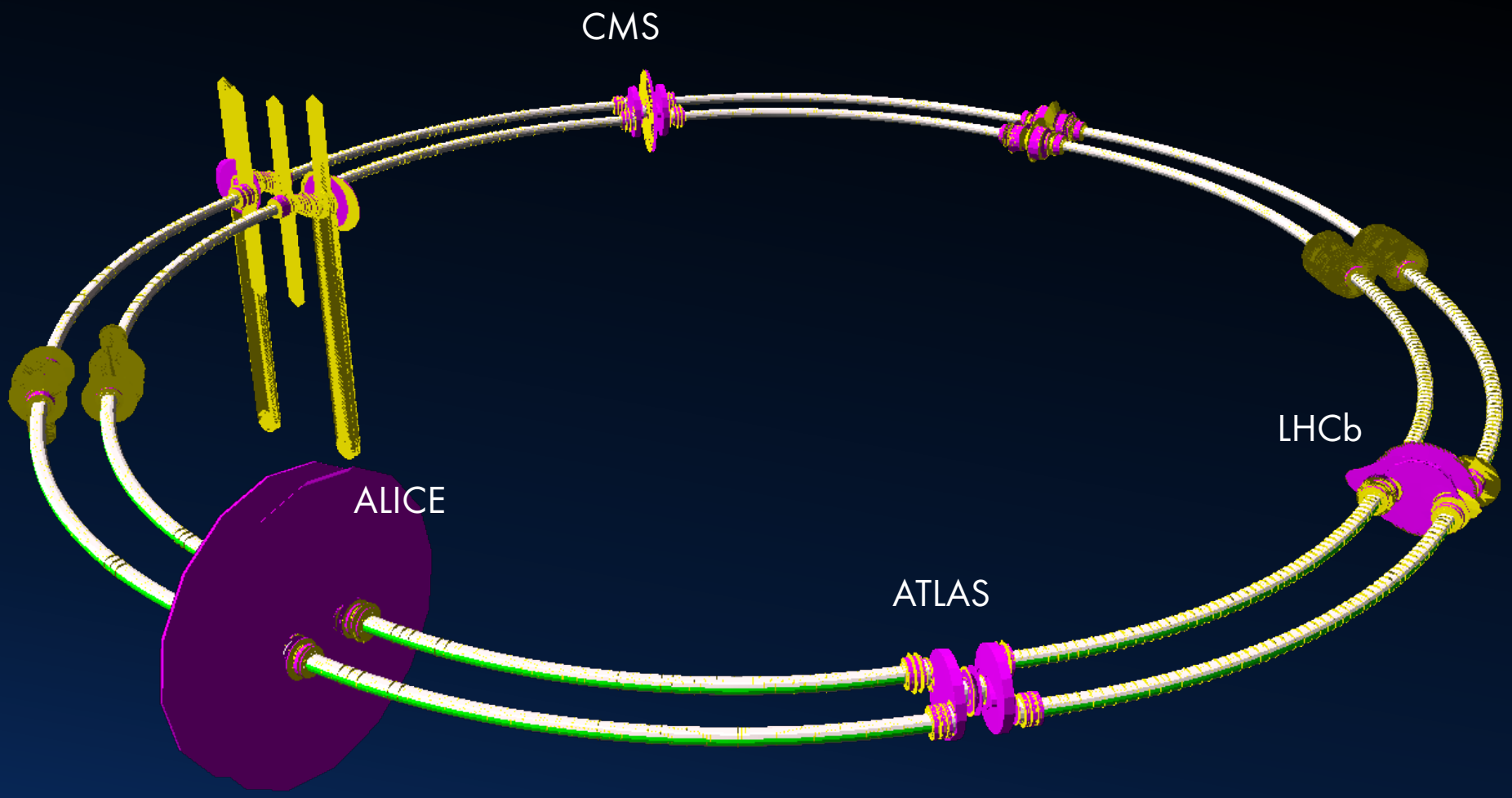
LHC Geometry



Parameters of rect-elliptic profile

- Based on LHC Layout database
  - About 10 000 elements
- Simplified geometry with only Eliptic/rectangular profiles

- 3D model for SynRad
- Chamber properties as a function of distance for pyECLOUD and VASCO

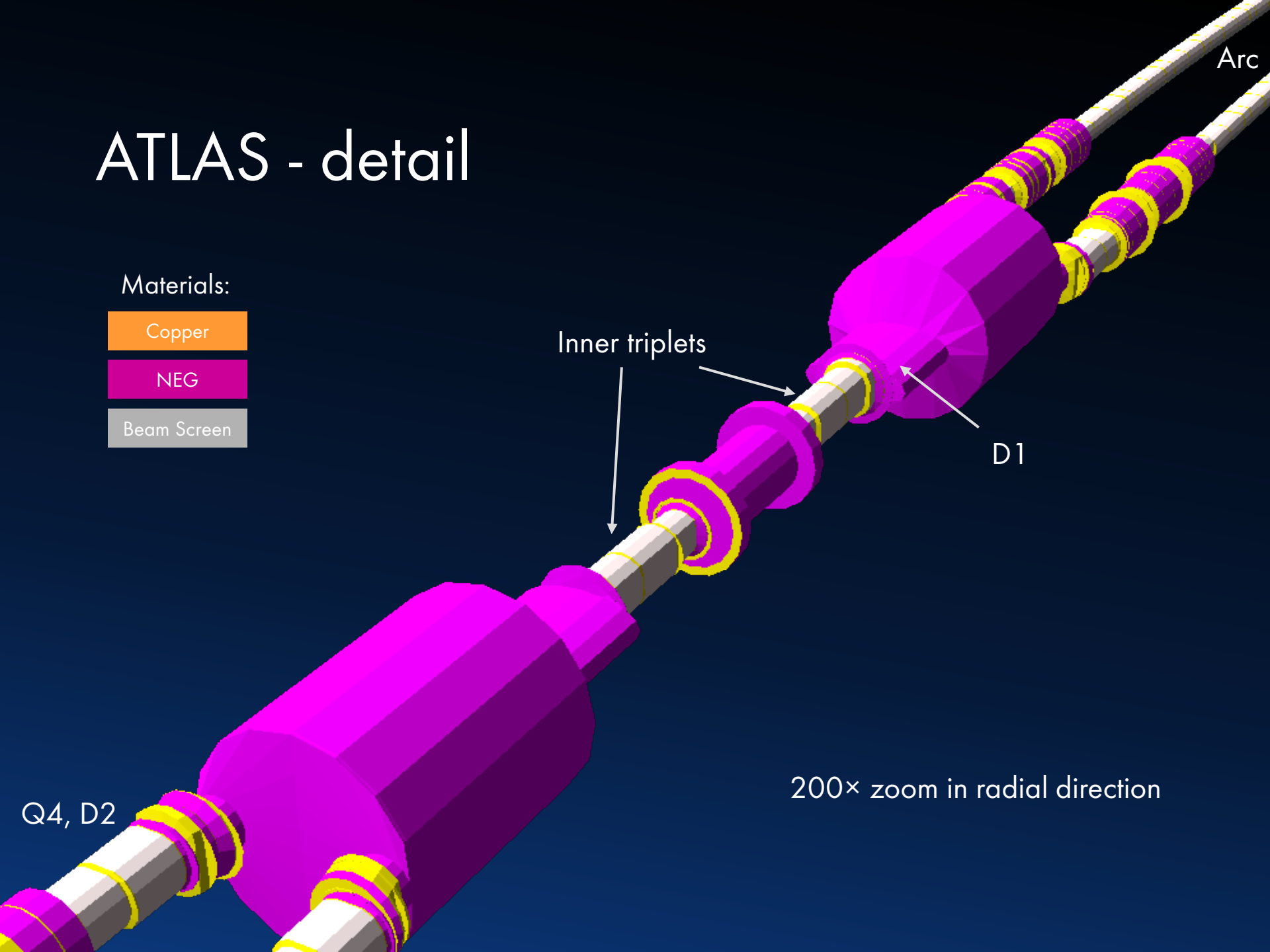


Materials:

- Copper
- NEG
- Beam Screen

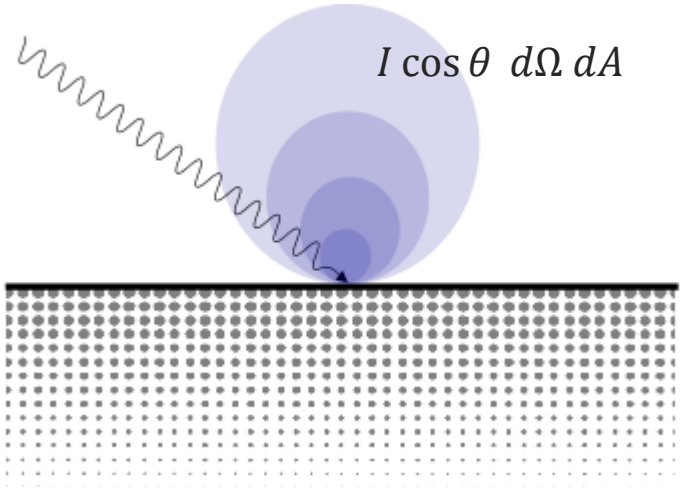
2000× zoom in radial direction

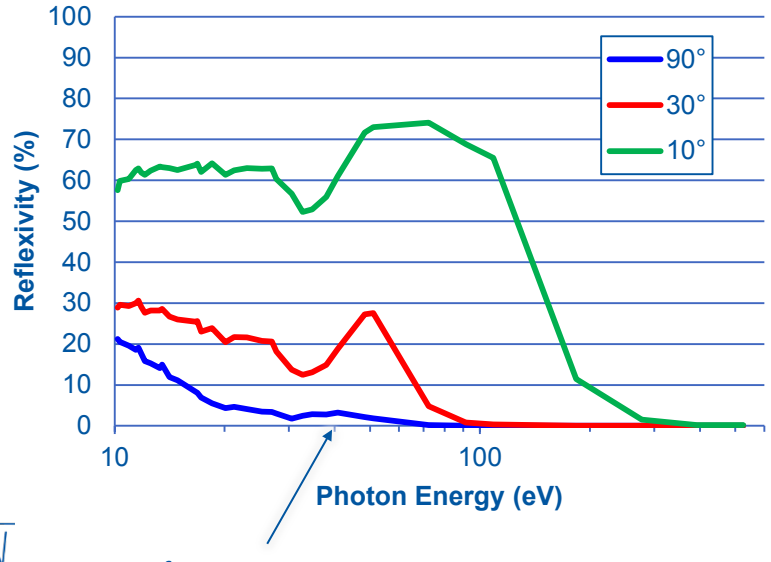
ATLAS - detail



Materials: NEG Coating

- Warm chambers in LSS
- Absolute diffuser assumption
- 20% reflectivity

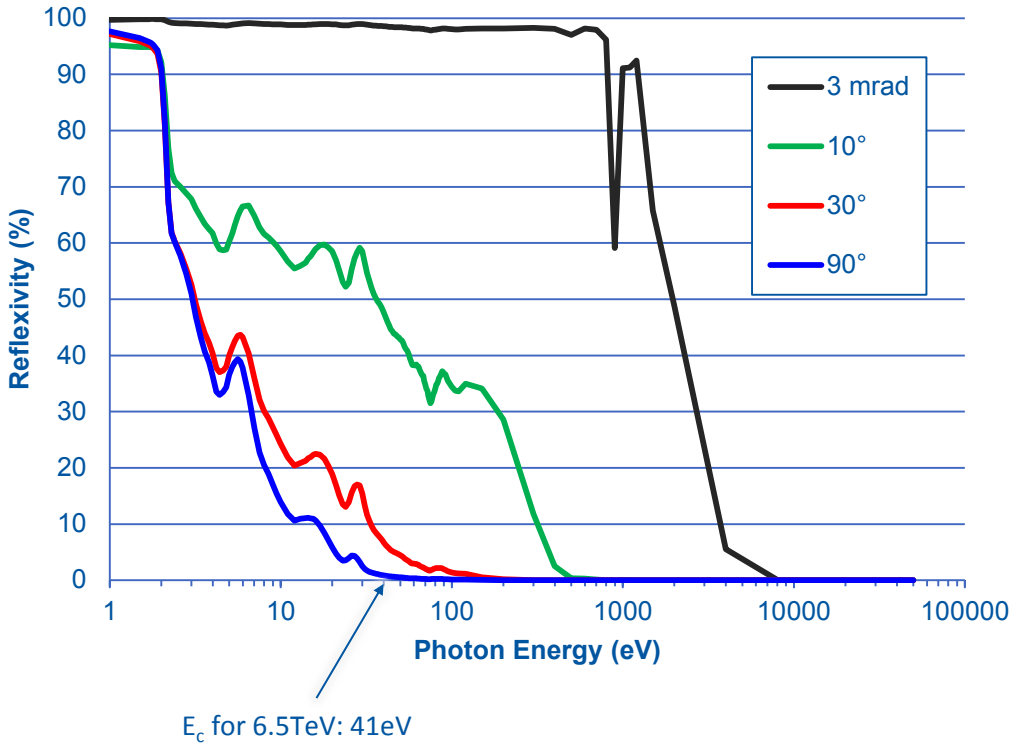




- NO ECLOUD (SEY<1.1 if activated)

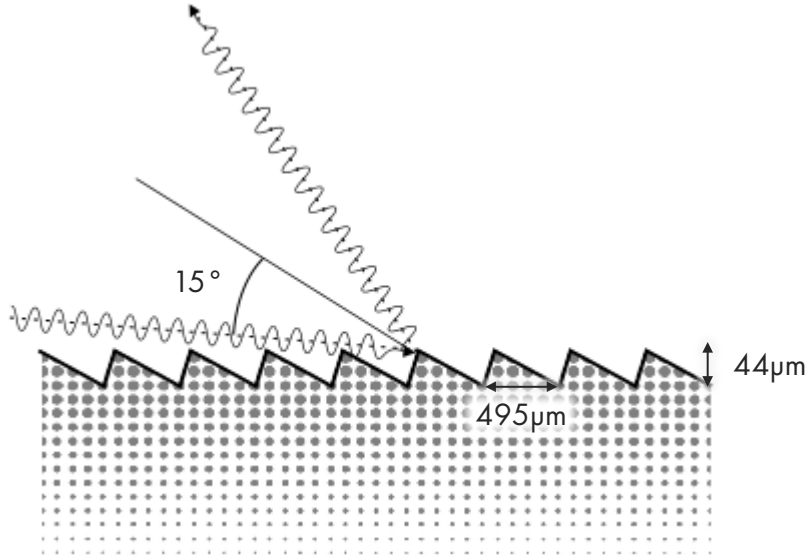
Materials: Copper

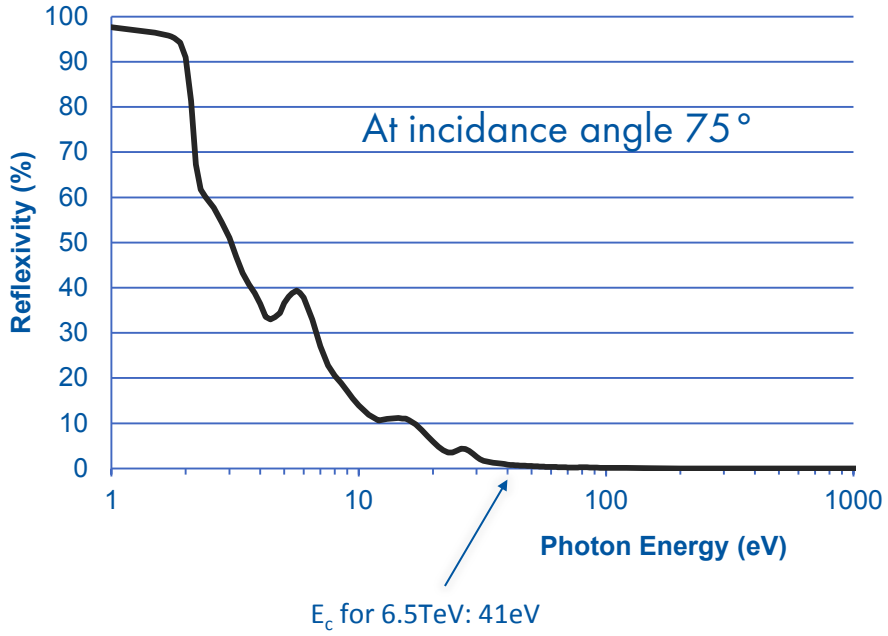
- High reflexivity for low angles of incidence
- Incidence angle 3.8 mrad in arcs
- 98.1% Reflexivity for synchrotron radiation of main dipoles at 3.8mrad



Materials: Copper Saw-Teeth

- 75° incidence angle due to sawtooth-like surface





- Aproximation with 100% photon absorption
- Reality: 7.6% reflection of the first hit

- Overview of simulation
- Geometry of LHC and materials
- **Synchrotron radiation**
- Electron cloud effect
- Dynamical vacuum

SynRad simulation: Overview

Materials:

- NEG coating – avarage data for Ti and V low energy reflection
- Cu low energy reflection
- Saw teeth –total absorption

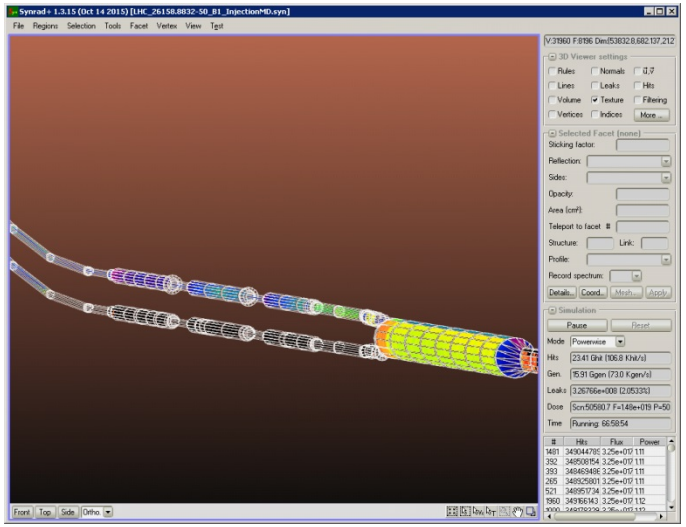
Magnets & optics:

- Two optical setups – after ramp up of energy, during collisions
- All dipoles and quadrupoles
- Energy 6 500 GeV
- 2 808 bunches with 1.2×10^{11} particles

$$P \propto E^4 I$$

Simulation setting:

- Experimental point ±500 m
- Texture precision: 0.05 m
- Curved part facet lenght: 0.1 m

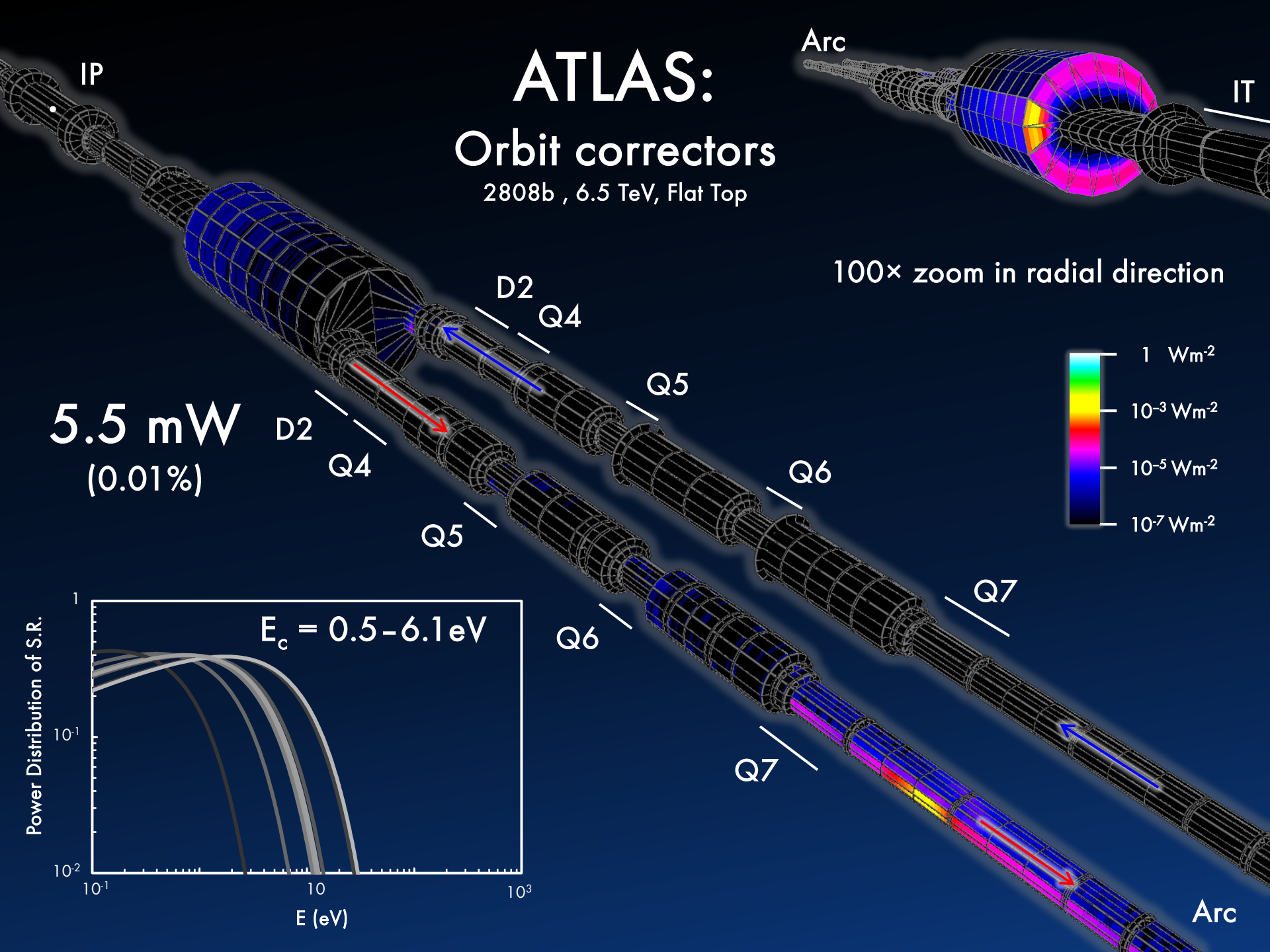


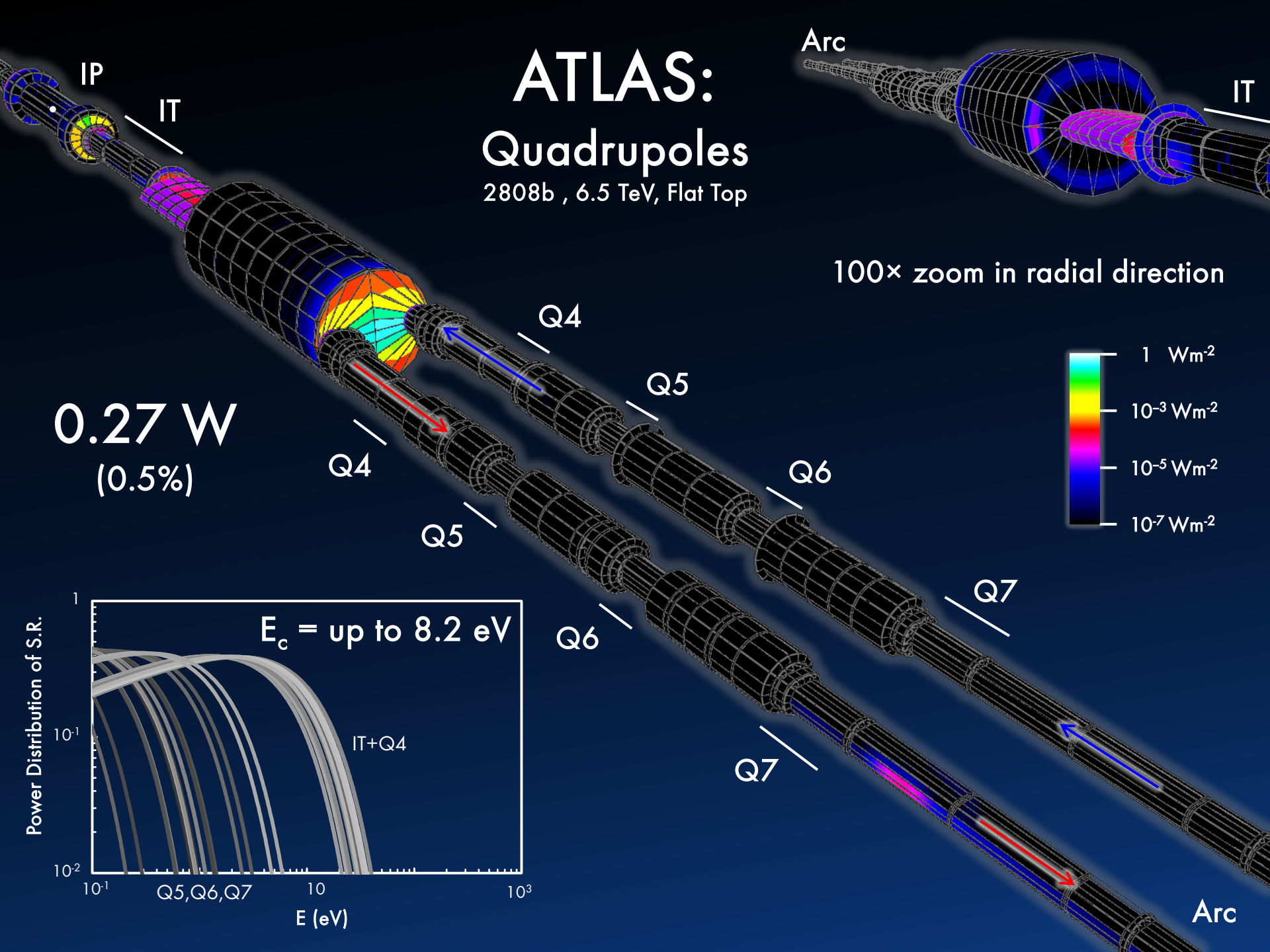
Example of simulation in SynRad

ATLAS:

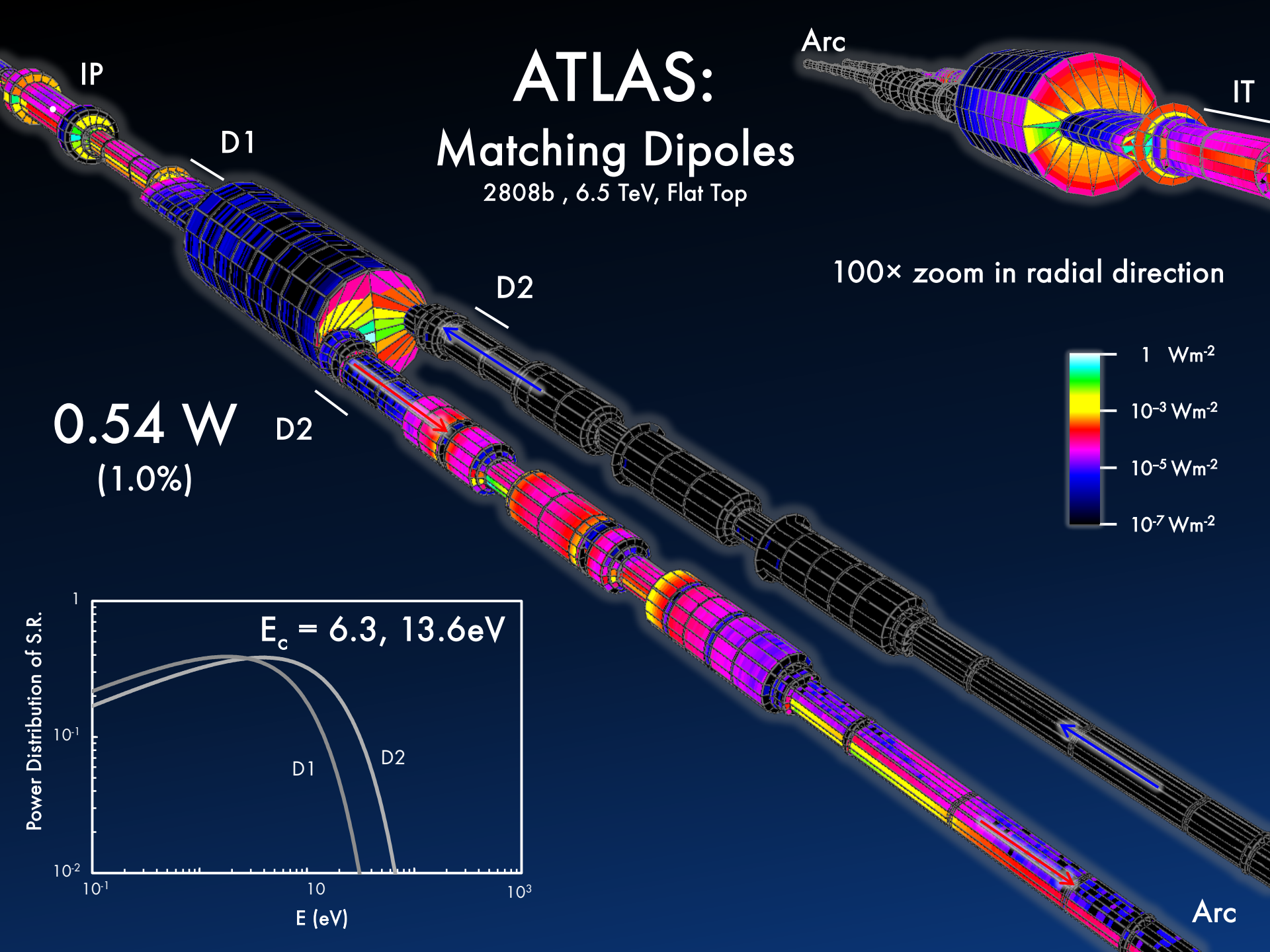
Orbit correctors

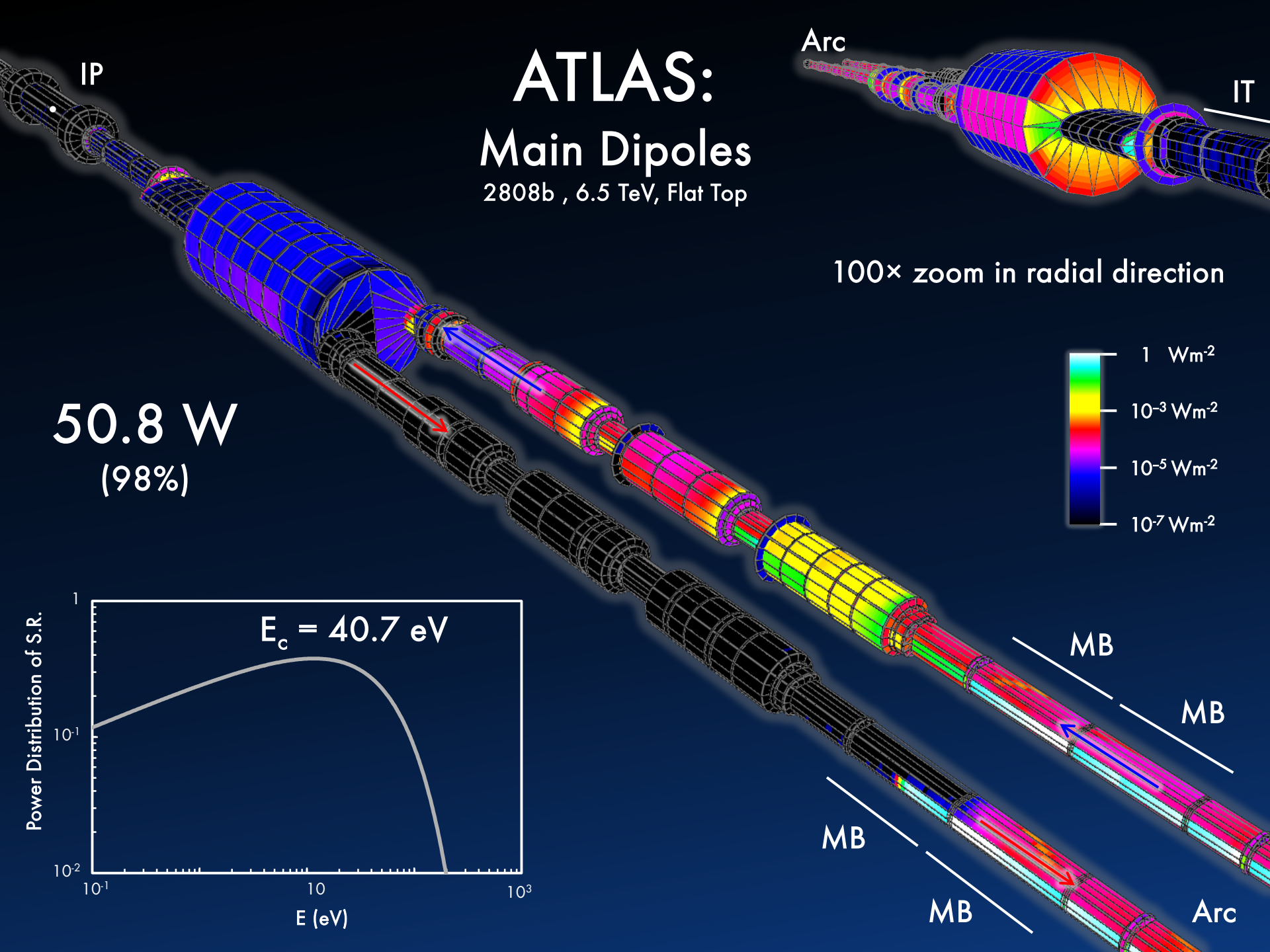
2808b , 6.5 TeV, Flat Top

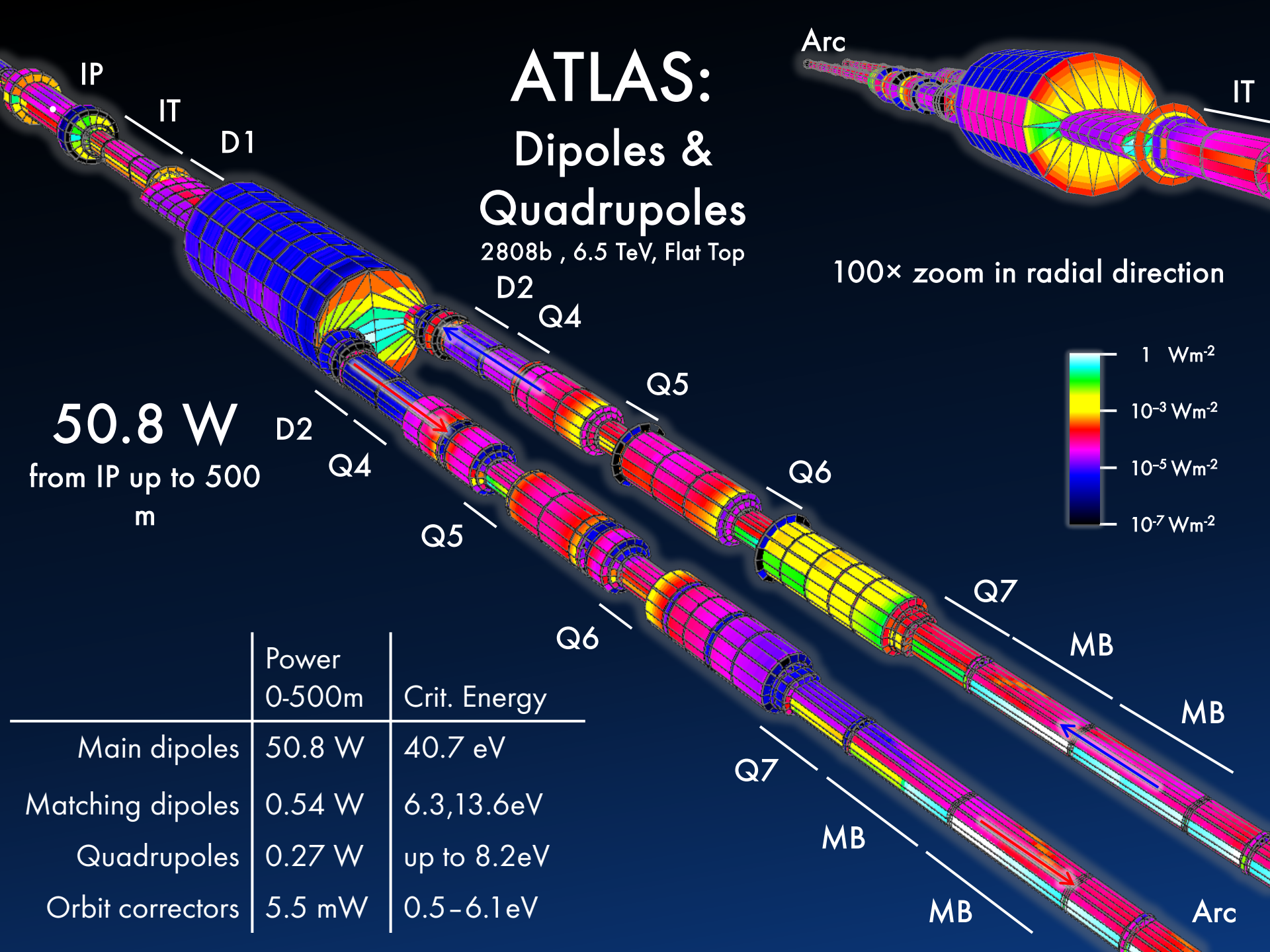



ATLAS:
Quadrupoles
2808b , 6.5 TeV, Flat Top
IP
IT
Arc
IT
100× zoom in radial direction
1 Wm-2
10-3 Wm-2
10-5 Wm-2
10-7 Wm-2
0.27 W
(0.5%)
Q4
Q5
Q6
Q7
Q4
Q5
Q6
Q7
Arc
Ec = up to 8.2 eV
IT+Q4
Q5,Q6,Q7
Power Distribution of S.R.
E (eV)
1
10-1
10-2
10-1
10
103

ATLAS:
Matching Dipoles
2808b , 6.5 TeV, Flat Top



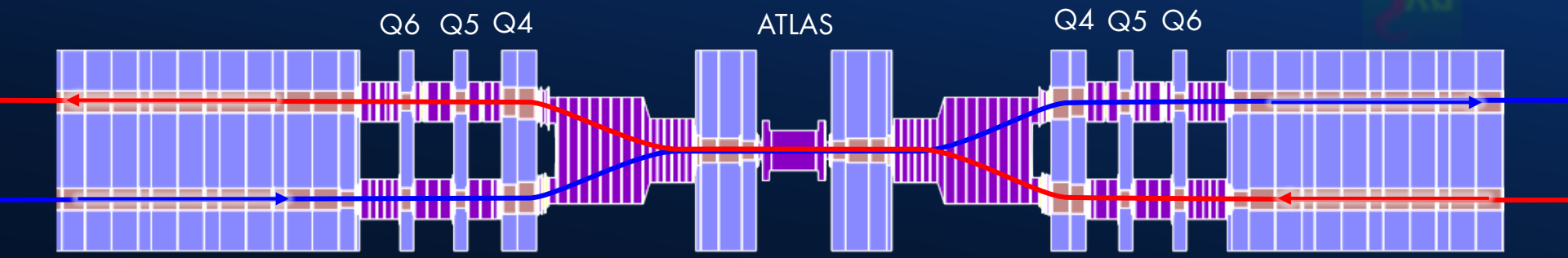

ATLAS:
Main Dipoles
2808b , 6.5 TeV, Flat Top
IP
Arc
IT
100× zoom in radial direction
1 Wm-2
10-3 Wm-2
10-5 Wm-2
10-7 Wm-2
50.8 W
(98%)
MB
MB
MB
MB
Arc
Ec = 40.7 eV
Power Distribution of S.R.
1
10-1
10-2
10-1
10
103
E (eV)

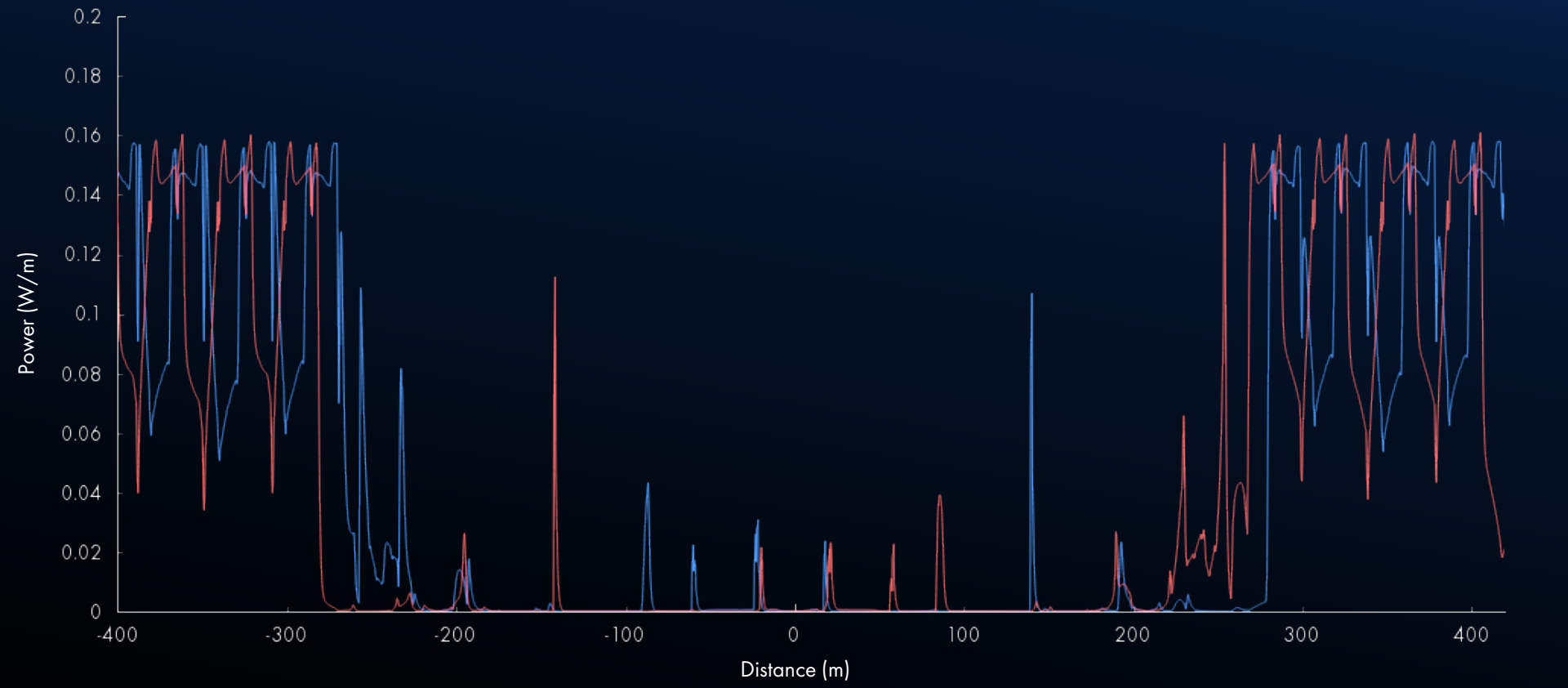


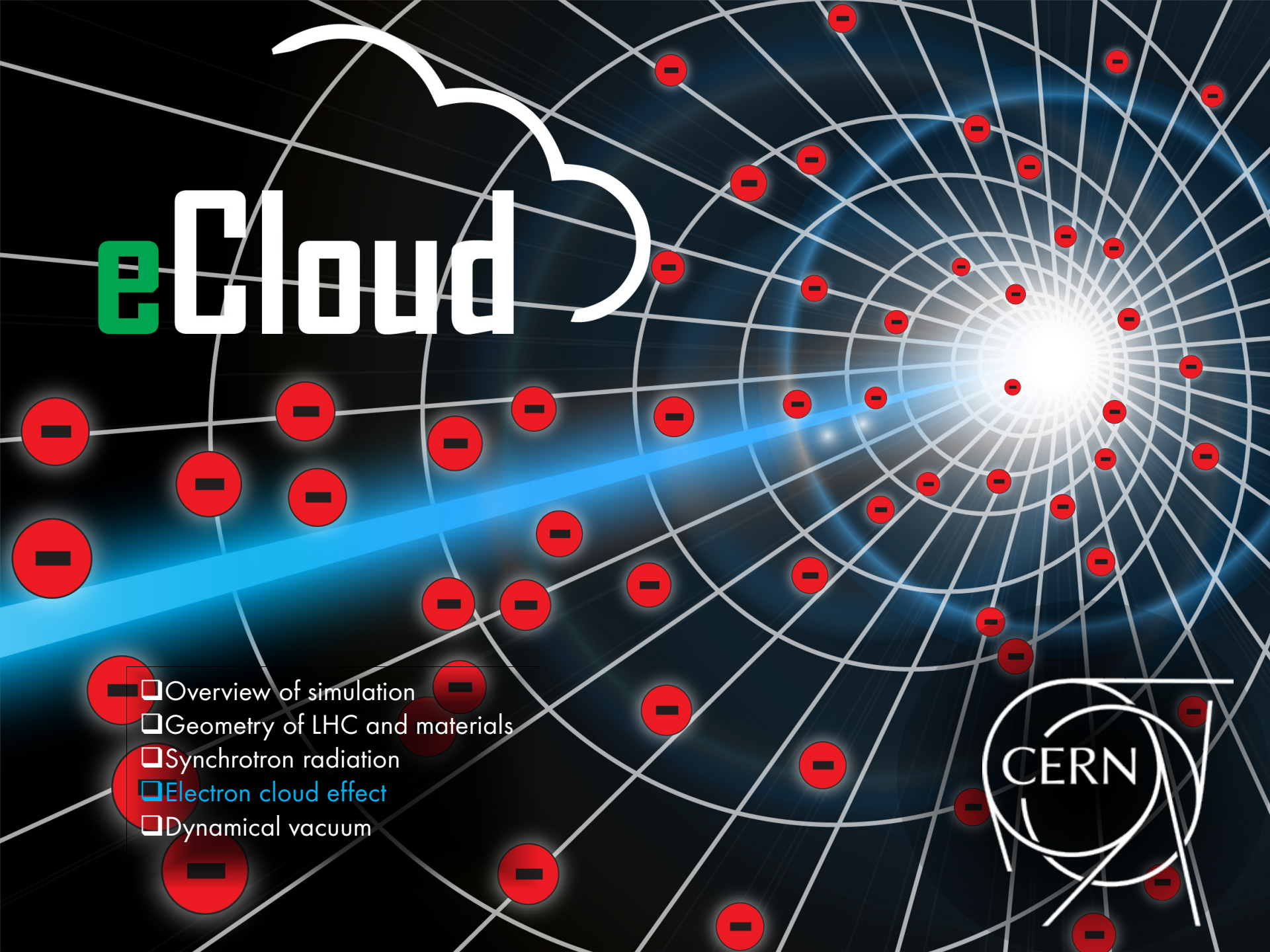
	Power 0-500m	Crit. Energy
Main dipoles	50.8 W	40.7 eV
Matching dipoles	0.54 W	6.3,13.6eV
Quadrupoles	0.27 W	up to 8.2eV
Orbit correctors	5.5 mW	0.5–6.1eV

SynRad simulation: Results

2748b , 6.5 TeV, Flat Top






eCloud
Overview of simulation
Geometry of LHC and materials
Synchrotron radiation
Electron cloud effect
Dynamical vacuum
CERN

Electron Cloud Effect

$$L = \frac{1}{2}m(\dot{x}^2 + \dot{y}^2 + \dot{z}^2) - q\dot{z}A_z(x,y) + q\varphi(x,y)$$

Kinetic Energy — Magnetic Field — Beam acceleration

Constant of the motion:

$$p_z = \frac{\partial L}{\partial \dot{z}} = m\dot{z} - qA_z(x,y)$$

Without field:

$$\dot{z} = const$$

Dipole:

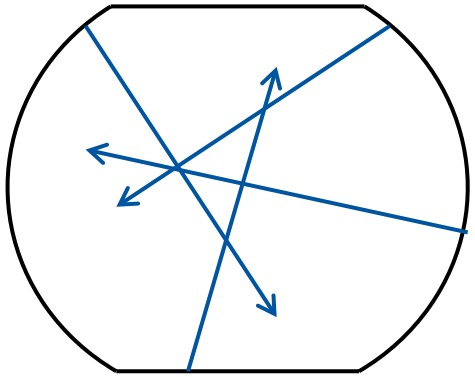
$$m\dot{z} - qBx = const$$

Quadrupole:

$$m\dot{z} - qK(x^2 - y^2) = const$$

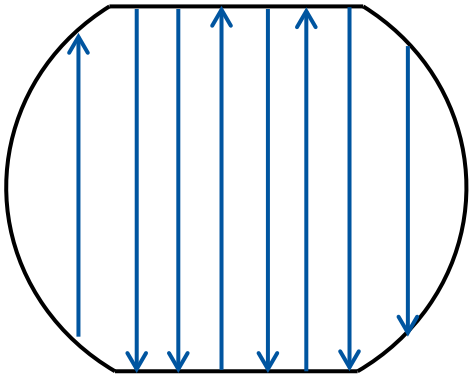
ECLOUD: Trajectories

Without field:



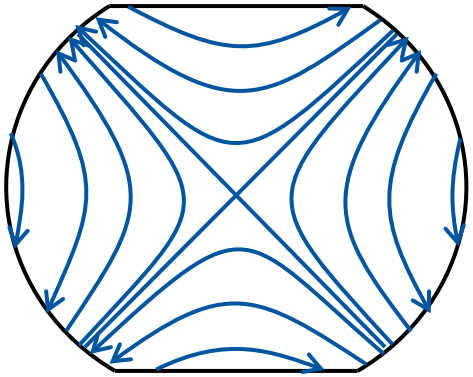
$\dot{z} = const$

Dipole:



$m\dot{z} - qBx = const$

Quadrupole:



$m\dot{z} - qK(x^2 - y^2) = const$

Accelerating field does not change axis of the curve around which electron oscilate!

ECLOUD: Effect of Magnetic Field

Period of oscilations:

$$\mathrm{T} = \frac{2\pi m}{qB}$$

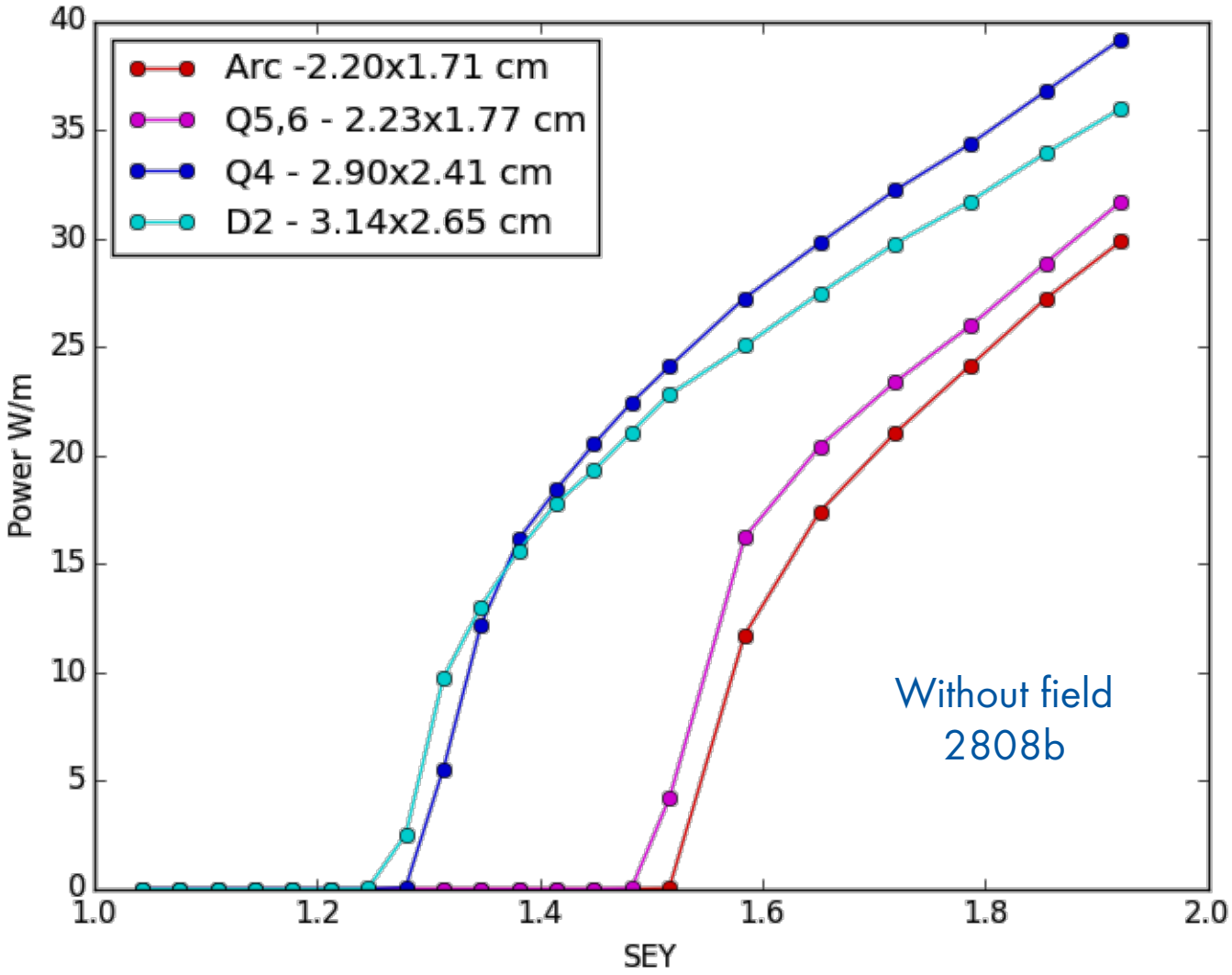
If $T \ll \tau_{beam}$ (1ns) accelerating only in the direction of the field lines

- true for main LHC dipoles and D1, D2 as well

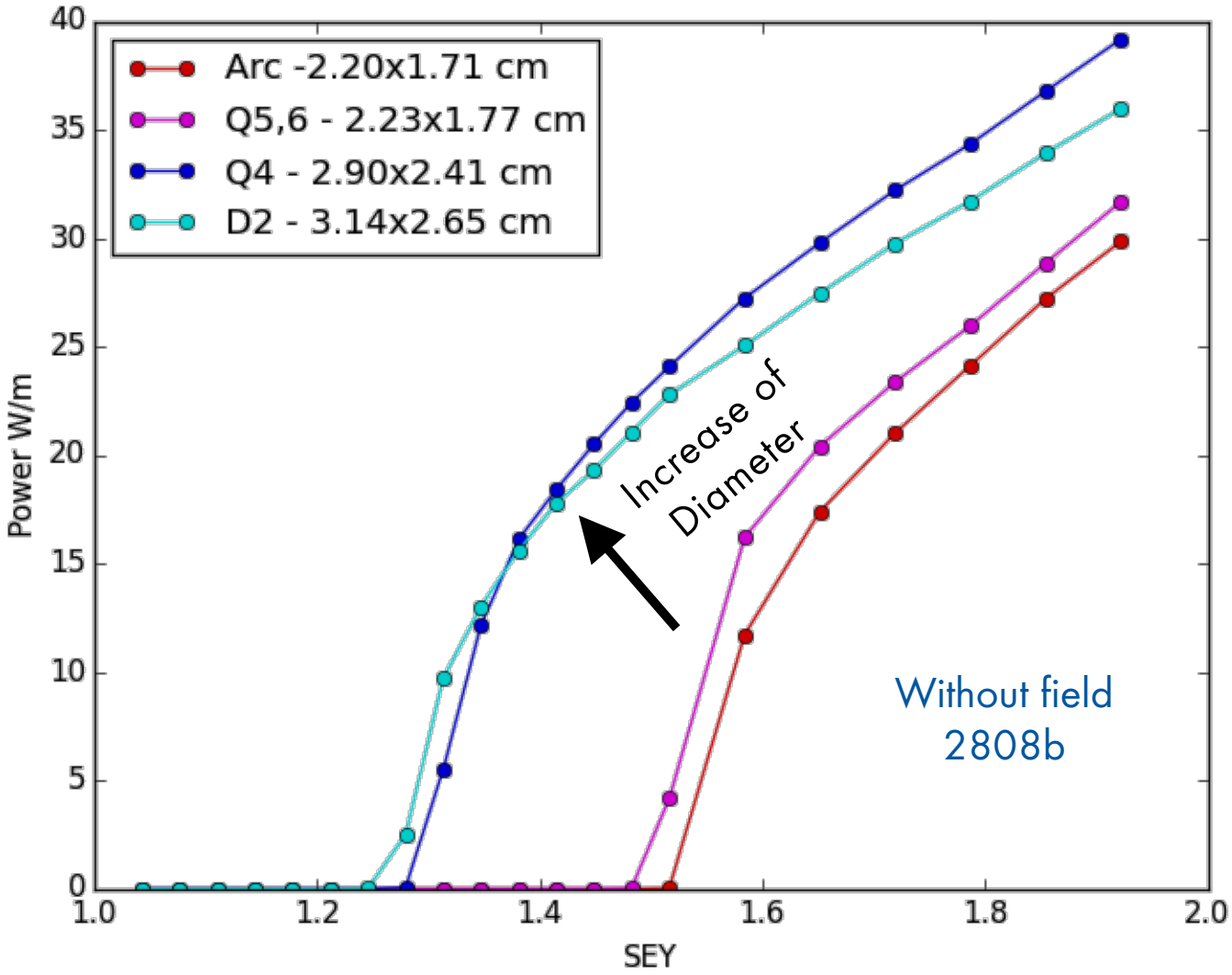
If it is comparable (B≈20mT) the transverse spiral motion of electron is boosted

- Some orbit correctors in LHC, Area in Quadrupoles close to optical axis

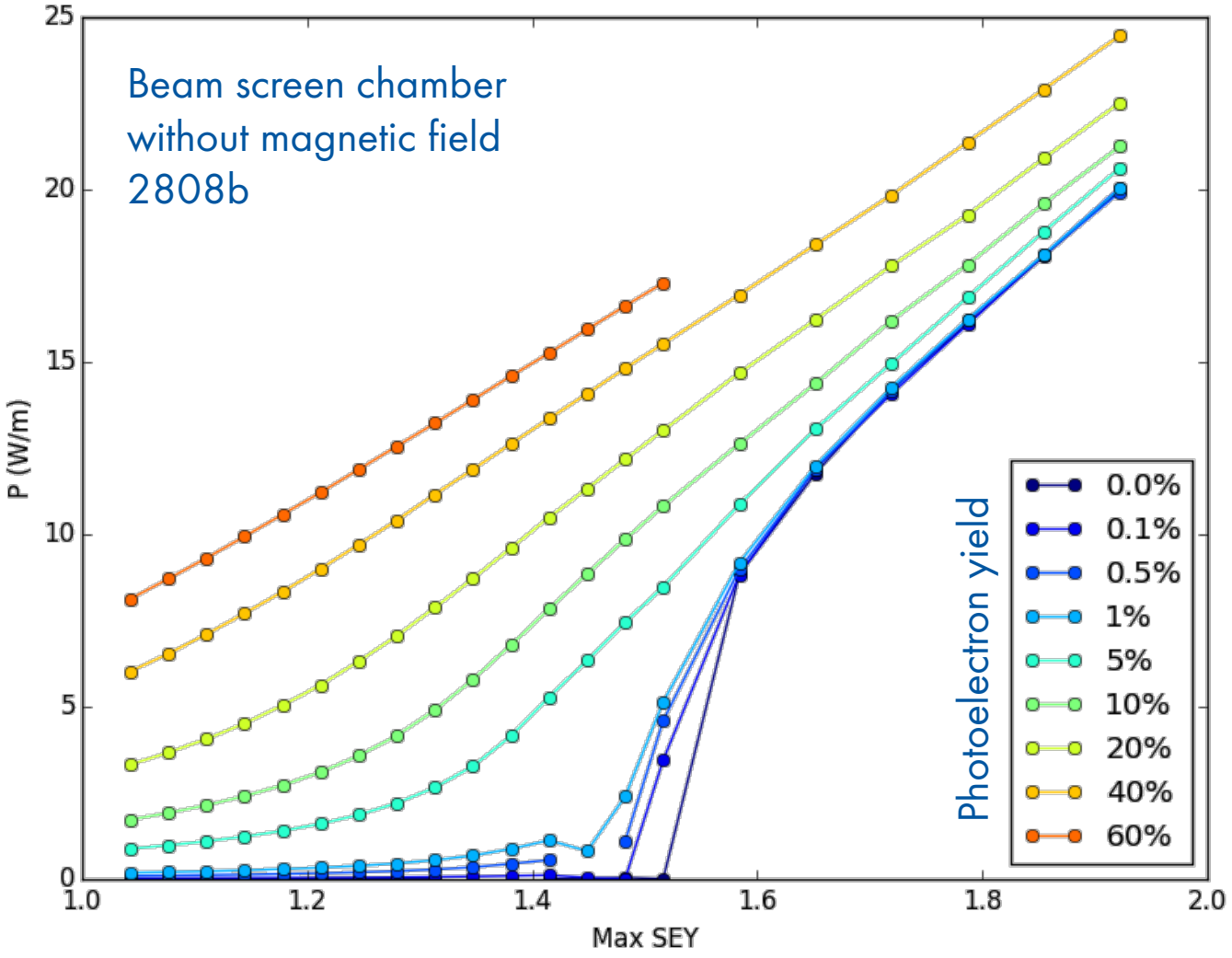
ECLOUD: Effect of Chamber Diameter



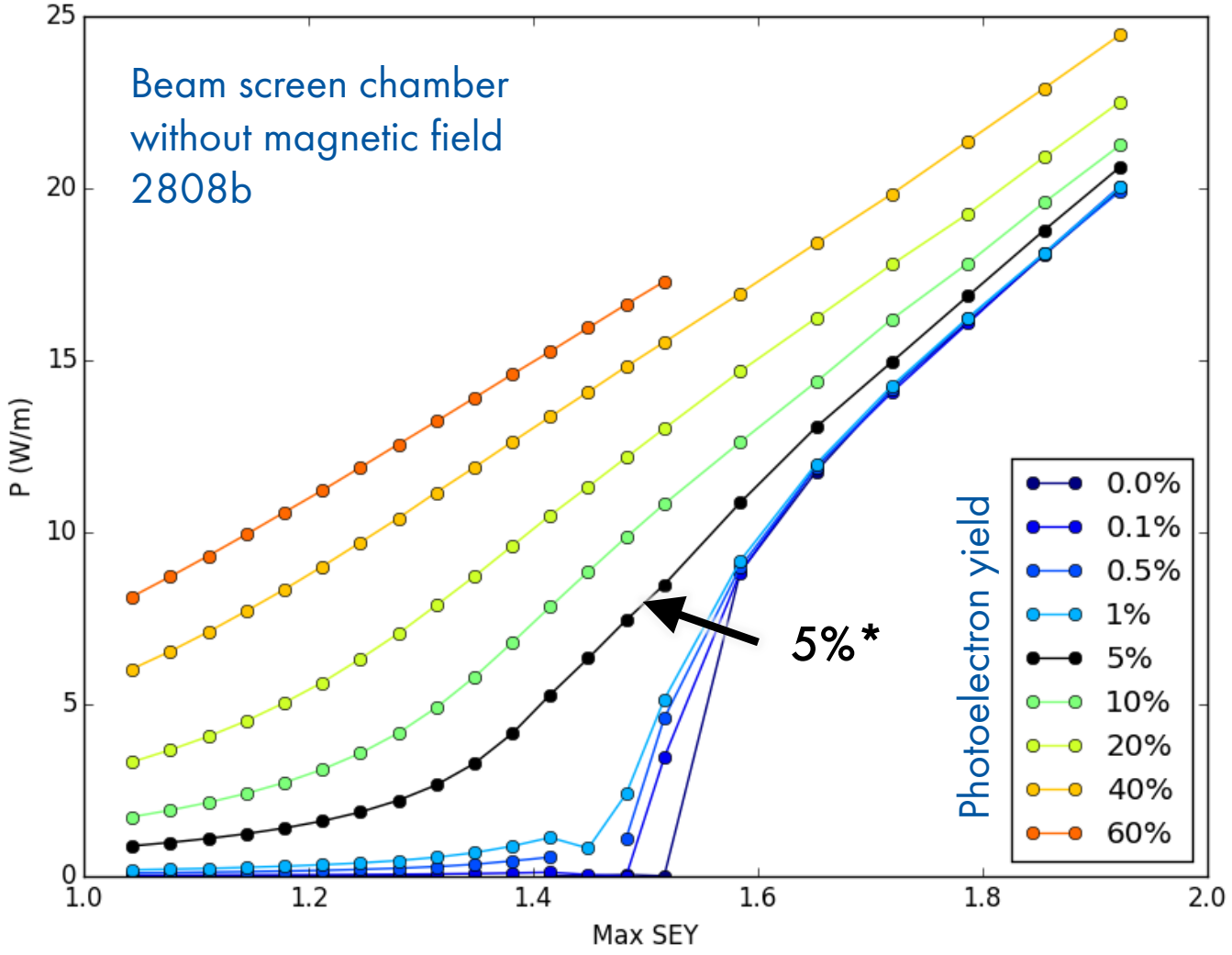
ECLOUD: Effect of Chamber Diameter



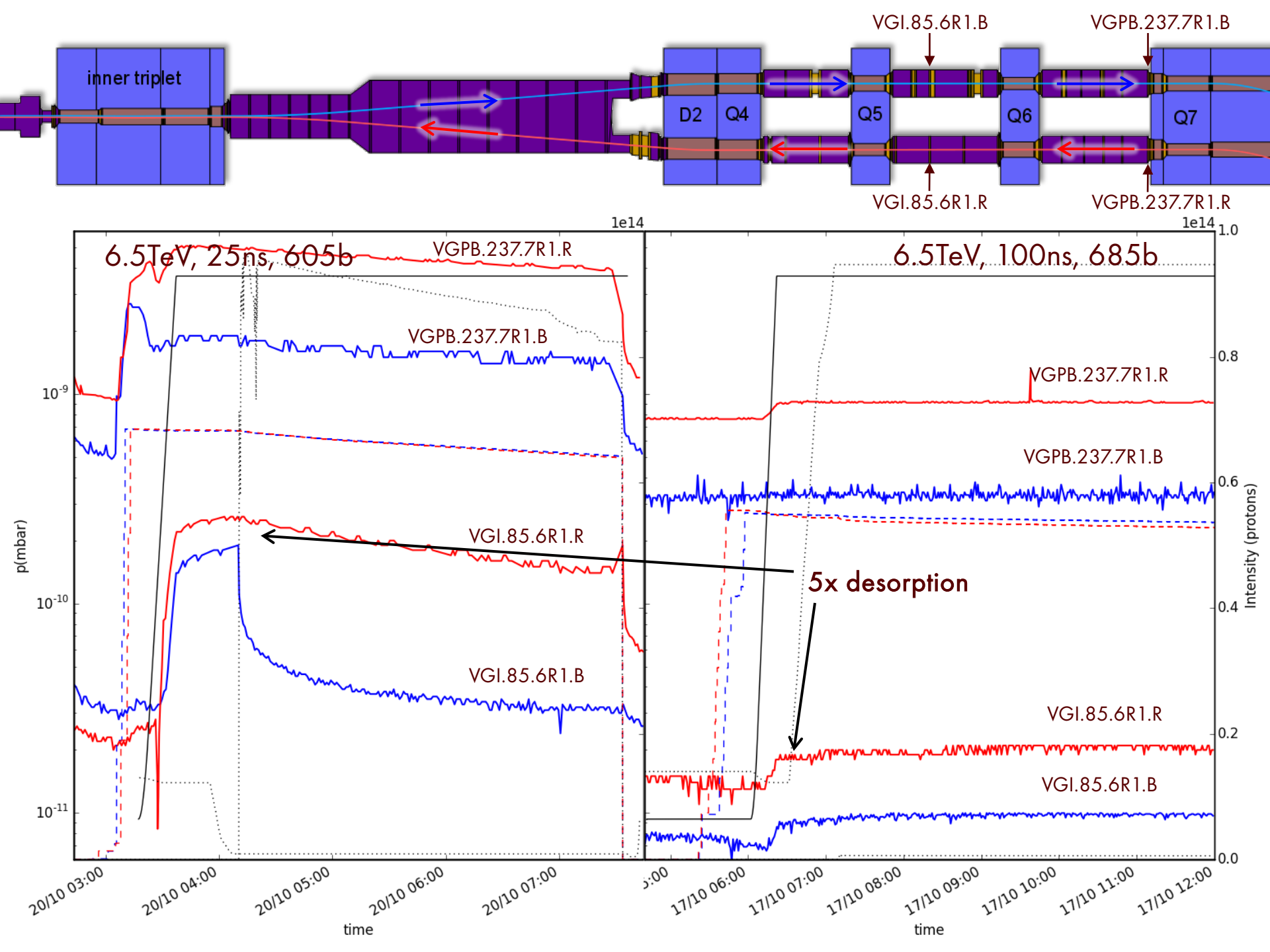
ECLOUD: Boost by Syn. Radiation



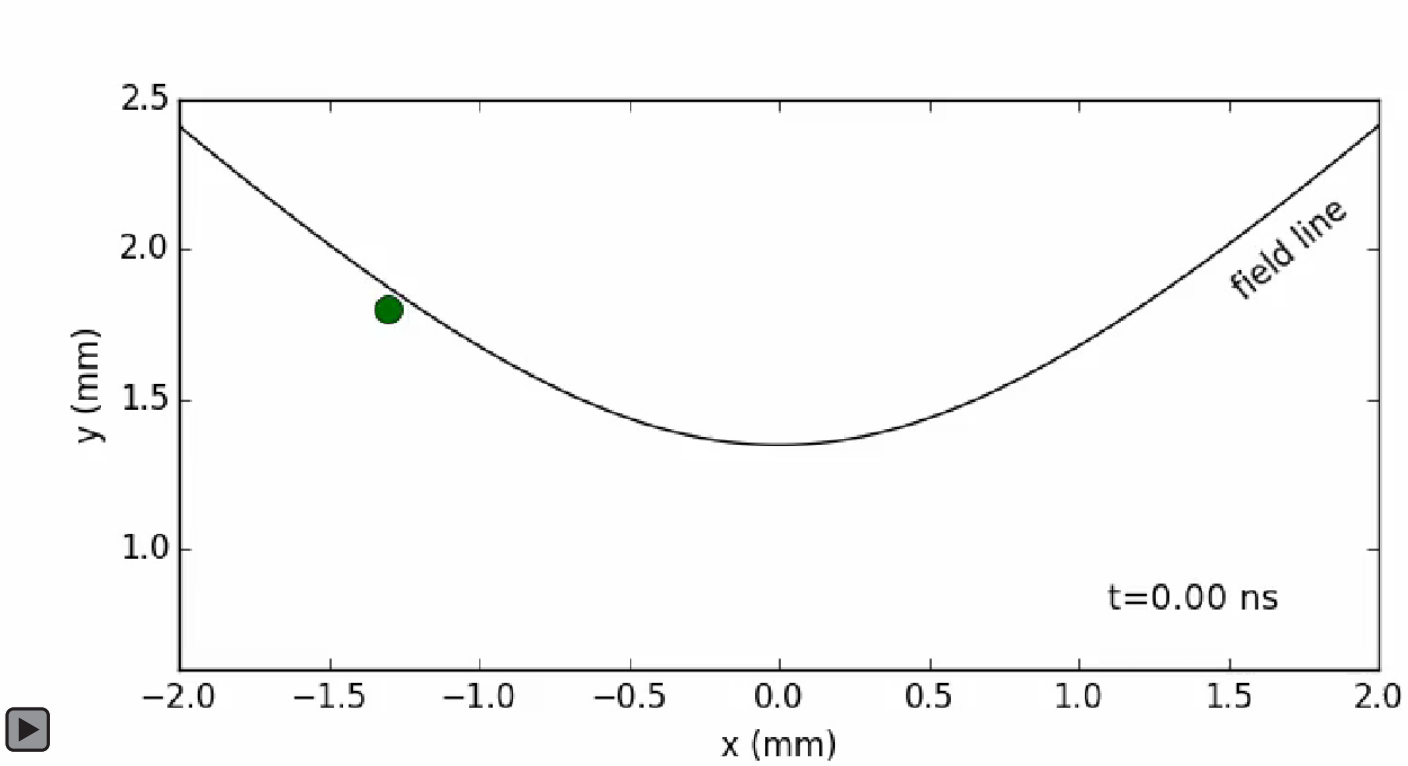
ECLOUD: Boost by Syn. Radiation



*V. Baglin

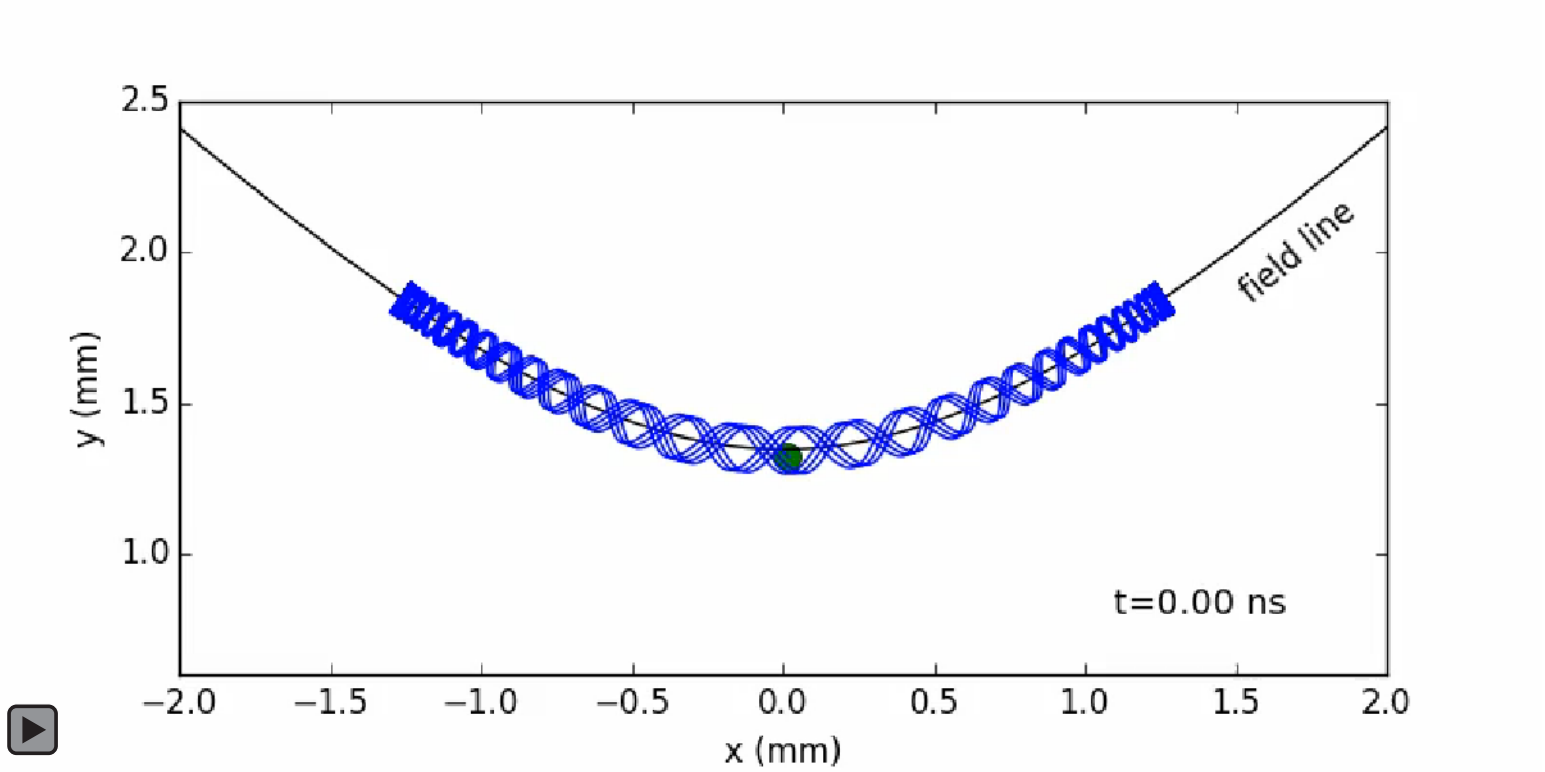

inner triplet
D2
Q4
Q5
Q6
Q7
VGI.85.6R1.B
VGPB.237.7R1.B
VGI.85.6R1.R
VGPB.237.7R1.R
6.5TeV, 25ns, 605b
6.5TeV, 100ns, 685b
1e14
1e14
VGPB.237.7R1.R
VGPB.237.7R1.B
VGI.85.6R1.R
VGI.85.6R1.B
5x desorption
p(mbar)
Intensity (protons)
time
time
20/10 03:00
20/10 04:00
20/10 05:00
20/10 06:00
20/10 07:00
17/10 06:00
17/10 07:00
17/10 08:00
17/10 09:00
17/10 10:00
17/10 11:00
17/10 12:00

ECLOUD: Trapping effect



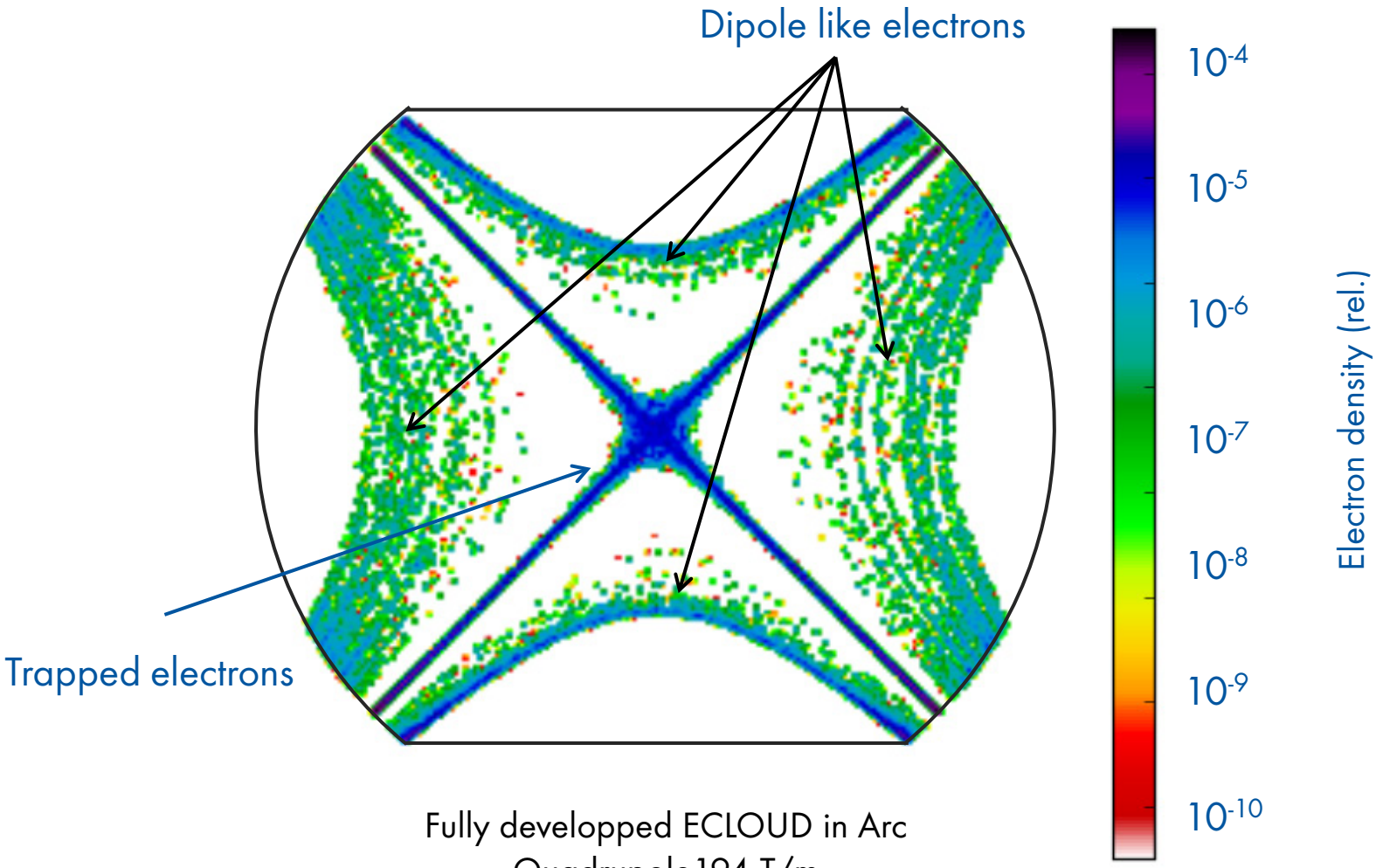
Quadrupole Field 40 T/m, Energy of electron 10 eV

ECLOUD: Trapping effect

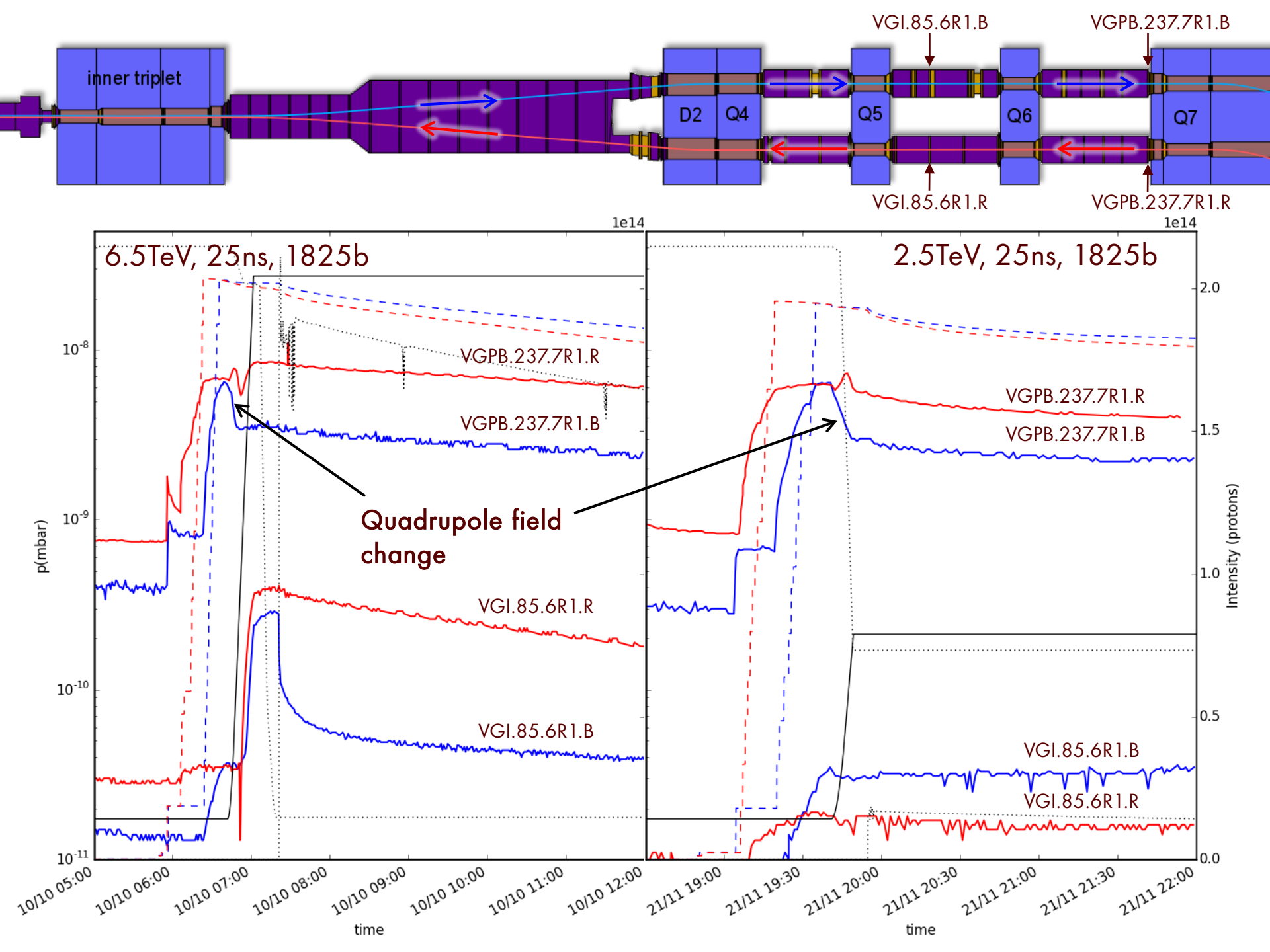


Quadrupole Field 40 T/m, Energy of electron 110 eV

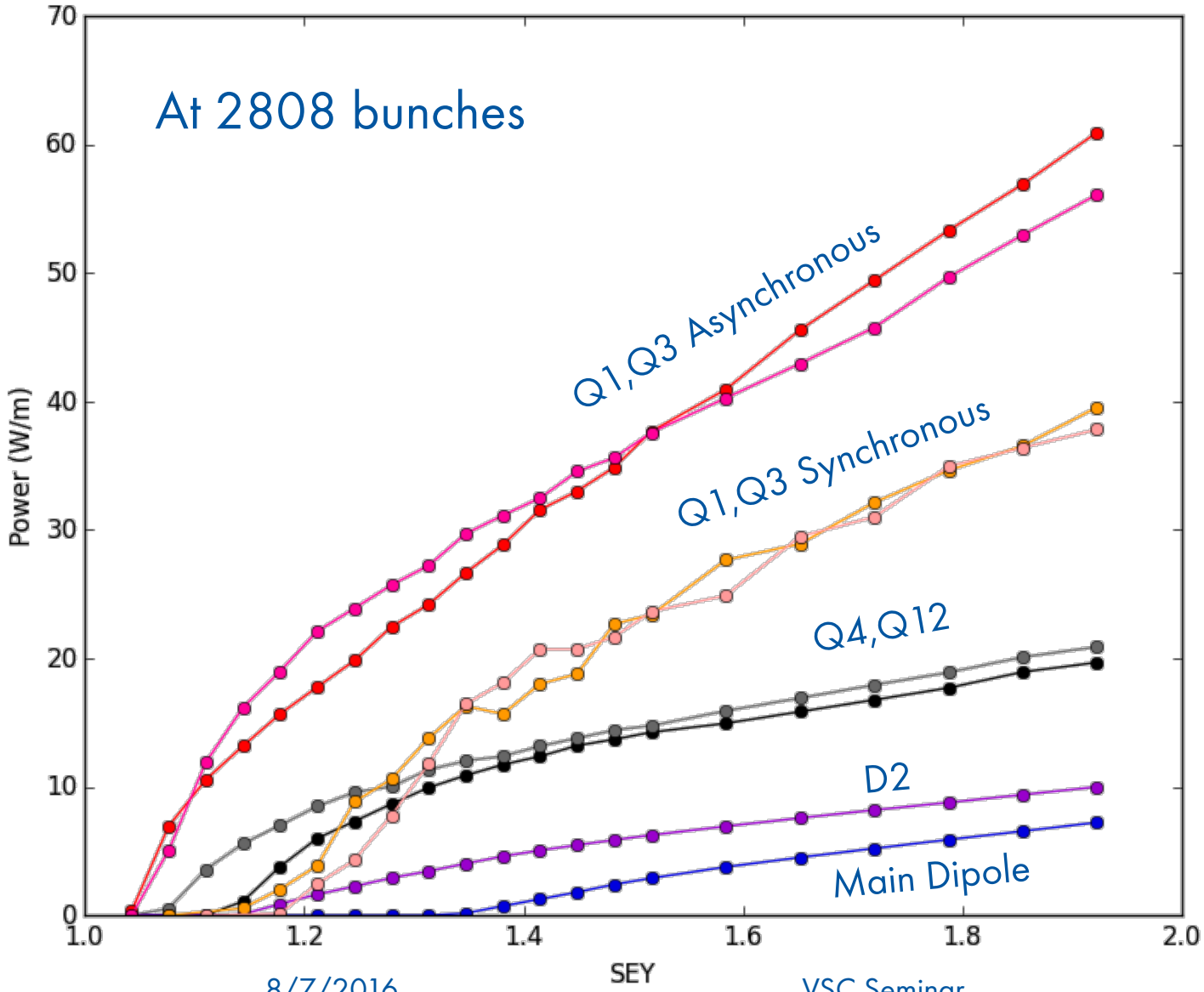
ECLOUD: Trapping effect



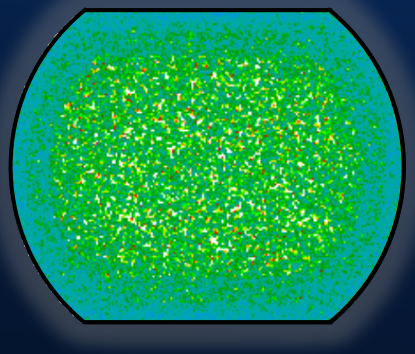
Fully developped ECLOUD in Arc Quadrupole194 T/m


VGI.85.6R1.B
VGPB.237.7R1.B
inner triplet
D2
Q4
Q5
Q6
Q7
VGI.85.6R1.R
VGPB.237.7R1.R
6.5TeV, 25ns, 1825b
2.5TeV, 25ns, 1825b
1e14
1e14
VGPB.237.7R1.R
VGPB.237.7R1.B
VGI.85.6R1.R
VGI.85.6R1.B
Quadrupole field change
p(mbar)
Intensity (protons)
time
time
10/10 05:00
10/10 06:00
10/10 07:00
10/10 08:00
10/10 09:00
10/10 10:00
10/10 11:00
10/10 12:00
21/11 19:00
21/11 19:30
21/11 20:00
21/11 20:30
21/11 21:00
21/11 21:30
21/11 22:00

ECLOUD: Magnets



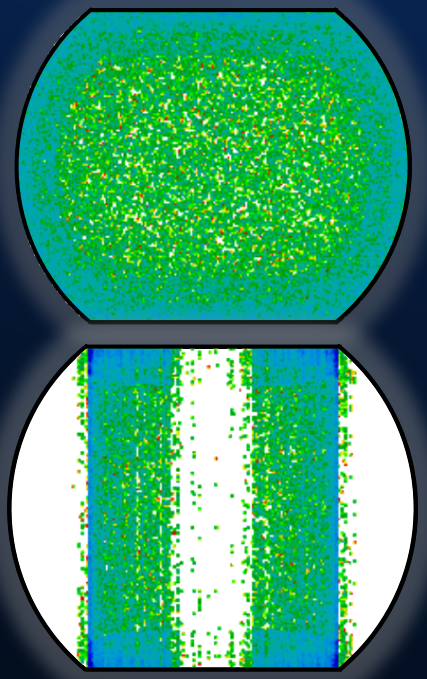
ECLOUD: Summary



Without Field:

- High treshold SEY
- Influenced by synchrotron radiation

ECLOUD: Summary



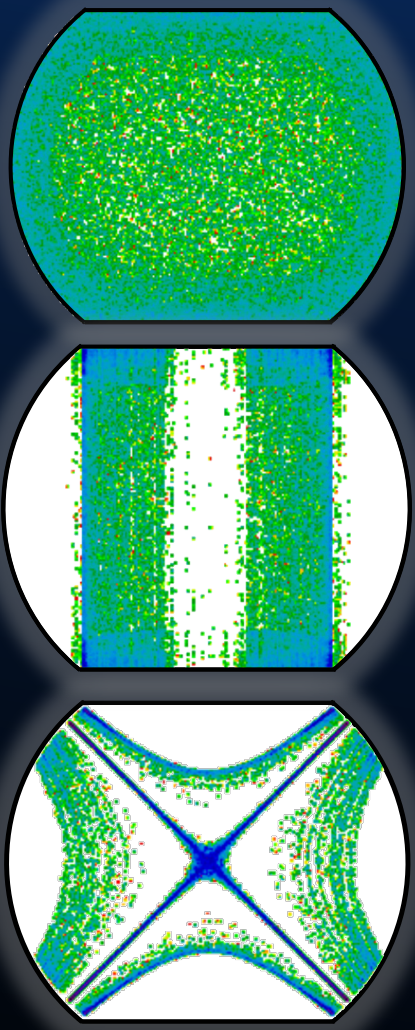
Without Field:

- High treshold SEY
- Influenced by synchrotron radiation

Dipole Field:

- No variation with magnetic field (if B»20mT)
- Main dipoles can be almost totally scrubbed

ECLOUD: Summary



Without Field:

- High treshold SEY
- Influenced by synchrotron radiation

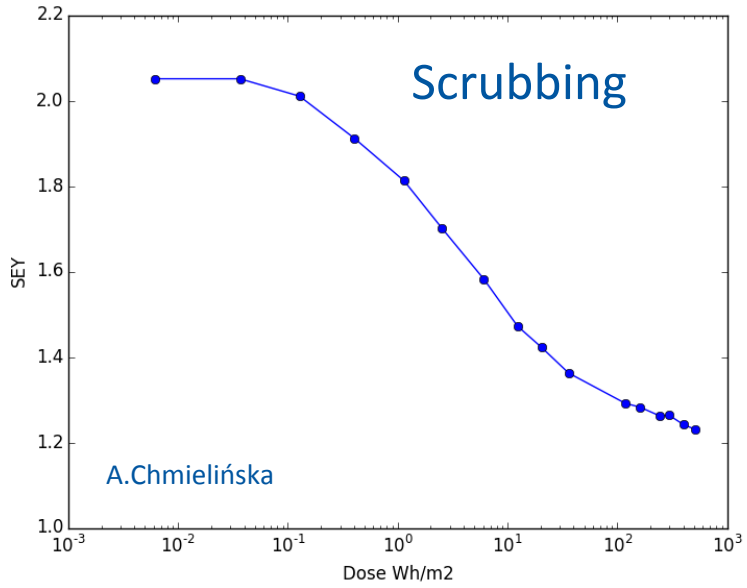
Dipole Field:

- No variation with magnetic field (if B»20mT)
- Main dipoles can be almost totally scrubbed

Quadrupole Field:

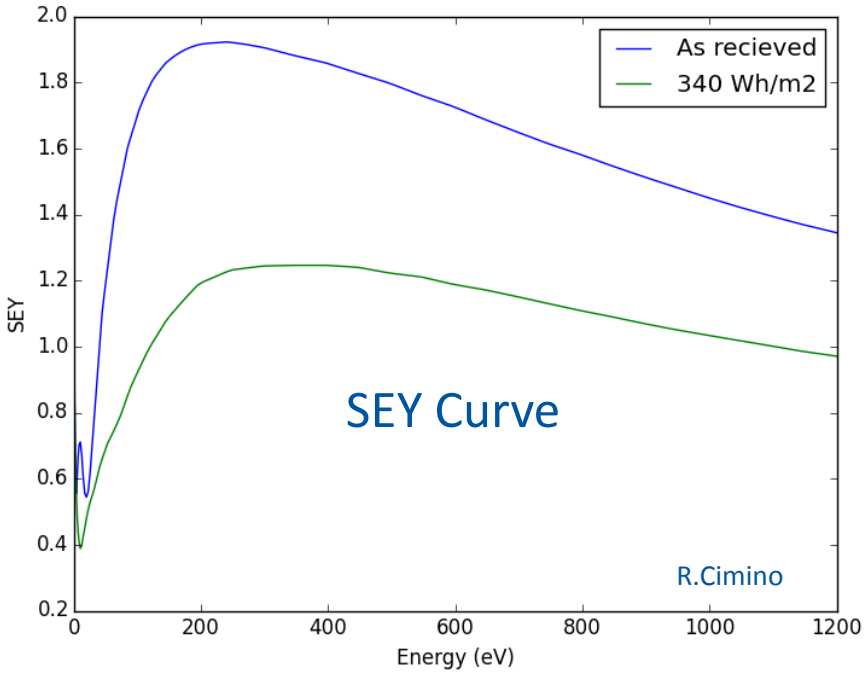
- Slow decay process of ECLOUD
- Trapping effect, area dependent on magnetic field

Materials: Copper - SEY



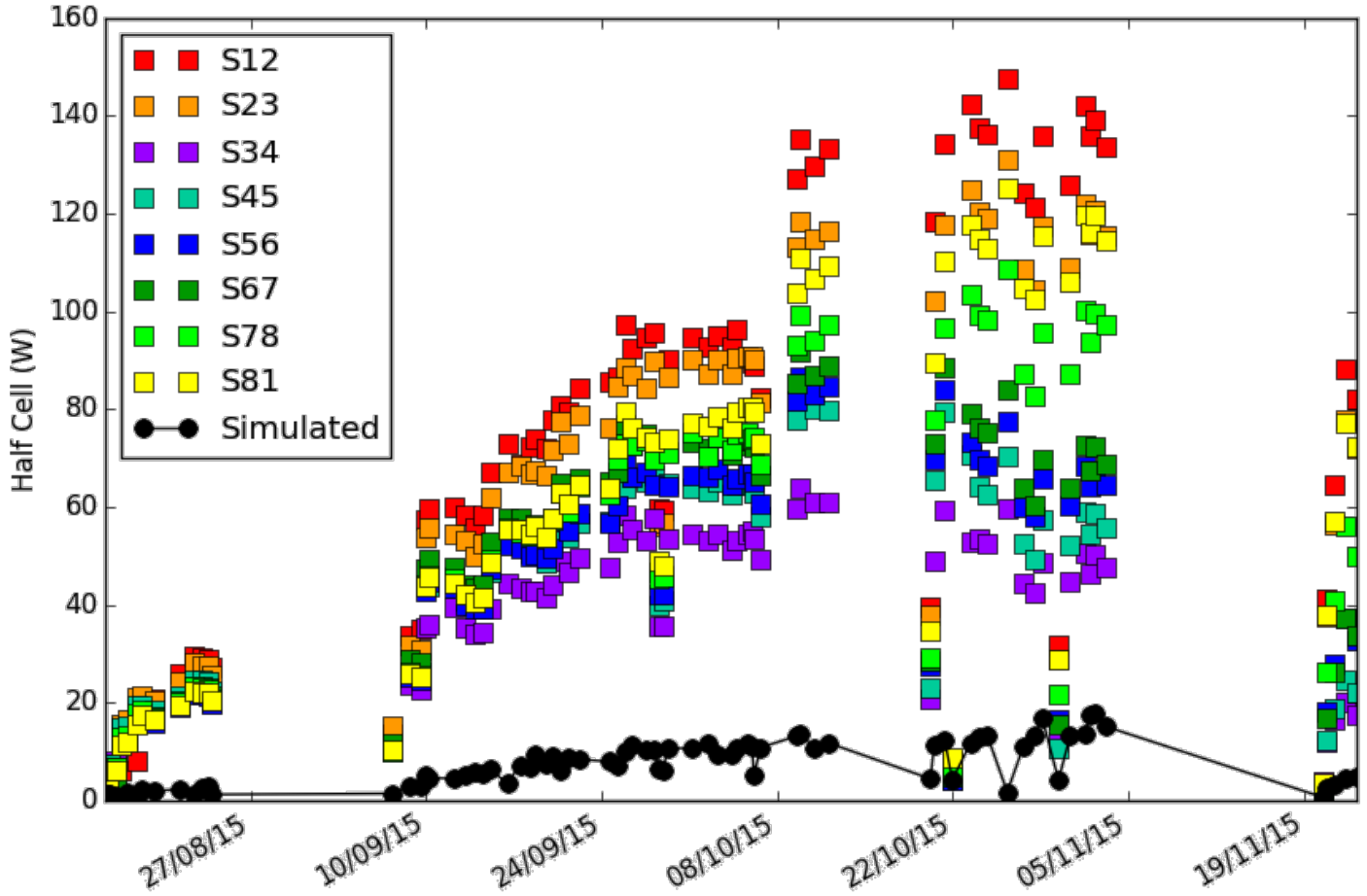
- Max SEY at the begining: 2.05
- Fully Scrubbed: 1.25
  (and possibly more)

- No difference between room temperature and cryo surfaces



HeatLoad in Arcs 2015

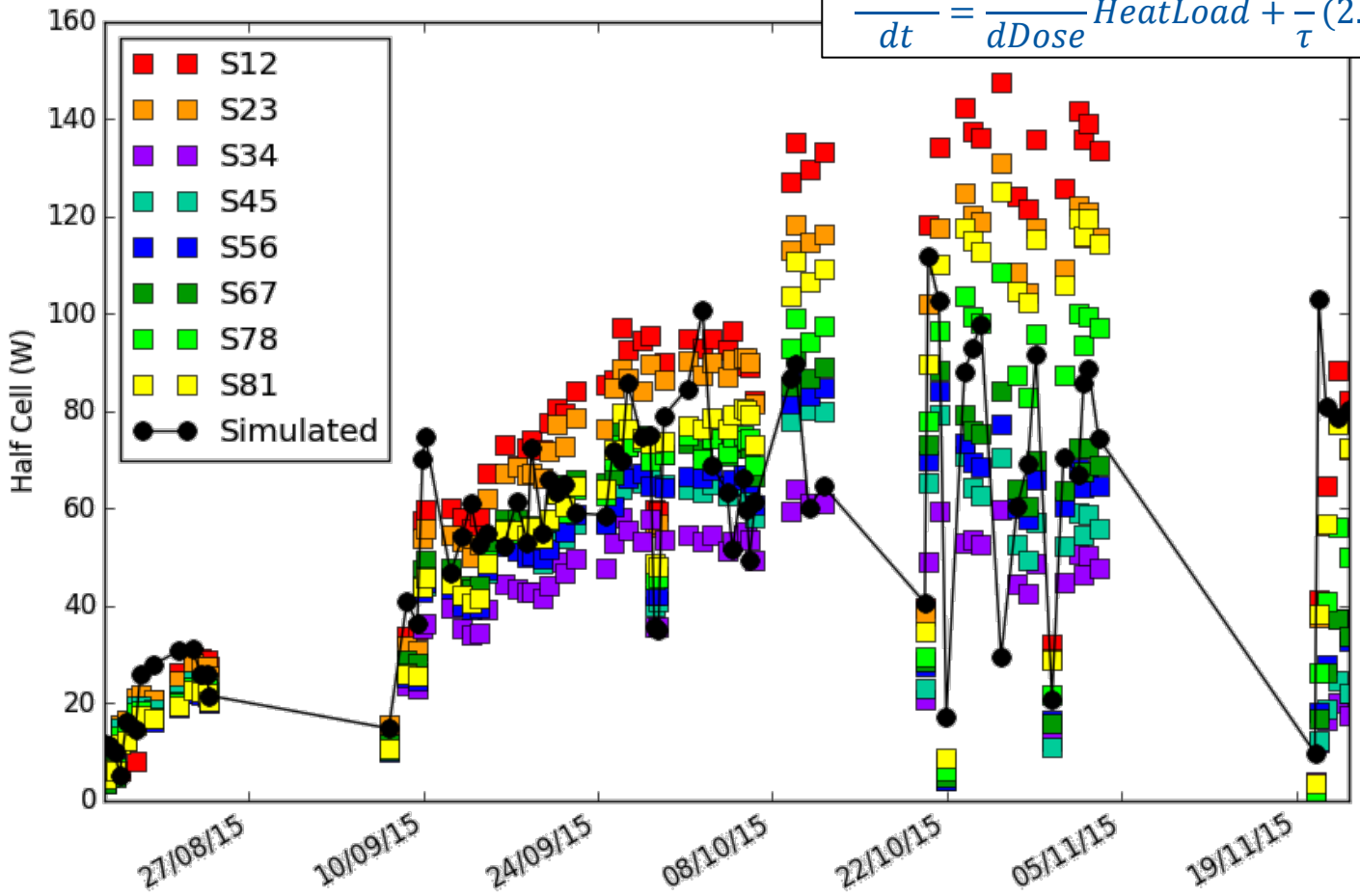
Synchrotron Radiation + Impedance + ECLOUD from Dipoles and Quadrupoles



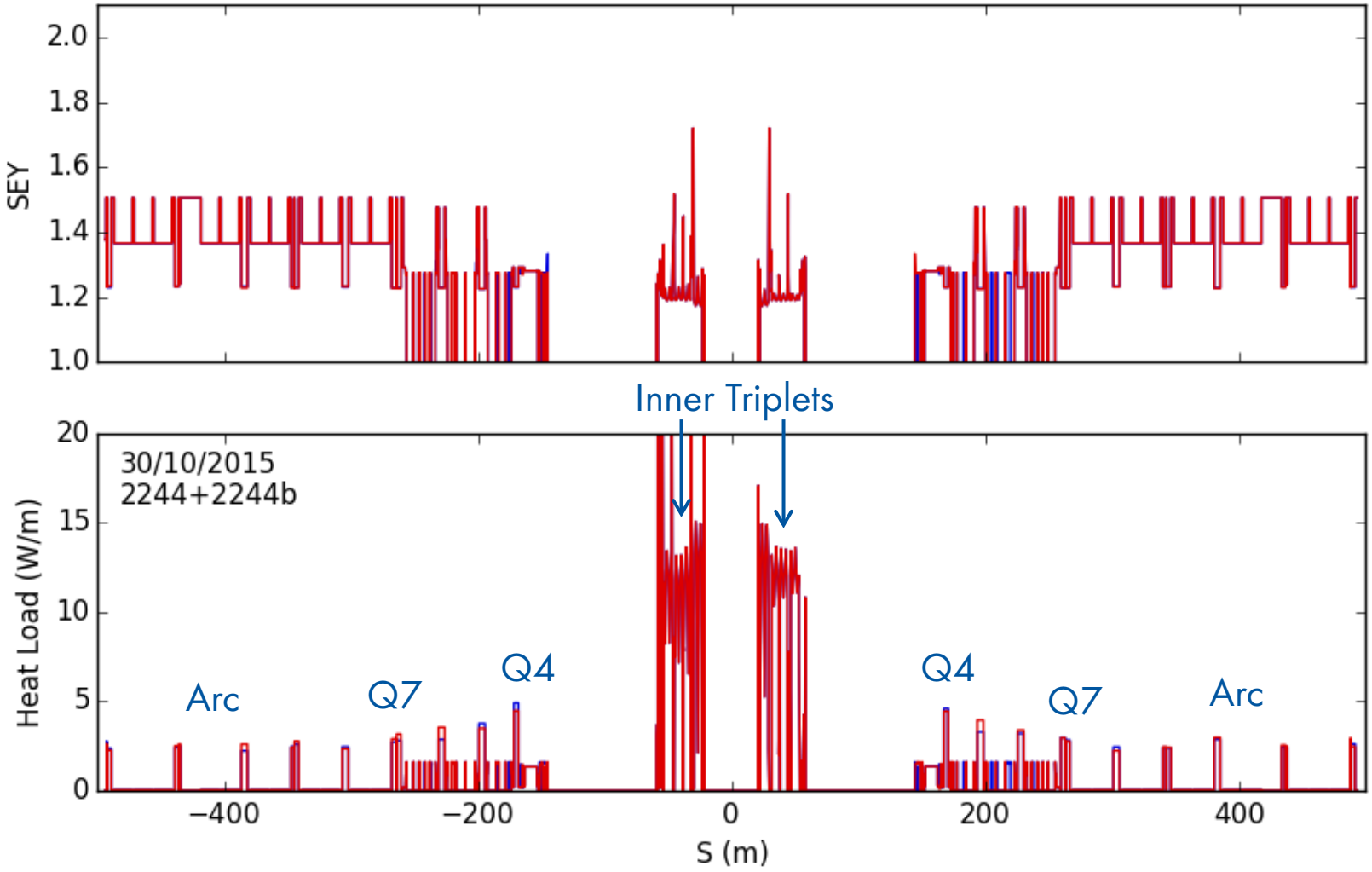
HeatLoad in Arcs 2015

67x slower conditioning + 40 days deconditioning effect

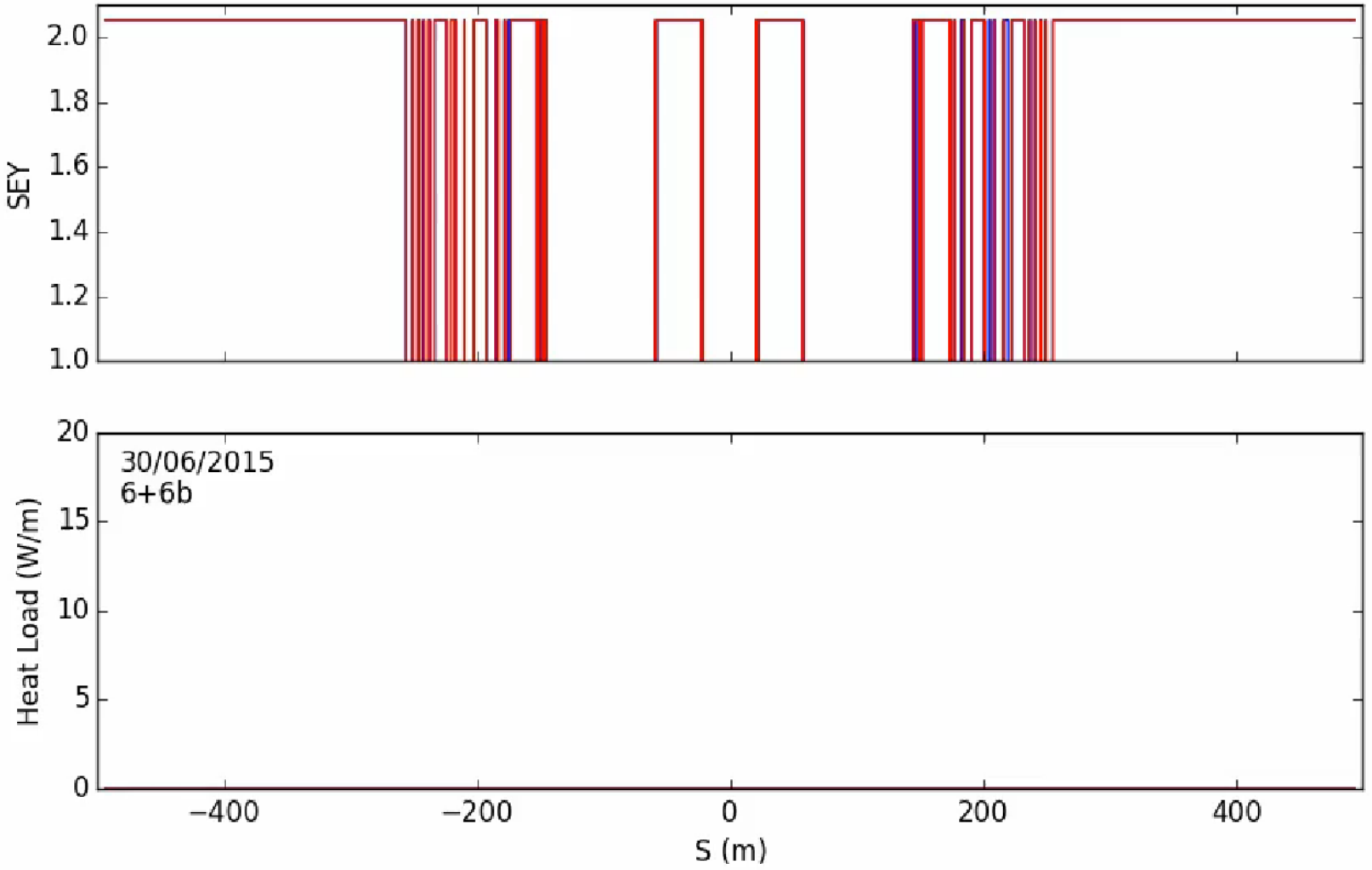
$$\frac{dSEY}{dt} = \frac{dSEY}{dDose} HeatLoad + \frac{1}{\tau}(2.05 - SEY)$$



ECLOUD: ATLAS LSS



ECLOUD: ATLAS LSS



- Overview of simulation
- Geometry of LHC and materials
- Synchrotron radiation
- Electron cloud effect
- **Dynamical vacuum**

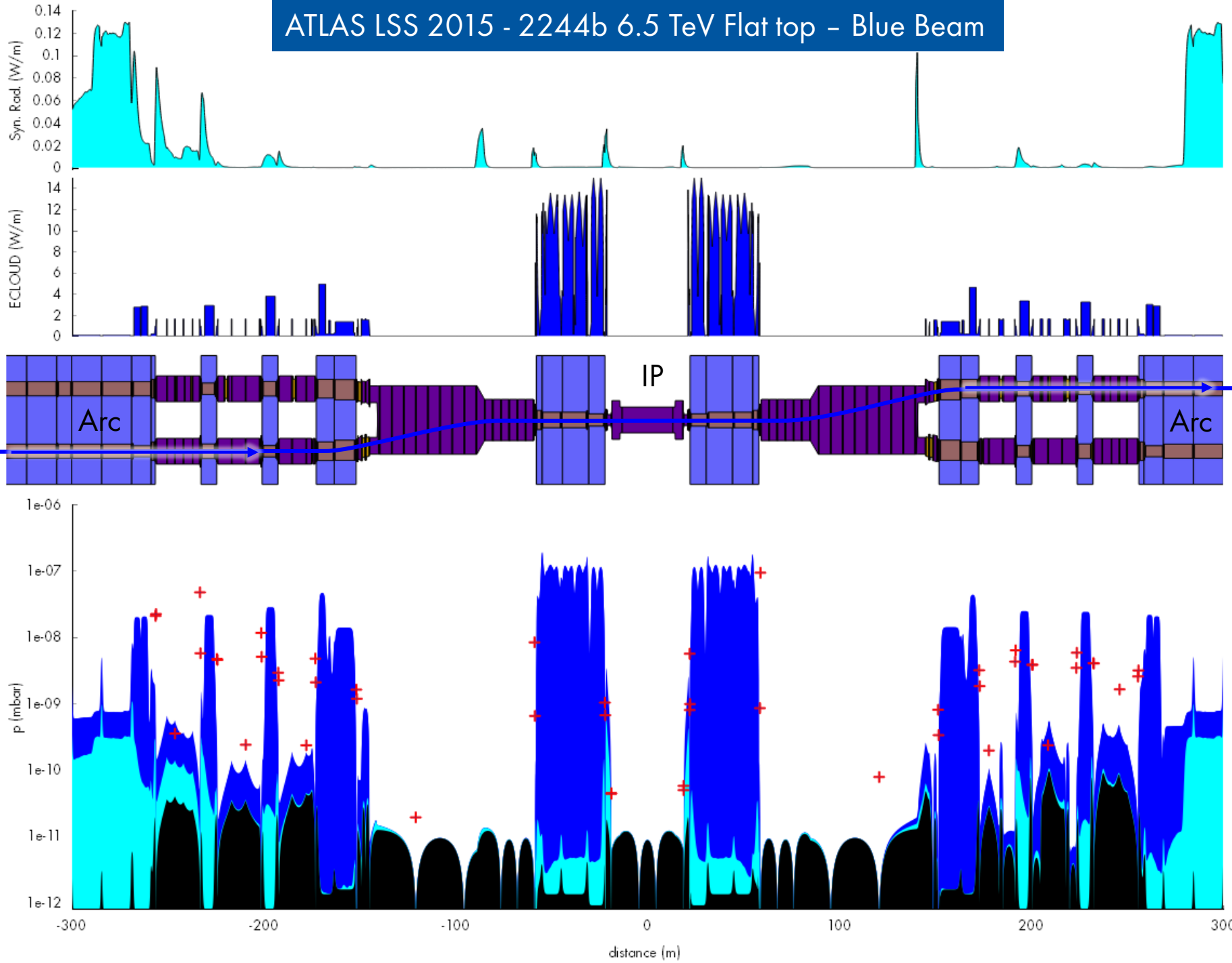
Vacuum simulation

VASCO

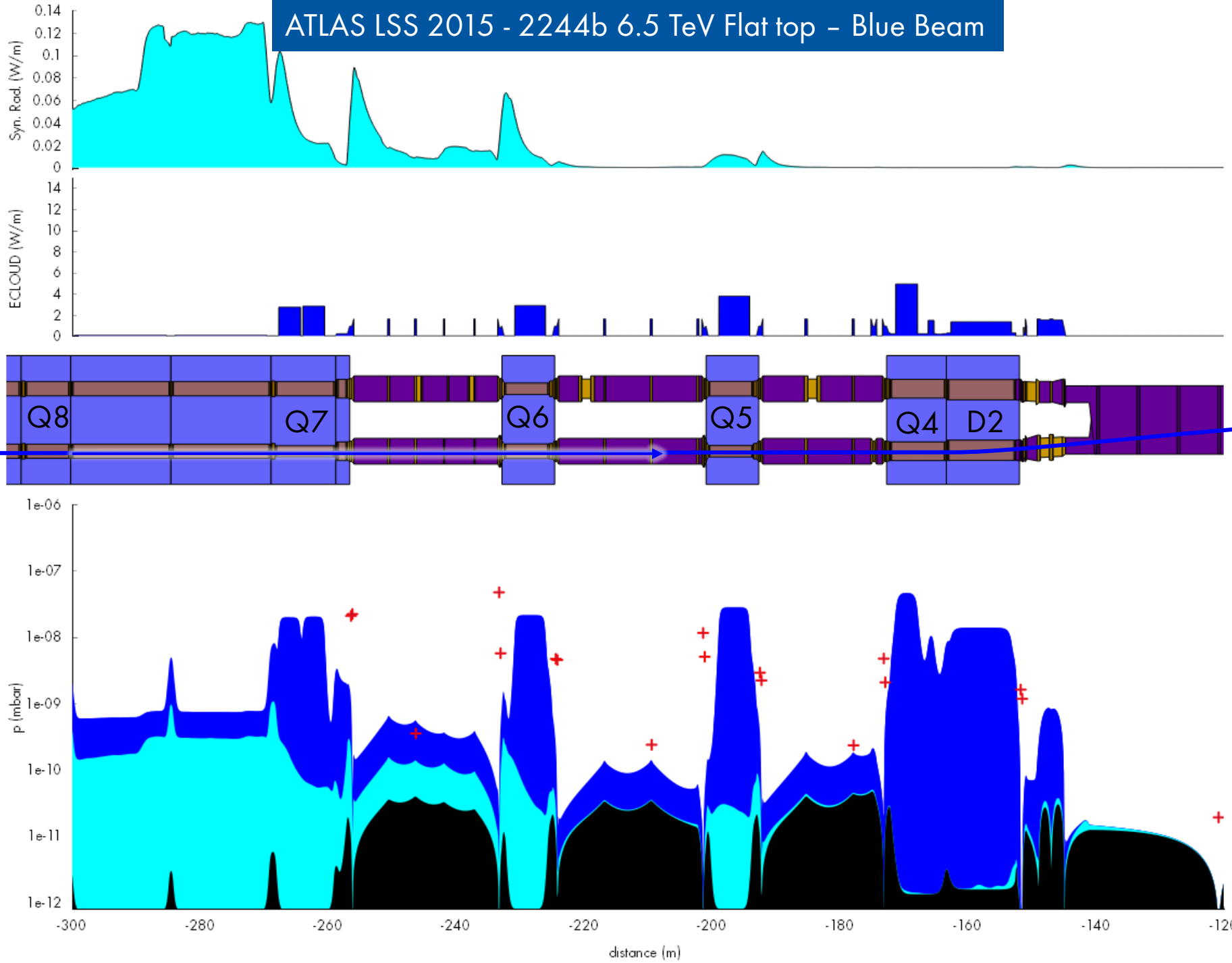
- Cu, NEG, Beam screen inside/outside coldmass
- Ionization pumps, NEG Cartidges
- No outgassing from instrumentation

- Static pressure
- Synchrotron radiation desorption
- ECLOUD desorption

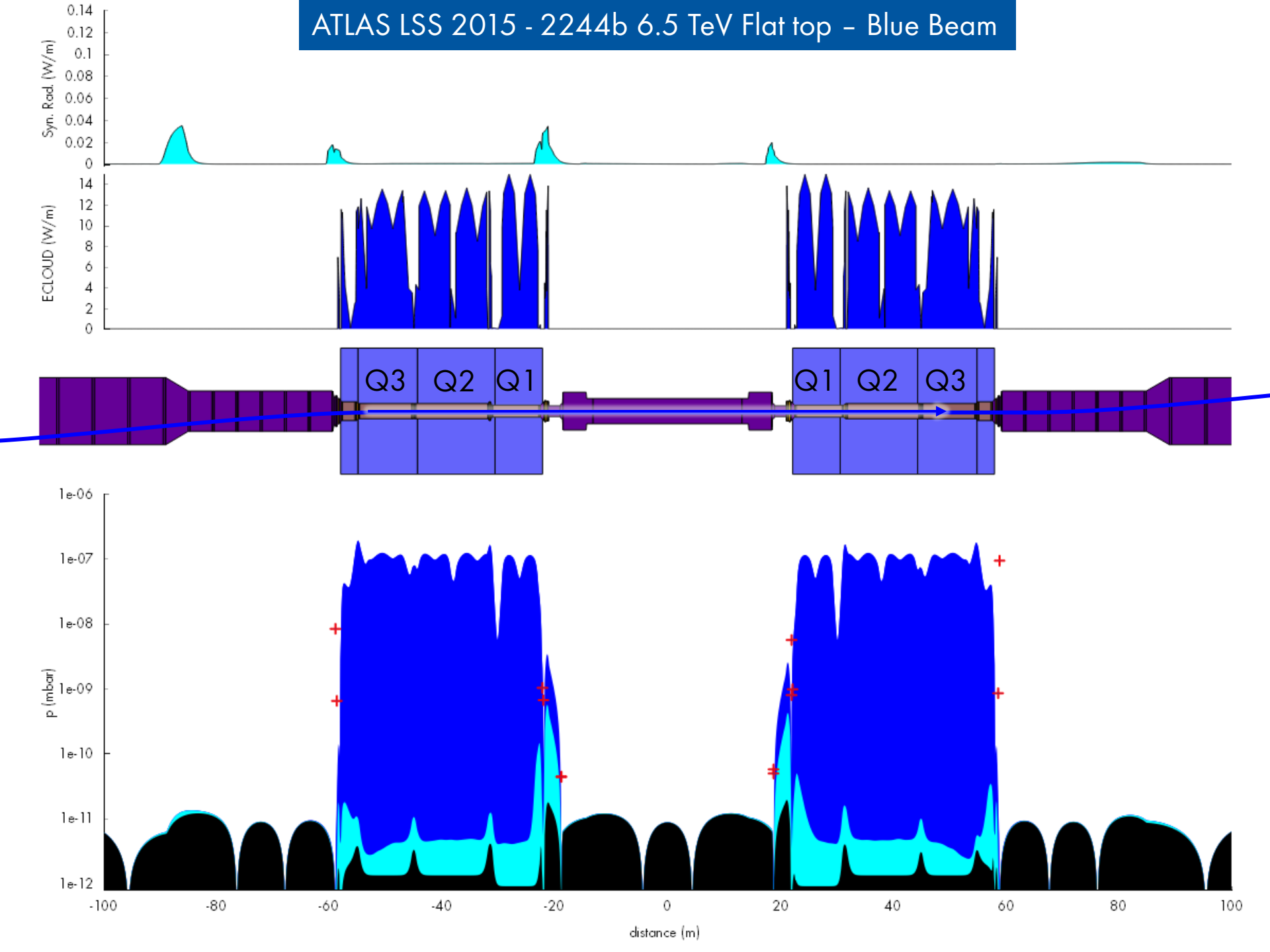
ATLAS LSS 2015 - 2244b 6.5 TeV Flat top – Blue Beam



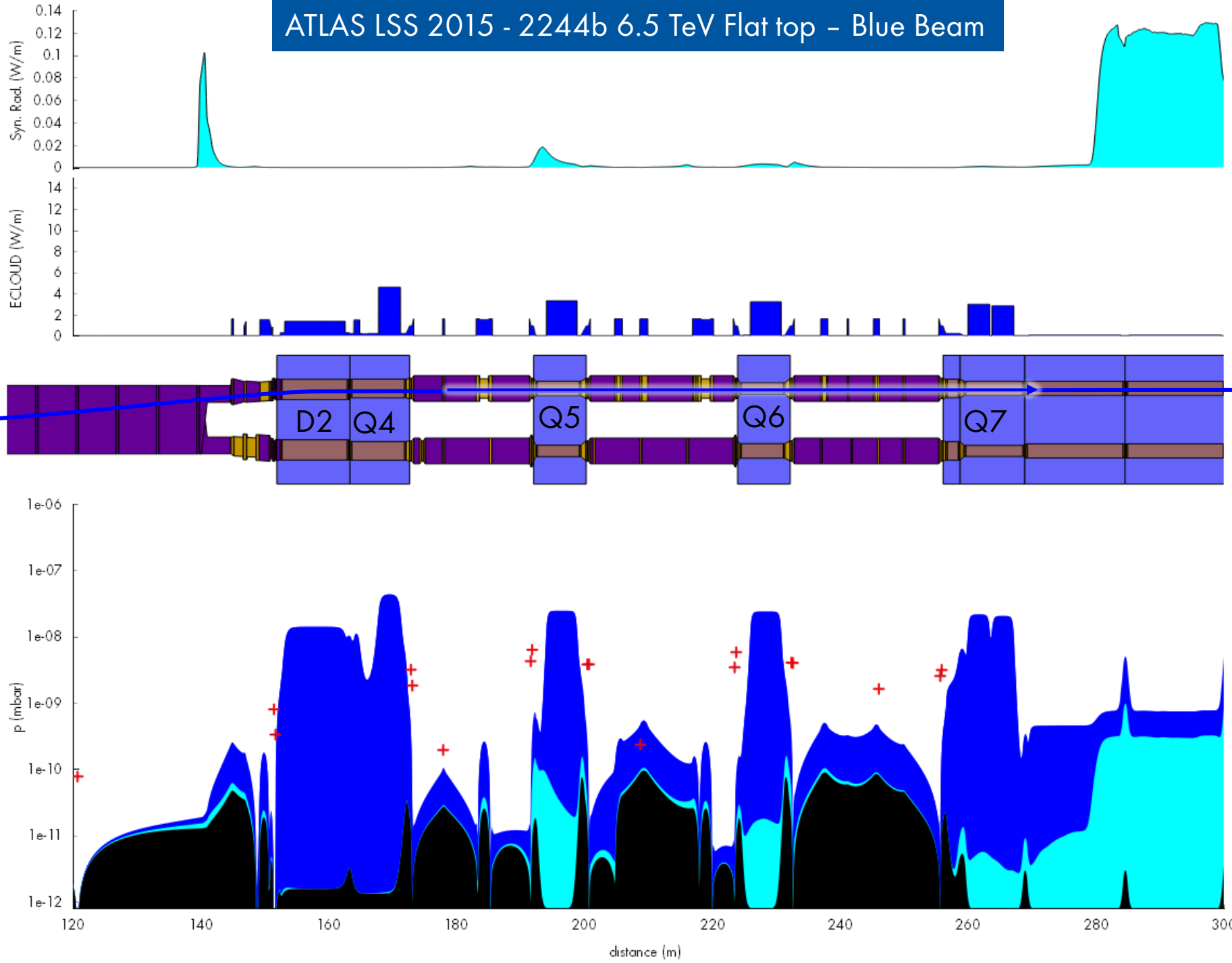
ATLAS LSS 2015 - 2244b 6.5 TeV Flat top – Blue Beam



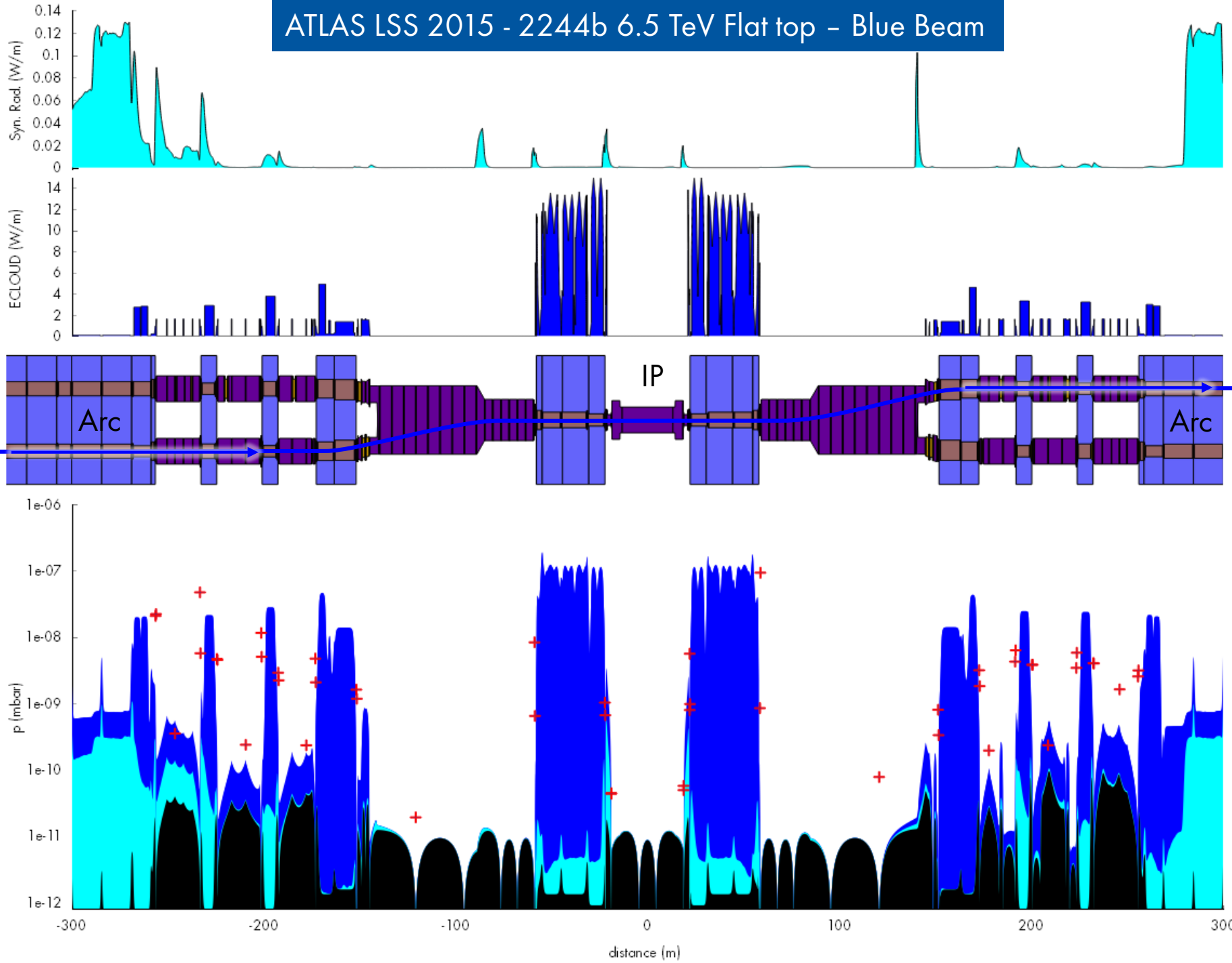
ATLAS LSS 2015 - 2244b 6.5 TeV Flat top – Blue Beam



ATLAS LSS 2015 - 2244b 6.5 TeV Flat top – Blue Beam



ATLAS LSS 2015 - 2244b 6.5 TeV Flat top – Blue Beam



Acknowledgement

Christina Yin Vallgren
Giuseppe Bregliozzi
Giovanni Iadarola
Marton Ady
Mauro Taborelli
Elisa Garcia-Tabares Valdivieso
Ida Aichinger

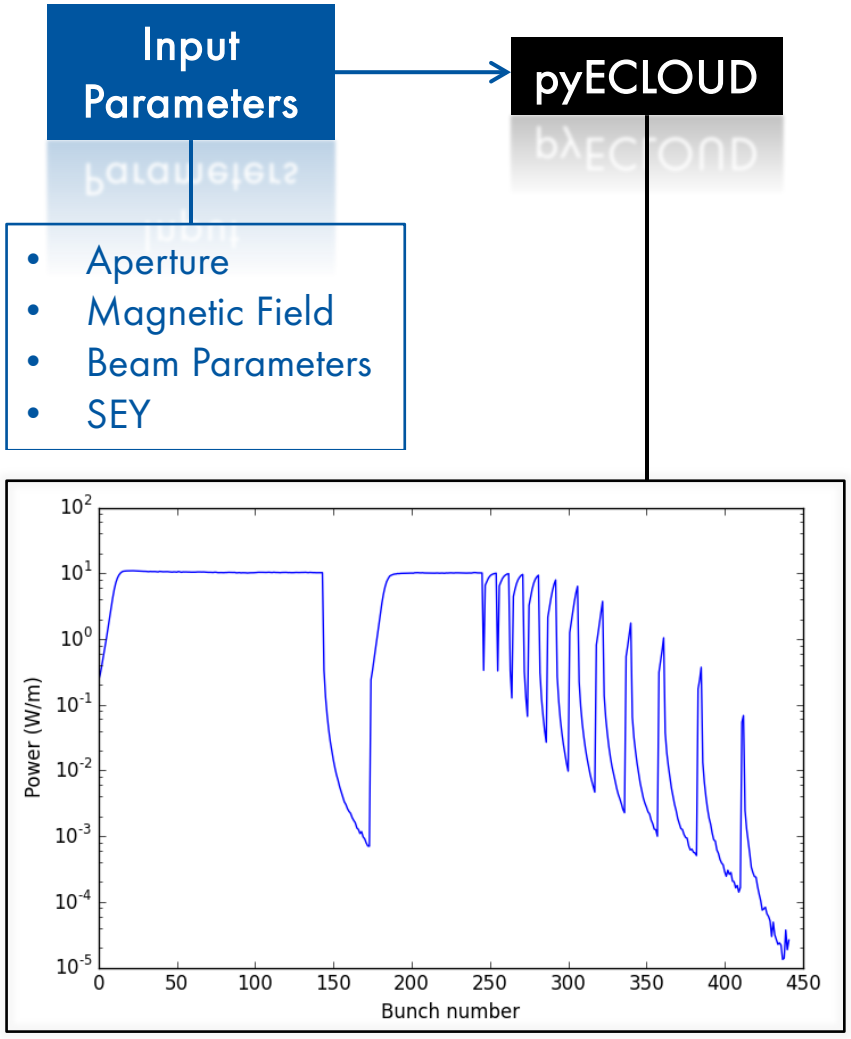
Thank you for your attention

ECLOUD Calculation

Input Parameters

- Aperture
- Magnetic Field
- Beam Parameters
- SEY

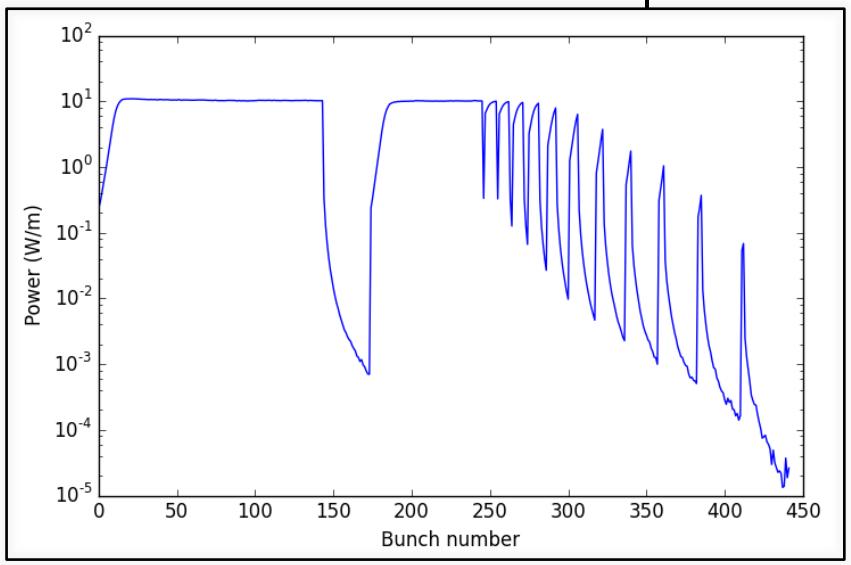
ECLOUD Calculation

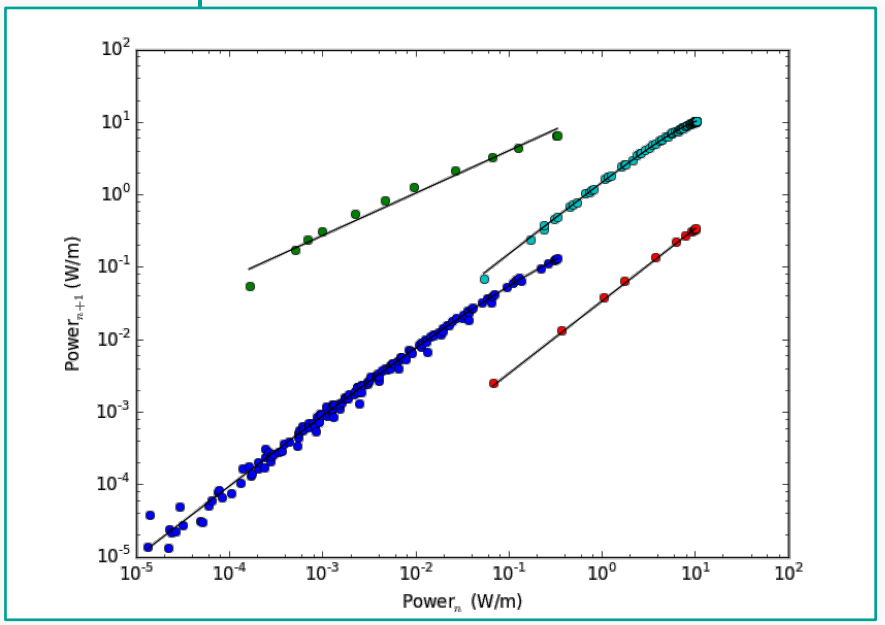


ECLOUD Calculation

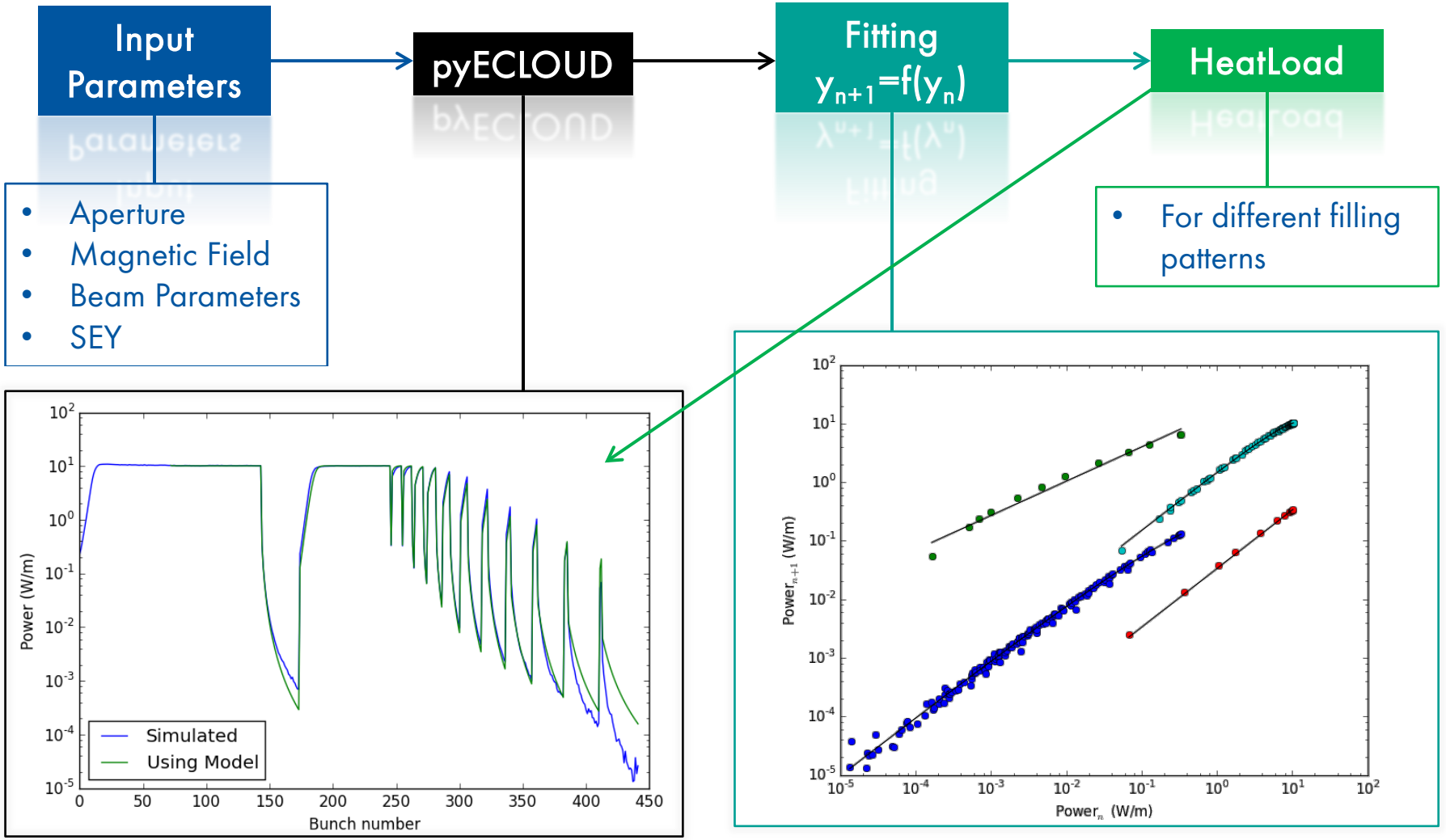
Input Parameters → **pyECLOUD** → **Fitting** $y_{n+1}=f(y_n)$

- Aperture
- Magnetic Field
- Beam Parameters
- SEY

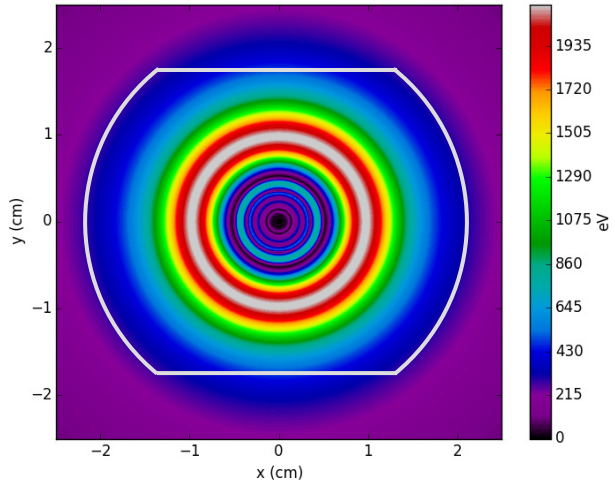




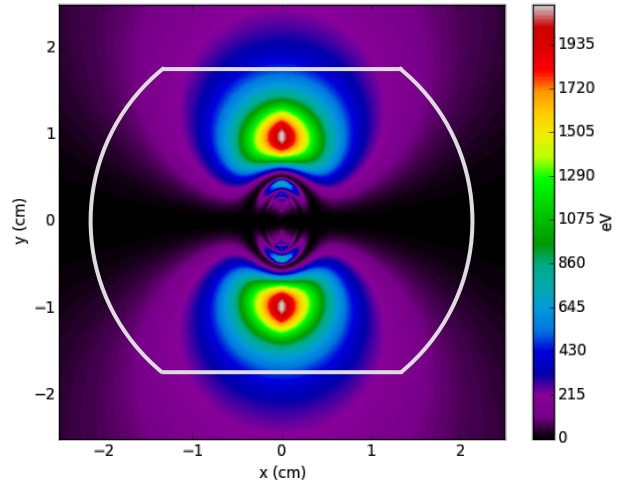
ECLOUD Calculation



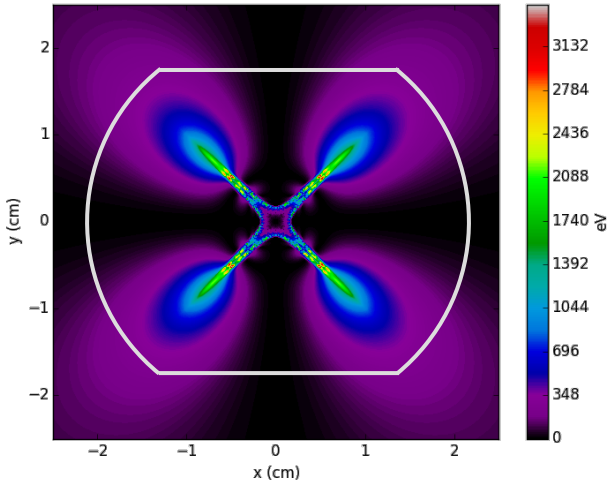
ECLOUD: Acceleration



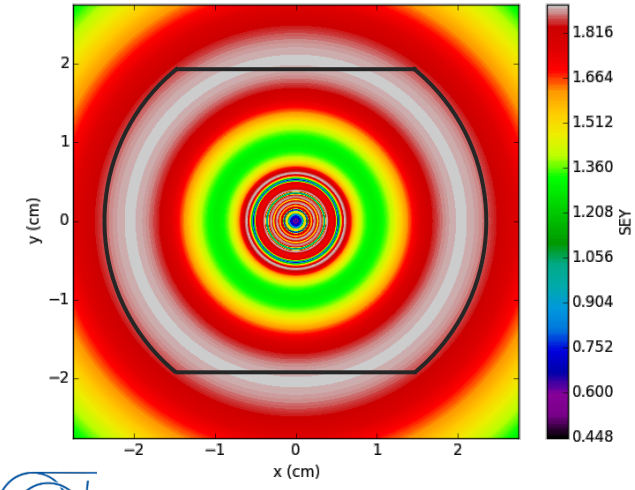
Without field

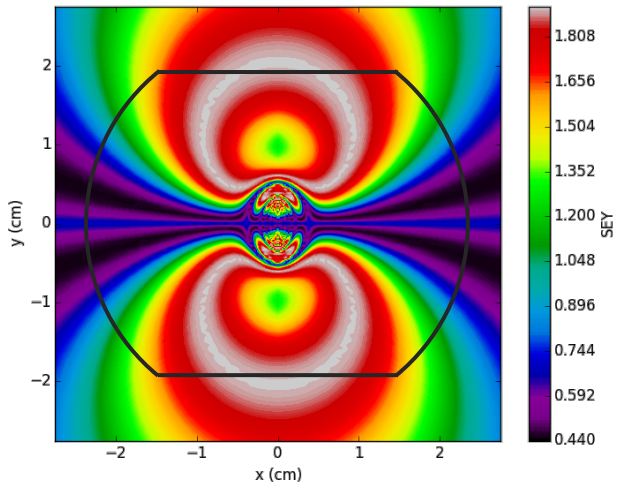


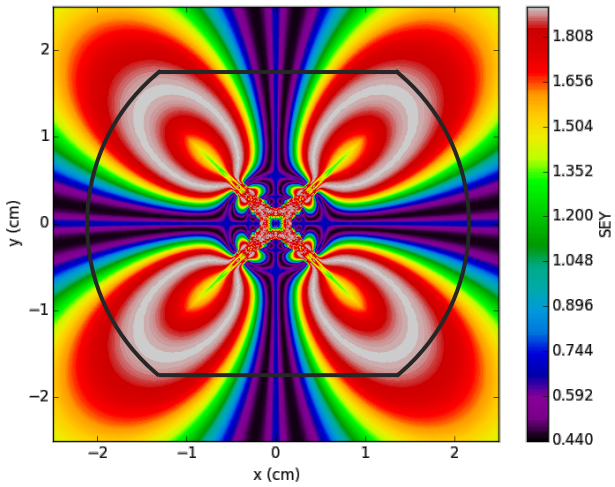
Dipole 7.7 T



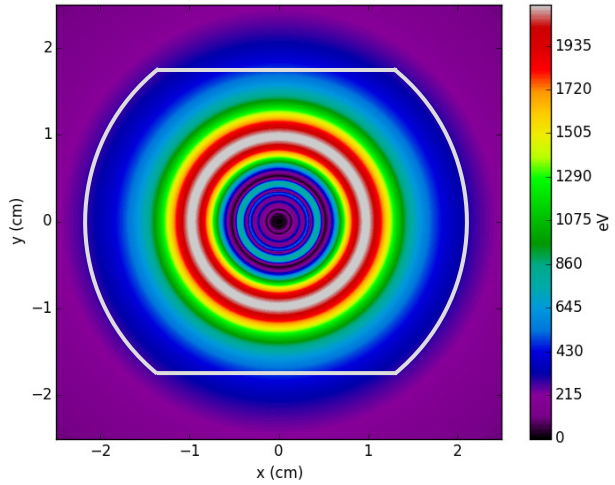
Quadrupole 100 T/m



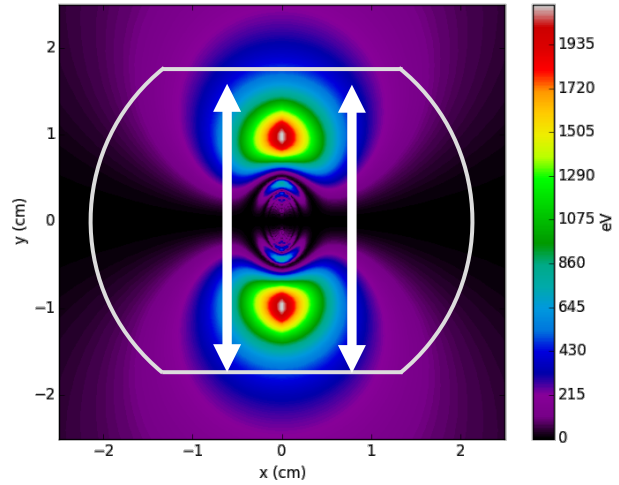




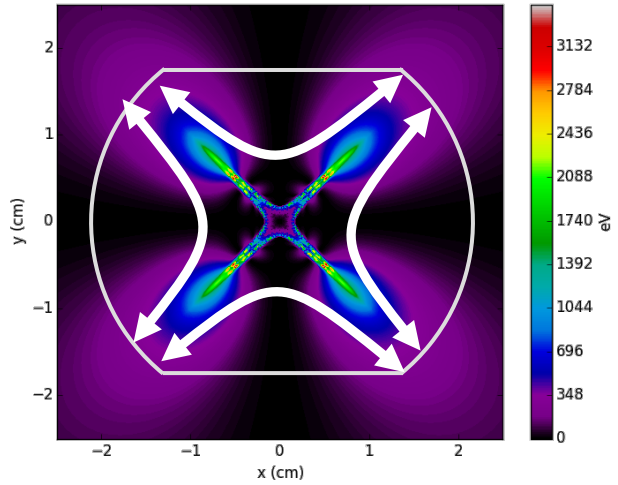
ECLOUD: Acceleration



Without field



Dipole 7.7 T



Quadrupole 100 T/m