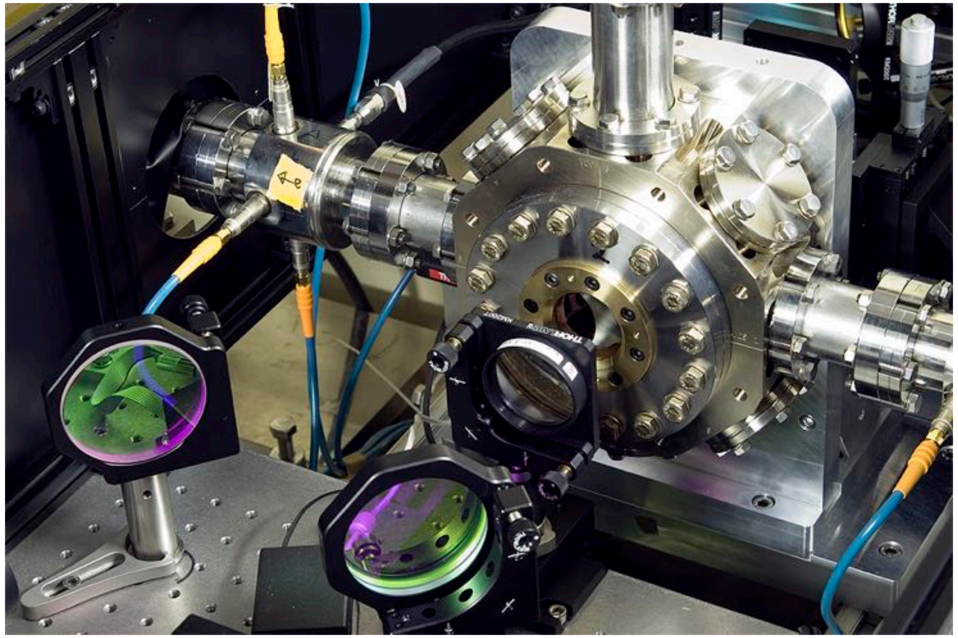
Laser system for single bunch, "photon production" option



Gamma Factory Meeting:
PoP Experiment
5 June 2019

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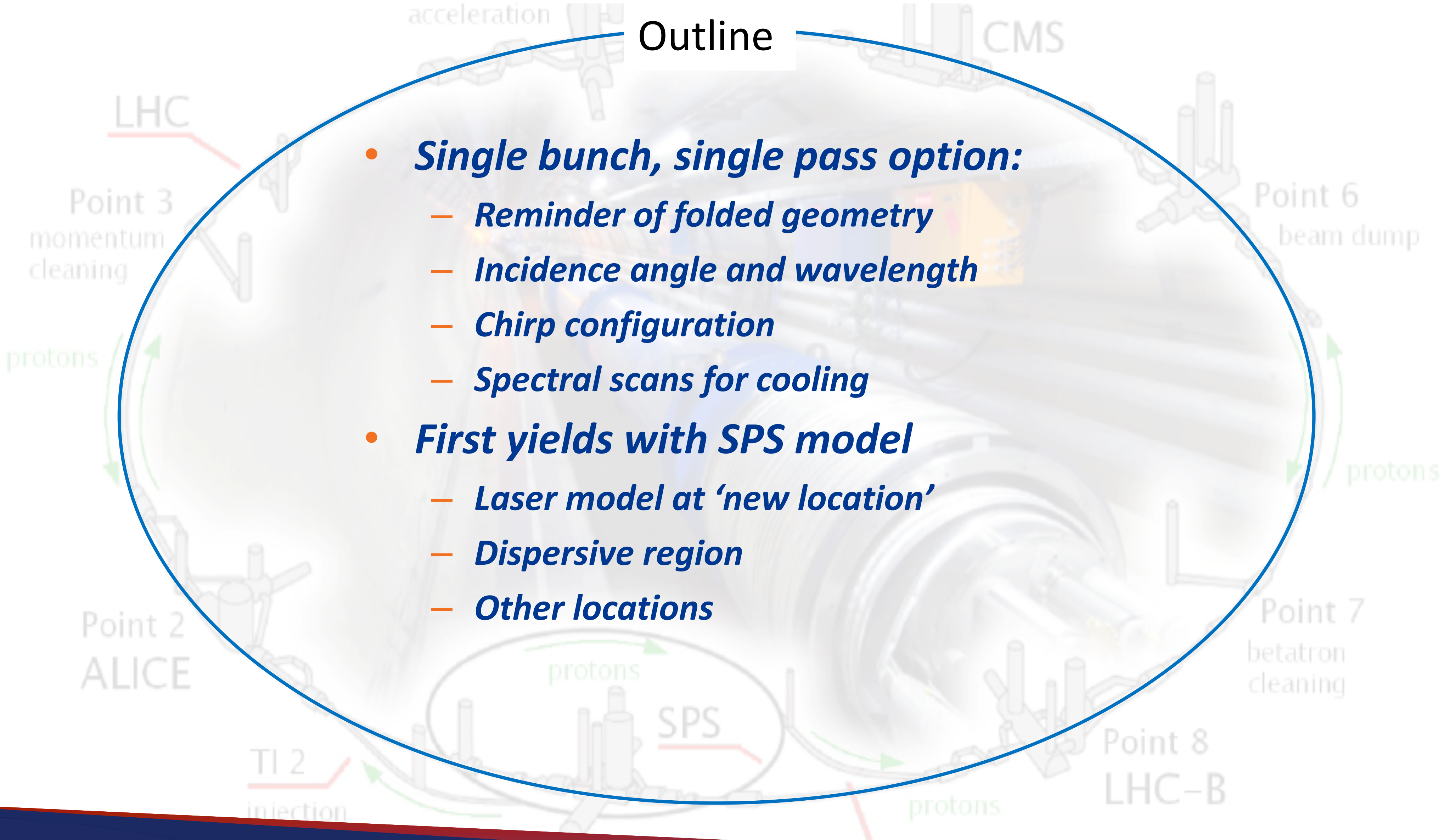
John Adams Institute for Accelerator Science

Royal Holloway, University of London, UK

Overview



Outline

- ***Single bunch, single pass option:***
  - ***Reminder of folded geometry***
  - ***Incidence angle and wavelength***
  - ***Chirp configuration***
  - ***Spectral scans for cooling***
- ***First yields with SPS model***
  - ***Laser model at ‘new location’***
  - ***Dispersive region***
  - ***Other locations***

Reminder of aims of this talk

Laser design for SPS Proof of principle experiment:

- ***Baseline design*** is a pulsed 1030nm laser that is remote controlled and tolerant to SPS radiation levels so can be installed underground, with free-space transport to a Fabry Perot (FP) cavity [optical resonator] to amplify the pulse energy by a factor >5000 at interaction point, and a repetition rate matched to every bunch in the train: 40 (20) MHz.
- -> see talk by Kevin Cassou.

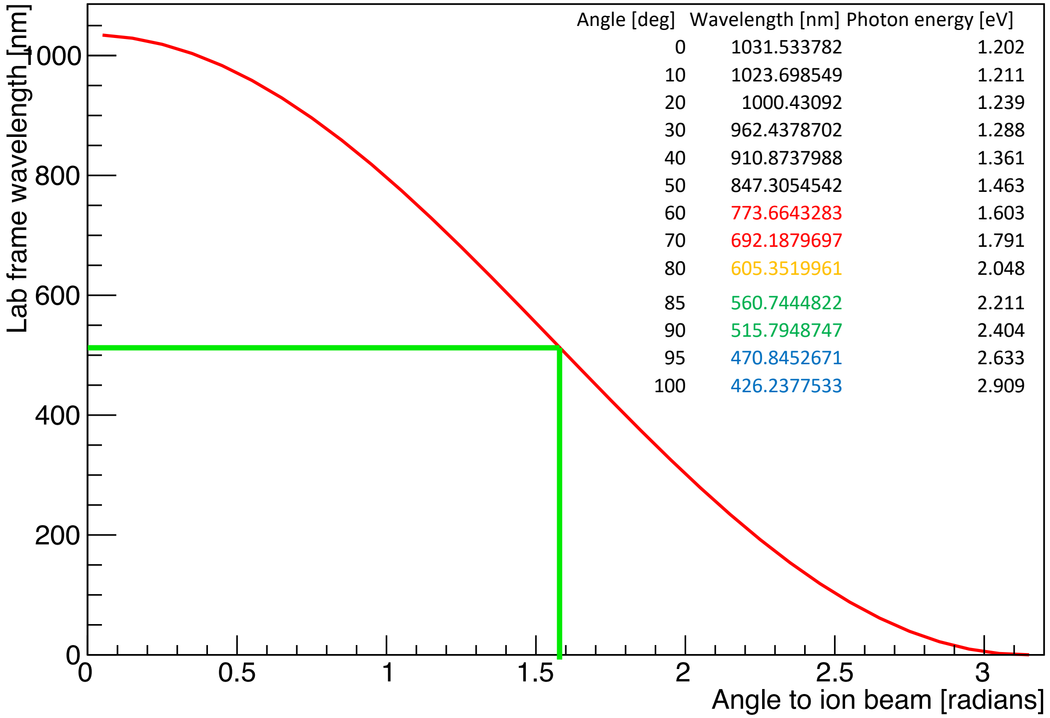
- This talk: asked to consider a "***fall back solution*** for a single pass laser."
- Aim to hit the same single bunch on each 23 μs turn:
  - SPS revolution frequency 43 kHz == repetition rate of laser.
  - Would like same laser pulse energy at IP, with much lower average energy.

Consider an alternative wavelength and geometry:

Laser parameter

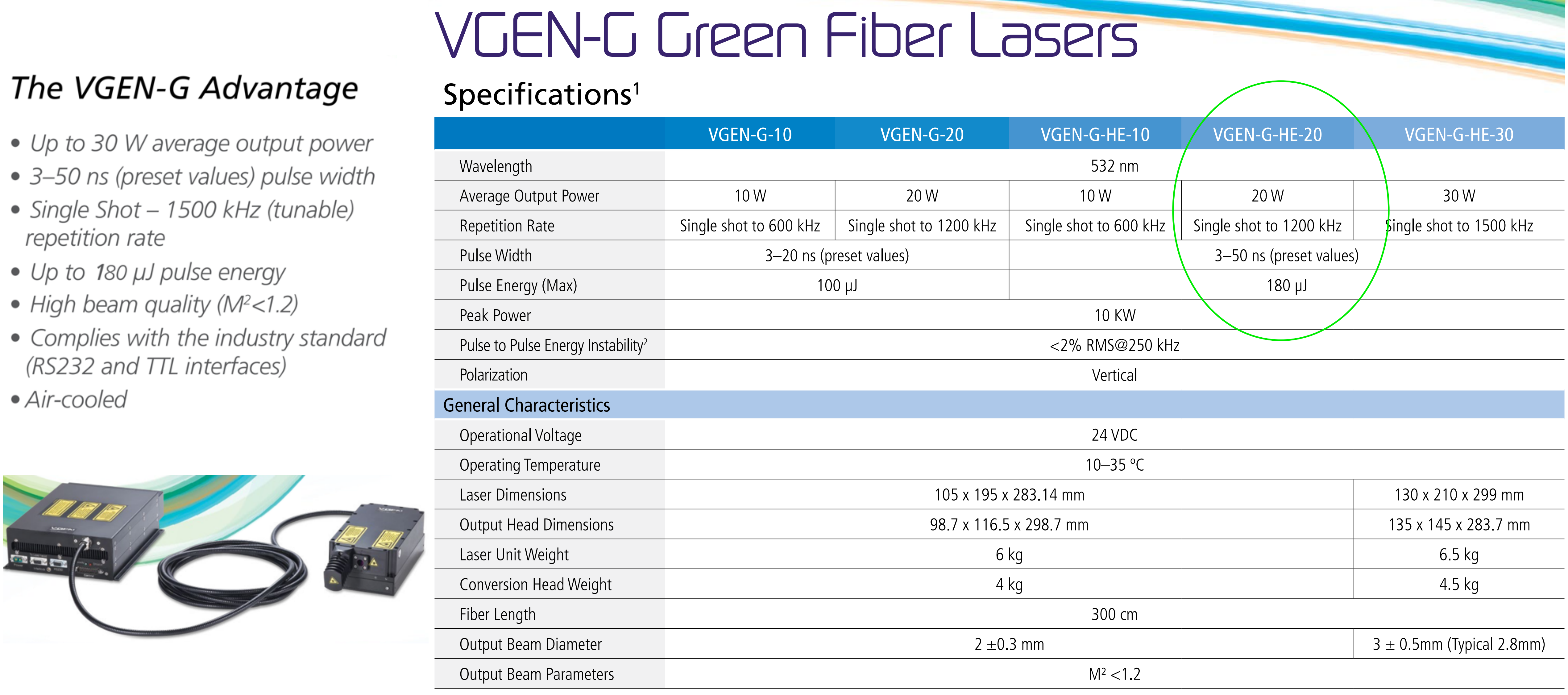
- Optimisations so far based on nearly head-on (2.6°) PSI-photons collisions using 1030nm (1.2 eV) laser, doppler shifted by γ =96.3 to the atomic transition energy (230.76 eV).
- ***Consider a radical change of wavelength and geometry:***

- A green laser was previously ruled out for FP cavity scenario mainly because a frequency doubled laser (532nm) has an inherent loss of pulse energy, and wavelength increases absorption at mirrors.
- For single pass design however, absorption is not critical, and the orthogonal geometry enables photon flux to be enhanced by squeezing the beam with focusing optics.



Angle [deg]	Wavelength [nm]	Photon energy [eV]
0	1031.533782	1.202
10	1023.698549	1.211
20	1000.43092	1.239
30	962.4378702	1.288
40	910.8737988	1.361
50	847.3054542	1.463
60	773.6643283	1.603
70	692.1879697	1.791
80	605.3519961	2.048
85	560.7444822	2.211
90	515.7948747	2.404
95	470.8452671	2.633
100	426.2377533	2.909

Multi pass, single bunch laser options: V-gen 532nm



VGEN-G Green Fiber Lasers

The VGEN-G Advantage

- *Up to 30 W average output power*
- *3–50 ns (preset values) pulse width*
- *Single Shot – 1500 kHz (tunable) repetition rate*
- *Up to 180 µJ pulse energy*
- *High beam quality ($M^2<1.2$)*
- *Complies with the industry standard (RS232 and TTL interfaces)*
- *Air-cooled*

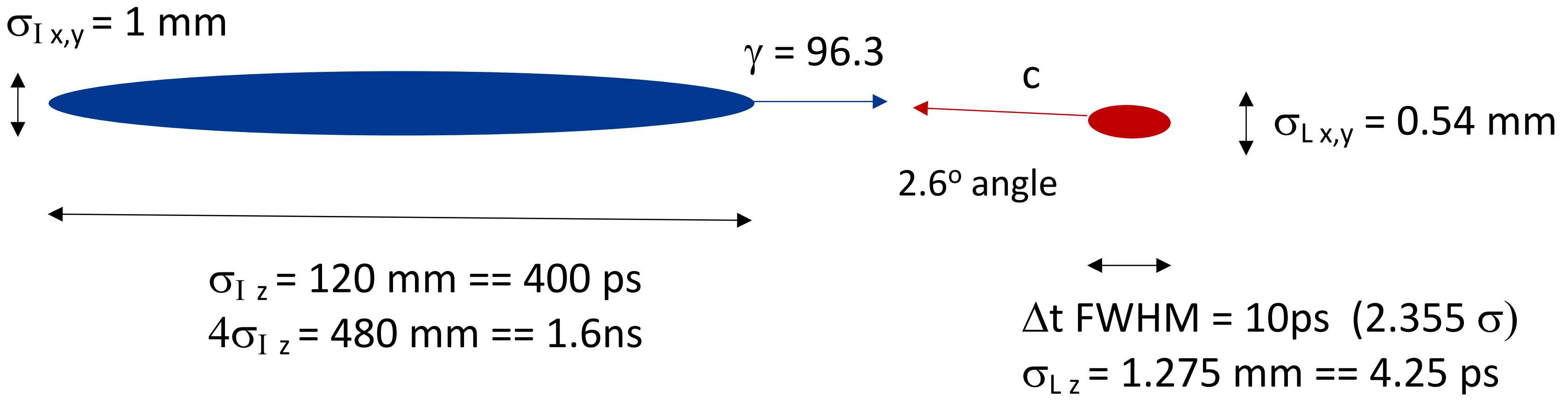
Specifications[1]

	VGEN-G-10	VGEN-G-20	VGEN-G-HE-10	VGEN-G-HE-20	VGEN-G-HE-30
Wavelength	532 nm				
Average Output Power	10 W	20 W	10 W	20 W	30 W
Repetition Rate	Single shot to 600 kHz	Single shot to 1200 kHz	Single shot to 600 kHz	Single shot to 1200 kHz	Single shot to 1500 kHz
Pulse Width	3–20 ns (preset values)		3–50 ns (preset values)		
Pulse Energy (Max)	100 µJ		180 µJ		
Peak Power	10 KW				
Pulse to Pulse Energy Instability[2]	<2% RMS@250 kHz				
Polarization	Vertical				
General Characteristics					
Operational Voltage	24 VDC				
Operating Temperature	10–35 °C				
Laser Dimensions	105 x 195 x 283.14 mm				130 x 210 x 299 mm
Output Head Dimensions	98.7 x 116.5 x 298.7 mm				135 x 145 x 283.7 mm
Laser Unit Weight	6 kg				6.5 kg
Conversion Head Weight	4 kg				4.5 kg
Fiber Length	300 cm				
Output Beam Diameter	2 ±0.3 mm				3 ± 0.5mm (Typical 2.8mm)
Output Beam Parameters	$M^2 < 1.2$				

PSI : photon pulse interaction region

Initial ion bunch

Laser pulse, λ = 1030 nm, 5 mJ



$\sigma_{I\ x,y}$ = 1 mm

γ = 96.3

c

$\sigma_{L\ x,y}$ = 0.54 mm

2.6° angle

$\sigma_{I\ z}$ = 120 mm == 400 ps

$4\sigma_{I\ z}$ = 480 mm == 1.6ns

Δt FWHM = 10ps (2.355 σ)

$\sigma_{L\ z}$ = 1.275 mm == 4.25 ps

- Note the ion bunch is rather circular in cross section, $\sigma_x \sim \sigma_y$ and the laser pulse has transverse dimension slightly smaller than the ion bunch: the laser pulse moves longitudinally *and transversely* through the ion bunch.
- Fraction of ions excited depends on **spatial-temporal overlap** of the two beams.
- Probability of excitation depends on **photon flux** and **time spent by ion in laser field.**

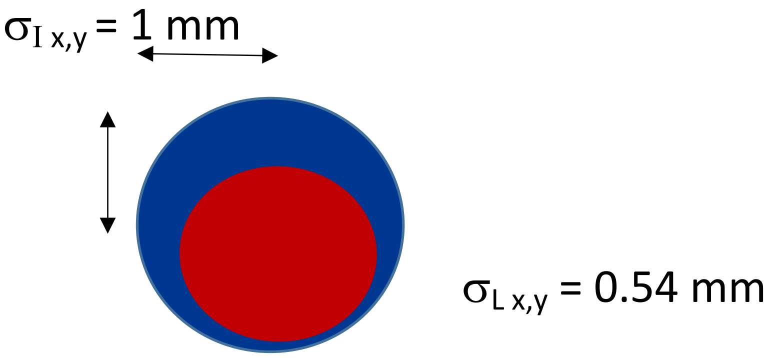
$$P_s = 1 - exp^{-\sigma(\lambda)\rho(x,y,z)t}$$

Photon flux enhancement: laserwire configuration

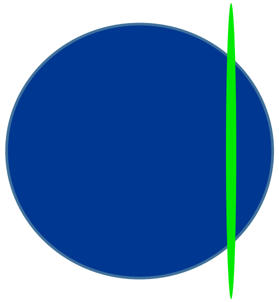
Reduce geometrical overlap

- Orthogonal geometry gives narrow beam of photons (laserwire): this reduces the interaction volume and increases the photon flux for the ions that pass through this region.

Transverse (XY) views of ion bunch in blue



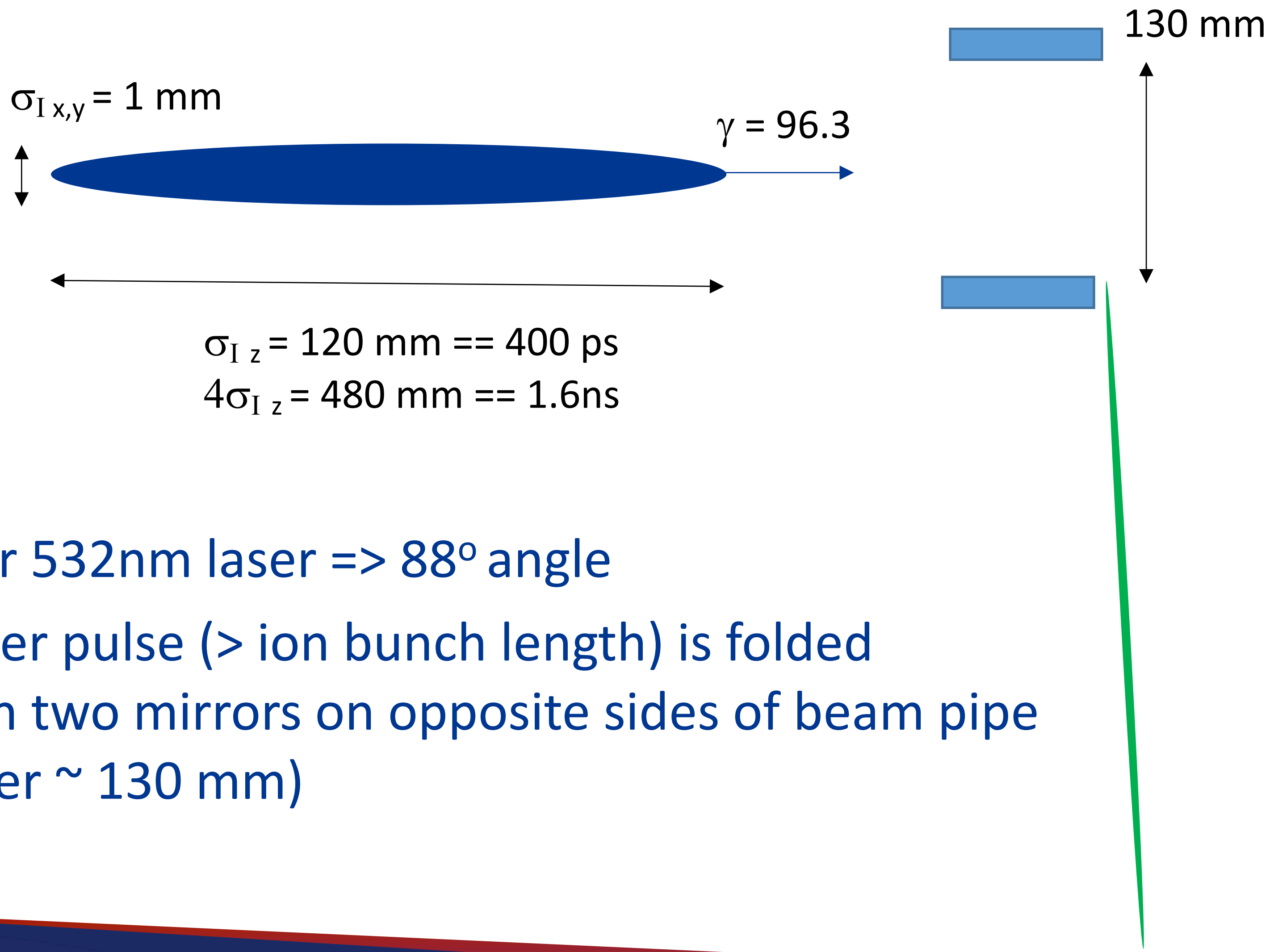
1030 nm head on (2.6^{o}) pulse, spreads over most of bunch in transverse plane
Individual ions see less photon flux



532nm orthogonal pulse, focus photons in specific slice of ion bunch.
Laserwire waist << 100um

Green fibre laser, folded geometry:

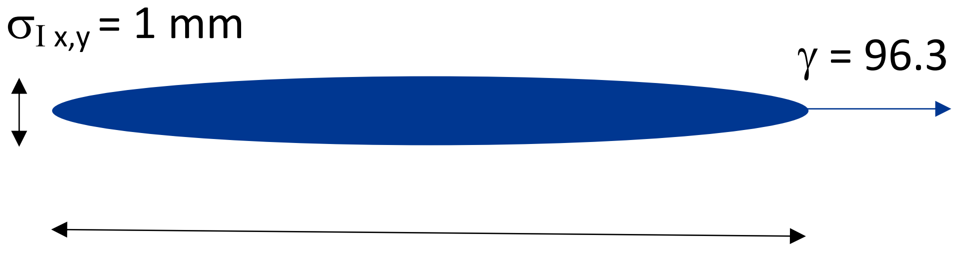
Ion bunch interaction



- Consider 532nm laser => 88^{o} angle
- Long laser pulse (> ion bunch length) is folded between two mirrors on opposite sides of beam pipe (diameter ~ 130 mm)

Green fibre laser, folded geometry:

Ion bunch interaction



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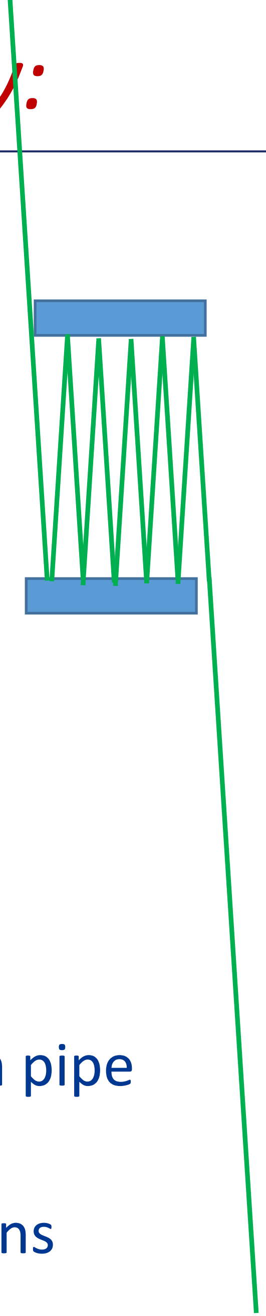
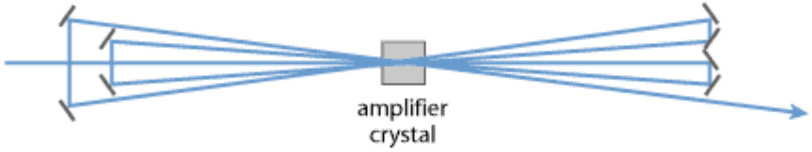


Note vertical laserwire

Similar to multi pass amplifier

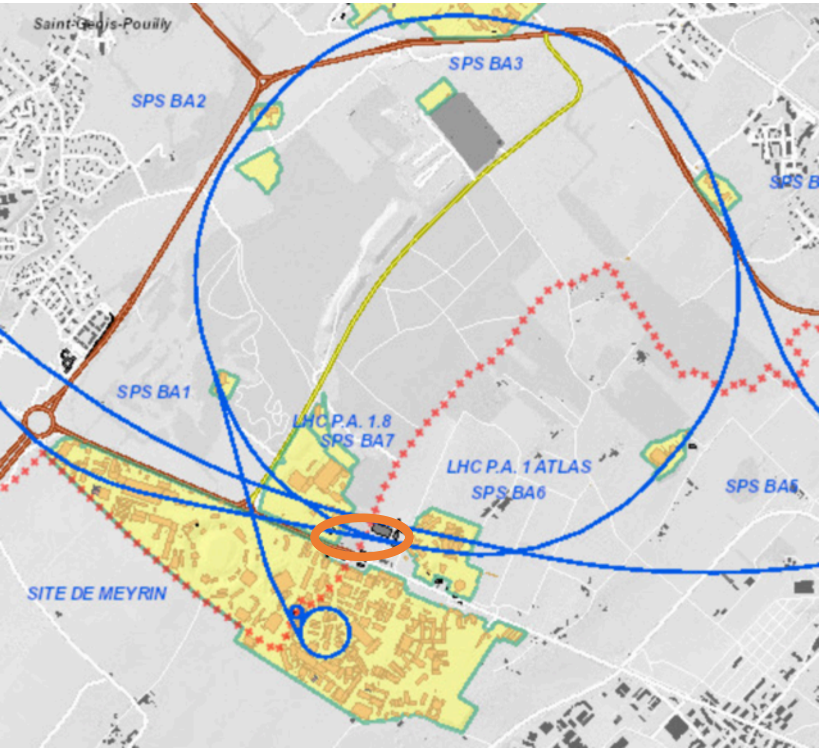


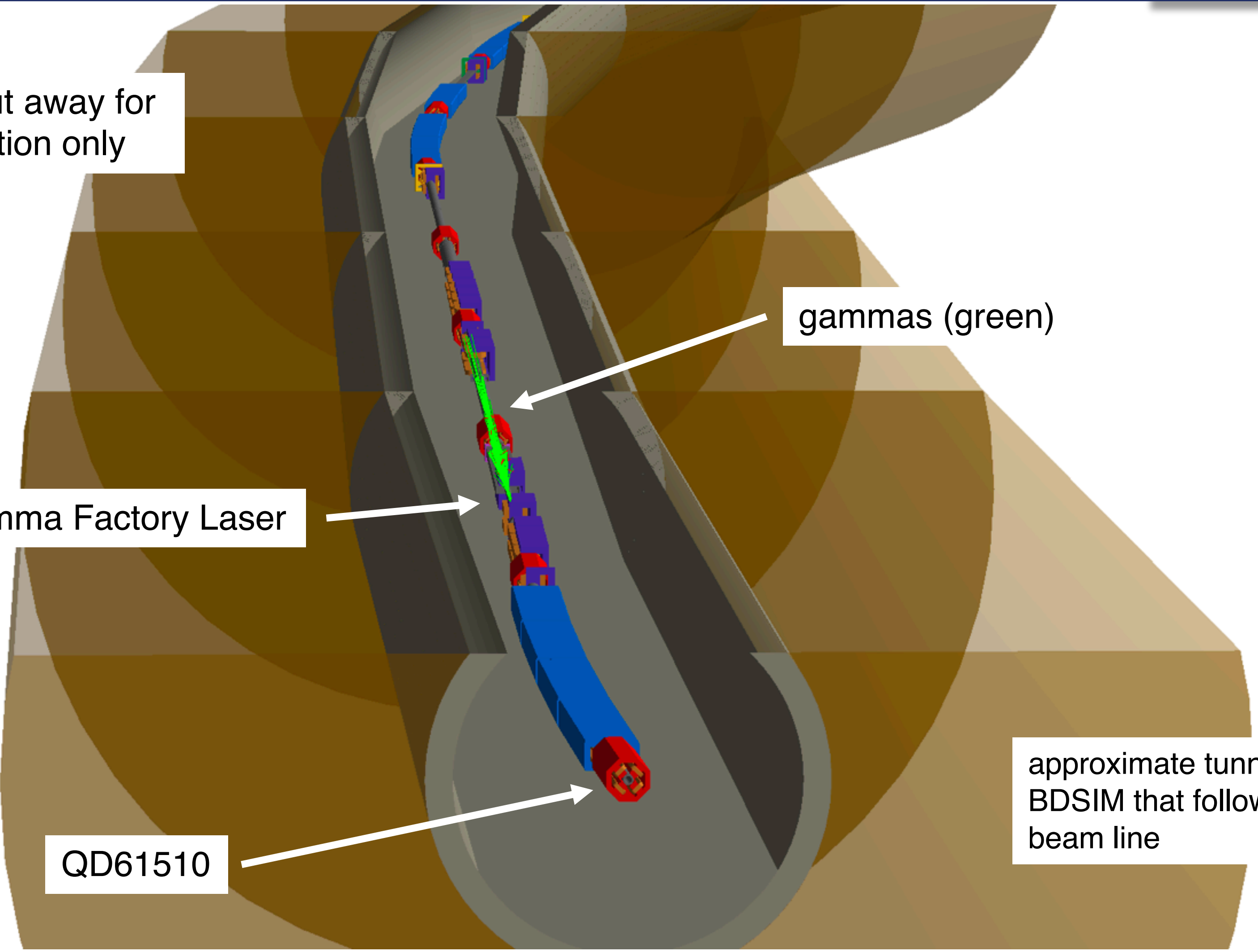
Effectively amplifies by factor of number of reflections ~10 (minor mirror absorption)

For ~130mm between mirrors, want laser pulse length of 1.3m ~ 4ns

- Consider 532nm laser => 88° angle
- Long laser pulse (> ion bunch length) is folded between two mirrors on opposite sides of beam pipe (diameter ~ 130 mm)
- Fast moving ion bunch passes through all photons

BDSIM model of SPS original location near QD61510





tunnel cut away for visualisation only

gammas (green)

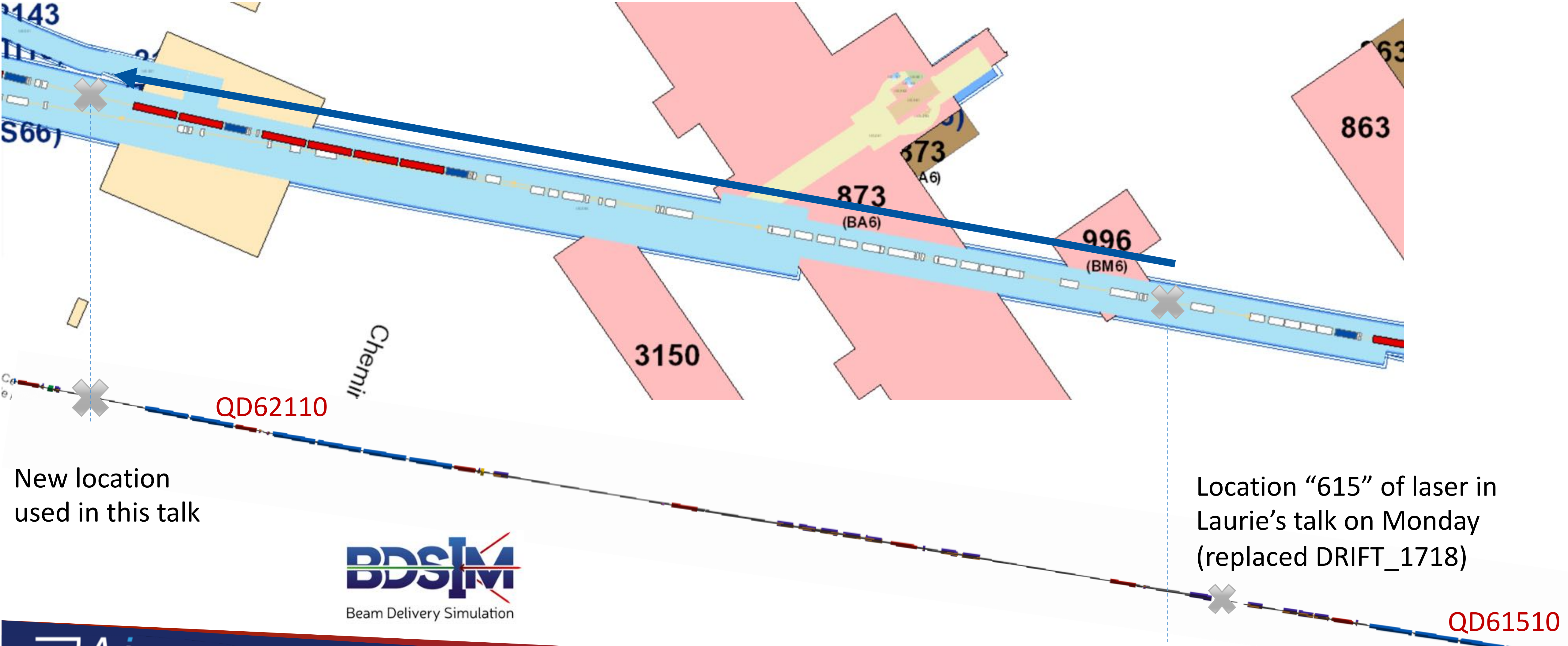
Gamma Factory Laser

QD61510

approximate tunnel by BDSIM that follows beam line

BDSIM model at SPS new location

New location from Yann's slides:

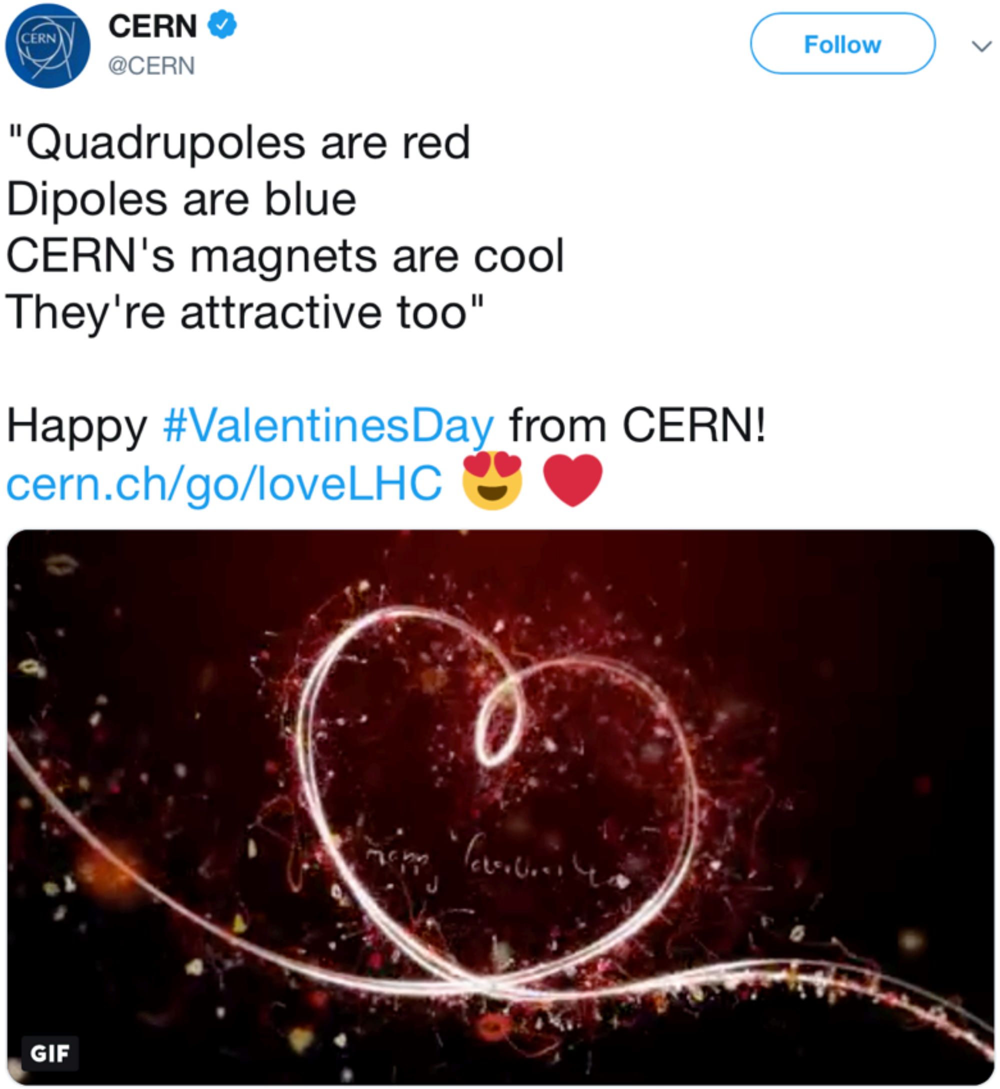


New location
used in this talk

Location "615" of laser in
Laurie's talk on Monday
(replaced DRIFT_1718)

Beam Delivery Simulation

SPS colour scheme…!



CERN
@CERN

"Quadrupoles are red
Dipoles are blue
CERN's magnets are cool
They're attractive too"

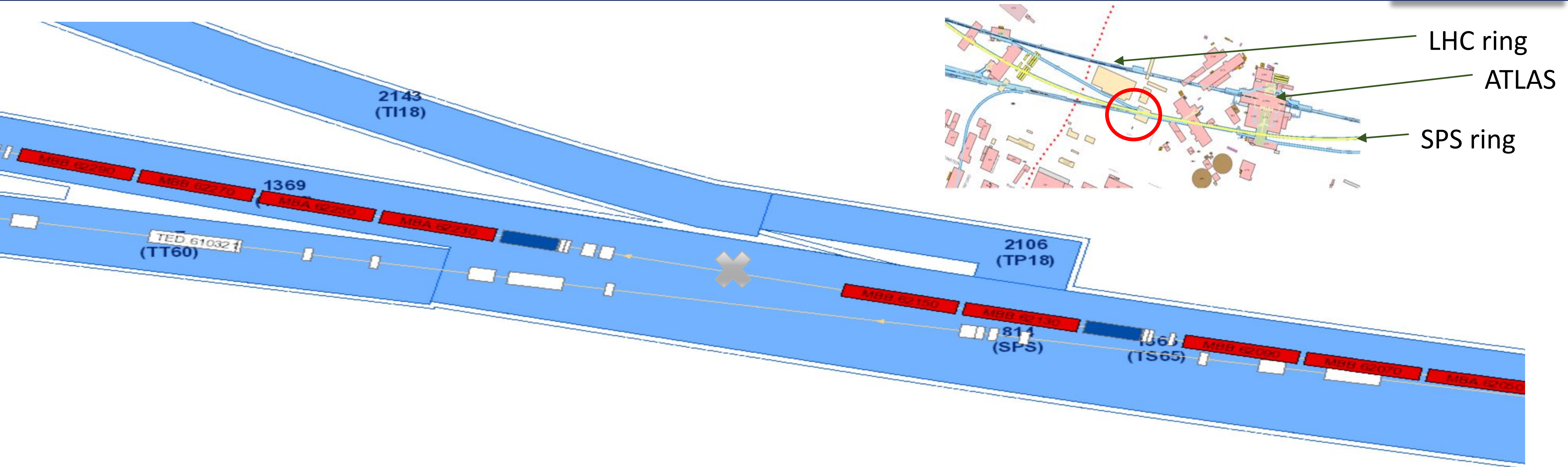
Happy #ValentinesDay from CERN!
cern.ch/go/loveLHC 😍 ❤️

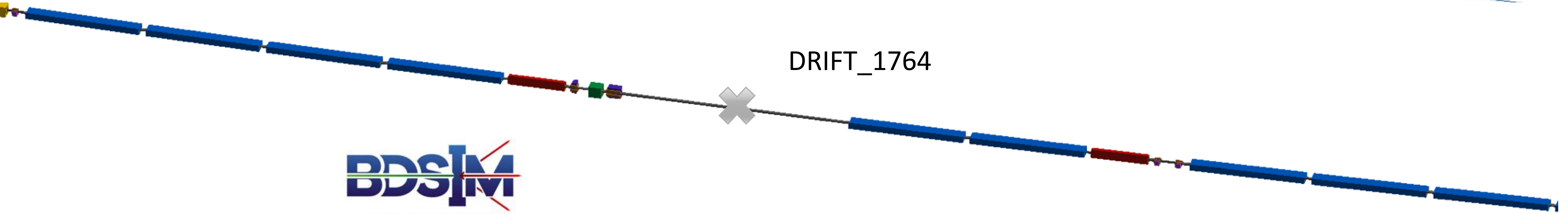
LHC

SPS

QD61510

BDSIM model at SPS new location

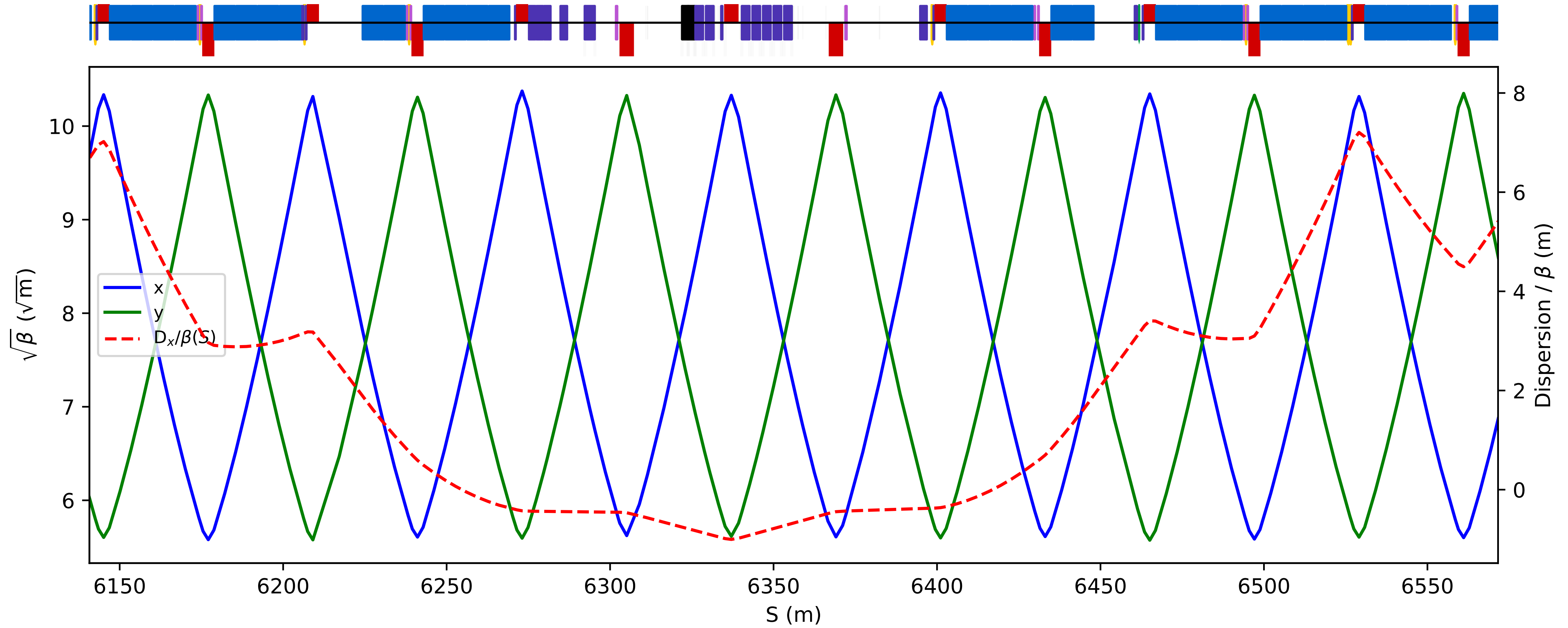




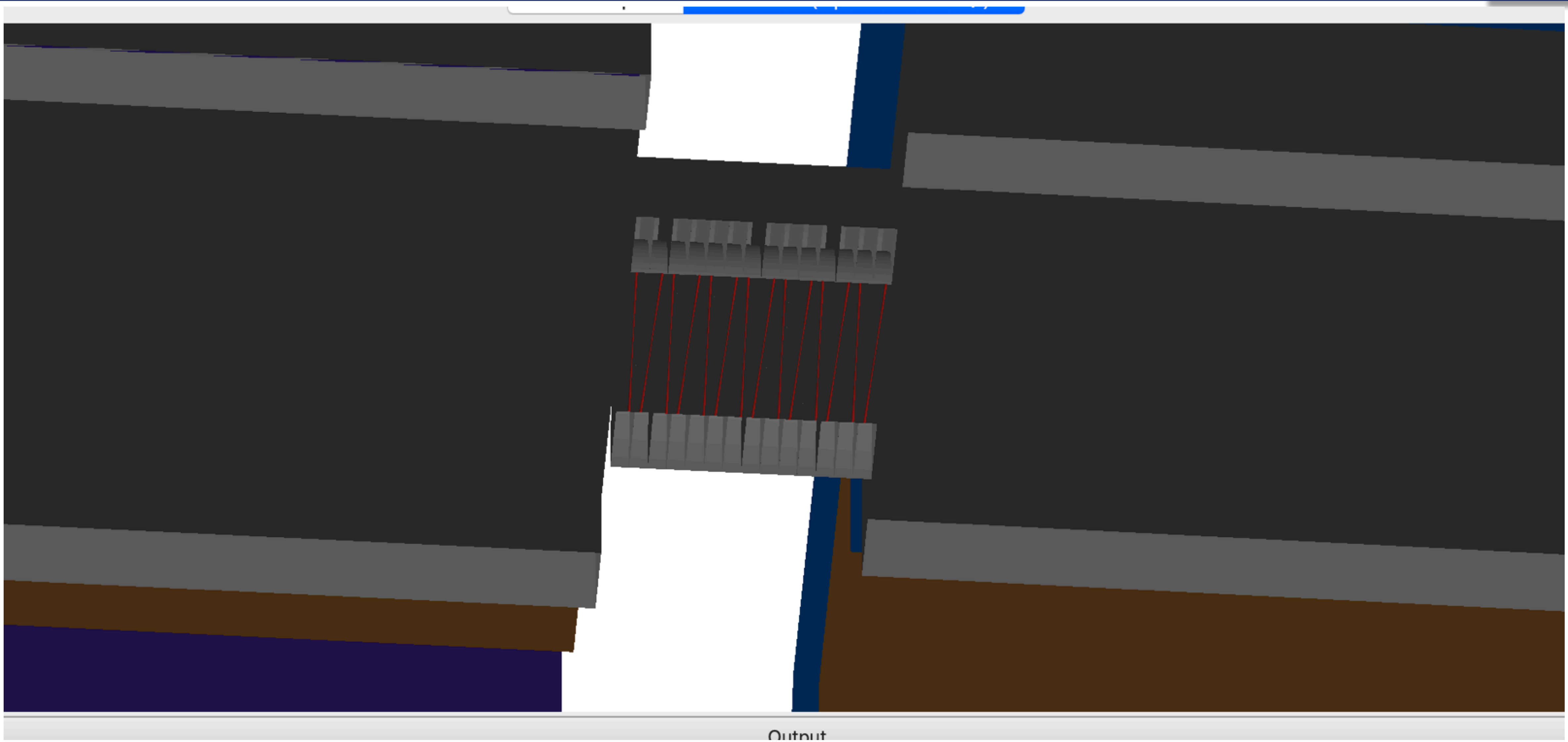
Beam Delivery Simulation

BDSIM model optics: beta functions and dispersion

✖ 'DRIFT_1764' replaced by laser:
6449.455402325



Folded laser geometry: initial try with w_o 0.05mm, narrow laserwire



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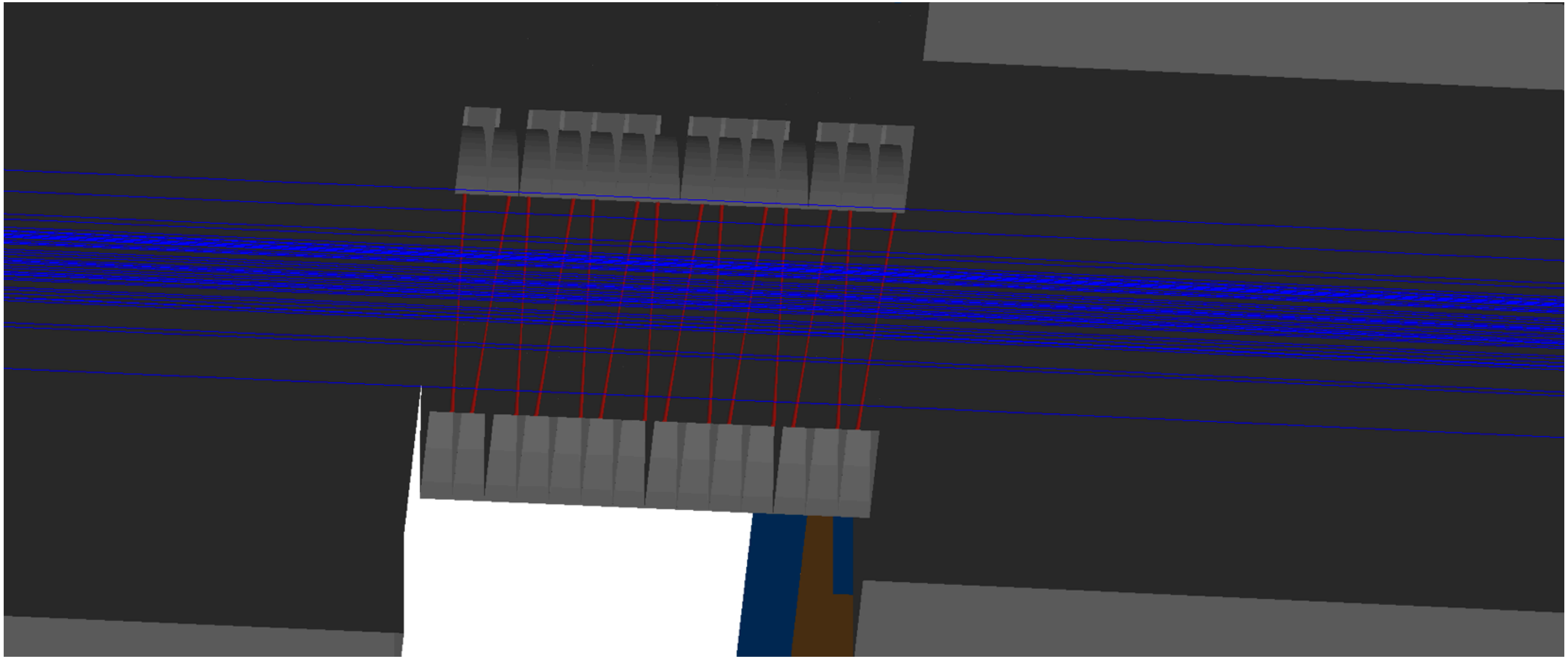
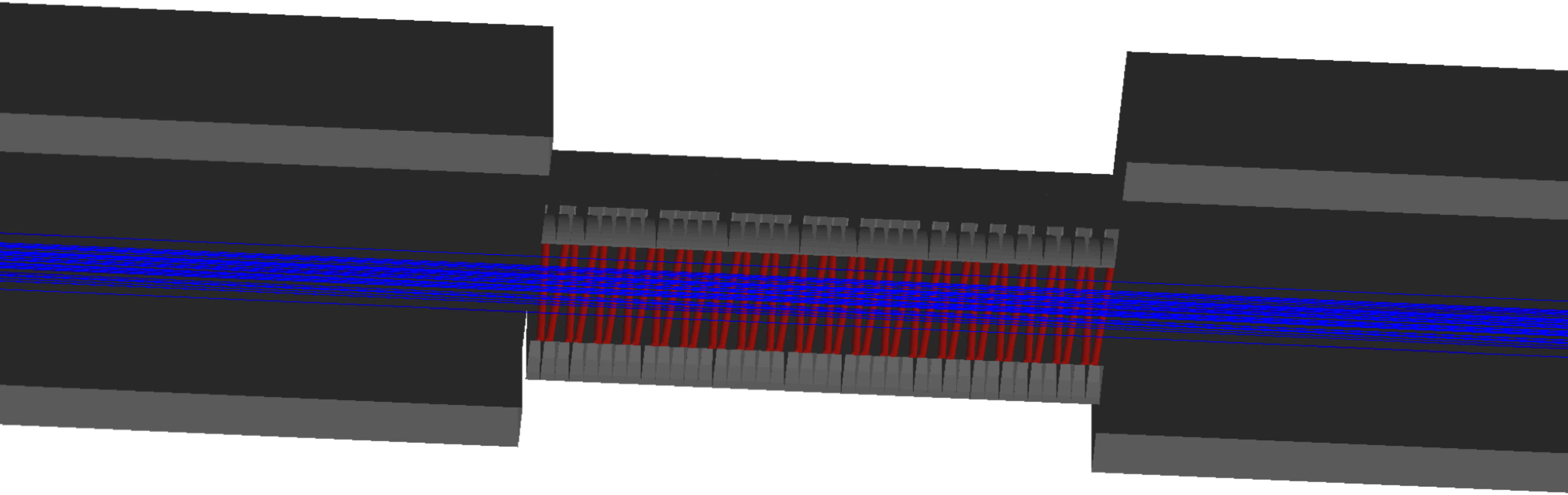
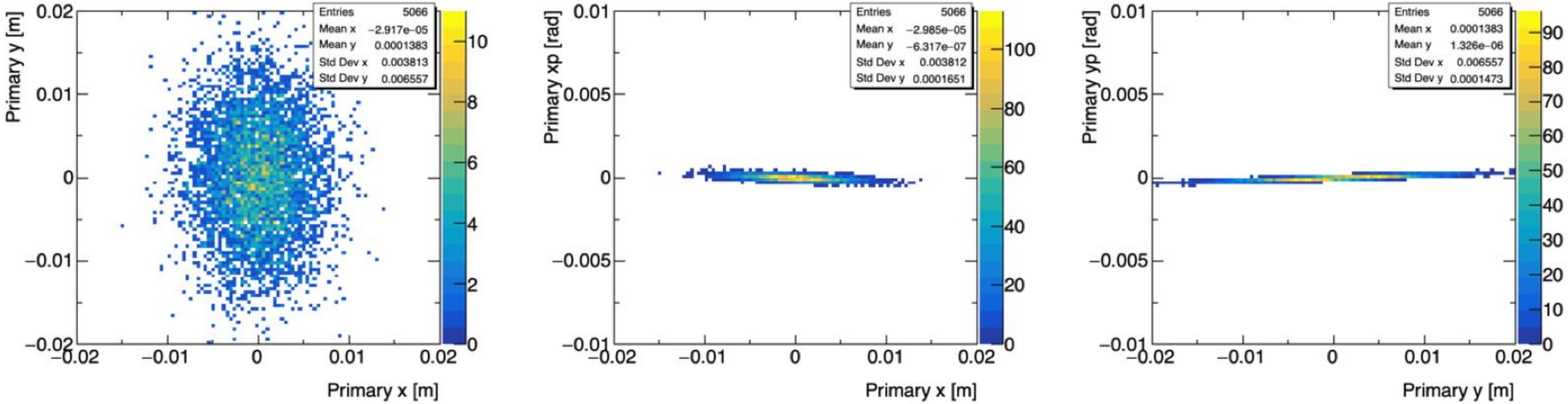


Folded laser geometry: 0.5mm wider laserwire

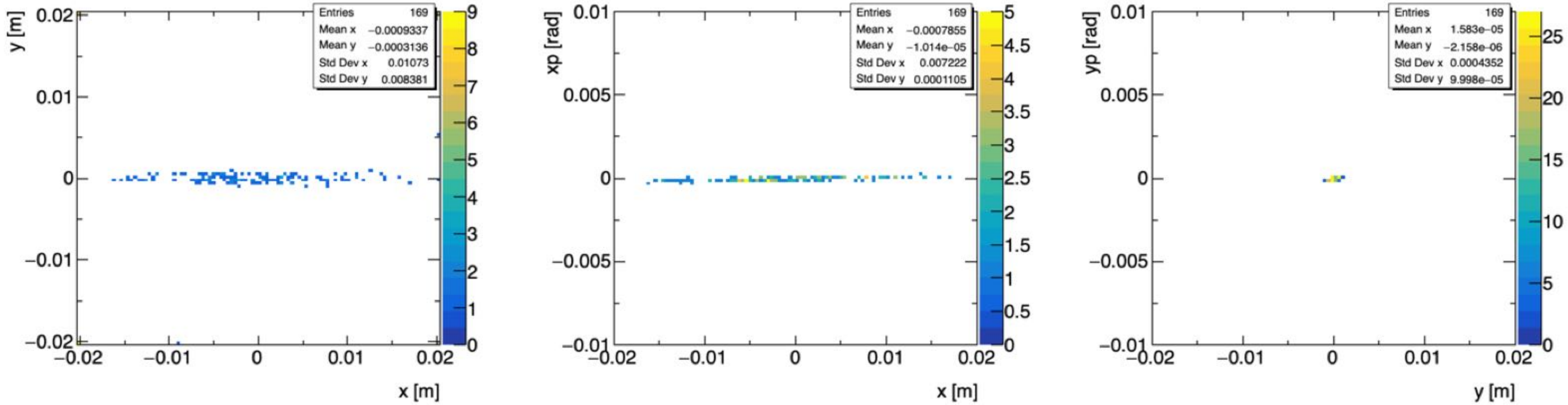


First look, H- beam, 0.5mm laserwire, forced photo-detachment interaction:

Primary input to model



Electrons (or H0) liberated, just after folder laser section:



Summary

- Rethinking geometry & wavelength for the single bunch option could enhance photon flux, to demonstrate ‘photon production’.
- Commercial Q-switched laser options available.

- Preliminary model developed in BDSIM:
- Folded laser geometry within new location region of SPS
- Interactions observed when simulating with H- ions and photo-detachment
- Ion excitation to be implemented for future studies.

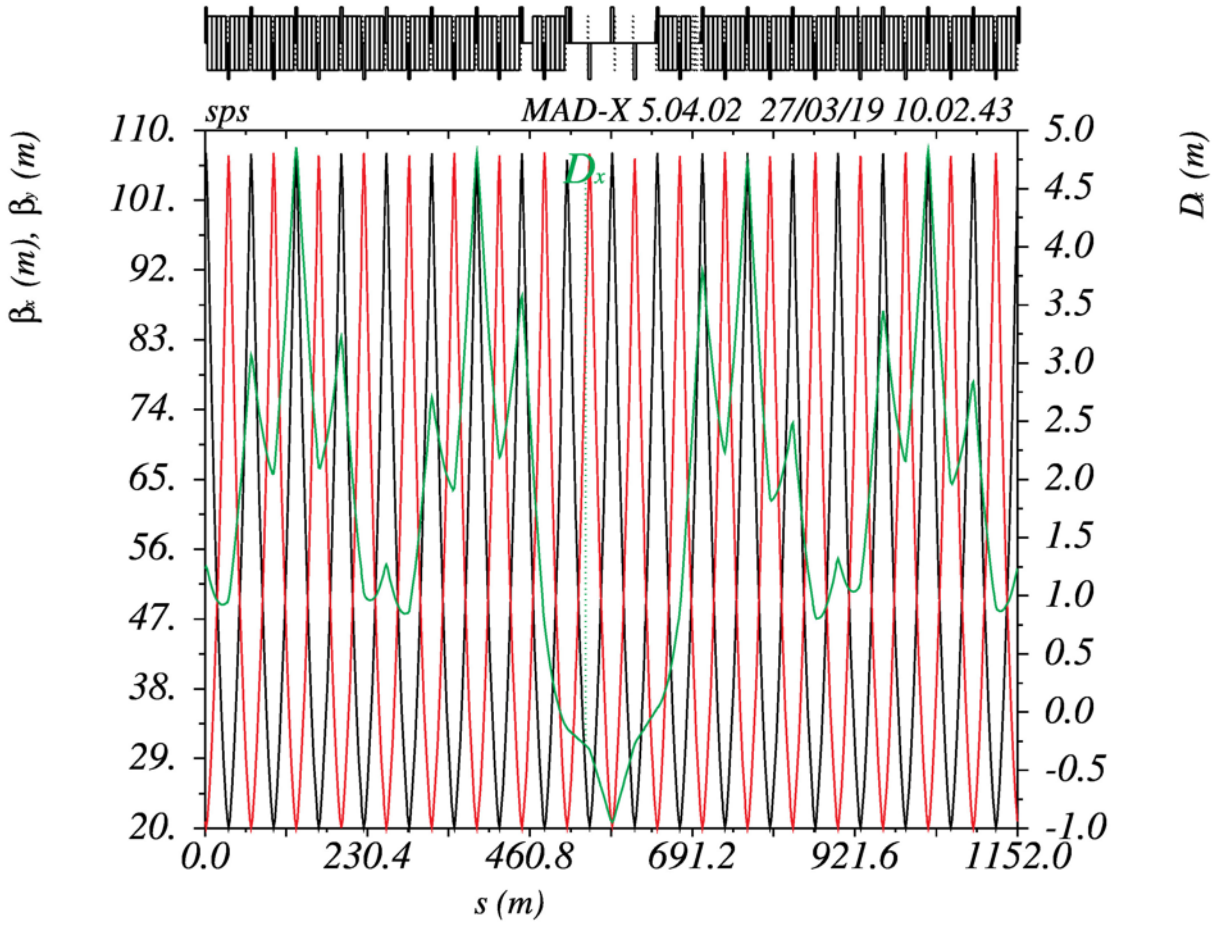
Back up

Dispersion and spatial targeting of most energetic ions

Reduce energy and spatial overlaps

- Instead of 1030 nm, 10ps pulse, with broad line width, spread over the full momentum range and spatial extent of the ion bunch, consider a 532nm long pulse, and narrow line width, targeting only the high energy ions in the bunch

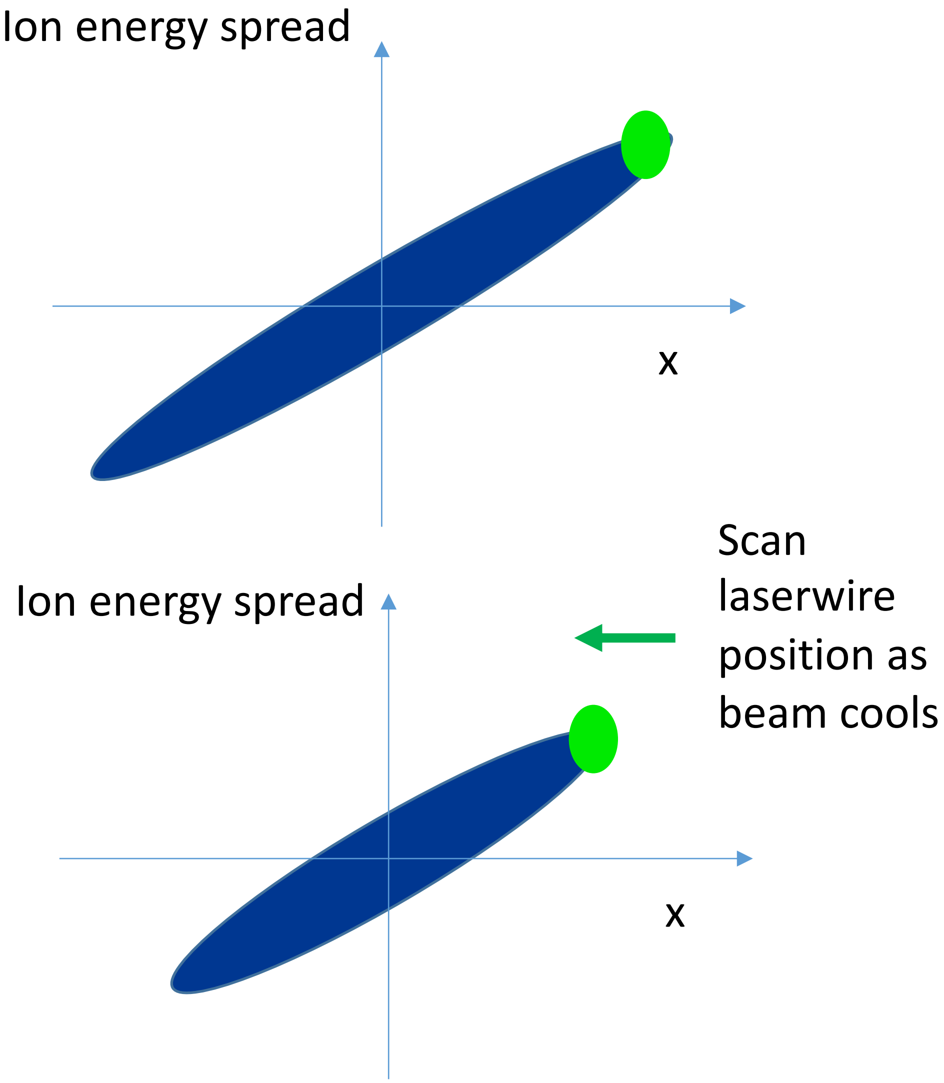
- If laser is in high dispersive region, the correlation with transverse beam position x, can be used to target high energy ions required to be cooled.



Dispersion and spatial targeting of most energetic ions

Energy scans

- Target spatially the ion energies required to be cooled, in a dispersive region of the accelerator.
- As the phase space is cooled, move the laserwire laterally in x to cool to lower energies.
- Or could use multiple vertical laserwires to cover x.
- Spectral scans could alternatively be achieved by varying the incident angle / mirror chirp (or tuning the laser wavelength).



Scan laserwire position as beam cools