

Accurate Spin Tracking on Modern Computer Architectures for Electron-Ion Colliders

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DOE/NP SBIR/STTR Exchange Meeting Meeting

Gaithersburg, MD

13–14 August 2019

RadiaSoft Provides a Gateway to Scientific Computing



Supported Codes

elegant

JSPEC (electron cooling)

Synergia

SRW (Synchrotron Radiation Workshop)

Warp VND (Vacuum Nanoelectronic Devices)

Warp PBA (Plasma-Based Accelerators)

Zgoubi

Advantages of using Sirepo

Easy to use: nothing to install, build, or maintain

Instantaneous collaboration: share your work with a single link

Archive & save: resume work weeks later with zero start-up time

You're not locked in: export files for command-line execution

RadiaSoft Contributes to the Community

At the *US Particle Accelerator School*, [RadiaSoft's JupyterHub server](#) provides access to scientific codes for simulating particle accelerators, FELs, and x-ray optics. The codes are preinstalled and can be executed from a browser-based terminal window, or from IPython notebooks.

USPAS:

- 2018W: Simulation of Beam and Plasma Systems (D. Bruhwiler co-taught + Sirepo/elegant)
- 2018S: Classical Mechanics and Electromagnetism (S. Webb taught 2 days)
- 2019W: Fundamentals of Accelerator Physics and Technology (K. Ruisard used Sirepo/elegant)
- 2019S: Fundamentals of Accelerator Physics and Technology (N. Neveu used Sirepo/elegant)
- *2020S: Spin Dynamics (F. Méot and D. Abell + Sirepo/Zgoubi)
- *2020S: Measurement and Control of Beams (M. Minty, F. Zimmerman, J. Edelen)

RadiaSoft Scholarship Students at USPAS:

- River Robles, 2019
- Jonathan Ang Sixian, 2018
- Maria Simanovskaia, 2018

Other Education:

- 1st Korea University Accelerator School, 2018 (C. S. Park used Sirepo/Synergia)
- NS3 Nuclear Science Summer School (S. Lund used Sirepo/elegant)

DOE/NP Interest: High-fidelity Simulations of Spin Dynamics Help Reduce Risk in Designs for EICs

In the *The 2015 Long Range Plan for Nuclear Science Origin*, the Nuclear Science Advisory Committee (NSAC) recommends “a high-energy high-luminosity polarized electron ion collider (EIC) as the highest priority for new facility construction following the completion of FRIB.”

The origin of nuclear spin remains a significant puzzle in nuclear science.

Because the relevant statistical errors $\propto 1/P^2$, highly polarized beams make the experimental effort more efficient.

Plans for Zgoubi Include Enhancements to both Performance and Usability

Implement a Zgoubi graphical interface in Sirepo. (80%)

Implement single-click execution of Zgoubi on available linux clusters. (25%)

GUI

Update the Zgoubi code base to the Fortran 2018. (80%)

Re-implement Zgoubi's particle update algorithm. (65%)

performance

Parallelize Zgoubi using Fortran 2018. (35%)

Implement symplectic tracking for field maps. (30%)

Add closed-orbit correction to Zgoubi. (85%), with F. Méot

capabilities

Assess and improve the spin dynamics in electron and ion rings for the eRHIC design. (starting this month)

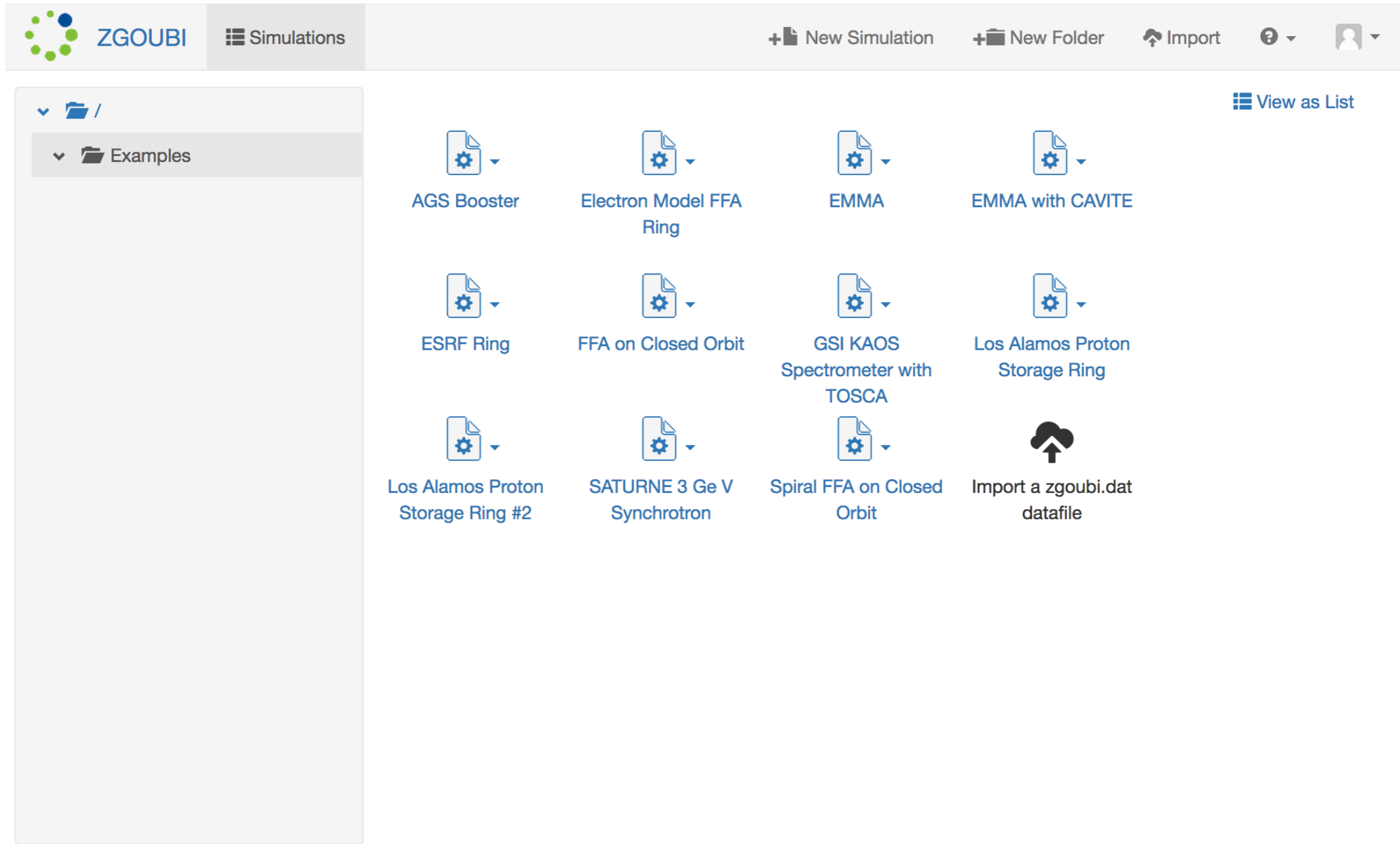
Benchmark Zgoubi with BMad and other codes used for simulating JLEIC ring designs. (15%)

science

Plans for Zgoubi Include Enhancements to both Performance and Usability

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 - Add closed-orbit correction to Zgoubi. (85%), *with F. Méot*
 - Assess and improve the spin dynamics in electron and ion rings for the eRHIC design. (*starting this month*)
 - Benchmark Zgoubi with BMad and other codes used for simulating JLEIC ring designs. (15%)
- GUI**
- performance**
- capabilities**
- science**

Streamline Zgoubi Simulations: A Sirepo Interface for Zgoubi

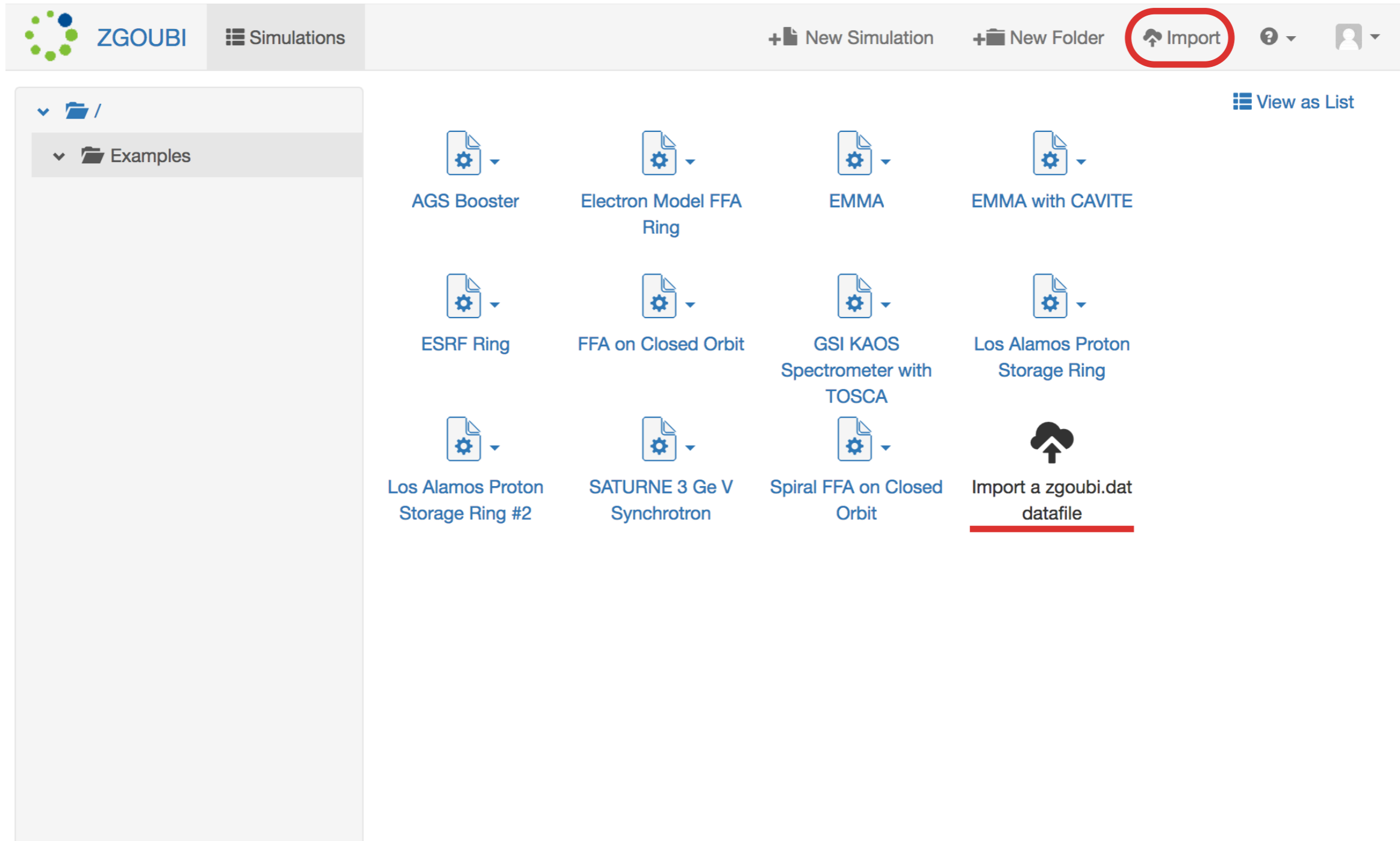


The screenshot displays the Sirepo interface for ZGOUBI simulations. The top navigation bar includes the ZGOUBI logo, a 'Simulations' tab, and action buttons for 'New Simulation', 'New Folder', 'Import', a help icon, and a user profile icon. A left sidebar shows a file tree with an 'Examples' folder. The main area displays a grid of simulation examples, each with a gear icon and a dropdown arrow. The examples are:

- AGS Booster
- Electron Model FFA Ring
- EMMA
- EMMA with CAVITE
- ESRF Ring
- FFA on Closed Orbit
- GSI KAOS Spectrometer with TOSCA
- Los Alamos Proton Storage Ring
- Los Alamos Proton Storage Ring #2
- SATURNE 3 Ge V Synchrotron
- Spiral FFA on Closed Orbit
- Import a zgoubi.dat datafile

A 'View as List' button is located in the top right corner of the main area.

The Sirepo Interface for Zgoubi: Import, Build, and Edit a Lattice



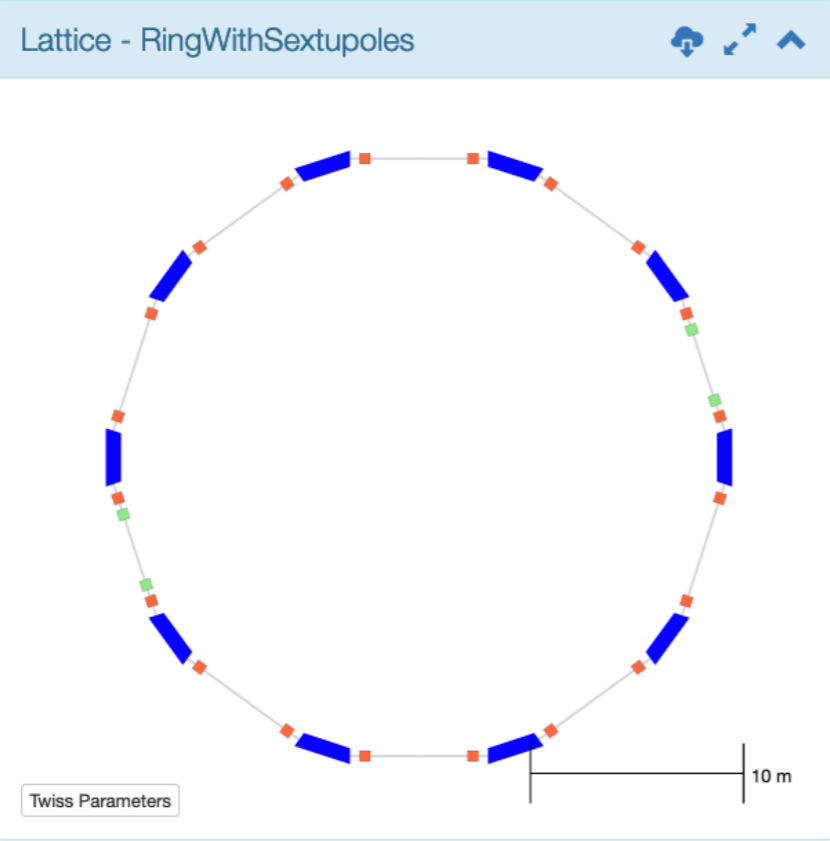
The screenshot shows the Sirepo ZGOUBI interface. The top navigation bar includes the ZGOUBI logo, a 'Simulations' tab, and buttons for 'New Simulation', 'New Folder', and 'Import' (circled in red). A 'View as List' button is also present. On the left, a sidebar shows a folder structure with 'Examples' expanded. The main area displays a grid of simulation examples, each with a gear icon and a dropdown arrow. The examples are:

- AGS Booster
- Electron Model FFA Ring
- EMMA
- EMMA with CAVITE
- ESRF Ring
- FFA on Closed Orbit
- GSI KAOS Spectrometer with TOSCA
- Los Alamos Proton Storage Ring
- Los Alamos Proton Storage Ring #2
- SATURNE 3 Ge V Synchrotron
- Spiral FFA on Closed Orbit
- Import a zgoubi.dat datafile (underlined in red)

The Sirepo Interface for Zgoubi: Import, Build, and Edit a Lattice—cont.

ZGOUBI Simulations Los Alamos Proton Storage Ring #2 Lattice Bunch Twiss Visualization

Lattice - RingWithSextupoles



Twiss Parameters

Beamlines

Name	Description	Length	Bend
BL1	(D1,QD,D2,SBEND,D2,QF,D1)	9.022m	36.0°
BL2	(D1,QD,D2,SBEND,D2,QF,D3,SF,C)	9.022m	36.0°
BL3	(D4,SD,D3,QD,D2,SBEND,D2,QF,I)	9.022m	36.0°
Ring	(BL1,BL1,BL1,BL1,BL1,BL1,BL1,E)	90.22m	0.0°
RingWithSextupoles	(BL1,BL2,BL3,BL1,BL1,BL1,BL2,E)	90.22m	0.0°

Beamline Editor - RingWithSextupoles

drag and drop elements here to define the beamline

BL1

BL2

BL3

BL1

BL1

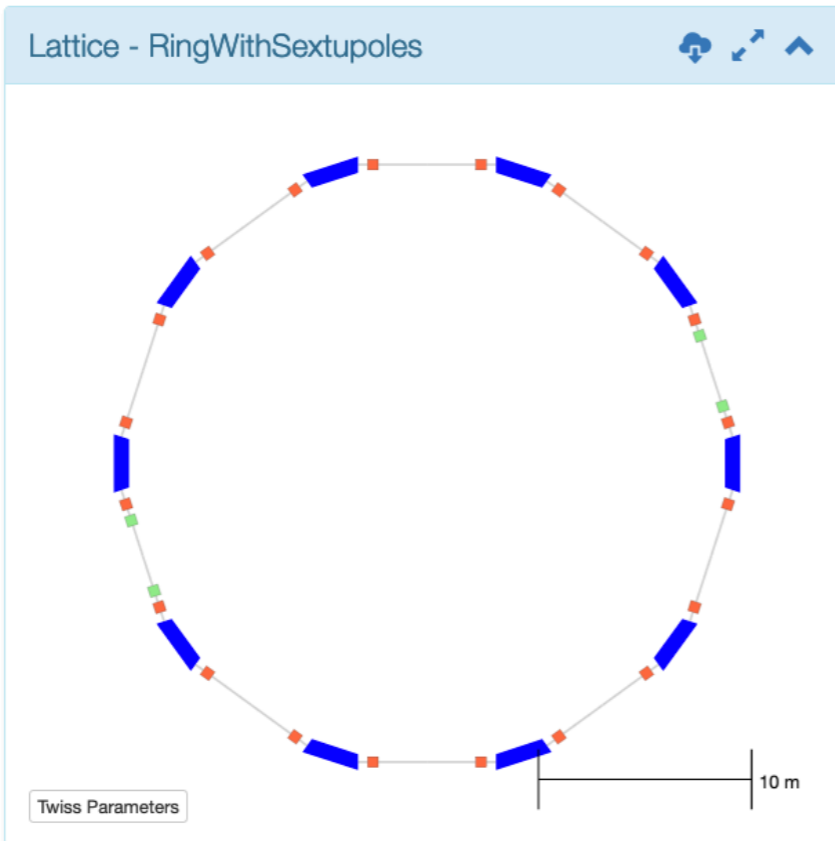
Beamline Elements

Name	Description	Length	Bend
BEND			
SBEND	B1=12,CS_0=0.2401,CS_1=1.863	2.508m	36.0°
DRIFT			
D1		2.286m	
D2		450.0mm	
D3		300.0mm	
D4		1.486m	
QUADRUPO			
QD	B_0=-2.68,CS_0=0.1122,CS_1=6.	500.0mm	
QF	B_0=1.95,CS_0=0.1122,CS_1=6.2	500.0mm	
SEXTUPO			
SD	B_0=-0.24,CS_0=0.1122,CS_1=6.	500.0mm	
SF	B_0=0.16,CS_0=0.1122,CS_1=6.2	500.0mm	

The Sirepo Interface for Zgoubi: Import, Build, and Edit a Lattice—cont.

ZGOUBI Simulations Los Alamos Proton Storage Ring #2 **... Lattice** Bunch Twiss Visualization

Lattice - RingWithSextupoles



Twiss Parameters

Beamlines

Name	Description	Length	Bend
BL1	(D1,QD,D2,SBEND,D2,QF,D1)	9.022m	36.0°
BL2	(D1,QD,D2,SBEND,D2,QF,D3,SF,C)	9.022m	36.0°
BL3	(D4,SD,D3,QD,D2,SBEND,D2,QF,I)	9.022m	36.0°
Ring	(BL1,BL1,BL1,BL1,BL1,BL1,BL1,F)	90.22m	0.0°
RingWithSextupoles	(BL1,BL2,BL3,BL1,BL1,BL1,BL2,F)	90.22m	0.0°

Beamline Editor - RingWithSextupoles

drag and drop elements here to define the beamline

BL1

BL2

BL3

BL1

BL1

Beamline Elements

Name	Description	Length	Bend
BEND			
SBEND	B1=12,CS_0=0.2401,CS_1=1.863	2.508m	36.0°
DRIFT			
D1		2.286m	
D2		450.0mm	
D3		300.0mm	
D4		1.486m	
QUADRUPO			
QD	B_0=-2.68,CS_0=0.1122,CS_1=6.	500.0mm	
QF	B_0=1.95,CS_0=0.1122,CS_1=6.2	500.0mm	
SEXTUPOL			
SD	B_0=-0.24,CS_0=0.1122,CS_1=6.	500.0mm	
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The Sirepo Interface for Zgoubi: Import, Build, and Edit a Lattice—cont.

ZGOUBI Simulations Los Alamos Proton Storage Ring #2 Lattice Bunch Twiss Visualization

Lattice - RingWithSextupoles

Twiss Parameters

Beamlines

Name	Description	Length	Bend
BL1	(D1,QD,D2,SBEND,D2,QF,D1)	9.022m	36.0°
BL2	(D1,QD,D2,SBEND,D2,QF,D3,SF,C)	9.022m	36.0°
BL3	(D4,SD,D3,QD,D2,SBEND,D2,QF,I)	9.022m	36.0°
Ring	(BL1,BL1,BL1,BL1,BL1,BL1,BL1,E)	90.22m	0.0°
RingWithSextupoles	(BL1,BL2,BL3,BL1,BL1,BL1,BL2,E)	90.22m	0.0°

Beamline Elements

Name	Description	Length	Bend
BEND			
SBEND	B1=12,CS_0=0.2401,CS_1=1.863	2.508m	36.0°
DRIFT			
D1		2.286m	
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D3		300.0mm	
D4		1.486m	
QUADRUPO			
QD	B_0=-2.68,CS_0=0.1122,CS_1=6.	500.0mm	
QF	B_0=1.95,CS_0=0.1122,CS_1=6.2	500.0mm	
SEXTUPO			
SD	B_0=-0.24,CS_0=0.1122,CS_1=6.	500.0mm	
SF	B_0=0.16,CS_0=0.1122,CS_1=6.2	500.0mm	

Beamline Editor - RingWithSextupoles

drag and drop elements here to define the beamline

BL1

BL2

BL3

BL1

BL1

BL1

BL2

BL3

BL1

BL1

The Sirepo Interface for Zgoubi: Import, Build, and Edit a Lattice—cont.

ZGOUBI Simulations Los Alamos Proton Storage Ring #2 Lattice Bunch Twiss Visualization

Lattice - RingWithSextupoles

Beamlines

Name	Description	Length	Bend
BL1	(D1,QD,D2,SBEND,D2,QF,D1)	9.022m	36.0°
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Ring	(BL1,BL1,BL1,BL1,BL1,BL1,BL1,F)	90.22m	0.0°
RingWithSextupoles	(BL1,BL2,BL3,BL1,BL1,BL1,BL2,F)	90.22m	0.0°

Beamline Elements

	Length	Bend
D1,CS_1=1.863	2.508m	36.0°
	2.286m	
	450.0mm	
	300.0mm	
	1.486m	
QD	B_0=-2.68,CS_0=0.1122,CS_1=6.	500.0mm
QF	B_0=1.95,CS_0=0.1122,CS_1=6.2	500.0mm
SEXTUPOL		
SD	B_0=-0.24,CS_0=0.1122,CS_1=6.	500.0mm
SF	B_0=0.16,CS_0=0.1122,CS_1=6.2	500.0mm

New Beamline Element

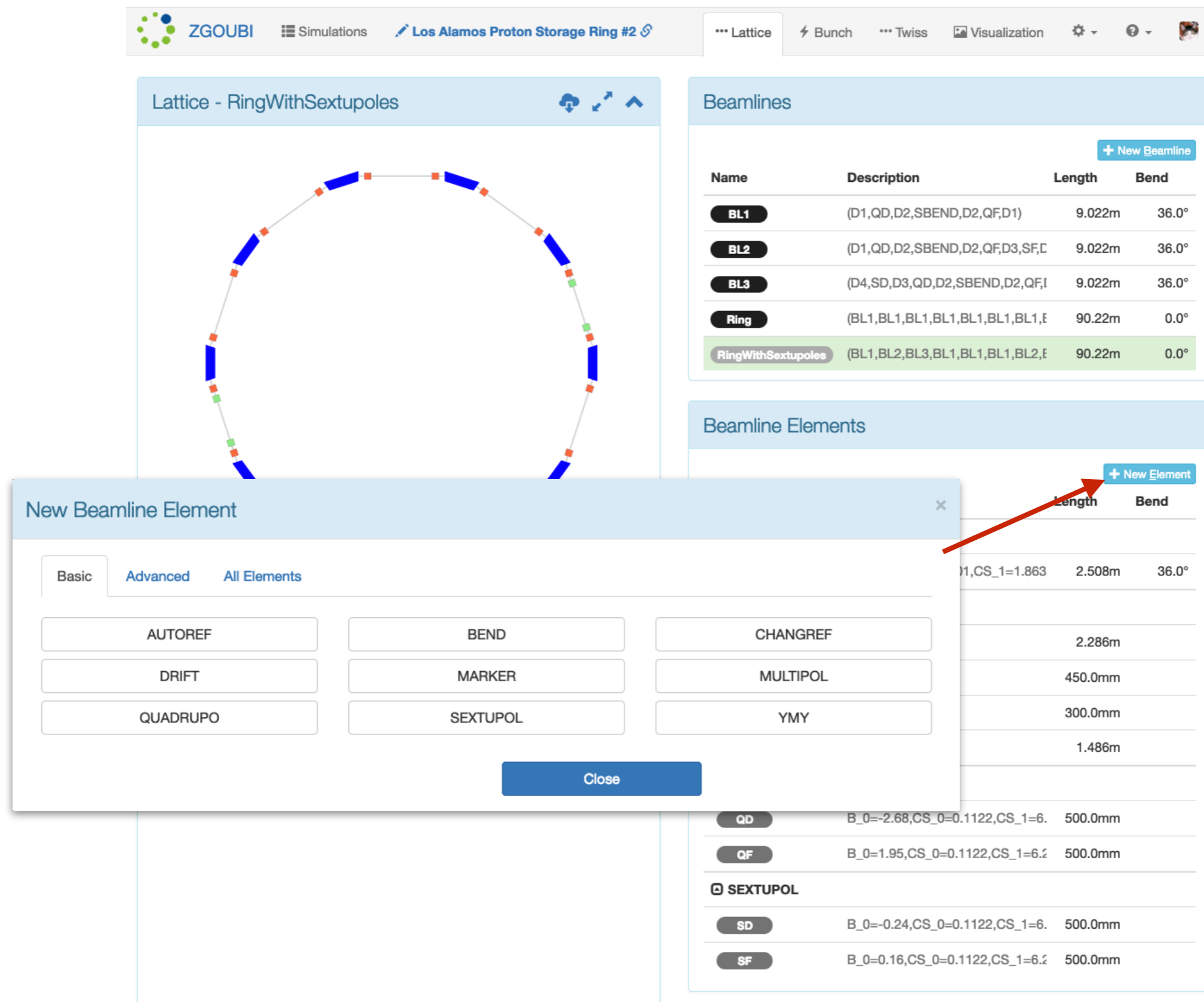
Basic Advanced All Elements

AUTOREF BEND CHANGREF

DRIFT MARKER MULTIPOL

QUADRUPO SEXTUPOL YMY

Close



The Sirepo Interface for Zgoubi: Import, Build, and Edit a Lattice—cont.

ZGOUBI Simulations Los Alamos Proton Storage Ring #2 Lattice Bunch Twiss Visualization

Lattice - RingWithSextupoles

Twiss Parameters

Beamlines

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BL1	(D1,QD,D2,SBEND,D2,QF,D1)	9.022m	36.0°
BL2	(D1,QD,D2,SBEND,D2,QF,D3,SF,C)	9.022m	36.0°
BL3	(D4,SD,D3,QD,D2,SBEND,D2,QF,I)	9.022m	36.0°
Ring	(BL1,BL1,BL1,BL1,BL1,BL1,BL1,E)	90.22m	0.0°
RingWithSextupoles	(BL1,BL2,BL3,BL1,BL1,BL1,BL2,E)	90.22m	0.0°

Beamline Elements

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QUADRUPO			
QD	B_0=-2.68,CS_0=0.1122,CS_1=6.	500.0mm	
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SEXTUPO			
SD	B_0=-0.24,CS_0=0.1122,CS_1=6.	500.0mm	
SF	B_0=0.16,CS_0=0.1122,CS_1=6.2	500.0mm	

Beamline Editor - RingWithSextupoles

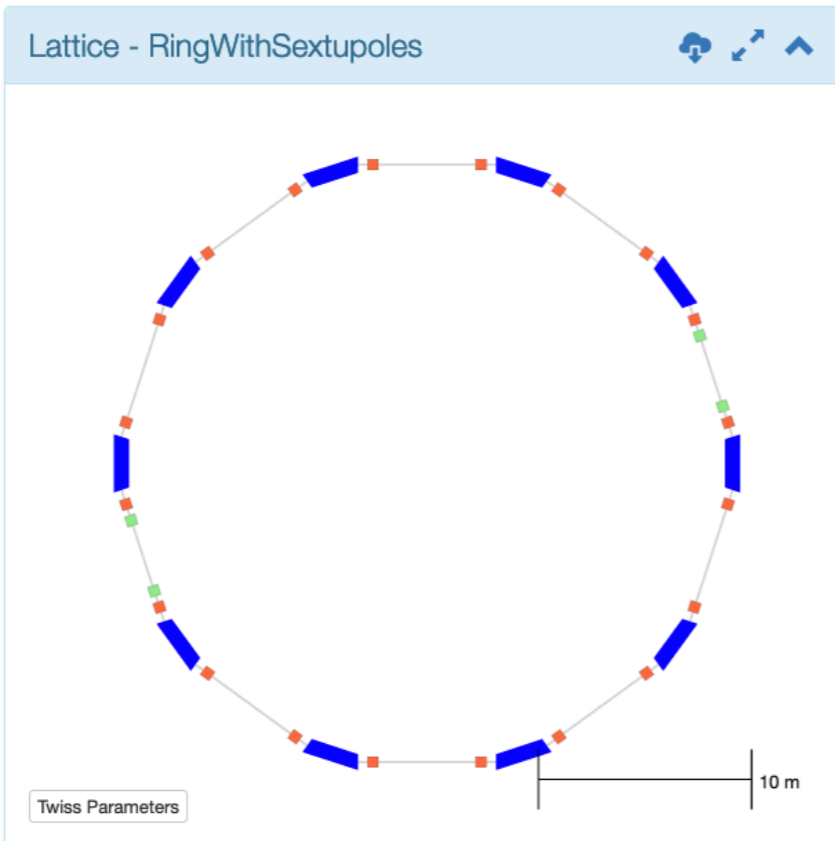
drag and drop elements here to define the beamline

BL1 BL2 BL3 BL1 BL1
BL1 BL2 BL3 BL1 BL1

The Sirepo Interface for Zgoubi: Import, Build, and Edit a Lattice—cont.

ZGOUBI Simulations Los Alamos Proton Storage Ring #2 Lattice Bunch Twiss Visualization

Lattice - RingWithSextupoles



Twiss Parameters

Beamlines

Name	Description	Length	Bend
BL1	(D1,QD,D2,SBEND,D2,QF,D1)	9.022m	36.0°
BL2	(D1,QD,D2,SBEND,D2,QF,D3,SF,C)	9.022m	36.0°
BL3	(D4,SD,D3,QD,D2,SBEND,D2,QF,I)	9.022m	36.0°
Ring	(BL1,BL1,BL1,BL1,BL1,BL1,BL1,E)	90.22m	0.0°
RingWithSextupoles	(BL1,BL2,BL3,BL1,BL1,BL1,BL2,E)	90.22m	0.0°

Beamline Editor - RingWithSextupoles

drag and drop elements here to define the beamline

BL1

BL2

BL3

BL1

BL1

BL1

BL2

BL3

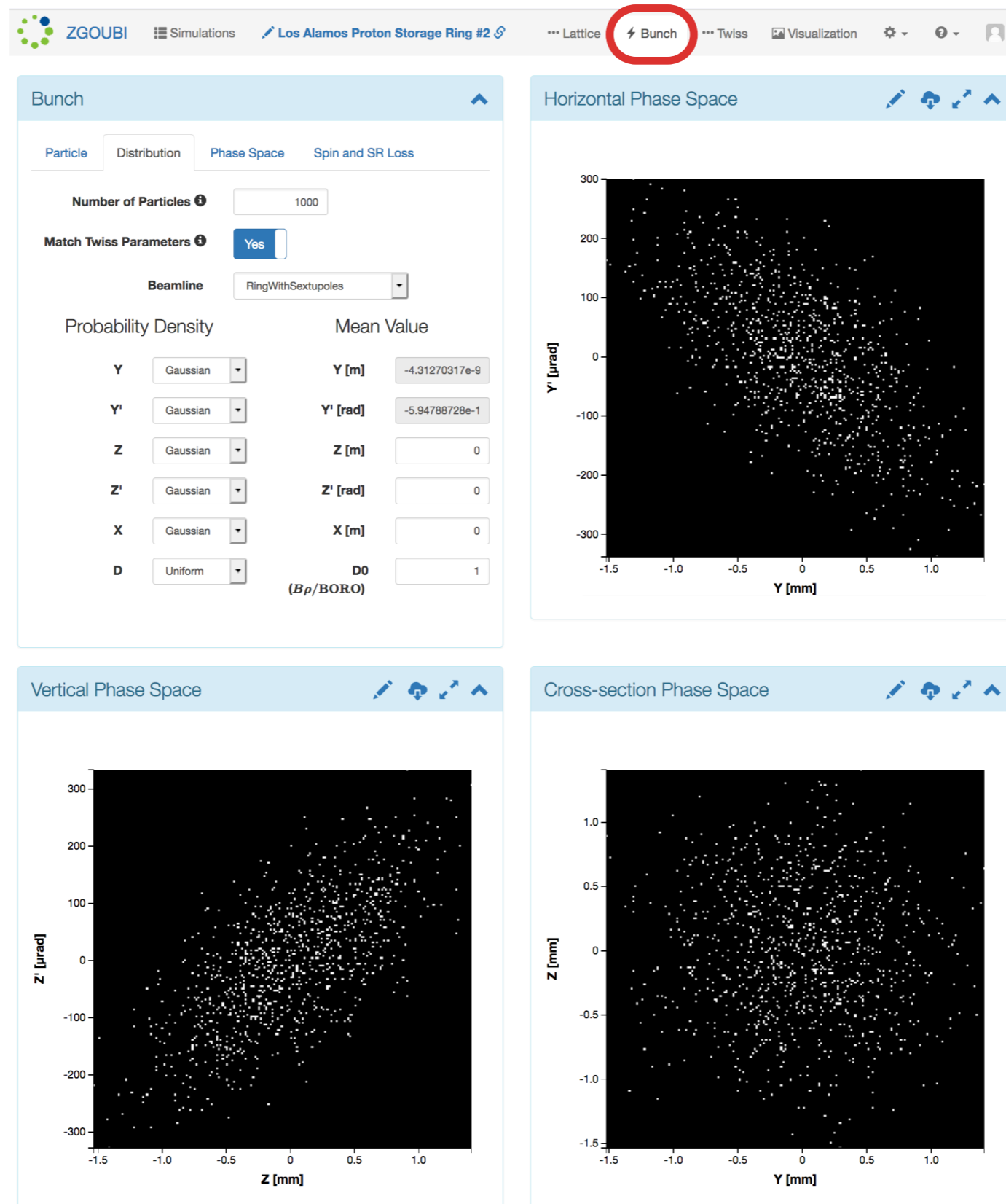
BL1

BL1

Beamline Elements

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SBEND	B1=12,CS_0=0.2401,CS_1=1.863	2.508m	36.0°
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D1		2.286m	
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D3		300.0mm	
D4		1.486m	
QUADRUPO			
QD	B_0=-2.68,CS_0=0.1122,CS_1=6.	500.0mm	
QF	B_0=1.95,CS_0=0.1122,CS_1=6.2	500.0mm	
SEXTUPOL			
SD	B_0=-0.24,CS_0=0.1122,CS_1=6.	500.0mm	
SF	B_0=0.16,CS_0=0.1122,CS_1=6.2	500.0mm	

The Sirepo Interface for Zgoubi: Generate a (matched) bunch



The screenshot displays the Sirepo interface for Zgoubi, specifically the 'Bunch' configuration panel and three phase space plots. The 'Bunch' panel is on the left, and the plots are on the right.

Bunch Configuration Panel:

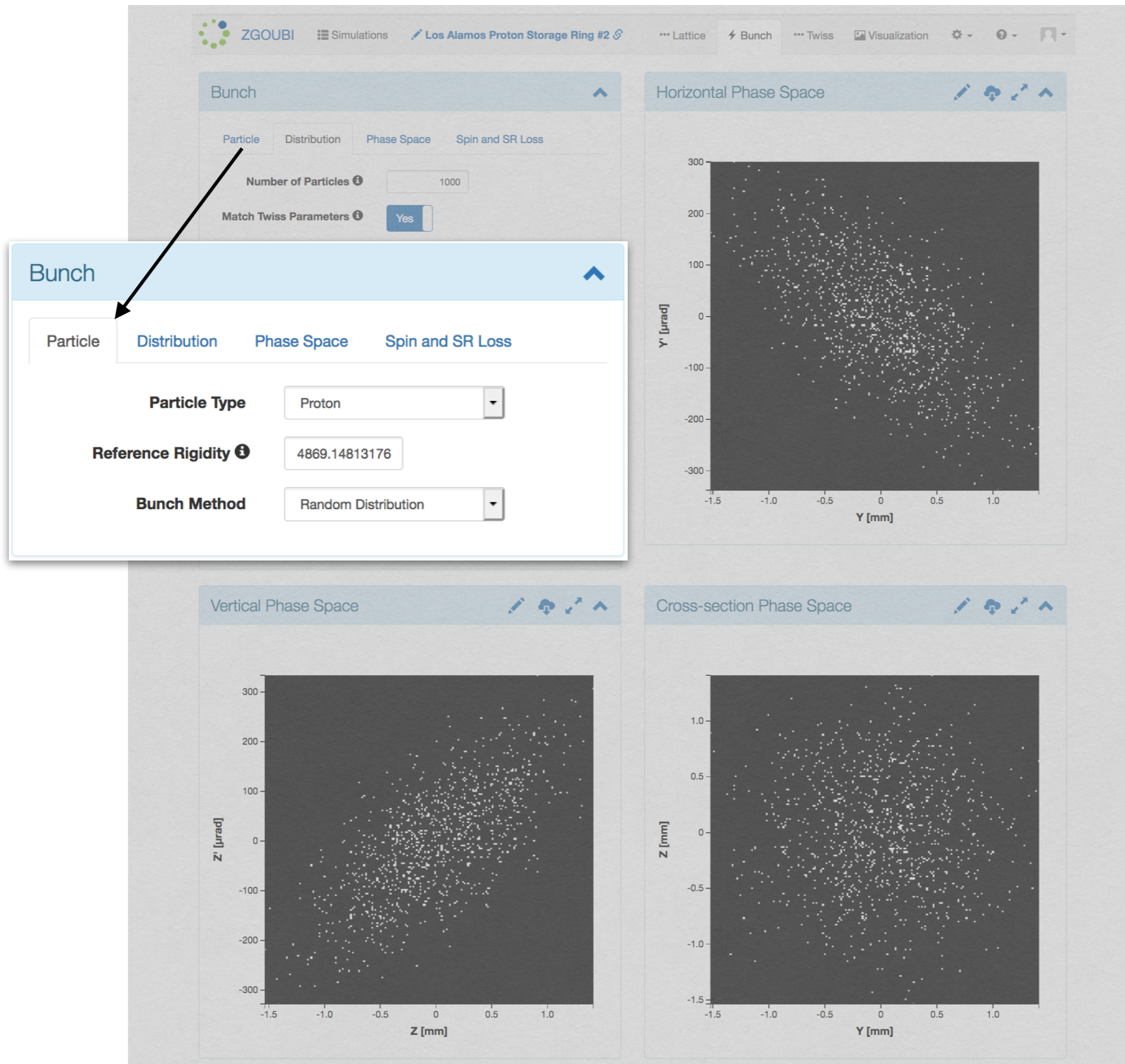
- Number of Particles: 1000
- Match Twiss Parameters: Yes
- Beamline: RingWithSextupoles
- Probability Density and Mean Value settings:
 - Y: Gaussian, Y [m]: -4.31270317e-9
 - Y': Gaussian, Y' [rad]: -5.94788728e-1
 - Z: Gaussian, Z [m]: 0
 - Z': Gaussian, Z' [rad]: 0
 - X: Gaussian, X [m]: 0
 - D: Uniform, D0 (Bρ/BORO): 1

Horizontal Phase Space Plot: Shows the distribution of particles in the Y-Y' plane. The Y-axis is Y [mm] (ranging from -1.5 to 1.0) and the Y' axis is Y' [μrad] (ranging from -300 to 300).

Vertical Phase Space Plot: Shows the distribution of particles in the Z-Z' plane. The Z-axis is Z [mm] (ranging from -1.5 to 1.0) and the Z' axis is Z' [μrad] (ranging from -300 to 300).

Cross-section Phase Space Plot: Shows the distribution of particles in the Y-Z plane. The Y-axis is Y [mm] (ranging from -1.5 to 1.0) and the Z-axis is Z [mm] (ranging from -1.5 to 1.0).

The Sirepo Interface for Zgoubi: Generate a (matched) bunch—cont.



The screenshot displays the Sirepo interface for Zgoubi, showing the configuration for generating a bunch. The main window is titled "ZGOUBI" and includes a navigation bar with "Simulations", "Los Alamos Proton Storage Ring #2", "Lattice", "Bunch", "Twiss", and "Visualization".

The "Bunch" panel is active, showing the following settings:

- Number of Particles: 1000
- Match Twiss Parameters: Yes

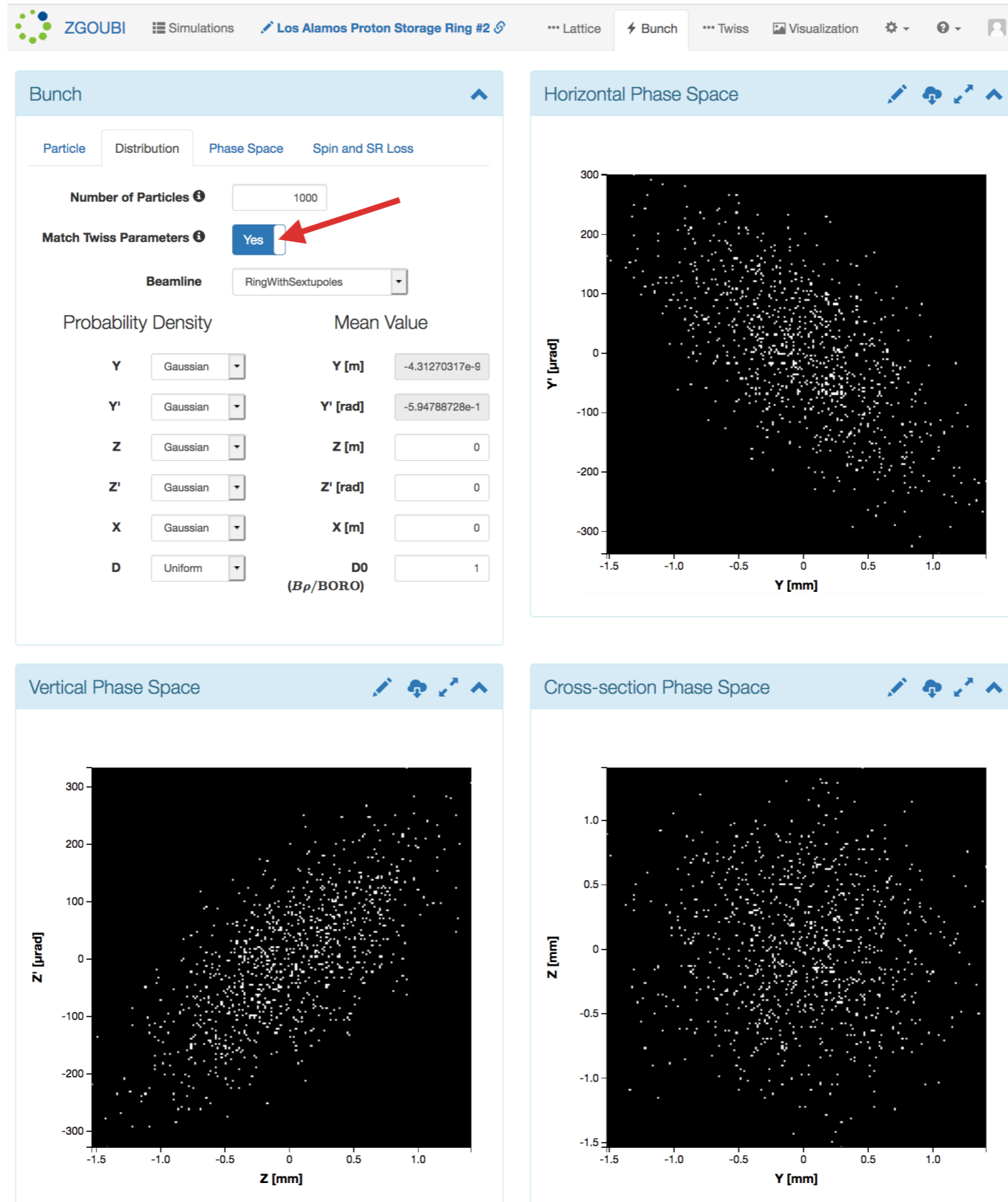
A detailed view of the "Bunch" panel settings is shown in a callout box:

- Particle Type: Proton
- Reference Rigidity: 4869.14813176
- Bunch Method: Random Distribution

The interface also displays three phase space plots:

- Horizontal Phase Space:** A scatter plot showing the distribution of particles in the horizontal plane, with the vertical axis labeled Y' [μrad] and the horizontal axis labeled Y [mm].
- Vertical Phase Space:** A scatter plot showing the distribution of particles in the vertical plane, with the vertical axis labeled Z' [μrad] and the horizontal axis labeled Z [mm].
- Cross-section Phase Space:** A scatter plot showing the distribution of particles in the cross-section plane, with the vertical axis labeled Z [mm] and the horizontal axis labeled Y [mm].

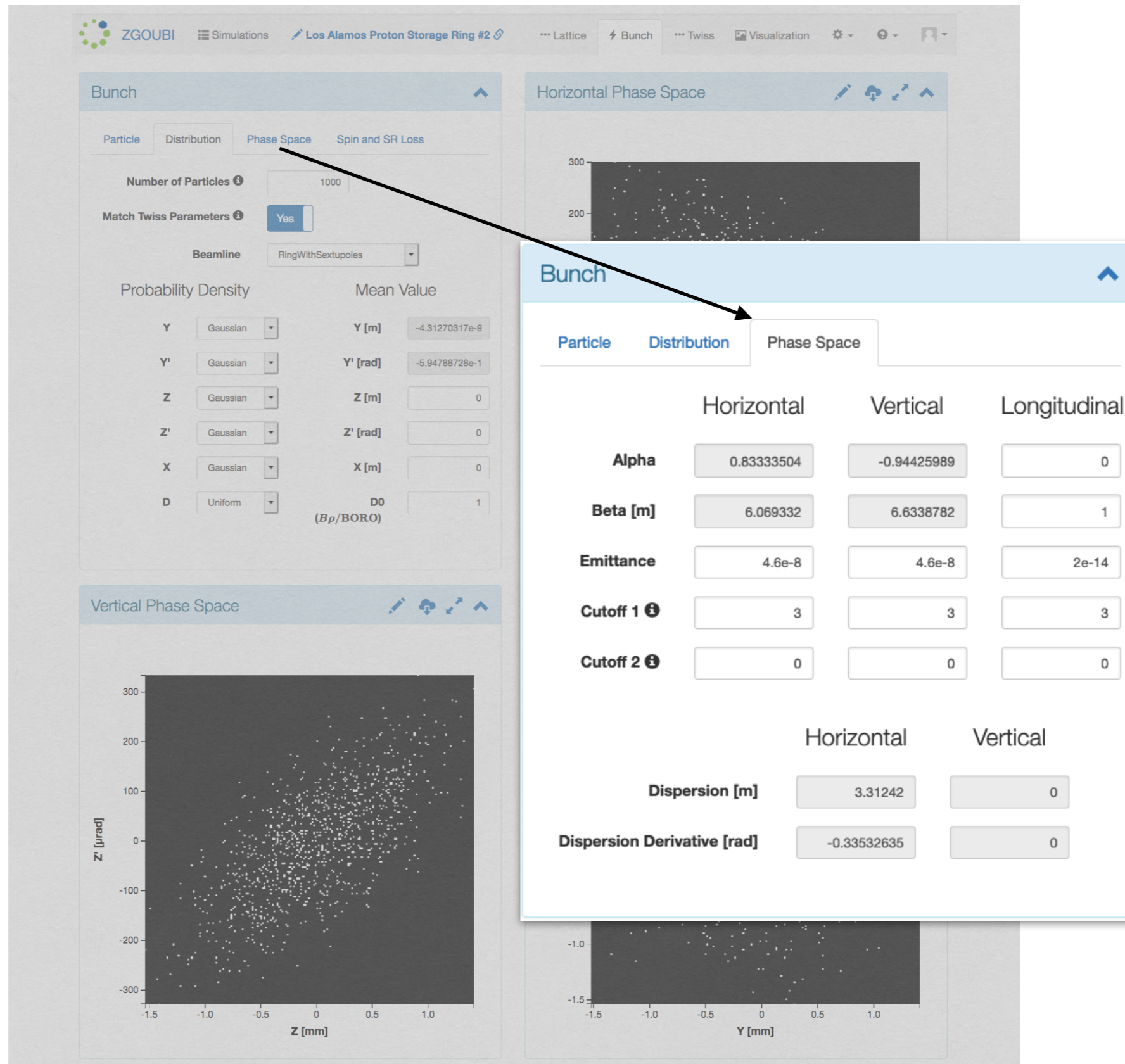
The Sirepo Interface for Zgoubi: Generate a (matched) bunch



The screenshot displays the Sirepo interface for Zgoubi, showing the configuration for generating a bunch. The interface includes a top navigation bar with tabs for Simulations, Los Alamos Proton Storage Ring #2, Lattice, Bunch, Twiss, Visualization, and settings. The main panel is divided into four sections:

- Bunch Configuration:** This section allows setting the number of particles (1000) and matching Twiss parameters (Yes, indicated by a red arrow). The beamline is set to 'RingWithSextupoles'. The probability density and mean values for Y, Y', Z, Z', X, and D are specified.
- Horizontal Phase Space:** A scatter plot showing the distribution of particles in the Y-Y' plane. The Y-axis is in microradians (μrad) and the Y-axis is in millimeters (mm).
- Vertical Phase Space:** A scatter plot showing the distribution of particles in the Z-Z' plane. The Z-axis is in microradians (μrad) and the Z-axis is in millimeters (mm).
- Cross-section Phase Space:** A scatter plot showing the distribution of particles in the Y-Z plane. The Y-axis is in millimeters (mm) and the Z-axis is in millimeters (mm).

The Sirepo Interface for Zgoubi: Generate a (matched) bunch—cont.



The screenshot shows the Sirepo interface for Zgoubi. The main window displays the 'Bunch' configuration panel on the left and phase space plots on the right. The 'Bunch' panel includes settings for the number of particles (1000), matching Twiss parameters (Yes), and beamline selection (RingWithSextupoles). It also features a 'Probability Density' section with Gaussian distributions for Y, Y', Z, Z', X, and D, and a 'Mean Value' section with input fields for Y [m], Y' [rad], Z [m], Z' [rad], X [m], and D0 (Bρ/BORO).

The 'Horizontal Phase Space' plot shows a distribution of particles in the Y-Z plane. The 'Vertical Phase Space' plot shows a distribution in the Z-Z' plane. A 'Bunch' panel is overlaid on the right, showing detailed parameters for the bunch distribution.

	Horizontal	Vertical	Longitudinal
Alpha	0.83333504	-0.94425989	0
Beta [m]	6.069332	6.6338782	1
Emittance	4.6e-8	4.6e-8	2e-14
Cutoff 1 ⓘ	3	3	3
Cutoff 2 ⓘ	0	0	0

	Horizontal	Vertical
Dispersion [m]	3.31242	0
Dispersion Derivative [rad]	-0.33532635	0

The Sirepo Interface for Zgoubi: View Lattice Parameters

ZGOUBI Simulations [Los Alamos Proton Storage Ring #2](#) Lattice Bunch **Twiss** Visualization

Simulation Settings

Beamline: RingWithSextupoles

Twiss Summary

Particle energy [GeV]	1.735274452
Particle gamma	1.849436407
Beamline length [m]	90.224
Momentum compaction factor	0.2256970818
Orbit5 [m]	0
Transition energy gamma	2.104926948
Energy difference	0

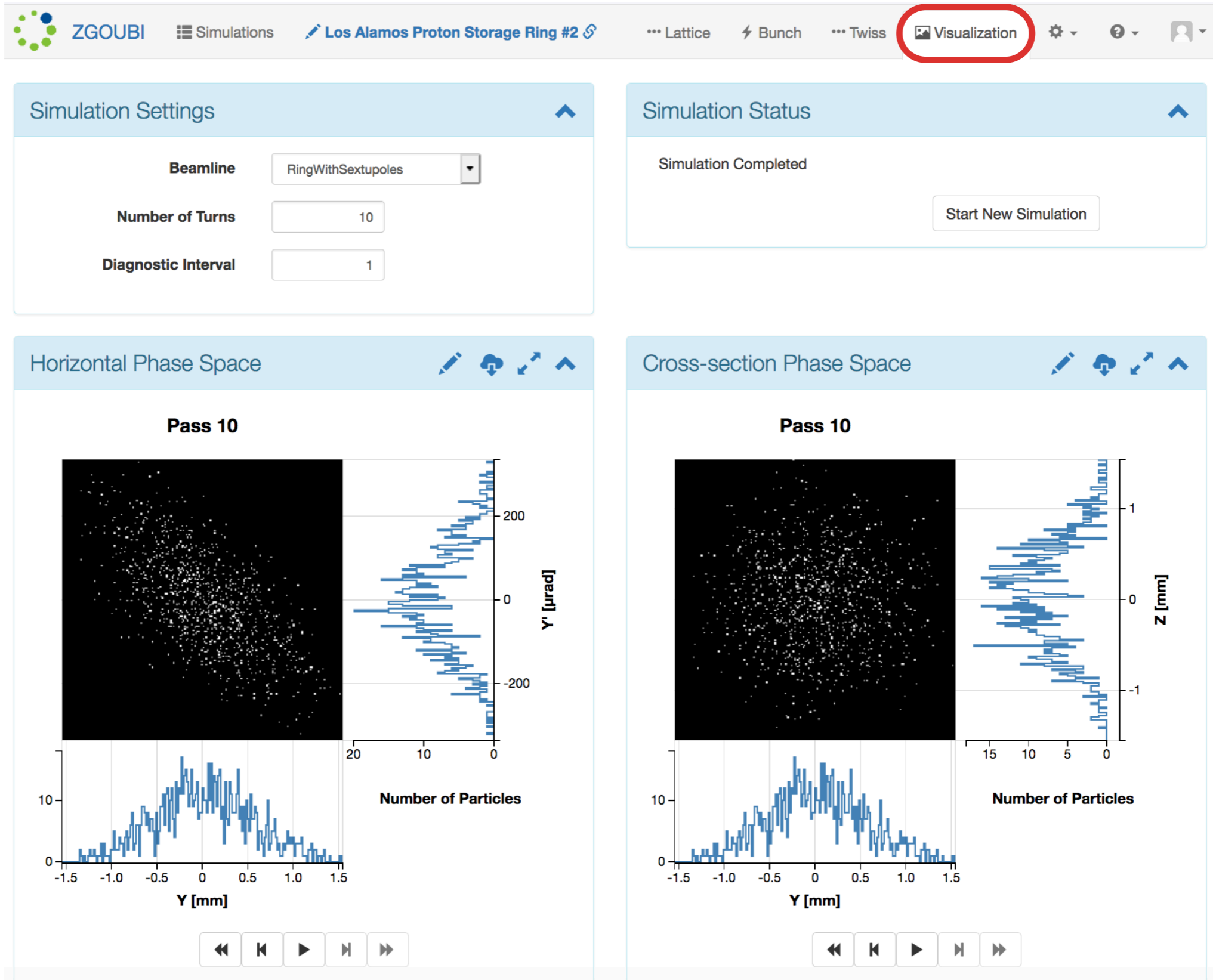
	Horizontal	Vertical
Tune (fractional)	0.254059634	0.2499258355
Chromaticity	0.06118138587	0.165473148
Maximum dispersion [m]	4.07913686	0
Minimum dispersion [m]	2.54570295	0
Closed orbit maximum deviation [m]	7.7049917e-7	0
Closed orbit minimum deviation [m]	-7.65844165e-7	0
Maximum beta [m]	11.6845897	12.4426201
Minimum beta [m]	3.71808947	3.8065672
Closed orbit RMS deviation [m]	4.28720024e-7	0
RMS dispersion [m]	0.63471242	0

Twiss Parameters

Legend:
● Horizontal beta [m]
● Vertical beta [m]
● Horizontal dispersion [m]

Optics

The Sirepo Interface for Zgoubi: Visualize the Beam



The screenshot shows the Sirepo interface for Zgoubi simulation. The top navigation bar includes the ZGOUBI logo, a menu icon, and navigation options: Simulations, Los Alamos Proton Storage Ring #2, Lattice, Bunch, Twiss, Visualization (highlighted with a red circle), settings, help, and user profile.

Two panels are visible at the top:

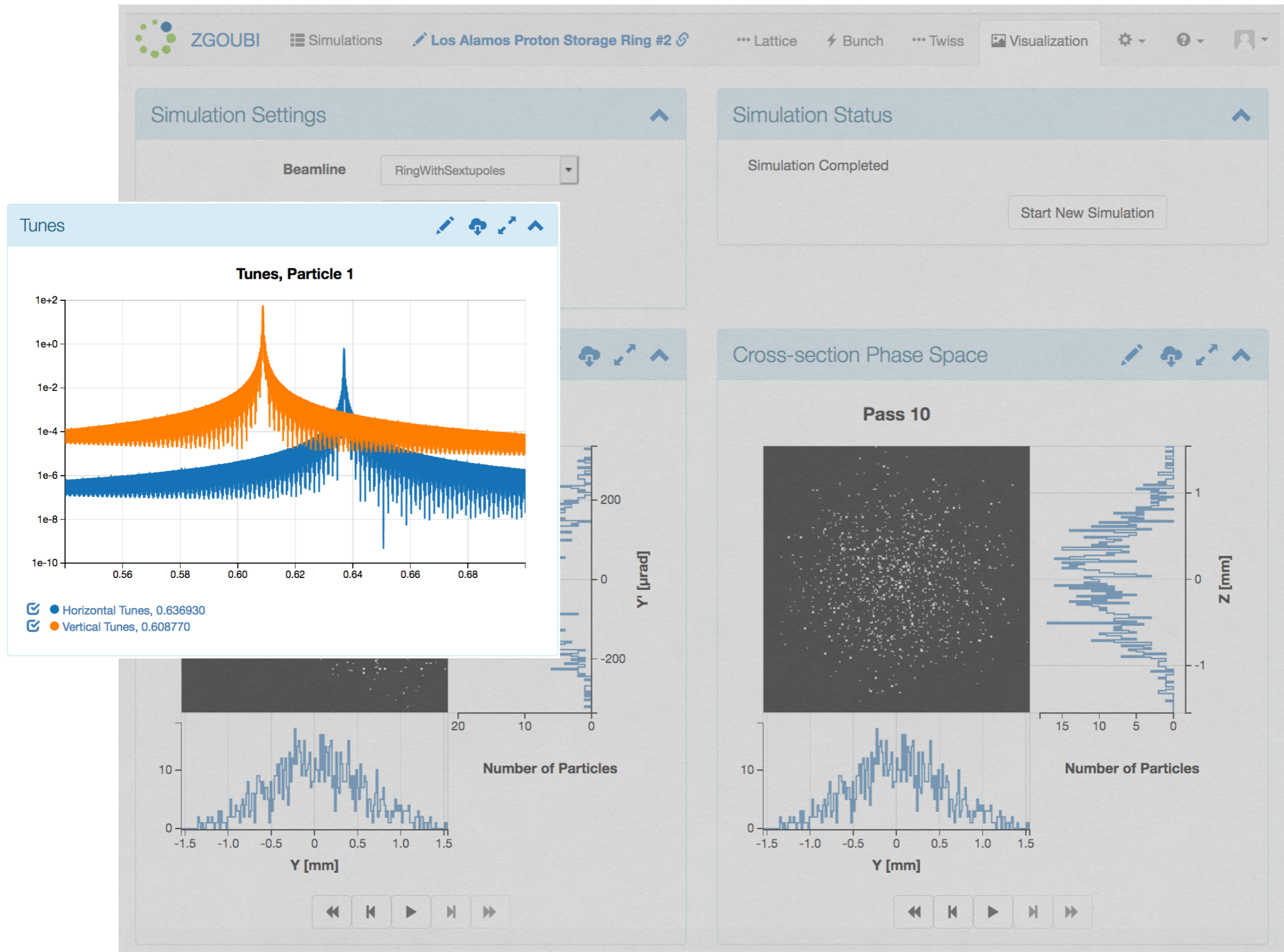
- Simulation Settings:** Beamline (RingWithSextupoles), Number of Turns (10), Diagnostic Interval (1).
- Simulation Status:** Simulation Completed, Start New Simulation button.

Two phase space plots are shown below:

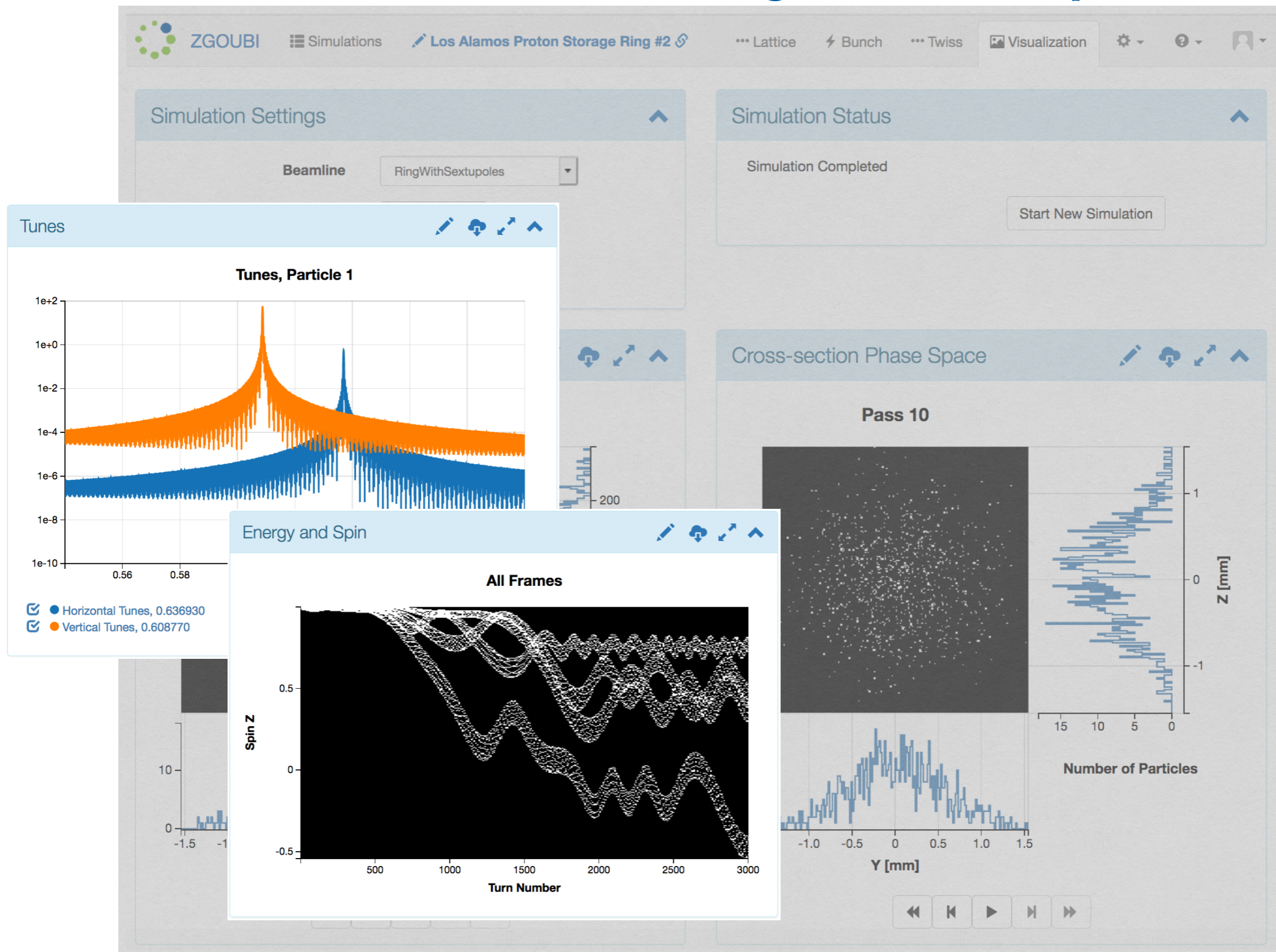
- Horizontal Phase Space (Pass 10):** A scatter plot of Y' [μrad] vs Y [mm] with a marginal histogram of Y [mm]. The Y-axis ranges from -200 to 200 μrad, and the X-axis ranges from -1.5 to 1.5 mm. The histogram shows a distribution centered at 0 mm.
- Cross-section Phase Space (Pass 10):** A scatter plot of Z [mm] vs Y [mm] with a marginal histogram of Y [mm]. The Z-axis ranges from -1 to 1 mm, and the X-axis ranges from -1.5 to 1.5 mm. The histogram shows a distribution centered at 0 mm.

Both plots include a 'Number of Particles' histogram at the bottom and navigation controls (back, forward, stop, etc.).

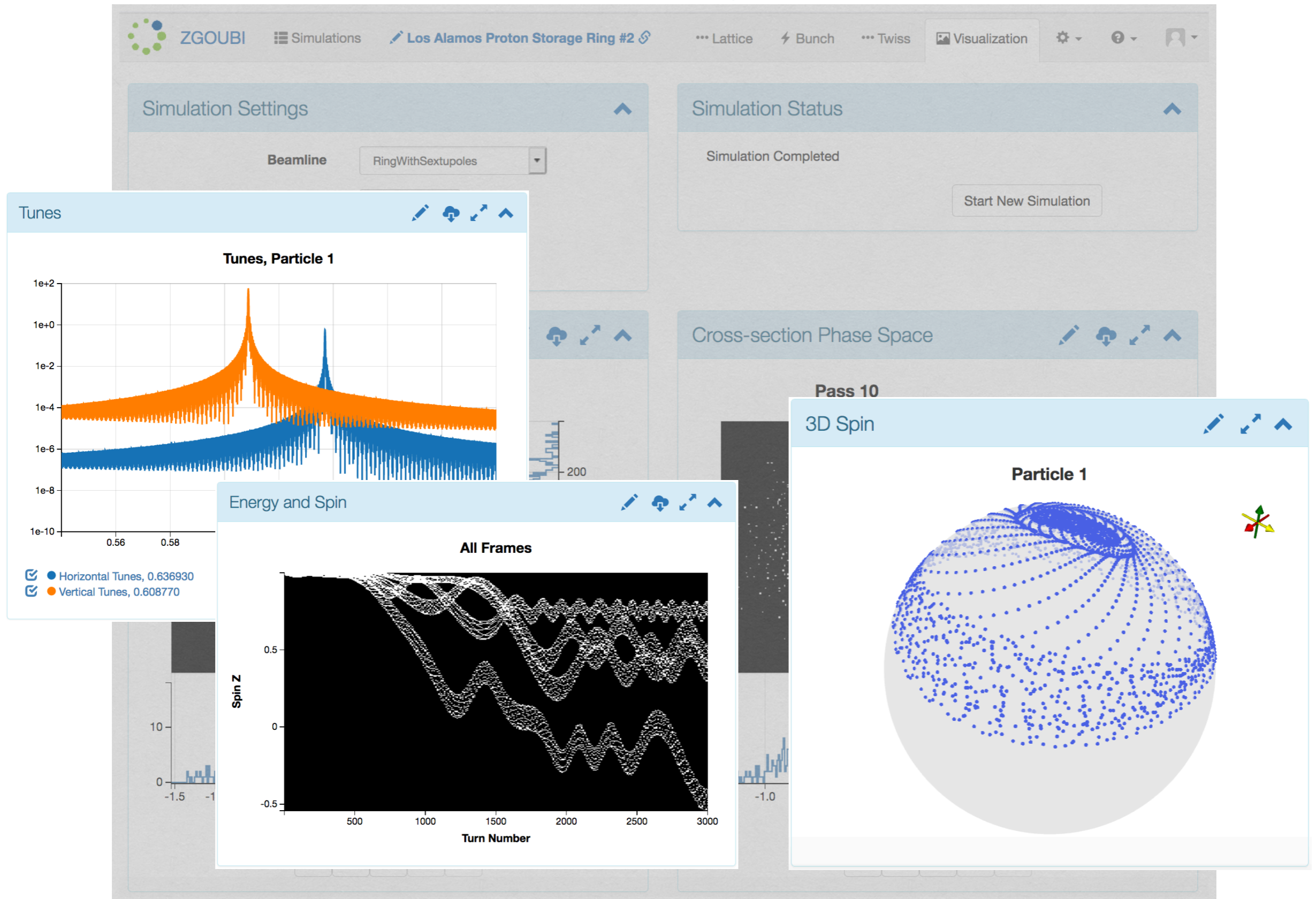
The Sirepo Interface for Zgoubi: Visualize the Beam—including tunes




The Sirepo Interface for Zgoubi: Visualize the Beam—including tunes and spin



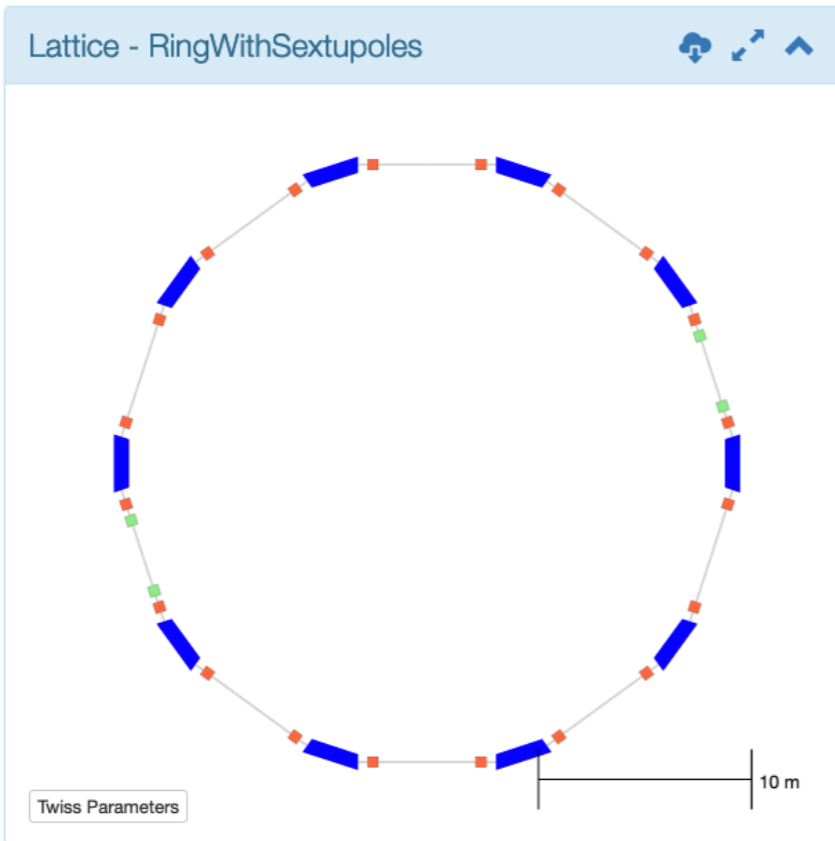
The Sirepo Interface for Zgoubi: Visualize the Beam—including tunes and spin



The Sirepo Interface for Zgoubi: Share your Work—Effortlessly!

ZGOUBI Simulations **Los Alamos Proton Storage Ring**  Lattice Bunch Twiss Visualization

Lattice - RingWithSextupoles



Twiss Parameters

Beamlines

Name	Description	Length	Bend
BL1	(D1,QD,D2,SBEND,D2,QF,D1)	9.022m	36.0°
BL2	(D1,QD,D2,SBEND,D2,QF,D3,SF,C)	9.022m	36.0°
BL3	(D4,SD,D3,QD,D2,SBEND,D2,QF,I)	9.022m	36.0°
Ring	(BL1,BL1,BL1,BL1,BL1,BL1,BL1,F)	90.22m	0.0°
RingWithSextupoles	(BL1,BL2,BL3,BL1,BL1,BL1,BL2,F)	90.22m	0.0°

Beamline Editor - RingWithSextupoles

drag and drop elements here to define the beamline

BL1

BL2

BL3

BL1

BL1

BL1

BL2

BL3

BL1

BL1

Beamline Elements

Name	Description	Length	Bend
BEND			
SBEND	B1=12,CS_0=0.2401,CS_1=1.863	2.508m	36.0°
DRIFT			
D1		2.286m	
D2		450.0mm	
D3		300.0mm	
D4		1.486m	
QUADRUPO			
QD	B_0=-2.68,CS_0=0.1122,CS_1=6.	500.0mm	
QF	B_0=1.95,CS_0=0.1122,CS_1=6.2	500.0mm	
SEXTUPO			
SD	B_0=-0.24,CS_0=0.1122,CS_1=6.	500.0mm	
SF	B_0=0.16,CS_0=0.1122,CS_1=6.2	500.0mm	

Improve Performance: Parallelize Zgoubi using Fortran 2018

Modern Fortran provides facilities for **two levels of parallelism**:

Fine-grain, at the loop level—requires *pure* functions (no side effects allowed!)

```
do concurrent(iord = 0:nord)
  B(iord+1) = derivB(iord)
end do
```

Coarse-grain, at the processor level—*collective operations*

```
co_min(a)
co_max(a)
co_sum(a)
co_reduce(a, op)
```

and *coarrays*, which “answer the question, ‘What is the smallest change required to convert Fortran into a robust and efficient parallel language?’” —John Reid, *ISO/IEC JTC1/SC22/WG5, N1824 (2010)*

Coarray syntax implements a Single Program Multiple Data (SPMD) model. A single program is replicated in units called *images*, and the number of images may be chosen at run time. You must still devise appropriate parallel algorithms, but the case of non-interacting particles is essentially trivial.

```
real :: a[*] ! scalar coarray
real, dimension(10) :: x[*], y[*] ! array coarray
real :: m(0:21,6)[*] ! matrix coarray
type(particle) :: ptcl(128)[*] ! derived type coarray

x(:) = y(:)[q] ! access remote data on image q
```

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A coindex indicates communication.

The programmer must ensure that

- * coarray indices are properly resolved
- * synchronization occurs as appropriate.

The new Fortran standard includes new intrinsics that simplify the process, e.g. `random_init`.

Improve Performance:

Parallelize Zgoubi using Fortran 2018—cont.

Opportunities for parallelizing Zgoubi:

Distribute particles on multiple processors

Distribute lattice computations

Distribute machine energies

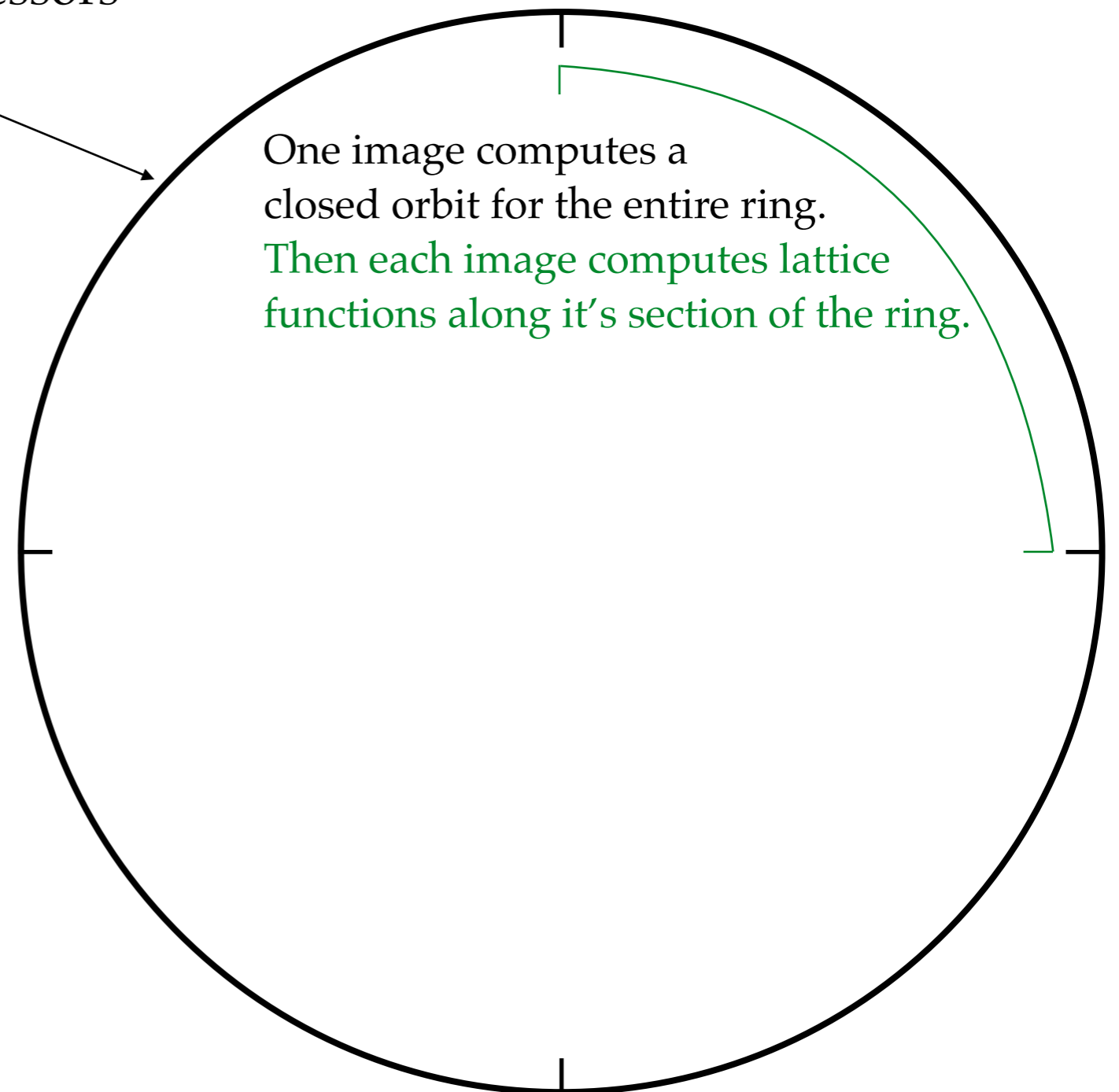
Distribute misalignments

Various scans:

dynamic aperture

polarization studies

etc.



Improve Performance: Parallelize Zgoubi using Fortran 2018—cont.

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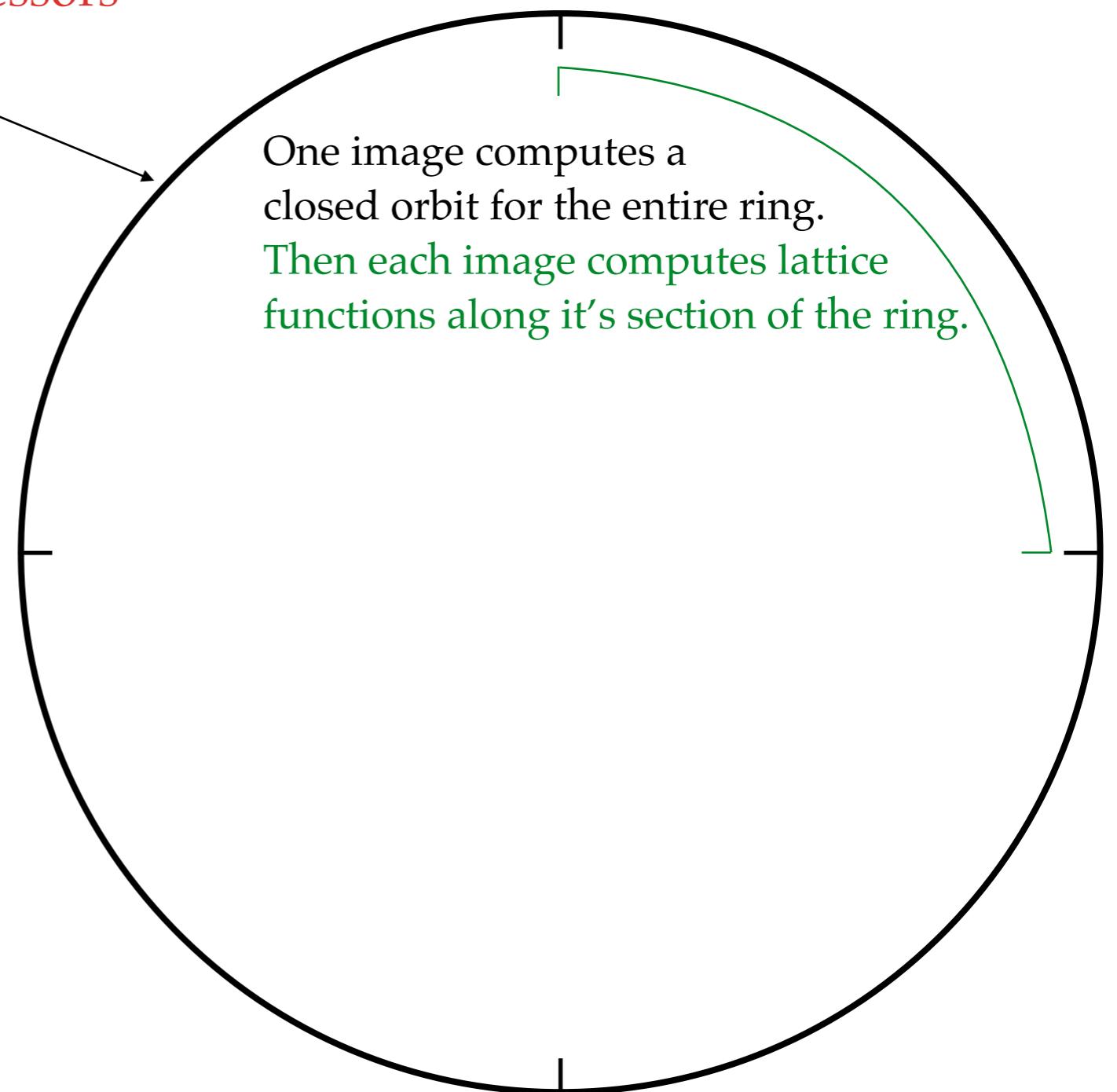
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RadiaSoft Revenue Model

Consulting and Contract R&D

- Problem solving across many domains
 - *Accelerator Design*
 - x-ray optics
 - electron linear accelerators
 - free-electron lasers
 - synchrotron radiation
 - high-intensity proton synchrotrons
 - compact ion and accumulator rings
 - *Vacuum Nanoelectronics and Thermionic Converters*
 - *Control Systems*
 - *Machine Learning*
 - *Medical Physics and Treatment Planning*
 - *Theoretical analysis*
 - *Algorithm development*
 - *High-performance computing and computational studies to improve the performance of particle accelerators*
- Custom simulations
 - *Open source codes to eliminate licensing fees*
 - *COMSOL Multiphysics models*
 - *GUIs for customer codes*

Software Design and Development

- Sirepo
 - *Graphical User Interfaces for open-source physics codes*
 - browser-based
 - no installation
 - no maintenance
 - instantaneous collaboration with colleagues
 - high-intensity proton synchrotrons
 - compact ion and accumulator rings
- Sirepo Enterprise
 - *Full instance of Sirepo*
 - *Installed and supported on customer premise*
 - *Protects corporate data and IP*
- **HPC Cluster Access On Demand**
 - *Pay-as-you-go and subscription access for HPC simulations*
- COMSOL Application Builder
 - *Turn your COMSOL models into apps for increased usage*

Summary and Future Work

RadiaSoft provides an easy-to-use gateway for simulations using a range of well-established scientific codes: please visit <https://sirepo.com/>.

To share simulations and results with collaborators, simply email the web link.

Responding to feedback as we complete the Sirepo / Zgoubi graphical interface.

Zgoubi Workshop in Boulder, CO; 26–30 August 2019. Participants from BNL, JLab, Argonne, as well as England, Italy, France, and Australia.

Complete the technical work on Zgoubi, with a focus on the needs for our scientific collaboration with BNL on eRHIC, and with JLab on JLEIC.

Summary and Future Work—cont.

Collaborate with BNL to assess and improve the spin dynamics in electron and ion rings for the eRHIC design:

Imperfection resonances are expected to dominate the beam polarization loss during the acceleration ramp. We will extend simulations done so far to use as many as 10^5 particles. This will enable an improved exploration of the full 6-D phase space, including a full range of magnet misalignments, correction settings, and noise in the rf control system.

Collaborate with JLab to benchmark Zgoubi with BMad and other codes used for simulating JLEIC ring designs:

JLab's EIC designs (JLEIC) use a novel figure-8 shape ring possessing a number of beneficial spin dynamics features. New polarization preservation and control techniques have been developed for both ion and electron beams. To improve confidence in the understanding of spin dynamics in the JLEIC designs, we will perform benchmarking simulations between BMAD, SLICK/SLICKTRACK, and Zgoubi.

Thank you!

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Office of Nuclear Physics, including Award No. DE-SC0017181.

 **Sirepo** <https://sirepo.com/>