Writing Physics Applications and Services with EPICS V4

Greg White, SLAC, EPICS Fall 2014 Meeting, Saclay.

SLAC Accelerators: LCLS (FEL), FACET (e- plasma wakefield)

EPICS V4 by example of optics

- Demonstrate EPICS V4 by example of key goal of accelerators - minimize emittance
- As described by the “Optics”
  - Twiss Parameters
  - Response matrices
- Example Applications
- Performance
- Demo

Emittance (ε) is central to accelerator figures of merit. Low Emittance = Good.

Colliders: ε ∝ 1 / Luminosity

$$L = H_D \frac{f N_1 N_2}{4\pi \sigma_x \sigma_y}$$

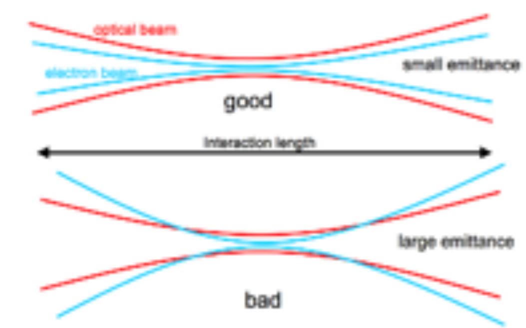
Where:

- f = collision frequency
- $N_1 N_2$ = Charge in bunches
- $\sigma_{x,y}$ = RMS beam size (horiz, vert)
- H_D = Beam-beam focusing factor

Free Electron Lasers:

ε ∝ 1 / Gain

$$G = -\frac{m_e c^2 \gamma_r n_e}{\varepsilon_0 E_0^2 k_u} \cdot < \dot{\psi} >$$

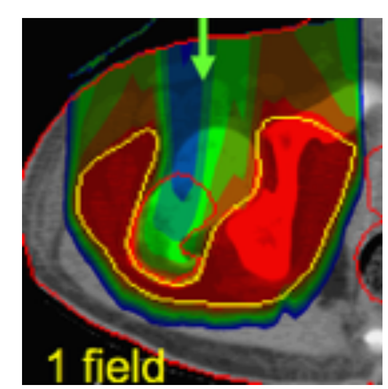


Off-axis e- → Diff focusing (K)
→ Don't lase

Beam Radiotherapy:

ε ∝ 1/Dose Quality &
1/Dose Accuracy

ε ⇔ "divergence"

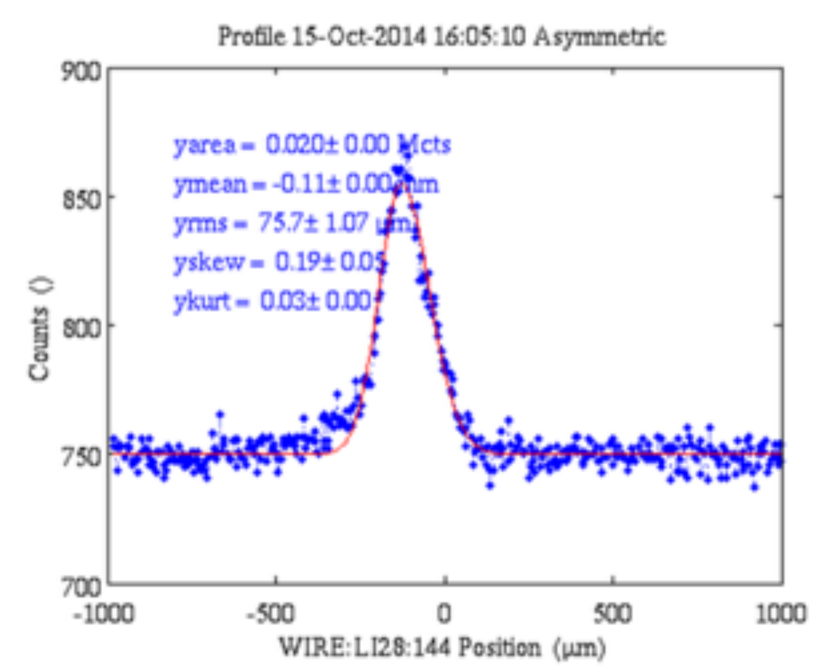


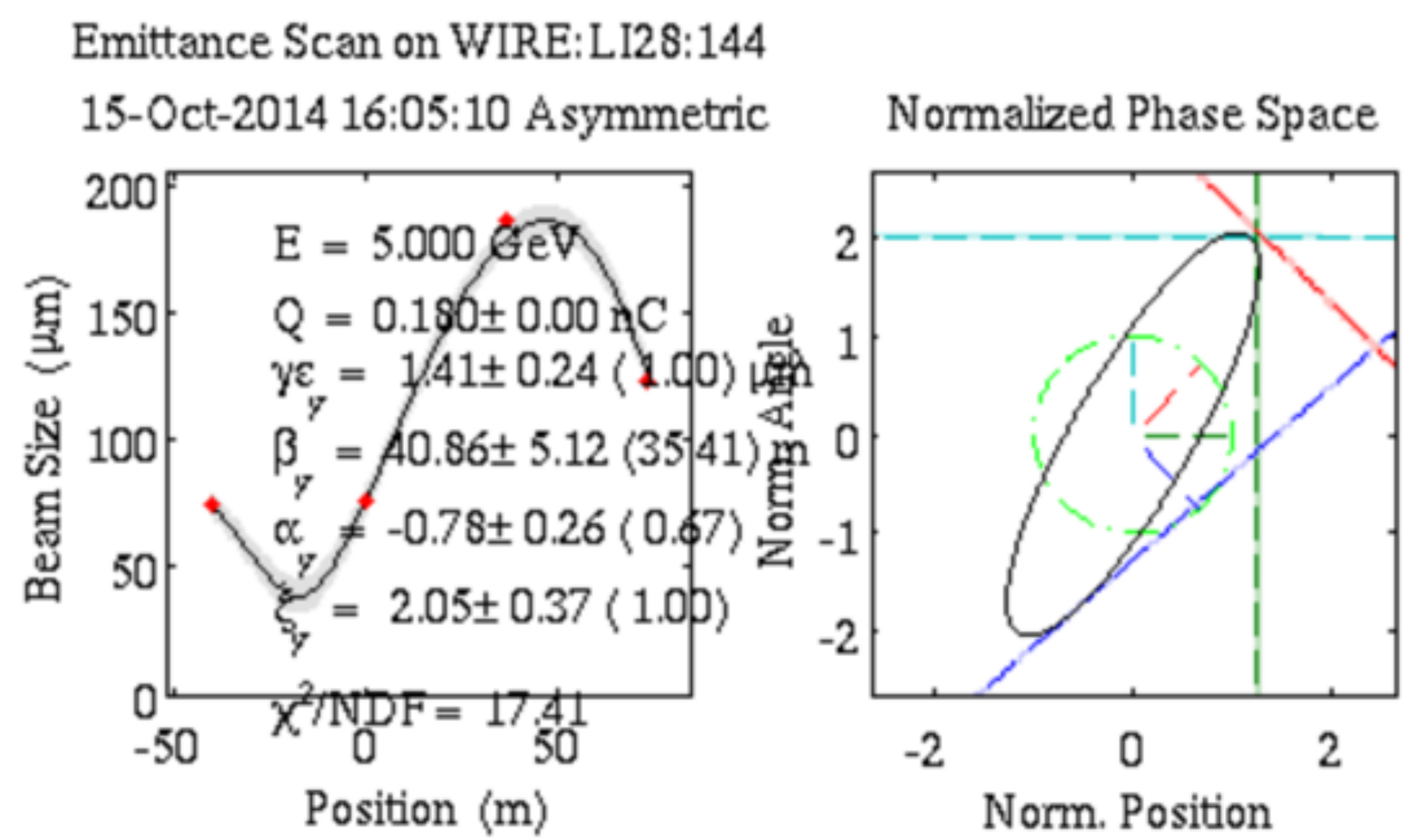
P. Tenenbaum, N. Thompson, M. Schippers, K. Markey

Physics Applications ≈ Minimizing Emittance

Emittance is basically beam size
or really, the propensity of the beam to
change size, as it propagates

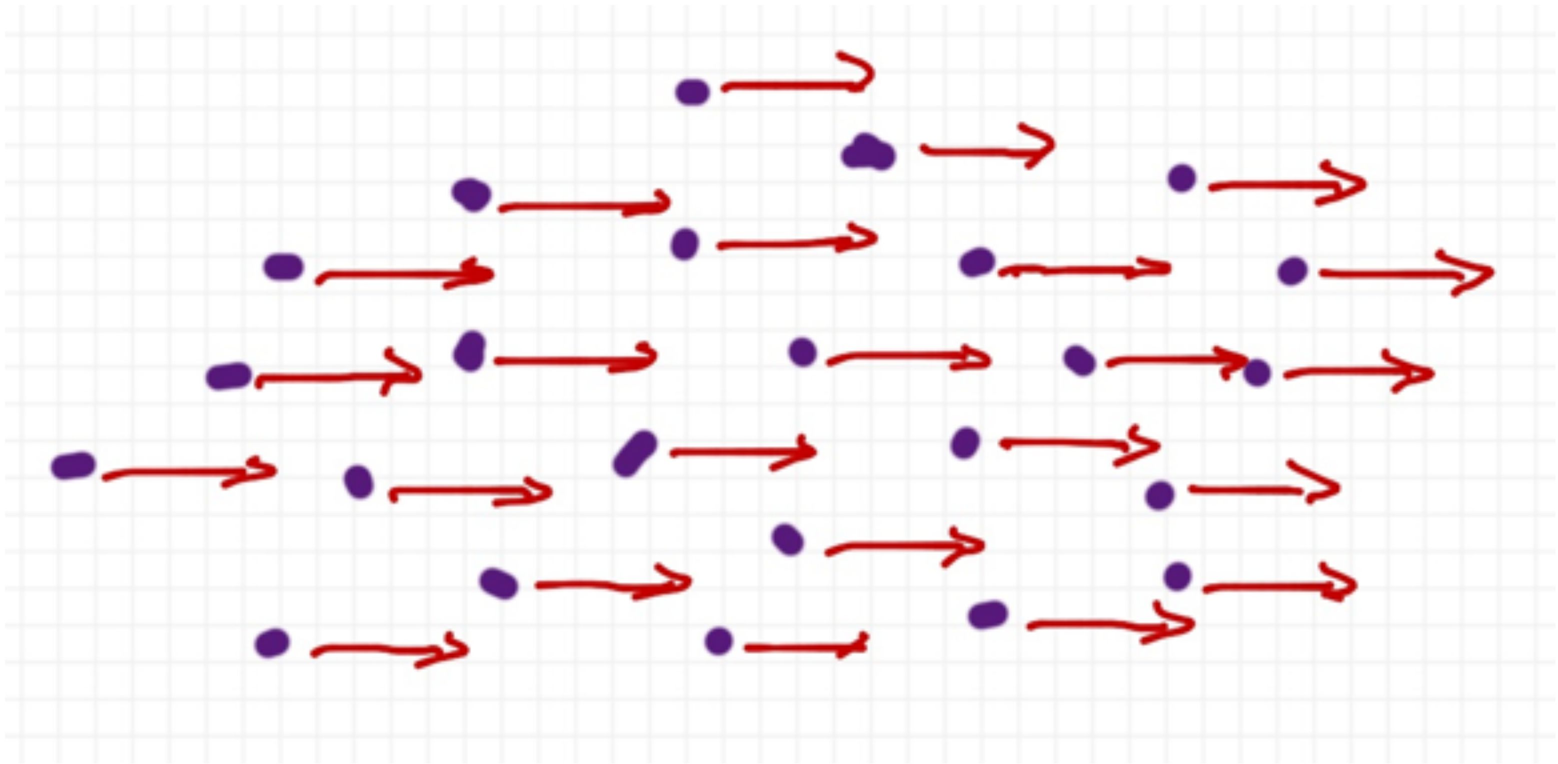
Example: Vertical Emittance as measured at one wire:





Particle Bunch

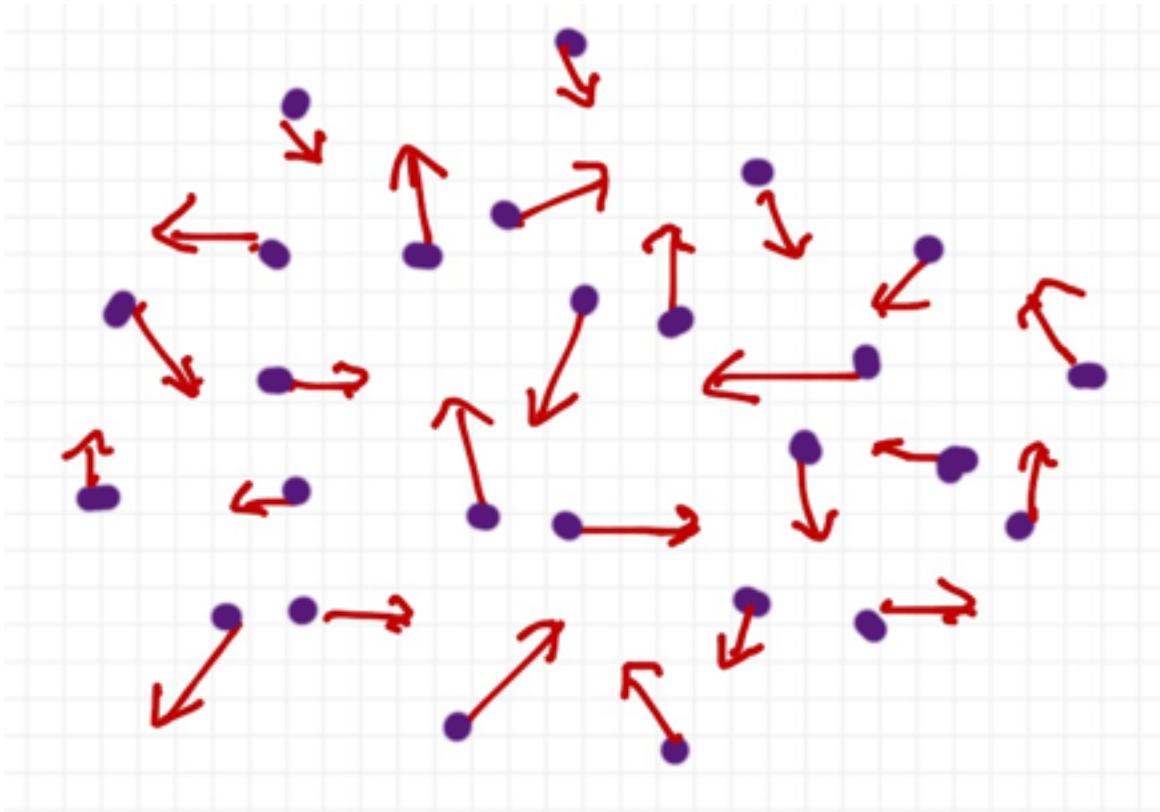
Bunch in frame of the laboratory, looks uniform, all heading in same direction



From illustration in lecture by Nicolas Delarue

Particle Bunch

Bunch in their frame, in the Center of Mass of the bunch,
all heading every which way,
with different momenta



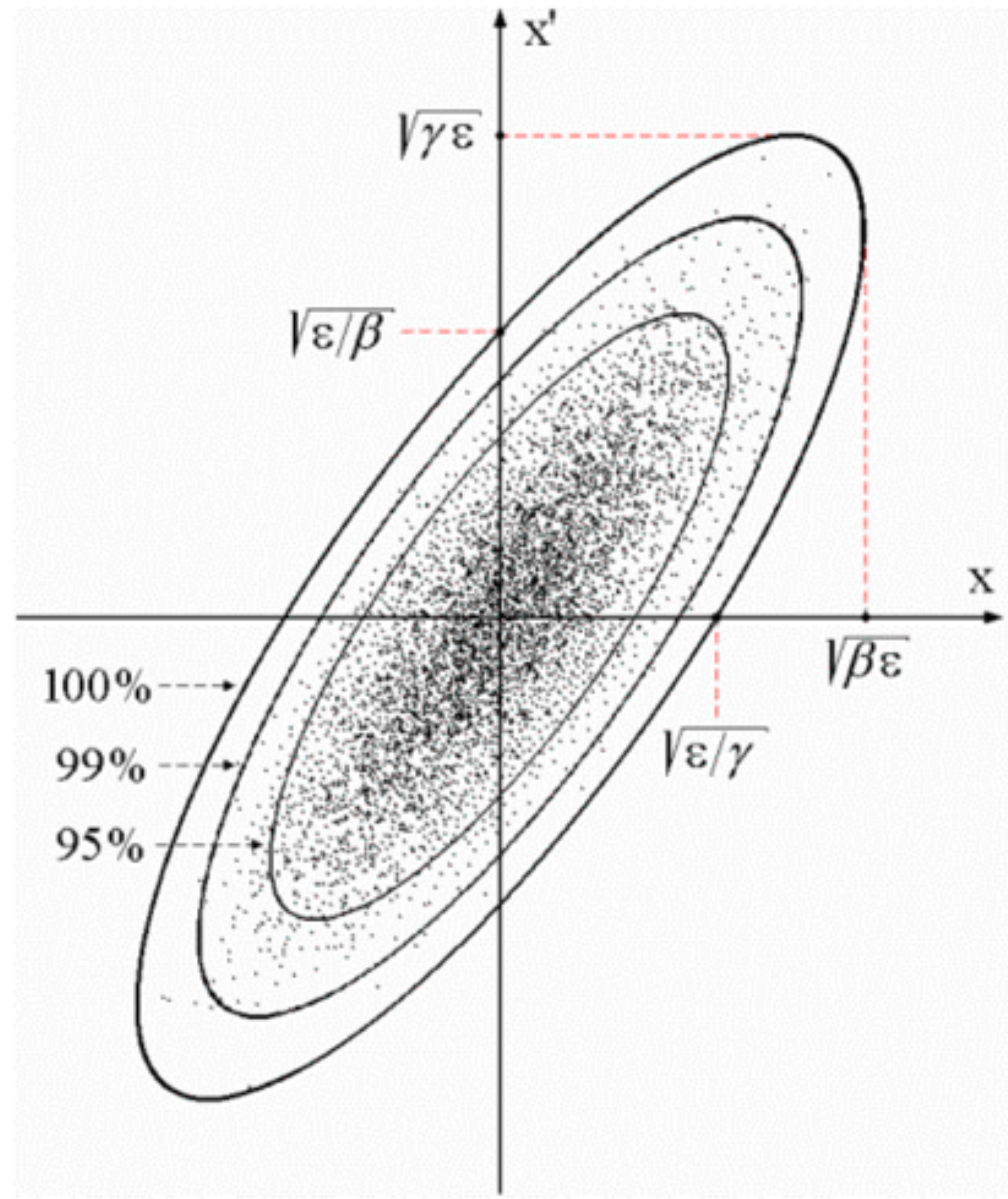
Product of particles' position x momenta = Emittance

From illustration in lecture by Nicolas Delarue

Emittance ellipse in trace-space

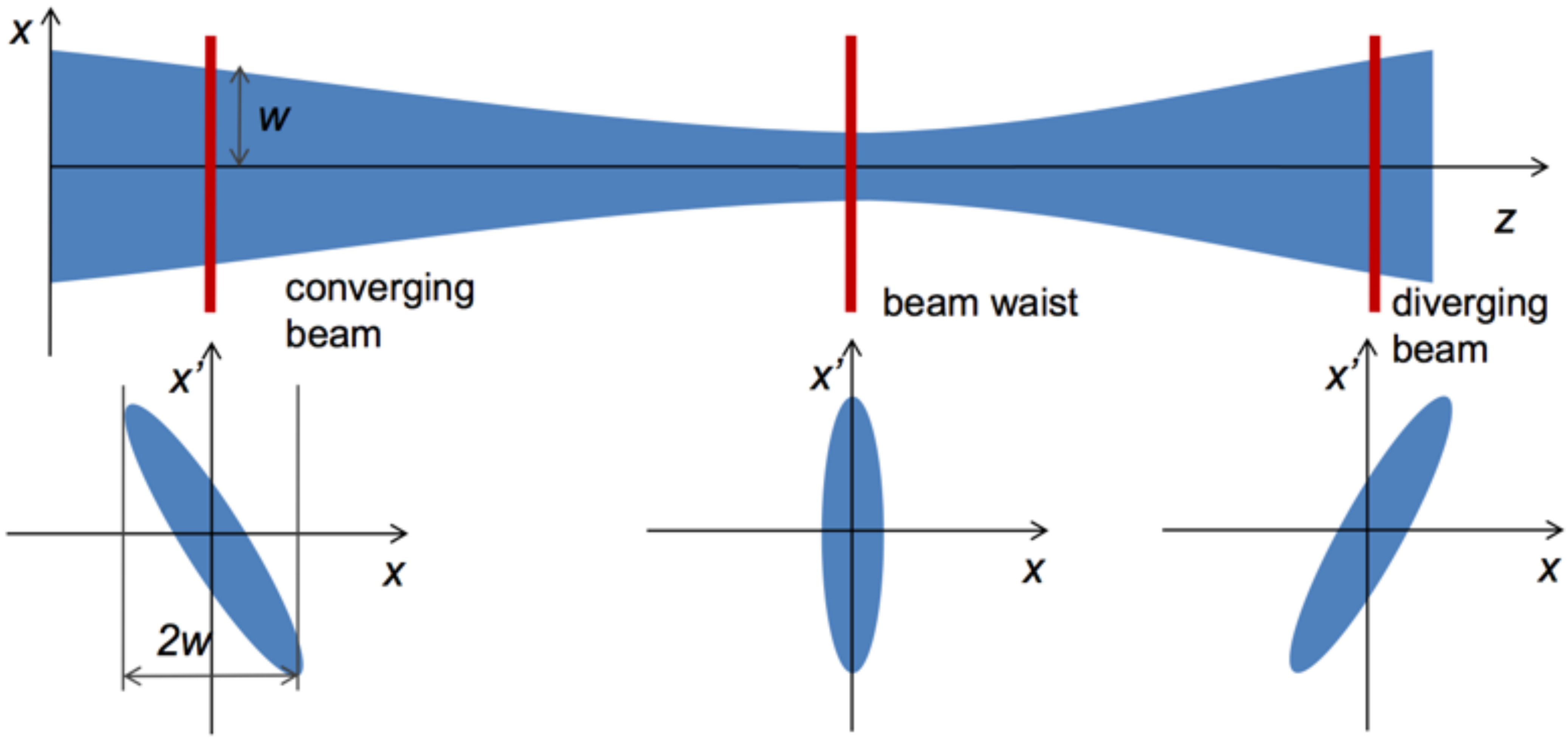
- Aggregate description of particles in their frame is given by Emittance (ε) ellipse in trace-space
- Quantitatively: Emittance is the area of ellipse, over π
- where "area" might be defined as 1 or 2 sigma RMS, or in %.

$$\varepsilon = \gamma x^2 + 2\alpha x x' + \beta x'^2$$



N. Delerue

Emittance and focusing



Along a beamline the orientation and aspect ratio of beam ellipse in x, x' plane varies, but area $\pi\varepsilon$ remains constant

Beam width along z is described with $w(z) = \sqrt{\beta(z)\,\varepsilon}$

Hans Braun

So, the Twiss parameters describe the beam shape, and it’s evolution in space

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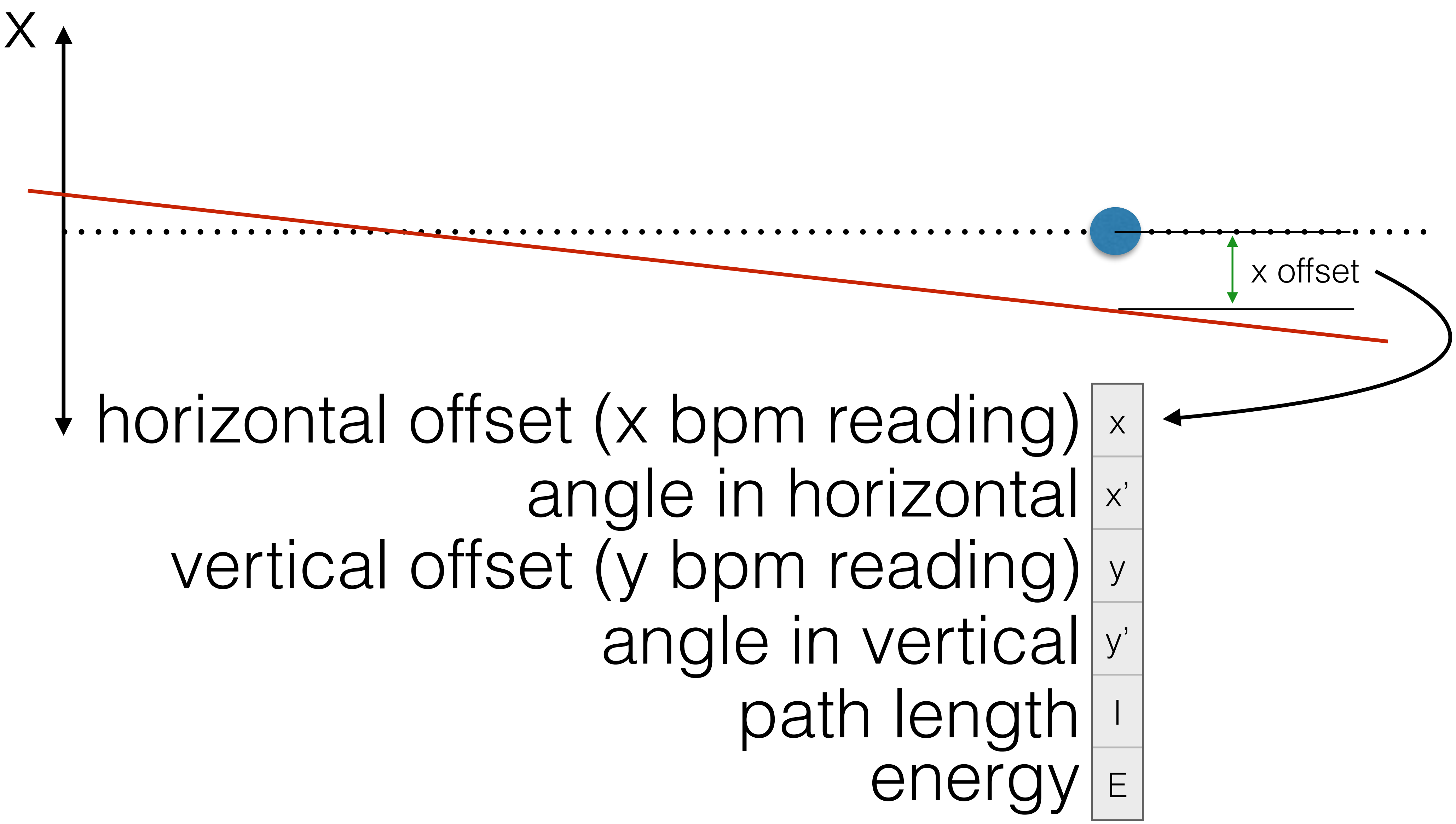
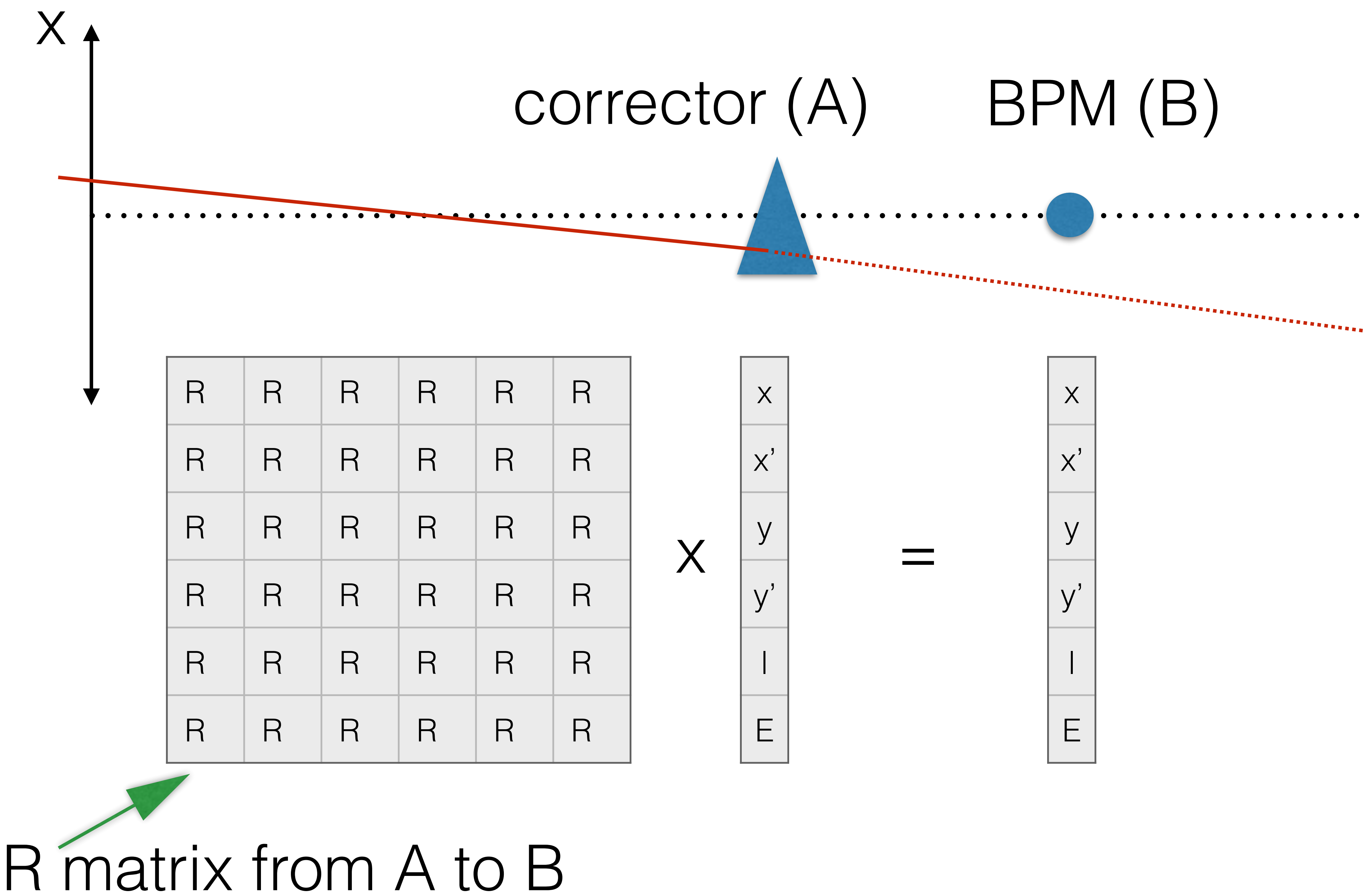
The beam sausage

Orbit description



Response Matrices

(aka “R” aka “T” matrices)



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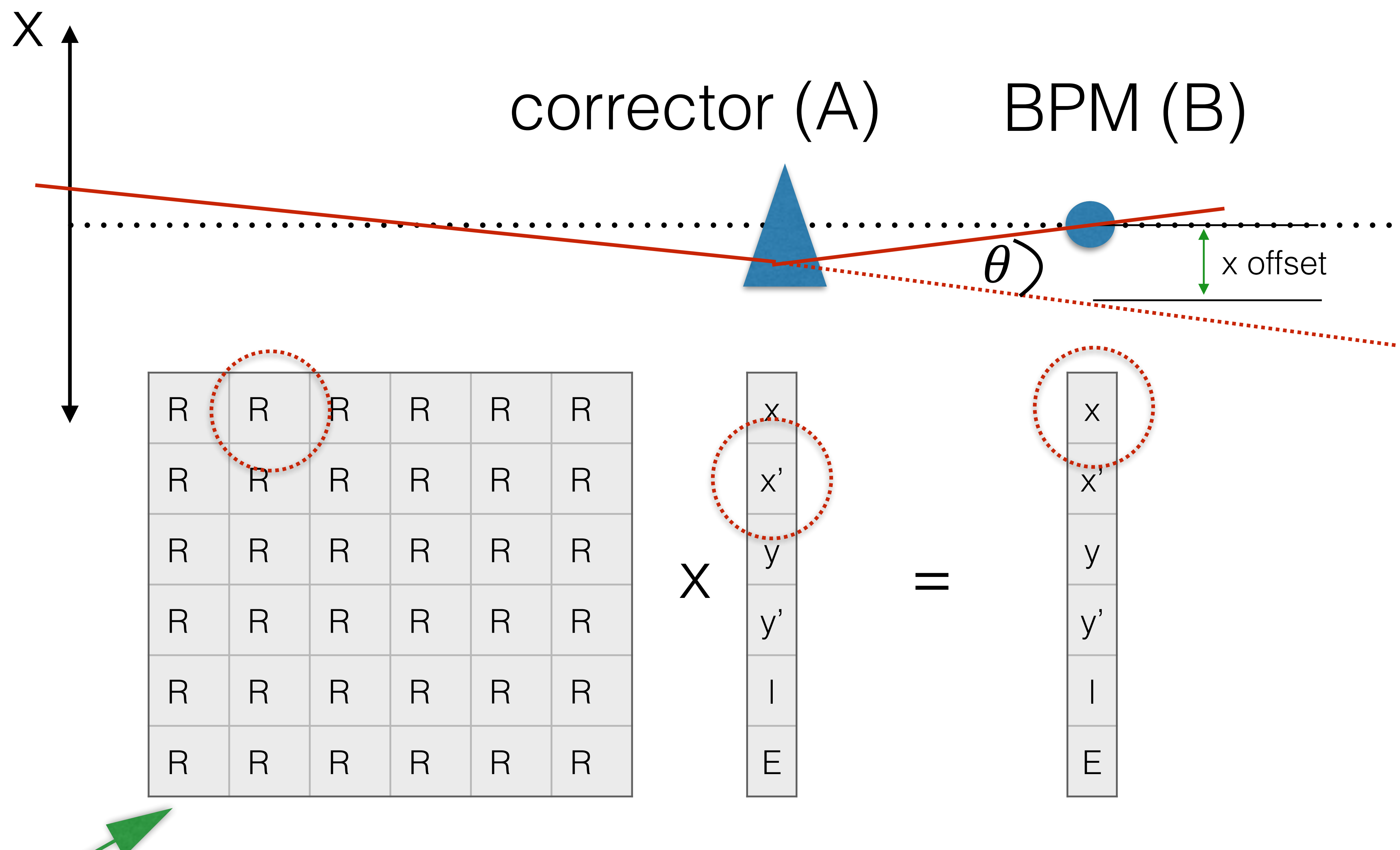

R matrix from A to B

R12 is influence of X angle at A on X position at B

Response Matrices

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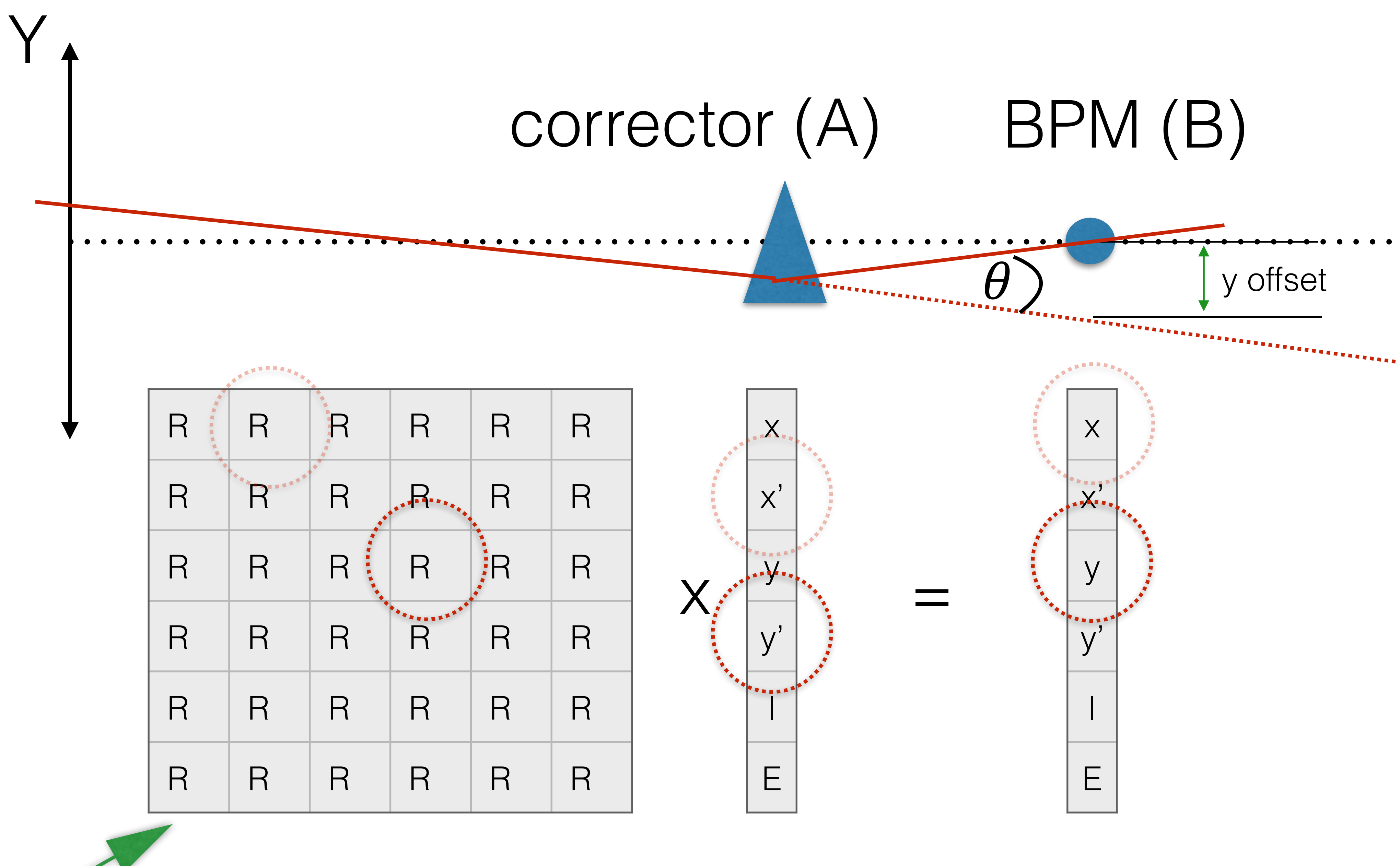
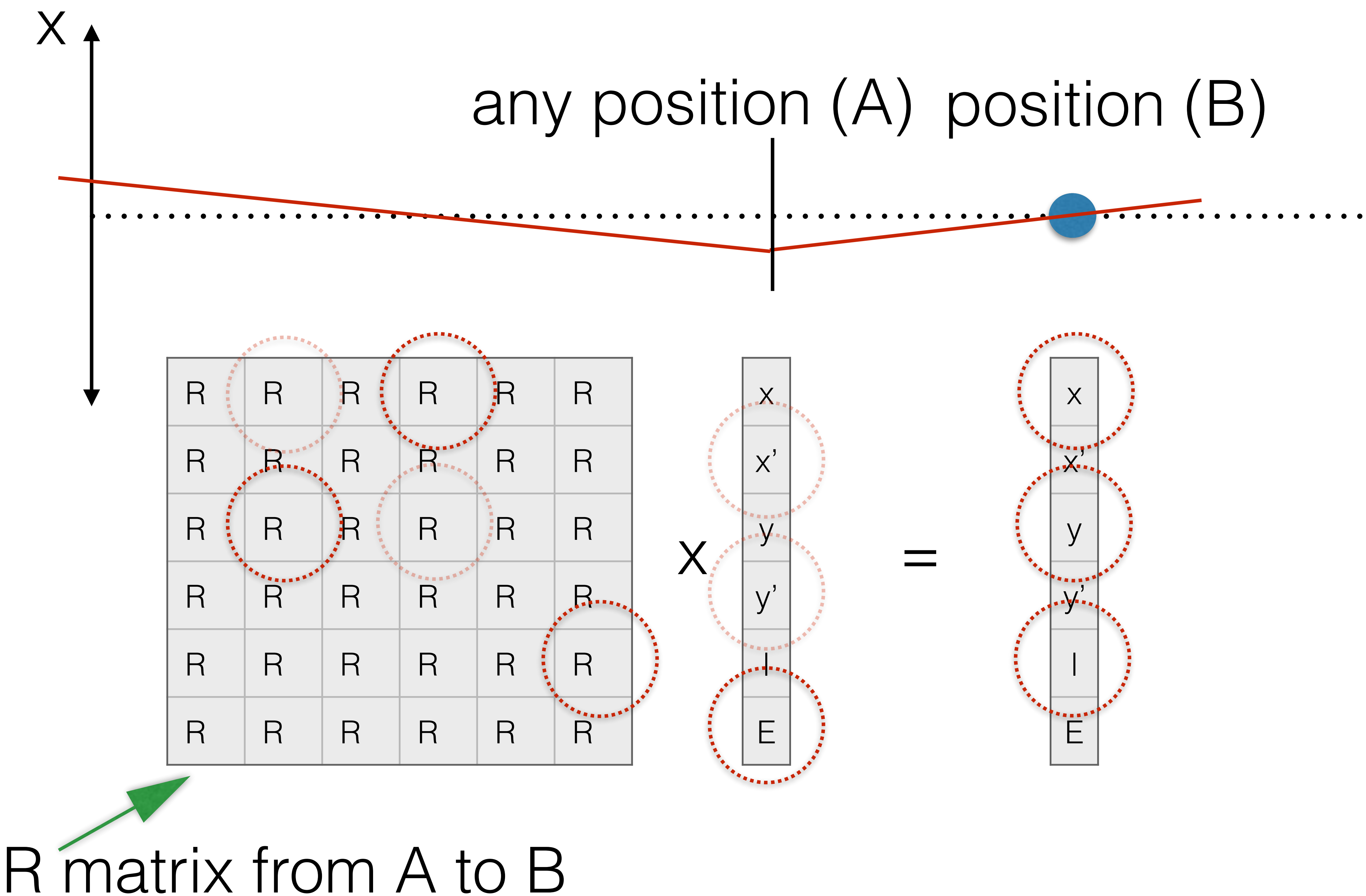


R matrix from A to B

R34 is influence of Y angle at A on Y position at B

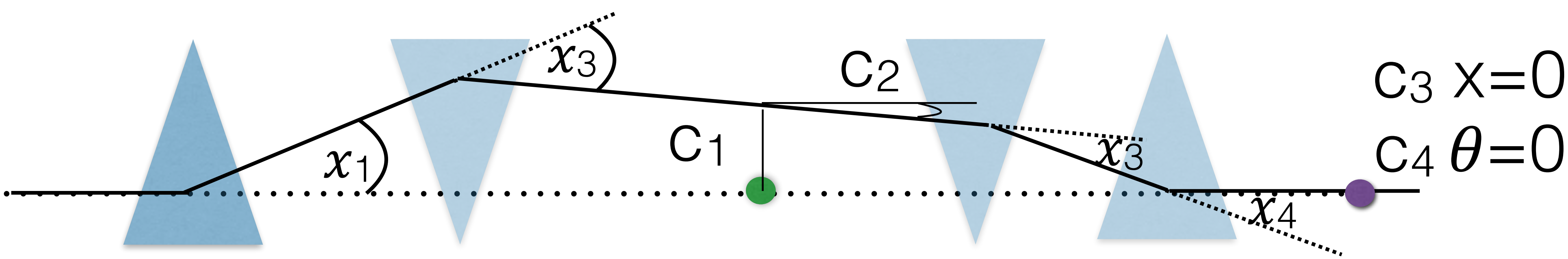
Response Matrices

(aka “R” aka “T” matrices)



Response Matrices are the basis of most online accelerator optimizations

Example 1, a so-called “4-bump”: calculating corrector settings to get a particular offset and angle somewhere, like at a diagnostic device



4 equations in 4 unknowns (the 4 desired corrector angles)

Orbit Correction (aka Steering)

Minimizing the RMS of the Orbit

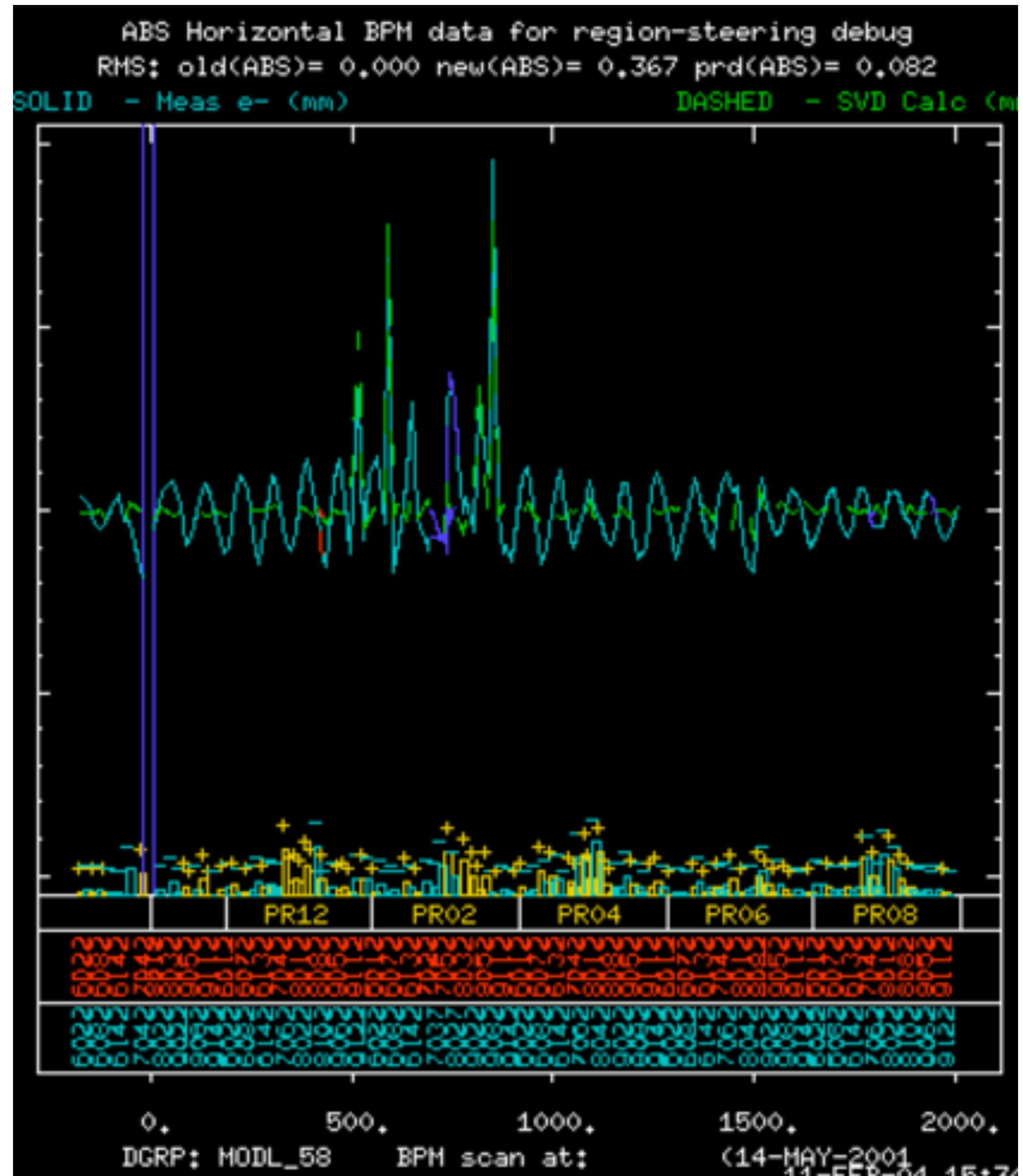
Solves the system of equations that describe the influence of every dipole corrector on every BPM:

$$
\begin{aligned}
T_{12}^{11}\Delta\theta_1 + T_{12}^{12}\Delta\theta_2 + \cdots + T_{12}^{1N}\Delta\theta_N &= \Delta BPM_1 \\
T_{12}^{21}\Delta\theta_1 + T_{12}^{22}\Delta\theta_2 + \cdots + T_{12}^{2N}\Delta\theta_N &= \Delta BPM_2 \\
&\vdots \\
T_{12}^{M1}\Delta\theta_1 + T_{12}^{M2}\Delta\theta_2 + \cdots + T_{12}^{MN}\Delta\theta_N &= \Delta BPM_M
\end{aligned}
$$

$$\|\mathbf{Ax} - \mathbf{b}\|_2$$

$$\text{subject to } \mathbf{x}_j \leq \mathbf{x}_j^{\max}$$

$$
\begin{bmatrix}
T_{12}^{11} & T_{12}^{12} & T_{12}^{13} & \cdots & T_{12}^{1N} \\
T_{12}^{21} & T_{12}^{22} & T_{12}^{23} & \cdots & T_{12}^{2N} \\
 & & \vdots & & \\
T_{12}^{M1} & T_{12}^{M2} & T_{12}^{M3} & \cdots & T_{12}^{MN}
\end{bmatrix}
\cdot
\begin{bmatrix}
\Delta\theta_1 \\ \Delta\theta_2 \\ \vdots \\ \Delta\theta_N
\end{bmatrix}
=
\begin{bmatrix}
\Delta b_1 \\ \Delta b_2 \\ \vdots \\ \Delta b_M
\end{bmatrix}
$$



$\mathbf{A}$ may be very large (millions), calculated from 1000s of R matrix elements, which must be from a very well known precomputed model

The R-matrix parameters describe how changes in each place in the beam, affect all the others

What's peculiar about optics PVs?

- Complex data type: a set for each lattice element: structures and matrix
- Further a set of sets at any point in time
- So, both device and whole machine oriented
- Parameterized:
  - Beginning, middle, end of thick elements
  - Must know design values and those from real machine
  - Want values from simulation, and from controlled conditions both

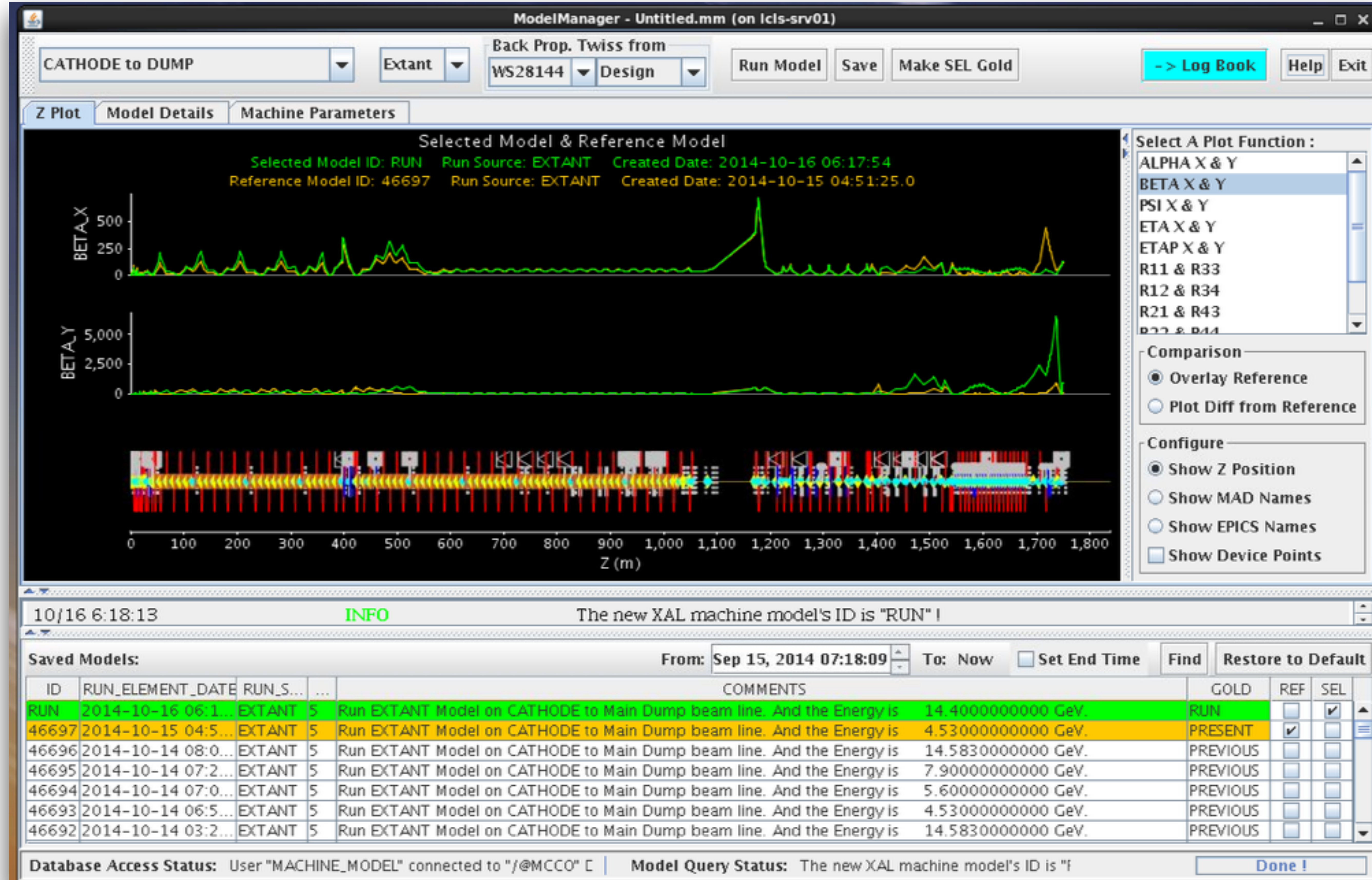
Conclusion: EPICS V4 for complex types and RPC

EPICS V4 services at SLAC

- Names. Now using old system. ChannelFinder based one in prototype
- Twiss
- R-matrices
- Elements (aka lattice)
- Oracle database general service (pvname -> sql lookup table)
- Archive (in development)
- Orbit (planned)

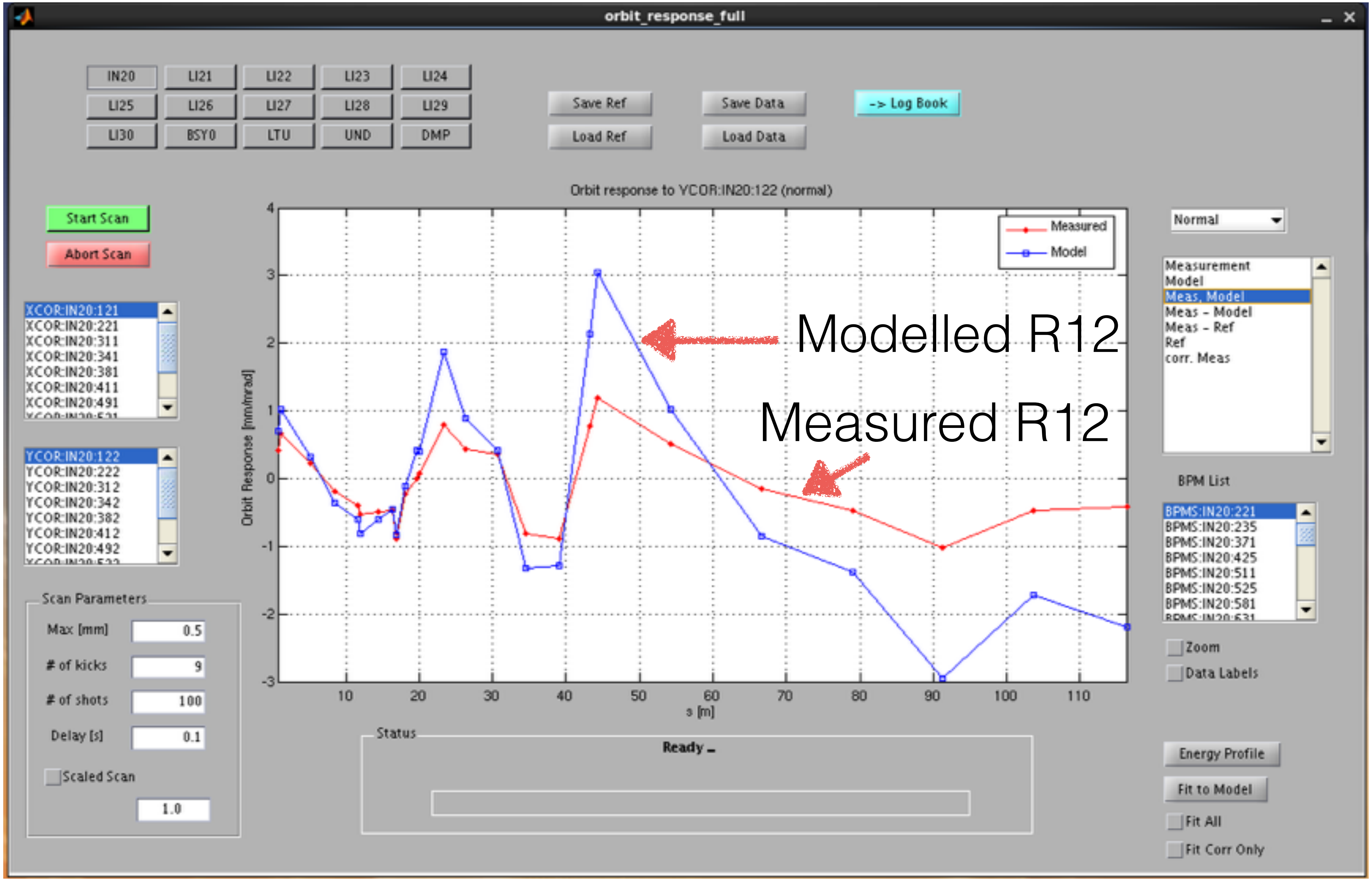
Interfaces from command line, c++, java, easyJava, Matlab

Model App



Quan Gan, Paul Chu, Sergei Chevtsov, Greg White

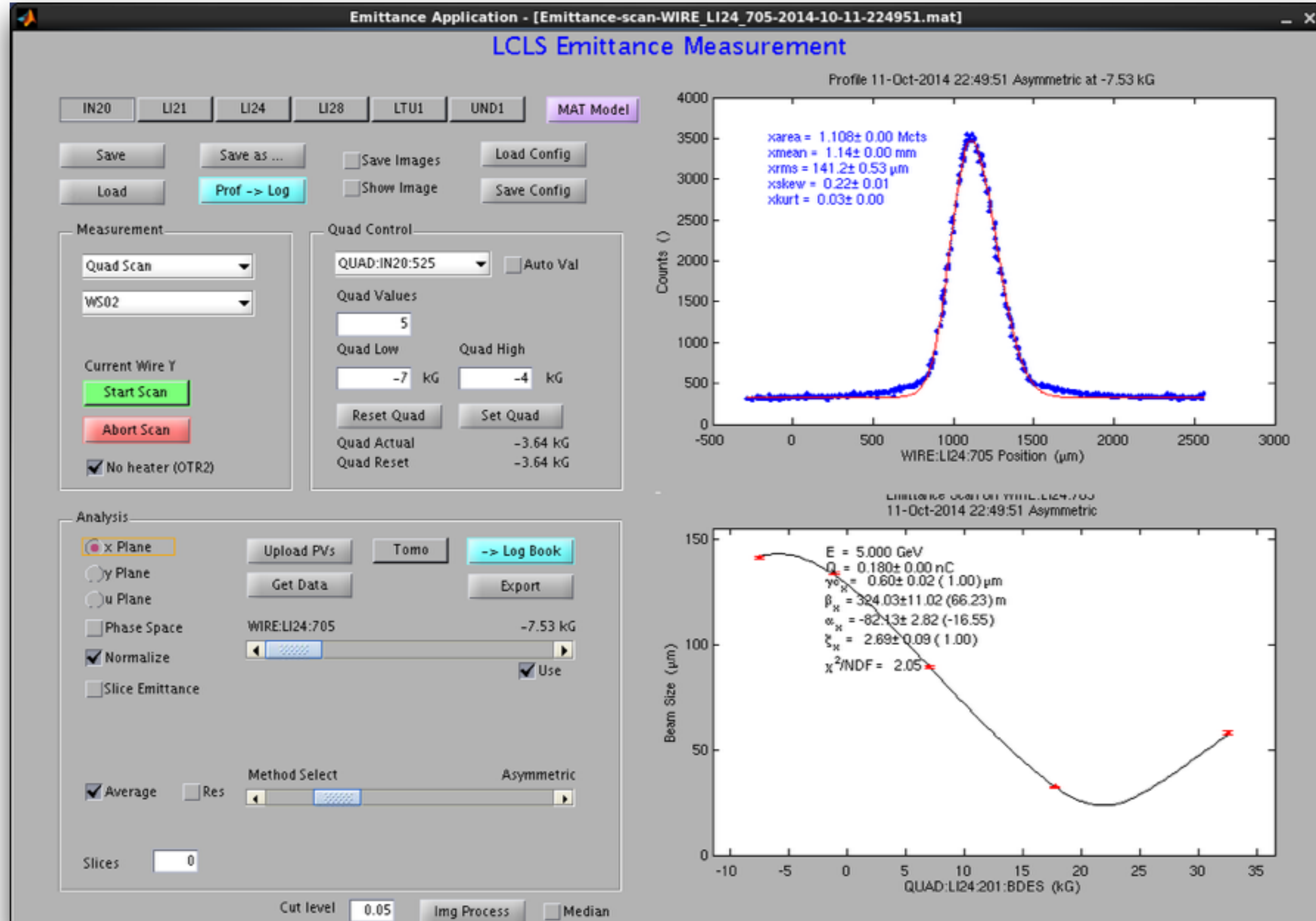
Orbit Response App



Compares measured to modelled response (R) matrices, that is, downstream response of the beam's position to a change in its angle upstream

Emittance Measurement App

Uses transfer matrices (R-matrices) and profile measurement to compute twiss and hence emittance



Henrik Loos

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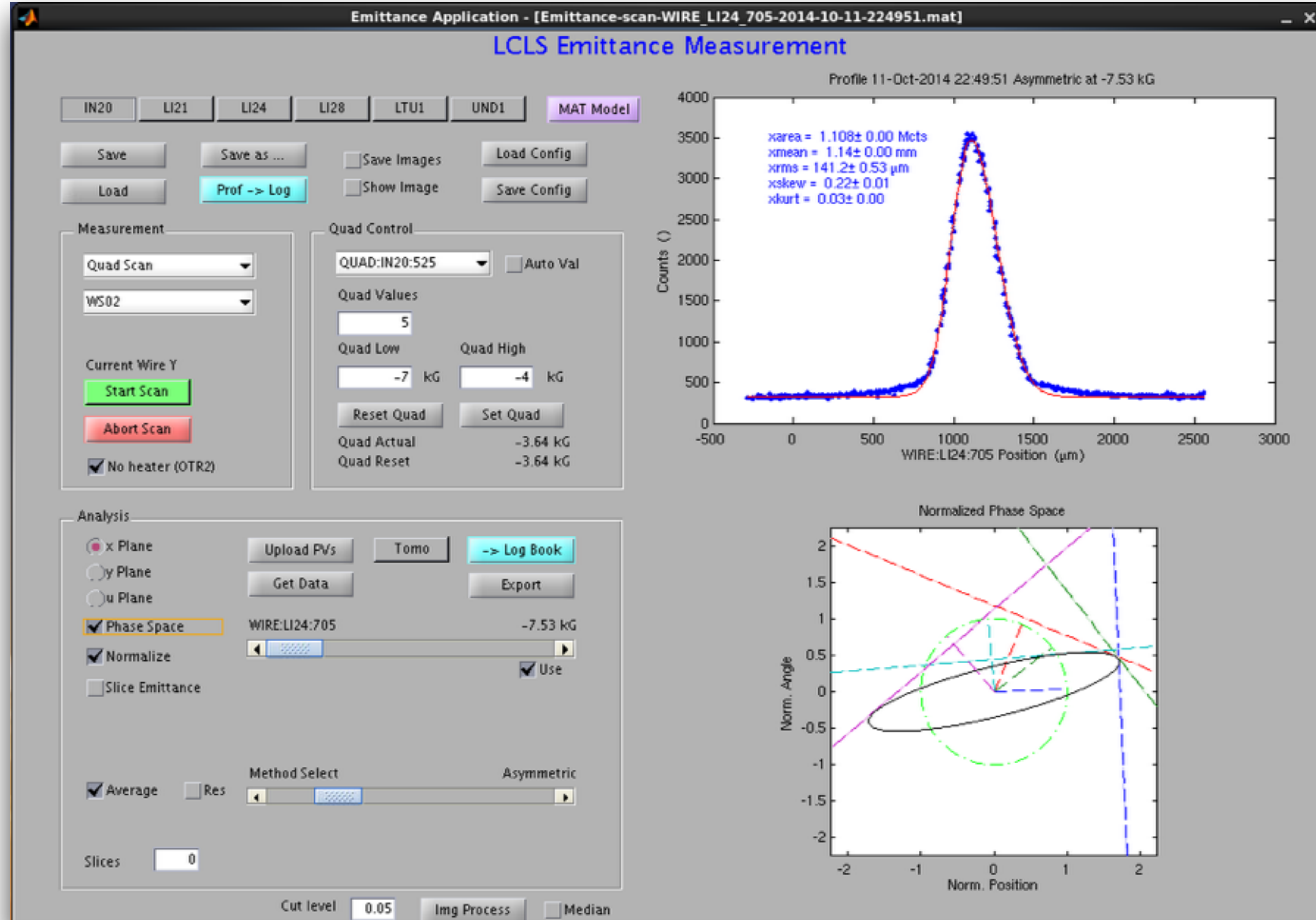

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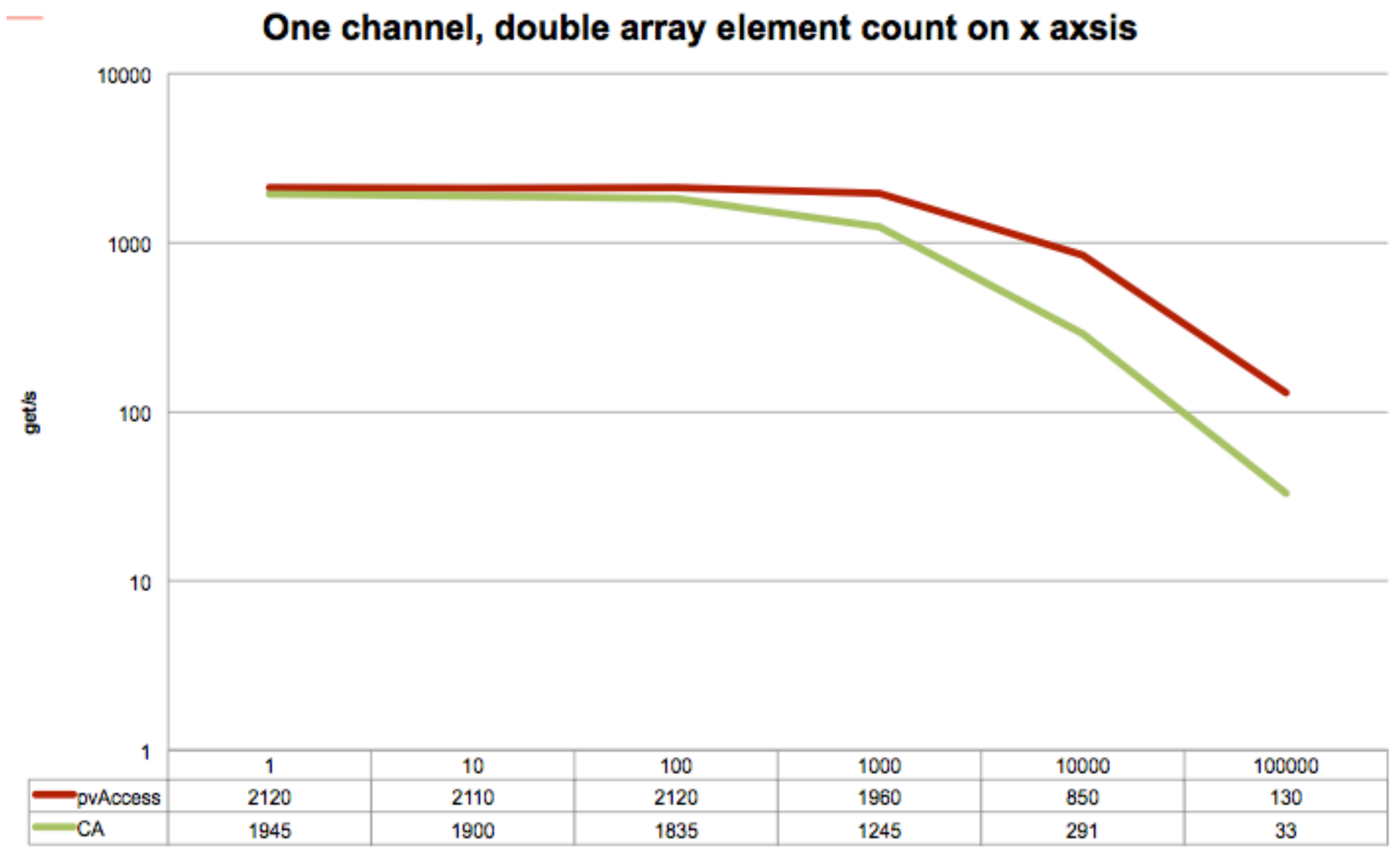
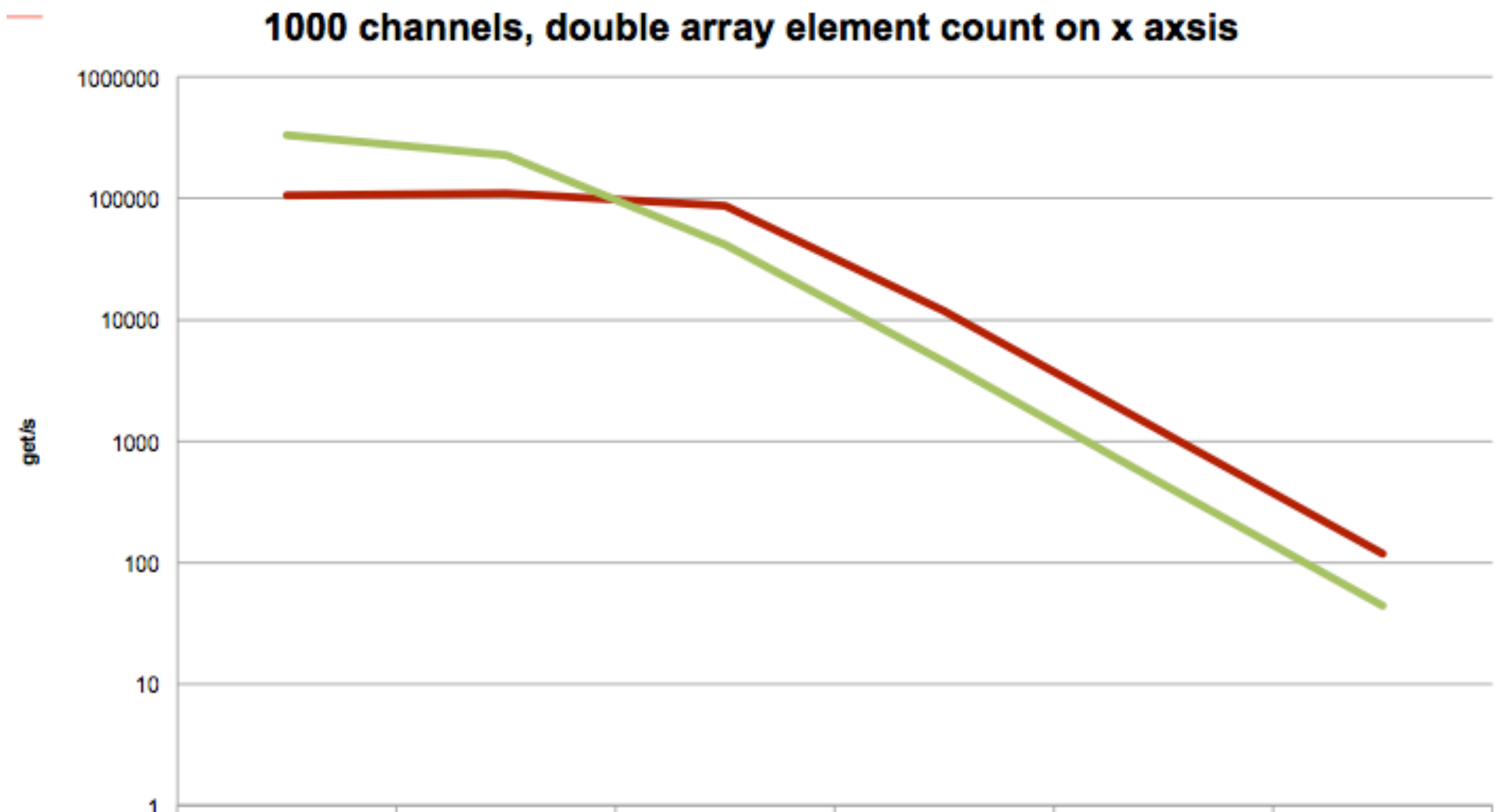


	1	10	100	1000	10000	100000
pvAccess	2120	2110	2120	1960	850	130
CA	1945	1900	1835	1245	291	33

pvAccess vs CA performance

Largely the same for 1pv up to 100 elem. Then pvAccess faster by up to factor 2-4 for larger arrays.



	1	10	100	1000	10000	100000
pvAccess	106000	111000	86600	11800	1183	118
CA	333000	228000	41570	4510	443	44

pvAccess vs CA many channels

CA largely faster for many small channels, pvAccess faster for many large channels

Status, Conclusions

- 5 V4 services in place now. Working, fast, reliable. 2 more very soon.
- LCLS and LCLS-II projects bought in.
- 2 optics modelling services now: defined conditions (XAL) and simulator (MAD). Working to make both MAD
- Next: Add computation of optics from archived values

References

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