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Accelerator Physics PhD
Status report
Sapienza University of Rome

High level applications and beam commissioning strategies development for ELI-NP

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Outlook

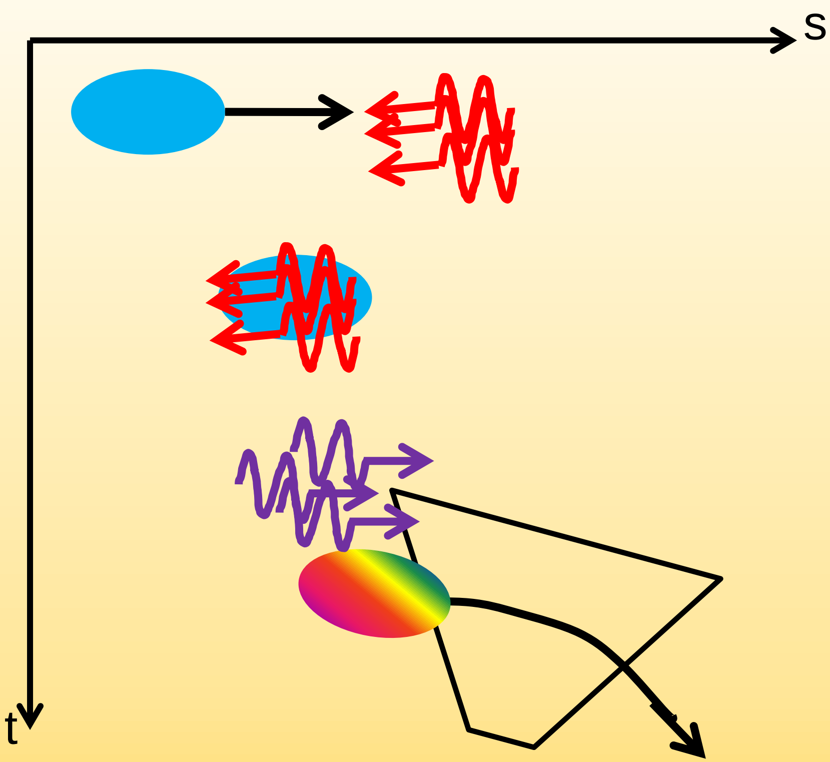
- ELI-NP project introduction
- Why high level applications?
- Development framework
- HLA status
- Trajectory correction
- Summary & next steps

ELI – Nuclear Physics

User facility for Nuclear Photonics experiments

using a light source based on **Compton Back-Scattering (CBS)** of trains of 32 bunches of relativistic electrons accelerated in a LINAC and a laser beam recirculated through a complex optical cavity **(Gamma Beam System).**

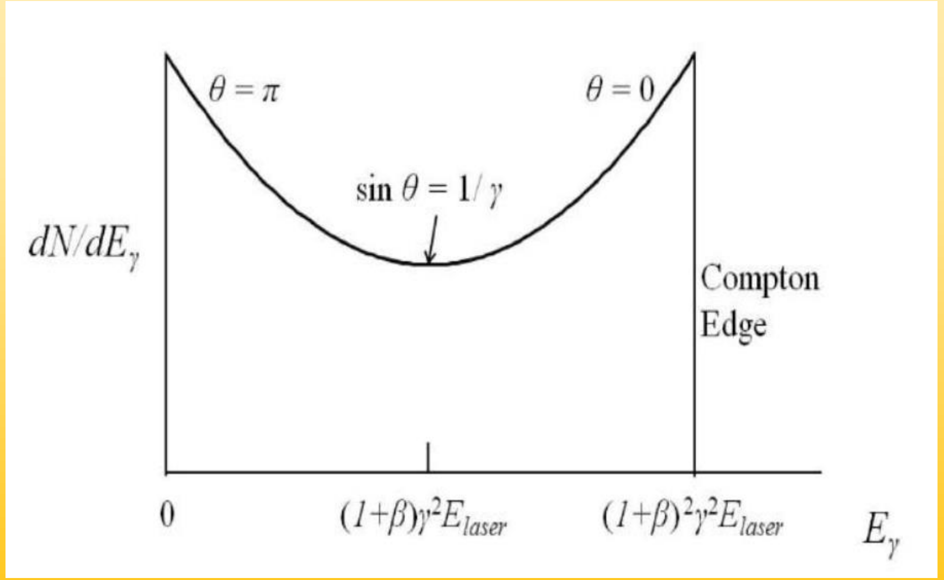
Compton Backscattering



If head-on collision, ultra-relativistic electrons, lower energy photons, then max energy is

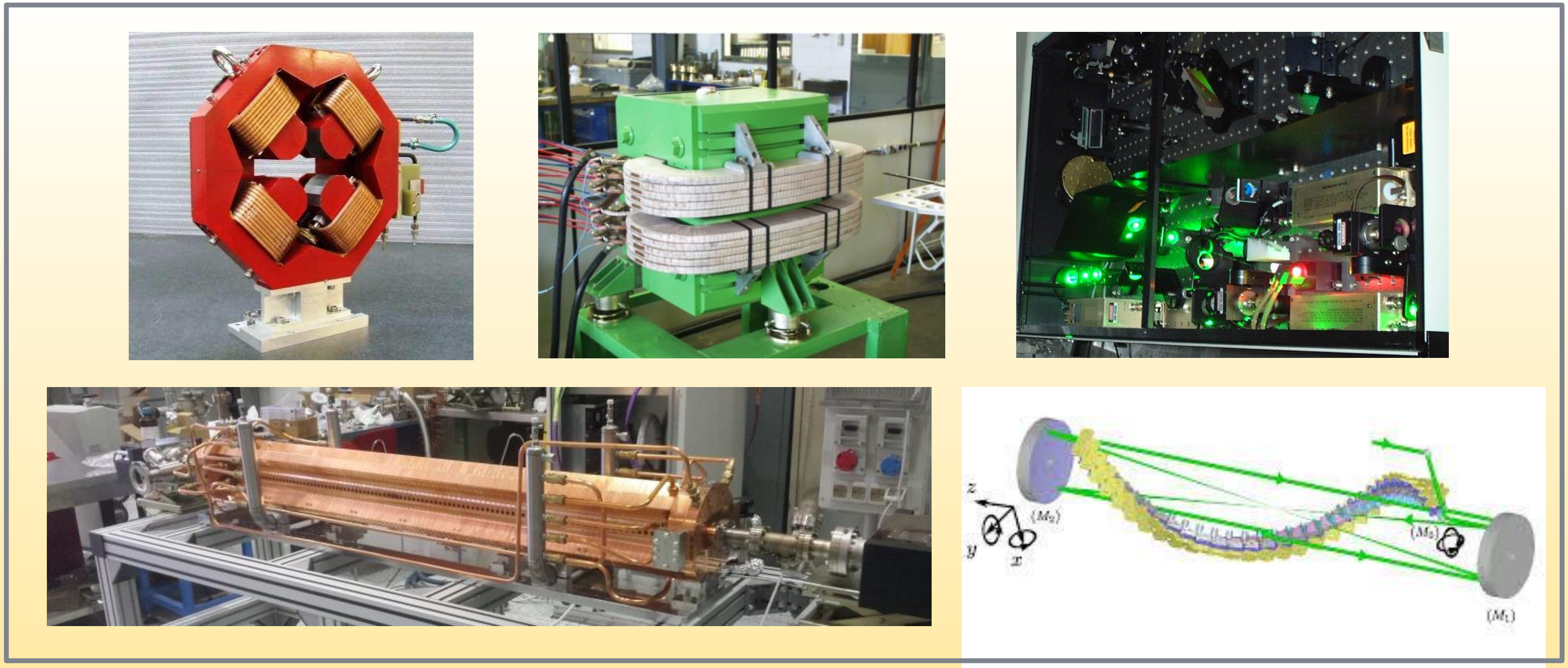
$$\omega_2 \approx 4\gamma^2\omega_1$$

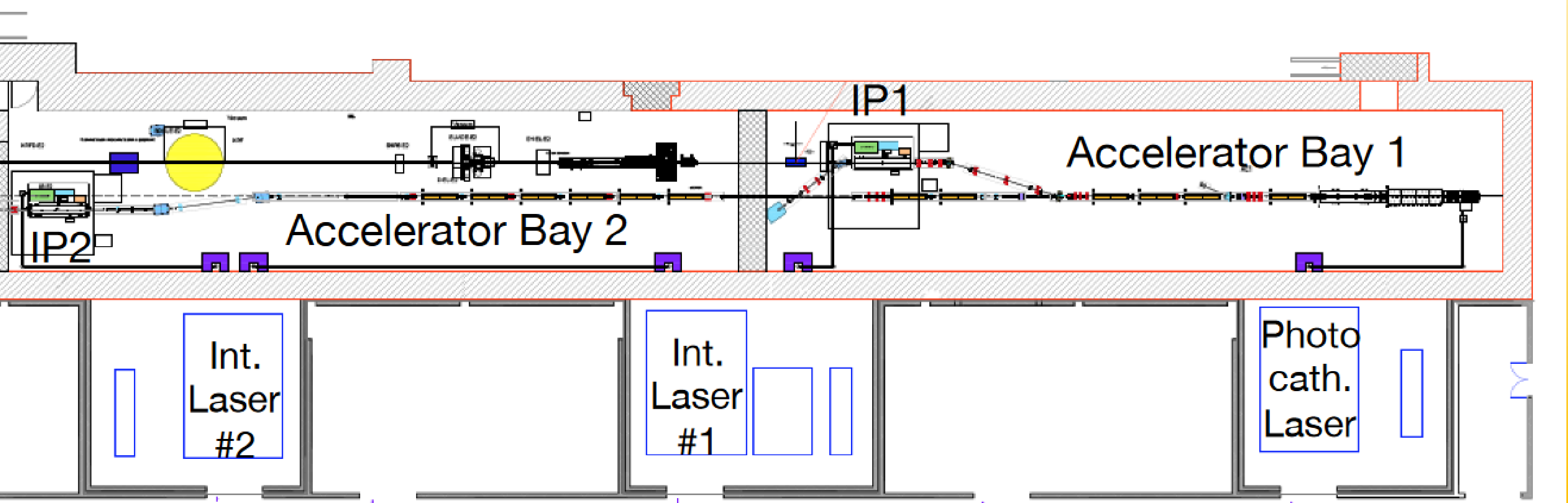
The spectral shape is given by
The differential cross section



To optimize the spectral photon density:

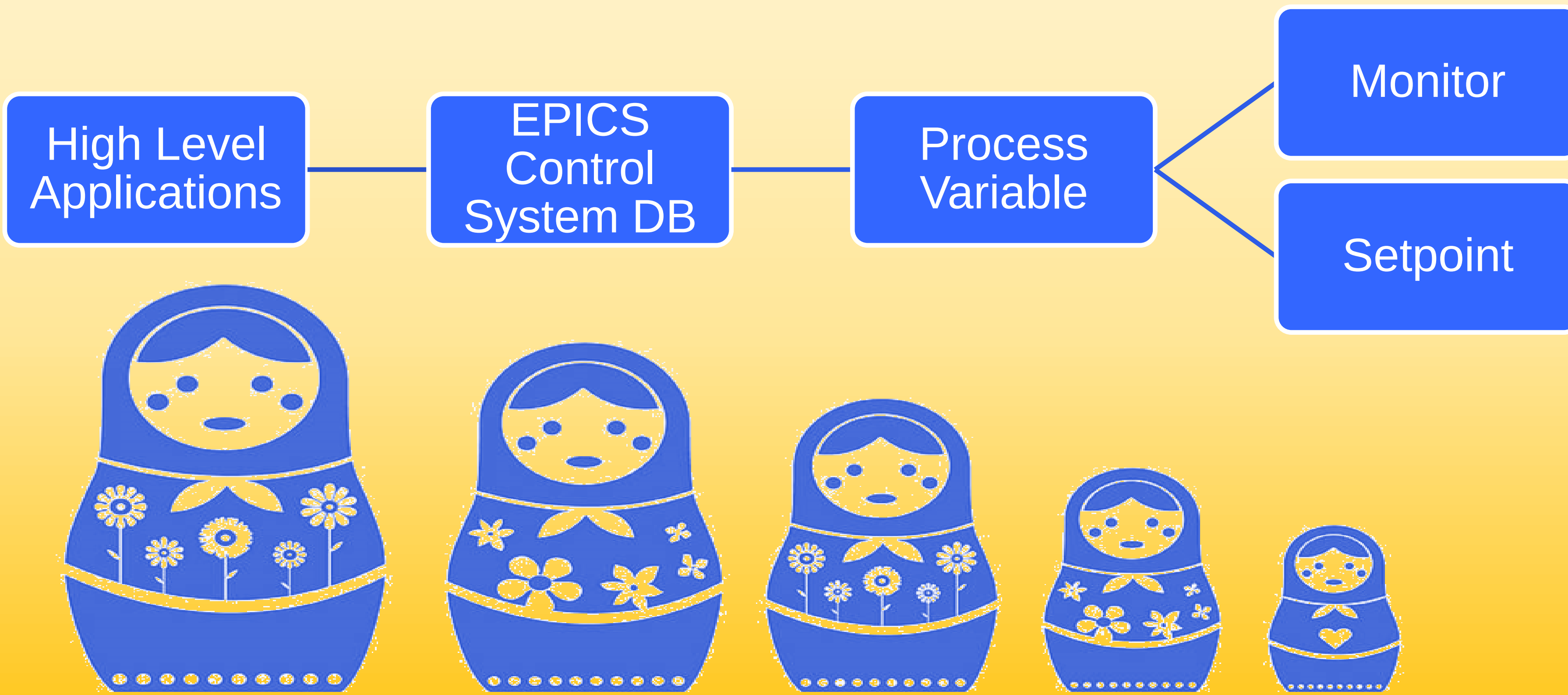
$$SPD \equiv N_\gamma^{bw}/\sqrt{2\pi}h\Delta\nu \propto \frac{Q}{\varepsilon_n^2}.$$




IP1
Accelerator Bay 1
Accelerator Bay 2
IP2
Int.
Laser
#2
Int.
Laser
#1
Photo
cath.
Laser

High Level Applications

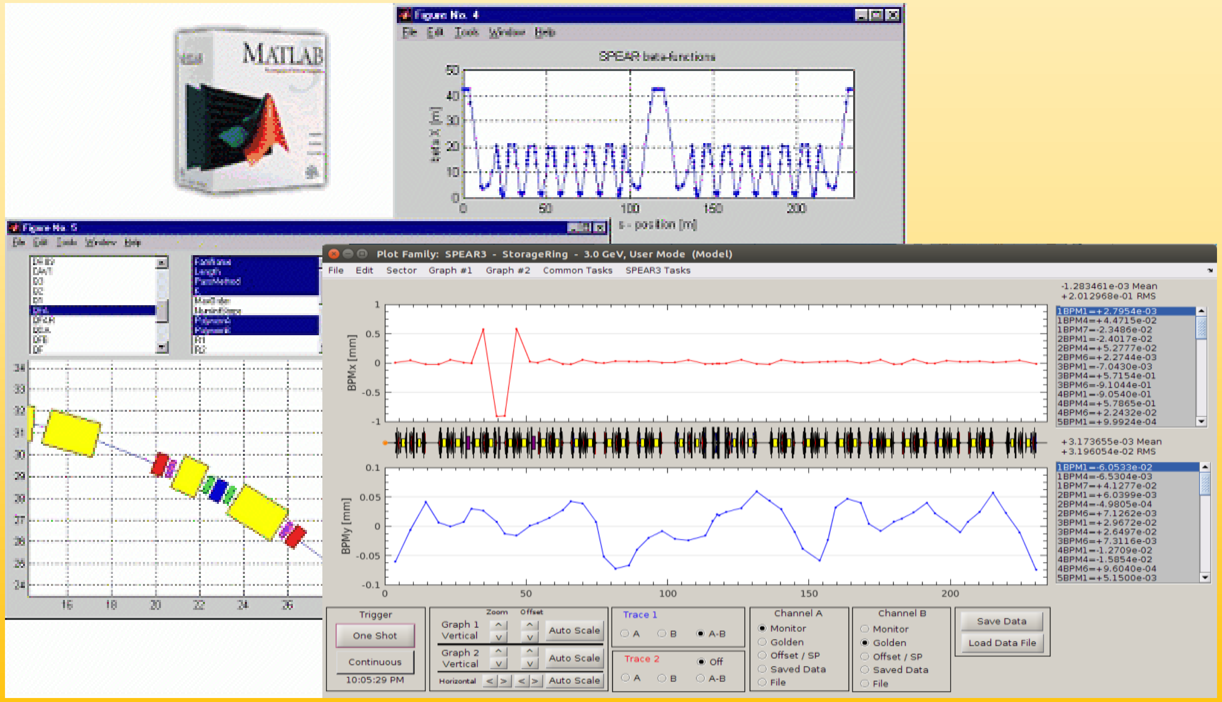
An **High Level Application (HLA)** is a **set of automated commands and operation** to perform a specific operation/measurement on the machine



MATLAB Middle Layer (+ Accelerator Toolbox)

Set of tools to model and control particle accelerators, **to make the particle accelerator operation more similar to running simulations.**

Simple “all-in-one” package, by G. Portmann(LBNL) and J.Corbett(SLAC) and used by many (ring) light sources



MML fundamentals

- **AO** = Accelerator Object (aoinit.m), must contain all of the families in the lattice and relative parameters
  - AO = getao;
- **AD** = Accelerator Data (setoperationalmode.m)
  - AD = getad;

Naming Convention

Family = Group descriptor (text string)
Field = Subgroup descriptor (text string)
DeviceList = [Sector Element-in-Sector]

Basic Functions

getpv(Family, Field, DeviceList);
setpv(Family, Field, Value, DeviceList);
steppv(Family, Field, Value, DeviceList);

AT basics

- Each element feature is stored in a field of a MATLAB structure, which is a variable with any number of fields (like a variable containing the elements of a table)
- Es. drift space

```
DR.Length = 1;
DR.FamName = 'Dr';
DR.PassMethod = 'DriftPass';
```

```
DR = atdrift('Dr',1);
```

Var name	Length	FamName	PassMethod
DR	1	'Dr'	DriftPass

- The full lattice is stored in a MATLAB cell array, containing the components variables in the order they appear in the lattice
- Es. LINE = {Drift Bend Drift}; LINE{1} -->Drift

Light sources using MML

- Currently: ALS, Spear, BNL (vuv and x-ray ring), CLS.
- Australian light source, DIAMOND, Soleil, Desy, and ALBA are experimenting with it (maybe more).
- The semi-machine independent software has fostered collaboration and code sharing between laboratories
- Integration of the AT model is good for debugging software without using accelerator time but limited simulation accuracy for LINACs physics → need for a different accelerator physics engine for our LINAC model

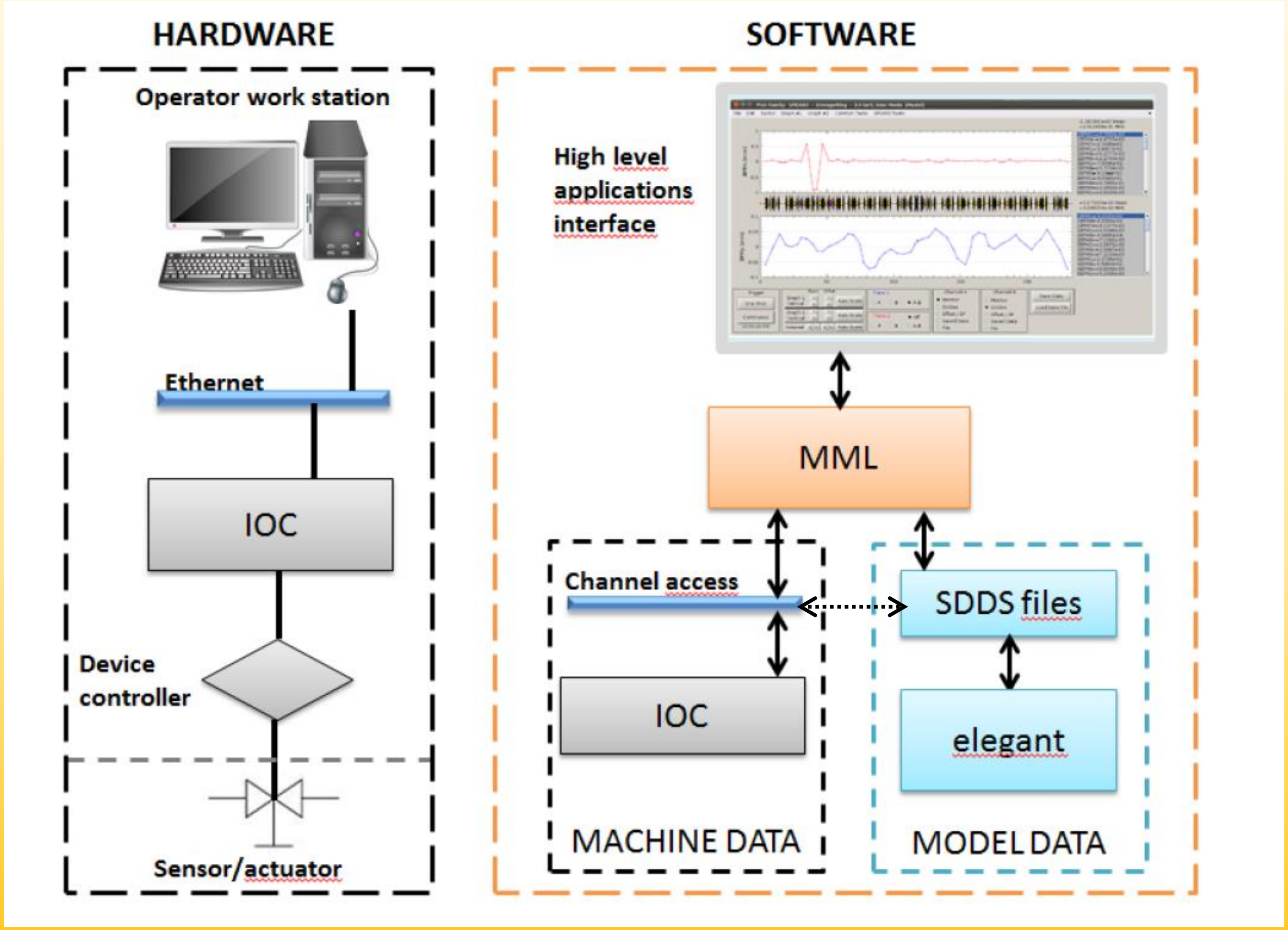
elegant

- Powerful and excellently documented tracking code for LINACs and rings,

  by M. Borland(ANL) and collabotators
- **SDDS = Self Describing Data Sets**
  - "An SDDS file is referred to as a "data set". **Each data set consists of an ASCII header describing the data**.

    […] while the specific data may vary from page to page, the structure of the data may not. The names, units, data types, and so forth of data elements are **defined in the header.** […]" – *from elegant manual*
  - EPICS data can be made SDDS compliant!

HLA architecture overview



eleMML basic functions

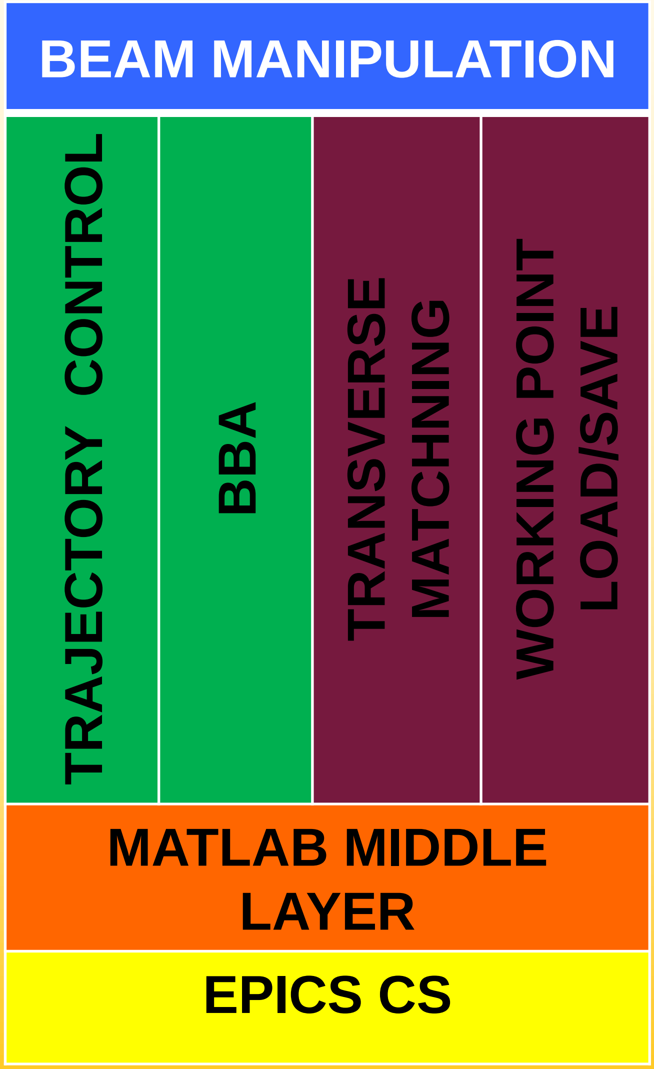
[AM, tout, DataTime, ErrorFlag] = getpv(..,..,..,’Mode’,’Model’)

array = sddsreadany(filename, col_par, col, pag)

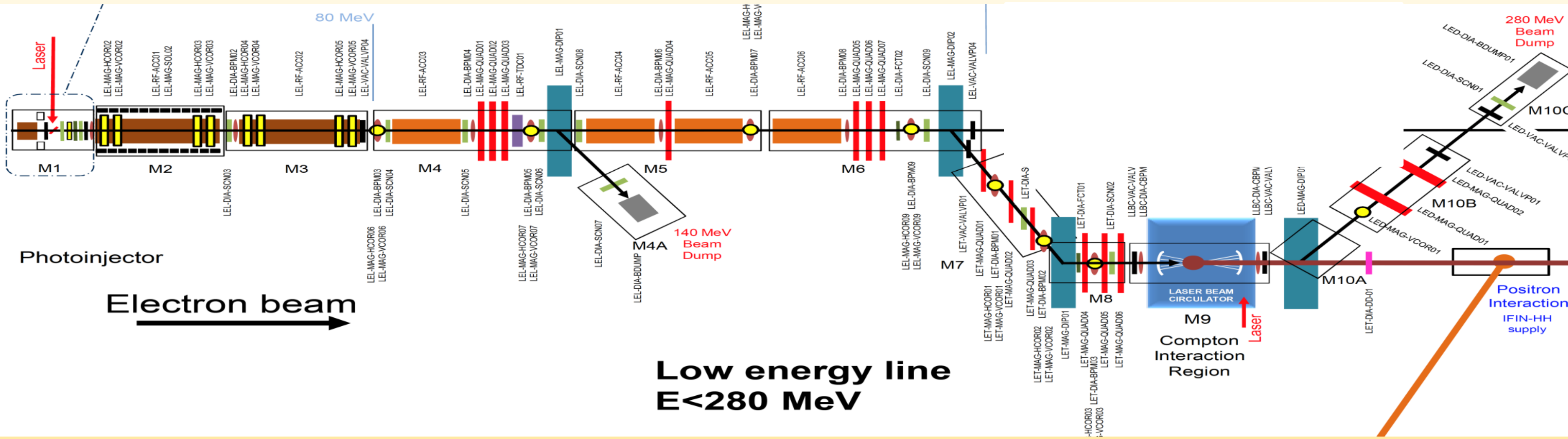
ErrorFlag = setpv(..,..,..,’Mode’,’Model’)

[Status, Result] = system([‘elegant virtualacc.ele -macro=’ ...
AO.(thisFam).FamilyName ‘=’ …
AO.(thisFam).SetPoint])

HLA status

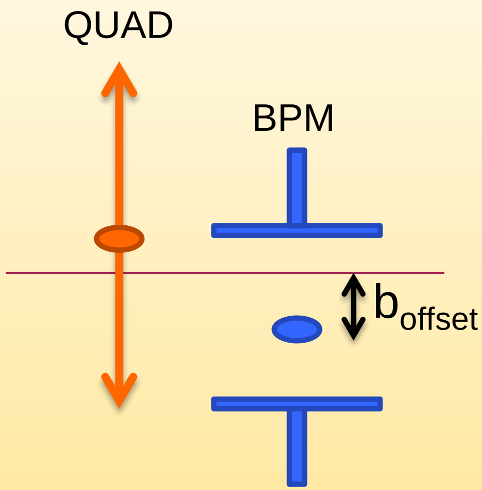

BEAM MANIPULATION
TRAJECTORY CONTROL
BBA
TRANSVERSE MATCHNING
WORKING POINT LOAD/SAVE
MATLAB MIDDLE LAYER
EPICS CS

Simulation parameters



Parameter	Value	Unit
γ source	2	MeV
E_e	234	MeV
$\Delta E/E$	<0.1	%
Q	250	pC
ϵ_n	0.44	$\mu m - rad$
σ_z	273	μm
$\sqrt{\sigma_x^2 + \sigma_y^2} = \sigma_t$	19.6	μm

Electron beam trajectory studies



Method Name	Minimization problem to solve
One-to-one	$\theta_i \parallel y_{i+1}^{BPM} = 0 \; \forall i = 1, \ldots, m$
Global or Fast Orbit Feedback (FOF)	$\mathbf{y} = \mathbf{R}\theta$
Dispersion Free Steering (DFS)	$\begin{pmatrix} \mathbf{y}(E_0) \\ \omega \cdot \Delta \mathbf{y} \\ \mathbf{0} \end{pmatrix} = \begin{pmatrix} \mathbf{R}(E_0) \\ \omega \cdot \Delta \mathbf{R} \\ \beta \cdot \mathbf{I} \end{pmatrix} \theta$

$$\Delta y_i = y_i(E_0) - y_i(E_0(1-\delta)) =$$
$$= b_i(E_0) + b_{offset} - (b_i(E_0(1-\delta)) + b_{offset}) =$$
$$= b_i(E_0) - b_i(E_0(1-\delta))$$

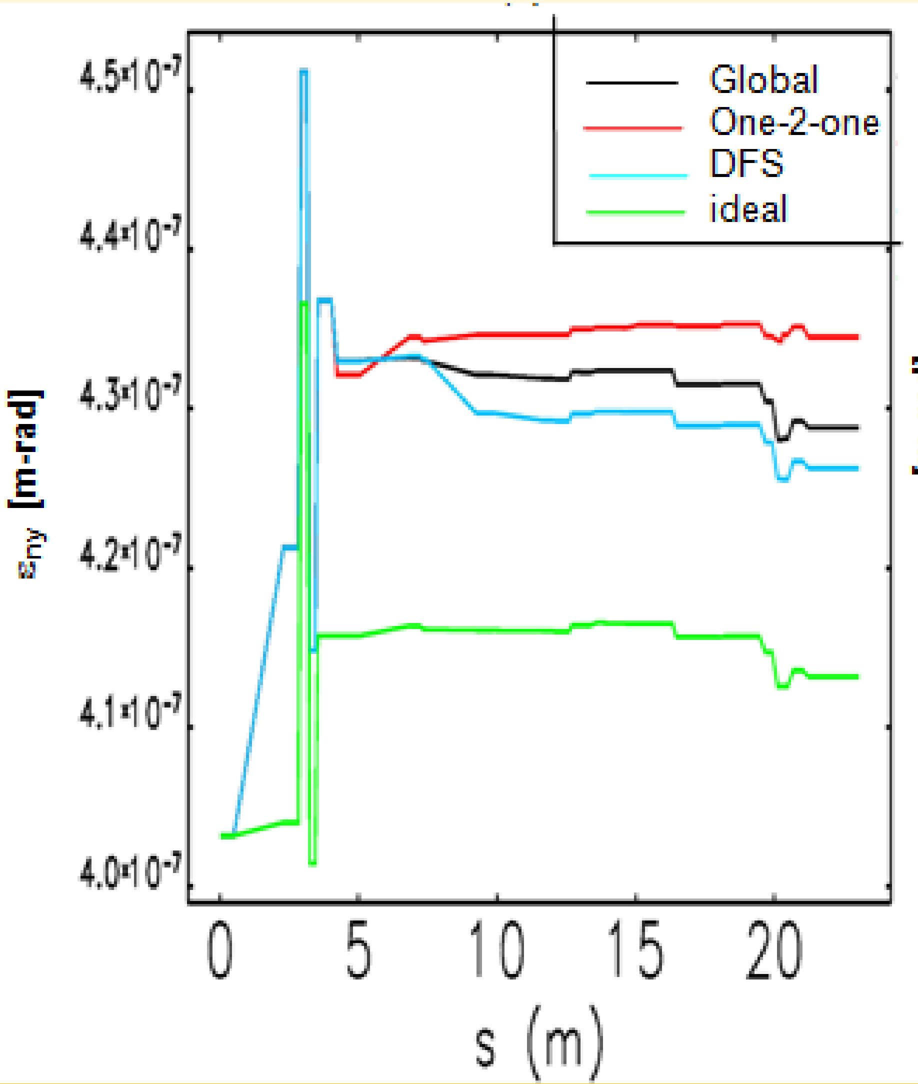
$$\Delta \mathbf{R} = \mathbf{R}(E_0) - \mathbf{R}(E_0(1-\delta))$$
$$R_{ij} = \frac{\partial y_i}{\partial \theta_j}$$

	symbol	μm
Quadrupole misalign.	σ_{quad}	70
RF sections misalign.	σ_{rfcav}	70
BPM misalign.	σ_{BPM}	70
BPM noise	σ_{noise}	5

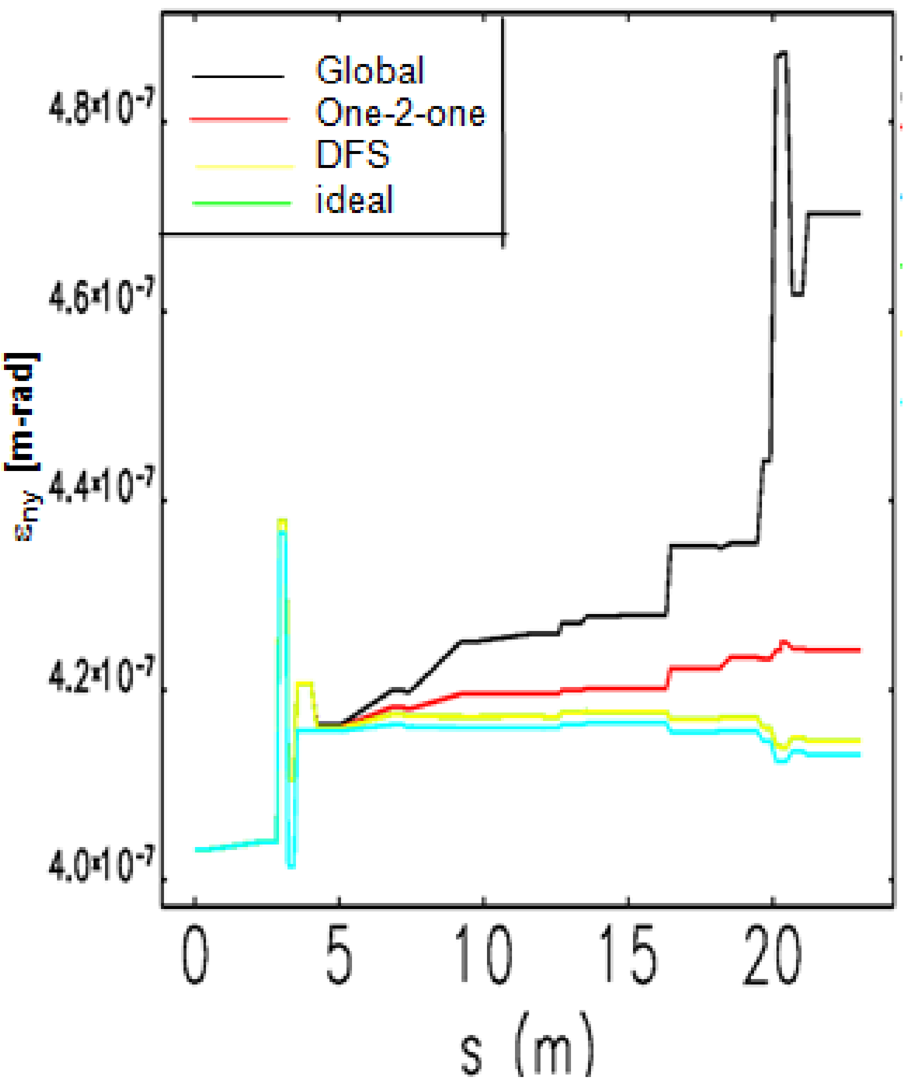
- Errors distributed on a 2σ-truncated Gaussian
- Energy different between test beam an nominal beam ΔE/E = 8%

Emittance comparison

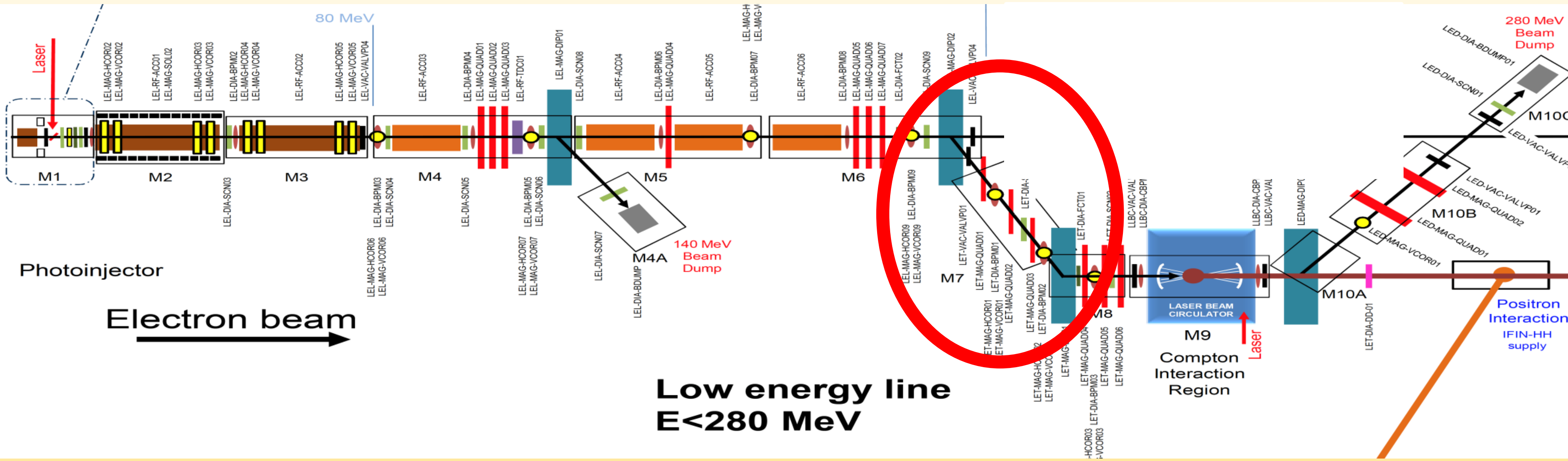
with RF misalignments



Without RF misalignments



Matched Dispersion Steering



- The horizontal design dispersion is not zero
- **MDS**: same as DFS except that the difference trajectory is defined as

$$\Delta x = x_i^{BPM}(E_0) - x_i^{BPM}(E_0(1-\delta)) - \Delta_i$$

where Δ_i is the design difference of the trajectories due to dispersion.

Summary

- ✓ High Level Applications are needed to commission and operate the machine
- ✓ Matlab Middle Layer, the Accelerator Toolbox, elegant and SDDS toolkit are exploited in a new way to develop HLAs
- ✓ We have studied different trajectory control, in particular DFS and MDS methods, on the low enegy line and developed the corresponding application

Next Steps

More high level applications will be developed in particular:

- **General purpose**: dark current measurement
- **Beam manipulation:** transverse matching, working point setup
- **Diagnostics:** emittance measurement
- **Interaction Point:** orbit feedback for luminosity optimization

We will also test switch between virtual accelerator and real machine components

References

M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation" , Advanced Photon Source LS-287, September 2000.

A. Terebilo, “Accelerator Modeling with MATLAB Accelerator Toolbox”. Particle Accelerators Conference 2001

J. Corbett, et al. High-Level MATLAB Application Programs For SPEAR3, SLAC Technical note

G. Portmann, et al. An Accelerator Control Middle Layer Using MATLAB, SRRL/SLAC, Stanford, CA, 94309 U.S.A

T.O. Raubenheimer, R.D. Ruth, Nucl. Instrum. Meth . A302: 191-208, 1991

O.Adriani et al., Technical Design Report EuroGammaS proposal for the ELI-NP Gamma beam System,arXiv:1407.3669

Publications

Journal articles

- G. CAMPOGIANI, S. Guiducci, A. Giribono, C. Vaccarezza, A. Variola, “Electron beam trajectory and optics control in the ELI-NP Gamma Beam System”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* http://dx.doi.org/10.1016/j.nima.2016.08.055.

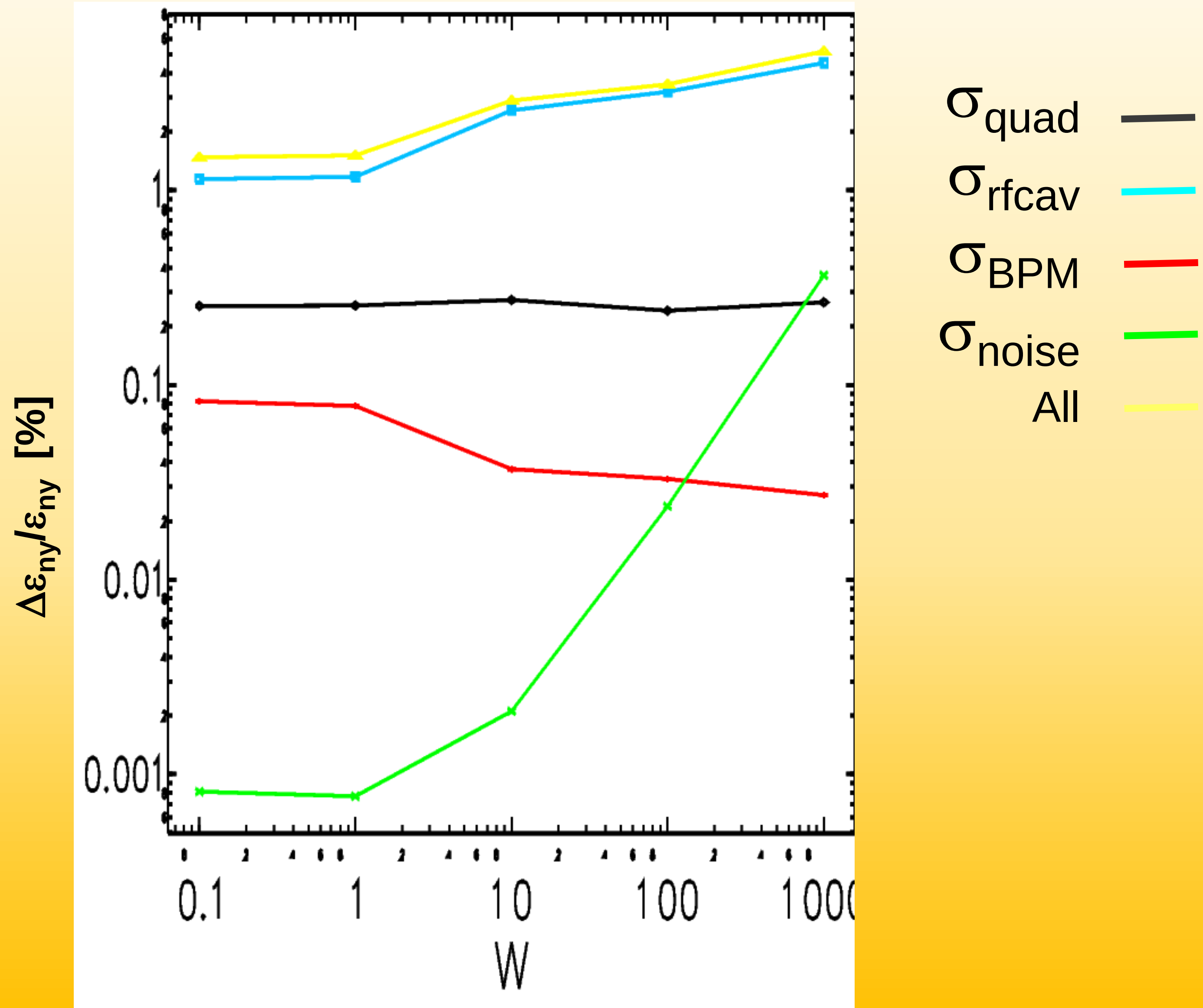
Conference Proceesings

- C. Vaccarezza *et al.*, “Optimization Studies for the Beam Dynamic in the RF Linac of the ELI-NP Gamma Beam System”, in *Proc. 7th International Particle Accelerator Conference (IPAC'16)*, Busan, Korea, May 2016, paper TUPOW041, pp. 1850-1853, ISBN: 978-3-95450-147-2, doi:10.18429/JACoW-IPAC2016-TUPOW041
- A. Giribono *et al.*, “Electron Beam Dynamics Studies for ELI-NP GBS Linac”, in *Proc. 7th International Particle Accelerator Conference (IPAC'16)*, Busan, Korea, May 2016, paper TUPOW043, pp. 1857-1860, ISBN: 978-3-95450-147-2, doi:10.18429/JACoW-IPAC2016-TUPOW043
- G. CAMPOGIANI, Y. Papaphilippou, “Beam Dynamics Studies to Develop a High-energy Luminosity Model for the LHC",in Proc. *6th International Particle Accelerator Conference,* Richmond, VA, USA, paper MOPWA050, pp. 233-235, ISBN: 978-3-95450-168-7,2015.

Other Publications

- Are light and charged particle beams two sides of a same coin? (IYL Blog, 2015)

Dispersion minimization weigth



GBS – Beam Specifications

TUPOW041 Proceedings of IPAC2016, Busan, Korea

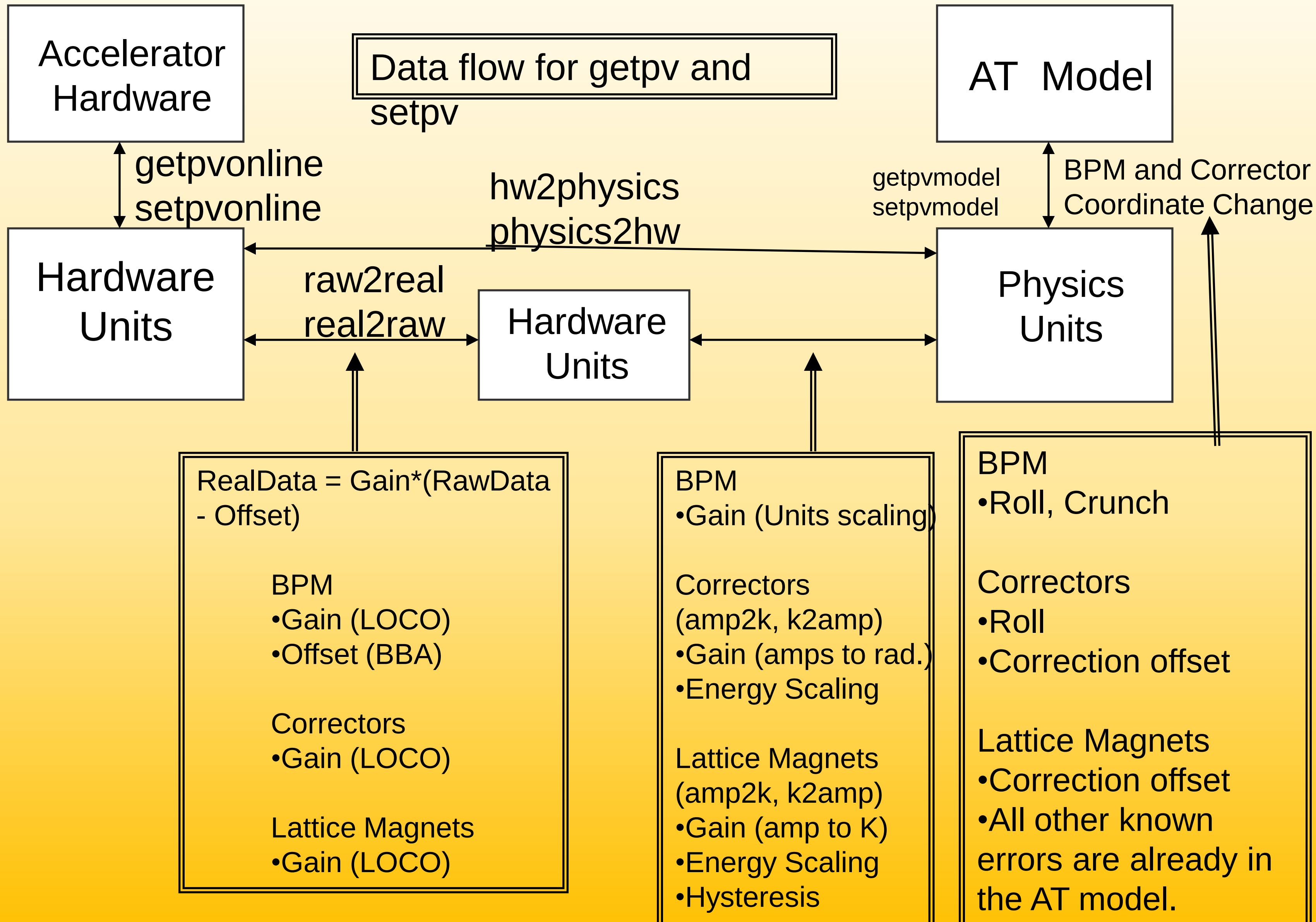
Table 2: Electron Beam Parameter List for the Different Working Points relative to the Gamma-Ray Source Energies.

γ-ray energy	**0.2**	**1.0**	**2.0**	**3.5**	**10.0**	**13.5**	**19.5**	***MeV***
e^- energy	75	165	234	312	530	605	740	*MeV*
e^- energy spread	1.14	0.86	0.82	0.80	0.45	0.43	0.48	‰
e^- rms bunch length	275	274	273	278	272	273	278	*μm*
e^- $\varepsilon_{n\ x,y}$	0.51	0.44	0.44	0.41	0.44	0.44	0.41	*mm mrad*
e^- $\beta_{x,y}$	0.16	0.43	0.43	0.55	0.71	0.71	0.95	*m*
e^- beam spot size at IP	23.5	20.0	19.6	19.4	17.3	17.3	16.2	*μm*

GBS – Beam Specifications

Energy [MeV]	0.2 – 19.5
Spectral Density [ph/s·eV]	0.8 – $4 \cdot 10^4$
Bandwidth rms [%]	≤ 0.5
# photons/pulse within FWHM bdw.	≤ $2.6 \cdot 10^5$
# photons/s within FWHM bdw.	≤ $8.3 \cdot 10^8$
Source rms size [mm]	10 – 30
Source rms divergence [mrad]	25 – 200
Peak brilliance [$N_{ph}/s \cdot mm^2 \cdot mrad^2 \cdot 0.1\%$]	10^{20} – 10^{23}
Radiation pulse length rms [ps]	0.7 – 1.5
Linear polarization [%]	> 99
Macro repetition rate [Hz]	100
# pulses per macropulse	32
Pulse–to–pulse separation [ns]	16
Polarization axis wiggling [deg]	< 1
Synchronization to an external clock [ps]	≤ 0.5
Source position transverse jitter [mm]	< 5
Energy jitter pulse–to–pulse [%]	< 0.2
# photons jitter pulse–to–pulse [%]	≤ 3

MML data flow diagram



Courtesy of G. Portmann

Scripting example

```
Y0 = getpv('BPMy');
% Get the Vertical response matrix from the model
Ry = getrespmat('BPMy', getlist('BPMy'), 'VCM');
% Computes the SVD of the response matrix
Ivec = 1:10;
[U, S, V] = svd(Ry, 0);
% Find the corrector changes use 55 singular values
DeltaAmps = -V(:,Ivec) * S(Ivec,Ivec)^-1 * U(:,Ivec)' *  (Y-Y0);
% Changes the corrector strengths
steppv('VCM', 'Setpoint',DeltaAmps);
```