MAD-X Progress and Future Plans
ICAP 2012, Warnemünde

Laurent Deniau

CERN-BE/ABP

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Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Part I — Status

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Methodical Accelerator Design (MAD) 1/2

- Single Particle Beam Dynamic Code
  - ➡ Motion of particles in 6D phase space under external fields (e.g. Lorenz Forces)
  - ➡ MAD language (lattice description)
  - ➡ Modular for the physics

- Linear motion (MAD-X)
  - ➡ 2D geometry (stacked elements + field and alignment errors)
  - ➡ Element slicing (Makethin, drift-kick-drift)
  - ➡ 2^{nd} order optics functions (Twiss, **X,R,T,** *not symplectic*)
  - ➡ High order thin tracking (Track, **X**, *symplectic*)
  - ➡ Optimization (Match)
  - ➡ Other modules: Survey, Aperture, Correct, Dynap, IBS, Emit, Touschek, Plots, ...

- Non-linear motion (PTC)
  - ➡ 3D geometry
  - ➡ Differential algebra, Taylor maps
  - ➡ High order tracking (Lie maps)
  - ➡ High order analysis (normal forms)

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Methodical Accelerator Design (MAD) 2/2

- Management philosophy
  - ➡ One custodian (person centric)
  - ➡ Modules keepers (collaborations)
  - ➡ Almost frozen during 2006-2011
  - ➡ Last big improvements
    - PTC/FPP inclusion into MAD-X (2003)
    - PTC_TWISS, PTC_TRACK, PTC_NORMAL (2005)

- Programming philosophy
  - ➡ Mixed C (Core), C++ (TPSA), Fortran 90 (PTC), Fortran 77 (MAD8)
  - ➡ ~165K SLOC (50% PTC), ~40K SLOC in C/C++
  - ➡ MAD-X code is not modular (global namespace & variables)
  - ➡ PTC is modular (F90 modules)
  - ➡ Release for Linux (Mac and Windows aside)

Emotional interlude (Oct. 2011)

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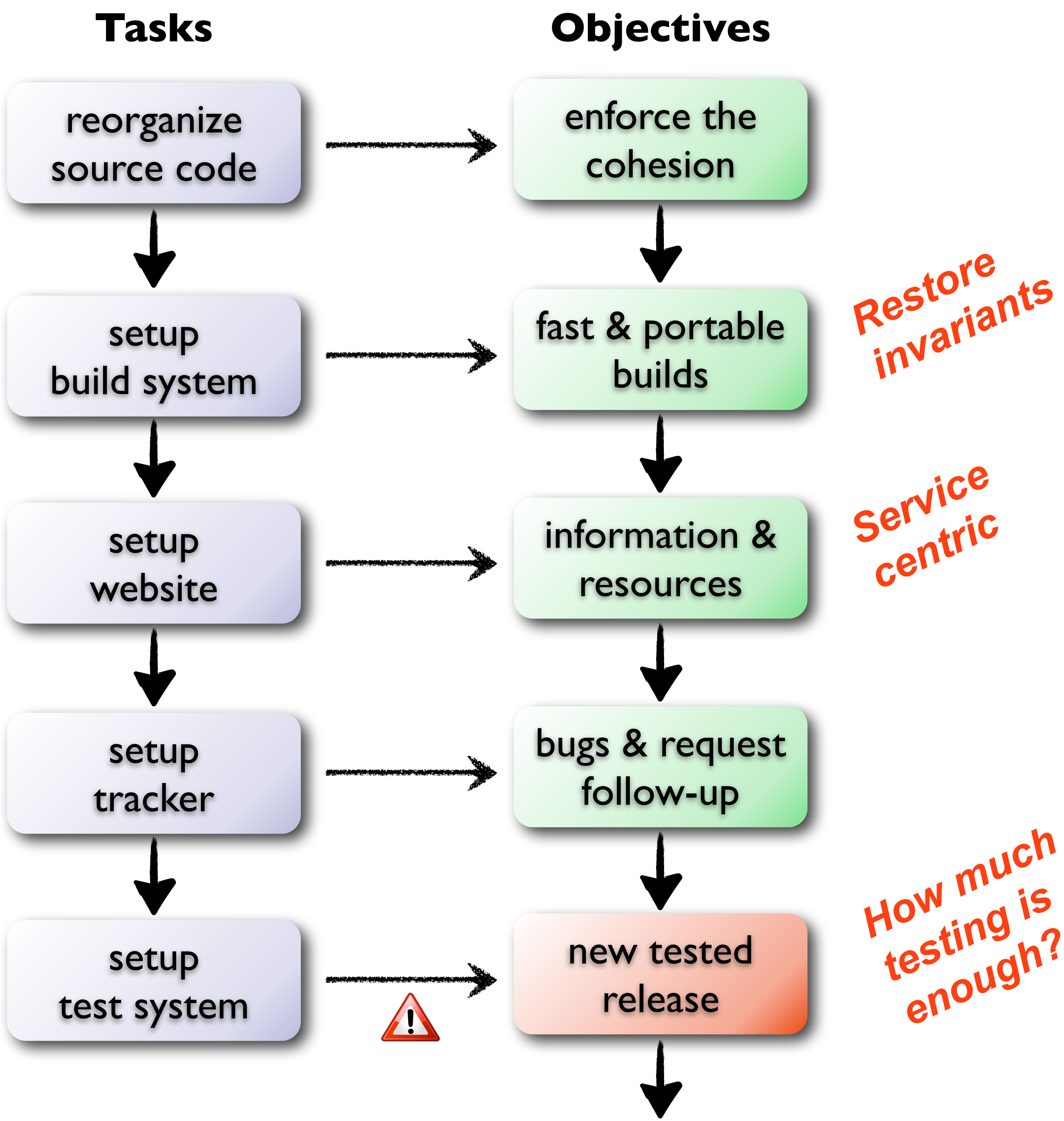
Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Improvement strategy

- Keep it working
  - ➡ Debug and request follow-up
  - ➡ Legacy code support
  - ➡ Service centric
- Improve the existing
  - ➡ From outside to inside layers
  - ➡ Structured documentation
  - ➡ Build & test uniformity (Windows, Mac, Linux)
  - ➡ Disentangle I/O (C vs. Fortran I/O)
  - ➡ Ensure no regression
  - ➡ Save resources
- Code reorganization (Preliminaries to new development)
  - ➡ Enforce the cohesion (close modules)
  - ➡ Reduce the coupling (remove globals)
  - ➡ Reduce the complexity (new design)
  - ➡ Improve reentrancy (new design)

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Project status (roadmap phase-1: 24 tasks)



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Website: http://cern.ch/mad

BE Beams Department

- New structure
- Easy access to material, information, documents, examples, releases, mailing lists...
- Project roadmap

European Laboratory for Particle Physics

MAD - Methodical Accelerator Design

CERN - BE/ABP Accelerator Beam Physics Group

Introduction

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Communication
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updated 2012.06.29

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MAD is a project with a long history, aiming to be at the forefront of computational physics in the field of particle accelerator design and simulation. The MAD scripting language is *de facto* the standard to describe particle accelerators, simulate beam dynamics and optimize beam optics.

MAD-X is the successor of MAD-8 and was first released in June, 2002. It offers most of the MAD-8 functionalities, with some additions, corrections, and extensions. The most important of these extensions is the Polymorphic Tracking Code (PTC) of E. Forest (see documentation).

MAD-X is released for the Linux, Mac OS X and Windows platforms for 32 bit and 64 bit architectures (see releases). The source code is written in C, C++, Fortan90 and Fortran77. The architecture of MAD-X is under complete review and reorganization in order to improve its maintainability, its flexibility and its performance with full backward compatibility. This long process should be completely transparent for the end users (see roadmap).

The support and maintainance strategy of MAD-X is based on the module keepers/helpers to debug and improve the legacy code (see contributors). This task is extremely complex within the legacy code and finding effective correction can take significant time.

MAD on the web

- MAD http://cern.ch/mad (this website, currently an alias for madx)
- MAD-X http://cern.ch/madx
- MAD-9 http://cern.ch/mad9
- MAD-8 http://cern.ch/mad8

The links above are the officially maintained MAD links, but the previous MAD-X website is still online.

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Tracker

IT Department

Search

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Wiki | Timeline | Roadmap | Browse Source | View Tickets | New Ticket | Search | Admin

Available Reports | Custom Query

{6} All Tickets By Milestone (Including closed) (173 matches)

A more complex example to show how to make advanced reports.

Edit report | Copy report | Delete report

Results (1 - 100 of 173)

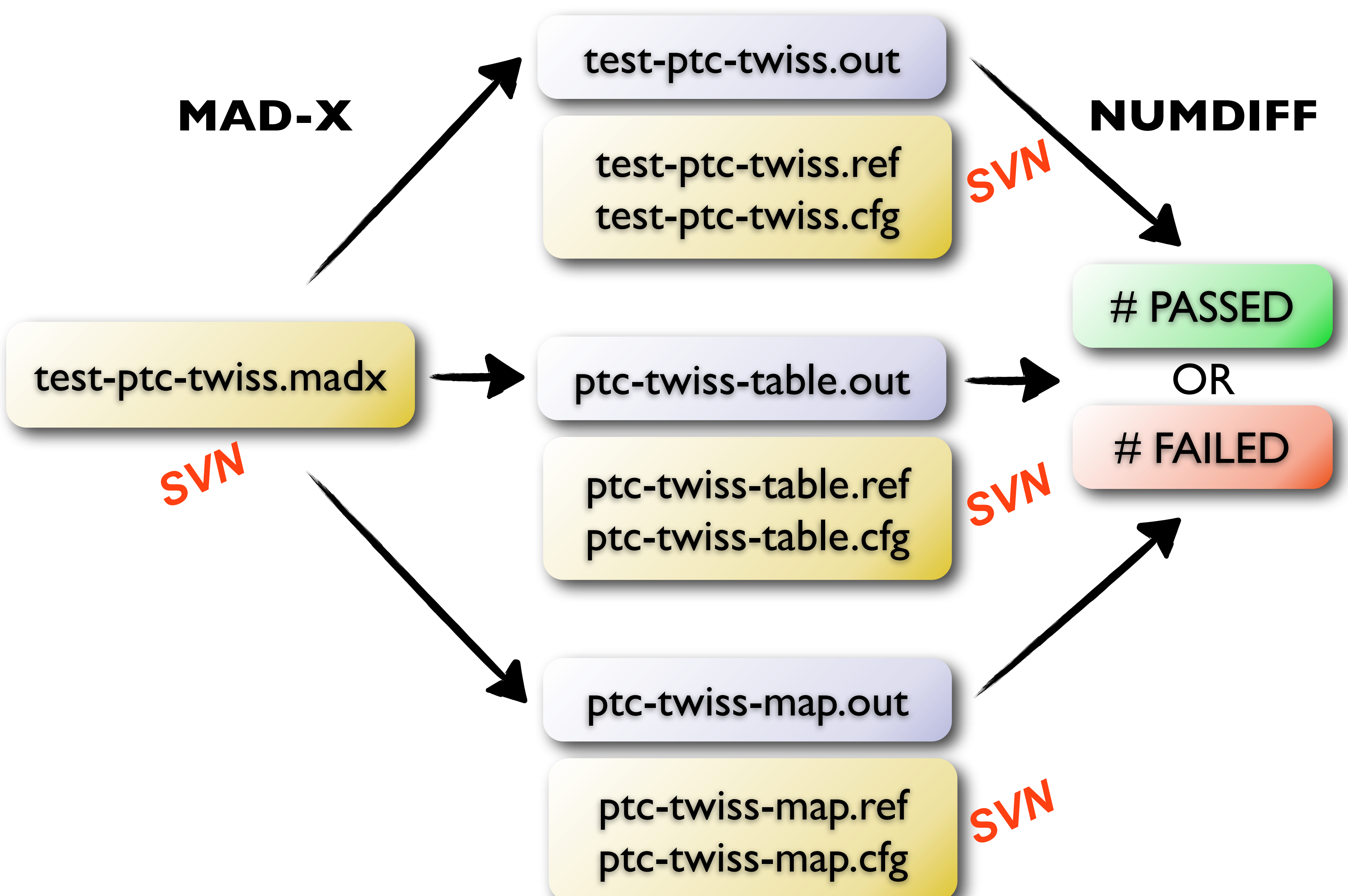
1 2 →

Ticket	Summary	Component	Status	Resolution	Version	Type	Priority	Owner	Reporter	Created
#173	Invalid format does not report an error	core_table	closed	wontfix	5.00	defect	minor		Olav.Ejner.Berrig	15/08/12
#172	Proposal for tests and changes in the MADX code	core_sequence	new		5.00	request	major		stephane.fartoukh	18/07/12
#171	Parser silently ignore **	core_parser	new		5.00	defect	major		stephane.fartoukh	12/07/12
#170	Numdiff problem in test-jacobian-knobs	_tests	closed	fixed	5.00	defect	major	laurent.deniau	ylevinse	04/07/12
#169	PLOT crash	mod_plot	closed	fixed	5.00	defect	blocker	skowron	skowron	03/07/12
#168	Test-match is failing	_tests	new		5.00	test	major		ylevinse	03/07/12
#167	Connect beam-beam PTC element to MAD-X element	ptc_proper	closed	fixed	5.00	request	major	piotr.skowronski	massimo.giovannozzi	27/06/12
#166	Plot does not work on Windows	mod_plot	closed	fixed	5.00	defect	major	laurent.deniau	angelina.parfenova	27/06/12
#165	Too many commas in twiss command not handled	core_command	new		5.00	defect	major		yngve.inntjore.levinsen	26/06/12
#164	Problem with plot when generating postscipt file	mod_plot	new		5.00	defect	major		frank.schmidt	25/06/12
#163	Jacobian run infinitely when madx is compiled with gfortran	_build	closed	fixed	5.00	defect	major	ldeniau	laurent.deniau	25/06/12
#162	DA becomes unstable during ptc_twiss	ptc_proper	new		5.00	defect	major		laurent.deniau	25/06/12
#161	Output is 80 columns when compiled on Windows with Ifort	core_stream	closed	fixed	5.00	defect	major	laurent.deniau	laurent.deniau	25/06/12
#160	Output is desynchronized when compiled with gfortran >= 4.4	core_stream	closed	fixed	5.00	defect	major	laurent.deniau	laurent.deniau	25/06/12
#159	Redirection not detected on Windows	_windows	closed	fixed	5.00	defect	major	laurent.deniau	laurent.deniau	25/06/12
#158	Multipole kick in Track ignores parameter deltap	mod_track	closed	fixed	5.00	defect	major	andrea.latina	andrea.latina	25/06/12
#157	Aperture documentation for racetrack shape	_doc	closed	fixed	5.00	defect	minor	laurent.deniau	massimo.giovannozzi	25/06/12
#156	Use madx as a shared library	_build	closed	fixed	5.00	request	major	laurent.deniau	riccardo.de.maria	25/06/12
#155	Implicit drifts produced differently	_tests	new		5.00	defect	major		yngve.inntjore.levinsen	22/06/12
#154	Improve makethin teapot method beyond 4 slices	mod_mkthin	assigned		5.00	request	major	helmut.burkhardt	massimo.giovannozzi	14/05/12
#153	Memory overflow and input bug on windows	_windows	new		5.00	defect	major		gajendra.kumar.sahoo@...	18/04/12
#152	PTC does not find the closed orbit	ptc_twiss	new		5.00	defect	major		sugahara.kengo@...	16/04/12
#151	Significant memory leak in PTC	ptc_twiss	closed	fixed	5.00	defect	major	laurent.deniau	harry.renshall	05/04/12
#150	plot with interpolate changes value of bending angle	mod_plot	new		5.00	defect	major		piotr.skowronski	03/04/12
#149	Lost particles differ from previous version	mod_track	new		5.00	defect	major		simone.maria.liuzzo@...	01/04/12
#148	Incorrect beam parameters retrieval	_doc	closed	worksforme	5.00	defect	minor	laurent.deniau	massimo.giovannozzi	29/03/12
#147	Silent bug in the parser when ; is forgotten.	core_parser	closed	wontfix	5.00	defect	major		cedric.hernalsteens	27/03/12
#146	Beam parameters are set to electron	core_variable	closed	worksforme	5.00	defect	major	laurent.deniau	andriyrusanov@...	27/03/12
#145	Buserror in PTC twiss	ptc_twiss	new		5.00	defect	major		laurent.deniau	22/03/12
#144	Invalid dispersion calculation with expression for e1, e2	mod_twiss	closed	fixed	5.00	defect	major	laurent.deniau	A.V.Bogomyagkov@...	21/03/12

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Test system: black-box testing

- Principle: *compare the outputs with the references under constraints*
- Ensure consistent results through cross-platforms



Test system: test levels

- Unit tests (not implemented)
  - ➡ very fast, should take <10 seconds
  - ➡ run as often as possible
  - ➡ requires a complete redesign of madx code (not foreseen in 2012)

- **Test cases**
  - ➡ fast, should take <10 minutes
  - ➡ light, should not depend on large lattice files
  - ➡ run during development to validate **modules** after changes in the code

- **User cases**
  - ➡ longer, can take hours
  - ➡ can depend on large lattice files shared across studies (e.g. LHC optics)
  - ➡ run before releasing to validate **studies** and avoid backward incompatibilities

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Test system: numdiff

- How numbers are compared?
  - Absolute: $|a - b| \leq \texttt{abs}$
  - Relative: $|a - b| \leq \texttt{rel} \cdot \min(|a|, |b|)$
  - Digits: $|a - b| \leq \texttt{dig} \cdot \min(|a|, |b|) \cdot 10^{-\texttt{ndig}}$
    - `ndig` is the max number of significant digits read from input (i.e. adaptive)
  - a = 0 or b = 0 ➟ min = 1
    - Relative ➟ Absolute

- What is a line? *(row count)*
  - Everything up to \n (Unixes), \r\n (Windows) or \r (Old Mac)
  - Portable across operating system

- Constraints can overlap
  - Last constraints in the constraints file prevail
  - Define weak constraints first, then refine tolerances
  - Rule #0 (default) is equivalent to "`* * abs=DBL_MIN`" (DBL_MIN = 2.22507e-308)

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Test system: examples

- Configure tests

```
# Test config for the Jacobian knobs (test-jacobian-knobs.cfg)
# rows      cols      constraints
1-7         *         skip           # head banner
149-$       *         skip           # tail banner
# first matching
37-38       1-2       rel=1e-12
39          2         abs=1e-21      # from job
41          1         rel=1e-12
# second matching
109-110     1-2       rel=1e-12
111         2         abs=1e-21      # from job
113         1         rel=1e-12
```

- Run tests

```
[ Jacobian testsuite ]
 + test-jacobian                    (0.00 s) -   1/ 1 : PASSED
 + test-jacobian-2                  (0.00 s) -   1/ 1 : PASSED
 + test-jacobian-knobs              (0.00 s) -   2/ 2 : PASSED
[ RF multipole testsuite ]
 + test-rfmultipole                 (0.00 s) -   9/ 9 : PASSED
 + test-rfmultipole-2               (0.00 s) -   2/ 2 : PASSED
 + test-rfmultipole-3               (0.00 s) -   2/ 2 : PASSED
 + test-rfmultipole-4               (0.00 s) -   2/ 2 : PASSED
[ PTC Twiss testsuite ]
 + test-ptc-twiss                   (0.00 s) -   4/ 4 : PASSED
```

Documentation

- New structure
- Better language description
- Clarify lattice description
- Improve the learning curve of new comers

European Organization for Nuclear Research

MAD Language

Content | Index | MAD Language | MAD Commands | Machine Description | MAD-X | PTC | I/O & Plots

Keywords

- **Identifiers**

  An identifier is a sequence of letters, digits, decimal points, and/or underscores that the user chooses. An identifier has to begin with a letter; it cannot begin with a digit. Characters beyond the sixteenth are dropped. Uppercase and lowercase letters are treated indistinctly as lowercase (i.e. case insensitive).

  Syntax:

  ```
  [a-zA-Z][a-zA-Z0-9._]*
  ```

  Examples:

  ```
  abcd , ab_cd , adcb10 , ab.cd          (valid identifiers)
  10abcd ,  _abcd , .abcd , ab!cd        (non-valid identifiers)
  ```

- **Labels**

  A label is made up of an identifier followed by ":".

  Syntax:

  ```
  identifier-name:
  ```

- **Reserved Keywords**

  MAD keywords are reserved identifiers, using MAD keywords as identifiers result in an error.

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Emotional interlude (May 2012)

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Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

New element: RF-Multipole

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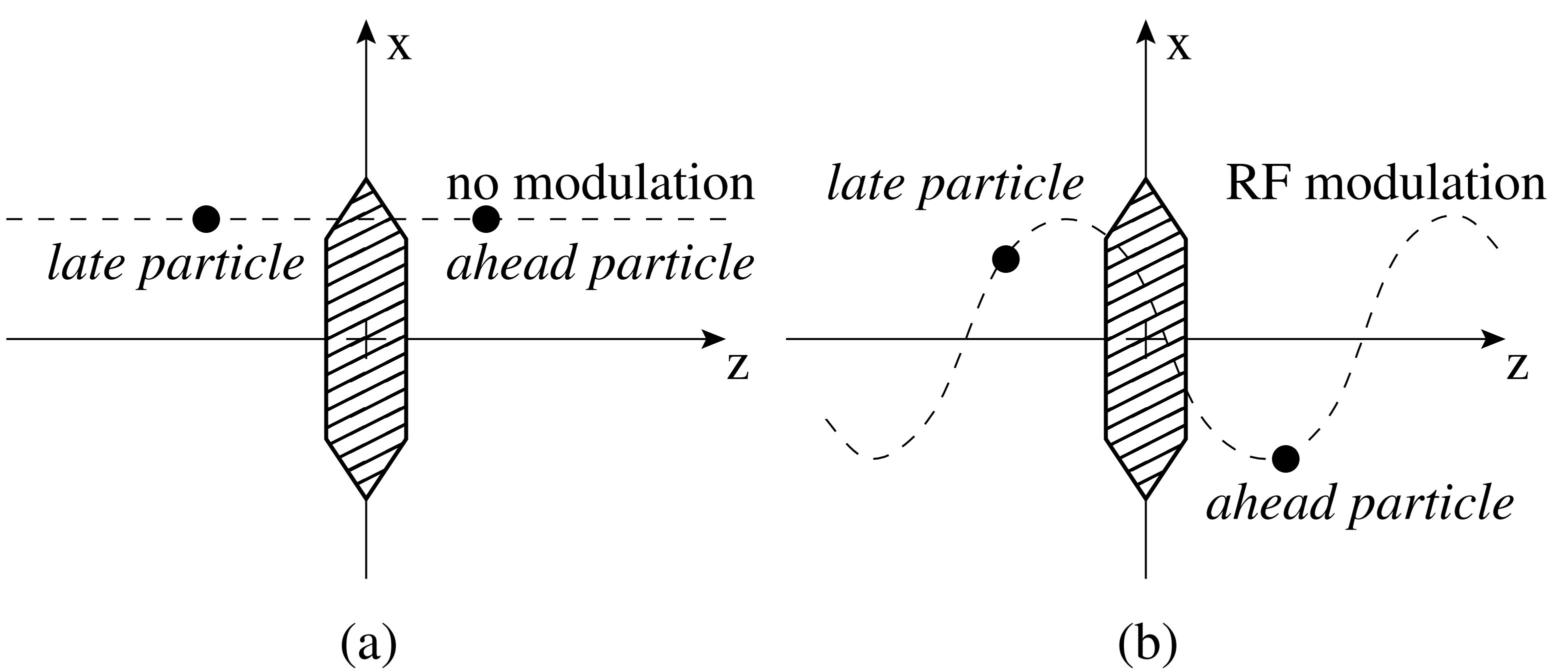
- Thin multipole element with RF modulation (rotating harmonics) and longitudinal kick (acceleration)
- Harmonics: $B_n + iA_n = \frac{1}{n!}\left[K_{N,n}L + iK_{S,n}L\right] = \frac{1}{n!}\left[K_{N,L,n} + iK_{S,L,n}\right]$
- Hamiltonian:

$$H = -\frac{1}{k_{\mathrm{RF}}}\frac{qV_{\mathrm{RF}}}{p_s c}\cos(\vartheta_{\mathrm{RF}} - k_{\mathrm{RF}}z) + \sum_{n=0}^{N}\frac{1}{(n+1)!}\mathrm{Re}\Big[\Big(K_{N,L,n}\cos(\vartheta_n - k_{\mathrm{RF}}z) + iK_{S,L,n}\cos(\varphi_n - k_{\mathrm{RF}}z)\Big)(x+iy)^{n+1}\Big]$$

Courtesy to
R. De Maria (Hamiltonian)
A. Latina (implementation)

- Effects relative to the reference particle: (a) multipole, (b) RF-multipole



New element: Nonlinear elliptical lens

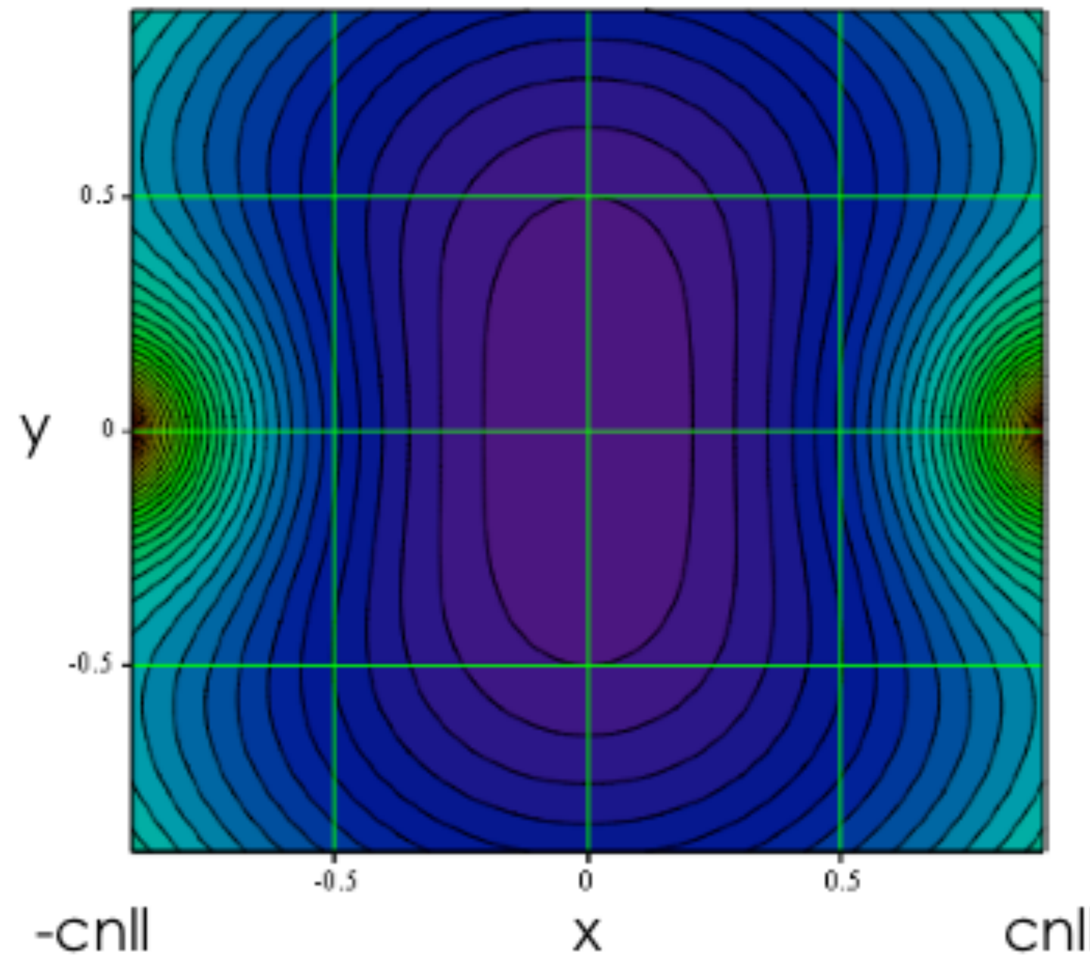
- Nonlinear thin lens with potential of elliptic shape

$$U(x,y) = \frac{k}{c} \frac{\xi\sqrt{\xi^2-1}\,\mathrm{acosh}\,\xi + \eta\sqrt{1-\eta^2}(\mathrm{acos}\,\eta - \pi/2)}{\xi^2-\eta^2}$$

Courtesy to
A. Valishev (implementation)

$$\xi = \frac{\sqrt{(x+c)^2+y^2}+\sqrt{(x-c)^2+y^2}}{2c}$$

$$\eta = \frac{\sqrt{(x+c)^2+y^2}-\sqrt{(x-c)^2+y^2}}{2c}$$



- KNLL: The integrated strength of lens [m]. The strength is parametrized so that the quadrupole term of the multipole expansion is k1=2*KNLL/CNLL^2
- CNLL: The dimensional parameter of lens [m]. The singularities of the potential are located at X=-CNLL,+CNLL and Y=0

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Part II — Future

Purpose of optics codes

1. **Definition**: define or modify machine parameters using the MAD language.

2. **Tracking**: track particles or maps to find periodic, quasi-periodic or constrained solutions, i.e. one-turn map and closed orbit.

3. **Analysis**: compute optics functions for the one-turn map, use normal forms for high-order terms.

4. **Optimization**: optimize the design with user-defined constraints, e.g. interaction regions matching.

5. **Validation**: perform single-particle tracking campaign to validate the design, e.g. check the dynamic aperture.

Loop over previous steps

The amazing discrepancy between codes has its origin mainly in the integrator scheme

L. Nadolski

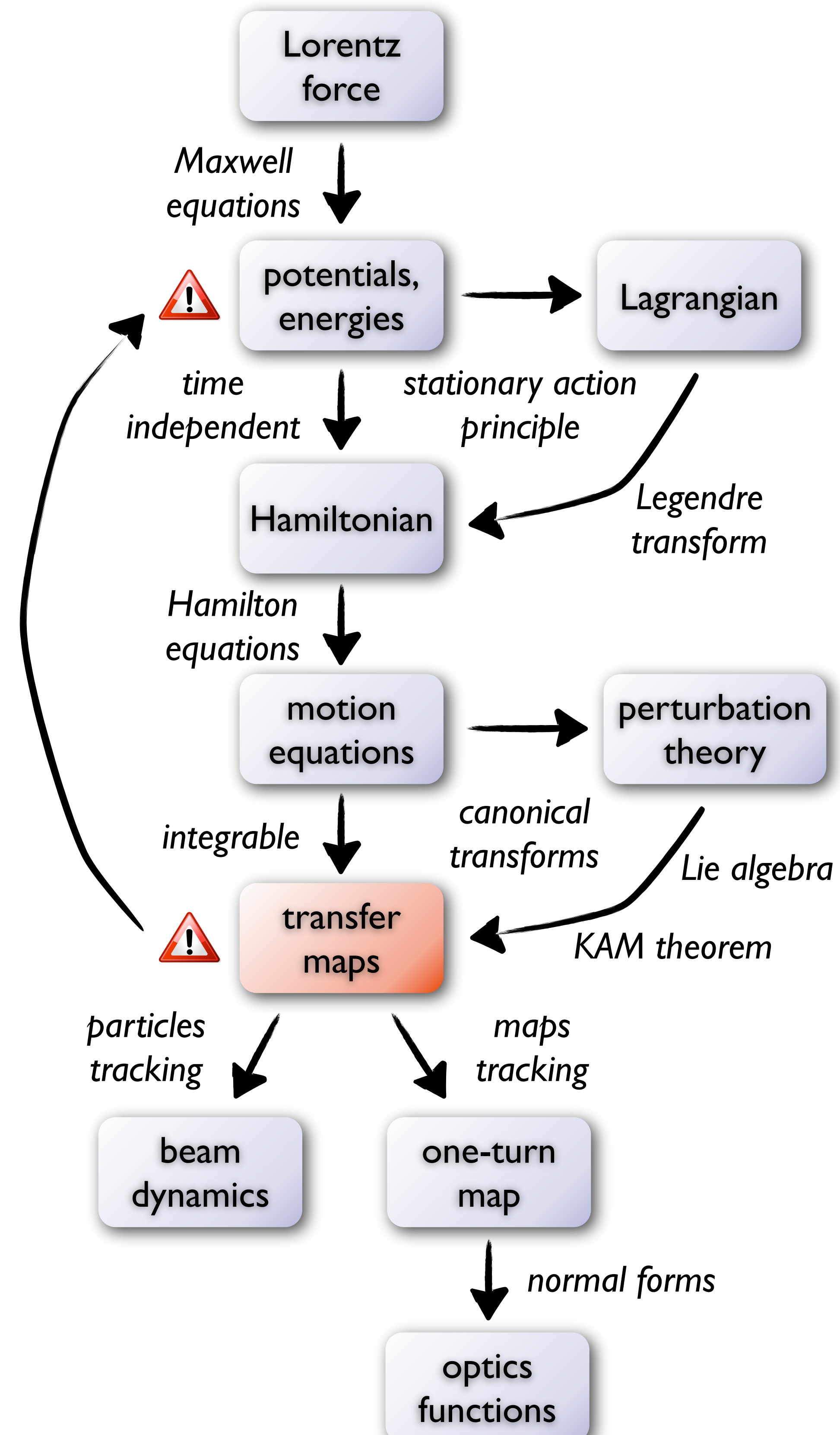
Optic calculations

- Lattice model
  - ➡ **Track**: D-K-D, symplectic, 0^{th} order (orbit)
  - ➡ **Twiss**: M-K-M, non-symplectic, 2^{nd} order (orbit, **R**, **T**)
  - ➡ **PTC**: D-K-D & M-K-M, symplectic, exact, high order (TPSA)
- Symplectic integration (?)
  - ➡ Knowledge of the energies (Hamiltonian)
  - ➡ Knowledge of the transfer maps (motion)
  - ➡ Knowledge of the slicing scheme (order)
- Tracking maps
  - ➡ Differential algebra, Taylor maps
  - ➡ Truncated power series algebra (TPSA)
- One-turn-map analysis (?)
  - ➡ Normal forms (Jordan forms)
  - ➡ Lie algebra (non-linear analysis)
- Matching (optimization, fixed points)
- Dynamic aperture (long-term behavior)

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Symplectic integrators: approximations

- Lattice models
- Element models
- Integrators schemes
  - ➡ Approximate solution to exact Hamiltonian
  - ➡ Exact solution of approximate Hamiltonian
- Approximations
  - ➡ composition method
  - ➡ series truncation
  - ➡ paraxial approximation
  - ➡ radius of convergence
  - ➡ Lorenz transform ($0 < \beta \leq 1$)
- Parameters
  - ➡ small $p_0 c$
  - ➡ large $\Delta p/p$
  - ➡ fixed point stability (beamlines *closed orbit*)
  - ➡ large aperture A vs. integrated strength KL
  - ➡ off momentum, off axis beams vs. small field length L and curvature radius ρ



Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Emotional interlude (now)

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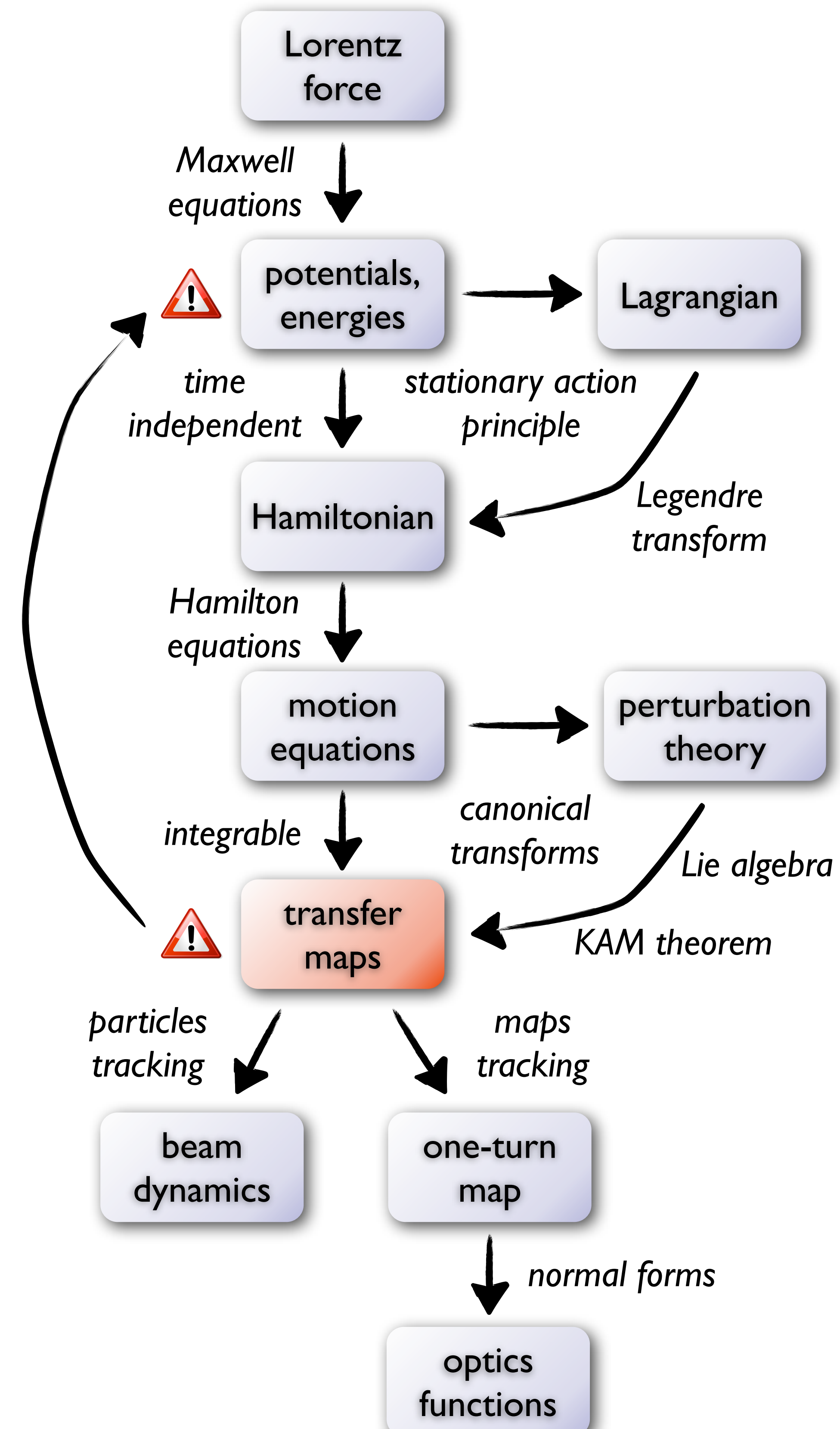
Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Symplectic integrators: benchmarking

- Element models
  - ➡ O. Berrig, "*Comparison of transfer maps of PTC and MAD-X for the dipoles magnets*", CERN, 2008
- Lattice models
  - ➡ V. Danilov and S. Nagaitsev, "*Nonlinear accelerator lattices with one and two analytic invariants*", Phys. Rev. Spec. Topics.
  - ➡ A. Valishev, *et al* "*Ring for test of nonlinear integrable optics*", PAC 2011
  - ➡ E. Keil, "*Emma in MAD-X and comparison with other programs*", CERN ATS note 2010-044 (FFAG)
  - ➡ M. Giovannozzi, "*Multi-turn extraction studies and PTC*", CERN, 2011.
- Symplectic integrators models
  - ➡ L. Yang, "*Symplectic integrator and beam dynamics simulations*", Acc. Phys. Group, 2010.
  - ➡ F. Schmidt, "*PTC - the first 10 years*", CERN, 2011.



Symplectic integrators: benchmarking

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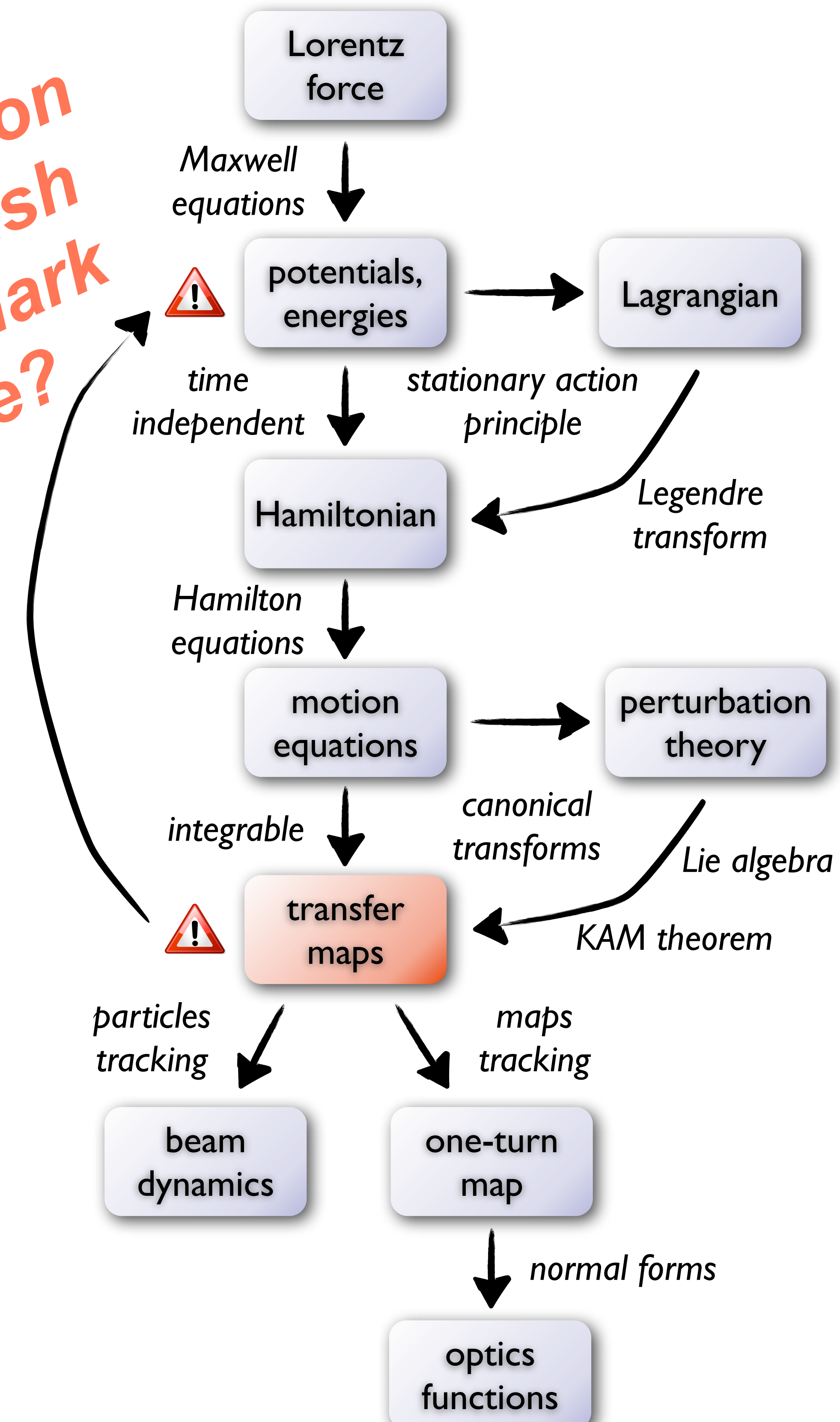
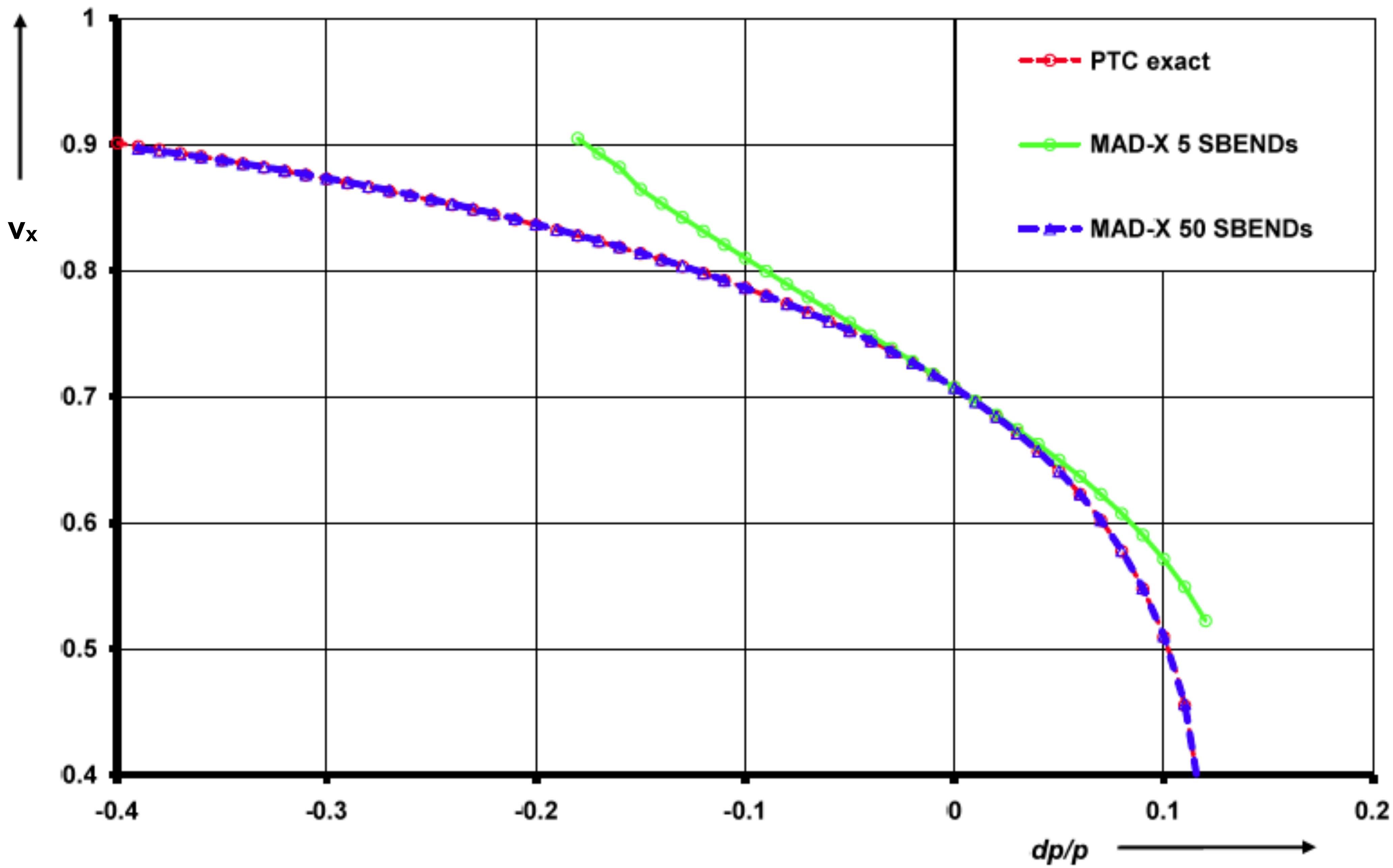
Collaboration to establish benchmark suite?



Symplectic integrators: slicing

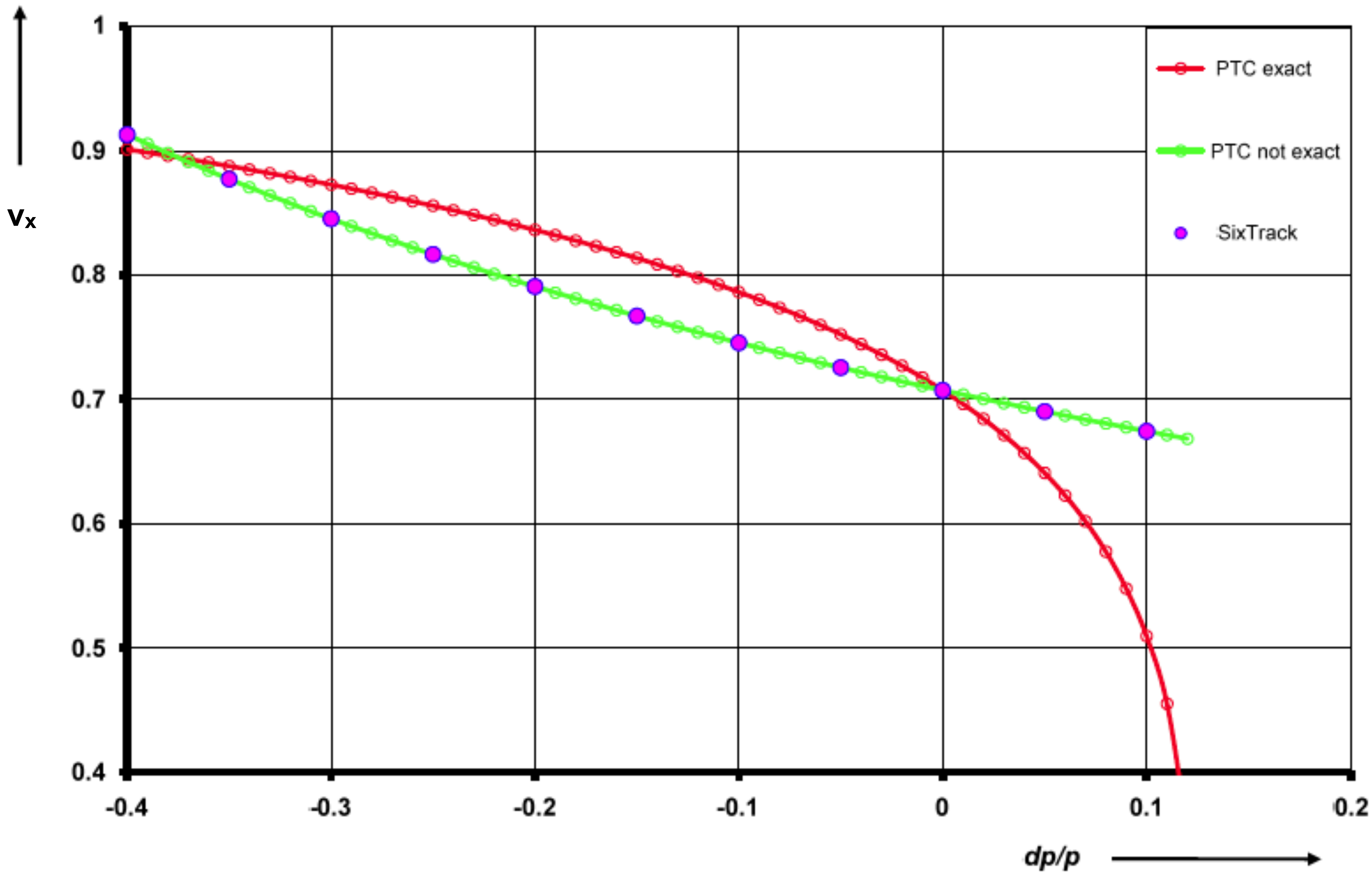
- Simple Cyclotron (SBENDs)



Courtesy to F. Schmidt

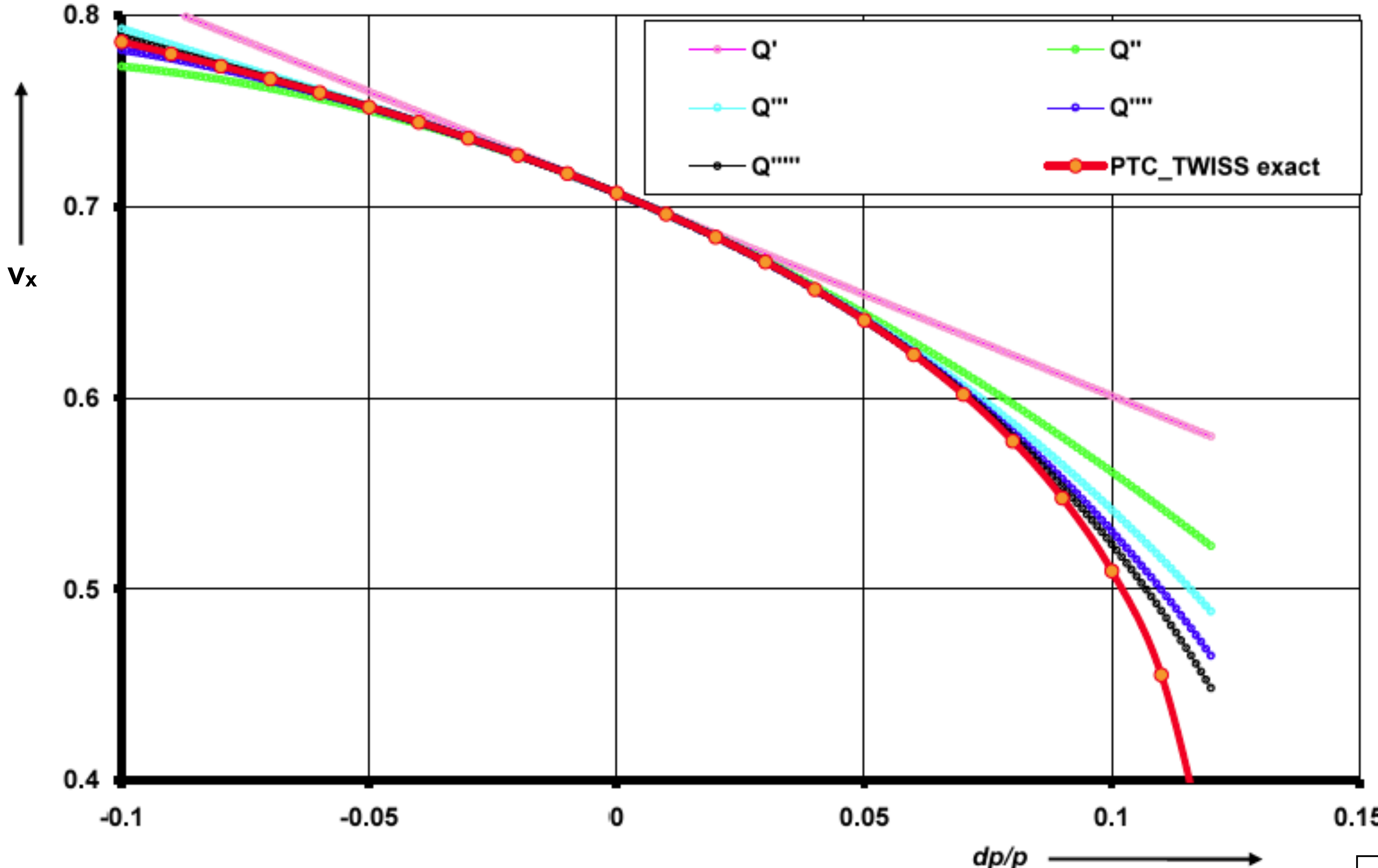
Symplectic integrators: exact

- Simple Cyclotron (SBENDs)



Courtesy to F. Schmidt

- Simple Cyclotron (SBENDs)



Courtesy to F. Schmidt

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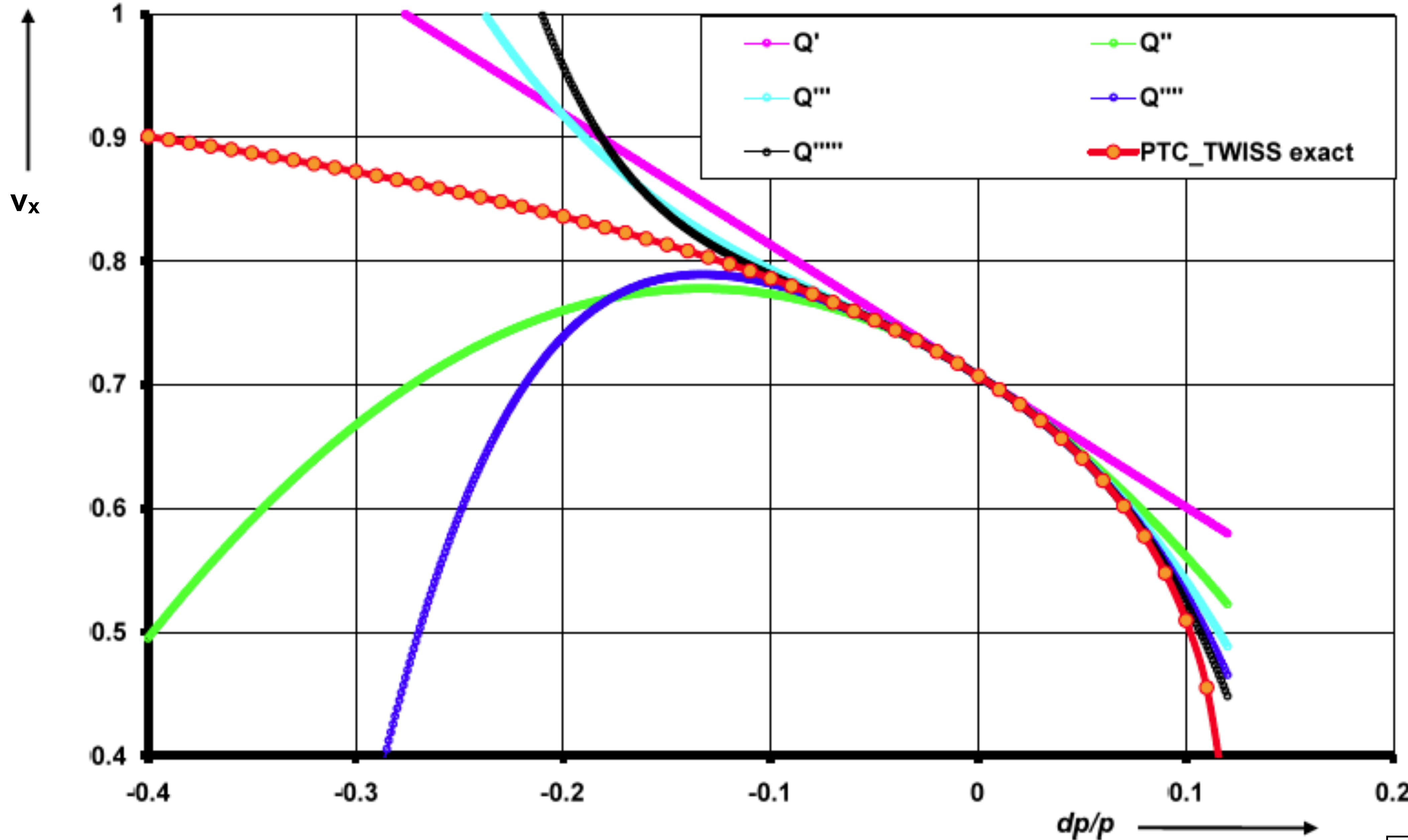

Courtesy to F. Schmidt

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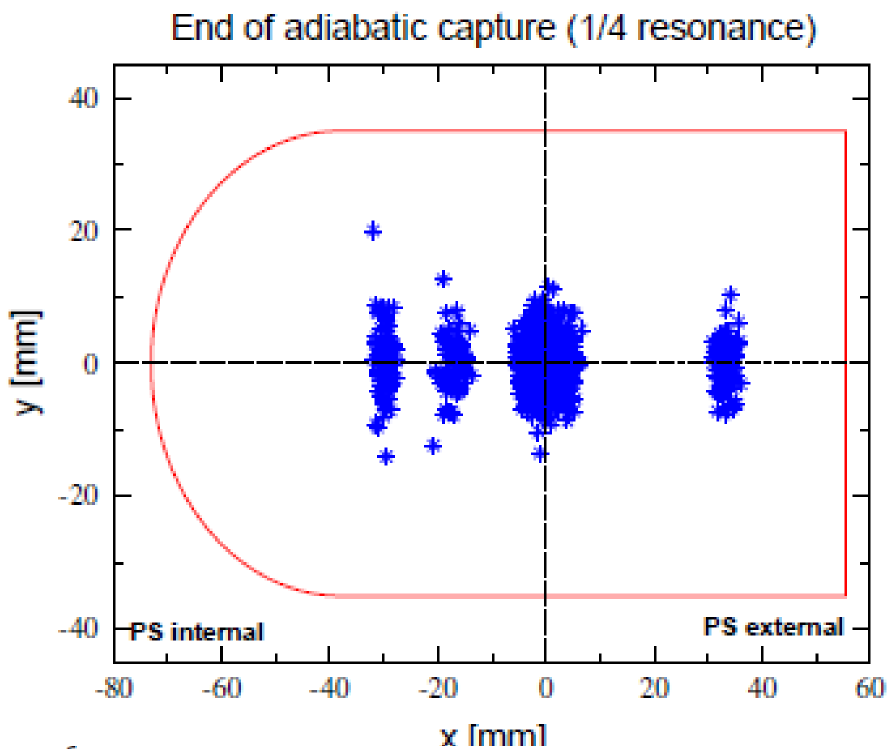
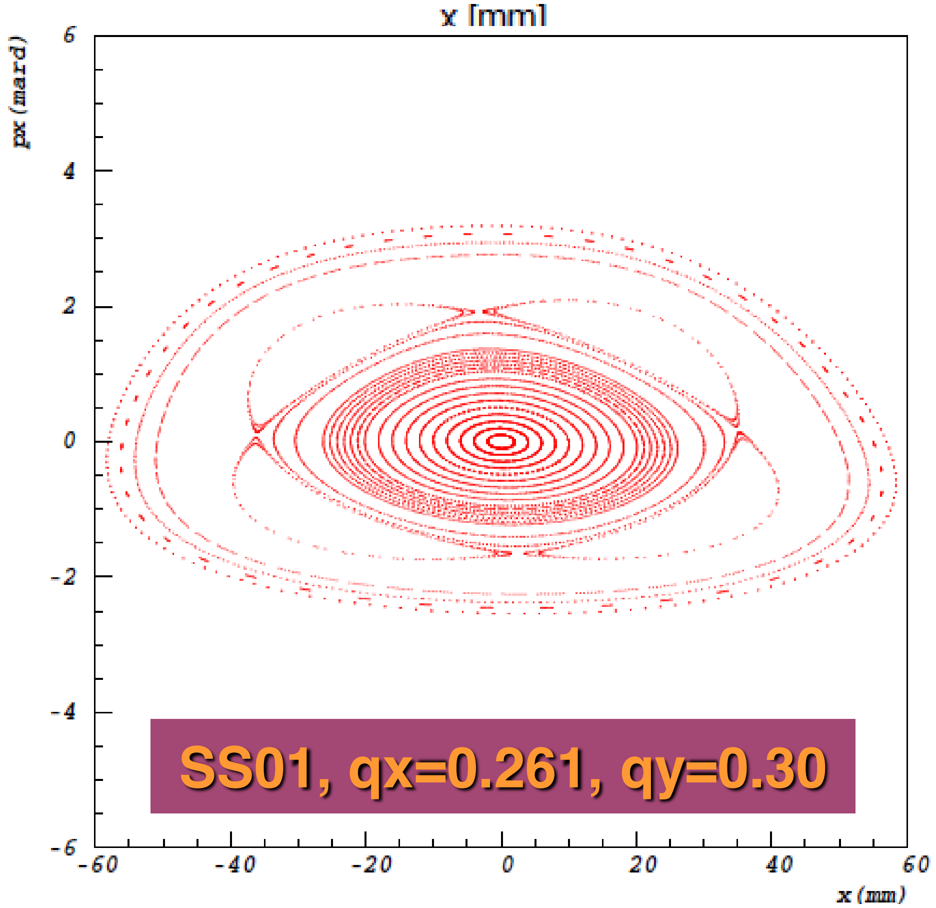
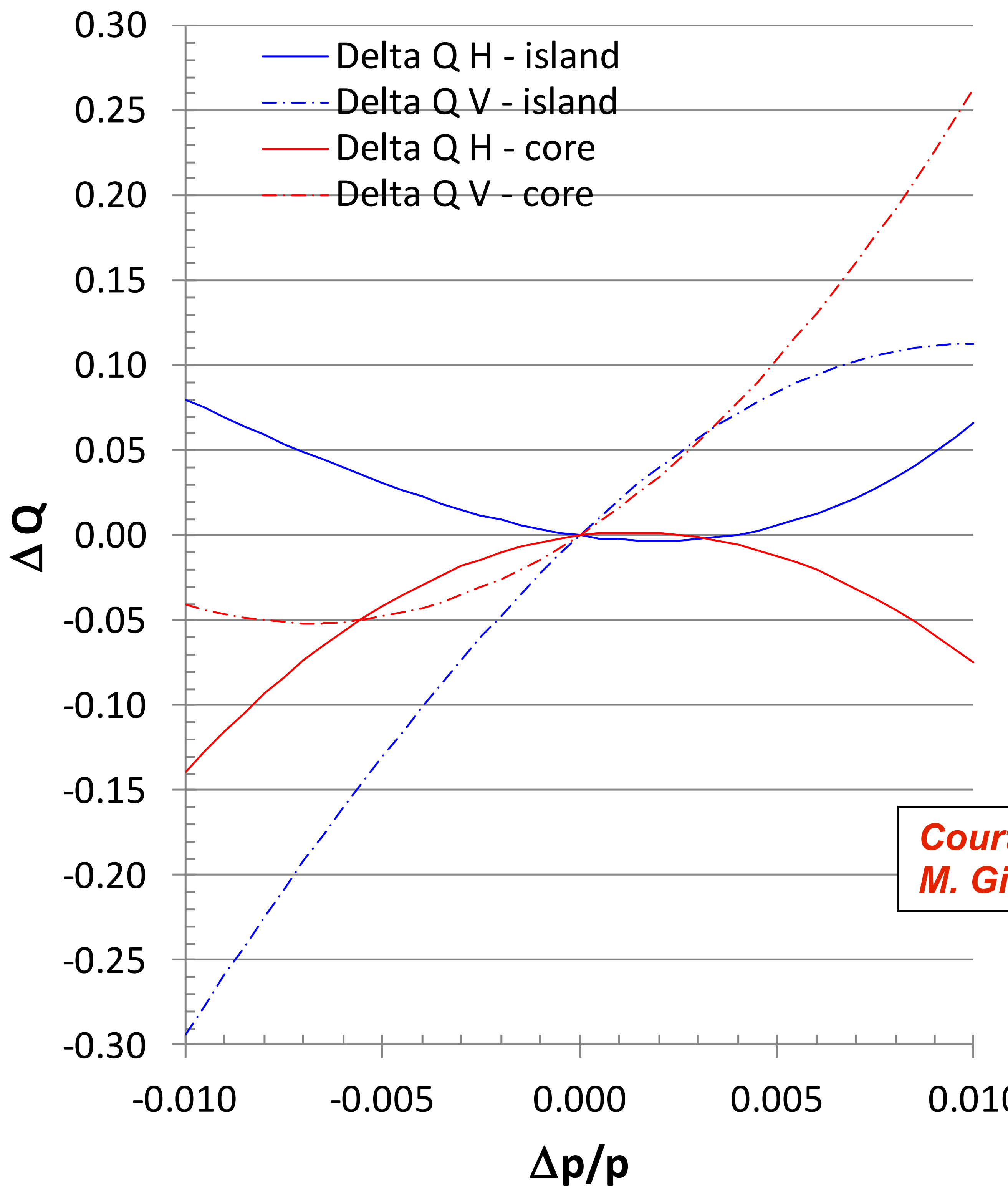
- Multi-turns extraction in the CERN-PS: MAD-X/PTC simulations







Courtesy to M. Giovannozzi

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

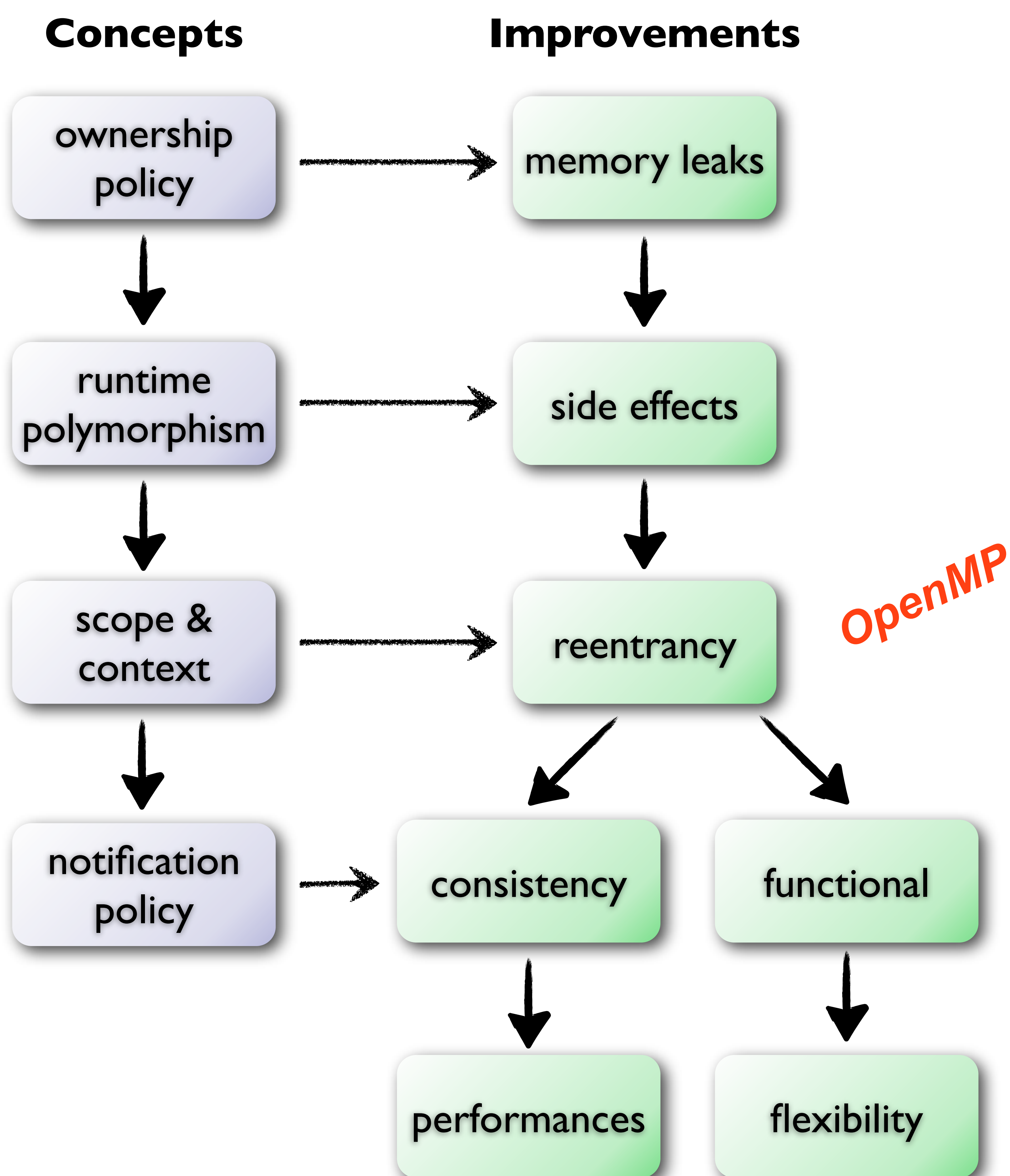
Application logic: complaints

- Classification of complaints
  - 77% core, 23% physics
- Major problems
  - Memory leaks (one shot run)
  - Data sharing (no ownership)
  - Data lookup (dangling pointers, string comparison, performance)
  - Side effects (no reentrancy, interdependence)

Groups	#	Tickets no
interpreter	14	56, 57, 64, 67, 73, 89, 109, 110, 124, 125, 132, 136, 147, 165, 171
table, select	10	48, 81, 85, 99, 122, 123, 130, 139, 141, 148
sequence, use	7	61, 74, 80, 89, 93, 120, 126
plots	12	42, 69, 71, 76, 85, 86, 102, 115, 116, 131, 150, 164
memory leaks	7	1, 3, 4, 92, 111, 151, 153
MAD-X physics	13	68, 77, 79, 83, 88, 106, 112, 117, 127, 135, 137, 138, 149
PTC physics	2	75, 118

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

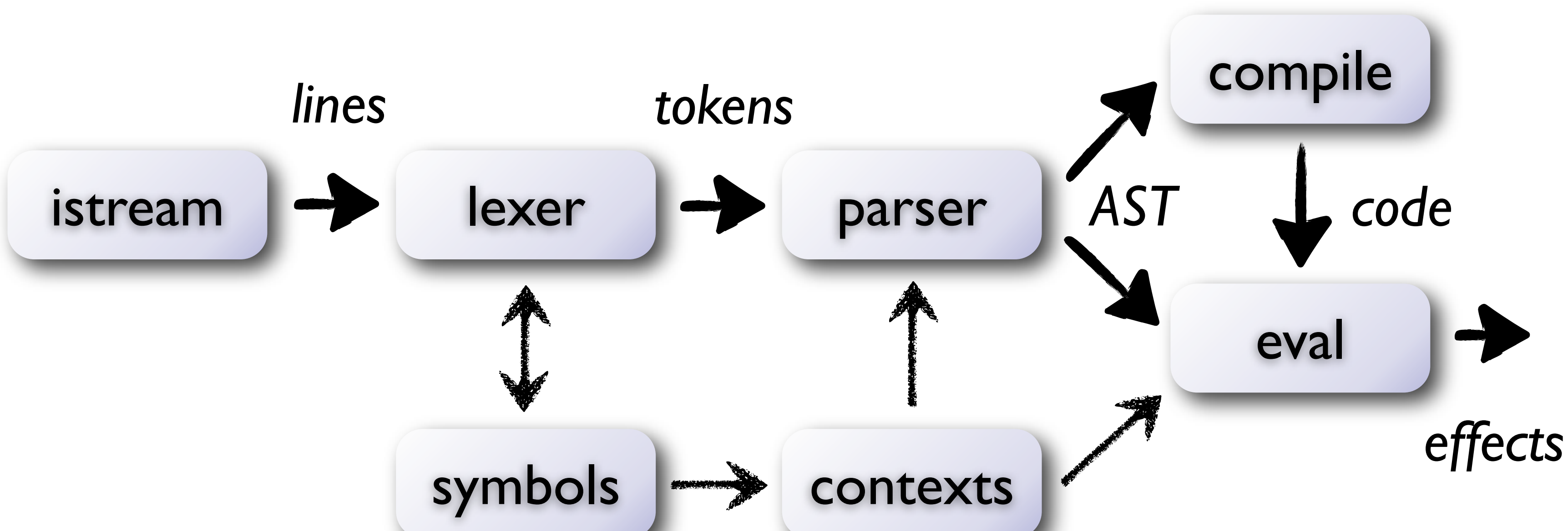
Application logic: concepts



Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Application logic: interpreter

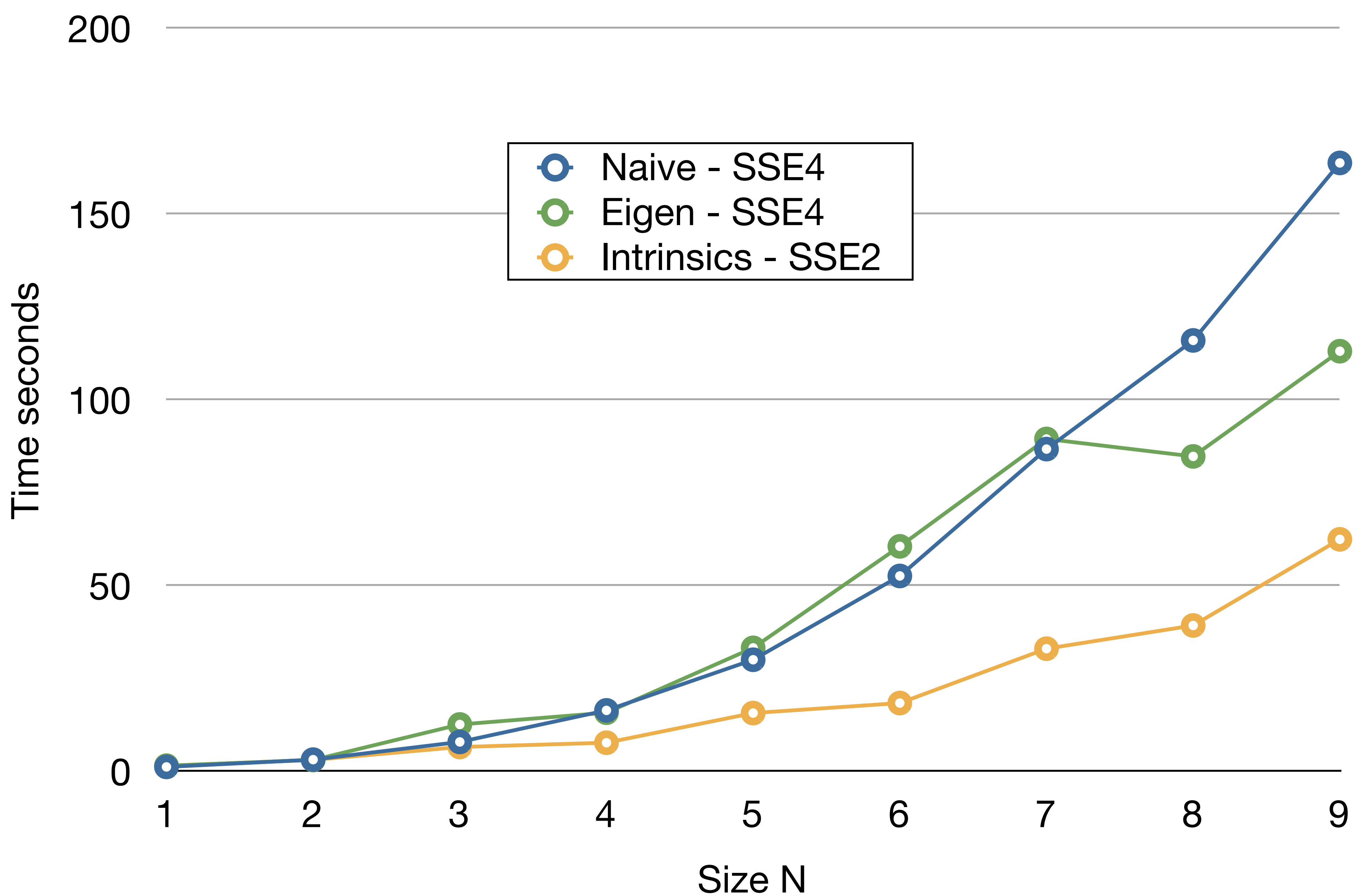
- Recursive descent parser
  - ➡ polymorphic
- Parser requires
  - ➡ objects factory
  - ➡ ownership policy
  - ➡ runtime polymorphism (i.e. interface oriented programming)
- Parser provides
  - ➡ syntax, grammar, scopes & contexts
  - ➡ very efficient evaluator (e.g. evaluates `x=x+1`, 1.6 10^8 times per second)



Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Application logic: math kernel

- Matrix expression $M = M_1 * M_2 + M_3 * M_4$ evaluated 10^8 times (dynamic sizes)
- Take advantage of data structure topology vs. intrinsics (beyond compiler optimization)
- Applicable to dense multivariate polynomials (TPSA)



Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Application logic: documentation

- First impression of the project (with the website)
  - ➡ Professionalism

- Structured documentation
  - ➡ Separation of Concerns principle
  - ➡ Reflects the code (quality)
  - ➡ High priority

- On the model of MAD8 and SixTrack
  - ➡ MAD-X user's guide
  - ➡ MAD-X physics guide
  - ➡ MAD-X developer's guide

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Future plans

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

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- Short term (2012)
  - ➡ Setup more tests (~100)
  - ➡ Cleanup examples
  - ➡ Cleanup documentation
  - ➡ Debug, test, debug, test, debug, ...
  - ➡ Produce pro release 5.01.00

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- Long-Term (2014+)
  - ➡ Clarify models (Hamiltonians, slicing models)
  - ➡ Unify modules (Track, Twiss, Makethin, PTC)
  - ➡ Improve optimization (Match)
  - ➡ Convert/Rewrite Fortran to C (?)

Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

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Laurent Deniau, CERN BE/ABP, 1211 Geneva 23, laurent.deniau@cern.ch

Thank you for your attention

`http://cern.ch/mad`

`mad@cern.ch`