IOTA Workshop – WG1

Experiments on Nonlinear Dynamics with Space Charge

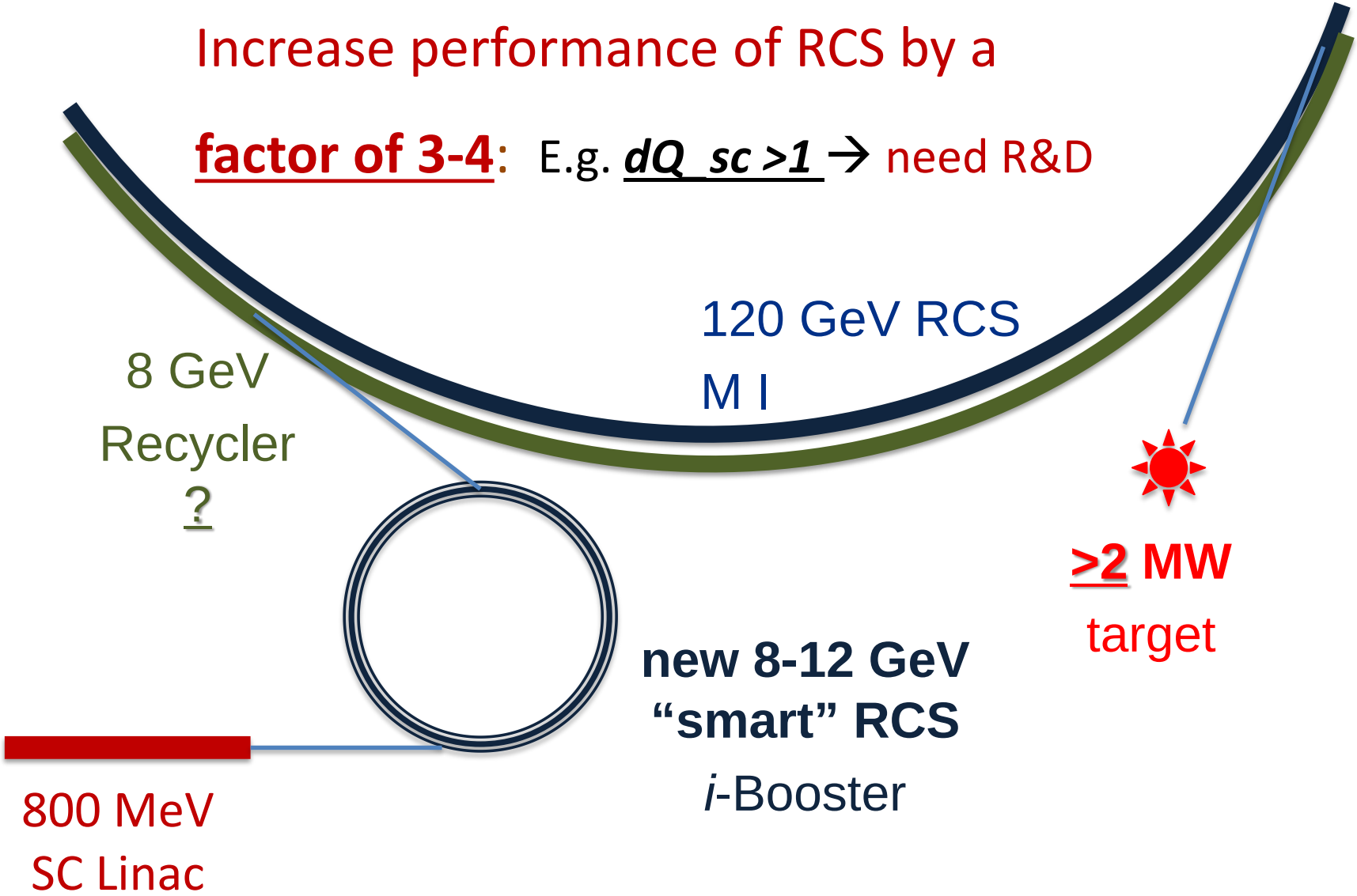
Summary

R.Kishek (UMD), V.Shiltsev (FNAL)

PIP-III "multi-MW"- Option A: 8+ GeV smart RCS

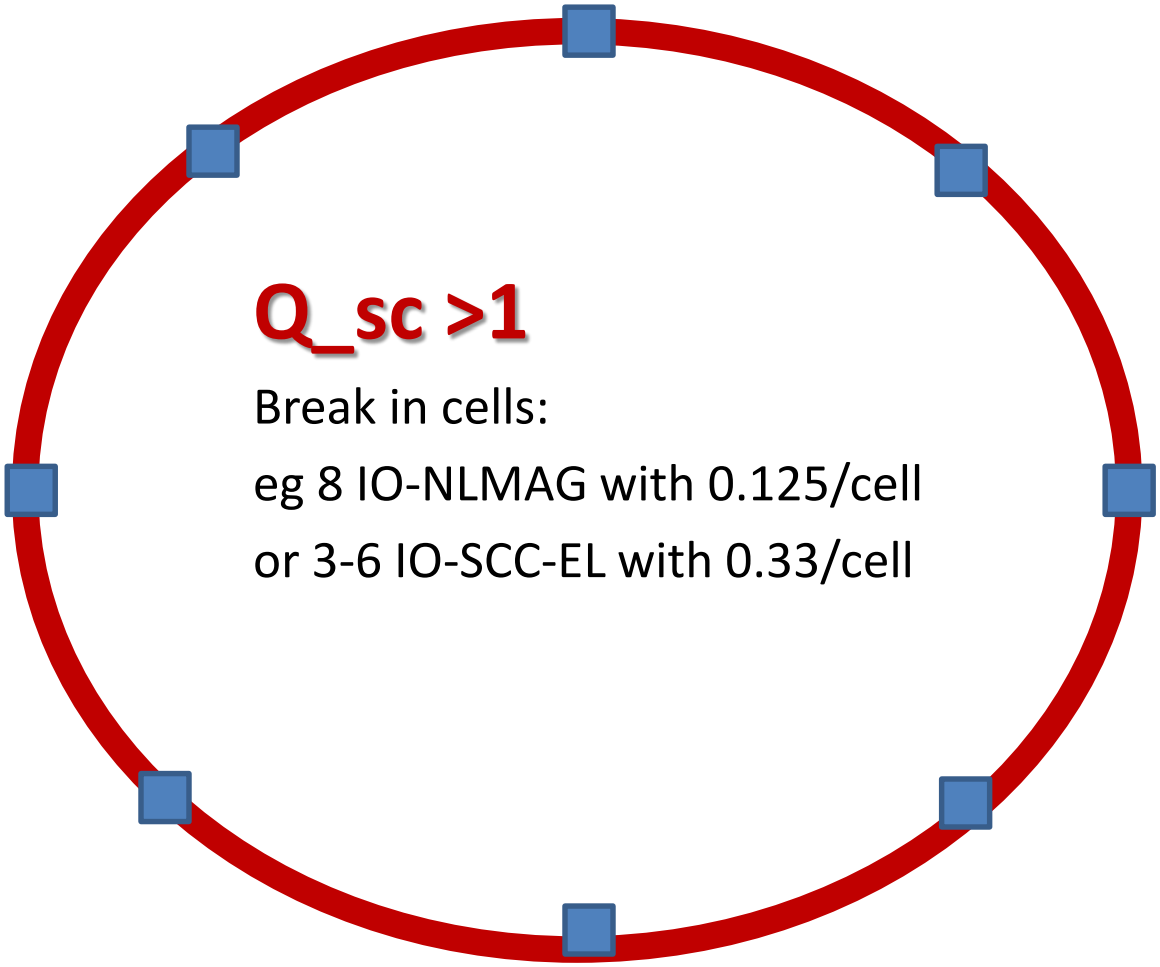
Increase performance of RCS by a

factor of 3-4: E.g. ***dQ_sc >1*** → need R&D



Approach:

- Novel Nonlinear Dynamics Ring



- IOTA represents one full realistic cell of NDD

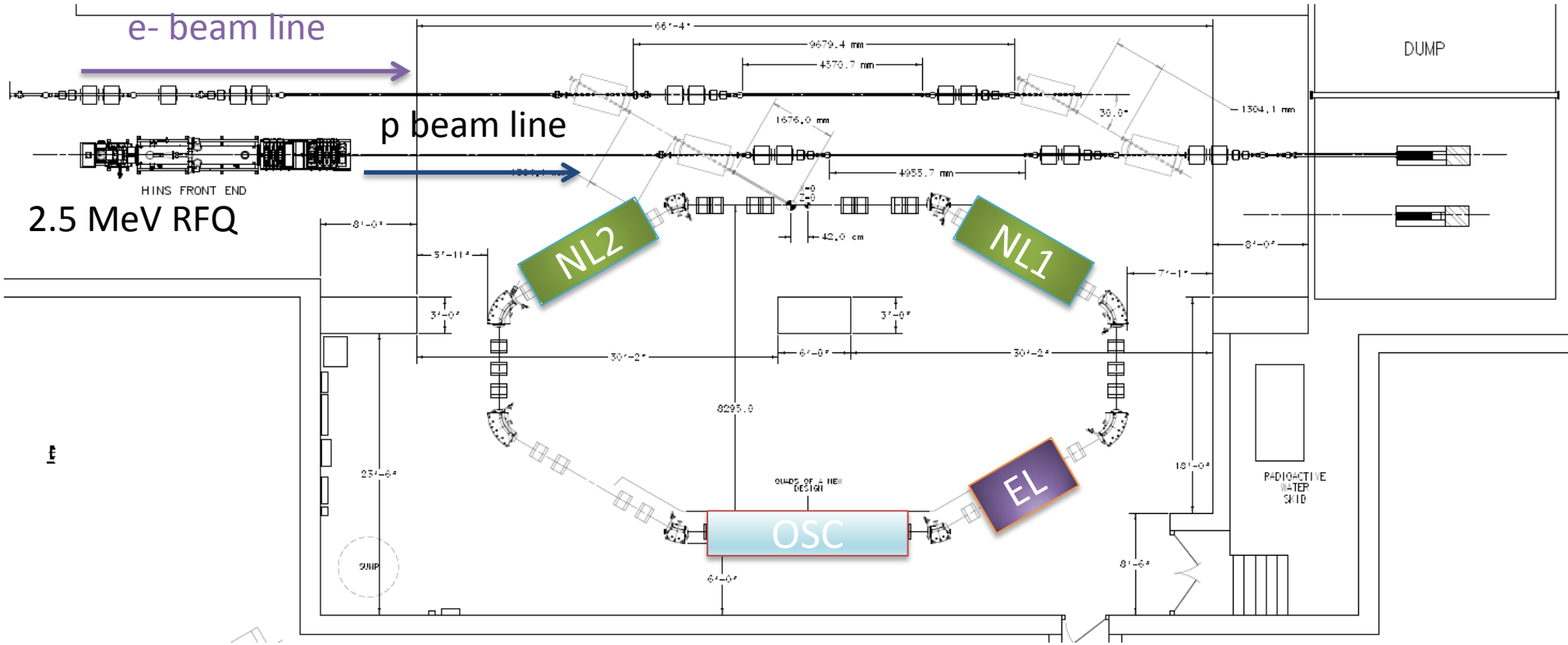
Scope of NND Studies at IOTA

A) Integrable Optics with NL magnets → one(2) cells with dQ=0.125/cell

B) IO/Space Charge Comp with Elenses → one cell with dQ=0.3/cell

C) Many auxiliary studies/systems:

e-columns / octupoles / collimation / inj / extraction / long.dynamics



Conclusions: High Level

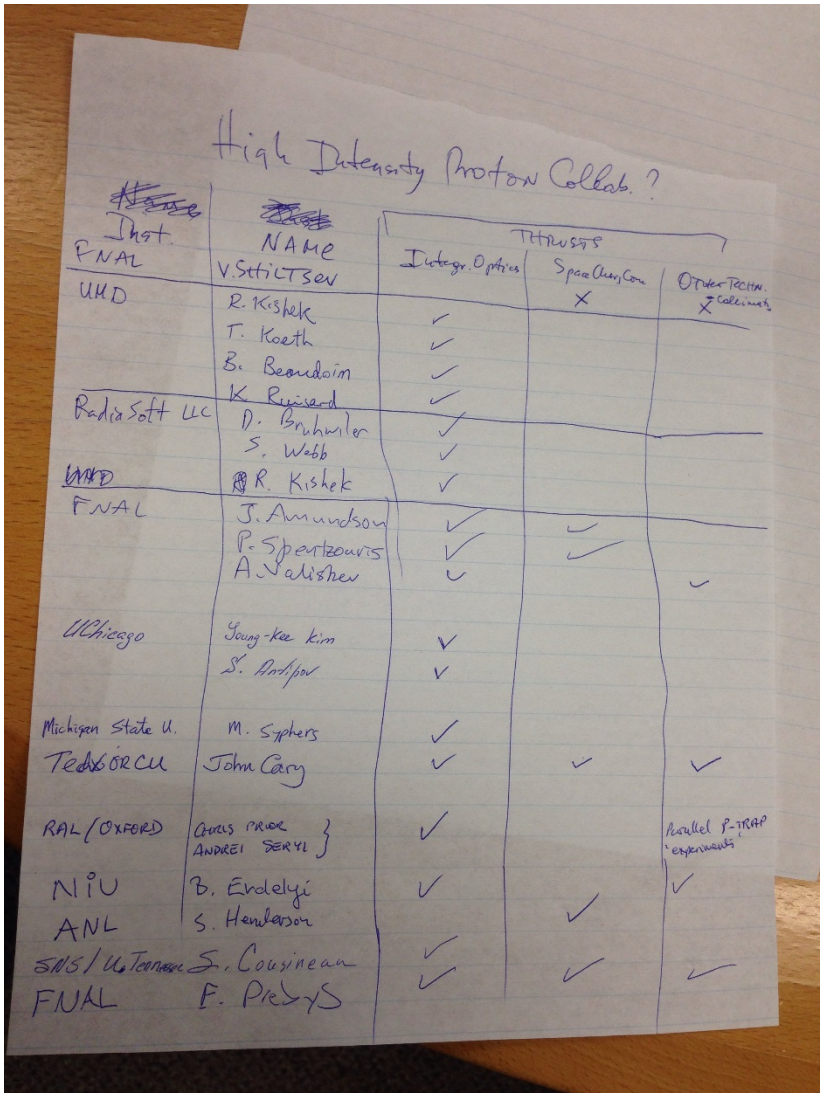
- *Novel Nonlinear Dynamics(NND)* approaches to Space Charge and other high intensity proton issues are very promising and "rich of beam science"
- Proto-collaboration is being formed on coherent exploration of these aspects at IOTA, with three areas: "IO with NL magnets", "IO and SCC with elenses", "other"
- Our WG considers it's ***critical*** to have ability to make single-particle explorations of the *NND* with pencil e-beams – that is absolutely essential to understand important aspects of new dynamics
-

Conclusions

- The demonstration of nonlinear integrable optics on IOTA (both with electrons and protons) will be a game-changing development in beam physics.
- The science involved is not specific to FNAL. Many other applications of high-intensity rings stand to benefit from this program.
- The IOTA ring is unique in being able to address this experimentally.
- Expect many high profile publications

(Proto-) collaboration *HIPE (?)*

expansion of existing Space-Charge Collaboration… 20+ names



High Intensity Proton Collab. ?

Inst.	NAME	THRUSTS: Integr. Optics	Space Charge Core	Other Techn. (collimat.)
FNAL	V. Shiltsev		×	×
UMD	R. Kishek	✓		
	T. Koeth	✓		
	B. Beaudoin	✓		
	K. Ruisard	✓		
RadiaSoft LLC	D. Bruhwiler	✓		
	S. Webb	✓		
~~UMD~~	R. Kishek	✓		
FNAL	J. Amundson	✓	✓	
	P. Spentzouris	✓	✓	
	A. Valishev	✓		✓
UChicago	Young-Kee Kim	✓		
	S. Antipov	✓		
Michigan State U.	M. Syphers	✓		
Tech-X/ORCU	John Cary	✓	✓	✓
RAL/OXFORD	CHRIS PRIOR, ANDREI SERYI	✓		Parallel P-TRAP experiments
NIU	B. Erdelyi	✓		✓
ANL	S. Henderson		✓	
SNS/U. Tennessee	S. Cousineau	✓		
FNAL	F. Pilat	✓	✓	✓

Collaborations: Ongoing and Prospective

- Everyone in WG1 expressed interest in collaborating with the IOTA team (see list).
- Three areas: nonlinear optics, space charge compensation, and other beam dynamics topics.
- The proton beam experiments in particular have a sufficient lead time to be attractive to participation from universities.
  - UMER experiments can be directly relevant to proton beams on IOTA

List of Presentations

- D. Bruhwiler, Radiasoft
- J. Cary, Tech-X
- C. Prior, RAL, UK
- R. Kishek, Radiasoft and UMD
- E. Prebys, FNAL
- J. Amundson, FNAL
- K. Ruisard, UMD

Technical Recommendations

- Prior: Suggestion to use the RAL Paul Trap to simulate IOTA Physics
- Cary: near equilibrium distributions for nonlinear lattices, can phase-paint into these distributions
- Valishev: latest IOTA designs and parameters online, invites everyone to use them.
- Prebys/Kishek: WARP/Synergia comparison with space charge in order using same lattice and same numbers.

Technical Recommendations (2)

- Amundson/Kishek/Bruhwiler: Look into multi-stream instability from overlapping bunches at injection into IOTA – formula from Beaudoin, IPAC2013.
- Ruisard: UMER experiments can be directly relevant to proton beams on IOTA
- Kishek: established procedure to match the IOTA lattice with space charge and demonstrated with WARP.

Nonlinear Integrable Optics Experiments

- First Question: How do we ascertain that the nonlinear elements behave as predicted, and that the optics are integrable?
- This led to a discussion of Indicators of Success:
  - Single particle dynamics with electron beam
  - Proton beam and full space charge

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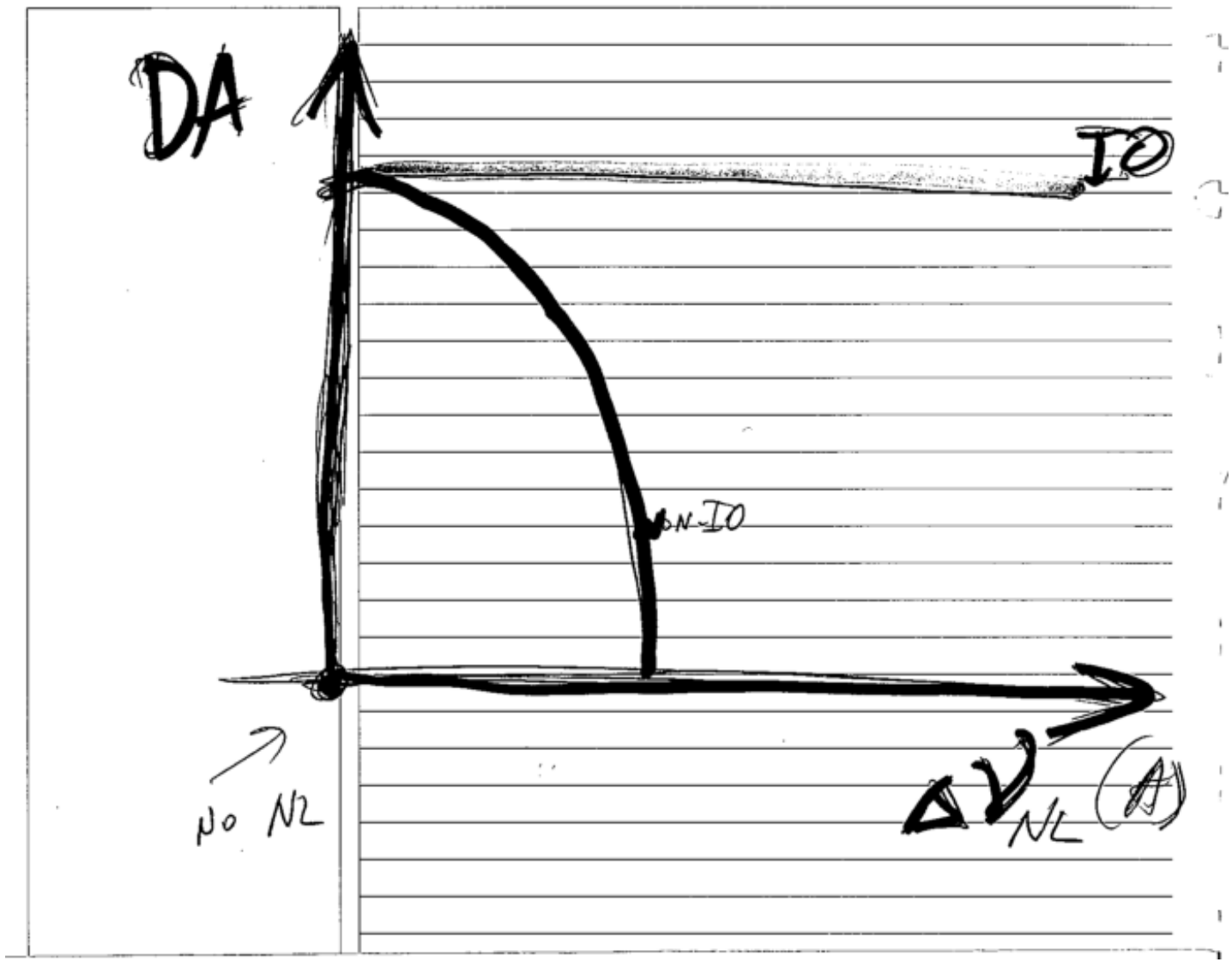
Electron Beam: Success

1. Measure predicted tune shift without degradation of dynamic aperture
   - Control: dynamic aperture reduction without nonlinear elements
2. Measure constants of motion and demonstrate conservation. (accuracy issue)
3. Map phase space trajectory (difficult)

Electron Beam Test #1



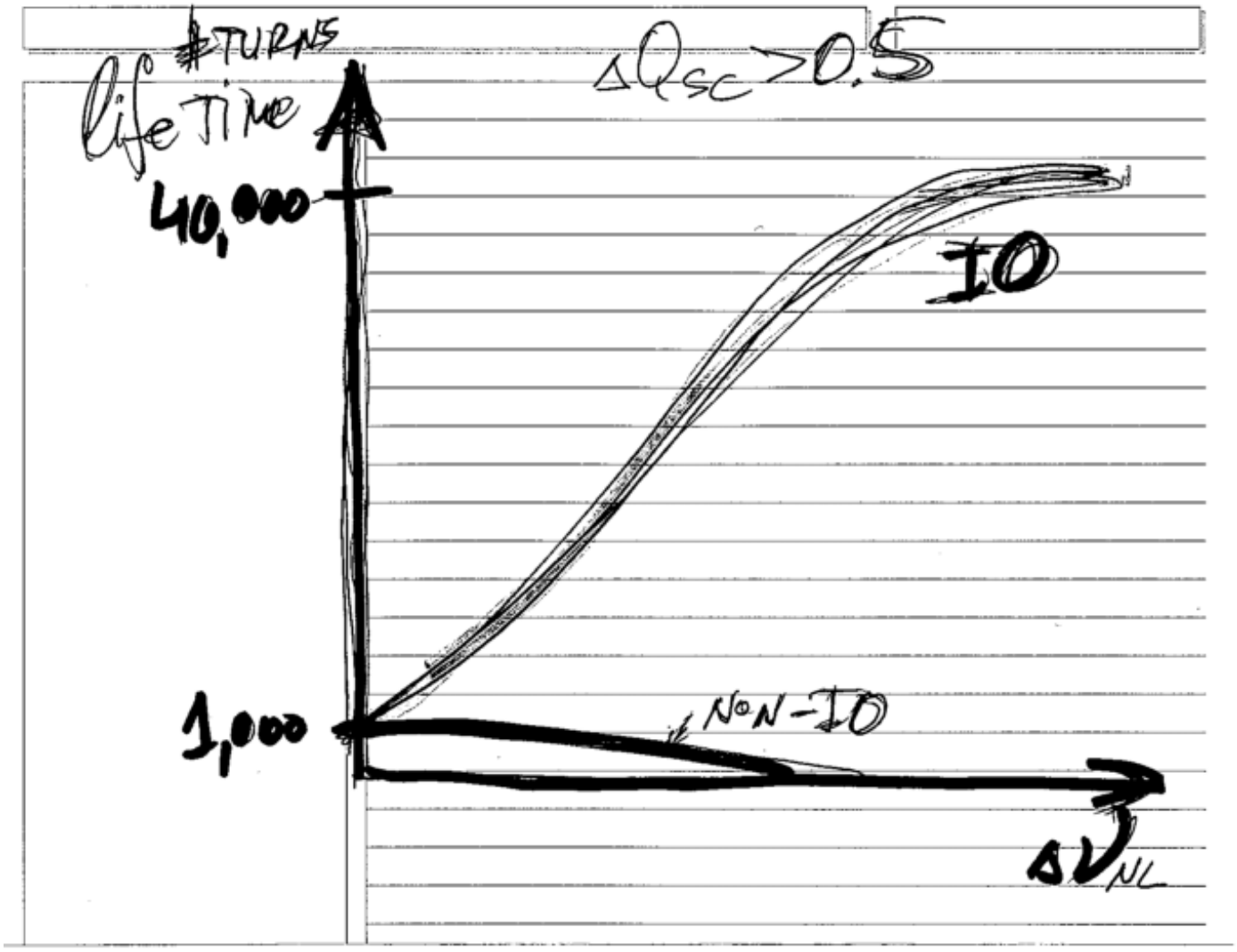
Electron beam experiments: Issues

- Is 100 μm single-turn resolution on the BPMs sufficient?
- Use synchrotron radiation to measure position?
- Community help is needed in simulation, checking the model, help with tuning the integrable optics.

Proton Beam: Success

1. Demonstrate storage of beam for > 40,000 turns with space charge tune shift > 0.5 and loss < 10^{-4}.
   - Control: without integrable nonlinear elements, beam lost more quickly
2. Introduce anti-damper to excite coherent instability
3. Use beam halo as a diagnostic
4. Decoherence

Proton Beam Test #1



Proton Beam: Needs

There is much room for community involvement and help with the design of proton beam experiments and selection / choice of diagnostics.

- What if the beam doesn't go through? How do we determine what is wrong?
- Experiments on UMER in near term (2-3 years) can inform IOTA proton beam effort.

Diagnostic and Tools: Wish List

1. Profile Monitors
2. Loss Monitors
3. Scrapers
4. Halo profiles
5. Core profiles (Gas jet)
6. Turn-by-turn extractions onto screen
7. Pencil beam for local analysis
8. Second-moment detector (e.g. 16-plate BPM, Beaudoin)
9. Phase paint injection
10. Damper/anti-damper systems for Q-measurement
11. Emulate space charge with E-lens e-beam
12. Simulations with Space Charge (Prebys/Kishek/Bruhwiler)

Equilibration, Diffusion and Halo –

Suggested experiments with proton beams in IOTA

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Workshop on Scientific Opportunities in IOTA

28,29 April 2015 – Fermilab

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Summary & Future Work

- *Diffusion of invariants is predicted over 100s of turns*
  - *this can in principle be observed in IOTA*

- *Proposed experiments*
  - *kick beam and measure rate of return to <x>=<y>=0*
    - *very fast (just a few turns)*
  - *measure 2nd moments accurately over 100s of turns*
    - *need to understand 2nd moments of phase space*
    - *numerical work is required to infer distribution in H, I*
    - *theoretical work should help*

- *Experimental measurement of diffusion in a Hamiltonian system could be a Nature paper*