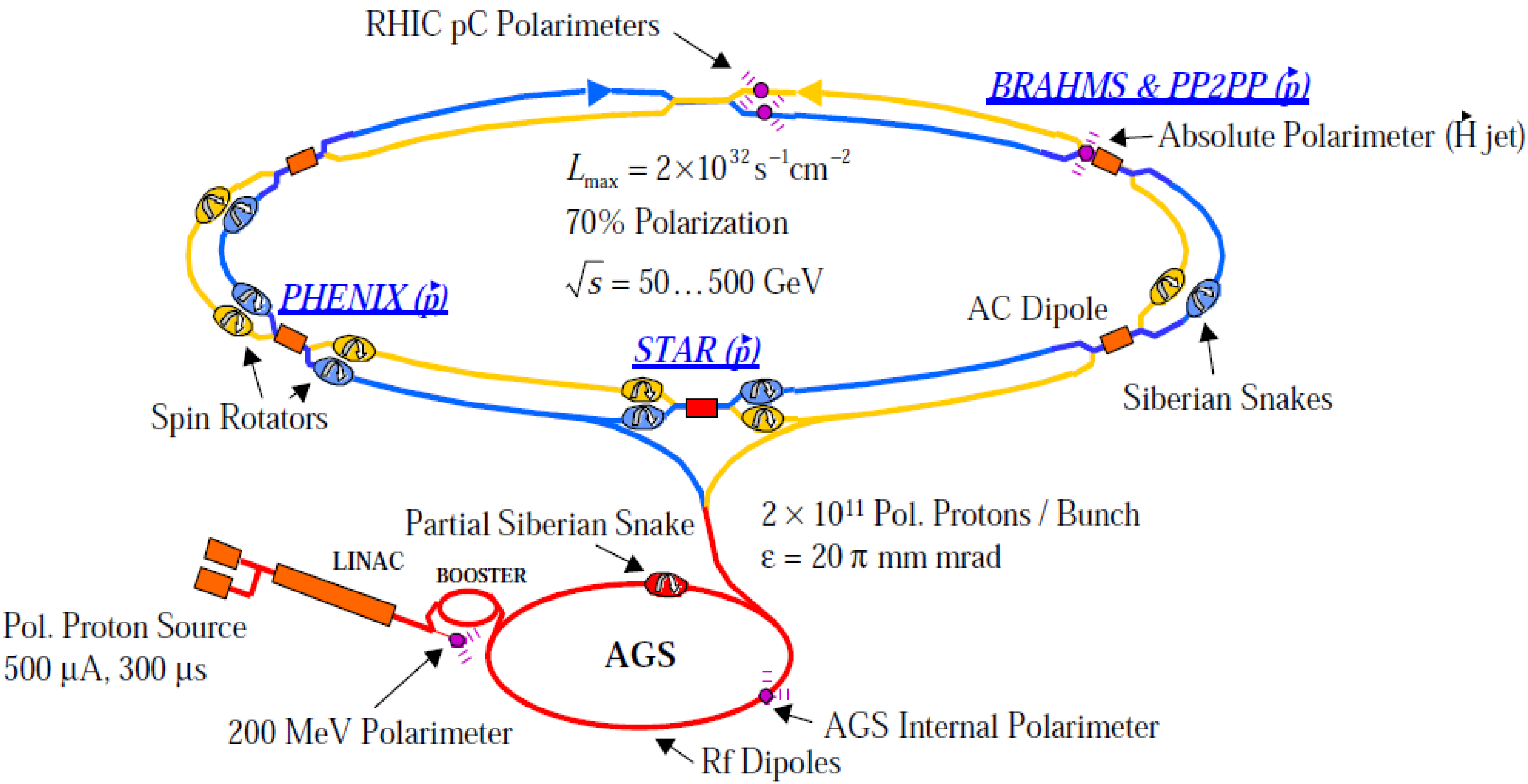
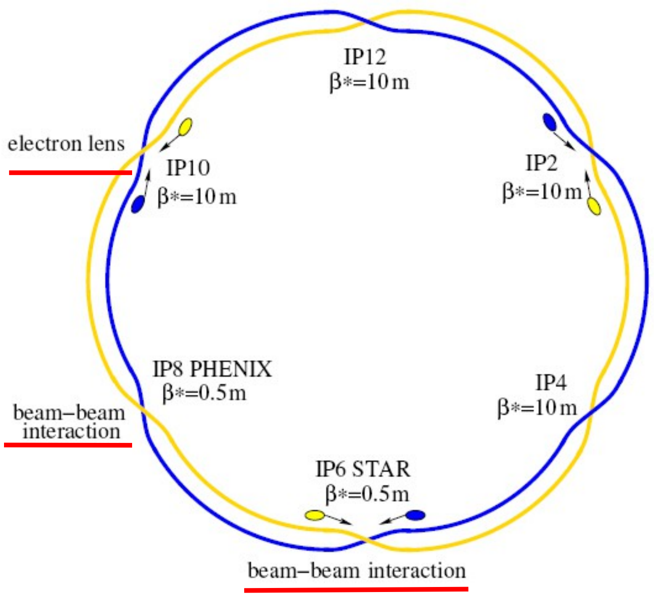
Effect of Overlapping Intrinsic Spin Resonances on E-lens lattices from FY13 Polarized Proton run

V. H. Ranjbar

AGS-RHIC COMPLEX



Electron lenses – partial head-on beam-beam compensation

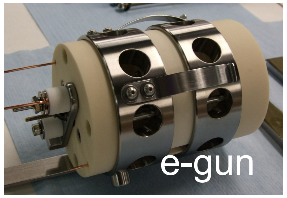


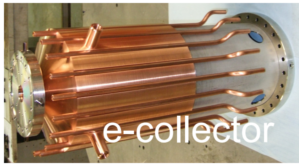
Basic idea:

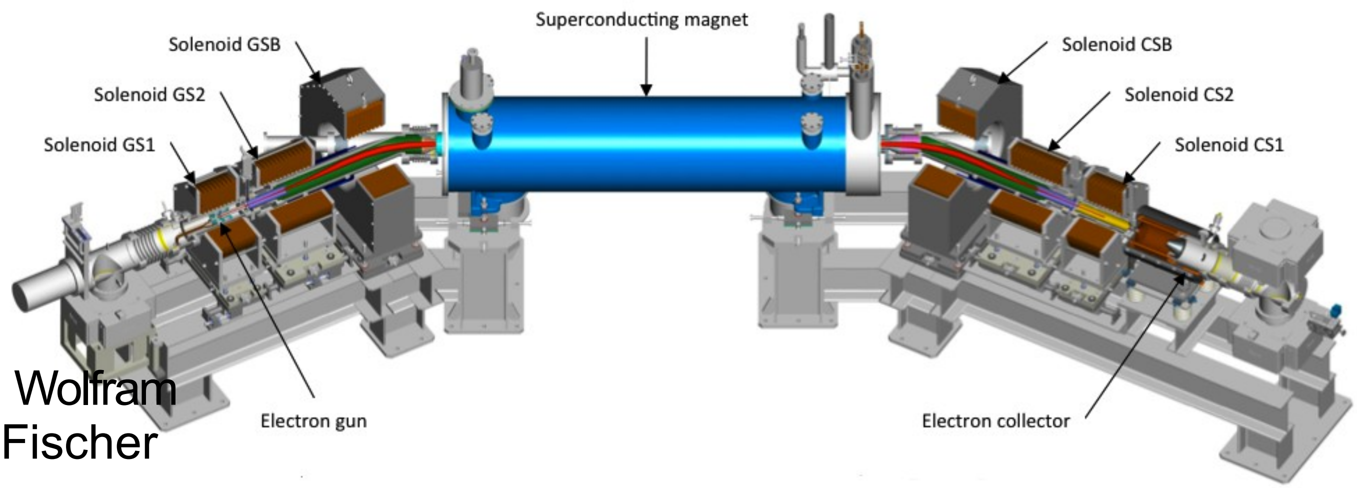
2 beam-beam collisions with **positively** charged beam
Add collision with a **negatively** charged beam – with matched intensity and same amplitude dependence

Compensation of nonlinear effects:

e-beam current and shape
=> reduces tune spread
$\Delta\psi_{x,y} = k\pi$ between p-p and p-e collision
=> reduces resonance driving terms

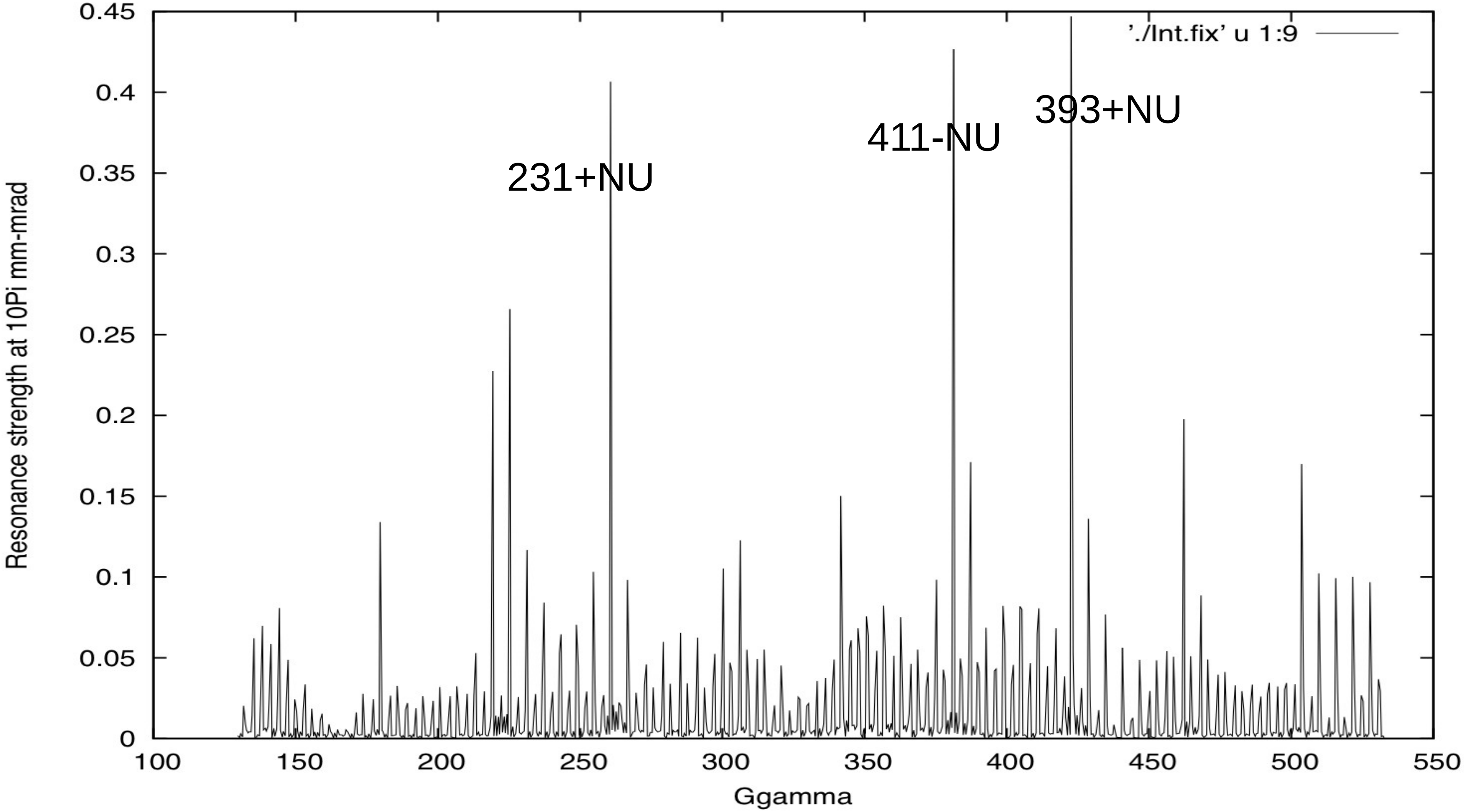






Wolfram Fischer

Overview of Resonances on RHIC ramp



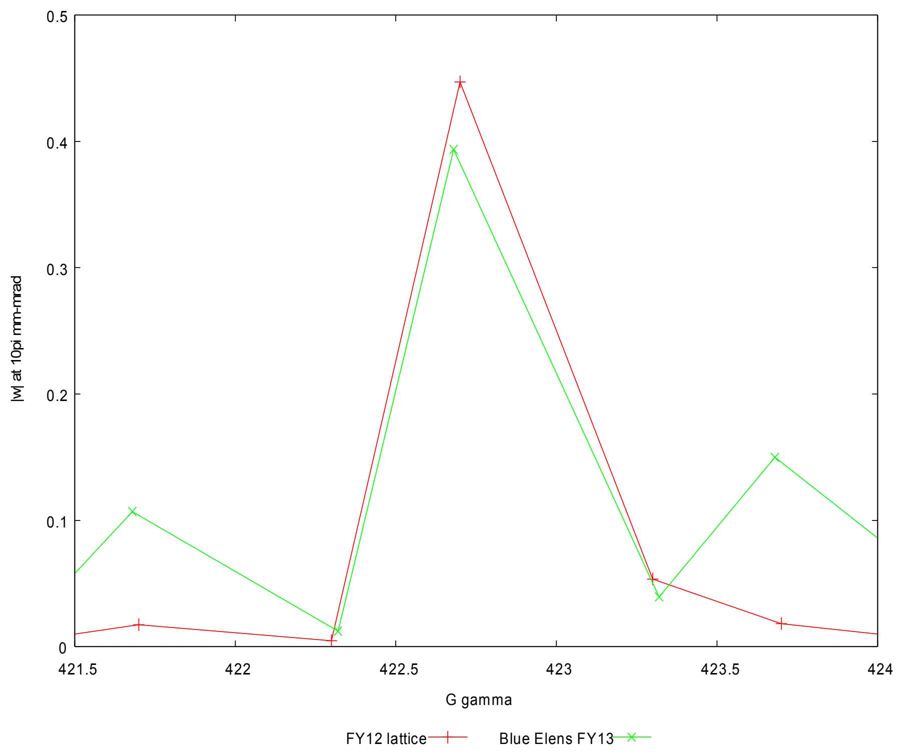
e-lens Lattice Design

- In order for e-lens to operate correctly there needs to be proper phase advance between IP and e-lens compensation.
- To achieve this phase advance new phase shifter shunt power supplies were implemented and a new lattice designed at new working point
  - Fundamentally different approach to designing and controlling our lattice and on-line model.
  - Also the introduction of the phase shifters had a large impact on the intrinsic spin resonance of the lattice for both good and ill. So this needed to be accounted for in the lattice design.

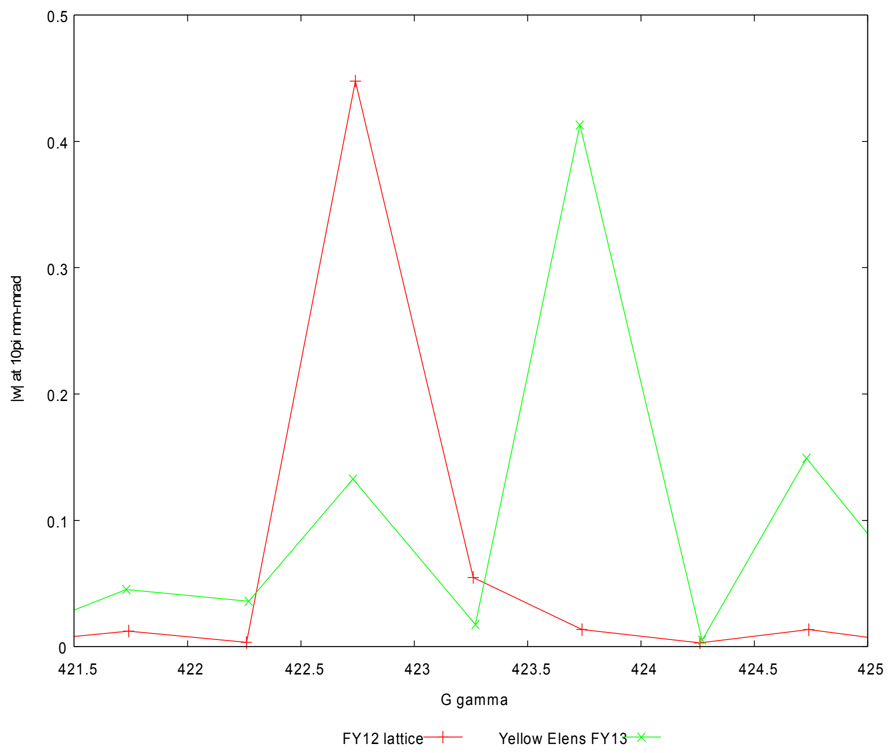
Reduced peak Resonances by 10 to 14%

Spin Resonance	Blue (new-old)	Yellow (new-old)
231+NU	-0.0387	-0.0415
411-NU	-0.06134	-0.0655
393+NU	-0.05347	-0.0347

But increased size of neighboring resonances



Blue Lattices at 393+NU



Yellow Lattices at 393+NU

Is this a problem?

- Theory of overlapping resonances with snakes is undeveloped still.
  - If each resonance could be treated in isolation then the two snakes should be more than enough to prevent degradation of polarization aperture.
  - Generally we know that without snakes
    - If $|K_0-K_1| >> |w|$ they can be treated separately not clear if that translates to case with snakes
    - This Places our region of interest to be less than 1 unit of $G\gamma$

4^{th} order Magnus Integration

Using a 4th order Magnus Gaussian quadrature integrator described in [5] our code can integrate an Eq. 1 for an arbitrary $\xi(\theta)$. Where the snakes are added into the lattice as thin spin kicks.

$$\frac{d\Psi}{d\theta} = -\frac{i}{2}\begin{pmatrix} f_3 & -\xi \\ \xi^* & -f_3 \end{pmatrix}\Psi. \qquad (1)$$

Where $\xi(\theta) = F_1 - iF_2$ and $f_3 = (1 + F_3)$ with,

$$\begin{aligned} F_1 &= -\rho z''(1 + G\gamma) \\ F_2 &= (1 + G\gamma)z' - \rho(1 + G)\left(\frac{z}{\rho}\right)' \\ F_3 &= -(1 + G\gamma) + (1 + G\gamma)\rho x''. \end{aligned} \qquad (2)$$

Benchmarked against S. Mane's analytical solution for the n-vector.

Study of Effects of Nearby Resonances

$$\xi(\theta) = F_1 - iF_2 = \sum_K \varepsilon_K e^{-iK\theta}$$

Polarization Aperture for a single resonance (avoiding snake resonances):

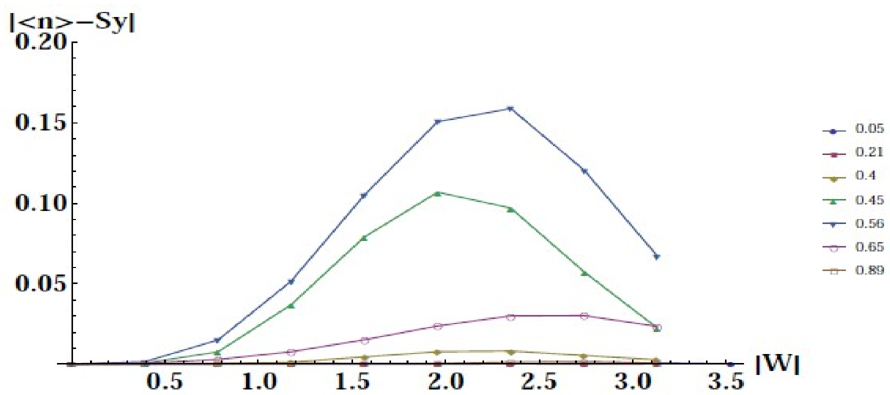


FIG. 3. (Top) Plot of Resonance amplitude versus deviation from final stable spin direction for several betaron tunes [Q] crossing a single resonances at RHIC standard accleration rate $\frac{d\gamma}{dt} = 1.12/sec.$ (Bottom) Plot of fractional betatron tune

Generally if you avoid bad tunes you can go to very high amplitude without effect. For RHIC 0.45 represents 10π mm-mrad

Adding nearby Intrinsic Resonance

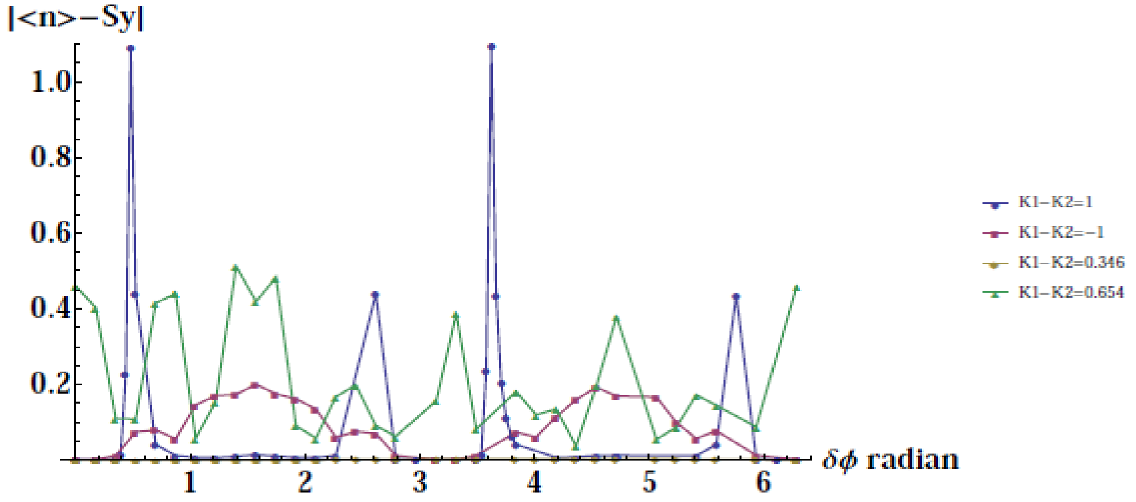


FIG. 4. Polarization response for particle at $\epsilon_{K_1} = 0.587$ and $\epsilon_{K_2} = 0.15$. The resonances are separated by $\Delta G\gamma = -1, 1, 0.346$ representing the neighboring three intrinsic resonances. The relative phase between the two resonances are scanned between 0 and 2π. Acceleration rate is nominal RHIC ramp rate $d\gamma/dt = 1.12$ and fractional vertical tune $Qy = 0.673$.

Interesting that those further away from central resonance 1 unit of Gγ can have a huge effect.

So we need to worry about nearby resonance ~ 0.1 at 10π mm-mrad

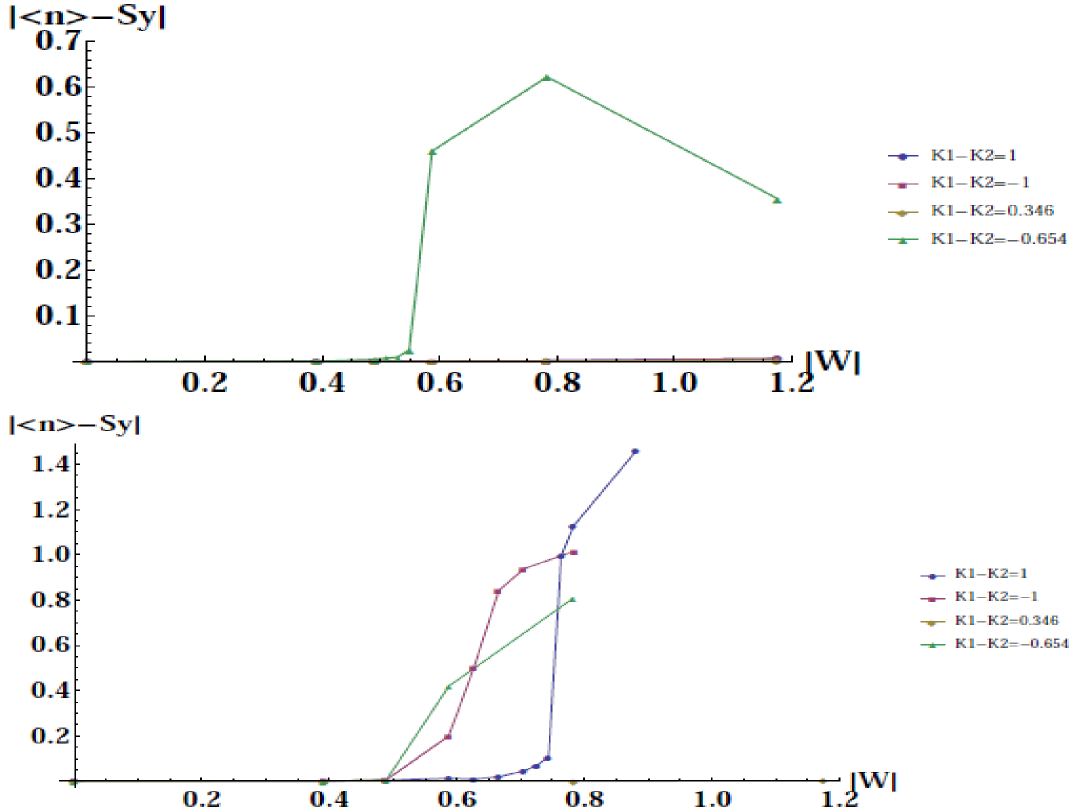
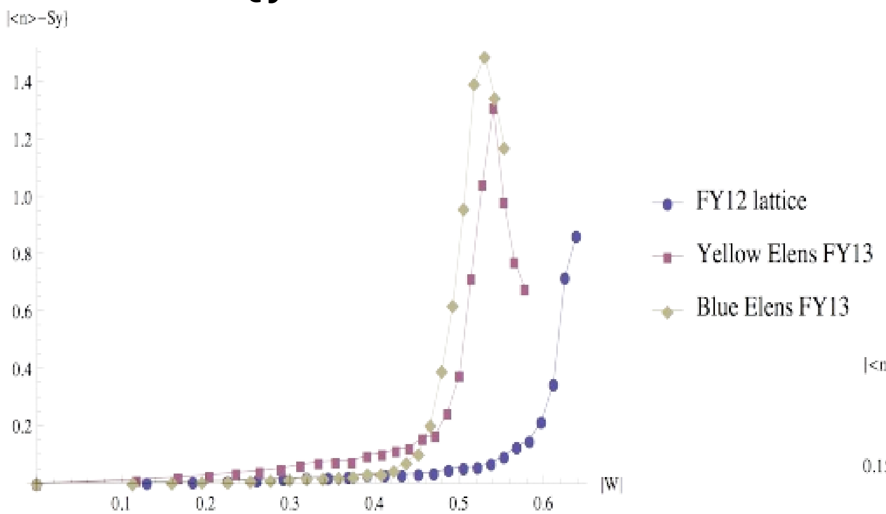


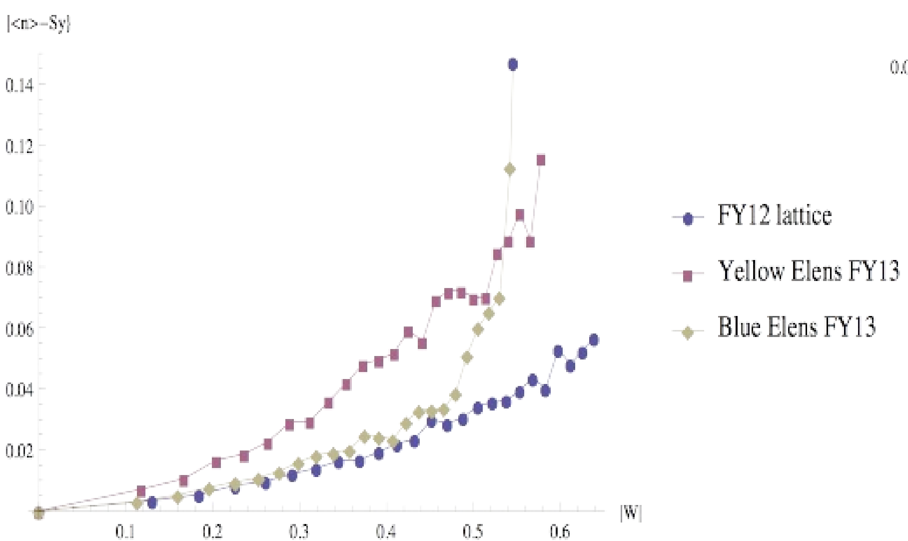
FIG. 6. Polarization response to resonance strength for 8 particles with base $\epsilon_{K_1} = 0.3914$ and $\epsilon_{K_2} = 0.1$. The magnitude of both resonances are then scaled together. Two resonances are considered seperated by $\Delta G\gamma = -1, 1, 0.654, 0.346$ representing the neighboring four intrinsic resonances. The relative phase between the two resonances are 0 (top) and $\pi/2$ (bottom). Acceleration rate is nominal RHIC ramp rate $d\gamma/dt = 1.12$ and fractional vertical tune $Qy = 0.673$.

Direct 2D Spin Tracking. Crossing 393+NU using Teaspink

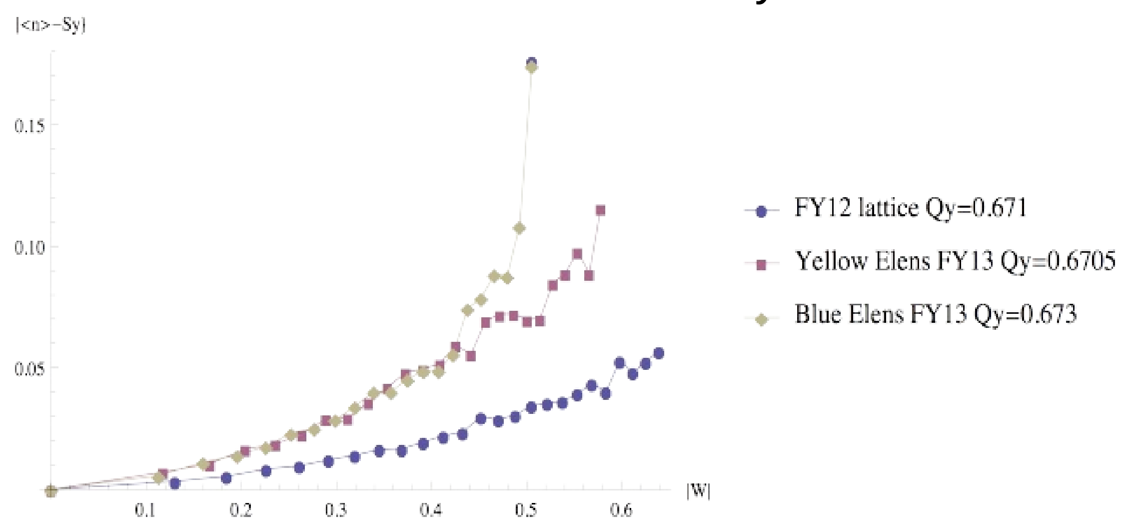
Qy=0.675



Qy=0.671

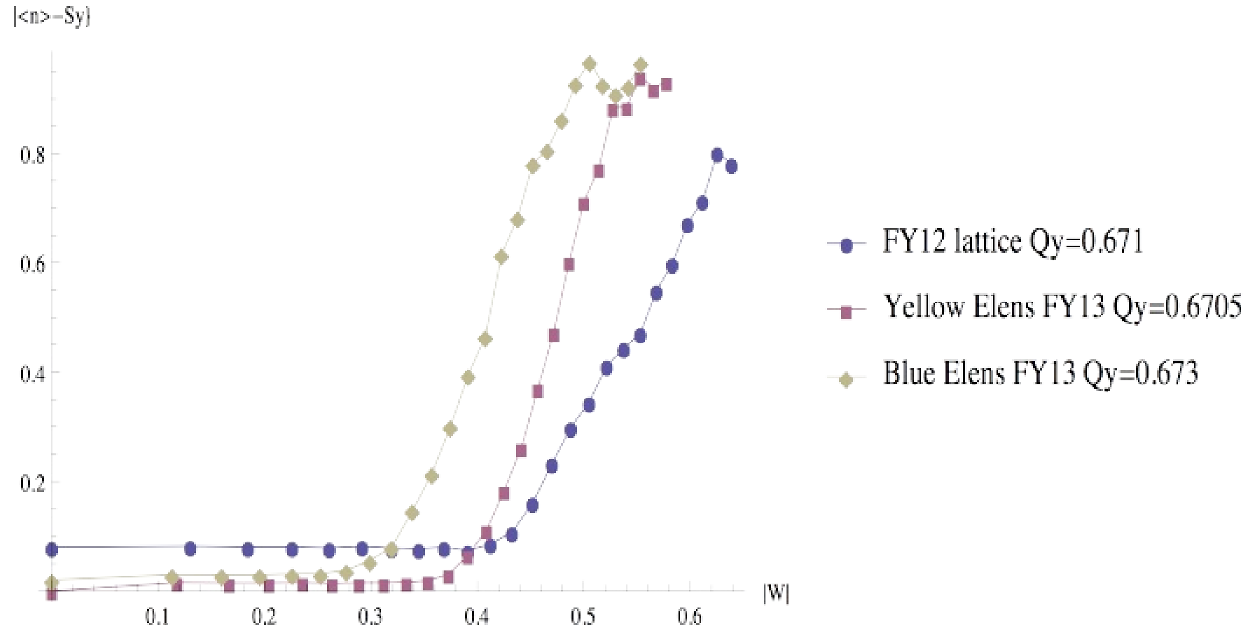


What we actually ran



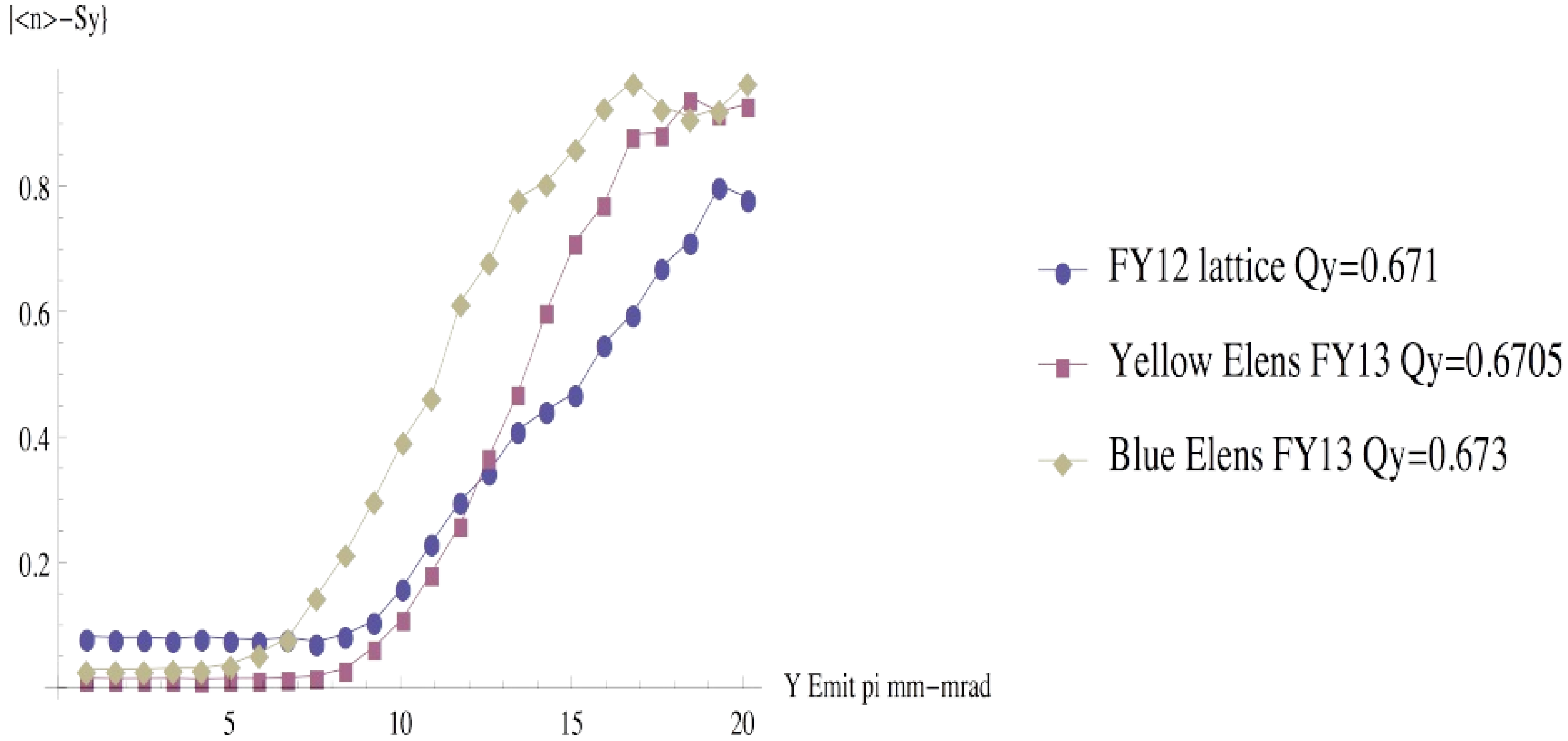
Running 5K Particles with zero x emit and On momentum. The resonance on the x-axis Is strength of the peak resonance the particle Sees at that amplitude.

Direct 6D Tracking Crossing 393+Nu with Teaspink



Running 32K particles with X=Y emit out to 20pi mm-mrad. This direct tracking code Has been under development for several years by Tech-X (Dan Abel and Dominic Meiser) runs on GPU cluster, with some important advances in direct spin integration.[6]

Should Compare in Emittance Space

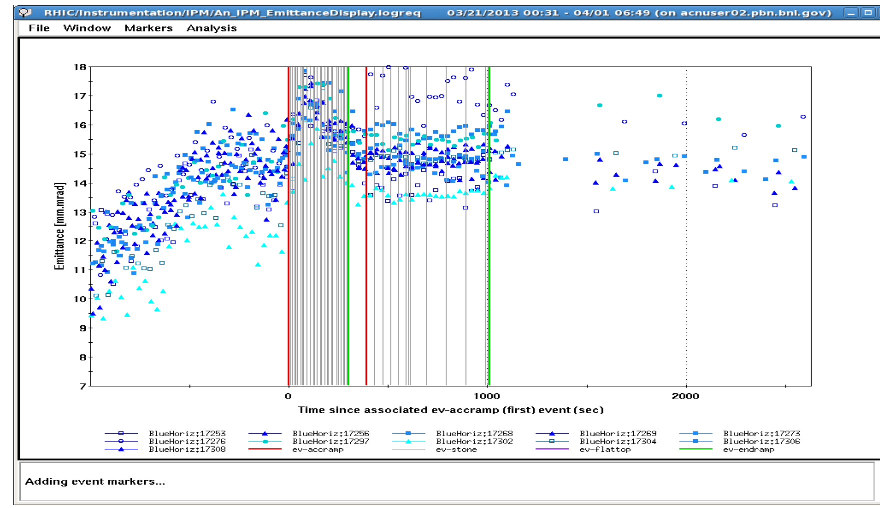


In this space Yellow maybe not so bad. So we expect FY12 standard lattice to perform best Next the Yellow Elens lattice and finally the Blue Elens lattice.

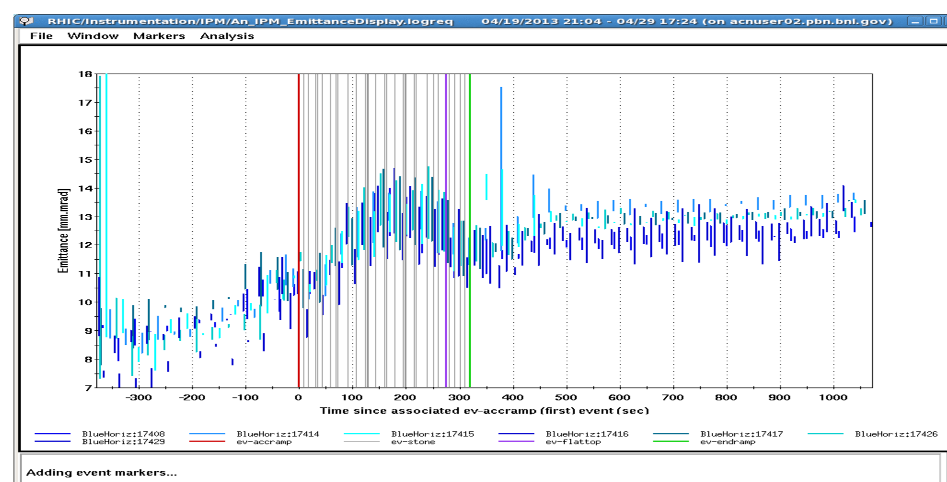
What Actually Happened?

- Hard to dissect causes of polarization losses
  - Losses on ramp
    - Emittances (blowing up early part of run)
    - Tunes (some lattices tolerated running near 2/3rds better)
    - Snake calibration
    - coupling
  - Losses during rotator ramp/going into collision
    - Emittances (e-cloud driven)
    - Orbit (offset at rotators 5mm)
      - spin tune
    - Tune
    - Rotator Calibration

Horizontal emittance through energy ramp before AGS LLRF fix



Horizontal emittance through energy ramp After AGS LLRF fix



How did we do?

Lattice (before LLRF fix)	Avg Jet Pol. *	Avg. CNI Ramp Eff. **	Avg R ratio **
Blue e-lens	47.7± 0.7%	0.8202+- 0.0059	0.2381
Blue FY12	42.7% ± 0.8%	0.7805+- 0.0089	0.3129
Yellow e-lens	44.1% ± 0.8%	0.8324+- 0.0064	0.2447
Yellow FY12	50.0% ± 0.9%	0.8469+- 0.0105	0.2452

Lattice (after LLRF fix)	Avg Jet Pol. *	Avg. CNI Ramp Eff. **	Avg R ratio **
Blue FY12	51.7 %± 0.3%	0.8842+- 0.0057	0.1287
Yellow FY12	55.1%± 0.4%	0.8834+- 0.006	0.1403

* Jet Number Courtesy H. Huang ** CNI Ramp Eff. Courtesy D. Smirnov

Conclusion

- While its difficult to draw firm conclusions from the experimental evidence
  - We can see that generally the Yellow standard lattice outperformed all other lattices which is consistent with what simulation tells us.
  - Blue standard lattice suffered but the causes are probably external to the resonance structure since they both Yellow and Blue should have the same intrinsic resonance structure.
  - Yellow E-lens performed worse than the Blue Elen, this contradicts what we would expect from our simulation. However as we see with the Blue and Yellow standard lattice other effects probably have obscured this.
- Future prospects:
  - Try and construct an empirical model to capture the polarization response as a function of primary resonance and secondary resonance, phase and tune.

[5] S. Blanes, F. Casas, J. A. Oteo, and J. Ros, Physics Reports 470, 151 (2009).
[6] D. Abell, et al. IPAC 13 Shanghai pp 1037-1039