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BNL C-AD
June 17, 2019

ON POLARIZATION PROFILE TOOLING FOR THE EIC

In the AGS

Y. Dutheil, PhD research - 2010-2014

The polarization is not defined by the projection of the spin vectors on the vertical axis but by the projection on the stable spin direction

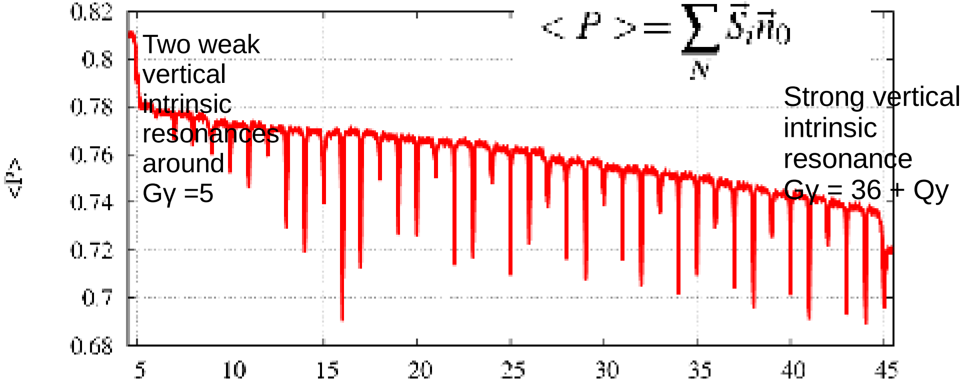


Figure 4.7 Average of the projected spin vector on the stable spin direction on the closed orbit during a typical multiturn tracking.

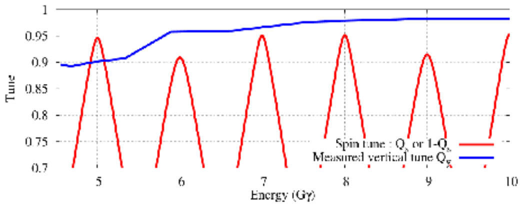


Figure 4.9 Fractional part of the vertical tune and spin tune at low energy as a function of the energy in the AGS.

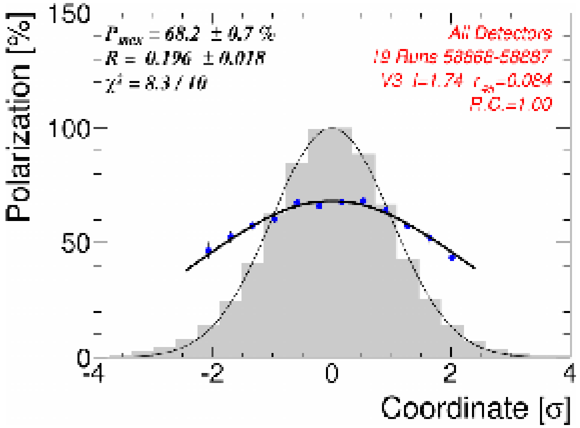
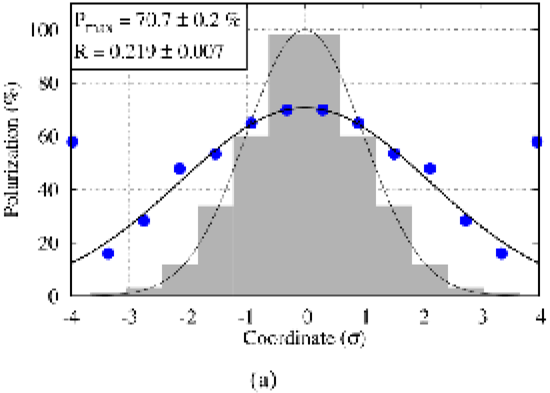
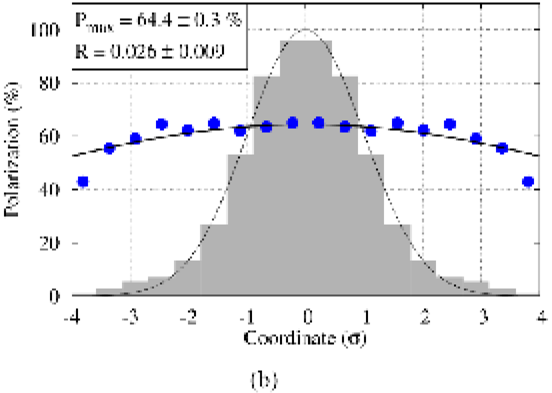


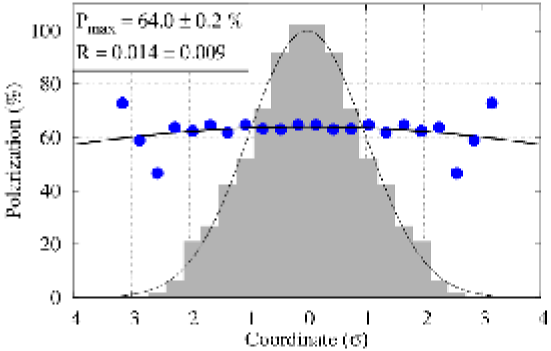
Figure 4.8 Measured horizontal polarization profile in the AGS at extraction energy. Grey: beam intensity profile; blue dots: polarization profile. This measurement took 5 hours.

- The profiles are expected to be symmetrical, so the binning is done symmetrically, effectively only filling half of the bins and symmetrizing afterwards. This allows mitigating the relatively small statistics.





- This type of profile is usually obtained by tracking ~4-5000 particles. Accuracy on R not at its best.



Transverse emittances:

$$\epsilon_z^{N,95\%} = \beta\gamma\, 6\pi\sqrt{< z^2 >< z'^2 > - < zz' >^2}$$

Longitudinal emittance:

$$\epsilon_l^{N,95\%} = 6\pi \frac{C}{h2\pi\beta c}\sigma(\phi)\, M_0\gamma\beta^2\sigma(dp/p)$$

Polarization profiles in a bunch at Gγ = 45.5 in the AGS, from multiturn tracking. Horizontal (a), vertical (b) and longitudinal (c) planes.

- Simulated polarization profiles do not depend on the location around the AGS as the effect of the dispersion is removed.
- Tracking 4~5000 particles over 130,000 turns (the AGS cycle) requires 2+ CPU hours per particle. Which also means 2hrs overall on a computer farm – NERSC.

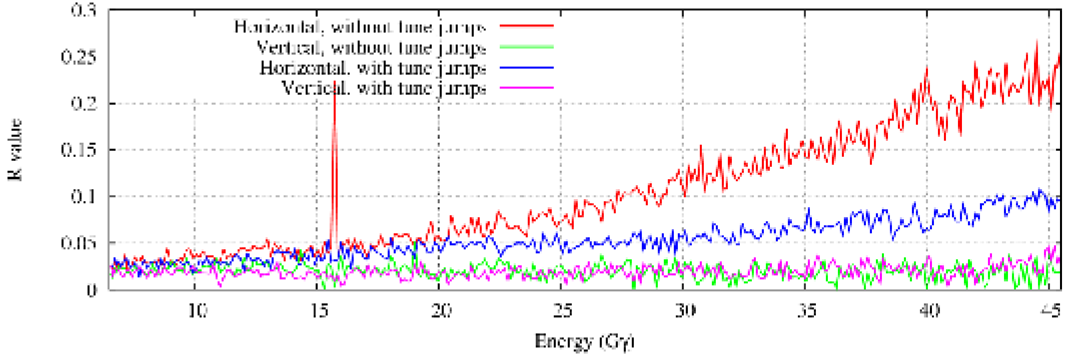
Effect of the sample size on the mean polarization and horizontal R-value.

Number of particles	1000	2000	4416	17664
Mean Polarization(%)	84.16	81.65	81.31	81.31
Standard deviation	5.2	0.5	0.15	-
Mean horizontal R value	0.189	0.192	0.194	-
Standard deviation	0.012	0.014	0.007	-

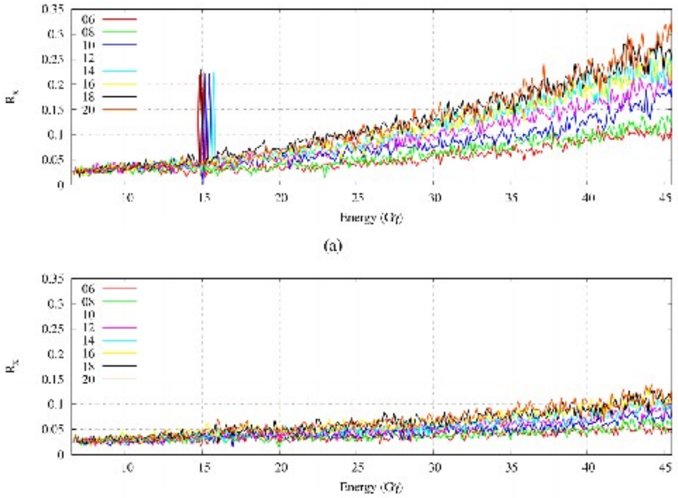
Comparison of simulated polarization profiles with measurements (AGS ppRun 14). Measurements show unexpectedly strong V profiles.

Measured [5]		Simulated		Machine conditions
R_x	R_y	R_x	R_y	
0.206 ± 0.020	0.181 ± 0.033	0.250 ± 0.007	0.021 ± 0.007	Without tune jumps
0.127 ± 0.019	0.124 ± 0.026	0.100 ± 0.007	0.035 ± 0.007	With tune jumps

Simulated polarization is qualitatively conform to expectations. Measured values of horizontal polarization profiles are successfully predicted by tracking.

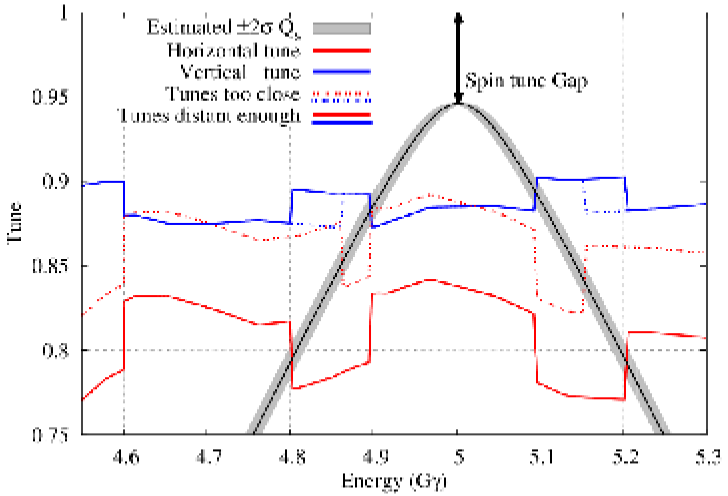


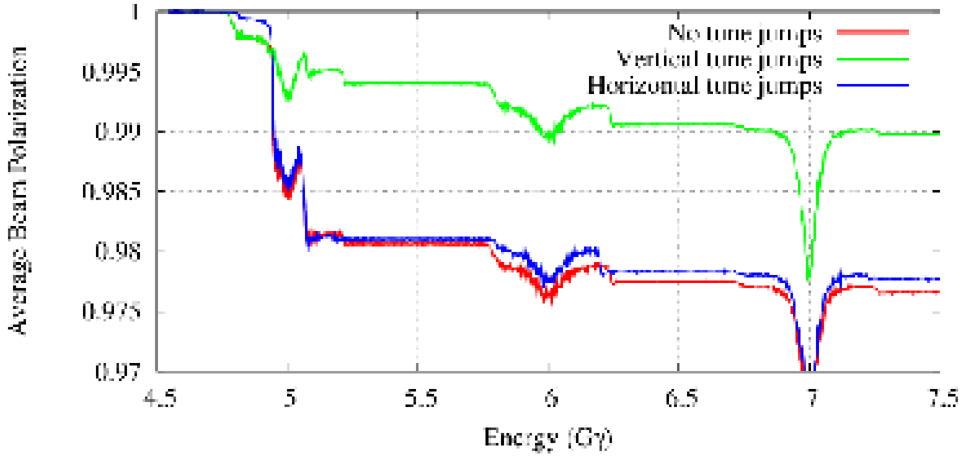
Polarization profiles from bunch tracking, from Gγ = 6.5 to 45.5, accountig for typical beam and machine conditions.



Simulated horizontal polarization profile as a function of energy for different initial beam horizontal emittances (in 95% πmm.mrad normalized and at Gγ = 6.5) without (a) and with tune jumps (b).

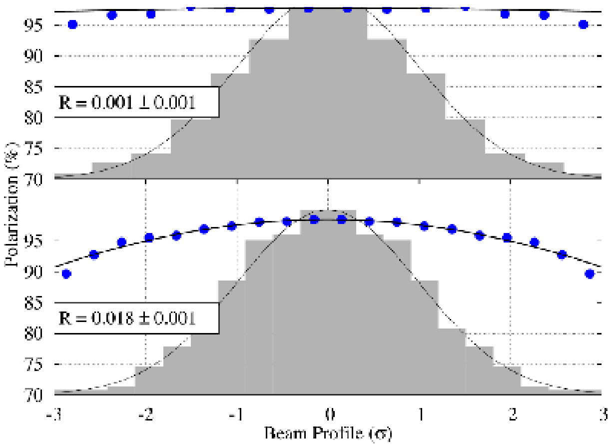
Vertical tune jumps at Gg=5

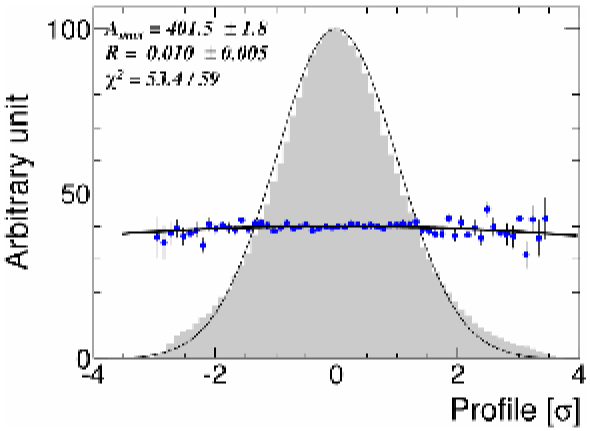




Average bunch polarization over Gy = 4.5 → 7.5

At Gy = 7.5: H and V polarization profiles obtained from tracking over Gy = 4.5 → 7.5.





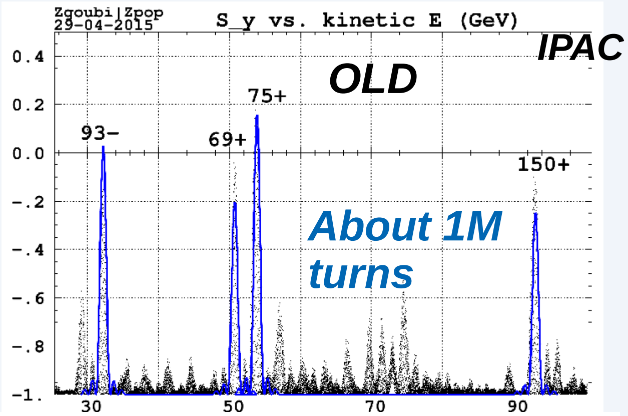
Vertical polarization profile, measured

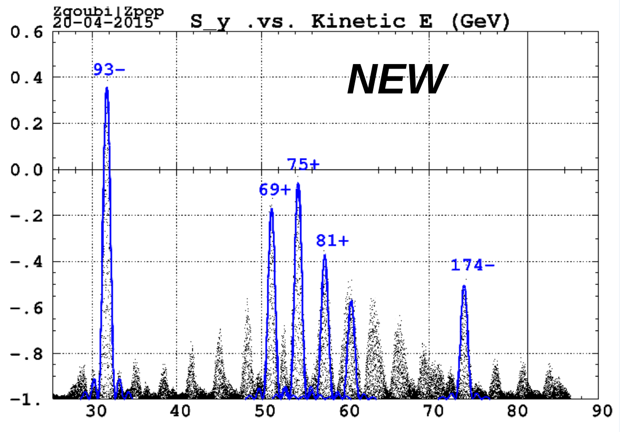
In RHIC

A lot has been done over the years, typically amenable to polarization profile computation

6D+spin. Comparing RHIC optics, preparation Run 15.
Blue envelop is theory [SYL]!

IPAC 15

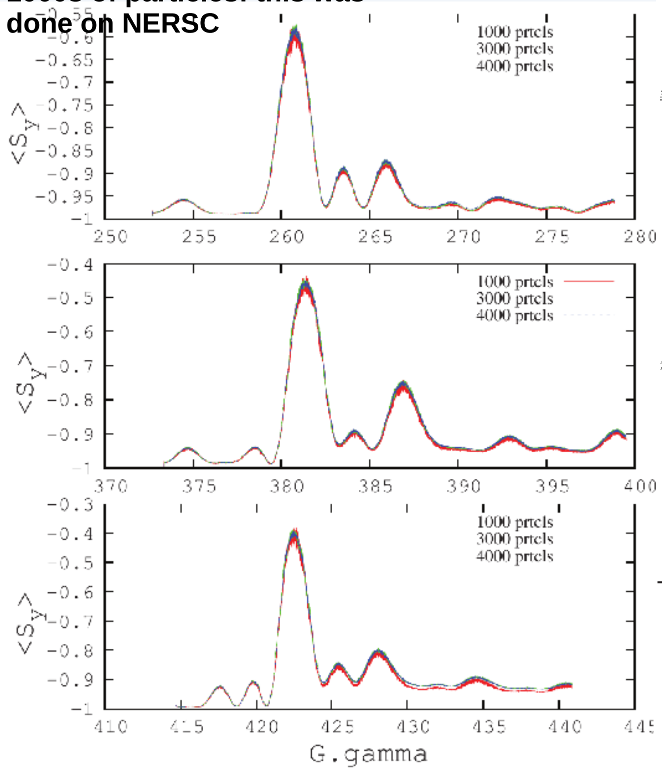




Code benchmaring, 6D+spin, tracking 1000s-particle bunches

IPAC 12

1000s of particles: this was done on NERSC



Average of the projection of spins on the vertical, turn by turn, at Gy =231+Qy, 411-Qy, 393+Qy.

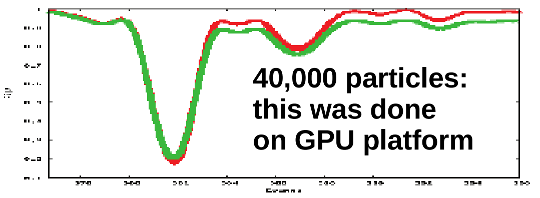


Figure 8: Crossing of 411 Q_y, 4-D tracking (red curve) and 6-D tracking (green curve).

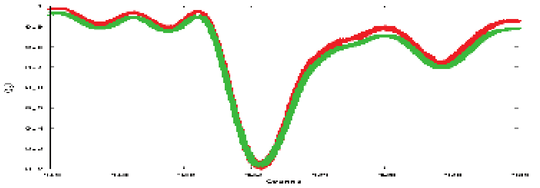


Figure 9: Crossing of $393 + Q_y$, 4-D tracking (red curve) and 6-D tracking (green curve).

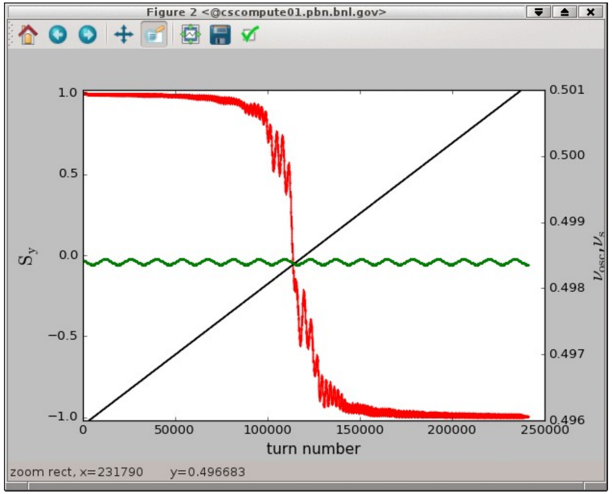
Table 1: Polarization Transmission

	Orbits set		No orbit	
	At start	At end	At start	At end
(1) 231+Qy:				
$<S_y>$	-0.9889	-0.9834	-0.9891	-0.9889
Polar. ratio	1	0.99444	1	0.99987
(2) 411-Qy:				
$<S_y>$	-0.9864	-0.9498	-0.9871	-0.9777
Polar. ratio	1	0.96284	1	0.99052
(3) 393+Qy:				
$<S_y>$	-0.9939	-0.9324	-0.9943	-0.9624
Polar. ratio	1	0.9382	1	0.9679

These past months: simulation of RHIC spin-flipper, 6D+spin

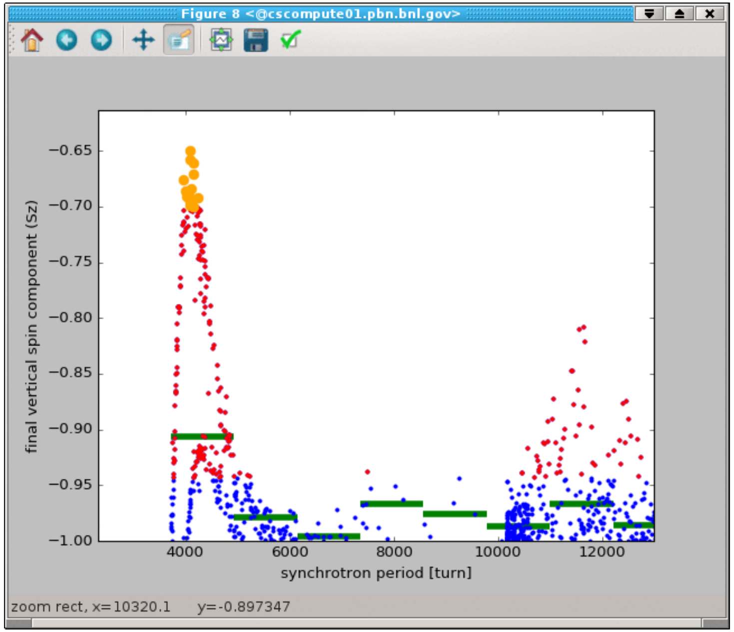
Petra Adams
C-AD OP

- A sweep at 24GeV requires up to 250,000 turns (3 sec.)
- Shorter at 255 GeV, < 1 sec., 70,000 turns



/home/cfsd/padams/spin_flipper/blue_injection/noIPBumps/Nersc/**Dp3.45mrad/**9MHz197MHz/inj_Dp3.45mrad_**sweep234000**_edisoned/Run1

Last night:
a correlation between synchrotron frequency and final polarization

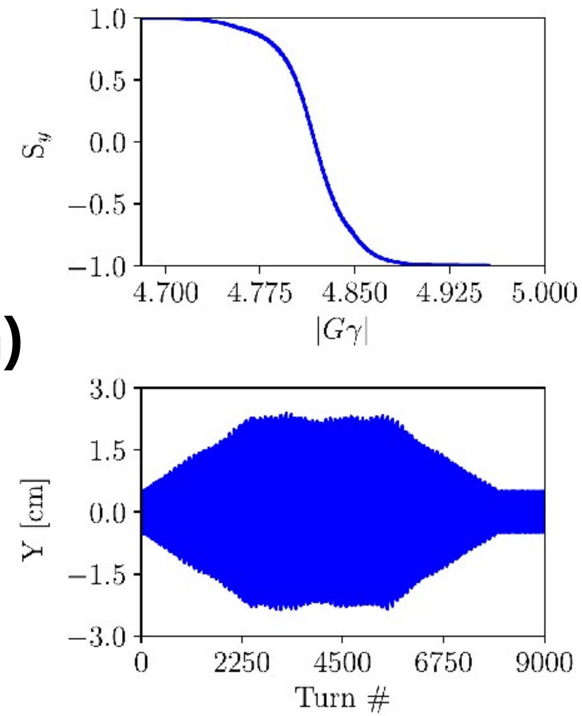


Average of the vertical spin component in bins

At RHIC - There is more 6-D spin tracking, amenable to polarization profile studies:

- ^{3}He in Booster, high-rigidity injection in AGS (Kiel Hock, C-AD OP, PhD research, 2015 - on)

- D is in the plans



The mechanical design is shown in Fig. 2, and shows no programmatic drawbacks.

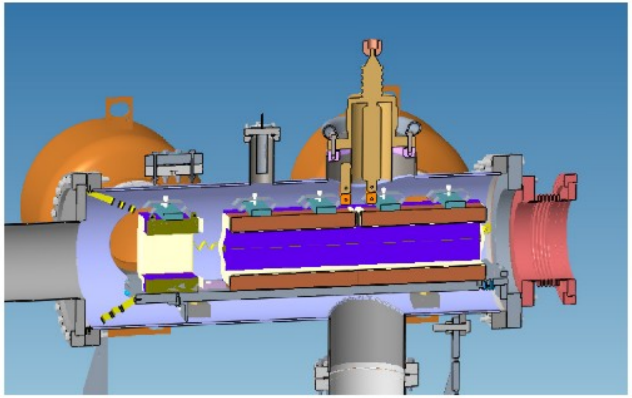
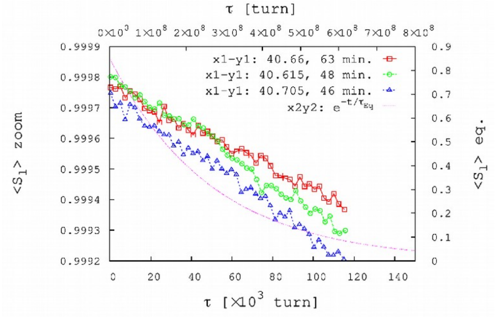


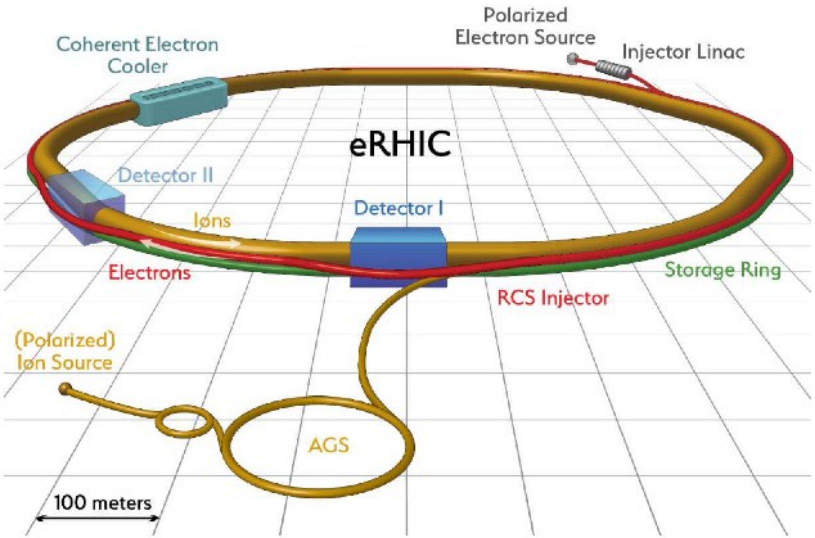
Figure 2: Cross section of the new assembly for the E3 section of the Booster. Inside the transparent vacuum chamber is the new AC-dipole, and a new tune kicker, can be seen. On the exterior of the vacuum chamber are the feed-throughs for the two magnets.

Some extra ads: electrons.

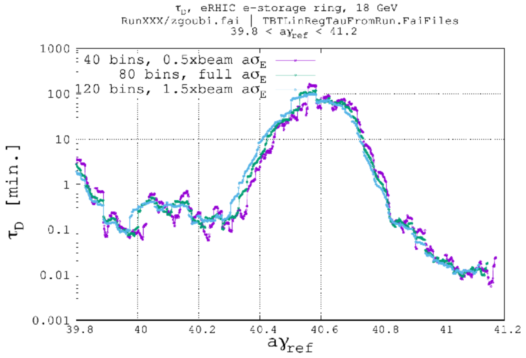
In eRHIC e-storage ring

Steve's Tepikian latttice, time dependence of 6-D polarization is tracked. Takes few 10^4 turns.

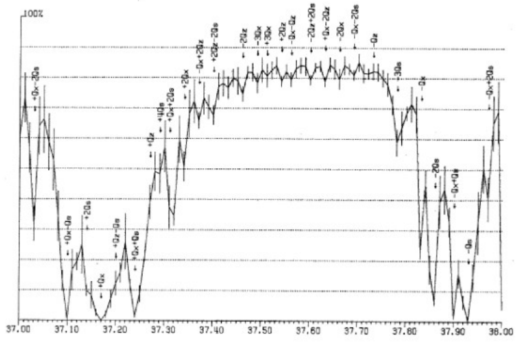




Resulting polarization vs. ring rigidity - awaiting polarization profile criteria...



@ HERA for comparison



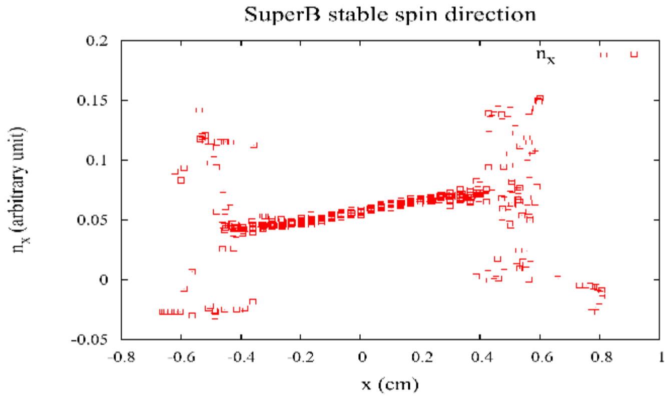
HERA-e, linear, res. non-corrected

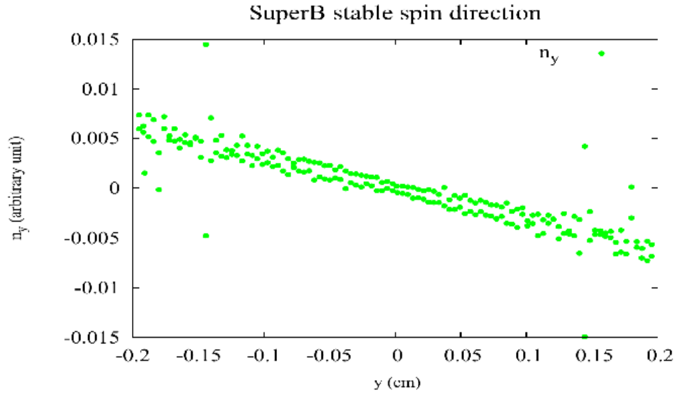
ISF is a sub-product of ray-tracing capabilities. e.g., @ Super-B:

- *Spin dynamics tool developments for* ***ISF computation*** *at super-B,*
  N. Monseu (PhD research) – cf. IPAC 11

- Time-wise this is fine – there is clever, rapid algorythms,

  and see next slide





Finally, to be brief: there is more 6-D+spin hadron (and electron) tracking amenable to beam polarization profile, @ JLab EIC

- See Morozov et als.,

  IPAC and other joint BNL-JLab EIC meetings

CPU-wise

- **Polarization profiles may require several 1000s of particles, to be tracked up to several 100,000s turns**

  We don't want tracking trials to take too long...

  We work on NERSC → duration of tracking does not depend on # of particles

  Doable, essentially: at most a matter of overnight computation

- **Basic data:**

  - RHIC: 1000turns/CPU-minute. On a recent CPU, crossing a resonance takes ~10^5 turns, ~1 hr

  - RHIC spin flipper: A sweep at 24GeV requires up to 250,000 turns (3 sec flight time) → ~2 hrs

  - eRHIC e-storage ring: computing polarisation survival requires a few 1000 turns, 10 x less than RHIC → 0.2 hrs

Send us your student

We will teach her/him how to compute polarization profiles in the EIC e and A rings