F. Méot / BNL C-AD

On the possibility of polarized e-beam R&D at CHESS, for EIC

With much input from an *ad hoc* BNL/Cornell/JLab collaboration

Subtitle: Starting now, the accelerators for that are there.

- construct equipments: beam instrumentation and polarimetry
- for good or prototypes
- install/test/develop these at CHESS
- move to EIC when doable
- form people in view of EIC commissioning

Contents

1 MOTIVATIONS

- Acceleration of polarized e-beam for injection into EIC ESR will use an RCS.

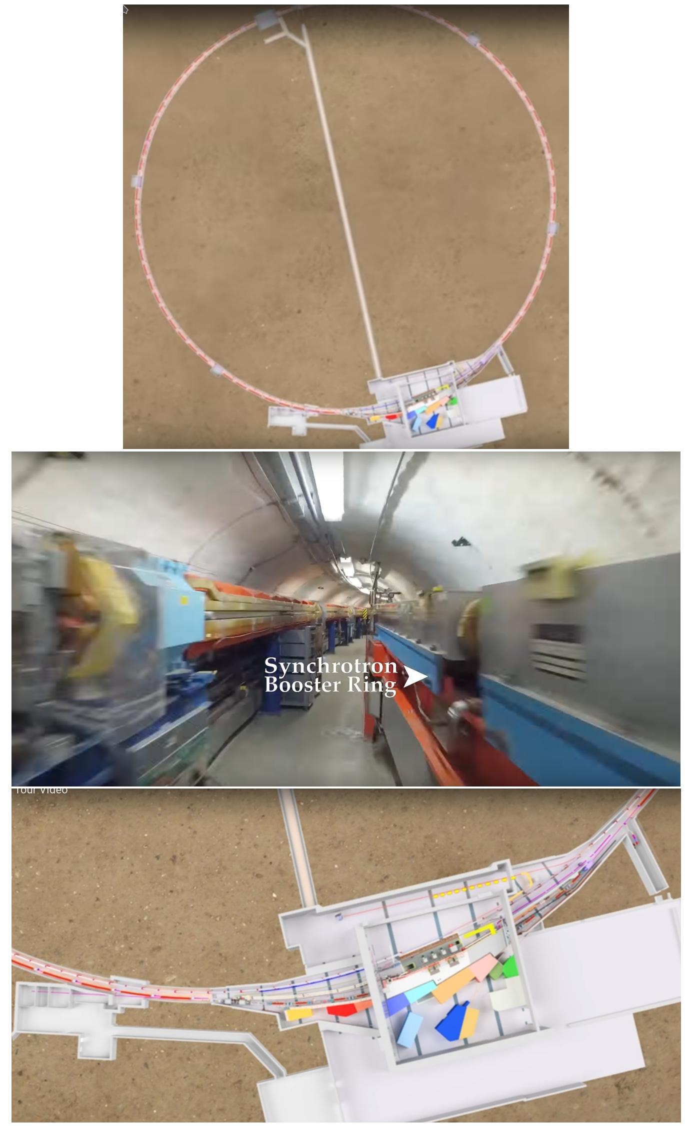
  ◇ RCS acceleration allows the necessary rep. rate for maintaining 70% average polarization at store at 18 GeV.

- Context of the present proposal of R/D at CHESS:

  ◇ The principle of a full-scale experiment at CHESS goes back to early 2017, the context was eRHIC (at the time) RCS design, together with tight BNL/Cornell collaboration for the construction of CBETA at Wilson Lab - discussions there fostered ideas...

  ◇ The experiment was recognized to be of interest, at April 2017's "Committee Report for the eRHIC Design Choice Validation Review", BNL, April 2017 (excerpts):

  - The RCS concept can be validated by simulations, but relevant experimental studies at Cornell would be helpful. Particularly crucial will be the transmission through the RCS for which there is no experience.



- We had however no doubt that the supersymmetric "eRHIC RCS" design does work.

- Thus, the concept was promptly pushed beyond being just a (possibly useless) proof-of-principle,

  ◇ towards exploring the possibility of a full scale "pre-EIC" facility, based on CHESS RCS capabilites proper, including the development of accelerator instrumentation,

  ◇ towards using this polarized e-beam installation to develop EIC polarimetry equipment - polarimetry equipment being anyway necessary for beam studies - to be moved to EIC when times for that come.

- A collaboration meeting: BNL(5)/Cornell(5)/JLab(4), was held to start discussing, over May-October 2017, involving e-source, polarimetry and accelerator experts, to discuss

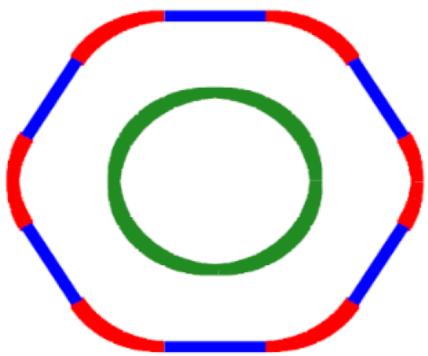
  - the possibility of polarized e-beam production and acceleration to several GeV,

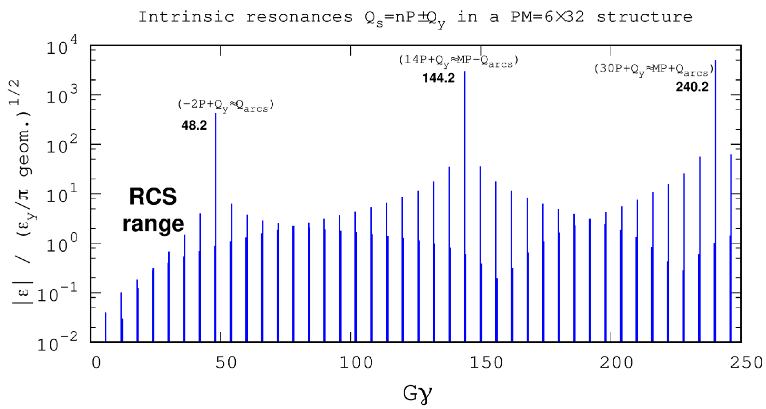
  - the possibility of developing polarimetry equipment for the EIC, in that context.

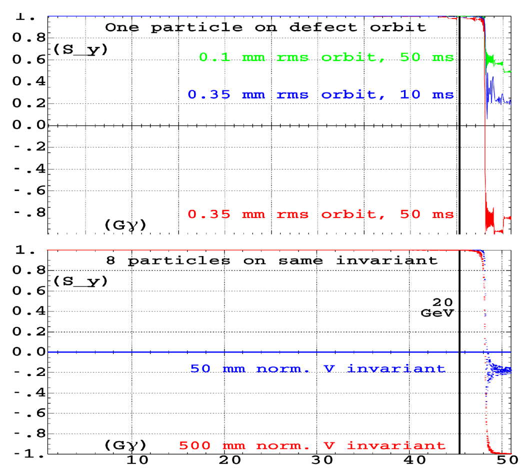
Polarimetry means foreseen included (but not exclusively) using a possible extraction line (an existing project at CHESS), or injection into CESR.

COMPARABLE RESONANCE STRUCTURE

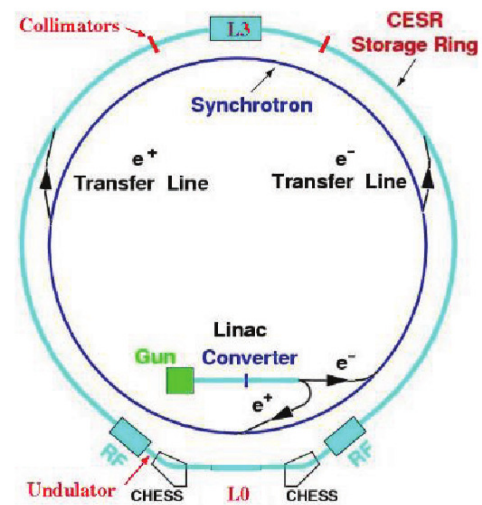
EIC RCS, HIGHLY SYMMETRIC LATTICE

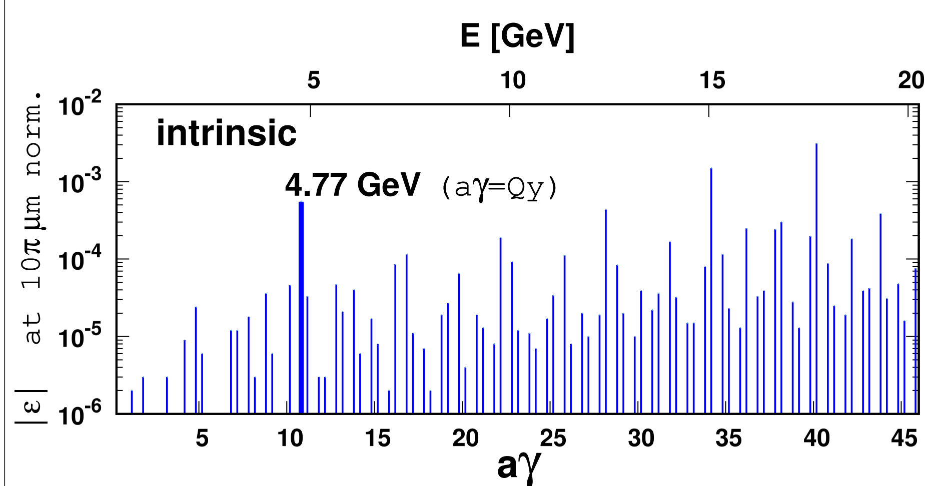






CHESS RCS





2 COMMENTS ON POLARIZATION AT CHESS RCS

		CHESS RCS	EIC RCS
Injection energy	MeV	320	400
Operated up to	GeV	1.8 to 5.3	5, 10 or 18
$\mathcal{C}$	m	756	3830
Bunch			
Bunch charge	nC	0.03	
Numb. of bunches/cycle		16	
Interval between bunches	ns	14	
ε_x, ε_y (5.3 GeV)	nm	400, 110	
Bunch length (5.3 GeV)	mm	6	
Bunch dE/E at injctn, 5.3 GeV		$< 1\%, 2 \times 10^{-4}$	
lattice		combined function	FODO
Cell type, numb.		FFDD, 48	
Phase advance/period	^{o}	75.4	
Nb of magnets		192	
Main field at 0.2, 10, 20 GeV	kG	0.02, 3.3, 6.6	
Max. β_x, β_y	m	$25 \sim 30$	
Q_x, Q_y, typical		10.75	
ξ_x, ξ_y		-12	
The lattice includes two quads at L0, and at L3 straight			
Longitudinal, RF			
f_{rf} ($\frac{1}{4}$ linac frequency), harm.	MHz	713.94, 1800	
Nb of accel. stations		4	
rep. rate	Hz	60	few
voltage/turn to 10 GeV: $4.4(\sin\omega t + 2\sin^8\frac{\omega t}{2})$ *(!1 synac for 5 GeV)*			
Max. voltage at 5.3 GeV	MV	5.2	
Radiation damping (AG lattice)			
$J_x = 1 - \mathcal{D}$		< 0 (x-anti damped)	
τ_{SR} ($\approx 2.5/E^3$) at 5, 10, 15 GeV	ms	20, 2, 1	
σ_x at 10 GeV, 15 GeV	cm	1, 5	

• CHESS RCS RF Ramp

◇ RF voltage per turn for 10 GeV :

$$\mathbf{V(t) = 4.4 \sin \omega t + 8.8 \sin^8 \frac{\omega t}{2}}$$

→ **intrinsic resonance crossing speed $\alpha > 10^{-3}$, all the way**

[M. Tigner, IEEE Trans.]

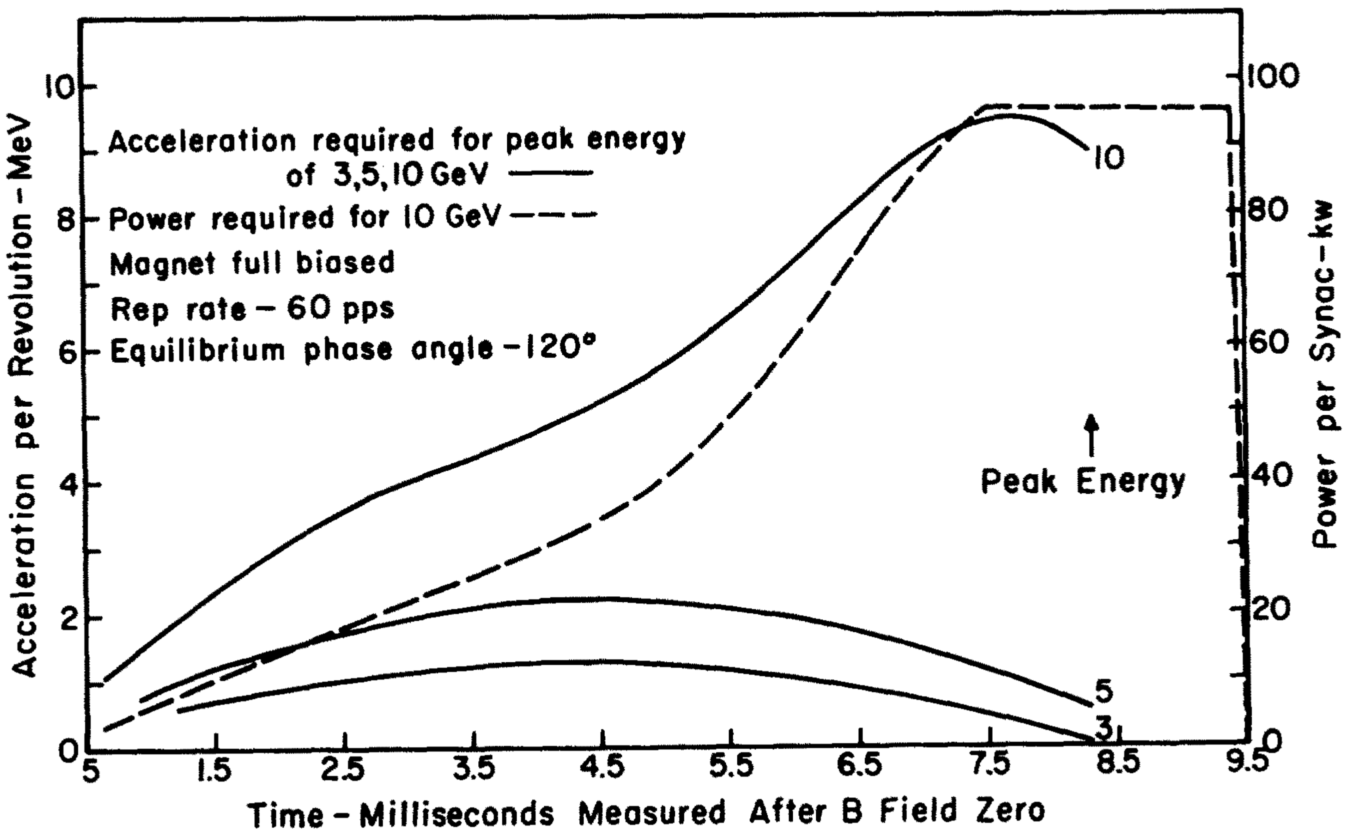


Fig. 1. Acceleration Required for Peak Energy of 3, 5, 10 GeV.

- **RCS optics**

```
@ LENGTH      %le     755.8699089
@ ALFA        %le    0.9883981798E-02
@ ORBIT5      %le                   -0
@ GAMMATR     %le     10.05851879
-------- TUNES :
@ Q1          %le    10.6192017265
@ Q2          %le    10.8212950059
----------------
@ DQ1         %le    -12.24979921
@ DQ2         %le    -12.52138684
@ DXMAX       %le     3.18106746E+00     @ DXMIN      %le  1.13381295E-01
@ DYMAX       %le     0.00000000E+00     @ DYMIN      %le  0.00000000E+00
@ XCOMAX      %le     4.70919093E-04     @ XCOMIN     %le -5.24526127E-04
@ YCOMAX      %le     0.00000000E+00     @ YCOMIN     %le  0.00000000E+00
@ BETXMAX     %le     2.89933865E+01     @ BETXMIN    %le  4.94741348E+00
@ BETYMAX     %le     2.58408796E+01     @ BETYMIN    %le  5.41423967E+00
@ DXRMS       %le     6.24872216E-01
@ DYRMS       %le     0.00000000E+00
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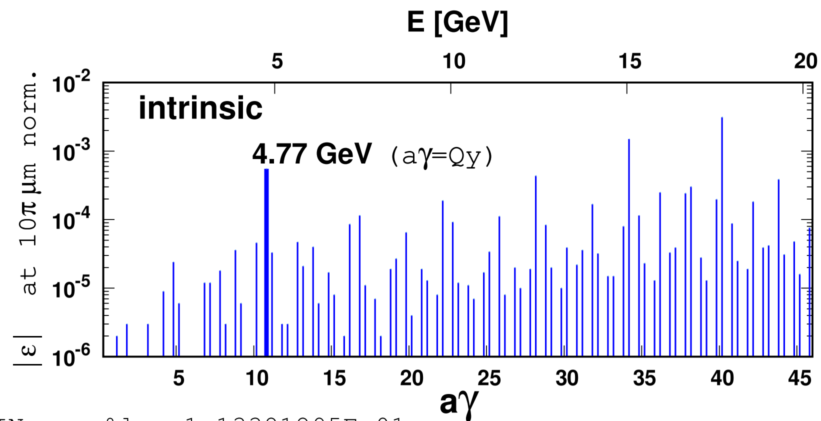
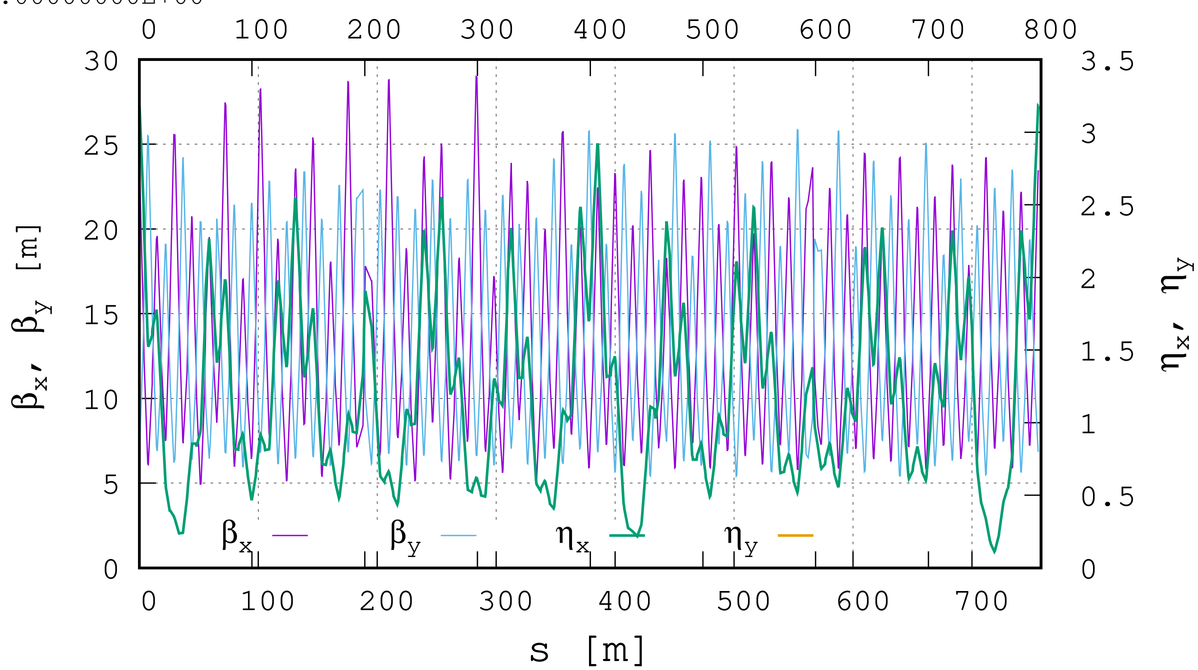
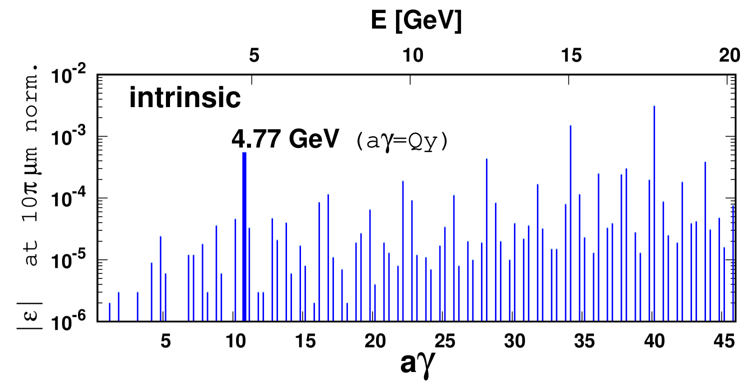




Betatron functions and dispersion.

• Effect of intrinsic resonances, quick estimate :

• Consider acceleration up to just upstream of $a\gamma = Q_y$



◇ Take invariant on larger side $\varepsilon_{\rm y,N} = 10^4\pi\ \mu$m, (10 times *rms* bunch emittance),

thus experienced strength is $|\epsilon|_{10^4\mu m} = |\epsilon|_{10\mu m}\sqrt{10^3} \approx 5\,10^{-5}\sqrt{10^3}$ $\approx 1.5\,10^{-3}$

◇ Take crossing speed on lower side, $\alpha : 10^{-3}$ $\rightarrow 3\times 10^{-3}$ for $E : 0.32 \rightarrow 5$ GeV

◇ That yields an encouraging, single-resonance, $\frac{\rm P_f}{\rm P_i} = 2\exp(-\frac{\pi}{2}\frac{|\epsilon|^2}{\alpha}) - 1 \approx 0.986$

• Push further : cumulated effect of resonance series from injection to $a\gamma < Q_y$:

◇ for all resonances take upper value $|\epsilon_j| = 1.5\,10^{-3}$, lower value $\alpha_j = 10^{-3}$:

◇ overall, $\frac{\rm P_{N,f}}{\rm P_{1,i}} = \frac{\rm P_{N,f}}{\rm P_{N,i}} \times \frac{\rm P_{N-1,f}}{\rm P_{N-1,i}} ... \times \frac{\rm P_{1,f}}{\rm P_{1,i}} \approx 1 - \sum_{\rm j=1,N} \frac{\pi|\epsilon_{\rm j}|^2}{\alpha_{\rm j}}$
with $|\epsilon_{\rm j}|$ and $\alpha_{\rm j}$ the strength and crossing speed at resonance j.

◇ So that,

$$\frac{\rm P_{a\gamma=Q_y^-}}{\rm P_{injection}} \approx 0.93$$

CHECK THAT WITH BASIC SIMULATIONS

• **Working hypotheses:**

◇ Gaussian bunch, huge initial emittances
$\epsilon_x/\pi = \epsilon_y/\pi = 25\ \mu$m geometrical at 320 MeV
(9 mm normalized),

◇ initial $\mathrm{dp/p} \in \pm 10^{-3}$ uniform.

◇ acceleration range : 320 MeV $\rightarrow$ 5 GeV

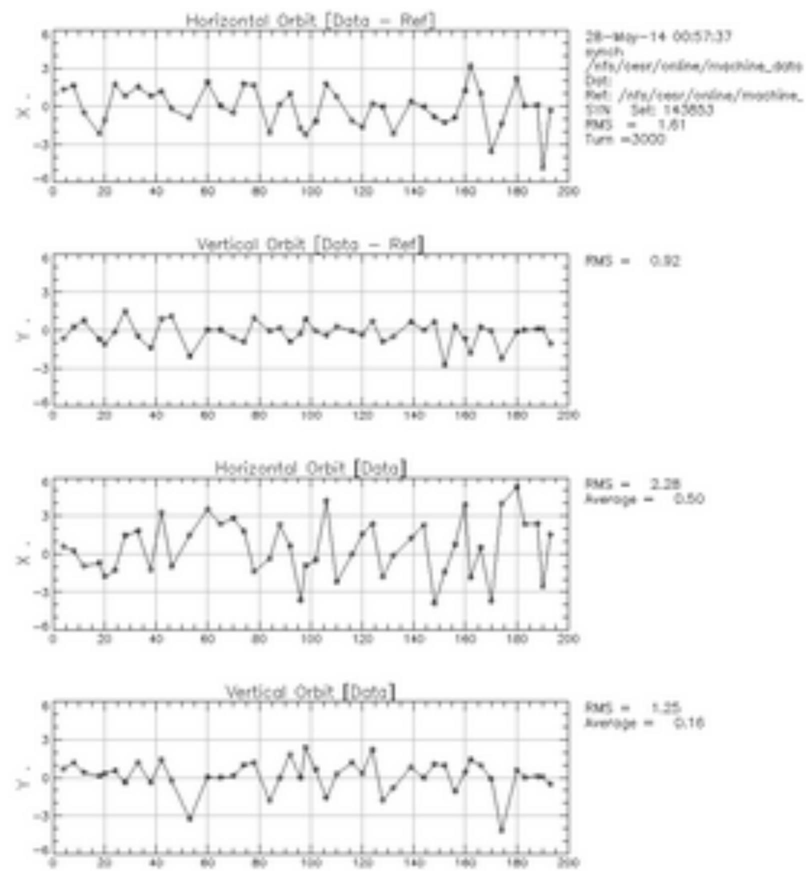
◇ Vertical closed orbit:

- realistic amplitudes considered, from random kicks in vertical correctors and roll angle.

- based on real-life orbit records:

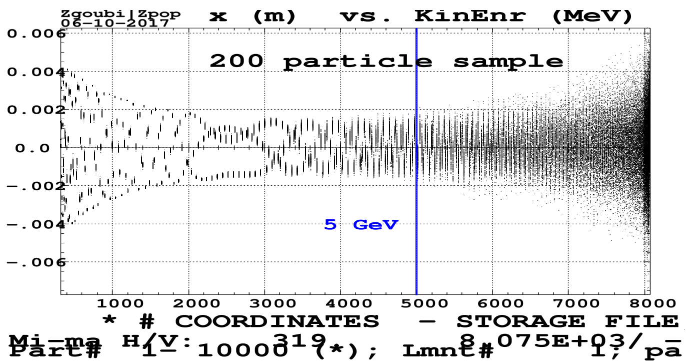
Horizontal : 1.61 mm rms

vertical : is 0.92 mm rms

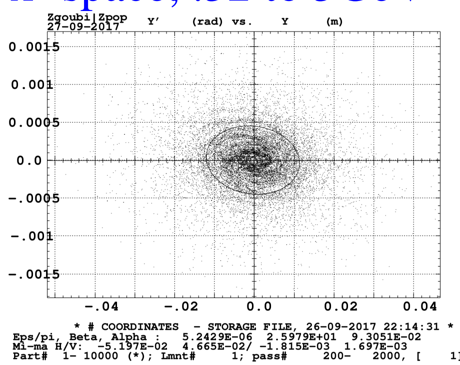


• Some beam monitoring, to make sure...

x-motion to 8 GeV

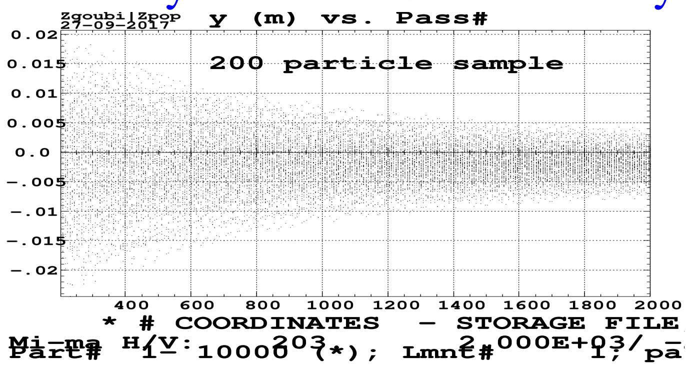


x - x' space, .32 to 5GeV

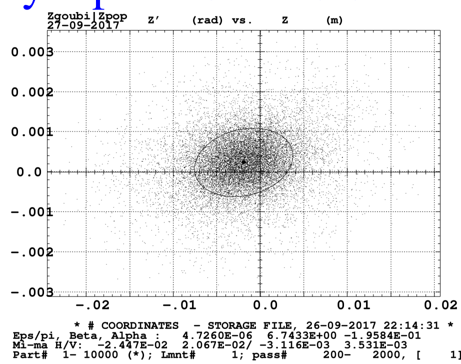


◇ Note no more damping beyond 1400+ turns/3 GeV

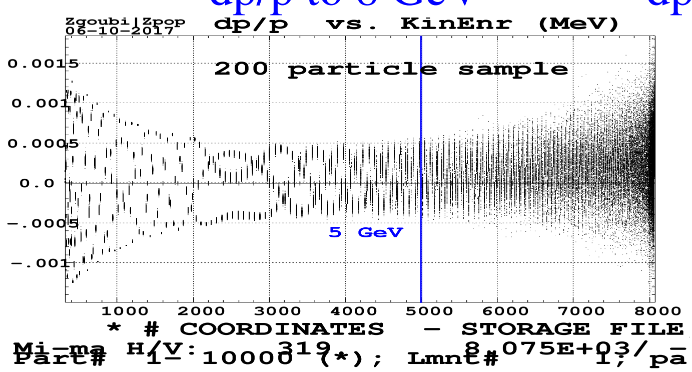
y-motion to 5 GeV



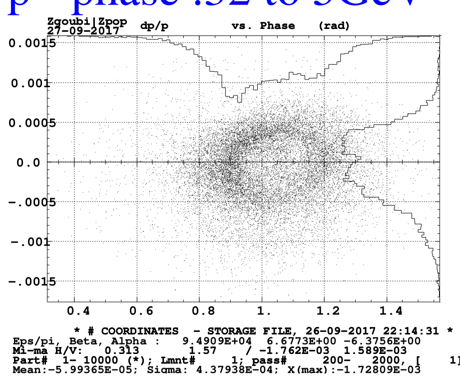
y - y' space .32 to 5GeV



dp/p to 8 GeV



dp/p - phase .32 to 5GeV



In passing : matter for benchmarking vs. theory, here :

$$\frac{dU_z}{dt} = -\frac{2}{\tau_z(t)} U_z + C_z(t) - \frac{1}{p}\frac{dp}{dt}$$

$$U_z \ \ (z = x \ or \ y)$$

$$\frac{d(\hat{\Delta E})^2}{dt} = -\frac{2}{\tau_l}(\hat{\Delta E})^2 + (\dot{N} < \epsilon^2 >)(t)$$

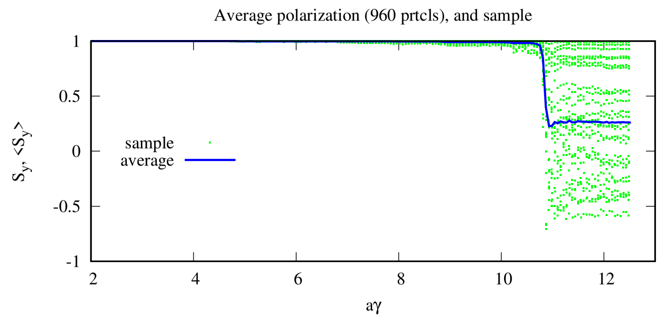
$$+\frac{1}{2E}\frac{dE}{dt}(\hat{\Delta E})^2$$

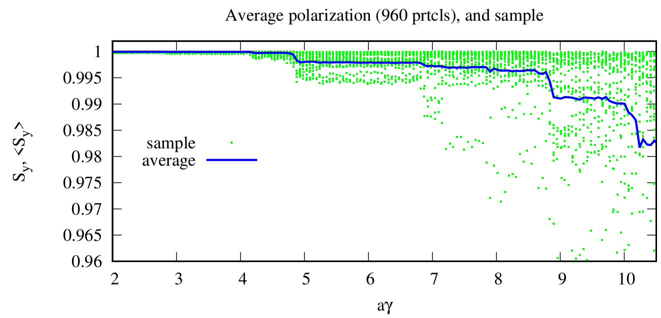
• Results, up to 4.5 GeV with orbit errors

- Green dots : sample particles, vertical spin component
- Blue curves : average polarization, 1000 particles; right column: zoom in on $< S_y >$.

• V orbit 1 mm ; $\delta K1$ 1%

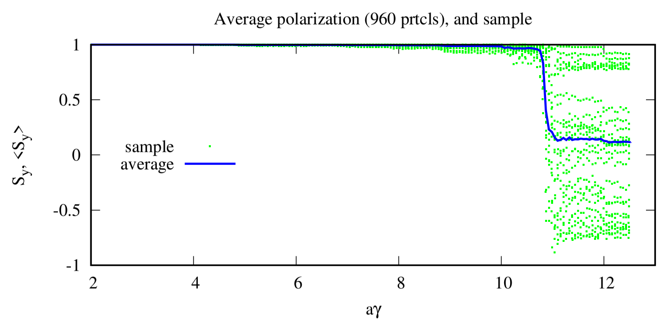
Final polarization at 4.5 GeV : 98.3%

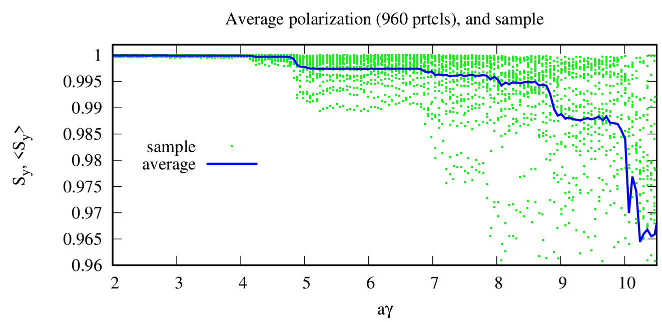




• V orbit 5 mm ; $\delta K1$ 1%

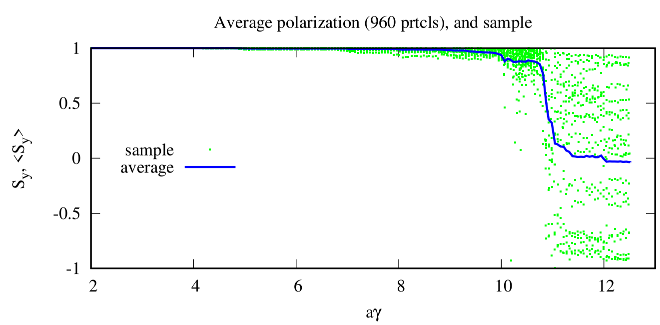
Final polarization at 4.5 GeV : 96.5%

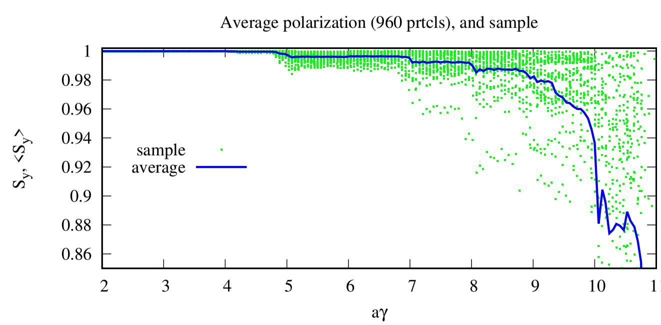




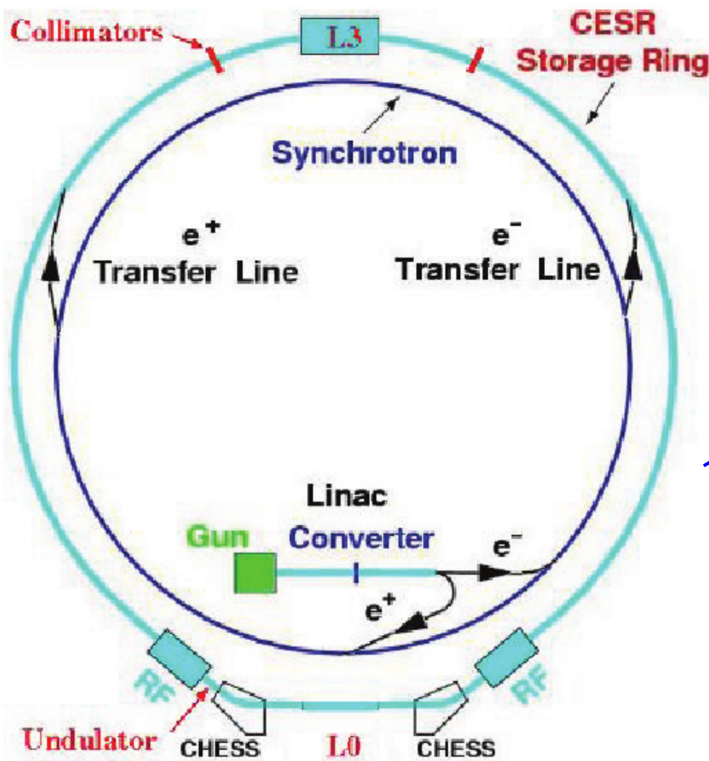
• V orbit 10 mm ; $\delta K1$ 1%

Final polarization at 4.5 GeV : 88%





3 POLARIMETRY



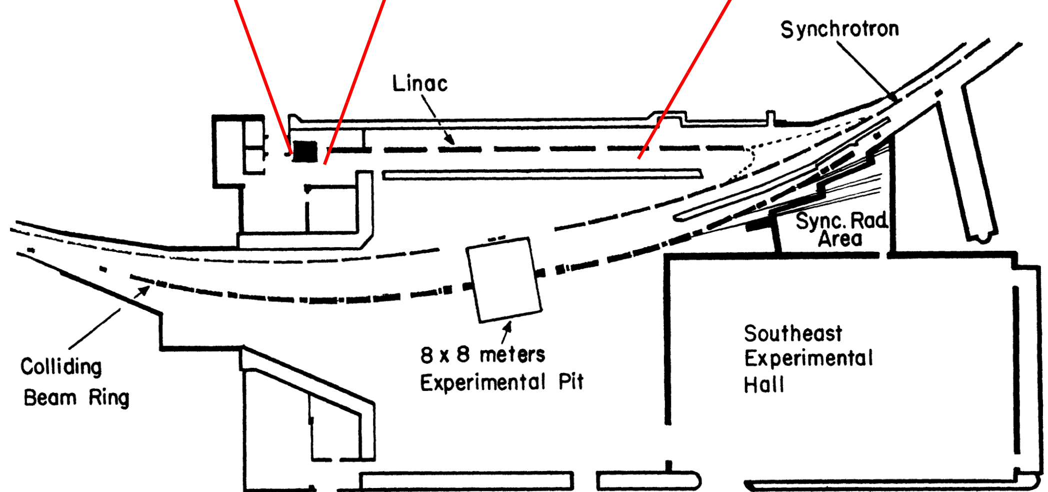
Add
Moeller
polarimeter

Beam can be destroyed (Compton polarimeter is more expensive)

Add $\vec{e}^-$ source + rotator

Add Mott polarimeter at source...

... or Moeller pol. along linac



- Polarized e-beam acceleration and measurements require development/installation of (a non-exhaustive list...)
  - ◇ A polarized electron source followed by a spin rotator
  - ◇ Beam instrumentation for orbit control
  - ◇ Polarimetry
    - low- or medium-energy polarimetry, upstream of RCS
    - high energy polarimetry, in transfer line to, or in, CHESS, or in extraction line.

- Both source and polarimetry could be EIC R/D proper: prototyping, tests, construction, to be moved to EIC when doable.

- Some challenging to implementation:
  - ◇ Existing linac is very crowded.
  - ◇ Space for polarized gun is limited.
  - ◇ Need to preserve current operations capability for existing CHESS light source.

Existing 150kV Thermionic Gun

- On the good news side:
  - ◇ Space available for polarimetry in linac at full energy.
  - ◇ Space (5 m) may be available in North Area straight section of synchrotron or in
  - ◇ injection lines after synchrotron.
  - ◇ Dedicated run for machine studies is a viable (and perhaps preferred) option.

Space for Polarimeter at end of Linac (3-4m)

THANKS FOR YOUR ATTENTION