31st CANU and 8th JCHP-FFE Workshop

Physikzentrum Bad Honnef, December 16 and 17, 2013

Spin Coherence Time Studies at COSY

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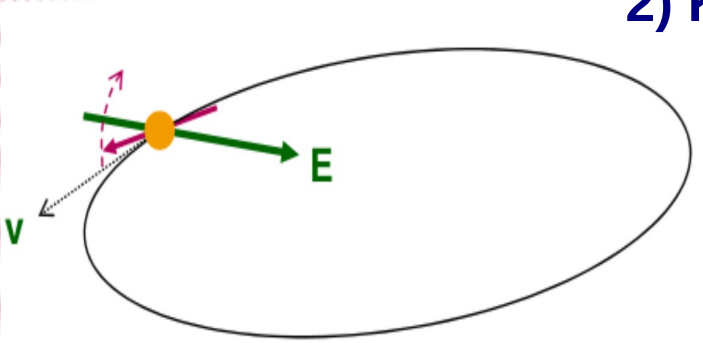
How to measure the EDM of a charged particle

Electric Dipole Moment (EDM)

- charge displacement within the particle volume
- **Lies along the spin axis**

Proposed solution: **1) Storage ring**
2) Keep spin aligned with velocity

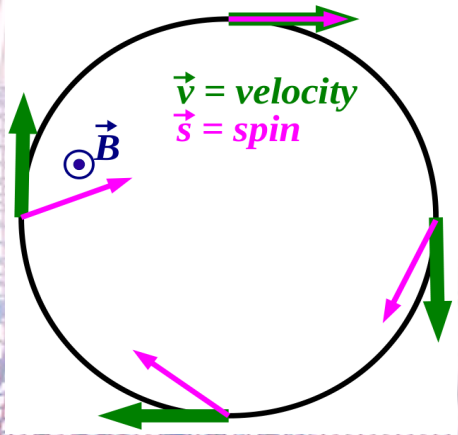


$$\frac{d\vec{s}}{dt} = \vec{d} \times \vec{E}$$

EDM signal = spin precession in the vertical plane

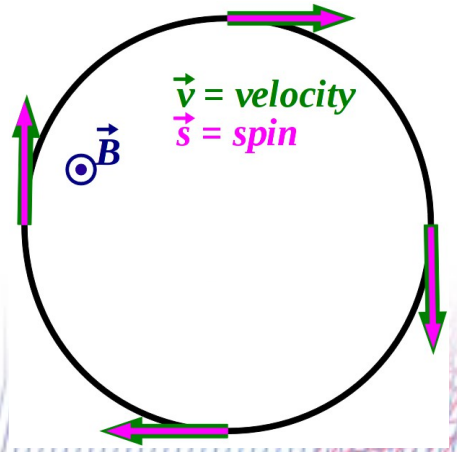
All rings have inward electric field in particle frame

Anomalous magnetic moment causes spin to precess different than velocity



FROZEN SPIN

Rebalancing central forces from electric and magnetic fields



PROTONS
Pure electric ring
p=0,7 GeV/c

DEUTERONS
Magnetic ring
Outward E field

Technical issue: vertical axis = the stable spin direction

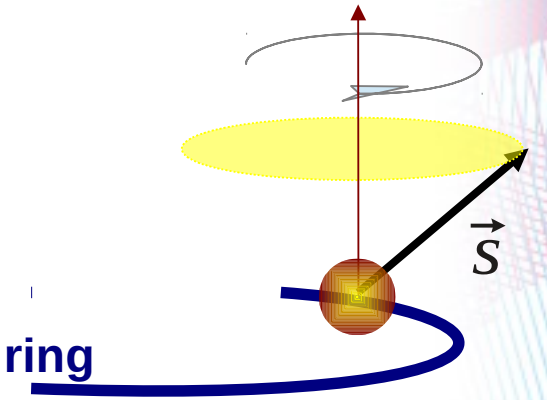
1) Spin tune

At injection: vertically polarized → RF solenoid rotates the polarization into the horizontal (ring) plane

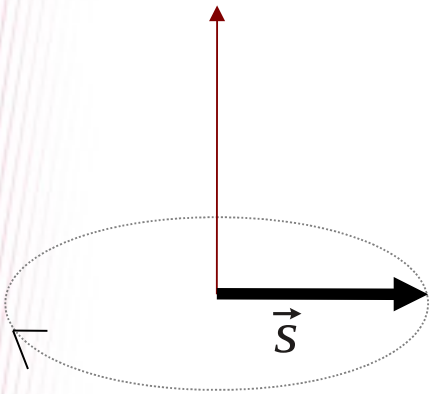
Spin tune $\nu_s = G\gamma$ **number of spin precessions per turn**

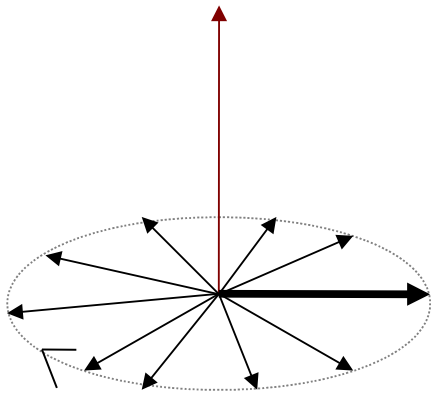
Anomalous magnetic moment

Relativistic gamma



2) Spin Coherence Time





At injection:

all the spins are aligned

After some time:

Particles have different velocities

Spins out of phase in the horizontal plane

Horizontal pol. Lifetime = Observation time = Spin coherence time

Bunching the beam removes first-order spread from Δp/p

Spin Coherence Time Studies

AIM

Demonstrate **sextupole fields** can counteract the spread of spin tunes associated with **emittance** and $\mathbf{(\Delta p/p)^2}$.

Second order effects!

History

2012: First direct measurement of SCT

- Dedicated **DAQ** to measure horizontal polarization as a function of time.

- **Slow beam extraction** onto a thick carbon target

- **Bunched beam** to remove first order momentum spread distribution (Δp/p).

Spin Coherence Time Studies

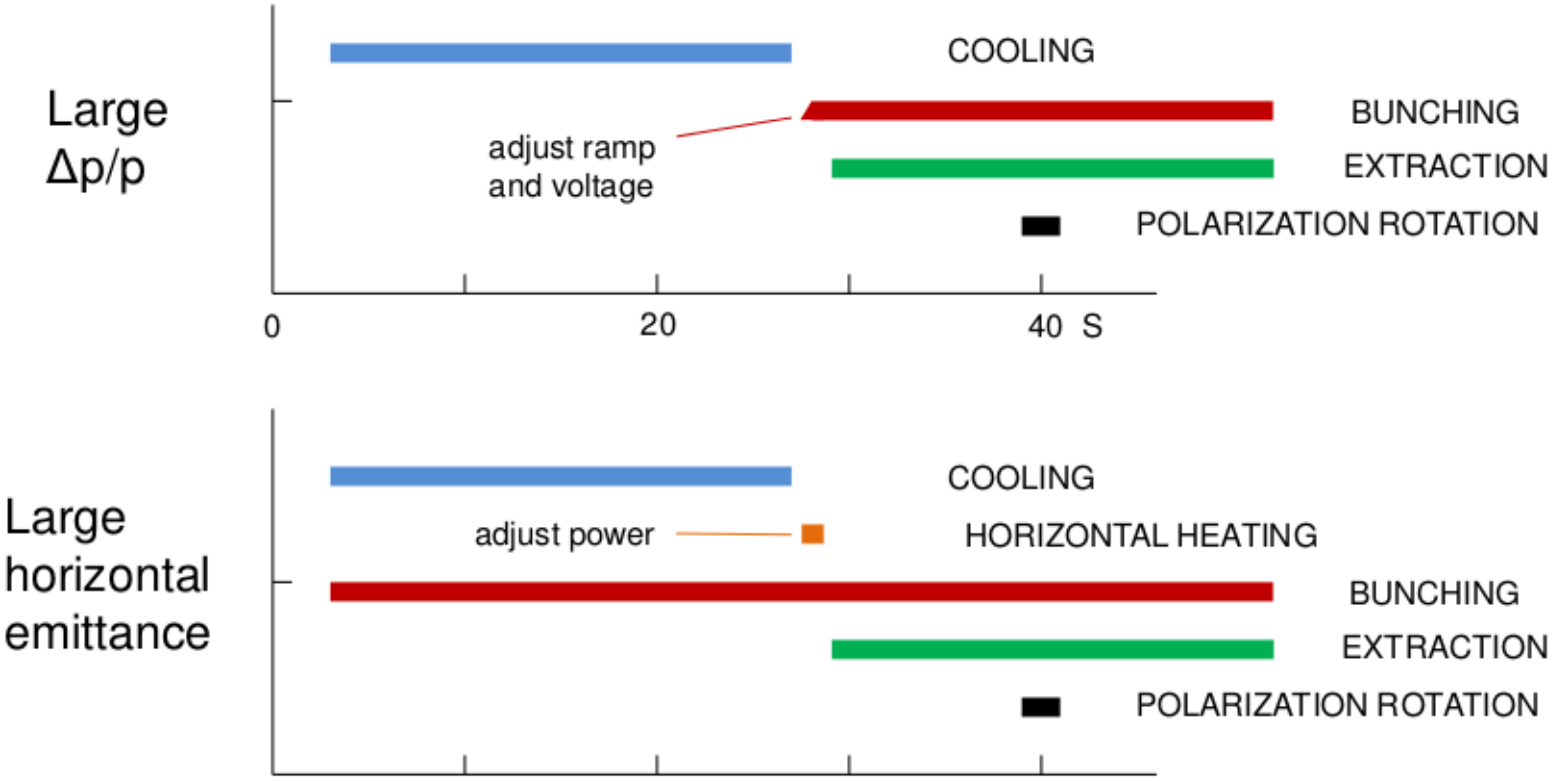
1) EXPERIMENTAL SETUP Bunched beam (h=1)

Polarized DEUTERON beam with p=0.97 GeV/c

Horizontal polarization with RF solenoid

Beam preparation

Because of limited vertical acceptance in the arcs, **vertical emittance was not available for study**



Spin Coherence Time Studies

1) EXPERIMENTAL SETUP

Beam extractions

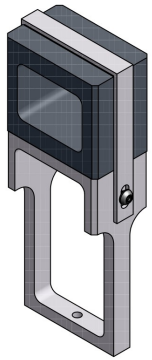
- local bump

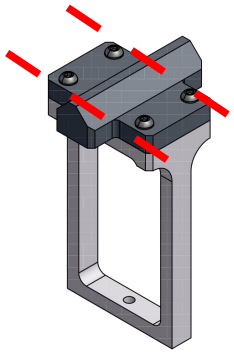
- white noise (vertical direction)

beam

Carbon targets

TUBE target

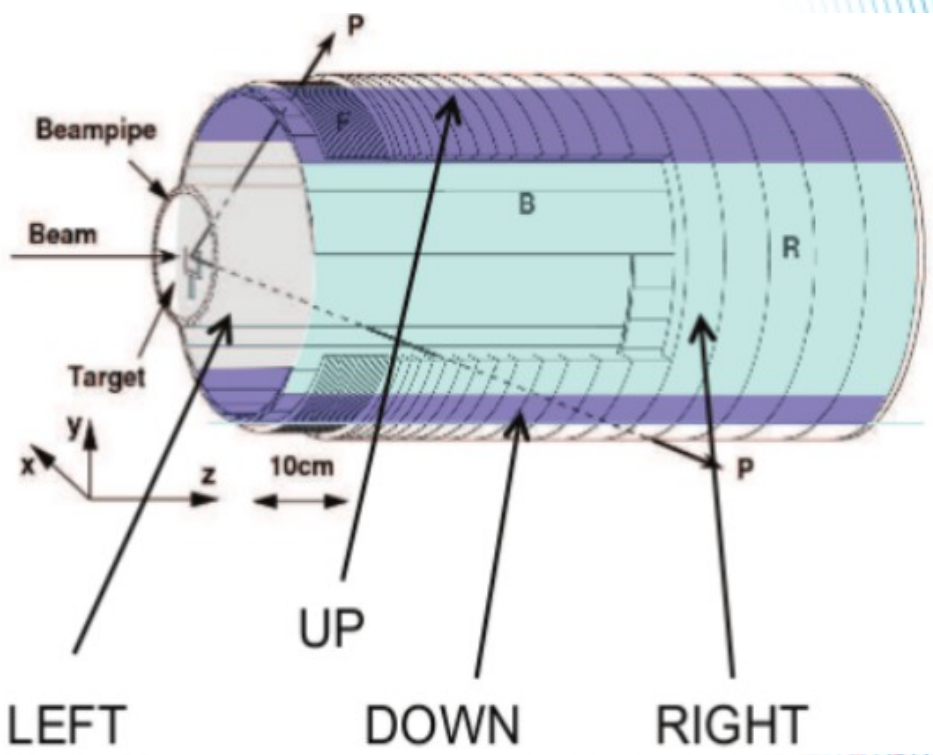




RIDGE target
Shaped to match tube target thickness

Polarimeter: EDDA

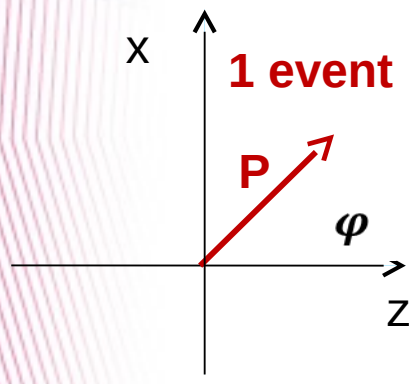
- Continuous extraction of the beam
- Asymmetries L/R ⟶ $\mathbf{p_v}$ and U/D ⟶ $\mathbf{p_h}$



Spin Coherence Time Studies

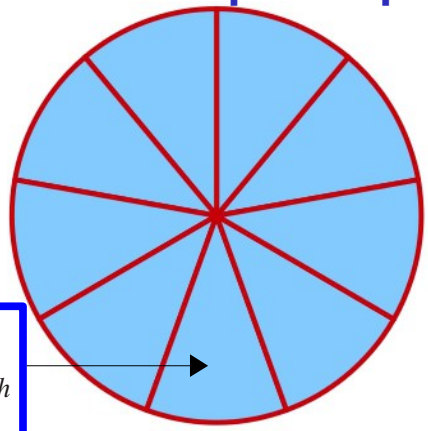
2) DATA ACQUISITION SYSTEM

Synchronized with the cyclotron frequency ⟶ TURN NUMBER



Horizontal plane

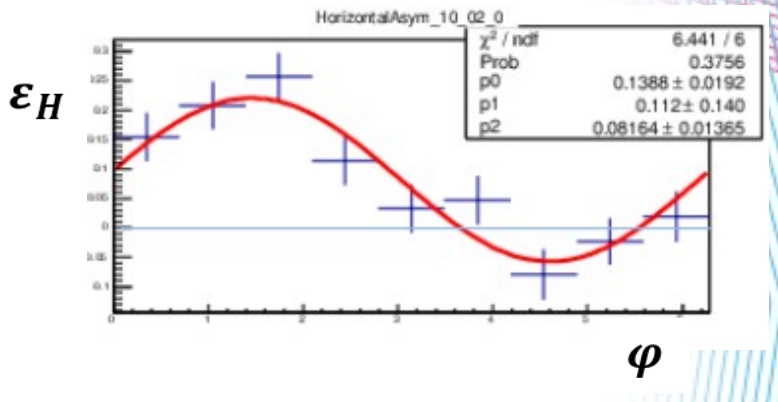
Precession phase pie



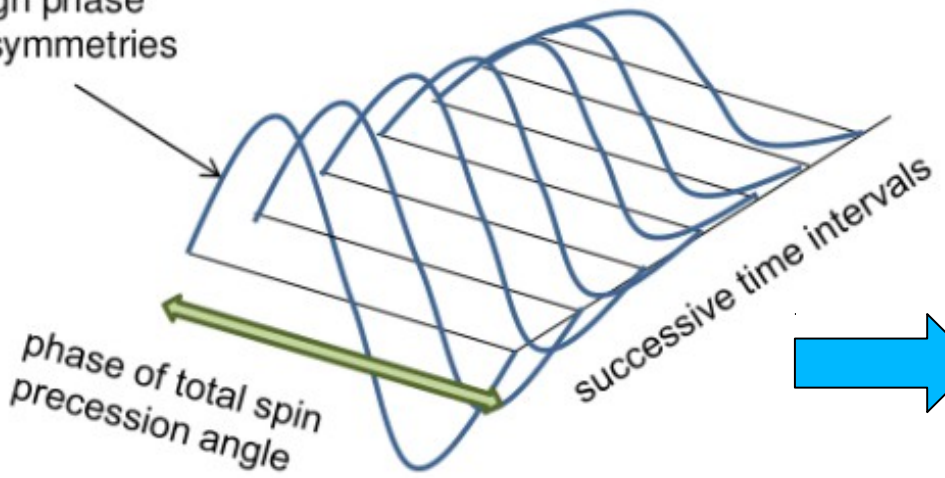
$$\epsilon = \frac{U - D}{U + D} \propto p_h$$

Filled for 1 s

to accumulate statistics

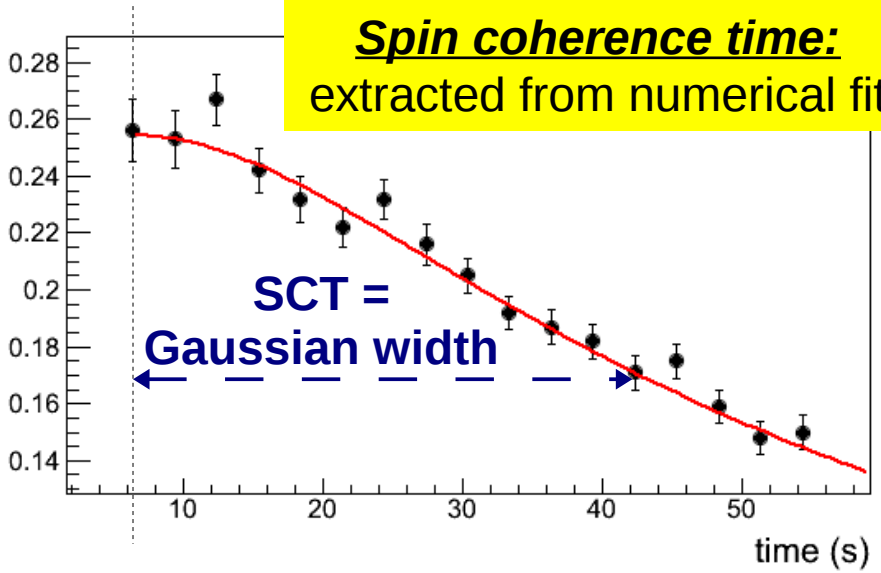


smooth curves through phase bin asymmetries



Amplitude vs time

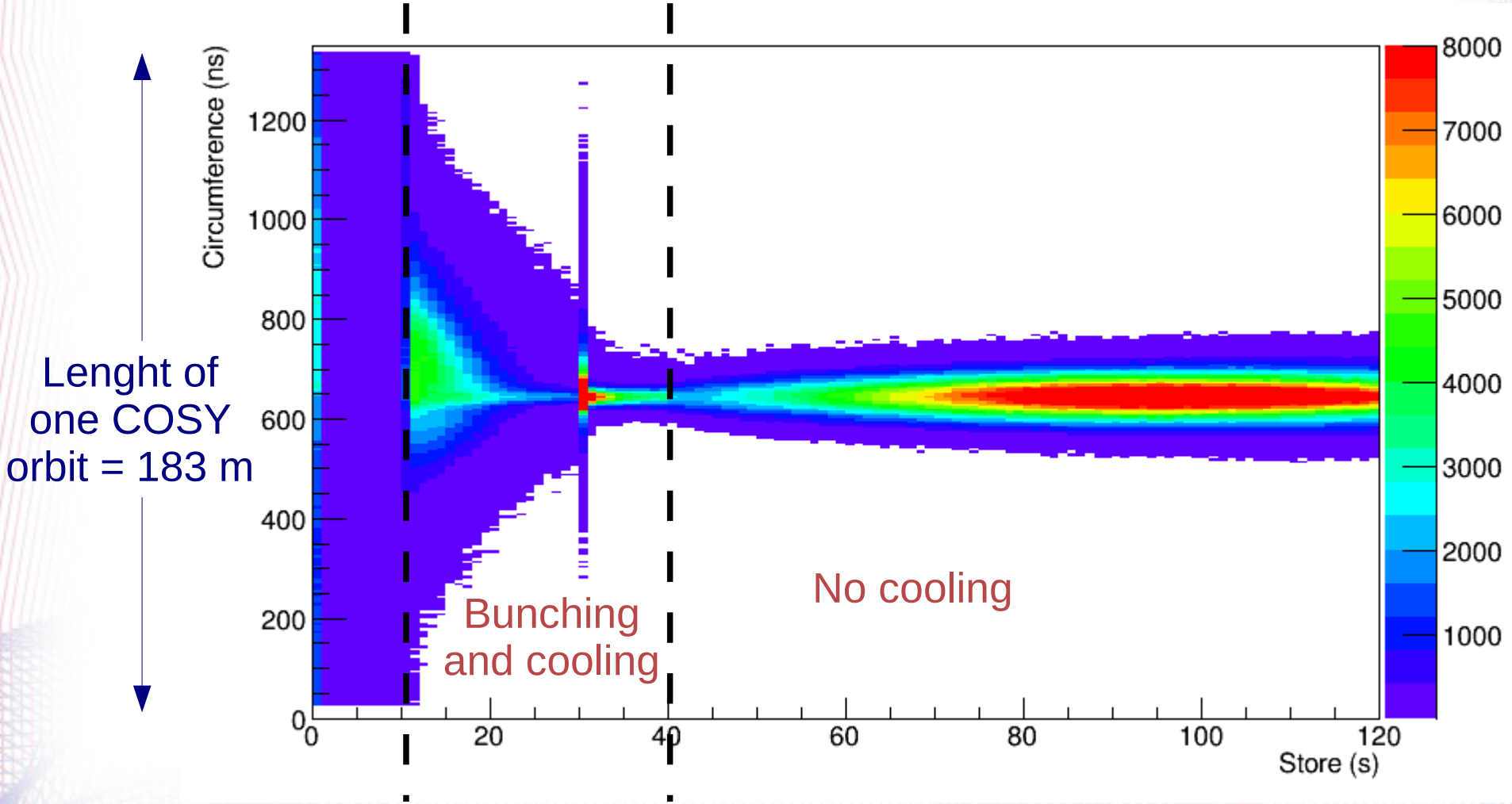
Spin coherence time:
extracted from numerical fit



Spin Coherence Time Studies

3) LONGITUDINAL profile measurements

DAQ provides particle positions in the ring as a function of the storage time



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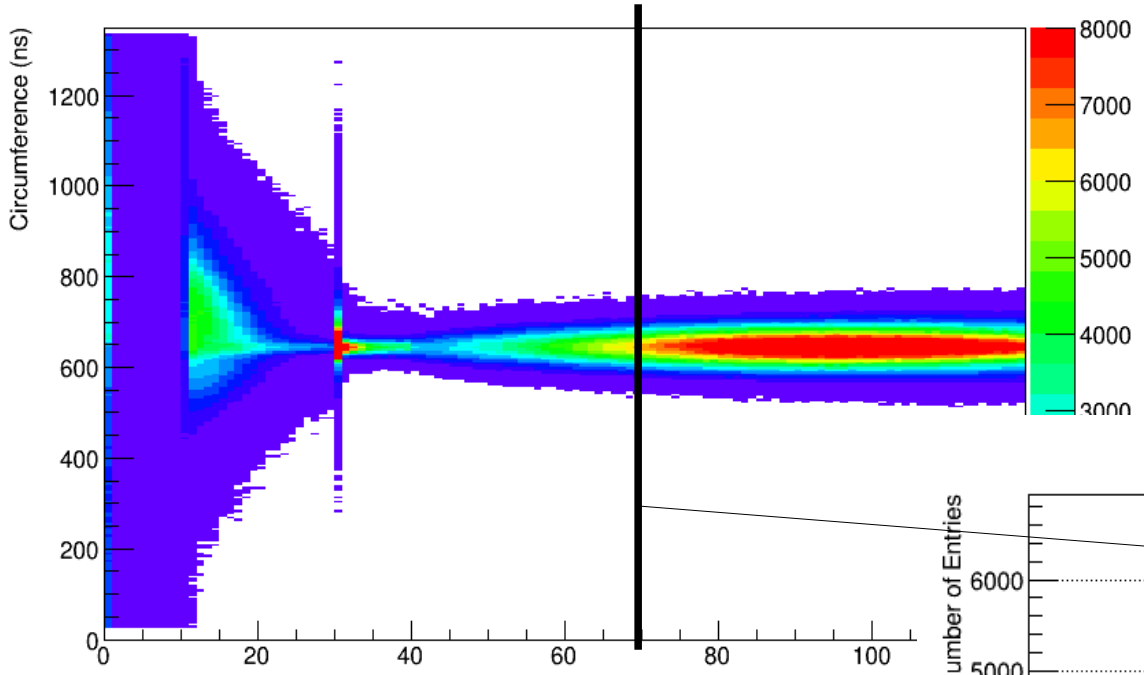
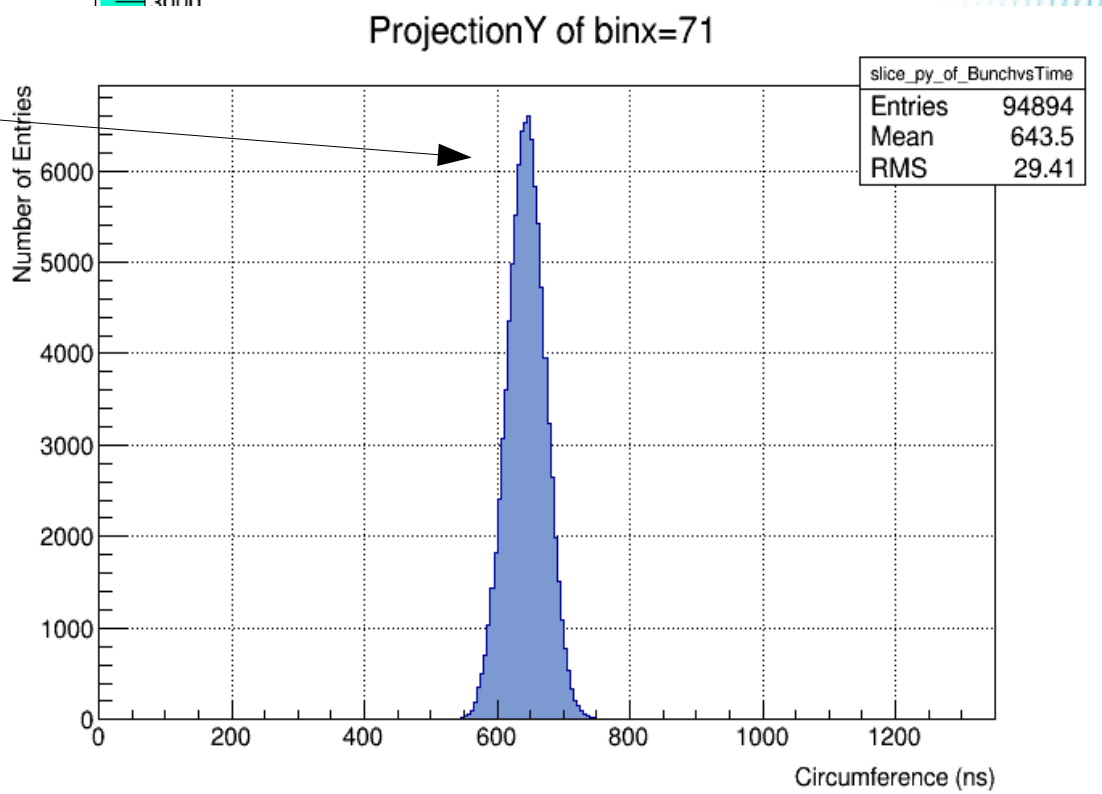




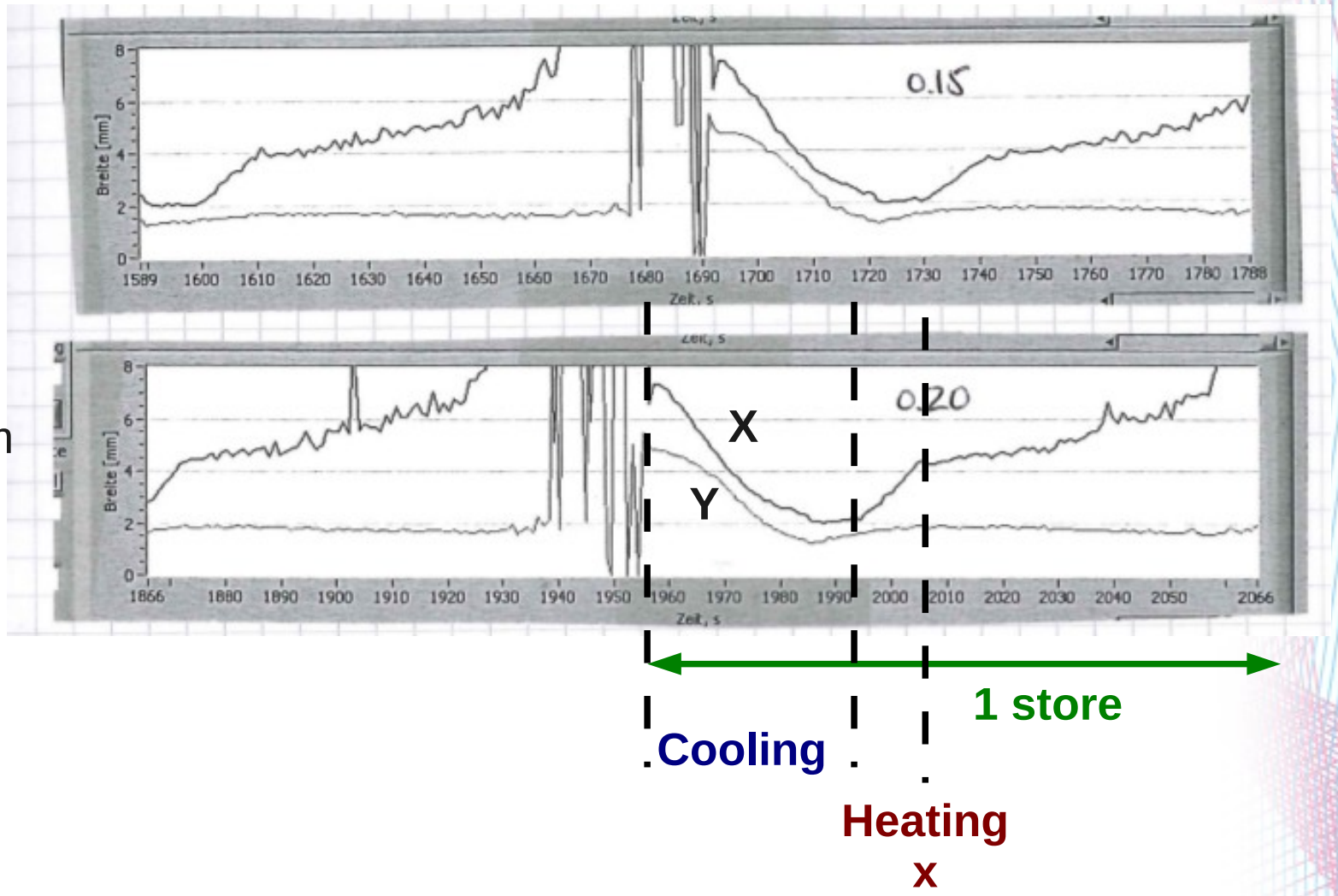
Particle distribution in the bunch at one time of the storage

Useful to **extract the synchrotron amplitude distribution**

Spin Coherence Time Studies

4) EMITTANCE profile measurements

Gaussian beam witdth (mm)



NEW (2013): analysis improved to a double Gaussian fit to correct for beam tails produced by cooling

Spin Coherence Time Studies

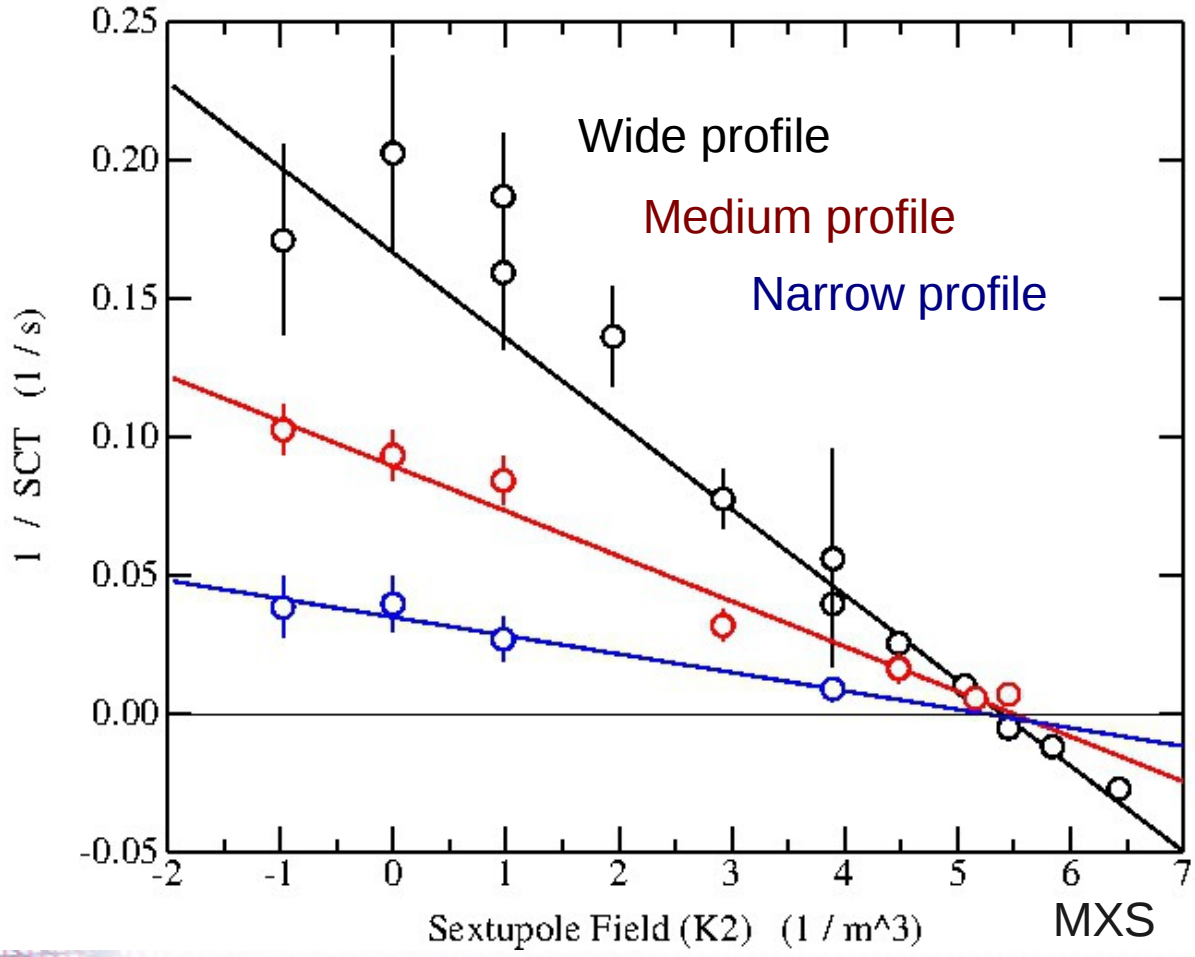
Run Summaries

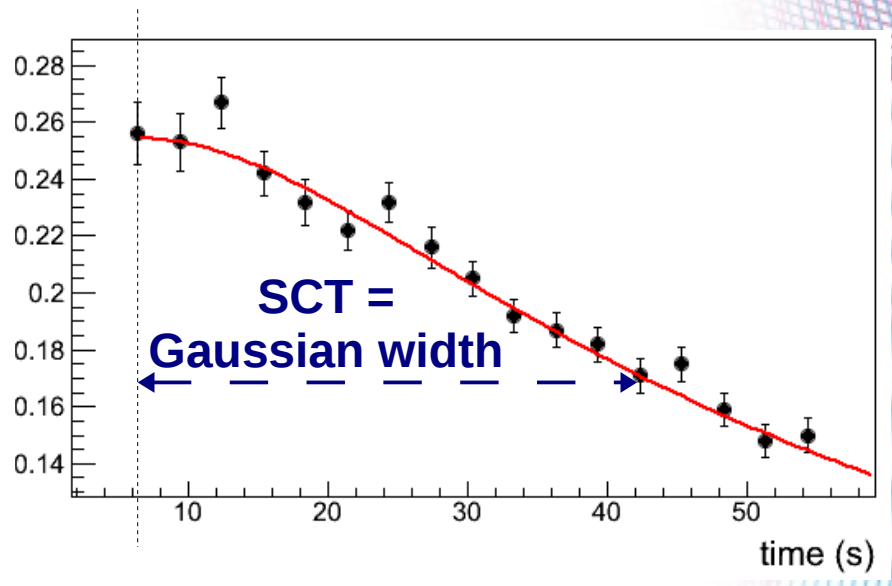
	May 2012	Feb 2013	Aug 13
BCT	6*10^8	2*10^9	1*10^9
Target	Tube	Tube	Ridge
Extraction	Ramped	Ramped	White noise/Ramped
Large Hor. Emittance	Yes	Yes	Yes
Large DeltaP/P	No	No	Yes
Aim	Correction of emittance effect on SCT with sextupole (MXS)	Correction of emittance effect + chromaticity measurements	Correction of emittance effect and 2nd order DeltaP/P effects with sextupoles. (2-D map MXS-MXG)
Comments	Proved!	50 Hz=Rate effect	Wonderful set of data

Results: May 2012

Sextupole field corrections for horizontal emittance effects

Spin Coherence Time =**SCT** extracted from TEMPLATE BASED ANALYSIS





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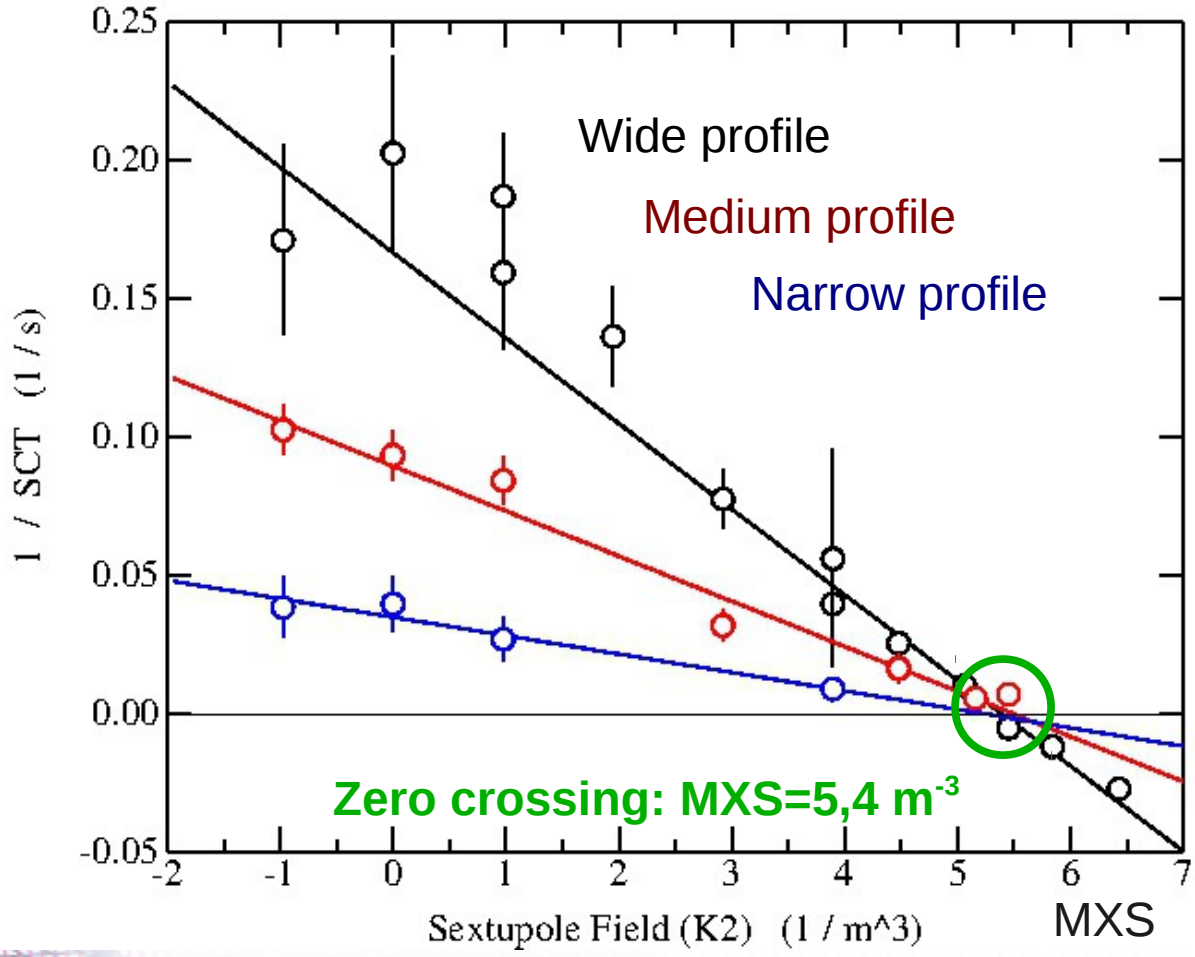


$$\frac{1}{SCT} = |A + a_1 K_2| \sigma_x^2$$

Sextupole field — Beam profile width

Various horizontal profiles σ_x

- Flip **SCT** sign above zero crossing
- Different slopes
- **SCT** does not go to infinity.

  Point near zero may be above or below the line due to other contributions.

- The **same zero crossing**, independent of heating width

Sextupole fields can be used to increase SCT

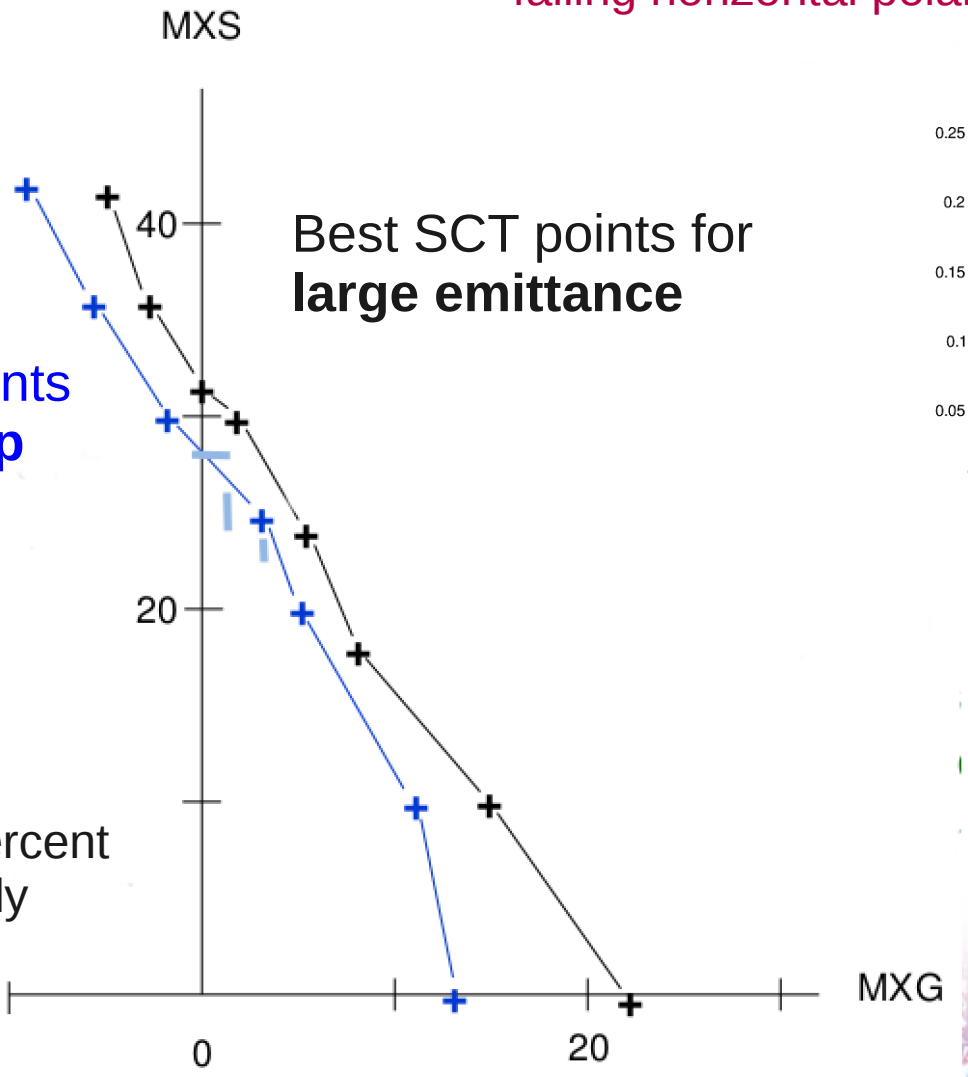
Results: Aug 2013

2D map of sextupole field corrections

MXS: 6-poles where β_x is large

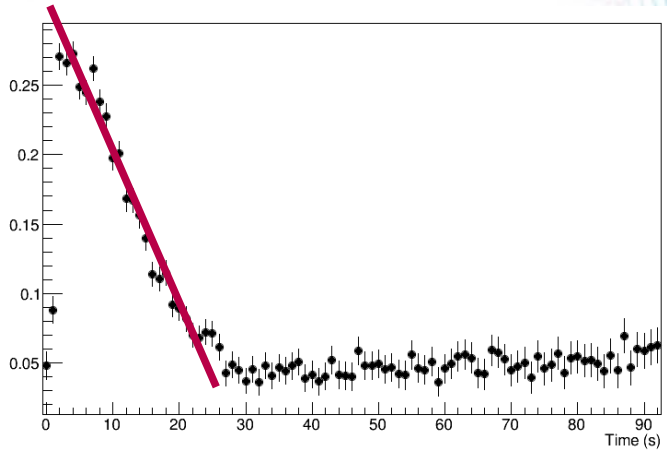
MXG: 6-poles where D is large

Spin Coherence Time = **SCT** extracted from INITIAL SLOPE of the falling horizontal polarization



Best SCT points for **large emittance**

Best SCT points for **large Δp/p**



Units are in percent of power supply full scale.

Results: Aug 2013

2D map of sextupole field corrections

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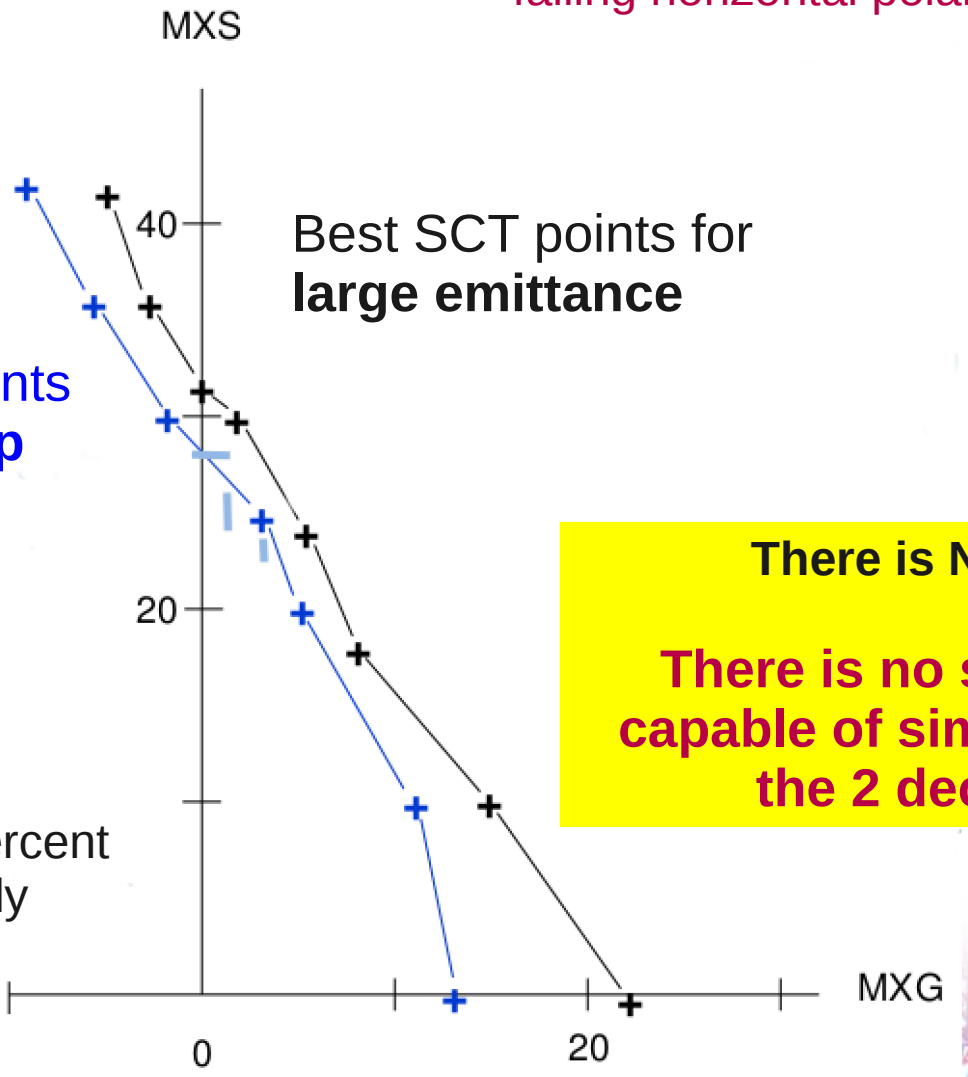


Best SCT points for **large emittance**

Each point represents the results of a scan across the locus.

Best SCT points for **large Δp/p**

Units are in percent of power supply full scale.

There is NO CROSSING POINT

There is no sextupole combination capable of simultaneous correction of the 2 decoherence sources

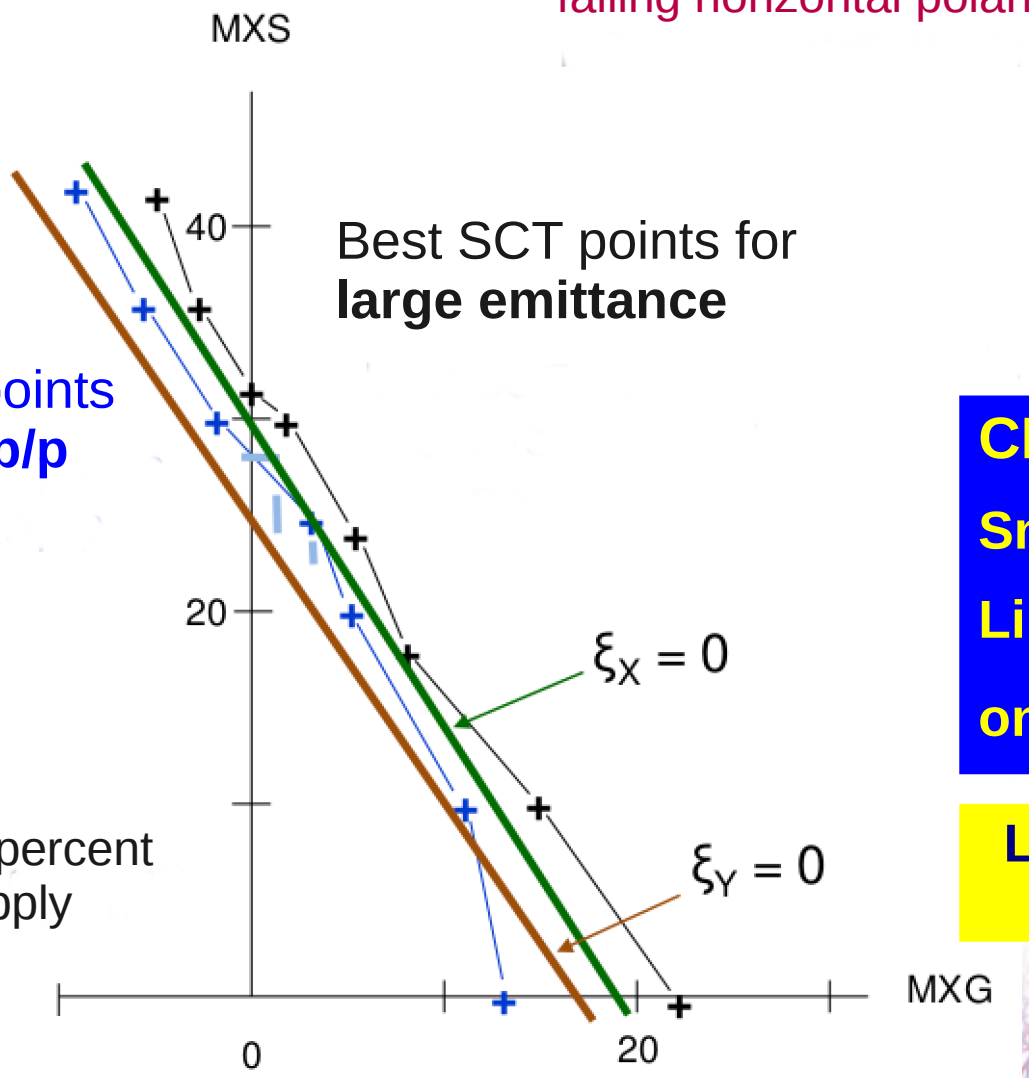
Results: Aug 2013

2D map of sextupole field corrections

MXS: 6-poles where β_x is large

MXG: 6-poles where D is large

Spin Coherence Time = **SCT** extracted from INITIAL SLOPE of the falling horizontal polariztion



Best SCT points for **large emittance**

Best SCT points for **large Δp/p**

Each point represents the results of a scan across the locus.

CHROMATICITY

Smooth plane

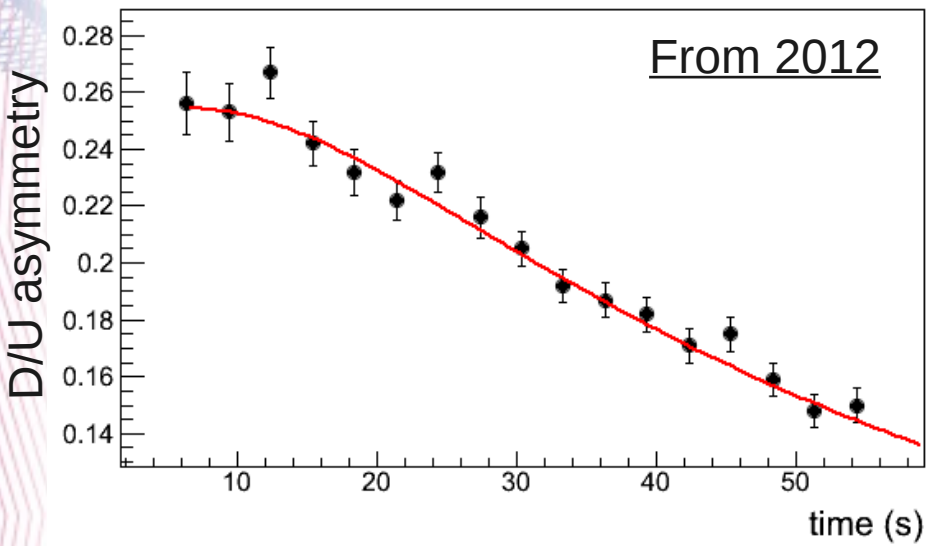
Lines show when ξ = 0

on this side $\xi_x > 0$, $\xi_Y < 0$

Units are in percent of power supply full scale.

Large SCT and **ξ = 0** are close to each other

Ago 2013: new issues



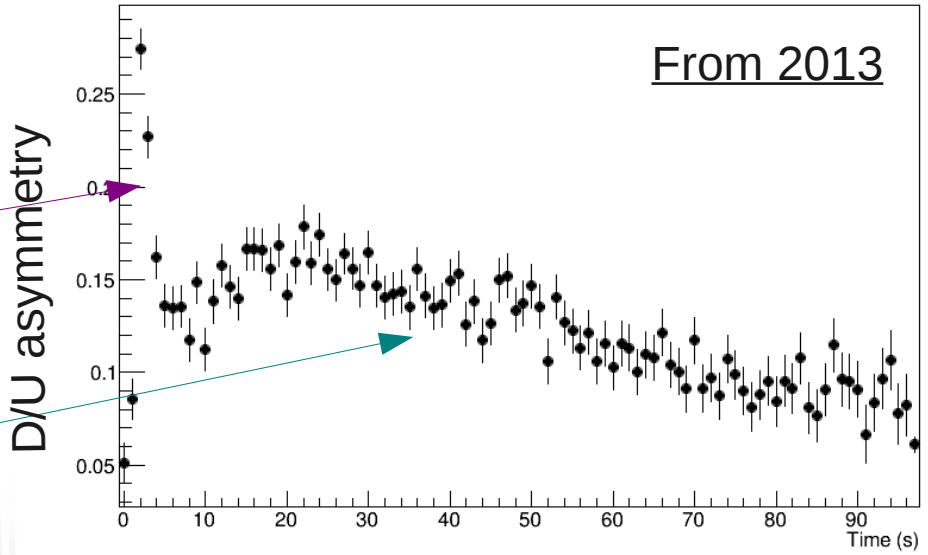
Wide horizontal profile

- **Balck dots**=data points
- **Red line**=template function based on **Gaussian spin distribution**

Wide horizontal profile
double slope

Early slope
Depends on:
Heating, tunes,
sextupole settings.

Late Slope
featureless



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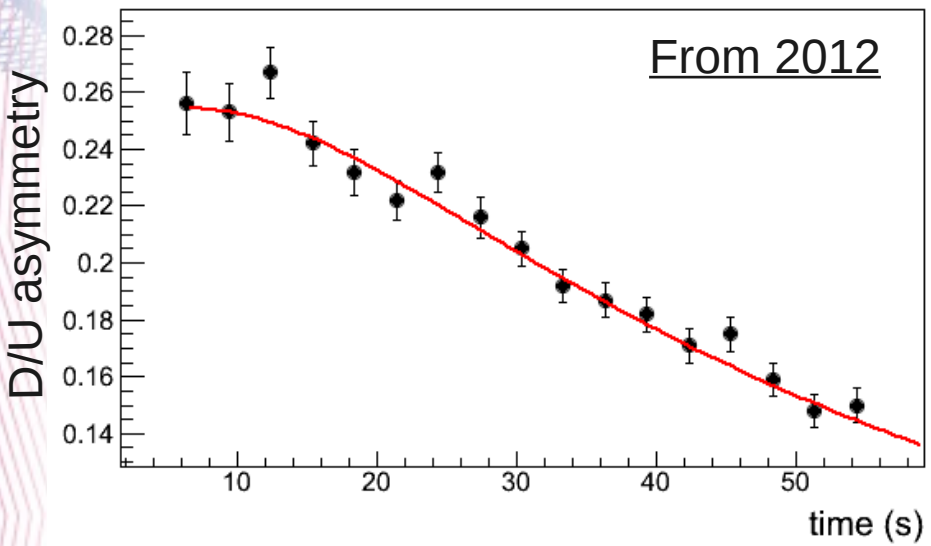

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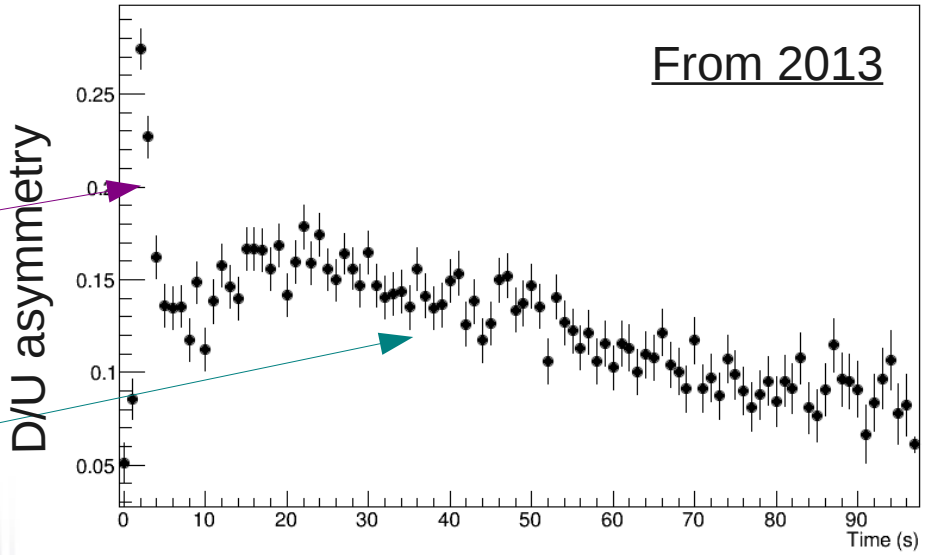
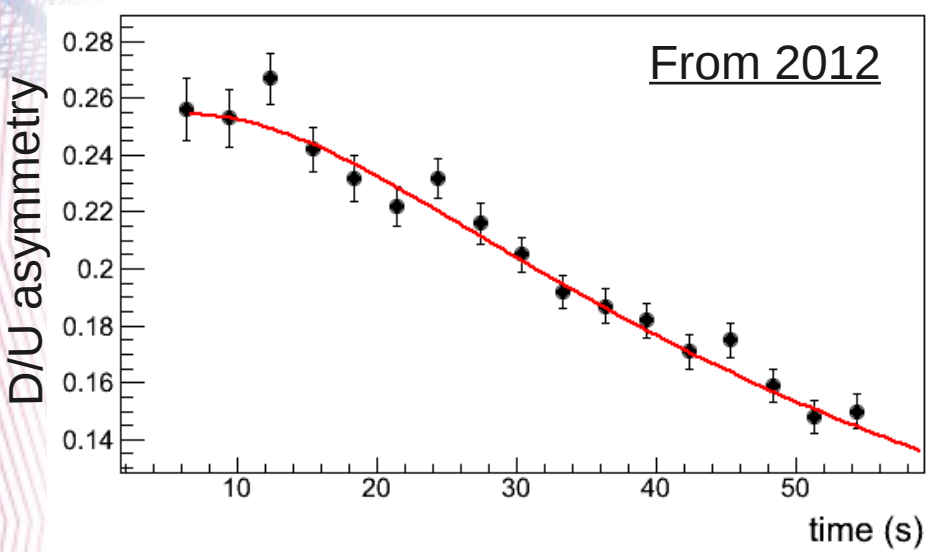


Ago 2013: new issues



Wide horizontal profile

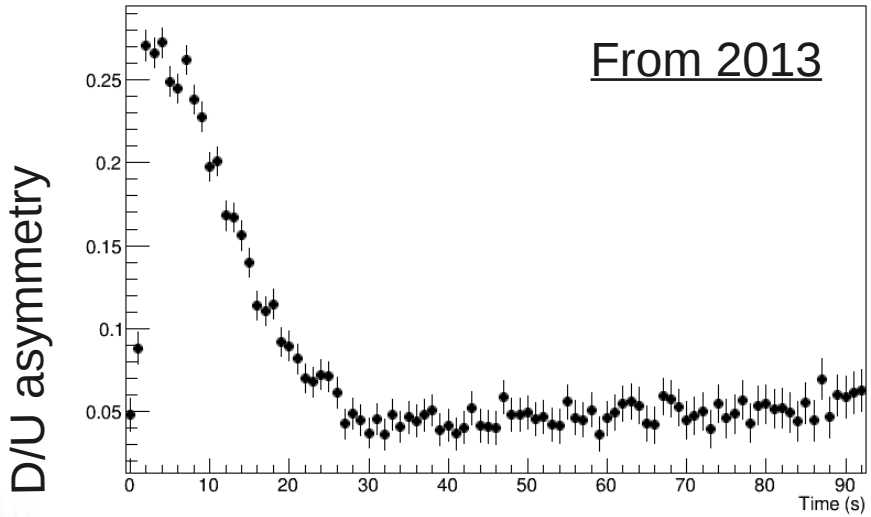
- **Balck dots**=data points
- **Red line**=template function based on **Gaussian spin distribution**

Wide Δp/p distribution

We probably need **new template curves**

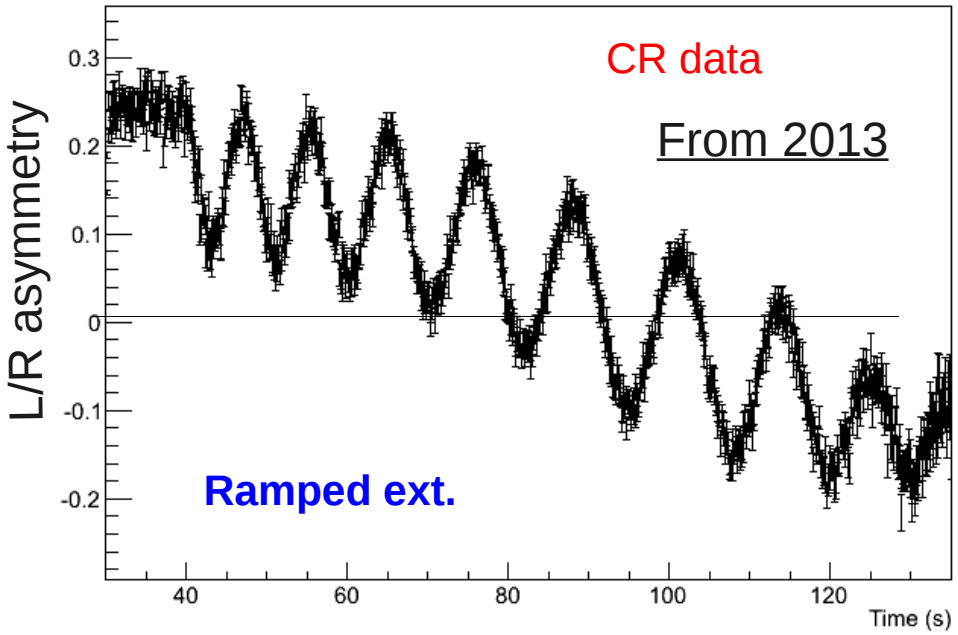
- the **distribution of synchrotron amplitudes is not gaussian**

- synchrotron oscillations are not simple harmonic solution (sinusoidal potential)



Ago 2013: new issues

Wide Δp/p distribution

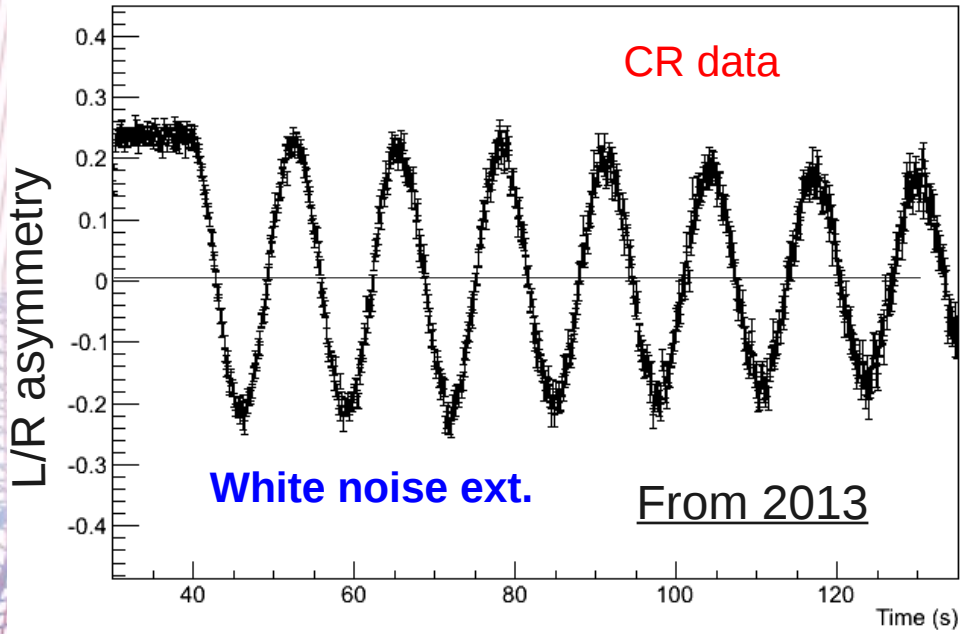


Extraction method:
Ramping changes the spin tunes

↓

small Froissart-Stora scan that flips the polarization

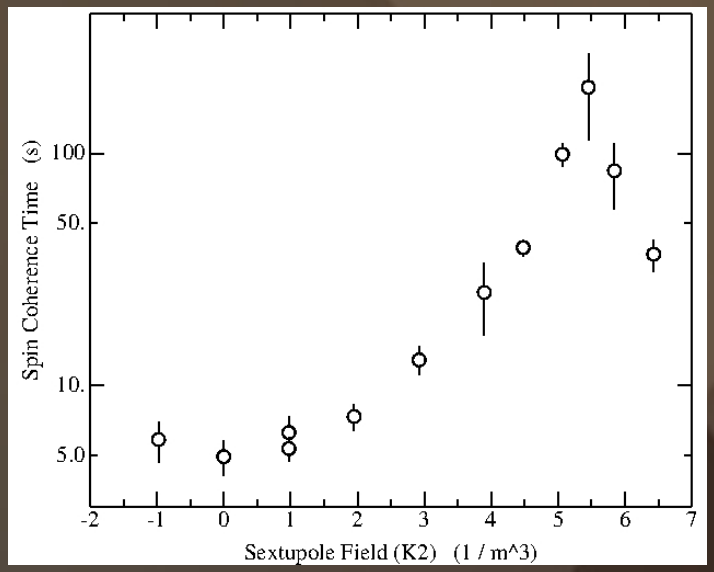
Wide Δp/p distribution



It may be possible to reproduce the data with “no-lattice” model.

Conclusions

HUGE SET OF DATA to analyze!!



Sextupole fields are powerful tools with which to extend the lifetime of in-ring-plane polarization.

Because of correlations between the different sources of decoherence, it was not possible to find sextupole settings that even in combination minimize more than one source of decoherence

Sextupole fields must be used in combination with beam preparation that reduces the decoherence source terms in order to achieve the polarization lifetime goals of the EDM storage ring

Serious theoretical effort is needed to understand the connections between difference sources of decoherence.

THANKS TO ALL WHO HELPED:

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Thanks for your attention!