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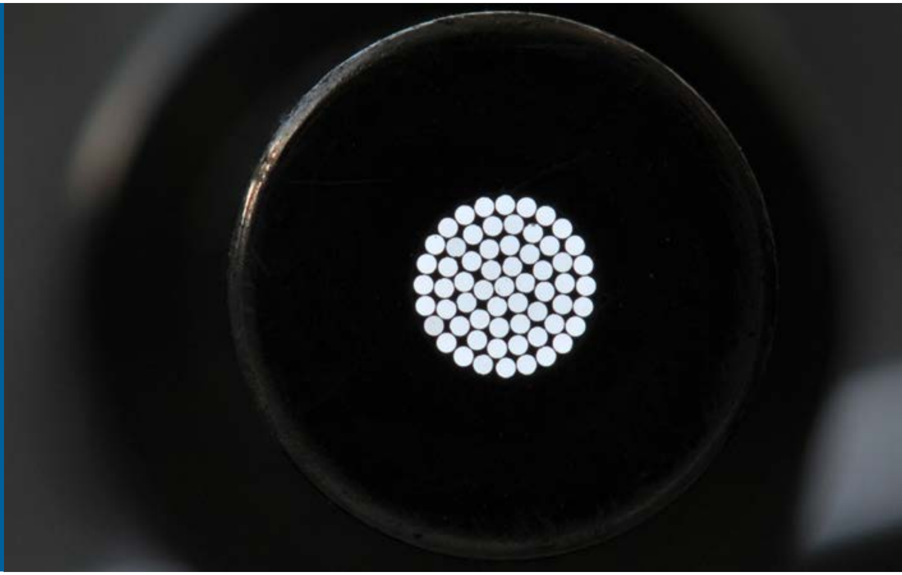
OPERATIONAL EXPERIENCE WITH FAST FIBER-OPTIC BEAM LOSS MONITORS FOR THE ADVANCED PHOTON SOURCE STORAGE RING SUPERCONDUCTING UNDULATORS



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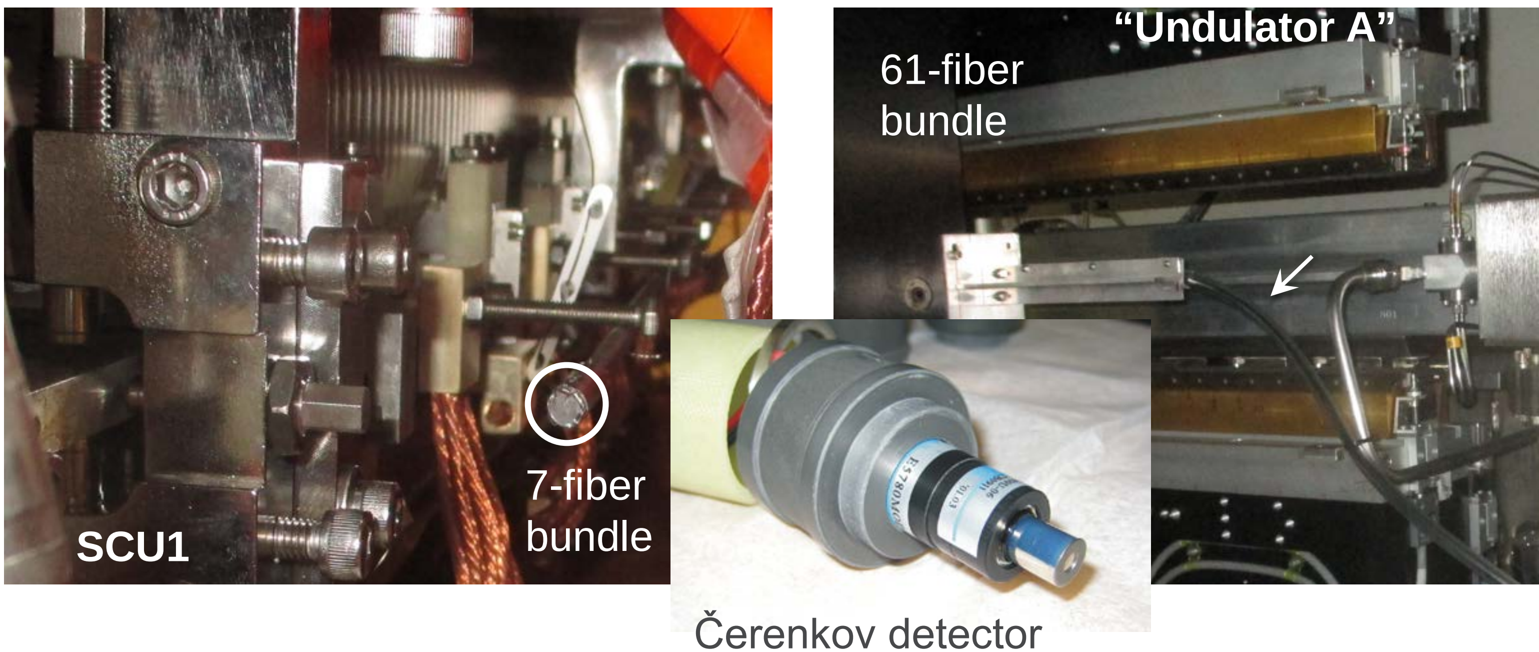
OUTLINE

- Introduction—Fast Beam Loss Monitors—why they're useful, geometry
- Analysis
- Calibration
- Abort kicker tuning to protect the superconducting undulators (SCUs)
- Diagnostic—Early losses and injection losses
- Summary

INTRODUCTION

High-purity fused silica radiators provide fast beam loss fast data, are radiation hard, and insensitive to x-rays

- Fused silica radiators can come in various geometrical forms—we use minimum surface-to-volume cylinders and fiber bundles, 2-4 m in length
- Fast electrons generate light in the radiator volume (Čerenkov) and surface (optical transition radiation, OTR).



ANALYSIS

Cerenkov power proportional to the integrated electron (or positron) track length in the radiator; OTR power depends in a more complicated manner on surface and surface roughness. Both depend on incident angle

- Cerenkov—energy and photon number per unit length and frequency

$$\frac{d^2E_{CR}}{dxd\omega} = \frac{e^2\mu(\omega)}{4\pi}\omega\left[1-\frac{1}{\beta^2n^2(\omega)}\right]$$

$$d^2N_{CR} = \frac{d^2E_{CR}}{\hbar\omega} = \frac{\mu(\omega)e^2}{4\pi\hbar}\left(1-\frac{1}{\beta^2n^2}\right)d\omega dx$$

constant no. of photons per unit freq. —light is blue

- OTR—energy per frequency and solid angle

$$\frac{d^2W_O}{d\omega d\Omega} = \frac{e^2}{16\pi^3\epsilon_o c}\frac{\beta^2 sin^2\theta}{(1-\beta cos\theta)^2}$$

$$\frac{dW_O}{d\omega} = \frac{e^2}{16\pi^3\epsilon_o c}\int_0^{2\pi}d\phi\int_0^{\pi/2}d\theta\frac{sin^3\theta}{(1-\beta cos\theta)^2} \approx \frac{e^2}{8\pi^2\epsilon_o c}\left[\ln\left(4\gamma^4\right)-3\right]$$

$$N_O = \frac{W_O}{\hbar\omega_{av}} = \frac{e^2}{8\pi^2\epsilon_o c}\left[\ln\left(4\gamma^4\right)-3\right]\frac{2}{\hbar}\frac{\omega_2-\omega_1}{\omega_2+\omega_1}$$

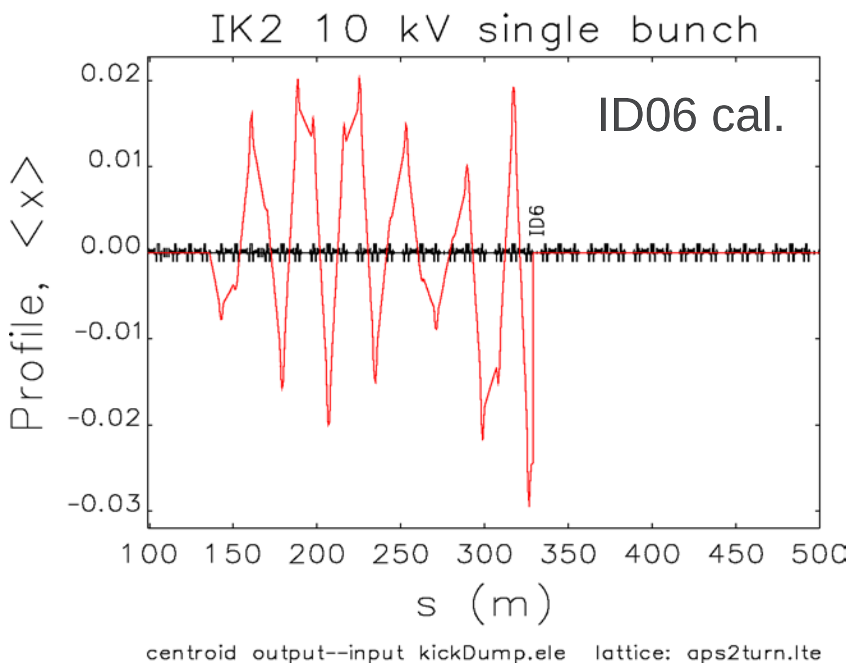
photons per unit freq. ~ 1/ω—light is white

OTR: complex geometry and energy dependence in FO

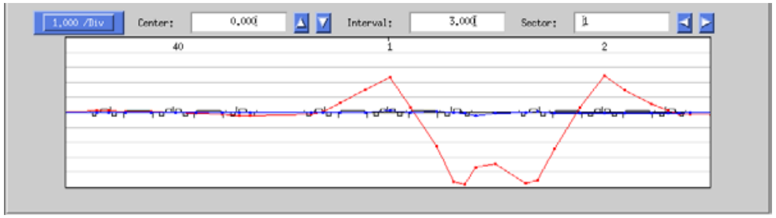
CALIBRATION

Single-bunch, single-turn loss in location of interest (ID01 or ID06)

- Employed ELEGANT modeling to set kicker strength
- Vary storage-ring charge

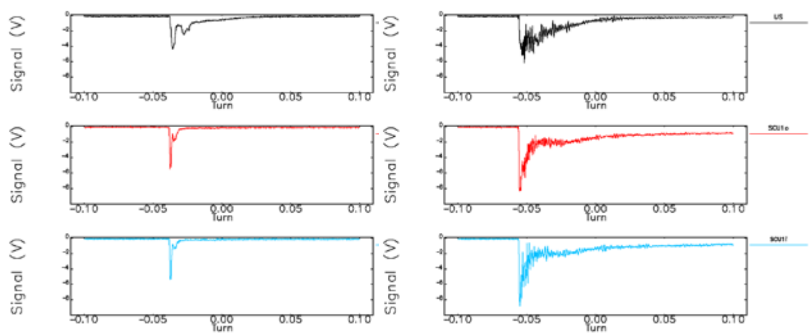


For ID01 calibration, needed to set up a -4 mm horizontal bump



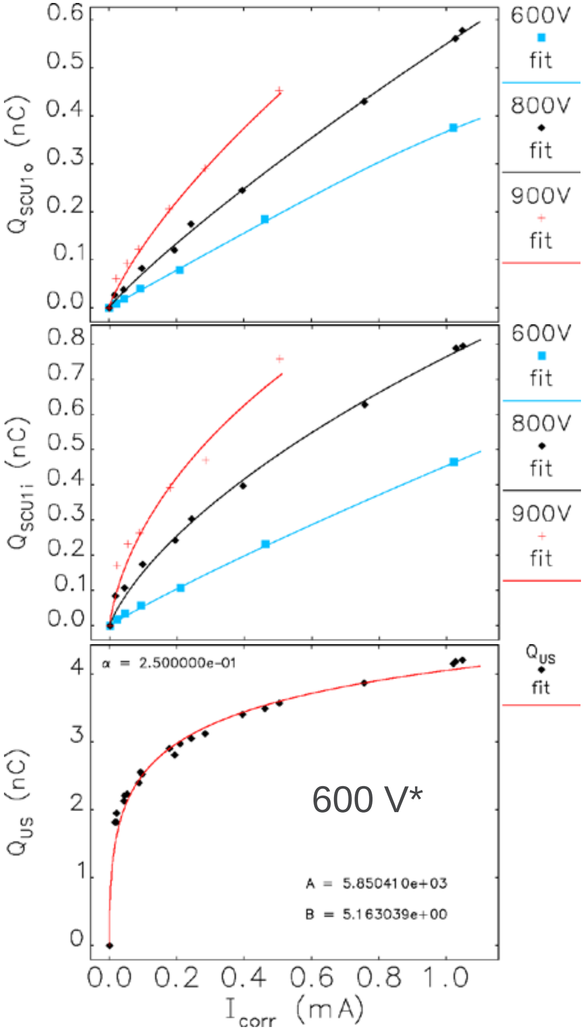
0.02 mA= 74 pC

1.07 mA=3.94 nC



CALIBRATION—DATA & SATURATION MODEL

ID01 data



* All bias voltages are negative

$$Q_o(I) = \frac{AI}{(1 + BI^{\alpha})^{1/\alpha}}$$

When 1/α is an integer, the equation can be recast as a polynomial of order 1/α. Let $u=BI^{\alpha}$. Limit the range of α to 0.25-4.0

Detector	Bias (V)	A (nC/mA)	B ($mA^{-\alpha}$)	α
SCU1i	-600 V	0.7073	0.1171	0.25
	-800 V	4.6707	0.5722	0.25
	-900 V	17.244	1.0332	0.25
SCU1o	-600 V	0.3886	0.2613	4.0
	-800 V	1.0185	0.1668	0.25
	-900 V	2.9575	0.4199	0.25
US	-600 V	5850	5.163	0.25

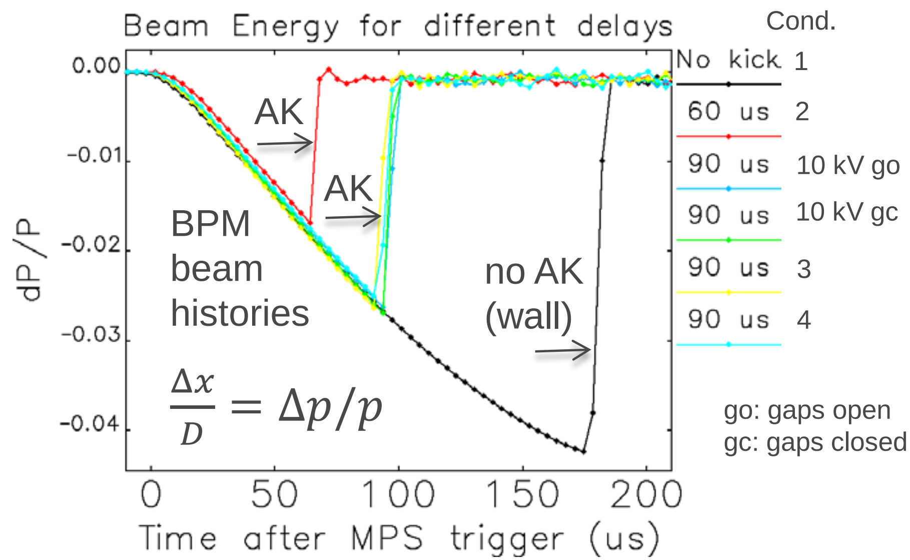
Model allows for effective improvement in dynamic range (presently 8 bit)

ABORT KICKER (AK)

Fast loss monitors verified timing and amplitude adjustments

- Use the Machine Protection System (MPS) to trigger the AK
- The AK significantly reduced losses in ID06 but not in ID01
- AK-deflected-beam hit photon absorber (PA) that showered into ID01
- Found that by delaying the AK, beam would spiral inboard sufficiently to avoid the PA

See K. Harkay et al., WEPOB05



100 mA, 24-bunch fill pattern

	Conditions	ID01: Q_{US} (nC)	Q_o (nC)	Q_i (nC)	ID06: Q_{ave} (nC)
1	MPS only, 0 kV	0.16	12.79	10.13	0.29
2	10 kV, 60 μs	0.021	0.36	0.29	0.060
3	10 kV, 90 μs, SCUs energized	0.0016	0.041	0.047	0.0028
4	8 kV, 90 μs	0.074	0.61	0.51	0.054

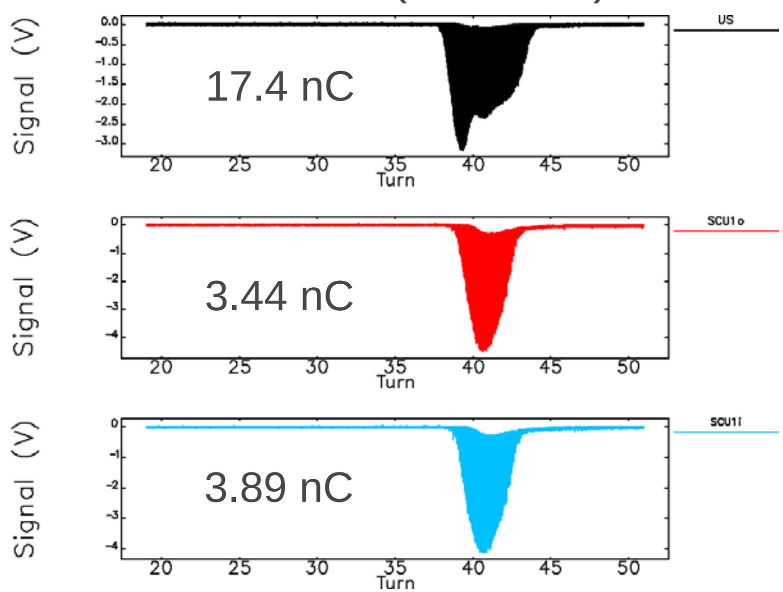
AK amplitude of 10 kV and delay of 90 µs worked to protect ID01 SCU

FAST FO BLM OBSERVATIONS IN ID01

With and without the abort kicker (AK), 24-bunch fill pattern

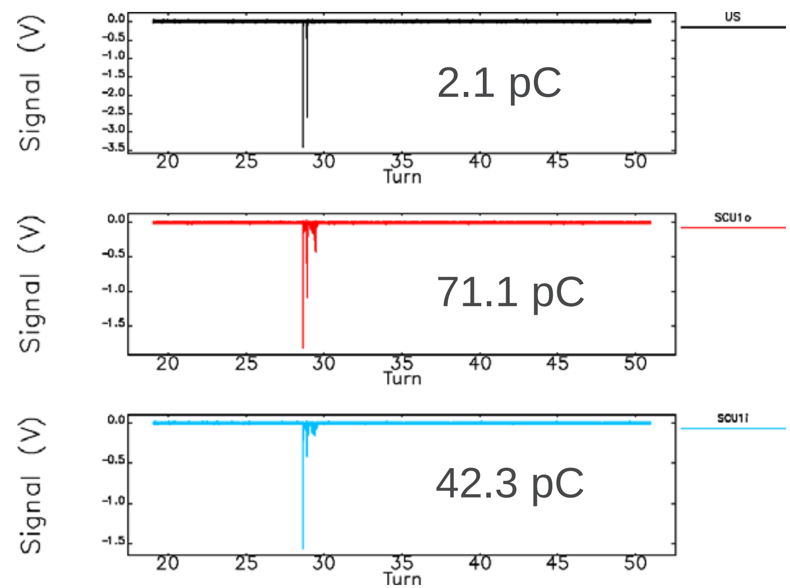
- A Turn represents one period around the SR (3.6825 μs).
- Turn=0 is the moment when the MPS is triggered.
- A delay of 90 μs is 24.4 Turns

without AK (10/08/15)



SCU1 quenched

with AK (02/04/16)

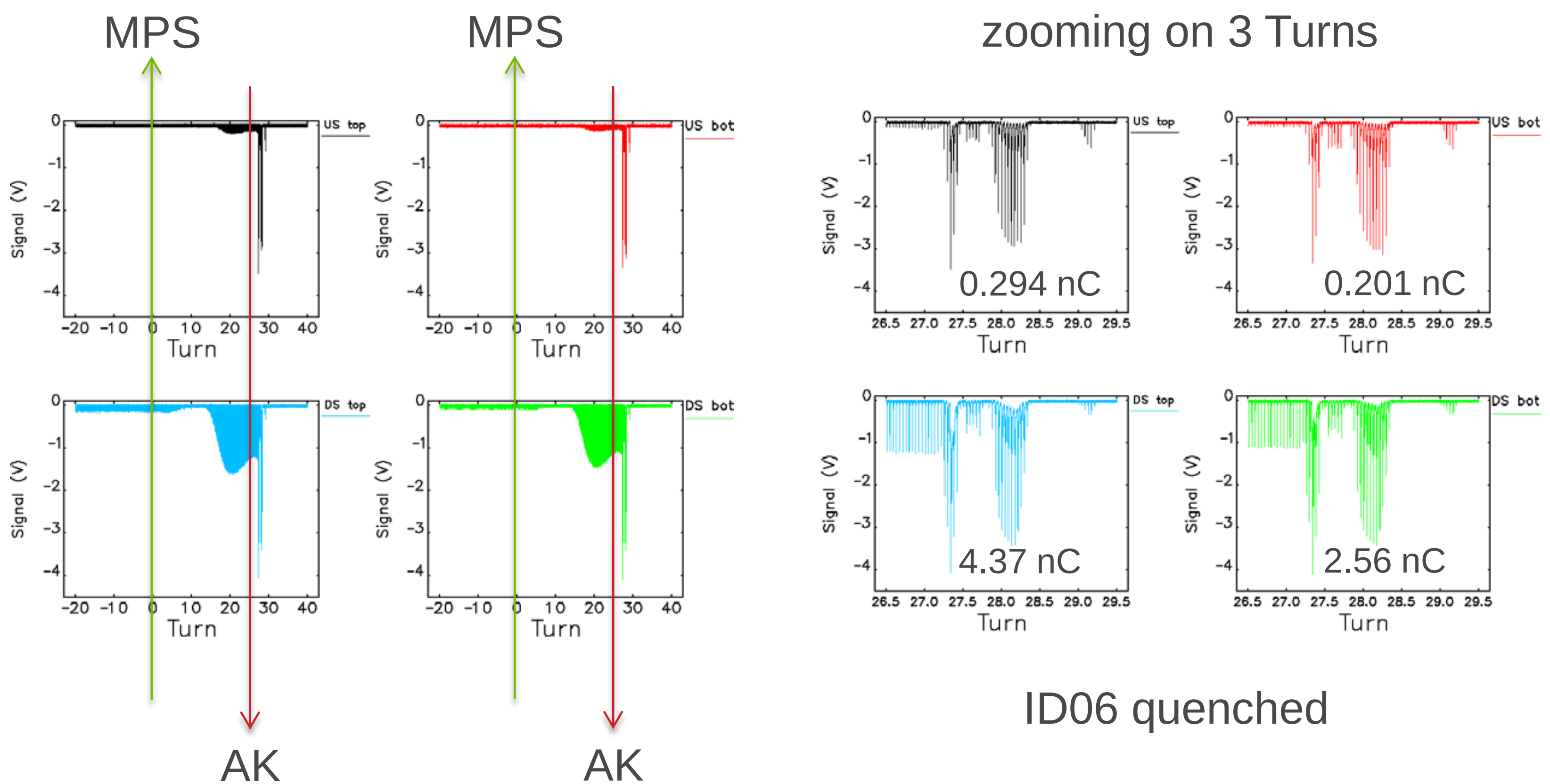


SCU1 did not quench

EARLY LOSSES

Personnel Safety System (PSS) initiates beam dumps by switching off the SR main dipole supply.

- Can lead to early losses to which the MPS does not respond or responds too late
- 03/31/16, ID06

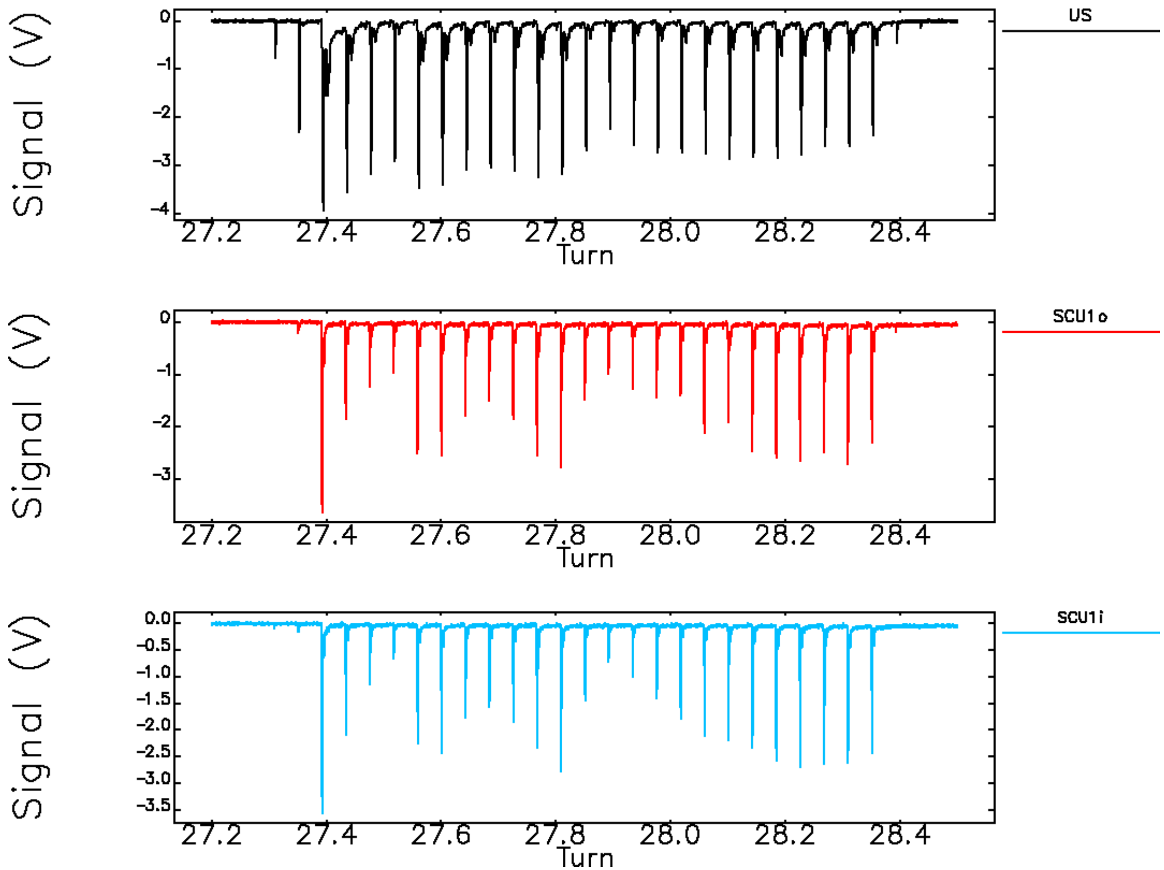


Argonne NATIONAL LABORATORY

EARLY LOSSES

Same beam loss event in ID1, 03/31/16

- ID1 quenched
- Beam loss not present until AFTER the AK fires



Qcal

0.055 nC

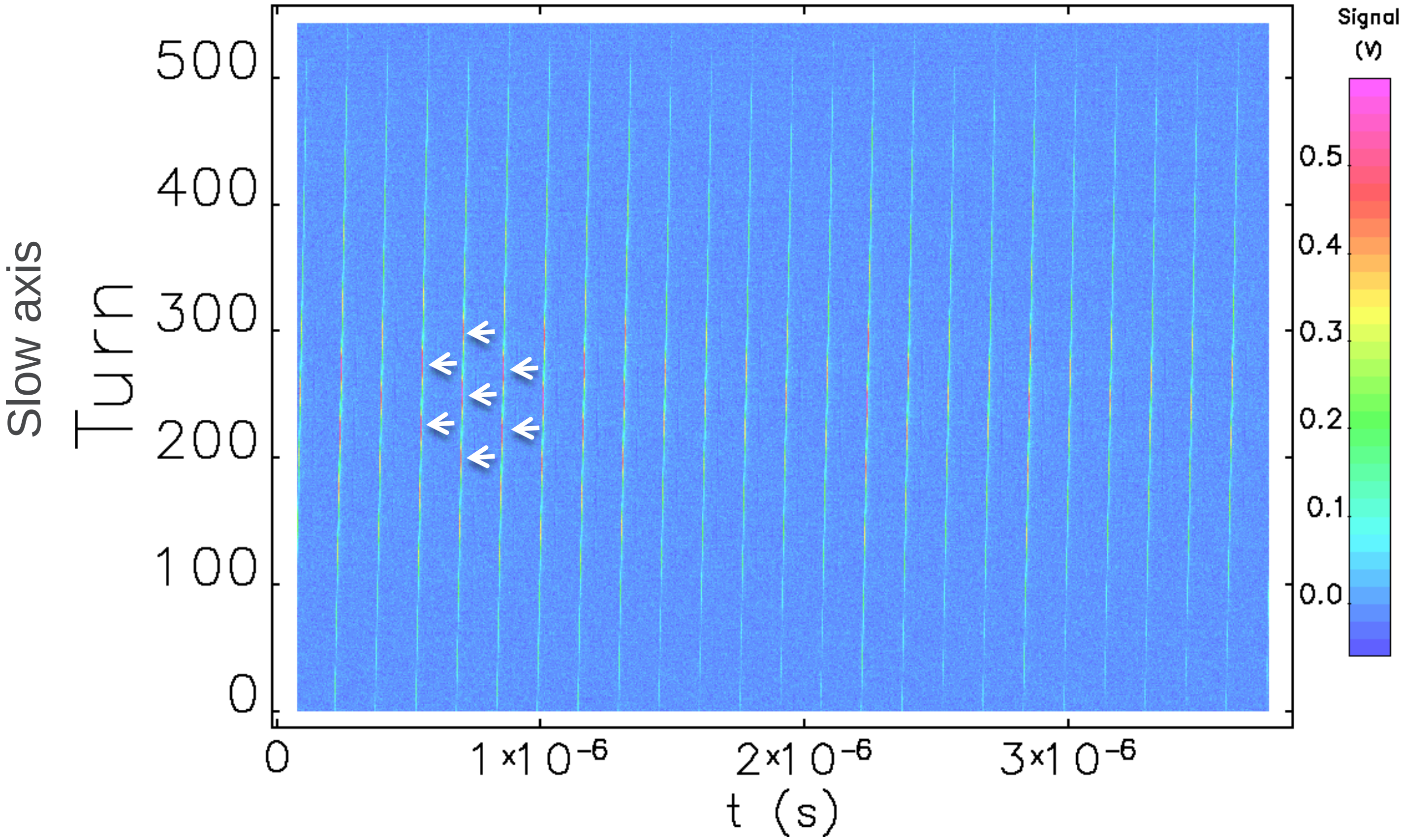
1.50 nC

1.21 nc

STUDIES TO RECREATE EARLY BEAM LOSS

Early loss with MPS triggering

- Nominal SR main dipole current: 447.8 A, ΔI=-2A
- No MPS triggering, self-triggering in ID04—long loss similar to PSS

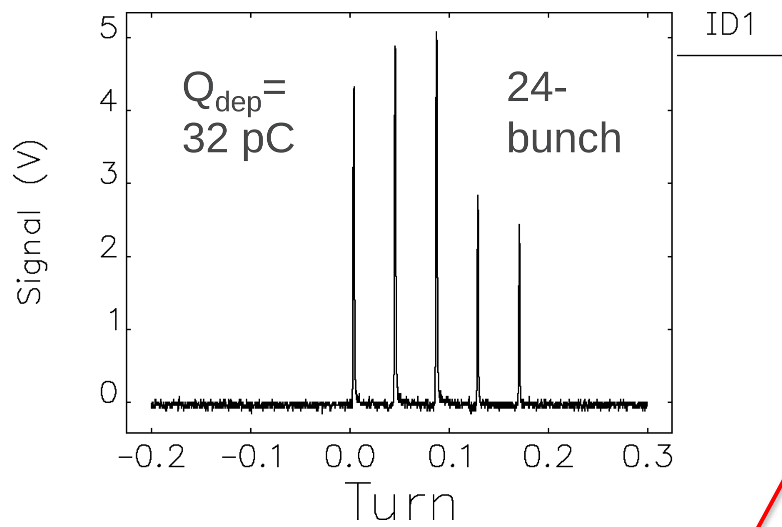


Periodicity of 50 Turns = 180 μs

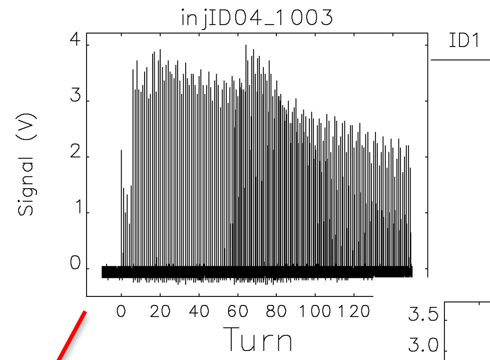
Fast axis

INJECTION LOSSES

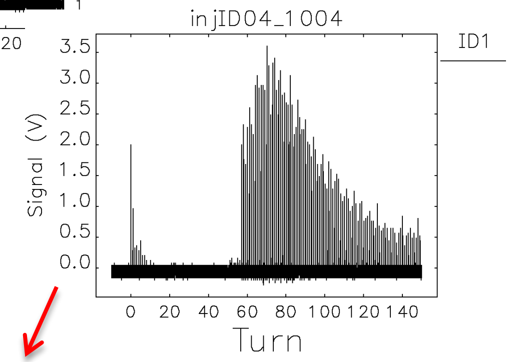
Prior to installation of SCU1



In ID04—SR IK issue

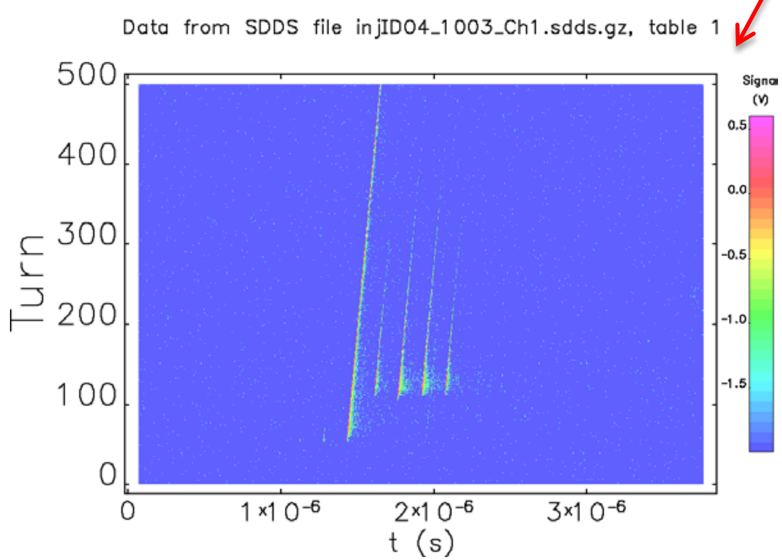


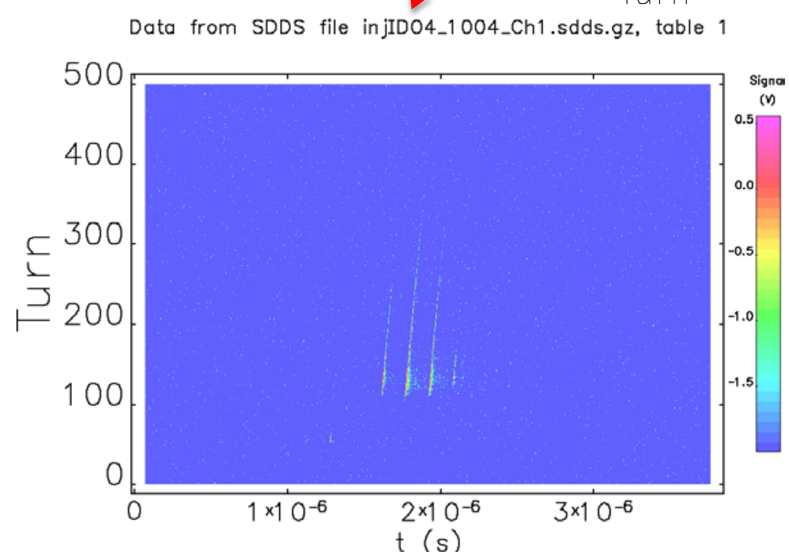
24-
bunch



injection

no injection





SUMMARY

- Provides loss charge timing and quantity allowing us to properly set up the AK
- Identified early loss problem with AK—coupling of MPS and PSS
- Quench threshold ~ 1 nC, at nominal SCU operating conditions (coil currents)
- Effective at measuring fast losses with broad dynamic range
- With calibration, provides fast dosimetry—sees beam when other diagnostics cannot—out of the machine; i.e. complements BPMs
- Quantification and visualization of loss dynamics
- Important diagnostic as we push to higher currents, brighter beams, and smaller apertures