Diamond Detectors as Beam Monitors

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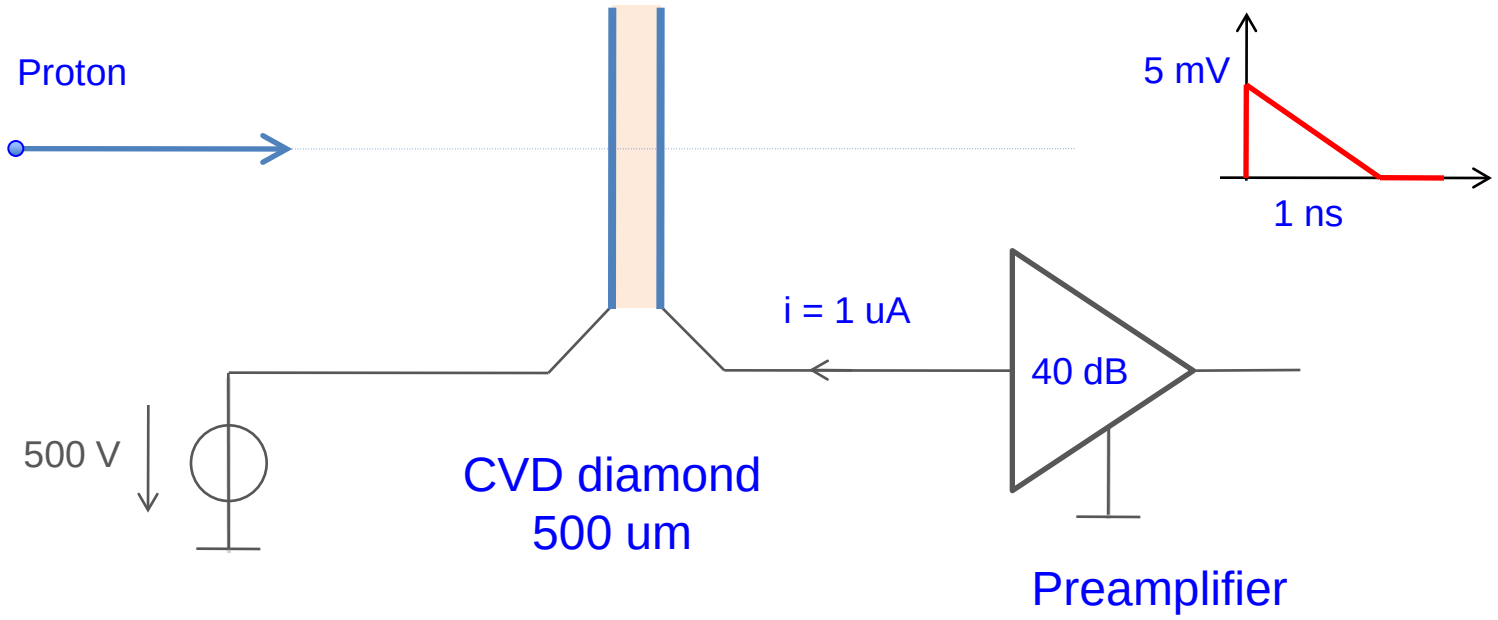
CVD Diamond

- Solid-state ionization chamber
- Compact design (10 mm x 10 mm x 0.5 mm)
- Size limitation (< 130 mm)
- Proven technology: Diamond Detectors (GB), Diamond Materials (GER), II-VI (USA)
- Developed in RD42 at CERN (starting 1995)
- Implemented in all four LHC experiments (ATLAS, CMS, LHCb and Alice)

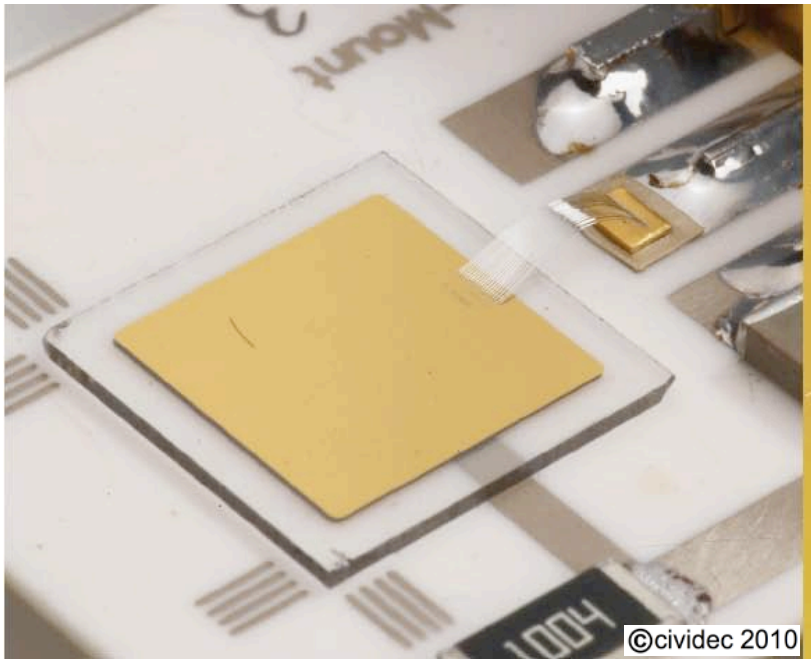
Principle


Proton
5 mV
1 ns
i = 1 uA
40 dB
500 V
CVD diamond
500 um
Preamplifier

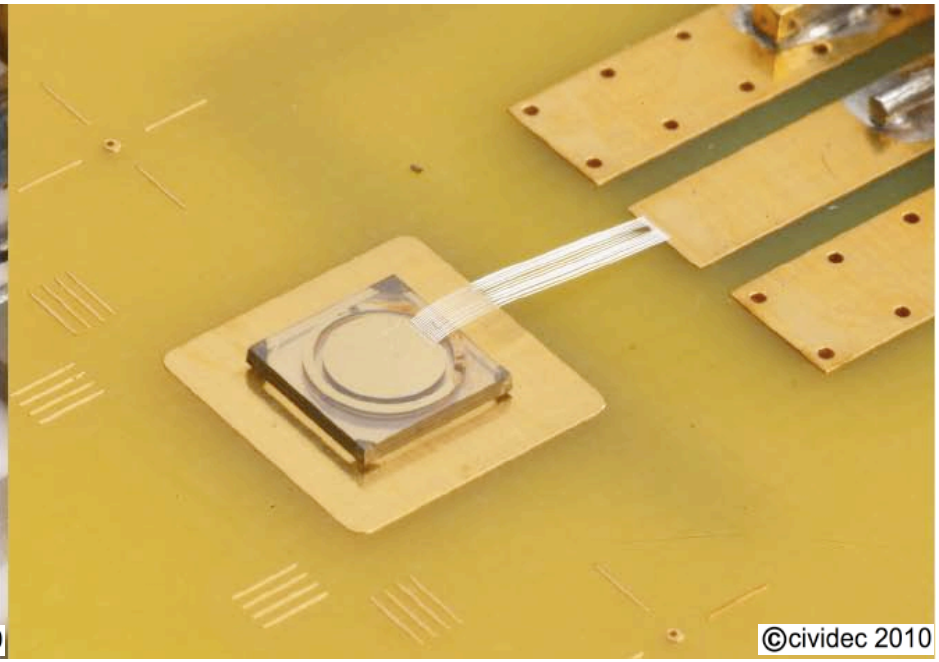
Properties of CVD Diamond

- Sensitive (single-particle detection)
- Robust (high-intensity DC applications)
- Fast (ns time response)
- Radiation resistant (10 MGy)
- High thermal conductivity (5x copper)

Diamond Materials

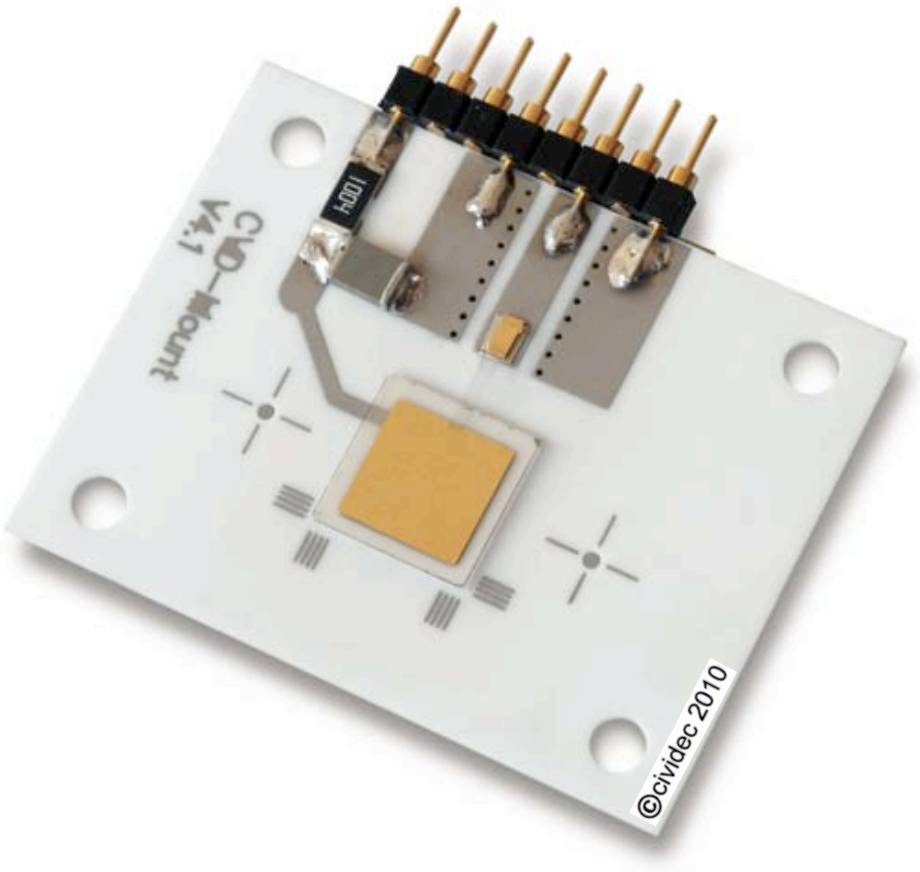


pCVD, 10 mm x 10 mm



sCVD, 5 mm x 5 mm

Diamond Detector



Detector + Preamplifier

Preamplifier

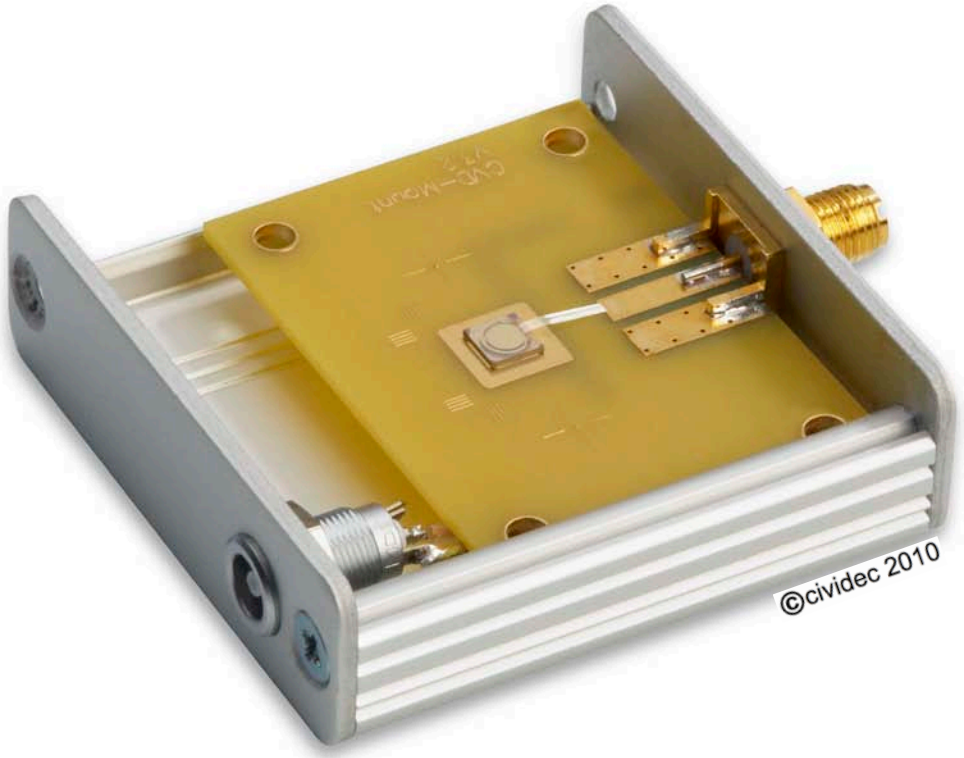
- Current amplifier
- Gain 20 dB, 40 dB
- Noise < 1 mV rms
- 4 mV/MIP max. 1 V
- Rise time < 1 ns
- Pulse width < 2 ns

Three Examples

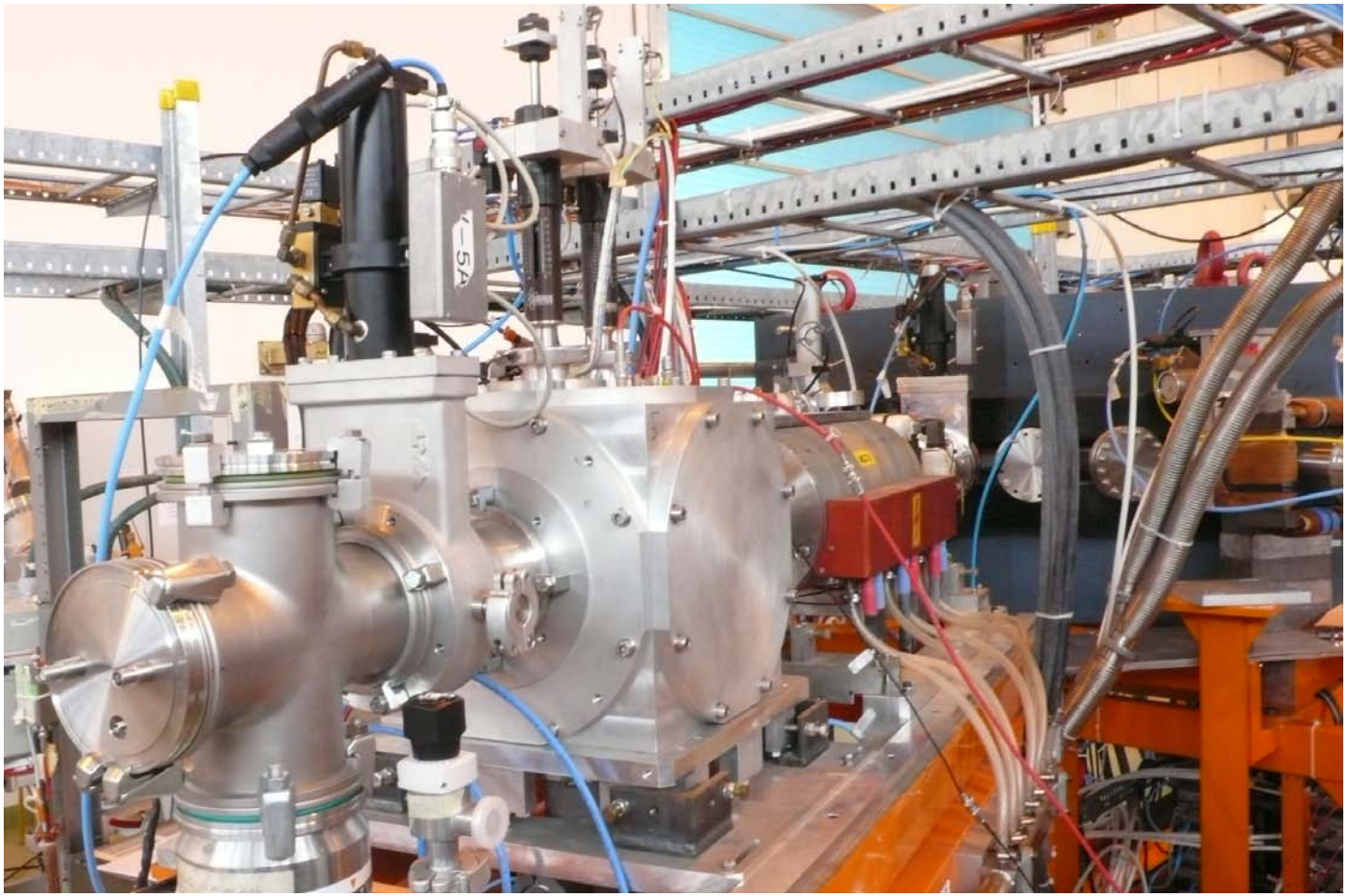
1. CERN REX-ISOLDE
2. CERN - SPS
3. CERN - LHC

Example 1: REX-ISOLDE

REX-ISOLDE Detector



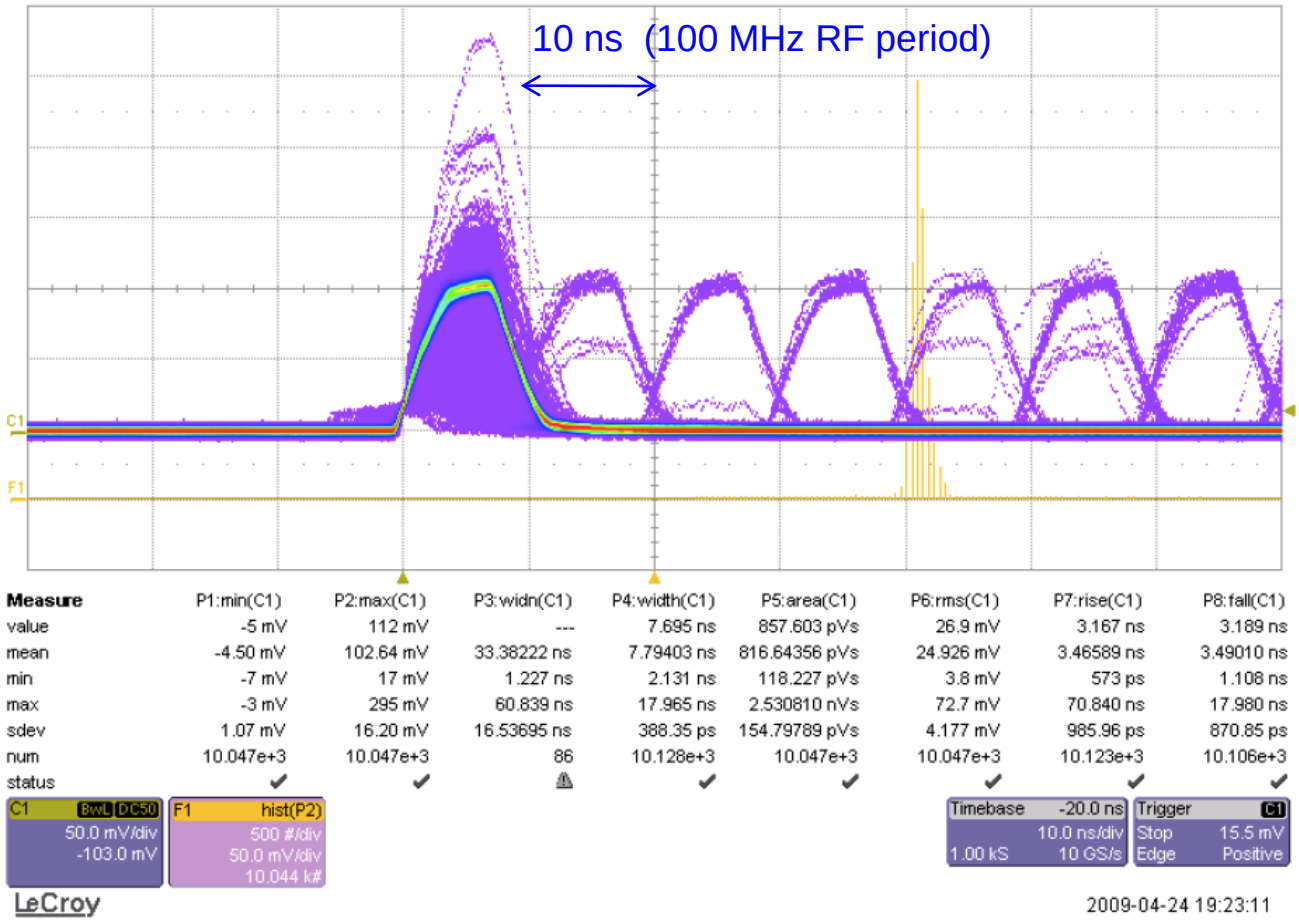
REX-ISOLDE



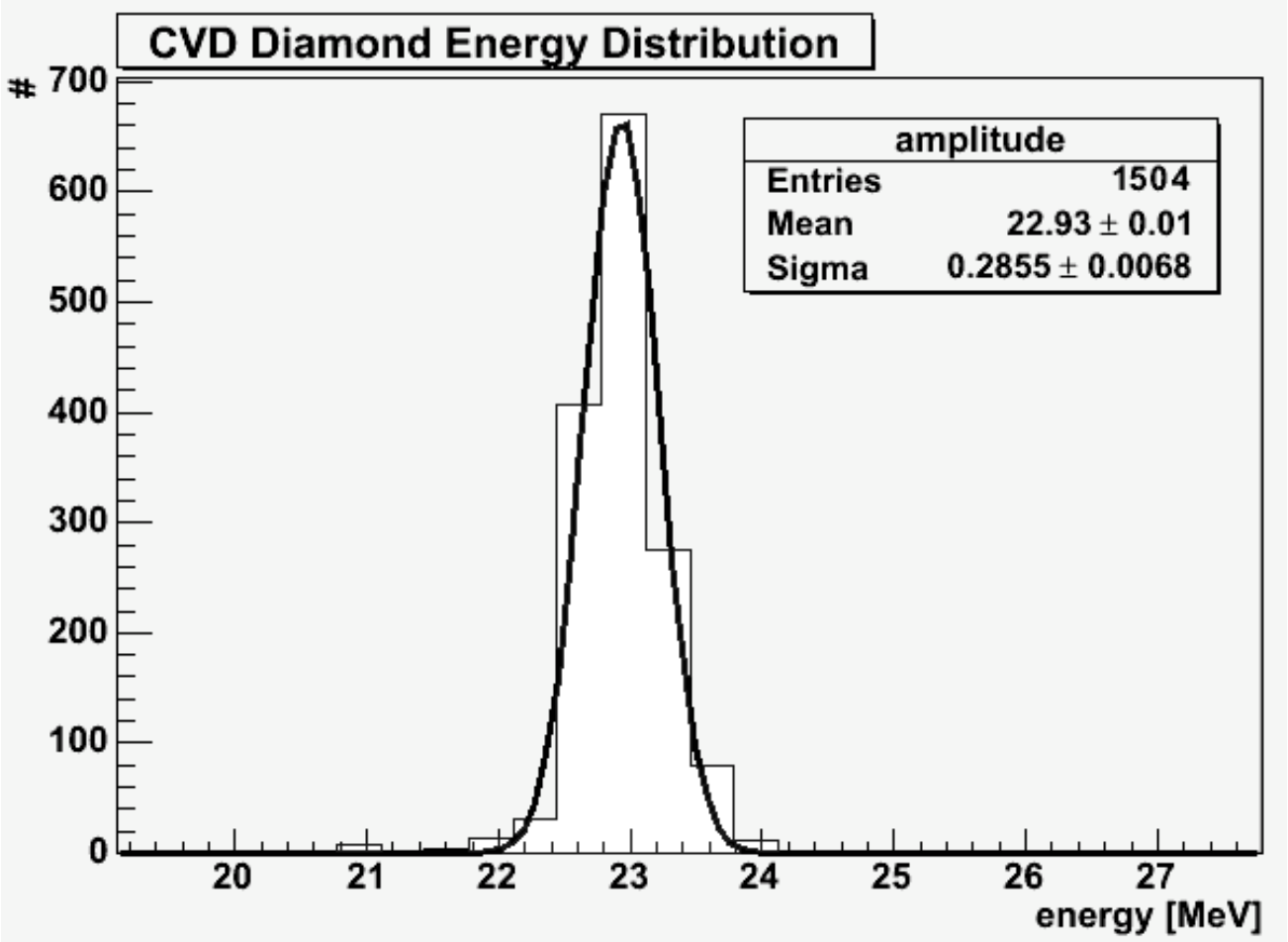
ISOLDE Test

- sCVD diamond detector
- 22.8 MeV C-ions (10 um penetration)
- Installation in vacuum
- In cooperation with Bergoz Instrumentation

Single-Particle Response



Energy Resolution

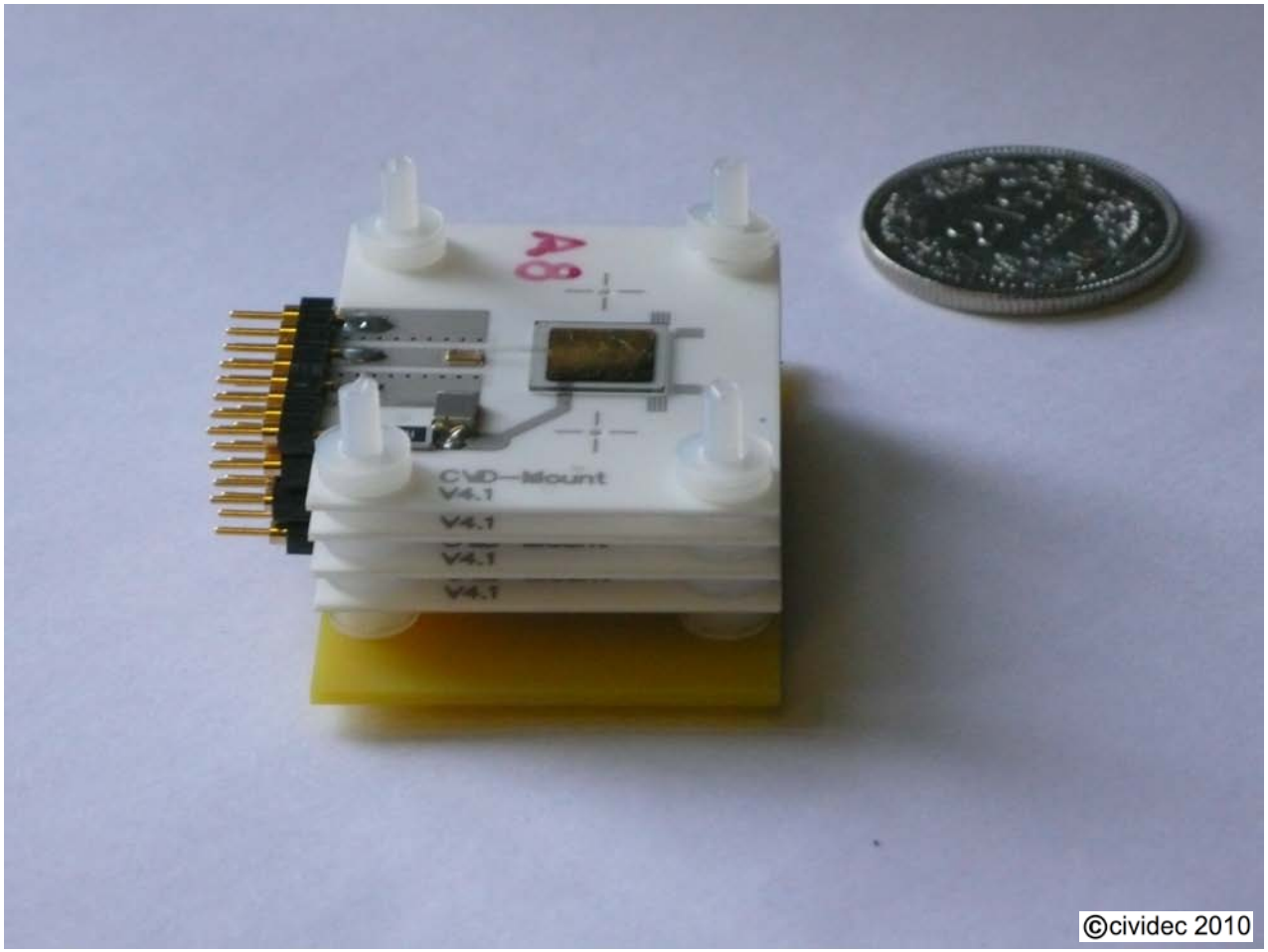


ISOLDE Summary

+ Energy resolution = 0.6%
+ Intrinsic time resolution = 30 ps
+ Double pulse resolution = 10 ns
+ Reproducibility for low intensities
- Problems with pile up

Example 2: CERN - SPS

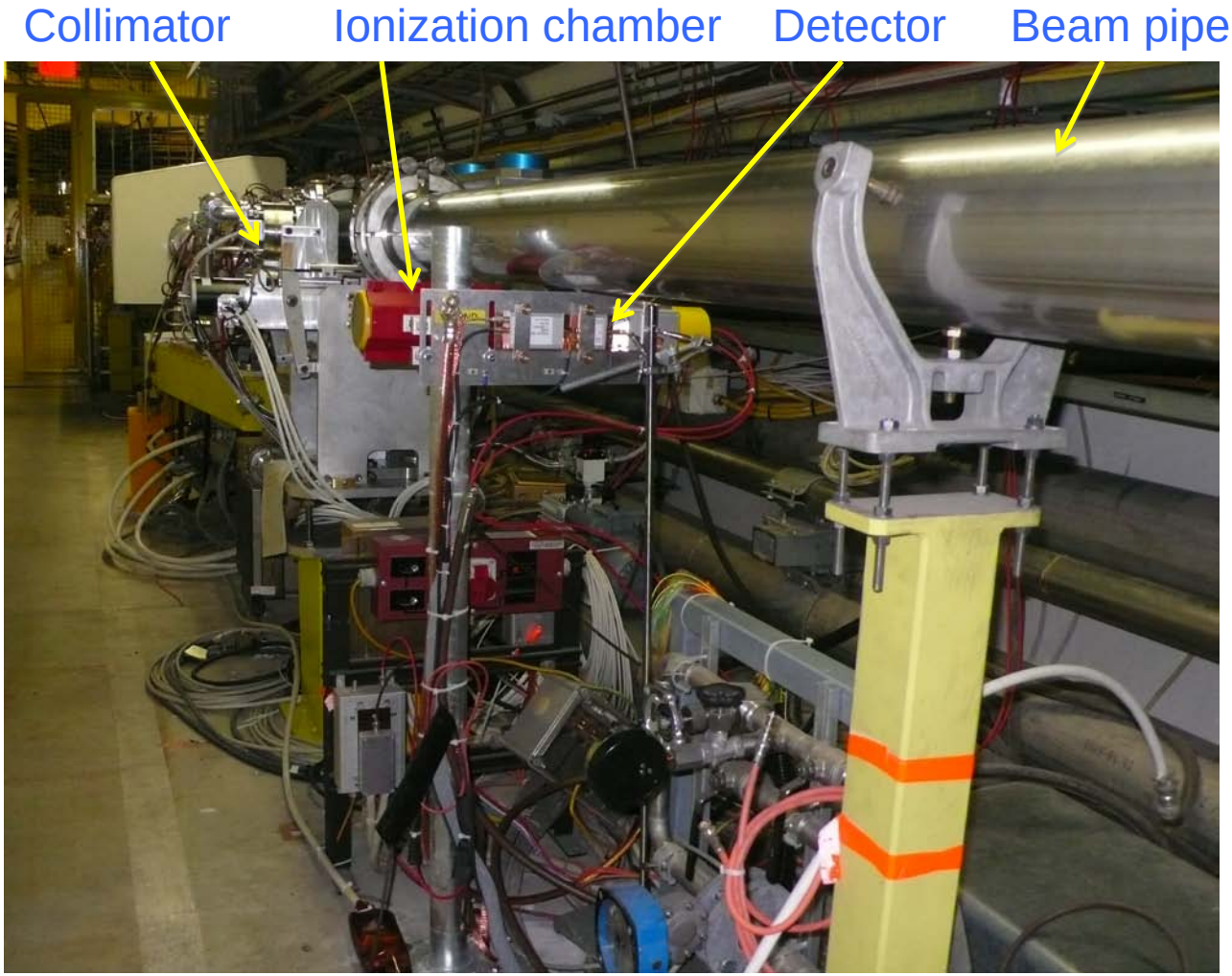
SPS Detector



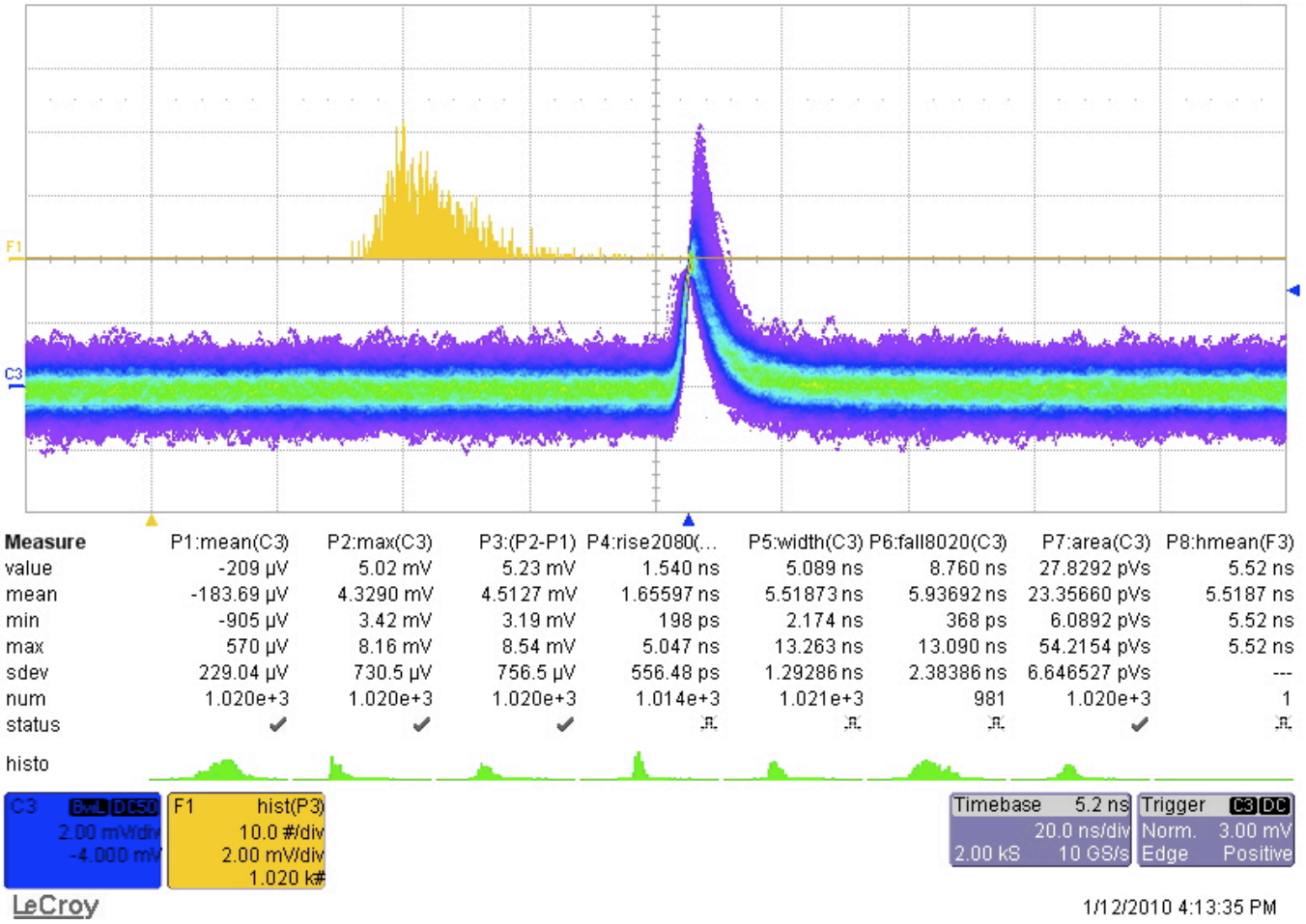
SPS Test

- pCVD diamond beam monitor
- Beam-halo monitoring
- SPS BA5 downstream of a LHC collimator
- 250 m cable (CK50, RF coaxial low-loss)
- CERN BI, CIVIDEC Instrumentation

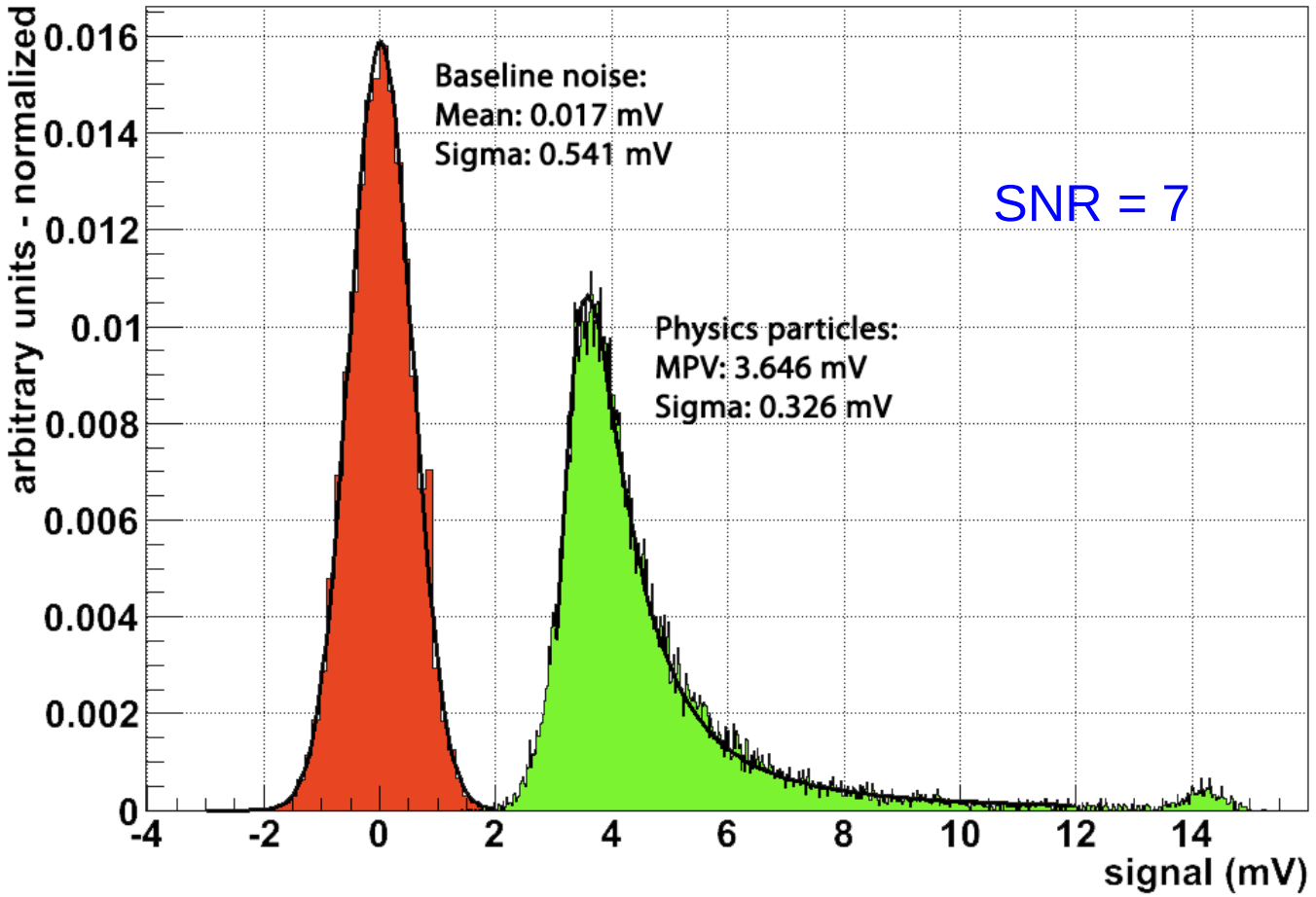
SPS Installation



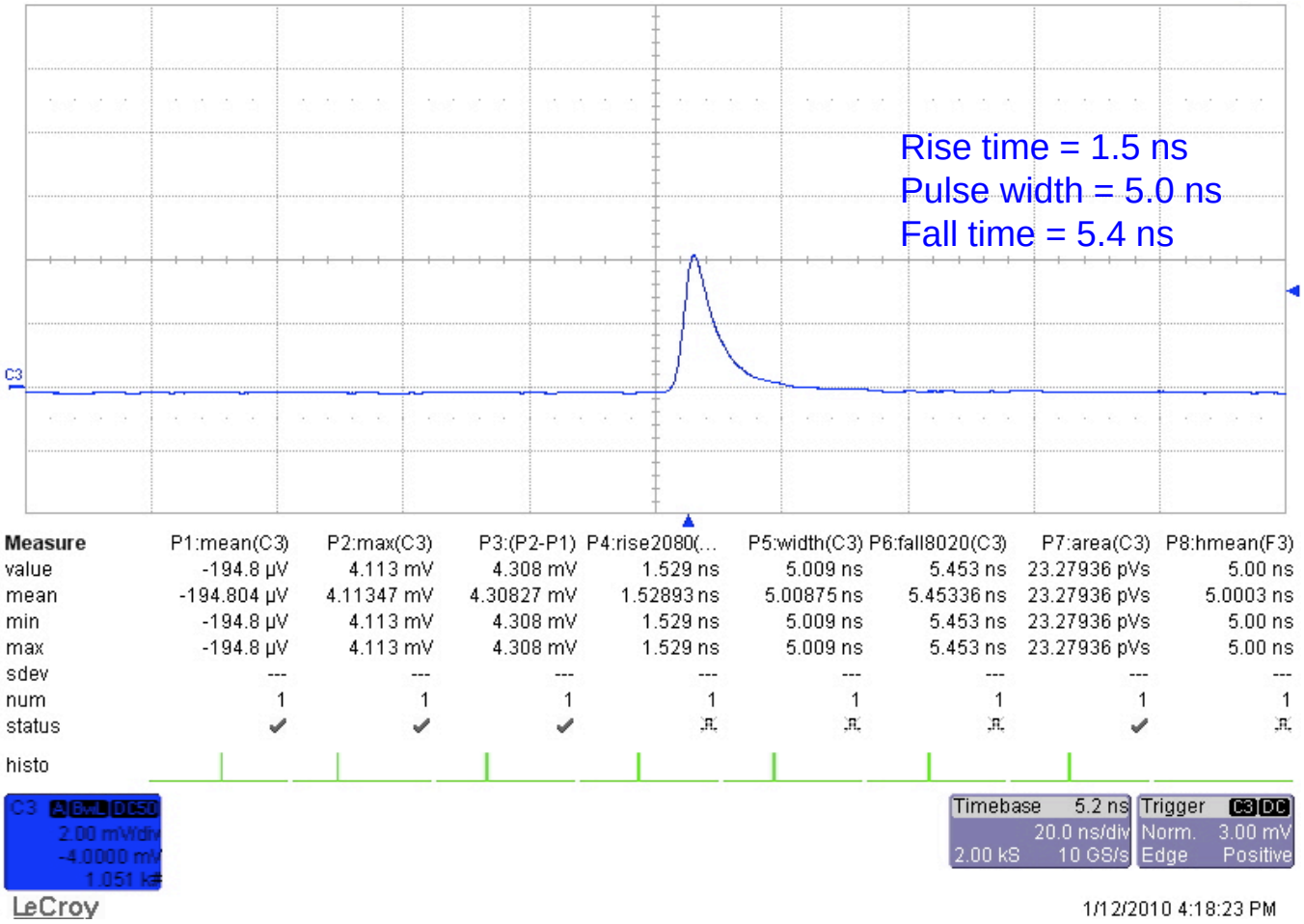
Calibration with Sr^{90} Source



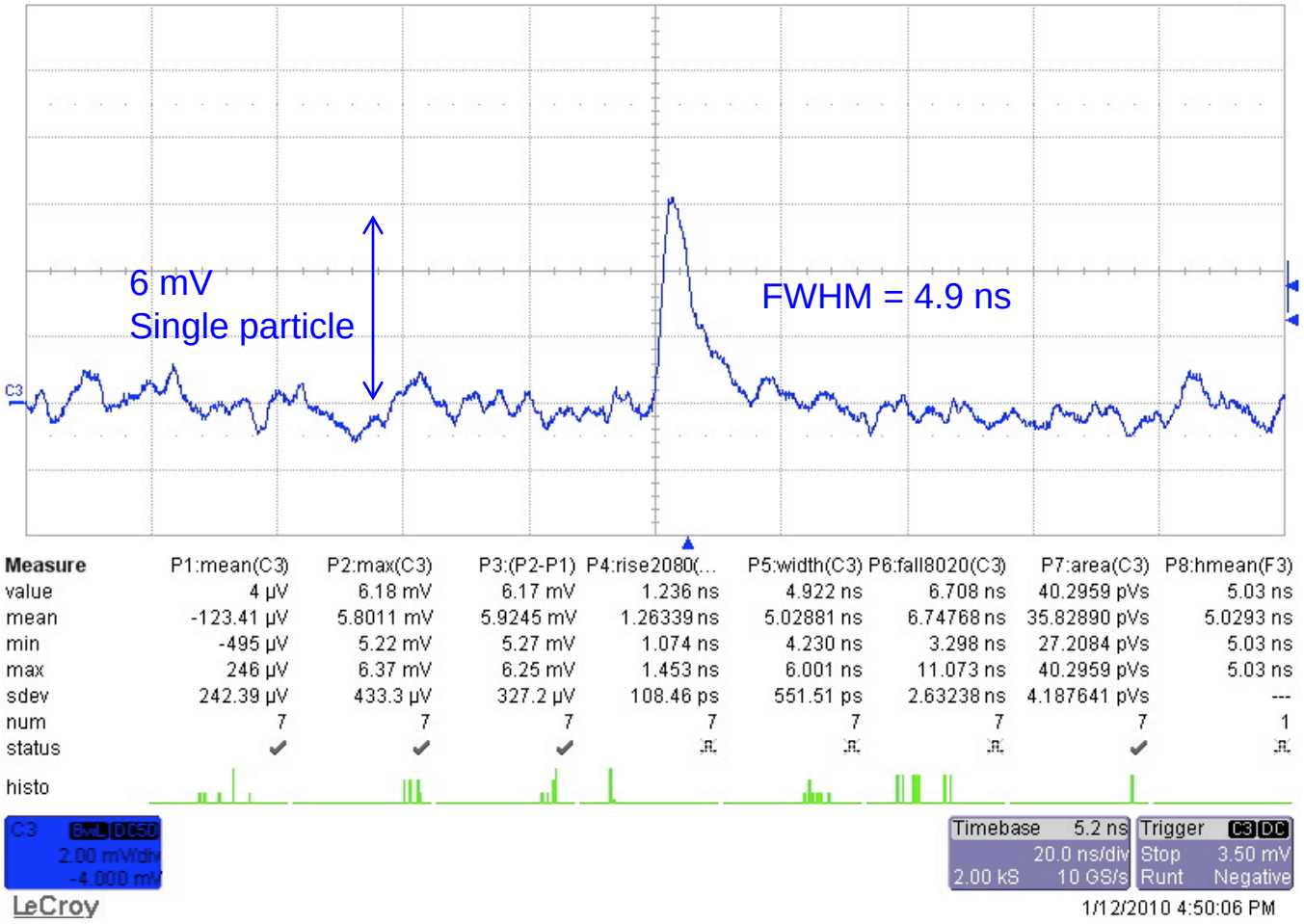
Signal & Noise



Average Pulse Shape

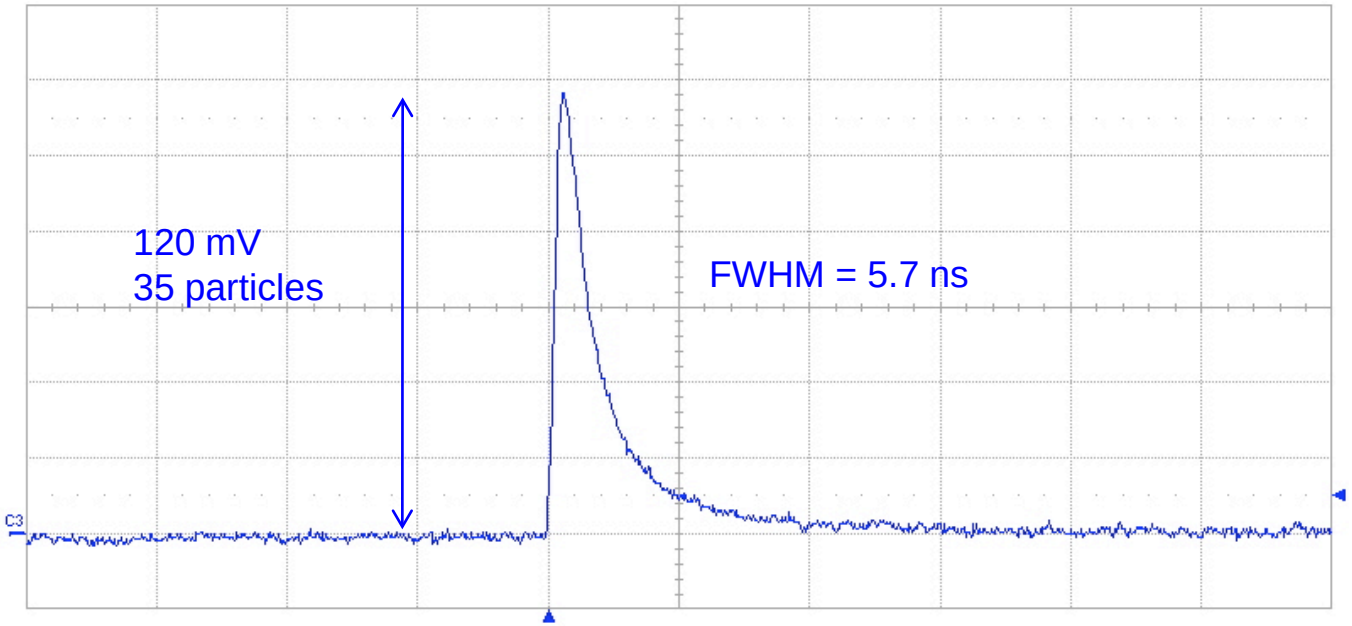


Physics Particles



Measure	P1:mean(C3)	P2:max(C3)	P3:(P2-P1)	P4:rise2080(...	P5:width(C3)	P6:fall8020(C3)	P7:area(C3)	P8:hmean(F3)
value	4 µV	6.18 mV	6.17 mV	1.236 ns	4.922 ns	6.708 ns	40.2959 pVs	5.03 ns
mean	-123.41 µV	5.8011 mV	5.9245 mV	1.26339 ns	5.02881 ns	6.74768 ns	35.82890 pVs	5.0293 ns
min	-495 µV	5.22 mV	5.27 mV	1.074 ns	4.230 ns	3.298 ns	27.2084 pVs	5.03 ns
max	246 µV	6.37 mV	6.25 mV	1.453 ns	6.001 ns	11.073 ns	40.2959 pVs	5.03 ns
sdev	242.39 µV	433.3 µV	327.2 µV	108.46 ps	551.51 ps	2.63238 ns	4.187641 pVs	---
num	7	7	7	7	7	7	7	1
status	✔	✔	✔				✔	
histo								

Multi-Particle Pulse



Measure	P1:ampl(C3)	P2:rms(C3)	P3:rise(C3)	P4:width(C3)	P5:fall(C3)	P6:mean(C1)	P7:- - -	P8:- - -
value	119.7 mV	17.23 mV	1.707 ns	5.709 ns	17.924 ns			
mean	26.879 mV	5.1542 mV	7.68718 ns	9.12046 ns	22.97279 ns			
min	5.8 mV	1.86 mV	1.625 ns	3.768 ns	11.330 ns			
max	119.7 mV	17.23 mV	33.700 ns	49.682 ns	49.504 ns			
sdev	26.645 mV	3.8931 mV	10.68577 ns	11.76861 ns	9.07870 ns			
num	15	15	15	13	14			
status		✔						

C3 DC50
20.0 mV/div
-60.00 mV

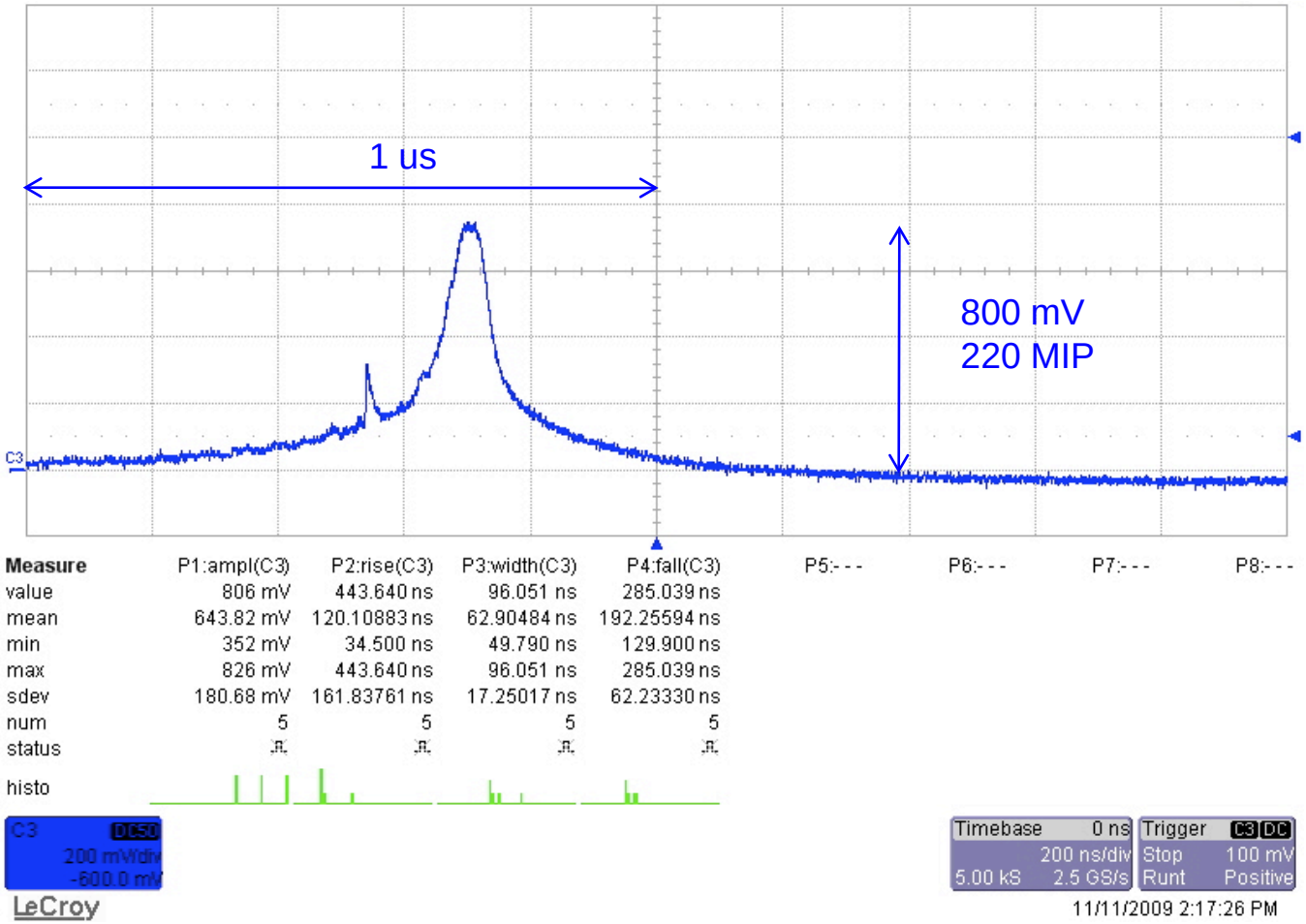
LeCroy

Timebase -20.0 ns
20.0 ns/div
1.00 kS 5.0 GS/s

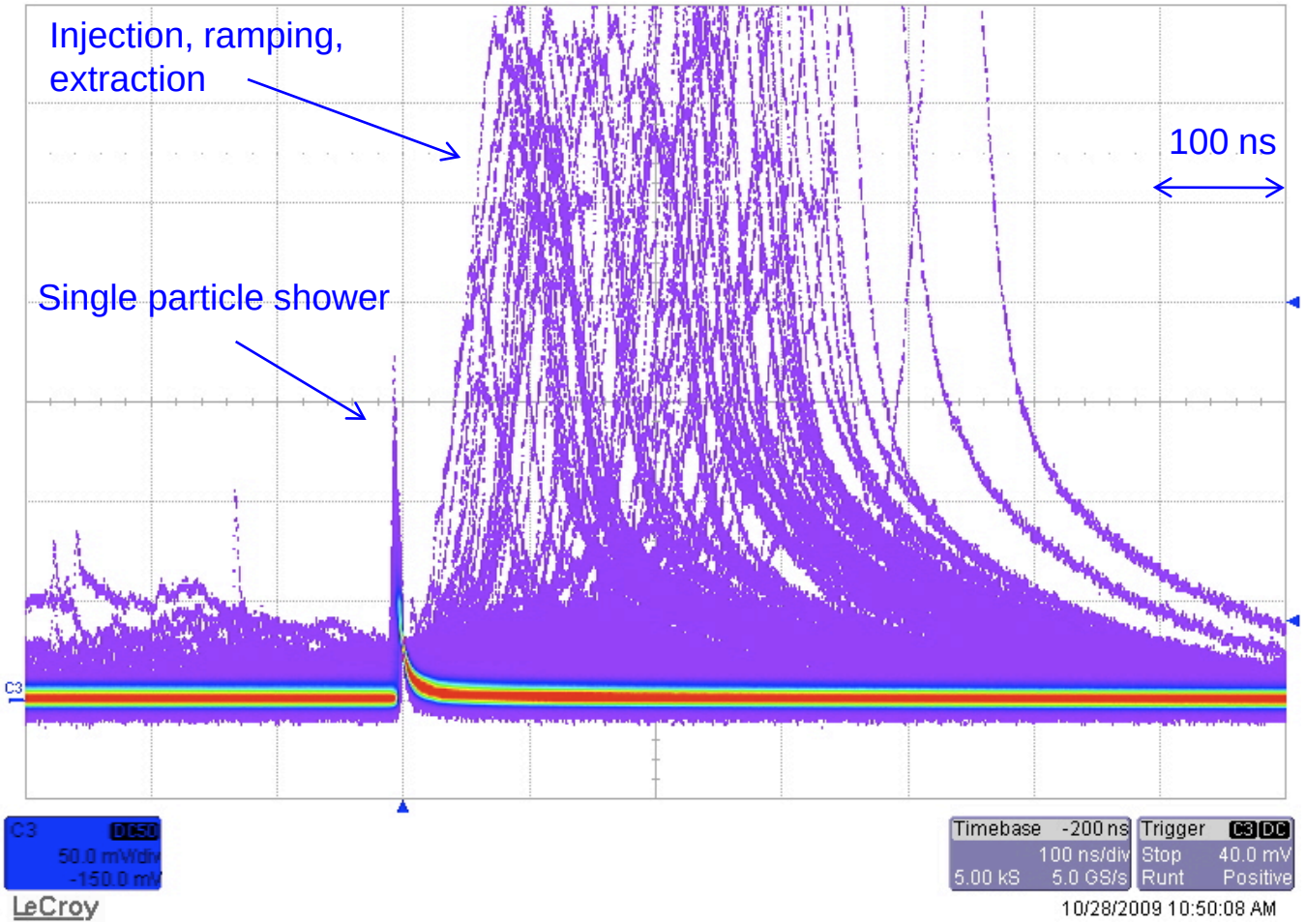
Trigger C3 DC
Stop 10.0 mV
Edge Positive

10/11/2009 10:31:46 PM

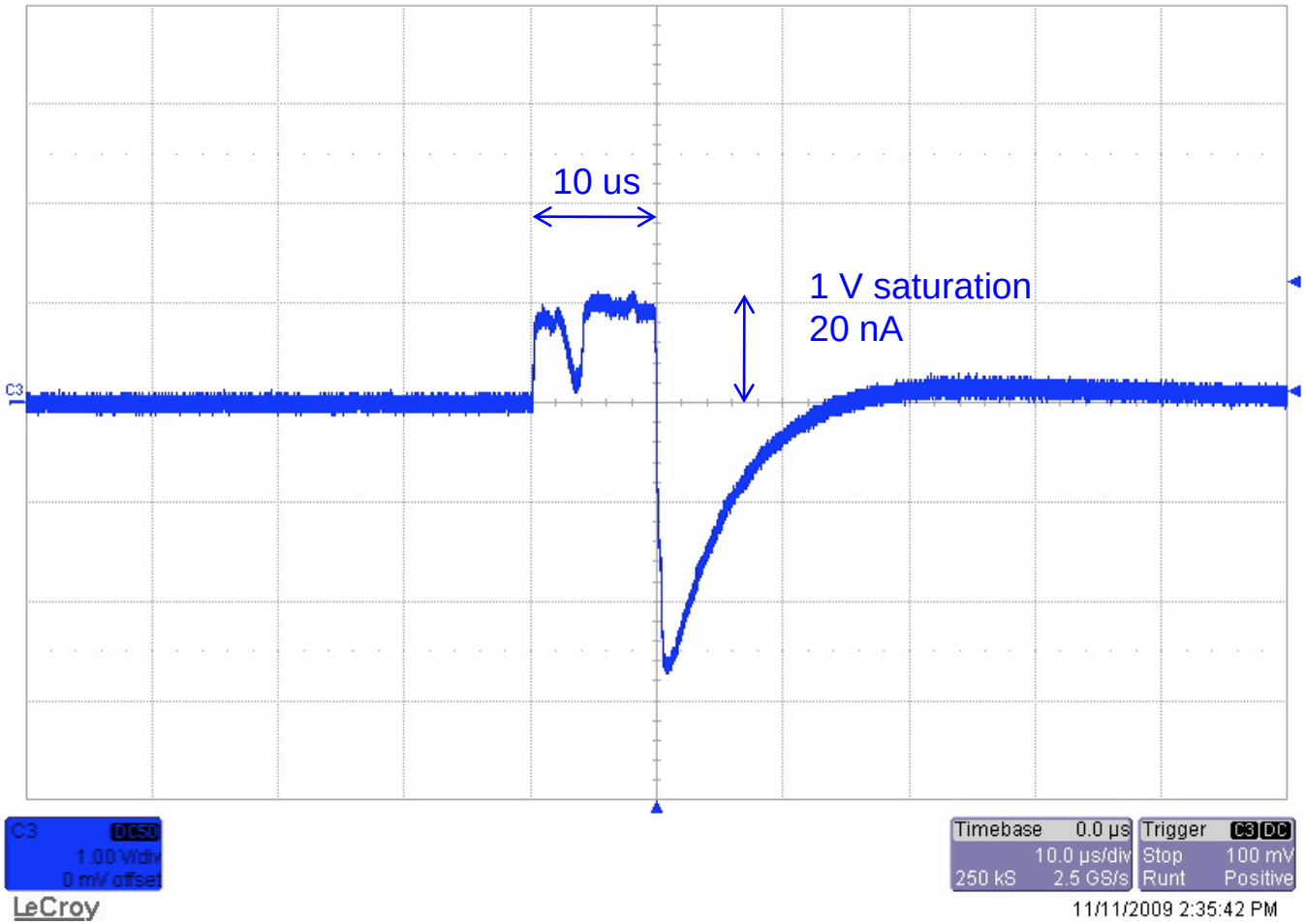
Particle Cascade



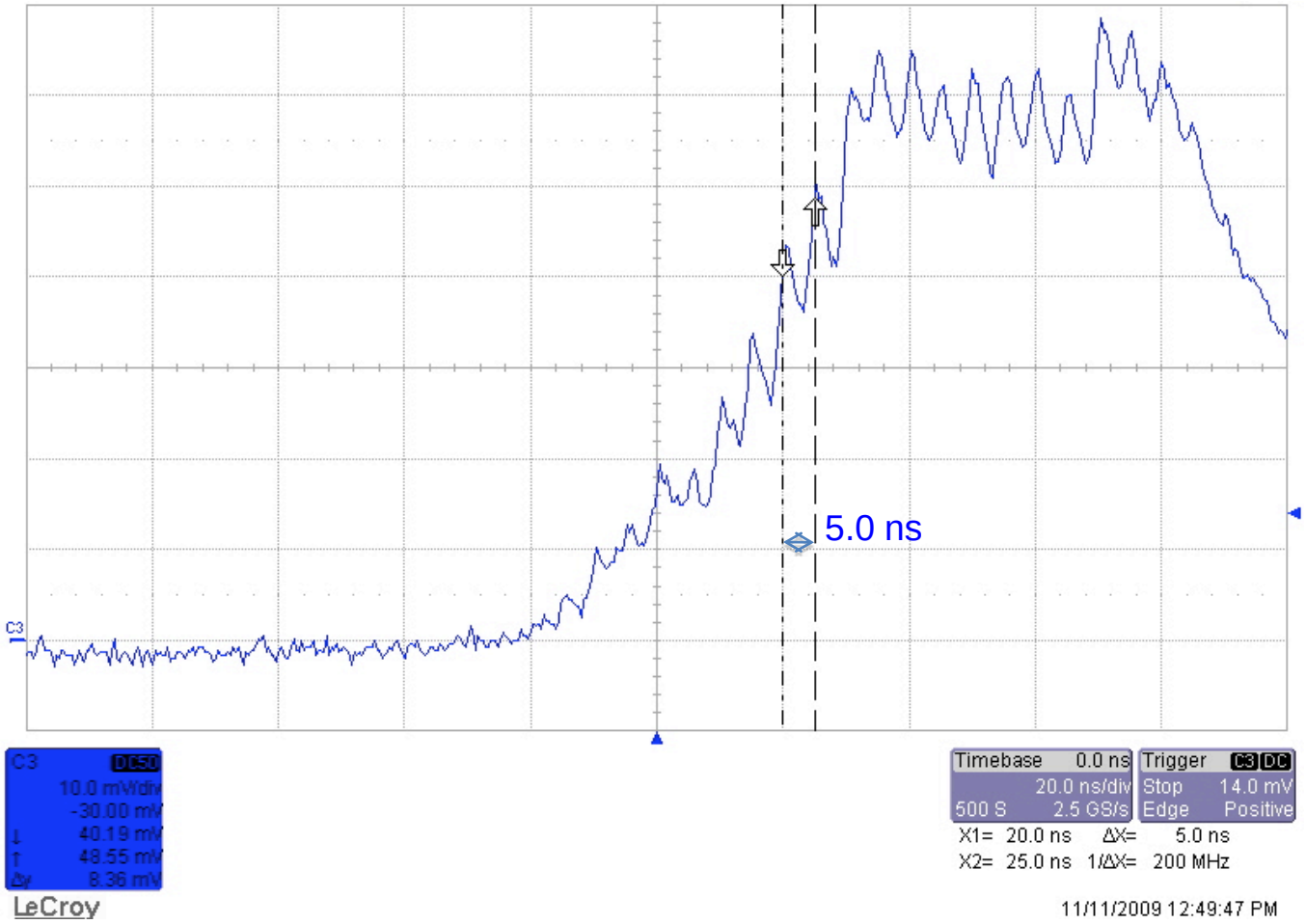
Beam Losses


Injection, ramping, extraction
100 ns
Single particle shower
C3
C3 DC50
50.0 mV/div
-150.0 mV
LeCroy
Timebase -200 ns
100 ns/div
5.00 kS 5.0 GS/s
Trigger C3 DC
Stop 40.0 mV
Runt Positive
10/28/2009 10:50:08 AM

High-Intensity Losses



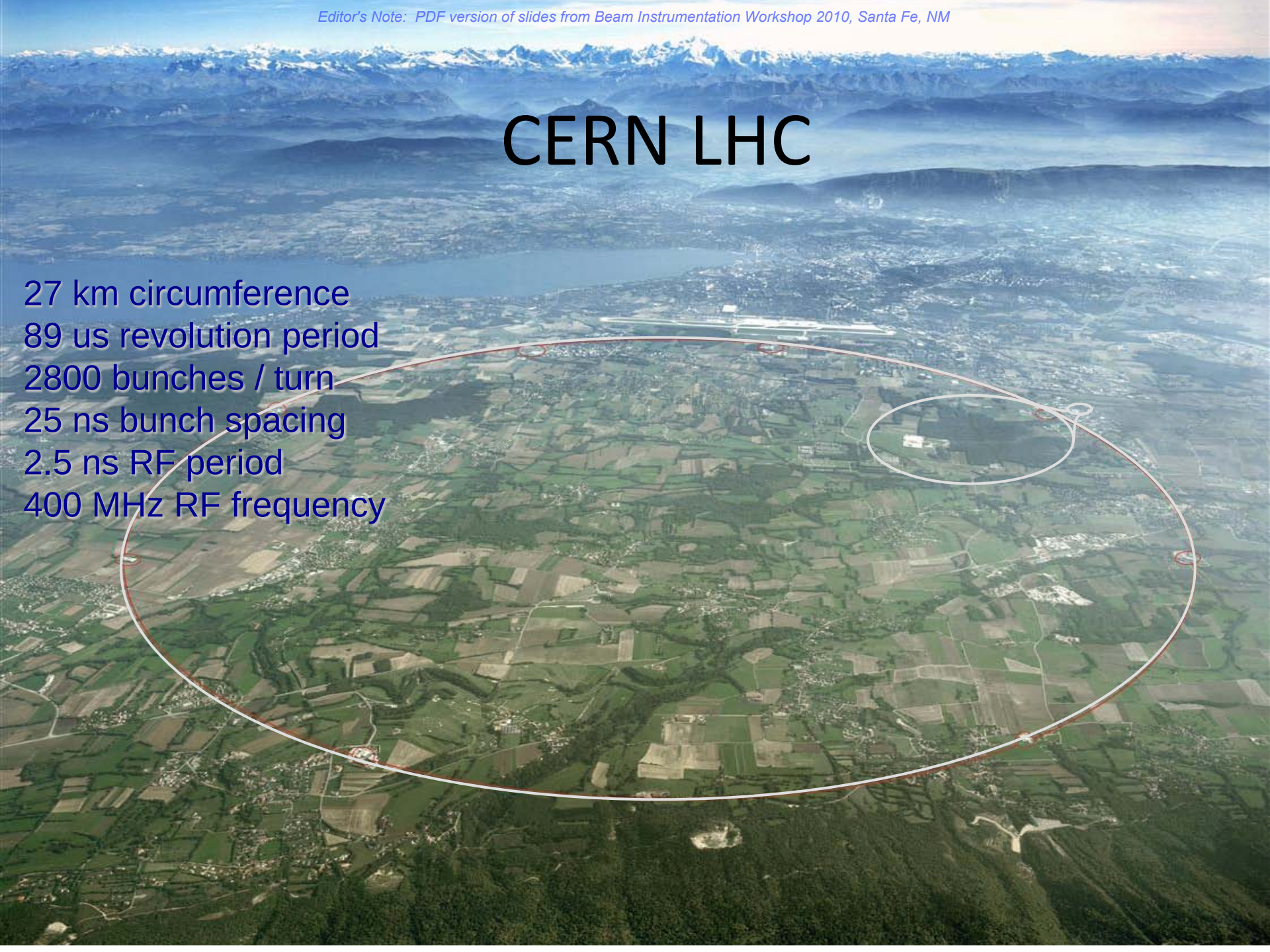
200 MHz SPS RF-Frequency



Example 3: CERN - LHC

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

CERN LHC



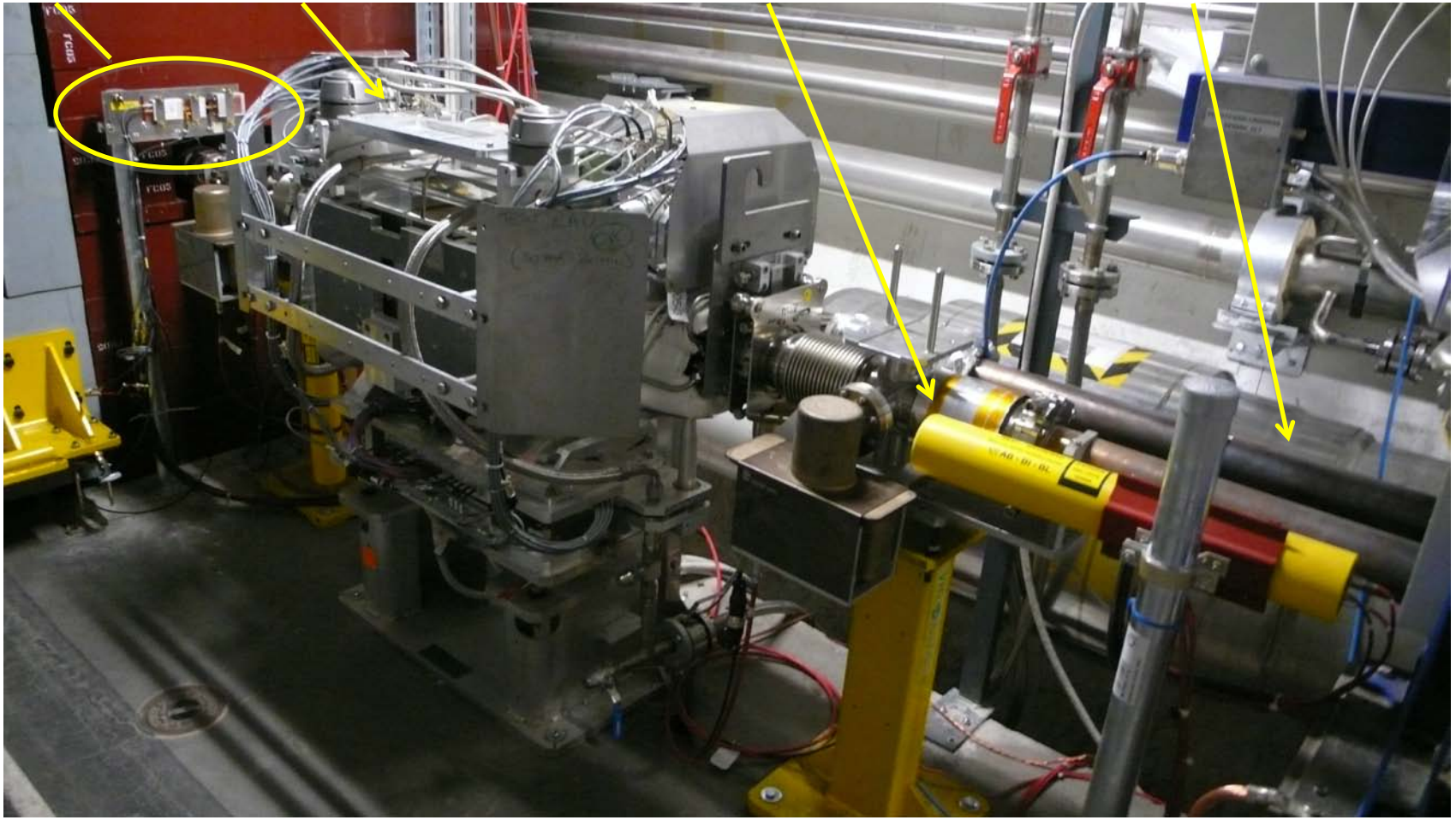
27 km circumference
89 us revolution period
2800 bunches / turn
25 ns bunch spacing
2.5 ns RF period
400 MHz RF frequency

LHC Test

- pCVD diamond beam monitors
- Beam-halo measurements
- Mounted in the LHC collimation area
- 200 m cable (CK50)
- CERN BI, CIVIDEC Instrumentation

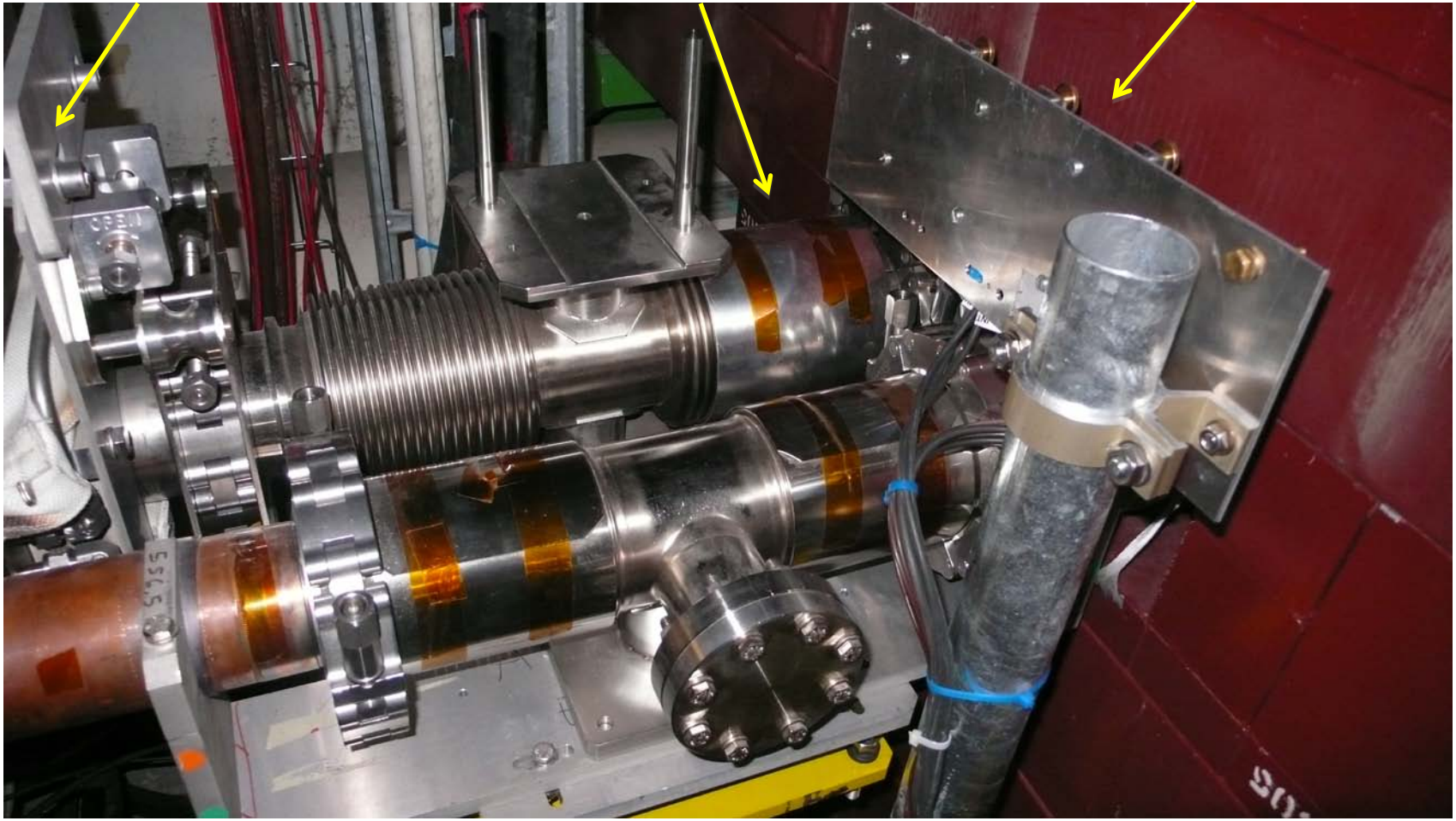
LHC Installation

Detector Collimator Ionization chamber Beam pipes



LHC Installation

Collimator Beam pipes Detector



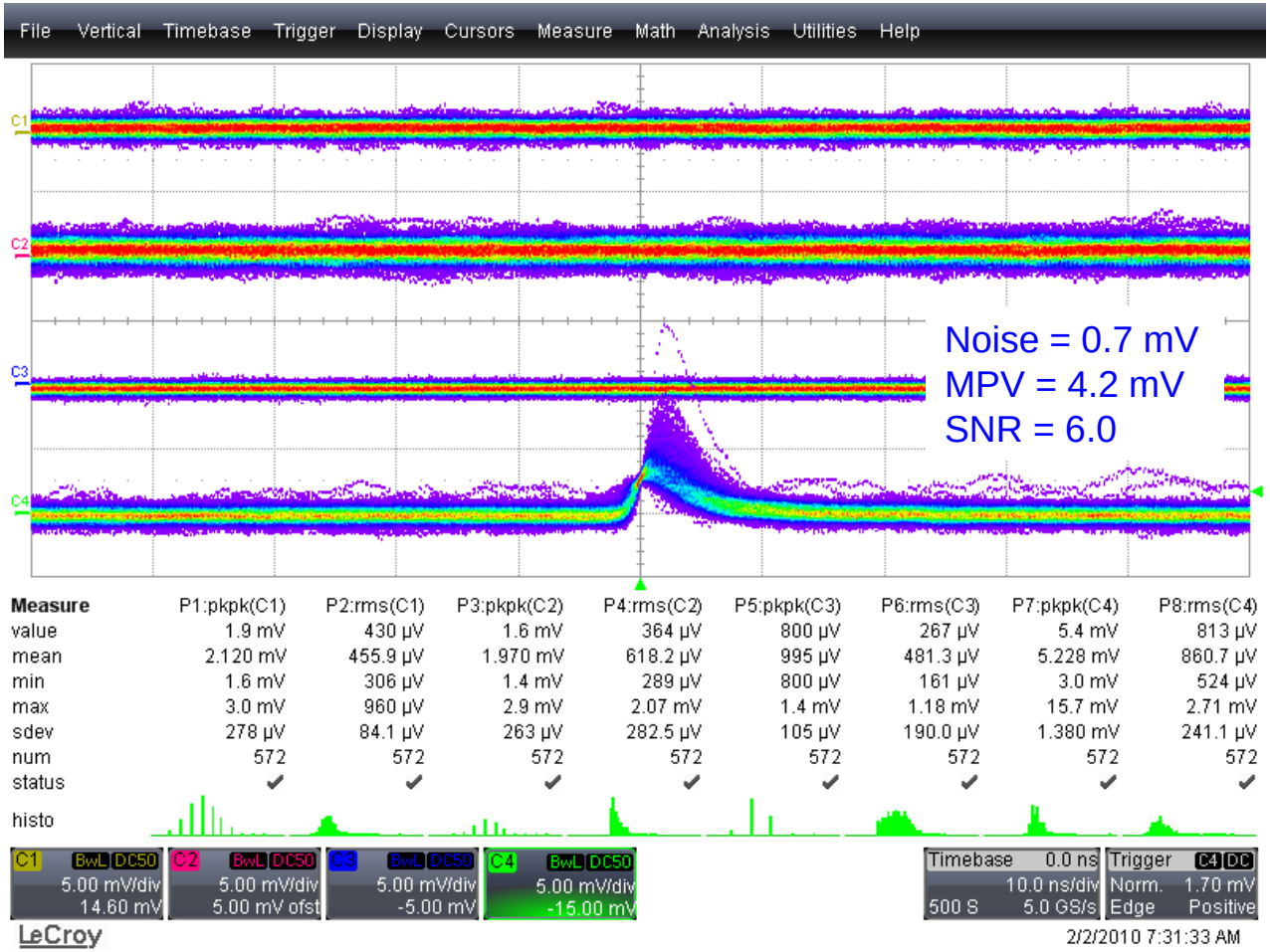
Calibration

Channel 1

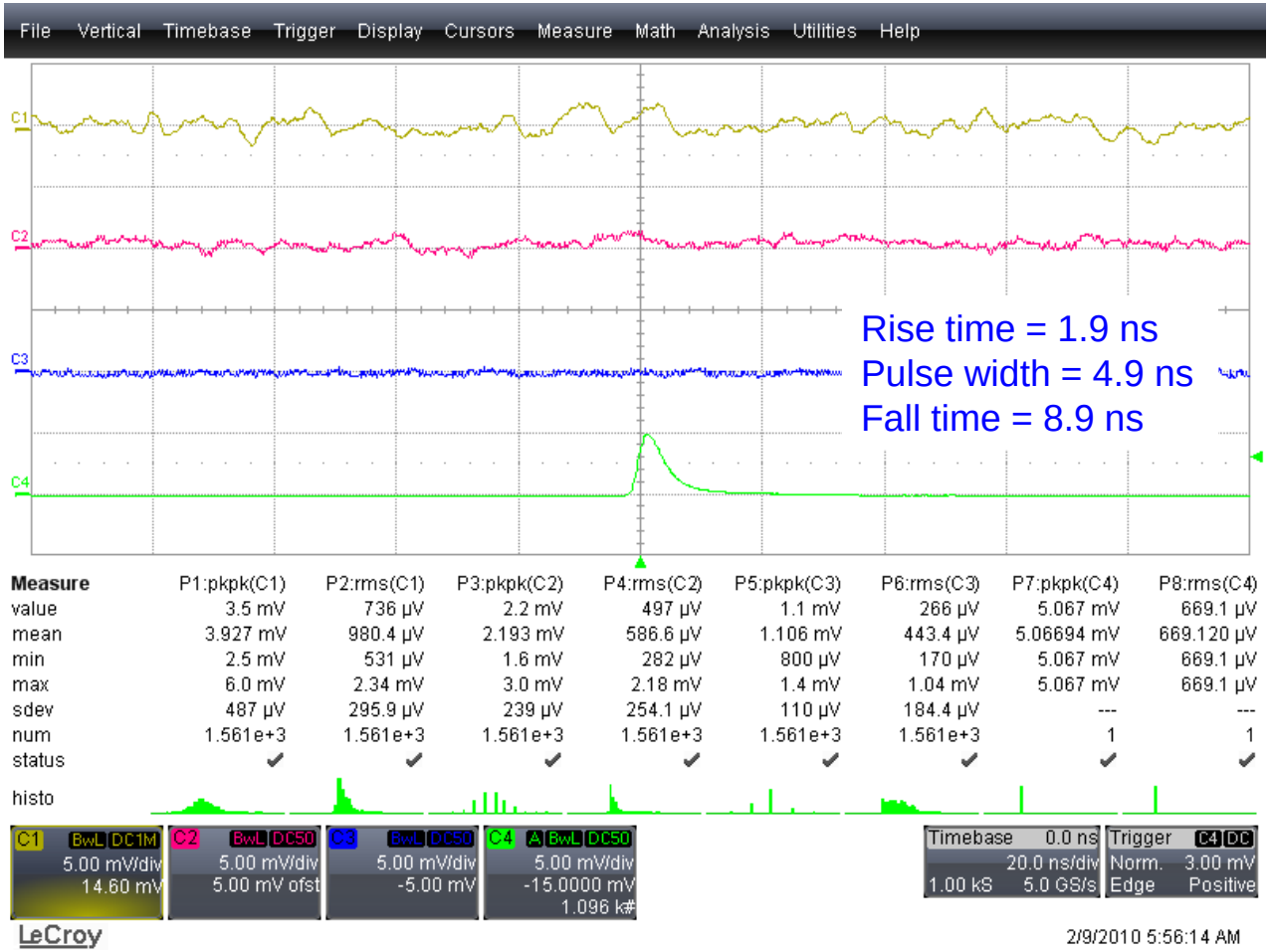
Channel 2

Channel 3

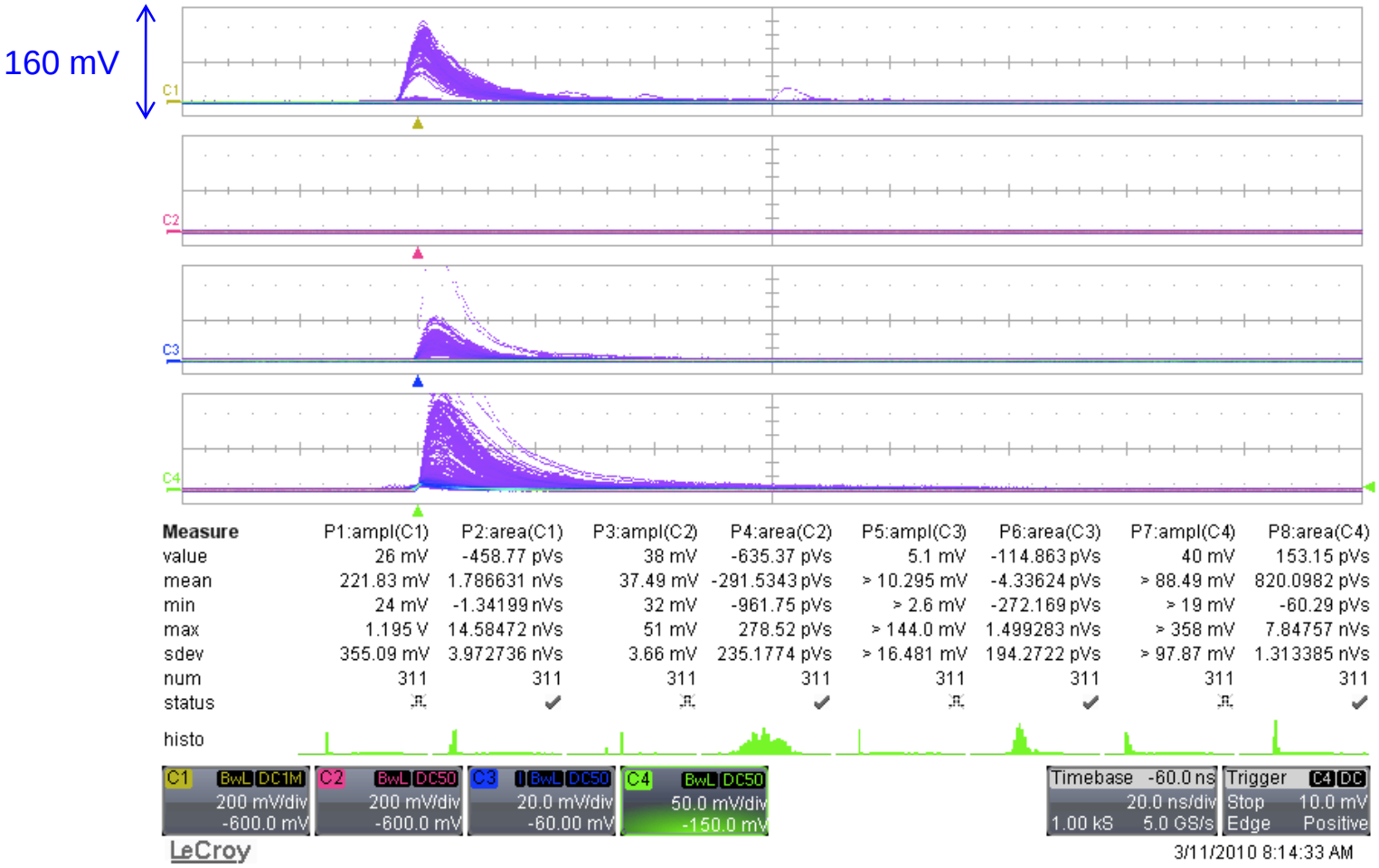
Channel 4



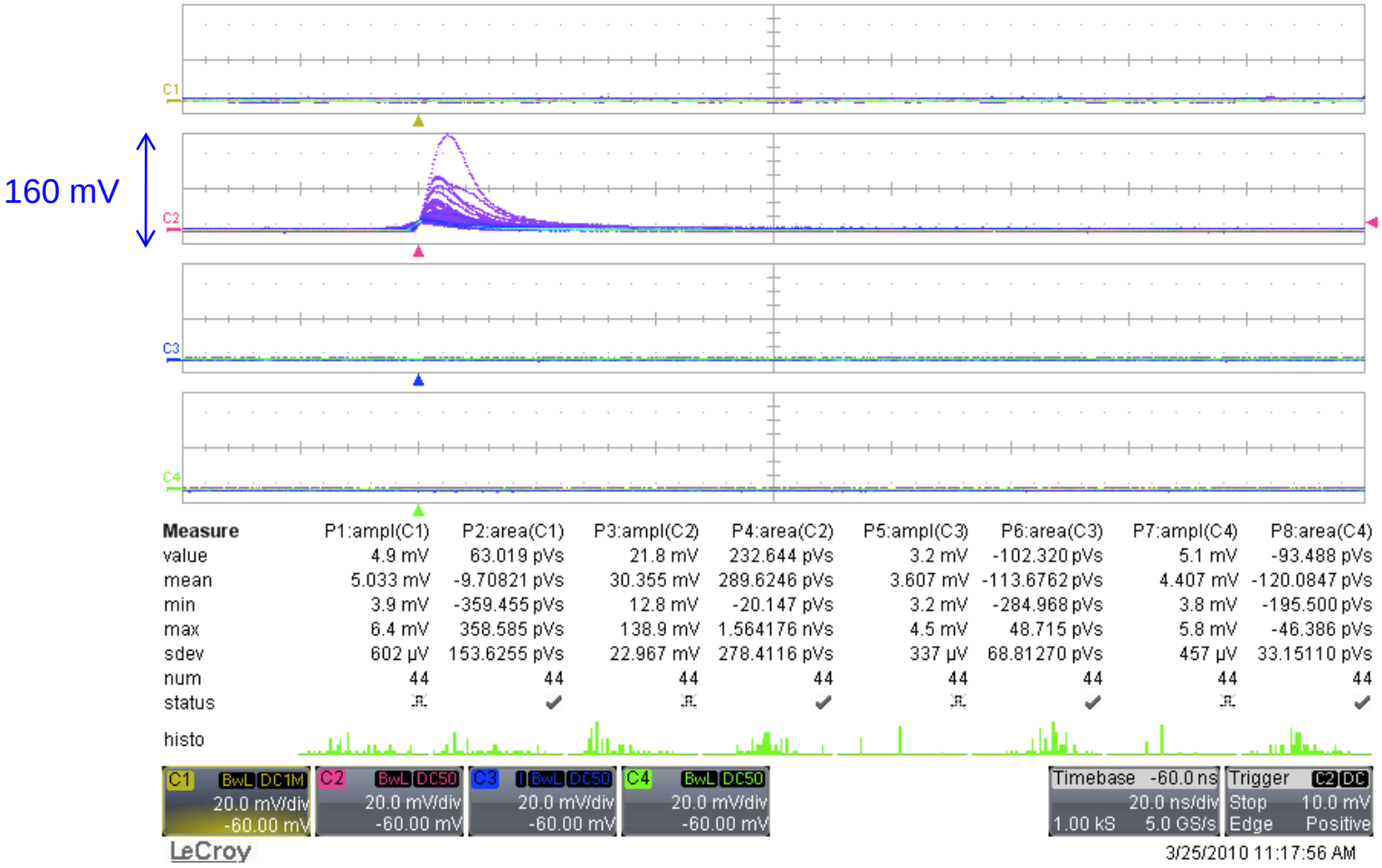
Calibration



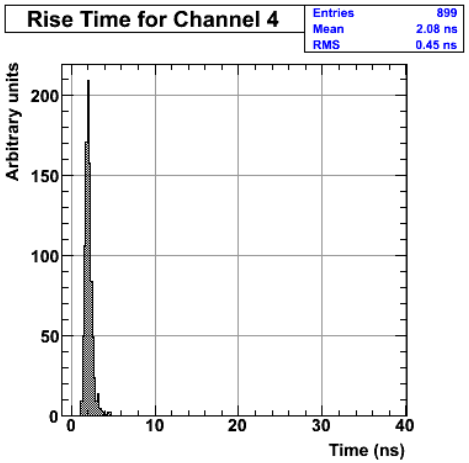
Physics Events - Right Side

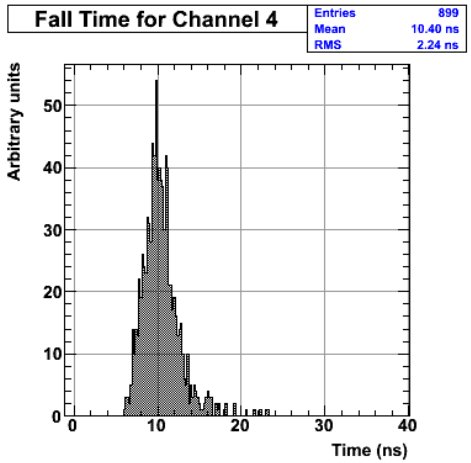


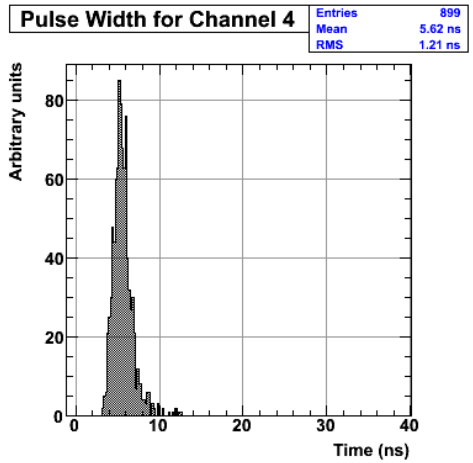
Physics Events - Left Side

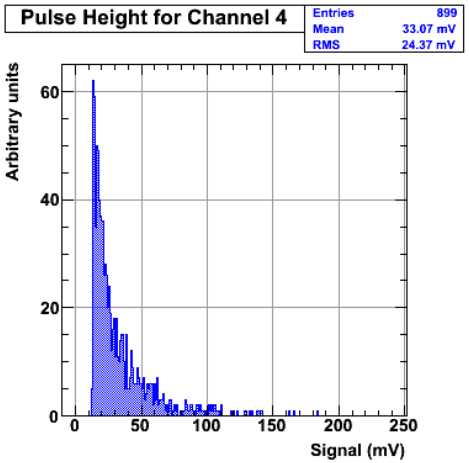


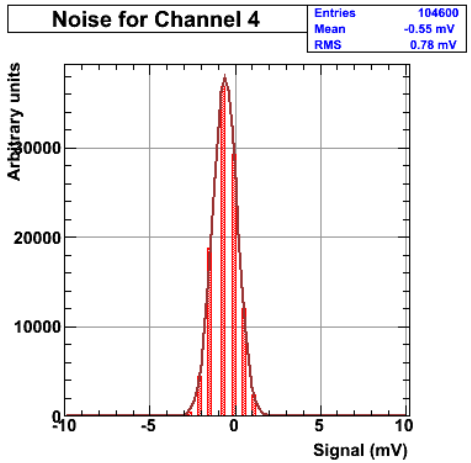
Timing Properties





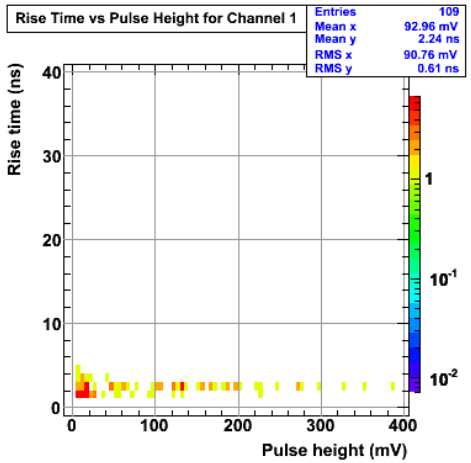


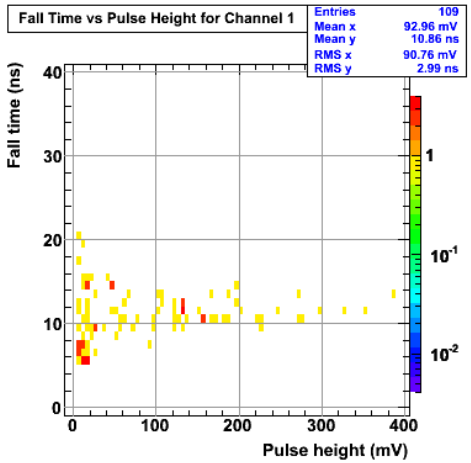


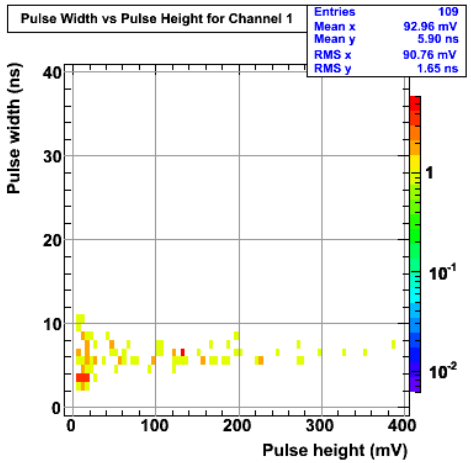


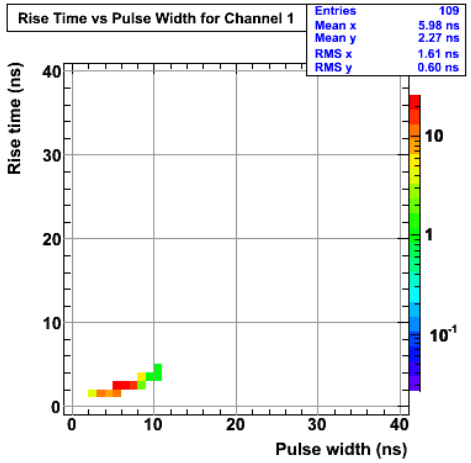
Rise time = 2 ns
Pulse width = 5 ns
Fall time = 10 ns
Noise = 0.7 mV rms

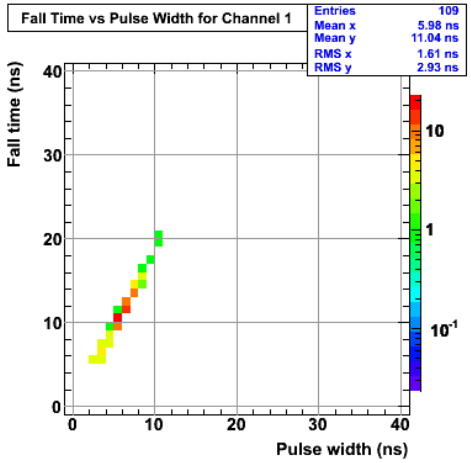
Linearity


Rise Time vs Pulse Height for Channel 1
Entries 109
Mean x 92.96 mV
Mean y 2.24 ns
RMS x 90.76 mV
RMS y 0.61 ns
Rise time (ns)
Pulse height (mV)

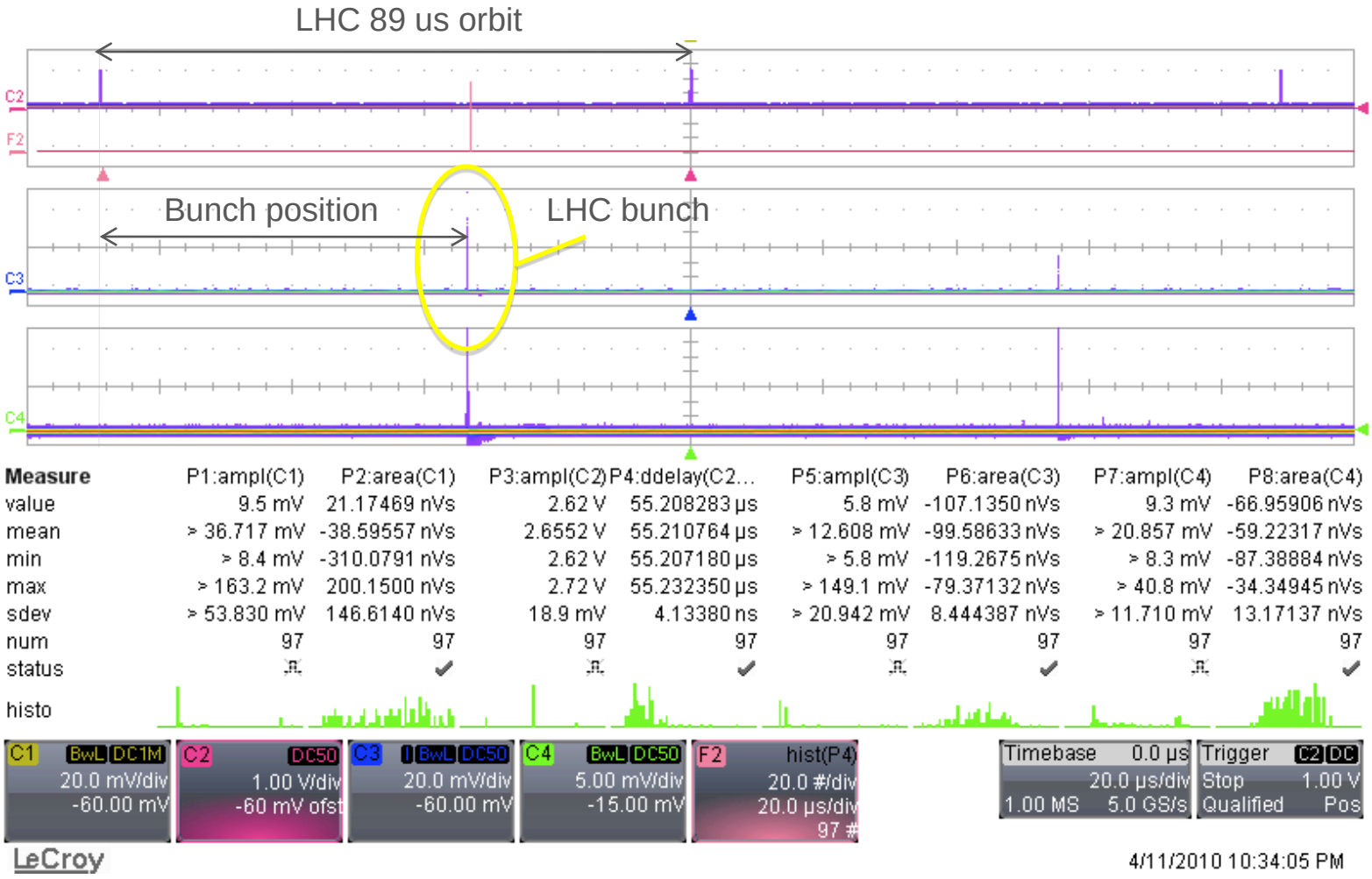

Fall Time vs Pulse Height for Channel 1
Entries 109
Mean x 92.96 mV
Mean y 10.86 ns
RMS x 90.76 mV
RMS y 2.99 ns
Fall time (ns)
Pulse height (mV)


Pulse Width vs Pulse Height for Channel 1
Entries 109
Mean x 92.96 mV
Mean y 5.90 ns
RMS x 90.76 mV
RMS y 1.65 ns
Pulse width (ns)
Pulse height (mV)

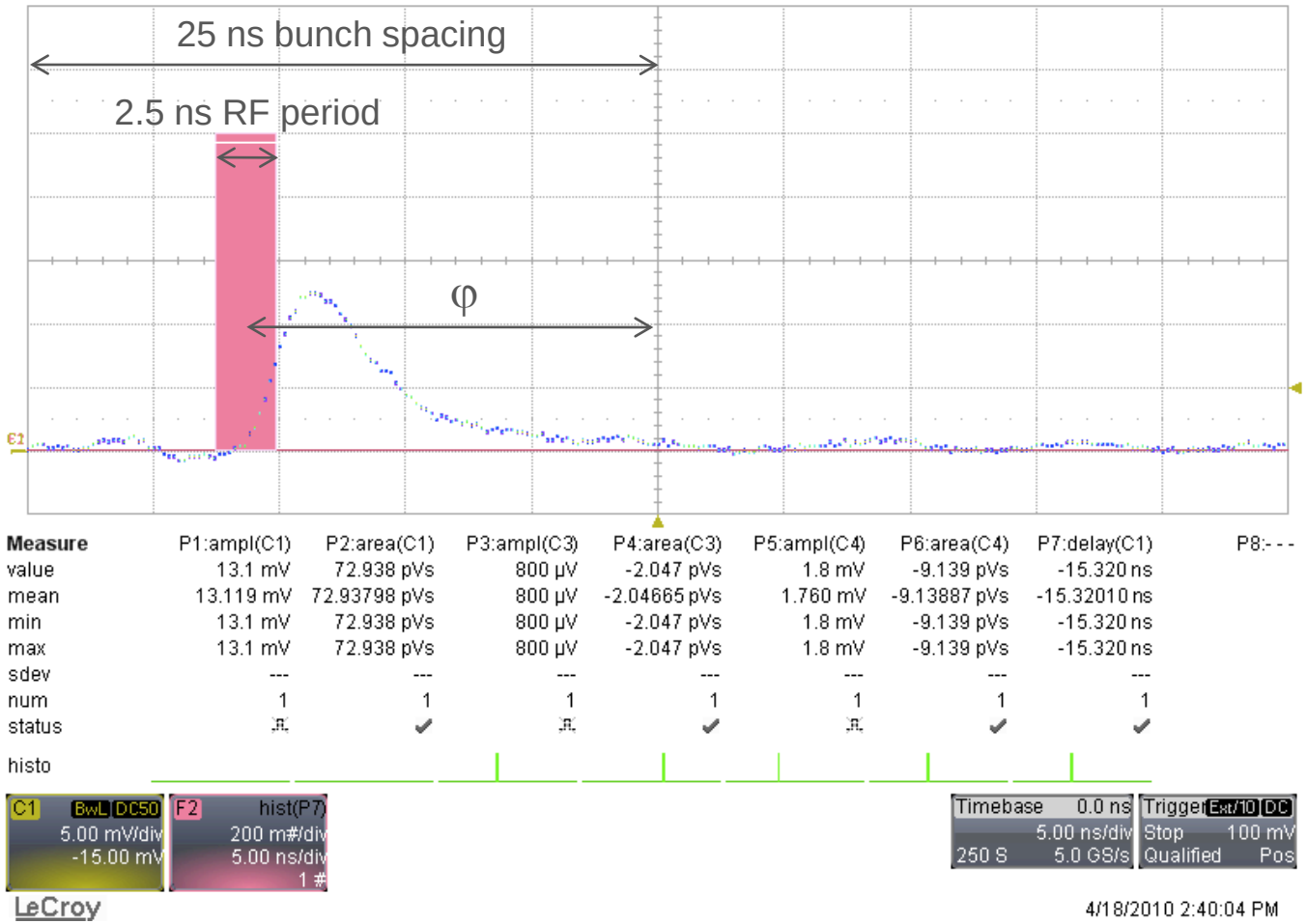

Rise Time vs Pulse Width for Channel 1
Entries 109
Mean x 5.98 ns
Mean y 2.27 ns
RMS x 1.61 ns
RMS y 0.60 ns
Rise time (ns)
Pulse width (ns)


Fall Time vs Pulse Width for Channel 1
Entries 109
Mean x 5.98 ns
Mean y 11.04 ns
RMS x 1.61 ns
RMS y 2.93 ns
Fall time (ns)
Pulse width (ns)

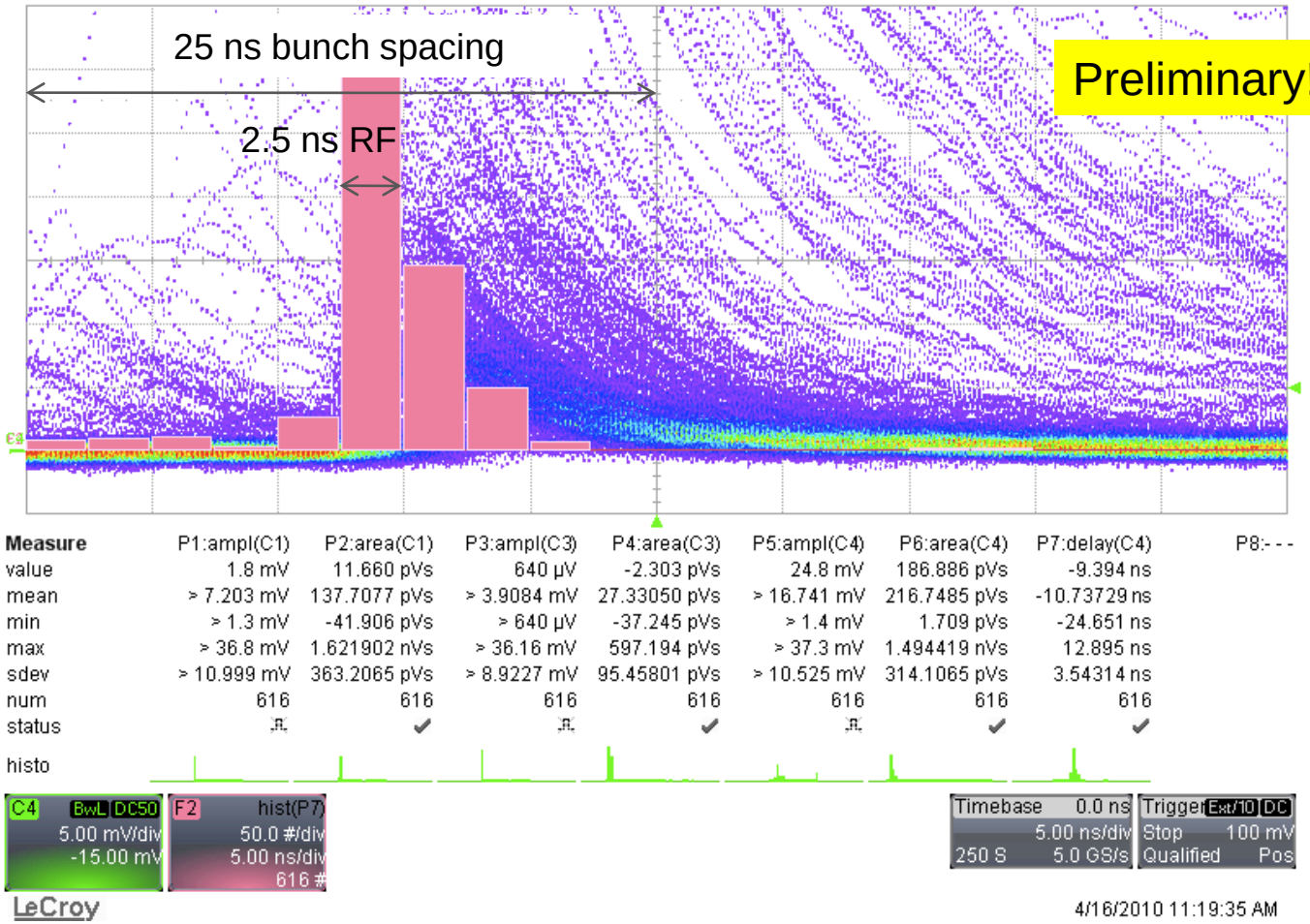
LHC Orbit


LHC 89 us orbit
C2
F2
Bunch position
LHC bunch
C3
C4
Measure P1:ampl(C1) P2:area(C1) P3:ampl(C2) P4:ddelay(C2... P5:ampl(C3) P6:area(C3) P7:ampl(C4) P8:area(C4)
value 9.5 mV 21.17469 nVs 2.62 V 55.208283 µs 5.8 mV -107.1350 nVs 9.3 mV -66.95906 nVs
mean > 36.717 mV -38.59557 nVs 2.6552 V 55.210764 µs > 12.608 mV -99.58633 nVs > 20.857 mV -59.22317 nVs
min > 8.4 mV -310.0791 nVs 2.62 V 55.207180 µs > 5.8 mV -119.2675 nVs > 8.3 mV -87.38884 nVs
max > 163.2 mV 200.1500 nVs 2.72 V 55.232350 µs > 149.1 mV -79.37132 nVs > 40.8 mV -34.34945 nVs
sdev > 53.830 mV 146.6140 nVs 18.9 mV 4.13380 ns > 20.942 mV 8.444387 nVs > 11.710 mV 13.17137 nVs
num 97 97 97 97 97 97 97 97
status
histo
C1 BwL DC1M 20.0 mV/div -60.00 mV
C2 DC50 1.00 V/div -60 mV ofst
C3 BwL DC50 20.0 mV/div -60.00 mV
C4 BwL DC50 5.00 mV/div -15.00 mV
F2 hist(P4) 20.0 #/div 20.0 µs/div 97 #
Timebase 0.0 µs 20.0 µs/div 1.00 MS 5.0 GS/s
Trigger C2 DC Stop 1.00 V Qualified Pos
LeCroy
4/11/2010 10:34:05 PM

400 MHz LHC RF



LHC Phase Measurement



Summary (1/3)

CVD Diamond Beam Monitors are:

- Sensitive: single-particle detection
- High dynamic range: limited by electronics
- Intrinsically fast: 1 ns rise time, 2 ns pulse width

Summary (2/3)

For beam instrumentation applicable to:

- Halo measurements (2 ns double pulse resolution)
- Beam intensity monitoring (dynamic range)
- Energy measurement (< 1% resolution)
- Particle counting (up to GHz)
- TOF measurements (30 ps resolution)

Summary 3/3

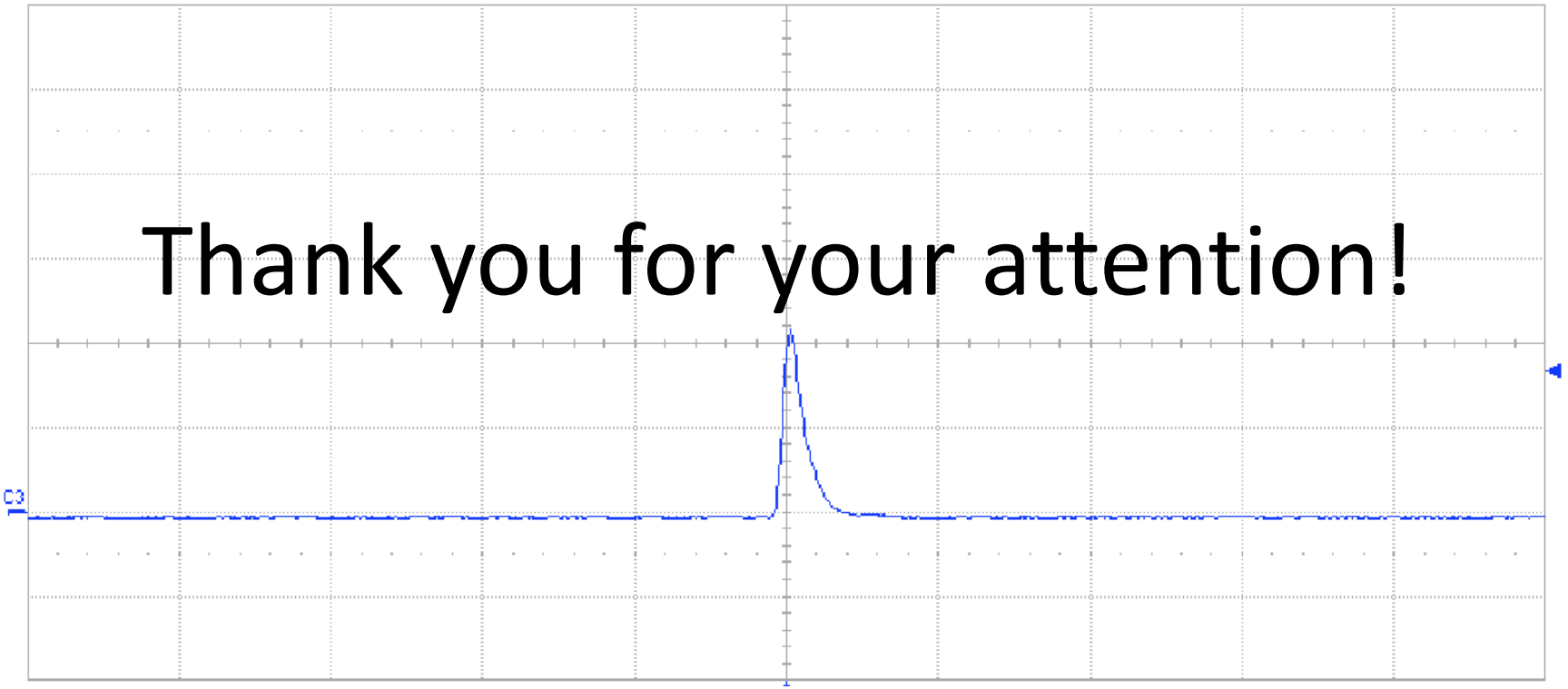
Potential use in:

- HEP accelerators (beam loss monitoring, beam protection for protons, ions)
- Synchrotron light sources
- Medical facilities

Future:

- Photon measurements
- Neutron measurements

Thank you for your attention!



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cividec Instrumentation