“Operational experience with CNGS Primary Beam Line Instrumentation”

Covered:

- BI issues
- OP performance

Acknowledgements:

- J. Wenninger (BE/OP)
  - http://jwenning.web.cern.ch/jwenning/CNGS.html
- E. Gschwendtner (EN/MEF)
- M. Meddahi (TE/ABT)
- BE/BI colleagues

Overview

- A few words about specifications
- A reminder about the SPS cycle
- BI systems involved
- Conclusions

Specifications #1

- Detailed in EDMS document: 376330/2
- Relevant parameters for the primary beam-line

Table 1: Time structure of the SPS pulse for CNGS

Parameter	*value*
Number of trains	2
Train separation	50 ms
Number of bunches in a train	2100
Bunch separation	5 ns
Train duration	10.5 μs
Minimum repetition period	6s

It was not foreseen to use LHC-type beams for the CNGS line

Table 2: Parameters of the CNGS beam

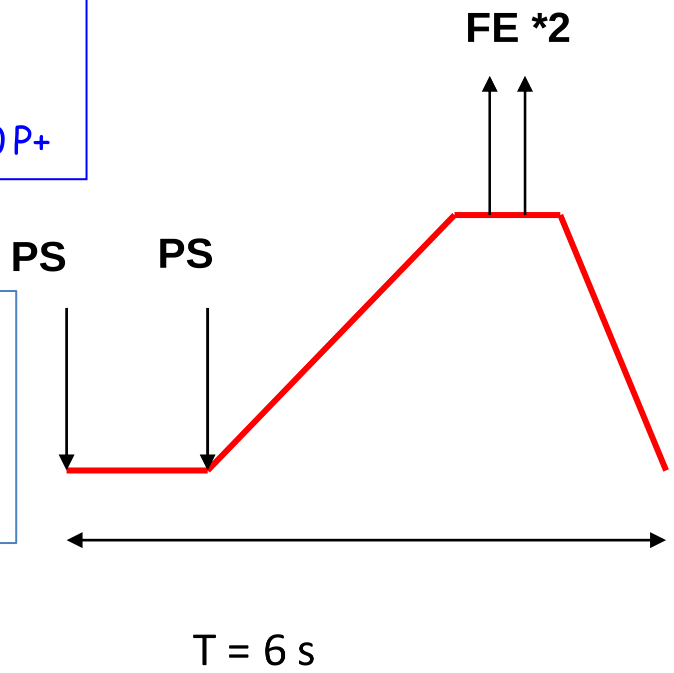
parameter		*nominal*	*expected range*	*Unit*
Momentum		400	350 to 450	GeV/c
Normalized emittance (1σ)	H	12	10.8 to 13.2	10^{-6} m·rad
	V	12	7 to 13.2	
Physical emittance (1σ)	H	28	25 to 32	10^{-9} m·rad
	V	28	16.3 to 32	
Train Charge		$2.4\ 10^{13}$	$1.0\ 10^{12}$ to $3.5\ 10^{13}$	p
Bunch Charge		$1.14\ 10^{10}$	$4.8\ 10^{8}$ to $1.7\ 10^{10}$	p
Bunch length (4σ)		2		ns
Momentum spread (1σ)		0.07	0.056 to 0.084	%
Beam size at target (1σ)		0.53	0.27 to 0.80	mm
Beam divergence at target (1σ)		0.053	0.035 to 0.1	mrad

Since several years, train-intensity has been half the maximum (~1.8E13 charges) (radiation concerns in the injectors)

SPS Cycle (another reminder)

- 2 Injections at 0 and 1200 ms (14GeV)
- Ramp from 1260 to 4200 ms (->400GeV)
- Flat top from 4200 to 4290 ms
- 2 Fast extractions spaced by only 50ms
- ***Care needed for acquisitions/interlocks***
- Cycle length 6 s – 5 BPs
- Typical total beam intensity at flat-top 3600E10 P+

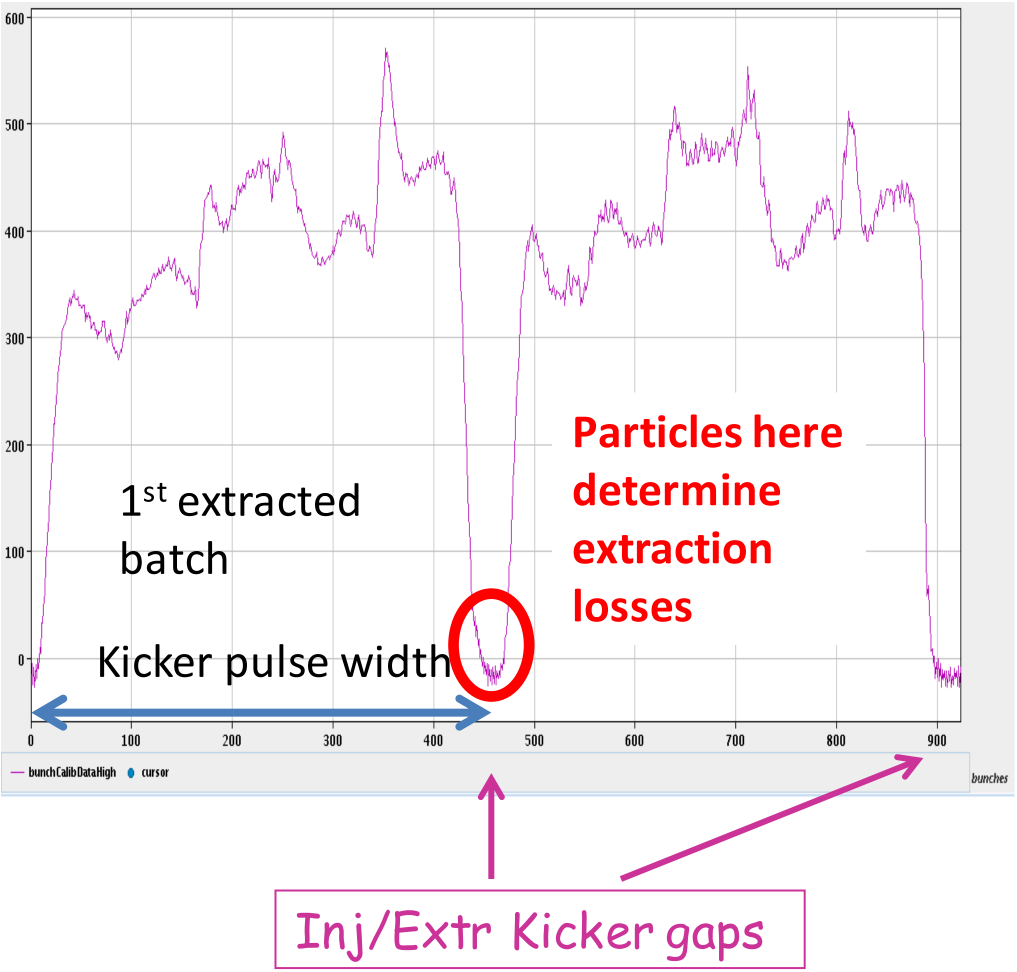
Several 100kW beam power
⇒ Interlocks needed
⇒ SW based for BE/BI with hardware (electrical) interface to SPS/CNGS BIS



BI Systems

- Fast BCT
  - SPS ring for intensity profile
  - Beginning and end of CNGS transfer-line
- BPM
  - Bumped orbit in SPS for extraction position interlock
  - Transfer-line trajectory
- BLM
  - 8 Ionisation chambers in SPS extraction region
  - 18 Ionisation chambers in transfer-line
  - 42 Ionisation chambers as muon detectors
    - Used for target steering
  - Diamond detectors
- BTV Single-pass Beam profile based on OTR

Fast SPS Ring BCT



Very useful tool to visualise SPS filling pattern from 1st PS injection to fast extractions (capture losses etc)

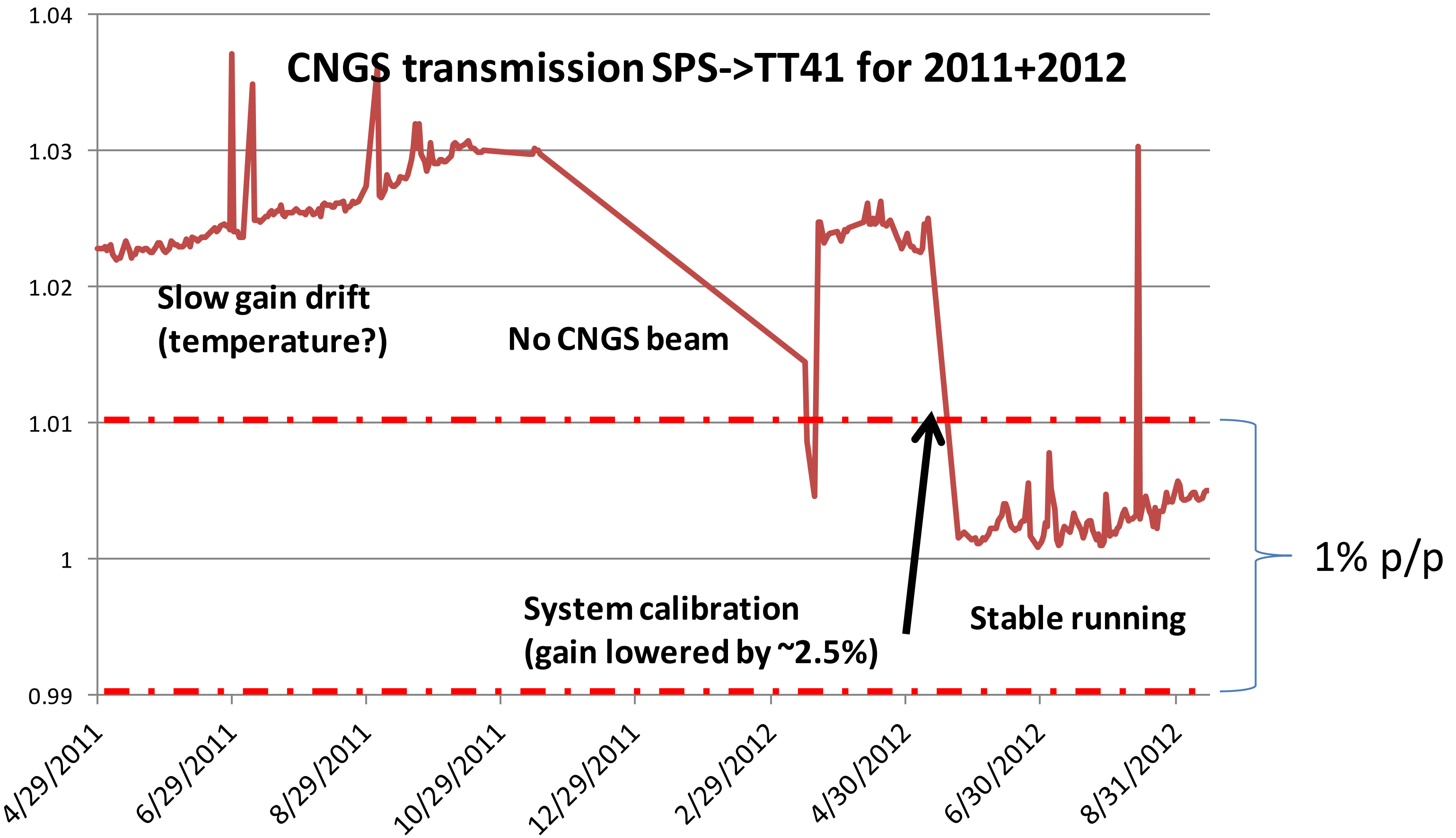
- Standard SPS Fast BCT tank and toroid
- Analogue 2MHz bandwidth

Transfer-line BCTs #1

- Specification:
  - Absolute precision of 1% (above 1E12 charges)
  - Must not be affected by the transverse beam position within +- 16mm
- Technical implementation:
  - LHC-type analogue integrators (40MHz) with 3MHz analogue filtering for total intensity
  - Very long signal cable (>1km) from downstream detector to acquisition system (not radiation hard)

Transfer-line BCTs #2

- Results using **SPS DC BCT** as reference:

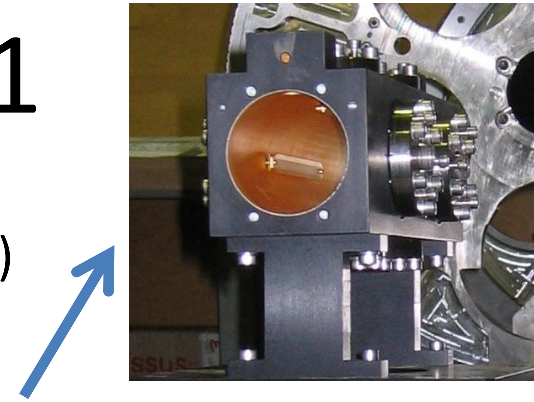


SPS Orbit Position Interlock

- Before extraction the SPS beam is bumped out by ~ 31 mm to approach the magnetic septum
  - Non-linear behaviour of “BPCE” coupler requires polynomial correction (additional ~10% gain at 30mm)

  (http://cdsweb.cern.ch/record/702777/files/ab-note-2003-046.pdf)
- ~20 ms before each fast extraction, active beam permit must be given (extraction interlock system) to protect extraction channel and transfer lines
- Performance deemed adequate for CNGS operation
  - Commissioning of independent system not successful

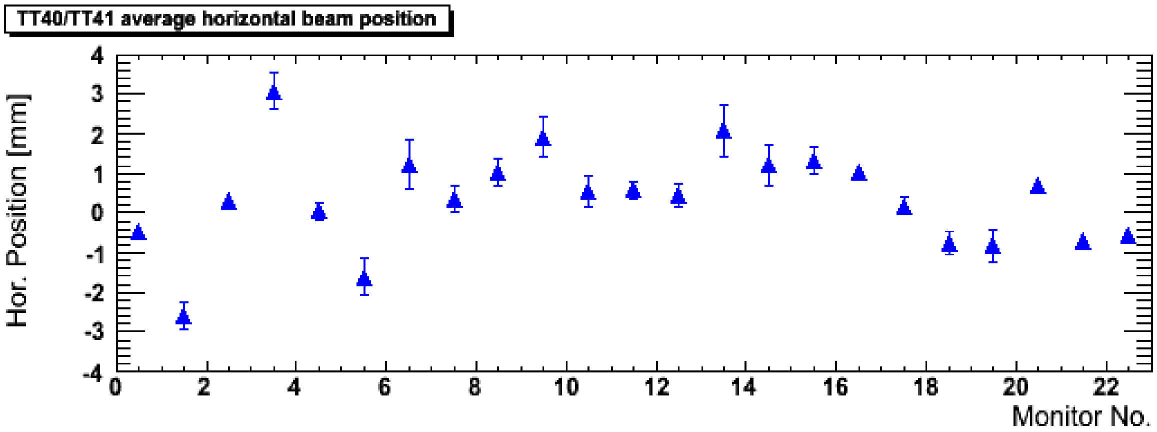
Transfer-line BPMs #1

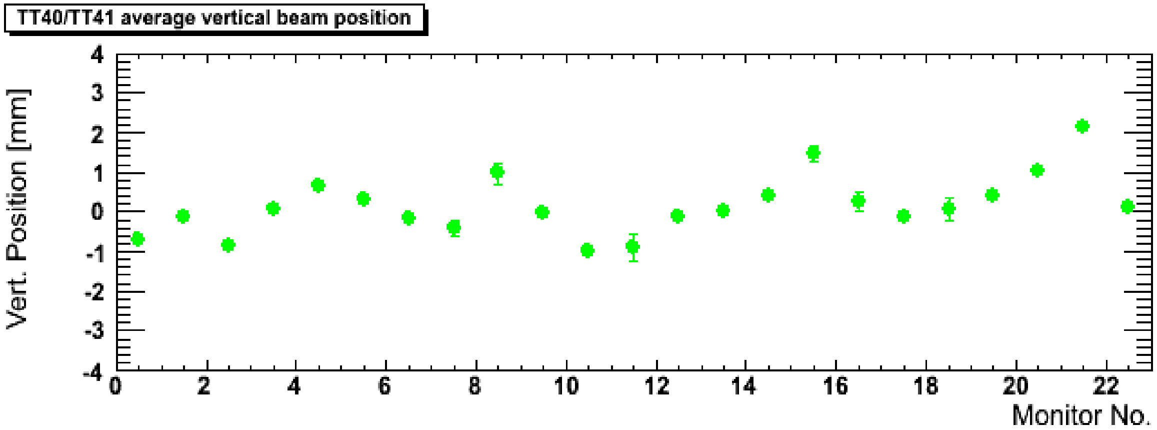


- Specifications:
  - Transfer-line (60 mm vacuum chamber aperture)
    - Accuracy (RMS uncertainty): 0.25mm
    - Resolution: 0.5mm
  - Target (smaller aperture required due to upstream collimator)
    - Accuracy (RMS uncertainty): 0.1mm
    - Resolution: 0.2mm
    - Requirement to work in air (no vacuum after exit window)
- Implementation (see NBI'2006 talk by R. Jones)
  - Auto-triggered system with ADCs in tunnel/gallery (low radiation)
    - **Ease of setting-up (no external 'fast' timing required) + low cable cost**
    - **Difficulties encountered with external noise sources close to target**
      - 2012: had to disable 2 BPMs towards the end of TT41 (no time to investigate)
  - Large integration window (8us out of 10.5us) helps reducing noise
  - System also seen to work with LHC-type bunches spaced by 100nsec (using shorter integration time)

Transfer-line BPMs #2

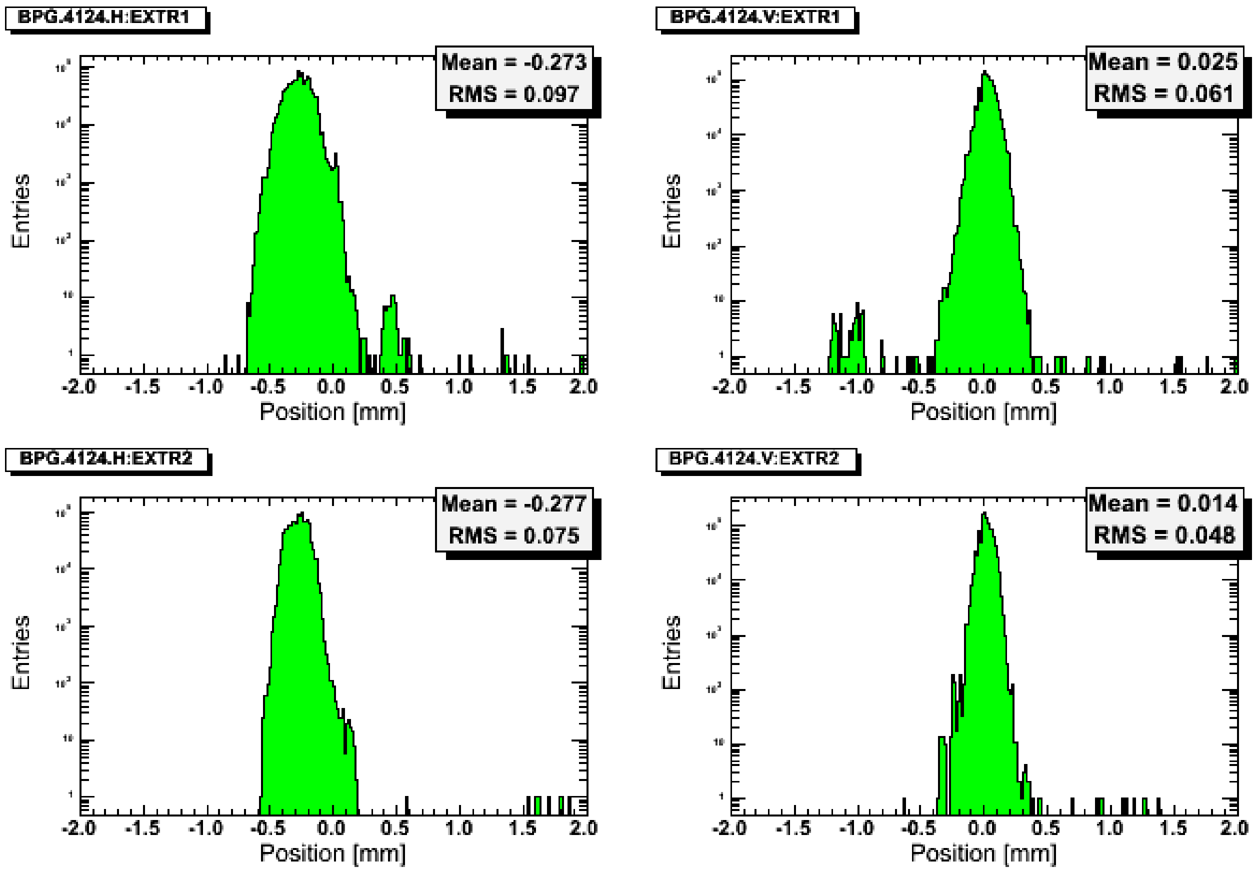
- RMS position change over the entire run 0.1-0.2 mm
- Effect of dispersion on arc monitors in horizontal plane (energy spread fluctuations)
- Positions interlocked (per extraction) typical limits: 2.5 mm in line, 1.5mm on target BPM



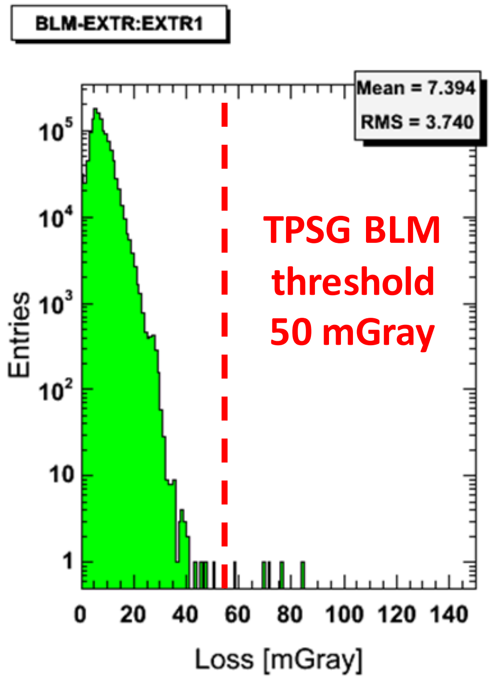


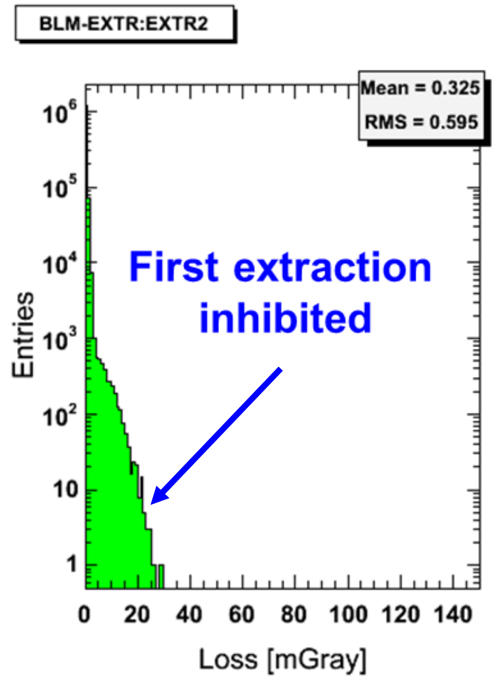
Target beam position #1

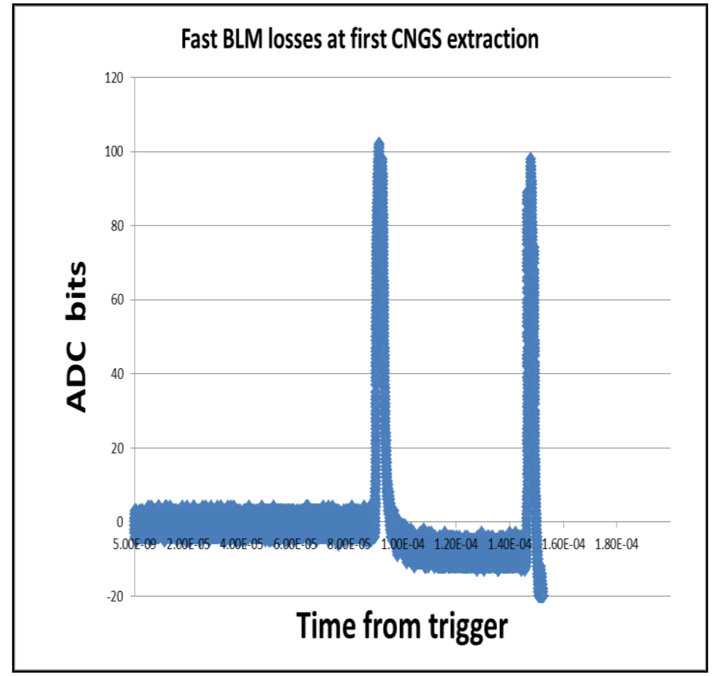
- Position stability of extracted beam was excellent, ~90 um in H and 60 um in V
- Target steering is since 2011 done using centroid of downstream muon monitors
  - **Very long lever arm gives additional gain in resolution**
- Minor manual corrections performed by OP ~4 times/day (effect not yet understood)



SPS Extraction BLMs #1





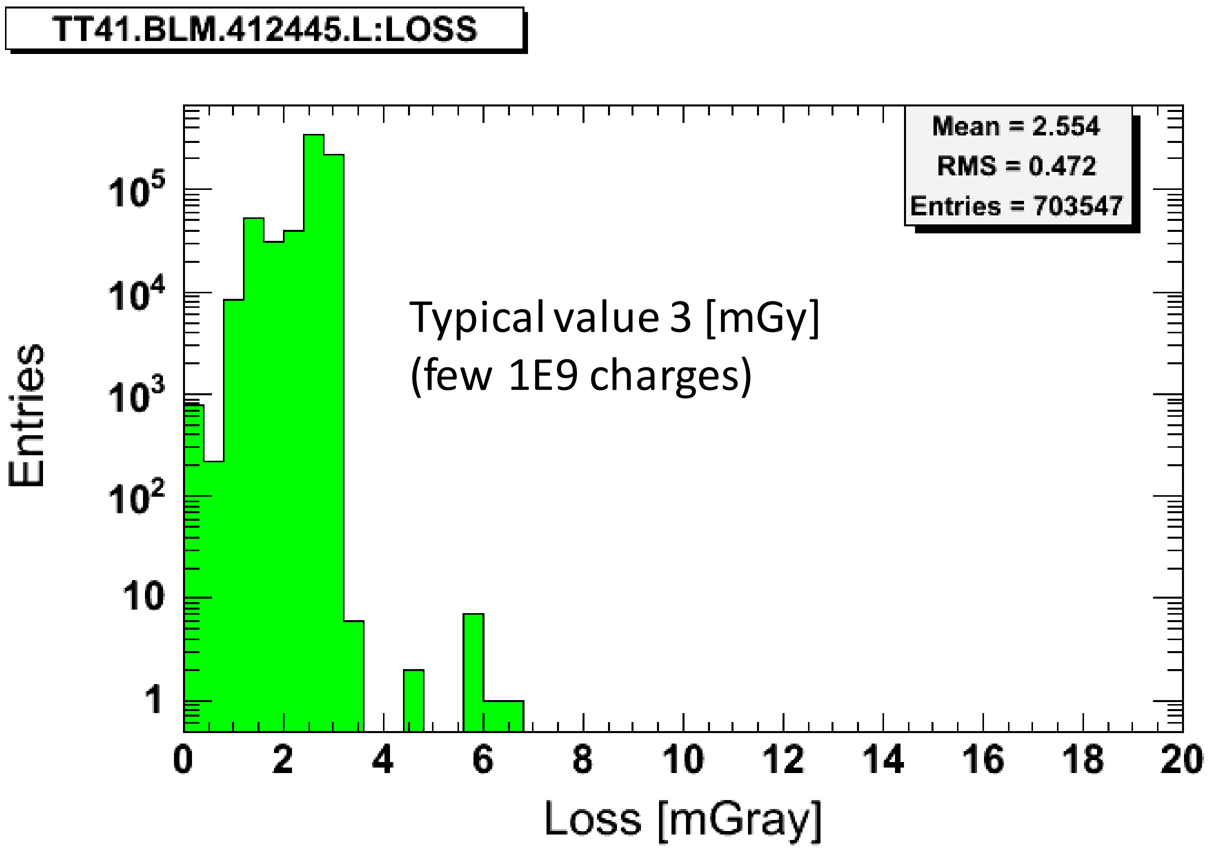


- *No specifications were provided – electronics based on existing system (SPS->LHC transfer) with ~200 micro-Gray resolution*
- *Losses at first extraction higher than 2nd (beam in kicker gaps)*
- *Hardware interlock dumps beam in the SPS (for 1st extraction)*

- *Diamond-based BLM detectors with oscilloscope read-out (Fs = 500MHz)*
- *Recent addition to BE-BI tool-box*
- *Complete understanding of analogue signals still to be reached*

SPS Extraction BLMs #2

Losses on target collimator (~1mm diameter)



Beam Profile devices "BTV"

- Performance covered during NBI'2006 (E. Bravin)
  - https://edms.cern.ch/file/771826/1/presentation.pdf
- OTR screens:
  - 75 μm carbon for high intensity
  - 12 μm titanium for low intensity
- Performance obtained:
  - **~10% precision on the sigma in the beam-line (ok for optics checks)**
  - **Difficult conditions close to the target (small beam sizes and high radiation)**
- Long-term radiation hardness vs. image quality difficult problem
- Devices in extraction area for extraction setting-up (visual observation) adequate (~1Mrad lifetime)
- Normal CCD devices used in TT41 transfer-line
  - **Some issues seen close to target area due to radiation**
    - Could be used during optics change
- Rad-hard cameras near T40 target died after ~2 years of operation
  - Saw signal deterioration very quickly after start-up with high intensity
  - Hardware obsolete and not required for daily operation so was not replaced

Conclusions

- Primary beam-line instrumentation (BPM, BCT and BLM) very reliable
  - Useful experience gained for future projects (AWAKE, CERN Short base-line neutrino facility..)
  - New instrumentation based on fast diamond-detectors bring additional functionality (See: H. Jansen's talk in next session)
- Performance adequate for daily operation
  - Fast BCT shows sign of slow gain drifts
    - Frequent calibration campaigns required to maintain 1% accuracy
  - BTV devices suffer from radiation damage
- Lessons for future installations
  - BPM
    - Target BPM in air was very useful & worked well from the beginning
    - Combination of log-amp electronics & button BPMs gives linear response
    - Auto-trigger system useful for commissioning but susceptible to external noise
  - Muon monitors used for beam steering on the target
  - Solution for rad-hard electronics & cameras needed
  - Interlock requirements need to be specified & included at early stage
  - Well instrumented line allows for fast set-up and stable operation