International Beam Instrumentation Conference
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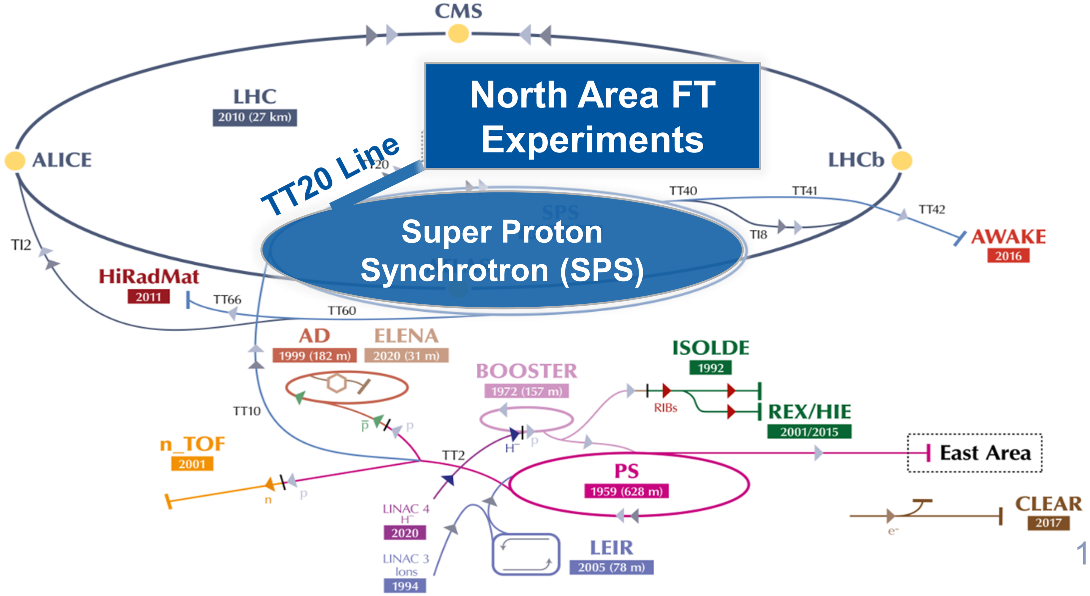
2022 IBIC

WE3C3: Fast Spill Monitor Studies for the SPS Fixed Target Beams

F.Roncarolo, CERN SY-BI



S.Mazzoni, D.Belohrad , S. Burger, M.Martin
E.Calvo, E.Effinger, C.Zamantzas
J.Storey. J.Tan, I.Ortega
V.Kain, M.Fraser, F.M.Velotti, P.A. Arrutia Sota
F.Addesa, L.Esposito

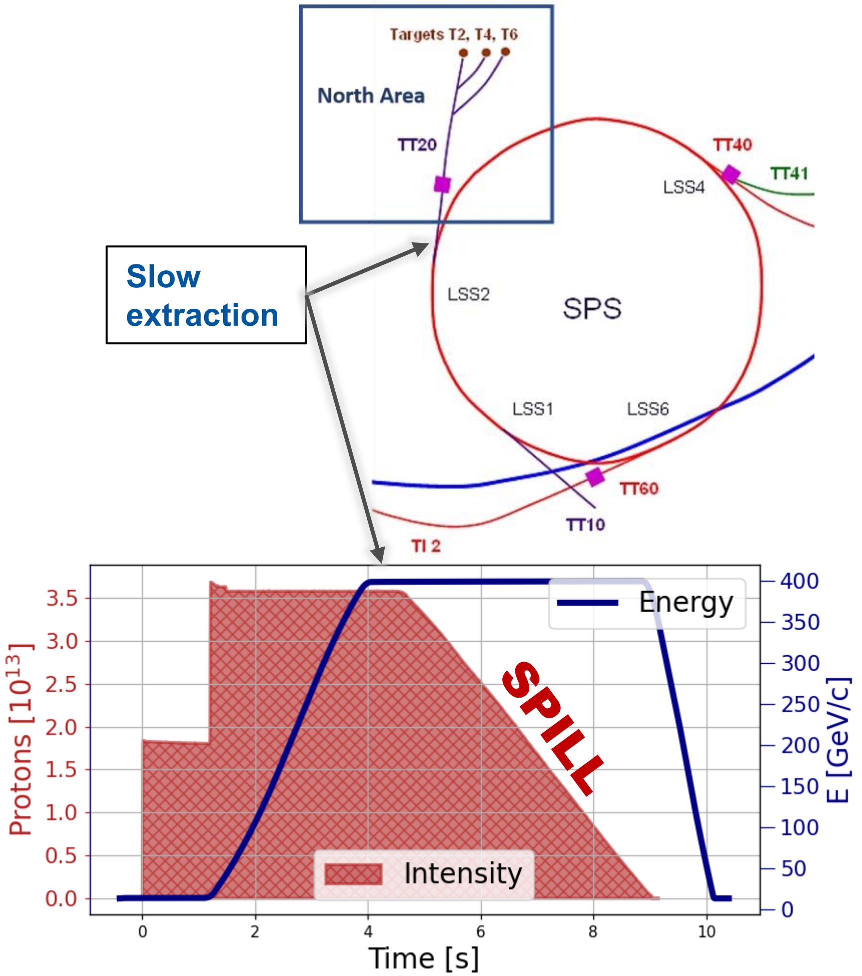
CERN SPS for Fixed Target Experiments

Protons @ 400 GeV sent towards NA experiments via **Slow Extraction** process

– RF disabled at flat top, ideally **fully de-bunched** beam is sent to transfer line

Spill '**quality**' affected at macro and micro-structure level by:

– **hysteresis**, non-reproducibility of **momentum distribution**, regulation and **ripples** of power supplies, **spikes** at RF switch-off

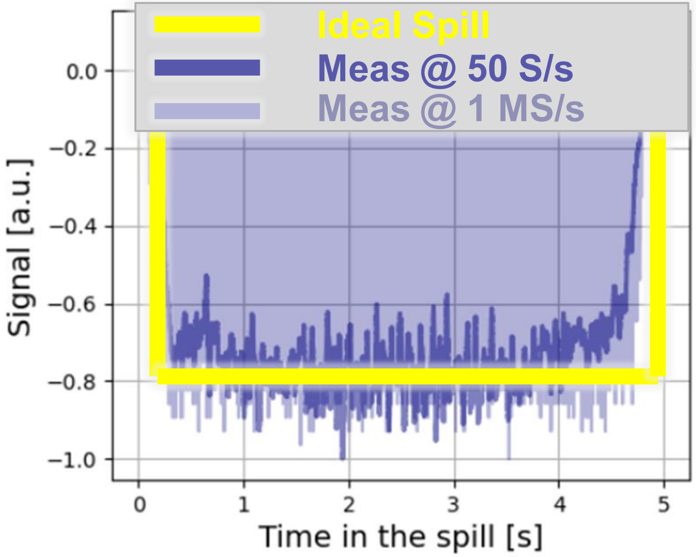


V.Kein @ :

ICFA Mini-Workshop on Slow Extraction, 2022
24 Jan 2022, 06:00 → 28 Jan 2022, 08:40 Asia/Tokyo

SPS_SX_status_plans_Jan2022 (kek.jp)

Spill Structure



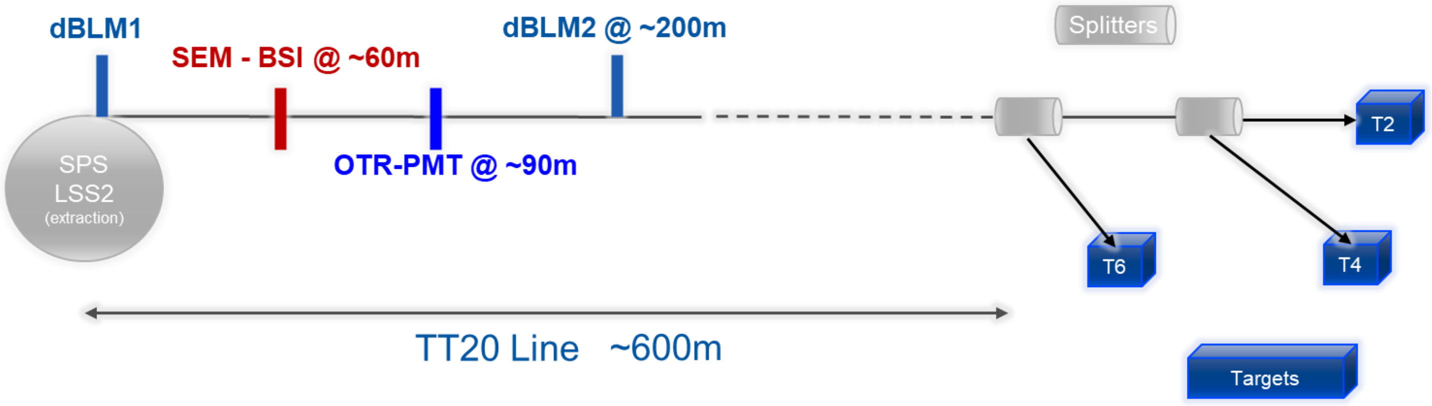
Key parameters of interest for the SPS spill monitors requirements

Parameter	Value or Range	Comment
Spill Duration	4.8 [s] 1 [s]	present operation future, e.g. PBC
Beam Intensity	1-400 [1e11p]	
Spectrum Harmonics of interest	50 Hz,100 Hz 43.86 kHz 476 kHz 200 MHz 800 MHz 10 GHz	e.g. Noise, PC ripples SPS 1^{st} and 2^{nd} Harmonics* PS 1st Harmonic** RF capture RF long. blow-up Future, e.g. PBC

Monitoring the 'spill quality'

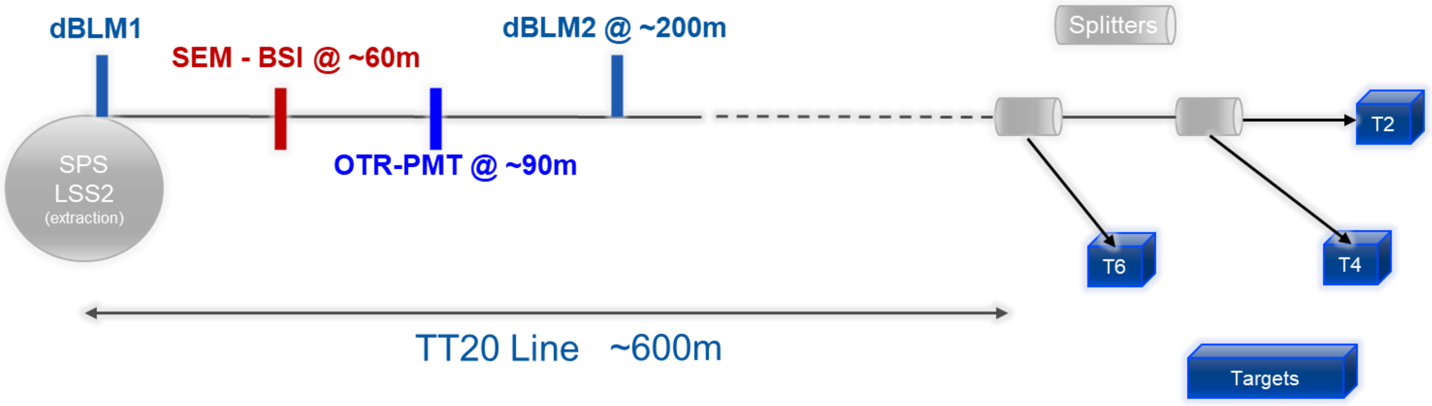
- **Essential** for spill control and successful physics in NA
- **Challenging**, at first because single pass de-bunched beams can't be measured by standard synchrotron diagnostics as Beam Current Transformers

From few nA to few uA
From few Hz to several GHz



CERN SPS Present Spill Monitors

1. Secondary Emission Monitor (SEM)
2. 2 x Diamond Beam Loss Monitors (dBLM)
3. Optical Transition Radiation – Photomultiplier Monitor (OTR-PMT)



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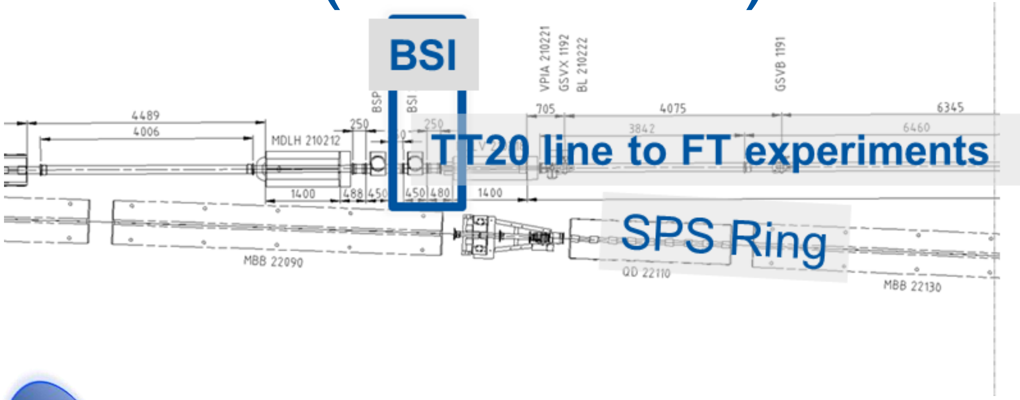
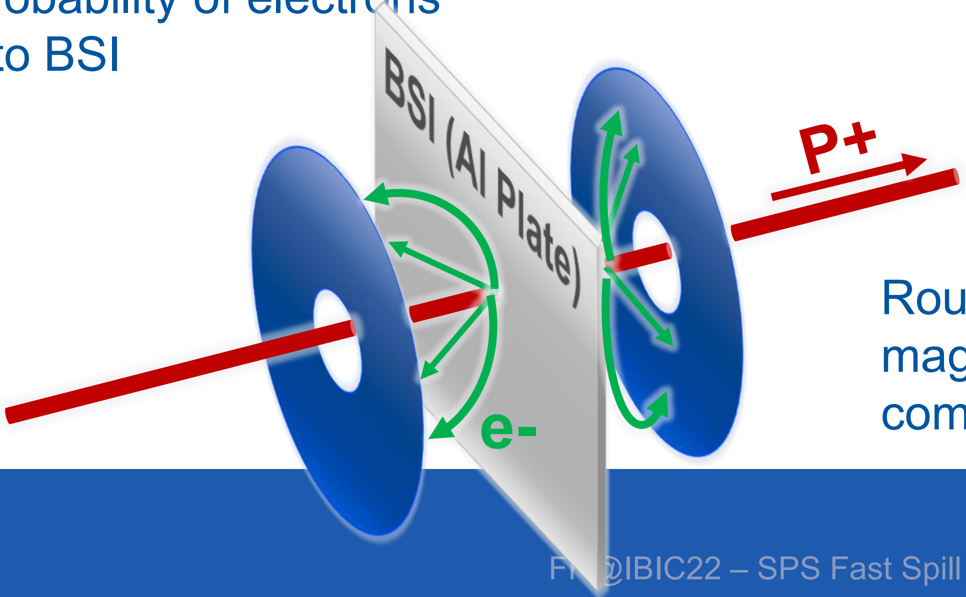
Secondary Emission Monitor (SEM - BSI)



SEM BSI = Aluminum foil
Proton beam generates **Secondary Electrons** , pulled by **bias (+200V) plates** to minimize probability of electrons going back to BSI



Routinely used to **feedforward** magnet power converters and compensate **50-100Hz** ripples

Secondary Emission Monitor (SEM)

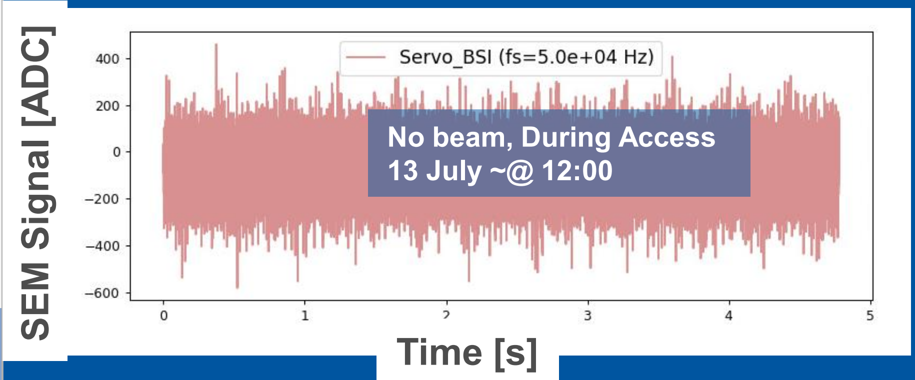
DAQ

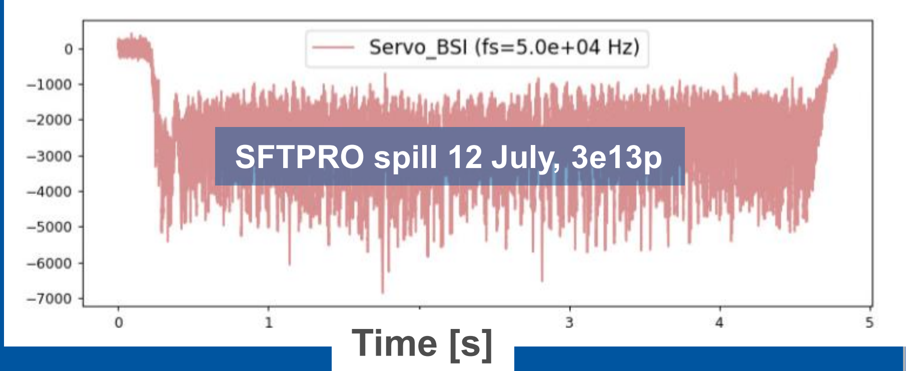
- Signal = SE from Al sheet
- Amplifier in the tunnel (10MHz BW)
- CK50 cables (>200m)
- Low pass filter (1kHz) to suppress high freq noise
- VME ADC (100kHz BW, 200kS/s, 16bit)

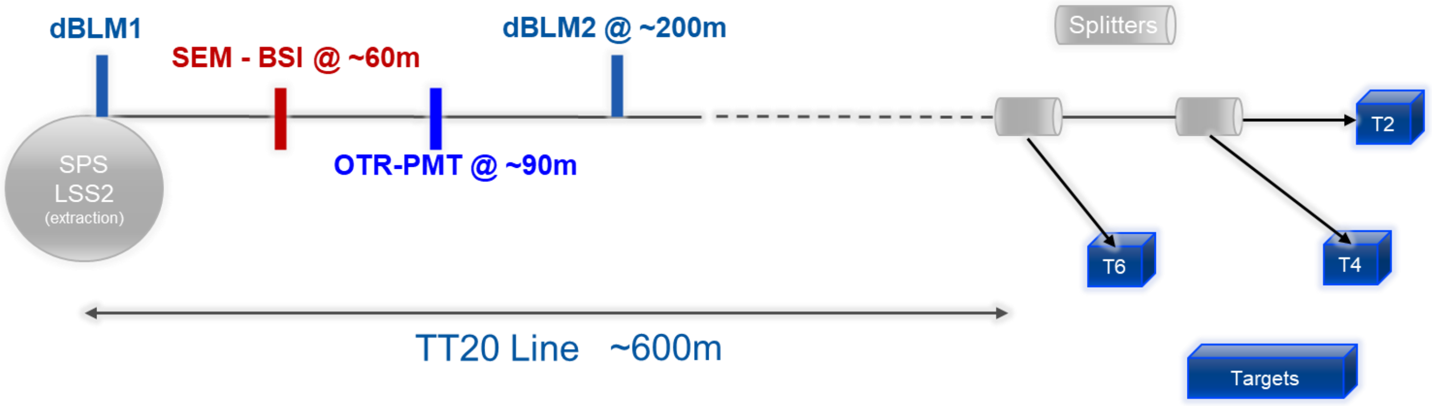
Signal / Noise Ratio

- Low signal (SEY=~4%) and pickup noise
- **SNR** = ~ 4000 / 800 (p2p) [ADC counts] **~= 5** in this example, after **low pass @ 1kHz**

Is noise picked up in vacuum?
Refurbishment of in vacuum detector + cabling foreseen end of 2022







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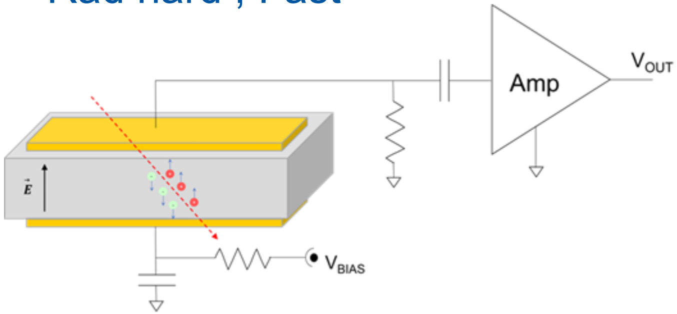
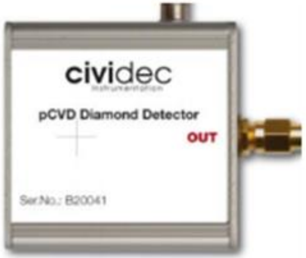
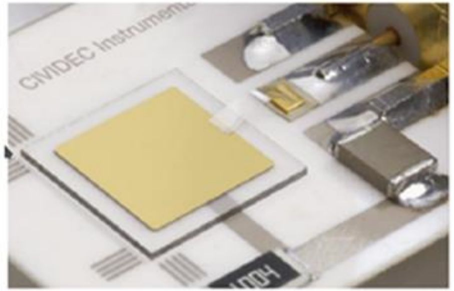
Diamond Beam Loss Monitors (dBLM)

- Chemical Vapor Deposition (CVD) , 1cm x 1cm , 500um thick, Gold Coated
- Electron-Hole pairs from ionizing radiation traversing the substrate
- Used for many years in CERN synchrotrons (LHC, SPS, PS, PSB) and inj/extr beamlines
- Rad hard , Fast

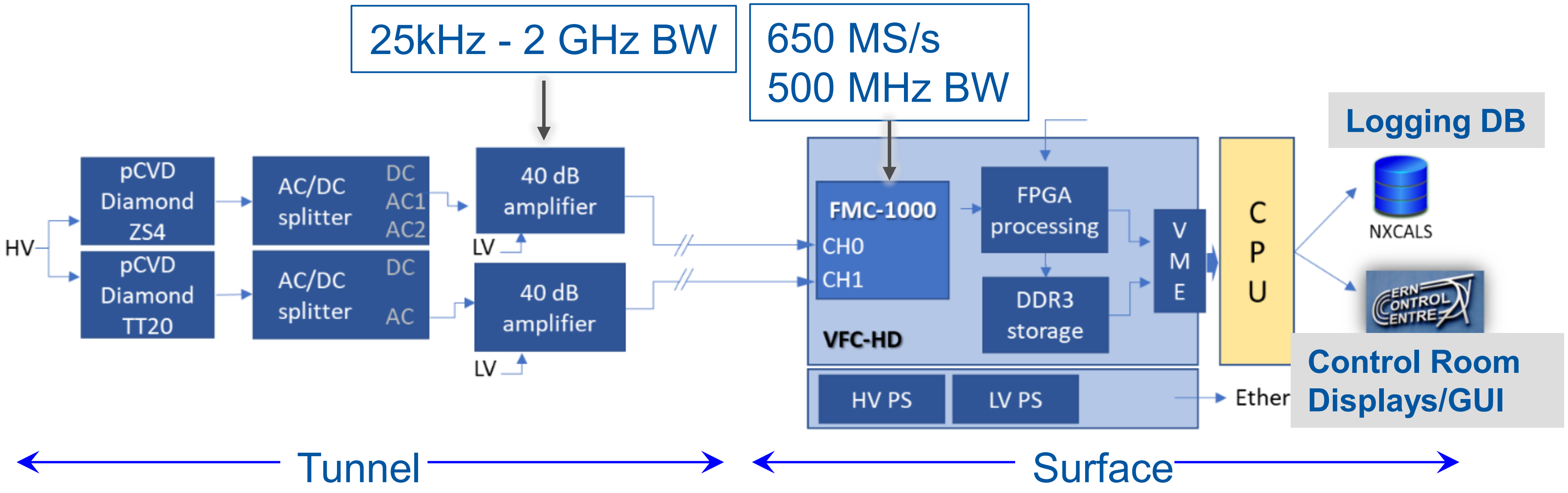






- **E. Calvo Giraldo et al., "The Diamond Beam Loss Monitoring System at CERN LHC and SPS", in These Proceedings, 2022. TU2C2**
- H. Frais-Kolbl, E. Griesmayer, H. Kagan, and H. Pernegger, "A fast low-noise charged-particle CVD diamond detector," IEEE Transactions on Nuclear Science, vol. 51, no. 6,pp. 3833–3837, 2004, doi:10.1109/TNS.2004.839366
- B. Dehning, E. Effinger, H. Pernegger, D. Dobos, H. Frais-Kolbl, and E. Griesmayer, "Test of a Diamond Detector Using Unbunched Beam Halo Particles," CERN, Tech. Rep., 2010, https://cds.cern.ch/record/1258407

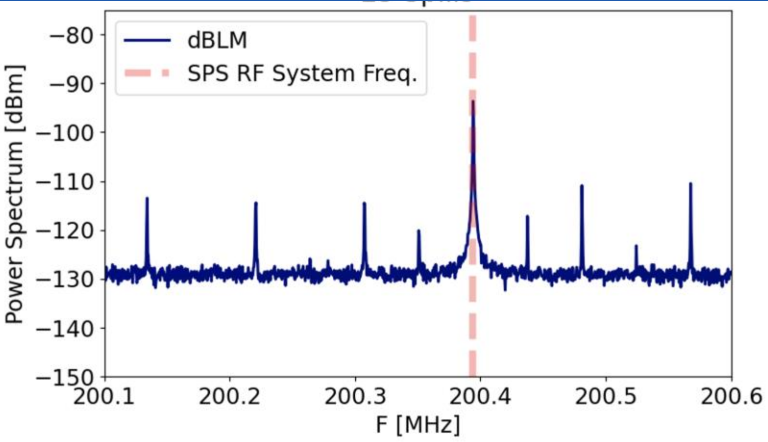
dBLM DAQ



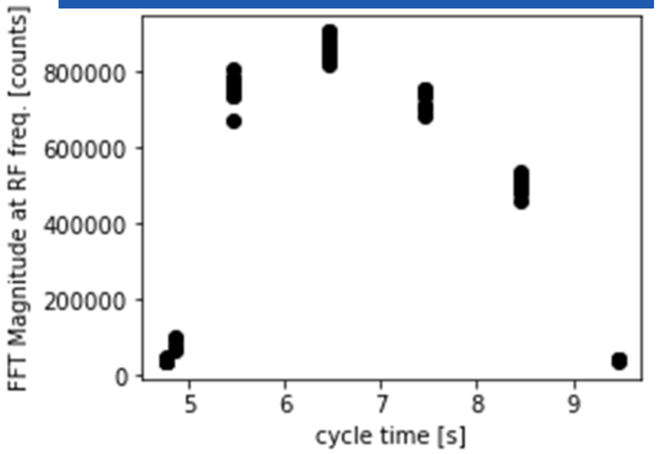
System fully integrated into CERN control system, data logged

dBLM – Measurement Example

200 MHz Harmonic in a 2ms ‘chunk’ of the spill

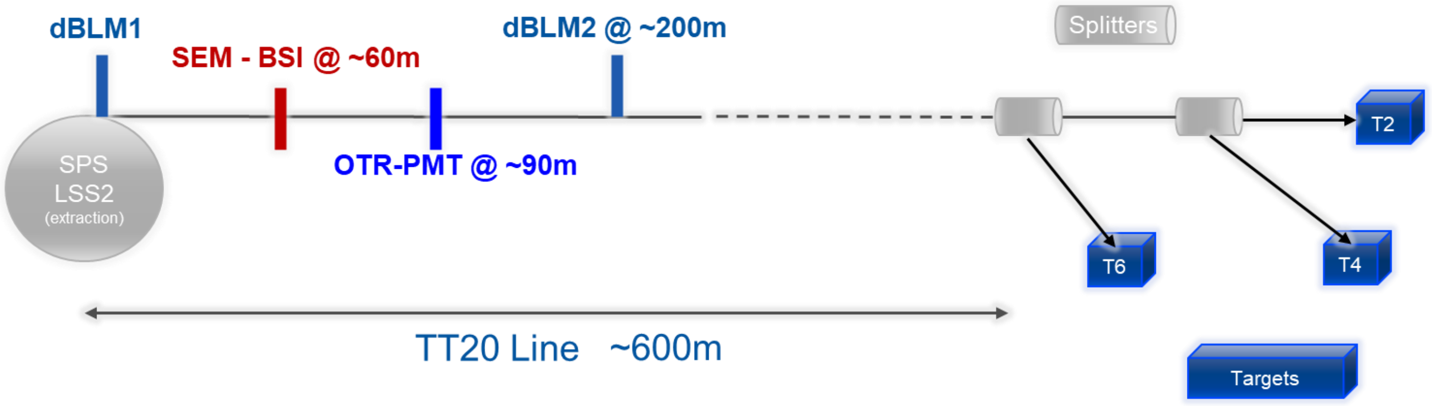


200 MHz Evolution along the spill



Measurements achieved after subtracting average signal spectrum without beam

P. A. Arrutia Sota et al. “dBlms first results and md planning, presentation at CERN SLAG” (2022), `https://indico.cern.ch/event/1155679`



CERN SPS Present Spill Monitors

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3. **Optical Transition Radiation – Photomultiplier Monitor (OTR-PMT)**

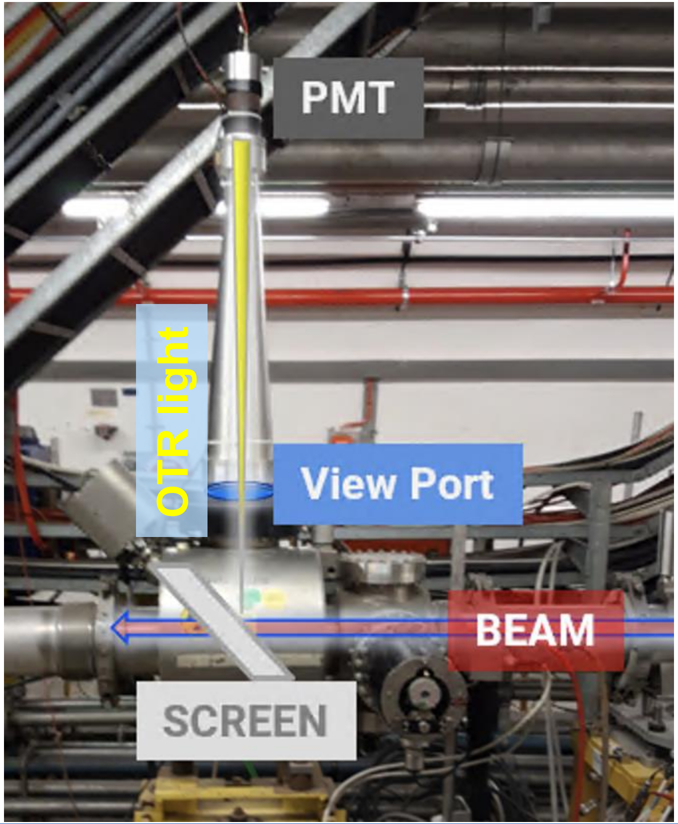
Optical Transition Radiation (OTR) – Photomultiplier (PMT)

Concept: count (instead of 'standard' imaging) photons from OTR

2021-22:
Old system refurbished with new Ti screen, PMT and amplifier

From the start we could measure spill structure and power spectrum from DC to 300 MHz

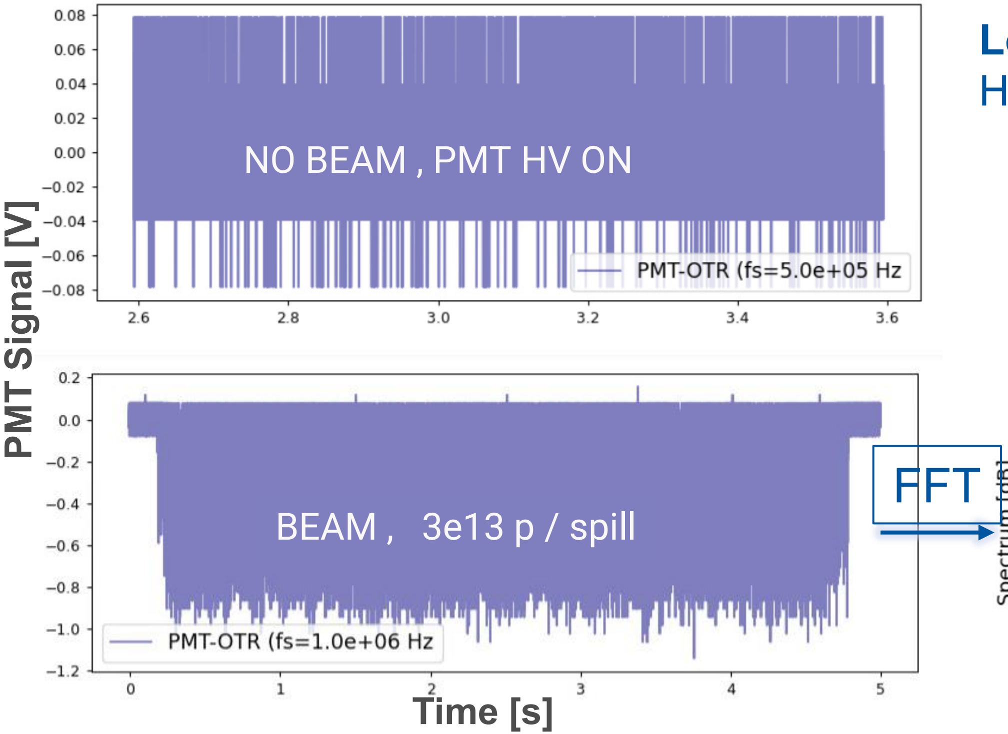
High signal even with OTR screen OUT …
→ System is sensitive to beam losses



PMT – OTR DAQ

- **Fast PMT** ~ 0.8 ns anode pulse rise time
- **Wide band (DC-300MHz) amplifier** @ PMT output
- CK50 cables to surface (>200m)
- Signal duplicated to 2 separate PicoScope® **digitizers (500MHz BW, 5GS/s, 2GS Memory)**
  1. Set at ~low rate (e.g. **1MHz**) to cover all spill (**5sec**)
  2. Set at high rate (e.g. **625MHz**) to cover 'chunks' of **1-10 ms** along the spill
- PicoScope® USB connection to Linux **PC integrated into CERN control system (FESA)**

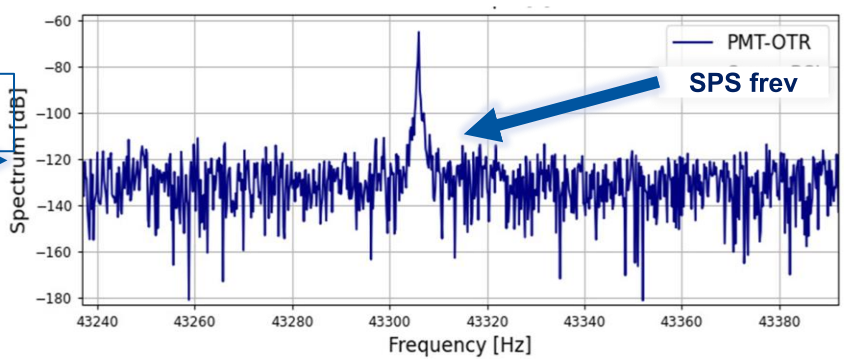
OTR – PMT (example with fs=1MHz)



Low noise.

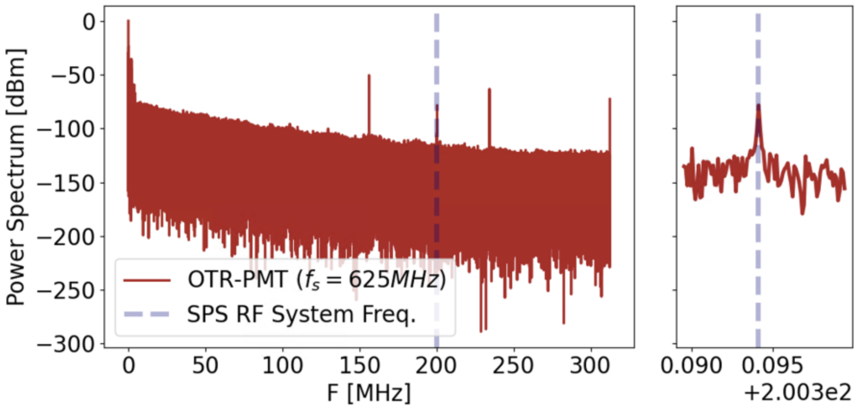
Here, with no beam and PMT HV ON

- **SNR**~=0.9/0.160=**5.6** in this example
- Similar to SEM, but here there is no low pass filter

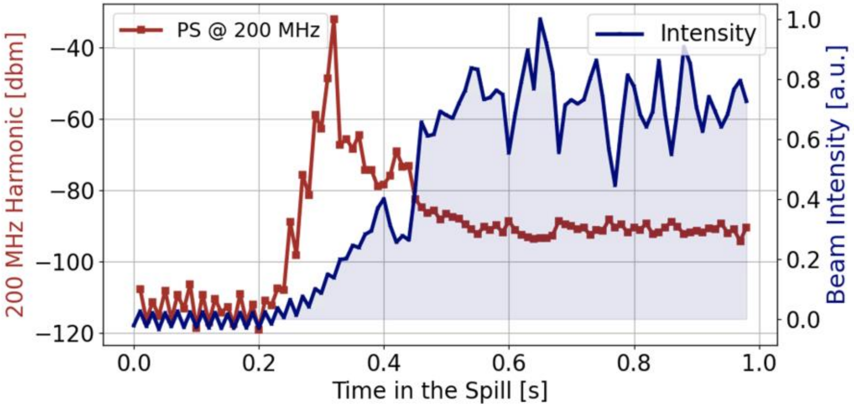


OTR – PMT (example with fs=625 MHz)

High frequency acquisition on a 'chunk' to study presence SPS RF (nominal=200.3941 MHz) in spill intensity



Scanned trigger delay to measure 200 MHz harmonic along the spill (here only first part of the spill)

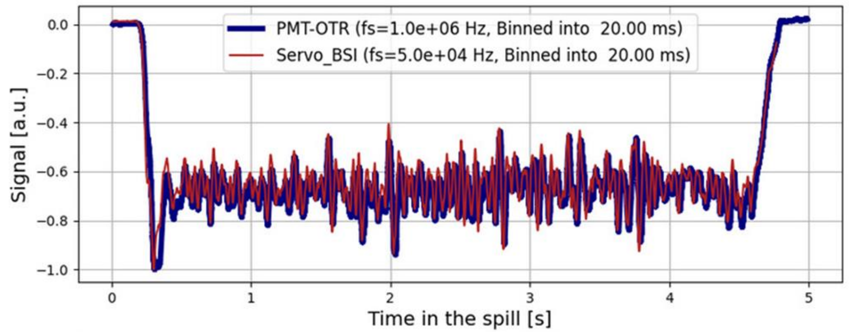


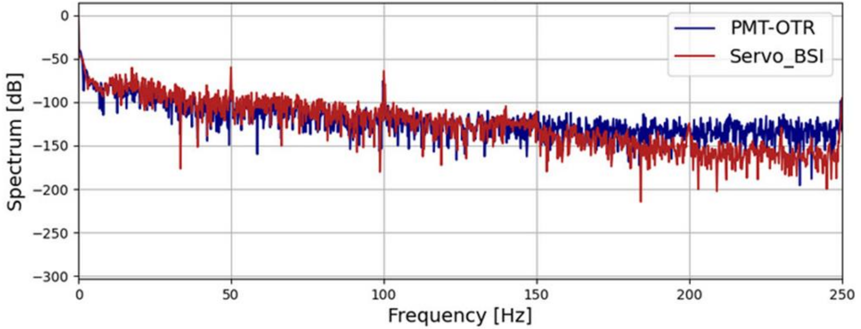
Comparison between SEM and OTR-PMT systems

OTR-PMT vs SEM

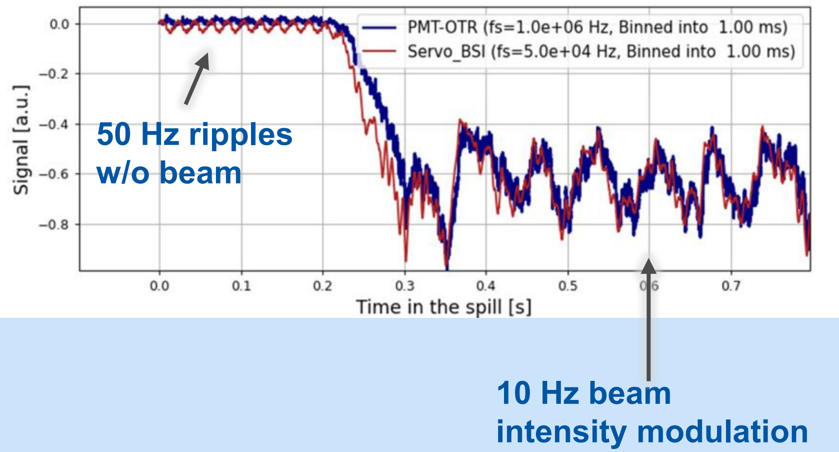
Binning both monitors in equal time intervals

@ 20 ms





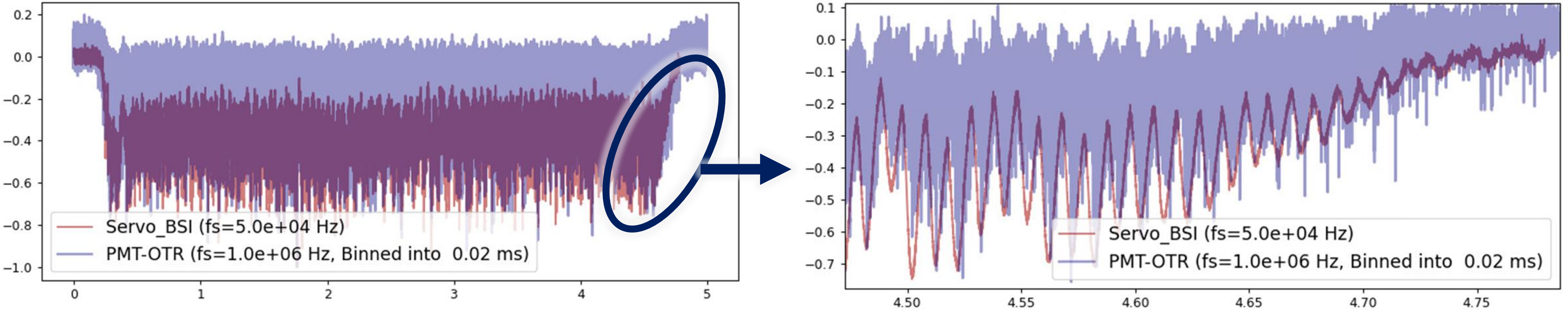
@ 1 ms (Zoom on Start of the Spill)



Impressive agreement between two systems based on different detector, DAQ and 30m apart

OTR-PMT vs SEM

SEM @ 50 kHz (20us), no binning
OTR-PMT @ 1MHz binned @ 50 kHz (20us)



As expected from **SEM** setup**: low pass filter (1kHz) reduces overall BW**, even when sampling at higher rate (50 kHz in this example)

OTR-PMT gives same envelope (100Hz beam intensity fluctuations) **but also measures higher frequency** beam intensity fluctuations

FUTURE OPTIONS / STUDIES

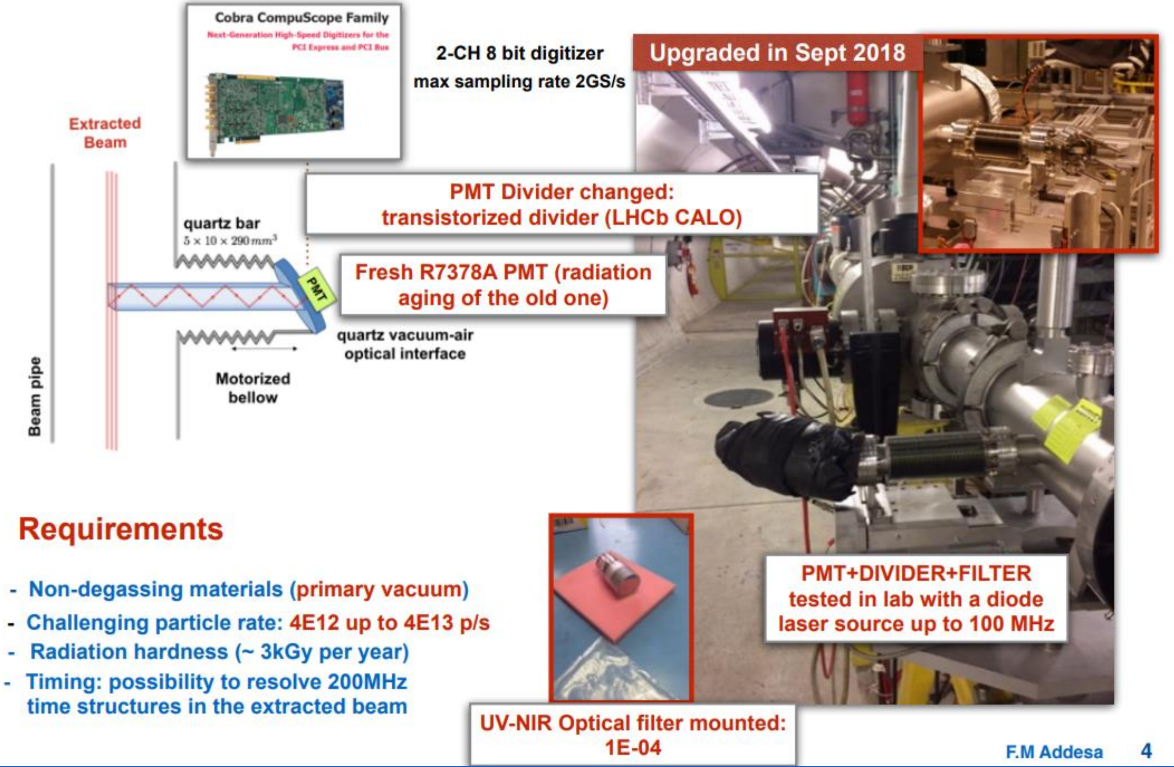
1. Gas Scintillation – (**used @ CERN PS, 24 GeV), see in backup slides**)
2. **Cherenkov detector** for proton Flux Measurement (CpFM)
3. **Timepix-based Gas Ionization** monitor

Cherenkov detector for proton Flux Measurement(CpFM)

F. M. Addesa et al. “In-vacuum Cherenkov light detectors for crystal-assisted beam manipulations,” https://cds.cern.ch/record/2661725

In vacuum quartz bar producing Cherenkov light

- System evolution of one used with low particle flux for crystal assisted extraction
- Can go to few GHz at least
- Validated in 2018 with custom made DAQ



Plan

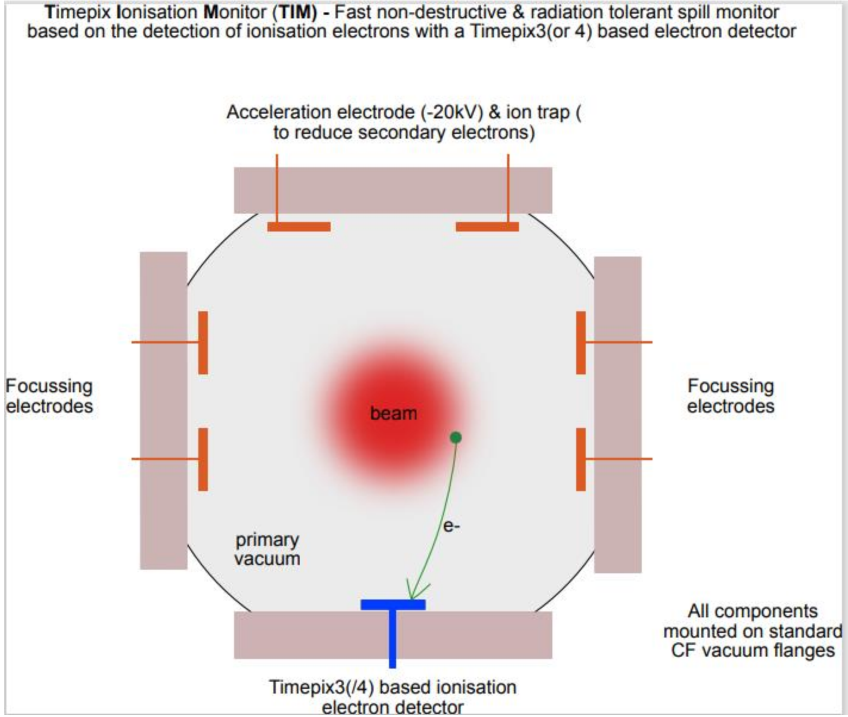
- Resurrect system
- Study ultimate bandwidth
- Propose ~standard DAQs

Spill monitor based on Timepix3(4)

- Similar to an Ionization Profile Monitor, with the addition of focussing electrodes(*) to help focus ionisation electrons onto Timepix
- ‘Detector Response’ ~ 5ns or better good for 200MHz
- Could work in primary and secondary beams

Very recent idea, to be studied

(*) Focussing electrodes inspired by this: http://tilde-gys.web.cern.ch/~gys/LHCb/PixelHPDs.htm



Summary (with present implementations)

System	Analog BW	Sampling	Max Acq Period
SEM	10 MHz (amplifier) 1 kHz (LP filter)	Up to 200 kS/s	Full Spill
dBLM	2 GHz Amplifier 500 MHz Digitizer Low Cutoff @ ~25kHz	650 MS/s (fixed)	~ 2ms
OTR-PMT	300 MHz Amplifier 500 MHz Digitizer	Up to 5 GS/s	Full spill @ few MHz ~ 3ms @ 5GS/s

The 3 systems have long Cu cables also limiting BW to < 500MHz

- **Digitization in the tunnel and optical signal transmission** is under study (see backup slide)

Limitations and plans

System	Limitation(s) that can be improved	Plan
SEM	SNR, Analog BW and Sampling rate	Refurbish in vacuum detector ,consider new amplifier and ADC, aim a removing 1kHz filter
dBLM	SNR	More beam based studies in TT20 Consider option of mono-crystalline detector + amplifier decoupling low and high frequencies ?
OTR-PMT	High signal with screen OUT	Dedicated beam based studies (signal vs beam position) Move or Duplicate PMT (away from losses)
Gas Scintillation	-	Study expected signal levels at SPS
Cherenkov Detector	-	Resurrect system Study fast DAQ that can be integrated into CERN control system
Timepix Gas Detector	-	Look more into numbers/possible implementations for SPS or elsewhere

Outlook / General Remarks

- **SEM detector is very robust** in measuring 50-100 Hz, plan to improve SNR
- **dBLMs surely suitable for high freq**. measurements. Poor SNR to be understood
- **OTR-PMT** system first results **promising**. Plan to move PMT away to be dominated by OTR radiation w.r.t. losses
- For **all monitors**: maximizing SNR, identifying and mitigating different sources of **noise, EMI and background**
  - If some of them are confirmed to be 'local', consider new locations
- Going to **> 1GHz** range implies DAQ upgrades (e.g. optical signal transmission) and/or new techniques (e.g. optical systems like CpFM)

- (CERN internal) strategic decisions to be taken on
  - which technique(s) pursue
  - joint efforts on fast DAQs