ESS BLM system – overview

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Outline

- BLM detectors: locations
- BLM detectors: types
- Conceptual design for the primary BLMs located in the Superconducting parts of the linac
- Summary

BLM detectors: locations

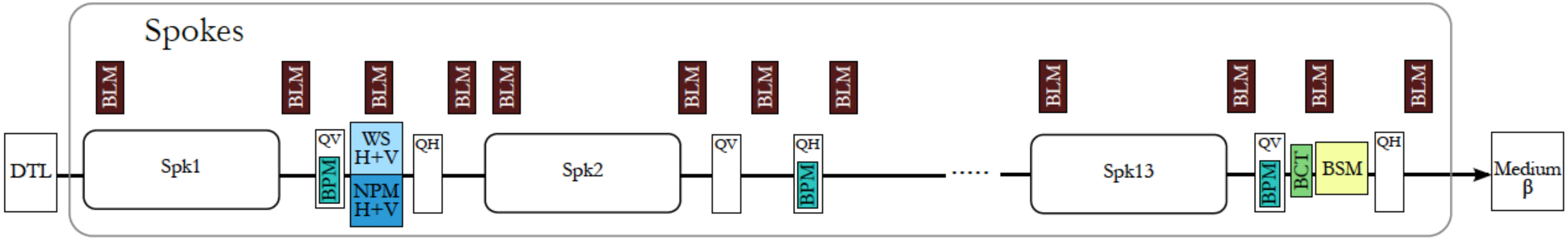
Normal conducting linac (NCL):

- 1-2 devices / m

Superconducting linac (SCL):

- 3-4 devices per doublet lattice cell: 4 where there is a cryomodule and 3 in the transport section.

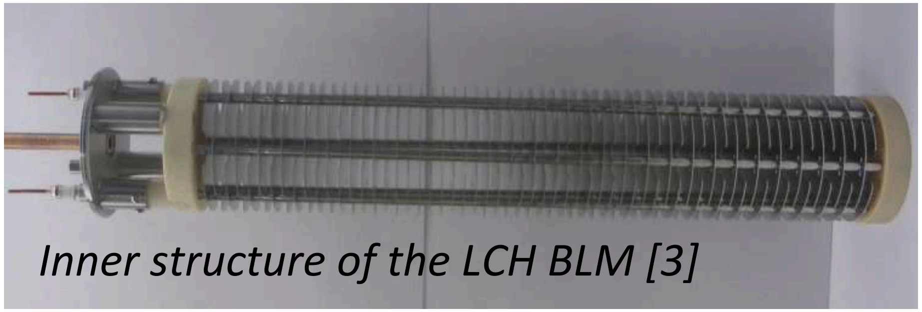
Linac section	Num. of devices IC	ND
RFQ	/	(1-2/m) 6
MEBT	/	(1-2/m) 4
DTL	(1/tank) 5	(1-2/m) 17
Σ	5	27
Spokes	13×4=52	/
Medium β	9×4=36	/
High β	21×4=84	/
HEBT	(3/q-pair) 15×3=45	/
dog leg	(3/q-pair) 7×3=21	/
	(1/dipol) 2	/
A2T	15	/
Dump line	6	/
Σ	261	/
ΣΣ	266	27
ΣΣΣ		293



BLM detector technologies (1/3)

3 types of BLM detectors planned:

1. **Ionisation chambers (ICs)**
    - Primary BLMs in the SCL parts
    - Parallel plate gas ICs developed for the LHC BLM system will be used – ordered in summer 2014, in production now
    - See the talk by S. Grishin regarding the status of the IC production



Inner structure of the LCH BLM [3]

From [1], [2]

Detector property property	Value
detector gas	N_2
pressure	1.1 bar
diameter	9 cm
length	50 cm
sensitive volume length	38 cm
num. of electrodes	61
electrode spacing	5.75 mm
electrode thickness	0.5 cm
electrode diamater	75 mm
bias	1.5 kV
max e^- drift time	300 ns
max ion drift time	83 μs
<energy> to create ion-e^- pair in N_2	35 eV
wall thickness:	
tube	2mm
bottom plate (facing el.box)	4mm
top plate	5mm

BLM detector technologies (2/3)

2. Micromegas detectors

- Likely to be the BLMs in the NCL parts – particle field expected to be dominated by neutrons and photons
- The idea is to design a micromegas detector sensitive to fast neutrons and "blind" to photons (X- and γ- rays) based on the signal height discrimination.
- Work on-going by micromegas experts from CEA Saclay (hopefully as an in-kind contribution) – see talk by T. Papaevangelou for more details

BLM detector technologies (3/3)

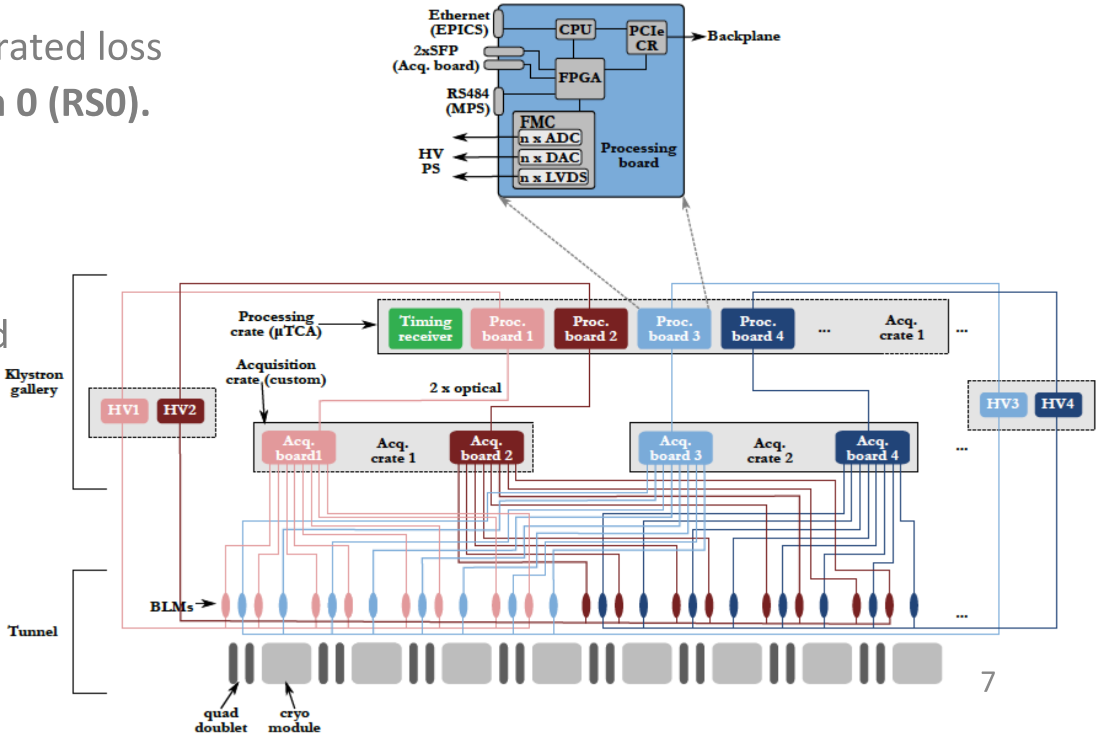
3. Advanced detectors

- Photon background due to RF cavities expected to cause baseline shifts in the IC signal – base line corrections needed
- Origin of this background: mainly due to field emission from electrons from cavity walls, resulting in bremsstrahlung photons created on cavities/beam pipe materials [4]
- Proper baseline correction for ICs is an difficult task due to time, power, cavity quality, and beam loading dependence
- Additional BLMs in SCL, insensitive to these photons, would offer a complementary/additional measurement to ICs
- Currently investigating an option to use Cherenkov based detectors in the higher energy parts of the SCL – Cherenkov photon production is a process inherently blind to photons.

IC BLM conceptual design

Current concept of the electronics for the ICs based BLMs in the SCL consist of 2 separate units:

- **Acquisition unit** serving as an analogue FE & digitizer board
  - Primary candidate: BLEDP card, developed for the new BLM system at CERN injector complex [5].
  - The BLEDP has a wide dynamic range (10pA – 200mA) - likely to fit our dynamic range even after the revision.
  - Provides the information on the integrated loss over a fixed time (2µs) – **Running Sum 0 (RS0).**
- Followed by a **Processing Unit**:
  - Planned to be the standard board, provided by the ICS division (equipped with FPGA(s) and the interfaces to BIS and EPICS).
  - Expected to provide additional **RSs** giving information on losses integrated over **longer time scales**.



Summary

Current strategy for monitoring the beam with BLMs:

- ICs will be used as the primary detectors in SC parts (see talk by S. Grishin regarding the production status). Presented current conceptual design for this part of the BLM system
- Plan to use micromegas detectors as neutron detectors in the NC parts of the linac – ongoing development by micromegas experts from Saclay (see talk by T. Papaevangelou for details)
- Photon background from cavities might be a concern for IC based BLMs – investigating an option to use a Cherenkov detectors in addition to ICs in the end parts of the SCL.

References

[1] M. Stockner, *"Beam loss calibration studies for High energy proton accelerators"*, PhD thesis

[2] M. Hodgson, *"Beam loss monitor design investigations for particle accelerators"*, PhD thesis

[3] M. Stockner et al, "*Classification of the LCH BLM ionisations chamber*", Proc. Of DIPAC 2007

[4] E. Donoghue et al, *"Studies of electron activities in SNS-type SC RF cavities"*, Proc. Of 12th Int. Workshop on RF Supercondictivity, Cornell Univ., USA

[5] W. Vigano et al, "*10 orders of magnitude current measurement digitisers for the CERN beam loss systems*", TWEPP 2013 (2014 JINST 9 C02011)

[6[L. Tchelidze et al, "Beam Loss Monitoring at the ESS", IBIC2013, (WEPC45), Oxford, UK

[7] A. Nordt, "*Beam Instrumentation interfaces to protection systems*", TAC12, https://indico.esss.lu.se/indico/event/315/session/9/contribution/32/material/2/1.pptx

[8] L. Tchelidze, "*How Long the ESS Beam Pulse Would Start Melting Steel/Copper Accelerating Components?"* ESS/AD/0031, http://docdb01.esss.lu.se/DocDB/0001/000168/001/Time_Response_Requirements_BLM.pdf

[9] W. Blokland et al, A new dierential and errant beam current monitor for the SNS accelerator , IBIC2013 (THAL2), Oxford, UK

[10] B. Cheymol, *"High power and high duty cycle emittance meter for the ESS warm linac commissioning"*, ESS-0038060

[11] B. Cheymol, *"ESS wire scanner conceptual design"*, ESS-0020237

[12] B. Cheymol, "*Proposal for a scintillator readout prototype*", ESS-0033505

Back up material

BLM: goals and requirements

- BLM goals:
  - Primary goal: **protection** - detect abnormal beam behaviour.
  - In addition: **monitoring** - provide the means to monitor the beam losses during the normal operation.
- BLM requirements:
  - Protection functionality requires us to know what are we protecting - **list of beam loss scenarios** to which BLM should react - translates to setting the **thresholds** and **measurement time constants**.
  - Protection functionality gives a constraint on the system's shortest **response time** and sets the upper limit of the system's **dynamic range**.
  - Monitoring functionality sets the lower limit on the system's dynamic range.

  - *Note*: both thresholds and dynamic range are tightly related to detector **locations,** which in turn should be selected based on the inputs (beam loss scenarios & damage potential)
  - *Note*: each time constant relates to certain current/particle flux range – upper and lower dynamic range require different time constants

Dynamic range, thresholds & time constants

- **Dynamic range**
  - Needs to be determined in order to select suitable FE electronics
  - Preliminary estimations on the values for the SCL have been set in the past [6]

    “BLM is required to be able to measure at least 1% of 1W/m loss during normal. operation and up to 1% of the total beam loss” - gave an estimation on input FE current range 800nA – few mA for the BLMs in SC linac.
  - Needs a revision (need to be correlated with time constants) – work ongoing.
- **Measurement time constants**
  - Preliminary list can be based on the expected beam modes.
  - Need to correlate with the time constants of the components that can fail. – work ongoing.
- **Thresholds**
  - More detailed inputs (beam loss scenarios & damage potentials) needed to be able to addressed this issue
  - Not urgent - work related to inputs ongoing, threshold determination will follow after that

Response time (1/2)

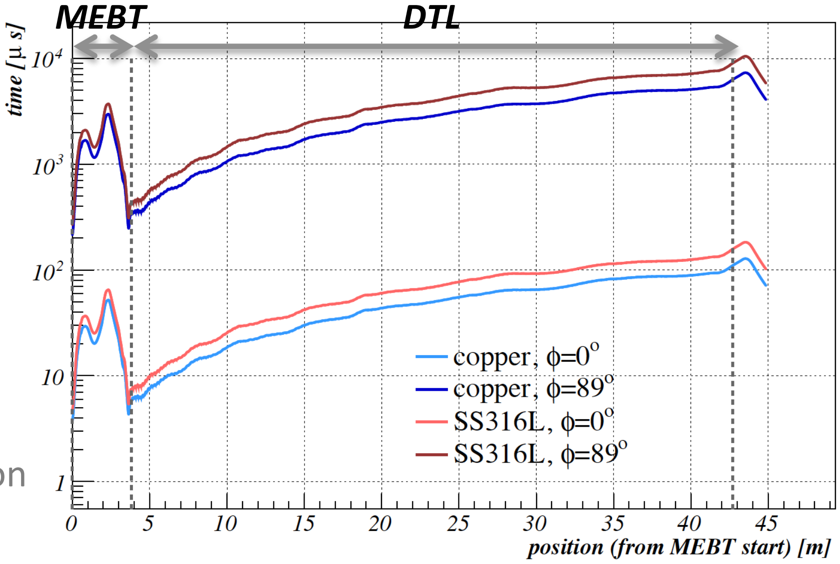
- Time response requested by machine protection [7]:
  - In NC linac: ~1 µs.
  - In SC Linac: ~10 µs.
  - Based on a simplified melting time calculations when a uniform beam hits a block of material under rectangular incidence [8].

- Rechecked the calculations with updated parameters. Assumptions:
  - Proton beam with a Gaussian profile (instead of uniform) and 62.5mA current (instead of 50mA) hits a block of material under perpendicular (Φ=0^o) or shallow (Φ=89^o) incident angle.
  - Calculated time to reach the melting point in the volume bin with highest temperature (see next page).
  - Highest temperature under constant irradiation expected in a small small volume of material around the Bragg peak.
  - No cooling.
  - SRIM calculations used to estimate energy deposition at the Bragg peak.

Response time (2/2)

- Observations – NC linac
  - Time to melt strongly depends on incident angle and reaches below 5μs at the beginning of the MEBT – need for revision of the 1μs limit in NC linac?
  - Not that a simplified model used for the estimation, no cooling processes.
  - Conductive cooling might be efficient for a thin layer
  - Also: the worst case scenario with full beam at perpendicular incidence is expected only when the valve enters the beam. The primary layer of protection for this case is expected to be the Local Protection system.

Time needed to reach melting temperature with beam parameters expected along the MEBT and DTL



- Observations – SC linac
  - Calculated time to melt ~100μs at the beginning of the SC parts – fits with the 10μs response time limit set for the SC linac.
- However, experience at SNS raises a concern:
  - Degradation of cavities observed at SNS after loosing ~20μs pulse of 26mA beam ~10/day [9]
  - Do we need to be faster in order to detect this type of events in time?

Response time - summary

Rechecked the calculations with updated parameters

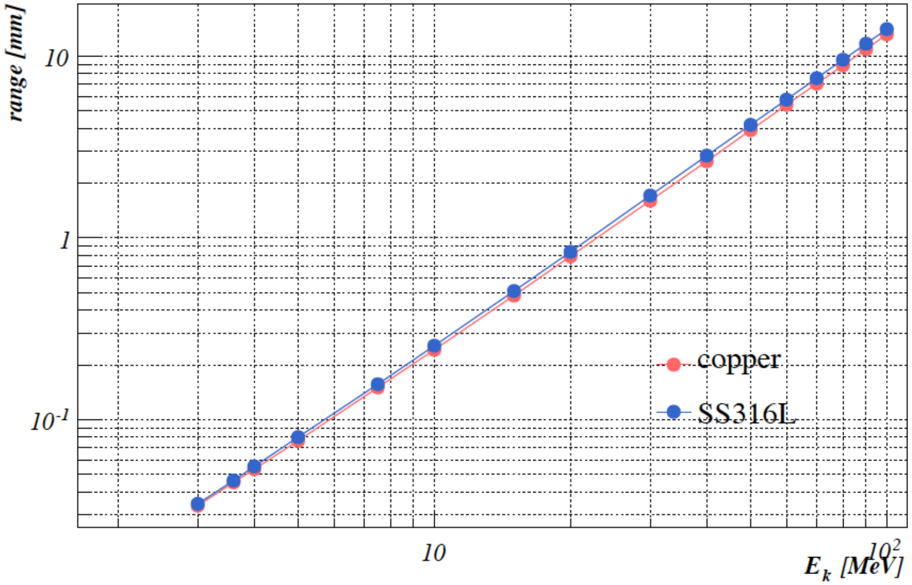
- **NC linac:** the calculations imply that we should be even faster than 1µs. But
  - Note that these are simplified calculation that give a conservative result on melting times: no cooling included, conductive cooling might be efficient for a thin layer [10] – a realistic option for this case.
  - Calculations are focused on worst case scenario with full focused beam at perpendicular incidence – only realistic scenario where valve enters the beam - The primary layer of protection for this case is expected to be the Local Protection System.

- **SC linac**: the 10µs requirement for response time fits well with these calculations
  - However, experience at SNS raises a **concern**.
  - Degradation of cavities observed at SNS after loosing <15µs pulse of 26mA beam ~10/day [9].
  - Do we need to be faster in order to detect this type of events in time

BLM detectors: NC linac

- DTL:
  - Tank walls ~3cm stainless steel.
  - Protons (3.6 – 90 MeV) will be stopped in the walls of the tanks.
- Expected particle fields outside of the DTL tanks dominated by neutrons and photons.
- Similar holds for RFQ and MEBT.

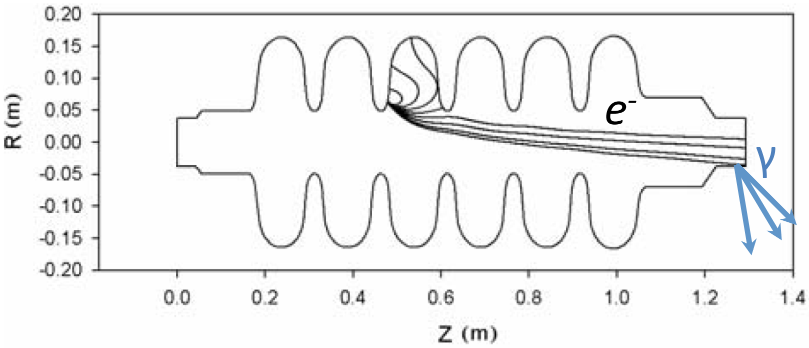
Range of protons in copper and SS316L (calculations with SIRM)



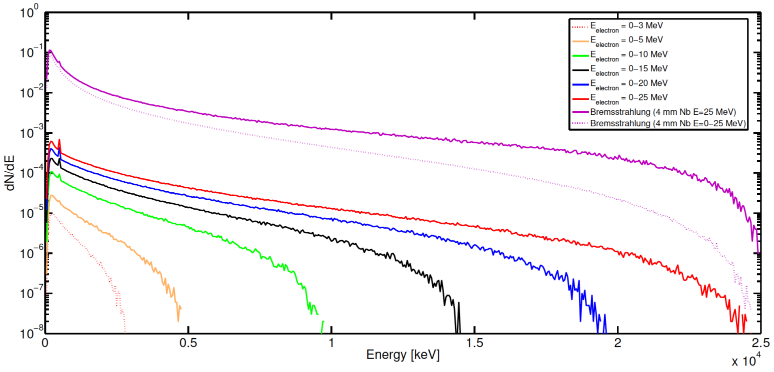
- Currently considering to use micromegas detectors in the low energy part of the linac.
- The idea is to design a micromegas detector sensitive to fast neutrons and “blind” to photons (X- and γ- rays) based on signal discrimination.

Background photons due to the RF cavities (1/5)

- Photon background due to the RF cavities mainly due to field emission from electrons from cavity walls, resulting in bremsstrahlung photons created in the field of nuclei of cavity/beam pipe materials [4].



- Energy spectra estimations show that photons up to few tens of MeV can be expected [11]:
  - A MC code (FLUKA) was used for these estimations where a pencil electron beam is impacting a 4mm niobium foil.
  - Purple curves on the plot on the left show expected energy spectra for the photons produced at the exit of the foil:
    - Solid line – for the monochromatic beam of electrons with energy of 25MeV
    - Dotted line – for the beam of electrons with uniform energy distribution from 0 to 25MeV.
    - Spectra are normalised per number of primaries.

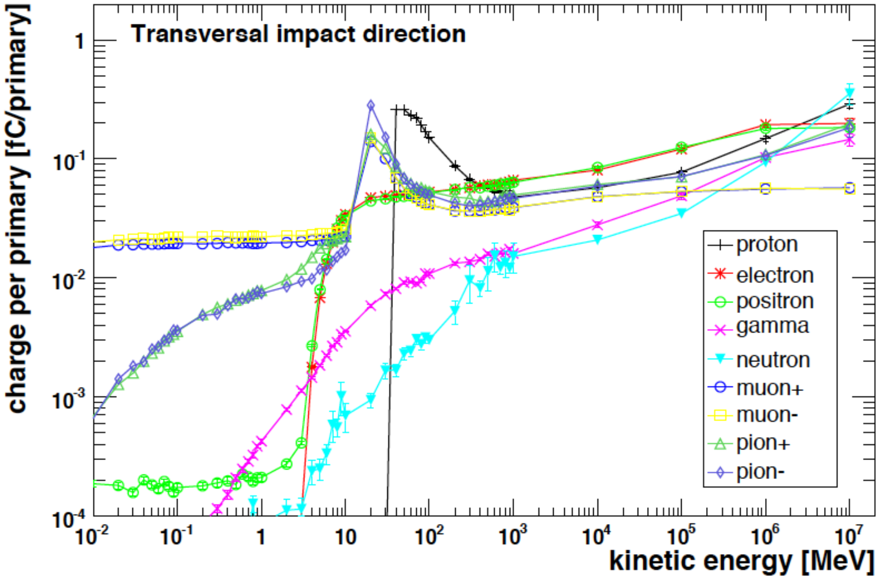


  - Note: maximum acc. Gradient expected at ESS ~25MeV/m, cavity size ~1m.

Background photons due to the RF cavities (2/5)

What we should consider when using ICs in SCL:

- Photon background due to the RF cavities:
  - Mainly due to field emission from electrons from cavity walls, resulting in bremsstrahlung photons created on cavities/beam pipe materials.
  - Levels are difficult to predict numerically – they depend on the quality of cavities.
  - Energy spectra estimations show that photons up to few tens of MeV can be expected (previous slide, [11])
- ICs are not insensitive to photons:
  - For the LHC ICs the "cut off" for transversal incidence for photons and electrons is below ~2MeV and
  - 30MeV for protons and neutrons [3].



LHC BLM IC response functions [3]

Background photons due to the RF cavities (3/5)

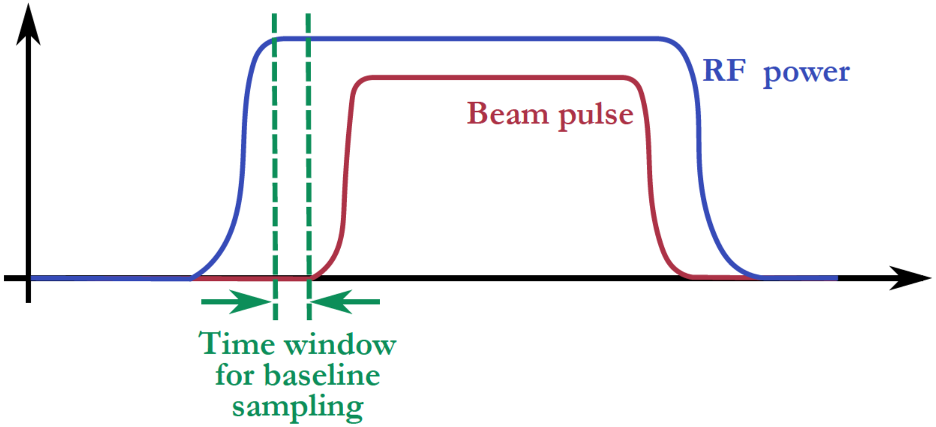
Estimation of the background levels due to the RF:

- Plan to do assess this with tests at the RF test stand in Uppsala (Spokes) and potentially in CEA/Saclay (elliptical).
- The tests can potentially give an upper limit on the RF background level, since:
  - Tests are performed without beam.
  - Tests are probably done with higher RF power than used for normal operation.
  - Less material for "shielding" (magnets,…) is expected.
- However, these tests can not give the full insight, since this background depends on the quality of the cavities and is influenced by beam loading.

Background photons due to the RF cavities (4/5)

How can we address this:

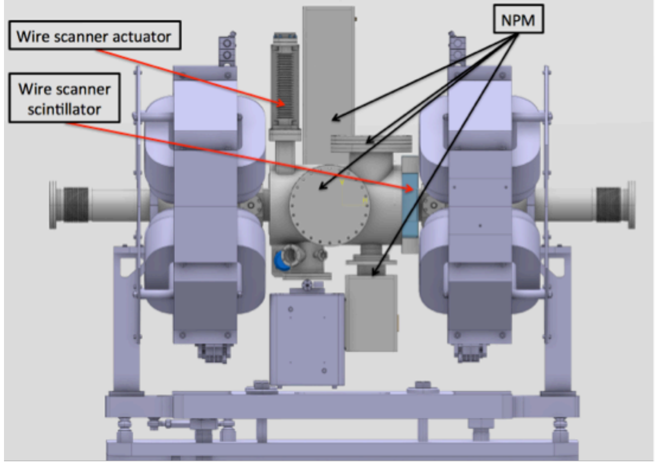
- Plan to do the baseline subtraction (also done at SNS):
  - The background is cavity and time dependent.
  - Need to estimate the baseline for each BLM detector separately.
  - For each pulse we would like to sample the data for the baseline calculation in the time window after the RF is turned on and before the beam pulse arrives in order to correct the thresholds or raw data in the pulse accordingly.

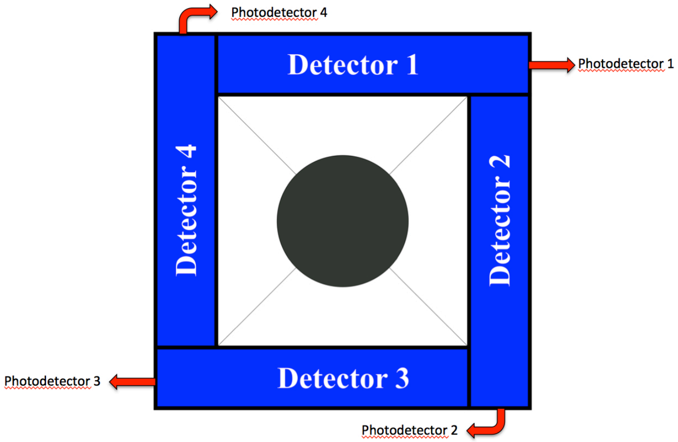


- In addition to ICs we could also use Cherenkov based detectors - not effected by the background due to the RF cavities.

Background photons due to the RF cavities (5/5)

- Background from cavities is a concern also for the Wire Scanner (WS) measurements in the Elliptical section.
    - Proposed dual readout based on collecting both the scintillator and Cherenkov photons separately [11] [12].
    - Planned to be used for beam energies above 200MeV, 3 devices in Medium and 1 in High β section.
- For the BLM we would like to make use of the proposed photon based dual readout for the WS:
    - The idea is to use the Cherenkov part of the readout as a BLM during normal operations (when no wire is inserted in the beam).
    - Plan to do series of Monte Carlo simulations to investigate if this is an option for BLM.
    - Depending on the outcome of the study there is a possibility to increase the number of these devices.

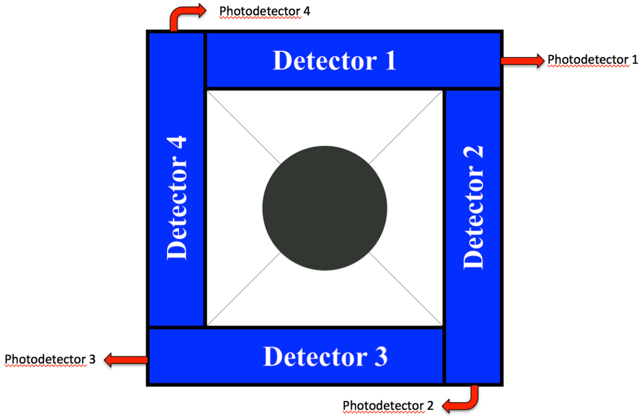




Photon based dual readout for WS system & BLM (1/2)

WS system at high energies

- For proton energies > 200 MeV, SEM current is to low for profile measurements, while flux of secondaries produced on the wire are energetic enough to cross the vacuum chamber.
- The idea is to use this secondaries and detect them with a "ring" of 4 scintillator rods placed around the beam pipe downstream of the wire.
- The light could be collected with a photodiodes attached to one scintillator ends.
- In order to avoid the background from the cavities (when they are on) a dual readout is currently under investigation:
  - Light from the scintillator can be collected with a photodiode.
  - A WLS fiber can used to produce and transport Cherenkov photons to a photodetector.
  - A groove for placing the fiber can be machined in the scintillator.
  - The scintillating material should have a the emission peak (BGO, ~500nm), which does not match the absorption peak of the fiber (eg. Kuraray B# ~350nm).
  - Details on alternative geometry in [12].



Photon based dual readout for WS system & BLM (2/2)

Dual readout as part of BLM & WS systems

- The data from the dual readout can additionally serve for BLM purposes.
- The idea is to use the WLS fiber as a BLM detector during normal operation (no wire in the beam) in addition to its functionality for the WS system during profile measurements.
- Plan to do series of Monte Carlo simulations in order to see if this fiber can serve as a BLM and to optimize the design (geometry/ placement of the fiber, materials).
- This WS system is planned to be used for beam energies above 200MeV, 3 devices in Medium and 1 in High β section.
- Depending on the out come of the study there is a possibility to increase the number of these devices.