BEAM LOSS MONITORS FOR CLIC

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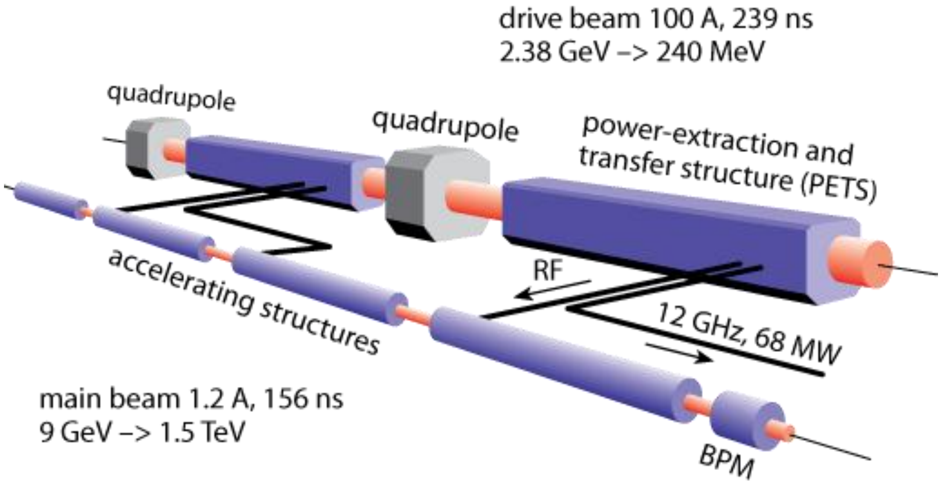
Outline

- **Introduction** – BLM for CLIC
  - BLM Design Considerations (Loss Limits, etc)
- **Conceptual Design Report (CDR) Phase (until Jan 2011)**
  - FLUKA Simulations, baseline technology choice – Ionization chambers
  - CDR Summary
- **Post CDR Phase (Jan 2011 - present)**
  - Investigating Cherenkov Fibers as a BLM system
  - Simulations, Results Summary
- **Outlook**

INTRODUCTION (CLIC BLM CONSIDERATIONS)

Compact Linear Collider Study (CLIC)

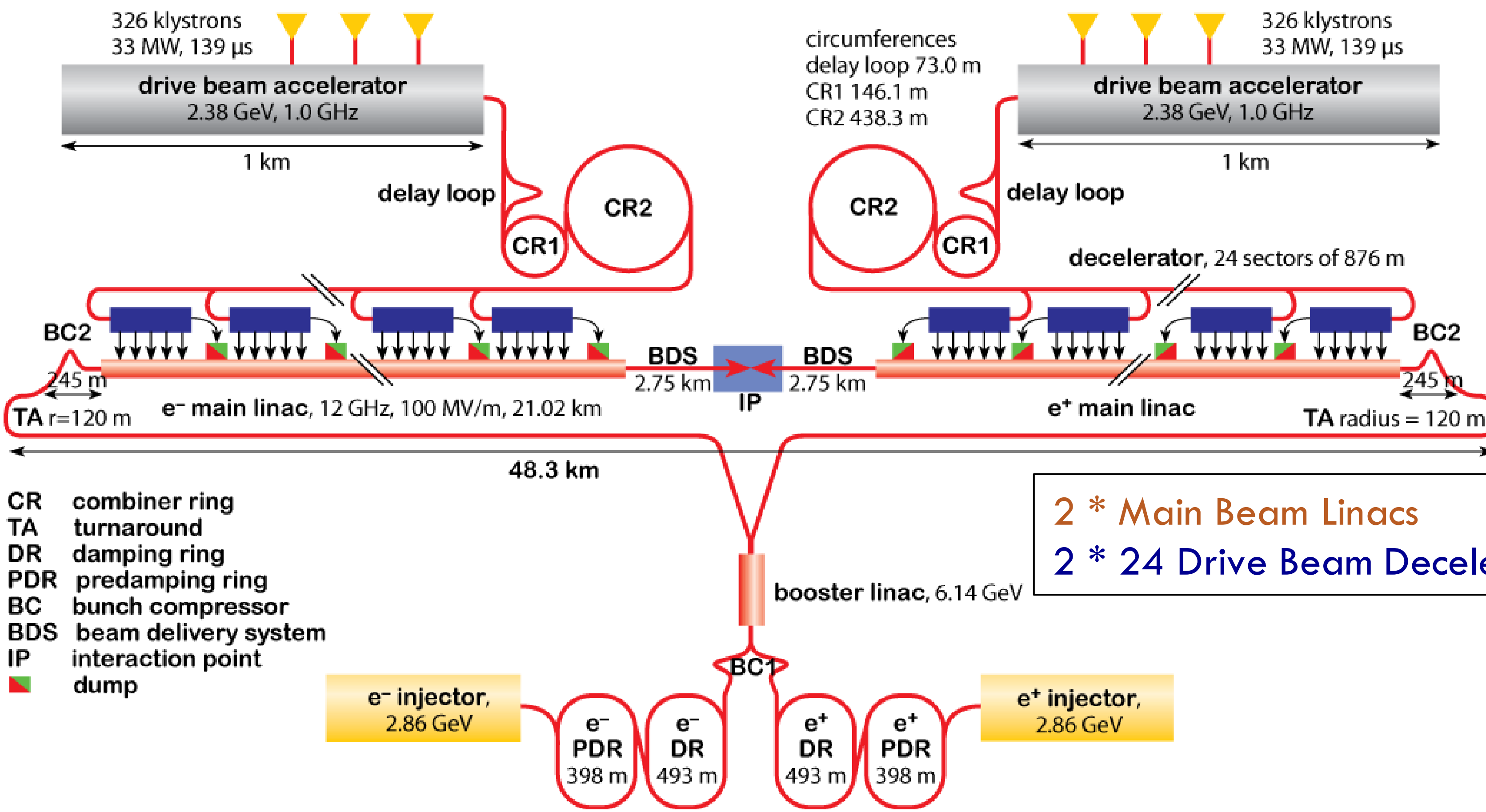


- Future e+e- collider, Centre of Mass Energy of 3TeV
- High accelerating gradients - Novel 2 Beam Acceleration Method
- High Intensity Drive Beam decelerated in power extraction structures (PETS)
- RF power at 12GHz is transferred to Main Beam

	Energy range (GeV)	Rep rate	**Pulse length**	Bunch frequency	Bunch charge	Bunches per train	**Electrons per train**
Drive Beam	**2.4 → 0.24**	50 Hz	**239ns**	12 GHz	8.4nC	2922	**1.53e14**
Main Beam	**9 → 1500**	50 Hz	**156ns**	12 GHz	0.6nC	312	**1.16e12**

Beam Parameters in the “Two Beam Modules”

Compact Linear Collider Study (CLIC)



2 * Main Beam Linacs

2 * 24 Drive Beam Decelerators

CLIC Machine Protection Strategy

- Based on **Passive protection** and a "**Next cycle permit**"
- Primary role of the BLM system as part of the Machine Protection System is to prevent **subsequent** injection into the Main Beam linac and the Drive Beam decelerators when potentially dangerous beam instabilities are detected.
- Option of CLIC at 100Hz → **Minimum Response time <8ms required by BLMs** (except damping rings) to allow post pulse analysis

Failure Scenario

- Possible failure scenarios in two beam modules under investigation (PLACET Simulations C. Maidana, TE-MPE-PE)
- → For BLMs detection requirements: Currently consider destructive limits (fraction of beam hitting single aperture). Destructive potential: **not** determined by Beam Power but by Power Density, i.e. Beam Charge / Beam Size.
  - Main Beam (damping ring exit) 10000 * safe beam

    0.01% of a bunch train – 1.16e8 electrons
  - Drive Beam decelerators 100 * safe beam

    1.0 % of a bunch train – 1.53e12 electrons

Standard Operational Losses

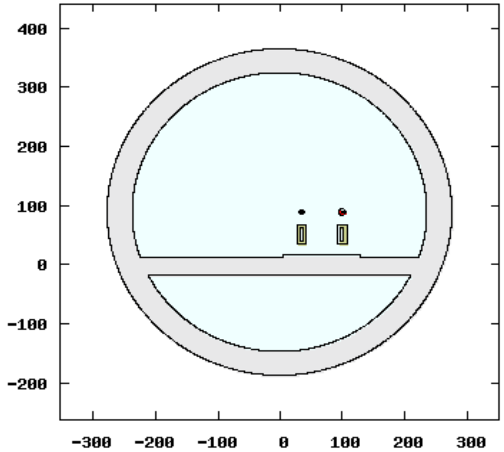
Limits in the Two Beam Modules

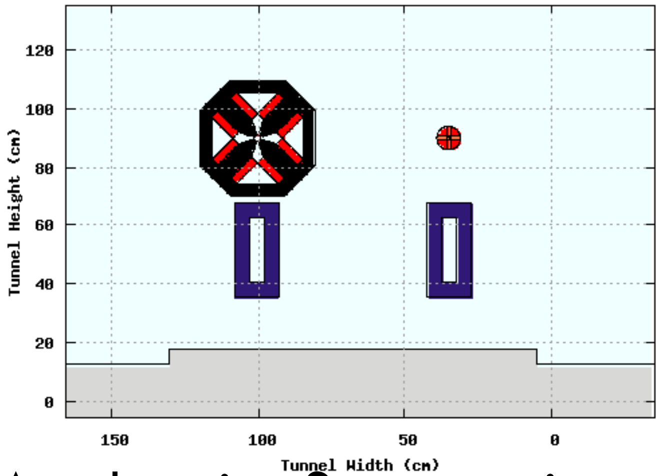
- **Beam Dynamics Considerations** *(luminosity losses due to beam loading variations) D.Schulte*
  - *10^{-3} of full intensity of the Main Beam over 20km linac*
  - *10^{-3} of full intensity of the Drive Beam over 875m decelerator*
- **Activation** *(Residual Dose Rates – Access Issues)*
- **Damage to beamline components**
- **Damage to electronics** (*SEE's, Lattice Displacement, Total Ionizing Dose*)

CLIC CONCEPTUAL DESIGN REPORT (SUMMARY OF BLM WORK)

FLUKA Loss Simulations

- Model includes tunnel, floor beam line components and silicon carbide girders



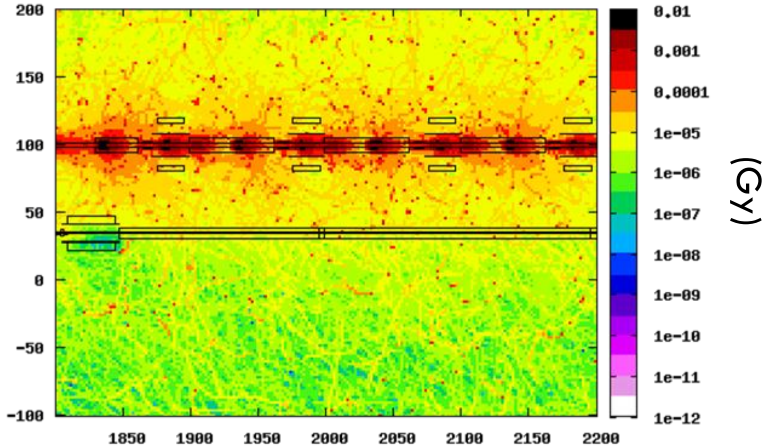


- Loss location: End of PETS/Accelerating Structures just upstream of quadrupoles
- Drive Beam at 2.4 GeV, 0.24 GeV
- Main Beam at 1500 GeV, 9 GeV

CLIC Conceptual Design Report, BI Chapter

Sensitivity Requirements

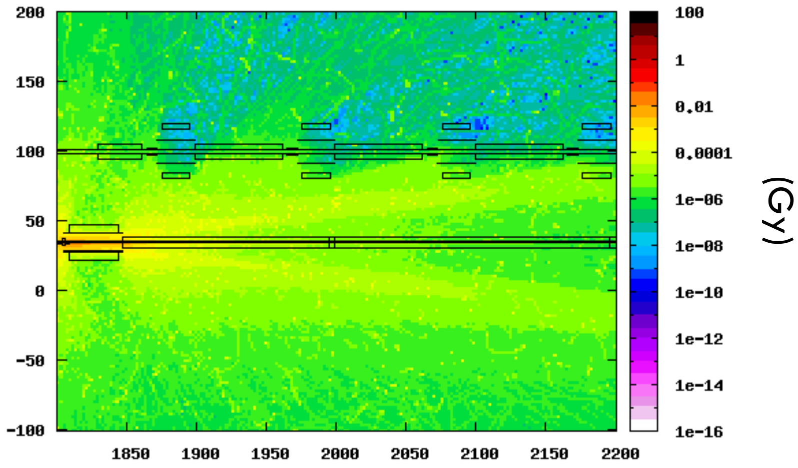
- Standard Operation Losses (mainly due to beam gas scattering)
- FLUKA – losses are distributed longitudinally
- **Lower Limit of Dynamic Range:** 1% loss limit for beam dynamics requirements (to detect onset of such losses)
  - 10^{-5} train distributed over MB linac, DB decelerator



Example: Spatial distribution of absorbed dose for maximum operational losses distributed along aperture (DB 2.4 GeV) Scaling: 10^{-3} bunch train/875m

Destructive Losses

- Detect onset of Dangerous losses
- FLUKA Loss at single aperture
- **Upper Limit of Dynamic Range,** 10% Destructive loss:
  - 0.1% DB bunch train, 0.001% bunch train MB



Example: Spatial distribution of absorbed dose resulting from loss of 0.01% of 9 GeV Main Beam bunch train at a single aperture

BLM Requirements - *Summary Table*

Machine Sub-Systems	Dynamic Range	Sensitivity (Gy/pulse)	Response time (ms)	Quantity	Recommended
Main Beam					
e⁻ and					
Pre-D					tive to Rad.
RTML					
Main					h losses DB
Beam collin					
Beam spoile					
Beam collin					
Spen					
Inject					
Decelerator	5.10^{6}	5.10^{-8}	<8	41484	Distinguish losses from MB
Dump lines	tbd	tbd	<8	48	

- *Ionization Chambers fulfill necessary requirements for a machine protection system (except MB Damping Rings – where Cherenkov Radiators + PMT recommended)*
- *Large Number BLMs Required*

*→ Investigate **Alternative Technologies** for the Two Beam Modules in the post CDR phase*

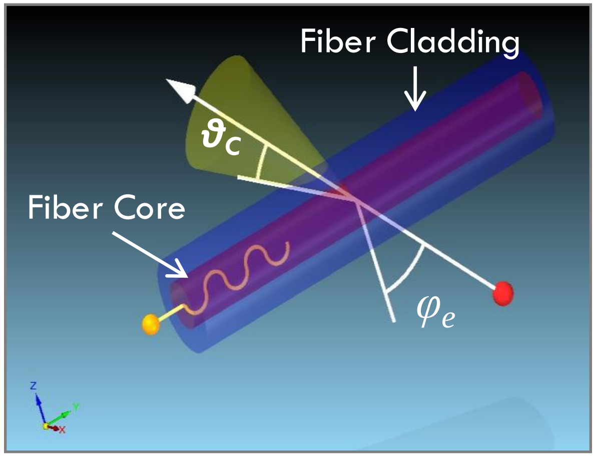
INVESTIGATION OF CHERENKOV FIBERS AS A BLM SYSTEM

Cherenkov Signal in Fibers - Considerations

Cherenkov Radiation

- When a charged particle with v>c enters the fiber photons are produced along Cherenkov cone of opening angle

$$\cos\theta_c = \frac{1}{n\beta}$$



Need to Consider Both:

- The **Number of photons generated** in fiber

$$\frac{d^2N_{ph}}{d\lambda dL} = \frac{2\pi\alpha z^2 \cdot \sin^2\theta}{\lambda^2}$$

- The **Proportion of those photons transmitted,** (Cerenkov Efficiency)

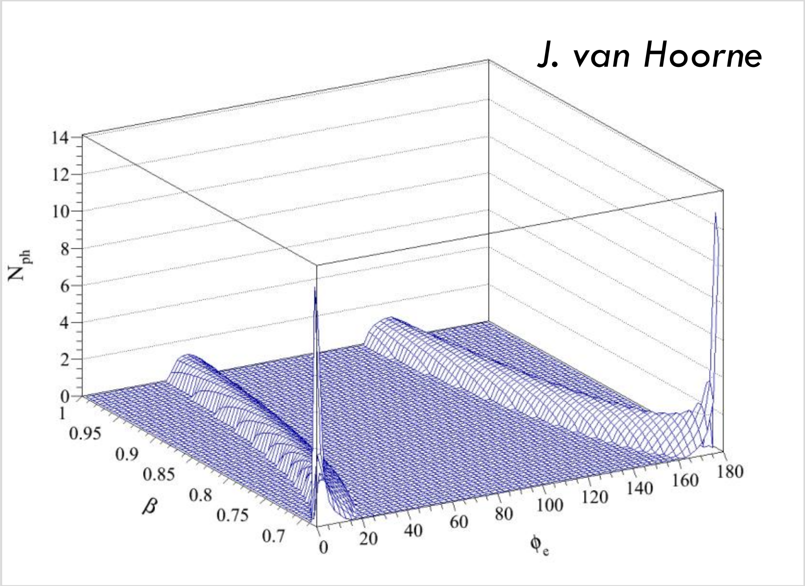
$$CE \propto \cos^{-1}\left[\frac{\beta\sqrt{n^2 - NA} - \cos\varphi_e}{\sin\varphi_e\sqrt{\beta^2 n^2 - 1}}\right]$$

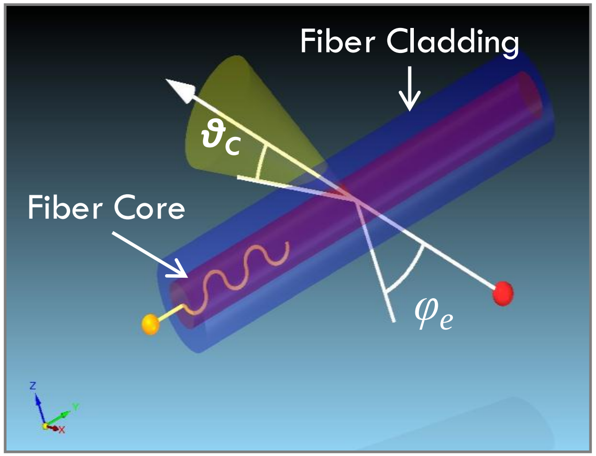
NA is the 'numerical aperture' of the fiber

$$NA = \sqrt{n^2_{core} - n_{clad}^2}$$

Cherenkov Signal - Analytical Model

Analytical Model (Jacobus van Hoorne – Master's thesis)





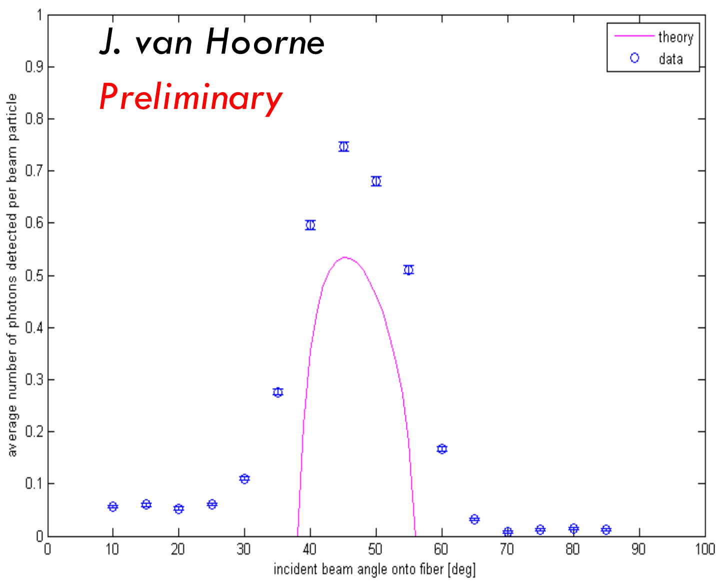
- Number of **transmitted photons** per **charged particle** crossing the fiber as a function of β and ϕ_e for a fiber of **0.365 mm diameter and NA = .22**

NA is the 'numerical aperture' of the fiber

$$NA = \sqrt{n^2_{core} - n_{clad}^2}$$

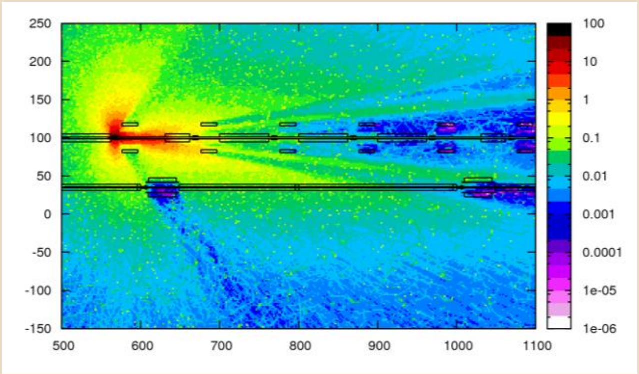
Model Verification – preliminary results

- Tests performed at North Area to characterize fiber systems & verify analytical model – Finalizing results - to be presented DITANTET BLM workshop (next month)
  - Photon yield dependence on the incident angle beam w.r.t. fiber axis
  - Photon yield dependence on the diameter of the fiber core
  - Dispersion in fiber

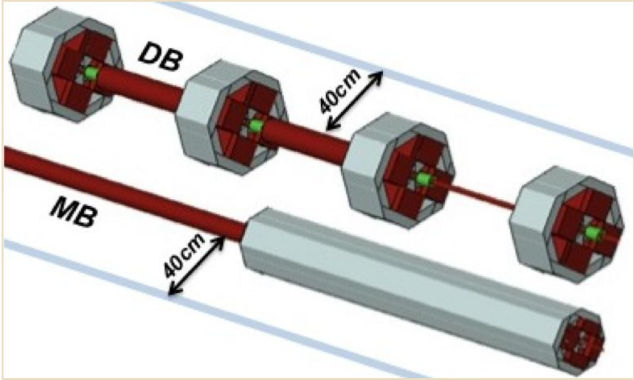


FLUKA Simulations – Cherenkov Fibers

- *Improved representation of aperture restriction and failure loss scenario*
- *Score angular and velocity distribution of charged particles at possible fiber locations*
    - *5cm high, 40cm from beamline, parallel to beamline*



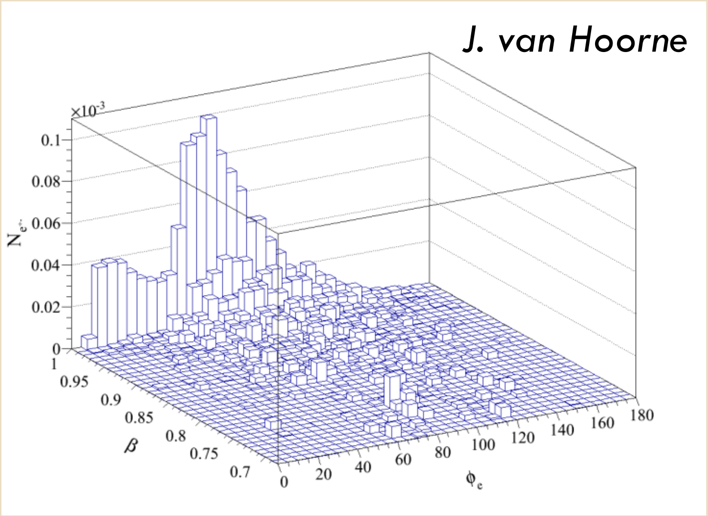
Spatial Distribution of absorbed dose - DB loss at 2.4 GeV



Blue lines indicate location of boundaries

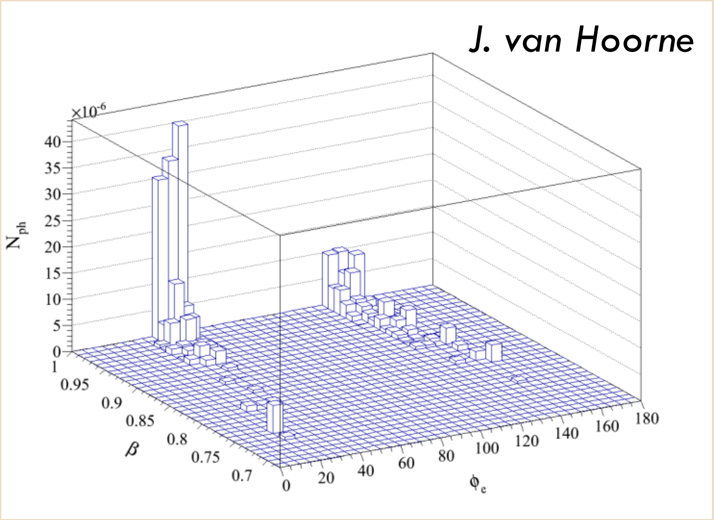
FLUKA Simulations – *Cherenkov Fibers*

PARTICLE SHOWER DISTRIBUTION (FLUKA)



Loss shower distribution, normalized to one lost beam electron, for single loss at 2.4 GeV in the DB

CORRESPSONDING 'TRAPPED' PHOTONS



Transmitted photon distribution, normalized to one lost beam electron, for single loss at 2.4 GeV in the DB.

FLUKA Simulations – *Cherenkov Fibers*

Sensitivity and Dynamic Range Requirements

- *Dynamic Range (considered rate of arrival of photons)*
- *Sensitivity and dynamic range requirements for a downstream photodetector allows the use of Silicon Photomultipliers (SiPM) (100m fiber)*

	Sensitivity* (N_{ph}/train)	**Dynamic Range**
DB 0.24 GeV	$5 \cdot 10^2$	$5 \cdot 10^4$
DB 2.4 GeV	$5 \cdot 10^3$	$2 \cdot 10^4$
MB 9 GeV	$4 \cdot 10^1$	$1 \cdot 10^3$
MB 1.5 TeV	$8 \cdot 10^2$	$5 \cdot 10^3$

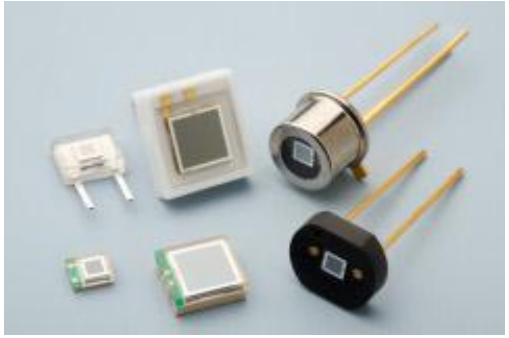
Arrival duration of the photons 410 ns (DB) and 323 ns (MB) (100m fiber)

IPAC 11: wepc171.pdf

Outlook

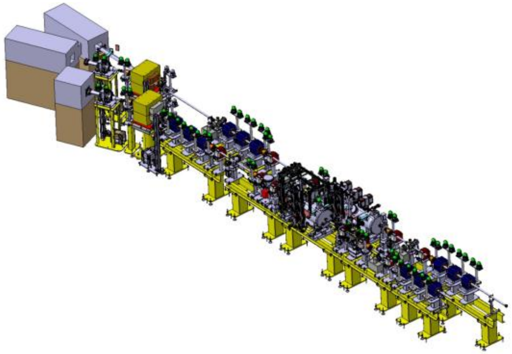
Investigate choice of photodetectors:

SiPMs are cheap, radiation hard, require low operating voltage (<100V), insensitive to magnetic field. However, the dynamic range is low c.f. standard PMTs (limited by number of pixels)



Installation at CTF3/CLEX

- *The longitudinal position resolution which can be achieved (standard PMT AND SiPMs) at Test Beam Line*
- *Investigate Cross talks issues at Two Beam Test Stand*
- *Determine operational losses for feedback and tuning*



Outlook

CLIC REQUIREMENTS

Two Beam Modules

- Verify expected Signal in Cherenkov Fibers
  - Continue to Cross Check photon production and transport between analytical model, Monte Carlo (FLUKA, GEANT 4) & experimental data
- Consider Photons travelling in fiber upstream direction (for timing)
- Include any updates on Loss scenarios or loss limits (M. Jonker, C. Maidana)

Damping Rings

- Develop BLM System. Cherenkov Radiator + PMT (Fast and Insensitive to synchrotron radiation). Design such that PMT is shielded from x-rays, etc.
- Investigate BLMs used at Synchrotron Light Sources

And Finally

Thank you for your attention!

Cherenkov Fibers - Summary

- *A method has been developed to determine the Cherenkov signal in fibers at the CLIC two beam test modules*
- *Cherenkov fibers seem to be a suitable candidate for a BLM system in terms of dynamic range, sensitivity, temporal and spatial resolution*
- *Cherenkov fibers will be installed in the CLIC Test Facility (CTF3) in the next year to further test the feasibility of a Cherenkov fiber system*

CDR - *Summary*

- *Ionization Chambers fulfill necessary requirements for a machine protection system (except MB Damping Rings – where Cherenkov Radiators + PMT recommended, as baseline technology choice)*

- *LHC Ionization Chamber + readout electronics*
  - *Dynamic Range 10^5 (10^6 under investigation)*
  - *Sensitivity $7e10^{-9}$ Gy*

The MB linac and DB decelerator could also be safely operated at a reduced dynamic range, should 10^6 turn out to be too challenging

- *Large Number BLMs Required – Cost Concern*

*→ Investigate **Alternative Technologies** for the Two Beam Modules in the post CDR phase*

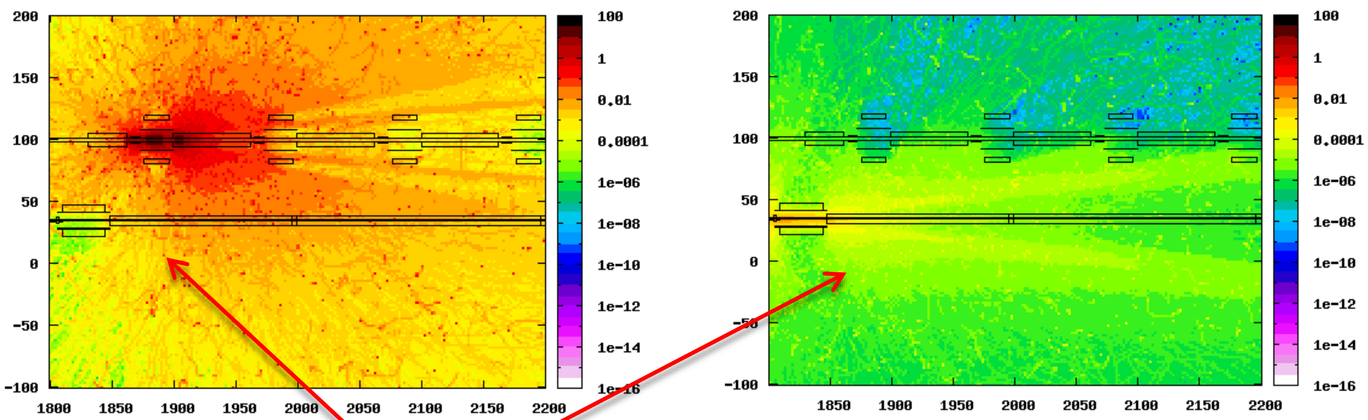
FLUKA Simulations - *CDR*

Cross Talk Issues

- Desirable to distinguish between a failure loss from each of the beams

Destructive DB 1.0% of bunch train hits single aperture restriction

Destructive MB 0.01% of bunch train hits single aperture restriction



Spatial Distribution of prompt Absorbed Dose (Gy) resulting from FLUKA Simulation of dangerous loss at single aperture restriction for the 2.4 GeV Drive Beam (left), 9 GeV Main Beam (right)

- Loss of 1.0% in DB provokes similar signal as a loss of 0.01% of MB in region close to MB quadrupole.
- Due to a different time structures of the two trains, a detector with adequate time resolution could be used distinguish losses from either beam
- Not a Machine Protection Issue – Dangerous loss would never go unnoticed