Towards a proposal for a 10 TeV detector concept

Federico Meloni (DESY),
with several inputs and discussions started at KITP

Detector and MDI meeting, 16/05/2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

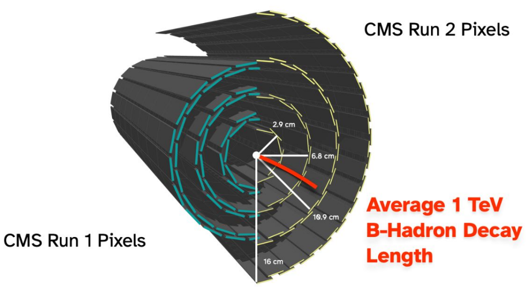
Starting point

See the excellent
talk from Larry Lee at KITP

Major Tent Poles

- **Energy Scale**
  - @ a 10 TeV μC, typical hard scatter at 10 TeV scale!
  - Multi-TeV objects will be the **norm** which will affect how to design the detector

To give a taste: Remember at 1 TeV, a B-hadron travels 10 cm into the detector



Decays happening well into tracker! A lot more precision silicon tracking required.

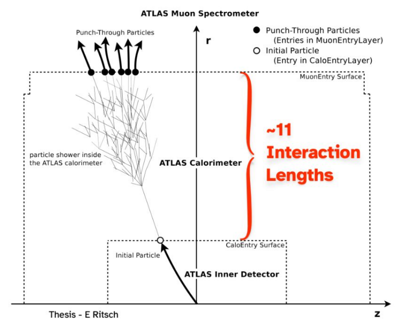
("B-*layer*" not enough. Need "B-*detectors*"!)

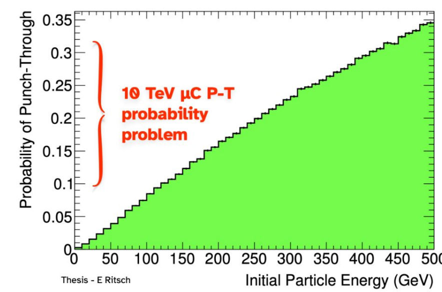
"Exotic" signatures will become Bread and Butter

Major Tent Poles

- **Energy Scale**
  - @ a 10 TeV μC, typical hard scatter at 10 TeV scale!
  - Multi-TeV objects will be the **norm** which will affect how to design the detector

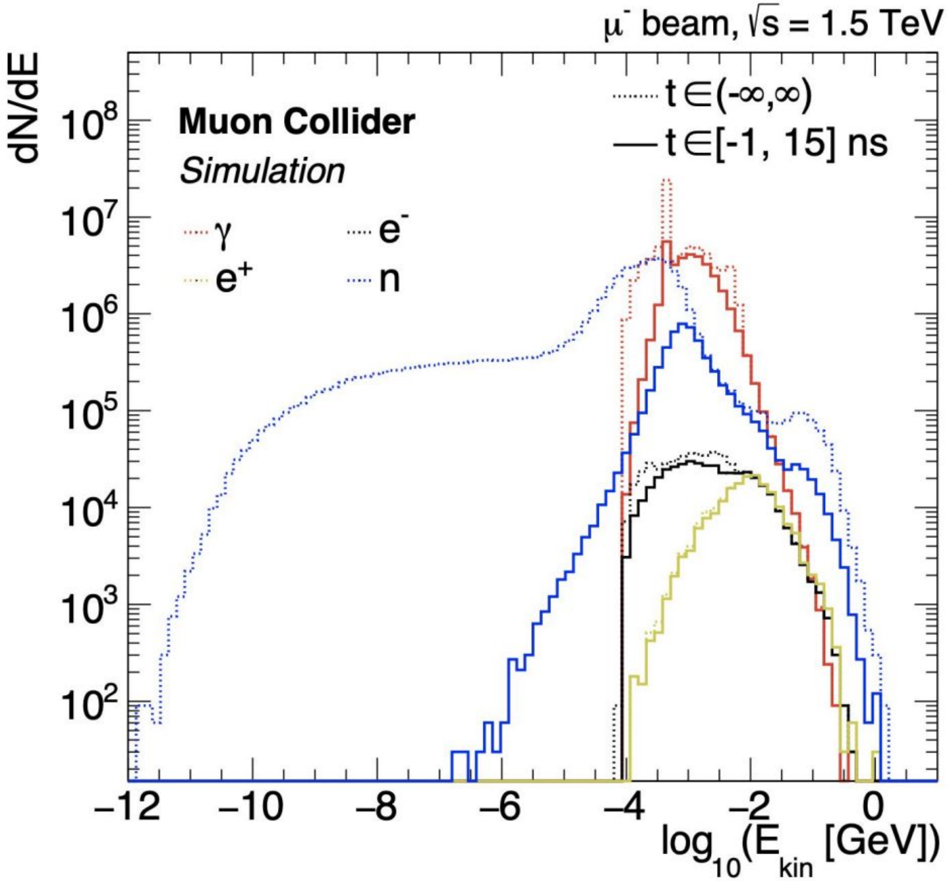
To give a taste: Need more interaction lengths to contain very energetic calorimeter showers

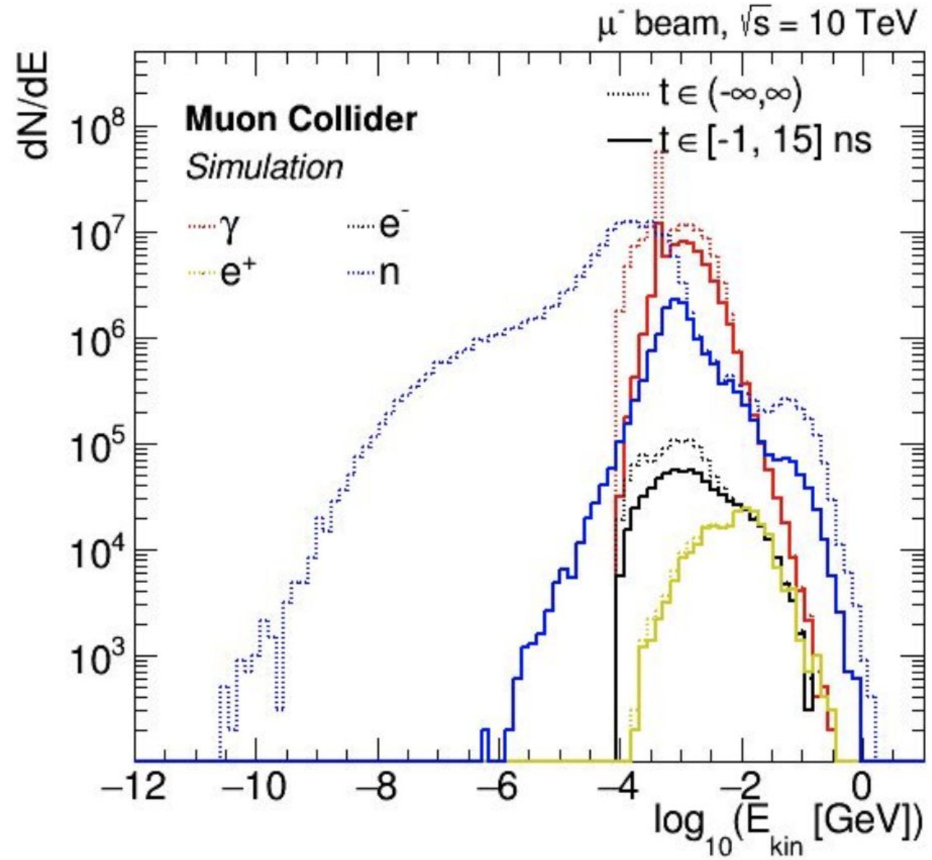




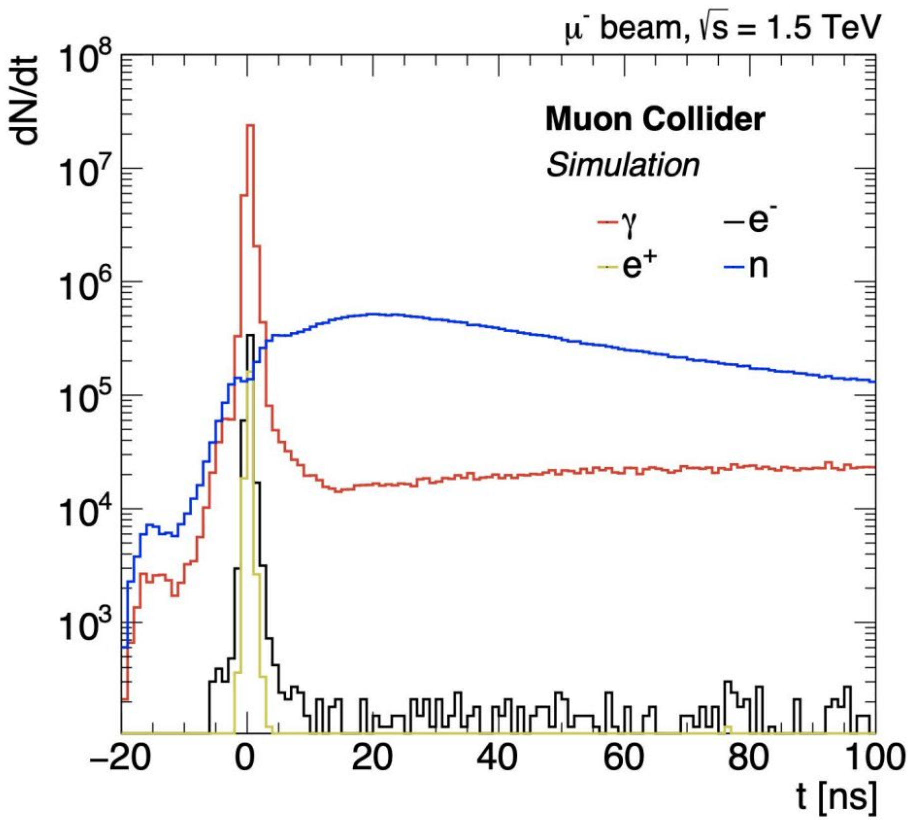
Most events at 10 TeV will come from VBF processes, so should not only optimise for pairs of ~5 TeV objects.

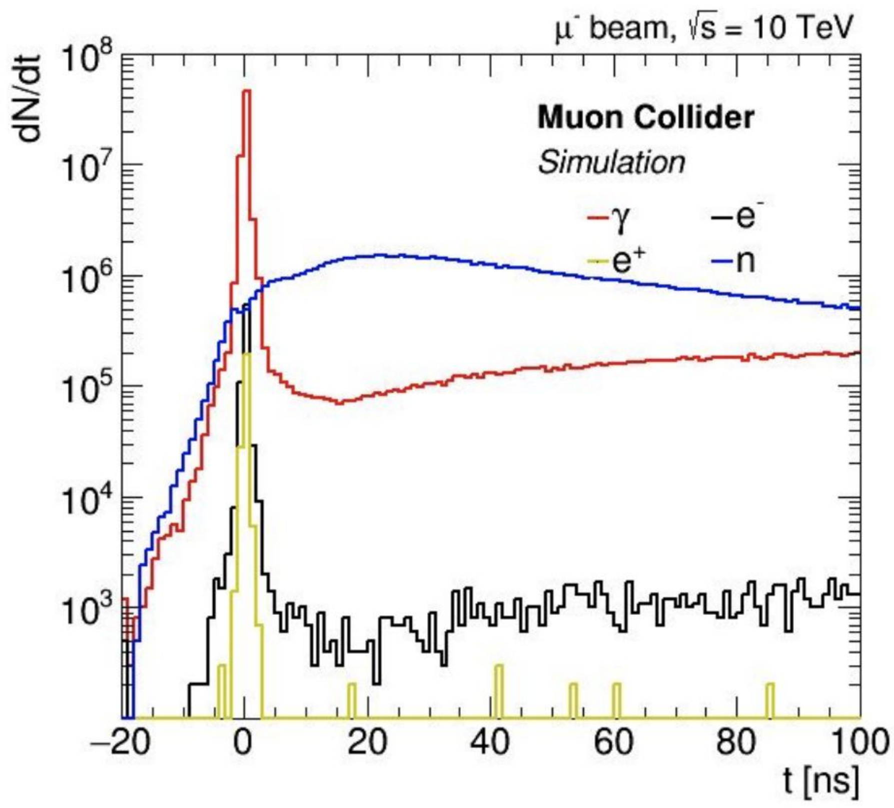
Early look at 10 TeV BIB: energy



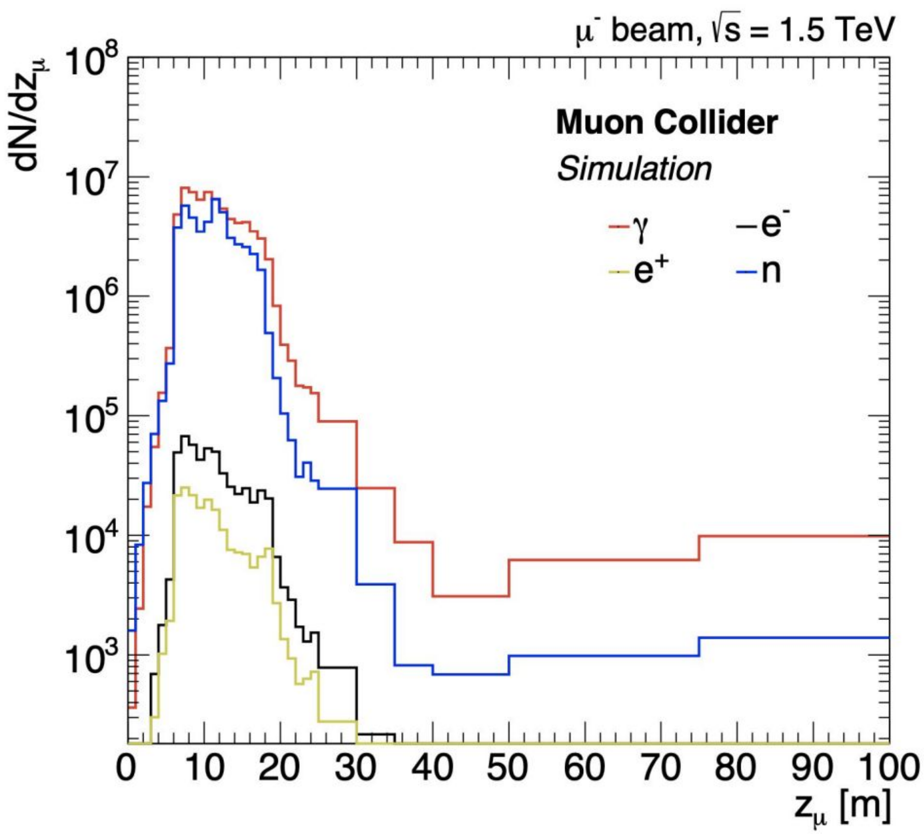


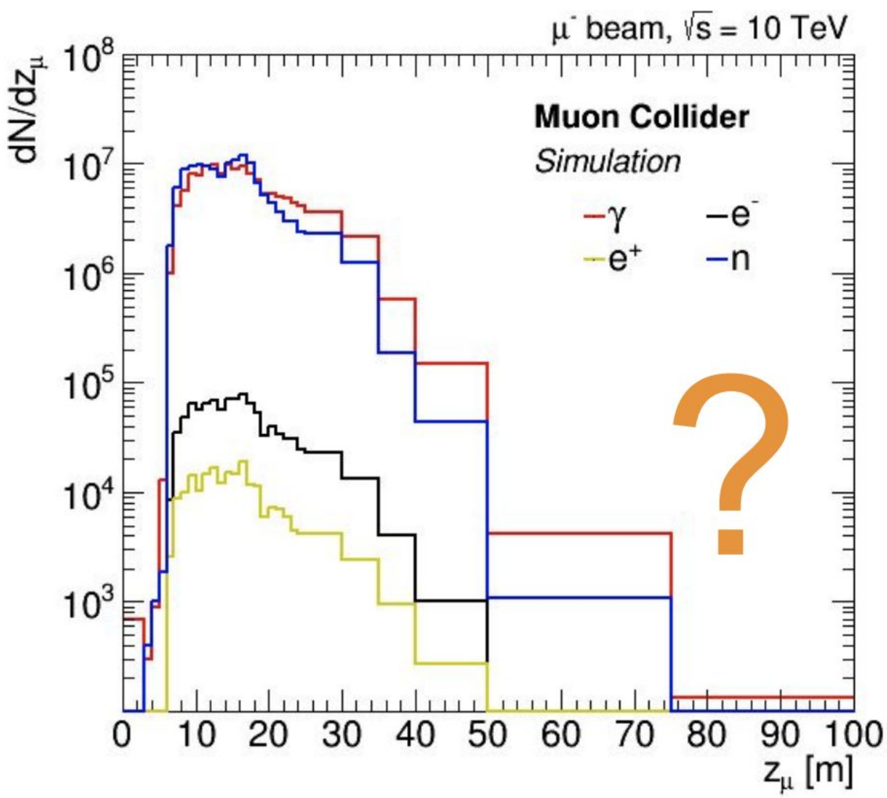
Early look at 10 TeV BIB: time





Early look at 10 TeV BIB: μ decay position



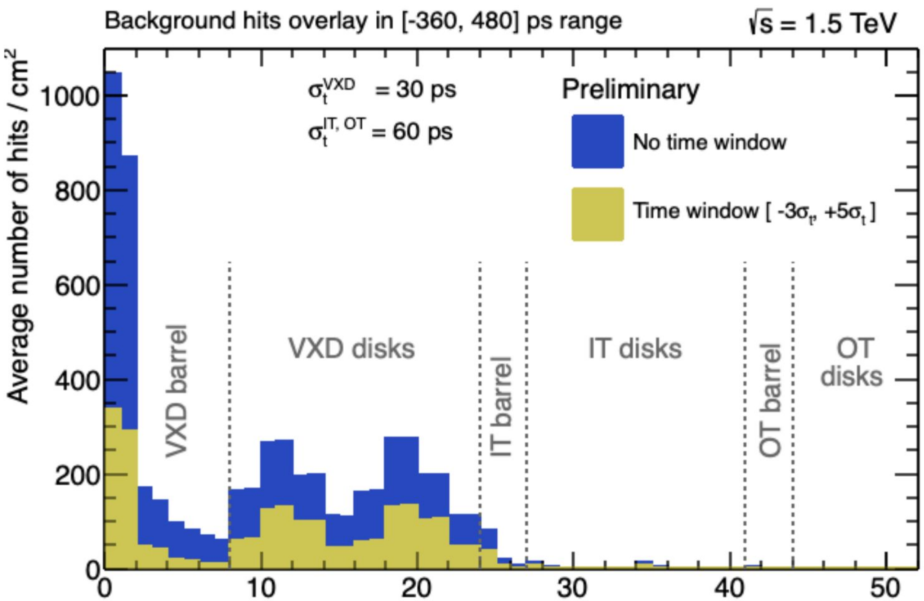


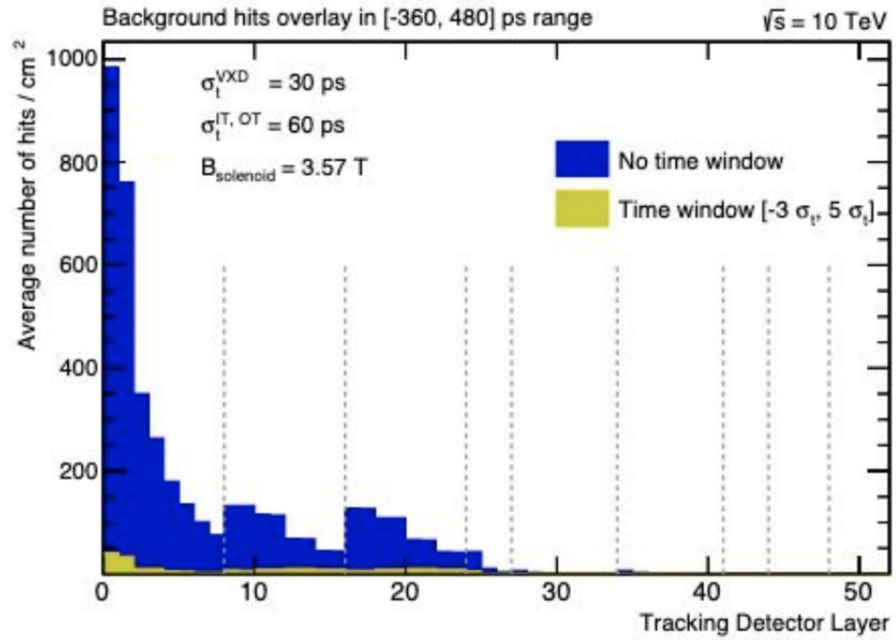
Lack of very-long tail comes from better modelling in FLUKA (now including synchrotron radiation)

- See more in Daniele's talk

Occupancies: tracker

~consistent with
Nazar's 10 TeV BIB findings



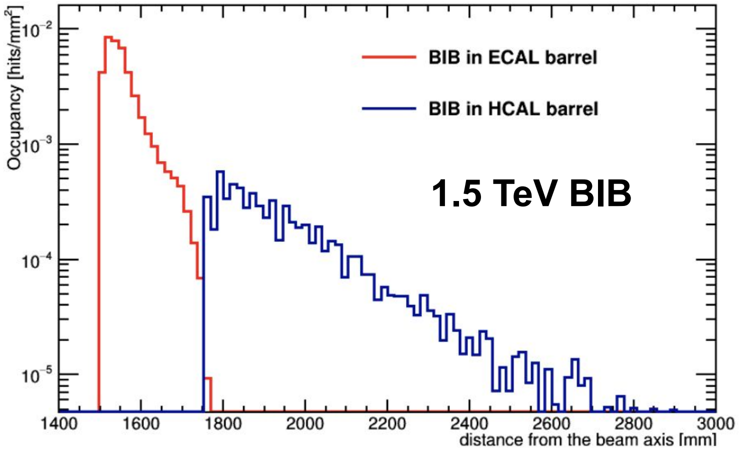


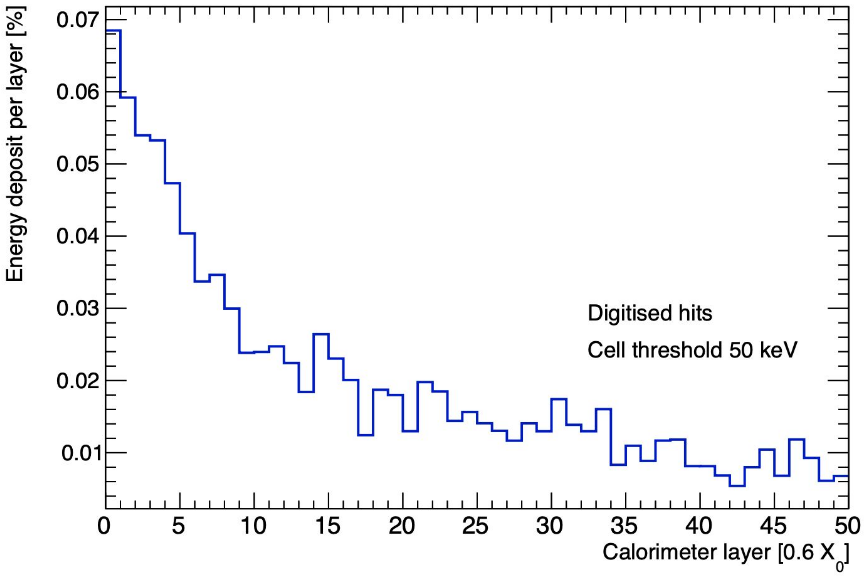
Increasing solenoid field to 5T has an effect of the order of 10% pre-timing

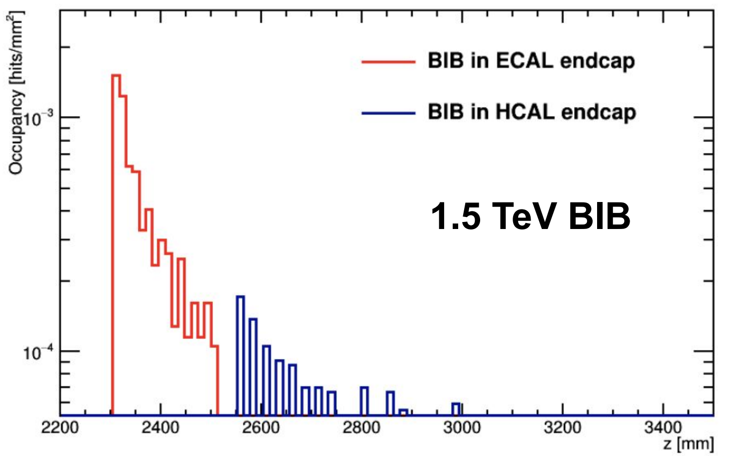
Things to study further:

- Different BIB structure in endcaps
- Timing selections seem much more effective than at 3 TeV

Occupancies: calorimeters







“Trivially needed” changes

Update the tracker

- Move closer to beam axis for innermost layer (if occupancy results confirmed)
- Increase granularity at large radii
- Reconsider double layers
- Re-design endcap region close to nozzles

Make the calorimeters thicker

- More energetic showers require more radiation/interaction-lengths to be contained (see studies from Laura Buonincontri and others)
- Rethink reconstruction for partly-contained showers?
- Revisit cell energy thresholds, or think about some level of “BIB shielding”

Options (that I am aware of / could think of)

1. Keep the same CLIC/CMS-like detector concept
   a. Push solenoid dimensions and field to the maximum
   b. Change sampling fraction, technologies and volumes to fit in the available space

2. **Break free of the solenoid**
   a. Move the solenoid inside the detector to gain freedom on the outer side
      i. Different calorimeter concepts (Dual readout, LAr, …)
      ii. Standalone muon spectrometer (with dedicated magnetic field for better high-p_T muon momentum resolution)
   b. Use solenoid as BIB shield!
   c. Material in front of the calorimeters will degrade energy resolution, but BIB does too. Risky trade-off: unclear without dedicated studies

3. Paradigm-changing ideas
   a. Many-solenoids idea from John Hauptman

Modifying the solenoid

Based on emails with Luca Bottura, Herman Ten Kate, Akira Yamamoto and the PDG

1. The conductor consisting of the current-carrying superconducting material (usually Nb-Ti/Cu) and the quench protecting stabilizer (usually aluminum) are wound on the inside of a structural support cylinder (usually aluminum also). The coil thickness scales as B^2R, so the thickness in radiation lengths (X_0) is

$$t_{\rm coil}/X_0 = (R/\sigma_h X_0)(B^2/2\mu_0)\ , \qquad (34.47)$$

where $t_{\rm coil}$ is the physical thickness of the coil, X_0 the average radiation length of the coil/stabilizer material, and σ_h is the hoop stress in the coil [308]. $B^2/2\mu_0$ is the magnetic pressure. In large detector solenoids, the aluminum stabilizer and support cylinders dominate the thickness; the superconductor (Nb-TI/Cu) contributes a smaller fraction. The main coil and support cylinder components typically contribute about 2/3 of the total thickness in radiation lengths.

I scaled the 3 TeV solenoid using this relation: it's thick (~3 X_0)!

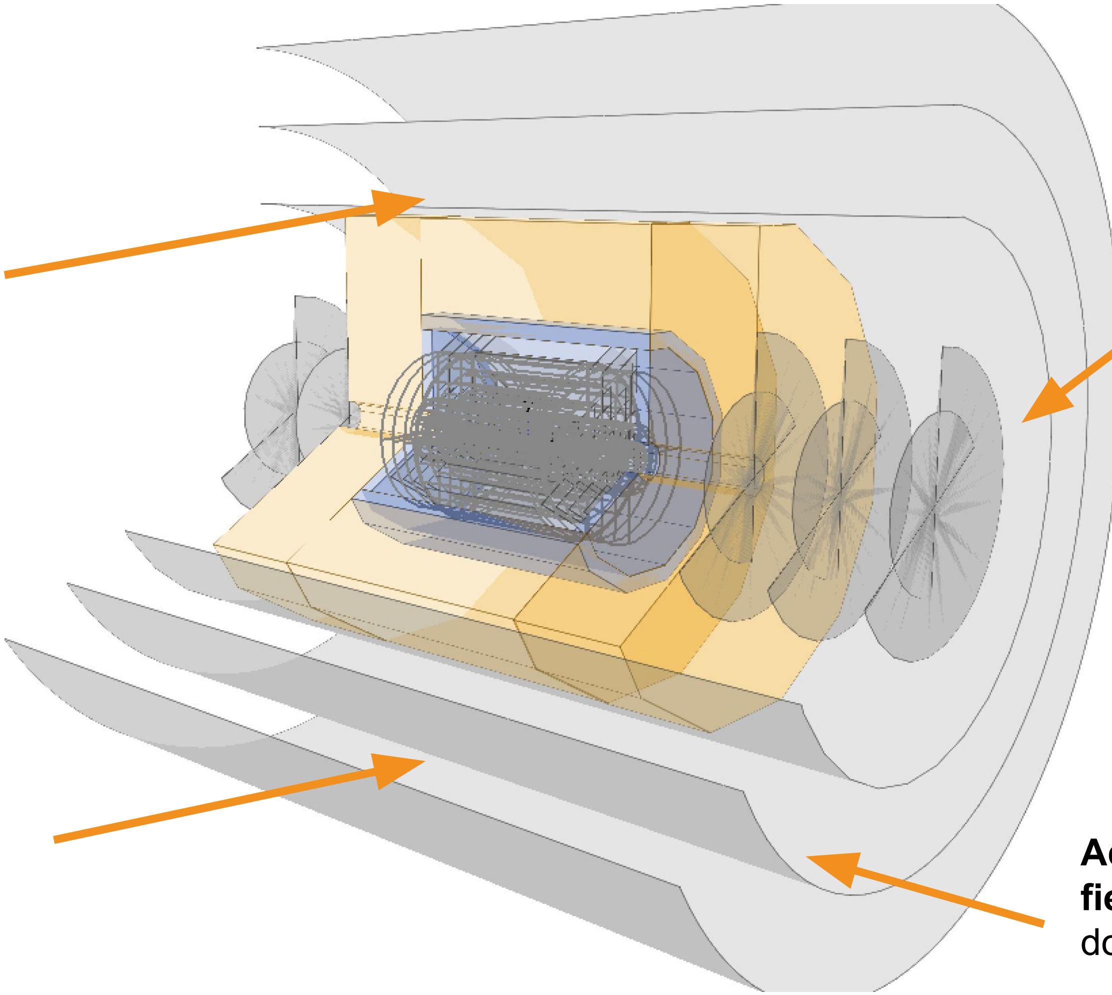
Thickness	344	mm	264,90	mm
B	3,57	T	5	T
R	3821	mm	1500	mm

Atomic and nuclear properties of aluminum (Al)

Quantity	Value	Units	Value	Units
Atomic number	13			
Atomic mass	26.9815385(7)	g mol^{-1}		
Density	2.699	g cm^{-3}		
Mean excitation energy	166.0	eV		
Minimum ionization	1.615	MeV g^{-1}cm^2	4.358	MeV cm^{-1}
Nuclear interaction length	107.2	g cm^{-2}	39.70	cm
Nuclear collision length	69.7	g cm^{-2}	25.81	cm
Pion interaction length	136.6	g cm^{-2}	50.62	cm
Pion collision length	95.6	g cm^{-2}	35.41	cm
Radiation length	24.01	g cm^{-2}	8.897	cm
Critical energy	42.70	MeV (for e^-)	41.48	MeV (for e^+)
Muon critical energy	612.	GeV		
Molière radius	11.93	g cm^{-2}	4.419	cm
Plasma energy $\hbar\omega_p$	32.86	eV		
Melting point	933.5	K	660.3	C
Boiling point @ 1 atm	2792.	K	2519.	C

Very early look at detector concept

No need for a Yoke: B field returned by iron in HCAL



Still buggy: **meant to extend up to the barrel**

Simplified muon detector (implemented as a tracker)

Adding toroidal field never really done before

Always check for overlaps!

FCC Terascale Soft Tut, Nov 28, '22 A. Sailer – Changing Geometry in DD4hep 15 / 38

Running the Geant4 Overlap Check

Create the following file as `overlap.mac`

```
/geometry/test/run
exit
```

And then we run `ddsim` with this macro file, and dump the output to a text file for easy browsing

```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --runType run \
      --macroFile overlap.mac > overlapDump &
```

- With the full detector model including the tracker this would take about 30 minutes

(Excellent) slides from A. Sailer at
Key4hep Software Tutorial for Future Collider studies

Several methods were brought up last week

- **Documentation in MuC tutorial planned**

Sharing samples

As a part of this exercise a few particle gun samples were produced for v1 geometry, which might be interesting for others

- I (?) can't write to the IMCC CERN EOS resources (maybe something weird with the egroup access? It would be good to document the instructions for how to use these somewhere)

In the meanwhile, data is available on snowmass21.io cluster:
/collab/project/snowmass21/data/muonc/fmeloni/DataMuC_MuColl_v1

- Directory structure hopefully self explanatory
- Several (~all) datasets available also in edm4hep format (mini-warning: these were produced via my build of key4hep, which should be equivalent to the v02-07-MC release)

Summary and plans

Presented some ideas initially discussed and further developed with several colleagues present at the KITP workshop

Initial goal is to come up with an as complete as possible set of particle-gun level studies to explore this initial detector proposal by the annual IMCC meeting

If it works well enough to be worth pursuing further, then plan to follow-up and refine during summer

- Use exercise as training ground for fresh students from KITP workshop
- Ideally organise recurrent reports at the off-week detector meetings (i.e. Lorenzo and Massimo's) to foster visibility of students involved in developing the concept

Thank you!