# Towards a muon collider

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Federico Meloni
(DESY)

LPHE Seminar

EPFL, 09/10/2023

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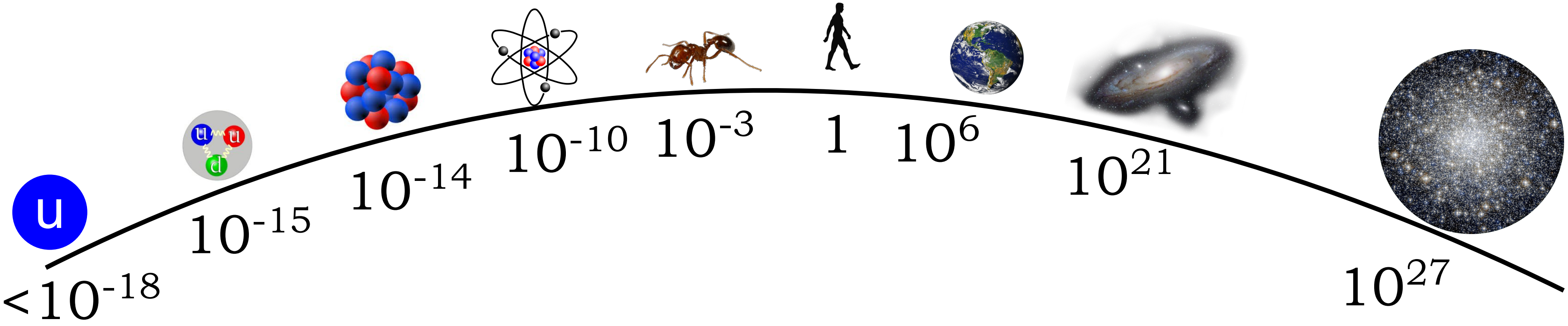
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

# Exploring the energy frontier

**Universe scales in metres**



$$\lambda \sim \frac{1}{p}$$

$$E = mc^2$$

physics/9901022

# High-energy microscopes

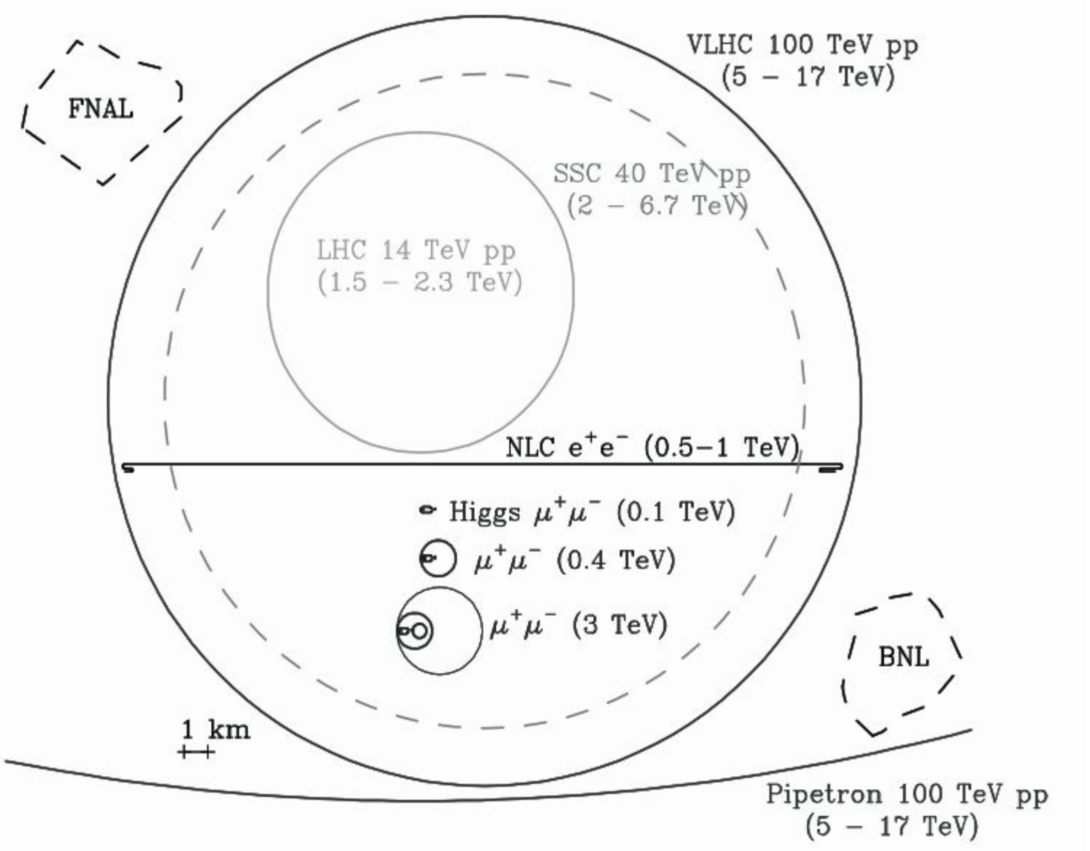
We conventionally probe shorter distances with either precision (indirect) or energy (direct)

**Muon colliders blur this dichotomy**

The muon mass (105.7 MeV/c$^2$, 207 x $e^\pm$ mass) means:

- Negligible synchrotron radiation emission
- Negligible beamstrahlung at collision

**Major technical challenges**



# A brief history of muon colliders

**1970/90 Initial proposal**

*G.I. Budker, Accelerators and colliding beams, 1969*
*A.N. Skirnsky, Intersecting storage rings at Novosibirsk, 1971*
*D. Neuffer, Multi-TeV muon colliders, 1986*

**2013 - LEMMA**

- Propose positron-driven scheme

**2019 - MICE**

- Demonstrates ionisation cooling

**IMCC**

**2011 - 2014 US Muon Accelerator Program MAP**

- Short- and long-baseline neutrino facilities
- Higgs factory with good energy resolution
- TeV-scale muon collider

*Muon Accelerators for Particle Physics*

**European Strategy for Particle Physics Update 2020**

- Set up an international collaboration

# The International Muon Collider Collaboration

**Objective**

Establish whether the investment into a full CDR and a demonstrator is scientifically justified

It will provide a baseline concept, well-supported performance expectations, and assess the associated key risks as well as cost and power consumption drivers

Link to website

**Scope**

- Focus on two energy ranges:

3 TeV 10+ TeV

- Explore synergy with neutrino/higgs factory
- Define R&D path

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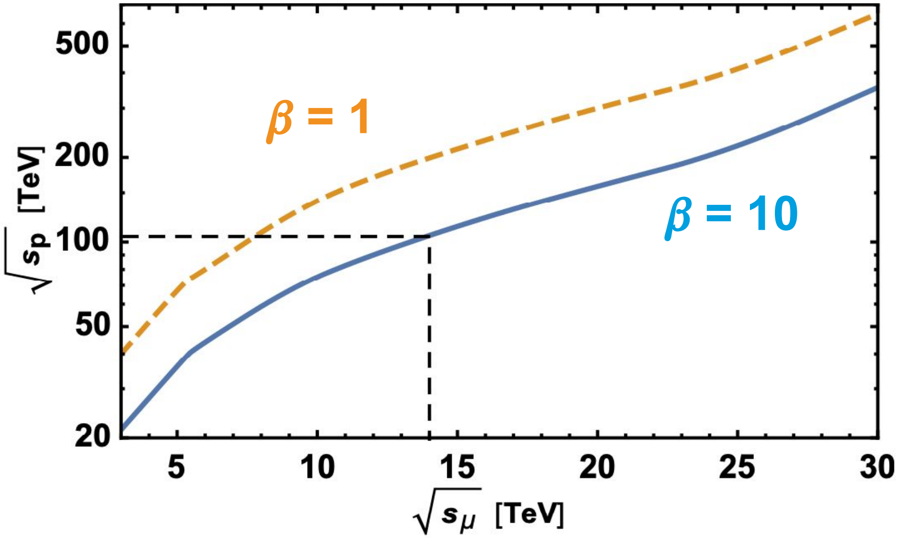
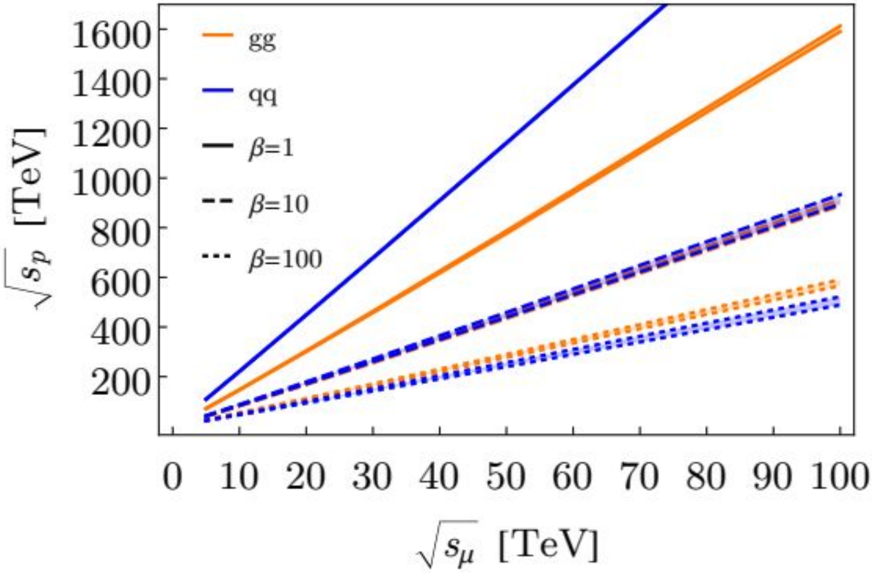
# Comparison to proton-proton machines

$$\beta \equiv [\hat{\sigma}]_p / [\hat{\sigma}]_\mu$$

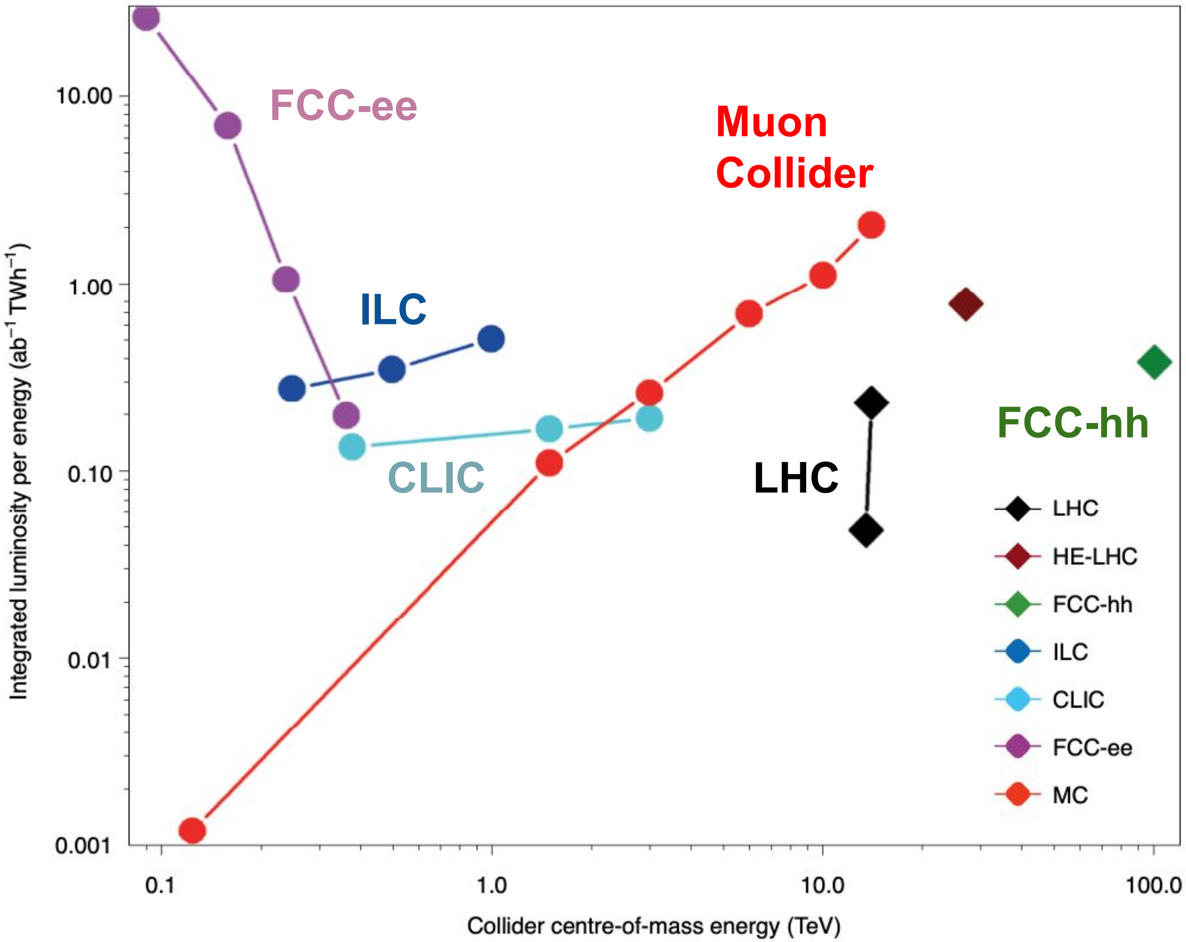




**Leptons are the ideal probes of short-distance physics**

- All the energy is stored in the colliding particle
- No energy “waste” due to parton distribution functions
- High-energy physics probed with much smaller collider energy

# Sustainability



**ROUGH RULE OF THUMB**

Cost $\propto$ Energy

Power $\propto$ Luminosity

High luminosity with **reasonable wall plug power** needs (~½ CLIC)

Cost-effective construction and operation

**Possible staging** / re-use of existing facilities

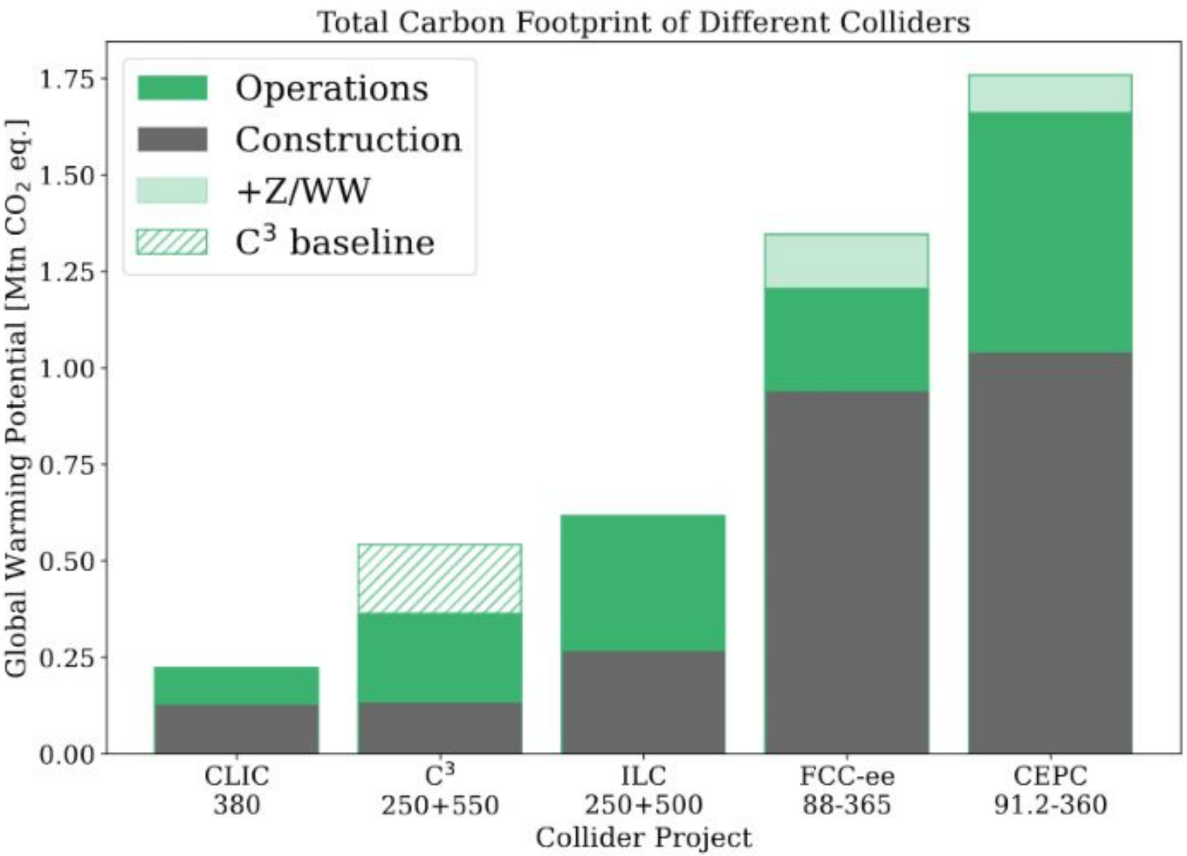
# Sustainability

Important aspect for next HEP projects

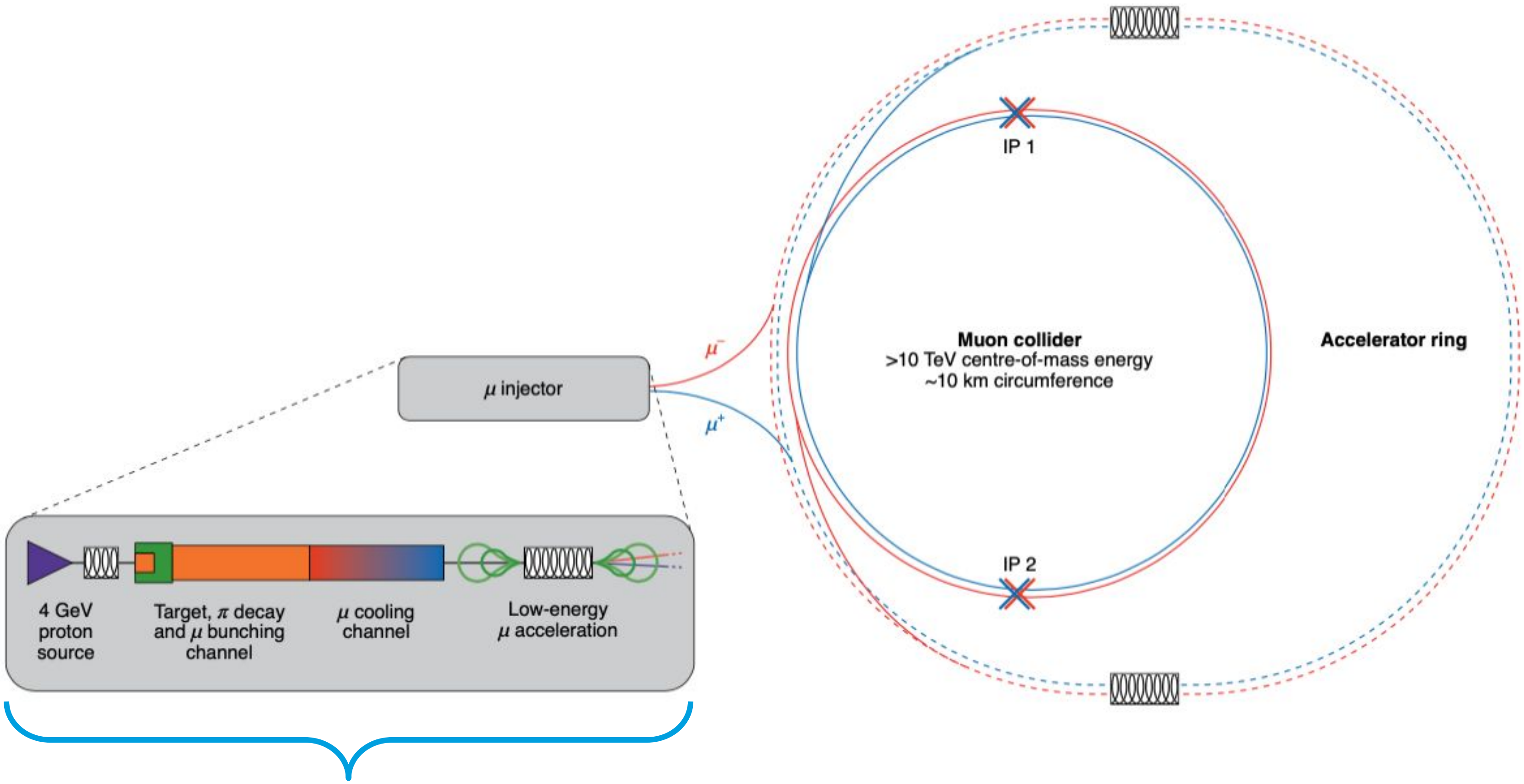
- Aim to progress in a sustainable way

<u>Life-cycle assessment</u>

- identify leading $CO_2$ sources



# Collider overview



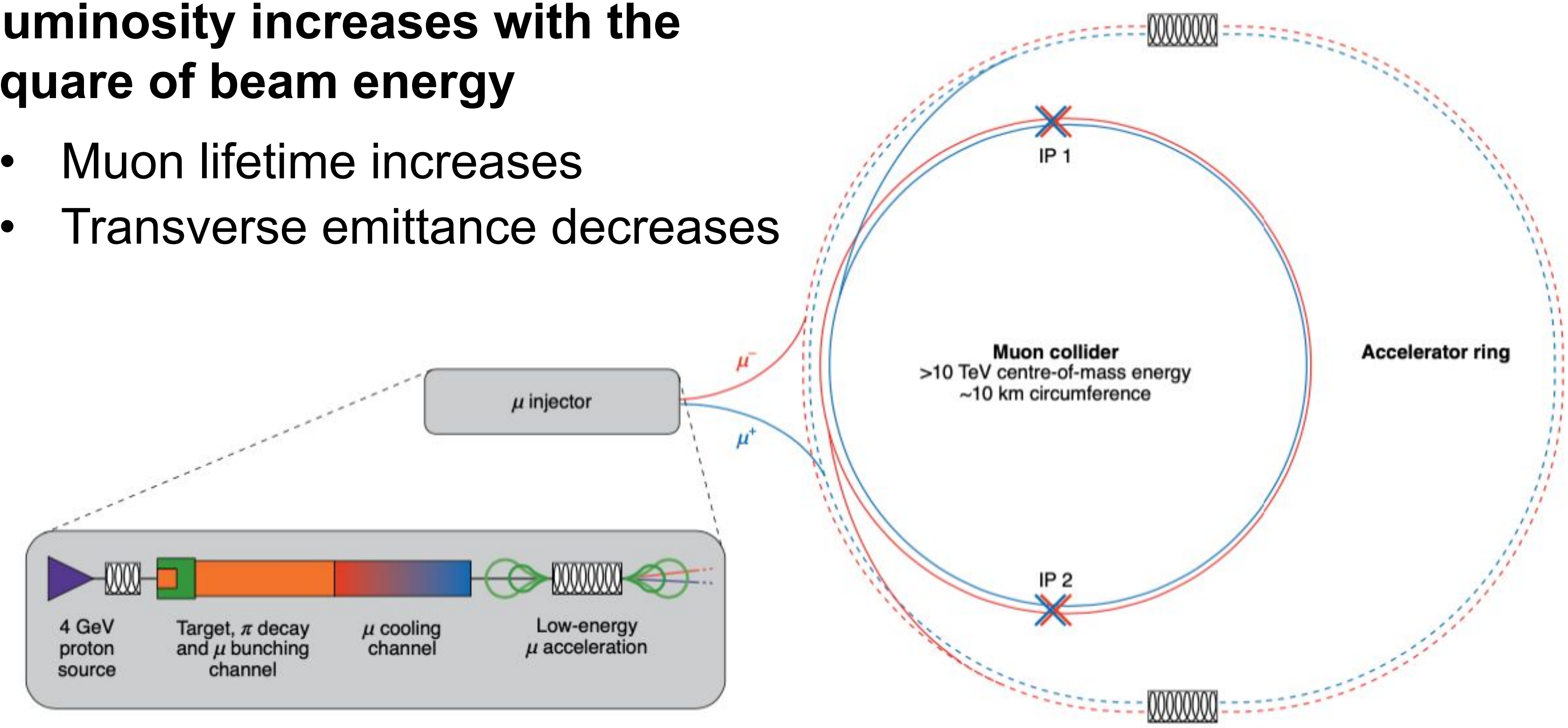
**Proton-driven scheme**

# Collision paradigm

Circulate two bunches and re-fill when they are depleted

**Luminosity increases with the square of beam energy**

- Muon lifetime increases
- Transverse emittance decreases



**1000 times lower collision rate than LHC!**

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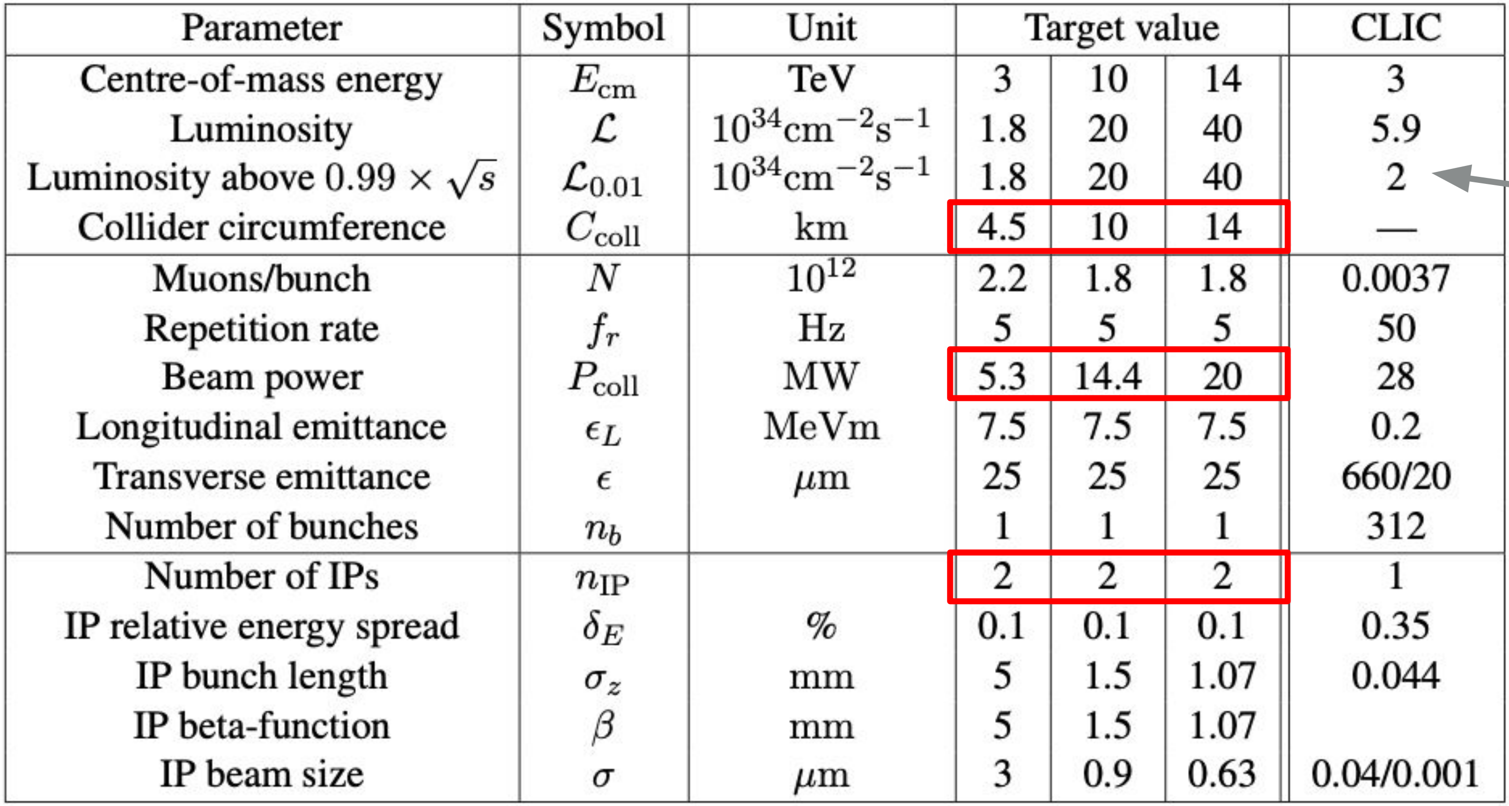
# Muon collider target parameters



| Parameter | Symbol | Unit | Target value | | | CLIC |
|---|---|---|---|---|---|---|
| Centre-of-mass energy | $E_{\mathrm{cm}}$ | TeV | 3 | 10 | 14 | 3 |
| Luminosity | $\mathcal{L}$ | $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | 1.8 | 20 | 40 | 5.9 |
| Luminosity above $0.99 \times \sqrt{s}$ | $\mathcal{L}_{0.01}$ | $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | 1.8 | 20 | 40 | 2 |
| Collider circumference | $C_{\mathrm{coll}}$ | km | 4.5 | 10 | 14 | — |
| Muons/bunch | $N$ | $10^{12}$ | 2.2 | 1.8 | 1.8 | 0.0037 |
| Repetition rate | $f_r$ | Hz | 5 | 5 | 5 | 50 |
| Beam power | $P_{\mathrm{coll}}$ | MW | 5.3 | 14.4 | 20 | 28 |
| Longitudinal emittance | $\epsilon_L$ | MeVm | 7.5 | 7.5 | 7.5 | 0.2 |
| Transverse emittance | $\epsilon$ | $\mu$m | 25 | 25 | 25 | 660/20 |
| Number of bunches | $n_b$ | | 1 | 1 | 1 | 312 |
| Number of IPs | $n_{\mathrm{IP}}$ | | 2 | 2 | 2 | 1 |
| IP relative energy spread | $\delta_E$ | % | 0.1 | 0.1 | 0.1 | 0.35 |
| IP bunch length | $\sigma_z$ | mm | 5 | 1.5 | 1.07 | 0.044 |
| IP beta-function | $\beta$ | mm | 5 | 1.5 | 1.07 | |
| IP beam size | $\sigma$ | $\mu$m | 3 | 0.9 | 0.63 | 0.04/0.001 |

Beamstrahlung

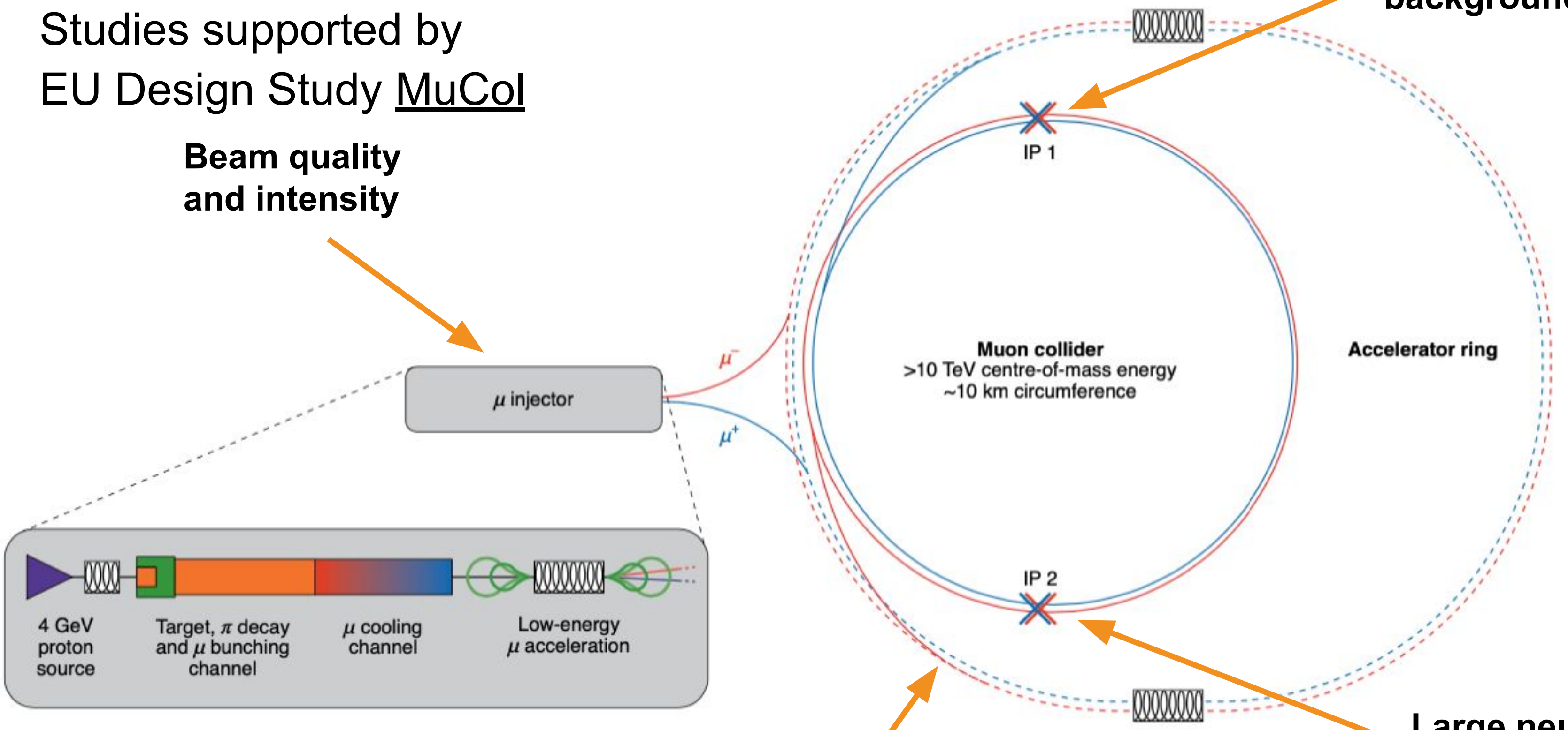
Based on extrapolation of the MAP parameters

- Plan to operate 5 years at each centre-of-mass energy (FCC-hh to operate for 25 years)

# Key challenges

Muons have a **limited lifetime**: 2.2 $\mu$s at rest

- Studies supported by EU Design Study MuCol



**Beam induced backgrounds**

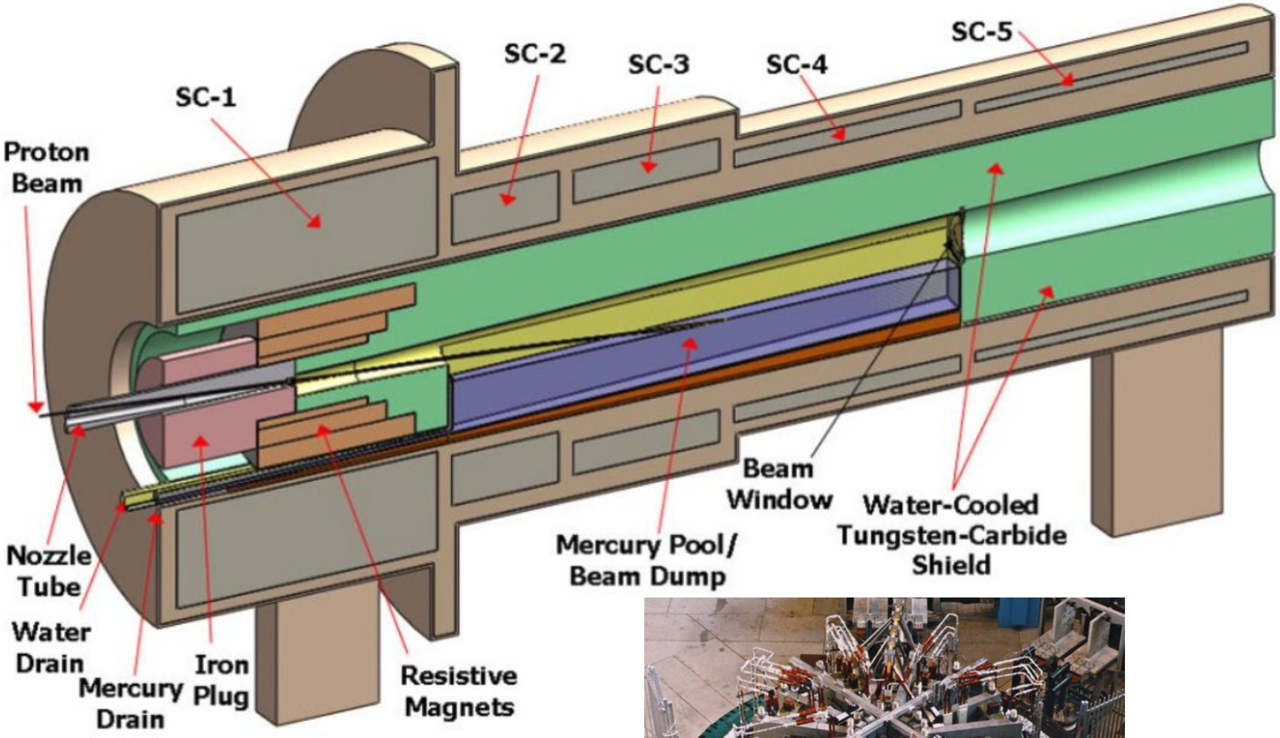
**Beam quality and intensity**

**Large neutrino flux**

**Cost and power**

# Proton target

**High-field required** to efficiency collect pions and muons

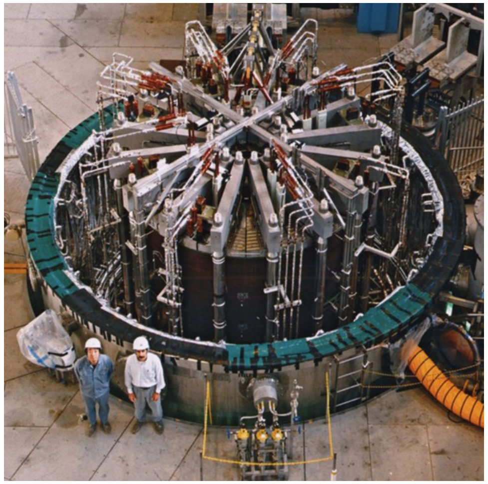


**2-4 MW proton beam**

- Simulated graphite target ok
- Operation at 2000°C

**Large aperture O(1m)** to allow shielding

- Synergy with ITER 13 T in 1.7 m



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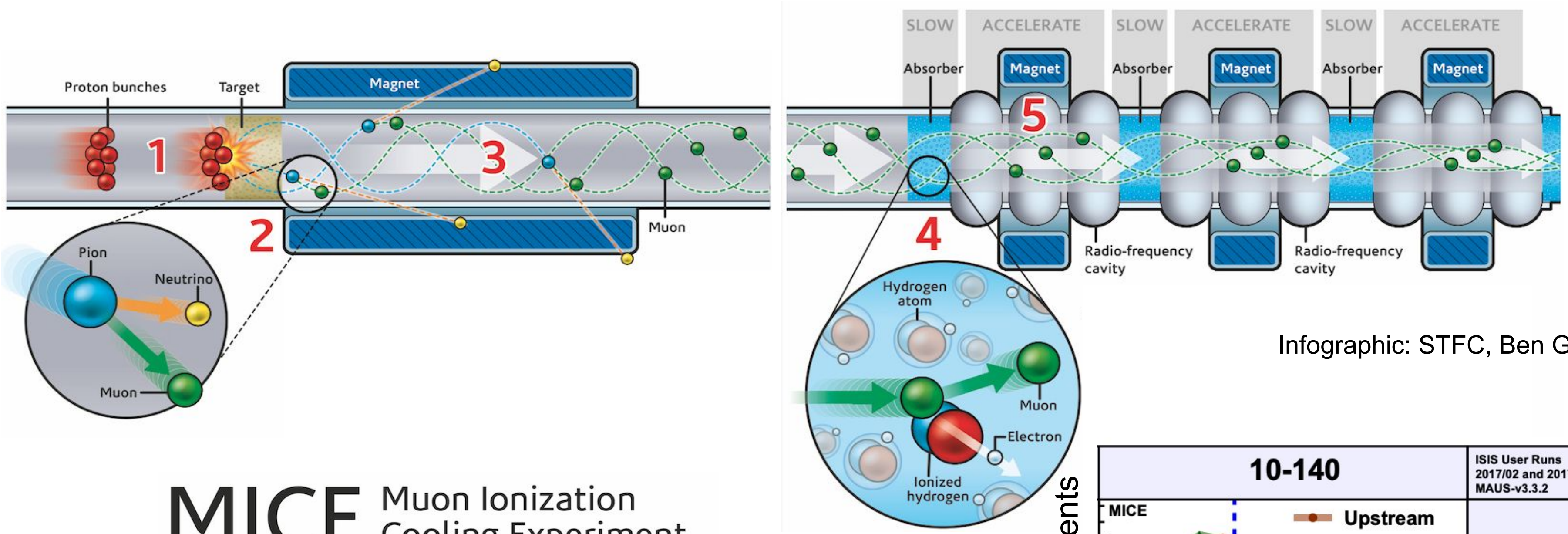
# Cooling the beams

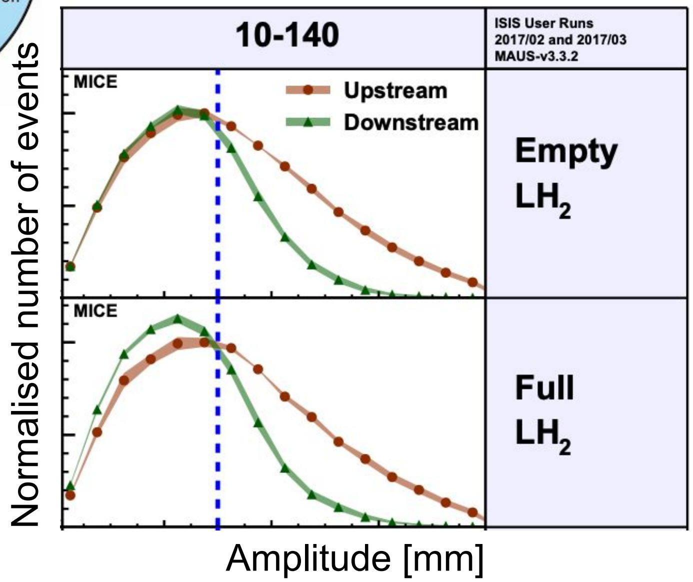


Infographic: STFC, Ben Gilliland

**MICE** Muon Ionization Cooling Experiment

**Need $10^6$ emittance reduction!**

- Demonstrator with RF and more than one stage required



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Nature Phys. 8 (2012) 243-247

# Accelerator ring

Ramp magnets to follow $E_{beam}$

- **Fast-ramping synchrotron magnets** (−2T to 2T in 2 ms)

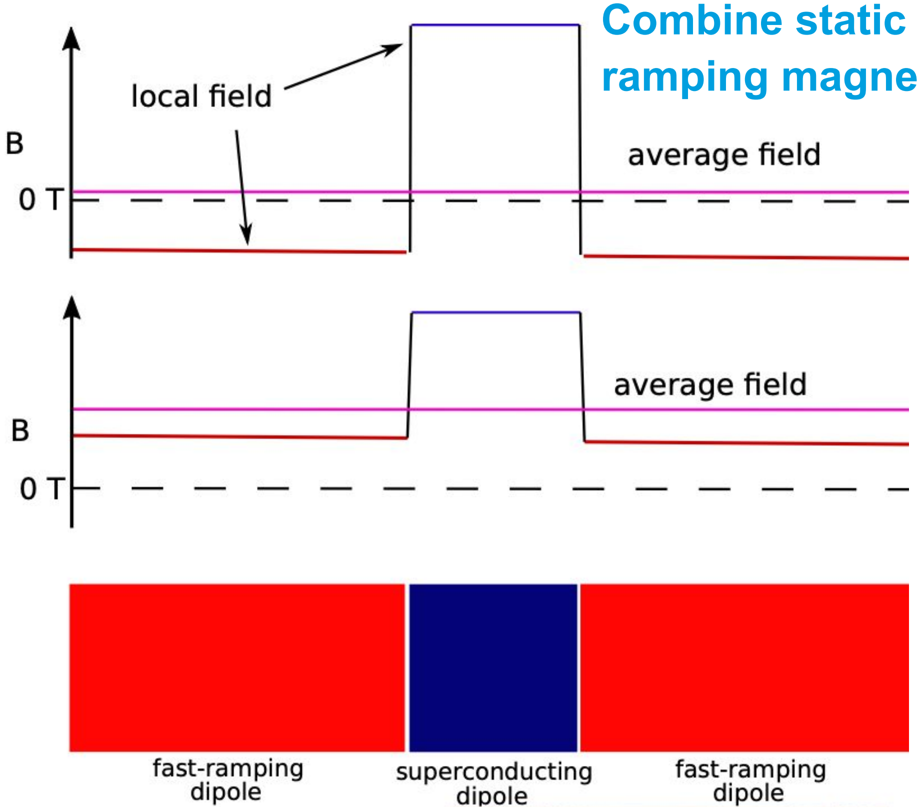
Demonstrated:

- Normal-conducting magnets (2.5 T/ms with peak of 1.81 T)
- HTS (12 T/ms, peak of 0.24 T)

Need 5 km of 2T magnets per TeV or fast HTS dipoles

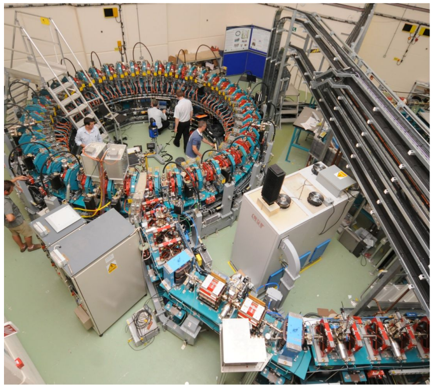
**Fixed-Field alternating gradient Accelerator** (alternative)

- Complex high-field magnets
- Challenging beam dynamics

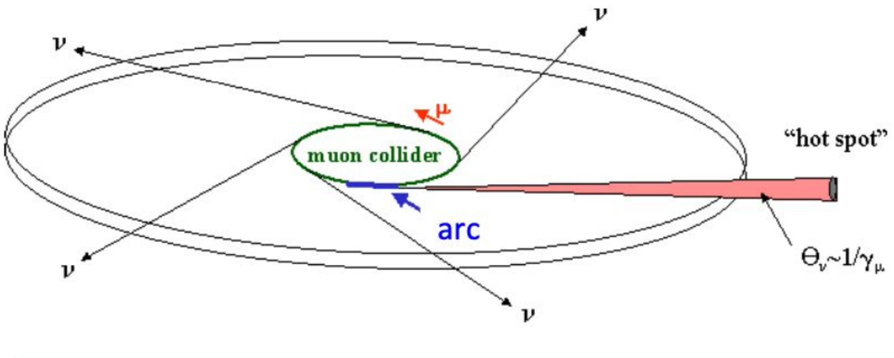


**Combine static and ramping magnets**

**EMMA proof of FFA principle**



# Neutrino flux



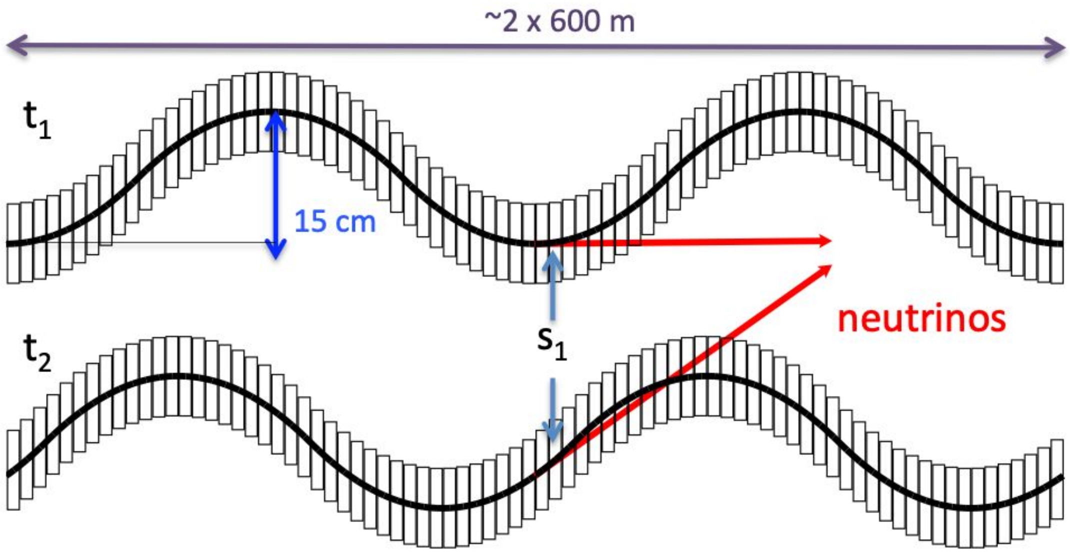
**Legal limit:** 1 mSv/year
**MAP goal:** < 0.1 mSv/year

**IMCC goal:** arcs below threshold for legal procedure < 10μSv/year
**LHC achieved:** < 5 μSv/year

**3 TeV, 200 m deep tunnel ~ OK**

**Need mitigation in collider arcs at 10+ TeV**: move collider ring components

Example: vertical bending

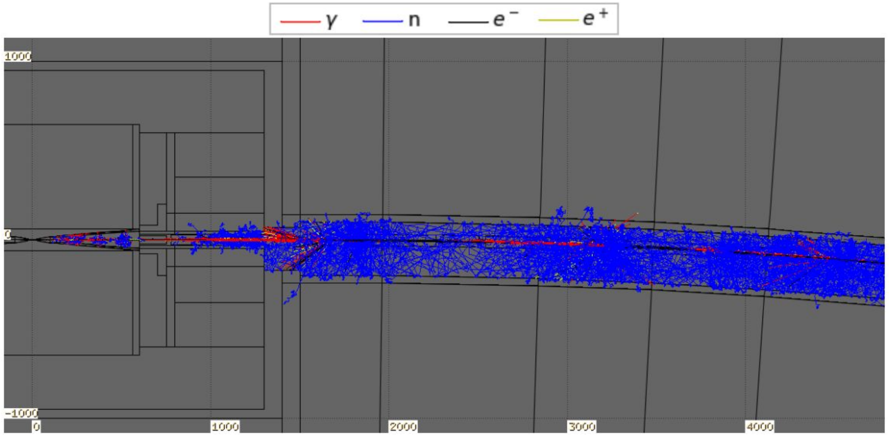


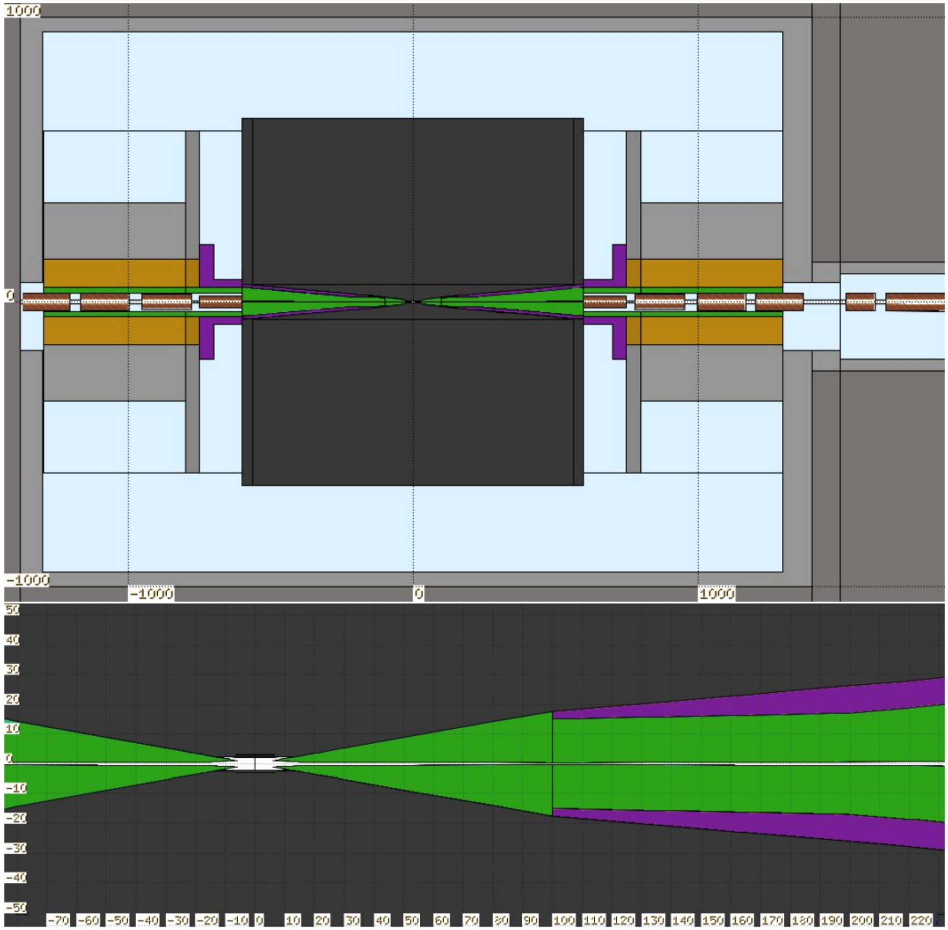
Sketch credit: D. Schulte

**Opening angle of 1 mradian makes 14 TeV collider comparable to LHC**

Need to engineer mover system and study impact on beams

# The beam-induced backgrounds (BIB)





Huge number of particles from muon decays ($4\times10^5$ per metre of lattice) and their byproducts

- Shieldeding with tungsten nozzles with borated polyethylene ($BCH_2$) coating

**Unique challenge of Muon Colliders**

# Machine-Detector interface

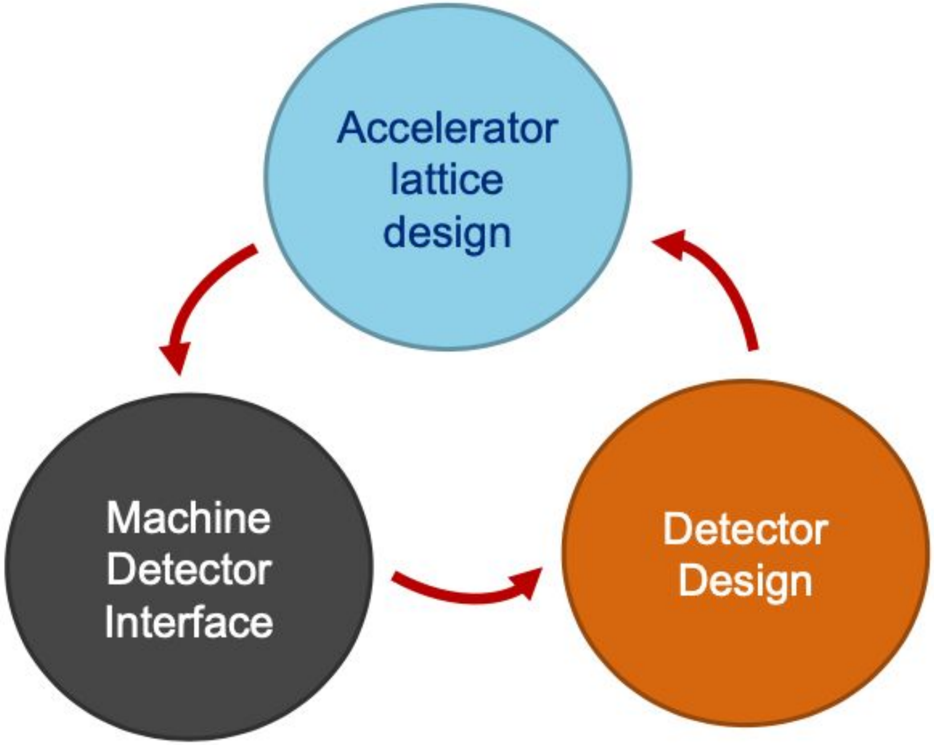


Diagram credit: S. Jindariani

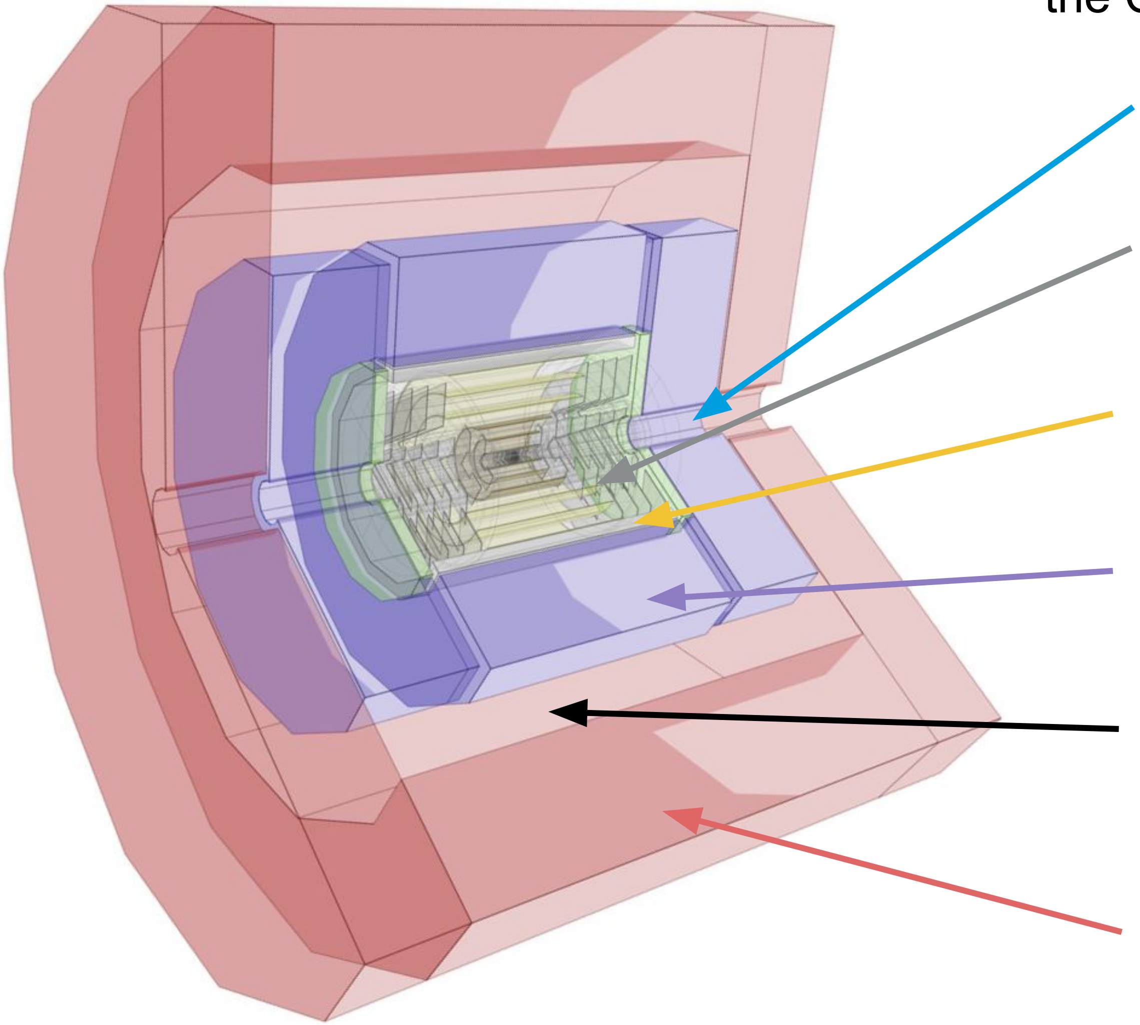
Muon Collider detector design has to be carried out in close collaboration with accelerator and MDI designers!

**STATUS**

| √s | IP design | MDI | Detector |
|---|---|---|---|
| 3 TeV | ✔ | 1.5 TeV BIB | ✔ |
| 10 TeV | ongoing | ongoing | ongoing |

# 3 TeV detector layout

The detector model is based on the CLIC concept



Nozzles

All-silicon tracker

ECAL (Tungsten+Silicon)

HCAL (Steel+Scintillators)

3.57 T Solenoid

Muon chambers (RPC) in magnet yoke

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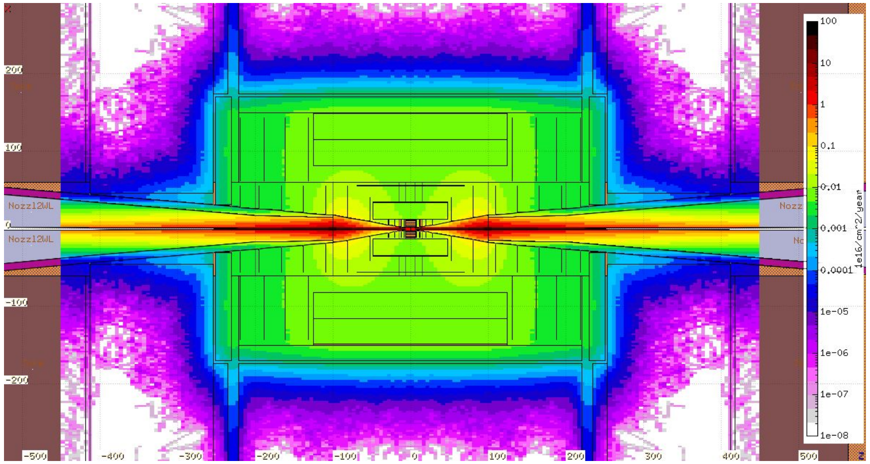
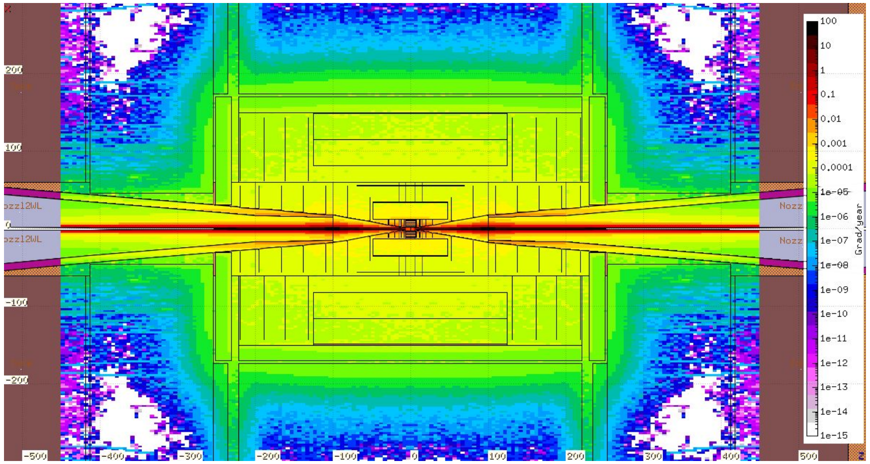
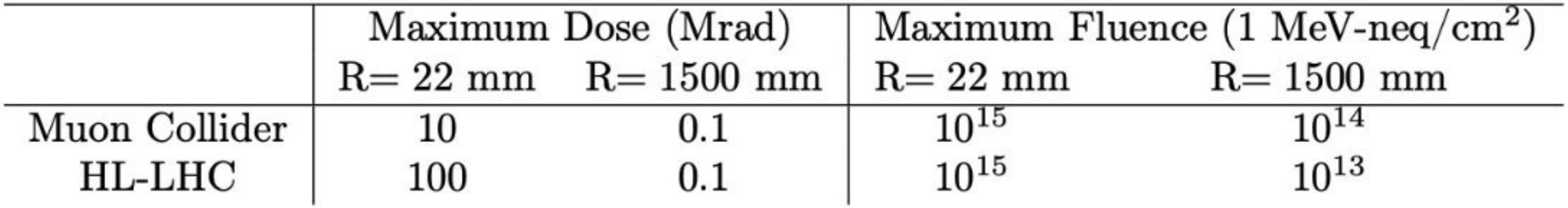
# Detection Environment



1-MeV-$n_{eq}$/$cm^2$ fluence for 200 days of operation



Total Ionising Dose for 200 days of operation

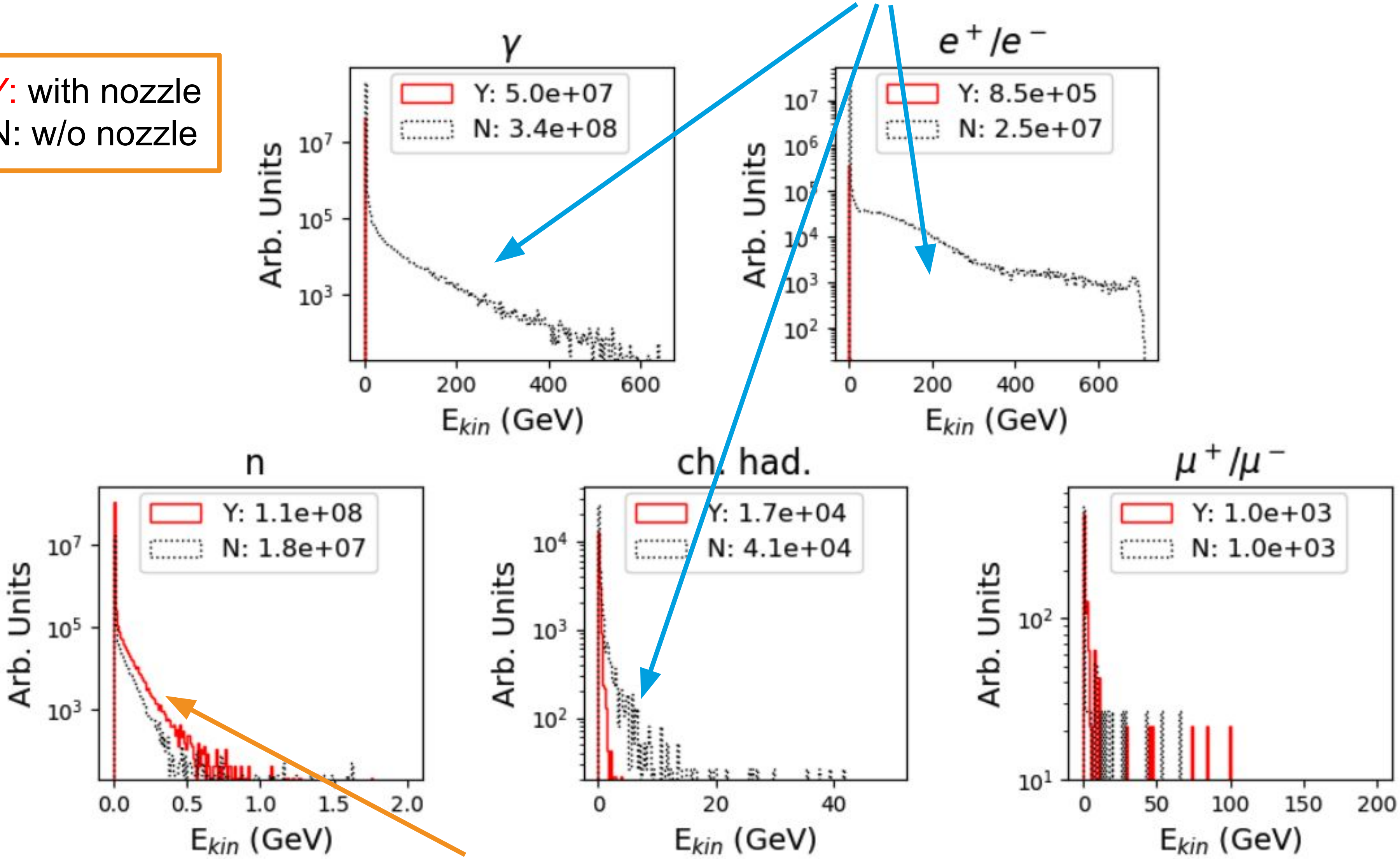


| | Maximum Dose (Mrad) | | Maximum Fluence (1 MeV-neq/$cm^2$) | |
|---|---|---|---|---|
| | R= 22 mm | R= 1500 mm | R= 22 mm | R= 1500 mm |
| Muon Collider | 10 | 0.1 | $10^{15}$ | $10^{14}$ |
| HL-LHC | 100 | 0.1 | $10^{15}$ | $10^{13}$ |

FCC-hh requirements
~$10^{18}$ 1 MeV-$n_{eq}$/$cm^2$

# Impact of nozzles

Y: with nozzle
N: w/o nozzle



High-energy component absorbed

Increase in neutron flux

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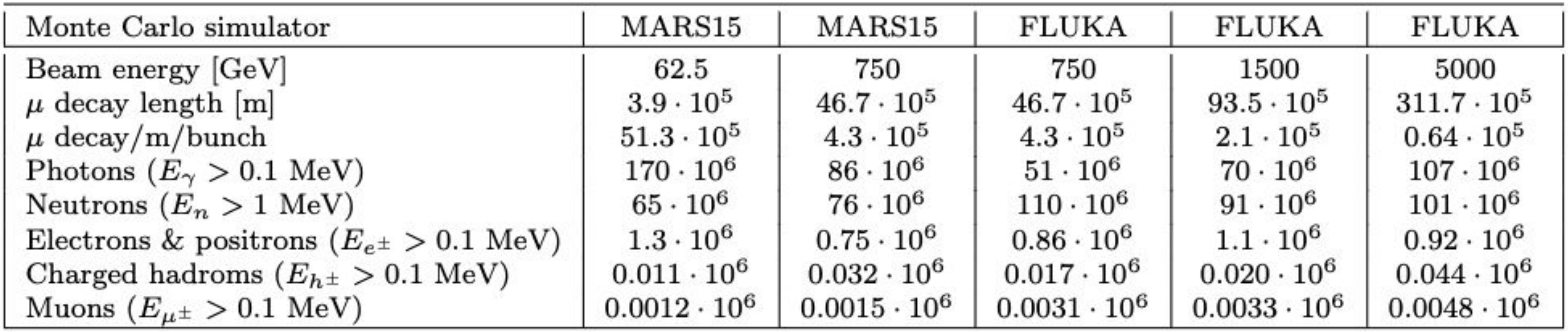
# Impact of nozzles



| Monte Carlo simulator | MARS15 | MARS15 | FLUKA | FLUKA | FLUKA |
|---|---|---|---|---|---|
| Beam energy [GeV] | 62.5 | 750 | 750 | 1500 | 5000 |
| $\mu$ decay length [m] | $3.9 \cdot 10^5$ | $46.7 \cdot 10^5$ | $46.7 \cdot 10^5$ | $93.5 \cdot 10^5$ | $311.7 \cdot 10^5$ |
| $\mu$ decay/m/bunch | $51.3 \cdot 10^5$ | $4.3 \cdot 10^5$ | $4.3 \cdot 10^5$ | $2.1 \cdot 10^5$ | $0.64 \cdot 10^5$ |
| Photons ($E_\gamma > 0.1$ MeV) | $170 \cdot 10^6$ | $86 \cdot 10^6$ | $51 \cdot 10^6$ | $70 \cdot 10^6$ | $107 \cdot 10^6$ |
| Neutrons ($E_n > 1$ MeV) | $65 \cdot 10^6$ | $76 \cdot 10^6$ | $110 \cdot 10^6$ | $91 \cdot 10^6$ | $101 \cdot 10^6$ |
| Electrons & positrons ($E_{e^\pm} > 0.1$ MeV) | $1.3 \cdot 10^6$ | $0.75 \cdot 10^6$ | $0.86 \cdot 10^6$ | $1.1 \cdot 10^6$ | $0.92 \cdot 10^6$ |
| Charged hadroms ($E_{h^\pm} > 0.1$ MeV) | $0.011 \cdot 10^6$ | $0.032 \cdot 10^6$ | $0.017 \cdot 10^6$ | $0.020 \cdot 10^6$ | $0.044 \cdot 10^6$ |
| Muons ($E_{\mu^\pm} > 0.1$ MeV) | $0.0012 \cdot 10^6$ | $0.0015 \cdot 10^6$ | $0.0031 \cdot 10^6$ | $0.0033 \cdot 10^6$ | $0.0048 \cdot 10^6$ |

The MDI optimised for the centre-of-mass energy of 1.5 TeV is assumed

- Simulation available in MARS15 and FLUKA
- **BIB rates in detector volume approximately constant!**

→ higher centre-of-mass energies possible

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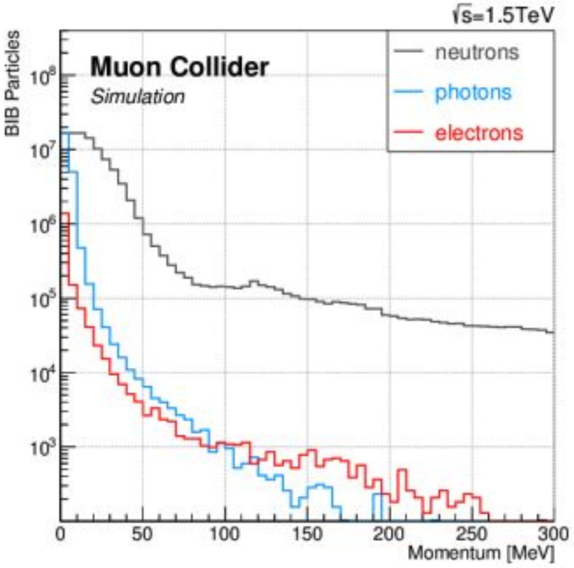
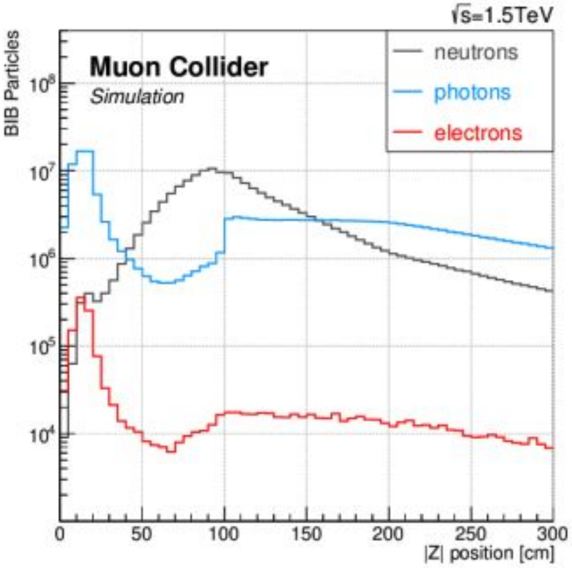
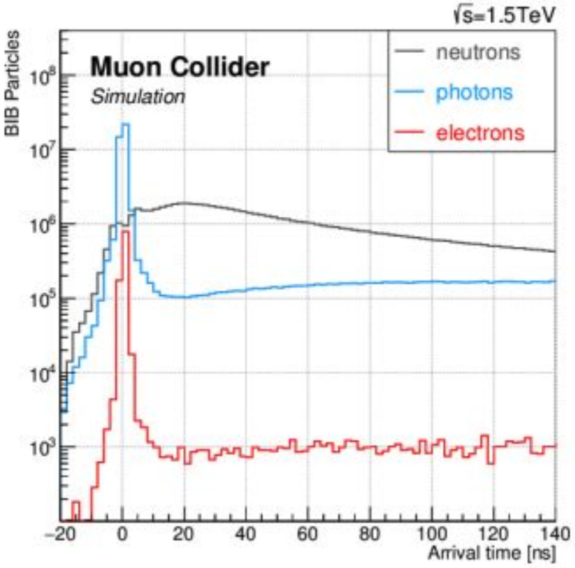
# Beam-induced background properties



**Low momentum**

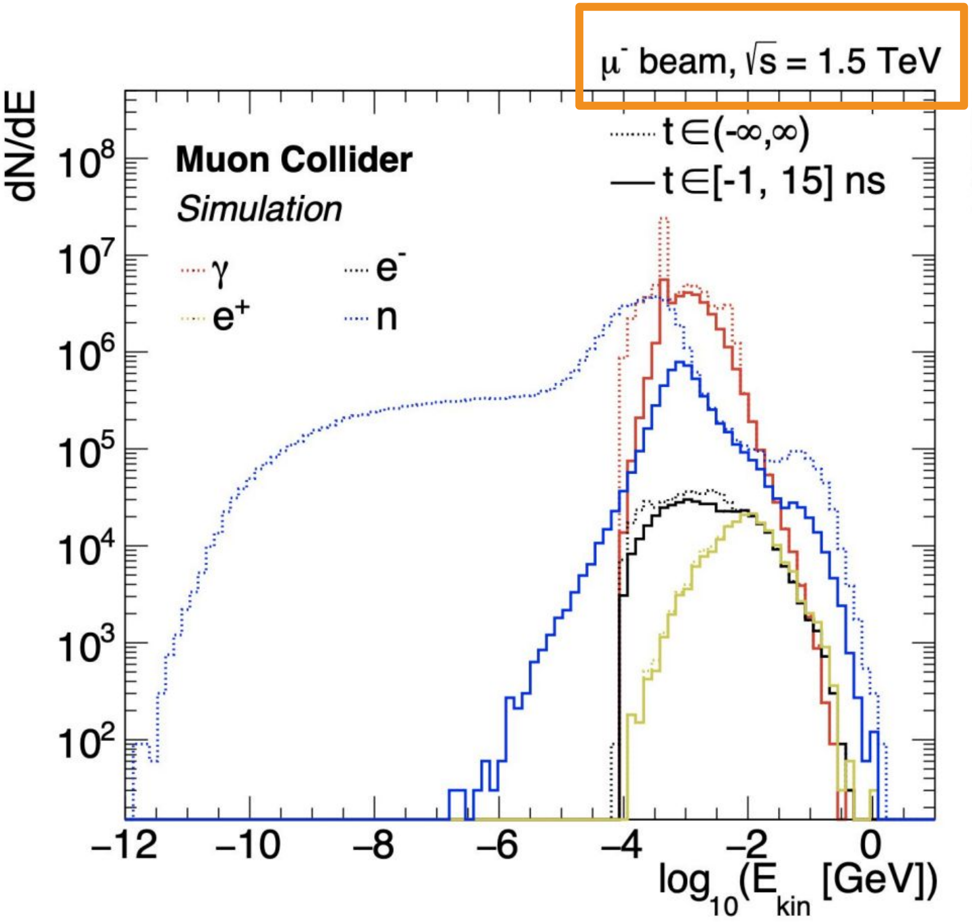


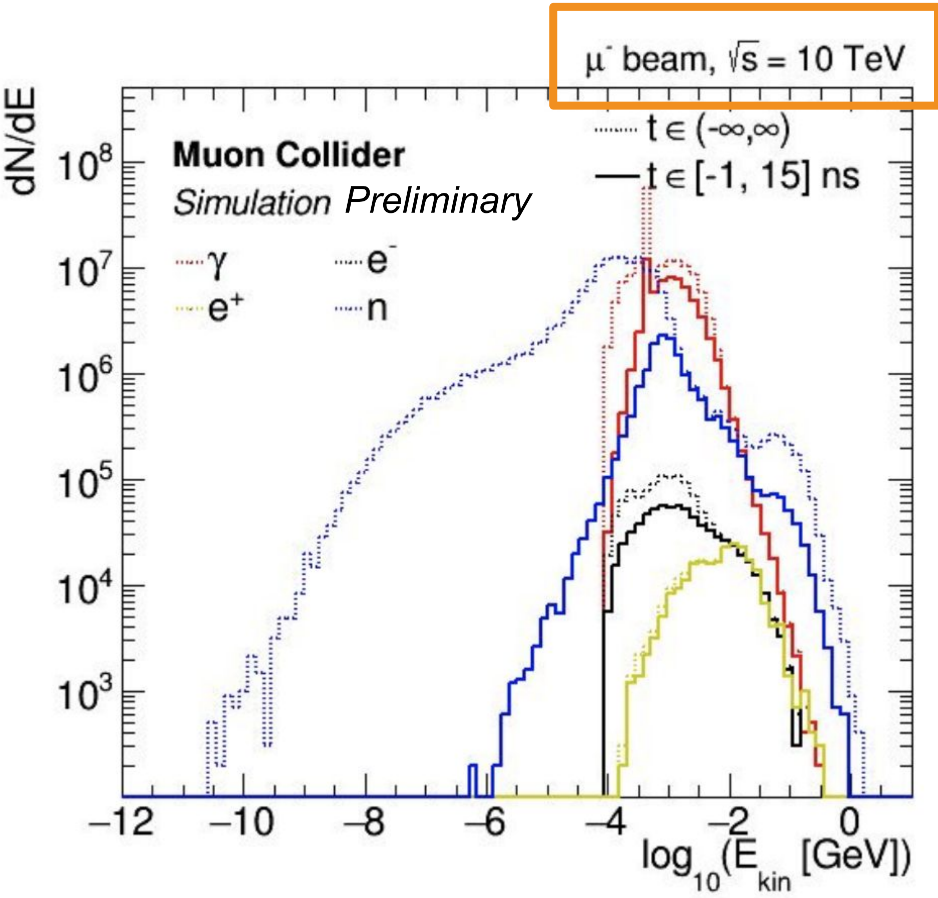
**Origin and direction**



**Timing**

# Preliminary look at 10 TeV BIB





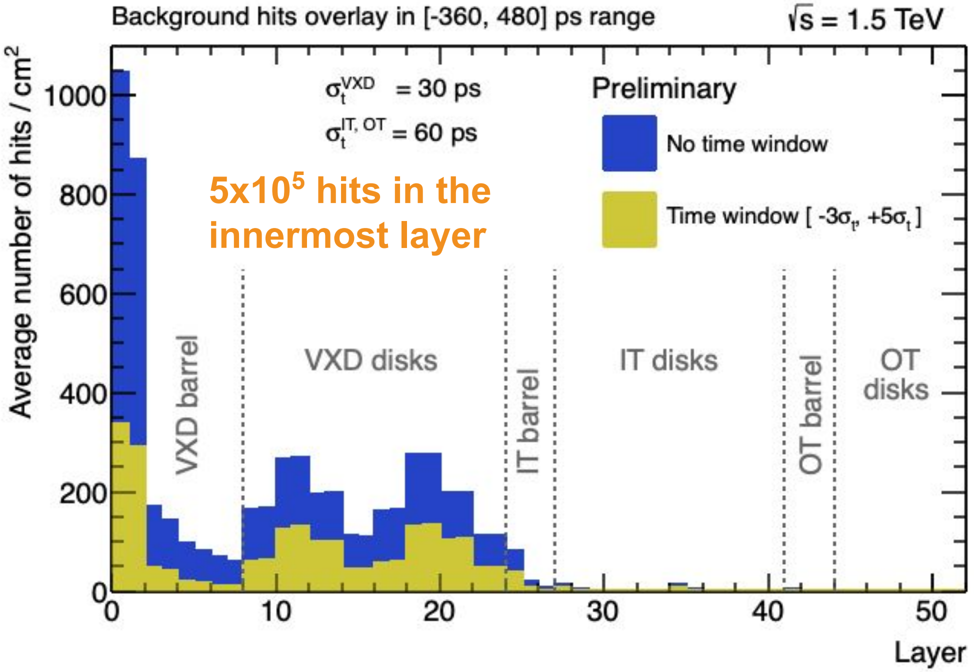
# Tracking detectors

**Goal: tracker occupancy < 1%**

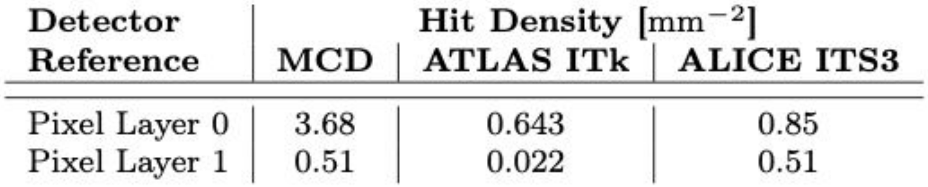
- Other requirements are not unique: **low mass/power, radiation tolerance, low noise**

**On- and off-detector filtering:**

- **Timing**
- Clustering
- Energy deposition
- **Local track angle**
- Pulse shapes



5x10$^5$ hits in the innermost layer



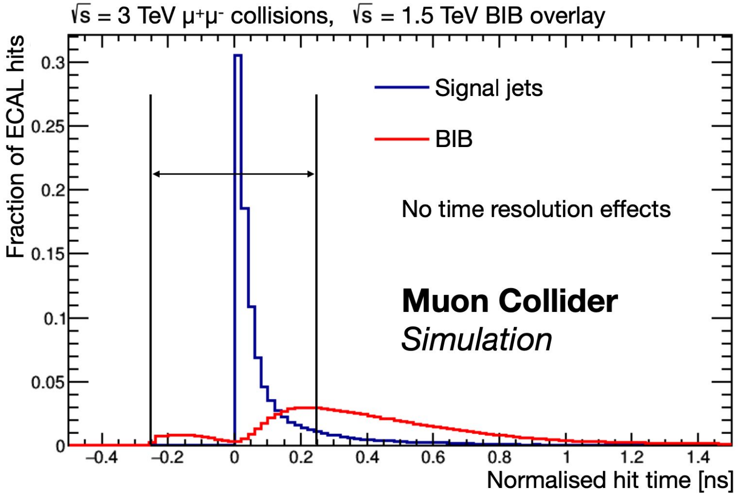
| Detector Reference | Hit Density [mm$^{-2}$] MCD | ATLAS ITk | ALICE ITS3 |
|---|---|---|---|
| Pixel Layer 0 | 3.68 | 0.643 | 0.85 |
| Pixel Layer 1 | 0.51 | 0.022 | 0.51 |

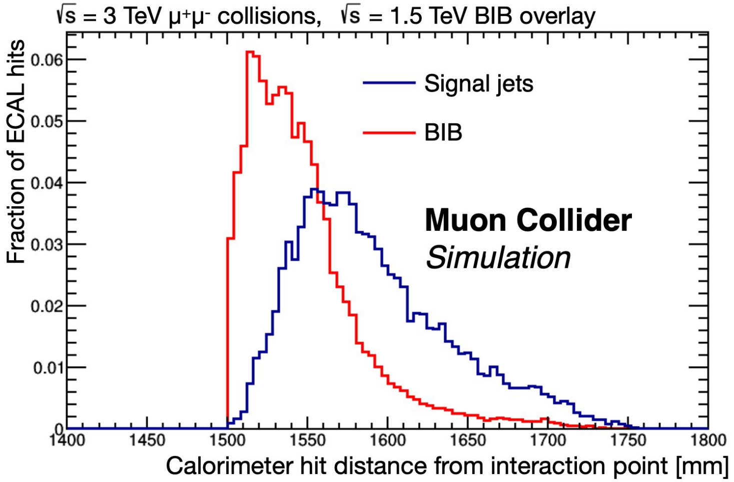
**Compared to HL-LHC**

~10x hit density

~1/1000 bunch crossing rate

# Calorimetry





BIB dominated by neutral particles: photons (96%) and neutrons (4%)

**Ambient energy about 50 GeV per unit area** (~40 GeV in HL-LHC)

- High granularity
- Precise hit time measurement O(100ps)
- Longitudinal segmentation
- Good energy resolution 10%/√E for photons and 35%/√E for jets or better

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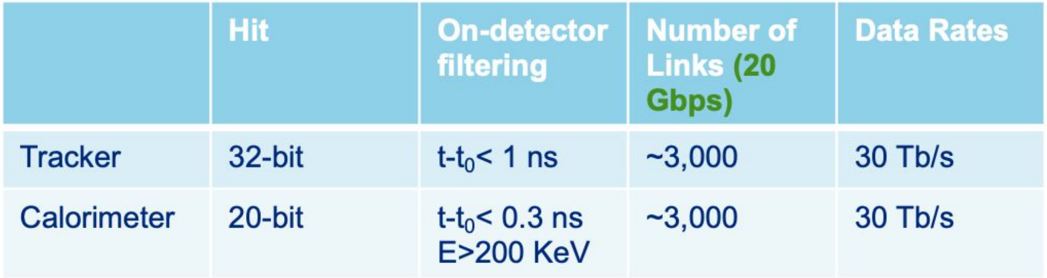
# Readout and DAQ

Instantaneous luminosity of **$10^{34}$-$10^{35}$ cm$^{-2}$s$^{-1}$**

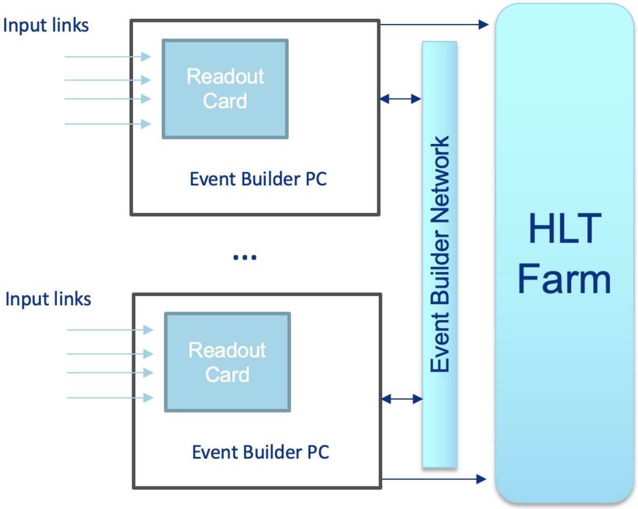
Beam crossings **every 10 μs**

**Streaming approach**: availability of the full event data → better trigger decision, easier maintenance, simplified design of the detector front-end…



| | Hit | On-detector filtering | Number of Links (20 Gbps) | Data Rates |
|---|---|---|---|---|
| Tracker | 32-bit | $t-t_0 < 1$ ns | ~3,000 | 30 Tb/s |
| Calorimeter | 20-bit | $t-t_0 < 0.3$ ns<br>E>200 KeV | ~3,000 | 30 Tb/s |

Table credit: S. Jindariani



Total data rate similar to HLT at HL-LHC

- **Streaming operation likely feasible**

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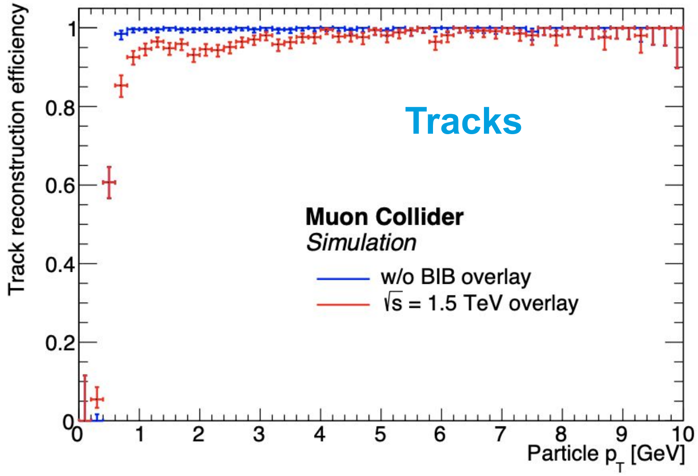
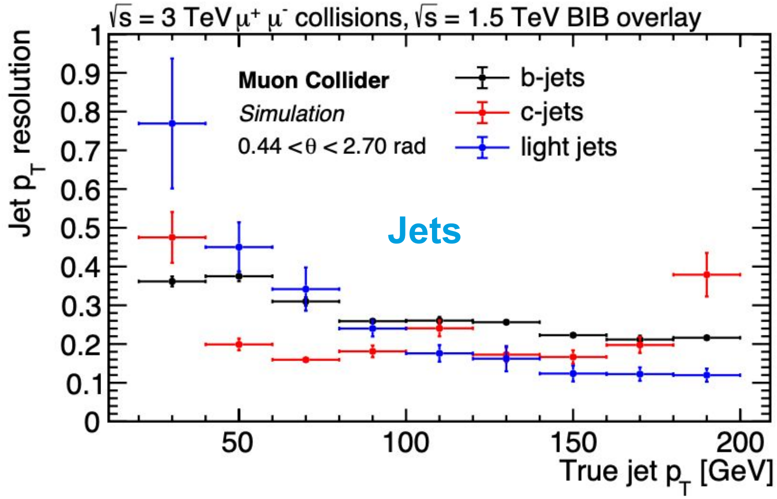
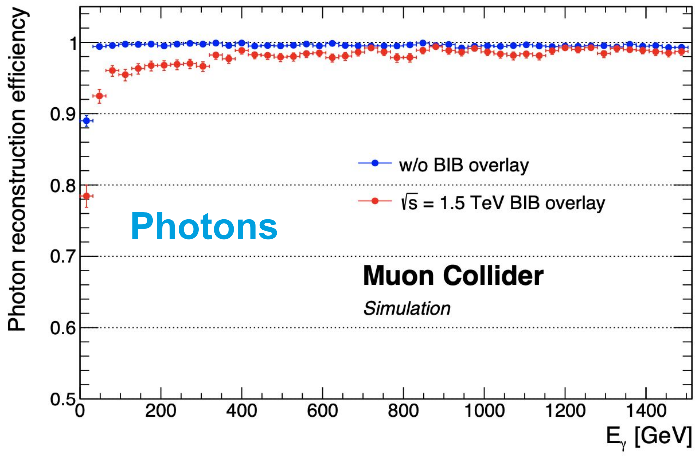
# Snapshot of 3 TeV performance

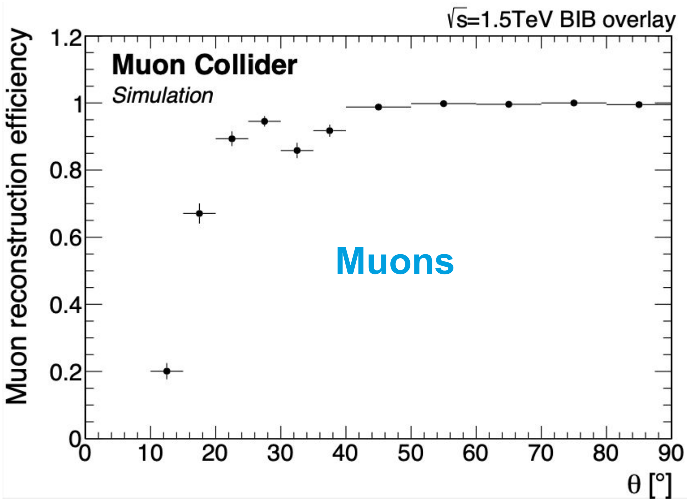
**Achieved “LHC-level” performance** without using dedicated techniques

- Huge potential to improve further









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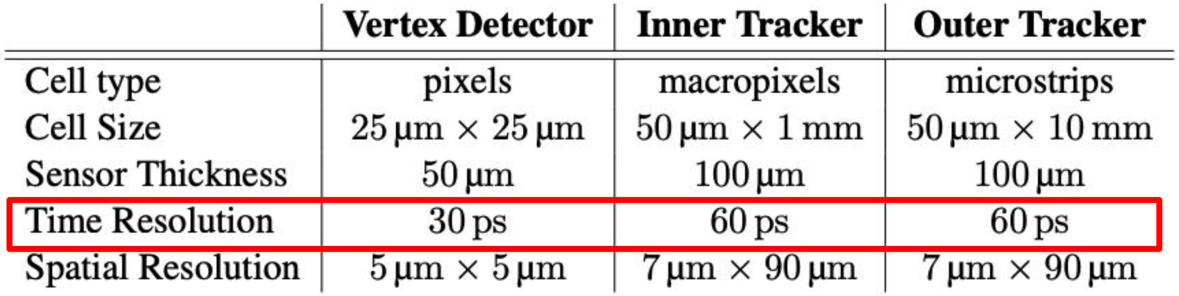
PoS Vertex2014 (2015) 045

# R&D: 4D tracking detectors



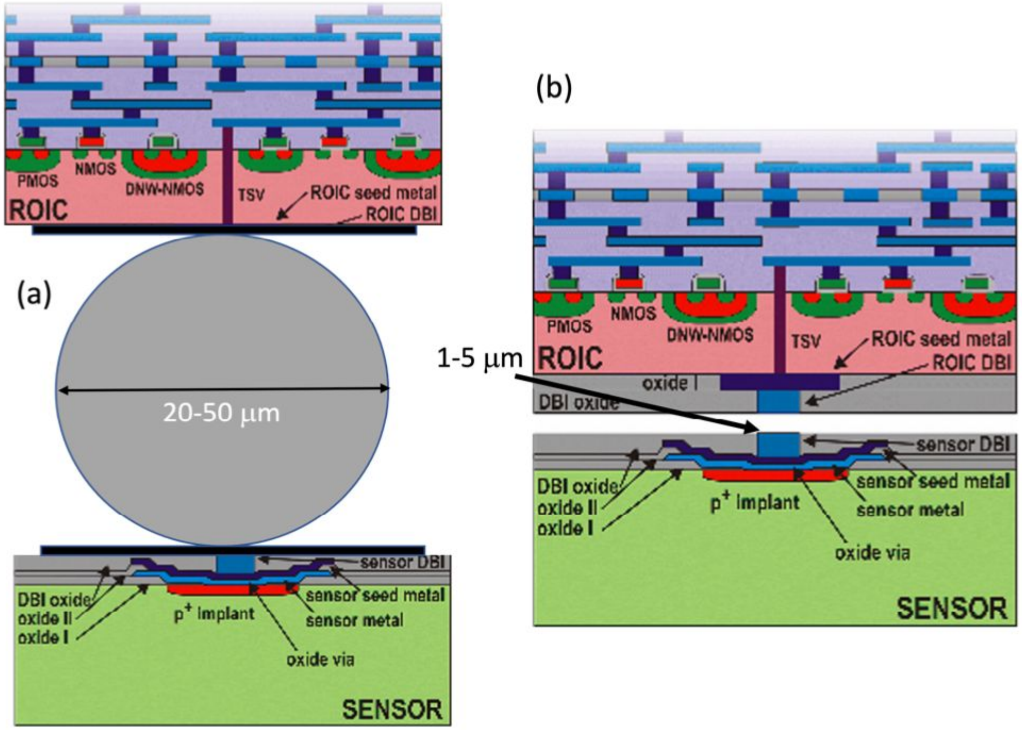
| | Vertex Detector | Inner Tracker | Outer Tracker |
|---|---|---|---|
| Cell type | pixels | macropixels | microstrips |
| Cell Size | $25\,\mu m \times 25\,\mu m$ | $50\,\mu m \times 1\,mm$ | $50\,\mu m \times 10\,mm$ |
| Sensor Thickness | $50\,\mu m$ | $100\,\mu m$ | $100\,\mu m$ |
| Time Resolution | 30 ps | 60 ps | 60 ps |
| Spatial Resolution | $5\,\mu m \times 5\,\mu m$ | $7\,\mu m \times 90\,\mu m$ | $7\,\mu m \times 90\,\mu m$ |

**R&D efforts crucial**

Promising technologies exist

Example: Advanced hybrid bonding tech can give < 5 µm pitch and low input capacitance

- 20-30 ps time resolution



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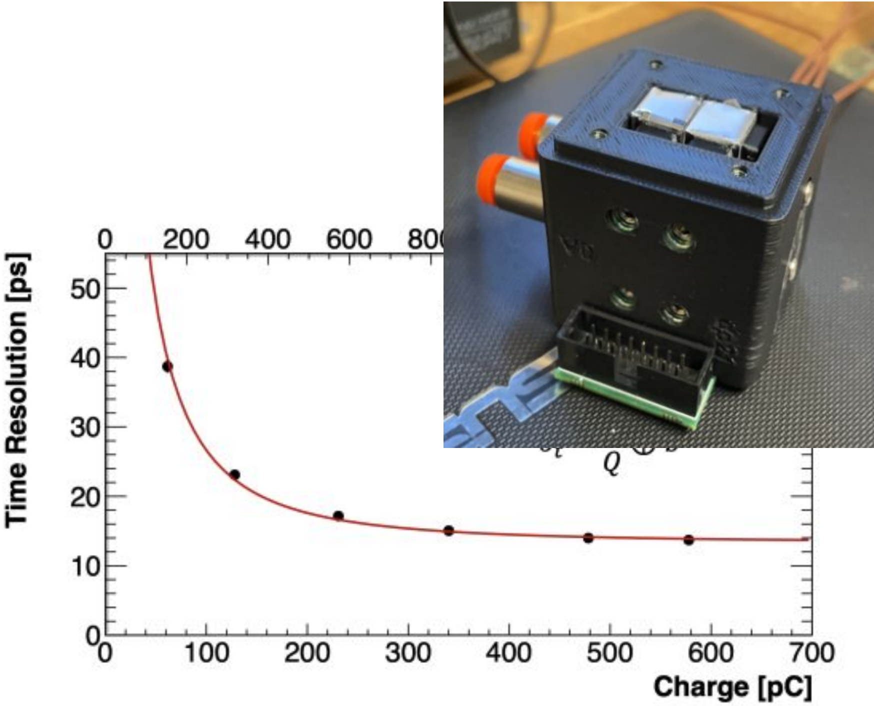
# R&D and HL-LHC “technology transfer”

**Crilin calorimeter**

Semi-homogeneous calorimeter based on Lead Fluoride ($PbF_2$) crystals

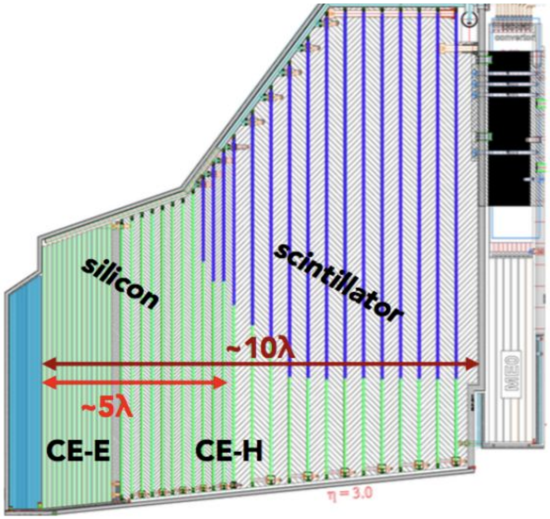
- Segmented longitudinally
- Stackable submodules composed of matrices of crystals



**CMS High-granularity Calorimeter**

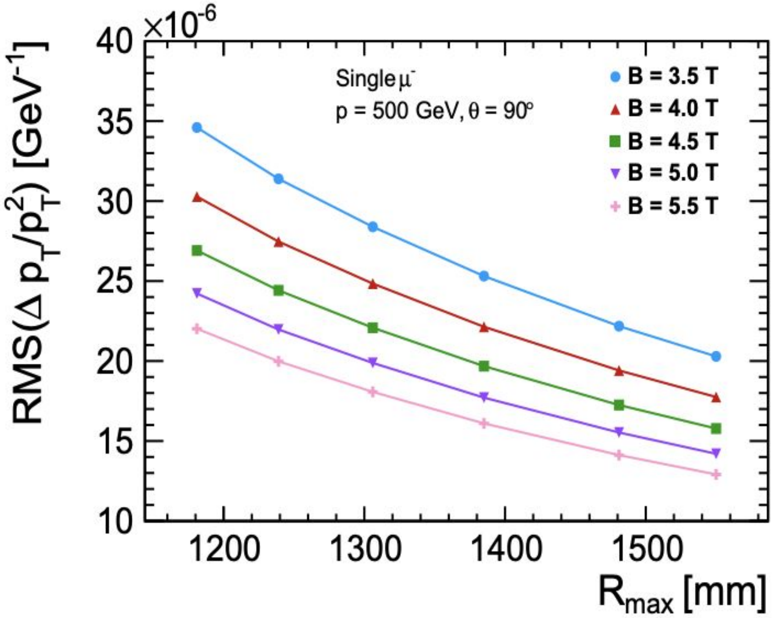
Mix of silicon and scintillator-based high-granularity cells (6.5M channels)

- Large-scale particle flow demonstration
- Achieves O(10) ps time resolution for multi-MIP signals



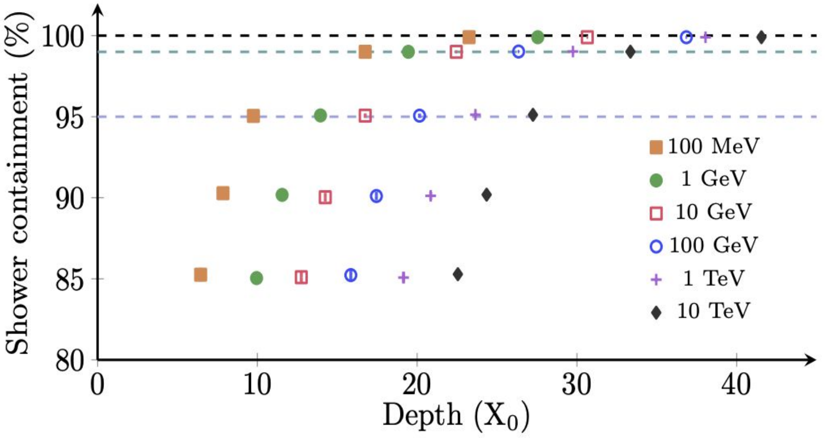
CLICdp-Note-2017-001
CERN-FCC-PHYS-2019-0003

# Designing a 10 TeV detector



### Update the tracker

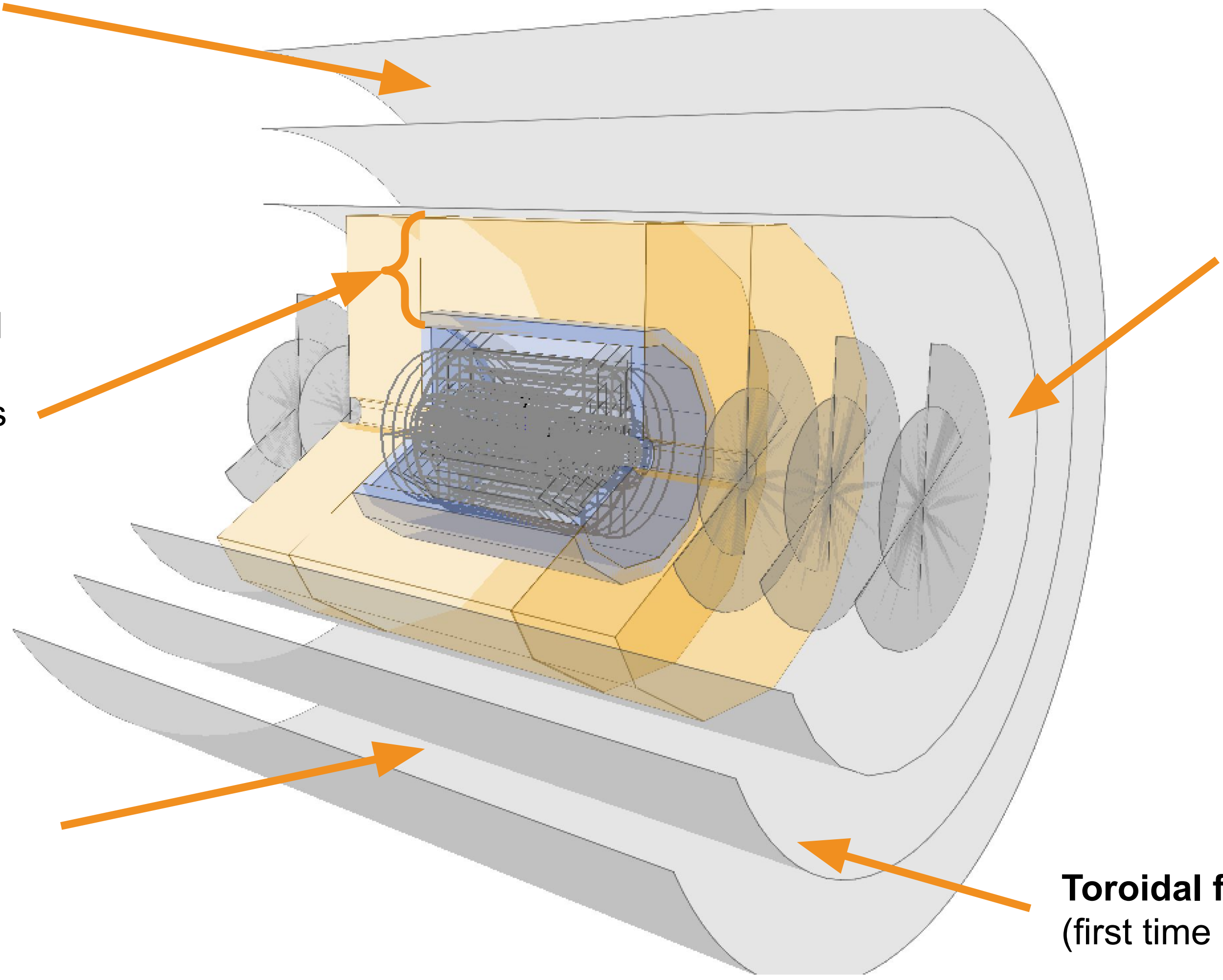
- Move innermost layer closer to beams
- Increase granularity at large radii
- Reconsider double layers
- Re-design endcap region



### Make the calorimeters thicker

- More radiation/interaction-lengths for containment
- Revisit cell energy thresholds, or think about some level of “BIB shielding”

# Fast evolution from concept (March ‘23) …



**No need for a Yoke**

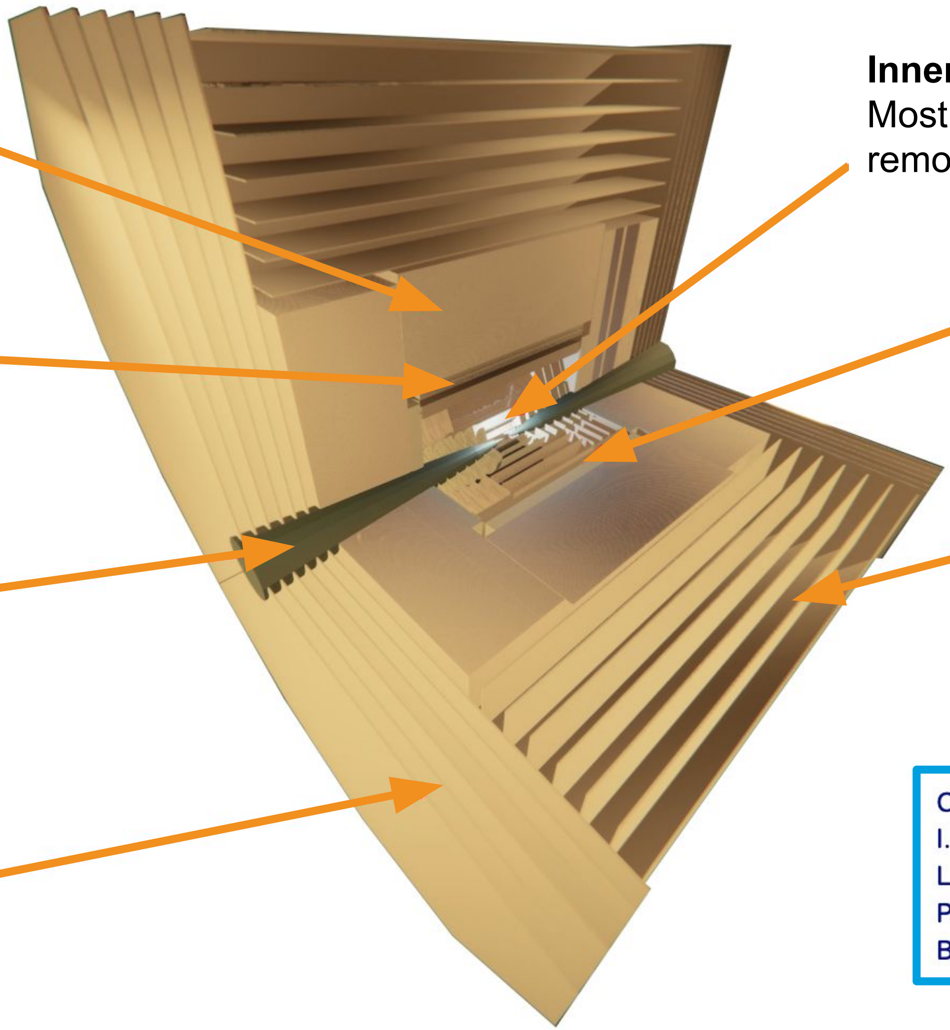
**Calorimeter depth optimised** with photon and pion gun samples (changed both sampling fraction and $N_{layers}$)

**Simplified muon system**

Visualisation glitch **(extend up to the barrel)**

**Toroidal field** (first time in key4hep)

# … to design (October ‘23)



**HCAL**
Fe+Scillator
Return B field

**ECAL**
Si+W

**Shielding nozzle**
Dimensions to be optimised

**In-air muon system**
RPC-based

**Inner tracker**
Most double layers removed

**Solenoid**
5 T
3m diameter

Toroidal field could be added

C. Bell, D. Calzolari, K. DiPetrillo, M. Hillman, I. Hirsch, T. Holmes, S. Jindariani, B. Johnson, L. Lee, T. Madlener, F. Meloni, I. Ojalvo, P. Pani, S. Pagan Griso, K. Pedro, R. Powers, B. Rosser, L. Rozanov, A. Vendrasco, J. Zhang

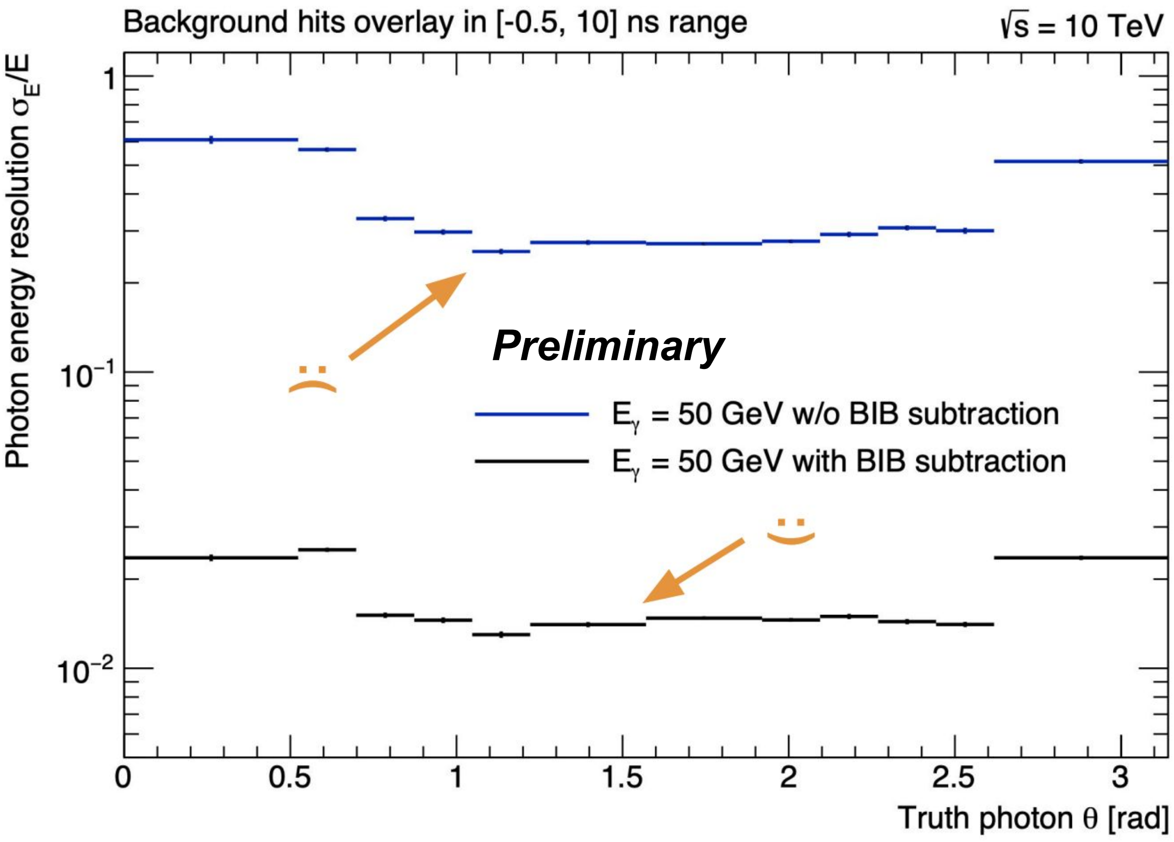
# Reconstruction evolving at the same speed

Developed calorimeter cluster selection methods and BIB subtraction

Test on particle particle gun samples

**Drastic improvement in energy resolution**

- Original targets surpassed



# Physics potential

A high-energy muon collider is a dream machine:

- Allows to probe unprecedented energy scales, exploring several different directions at once!

**Direct searches**

Pair production, Resonances, VBF, Dark Matter, …

**High-rate measurements**

Higgs single and self-couplings, rare decays, top, …

**High-energy probes**

Di-fermion, di-boson, EFT, Higgs compositeness, …

**Muon flavour physics**

Lepton Flavor Universality, b→sμμ, g-2, …

Tens of papers submitted to the arXiv in the past few months!

$$\mathcal{L}_{\text{int}} = 10\,\text{ab}^{-1} \times \left(\frac{E_{\text{cm}}}{10\,\text{TeV}}\right)^2$$

**Required to perform measurements with %-level precision**

# WIMP dark matter reach

**Direct searches**

Pair production, Resonances, VBF, Dark Matter, …

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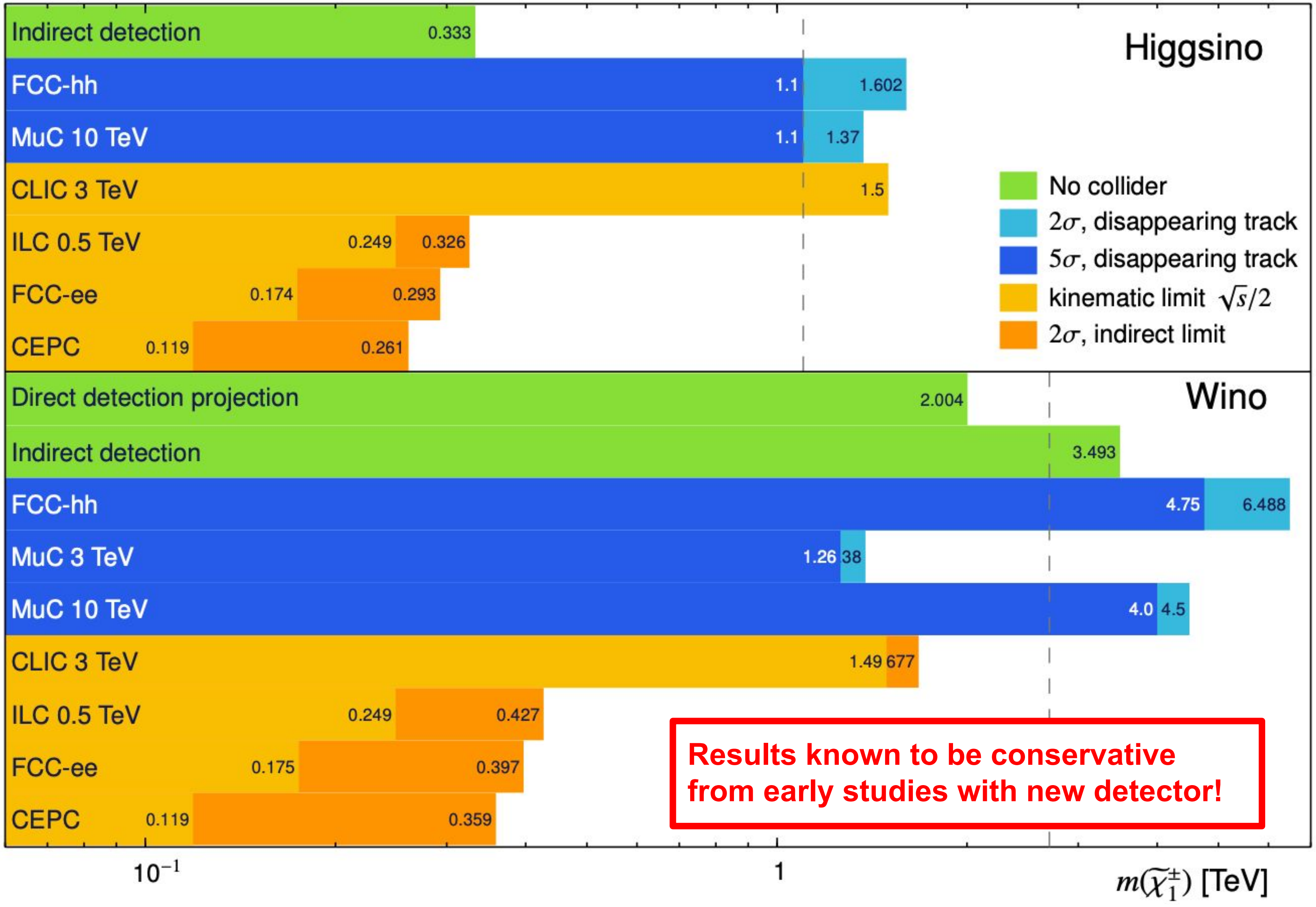
2102.11292



**Results known to be conservative from early studies with new detector!**

# The Higgs factory

**High-rate measurements**

Higgs single and self-couplings, rare decays, top, …

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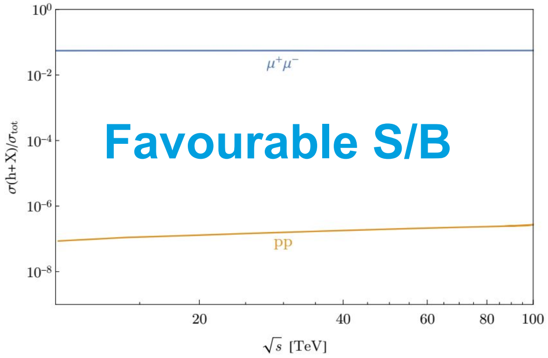
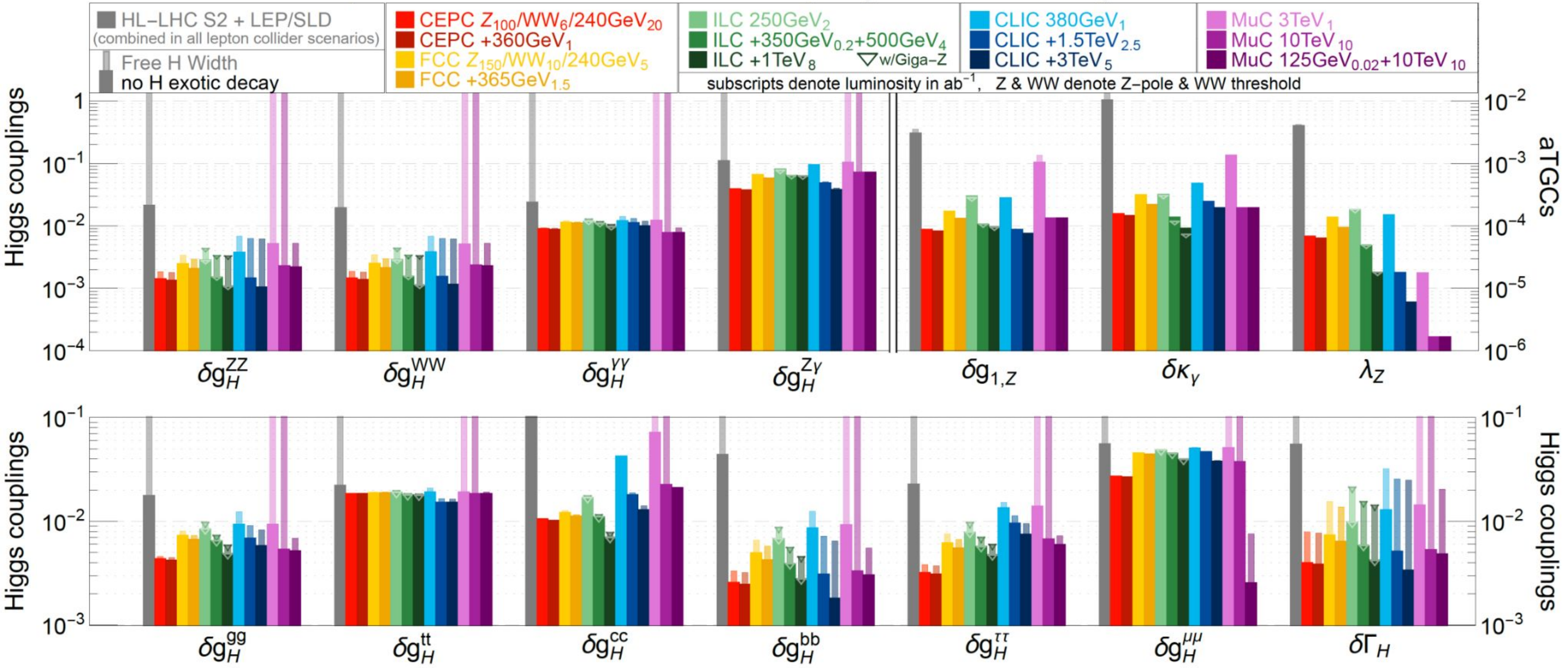
The Higgs itself is key

At 10 TeV, x10 Higgses wrt $e^+e^-$ Higgs factories

- Great potential for exotic decays



**Favourable S/B**



2201.07895

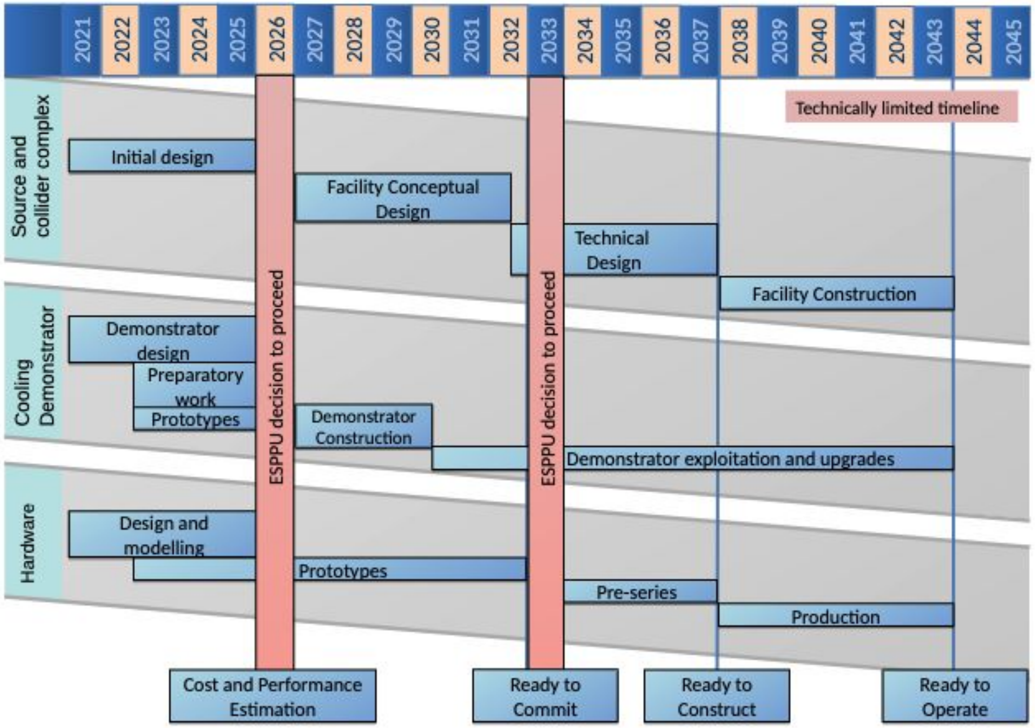
# Accelerator roadmap

On request by CERN Council LDG developed R&D Roadmap

- Global community participated
- Estimates of resources

**No insurmountable obstacle found for the muon collider**

- Important need for R&D
- Implementation plan in the works

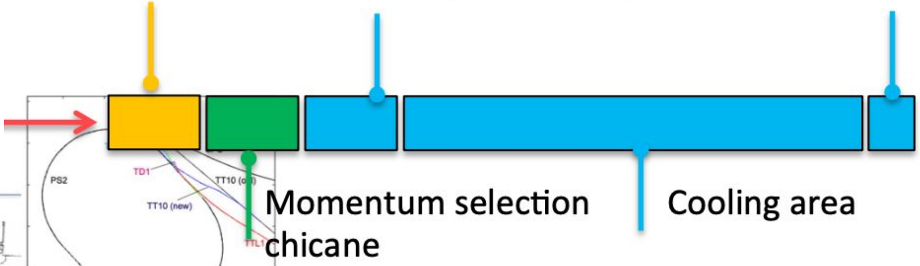


# Demonstrator programme

Planning demonstrator facility with muon production target and cooling

- Intensity below real collider (e.g. 10 kW target)

Suitable site exists on CERN land and can use PS proton beam



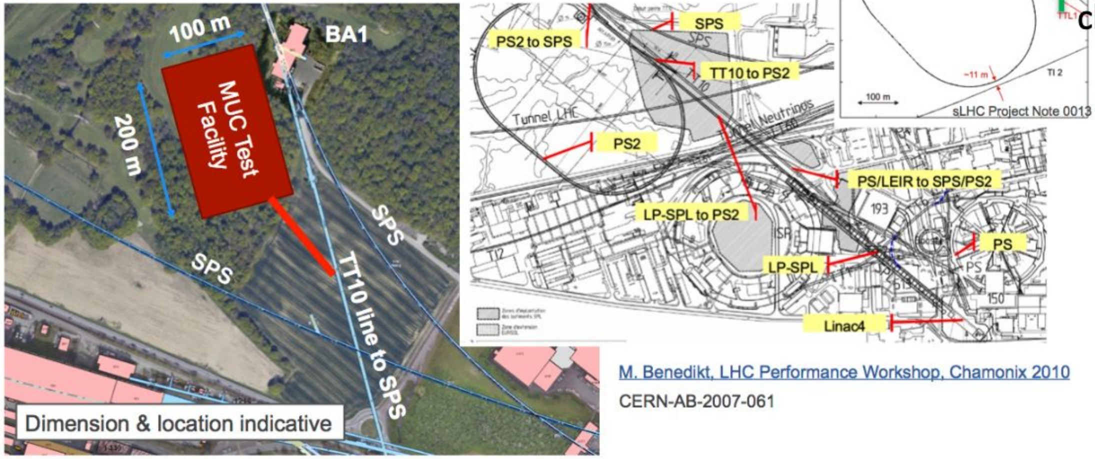
Target + horn (1st phase) / + superconducting solenoid (2nd phase)

Collimation and upstream diagnostics area

Downstream diagnostics area

Momentum selection chicane

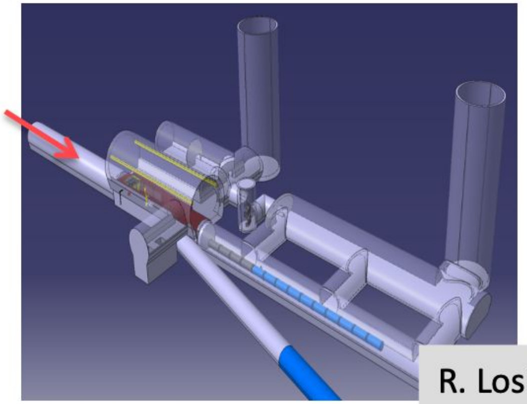
Cooling area



Dimension & location indicative

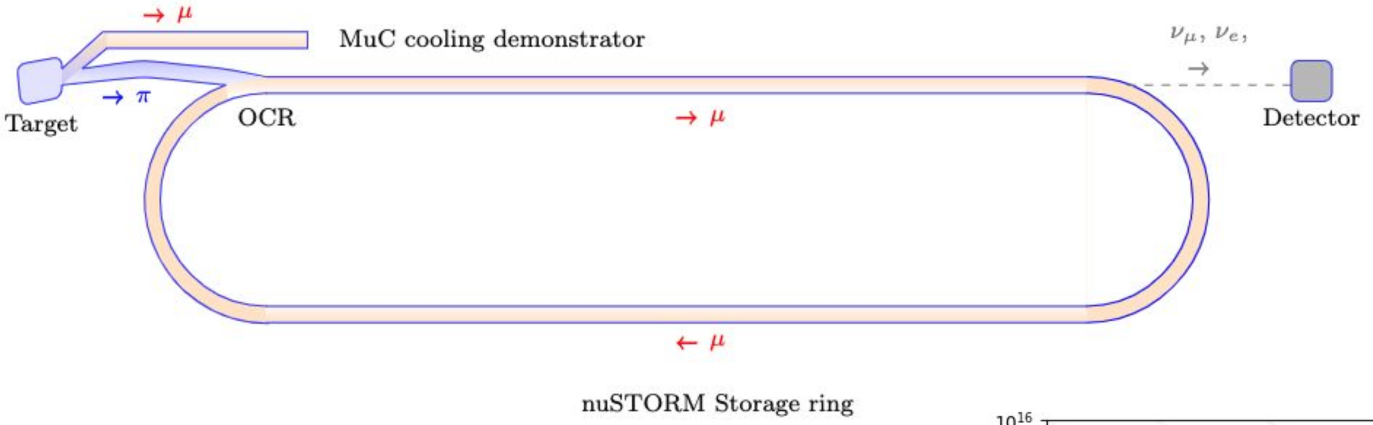
M. Benedikt, LHC Performance Workshop, Chamonix 2010

CERN-AB-2007-061



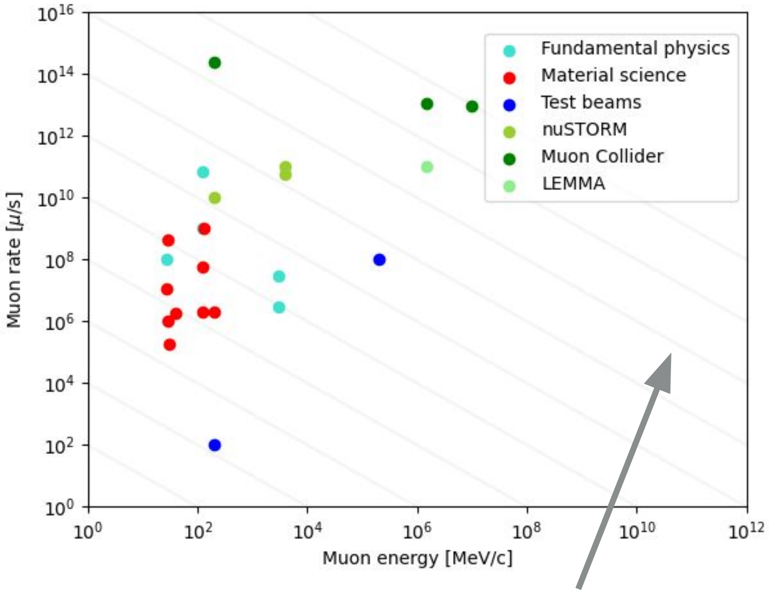
R. Losito et al.

# Demonstrator programme - synergies



Bright muon beams are the basis of neutrino physics facilities such as nuSTORM

- Potential to share an important part of the complex with a muon cooling demonstrator



Lines show equal beam power

# Summary

The muon collider presents **enormous potential for fundamental physics research** at the energy frontier

Need to develop concept to a maturity level that allows to make informed choices by the next ESPPU and other strategy processes

Important progress in development of workplan

Getting there won’t be simple: the road ahead is filled with challenging and interesting R&D!

Background image credit: L. Lee

# Thank you!

**Contact**

Federico Meloni
DESY-FH
federico.meloni@desy.de

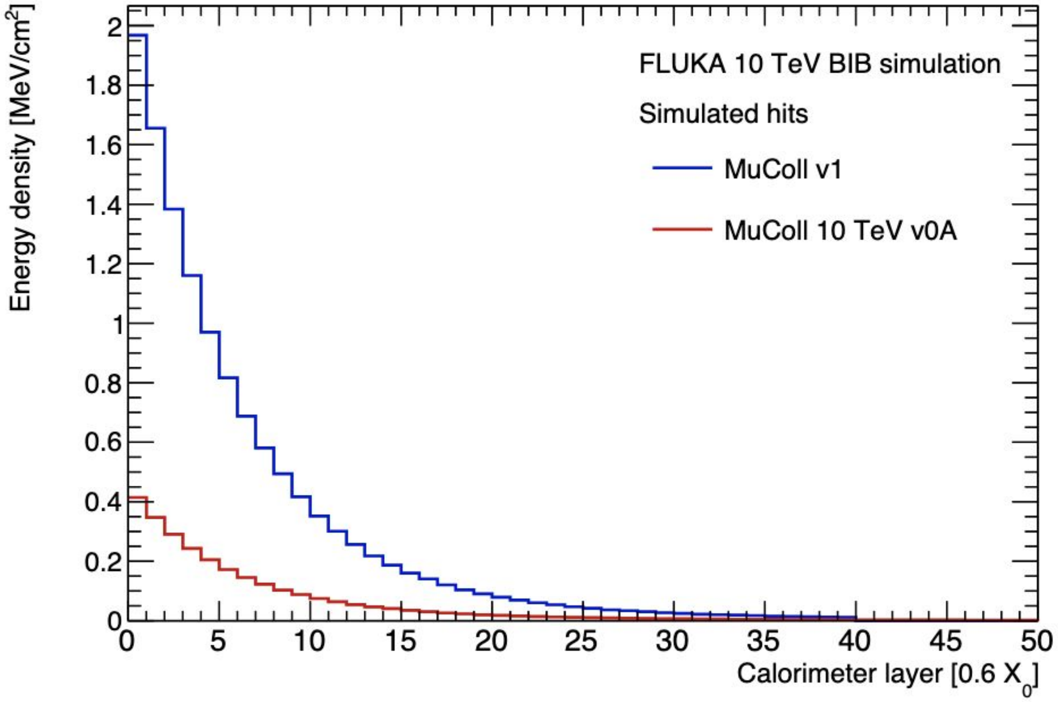
Background image credit: L. Lee

# The 12 challenges of a MuC

Many thanks to S. Jindariani,
D. Schulte, and M. Wing for inputs
and useful discussions

| | Target | Status | Notes | Future work |
|---|---|---|---|---|
| **Pulse compression** | 1-3 ns | SPS does O(1) ns | Need higher intensity. O(30) ns loses only factor 2 in the produced muons. | Refine design, including proton acceleration. Accumulation and compression of bunches. |
| **High-power targets** | 2 MW | 2 MW | Available for neutrino and spallation neutrons. Aim for 4 MW to have margin. | Develop target design for 2 MW, O(1) ns bunches create larger thermal shocks. Prototype in 2030s. |
| **Capture solenoids** | 15 T | 13 T | ITER central solenoid. | Study superconducting cables and validate cooling. Investigate HTS cables. |
| **Cooling solenoids** | 50 T | 30-40 T | 30 T leads to a factor 2 worse transverse emittance with respect to design. | Extend designs to the specs of the 6D cooling channel. Demonstrator. |
| **RF in magnetic field** | >50 MV/m | 65 MV/m | MUCOOL published results.<br>Requires test in non-uniform B. | Design to the specs of 6D cooling.<br>Demonstrator. |
| **6D cooling** | $10^{-6}$ | 0.9 (1 cell) | MICE result (no re-acceleration).<br>Emittance exchange demonstrated at g-2. | Optimise with higher fields and gradients.<br>Demonstrator. |
| **RCS dynamics** | - | - | Simulation. 3 TeV lattice design in place. | Develop lattice design for a 10 TeV accelerator ring. |
| **Rapid cycling magnets** | 2 T/ms<br>2 T peak | 2.5 T/ms<br>1.81 T peak | Normal conducting magnets.<br>HTS demonstrated 12 T/ms, 0.24 T peak. | Design and demonstration work.<br>Optimise power management and re-use. |
| **Ring magnets aperture** | 20 T quads | 12-15 T (Nb3Sn) | Need HTS or revise design to lower fields. | Design and develop larger aperture magnets, 12-16 T dipoles and 20 T HTS quads. |
| **Collider dynamics** | - | - | 3 TeV lattice in place with existing technology. | Develop lattice design for a 10 TeV collider. |
| **Neutrino radiation** | 10 $\mu$Sv/year | - | 3 TeV ok with 200 m deep tunnel.<br>10 TeV requires a mover system. | Study mechanical feasibility of the mover system impact on the accelerator and the beams. |
| **Detector shielding** | Negligible | LHC-level | Simulation based on next-gen detectors. | Optimise detector concepts. Technology R&D. |

# Calorimeters: ECAL energy density

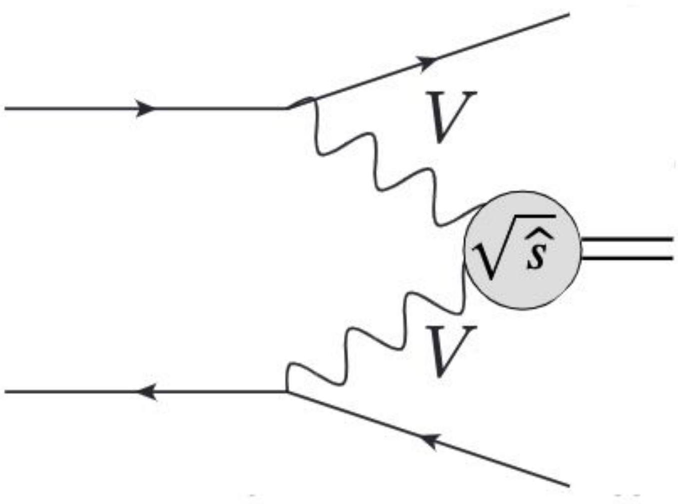


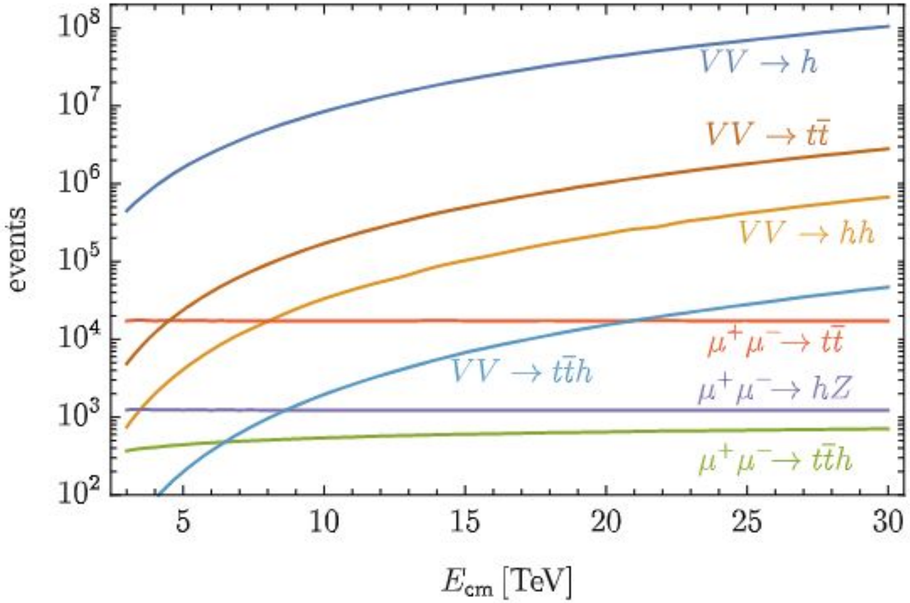
The presence of the solenoid acting as “BIB shield” can be seen in the calorimeter energy density.

**High-energy probes**

Di-fermion, di-boson, EFT, Higgs compositeness, …

# Muon colliders as vector boson colliders





Vector boson fusion dominates well above threshold due to logarithmic growth with centre-of-mass energy

**Opportunity to tag forward muons and distinguish between charged and neutral VBF processes is unique at muon colliders**

- Requires dedicated detector design!

# Status of components

Need cavities with **high accelerating gradient** and a **strong magnetic field**

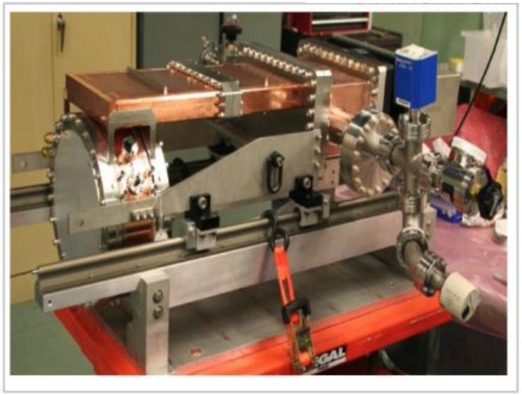
**Very strong solenoids** required for final cooling

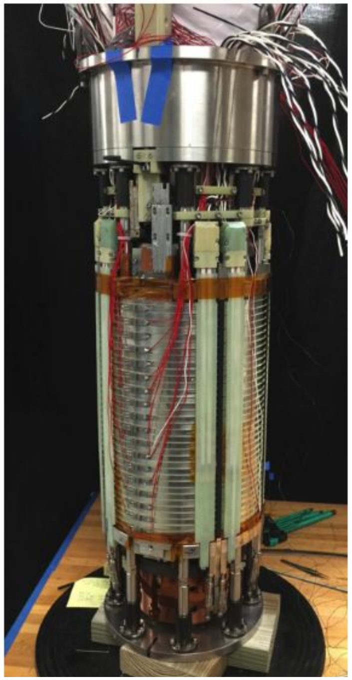
- Luminosity is proportional to the B field

**Promising prototypes, need more R&D**

**MuCool**
>50 MV/m, 5 T field

Two solutions
- Copper cavities filled with hydrogen
- Be end caps



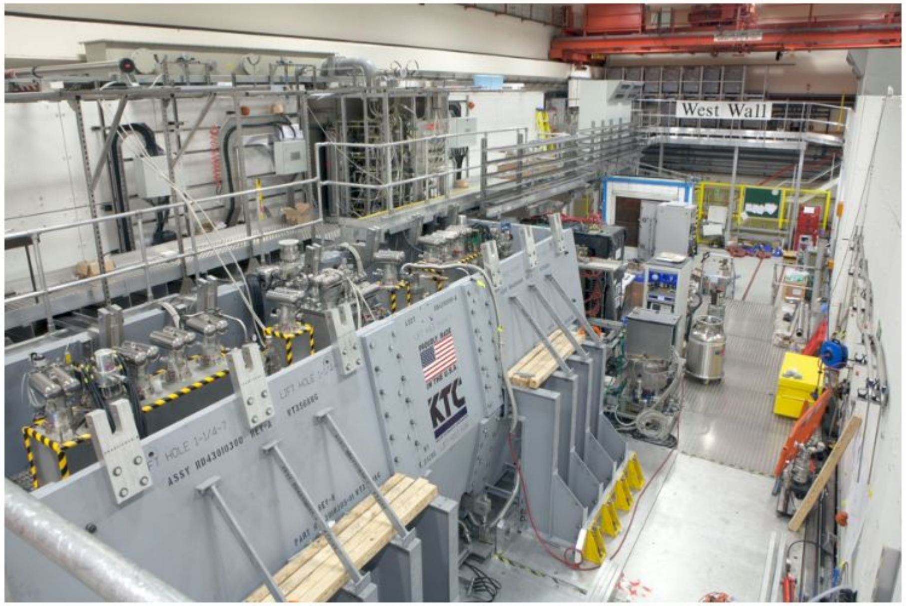


**National High Magnetic Field Laboratory**
32 T solenoid with HTS

Several developments towards higher fields

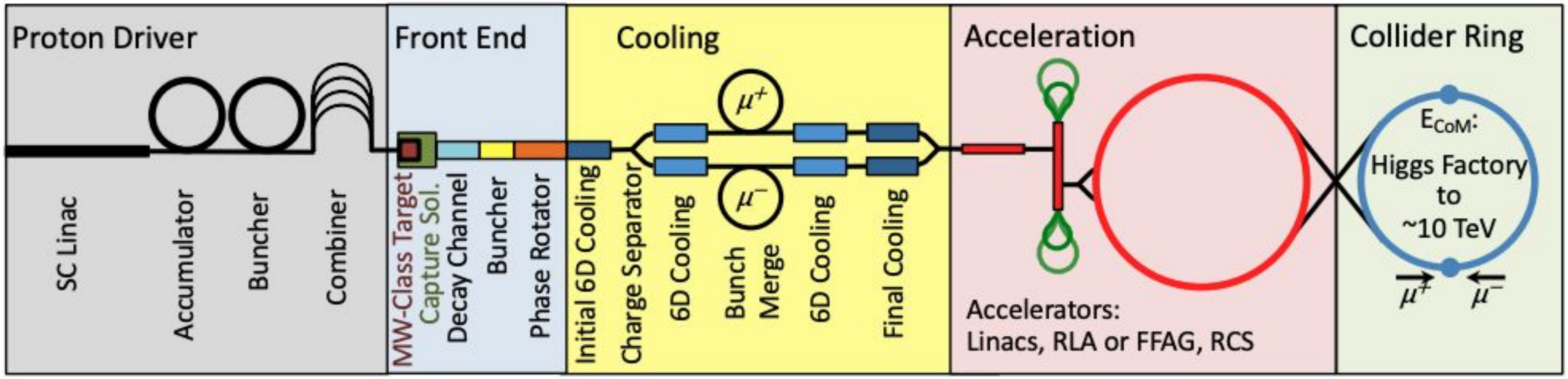
Commercial MRI magnets are now available with fields of 28 T

MICE
(UK)



# Machine designs

## Proton or positron-driven sources?



Proton-driven scheme from MAP

- Generally viable, needs novel cooling

Positron-driven LEMMA

- Requires consolidation for higher muon intensities

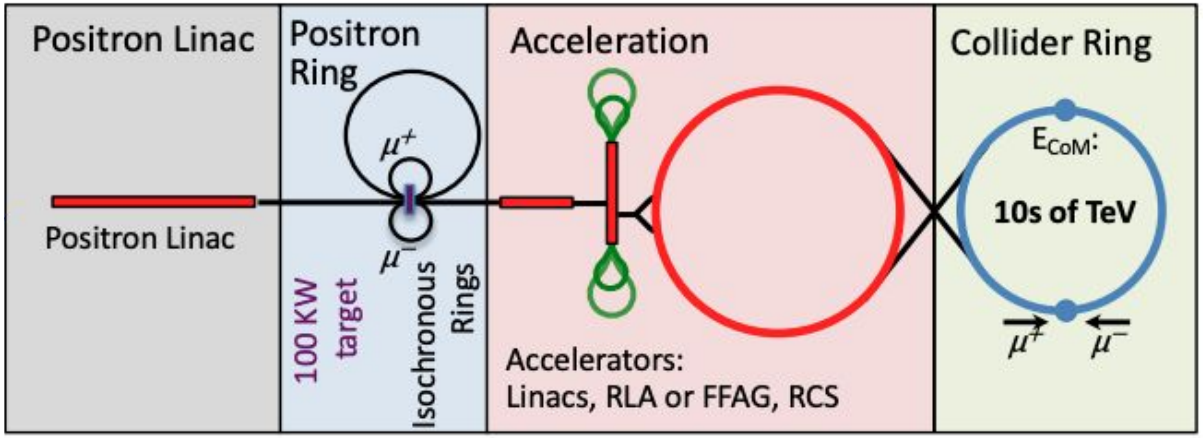
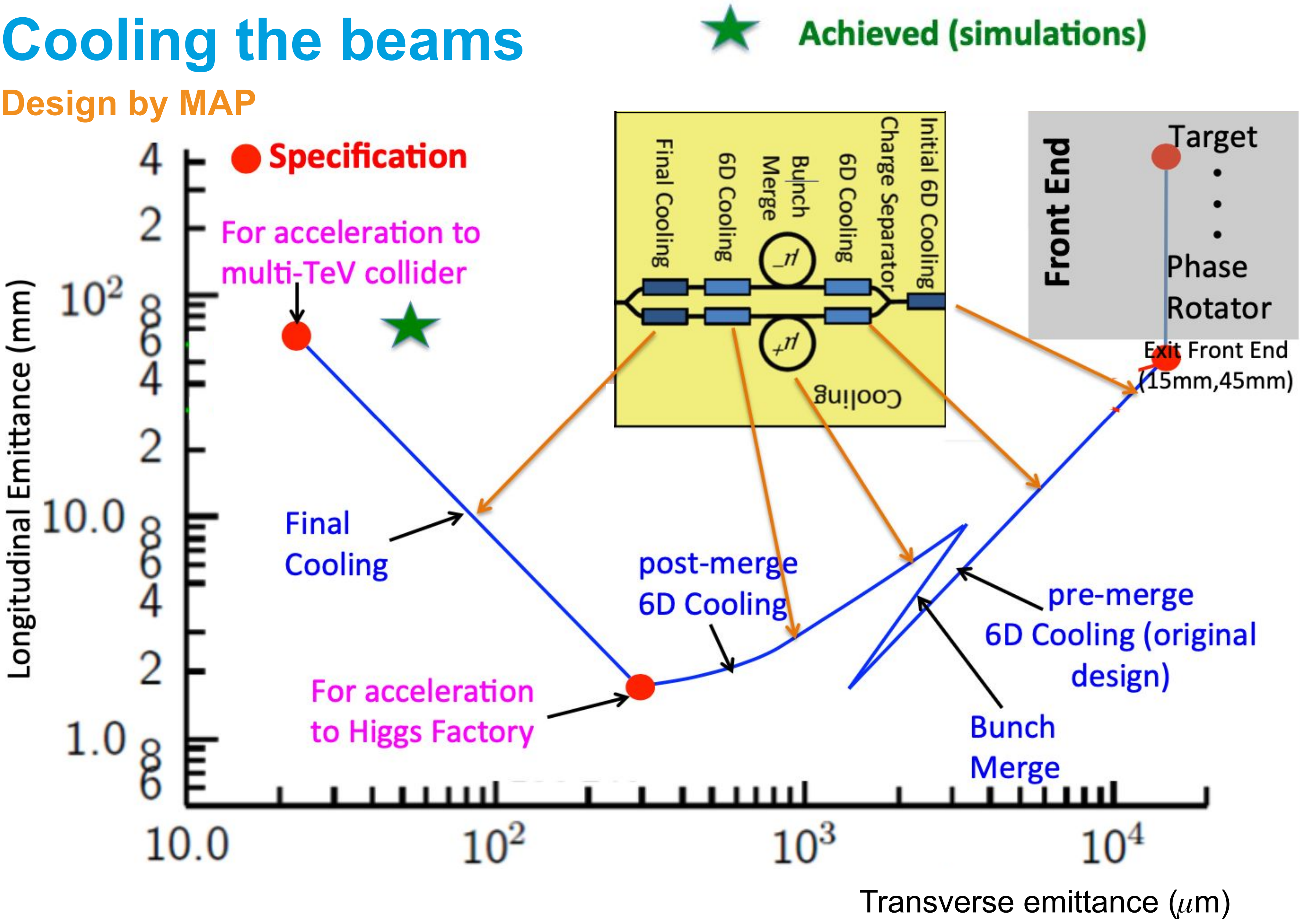


Image source

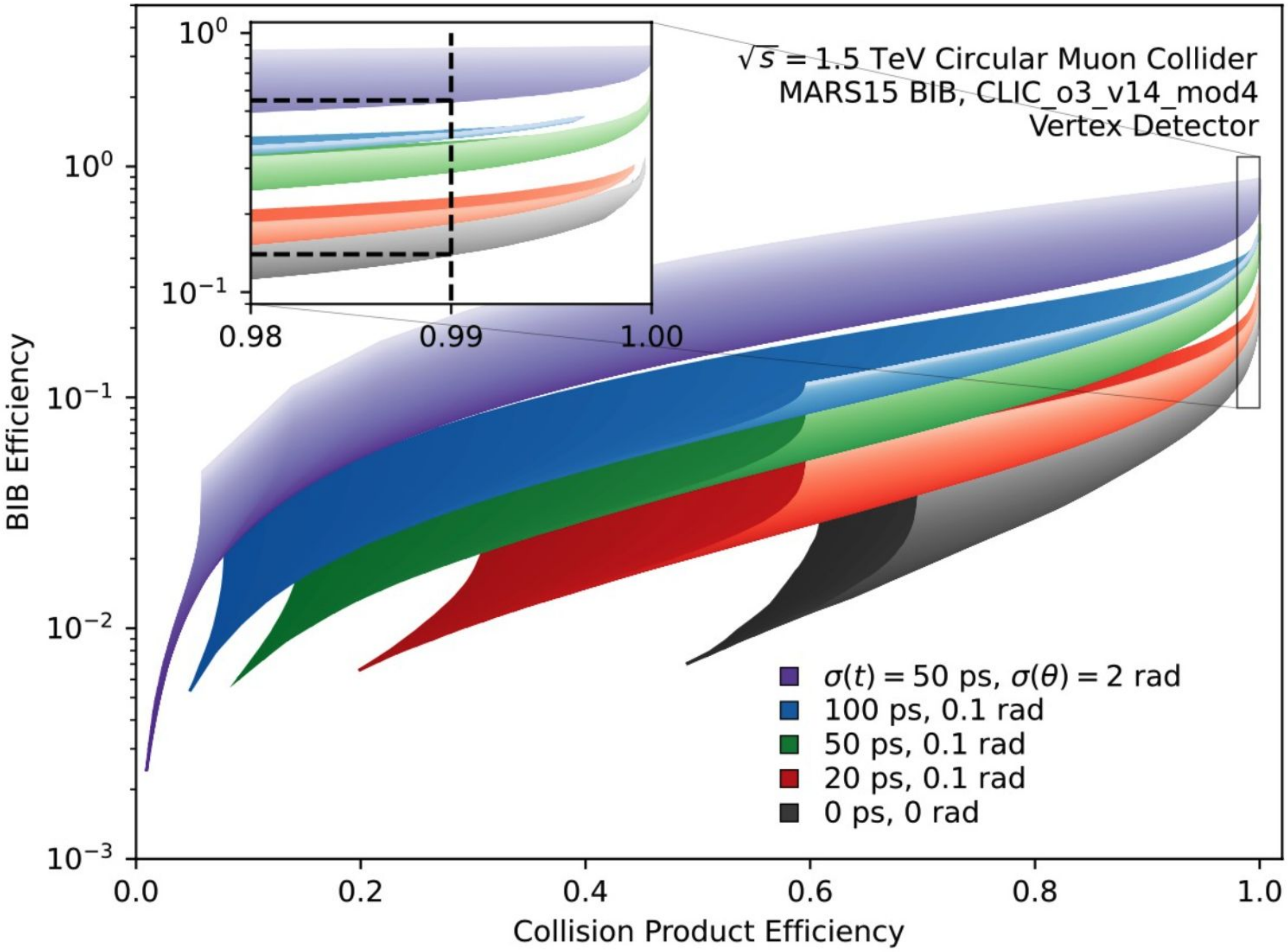
# Cooling the beams

## Design by MAP



# Beam-induced background rejection

## Exploiting timing and pointing in the tracking detectors



# Power and space

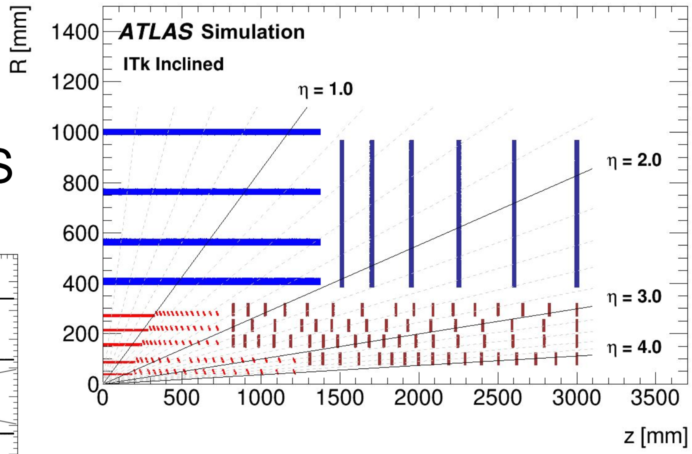
Estimation of power constraints on vertex detector (assume 25 **μ**m$^2$ pixels with four barrel layers and eight endcap disks, conventional scaled CMOS electronics and extrapolations of optical-based data transmission).

- 450 W for analog bias
- 100 W for sensor bias
- 1.5 kW for data transmission

New technologies might change the picture completely.

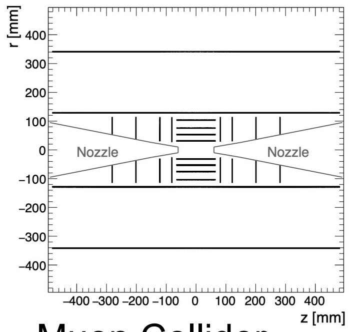
- Extrapolation of current LGAD technology to smaller pixel size would require reduction of O(10$^2$) to stay in same budget of ATLAS/CMS timing detectors.

CERN-LHCC-2017-021



Furthermore, the detector is expected to be very compact.

- Need to **minimise space required by services**



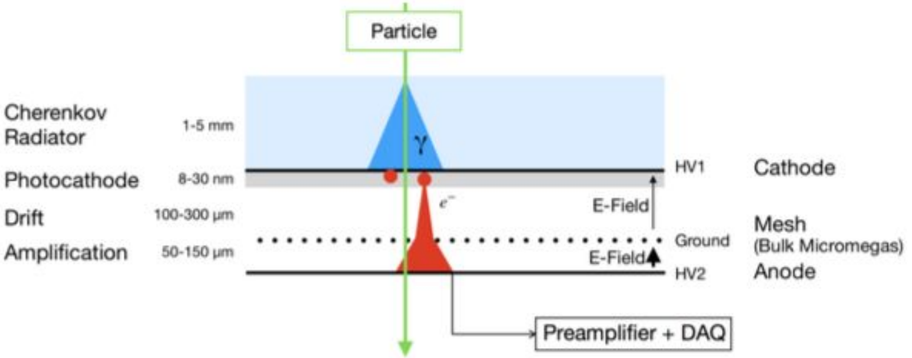
Muon Collider tracker layout

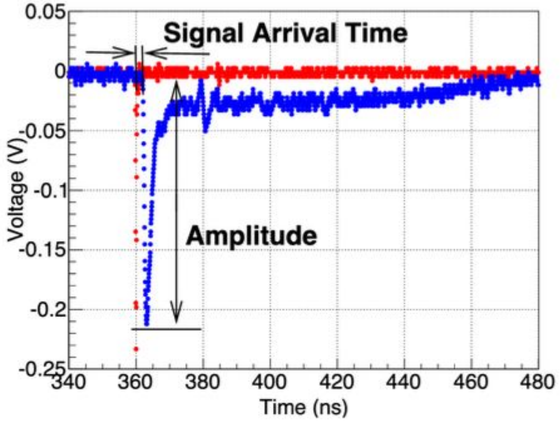
# R&D examples: PICOSEC

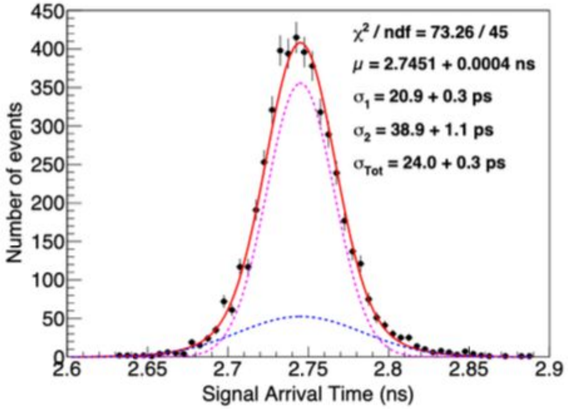
Detect charged particles through **UV Cherenkov photons**.

Absorbed at the photocathode and partially convert into electrons.

Electrons are then amplified in two high-field drift stages and induce a signal which is measured between the anode and the mesh.



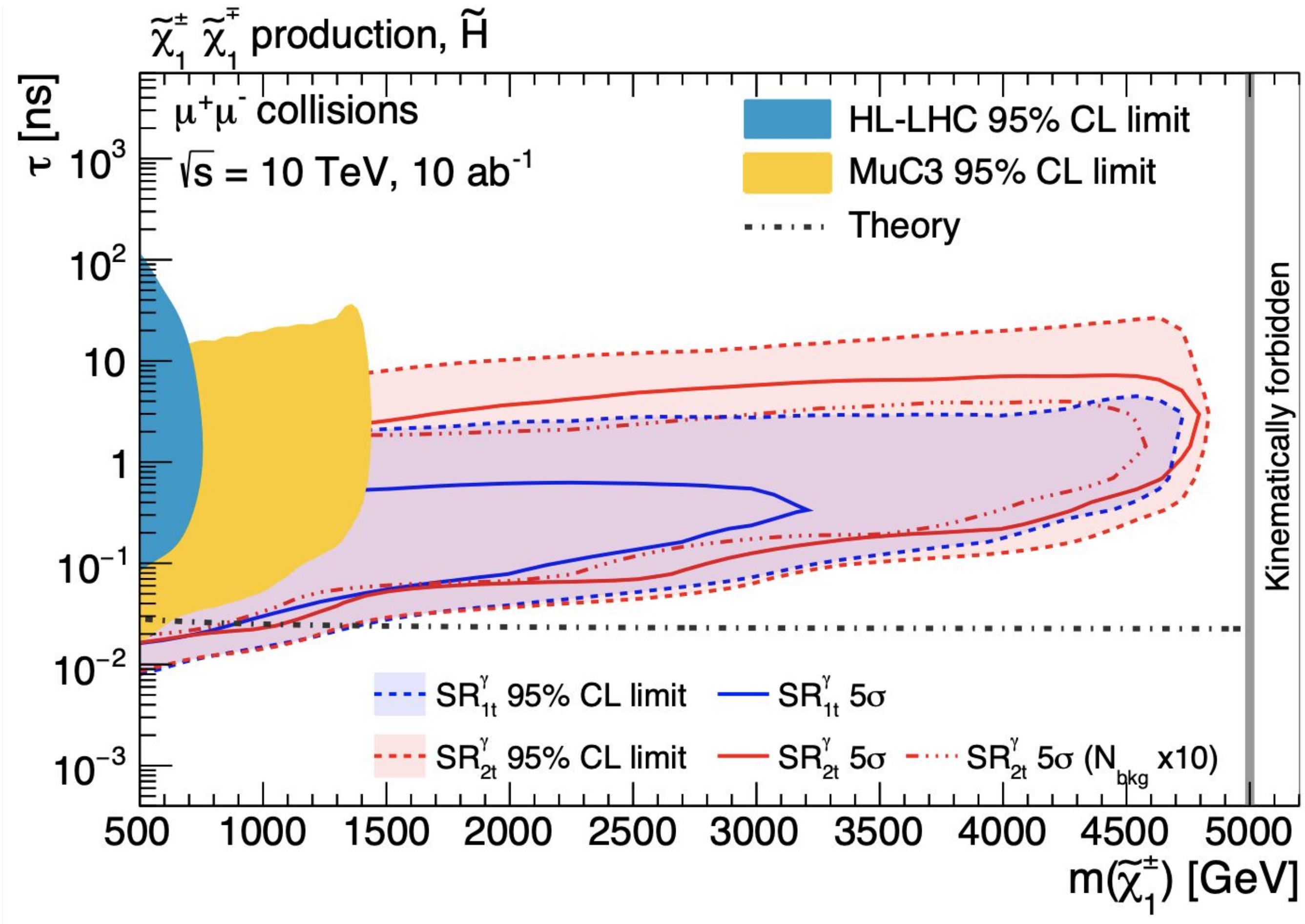




# Expected sensitivity

## Pure higgsino models at MuC 10

**3 TeV detector**
**1.5 TeV BIB overlay**
**Extrapolated to 10 TeV**

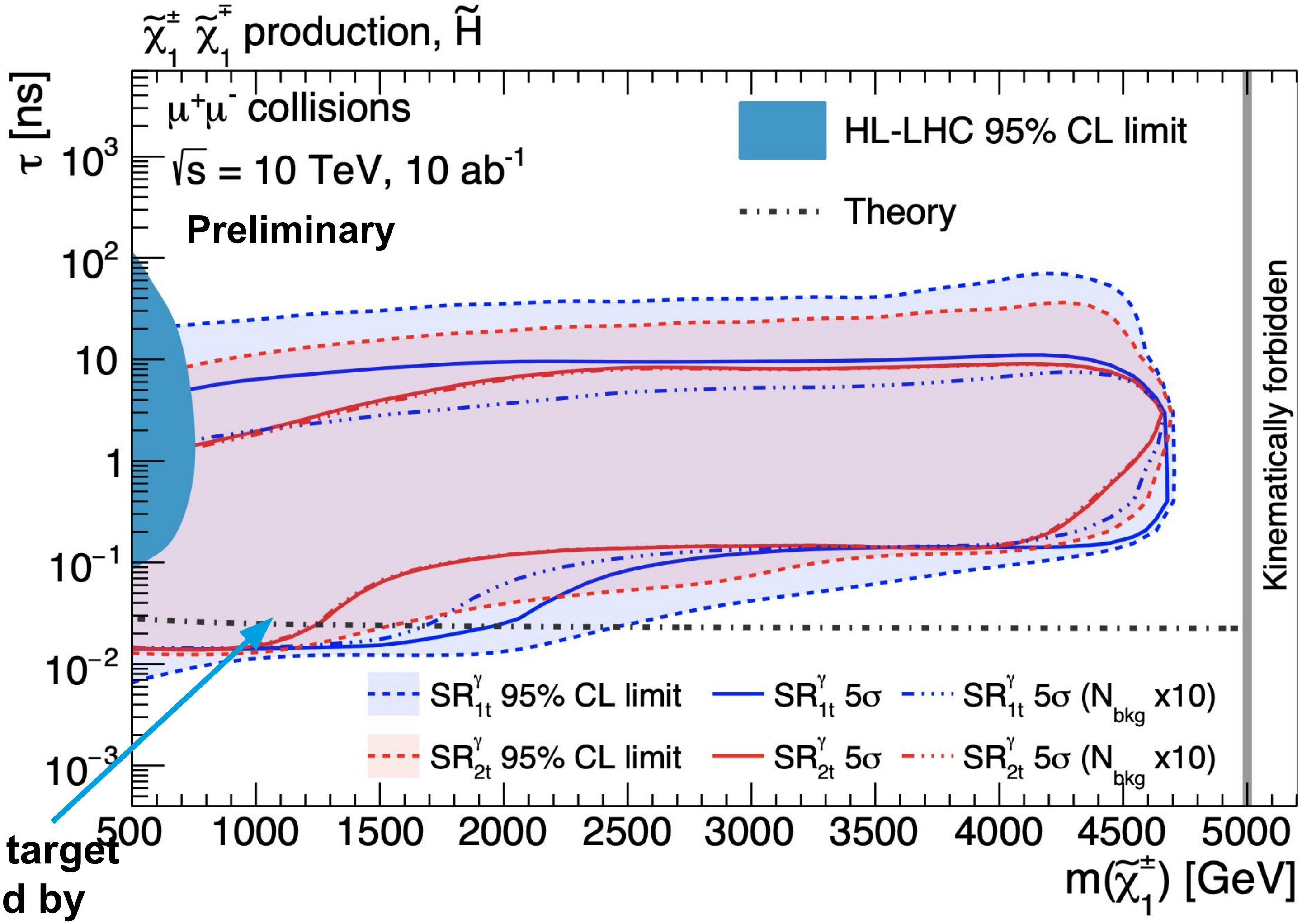


See also detailed comparison with fast sim results from Han, Liu, Wang, Wang [2009.11287, 2203.07351] in MuC Forum report [2209.01318]

# Expected sensitivity

## Pure higgsino models at MuC 10

**10 TeV detector**
**Preliminary 10 TeV BIB overlay**

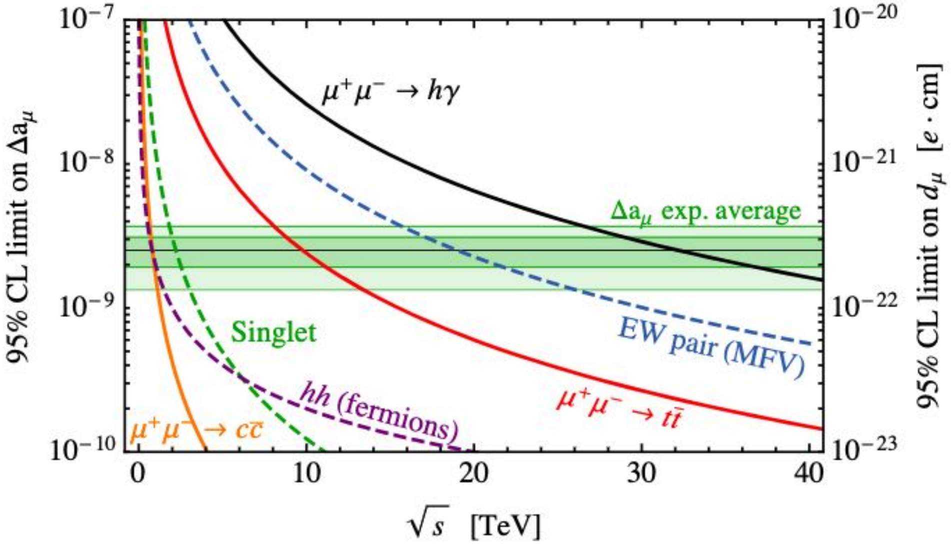


**Thermal target covered by both selections**

# Muon-related anomalies

**Muon flavour physics**

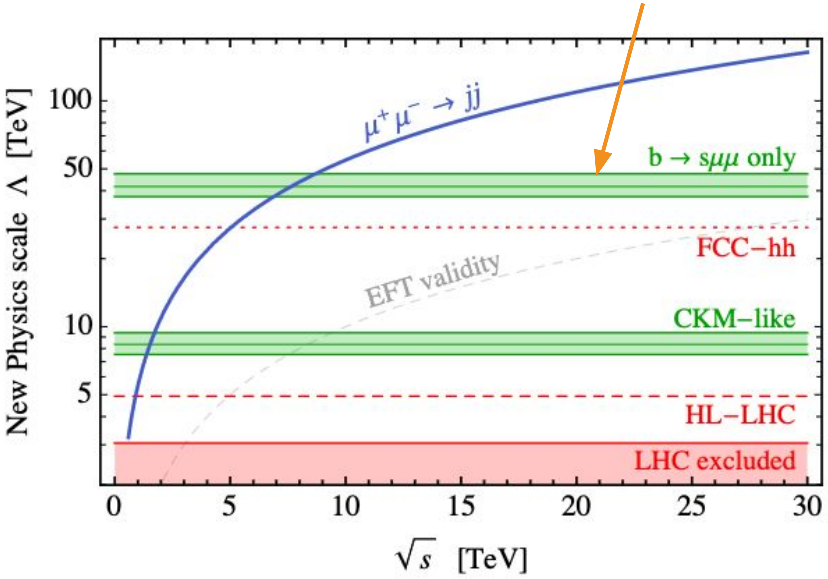
Lepton Flavor Universality, b→sμμ, g-2, …



## Model independent test of g-2

- Solid lines correspond to limits on contact interactions
- Dashed lines illustrate the sensitivity to specific classes of models

$R_{K(*)}$ anomaly



## Potential to probe flavour anomalies

Assuming EFT validity:

- Better reach than FCC-hh
- Realistic models accessible also at low centre-of-mass energies