Machine Detector Interface Summary

International
MUON Collider
Collaboration

Donatella Lucchesi,
Sergo Jindariani, Nikolai Mokhov,
Christian Carli, **Nadia Pastrone**
Yunhai Cai, Francesco Collamati,
Matthias Mentink, Yuri Nosochkov,
Physics&Detector Group

1st Community Meeting - May 21, 2021

MDI Session

61 - Common issues (including physics and detector considerations)	Donatella Lucchesi et al.	
Zoom	14:15 - 14:40	
62 - MARS IR and nozzle optimization @ 0.125, 1.5 and 3 TeV	Nikolai Mokhov	
63 - Studies @1.5-3.0 TeV with FLUKA	Dr Francesco Collamati	
77 - Discussion		
65 - Extrapolations to 6-10, what is needed (interaction region design, etc.)	Yunhai Cai et al.	
Zoom	15:30 - 15:55	
124 - A Superconducting Detector Magnet for the Muon Collider	Matthias Mentink	
54 - Joined session with HEC and RPOT in RPOT room		

Is the investment into a full CDR scientifically justified?

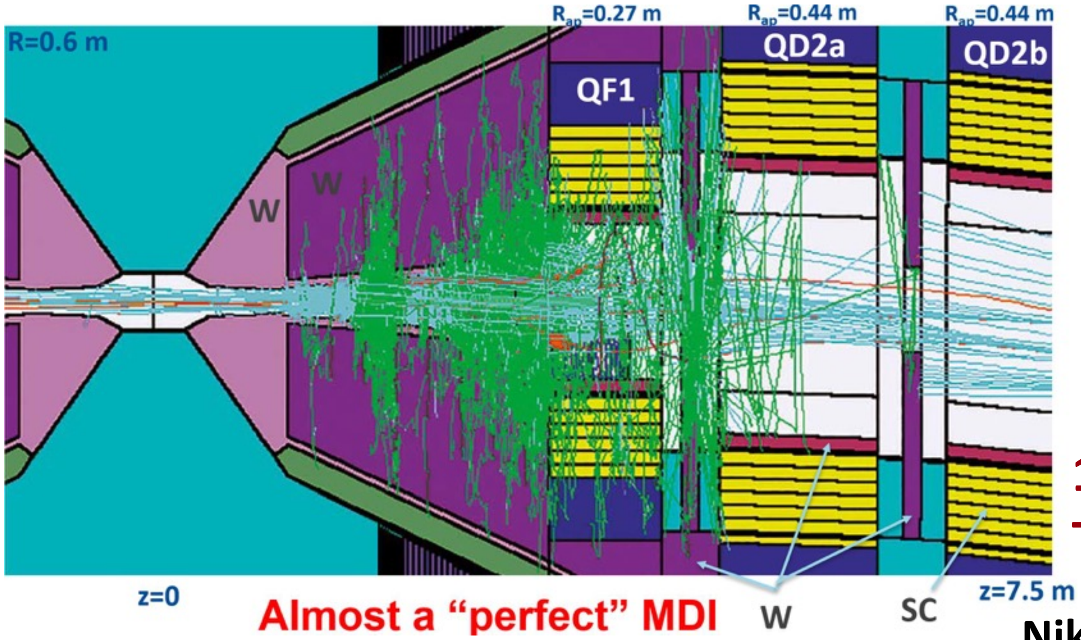
Is the 10+ TeV energy region feasible demonstrating the physics potential with sufficient instantaneous luminosity?

118 - Introduction	Claudia Christina Ahdida
Zoom	17:15 - 17:40
119 - Neutrino hazard & mitigation	Nikolai Mokhov
Zoom	17:40 - 18:05
120 - Mitigation methods from machine side	Christian Carli
Zoom	18:05 - 18:30
121 - Movers in the arcs	Helene Mainaud Durand
Zoom	18:30 - 18:55

The physics goals of a Muon Collider can only be achieved with self-consistent designs of the ring, IR, high-field SC magnets, MDI and detector

MDI goal

suppress by several orders of magnitude the beam induced background (BIB) rates in the detector volume



125-GeV Higgs Factory
Thoroughly Optimized MDI

Nikolai Mokhov

MDI studies at present

Studies 1994-2014 (MAP 2011-2018) +++

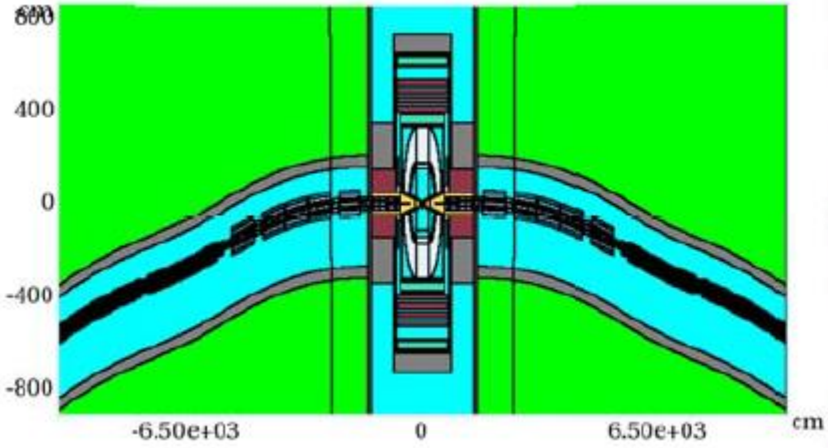
- coherent dedicated efforts on the lattice design (led by Yuri Alexahin)
- high-field large-aperture SC magnet design (led by Sasha Zlobin)
- mitigating BIB on IR and detector optimized in MARS (led by Nikolai Mokhov)
- First tracker detector studies in MARS15/ILCRoot/Geant4 (led by Vito Di Benedetto & C. Gatto)

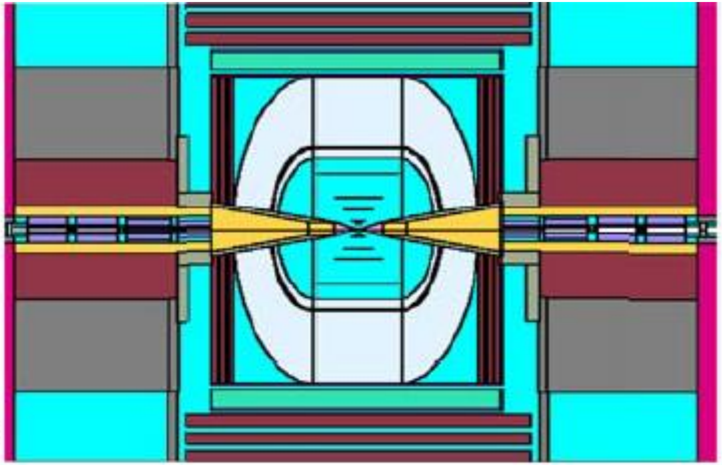
Physics&Detector Group studies 2018-on going

- MAP lattice and BIB in FLUKA ➔ new tool for physics&detector full simulation effort ready to implement new optics design (led by Donatella Lucchesi)
- New full detector with improved capabilities in FLUKA/ILCsoft/Geant4 to be redesigned for higher energies (led by Donatella Lucchesi)

MDI studies @1.5 TeV

with $2\times10^{12}\mu$/bunch ➔ 2×10^{5}decays per meter of lattice single pass





Three sources of beam-induced backgrounds (BIB) and radiation loads in MC:

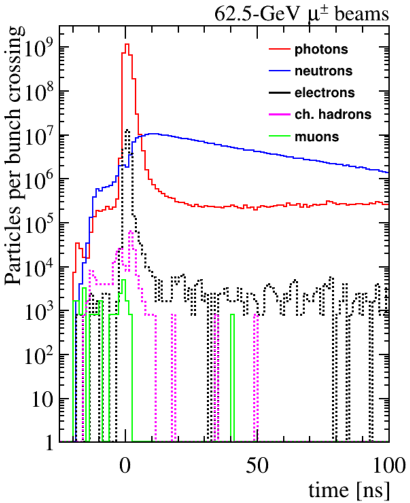
incoherent e+e- pair production at the IP

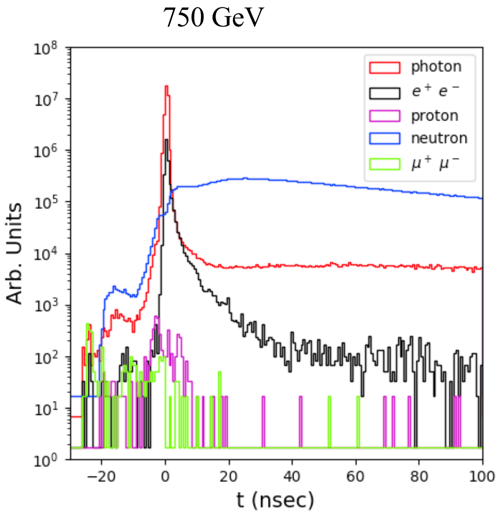
beam halo loss on limiting apertures

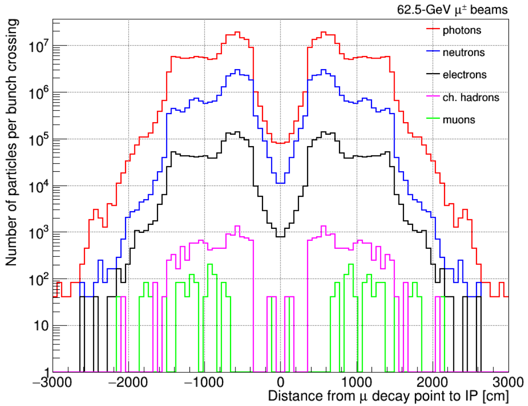
muon beam decays

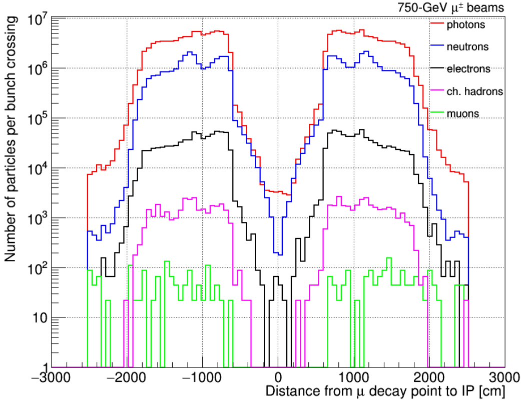
Nikolai Mokhov

BIB Characteristics comparison 125 GeV/1.5 TeV









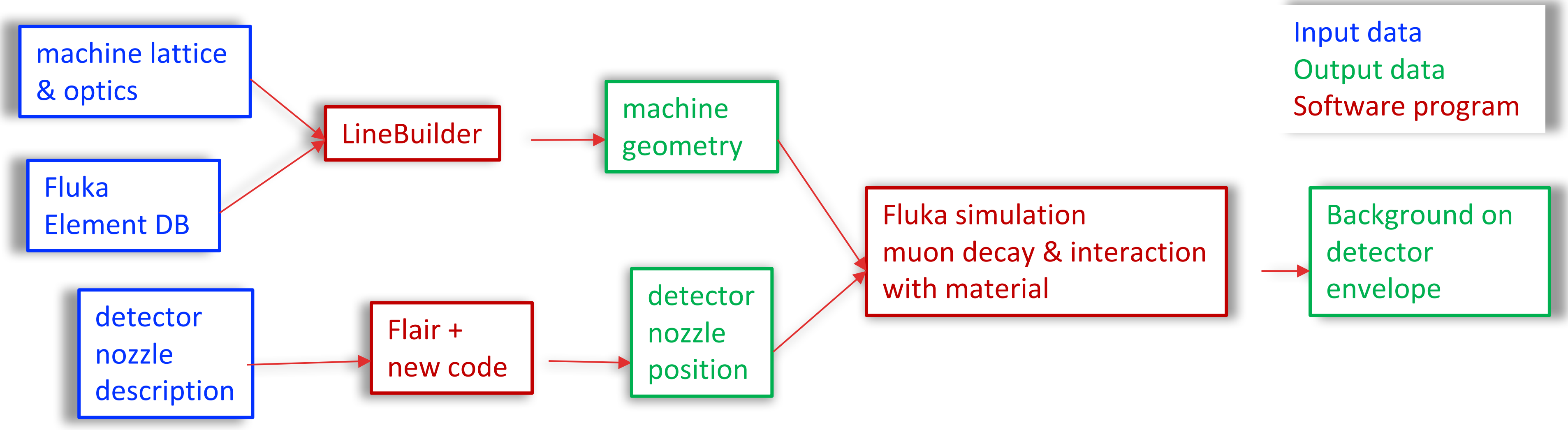
Comparison between $\sqrt{s}$ =1.5 TeV and $\sqrt{s}$ = 125 GeV

- BIB absolute fluxes very similar
- Momentum distribution quite different
- Time distribution as expected and Z distribution very similar

The IR has been designed to obtain that.

Would be possible to do it also at high energy?

Simulation tool structure

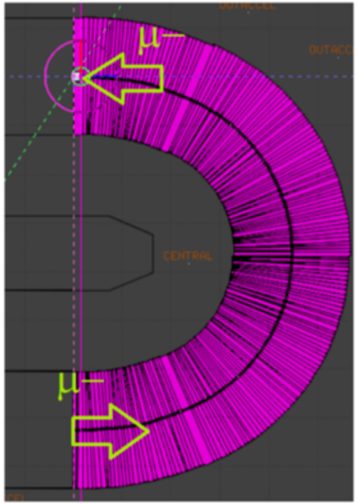


MDI Layout Description @1.5 TeV

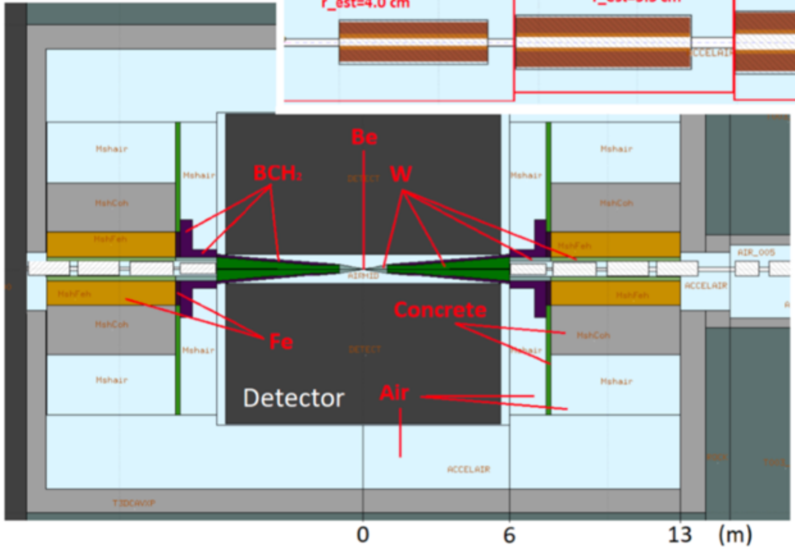
Francesco Collamati

Simulation tool: **LineBuilder + FLUKA**
Data analysis: **Python**

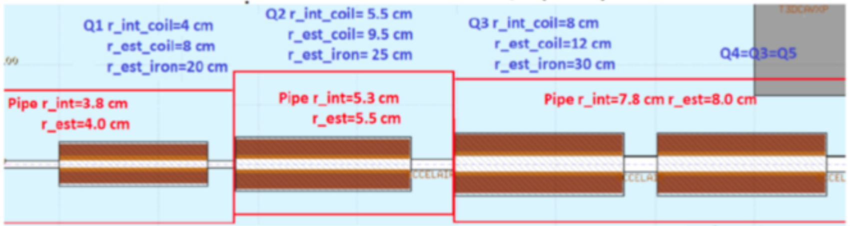
750 GeV muon beam travels half ring to IP



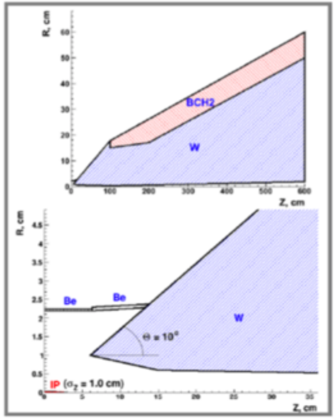
IR



IR Quadrupoles



Nozzle



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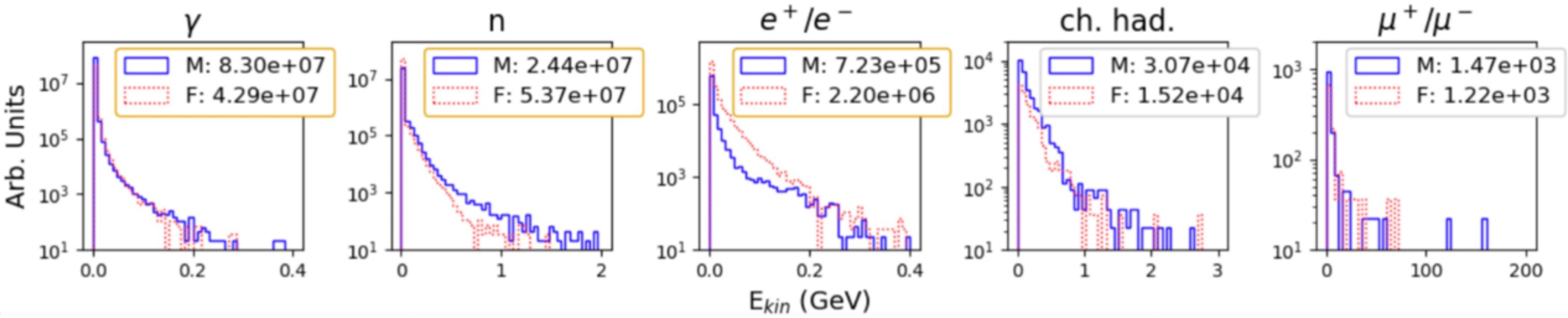
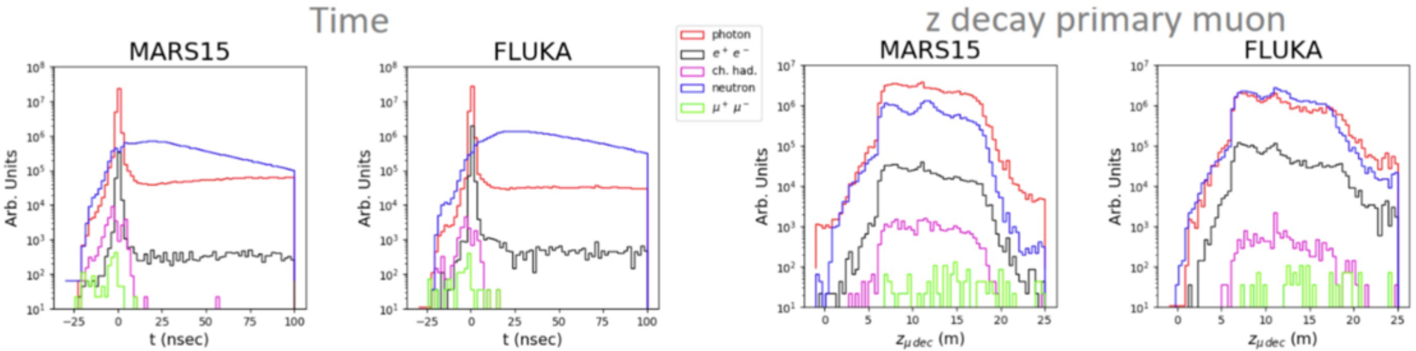
The 1.5TeV case benchmark

MARS-FLUKA Results Comparison



MARS
FLUKA



Residual discrepancies in **particles time and energy distribution**:

- Minor layout differences (passive elements, absorbers)
- Intrinsic differences between codes

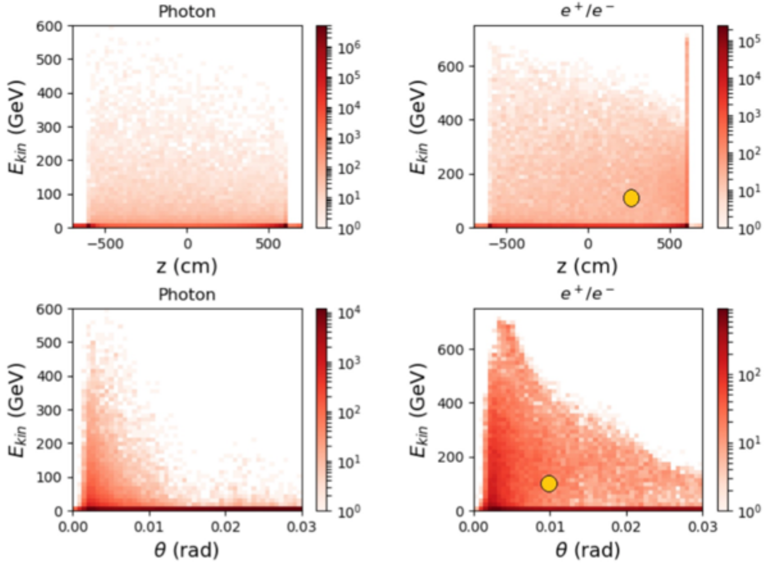
Francesco Collamati

The 1.5TeV case benchmark

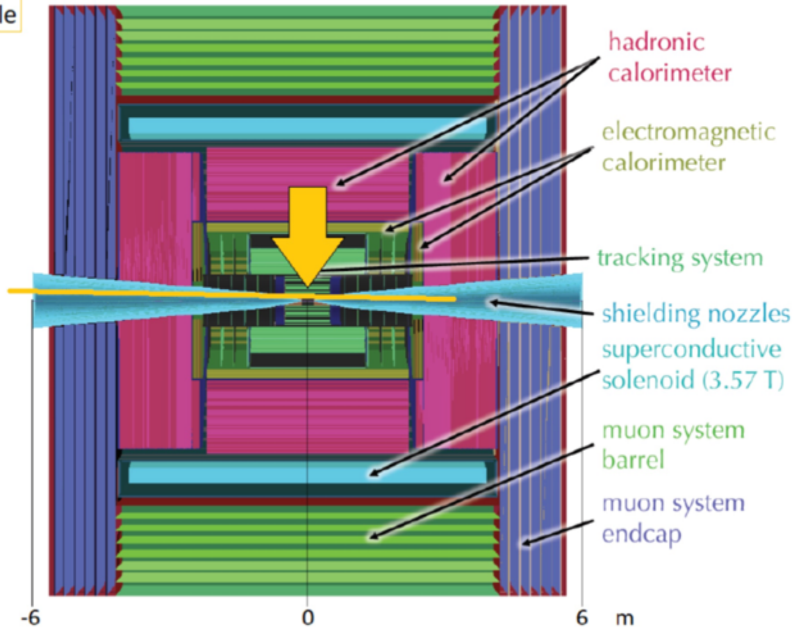
MARS-FLUKA Results Comparison

The role of the Nozzle:

Ex: 100 GeV electron exit at 3 m with 0.01 rad angle

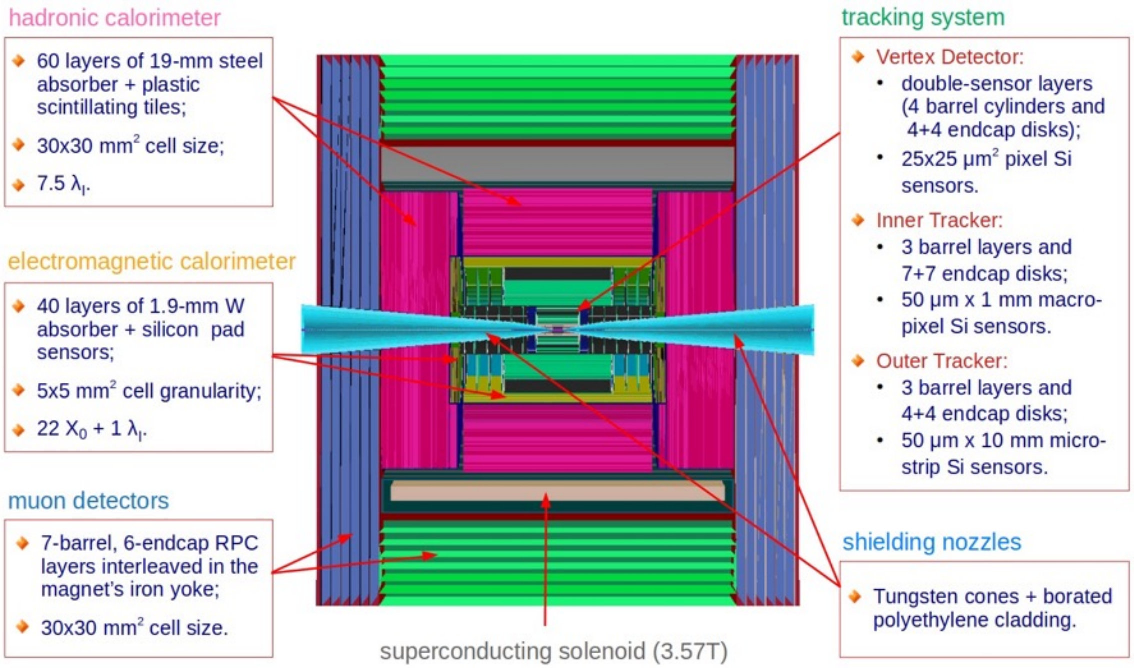


reaches the inner layers of the tracking system



Francesco Collamati

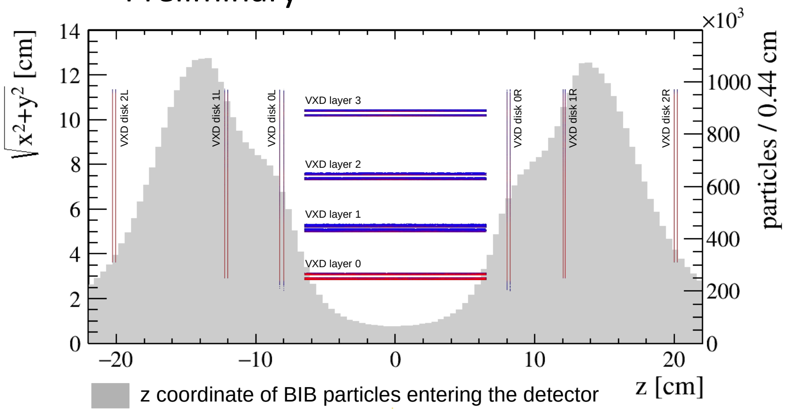
New detector configuration @ 1.5 TeV

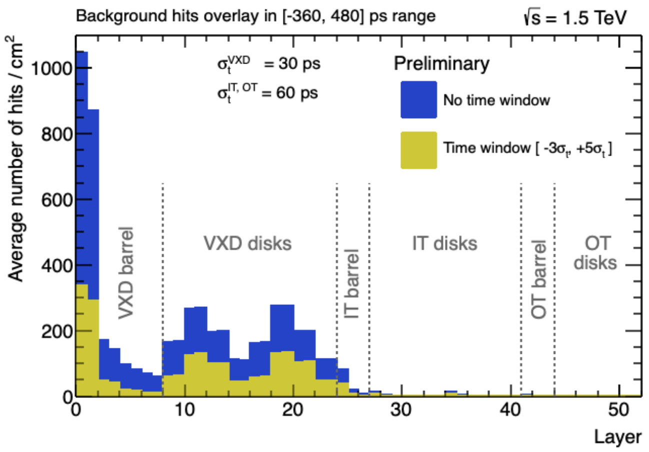


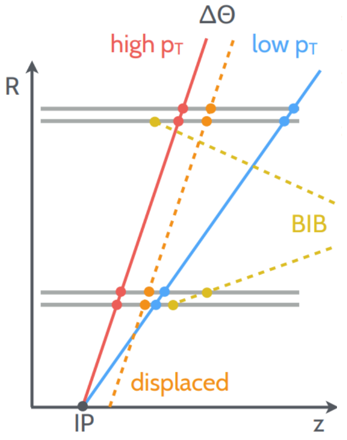
CLIC Detector technologies adopted with important modifications to cope with BIB

TO BE IMPROVED TUNED at higher $\sqrt{s}$

Tracker detector considerations





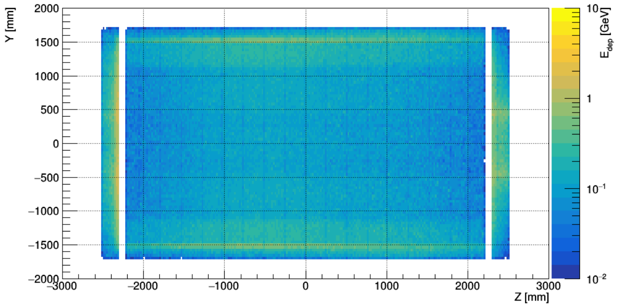


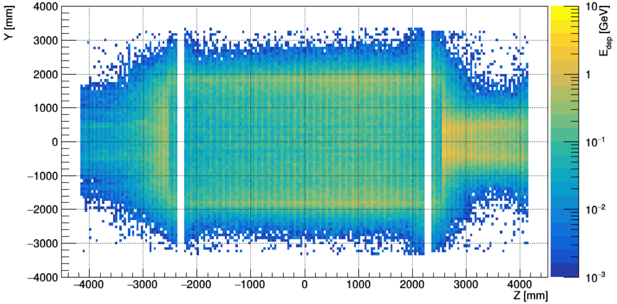
- Timing window applied to reduce hits from out-of-time BIB
- Granularity optimized to ensure $\lesssim$ 1% occupancy
- Realistic digitization in progress ➔ BIB suppression based on cluster shape
- If primary vertex could be known before ➔ effective angular matching of hit doublets
- To be tuned in presence of secondary vertices or long-lived particles

Other detector considerations

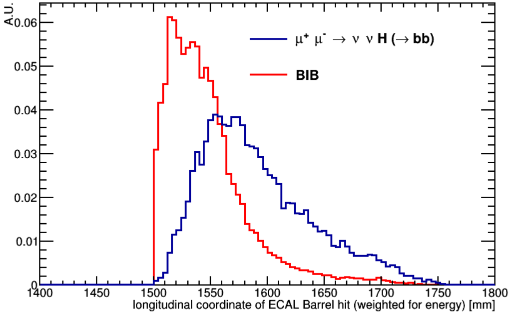
Calorimeters

BIB deposits large amount of energy in both ECAL and HCA



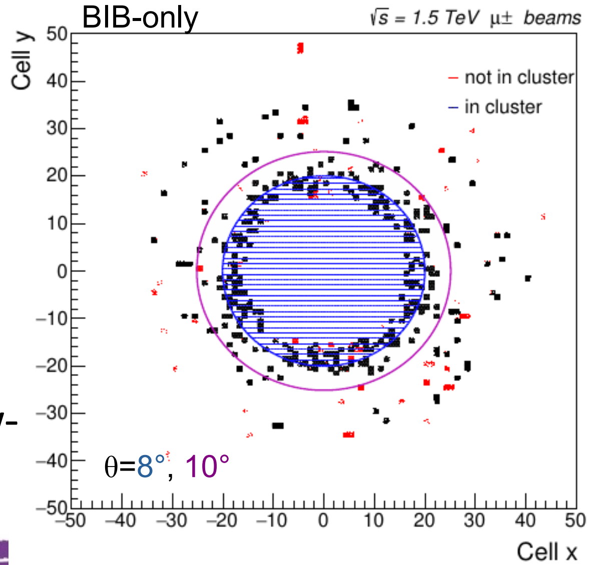


Timing and shower profile should be used in clusters reconstructions



Muon System

Low BIB contribution, concentrated in the low-radius endcap region



First look at a Muon Collider detector magnet design

International MUON Collider Collaboration

M. Mentink, A. Dudarev, and B. Cure

Property	Value
Magnetic field at IP [T]	3.6
Cold mass length [m]	7.89
Free bore diameter [m]	6.85

CLIC-like Superconducting Solenoid, with 3.6 T at the interaction point

- 3.6 T at IP and with return yoke
  → 1.8 GJ stored magnetic energy
- For reference, Compact Muon Solenoid has stored energy of 2.6 GJ

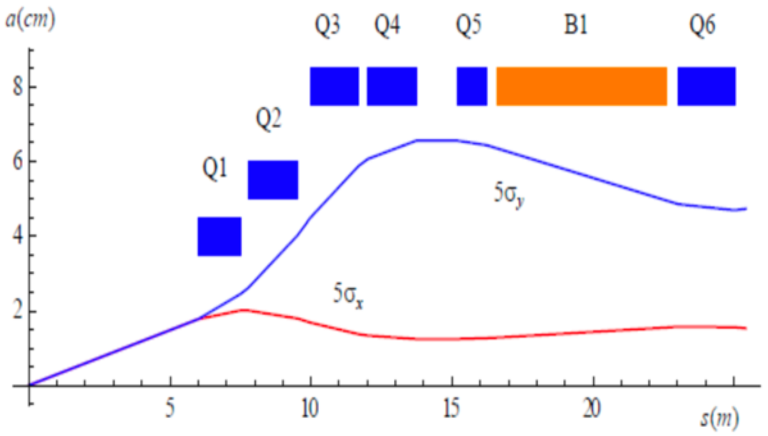
Similar to Compact Muon Solenoid
First-order cost estimate: ~80-100 MCHF (2008)

Organizational challenges
 requires a long-term (15-20 years) schedule and support from multiple institutes

Conductor challenge

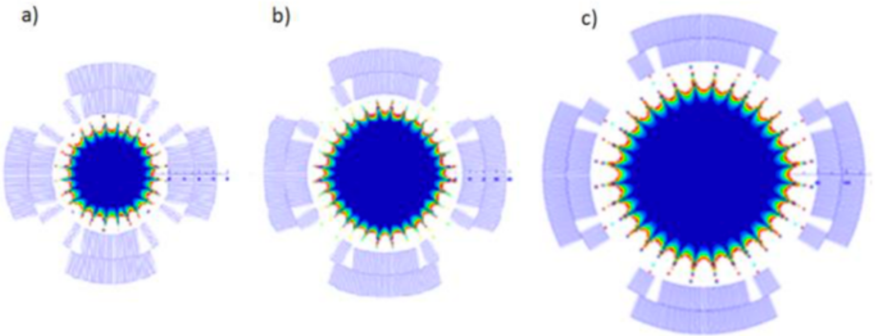
Consideration of HTS-based detector magnets for potential future cost savings

IR Lattice & Magnet Design @ 1.5 TeV



Beam sizes and aperture of the FF magnets
$a \geq 5\sigma_{max} + 1$ cm, B=8T in dipole.
L_B = 1.5 to 1.7 m in quads and 6 m in B1

Important role is played by the absorber materials

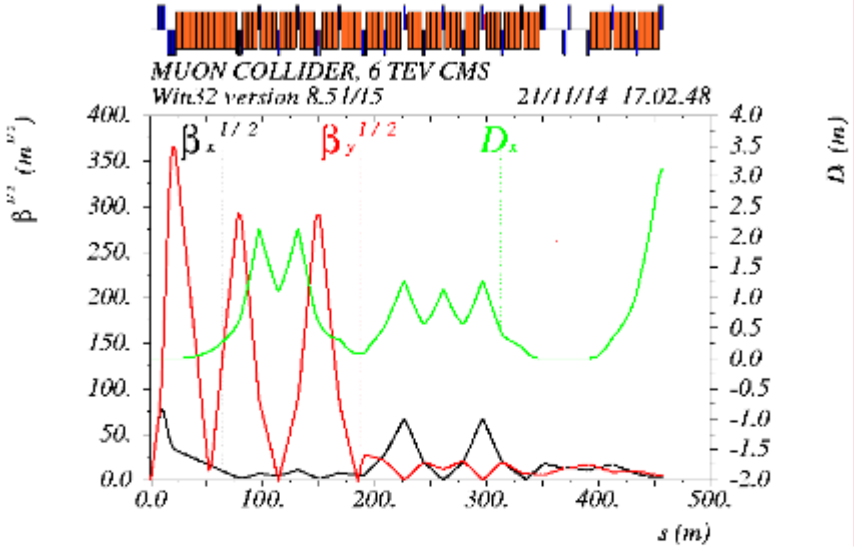


Cross-sections and good-field regions ($|\delta B/B|<10^{-4}$) of Q1, Q2 and Q3-Q5 quads with G = 250, 187 and -130 T/m, respectively

Deposited power density in Q1 (mW/g)

IR Linear Optics @ 6 TeV Design

Yunhai Cai and Yuri Nosochkov



Field@poletip:
<15 T in quads
<20 T in bends

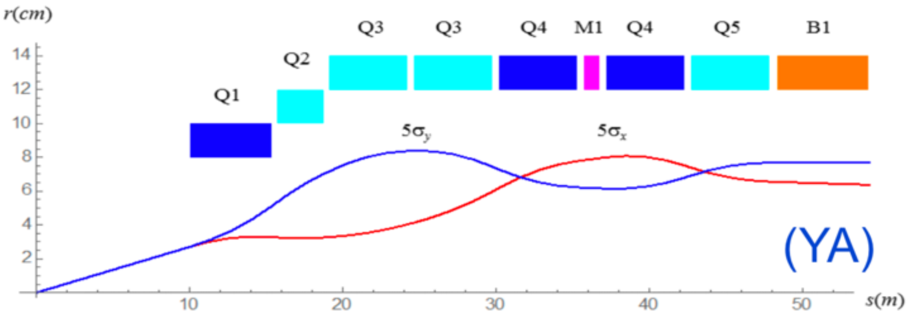
$\beta^*_{x,y}$ =1 cm
L* =6 m

Y. I. Alexahin, E. Gianfelice-Wendt, V.V. Kashikhin, N.V. Mokhov, A.V. Zlobin, V.Y. Alexakhin, PRSTAB 14, 061001 (2011)

M.-H. Wang, Y. Nosochkov, Y. Cai, M. Palmer, 2016 JINST 11 P09003

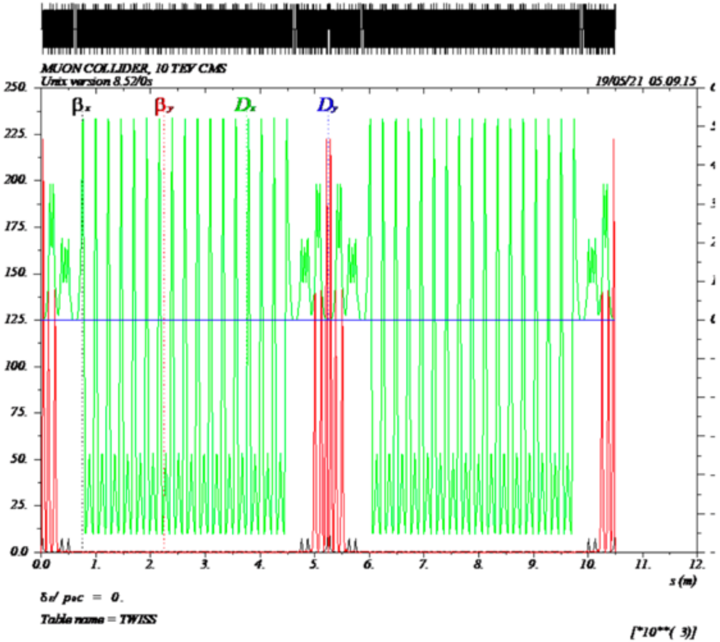
6 TeV IR and MDI studies

Several LOIs were submitted to Snowmass, a kind of a pre-feasibility study to address design of a lattice for the average luminosity of 10^{35} cm^{-2}s^{-1} with β^*=3 mm, high-field / high-gradient superconducting magnets with the coil apertures as large as 25 cm in IR and 15 cm in the arcs, abs(G) = 78 to 200 T/m, 8-T dipoles with hybrid multilayer coils made of HTS and LTS with the stress management (AZ), optimized MDI with tungsten liners, masks, nozzles etc, detector BIB mitigation techniques as well as appropriate measures to mitigate neutrino hazard.



IR Linear Optics @ 10 TeV scaled

Yunhai Cai and Yuri Nosochkov



- Scaled from 6 TeV design with factor: F=10/6
  - All: Length->Length*F
  - Bending angle kept same
  - K_1->K_1/F^2
  - K_2->K_2/F^3
- Keep phase advances same
- No change of beam size

$\beta^*_{x,y}$ =1.7 cm, L* =10 m, Circumference=10.5 km

Parameters

Parameter	Unit	1.5 TeV design	3 TeV design	6 TeV design
Beam energy	TeV	0.75	1.5	3.0
Number of IPs		2	2	2
Circumference	m	2730	2767	6302
β^*	cm	1	1	1
Tune x/y		18.56/16.58	20.13/22.22 (temporary)	38.23/40.14 (temporary)
Momentum compaction		-1.30E-5	-2.88E-4	-1.22E-3
Normalized emittance	(π)mm·mrad	25	25	25
Momentum spread	%	0.1	0.1	0.1
Bunch length	cm	1	1	1
Muons/bunch	10^{12}	2	2	2
Repetition rate	Hz	15	15	15
Average luminosity	10^{34} cm^{-2}s^{-1}	1.1	4.5	7.1

Yunhai Cai and Yuri Nosochkov

Daniel Schulte

International MUON Collider Collaboration

Tentative target parameters
Scaled from MAP parameters

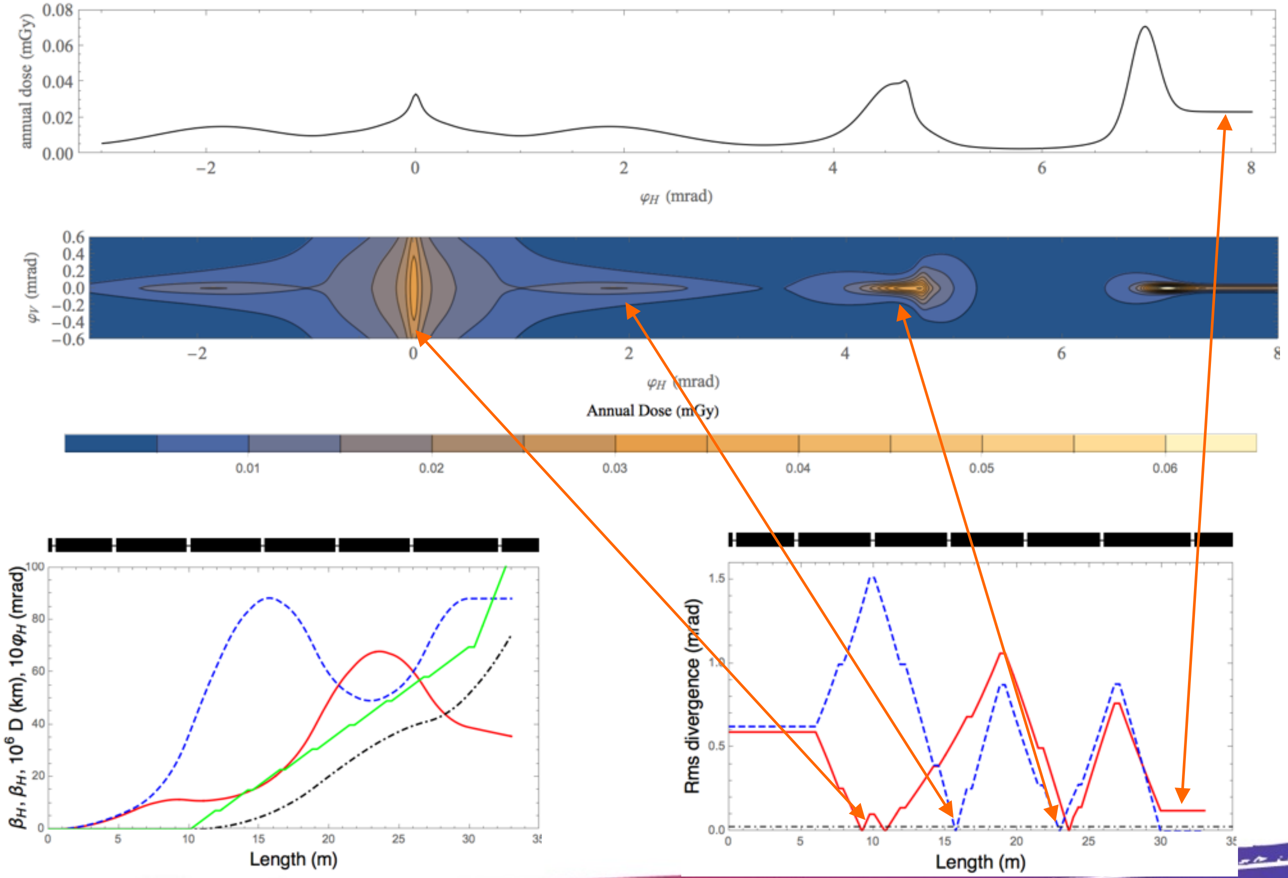
Comparison:
CLIC at 3 TeV: 28 MW

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} cm^{-2}s^{-1}	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
<B>	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	µm	25	25	25
$\sigma_{x,y}$	µm	3.0	0.9	0.63

Application to 3 TeV Lattice from MAP

Neutrino radiation from region around IP

Christian Carli



Assuming 100 m in depth

Next steps: simulation studies

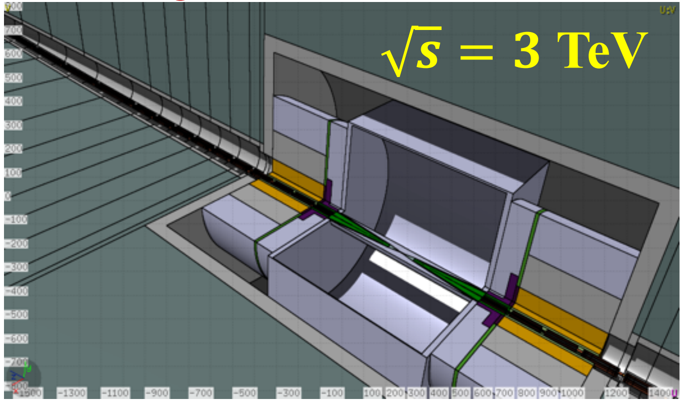
Results are in publication *(arXiv:2105.09116)*

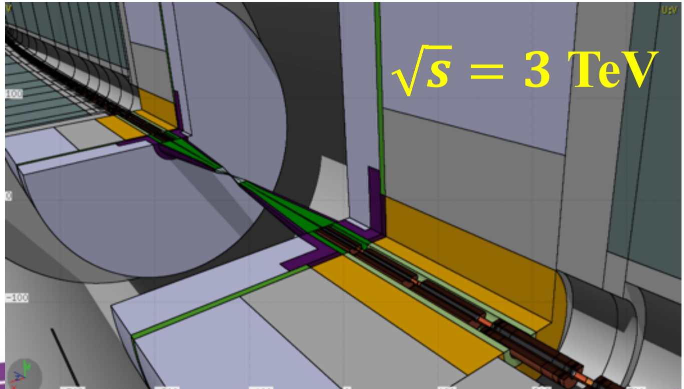
Donatella Lucchesi

- Study Beam-Induced Background at $\sqrt{s} = 3$ TeV, use MAP IR and the nozzle of $\sqrt{s} = 1.5$ TeV, then
  - Optimize nozzle
  - Optimize IR

- Detector studies are just at the first step, a lot of room for improvements!
- Physics objects performance are very good even if not optimize, room for improvements in particular with ML techniques
- Dedicated studies and optimization is needed for the forward region, covered by the nozzle

A. Mereghetti





Strong collaboration between accelerator and detector physicists is mandatory for the proper MDI design

Thanks to the speakers and everybody who contributed to the work and discussion