Attività simulazioni di fisica ed esperimento

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Riunione Referee RD_MUCOL – 14 settembre 2021

Outline

- Physics studies with the detector full simulation.
- Full-simulation detector studies with the beam-induced background and latest software developments (with focus on the tracker).

Physics studies with detector full simulation

Baseline detector model

hadronic calorimeter

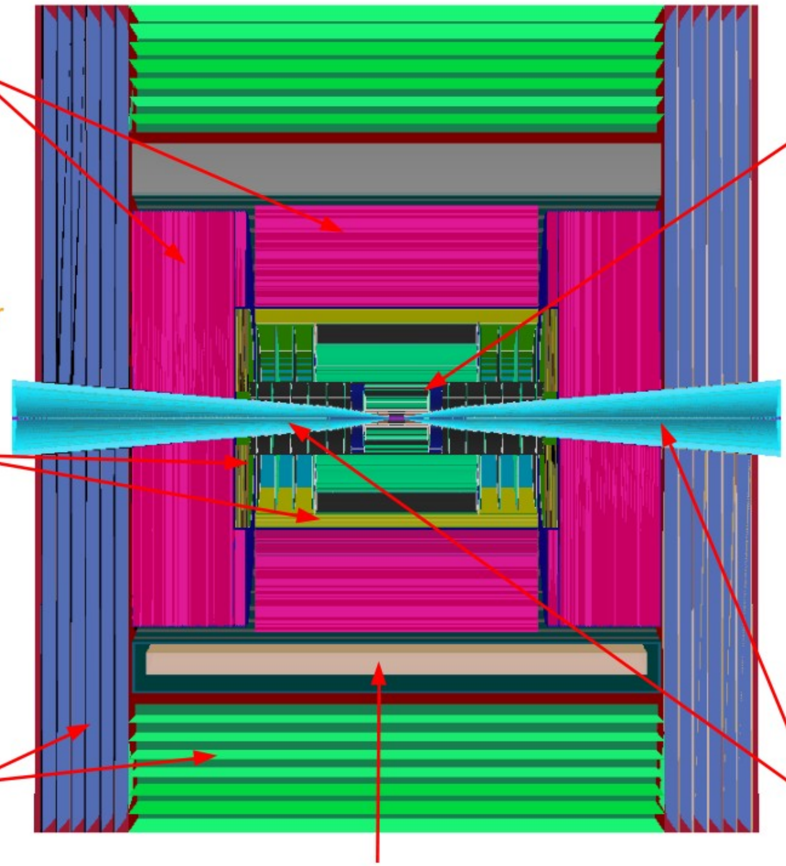
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 μm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 μm x 10 mm micro-strip Si sensors.

shielding nozzles

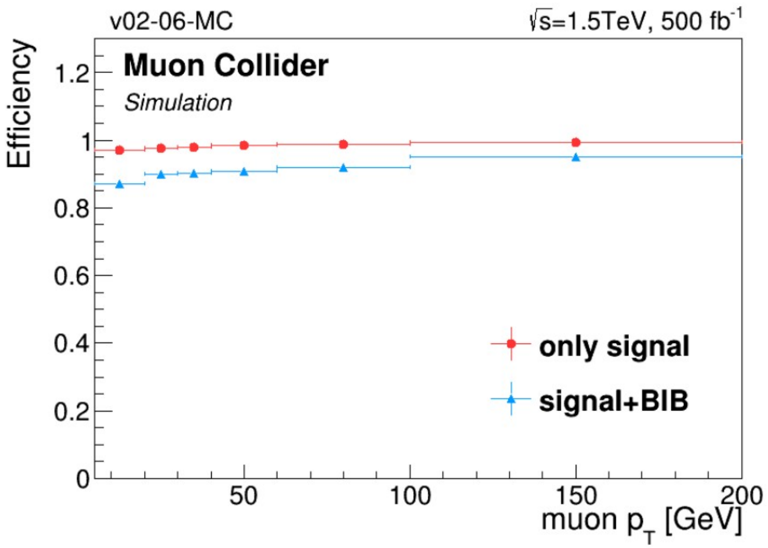
- Tungsten cones + borated polyethylene cladding.

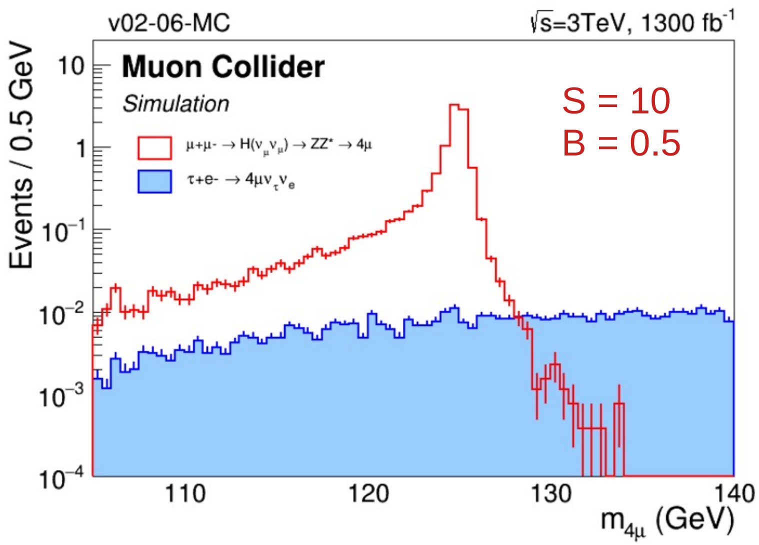
- Based on CLIC's model + the MDI and vertex detector designed by MAP.

$H \rightarrow ZZ^* \rightarrow \mu\mu\mu\mu$ @ 1.5 and 3 TeV

- Study of the channel $H \rightarrow ZZ^* \rightarrow 4\mu$ at 1.5 (0.5 ab^{-1}) and 3 TeV (1.3 ab^{-1}).
- Sensitivity to the HZZ coupling.

BA



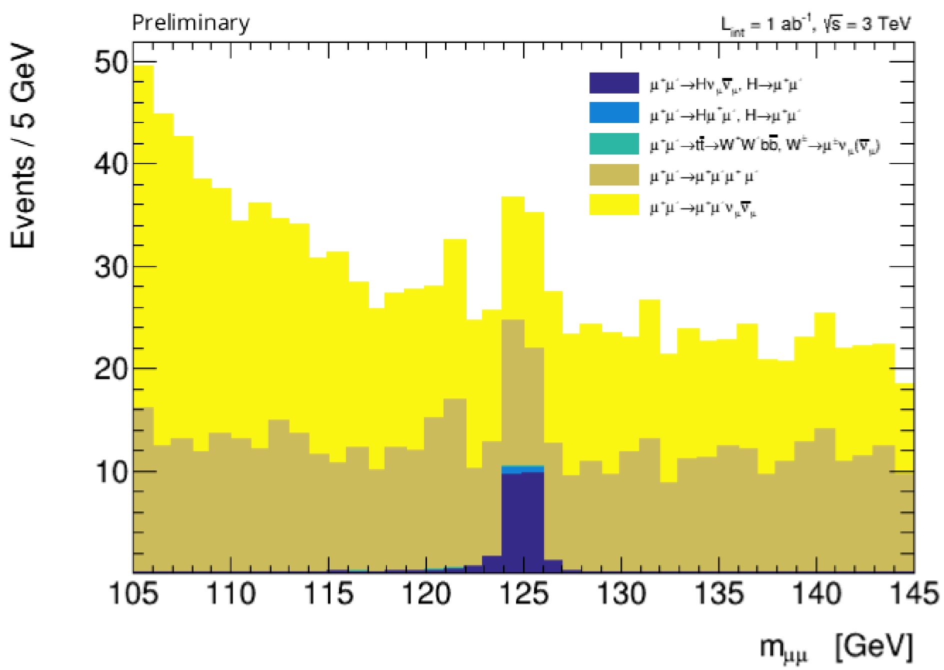


Muon Collider, channel $H \rightarrow ZZ^* \rightarrow 4\mu$				
Results	$\sqrt{s}$ = 1.5 TeV, L = 500 fb^{-1}		$\sqrt{s}$ = 3 TeV, L = 1300 fb^{-1}	
	significance	$\frac{\Delta g_{HZZ}}{g_{HZZ}}$ (%)	significance	$\frac{\Delta g_{HZZ}}{g_{HZZ}}$ (%)
without BIB	3.61	30.09	6.85	15.83
with BIB	3.08	35.75	-	-

[A. Zaza, poster at LHCP2021]

H → μμ @ 3 TeV

TS



Process	Expected events with $105 < m_{\mu\mu} < 145$ GeV
$\mu^+\mu^- \to H\nu_\mu\bar{\nu}_\mu,\ H \to \mu^+\mu^-$	24.2
$\mu^+\mu^- \to H\mu^+\mu^-,\ H \to \mu^+\mu^-$	1.6
$\mu^+\mu^- \to \mu^+\mu^-\nu\bar{\nu}_\mu$	636.5
$\mu^+\mu^- \to \mu^+\mu^-\mu^+\mu^-$	476.4
$\mu^+\mu^- \to t\bar{t} \to W^+W^-b\bar{b},\ W^\pm \to \mu^\pm\nu_\mu(\bar{\nu}_\mu)$	1.1

- Prospects for the measurement of $\sigma_H \times BR(H \to \mu\mu)$ at 3 TeV
- Assuming an integrated luminosity of 1 ab^{-1} and no BIB effects:

$$\frac{\Delta\sigma_H}{\sigma_H} \sim 38\,\%$$

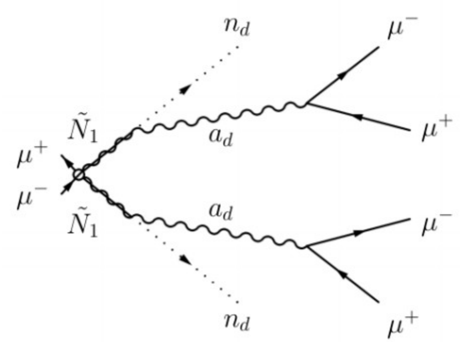
- CLIC estimate at 3 TeV with 2 ab^{-1}: 26% [Eur. Phys. J. C 73 (2013) 2290].

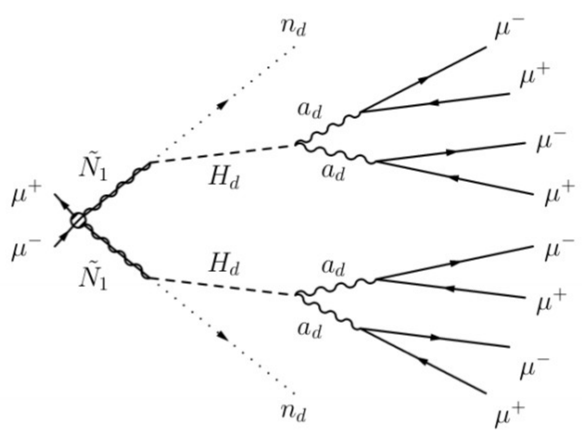
[A. Montella, poster at EPS2021 and talk at Higgs2021]

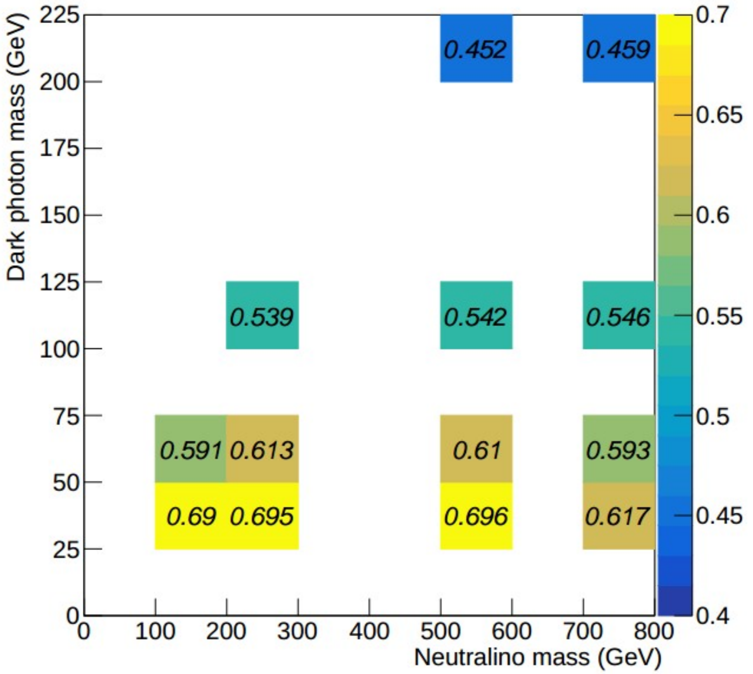
Dark SUSY @ 3 TeV

PV

- Search for a massive dark photon produced from neutralino decays in Dark SUSY model: preliminary estimate of signal reconstruction efficiency in unexplored phase-space region.
- Two search channels with 4 and 8 muons in the final state.







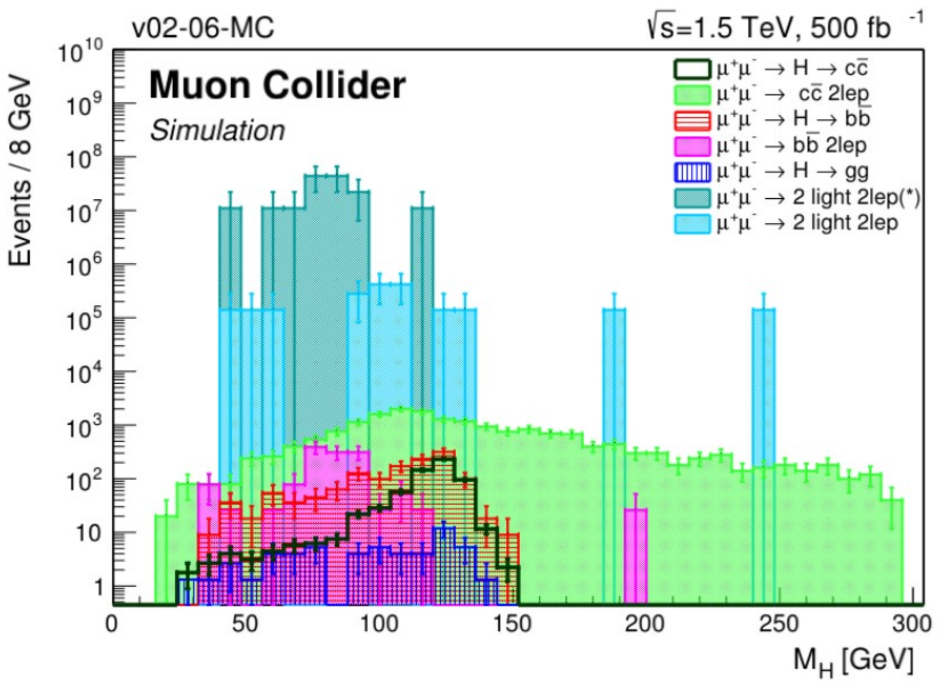
	m(H_d) = 30 GeV		m(H_d) = 50 GeV		m(H_d) = 70 GeV	
	loose	tight	loose	tight	loose	tight
m(a_d) = 1 GeV	34.5%	32.2%	33.0%	30.5%	---	---
m(a_d) = 10 GeV	60.7%	57.1%	69.4%	64.3%	70.7%	65.4%
m(a_d) = 20 GeV	---	---	70.2%	62.7%	76.1%	67.2%
m(a_d) = 30 GeV	---	----	---	---	73.6%	66.3%

[C. Aimè, talk at APS2021 and poster at EPS2021]

H → cc @ 1.5 and 3 TeV

BA

- Search for H → cc at 1.5 at 1.5 (0.5 ab^{-1}) and 3 TeV (1.3 ab^{-1}).
- Sensitivity to the Hcc coupling.



Physics process	N. of events in the Higgs region after all selections	Absolute efficiency
$\mu^+\mu^- \to H\nu\bar{\nu} \to c\bar{c}\,\nu\bar{\nu}$	378 ± 19	0.0849 ± 0.0028
$\mu^+\mu^- \to c\bar{c}\,2lep$	619 ± 25	0.0031 ± 0.0006
$\mu^+\mu^- \to H\nu\bar{\nu} \to b\bar{b}\,\nu\bar{\nu}$	567 ± 24	0.0063 ± 0.0008
$\mu^+\mu^- \to H\nu\bar{\nu} \to gg\,\nu\bar{\nu}$	19 ± 4	0.0014 ± 0.0004

$\sqrt{s}$ $[TeV]$	$\mathcal{L}$ $[fb^{-1}]$	S	B	$S/\sqrt{S+B}$	$\Delta\sigma/\sigma$	$\Delta g_{Hcc}/g_{Hcc}$
1.5	500	378	1205	9.5	10.5 %	5.5 %
3.0	1300	1565	4337	20.4	4.9 %	2.6 %

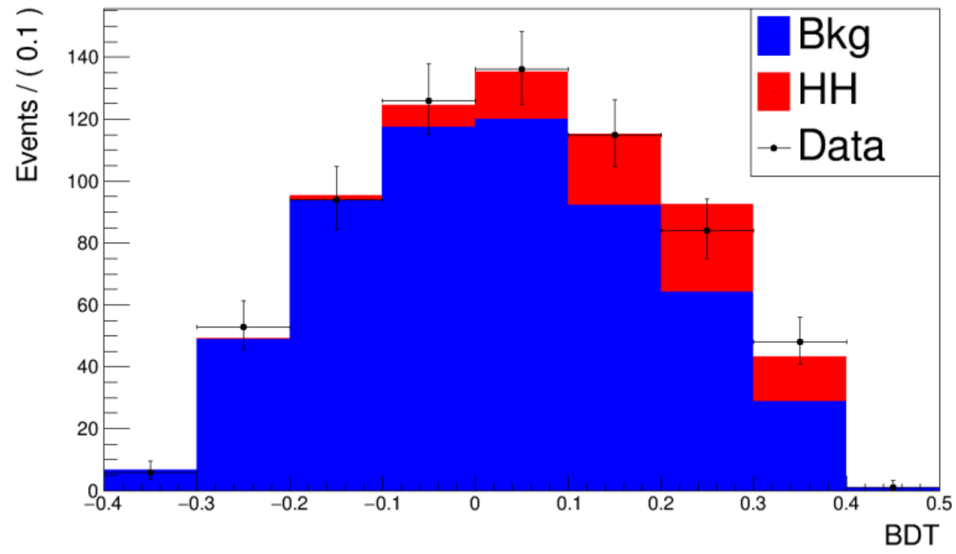
CLIC (350 GeV + 1.4 TeV + 3 TeV) ~ 2%

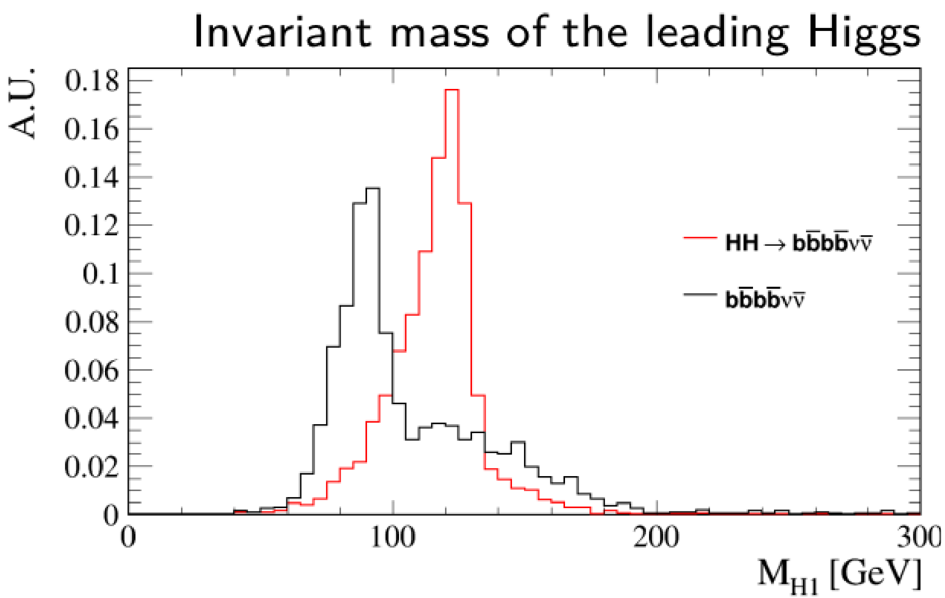
[P. Mastrapasqua, poster at LHCP2021]

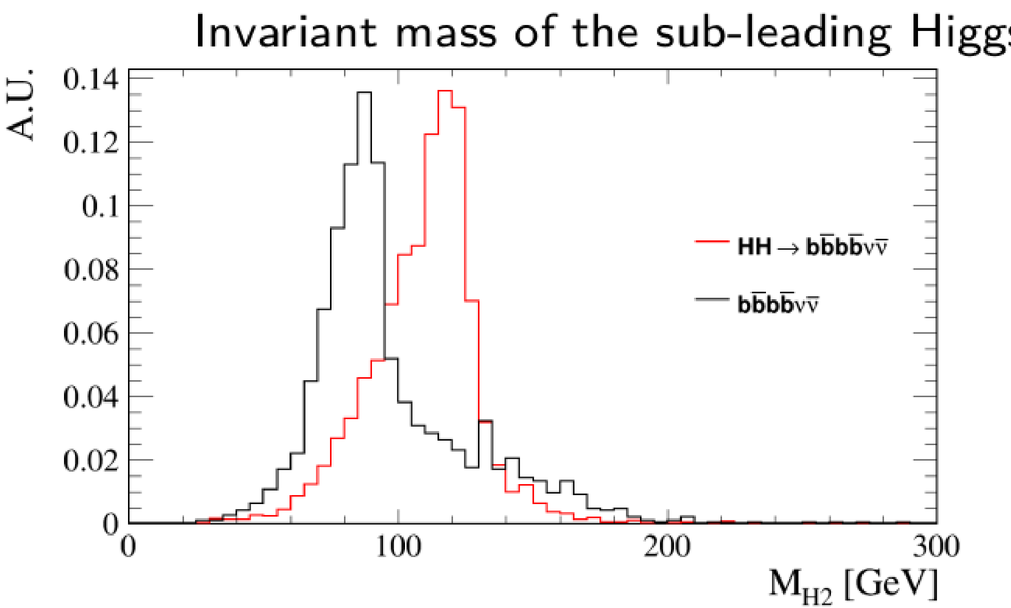
HH → bbbb @ 3 TeV

- The HH channel represents a gateway to the trilinear Higgs self-coupling.
- Expected yield at $\sqrt{s}$ = 3 TeV with 1.3 ab^{-1}: S = 65
  B = 561

$$\frac{\Delta\sigma_{HH}}{\sigma_{HH}} \sim 30\,\%$$



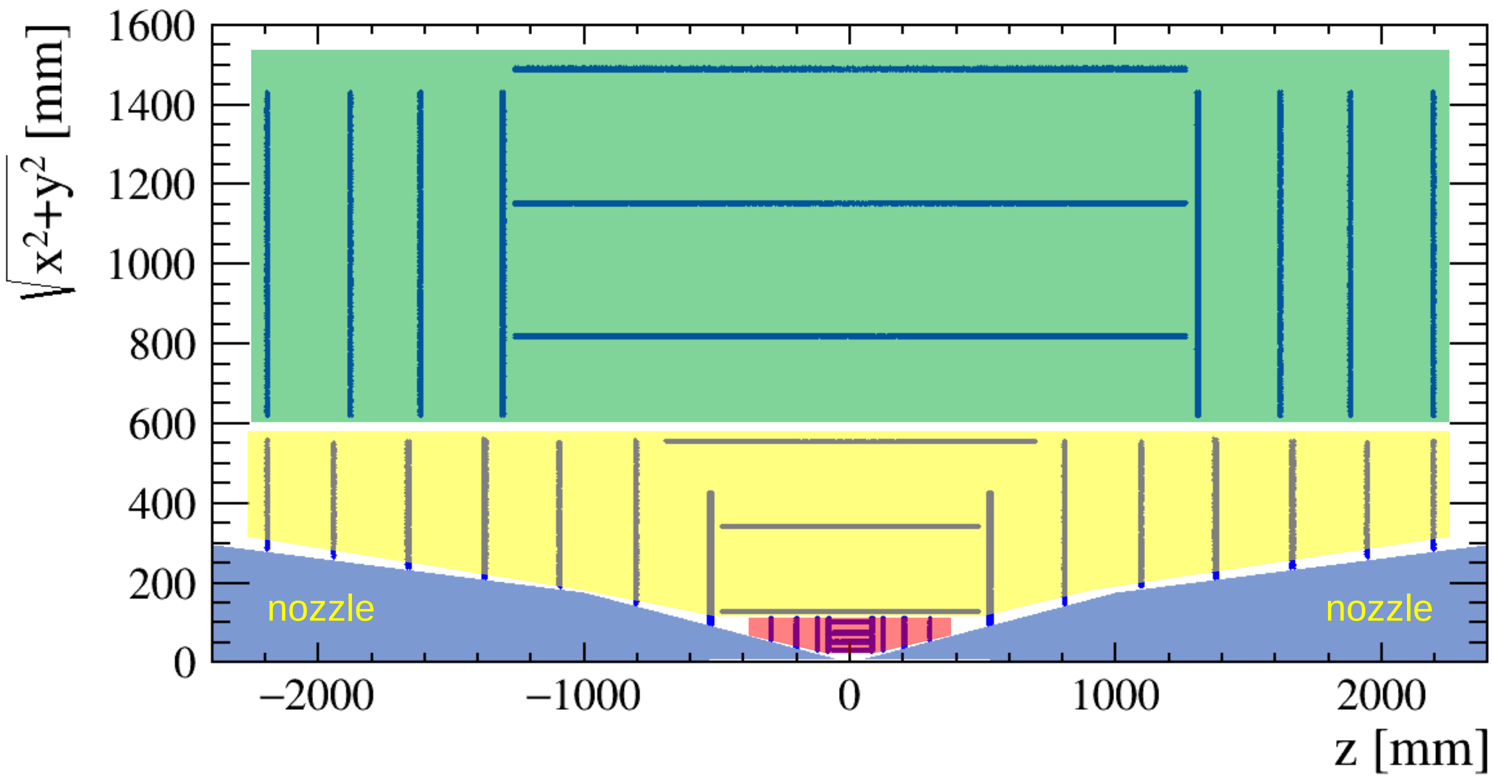




[L. Buonincontri, talks at APS2021 and EPS2021]

Detector studies and software development

Tracker layout



Vertex detector (VXD)

- barrel: 4 cylindrical layers
  endcaps: 4 + 4 disks
- double-layer Si sensors:
  25x25 μm² pixels
  50 μm thick
  σ_T = 30 ps

Inner Tracker (IT)

- barrel: 3 cylindrical layers
  endcaps: 7 + 7 disks
- Si sensors:
  50 μm x 1 mm macro-pixels
  100 μm thick
  σ_T = 60 ps

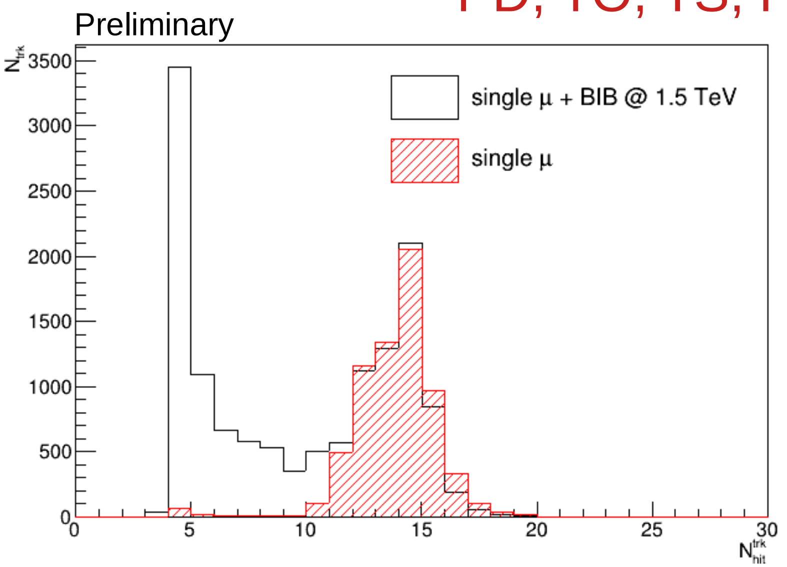
Outer Tracker (OT)

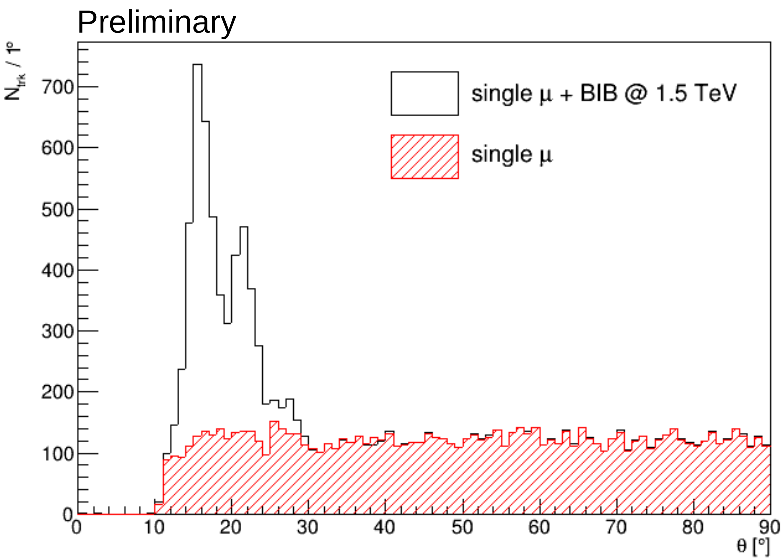
- barrel: 3 cylindrical layers
  endcaps: 4 + 4 disks
- Si sensors:
  50 μm x 10 mm micro-strips
  100 μm thick
  σ_T = 60 ps

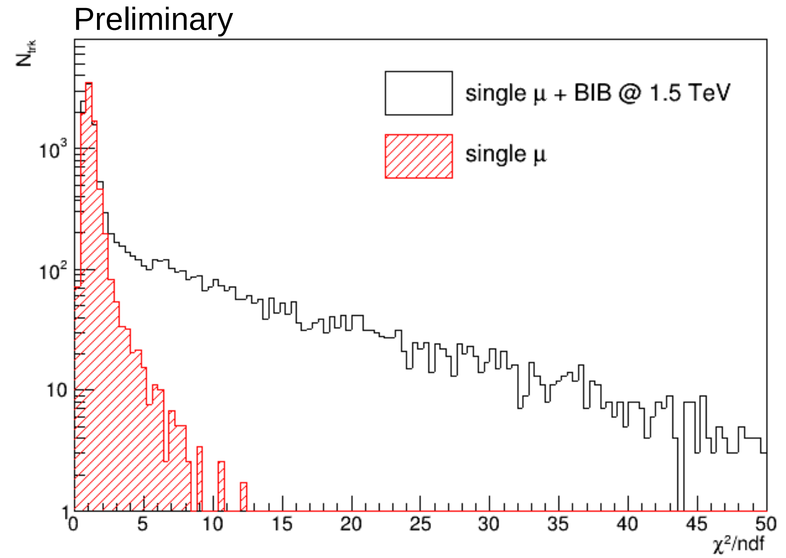
Muon ROI tracking

PD, TO, TS, FNAL

- Sample: 10k single prompt muons with p = 10 GeV + BIB @ 1.5 TeV.
- Timing + double-layer selection applied.
- Tracking performed in a region of interest (ROI): only hits in a cone around the muon direction are used (ΔR = 0.05).

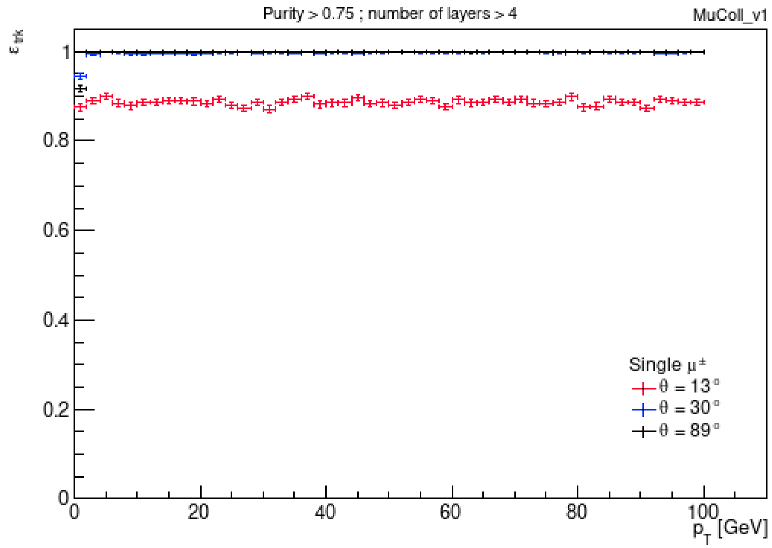


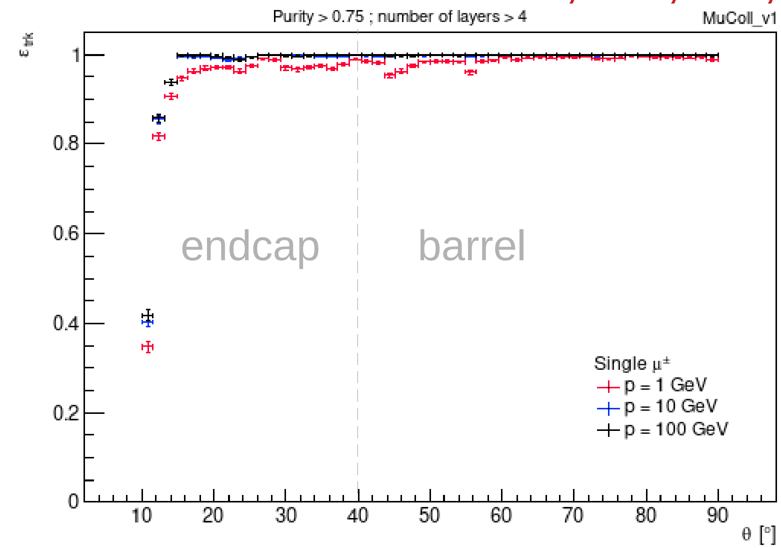


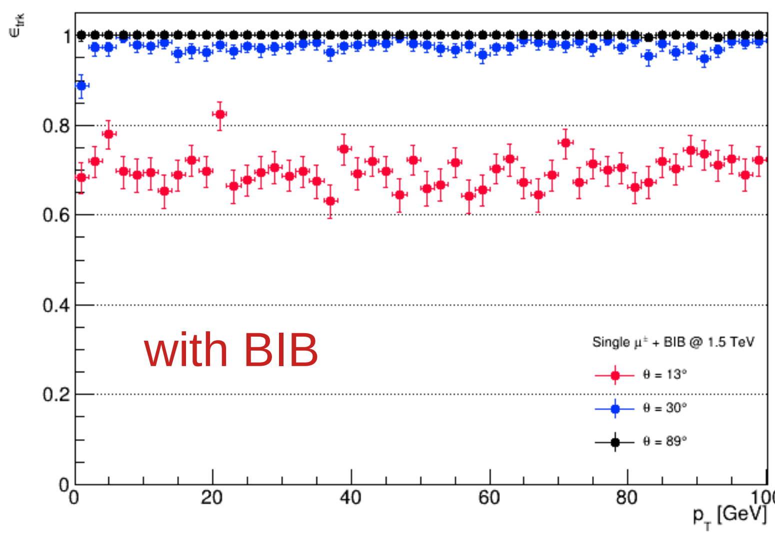


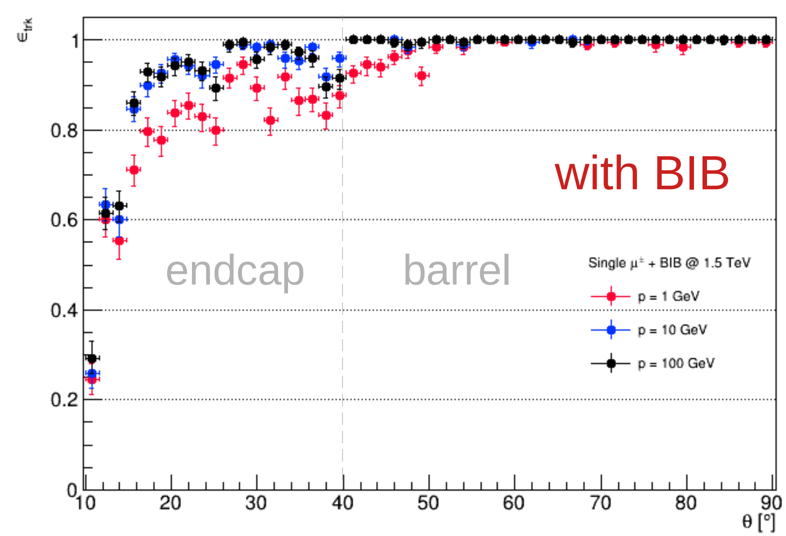
Muon tracking efficiency w/ BIB

PD, TO, TS, FNAL



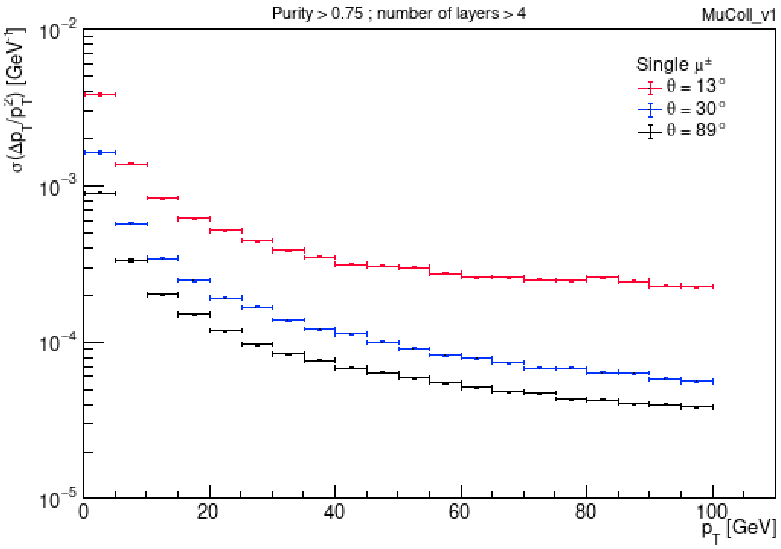


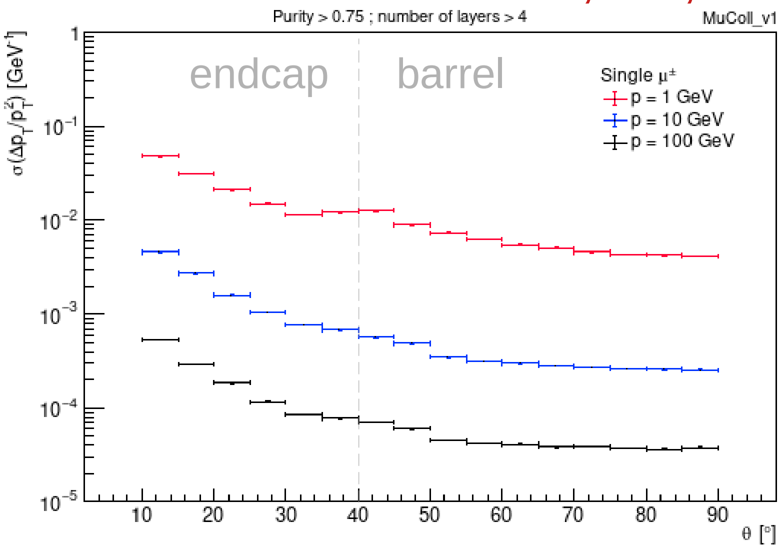


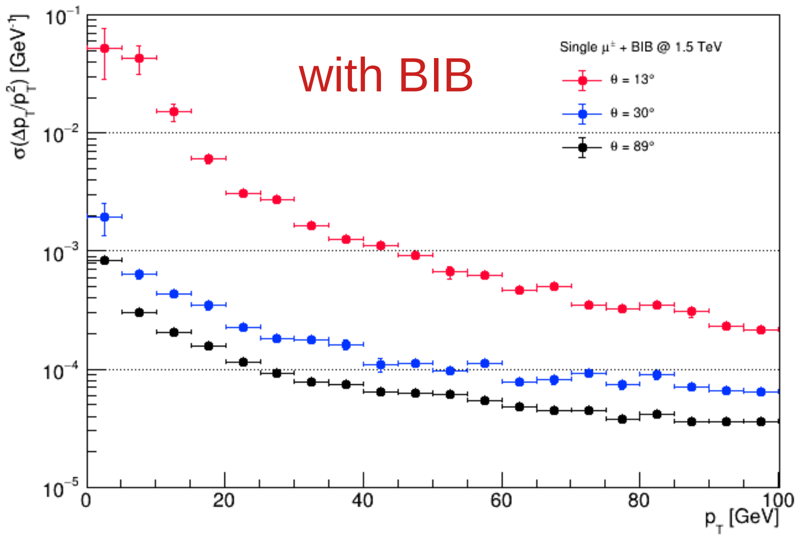


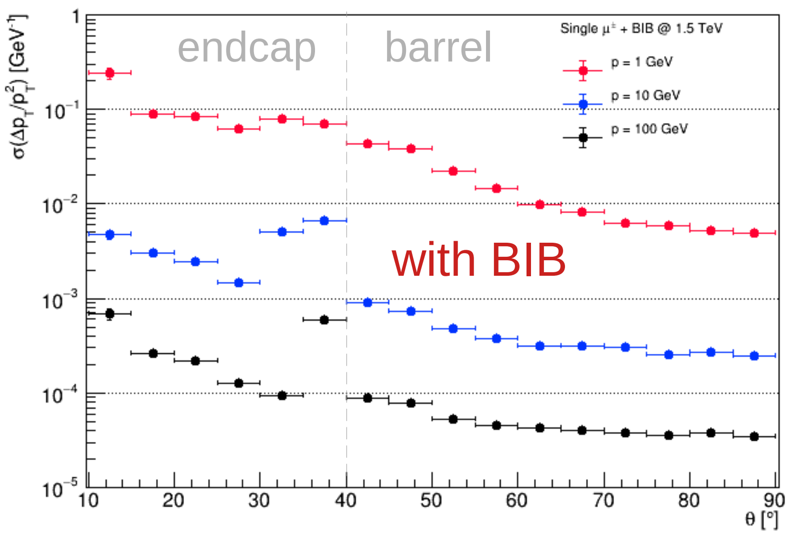
Muon p_T resolution w/ BIB

PD, TO, TS. FNAL



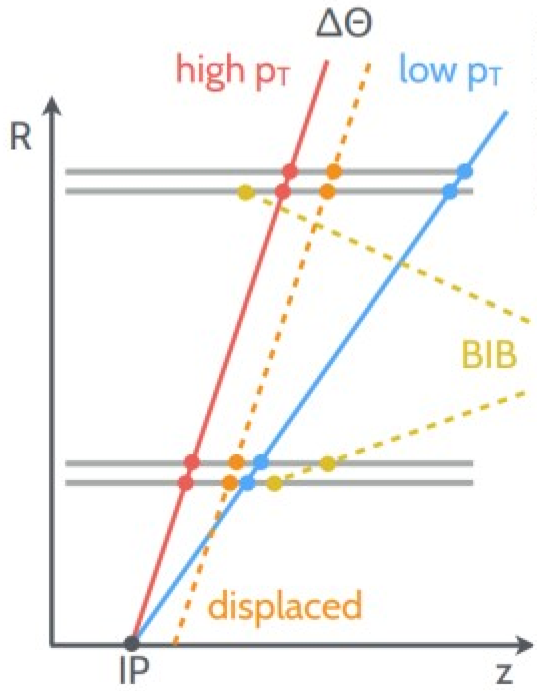


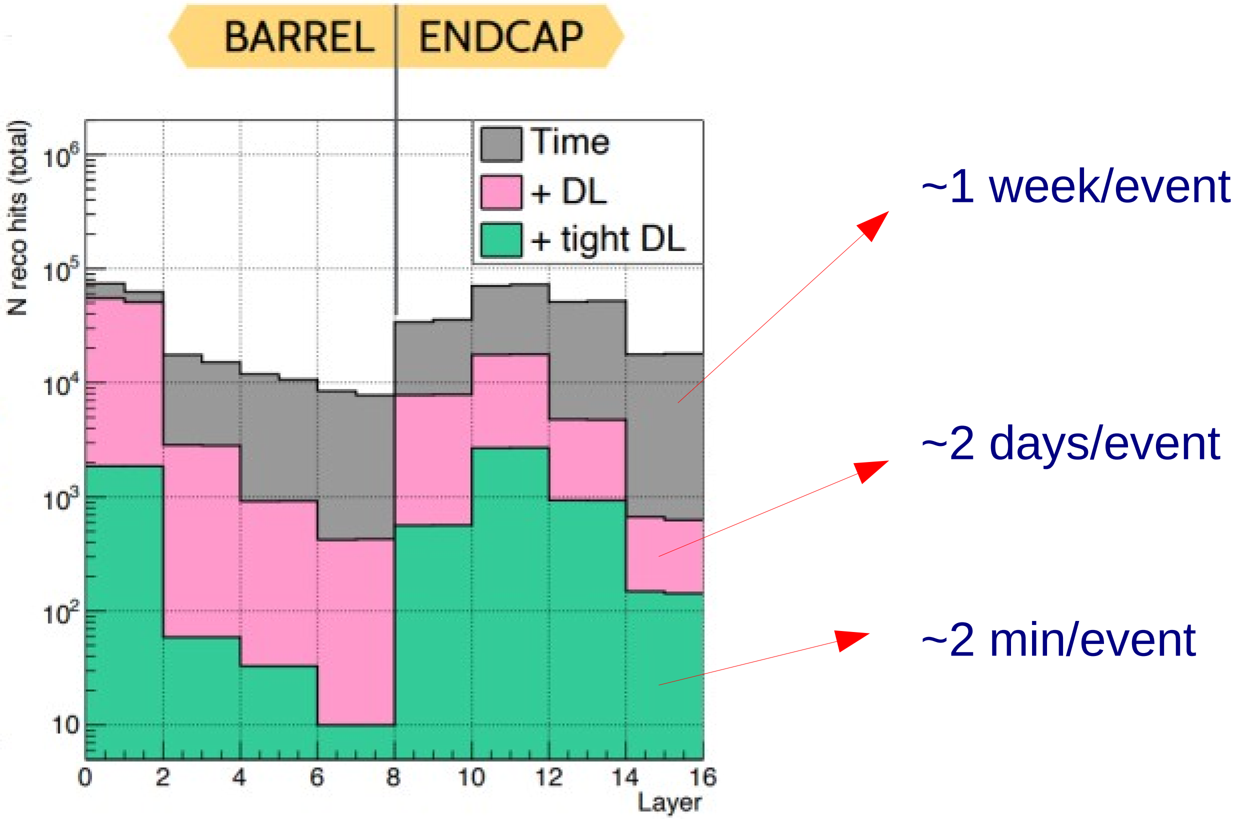




Double-Layer filter

TO

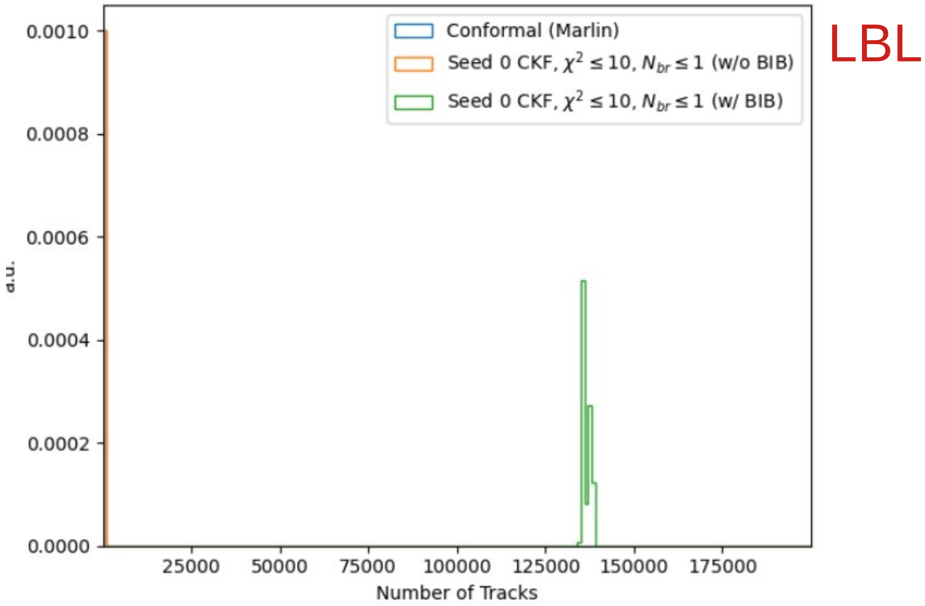


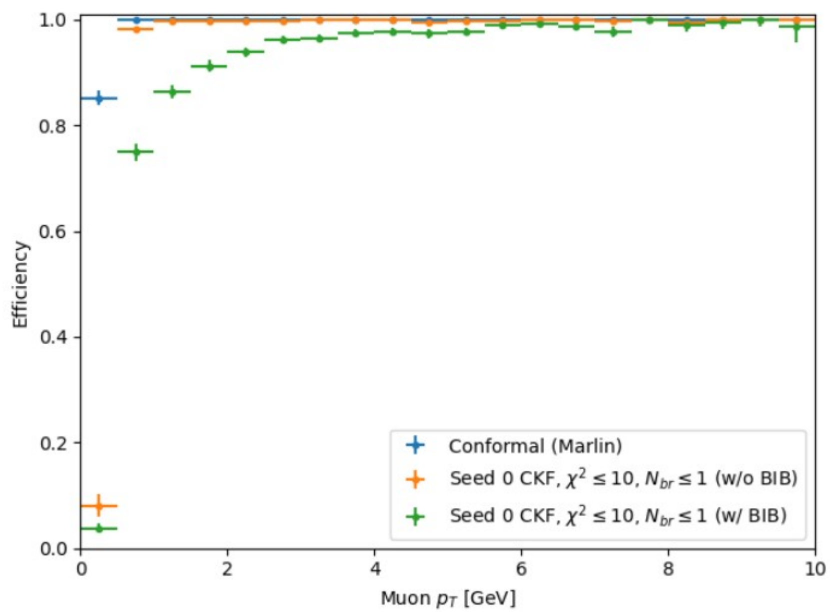


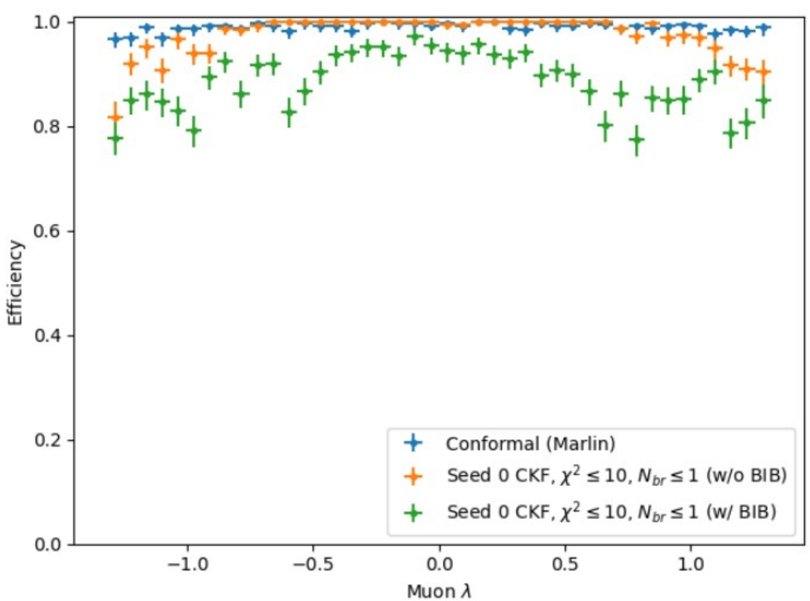
- Loose DL: requires compatiblity with beamspot region within ~10mm;
- tight DL: assumes knowledge of primary vertex position.

CKF tracking with ACTS

- Implementation of a Combinatorial Kalman Filter with the ACTS package.
- Integration into MuonCollSoft.
- Tuning and optimization underway.
- Very promising tracking and computational performance: ~4 min/event with BIB.

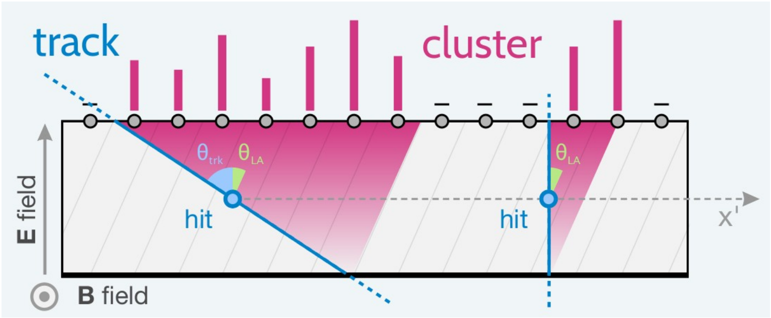


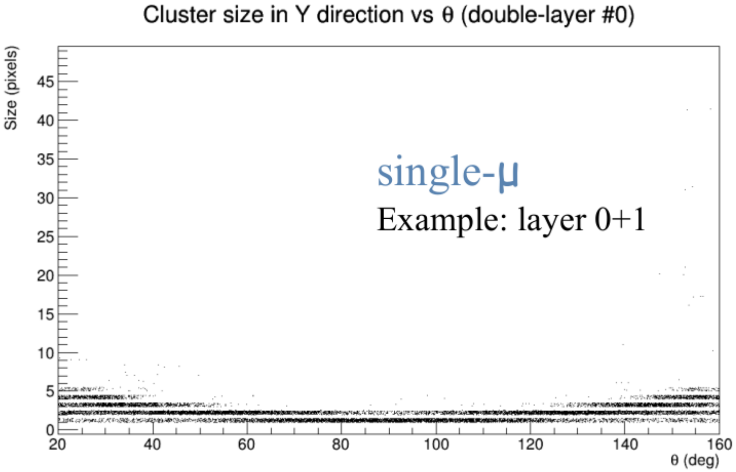


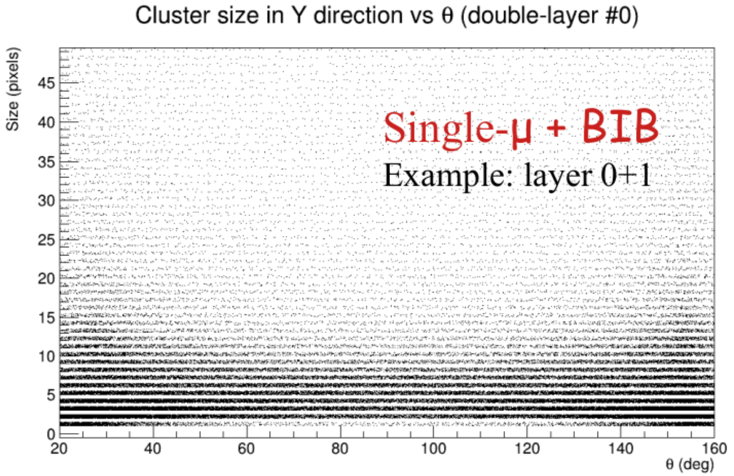


VXD realistic digi and reco

PD, LBL







- Digitizatoin:
  - energy deposition fluctuations;
  - Lorentz angle effects;
  - charge drift and diffusion;
  - threshold dispersion;
  - FE chip's noise;
  - charge discretization.
- Reconstruction:
  - pixel clusterization.
- Cluster shape and size handle to reject BIB.

Cut Efficiency	Loose	Tight
Single muon	99.7%	99.6%
Single muon + BIB	55.2%	43.7%

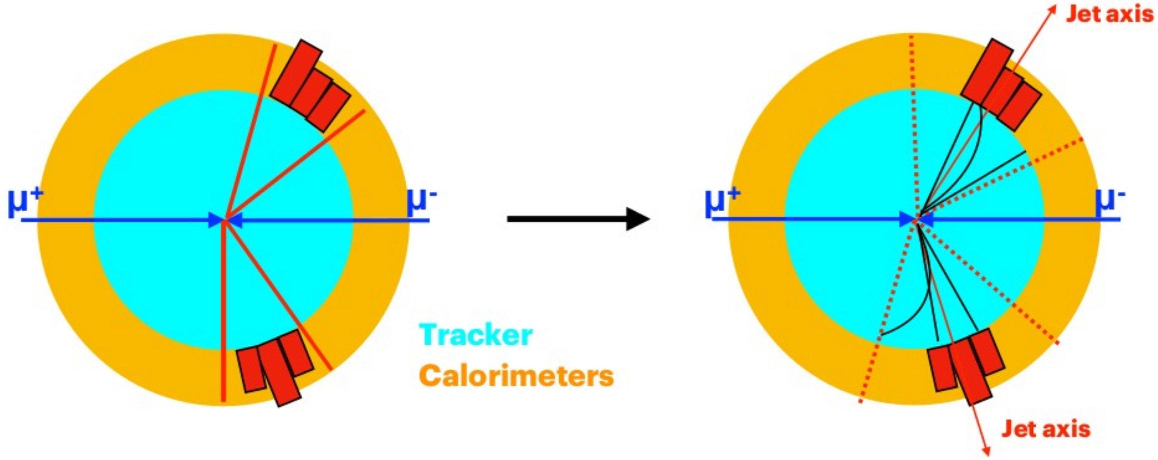
ROI reconstruction of jet tracks

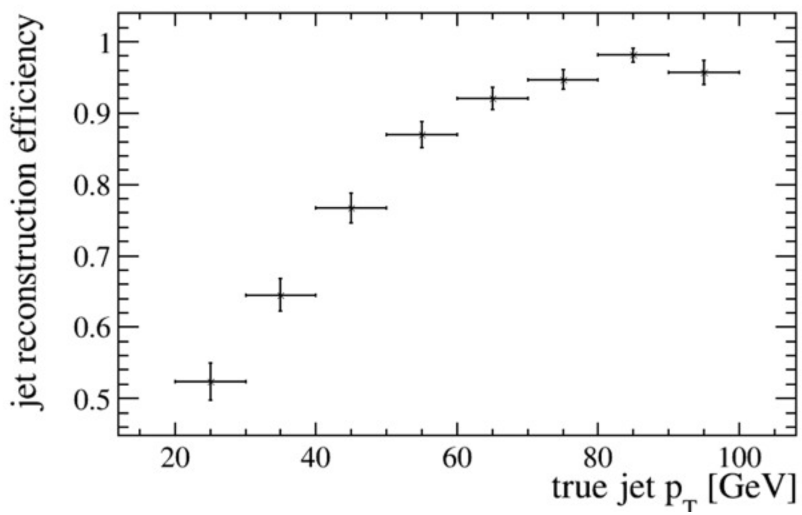
PD

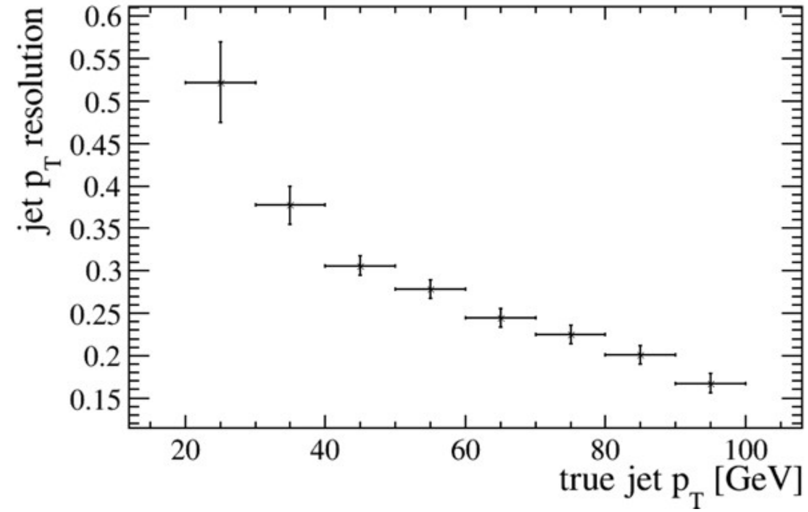
Step 1: calorimeter jet reconstruction with PandoraPFA and kt (R=0.5)

Step 2: regional tracking in cones (R=0.7) defined by the calorimeter jet directions

Step 3: final jet clustering using calorimeter clusters and tracks with PandoraPFA and kt (R=0.5)



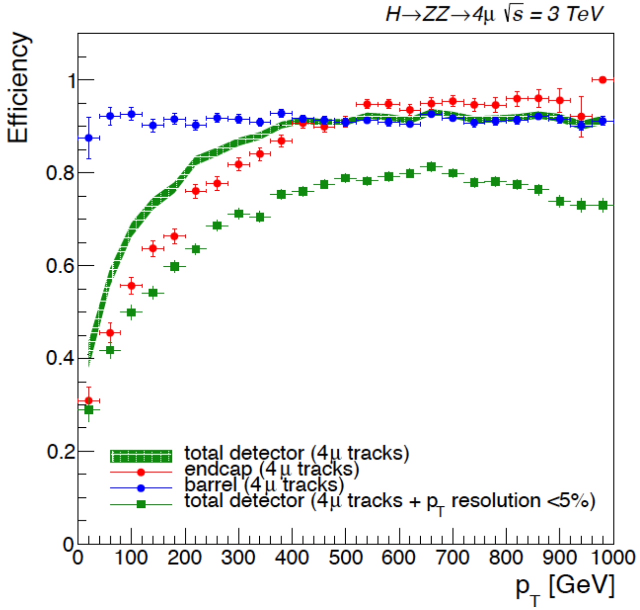


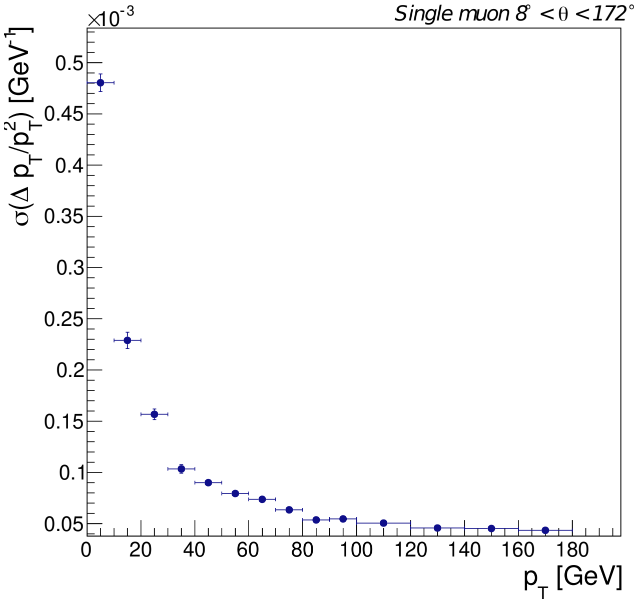


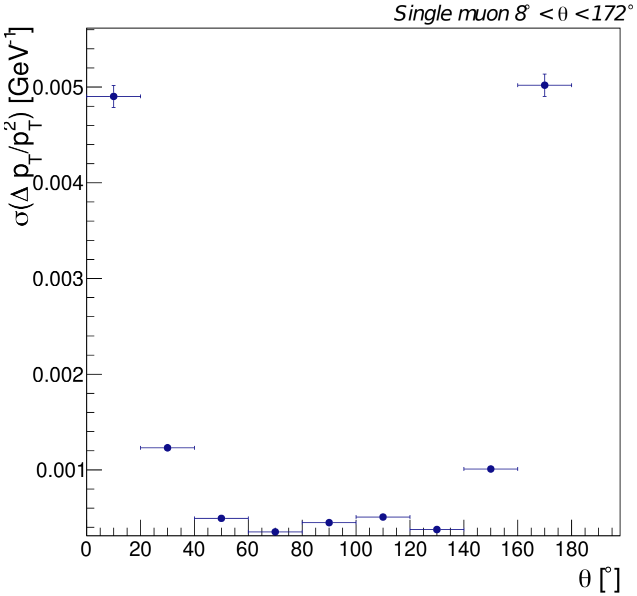
Muon reconstruction

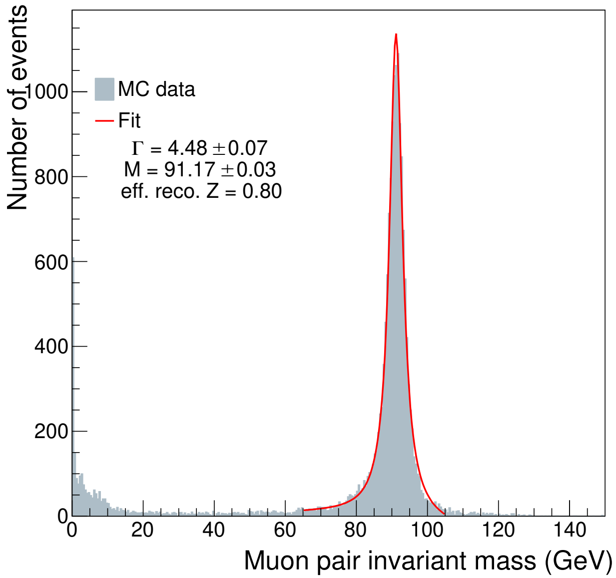
- The muon RPCs, installed in the outermost region of the detector, are only marginally affected by the beam-induced background.
- Bigger effects in the endcap regions closer to the beamline.

PV



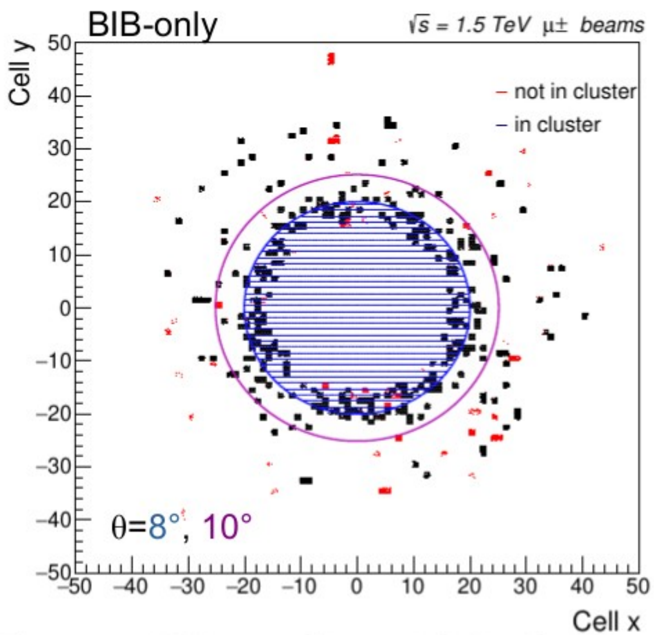


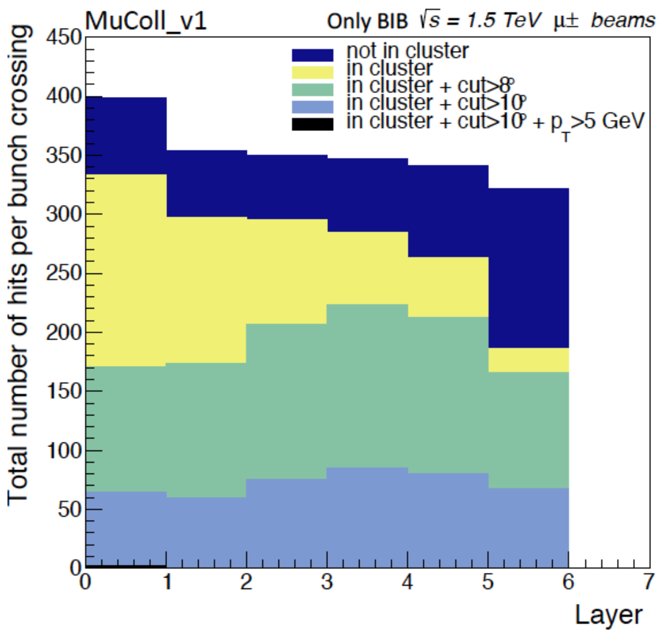




BIB effects on muon detectors

PV





BIB particles flux [Hz/cm^2] in different regions (bunch crossing time 10 μs):

Particle	Endcap (θ >12°)	Endcap (8° < θ < 12°)	Endcap (θ < 8°)	Barrel
neutrons	$1.2 \cdot 10^3$	$5 \cdot 10^4$	$1.2 \cdot 10^6$	$1.4 \cdot 10^2$
protons	16	$3 \cdot 10^2$	$2.4 \cdot 10^4$	----
photons	$6.2 \cdot 10^2$	$1 \cdot 10^4$	$7.2 \cdot 10^5$	5
e+ e-	3	$3.3 \cdot 10^2$	$5 \cdot 10^3$	< 1
μ+ μ-	3	$3.7 \cdot 10^2$	$1.2 \cdot 10^4$	----
pions, kaons	< 1	70	$1 \cdot 10^3$	----
Total	≈ 2 kHz/cm^2	≈ 60 kHz/cm^2	≈ 2 MHz/cm^2	≈ 200 Hz/cm^2

- Higher fluxes of hits from BIB particles in the endcaps, in particular in the region around the beamline.

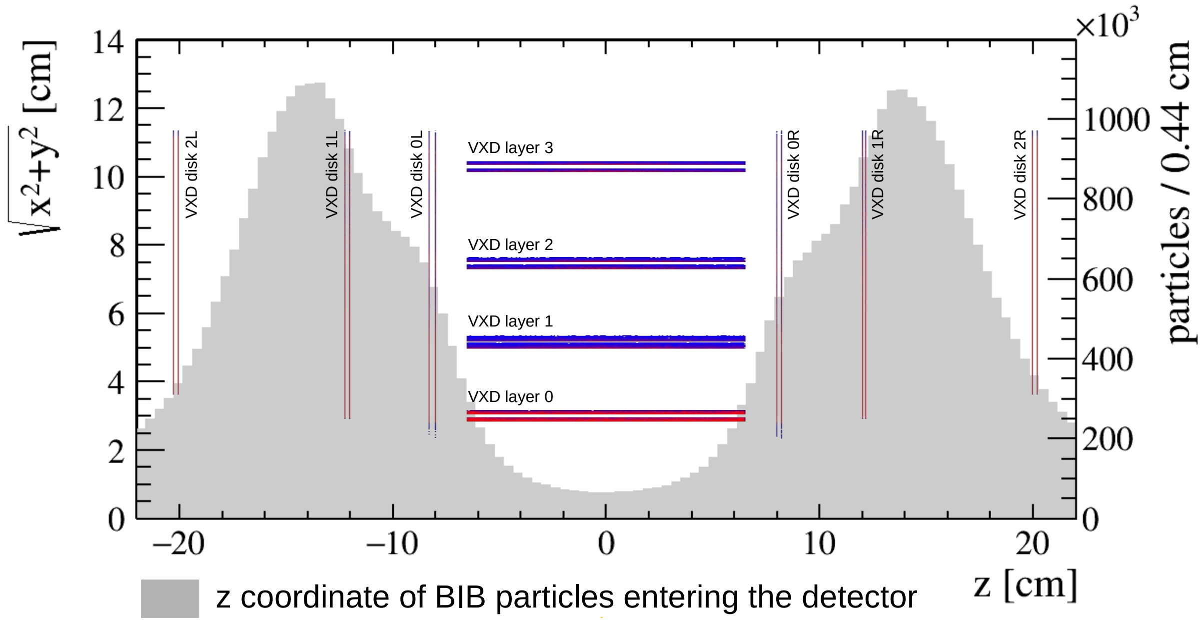
Other on-going activities

- Study of the channels: $H \to bb$, $H \to WW$, dark photon and ALP with a monophoton signature.
- Reconstruction performance of the secondary vertices and performance of the b-jet tagging.
- Optimization of the selection time windows for the tracker hits to maximize the acceptance for slow particles.

Backup slides

MAP's vertex detector

- MAP's VXD geometry:
  - the cylindrical layers of the vertex detector barrel are designed in such a way not to overlap with two BIB hot spots at z = ±15 cm around the interaction region.



Tracker hits from BIB

- Being the closest detector to the beamline, the tracker is affected the most by the BIB, which produces a huge number of spurious hits. If not mitigated, it could severely compromise:
  - the detector operations (too many data to be read out);
  - the track reconstruction performance (huge combinatorics).
- A big fraction of BIB particles reaches the detector out of time w.r.t. the bunch crossing ➔ exploit hit timing information.