A hybrid muon detector design with RPC and plastic scintillator for the experiment at the Super Tau-Charm Facility

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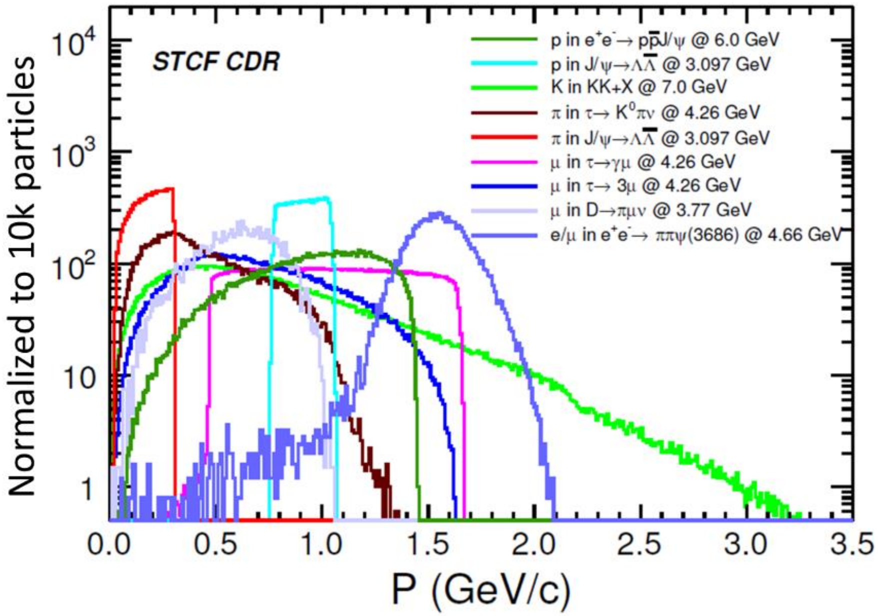
On behalf of the STCF detector working groups

Outline

1. **Introduction**
2. Detector design and optimization
3. Performance simulation
4. Summary

Requirements for MUD

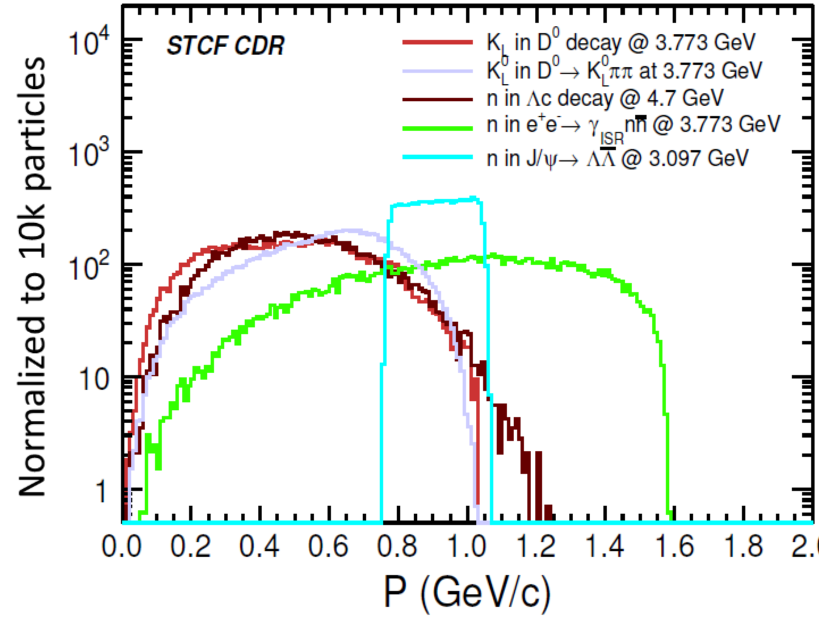
Muon identification



Major background: pion

Momentum range：0-2.0 GeV/c

Neutral hadron detection and identification



Major background: photon

Momentum range：~0.2-1.2 GeV/c

Requirements for MUD

MUD design requirements：

- High muon identification efficiency

  i.e.: 0.4 GeV/c<p<1 GeV/c：as high as possible

  p>1 GeV/c：ε>95%@97%pion rejection rate

- Auxiliary neutral hadron detector (to be a good support to ECAL)

- Good background tolerance, with $L=10^{35}$ /cm^2/s
- 1~2 cm spatial resolution
- High robustness, simple structure, acceptable cost with ~1000 m^2 area

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MUD alternative detector choice

Resistive Plate Chamber (RPC)

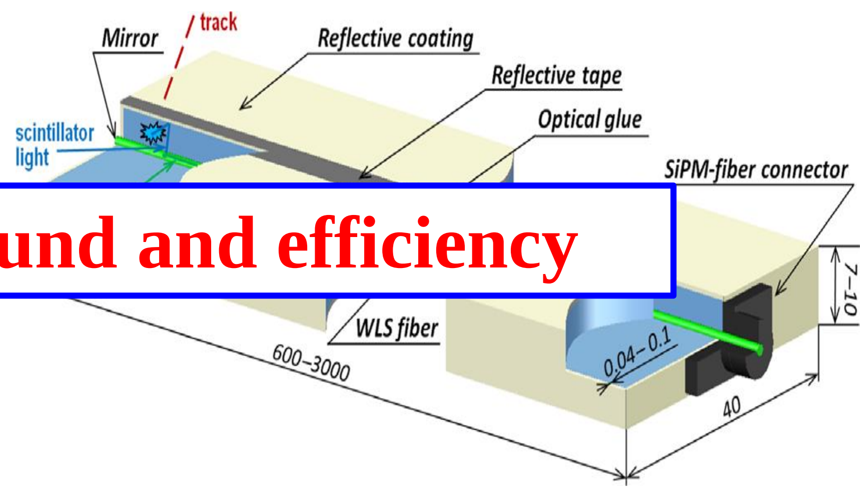
- **Low background interference**
- Low cost with large detection area
- Not sensitive to neutral particles
- Low rate capability for Glass-RPC

Plastic Scintillator detector

- **Sensitive to neutral particles**
- High rate capability
- Easy to maintain
- More background response

Parameter	Mode	**Bakelite-RPC**	**Glass-RPC**
Bulk Resistivity [Ω·cm]		10^{10}-10^{12}	>10^{12}
Mech perforn			
Rate capability [Hz/cm2]	Streamer	100@92%	
	Avalanche	**10 k**	**100**@95%
Noise rate [Hz/cm2]	Streamer	<0.8	0.05

Compromise: background and efficiency



STCF MUD background level

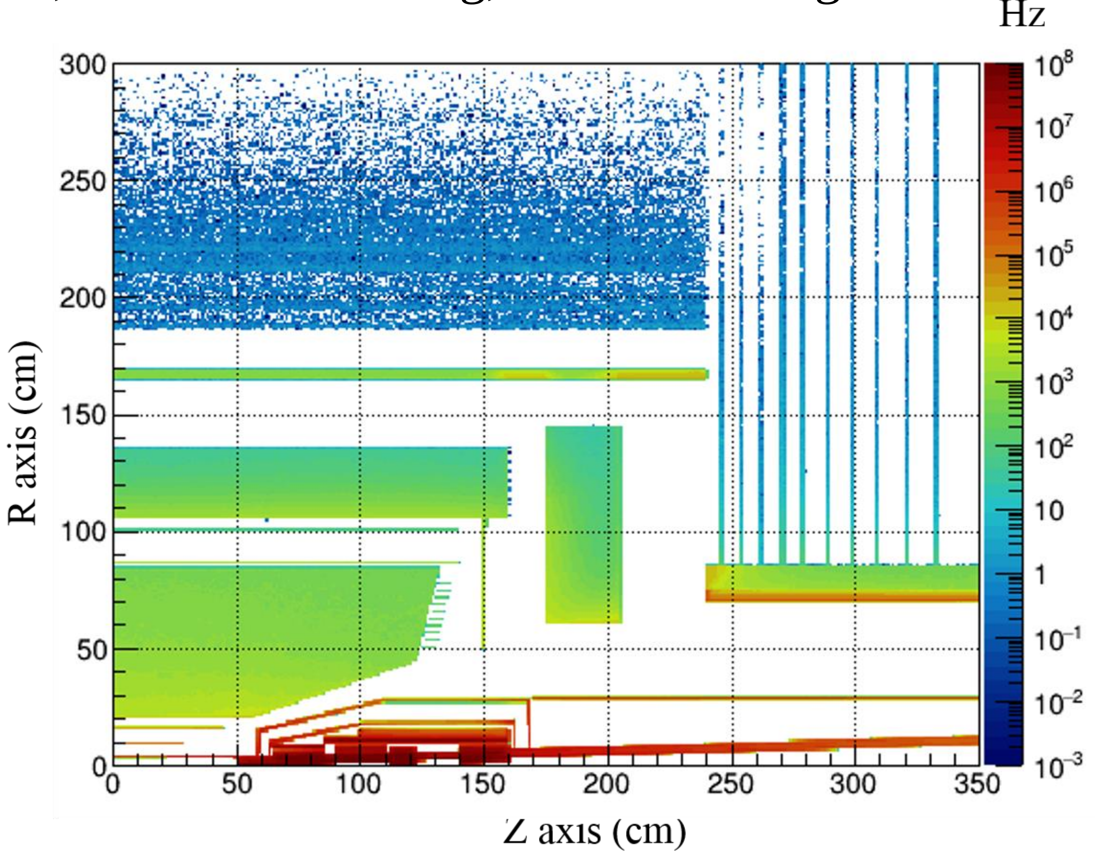
Full simulation on STCF background:

- RBB scattering, two-photon process
- Touschek effect, coulomb scattering, bremsstrahlung

- Background level:

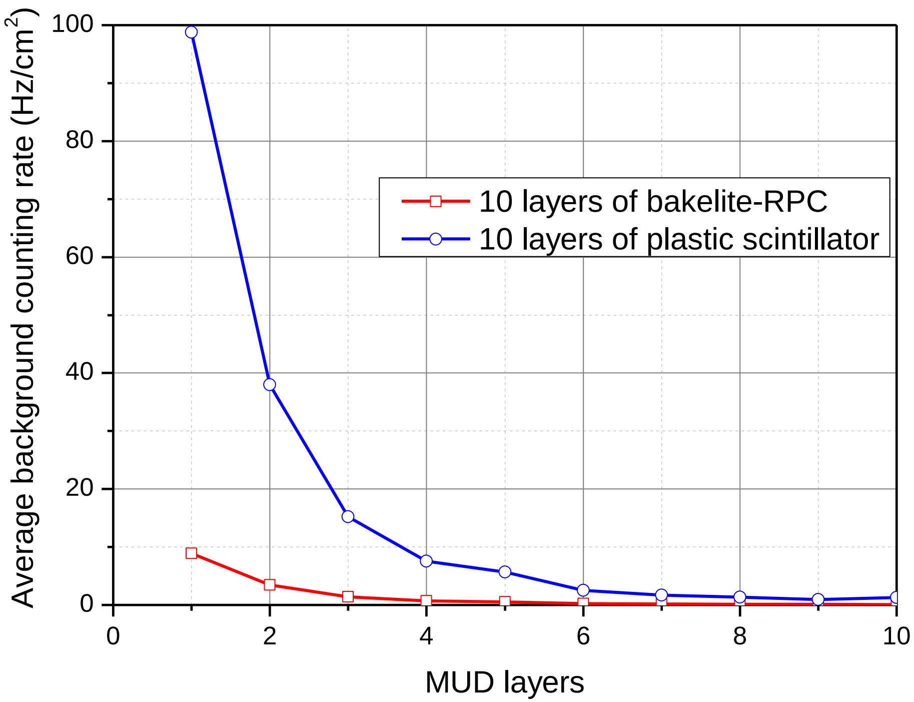
  ~10 Hz/cm^2 in Barrel

  ~40 Hz/cm^2 in Endcap

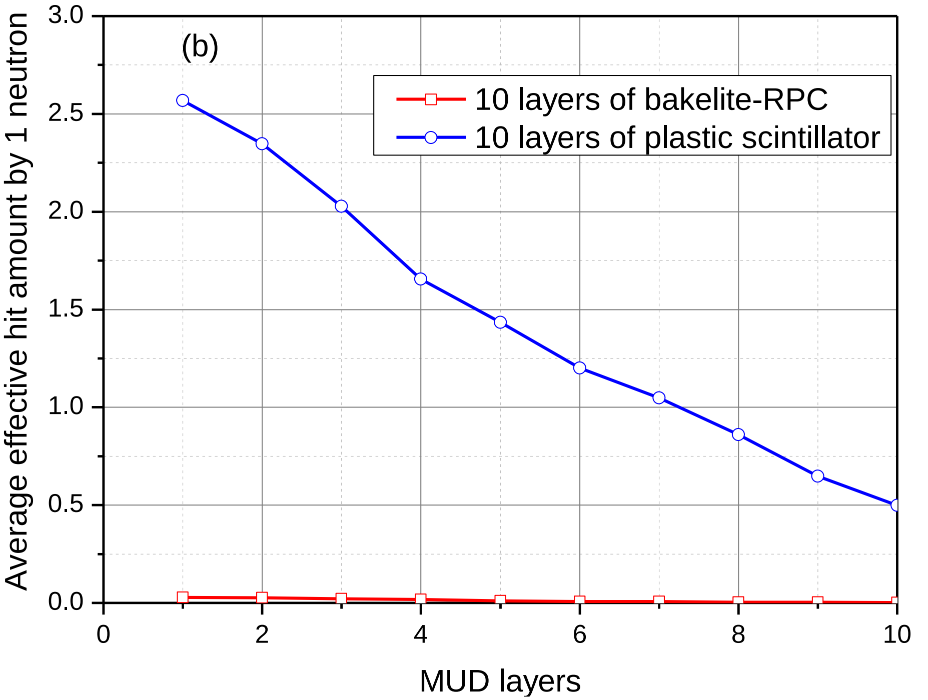


Detector response simulation

Background sensitivity simulations

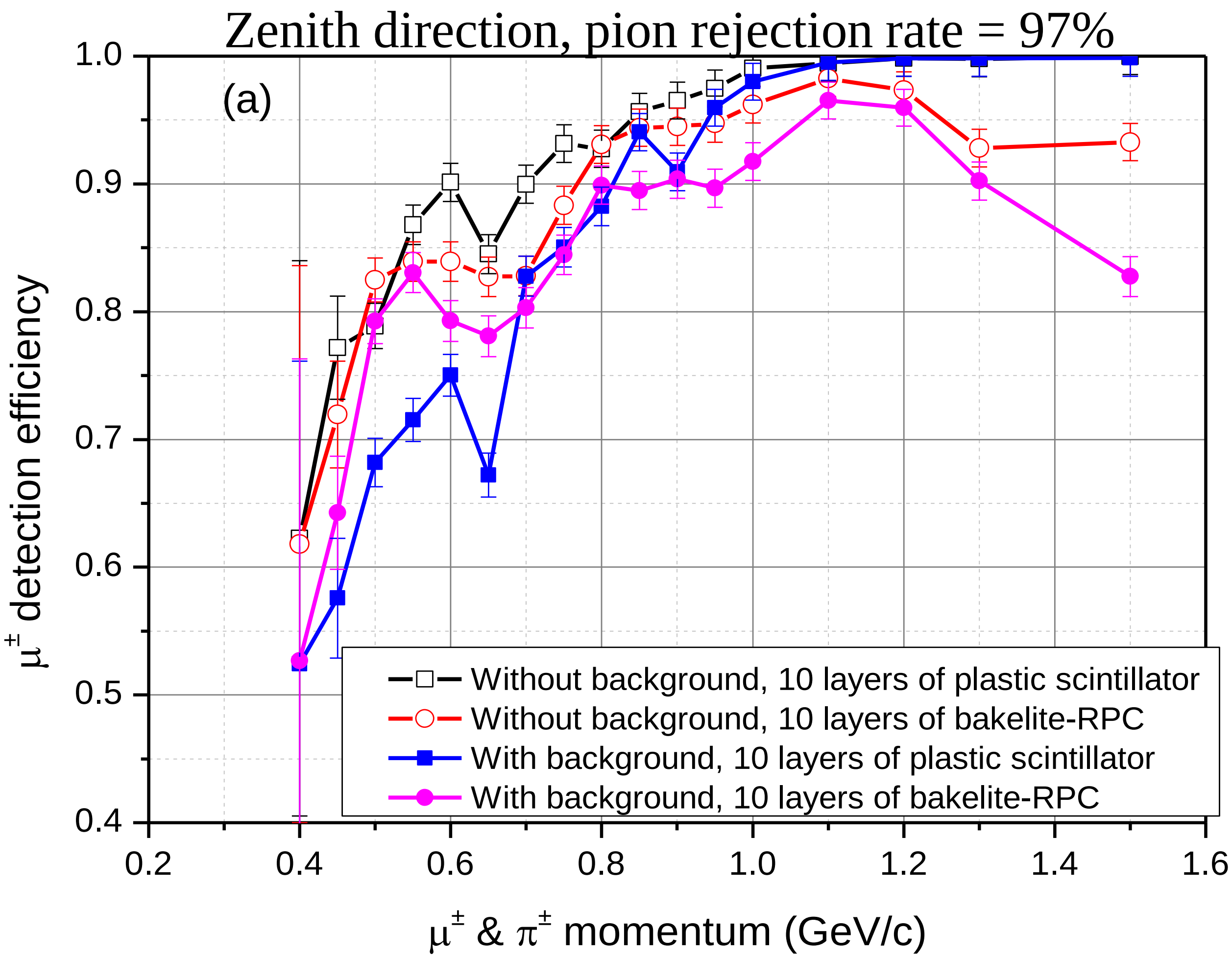


Neutron sensitivity simulations



- Scintillator-MUD has 10.7 times higher background counting rate.
- RPC-MUD merely has no neutron detection efficiency.

Detector response simulation

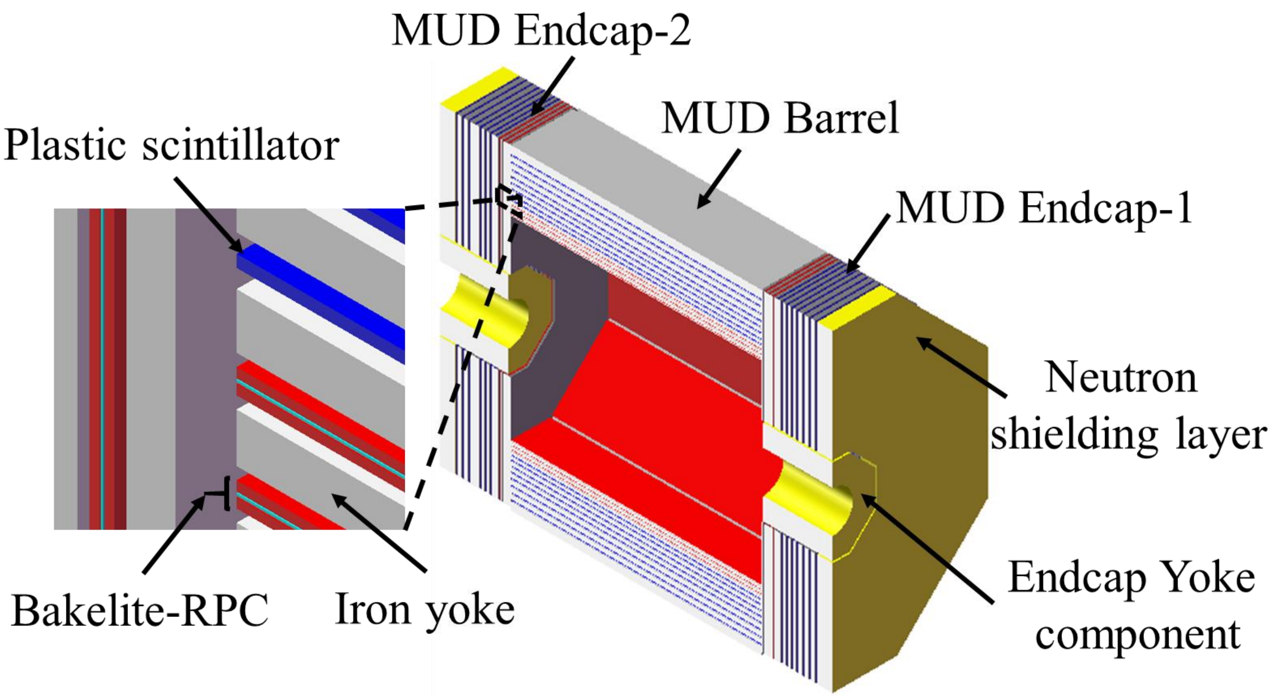


- Even with background removing algorithm, the muon detection efficiency with plastic scintillator is lower than bakelite-RPC with ~10% in range of [0.4, 0.7]GeV/c.

STCF MUD baseline design

STCF MUD:

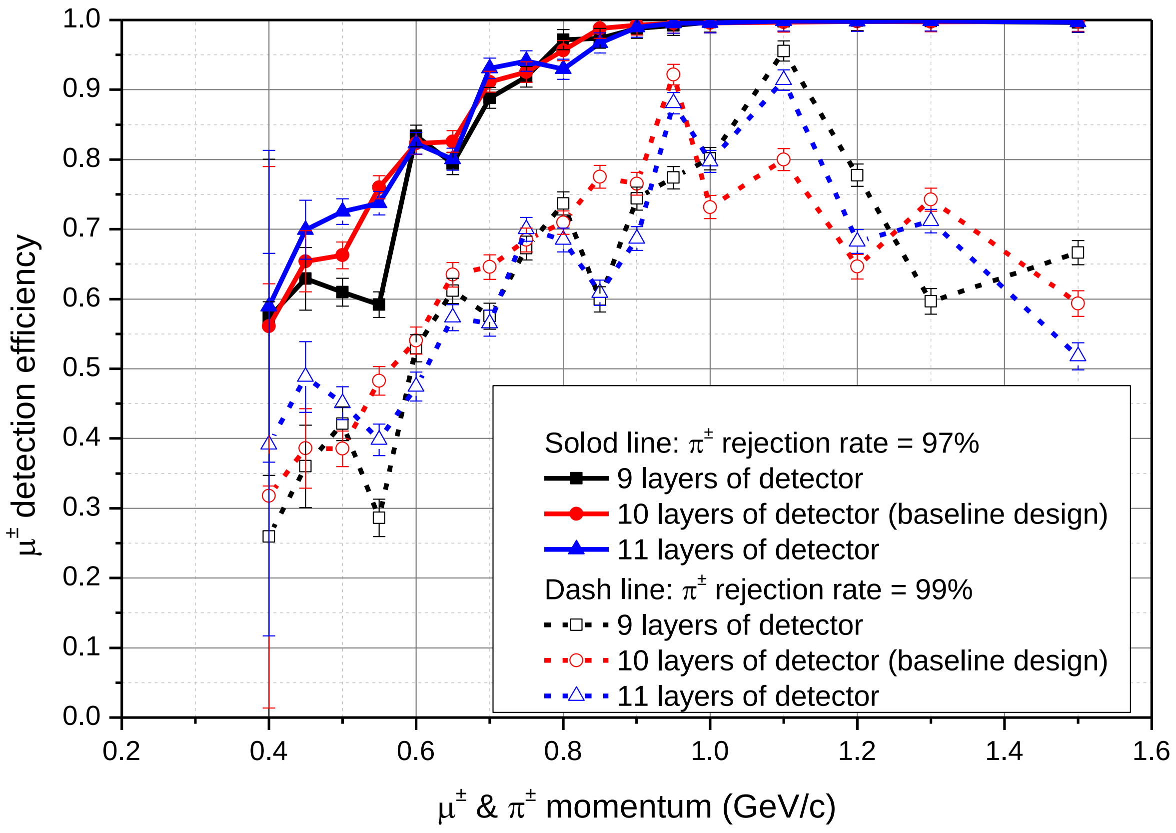
- **bakelite-RPC** in inner part
- **plastic scintillator** in outer part



Iron yoke and detector layers

Alternative:

- 50-60 cm thick iron
- More layers of detector
- Simple structure



Final choice:

- 51 cm thick iron
- 10 layers of detector in total

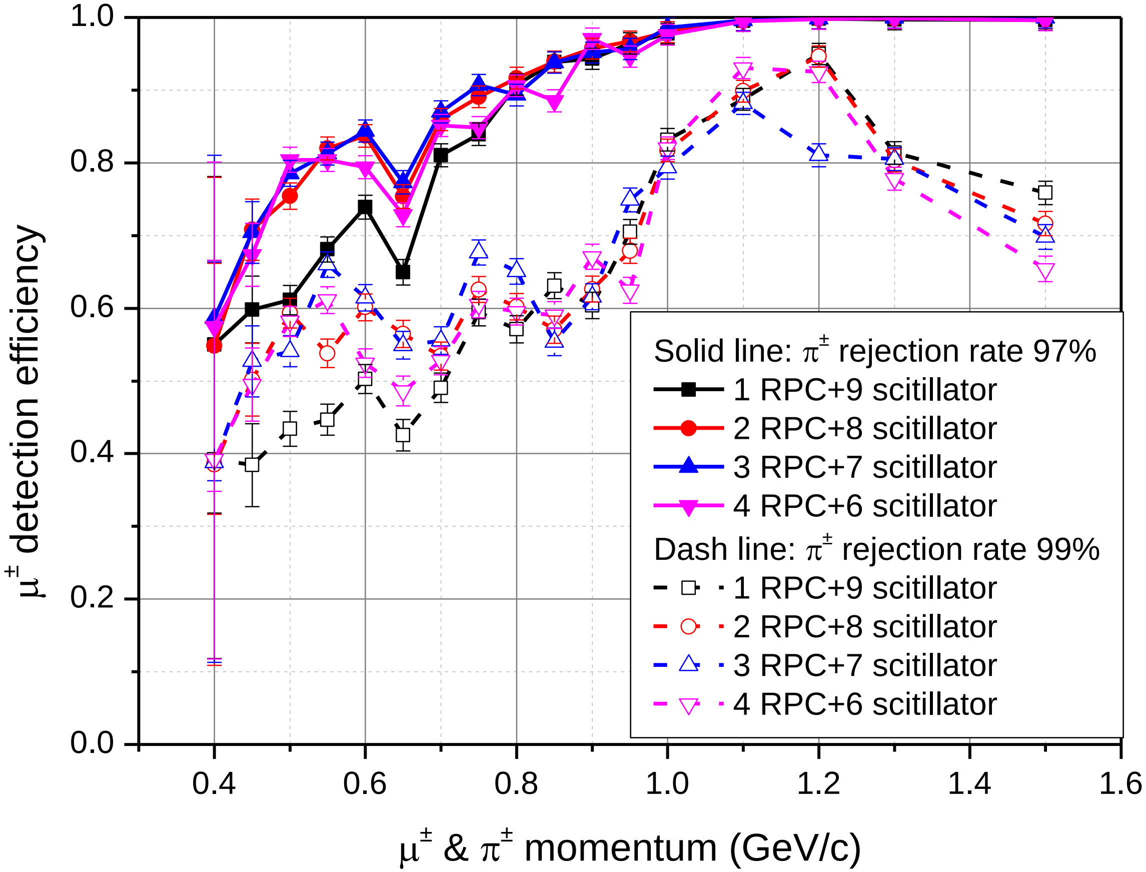
Arrangement of detectors

Alternative:

- 2-4 layers of bakelite-RPC
- 8-6 layers of plastic scintillator

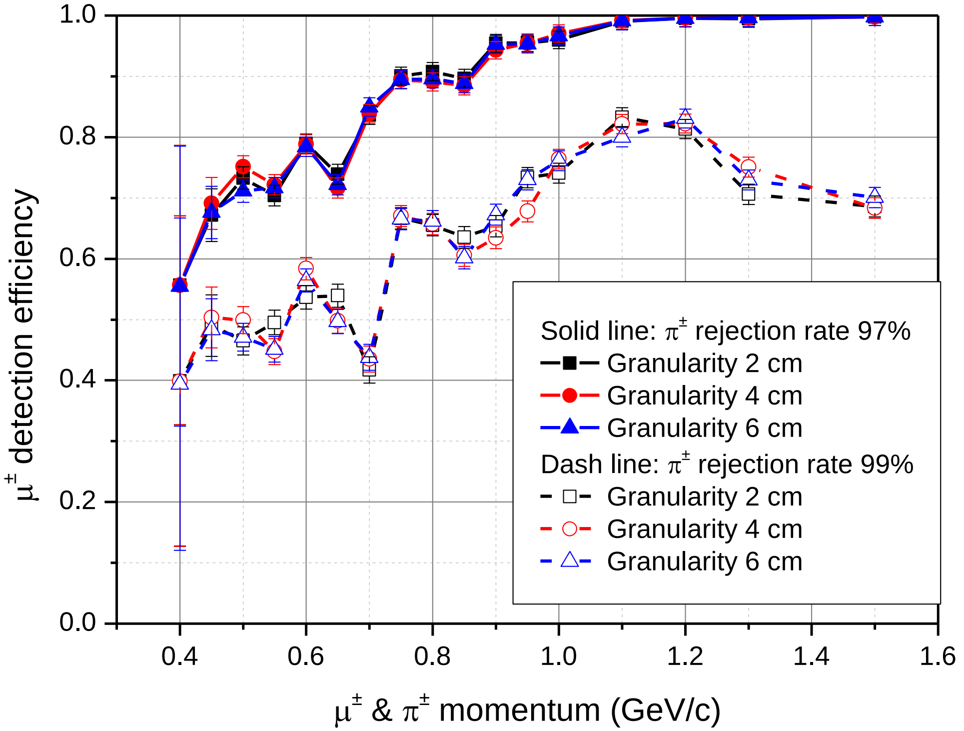
Final choice:

- 3 layers of bakelite-RPC
- 7 layers of plastic scintillator
- potential fluctuations in the background level or the future upgrades of STCF

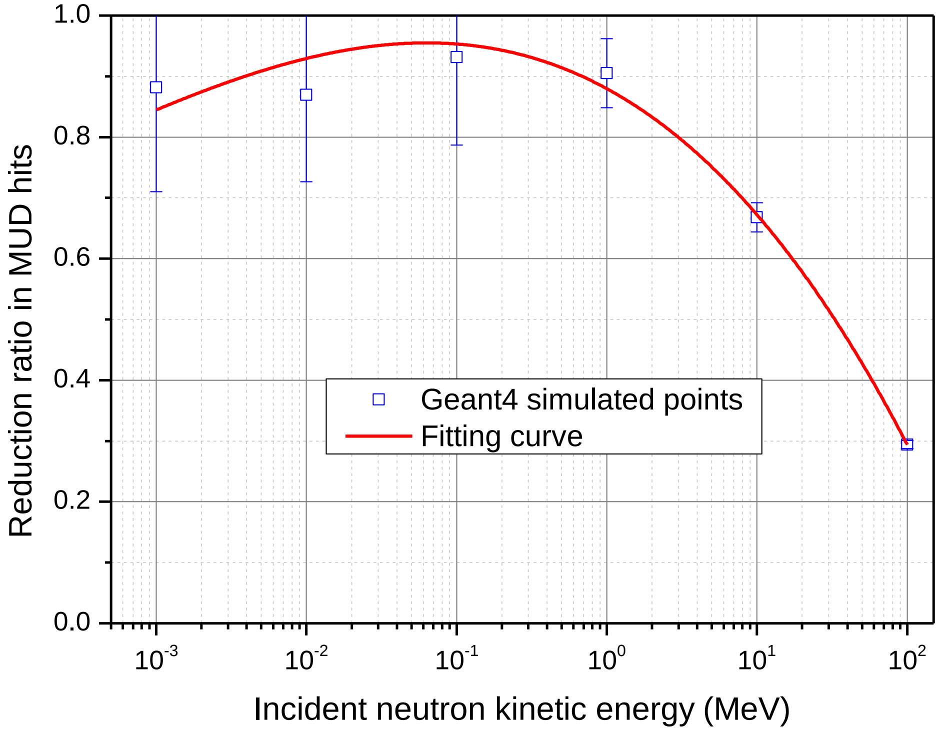


Detector granularity & neutron shielding

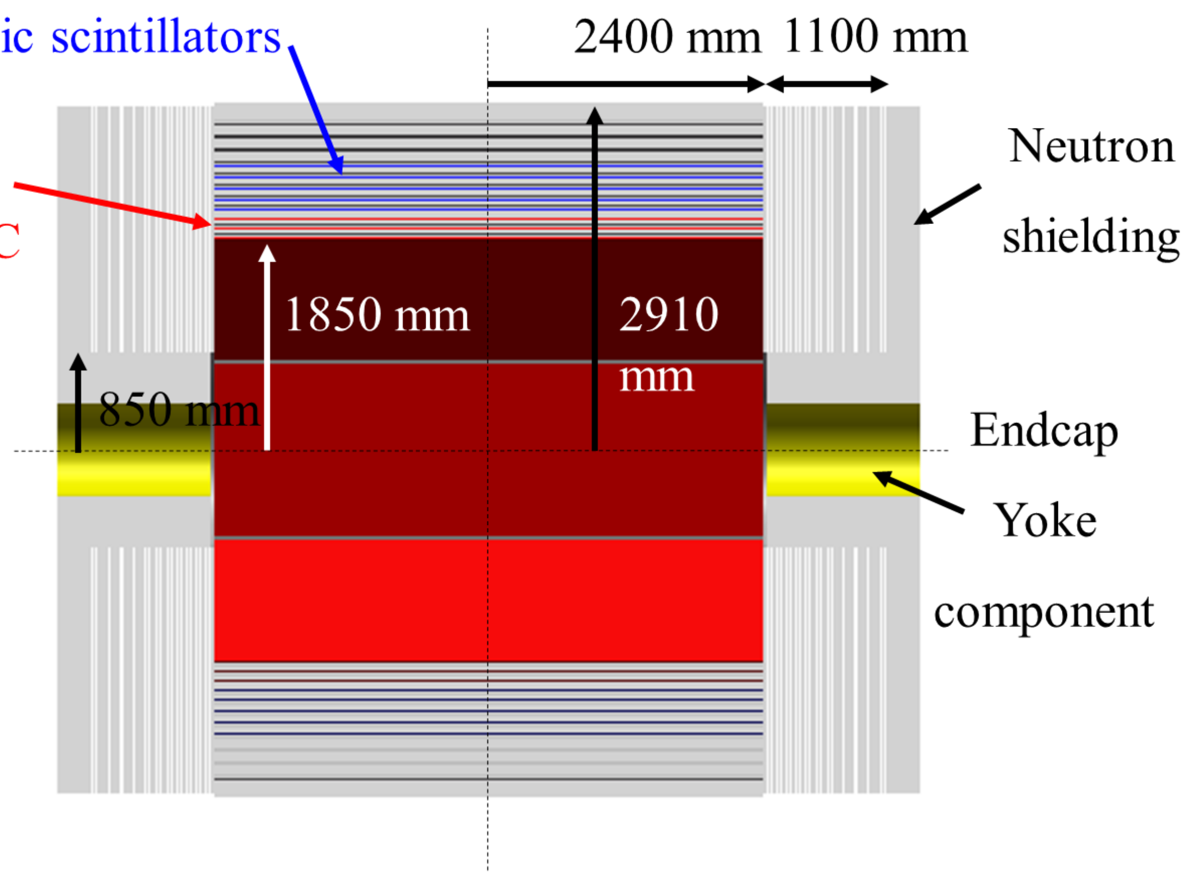
- 4 cm of bakelite-RPC strips and plastic scintillator width



- 5 cm lead and 10 cm boron-doped polyethylene (10 wt.% of ^{nat}boron)



STCF MUD conceptual design



Detector layer	**10**	Occupancy	94% × 4π in total
Yoke thickness[cm]	**4/4/4.5/4.5/6/6/6/8/8**	Detection area [m^2]	~1237 in total
(λ=16.77 cm)	Total: 51 cm, 3.04 λ		

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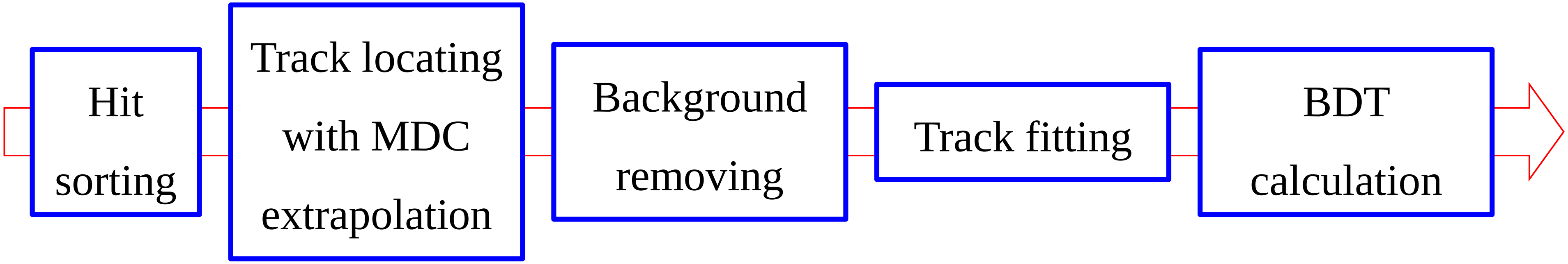
Muon identification

- Mainly focused on muon with momentum in range **[0.4 GeV/c, 1.5 GeV/c]**
- Using BDT algorithm with **14 variables** (size and shape parameters of track)
- The MUD hits should be identified as **track** first (be matched with MDC/ECAL hits)



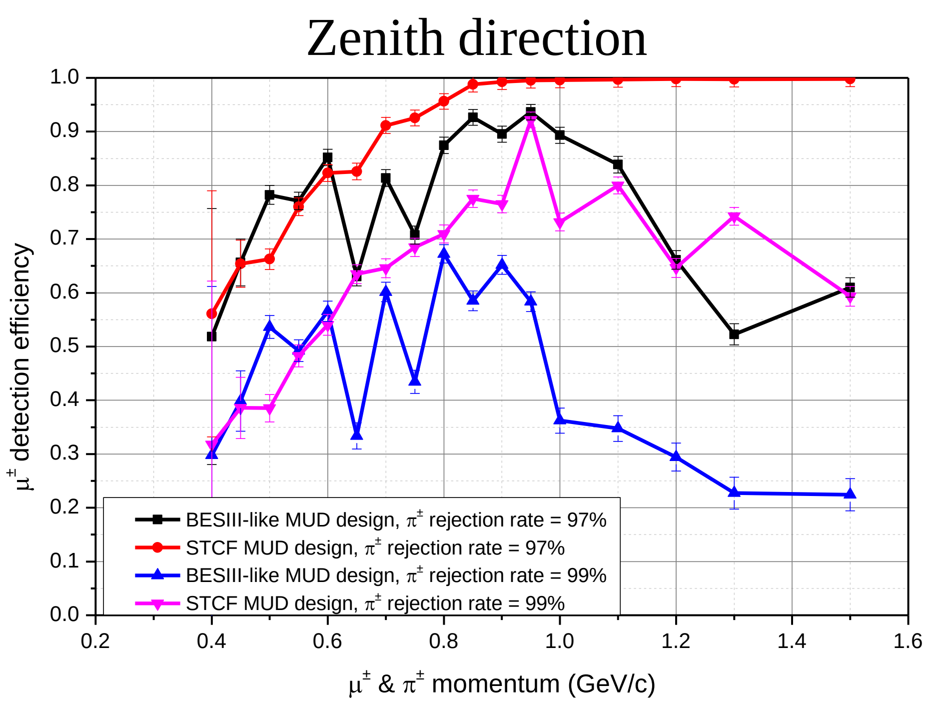
BDT variables definition

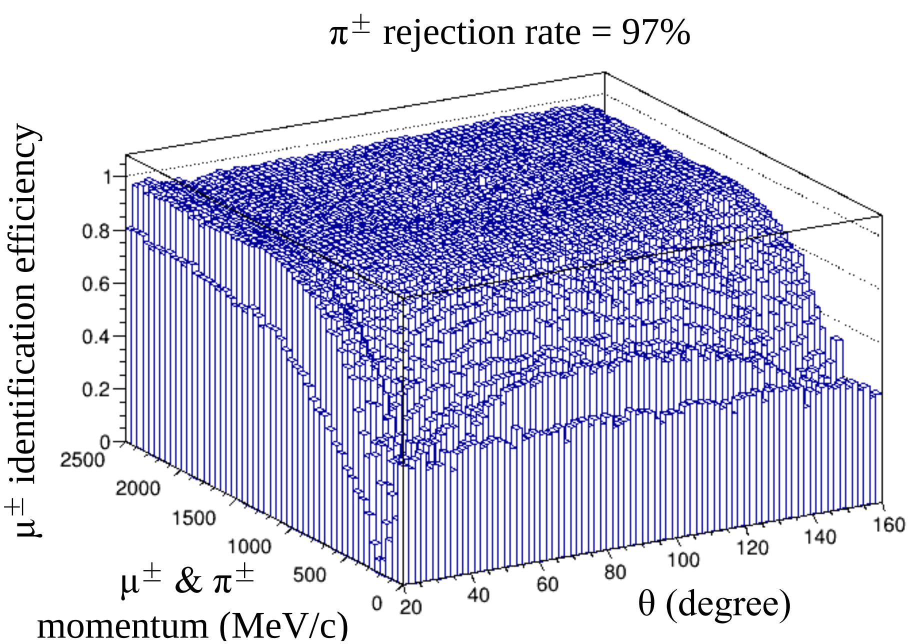
Parameter	Definition
E_{ecal}	Energy deposited in ECAL
$L_{distancetoip}$	Distance from track's last hit to IP
T_{time}	Detected time of track in the first detector layer
$N_{maxhitlayer}$	Layer number that has the maximum hits
$N_{lastlayer}$	Layer number that has the last hit
$L_{meandistance}$	Mean distance from each two neighborhood hits in the track
$N_{totalhit}$	Total hit amount in 10 layers of detector
$N_{first3hit}$	Hit amount in the first 3 layers of detector
$N_{last7hit}$	Hit amount in the last 7 layers of detector
$N_{noisthit}$	Hit amount that was identified as background
A_{theta}	Reconstructed polar angle of the track in R-Z plane
A_{phi}	Reconstructed azimuth of the track in X-Y plane
Q_{tc}	Reconstructed type of hits (track, cluster, single point)
Q_{track}	Quality of the track

Muon identification simulations

Zenith direction:

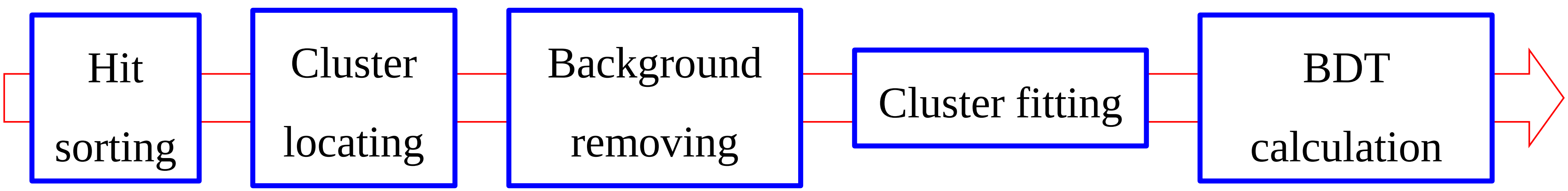
- 0.7 <p<0.8 GeV/c： ε>90%@97%pion rejection rate
- p>0.8 GeV/c： ε>95%@97%pion rejection rate





Neutral hadron identification

- Mainly focused on neutron/KL with momentum **[0.2 GeV/c, 1.2 GeV/c]**
- Using BDT algorithm with **24 variables** (size and shape parameters of MUD cluster, shape of ECAL cluster)
- The MUD hits should be identified as **cluster** first (no corresponded hits in MDC, few energy deposit in ECAL)



- ~30% of neutron won't get showed in ECAL
- ~40% of neutron deposits few energy in ECAL (<10 MeV, including 0)

MUD focuses on these neutral hardon

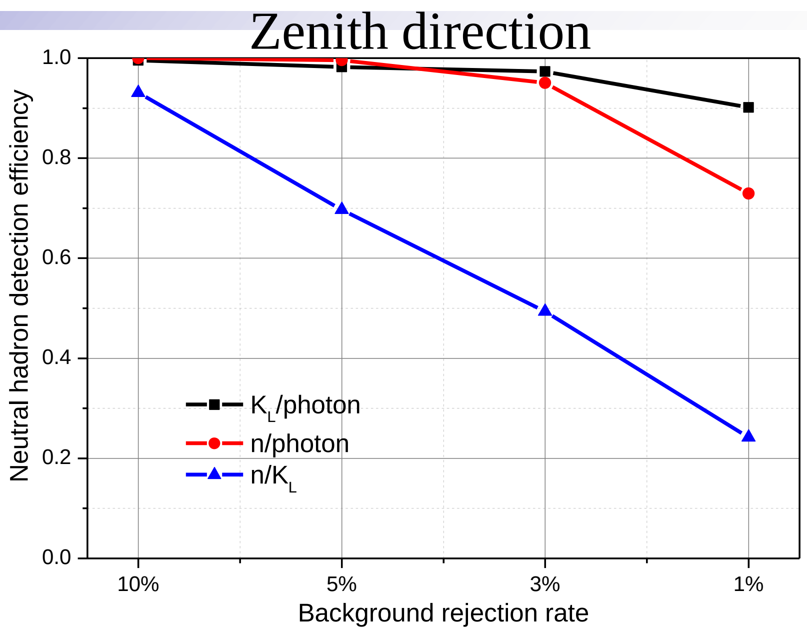
BDT variables definition

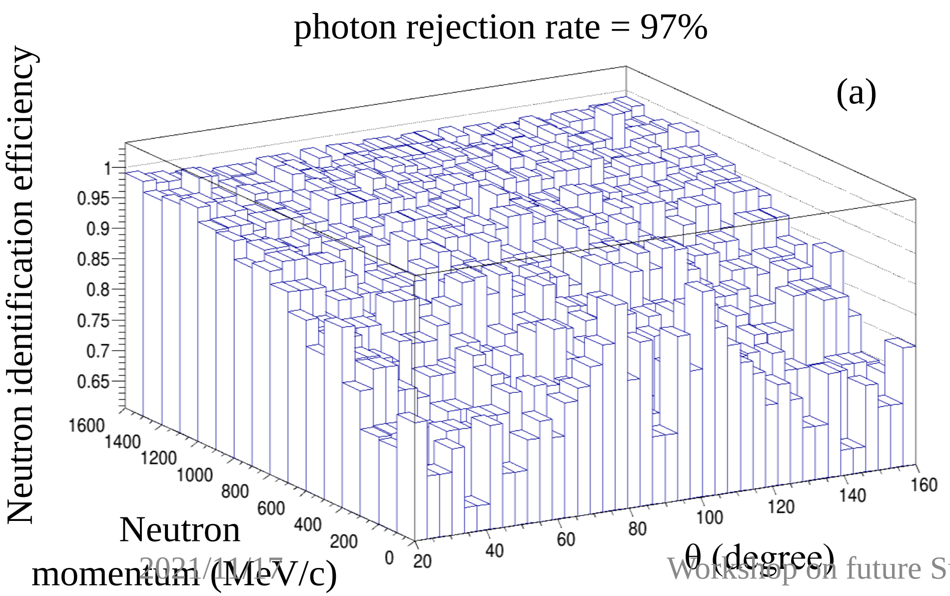
Parameter	Definition
E_{ecal}	Energy deposited in ECAL
$L_{distancetoip}$	Distance from cluster's last hit to IP
T_{time}	Detected time of cluster in the first detector layer
$N_{maxhitlayer}$	Layer number that has the maximum hits
$N_{lastlayer}$	Layer number that has the last hit
$L_{meandistance}$	Mean distance from each two neighborhood hits in the MUC cluster
$N_{totalhit}$	Total hit amount in 10 layers of detector
$N_{first3hit}$	Hit amount in the first 3 layers of detector
$N_{last7hit}$	Hit amount in the last 7 layers of detector
$N_{noisthit}$	Hit amount that was identified as background
$N_{scintillatorcenter}$	The mean layer number of scintillator hits
$N_{belowscintillatorcenter}$	Scintillator hit amount that below the center of all the scintillator hits
$L_{meanscintillatordistance}$	Mean distance from point of scintillator hit to the center of scintillator hits
$L_{stdscintillatordistance}$	Standard deviation of distance from point of scintillator hit to the center of scintillator hits
N_{mdc}	Hit amount in MDC
Necal	Hit amount in ECAL
Q_{tc}	Reconstructed type of hits (track, cluster, single point)
$R_{1/3}$	ECAL energy deposited ratio between maximum crystal and 3×3 array
$R_{1/5}$	ECAL energy deposited ratio between maximum crystal and 5×5 array
$R_{2/3}$	ECAL energy deposited ratio between 2×2 and 3×3 array
$R_{2/5}$	ECAL energy deposited ratio between 2×2 and 5×5 array
$R_{3/5}$	ECAL energy deposited ratio between 3×3 and 5×5 array
SOM3	Second-order moment of energy deposition in the 3×3 ECAL crystal array
SOM5	Second-order moment of energy deposition in the 5×5 ECAL crystal array

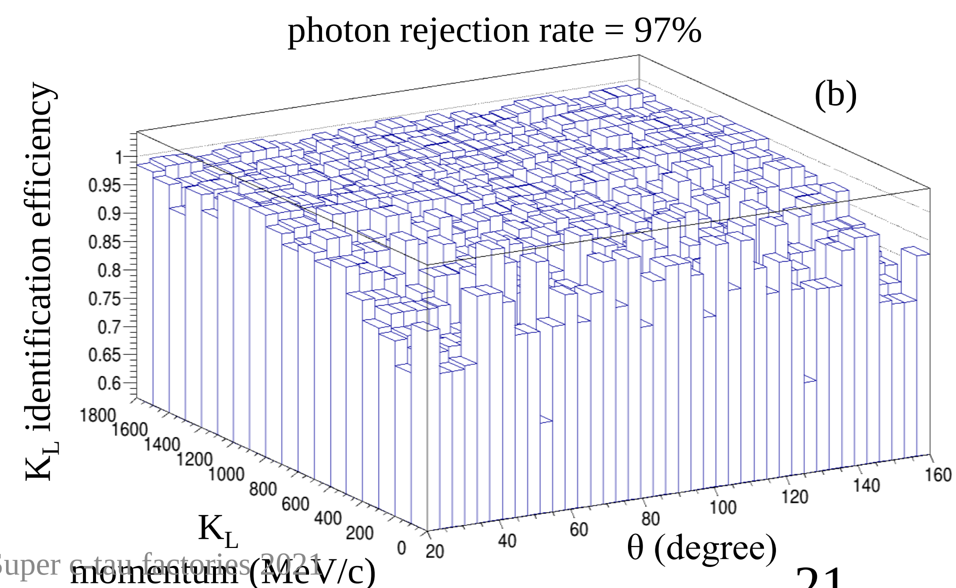
Neutral hadron identification

- If neutrons survive after penetrating the ECAL (or depositing a small amount of energy in the ECAL):

average ε>95%@97%photon rejection rate

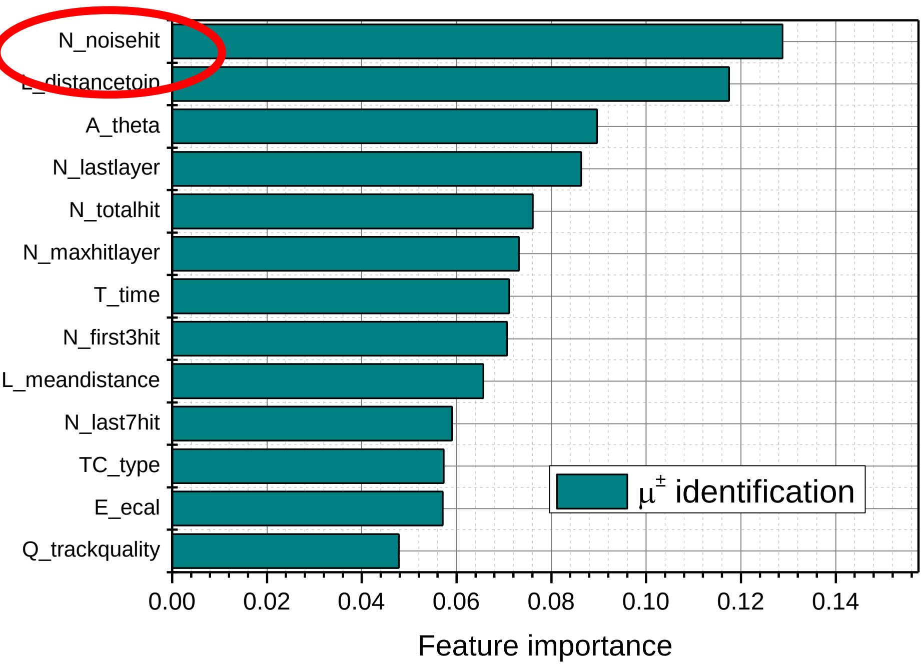




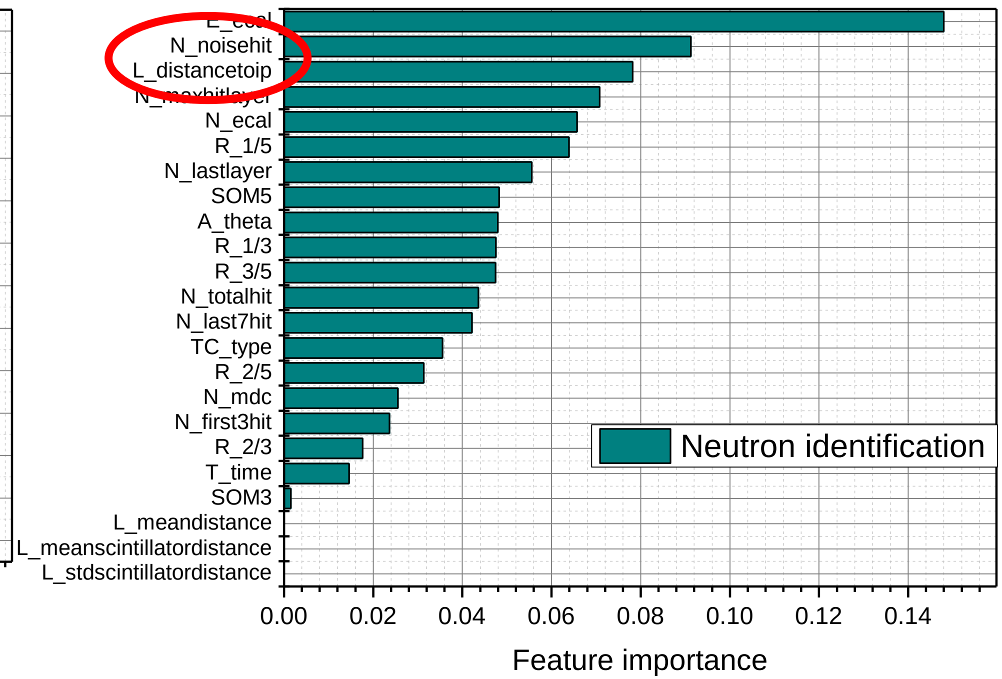


BDT parameter feature importance

Muon identification



Neutral hadron identification



- Hit amount that was identified as background
- Distance from track's last hit to IP

Outline

Summary

A hybrid MUD design is researched for STCF:

- **3 layers of bakelite-RPC and 7 layers of plastic scintillator**
- Parameters are optimized: iron thick, detector layer number and layout, detector granularity, and neutron shielding layer
- Muon identification efficiency: p>0.8 GeV/c, ε>95%@97% pion rejection rate
- Neutral hadron identification efficiency: ε>95%@97% photon rejection rate & low E_{dep} in ECAL

THANKS FOR YOUR ATTENTION