Simulation of μRWELL-based cylindrical inner tracker for Super Tau-Charm Facility (STCF)

USTC

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On behalf of the STCF detector working groups

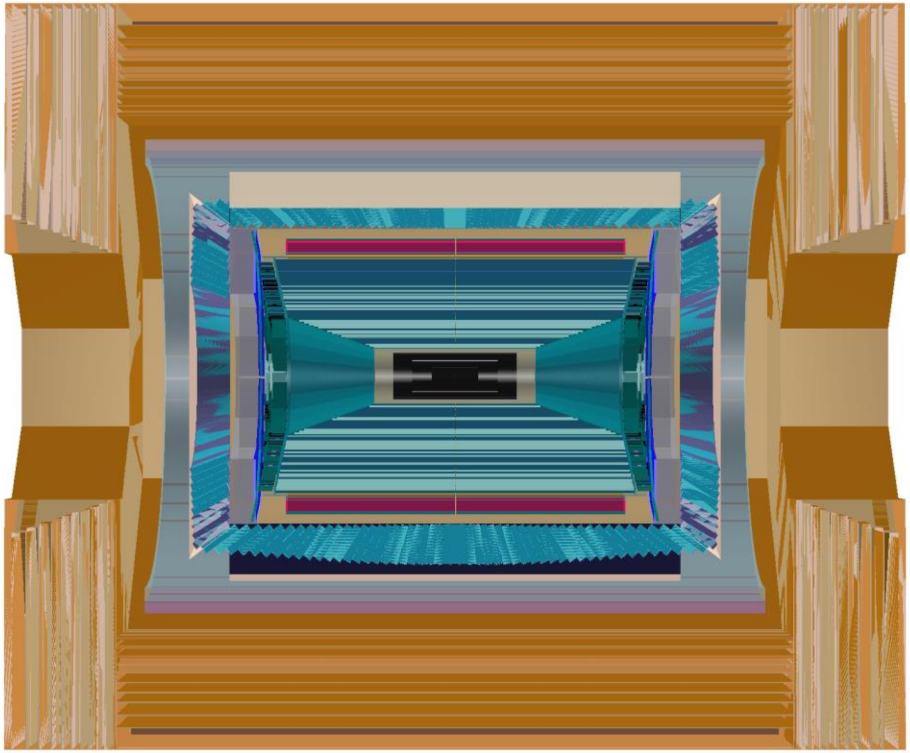
Outline

1. STCF detector system
2. μRWELL-based cylindrical inner tracker for STCF
3. Detector optimization research
4. Multi-hit reconstruction and spatial resolution simulation
5. Discussion and conclusion

Overview: STCF

Super Tau-Charm Facility:

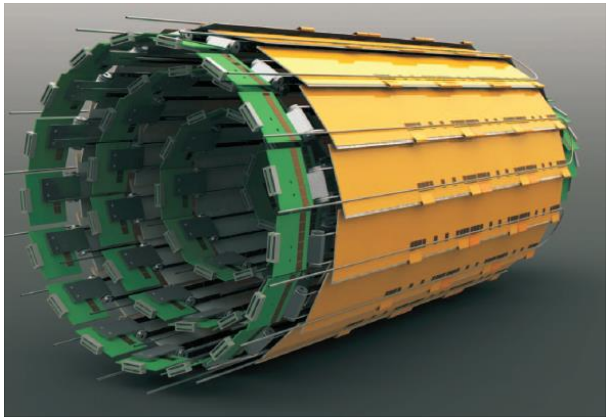
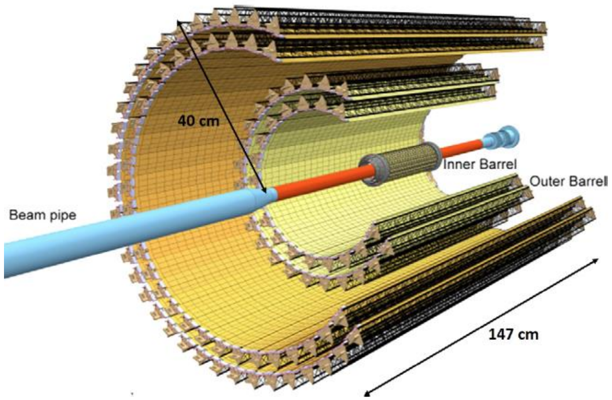
- Newly designed e^-e^+ collider
- Luminosity: 0.5×10^{35} /cm^2/s
- Center of mass energy region: 2-7 GeV/c



Detector system:

- **Inner tracker**
- Main drift chamber
- Particle identifier
- Electromagnetic calorimeter
- Muon detector

Alternative inner trackers

Silicon pixel detector	Silicon strip detector	MPGD
		

Silicon pixel detector

Advantages:

- Low material budget (0.15-0.2% X/X_0)
- High counting rate capability

Disadvantages:

- Limited detector size

Silicon strip detector

Advantages:

- Large detection area
- High counting rate capability

Disadvantages:

- Medium-high material budget (0.5%-1% X/X_0)

MPGD

Advantages:

- Large detection area

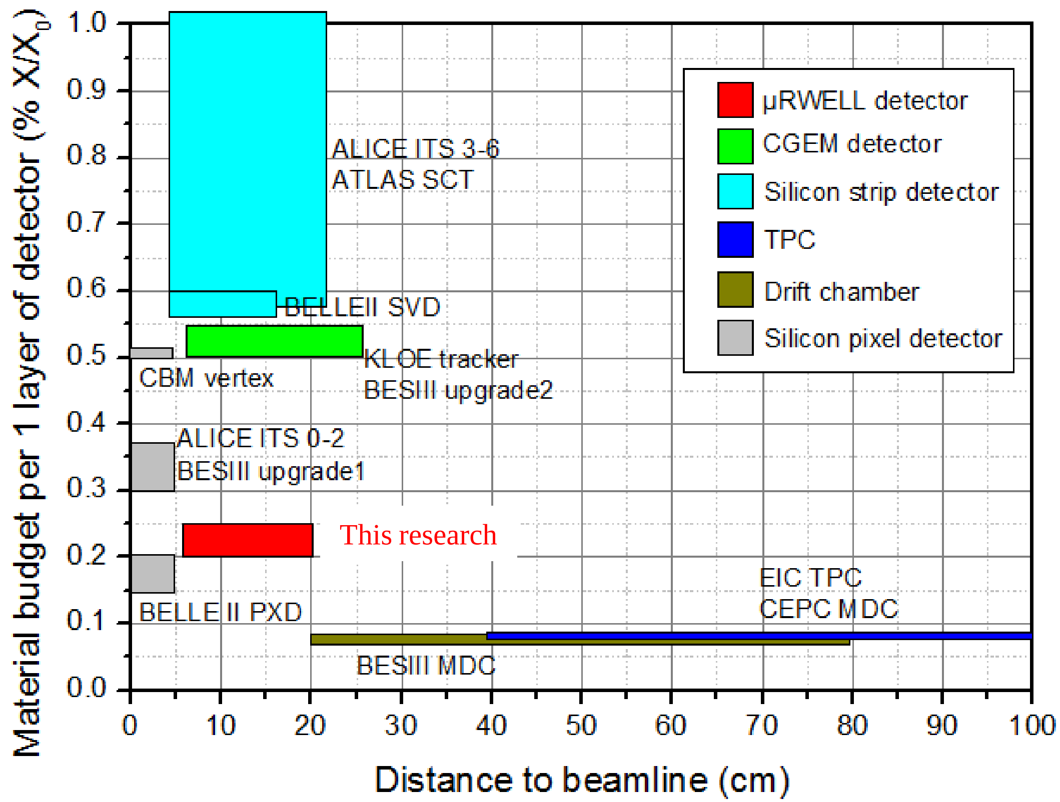
Disadvantages:

- Medium material budget (0.5%-0.6% X/X_0)
- Complex detector structure

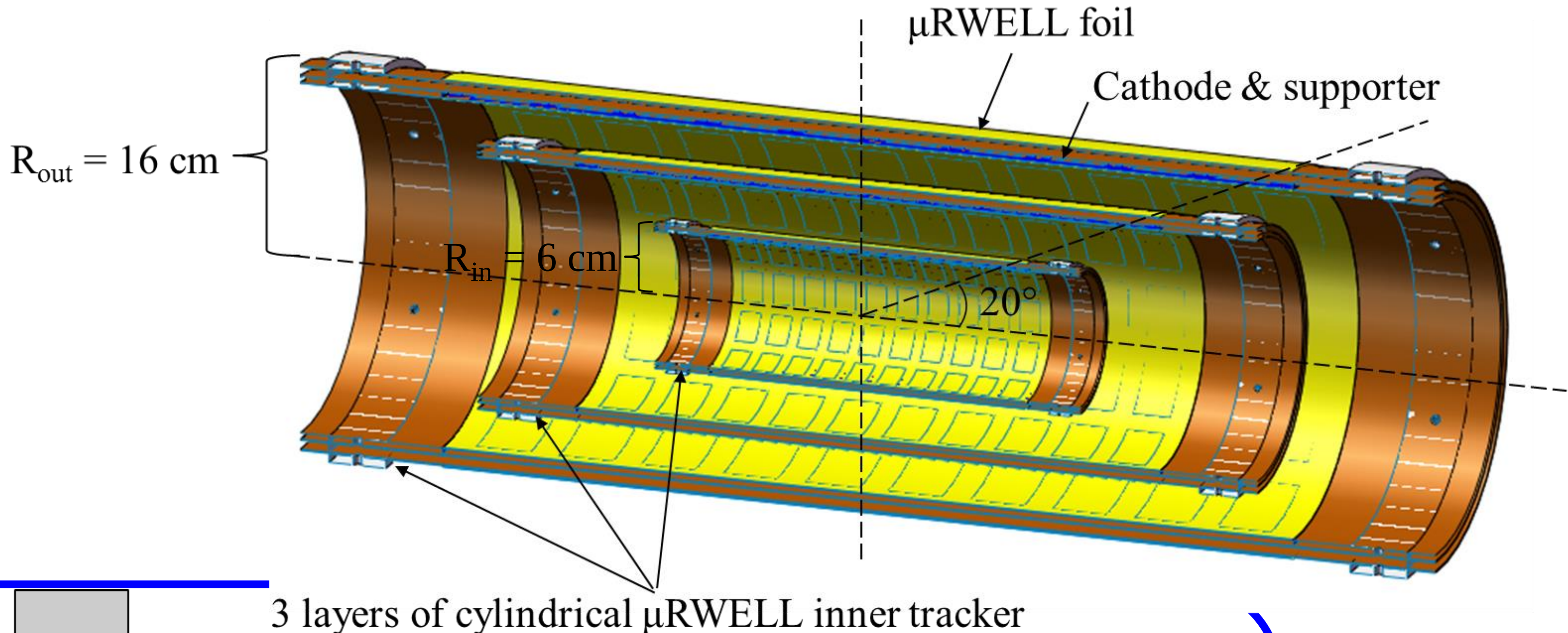
μRWELL-based cylindrical inner tracker

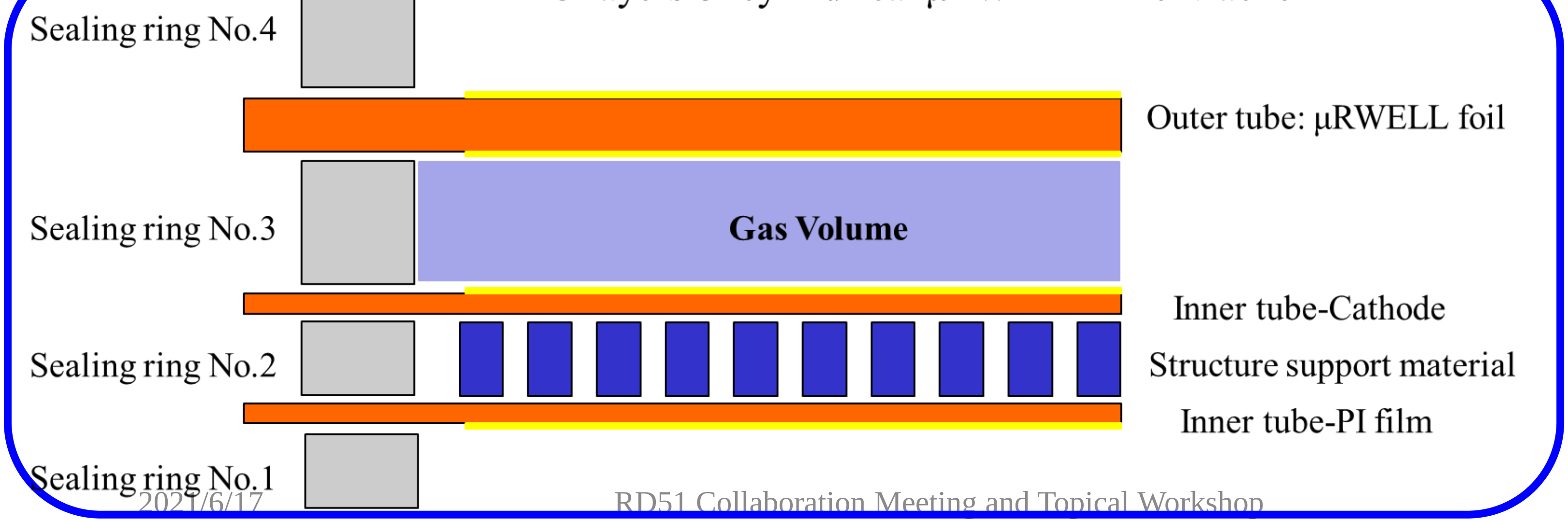
μRWELL detector

- **Low material budget**
  (below 0.25% X/X_0)
- **Good spatial resolution**
  (~ 60 μm)
- **High counting rate capability**
- **High radiation hardness**



Detector design





Detector optimizations

Optimization aspects	Influenced performance
• Detector structure • Gas component • Working point • Readout design	• Structural strength • Material budget • Spatial resolution • Occupancy

Geant4 & Garfield++ simulations

Parameters: spatial resolution

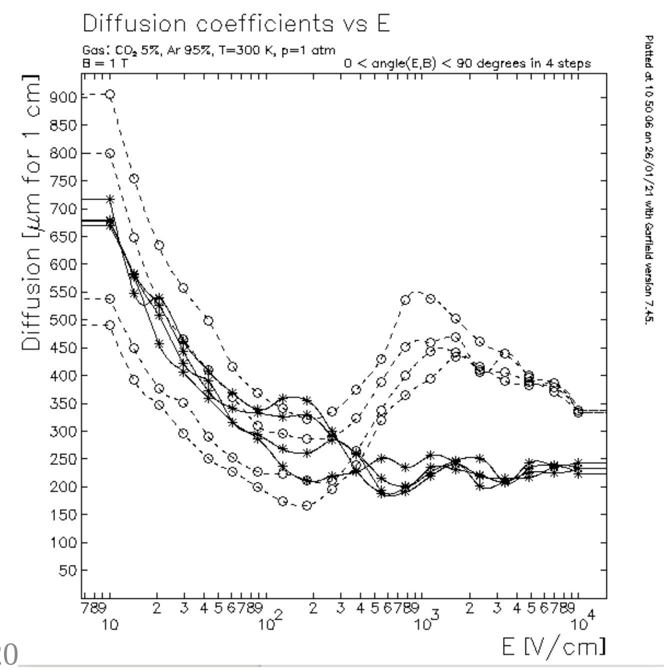
Due to the 1 T magnetic field in Z direction, situations are different:

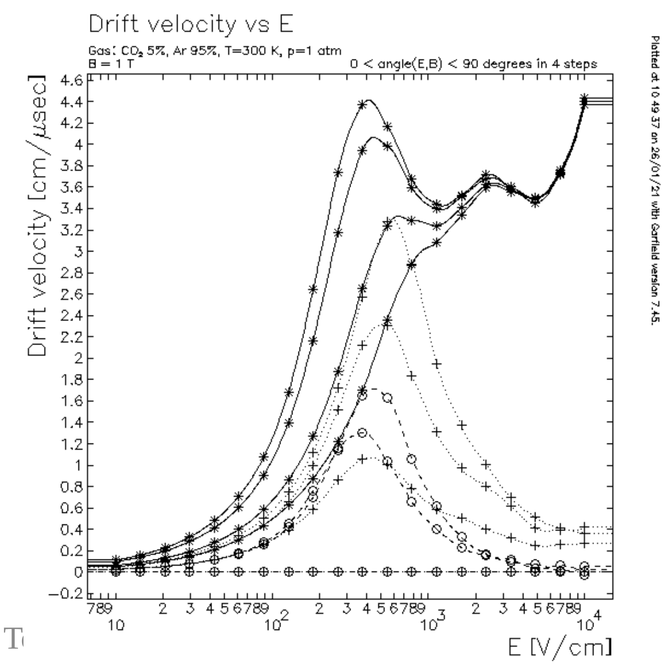
- Electron drift velocity
- Transverse & longitude diffusion coefficients
- Lorenz angle
- …

Gas volume width

Gas component

Drift electric field strength



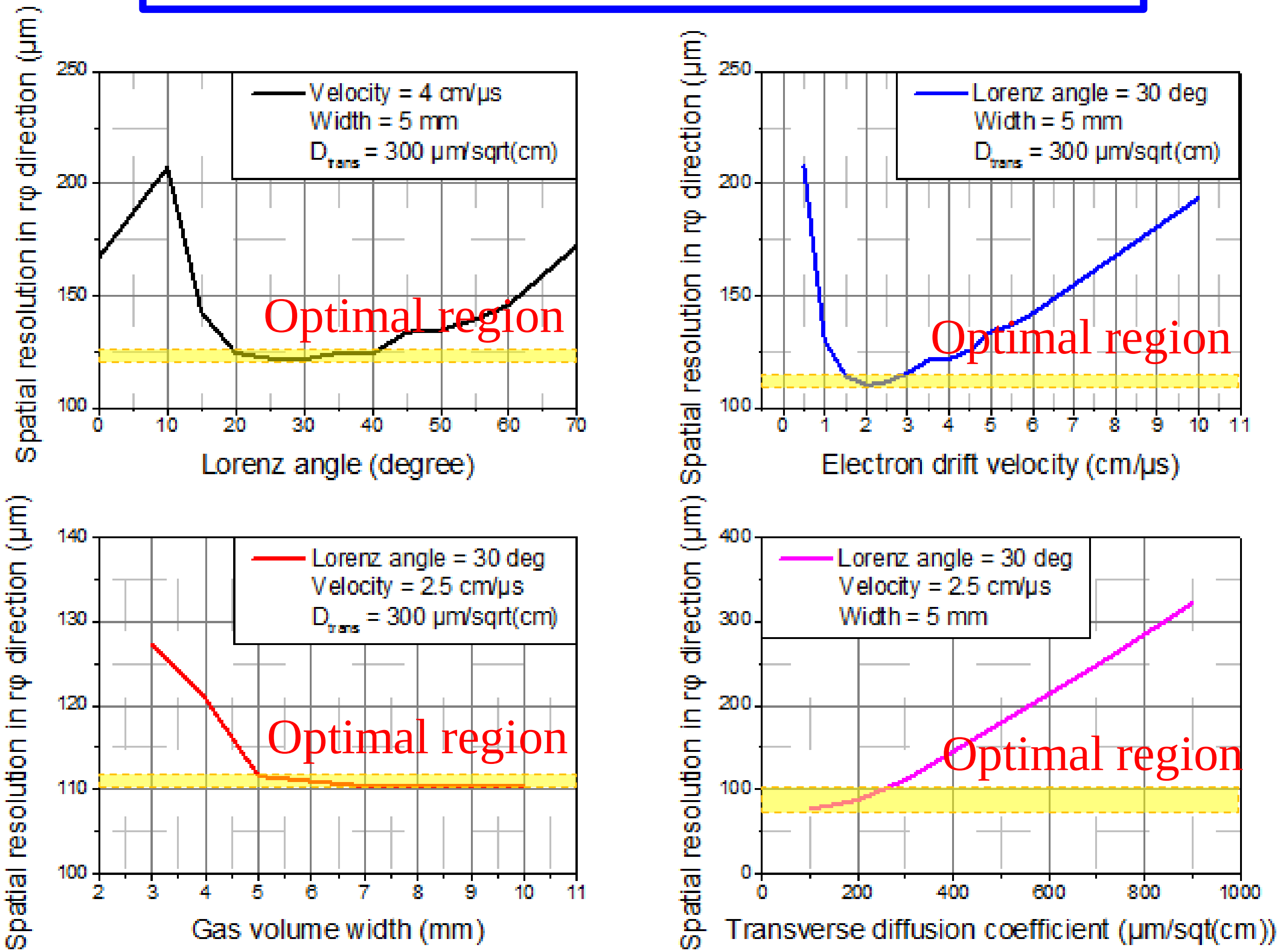


Ideal parameters simulation

Gradient descent method in multi-dimensions

Optimal region:

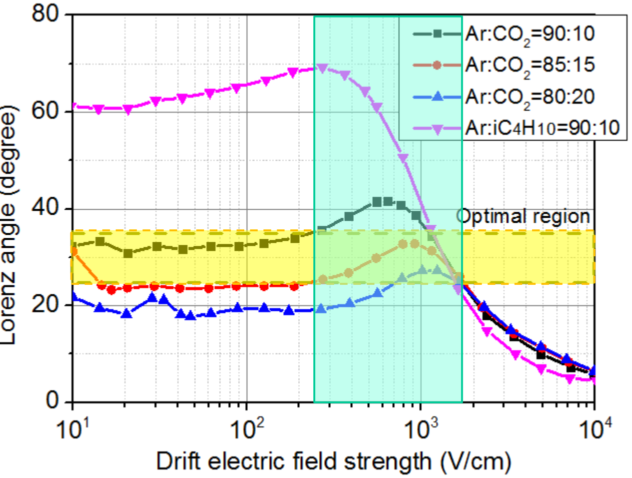
- Gas width: 5 mm
- Lorenz angle: 20-40 deg
- V_{drift}: ~2 cm/μs
- $\sigma_{Transverse}$ < 100 μm/sqrt(cm)



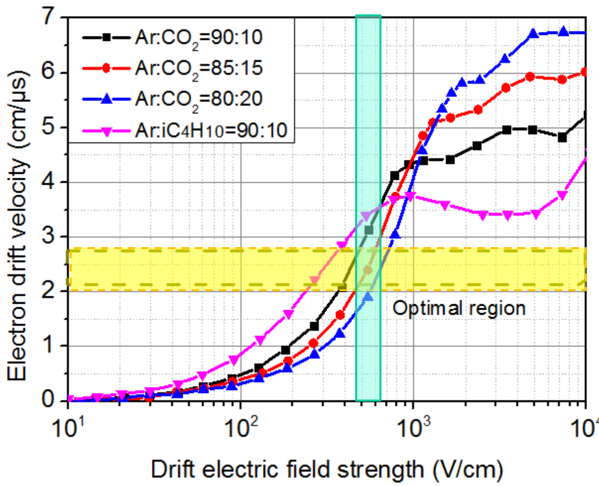
Real situation optimization

Target: tens of gas components from Garfield database

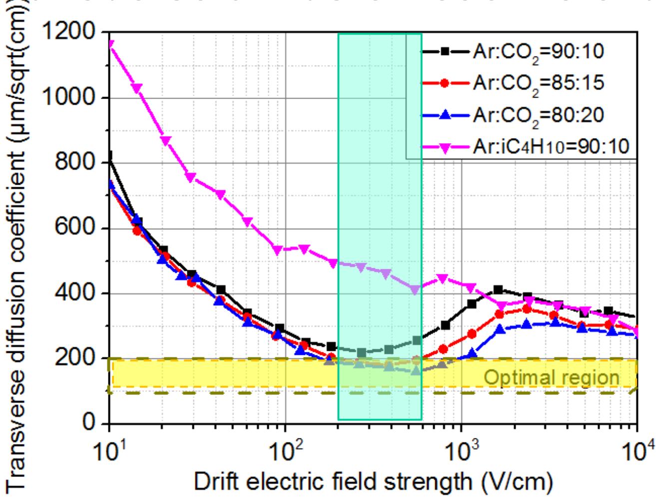
Lorenz angle



Electron drift velocity



Transverse diffusion coefficient



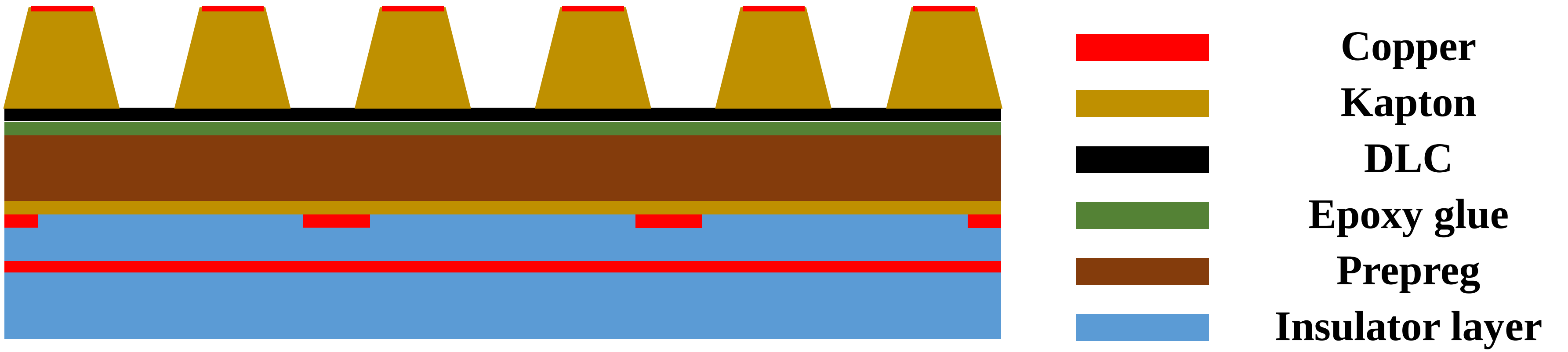
Gas volume width in this step: 5 mm

Optimal gas component: Ar:CO_2=85:15

(or Ar:DME=90:10)

Optimal electric drift field strength: 500 V/cm

Readout strip design



X strips (Top): 80 μm
V strips (Bottom): 320 μm
Pitch: 400 μm
X/V strip angle: 15 degree

Insulator layer between DLC & readout strip: 20 μm
Insulator layer between Top & Bottom readout strips: 25 μm

Multi-hit simulation

Generate signals and backgrounds:

Signal: p_T=100 MeV/c mu^+, 1 particle

Background: "STCF background full simulation generator",

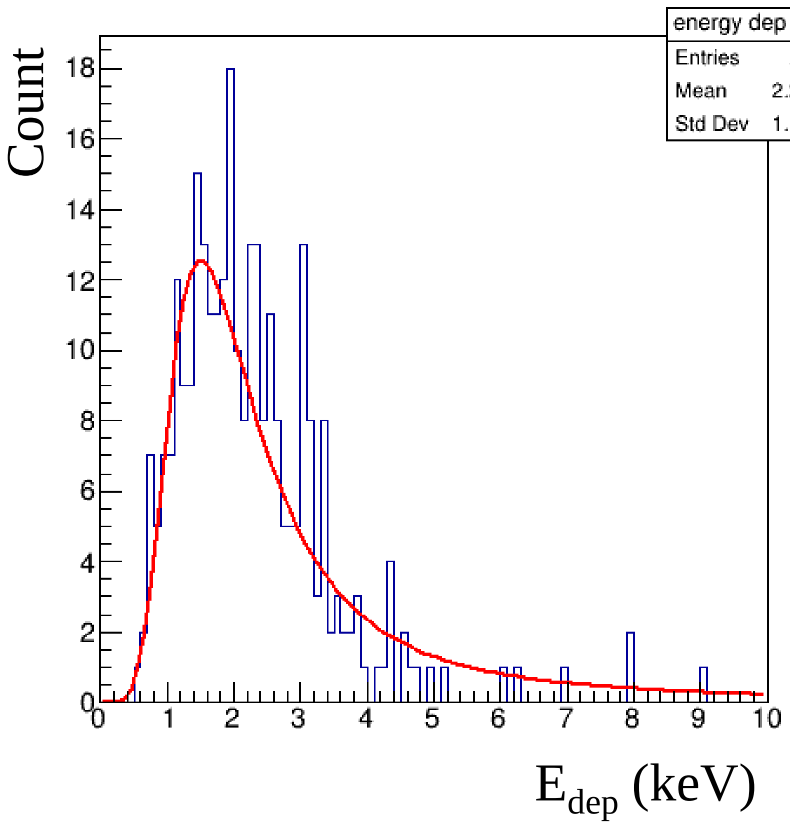
~5 charged particles

Parameterize the physical processes in Geant4 (fast simulation):

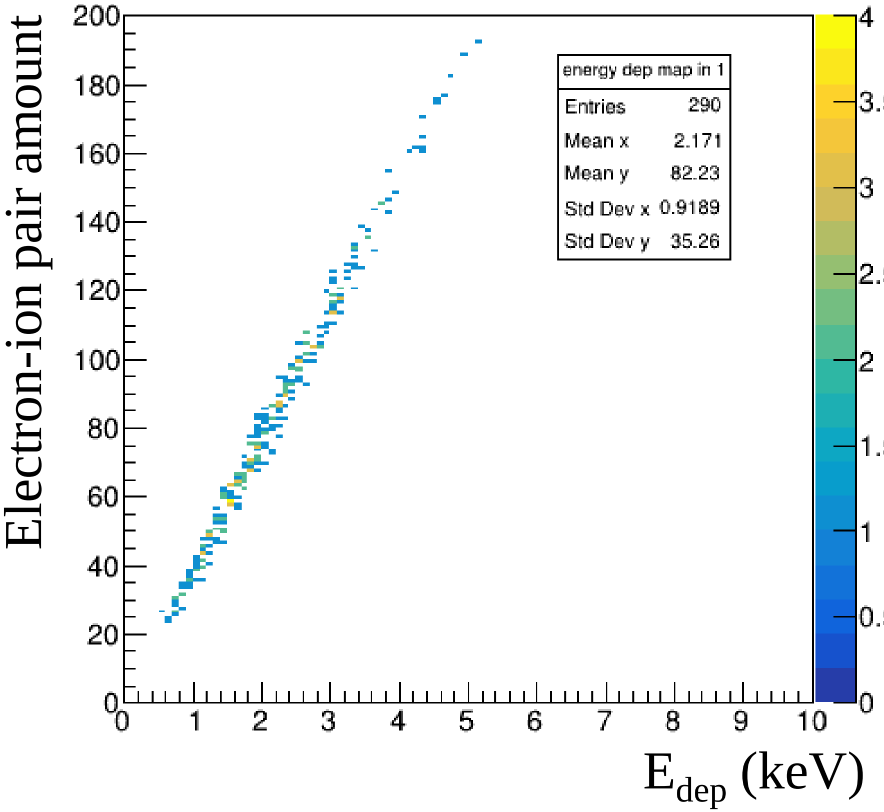
- Ionizing and primary electron generation (Sampling: Fano distribution)
- Electron migration (Sampling: transverse and longitude diffusion)
- Electron multiplication (Sampling: polya distribution)
- Induced signal generation in readout array (Garfield++: weighting potential)
- Waveform generation (Hit pile-up)

Fast simulation

Energy deposit in 5 mm gas

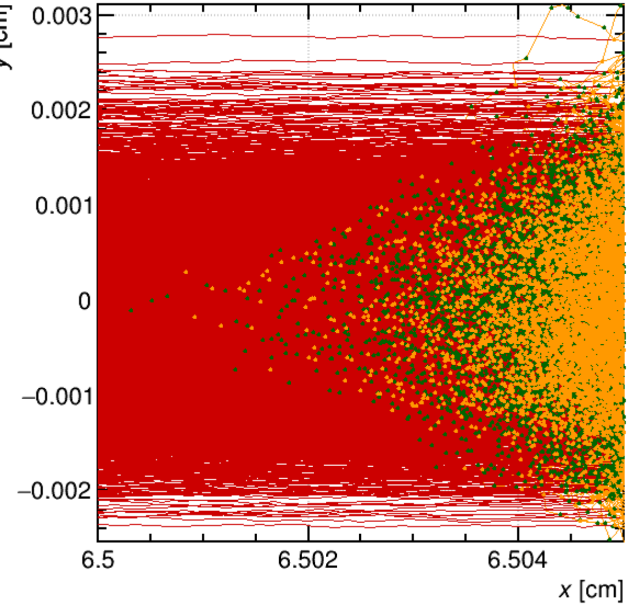


Number of primary ionized electron-energy deposit distribution

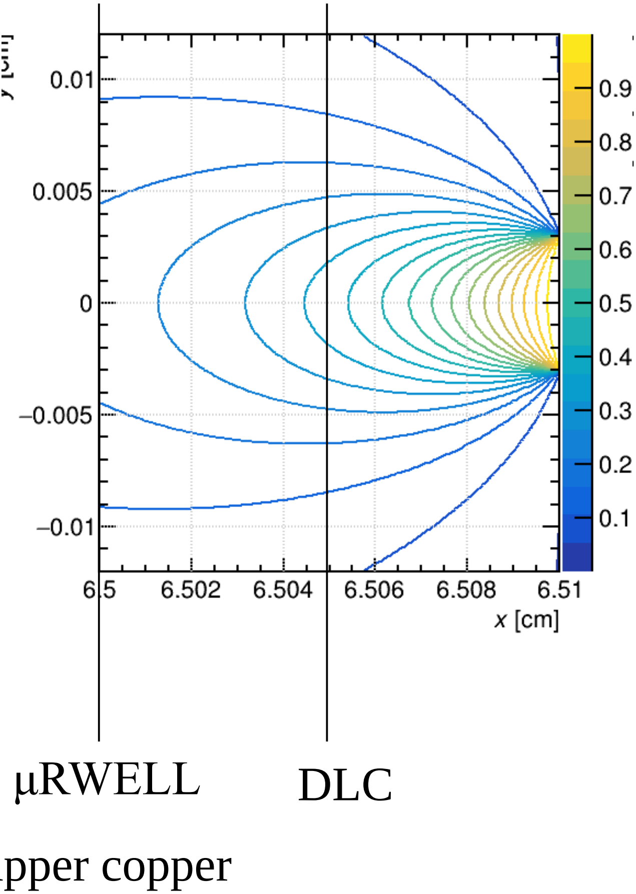


Fast simulation

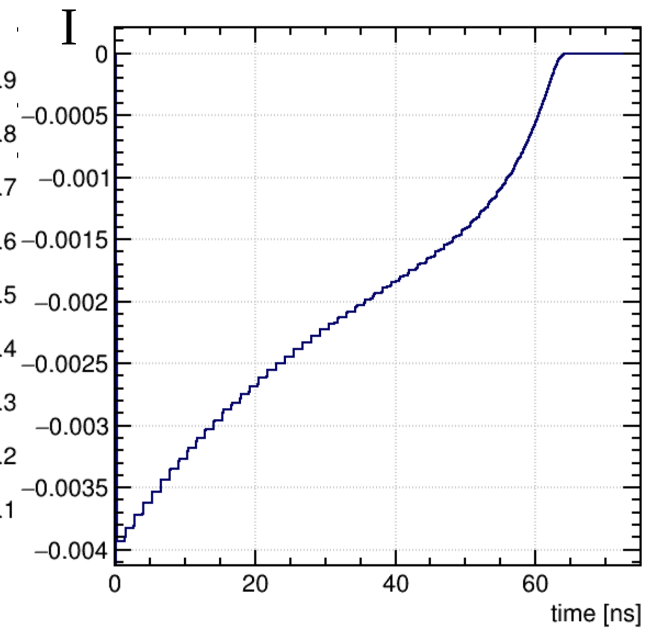
Electron multiplication



Weighting potential



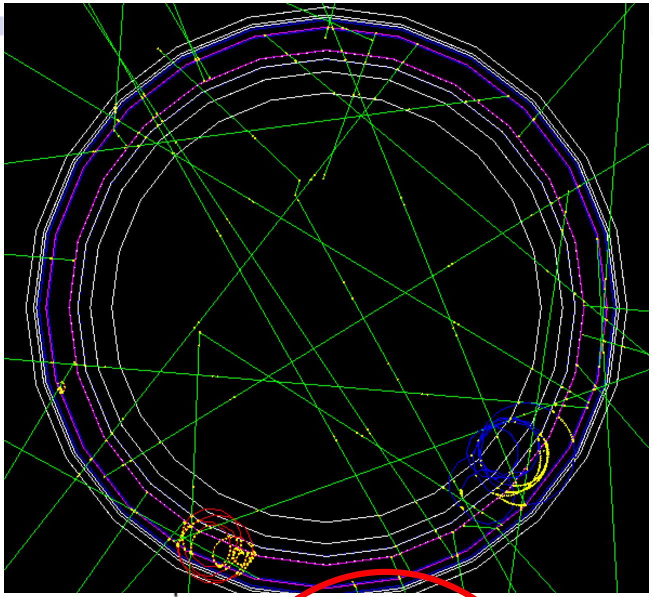
Single electron induced current

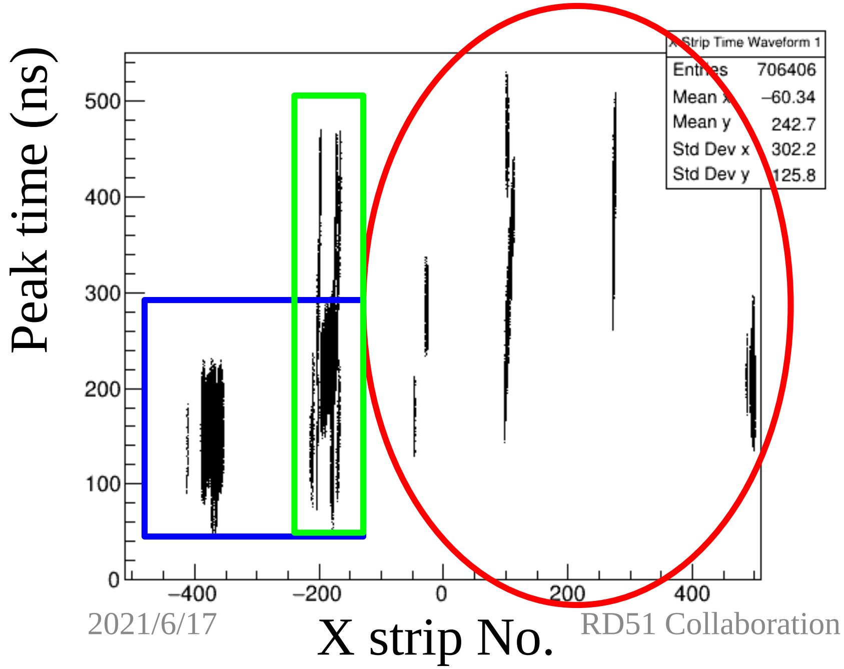


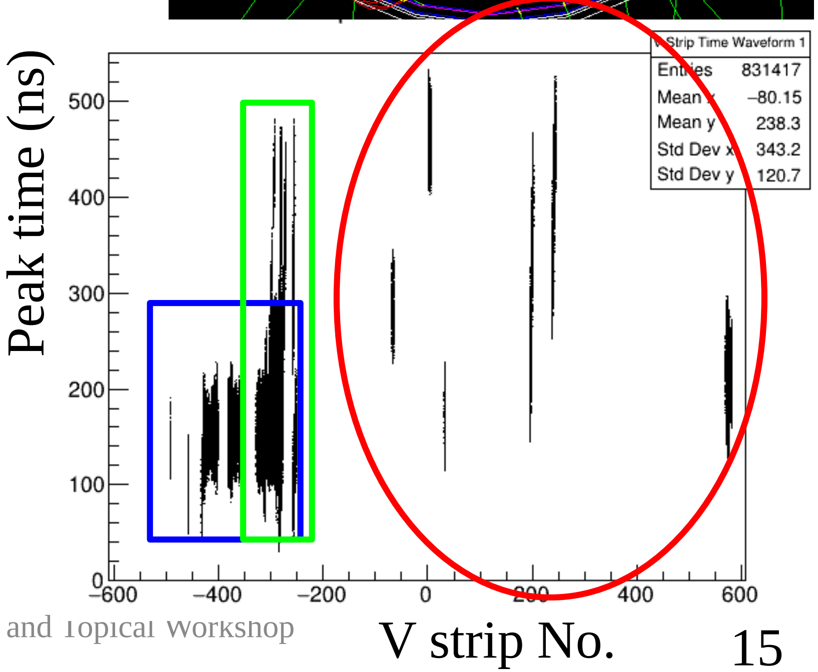
Multi-hit reconstruction

Multiple hit reconstruction:

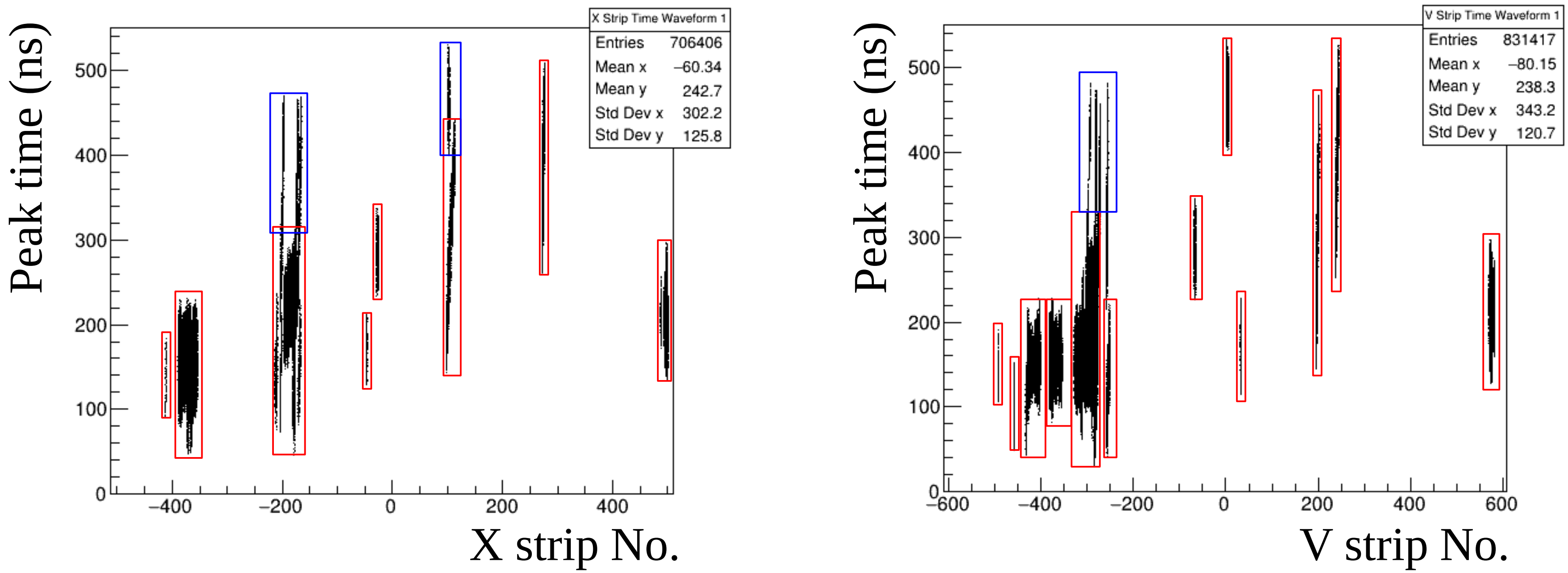
- Identify single-track signal as single hit
- Combine spiral-hits as a signal cluster
- Ignore pile-upped signals (no waveform sampling)







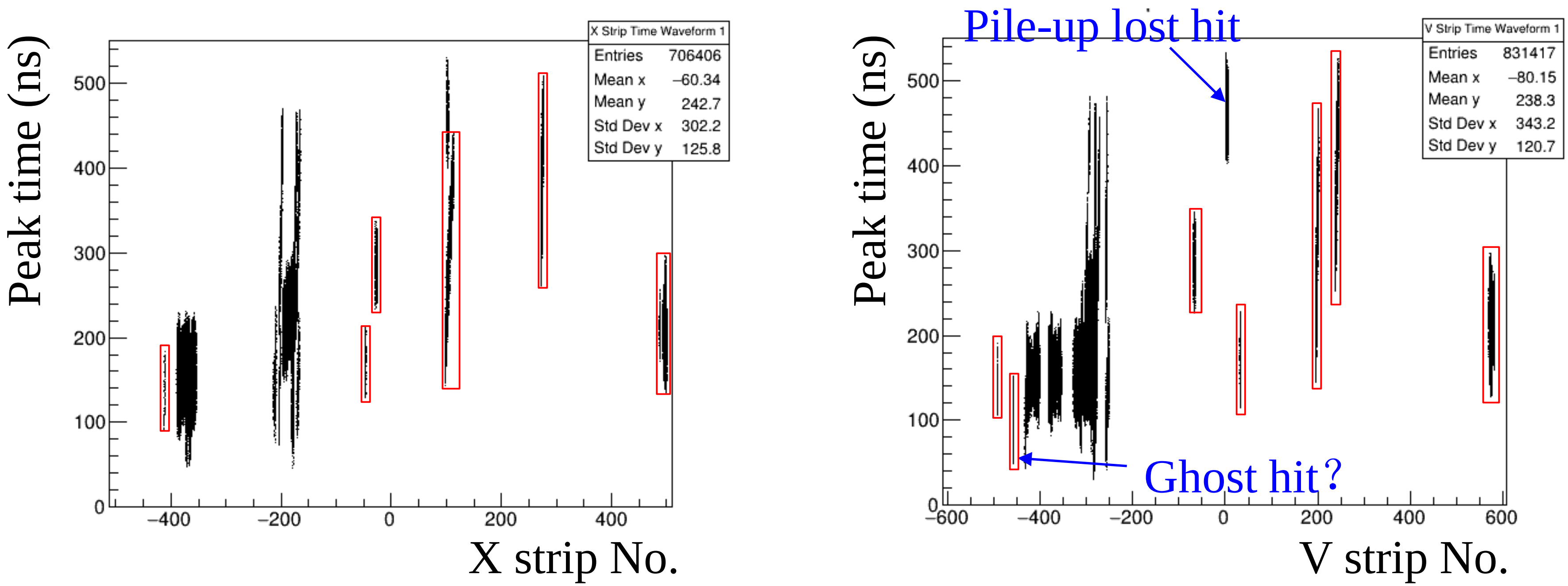
Multi-hit reconstruction



Reconstruction process:

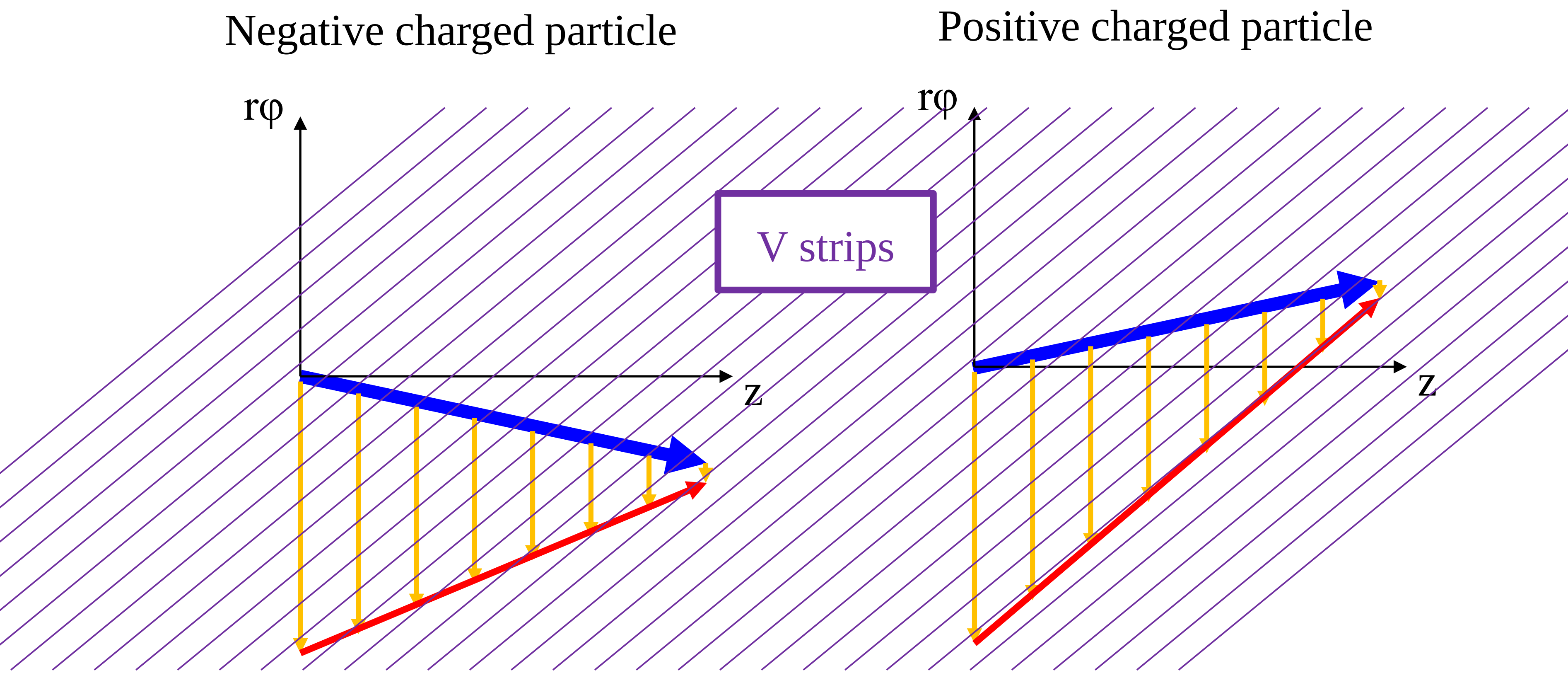
- Separate multiple hits in space and time
- Matching hits in X and V strips by peak time, fired-strip amount, total induced charge
- Combine the unmatched hits as clusters

Reconstruction performance



- Signal hit: ~92% can be reconstructed.
- Single background hit: ~80% reconstructed.
- Pile-up lost hit
- Ghost hit

Influence of magnetic field



Blue: particle track projection in z-rφ

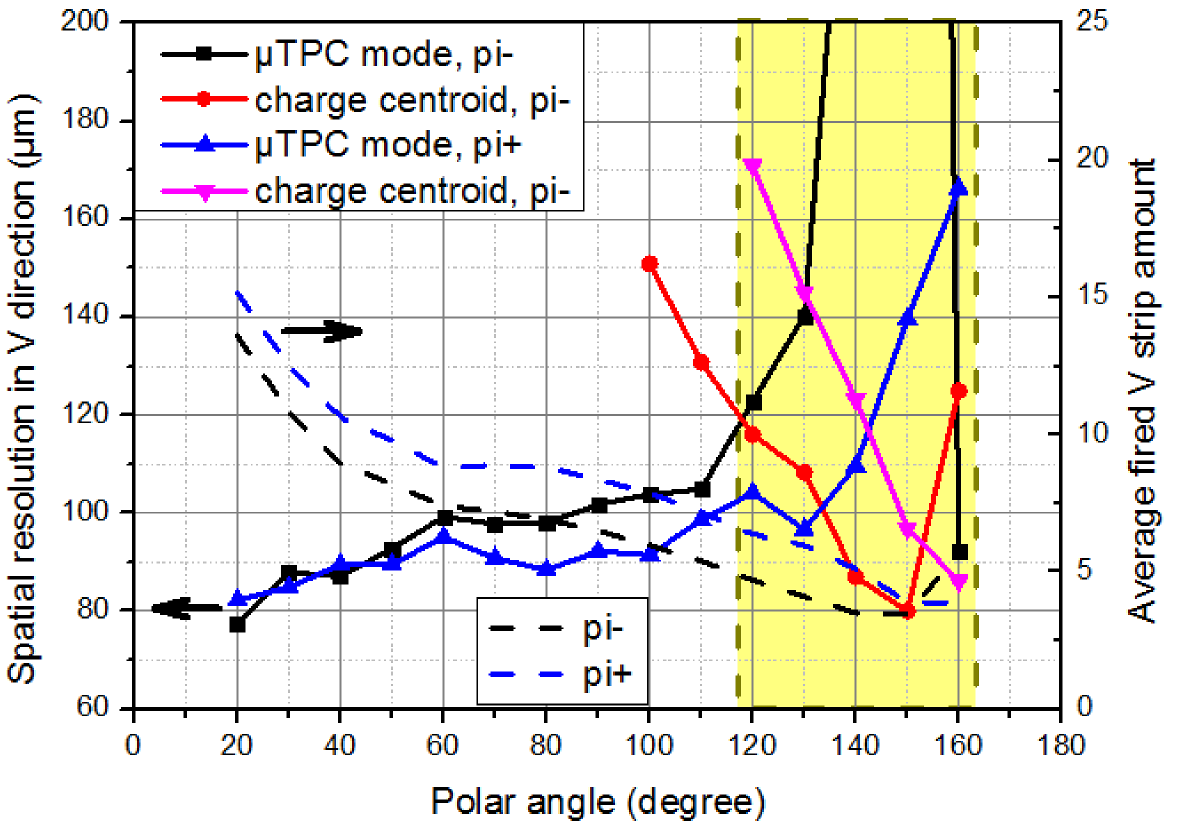
Yellow: electron drift projection influenced by magnetic field

Red: real hits distribution

Influence of magnetic field

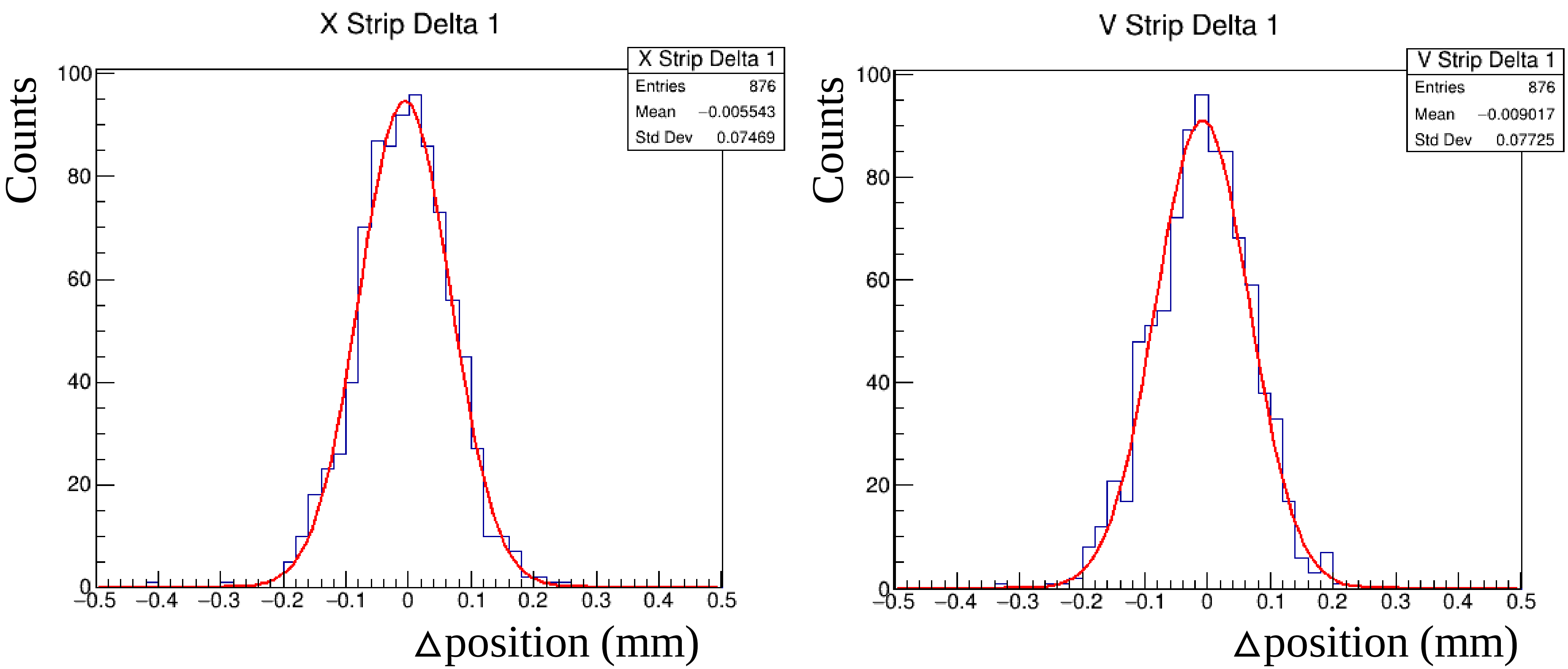
Real hits distribution may parallel to V strips:

- μTPC mode (for most cases)
- Charge center-of-gravity method (when real hits parallels to V strips)



Spatial resolution simulations

For p_T=100 MeV/c $kaon^+$: residual distribution of reconstructed hit point



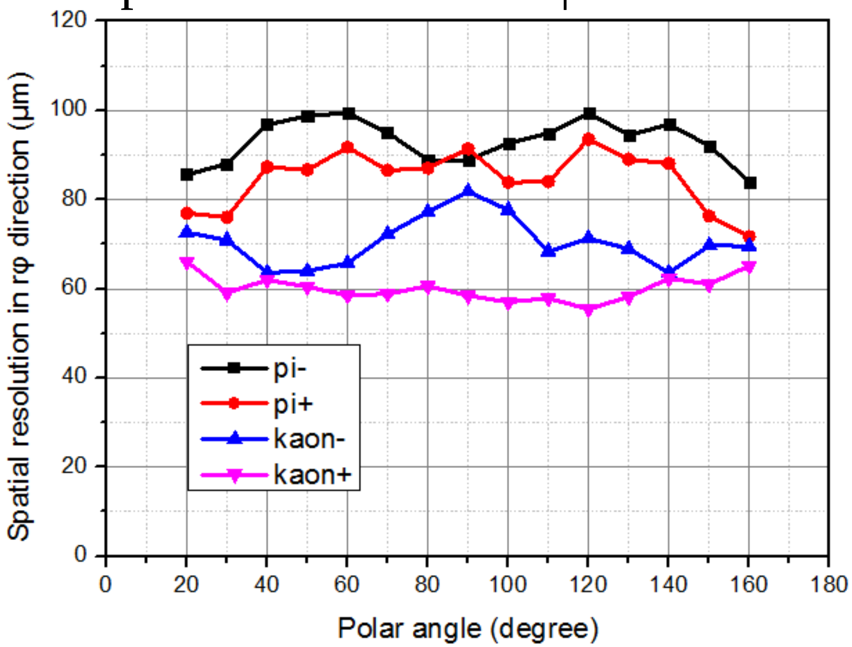
Spatial resolution simulations

Many parameters influences the spatial resolution:

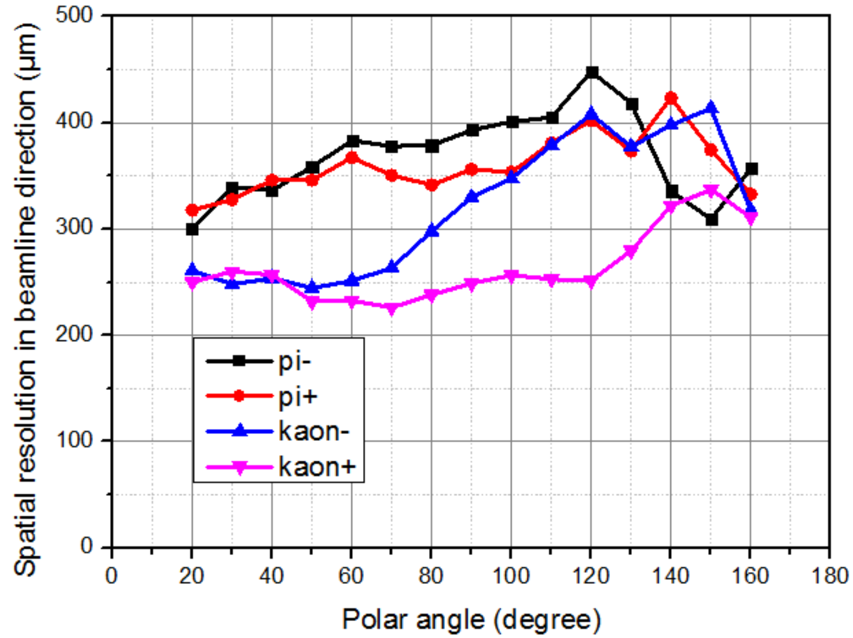
- p_T of charged particle
- Polar angle of particle
- Negative/positive charged

Spatial resolution: ~100 μm in rφ and 400 μm in z direction

Spatial resolution in rφ direction



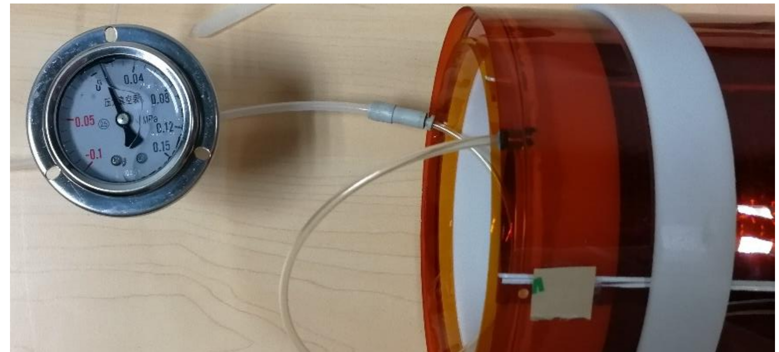
Spatial resolution in z direction



Discussion

Realizing μRWELL-based cylindrical detector:

- Detector manufacturing technology
- Making μRWELL film to cylindrical shape



We want to test the prototype detector within 1 year

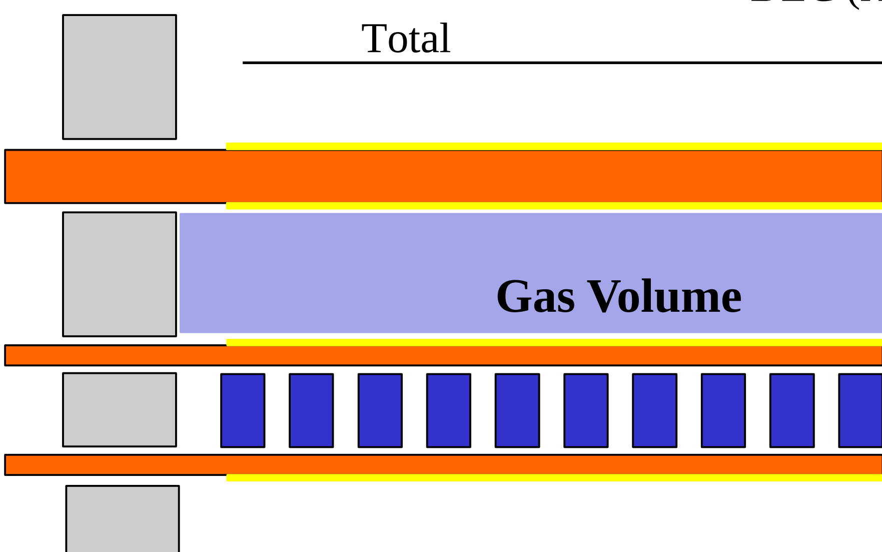
Conclusion

1. A μRWELL-based cylindrical inner tracker design is proposed for STCF, mainly for the low material budget and low cost in large detection area.
2. The predicted budget is 0.2%-0.25% X/X_0 per layer of detector.
3. By Geant4 & Garfield++ simulation, the optimal gas component is determined as $Ar:CO_2$=85:15, with a electron drift field as 500 V/cm.
4. Under STCF background level, around 92% of signal hit can be reconstructed, with a spatial resolution of around 100 μm and 400 μm in rφ and z direction, respectively.

THANKS FOR YOUR ATTENTION

Detector structure & material

Structure	Material	Thickness (cm)	Material budget (X/X_0)
Inner tube	Aluminum (X_0=8.897 cm)	0.001	**0.011%**
	Polyimide (X_0=28.57 cm)	0.01	**0.035%**
	Aramid honeycomb/Rohacell foam (X_0≈267 cm)	0.2	**0.075%**
Gas Volume	Argon-based gas mixture (X_0=11760 cm)	0.5	0.0043%
Outer tube (μRWELL film)	Aluminum (X_0=8.897 cm)	0.0015	0.017%
	Polyimide (X_0=28.57 cm)	0.03	0.106%
	DLC (X_0=12.13 cm)	0.0001	0.00082%
Total			**0.249%**



STCF inner tracker

Detector realization:

- Low budget material selection
- Cylindrical formation
- New bonding method
- Non-destructive detector assembly method

	Kapton 1	Glue 1	Structural material	Glue 2	Kapton 2	total
Honeycomb-based	0.028%	0.009%	0.033%	0.009%	0.030%	0.105%
Rohacell-based	0.028%	0.009%	0.010%	0.008%	0.029%	0.084%