Metal Artifact Correction Methods for Liquid CT Scan

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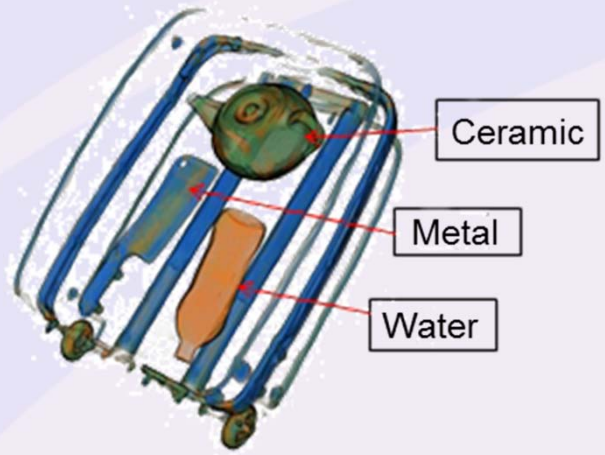
Brief Introduction

- **Application background**
  - An emerging considerations of lifting the restrictions on carry-on liquids
  - CT technology detects explosive materials with high reliability and accuracy
- **Problems with metallic containers**
  - High density metals -> Beam hardening effect
  - Thin containers -> The partial volume effect (PVE)

  Result: *Unnegligible error for liquid detection tasks;*

  A increase of false alarm rate.
- **Algorithms and solutions**
  - Projection splitting reconstruction method
  - Container edge estimation algorithm
  - An attempt to over come both effects with single energy CT
- **Conclusions**
  - Prior knowledge of the container helps to solve the problem
  - Accurate and easy-implementing methods to discriminate objects inside metallic containers are achievable



Nuctech's CT LEDS

Background

- **Easing restrictions on carry-on liquids**

  European Commission's aviation security policy:

  – "a temporary restriction to be lifted when suitable technology to screen liquids for explosives became readily available"

  – Goal: "a complete lifting ... as of January 2016."

- **Benefits it brings**

  – **Passenger**

    » Convenient

    » Shorter boarding time

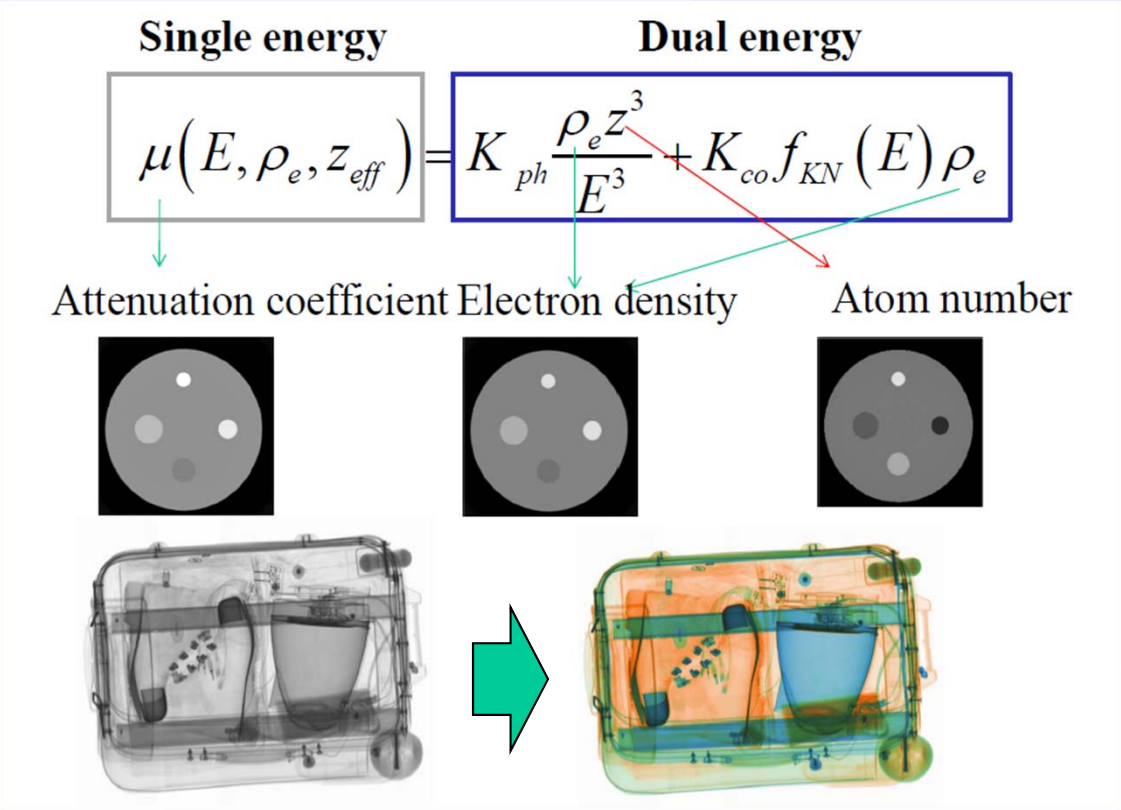
  – **Airport**

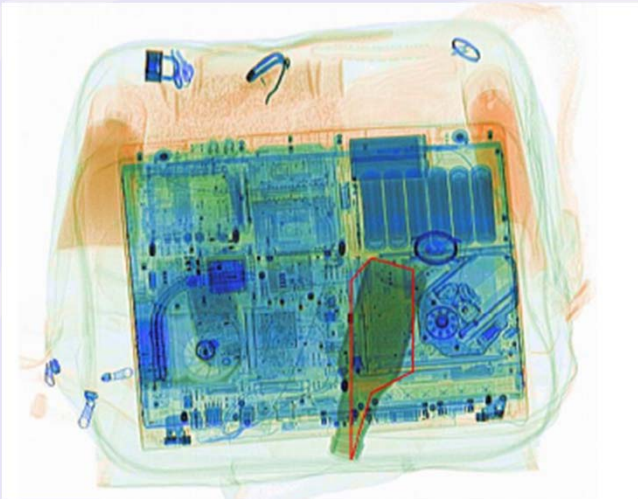
    » Less checked luggages

    » More sales revenue

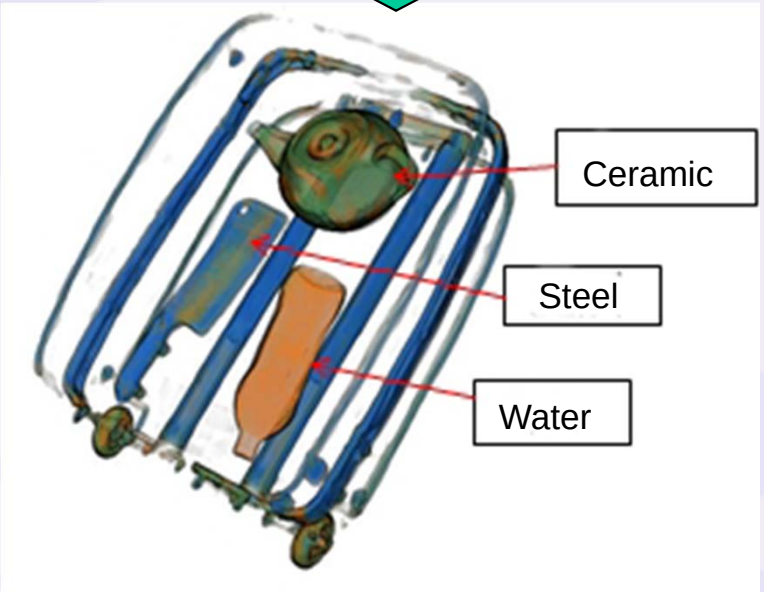
Background

- **Liquid explosive detection with X-CT scan**
  - X-Ray: Non-invasive inspection
  - CT technique: Avoid object overlapping
  - Dual-energy: Better material discrimination





Overlapped 2D image

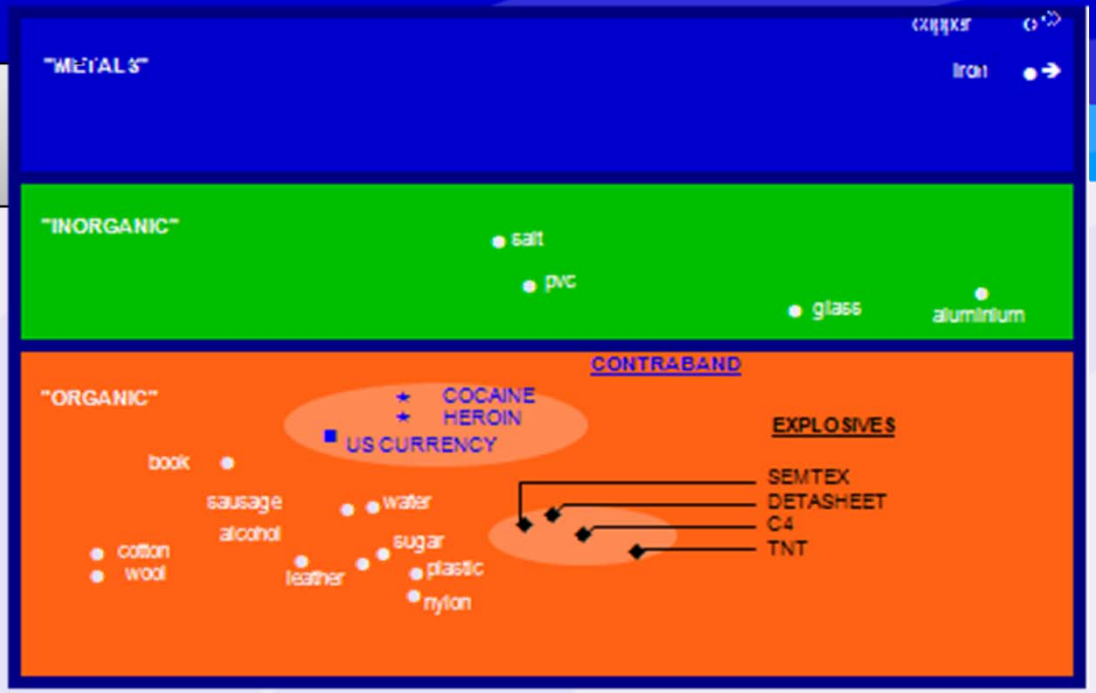


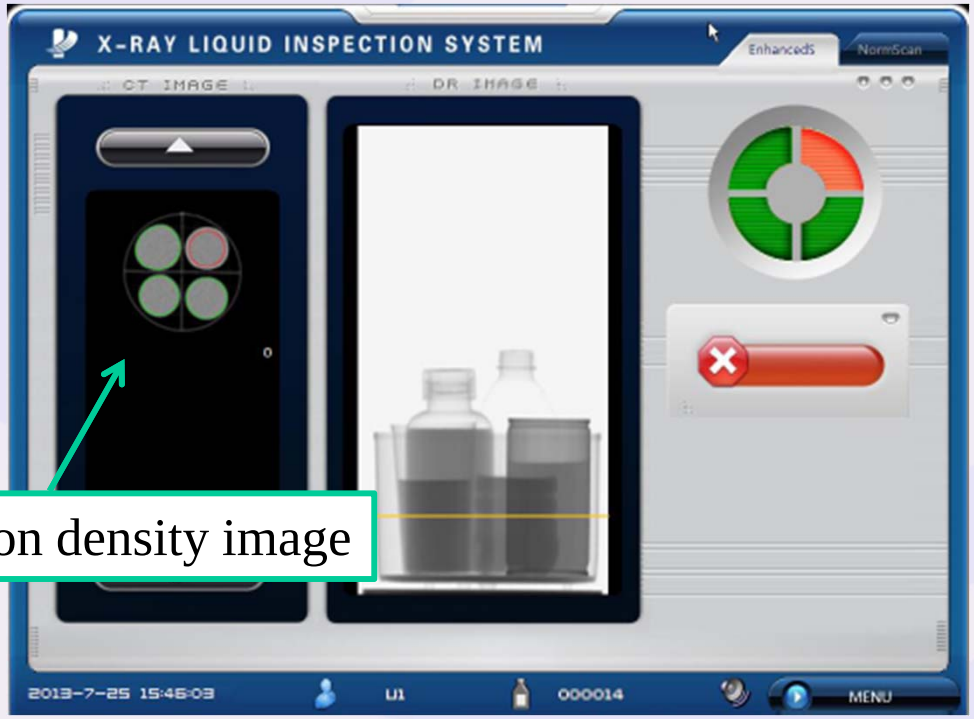
CT image with no overlapping

Background

Dual energy CT for liquid inspection

Liquid CT scanner





CT electron density image

The Problem

- **Nuctech's liquid CT inspection systems**

XT2080

XT2080SI

EDS+LEDS

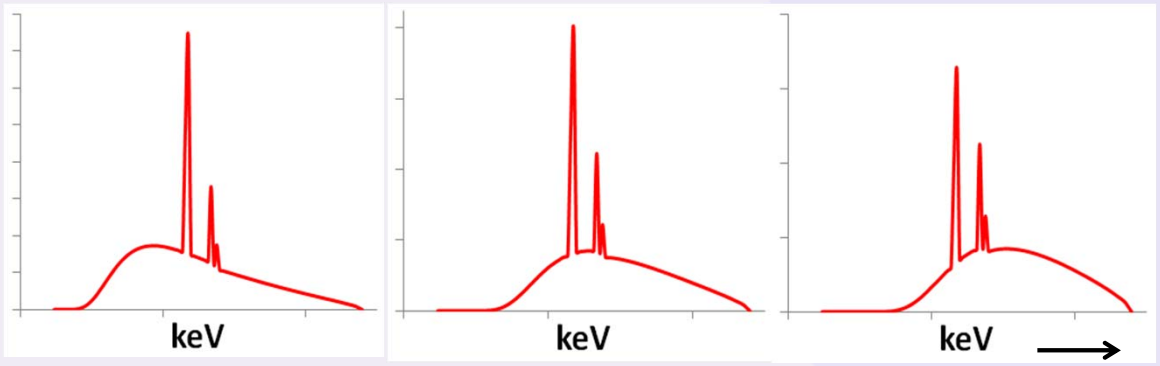
LS1516BA

XT2080AD

The Problem

- **Metal container and image quality downgrading**

X-Ray spectrum shifts as it passes through objects (the beam hardening effect)



Tube spectrum, mean: 60.7keV

0.5 mm copper, mean: 71.6 keV

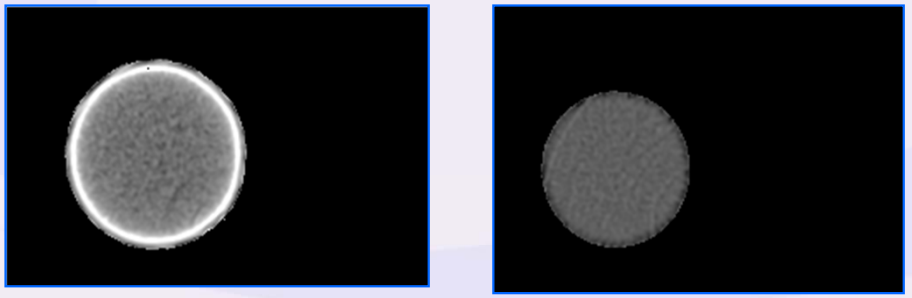
1.0 mm copper mean: 77.2 keV

Large spectrum change occurs while penetrating dense metals

FBP reconstruction examples

water w/ steel bottle

water w/ PET bottle

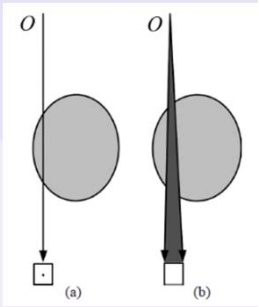


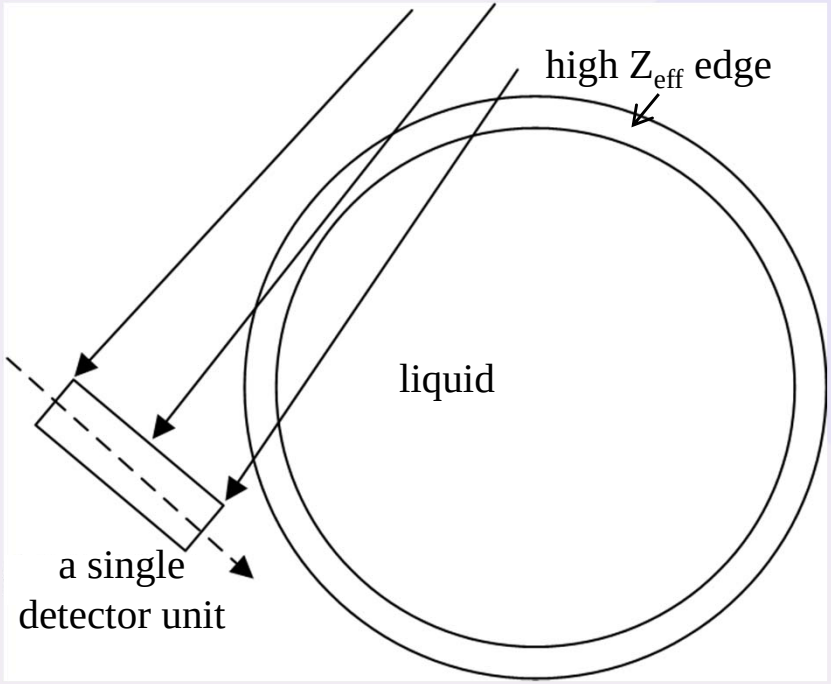
CT slice (Z_{eff})
Avg. bias: 15%

CT slice (Z_{eff})
Avg. bias: 0.8%

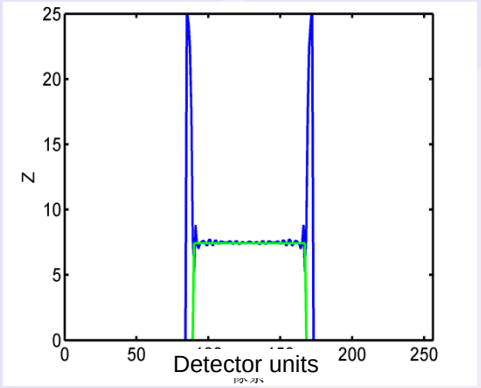
The Problem

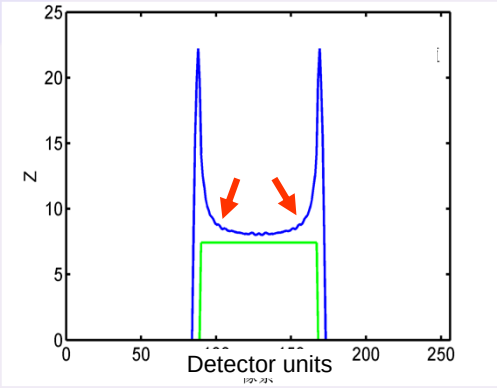
- **The partial volume effect (PVE)**
  - Width of detector unit is usually larger than the thickness of container
  - Output signal is an average of each ray path
  - Beer's law is no longer well followed on edge data points



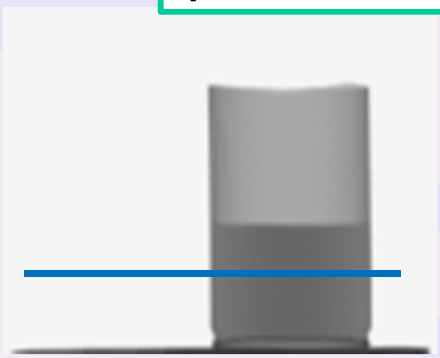


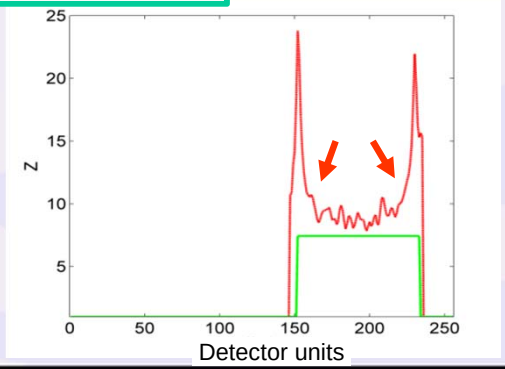
simulation of PVE





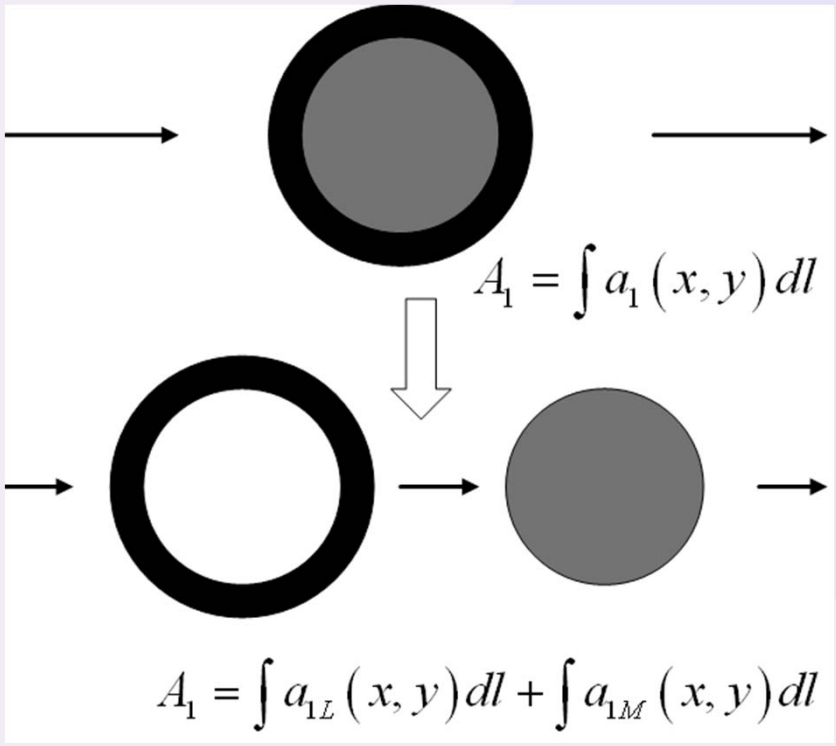
profile on real data





Method

- **Projection splitting**
  - **Separate container and liquid**



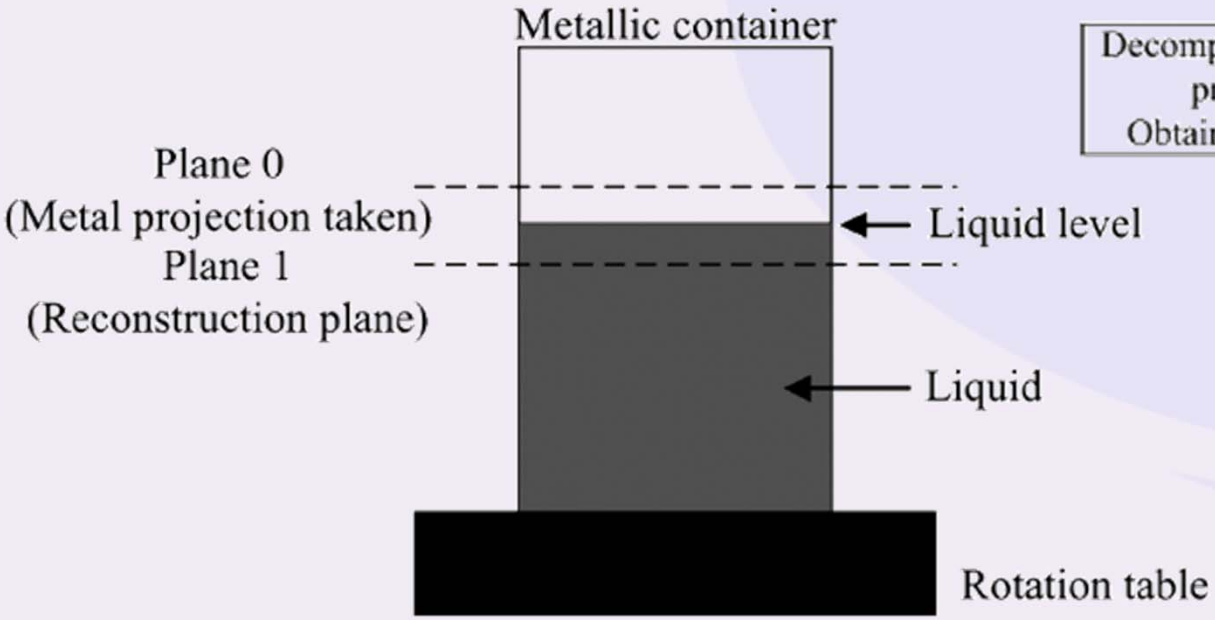
$$A_1 = A_{1L} + A_{1M}$$

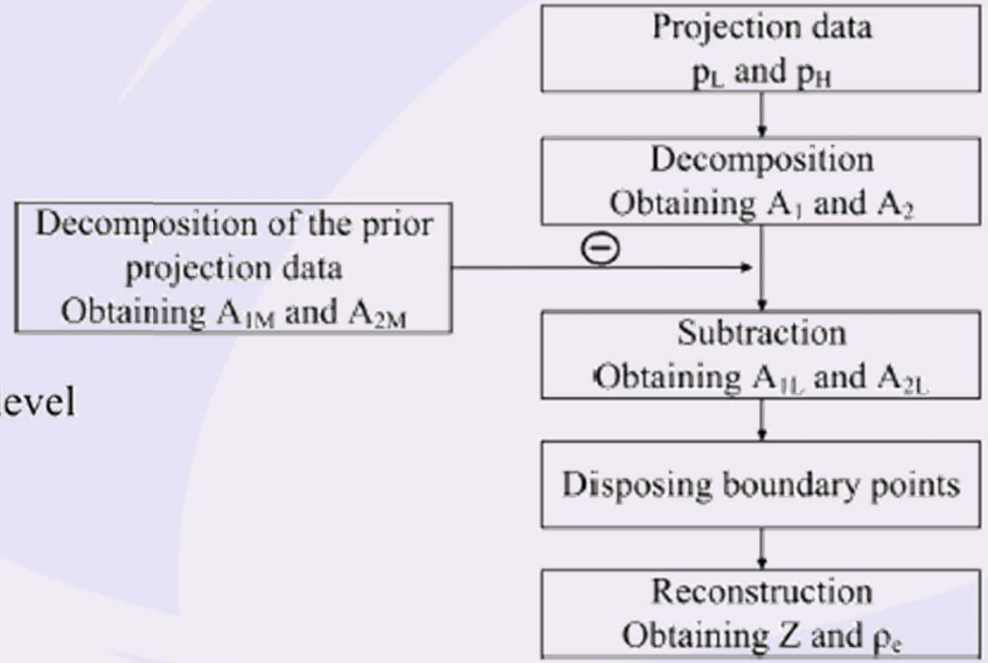
$$A_{1L} = A_1 - A_{1M}$$

Method

- **Projection splitting on real data**
  - **Two dual-energy scans**
    - » **Above and below the liquid level**
  - **Requires a vertically uniform container wall**

Scan configuration

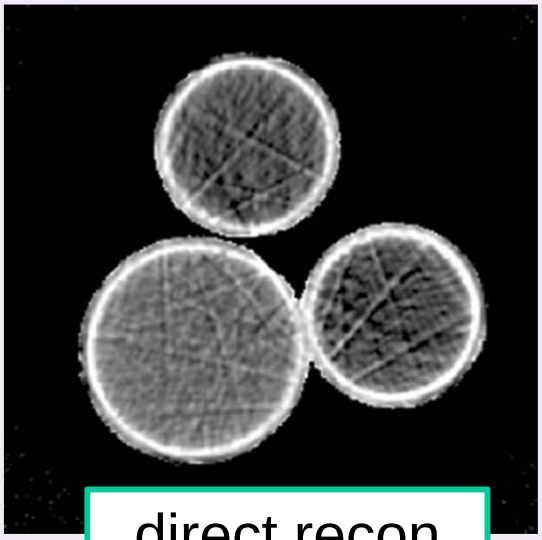




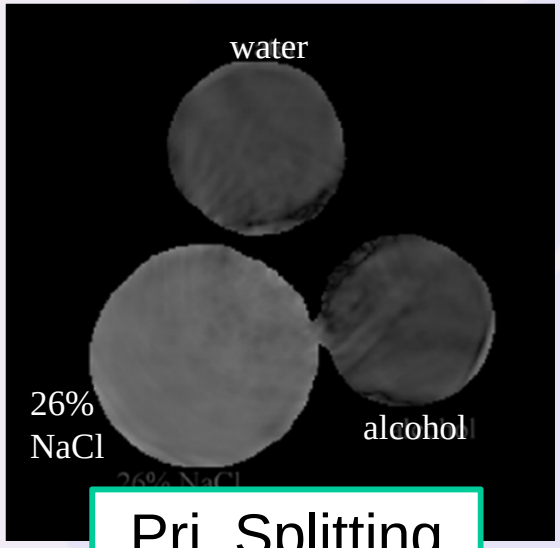
Steps of the method

Results

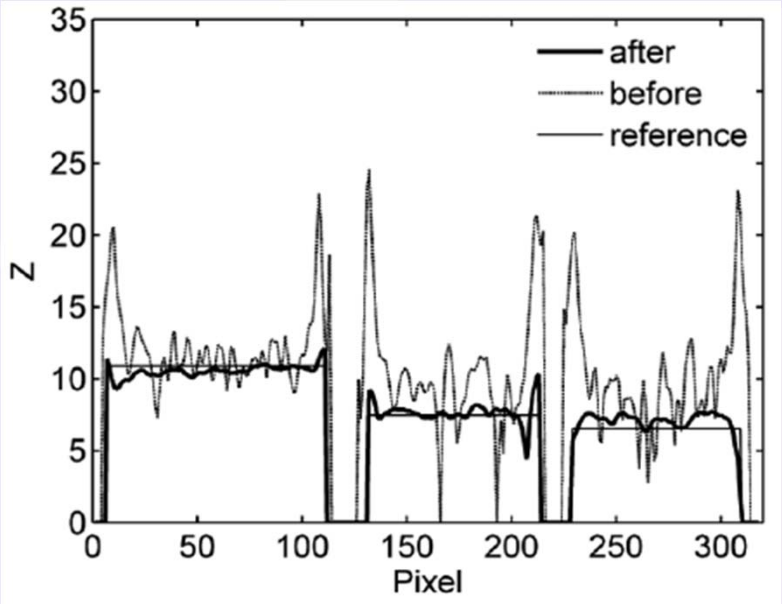
- **Projection splitting on real data**



direct recon



Prj. Splitting

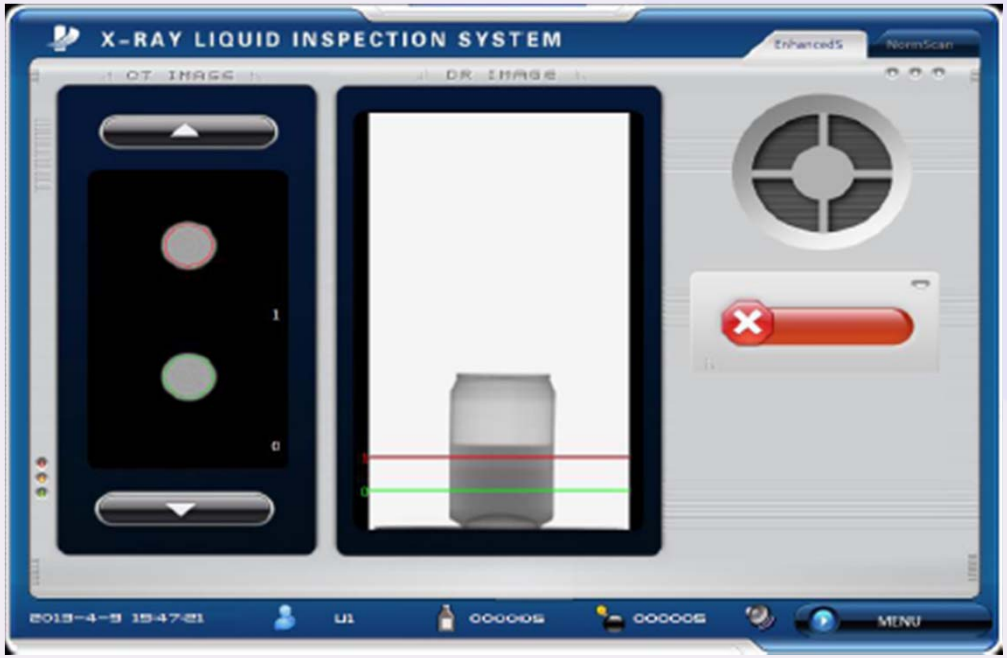


Average of means of Z_{eff} and relative errors

Materials	Reference	Average of means		Relative error	
		Before	After	Before	After
Water	7.49	8.89	7.64	18.7%	2.0%
Alcohol	6.53	8.58	6.88	31.4%	5.4%
26% NaCl	10.90	11.61	10.72	6.5%	1.7%

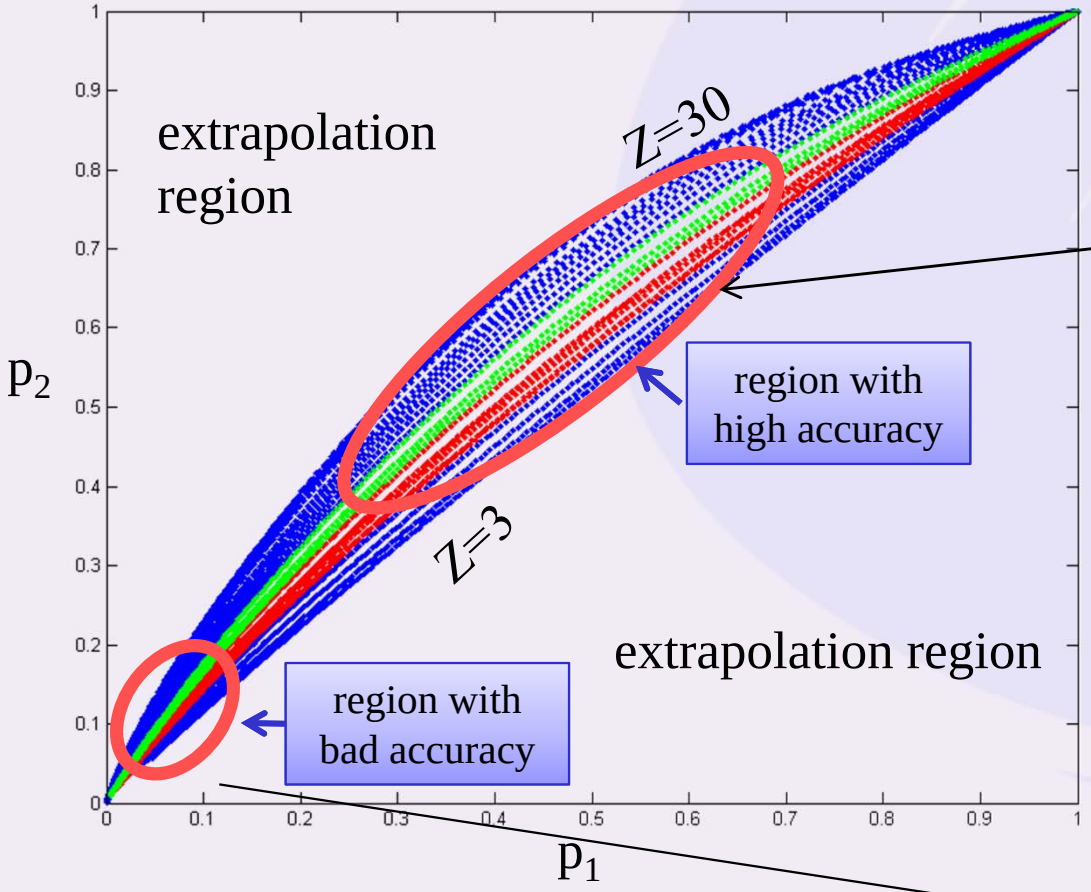
Discussion

- **Advantages**
  - Easy implementation / fast computation
- **Disadvantages**
  - A uniform container wall may be required
  - Large dual-energy decomposition error



Discussion

- **The accuracy of dual-energy decomposition**
  - **Error increases as p1,p2 goes close to two end points**

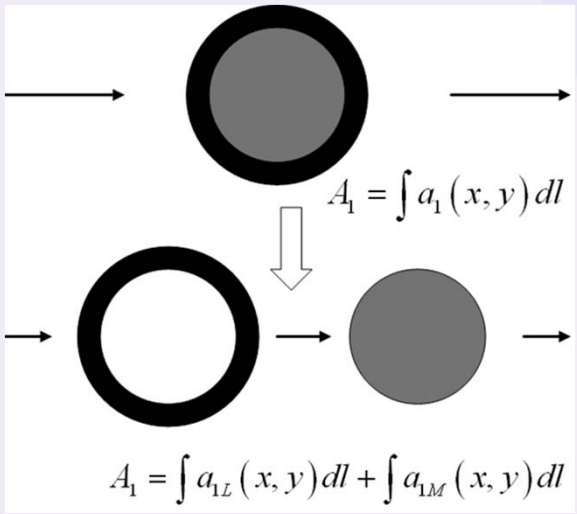


Plastic container

Steel container

Method

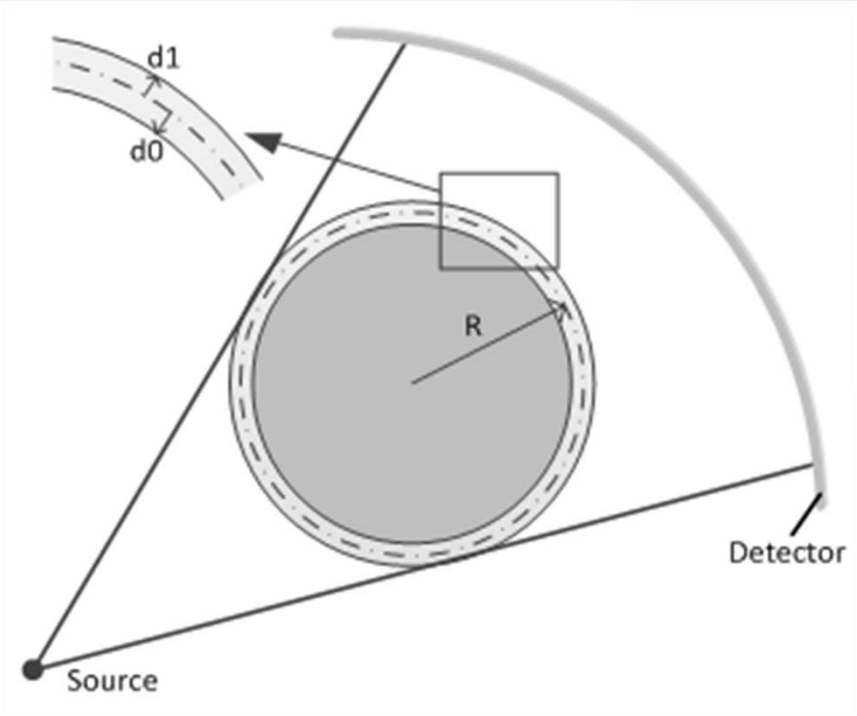
- **A hybrid projection reconstruction method**
  - **To get better separation between walls and target object**
  - **a more realistic physical simulation**
    - » source spectrum / detector response
  - **extra prior information utilized**
    - » thickness uniformity & material information of the container



Consider the problem under a more realistic physical model ?

Realistic Physical Modeling

- **Issue 1: The partial volume effect**
  - **Thickness of the container less than detector unit size**
    - » can be well simulated in projection computation
  - **get a close estimation of the thickness?**
    - » parameterized description of the boundary

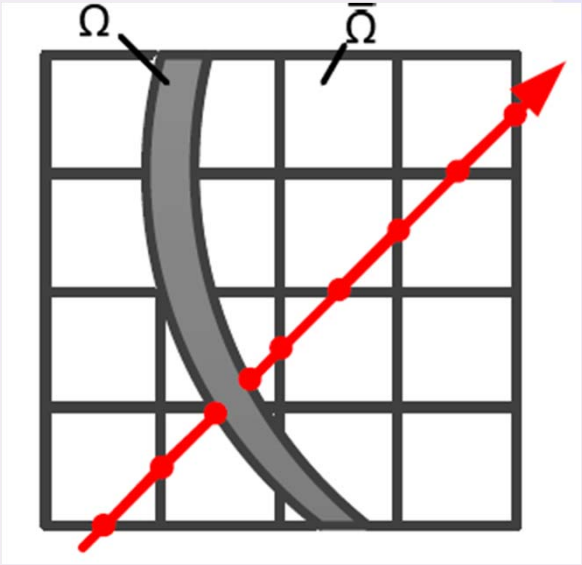


Assumptions:
- unified thickness of wall
- circular ring shape

Parameters:
- Center position of ring: *C*
- Radius: *R*
- Half thickness: *d0*, *d1*

Realistic Physical Modeling

- **Determine the parameters**
  - **Hybrid projection calculation**
    - » Mixed with pixels and parameterized shape
    - » Mixed polychromatic and monochromatic projection
  - **A optimization problem**
    - » Minimize the total variation of pixel area ($\bar{\Omega}$)



Hybrid poly-/mono- chromatic projection

$$I_{\Omega+\bar{\Omega}} = \int I_0 \omega(E)\eta(E) e^{-\int (\mu_{\Omega}(\vec{r},E) + \mu_{\bar{\Omega},\epsilon}(\vec{r}))d\vec{r}} dE$$

Minimization problem

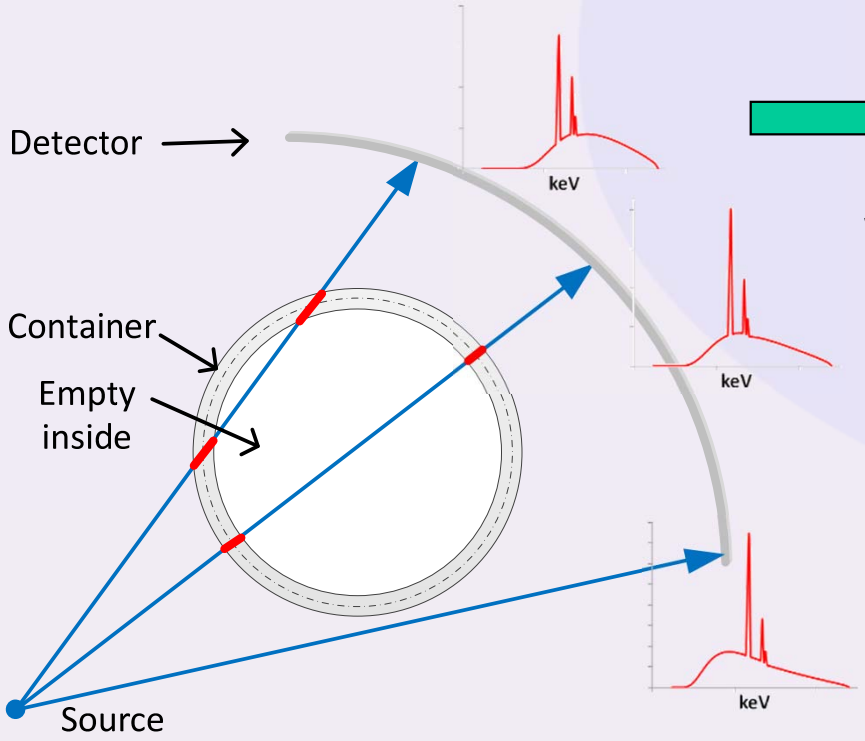
$$\min_{d_0,d_1,R} \|X_{\bar{\Omega}}\|_{TV}, s.t. P_{\text{forward}}(X) = P_0$$

Compute data without container

$$P_{\bar{\Omega}} = -\log(I_{\Omega+\bar{\Omega}}/I_{\Omega})$$

Realistic Physical Modeling

- **Issue 2: Beam hardening**
  - **Large spectrum shifts while penetrating metals**
    - » Each projection ray has its own spectral changes
    - » Necessary correction required
    - » Simple approach: scale each projection to unify spectrum



Correct ray by ray

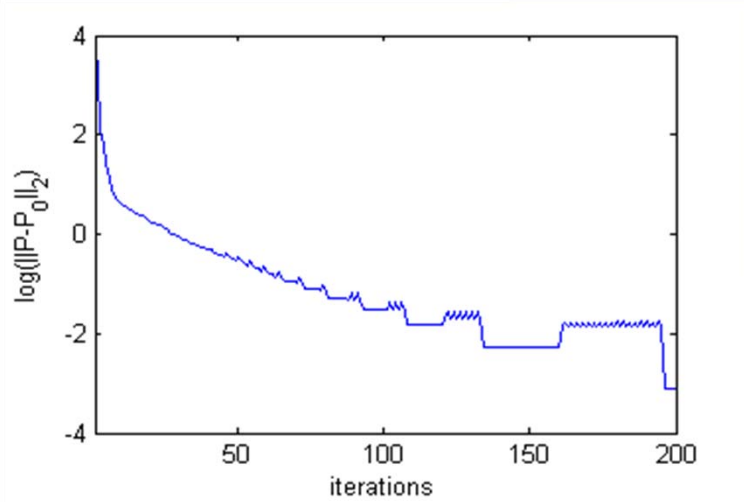
Scaling factor:

$$\alpha = \frac{\mu_{\text{water}}(\bar{E}_{org})}{\mu_{\text{water}}(\bar{E}_{metal})}$$

No correction applied

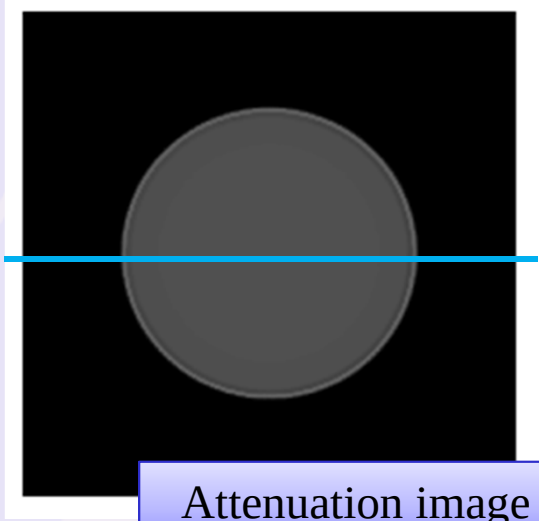
Preliminary Result

- **Edge estimation**
  - » Center: (0, 0)
  - » Liquid radius: 3.0mm
  - » Container thick: 0.4mm
  - » Estimated thick: 0.409 mm
  - » ISO estimation error: <0.1%
  - » Thick estimation error: 2.9%

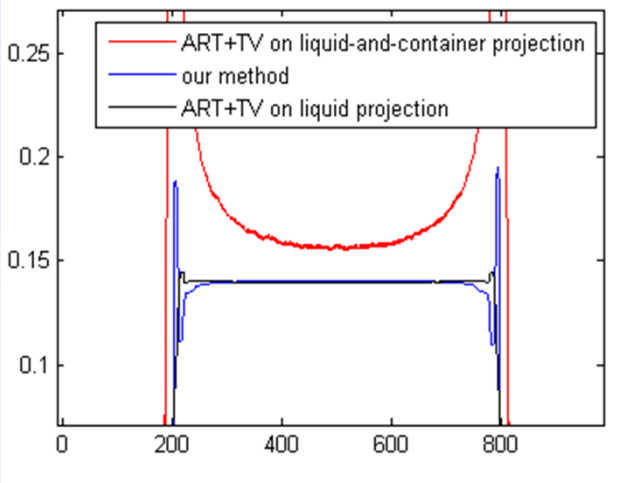


Total iterations: 200

- **CT image**
  - » Liquid material: gasoline

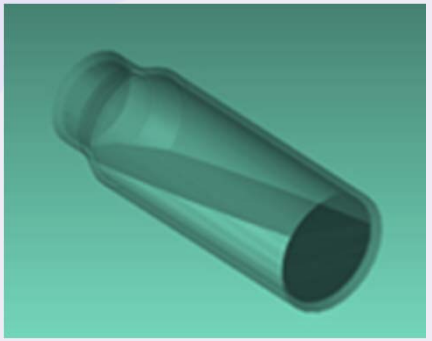


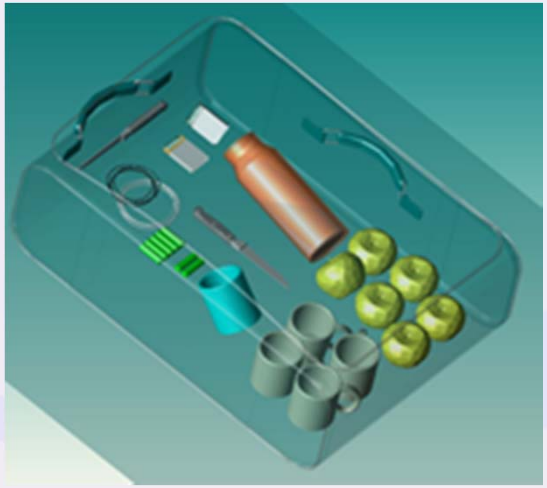
Attenuation image



Discussion

- **Advantages**
  - Requires only single-energy CT scan
  - Capable to remove both PVE and Beam hardening effect
- **Disadvantages**
  - Requires material information of the container
  - A uniform thickness of the wall
- **Future work**
  - Other shapes of the container wall
  - Reconstruct under multiple containers/objects
  - Container material estimation
  - Benefits from dual-energy scan?





Conclusion

- The PVE and beam hardening effects are two major factors that influence the accuracy of liquid CT scans on metallic containers
- Additional prior information can be found to assist the CT reconstruction as well as accurate physics models
- Two methods were proposed to overcome the effects
- Better liquid CT reconstruction can be achieved

THANK YOU!

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