A Magnetized Muon Range Detector for TITUS

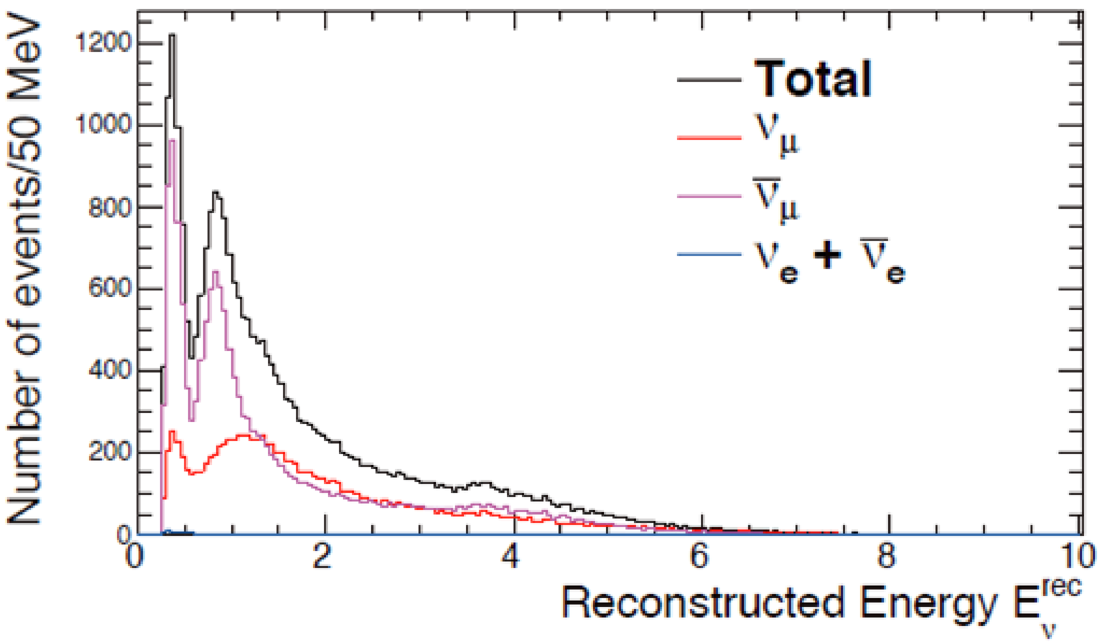
Mark Rayner (Université de Genève) for TITUS

6th Open Meeting for the Hyper-Kamiokande Project

31 January 2015, Kavli IPMU, University of Tokyo, Kashiwa

N.B. Lots of work here by Etam Noah and Alain Blondel

There is a significant wrong-sign component in anti-neutrino mode



A near detector with the right nucleus and the capacity to directly constrain the wrong-sign component is quite a rational proposition for a superbeam experiment focussed on CP violation

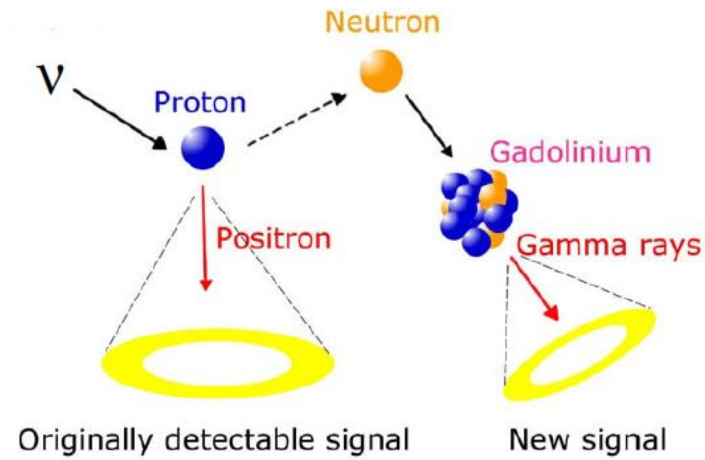
Gadolinium is exciting, but somewhat untested, and not 100% efficient

$$\upsilon\, n \rightarrow \ell\, p$$

$$\bar{\upsilon}\, p \rightarrow \ell\, n$$

detect with Gd

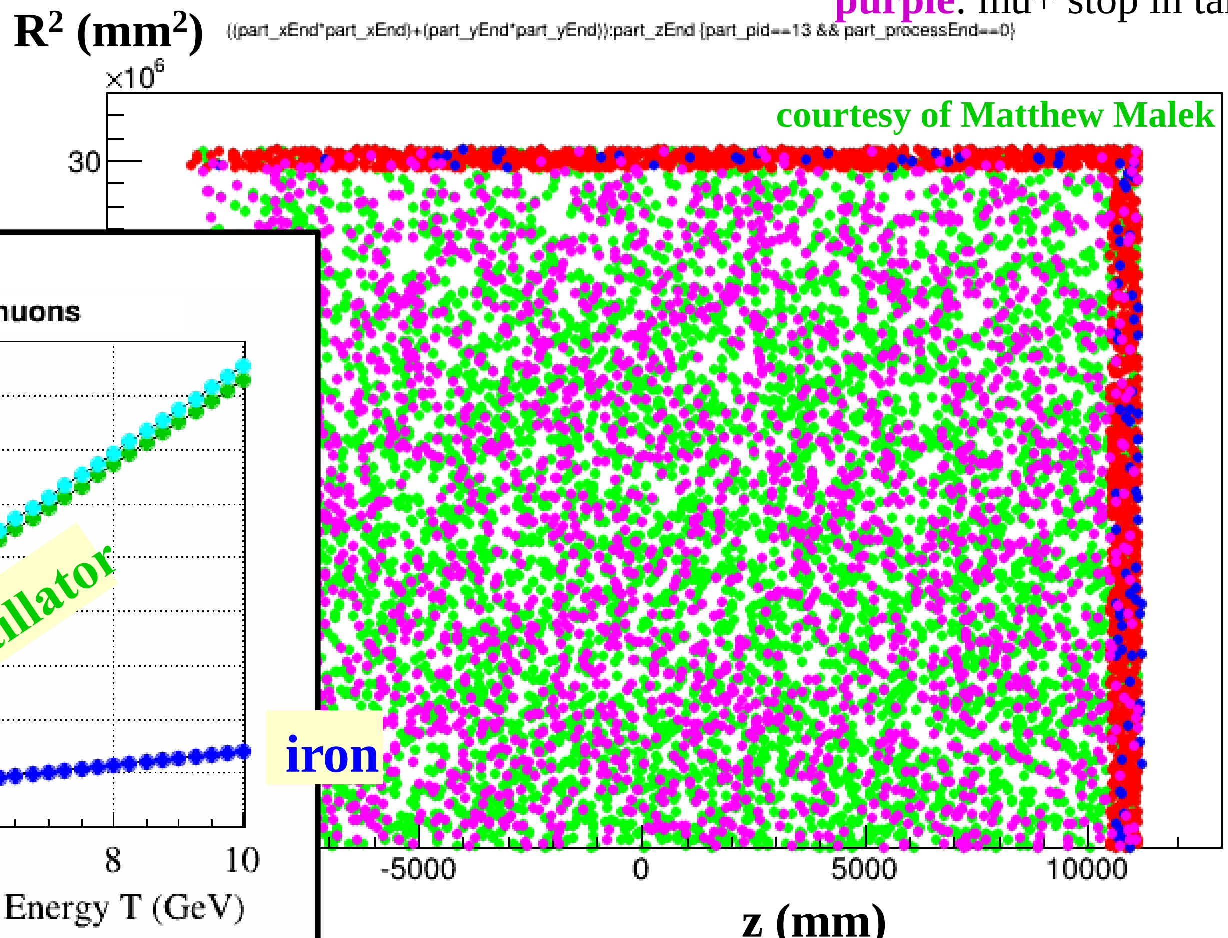
$\varepsilon_Q \approx 90\%$

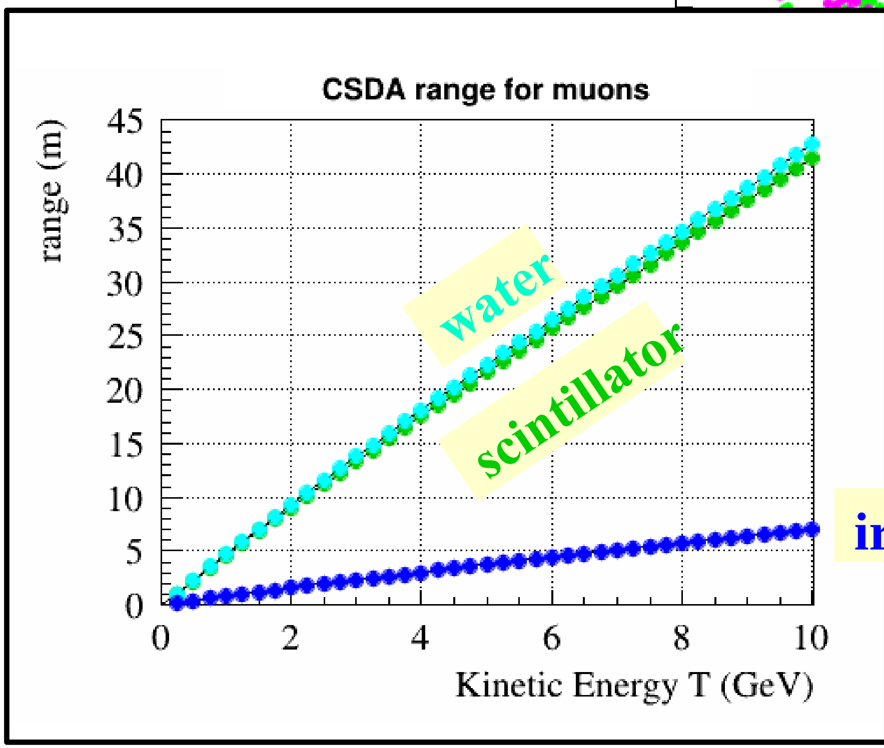


A magnetized MRD can achieve very high charge reconstruction efficiencies

red: mu- leave tank
blue: mu+ leave tank
green: mu- stop in tank
purple: mu+ stop in tank

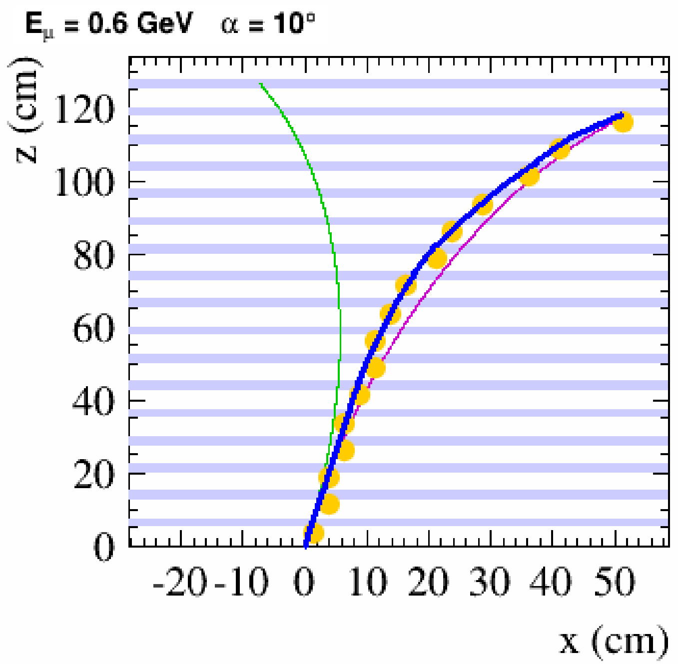
18% of muons escape the tank





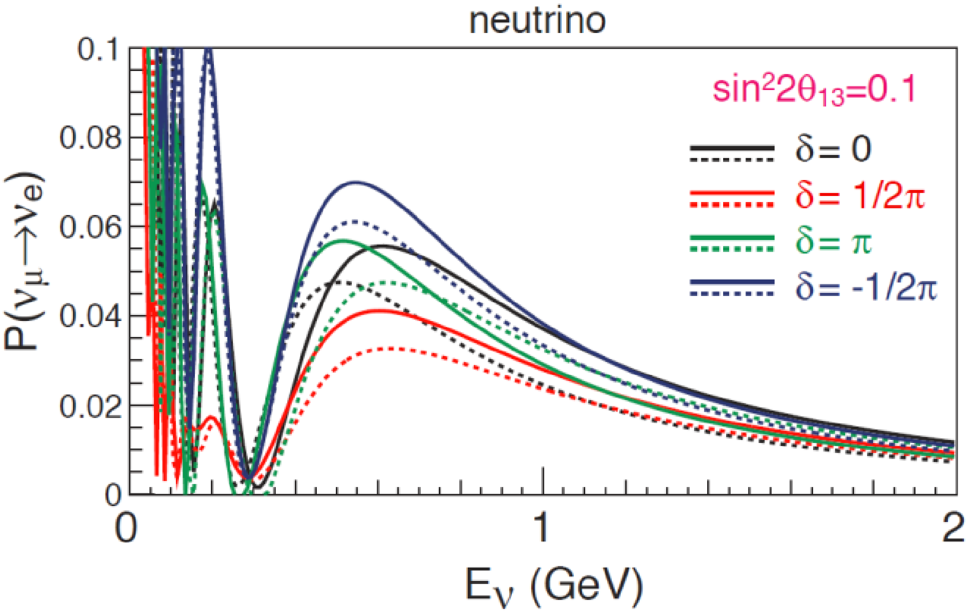
NB Many interesting muons don't escape
(The nature of a large detector, and indeed by design…)

Reconstructing the charge of long, high energy, tracks is easy



Compare χ^2 in the + and – hypotheses (well known from past experiments)

Let's optimize reconstruction in the interesting E_ν < 2 GeV region



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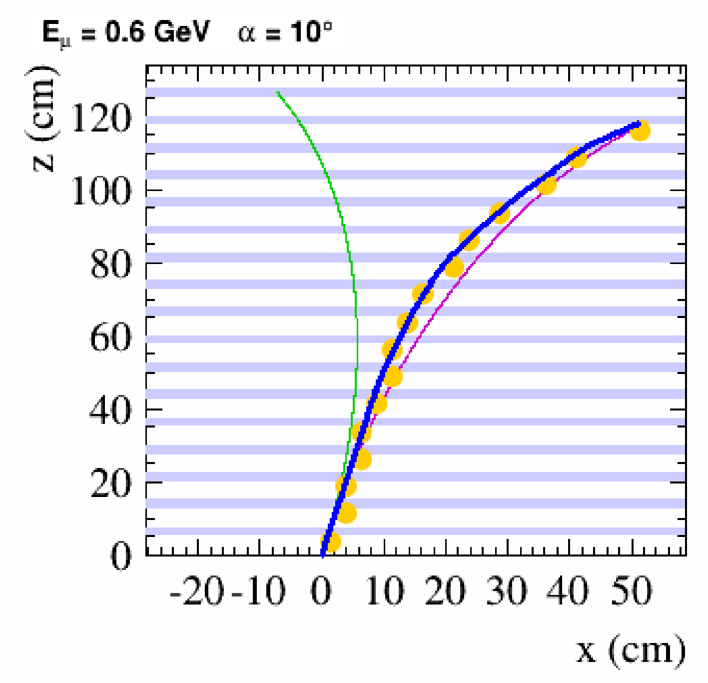

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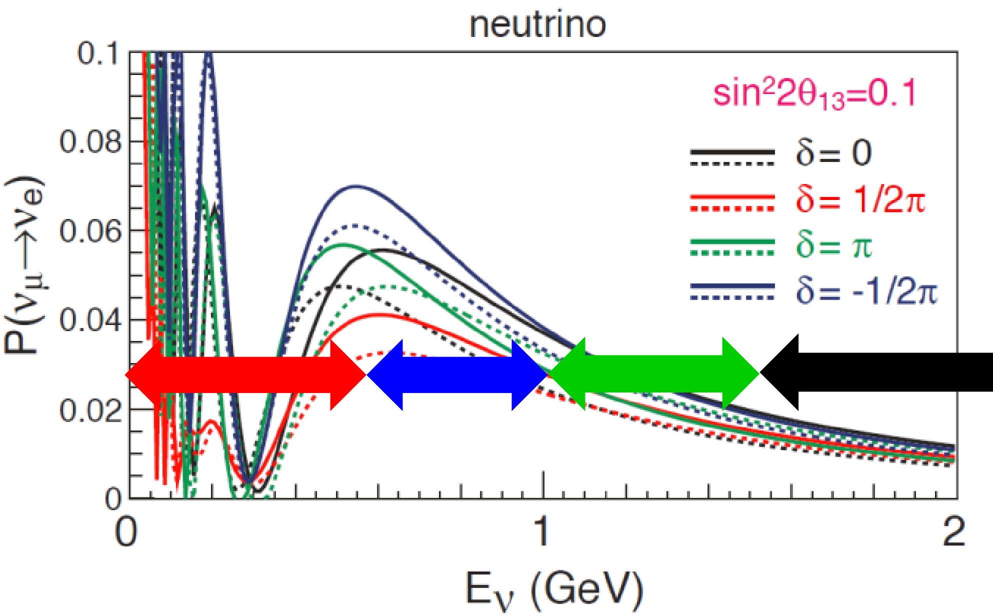
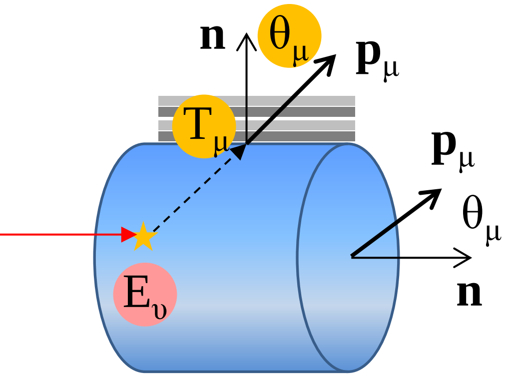
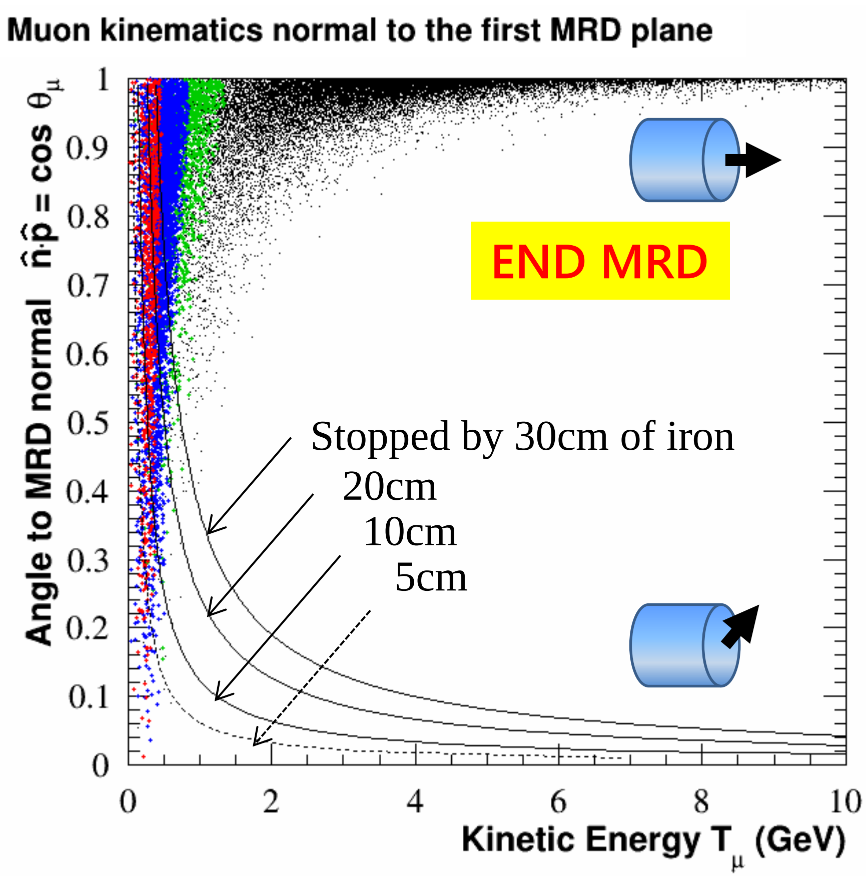
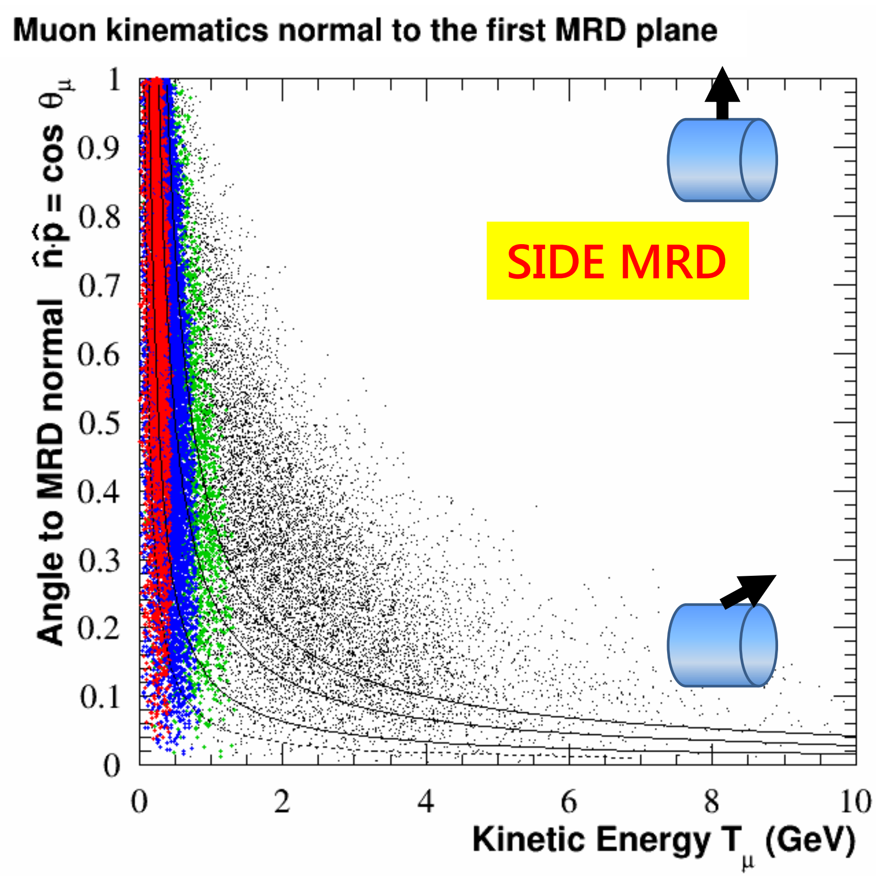


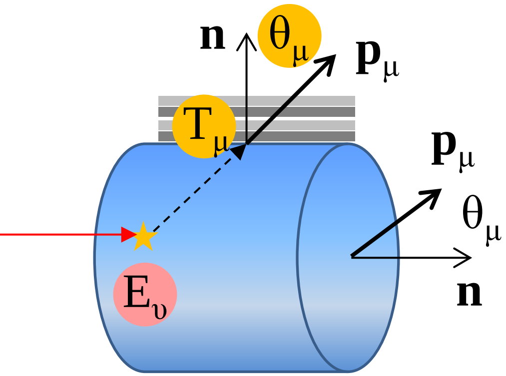


Muon kinematics of υ_μ CC events entering the MRD

$0 \text{ GeV} < E_\upsilon < 0.6 \text{ GeV}$
$0.6 \text{ GeV} < E_\upsilon < 1.0 \text{ GeV}$
$1.0 \text{ GeV} < E_\upsilon < 1.5 \text{ GeV}$
$E_\upsilon > 1.5 \text{ GeV}$

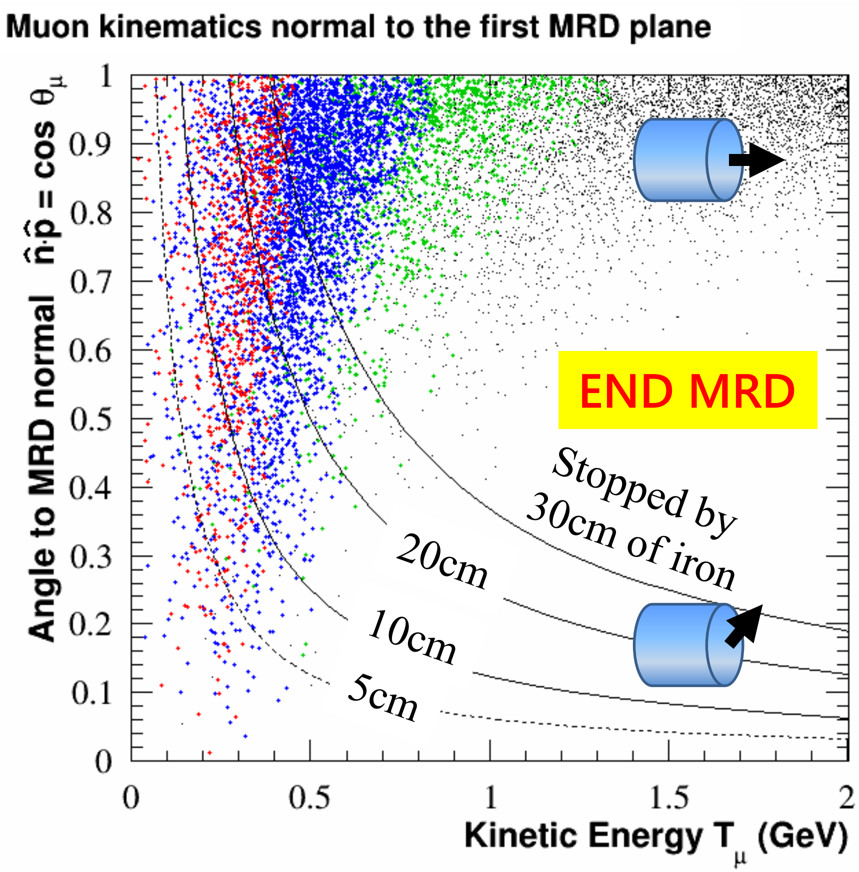


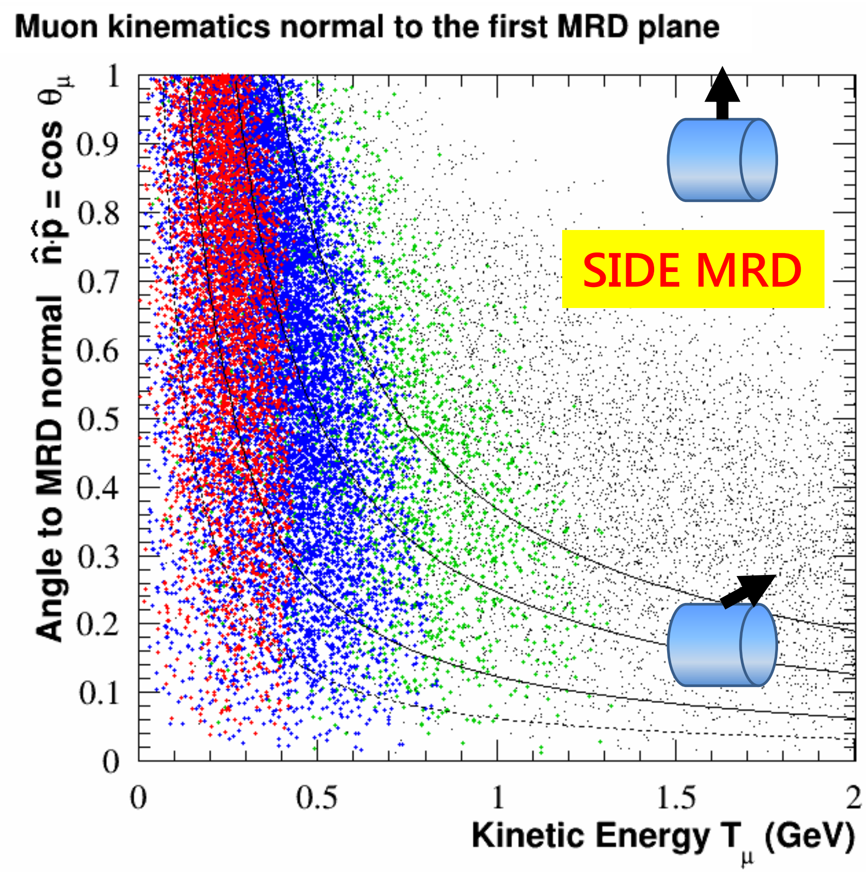




Muon kinematics of υ_μ CC events entering the MRD
ZOOM to oscillation region

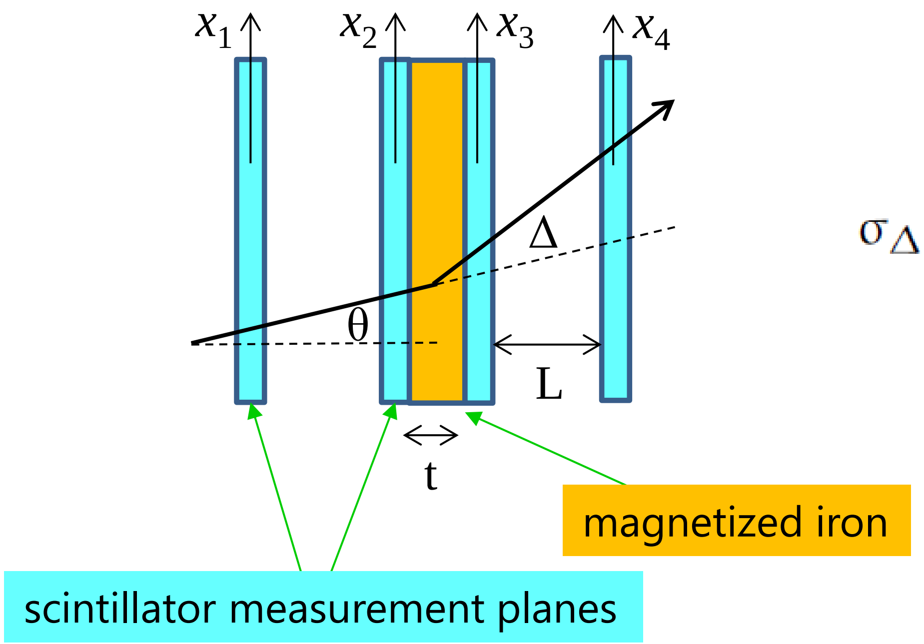
0 GeV < E_υ < 0.6 GeV
0.6 GeV < E_υ < 1.0 GeV
1.0 GeV < E_υ < 1.5 GeV
E_υ > 1.5 GeV



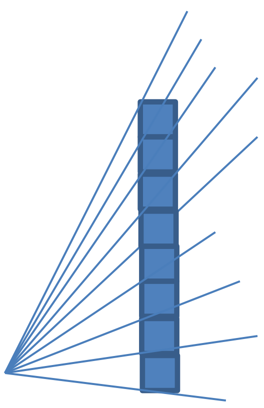


Multiple Scattering is the one unavoidable obstacle to charge reconstruction

In practice, however, track sampling resolution is just as big an effect



$$\sigma_\Delta \simeq \frac{2\sigma_x \cos^2\theta}{L}$$

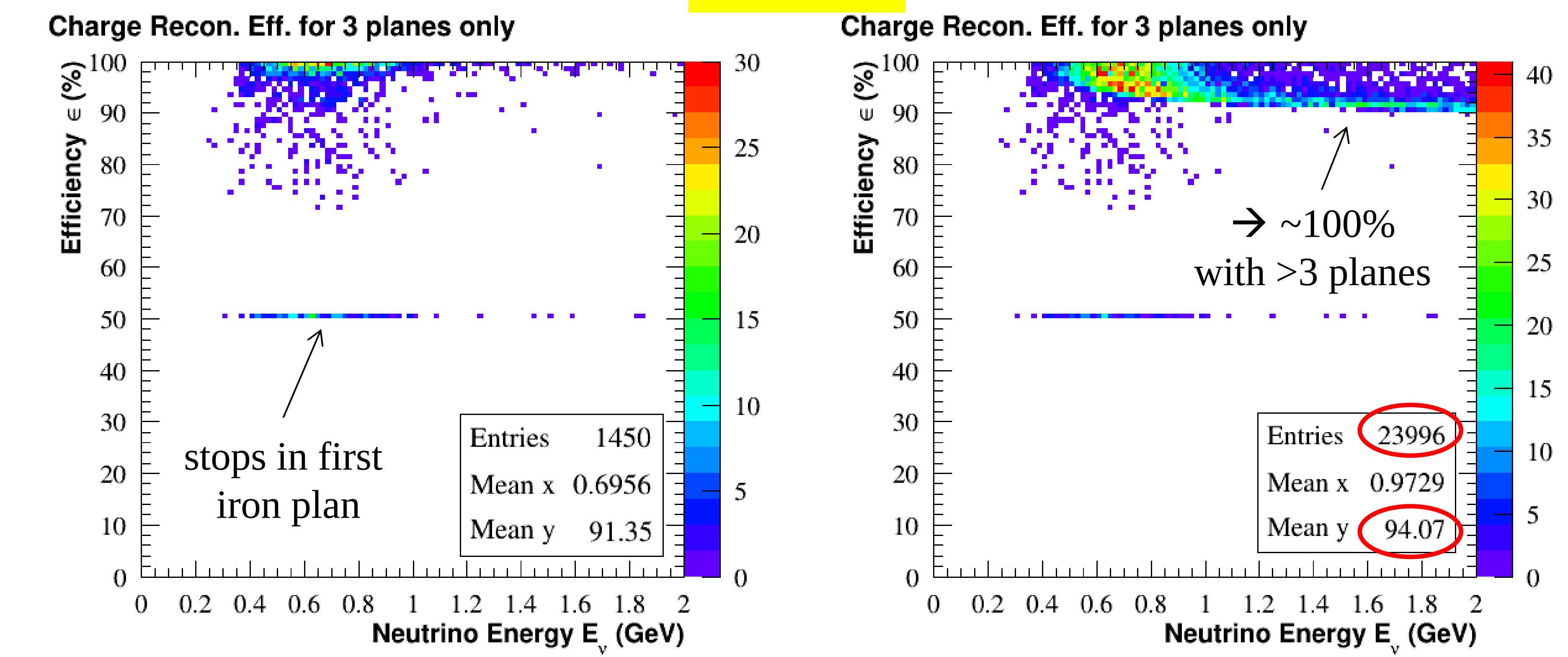


(or RPCs…?)

We can greatly improve the charge reconstruction of short tracks by including and optimizing a gap *L* between the initial few measurement planes

Reconstruction with just three 5cm magnetized planes (L=10cm)

END MRD



muons which stop in or before the fourth iron plane

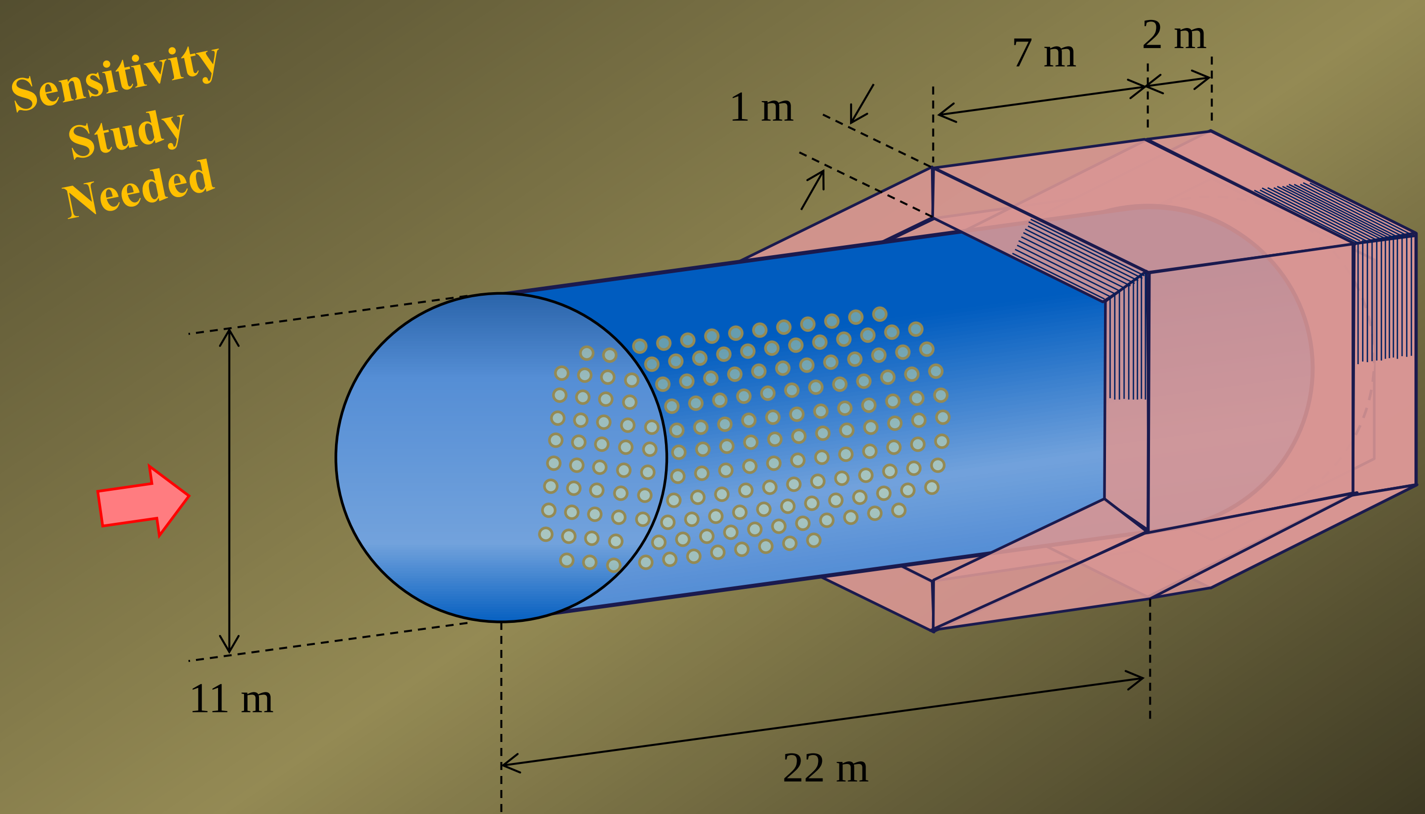
all muons with E_υ < 2 GeV

Estimated 94% charge reconstruction efficiency in the oscillation region

Need to demonstrate this with a detailed Monte Carlo

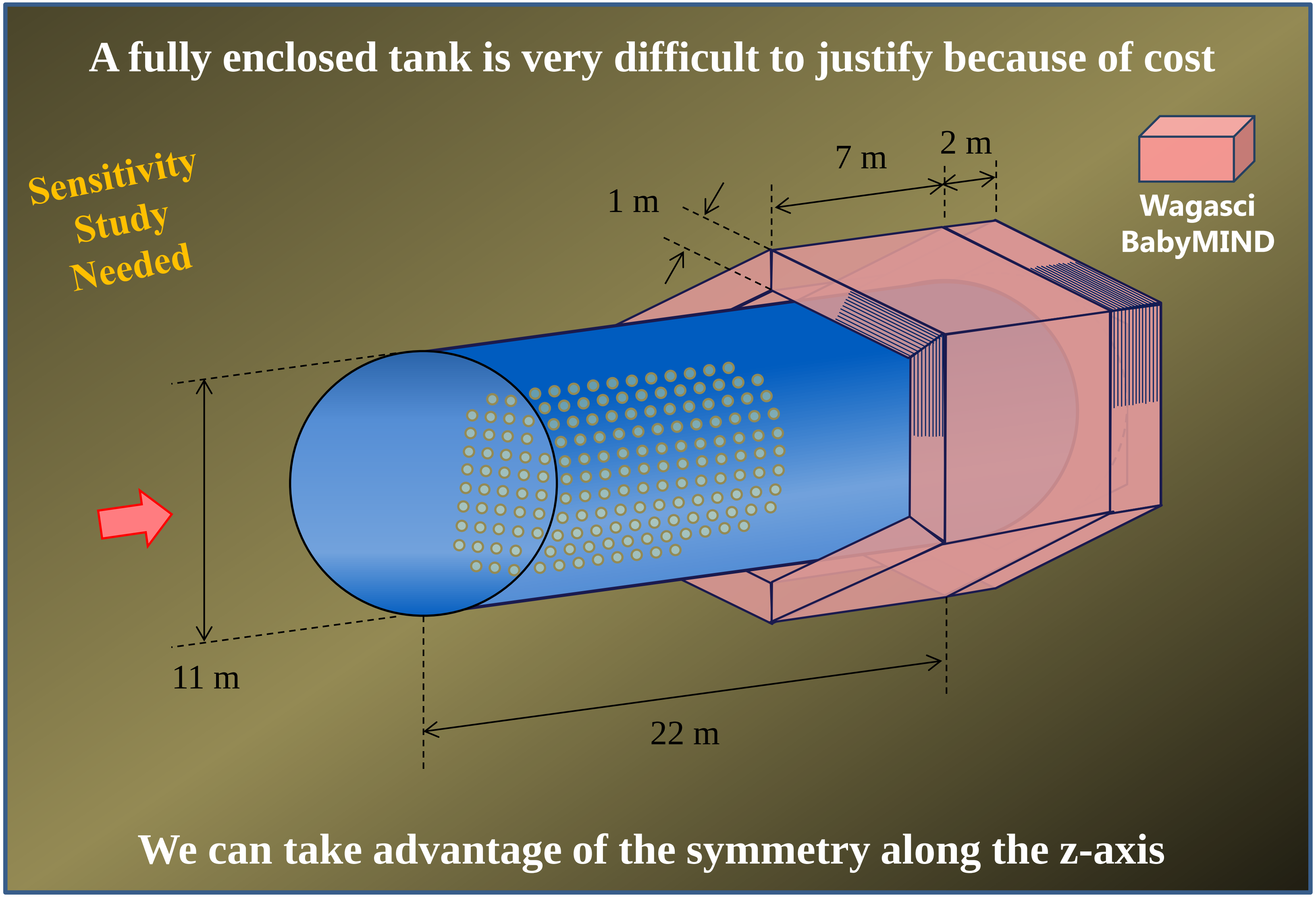
Option 1

A fully enclosed tank is very difficult to justify because of cost



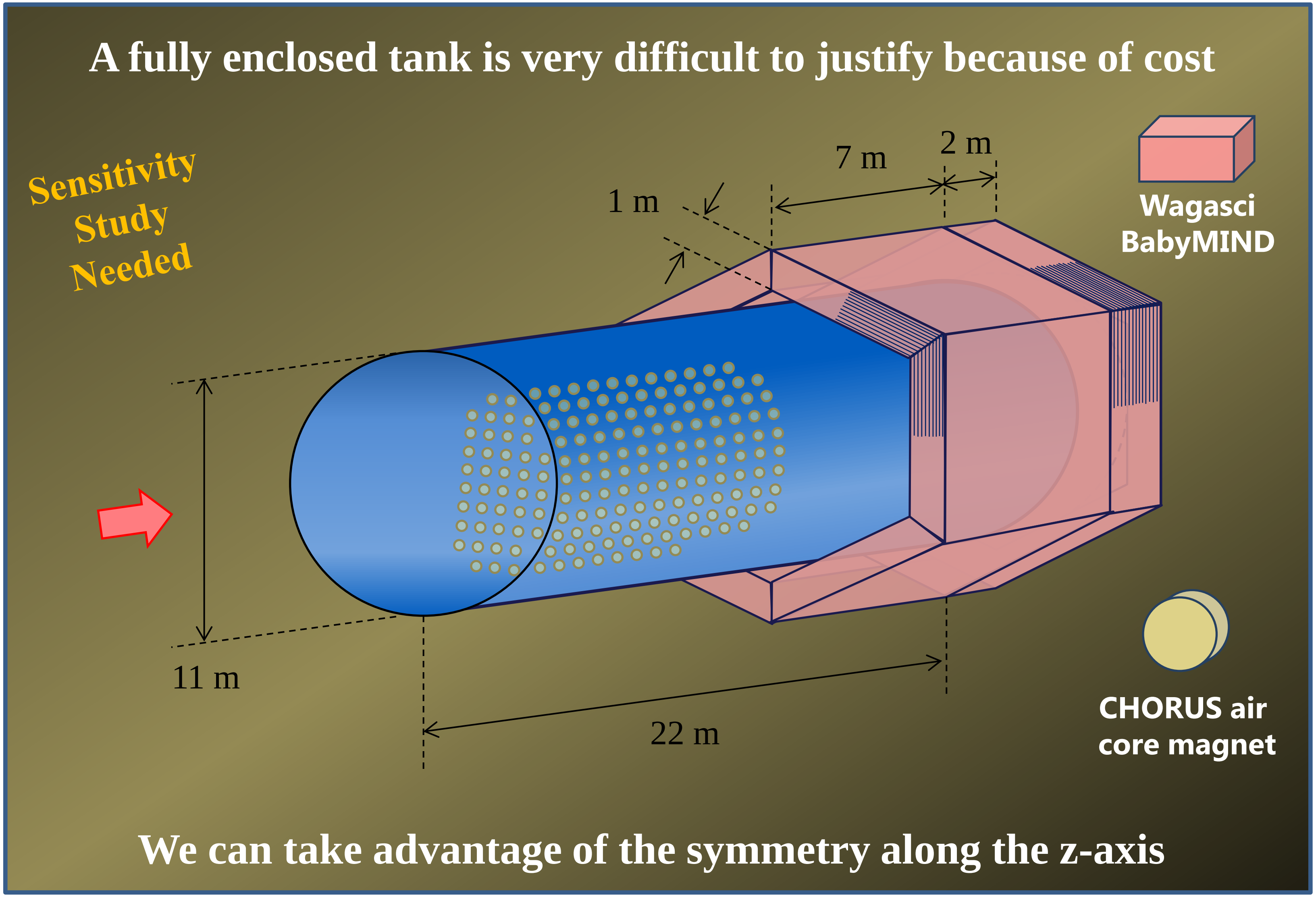
We can take advantage of the symmetry along the z-axis

Option 1



A fully enclosed tank is very difficult to justify because of cost
Sensitivity
Study
Needed
1 m
7 m
2 m
Wagasci
BabyMIND
11 m
22 m
We can take advantage of the symmetry along the z-axis

Option 1


A fully enclosed tank is very difficult to justify because of cost
Sensitivity Study Needed
1 m
7 m
2 m
Wagasci BabyMIND
11 m
22 m
CHORUS air core magnet
We can take advantage of the symmetry along the z-axis

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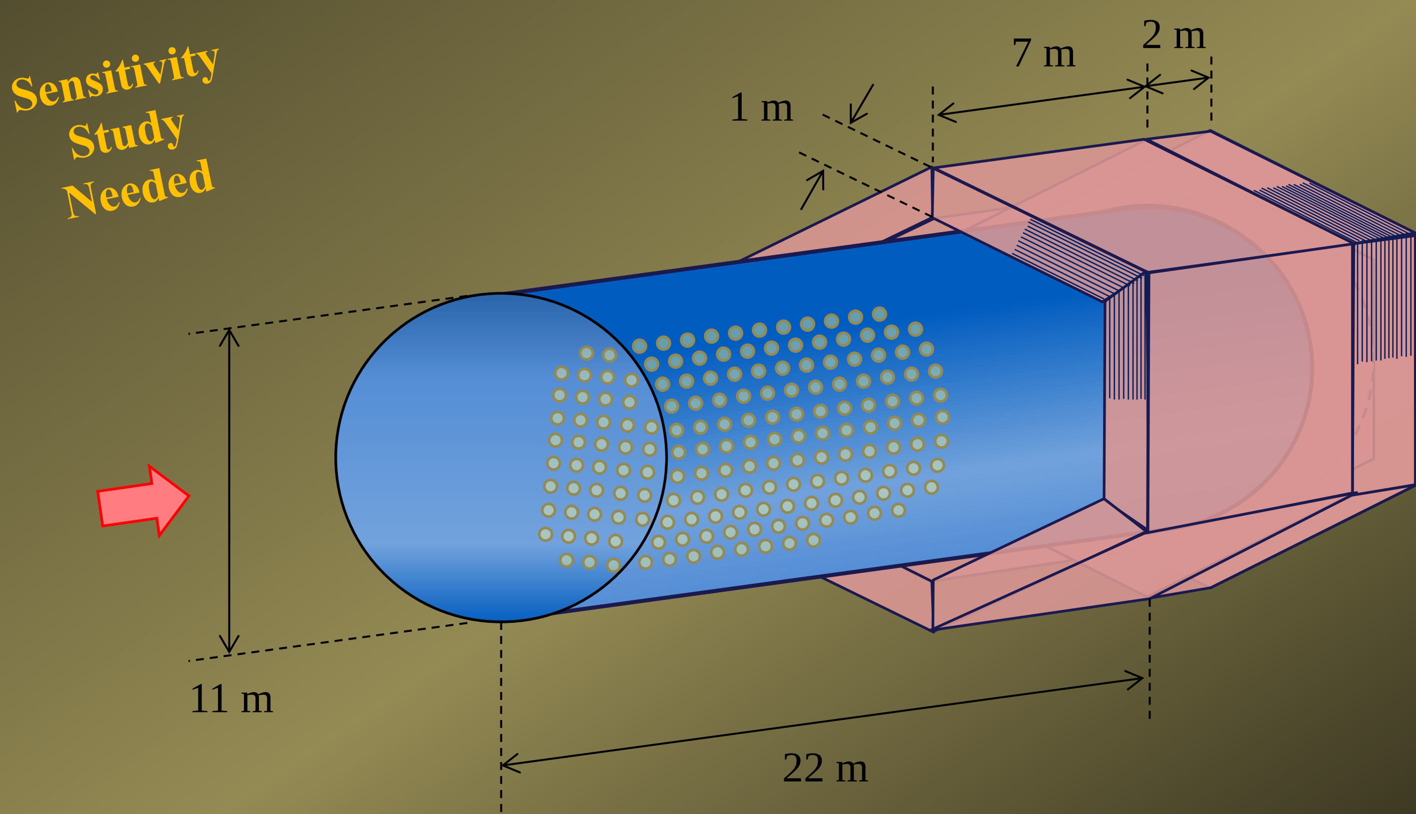
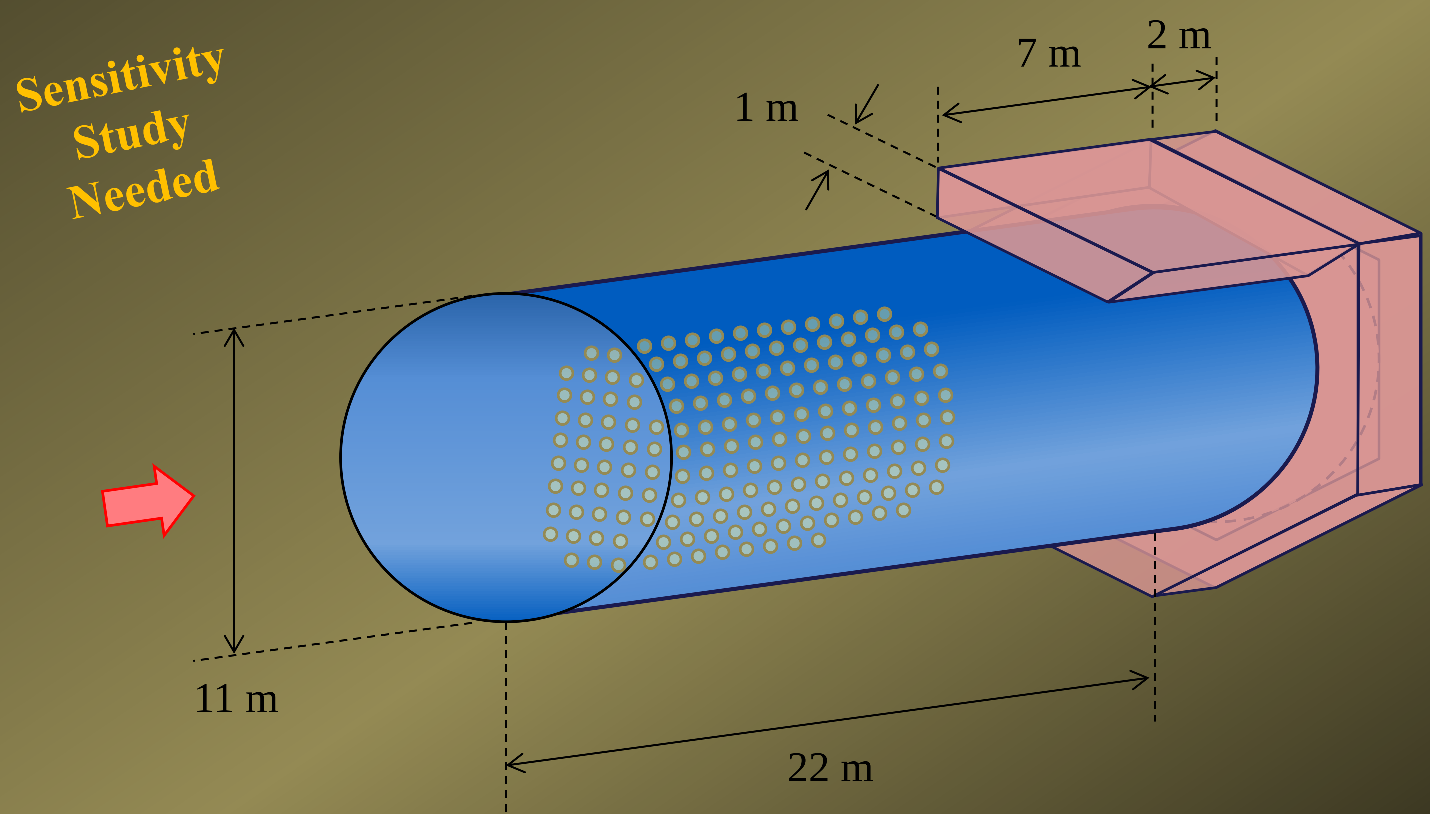


We can take advantage of the symmetry along the z-axis

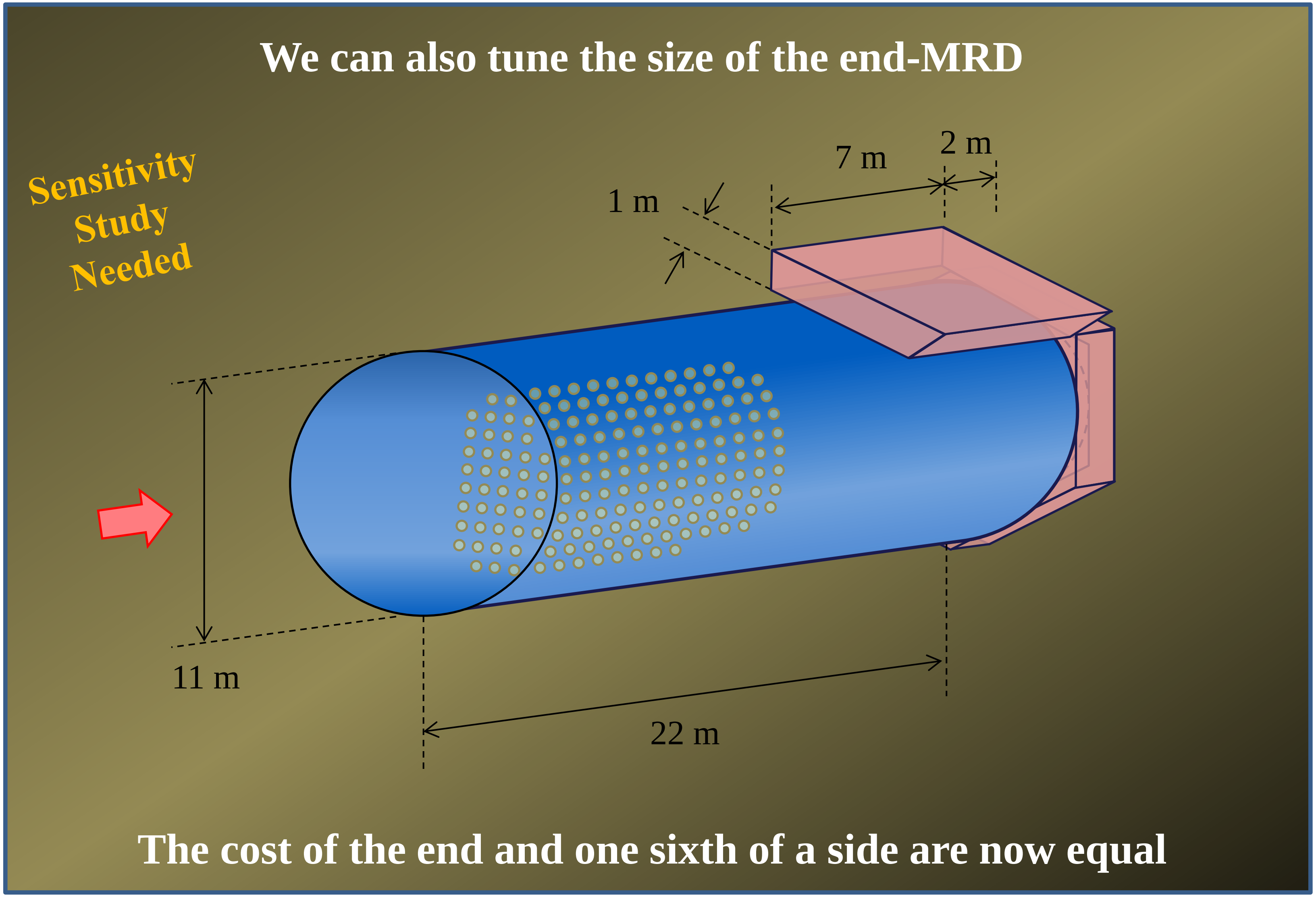
Option 2

There is also approximate azimuthal symmetry



Savings, and still reduced systematics on high-angle cross sections?

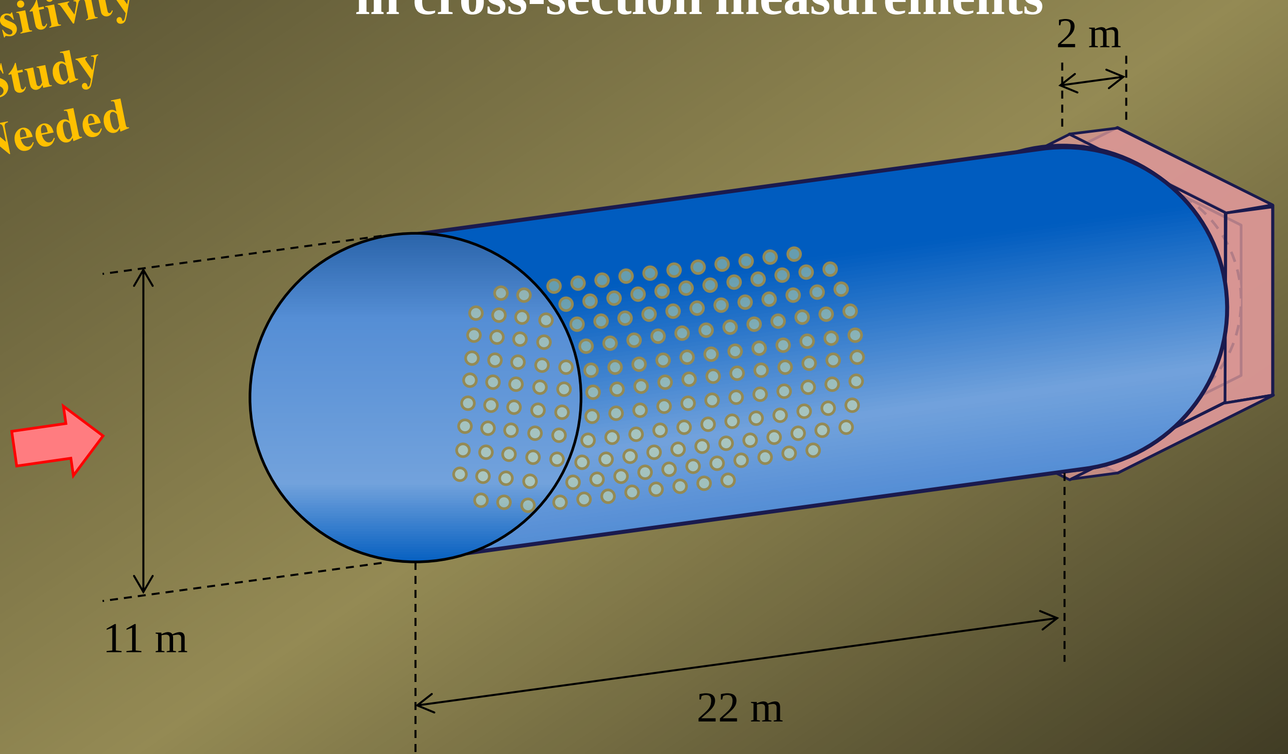
Option 3


We can also tune the size of the end-MRD
Sensitivity
Study
Needed
7 m
2 m
1 m
11 m
22 m
The cost of the end and one sixth of a side are now equal

Option 4

Entirely removing the side-MRD is also an option, though we lose the capability to constrain the wrong-sign BG for high-angle muons in cross-section measurements

Sensitivity Study Needed



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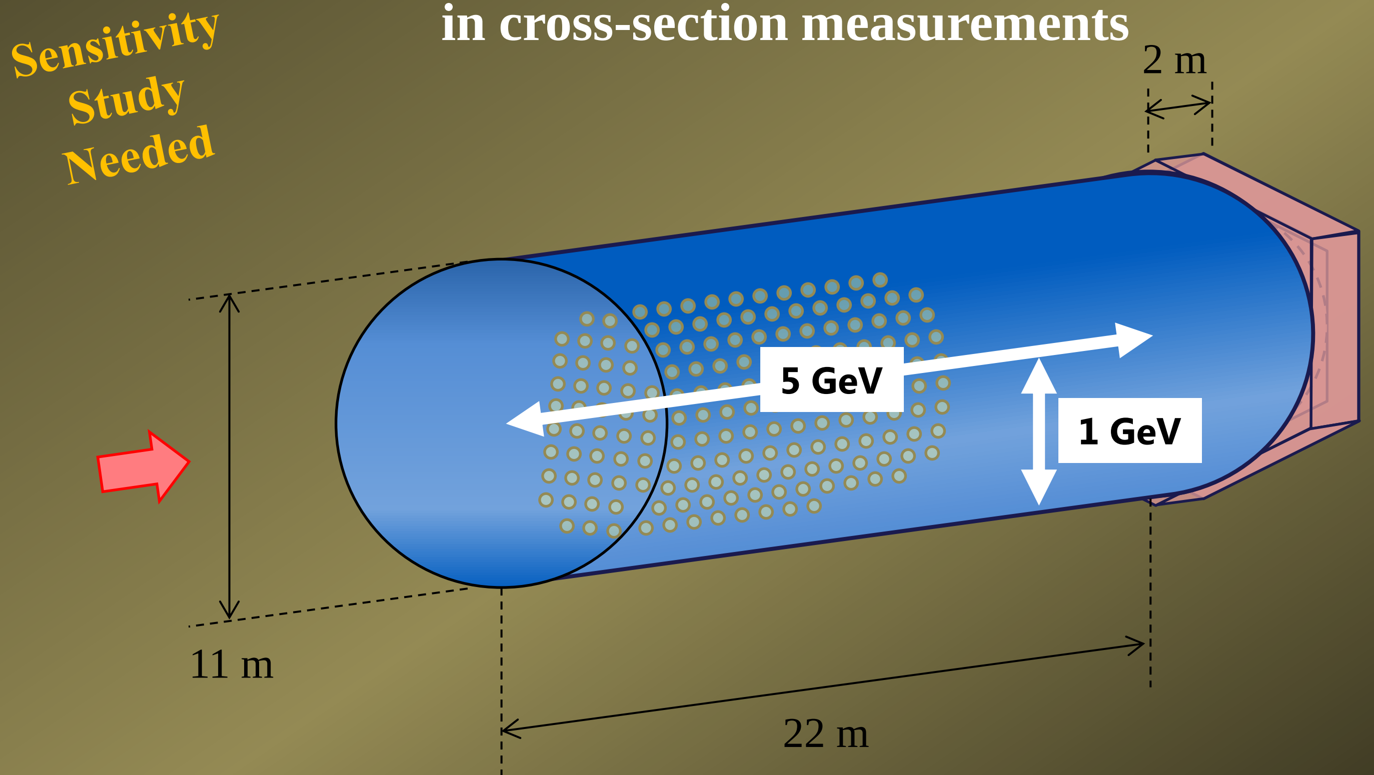
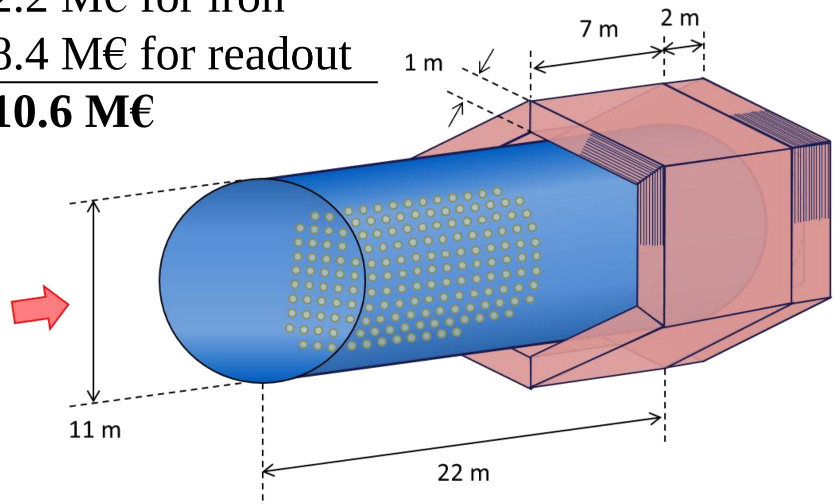
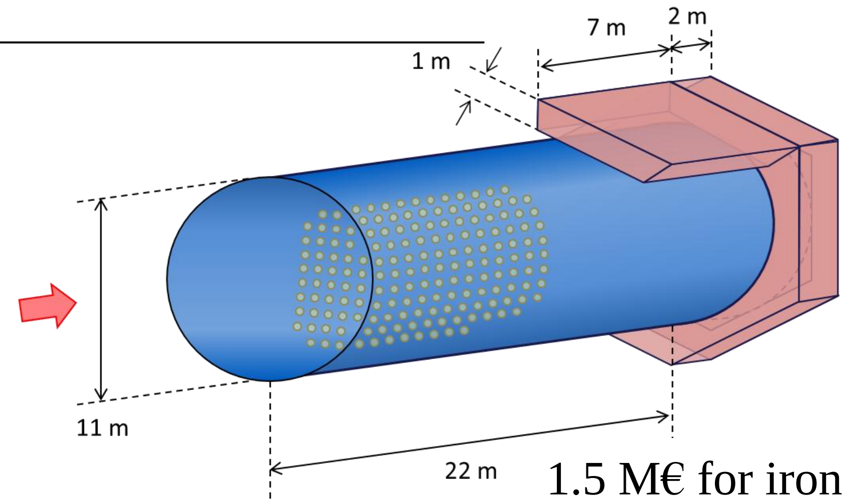


We can still benefit from a larger sample, by using calorimetry by muon range to include muons which exit the tank downstream

Rough, 'Ballpark' Cost Estimates

2.2 M€ for iron
8.4 M€ for readout
10.6 M€

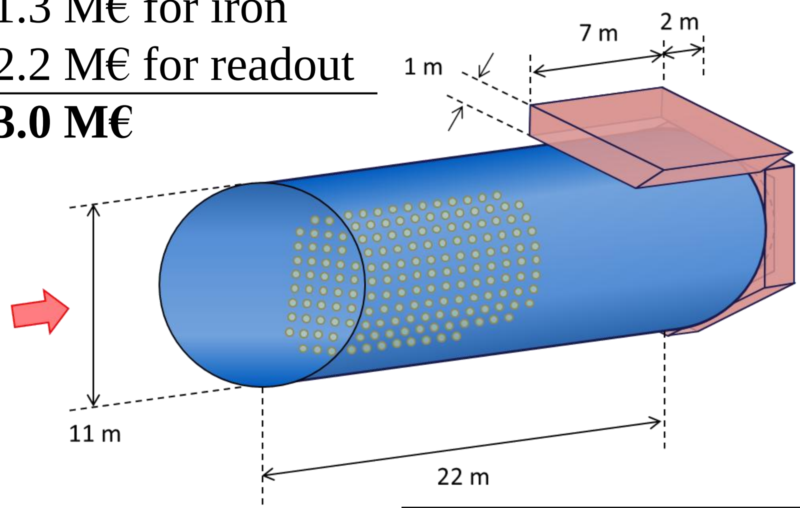


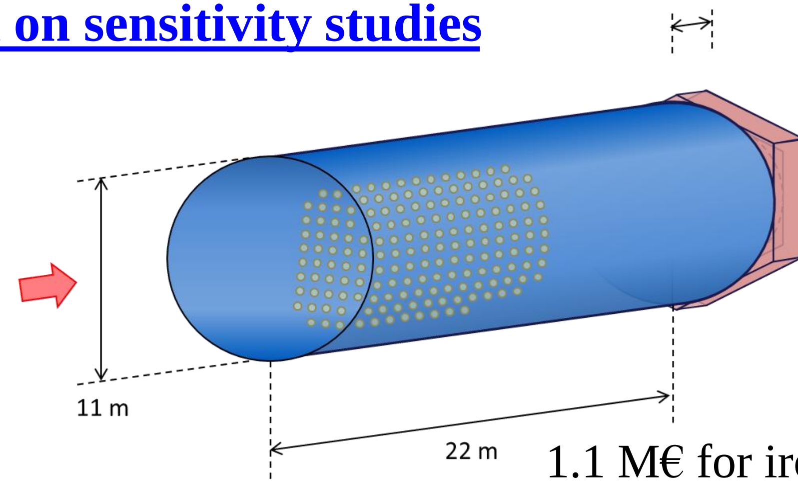


1.5 M€ for iron
2.5 M€ for readout
4.0 M€

We will decide based on sensitivity studies

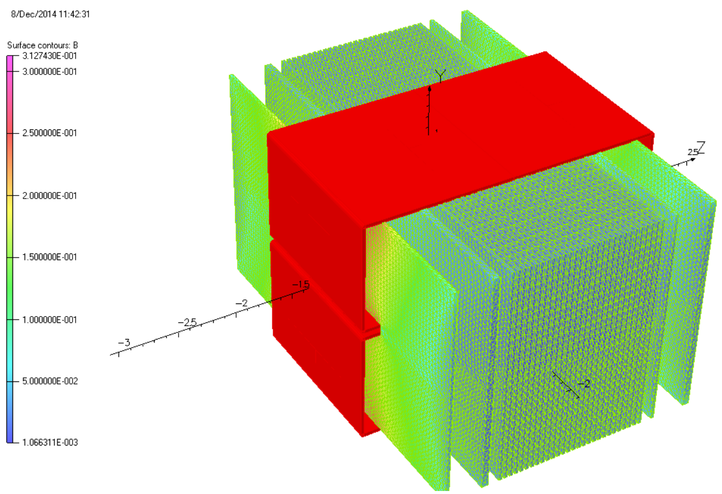
1.3 M€ for iron
2.2 M€ for readout
3.0 M€

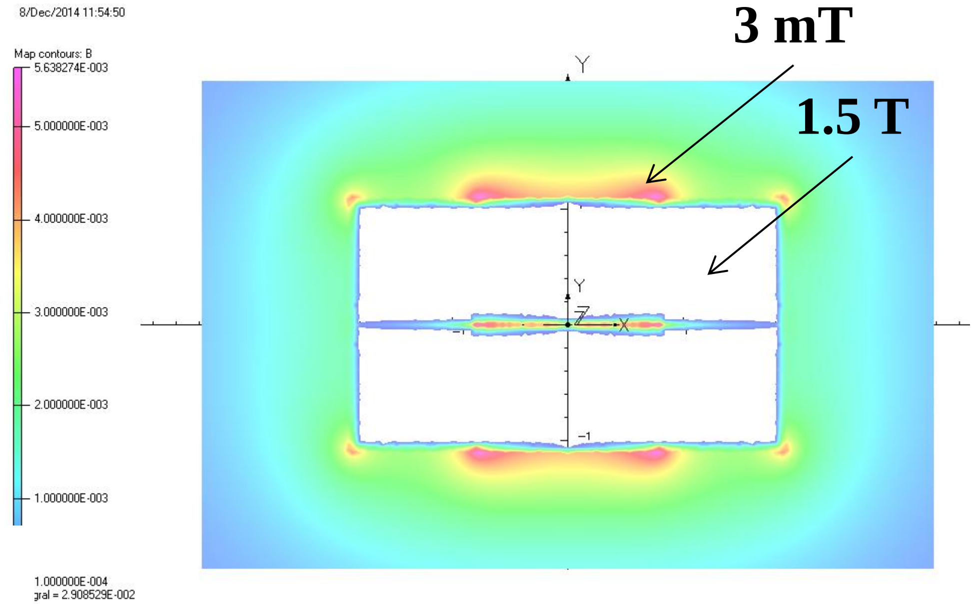


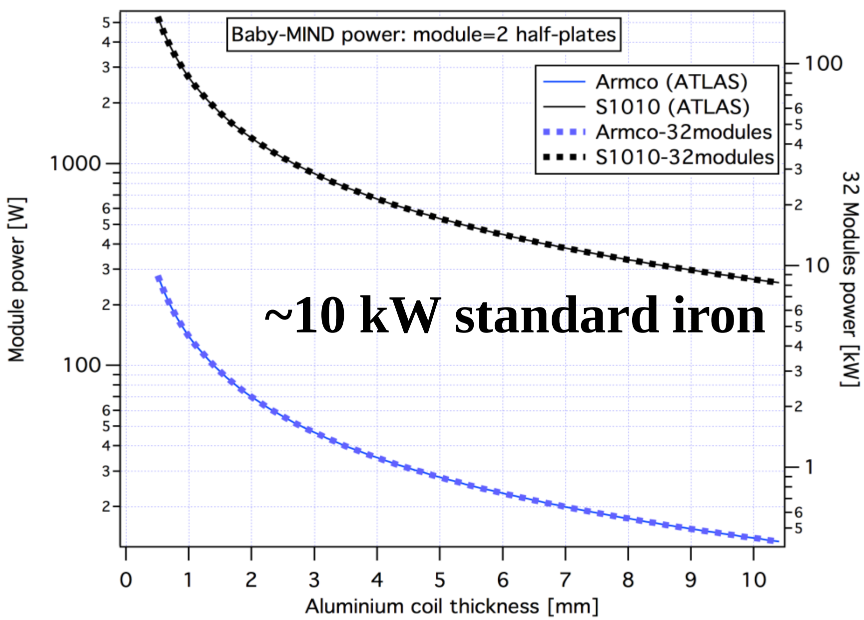


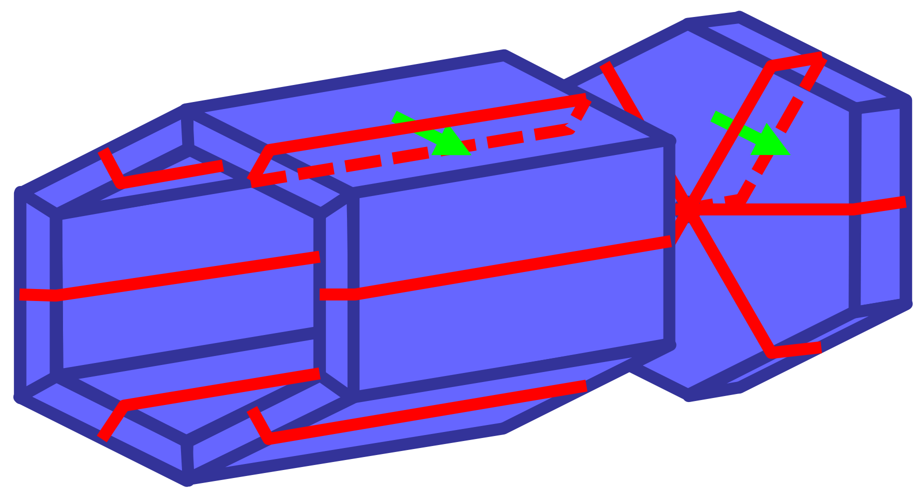
1.1 M€ for iron
1.1 M€ for readout
2.2 M€

Magnetization of the MRD









Summary

— There are three main benefits to adding an MRD to TITUS

1 Increased sample size *via* calorimetry by muon range

– Include muons which exit the tank but range out in MRD
– Possibility to save money by shrinking the tank, with same statistics?

2 Direct constraint on wrong-sign contamination

Pro: Well understood physics, high reconstruction efficiency
Con: Sample limited to muons which exit the tank

3 Validation of gadolinium performance

– Gd is a relatively new analysis technique
– Cross-checking with 2 will give us the confidence to really exploit it

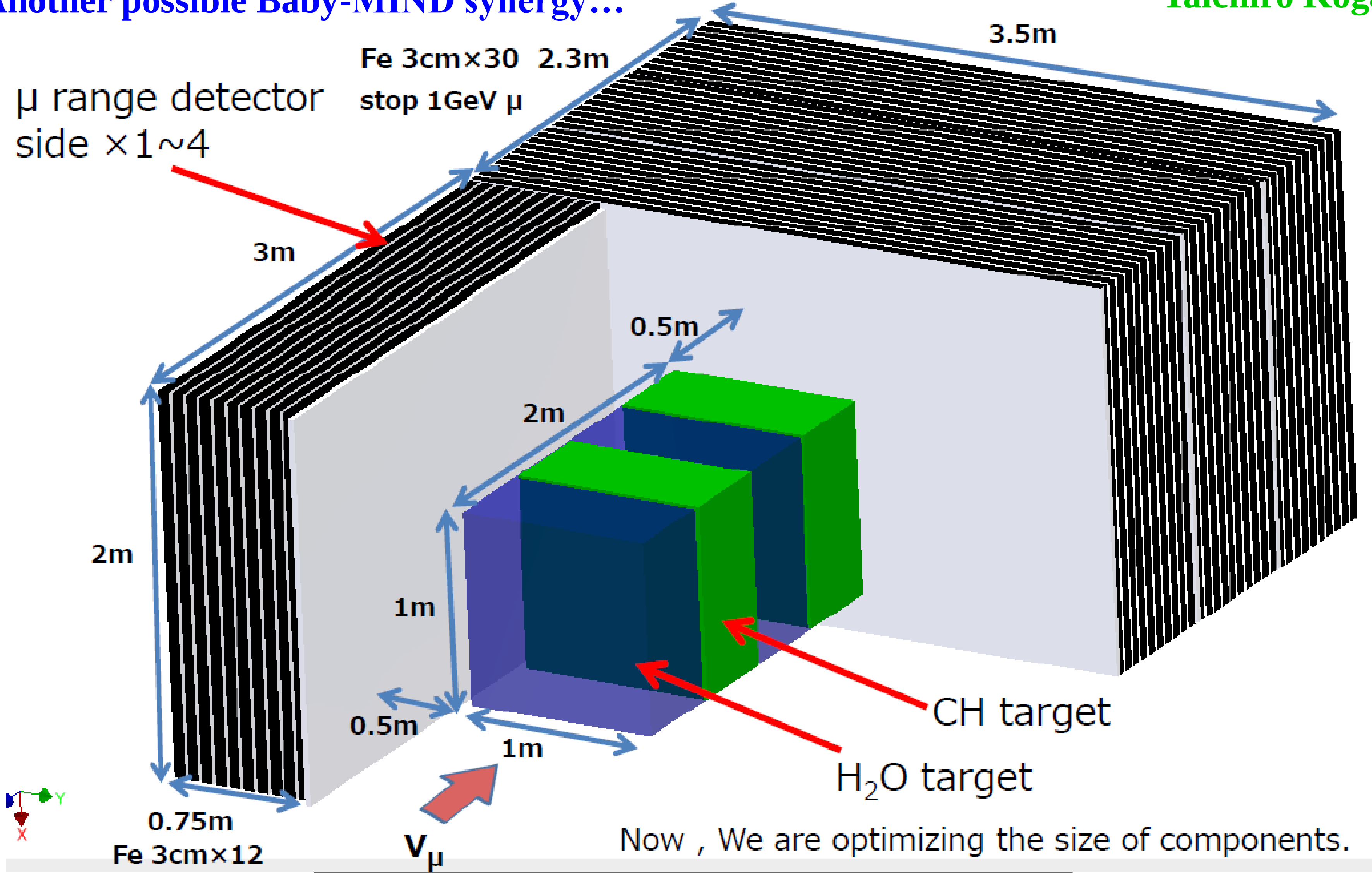
— The sensitivity of several options needs to be investigated
— We will learn from the Wagasci experience with a low-E magnetized MRD

Backup slides

The B2 experiment / 'WAGASCI'

Another possible Baby-MIND synergy…

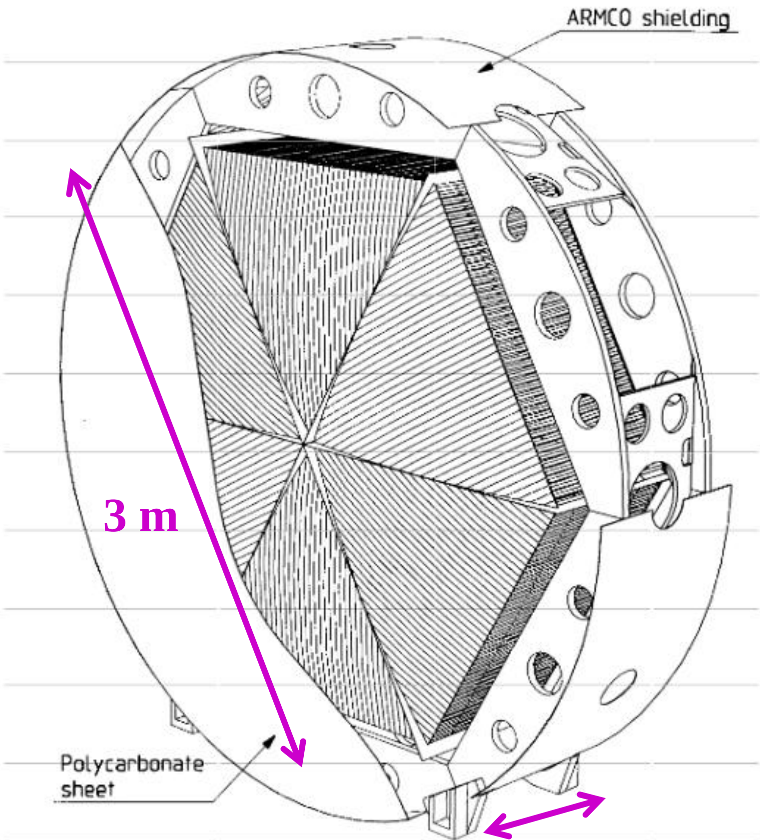
Taichiro Koga



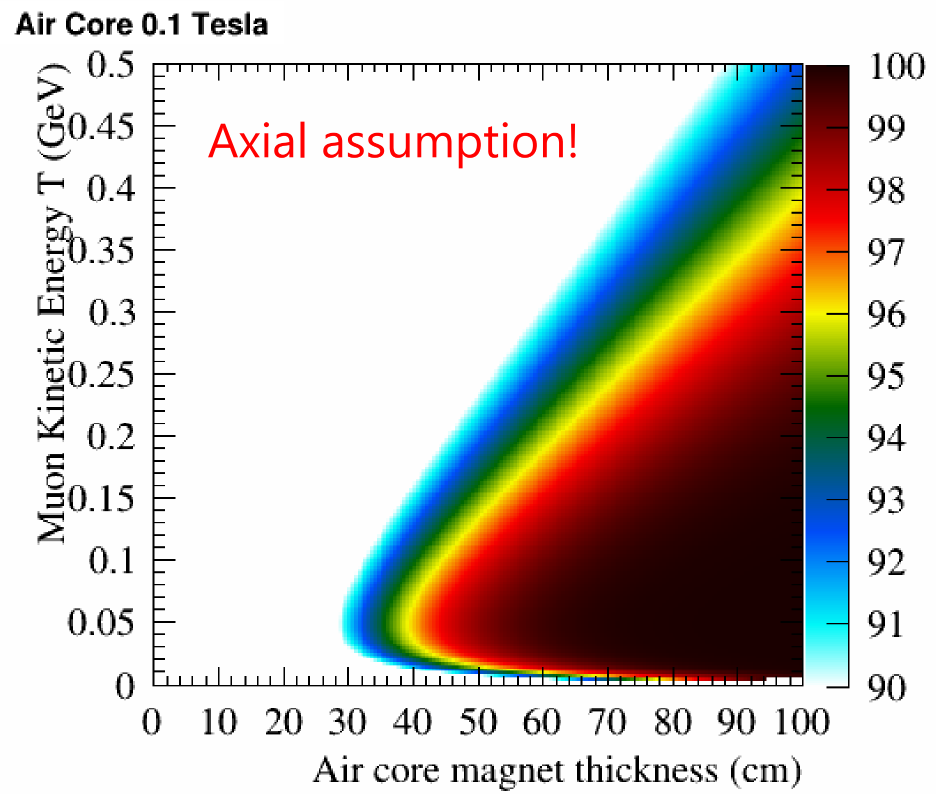
And finally, a fascinating suggestion from Gabriella and Emilio:
➔CHORUS style toroidal air core magnets

Can neglect multiple scattering in air as X_0 = 300 m, compared to 1.8 cm in Fe

The front and back coils are 2.5 mm thick and present 5.6% z/X_0 each



CERN–PPE/94–176, 10 November 1994, F. Bergsma *et al.*



➔ High efficiency and no energy threshold problem

Baby-MIND and TASD: H8 beamline in North Area

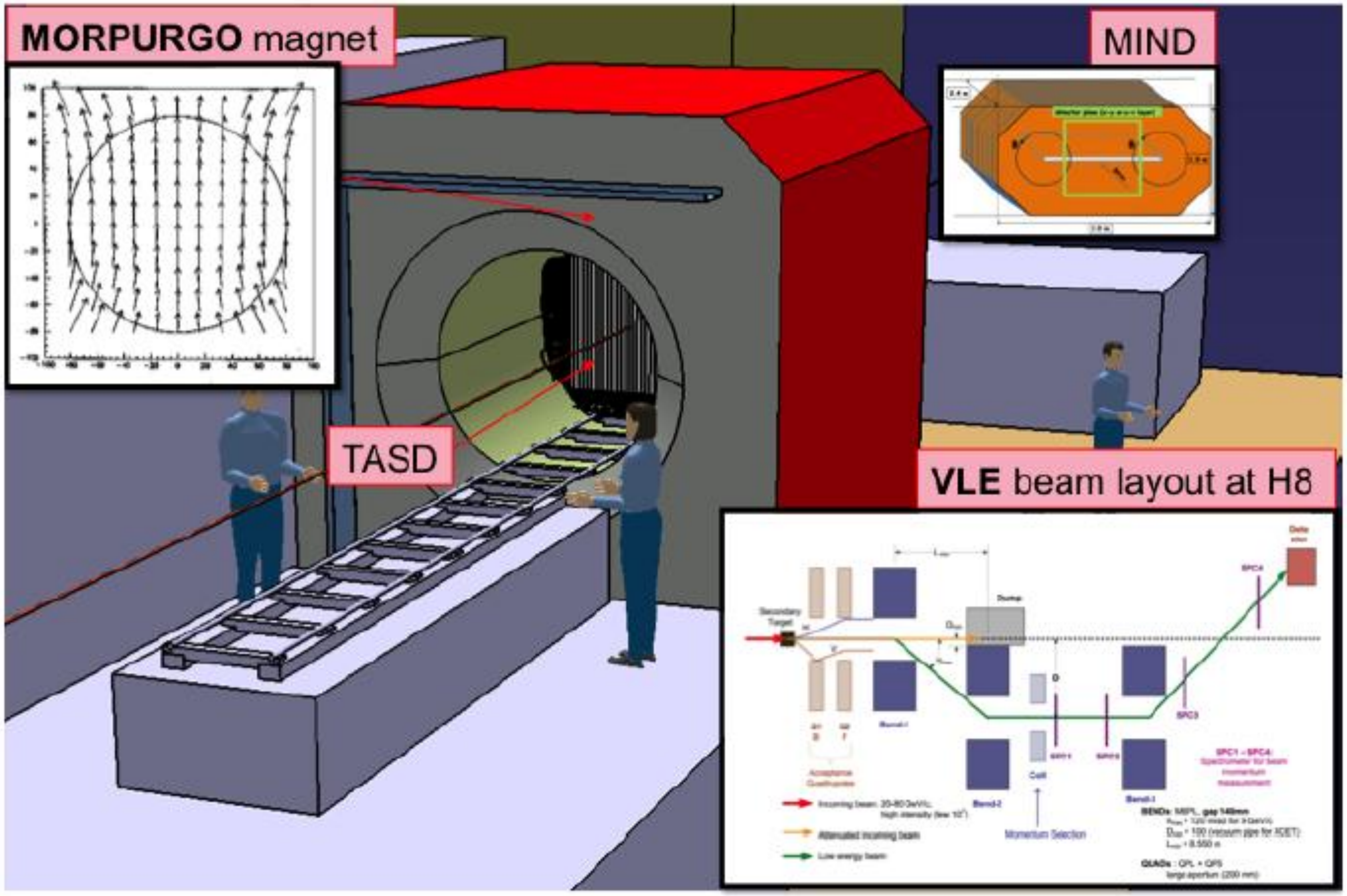
(or possibly behind the LBNO-Demo)

1.5 Tesla

3 m

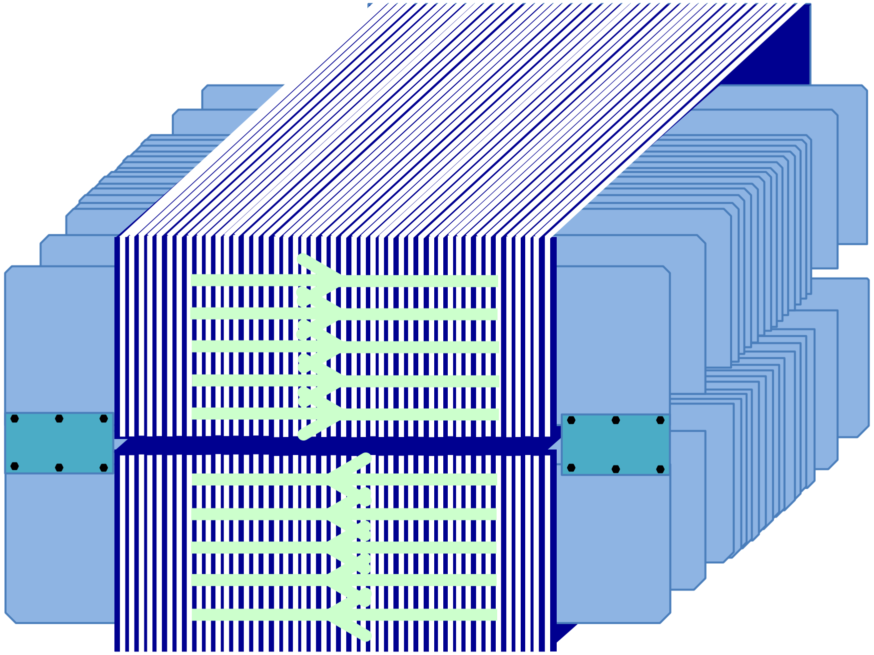
2.5 m

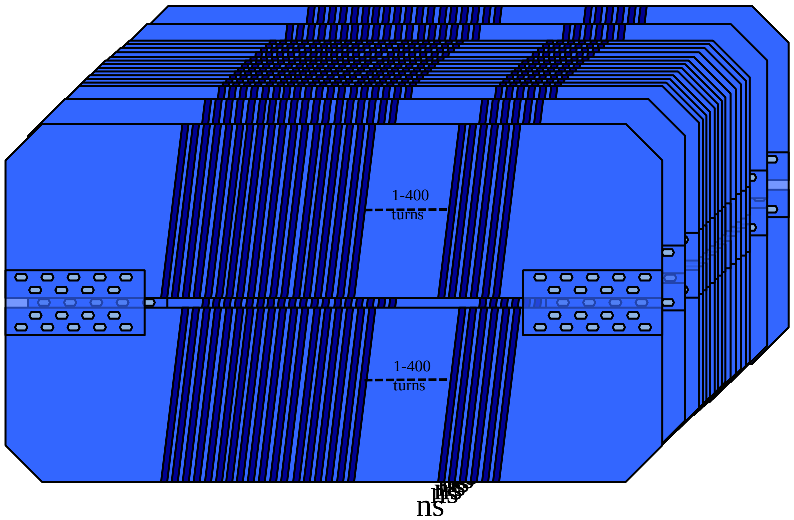
1.5 m



Could also be a practical demonstration of the TITUS MRD charge reconstruction

Contact: *Etam Noah, University of Geneva*





Option 1)
2 large coils – one upper, one lower coil each coil wound around half the height of the iron plate assembly,
Pros: field lines are "in principle" very uniform over a wide surface area,
Cons: coil assembly is large and difficult to manipulate. Integration of detector modules is challenging.

Option 2)
Each "half-plate" has its own coil
Pros: Straightforward assembly of detector planes,
Cons: Need technical solution to wind coils.

Some numbers

18% of muons escape the tank

- Of these ¾ leave through through the sides
- But the sides have eight times the area of the end, and the event rate is much lower
- However a partial side MRD could be thinner as there are few high energy muons

Calculations predict good charge reconstruction for a TITUS end-MRD

- ~100% in the high energy tail (could test the ~80% efficient Gd method)
- ~95% efficiency in the oscillation region – to be demonstrated with full Monte Carlo!
- Optimum low-energy charge reconstruction at t = 5 cm iron plate thickness, but this is not a very sensitive parameter – both θ_{MS} and θ_B increase with iron thickness

Charge reconstruction in a magnetized side-MRD is trickier

- The angle to the MRD normal vector is higher ➔ reconstruction efficiency is lower

Magnetizing the MRD is not trivial

- I suggest it would be ambitious to magnetize more than a portion of a side-MRD
- Gaps between plates may significantly increase power requirements
- Still in the process of being understood – we can learn from the Wagasci experience
- Wagasci has CERN’s support for design and construction and a timescale of ~ 1 year