Hadron Measurement with Transition Radiation

Intro
A Transition radiation primer
TR for hadrons in DUNE
Rates
Optics and photon detection

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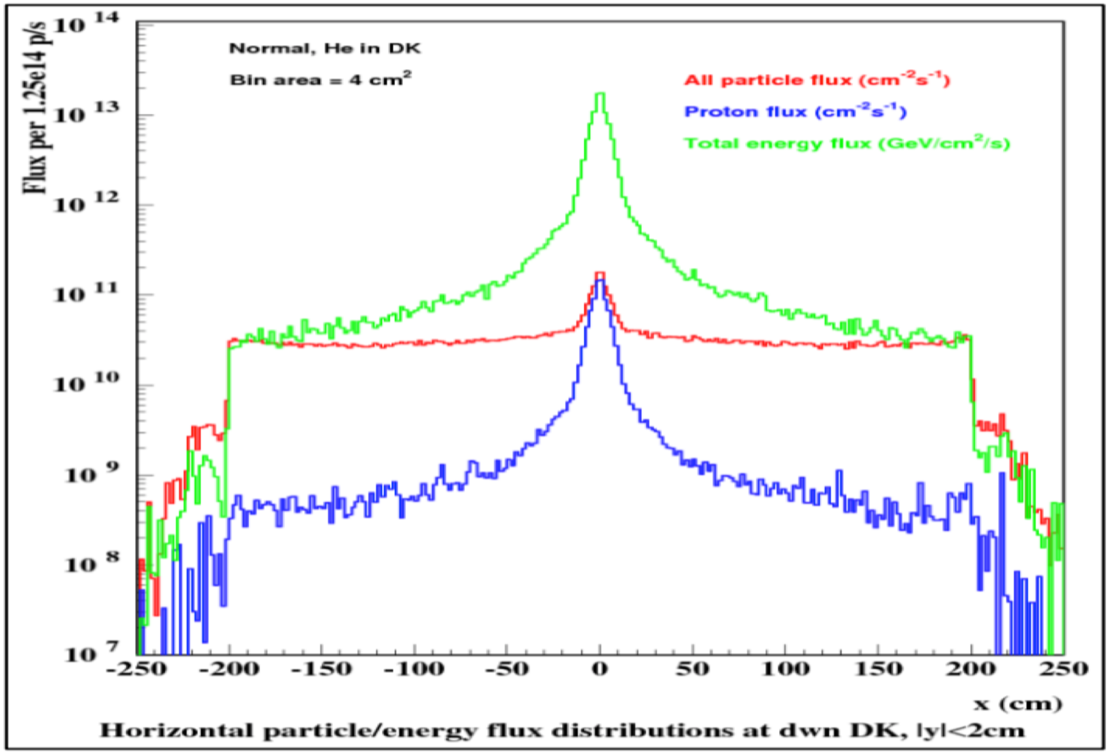
Introduction

- We would *really* like to know about the hadrons in the decay pipe
- To this end, we had a fairly advanced proposal to put a spectrometer in the beamline
- At the last collaboration meeting we had a presentation by Cody Milne (Idaho State)
- I think the last experiment to try this was K2K. They put a Chernkov counter upstream of the hadron monitors; set the index of refraction, n, so that it was blind to protons that had not interacted in the target.
  - The analysis did go into their final result
  - They didn't try it again for T2K
  - Setting n like that makes them blind to most of the $\pi^{\pm}$ and all of the $K^{\pm}$ spectrum

Introduction



CDR Annex 3
Fig 2-91

2.4 MW on target

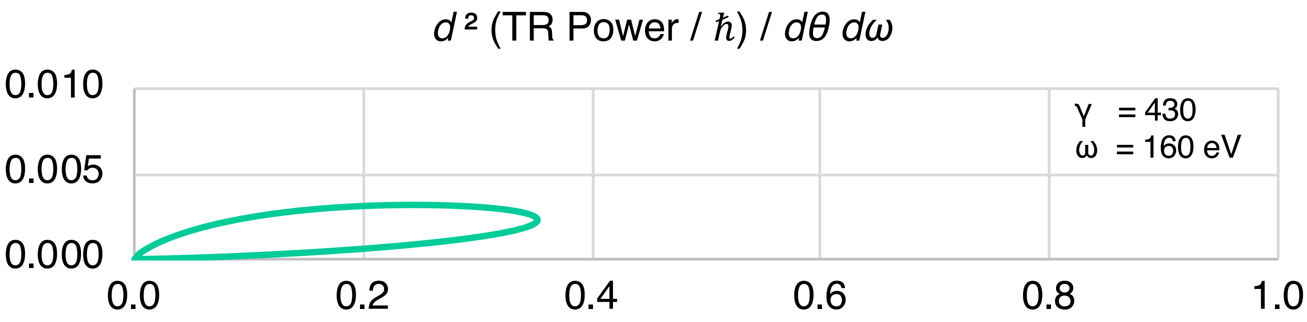
time-averaged rate

(Mokhov)

Our protons are a large part of the flux only within 30cm of the beamline axis… could think of Cherenkov outside that region. But rates are very high... so try transition radiation which typically produces less light than Cherenkov radiation

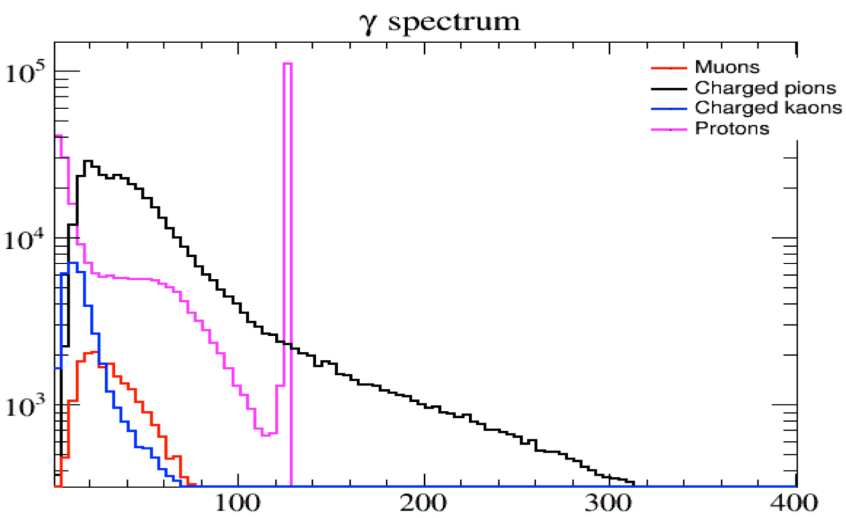
A Transition Radiation Primer

- **A moving charged particle in vacuum has some EM fields and does not radiate**
- **That same particle in a material (of plasma frequency ω_p) has different fields and does not radiate either**
- **The transition from one set of fields to the other accelerates the electrons in the material, thereby producing radiation**
- **Most of the radiation is forward, at angle $\theta \approx 1/\gamma$**

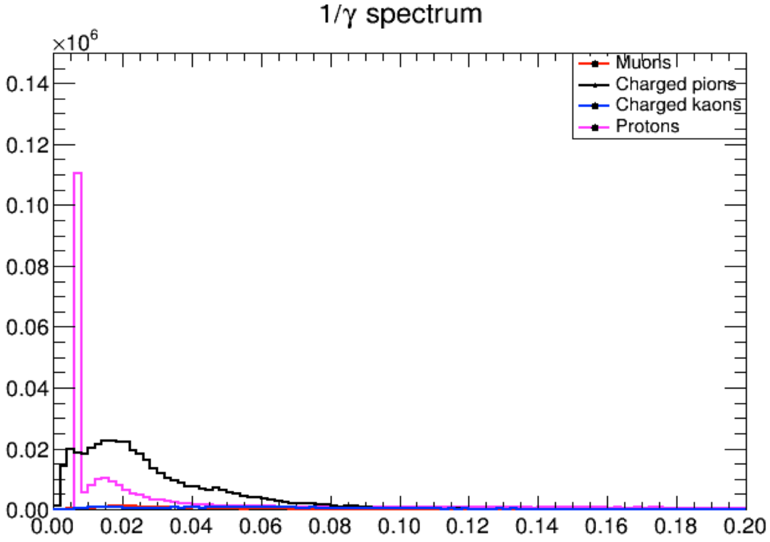


- **Total radiated energy is proportional to γ: $I = \alpha\hbar\omega_p\gamma / 3$**
- **Nearly all the radiation happens at frequencies below $\gamma\omega_p$**
- **Interested in $\gamma \cong 2$ (1 GeV $K^{\pm}$) to $\gamma \cong 250$ (35 GeV $\pi^{\pm}$)**

TR for hadrons in DUNE



Showing particles that enter `g4lbne` decay pipe at angle so that they'd exit end of pipe if they don't decay



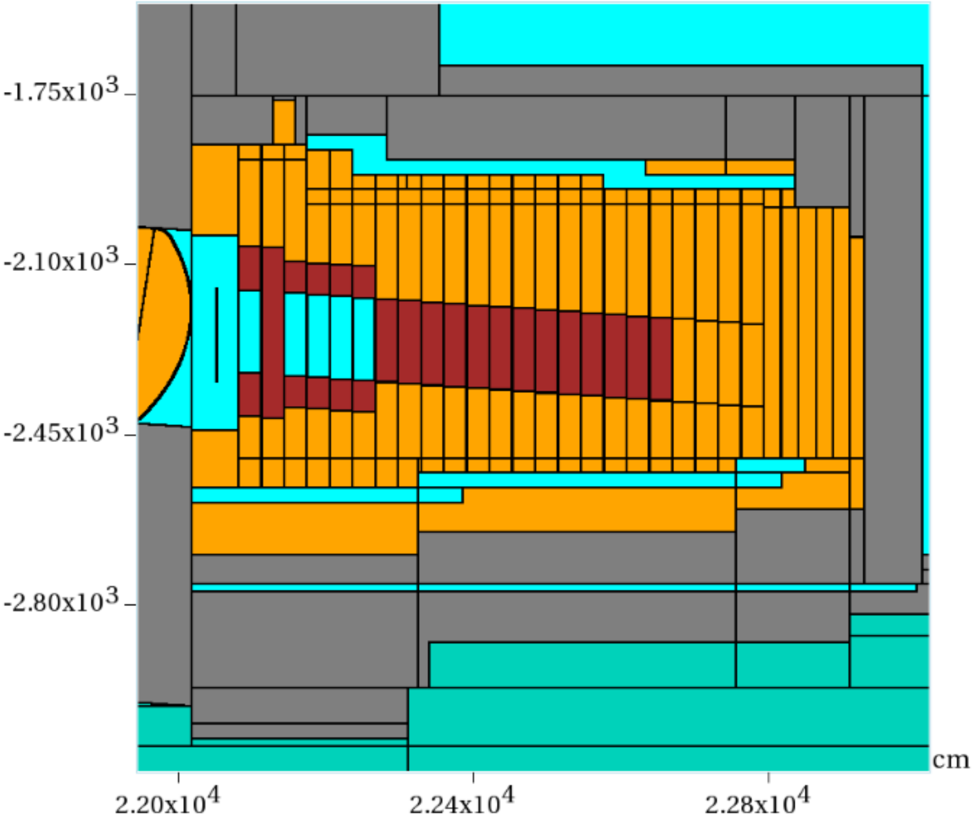
$1/\gamma$ spectrum suggests we want angular resolution ~ 1-2 mrad

$e^{\pm}$ are bright sources of TR but we have them only from interactions in upstream material and so are at low momentum

Angle spanned by decay pipe endcap ≈ 9 mrad

TR for hadrons in DUNE

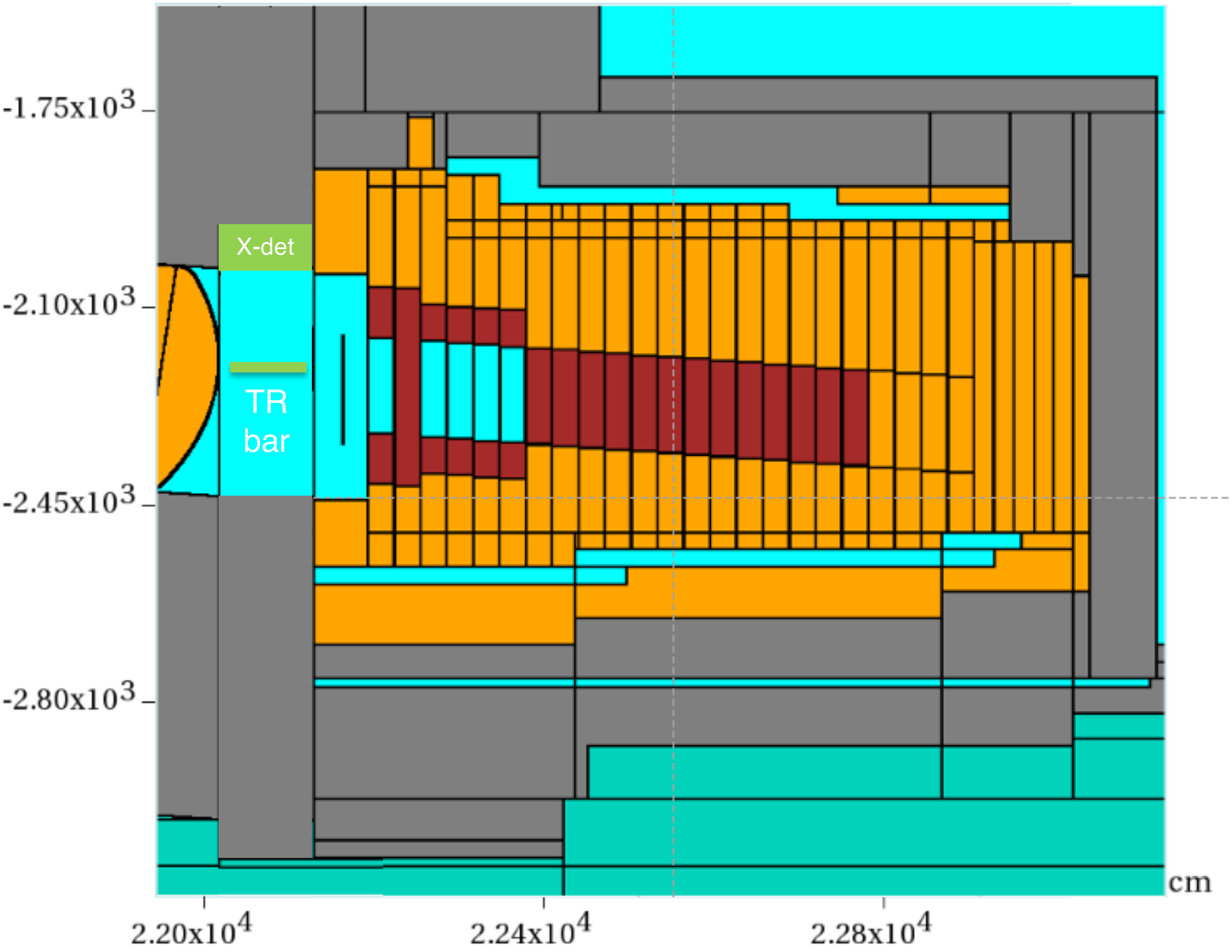
- Not a lot of space between decay pipe & absorber – about 0.6m & the hadron monitor has to fit there
- Assume that ≈1m could be found between decay pipe and hadron monitor
- Detection of the TR has to be behind cement, above beamline



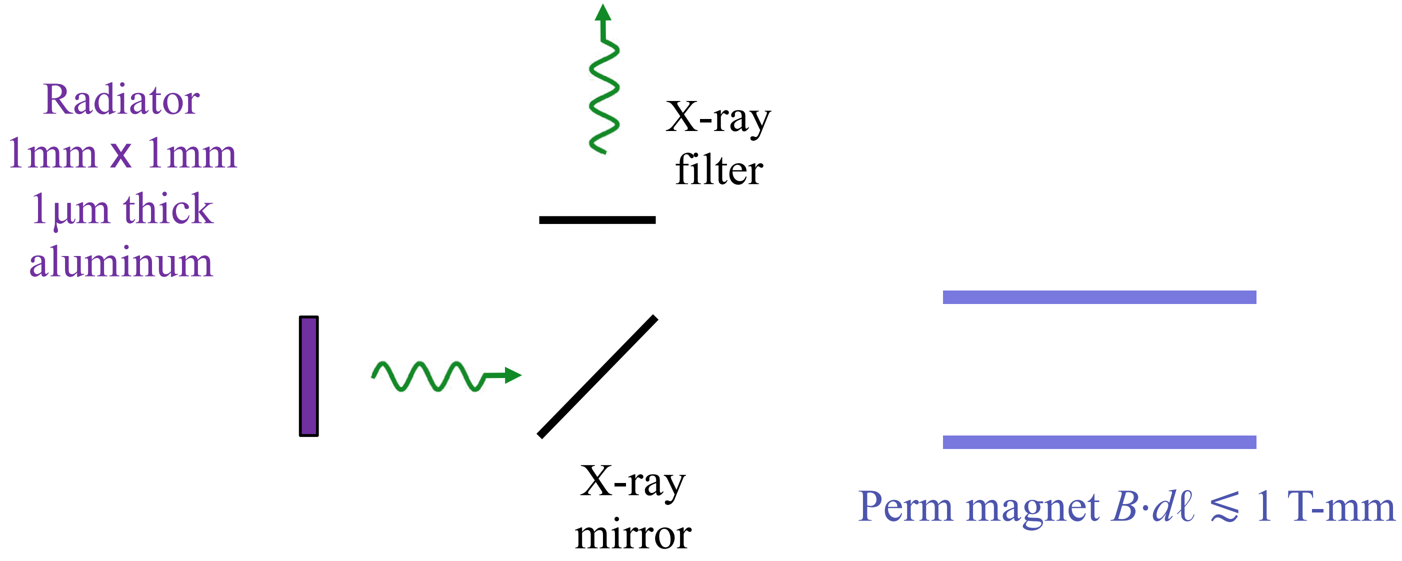
- Two TR radiators, ~1m apart, make X-ray TR, followed by mirrors to bounce it up behind the cement

TR for hadrons in DUNE

- **Need vacuum between TR bar & γ det, but could be poor vacuum - pump & close**
- **Smaller intrusion than spectrometer**
- **No PID though - just spectrum of γ for charged particles at a single (or few) points, angles in the beam**



TR bar – upstream end



Radiator
1mm x 1mm
1μm thick
aluminum

X-ray
filter

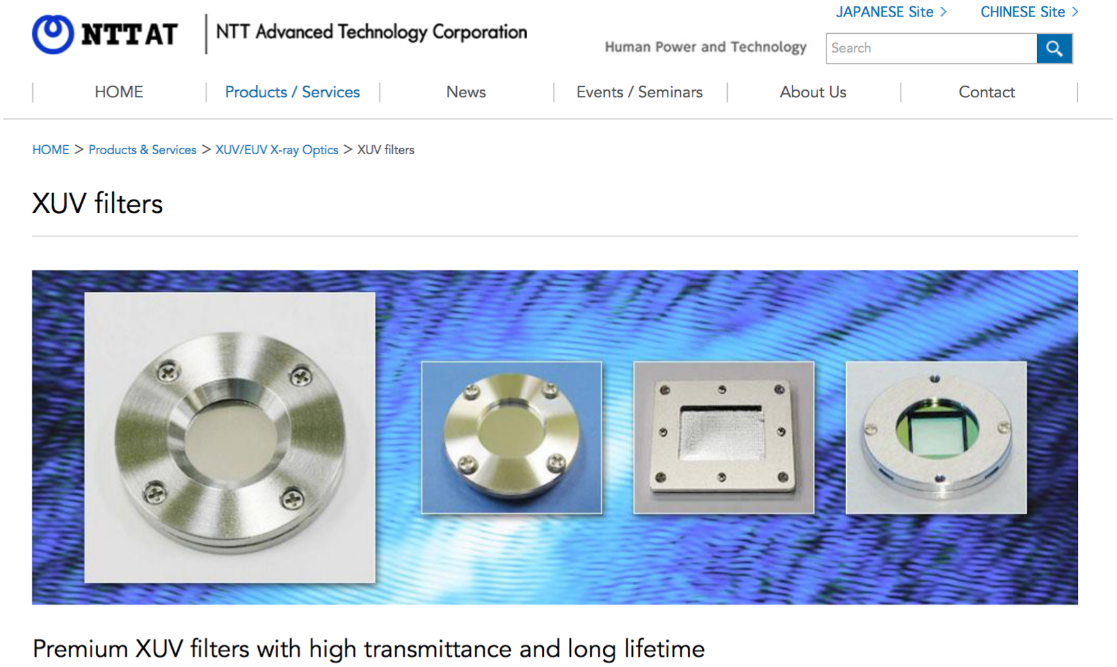
X-ray
mirror

Perm magnet $B \cdot d\ell \lesssim 1$ T-mm

Al has high plasma frequency ω_p, = 32.9 eV. 1μm thickness for absorption.
Lumpkin et al. use this for their optical TR radiators.
Absorption limits to $E(\gamma) < 70$ eV (even from the back)

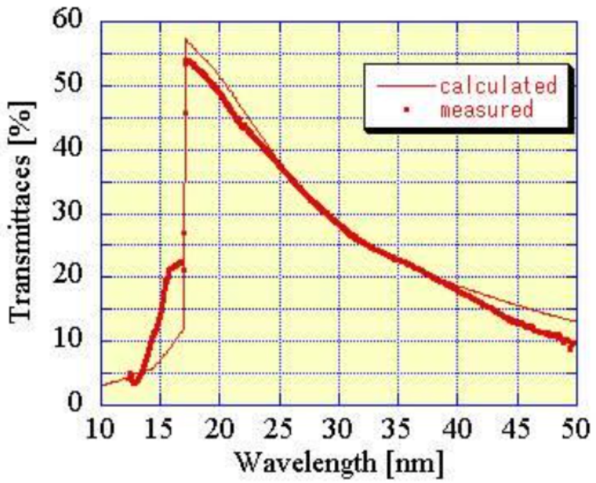
X-ray mirrors use total external reflection (metals have $\Re(n) < 1$ in X-ray)
Only grazing angles reflect & ($\theta_{\max}$)(E_γ [eV]) = const.
For Au, const. ~ 80 mrad keV, so a 70 eV X-ray reflects through
$\leq 2 \times 66^\circ$

X-ray filter



XUV filters

Premium XUV filters with high transmittance and long lifetime

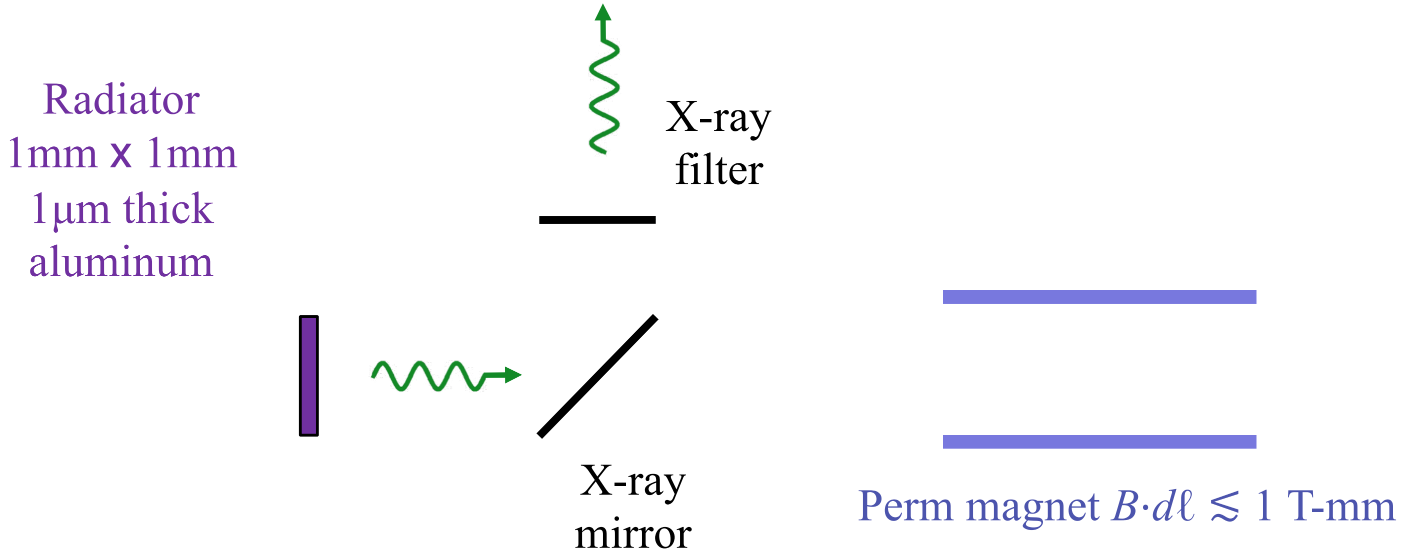


X-ray filters are commercially available

They are ~100nm thin films 1cm across – pulse heating could be a mechanical issue

I'll use 18 – 45nm (27-70 eV) bandpass for flux calculations, 25% efficiency

TR bar – upstream end



Radiator
1mm x 1mm
1μm thick
aluminum

X-ray
filter

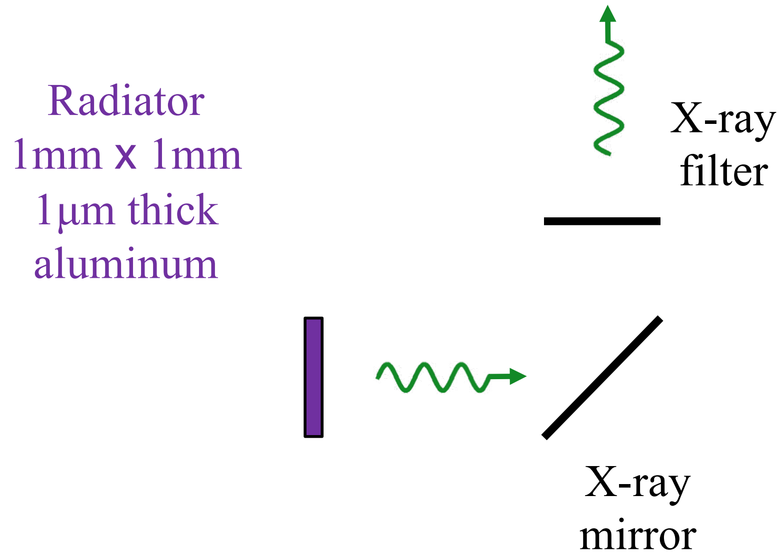
X-ray
mirror

Perm magnet $B\cdot d\ell \lesssim 1$ T-mm

There will be electrons of low energy from 2ndary emission upstream

If they are below 100 MeV, and looking for a ~4 mrad bend, need $B\cdot\ell = 1.3$ T mm. That's 1mm of Neodymium magnet

TR bar – downstream end



The same thing, but no sweeper magnet.
1 m downstream to get ~1mrad resolution

Rate calculation

The PDG gives the Nº of photons with E > $\hbar\omega_0$ *for 1 transition*

$$N_\gamma(\hbar\omega > \hbar\omega_0) = \frac{\alpha}{\pi}\left[\left(\ln\frac{\gamma\hbar\omega_p}{\hbar\omega_0} - 1\right)^2 + \frac{\pi^2}{12}\right]$$

not exact as the derivation assumes $\gamma >> 1$, *but we want to go down to* $\gamma = 2$

For range 18 – 45 nm, N_γ *ranges from* 0.0083 ($\gamma = 2$) *to* 0.0259 ($\gamma = 250$)

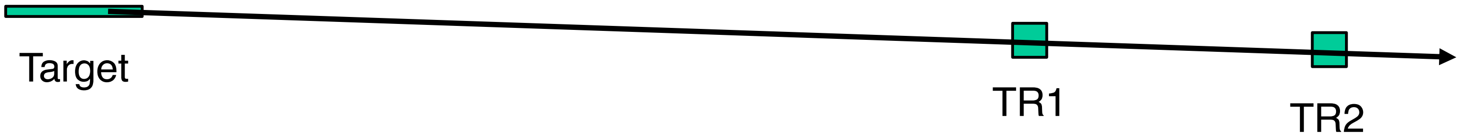
Instantaneous flux is (1.2 s/10 μs)(~3 x 10^{10} Hz/cm^2) = 3.6 x 10^{15} Hz/cm^2; times 0.1 cm x 0.1 cm, that's 36 THz.

Times (0.0083 · 0.25)^2, 155 MHz; *times* (0.0259 · 0.25)^2, 1510 MHz *assuming no losses in reflection and detection (neither is plausible)*

For 10 μs, between 1550 and 15100 signal coincidences per cycle

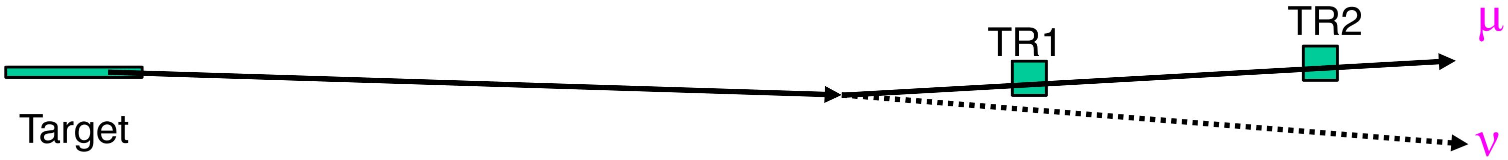
Rate calculation

This calculation assumes all the flux is in a straight line from target



Actually a lot of the beam is muons that have substantial angle re target
Could tilt TR2 relative to TR1 and go off axis to see mostly muons,

1. *reducing the signal coincidence rates*
2. *getting a more direct measure of the π→νμ decay*



Photon detection

Wire chambers using Xe gas, Si are common X-ray detectors

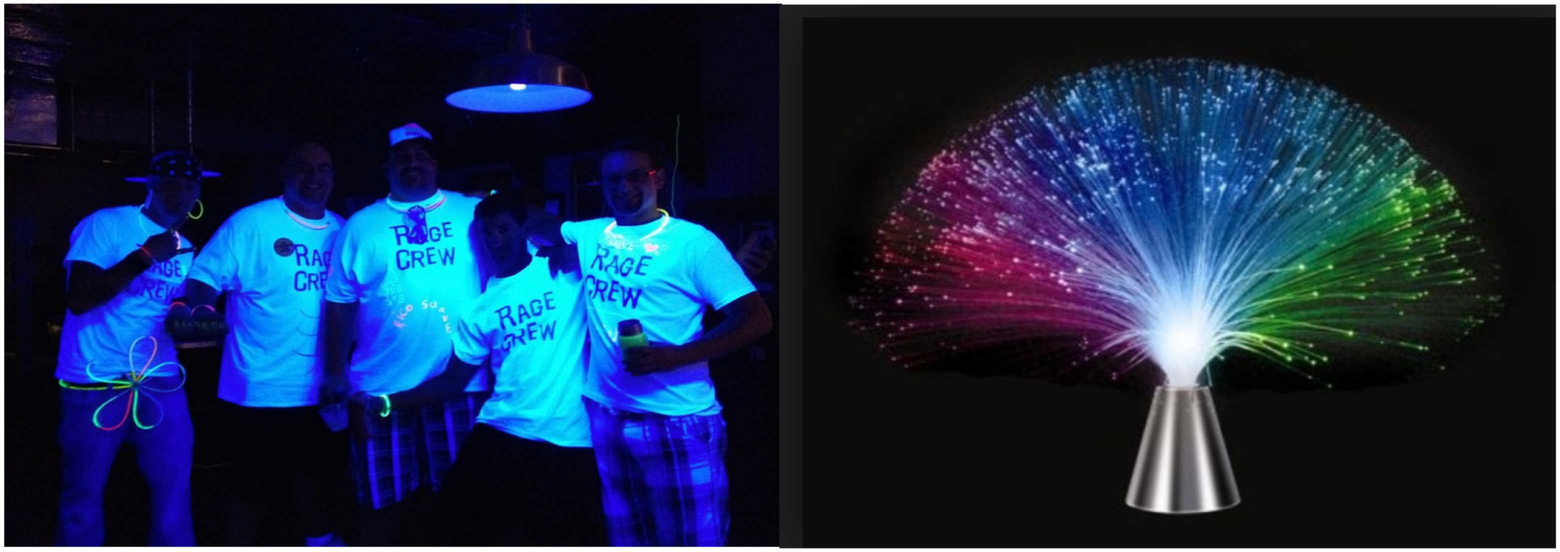
Even behind the cement, there is still a large flux of $\mu^{\pm}$

They are very different from the X-ray photons – they form tracks, have different energy deposits. There are plenty of discriminants between the two. But hits from tracks can kill acceptance of the signal

It would be better to have a purely photonic system rather than an electronic one

Photon detection

Maybe a wavelength shifter & light pipes to a low-rad zone?

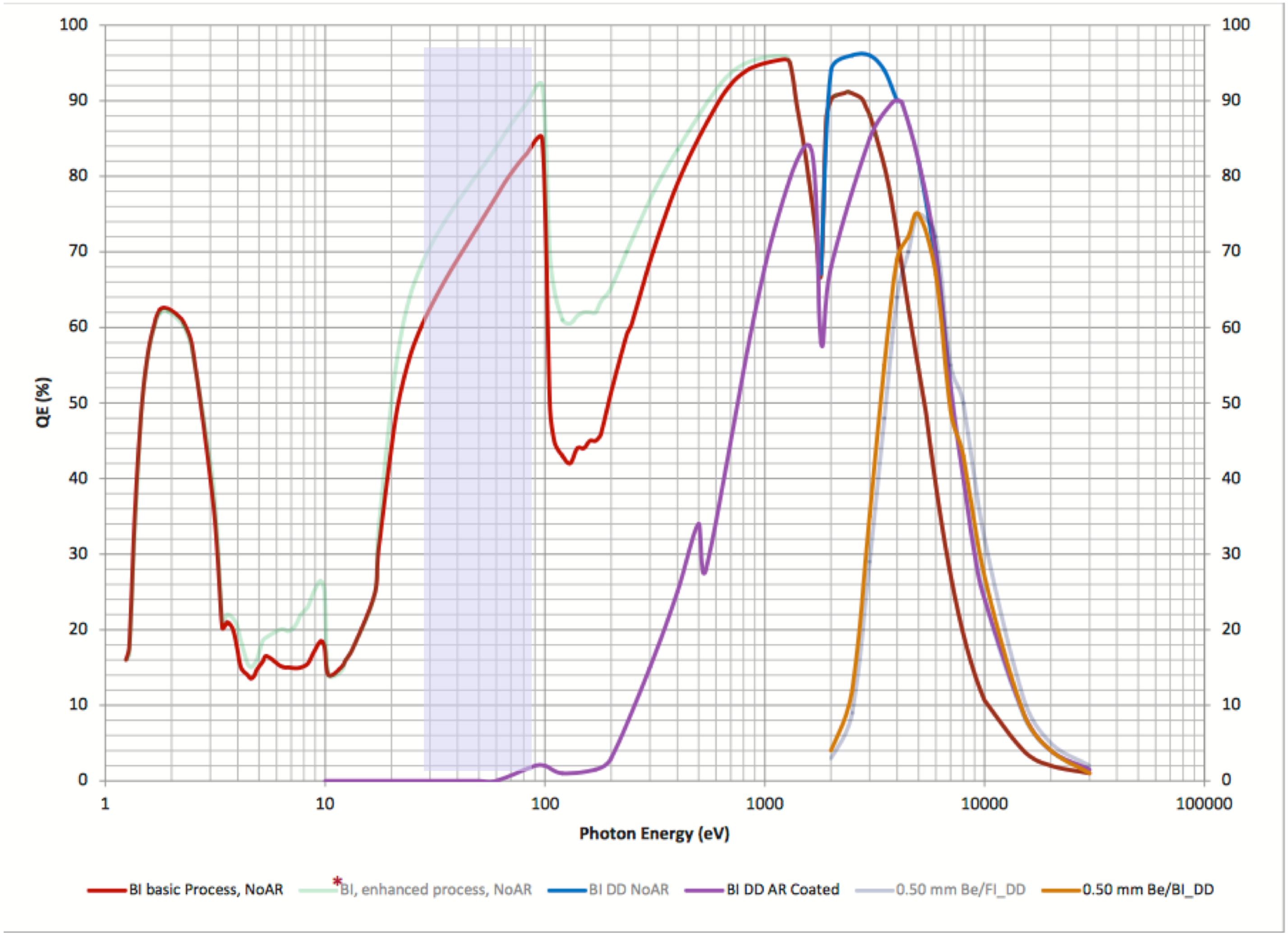


Tetraphenyl butadiene, p-terphenyl, and diphenyl stilbene have been used at 58.4 nm, not that far from that filter's bandpass
McKinsey et.al., NIM 132 (1997) 351

Princeton Instruments uses proprietary compound (which might be $GdO_2S:Tb$) for this energy range →

Some literature work needed here…

Photon detection



Obviously a long way to go

Photon detection: will the wavelength shifters be sensitive to Cherenkov from $\mu^{\pm}$?

Singles rate still pretty high for full intensity

Radiation hardness of permanent magnet?

Calibration – can't get an absolute spectrum without it

Alignment & thermal shock

What do we learn from measurement of the γ spectrum at a few points & directions at end of pipe?

A direct measurement of the hadronic momentum spectra near full beam power might not be a 100% insane idea.

Obviously a long way to go

Photon detection: will the wavelength shifters be sensitive to Cherenkov from $\mu^{\pm}$?

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Alignment & thermal shock

What do we learn from measurement of the γ spectrum at a few points & directions at end of pipe?

Might be only a 99% insane idea.