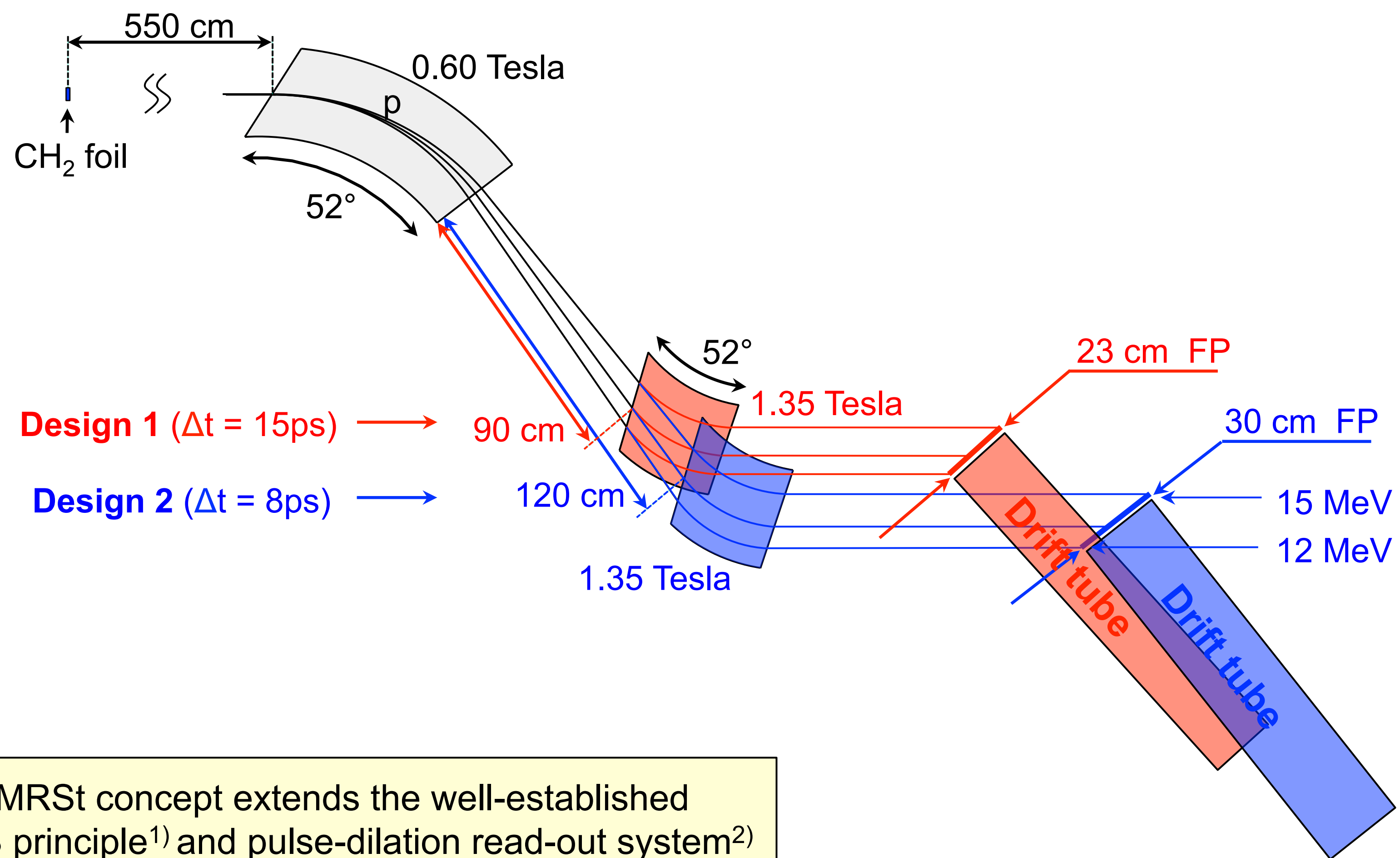
MRSt for time-resolved measurements of the neutron spectrum at the NIF



The MRSt concept extends the well-established MRS principle[1)] and pulse-dilation read-out system[2)]

[1)] Frenje et al., POP (2010); [2)] Hilsabeck et al., RSI (2011).

Johan Frenje
MIT

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Collaborators and Sponsor

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Summary

The MRSt will provide essential info on the evolution of fuel assembly/hot-spot formation/α-heating for Y_n > 5×10[15]

- **The MRSt-point design (Rev 3) meets the top-level requirements of measuring $Y_n(t)$, $T_i(t)$ and $\rho R(t)$ with a Δt <20ps and accuracy of <7% for Y_n> 5×10^{15}.**

- **The MRSt-point design consists of:**
  - — 1-mm diameter, 20-μm thick CH_2 foil positioned 0.3 cm from TCC.
  - — 2 electro-magnets positioned just outside the chamber.
  - — A pulse-dilation-drift-tube detector for detecting recoil protons (12-15 MeV).
  - — Shielding surrounding the detector.

- **Path forward:**
  - — 2^{nd}-order aberrations will be corrected for by introducing curved pole boundaries and a field gradient in the 2^{nd} magnet.
  - — Shielding will be designed/optimized to reduce background to required level.
  - — More refined simulations, compared to hydro modeling, will be done to raise the fidelity of the MRSt design and performance.

Outline

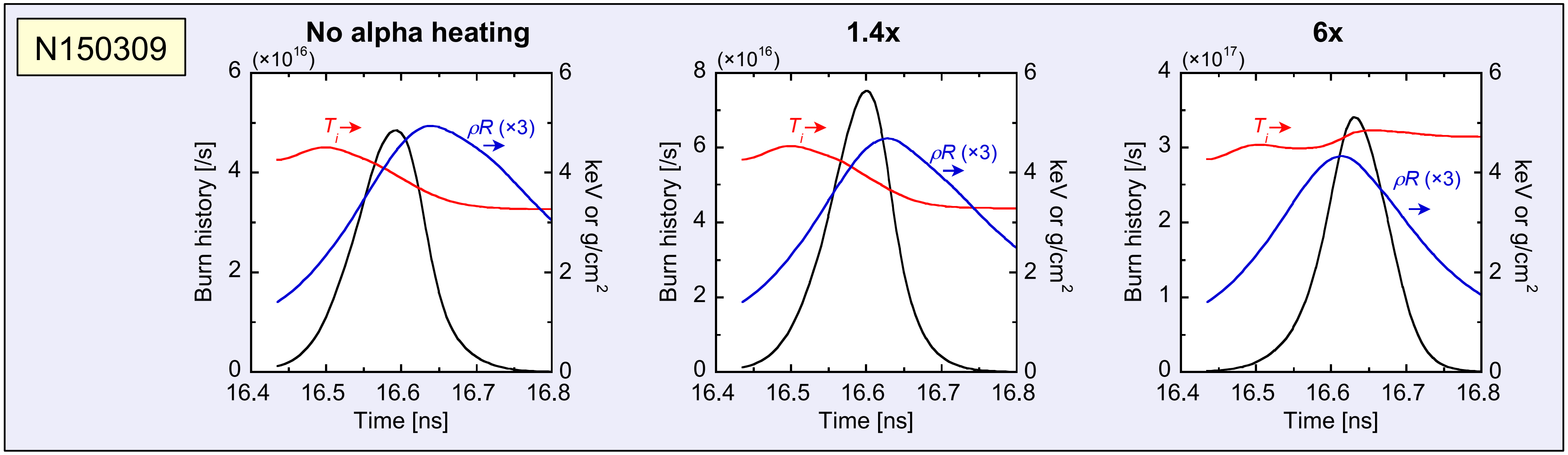
- **Motivation and Requirements**

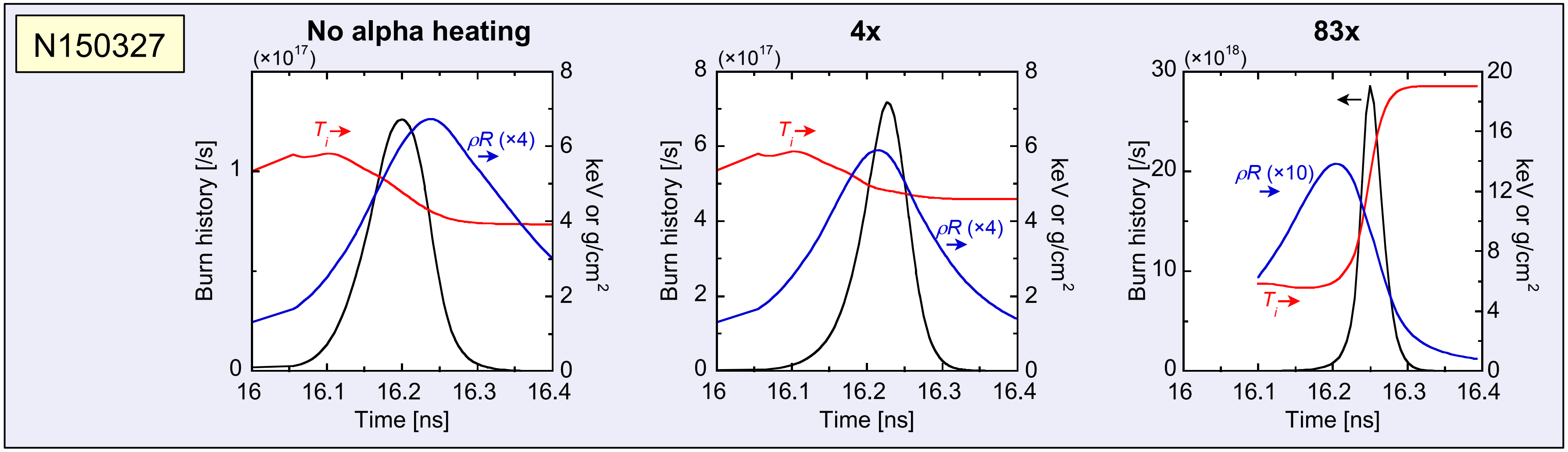
- **MRSt-point design (Revision 3)**
  - — Magnet system
  - — Foil
  - — Detector system

- **Signal considerations**
  - — Δt and efficiency (ε) vs magnet-aperture area.
  - — $\Delta t_{ion\text{-}optics}$, $\Delta E_{ion\text{-}optics}$ and time skew vs MRSt location
  - — Signal distribution for 3 NIF implosions

- **Path forward and Schedule**

Timing and evolution of $Y_n(t)$, $T_i(t)$ and $\rho R(t)$ provide essential info on evolution of fuel assembly/hot-spot formation/α-heating





Info on $Y_n(t)$, $T_i(t)$ and $\rho R(t)$ can be obtained through time-resolved measurements of the neutron spectrum

Requirements

$Y_n(t)$, $T_i(t)$ and $\rho R(t)$ must be determined with a time resolution of <20ps and an accuracy of <7% to assess effect of alpha heating

Parameter	Requirement
Time resolution (Δt)	< 20 ps [1)]
Energy resolution (ΔE_l)	< 300 keV [2)]
Efficiency (ε_{12MeV})	$>5\times10^{-12}$ for $Y_{n'} > 2\times10^{14}$ [3)]

1) Δt < Burn duration of 40 – 150 ps.

2) $\Delta E_l < \Delta E_{Doppler}$ at 3 keV.

3) $\varepsilon_{12MeV} > (1\times5(\text{time bins}) / 0.07^2)*(1/2e^{14}) \sim 5\times10^{-12}$

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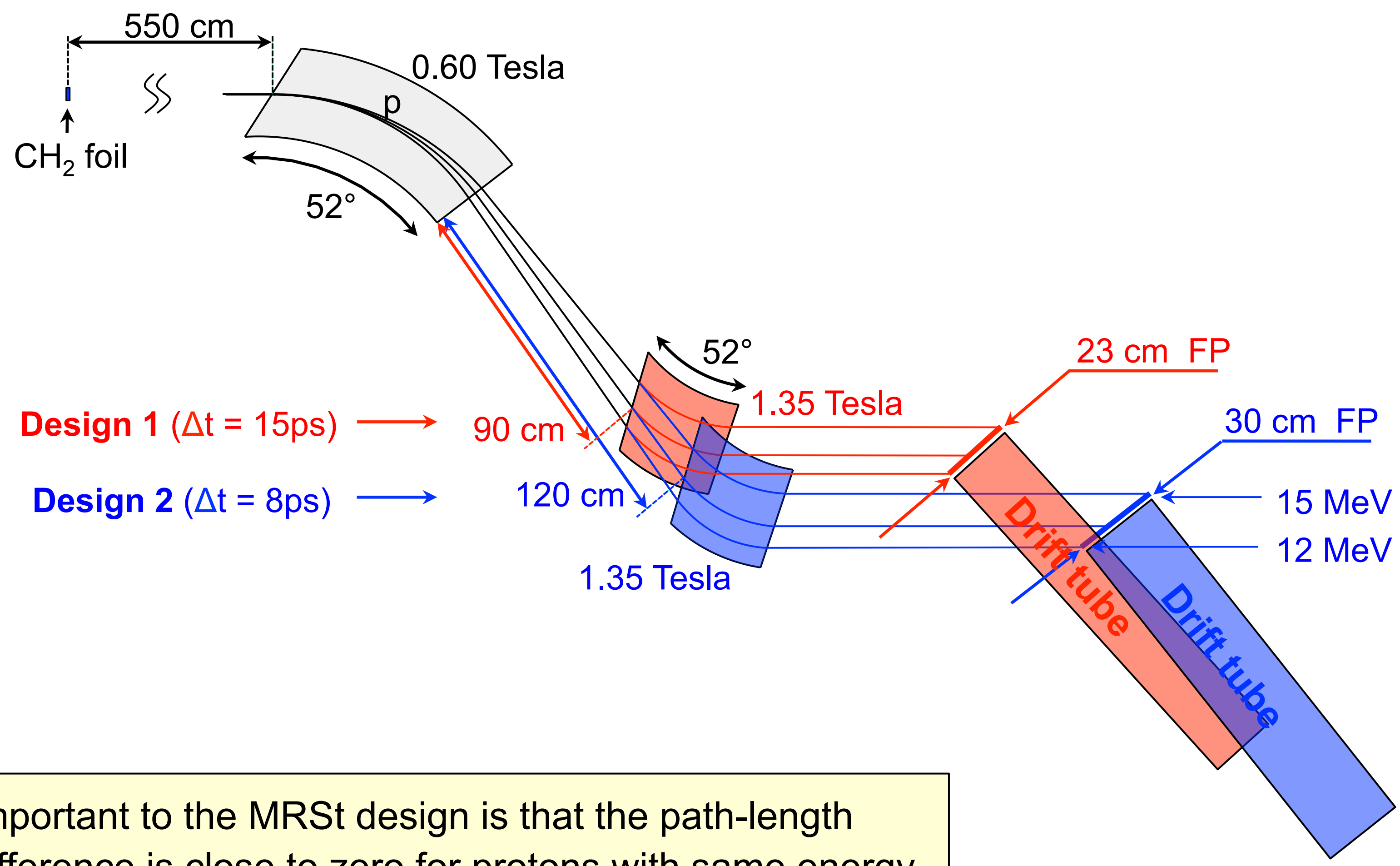
- **Path forward and Schedule**

A 1st-order MRSt design (Rev. 3) has been found that meets the 20-ps time-resolution requirement



Important to the MRSt design is that the path-length difference is close to zero for protons with same energy

1) Frenje et al., POP (2010).
2) Hilsabeck et al., RSI (2011).

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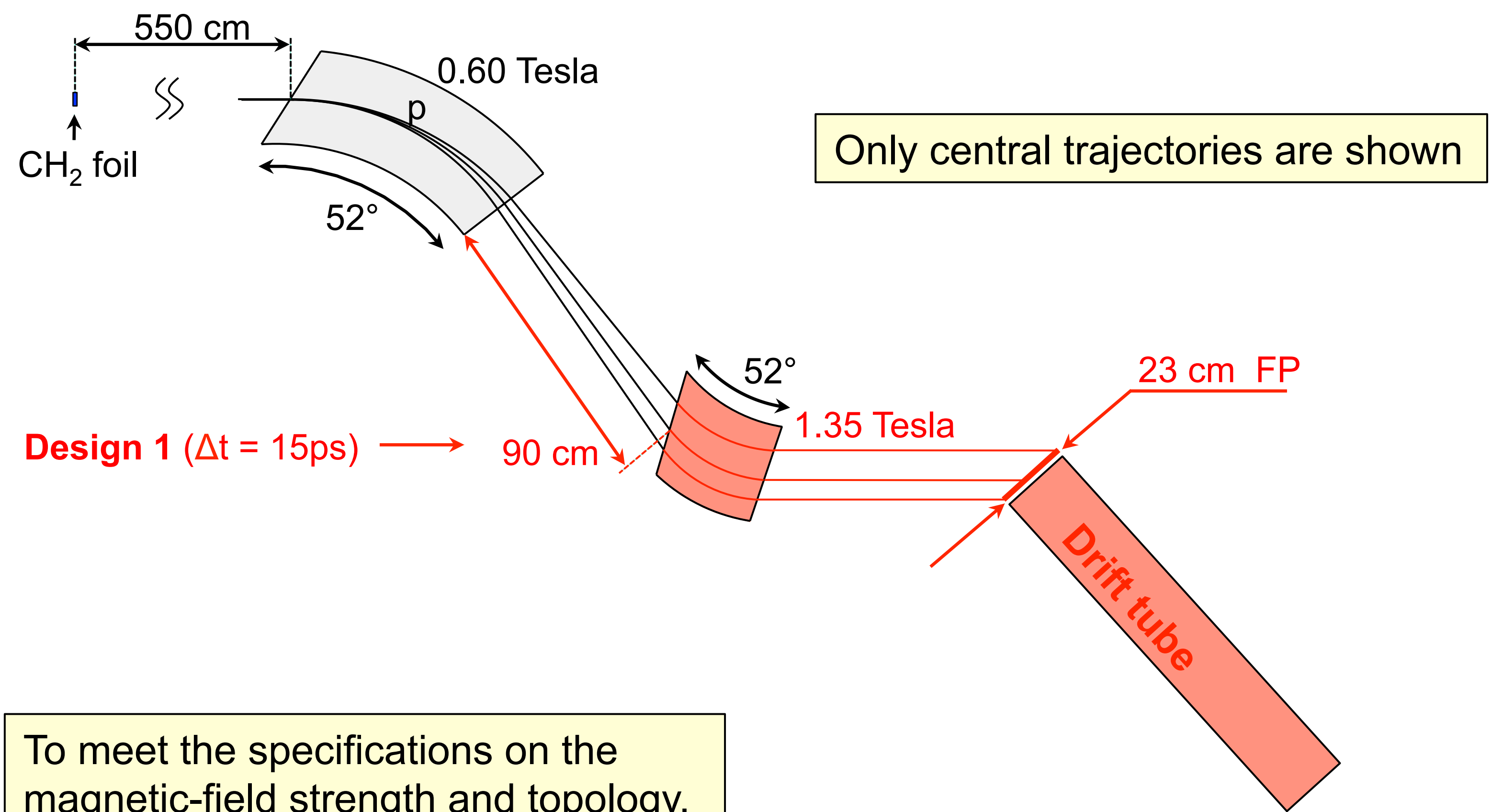
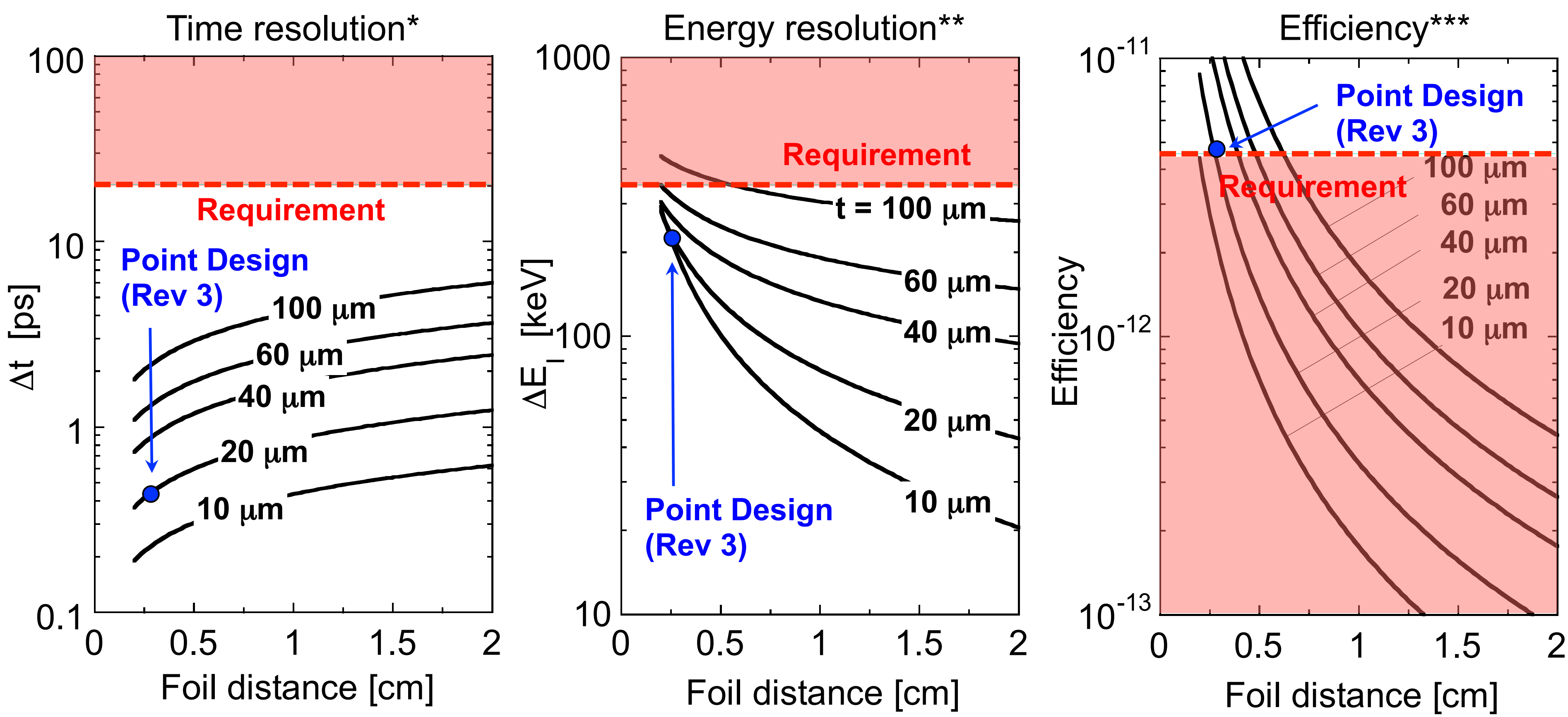


To meet the specifications on the magnetic-field strength and topology, electro-magnets must be used

1) Frenje et al., POP (2010).
2) Hilsabeck et al., RSI (2011).

A 1-mm diameter, <100 um thick CH_2 foil must be positioned <0.7 cm from TCC to meet the top-level requirements

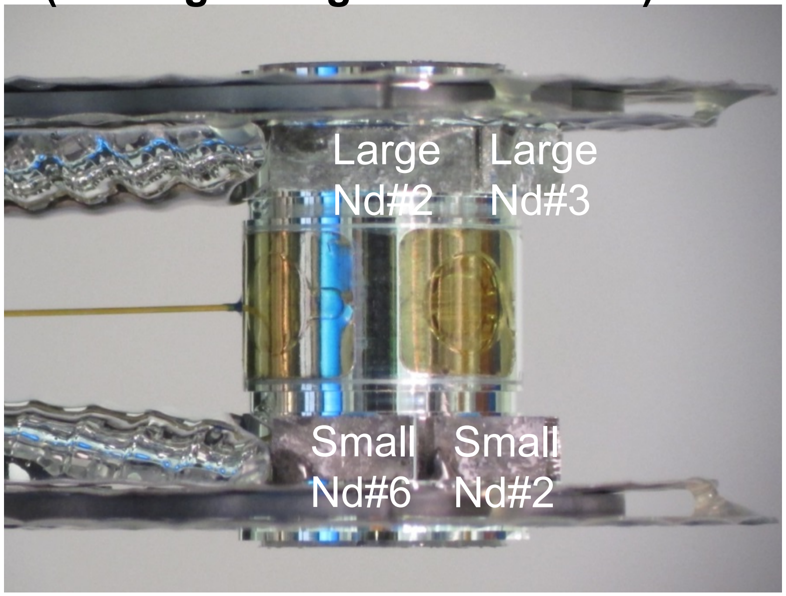


A small CH_2 foil very close to TCC is key to the MRSt performance

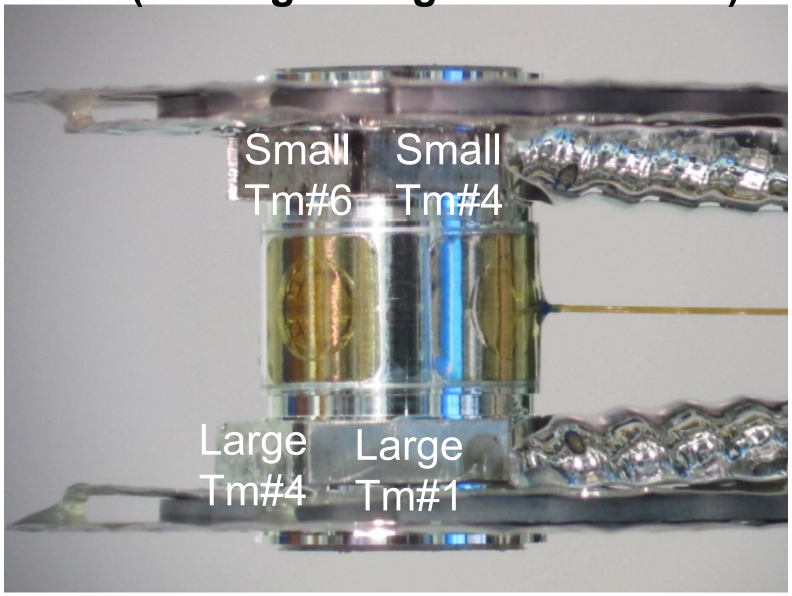
* Time spread of neutrons producing protons with one energy.
** Energy spread of neutrons producing protons with one energy.
*** A magnet aperture of 2×2 cm^2 was used in these calculations.

In similar spirit to Charles Yeaman's work, the current plan is to attach the 1-mm diameter CH_2 foil to the Hohlraum

Nd side
(looking at target from 90-105)

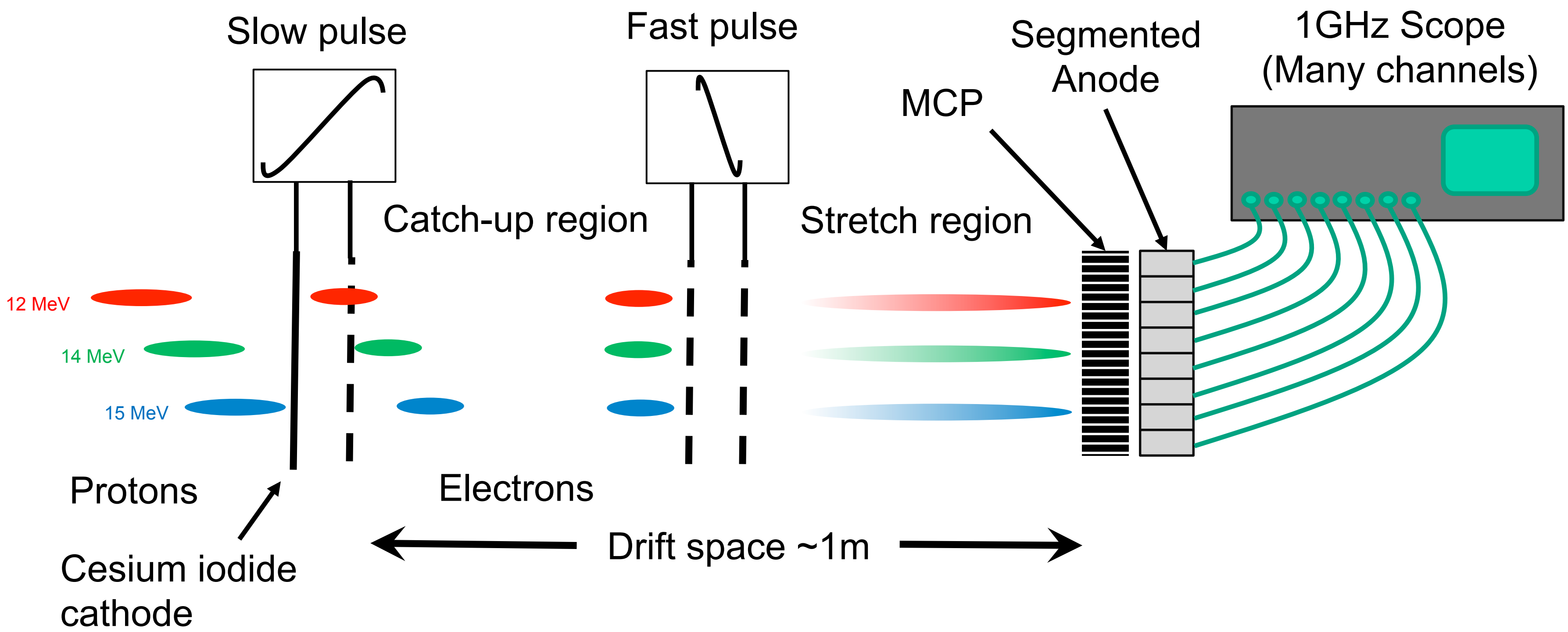


Tm side
(looking at target from 90-285)



- This solution does not require a DIM or TANDM for the insertion of the foil.
- Since the foil will be disposable, a CH_2 foil is preferable over a CD_2 foil
- This approach can easily be tested using a WRF-proton spectrometer.

A segmented anode pulse-dilation drift tube with 1GHz digitizer readout is being explored for the MRSt



Protons hit the CsI photocathode -> 2-3 secondary electrons are accelerated by a time varying electric field -> signals aligned in time at 2nd accelerating region -> signal stretches as it traverses the drift region -> Gain with MCP -> segmented anode with many channels read out on 1GHz digitizers.

For more details, see next talk by Terry.

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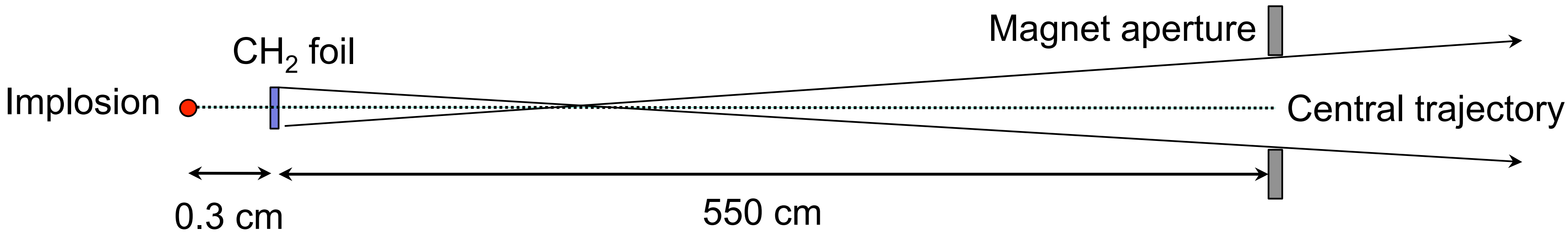
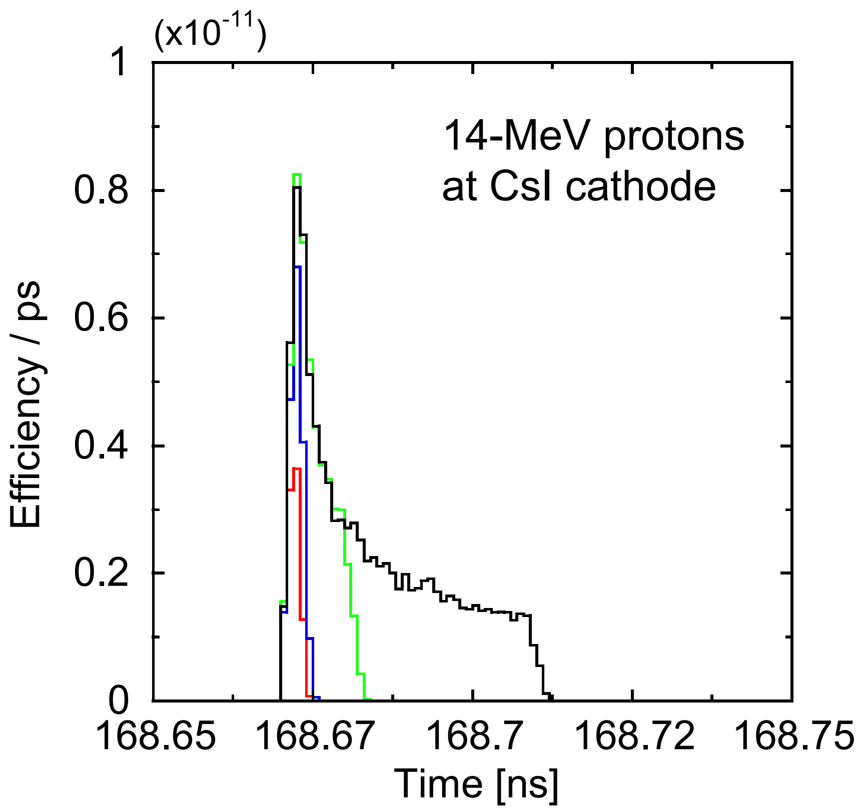
- **Path forward and Schedule**

Simulations indicate that the magnet-aperture area must be smaller than 5×2 cm^2 to meet the time-resolution requirement

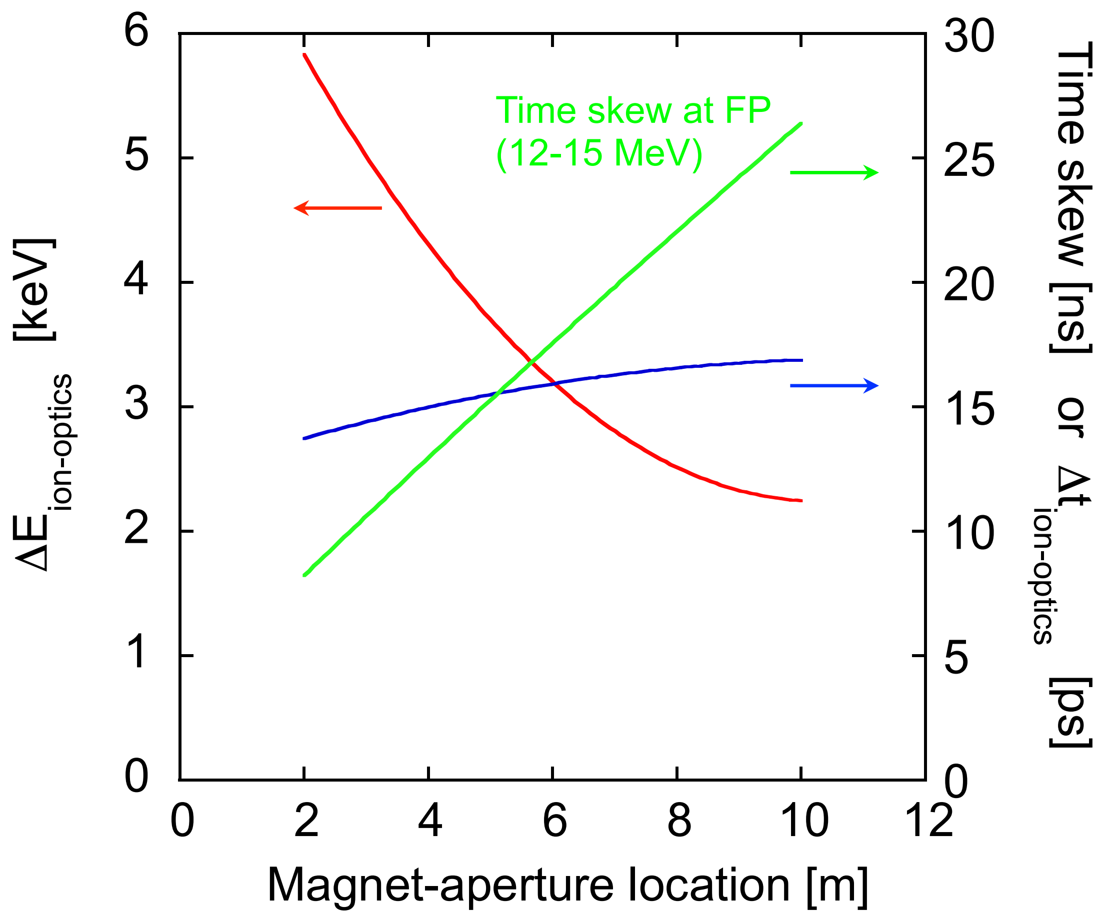




Aperture area [cm^2]	Time spread [ps]	Efficiency*
1×2	5 ps	2×10^{-12}
2×2	6 ps	4×10^{-12}
5×2	15 ps	10^{-11}
10×2	42 ps	4×10^{-10}

* MRS efficiency (super-high res) = 4×10^{-12}

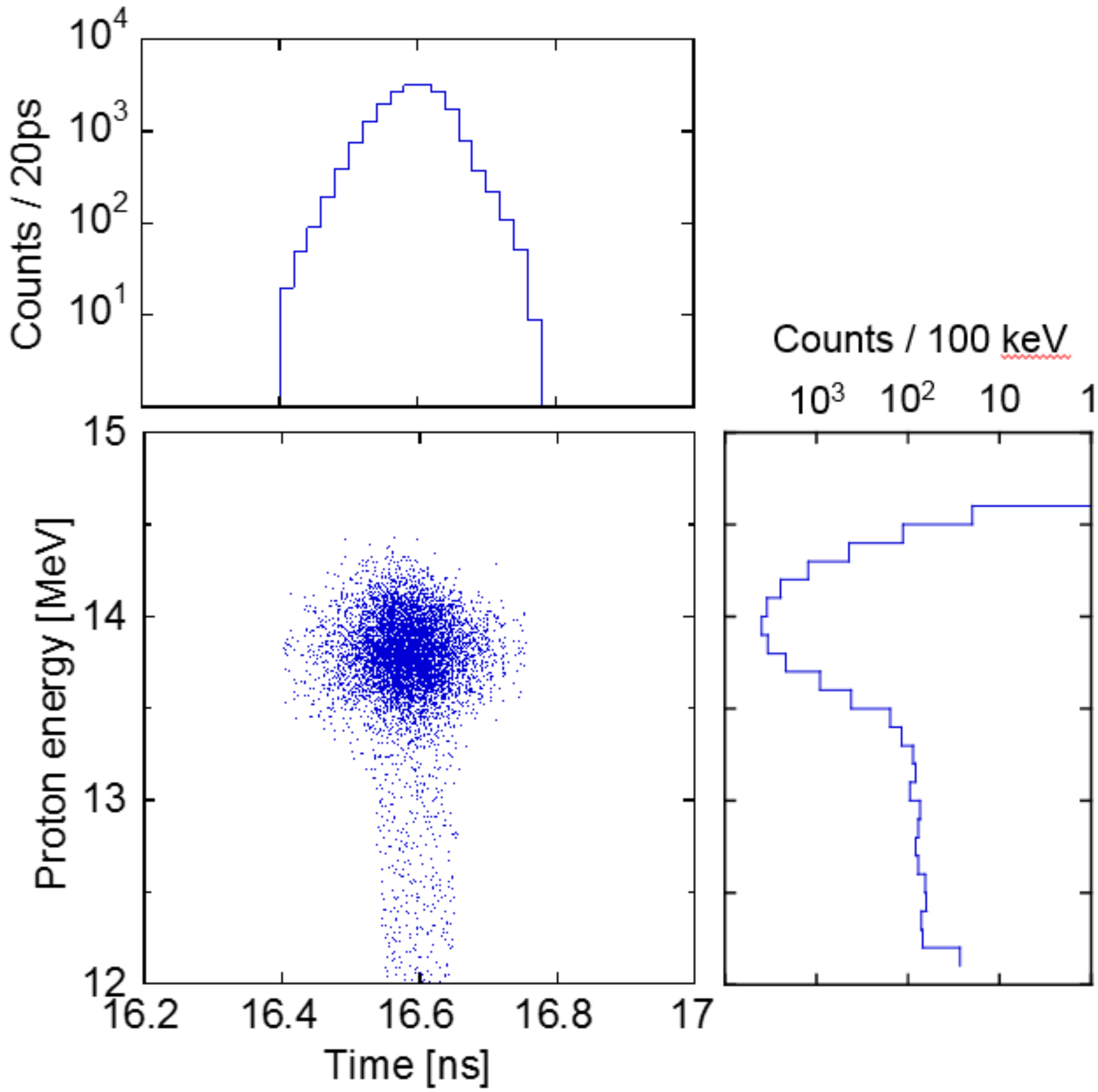
Positioning the MRSt-magnet aperture closer to TCC than 550 cm does not significantly improve time resolution



Signal considerations

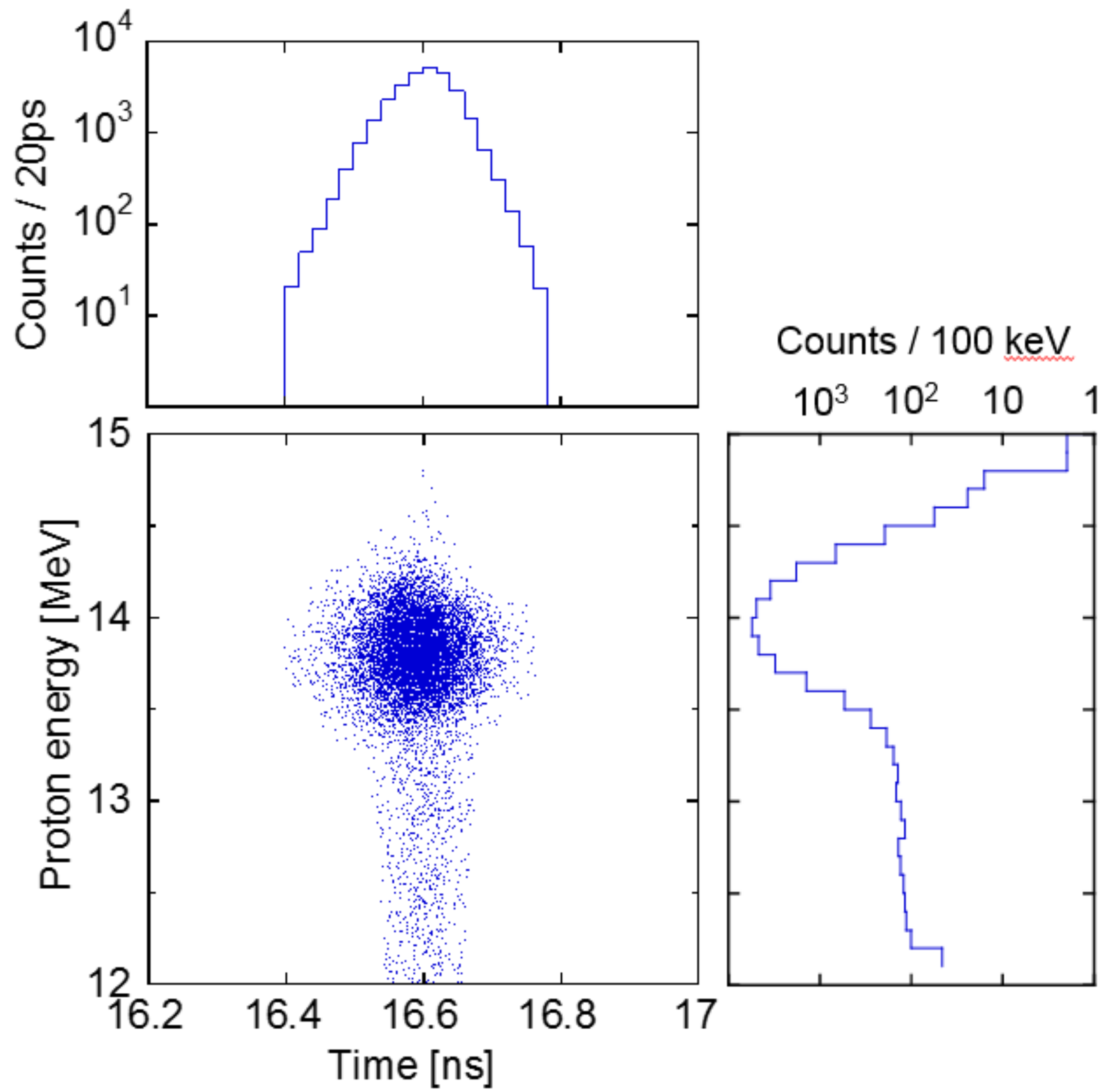
The MRSt-point design will be able to measure $Y_n(t)$, $T_i(t)$ and $\rho R(t)$ with a Δt <20ps and accuracy of <7% at $Y_n = 5.7\times10^{15}$

N150309
$Y_n = 5.7\times10^{15}$
No alpha heating



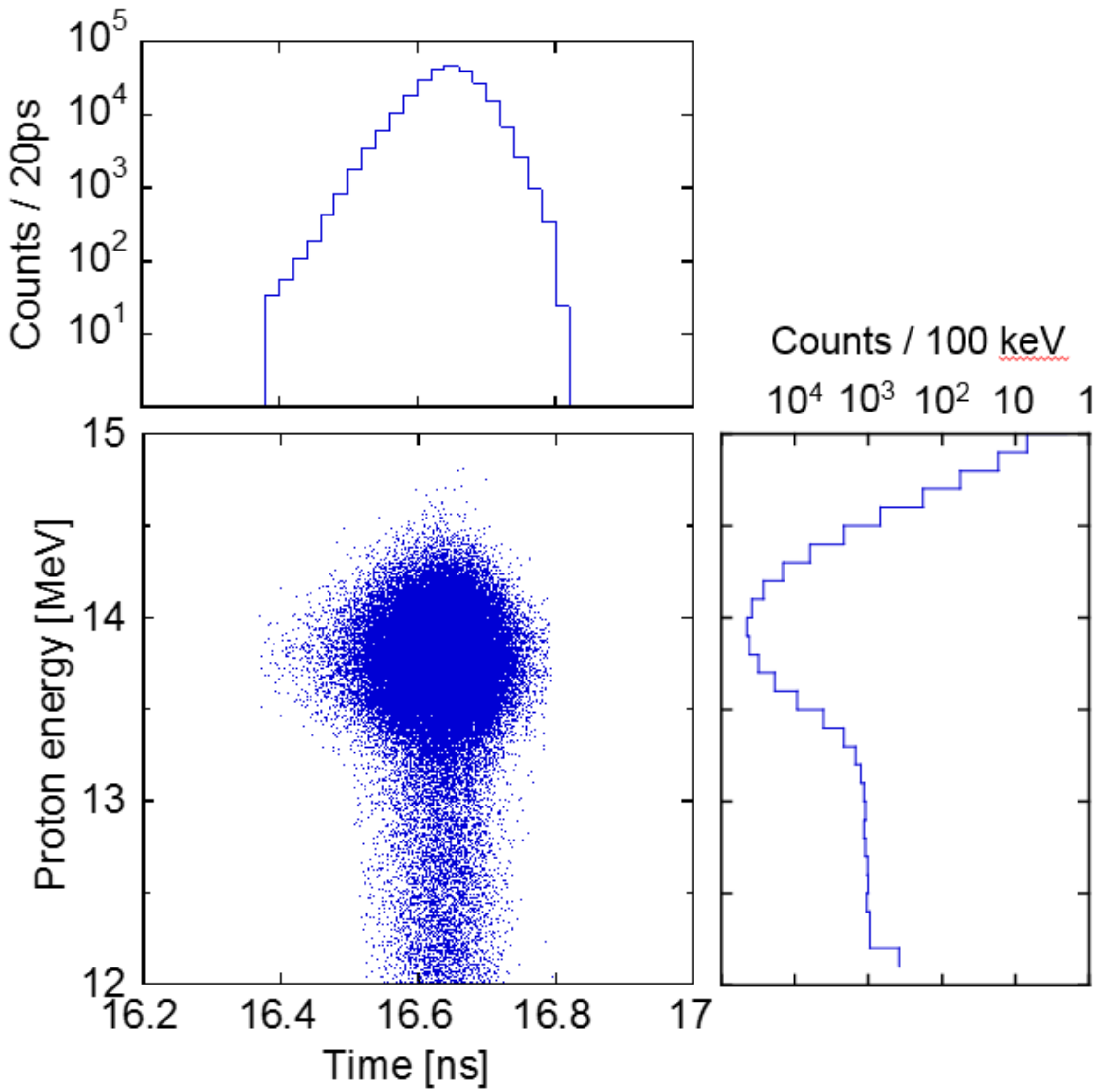
At $Y_n = 8.1\times10^{15}$, the MRSt-point design will be able to provide info on evolution of fuel assembly and effect of α-heating

N150309
$Y_n = 8.1\times10^{15}$
1.4x Y_n enhancement due to alpha heating



At $Y_n = 3.6\times10^{16}$, the MRSt-point design will provide detailed info on evolution of fuel assembly and effect of α-heating

N150309
$Y_n = 3.6\times10^{16}$
6x Y_n enhancement due to alpha heating



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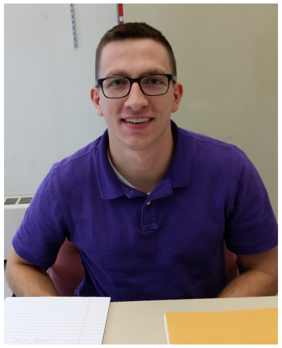
- **Path forward and Schedule**

Path forward will involve magnet-design improvement, S/B optimization and more refined simulations

Chris Wink



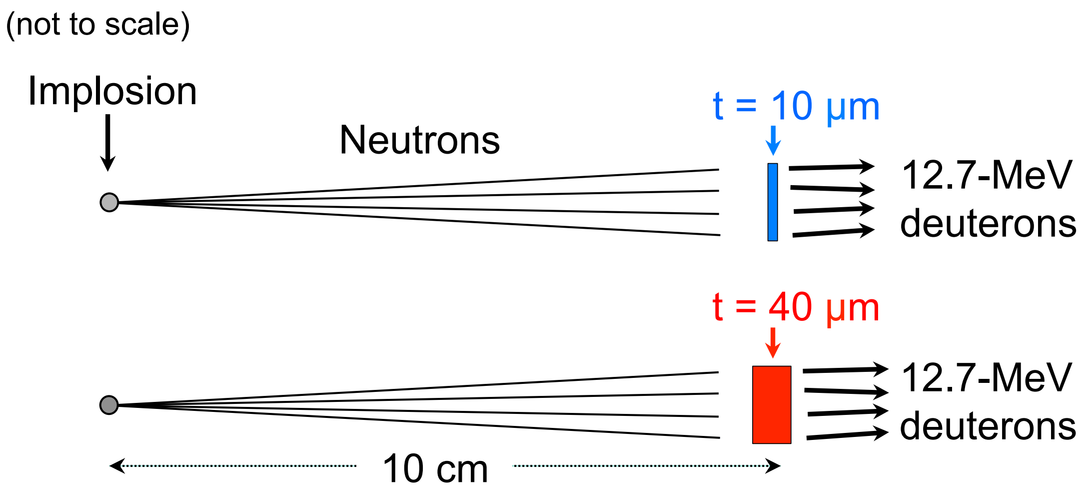
- The optimized and final MRSt-magnet design will be determined using numerical simulations (Geant4 and Comsol).
- 2nd-order aberrations will be corrected for by introducing curved pole boundaries and a field gradient in the 2nd magnet.
- This effort will be done with DanFysik (Denmark), SigmaPhi (France), Scanditronix (Sweden) or Everson Tesla (US), and reviewed by Georg Berg at Notre Dame.
- Shielding will be designed and optimized to reduce background to required level.
- More refined simulations, contrasted to hydro modeling, will be done to raise the fidelity of the MRSt design and performance.

Schedule from October 2014

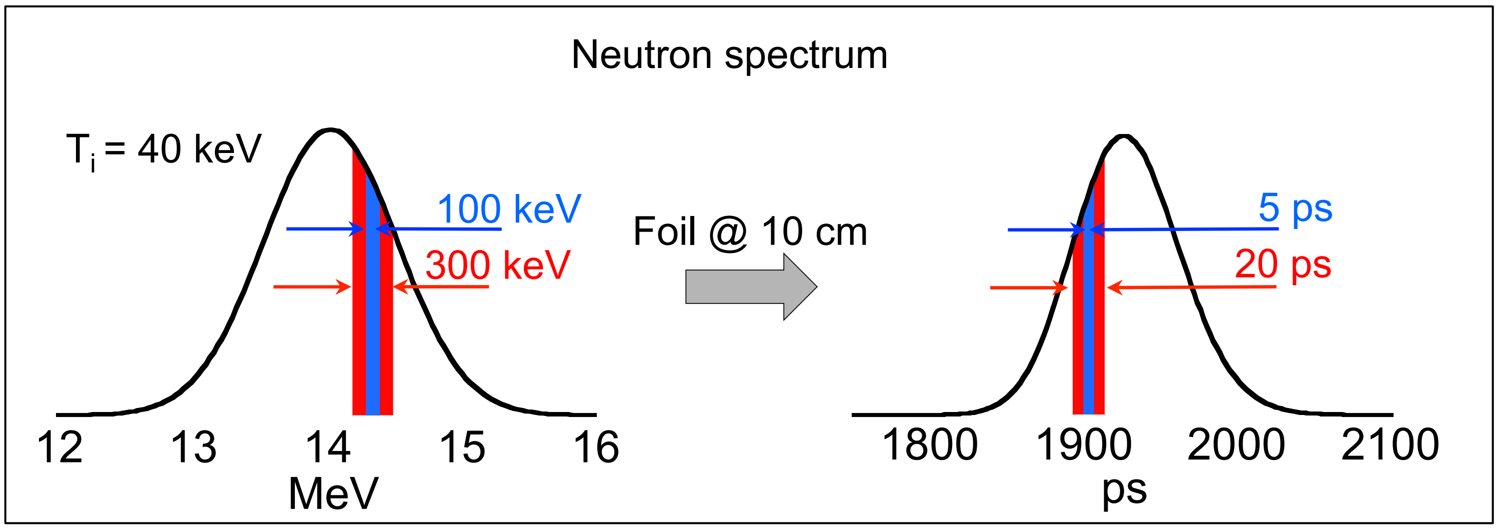
- Define top-level physics requirements (FY15). ✓
- Define optimal foil characteristics and location (FY15). ✓
- Define optimal magnet design (FY15). In progress
- Define optimal pulse-drift-tube design (FY15-16). In progress
- Define optimal shielding for γ's/n's (FY15-16). In progress
- Build/characterize CD foils (FY16-17). ✓
- Define engineering design, (FY16-17).
- Build/characterize detector (FY16-17).
- Build/characterize magnet (FY17-18).
- Installation on the NIF (FY19)

Extra

Time resolution (Δt) for the MRSt is dictated in part by position, area and thickness of the CD foil

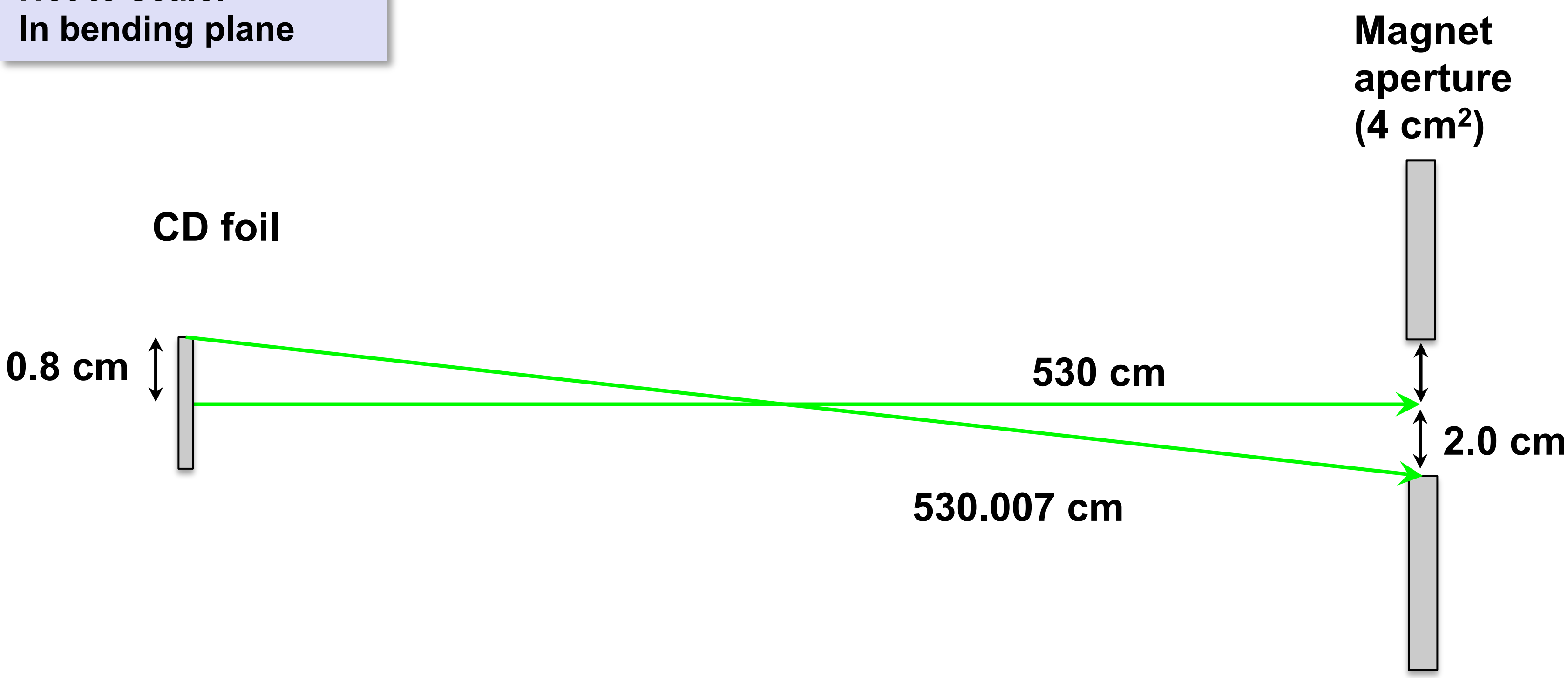


Additional time dispersion of 12.7-MeV deuterons is not introduced with an achromatic MRSt



The deuteron path-length difference from foil to aperture is insignificant, resulting in no additional temporal broadening

Not to scale.
In bending plane



The maximum path-length difference between the foil and magnet aperture is ~0.07 mm, which corresponds to ~1 ps for 12.4 MeV d