Expected Results from Channeling Radiation Experiments at FAST

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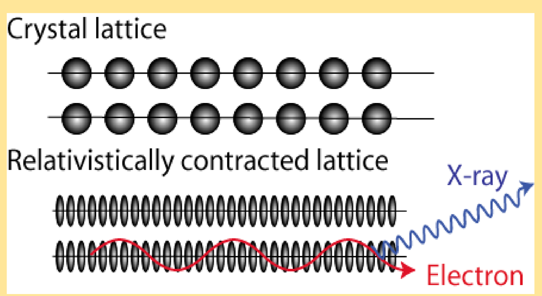
ABSTRACT

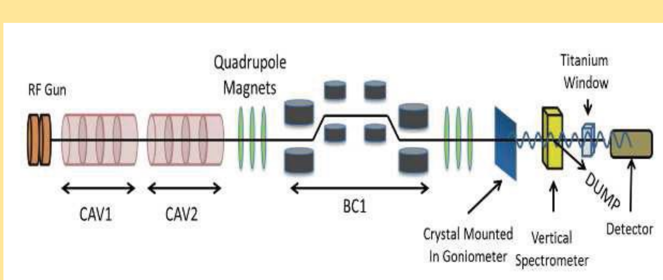
The photoinjector at the new Fermilab FAST superconducting linac will accelerate electrons to about 50 MeV. After beam commissioning, channeling radiation experiments to generate hard X-ray will be carried out. In the initial stage, low bunch charge will be used to keep the photon count rate low and avoid pileup in the detector. We report here on optics solutions, and the expected channeling spectrum including background from bremsstrahlung. At higher bunch charge, a Compton spectrometer will be used to mitigate pileup.

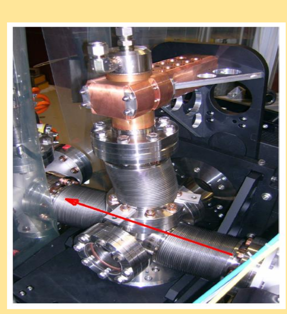
MOTIVATION



Scaling Laws

	Electron Energy
Critical angle	$1/\sqrt{\gamma}$
No. of bound states	$\sqrt{\gamma}$
X-ray energy E_X	$\gamma^{5/3}$
Linewidth	γ^2
Photon yield/(e^--sr)	$\gamma^{5/2}$



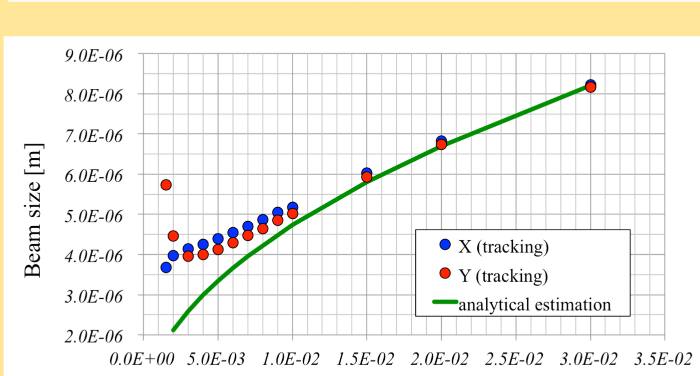


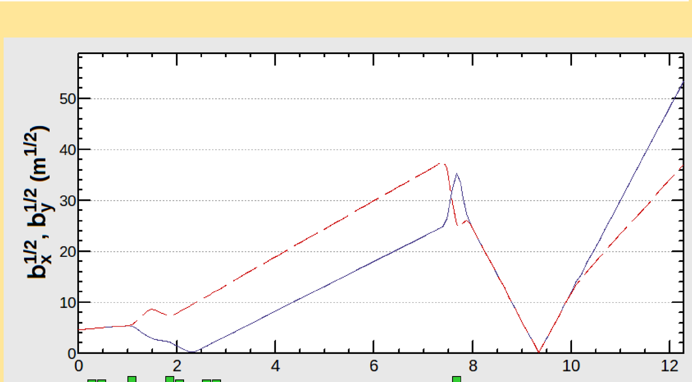
- Increase spectral brilliance of CR with a low emittance beam
- Characterize CR by electron beam properties - energy, charge, emittance, divergence
- Establish FAST as a model for a compact X-ray source

OPTICS

$$\mathbf{B_N = (d^2\,N/d\omega d\Omega)(I_{av}/e)E_X\,10^{-3}/\sigma_e{}^2}$$

Parameter	Value
Beam energy	40 – 50 MeV
Bunch charge	1 - 200 pC
Bunch frequency	1 MHz
Transverse emittance	0.02 – 0.5 µm
Bunch length	< 1 mm
Energy spread	~ 0.1%
Crystal, plane	Diamond, (110)
Critical angle	1mrad(50MeV)

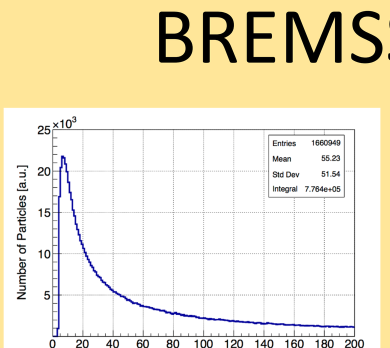


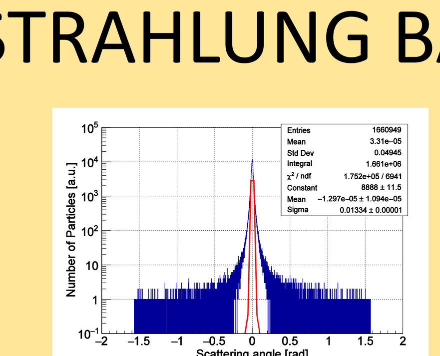


- Beam divergence at the crystal < critical angle for channeling.
- Maximizing the yield requires smallest divergence
- Maximizing the spectral brilliance requires the smallest beam size compatible with channeling
- Below β = 3mm (for 20pC), chromatic aberrations increase the beam size.

Charge [pC]	ϵ_N [mm-mrad]	σ_{cr} [μm]	σ'_{cr} [mrad]	$\sigma_x^{max}, \sigma_y^{max}$ [mm]
1	0.023	1.3	0.3	(0.54, 0.6)
20	0.19	4	0.86	(1.5, 1.7)
200	0.52	9.8	0.9	(1.7, 2.0)

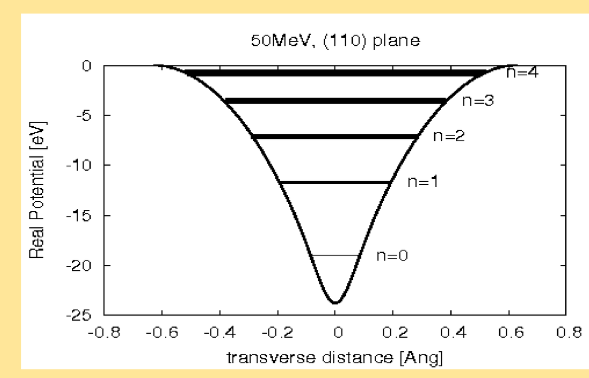
BREMSSTRAHLUNG BACKGROUND

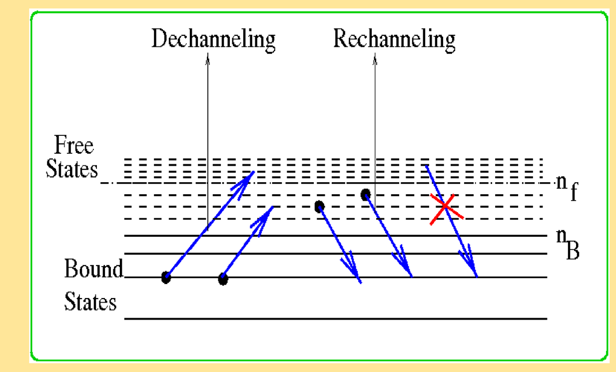


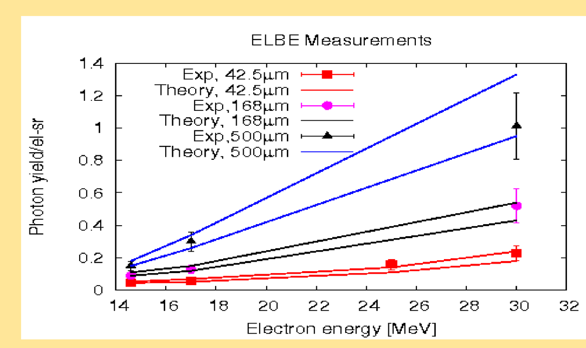


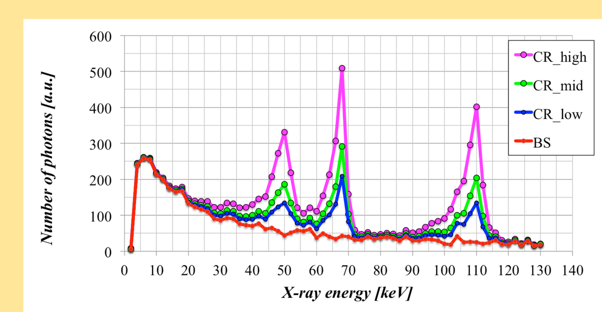
- BS spectrum extends to ~40MeV
- Angular spread is large
- To be measured with crystal out of channeling orientation

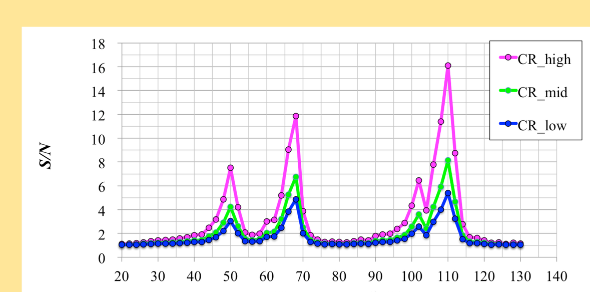
CHANNELING SPECTRUM











- Photon yeilds are determined by radiative transitions between states

$$\frac{d^2N}{d\Omega dz} \propto |\langle\psi_m|\frac{d}{dx}|\psi_n\rangle|^2 P_n(z)$$

$P_n(z)$: Probablity of occupation of state $|\psi_n\rangle$ at distance z.

Selection rule: $|m-n|=$ odd

- Thermal scattering off lattice vibrations determine $P_n(z)$

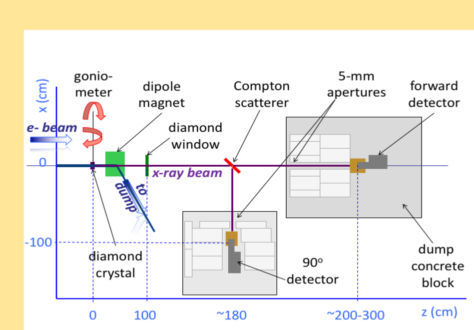
$$\begin{aligned}\frac{dP_n}{dz} &= \sum_{m<n_f} W_{mn}P_m(z) - \sum_{m=1} W_{mn}P_n(z), \quad n<n_f \\ \frac{dP_n}{dz} &= \sum_{m=1} W_{mn}P_m(z) - \sum_{m\geq n_f} W_{mn}P_n(z), \quad n\geq n_f \\ W_{mn} &= \frac{2}{hv}|\langle\psi_m|V^I|\psi_n\rangle|\end{aligned}$$

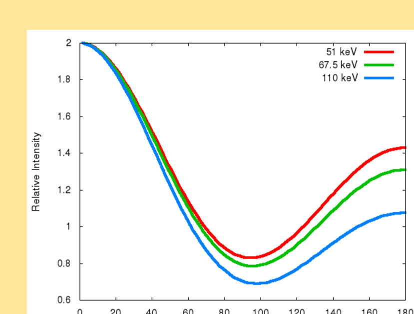
Model includes effects of dechanneling and rechanneling

Approximate selection rule: $|m-n|$=even

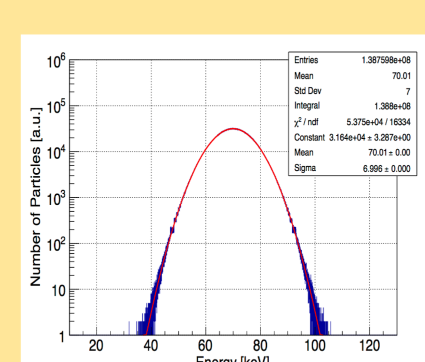
- Within error bars, model agrees with measurements at ELBE linac
- At 43MeV beam energy, X-ray lines at 51, 67.5, 110 keV
- Expect signal about 5-6 times above bremsstrahlung background

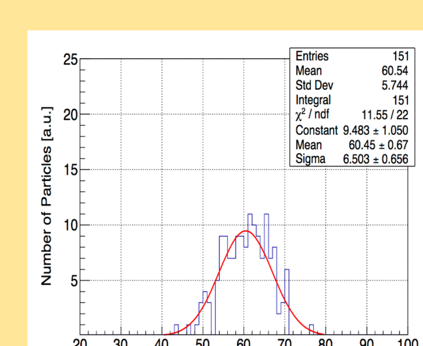
COMPTON SPECTROMETER





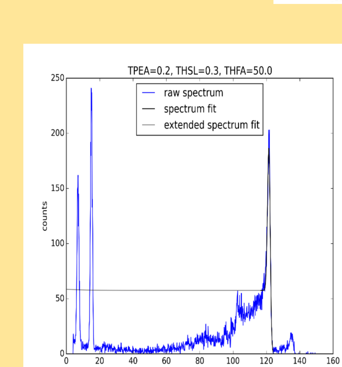
$$E_{scat} = E_{init}\left[\frac{1}{1+(E_{init}/m_e c^2)(1-\cos\theta)}\right]$$

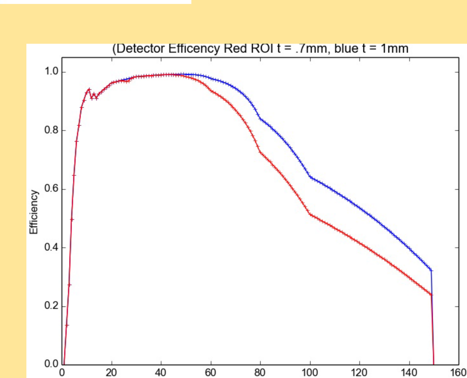




- Polycarbonate plate as a Compton scatterer
- Needed to mitigate pile up at high bunch charge
- Expect reduction by 6 orders of magnitude at 90°

X-RAY DETECTOR CALIBRATION





- Calibrated with Co57 spectrum
- Peak at 122keV shows "hole-tailing". Region of interest goes to FW0.1M
- Detector efficiency calculated with data over energy range

OUTLOOK

- CR experiments over several phases: emittance measurement, beam-based alignment of crystal & detector, observation and detailed characteristics of CR over a range of bunch charges
- Field emitter cathodes could allow nm scale emittances