Design of the Energy Selection System for Proton Therapy Based on GEANT4

Speaker：Zhikai Liang

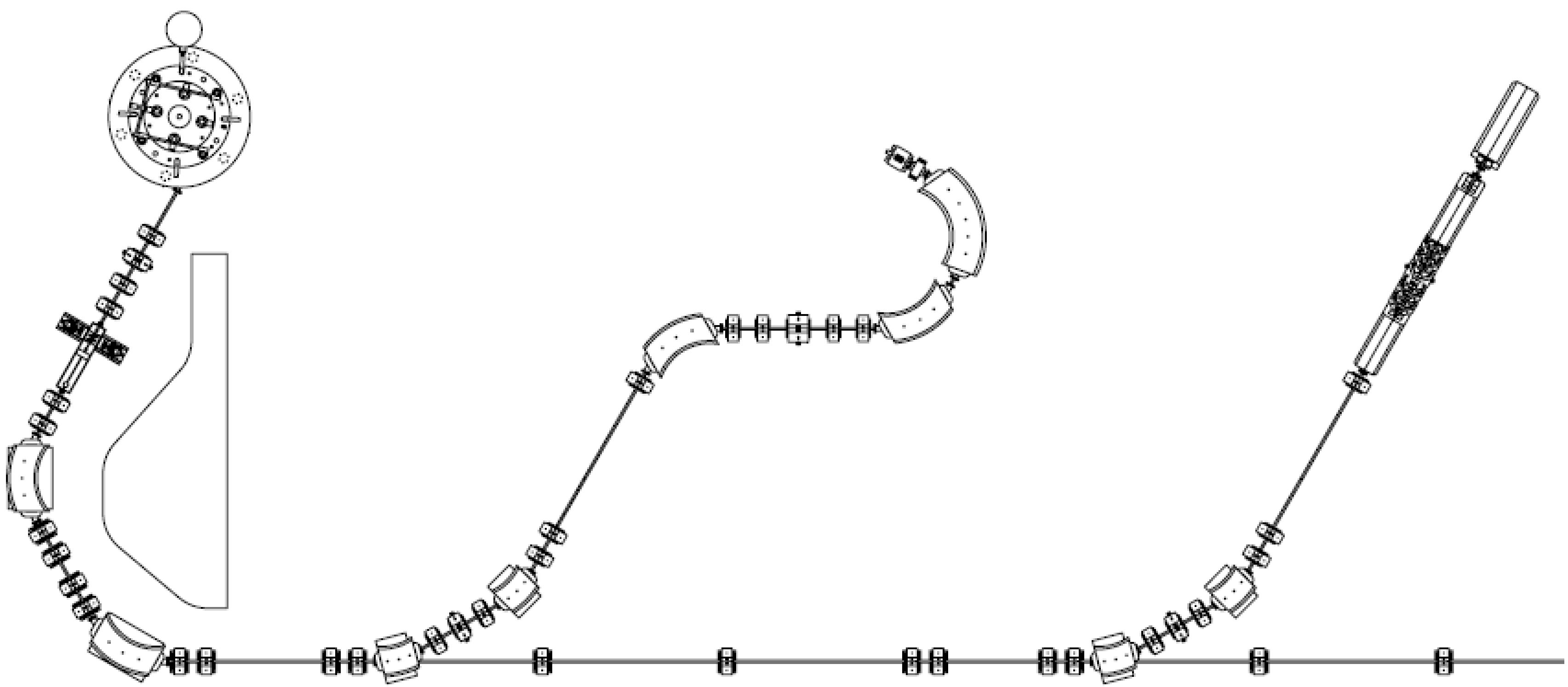
Huazhong University of Science and Technology, Wuhan, China

Outline

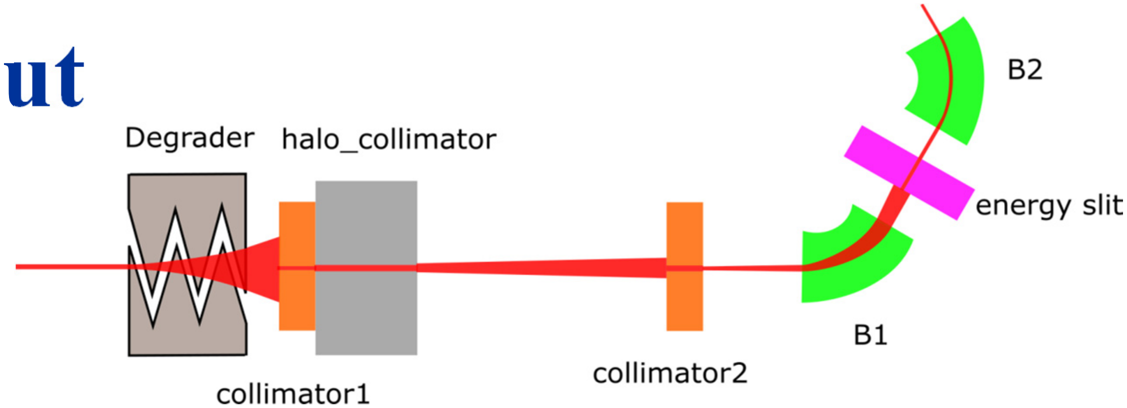
- Layout
- Physical process
- Simulation process
- Beam parameter simulation results
- Secondary particle energy spectrum
- Optimization
- Conclusion

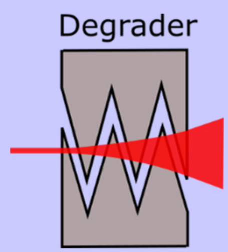
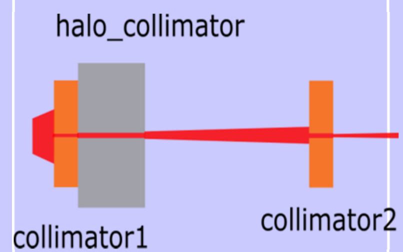
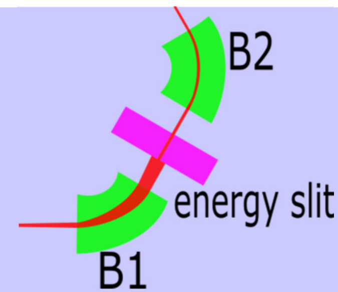
Layout

ESS

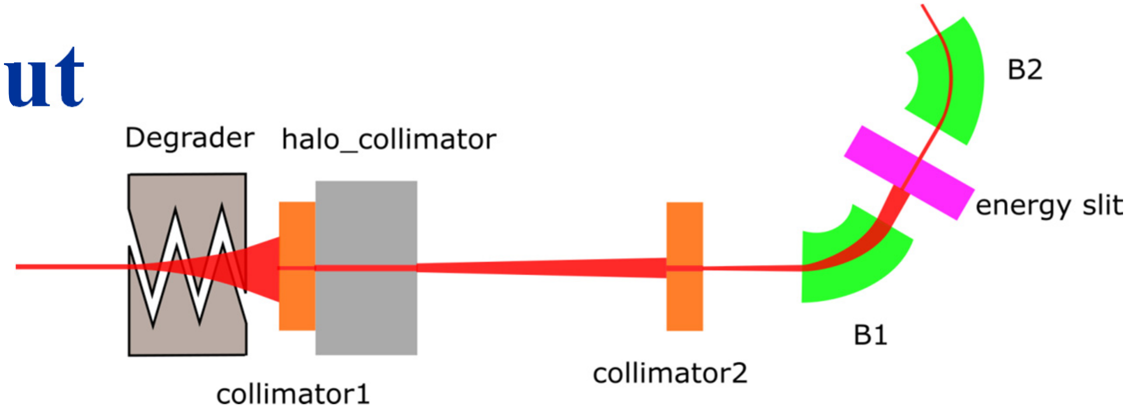


Layout



			
Energy	decrease		
Emittance	increase	decrease	decrease
Energy spread	increase	decrease	decrease
Transmission	decrease	decrease	decrease

Layout



Location	Parameter	Design value
Before ESS	Energy	250MeV
	Current	500nA
	Emittance	5π mm·mrad
	Energy spread	0.5%
After ESS	Energy range	70~250MeV
	Transmission	0.2%
	Emittance	10π mm·mrad
	Energy spread	±0.5%

Physical process

	extranuclear electron	nucleus
inelastic interactions	Ionization energy loss	Bremsstrahlung
elastic interactions	Coulomb interaction	Coulomb scattering

Physical process

	extranuclear electron	nucleus
inelastic interactions	Ionization energy loss	Bremsstrahlung
elastic interactions	Coulomb interaction	Co

Particle: light (photon or electron…)
Material: heavy

Physical process

	extranuclear electron	nucleus
inelastic interactions	Ionization energy loss	Bremsstrahlung
elastic interactions	Coulomb interaction	Coulomb scattering

Particle: low energy electron(100eV)

Physical process

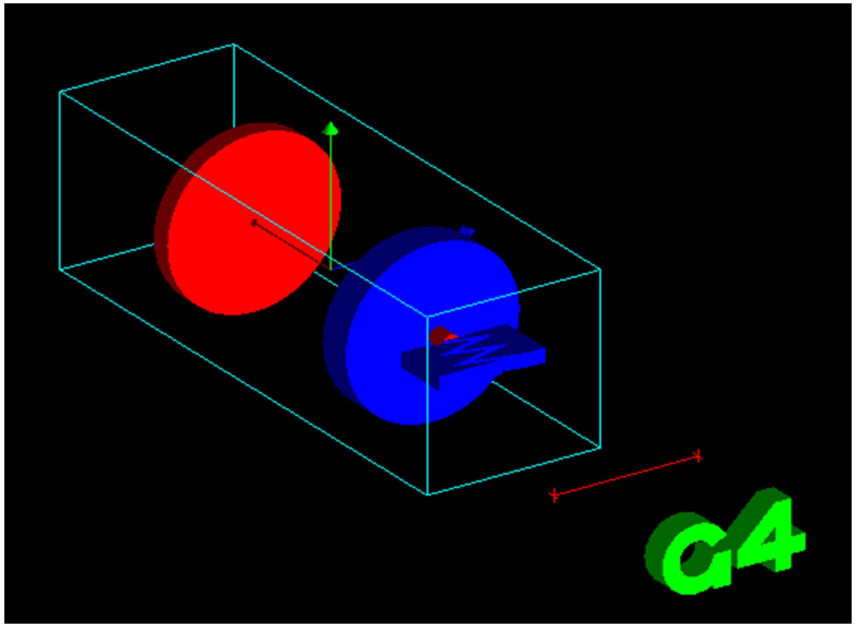
	extranuclear electron	nucleus
inelastic interactions	Ionization energy loss	Bremsstrahlung
elastic interactions	Coulomb interaction	Coulomb scattering

- **Ionization energy loss** → **Energy degradation**
- **Coulomb scattering** → **Emittance growth**
- **Nuclear reaction** → **Secondary particles production**

Simulation process

- Construct the model's structure and material
- Define the physics and particles
- Run the simulation and obtain the data
- Process the data and get the useful information

Before running



Simulation process

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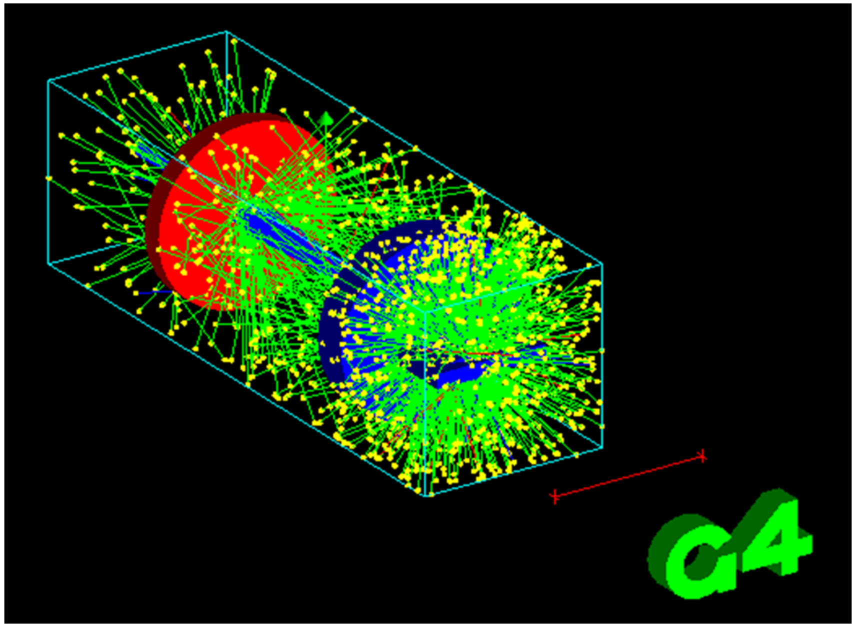
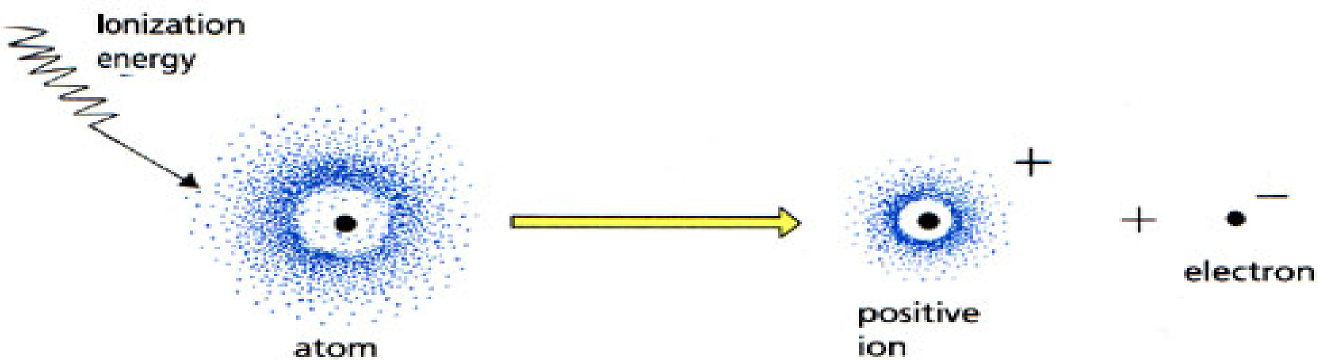
After running



Energy degrading

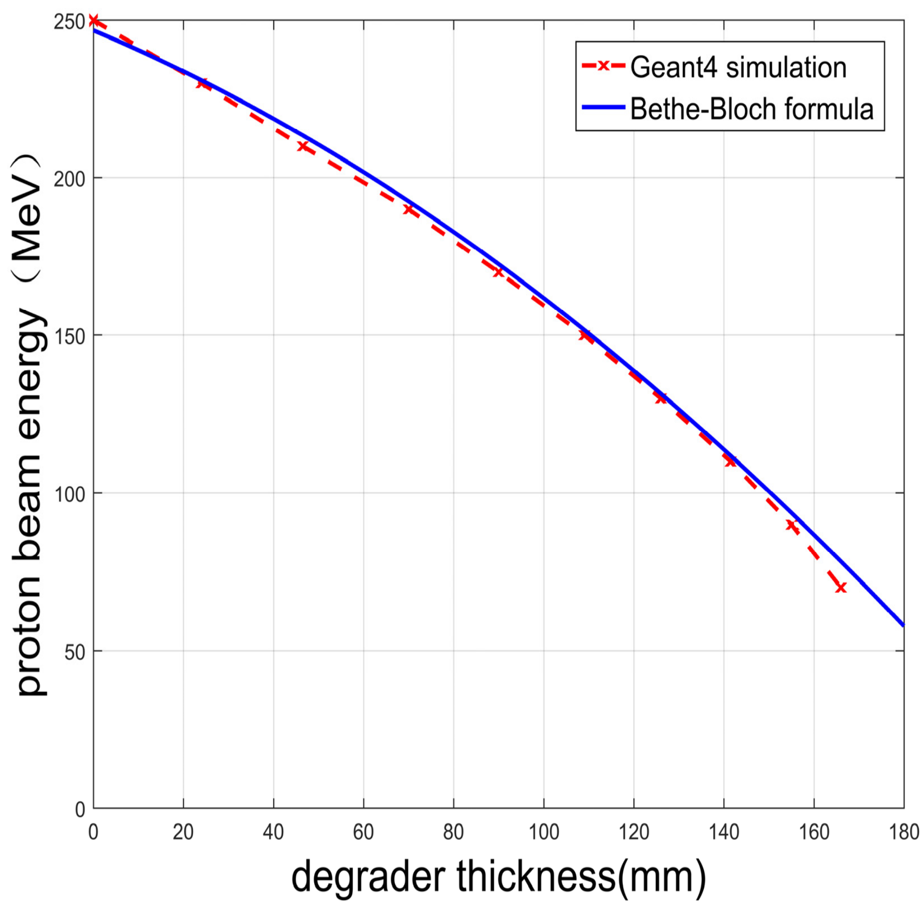
- Ionization energy loss



- Bethe-Bloch formula

$$-\left(\frac{\mathrm{dE}}{\mathrm{dx}}\right)=4\pi \mathrm{N}_a r_e^2 m_e c^2 z^2 \left(\frac{Z}{A}\right)\left(\frac{1}{\beta^2}\right)\left[\ln\left(\frac{2m_e c^2 \gamma^2 \beta^2}{I}\right)-\beta^2-\frac{\delta}{2}\right]$$

Energy degrading

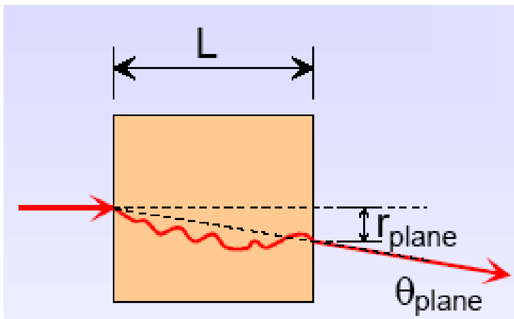


- **Energy 250~70MeV**
  degrader 0~166mm

- **When L=166mm, (dE/dL)max=1.46MeV/mm (high positional precision)**

Emittance growth-degrader

- Multiple Coulomb scattering



- Multiple scattering angle

$$\theta_0 = \frac{13.6z}{\beta cp}\sqrt{\frac{L}{L_0}} \times \left(1 + 0.038\ln\left(\frac{L}{L_0}\right)\right)$$

L0:material radiation length

lower atomic number material
—larger L0—lower θ0

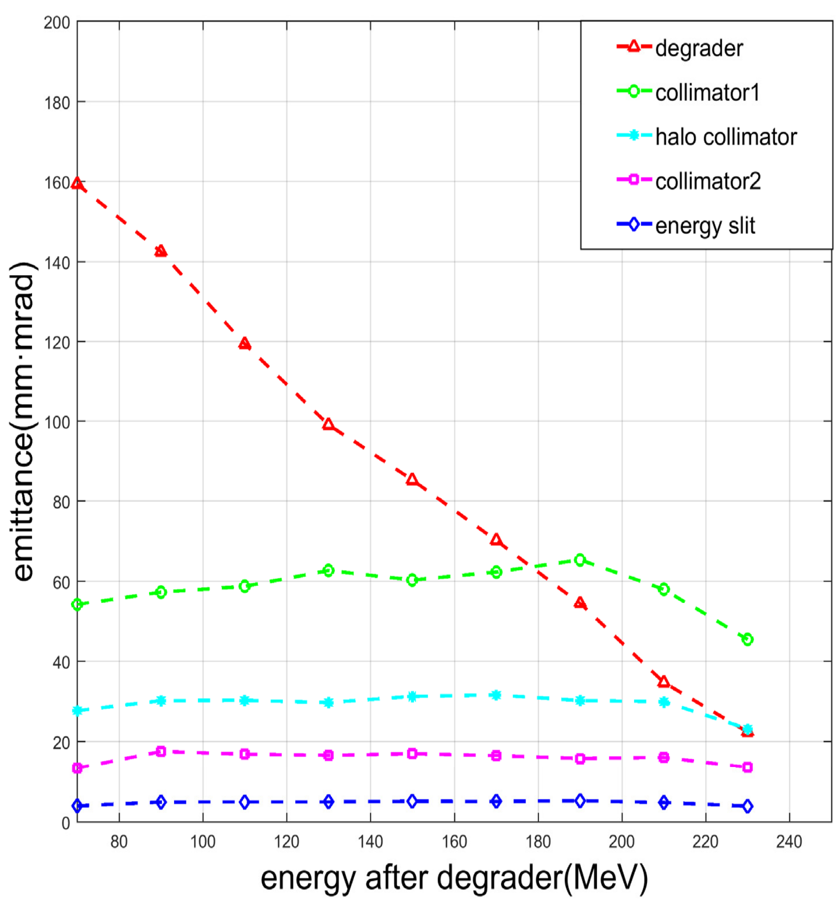
- Emittance after degrader

$$\varepsilon_{\deg} = \varepsilon_0 + \beta\theta_0^2$$

lower β、lowerθ0
—lower emittance growth

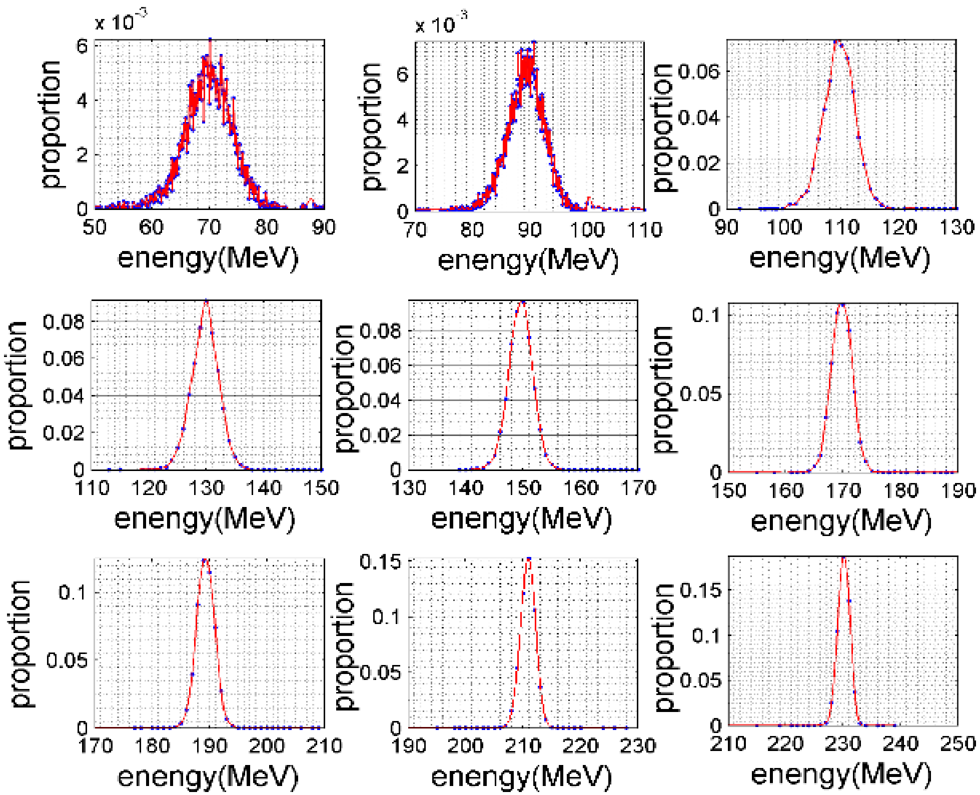
Emittance decrease

- collimator $$\varepsilon_{\mathrm{col}} = \frac{2r_1 \cdot r_2}{L}$$



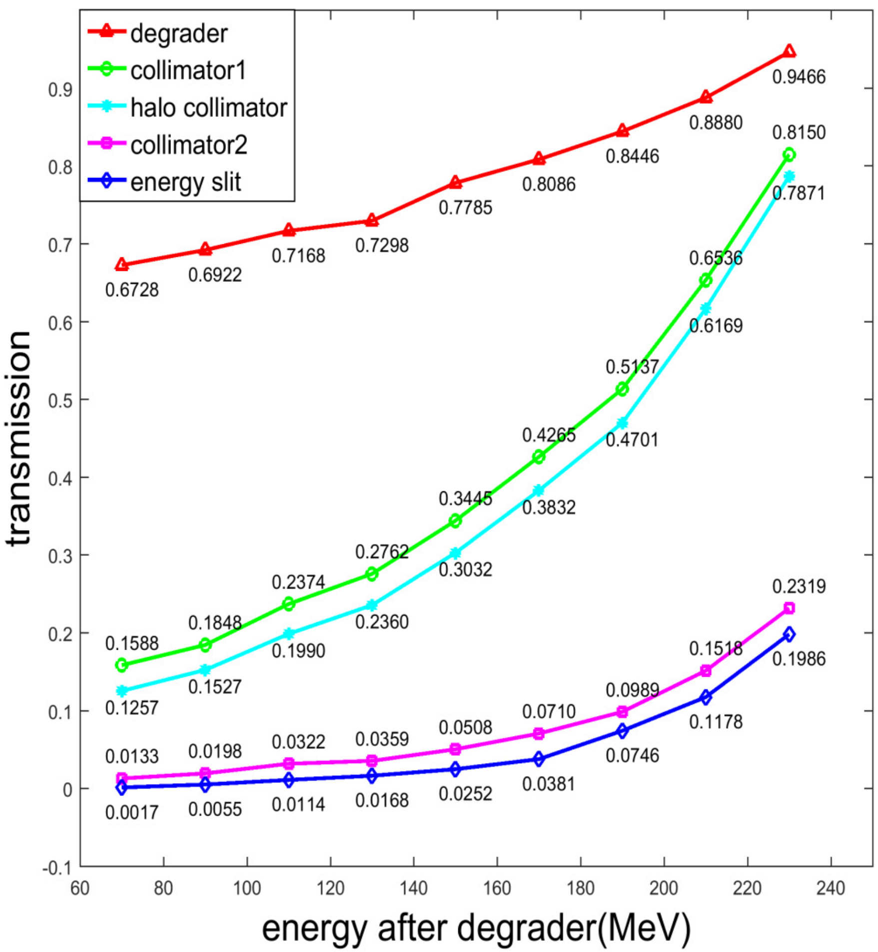
- Thicker degrader —larger emittance
- Collimator maintain low emittance(13π)
- Energy slit further decrease emittance(5π<10π(designed))

Energy spread



- **Thicker degrader**
  —larger energy spread
- **Maximum:**
  4.9% after degrader
- **Energy slit decreases energy spread to ±0.5%**

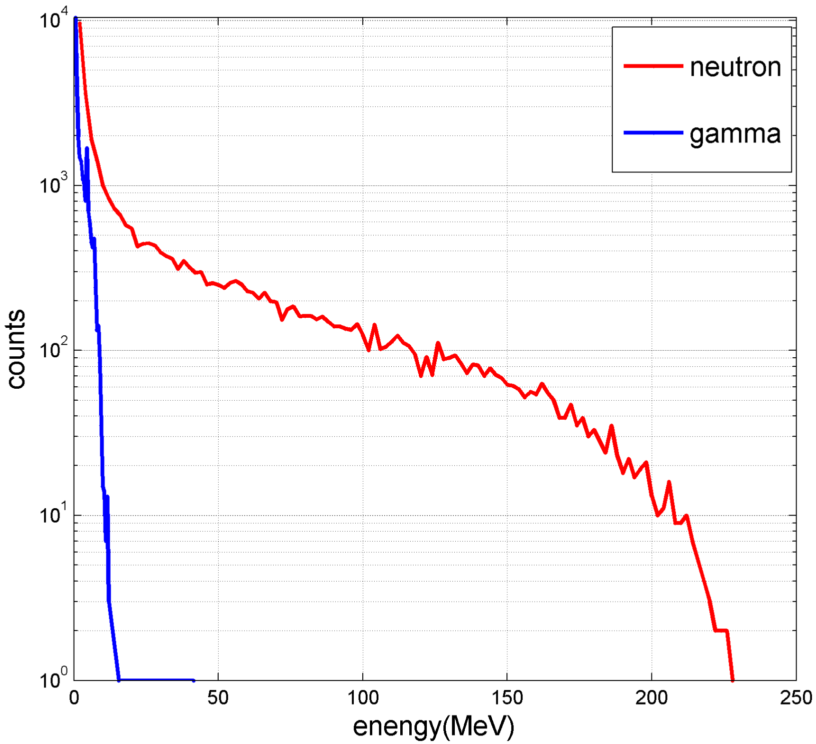
Transmission



- **Thicker degrader**
  —lower transmission
- **Beam losses happen in every component**
- **Final transmission:**
  0.17%~19.56%
  (designed transmission 0.2%)

Secondary particles' energy spectrum

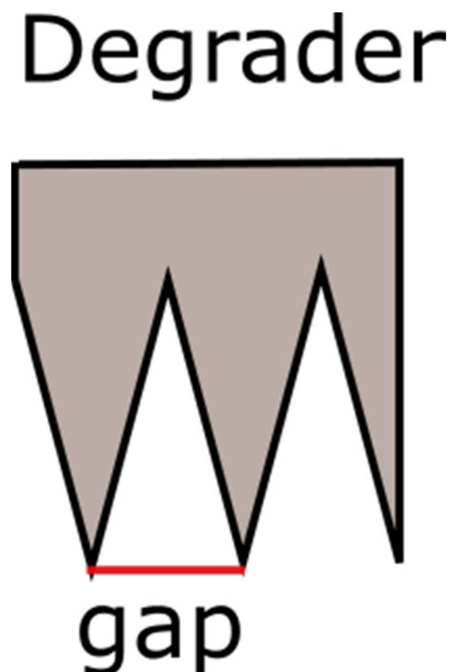
- Neutron and gamma photon



➢ **Neutron energy spectrum higher and wider than gamma**

Optimization

$$\varepsilon_{\deg} = \varepsilon_0 + \beta\theta_0^2$$

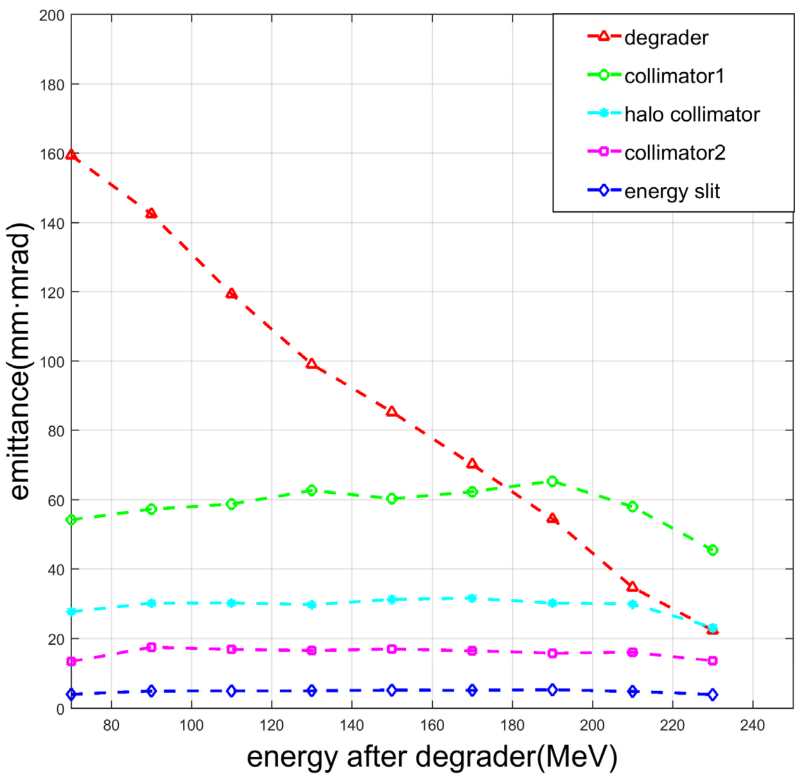


cooling | monitor | ……

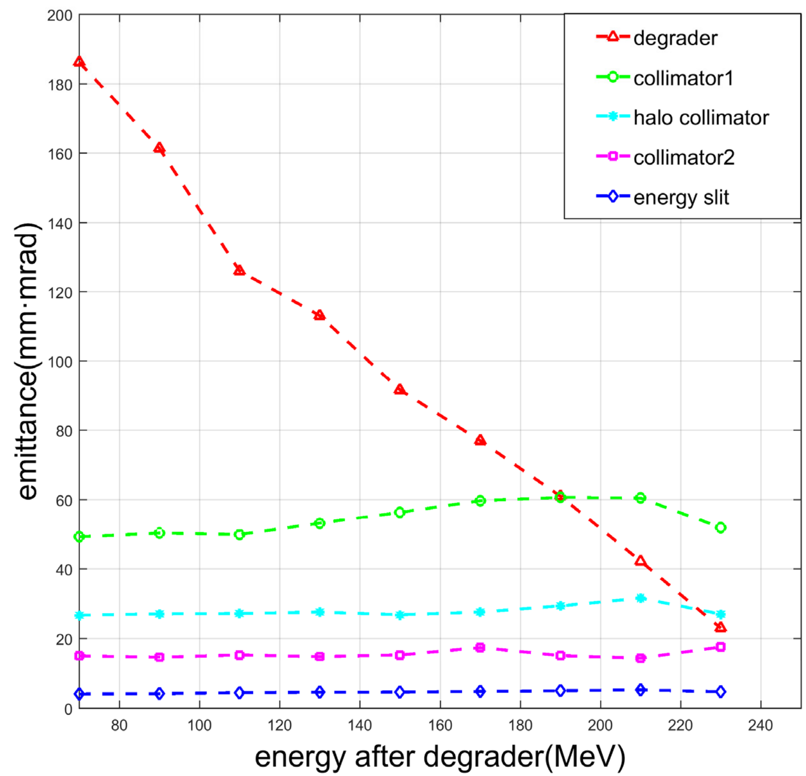
Optimization $\varepsilon_{deg} = \varepsilon_0 + \beta\theta_0^2$

- Larger degrader gap—larger β—larger emittance

degrader length:200mm



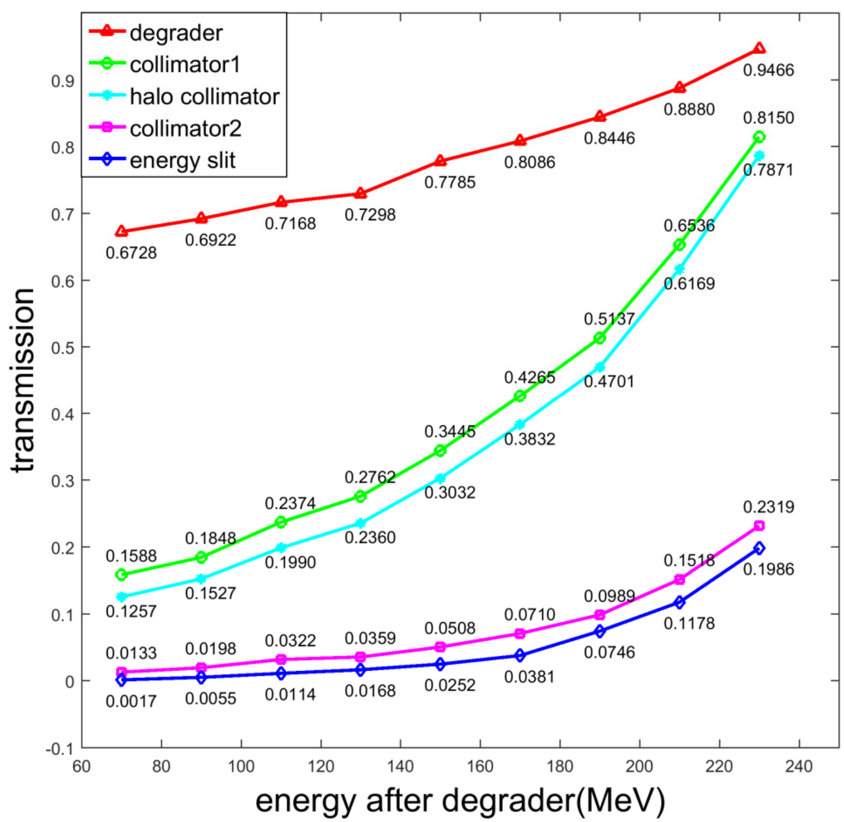
degrader length:260mm



Optimization

- transmission

degrader length:200mm



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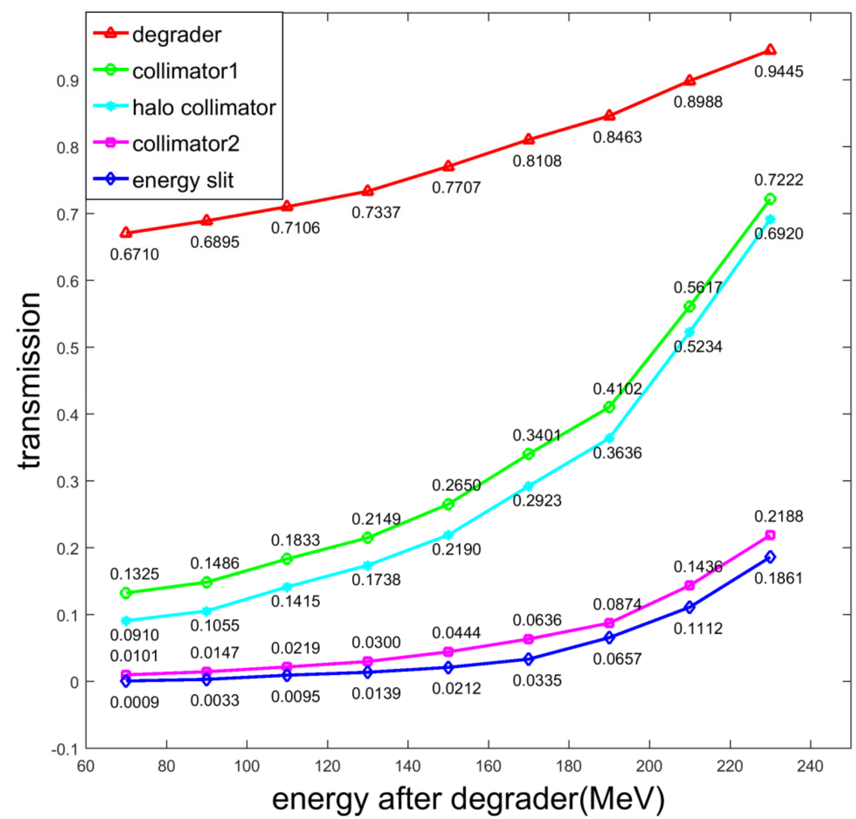

Conclusion

- The final simulated parameter:

70~250MeV, 5πmm·mrad, transmission>0.17% , energy spread=0.5%

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- Optimization methods:

➢ larger material radiation length(material with lower atomic number)

➢ Smaller twiss parameter β(more compact degrader or optimize the beam line)

- Future work:

➢ Radiation protection based on the secondary energy spectrum

➢ Control system for the special range of motion, speed, position precision, response time……

Thanks for your listening!