

Photocathodes with VUV-UV-Vis full range response for fast timing and imaging applications

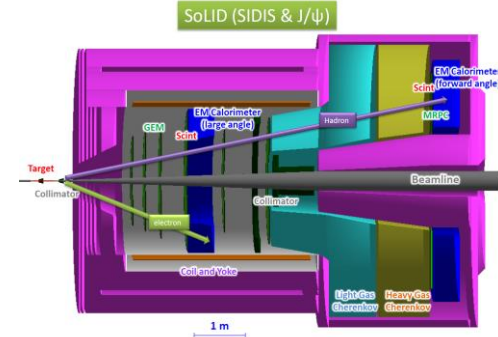
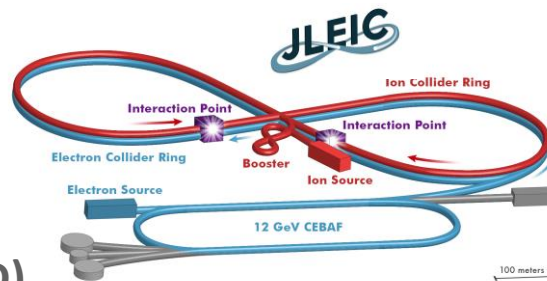
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Motivation: Direct VUV-UV-Vis photon detection for various detectors



Nuclear Physics

- **Particle identification detectors (PID)**

Higher Cherenkov radiation photon counts at UV range:

- The Electron ion collider (EIC)
- The Pioneering High Energy Nuclear Interaction eXperiment upgrade (sPHENIX)
- The Solenoidal Large Intensity Device (SoLID)

High Energy Physics



- **Neutrino oscillation experiments with liquid Ar detector (128 nm):**

- The short-baseline neutrino (SBN) program
- The Deep Underground Neutrino Experiment (DUNE)

- **Direct dark matter search experiments with liquid Xe detector (175 nm):**

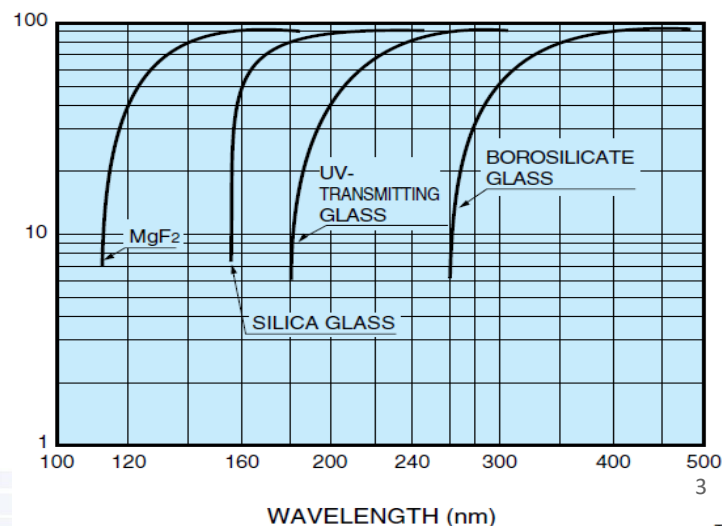
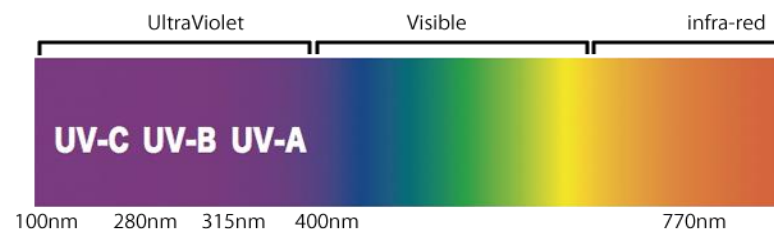
- The LZ experiment
- The DARWIN experiment
- The PandaX experiment



A detector with VUV-UV-Vis photon detection would benefit these future experiments

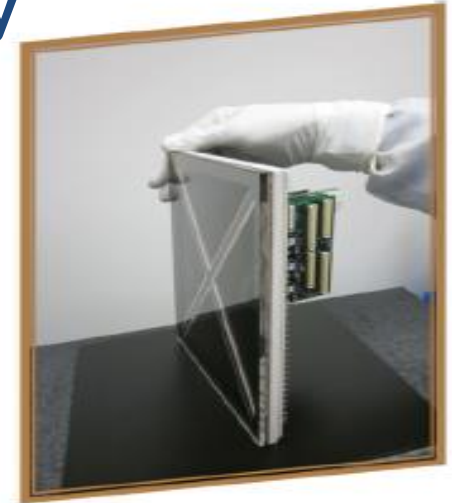
Motivation: Current photomultipliers

- ❑ Alkali photocathodes are coated in the inner surface of inexpensive glass package, suitable for large experiments, but detection limited by the transmission property of windows material
- ❑ Price may double or triple if the whole package is replaced with UV-transparent materials
- ❑ Alkali photocathodes are extremely sensitive to air and water, preventing detailed understanding of the material properties
- ❑ Developments were mainly achieved by industry based on empirical experience and recipes were kept as secrets
- ❑ Developments were focused on visible wavelength, especially around 400 nm for water based neutrino experiments
- ❑ Lack of studies below 300 nm wavelength



Strategy for bialkali photocathode study

- ❑ The compact MCP-PMT opens the opportunity of expanding the detection range to VUV-UV-Vis with affordable cost increase
- ❑ Detailed understanding of the bialkali photocathode properties for high performance development



OUR STRATEGY

Research

- *In situ* characterization during photocathode growth
 - **Structure:** X-ray diffraction, Grazing incidence small angle x-ray scattering
 - **Chemistry:** X-ray reflectivity, X-ray diffraction, X-ray fluorescence
 - **Surface morphology:** X-ray reflectivity, Atomic force microscopy

Development

- Understand the cathode microscopic properties
- Develop new growth recipes for high QE photocathode

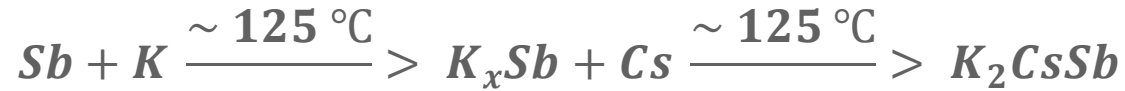
Application

- Transfer the recipes to Argonne facility for detector fabrication

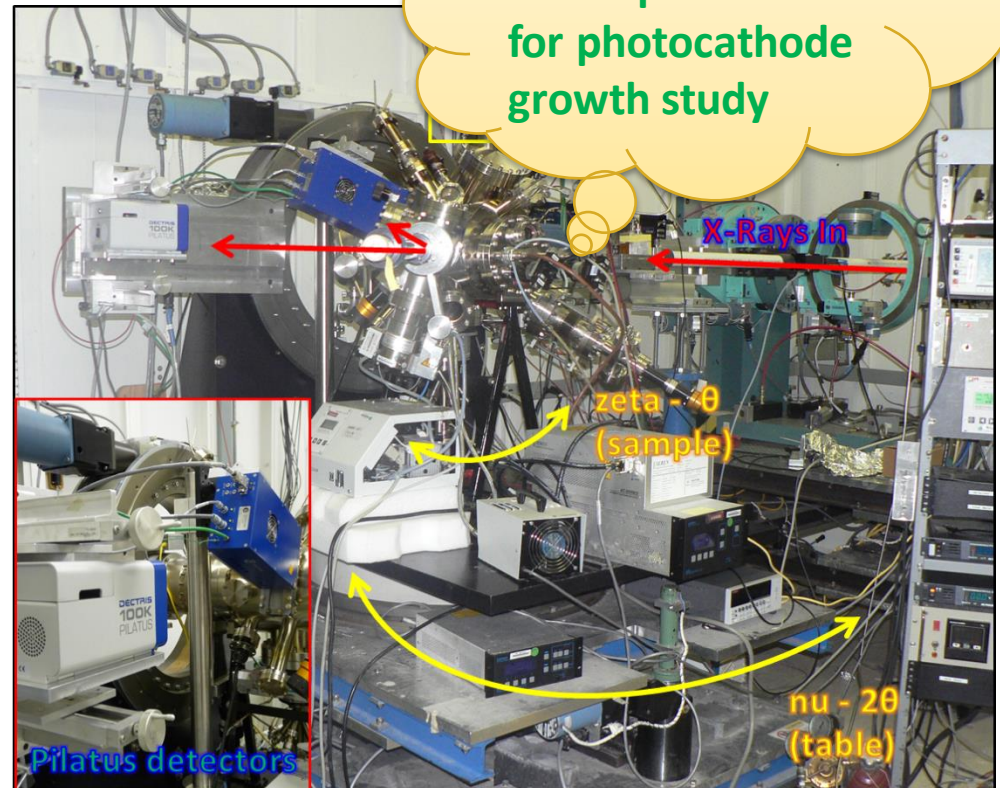
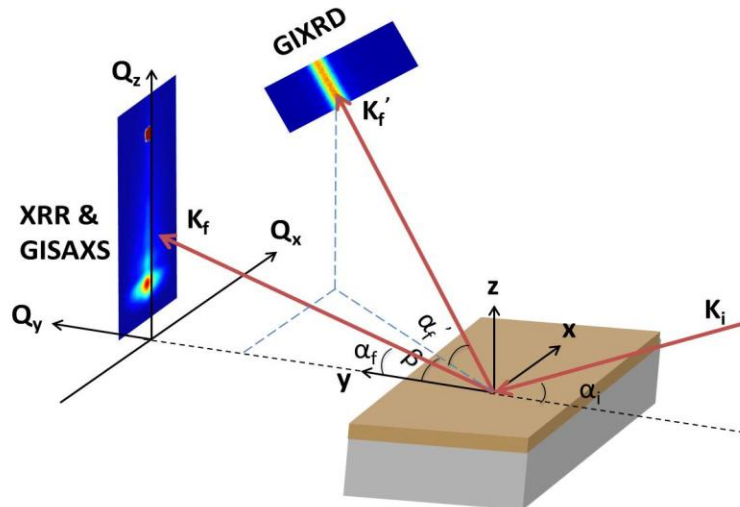
Approach: *In situ* X-ray techniques

Photocathode collaboration with BNL, LBNL, Stony Brook Univ.

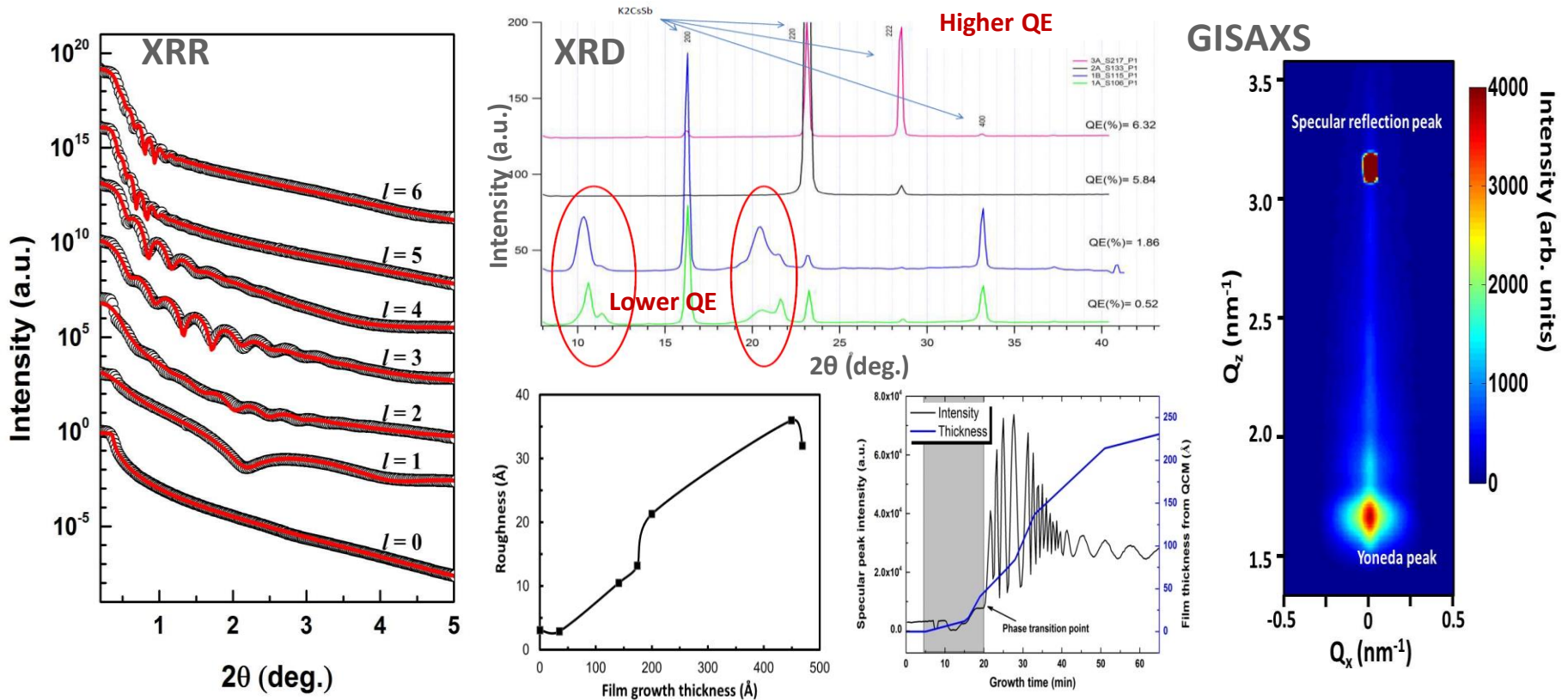
Collaboration effort to improve the performance of alkali antimonides (K_2CsSb) based on characterization of cathode formation during traditional sequential growth process



- X-ray Reflection (XRR)
- X-ray Diffraction (XRD)
- Grazing Incidence Small Angle X-ray Scattering (GISAXS)
- QE monitor during growth



X-ray analysis results

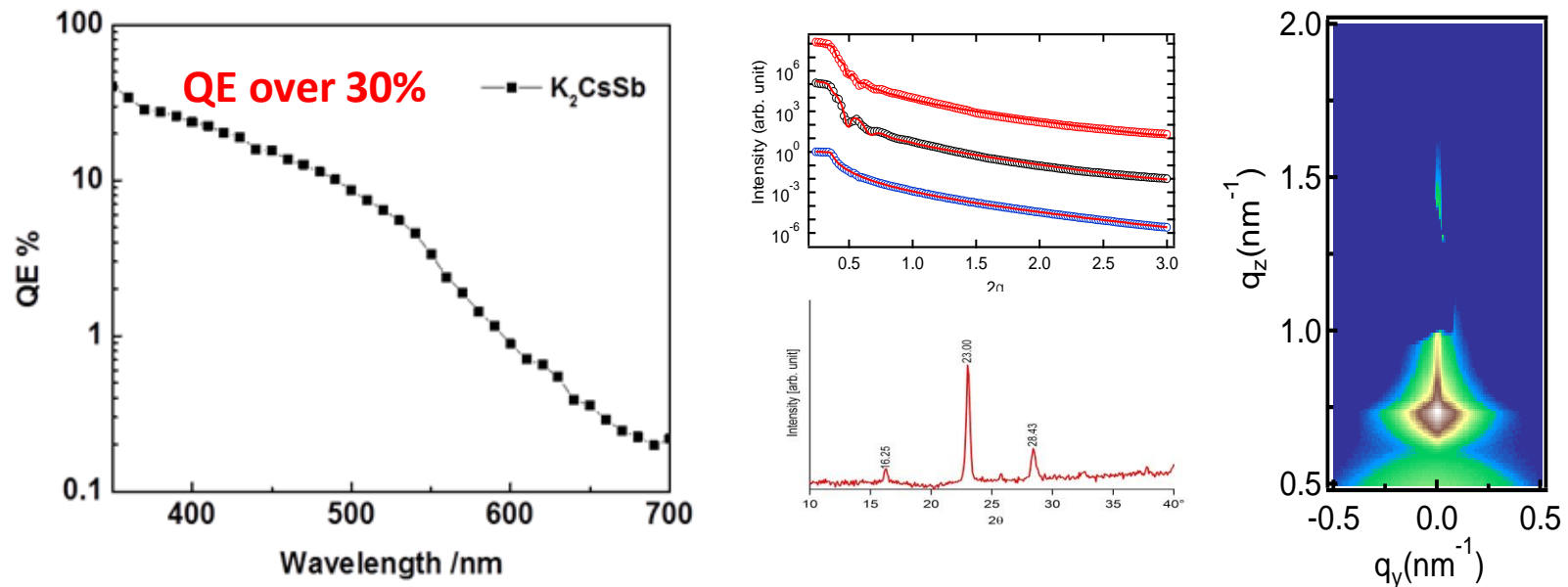


- Sb film **phase transition** (amorphous to crystalline) at thickness of ~ 40 Å.
- K₂CsSb **photocathode thickness** is around 5 times that of the total deposited Sb film.
- **Surface roughening** mainly occurs during K diffusion process, faster growth results in rougher surface morphology.
- High QE cathode exhibits **single K₂CsSb compound**, low QE cathodes exhibit mixture of different compositions.

New recipe for high QE photocathode

- **Right chemical stoichiometry** is the key point to achieve high QE photocathode
 - > Better crystallinity
 - > Reduce defect scattering & improve electron mean free path
 - > High QE

High QE photocathode via co-evaporation recipe, controlling the elements growth ratio



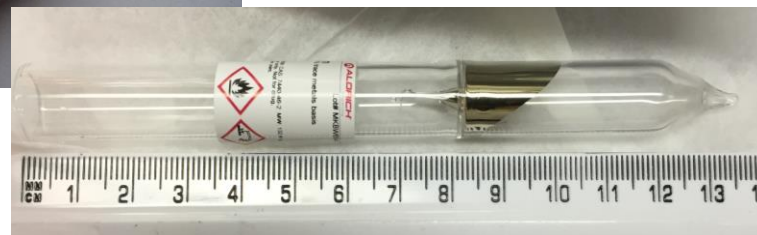
Photocathode with right stoichiometry was achieved, exhibiting QE over 30% at 380 nm, fulfilling the requirement of most HEP experiments

These studies focused on understanding materials properties and performance improvement

New alkali sources for mass production



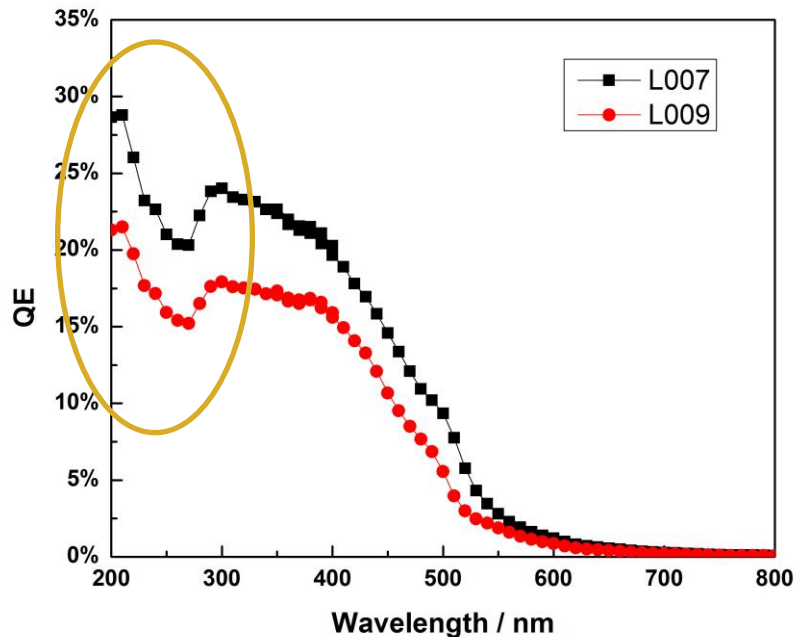
Alkali dispensers for previous studies
Suitable for small amount studies



Alkali metals (>99.95% purity)
Suitable for mass production

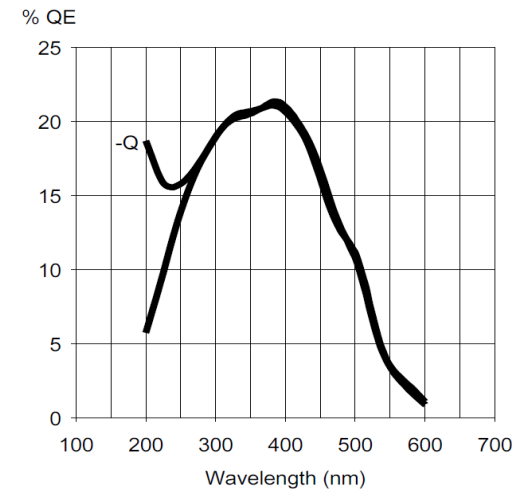
Chemicals	Vender	Package amount	Lead time	Price
K dispenser	SAES	50 pieces	6 months	\$700
Cs dispenser	SAES	30 pieces	6 months	\$450
Pure K metal	Aldrich	5 g	2 weeks	\$182
Pure Cs metal	Aldrich	1 g	2 weeks	\$97

Recent experiment with UV response characterization



Interesting observation:
Enhanced UV photo response for bialkali photocathode!

Further investigation of the X-ray data for structure, composition details are undergoing to explain this observation



Photonis XP85112 data sheet

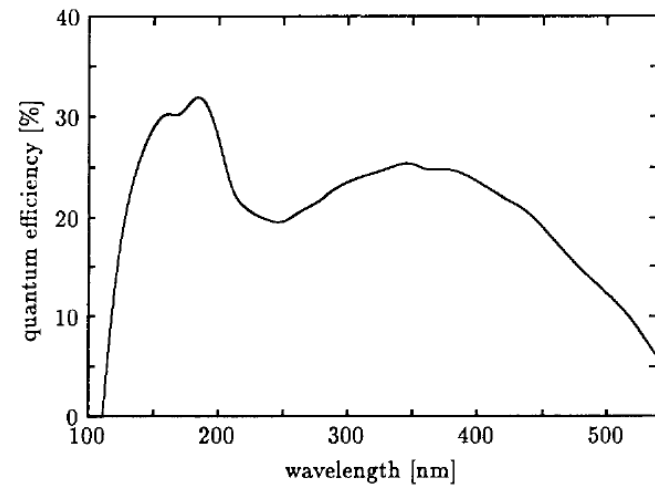


Fig. 1. The quantum efficiency of the Thorn EMI 9426 photo-multiplier tube (serial number 809).

Summary

- Full range response (VUV-UV-Vis) detector is called for future experiments.
- Structure, surface details were revealed using in-situ X-ray techniques.
- New recipe were developed to achieve high performance photocathodes.
- New alkali sources were tested for photocathode mass production.
- Enhanced photo response was observed at UV range for bialkali photocathode.

Ongoing and future works

- Investigate the X-ray experiment data on structure and composition details to explain the observation
- Modify detector production facility and adapt these new recipes and sources to detector productions.



Acknowledgments

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Thank you for your attention!

Questions?

