

RF7: Hadron Spectroscopy

Welcome and Summary of RF7 activities

Conveners:

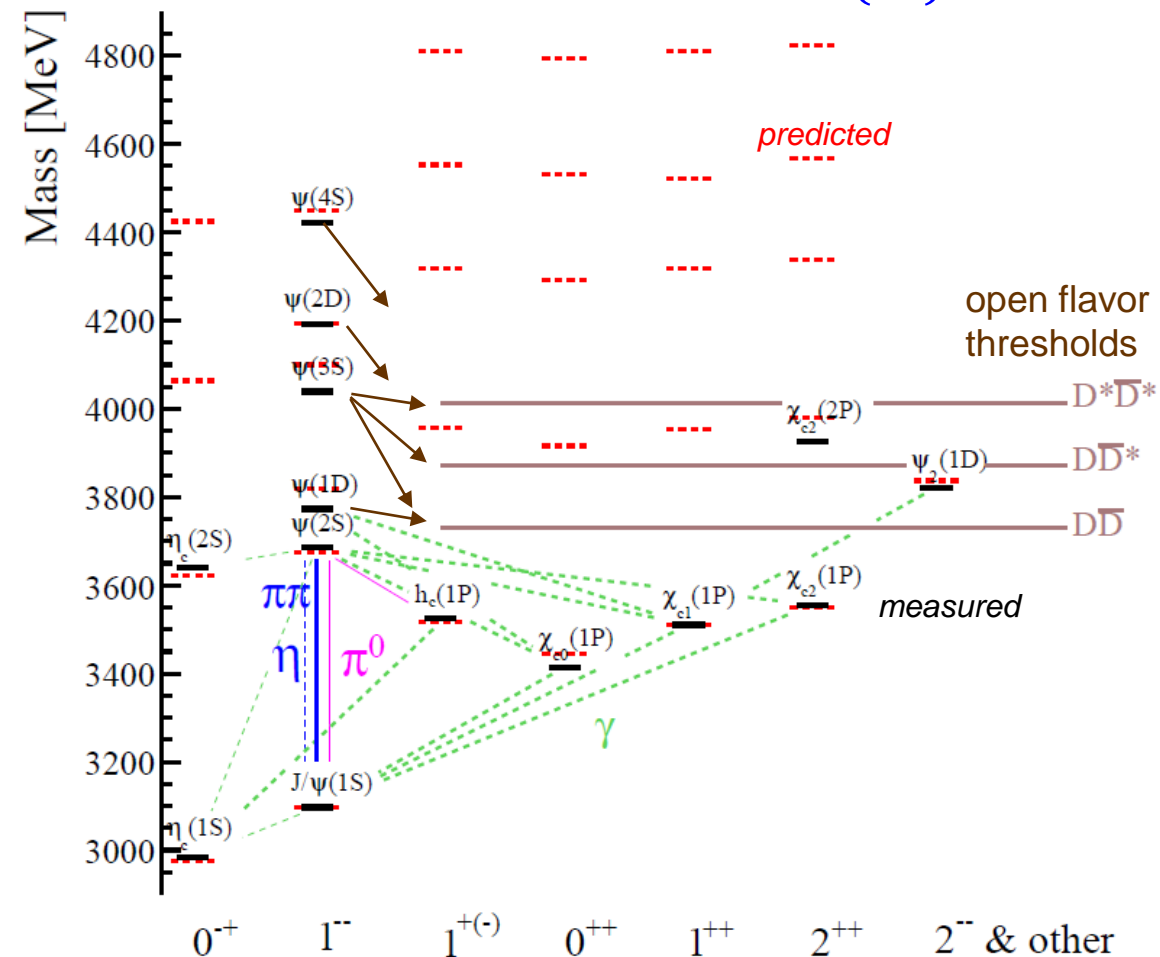
Richard Lebed, *Arizona State University*, Richard.Lebed@asu.edu

Tomasz Skwarnicki, *Syracuse University*, tskwarni@syr.edu

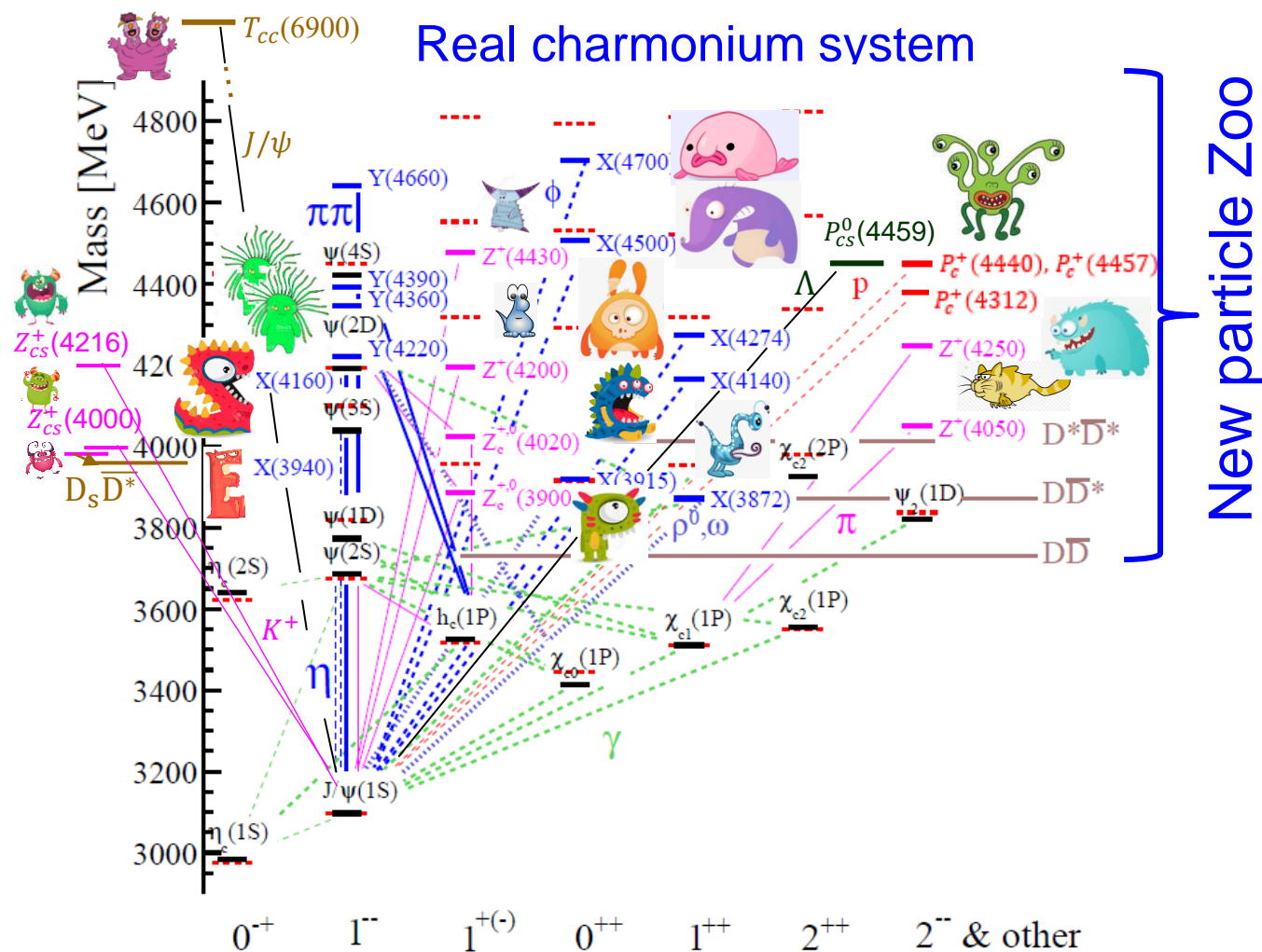


Hadron Spectroscopy is in crisis

Charmonium in textbooks ($c\bar{c}$)

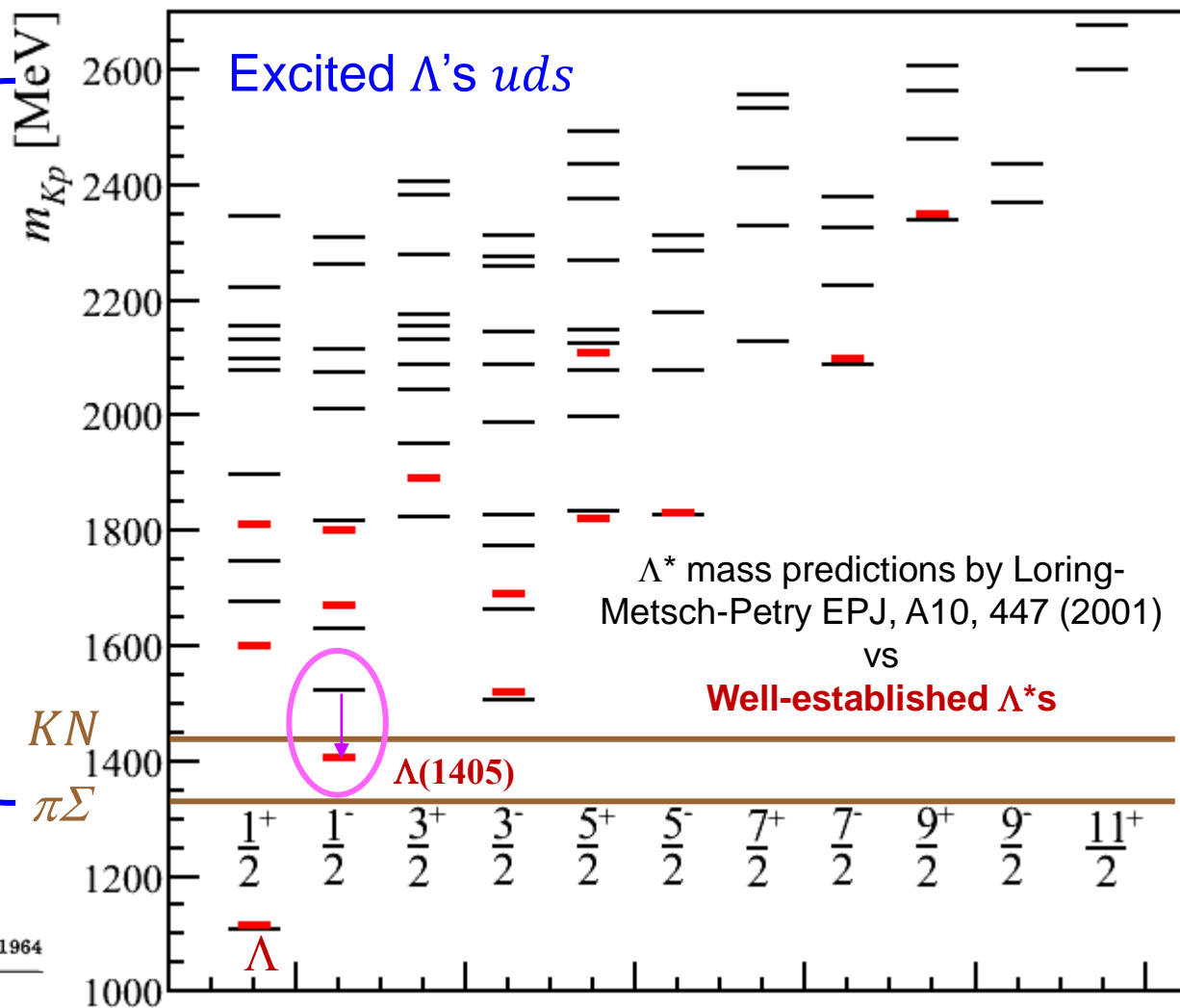
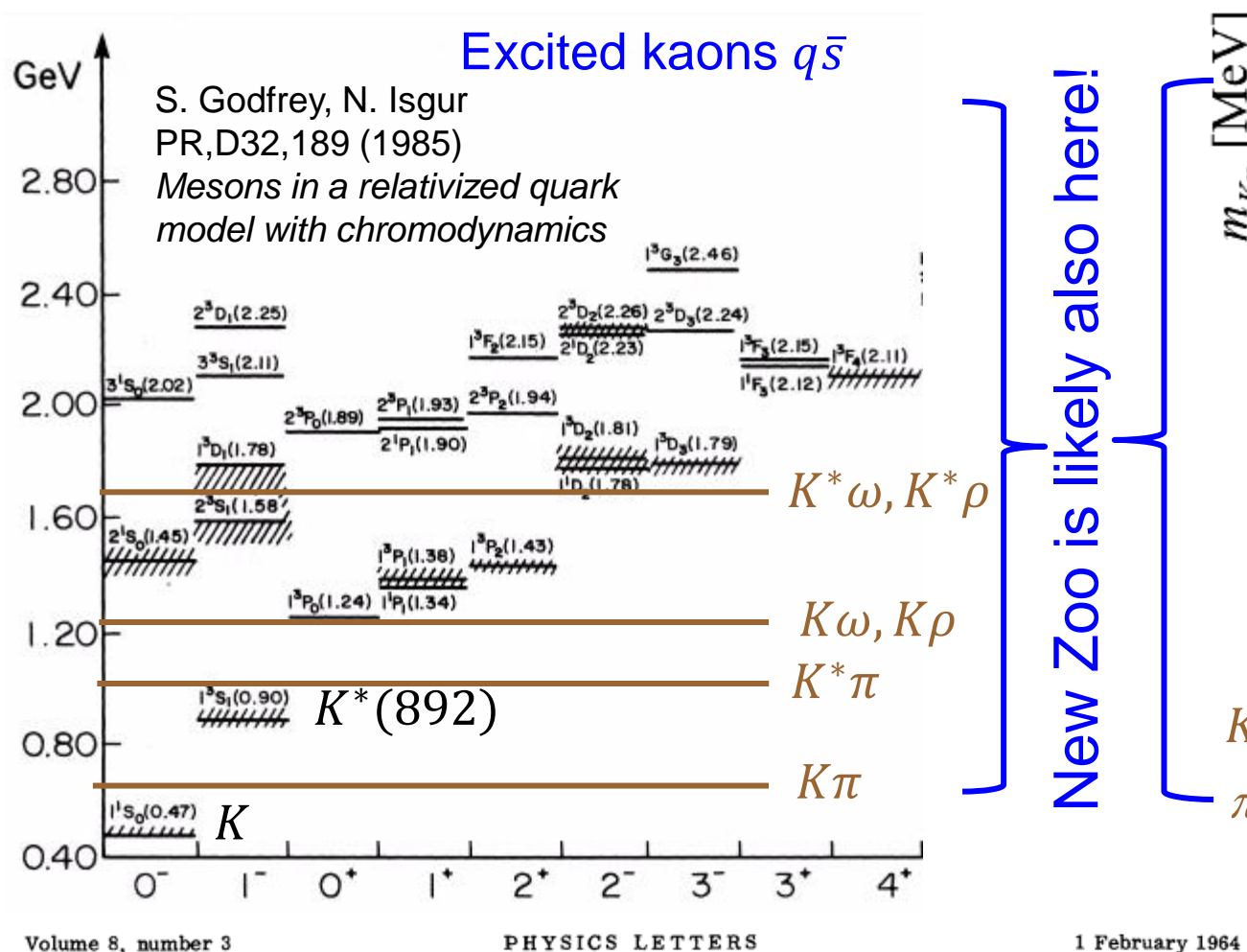


Real charmonium system



- Internal structure of the new particle Zoo is poorly understood

It is time to stop pretending that we understand hadrons



A SCHEMATIC MODEL OF BARYONS AND MESONS

the triplet as quarks u, d, s and the members of the anti-triplet as anti-quarks $\bar{u}, \bar{d}, \bar{s}$. Baryons can now be constructed from quarks by using the combinations (qqq) , $(qqq\bar{q}\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the represen-

Didn't Gell-Mann tell us so?

Summary of RF7 activities – topical group structure

- June 24, 2020 session on [“Hadron Spectroscopy” within EF06](#)
- **Hadron Spectroscopy** added as its own Topical Group [first time ever for Snowmass] within Rare and Precision Frontier in July, 2020 (**RF7**) with *Rich Lebed (Arizona State U.)* and *T.S. (Syracuse U.)* as conveners, who invited many subconveners for a good representation of the broad *experimental* and *theoretical* communities studying topics we concentrated on:

Heavy-Quark Conventional Hadrons

- Bryan Fulsom (PNNL), Alexis Pompili (U. of Bari), *Elena Santopinto (INFN Geona)*

Heavy-Quark Exotic Hadrons:

- Liupan An (CERN), Ryan Mitchell (Indiana U.), *Sasa Prelovsek (U. of Ljubjana)*

Light-Quark Exotic Hadrons:

- Sean Dobbs (Florida State U.), Justin Stevens (College of William&Mary), *Adam Szczepaniak (Indiana U.)*

Summary of RF7 activities - meetings

- Three early workshops to review each subtopics (7-8 presentations each, good attendance virtual attendance):
 - Sep.16, 2020 [Heavy-Quark Exotic Hadrons](#)
 - Sep.23, 2020 [Heavy-Quark Conventional Hadrons](#)
 - Sep.30, 2020 [Light-Quark Exotic Hadrons](#)
- Oct.2, 2020 [Review 14 Lols at RPF Townhall meeting](#)
- Two additional workshops to review remaining topics:
 - Nov.18, 2020 [Opportunities in Hadron Spectroscopy](#)
 - Dec.16, 2020 [Joint Session with Energy Frontier](#) (EF06,EF07) on hadron production (there is also a joint discussion session at this meeting on Friday, July 21, 2022 at 10:30am)
- Workshop to restart activities after a COVID pause:
 - Oct.25, 2021 [Update on Hadron Spectroscopy](#)
- This year activities:
 - Consolidation of Lols into ~10 White Papers relevant to our subgroup
 - May 17, 2022 Presentations of [white papers in parallel session of RPF Cincinnati Meeting](#)

RF7 White Papers

- **Future Physics Potential of LHCb**, LHCb collaboration, LHCb-PUB-2022-012, CERN-LHCb-PUB-2022-012, in 2022 Snowmass Summer Study, 2022, <https://cds.cern.ch/record/2806113>
- **Physics with the Phase-2, ATLAS and CMS Detectors**, ATLAS and CMS collaborations, CMS PAS FTR-22-001, ATL-PHYS-PUB-2022-018 <http://cds.cern.ch/record/2806962>
- **Review of CMS Contribution to Hadron Spectroscopy (Snowmass 2021 White Paper)**, R. Chistov, V. Papadimitriou, S. Polikarpov, A. Pompili and A. Sanchez-Hernandez, [arXiv:2204.06667](https://arxiv.org/abs/2204.06667)
- **Belle II Physics Reach and Plans for the Next Decade and Beyond**, Belle II collaboration, [arXiv:2207.06307](https://arxiv.org/abs/2207.06307)
- **Physics in the Tau-Charm Region at BESIII**, BESIII collaboration, [arXiv:2204.08943](https://arxiv.org/abs/2204.08943)
- **Hadron Spectroscopy at STCF**, F.-K. Guo, H. Peng, J.-J. Xie and X. Zhou, [arXiv:2203.07141](https://arxiv.org/abs/2203.07141)
- **Hadron Spectroscopy in Photoproduction**, M. Albaladejo, L. Bibrzycki, S. Dobbs, C. Fernandez-Ramirez, A. Hiller Blin, V. Mathieu et al., [arXiv:2203.08290](https://arxiv.org/abs/2203.08290)
- **Substructure of Multiquark Hadrons**, M. Karliner, E. Santopinto et al., [arXiv:2203.16583](https://arxiv.org/abs/2203.16583)
- **Need for Amplitude Analysis in the Discovery of New Hadrons**, JPAC collaboration, [arXiv:2203.08208](https://arxiv.org/abs/2203.08208)
- **Hadron Spectroscopy with Lattice QCD**, J. Bulava et al., [arXiv:2203.03230](https://arxiv.org/abs/2203.03230)

RF7 Summary Report

- Drafted by R.L. and T.S. with input from the submitted white papers and their editors
- Feedback from the RF7 community at the RPF Cincinnati meeting (May 18, 2022)
- The improved [draft](#) circulated to the RF7 mailing list on July 11.
- We are accepting comments until the end of the Seattle meeting (July 26, 2022)
- We expect to submit it to arXiv by early August

Executive Summary

- Numerous new hadronic states have been discovered in the past 20 years, many exhibiting “exotic” features that are not compatible with a conventional meson or baryon interpretation. No single theoretical model accommodates all the new states. Several different binding mechanisms are likely at play; even mixtures are possible. At present, hadron spectroscopy is the least-understood sector of the Standard Model, and thus impacts our ability to estimate hadronic effects in BSM searches, to correctly model neutron stars, and to understand the spectrum of other strongly coupled theories.
- In the next two decades, the LHC will be the most important facility for hadron spectroscopy, thanks to its high collision energy, large strong-production cross sections, and high luminosity. The LHCb upgrades will have the greatest experimental reach, by exploring a wide variety of heavy tetraquark and pentaquark configurations, thereby probing hadron structure in different kinematic and dynamical regimes. In addition to continued support for LHCb data-taking and analysis, investments are needed for detector R&D, and later for construction of Upgrade-II subsystems. CMS and ATLAS present opportunities for studying final states not requiring full hadron identification.
- Belle II complements LHCb via unique access to bottomonium-like vector states and their transitions to other exotics, as well as its ability to reconstruct decay modes with multiple neutrals, and to exploit unique production channels. Support for detector upgrades is needed to keep up with increasing luminosity, especially after the major SuperKEKB upgrade in a few years.
- The BESIII program is the best poised to explore the anomalous charmonium-like vector states and exotic states seen in their decay, as well as to study glueballs in J/ψ decays. The proposed Super Tau-Charm factory would increase luminosity by two orders of magnitude and lead to precision studies in these sectors. Participation in data taking and analysis by U.S. physicists is strongly recommended.
- GlueX, the proposed JLab24 upgrade, and the EIC experiment offer a U.S. option for hadron spectroscopy. While their electro- and photo-production cross sections and effective collision energies are limiting factors, these facilities may succeed in production of numerous heavy-quark exotic states, providing additional insight into their nature.
- Theoretical analysis of the new states has been slowed in the U.S. by limited support, in contrast to a much broader backing for such research in Europe and Asia.
- Modern hadron-spectroscopy analysis will require collaborations featuring frequent interactions between experimentalists and theorists, and also the collective work of multiple theory researchers. Lattice-QCD simulations form an essential ingredient of both of these efforts, and their progress requires substantial computing resources. We therefore call for funding to support consortia of both of these types of group efforts.
- Collaboration across nuclear and high-energy communities is also essential for the exchange of expertise and for the development of unified approaches for light- and heavy-quark hadrons, and requires a flexible approach from the relevant funding offices.

Today session

- Short review presentations (10 + 2 min) by the representatives of the major stakeholders
- Please stick to your allocated time!
- More of discussion opportunities at the Friday joint session with EF 10am-12pm, MGH, Rm 248 (no talks scheduled!)

10:00	Welcome and Summary of RF7 activities	Tomasz Skwarnicki
	337, HUB	10:00 - 10:06
	Future of Hadron Spectroscopy at LHC	Matt Durham
	337, HUB	10:06 - 10:18
	Future of Hadron Spectroscopy at Belle II	Jake Bennett
11:00	337, HUB	10:18 - 10:30
	Future of Hadron Spectroscopy at BESIII and Super Tau-Charm Factory	N Huesken
	337, HUB	10:30 - 10:42
	Future of Hadron Spectroscopy at Photoproduction Experiments	Sean Dobbs
	337, HUB	10:42 - 10:54
11:00	Amplitude Analyses in Hadron Spectroscopy	ARKAITZ RODAS
	337, HUB	10:54 - 11:06
	Hadron Spectroscopy with Lattice QCD	M Padmanath
11:00	337, HUB	11:06 - 11:18
	Future of Phenomenology of Hadron Spectroscopy	Richard Lebed
	337, HUB	11:18 - 11:30