The K^0_L Facility at

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Moskov Amaryan

Old Dominion University

The GlueX Collaboration Meeting, Feb. 16, 2017

A Letter of Intent to Jefferson Lab PAC-43.

Physics Opportunities with a Secondary K_L^0 Beam at JLab.

Moskov J. Amaryan (spokesperson),[1,*] Yakov I. Azimov,[2] William J. Briscoe,[3] Eugene Chudakov,[4] Pavel Degtyarenko,[4] Gail Dodge,[1] Michael Döring,[3] Helmut Haberzettl,[3] Charles E. Hyde,[1] Benjamin C. Jackson,[5] Christopher D. Keith,[4] Ilya Larin,[1] Dave J. Mack,[4] D. Mark Manley,[6] Kanzo Nakayama,[5] Yongseok Oh,[7] Emilie Passemar,[8] Diane Schott,[3] Alexander Somov,[4] Igor Strakovsky,[3] and Ronald Workman[3]

[1]*Old Dominion University, Norfolk, VA 23529*
[2]*Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188300, Russia*
[3]*The George Washington University, Washington, DC 20052*
[4]*Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606*
[5]*The University of Georgia, Athens, GA 30602*
[6]*Kent State University, Kent, OH 44242*
[7]*Kyungpook National University, Daegu 702-701, Korea*
[8]*Indiana University, Bloomington, IN 47405*

(Dated: May 15, 2015)

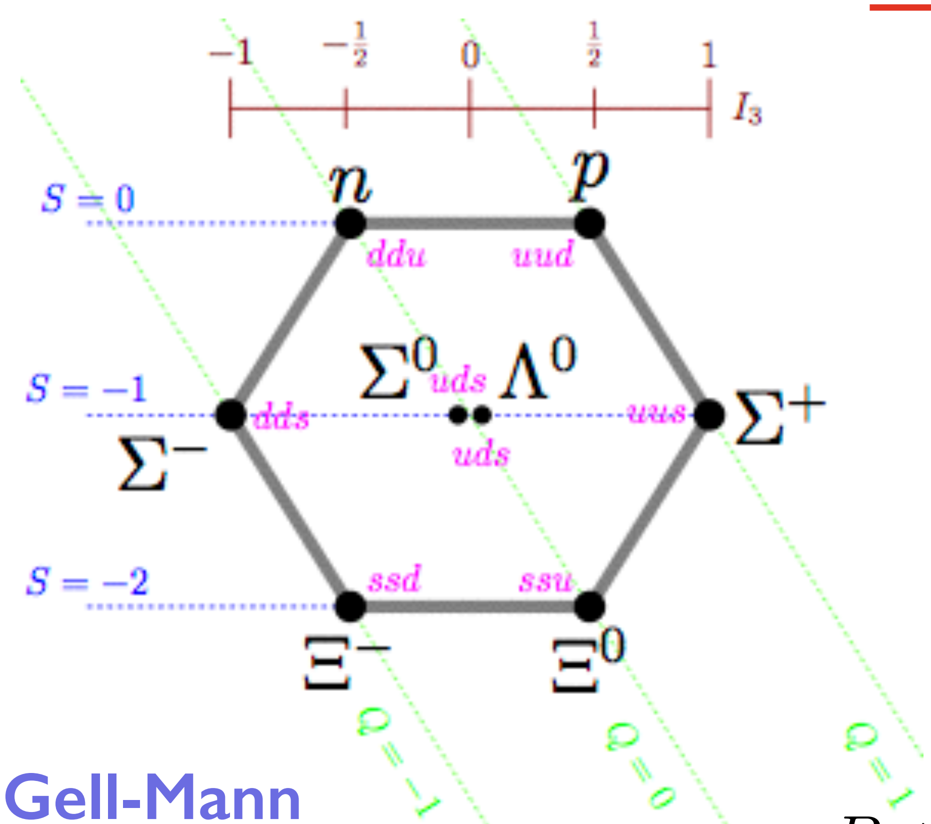
Outline

- Introduction
- Baryon Multiplets and Missing states
- Experimental Arrangement
- K^0_L Beam at GlueX
- Expected rates
- What can be studied and why it is interesting
- Summary

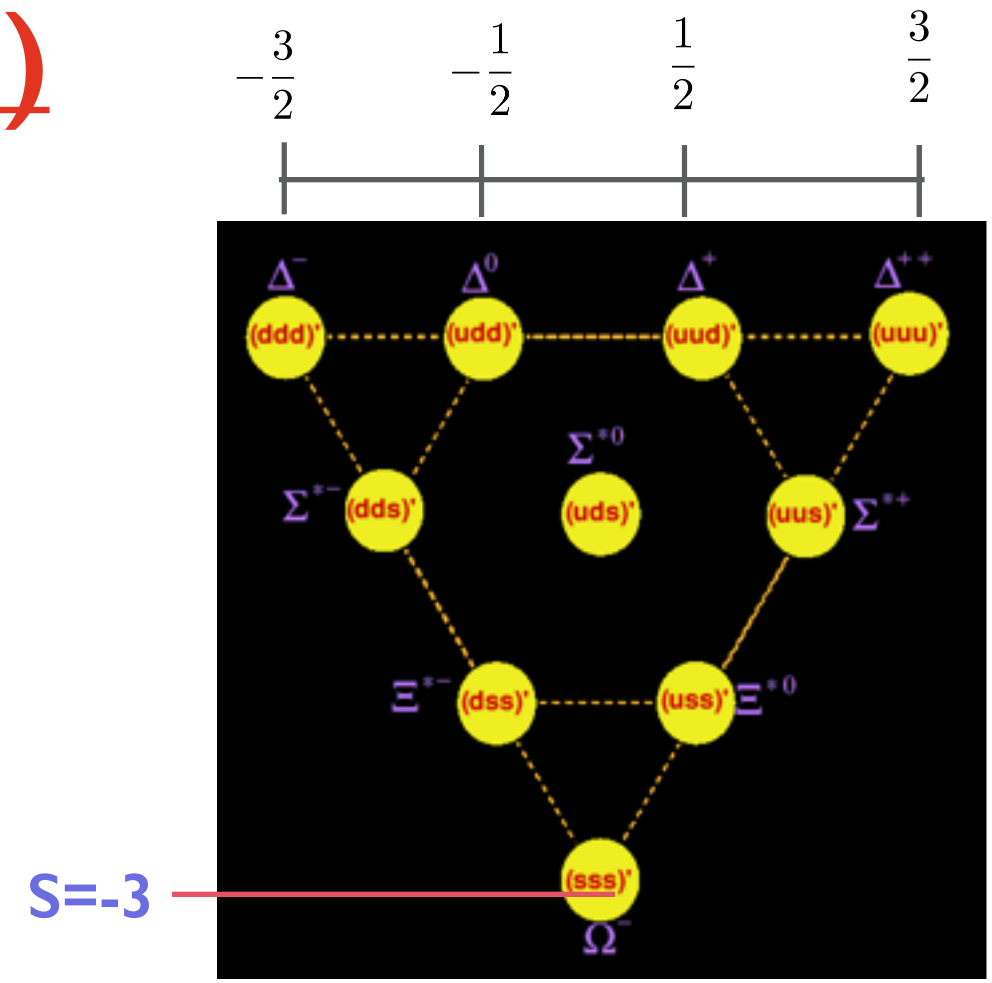
Constituent Quark Model

SU(3)

Octet



Decuplet



Gell-Mann Nishidjima

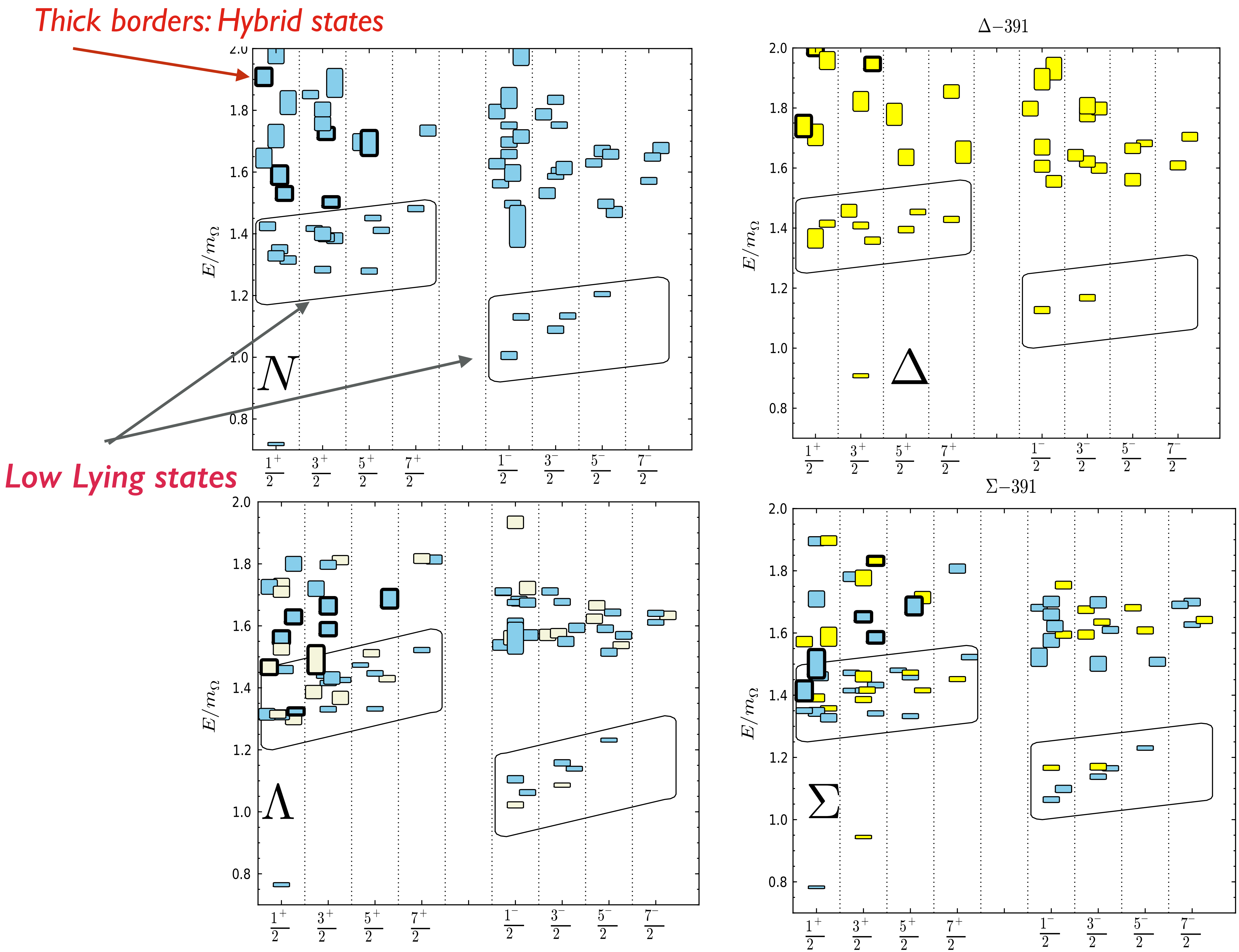
$$Q = I_3 + \frac{B+S}{2}$$

But there are many more states predicted, where are they?

Where are hybrids, glueballs, multiquark states ?

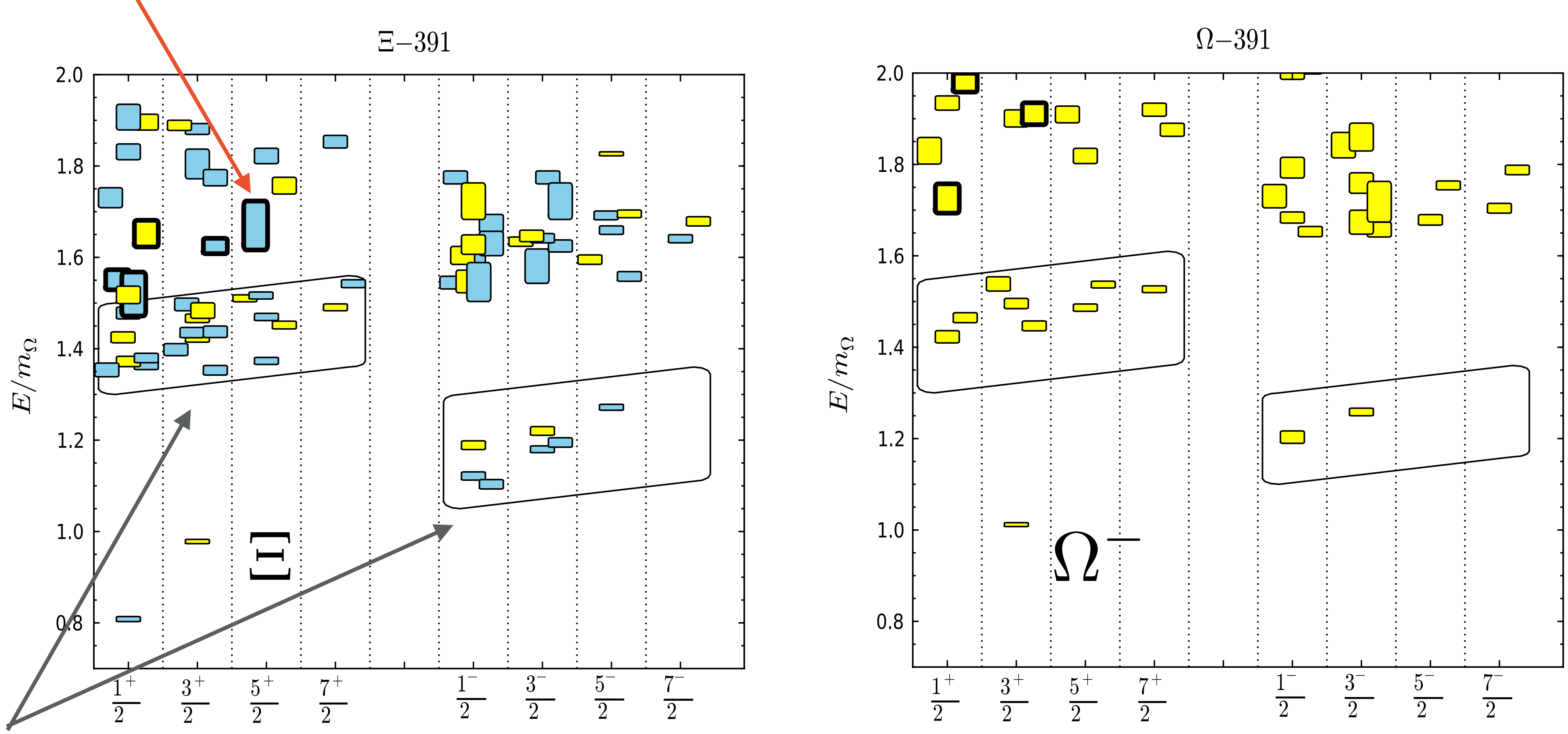
Did we already observe some of them?

Lattice QCD calculations



Lattice QCD calculations

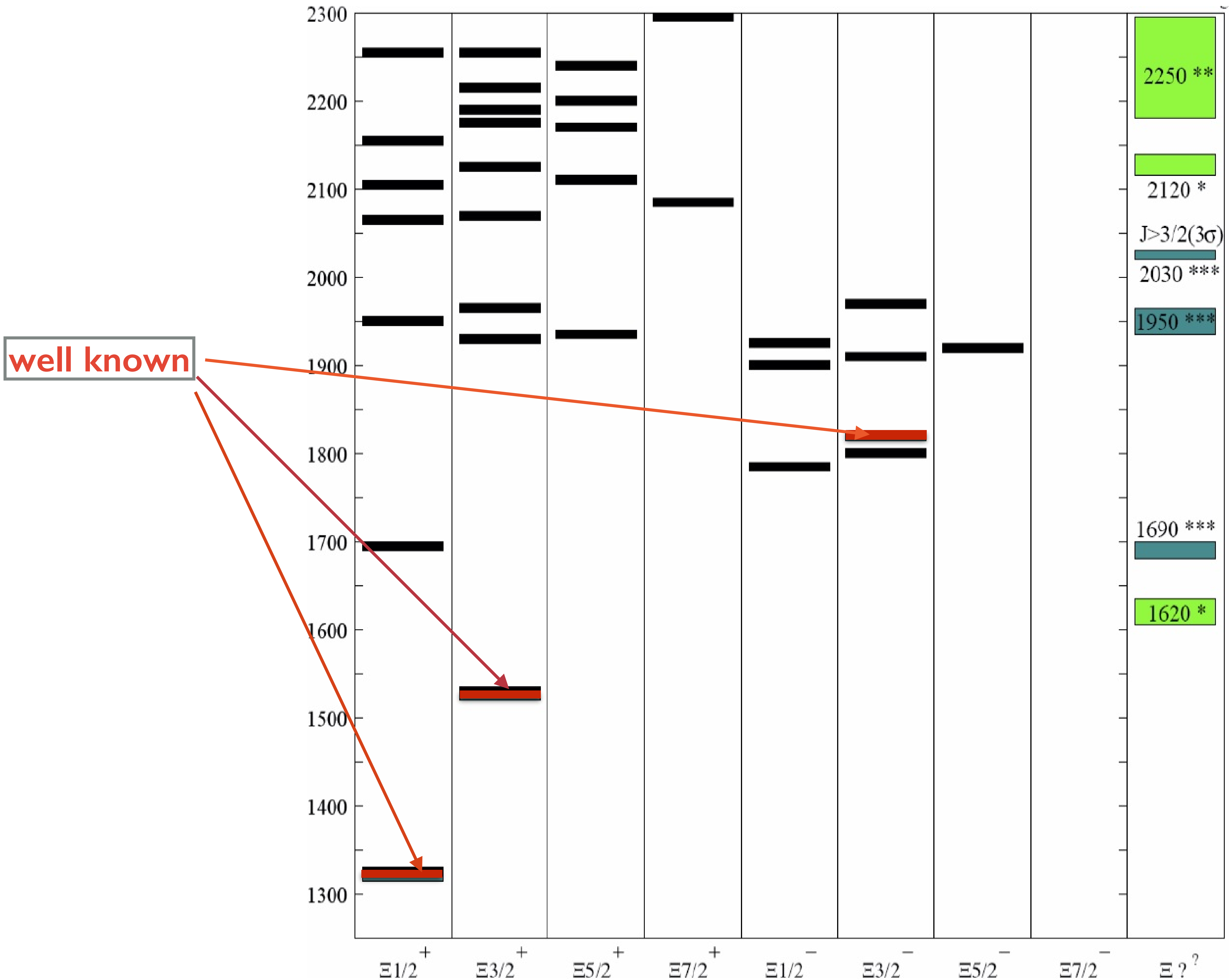
Thick borders: Hybrid states



Low Lying states

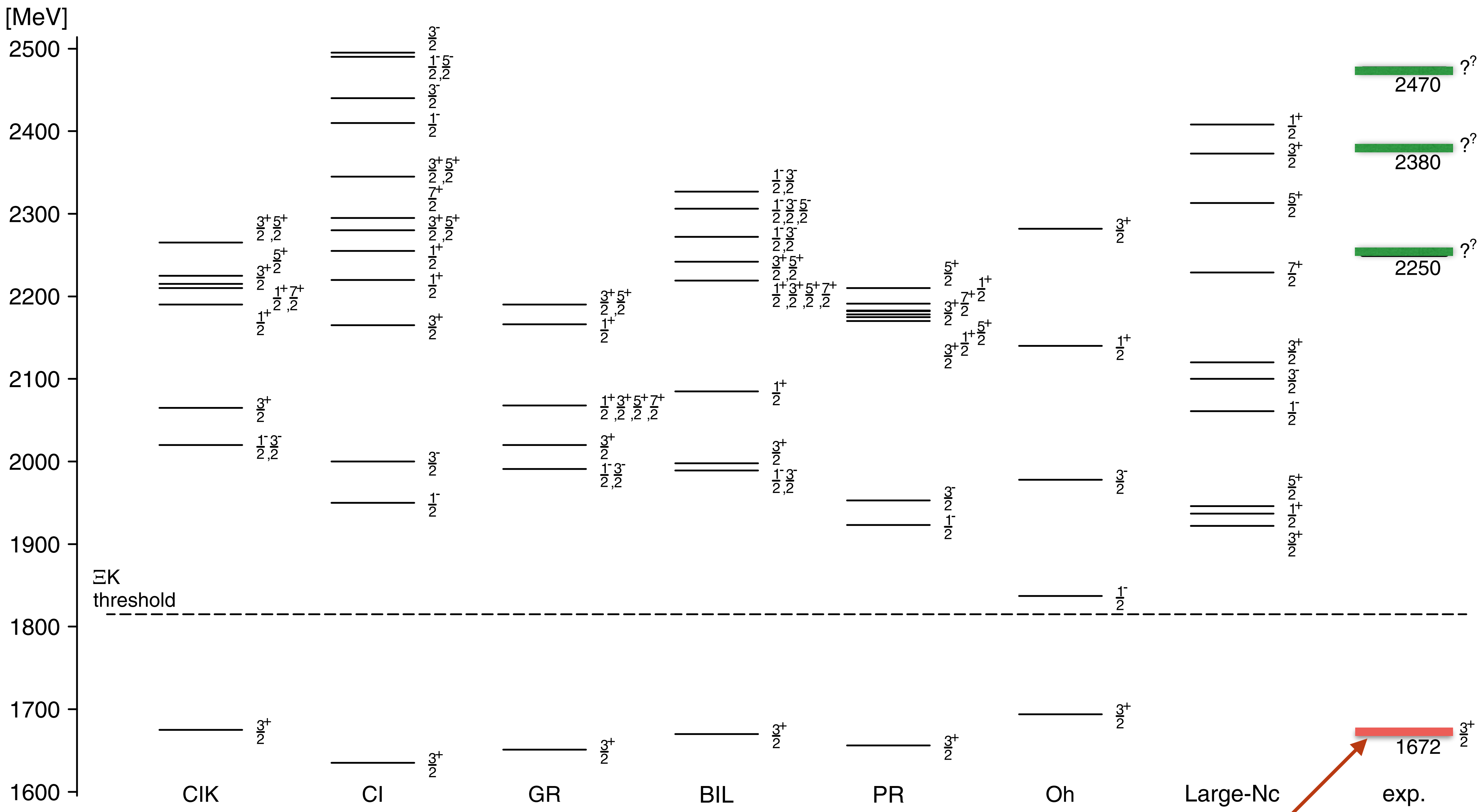
Edwards, Mathur, Richards and Wallace
Phys. Rev. D 87, 054506 (2013)

Status of Ξ^*



well known
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
2250 **
2120 *
J>3/2(3σ)
2030 ***
1950 ***
1690 ***
1620 *
Ξ1/2 +
Ξ3/2 +
Ξ5/2 +
Ξ7/2 +
Ξ1/2 −
Ξ3/2 −
Ξ5/2 −
Ξ7/2 −
Ξ ? ?

Status of Ω^{-*}



only one well known state?

- **Three light quarks** can be arranged in **6** baryonic families, **N***, Δ*, Λ*, Σ*, Ξ*, & Ω*.
- **Number of members** in a family that can exist **is not arbitrary**.
- If **SU(3)$_F$** symmetry of **QCD** is controlling, then:

Octet:	**N***, Λ*, Σ*, Ξ*
Decuplet:	Δ*, Σ*, Ξ*, & Ω*

  - Number of experimentally identified resonances of each baryon family in PDG summary tables is **17 N***, **24** Δ*, **14** Λ*, **12** Σ*, **7** Ξ*, & **2** Ω*.
  - **Constituent Quark** models, for instance, predict existence of no less than **64 N***, **22** Δ* states with **mass < 3** GeV.

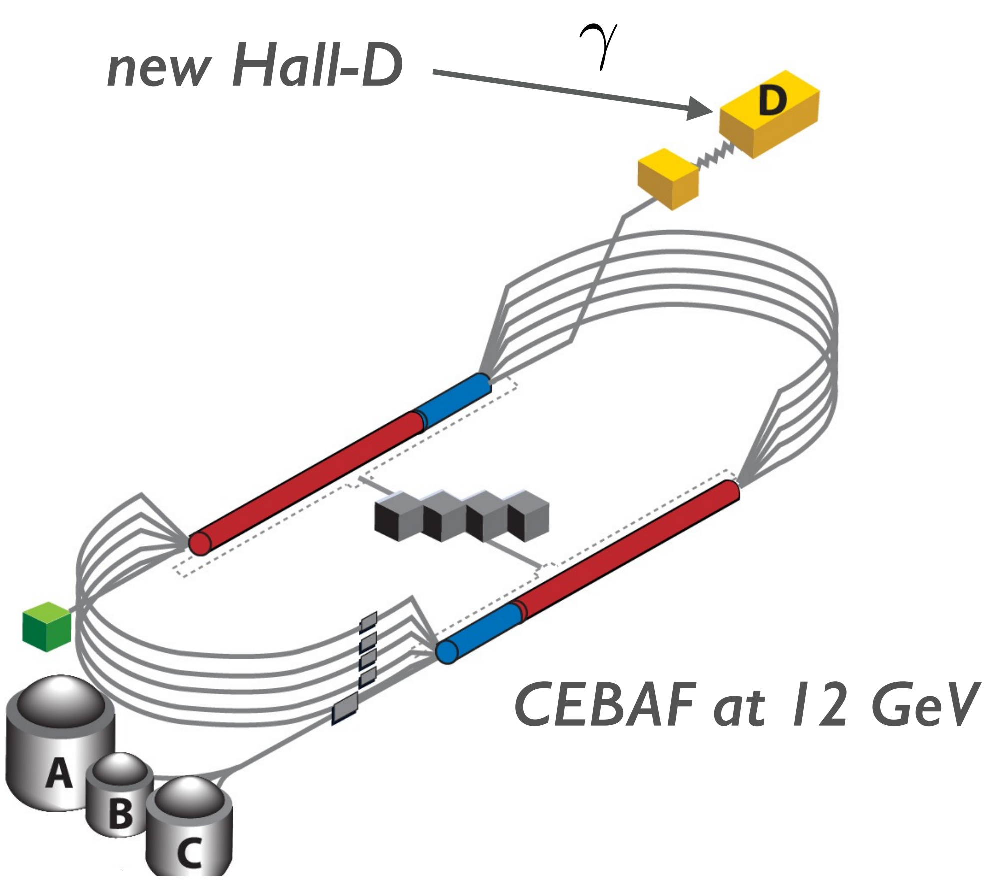
- Seriousness of "**missing-states**" problem is obvious from these numbers.

- To complete **SU(3)$_F$** multiplets, one needs no less than **17** Λ*, **41** Σ*, **41** Ξ*, & **24** Ω*.

How to make a kaon beam?

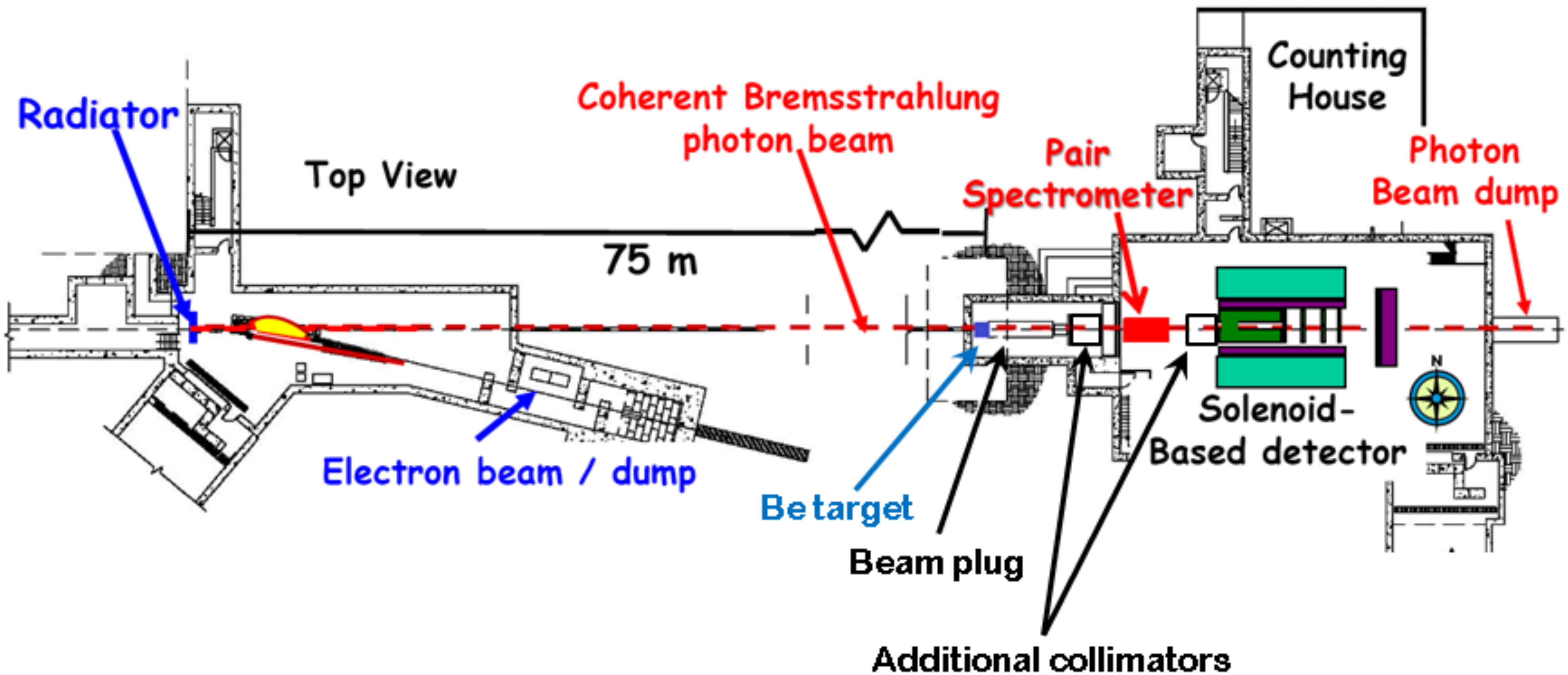
Thomas Jefferson National Accelerator Facility

Aerial View

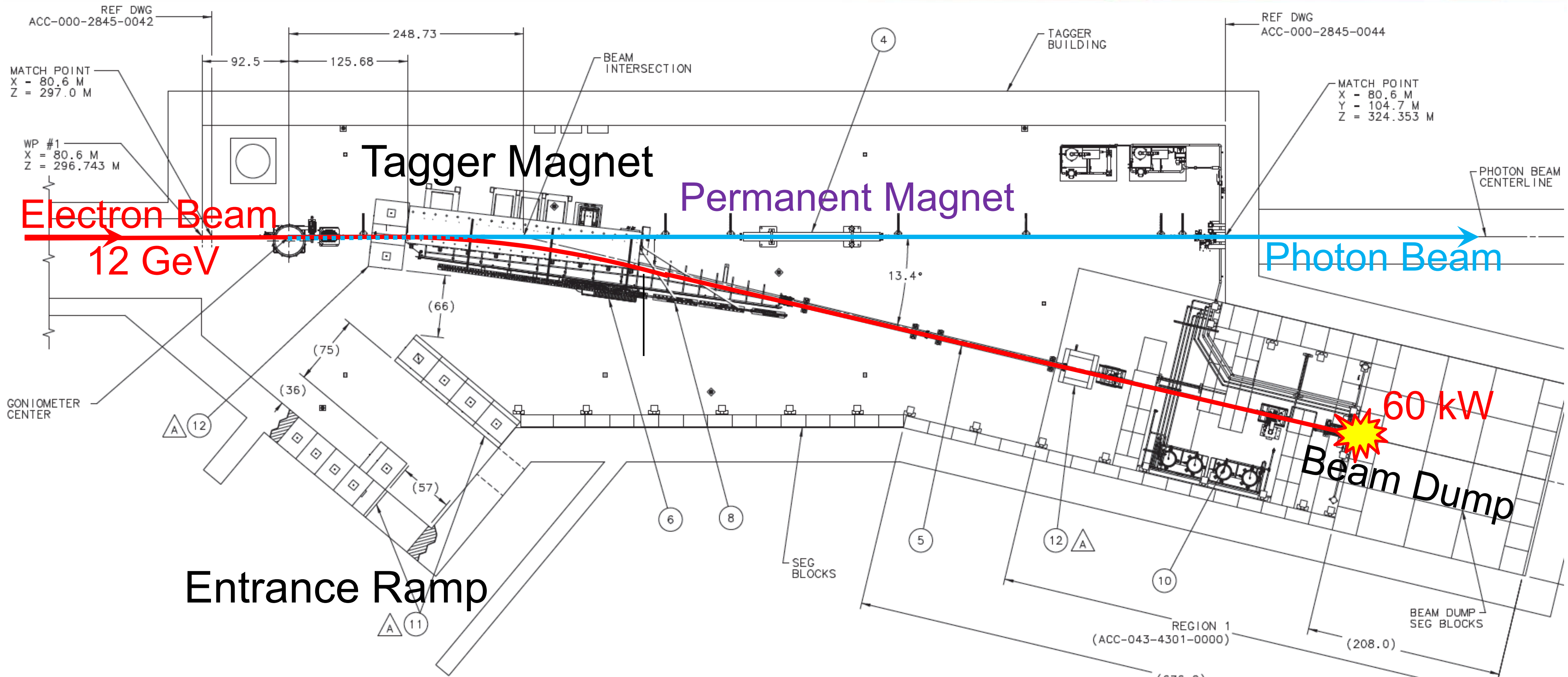


Hall D Beamline

Current setup



Hall D Tagger Area



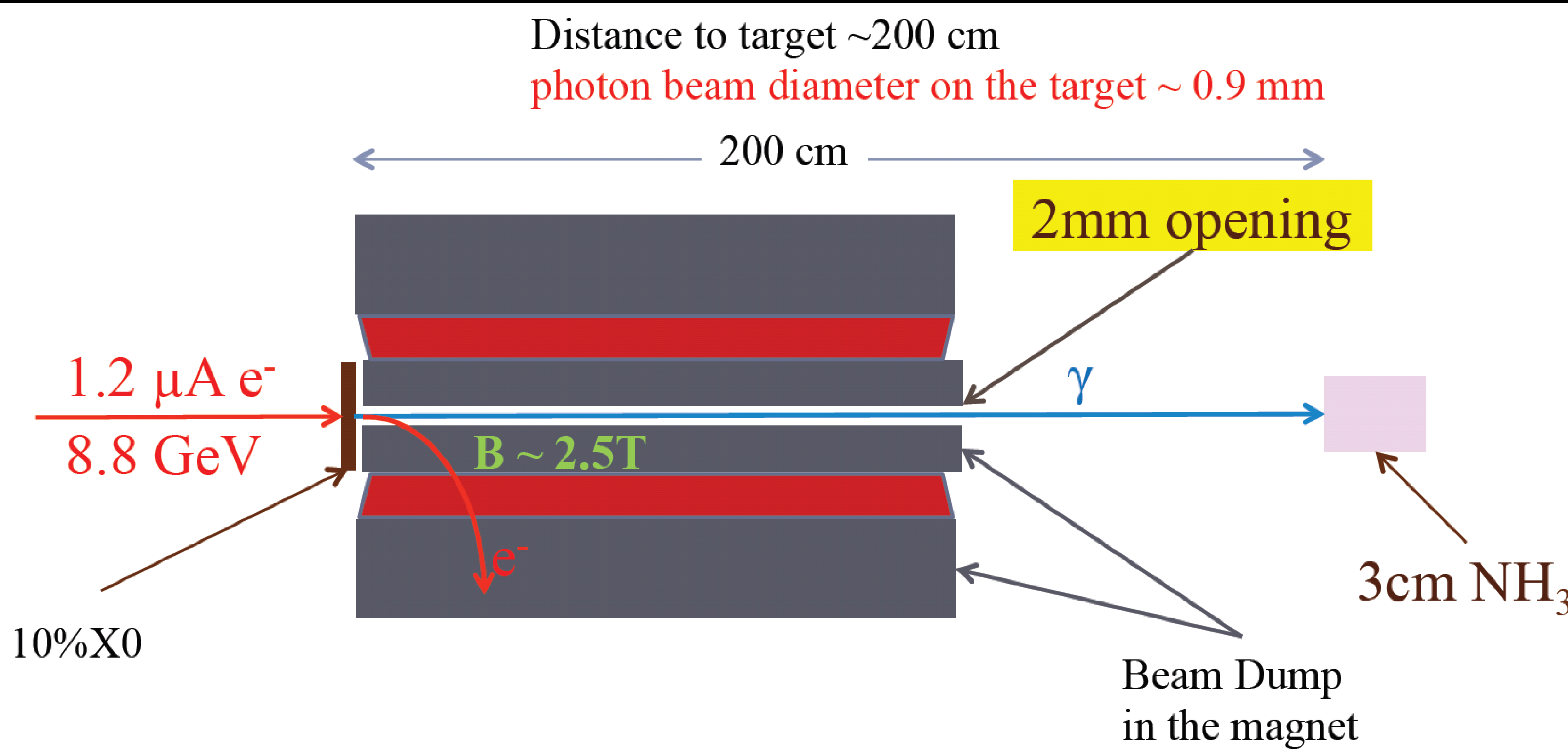
- Design beam current limits: 5 μA (60 kW) max
- Design radiator thickness: ~0.0005 Radiation Lengths max
- Challenge: Increase radiator thickness to 0.05-0.10 R.L.?!

Compact Photon Source Concept

- Strong magnet after radiator deflects exiting electrons
- Long-bore collimator lets photon beam through
- Electron beam dump placed next to the collimator
- Water-cooled Copper core for better heat dissipation
- Hermetic shielding all around and close to the source
- High Z and high density material for bulk shielding
- Borated Poly outer layer for slowing, thermalizing, and absorbing fast neutrons still exiting the bulk shielding
- No need in tagging photons, so the design could be compact, as opposed to the Tagger Magnet concept

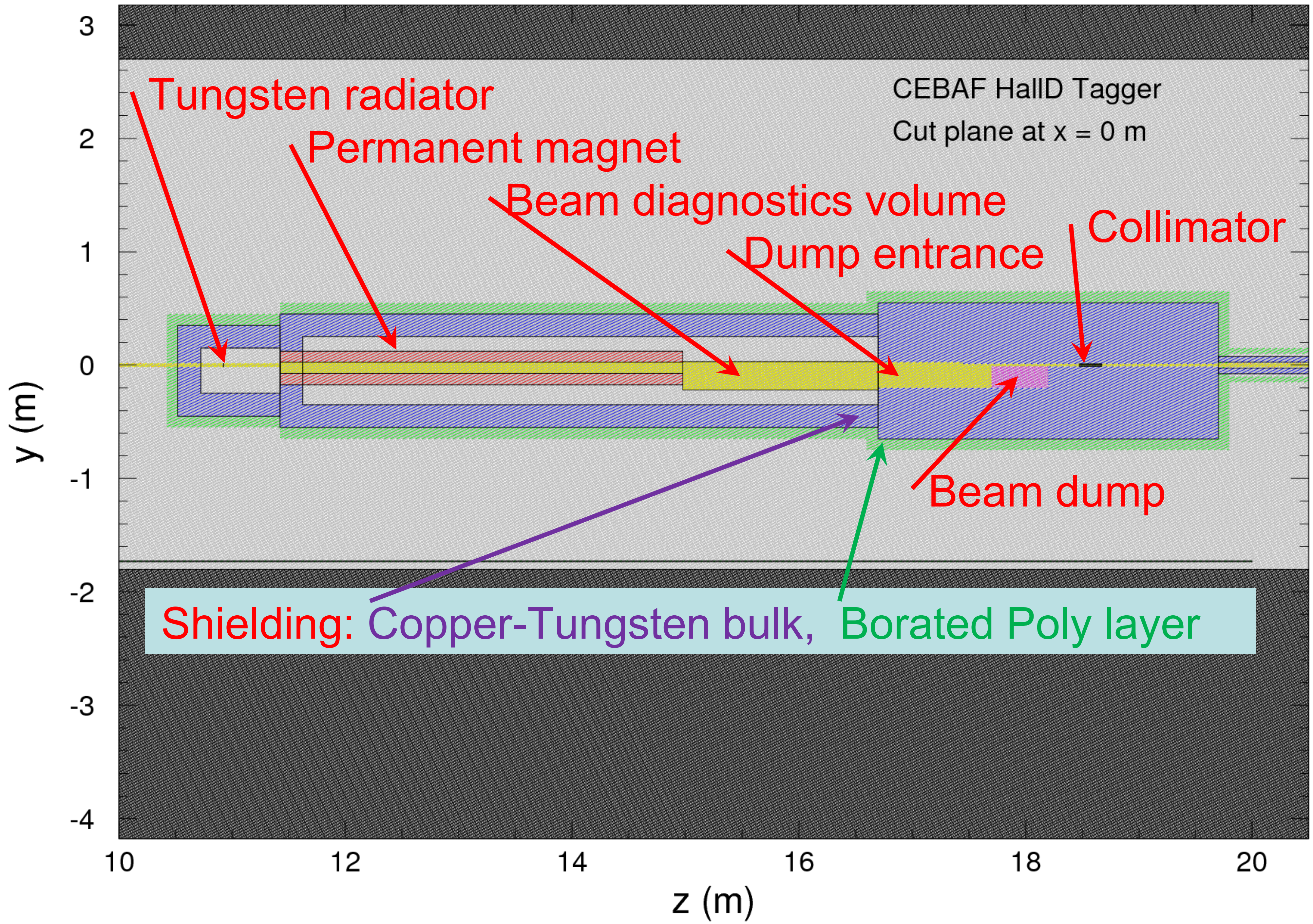
CPS: PR12-15-003 Proposal at JLab

Application example: CPS concept for new experiment in Hall A

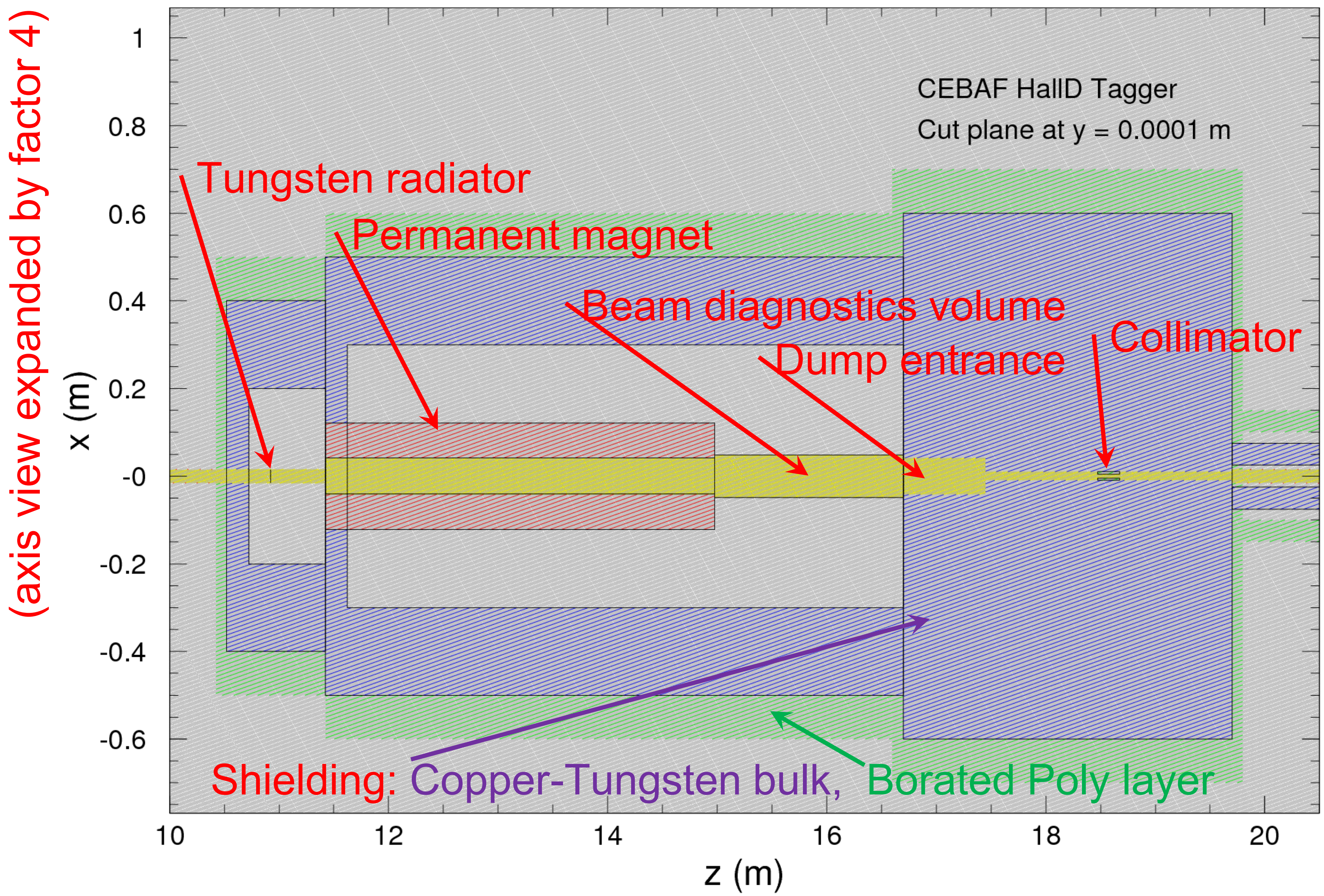


MC simulation and direct calculations show acceptable background rates on SBS and NPS.

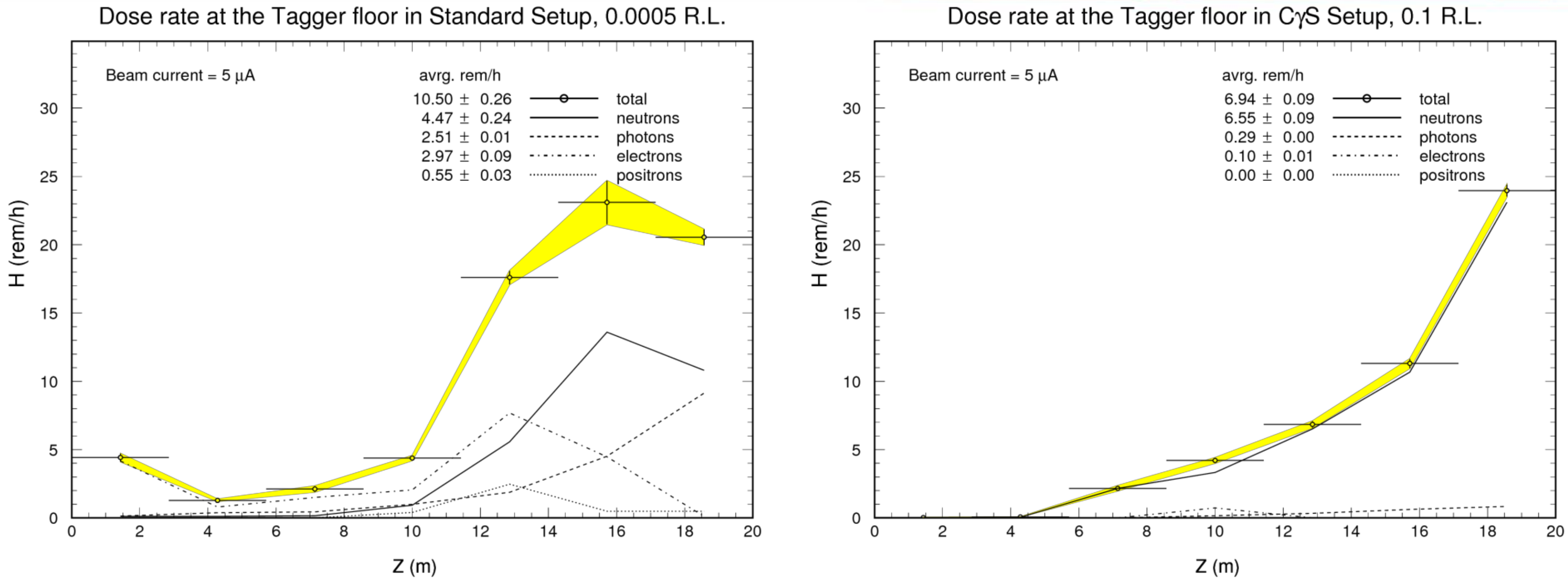
CPS at the Hall D Tagger Area



CPS, horizontal plane (1)



Dose Rate Evaluation and Comparison



- The dose rates in the Tagger vault for the CPS setup with 10% R.L. radiator are close to Standard XD ops
- The radiation spectral composition is different; most of the contribution in the CPS setup is from higher energy neutrons

Dose Rate Evaluation and Comparison

- The plots show comparison of dose rate estimates in the Tagger Area in two conditions: (1) nominal Hall D operation with the standard amorphous radiator at 0.0005 R.L., - with (2) radiator at 0.1 R.L., used as part of the Compact Photon Source setup.
- The comparison indicates that at equal beam currents, gamma radiation dose rates are much smaller for the CPS run (~order of magnitude), and neutron dose rates in the area are comparable.
- Design and shielding optimization may improve the comparison further in favor of the CPS solution

More discussions on CPS at the Workshop

„New Opportunities with High-Intensity Photon Sources“ February 6-7, 2017 at CUA

https://www.jlab.org/conferences/HIPS2017/

K^0_L beam (continued)

-Electron beam with $I_e = 5\mu A$

-Delivered with 64 ns bunch spacing avoids overlap in the range of P=0.3-10.0 GeV/c

-Momentum measured with TOF

-K^0_L flux mesured with pair spectrometer

-Side remark: Physics case with polarized targets is under study and feasible

Rate of neutrons and K^0_L on GlueX target

- **PRL22.996 (1969) Brody et al.**

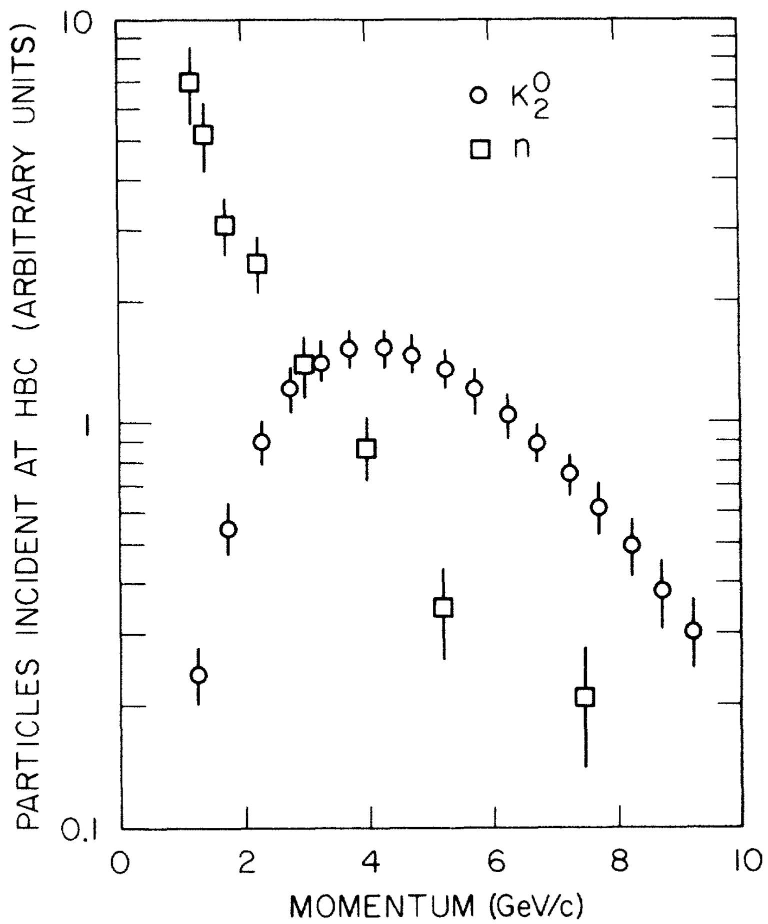
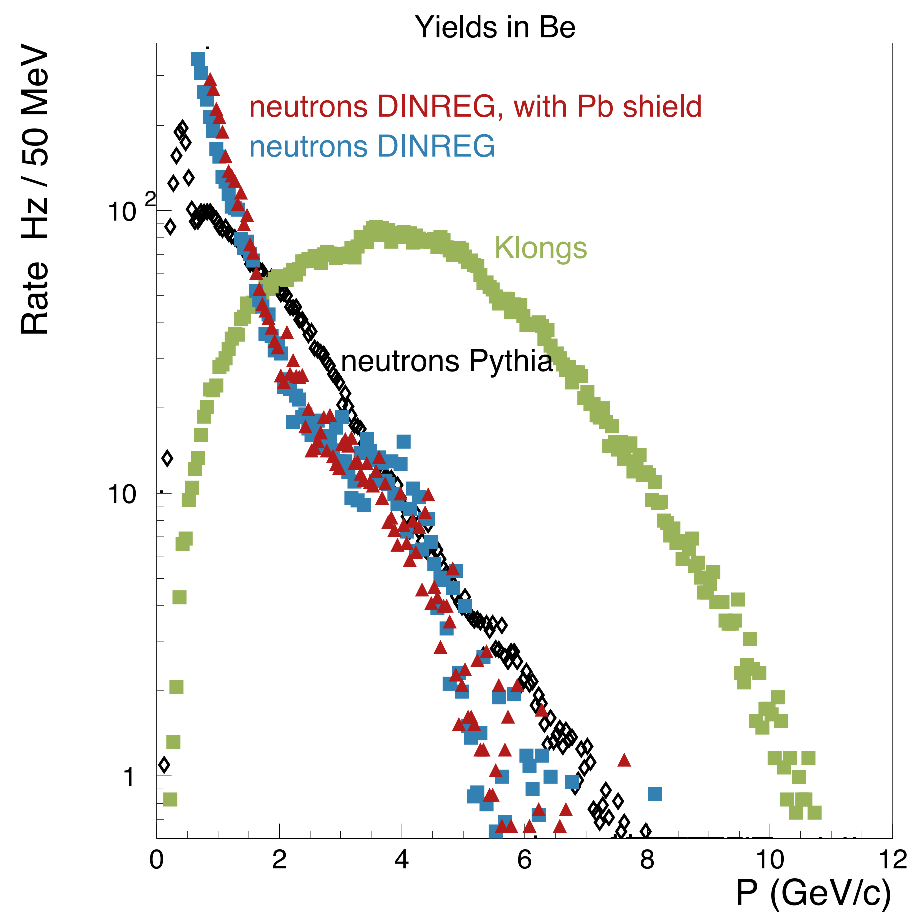


FIG. 2. Comparison of the neutron and $K_2{}^0$ fluxes at the hydrogen bubble chamber for 2° production with 16-GeV electrons.

- **JLAB**



- **With a proton beam ratio $n/K_L = 10^3\text{-}10^4$**

- **ProjectX (Fermi Lab) arXiv:1306.5009**

Table III-2: Comparison of the K_L production yield. The BNL AGS kaon and neutron yields are taken from RSVP reviews in 2004 and 2005. The *Project X* yields are for a thick target, fully simulated with LAQGSM/MARS15 into the KOPIO beam solid angle and momentum acceptance.

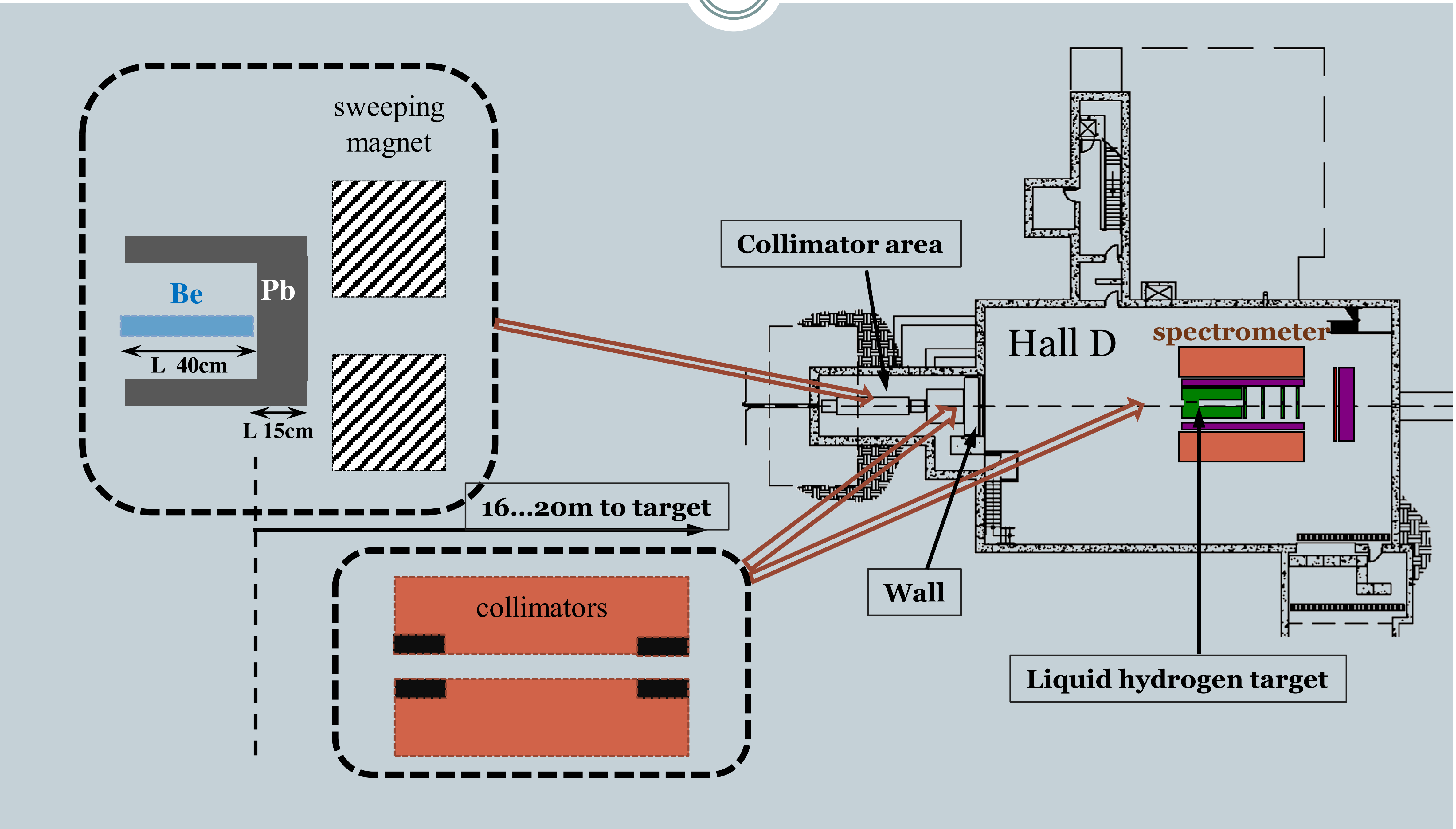
	Beam energy	Target (λ_I)	$p(K)$ (MeV/c)	K_L/s into 500 μsr	$K_L : n$ ($E_n > 10$ MeV)
BNL AGS	24 GeV	1.1 Pt	300-1200	60×10^6	$\sim 1:1000$
Project X	3 GeV	1.0 C	300-1200	450×10^6	$\sim 1:2700$

KL beam can be used to study rare decays
However it will be impossible to use it for hyperon spectroscopy because of momentum range and n/K Ratio

K^0_L beam

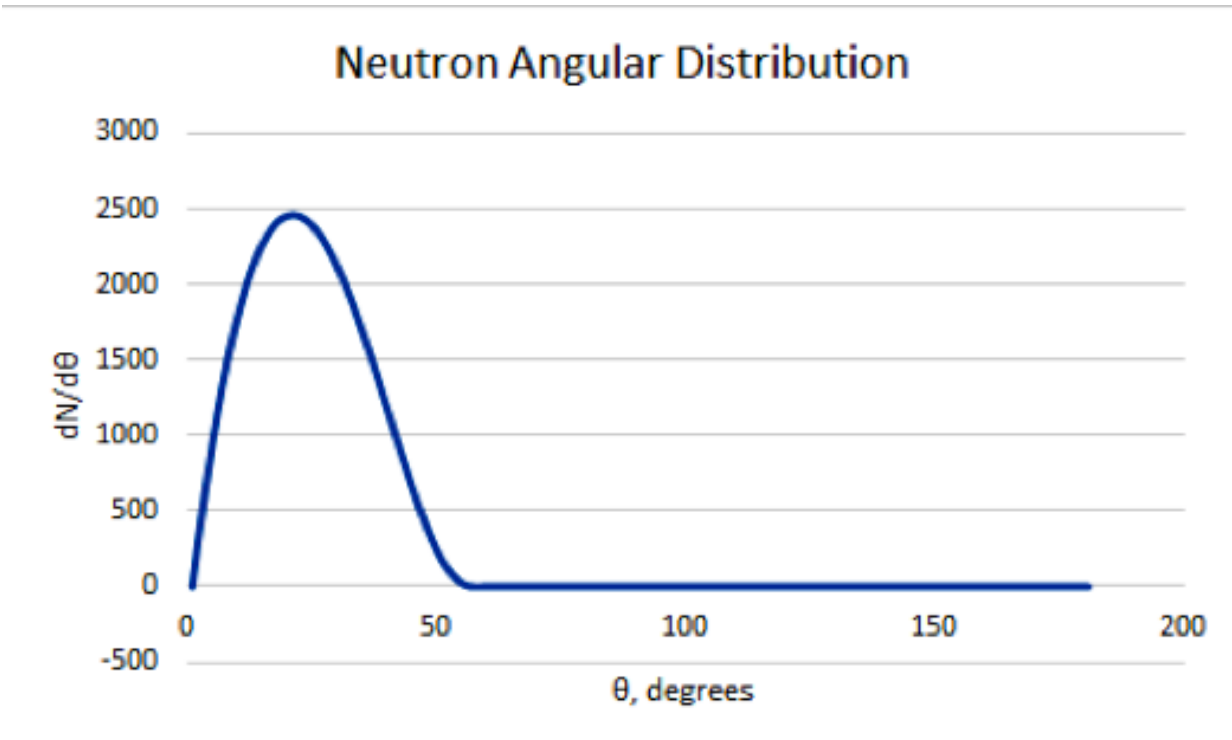
Electron beam	$E_e = 12GeV; I_e = 5\mu A$
Radiator (rad. length)	10%
Be target (R=3cm)	$L = 40cm$
LH2 target(L=30cm)	$R = 3cm$
Distance Be-LH2	16m
K_L Rate/sec	~10^4

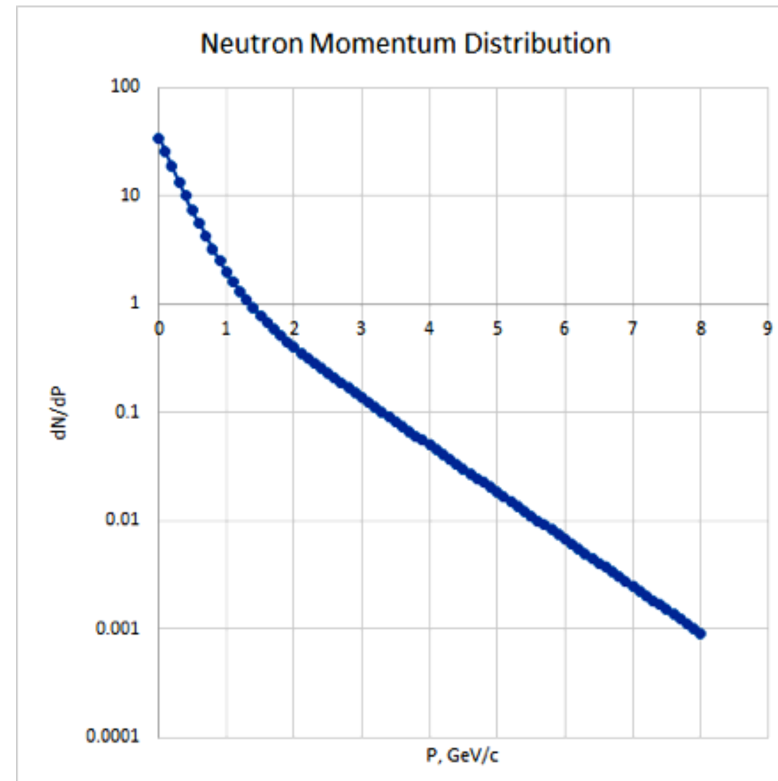
K_L-beam line

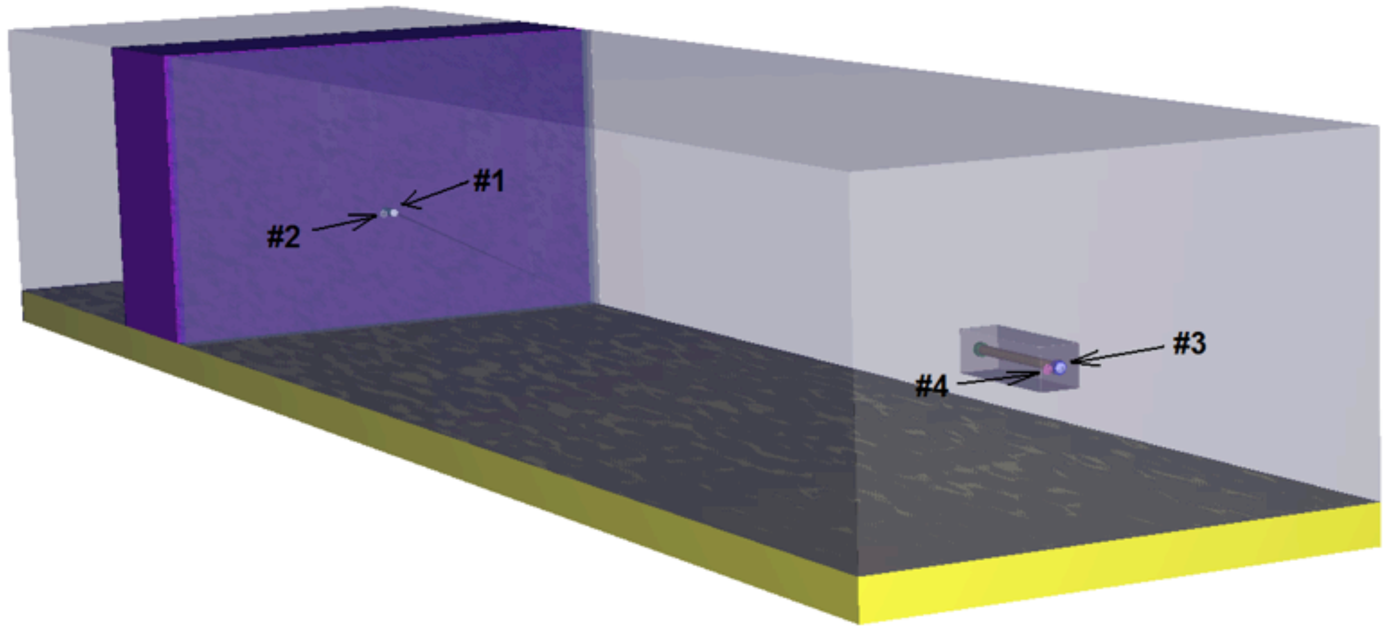

sweeping
magnet
Be
Pb
L 40cm
L 15cm
16...20m to target
collimators
Collimator area
Hall D
spectrometer
Wall
Liquid hydrogen target

Neutron Background

Neutron calculations for the KLF Project using MCMP6



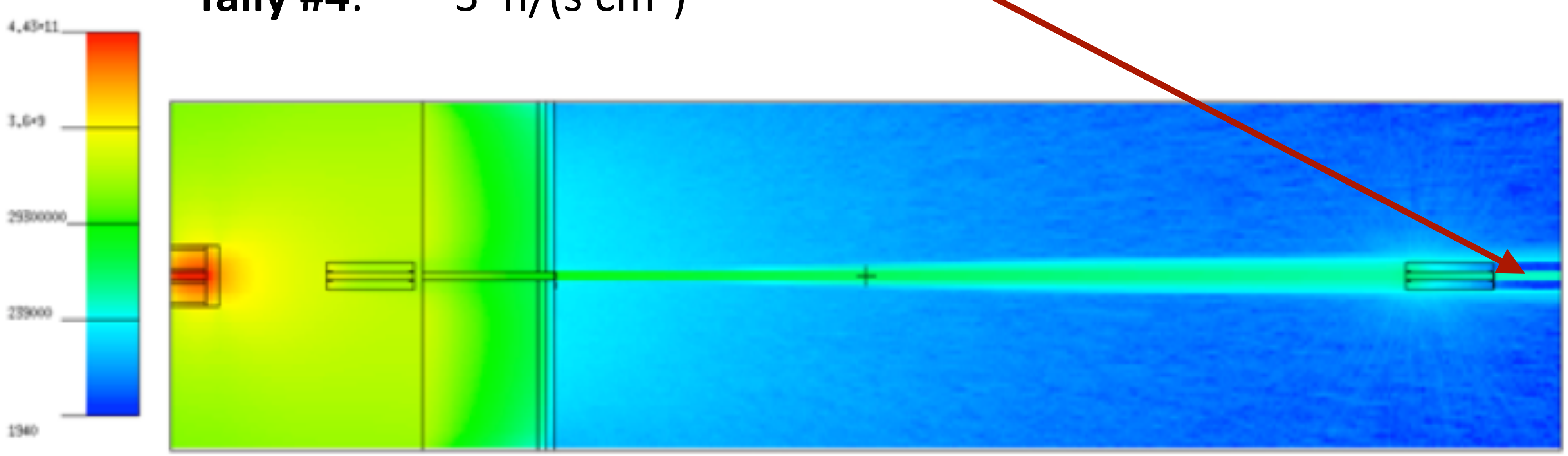




Results:

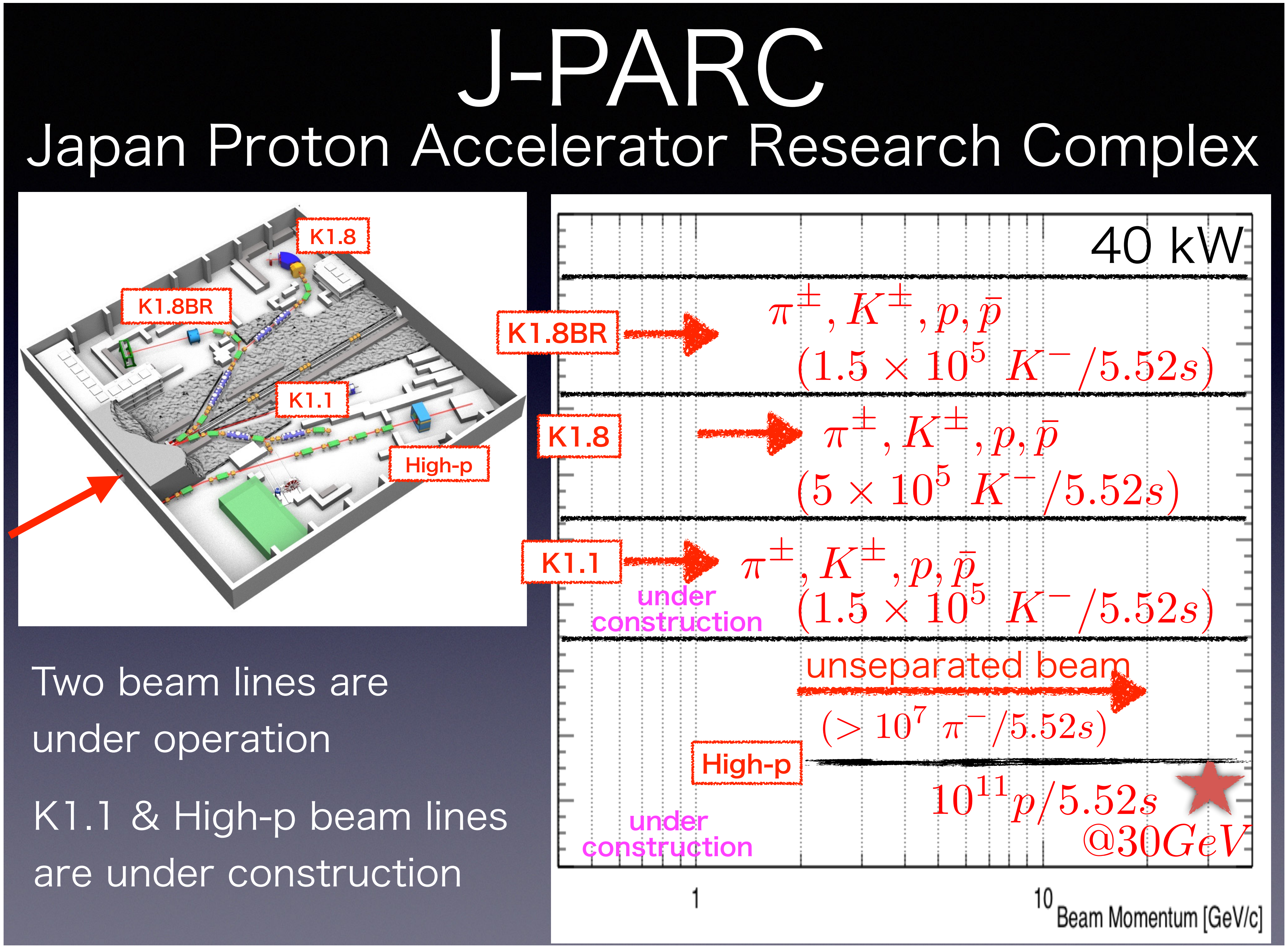
Tally #1: 3200 n/(s cm^2)
Tally #2: 40 n/(s cm^2)
Tally #3: 140 n/(s cm^2)
Tally #4: 3 n/(s cm^2)

Neutron Flux



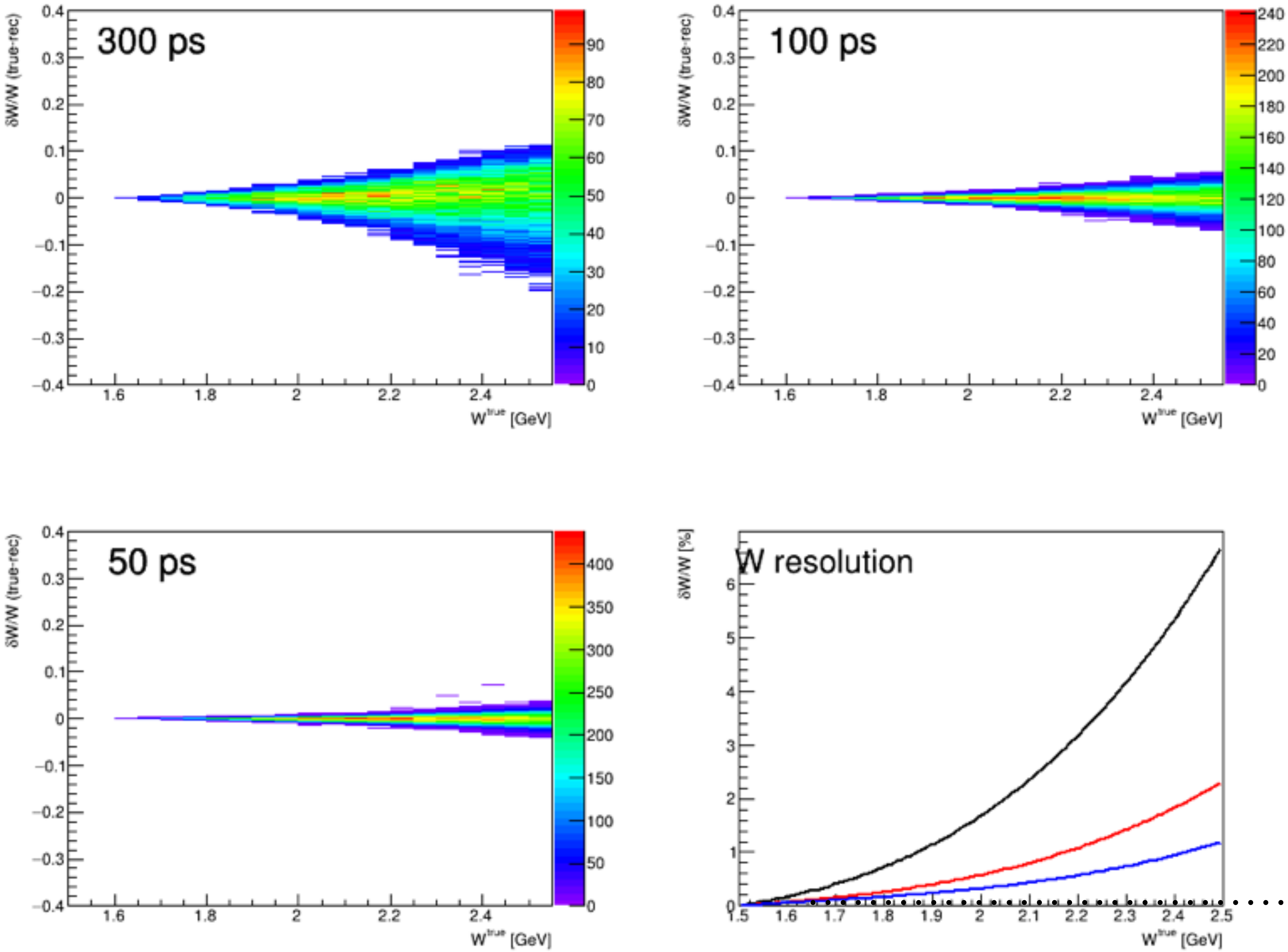
- **Conclusion: Neutron Flux in Hall D is tolerable**

Other Facilities



Talk by Onishi at KL2016

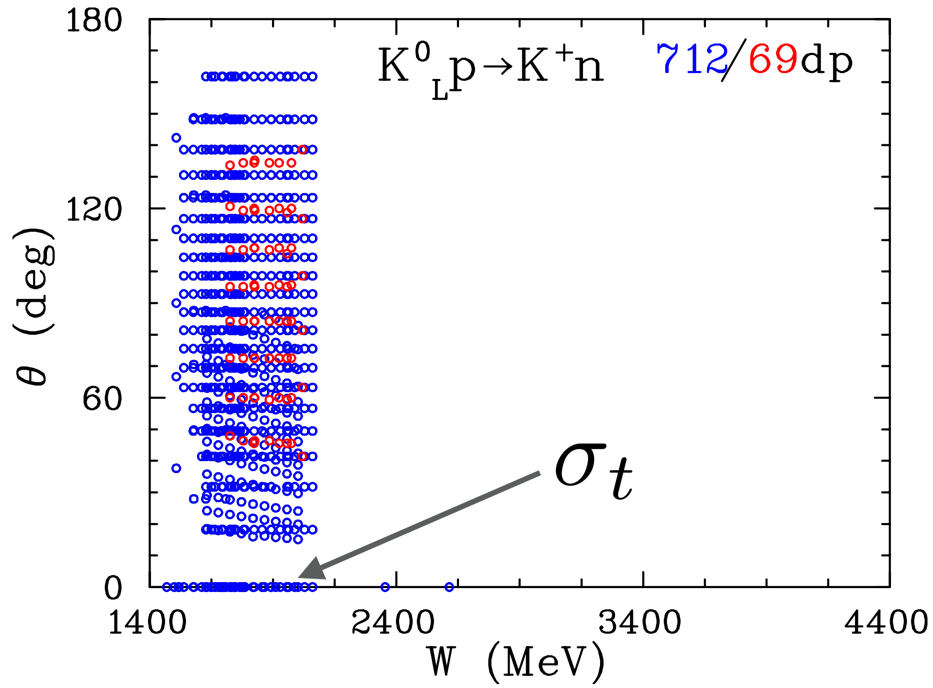
W Resolution

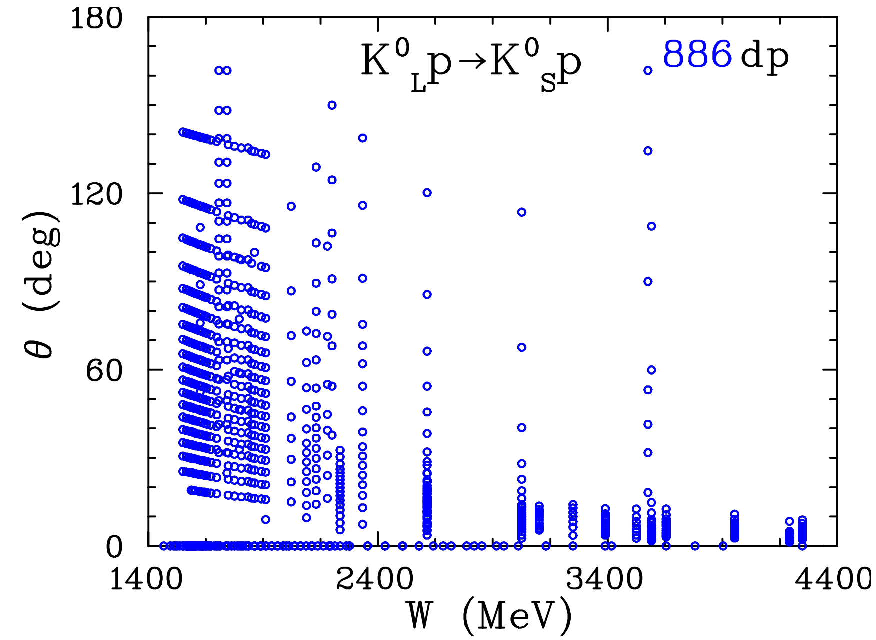


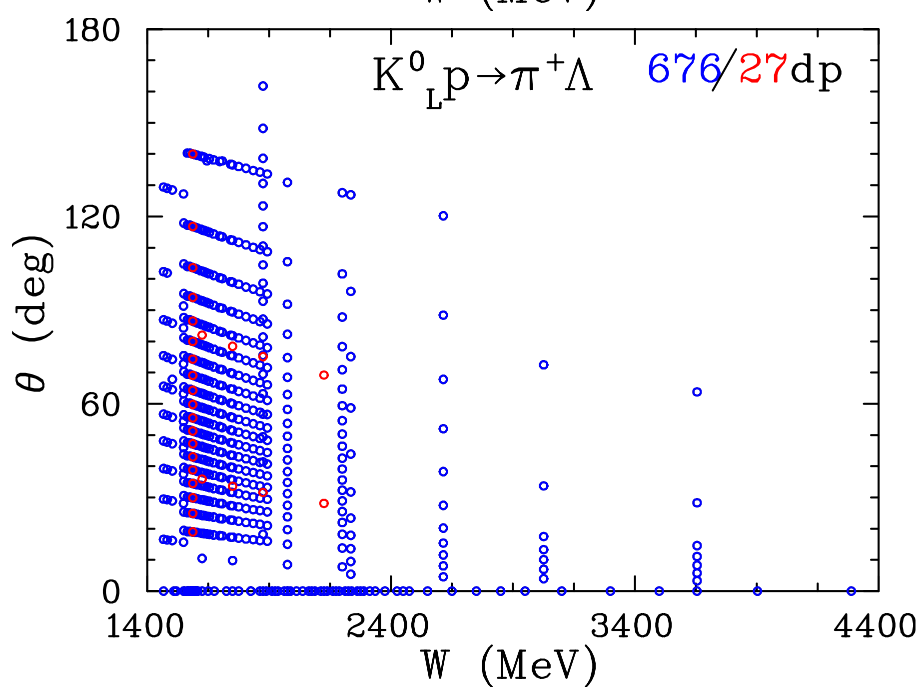
Very Limited World Data with K_L beam

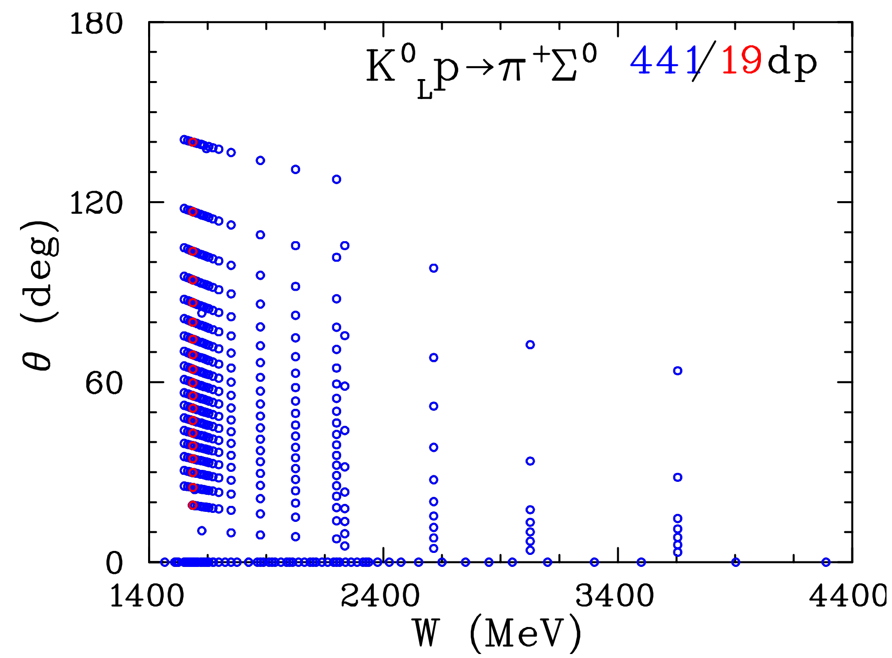
(Mainly low stat. bubble chamber data. Compilation by I. Strakovsky)

blue points: $d\sigma/d\Omega$ *red points: Polarization*





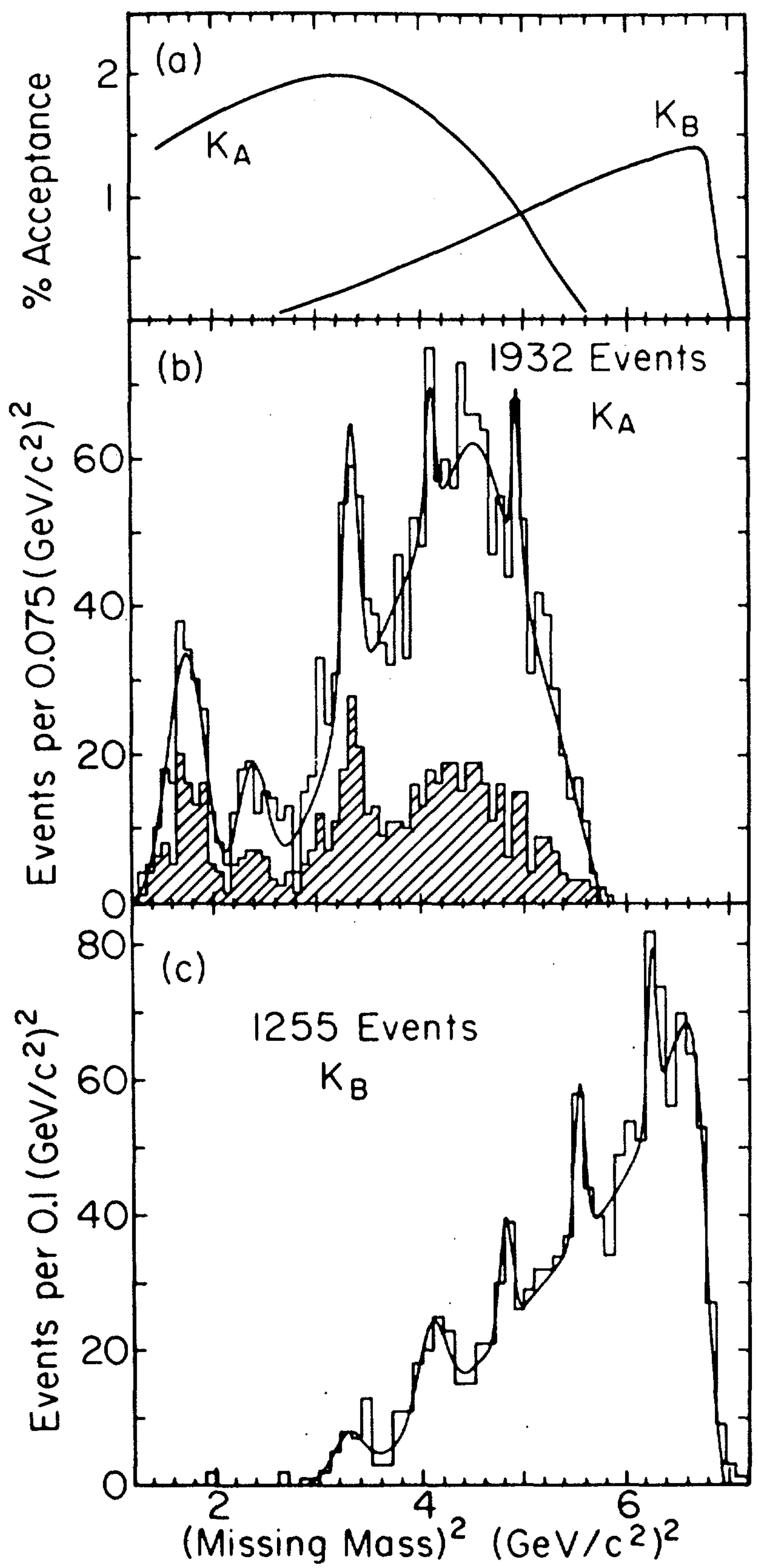




we are not aware of any data on Neutron target

Status of Ξ^*

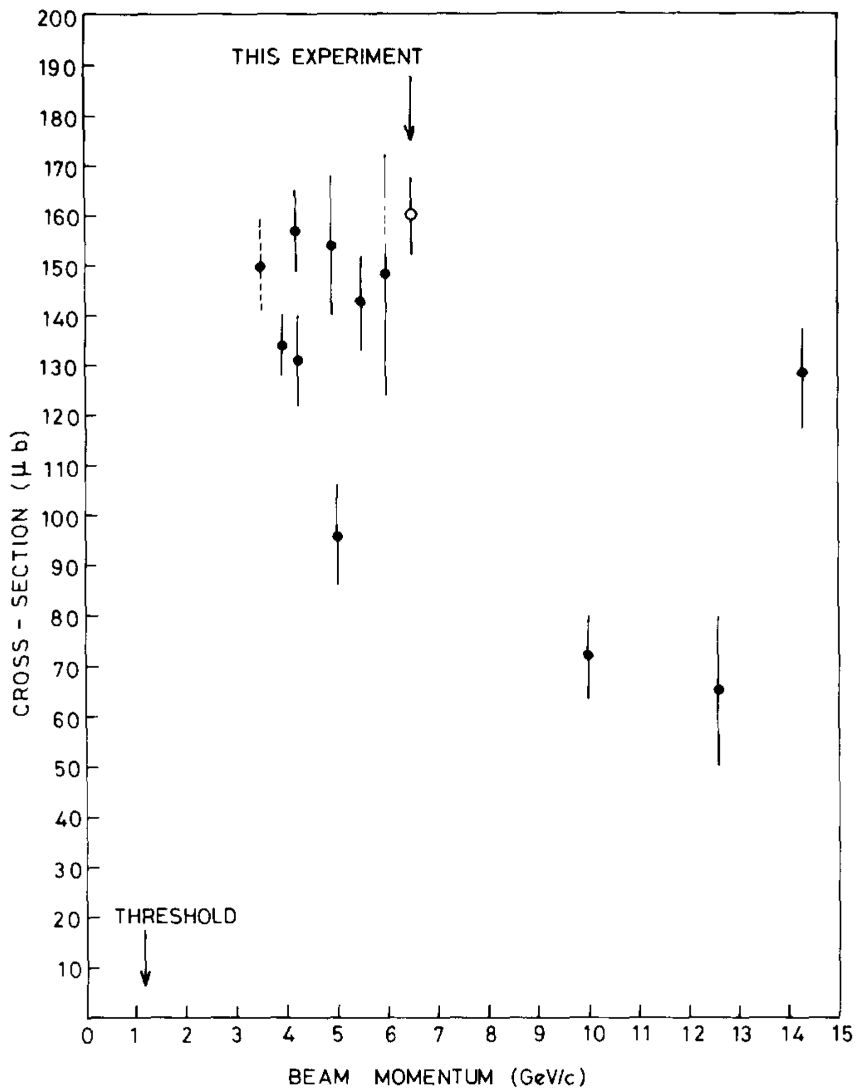
Very poorly measured at AGS (BNL) 32 years ago



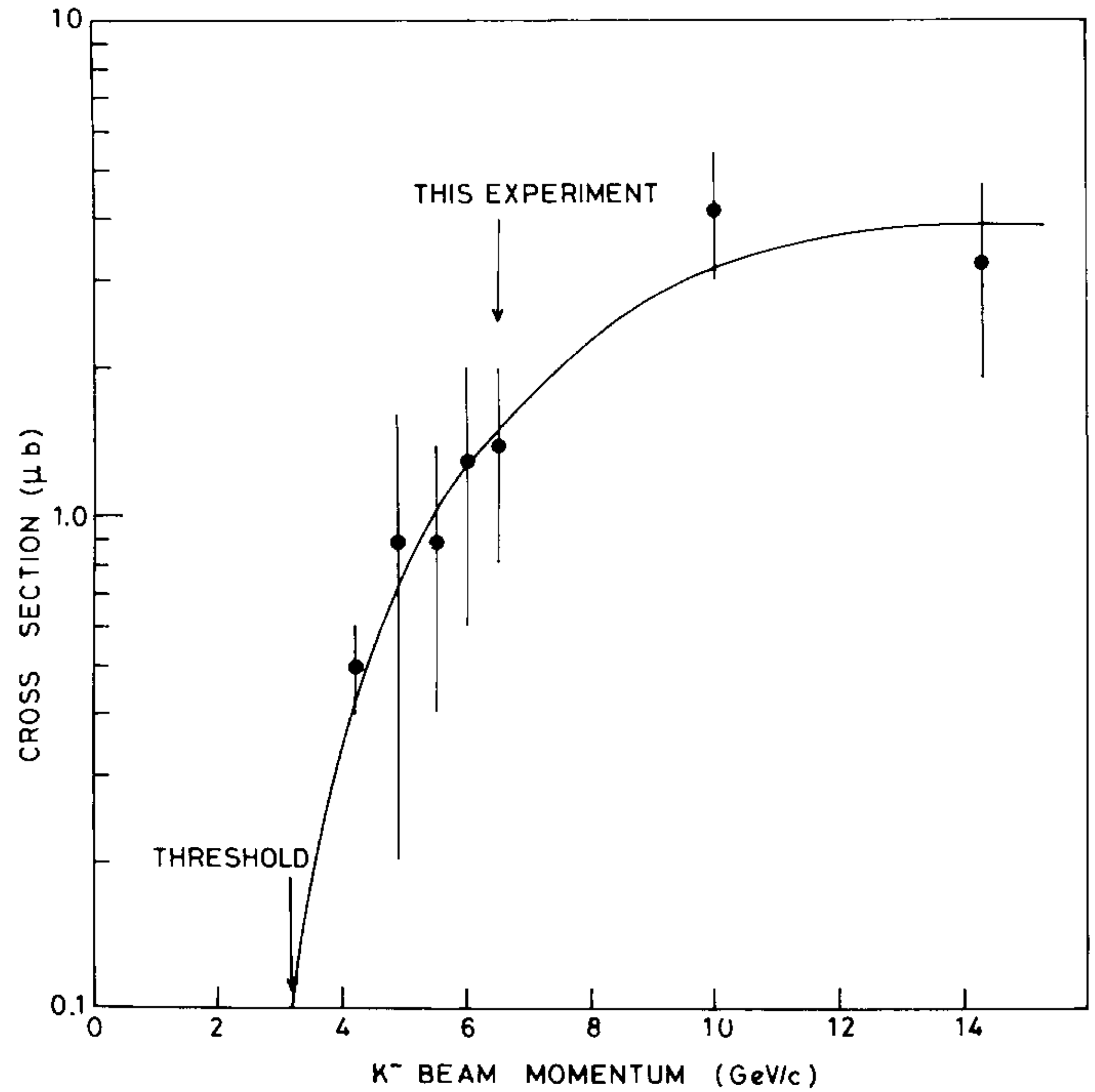
. C.M. Jenkins et al., Phys. Rev. Lett. 51, 951 (1983)

Cross Sections

$$K^- p \to \Xi^- X$$



$$K^- p \to \Omega^- X$$



J.K. Hassal et al., NPB 189 (1981)

Expected rates

Production	J-PARC*	Jlab (this proposal)
flux/s	$3 \times 10^4 K^-$	$10^4 K_L^0$
$\Xi^*/month$	3×10^5	2×10^5
$\Omega^{-*}/month$	600	4000

* H.~Takahashi, NP A 914, 553 (2013)
M.~Naruki and K.~Shirotori, LOI-2014-JPARC

What can be learned with a K^0_L beam ?

List of reactions:

Elastic and charge-exchange

$$K^0_L p \to K^0_S p$$
$$K^0_L p \to K^+ n$$

Two-body with S=-1

$$K^0_L p \to \pi^+ \Lambda$$
$$K^0_L p \to \pi^+ \Sigma^0$$

Two-body with S=-2

$$K^0_L p \to K^+ \Xi^0$$
$$K^0_L p \to K^+ \Xi^{0*}$$

Three-body with S=-2

$$K^0_L p \to \pi^+ K^+ \Xi^-$$
$$K^0_L p \to \pi^+ K^+ \Xi^{-*}$$

Three-body with S=-3

$$K^0_L p \to K^+ K^+ \Omega^-$$
$$K^0_L p \to K^+ K^+ \Omega^{-*}$$

Expected Cross Sections vs Bubble Chamber Data

- **GlueX** measurements will span **cosθ** from **–0.95** to **0.95** in c.m. above **W** = **1490** MeV.

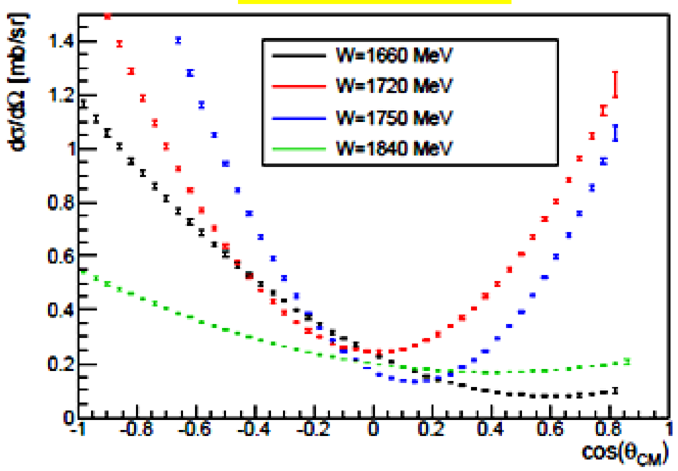
- K_L rate is **10^5** K_L/s.
- Uncertainties correspond to **100** days of running time.
- Cross section uncertainty estimates (statistics only) for

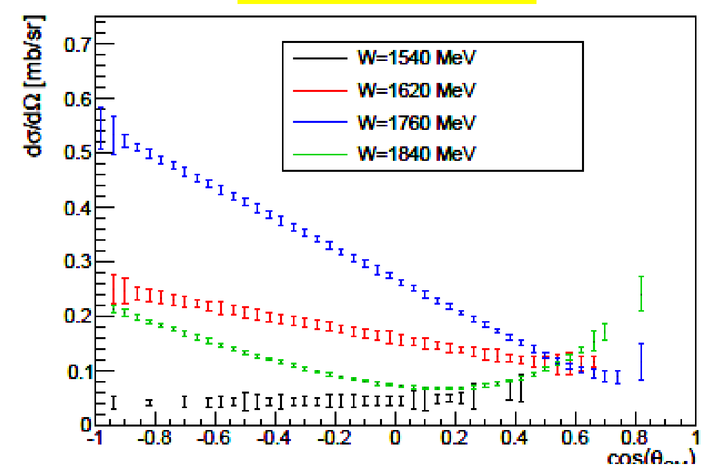
Courtesy of Simon Taylor, KL2016
Mark Manley, KL2016

$K_L p \to K_S p$

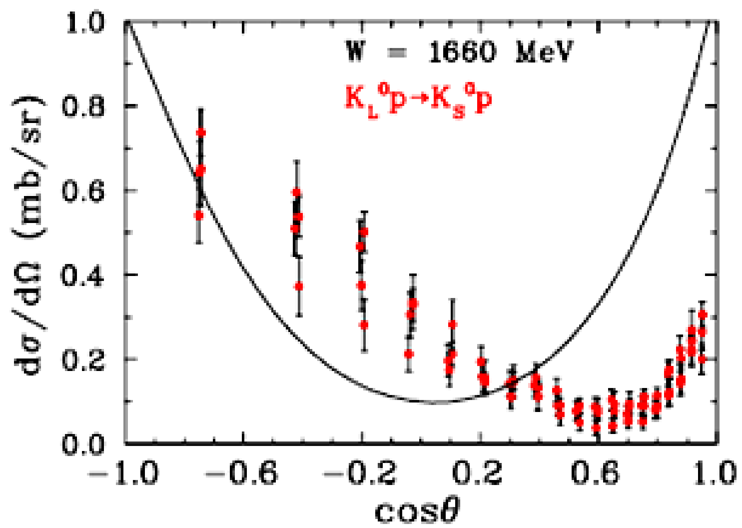
$K_L p \to \pi^+ \Lambda$

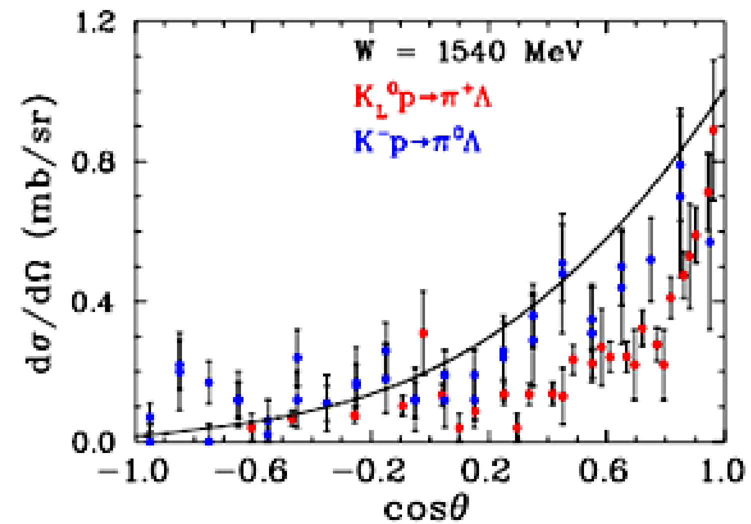
Expected **GlueX** Data





BC Data

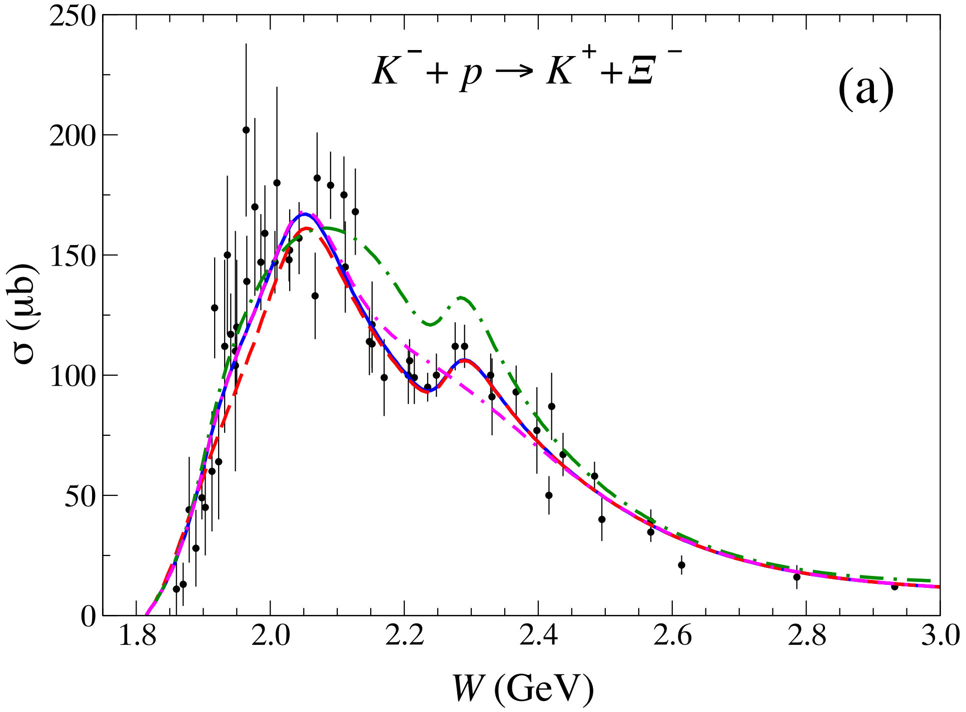


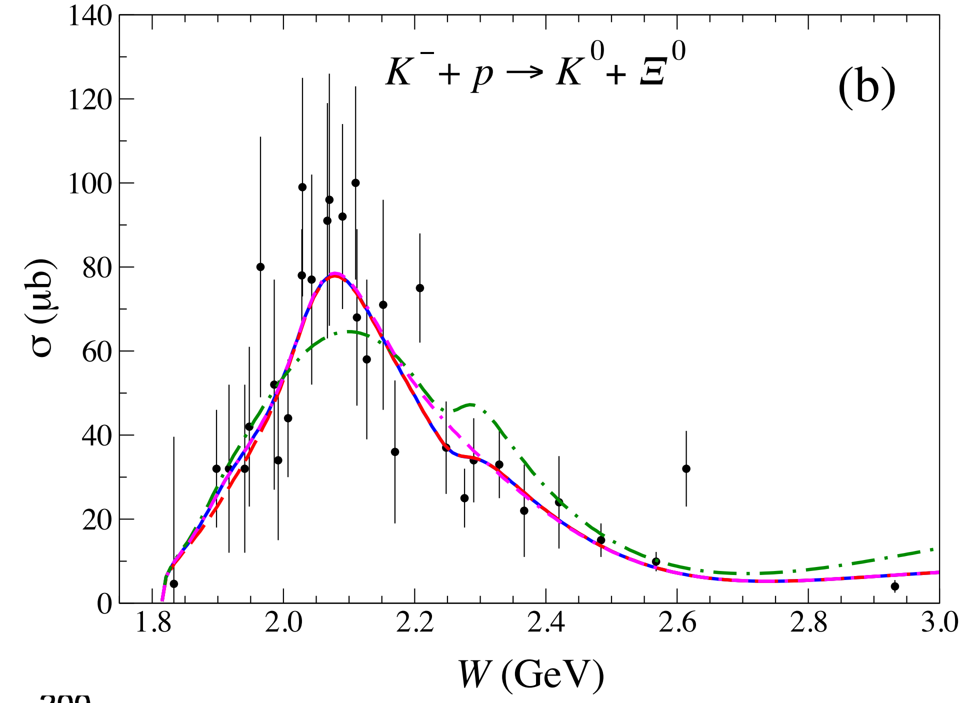


More details in KL2016 Workshop Proceedings

arXiv: 1604.02141

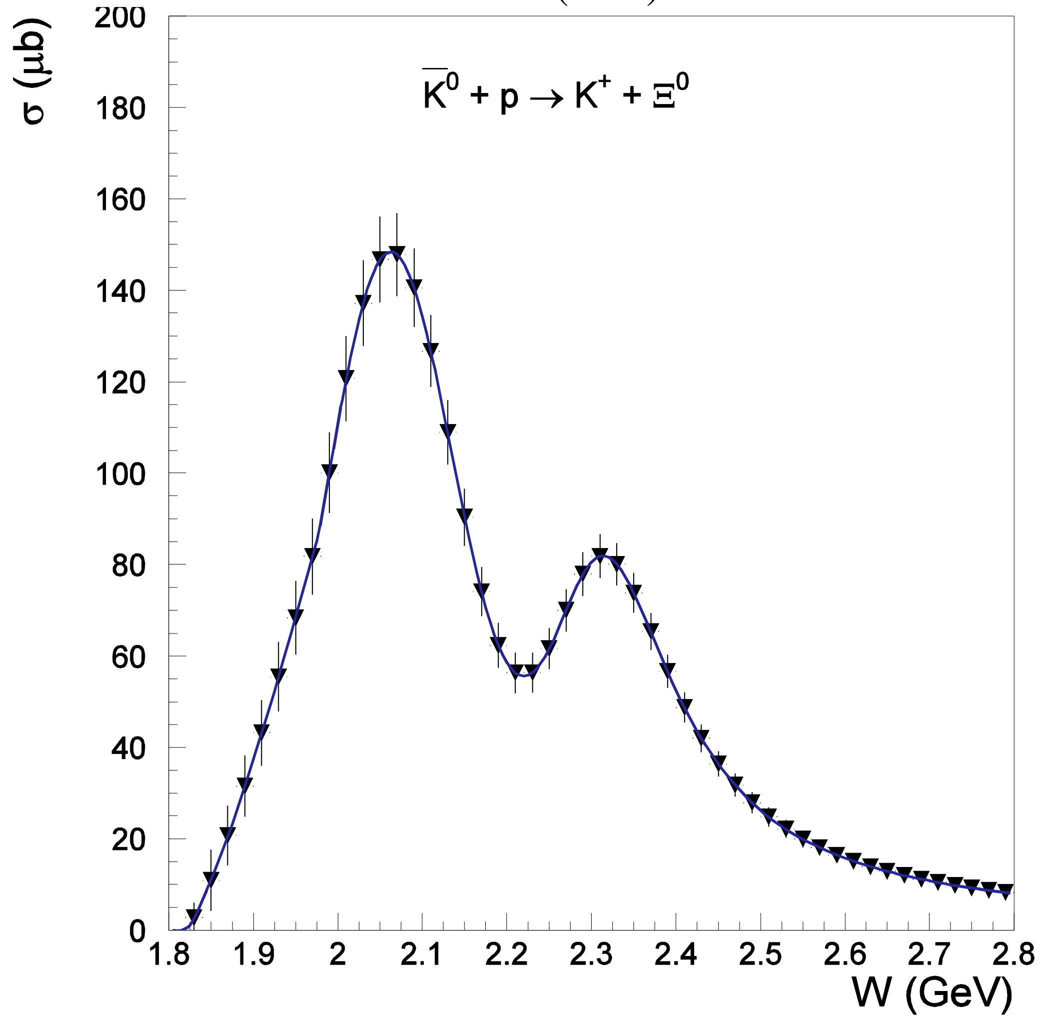
World Data on Ξ





Simulated with GlueX

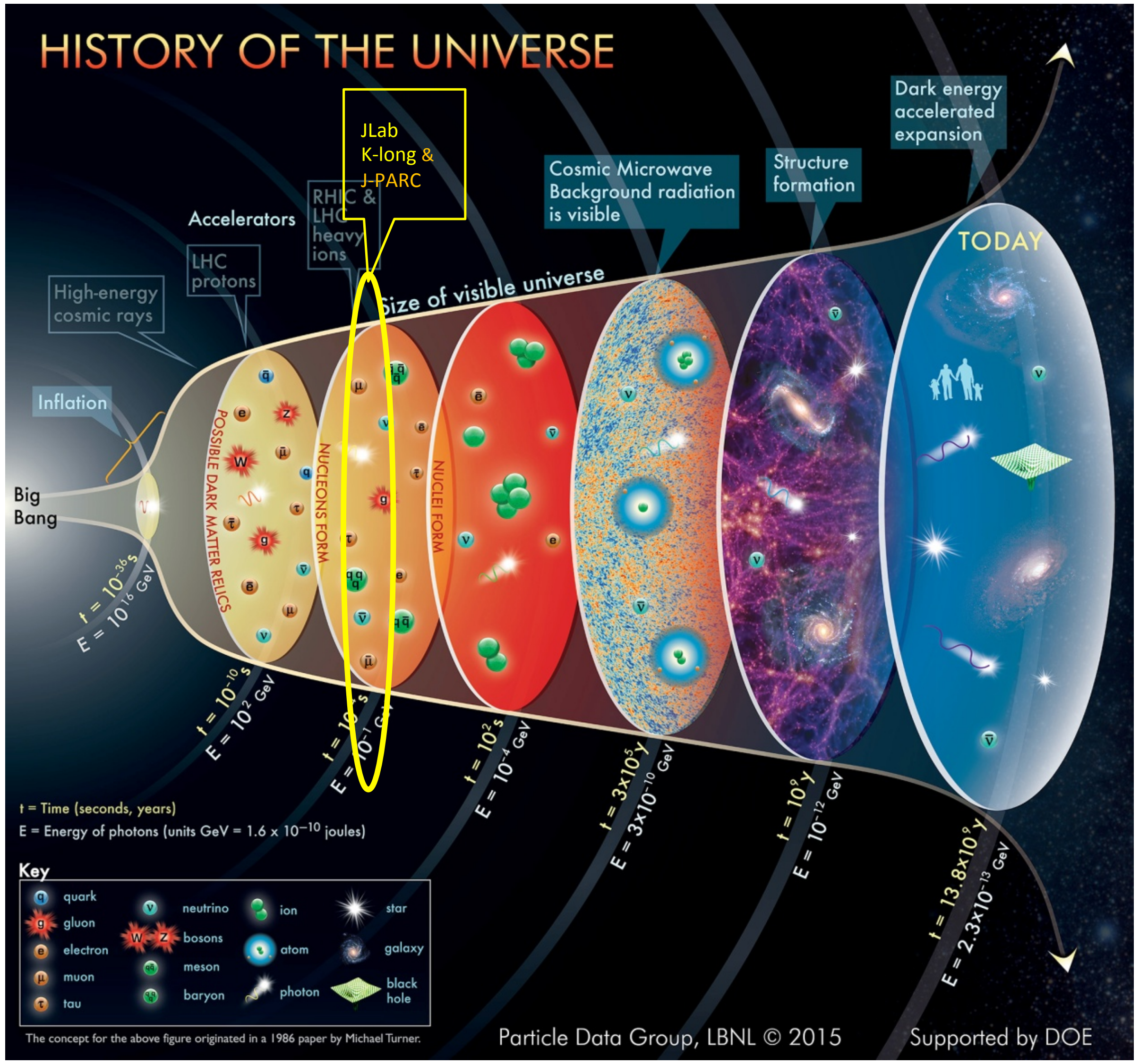
10^4 K_L/sec, one day of running



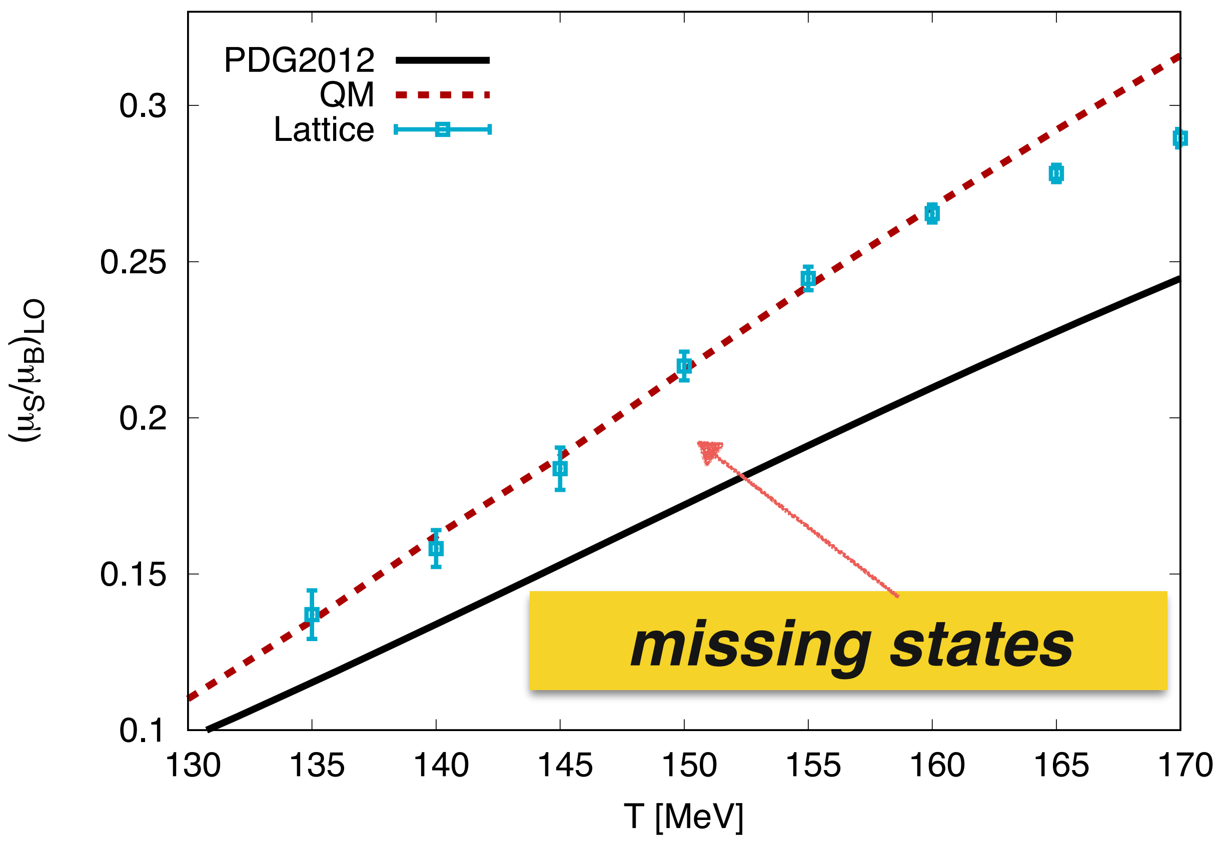
Jackson, Oh, Haberzettl, Nakayama

Phys. Rev. C 91, 065208 (2015)

Evolution of an Early Universe at Freeze-out



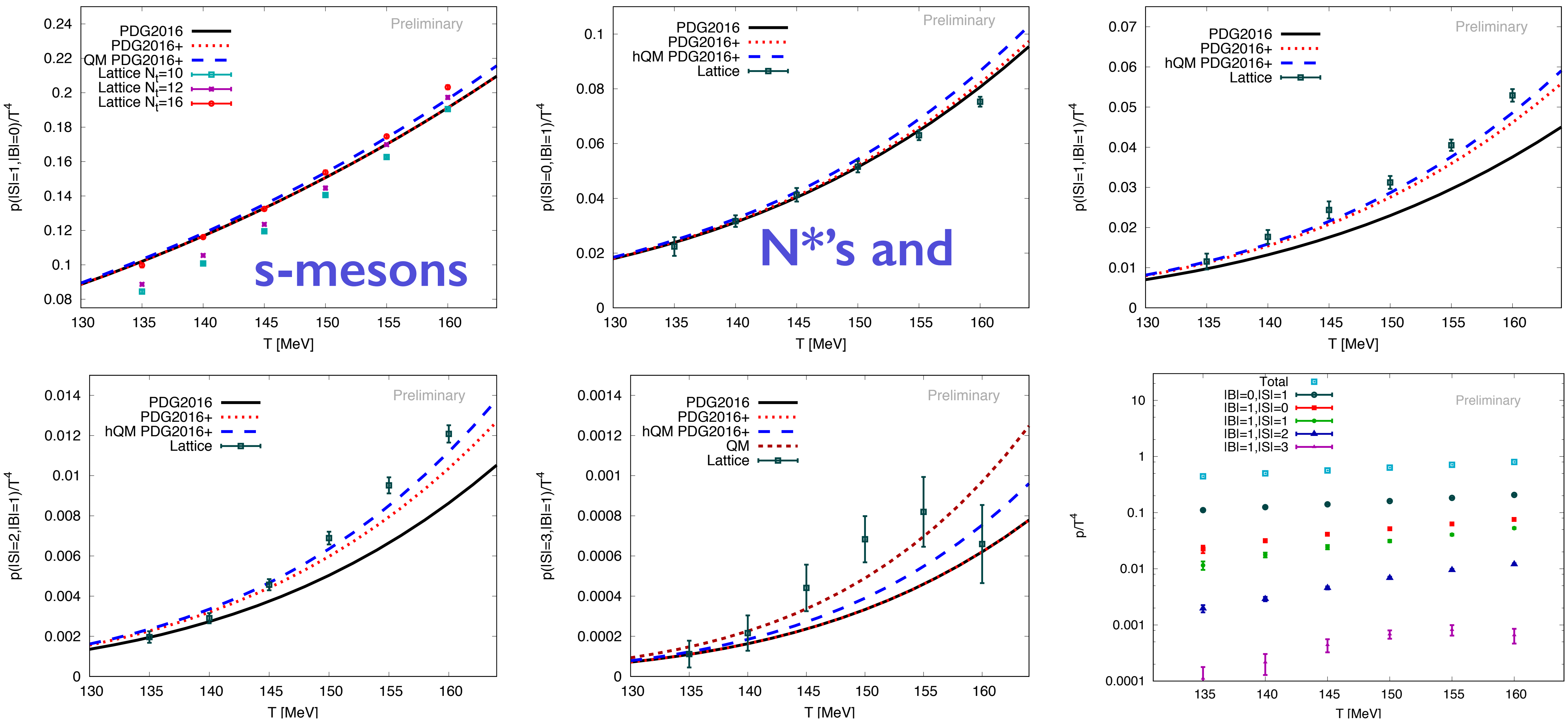
Chemical potential



YSTAR2016 Proceedings arXiv: 1701.07346

YSTAR2016 Proceedi 1701.07346

Partial pressure P/T^4



YSTAR2016 Proceedings arXiv:1701.07346

1.1 Why Kπ scattering is important?

• Hadron spectroscopy: determine resonances and their nature
– P-wave: K*(892), K*(1410), K*(1680), …
– S-wave: "κ(~800)", …
– Exotics,…

• ππ and Kπ building blocks for hadronic physics:
- Test of Chiral Dynamics
- Extraction of fundamental parameters of the Standard Model
- Look for physics beyond the Standard Model: High precision at low energy as a key to new physics?

Very important when Final State Interactions at play!

Emilie Passemar, KL2016 Workshop

3.2 K*(892) mass and width

PDG'15

$K^*(892)$ MASS

CHARGED ONLY, HADROPRODUCED

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
891.66±0.26 OUR AVERAGE					
892.6 ±0.5	5840	BAUBILLIER 84B	HBC	−	8.25 $K^- p \to \overline{K}^0 \pi^- p$
888 ±3		NAPIER 84	SPEC	+	200 $\pi^- p \to 2K^0_S X$
891 ±1		NAPIER 84	SPEC	−	200 $\pi^- p \to 2K^0_S X$
891.7 ±2.1	3700	BARTH 83	HBC	+	70 $K^+ p \to K^0 \pi^+ X$
891 ±1	4100	TOAFF 81	HBC	−	6.5 $K^- p \to \overline{K}^0 \pi^- p$
892.8 ±1.6		AJINENKO 80	HBC	+	32 $K^+ p \to K^0 \pi^+ X$
890.7 ±0.9	1800	AGUILAR-... 78B	HBC	±	0.76 $\overline{p} p \to K^\mp K^0_S \pi^\pm$
886.6 ±2.4	1225	BALAND 78	HBC	±	12 $\overline{p} p \to (K\pi)^\pm X$
891.7 ±0.6	6706	COOPER 78	HBC	±	0.76 $\overline{p} p \to (K\pi)^\pm X$
891.9 ±0.7	9000	[1] PALER 75	HBC	−	14.3 $K^- p \to (K\pi)^- X$
892.2 ±1.5	4404	AGUILAR-... 71B	HBC	−	3.9,4.6 $K^- p \to (K\pi)^- p$
891 ±2	1000	CRENNELL 69D	DBC	−	3.9 $K^- N \to K^0 \pi^- X$
890 ±3.0	720	BARLOW 67	HBC	±	1.2 $\overline{p} p \to (K^0 \pi)^\pm K^\mp$
889 ±3.0	600	BARLOW 67	HBC	±	1.2 $\overline{p} p \to (K^0 \pi)^\pm K^\mp$
891 ±2.3	620	[2] DEBAERE 67B	HBC	+	3.5 $K^+ p \to K^0 \pi^+ p$
891.0 ±1.2	1700	[3] WOJCICKI 64	HBC	−	1.7 $K^- p \to \overline{K}^0 \pi^- p$

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
893.5 ±1.1	27k	[4] ABELE 99D	CBAR	±	0.0 $\overline{p} p \to K^+ K^- \pi^0$
890.4 ±0.2 ±0.5	80±0.8k	[5] BIRD 89	LASS	−	11 $K^- p \to \overline{K}^0 \pi^- p$
890.0 ±2.3	800	[2,3] CLELAND 82	SPEC	+	30 $K^+ p \to K^0_S \pi^+ p$
896.0 ±1.1	3200	[2,3] CLELAND 82	SPEC	+	50 $K^+ p \to K^0_S \pi^+ p$
893 ±1	3600	[2,3] CLELAND 82	SPEC	−	50 $K^+ p \to K^0_S \pi^- p$
896.0 ±1.9	380	DELFOSSE 81	SPEC	+	50 $K^\pm p \to K^\pm \pi^0 p$
886.0 ±2.3	187	DELFOSSE 81	SPEC	−	50 $K^\pm p \to K^\pm \pi^0 p$
894.2 ±2.0	765	[2] CLARK 73	HBC	−	3.13 $K^- p \to \overline{K}^0 \pi^- p$
894.3 ±1.5	1150	[2,3] CLARK 73	HBC	−	3.3 $K^- p \to \overline{K}^0 \pi^- p$
892.0 ±2.6	341	[2] SCHWEING...68	HBC	−	5.5 $K^- p \to \overline{K}^0 \pi^- p$

CHARGED ONLY, PRODUCED IN τ LEPTON DECAYS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
895.47±0.20±0.74	53k	[6] EPIFANOV 07	BELL	$\tau^- \to K^0_S \pi^- \nu_\tau$

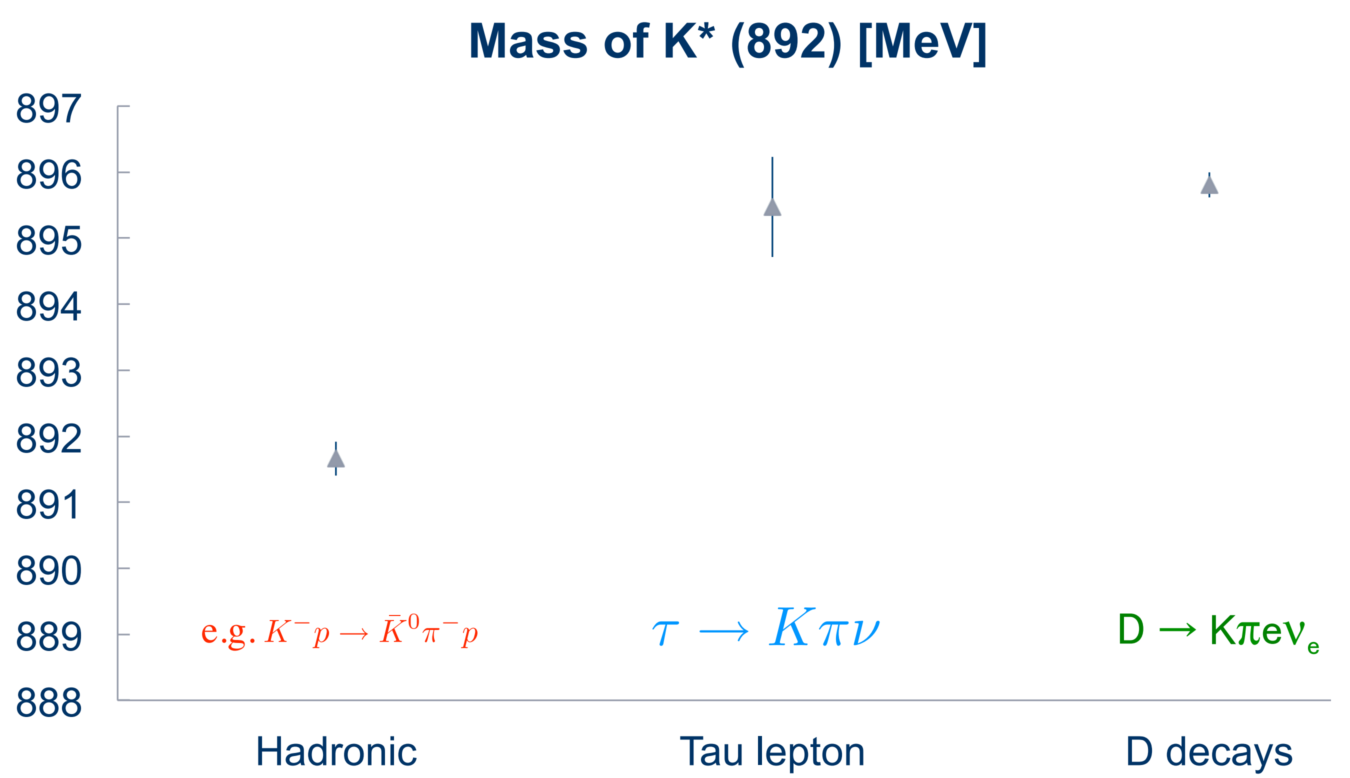
• • • We do not use the following data for averages, fits, limits, etc. • • •

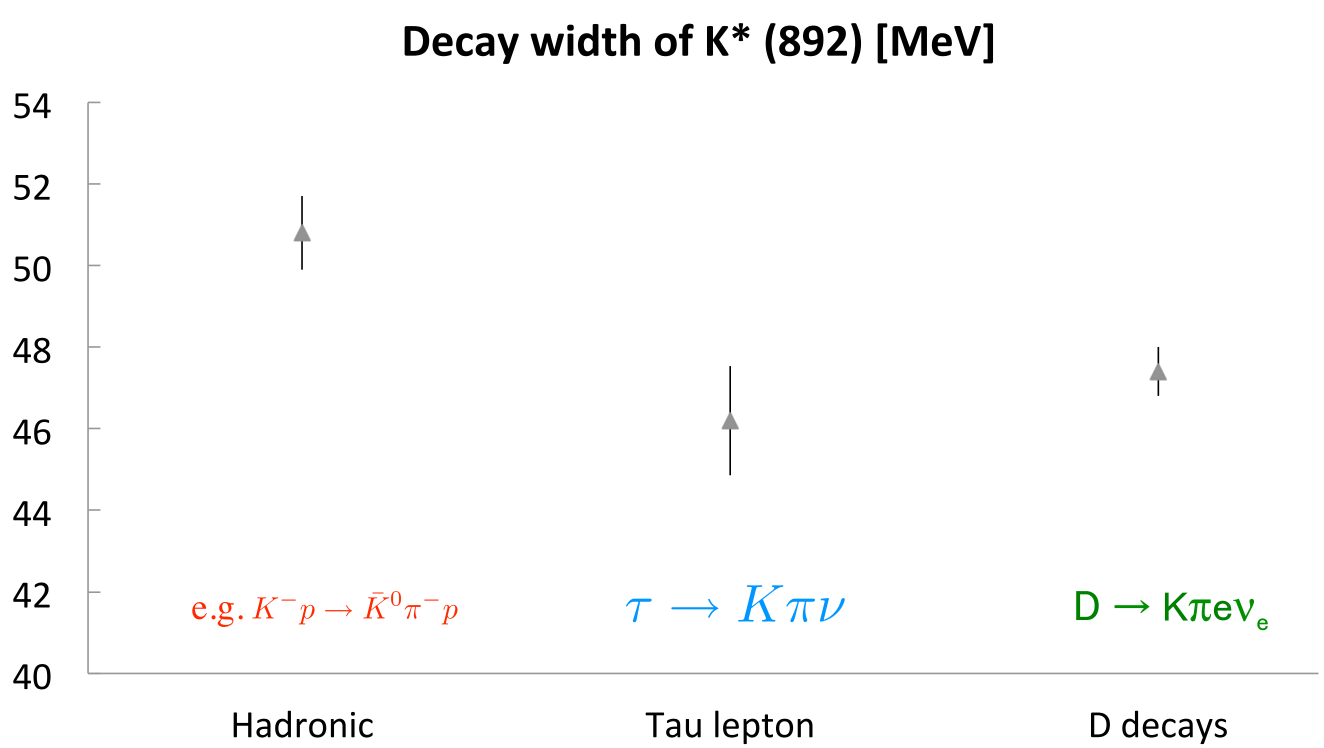
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
892.0 ±0.5		[7] BOITO 10	RVUE	$\tau^- \to K^0_S \pi^- \nu_\tau$
892.0 ±0.9		[8,9] BOITO 09	RVUE	$\tau^- \to K^0_S \pi^- \nu_\tau$
895.3 ±0.2		[8,10] JAMIN 08	RVUE	$\tau^- \to K^0_S \pi^- \nu_\tau$
896.4 ±0.9	11970	[11] BONVICINI 02	CLEO	$\tau^- \to K^- \pi^0 \nu_\tau$
895 ±2		[12] BARATE 99R	ALEP	$\tau^- \to K^- \pi^0 \nu_\tau$

NEUTRAL ONLY

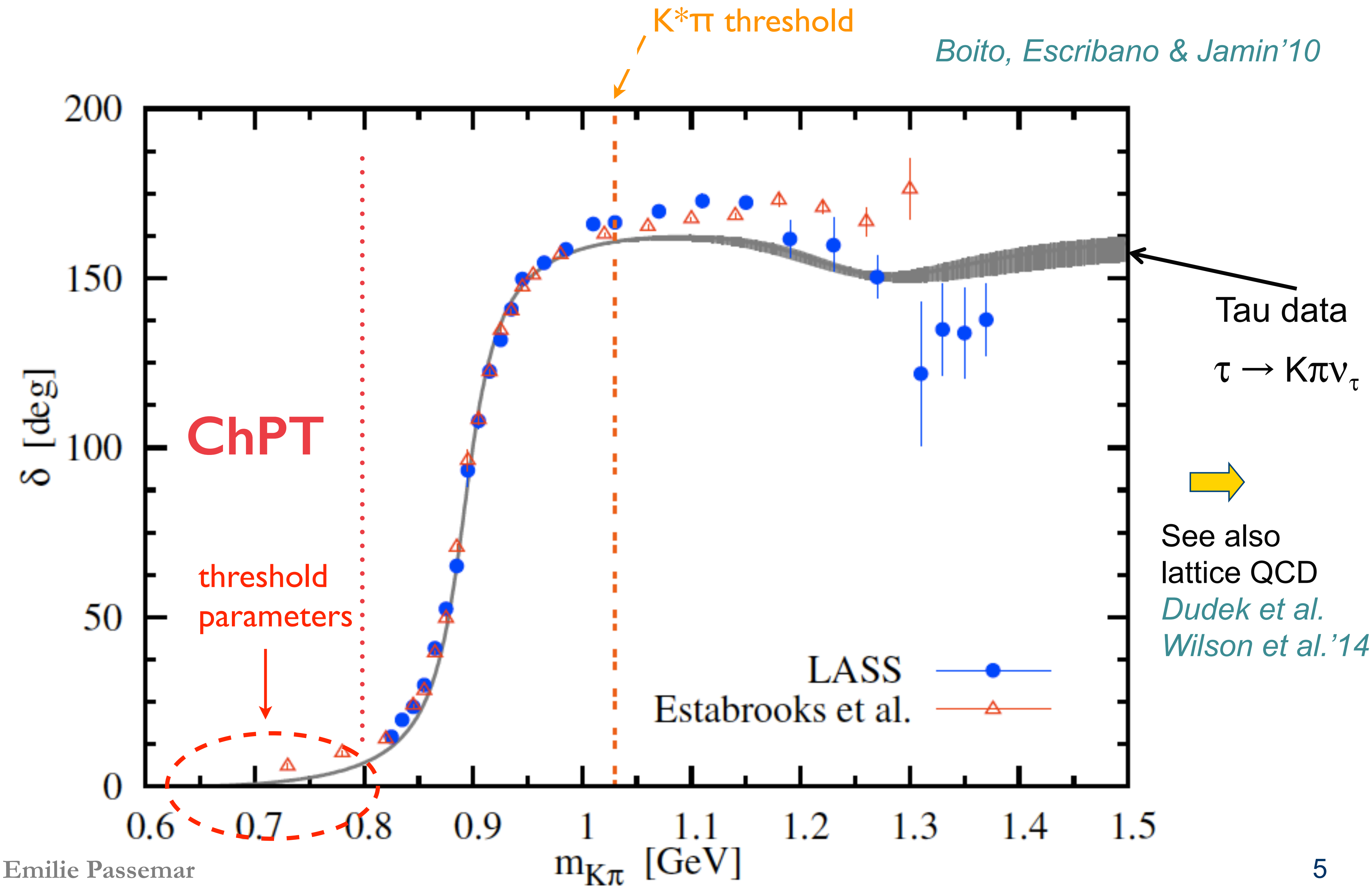
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
895.81±0.19 OUR AVERAGE		Error includes scale factor of 1.4. See the ideogram below.		
895.4 ±0.2 ±0.2	243k	[13] DEL-AMO-SA...11I	BABR	$D^+ \to K^- \pi^+ e^+ \nu_e$
895.7 ±0.2 ±0.3	141k	[14] BONVICINI 08A	CLEO	$D^+ \to K^- \pi^+ \pi^+$
$895.41 \pm 0.32^{+0.35}_{-0.43}$	18k	[15] LINK 05I	FOCS	$D^+ \to K^- \pi^+ \mu^+ \nu_\mu$
896 ±2		BARBERIS 98E	OMEG	450 $pp \to p_f p_s K^* \overline{K}^*$
895.9 ±0.5 ±0.2		ASTON 88	LASS	11 $K^- p \to K^- \pi^+ n$

3.2 K*(892) mass and width





1.2 Ex: Kπ scattering: P-wave



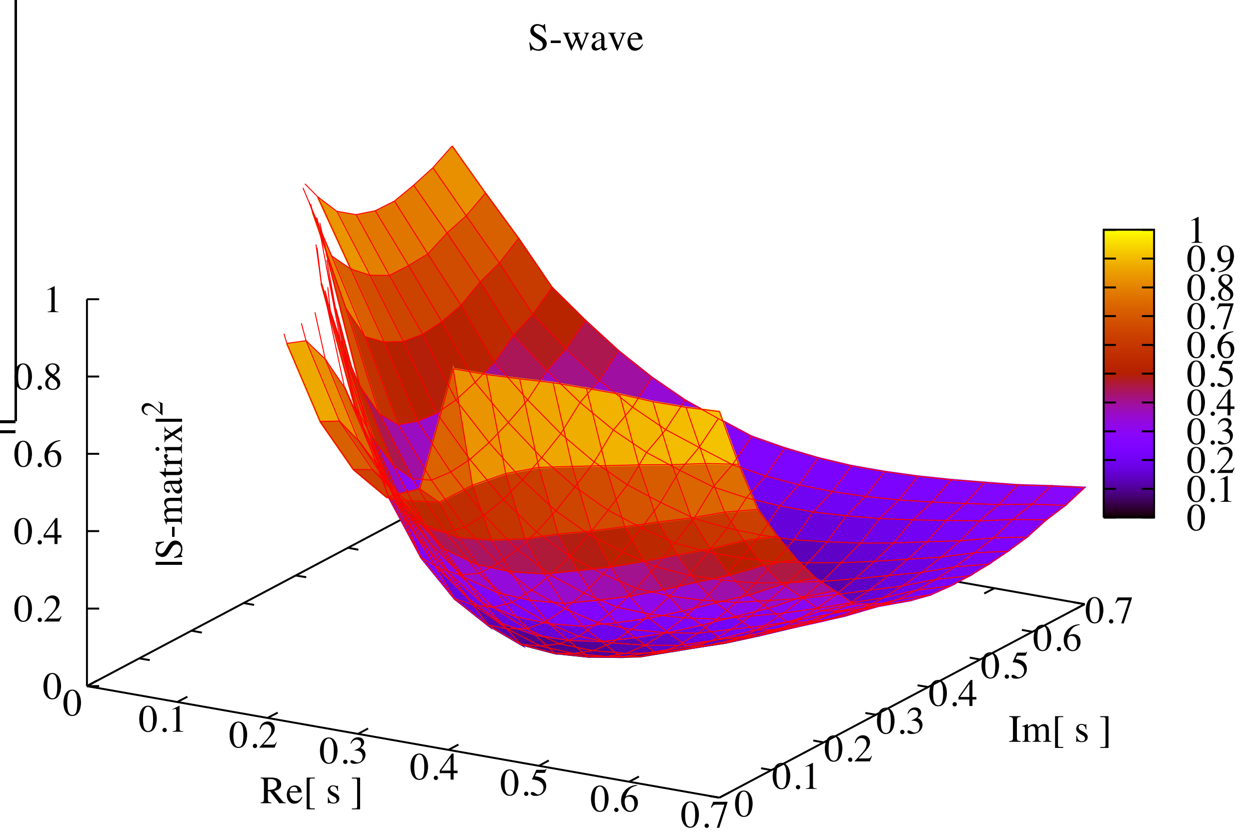
Important Input for CP violation in heavy meson decay

3.3 Kappa(800)

- The results coming from Roy-Steiner and data at higher energy not in agreement with low energy experimental data ⇨ need improvement!
  Problem: no other precise data

Descotes-Genon, Moussallam'06

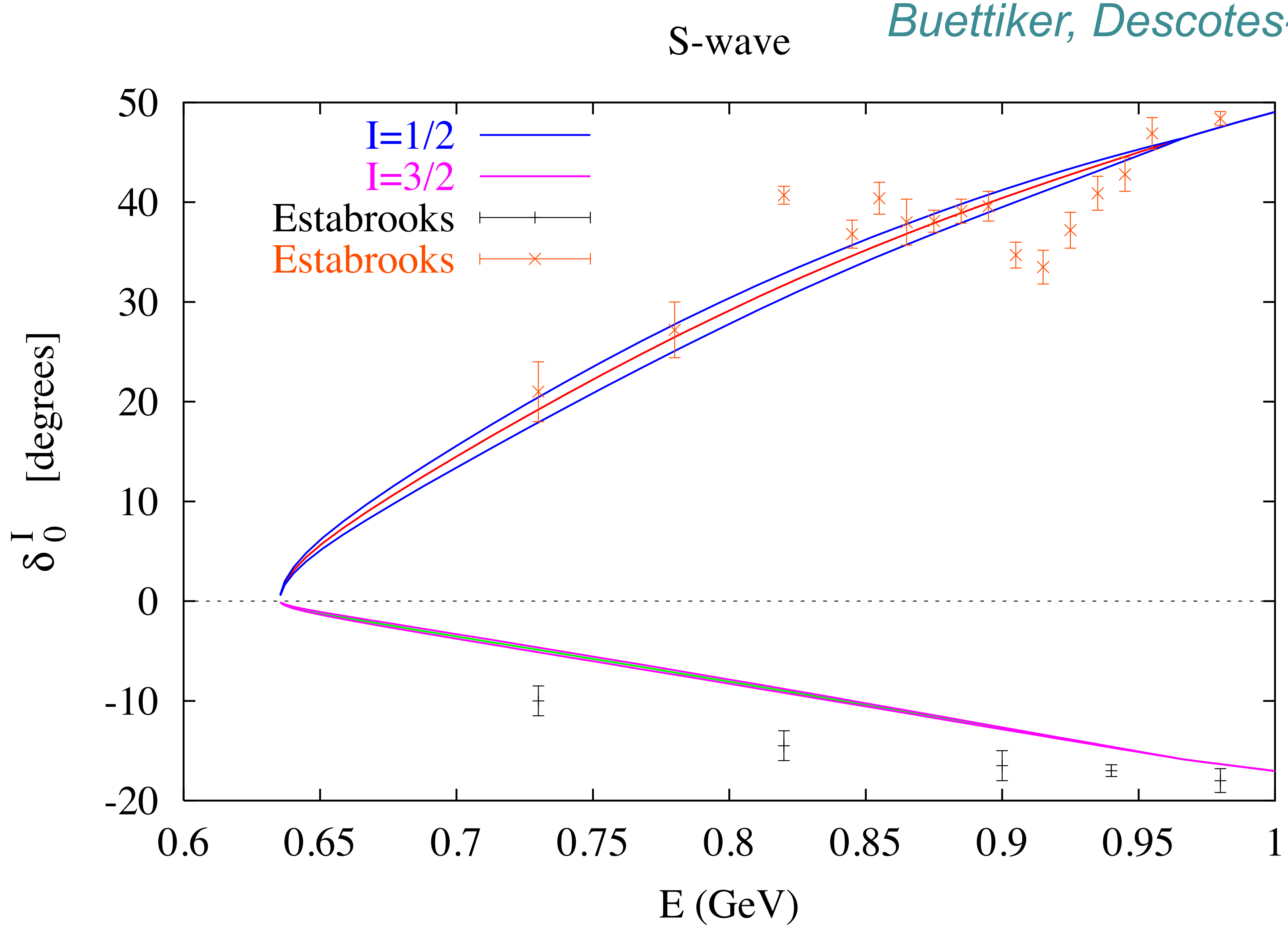
	M_κ (MeV)	Γ_κ (MeV)
This work	658 ± 13	557 ± 24
Zhou, Zheng [16]	694 ± 53	606 ± 89
Jamin et al. [18]	708	610
Aitala et al. [7]	$721 \pm 19 \pm 43$	$584 \pm 43 \pm 87$
Pelaez [19]	750 ± 18	452 ± 22
Bugg [9]	750^{+30}_{-55}	684 ± 120
Ablikim et al. [20]	$841 \pm 23^{+64}_{-55}$	$618 \pm 52^{+55}_{-87}$
Ishida et al. [14]	877^{+65}_{-30}	668^{+235}_{-110}



3.3 Kappa(800)

- The results coming from Roy-Steiner and data at higher energy not in agreement with low energy experimental data ⇨ need improvement!

Buettiker, Descotes-Genon, Moussallam'04



12 GeV Approved Experiments by PAC Days

Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD		119		540		**659**
The transverse structure of the hadrons	145.5	85	102	25		**357.5**
The longitudinal structure of the hadrons	65	230	165			**460**
The 3D structure of the hadrons	409	872	212			**1493**
Hadrons and cold nuclear matter	180	175	201		14	**570**
Low-energy tests of the Standard Model and Fundamental Symmetries	547	180		79	60	**866**
Total Days	**1346.5**	**1661**	**680**	**644**	**74**	**4405.5**
Total Days – Without MIE Days	**697.5**	**1661**	**680**	**644**	**28**	**3710.5**
Total Approved Run Group Days (includes MIE)	**1346.5**	**826**	**637**	**424**	**74**	**3307.5**
Total Approved Run Group Days (without MIE)	**528.5**	**826**	**637**	**424**	**28**	**2443.5**
Total Days Completed	**20**	**15**	**0**	**25**	**0**	**60**
Total Days Remaining	**508.5**	**811**	**637**	**399**	**28**	**2383.5**

60 weeks

U.S. DEPARTMENT OF ENERGY | Office of Science | JSA June 2016 11 Jefferson Lab

- **Bob McKeown's talk at 2016 UG meeting**

JLab Operations Budget ONP Briefing

- During FY01-FY12, CEBAF ops averaged 34.5 weeks/year (best year FY05 at 42 weeks)
- For 12 GeV era we estimate "optimal" operations at 37 weeks per year
- FY17 Pres. Budget includes JLab ops at $104M
  - would fund 23 weeks (+ 3 weeks from 12 GeV project)
- FY18+ at cost of living implies 23 weeks/year running (62% of optimal)
- We propose FY18+ at 30 weeks/year (81%), will require ~$6M increase in operations budget.

- Slide from Mont's talk at 2016 UG meeting
- Hall D Physics Program will be completed in 2-3 years

Summary

- KN scattering still remains very poorly studied

- lack of data on excited hyperon states requires significant experimental efforts to be completed

- Experimental data on Kpi system needs to be updated for many different reasons

- Our preliminary studies show that production of few times $10^4 K^0_L$/s at GlueX target in Hall D is

-Proposed setup will have highest intensity K^0_L beam ever used for hadron spectroscopy

-Data obtained at Jlab will be unique and partially complementary to charged kaon data

Thank You!