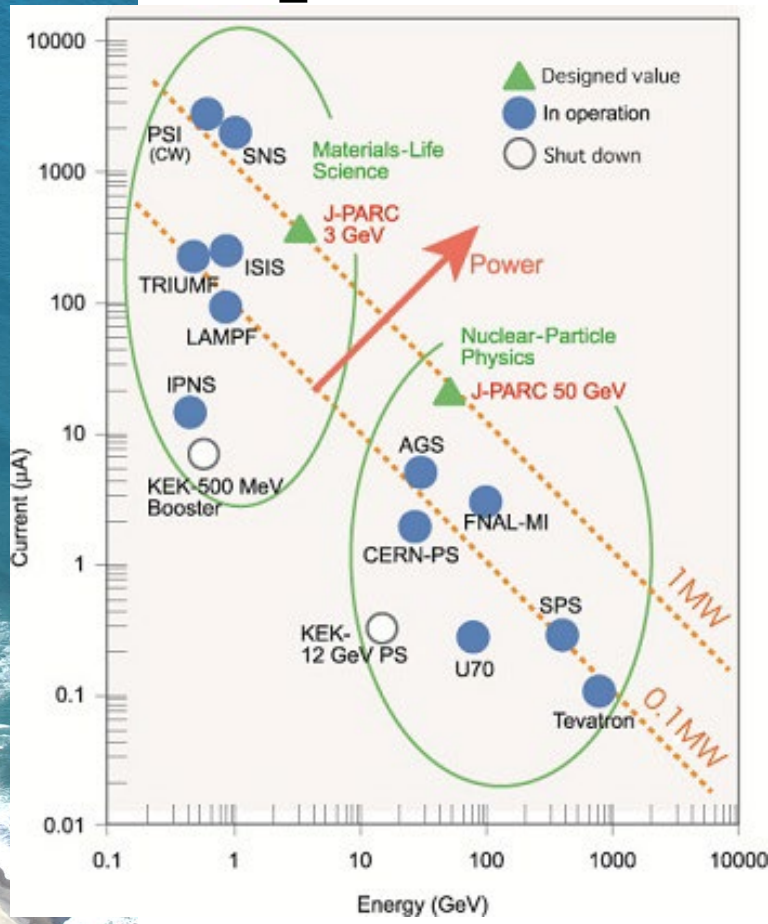
Baryon Spectroscopy at J-PARC

M. Naruki (Kyoto Univ.)
2024/4/5, Glasgow
Hadron Spectroscopy with Strangeness workshop

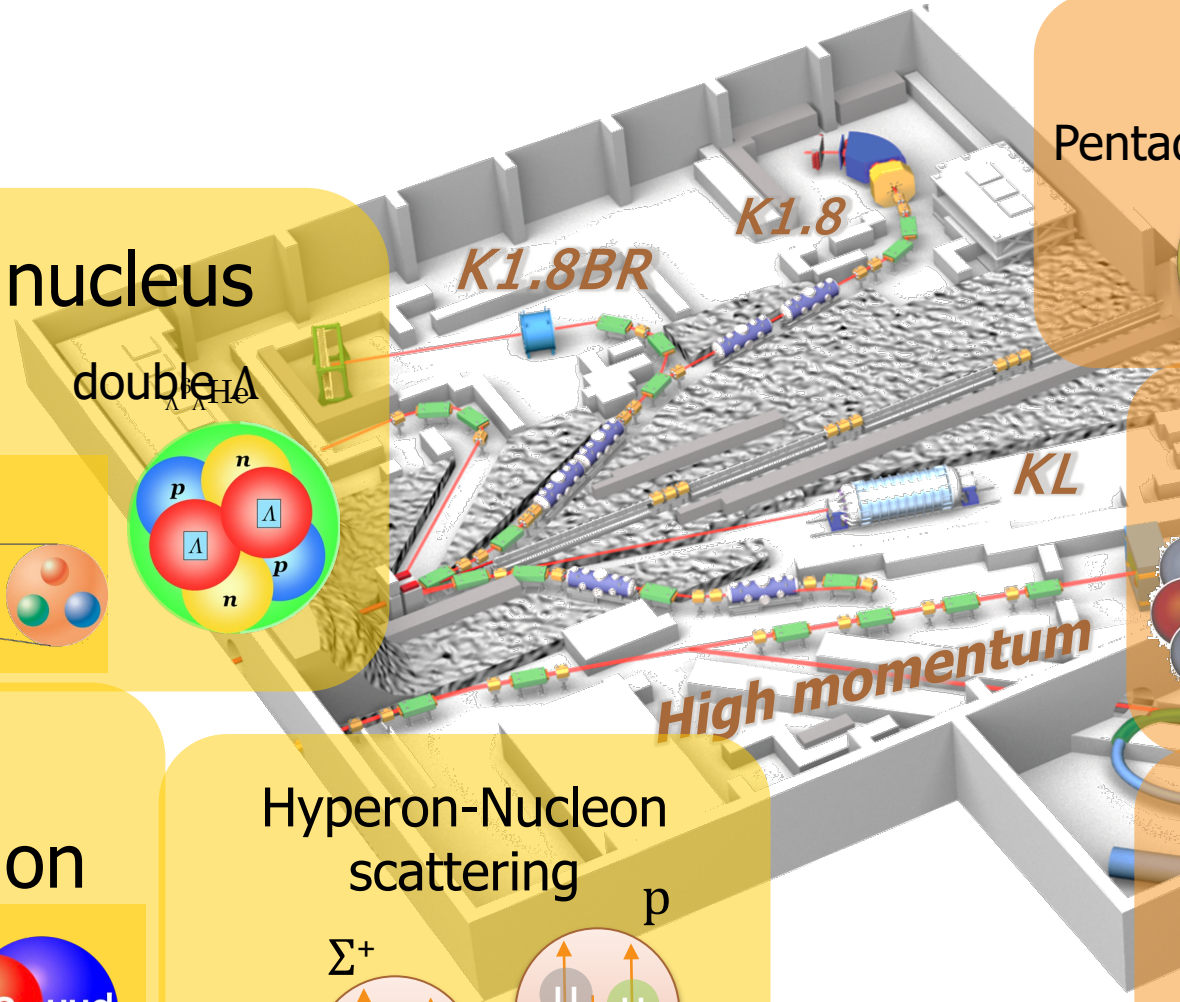
Contents

Japan Proton Accelerator Research Complex



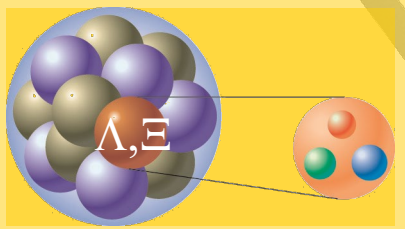
Tokai, Ibaraki

Physics at J-PARC Hadron Facility



Hyper nucleus

Ξ(qss)

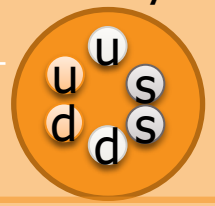


double Λ

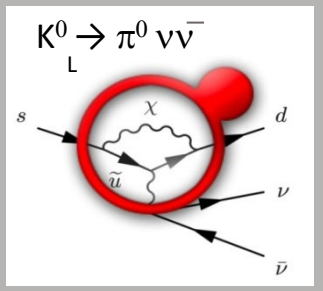
Exotics

Pentaquarksa Θ+

H dibaryon

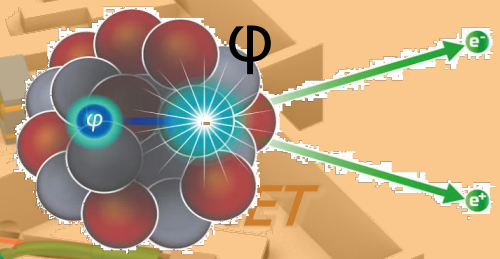


CP violation

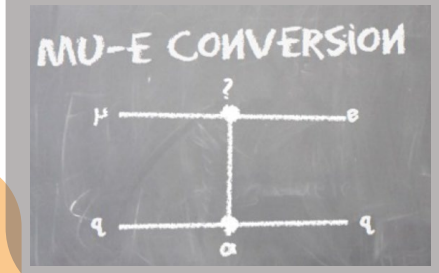


Hadron Mass

φ

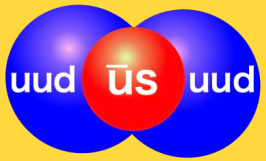


Lepton Flavour Violation



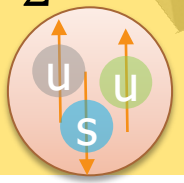
KN interaction

K-pp

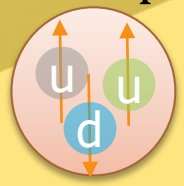


Hyperon-Nucleon scattering

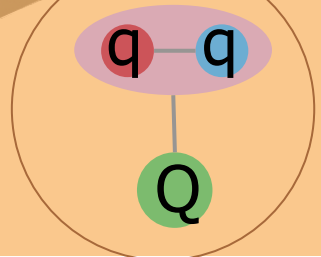
Σ+



p

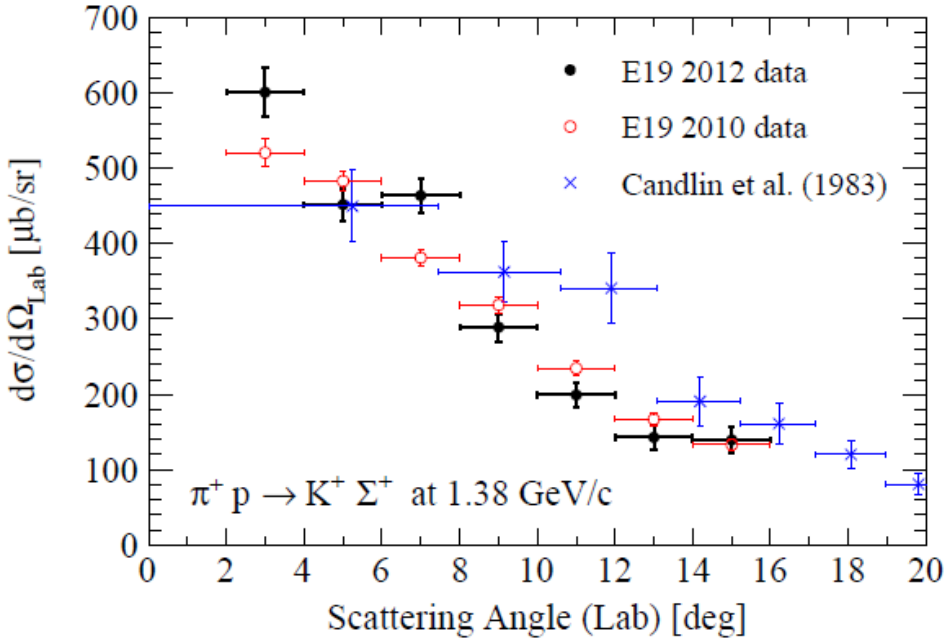


Baryon spectroscopy

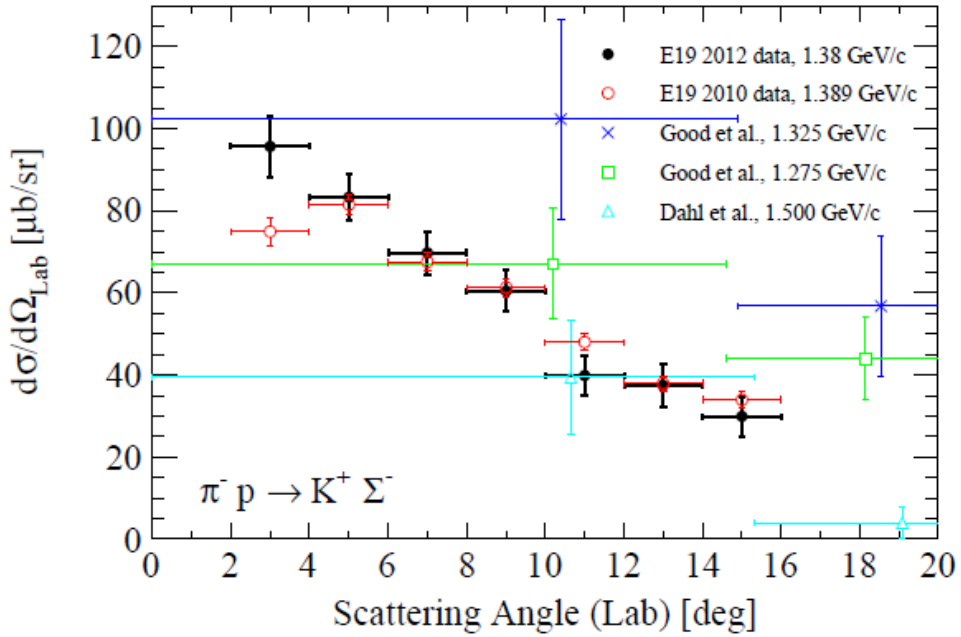


Σ production cross section

$\pi^+ + p \rightarrow K^+ + \Sigma^+$ @ 1.38 GeV/c



$\pi^- + p \rightarrow K^+ + \Sigma^-$ @ 1.38 GeV/c

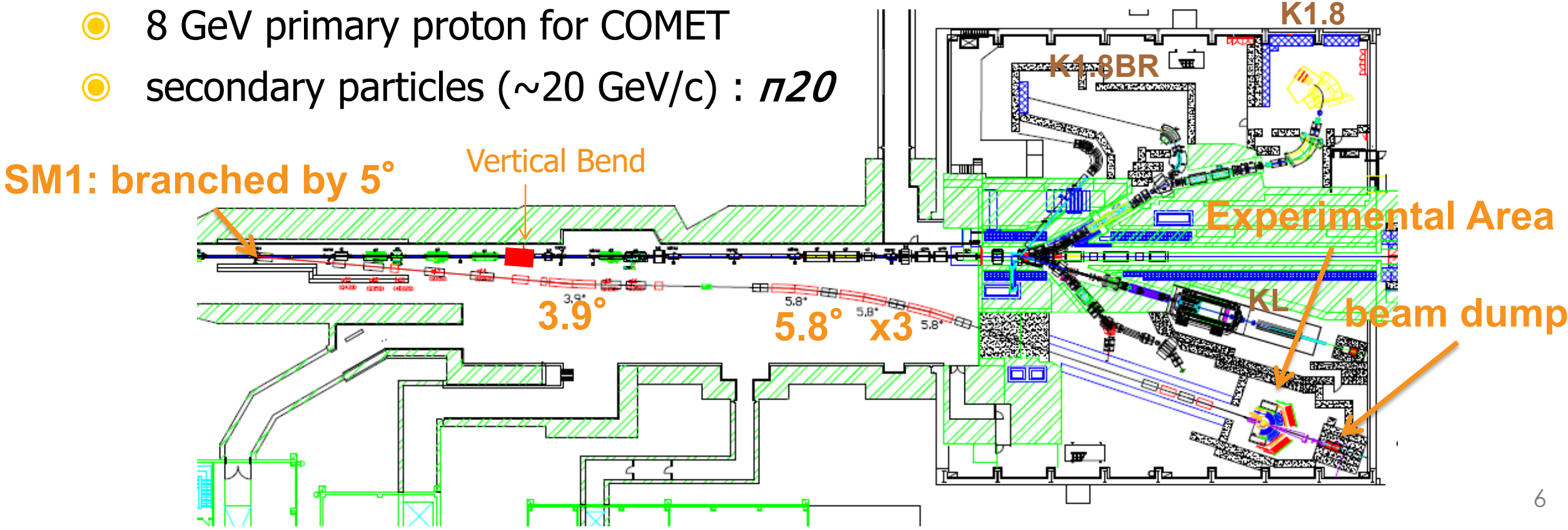


K. Shirotori *et al.*, PRL 109 (2012) 132002

- precise measurement by J-PARC E19

High-momentum beam line

- protons branches off from the primary line at SM1
- 30 GeV primary proton (10^{10}/s)
- 8 GeV primary proton for COMET
- secondary particles (~20 GeV/c) : ***π20***



Beam line specifications

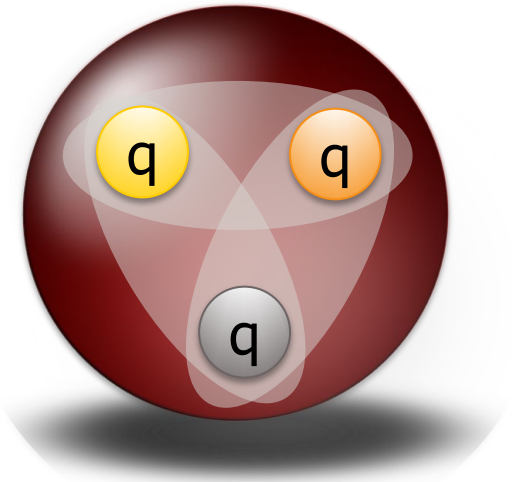
Name	Particles	P_{max}	Intensity
K1.8	π, K, $\bar{p}$	2.0 GeV/c	10^6 K^- 's
K1.8BR	π, K, $\bar{p}$	1.1 GeV/c	10^6 K^- 's
KL	neutral K		
K1.1BR	π, K, $\bar{p}$	0.8 GeV/c	10^6 K^- 's
High-p	proton	31 GeV/c	10^{10} p
π20 (High-p secondary)	π/K/$\bar{p}$ (unseparated)	20 GeV/c	10^6 K^- 's
K10	π, K, $\bar{p}$	10 GeV/c	10^6 K^- 's

2020 May~

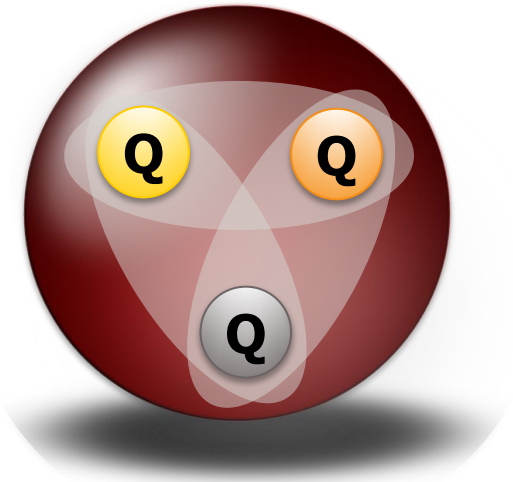
planned

$\sqrt{s} = 2.2$ GeV → $\sqrt{s} = 6.2$ GeV in 20GeV/c πp/Kp reactions

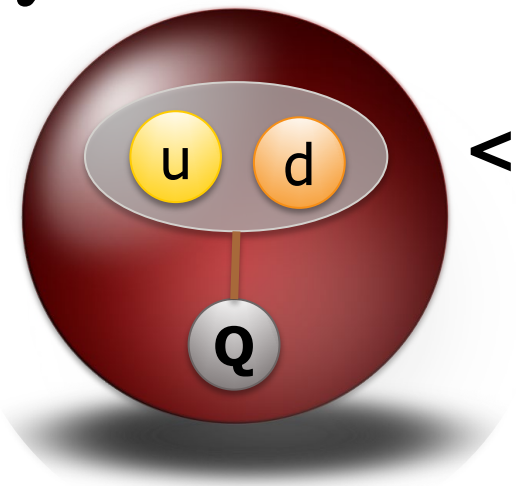
Strange & Charm Baryon Spectroscopy



N/Δ

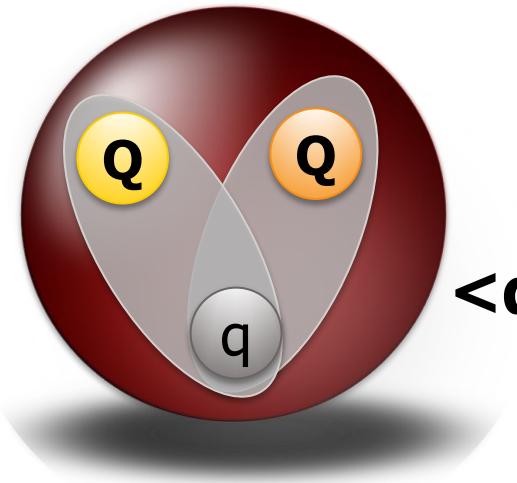


Ω



<qq>

Λ_c



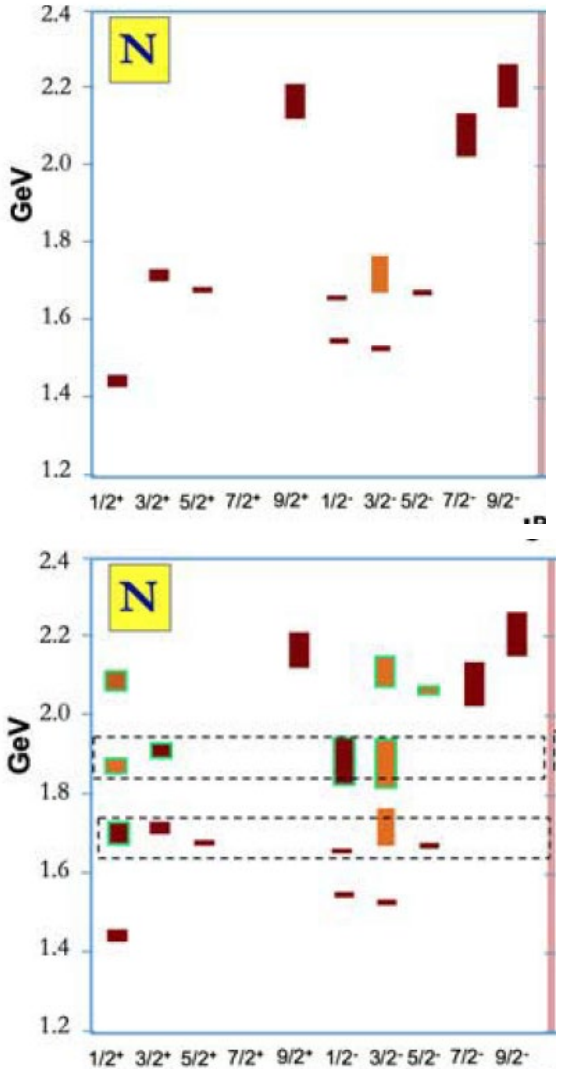
<qs>

Ξ

N* spectroscopy at JLab

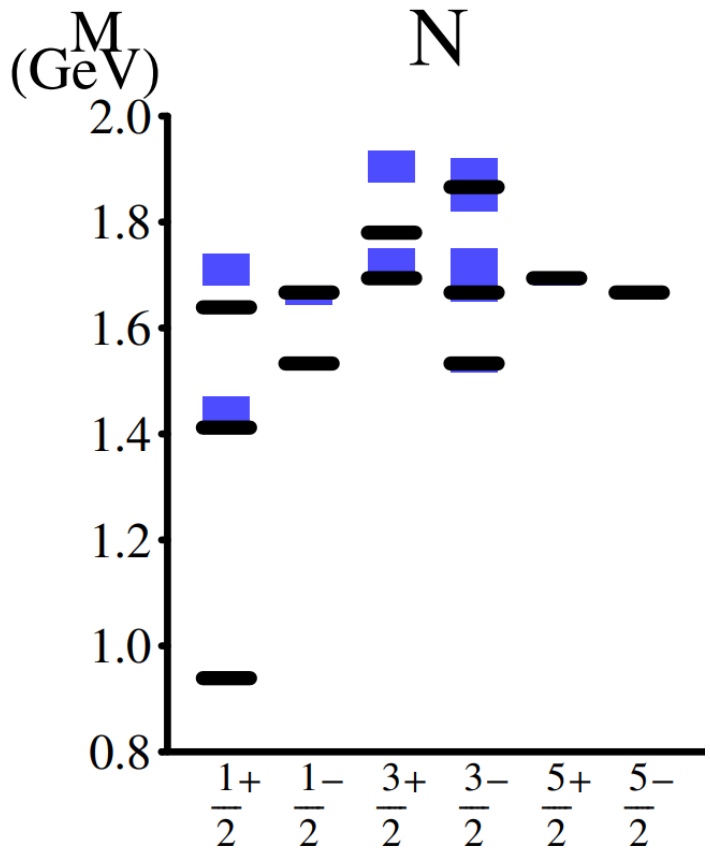
Experiment

State N((mass)J^P	PDG 2010	PDG 2018
N(1710)1/2$^+$	***	****
N(1880)1/2$^+$		***
N(2100)1/2$^+$	*	***
N(1895)1/2$^-$		****
N(1900)3/2$^+$	**	****
N(1875)3/2$^-$		***
N(2120)3/2$^-$		***
N(2060)5/2$^-$		***



V.D. Burkert, EPJ WoC 241 (2020) 01004

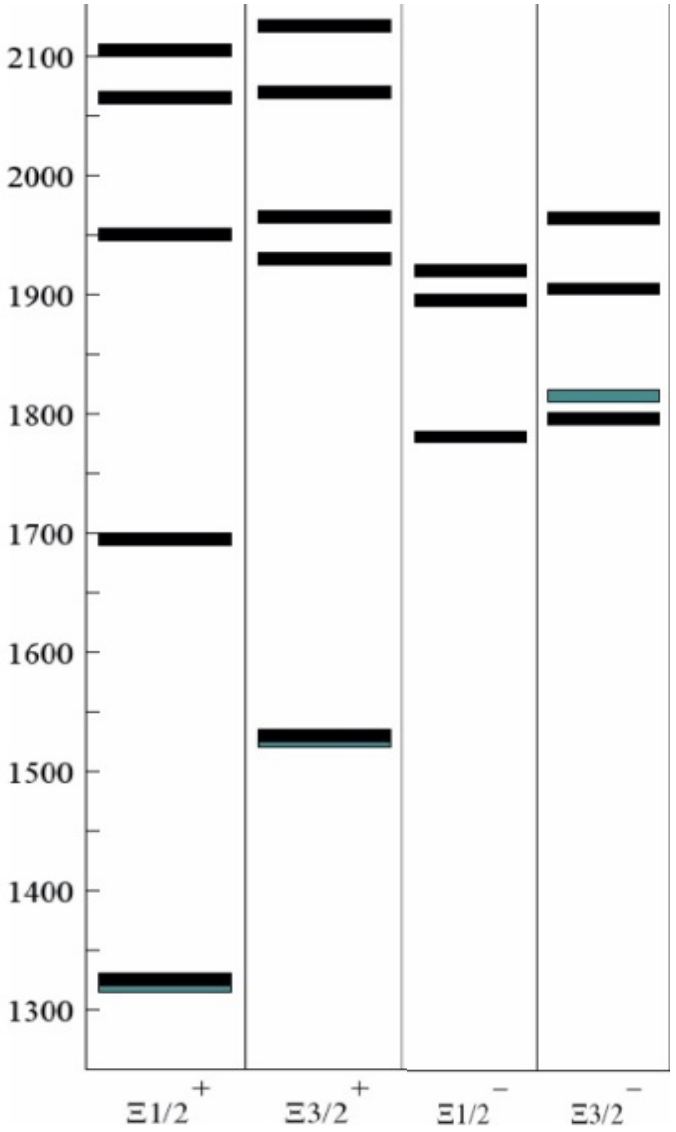
quark-diquark model
Quark Model



Capstick & Isgur PRD34(1986)2809

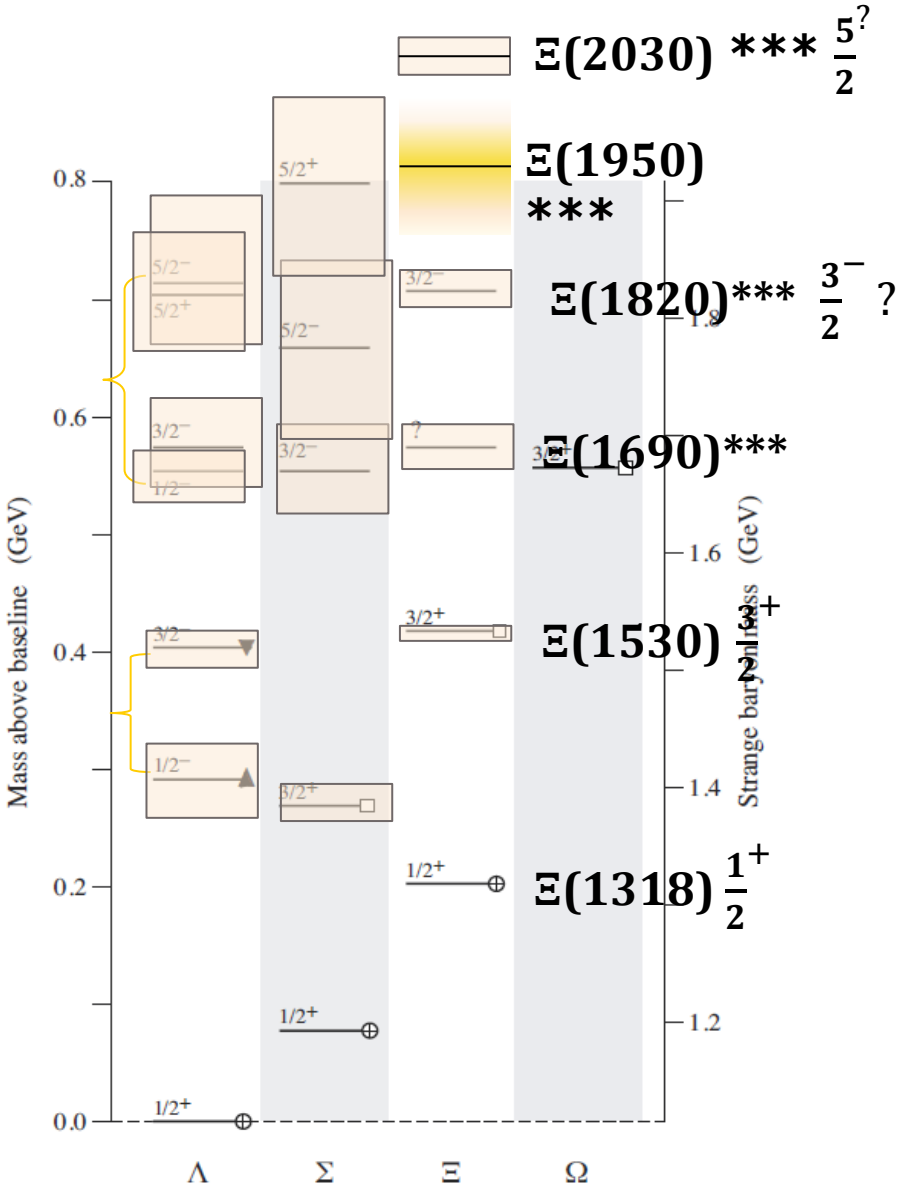
Ξ Baryons spectrum

Quark Model

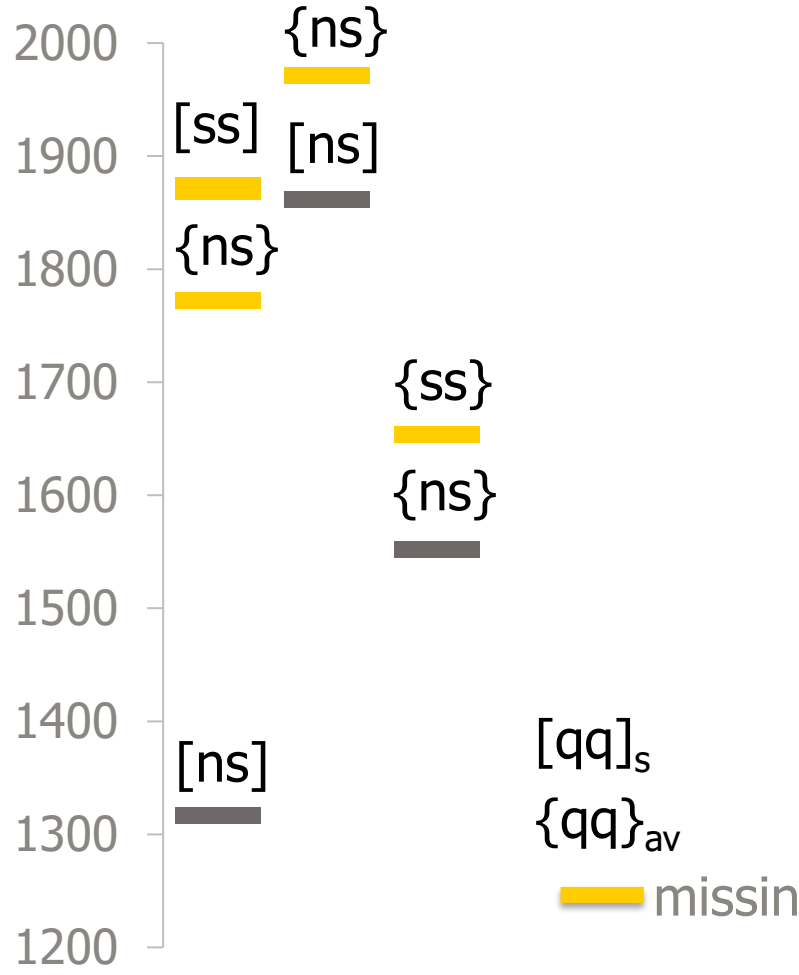


Chao, Isgur & Karl

Experiment



diquark model



Santopinto & Ferretti
PRC92(2015)025202

K^-p Spectrometer Experiment

Jenkins at al., PRL51('83)951

- Ξ^* production in 5 GeV/c $K^-p \rightarrow K^+X$

at Medium Energy Separated Beamline at AGS

- Ξ^* up to 2.5GeV are identified on the missing mass spectra.

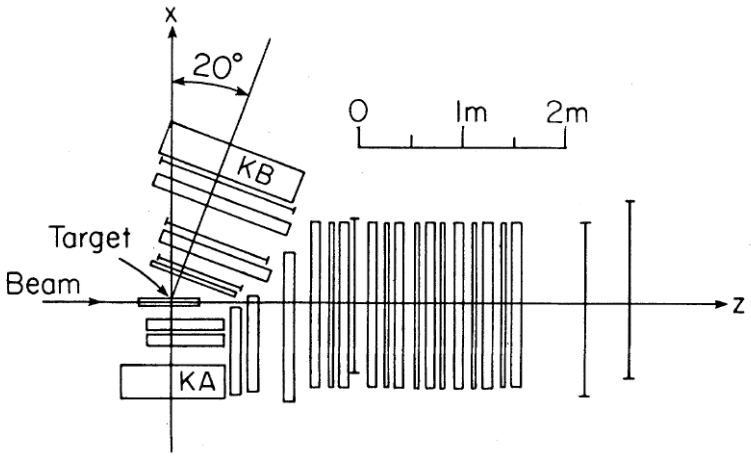
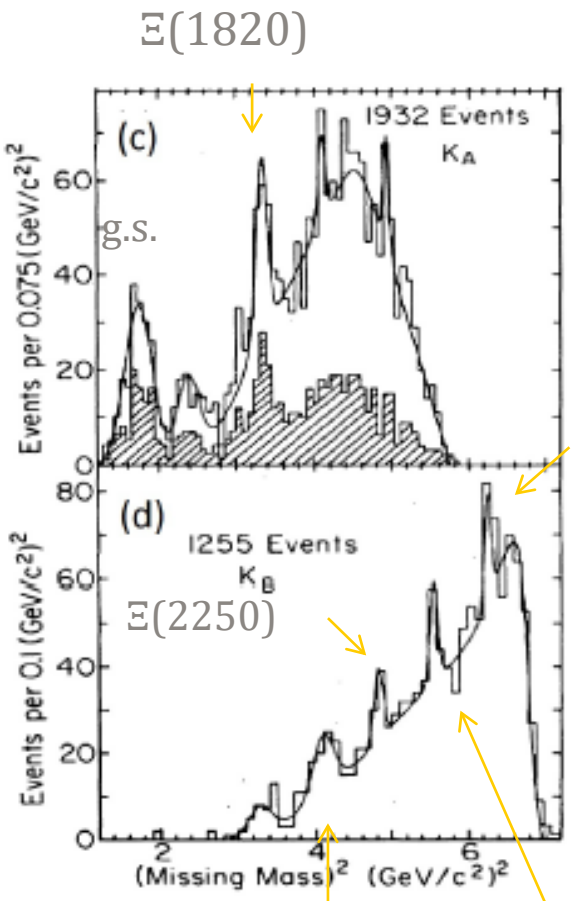


FIG. 1. MPS (top view). K_A and K_B are K^+ detectors, single lines are proportional multiwire chambers, and rectangles are spark chambers.

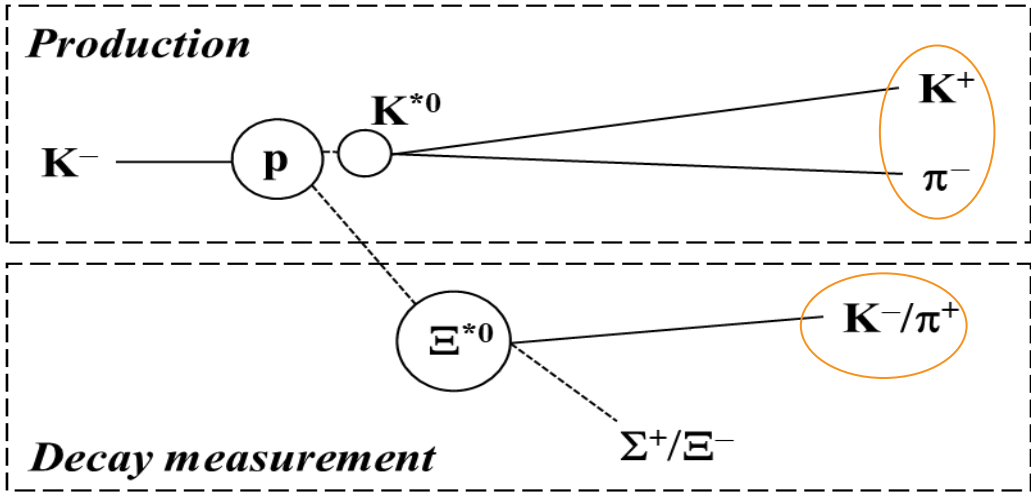
State	PGD	K_A and/or K_B σ (μb)	Mass (MeV)
$\Xi(1320)$	4	7.2 ± 0.6	1320 ± 6
$\Xi(1530)$	4	2.8 ± 0.6	1541 ± 12
$\Xi(1630)$	2	< 1.0	
$\Xi(1680)$	2		
$\Xi(1820)$	3	3.1 ± 0.5	1822 ± 6
$\Xi(1940)$	2	< 0.8	
$\Xi(2030)$	3	1.7 ± 0.4	2022 ± 7
$\Xi(2120)$	1	< 1.1	
$\Xi(2250)$	1	1.0 ± 0.3	2214 ± 5
$\Xi(2370)$	2	0.9 ± 0.3	2356 ± 10
$\Xi(2500)$	2	1.0 ± 0.5	2505 ± 10



ΔM~30MeV

Ξ production in Kp reaction

- Reaction: 8 GeV/c $K^- p \rightarrow K^{*0} \Xi^{*0}$
- **Missing mass technique**: K^+ / K^{*0} tagging
- **Decay measurement**: $\Sigma^+ K^-$ / $\Xi^- \pi^+$
  - Decay products measured with missing-mass technique



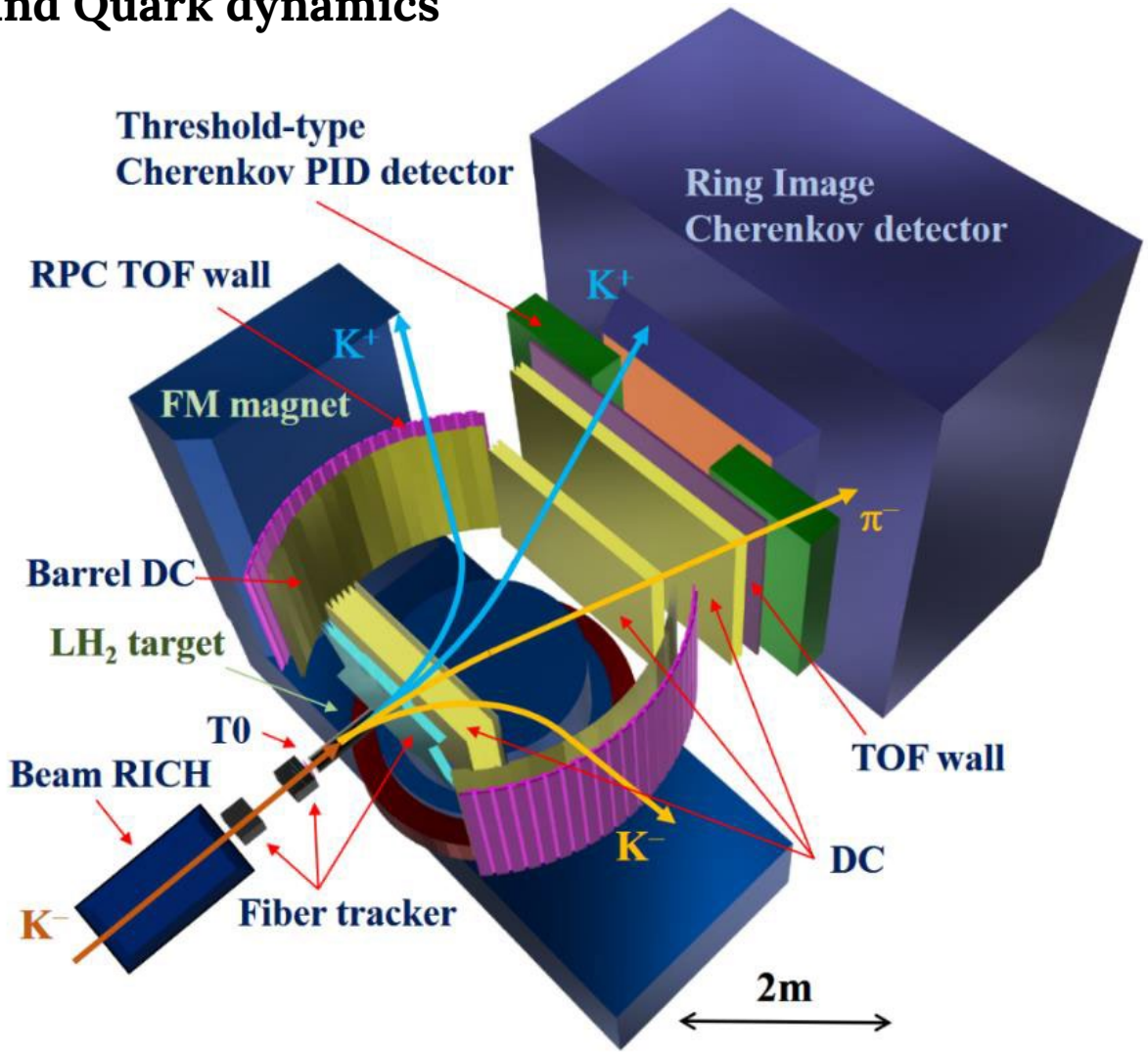
Physics cases at high-momentum beamline

- Primary proton beam
  - Dilepton measurement in pA reaction (E16) - ongoing
  - Medium modification with ϕ->KK decays (E88)
  - Dilepton measurement in HI collision (P87)
  - Intrinsic charm with J/ψ (P91)
- π20 - Secondary beam
  - Beamline commissioning (P93)
  - Cascade baryon spectroscopy (E97)
  - Charm baryon spectroscopy (E50)
  - Search for dibaryon with I=3 (E79)

MARQ Spectrometer

Multi-purpose Analyzer for Resonances and Quark dynamics

- Multi-purpose spectrometer
- High resolution, Large acceptance & High-rate capability
  - acceptance (50% for K* / 60% for D*)
  - high-resolution (dp/p=0.2%)
  - Cope with reaction rate of 5M /spill
  - upstream part is ready,
  - R&D for downstream part is ongoing
    - backward: DC almost ready, TOF in R&D
    - Main part of construction budget is secured.

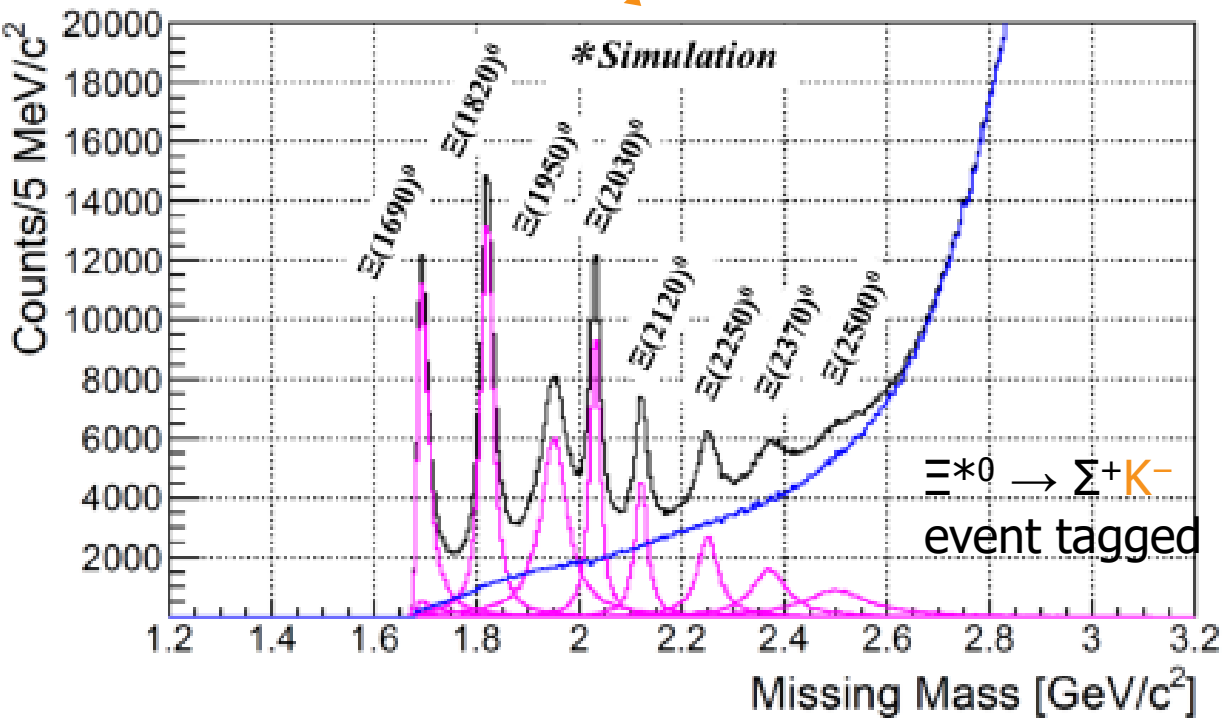


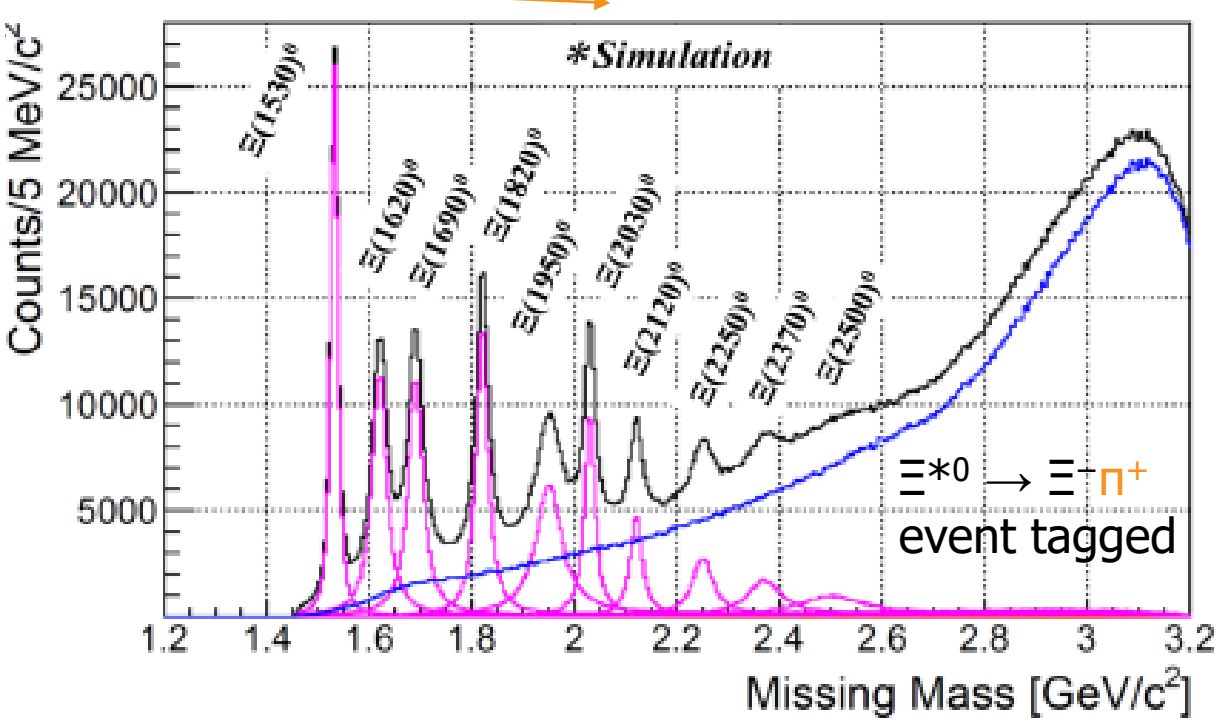
Expected missing mass spectra

combined with decay measurements

$K^- p \rightarrow K^{*0} X$

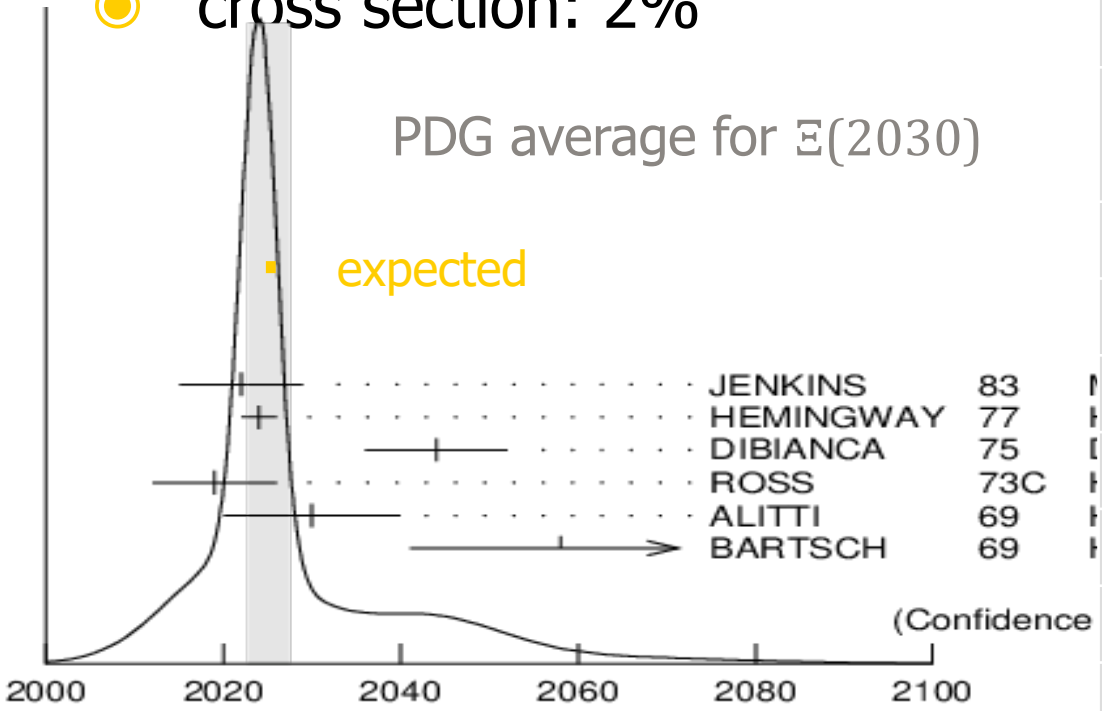
$\Xi^{*0} \rightarrow K^- \Sigma^+$ / $\pi^+ \Xi^-$ $\Delta M = 5.5$ MeV





Sensitivity

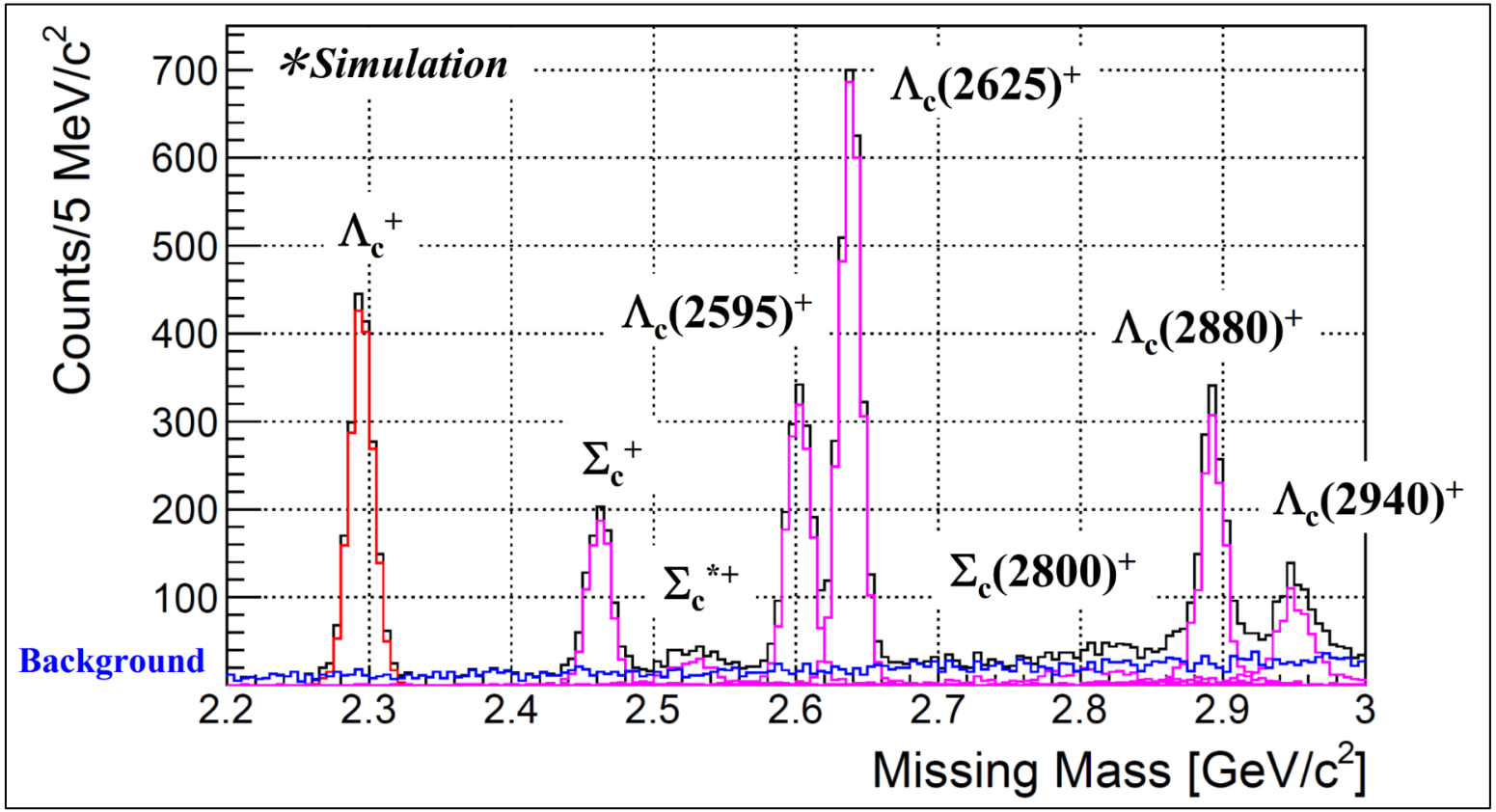
- mass: $\frac{\Delta M}{M} = 0.5\ \mathrm{MeV}$
- width: $\frac{\Delta \Gamma}{\Gamma} = 0.4\ \mathrm{MeV}$
- cross section: 2%



PDG mass & width | AGS

State	J^p	Mass [MeV/c²]	Γ [MeV]	σ [ub]
Ξ(G.S.)⁰	$1/2^+$	1314.9	-	7.2±0.6
Ξ(1530)⁰	$3/2^+$	1531.78±0.34	9.1±0.5	2.8±0.6
Ξ(1620)⁰	?	≈1620	21±7	<1
			40±15	
Ξ(1690)⁰	?	1690±4	20±15	<1
Ξ(1820)⁰	$3/2^-$	1823±5	24±5	3.1±0.5
Ξ(1950)⁰	?	1950±15	25~140	<0.8
Ξ(2030)⁰	1/2 (>5/2)	2025.1±2.4		1.7±0.4
Ξ(2120)⁰	?	≈2120	25±12	<1.1
Ξ(2250)⁰	?	≈2250	46±27	1.0±0.3
			130±80	
Ξ(2370)⁰	?	≈2370	75±69	0.9±0.3
			80±25	
Ξ(2500)⁰	?	≈2500	150+80−40	1.0±0.5
			59±27	

Expected spectrum in π-p$\rightarrow$D*-Y_c*+ reaction

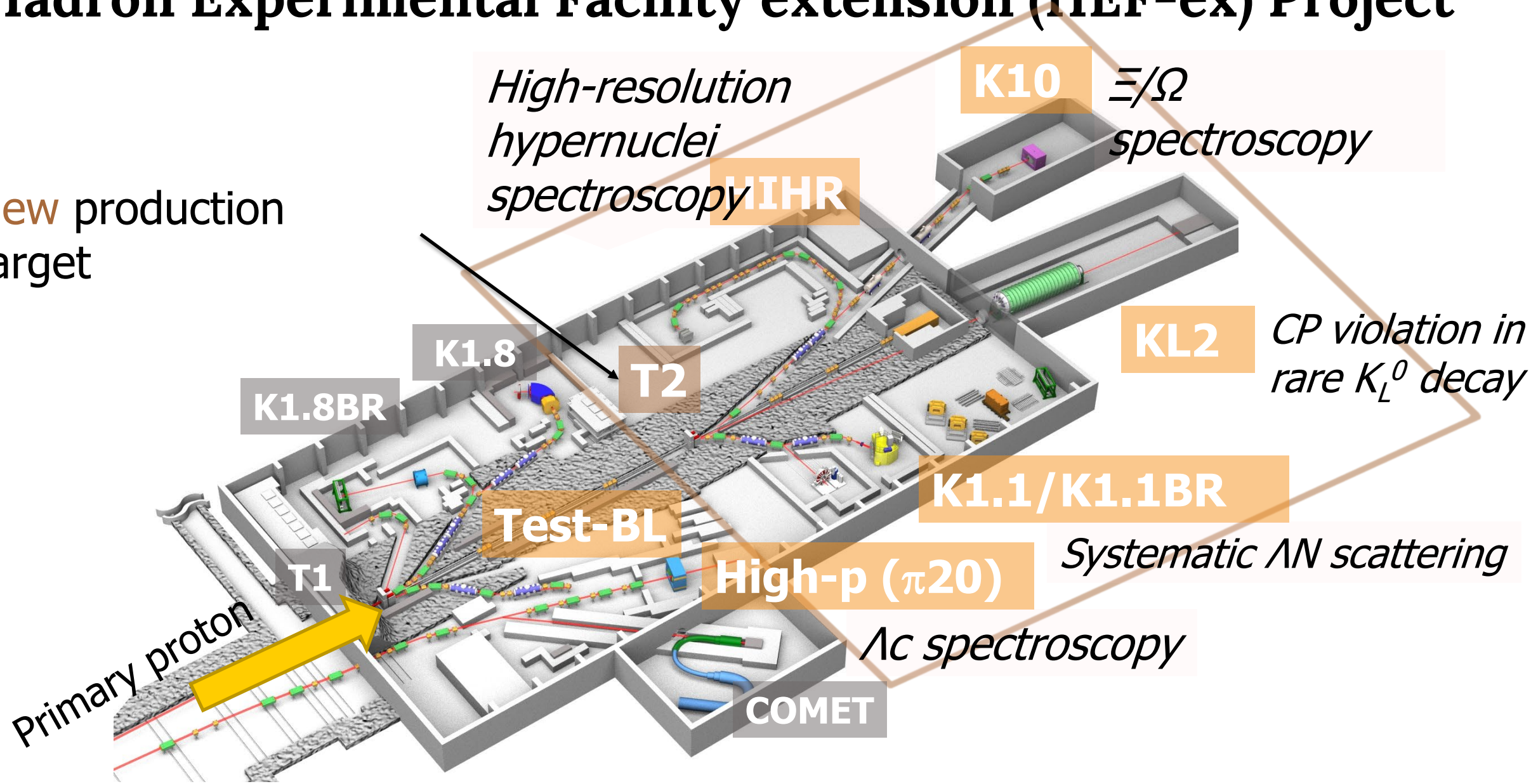


10M π beam + LH2

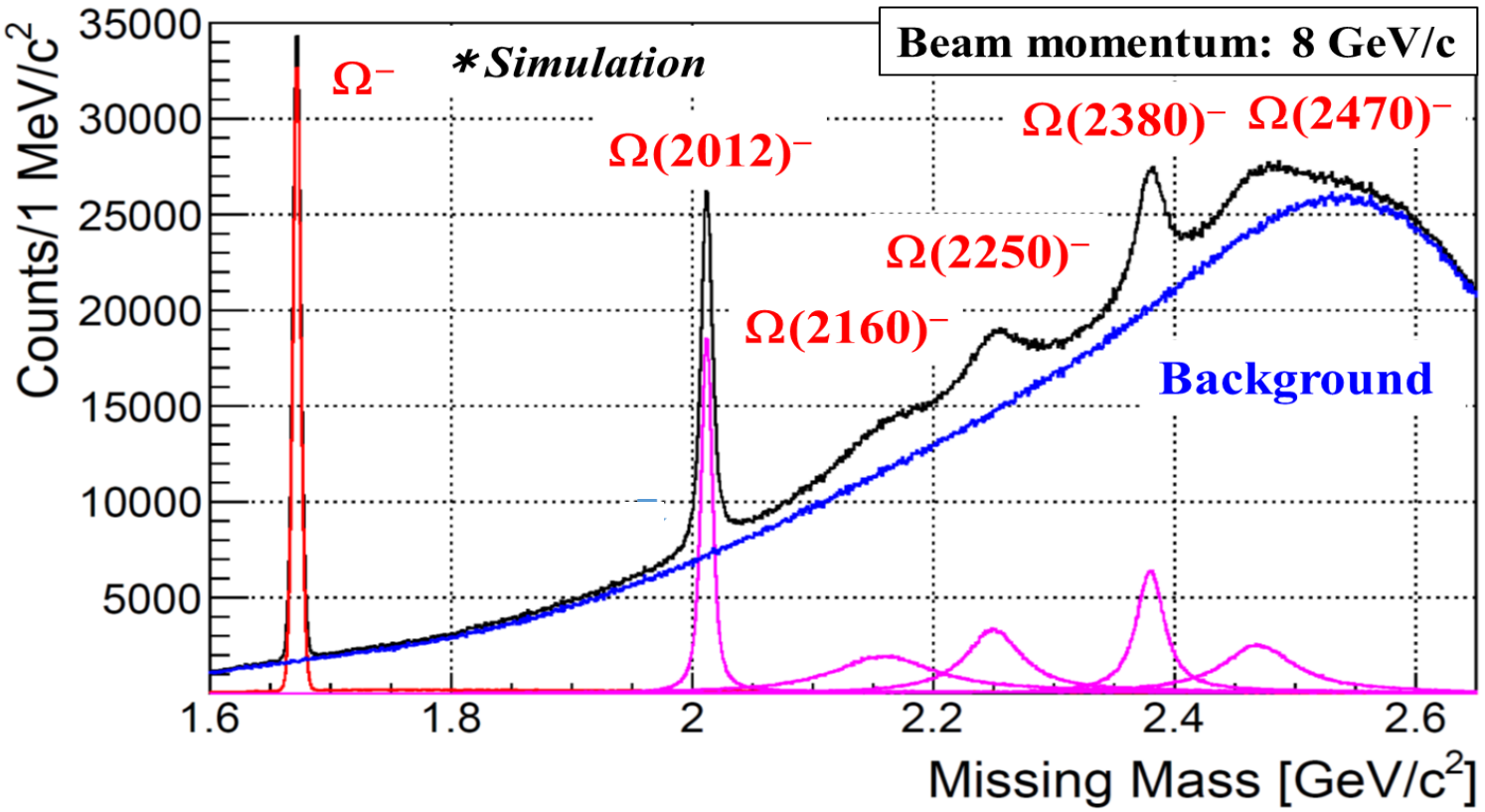
- Y_c^{*+} yields: 2k events assuming $\sigma_{G.S.}$ = 1 nb in 100 days
- ΔM=8 MeV

Hadron Experimental Facility extension (HEF-ex) Project

New production target



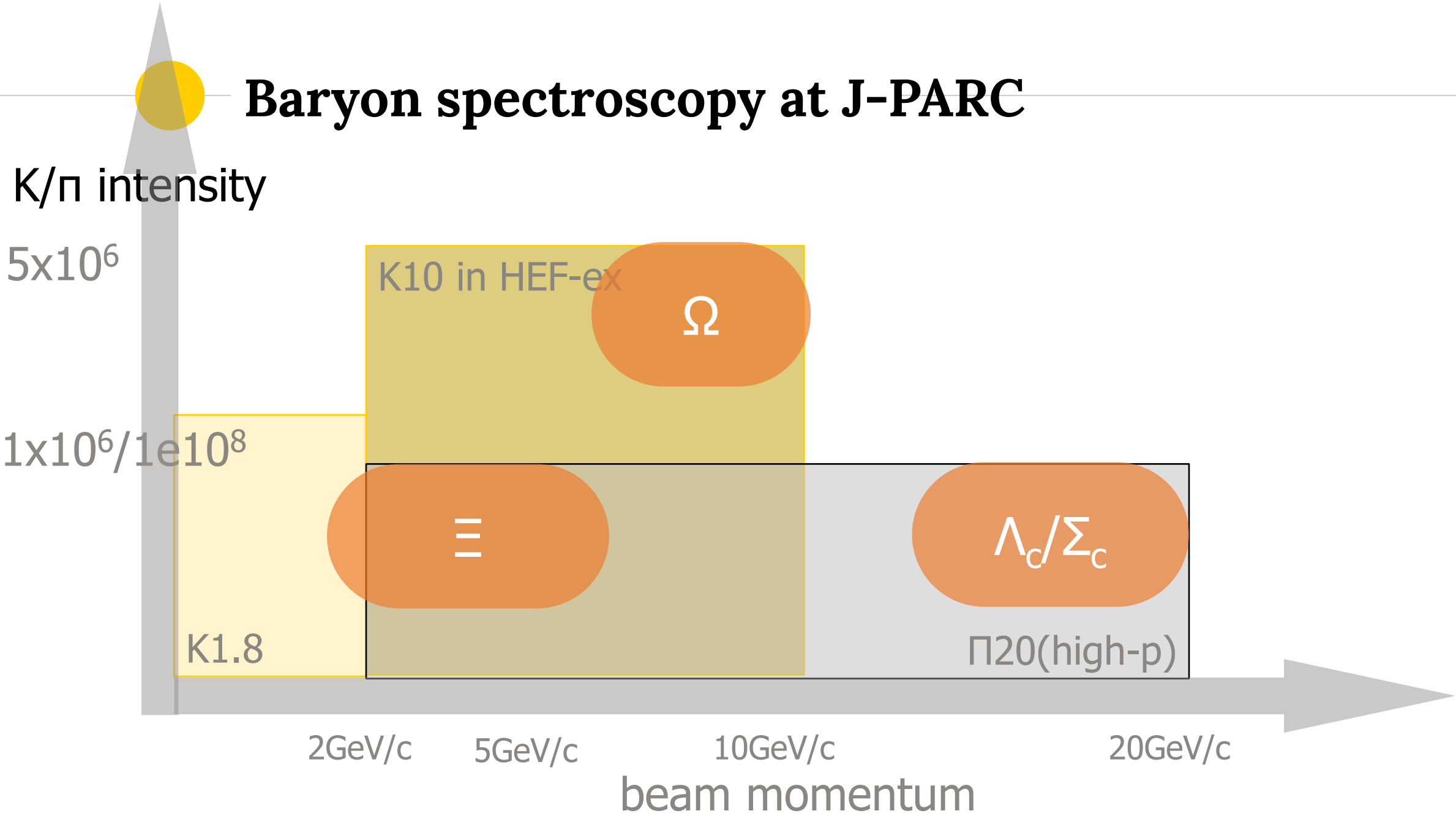
Expected mass spectrum: $K^- p \rightarrow K^{*0} K^+ \Omega^{*-}$



＊Background events Generated by K^- p reaction @ 8 GeV/c

- Ω^{*-} events: 3.3×10^5 events (100days, 63 nb: assuming for all resonances)
  - Acceptance : 30~50%, Mass resolution: ΔM ~5 MeV < Width (several 10 MeV)
- Background reduction by decay event: $\Omega^{*-} \rightarrow \Xi^{*0} K^-$ (Br = 0.3) ⇒ S/N×10

Baryon spectroscopy at J-PARC

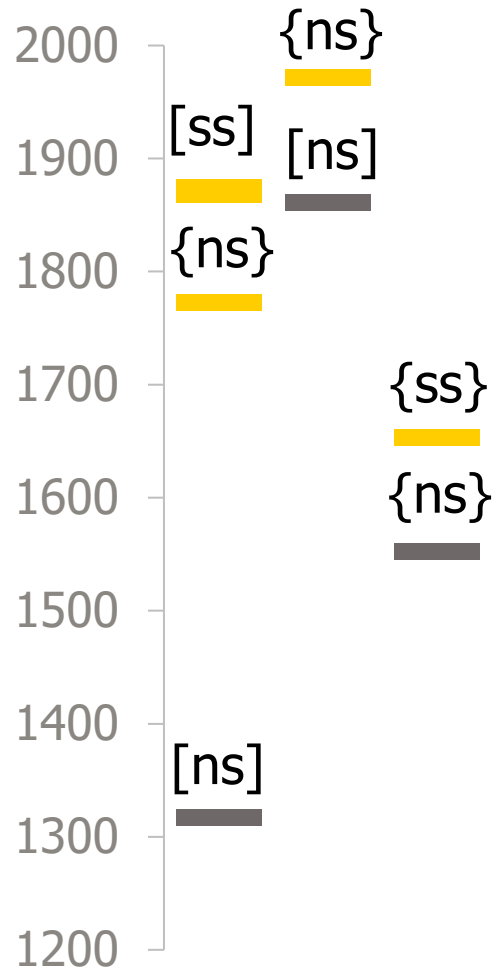


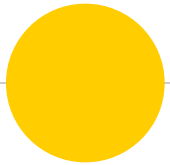
Wishlist

- LQCD calculation for Ξ^*, Λ_c^*, Ω^*
- How
  - the level scheme
  - decay pattern
  - production rate

changes depending on the internal structure

  - QM, q-diquark

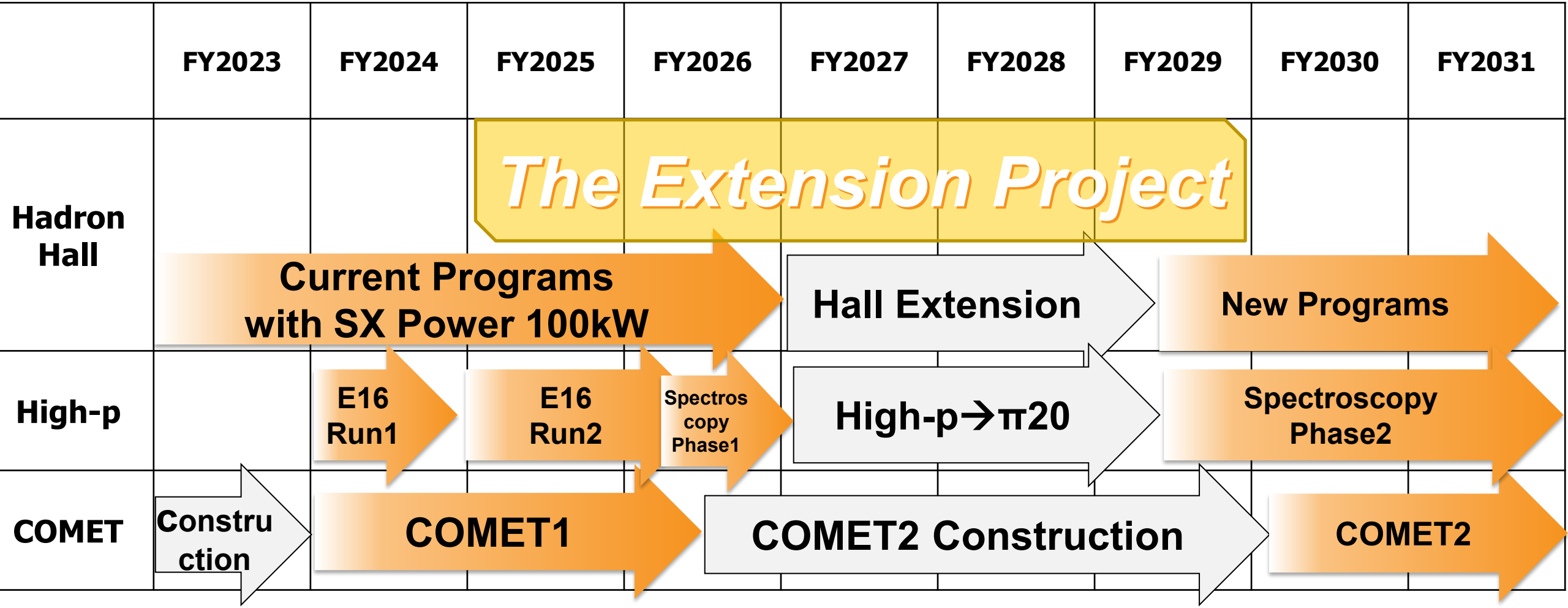




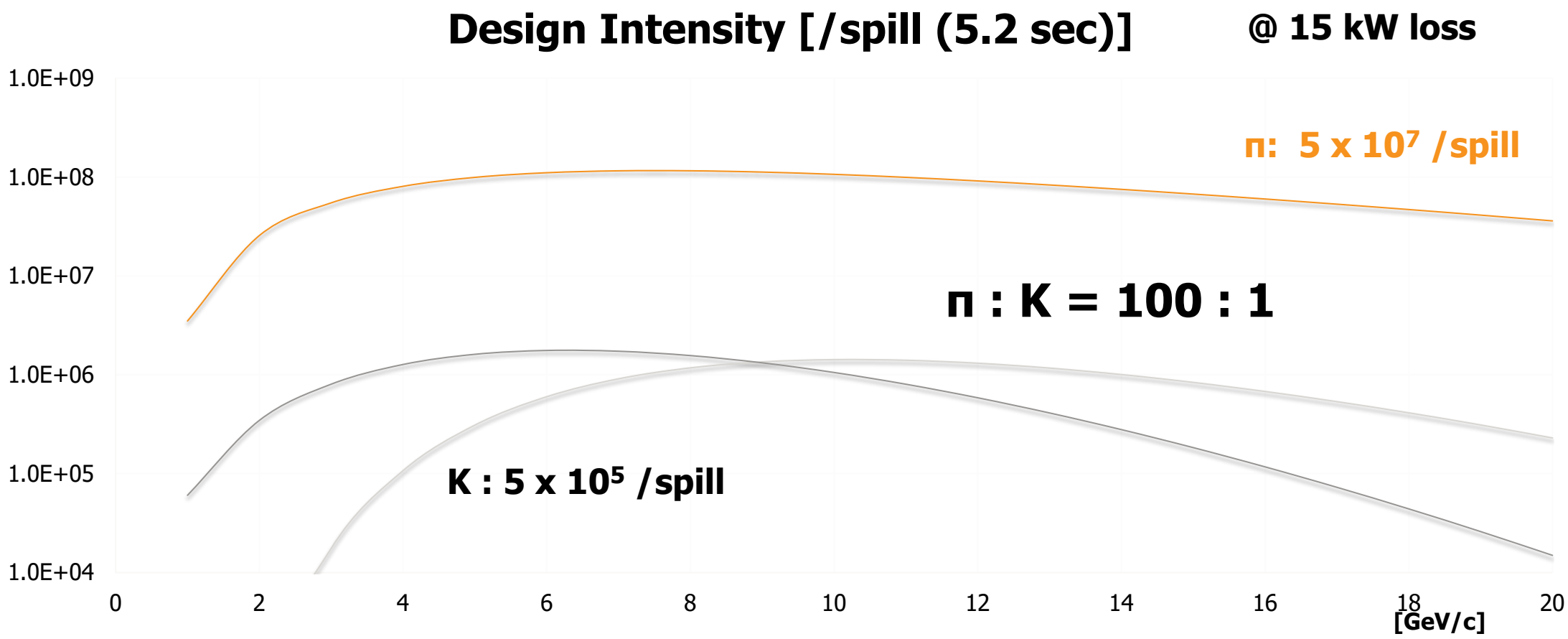
backups

Schedule

Listed as 1st priority in KEK Project Implementation Plan 2022



Beam Intensity at high-momentum secondary beamline



Beam Particle Identification

- π/K separation for beam particle is key
  - I_π/I_K ~ 100
- 5 GeV/c K - 20 GeV/c π
- RICH type detector
- Expected sensitivity
  - #photon ~ 10
    - cf. #photon(dark current) ~2
  - Δθ = 5mrad/1 p.e.