## A cross-community-driven hadron physics program at GSI/FAIR

Towards a white paper!

Frank Nerling & Johan Messchendorp, Super-FRS EC Meeting, October 30, 2024



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- Heavy-ion physics:
  - Exploring dense QCD matter
  - Probe strongly-interacting many-body systems
  - Hadrons as probes of the medium
  - Properties of hadrons in a dense environment



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### • Nuclear physics:

- Map out the nuclear spectrum in isospin and strangeness
- Properties of nuclei at the edge of stability, e.g. neutron-rich
- Probe baryon/meson degrees-of-freedom in many-body systems

[MeV] 200 Quarks and Gluons Critical point? Tempera Hadrons Color Super-Neutron stars conductor Nucle Net Baryon Density



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### Hadron physics: ightarrow

- Map out the hadron spectrum
- Search for "exotic" forms of hadrons
- "Microscopic" study of hadron-hadron interactions



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- Hadron physics: lacksquare
  - Map out the hadron spectrum
  - Search for "exotic" forms of hadrons *Enable spectroscopy of (new)*
  - "Microscopic" study of hadron-hadron meracuons  $\bullet$

**Hadron interactions:** Reference for understanding *medium effects* 

> **Hadron interactions:** in flavour SU(3)

Provide baryon-baryon data

eV 200 Quarks and Gluons Critical point? Hadrons Color Super-Neutron stars conductor? Nucle Net Baryon Density

**Hadron interactions:** hadronic matter







## Hadron Physics Facilities at FAIR





## Hadron Physics Facilities at FAIR

antiProtons ANnihilations at DArmstadt (PANDA)

~203x



High Acceptance Di-Electron Spectrometer (HADES) (FAIR Phase Zero)

### Today!

## Hadron Physics Facilities at FAIR

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~203x

 $\bar{p}, p...(\text{HESR})$ 



High Acceptance Di-Electron Spectrometer (HADES) (FAIR Phase Zero)

### Today!

 $\bar{p}, p...(\text{HESR})$ 

### *p*,*d*...(SIS100)

### Compressed Baryonic Matter (CB



# Hadron Physics Facilities at FAIR

antiProtons ANnihilations at **DArmstadt (PANDA)** 



High Acceptance Di-Electron Spectrometer (HADES) (FAIR Phase Zero)

### Another goldmine in hadron physics at GSI!



~203x



Today!

### *p*,*d*...(SIS100)

### onic Matter (CBM)

# Facilities at FAIR

antiProtons ANnihilations at DArmstadt (PANDA)



## Purpose of our white paper ...how it all started

- Initiative from FAIR-motivated group from within various collaborations, such as CBM, HADES, PANDA
- Promote the realisation of First Science+ (FS+) at FAIR
- Identify a QCD-inspired physics program with proton beams
- Strengthen collaborations among hadron-, nuclear- and heavy-ion communities
- Reach out for new collaborators from both experiment and theory!



### From SIS18 to SIS100 ...what could that add in hadron physics with protons?

	CBM <sup>VIII</sup> Experiment requirements									
			CBMVIII	Experiment	requiren	nents				
					lor	n type <sup>ix</sup>				
eam Parameters	р	<sup>40</sup> Ar	<sup>58</sup> Ni	<sup>107</sup> Ag	<sup>197</sup> Au	р	<sup>14</sup> N	<sup>40</sup> Ar	<sup>58</sup> Ni	
		Operation in MS								
Time structure	slow extraction									
Spill length [s]	5			10		5			10	
per of ions per cycle	1010	4x:	10 <sup>8</sup>	2x10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>12</sup>	1011	4x1	. <b>0</b> <sup>10</sup>	
gy range [GeV/u] <sup>x</sup>	5-11, 14- 29	3-11, 12.4- 12.6	2-11, 12-14	2-1:	1	5-11, 14- 29	3-11, 12-14	3-11, 12- 12.6	2-11 12- 13.6	
f. energy <mark>[</mark> GeV/u]	29			11		29			11	
nsverse emittance 4σ) [mm mrad]	1 x 0.6									
entum spread (2σ)					5	x 10 <sup>-4</sup>				
spot radius on tar- get [mm]						1				







### From SIS18 to SIS10 ...what could that add in hadron physics with

- **Energy upgrade:** 
  - From max 4.7 GeV (SIS18) to 29 GeV (SIS100) proton  $\bullet$ energy:  $\sqrt{s_{NN}} \approx 3.5 \,\text{GeV} \rightarrow 7.6 \,\text{GeV}$
  - Opening new realm: double+triple strangeness and even charm baryons and mesons!
  - Significant increase in production yield of hyperons ightarrow

ן	protons?

	reaction	$\sqrt{s}$ (GeV)	T <sub>lab</sub> (
	$pp \to K^+ \Lambda p$	2.548	1.6
SIS18	$pp \rightarrow K^+ K^- pp$	2.864	2.5
	$pp \rightarrow K^+ K^+ \Xi^- p$	3.247	3.7
	$pp \to K^+ K^+ K^+ \Omega^- n$	4.092	7.0
SIS100	$pp \rightarrow \Lambda \bar{\Lambda} pp$	4.108	7.1
	$pp \rightarrow \Xi^- \overline{\Xi}^+ pp$	4.520	9.0
$\checkmark$	$pp \rightarrow \Omega^- \overline{\Omega}^+ pp$	5.222	12.7
	$pp \rightarrow J/\Psi pp$	4.973	12.2

Picture credit: N. Herrmann, FAIR seminar, Krakow

GeV)	

### From SIS18 to SIS10 ...what could that add in hadron physics with

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### Intensity upgrade:

- From max #protons/cycle of 10<sup>12</sup> (SIS18) to 2x
- Even during "commissioning" (10<sup>10</sup> protons/cy LH<sub>2</sub> target: ~10 pb<sup>-1</sup> day<sup>-1</sup>

				read	ction		$\sqrt{s}$ (GeV)	T <sub>lab</sub> (G
				pp	$\rightarrow K^+ \Lambda p$		2.548	1.6
n protons?		S	SIS18	pp ·	$\rightarrow K^+K^-pp$		2.864	2.5
				pp ·	$\rightarrow K^+ K^+ \Xi^- \mu$	)	3.247	3.7
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proton				pp	$\rightarrow \Xi^- \overline{\Xi}^+ pp$		4.520	9.0
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s and even	Expected r @ 30 GeV/	econ / <i>c</i> for	structed 1 MHz	coui	nts / Day	. H (rał E		
erons	$\Xi^{-}  ightarrow \Lambda \pi^{-}$	_	~ 40 µ	Jp	<b>1.2·10</b> <sup>9</sup>	astSi		
	$\Omega^{-} \to \Lambda K$		~0.6	μb	<b>1.4·10</b> <sup>7</sup>	ylor Fa		
$(10^{13})$	$p \Lambda_C^0 D^0$		~0.1	μb	<b>2.7·10</b> <sup>₄</sup>	iny Ta		
	pp J/ψ		~ 1 r	ıb	<b>1.6·10</b> <sup>3</sup>	Jer		
cie) and 5 cm			() <sup>35</sup> <sup></sup>		$bb \rightarrow k$	$h^{-}(\rightarrow 5)$	pK <sup>-</sup> $\pi^+$ ) $\overline{D}_0$ ( $\rightarrow$ K % 3.8	, , , , , , , , , , , , , ,

Fast Simulations, J.M.







45 M<sub>Λ₀Đ₀</sub> (GeV)

40

### From SIS18 to SIS100 ....what could that add in hadron physics with protons?

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### Intensity upgrade:

- From max #protons/cycle of  $10^{12}$  (SIS18) to  $2\times10^{13}$  (SIS100) lacksquare
- Even during "commissioning" (1010 protons/cycle) and 5 cm LH<sub>2</sub> target: ~10 pb<sup>-1</sup> day<sup>-1</sup>

### **Detector enrichments:**

Towards high-rate capabilities and free-streaming DAQ's ightarrow

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Picture credit: N. Herrmann, FAIR seminar, Krakow



T. Galatyuk, NPA 982 (2019), update 2023 https://github.com/tgalatyuk/interaction\_rate\_facilities



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- **Detector enrichments:** 
  - Towards high-rate capabilities and free-streaming DAQ's ightarrow
- Theory enrichment:
  - Terra incognita: intellectual challenges in this energy regime!

	reaction	$\sqrt{s}$ (GeV)	T <sub>lab</sub> (C
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	Picture credit: N. Hei	rmann	

FAIR seminar, Krakow



T. Galatyuk, NPA 982 (2019), update 2023 https://github.com/tgalatyuk/interaction\_rate\_facilities





### 6-9 February 2024



### Physics opportunities with proton beams at SIS100



 $\bullet$ 

### Physics opportunities with proton beams at SIS100

### 6-9 February 2024 Wuppertal University

Europe/Berlin timezone

- Bring together experts from both theory and experiment
- Form a community connecting the common interest among different QCDdriven scientists
- Identify promising topics as a basis for a long-term proton-driven physics program
- Evaluate its complementarity with programs at other facilities
  - Prepare towards a white-paper





# Physics opportunities with proton beams at SIS100 $p, d, \pi, \bar{p}$ GSI/FAIR

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- Identify promising topics as a basis for a long-term proton-driven physics program
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- Prepare towards a white-paper

- Promising comprehensive physics program Strong support both theoretically and experimentally Provide a roadmap as basis for long-term endeavour Include the perspectives of *pion beams* at GSI/FAIR Involve the nuclear physics community



## A comprehensive **CCD** program at GSI/FAIR!

### Hadron structure

Mass-radius of the proton

E.m.+weak transition Form Factors of hyperons

Dilepton production sources

Production mechanisms axial and vector mesons

> Few-body interactions

Reference measurements for p+A,A+A

Polarisation sources

Near-threshold (anti) strange and charm production

Nuclear modification factors

**Heavy-ion** dynamics

### **Composition of hadrons**

### Hadron spectroscopy

Emergent Hadron Mass

Intrinsic charm of the proton

### protons@SIS100

Strange and charm High intensity Versatile detectors High-rate capabilities SU(3) baryon-like spectroscopy

 $N \rightarrow N/\Delta$  GPDs via 2->3 hadronic reactions

> Line-shape measurements of hyperon resonances

Femtoscopy

Hypernuclei via spallation Charm-nucleon interactions

> **Final-state** interactions using PWA

Search for exotic form of hadrons

> Hadron production

Production mechanisms of hadrons

Microscopic study of hadron-hadron interactions

![](_page_22_Picture_31.jpeg)

## A comprehensive **CCD** program at GSI/FAIR!

Hadron

structure

![](_page_23_Figure_1.jpeg)

Reference measurements for p+A,A+A

## dynamics

### **Composition of hadrons**

![](_page_23_Figure_5.jpeg)

hadron-hadron interactions

![](_page_23_Picture_7.jpeg)

## A roadmap towards a **QCD** program at FAIR!

![](_page_24_Figure_1.jpeg)

### White paper:

- Paper is in the making!
- ~75 contributors so far!
- Including leading theorists and experimentalist from strong-QCD communities
- Publication ~spring 2025

![](_page_25_Picture_5.jpeg)

### Hadron Physics at GSI and FAIR: Prospects for the Next Decade

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Editors: Frank Nerling, Johan Messchendorp

 $\mathbf{25}$ 27. . .  $\mathbf{27}$ 29atter 30 30 . . . 30 30 30 30  $\mathbf{31}$ 

### Coming up soon!

- White-paper workshop
- <u>November 11-14, 2024</u>, **GSI**
- Open plenary sessions with highlight talks
- Closed (parallel) working sessions

TUB

![](_page_26_Picture_6.jpeg)

https://indico.gsi.de/event/20301/overview

![](_page_26_Picture_8.jpeg)

![](_page_26_Picture_9.jpeg)

### **Pion beams at GSI/FAIR** *The* focus of HADES for next years!

![](_page_27_Figure_1.jpeg)

![](_page_27_Picture_2.jpeg)

![](_page_28_Figure_1.jpeg)

Joachim Stroth, POFV retreat

![](_page_28_Picture_3.jpeg)

![](_page_29_Figure_1.jpeg)

![](_page_29_Picture_3.jpeg)

![](_page_30_Figure_1.jpeg)

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![](_page_30_Picture_3.jpeg)

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![](_page_31_Picture_3.jpeg)

![](_page_32_Figure_1.jpeg)

![](_page_33_Figure_1.jpeg)

# What makes $\pi + p/A$ interactions so appealing? ....precision probe in subatomic physics!

![](_page_34_Figure_1.jpeg)

## What makes $\pi + p/A$ interactions so appealing? ....precision probe in subatomic physics!

- The pion-nucleon system elementary in hadron, nuclear, and heavy-ion physics Proven valuable probe of strong QCD, both
- theoretically and experimentally
- 'Simple' initial state with spin-zero Goldstone boson; 'Simple' final states, 2/3-bodies

![](_page_35_Figure_4.jpeg)

![](_page_35_Picture_5.jpeg)

## What makes $\pi + p/A$ interactions so appealing? ....precision probe in subatomic physics!

- The pion-nucleon system elementary in hadron, nuclear, and heavy-ion physics • Proven valuable probe of strong QCD, both
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- 'Simple' initial state with spin-zero Goldstone boson; 'Simple' final states, 2/3-bodies
- Theory: Lattice-QCD,  $(\chi)$ EFT in SU(3)<sub>F</sub>, Dyson-Schwinger BS: close to first principles of QCD!
- Experiment: sizeable cross sections w.r.t. electromagnetic beams, simple final states -> high acceptance, enable PWA, etc. ...

![](_page_36_Figure_6.jpeg)

![](_page_36_Picture_7.jpeg)

- Unique combination of pion beam and dilepton spectrometer + much more!
- Large phase space coverage + wide particle reconstruction capabilities
- $\sqrt{s}$  coverage and scan up to ~2 GeV, complementary photo-production exp<sup>s</sup>
- Respectable intensities beyond 10<sup>6</sup>/s
- Sizeable xsecs for strangeness production w.r.t. light hadrons, strangeness factory!
- Access to many observables: xsections, BF's, SDMEs, self-polarisation weak decay
- Precision studies combining hadron dynamics and electromagnetic structure

![](_page_37_Figure_9.jpeg)

![](_page_37_Picture_11.jpeg)

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![](_page_38_Figure_9.jpeg)

![](_page_38_Picture_11.jpeg)

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![](_page_39_Figure_9.jpeg)

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![](_page_40_Figure_9.jpeg)

### Pion beam program ... wide physics oppor Ū **Hadron Physics**

- Baryon |S|=0,1 spectroscopy in fo f.e. N\* up to 3<sup>rd</sup> resonance regions
- Polarisation studies in hyperon pr  $\pi^- p \rightarrow \overrightarrow{\Lambda} K^0 / \overrightarrow{\Sigma}^0 K^0 / \dots$  (self-ana **•** 10<sup>-6</sup>
- Vector-meson production:  $\pi^- p$  -0.2 extraction ( $\omega \rightarrow e^+ e^- / \pi^+ \pi^- \pi^0$  topologies)
- Strangeness production, e.g.  $\Lambda(1405, 1520)$
- Electromagnetic structure of |S|=0,1 baryons,  $N^* \rightarrow Ne^+e^-/\Lambda(1405, 1520), \Sigma(1385) \rightarrow Ne^+e^-/\Lambda(1405, 1520)$
- Light meson dynamics, f.e. in  $\pi\pi$ ,  $K\overline{K}$ ,  $K\pi$ ,  $\eta\pi$ , ...
- Rare (BSM) decays of mesons, f.e. X(17) with  $\eta$  decays lacksquare

![](_page_41_Figure_9.jpeg)

## Pion beam program ... wide physics opportunities **Nuclear and Heavy-ion Physics**

- Vector meson properties in dense matter including study of  $\rho - a_1$  mixing,  $\phi$  meson!
- Line-shape, transparency ratios, A-dependence,... (towards low momenta with high sensitivity)
- Hidden & open strangeness production in  $\pi + p/A$
- Precision data for transport models
- Hypernuclei studies, factory!
- $\overrightarrow{YN} \rightarrow \overrightarrow{YN}$  interactions
- Particle production xsection data for neutrino energy reconstruction in T2K, DUNE experiments

![](_page_42_Figure_8.jpeg)

![](_page_42_Figure_10.jpeg)

A "cold matter" *highlight* from 2014 pion beam at  $\sqrt{s} = 2 \,\text{GeV}$ 

![](_page_42_Figure_12.jpeg)

Latest work of Simon Spies

![](_page_42_Picture_14.jpeg)

A cross-community-driven hadron physics program at GSI/FAIR ...with pion and proton beams from SIS18+SIS100

- Ambition: long-term physics program inspired by strong-QCD and connecting hadron, nuclear, and heavy-ion communities
- Exploiting pion & proton beams (SIS18/100) together with available facilities: HADES, CBM, WASA(?) and interested researchers from all communities!
- Invitation to nuclear physics community to take part in the white-paper discussions and contribute!
- GPAC proposal: strengthen the pion-beam facility and corresponding physics program! Strategy involving WASA?

![](_page_43_Picture_6.jpeg)

![](_page_43_Picture_11.jpeg)

![](_page_44_Picture_0.jpeg)

### "Facilities exploiting exclusive hyperon studies"

Timolino			
	2025		2028
Probe:	FAIR	Phase 0	
$\pi + n/A$		Stage 1	HADES
			JF
n + n/A		HADES	@SIS18
			CERN ,
$\bar{p} + p/A$			
K + p/A			JPAR
$\gamma^{(*)} + p/A$	N	1AMI/ELSA/GLue	X/CLAS12
$e^+ + e^-$		BESIII/B	ellell

![](_page_45_Figure_2.jpeg)

## J-PARC ... competition, complementarity, collaboration? Key selling features of pion-beam facility at GSI

- Combination of a pion beam with a versatile setup with high acceptance and capabilities
- Broad applicability with multifaceted and efficient data collection enabling a program connecting physics topics from different fields (hadron, nuclear, heavy-ion) with(in) one setup/ collaboration/beam-time period
- Probing electromagnetic and hadronic aspects in pion-produced matter is unique

![](_page_46_Picture_7.jpeg)

## The process ...activities in the past years

- Many preparatory activities ongoing since 2023
- Discussions among physicists from various FAIR collaborations
- Kick-off satellite event at MESON2023 in June 2023
- Feasibility studies using Monte Carlo simulations
- Presentations at FAIR advisory boards ECE/ECSG/JSC at workshops, conferences, etc.
- Workshop "physics opportunities with proton beams at SIS100" in Wuppertal, February 2024
- Setup structure white paper, identify convenors, contributors, setup working groups, overleaf, mailinglists, etc.
- White paper workshop, 11-14th November, 2024 at GSI

![](_page_47_Picture_10.jpeg)

![](_page_47_Picture_11.jpeg)

![](_page_48_Picture_1.jpeg)

October 2023

![](_page_48_Picture_3.jpeg)

![](_page_49_Picture_1.jpeg)

- HADES = high-acceptance dilepton spectrometer and much more!
- Outstanding in dilepton spectrometry
- Excellent tracking & PID capabilities
- Modular at forward angles
- Additional photon detection
- Good angular coverage
- Designed for various SIS18 beams
- Including pion beams!

![](_page_49_Figure_11.jpeg)

![](_page_49_Picture_12.jpeg)

![](_page_49_Picture_13.jpeg)

![](_page_50_Picture_1.jpeg)

- HADES = high-acceptance dilepton spectrometer and much more!
- Outstanding in dilepton spectrometry
- Excellent tracking & PID capabilities
- Modular at forward angles
- Additional photon detection
- Good angular coverage
- Designed for various SIS18 beams
- Including pion beams!

October 2023

![](_page_50_Picture_11.jpeg)

![](_page_51_Picture_1.jpeg)

- HADES = high-acceptance dilepton spectrometer and much more!
- Outstanding in dilepton spectrometry
- Excellent tracking & PID capabilities
- Modular at forward angles
- Additional photon detection
- Good angular coverage
- Designed for various SIS18 beams
- Including pion beams!

"exclusive" reactions!! [Case study: Feb. 2022 run with 4.5 GeV protons]

![](_page_51_Picture_13.jpeg)

![](_page_51_Picture_14.jpeg)

![](_page_52_Figure_1.jpeg)

Extract Spin Density Matrix Elements

### 

### KEENGEENWEIER UNIFORWAARI $\pi N \rightarrow 2\pi N$ SCATTERING

A. The issue of unitarity rone de Gay mp 6 and key issues i . This constraint is maintained it nent of the scattering problem. The  $\alpha$  including  $\alpha \rightarrow \alpha$ ,  $\alpha \rightarrow \alpha$  including  $\alpha$  include  $\alpha$  include  $\alpha$ 

![](_page_53_Figure_8.jpeg)

HADES data

![](_page_53_Picture_9.jpeg)

![](_page_53_Figure_10.jpeg)

![](_page_53_Figure_11.jpeg)

- contribution (pion emFF)

![](_page_53_Figure_14.jpeg)

![](_page_53_Picture_15.jpeg)

![](_page_53_Picture_17.jpeg)

### 

### KEEncleenweith Uniforwardi $\pi N \rightarrow 2\pi N$ SCATTERING

rone de Gay mponant key issues i . This constraint is maintained it nent of the scattering problem. The  $\frac{1}{2}$ 

![](_page_54_Figure_9.jpeg)

![](_page_54_Picture_11.jpeg)

![](_page_55_Figure_0.jpeg)

### $\pi N \rightarrow 2\pi N$ SCATTERING

 $\frac{1}{2}$ 

![](_page_55_Figure_3.jpeg)

![](_page_55_Picture_4.jpeg)

![](_page_56_Picture_13.jpeg)

![](_page_56_Picture_14.jpeg)

- From heavy-ion perspectives:
  - Necessary reference to heavy-ion reactions

Detailed information on baryon resonances and meson-baryon couplings

![](_page_57_Picture_6.jpeg)

- From heavy-ion perspectives:
  - Necessary reference to heavy-ion reactions
- From nuclear perspectives:
  - (Ab-initio) baryon-baryon data in flavour SU(3)

Detailed information on baryon resonances and meson-baryon couplings

![](_page_58_Picture_9.jpeg)

- From heavy-ion perspectives:
  - Necessary reference to heavy-ion reactions
  - Detailed information on baryon resonances and meson-baryon couplings
- From nuclear perspectives:
  - (Ab-initio) baryon-baryon data in flavour SU(3)
- From hadron perspectives:
  - Controllable tool for hadron spectroscopy & structure studies in u,d,s,c sectors
  - Intermediate physics program with pions & protons towards antiprotons

![](_page_59_Picture_9.jpeg)

The ba	<b>pov</b> t mak	<b>Ver</b> (es us	of p s com	bion petit	beal ive & co	ms at GSI omplementary	$2^{0} \qquad 0.1^{10} \qquad \pi^{N->\pi N} \qquad \pi^{n} \qquad \pi^{n$	$\pi p \rightarrow M^{0} \Lambda$ $\pi p \rightarrow K^{0} \Lambda$ $\pi p \rightarrow K^{0} \Lambda$ $\pi p \rightarrow K^{0} \Lambda$
"2020	" pro	posa	1 (143	Shift	S)		0.01 - 1.2	$1.4 \qquad 1.6 \qquad 1.8$ $\sqrt{S}  (GeV)$
channel	$\varepsilon_{AR}$	$\sigma_H \ ({ m mb})$	$\sigma_C$ (mb)	$\sigma_{Ag} \ ({ m mb})$	BR	$\frac{C_2 H_4 \text{ target}}{\dot{N}_H / \dot{N}_{tot} \text{ (shift}^{-1})}$	$ \begin{array}{c} \hline C \text{ target} \\ \dot{N}_C(\text{shift}^{-1}) \end{array} $	$egin{array}{c} { m Ag targe} \ \dot{N}_{Ag} ({ m shift}^{-}) \end{array}$
$\pi^-\pi^+$ n	0.14	10	16	63	1	$3.4  imes 10^6 / 6.1  imes 10^6$	$3.8 \times 10^{6}$	$2.0 \times 10$
$\pi^-\pi^0~{ m p}$	0.09	6.5	10.4	41	1	$1.4~ imes 10^{6}/2.6~ imes 10^{6}$	$1.6 \times 10^{6}$	$8.6 \times 10^{\circ}$
$\pi^0\pi^0~{ m p}$	0.01	2	3.2	13	1	$4.9 \  imes 10^4 / 8.8 \  imes 10^4$	$5.4 \times 10^{4}$	$2.9\! imes\!10^4$
$\mathrm{K}^{0}\Lambda$	0.04	0.56	1.85	7.3	0.35	$1.9\times10^4/5.0\times10^4$	$4.3  imes 10^4$	$2.4 \times 10$
$\mathrm{K}^{0}\Sigma^{0}$	0.04	0.24	0.79	3.1	0.35	$8\times 10^3/2.2\times 10^4$	$1.9 \times 10^4$	$1.0 \times 10$
$K^+\Sigma^-$	0.13	0.23	0.76	3.0	1	$7.2\times10^4/1.9\times10^5$	$1.7  imes 10^5$	9.0  imes 10
ηn	0.01	1.2	3.96	15.6	0.39	$1.2\times 10^4/3.1\times 10^4$	$2.6  imes 10^4$	$1.4 \times 10$
ωn	0.015	1.5	4.95	19.5	0.89	$4.9\times10^4/1.3\times10^5$	$1.1 \times 10^5$	$4.0 \times 10$
$ ho  ightarrow { m e}^+ { m e}^-$	0.25	2.1	6.93	90.3	$610^{-5}$	78/204	176	95
$\omega \rightarrow e^+e^-$	0.31	1.7	5.61	73.1	$7.410^{-5}$	84/222	190	104

## Existing "2020": $\sqrt{s} = 1.67 - 1.79 \,\text{GeV}$

![](_page_60_Figure_4.jpeg)

<b>The</b> <i>wha</i> <i>"</i> 2020	pov t mak	<b>Ver</b> (es us posa	of r s com	Dion opetit S shift	bear ive & co	ms at GSI omplementary	$2^{2} = 0.1^{10} = 0.1^{10} = 1.2^{10}$	$\pi p \rightarrow \eta n$ $\pi p \rightarrow \kappa^{0} \Lambda$
channel	$\varepsilon_{AR}$	$\sigma_H$	$\sigma_C$	$\sigma_{Ag}$	BR	$C_2H_4$ target	C target	Ag targe
		(mb)	(mb)	(mb)		$\dot{N}_H / \dot{N_{tot}}$ (shift <sup>-1</sup> )	$\dot{N}_C(\mathrm{shift}^{-1})$	$\dot{N}_{Ag}(\mathrm{shift})$
$\pi^-\pi^+$ n	0.14	10	16	63	1	$3.4 \  imes 10^6 \ / 6.1 \  imes 10^6$	$3.8 \times 10^{6}$	$2.0 \times 10^{\circ}$
$\pi^-\pi^0~{ m p}$	0.09	6.5	10.4	41	1	$1.4 \  imes 10^{6} / 2.6 \  imes 10^{6}$	$1.6 \times 10^{6}$	$8.6 \times 10^{-10}$
$\pi^0\pi^0~{ m p}$	0.01	2	3.2	13	1	$4.9 \times 10^4 / 8.8 \times 10^4$	$5.4 \times 10^4$	$2.9\! imes\!10^4$
${ m K}^0 \Lambda$	0.04	0.56	1.85	7.3	0.35	$1.9 imes10^4/5.0 imes10^4$	$4.3  imes 10^4$	2.4  imes 10
$\mathrm{K}^{0}\Sigma^{0}$	0.04	0.24	0.79	3.1	0.35	$8\times 10^3/2.2\times 10^4$	$1.9 \times 10^4$	$1.0 \times 10^{\circ}$
$K^+\Sigma^-$	0.13	0.23	0.76	3.0	1	$7.2\times10^{4}/1.9\times10^{5}$	$1.7  imes 10^5$	9.0  imes 10
ηn	0.01	1.2	3.96	15.6	0.39	$1.2 imes10^4/3.1 imes10^4$	$2.6  imes 10^4$	$1.4 \times 10^{\circ}$
ωn	0.015	1.5	4.95	19.5	0.89	$4.9  imes 10^4 / 1.3  imes 10^5$	$1.1 \times 10^5$	$4.0 \times 10^{\circ}$
$ ho  ightarrow e^+ e^-$	0.25	2.1	6.93	90.3	$610^{-5}$	78/204	176	95
$\omega \rightarrow e^+e^-$	0.31	1.7	5.61	73.1	$7.410^{-5}$	84/222	190	104

## Existing "2020": $\sqrt{s} = 1.67 - 1.79 \,\text{GeV}$

New "2024":  $\sqrt{s} = 1.37 - 2.3 \,\text{GeV}$ 

![](_page_61_Picture_5.jpeg)

![](_page_61_Picture_6.jpeg)