Physics reach of Kaon-induced Drell-Yan and Charmonia production with conventional M2 beamline

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Perceiving the emergence of hadron mass

AMBER
Apparatus for Meson and Baryon Experimental Research

NSF

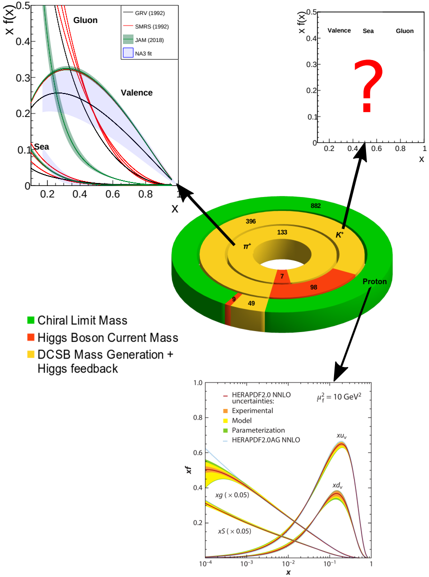
Hadron structure and the origin of hadron mass

Different origin of the mass budget of π, K, p,
it must be reflected in the structure: PDF and PDA

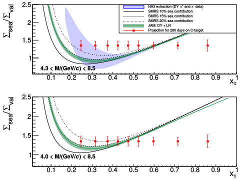
What is the status?

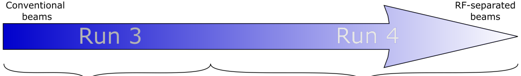
- Proton: the best known particle
- Pion: basic but in improvement
- Kaon: basically nothing

Where and How can we contribute?



Initial timeline and expectations





Phase-1

Proton charge radius
Antiproton production cross-section
Pion structure

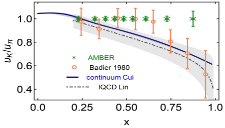
Approved on December 2020

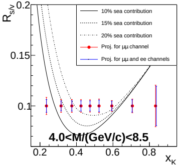
Nucleon GPD E
Heavy quark exotics

Phase-2

Kaon structure
Nucleon TMDs
High precision strange-meson spectrum
Spin density matrix elements

Drafting proposal
To be ready for PBC 2022





All intensity numbers are for instantaneous intensity in spill

Phase 1:

- 2 years (280 d) with 70 MHz h^+:h^- (3:1)
- Vertex detector to extend the mass range
- Investigation of intensity increase
- Before LS3 (∼2026)

⇒ π^+ more than 6× existing stat.

Phase 2:

- RF-separated beam
- 2 years with 20 MHz K^+:K^- (1:1)
- Active absorber
- Not before LS3,... maybe even later

⇒ K^- more than 35× existing stat.

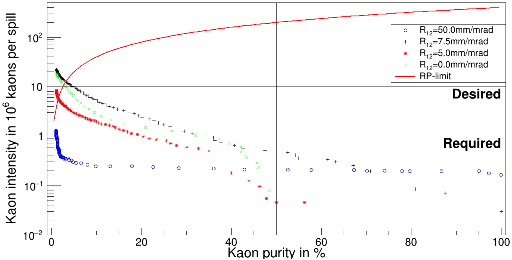
Outcome of RF-separated workshop (September 2021)

See Alexander Gerbershagen's talk

- Complete model for the beam line
- First real estimate of flux at AMBER
- Assumed in LoI: $\sim 10^8$ kaon/spill

with RF: beam energy < 70 GeV

Fabian Metzger: RF-separated workshop



Parallel beam at cavities: best for the separation but limitation due to finite cavity iris

Beam size matching cavity iris and deflection: Optimisation of the kick

Focused beam at cavity: Investigation for smaller cavity iris, not optimal for separation

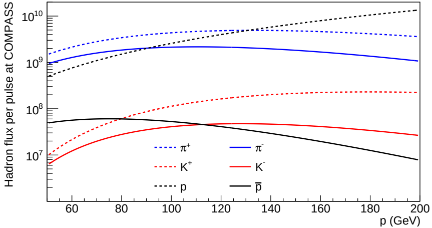
Beam size matching cavity iris: compromise between transmission and separation

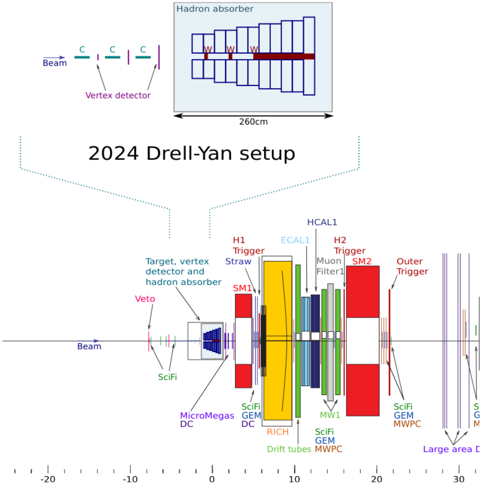
Current study: Intensities are two orders of magnitude lower than expected!

No clear advantage compared to conventional beam

Possibility with conventional beams

- No limitation on energy $\rightarrow$ 190 GeV
  - Larger cross section for $M\mu\mu > 4$ GeV$/c^2$
  - Access to lower x of the beam
- Same apparatus as for π-induced Drell-Yan measurements
- Intensity 1.4×10^6K/s ($\sim$2% total beam) $\Rightarrow$ due to current RP constraints





Radiation shielding from CERN HSE-RP and BE-EA

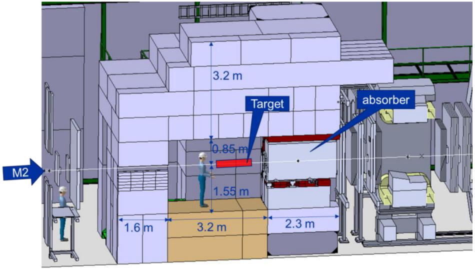
Study and optimisation of the shielding to:

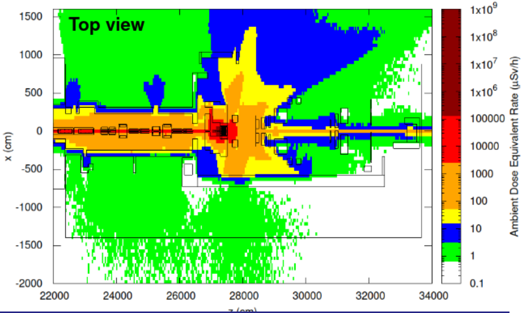
- Contain the radiation
- Minimise the environmental impact
- Comply with regulations

⇒ Compatible with 2×current Intensities

⇒ ECR to be submitted

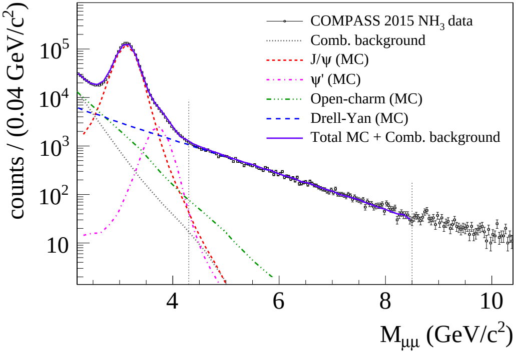
	Area	Annual dose limit (year)	Ambient dose equivalent rate		Sign
			permanent occupancy	low occupancy	RADIATION
	Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Radiation Area	Supervised	6 mSv	3 µSv/h	15 µSv/h	
Radiation Area / Controlled Area	Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE CONTROLLED / CONTRÔLÉE SIMPLE
Radiation Area / Controlled Area	Limited Stay	20 mSv	-	2 mSv/h	LIMITED STAY / SÉJOUR LIMITÉ
Radiation Area / Controlled Area	High Radiation	20 mSv	-	100 mSv/h	HIGH RADIATION / HAUTE RADIATION
Radiation Area / Controlled Area	Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY DÉFENSE D'ENTRER





Di-muon mass spectrum

How to further gain in statistics? **Improving the mass resolution!**



- Reduce the combinatorial
- Extend the analysis of DY to lower masses
- Improve the J/ψ and ψ' separation

$\rightarrow$ Need for a vertex detector

Vertex detector

as FVTX from PHENIX:

- Silicon sensor
- Large surface: $\pm$20cm
- Time resolution: $\sim$ ns
- Spatial resolution: $\sim 20\mu$m

Simulations and optimisation of the apparatus and reconstruction ongoing

Preliminary:
$\rightarrow \sigma_{\mu\mu} \sim 110$ MeV$/c^2$

$M_{\mu\mu} >$4.3 GeV$/c^2$ $\rightarrow$ $M_{\mu\mu} >$4.0 GeV$/c^2$:
$\Rightarrow$ $\sim$50% gain in DY statistics

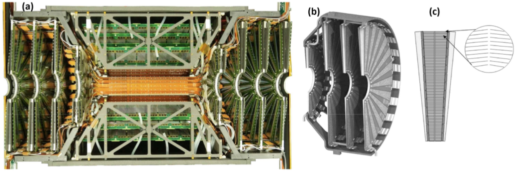
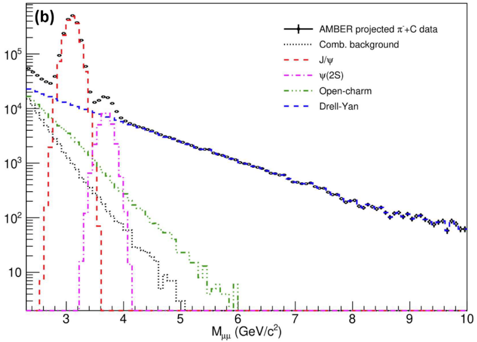
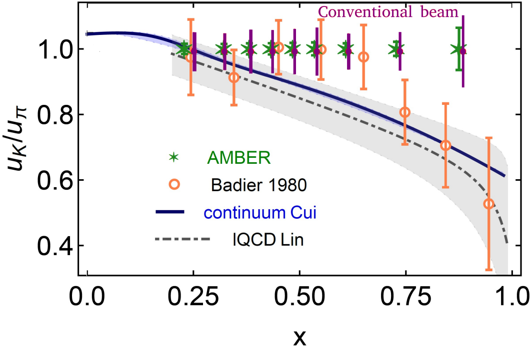
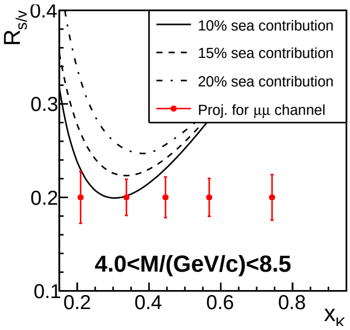


Figure 7 **(a)** A completed half FVTX detector, with sensors, frontend electronics, supporting structures, and cooling system. Two half FVTX endcaps are shown on either end. The overall length is about 80 cm. **(b)** A structural illustration of one endcap of the FVTX. One small disk and three large disks are included in one endcap. **(c)** A segment (wedge) of the FVTX sensor. Each wedge holds two columns of the silicon strips as shown in the zoomed-in portion.



Kaon-induced Drell-Yan





- Measurement potentially available from 2025
- Provided the intensity increase from RP and vertex detector → 1 year of data taking
- Three times the world data (6 times for two years)

Parallel measurements with J/ψ production: up quark content

Purely strong interaction: all partons contribute on the same footing

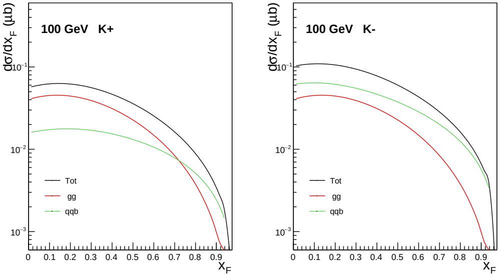
Using two kaon beam charges, one can access:

- $\bar{u}^K u^N \propto \sigma^{K^-}_{J/\psi} - \sigma^{K^+}_{J/\psi}$
- Infer the kaon gluon distribution from a model dependent way

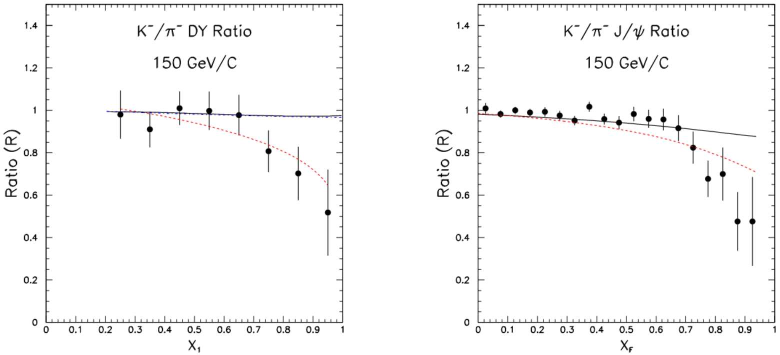
In 1 year with twice larger intensity:

- K^- J/ψ events: $\sim$ 60,000
- K^+ J/ψ events: $\sim$ 22,000

J/ψ subprocess contribution as obtained from Color Evaporation Model



Parallel measurements with J/ψ production: up quark content



- NA3 experiment measured a similar suppression of K/π at large x_F

J. Badier *et al.* Phys. Lett. B93, 354 (1980), Z. Phys. C20, 101 (1983)

- Same modelisation of Kaon PDFs describe the cross-section ratios similarly well

J.C. Peng *et al.* arXiv:1711.00839

- AMBER will provide measurements about 3 (6) times more precise in 1 (2) year(s)

Parallel measurements with J/ψ production

J/ψ polarisation can be used to determine the fraction of quark/gluon content

$$\frac{d\sigma^{J/\psi}}{d\Omega} \sim 1 + \lambda_{\theta}^{CS} cos^2(\theta)$$

- From $q\bar{q} \rightarrow$ J$_z$=$\pm1 \rightarrow \lambda = -1$
- From $gg \rightarrow$ J$_z$=0 $\rightarrow \lambda = 1$

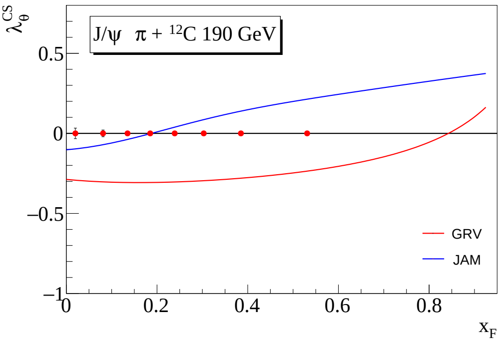
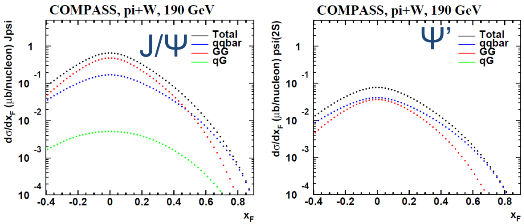


Illustration of the sensitivity with pion beam

- Free from feed-down contribution
- Provide insights on Charmonia production mechanism
- Complement DY and J/ψ measurements for PDFs

Calculation with NRQCD from W.-C. Chang



Thanks to vertex detectors, one may expect similar statistics as for high-mass Drell-Yan

Beam PID

π-K separation beneficial for π-induced DY

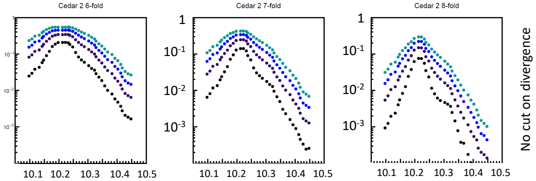
Essential for K-induced DY

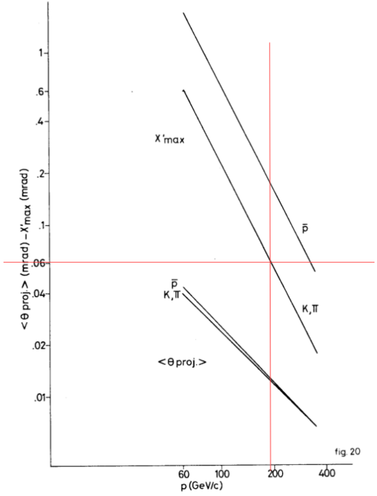
- Efficient majority discrimation
  $\rightarrow$ low divergence
- Divergence @ M2: $\sim 130\mu$rad $> 60\mu$rad

How much can be improved ?

$\Rightarrow$ see talk from Dipanwita Banerjee

Pressure Scan – COMPASS DAQ (High Int.)





DIVERGENCE AND MULTIPLE SCATTERING IN CEDAR-N

Beam PID

- Use trajectory information from AMBER beam telescope
- Back propagate information to CEDAR
- Evaluate a likelihood for the PMT pattern

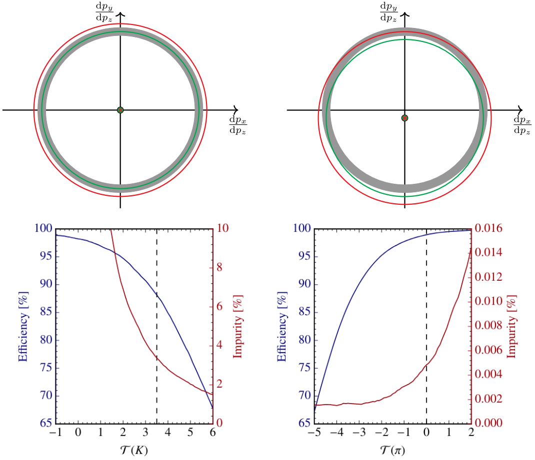
⇒**Recovers efficiency with high purity**

Requires: Beam instrumentation

- Confirm extrapolation
- Monitoring of beam stability
- P_{beam} measurement

Public note: Steffan Wallner *et al.* COMPASS 2017-1

Beam parallel to optical axis | Beam with finite inclination with respect to optical axis



(a) Kaon PID (b) Pion PID

Outlook

- Drell-Yan process in high mass is a rare process $\rightarrow$ High intensity requires
- Measurements with conventional beam can provide $\approx 6\times$ more data than available
- K-induced DY and charmonia production can be measured in parallel to the π one $\rightarrow$ potentially from 2025
- Beam identification is crucial (90% eff. and 100% pur. in this report) $\rightarrow$ high efficiency and purity should be guaranteed

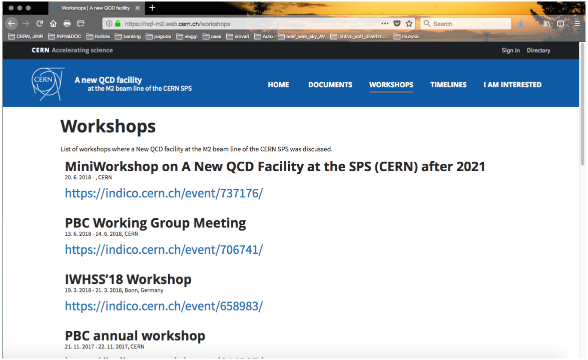
AMBER with conventional beam paves the way for meson structure until complementary measurements are performed at the EIC

See next sessions for additional measurements with RF separated beams

BACKUP

A new QCD facility

- Letter of Intent arXiv:1808.00848
  DY, Spectroscopy, muon-p elastics scattering, . . .
- A web page

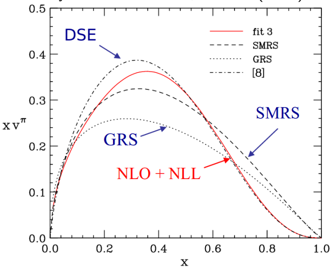


New ideas and collaborators are welcome

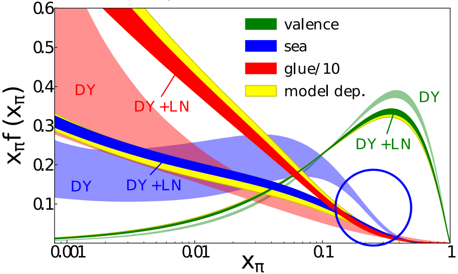
Proposal available

Renewed interest in pion structure

Phys. Rev. Lett. 105, 252003 (2010)



P. C. Barry *et al.* arXiv:1804.01965v1



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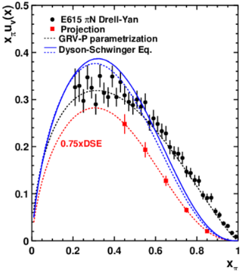

- Agreement between DSE and fit to E615 data at NLO+NLL
- First extraction of PDFs with Hera data (DIS with leading neutron)
- Foreseen measurement of Tagged DIS at JLab and at EIC

Aim for direct data in the circled area

Pion induced Drell-Yan statistics for 2 years

Experiment	Target type	Beam energy (GeV)	Beam type	Beam intensity (part/sec)	DY mass (GeV/c^2)	DY events
E615	20cm **W**	252	π^+ π^-	17.6×10^7 18.6×10^7	4.05 – 8.55	5,000 30,000
NA3	30cm H_2	200	π^+ π^-	2.0×10^7 3.0×10^7	4.1 – 8.5	40 121
	6cm **Pt**	200	π^+ π^-	2.0×10^7 3.0×10^7	4.2 – 8.5	1,767 4,961
NA10	120cm D_2	286 140	π^-	65×10^7	4.2 – 8.5 4.35 – 8.5	7,800 3,200
	12cm W	286 140	π^-	65×10^7	4.2 – 8.5 4.35 – 8.5	49,600 29,300
COMPASS 2015 COMPASS 2018	110cm NH_3	190	π^-	7.0×10^7	4.3 – 8.5	35,000 45,000
This exp	100cm **C**	190	π^+	1.7×10^7	4.3 – 8.5 3.8 – 8.5	**23,000** 37,000
		190	π^-	6.8×10^7	4.3 – 8.5 3.8 – 8.5	22,000 34,000
	24cm W	190	π^+	0.2×10^7	4.3 – 8.5 3.8 – 8.5	7,000 11,000
		190	π^-	1.0×10^7	4.3 – 8.5 3.8 – 8.5	6,000 9,000

Use of lighter and isoscalar target as compared to past experiments