Towards a full Lagrangian model for two pion production

Xu CAO

Workshop on two-pion and e^+e^- production in hadronic reactions

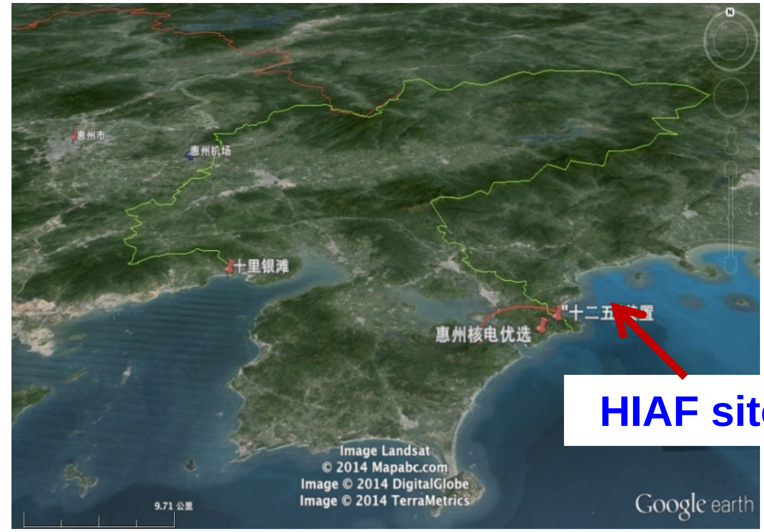
22-24 May, 2018

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

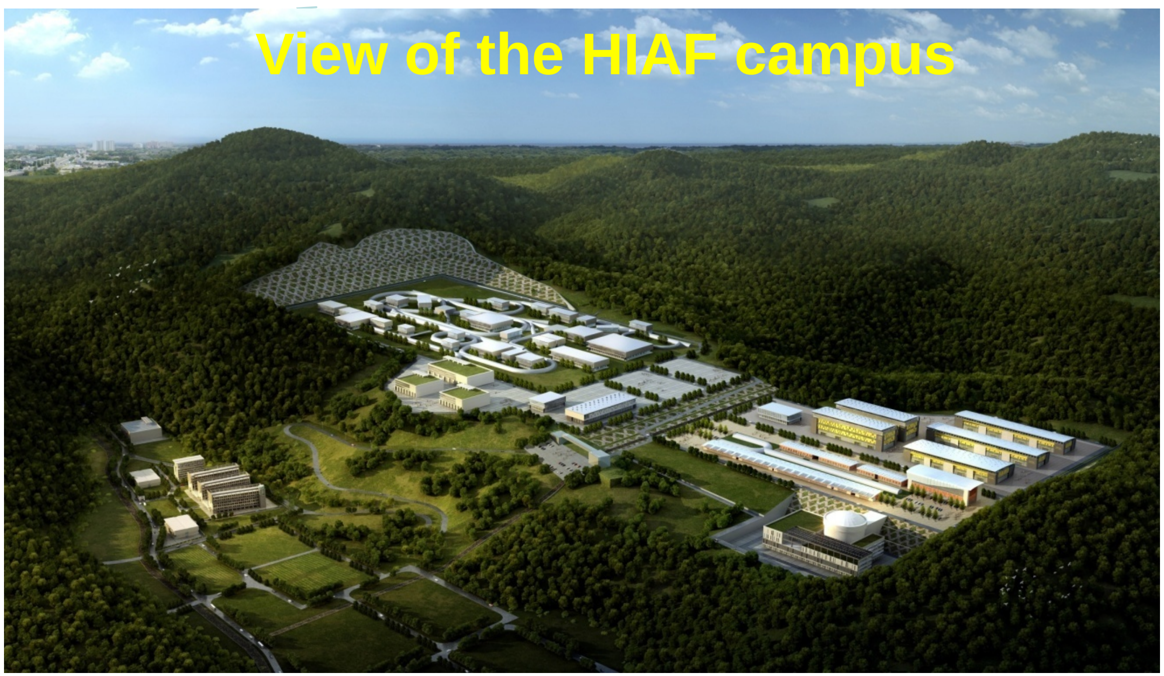
Site of HIAF project-new campus

HIAF will be in Huizhou, Guangdong Province.

HIAF site



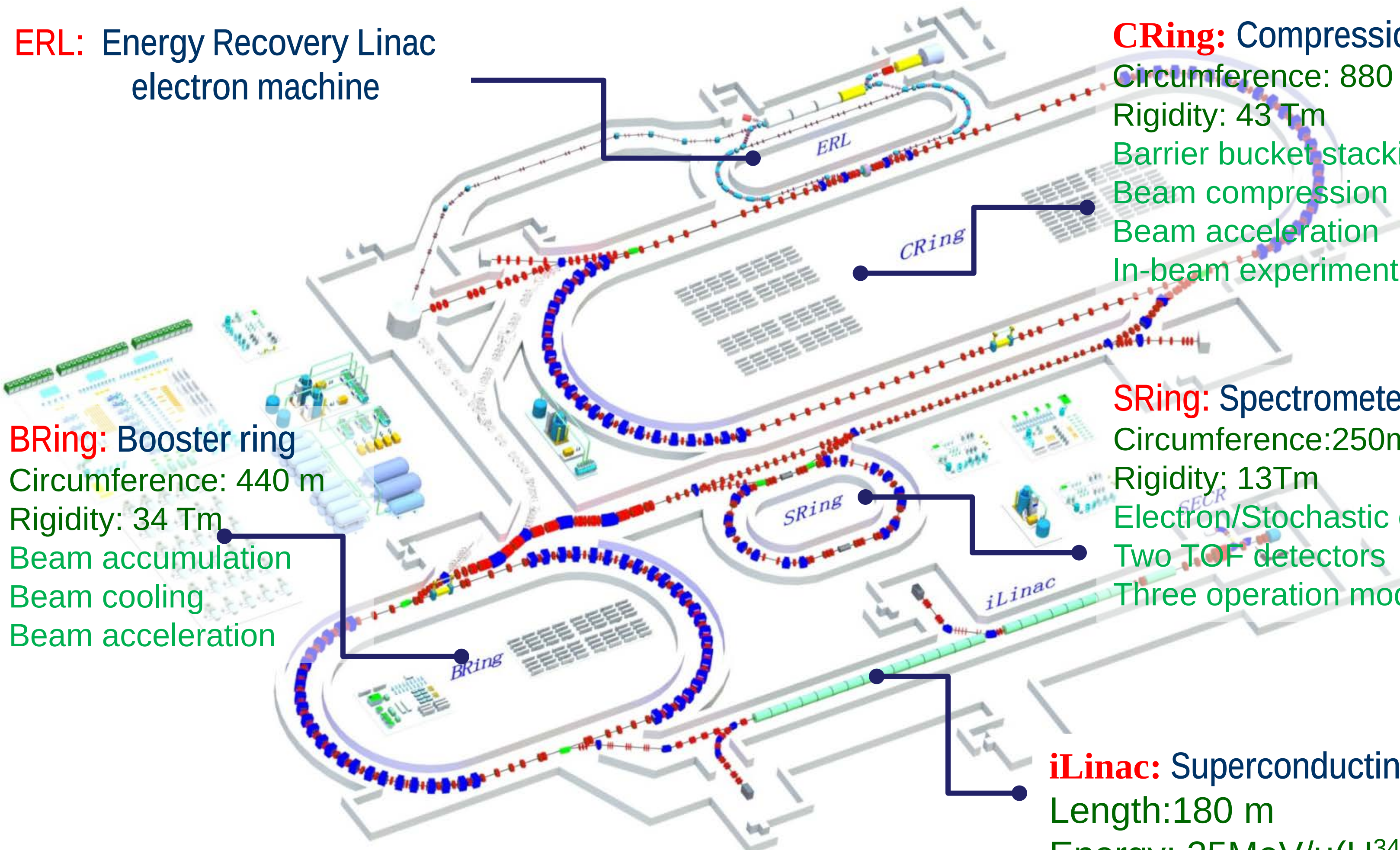
HIAF site



General description & status

HIAF layout-First Phase:

Multi-purpose facility **with unprecedented parameters**



ERL: Energy Recovery Linac electron machine

CRing: Compression ring
Circumference: 880 m
Rigidity: 43 Tm
Barrier bucket stacking
Beam compression
Beam acceleration
In-beam experiment

SRing: Spectrometer ring
Circumference:250m
Rigidity: 13Tm
Electron/Stochastic cooling
Two TOF detectors
Three operation modes

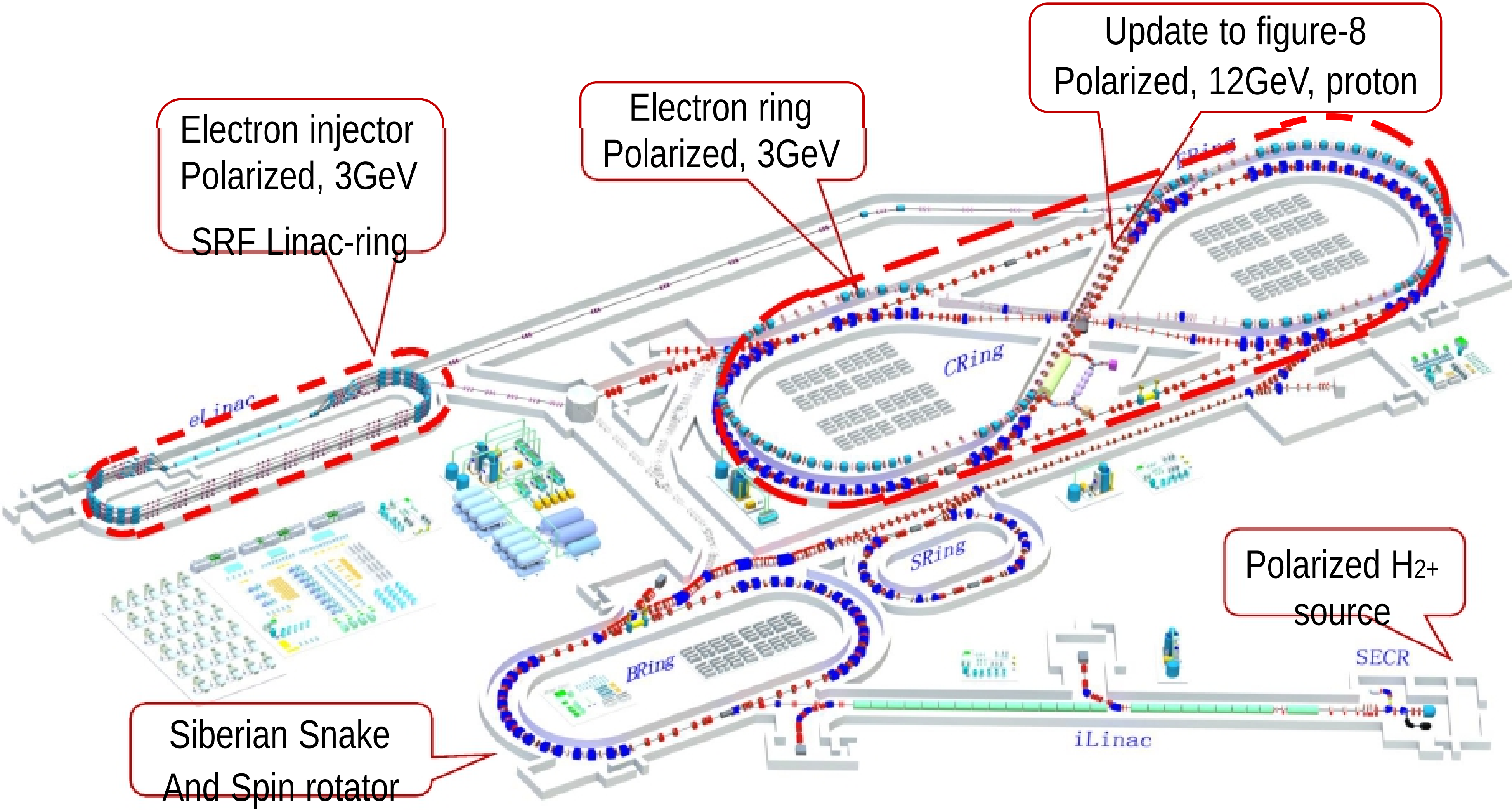
BRing: Booster ring
Circumference: 440 m
Rigidity: 34 Tm
Beam accumulation
Beam cooling
Beam acceleration

iLinac: Superconducting linac
Length:180 m
Energy: 25MeV/u(U^{34+})

Second phase for HIAF-EIC

A High Luminosity for Electron-Ion Collider
A New Experimental Quest to Study the Sea quark and Gluon

HIAF design maintains a well defined path for EIC



Budget of HIAF (1st phase)

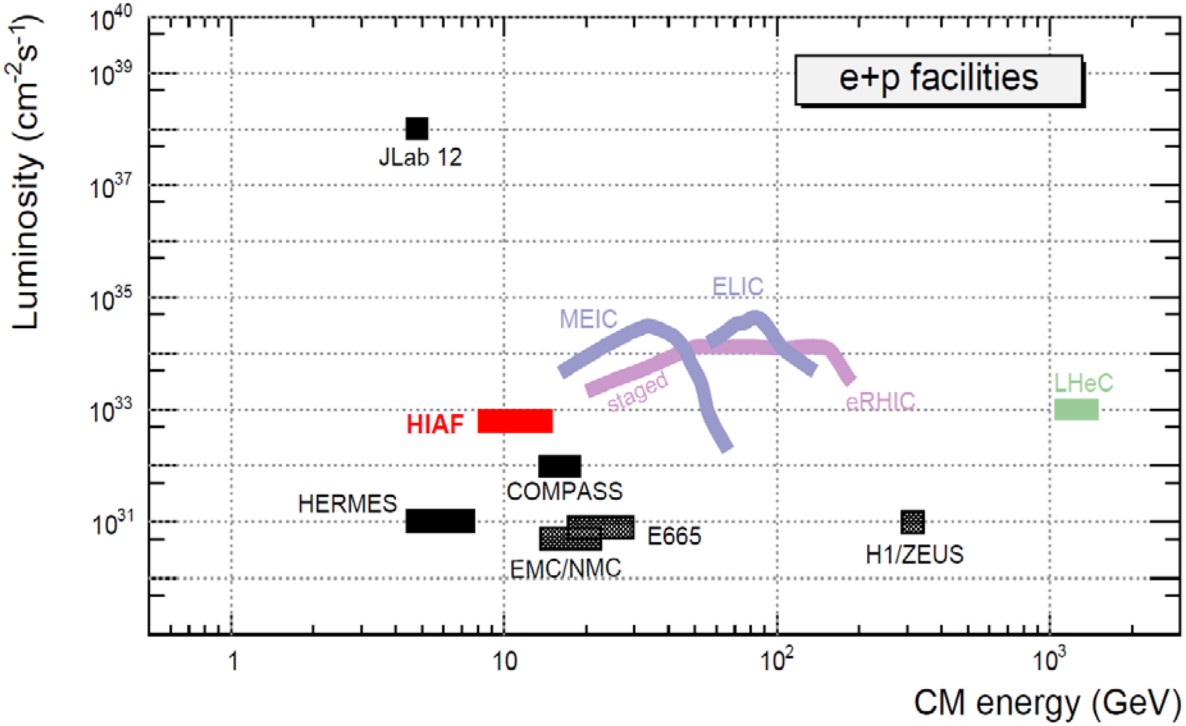
Items	1st phase (MRMB)
iLinac	360
BRing	350
CRing	
eLinac	
ERing	
High energy electron cooling	
Beam transfer line	50
Experiment setups	240
Cryogenics	80
Civil engineering	190
Tunnel construction	160
Contingency cost	100
Total of facility	1530 (central government)
Land & infrastructure	1400 (local government)
Total	2930

Preliminary budget of HIAF-EIC

Items	**EIC** Budget(100MRMB)
iLinac	
BRing	0.1
CRing	1.9
eLinac	3.57
ERing	4.0
Highenergyelectroncooling	1.0
Beamtransferline	0.25
Experimentsetups	3.1(EIC Detector)
Cryogenics	1.2
Civilengineering	1.73
Tunnelconstruction	0.9
Contingencycost	1.3
Total	**19.35**

Lepton-Nucleon Facilities

HIAF: e(3GeV) +p(12~16 GeV), both polarized, L>= $4*10^{32}cm^2/s$



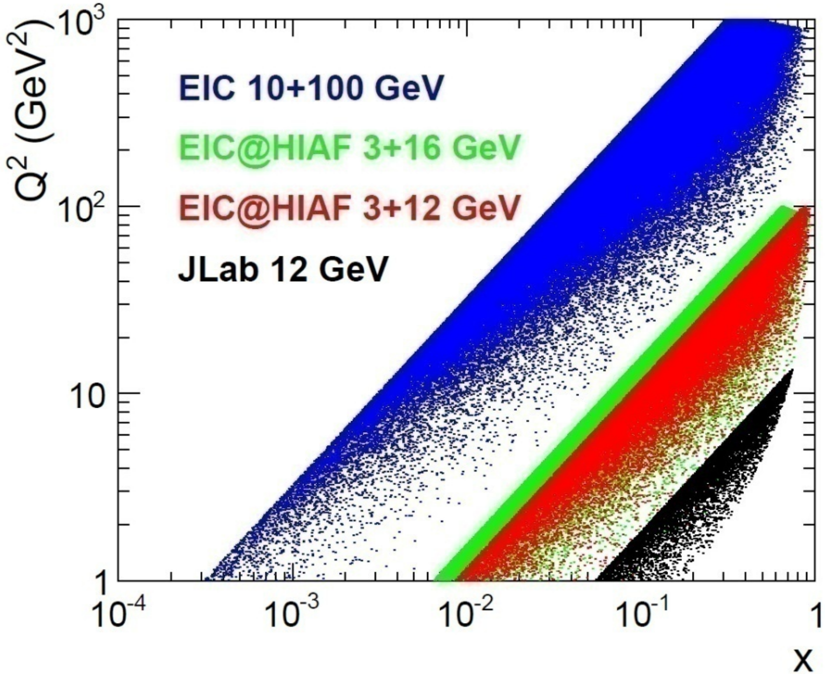
●The energy reach of the EIC@HIAF is significantly higher than JLab12 but lower than the full EIC being considered in US

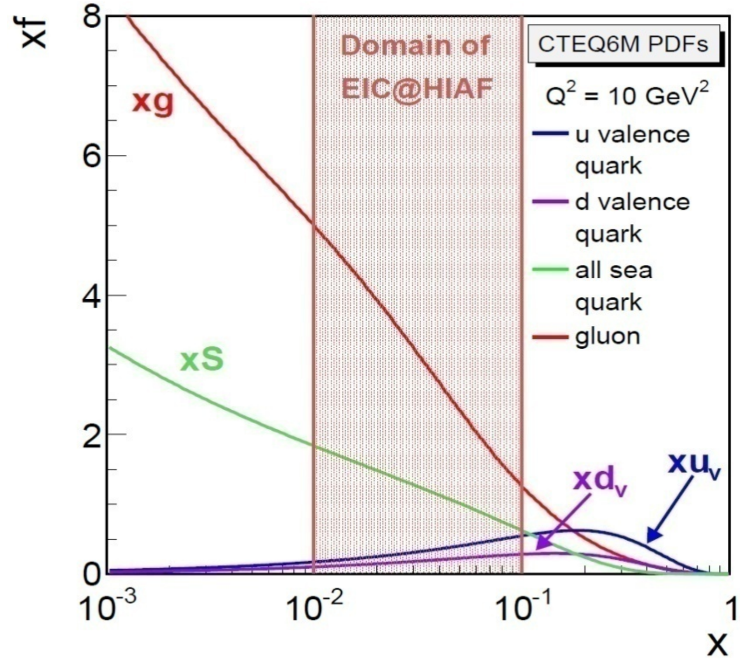
●COMPASS has similar (slightly higher) energy, but significantly lower polarized luminosity (about a factor of 200 lower, even though the unpolarized luminosity is only a factor of 4 lower)

●HERA only has electron and proton beams collision, but no electron and light or heavy ion beams collision, no polarized beams and its luminosity is low (10^31).

EIC@HIAF Kinematic Coverage

Comparison with JLab 12 GeV





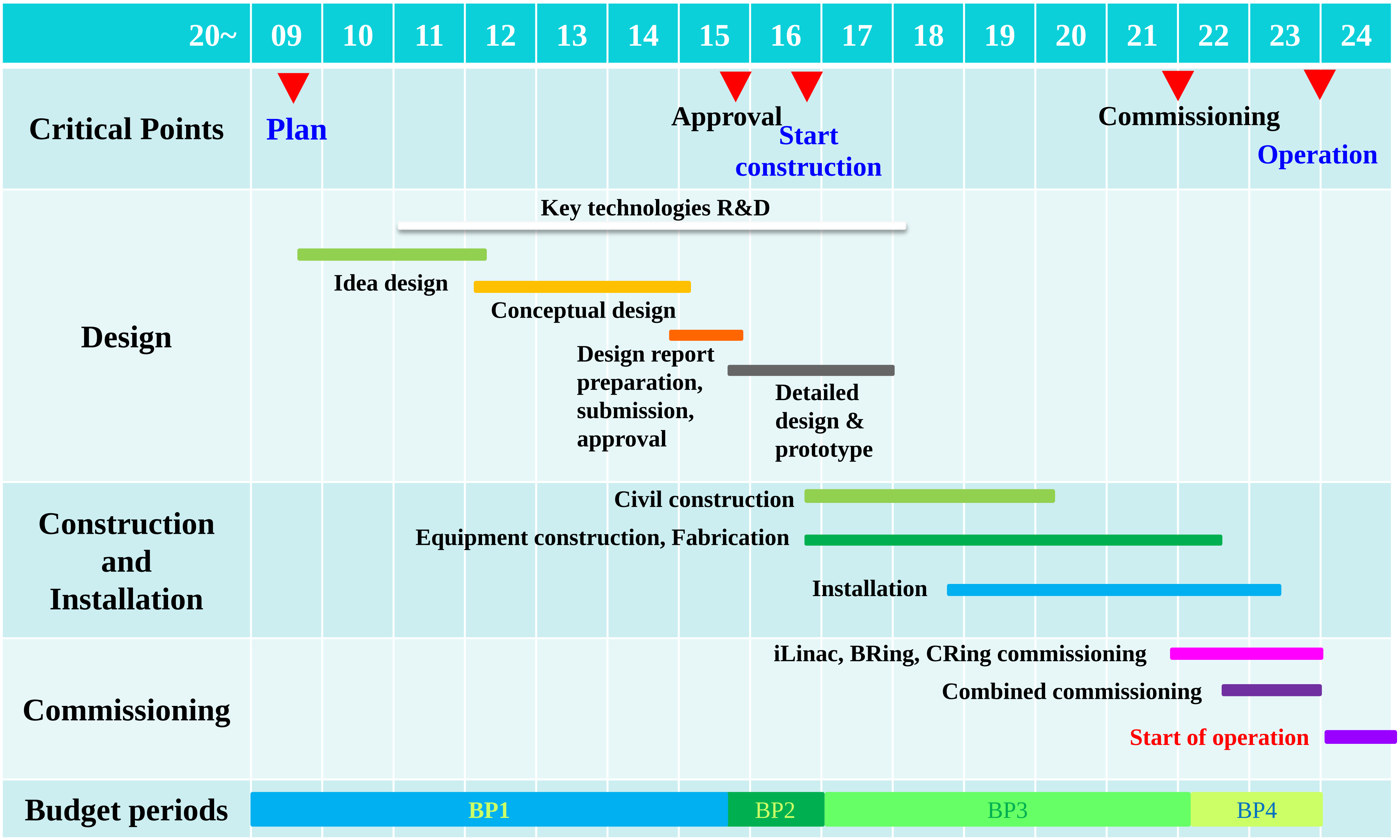
EIC@HIAF :

Explore the spin and spatial structure of valence & sea quarks in nucleons

The best region for studying sea quarks (x > 0.01)

higher Q^2 in valance region, Allows some study gluons

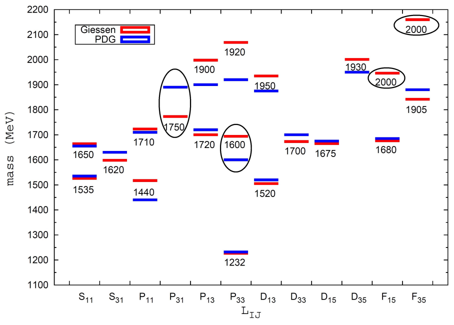
Schedule for the HIAF (1st phase)



Methodology for study of resonances

Conventional quark model

- misssing resonance
  1. More states are predicted in quark models than seen in the πN scattering
  2. Problem reappears in lattice calculations in finite volume? Edwards et al. Phys.Rev. D84 (2011) 074508. $m_\pi = 396 MeV$
  3. Dyson-Schwinger and Faddeev equations (Fisher@Giessen)



Methodology for study of resonances

- resonance: unstable and couple strongly to meson-baryon states
- Phenomenological models to extract their parameters from data

- $(\pi, \gamma)N$ reactions
  Unitarity,Analiticity....

1. isobar models
2. coupled-channel models
   - KSU
   - GWU/SAID
   - Mainz/MAID
   - Bonn-Gatchina
   - Giessen
   - Juelich
   - EBAC
   - ....

- *NN* reactions
  Unitarity,Analiticity?

1. 3-body final states at least
2. Final state interaction?
3. isobar models
   many up to now!
4. PWA may be inconclusive.

Methodology for study of resonances

- cascade decay of resonances: begin recently
- two-meson final states in reactions: $\pi\pi$, $\pi\eta$....

- $(\pi, \gamma)N$ reactions
  Unitarity,Analiticity?

1. exp. groups
   - CLAS@JLab
   - CBELSA@ELSA
   - GRAAL@ESRF
   - Crystal Ball@MAMI
   - A2@MAMI
2. isobar models
   - Mainz/MAID
   - Bonn-Gatchina
3. coupled-channel models?

- NN reactions
  Unitarity,Analiticity?

1. 4-body final states at least
2. Final state interaction?
3. isobar models
   only Four up to now
4. PWA may be inconclusive.

Methodology for study of resonances

- Other aspects for $NN \to NN\pi\pi$ reactions
- Beyond the study of baryonic resonances!

- an input to baryon and baryon resonances in nuclear matter
  ref. H. Lenske, M. Dhar, T. Gaitanos, X. C., PPNP 98 (2018) 119

  an input to transport model (at SIS energies)
  ref. J. Weil, H. van Hees, U. Mosel, EPJA **48** (2012) 111

  a basic ingredient of 2π production in *pd* & *dd* reactions (dibaryons?)
  ref. H. Clement, PPNP 93 (2017) 195
  also ref. Skorodko and Bashkanov's talk

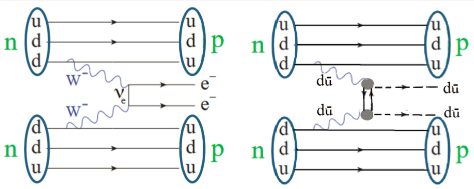
Methodology for study of resonances

- Other aspects for $NN \to NN\pi\pi$ reactions
- Beyond the study of baryonic resonances!

- Double Charge Exchange (DCE) reactions:

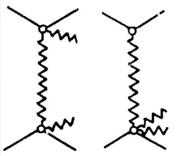
$$nn \to ppe^-e^- \text{ versus } nn \to pp\pi^-\pi^-$$
$$0\nu 2\beta \text{ versus } pp \to nn\pi^+\pi^+$$

an input to heavy-ion induced DCE reactions
ref. NUMEN project, Eur. Phys. J. A **54** (2018) 72
and H. Lenske et al., arXiv:1803.06290v1 [nucl-th]



History of theory and exp.

1. E. Ferrari, Nuovo Cimento, 1963
   - OPE model



2. Valencia Model, Nucl. Phys. A, 1999
   - double-Δ,N^*(1440),non-resonant
3. Xu CAO et al., Lanzhou, PRC 2010, IJMPA 2011, NPA 2011
   - more resonances from PDG and OBE
4. Jerusalimov, Dubna, 2012
   - reggeized π exchange(OPER) + one baryon exchange(OBE)

History of theory and exp.

- data before '1985: bubble-chamber, tcs only
- data from '2000 to '2012:

Channel	Group (Tp(MeV))
$pp\to pp\pi^+\pi^-$	CELSIUS(650, 680, 750, 775, 895, 1100, 1360), Gatchina(717, 818, 861, 900, 980), COSY(750, 800) KEK(698, 780, 814, 908, 995, 1083, 1172)
$pp\to pp\pi^0\pi^0$	CELSIUS(650, 725, 750, 775, 895, 1000, 1100, 1200, 1300, 1360)
$pp\to nn\pi^+\pi^+$	CELSIUS(800, 1100)
$pp\to pn\pi^+\pi^0$	CELSIUS(725, 750, 775, 1100)
$pn\to pn\pi^+\pi^-$	KEK(698, 780, 814, 908, 995, 1083, 1172)
$pn\to pp\pi^-\pi^0$	KEK(698, 780, 814, 908, 995, 1083, 1172)

History of theory and exp.

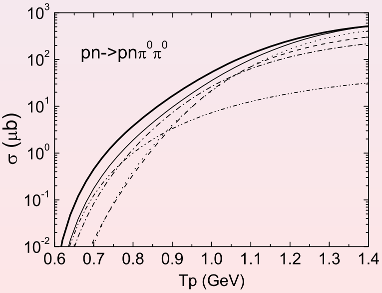
- data before '1985: bubble-chamber, tcs only
- data from '2012 to '2018:

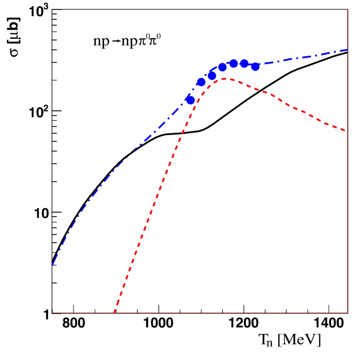
Channel	Group (Tp(MeV))
pp->pp$\pi^+\pi^-$	WASA@COSY(1080 ~ 1360), HADES@GSI(3500)
pp->pp$\pi^0\pi^0$	WASA@COSY(1400)
pp->nn$\pi^+\pi^+$	
pp->pn$\pi^+\pi^0$	
pn->pn$\pi^+\pi^-$	HADES@GSI(1250), JINR(1100,1500)
pn->pp$\pi^-\pi^0$	WASA@COSY(1200)
pn->pn$\pi^0\pi^0$	WASA@COSY(1075, 1100, 1125, 1150, 1176, 1201, 1227)

History of theory and exp.

$$2[\sigma(pp \to pp\pi^+\pi^-) + \sigma(pn \to pn\pi^+\pi^-) + \sigma(pp \to nn\pi^+\pi^+)] =$$
$$4\sigma(pp \to pp\pi^0\pi^0) + 4\sigma(pn \to pn\pi^0\pi^0) + \sigma(pp \to pn\pi^+\pi^0) + 2\sigma(pn \to pp\pi^-\pi^0)$$

- only six independent channels! (ref. C. Wilkin)
- $pn \to pn\pi^0\pi^0$ channel 'predicted' from the isospin relation
  Xu CAO et al., Int.J. Mod.Phys. A 2011
  versus WASA@COSY, PLB 2015



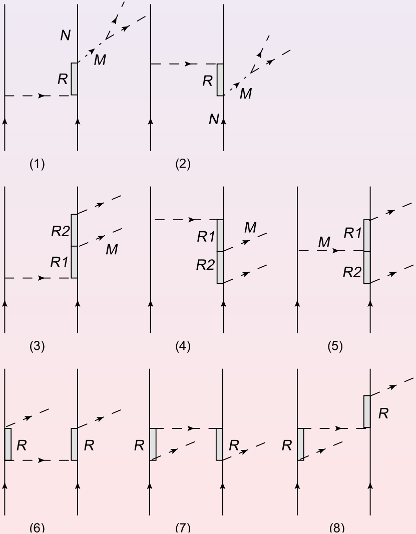


Effective Lagrangian model

- Feynman diagrams: tree level. The interference terms between different diagrams are neglected because the relative phases of amplitudes are not known.
- Resonances which are experimentally observed are included in our model. Mesons exchanged are restricted to those observed in the decay channels of the adopted resonances.
- Effective Lagrangians: Lorentz covariant orbital-spin scheme for the vertices. The coupling constants appearing in relevant resonances could be determined by the empirical partial decay width of the resonances taken from Particle Data Group.
- Final state interactions: usually important for describing the near threshold behavior.
  Watson-Migdal factorization: only serve as a qualitative illustration.
- Cutoff parameters in the form factors: fit to the empirical data.

Effective Lagrangian model

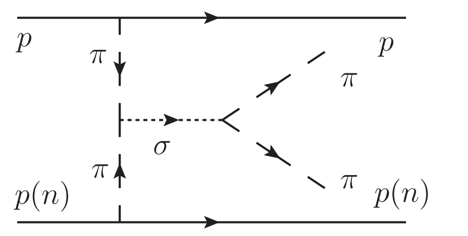
- $R \rightarrow NM$
  single decay
- $R \rightarrow RM$
  cascade decay
- double-R
  R-R'



Effective Lagrangian model

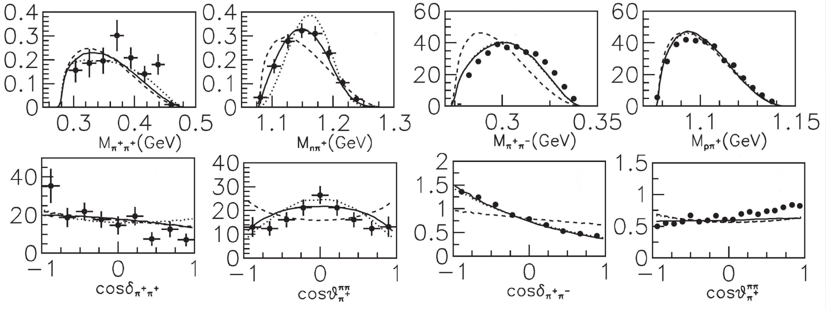
- the 'missing'σ- and ρ-mesonic currents
  — hanged diagrams (Jerusalimov)

()



Channel	ρ-messonic current	σ-messonic current
pp->pp$\pi^+\pi^-$	x	√
pp->pp$\pi^0\pi^0$	x	√
pp->nn$\pi^+\pi^+$	x	x
pp->pn$\pi^+\pi^0$	√	x
pn->pn$\pi^+\pi^-$	√	√
pn->pp$\pi^-\pi^0$	√	x
pn->pn$\pi^0\pi^0$	x	√

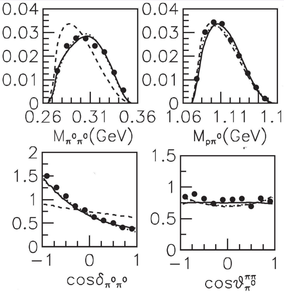
Effective Lagrangian model

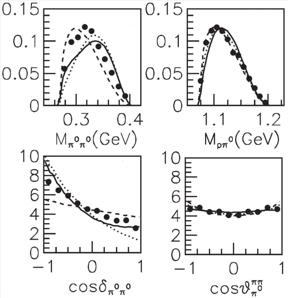


- $pp \to nn\pi^+\pi^+$
- $T_p = 1100$ MeV
- no mesonic current

- $pp \to pp\pi^+\pi^-$
- $T_p = 750$ MeV
- σ-mesonic current only

Effective Lagrangian model

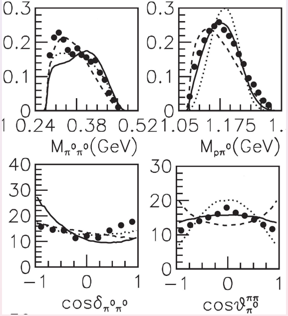


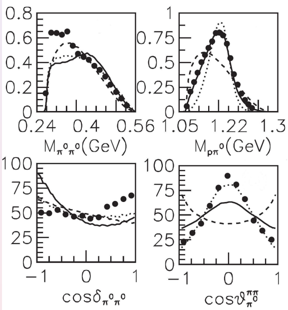


- $pp \to pp\pi^0\pi^0$
- $T_p = 775$ MeV
- σ-mesonic current only

- $pp \to pp\pi^0\pi^0$
- $T_p = 895$ MeV
- σ-mesonic current only

Effective Lagrangian model



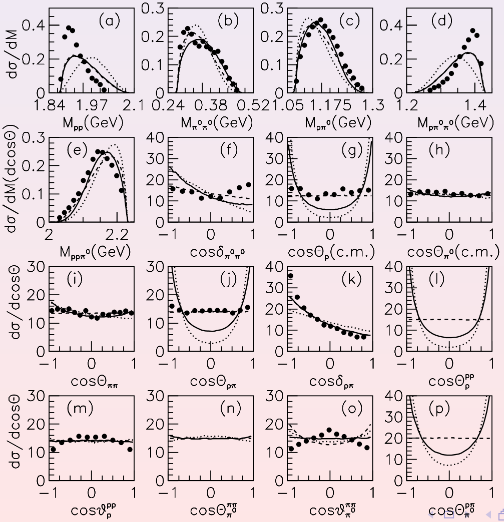


- $pp \to pp\pi^0\pi^0$
- $T_p = 1100$ MeV
- σ-mesonic current only

- $pp \to pp\pi^0\pi^0$
- $T_p = 1300$ MeV
- σ-mesonic current only

Effective Lagrangian model

- $pp \to pp\pi^0\pi^0$ at $T_p = 1100$ MeV
- $m_\sigma = 250$ MeV (ρ-mesonic current forbidden)



Effective Lagrangian model

Table: Ongoing update: Resonances with mass below 2.0 GeV from PDG. Cascade decay of higher lying resonances?!

Resonance	BW Width	Decay Mode	Decay Ratio	$g^2/4\pi$
$\Delta^*(1232)P33$	118	$N\pi$	1.0	19.54
$N^*(1440)P11$	300	$N\pi$	0.65	0.51
		$N\sigma$	0.075	3.20
		$\Delta\pi$	0.135	4.30
$\Delta^*(1600)P33$	350	$N\pi$	0.175	1.09
		$\Delta\pi$	0.55	59.9
		$N^*(1440)\pi$	0.225	289.1
$\Delta^*(1620)S31$	145	$N\pi$	0.25	0.06
		$N\rho$	0.14	0.37
		$\Delta\pi$	0.45	83.7

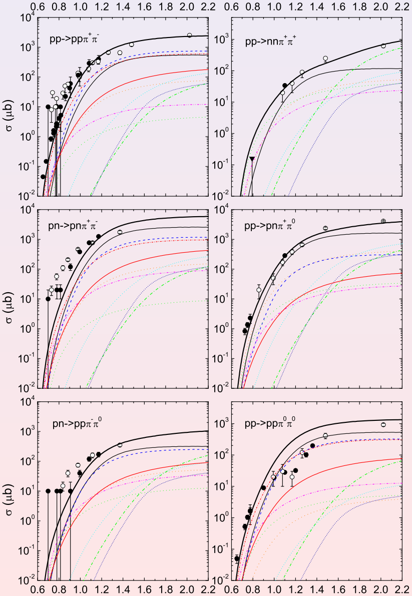
Effective Lagrangian model

- Negligible contributions at low energies

- small branching ratios of double pion channel:
  $S_{11}(1535), S_{11}(1650), D_{13}(1700)$
- higher partial waves:
  $D_{13}(1520), D_{15}(1675)$
- lying beyond the considered energies:
  $F_{15}(1680), D_{33}(1700), P_{11}(1710), P_{13}(1720)$
- Resonances with mass bigger than 1720MeV:
  the two pion branching ratios have large uncertainties

- but would be important at HADES 3.5 GeV, ref. Belounnas's talk

Effective Lagrangian model



← $P_{33}(1600)$ in $pp \to nn\pi^+\pi^+$

← Good description in pn reactions

← $P_{11}(1440)$: isoscalar excitation

← a step in $pp \to pp\pi^0\pi^0$

interference of $N^*(1440)$ and Δ

or dibaryon?

Summary and Outlook

1. A full Effective Lagrangian model including properly the interference and $\pi\pi$ dynamics are outlined.
2. main contribution: nucleon pole,Δ,$N^*(1440)$,$\Delta(1600)$,$\Delta(1620)$ ...
3. Some difficulties in the model building are addressed, e.g.,
   The couplings of resonances to $\pi\pi N$ in cascade decay have big uncertainties because of the less-known branching ratios of high-lying resonances.
4. Efforts in $(\pi,\gamma)N \to \pi\pi N$ are useful to pin down the parameters.
5. General feature of $NN \to NN\pi\pi$ is described properly, but...

Summary and Outlook

- Further understanding is definitely needed and in processing.
    - dibaryon and structures in tcs of $pN \to pN\pi^0\pi^0$?
    - extension to 2π production in pd and dd reactions?
- Ongoing update of the model:

1. R-R' in diagrams of double resonances
2. mesonic currents in $\pi\pi$ spectrum
3. relative phases among interferences fitted to the data
4. form factors treated carefully (up to high energies!)
5. Portable with flexible energies&amplitudes to produce MC events
6. Stay tuned...

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Thanks for your attention!!!

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