The Search for Critical Behavior (and Other Features of the QCD Phase Diagram)

Status and Future

The Phases of QCD

Quark-Gluon Plasma

Vacuum

Hadron Gas

Nuclear Matter

Critical Point?

1st Order Phase Transition

Baryon Chemical Potential $\mu_B$(MeV)

Temperature (MeV)

Helen Caines, Yale
Critical point expectations

Still theoretical debate as to Critical Points existence

Lattice Gauge Theory calculations are becoming increasingly accurate

$T_c = 154(9) \text{ MeV}$

and sophisticated away from $\mu_B=0$

Calculations suggest C.P. above $\mu_B/T > 2$ and $T/T_c(\mu_B=0) > 0.9$
Critical point expectations

We are focusing in on the right region

Calculations suggest C.P. above \( \mu_B/T > 2 \) and \( T/T_C(\mu_B=0) > 0.9 \)
Establishing the “basics”: Energy density

\( \frac{E_T}{N_{\text{ch}}} \) relates to average transverse mass of produced particles

rises, plateaus, rises again constant as function of \( N_{\text{part}} \)

Leveling off starts around \( \sqrt{s} \sim 7 \text{ GeV} \)
Establishing the “basics”: Energy density

\[ \frac{E_T}{N_{ch}} \] relates to average transverse mass of produced particles rises, plateaus, rises again constant as function of \( N_{part} \)

Leveling off starts around \( \sqrt{s} \sim 7 \text{ GeV} \)

For central events:
Bjorken energy density \( \times \tau > 1 \text{ GeV/fm}^2c \)
\( \epsilon_{BJ} \tau \) follows power law behavior
\( \epsilon_{BJ} \tau \sim e^{[b \times \log(\sqrt{s_{NN}})]} \); \( b = 0.422 \pm 0.035 \)
\( \epsilon_{BJ} \tau < 1 \) for low energy peripheral events
Can we establish \( \tau \)?
Establishing the “basics”: Yields

Moving towards full phase space measurements

Good agreement between experiments

Rapidity Density Distribution of $\pi^+$

Systematic error shown for STAR and E895

Results are not feed-down or background corrected.

$\sqrt{s} = 4.5$ GeV

π$^-$

Open symbols are reflected

Distributions are fit with Gaussian functions with means fixed to $y = 0$.

Good agreement between experiments
Establishing the “basics”: Hadro chemistry

Thermal fits “work” at √s = 2.4 GeV

No longer in equilibrium?

“ALL” strange hadrons needed in fits (STAR)

Lattice based calc. using fluctuations: ~agreement with Thermal model (PHENIX)
(PRС 93, 011901 (2016))

At low √s baryonic resonances required in models (HADES)
Establishing the “basics”: Kinetic freeze-out

Stronger collectivity at higher $\sqrt{s}$

Central collisions:
Lower $T \rightarrow$ higher $\beta$

$T_{\text{kin}} \sim T_{\text{ch}}$ below $\sqrt{s} \sim 7$ GeV
Disappearance of QGP?

Several standard signatures disappear at $\sqrt{s} < 15$ GeV

B-M $v_2$ separation gone

$\phi$ $v_2 \sim 0$

High $p_T$ suppression gone

$v_3 \sim 0$
First order phase transition?

Low $\sqrt{s}$: slope $v_1$(baryons) positive
slope $v_1$ (mesons) negative

Beam energy baryon $dv_1/dy$ trend
complex interplay of:

$v_1$ baryons transported from beam
$v_1$ from pair production

\[ \text{slope near mid-rapidity} \]
\[ 0.082 \pm 0.009 \]

Directed flow of protons
and pions at $s_N = 4.5$ GeV

• Proton flow is “positive”
• Pion flow is “negative”
• $p^+$ flow twice that of $p^-$

Open symbols are reflected
Statistical errors only
First order phase transition?

Low $\sqrt{s}$: slope $v_1(b)$ positive
slope $v_1(m)$ negative

Beam energy baryon $dv_1/dy$ trend
complex interplay of:

$v_1$ baryons transported from beam
$v_1$ from pair production
First order phase transition?

Low $\sqrt{s}$: slope $v_1$(baryons) positive
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Beam energy baryon $dv_1/dy$ trend
complex interplay of:

$v_1$ baryons transported from beam
$v_1$ from pair production

Net-proton isolates directed flow of transported baryons:

Double sign change in $dv_1/dy$
Not seen in net-kaons

Results not yet reproduced by theory

Softening of EoS?
Stalling of the expansion?

d final state coalescence access to nucleon freeze-out volume

\[
E_A \frac{d^3 N_A}{d^3 p_A} \approx B_A \left( E_p \frac{d^3 N_p}{d^3 p_p} \right)^A B_2 = \frac{6\pi^3 R_{np} m_d}{m_p V_f}
\]

B\text{\textsubscript{2}} minimum (V maximum) \sqrt{s_{NN}} \sim 20 \text{ GeV}
Stalling of the expansion?

d final state coalescence access to nucleon freeze-out volume

\[ E_A \frac{d^3N_A}{d^3p_A} \approx B_A \left( E_p \frac{d^3N_p}{d^3p_p} \right)^A \]

\[ B_2 = \frac{6\pi^3 R_{np} m_d}{m_p V_f} \]

B₂ minimum (V maximum) \( \sqrt{s_{NN}} \sim 20 \text{ GeV} \)

(R²_out - R²_side) sensitive to emission duration

Maximum at \( \sqrt{s_{NN}} \sim 20 \text{ GeV} \)

Softening of EoS?

Sign of entering compressed baryonic matter regime?
Eccentricity at freeze-out

Accessed via azimuthal HBT

Sensitivity to the EoS

trend smooth over all $\sqrt{s}$

No evidence of change in EoS

STAR data does not confirm CERES data
**HBT and the CP**

$(R^2_{\text{out}} - R^2_{\text{side}})$ sensitive to emission duration

Finite size scaling effects can be used to extract location of deconfinement transition

Plot of $\max (R^2_{\text{out}} - R^2_{\text{side}})$ as function of $R_{\text{glauber}}$ - Lifetime to initial transverse size of system mapping?

Slope and intercept give information on location of CP at infinite volume and the critical exponents

Infinite volume $\sqrt{s_{NN}} = 47$ GeV

$T^{\text{cep}} : 165$ MeV, $\mu_B^{\text{cep}} : 95$ MeV

2nd order phase transition, location ruled out by Lattice

R. Lacey, PRL 114, 142301
**Presence of Critical Point?**

Critical Points:
- divergence of susceptibilities
e.g. magnetism transitions
- divergence of correlation lengths
e.g. critical opalescence

Correlation lengths diverge
\[ \rightarrow \text{Net-}p\ k\sigma^2 \text{diverge} \]
**Presence of Critical Point?**

**Critical Points:**
- **divergence of susceptibilities**
  - e.g. magnetism transitions
- **divergence of correlation lengths**
  - e.g. critical opalescence

**Top 5% central collisions:**
- Non-monotonic behavior
- Enhanced $p_T$ range $\rightarrow$ enhanced signal

**Peripheral collisions:**
- smooth trend

**UrQMD (no Critical Point):**
- shows suppression at lower energies
  - due to baryon number conservation

**Correlation lengths diverge**

$\rightarrow$ Net-$p$ $\kappa \sigma^2$ diverge

---

**Fig. 1:** (color online)
- (a) – the density plot of the function $\kappa_4$
- (b) – the dependence of $\kappa_4$ along the vertical dashed green line on the density plot above. This line is the simplest example of a possible mapping of the freezeout trajectory (Fig. 2). The units of $\kappa_4$ are arbitrary.

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**Fig. 2:** A sketch of the phase diagram of QCD with the freezeout curve and a possible mapping of the Ising coordinates $tH \rightarrow +105$. The chemical potential is increased along the freezeout curve, possibly turning negative, as the critical point is approached (see Fig. 2 in Ref. [10]).

In addition, the mapping of the freezeout curve certainly need not be negative in the sector bounded by two curved rays.

The trend described above appears to show in the re-instantiation of the coupling $\beta$...
Presence of Critical Point?

Critical Points:
- divergence of susceptibilities
  e.g. magnetism transitions
- divergence of correlation lengths
  e.g. critical opalescence

Top 5% central collisions:
- Non-monotonic behavior
- Enhanced $p_T$ range $\rightarrow$ enhanced signal

Peripheral collisions:
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UrQMD (no Critical Point):
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Correlation lengths diverge $\rightarrow$ Net-$p$ $\kappa\sigma^2$ diverge

STAR Preliminary $|y|<0.5$, $0.4<p_T<2$
**Presence of Critical Point?**

HADES data + upcoming FXT testing if mapping correct

New HADES data causing some tension

![Graph showing correlation lengths diverge](image)

Correlation lengths diverge

→ Net-ρ κσ² diverge

Hints of Critical Fluctuations

N.B. non-monotonic behavior not observed by PHENIX - due to different acceptances?

(PrC 93, 011901 (2016))
Fluctuations in pp and light-nuclei collisions

Inelastic pp:

EPOS has variable success

Net charge fluctuations not due to independent emission (Skellam)

$p_T$, multiplicity, and forward energy fluctuations also studied in Ar+Sc

Monotonic behavior of all fluctuations studied for both collision species - No evidence of CP
A lot is happening around $\sqrt{s_{NN}} = 20$ GeV

Hard to believe this is a conspiracy of different underlying causes
Improving on current data

Current low energy data:
Hints that at low $\sqrt{s}$
- QGP turns off
- Ordered phase transition
- Critical Point

Future data:
- Examine regions of interest
- Maximizing fraction particles measured
- Probe lower $\sqrt{s}$
- High(er) luminosities
- Change species

Turn trends and features into definitive conclusions
### Planned low energy running

<table>
<thead>
<tr>
<th>$\mu_B$ (MeV)</th>
<th>560 - 230</th>
<th>850 - 670</th>
<th>790</th>
<th>720 - 210</th>
<th>750 - 330</th>
<th>780 - 400</th>
<th>850 - 490</th>
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<tbody>
<tr>
<td>$\sqrt{s_{NN}}$ (GeV)</td>
<td>4.9-17.3</td>
<td>2-3.5</td>
<td>2.4</td>
<td>3-19.6</td>
<td>2.7-11</td>
<td>2.7-8.2</td>
<td>2-6.2</td>
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<td>Facility</td>
<td>SPS</td>
<td>NICA</td>
<td>SIS-18</td>
<td>RHIC</td>
<td>NICA</td>
<td>SIS-100</td>
<td>J-PARC HI</td>
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<td>Experiment</td>
<td>NA61/SHINE</td>
<td>BM@N</td>
<td>HADES/miniCBM</td>
<td>STAR</td>
<td>MPD</td>
<td>CBM</td>
<td></td>
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<tr>
<td>Start Year</td>
<td>2009</td>
<td>2017</td>
<td>2018</td>
<td>2019</td>
<td>2020</td>
<td>2025</td>
<td>2025 (earliest)</td>
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<td>Physics</td>
<td>CP &amp; Onset</td>
<td>Dense Baryon</td>
<td>Dense Baryon</td>
<td>CP and Onset</td>
<td>Onset &amp; Dense Baryon</td>
<td>Onset &amp; Dense Baryon</td>
<td>Onset &amp; Dense Baryon</td>
</tr>
</tbody>
</table>

Expect wealth of new insights over next ~5 years

V.Kekelidze, T.Sakaguchi, P. Senger QM2017
STAR upgrades for BES-II

Enhanced Acceptance
Enhanced PID mid and forward
Enhanced Event Plane Resolution
Enhanced Centrality Definition
Enhanced $\sqrt{s}$ range

iTPC, EPD, eTOF (from CBM), Fixed target
**BES-II: Onset of deconfinement**

NA49 - claim onset of deconfinement at $\sqrt{s} = 7.7$ GeV

Fixed target program
- Collider can’t run below 7.7 GeV
- Target in beam pipe at $z=210$ cm

Dedicated short runs
- More efficient
- Successful tests completed

TOF+iTPC:
- Forward acceptance in fixed target mid-rapidity range
- Reach 7.7 GeV for fixed target too

Precision investigation with new techniques and same detector
**BES-II: Softening of EoS**

Current data: Double sign change of $v_1$

Precision measurement of $dv_1/dy$ as function of centrality

**iTPC+ eTOF:**

Enhanced coverage at forward $y$

Signal larger - role of baryon stopping

[Simulation: UrQMD at 19.6 GeV]
**BES-II: Softening of EoS**

Current data: Double sign change of $v_1$

Precision measurement of $dv_1/dy$ as function of centrality

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**iTPC+ eTOF:**

Enhanced coverage at forward $y$

Signal larger - role of baryon stopping

**EPD:**

Enhanced 1st order EP resolution

Reduced systematics
**BES-II: Critical fluctuations**

Current data: Suggestive of non-trivial $\sqrt{s}$ dependence of net proton cumulant ratios

**iTPC:**
- Increase $\Delta y_p$ acceptance
- $\Delta y_p > \Delta y$ correlation

**EPD:**
- Improved centrality selection
- Use all TPC for measurement

Establish true nature of correlation
Subject actively pursued theoretically
Low mass di-lepton excess

In Au+Au excess scales as $N^{1.3}_{\text{part}}$

Low mass excess $\propto$ fireball lifetime for large range of beam energies and centralities

Results suggest excess from total baryon driven hot dense medium effects and the medium’s lifetime

Looking forward to adding more low energy and LHC data into trend plots
Change the total baryon number

**ρ**-meson broadening:

different predictions for di-electron continuum (Rapp vs PHSD)

iTPC: Significant reduction in sys. and stat. uncertainties

Enables to distinguish between models for $\sqrt{s} = 7.7$-19.6 GeV
Change the total baryon number

ρ-meson broadening:

different predictions for di-electron continuum (Rapp vs PHSD)

iTPC: Significant reduction in sys. and stat. uncertainties

Enables to distinguish between models for $\sqrt{s} = 7.7 - 19.6$ GeV

Low Mass Region:

iTPC: Significant reduction in sys. and stat. uncertainties

Disentangle total baryon density effects
Change the total baryon number

\[ \rho \text{-meson broadening:} \]

**different predictions for di-electron continuum (Rapp vs PHSD)**

**iTPC:** Significant reduction in sys. and stat. uncertainties

Enables to distinguish between models for \( \sqrt{s} = 7.7-19.6 \text{ GeV} \)

**Low Mass Region:**

**iTPC:** Significant reduction in sys. and stat. uncertainties

Disentangle total baryon density effects

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J. Butterworth HP2016, T. Galatyuk, QM2017
Summary

Data exists over wide range of $\sqrt{s}$ for heavy & light ions, p(d)-A, and pp

High statistics exploration of QCD phase diagram and its key features is about to begin

New data from FAIR, NICA, RHIC and SPS just around the corner

Significantly extended detection capabilities compared to existing data

Strong theoretical interest focussed in BEST and HICforFAIR, increased number of focussed workshops

In conjunction: Turn trends and features into definitive conclusions
BACK UP
Baryon density considerations

piN cross-section important at low \( \sqrt{s} \)
Baryon density considerations

[Graphs and data plots discussing Baryon density and freeze-out distributions, with emphasis on STAR and ALICE data.]
Current and expected data

LHC: 2760, 5000

RHIC: BES-I
BES-II - Fixed target
2.5 - 19.6
d+Au 200, 62, 38, 20
Cu+Au 200, 62

SPS: 5.1-17.3
Lighter ions

SIS: 2.6, 2.6

FAIR: 2.7-8.2

NICA: 2-11

J-PARC: 2-6.2

Wealth of data in hand and more coming soon
**Light and intermediate mass collisions**

The most interesting region of the phase diagram is accessible at the SPS. Onset of deconfinement at \( \tau \approx 30 \) \( A \) GeV (\( \div s_{\text{NN}} = 7.6 \) GeV) \( \text{PR C77, 024903, 2008} \).

**Critical point? Example:** \( (T_{\text{CP}}, \mu_B) = (162(2), 360(40)) \) MeV \( \text{JHEP 0404, 050, 2004} \).

**NA61/SHINE:** Comprehensive scan including variety of nuclei.

**NA61 collected data**

**NA61 future data**

**RHIC:**
- \( d+Au: 200, 62, 38, 20 \)
- \( Cu+Au: 200, 62 \)
- \( p+Au, p+Al \)
- \( He^3+Au: 200 \)

Can we see evidence of stepping across boundary while keeping \( \mu_B \) fixed?

Grabieszkow CPOD 2016, J. Velkovska QM2017
"Dale" in longitudinal expansion

Probe expansion dynamics:

Width of rapidity distribution compared to Landau hydro. expansion predictions

Minimum observed at $\sqrt{s} = \sim 7$ GeV

Minimum in the speed of sound?

$c_s^2 \sim 0.26$

Another indication of softening of EoS?

NA61/SHINE see minima in similar place for pp data

BES results for $\pi^+$ and $\pi^-$

Christopher Flores
QM2015 September 29, 2015

STAR sees an increase in the ratio of the measured pion width to the predicted hydro width confirming trend of previous NA49 measurements.

BRAHMS: I.G. Bearden et al., PRL 94, 162301
Longitudinal expansion

Fermi-Landau initial conditions
Ideal Hydrodynamic expansion

\[ p(\varepsilon) = c_s^2 \varepsilon \]

\[ \frac{dn}{dy} = \frac{K s_{NN}^{1/4}}{\sqrt{2\pi \sigma_y^2}} e^{-\frac{y^2}{2\sigma_y^2}} \sigma_y^2 = \frac{8}{3} \frac{c_s^2}{1 - c_s^4} \ln \left( \frac{\sqrt{s}}{2m_N} \right) \]

consistent results
however:
1. minimum is not well defined
2. similar behavior for p+p!
**Fluctuations at RHIC**

1) The results of net-Q and net-Kaon show flat energy dependence.
2) Net-p shows **non-monotonic energy dependence** in the most central Au+Au collisions starting at $\sqrt{s_{NN}} < 27$ GeV!

PHENIX: talk by P. Garg at QM2015;  
STAR: talk by J. Thöder and poster by J. Xu at QM2015
Net charge fluctuations at RHIC

Data in agreement with NBD calculations

Can’t make direct comparison because of differing acceptances
Horns and plateaus

K/π ratio:

Mid-rapidity same results at total yield

Baryon density peaks at $\sqrt{s} \sim 7$ GeV as models suggest

RHIC data suggests horn less pronounced

T_{kin}:

pp values lower but trend similar to A-A

A. Aduszkiewicz QM2017, K. Grebieszkow CPOD16
Critical Point and Onset of Deconfinement 2016 and Working Group Meeting of COST Action MP1304

Wrocław, Poland
May 30th - June 4th, 2016

Wrocław is the largest city in western Poland. It is on the River Oder in the Silesian Lowlands of Central Europe, roughly 350 kilometres (220 miles) from the Baltic Sea to the north and 40 kilometres (25 miles) from the Sudeten Mountains to the south. Wrocław is the historical capital of Silesia and Lower Silesia. See more from [wiki](#).

Wrocław was selected as the European Capital of Culture 2016. Throughout the year there will be dozens of cultural events and festivals. Thanks to a number of festivals ongoing in Wrocław during CPOD2016 (Ethno Jazz Festival and Simcha - Jewish culture festival), we were able to provide you with a list of recommended events. The list is presented in a handy form of calendar. You can find the basic information about the events below, as well as ticketing informations.

M. Gazdzicki and P. Seyboth, arXiv: 1506.08141

- Central Pb+Pb collisions (7.2%) vs. collision energy
- Flat strcture

- Collision centrality dependence at 158 GeV/c.
- Peak around C+C, Si+Si collisions

Real critical behavior?
QGP Creation: Jet Quenching

Cronin may be hiding $E_{\text{loss}}$

For $\sqrt{s_{NN}} \geq 14.5$ GeV central events show suppression compared to next peripheral bin

7.7 and 11.5 GeV results increase monotonically

200 GeV results decrease monotonically

Where does $d+Au$ data sit?
Splitting of the $v_2$

At large $\mu_B$, low collision energies, the number of quark scaling in $v_2$ is broken

(a) Hydro + Transport: Baryon results fit

(b) NJL model: Sensitive to vector-coupling, CME, $\mu_B$ driven.

(c) Hydro solution: Chemical potential $\mu_B$ and viscosity $\eta/s$ driven!
Decoupling of temperatures

Is this related to the softening of EoS?

\[ T_{\text{ch}}(\text{MeV}) \quad \text{and} \quad T_{\text{kin}}(\text{MeV}) \]

\[ \langle \beta \rangle \]


Chemical Freeze out

D. Mishra, QM 2015, Kobe, Japan


High Energy

Low Energy

Stephen Horvat (YALE)
HQ2016, South Padre Island

200 GeV

14.5 GeV

7.7 GeV

\[ T_{\text{ch}}(\text{GeV}) \]

\[ \mu_{B}(\text{GeV}) \]

Au+Au (GCE: Ratios)

\[ T_{\text{ch}}(\text{GeV}) \]

\[ \langle \beta \rangle \]
Comparisons of Observables

CPOD 2016, Wroclaw, 30 May 2016

Volker Friese

Restrictions: by rate and/or by instrumentation

- Charmonium
- Open charm
- Anti-hyperons
- IM dileptons
- LM dileptons
- Bulk flow, strangeness, fluctuations

Collision Energy $\sqrt{s_{NN}}$ [GeV]
CBM at FAIR

FAIR: One of the highest intensity accelerator complex in the 21st century

Precision measurements at high baryon density region for:

(i) Dileptons ($e$, $\mu$); (ii) High order correlations; (iii) Flavor productions ($s$, $c$)
FAIR-MSV Schedule

Module 0
SIS100, tunnels

Module 1
CBM/HADES
APPA cave exp

Module 2
NUSTAR Super-FRS exp

Module 3
PANDA, NUSTAR ring exp, APPA (SPARC@HESR)

Volker Friese
CPOD 2016, Wroclaw, 30 May 2016
**Baryonic Matter at Nuclotron (BM@N)**

**SPD (Spin Physics Detector)**

Ring circumference 503.04 m.

**MultiPurpose Detector (MPD)**
Heavy ion colliding beams up to $^{197}$Au$^{79+} + ^{197}$Au$^{79+}$
at $s_{NN} = 4 \div 11$ GeV, \quad $L_{\text{average}} = 1 \times 10^{27}$ cm$^{-2}$s$^{-1}$

Light-Heavy ion colliding beams of the same $s_{NN}$ and the same or higher $L_{\text{average}}$

Polarized beams of protons and deuterons in collider mode:
\[ \text{pp} \quad s_{pp} = 12 \div 26 \text{ GeV} \quad L_{\text{max}} \approx 1 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \]
\[ \text{dd} \quad s_{NN} = 4 \div 13.8 \text{ GeV} \]

Extracted beams of light ions and polarized protons and deuterons for fixed target experiments:
\[ \text{Li } \text{Au} = 1 \quad 4.5 \text{ GeV/u} \quad \text{ion kinetic energy} \]
\[ p, p = 5 \div 12.6 \text{ GeV} \quad \text{kinetic energy} \]
\[ d, d = 2 \div 5.9 \text{ GeV/u} \quad \text{ion kinetic energy} \]

Applied research on ion beams at kinetic energy above 3 MeV/u
QCD Matter Physics at NICA

BM@N:
- Fixed-target, \( E_{\text{beam}} = 1 \text{A} - 4.5 \text{A GeV} \) from Nuclotron
- Interaction rates up to 50 kHz
- Measurement of hadrons
- Time line: light ion beams 2017, heavy ion beams 2019

MPD:
- Collider experiment, \( \sqrt{s_{\text{NN}}} = 4 - 11 \text{ GeV} \)
- Interaction rate up to 10 MHz (depending on energy)
- Hadron and lepton measurements
- Time line (staged): 2019 - 2013
Additional ion acceleration scheme
Extracted beams for fixed-target experiments
Energy: 1A – 19A GeV
Extreme rates (4 x 10^{11} / cycle)
BES-II: Detailed Run Plan

Run in 2019 & 2020 will have **significant** physics impact

<table>
<thead>
<tr>
<th>Collision Energies (GeV):</th>
<th>7.7</th>
<th>9.1</th>
<th>11.5</th>
<th>14.5</th>
<th>19.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Potential (MeV):</td>
<td>420</td>
<td>370</td>
<td>315</td>
<td>260</td>
<td>205</td>
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<tr>
<td>Observables</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$R_{CP}$ up to $p_T$ 4.5 GeV</td>
<td>NA</td>
<td>NA</td>
<td>160</td>
<td>92</td>
<td>22</td>
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<tr>
<td>Elliptic Flow of $\phi$ meson ($v_2$)</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>300</td>
<td>400</td>
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<td>Local Parity Violation (CME)</td>
<td>50</td>
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<tr>
<td>Directed Flow studies ($v_1$)</td>
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<td>75</td>
<td>100</td>
<td>100</td>
<td>200</td>
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<td>asHBT (proton-proton)</td>
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<td>65</td>
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<td>net-proton kurtosis ($\kappa\sigma^2$)</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>200</td>
<td>400</td>
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<tr>
<td>Dileptons</td>
<td>100</td>
<td>160</td>
<td>230</td>
<td>300</td>
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**Proposed Number of Events:**

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<tr>
<th></th>
<th>100</th>
<th>160</th>
<th>230</th>
<th>300</th>
<th>400</th>
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<tr>
<td>BES-I stats.</td>
<td>4</td>
<td>N/A</td>
<td>12</td>
<td>20</td>
<td>36</td>
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</tbody>
</table>

Fixed target running enables data from $\sqrt{s} = 3$-7.7 GeV

**eCooling** - Enables the significant statistics enhancement
Event Plane Detector: EPD

2.1 < |η| < 5.0

Replacing BBCs

16 radial and 24 azimuthal sections

Greatly improved Event Plane Resolution especially 1st-order EP

Determine Centrality away from mid-rapidity

Better trigger & background reduction
**BES-II: Vorticity and Initial B-field**

**BES-I: First measurement of \( \Lambda \) Global Polarization**

Vortical + Magnetic Contributions:
- Current data barely stat. significant

**EPD:**
- Improved EP resolution

**BES-II:** 3\( \sigma \) effect

**Unique measurement of B**
Significant input to CME/CVE interpretations
Endcap Time-Of-Flight: eTOF

Compressed Baryonic Matter Experiment (CBM)
1/10th TOF modules installed inside East pole-tip

Large-scale integration test of system for CBM
Single TOF module for Run-17 - integration test

Forward PID over iTPC $\eta$ range
$-1.6 < \eta < -1.1$
TPC $dE/dx$ effic. drops rapidly in this range due to $p_z$ boost
iTPC

Increase in #channels in 24 inner sectors by ~factor 2

Provides near complete coverage

New electronics for inner sectors

Enhanced rapidity coverage

Old
-1 < \( \eta \) < 1
\( p_T > 125 \text{ MeV}/c \)

New
better \( dE/dx \);
-1.5 < \( \eta \) < 1.5;
\( p_T > 60 \text{ MeV}/c \).
Enhanced tracking and $dE/dx$ performance

STAR TPC in the BES-II

Increased coverage, efficiency and $dE/dx$ resolution out to $|\eta| < 1.5$