## **Plan for Today**



1.	LDRD office introduction & review charge (5')	8:00-8:05 Bill Priedhorsky
2.	LDRD overview and goals (35')	8:05-8:40 Ming Liu
	<ul> <li>High-level summary of Experiment and 1</li> </ul>	Theory
	<ul> <li>Cost &amp; schedule of LDRD</li> </ul>	
3.	Progress and Plan (I)	
	<ul> <li>Theory – Introduction and perturbative C</li> </ul>	CD (20') 8:40 – 9:00 Ivan Vitev
	<ul> <li>Soft Collinear Effective Theory for b-jet</li> </ul>	
	substructure (15')	9:00 - 9:15 Chris Lee
	c. Molecular Dynamics simulations (15')	9:15 - 9:30 Jerome Daligault
	d. Hydro and numerical computations (15')	9:30 - 9:45 Boram Yoon
Со	offee break – 15'	9:45-10:00

#### Coffee bro

#### 4. Progress and Plan (II)

- Physics & detector simulations (15')
- b. ALPIDE introduction & test stand (15')
- c. MVTX readout integration (15')
- d. Telescope & tracking test (15')
- e. MVTX mechanical conceptual design (15')
- Summary and transition plan MVTX proposal (25')
  - Cost & schedule of MVTX/sPHENIX

#### End of presentations, short break - 10'

- Executive closed session/Lunch (60')
- Panel meet with PI/co-PI (10')

- 10:00-10:15 Darren McGlinchey 10:15-10:30, Xuan Li 10:30-10:45 Alex Tkatchev
- 10:45-11:00 Sho Uemura
- 11:00-11:15 Walt Sondheim
  - 11:15-11:40 Cesar da Silva

11:50-12:50 Committee 12:50-13:00 Committee





## Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX

## Ming Liu (PI) P-25 02/01/2018

Thanks for the strong support from LDRD Office and LANL Program Management



UNCLASSIFIED

# The LDRD Team



### Experimental group

- P-25, AOT
- Detector readout and mechanical support R&D
- Detector modeling and simulations
- Physics simulations
- Theoretical group
  - T-2, T-5, CCS-7
  - Physics modeling & simulations
- Budget: 1.6M/Year, FY17-19
  - 1/3 on experimental T&E
  - 1/3 on theoretical T&E
  - 1/3 on Hardware & M&S



















































## Outline



- LDRD scientific goals
- Project scope, status and plan
- Mission impacts
- Transition Plan





The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE







## **QGP** Discovery



# nature

QGP discovery announced in 2004 by RHIC experiments, confirmed later at LHC

PHENIX mission completed in 2016 Upgrade path – sPHENIX @RHIC

innovation for our nation



- Unambiguous evidence for phase transition from ordinary nuclear matter to QGP (T<sub>QGP</sub>~175 MeV, ~10<sup>12</sup> degrees)
- Fundamental discovery: QGP is not a weakly interacting gas of quarks and gluons, but rather a strongly coupled **near-perfect liquid!**
- Exhibits strong collective behavior, has huge stopping power for color-charged particles (quarks, gluons the fundamental constituents)

## Big Question for Science: From what microscopic structure do these properties emerge?→Requires new observables!

# Bring Big Science to LANL



- sPHENIX the next US NP flagship heavy ion physics program, to study the inner workings of QGP
  - Granted CD0 9/2016; CD1 scheduled 5/2018
  - Constr. 2019 2022; Physics runs: 2023-2027+
- This LDRD will allows LANL to take a leadership role in sPHENIX and be a key player in the Heavy Ion physics frontier
  - Innovation: develop a new open heavy flavor physics program, identified as the 3<sup>rd</sup> Science Pillar of the sPHENIX experiment
  - Bring new state of the art technical capability to LANL applied program, also future EIC program





## **Complement & extend current and future RHIC and LHC QGP programs**



## LANL Proposed Monolithic-Active-Pixel-Sensor-based Vertex Detector (MVTX)



#### sPHENIX upgrade @RHIC



## **SPHENIX Tracking System with MVTX**





# **LDRD Scientific Goals**



- Develop a next generation QGP physics program with heavy quark jets at RHIC with full detector and physics simulation and modeling
- Carry out key detector R&D to demonstrate the open heavy flavor physics capability in the sPHENIX with MVTX
- Develop a proposal to DOE to build a state-ofthe-art MAPS-based Vertex Detector for the sPHENIX
- New theoretical study of QGP tomography with b-jets



#### B-jet suppression in QGP



Transverse Momentum [GeV/c]





## New Physics Reach with MVTX



#### Ivan and Darren's talks

- Heavy quarks unique probe of QGP w/ new scales, m<sub>c</sub>, m<sub>b</sub>
  - Study mass dependence
    - Jet quenching & energy loss
    - Flow interaction with medium
  - Access QGP properties
    - Temperature, density, coupling, transport coefficients, viscosity etc.

### "Money plots" from MVTX proposal



"B meson and b-jet modification"

### "B meson and b-jet flow"



# LDRD Project Scope



Established at the beginning of this project feasibility review 1/2017

### • Minimal scope

- Develop a MVTX prototype telescope with 4 ALPIDE sensors/staves with ALICE readout units, complete sPHENIX DAQ integration
- Complete R&D on mechanical conceptual design, sPHENIX system integration
- Develop b-jet tagging algorithms for p+p and Au+Au
- DOE MIE proposal submitted to fund the full detector construction
- Complete b-jet theory for precision tomography of QGP with sPHENIX

### • Desired scope

- Develop a full 4-production-staves MAPS telescope, test beam run with integrated sPHENIX DAQ
- $\bigcirc$  DOE MIE proposal approved for the full detector construction



# LORD Timeline: Experiment Los Alamos

#### **Milestones achieved**

- MOU with ALICE
- B-tagging in p+p and Au+Au
- BNL Director's Review, recom'ed to proceed w/ full proposal
- Full readout chain demonstrated
- Mechanical conceptual design
- Collaboration formed and full MVTX proposal submitted

Talks by Darren, Xuan, Alex, Sho, Walt, Cesar

### On track to succeed!



LDRD innovation for our nation

Ming Liu, LDRD Overview

# LDRD Scope: Theory

- Significant progress
  - New calculations and new observables
  - Met milestones, some ahead of time



Today





Ivan's talk

## **ALICE Pixel Detector (ALPIDE)**



### The 2<sup>nd</sup> generation state of the art MAPS technology

- ALPIDE highlights:
  - Very fine pitch (28x28 μm)
  - High hit efficiency (>99%) and low noise (<10<sup>-6</sup>)
  - Fast response, ~5µS
  - Ultra-thin/low mass,  $50\mu m$  (~0.3% X<sub>0</sub>)
  - On-pixel digitization, low power dissipation
  - Sensor chip: 1.5cm x 3.0cm, 0.5M pixels (512x1024)

### An ideal detector for QGP b-jet physics!





### Tower Jazz 0.18 µm CMOS

- feature size 180 nm
- metal layers 6
- gate oxide 3nm

substrate:	N <sub>A</sub> ~ 10 <sup>18</sup>
epitaxial layer:	$N_{A} \simeq 10^{13}$
deep p-well:	$N_{A} \simeq 10^{16}$

## LDRD Highlights (I)

**MVTX** Sensors, Readout and Control System Developed

#### Alex and Xuan's talks

NATIONAL LABORATORY

#### **ALPIDE pixel circuit**



### 1) Demonstrated full high-speed readout chain,

- 1 Stave + RU + FELIX + RCDAQ/sPHENIX
- Eliminated the highest technical risk "readout integration"
- ) ALPIDE and Power Unit control and monitor being evaluated



## LDRD Highlights (II)





### MOSAIC test bench in operation

- Allows high-speed readout of ALPIDE chip, 1.2Gbps
- Scanned sensor response parameters – optimization of operating point in progress
- Laser testing system setup in preparation
  - Laser pulses to inject MIP-level signal to each pixel
  - Scan full parameter space to optimize the operation point for sPHENIX







## **MVTX** Prototype Telescope Development



#### Sho and Darren's talks

#### • Goal: A 4-stave telescope

- Sensor response and cluster size, MC tuning
- Hit spatial resolution
- Tracking and offline reconstruction
- Full readout chain
- Cooling and mechanical stability
- 1st beam test at Fermilab, 3/2018
  - Multi-layer ALPIDE chips telescope being assembled at LANL
  - Readout system developed
  - MC and offline analysis code developed
- Cosmic test later 2018
  - Tracking and offline reconstruction
  - Benchmark MC response
- In process
  - Staves & readout electronics procurement
  - Negative pressure system design





LDRD Highlights (III) MVTX Detector Conceptual Mechanical Design Completed



#### Walt's talk

 View of MVTX half detector assembly with extended central barrel









## **LDRD Highlights (IV)** Simulation for *b*-jet and *B*-meson tagging







# **Procurements in FY17-18**



### ALPIDE Sensors

- 1 single chip with slow readout DAQ boards
- 5 single chip sensors with high-speed readout adaptor
  - 10 more to be produced locally
- 1 9-chip stave module
  - 5 more ordered for FY18
- Readout Units
  - 1 RU v1.0
    - 5 RU v1.x ordered FY18
- FELIX back end
  - 1 FELIX v1.5
    - 2 FELIX v2.0 available soon
- Linux DAQ server
  - 1 Linux in operation
- Power system
  - 1 32-chan power distribution boards
  - CEAN rad-hard power modules and server
    - CEAN rad-hard bulk power supply available later in FY18
- Telescope mechanical support
  - 1 box made
- Cooling system
  - Chiller purchased and tested

Negative-pressure system design in progress











## **FY18 Milestones**



### • Achieved:

- Developed full high-speed readout chain with ALPIDE sensors and stave and near final readout electronics RU and FELIX, and integrated the readout chain with sPHENIX RCDAQ
  - Removed the highest risk item in the project the readout system integration
- Completed initial sPHENIX MVTX mechanical system integration and layout
- Completed and benchmarked b-jet tagging for pp and AuAu with full detector GEANT simulations
- Completed and submitted the MVTX full proposal to BNL ALD

### • In progress:

- To construct a 4-stave/chip MVTX prototype telescope and take cosmic ray data
  - Mechanical enclosure completed
  - More Staves and RUs ordered
  - Cooling system under development
- To complete readout and control integration with the final electronics (RUv.1x and FELIXv2.0) for full system integration



## Major Tasks to Complete the Project



- ALPIDE sensor characterization and optimization
  - Readout and trigger optimization for sPHENIX
  - Laser system in preparation
  - Full readout and control integration in sPHENIX
    - Full readout with RHIC clock and trigger
      - RUv1.x, FELIXv2.0 and firmware & controls
      - Electronics production/procurements in process
      - sPHENIX DAQ system development in progress
- MVTX mechanical system integration in sPHENIX
  - Barrel section extension R&D
    - Signal extension and long SamTec cables
  - Mechanical system integration
    - MVTX & INTT
- MVTX prototype telescope final beam test at Fermilab
  - Demonstrate tracking capability, spatial resolution
  - High trigger rate (15kHz) at high event multiplicity











2019

2018

## Major Technical Challenges and Risks from Previous Feasibility Review Mitigated/Addressed



- Project Risks with timely procurements of R&D items from CERN
  - ALPIDE Sensors:
    - a "Plan-B" was developed to us ~4 single chip ALPIDE sensors.
  - Readout electronics and custom design
    - A prototype Readout Unit (RU) with Xilinx evaluation board KC705 was developed before the arrival of RUv1.0
    - An alternative path was successfully developed with ATLAS FELIX board to replace ALICE CRU
  - Risks mitigated, full readout chain electronics integration designed and tested.
- Needs of the test beam for the full proposal
  - With the successful R&D of the full readout chain and sensors, we have determined that a test beam is not required for the full proposal submission.
  - 1<sup>st</sup> teat beam in preparation, ahead of schedule, to study sensor response and readout characterization.
  - Full proposal completed and submitted
- Add more milestones to MIE proposal development
  - Implicit milestones in the LDRD project:
    - 1. To build a collaboration and submit a pre-proposal by the end of the first year FY17;
    - 2. To have science and technical reviews in the 2<sup>nd</sup> year and complete a full proposal by the end of FY18;
    - 3. To have the full proposal reviewed and approved by DOE by the end of FY19.
  - Achieved:

innovation for our nation

- 1. The 1<sup>st</sup> milestone in Feb 2017, ahead of plan; the MVTX detector collaboration is formed and growing, with 22 institutions from the world
- 2. The 2<sup>nd</sup> milestone in Jan 2018, ahead of plan. Successful MVTX BNL Directors review in July 2017.
- 3. LANL LDRD team is working closely with sPHENIX and BNL management to realize the full program.
- Full proposal completed and submitted
- Setup simulation milestones for the MIE proposal
  - A full sPHENIX tracking simulation package has been developed, milestones achieved and used for realistic b-jet tagging study for the full MVTX proposal.

Full proposal completed and submitted

# **Mission Impact**



This LDRD directly contributes to the LANL NPAC (Nuclear, Particle, Astrophysics and Cosmology) and DOE Nuclear Physics program, expand the leadership of LANL at national & international level:

- High impact on big science
  - New physics programs at RHIC and EIC
- Define the directions for LANL basic and applied programs
  - Long-term DOE NP Program
  - New hiring Xuan, Sho(P-25), Darren(XTD/P-25)
  - Promotions Mike(XCP), Cesar
  - Applications to LANL applied program

#### New ideas/proposals developed based on R&D from this LDRD project

- New x-ray imaging with MAPS
- New neutron detector with MAPS
- High-speed MAPS readout R&D for MARIE & EIC programs

### LDRD innovation for our nation

## NSAC Long Range Plan 2015 Recommendation #1 (RHIC):

The highest priority in this 2015 Plan is to capitalize on the investments made.

 The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.

### Recommendation #3 (EIC):

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.



## MVTX Full Proposal Development

#### • MVTX detector collaboration formed, 1/2017

- International collaboration of 22 institutions, and counting
- Bi-weekly detector R&D and physics simulation meetings
- Weekly project development meetings, project leaders from LANL, BNL, MIT and LBNL
- A pre-proposal completed and submitted through BNL ALD to DOE in Feb. 2017
  - Initial feedback from DOE, positive, compelling science
- Successful MVTX BNL Directors review, July 2017
  - Recommended to proceed with a full proposal
- Organized workshops for detector R&D and physics program development
  - MVTX physics and detector design, 1/2017, LBNL
  - Readout electronics R&D, 4/2017, UT-Austin
  - Cost & schedule workfest, 6/2017, BNL
  - MVTX and Heavy Flavor physics, 12/2017, Santa Fe

#### • A full MVTX proposal completed and submitted to BNL ALD 1/2018











# **Transition Plan**



Cesar's talk

- The transition plan details are still being worked out and evolving
  - Develop a long term DOE NP program
- MVTX funding news (received by MVTX group on 1/19/2018)
  - From email by BNL Associate Laboratory Director (ALD) Dr. Berndt Mueller:
    - DOE "appreciate the compelling science this instrument could enable ..." "but unfortunately in our present outlook, we do not foresee at this time that we would be able to identify new DOE funding for the purpose of implementing the MVTX" and "encourage efforts to secure such [external] contributions..."
- LDRD team is working closely with sPHENIX collaboration and BNL management to seek alternative path to fund the full MVTX detector.
  - Several options being explored within the sPHENIX collaboration
  - Possible direct and indirect foreign contributions



## Summary



### • Achieved all LDRD milestones, some ahead of time, risks mitigated

- Designed and tested full readout system
- Developed mechanical conceptual design
- Completed b-jet tagging and preliminary physics study with full simulations
- A MVTX prototype telescope being constructed
  - In preparation for the 1<sup>st</sup> beam test at Fermilab w/ sPHENIX
- New theoretical development
  - High impact papers published
- Developed a new heavy quark physics program for sPHENIX
  - Completed and submitted the full MVTX proposal to BNL ALD
  - DOE "appreciate the compelling science", but new funding is challenging at this time
- Broad impact on LANL NP and other applied programs
  - New hires and promotions, new ideas and proposals

## On track to meet LDRD goals for FY18 and FY19



## backup





# MVTX Cost and Schedule

- Total budget: 6.5M •
  - Production
  - Assembly
  - Integration
- About 9 months schedule float •



Figure 42: MVTX Funding Profile.

Major Items	Cost w/ 35% Cont. (\$M)	Schedule
Staves (WBS 1.5.3.1)	1.3	8/2018-5/2019
Readout & Controls (WBS 1.5.2)	1.3	1/2019-6/2019
Mechanics & Detector Assembly (WBS 1.5.3)	1.8	2019-2022, TBO
Integration (WBS 1.5.4)	1.0	2021-2022, TBO
Project Management	1.0	8/2018-1/2023



## **MVTX:MAPS-based Vertex Detector**



### A separate upgrade project for the baseline sPHENIX: Jet + B-tagging



		Dacalina
WBS	sPHENIX MIE Project Elements	Daselille
1.1	Project Management	
1.2	Time Projection Chamber	
1.3	Electromagnetic Calorimeter	
1.4	Hadron Calorimeter	
1.5	Calorimeter Electronics	
1.6	DAQ-Trigger	
1.7	Minimum Bias Trigger Detector	
$\mathbf{WBS}$	Infrastructure & Facility Upgrade	
1.8	SC-Magnet	
1.9	Infrastructure	
1.10	Installation-Integration	
		1

#### **Parallel Activities**

- MAPS-based Vertex Detector (MVTX)
- Intermediate Silicon Strip Tracker (INTT)

Upgrades



## **sPHENIX vs ALICE**



	ALICE (Run3)	sPHENIX
Pb+Pb / Au+Au	100 kHz (50kHz)	200 kHz
p+p	400 kHz (200kHz)	13 MHz
Trigger	50 kHz	15 kHz

Event size, dN/dq: sPHENIX = 1/3 ALICE (pp), 1/5 ALICE(AA)







### RHIC Multi-Year Plan: sPHENIX 2022-

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
2022	Au+Au	200	16.0	$7 \text{ nb}^{-1}$	$8.7 \text{ nb}^{-1}$	$34 \text{ nb}^{-1}$
2023	p+p	200	11.5		$48 \text{ pb}^{-1}$	$267 \text{ pb}^{-1}$
2023	p+Au	200	11.5		$0.33 \text{ pb}^{-1}$	$1.46 \text{ pb}^{-1}$
2024	Au+Au	200	23.5	$14 \text{ nb}^{-1}$	$26 \text{ nb}^{-1}$	$88 \text{ nb}^{-1}$
2025	p+p	200	23.5		$149 \text{ pb}^{-1}$	$783 { m ~pb^{-1}}$
2026	Au+Au	200	23.5	$14 \text{ nb}^{-1}$	$48 \text{ nb}^{-1}$	$92 \text{ nb}^{-1}$

- Precision 2<sup>nd</sup> vertexing for B-tagging:
  - Tracking resolution better than 50um @pT=1GeV
  - High multiplicity HI collisions
  - Low multiplicity but high rate p+p collisions
  - High efficiency and high purity

B hadrons/pT<15GeV: O(1M) b-jets/pT>15GeV: O(100K)





EVONINS

# LDRD Key Tasks/Milestones Los Alamos

### Original plan-A, 7/2017

