Notes on Large Collider Detectors for NP

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Leadership

- Set up your Ruling Triumvirate or Gang of Four early
  - Get it over with
  - Insist they drop commitments to other experiments
  - Hire a lead engineer (preferably with a few ‘singe marks’)
  - Find/hire someone who speaks EVMS
  - Find someone who can schedule in Primavera; arrange for their full attention
  - Find someone to head Simulations; make sure they understand it is a thankless task

- Set a master timeline
  - It takes 3 years to get to CD-3; by 10 years you want to be looking at collisions
- Set collaboration by-laws early
  - They establish ground rules for engagement and fair play (can always amend)
- Set up a Speaker’s Bureau early and use it
  - Advertise your experiment
  - Gain exposure for younger members
  - (ahem) Compel working to deadlines ;-)

Central Physics Design Group

- Set up a group of 8-10 physicists to act as a central design group
  - PHENIX called them the Young Turks
  - In days of e-mail they corresponded regularly and met monthly
  - The Bosses gave them a free hand, modulo non-infinite cash supplies
  - The Bosses insisted assertions be backed up by homework
  - The Bosses set minimum requirements for physics capability (photons and electrons below 1.5 GeV for PHENIX, triggerable, full event rate matched to accelerator)
- Empower them
- Expect it to take a year to define things
  - Sure, you will be reviewed before then
  - Designs mature from CD-1 to CD-2 to CD-3

Consider the Scale of the Enterprise

- Rubbia's rule (1983): One physicist can spend $100K/year
- Update to 2020: maybe $300K/year?
- That implies 1000 person-years effort "just to build the thing", or 160 full-time physicists assigned to detector construction for 6 years
- Double that (at least) for software type activities
- Double again for engineering, design and technician work

- PHENIX peaked at 650 people (350 physicists) circa 1997-1998 and cost $200M in today's dollars

R&D Program

- Define where you need R&D
  - This is NOT conceptual R&D – this is R&D for developing a manufacturable item
  - Include 1-2 rounds of concept check, then prototype, then pre-production prototype
  - Determine if you need a test beam and/or one or more cosmic ray test stands
    - Figure out where these need to be (FNAL or JLab or CERN for test beams?)
    - More than one Cosmic Ray test stand will be very helpful in 2-3 years
    - These also nucleate your DAQ group
- Obvious R&D topics
  - Photosensors
  - Radiation hardness – detectors and electronics both
  - PID method for e & γ, for $\pi/p/K$
- You cannot cost or schedule what you cannot define (think CD-2/3)

Estimating Notes

- Figure out how many engineers you will need – double it
- Figure out how many designers you will need – triple it
- Figure out how many techs you will need – hmm, add 50%
  - BUT – start figuring out where they will be employed and where they will work
- Figure out your factory space needs and start to find/commit the space
  - I had to build 4 clean rooms at JLab for 12GeV – that's $1.5-$2M of 'stuff' that you will not be installing into your detector

- Learn what Estimate Uncertainty and Risk Uncertainty are
  - Understand that they measure different things
  - DOE will expect a full-blown Risk Registry
- Acclimate yourself early on to saying "50% Contingency"

On or Off the DOE Budget

- Non-DOE contributions are encouraged; PHENIX was >50% non-DOE funds
- Other USA funding agencies; Other countries; Re-purposed equipment
- International contributions may require an MOA or "higher" agreement
- Timeline is critical – it would not be surprising if DOE tells you that if you do not have a firm commitment by CD-2/3, then the cost has to go into the DOE baseline
- START NOW
- Future additions are OK, but your baseline detector MUST PERFORM A PHYSICS PROGRAM
- Example: the barrel microMEGAS tracker and nTOF in CLAS12 – added a program of tagged recoil hadrons e.g. enhanced the SIDIS program. The south muon arm in PHENIX added the spin-physics program

Setting a Scale

- Compel yourselves to decide the following within the year
  - Physics ‘in or out’ – see ‘Young Turks’ slide earlier
  - angular coverages
  - PID workhorses (type of Cerenkov? TOF? dE/dx?)
  - segmentations
  - channel counts
  - minimum-acceptable resolutions
  - event rates and data volumes
  - Can Jim Yeck afford your data storage needs?
  - Can DOE afford the computing power to analyze it all?

- You cannot cost and schedule and staff what you cannot first define

Decide Your Tracking Technology

- PHENIX lost a year in these discussions, guided out of the wilderness by a junior professor who challenged the Elders
- Do you really have to have redundant coverage over a particular piece of phase space?
- What physics drives your resolution requirements?
- If the wonderous device which you just must have has not ever run in a physics experiment, decide how long you can hold the decision open while doing R&D work before you have to pick something known to work
    - 2 years for prototyping of an unproven concept is a very long time in 413-world

Decide the Required Calorimetry Performance

- The sPHENIX EMCAL will need refurbishment. The SiPMs will be wearing out. Aim for more areal coverage – improve the position non-uniformity
- The barrel HCAL ought to be OK
- The forward and backward calorimeters are going to cost a lot of money. Think very hard about what resolution you need and what e/h response you need. State-of-the-art hadron resolution is expensive. What physics program needs better than 100%/√E ?
- The electron-tagging calorimeter needs a very good constant term, better than 1%

Review the BaBar magnet

- Do this now. Your critics are not silent.
  - Talk to K. Amm, M. Anerella et al. from the Superconducting Magnet Division at BNL
  - They know the BaBar magnet, they know the risks, we've done a bit of groundwork for you
  - Maria Chamizo expects to hear from you
  - Talk to the JLab magnet group (R. Fair) – they recently built for the 12 GeV project some 7 new superconducting magnets in the relevant size-and-stored-energy range and also maintain, did surgery upon, and operate an older and larger superconducting magnet. They've written a report on possible issues with the BaBar magnet. They known their stuff. They are credible.

Decide the FEE and DAQ Architecture

- Event-builder or not – work out the implications and settle this
- Triggered or not – the resulting decisions on whether or not to buffer pending a trigger, in particular whether to buffer on-detector, are central to your architecture
- The trend is clearly away from event builders and if possible from triggers
  - Can you afford the resulting data volume and transport bandwidth?

- FADCs cost space, power, optical bandwidth, cooling and cabling
- Life is easier at lower power. How slow can you digitize?
- Decide if you can use community-available ASICs, if not then COMMIT to making your own
  - 12 GeV and sPHENIX decided for 3 existing ASICs, but in two cases did make straightforward modifications – allocate 2 years minimum to prove this out
  - PHENIX and STAR opted to roll their own – PHENIX did 14 different ones. That carries risk and needed several design groups totaling over 50 people. An advantage was a compact low-power setup with minimal cabling off the main detector
  - DO NOT UNDER ANY CIRCUMSTANCES ASSUME THE LARGER PHYSICS COMMUNTIY WILL RIDE TO YOUR RESCUE ON ASICS. BE PREPARED TO RECRUIT AND PAY FOR TALENT.

Hire Senior Engineers early on

- You need a principal engineer
  - How will you run reviews? Document designs? Decide a design is final? Decide a design is ready to produce/procure? Handle safety and QA? Recruit engineering and design talent? Assign people? Assign and enforce stay-clear zones?
- You need a lead engineer for installation
  - Deciding if things can be assembled, in what sequence, andover what timescale is a multi-year task, already at the design stage
  - Create the interface documents
  - Survey, tooling, fixtures, rigging, telescope sight-lines, crane weights, transports
  - Installation is an area where most collider detectors, probably dating back to Mark-I, have been overly optimistic (think factors of 2 or π)
- You need experienced engineers to guide mechanical and electronics choices
- You will need lead mechanical engineers on each subsystem

Define your Detector Lead Persons

- This is necessarily fluid until the detector scope starts to settle
- It is essential to move quickly at that point
  - These people need to lead the technical definition
  - They must guide costing, scheduling, staffing, venue definition
  - They must have a high tolerance for outside advice yet enough self-confidence to reject wise comments from Tribal Elders
- Junior people can do surprisingly well if you empower and trust them
  - Note that you will all be a decade older when you start data-taking
- Form these people into a Detector Council headed by your project director and manager
  - These people must understand that **Baselined Projects** are not democracies – they are much closer to top-down organizations once you start to build and have deadlines and budgets and 100 monthly reports over 8 years and reviews and more reviews and ever more reviews
- This is separate from Collaboration Council and Institutional Boards

Build Some Breathing Room into the Schedule

- Scheduling the work aggressively (“ASAP”) is a recipe for disaster
  - Take careful notes while you build prototypes
- It takes months to
  - Move funds to universities
  - Advertise contracts, evaluate bids, pick vendors, start actual work
  - Get time on uncommon machines (big lathes, specialty materials lines)
  - Await scheduled chip fabrication cycles
- Something major will go wrong
  - PHENIX – Gingrich’s government shutdown FY’95
  - 12 GeV – 2008-2010 Great Recession
  - sPHENIX – COVID-19

Building the Host Lab Group

- Following are some notes
  - Pre-history of RHIC
  - Timeline of the PHENIX experiment at RHIC
  - Build-up of the group at BNL from 1991-2000, with emphasis on skillsets

RHI Program Early Days

- 1983 NSAC LRP – a RHI collider of 30x30 GeV/A or higher
- 1984 DOE Office of Science Rejuvenation Plan (Al Trivelpiece)
  - Light sources to LBNL & ANL, neutron source to ORNL, RHIC to BNL
- 1986 startup of fixed target RHI programs
  - CERN at SPS – WA80/93/98, NA35/49, NA38/50, later NA44, NA45
  - BNL at AGS – E802/859/866, E814, E864
  - Continued through mid-1990s
- RHIC-inspired workshops 1983 (QM), 1984, 1985, 1987, 1988
  - 1984 and 1987 at LBNL (I think), others at BNL
  - Collaborations already forming at 1984 fall workshop
  - Experiment “concept” presentations at 1985 and later; major push 1988
- RHIC TAC review held fall 1990 – included costing
- RHIC PAC review and “decisions” held August 1991

PHENIX Origins

- Merger of four groups after “foundational” RHIC PAC of August 1991
  - Dimuon, OASIS, TALES, SPARC
  - Each emphasized lepton and photon detection
  - Differences about phase space covered, degree of PID, EMCal resolution (!)
- Dimuon and OASIS had members from BNL Physics

- Denoted RE2 for some time
- Formation at QM1991 conference (November 1991 Gatlinburg)
- Approvals:
  - Physics 1992
  - Technical 1993
  - Cost & Schedule 1994 – just in time for the FY 1995 government shutdown!

- About 3200 days from Formation (11/1991) to First Beam Run (8/2000)

Sources of People at BNL

- BNL AGS and CERN SPS RHI experiments were a key source, a bit for Day-1 BNL people but chiefly for those added over the next decade
- Others at BNL had worked at CERN ISR
- Others at BNL were part of D0 at FNAL Tevatron
- Others had worked on cyclotrons (10 MHz bunched-beam machines)
- Others had worked at Linacs (LAMPF; CEBAF had not yet started)

- RE2 started with maybe 200 people on the rolls of the 4 earlier collaborations
- PHENIX peaked at 650 people during construction (1997-1998)

Day-1 Skillsets, BNL Group

- Three with EMCal experience (leadglass, U-scint, LAr/Cu)
- One with tracking chamber experience
- One senior engineer with SLD/electronics/PM experience
- Only one person with experience working with Instrumentation Div
- No DAQ/trigger/online computing experience
- Modest experience on simulations, reconstruction, and offline analysis

Day-1000 Skillsets, BNL Group

- Added two EMCalorimeter people "post SSC"
- Added a tracking chamber person (pad type) in wake of major re-org
- Picked up three postdocs/junior staff with general calorimeter, neutral meson reconstruction and tracking reconstruction experience
- Picked up former atomic physicist with knack for organizing
- Picked up lead mechanical engineer and designers (D0 experience)
- Picked up senior tech (D0) who could direct designers and techs
- Started picking up technicians (went from 0 to 10 over a decade)

- Could lead an R&D effort with by then >400 collaborators, over half from outside USA

Day-2000 Skillsets, BNL Group

- Added three scientists with DAQ experience from AGS HEP program
- Added computer scientist for online controls
- Added mid-career electrical and electronics engineers
- Added postdoc/junior staff with online computing experience and another with DAQ experience, both from CERN program
- Developed links with large group in Instrumentation to handle timing system, TPC readout electronics, and general electronics control

- Could host very-early-days operations in 1008 Control room – first chain test of electronics
- Could direct design room efforts, 1008 installation, 1008 rack room build

Day-3000 Skillsets, BNL Group

- Added postdocs/junior staff for offline computing
- Added junior staff for online computing, data reconstruction at RCF, counting house operations, database construction/operation

- Co-Headed simulations and analysis data-challenges
- Lead all detector chain tests and initial DAQ commissioning
- Guided many nervous junior colleagues in bringing their detectors online for the first time

- Office staff went from one to two to handle visitor influx
- Physics analysis ‘interest areas’ were becoming established

- By this time a regular cycle of talks on physics and detector plans/progress was established

Start of RHIC Operations, BNL Group

- Peak was perhaps 80 people during 1996-1999 construction push
- DOE ONP had been inquiring since 1995 about long-term staffing
  - Magnitude of staffing needs came into focus after ONP took trip to CDF
  - Scale of RHIC operating budget discussed at NSAC circa 1995 – frankly a bit of a shock to the "NP" community – first ">$100M/year" operating budget
  - PHENIX prepared a management plan listing every group's commitments, staffing levels, long-term expectations – public version rather "thin", DOE version highly detailed and by name
- BNL PHENIX group by 2001 was 23 scientists, 10 techs, 5 engineers
  - Of the scientists, 12 were postdocs or had hired in earlier as postdocs
  - Eight senior staff came from what one would call HEP
  - Two senior staff from RHI NP, one from Atomic (BNL tandems)