PHENIX at RHIC
new perspectives

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Relativistic Heavy-Ion Collider (RHIC) @ BNL

Specifications:

3.83 km circumference

2 independent rings:

- 120 bunches/ring
- 106 ns crossing time

A + A collisions @ $\sqrt{s_{NN}}$ = 200 GeV

Luminosity: $2 \cdot 10^{26}$ cm^{-2} s^{-1} (~1.4 kHz)

p+p collisions @ $\sqrt{s_{max}}$ = 500 GeV

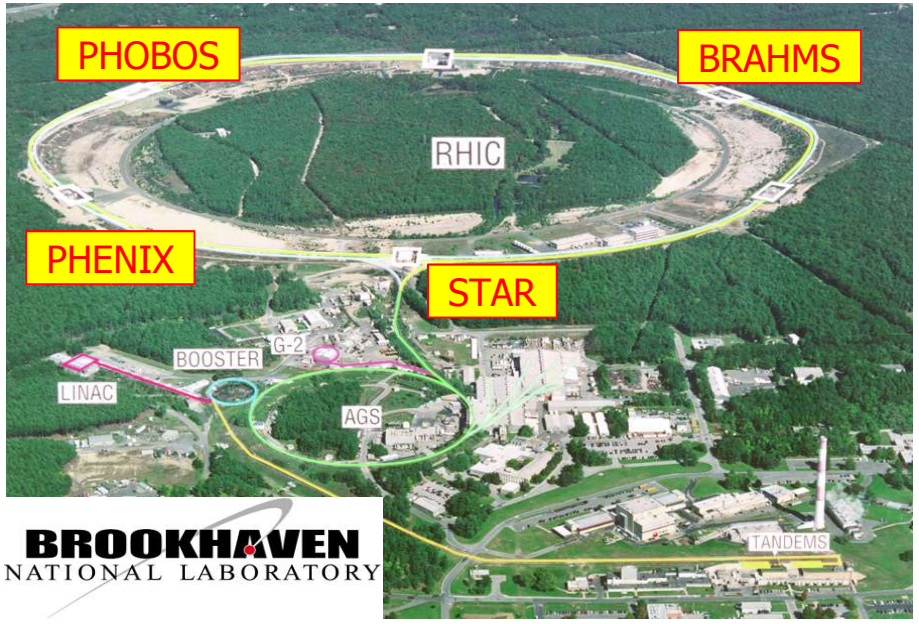
p+A collisions @ $\sqrt{s_{max}}$ = 200 GeV

4 experiments:

BRAHMS, PHENIX, PHOBOS, STAR

Runs 1 - 4 (2000 – 2004):

Au+Au @ 200, 130, 62.4 GeV
p+p @ 200 GeV
d+Au @ 200 GeV



Why RHIC ?

- **Different from p-p, e-p colliders**

  Atomic number A introduces new scale $Q^2 \sim A^{1/3} Q_0^2$

- **Different from previous (fixed target) heavy ion facilities**
  - **E_{CM} increased by order-of-magnitude**
  - ➡ **Accessible x (parton momentum fraction) decreases by ~ same factor**
  - ➡ **Access to perturbative phenomena**
    - **Jets**
    - **Non-linear dE/dx**

$$x \sim \frac{2\,p_T}{\sqrt{s}}$$

- **Its detectors are <u>comprehensive</u>**
  - ➡ **~All final state species measured with a suite of detectors that nonetheless have significant overlap for comparisons**
- **It's *a dedicated facility***
  - ➡ **Able to**
    - **Perform required baseline and control measurements**
    - **Respond rapidly to new opportunities (e.g., 62 GeV Run)**

γ, $\pi^{\pm}$, π^0, $K^{\pm}$, K^{*0} (892), K_s^0, η, p, d, ρ^0, ϕ, Δ, Λ, Σ^*(1385), Λ^* (1520), $\Xi^{\pm}$, Ω, D^0, $D^{\pm}$, J/Ψ's,

(+ anti-particles)

…

Summary

1. Energy densities:

- *Maximum $dE_T/d\eta$ ~ 600 GeV at midrapidity consistent with*
  initial ε > 5 GeV/fm^3 > ε_{crit}

2. Elliptic flow:

- *Strong elliptic flow v_2 consistent with*
  short thermalization times τ_0 ~ 1 fm/c

3. Soft particle spectra:

- *Shapes & yields consistent with*
  hydrodynamic (thermal+coll. velocity) source emission
- *Particles ratios consistent with*
  chemically equilibrated system before hadronization

4. Hard particle spectra:

- *Strong high p_T suppression in central A+A (relative to p+p, p+A & pQCD) consistent with*
  final-state partonic energy loss in dense system: dN^g/dy~1100

5. Intermediate p_T spectra:

- *Enhanced baryon yields & v_2 (compared to meson) consistent with*

All observations consistent with formation of thermalized dense partonic matter in central Au+Au collisions

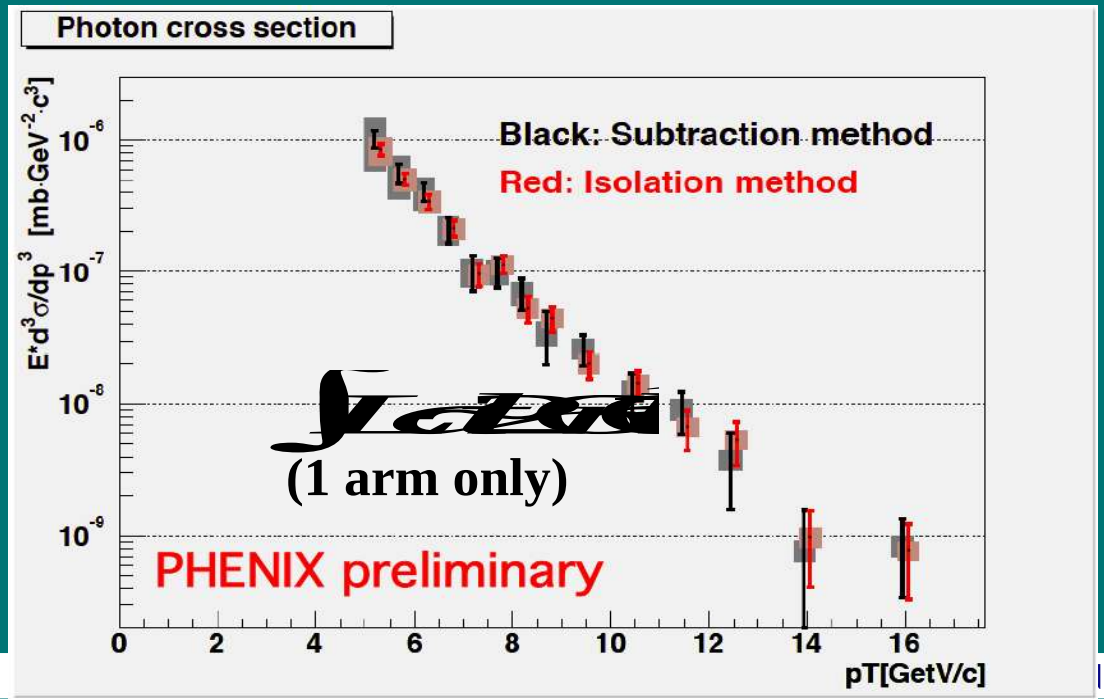
The Challenges For The Next Decade

A. ***Move from exploration of*** **new matter formed in A+A collisions to** ***characterization of*** **its properties**

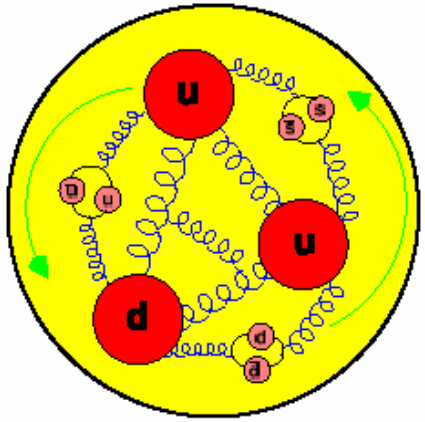
C. ***Accelerate progress*** **in the** ***developing spin*** **program**

E. ***Upgrade detectors*** **to maximize items A and B**

H. ***Upgrade RHIC*** **to maximize the outcome from A, B, C and D**



Spin Structure of the Proton at Hard Scales



Parton Distribution functions (PDF):

Helicity average distribution
quarks q(x) : well known
gluons G(x) : moderately well known

Helicity difference distribution
quarks $\Delta q(x)$: moderately well known
gluons $\Delta G(x)$: unknown

Helicity flip (transversity) distribution
quarks $\delta q(x)$: unknown

- **Fixed Target**

HERMES	27 GeV pol. e^+, e^-	pol. H,D (L/T)	DIS
COMPASS	160 GeV pol. μ^+	pol. LiD (L/T)	DIS, quasi-real Photons
JLAB Hall A	6 GeV pol. e^-	pol. ^{3}He	DIS (high x)
Hall B CLAS	6 GeV pol. e^-	pol. H,D	Resonance region
Hall C RSS	6 GeV pol. e^-	pol. H,D	Resonance region
SAMPLE Bates	200 MeV pol. e^-	unpol. H,D	Elastic
MAMI A4	855 MeV pol. e^-	unpol. H,D	Elastic
JLAB G0	6 GeV pol. e^-	unpol. H,D	Elastic
Jlab HAPPEX	6 GeV pol. e^-	unpol. H,D	Elastic

- **Collider**

STAR	200 GeV pol. p	Jetproduction, direct Photons...
PHENIX	200 GeV pol. p	Jetproduction, direct Photons...
BELLE	8 GeV e^-, 3.5 GeV e^+	Fragmentation..

Current Experiments on Nucleon Structure (as reported at DIS 2004)

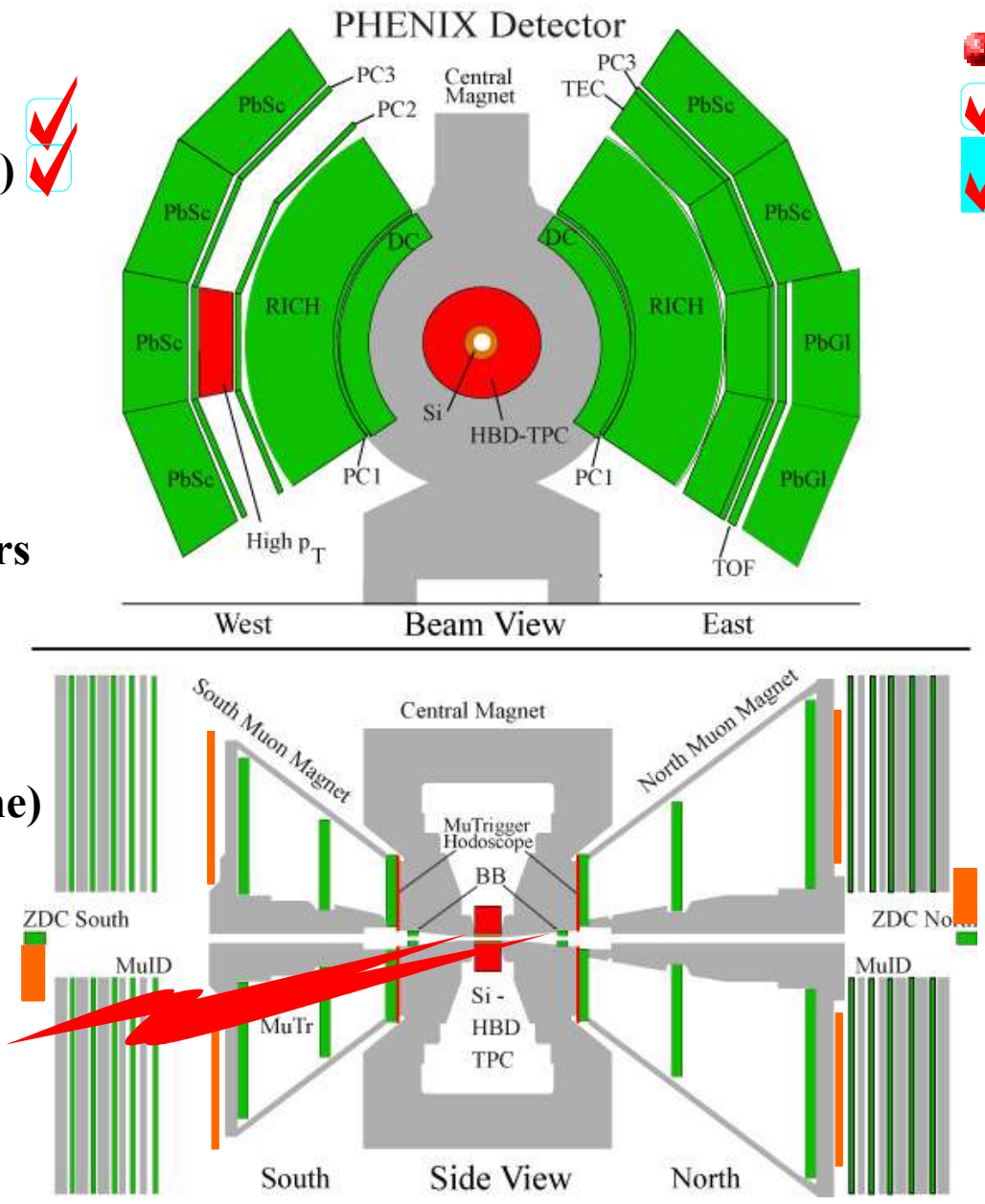
Field started with polarized electron sources and targets Yale/SLAC mid 70s

Can RHIC further extend the program started at HERA

	Physics Channels	What is unique at RHIC?
Gluon polarization $\Delta G(x)/G(x)$	Inclusive jets, hadrons, heavy flavor, direct photons, in STAR and PHENIX	o Robust extraction of spin dep. pdfs from pQCD analysis o Broad x-range: 0.001<x<0.3 o Multiple channels: good control of of sys. and theor. uncertainties ➔ determine G(x) and $\int\Delta G(x)dx$!
Flavor separation of quark polarizations $\Delta q(x)/q(x)$, $\Delta\bar{q}(x)/\bar{q}(x)$	Single lepton asymmetries $A_L(e,\mu)$ in W-production in STAR and PHENIX	o direct and theoretically clean flavor separation of spin dependent pdfs o sufficient statistical resolution ➔ sea quark spin vs gluon spin
Transverse spin structure of the Nucleon $\delta q(x)/q(x)$	A_N in STAR, PHENIX and BRAHMS back to back correlations, A_T in Collins- and interference fragmentation and A_{TT} in Drell Yan in STAR and PHENIX.	o high precision measurements of multiple single and double spin asymmetries at hard scales aim at a separation of Sivers and Transversity contributions

Upgrade to PHENIX

- enhanced particle ID
  - TRD (east)
  - Aerogel/TOF (west)



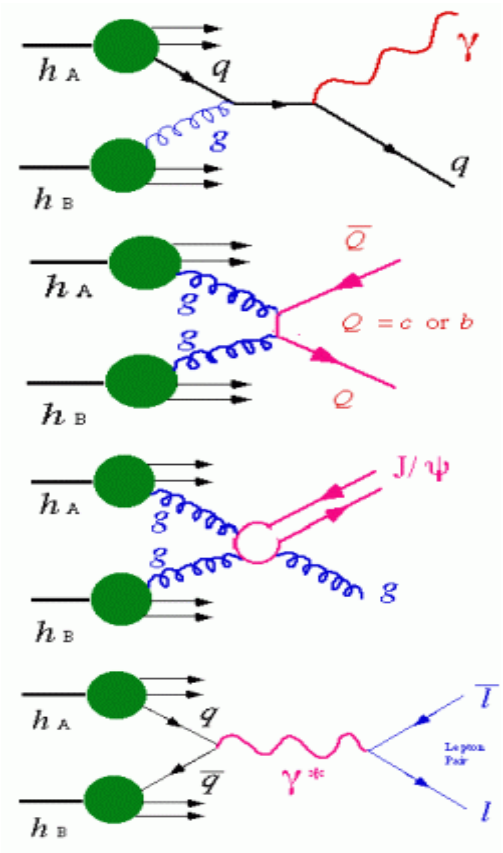
- Vertex Spectrometer
  - flexible magnetic field
  - silicon vertex tracke
  - TPC/HBD

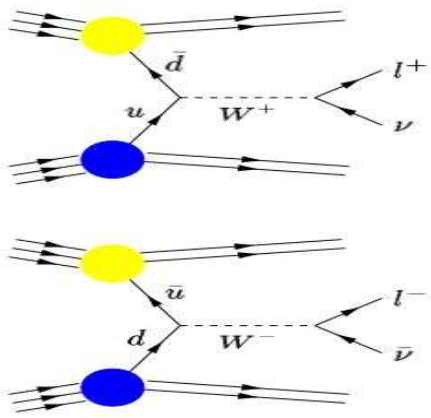
- Forward Spectrometers
  - New muon trigger chambers
  - Forward silicon detectors
  - Forward (Nosecone) calorimeters

- pA centrality detectors
  - Very forward hadr calorimeter

- DAQ/trigger

PHENIX Forward Upgrade



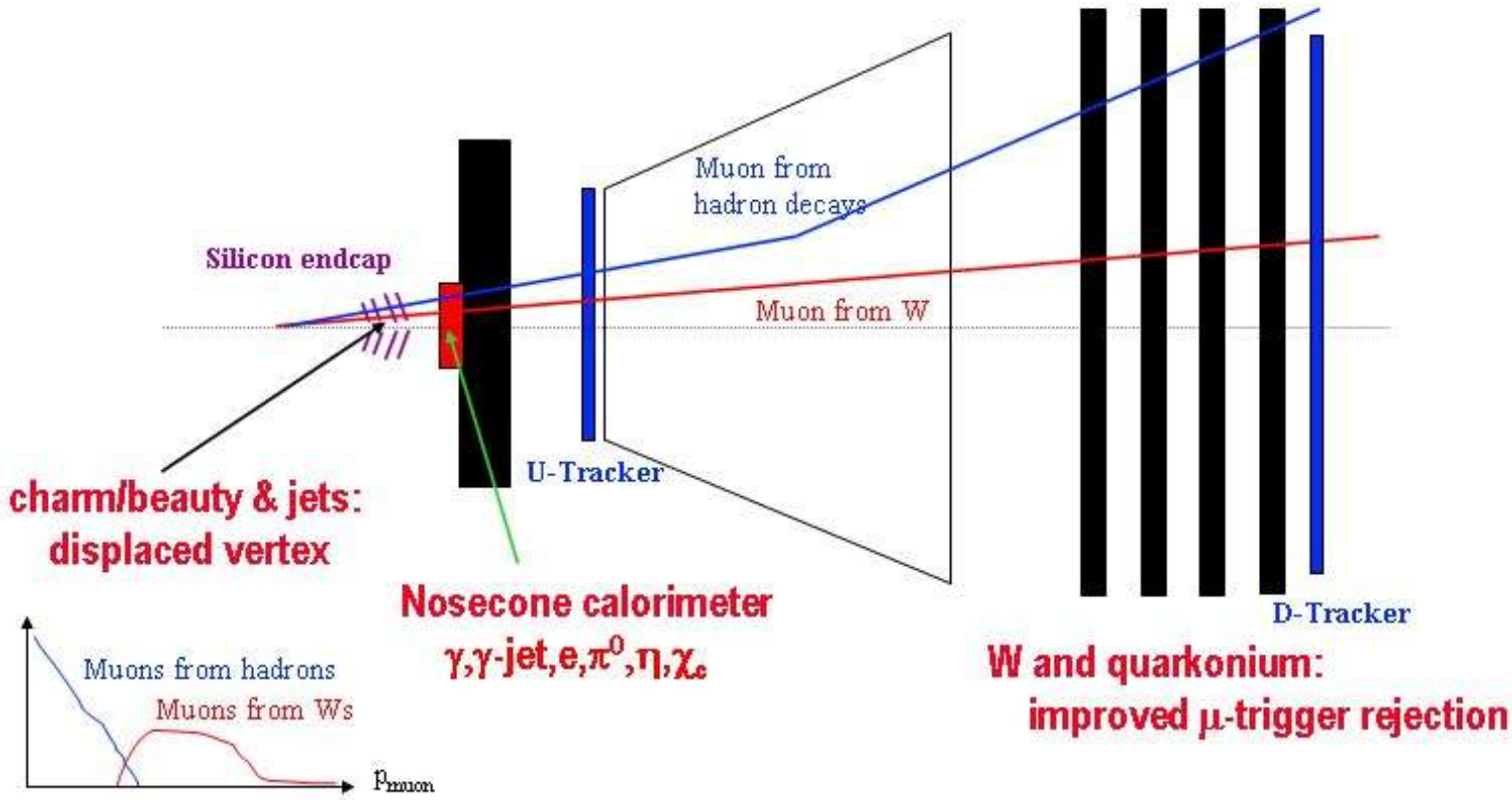


Nosecone Calorimeter

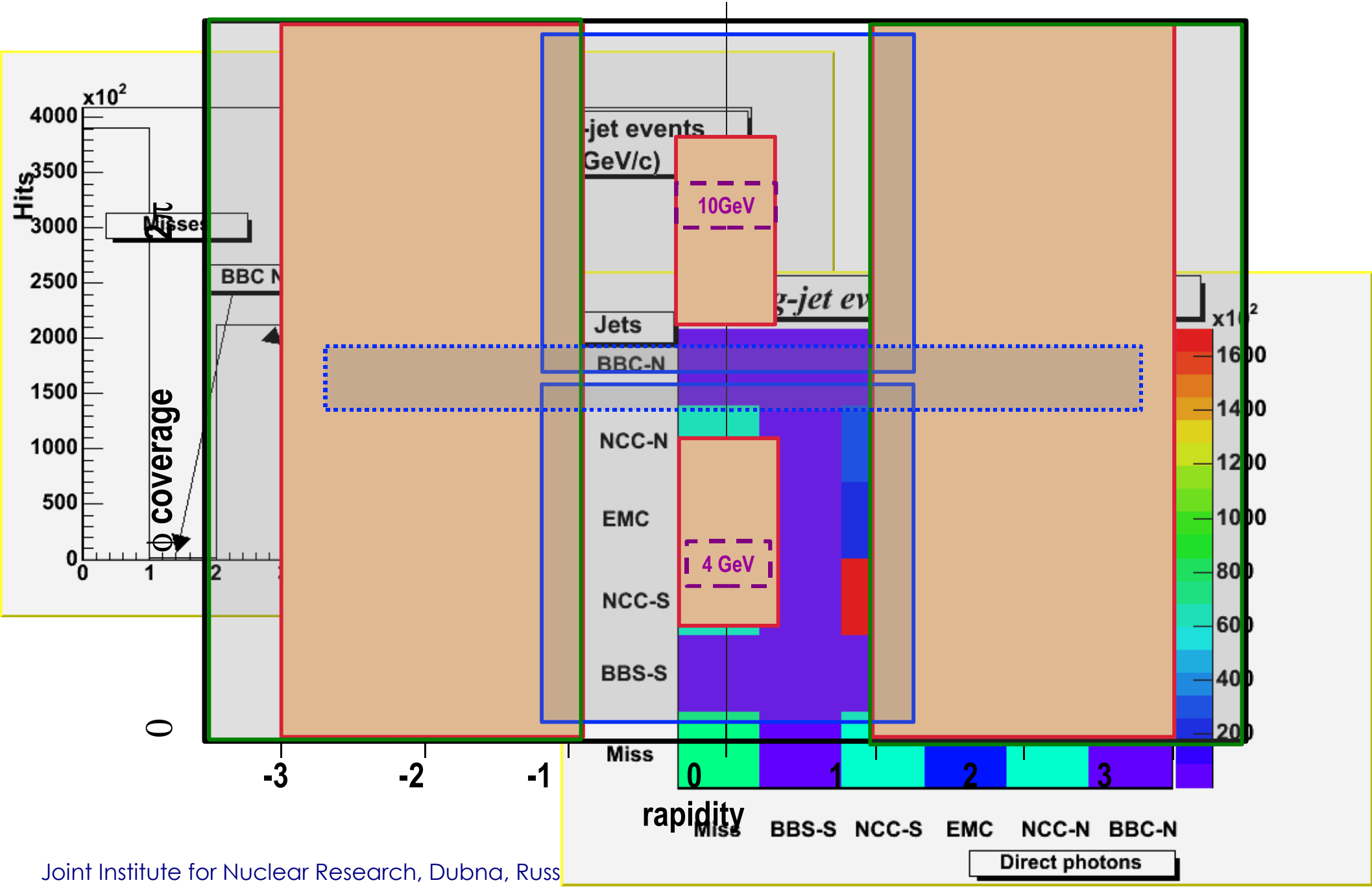
- » Sampling Tungsten-Silicon
- » Silicon photon / π^0 identifier layers

Muon trigger

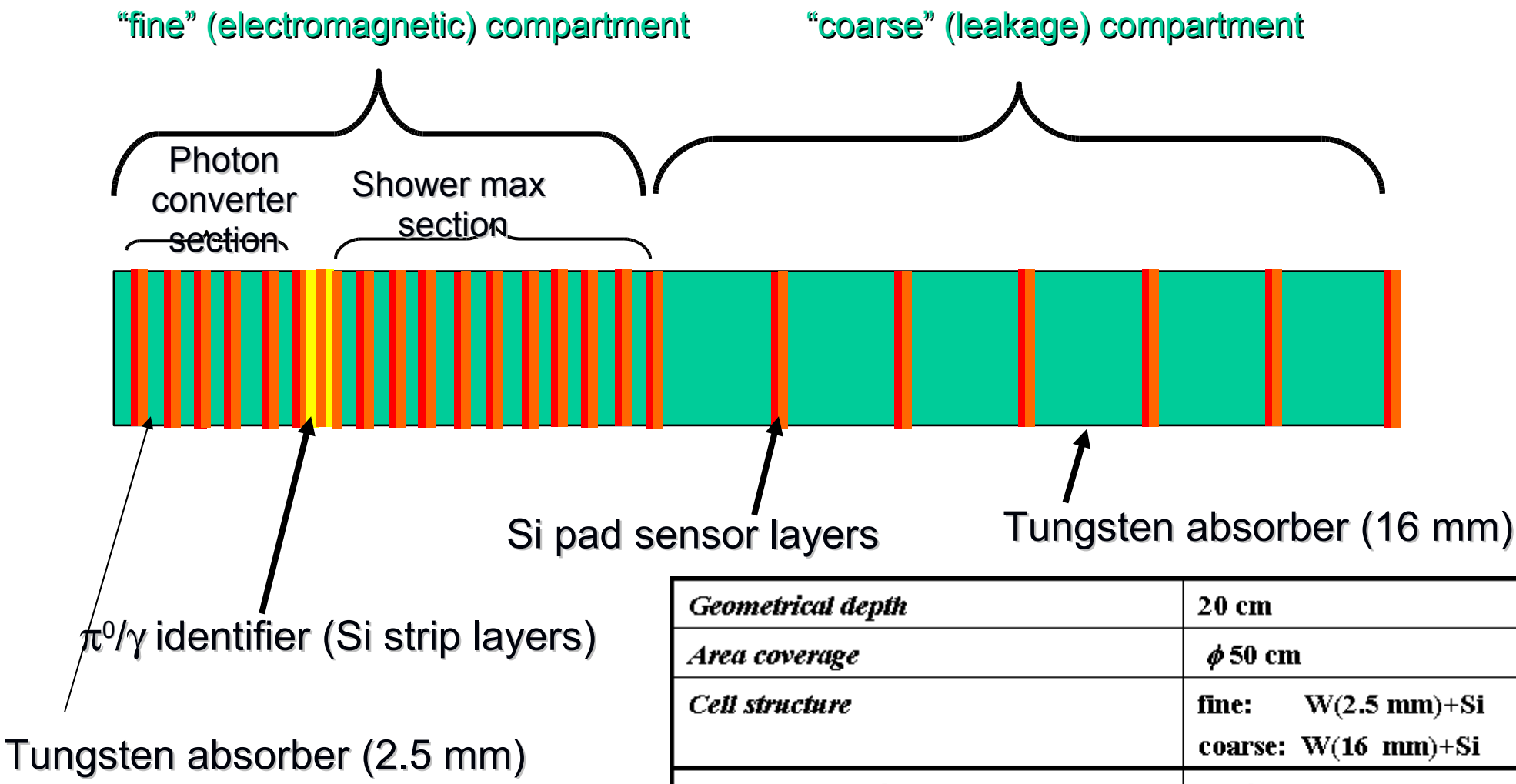
- » Upstream tracker (RPC or MuTr)
- » Downstream tracker (RPC's)



Upgraded PHENIX



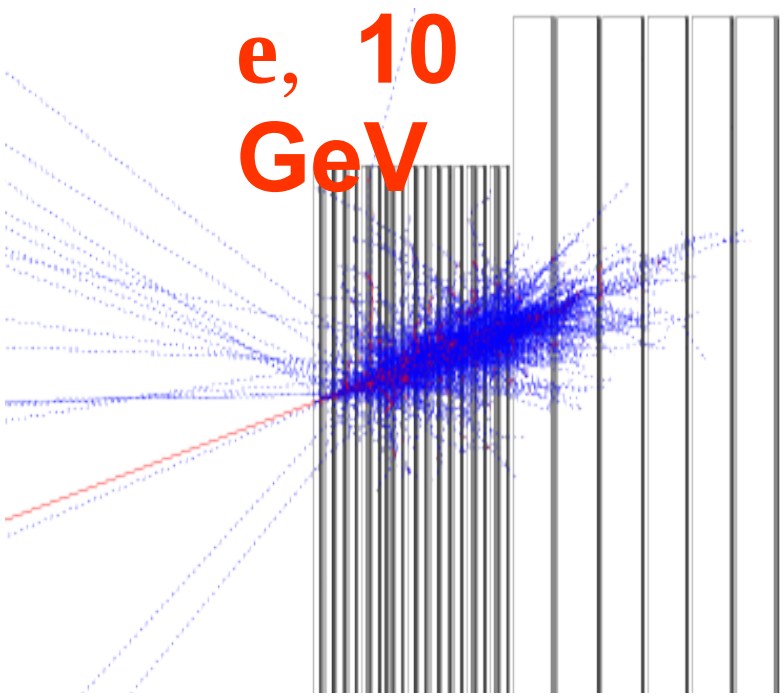
Ideas

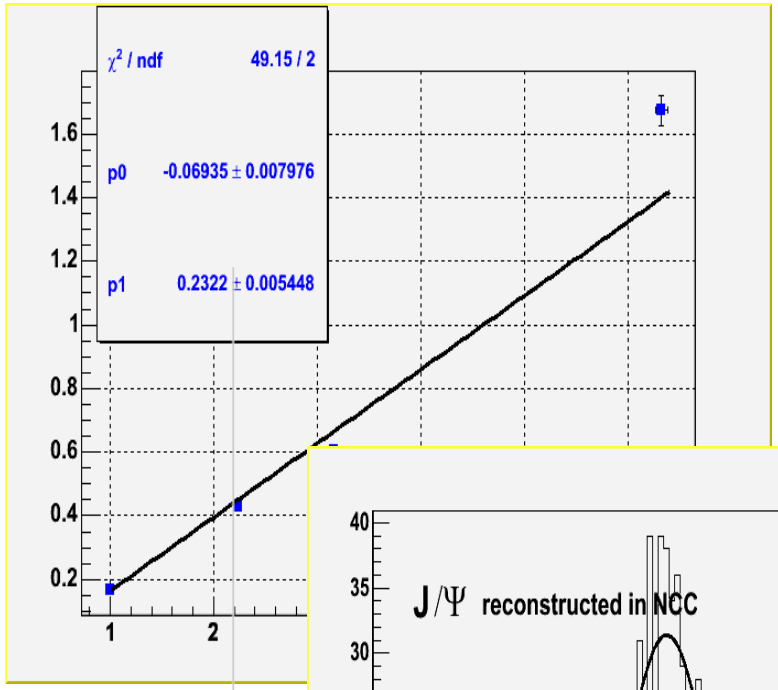


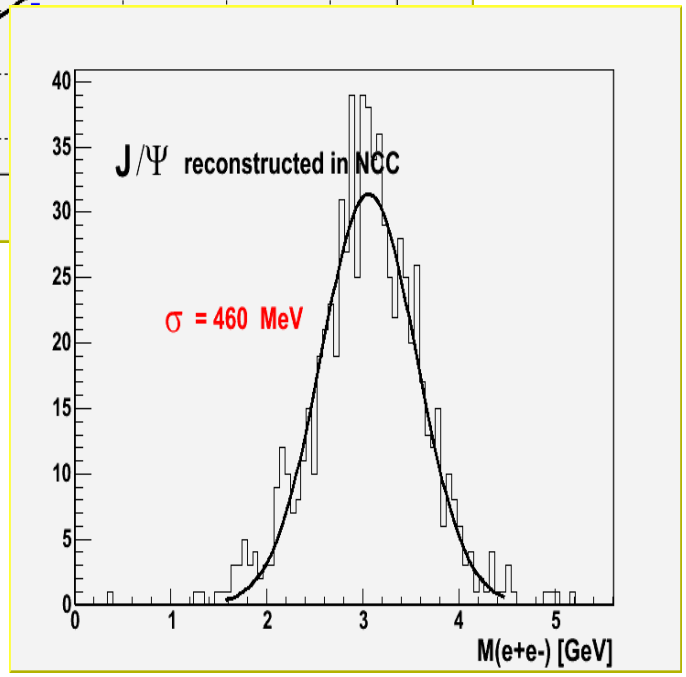
Geometrical depth	20 cm
Area coverage	ϕ 50 cm
Cell structure	fine: W(2.5 mm)+Si coarse: W(16 mm)+Si
Hadron absorption depth	1.6 Λ_{abs}
Photon absorption depth	43 X_0
Longitudinal segmentation	4 X_0 + 6 X_0 + 33 X_0
Lateral segmentation	1.5 x 1.5 cm^2 everywhere
γ/π^0 identifier	Two layers of 2 mm strips

Performance

Electromagnetic shower measurements

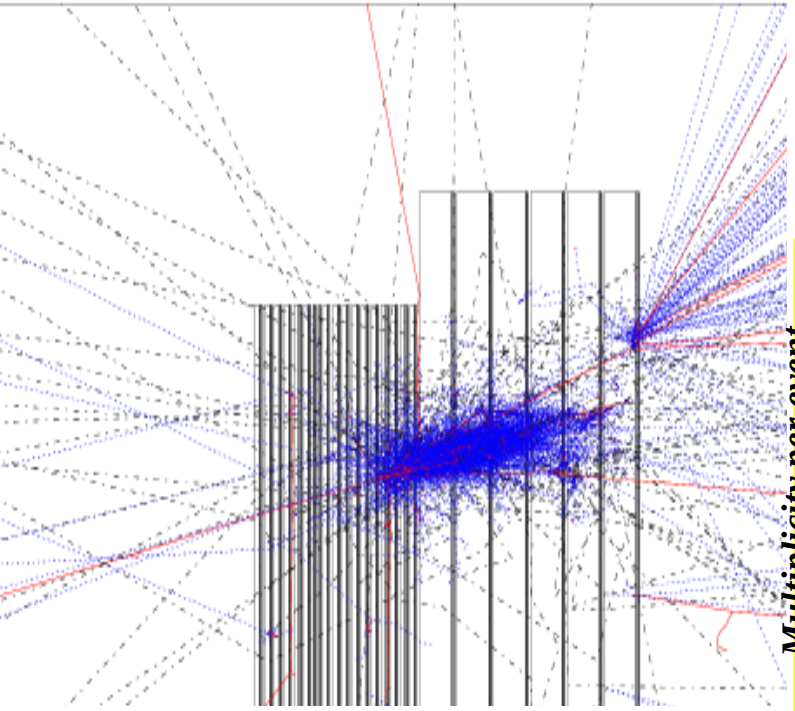


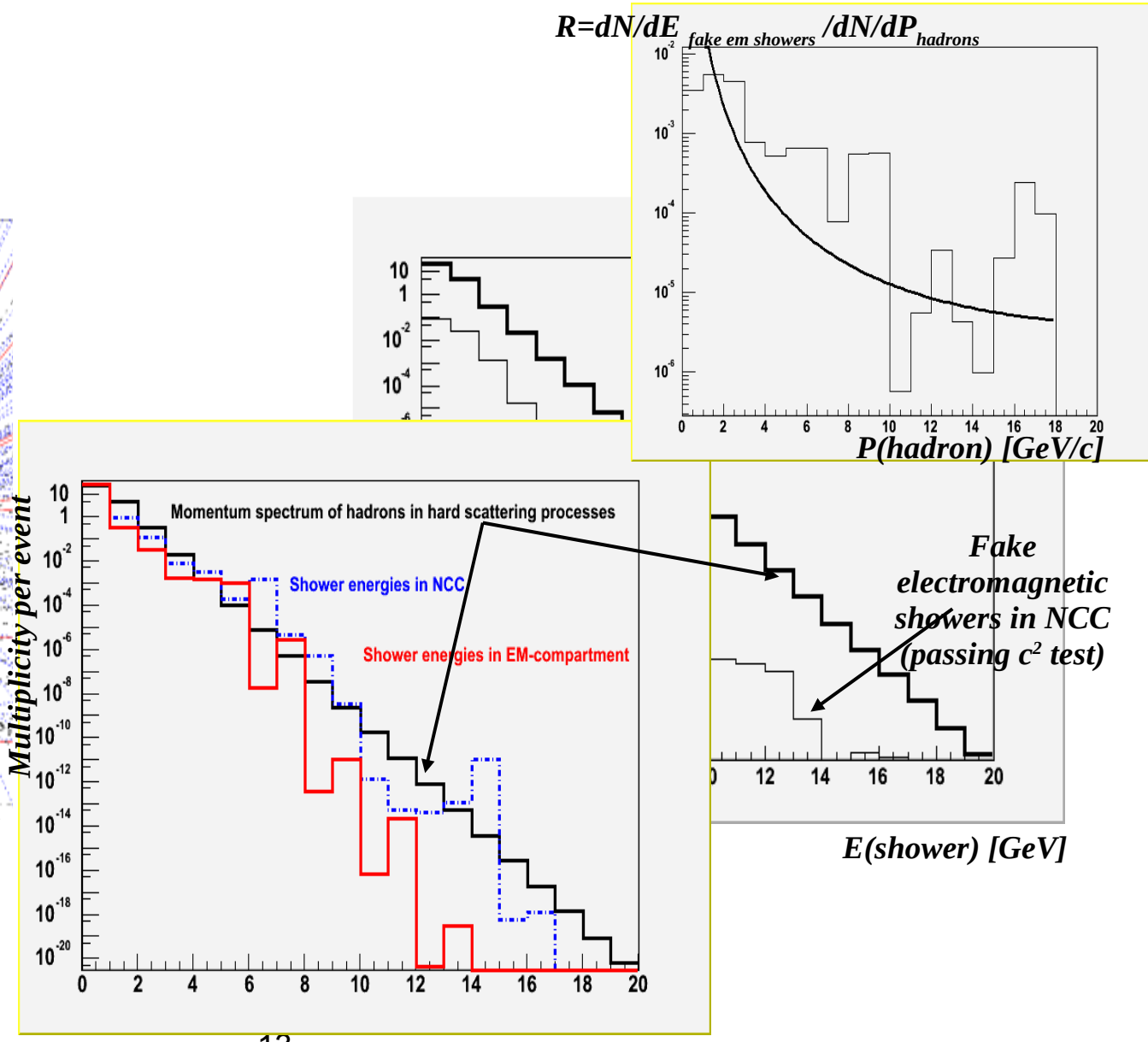




Performance

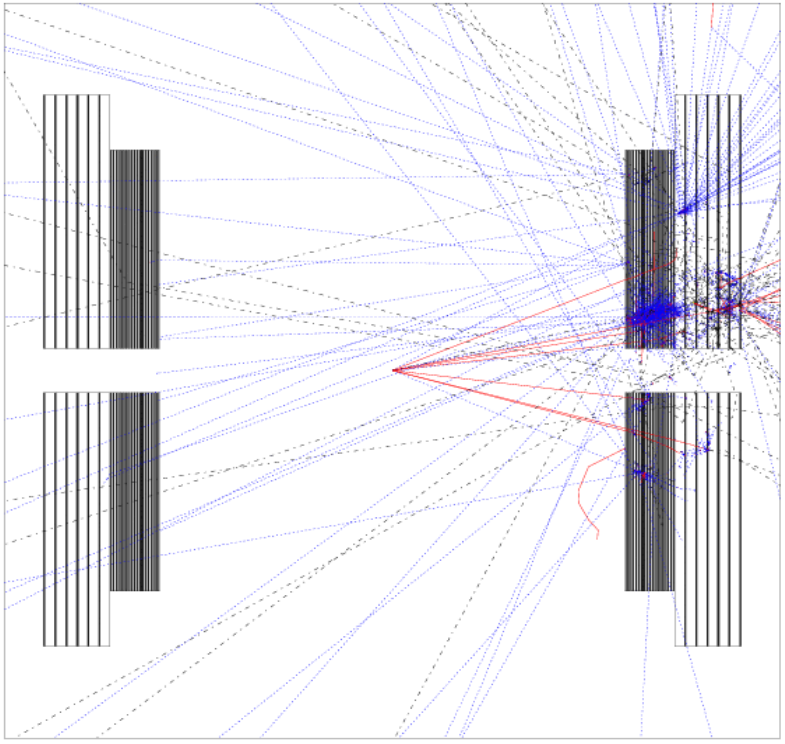
Hadronic shower rejection

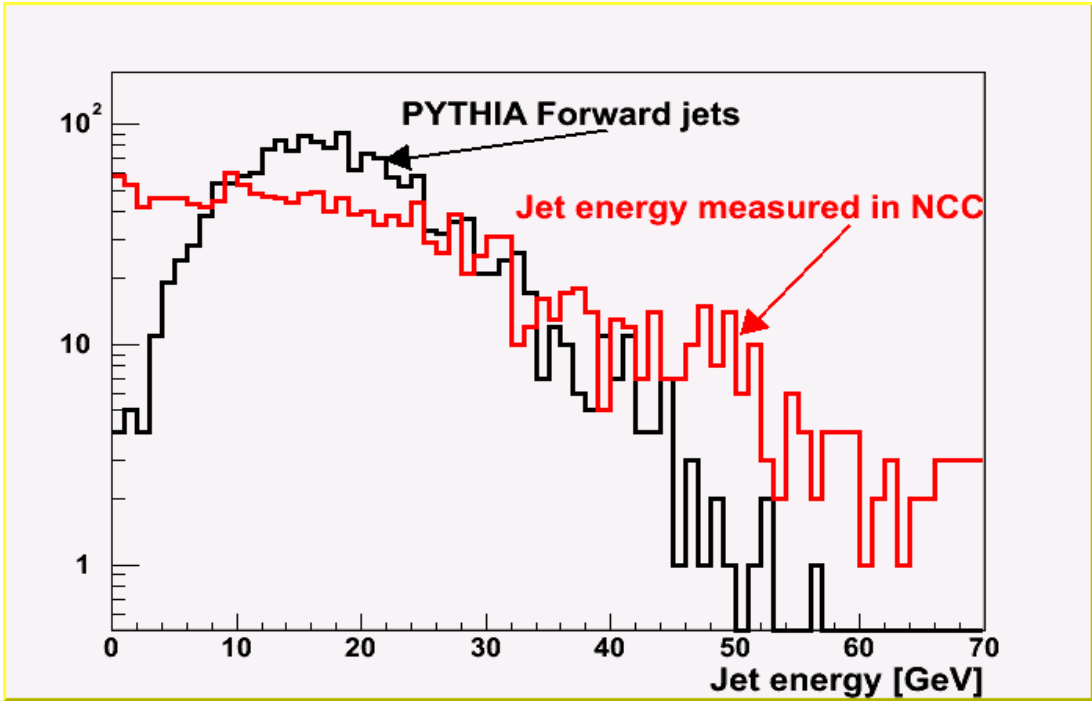




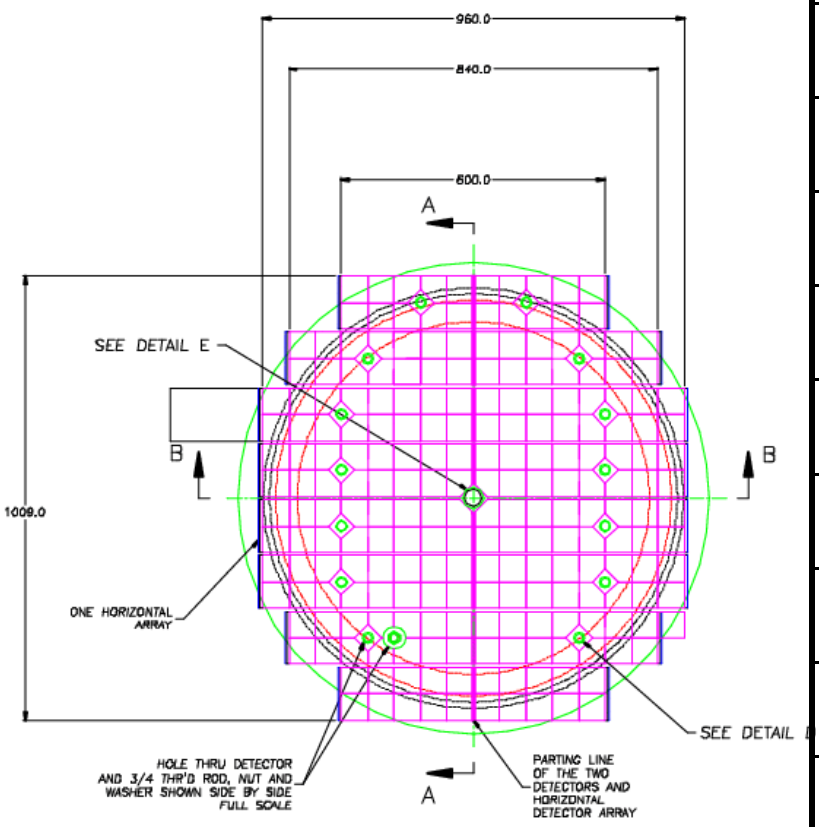
Performance

Jets



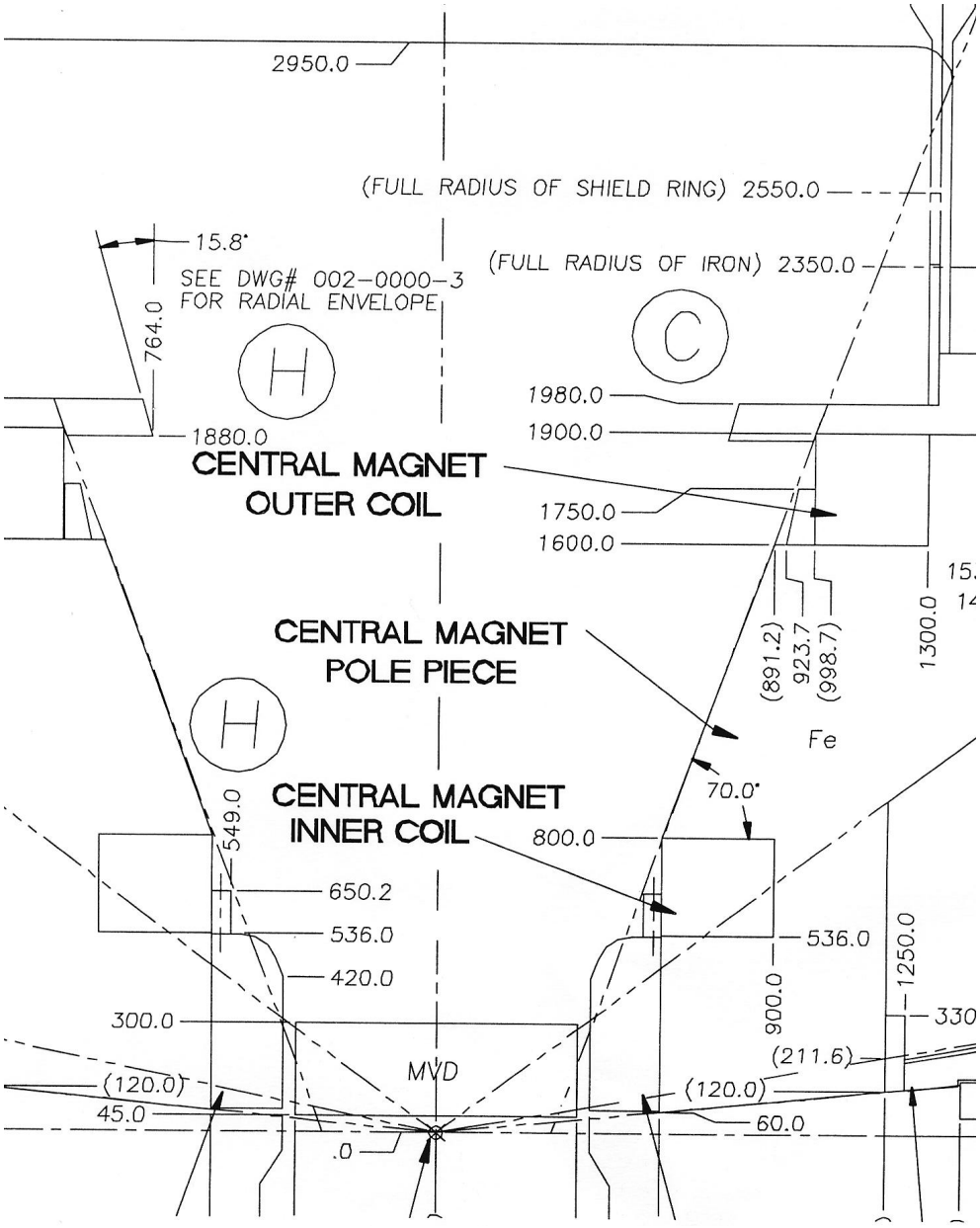


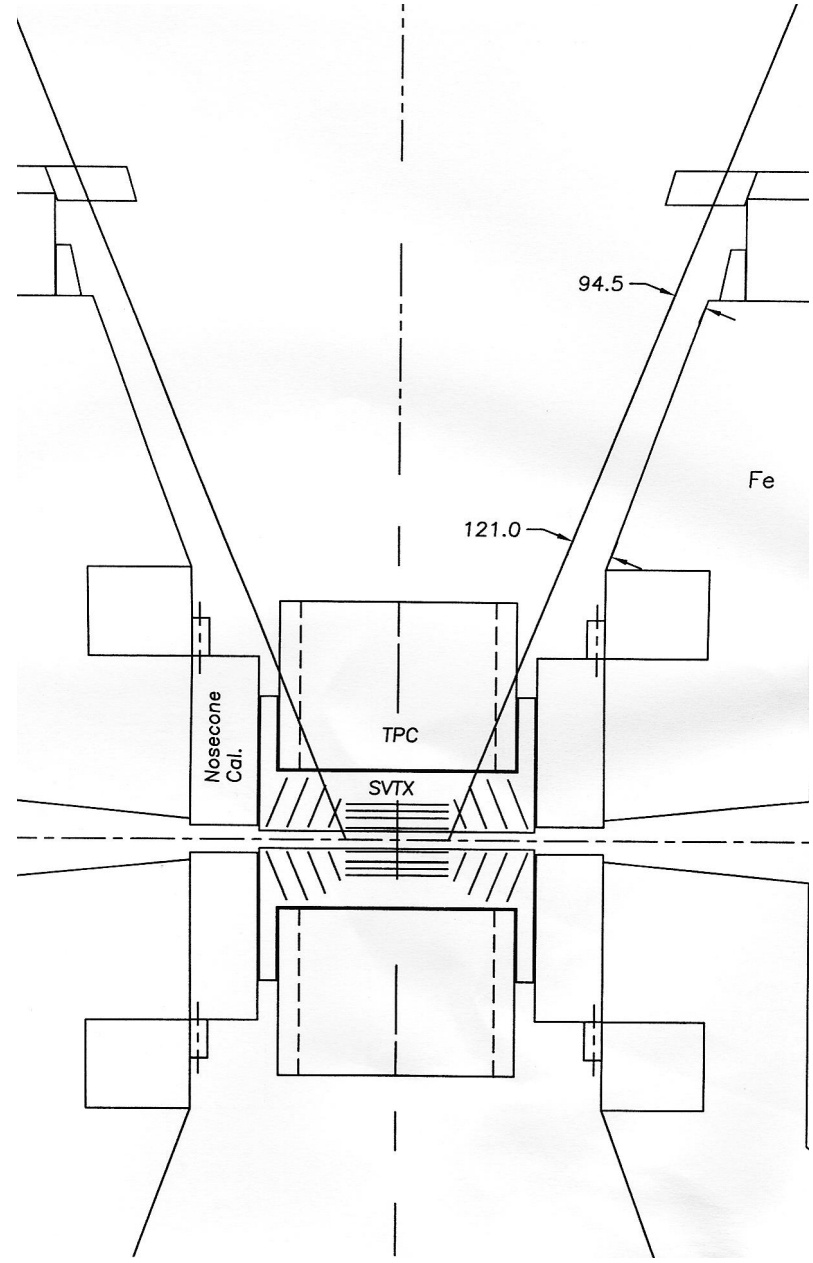
NCC Mechanical Concept



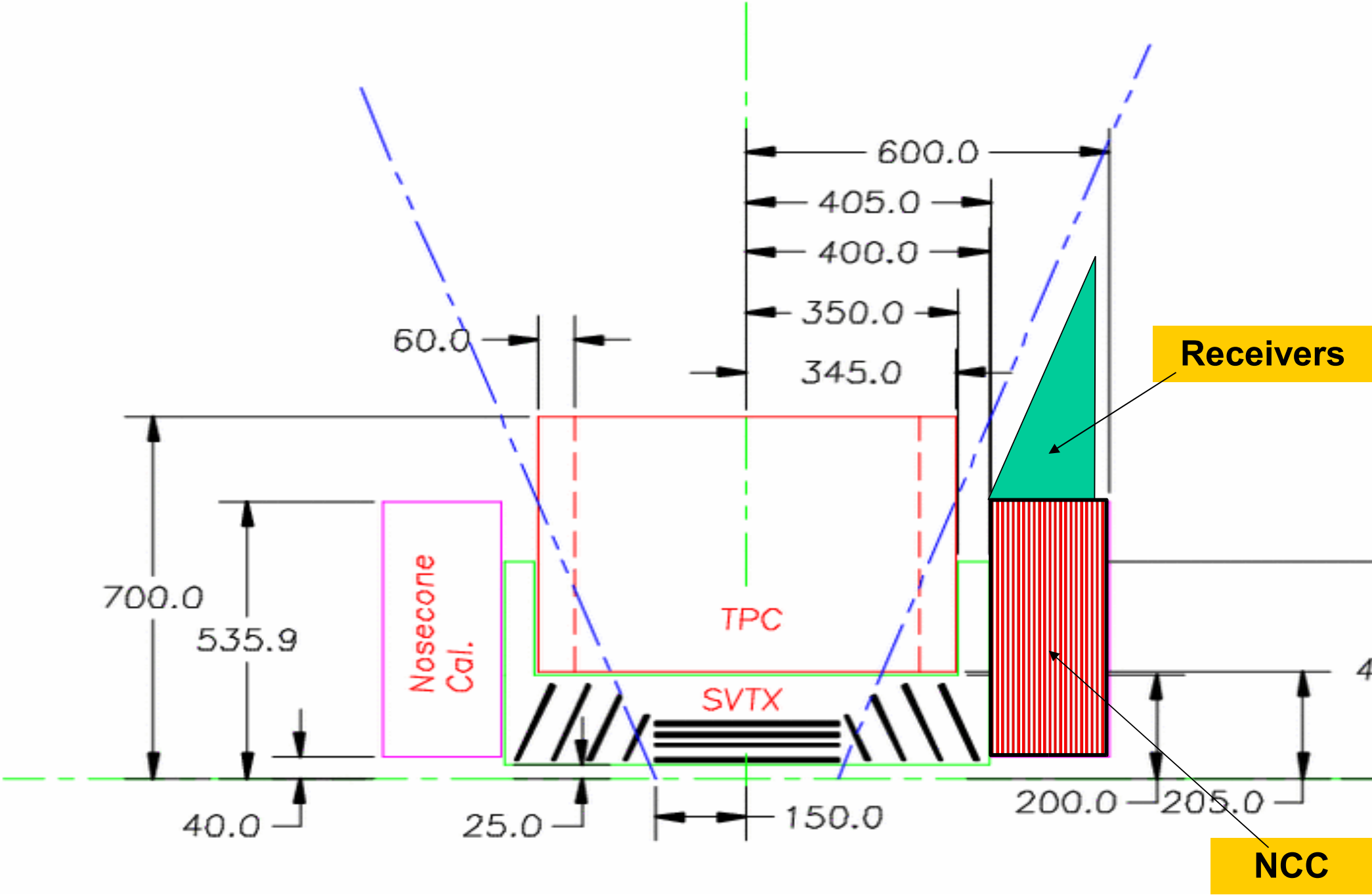
Item	Total	Cost
W	1.8 t	200k
Si (calorimeter)	14 m^2	780k
Si (g-p0 identifier)	1.15 m^2	80k
Cables	5184	200k
Readout units	384	100k
Preamps (16 ch)	3904	
SVX4	48	
Digitization (ch)	8704	
Pipeline		
Trigger		
Total known		~1.3 m

PHENIX Grand Central

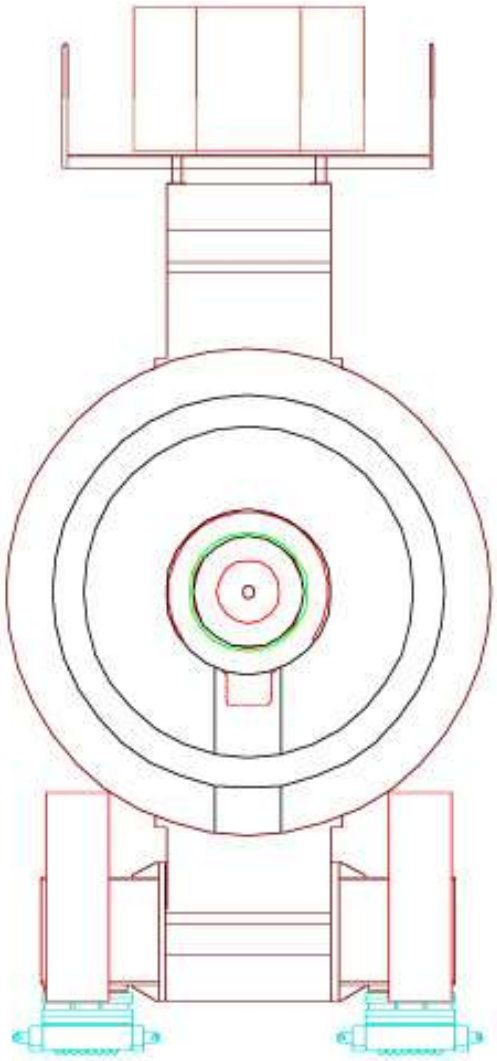


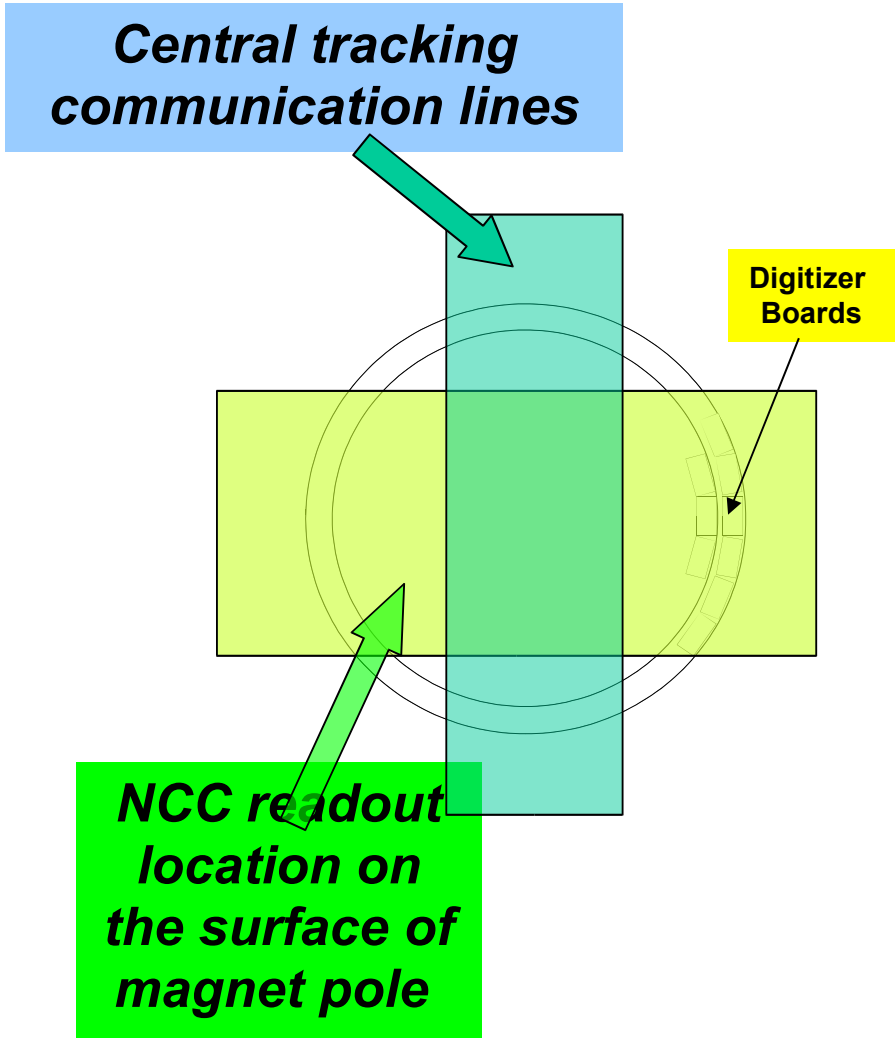


Terminal buildings ….



Real estate sharing





Schedule

(example: 32 week scenario → subject to change…)

L= $6\times10^{30}cm^{-2}s^{-1}$ $8\times10^{31}cm^{-2}s^{-1}$

P= 0.45 0.5 0.7 ……

√s= …….. 200 GeV …….....|

	2004	2005	2006	2007	2008	2009 ….
pp	5+1	5+10	5+11	0	5+9 ➔ $156pb^{-1}$	

Inclusive hadrons + Jets

Transverse Physics

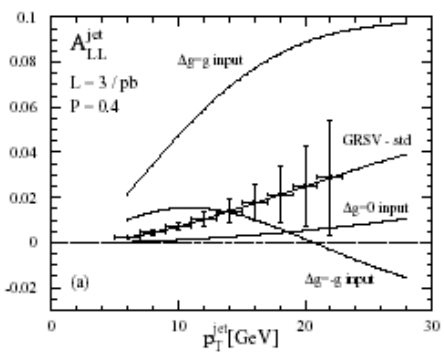
Charm Physics

direct photons

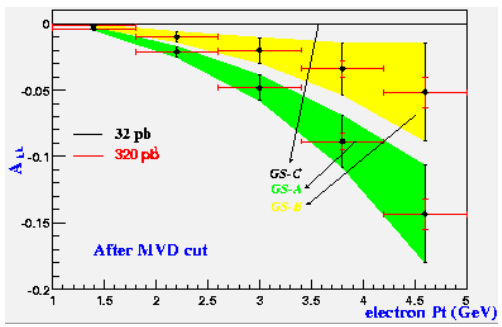
Bottom physics

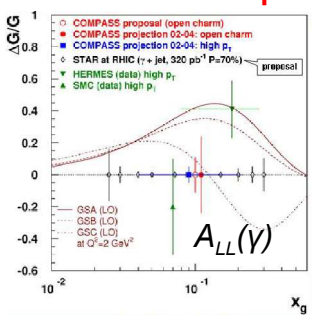
W-physics

A_{LL}(hadrons, Jets)

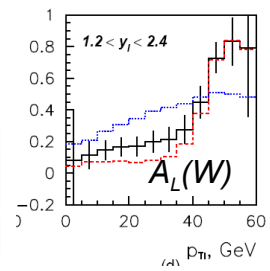


A_{LL}(charm)





$A_{LL}(\gamma)$



$A_L(W)$

Near Future

- **We have ongoing R&D program funded by UCR (R.Seto) and BNL (PHENIX Upgrade Funds) → new pad sensors and NCC proof-of-principle prototype.**
- **Prototype**
  - **pad-sensors, analog cables, readout units, front-end - MSU;**
  - **strip-sensors for the g/p0 identifier – Prague(?) or leftovers from earlier project in Trieste;**
  - **Readout for g/p0 identifier – Prague(?);**

Upgrade Summary

- We are at the beginning of a rich program studying nucleon structure in pp (mainly polarized) and pA(dA) collisions at RHIC.
- Integrated forward spectrometer upgrade is the precondition for PHENIX to stay competitive in this new field of physics.
- Excellent opportunity for new groups both in physics and instrumentation!
- RHIC spin builds on and succeeds DIS experiments on spin structure and makes essential contributions for the development of e-RHIC.