# PHENIX at RHIC
# Design of the W/Si calorimeter for the Forward Direction

-The needs for upgrade

-PHENIX Forward Upgrade

-Constrains & technology

-Design, R&D priorities

-Plans to succeed

*BNL, November 10, 2004*

*Edward Kistenev*
***PHENIX, BNL, USA***

# RHIC executive summary

## 1. Energy densities:

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

## 2. Elliptic flow:

- *Strong elliptic flow $v_2$ consistent with*
  *short thermalization times $\tau_0$ ~ 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*
  *quark recombination mechanisms in a thermal and dense system*

***All observations consistent with formation of thermalized strongly interacting 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**

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

***Upgrade detectors***

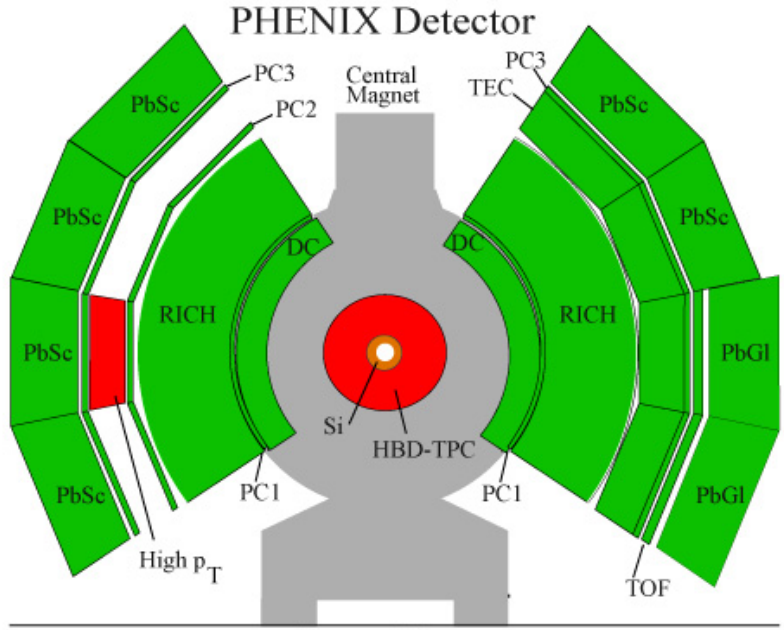
***Increase acceptance***
***Implement vertex tracking***
***Implement jet measurements***

***Upgrade RHIC***

***X40 increase in luminosity***

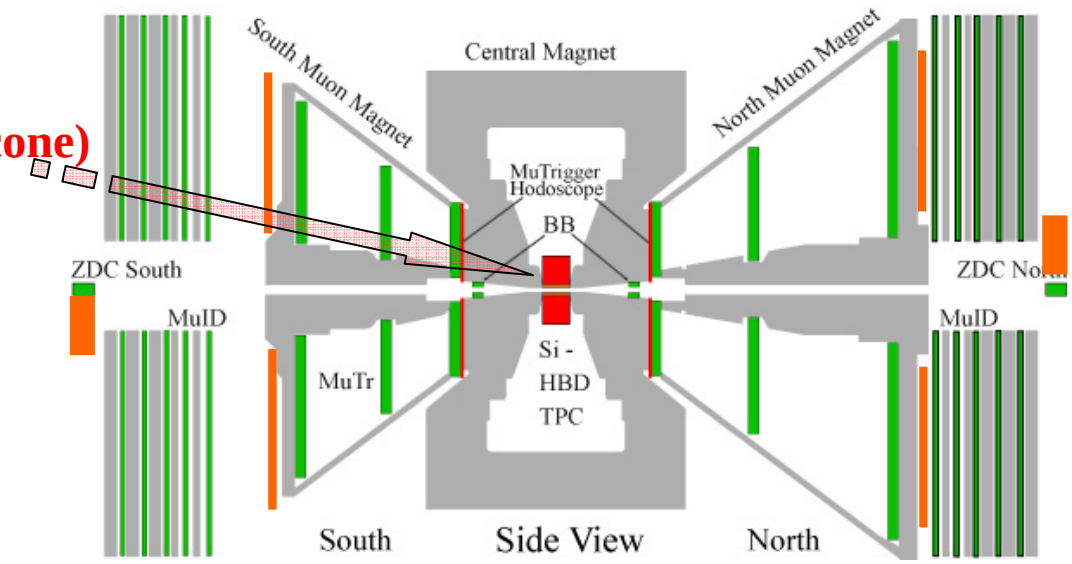
# Upgrades to PHENIX

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




- Vertex Spectrometer
  - flexible magnetic field
  - silicon vertex tracl
  - TPC/HBD/GEM's

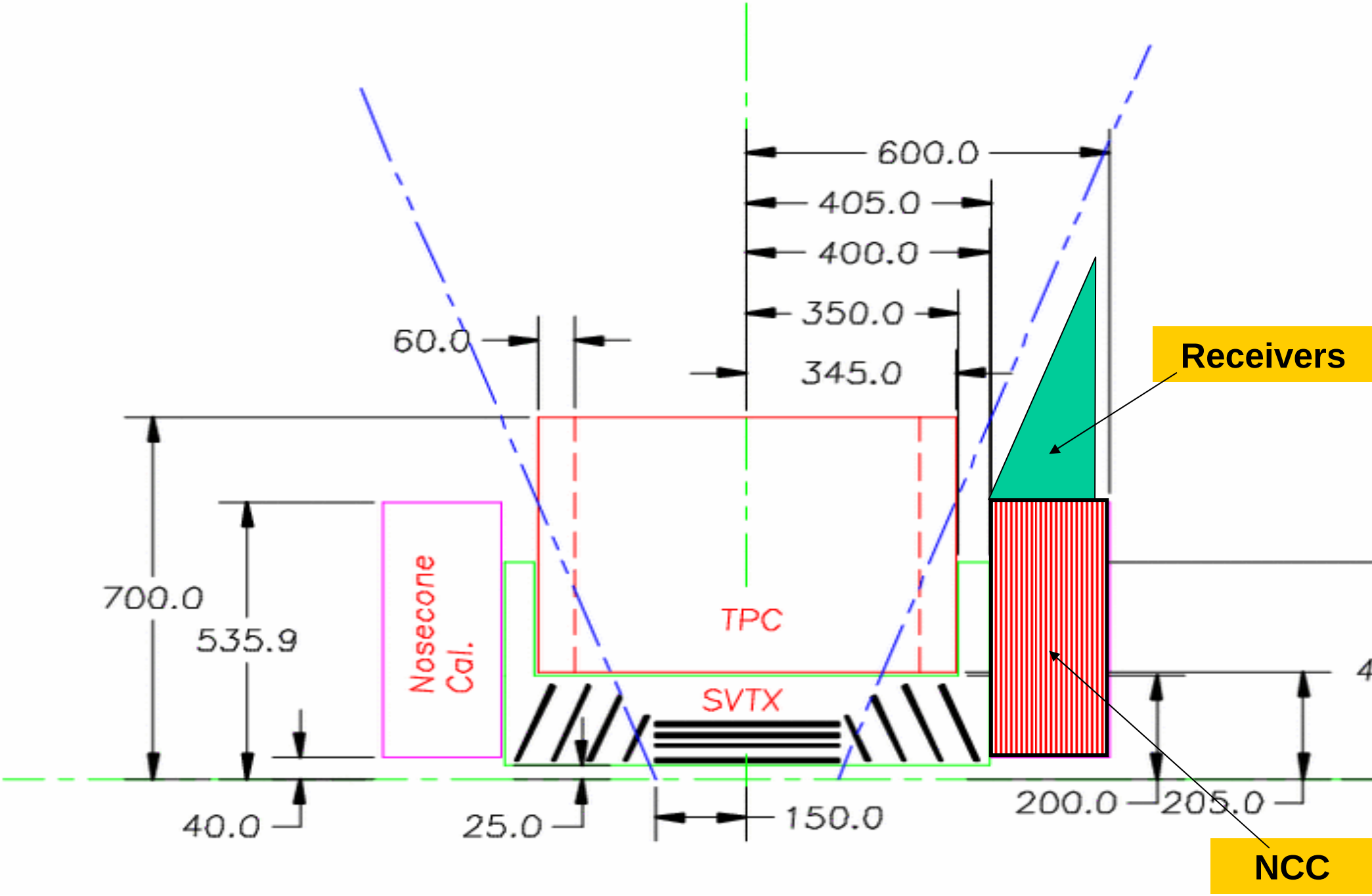
- Forward Spectrometers
  - New muon trigger chambers
  - Forward silicon detectors
  - Forward (Nosecone) calorimeters



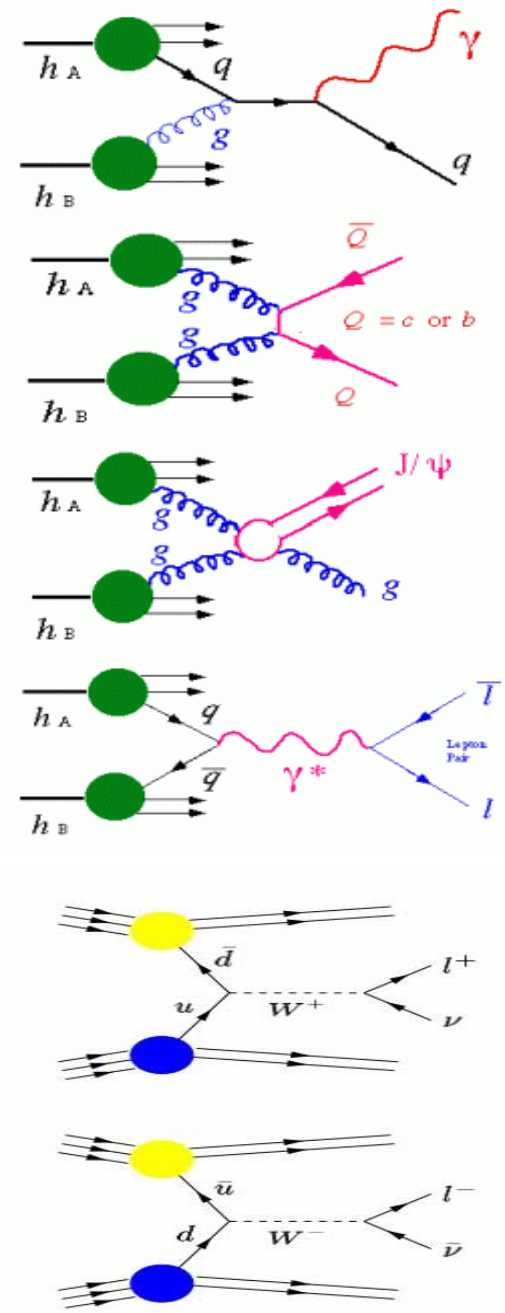

- pA centrality detectors
  - Very forward hadron calorimeter

- DAQ/trigger

# Real estate ….


600.0
405.0
400.0
350.0
345.0
60.0
Receivers
700.0
535.9
Nosecone Cal.
TPC
SVTX
40.0
25.0
150.0
200.0
205.0
NCC

# PHENIX Forward Upgrade

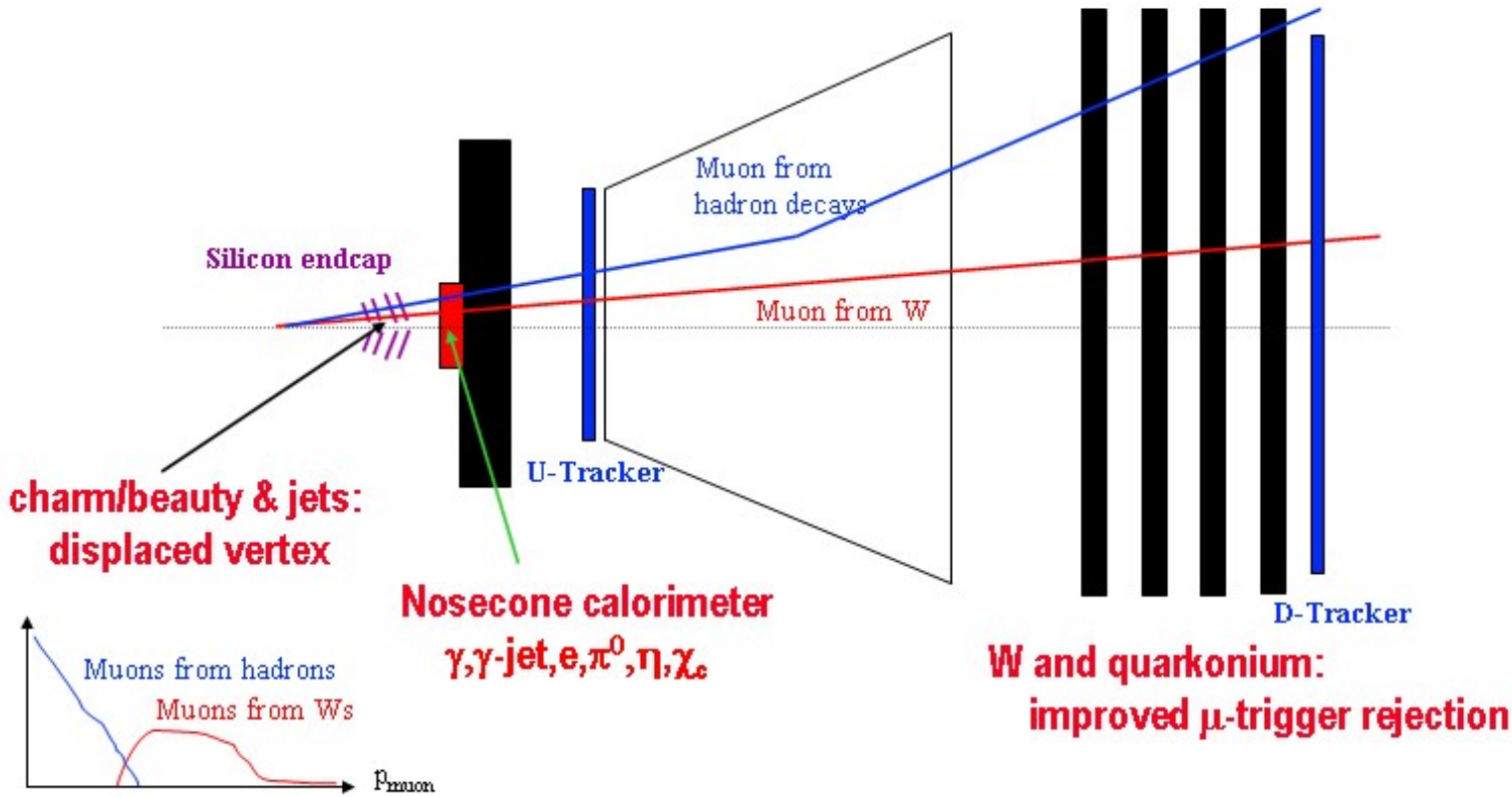



**Nosecone Calorimeter**

- » Sampling Tungsten-Silicon
- » Silicon photon / $\pi^0$ identifier layers

**Muon trigger**

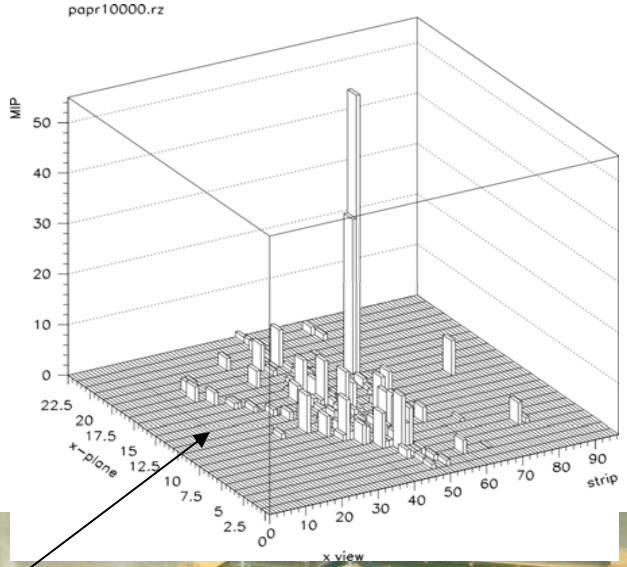
- » Upstream tracker (RPC or MuTr)
- » Downstream tracker (RPC's)

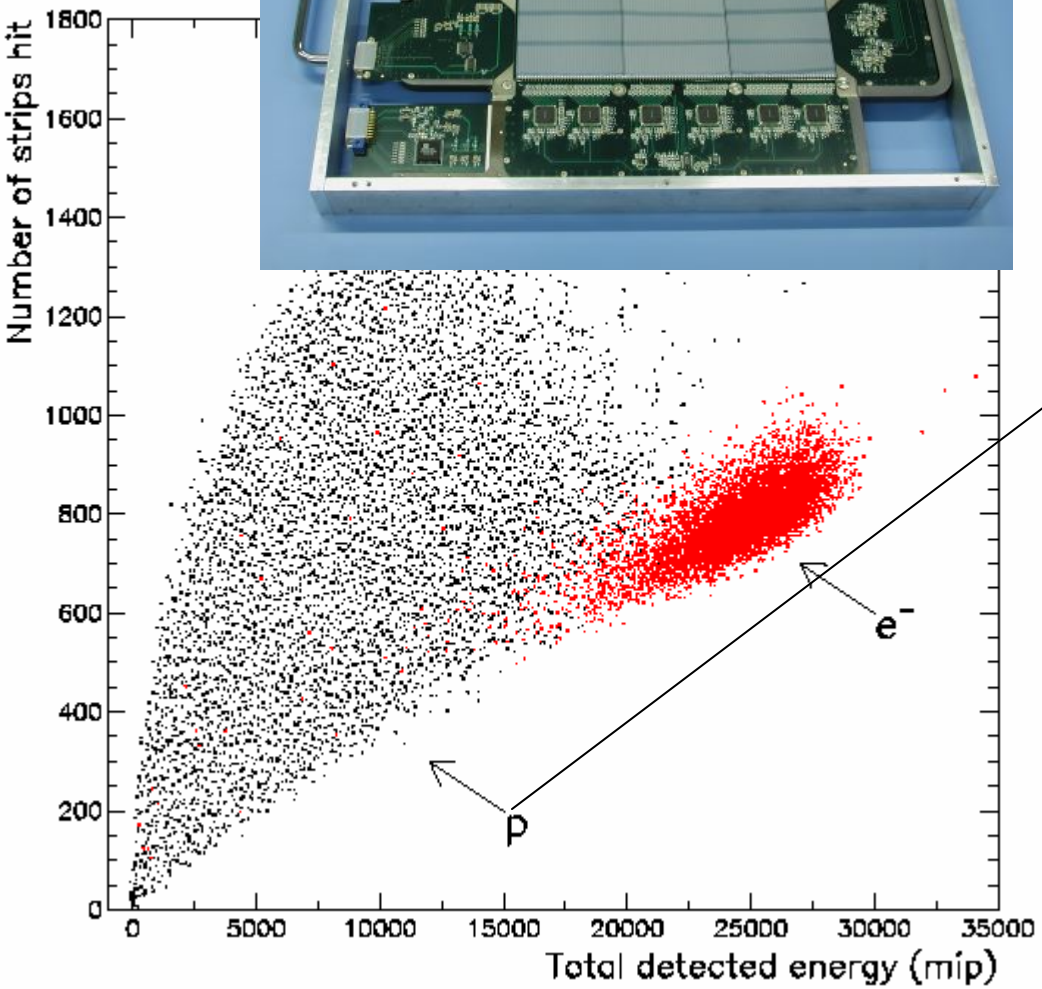


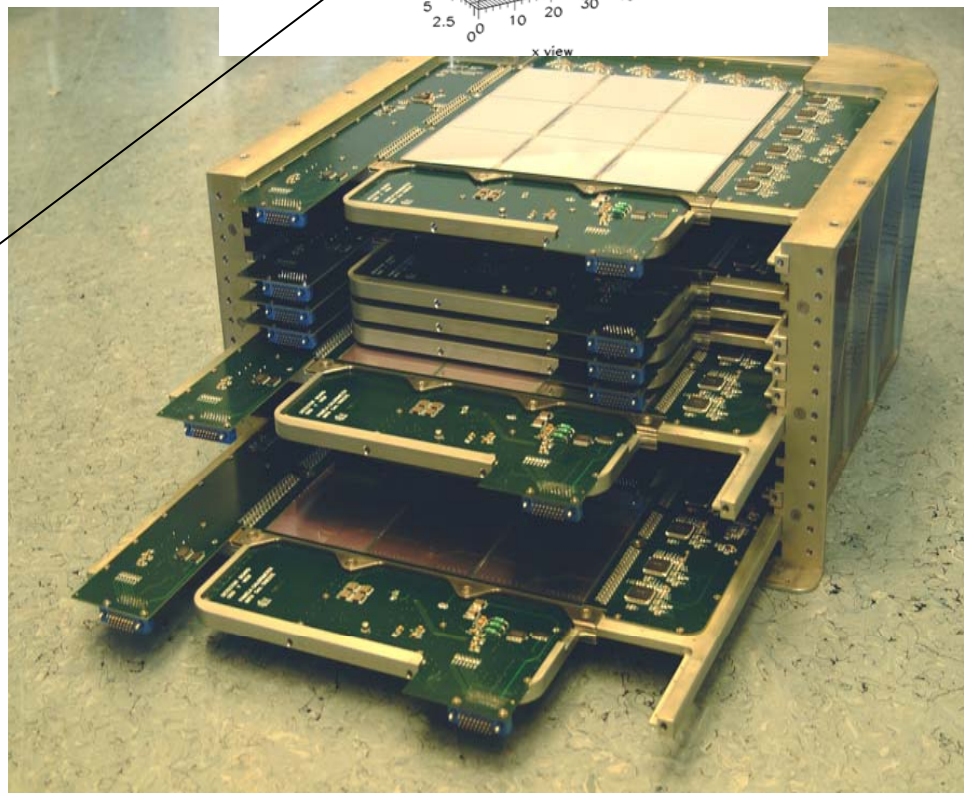



Edward Kistenev(BNL)

# Where is this technology today: PAMELA

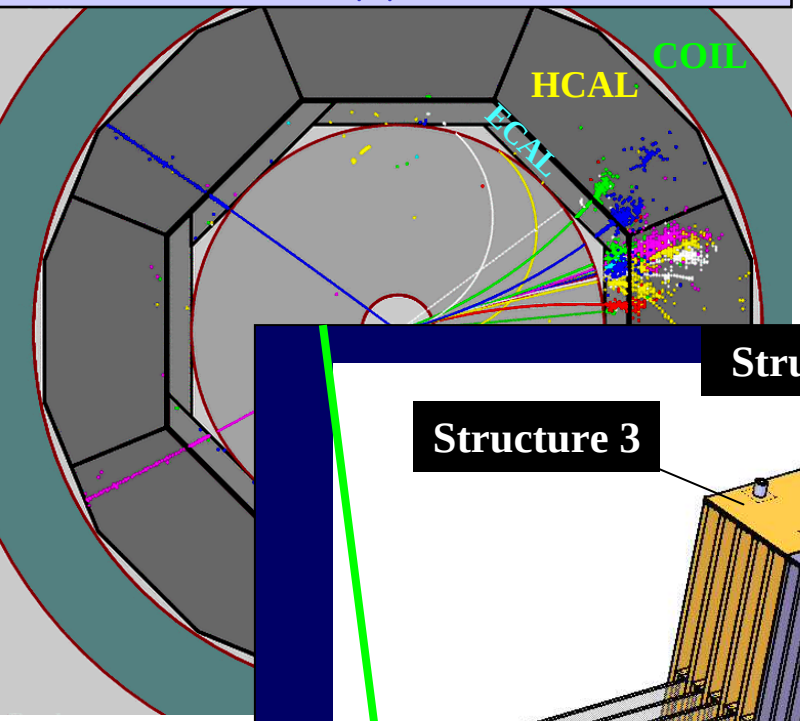


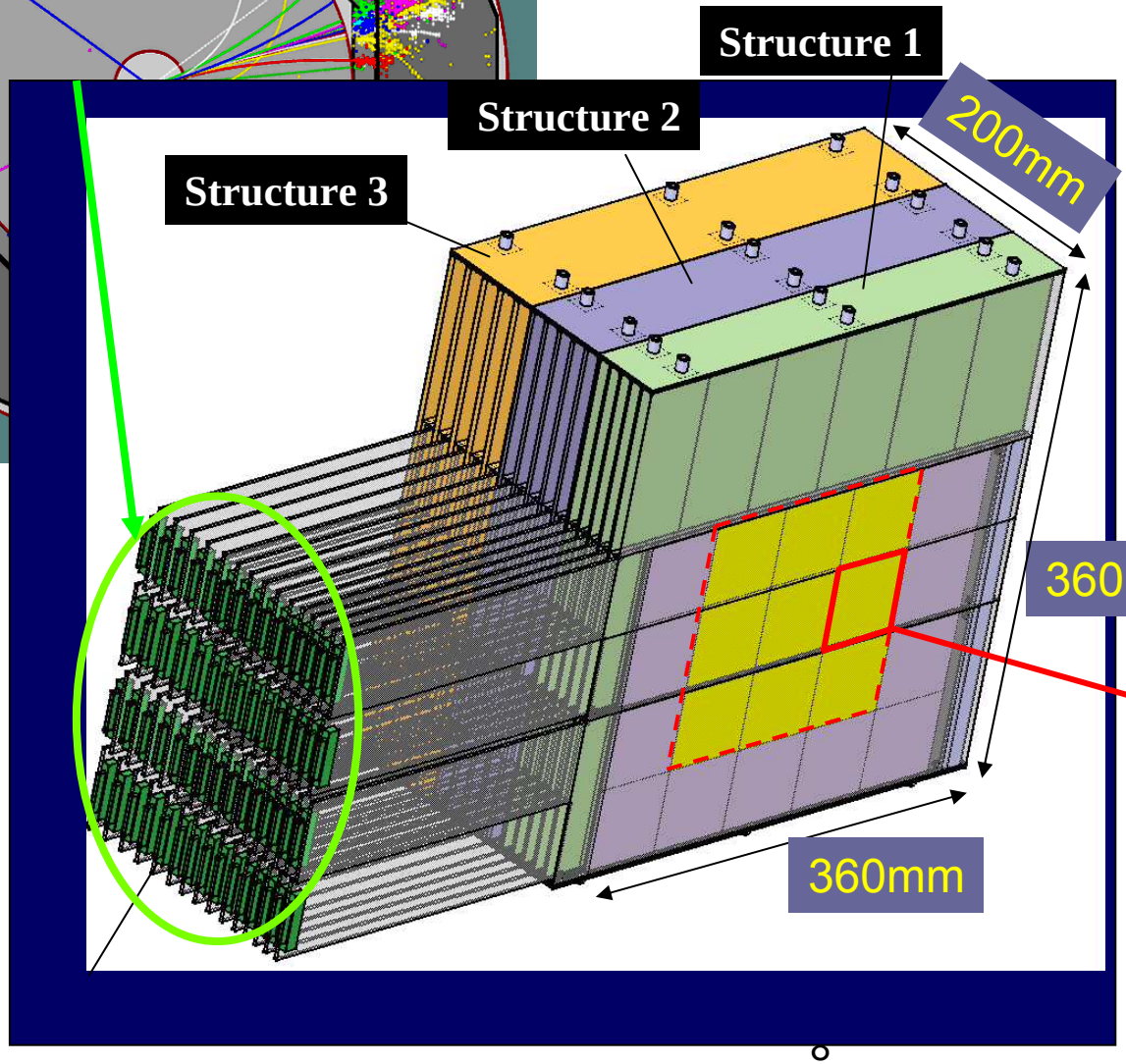
# dream: TESLA / CALICE

$e^+e^- \rightarrow ZH$, $Z \rightarrow \mu\mu$ at $\sqrt{s}$=500 GeV

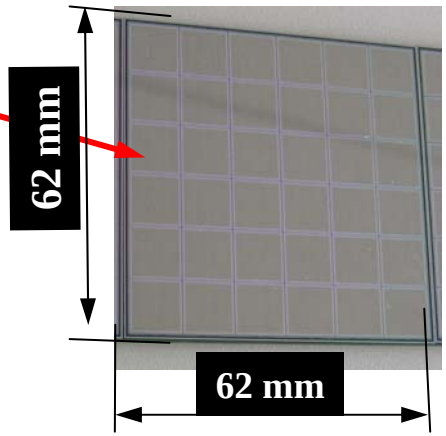



## CALICE ECAL

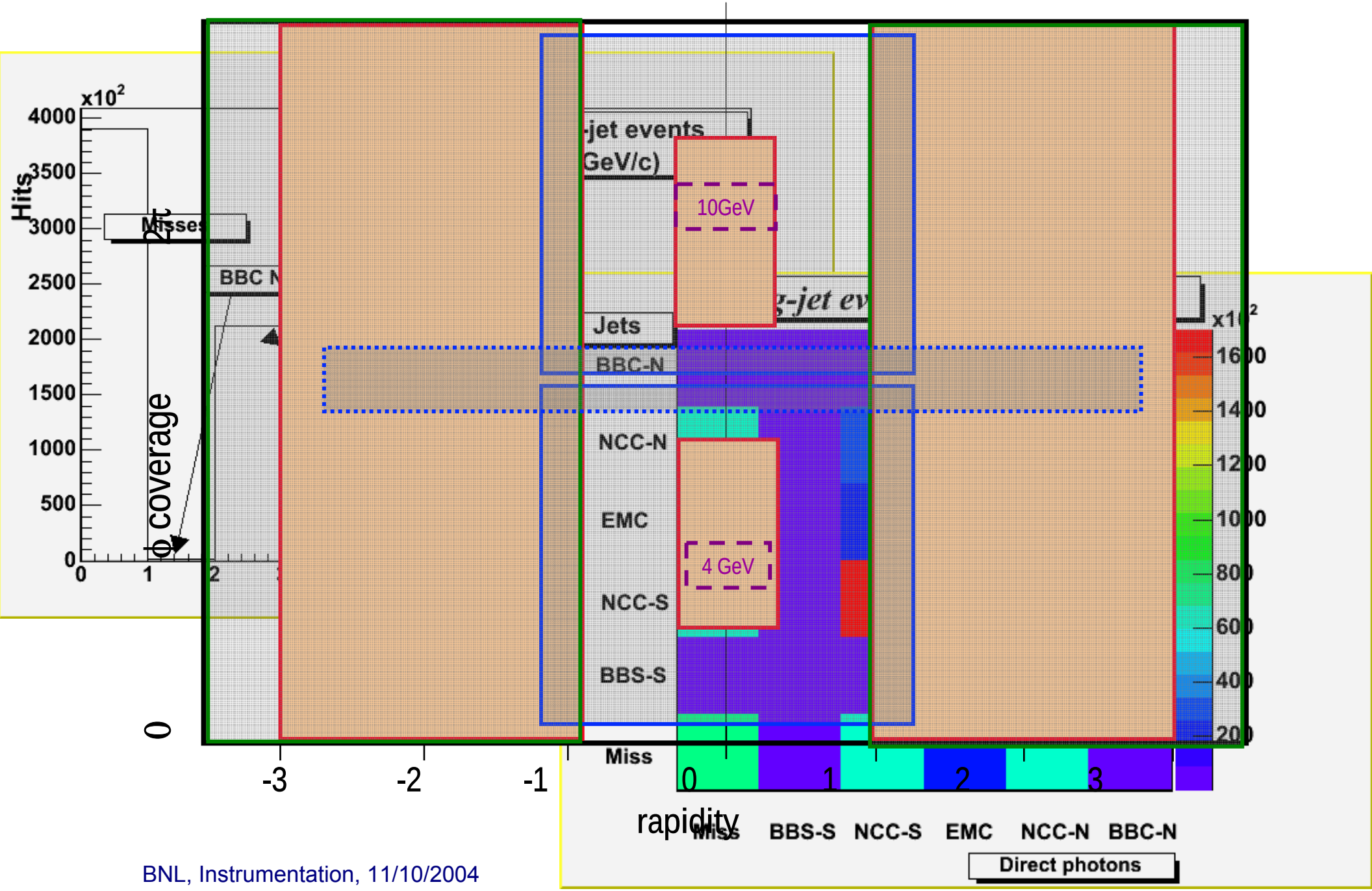
- LAL,LLR,LPC,PICM
- Imperial College, UCL, Cambridge, Birmingham, Manchester, RAL
- ITEP,IHEP,MSU
- Prague (IOP-ASCR)
- SNU,KNU



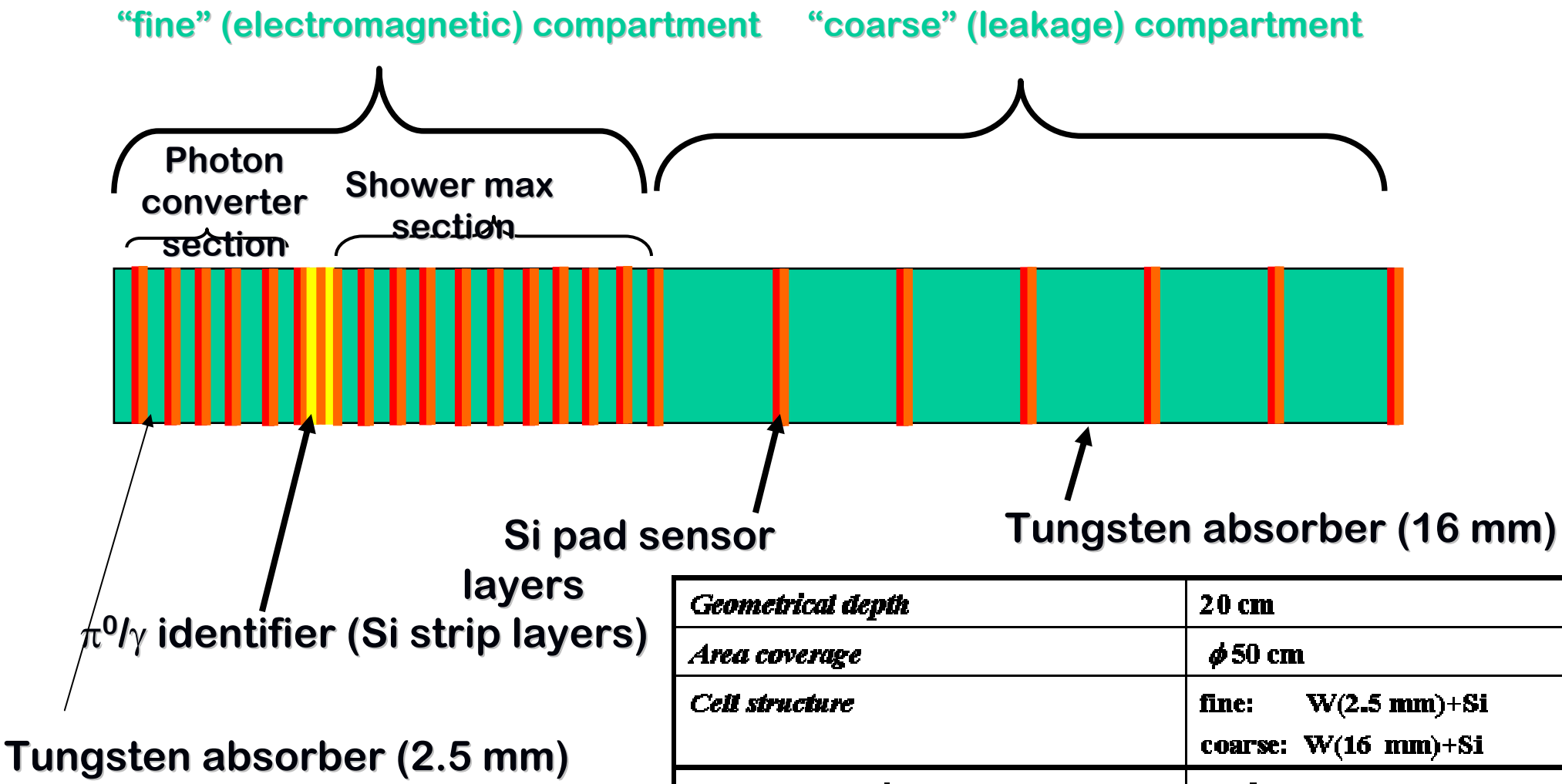

***Silicon wafers with 6×6 pads*** (10×10 mm²)



# Upgraded PHENIX



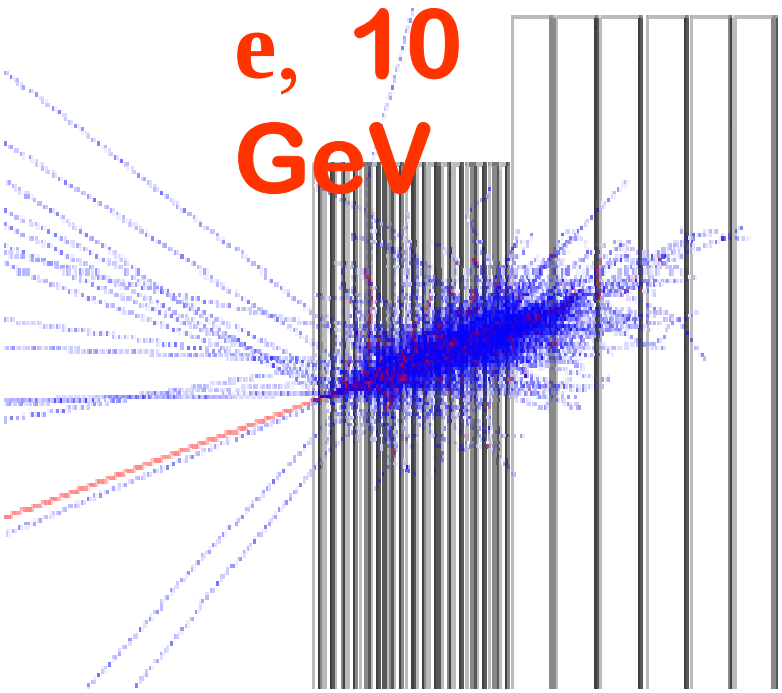
# Ideas

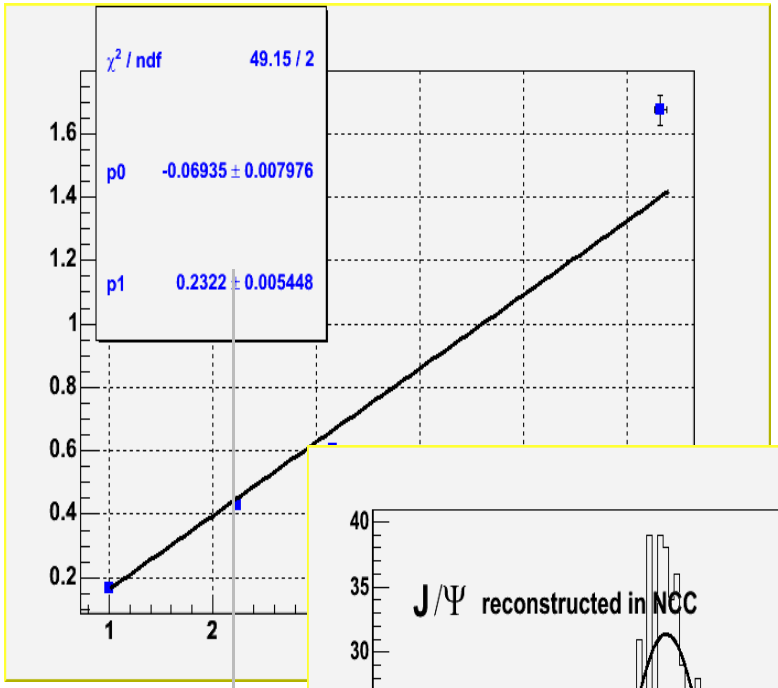


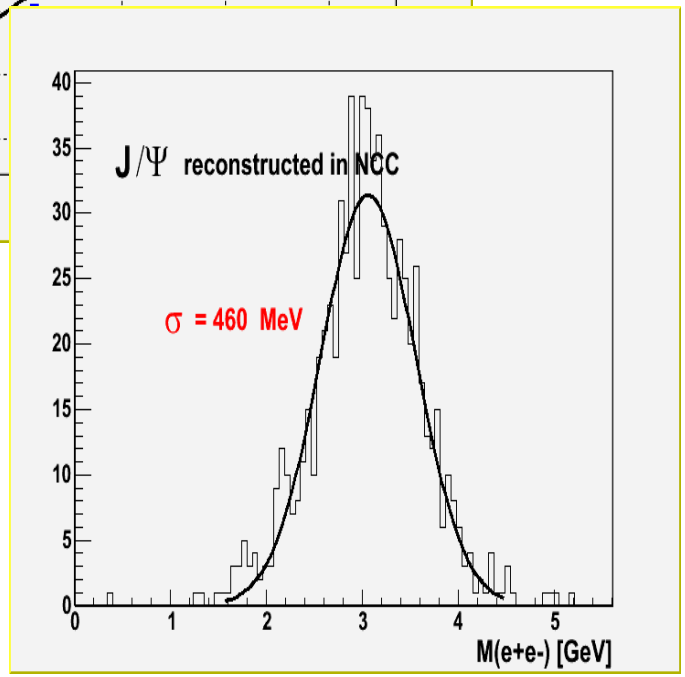

| | |
|---|---|
| *Geometrical depth* | 20 cm |
| *Area coverage* | $\phi$ 50 cm |
| *Cell structure* | fine: W(2.5 mm)+Si<br>coarse: W(16 mm)+Si |
| *Hadron absorption depth* | 1.6 $\Lambda_{abs}$ |
| *Photon absorption depth* | 43 $X_0$ |
| *Longitudinal segmentation* | 4 $X_0$ + 6 $X_0$ + 33 $X_0$ |
| *Lateral segmentation* | 1.5 x 1.5 $cm^2$ everywhere |
| *$\gamma/\pi^0$ identifier* | Two layers of 2 mm strips |

# Expected Performance

## *Electromagnetic shower measurements*

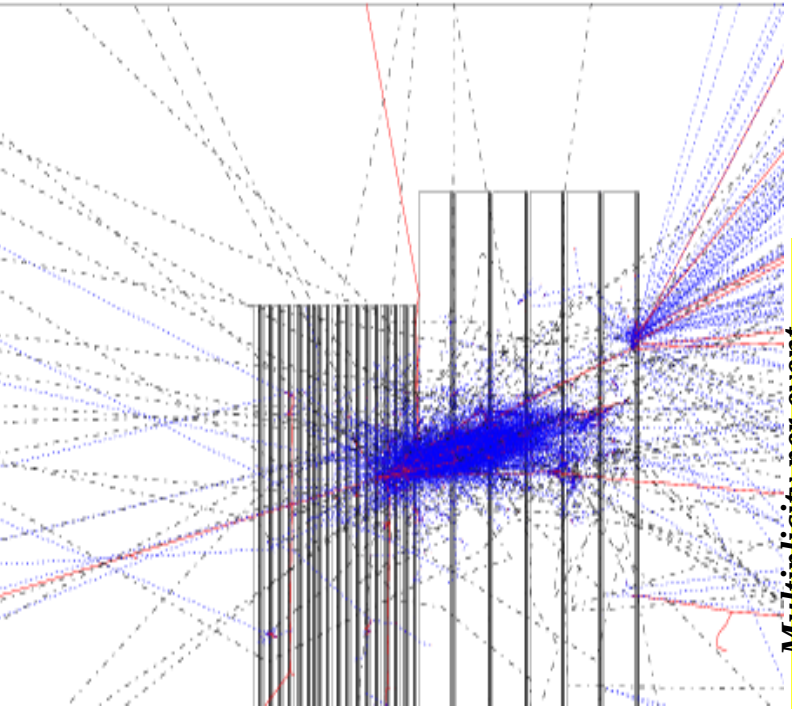


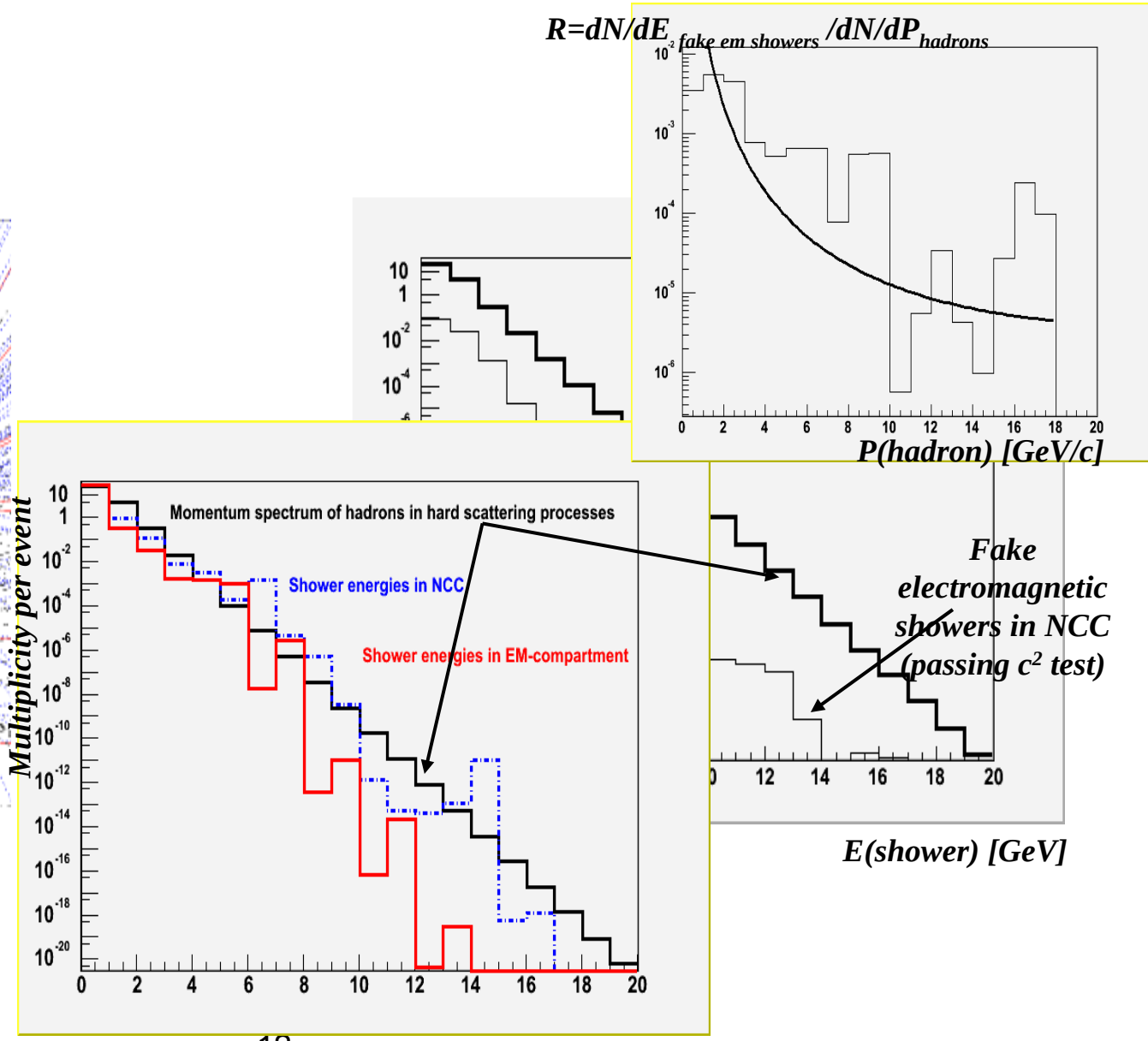



# Expected Performance

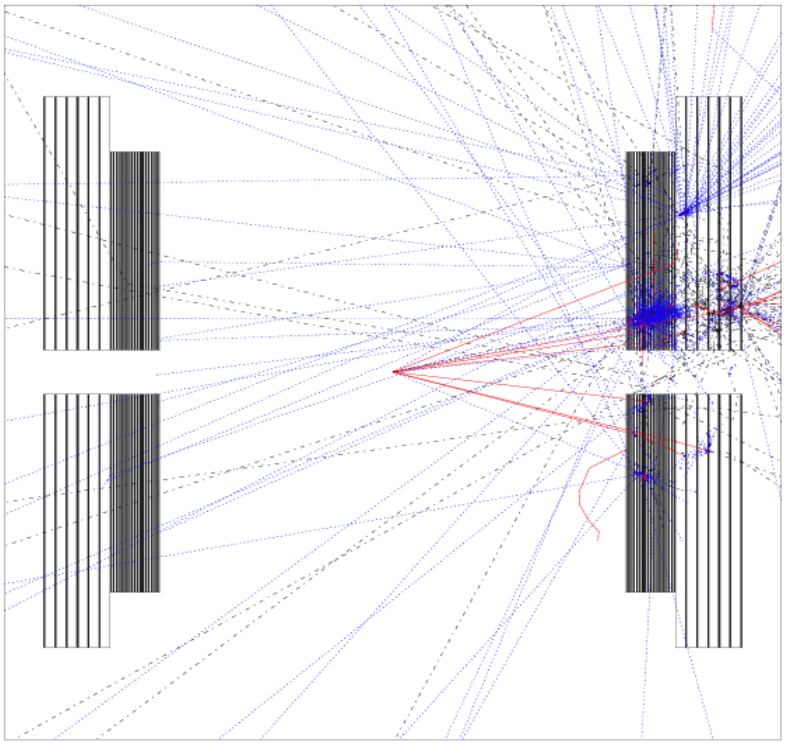
## *Hadronic shower rejection*

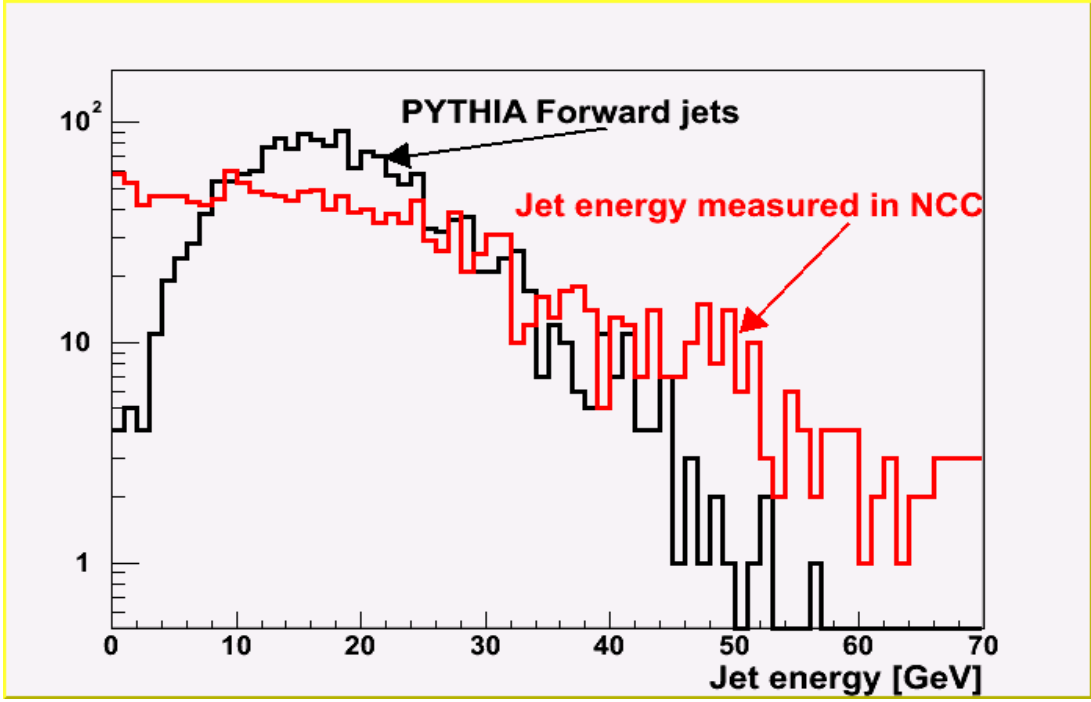




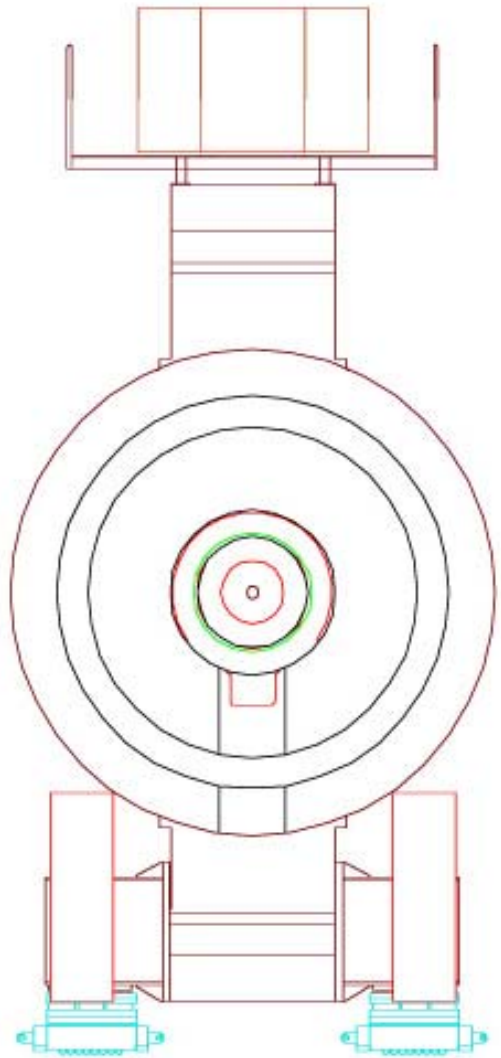
# Expected Performance

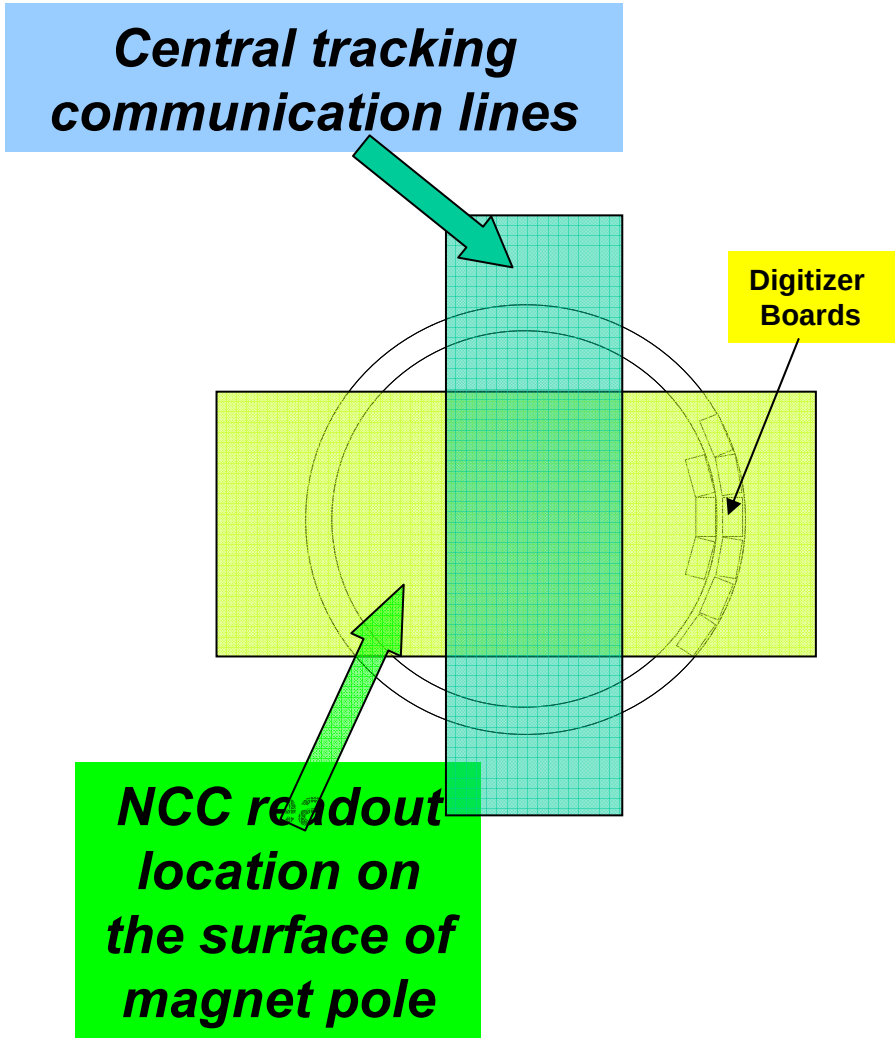
## *Jets*



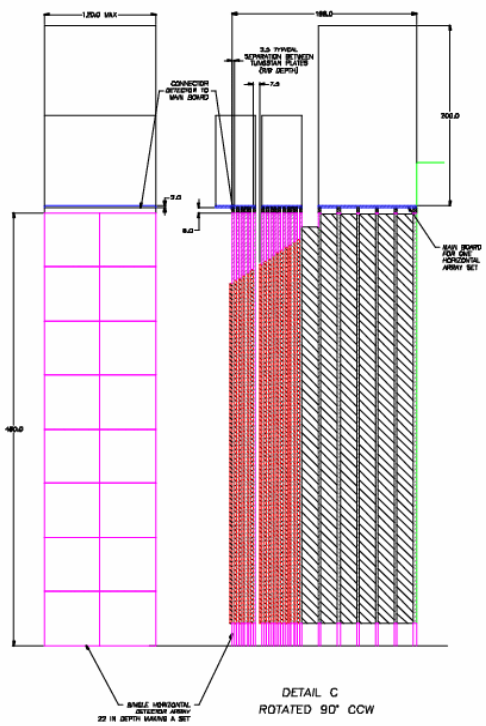


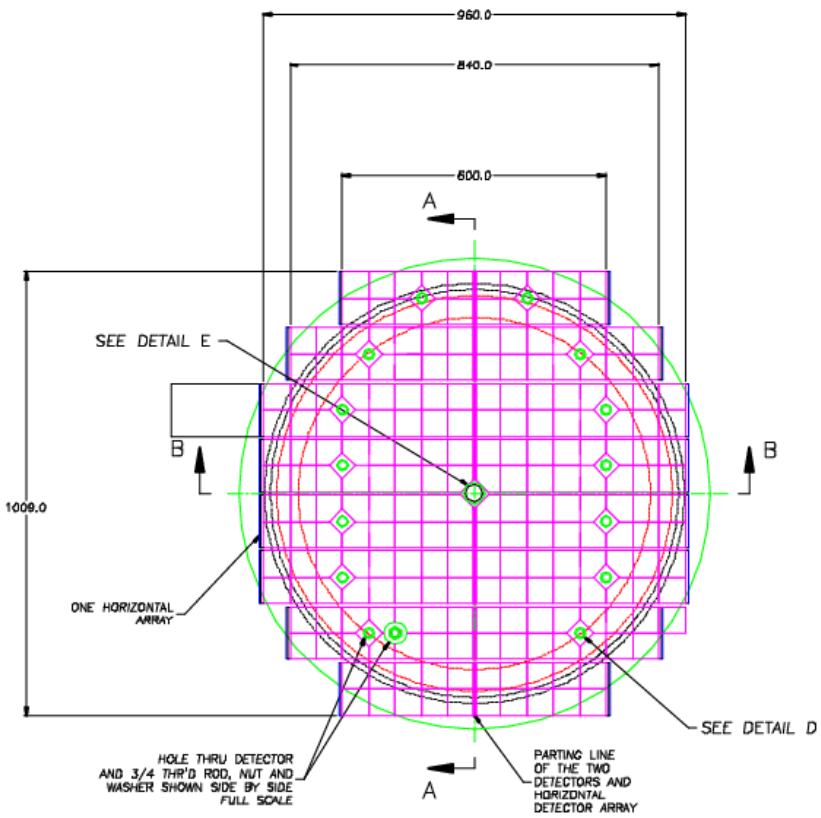
# Living together …





# NCC Mechanical Concept



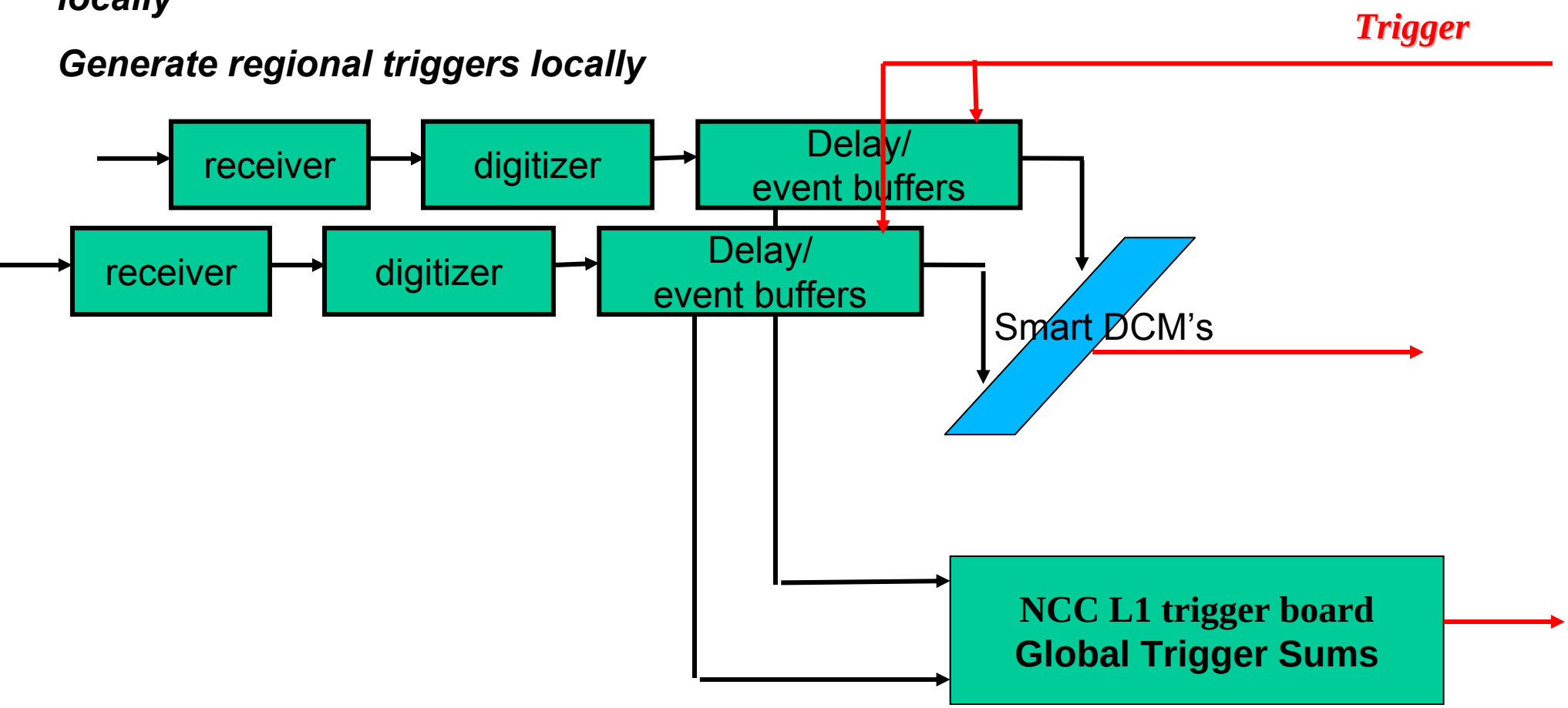

| Item | Total |
|---|---|
| W | 1.8 t |
| Si (calorimeter) | 14 $m^2$ |
| Si ($\gamma$-$\pi$0 identifier) | 1.15 $m^2$ |
| Readout units (calorimeter) | 288 |
| Readout units ($\gamma$-$\pi$0 identifier) | 24 |
| Preamps (16 ch) | 3776 |
| SVX4 | 48 |
| Digitization (subtowers) | 8448 |

# NCC readout concept (Chi)

***Digitize signal as early as possible***

***Generate low level trigger sums from the reduced bit ADC output locally***

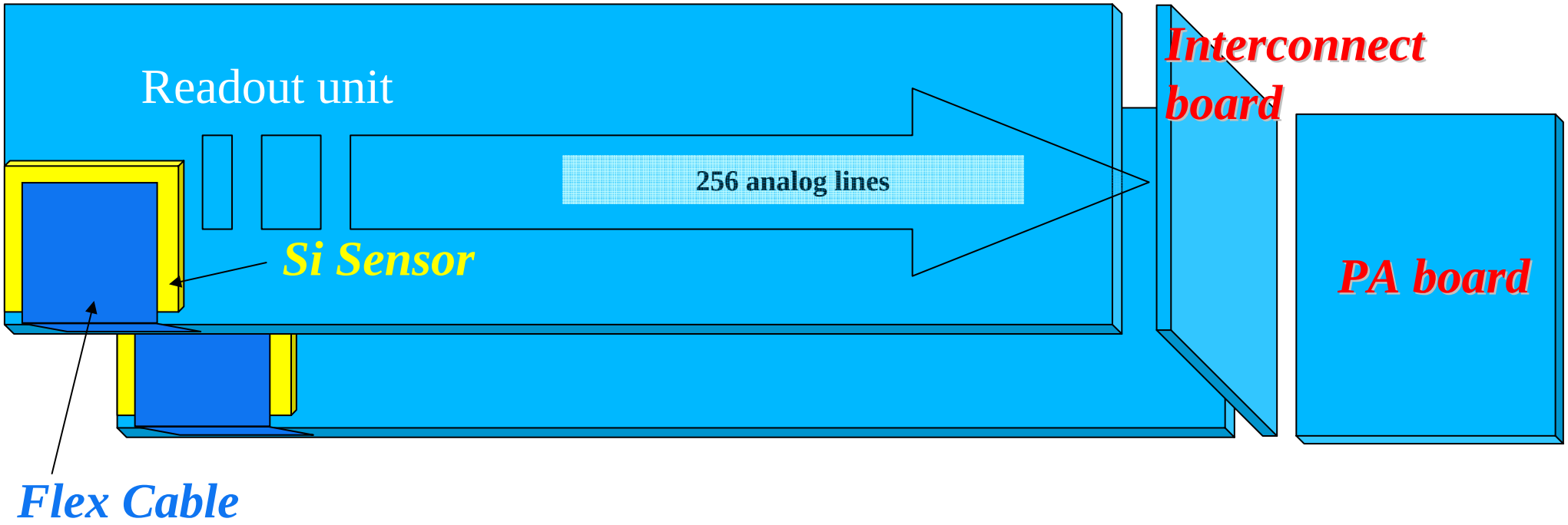
***Generate regional triggers locally***



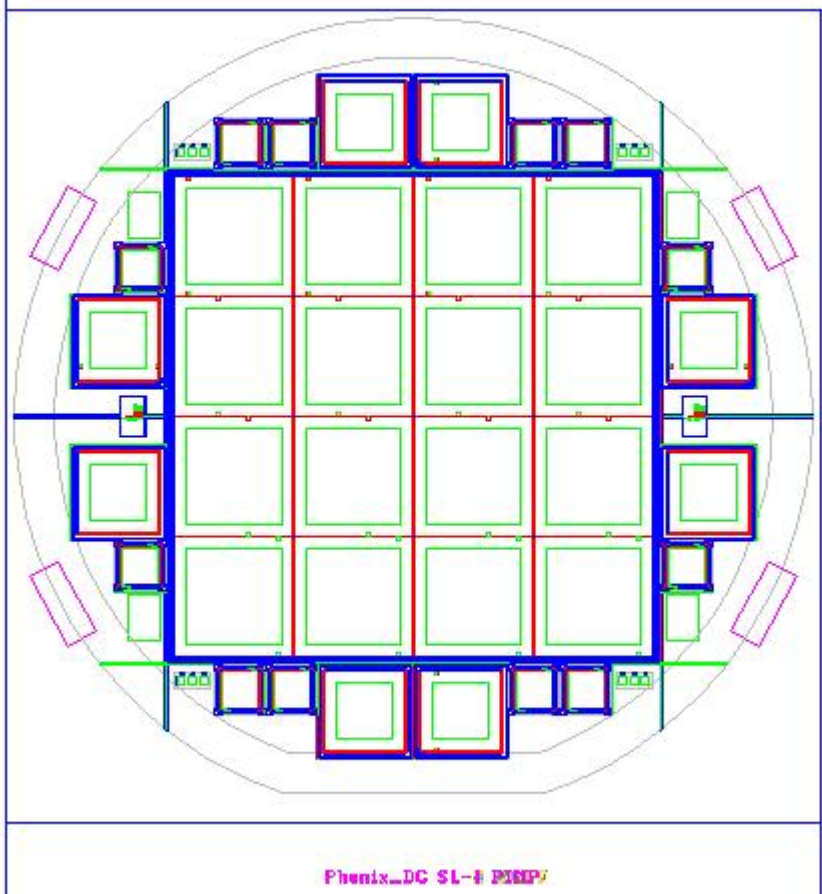
# NCC signal packaging concept

***-This is the calorimeter – all pads in the subtower are contributing to signal;***

***-Noise budget is set by physics: better is an enemy of the good;***



# Sensors




**4" High resistive wafer : 5 KΩcm**

**Thickness : 300 microns ± 3 %**

**Tile side : 62.0 + 0.0**

**- 0.1 mm**

**Guard ring**

**In Silicone ~80 e-h pairs / micron ⇒ 24000 $e^-$ / MiP**

**Capacitance : ~40 pF**

**Leakage current : 5 – 15 nA**

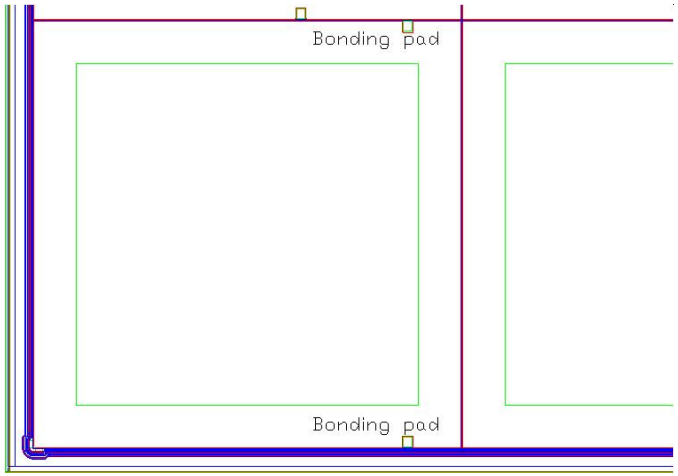
**Full depletion bias : ~100 V**

**Nominal operating bias : 200 V**

One wafer is a Matrix of 4 x 4 pixels of 2.25 $cm^2$.

Important point : manufacturing must be as simple as possible to be near of what could be the real production for full scale detector in order to :

- Keep lower price (a minimum of step during processing)
- Low rate of rejected processed wafer
- good reliability and large robustness



# AC ……

- **Usually implemented as an integrated SiO2+Si3N4+Polysilicon layer between the p-type region and the readout metal;**

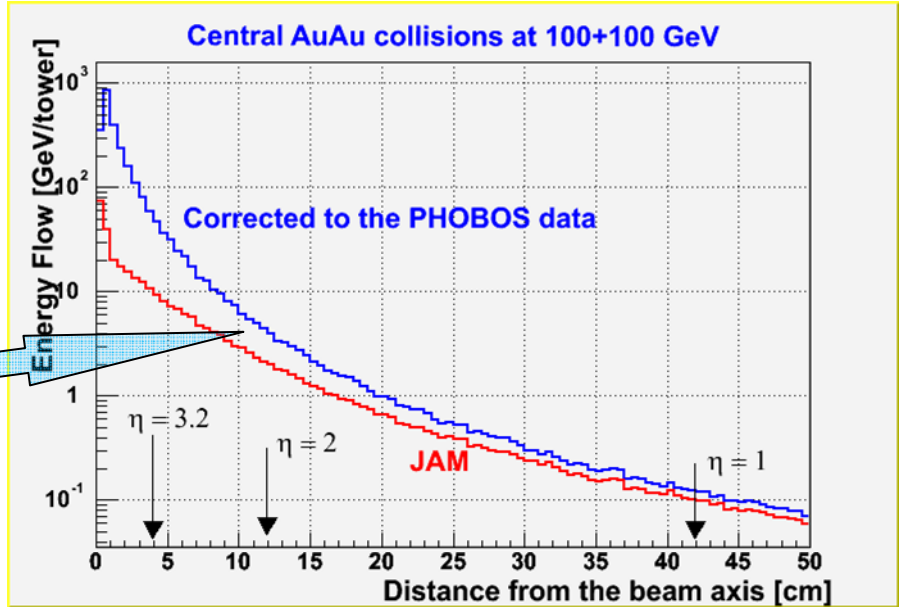
- **The technology is readily available to grow SiO2+Si3N4 layers up to 0.25 µm thick what is insufficient to insure the high production yield on finished sensors with large area cap's. Direct bonding to layers this thin is nearly impossible and may result in damaging the sensor if wire is bonded directly above the p-n junction point.**

- **We propose to grow thick Si02 + Si3N4 (total thickness should be about 1 µm). Developing this process will allow to create on the sensor capacitors with capacitances in excess of 1000 pF/cm2 able to sustain the voltages up to and above 150V. We expect production yields close to 70%.**

# Readout: Dynamic range

| | | |
|---|---|---|
| Dynamic range [GeV] | ~100 | Kinematical limit |
| MIP signal in a single Si layer (e) | 24k | ~300 mkm Si |
| MIP signal in a subtower (e) | 144k-240k | 6 to 10 Si layers |
| Max. charge per event in a subtower(e) | 2.1 $10^8$ or ~ 40 pC | 50 GeV deposition, 1.7% sampling fraction |
| Dynamic range | >10000 MIP<br>>1000 $MIP_{10}$ | $MIP_{10}$ is the signal summed up over all contributing layers (10 layers max) |

***Underlying event contribution can be neglected even in the central AuAu collisions***



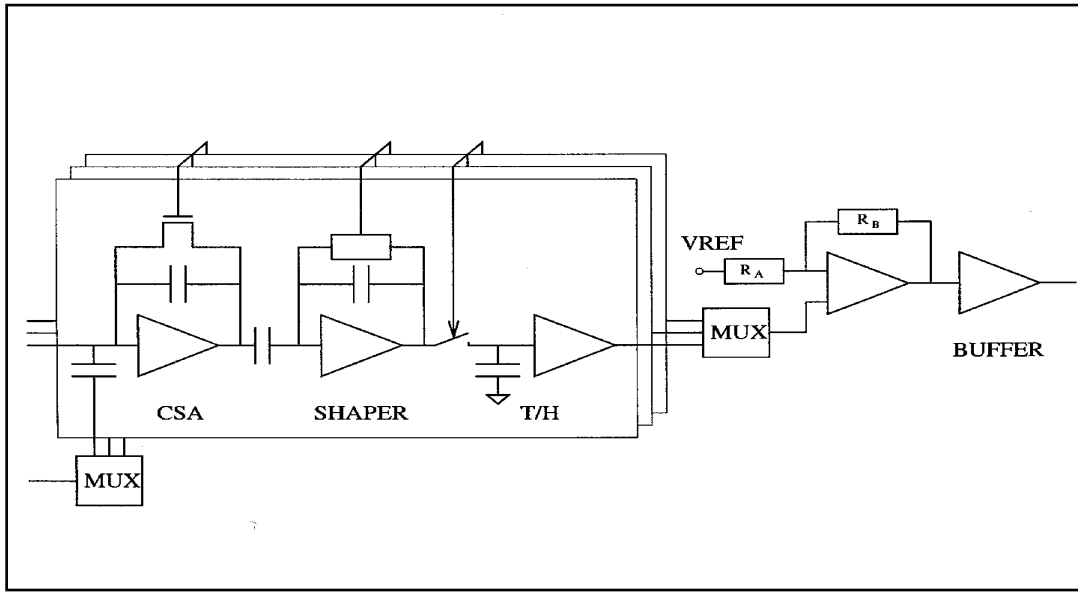
# Readout: Noise budget

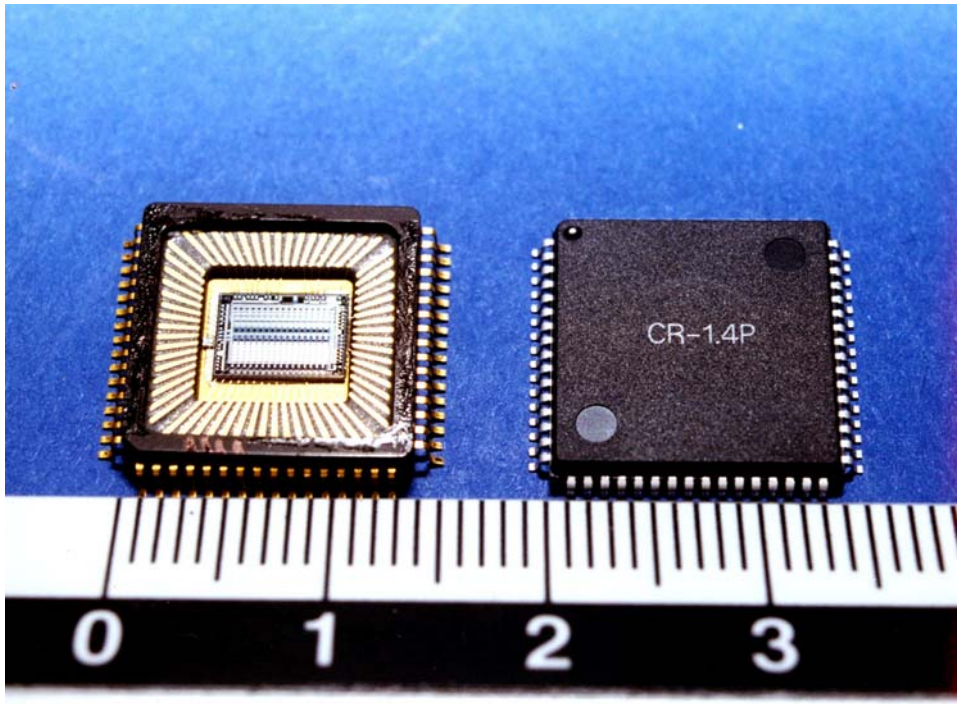
| Compartment | I | II | II |
|---|---|---|---|
| Sampling layers | 6 | 10 | 6 |
| Sampling fraction (%) | 1.7 | 1.7 | 0.26 |
| MIP energy loss [MeV] | 42 | 69 | 270 |
| MIP energy loss in Si [MeV] | 0.7 | 1.2 | 0.7 |
| Pad capacitance [pF] | 80 | 80 | 80 |
| Trace capacitance [pF] | 10-45 | 10-45 | 10-55 |
| Tower capacitance [pF] | 540-780 | 900-1300 | 540-900 |
| Energy range of interest [GeV] | 0.5 – 50 | | |
| Intrinsic energy resolution (em showers) [GeV] | 0.4-1.5 | | |
| Noise limit | 10 MeV | 15 MeV | 100 MeV |
| ENC budget [MeV] | 0.15 | 0.2 | 0.15 |
| ENC budget [electrons] | 40 k | 50 k | 40 k |

# Readout: Signal amplification

-Much will depend on the final judgement on dynamic range:

-planning for 50 GeV dynamic range and noise budget of 15 MeV allows to work with a single 12 bits range and rely on commercial 12 bit ADC's running at frequencies above 50 mhz




R&D phase from 1996 to 1998 (3 different prototypes tested)
10 wafers (about 1300 chips) produced between 1998 and 2000
Total yield > 70%
264 chips equip the FM of the PAMELA Calorimeter
Adopted also by the PAMELA TRD

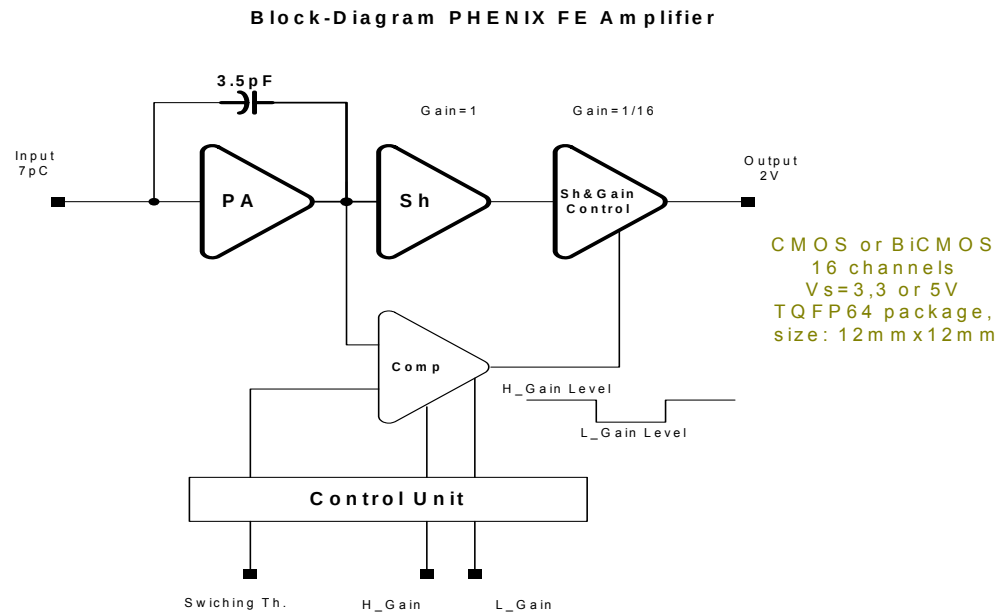
**Circuit design specs:**

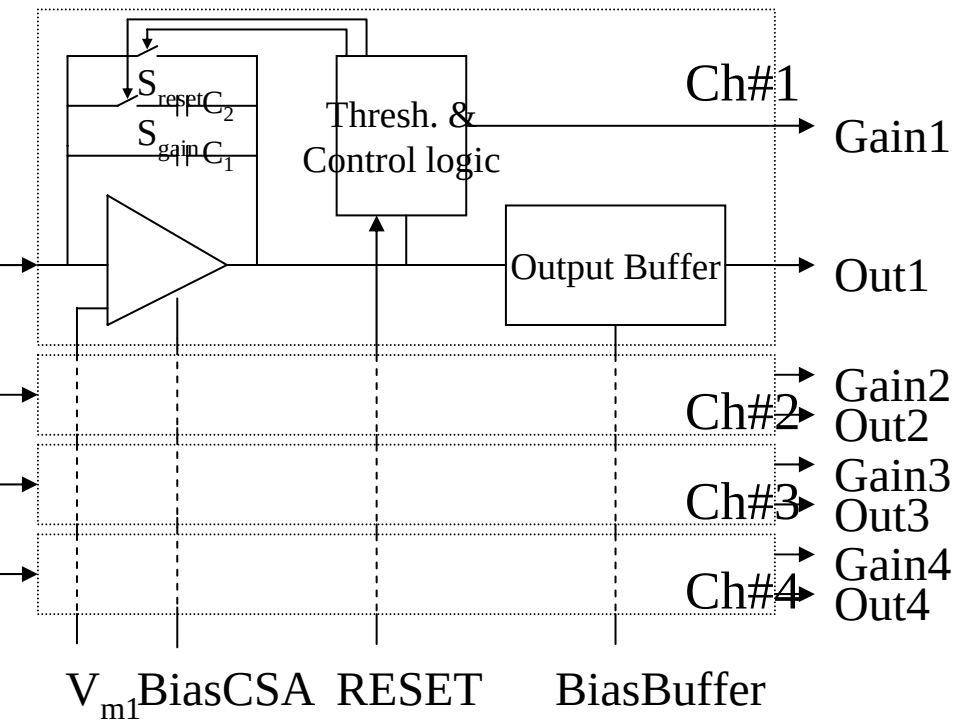
| | |
|---|---|
| - Number of channels/chip | 16 |
| - Linear dynamic range | 1400 MIPs |
| - Maximum output signal | 7 V |
| - Maximum detector leakage current | 100 nA |
| - Peaking time | 1 μs |
| - Detector capacitance | 180 pF |
| - $ENC_{max}$ @ 180 pF | 3000 $e^-$ rms |
| - Counting rate | 30 kHz |

# Readout: Signal amplification

**If further simulation will prove the 50 GeV dynamic range too tight**

**the solution can be an automatic gain switching**




- **New development CASIS (Trieste)**
  - ***10000 $MIP_1$ dynamic range***
  - ***S/N ratio on the single MIP 5:1.***
  - ***Double gain on CSA: automatic selection on 500 MIP threshold***

# Readout: Base restoration and signal shaping

- Classical CSA followed by 4-th order shaper was modelled with PSPICE;
- Rise time and shaping time were optimized to achieve optimum noise performance for any given base-to-base (1% level) pulse length on the ADC input;

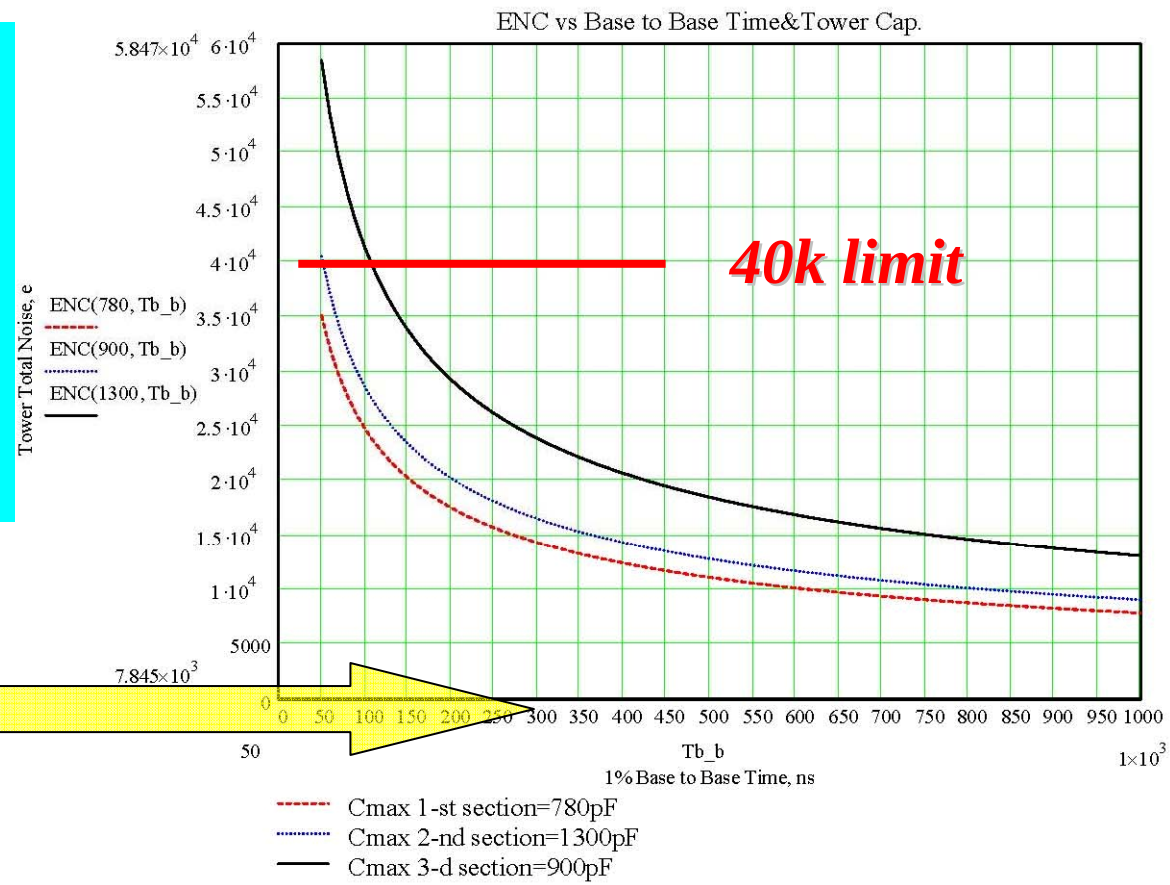
**PYTHIA:**

the probability for tower to receive a direct hit in the pp minimum bias event is ~3%

**GEANT**

Shower spreading results in the tower occupancy increased to 10%

***Base line restoration in 300 ns***



# Schedule

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 →

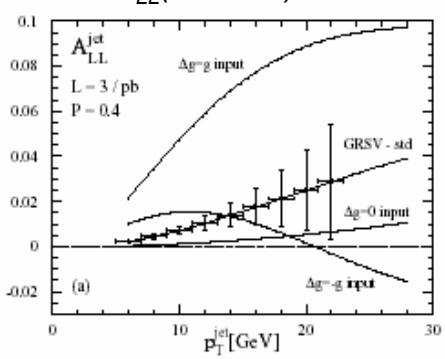
Charm Physics →

direct photons →

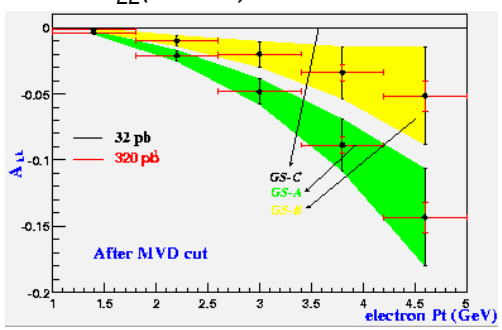
Jets →

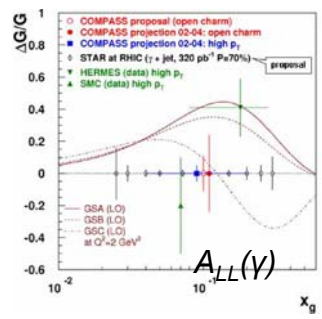
W-physics →

*$A_{LL}$(hadrons)*

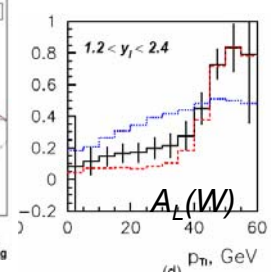



*$A_{LL}$(charm)*




*$A_{LL}(\gamma)$*




*$A_L(W)$*

# R & D program and milestones

**Prototype:**

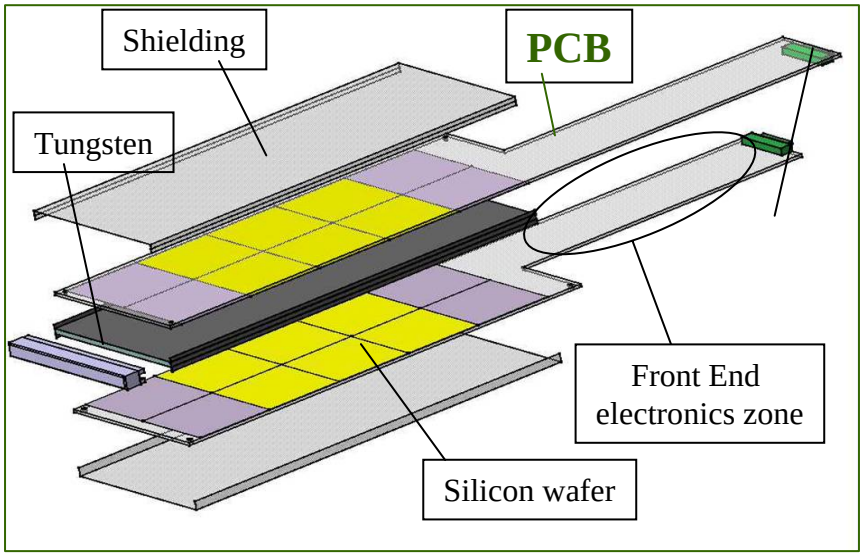
**22 layers 2 sensors wide**

**CR1-4P preamps**

**2 γ/π0 identification layers**

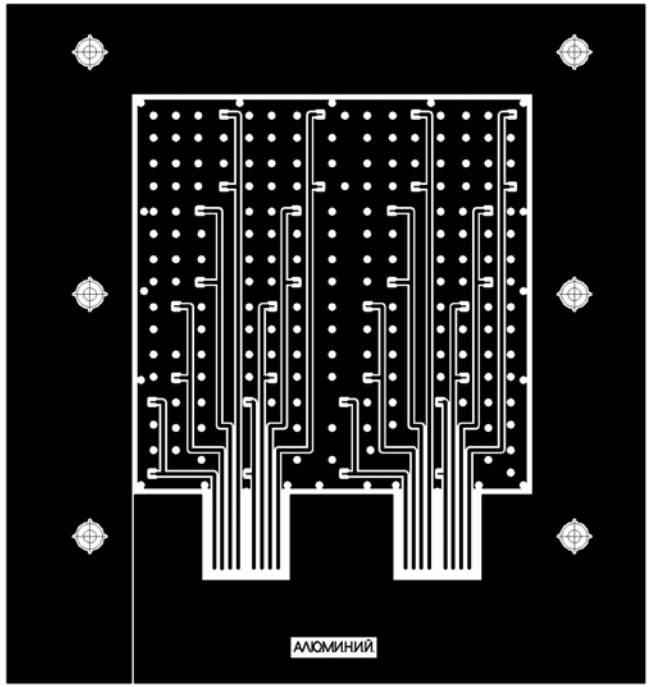
***Tasks***

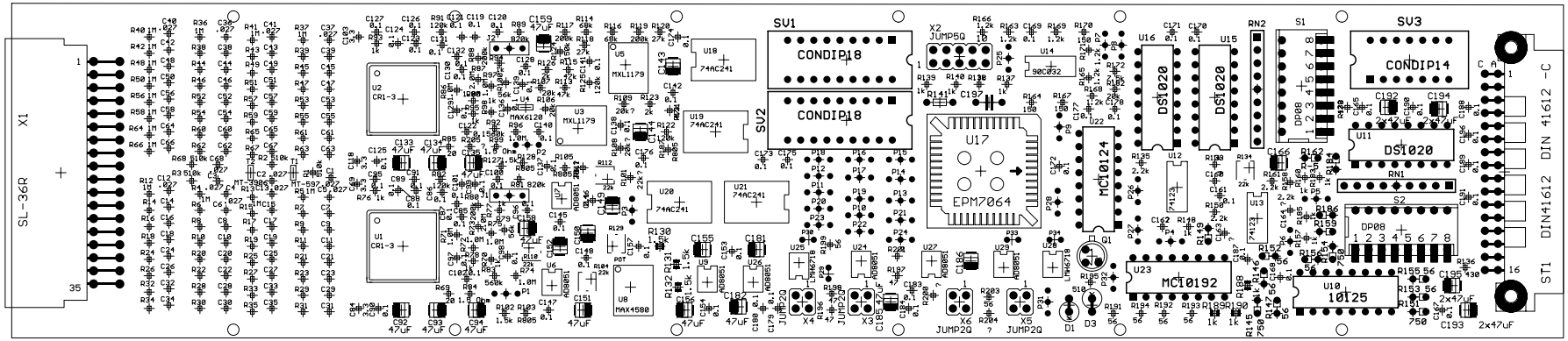
- **Silicon**
- **PCB**
- **Bonding & cables**
- **VFE Chip**
- **Mechanics**
- **Assembly**
- **DAQ**
- **Test beam**



# Already available

- pc-boards for readout units;
- flex cables;
- FEE pc boards;
- most of the components



# Near Term Priorities - CDR

- **Ongoing R&D program is funded by UCR (R.Seto) and BNL (PHENIX Upgrade Funds)**
  - **Prototype**
    - **pad-sensors, analog cables, readout units, front-end - MSU;**
    - **strip-sensors for the $\gamma/\pi^0$ identifier – Prague. Backup solution - from earlier project in Trieste;**
    - **Readout for $\gamma/\pi 0$ identifier – SVX4 (Prague). Backup solution – same as in the calorimetric layers (MSU).**

- **Preamplifier (decision for CDR)**
  - **New device developed at BNL;**
  - **Upgrade to CR3A developed as part of R&D program in Trieste – preferred but ….. ;**
  - **Upgrade to preamp developed as part of TESLA/CALICE program – under investigation;**
  - **New device developed in collaboration between MEPhI/MSU/BNL – proposal exists;**
  - **Just new device (dreams exist).**

- **Mechanics of the future detector (prototype and CDR)**
  - **Work started in Dubna (A.Litvinenko).**

- **Digital readout (CDR)**
  - **New group from Dubna (S.Bazylev) will be helping with CDR**

# Summary

o PHENIX has great plans for a program of new physics aimed to study nuclear effects in partonic structure functions down to a very small partonic momenta. It spans the whole range of pp (including polarized), pA and dA collisions at RHIC.

o Integrated forward spectrometer upgrade is the precondition for PHENIX to stay competitive in this new field of physics.

o We have technical solutions which match physics and present an excellent opportunity for new groups both in physics and instrumentation!