A proposed Forward Calorimeter upgrade for the PHENIX experiment at RHIC

Ondřej Chvála UC Riverside Spin Praha July 28 2009

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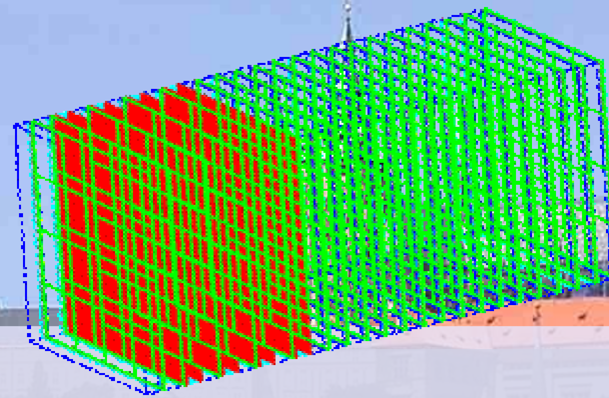


Outline:

PHENIX experiment layout

Physics motivation - Spin, Heavy Nuclei

Detector design and expected performance

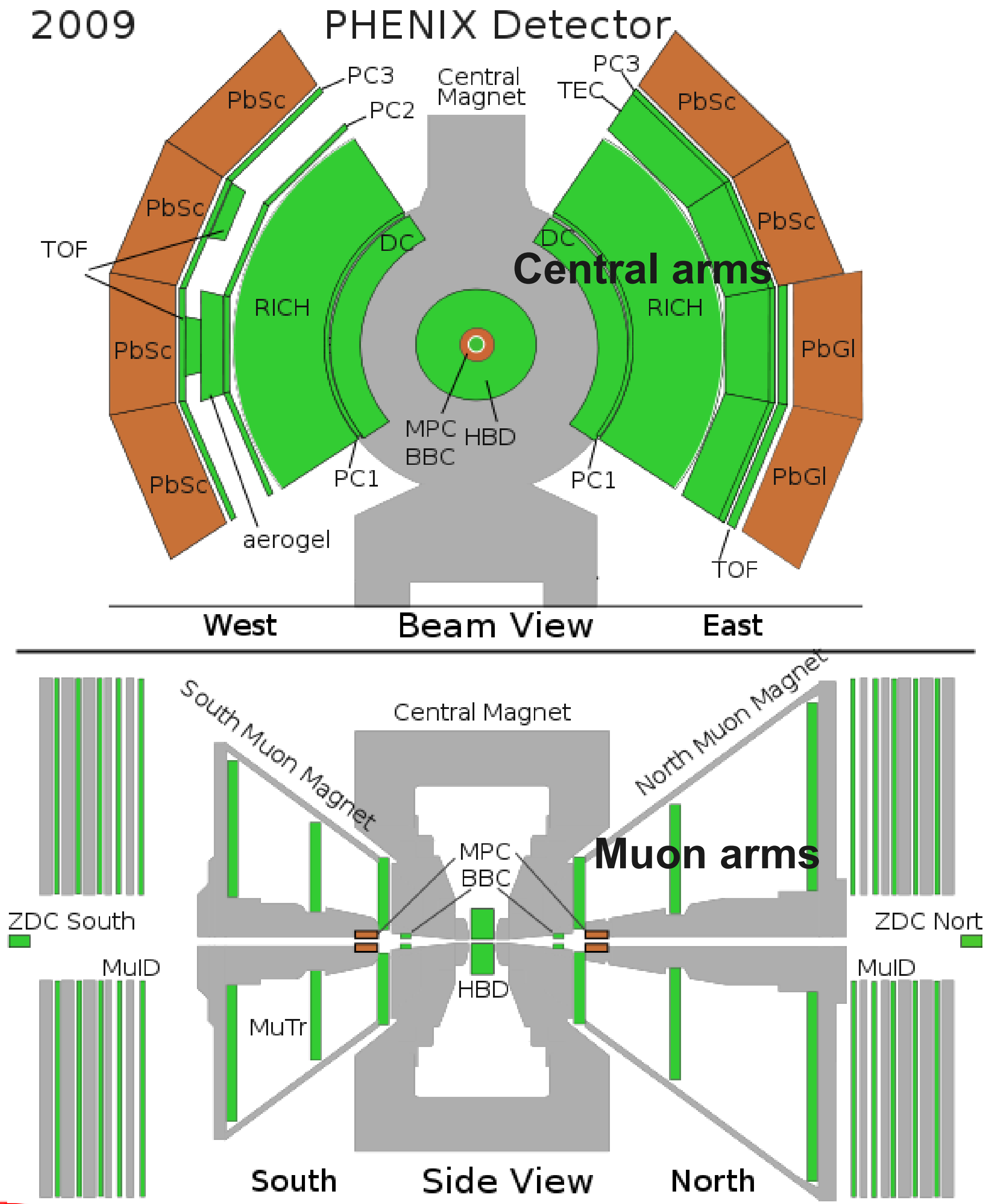
Prototype tests

Project Status, Conclusions

Many thanks to collaborators for slides, advices and other help!

Ondřej Chvála **UC Riverside** **Spin Praha July 28 2009**

PHENIX experiment at RHIC at BNL



PHENIX: Special purpose detector to measure <u>rare</u> processes involving **EM probes** (leptons and photons) at high rate but small coverage. Upgrades to improve acceptance and triggering.

Calorimetry:

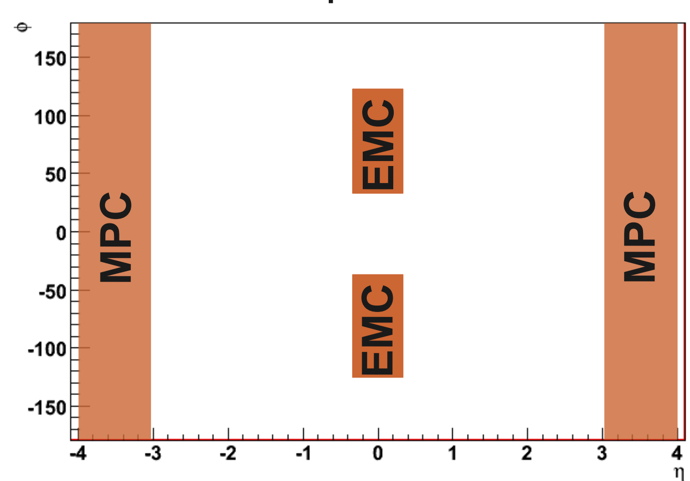
EMC in central arms (PbSc, PbGl)

$|\eta| < 0.35$

MPC in forward directions ($PbWO_4$)

$3 < |\eta| < 4$

acceptance

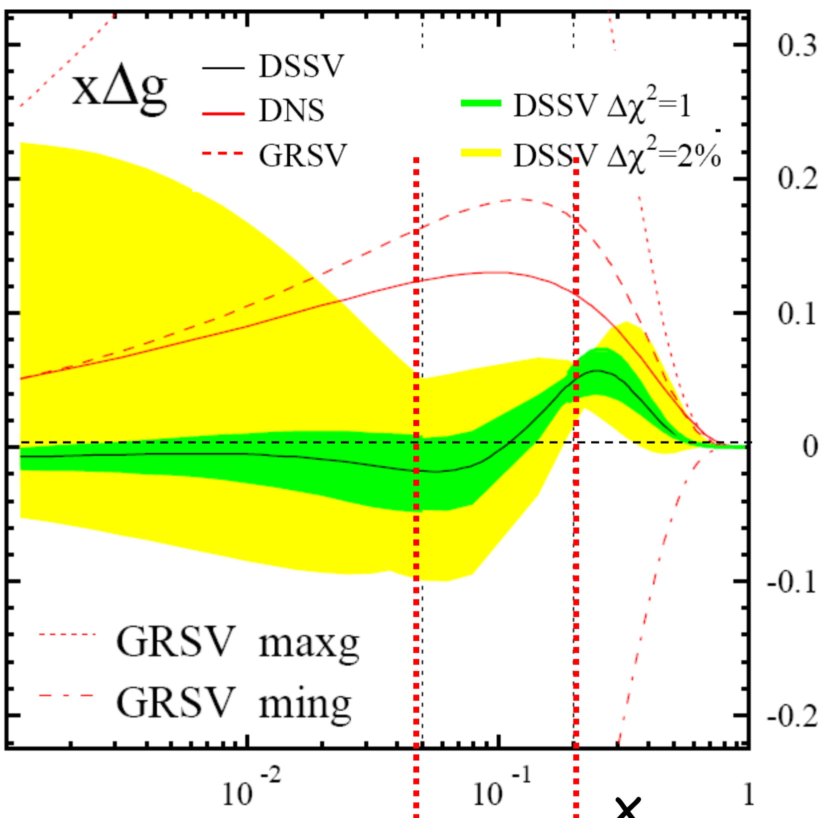


US National Science Academy Council Milestones

Year	#	NSAC Mile Stone	FOCAL
2012	DM8	Determine nuclear gluon densities at low x in cold nuclei via p+ Au or d + Au collisions.	Required
2013	HP12	Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination with global QCD analyses, to determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.	Low-x Direct γ
2014	DM10 (new)	Measure jet and photon production and their correlations in A≈200 ion+ion collisions at energies from medium RHIC energies to the highest achievable energies at LHC. DM10 captures efforts to measure jet correlations over a span of energies at RHIC and a new program using the CERN Large Hadron Collider and its ALICE, ATLAS and CMS detectors.	Marginal without FOCAL
2015	HP13 (new)	Test unique QCD predictions for relation between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering New Milestone HP13 reflects the intense activity and theoretical breakthroughs of recent years in understanding the parton distribution functions accessed in spin asymmetries for hard-scattering reactions involving a transversely polarized proton. This leads to new experimental opportunities to test all our concepts for analyzing hard scattering with perturbative QCD.	Required

Longitudinal Spin ΔG, $\Delta g(x)$

NLO global fit



small-x
$0.001 < x < 0.05$

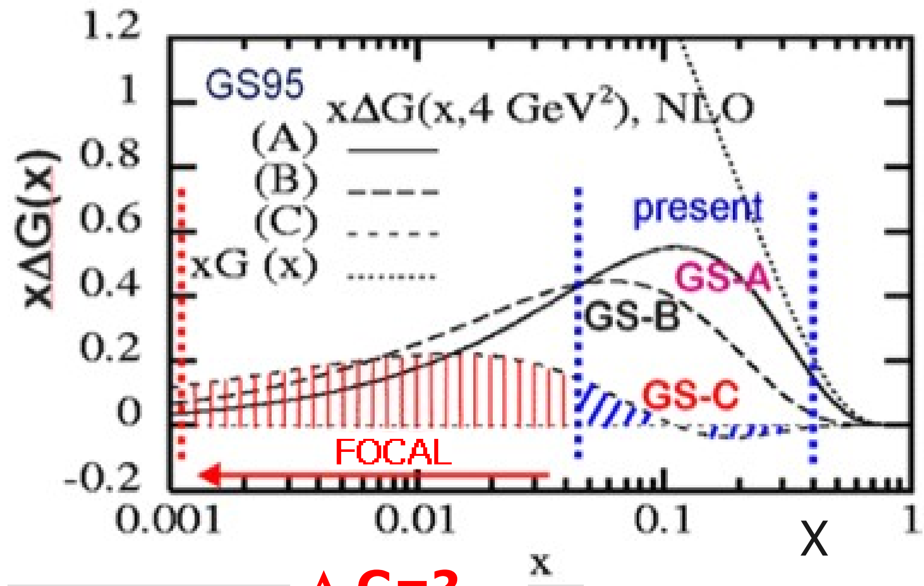
RHIC range
$0.05 < x < 0.2$

large-x
$x < 0.2$

Need to extend measurements to low-x

Gerhmann-Stirling models

GS-C consistent with present data



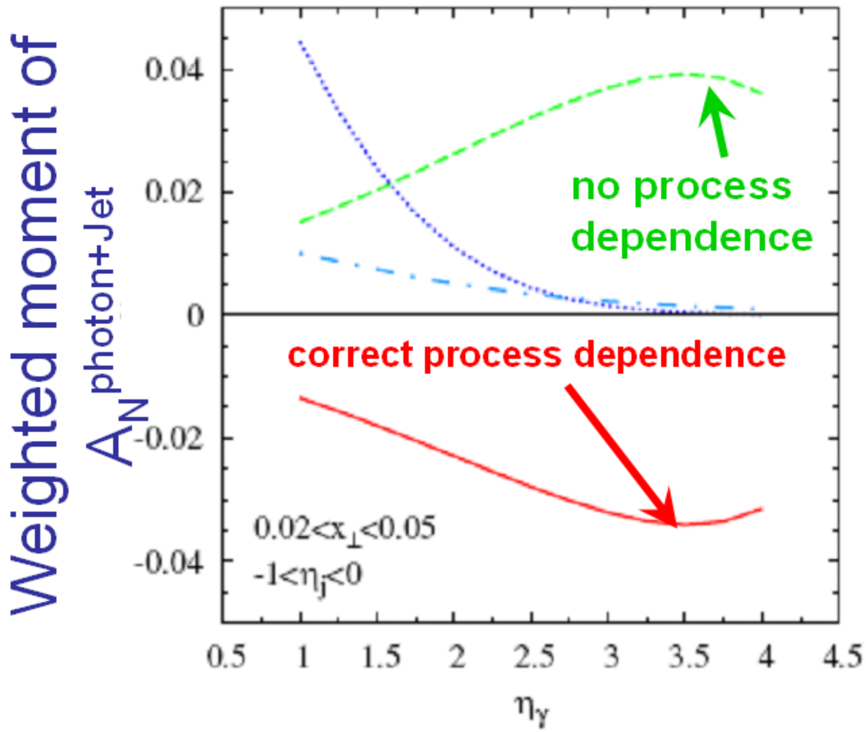
Δ G=?

- What is the gluon contribution to the proton spin. Is it at low-x?
- use γ-jet or π^0 π^0 to measure and probe regions of low-x

direct γ
jets –x resolution
forward η (low-x)
π^0

Transverse Spin Phenomena

Sivers



- Determination of the process dependence of the Sivers effect in γ+jet events
- What does Sivers tell us about orbital angular momentum?

- Use γ-jet to measure Sivers effect
- Use π^0 within the jet to measure Collins functions

direct γ -jet
π^0
forward η(low-x)
large η coverage

Nuclear Gluon PDF’s – unknown at low x

Eskola et al, JHEP0807:102,2008 hep-ph/0802.0139

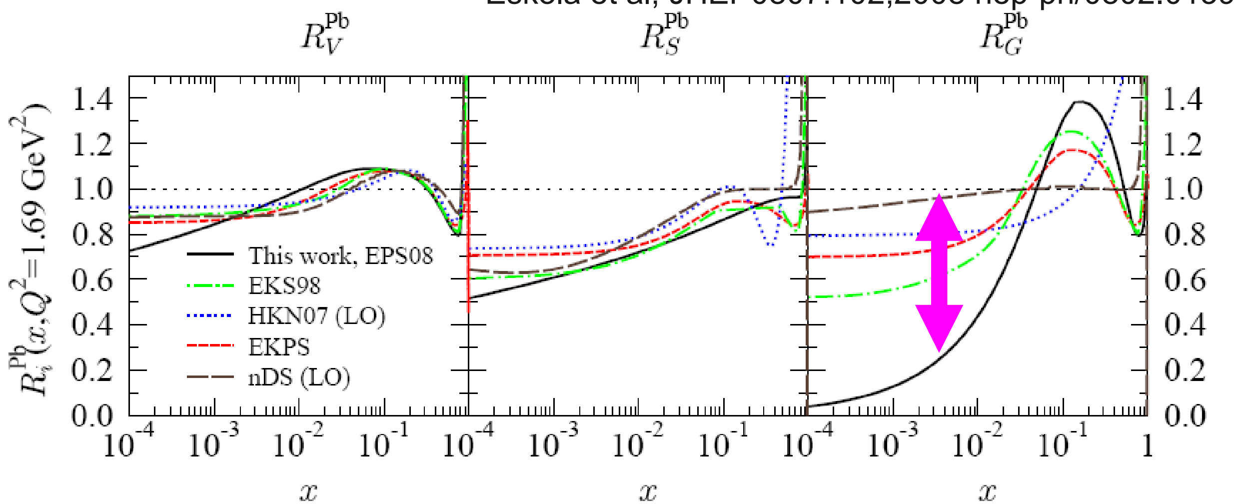
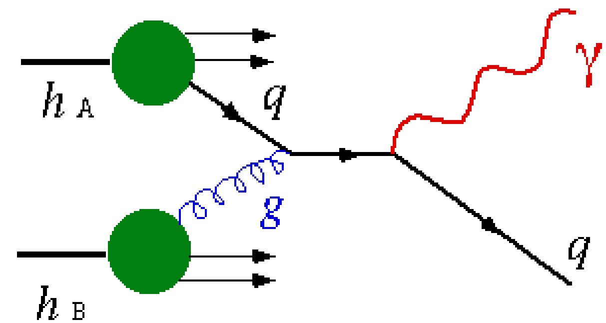


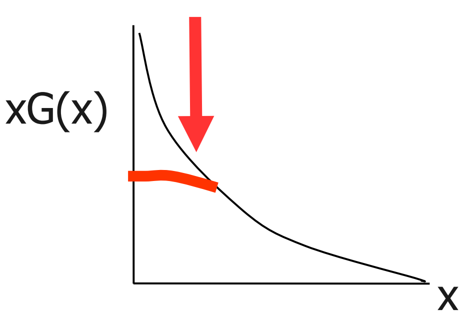
Figure 13: Comparison of the average valence and sea quark, and gluon modifications at $Q^2 = 1.69\ GeV^2$ for Pb nucleus from LO global DGLAP analyses EKS98 [2], HKN07 [7], nDS [6], EKPS [3] and this work EPS08.



$$x_1 = \frac{p_{T\gamma}}{\sqrt{s}}\left(e^{\eta_\gamma} + e^{\eta_{Jet}}\right)$$

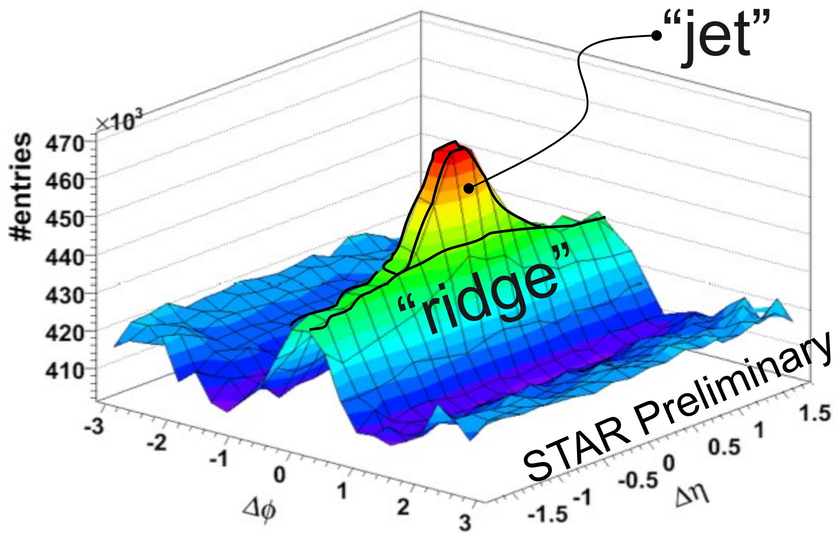
$$x_2 = \frac{p_{T\gamma}}{\sqrt{s}}\left(e^{-\eta_\gamma} + e^{-\eta_{Jet}}\right)$$

CGC predicts saturation of gluon density at low x

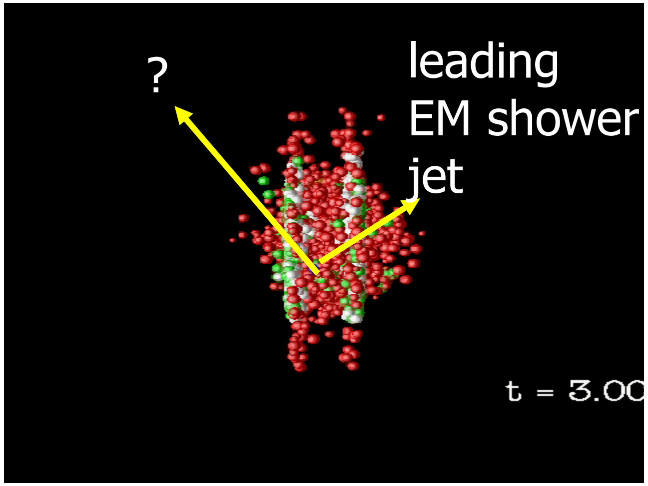


direct γ
jets –x resolution
forward η(low-x)

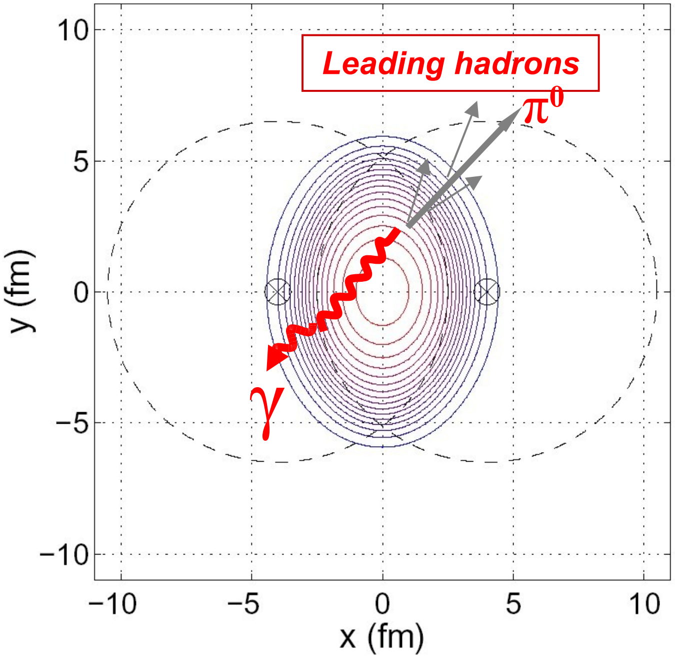
Correlations with jets in heavy Ion collisions



- Study the medium via long range correlations with jets
- Are these correlations from a response by the medium?



Jet correlations in AuAu

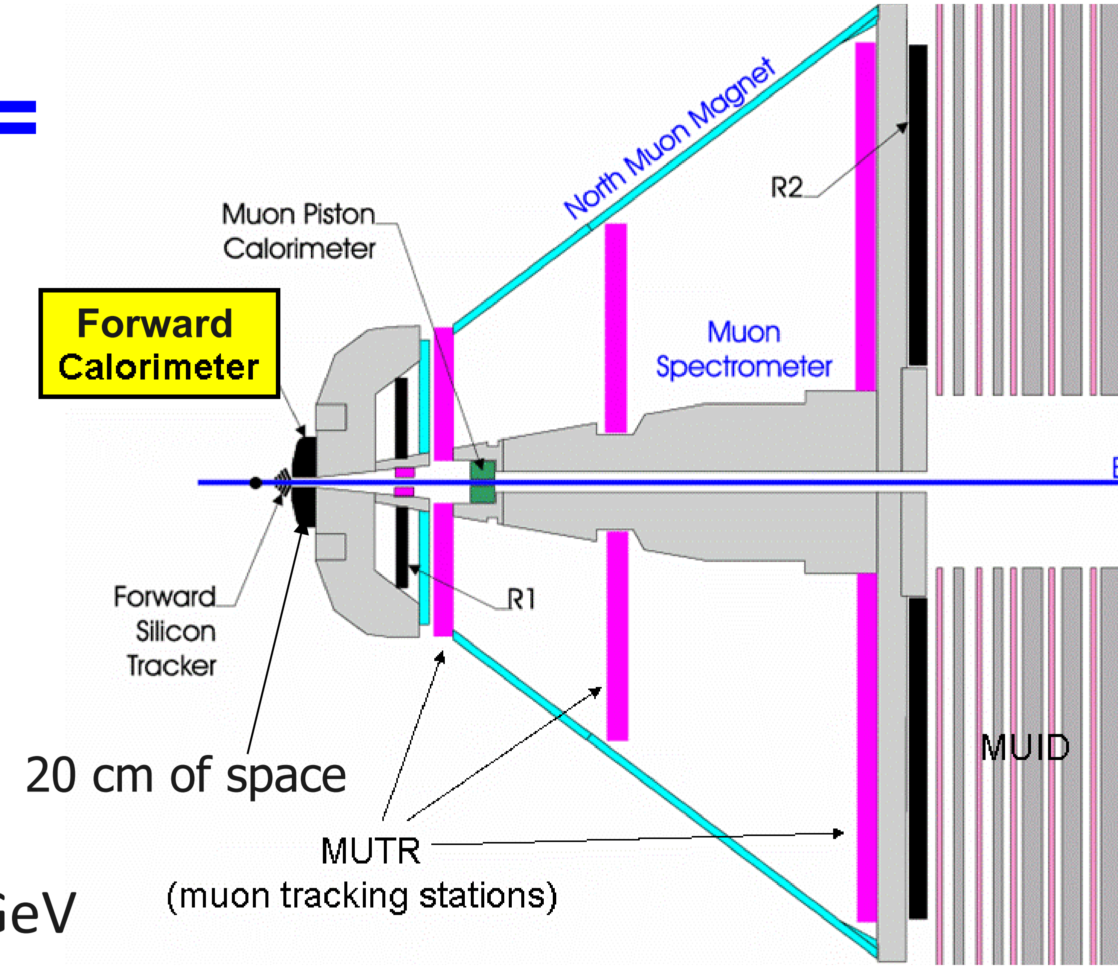


EM - shower large η coverage

What do we build?

To meet these goals we must have a detector that measures:

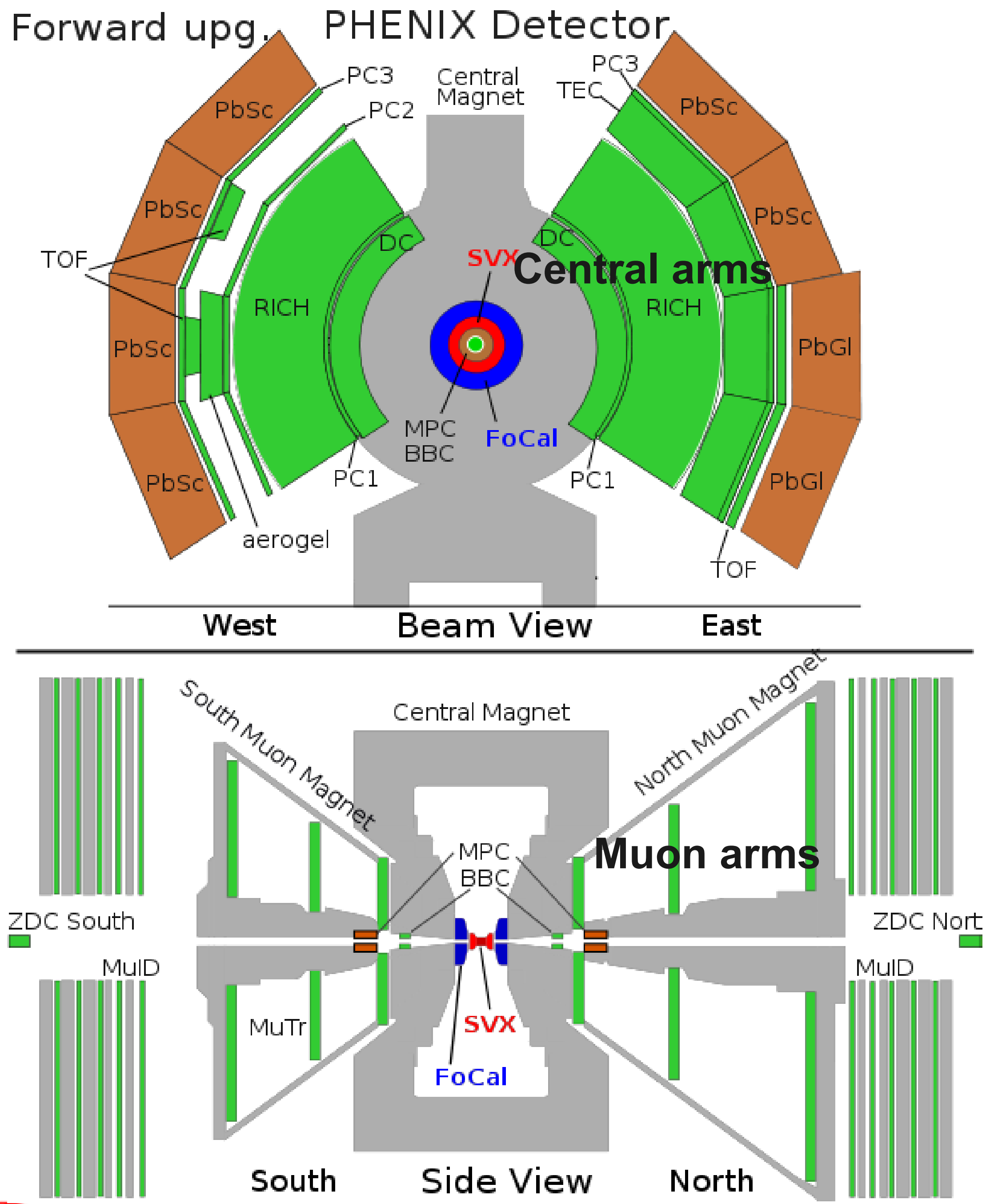
- direct γ and π^0s
- jet angles to obtain x_2
- forward η to reach low-x
- large η coverage



FoCal requirements:

- Measure photons and π^0's to 30 GeV
- Energy resolution < 25%/$\sqrt{E}$
- Ability to identify EM/hadronic activity → longitudinal segmentation
- Compact (20 cm depth): densest materials → Si-W
- Small Molière radius 14 mm
- Jet angular measurement
- High granularity ~ similar to central arms EMCal
- Large acceptance – rapidity coverage $x_2 \sim 0.001$

Forward upgrades of PHENIX



PHENIX: Special purpose detector to measure <u>rare</u> processes involving **EM probes** (leptons and photons) at high rate but small coverage. Upgrades to improve acceptance and triggering.

Calorimetry:

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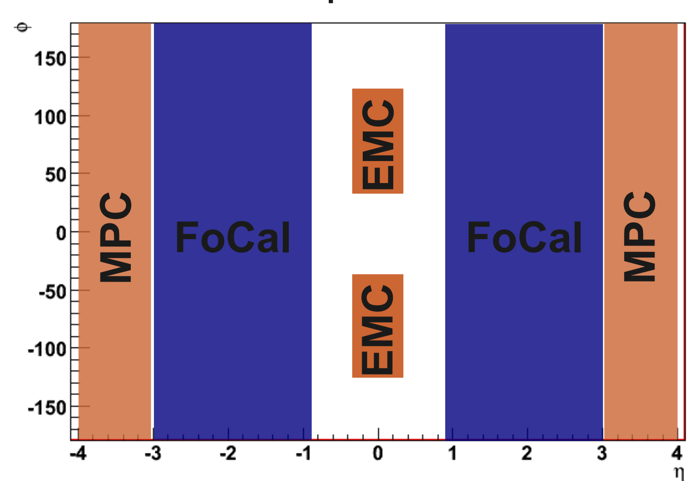
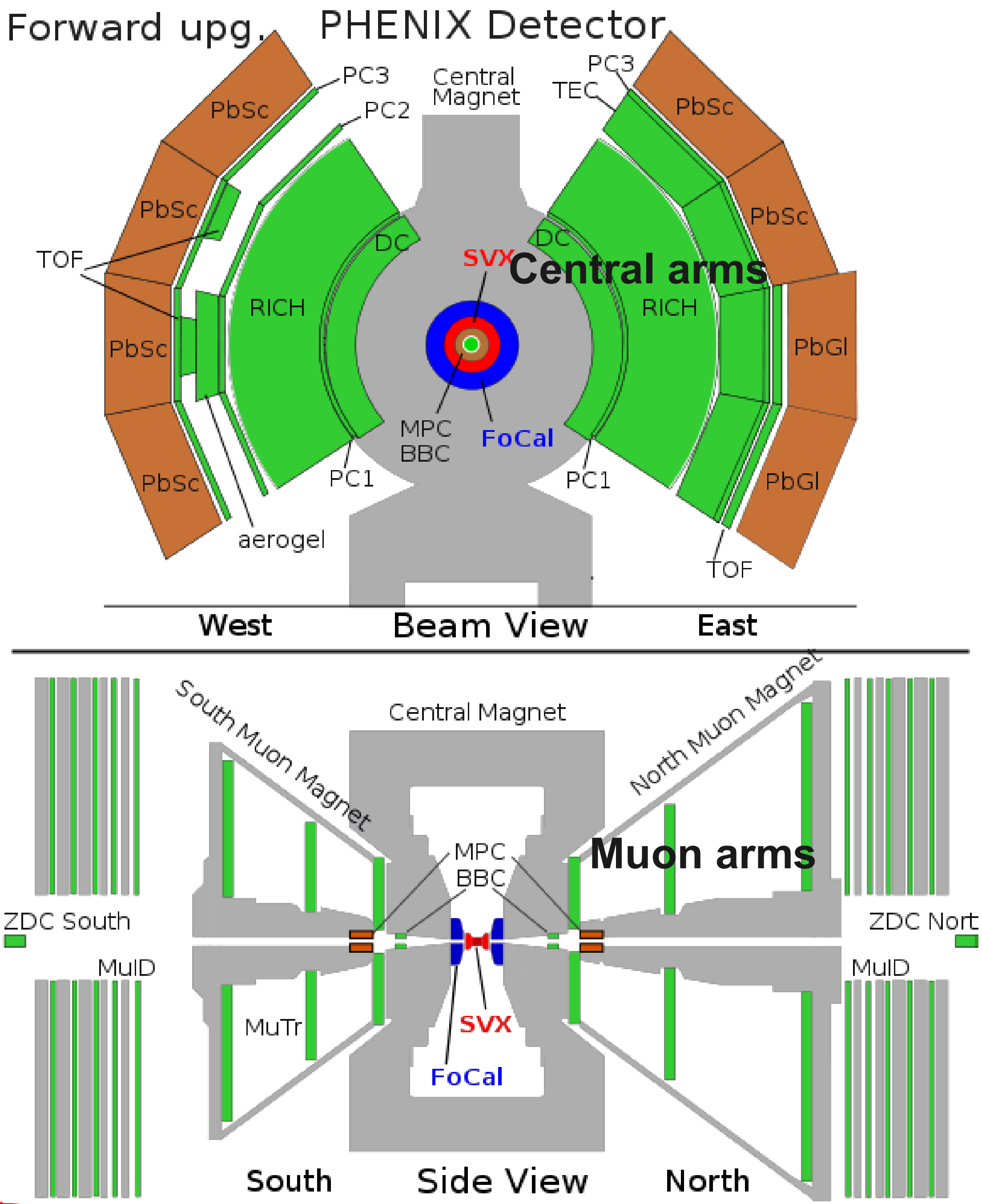
FoCal tracking calorimeter (WSi)

$1 < |\eta| < 3$ <u>~10x EMC acceptance</u>

acceptance



Forward upgrades of PHENIX



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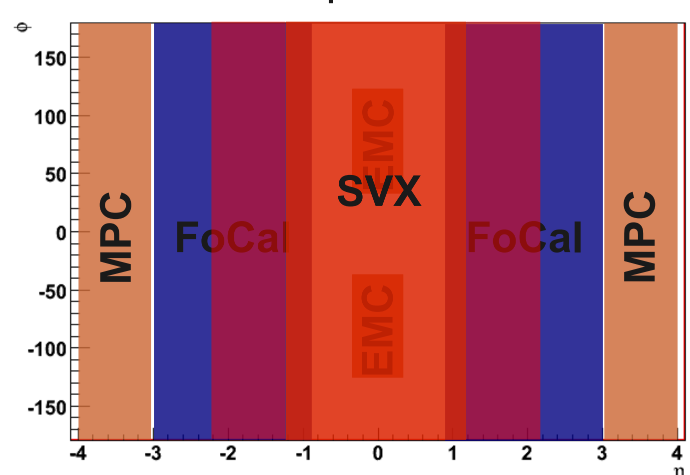
SVX: VTX Si tracker, $|\eta| < 2.2$

acceptance



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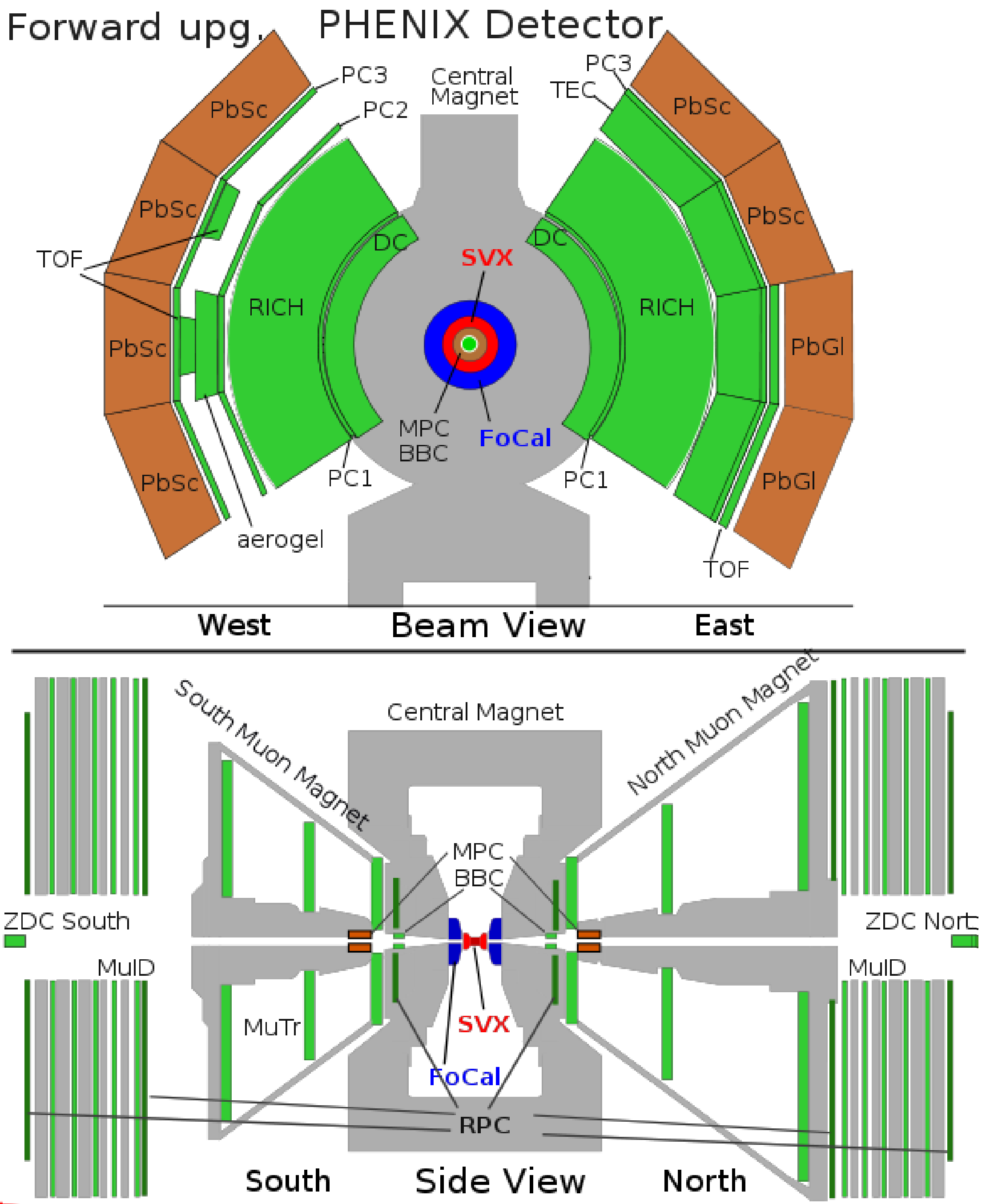

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NCC tracking calorimeter (W-Si)

$1 < |\eta| < 3$ <u>~10x EMC acceptance</u>

RHIC II – 10x luminosity

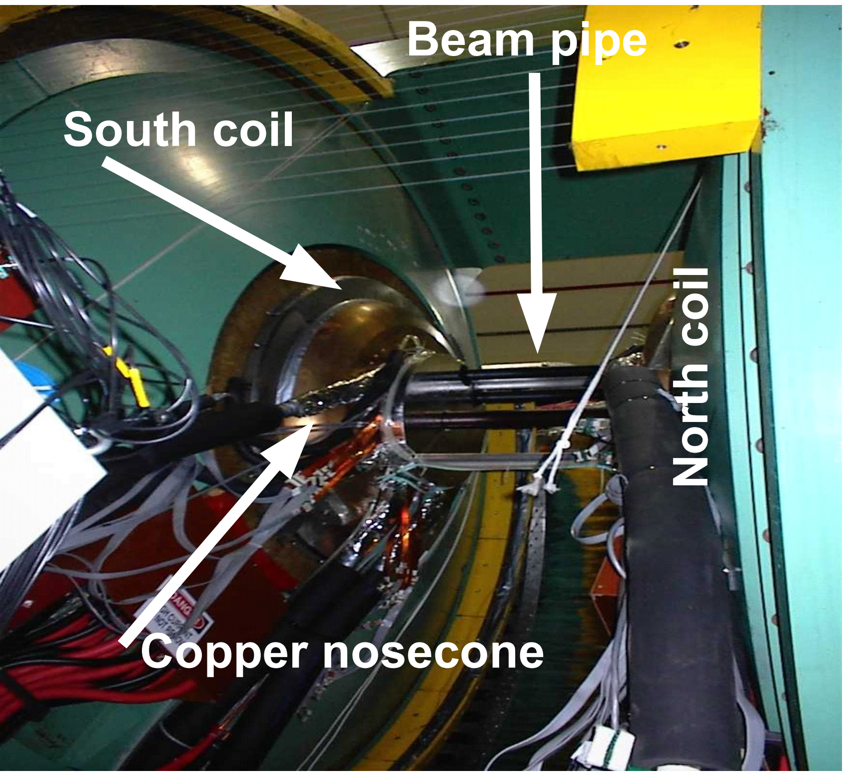
LL1 trigger upgrades - need rejection ~ 10 000

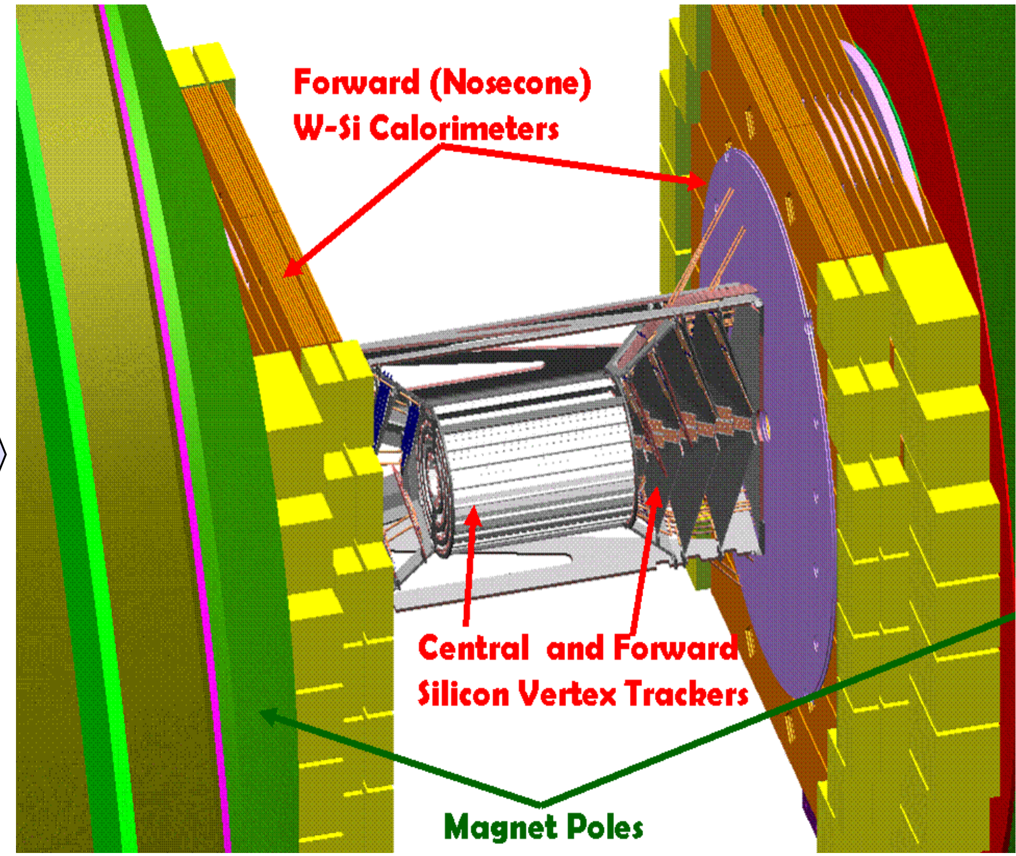
FoCal integrated in the trigger

FoCal description

Copper nosecone = perfect place for FoCal

FoCal: 17 cm thick W-Si sampling calorimeter with a radius of 50 cm. It will be mounted on the magnet coils.

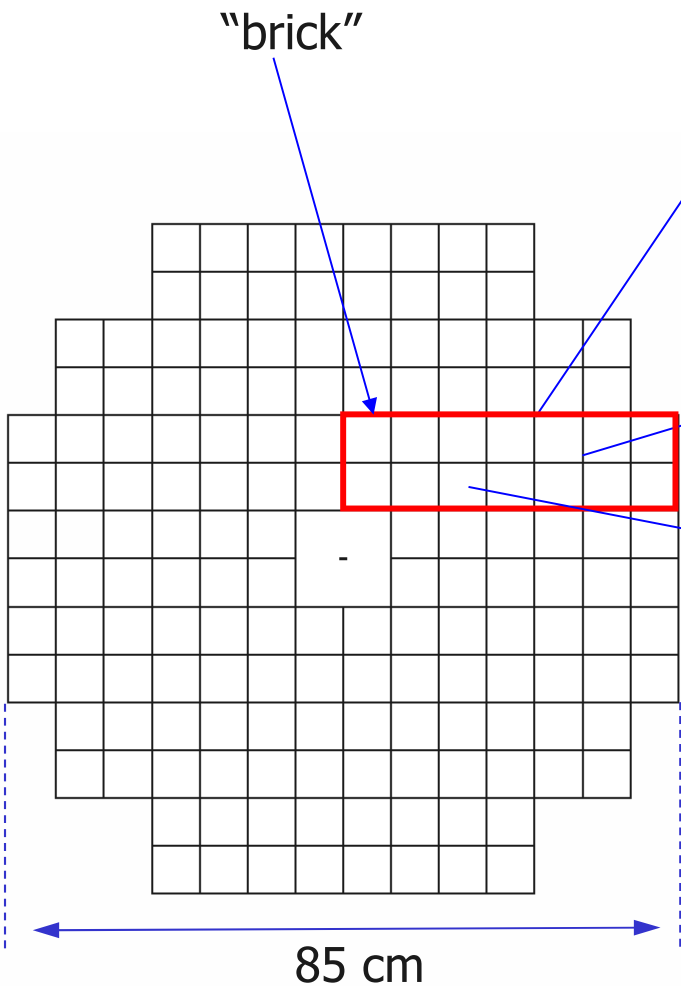


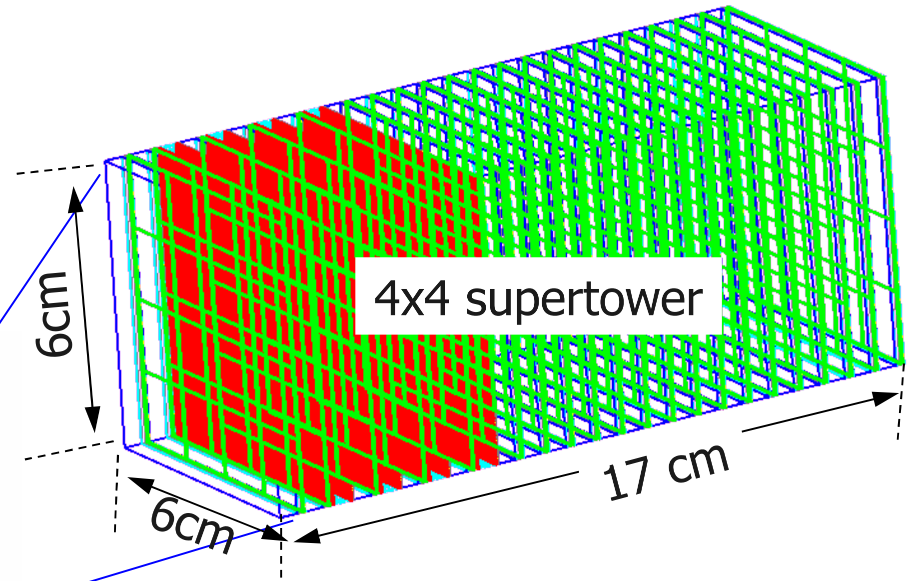


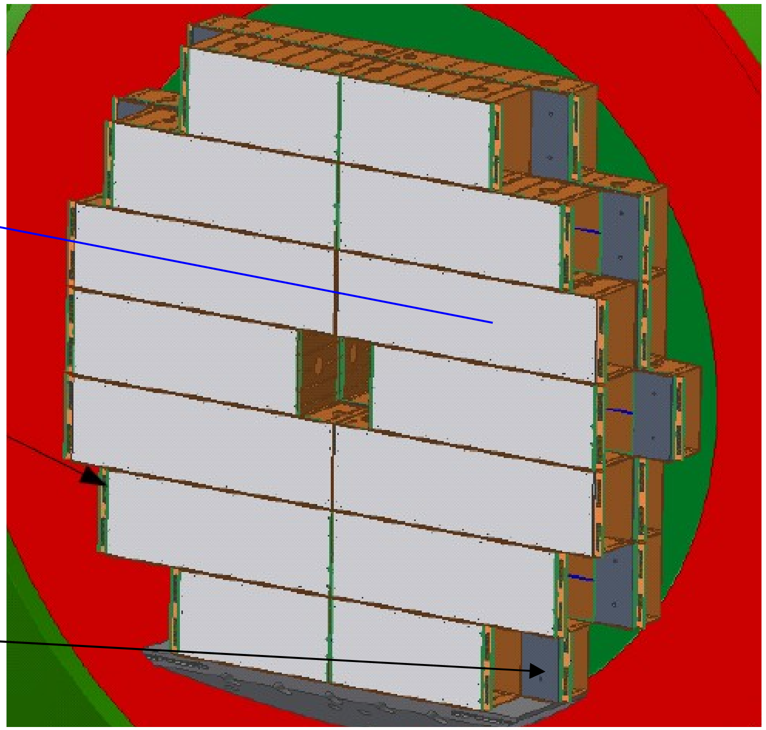
Space between the magnets is tight but doable

FoCal with silicon vertex tracker

Overall Detector – stack the bricks





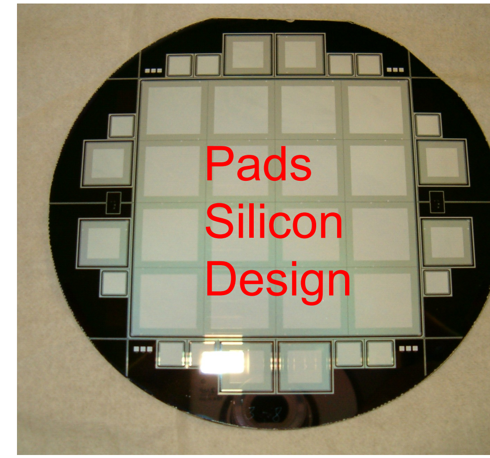


Note this
ledge may not be
in the final design

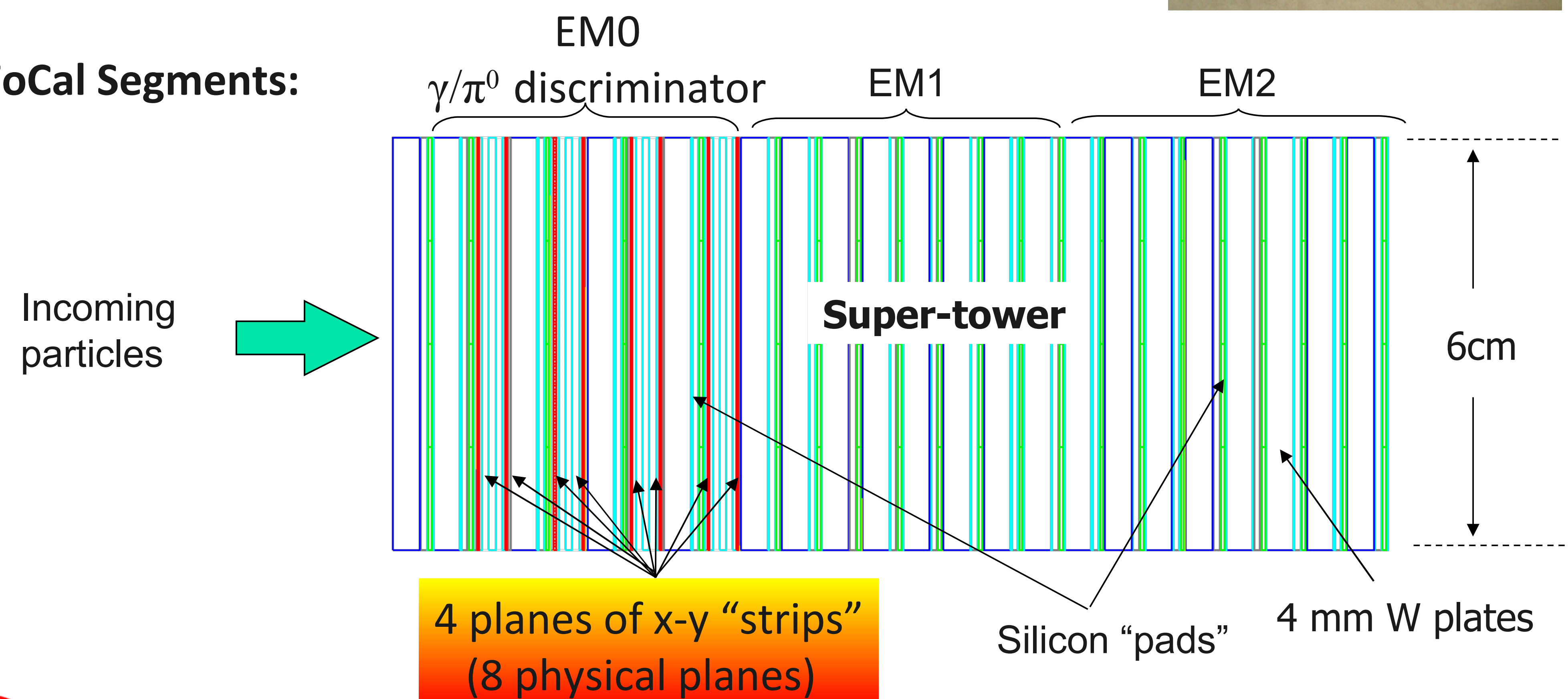
Silicon – Tungsten design

Pads: 21 layers in 3 segments (EM0, EM1, EM2)
- 535 μm silicon
- 1 Si wafer: 16 cells: 15.5mmx15.5mm

X and Y Strips: 4 layers
- x-y high resolution strip planes
  - 128 strips: 6.2cmx0.5mm

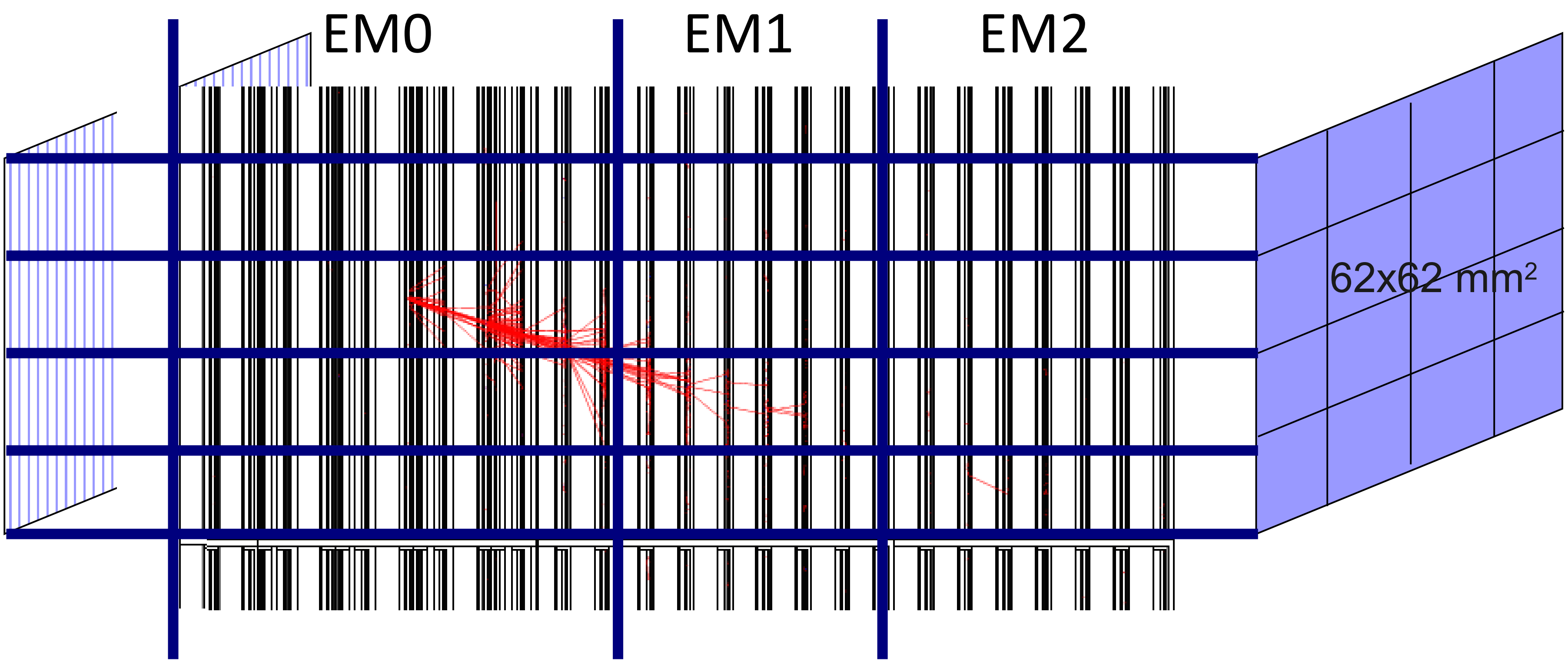


FoCal Segments:



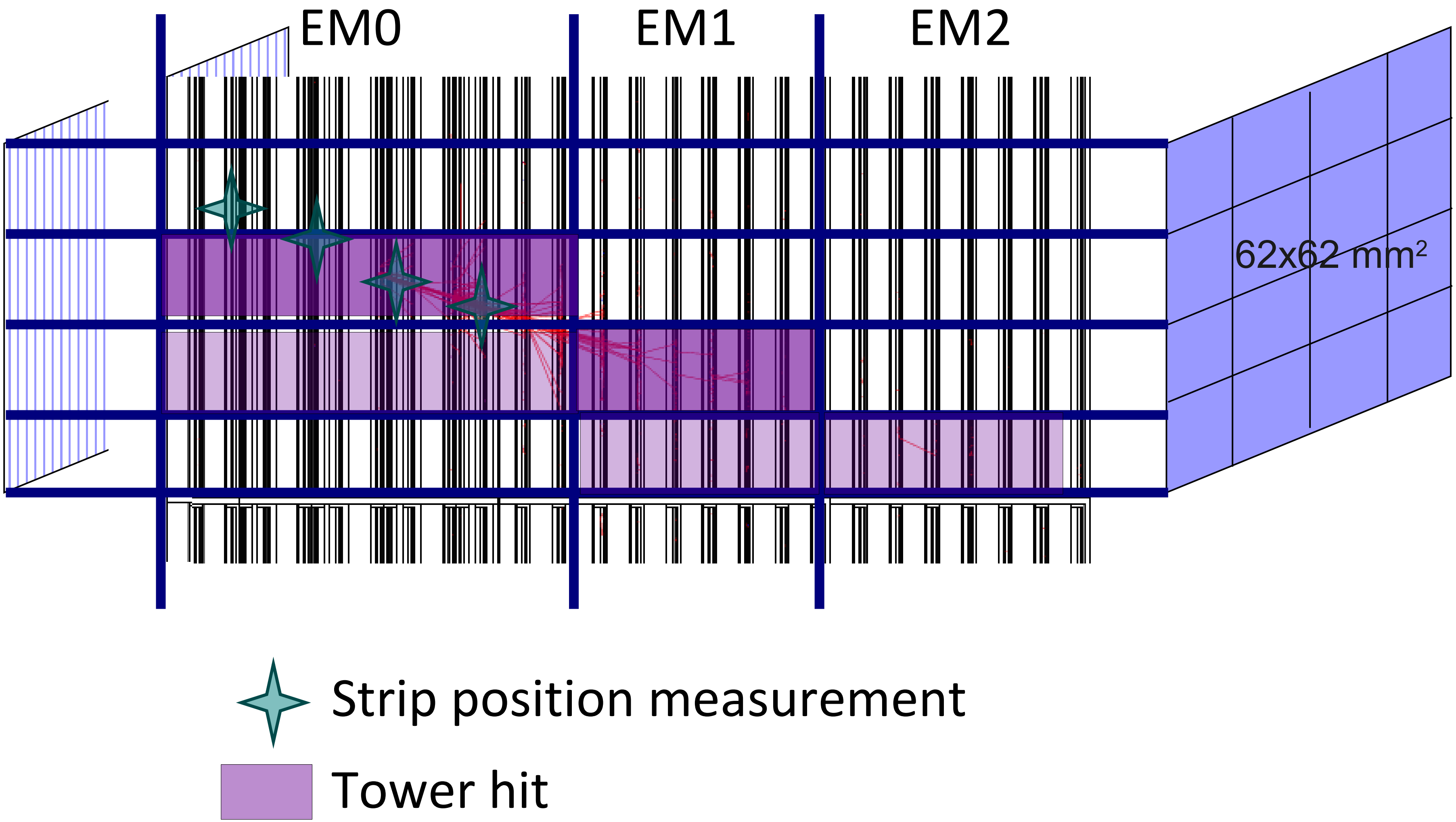
How does it work – tracking in FoCal

Super-tower



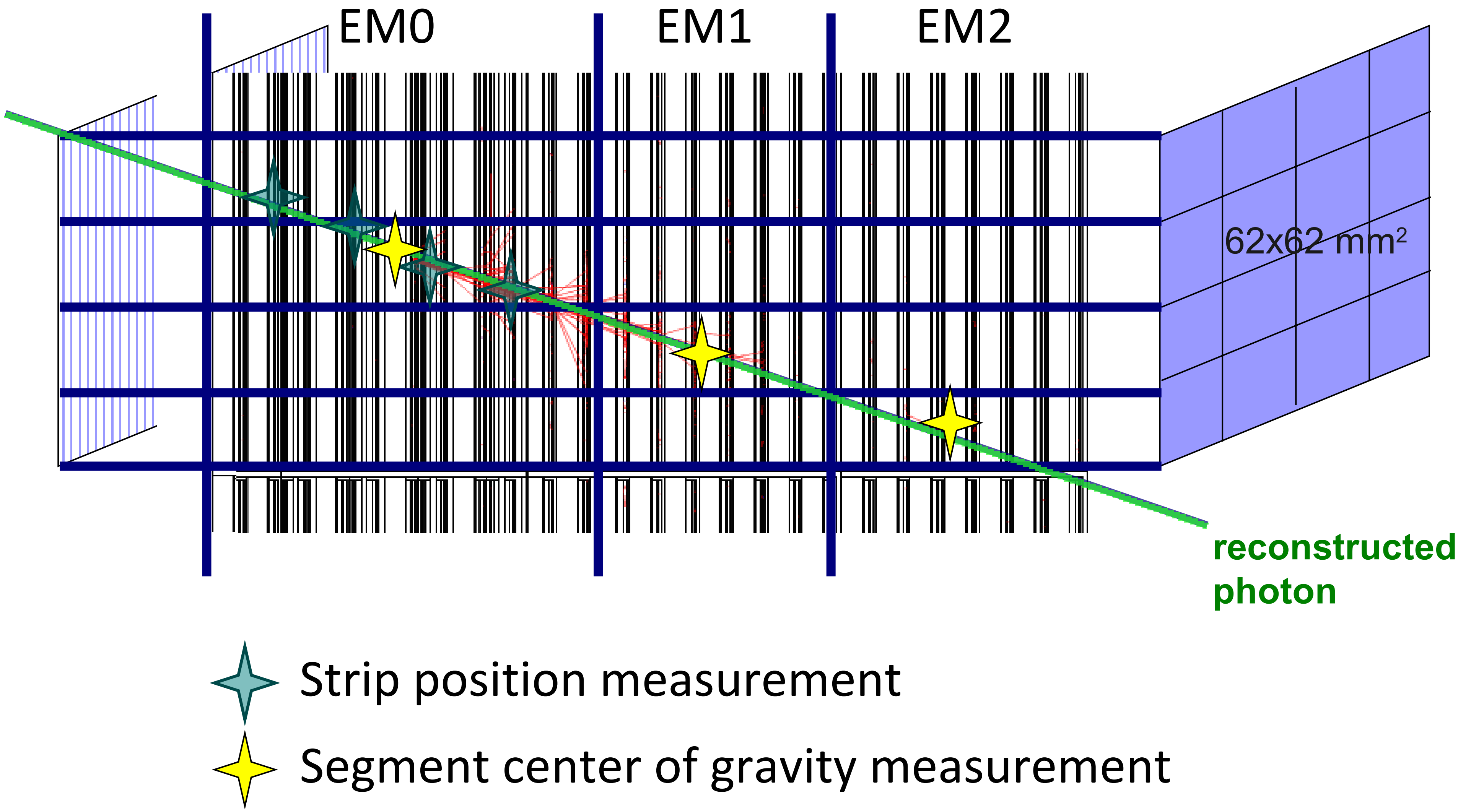
10 GeV photon shower – only electrons are shown (red)

How does it work – tracking in FoCal

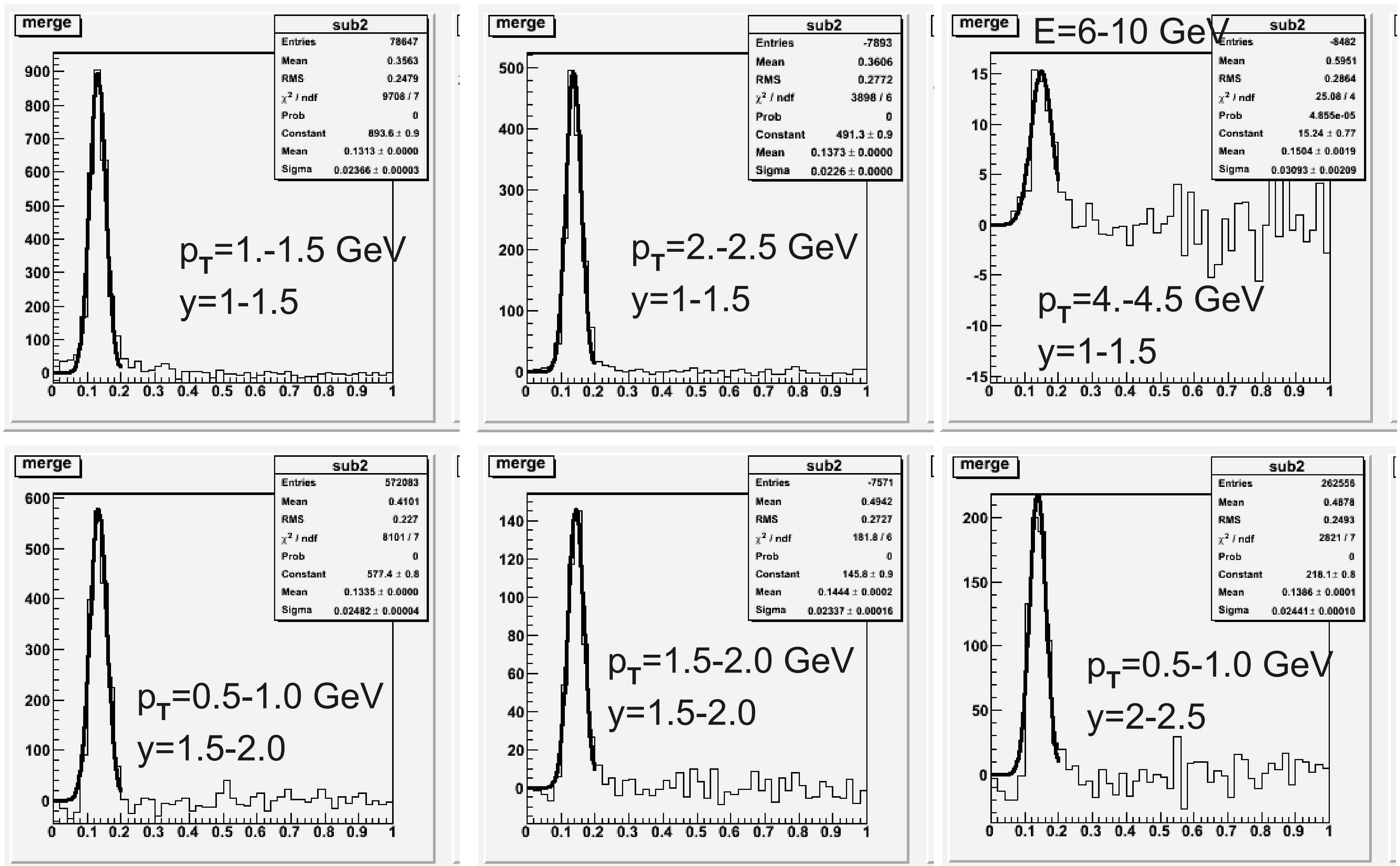


How does it work – tracking in FoCal

Reconstruction steps: cluster all components, find centers of gravity, assign tabulated errors, fit tracks including the collision vertex position



γ/π^0 identification: a) 2 track π^0 for p_T<5 GeV/c

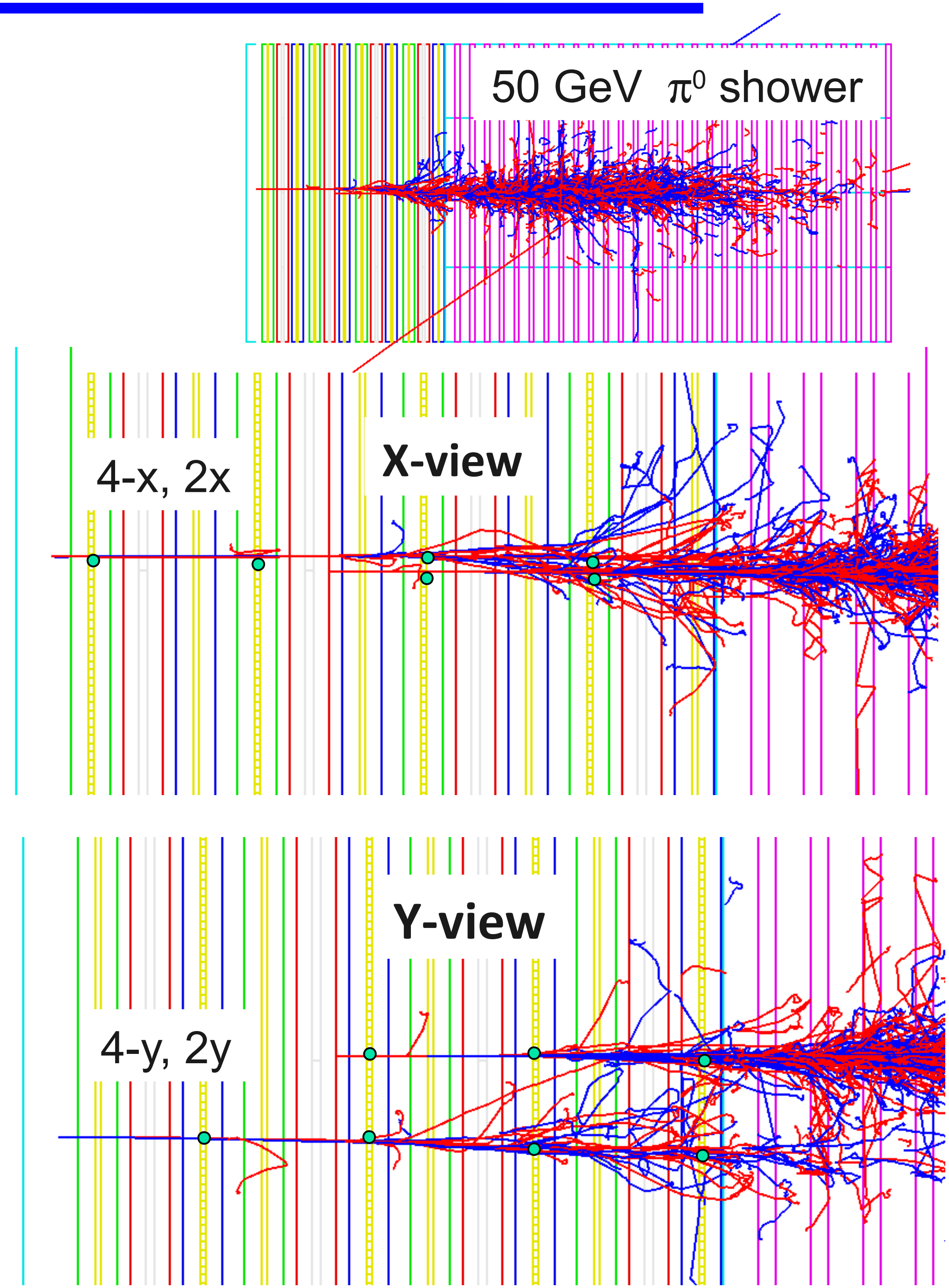


inv. mass [GeV] inv. mass [GeV] inv. mass [GeV]

γ/π^0 identification: b) single track γ/π^0

- Above p_T>5 GeV/c
  - showers overlap on pad level
  - use x/y + vertex to get opening angle
  - Energy from Calorimeter
  - Energy Asymmetry – assume 50-50 split as a first algorithm

single track invariant mass



- Tested at various energies and angles, so far at p+p multiplicities
- π^0
  - measured as π^0 50-60%
  - faked by single γ ~20%
- γ
  - measured as γ 60%
  - faked by π^0 ~5%

WORK IN PROGRESS

Hadron rejection – how it works

Assemble track of tower clusters and strips

Compute segment track energies and “track width” in segments and strip layers

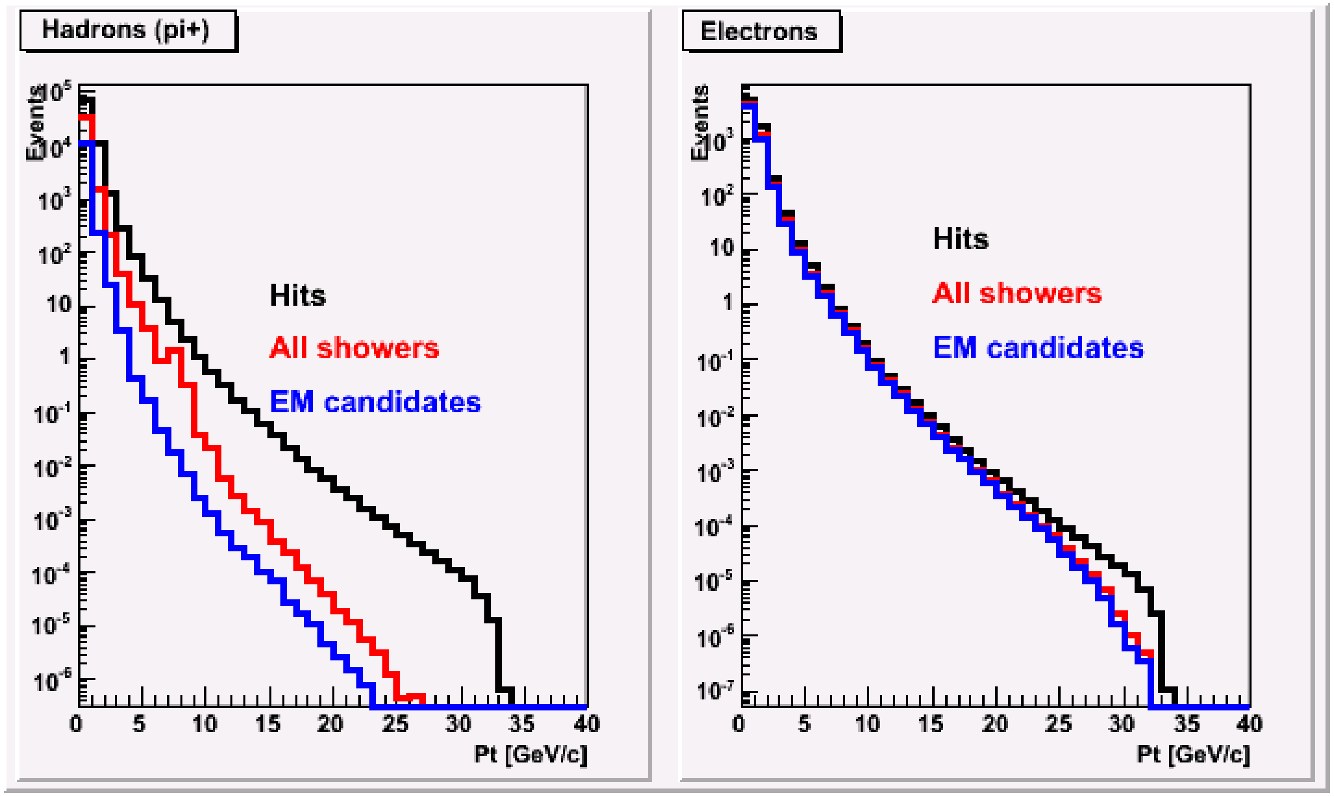
Build a χ^2-like estimator comparing parametrized and actual values

Spectra conversion (particles → showers)

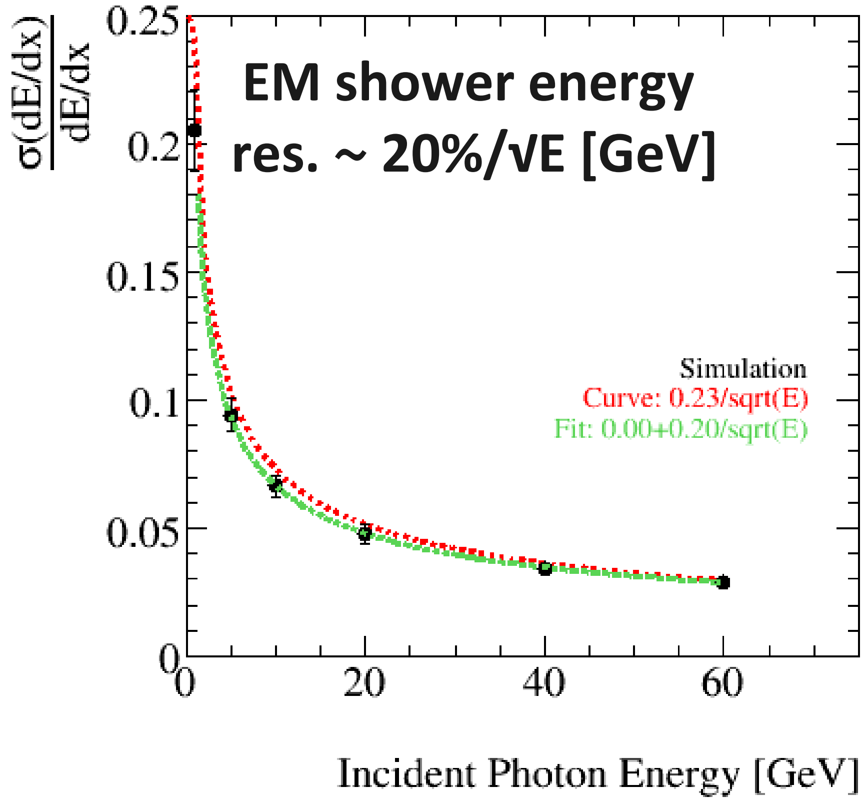
rejection ~ x100

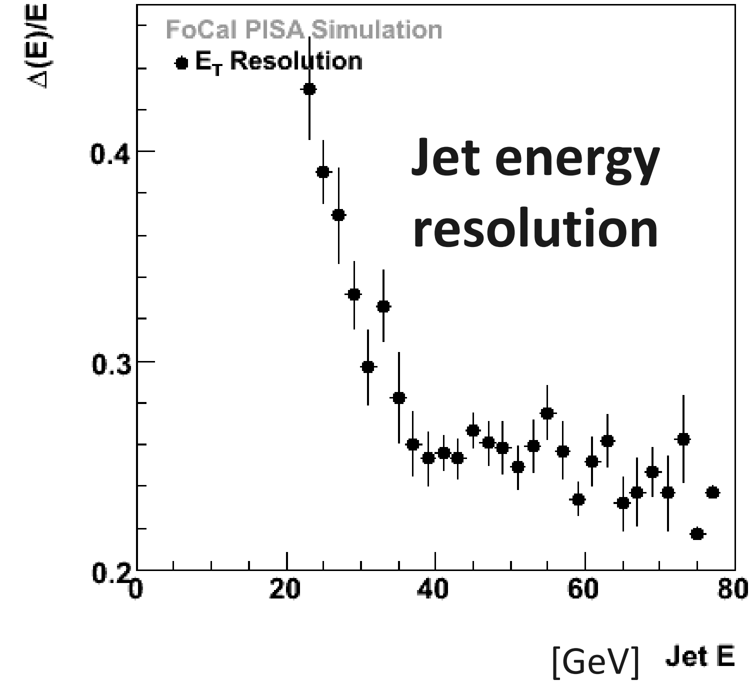
Shower shape measurements

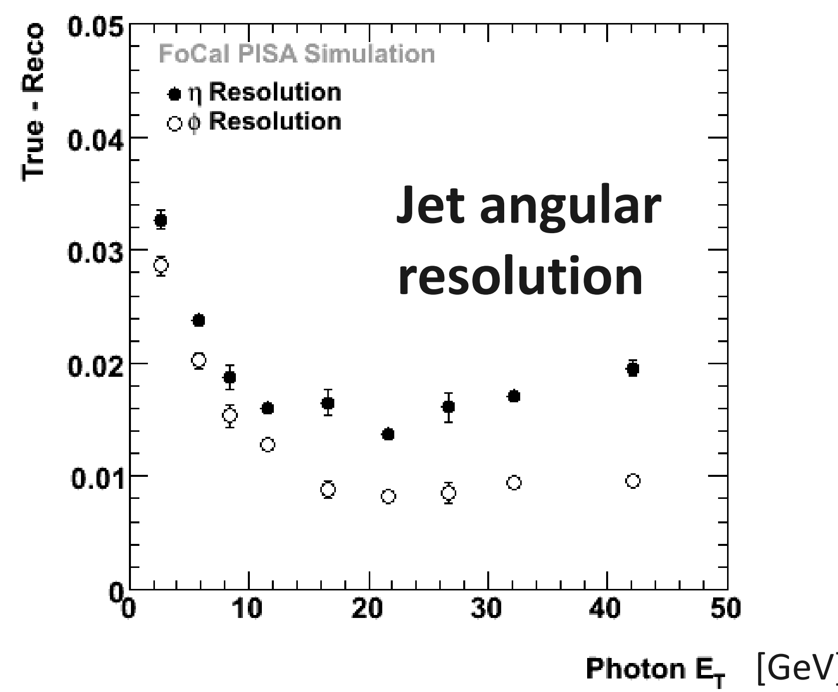
rejection ~ x10



FoCal simulations results





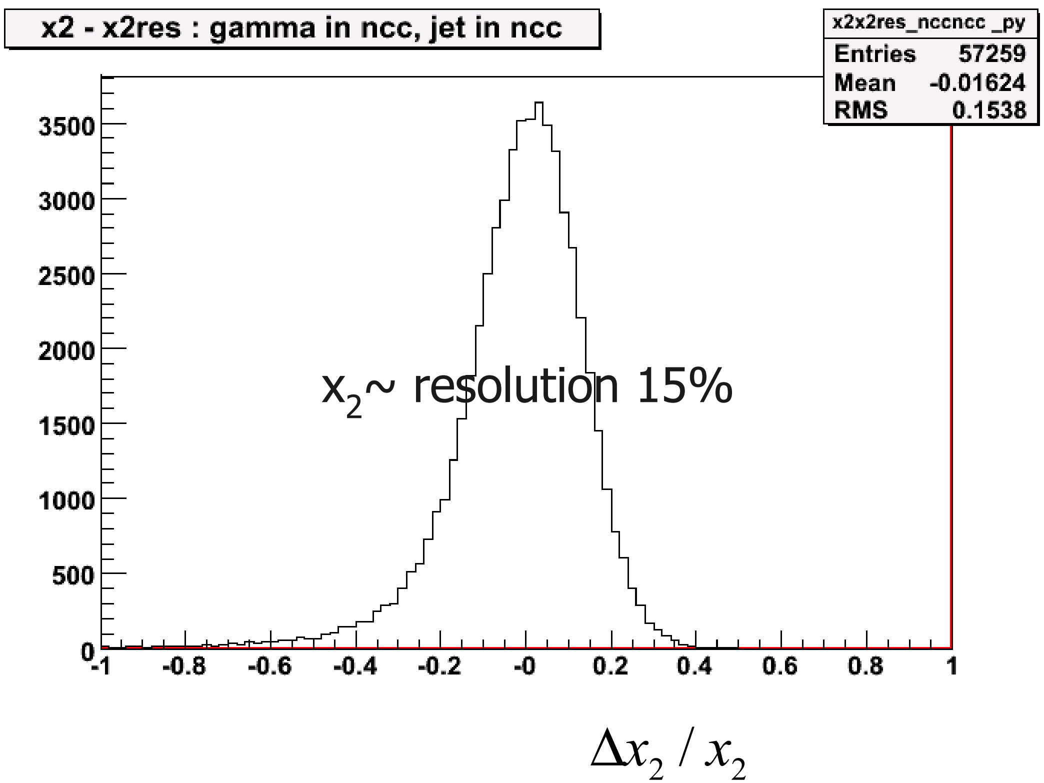


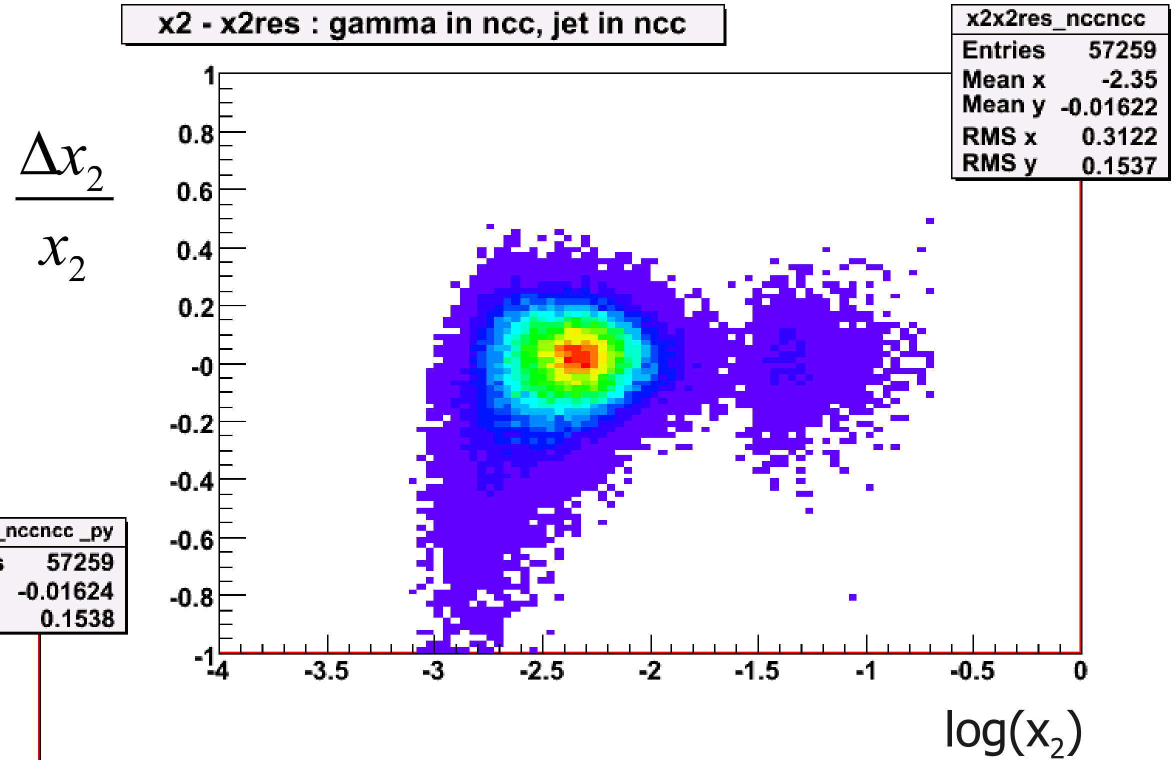
x_2 resolution in gamma-jet Pythia events

$$x_1 = \frac{p_{T\gamma}}{\sqrt{s}}(e^{\eta_\gamma} + e^{\eta Jet})$$

$$x_2 = \frac{p_{T\gamma}}{\sqrt{s}}(e^{-\eta_\gamma} + e^{-\eta Jet})$$

assume lowest x is x_{gluon}

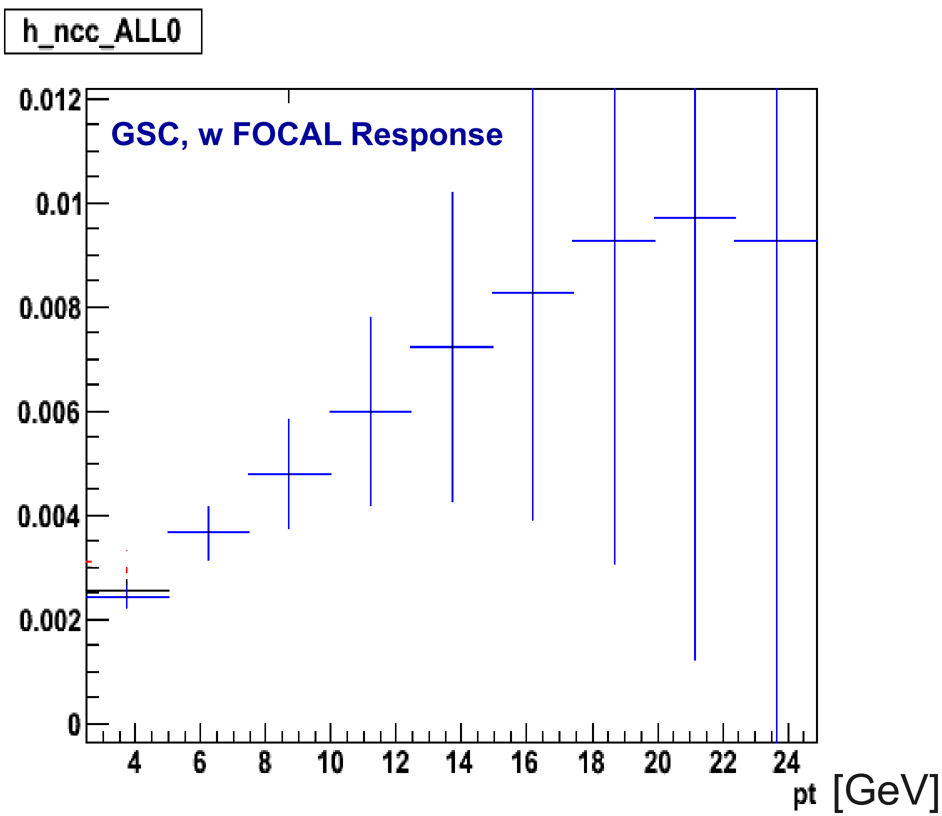


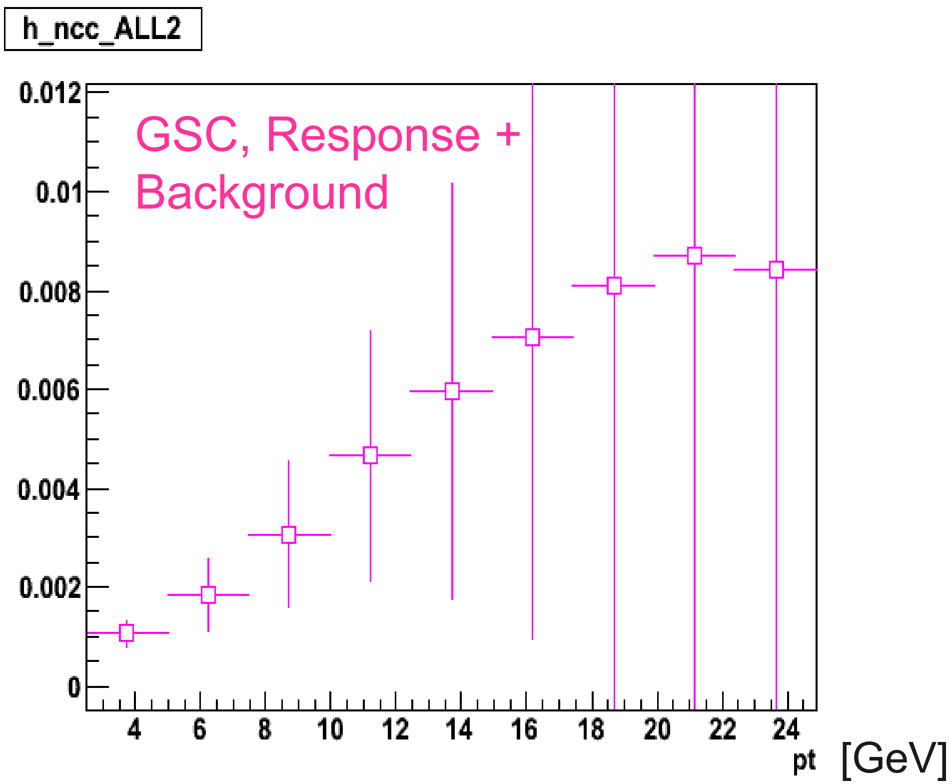


Radiative corrections not included
ToDo: NNLO QCD

Prelim. results: FOCAL Direct Gamma A_{LL} at 500 GeV

L = 150/pb, P = 0.7

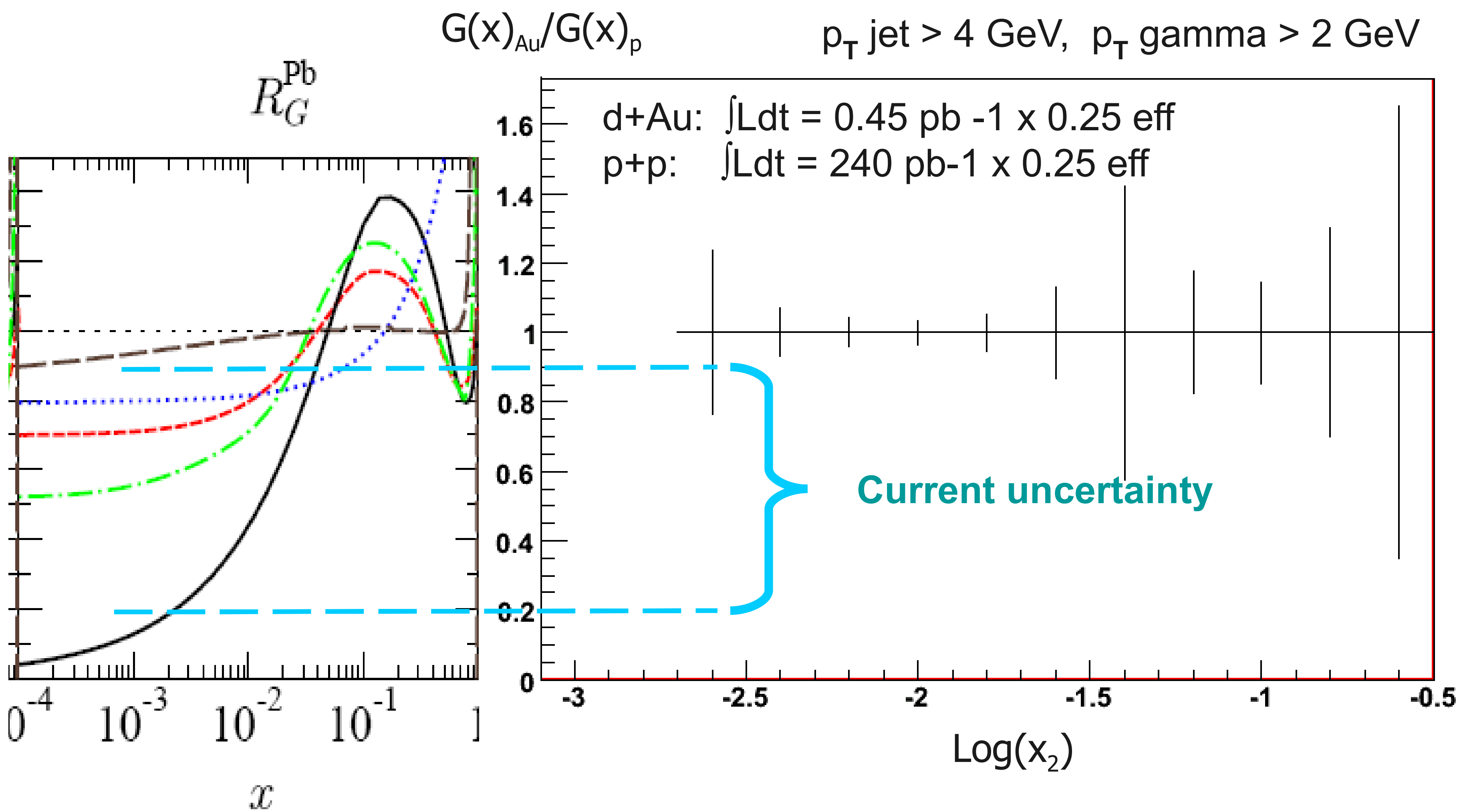




Fiducial cut 1<|y|<2
Isolation cut E<5%*Econe
Longitudinal profile cut
No background included

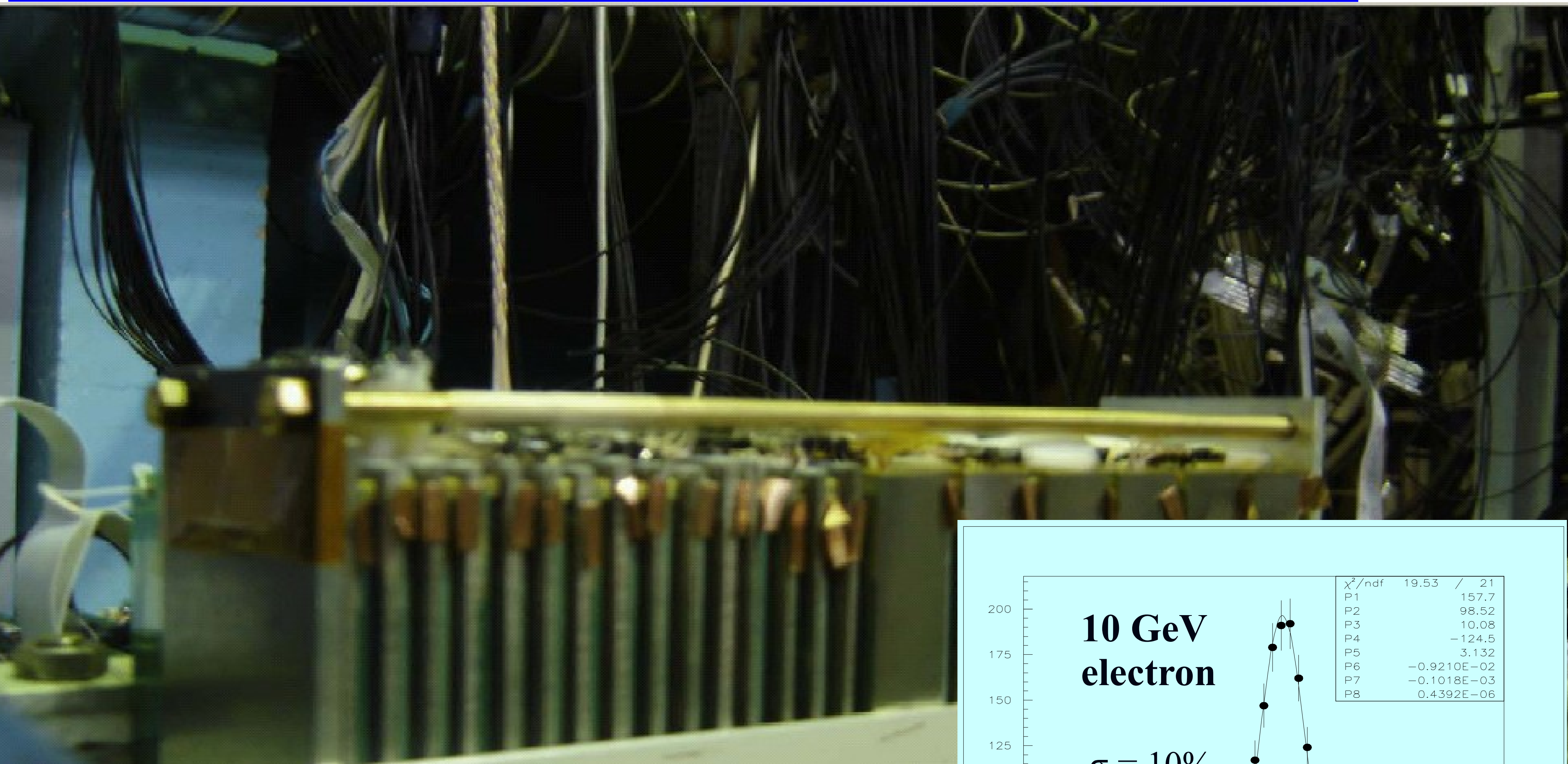
γ/π^0 Disc. Cuts (factor 7 S/B improvement)
Dilution from background included

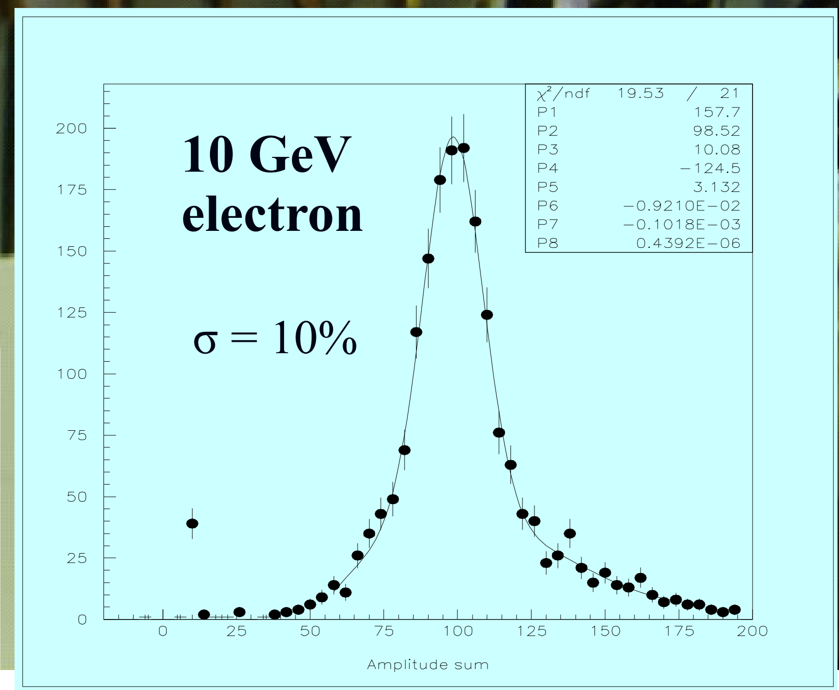
Preliminary results: Expected Error for $G_A(x)/G_p(x)$



Possibility for a dramatic improvement in understanding of G(x) in nuclei
Impact is widespread: Heavy Ions, Nuclear Structure, Nuclear Dynamics (CGC?)
Errors are statistical only

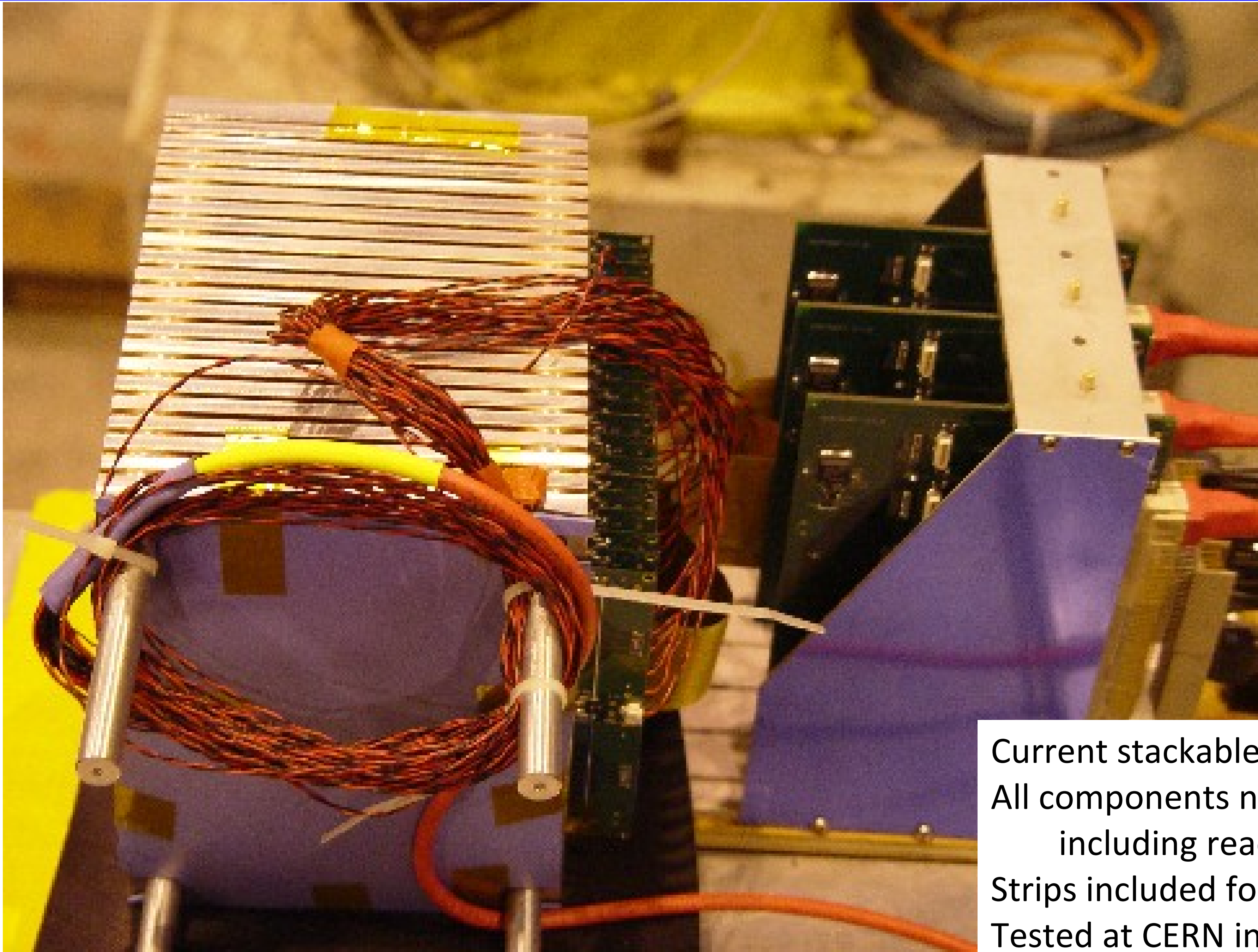
Prototype tests 1) proof of principle device





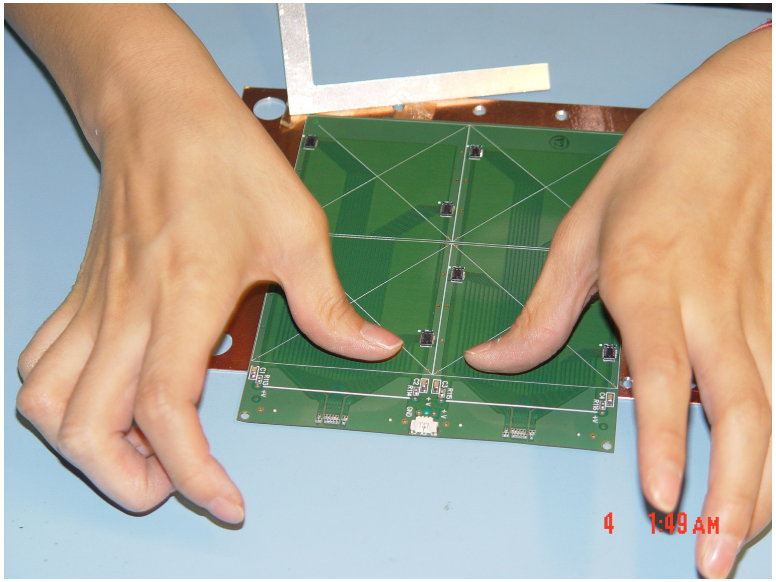
Tested at Protvino in November 2005
Early design
Channel to channel gain variations not complete
Electronics from other application
Present design gives σ~8% at 10 GeV

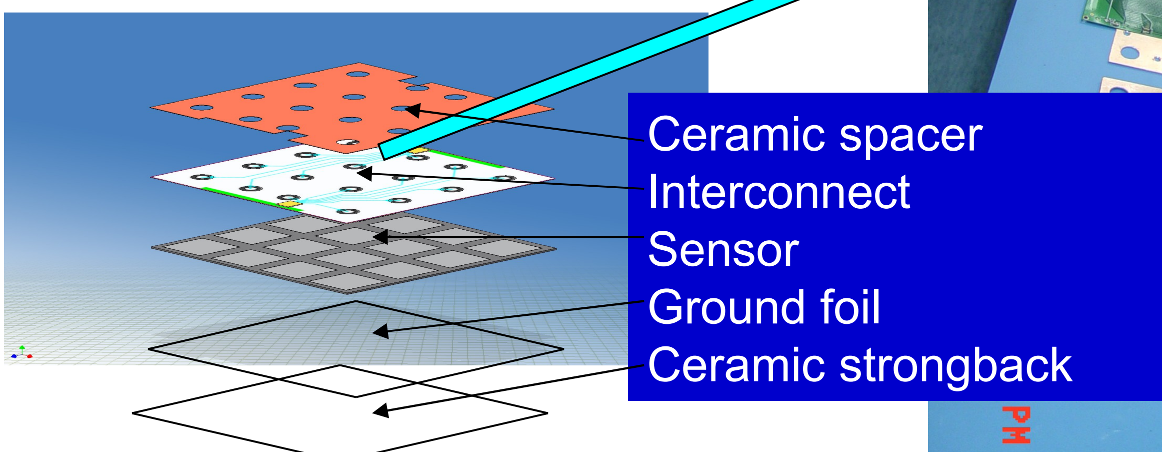
Prototype tests 2) 2x2 sensor prototype

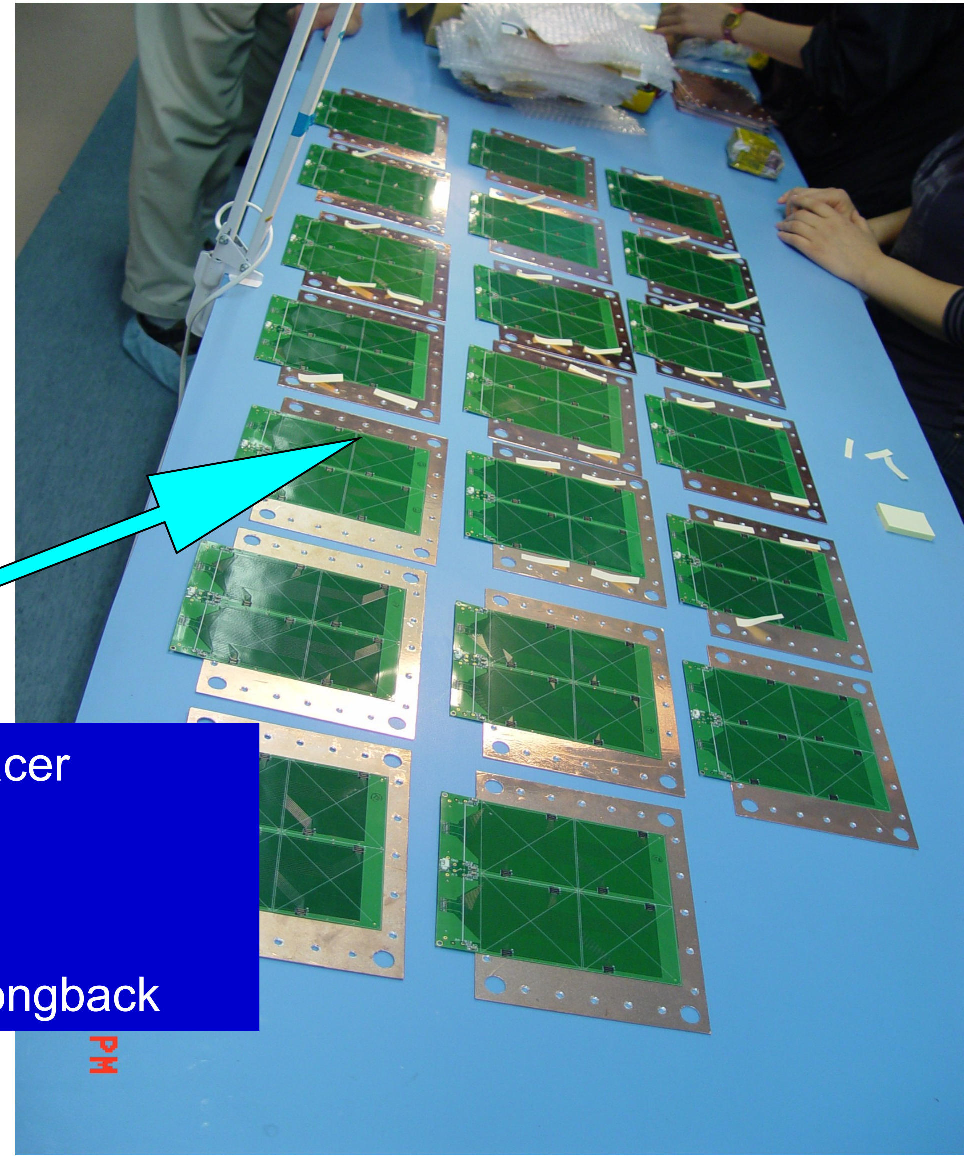


Current stackable design
All components nearly final
including readout
Strips included for R&D
Tested at CERN in Sept. 2007

Pad Micromodules and Carrier boards

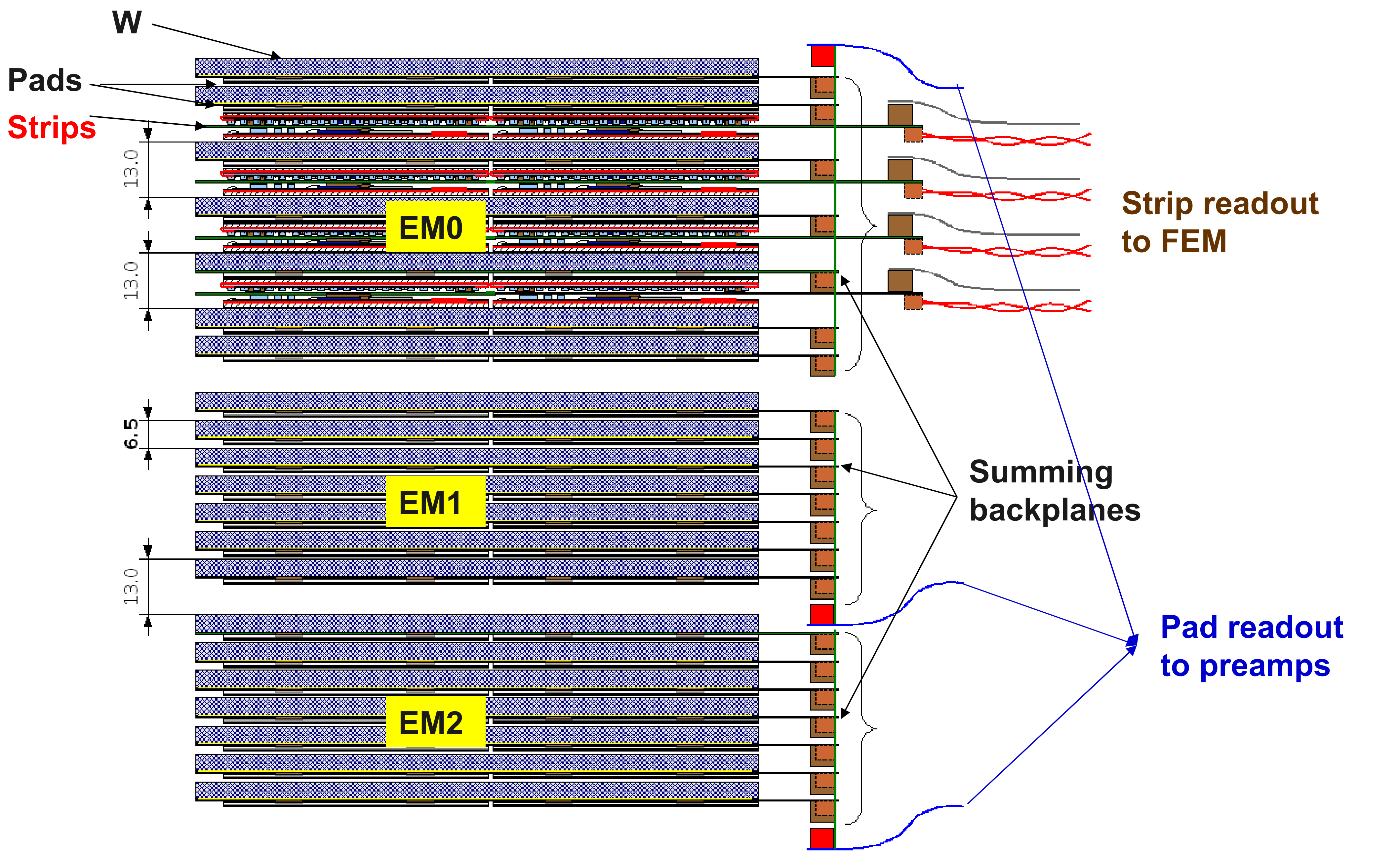






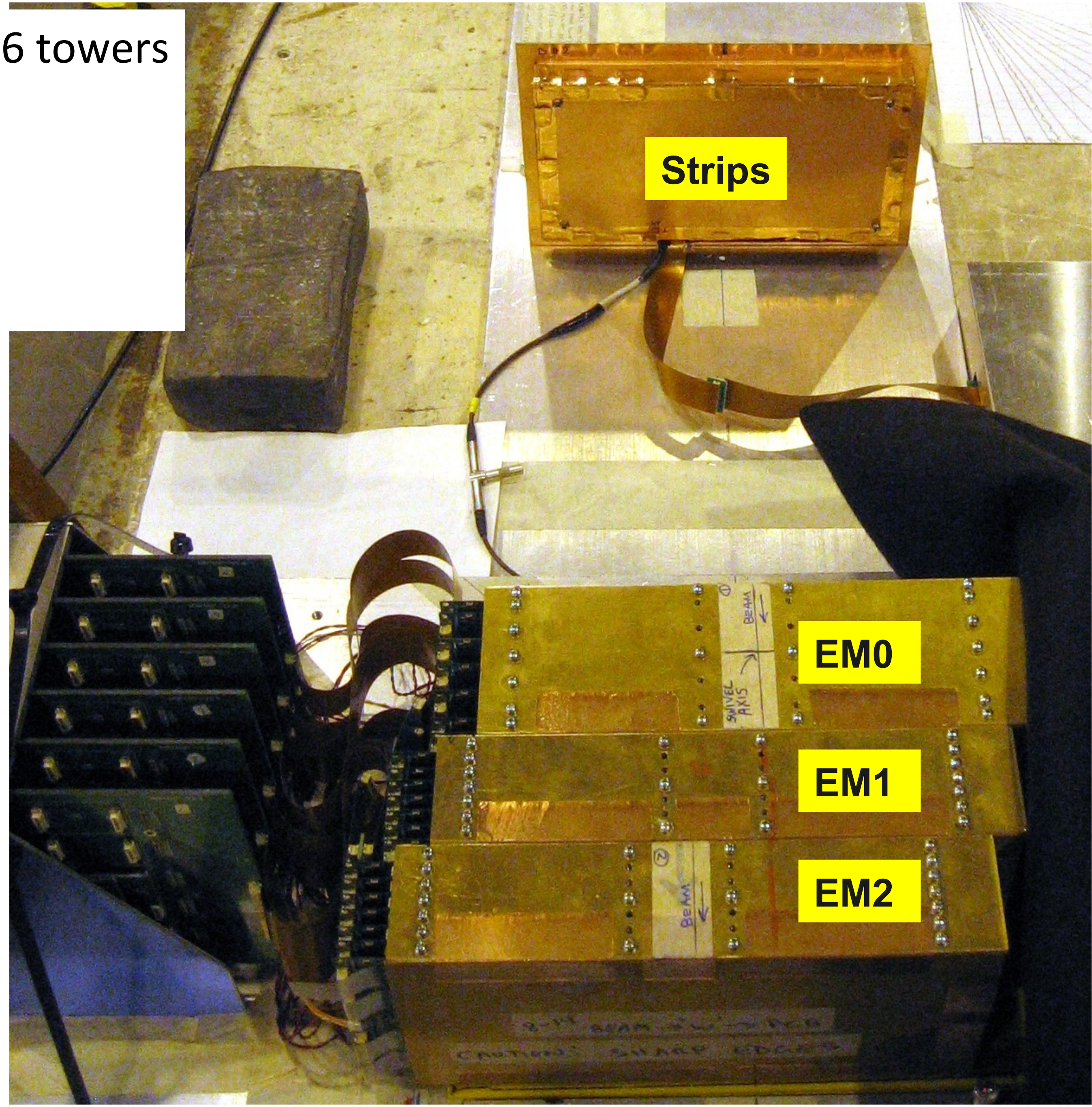
Positioning precision by component placement

Prototype tests: 3) 2x4 modules – the smallest brick



Prototype tests: 3) Protobrick

Protobrick = 2x4 modules, 8x16 towers
(the smallest FoCal brick)
Tested at PS and SPS at CERN
in May 2009

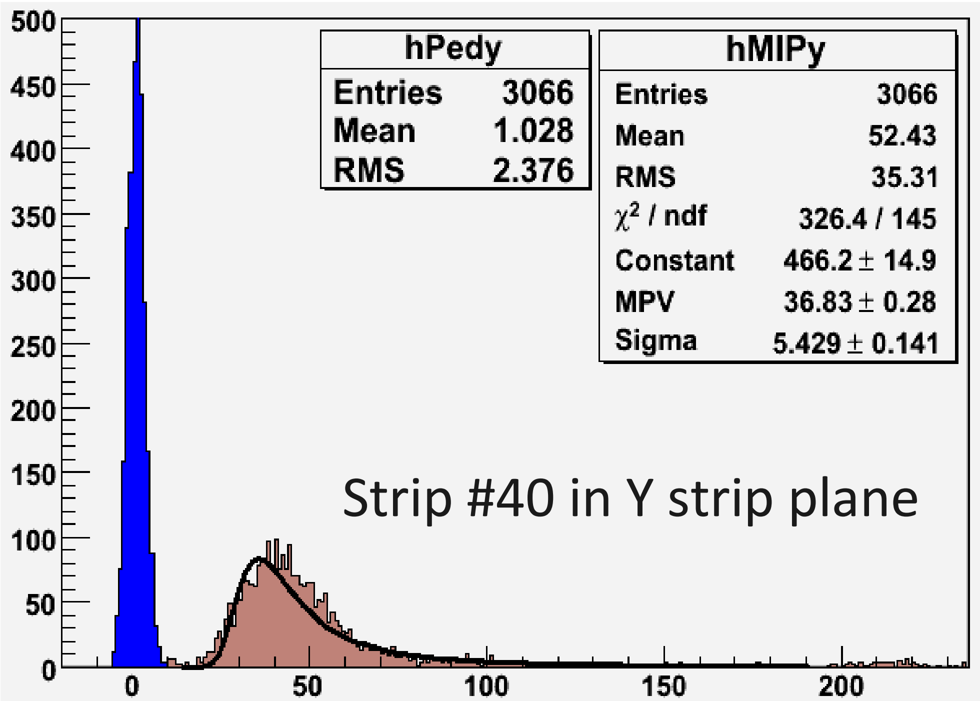


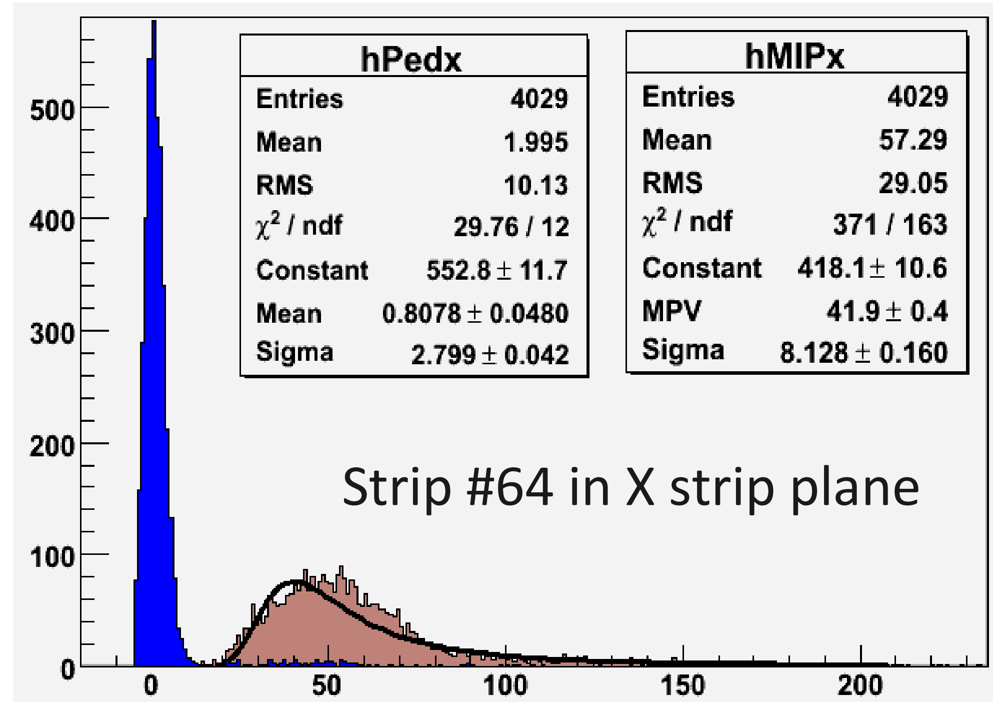
Final FoCal design including strips – tested as hodoscope (shown) and inside the detector positions (gaps)

Analysis in progress

Pad resolution OK

Performance of Strip Sensors – Signal and Noise

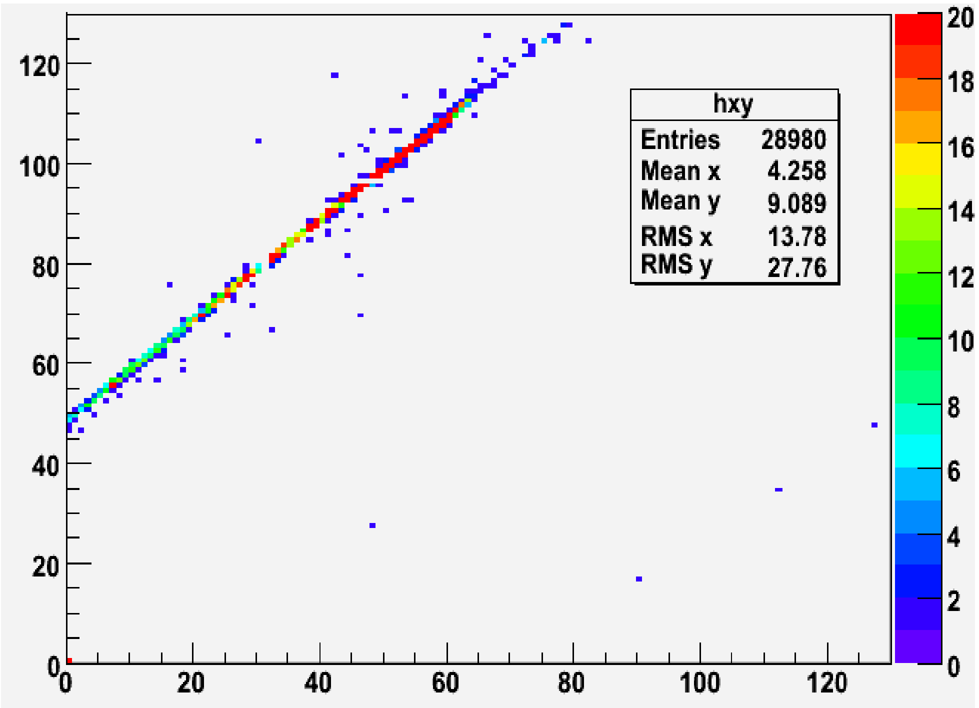




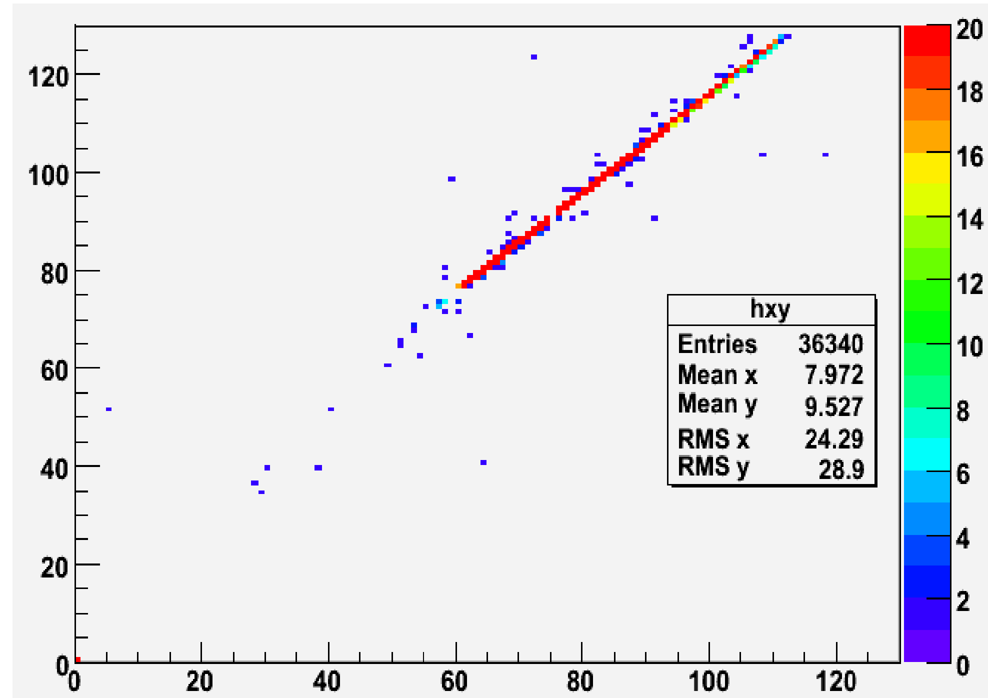
MIP peak (brown) and the pedestal peak (blue)

Typical energy resolution is 6.6 KeV, assuming MIP deposition = 82KeV

Current Status: Hit Position Correlation



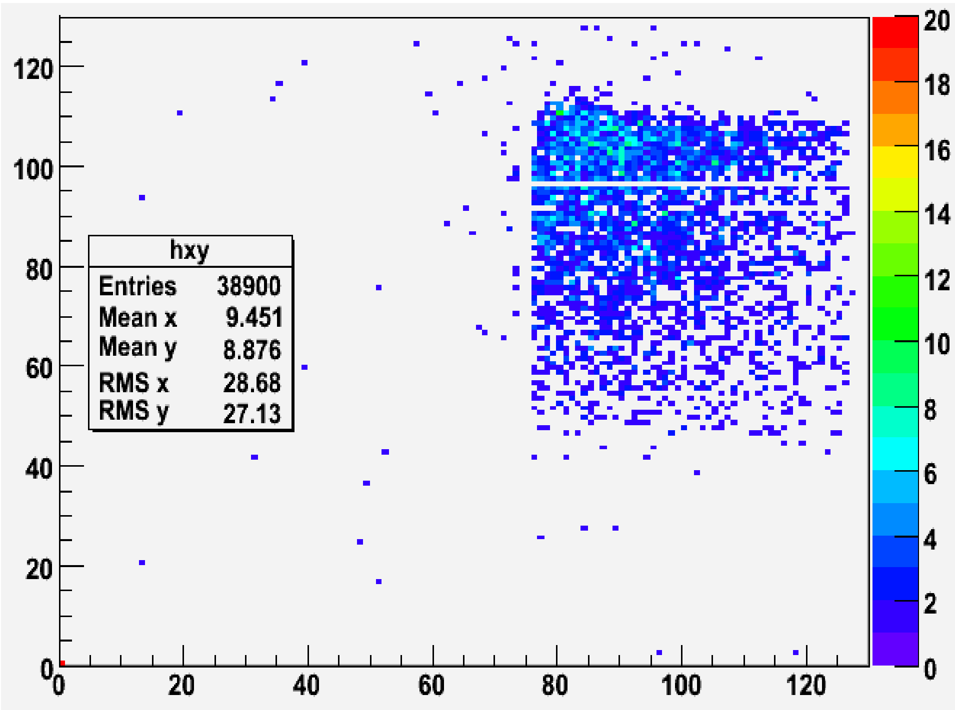
Y position in hodoscope



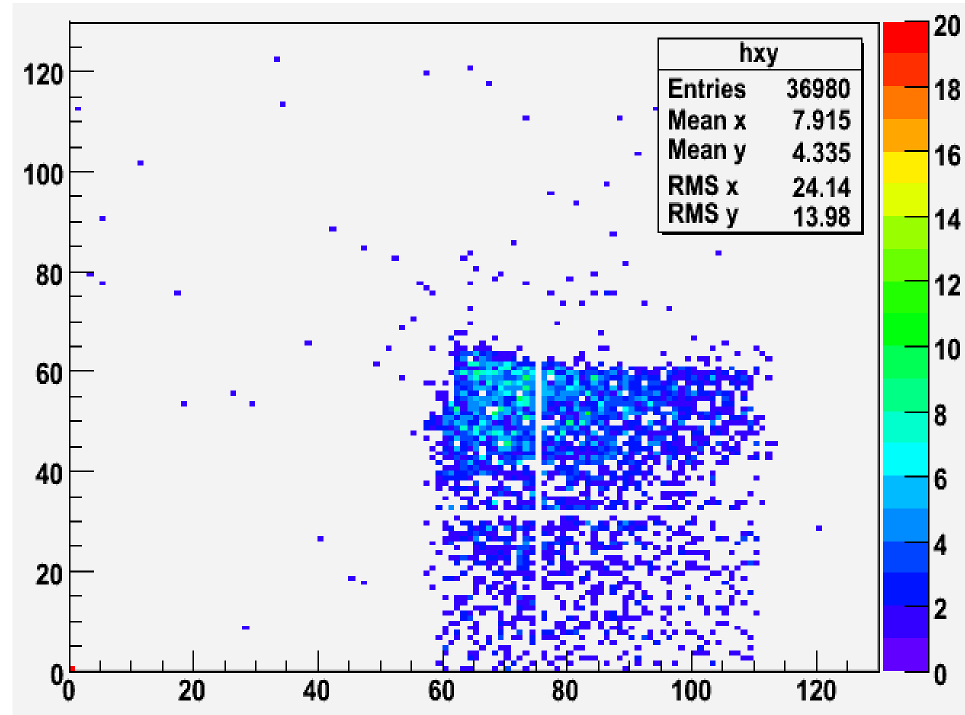
X position in hodoscope

Correlation between hit positions in strip planes in the calorimeter (Y-axis) versus the same in the hodoscope (X-axis)

Current Status: Beam Image



Beam image in hodoscope strip plane.



Beam image in strip plane inside the calorimeter

Project status

- Analysis of the May09 protobrick beam test is under way at BNL
- Simulations for a proposal are in progress
- By Fall 2009 – final proposal for BNL ready
- Ready for production, partial installation in 2011
- Installation and commissioning of one full FoCal arm by early 2012
- 1 arm minimum for all physics, we have space for two
  - Other side for asymmetric collisions (d+Au)
  - Different rapidity regions and larger coverage
  - Factor 2 in statistics → a RHIC run costs ~ $100M
- R&D continues, significant interest in the Si-W technology from other experiments (calorimeter for ILC, forward calorimeter for Alice)

Collaborating institutions

- University of California, Riverside,
  - K. Barish, O. Chvala, T. Hester, S. Rolnick, Ken Sedgewick, R. Seto, R. Hollis, A. Iordanova
- Physics Dept., Brookhaven National Laboratory,
  - S. Boose, M. Chiu, B. Johnson, E.P. Kistenev, D. Lynch, R. Nouicer, R. Pak, R. Pisani, S.P. Stoll, A. Sukhanov, C.L. Woody, C. Vale, G. David, D. Morrison
- Charles University
  - Michael Finger, Miroslav Finger, M. Slunecka
- Chonbuk University
  - J.B. Choi, E.J. Kim
- University of Colorado, Boulder
  - E. Kinney, J. Nagle
- Columbia University and Nevis Laboratories
  - C.Y. Chi
- Czech Technical University,
  - M. Virius, T. Liska
- Ewha Womans University
  - I.S. Hahn, A. Kim, J. Lee, N.H. Lee, S.W. Nam, I.H. Park, J.S. Yoo
- Institute of Physics, Academy of Sciences of Czech Republic
  - P. Mikes, J. Popule, P. Ruzicka, L. Tomasek, M. Tomasek, V. Vrba

Collaborating institutions (cont.)

- Iowa State University
  - J.C. Hill, J.L. Lajoie, F. Wei
- Joint Institute for Nuclear Research-
  - S. Afanasiev, S. Bazylev, A. Baskakov, A. Bychkov, A. Cheremukhin, V. Elsha, N. Gorbunov, A. Isupov, N. Kotsev, A. Litvinenko, A. Malakhov, V. Peresedov, P. Rukoyatkin, V. Slepnev, I. Slepnev, N. Zamyatin, L. Zolin, E. Zubarev
- University of Jyvaskyla/Helsinki Institute of Physics,
  - Kaskela, D.J. Kim, M. Oinonen, J. Rak, H. Steppanen
- Korea University,
  - B. Hong, H.H. Shim, K.S. Sim
- Myongji University,
  - K.S. Joo D.W. Kim, H.J. Moon
- RIKEN, The Institute of Physical and Chemical Research,
  - I. Nakagawa, A. Taketani
- Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University
  - G.A. Bogdanova, D. Karmanov, M. Merkin, V. Volkov, A. Voronin
- Institute of Physics, University of Tsukuba,
  - S. Esumi
- Yonsei University,
  - J.H. Kang, Y. Kwon, S. Kim

FoCal Conclusions

FoCal: dense W-Si tracking calorimeter with small Moliere radius
10x larger acceptance than central arms allows new physics studies

R&D well advanced, successful beam tests, installation in 2011-2012
Novell technology, significant interest outside PHENIX

FoCal provides:

- Precision measurements of EM showers in forward region(s)
- γ/π^0 discrimination similar to central arms, π^0 up to kinematic limit
- additional γ/hadron discrimination
- jet finding, jet energy and rapidity measurements
- data for fast LL1 triggering

Allows for studies:

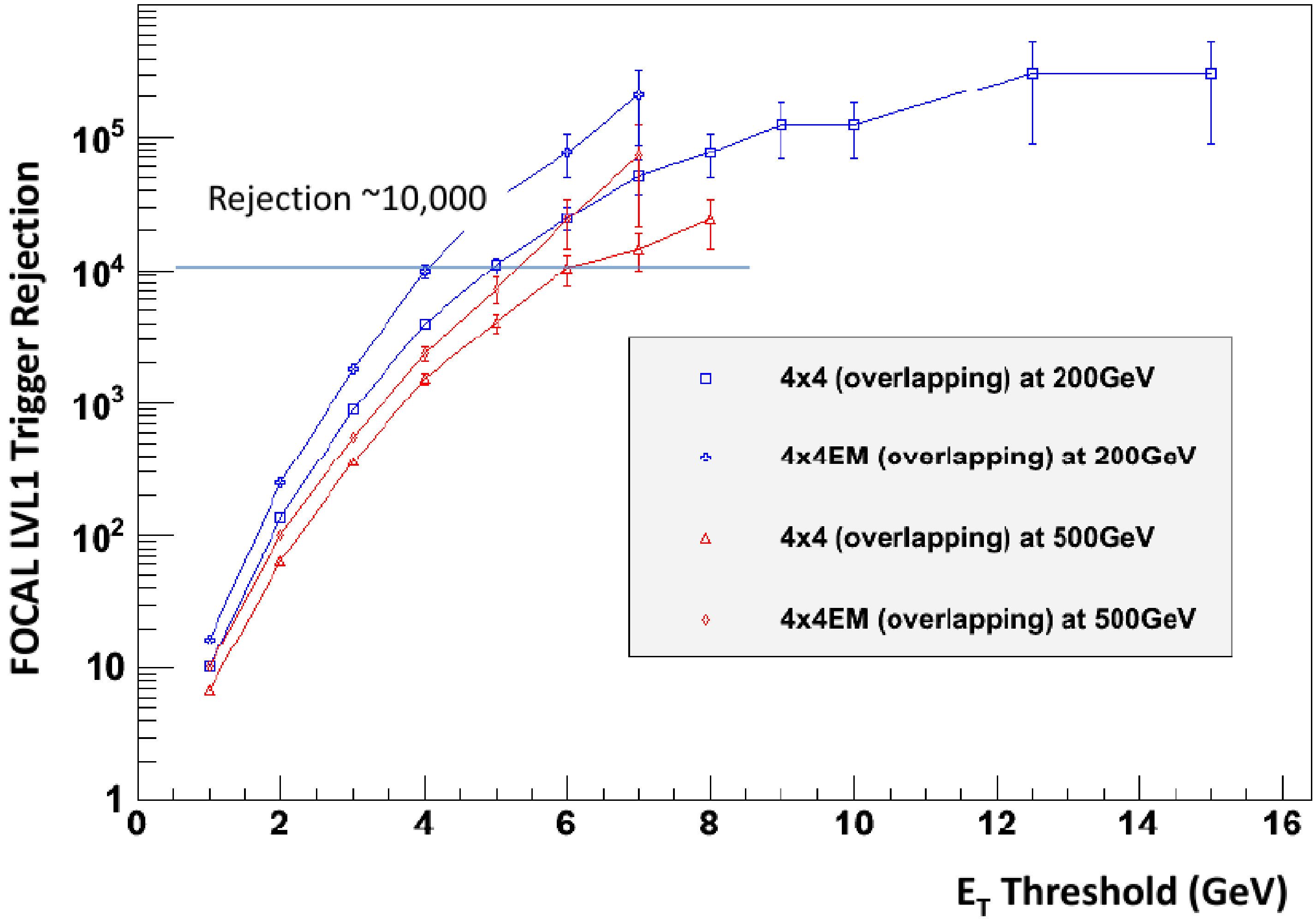
- Spin program
  - gluon and anti-q polarization
  - transverse physics
- d+Au collisions
  - gluon and anti-q distribution at low x
  - Cronin effect
- Heavy ions
  - suppression in forward region
  - opacity and temperature of sQGP
  - high resolution reaction plane measurement

Backup slides

FoCal LL1 trigger

Rejection at 200GeV and 500GeV

(NOTE: Rejection is now for **ONE FOCAL**)



FoCal Physics - Motivation

I. Heavy ions – hot nuclear matter

- R_{AA} in forward direction, esp. π^0 at high momentum
- γ-jet correlations to study opacity of sQGP
- Plasma temperature using charmonium suppression
- Open heavy flavor measurement via electrons (+FVTX)

II. d+Au collisions – cold nuclear matter

- Gluon structure function (saturation at low x?) by
  - Single hadrons via EM channels (π^0, η, ω, φ, J/ψ, …)
  - Direct photons, γ-jet correlations to fix kinematics
  - Dihadron production: π^0 or η in NCC and another in EMC
  - Open heavy flavor production
- Antiquark DF in nucleus at low x via Drell-Yan
- Cronin effect, x_F scaling of produced hadrons in p+A

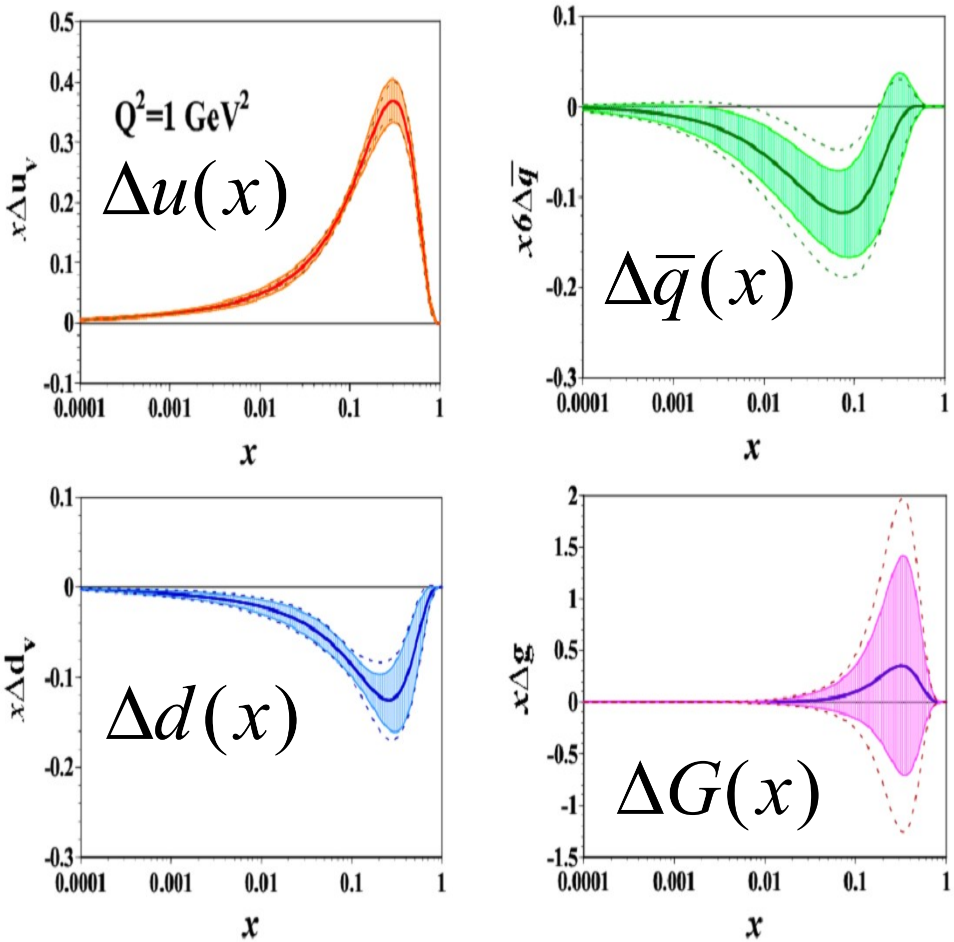
III. Polarized p+p interactions – spin structure of nucleon

- Polarized gluon distribution ΔG via single hadrons, direct γ, heavy flavor
- Antiquark contribution to Δg via W
  - e measurement, BG reduction for μ
- Transverse physics
  - single spin asymmetry A_N – Sivers, Collins, higher twist
  - trasversity δg

Technical design: novelties

- Concept of micromodule (single sensor ladder)
- Concept of positioning precision by component placement (connectors)
- Concept of passive summing circuits and optimal filtering to cancel impedance mismatches
- Pipelined signal processing and clock synchronized energy and timing measurements

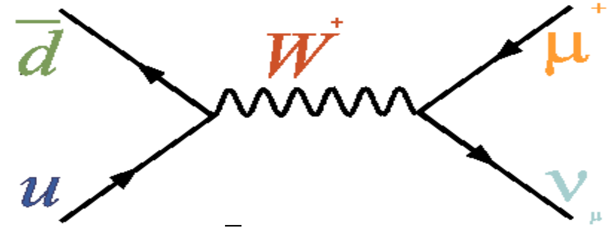
A Brief Introduction to W Spin Physics



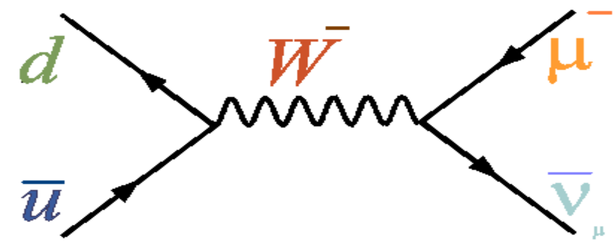
M. Hirai, S. Kumano, N. Saito, Phys. Rev. D 74, 014015 (2006)

The W boson in polarized proton collisions gives a unique ability to study the flavor dependence of quark polarization

- The W maximally violates parity (V-A); large analyzing power
- Selecting different y and p_T regions allows one to measure the polarization by flavor



$$A_L = u + \bar{d} \rightarrow W^+ \rightarrow \mu^+ + \nu_\mu$$



$$A_L = d + \bar{u} \rightarrow W^- \rightarrow \mu^- + \bar{\nu}_\mu$$

Single spin asymmetry for W^+ and W^-

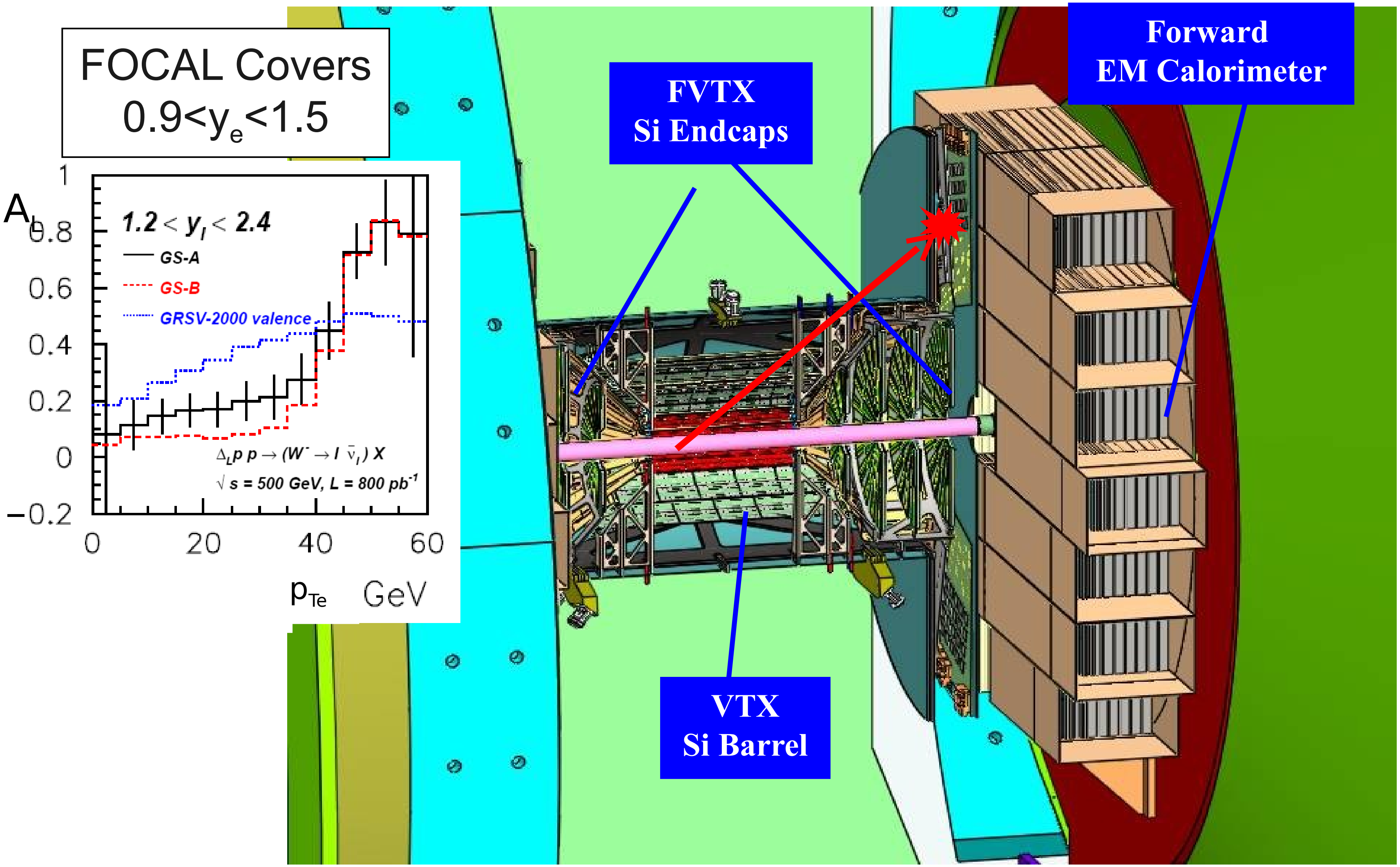
$$A_L^{w^+} = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$

$$A_L^{w^+} = \frac{-\Delta d(x_a)\bar{u}(x_b) + \Delta\bar{u}(x_a)d(x_b)}{d(x_a)\bar{u}(x_b) + \bar{u}(x_a)d(x_b)}$$

$$x_a >> x_b : A_L^+ \approx \frac{-\Delta u}{u}, A_L^- \approx \frac{-\Delta d}{d}$$

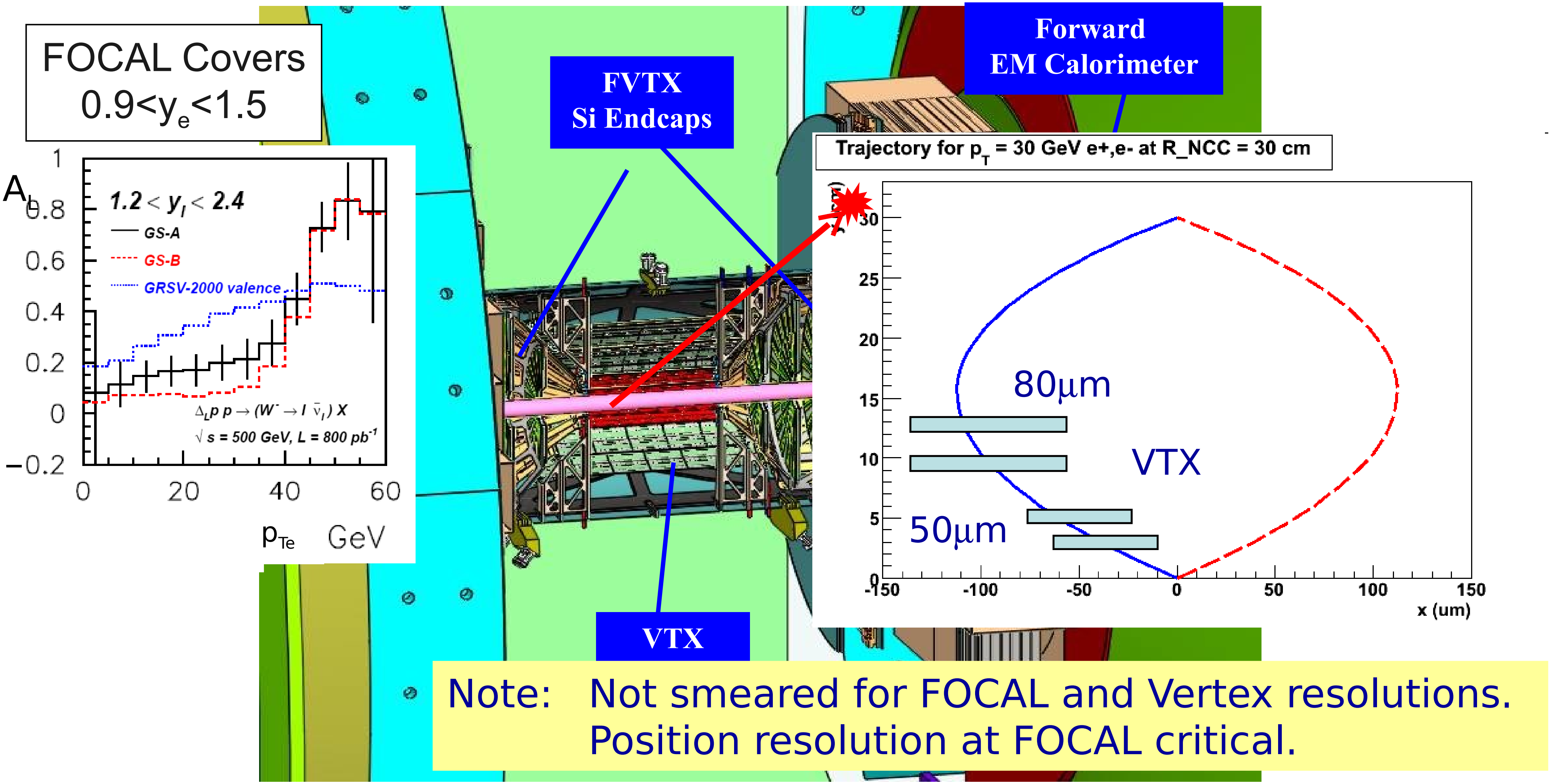
$$x_b >> x_a : A_L^+ \approx \frac{-\Delta\bar{d}}{\bar{d}}, A_L^- \approx \frac{-\Delta\bar{u}}{\bar{u}}$$

W Boson with FOCAL – worth pursuing?



- There is enough ∫Bdl to get a deflection which is on the order of the size of the VTX detector elements
- The FOCAL provides the electron momentum through Energy measurement
  - effectively gives a factor of two in measuring the sagitta.

W Boson with FOCAL – worth pursuing?



Note: Not smeared for FOCAL and Vertex resolutions. Position resolution at FOCAL critical.

- There is enough ∫Bdl to get a deflection which is on the order of the size of the VTX detector elements
- The FOCAL provides the electron momentum through Energy measurement
  - effectively gives a factor of two in measuring the sagitta.

Strategy: Plausibility scenario

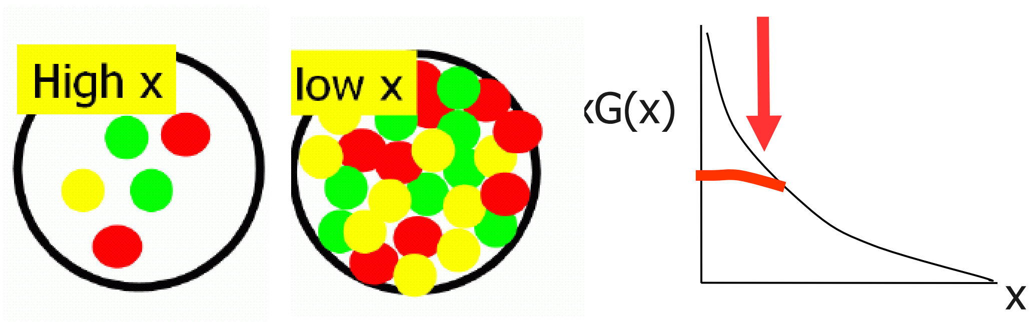
Run year	milestones	FC complete	Funding source	RBUP/PAC	Physics, priority
2009	Proposal	Prototype	BNL (funded)	Test beam 500 GeV pp	γ/π^0 identification EM PID, resolution
2010	Construction begins			200 AuAu 200 pp	
2011	Large scale test in PHENIX	Partial install	BNL	200 UU Low E AuAu	π^0 R_{AA} pt~5 GeV
2012	Install and commission 1st side – no strips	1st side No strips	BNL $2M	200 AuAu 500 pp	Particle-jet correlations ridge physics pp Collins@500
2013	Install γ/π^0	γ/π^0 1st side	NSF MRI/ RIKEN $1.5	200 UU/AuAu 500 pp	Particle-jet (auau-all in FOCAL) χ_{C}, γ-jet(pp –ΔG(low-x), Sivers/Collins@500
2014	earliest Install of 2nd side	2nd side	? $2.5M	200 pp Low E AuAu	γ-jet(pp – γ/jet jet/jet in FOCAL) ΔG(low-x), Collins, Sivers@200 AuAu – large η ridge physics
2015		done	done	P(d)A ? 200/500 pp?	γ-jet(dAu – γ/jet in FOCAL, gluon SF) χ_C in dAu, pp

Other FoCal physics in A+A

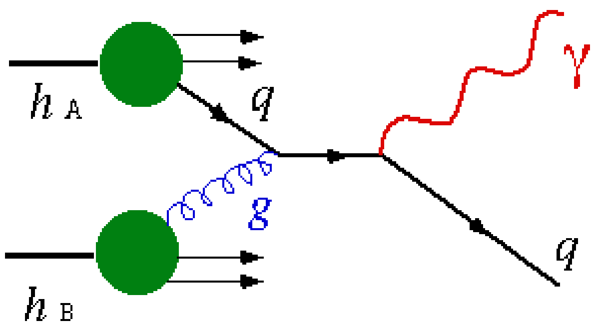
- Energy loss in medium via π^0 R_{AA} at forward rapidity
- Direct photons
- Charmonium production and suppression:
  - $\chi_c \rightarrow \gamma + J/\psi$
- High resolution reaction plane determination for geometry and path length dependence studies
- Critical point search through E_T fluctuations

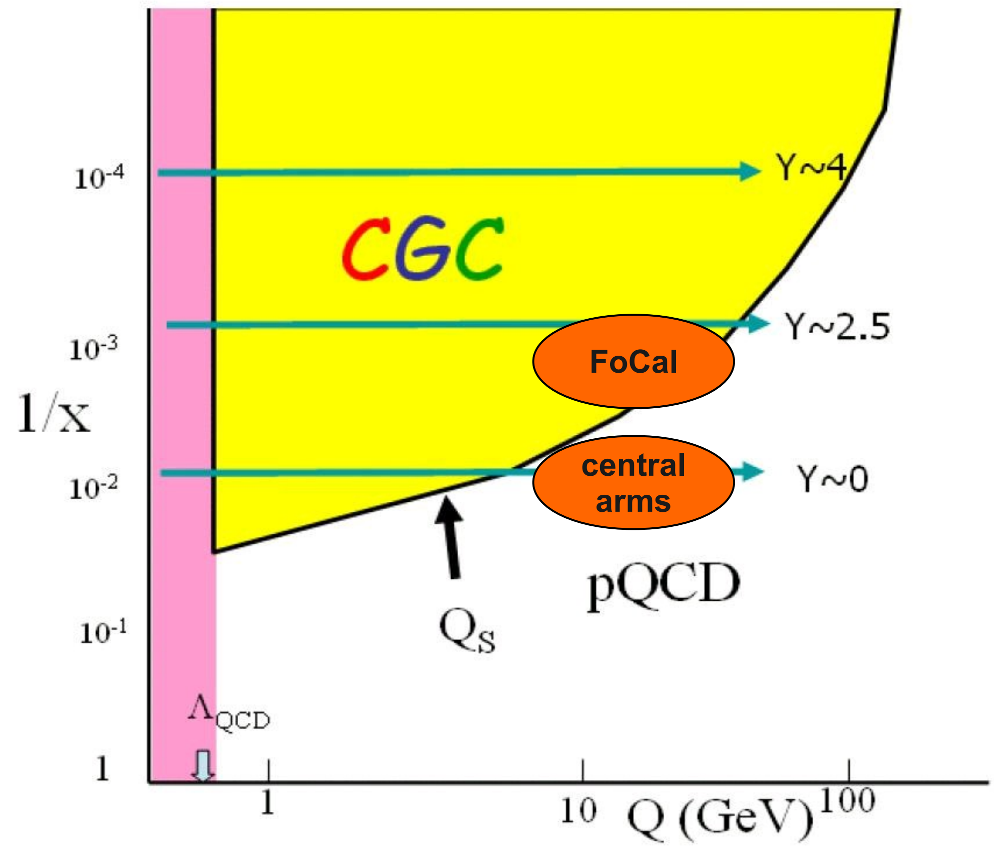
Nuclear Gluon PDF's

Saturation of gluon density at low x?



Measured by direct photons and jets





$$x_1 = \frac{p_{T\gamma}}{\sqrt{s}}(e^{\eta_\gamma} + e^{\eta Jet})$$

$$x_2 = \frac{p_{T\gamma}}{\sqrt{s}}(e^{-\eta_\gamma} + e^{-\eta Jet})$$

direct γ
jets –x resolution
forward η(low-x)