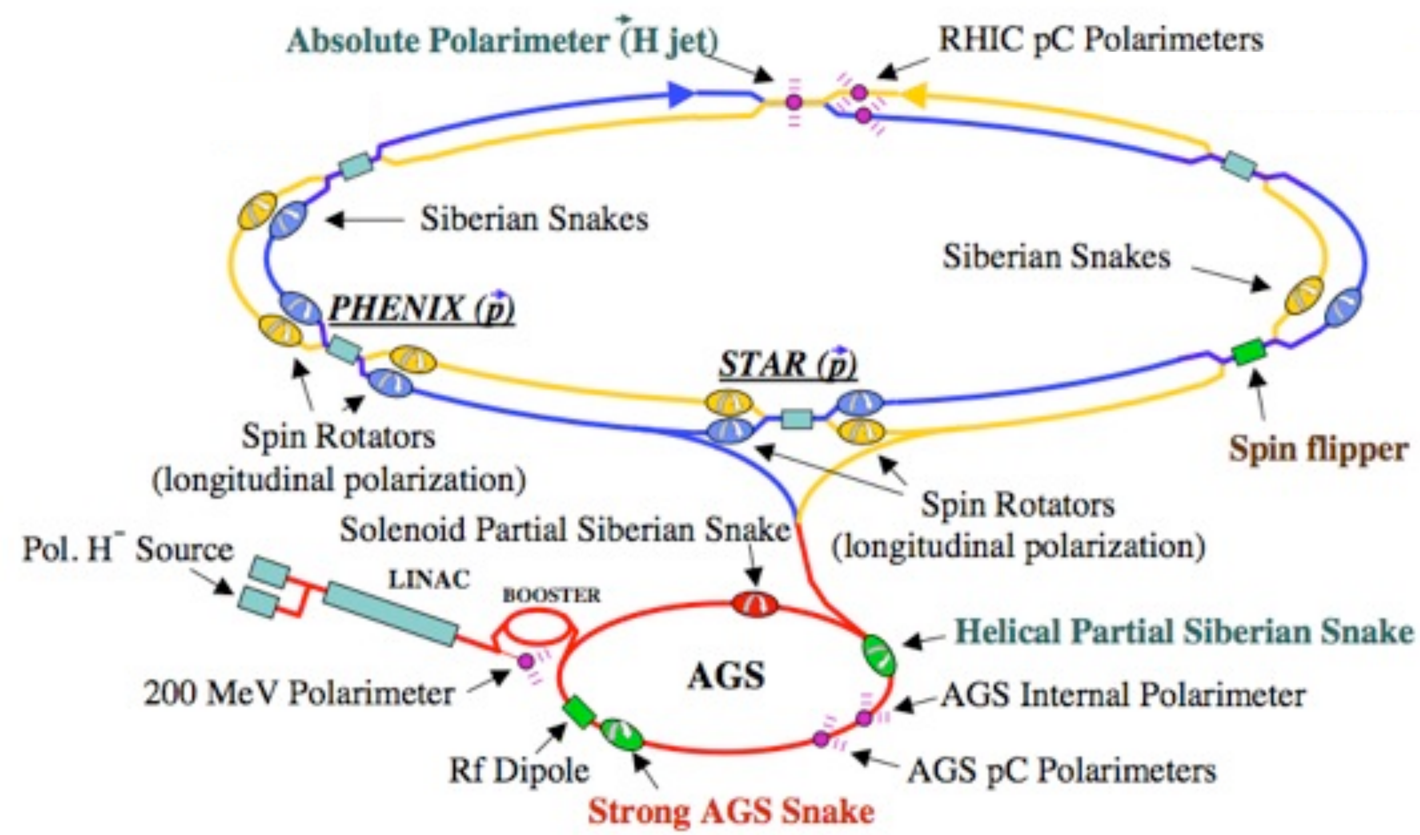
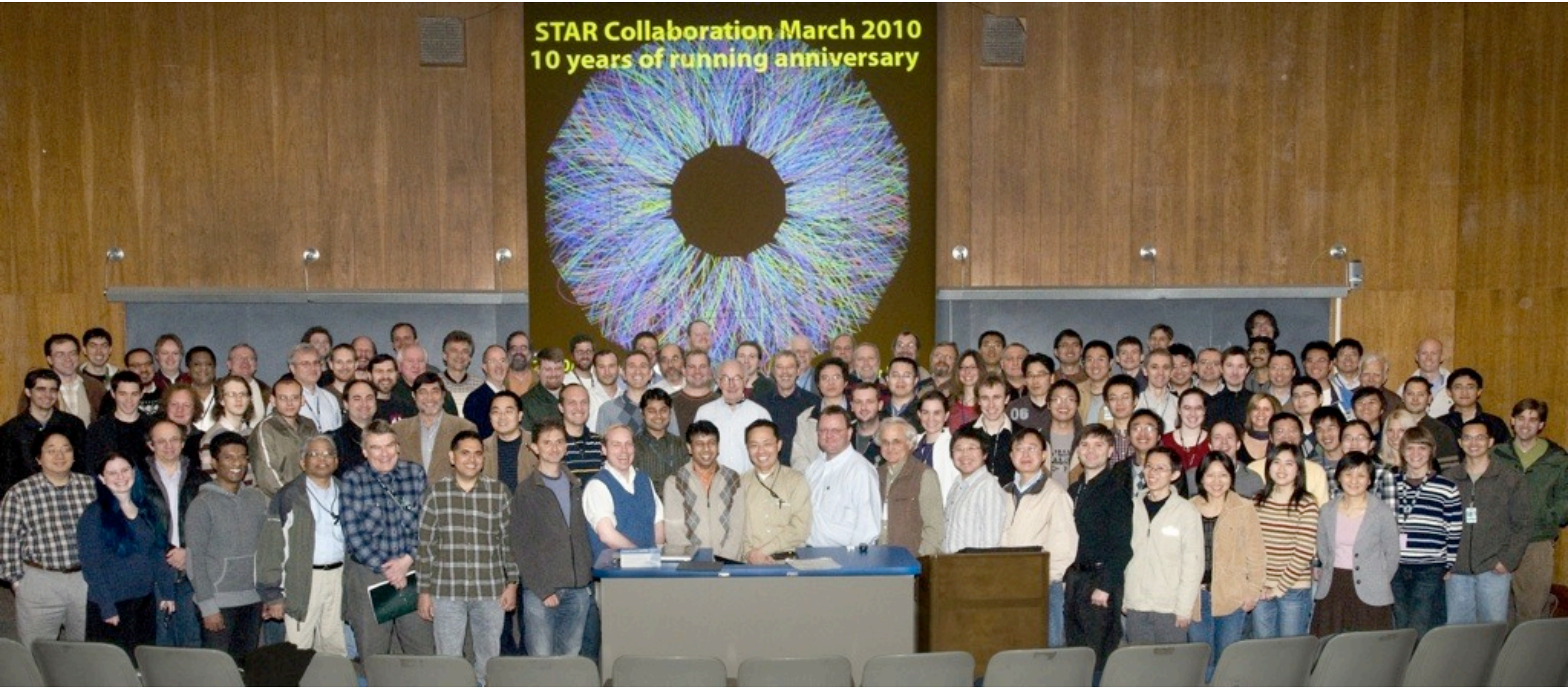
Drell-Yan Production at STAR Status and Plans

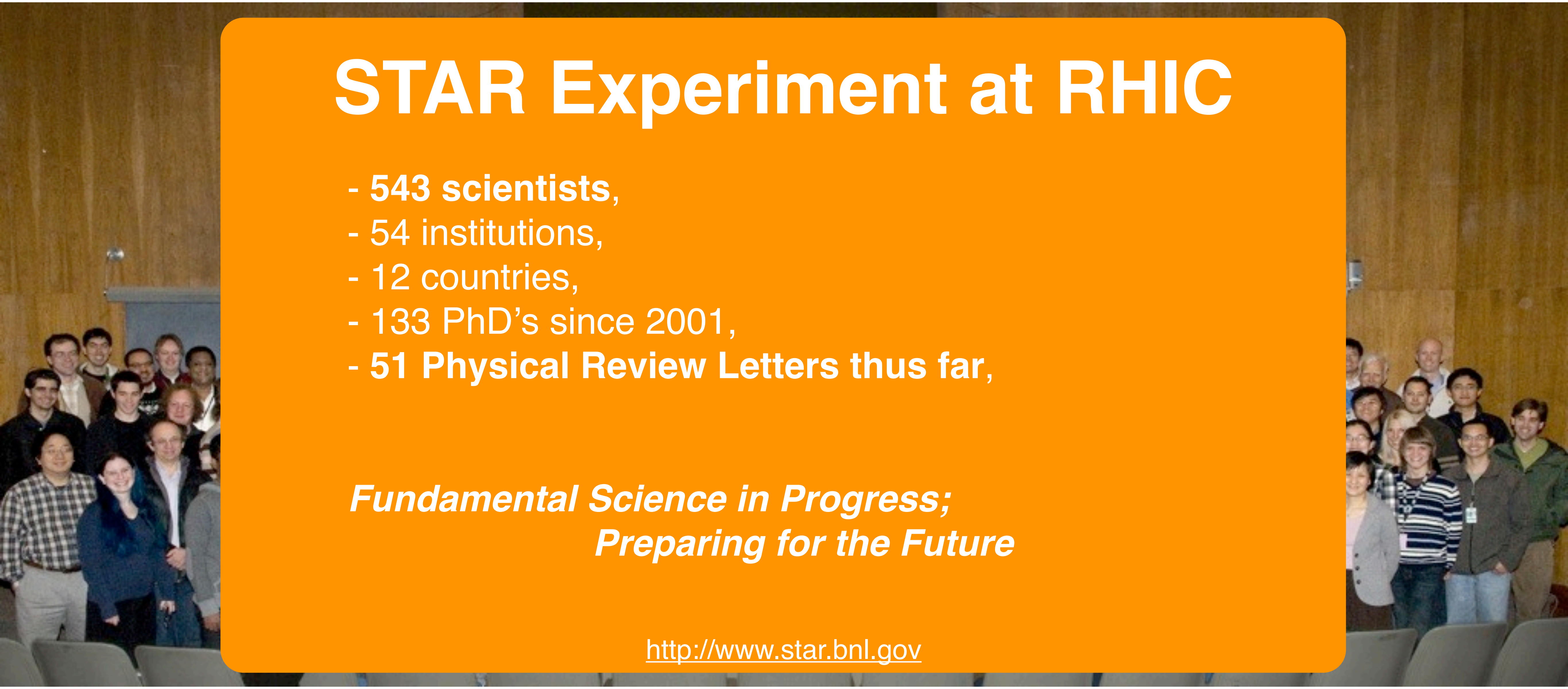
Ernst Sichtermann (LBNL)

for the STAR Collaboration



Opportunities for Drell-Yan Physics at RHIC
RIKEN BNL Research Center Workshop
May 11-13, 2011 at Brookhaven National Laboratory


STAR Collaboration March 2010
10 years of running anniversary



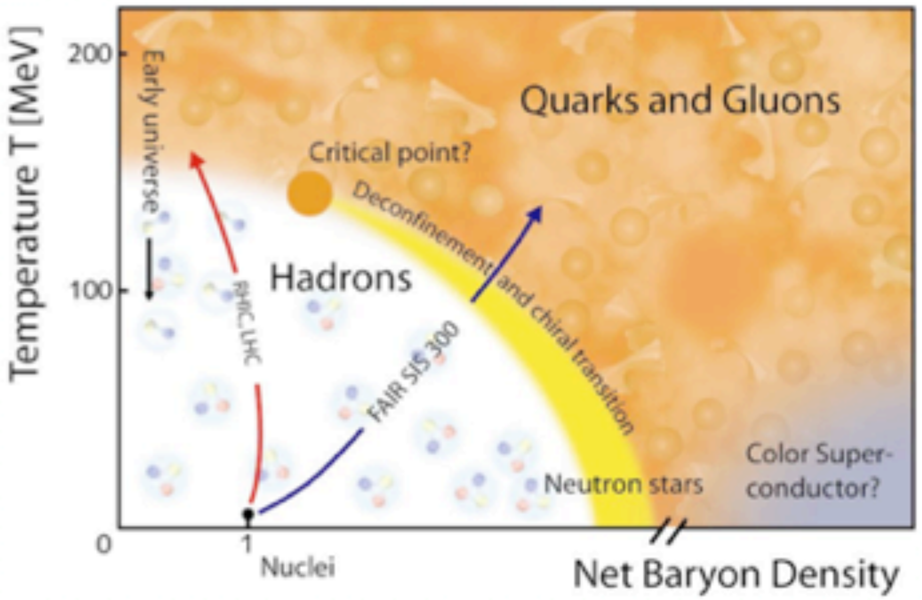
STAR Experiment at RHIC

- **543 scientists**,
- 54 institutions,
- 12 countries,
- 133 PhD's since 2001,
- **51 Physical Review Letters thus far**,

Fundamental Science in Progress;
Preparing for the Future

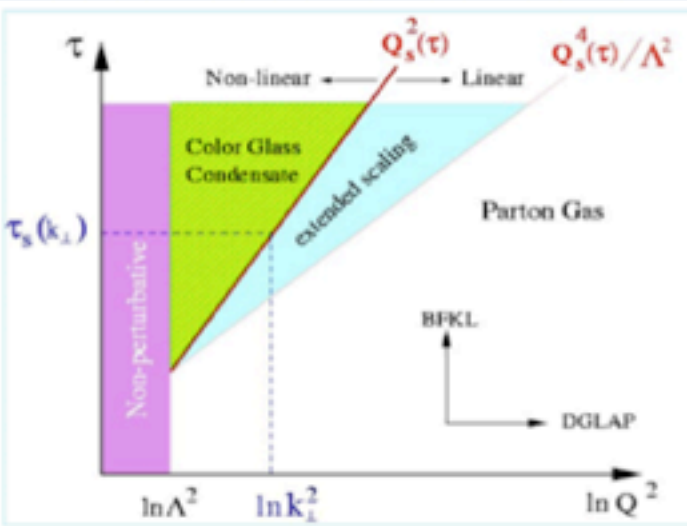
http://www.star.bnl.gov

STAR Physics - QCD Matter

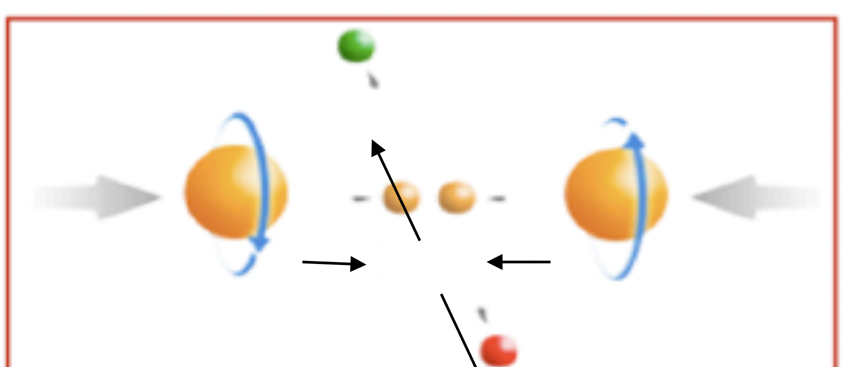


1) At 200 GeV top energy
- Study ***medium properties, EoS***
- pQCD in hot and dense medium

2) RHIC beam energy scan (BES)
- Search for the ***QCD critical point***
- Chiral symmetry restoration



Forward program
- Study low-x properties, initial condition, search for ***CGC***
- Study elastic and inelastic processes in pp2pp



Polarized *p+p* program
- Study ***proton intrinsic properties***
  role of spin in QCD

Preparing for the Future - see e.g. STAR Decadal Plan, http://www.bnl.gov/npp

STAR - Solenoid Tracker at RHIC

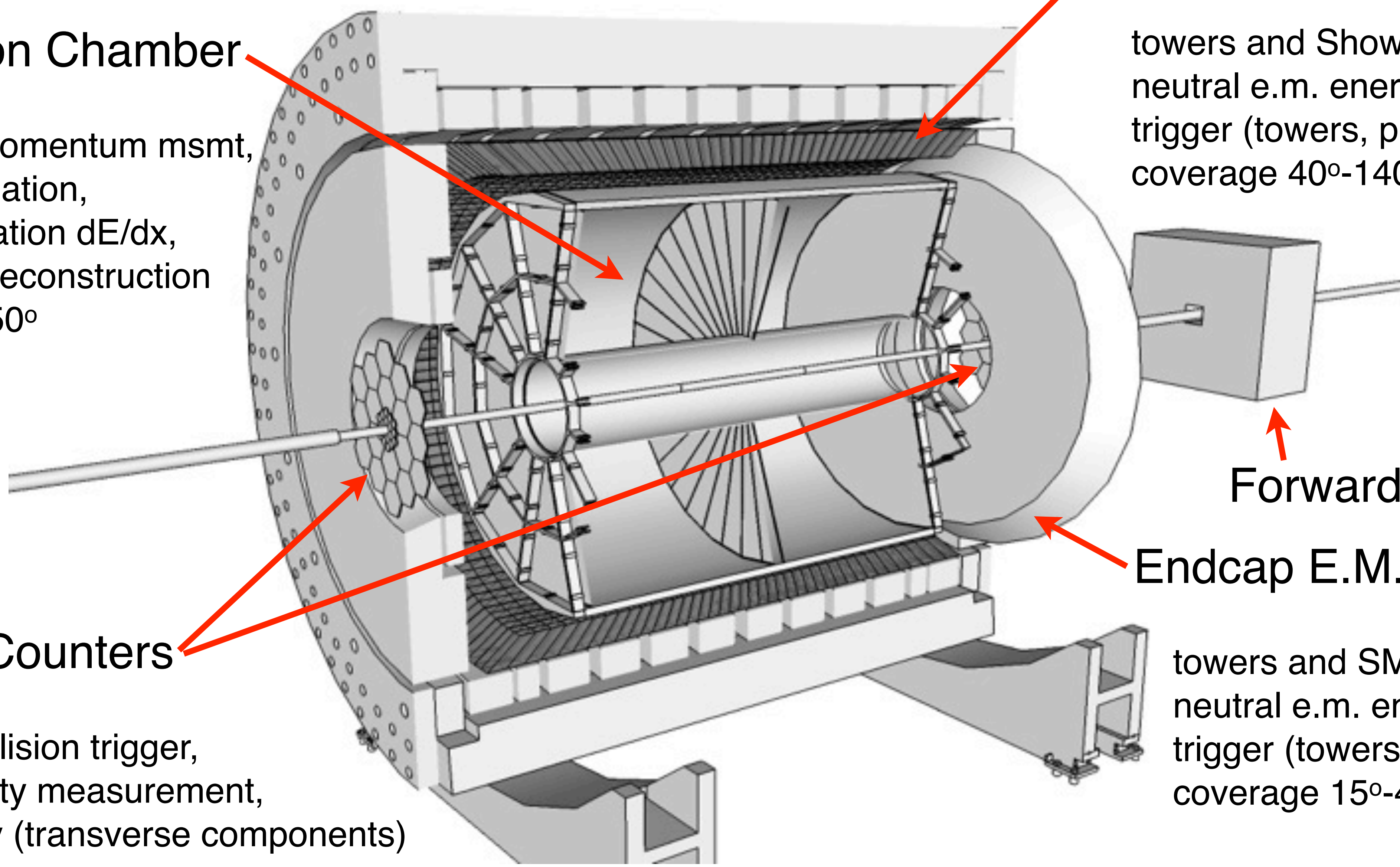
Nucl. Instrum. Meth. A499, 624, 2003

Time Projection Chamber

charged track momentum msmt,
charge determination,
particle identification dE/dx,
collision vertex reconstruction
coverage 30°-150°

Barrel E.M. Calorimeter

towers and Shower Maximum Det.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 40°-140°



Forward Meson Spectr.

Beam-Beam Counters

proton beam collision trigger,
relative luminosity measurement,
local polarimetry (transverse components)

Endcap E.M. Calorimeter

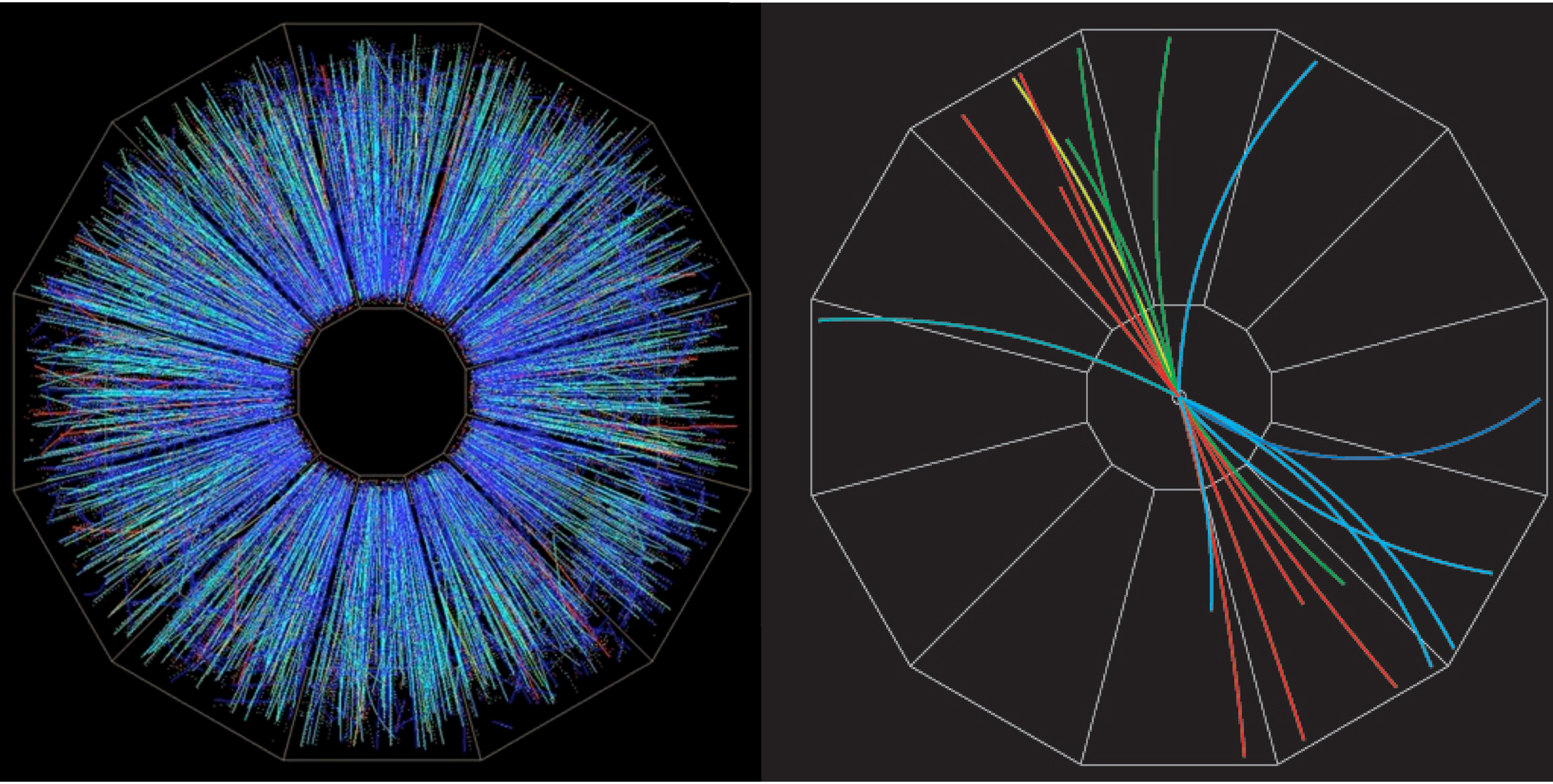
towers and SMD.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 15°-40°

0.5 T Solenoidal Magnetic Field

Several detectors not shown, e.g. ZDC, FPD, Time-of-Flight, Roman Pots, ...

A very versatile *general purpose* instrument, with an *evolutionary* and *physics-driven* upgrades.

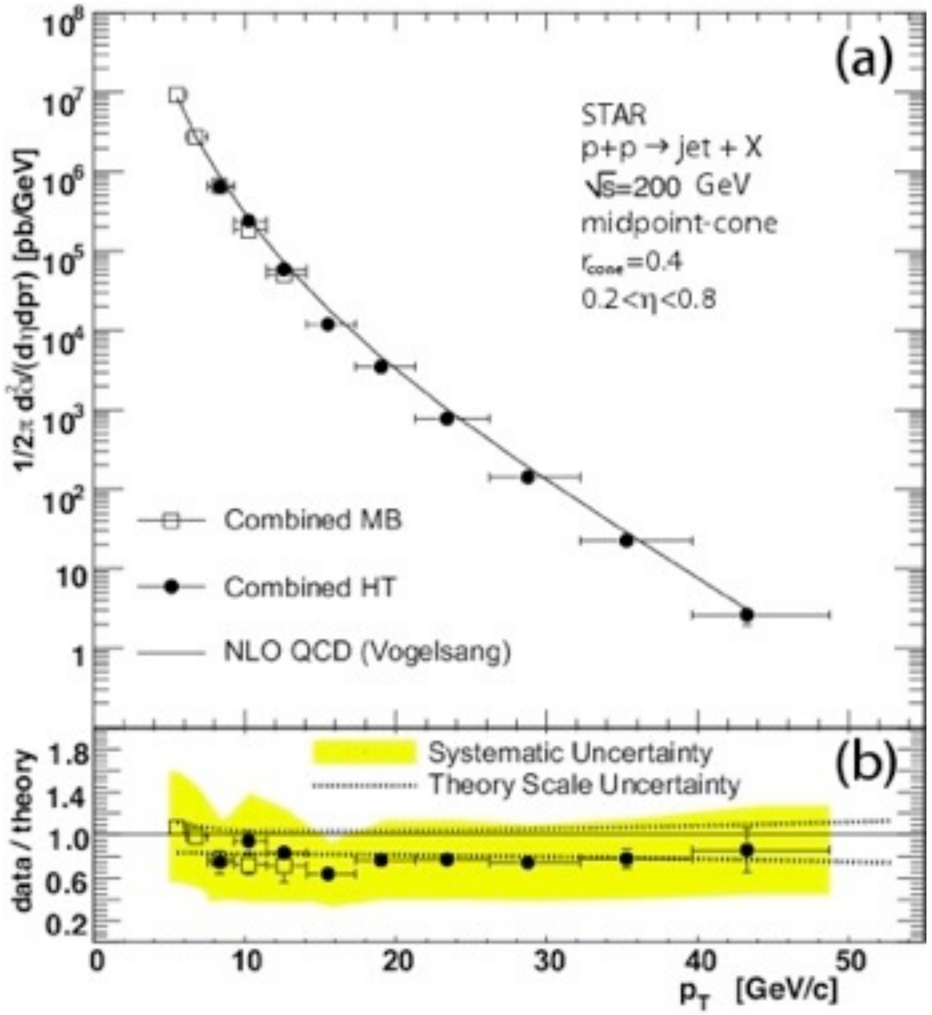
STAR - Solenoid Tracker at RHIC



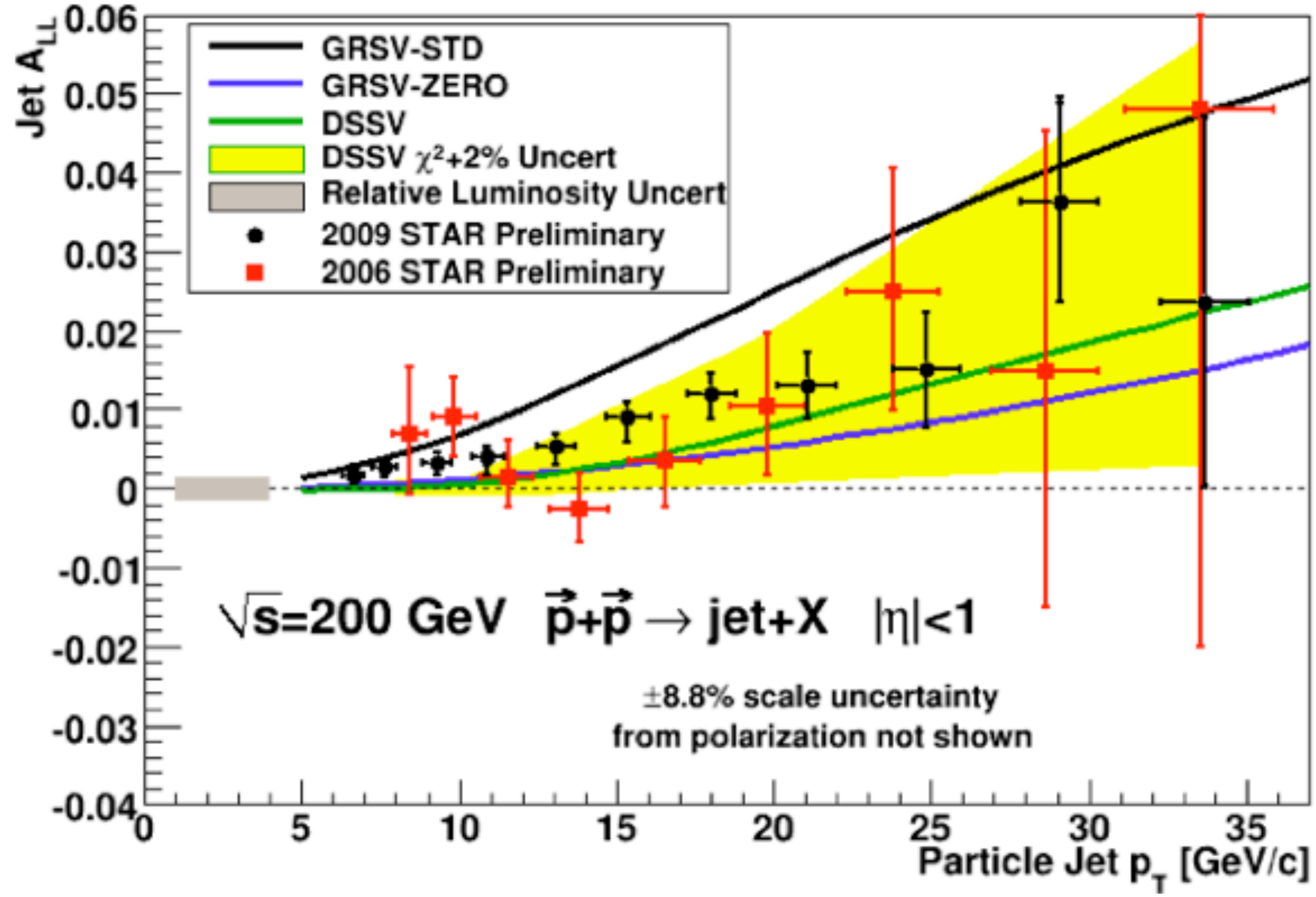
A versatile instrument to study QCD: Au+Au, d+Au, p+p, $\sqrt{s}$ = 7.7 - 500 GeV, polarization.

Strengths: Large acceptance at mid-central rapidities, particle identification,
Collective motion, jets, and correlations.

STAR - Selected Mid-rapidity Results



Pibero Djawotho, for the STAR collaboration, DIS2011

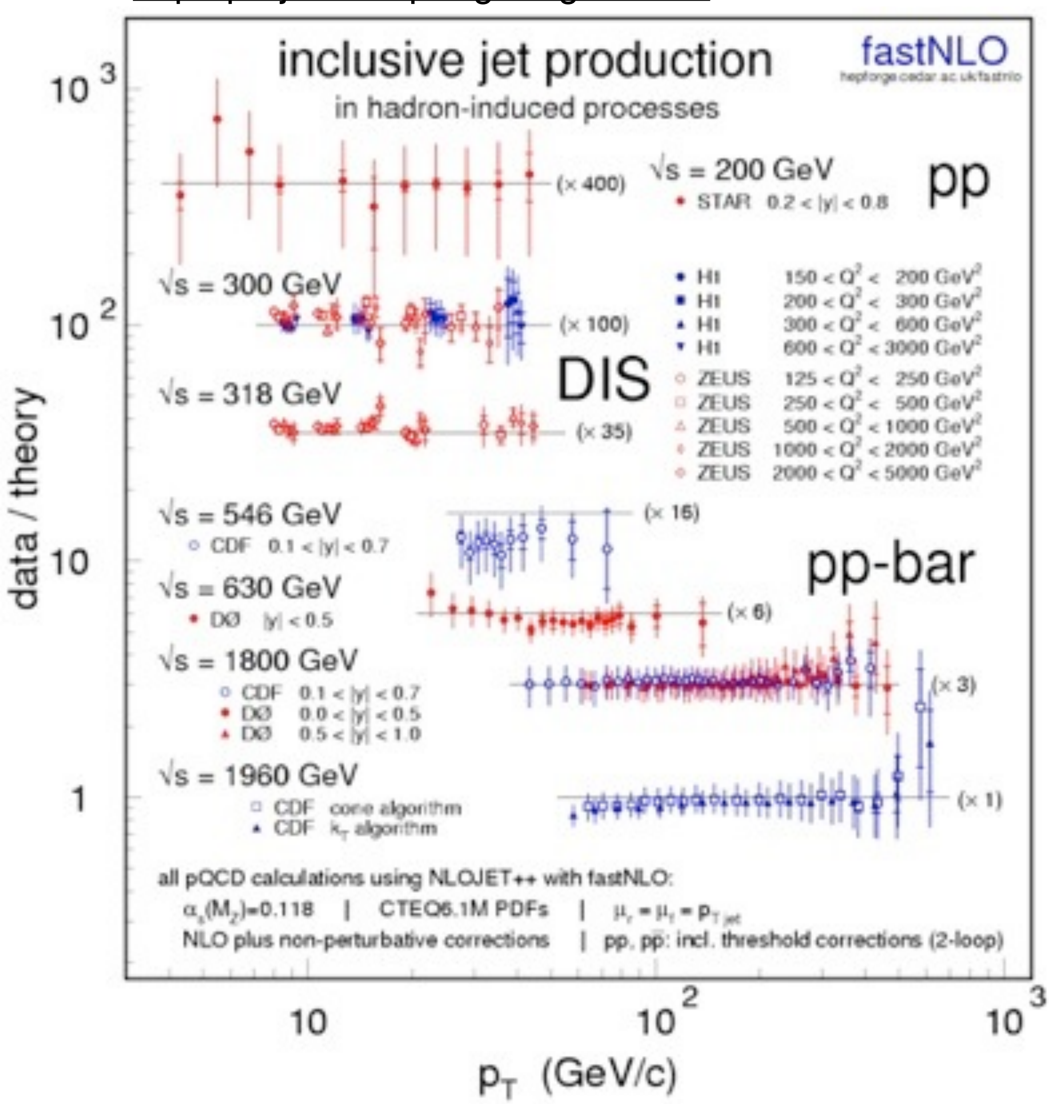


Collinear factorization forms a good description of the spin-averaged cross-section(s),

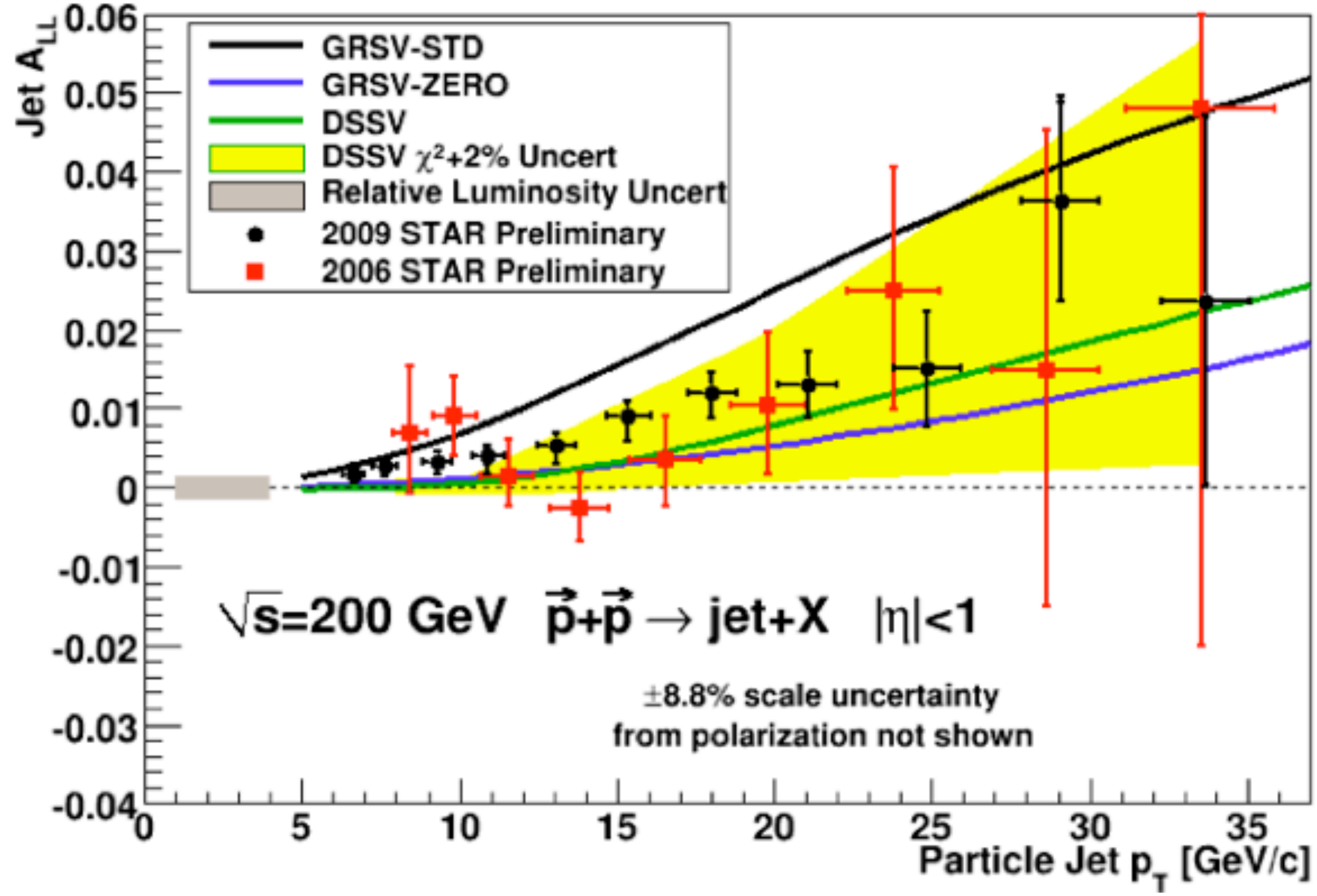
B. Abelev et al., Phys.Rev.Lett.97:252001,2006
B. Abelev et al., Phys.Rev.Lett.100:232002,2008

STAR - Selected Mid-rapidity Results

T. Kluge, K. Rabbertz, M. Wobisch,
http://projects.hepforge.org/fastnlo/



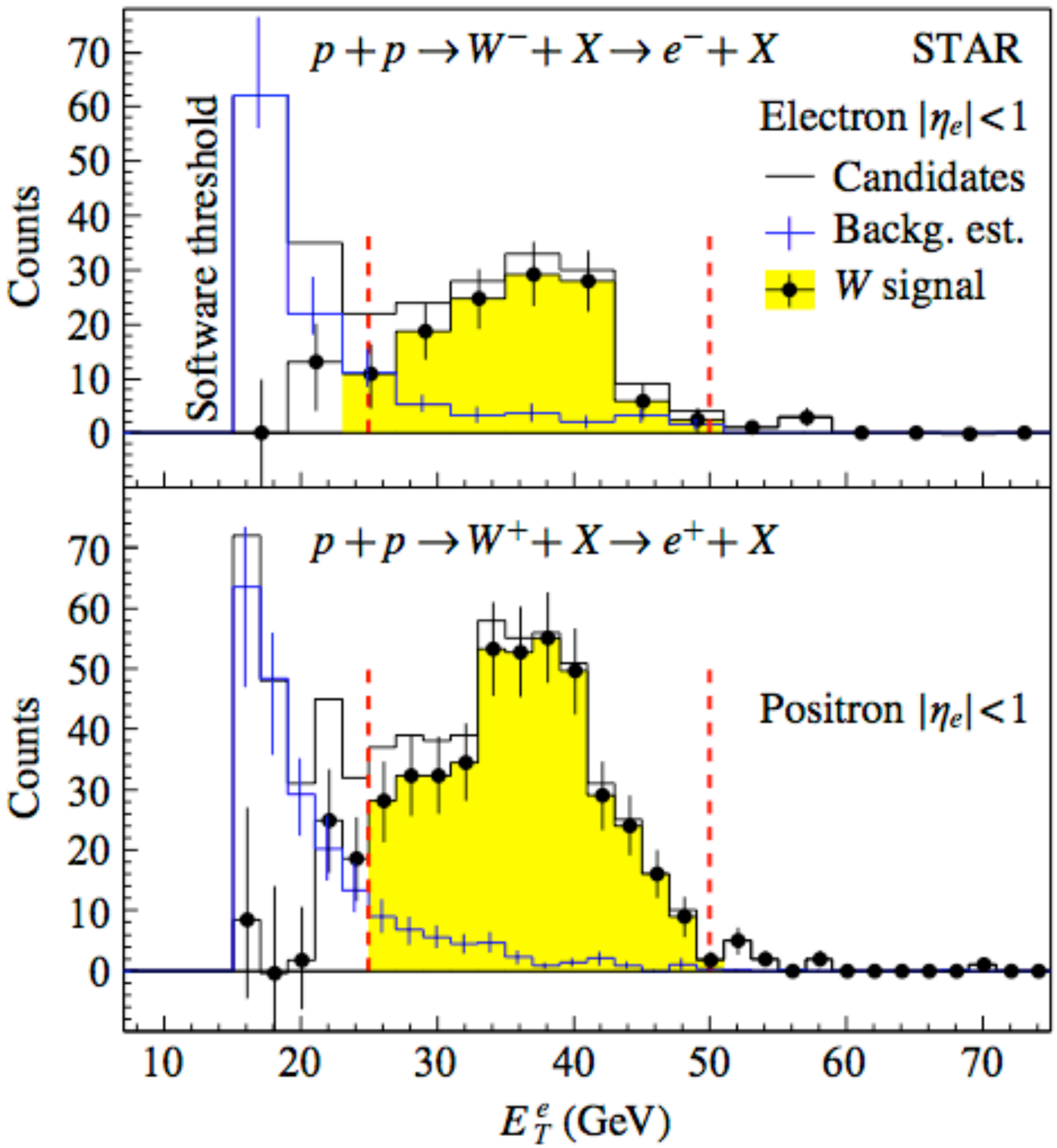
Pibero Djawotho, for the STAR collaboration, DIS2011

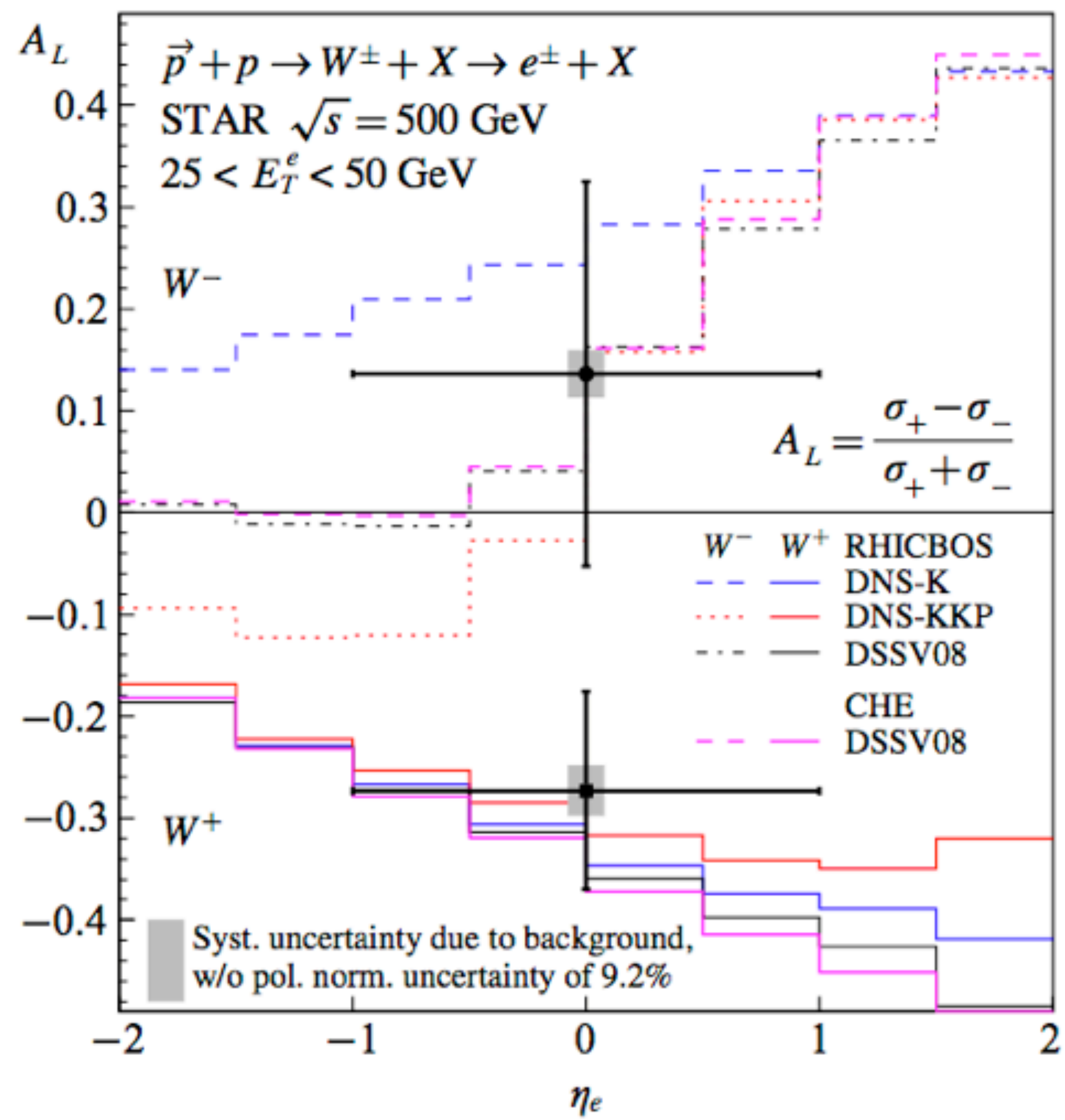


Collinear factorization forms a good description of the spin-averaged cross-section(s),
Precision insight in gluon polarization for ~0.03 < x < 0.3,
Key future steps resolve x (correlations) and extend its range (√s, pseudorapidity).

B. Abelev et al., Phys.Rev.Lett.97:252001,2006
B. Abelev et al., Phys.Rev.Lett.100:232002,2008

STAR - Selected Mid-rapidity Results





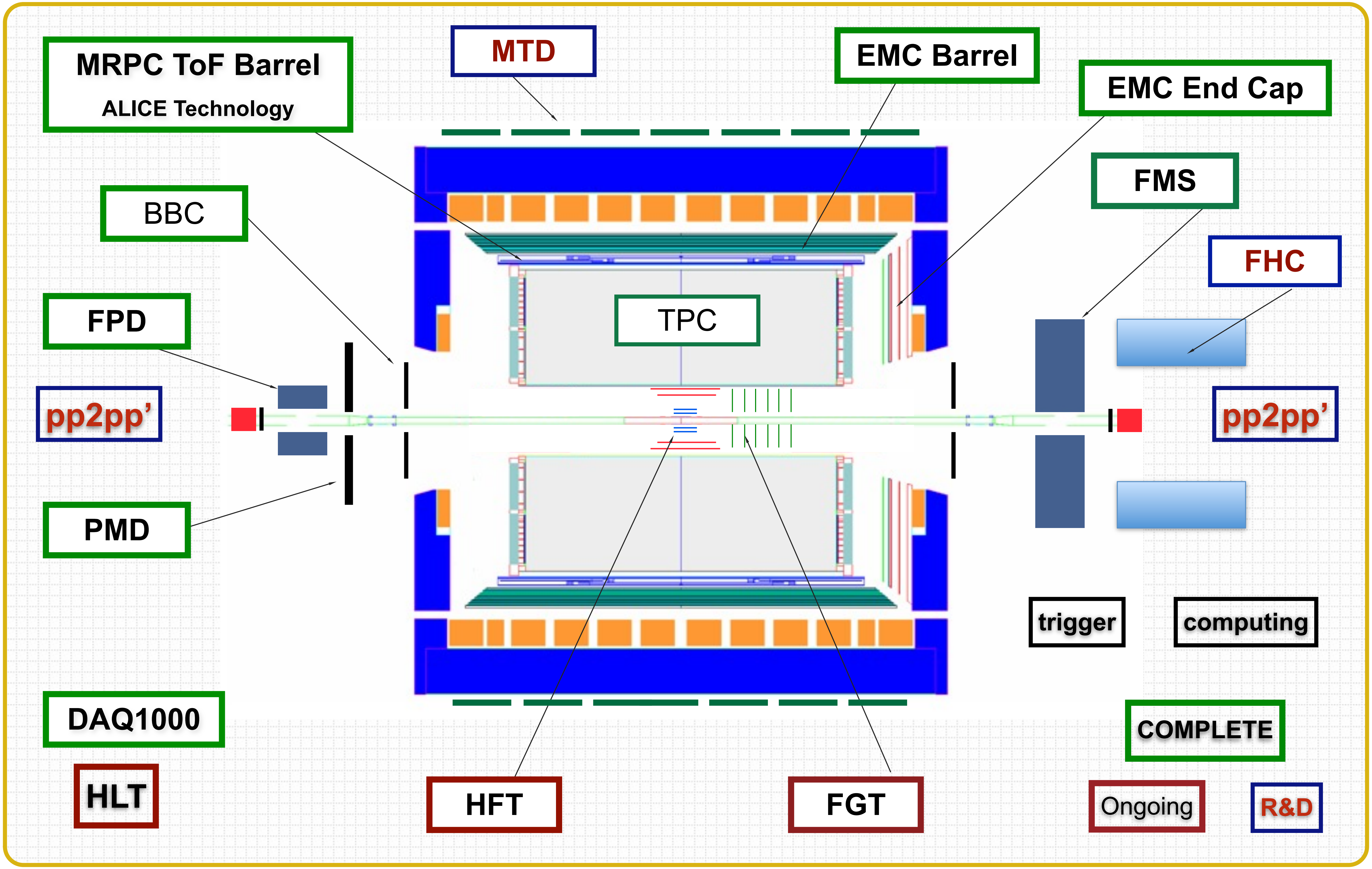
Experimental tour-de-force; RHIC $\sqrt{s}$ = 500 GeV, STAR e/h discrimination, STAR e^+, e^-

Yields agree with expectations, 139 W^- and 462 W^+ candidate events in 12 pb^{-1}

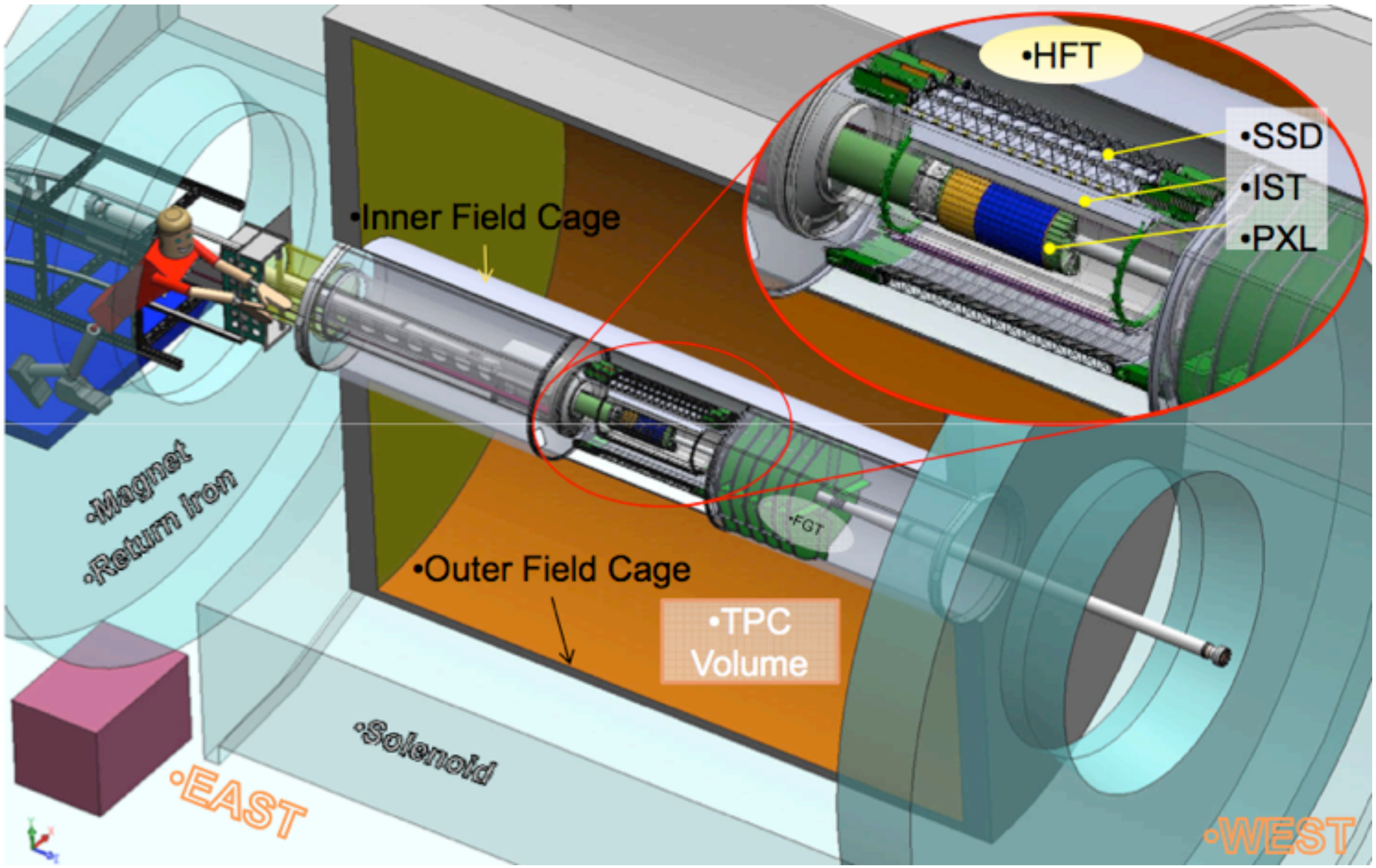
Next: precision, extend to forward region (FGT tracking upgrade).

M.M. Agarwal et al, Phys.Rev.Lett.106:062002,2011

STAR Experiment - Upgrades



STAR Experiment - Tracking Upgrades



FGT: charge discrimination for forward electrons/positrons from W decay,
installation planned before run-12, ~3 year physics operation.

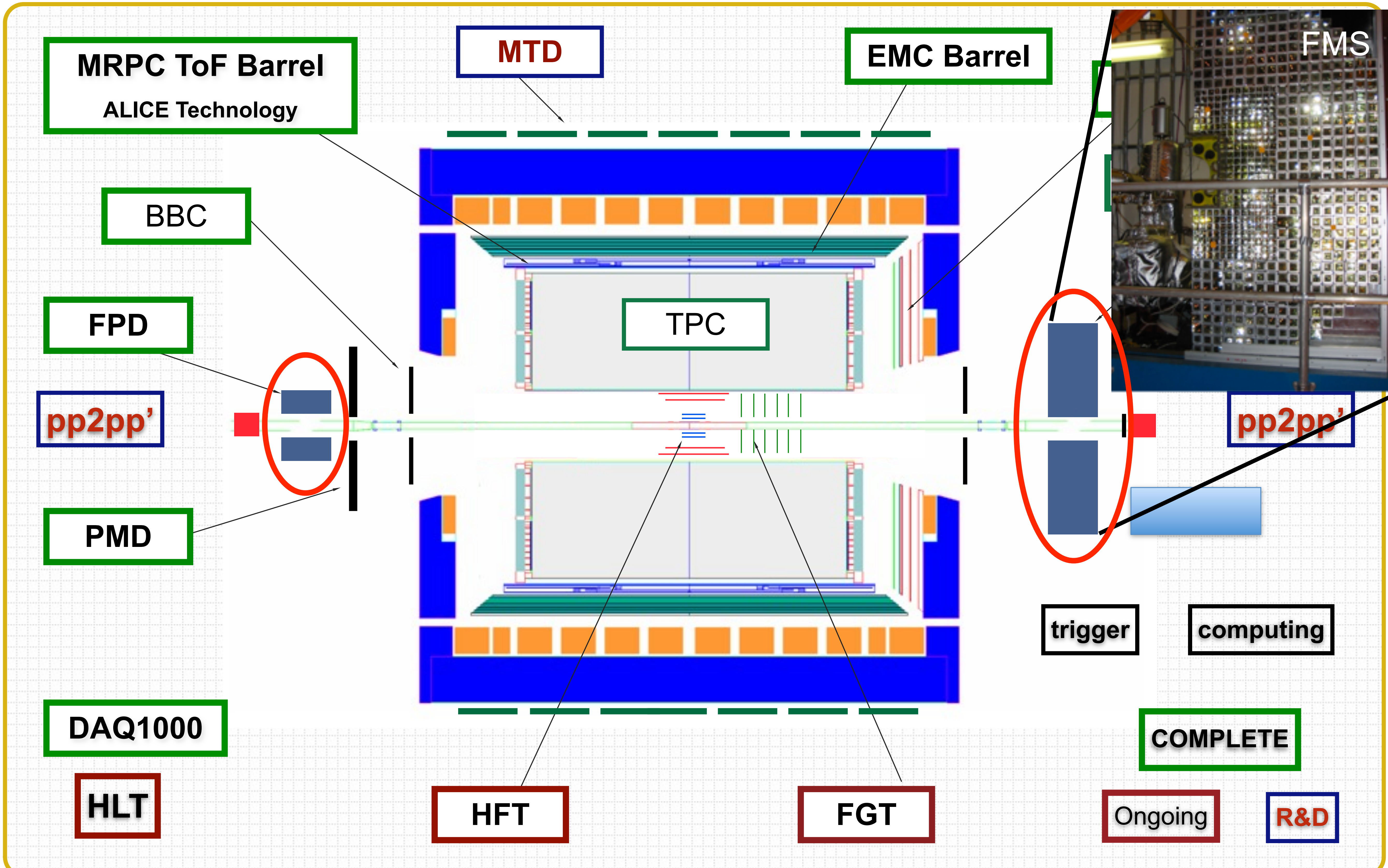
HFT: heavy quark measurements via precision topological identification of decays,
CD-1 approval as of August 31, 2010,
completion aimed for run-14, multi-year physics operation in Au+Au, p+p.

STAR - Summary of Measurement Plan

	Near term (Runs 11–13)	Mid-decade (Runs 14–16)	Long term (Runs 17–)
Colliding systems	p+p, A+A	p+p, A+A	p+p, p+A, A+A, e+p, e+A
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	$\Upsilon, J/\psi \to ee$, m_{ee}, v_2	$\Upsilon, J/\psi \to \mu\mu$, Charm v_2, R_{CP}, Charm corr, Λ_c/D ratio, μ-atoms	p+A comparison
(2) Mechanism of energy loss	Jets, γ-jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, c/b in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	$e-\mu$ corr, $\mu-\mu$ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	W A_L, jet and di-jet A_{LL}, intra-jet corr, $(\Lambda+\bar{\Lambda})$ D_{LL}/D_{TT}		$\bar{\Lambda}$ D_{LL}/D_{TT}, polarized DIS, polarized SIDIS
(7) QCD beyond collinear factorization	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ, F-F corr, Λ, DIS, SIDIS

STAR Decadal Plan, http://www.bnl.gov/npp

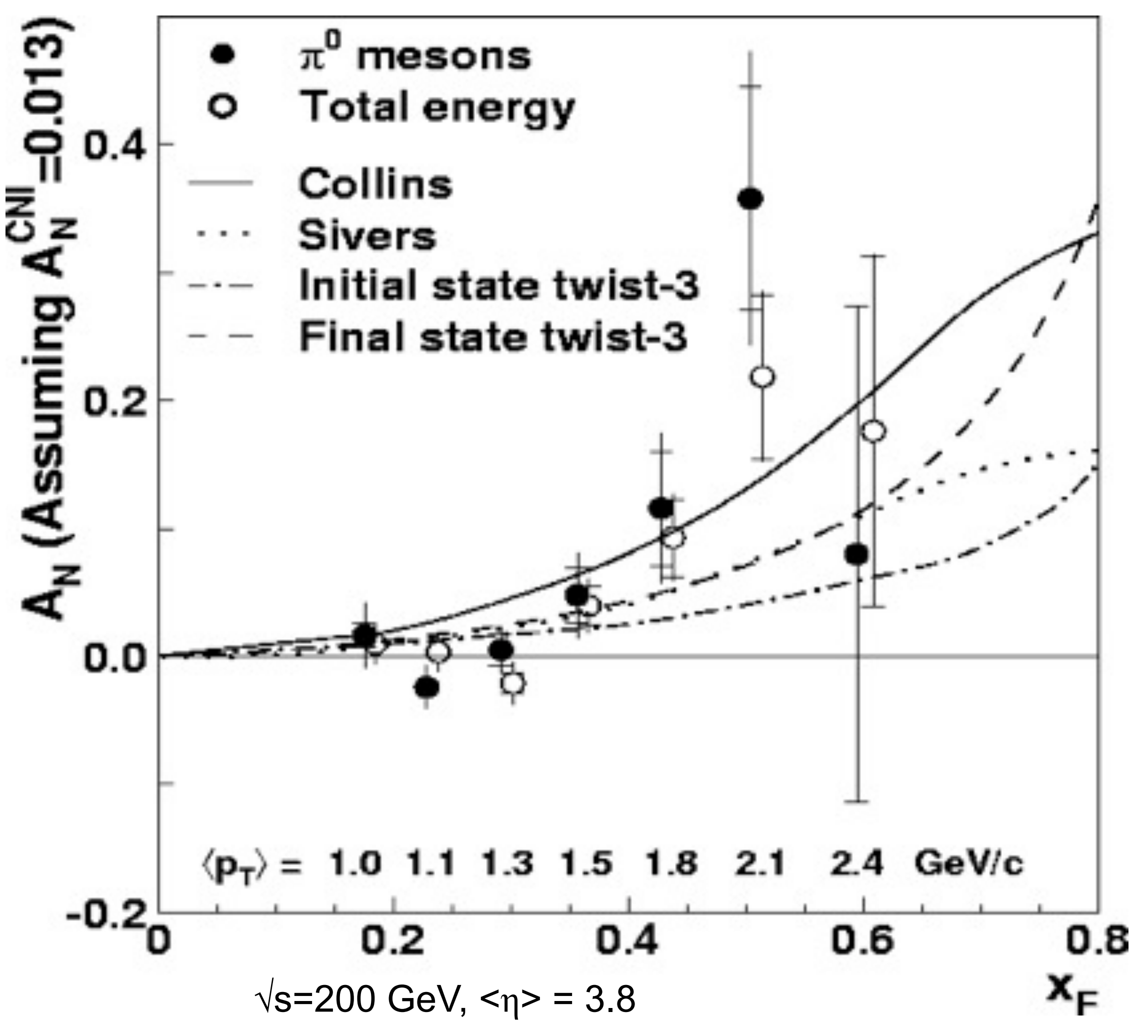
STAR Experiment - Forward Calorimeters



STAR - Transverse Spin Phenomena

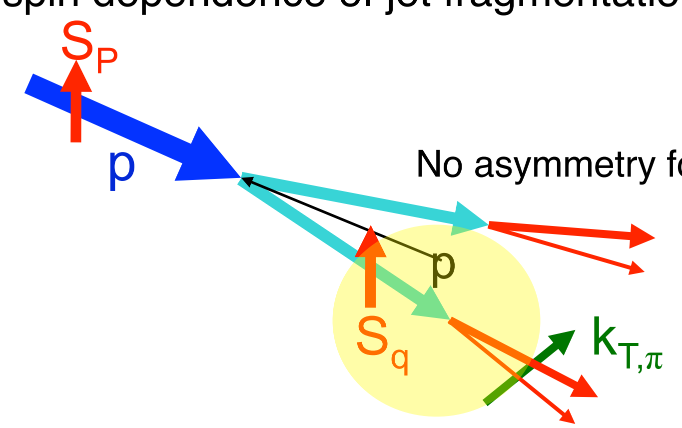
Large A_N observed at $\sqrt{s}$ = 200 GeV, in the pQCD regime,
- what causes this?
- a path beyond collinear pQCD?

PRL 92, 171801 (2004)

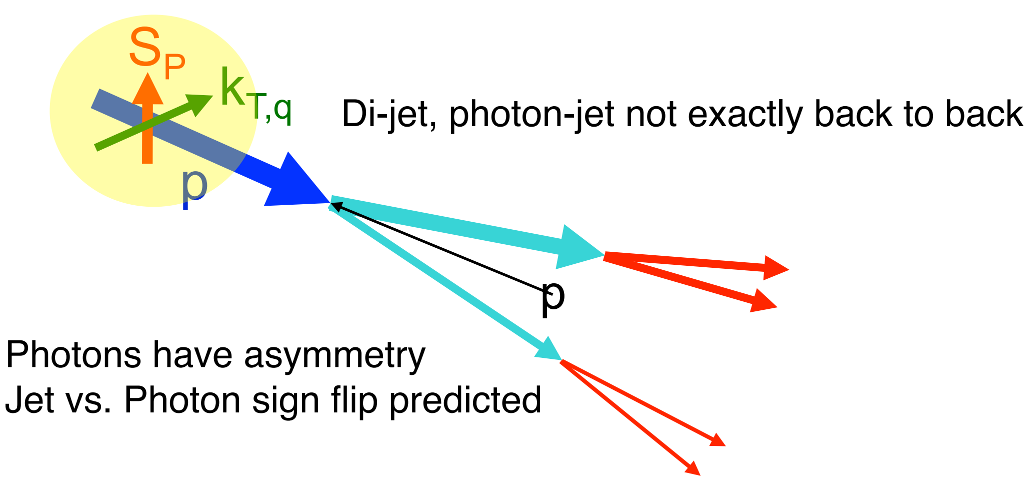


$\sqrt{s}$=200 GeV, <η> = 3.8

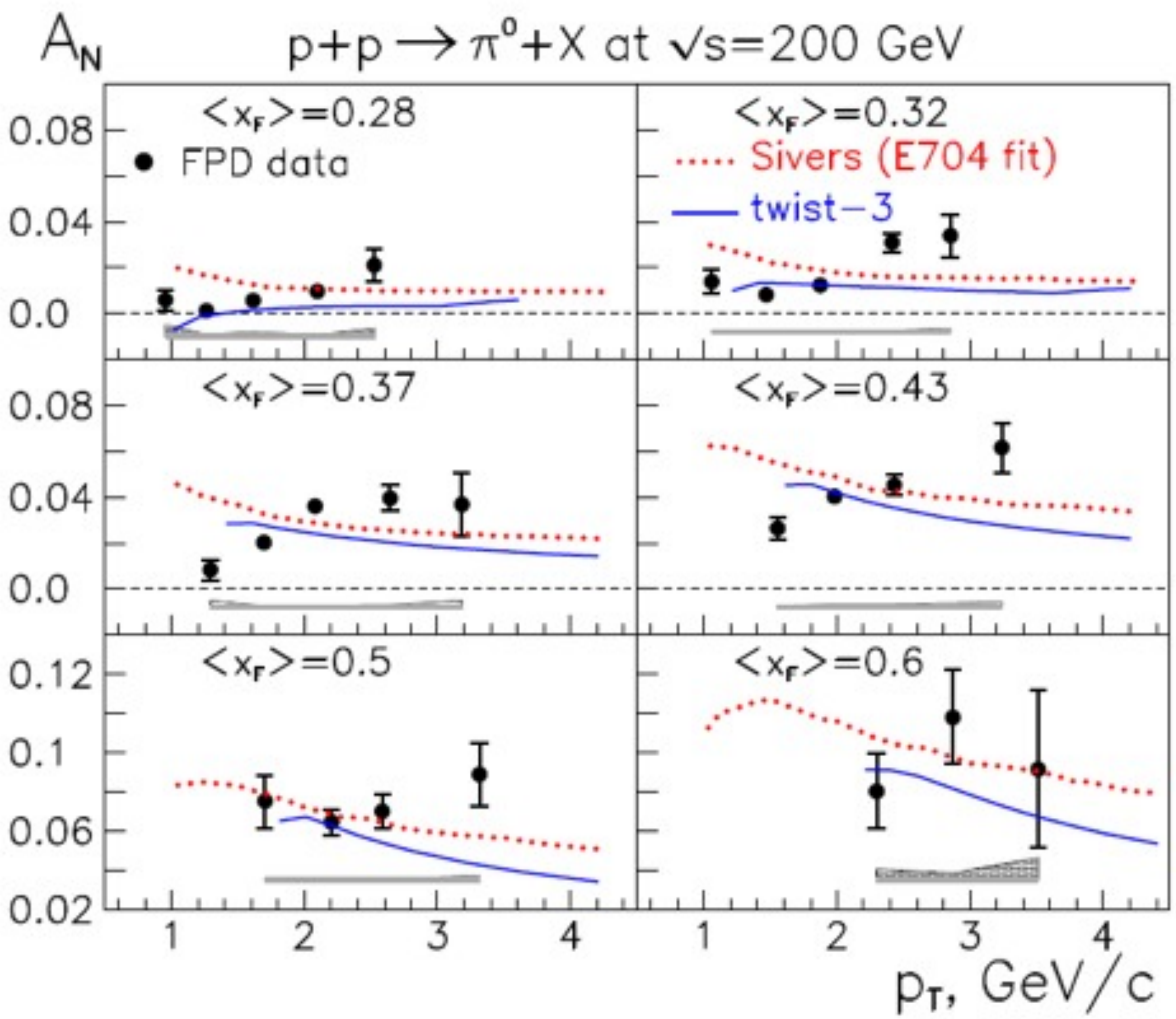
• **Collins effect**: asymmetry comes from the transversity and the spin dependence of jet fragmentation.



• **Sivers effect**: asymmetry comes from spin-correlated k_T in the initial parton distribution



STAR - Transverse Spin Phenomena



Phys.Rev.Lett.101:222001,2008

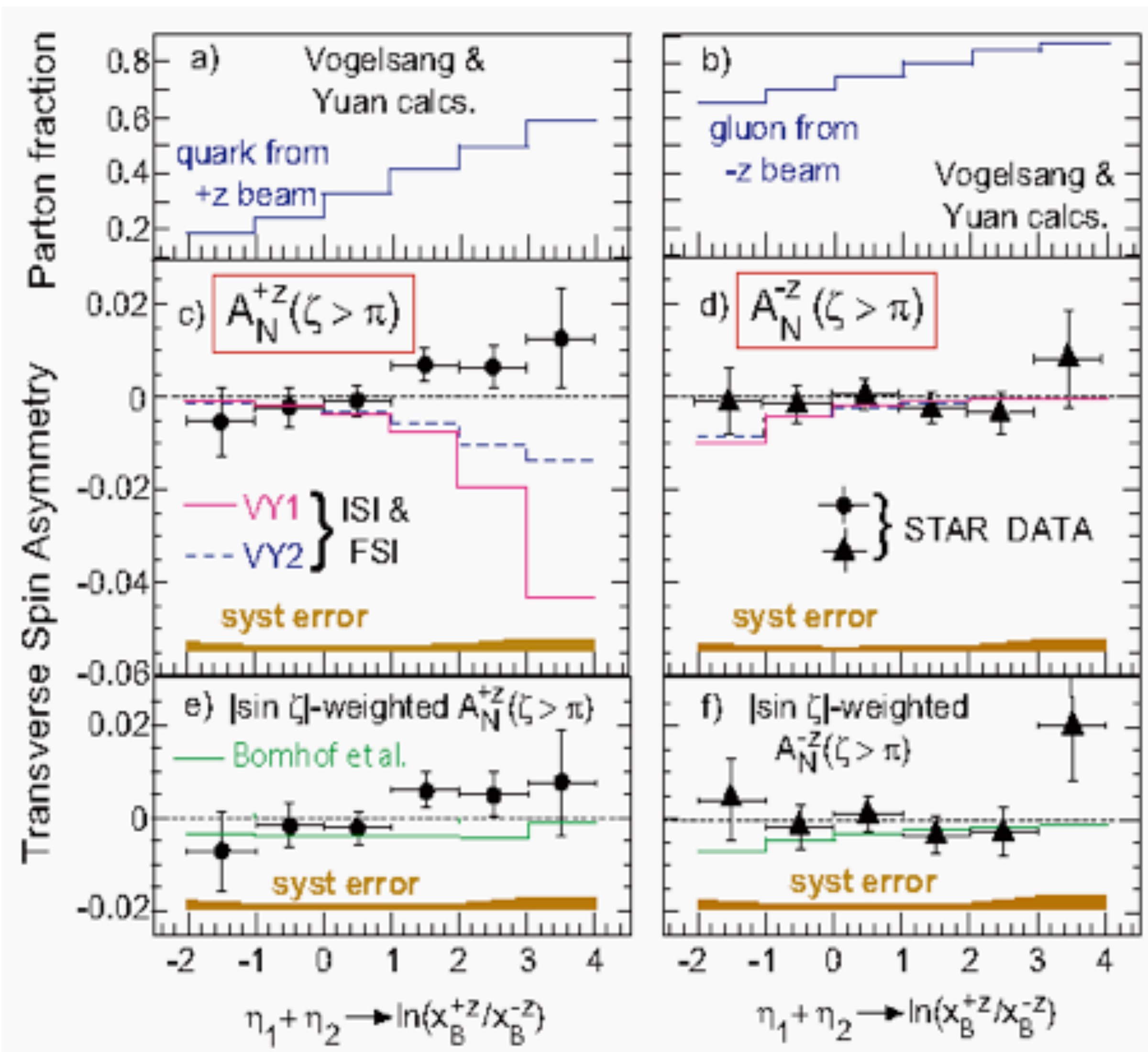
U. D'Alesio, F. Murgia, Phys. Rev. D **70**, 074009 (2004).

J. Qiu, G. Sterman, Phys. Rev. D **59**, 014004 (1998).

Model calculations can qualitatively explain x_F dependence of large A_N,

Models fall short for the p_T dependence,

STAR - Transverse Spin Phenomena



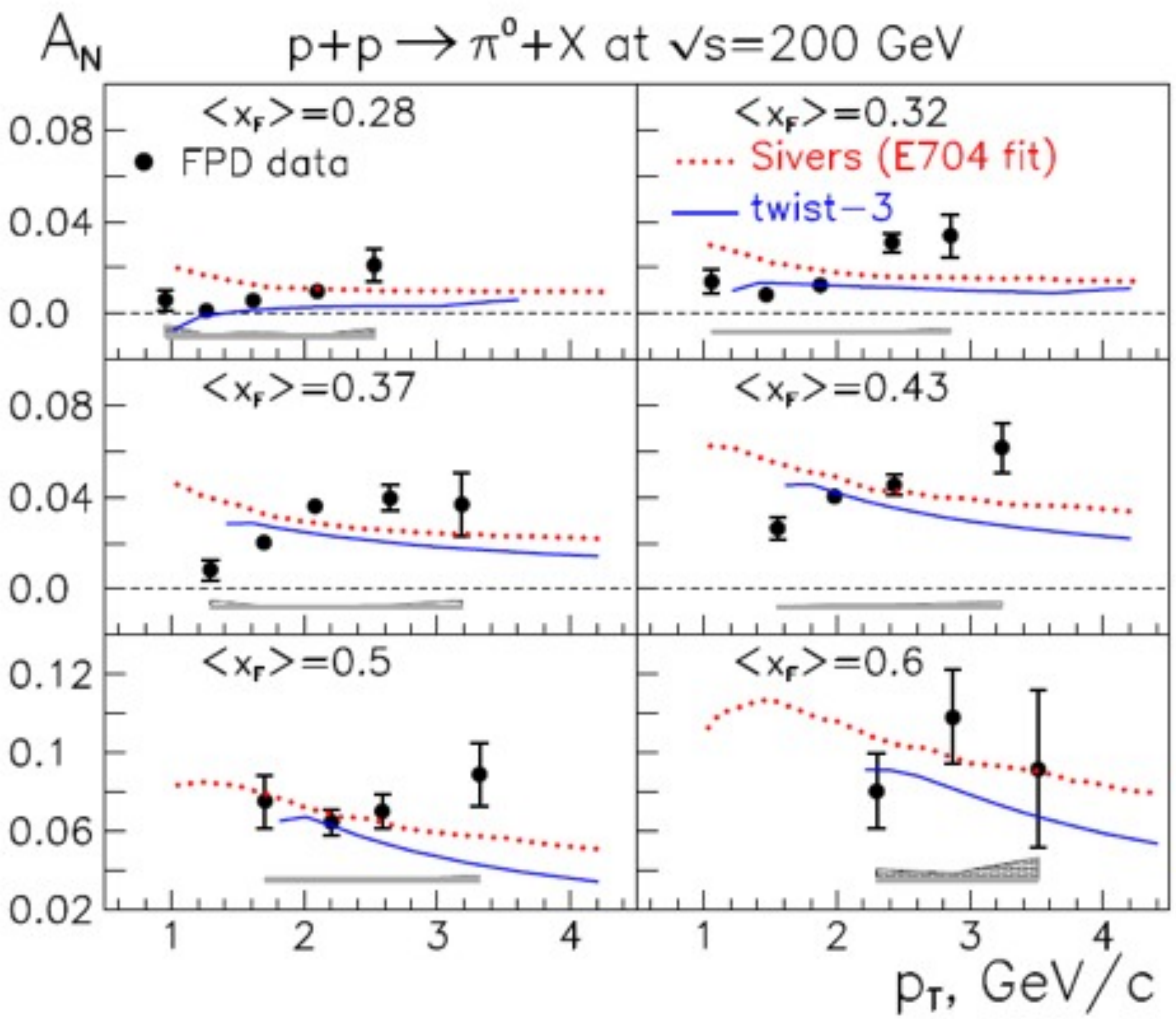
B. Abelev et al, Phys.Rev.Lett.99:142003,2007.

Model calculations can qualitatively explain x_F dependence of large A_N,

Models fall short for the p_T dependence,

We have mostly learned what can be learned at mid-rapidity,

STAR - Transverse Spin Phenomena



Phys.Rev.Lett.101:222001,2008

U. D'Alesio, F. Murgia, Phys. Rev. D **70**, 074009 (2004).

J. Qiu, G. Sterman, Phys. Rev. D **59**, 014004 (1998).

Model calculations can qualitatively explain x_F dependence of large A_N,

Models fall short for the p_T dependence,

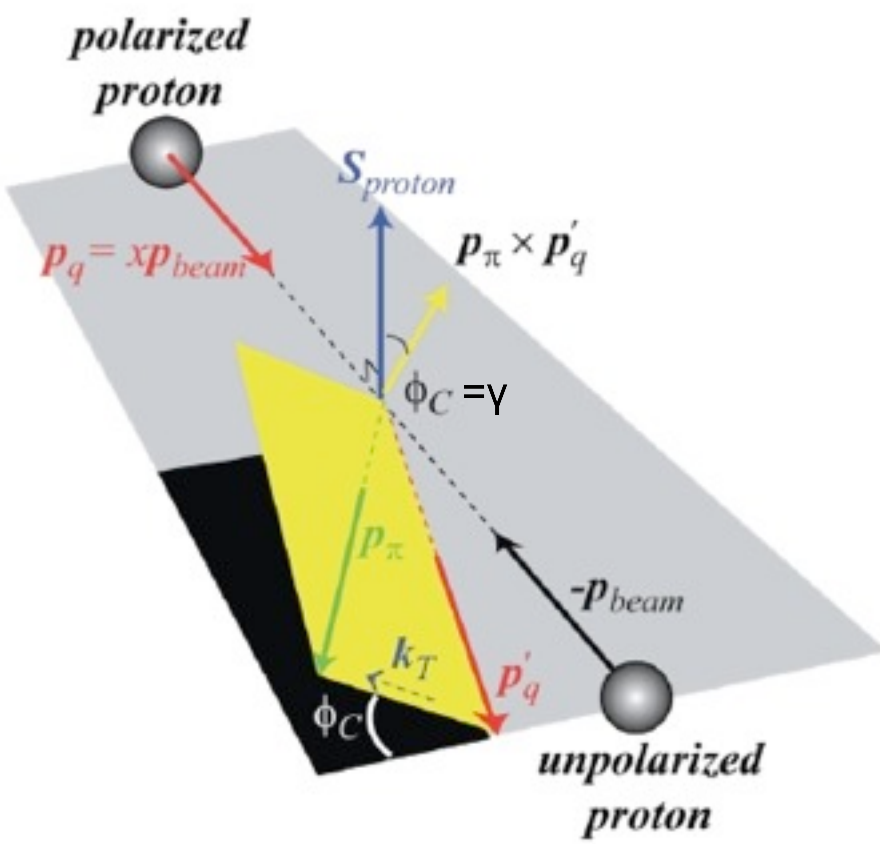
STAR aims to:

- characterize scaling properties *Run11*,
- step beyond inclusive pions to
  - etas *L.Eun, PhD thesis 2011,*
  - jet(-like) events *N.Poljak, SPIN'10*,
  - photons ($\sqrt{s}$ = 200 GeV, *Run13?*),
  - Lambda hyperons,
  - correlations, and
  - ultimately DY via e^+e^- pairs,

FMS is key to each of these.

STAR - Transverse Spin Phenomena

Run-6 FPD++ cluster-trigger data



Model calculations can qualitatively explain x_F dependence of large A_N,

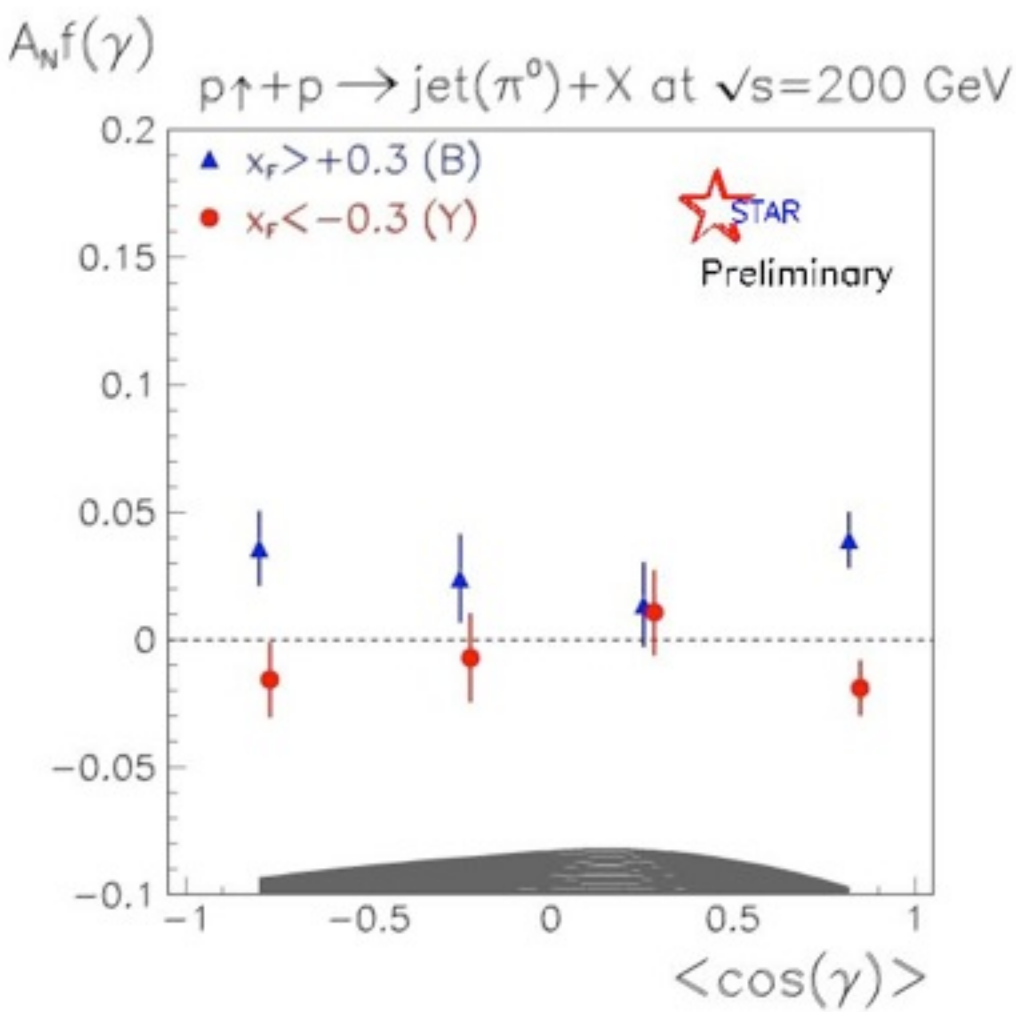
Models fall short for the p_T dependence,

STAR aims to:
- characterize scaling properties *Run11*,
- step beyond inclusive pions to
  - etas *L.Eun, PhD thesis 2011*,
  - jet-like events *N.Poljak, SPIN'10*,
  - photons ($\sqrt{s}$ = 200 GeV, *Run13?*),
  - Lambda hyperons,
  - correlations, and
  - ultimately DY via e^+e^- pairs,

FMS is key to each of these.

STAR - Transverse Spin Phenomena

Run-6 FPD++ cluster-trigger data



The average asymmetry for positive $x_F > 0.3$,
$A_N = 0.031 \pm 0.014$, tends to be positive for these jet-*like* events.
No evidence for a Collins dependence observed.

Non-zero jet A_N necessary for DY A_N

Nikola Poljak, for the STAR Collaboration, SPIN 2010

Model calculations can qualitatively explain x_F dependence of large A_N,

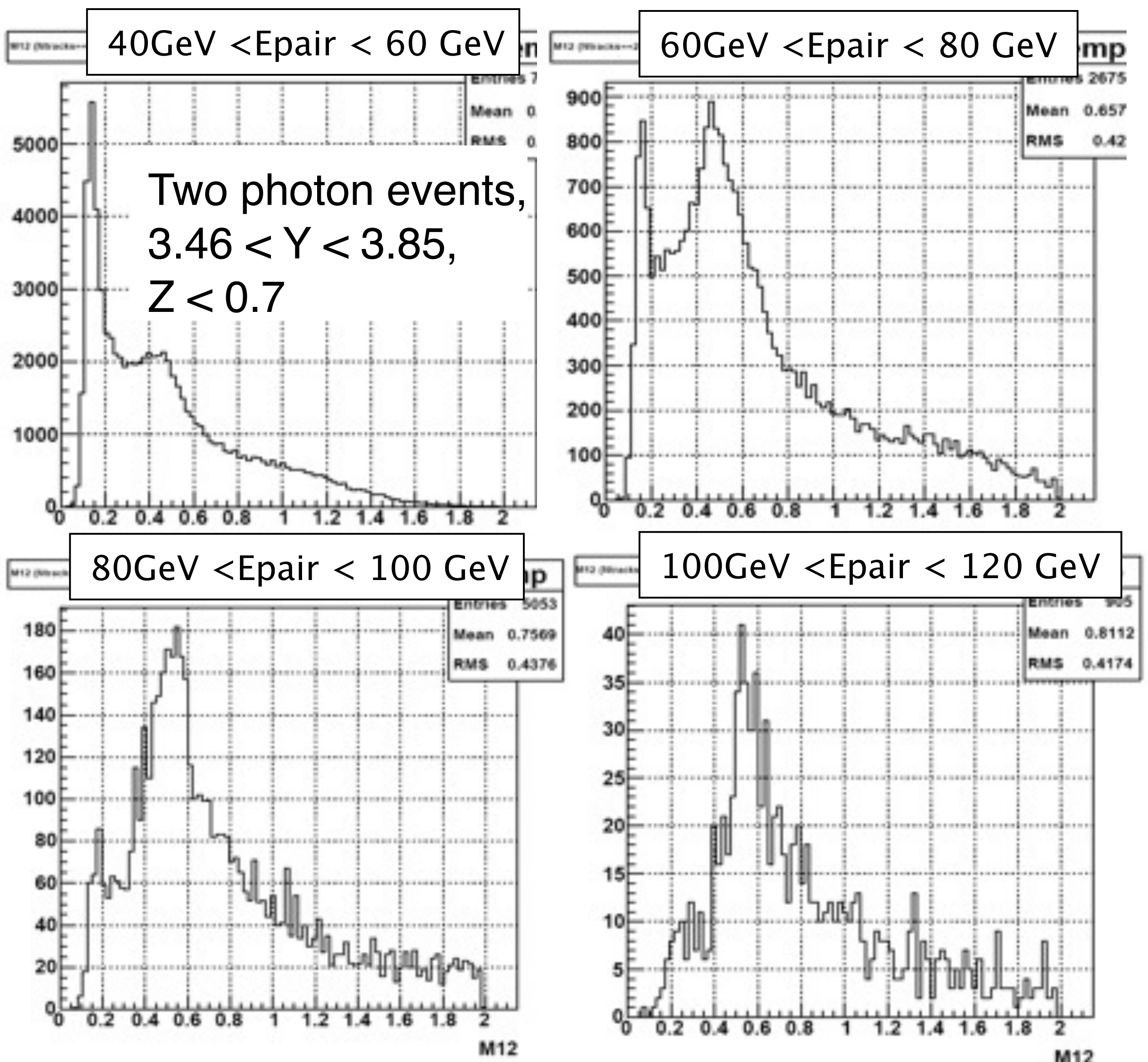
Models fall short for the p_T dependence,

STAR aims to:
- characterize scaling properties *Run11*,
- step beyond inclusive pions to
  - etas *L.Eun, PhD thesis 2011*,
  - jet-like events *N.Poljak, SPIN'10*,
  - photons ($\sqrt{s}$ = 200 GeV, *Run13?*),
  - Lambda hyperons,
  - correlations, and
  - ultimately DY via e^+e^- pairs,

FMS is key to each of these.

STAR - Transverse Spin Phenomena

Run11 transverse data $\sqrt{s}$ = 500 GeV



Photon Pair Invariant Mass in GeV

Very successful FMS commissioning and operation at $\sqrt{s}$ = 500 GeV

Model calculations can qualitatively explain x_F dependence of large A_N,

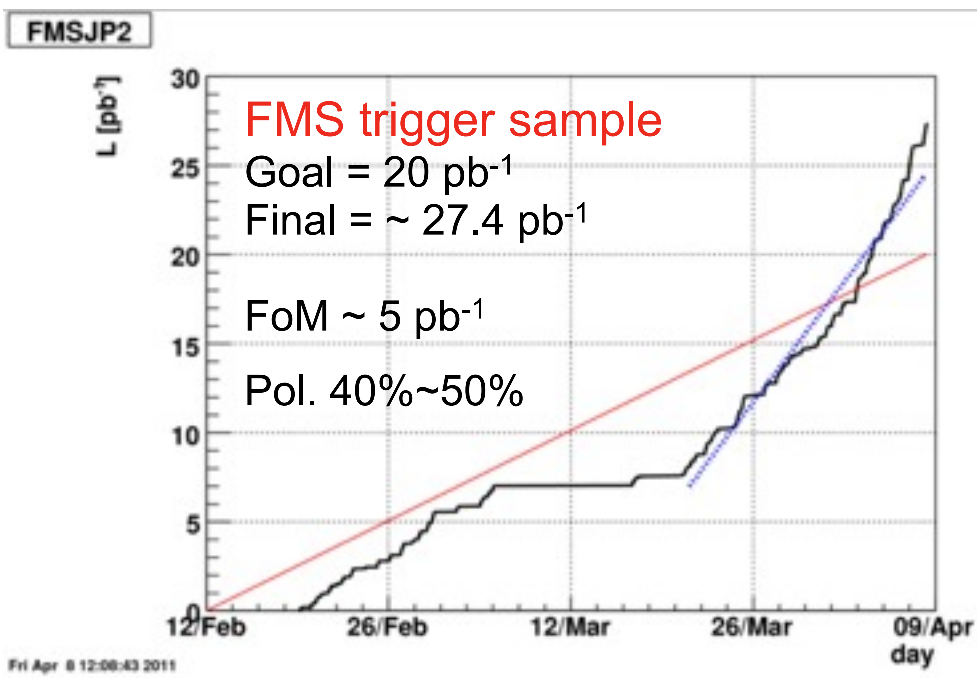
Models fall short for the p_T dependence,

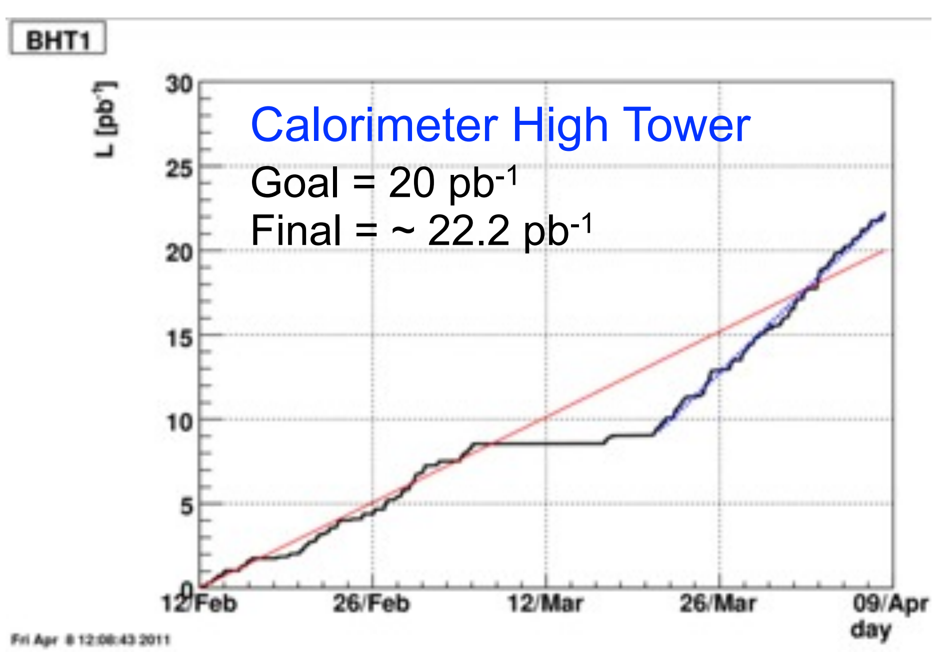
STAR aims to:
- characterize scaling properties *Run11*,
- step beyond inclusive pions to
  - etas *L.Eun, PhD thesis 2011,*
  - jet(-like) events *N.Poljak, SPIN'10*,
  - photons ($\sqrt{s}$ = 200 GeV, *Run13?*),
  - Lambda hyperons,
  - correlations, and
  - ultimately DY via e^+e^- pairs,

FMS is key to each of these.

STAR - Transverse Spin Phenomena

Run11 transverse data $\sqrt{s}$ = 500 GeV





Model calculations can qualitatively explain x_F dependence of large A_N,

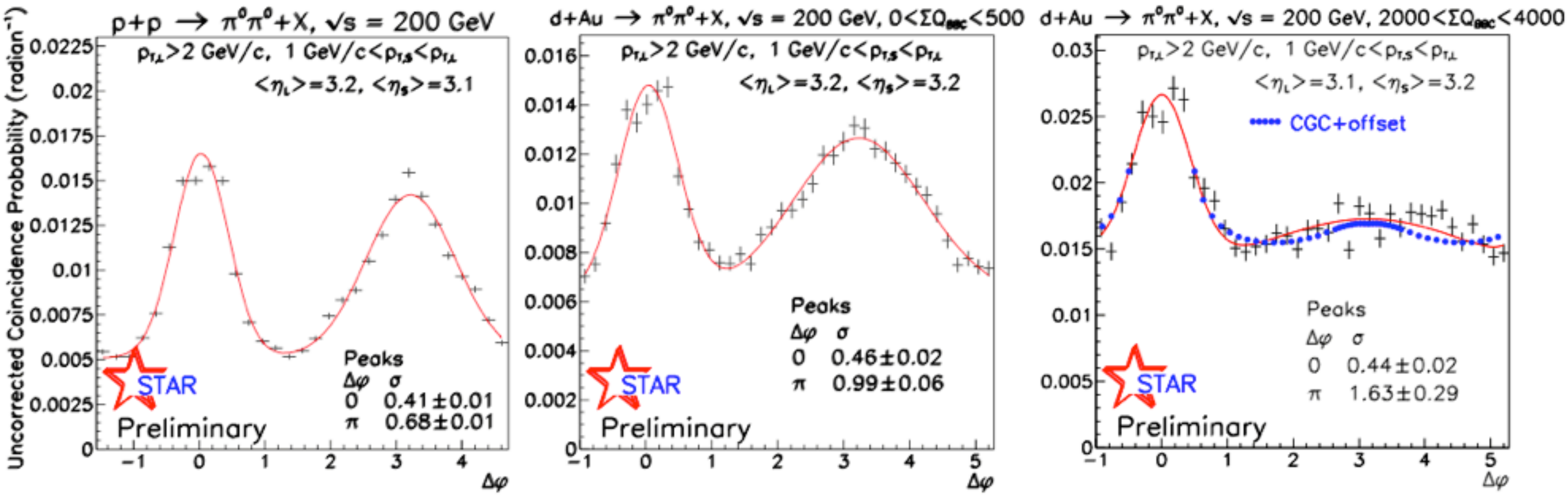
Models fall short for the p_T dependence,

STAR aims to:
- characterize scaling properties *Run11*,
- step beyond inclusive pions to
  - etas *L.Eun, PhD thesis 2011,*
  - jet(-like) events *N.Poljak, SPIN'10*,
  - photons ($\sqrt{s}$ = 200 GeV, *Run13?*),
  - Lambda hyperons,
  - correlations, and
  - ultimately DY via e^+e^- pairs,

FMS is key to each of these.

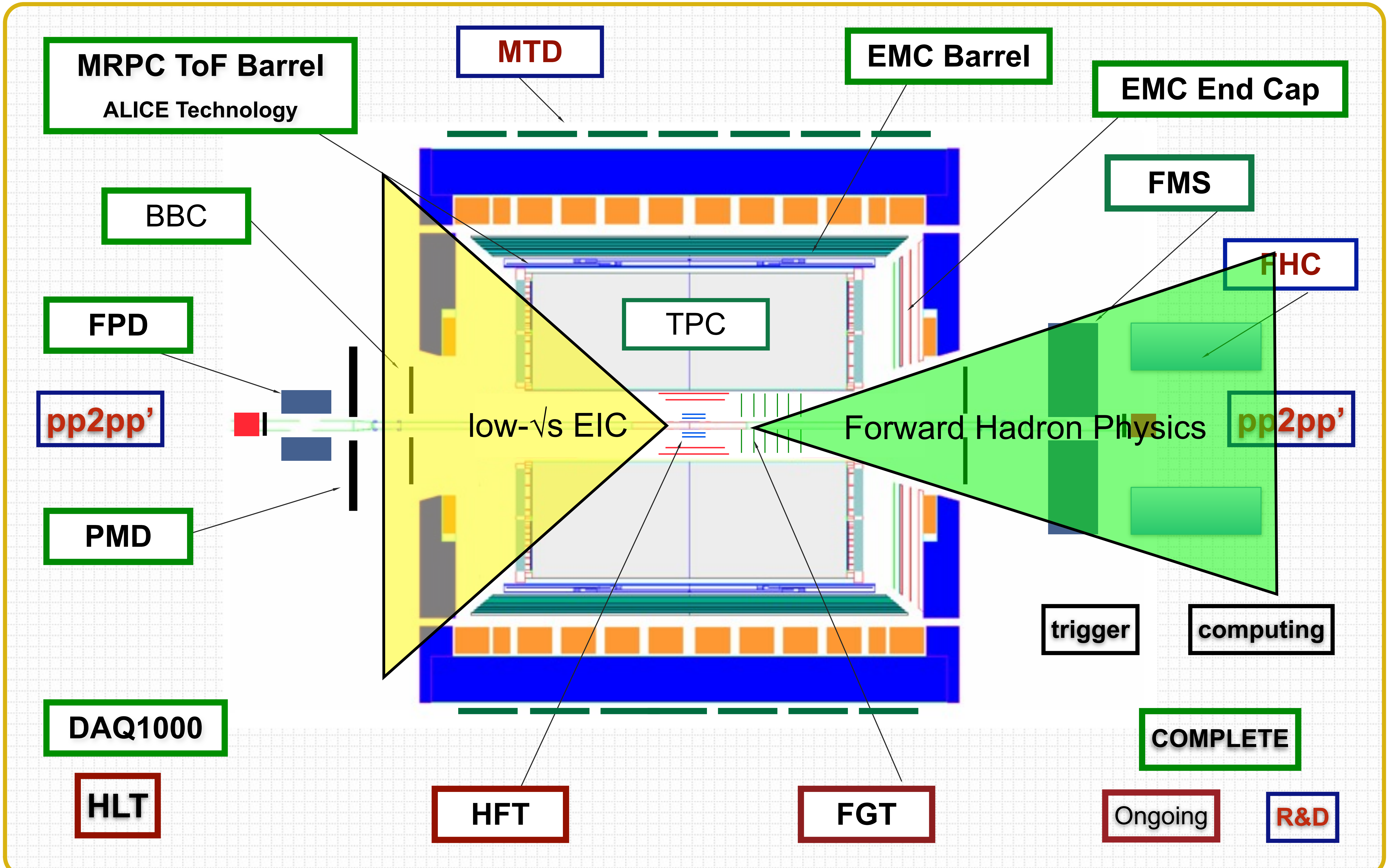
Feasibility of A_N for W, Z being studied.

STAR - Selected Forward Results



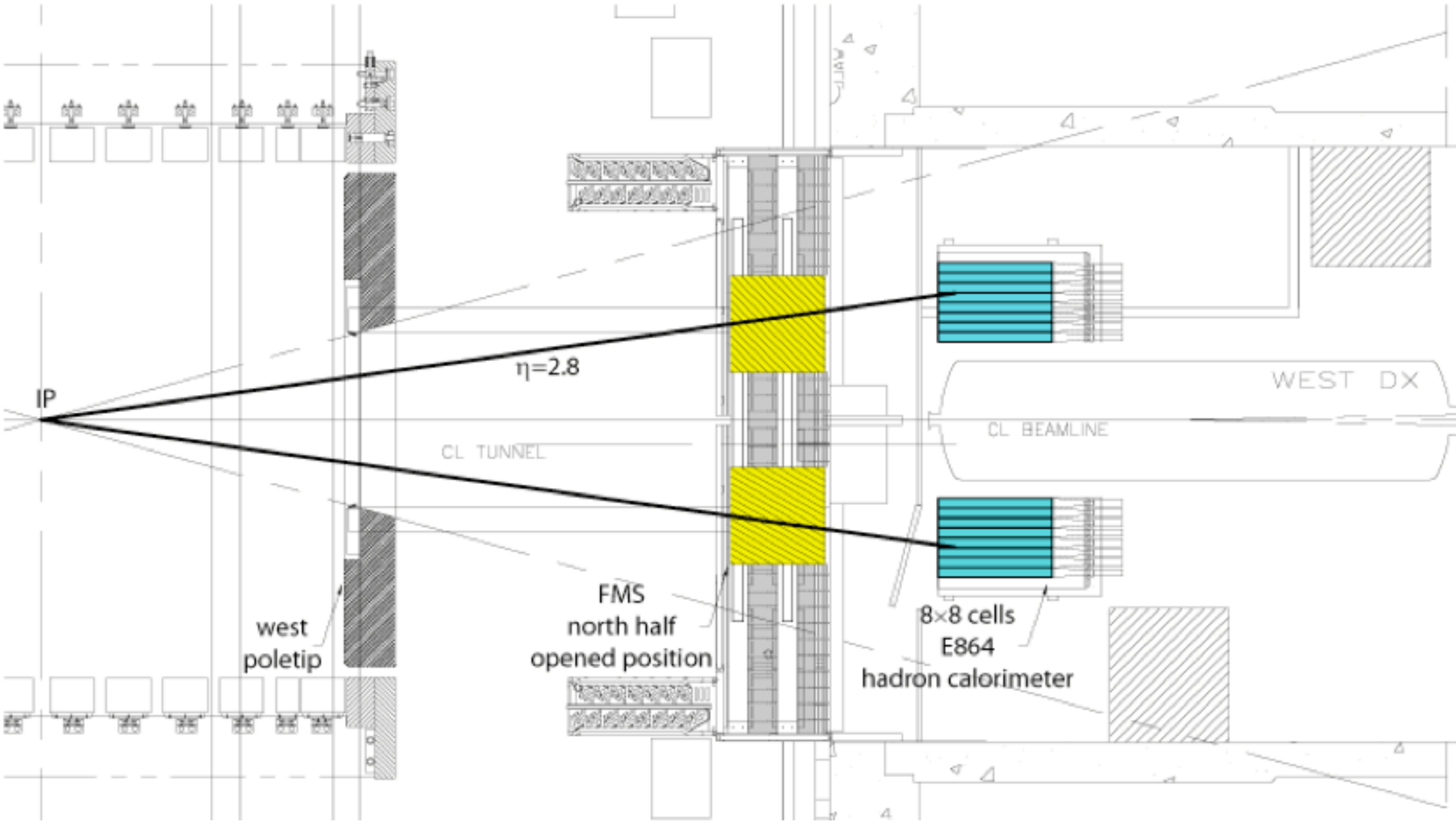
Ermes Braidot, *for the collaboration*, QM 2009

STAR Experiment - Upgrade Concepts



(e)RHIC beam directions: $\xrightarrow[A]{p,\ d,\ A}$ $\xleftarrow[electron]{A}$

STAR Experiment - Forward Upgrades



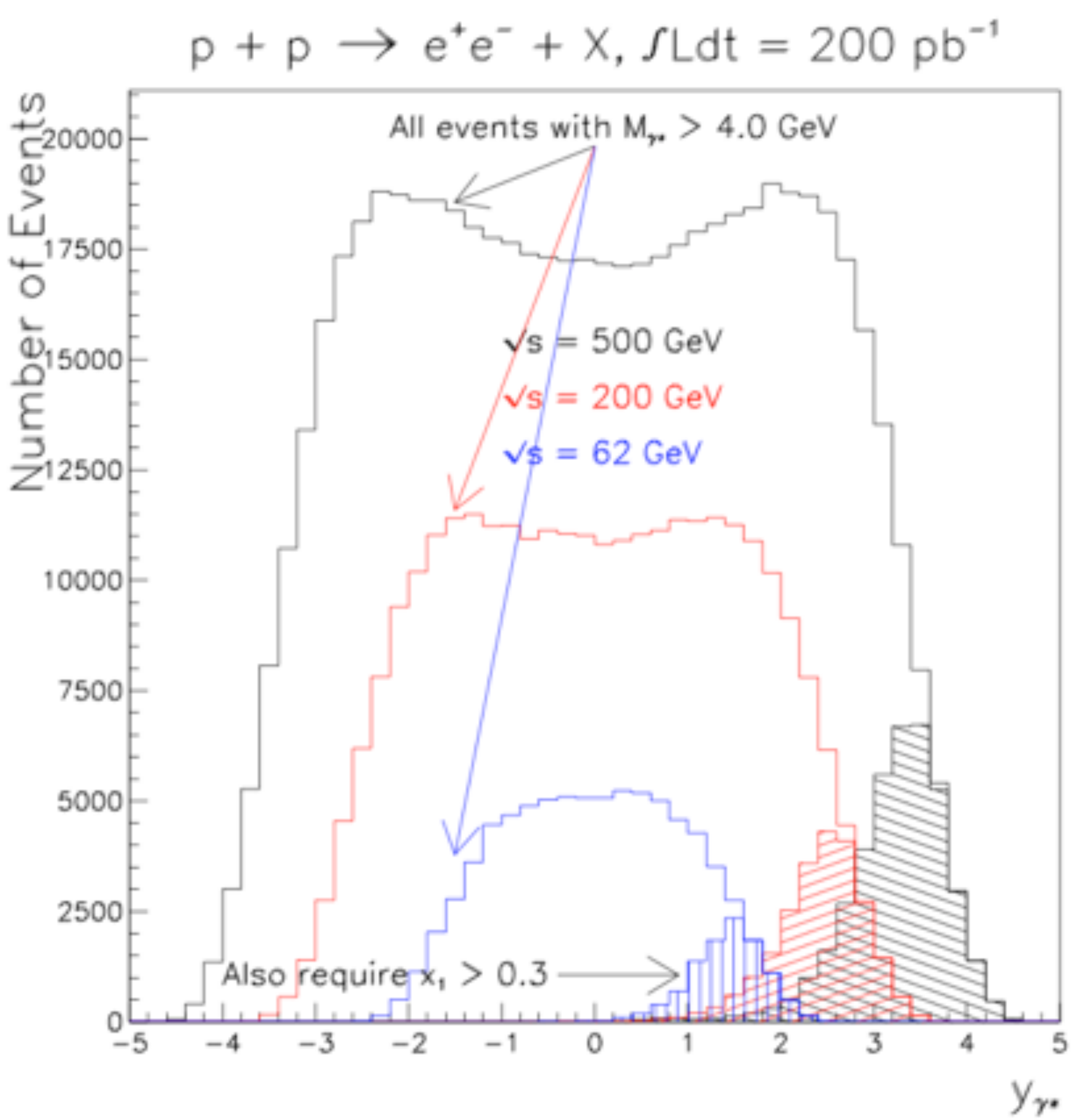
FHC: proposed hadronic calorimetry behind the FMS, currently at AnDY,
essential towards understanding of forward single-spin asymmetries,
enable forward (anti-)Lambda studies, ...

Part of a broader forward upgrade concept that is currently being studied/considered within STAR,
e.g. extended tracking in the form of additional FGT-like disks,
preshower or TRD, converter, and shower-maximum detector for the FMS,
possibly a RICH to separate protons and advanced trigger.

Drell-Yan

DY : ~7 x 10^{-5} mb at √s = 500GeV → Hadronic : ~30mb

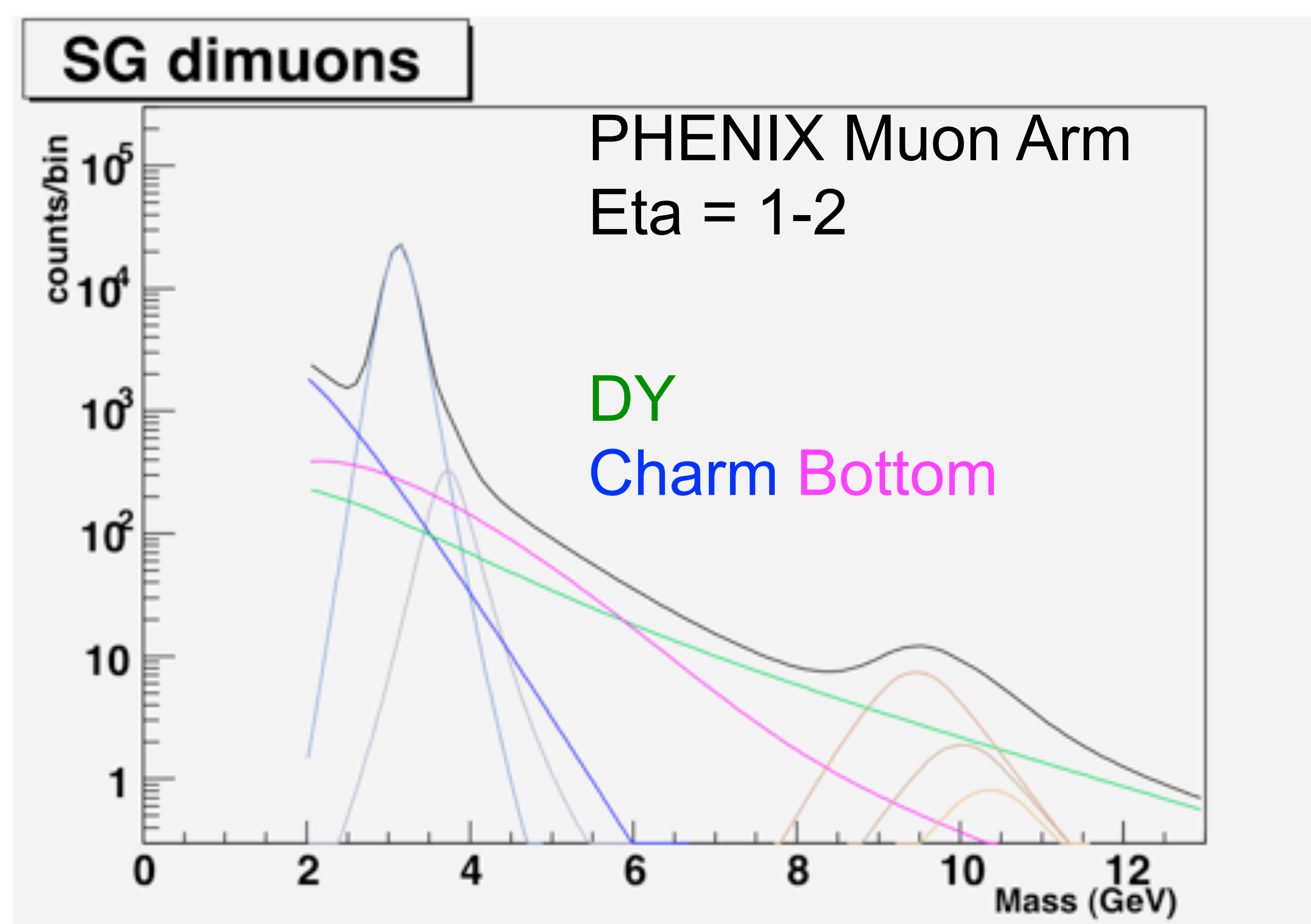
10^6



http://spin.riken.bnl.gov/rsc/write-up/dy_final.pdf

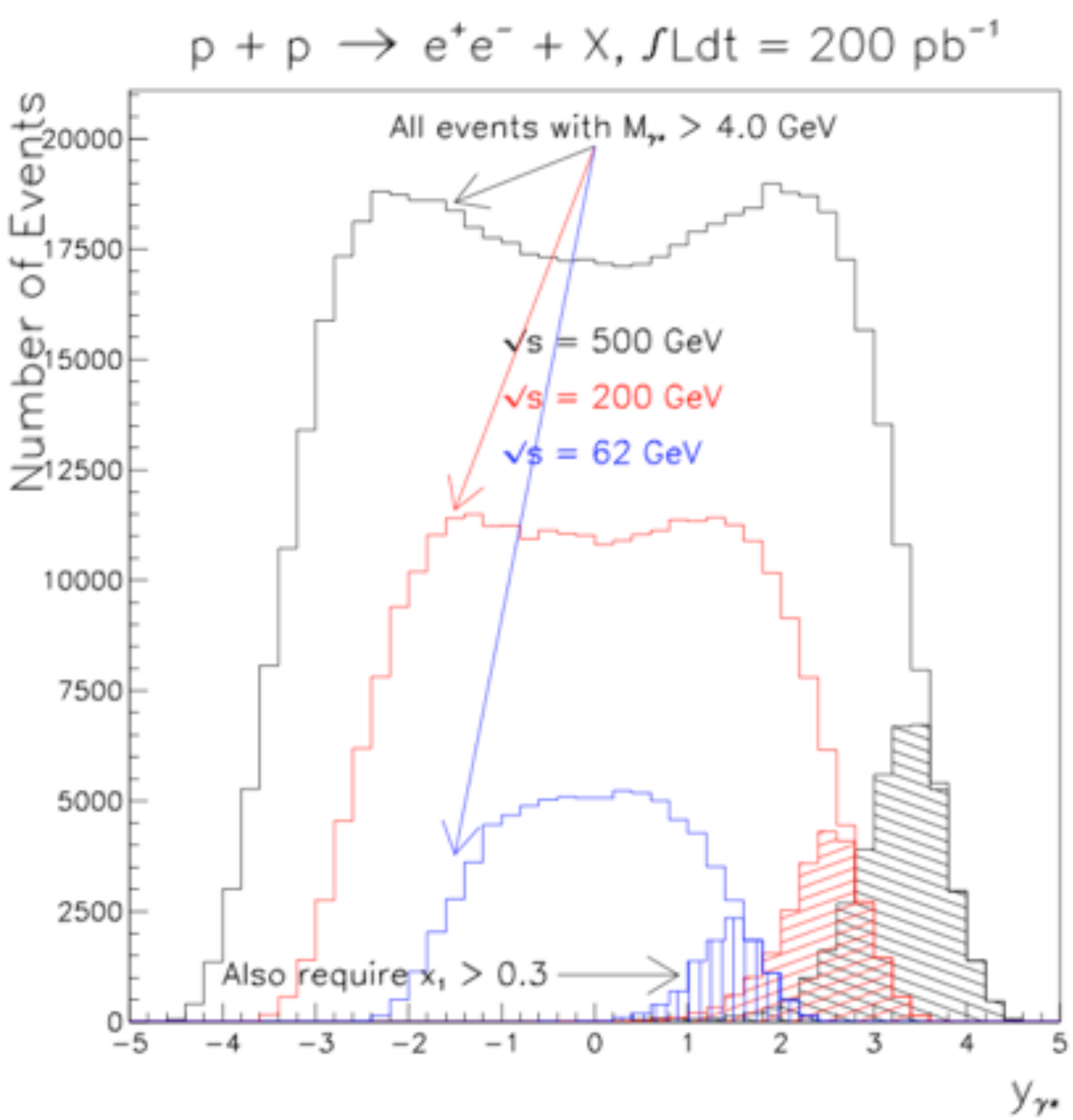
Hadron and photon backgrounds
Charm and bottom backgrounds

Background simulations ~10^{11} events.



Drell-Yan

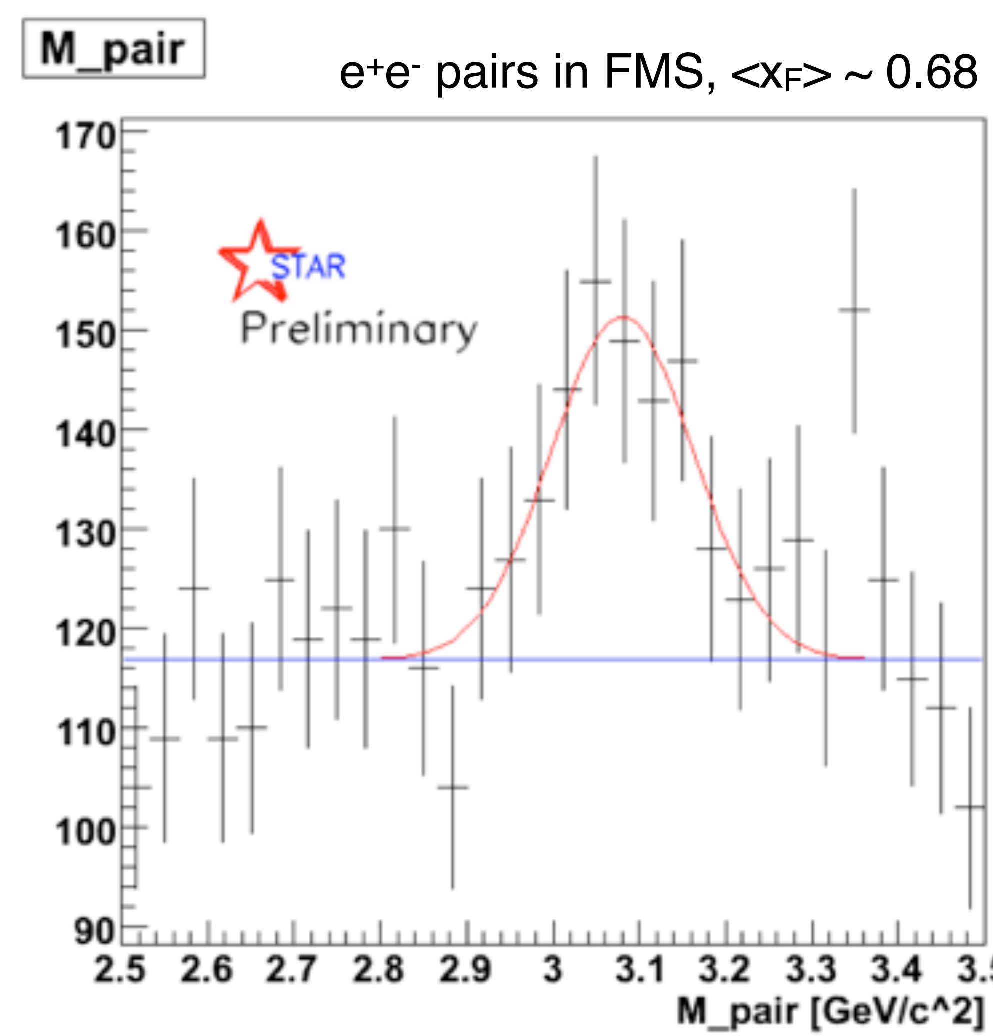
DY : ~7×10^{-5} mb at $\sqrt{s}$ = 500GeV $\xrightarrow{10^6}$ Hadronic : ~30mb



http://spin.riken.bnl.gov/rsc/write-up/dy_final.pdf

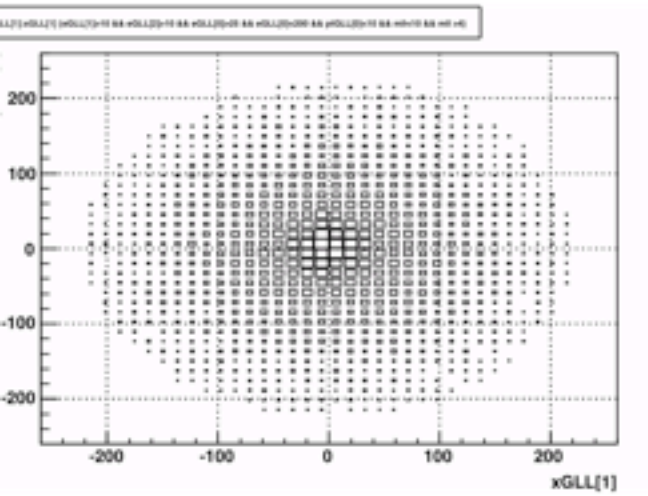
Hadron and photon backgrounds
Charm and bottom backgrounds

Background simulations ~10^{11} events.



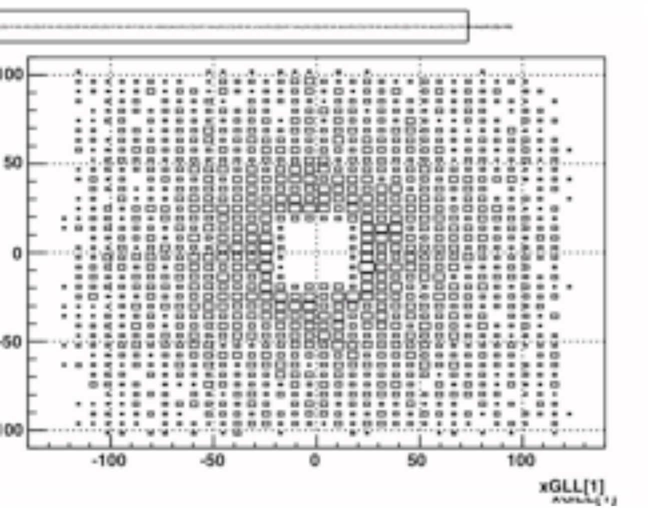
Chris Perkins, *for the collaboration*, QM 2009

Drell-Yan Simulated Signal



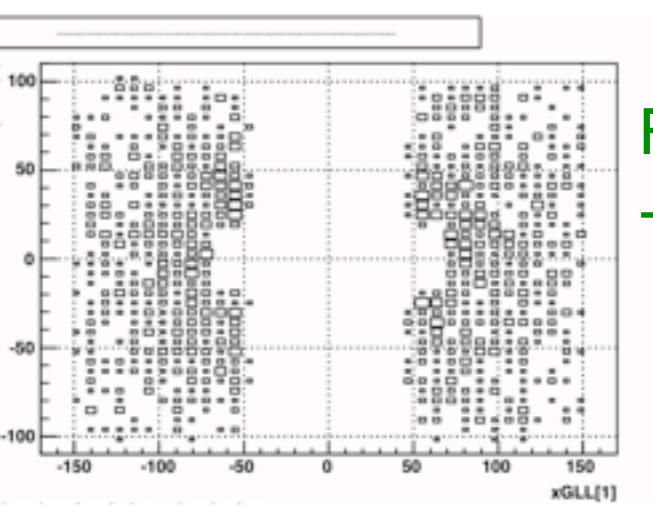
Everything $\eta>2$

14799 events



FMS closed
(FHC cannot be closed due to DX magnet)

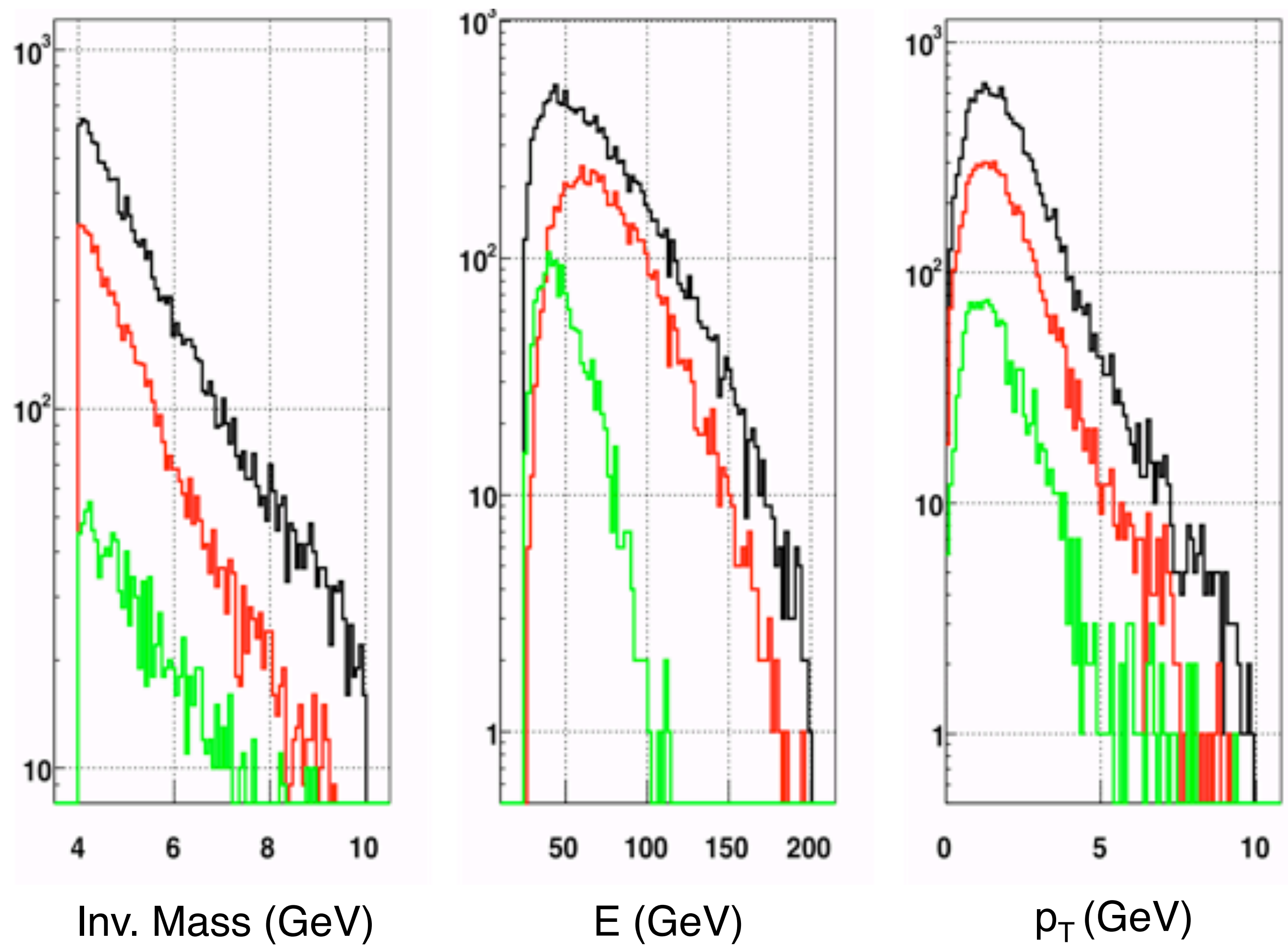
6512 events



FMS open (x=50cm)
+ FHC (x=60cm)

1436 events
(1/5 from closed)

pythia 6.222, p+p @ $\sqrt{s}$ = 500 GeV
4M DY events/7.10^{-5}mb ~ 60/pb
e^{+-} energy > 10GeV, and $\eta>2$
$x_F>0.1$ (25GeV)
4 GeV < invariant mass < 10 GeV

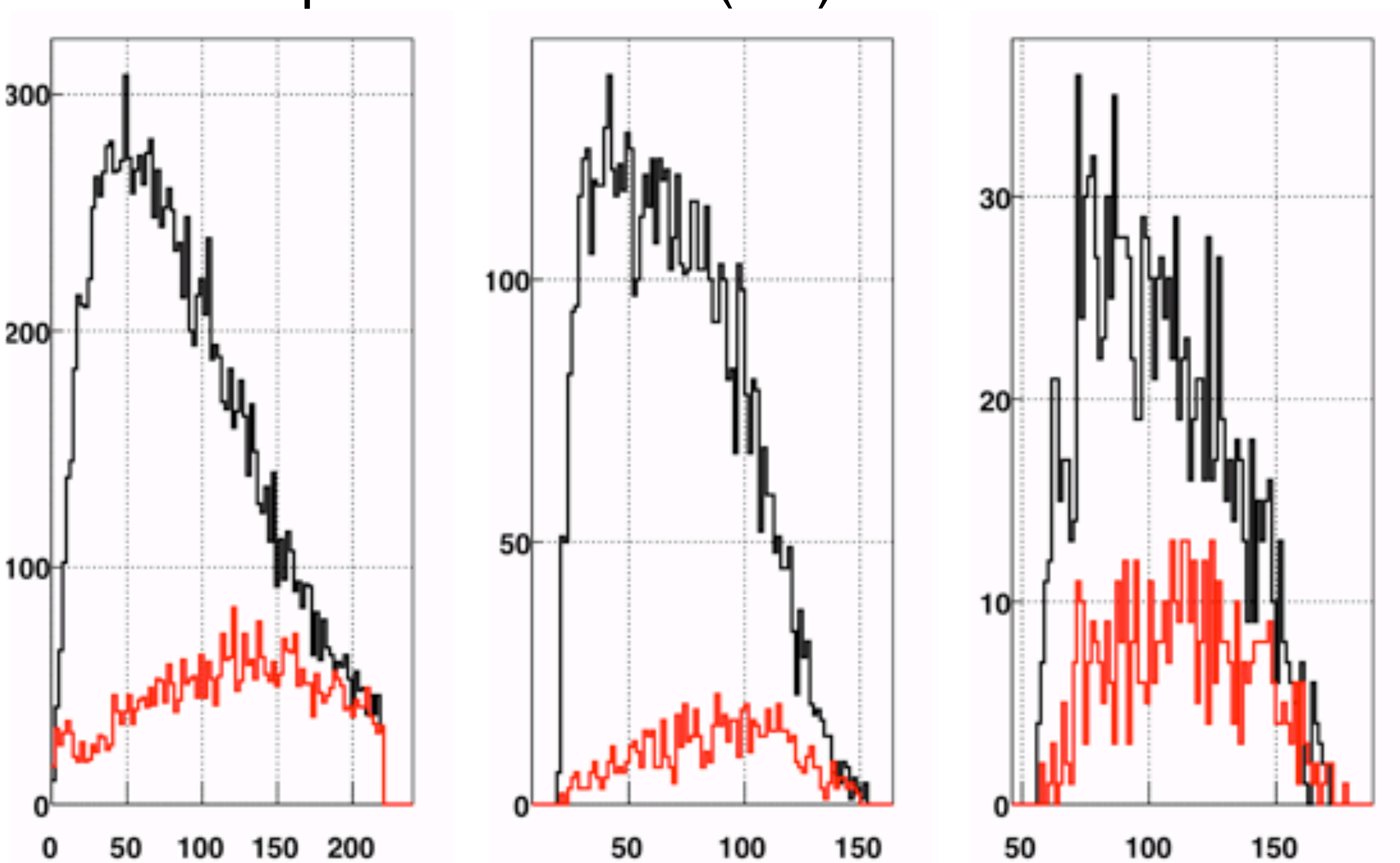


High-x_F Drell-Yan at STAR - Needs

- High $\eta \sim [2,4]$ coverage,
- Additional *e/h* separation $\sim 10^{-3}$ per hadron
- Additional e/γ separation $\sim 10^{-3}$, incl. $\gamma \rightarrow e^+e^-$
- Trigger upgrades,
- Forward tracking for charge-like and -unlike signs (?),
- Infrastructure
- ...

Direct Bottom Backgrounds - Drell-Yan

Electron/position radius (cm) from beam at FMS



Everything $\eta>2$ FMS closed FMS open (x=50cm) + FHC (x=60cm)

pythia 6.222, p+p @ $\sqrt{s}$ = 500 GeV
4M DY events/7.10^{-5}mb ~ 60/pb
e^{+-} energy > 10GeV, and $\eta>2$
$x_F>0.1$ (25GeV)
4 GeV < invariant mass < 10 GeV
300M B events/5.10^{-3}mb ~ 60/pb

DY
Direct B

FMS closed : small at high x_F and high eta; mostly unlike sign
FMS opened + FHC : significant at low x_F and small eta

Hadron, Photon Backgrounds - Drell-Yan

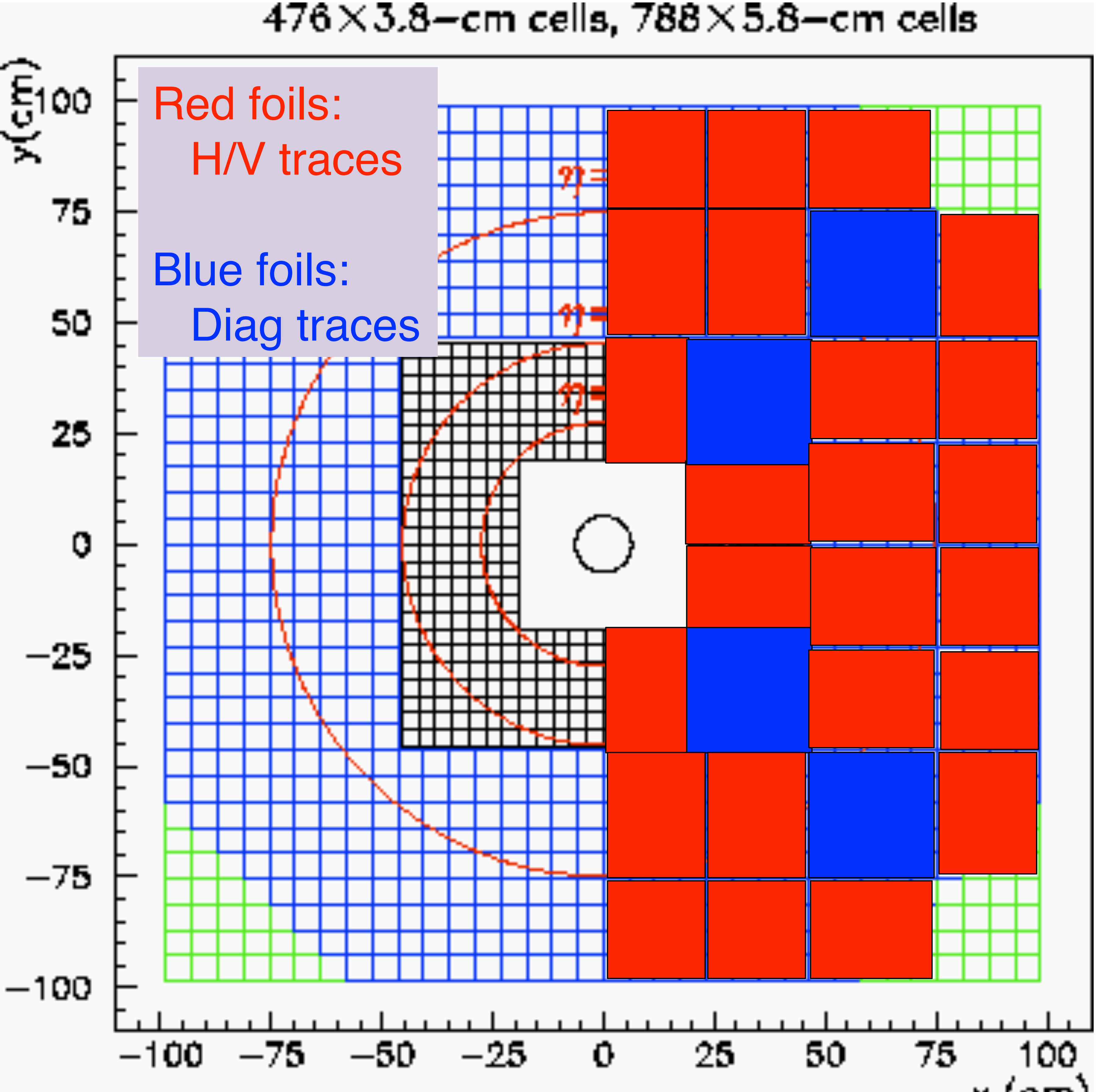
Hadron rejection:

FMS (EM-cal, rarely measures full hadronic energy),
FMS + FHC veto $\sim 10^{-1} - 10^{-3}$, depending on energy
but note space and other constraints (mostly at $\sqrt{s}$ = 500 GeV),
Converter and early shower detector $\sim 10^{-1}$
Electron-ID, in the form of a TRD or TR-Tracker $\sim 10^{-1} - 10^{-2}$
Off-line *E*-over-*p*; hard, initial insights from 200 GeV analysis,
will require detailed tracking simulation,
Off-line shower-shape analysis; needs study.

Photon rejection:

Neutral veto in pre-shower detector $\sim 10^{-2}$
Conversions in beam-pipe - thin pre-shower with good resolution
Off-line π^0 etc. reconstruction, tracking $\sim 10^{-1}$

Pre-shower and Early-shower concept



GEM based

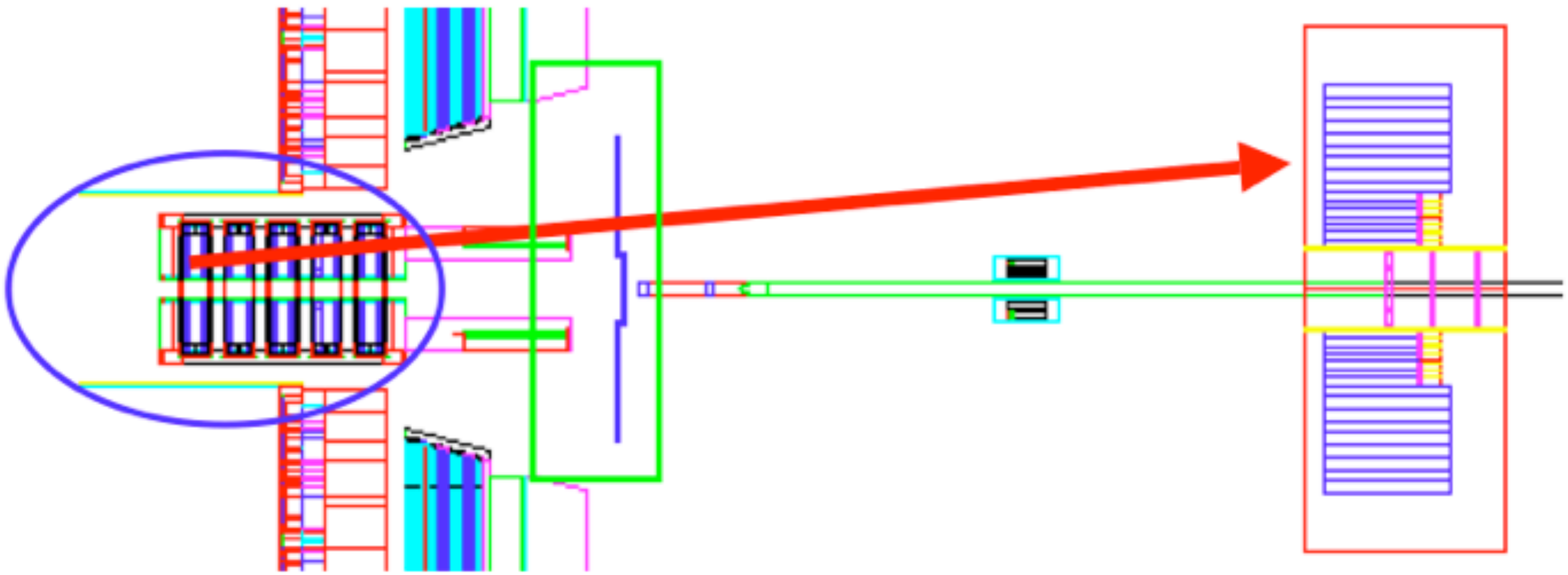
Pre-shower
0.3mm – 0.9mm pitch
55k channels

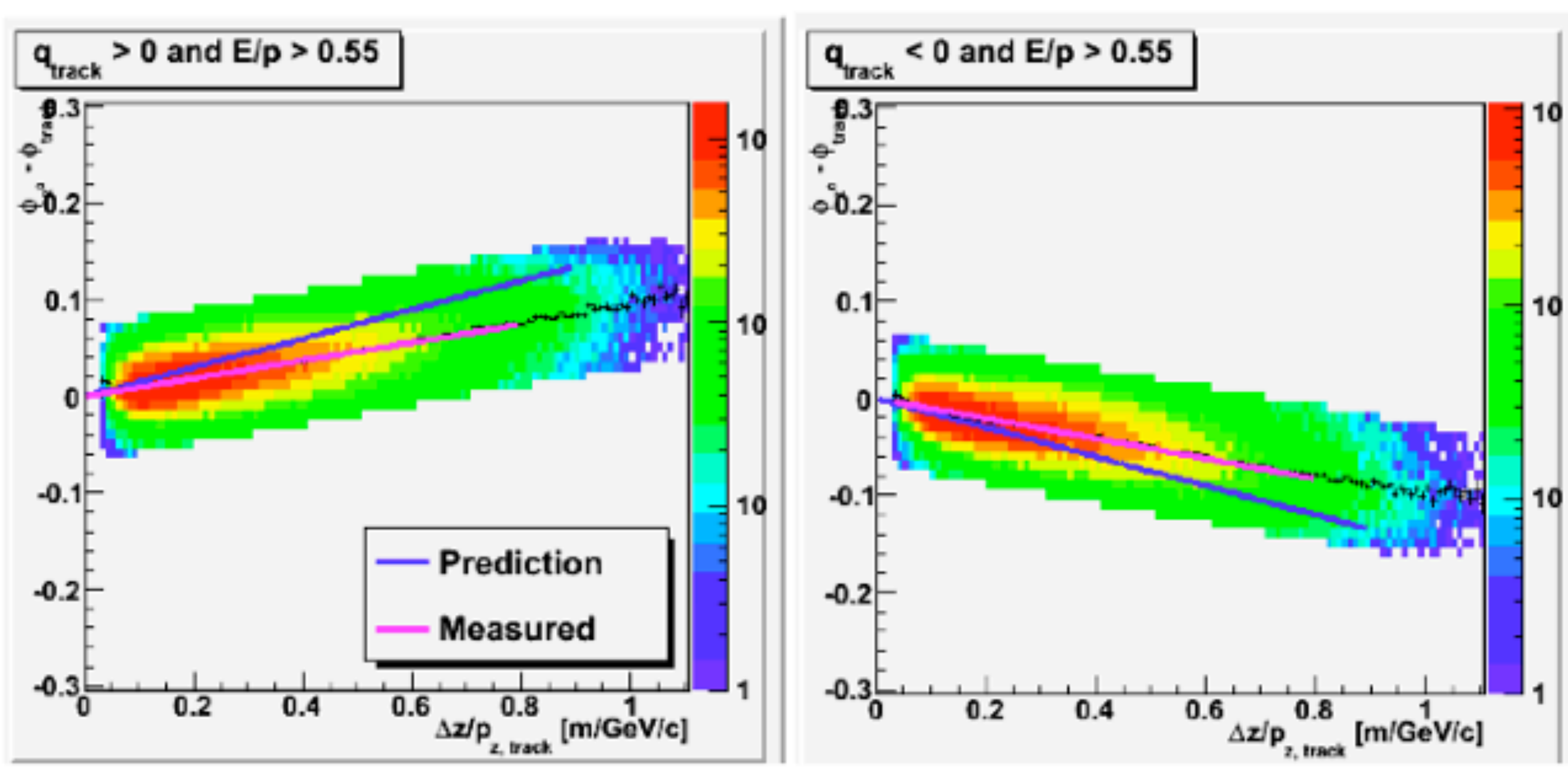
~2 X_0 Pb Converter

Early-shower
2mm -3mm pitch
11k channel

Total 66k channels

Foward Tracking - Present





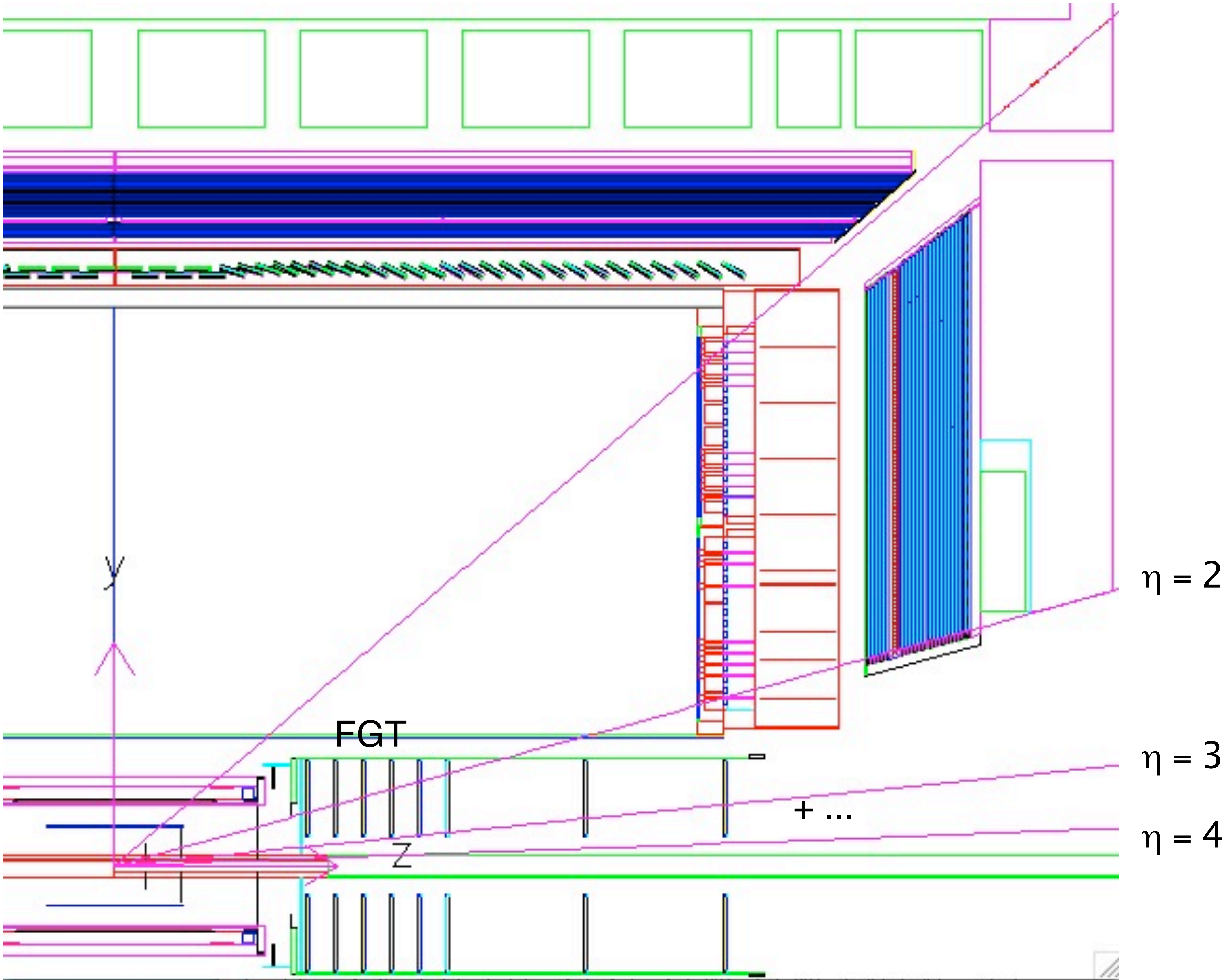
Uses data from STAR Forward TPC,

Forward TPC readout is slow and the Forward TPCs will be phased out soon,

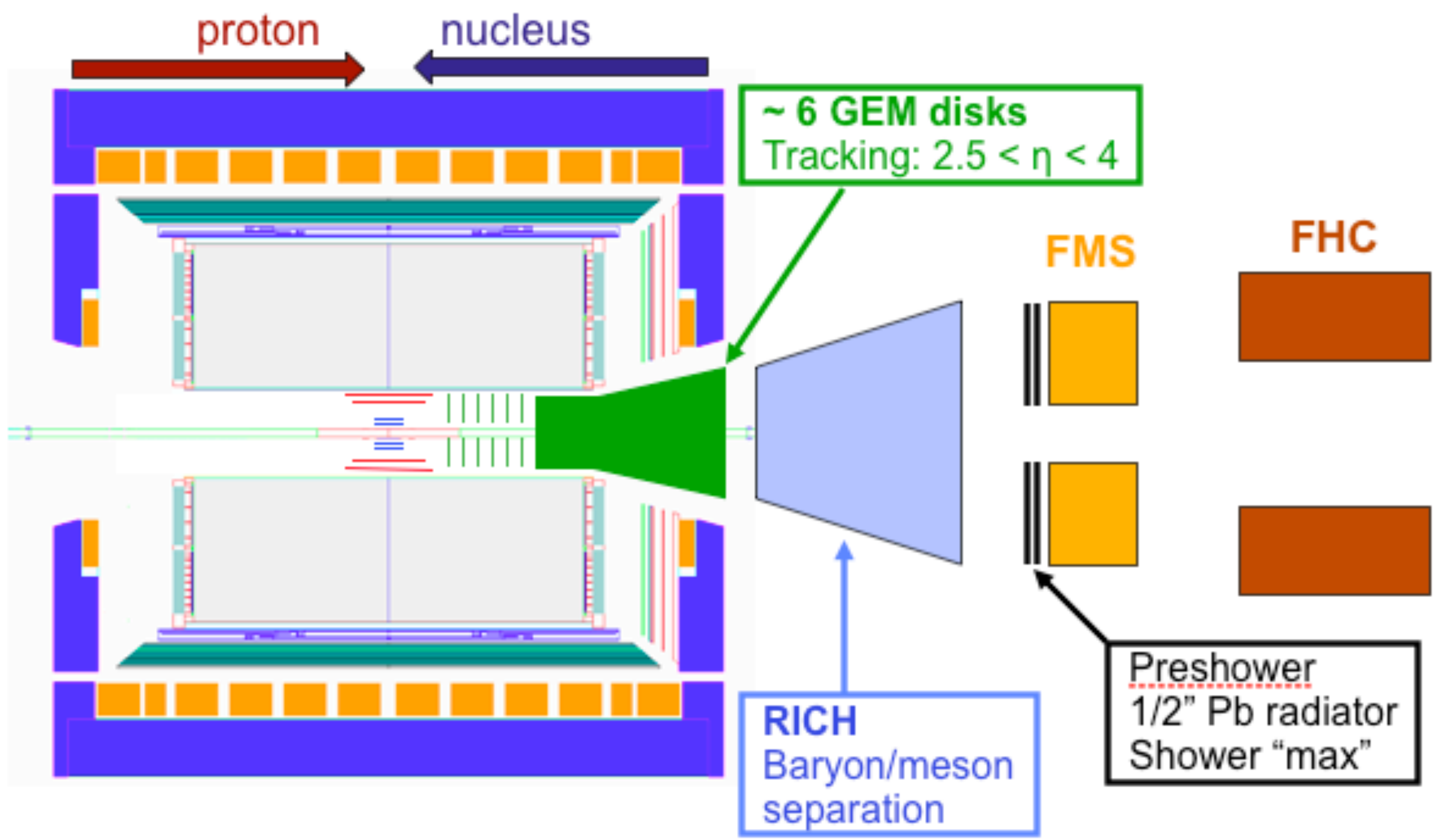
Charged track deflection by the Solenoid field is partially canceled by that in the fringe field.

Match between e^+, e^- hit locations at the FMS and the extrapolation from FTPC are strongly correlated and agree rather well with expectations.

Tracking concept - Far Foward GEM Tracker



A Possible Future Upgrade at STAR

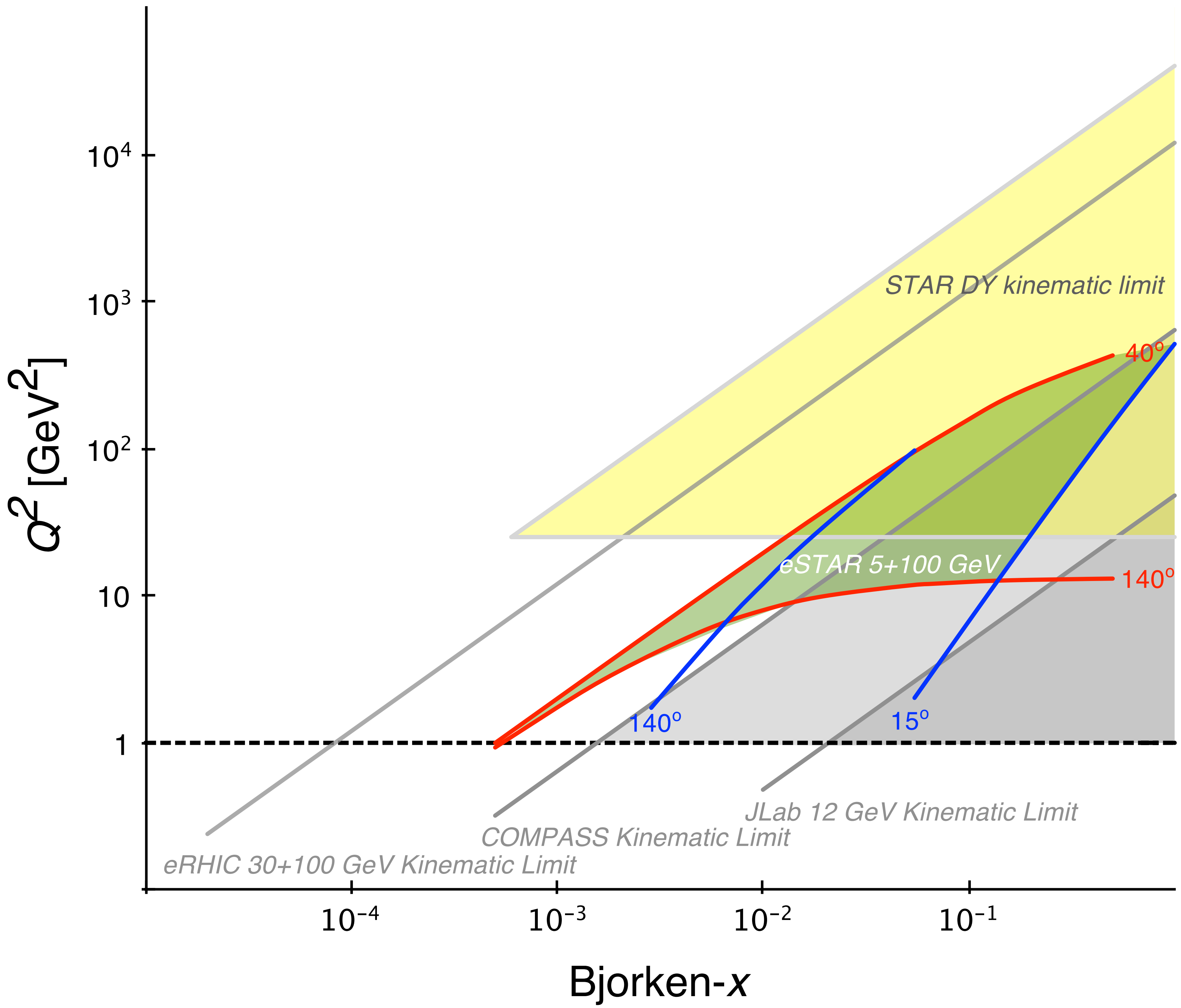


Forward upgrade driven by proton-nucleus and transverse spin physics considerations,

- charged particle tracking,
- electron-hadron and photon-neutral pion separation,
- Baryon meson separation.

Optimizations and full simulations to demonstrate capability are starting.

Drell-Yan, eRHIC, eSTAR



A talk by itself...

Note: this is an *illustration*, not a full simulation.

Here, M > 5 GeV for DY, central-rapidity for eSTAR

Concluding Remarks

STAR has prepared a new decadal plan for 2011-2020, http://www.bnl.gov/npp

Aims to address transverse physics and nuclear structure physics topics via Drell-Yan measurements in the second half of the decade, as part of a broader program that may culminate in an Electron-Ion-Collider,

The Forward Meson Spectrometer is a key part of this program, and has been very successfully commissioned and operated up to $\sqrt{s}$ = 500 GeV,

Anticipate at the level of 150 Drell Yan pairs in the FMS acceptance at $\sqrt{s}$ = 200 GeV, about equal for proton+nucleus and proton+proton collisions, based on RHIC projections,

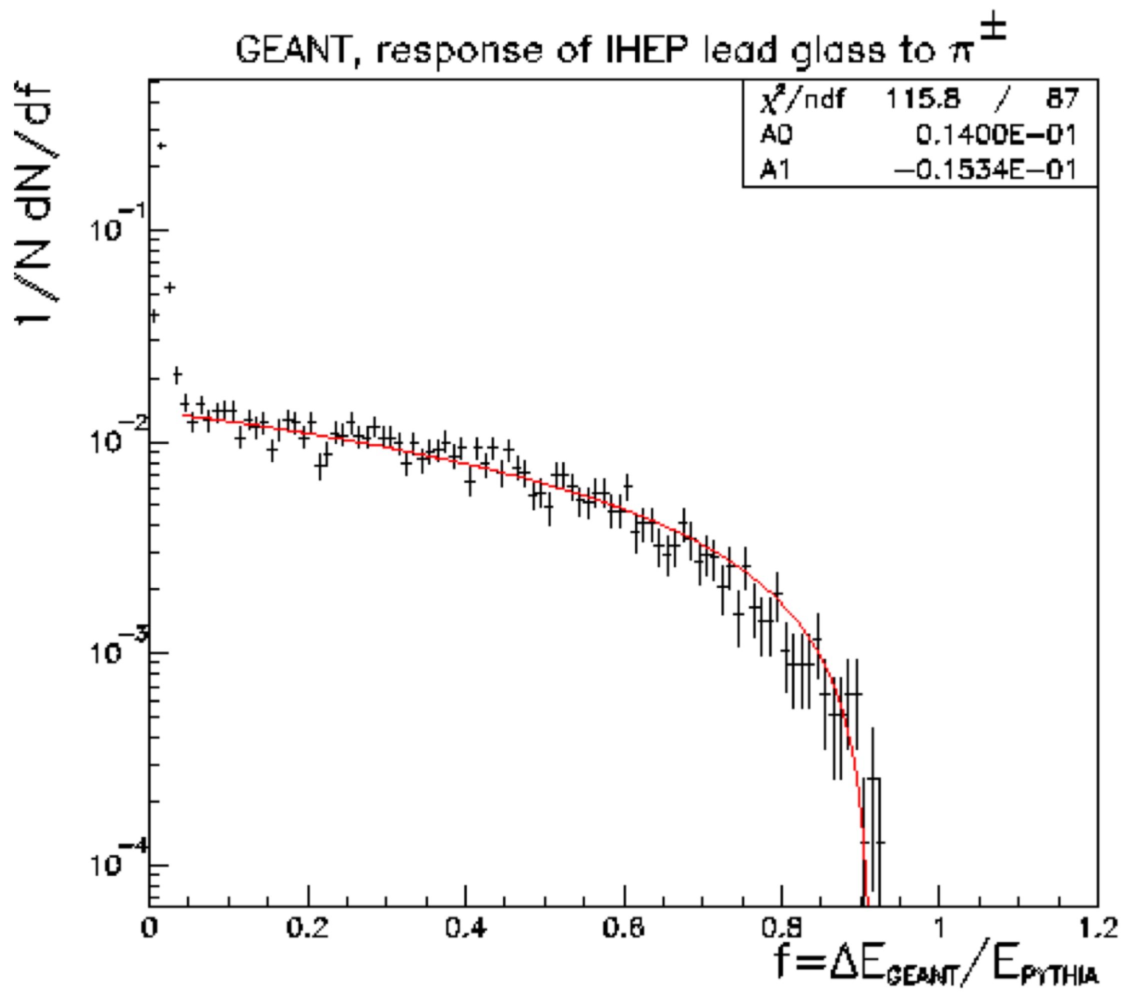
$\sqrt{s}$ = 500 GeV p+p projected rates are considerably higher, however,
detection at STAR will be considerably more challenging,
p+A collisions are not possible at this energy at RHIC,

Lots of work ahead,

- a number of key aspects are well understood/benchmarked,
- the foreseen upgrade path is evolutionary,
- efforts towards full simulations of measurement capability are starting,
- continued R&D, ...

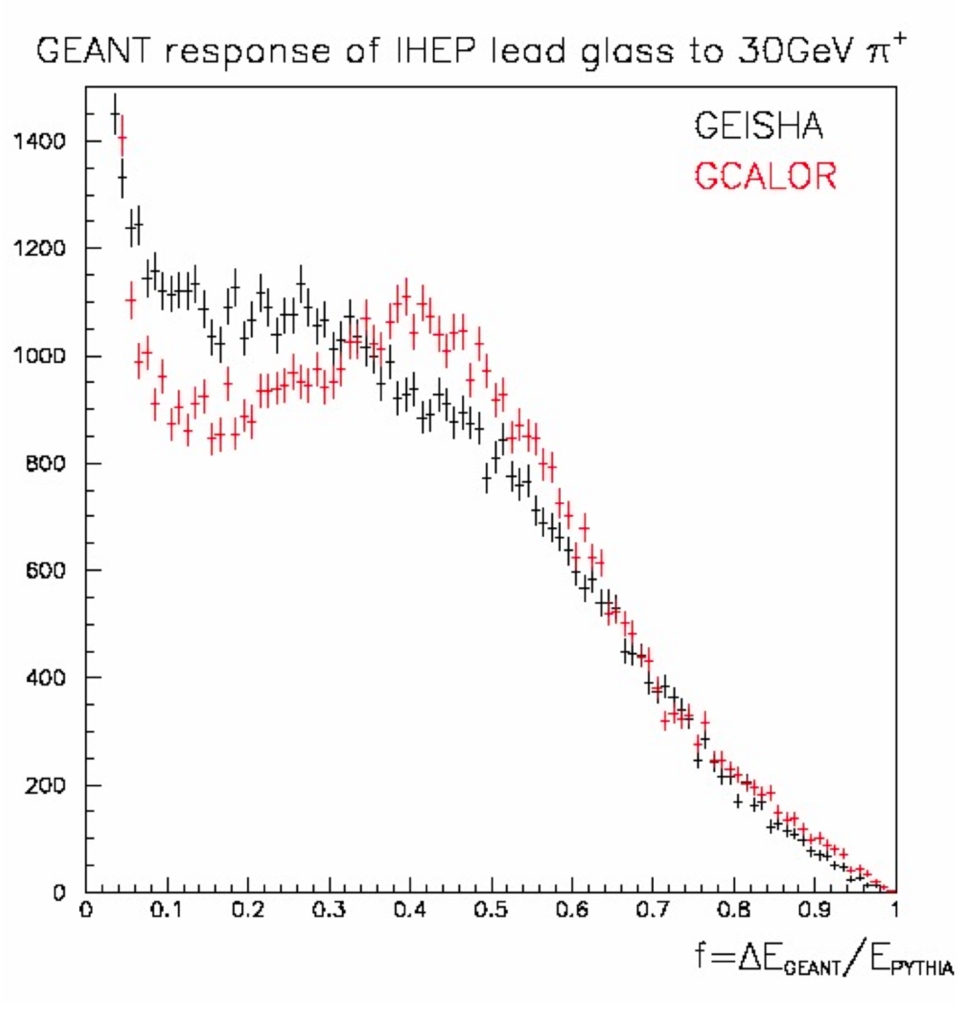
Thank you!

GEANT response of PbGl for sims



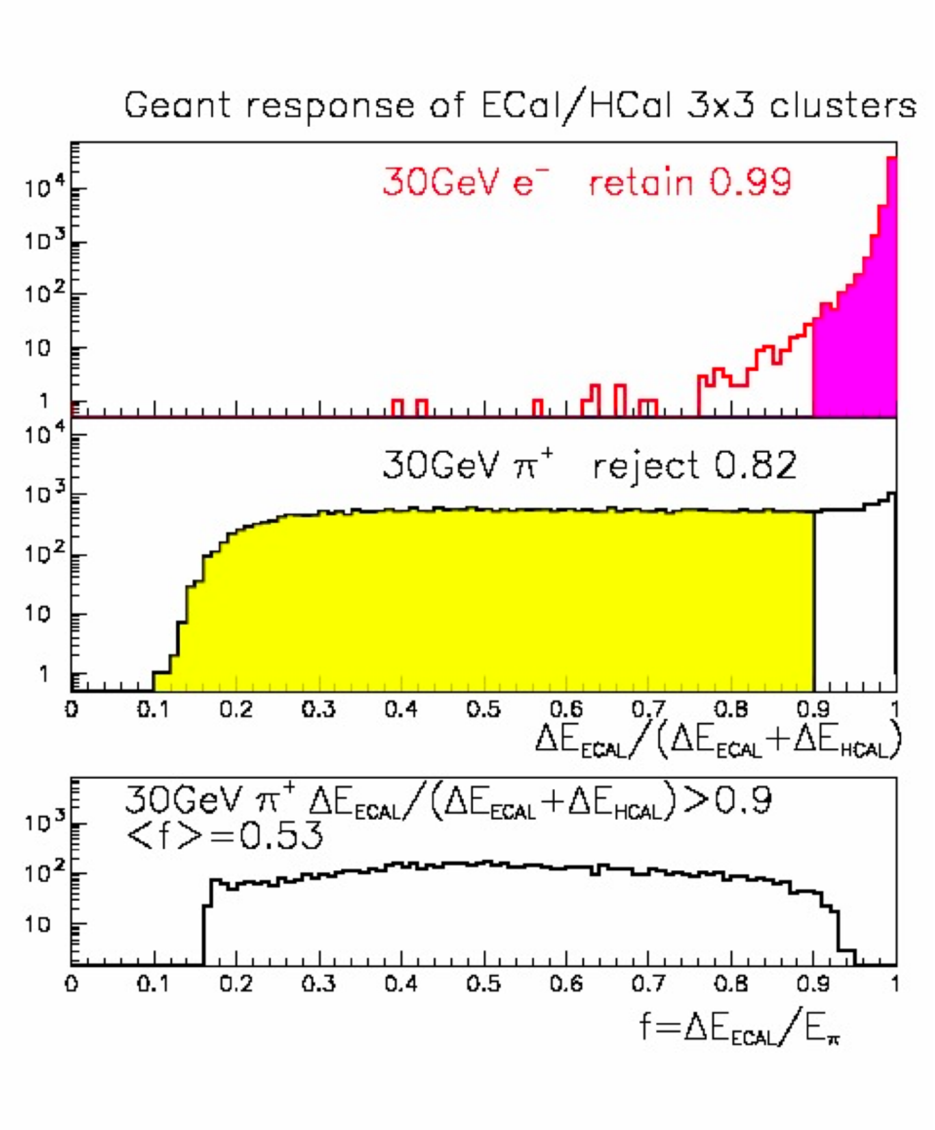
GEANT simulation of energy deposited in an EMcal built from 3.8 cm × 3.8 cm × 45 cm lead glass bars. Charged pions with E>15 GeV are used in this simulation. The fraction of the incident pion energy deposited in the EMcal is *f*. The dN/d*f* distribution is well represented by a linear function of *f*, at values larger than the peak from minimum-ionizing particles.

Sim Uncertainty



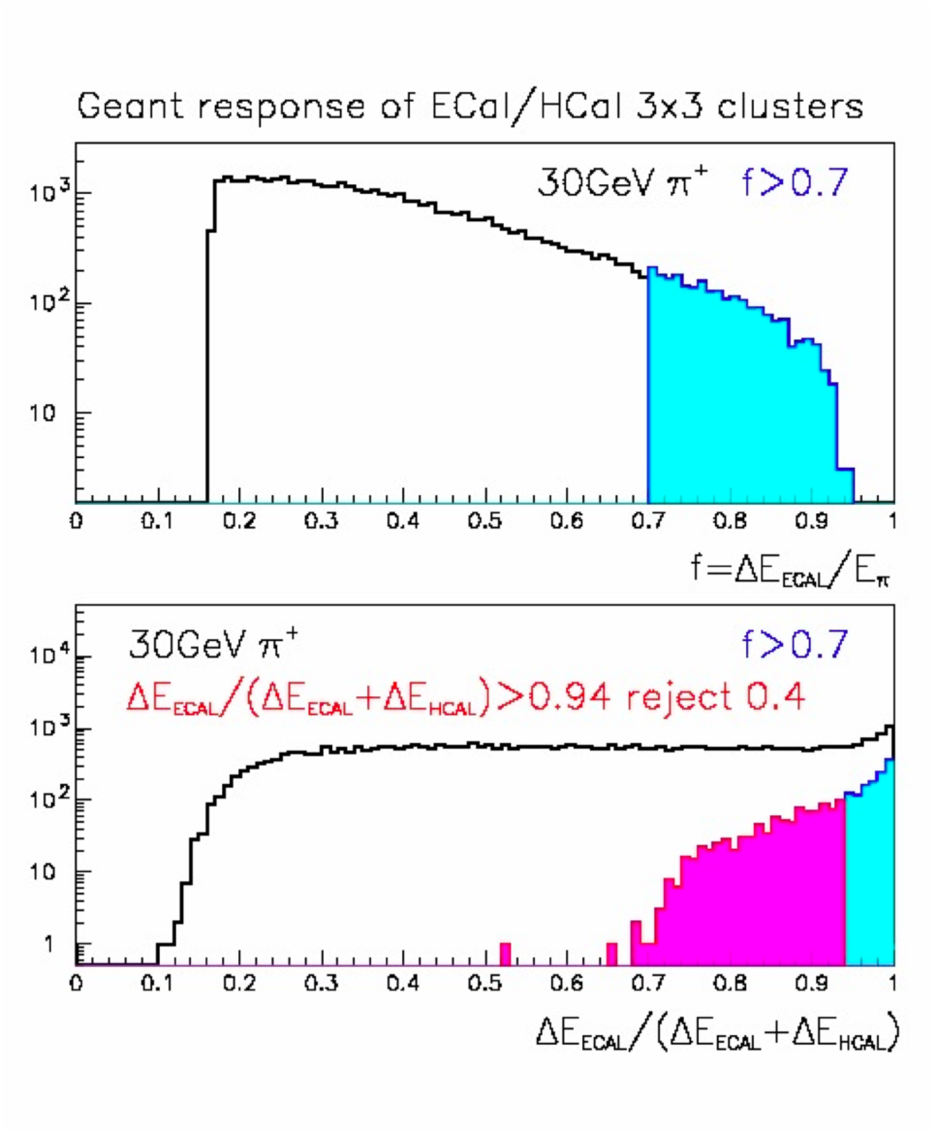
GEANT simulation with hadronic interaction package GEISHA (black) and GCALOR(red) of energy deposited in an EMcal built from 3.8 cm × 3.8 cm × 45 cm lead glass bars. Charged pions with E=30 GeV are used in this simulation. The fraction of the incident pion energy deposited in the EMcal is *f*.

Ecal and Hcal response - cuts



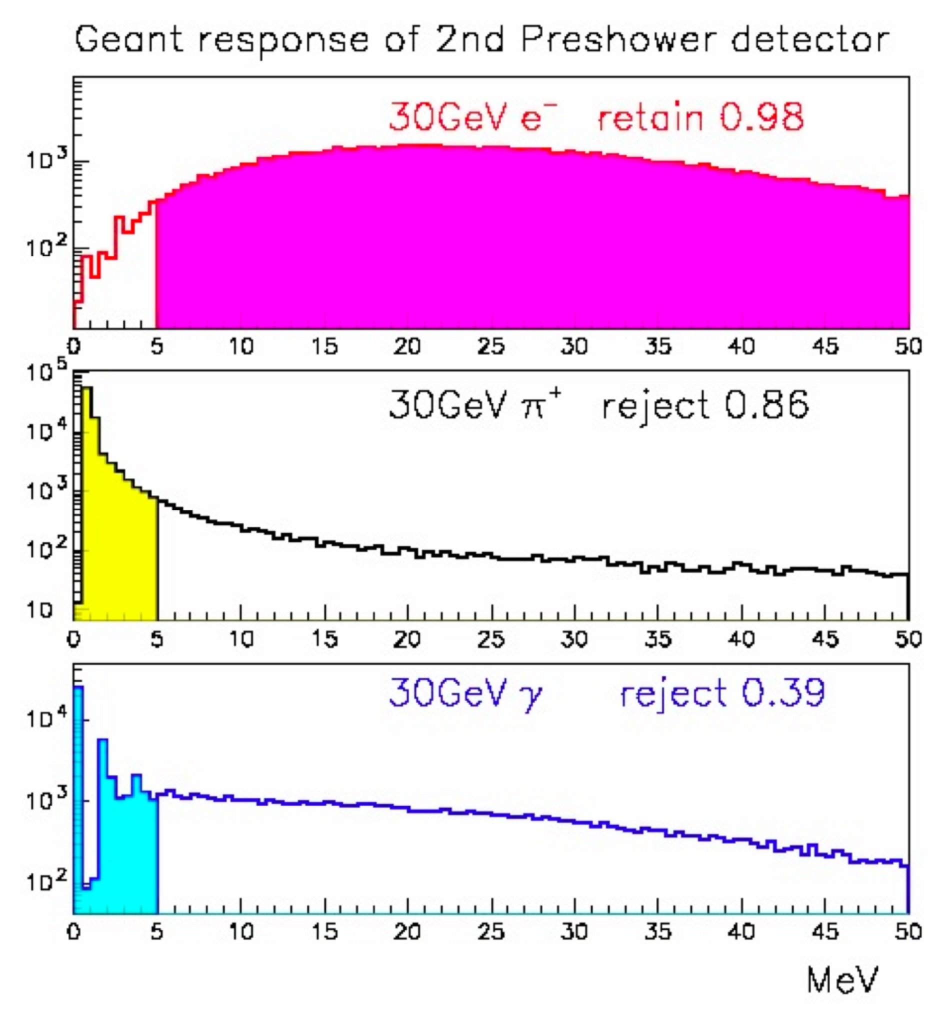
GEANT simulation for energy deposit in an EMcal and Hcal for 30GeV electrons and charged pions. A 3x3 cluster sum of deposited energy forms the ratio R=DE (EMcal)/(DE(EMcal)+DE(Hcal)) shown in top plot. With R>0.9 cut, EMcal+Hcal can reject 82% of hadrons while retaining 99% of electrons. The bottom plot shows distribution of f for hadrons that survive R>0.9 cut.

Ecal and Hcal Response - cuts



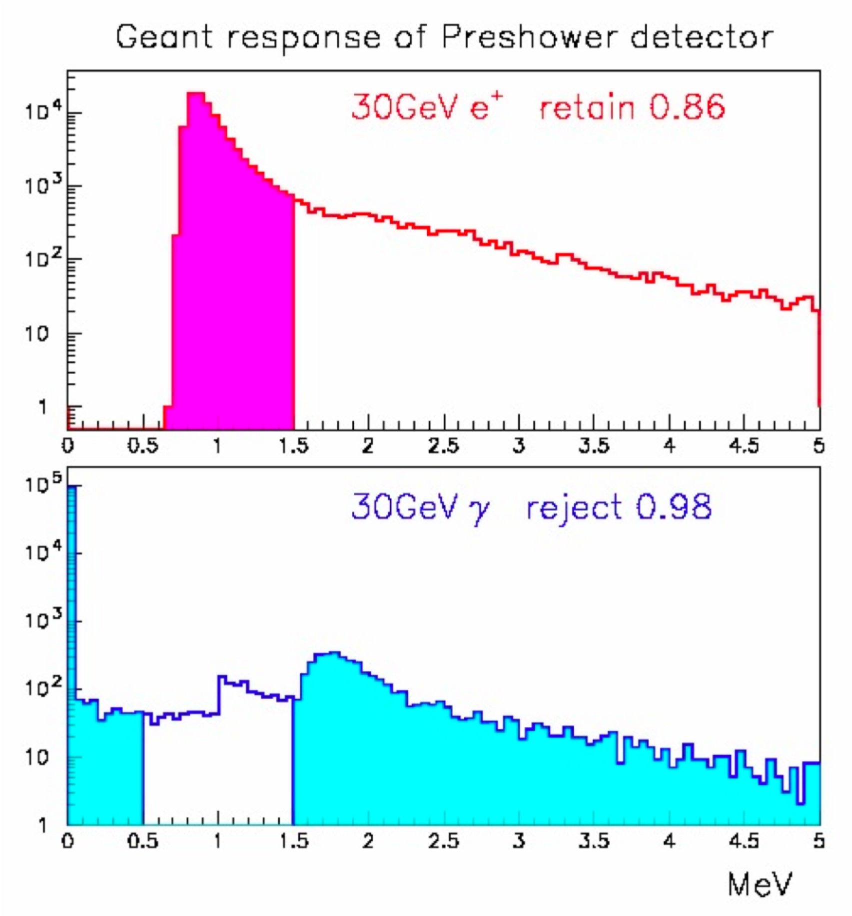
GEANT simulation for energy deposit in an EMcal and Hcal for 30GeV charged pions. The top plot shows the distribution of f in EMcal 3x3 clusters around the high tower. The bottom plot shows the ratio R=DE(EMcal)/(DE(EMcal)+DE (Hcal)). Blue shaded area is for hadrons surviving cut f>0.7. Red shaded area is hadrons which can be identified using Hcal by R>0.94 cut. This gives 40% hadron rejection for hadrons with f>0.7.

Preshower Cuts



GEANT simulation of 2nd pre-shower detector made of 0.5cm thick plastic scintillation counter placed after 1cm Pb converter. Responses for 30GeV electrons, charged pion and photons are simulated. A cut of energy deposit in the 2nd pre-shower above 5MeV will retain 98% of electrons, while rejecting 85% of pions and 39% of photons.

Preshower cuts



GEANT simulation of a pre-shower detector made of 0.5cm thick plastic scintillation counter. Responses for 30GeV electrons and photons are simulated. A cut of 0.5MeV < dE < 1.5MeV will retain 86% of electrons, while rejecting 98% photons including ones converted to e+e- pairs in beam pipe and preshower detector itself.