STAR Upgrades for the BES II Era

Jim Thomas
RHIC & AGS Users Meeting

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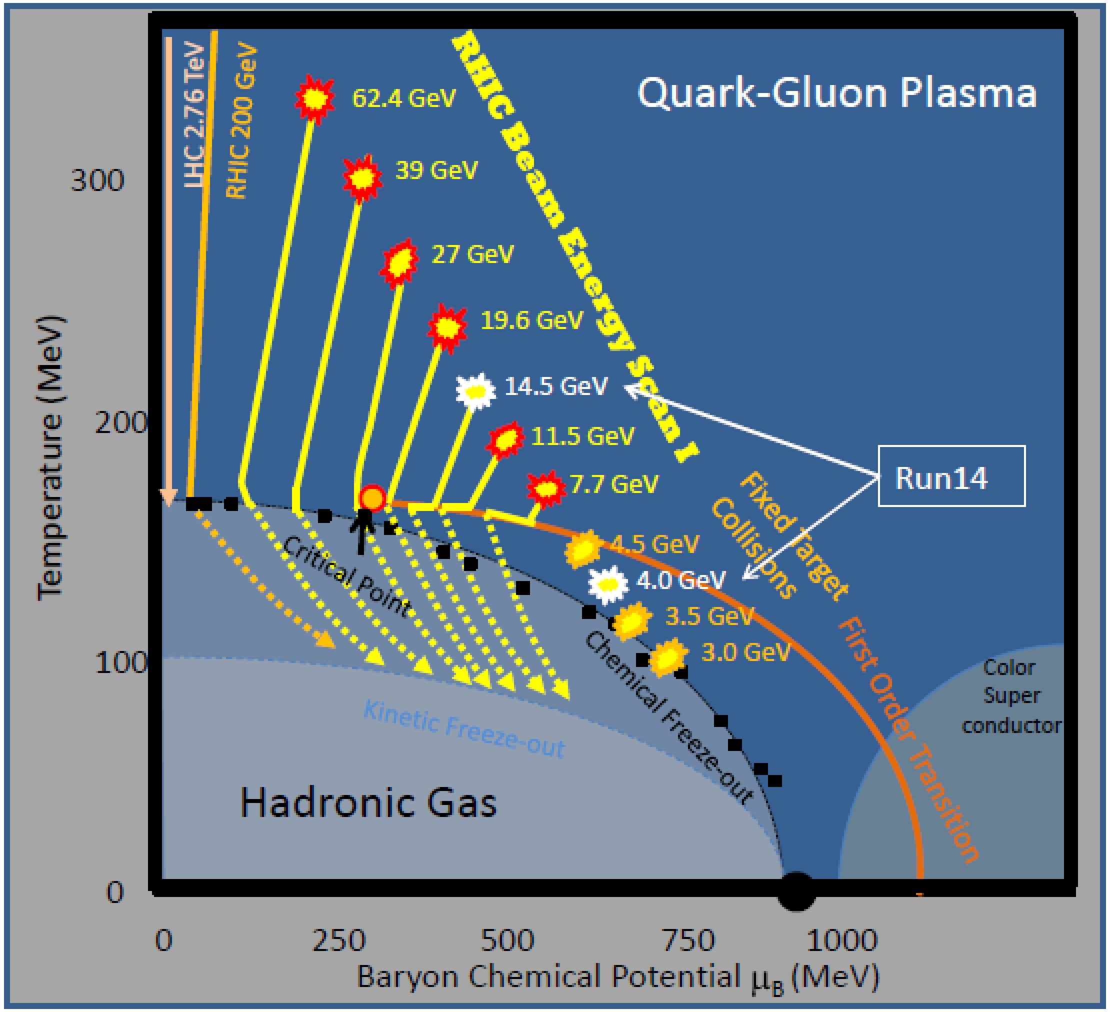
Introduction

- The Goal of the Beam Energy Scan Program is to explore the phase diagram of nuclear matter in greater detail
  - Locate the Critical Point on the phase diagram
  - Find evidence of a first-order phase transition
  - Look for the disappearance of potential QGP signatures

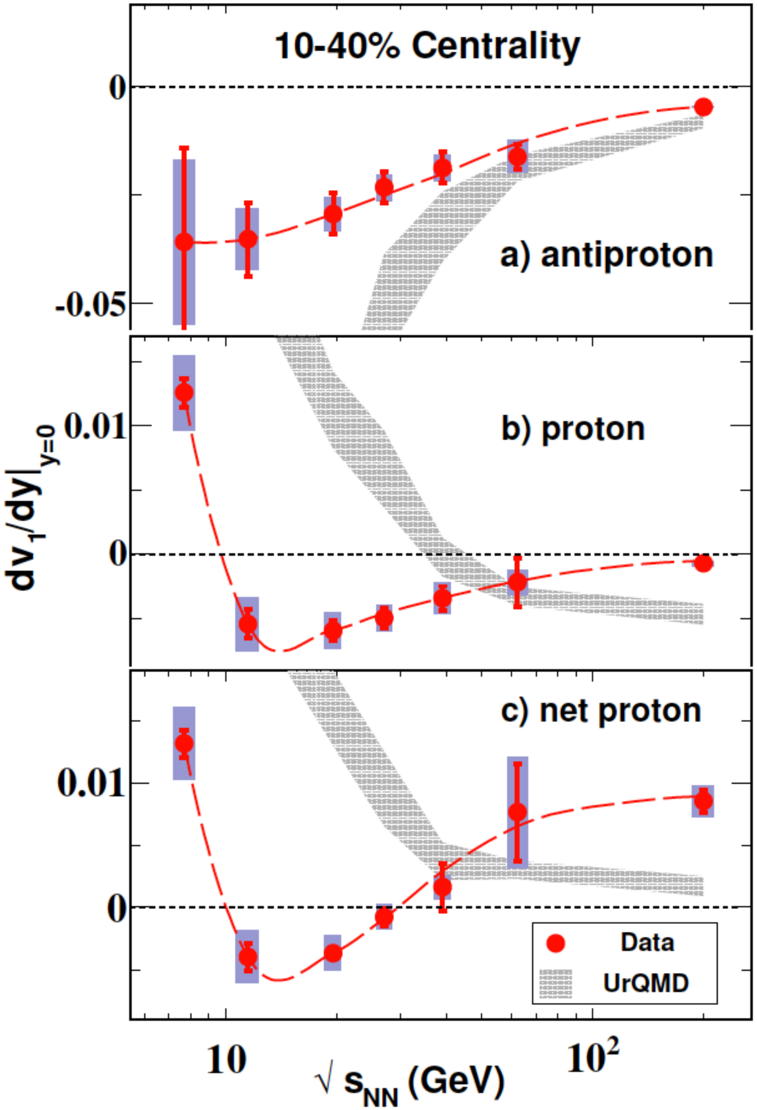
- Hardware Upgrades for BES-II in the 2018 time frame
  - The STAR iTPC upgrade will extend rapidity and dE/dx coverage
  - A new Event Plane Detector will give an improved and independent measure of event plan orientation and centrality
  - The Fixed-Target Program will extend the search & range for all of the features of the QCD phase diagram up to μ_B = 720 MeV
  - eTOF will give improved particle ID in the forward direction

A Beam Energy Scan at RHIC



- A cartoon of the phase diagram of QCD matter with indications of the regions that are to be explored by a Beam Energy Scan at RHIC
  - Approximately equal sized steps on the μ_B axis
  - Probe QCD matter above and below the line demarking the (assumed) first order phase transition

The Hunt for the softest point in the EOS



- Sign change of proton dv_1/dy between 7.7 and 11.5 GeV
- Dip of net proton dv_1/dy between 11.5 and 27 GeV
  - Possible signature for the softest point of the EoS
- Error bars for other particles and different centralities are large
  - more statistics needed, better event plane resolution needed
- Composition of particles used to determine how the event plane changes with energy and η
  - higher η granularity needed to distinguish produced & transported particles

PRL, 112 (2014) 162301

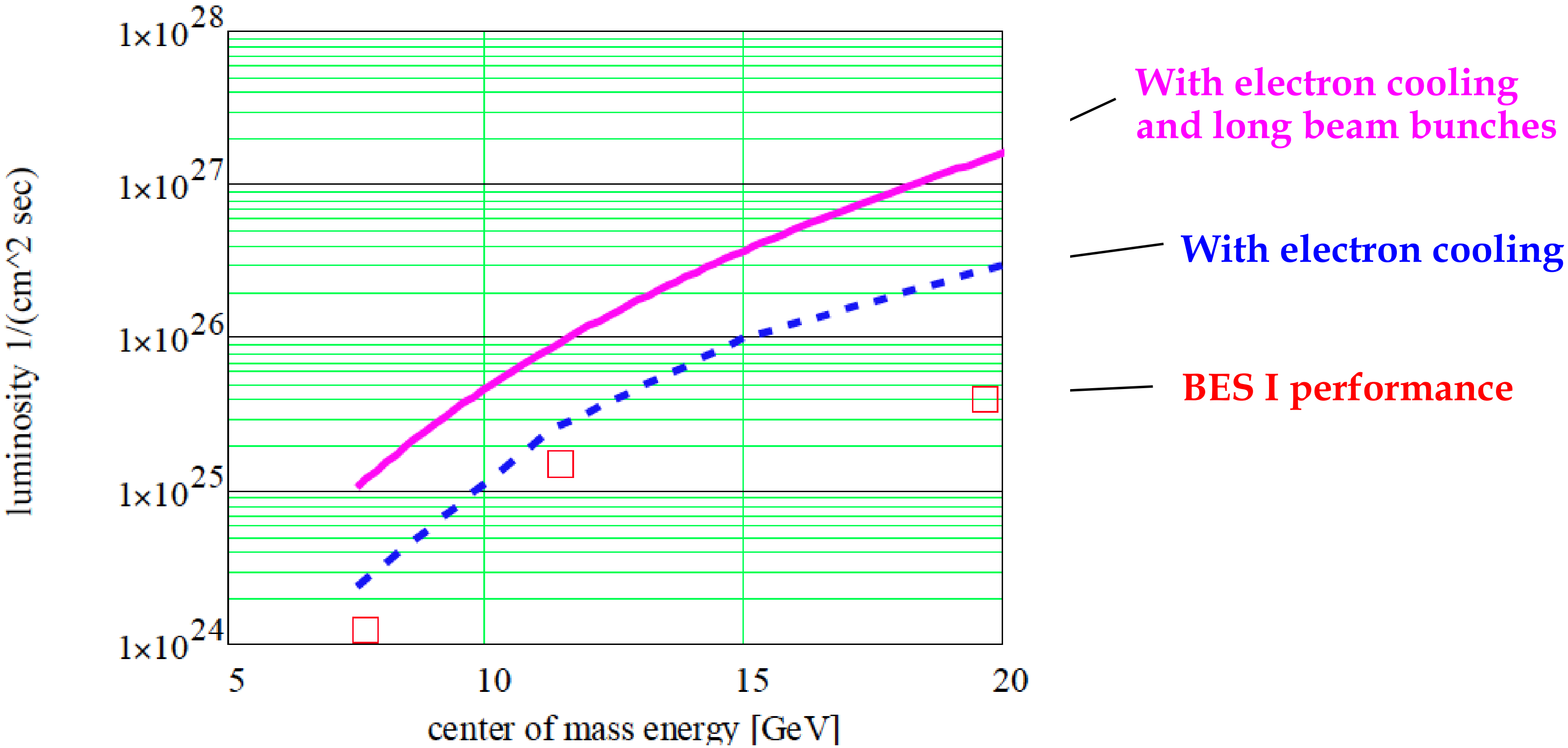
Beam Energy Scan Phase I and Phase II

STAR

	Collision Energy (GeV)	Fixed Target $\sqrt{s_{NN}}$	Center of Mass Rapidity	Single Beam Kinetic	Chemical Potential Collider	Chemical Potential μ_B (MeV)
✓	19.6	4.471	1.522	8.87	206	589
	17.2	4.214	1.456	7.67	230	608
✓	**14.5**	**3.904**	**1.370**	**6.32**	**264**	**633**
	13.0	3.721	1.315	5.57	288	649
✓	11.5	3.528	1.253	4.82	316	666
	9.1	3.196	1.134	3.62	375	699
✓	7.7	2.985	1.049	2.92	422	721

- **Energies under consideration for BES Phase II with columns for $\sqrt{s_{NN}}$, y_{CM}, AGeV, and μ_B.**
- **In 2014, RHIC was tuned for Au+Au beams with $\sqrt{s_{NN}}$ = 14.5 GeV Fixed target collisions produced events with $\sqrt{s_{NN}}$ = 3.9 GeV**
- **In 2010 and 2011, the collider was tuned for 7.7, 11.5, and 19.6 GeV These beams produced Au_{Halo}+$Al_{Beampipe}$ fixed-target events with $\sqrt{s_{NN}}$ = 3.0, 3.5, and 4.5 GeV respectively.**

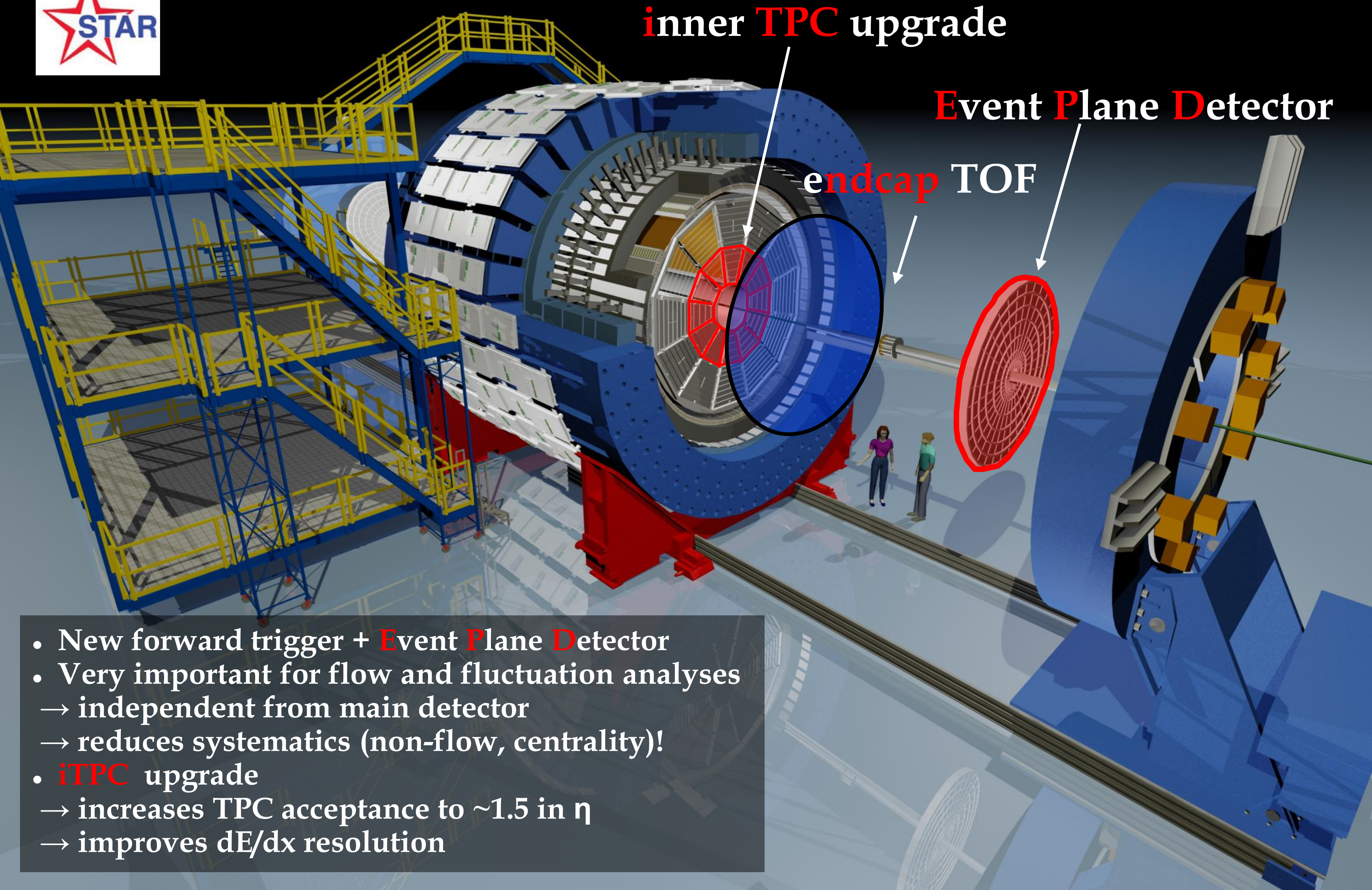
Luminosity improvements for BES II



- Electron cooling + longer beam bunches for BES II
  - Factor 4-15 improvement in luminosity compared to BES I
- Electron cooling helps at all energies

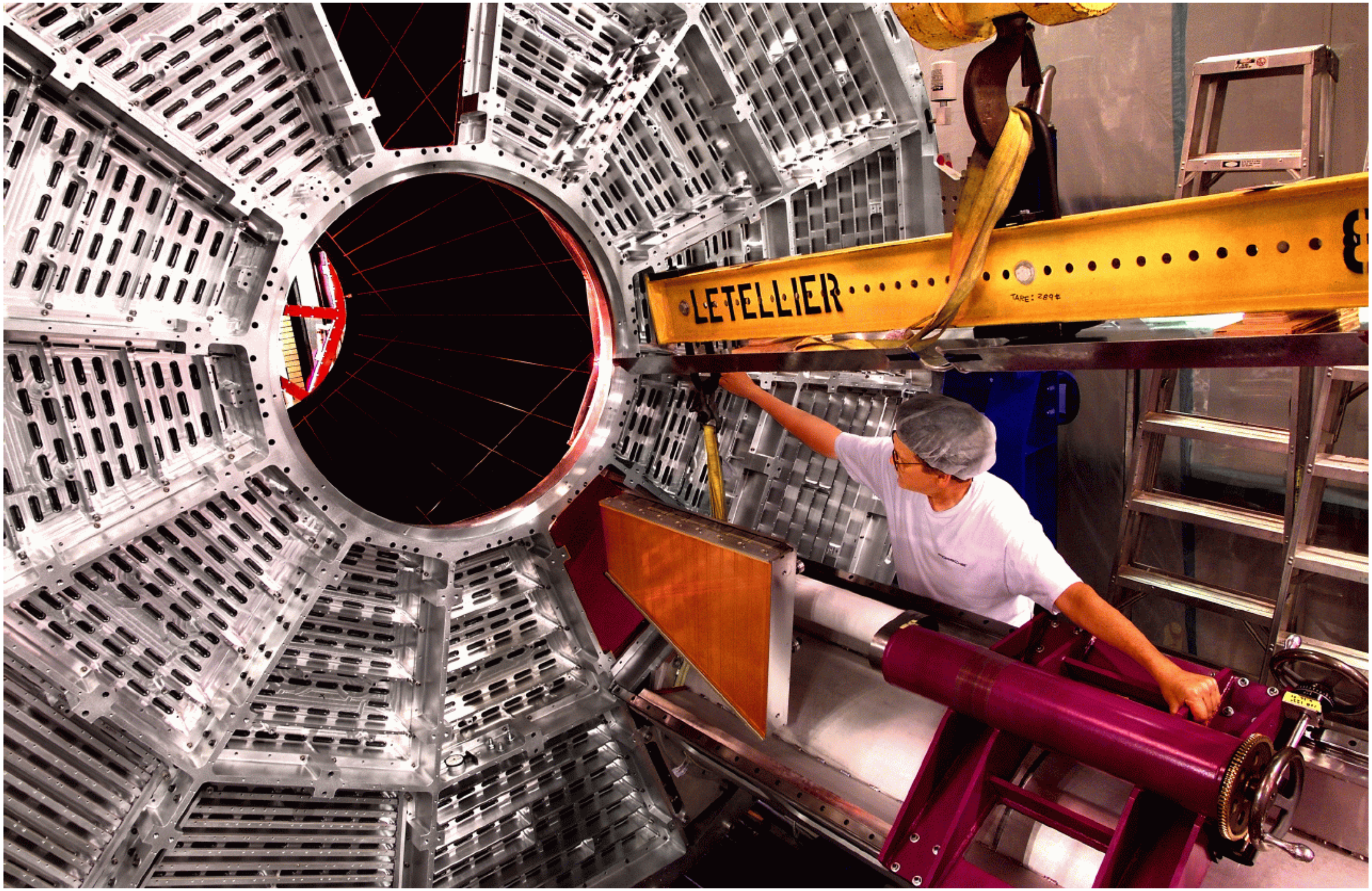
Improved statistics are needed at all BES energies

Detector Developments for BES II

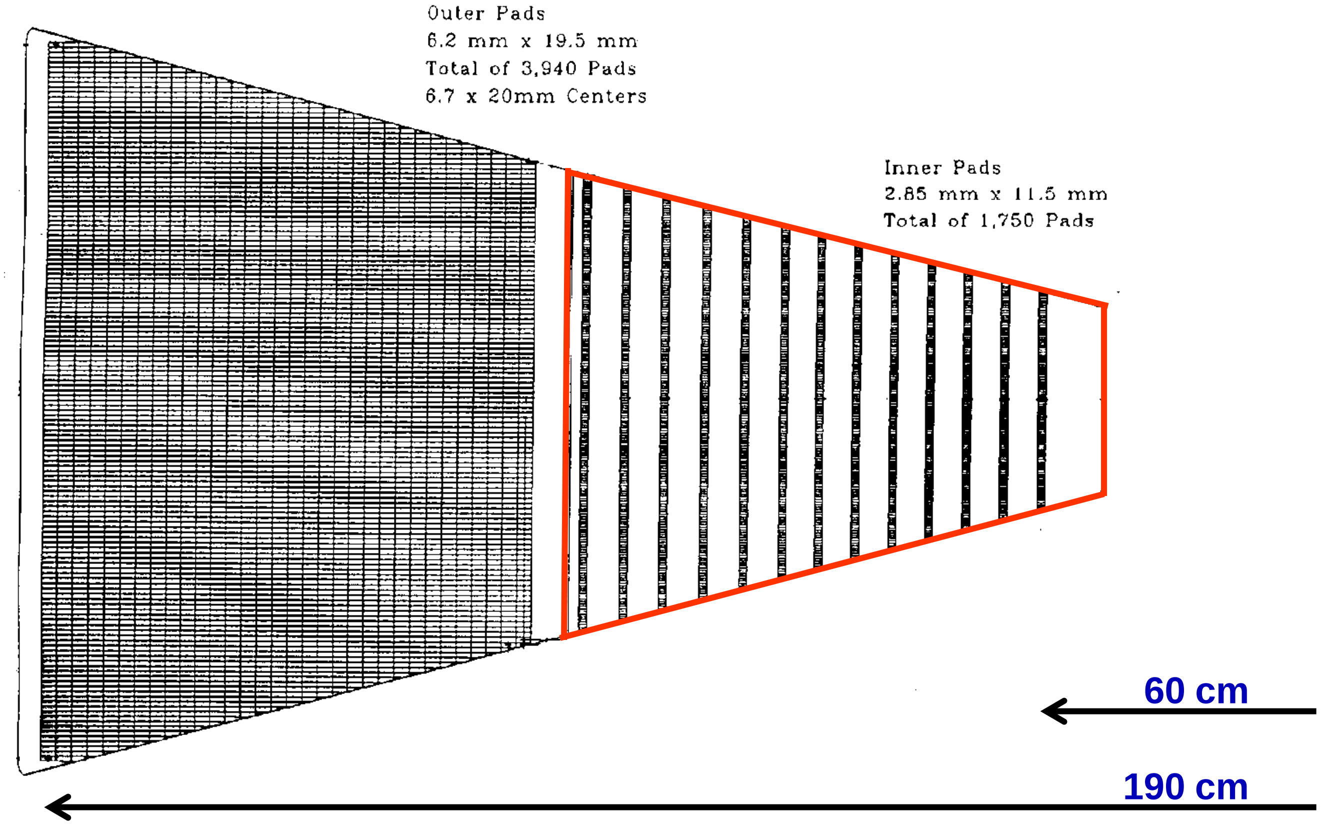


- New forward trigger + Event Plane Detector
- Very important for flow and fluctuation analyses
  → independent from main detector
  → reduces systematics (non-flow, centrality)!
- iTPC upgrade
  → increases TPC acceptance to ~1.5 in η
  → improves dE/dx resolution

The iTPC upgrade



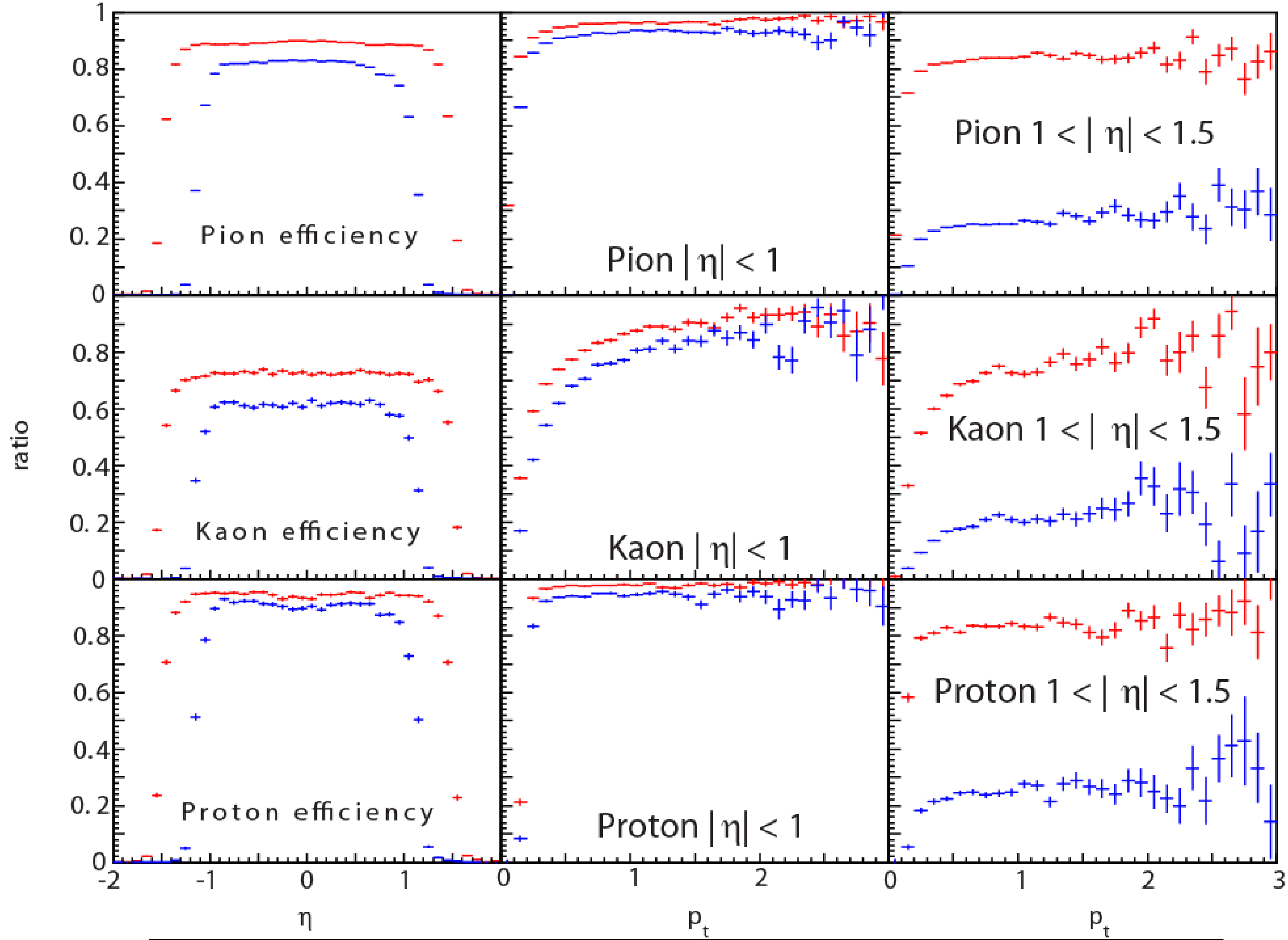
Why upgrade the Inner Sectors?



- The outer pad plane has full coverage while the inner pad plane does not
  - Increase the segmentation on the inner pad plane!
  - Renew the inner sector wires which are showing signs of aging

The upgrade will provide better momentum resolution, better dE/dx resolution, and improved acceptance at high η

Basic concept of the iTPC upgrade



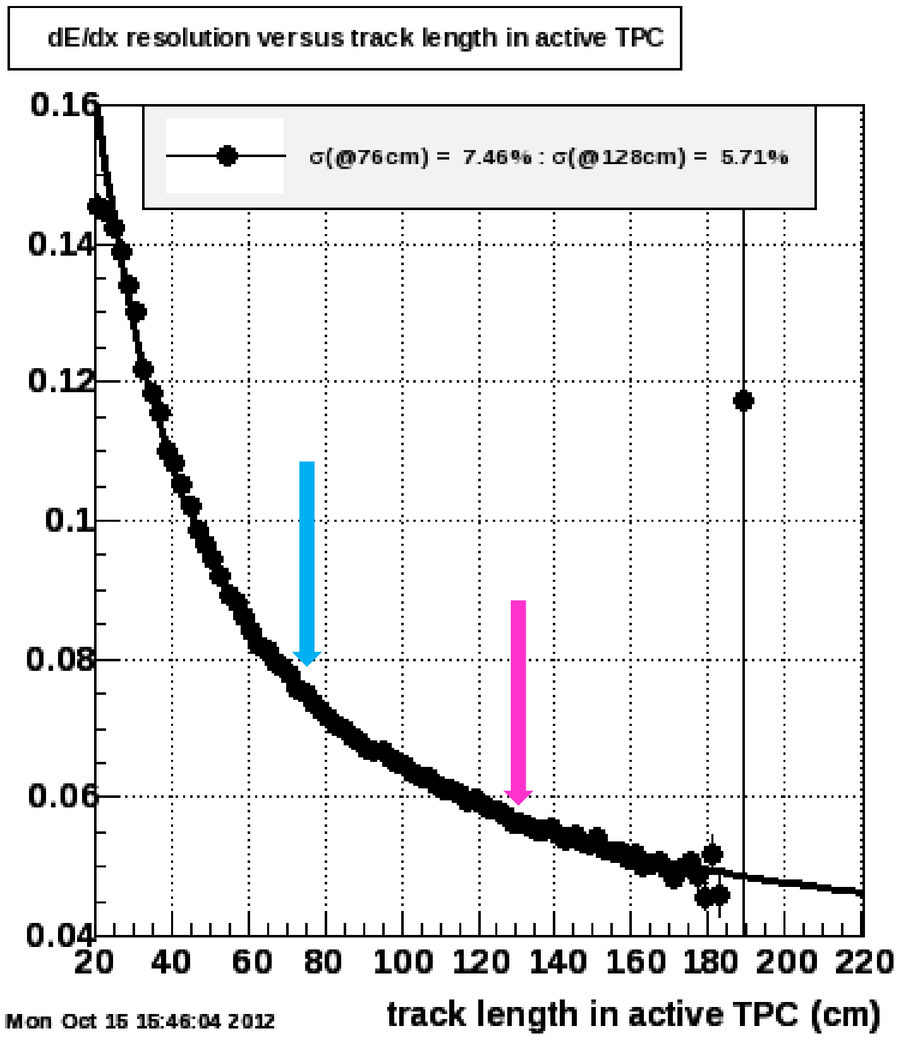
Hui Wang
Yuri Fisyak

Improved acceptance at high η. The upgrade extends the meaningful acceptance from 1.0 to 1.5 units for all particles.

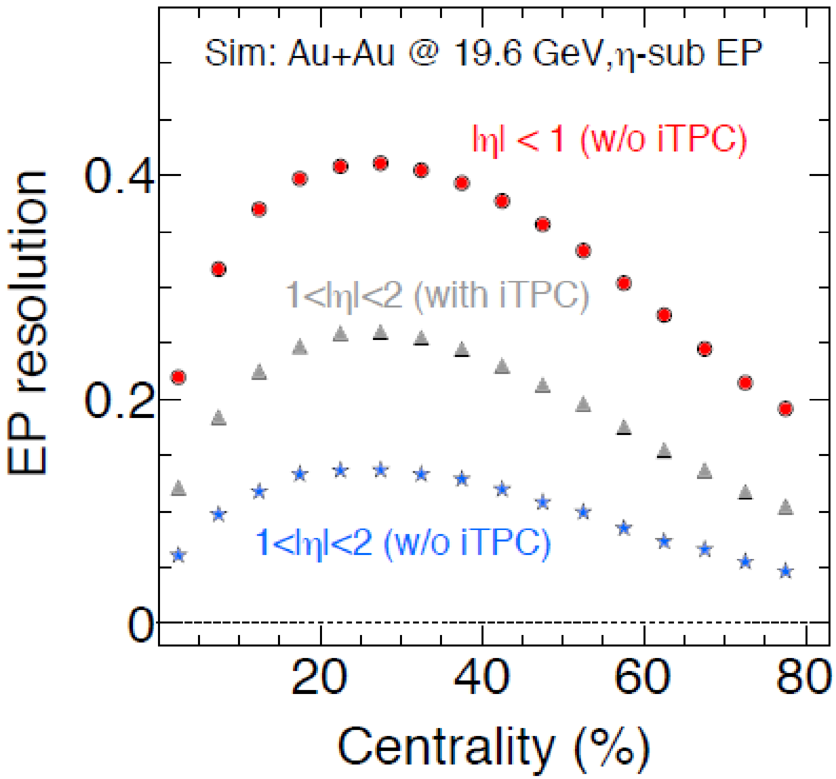
Simulation of improved dE/dx Resolution

Sampled Track Length vs dE/dx

Simulation from HiJing Au+Au 200 GeV



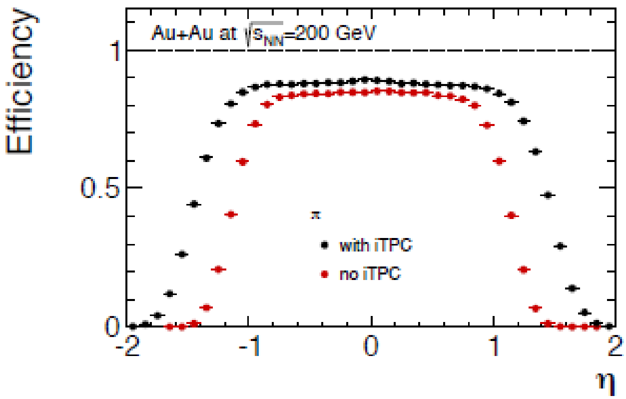
Elliptic flow Improvements with iTPC upgrade



Input v_2 and multiplicity to reproduce the event plane resolution at 19.6 GeV

Apply the efficiency from Hui Wang from 200 GeV (thanks to Hui)
http://www.star.bnl.gov/protected/bulkcorr/wanghui6/my_talks/iTPC/9_20_iTPC.pdf

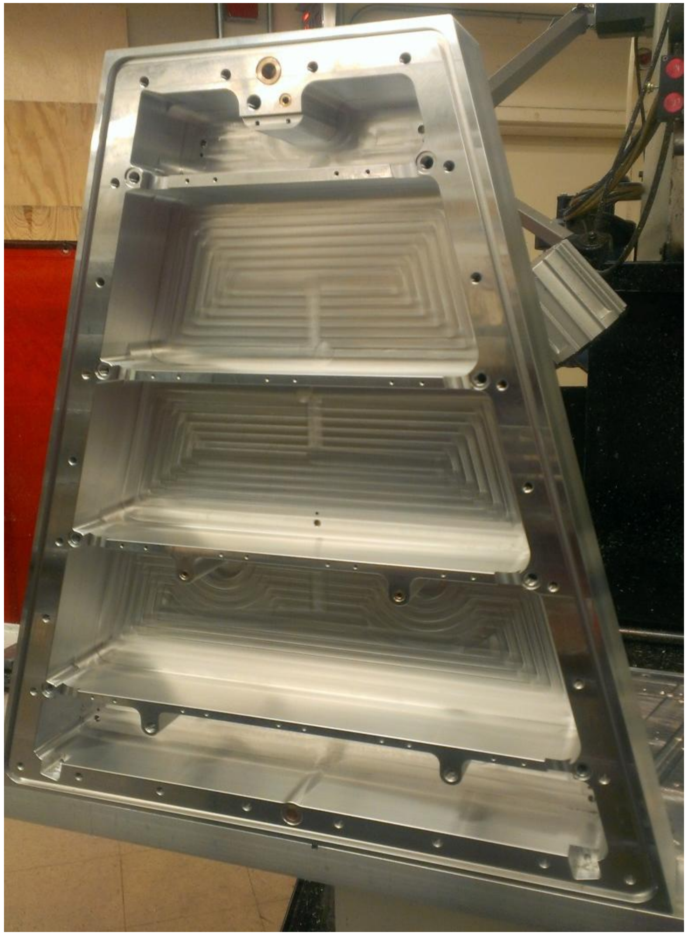
assume efficiency is the same at 19.6 GeV

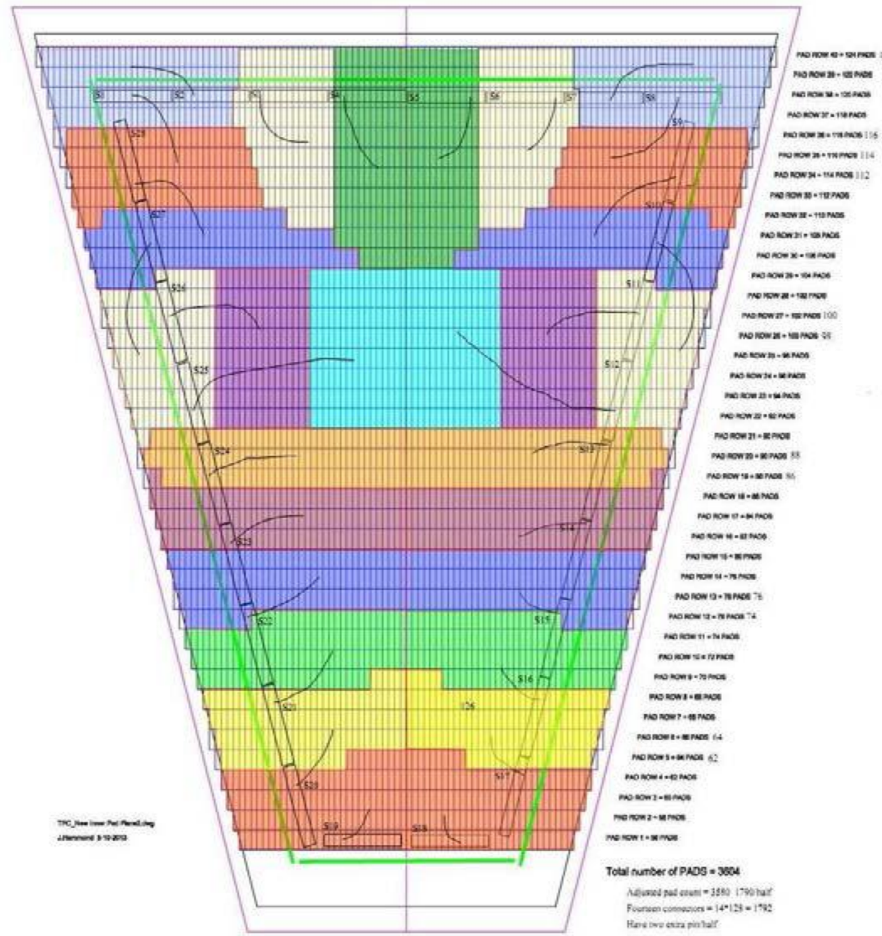


- A factor of ~2 improvement in $1<|\eta|<2$

H. Masui, A. Schmah / LBNL

Conceptual plan for a new inner pad plane design

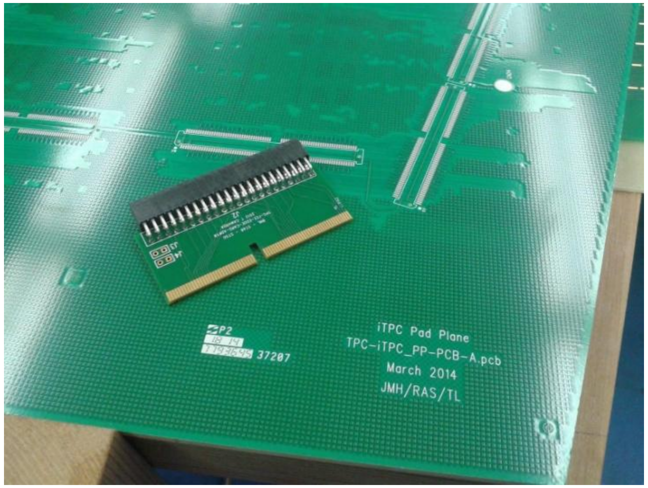




- **5 mm x 16 mm pads, 2 mm spacing, 40 rows, 3500 pads/sector**
- **Move all electronics (and connectors) to outer edges**
- **New, thinner, stiffening technologies to be explored**

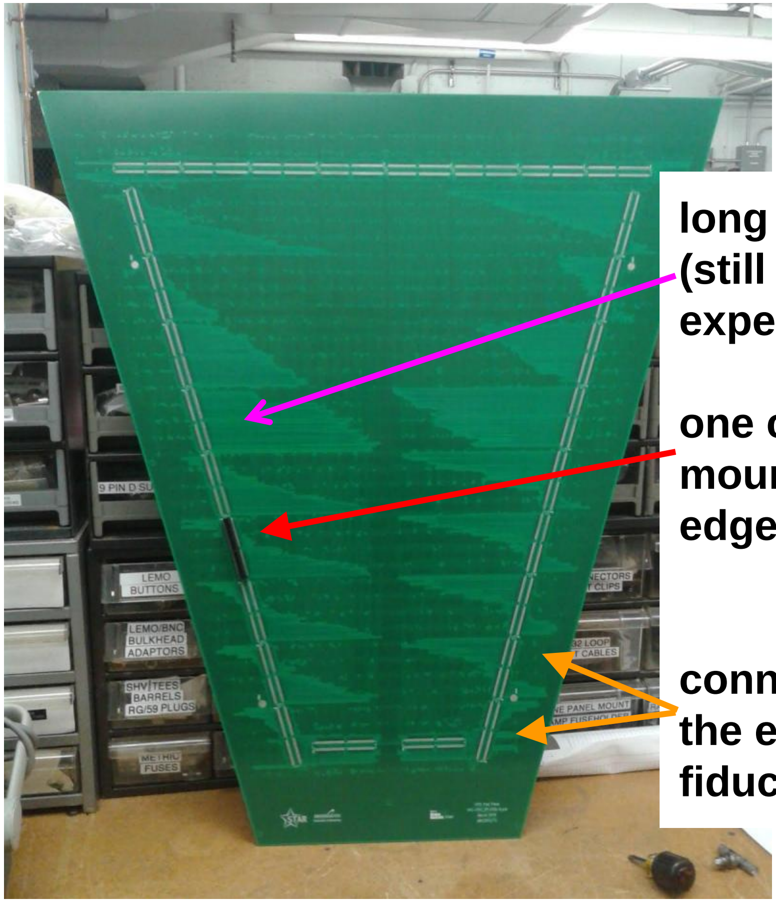
Padplane I

- **Large PCB, halogen-free**
- **Hard to find a vendor who deals with such large PCBs**
  - **$$$ solves all problems**
- **Prototype arrived in May**
- **We also made a few different adaptors which connect the new padplane high-density connector to our old/current TPC FEE cards**
  - **this enables noise & crosstalk tests of the new padplane with the current TPC electronics**
  - **and cross comparison of the old vs. new padplane**



Padplane II

Connector Side



long traces (still experimental)

one connector mounted on edge

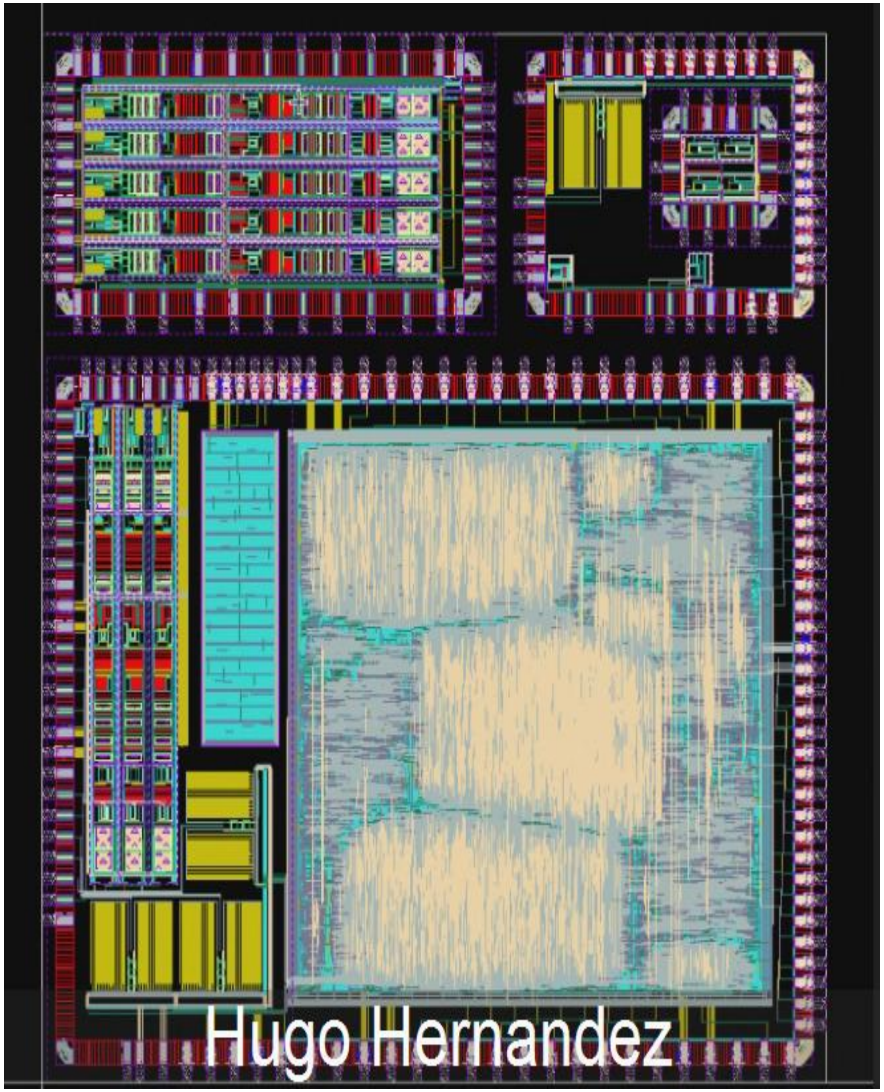
connectors at the edge of the fiducial surface

- **Noise tests with adaptor card and current TPC electronics started in May**
  - preliminary measurements show increase in noise due to long traces from the pads to the connector ⇒ as expected
    - but need to evaluate whether the noise is too high
    - we might consider abandoning FEE placement on the edges of the padplane
  - more measurements and comparisons to the old pad plane will be done in the near future

SAMPA ASIC I

- **Three separate chips have been laid out to be prototyped & tested**

  "Multi Wafer Prototype 1" or simply MWP1
  - **5 channels of analog preamp shaper (top left)**
  - **1 channel of ADC with digital backend (top right)**
  - **3 channels of "full" ASIC: preamp/shaper, ADC, digital manipulation & storage, pedestal memory, fast serial readout (lower, largest, chip)**
  - **Designed by Hugo Hernandez**



SAMPA ASIC II

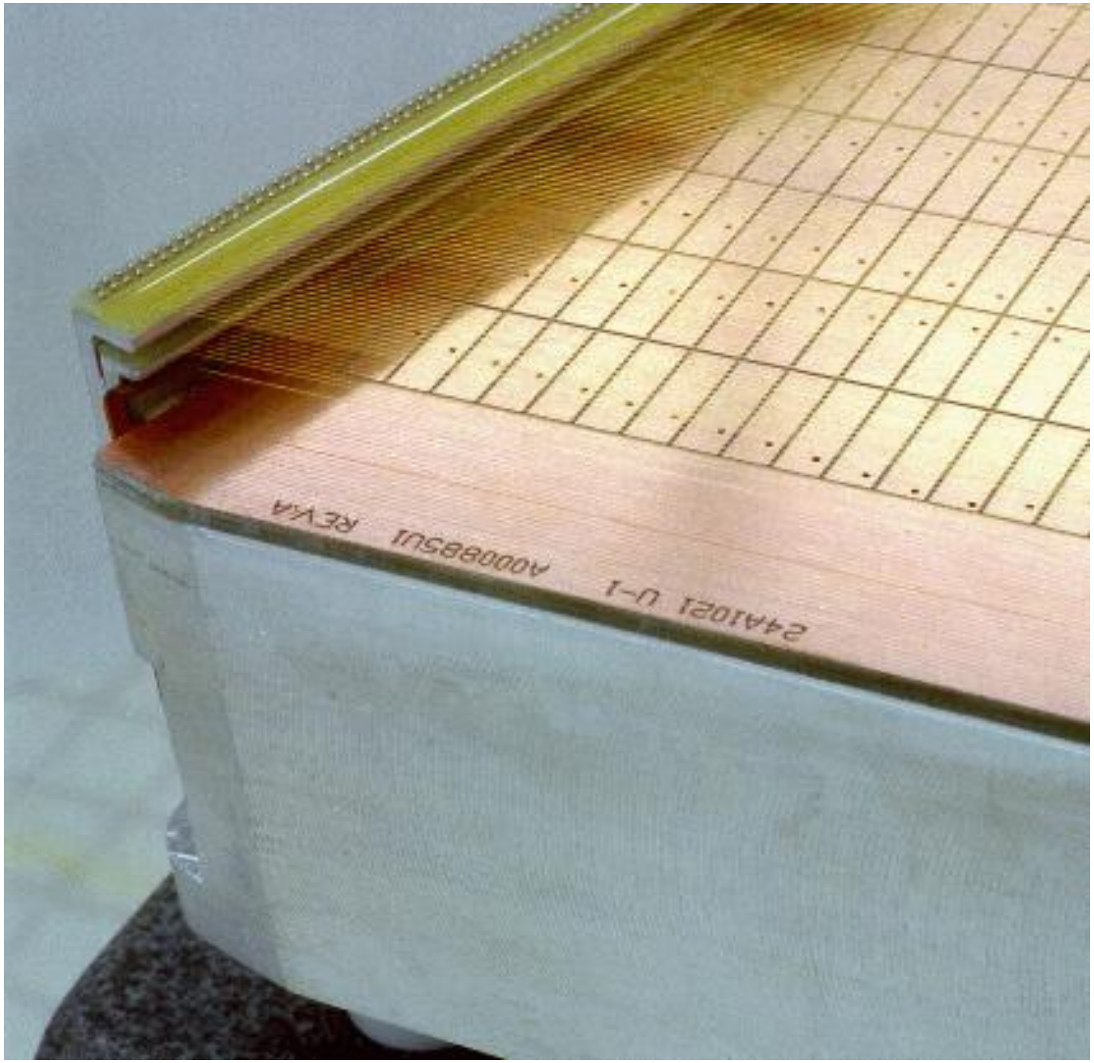
- **After some initial discussion with CERN we decided not to get involved at this early stage of chip design but to wait for a full 32 channel prototype**
  - **early 2015**

However

- **First prototype ("MWP1") sent to the foundry (TSMC, Taiwan) end of May ⇒ expected to be back end of July**

- **Schematics and design of the test PCBs for MWP1 progressing rapidly in CERN/Europe and expected to be ready as the chips arrive**

New wire grids and strongbacks required



- New, lower mass, strongbacks required
- Likely to be designed and fabricated in the US
- New wire grids required
- Wire grids to be designed and fabricated at Shandong University in China

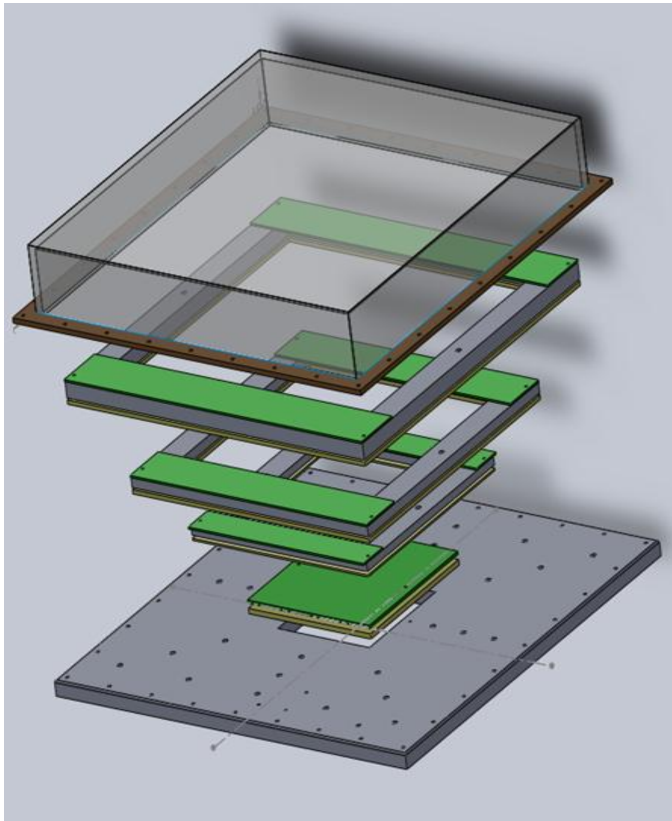
Preparation of SDU labs for iTPC construction

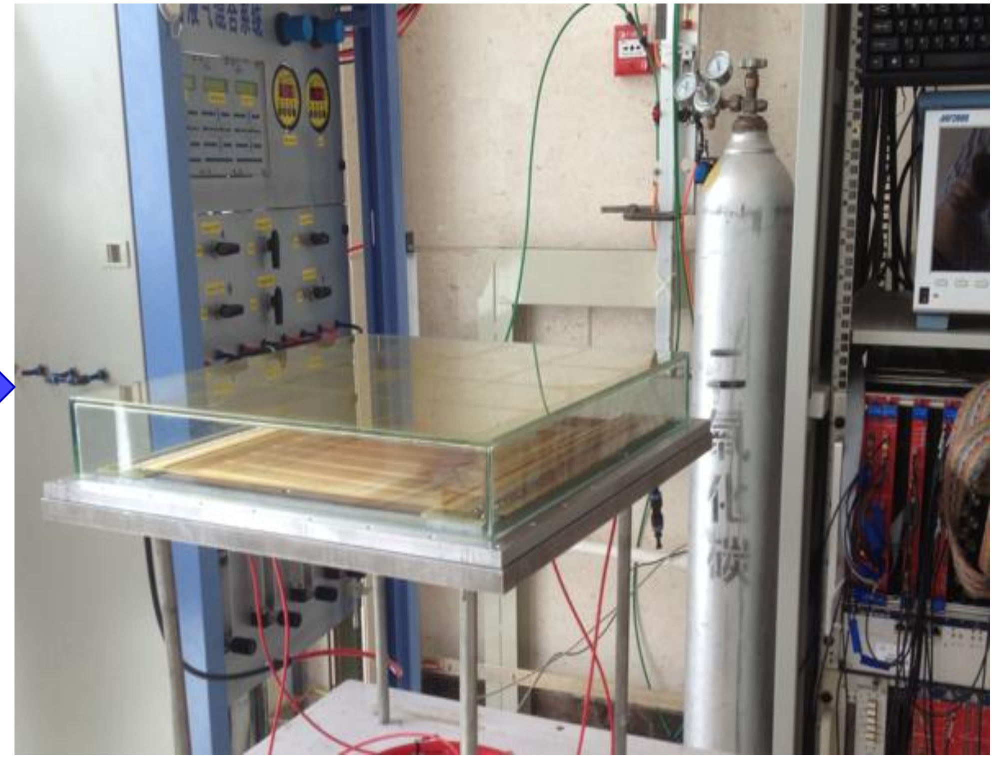
Recently refurbished November 2013
Dedicated space & clean room for
iTPC project

New lab ~150m^2 , with a clean room

Cosmic muon
test system

Small size TPC prototype at SDU



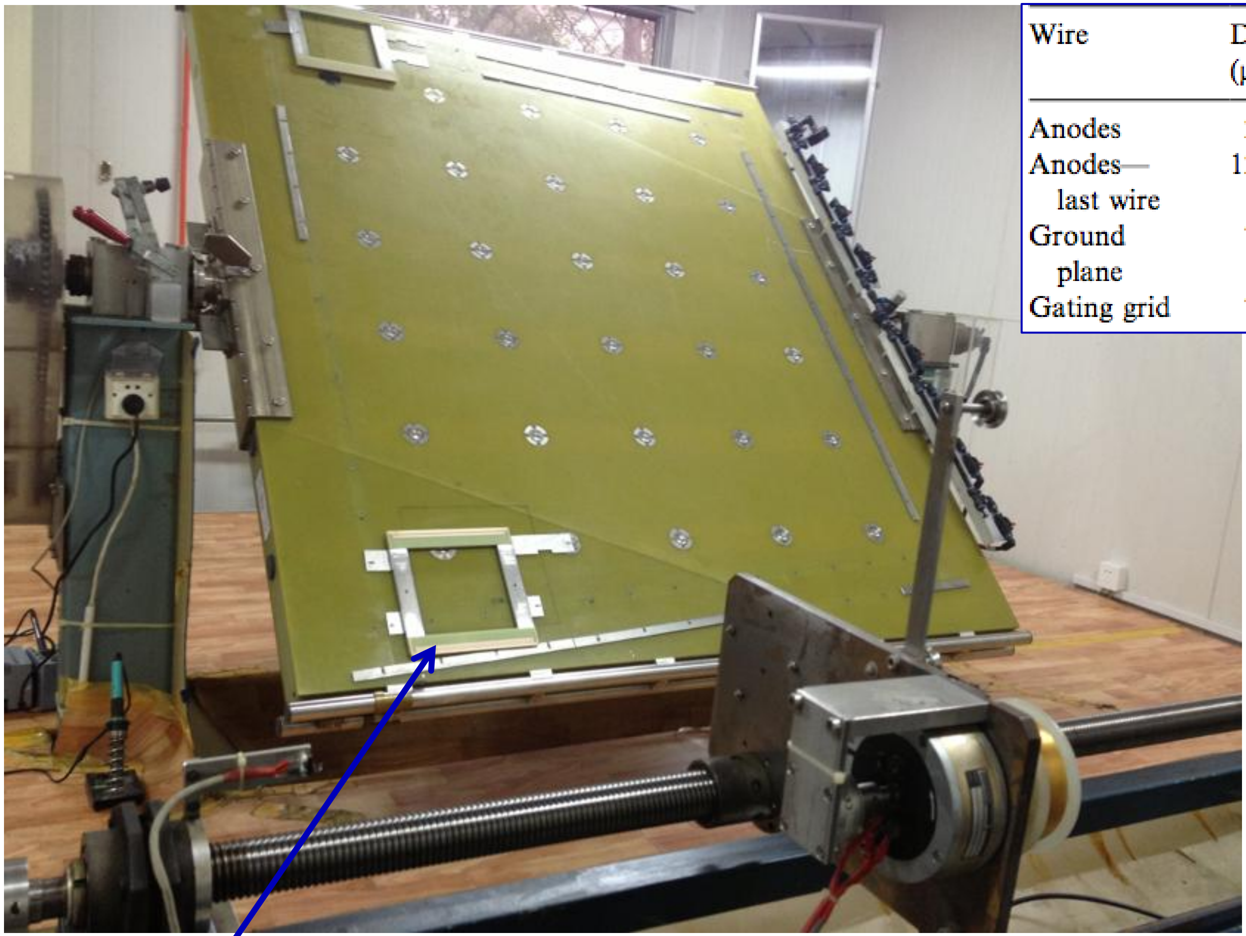


Dimensions: 50 x 50 x 10 cm

Exploded view of the small TPC prototype

Wire winding finished, ready to be tested with gas and cosmic rays

Wire winding setup and testing at SDU



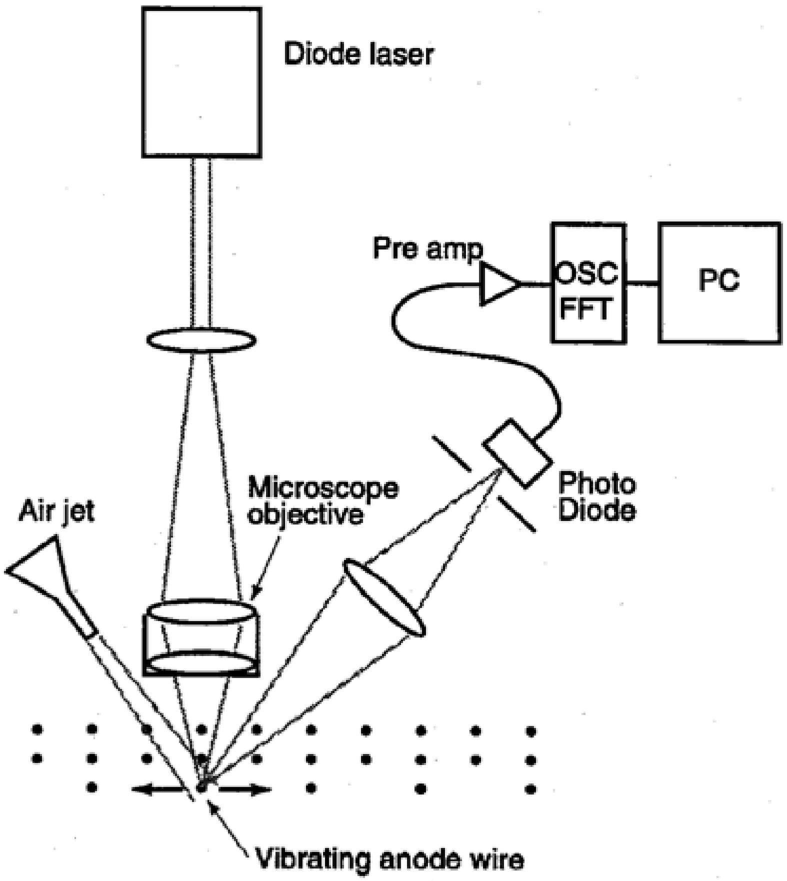
Wire	Diam. (μm)	Pitch (mm)	Composition	Tension (N)
Anodes	20	4	Au-plated W	0.50
Anodes—last wire	125	4	Au-plated Be–Cu	0.50
Ground plane	75	1	Au-plated Be–Cu	1.20
Gating grid	75	1	Au-plated Be–Cu	1.20

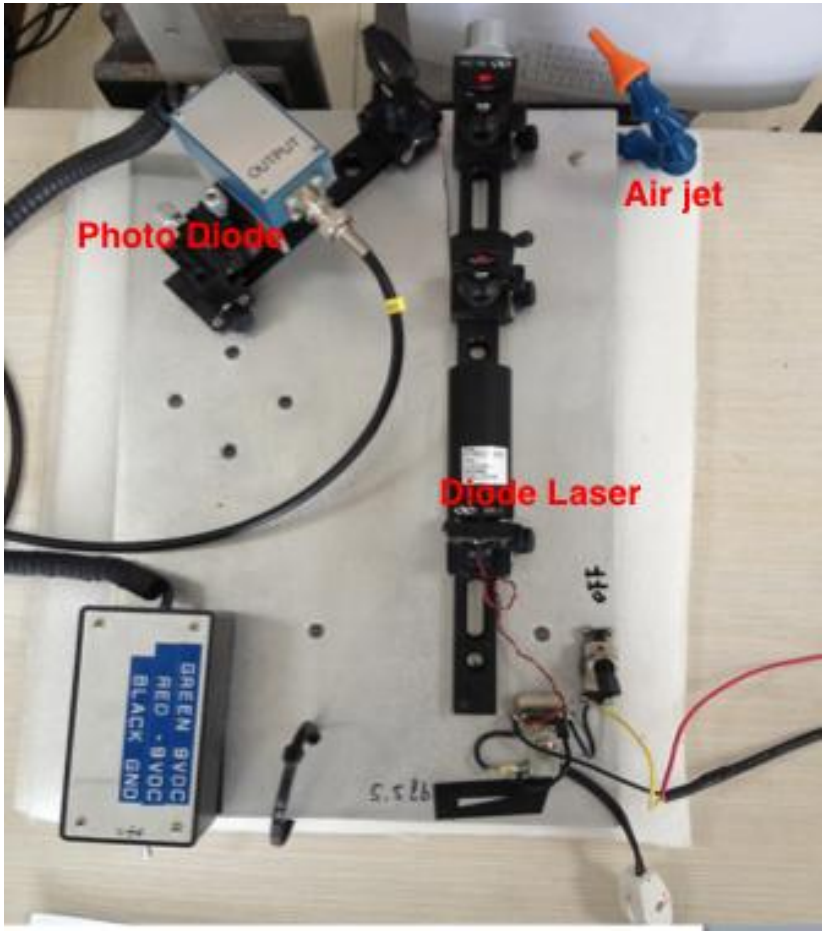
Wire frame for small TPC prototype

Wire pitch and tension controlled by winding machine

Wire tension measurement at SDU

Determine wire tension by optically measuring the vibration frequency



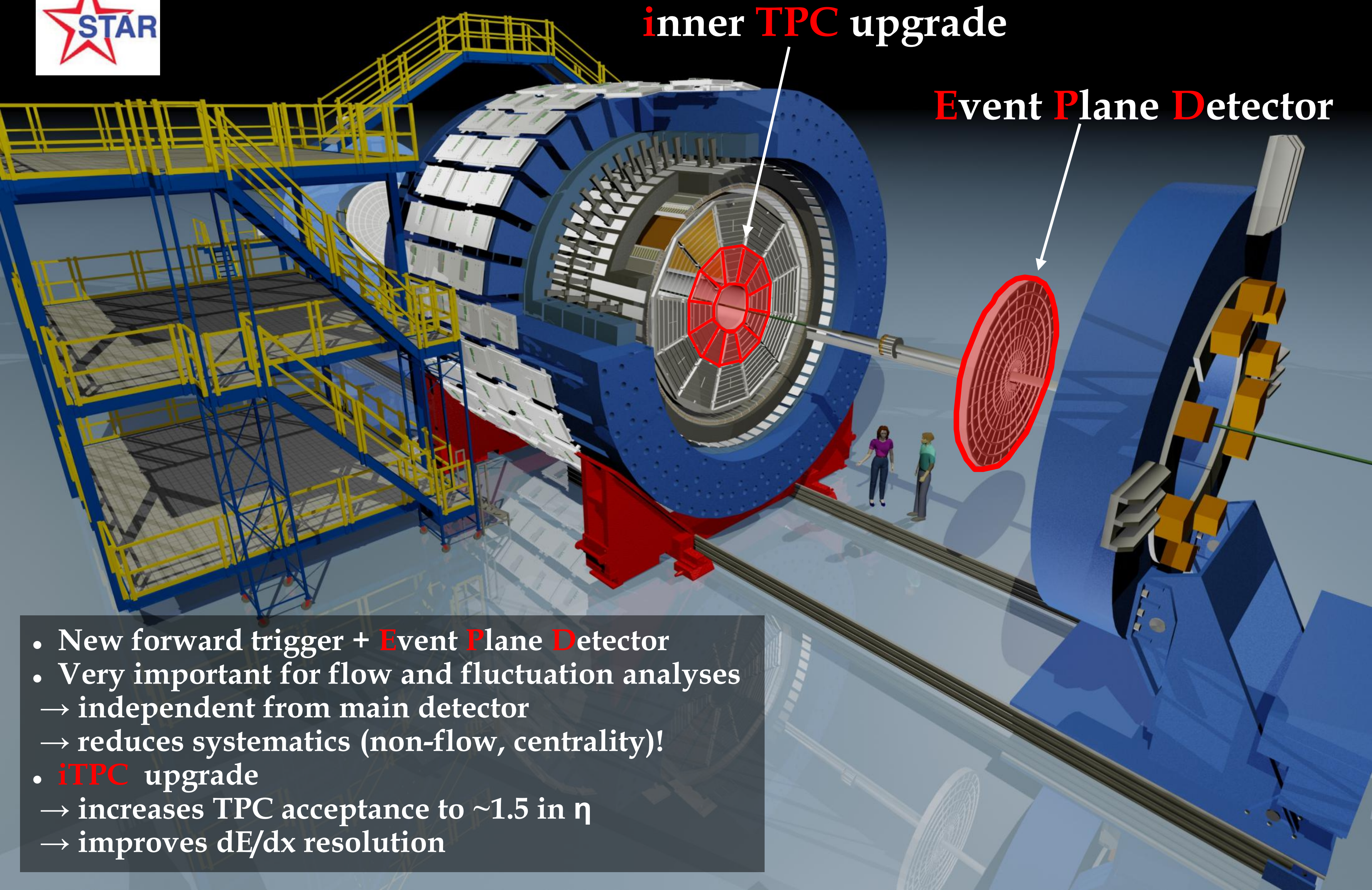


$$f = \frac{v}{\lambda} = \frac{n}{2l}\sqrt{\frac{T}{\rho_{1d}}}$$

Rough Schedule for the iTPC project

calendar	FY14 Q1-2	FY14 Q3-4	FY15 Q1-2	FY15 Q3-4	FY16 Q1-2	FY16 Q3-4	FY17 Q1-2	FY17 Q3-4
Electronics	iFEE+iRDO design + Prototype	Prototype SAMPA test	One TPC RDO test	Finalize Design	SAMPA production	Full Sector test	iFEE iRDO production	Installation for physics
Mechnics Design	Recover drawings	Design new strongback	Cooling+ supports					
Strongback	Replicate two		New prototype		production	finish		
Insertion tool	Secure engineer	Design	Product	Insertion exercise				
MWPC	Small prototype	Test + setup	Large chamber	Final procedure	Production		BNL assembly	Installation

Detector Developments for BES II



- New forward trigger + Event Plane Detector
- Very important for flow and fluctuation analyses
  → independent from main detector
  → reduces systematics (non-flow, centrality)!
- iTPC upgrade
  → increases TPC acceptance to ~1.5 in η
  → improves dE/dx resolution

Motivation for an improved EPD

- **Higher moments of particle distribution are sensitive to QCD critical point**
  Phys. Rev. Lett. 112 (2014) 32302

- **More statistics and better control of systematic error is needed**
  - **centrality determination, independent of the TPC, is needed**

- **Unexpected difference in v_2 between particles and anti-particles observed in BES**
  Phys. Rev. Lett. 110 142301 (2013)

- **Possible explanations include baryon transport, hadronic potentials, ...**

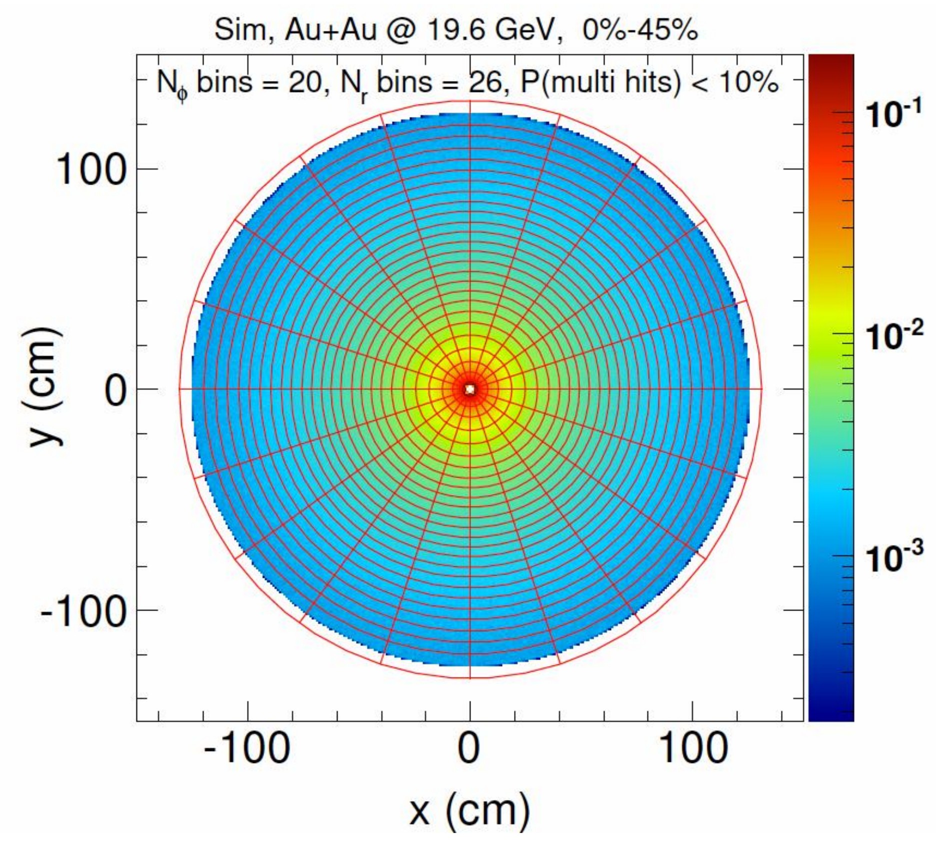
- **Further reduction of systematics, e.g. non flow, is important**
  - **large η gap, independent event plane fromTPC, needed**

A TPC independent reaction plane detector is an important part of making BES II a success

Essential Requirements for an EPD

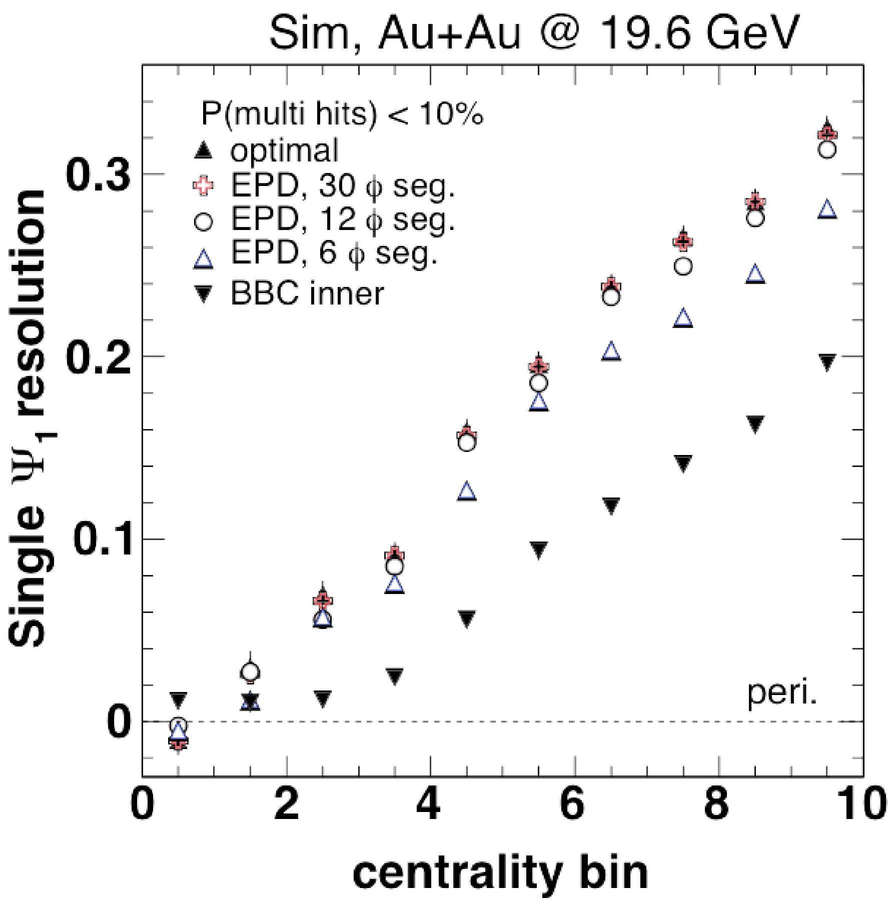
- **Large acceptance to maximize event plan resolution**
- **Fine granularity & single hit resolution for good event plane determination and centrality resolution**
- **Large rapidity gap with respect to the TPC to minimize non-flow effects and auto-correlations (and other correlations)**
- **Good radial segmentation (η segmentation) to reduce event plane biases**
- **Symmetric in pseudo-rapidity (East vs West) to achieve an unbiased event plane and to capture as many particles as possible**

EPD Conceptual Design



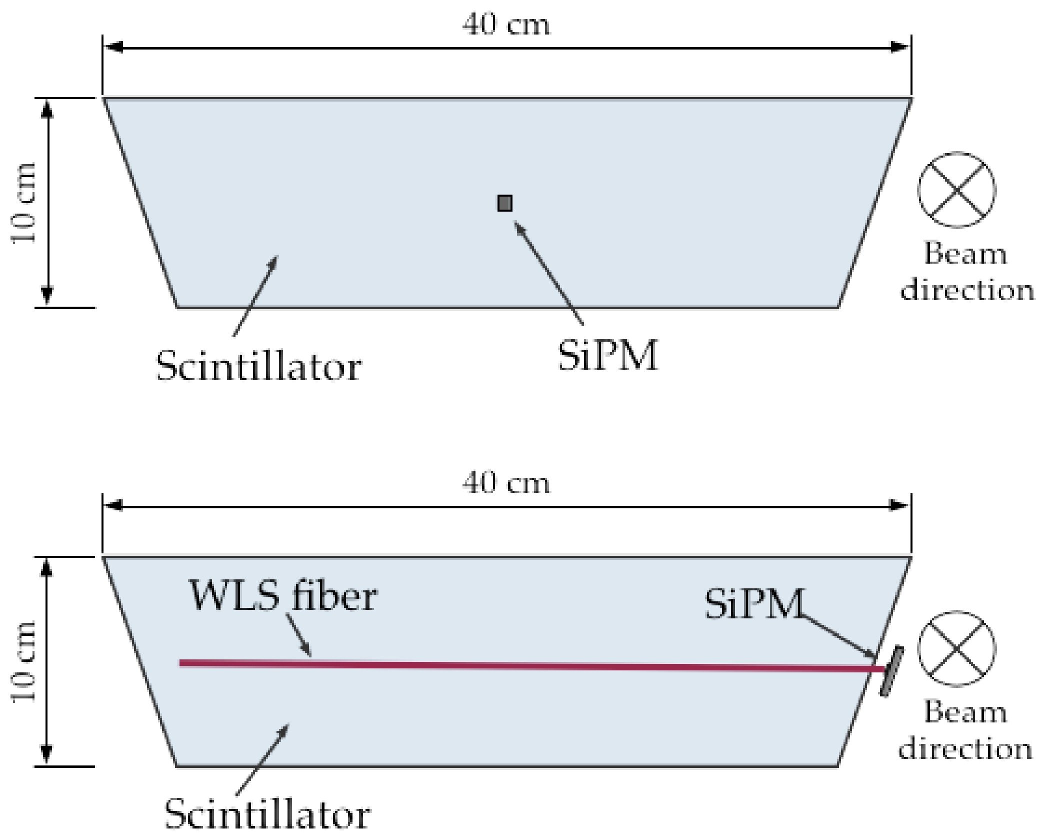
- **Pie shape detector is optimal**
  - **symmetry, η segmentation**
- **Detector will be optimized for a limited number of different tile shapes for cost effectiveness**
- **Large area coverage**
  - **plastic scintillator (fast, efficient, cheap)**
- **Silicon PhotoMultiplier (SiPM)**
  - **for readout of tiles**
  - **cheap, equivalent to standard photomultiplier**

Event Plane Resolution Studies



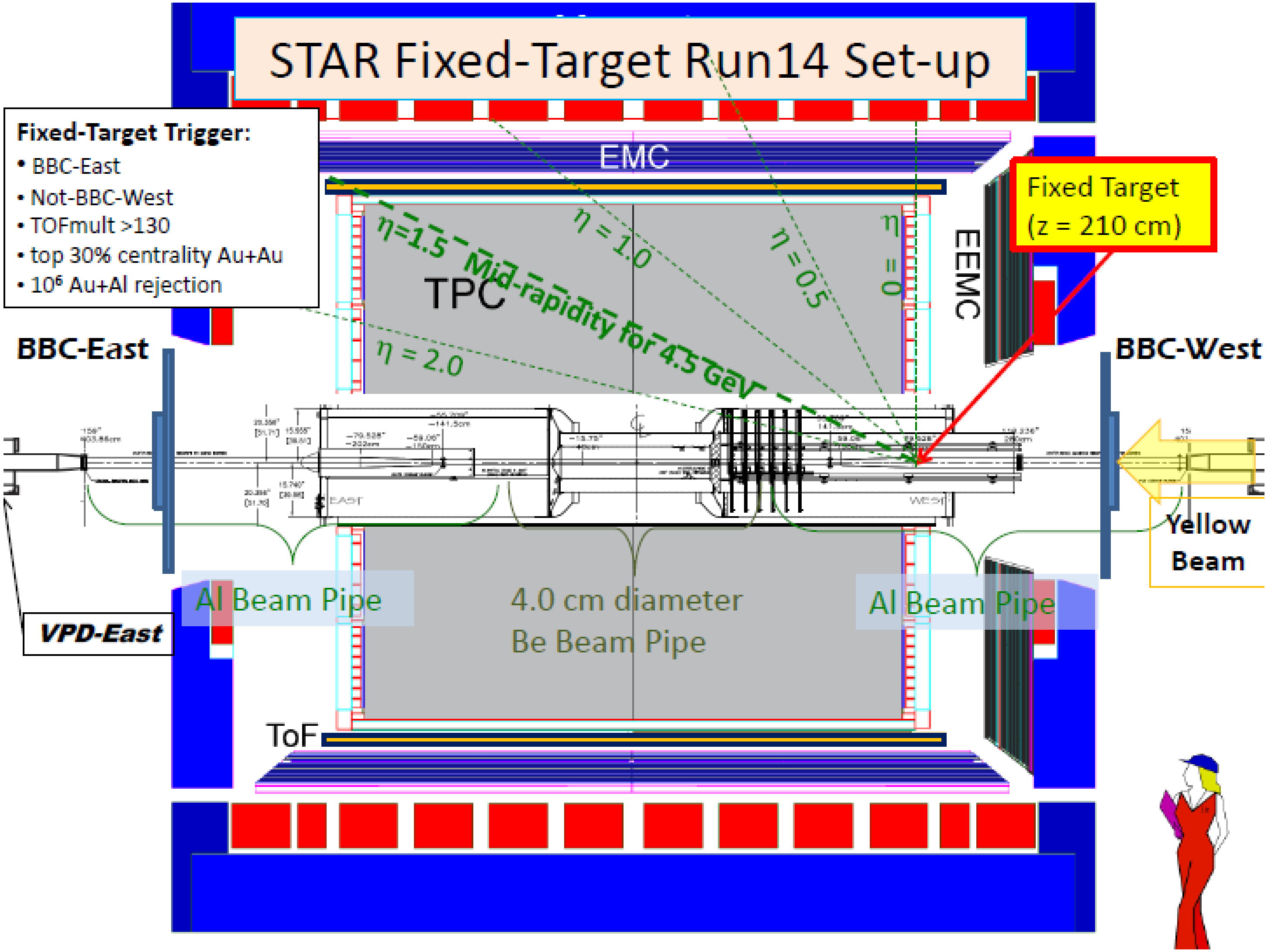
- The event plane resolution was studied as a function of centrality and for different EPD setups
- Optimum reached for ≥ 12 azimuthal segments
- Goal: a factor of 2 to 4 improvement for first order harmonic event plane resolution compared to BBC

“Partial Assembly Required” … R&D needed



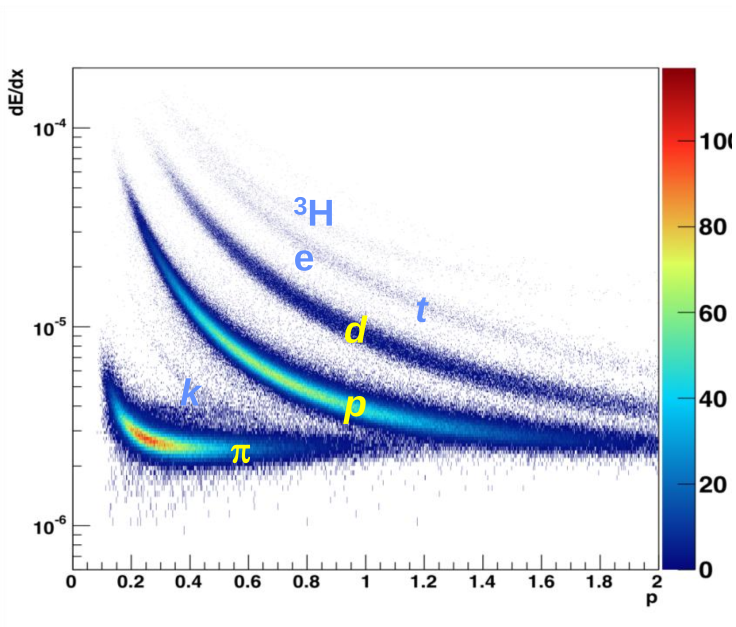
- **Various tile shapes and SiPM configurations to be tested**
- **Light collection for SiPM has to be optimized**
  - **Wave Length Shifting (WLS) fibers are likely to be used**
  - **Installation procedure is primary R&D goal**

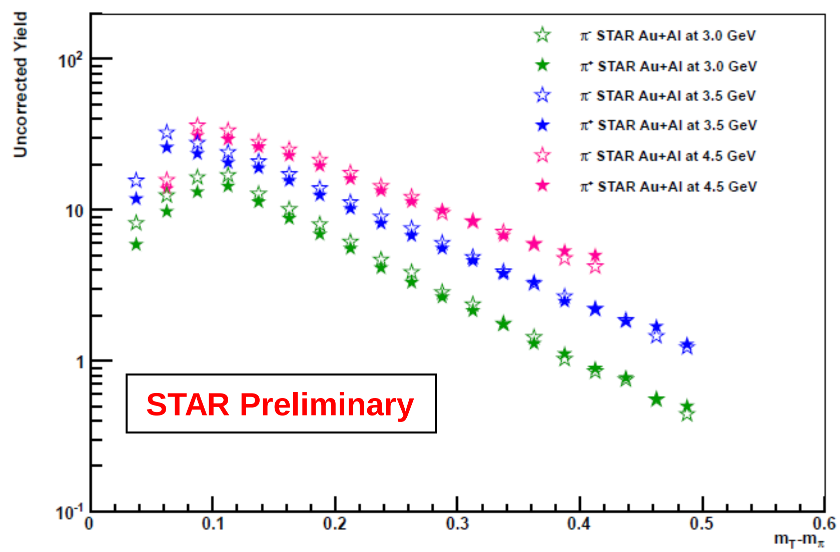
Fixed target geometry



- Schematic diagram of STAR showing the fixed-target location
- The target is a gold foil
- The projectiles are ions from the halo of the “yellow beam”

Proof-of-Principle Au_{Halo}+$Al_{Beampipe}$ Studies (2010 & 2011)

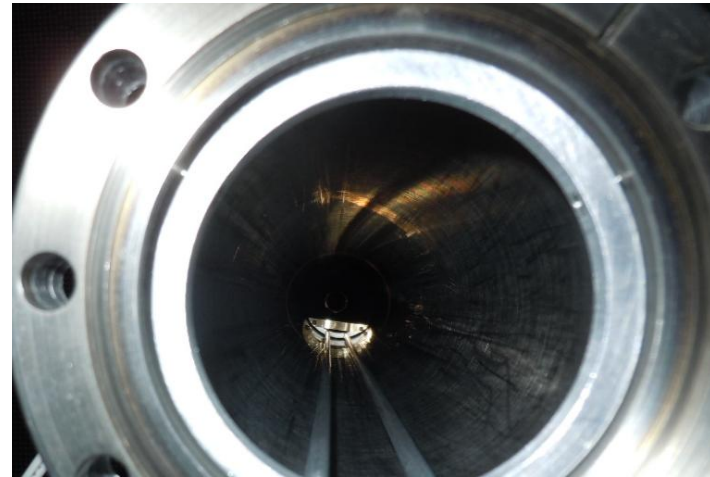




Particle identification is achieved using relative ionization in the TPC gas. A dE/dx versus momentum distribution is shown for 3.0 GeV Au+Al events with 1.5 m < $|V_z|$ < 2.0 m

Invariant pion yields for Au+Al collisions, top 10% centrality, for $\sqrt{s_{NN}}$ = 3.0, 3.5, 4.5 GeV. Efficiency corrections have not yet been applied to these preliminary spectra.

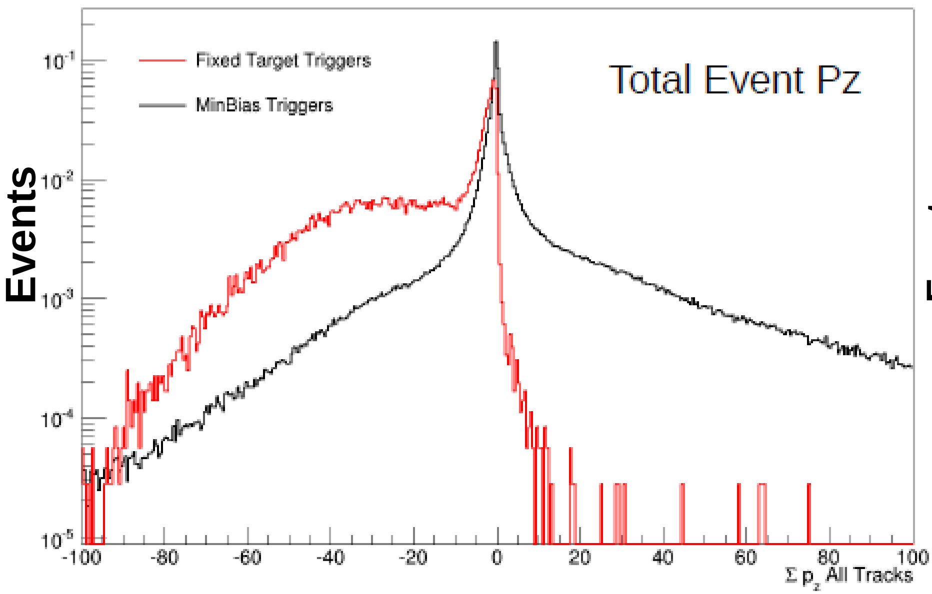
Gold target installation (2014)

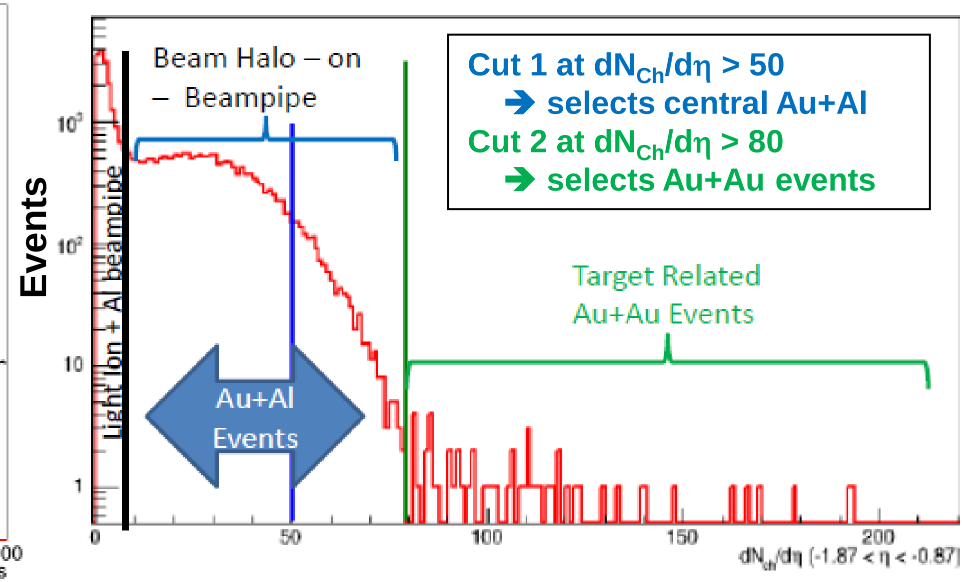


A technician holds the target mount prior to installation. Insets show an isolated view of the target mount. The mount holds the gold foil 210 cm from the center of the detector.

A view down the beam pipe shows the internal target mounting bracket installed in the west end of STAR. The inset shows how the 1 mm thick gold foil (4% target) is supported ~2 cm below the beam axis.

Fixed target trigger tests (2014)





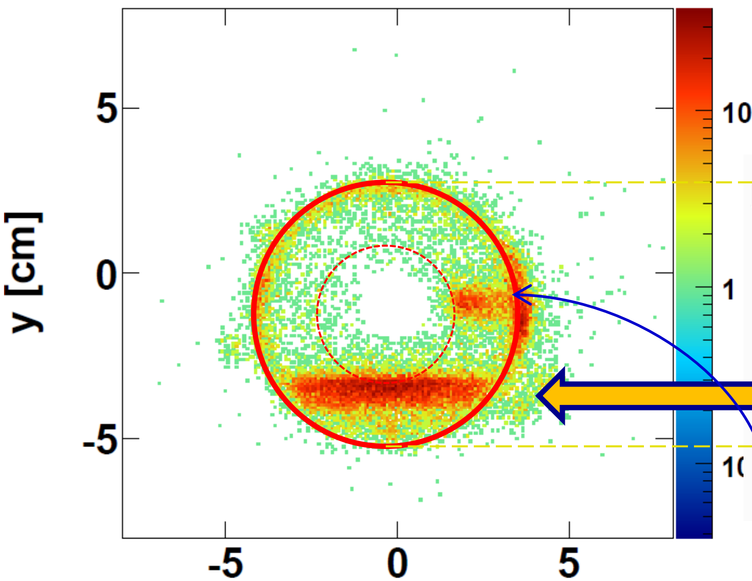
Au+Au collider events have zero momentum in the *z* direction, whereas collisions with a fixed-target (beampipe or gold target) won't.

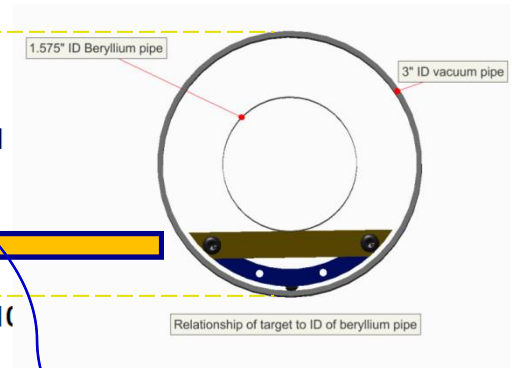
MinBias triggers (black curve) suffer background from both beams (East and West). The fixed-target trigger (red) selects events headed East (negative Σp_z).

$dN_{Ch}/d\eta$ of fixed-target trigger events. Three classes of events can be identified:

1) **Light ion induced reactions on the BP**
2) **Au ions incident on the beam-pipe**
3) **Au ions incident on the gold target**

Fixed target geometry and reconstructed events

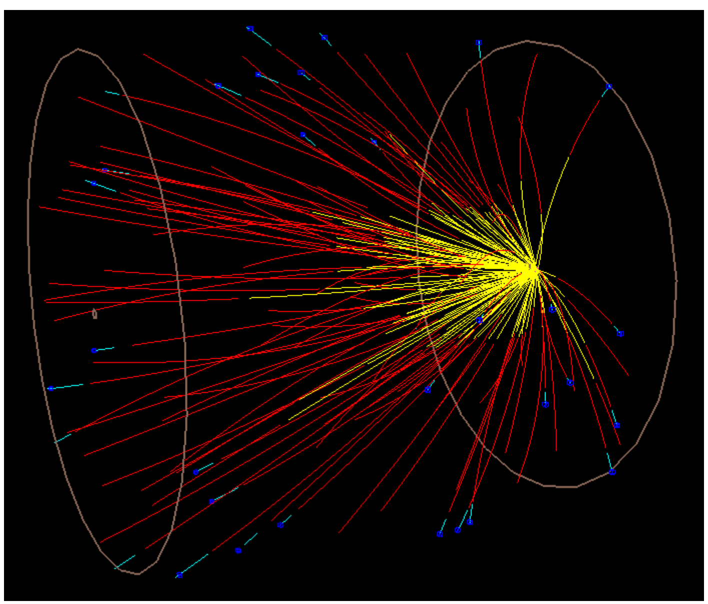




Left: *x*-*y* vertex location for events with $208.5 < V_Z < 210.2$ cm

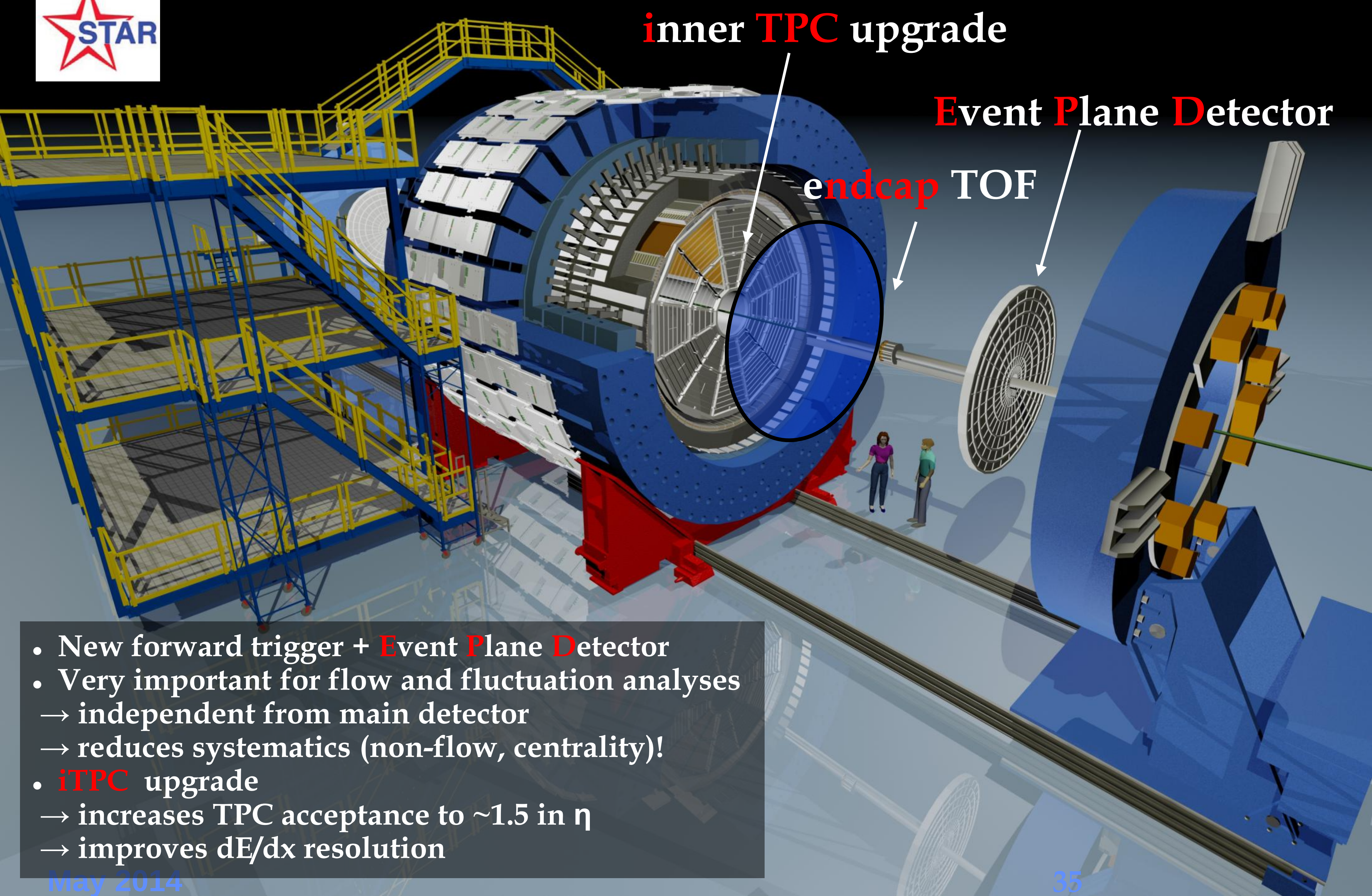
Right: Schematic of the target mount.

A significant source of background comes from beamlike projectiles deflected by the dipole magnets in the positive *x* direction.



Reconstructed tracks for an event coming from the gold target.

Detector Developments for BES II



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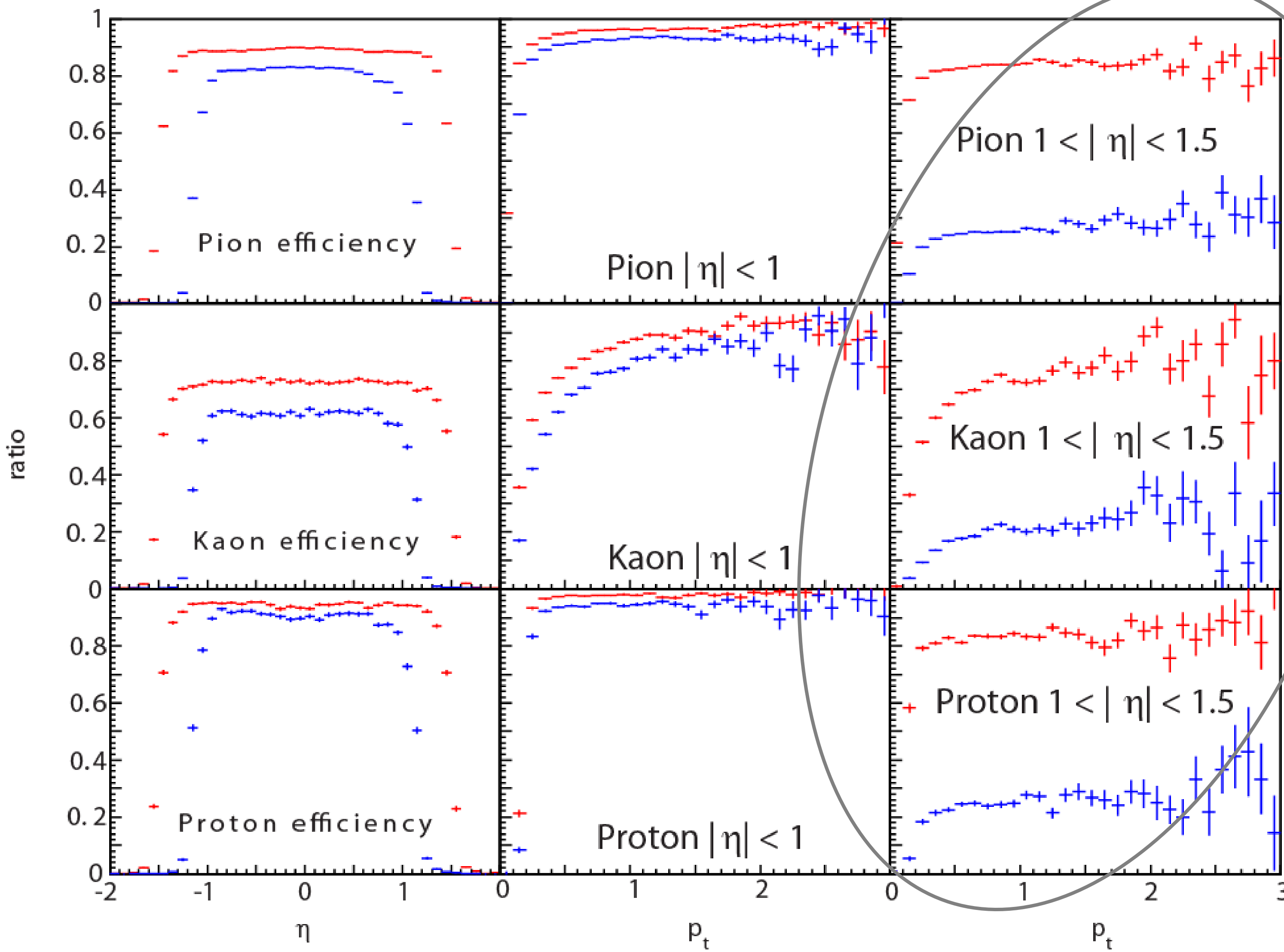
Motivation for EndCap TOF – improved PID



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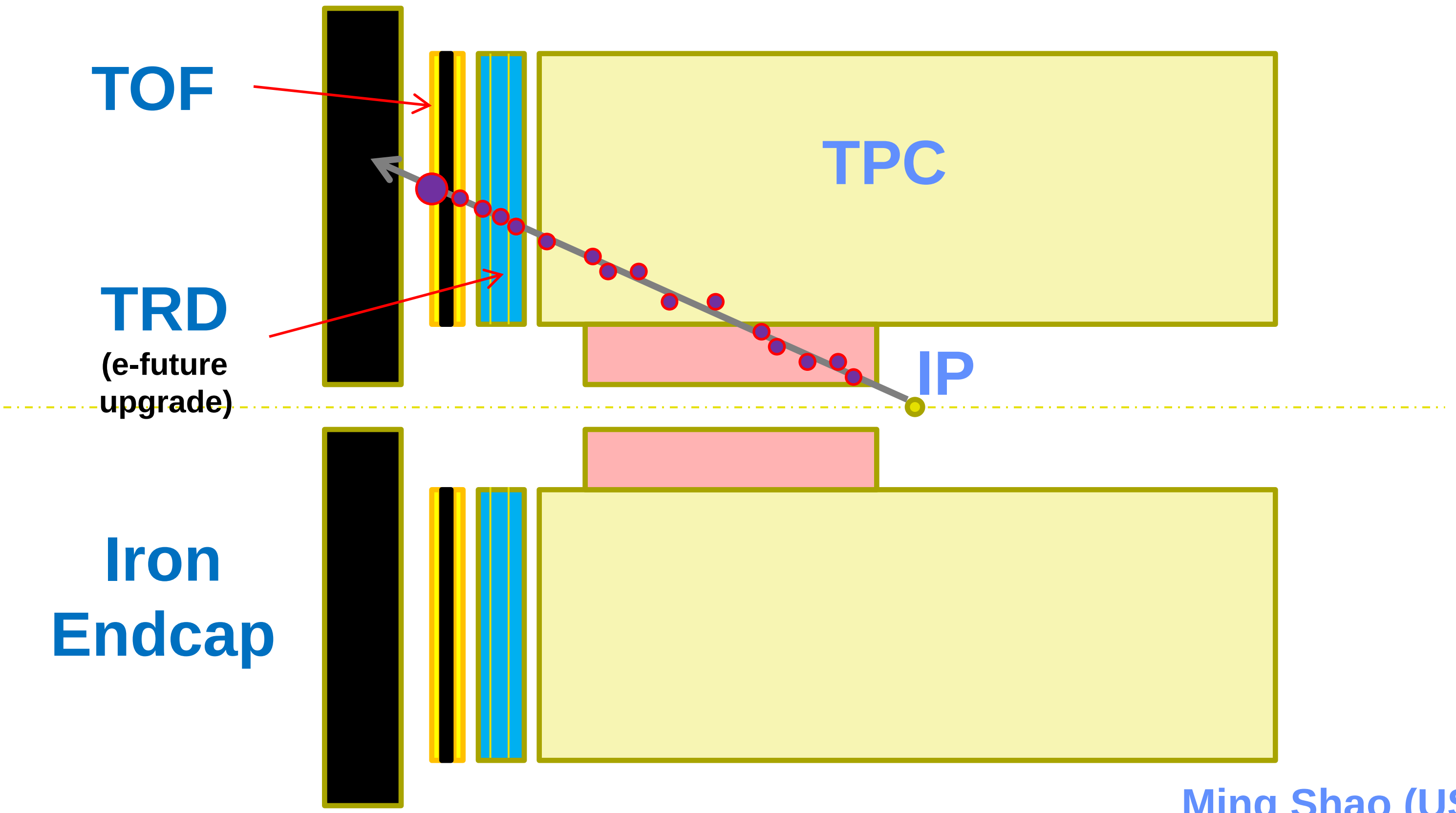
Improved PID in the forward direction is highly desireable

TOF at the Endcap (-2 < η < -1)



Ming Shao (USTC)

- Utilize space inside endcap (~50 cm)
- Extend track path length with precise points
- TOF for hadron PID & start-time for BTOF and MTD
- TOF + dE/dx for electron ID

Summary

- **STAR is actively planning for the Beam Energy Scan Phase II program**
- **The goal is to explore the phase diagram for hot nuclear matter near the critical point**
- **We will do this with a number of extensions and upgrades to the detector**
  - **Fixed target at 2 m from the nominal IP enables measurements at $\sqrt{s_{NN}}$ < 7.7 GeV**
  - **iTPC: improved segmentation and better tracking at small radii and larger rapidities**
  - **EPD: an event plane detector with improved segmentation in R and Phi**
  - **Perhaps even an endcap TOF upgrade … although this is unfunded at this time**

- **Thank you & Acknowledgements**
  - **Brooke Haag**
  - **Alex Schmah**
  - **Dan Cebra**
  - **Tonko Ljubicic**
  - **Qinghua Xu**
  - **Grazyna Odyniec**
  - **Bill Llope**
  - **Alexei Lebedev**
  - **Jamie Dunlop**
  - **Zhangbu Xu**
  - **and many more …**

References

- **Fixed target program**
  - **Outstanding QM Poster by Brooke Haag – Poster M-07**
    https://indico.cern.ch/event/219436/session/2/contribution/459

- **Physics at High Baryon Density – The Low Energy Scan**
  - **Outstanding QM talk by Alex Schmah**
    https://indico.cern.ch/event/219436/session/3/contribution/724
  - **Proposal to the STAR collaboration for a new Event Plane Detector**
    https://drupal.star.bnl.gov/STAR/system/files/STAR_R_and_D_proposal_EPD.pdf

- **eTOF – An Endcap Time of Flight system for STAR**
  https://drupal.star.bnl.gov/STAR/system/files/eTOF_RD.pdf

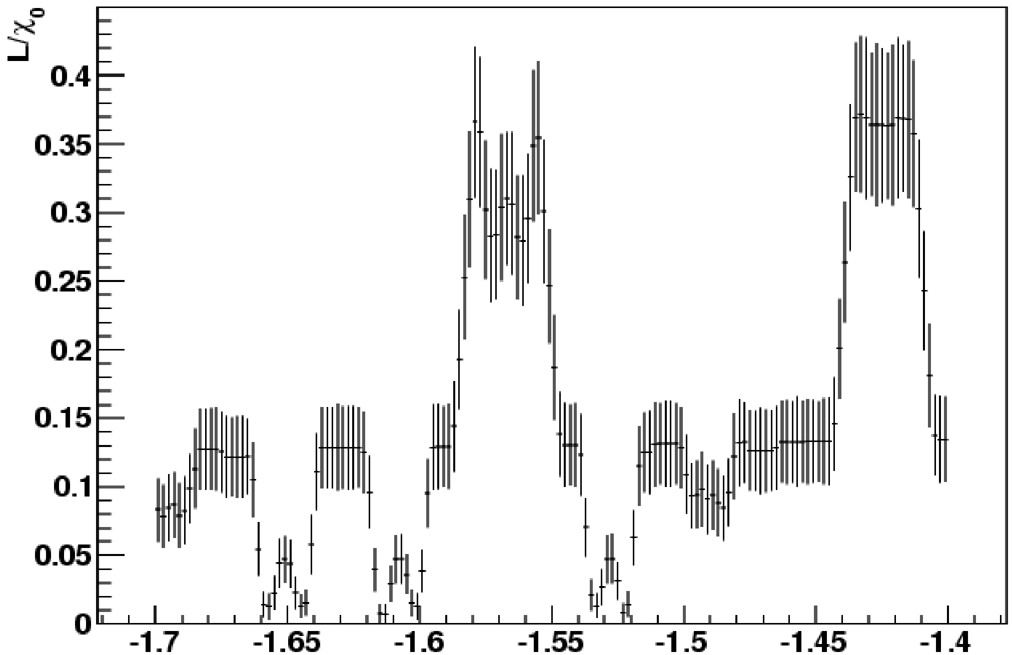
- **Beam Energy Scan White Paper – by the STAR Collaboration**
  https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

Obviously, I am only the rapporteur. A large number of people are involved in this work. Recent reports from the experts are listed above.

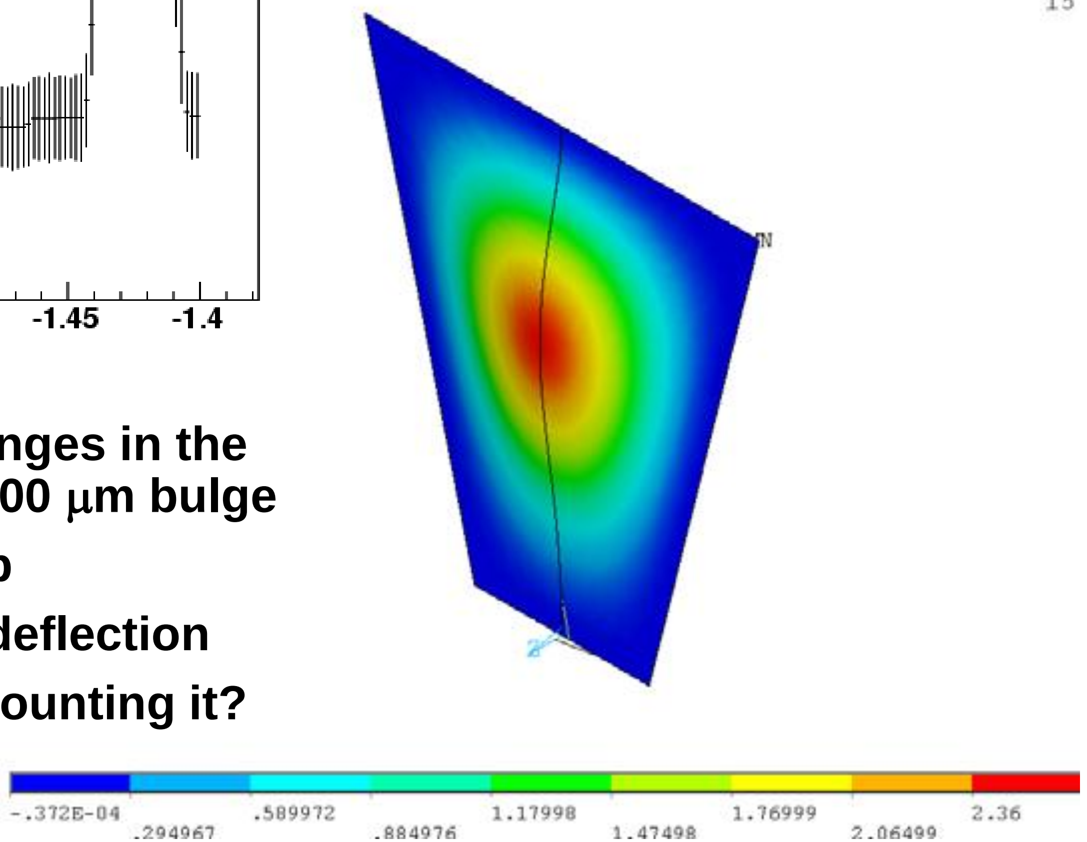
Backup Slides

A new strongback design is desirable

TPC sector material (no RDO/Cooling)

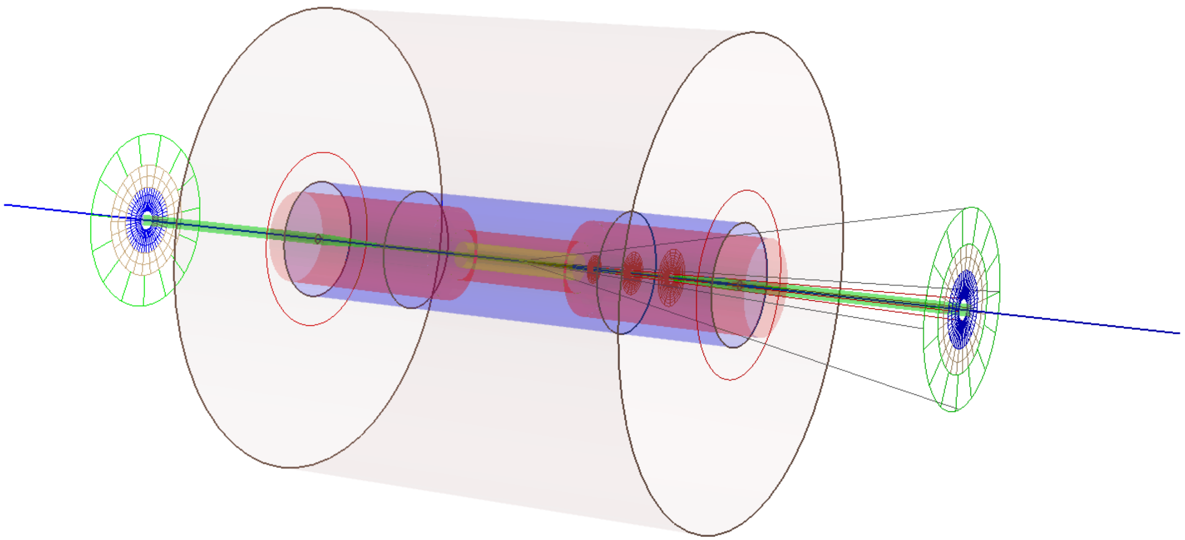


- The mass of the ribs is significant and affects p_T resolution in the forward direction (especially e^-)



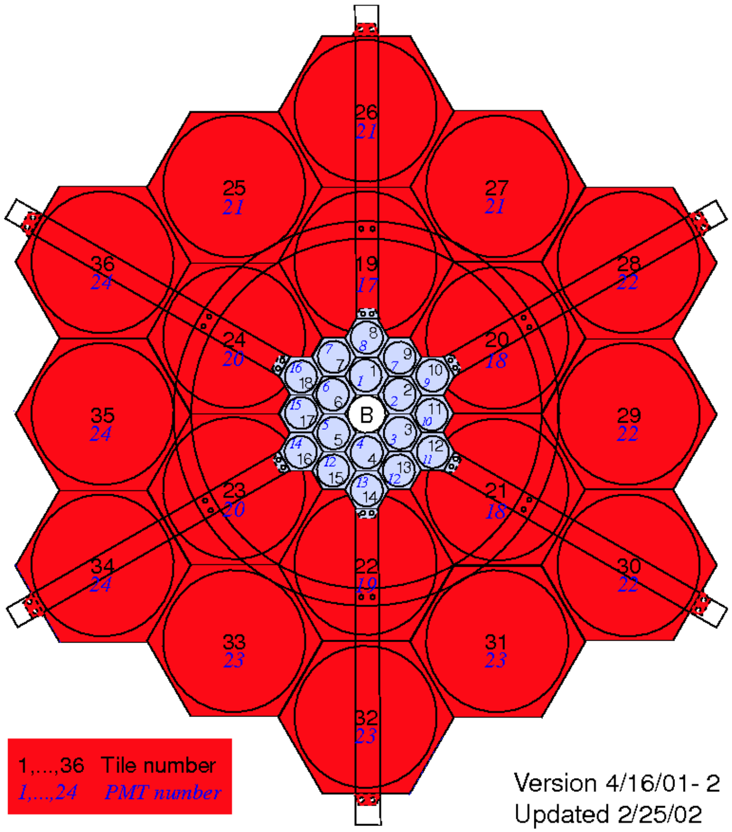
- Deflection due to pressure changes in the TPC (~2 mbar range) leads to 300 μm bulge
- Can be reduced by 8x with a rib
- Need to study wire tension vs deflection
- How to hold the sector while mounting it?

Location of the new Event Plane Detectors



Beam Beam Counters at STAR

STAR Beam-Beam Counter Schematic
Front View



Version 4/16/01- 2
Updated 2/25/02
12/4/02

- **18 inner tiles and 18 outer tiles**
- **16 inner PMTs, 8 outer PMTs**
- **Only inner tiles used (d = 9.64 cm)**
  - $3.3 < \eta < 5.0$
- **ADC value used to distinguish multiple hits**
- **Yeoman workhorse for STAR but not designed for high segmentation nor, especially, flow measurements**

Timeline and Goals

Achievement	Time estimate
Simulations for different tile geometries	mid of 2014
Basic tests with SiPM and scintillators	mid of 2014
Demonstrator for basic trigger tests	end of 2014
Polishing and wrapping technique developed	begin of 2015
Two sector prototype	mid of 2015
Integration of prototype into STAR + DAQ	end of 2015
Construction proposal	end of 2015

Table 1: Timeline and goals.

RHIC Run Schedule

STAR

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2014	15 GeV Au+Au 200 GeV Au+Au	Heavy flavor flow, energy loss, thermalization, etc. Quarkonium studies QCD critical point search	Electron lenses 56 MHz SRF STAR HFT STAR MTD
2015-16	p+p at 200 GeV p+Au, d+Au, ^{3}He+Au at 200 GeV High statistics Au+Au	Extract η/s(T) + constrain initial quantum fluctuations More heavy flavor studies Sphaleron tests Transverse spin physics	PHENIX MPC-EX Coherent e-cooling test
2017	No Run		Low energy e-cooling upgrade
2018-19	5-20 GeV Au+Au (BES-2)	Search for QCD critical point and onset of deconfinement	STAR ITPC upgrade Partial commissioning of sPHENIX (in 2019)
2020	No Run		Complete sPHENIX installation STAR forward upgrades
2021-22	Long 200 GeV Au+Au with upgraded detectors p+p, p/d+Au at 200 GeV	Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism Color screening for different quarkonia	sPHENIX
2023-24	No Runs		Transition to eRHIC

Table 2-1: A long-term view of the RHIC operations schedule leading to a transition to eRHIC.