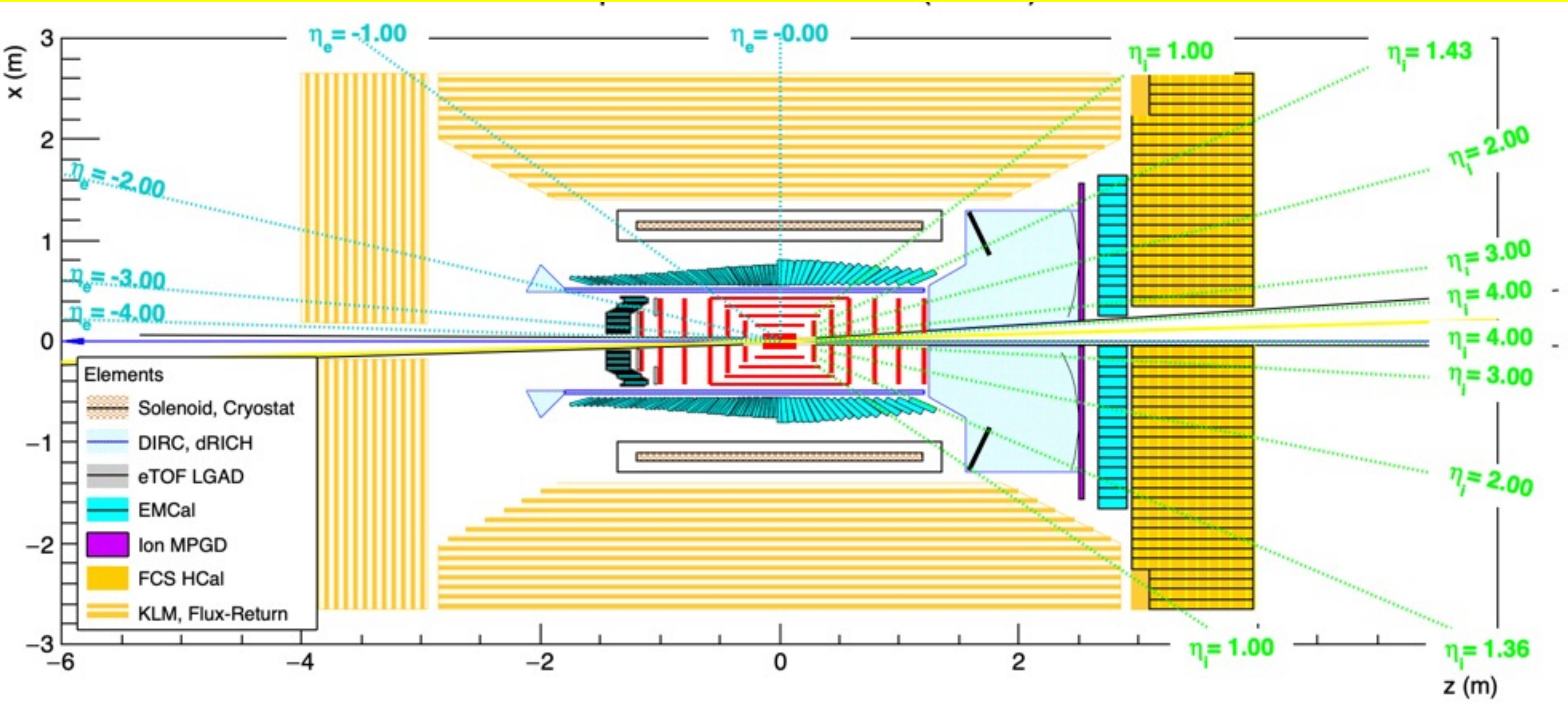
COmpact detectoR for the Eic (CORE)



EIC White Paper: Physics Goals

- Proton Spin:
  - Quark spin Σ, Gluon spin ΔG
- Motion of quarks and gluons in the proton.
  - Spin-dependent Transverse Momentum Distributions (TMDs)
- Tomographic (spatial) images of the proton
  - Spatial imaging and quark/gluon orbital angular momentum
- QCD matter at extreme gluon density
  - Coherent Diffraction on heavy nuclei
- Quark hadronization

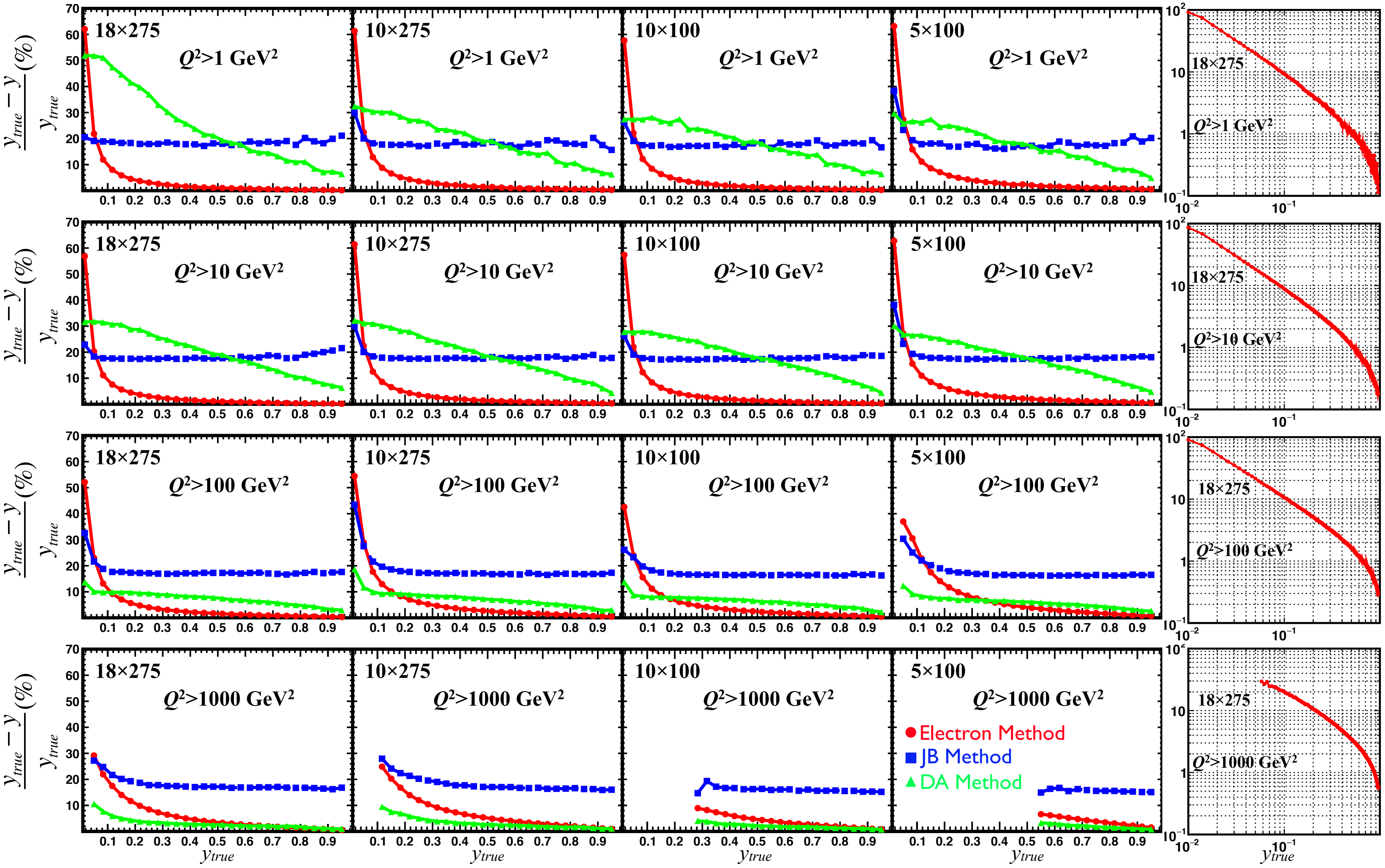
NAS: Science Case for EIC

- Chapter 2:
  - The Origin of Mass
    - Spatial Distribution of energy density and pressure
  - The Origin of Spin
    - Gluon spin
    - Quark and Gluon orbital angular momentum
  - Gluons in Nuclei
    - Gluons and Nuclear Binding
    - Gluon saturation in nuclei
    - Coherent Diffraction of heavy nuclei

Call for Collaboration Proposals

- CORE addresses the EIC White Paper and NAS Report science case.
- CORE meets or exceeds the design requirements of Yellow Report Table 3.1 https://physdiv.jlab.org/DetectorMatrix
  - CORE physics program would match the physics performance of any simulation based on these requirements.
- The central CORE detector is compatible with either the IR layout of the EIC CDR.
- CORE would benefit from some IR optimization:
  - CORE only requires a magnet-free space L* = 4m
  - Increase in luminosity, forward acceptance (1/L*) and decrease in chromaticity (L*) *vis-à-vis* CDR (4.5 m).
  - CORE is synergetic with a secondary focus currently implemented for IR8.
- CORE has distinct complementarity to the YR reference detector and offers unique opportunities for science beyond the EIC White Paper.

Precision DIS on proton & Nuclei



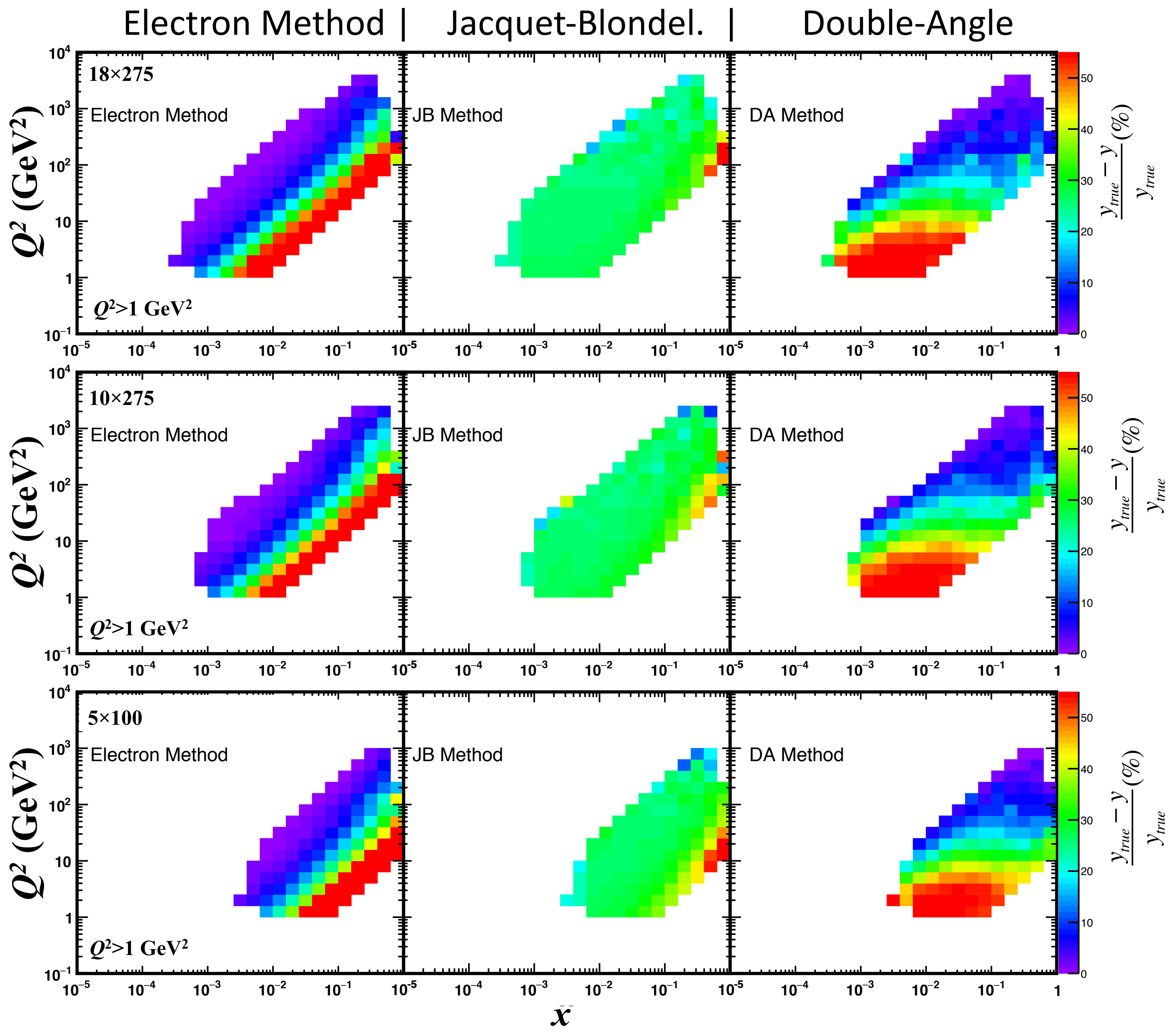
- Excellent tracking and EMCal for kinematic reconstruction
- $y = \dfrac{(q \cdot P)}{(k \cdot P)}$
- (e,e') best for *y>0.1 & $Q^2 \leq 100$*
- *Jacquet-Blondel ~20% for y≥0.05 (jet only)*
- *Double-angle best for $Q^2>100$ ($\theta_e \otimes \theta_{Jet}$)*
- Percent precision at large-*y* ➔ small x_B

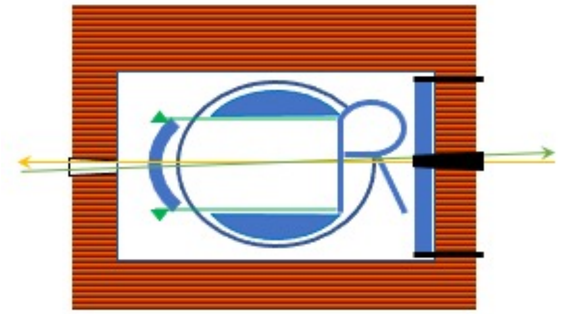
DIS in CORE

18x275

10x275

5x100





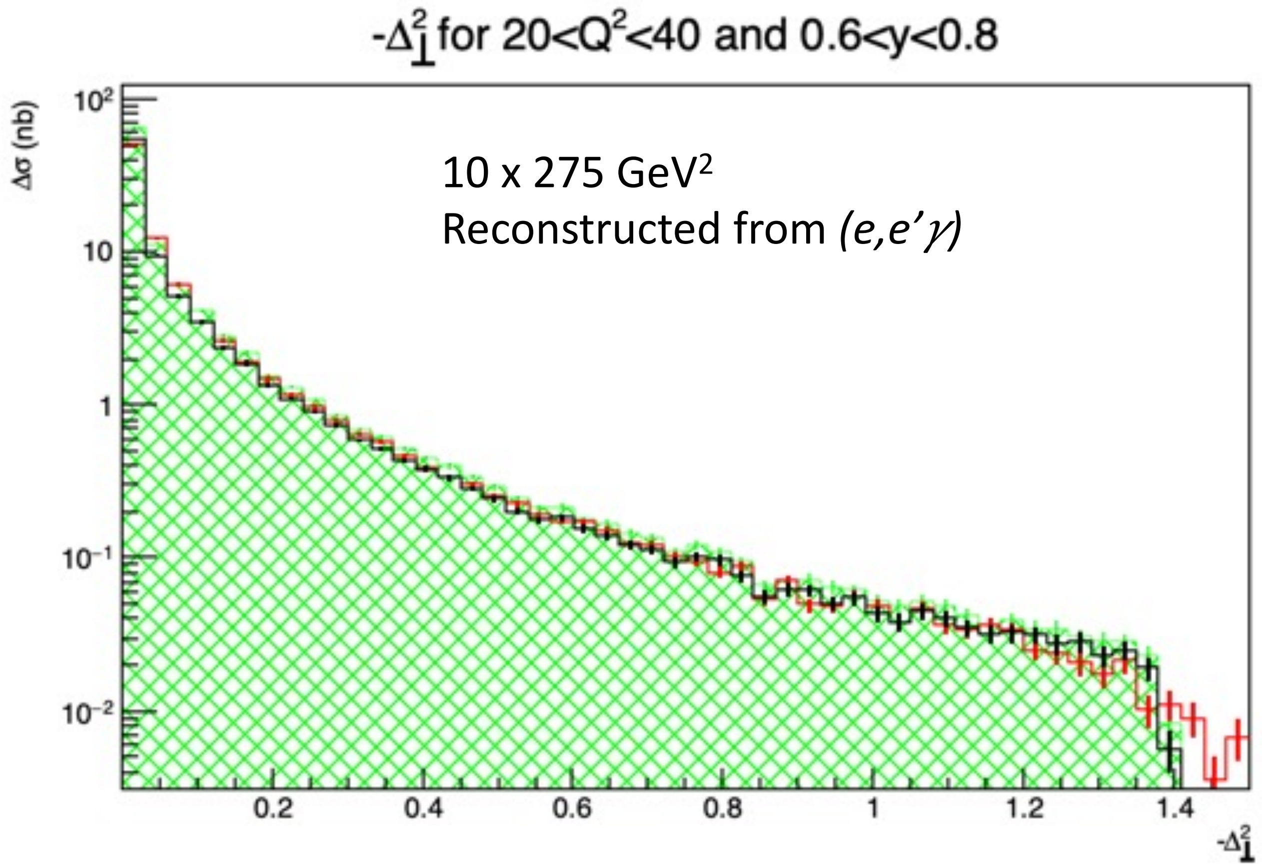
- $\sigma(y)/y$ reconstruction (color) in Q^2 vs x_B plane
- ~percent precision on *y* (and *x*) at low-*x*
  - Precision on depolarization factor for $g_1(x)$

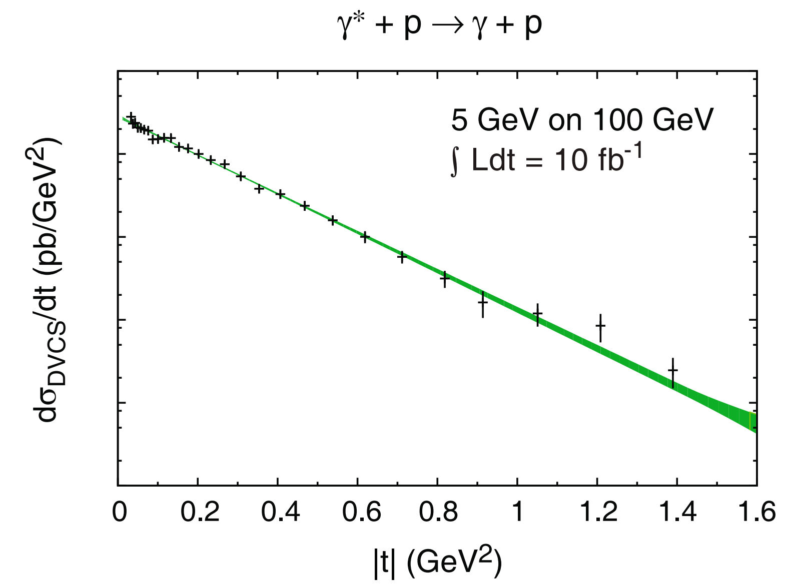
DVCS on the proton

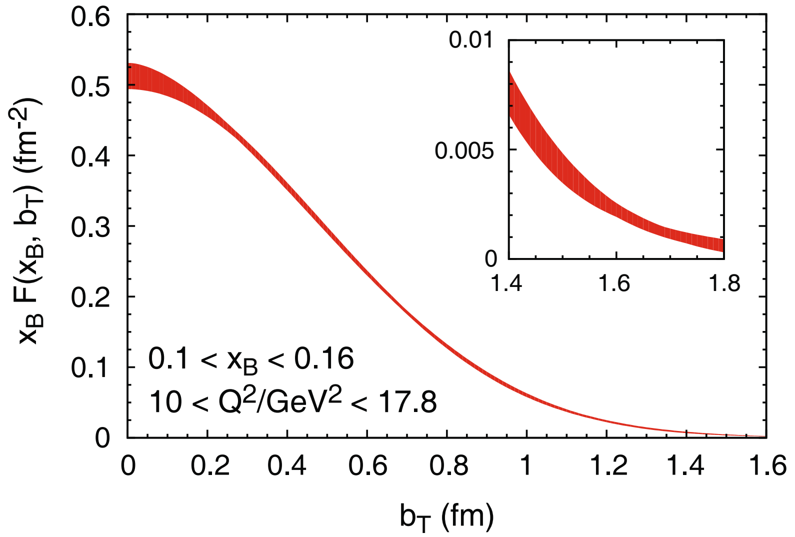
- *p(e,e'*γ*)p'*
- Momentum transfer to proton can be measured from proton in far-forward Roman Pot (RP) tracker
  - Resolution limited by hadron beam effects.
- CORE can measure momentum transfer with equal or better resolution via *(e,e'*γ*)*
  - Independent of incident proton intrinsic beam spread
  - Relies on good EM Cal resolution.
- Tagging proton in RP suppresses background
  - Identify exclusive final state.

Proton DVCS in CORE

- Excellent reconstruction with CORE EMCal
  - Generated (Green), Accepted (black), Reconstructed (red)



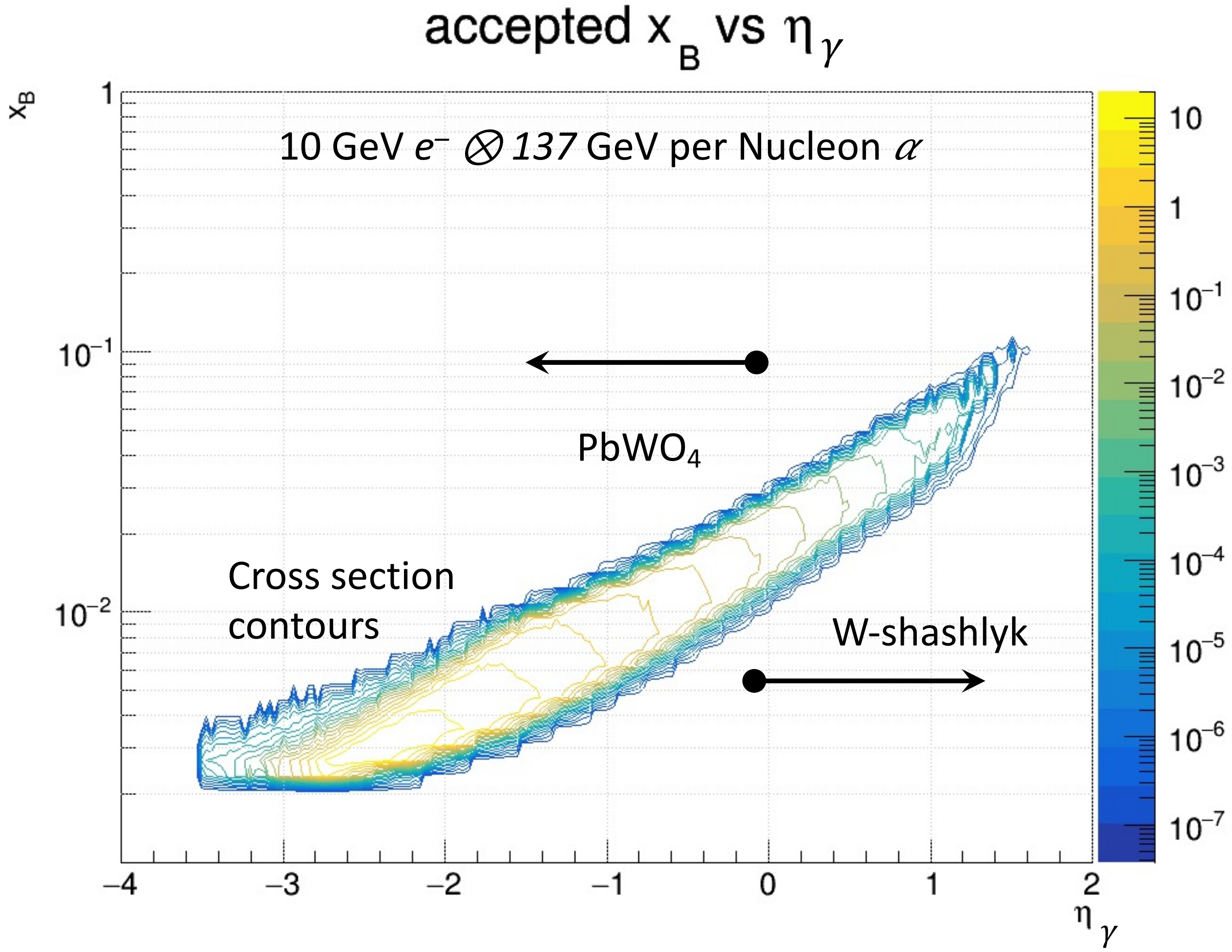




Deep Virtual Exclusive Scattering on Nuclei

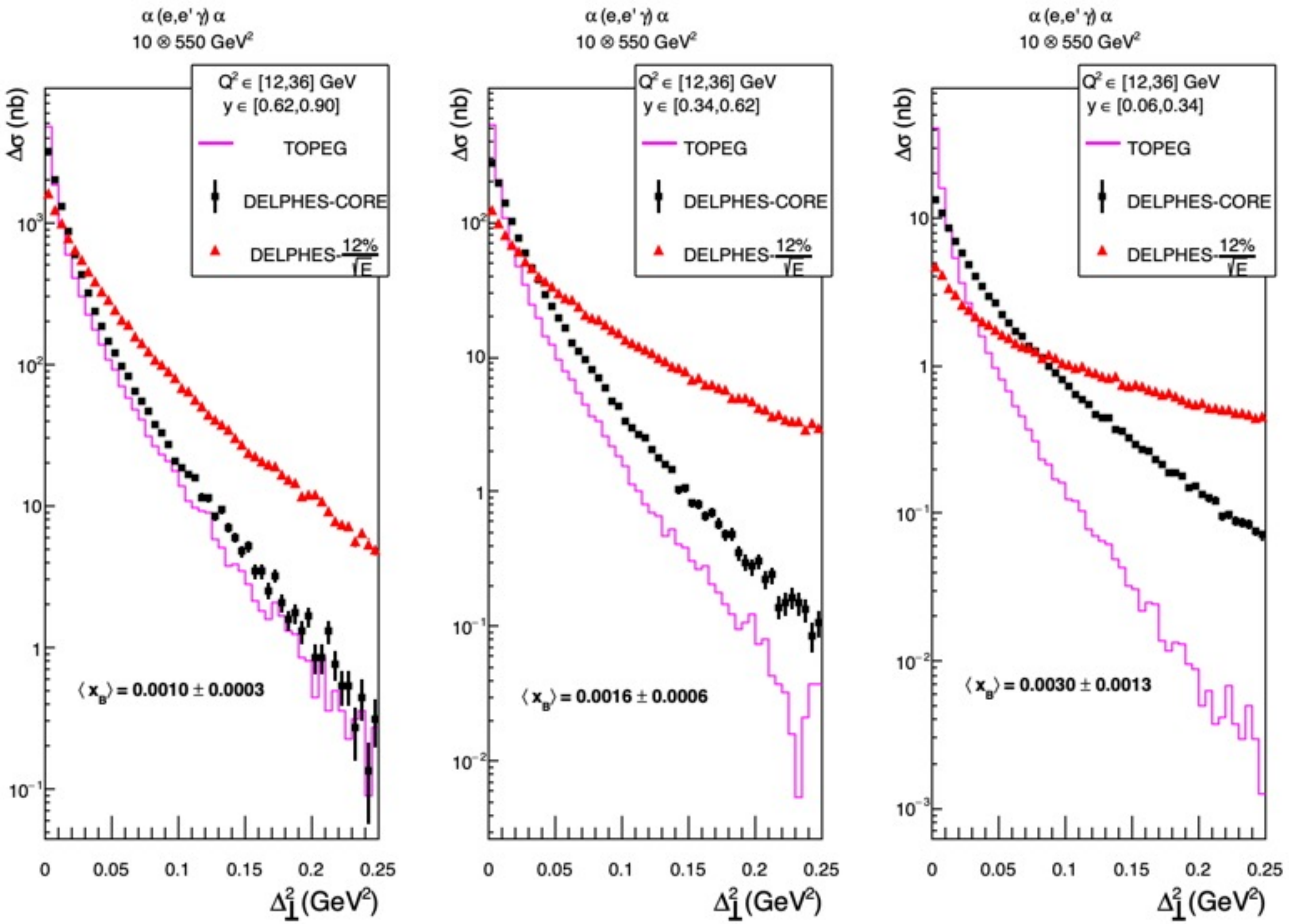
- CORE EMCal enables DVCS on light to medium mass nuclei
  - Even when final state nucleus is undetectable in beam envelope
- Illustrative example:
  Transverse imaging of quarks and gluons in ^{4}He as a function of parton lightcone momentum fraction *x:*
  - Measure the mass distribution in nuclei, as distinct from the charge distributions
  - Separation of quark and gluon densities → different sensitivity of key channels
  - $\alpha(e,e'\gamma)\alpha$, $\alpha(e,e'\phi)\alpha$ $\alpha(e,e'J/\Psi)\alpha$

Nuclear DVCS with CORE



- High-Resolution EMCal is an **enabling** feature of CORE:
- Resolution of $\Delta_\perp = (k\text{-}k'\text{-}q')_\perp$ for DVCS(γ) comparable to resolution for Deep-$\phi \rightarrow K^+K^-$ or Deep-$J/\Psi \rightarrow e^+e^-$, $\mu^+\mu^-$

Nuclear DVCS with CORE

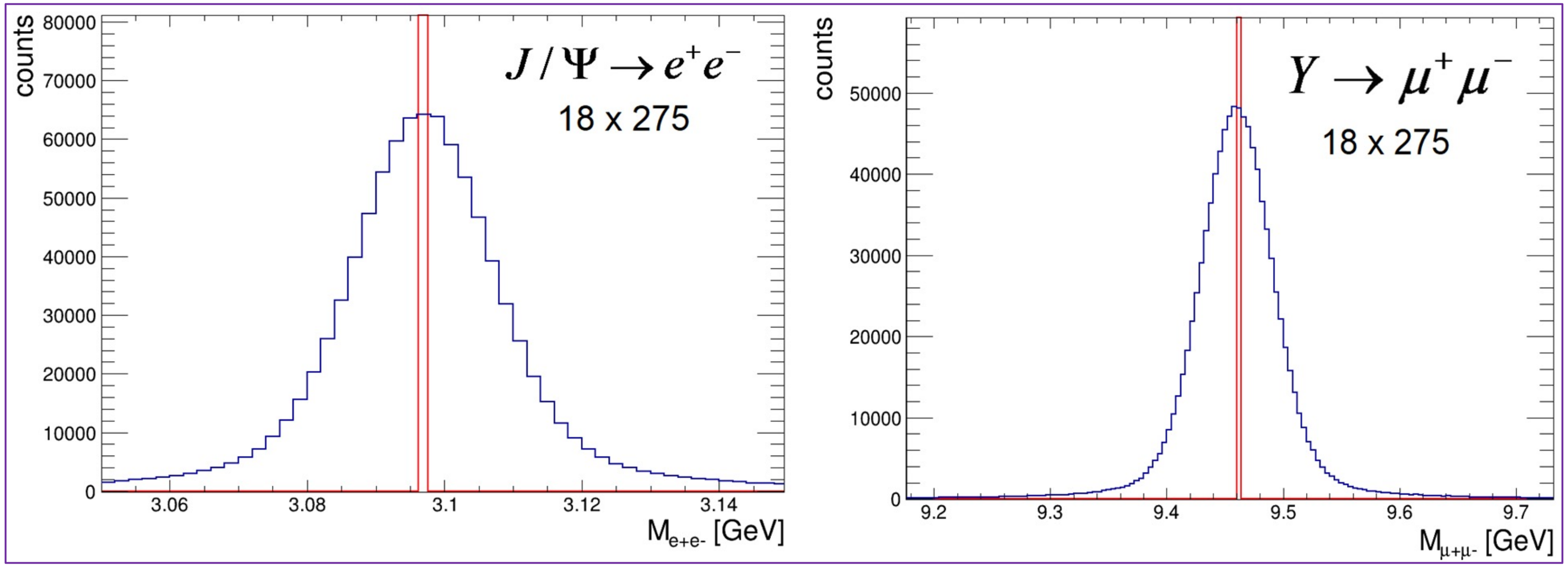


- Magenta = generated (TOPEG) cross section
- Black points = CORE measurement ➔ Excellent Reconstruction
- Red Triangles: Performance of a 12%/√E EMCal (Yellow Report) in Barrel

High-x will be improved by lower-s running

Exclusive ρ, ω, ϕ, J/Ψ, Υ production

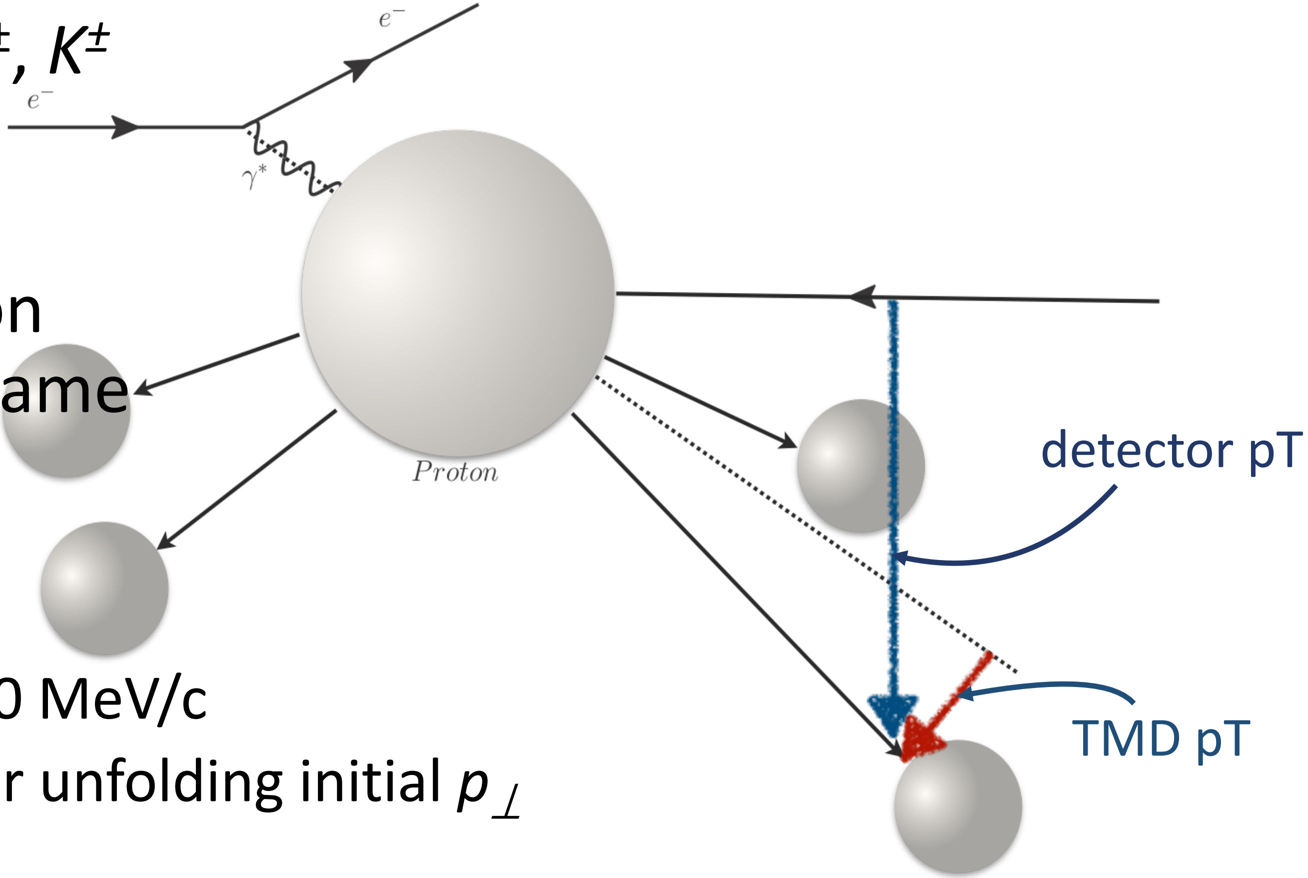
- $\vec{e} + \vec{p} \rightarrow e + p + \vec{V}$
- Heavy quarkonia are important for measuring gluon spatial distributions
- Heavy quarkonia near threshold (*e.g. p+Υ* final state) are sensitive to the QCD anomaly contribution to proton mass (X. Ji, and others).
- *Muon detection important*

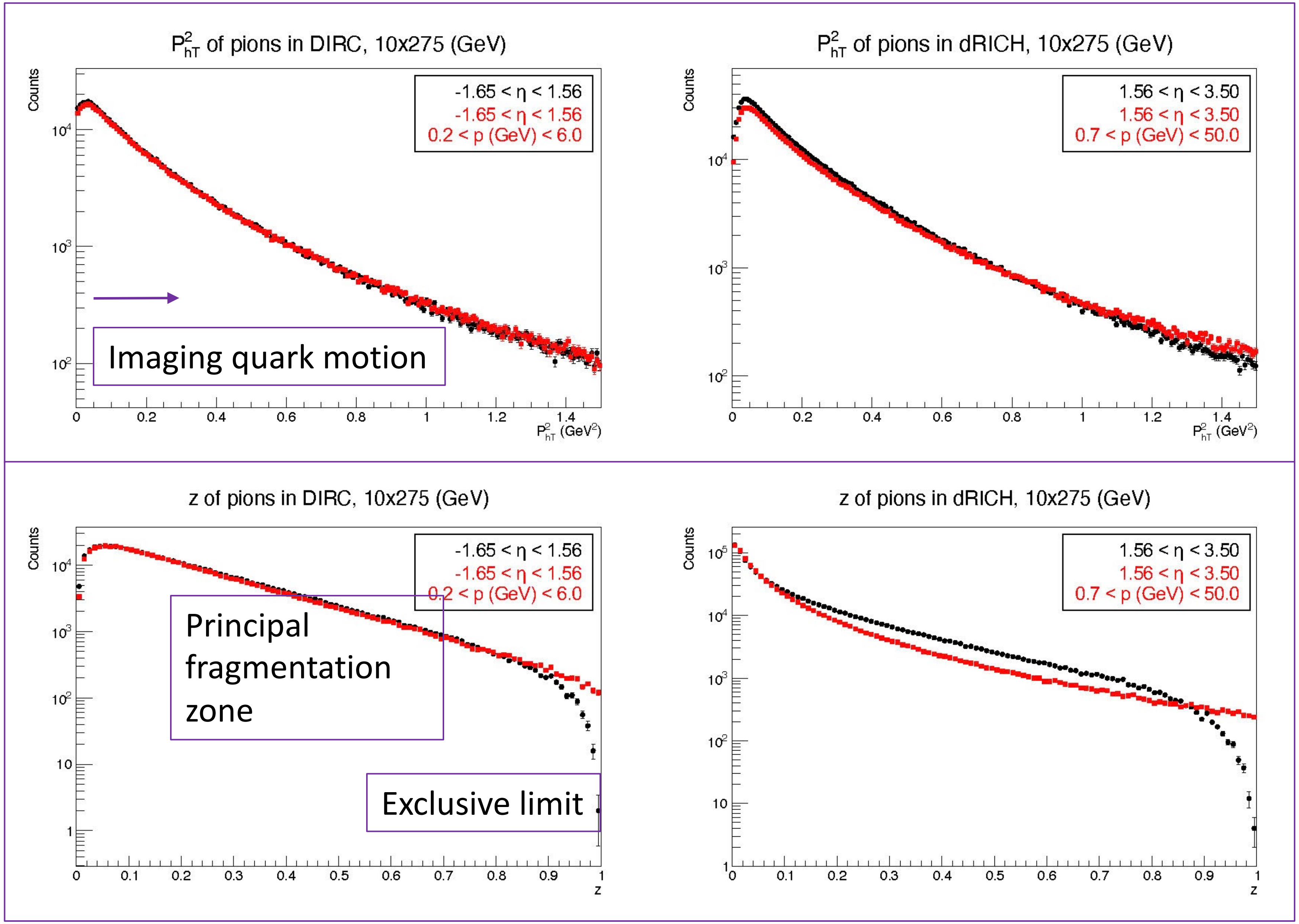


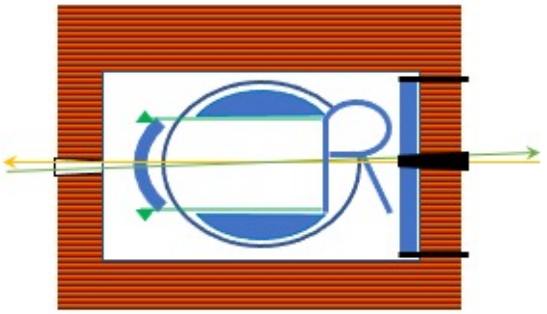
3D Motion of quarks & gluons

Semi-Inclusive Deep Inelastic Scattering: $\vec{p}(\vec{e}, e'h)X$

- Quark flavor sensitivity with $h = \pi^{\pm}, K^{\pm}$
  - Gluon distributions:
    di-hadron detection at high-mass
- Transverse Momentum Distribution (TMD) frame is not the detector frame
  - P_{hT} is relative to
    anti-collinear (k-k')$\otimes$ P_p frame
    (***not*** p_T in detector frame)
  - p_{hT} can be measured all the way to 0 MeV/c
  - Excellent P_{hT} resolution important for unfolding initial $p_{\perp}$ from hadronization $p_{\perp}$





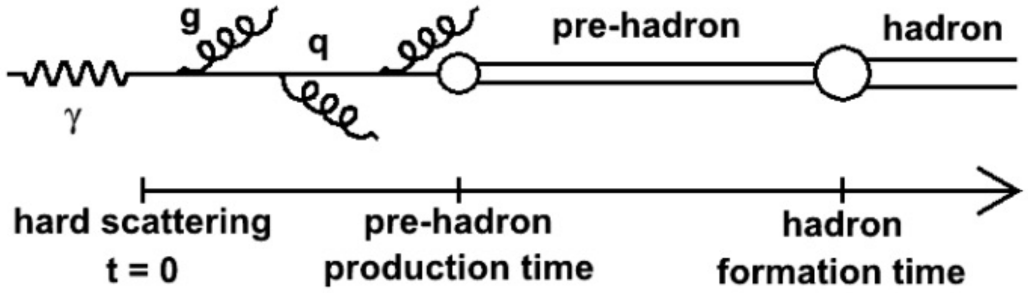


SIDIS in CORE 10x275 GeV^2

- Black = all pions
- Red = Identified π
- $z = \frac{p_h \cdot P}{q \cdot P}$
  - Full z-range covered, independent of PID threshold

Hadronization:

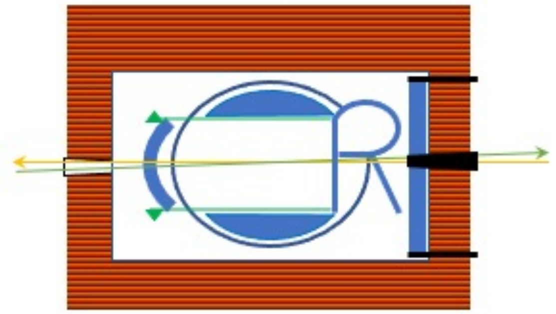
- The Nucleus as a hadronization filter
  - Quark evolves to small-size neutral pre-hadron and then to final state hadron
  - Distance scales vary with $\nu = q \bullet P/M = Q^2/(Mx_B)$ and $z = p_h \bullet P/q \bullet P$

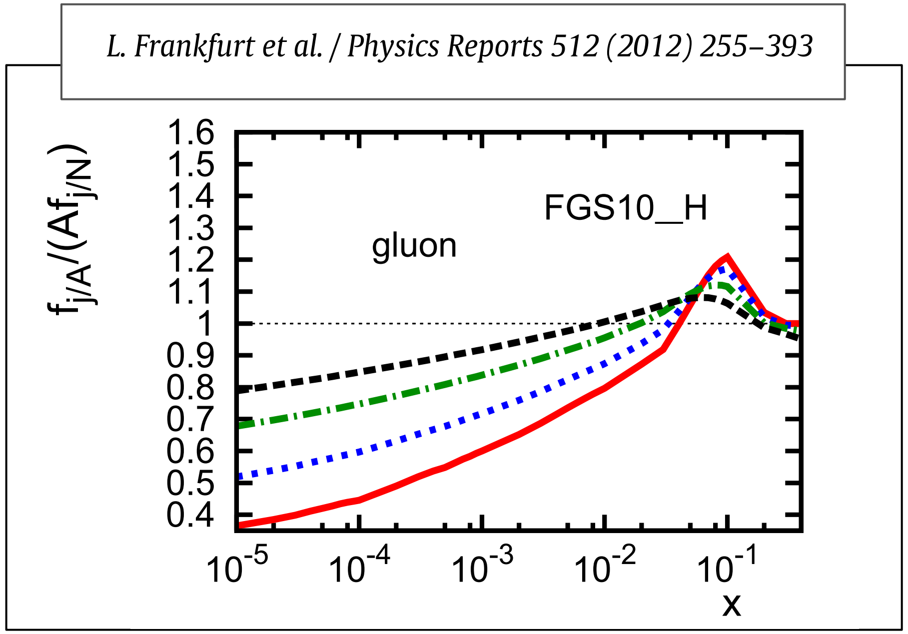


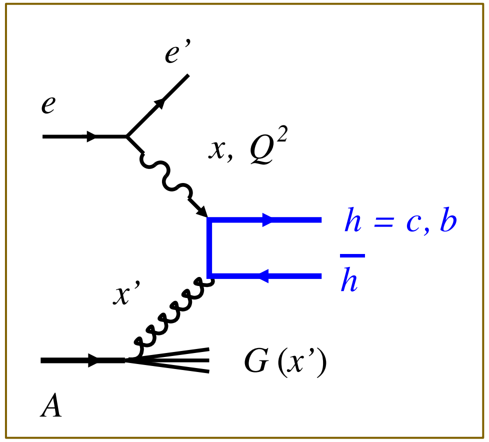
- SIDIS for various nuclei
  - Nuclear attenuation (compared to proton) as function of Q^2, x_B, z and A

Gluons in Nuclei

- Predictions of anti-shadowing at x ≈ 0.1
- Shadowing at x ≤ 0.01
- Saturation at x <<0.01 & $Q^2 > Q_S^2(x)$
- Gluons from QCD evolution of DIS
- Gluons from open charm production in DIS
  - Tagged with separated vertices &PID e.g.



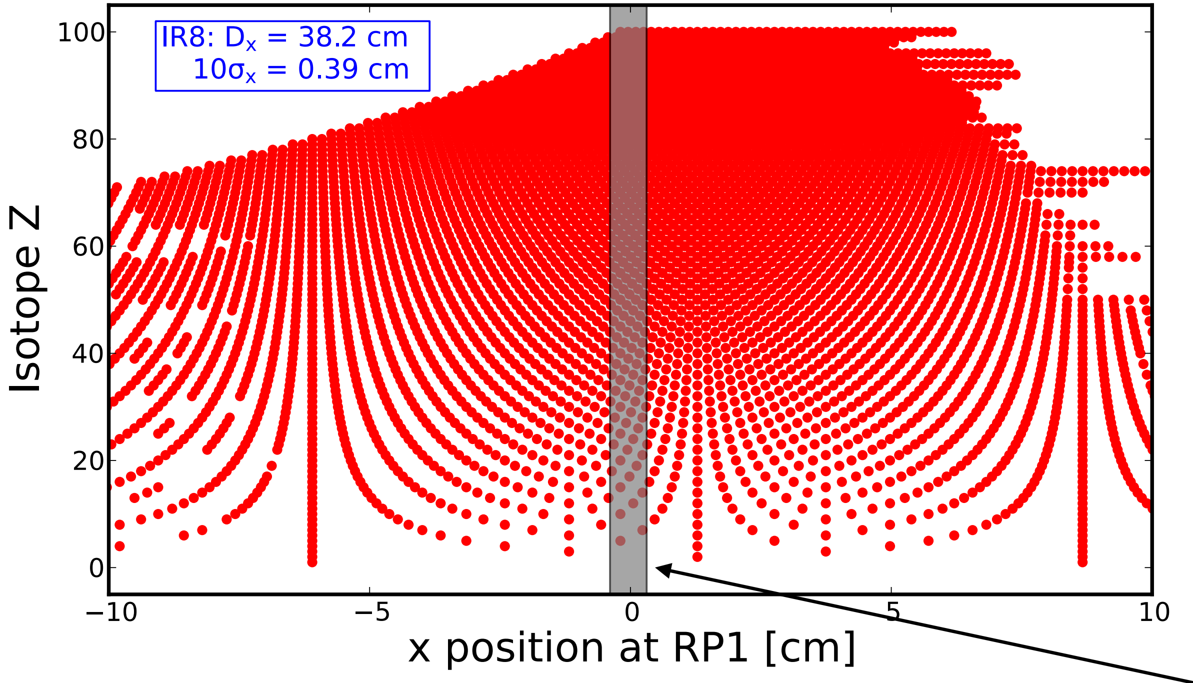




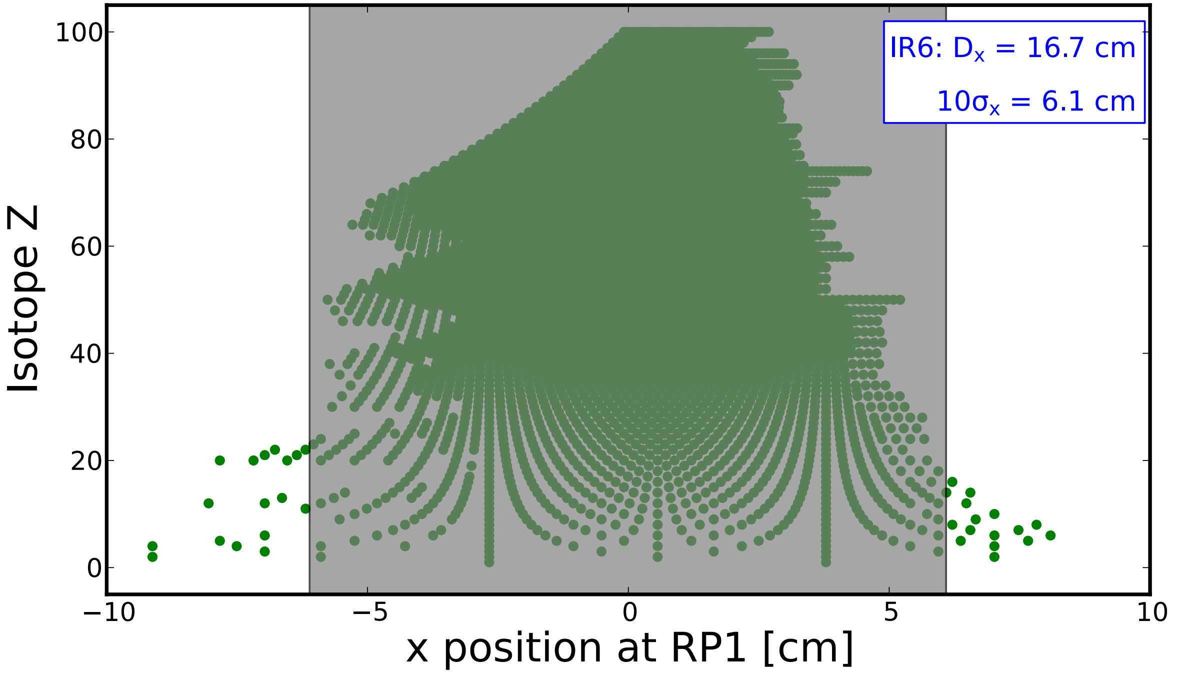
$c \rightarrow D^{*+} \rightarrow \pi^{+}_{slow} + D^{0} \rightarrow \pi^{+} K^{-}$

Secondary Focus and a new program in Rare Isotopes?

IR8



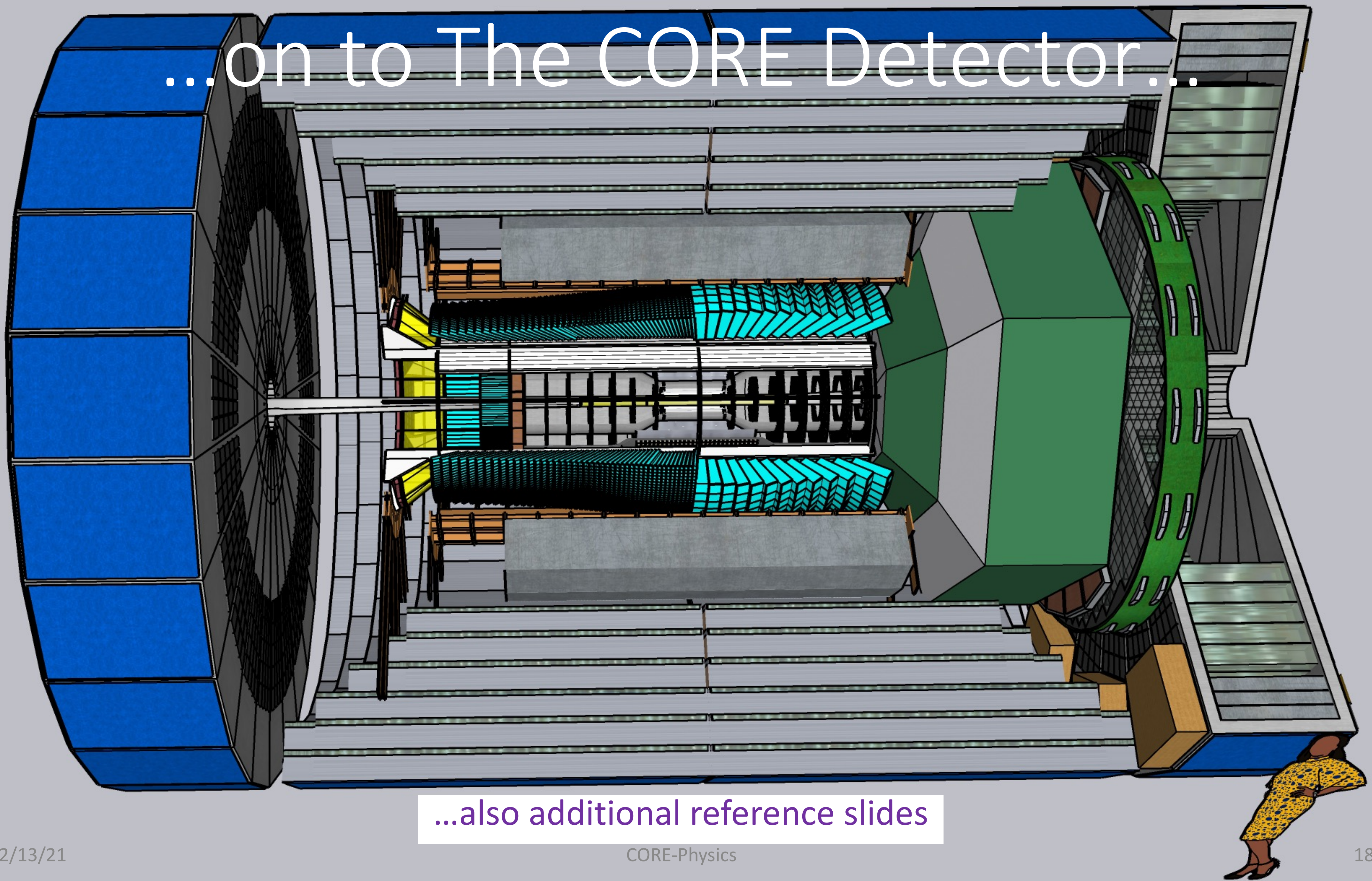
IR6



- Daughter nuclei from ^{238}U can be detected and identified at the IP8 Secondary Focus.
- Spectroscopy of short-lived rare-isotopes from boosted photons in ZDC

Grey bands are excluded by beam envelope
Generally illustrative of contrast of IR8 & IR6

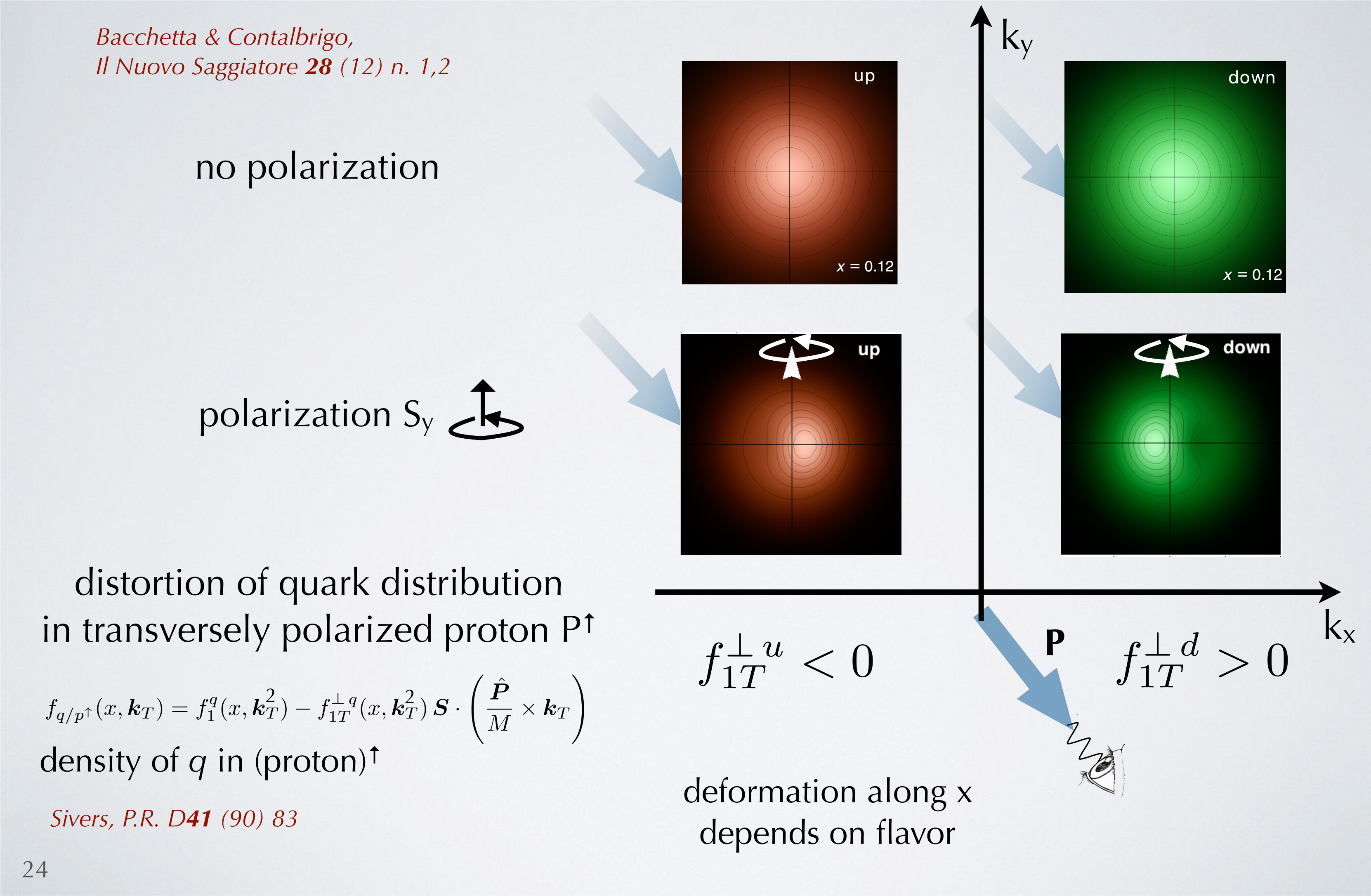
…on to The CORE Detector…



…also additional reference slides

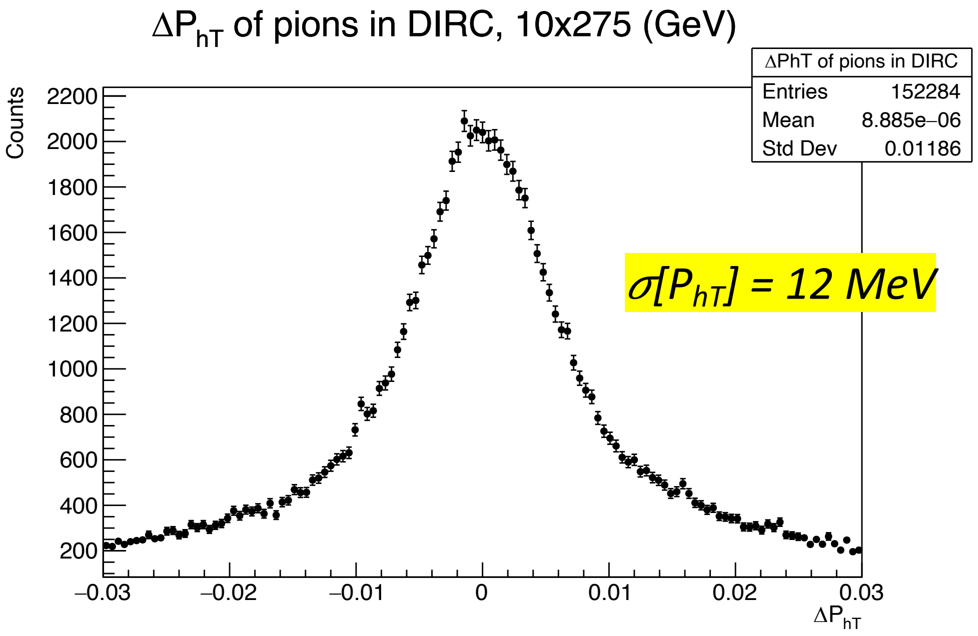
Transverse polarization of the proton

→Breaking of azimuthal symmetry of the parton structure.

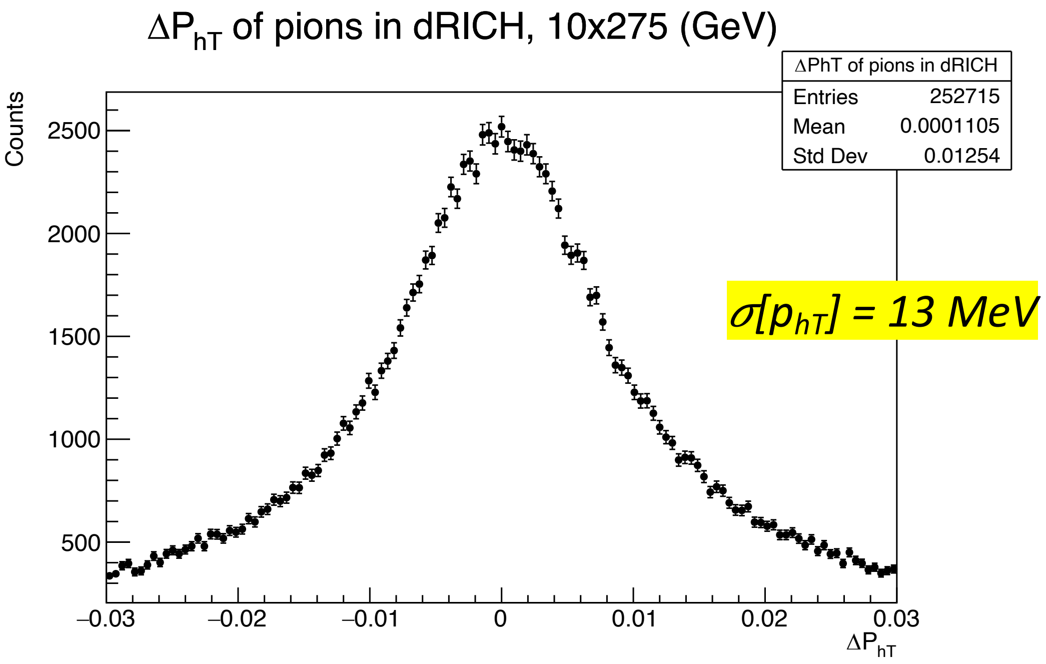


- The Sivers Effect
- Slide from https://indico.cern.ch/event/797767/

CORE P_{hT} Resolution: 10x275 GeV^2

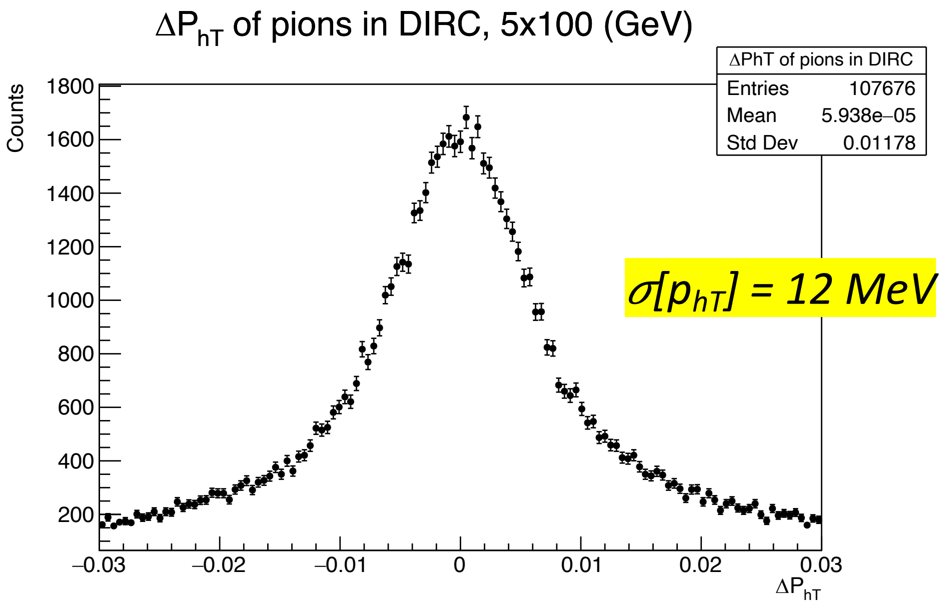


Pions in DIRC
(Central Barrel)



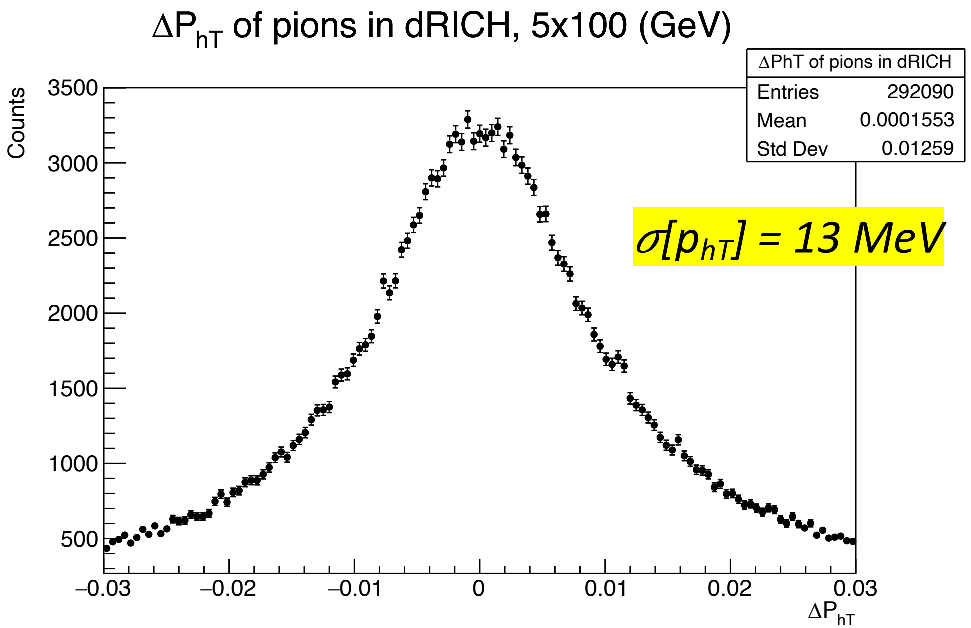
Pions in dual-RICH
(Forward Detector)

CORE $p(h)_\perp$ Resolution: 5x100 GeV^2



Pions in DIRC

(Central)



Pions in dual-RICH
(Forward Detector)

Exclusive ρ, ω, ϕ, J/Ψ, $\boldsymbol{\Upsilon}$ production

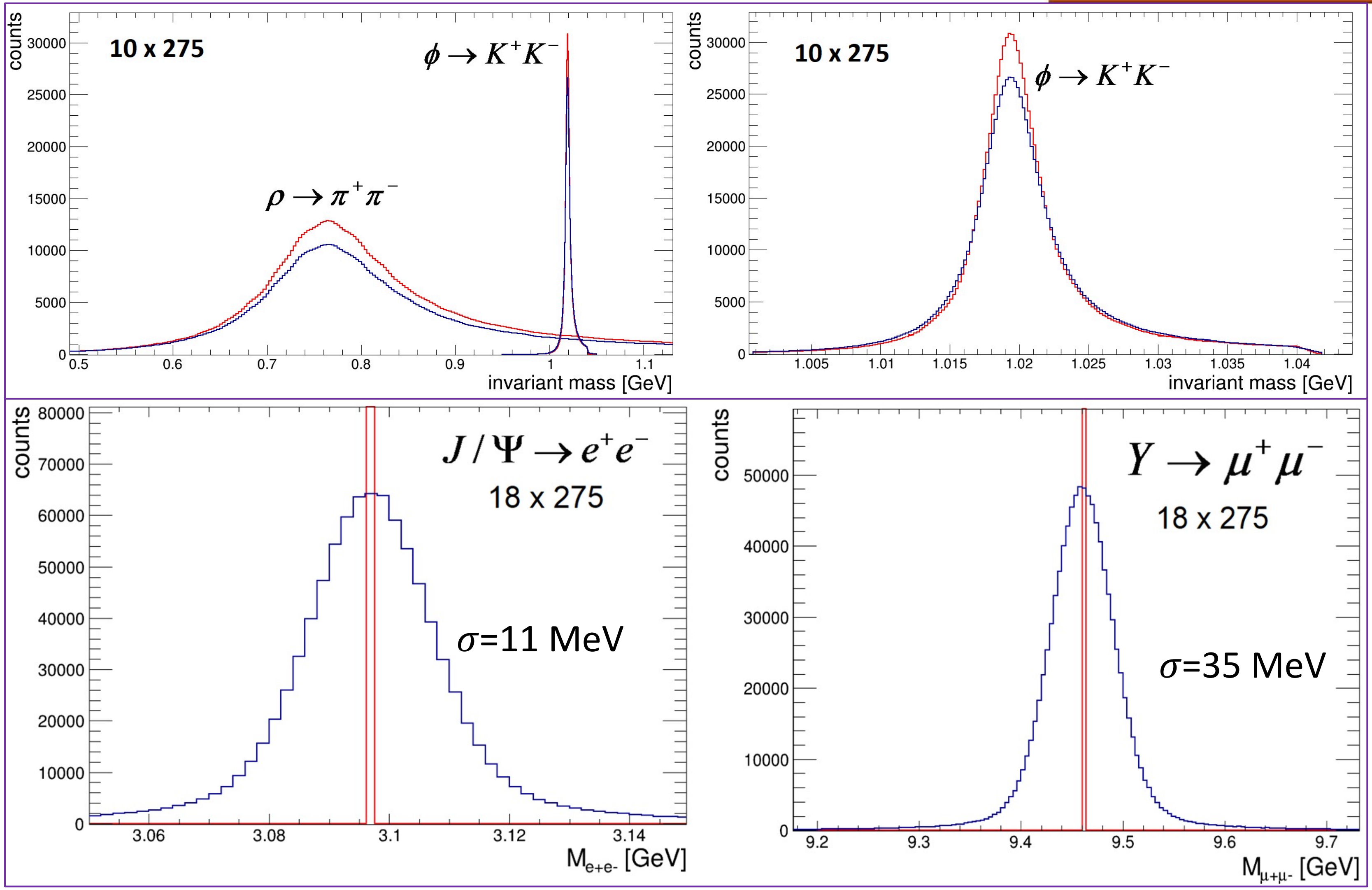
- $\vec{e} + \vec{p} \rightarrow e + p + \vec{V}$
- Vector meson decays are self-analyzing
  - Test of s-channel helicity conservation (not absolute, even at $Q^2=20$ GeV^2 , HERA)
  - Transverse ion polarization reveals spatial separation of up and down quarks and orbital angular momentum of quarks and gluons in the proton.
- $p+\boldsymbol{\Upsilon}$ near threshold in final state —for arbitrary *p(e,e')X* W^2—potentially sensitive to the gluon trace anomaly contribution to the proton mass (X. Ji, and others)

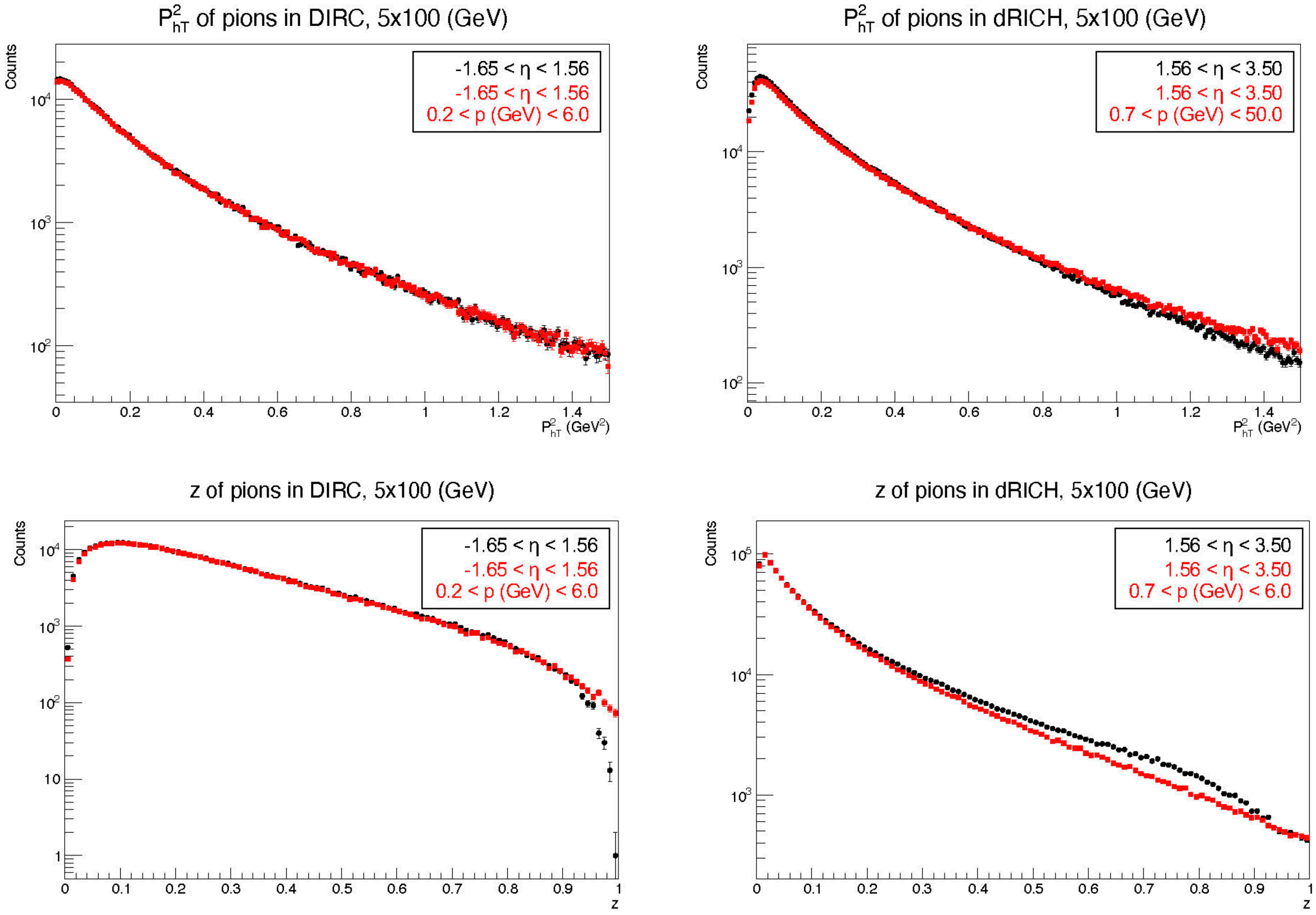
ρ, ϕ, J/Ψ, $\boldsymbol{\Upsilon}$

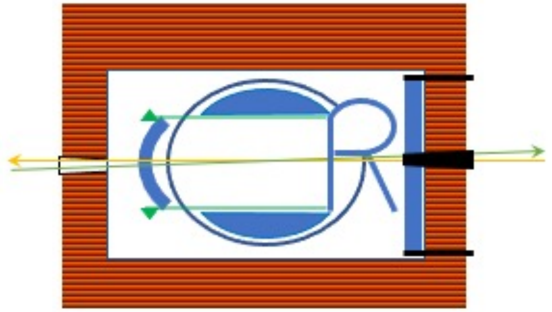
- Red = Generated $\vec{e} + \vec{p} \rightarrow e + p + \vec{V}$

(Exclusive samples from eStarLight)

- Blue = reconstructed



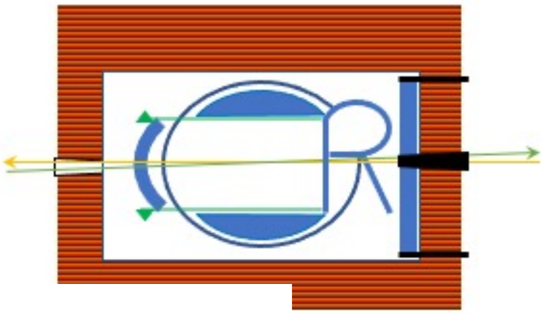


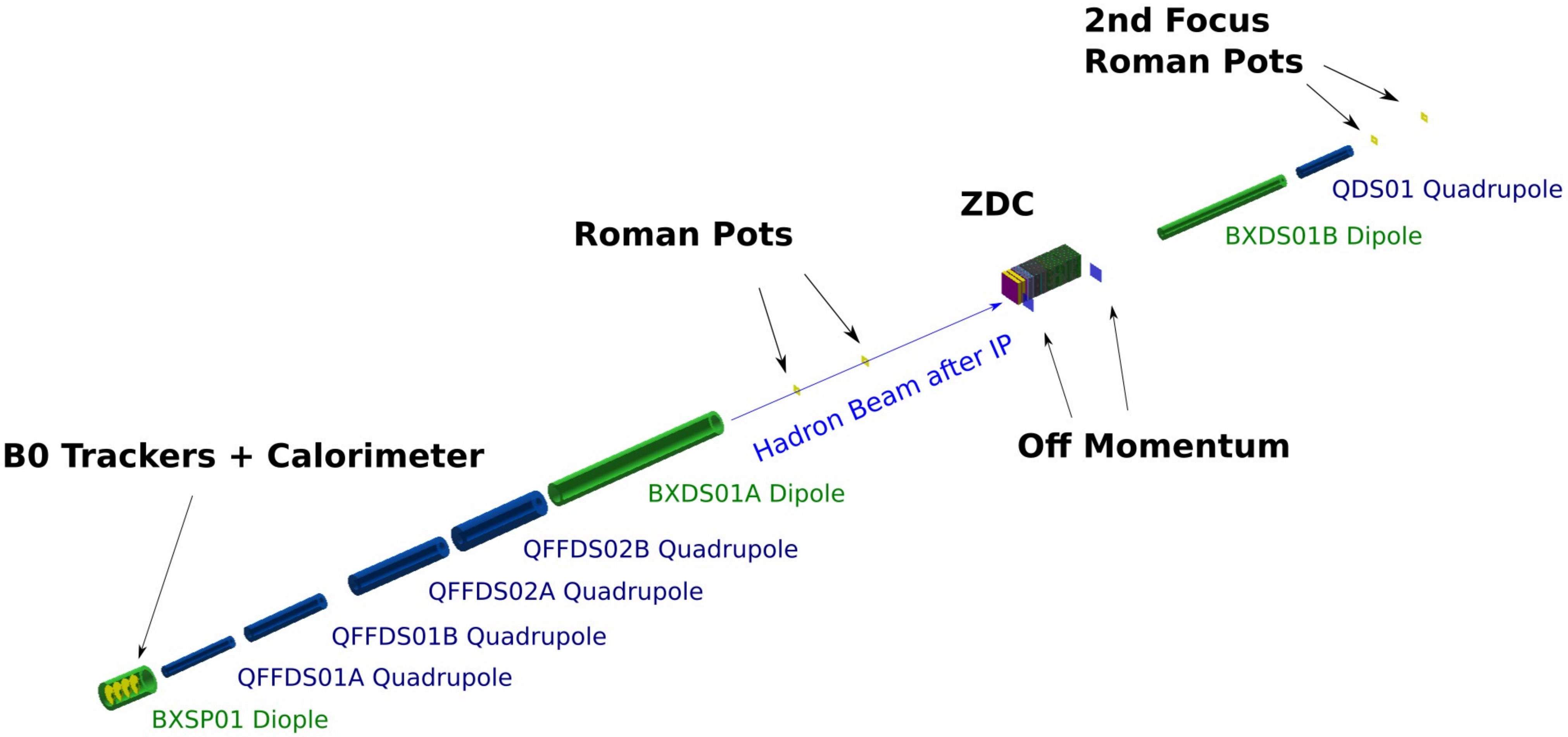


SIDIS in CORE 5x100 GeV^2

- $z = \frac{p_h \cdot P}{q \cdot P}$

IR8 Far-Forward Layout



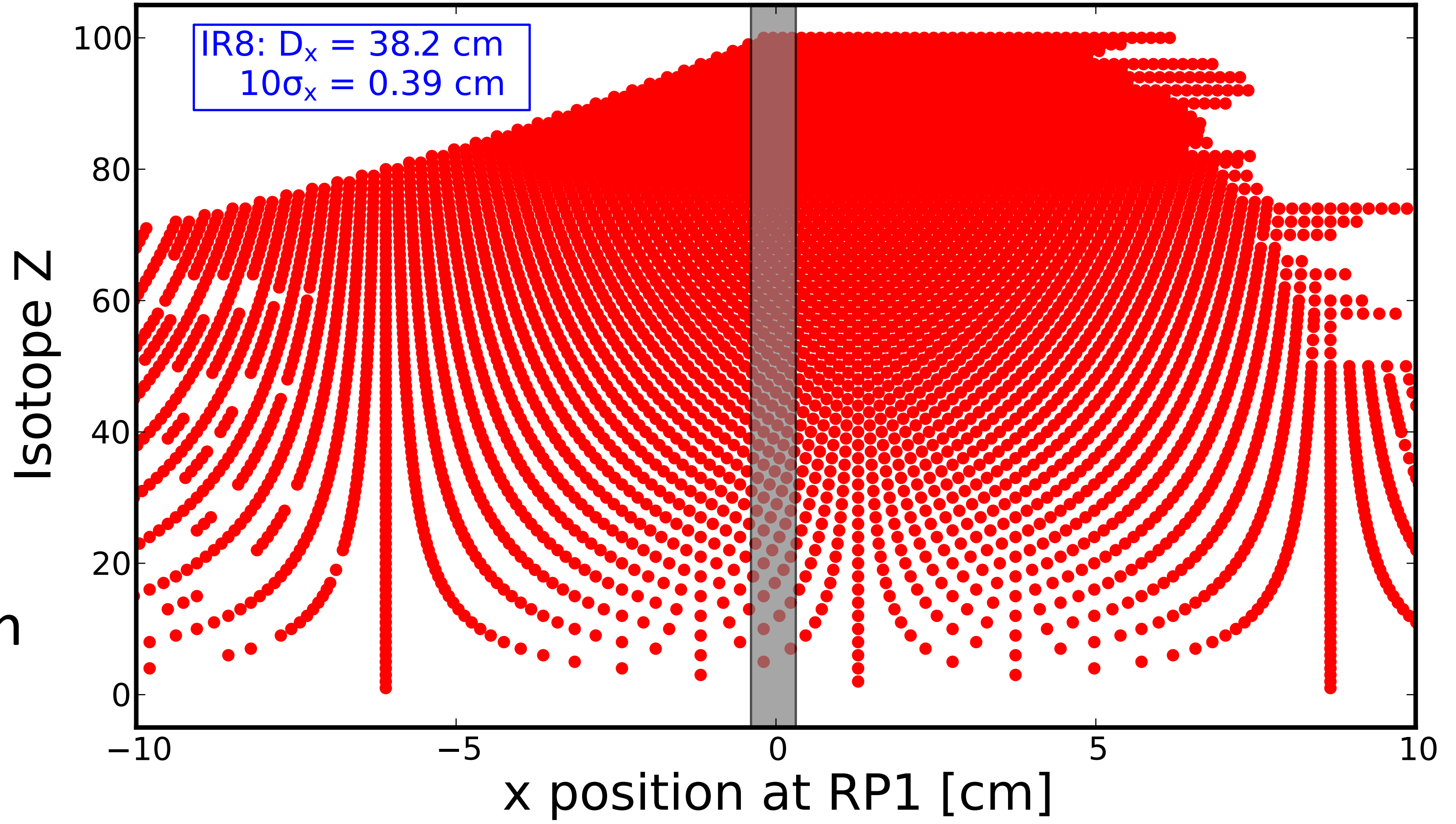


Far-Forward Tagging

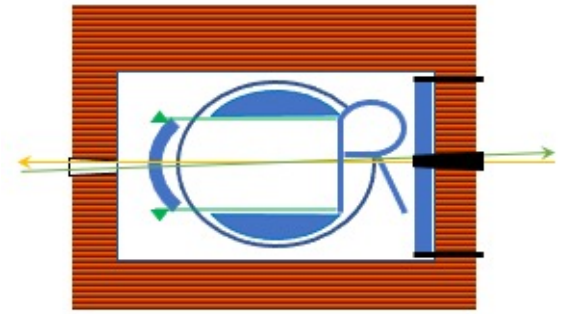
- Secondary Focus ~45 m downstream of IP in IR8
  - Measure any beam remnant with $|1\text{-}x_L|<0.01$
    and any beam remnant with $\theta_{IP} > 2$ mrad (relative to ion beam axis)
  - Logic OR: ($|1\text{-}x_L|<0.01$) || ($\theta_{IP} > 2$ mrad)
- Deep Virtual Exclusive Scattering (DVES)
  - Kinematics measured from (e,e'V): $\Delta=(k\text{-}k'\text{-}P_V)$
  - Exclusive final state must be determined either from tagging beam particle
    - Secondary focus offers greater acceptance than IP6 design
  - Or by veto break-up channels
    - Low mass N*→ π^0 n (ZDC) or → π^- p ($P'/P \approx M_p/M_{N*} \leq 0.75$ off-momentum-detectors)

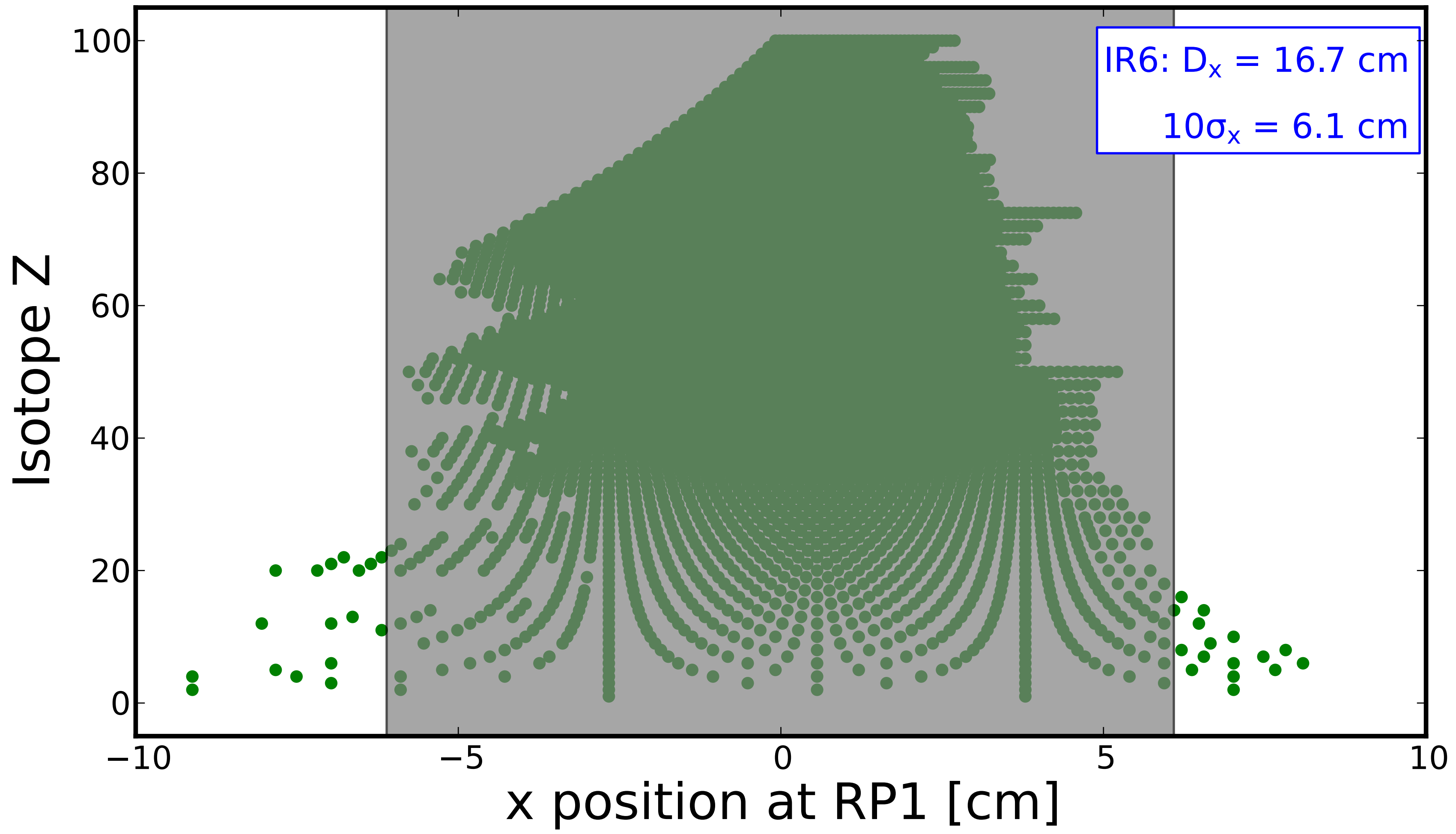
Secondary Focus and a new program in Rare Isotopes

- Nearly all daughter nuclei from ^{238}U can be detected and identified at the IP8 Secondary Focus.
  - Grey band is beam exclusion zone
- Boosted decay photons could be measured in a high resolution EMCal in front of the ZDC



Daughter Nuclei from ^{238}U at Roman Pots of IR6





- Grey band is exclusion zone of beam envelope