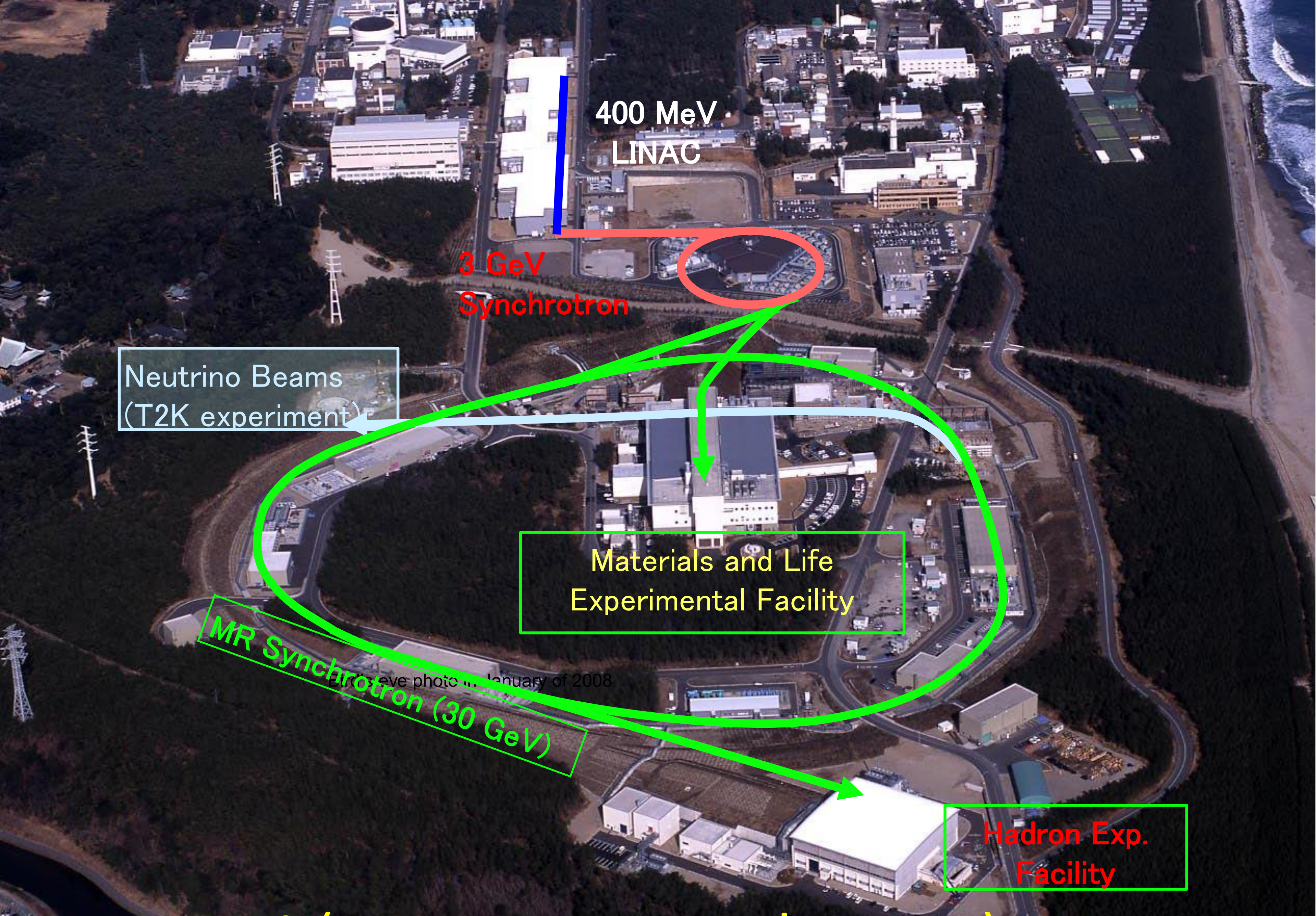
Baryon spectroscopy and Studies of extremely dense matter at J-PARC

Hiroyuki Sako (ASRC/J-PARC, JAEA)
for J-PARC E45 and J-PARC HI Collaboration

2015 HaPhy-HIM Joint Meeting: Experimental and Theoretical Nuclear Physics (28 Aug 2015)

1. Introduction (J-PARC)
2. Baryon spectroscopy (J-PARC E45)
3. Future heavy-ion experiment at J-PARC (J-PARC HI)
4. Summary

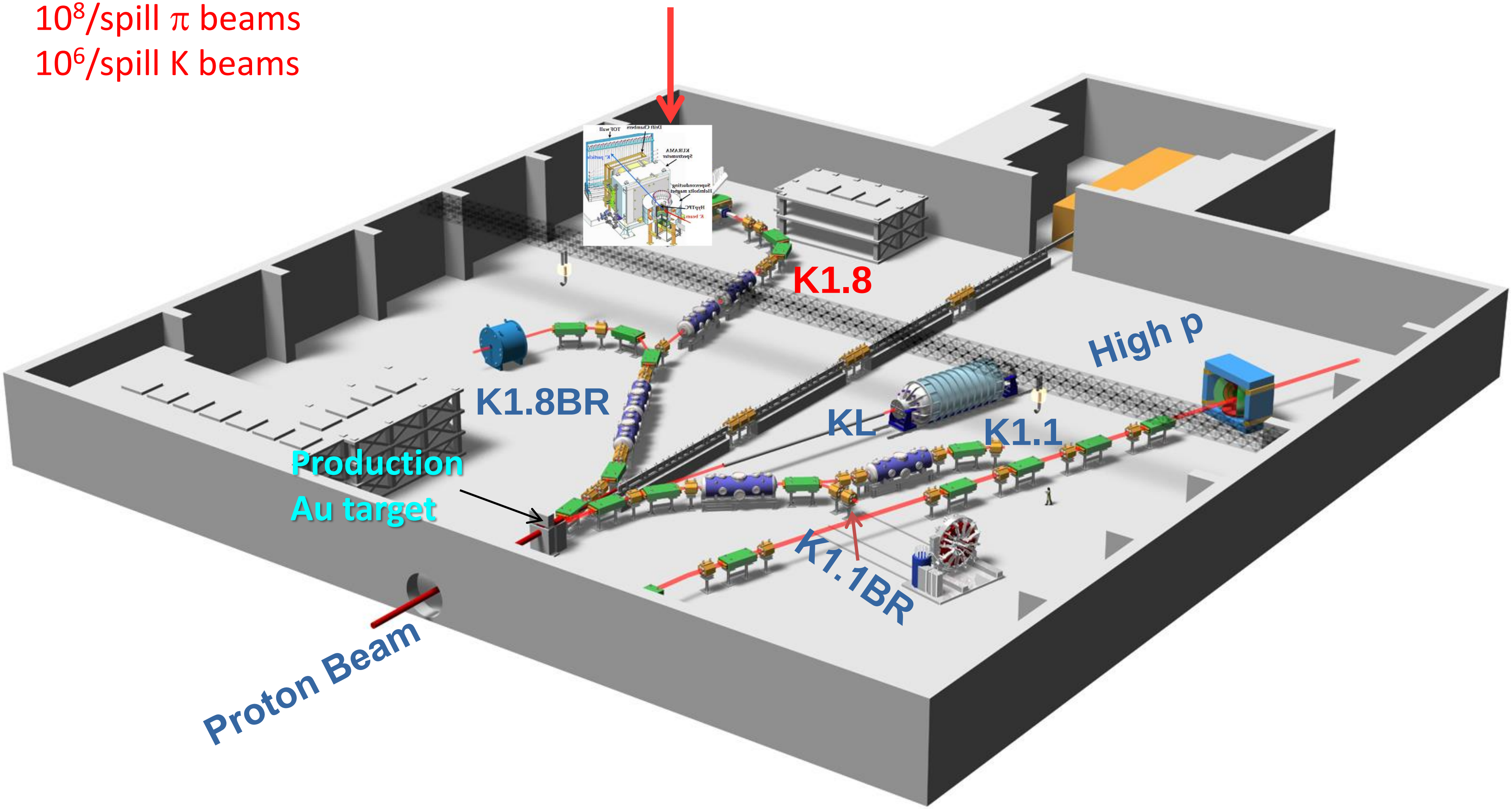


J-PARC (MW proton synchrotron)

Hadron Experimental Facility

10^{14}/spill p beams
10^{8}/spill π beams
10^{6}/spill K beams

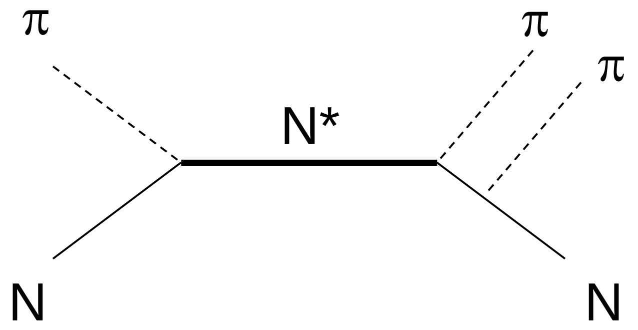
Hyperon spectrometer (E42/E45)



J-PARC E45

Studies of baryon resonances in (π,2π) reactions

- Precise measurements of baryon resonance properties
  - Many resonances have not been established experimentally
  - ππN has strong coupling to high mass resonances
  - Not enough (π,2π) experimental data since 1970's
- Deeper understanding of non-perturbative QCD
- Search for new baryon states
  - *e.g.* hybrid baryons (qqqg)

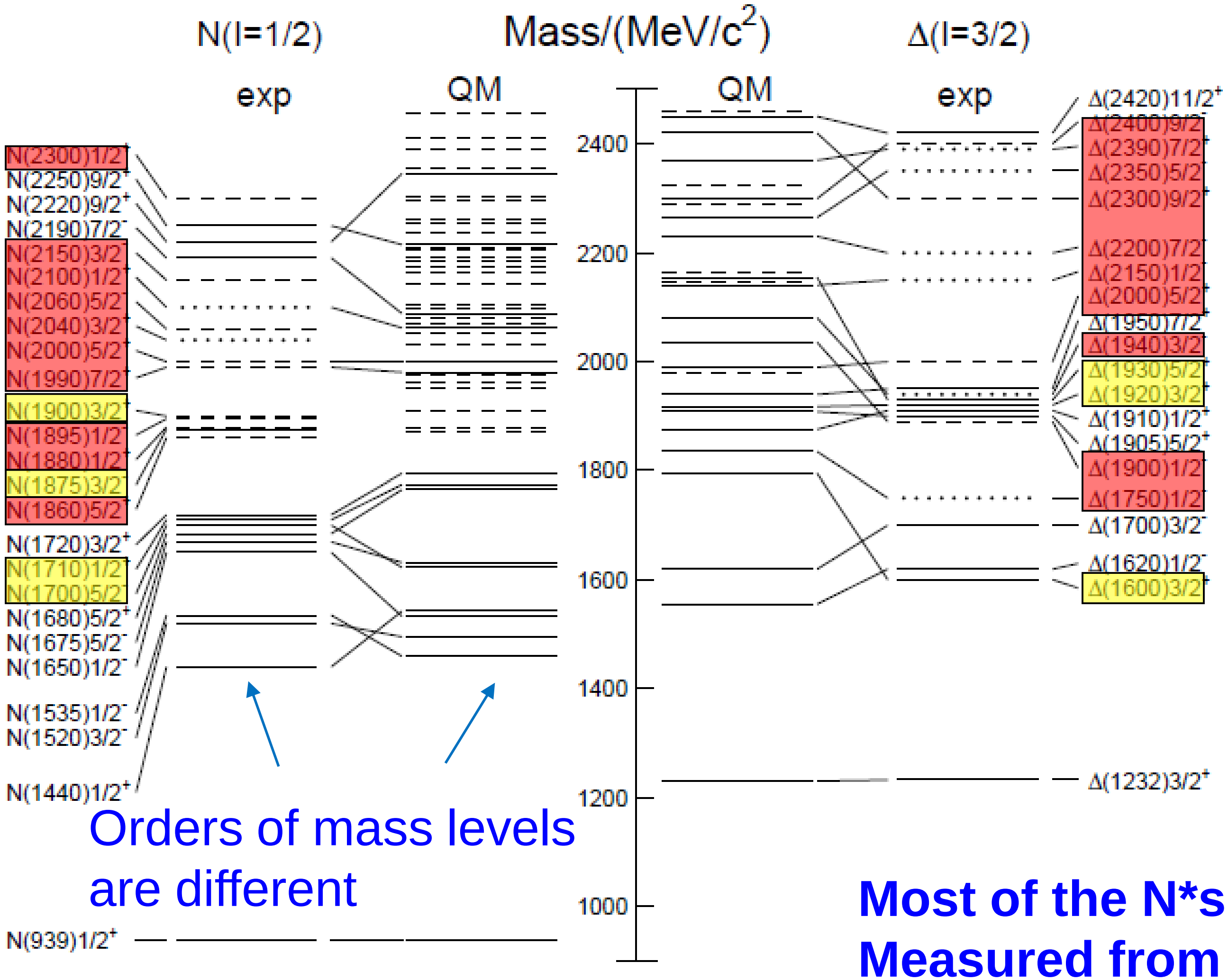


E45 collaboration list

K. H. Hicks, S. Chandavar, J. Goetz, W. Tang	(Ohio University, USA)
H. Sako, K. Imai, S. Hasegawa, S. Sato, S.H. Hwang, K. Hosomi, H. Sugimura, Y. Ichikawa, Y. C. Han, H. Ekawa, S. Hayakawa, Y. Nakada, S. Kinbara	(Japan Atomic Energy Agency, Japan)
K. Nakazawa, J. Yoshida	(Gifu University)
J.K. Ahn, J. W. Lee, S. H. Kim, J. B. Park, M. H. Kim, W. S. Jung, J. L. Kim	(Korea University, Korea)
K. Tanida, J. Y. Lee	(Seoul National University, Korea)
H. S. Lee	(RISP, Korea)
J.H. Park, K. Y. Baek	(Pusan National University, Korea)
H. Fujioka, S. Nakamura, M. Niiyama	(Kyoto University, Japan)
K. Ozawa	(KEK, Japan)
B. Bassalleck, Y. Han	(University of New Mexico, USA)
K. Joo, N. Markov, N. Harrison, T. O’Connell, E. Seder	(University of Connecticut, USA)
B. Briscoe, F. Klein, I. Strakovsky, R. Workman	(George Washington University, USA)
R. Schumacher	(Carnegie Melon University, USA)
D. M. Manley	(Kent State University, USA)
L. Guo	(Florida International University, USA)
P. Cole , A. Forest, D. McNulty	(Idaho State University, USA)
T.S.-H. Lee	(Argonne National Lab, USA)
T. Sato, H. Kamano	(Osaka University, Japan)
H. Kamano, K. Shirotori, S.Y. Ryu	(RCNP, Osaka University, Japan)
Y. Azimov	(Petersburg Nuclear Physics Institute, Russia)
V. Shklyar	(University of Giessen, Germany)
A. Svarc	(Ruder Boskovic Institute, Hungary)
S. Ceci	(RBI-Zagreb, Hungary)
M. Hadzimehmedovic, H. Osmanovic	(University of Tulza, Bosnia/Herzegovina)

From USA, Japan, Korea, and Europe

Baryon mass: Exp vs QM (PDG)



Orders of mass levels are different

PDG 2014

Missing baryons
Quark model does not describe well N* mass levels.

☐ **** established
🟨 ***
🟥 * **

Most of the N*s so far were Measured from

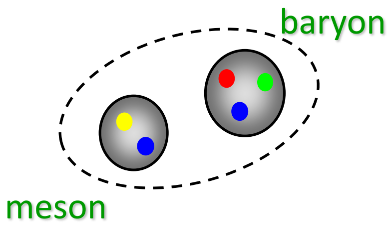
$$\pi N \rightarrow \pi N \ , \quad \gamma N \rightarrow \pi N$$

Dynamical coupled-channels model (ANL-Osaka)

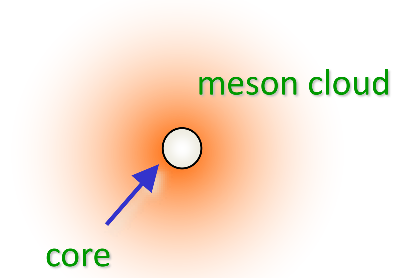
For details see Matsuyama, Sato, Lee, Phys. Rep. 439,193 (2007)
Kamano's talk (Apr 14)

✓

Physical N*s will be a "mixture" of the two pictures:



$$|N^*\rangle = |MB\rangle$$



$$|N^*\rangle = |qqq\rangle + |\mathrm{m.c.}\rangle$$

✓ Transition potentials:

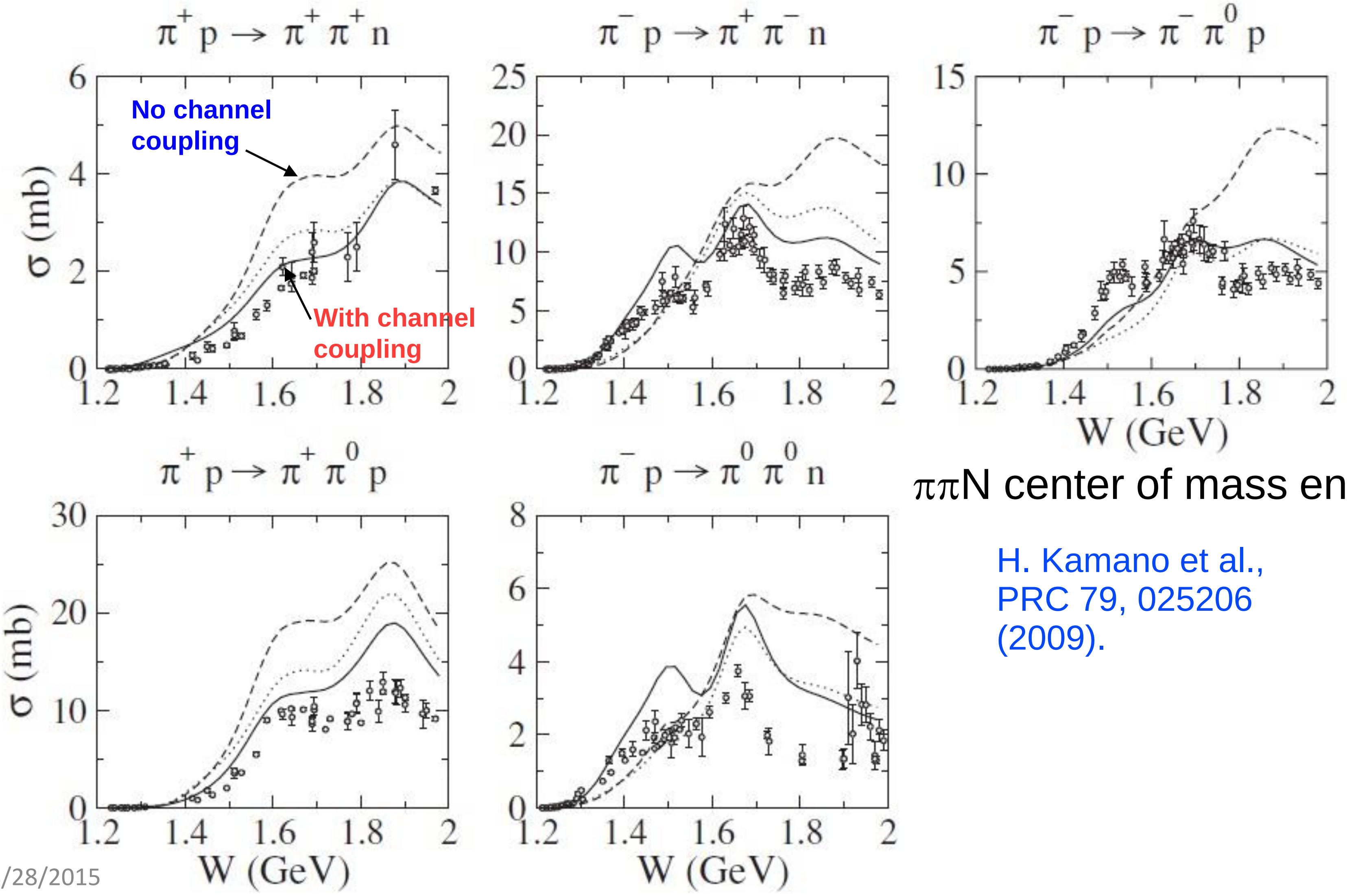
$$V_{a,b} = v_{a,b} + \sum_{N^*} \frac{\Gamma^\dagger_{N^*,a}\Gamma_{N^*,b}}{E - M_{N^*}}$$

exchange potentials of ground state mesons and baryons

bare N* states

World’s πN→ππN data

Only 240K bubble chamber data in 1970’s

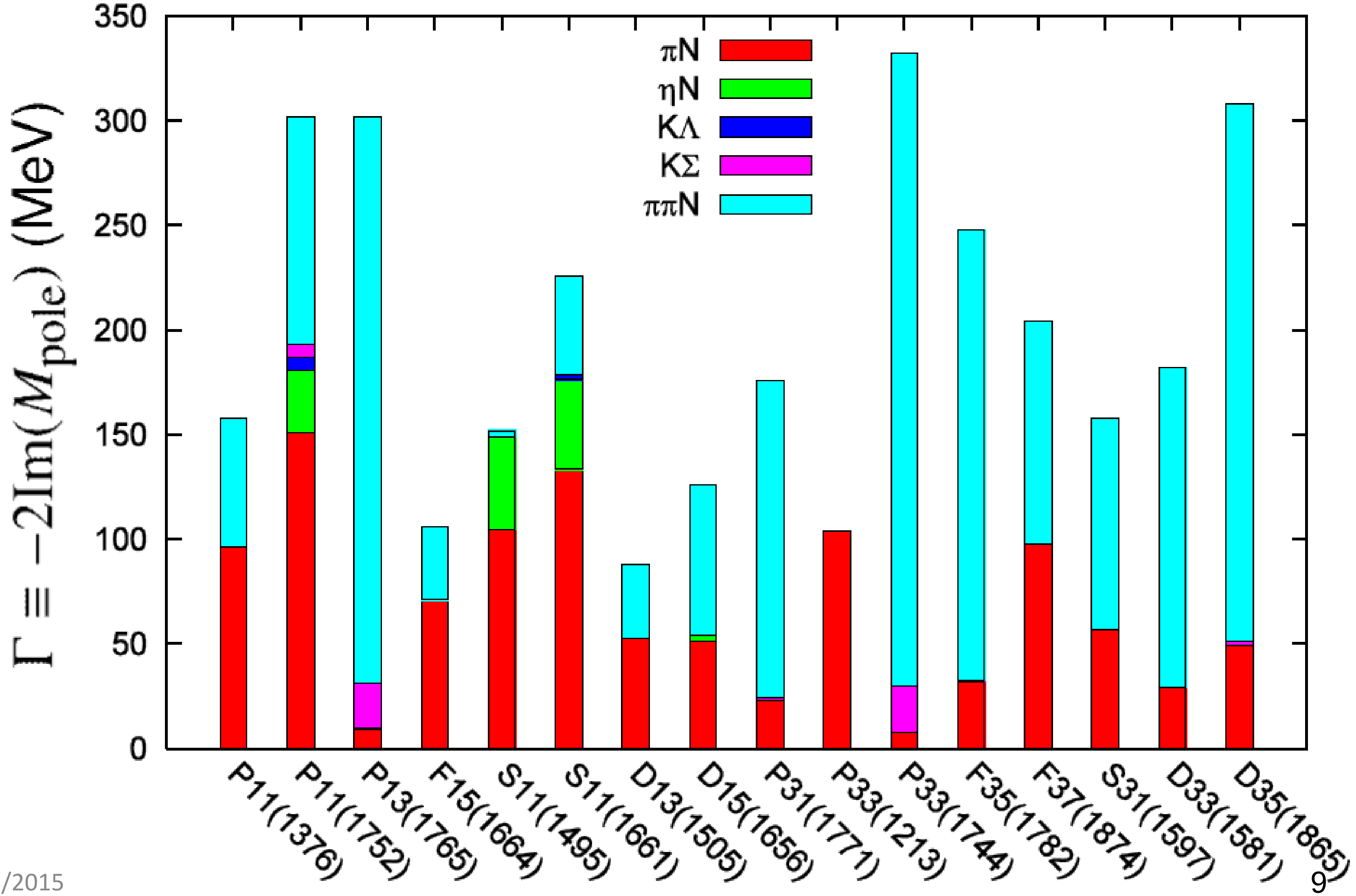


ππN center of mass energy

H. Kamano et al., PRC 79, 025206 (2009).

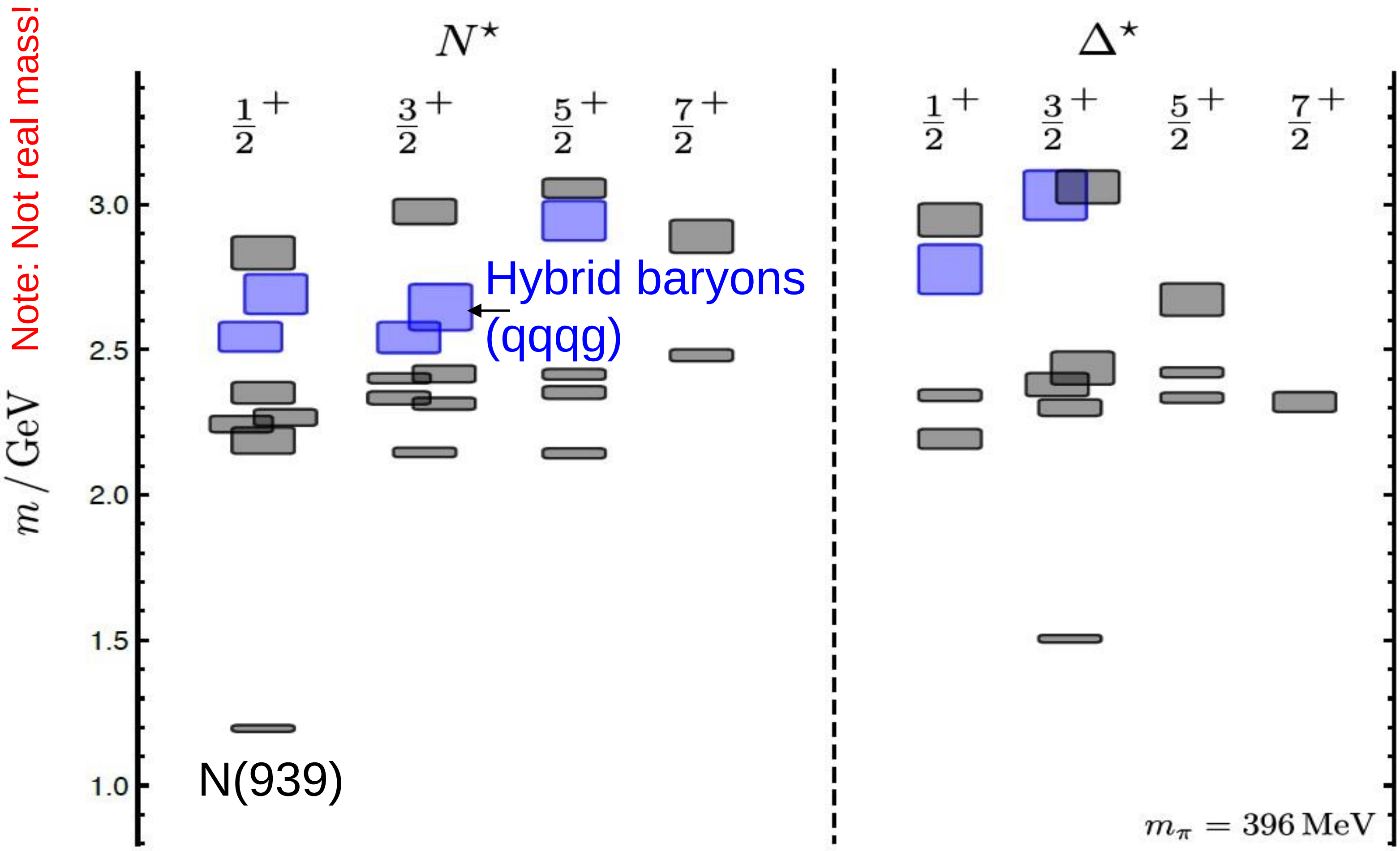
Importance of Nππ Decay

H. Kamano, et al. PRC 79 025206 (2009)



Recent Lattice QCD calculations

J. Dudek et al., PRD85 (2012) 054016



Note: Not real mass!

Hybrid baryons (qqqg)

N(939)

E45 HypTPC Spectrometer

Measure (π,2π) in large acceptance TPC in dipole magnetic field

$\pi^- p \to \pi^+ \pi^- n$, $\pi^0 \pi^- p$

$\pi^+ p \to \pi^0 \pi^+ p$, $\pi^+ \pi^+ n$

2 charged particles + 1 neutral particle

→*missing mass technique*

$\pi N \to KY$ *(2-body reaction)*

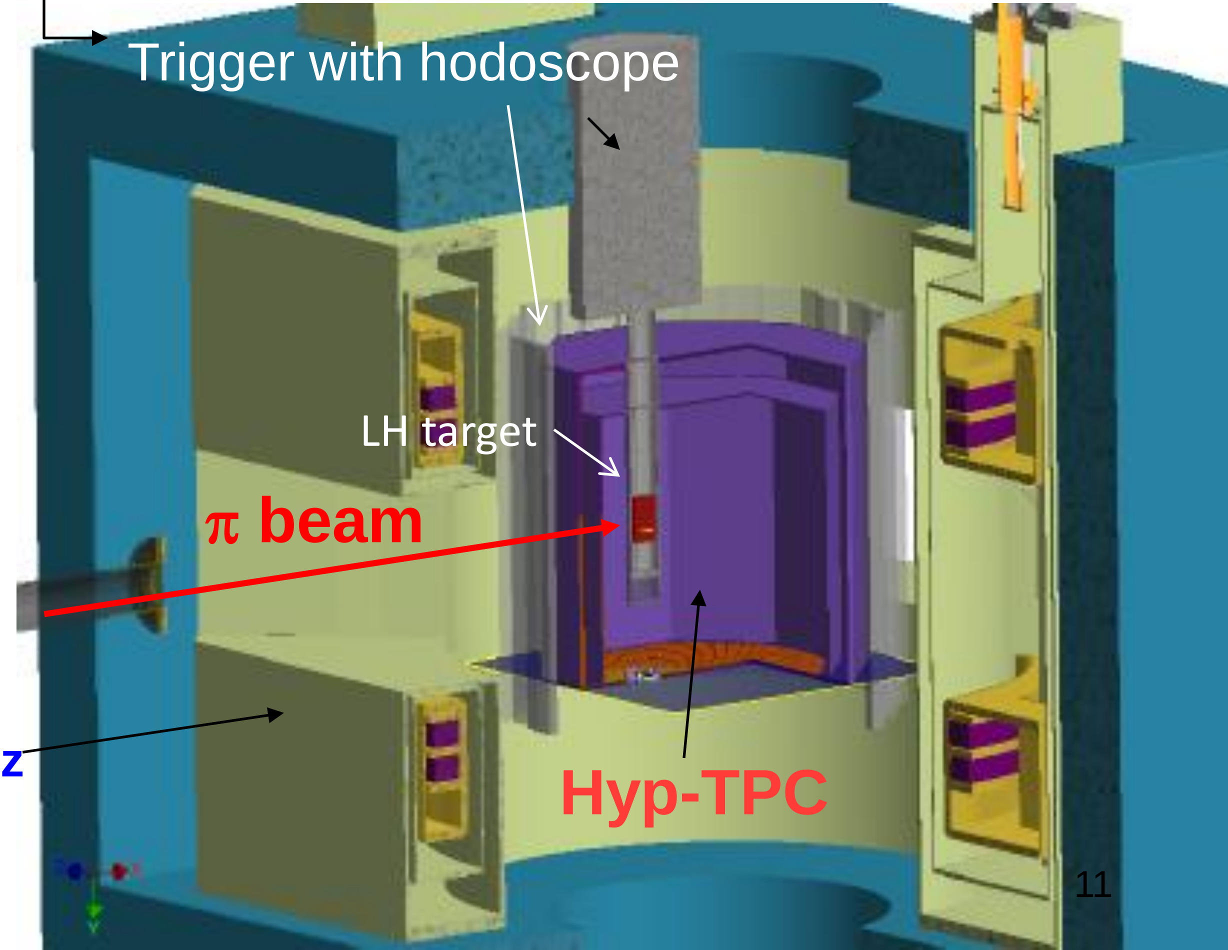
$\pi^- p \to K^0 \Lambda$,

$\pi^+ p \to K^+ \Sigma^+$ ($I=3/2$, Δ^*)

π^{+-} beam on liquid-H target

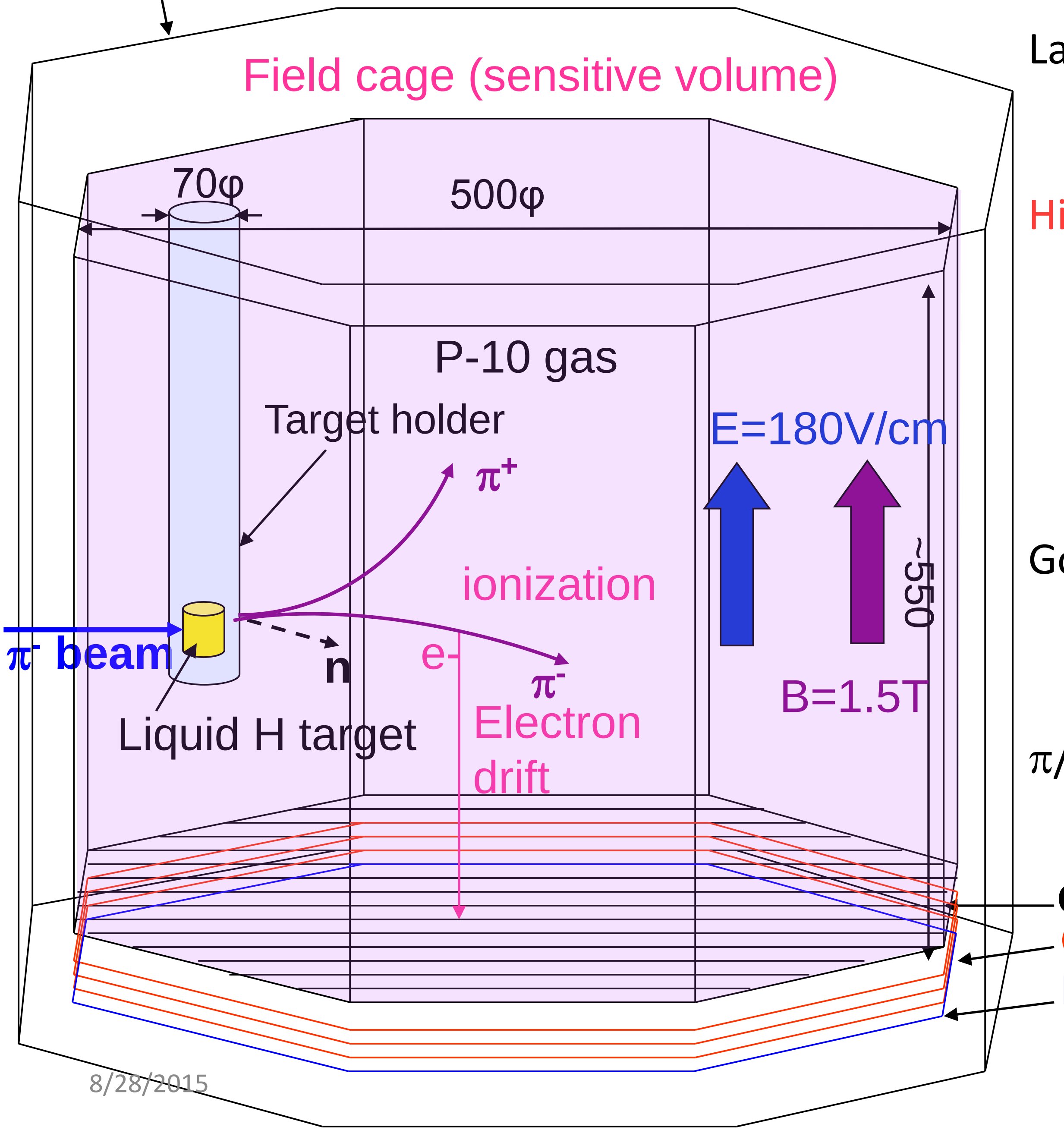
(p= 0.73 – 2.0 GeV/c

W=1.5-2.15 GeV)



Superconducting Helmholtz Dipole magnet

HypTPC



Large acceptance

- H-target inside TPC

High-rate capable TPC

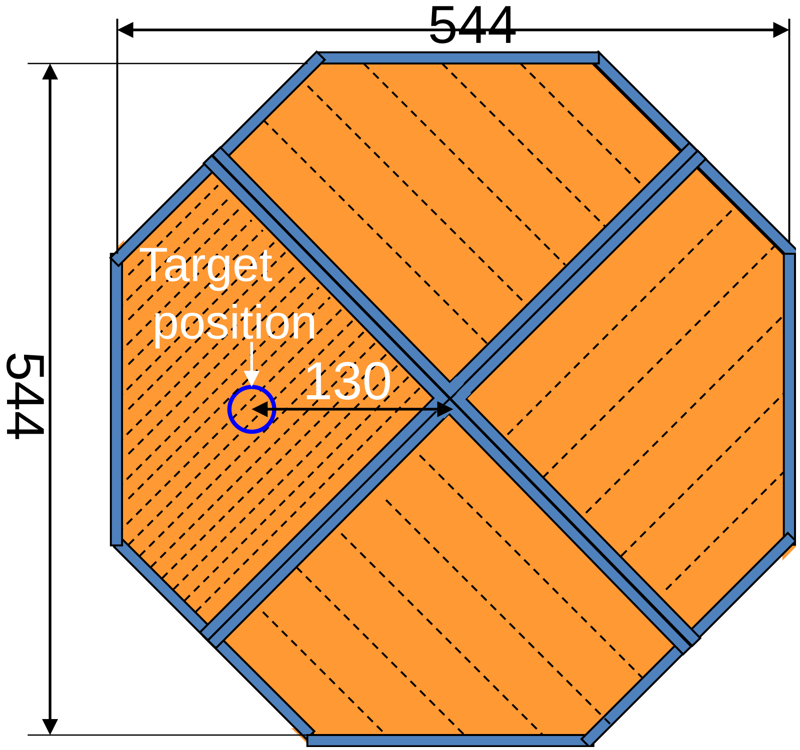
- Gating Grid
- GEM(Gas Electron Multiplier)
  - Suppression of positive-ion backflow causing position distortions

Good position resolution with magnetic field and fine-segmented pads

π/K/p separation

- dE/dx vs p

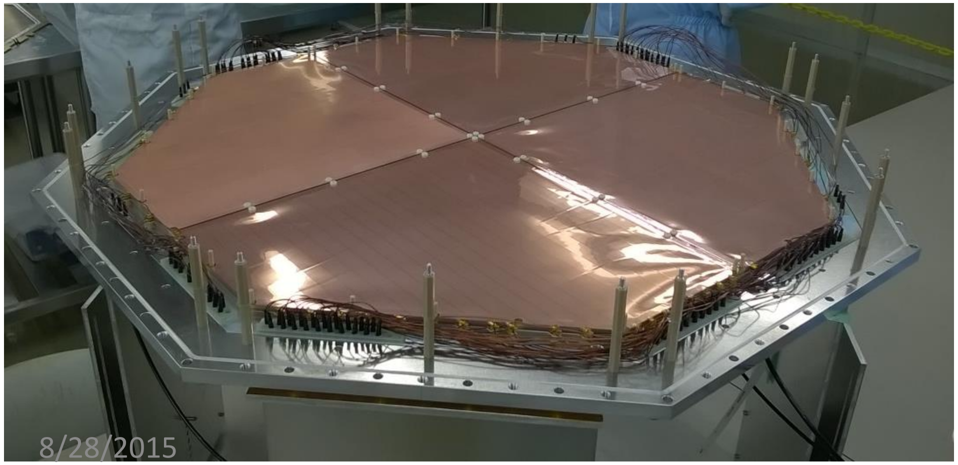
GEM (Gas Electron Multiplier)



- 4 GEM (250mmx250mm) sheets
- 3-GEM stack
  50μm + 50μm +100μm thickness
- Gain ~ 10^4

Segmented electrodes

- reduce discharge rate / electrode
- minimize acceptance loss in case an electrode is broken



Readout pads

Pad size

2.4 x 9 mm^2 (inner layer)

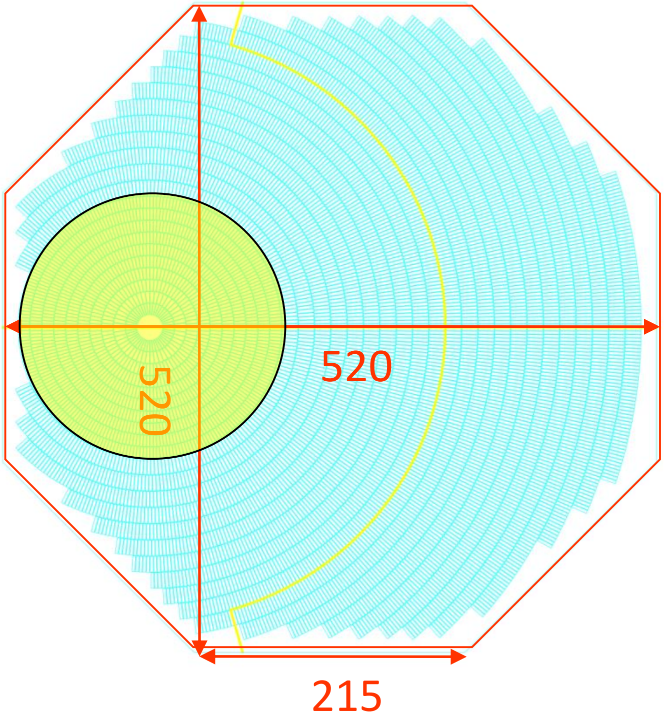
2.4 x 13 mm^2 (outer layer)

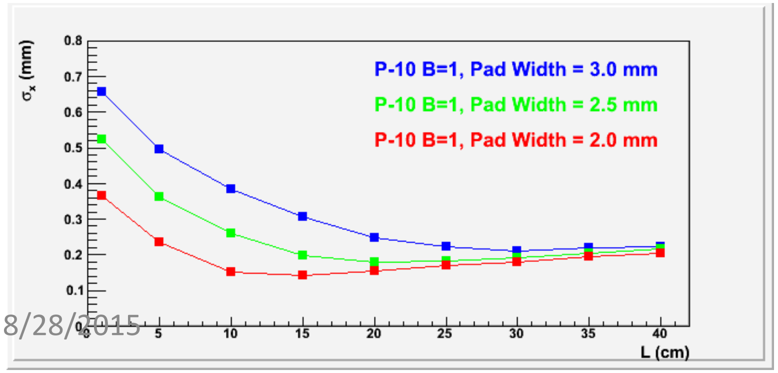
32 pad rows (rings)

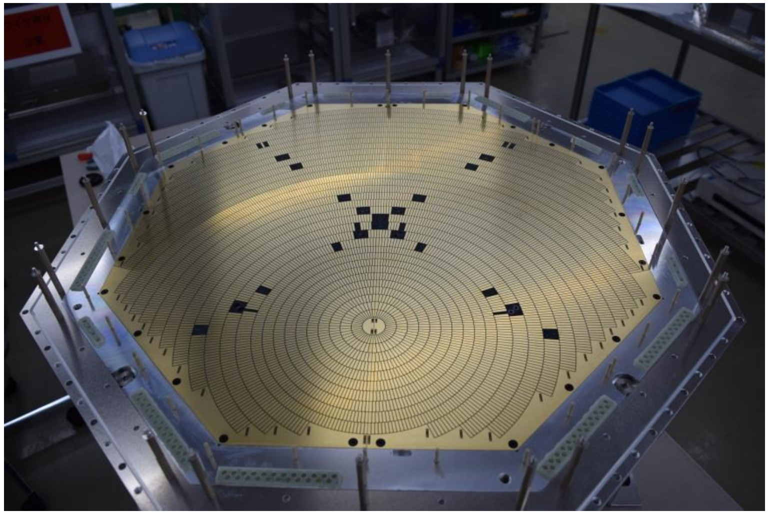
No. of pads = 5768

Position resolution <300μm (L>10cm)

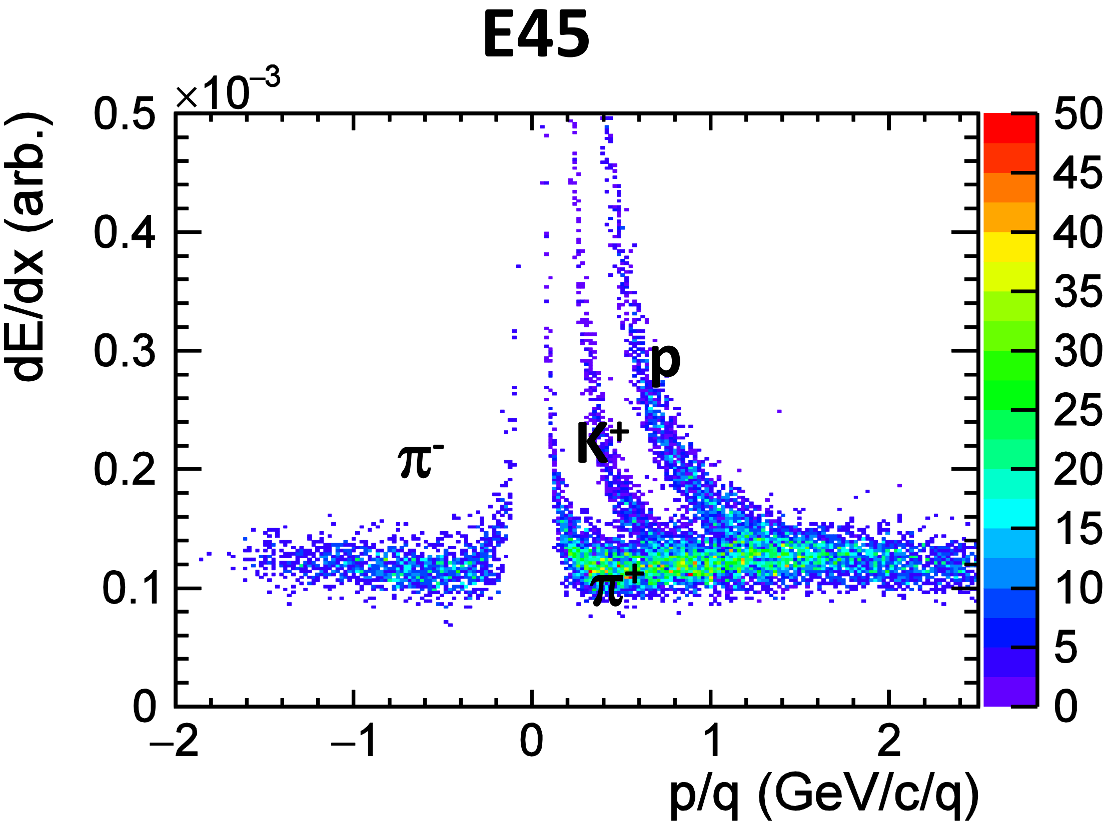
$\Delta p/p$=1-3% (π,p)







Particle identification with TPC



Courtesy of S.H. Hwang

π/K : p<=0.5 GeV/c

π/p : p<=1.1 GeV/c

Data statistics

- (π,2π) cross section : ~2 mb
- π beam rate : ~10^6 / cycle (6s)
- Liquid H target : 5cm length
- TPC acceptance : 40%

⇨ 160 events / cycle

Dominant background: elastic scattering
(σ_{total}= 40 mb → trigger rate = 3200 events / cycle
~ 800 Hz in maximum (4s flat top))

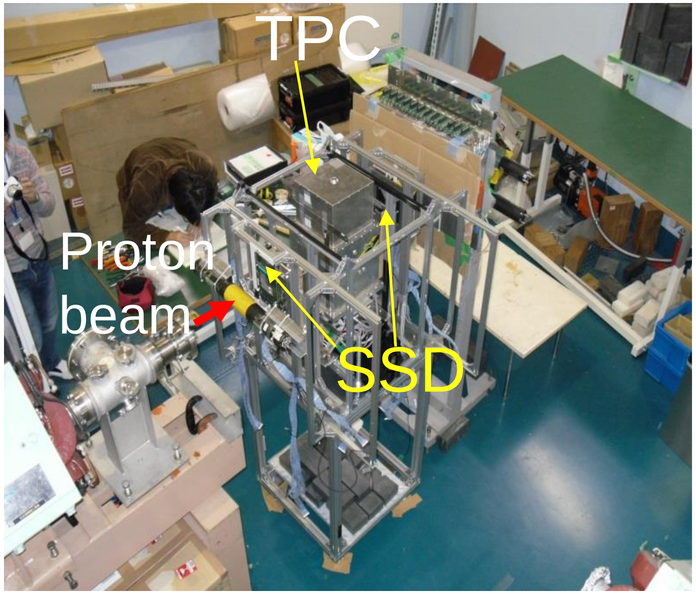
- Energy range : 1.50 – 2.15 GeV
- No. of bins (1000) π^- beam : 24 (energy) x 20 (angle)
  π^+ beam : 23 (energy) x 20 (angle)
- No. of events / bin : 32 K

30M events in 15 days

⇨ Increase world's $\pi\pi$N data (240K) by factor of 130

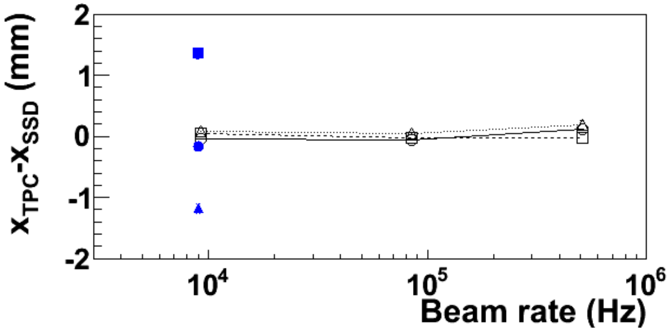
TPC prototype test

NIMA763(2014)65-81



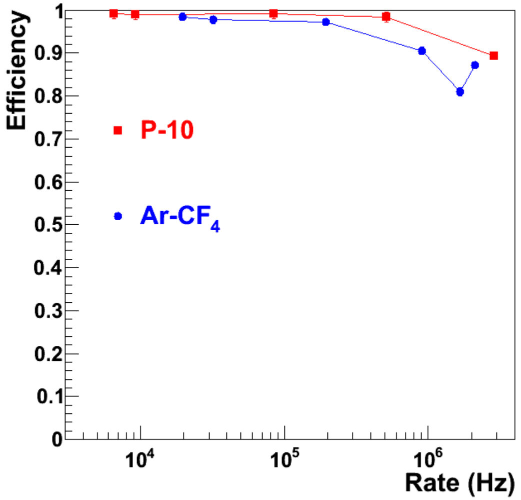
- Beam test at RCNP
  - Proton beam at 400 MeV
  - Beam rate up to 10^6 Hz /cm^2

Hit position distortion <0.1mm



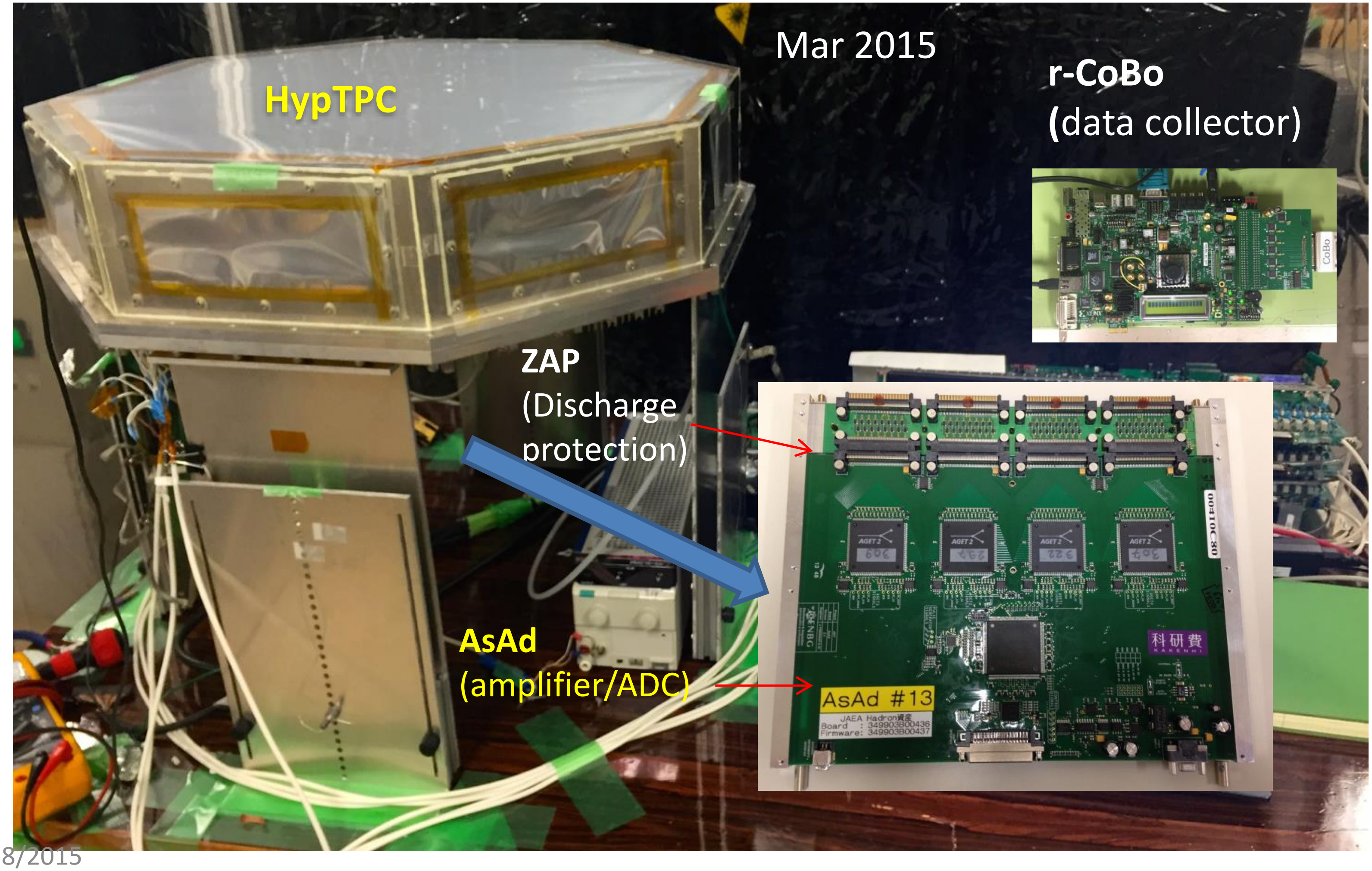
Ion backflow ~ 5% (bench test)

Efficiency vs rate



HypTPC test

Source tests with GET(General Electronics for TPC) readout system



Physics possibilities with HypTPC

- H-dibaryon (E42) : $K^-C \rightarrow K^+ H X$, $H \rightarrow \Lambda\Lambda, \Lambda\pi^- p$
- $\Lambda(1405)$: $\pi^- p \rightarrow K^0 \Lambda(1405)$

  $\Lambda(1405) \rightarrow \Lambda\gamma$ (KN compositeness, T. Sekihara, *PRC*89 (2014) 025202)
- K^-pp : $\pi^+ d \rightarrow K^+ K^- pp$

  $K^-pp \rightarrow \Lambda p, \Sigma^0 p, \Lambda\pi^0 p, \Sigma^0\pi^0 p$
- Ξ excited states:

  $K^-p \rightarrow K^+\Xi^{-*}$, $\Xi^{-*} \rightarrow \Lambda K^-, \Sigma^0 K^-, \Sigma^-\overline{K}^0, \Xi^-\pi^0, \Xi^0\pi^-, \Xi^-\gamma$

  $K^-p \rightarrow K^0\Xi^{0*}$, $\Xi^{0*} \rightarrow \Lambda\overline{K}^0, \Sigma^0\overline{K}^0, \Sigma^+K^-, \Xi^-\pi^+$

Summary : J-PARC E45

- We proposed J-PARC-E45 to study baryon excited states in $(\pi,2\pi)$ reactions, which will improve previous data statistics by two orders of magnitude.

- We have developed a large acceptance TPC for high rate beams and a superconducting Helmholtz magnet
  - They will be ready for beams in 2016

- Partial wave analysis with dynamical coupled channels model in collaboration with theorists (H. Kamano, T. Sato,..)

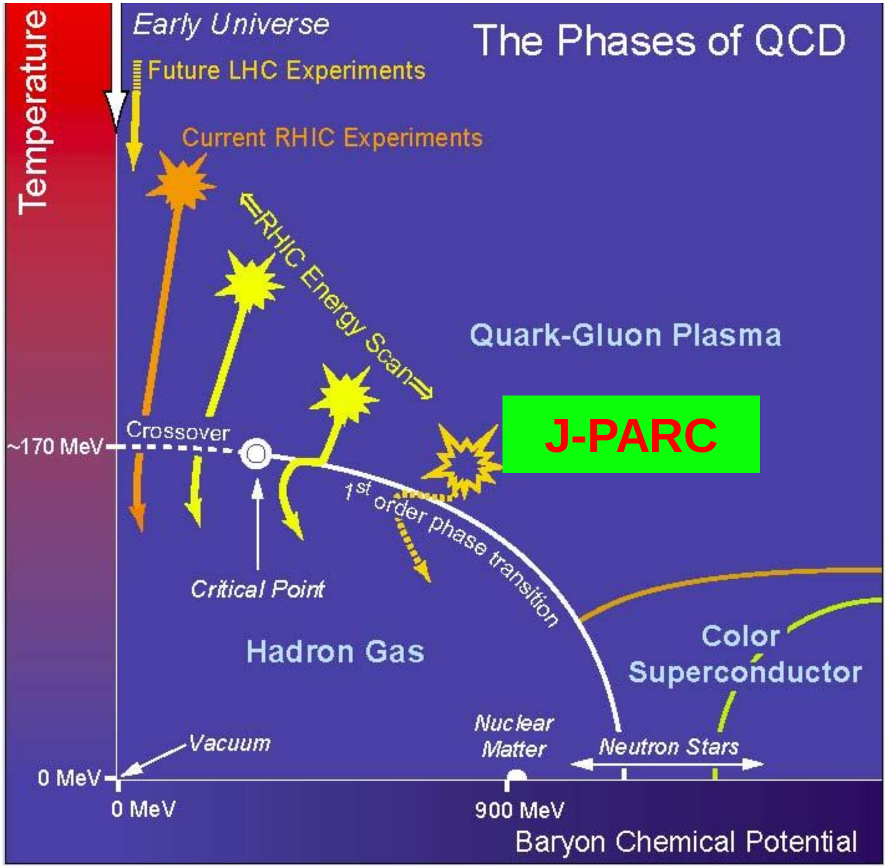
Future J-PARC Heavy-ion Program

In A+A collisions at RHIC and LHC, QGP has been discovered at high T and low ρ, but the phase transition is smooth cross over[1]

- High p_T hadron suppression[2]
- Thermal photon radiation[3]

At J-PARC, we aim at studies of QCD phase structures (critical point and phase boundary) in high density regime (~neutron star)

- high statistics data with world's highest intensity HI beams



[1] Y. Aoki et al, Nature 443 (2006) 675
[2] K. Adcox et al, PRL 89 (2002) 022301
[3] A. Adare et al, PRL 104 132301

J-PARC HI Collaboration

Nuclear Experimentalists and Accelerator Physicists

S. Nagamiya (JAEA/KEK/RIKEN)
H. Sako, K. Imai, K. Nishio, S. Sato, S. Hasegawa, K. Tanida, S. H. Hwang, H. Sugimura, Y. Ichikawa (ASRC/JAEA)
H. Harada, P. K. Saha, M. Kinsho, J. Tamura (J-PARC/JAEA)
K. Ozawa, K. Itakura, Y. Liu (J-PARC/KEK)
T. Sakaguchi, M. Okamura (BNL)
K. Shigaki (Hiroshima Univ.)
M. Kitazawa, A. Sakaguchi (Osaka Univ.)
T. Chujo, S. Esumi, B. C. Kim (Univ. of Tsukuba)
T. Gunji (CNS, Univ. of Tokyo)
H. Tamura, M. Kaneta (Tohoku Univ.)
K. Oyama (Nagasaki Institute of Applied Science)
H. Masui (Wuhan Univ.)

Heavy-ion programs in the world

Accelerator	Type	Beam energy (AGeV)	C.M. energy $\sqrt{s}$(AGeV)	Beam rate / Luminosity	Interaction rate (sec^{-1})	Year of experiment
RHIC Beam Energy Scan (BNL)	Collider		7.7-62	10^{26} -$10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ ($\sqrt{s}$=20AGeV)	600~6000 ($\sqrt{s}$=20AeV) (σ_{total}=6b)	2004-2010 2018-2019 (e-cooling)
NICA (JINR)	Collider Fixed target	0.6-4.5	4-11 1.9-2.4	10^{27} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ ($\sqrt{s}$=9AGeV Au+Au)	~6000 (σ_{total}=6b)	2019- 2017-
FAIR SIS100 (CBM)	Fixed target	**2-11(Au)**	**2-4.7**	**1.5×10^{10} cycle^{-1}** (10s cycle,U^{92+})	**10^{5}-10^{7}** (detector)	**2021-2024**
J-PARC	Fixed target	**1-19(U)**	**1.9-6.2**	**10^{10} -10^{11} cycle^{-1}** (~6s cycle)	**10^{7}-10^{8} ?** (0.1% target)	?

References

RHIC: A. Fedotov, LEReC Review, 2013

FAIR: FAIR Baseline Technical Review, C. Strum, INPC2013, Firenze, Italy; S. Seddiki, FAIRNESS-2013, C. Hoehne, CPOD2014

NICA : A. Kovalenko, Joint US-CERN-Japan-Russia Accelerator School, Shizuoka, Japan, 2013, A. Sorin, CPOD2014

Low and High energy programs

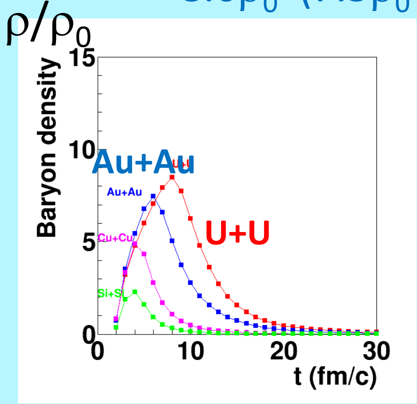
“Low energy” program (Linac)

for unstable nuclei research

- Ion species
  - Ne, Ar, Fe, Ni, Kr, Xe,…,U
- Beam energy
  - 1 - 10 AMeV (U)
- Beam current
  - 10-30 pμA
  - 10ms, 25Hz

“High Enegy” Program (50 GeV MR)

- Ion species
  - p, Si, Ar, Cu, Xe, Au(Pb), U
  - Also light ions for hypernuclei
  - Maximum baryon density in U+U
    - $8.6\rho_0$ ($7.5\rho_0$ in Au+Au)



JAM model, Y. Nara, Phys. Rev. C61,024901(1999)

- Beam energy
  - 1 - 19 AGeV(U, $\sqrt{s_{NN}} = 2-6.2\text{GeV}$)
- Rate
  - 10^{10}-10^{11} ions per cycle (~a few sec)

Advantages/limitation of RCS/MR for HI beam

- Existing 3 GeV and 50 GeV synchrotrons
  HI injector and injection section in RCS should be added

- Proven performance for high-rate proton beam for RCS and MR
  - Slowly extracted proton beams
    2.5×10^{13}/cycle →1.3×10^{14} /cycle (2017)

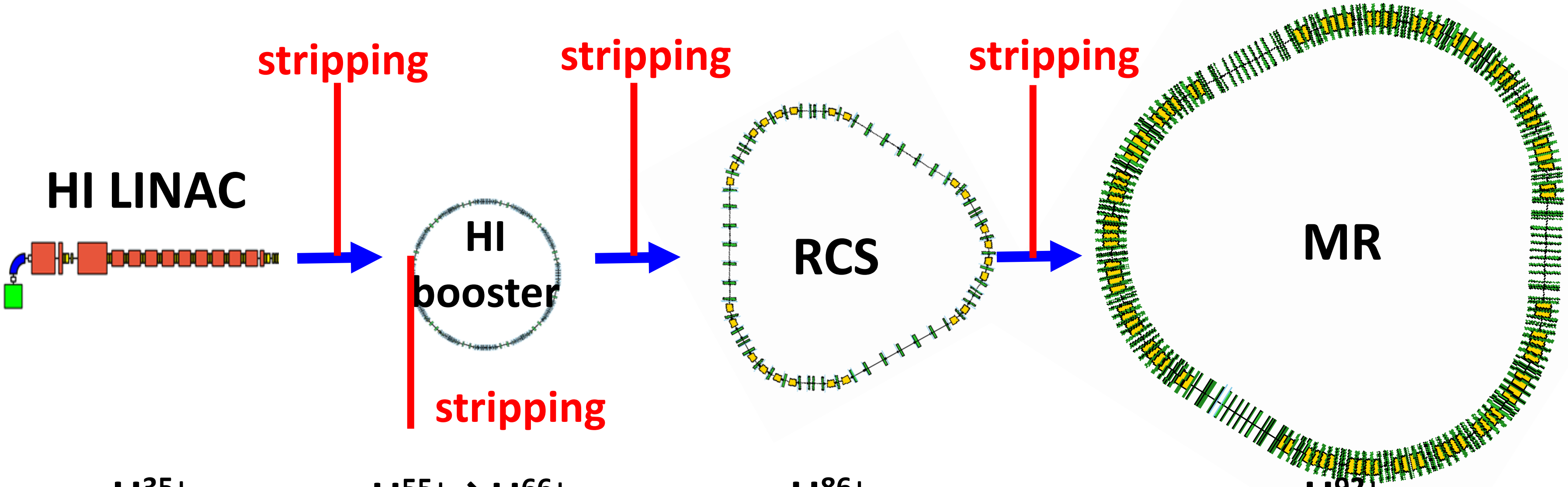
- **Parallel RCS operations for MR(HI) and MLF(proton) are a must (similarly to current proton operation)**

- Limited freedom in RCS for operation parameters (magnets, RF cavity…)

→ The injector must be designed to fit to RCS

J-PARC HI Accelerator scheme

(H. Harada, J-PARC)



$U^{35+}\rightarrow U^{55+}$
20.0→19.86
AMeV

$U^{66+}\rightarrow U^{86+}$
67.0→62.34
AMeV

$U^{86+}\rightarrow U^{92+}$
735.21→727.0
AMeV

stripping

stripping

stripping

HI LINAC

HI booster

stripping

RCS

MR

U^{35+}
20.0AMeV

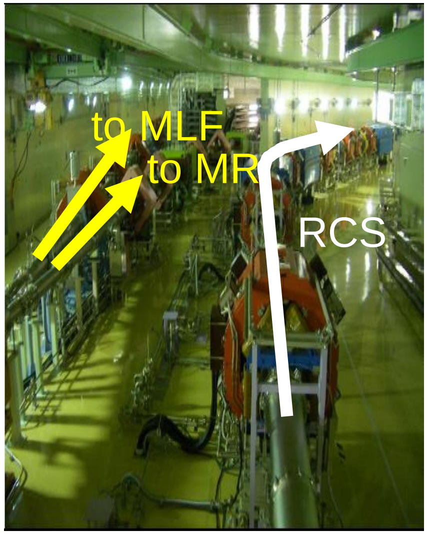
$U^{55+}\rightarrow U^{66+}$
19.86→67.0
AMeV

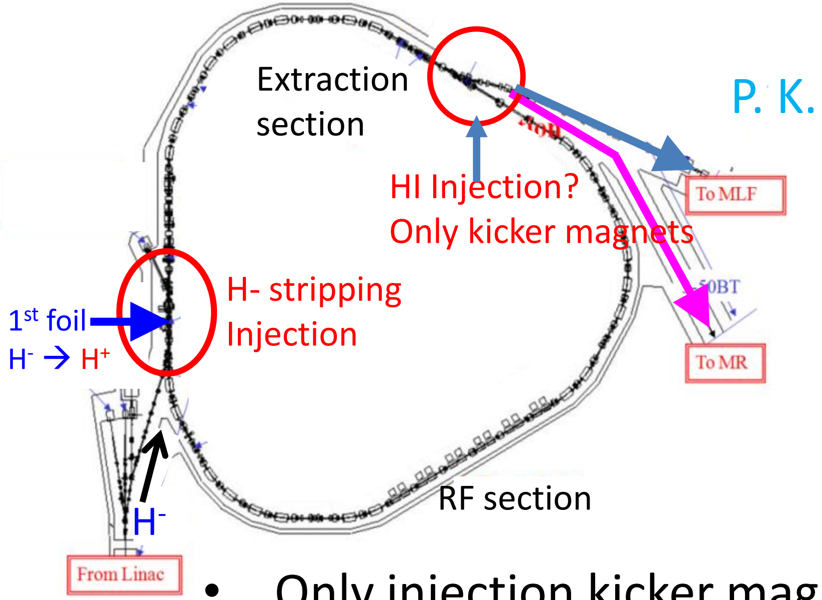
U^{86+}
62.34→735.2
AMeV

U^{92+}
727.0AMeV/u→11.15
AGeV
(30GeV for p)

HI injection and acceleration at RCS

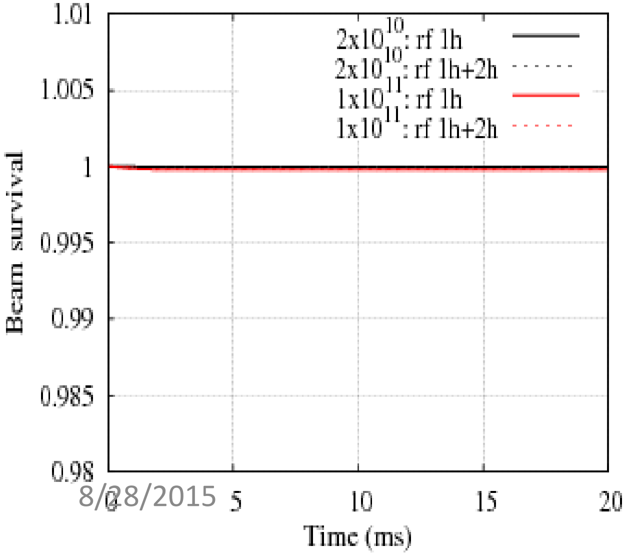
HI Injection candidate: end of extraction straight section





P. K. Saha, J-PARC

- Only injection kicker magnets necessary



Beam survival probability

at 2×10^{10} ~1×10^{11}/bunch

>= 99.97%

Loss point: Collimator (100%)

[For 1 MW proton : ~99.8%, beam loss mainly due to foil scattering]

Physics goals

- Dileptons (dielectron and dimuon)

  ⇔ J-PARC E16 p+A
- Systematic and high statistics hadron measurements
  - Strange meson and baryons
  - Event-by-event fluctuations
  - Two particle correlations

    (YN, YY correlations in high baryon density)
  - Collective flow (related to EOS?)
- Rare probes
  - Hypernuclei
  - Exotic hadrons
    - Λ(1405)
    - Dibaryon (H-dibaryon, ΩN, ΔΔ,…)
    - Kaonic nucleus (K^-pp,…)
  - Charm
    - J/ψ, D, charmed baryons

  ⇔ J-PARC π/K beams
- Photons
  - Thermal radiation from QGP

Onset of QGP

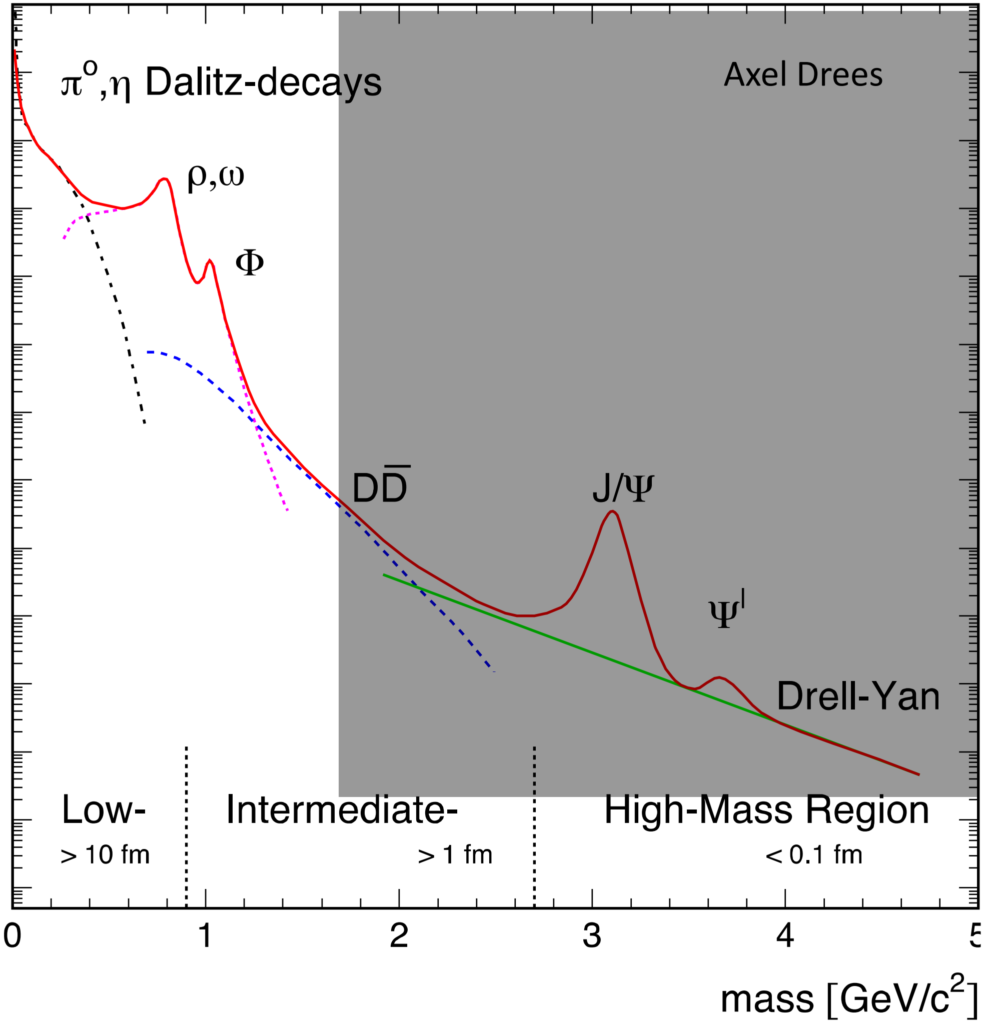
Search for critical point

Properties of
Dense matter

Dileptons at J-PARC energy

Penetrating probes of dense matter

- Low Mass Range
  - in-medium modification of vector mesons (link to chiral symmetry restoration)
- Intermediate Mass Range
  - $D\bar{D}$ is suppressed
  - Sensitive to QGP thermal radiation?

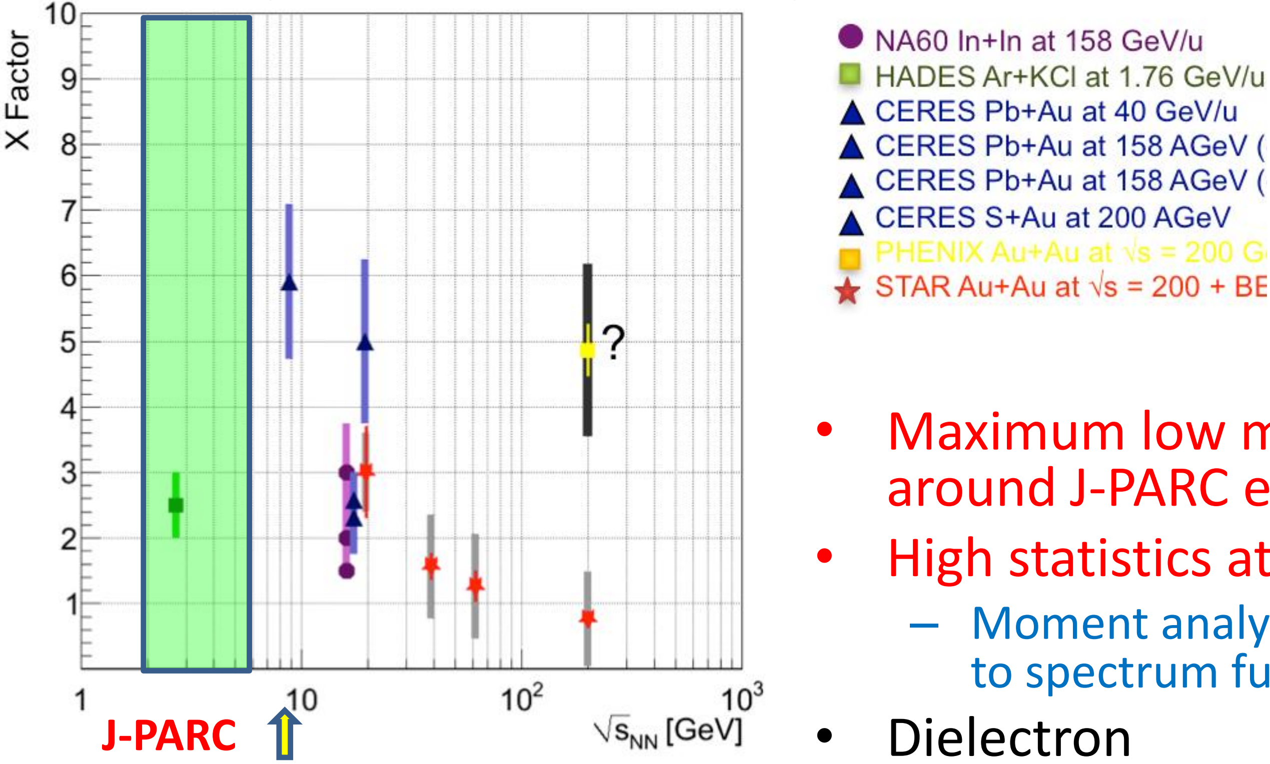


T. Sakaguchi, JHI2014

Low-mass dileptons

Low-mass dilepton enhancement factor

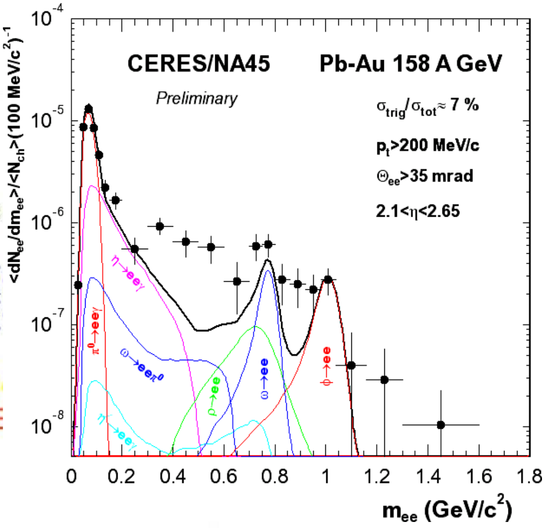
Measured / cocktail in m=0.2-0.8 GeV/c^2



Highest baryon density ~ 8GeV

(Randrup, PRC74(2006)047901)

T. Galatyuk, EM probes of Strongly Interacting Matter, ECT*, Trento 2007



- Maximum low mass enhancement around J-PARC energies?
- High statistics at J-PARC
  - Moment analysis→direct comparison to spectrum functions by theories

$$\int dm_{ee} N(m_{ee}) {m_{ee}}^{n}$$

- Dielectron
  - low p_T, lower m
  - γ conversion at low m
- Dimuon
  - high p_T, higher m
  - π,K → μ decay background
  - Utilize highest beam intensity

Event-by-event fluctuations

Search for the critical point

and phase boundary

w/ 3rd and 4th-order fluctuations

Direct comparison to lattice-QCD may be possible

$$S\sigma \cong \frac{\chi_B^3}{\chi_B^2}$$

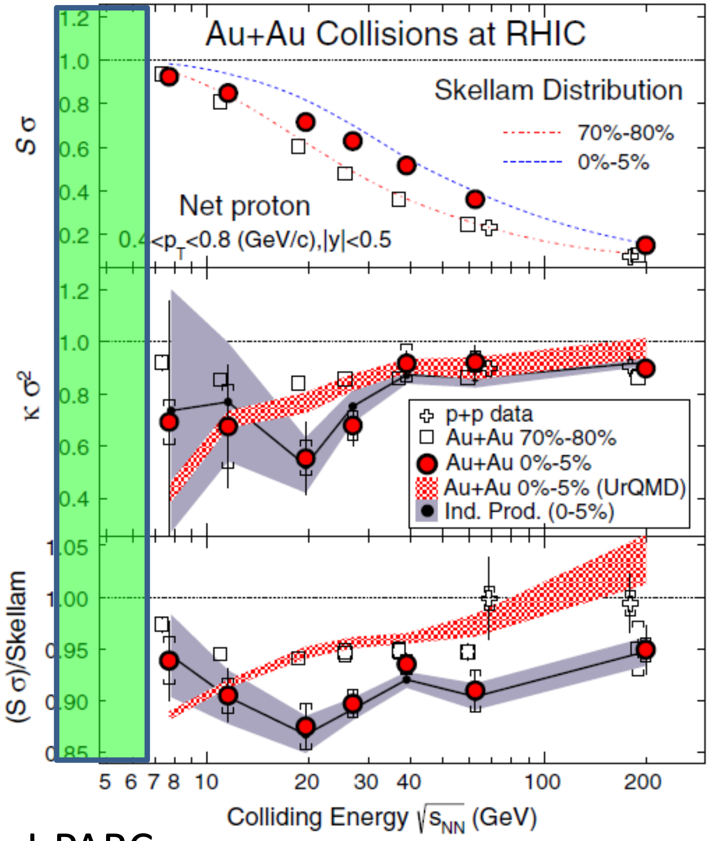
$$\kappa\sigma^2 \cong \frac{\chi_B^4}{\chi_B^2}$$

- Net-charge
- Net-proton (baryon)
- Strangeness

High statistics in J-PARC

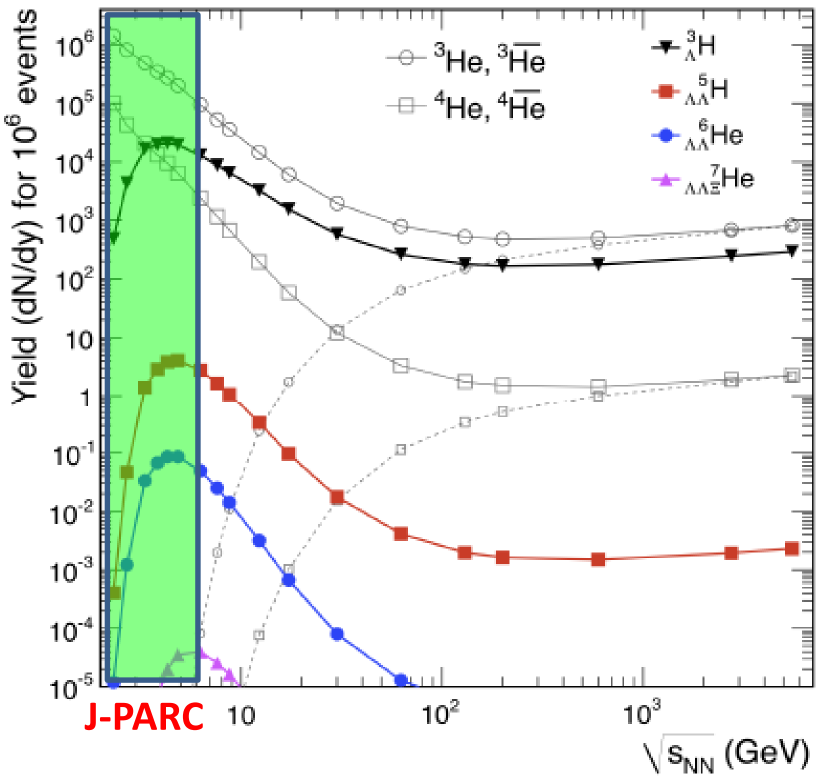
Wide y-p_T acceptance required

STAR PRL112 (2014) 032302



J-PARC

Hypernuclei



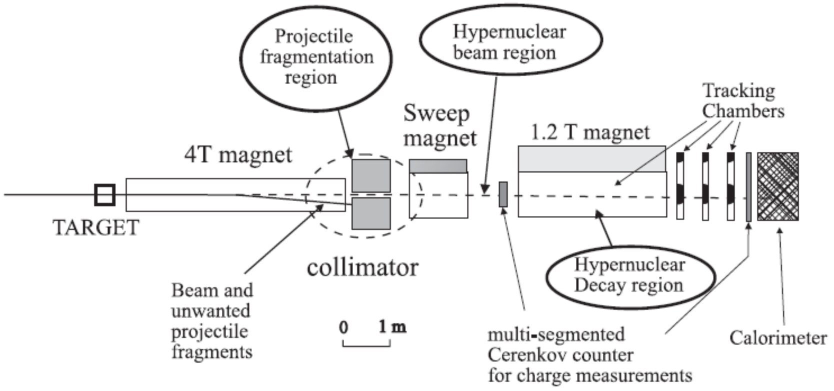
A. Andronic, PLB697 (2011) 203

Maximum yield at J-PARC

- Coalescence of high-density baryons

S=-3 Hypernuclei

- Precise secondary vertex reconstruction (mid rapidity)
- Closed geometry setup (beam rapidity)
  - Full intensity beam
  - Magnetic moment

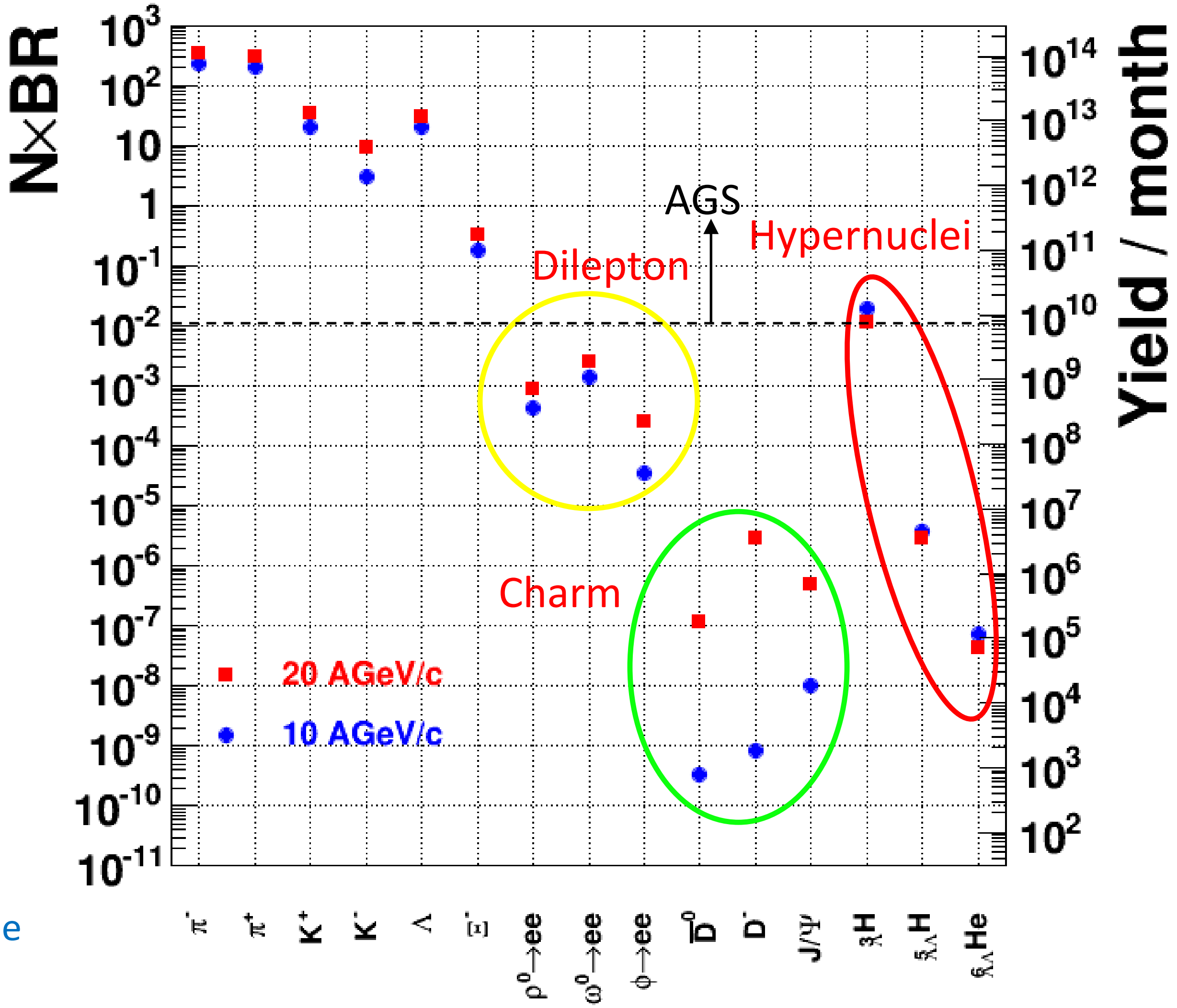


KEK Report 2000-11
Expression of Interest for Nuclear/Hadron Physics Experiments at the 50-GeV Proton Synchrotron

Particle production rates

Beam : 10^{10} Hz
0.1% target
→ Interaction rate 10^{7} Hz
Centrality trigger 1%
→ DAQ rate = 100kHz

In 1 month experiment:
$\rho,\omega,\phi \rightarrow ee$ 10^{7}-10^{9}
$D, J/\Psi$ 10^{5}-10^{6} (20AGeV)
(10^{3} -10^{4}(10AGeV))
Hypernuclei 10^{5} -10^{10}



Ref: HSD calculations in FAIR Baseline Technical Report (Mar 2006)
A. Andronic, PLB697 (2011) 203

Experimental challenges

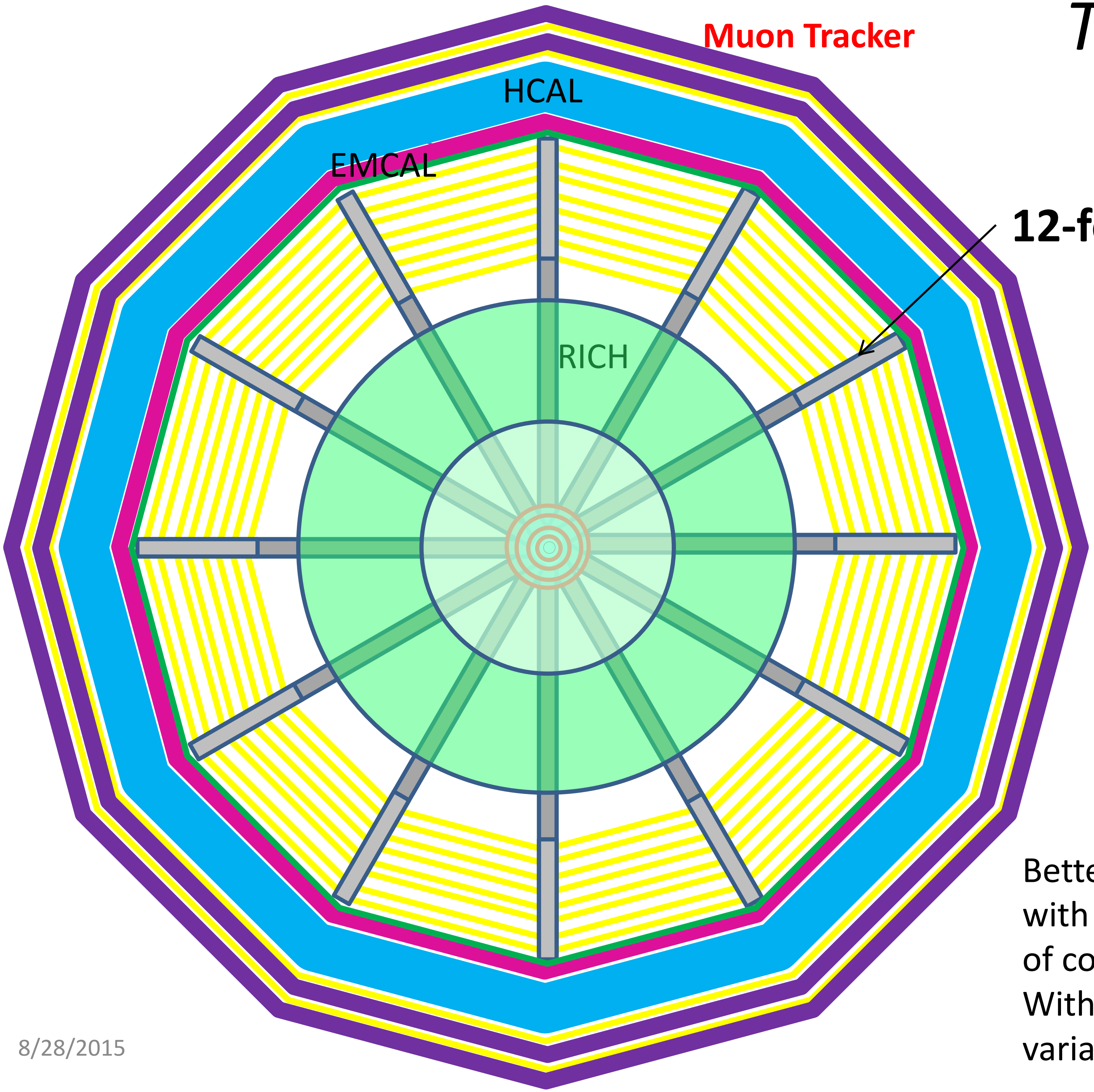
- High rate capability
  - Fast detectors
    - Silicon trackers, GEM trackers, …
  - Extremely fast DAQ → triggerless DAQ
    - >= 100kHz
- High granularity
  - Pixel size < 3x3mm^2

  (at 1m from the target, θ<2deg, 10% occupancy)
- Large acceptance (~4π)
  - Coverage for low beam energies (CBM<30^o , beam energy>=8AGeV/c)
  - Maximum multiplicity for e-b-e fluctuations
  - Backward physics (target fragment region)
- Electron measurement
  - Field free region for RICH close to the target

⇨ Toroidal magnet setup

Toroidal

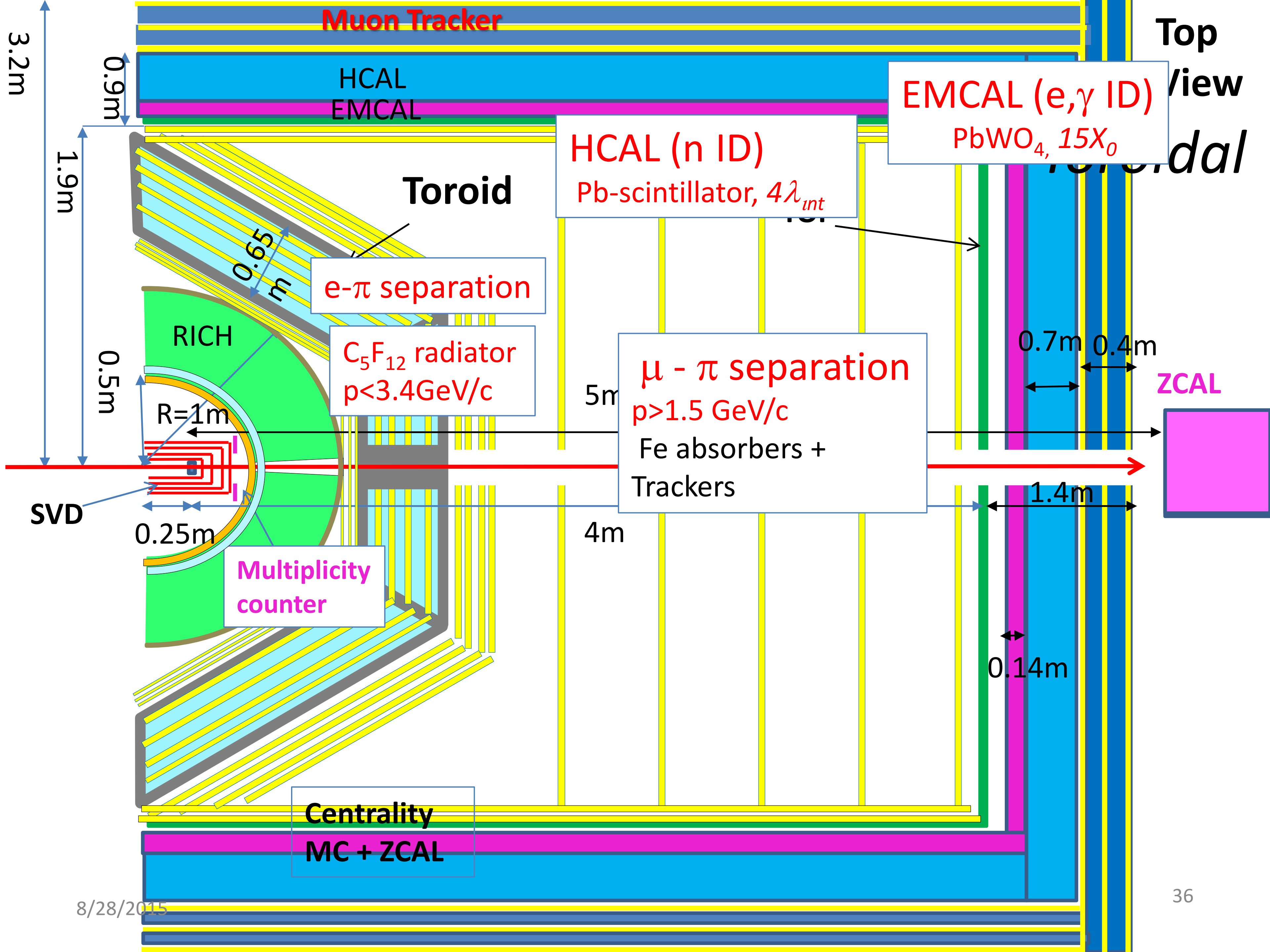
Beam View



12-fold Toroid coils

(Coils : dead area)

Better Bϕ uniformity with a larger number of coils
With 12 coils variations ~+-20%



EMCAL (e,γ ID)
$PbWO_4$, $15X_0$

HCAL (n ID)
Pb-scintillator, $4\lambda_{int}$

e-π separation

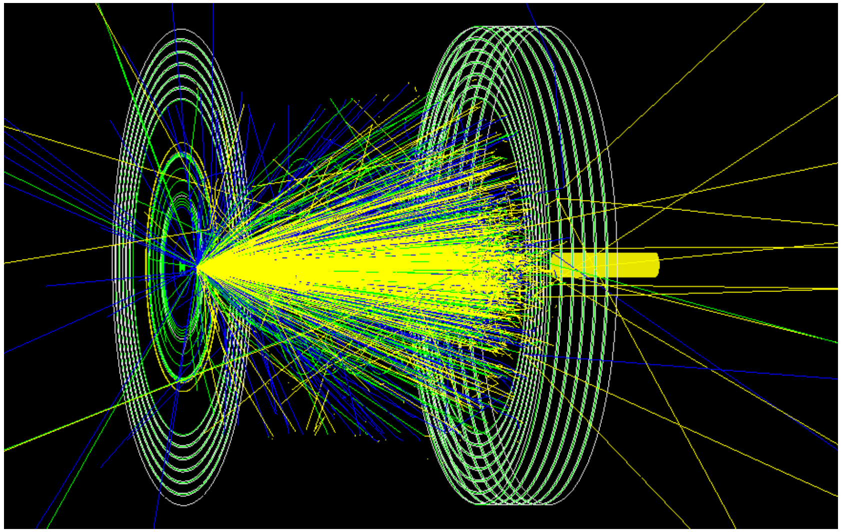
C_5F_{12} radiator
$p<3.4$GeV/c

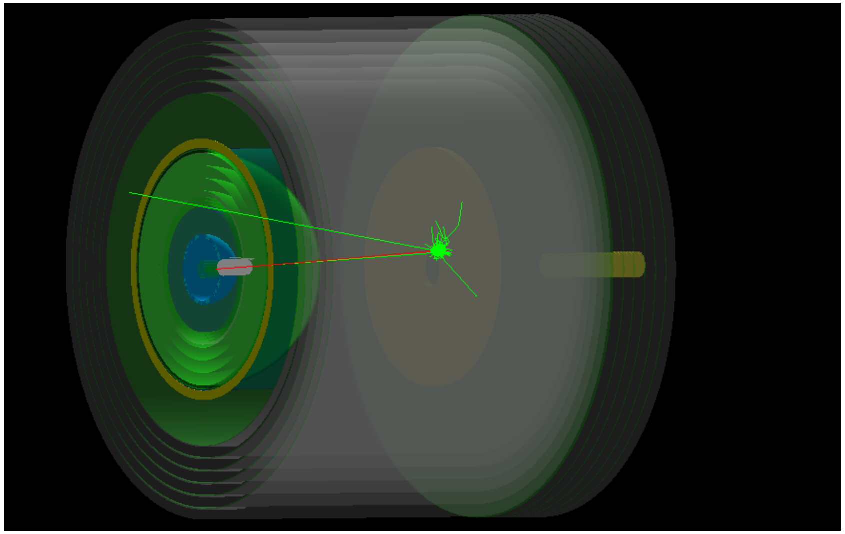
μ - π separation
$p>1.5$ GeV/c
Fe absorbers +
Trackers

Multiplicity
counter

Centrality
MC + ZCAL

GEANT4 (Toroidal) setup

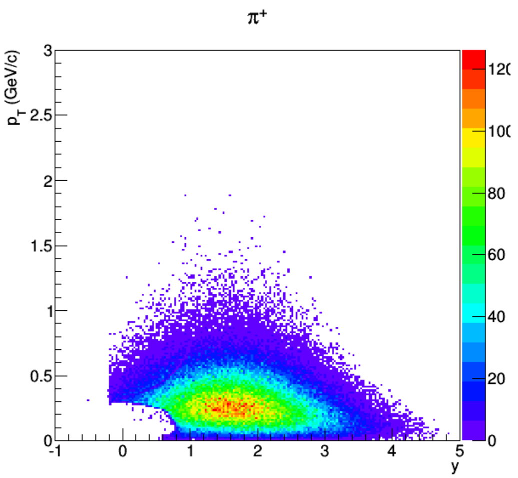




H. Sako, B.C. Kim

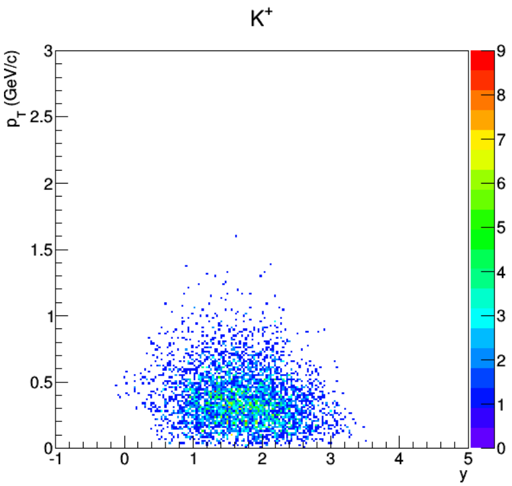
- U+U at 10AGeV/c with JAM
- Assumption for simplicity
  - Half-spherical toroidal shape
  - Uniform B_ϕ field
  - No dead area due to coils

Acceptance



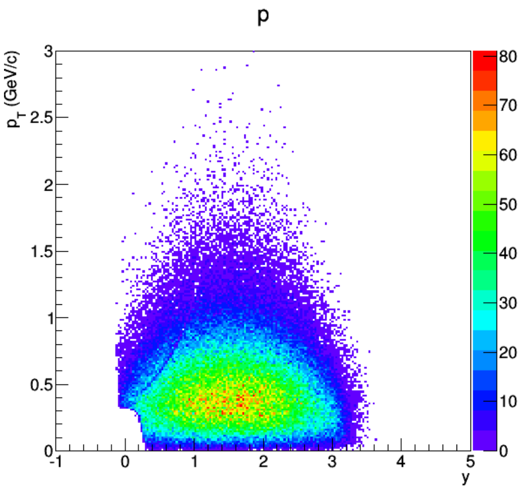
π^+

Acceptance = 77.5%



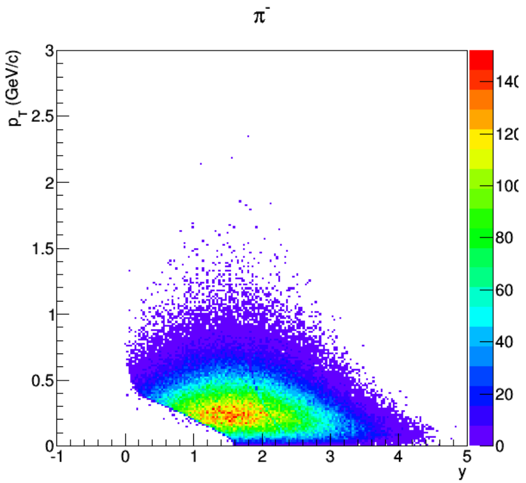
K^+

Acceptance = 64.2%



p

Acceptance = 95.0%

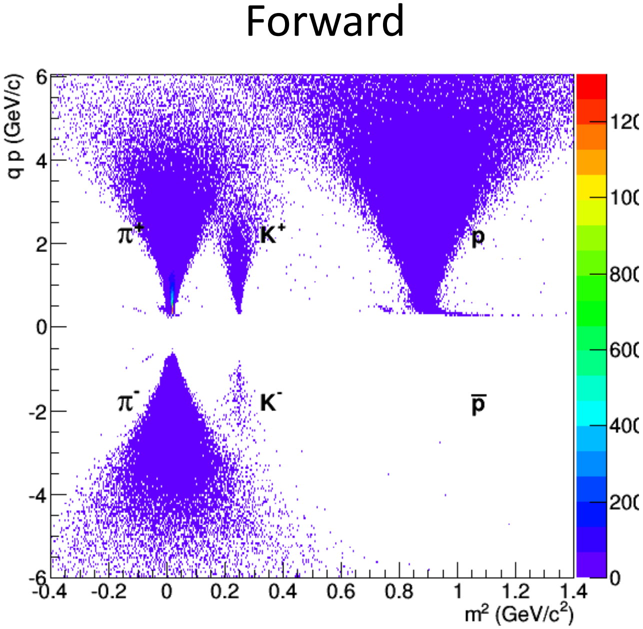


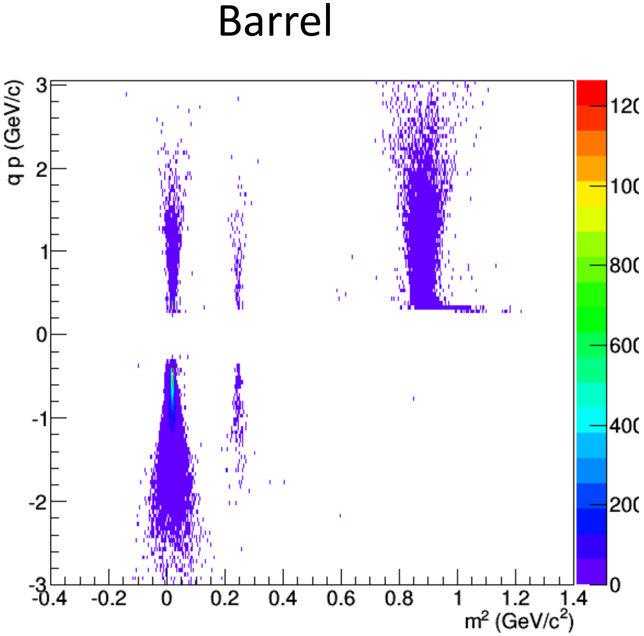
π^-

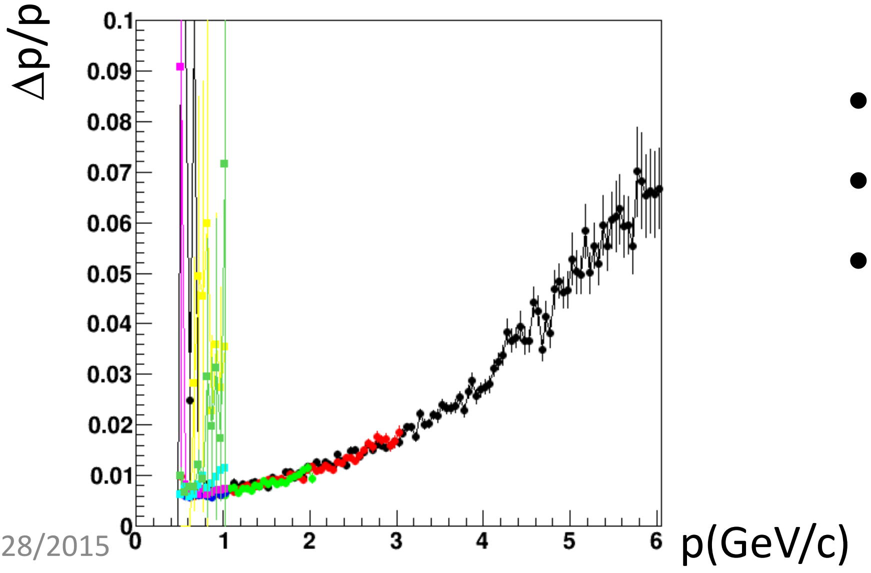
Acceptance = 70.9%

- TOF hits are required
- Acceptance includes decay loss

PID and momentum resolution

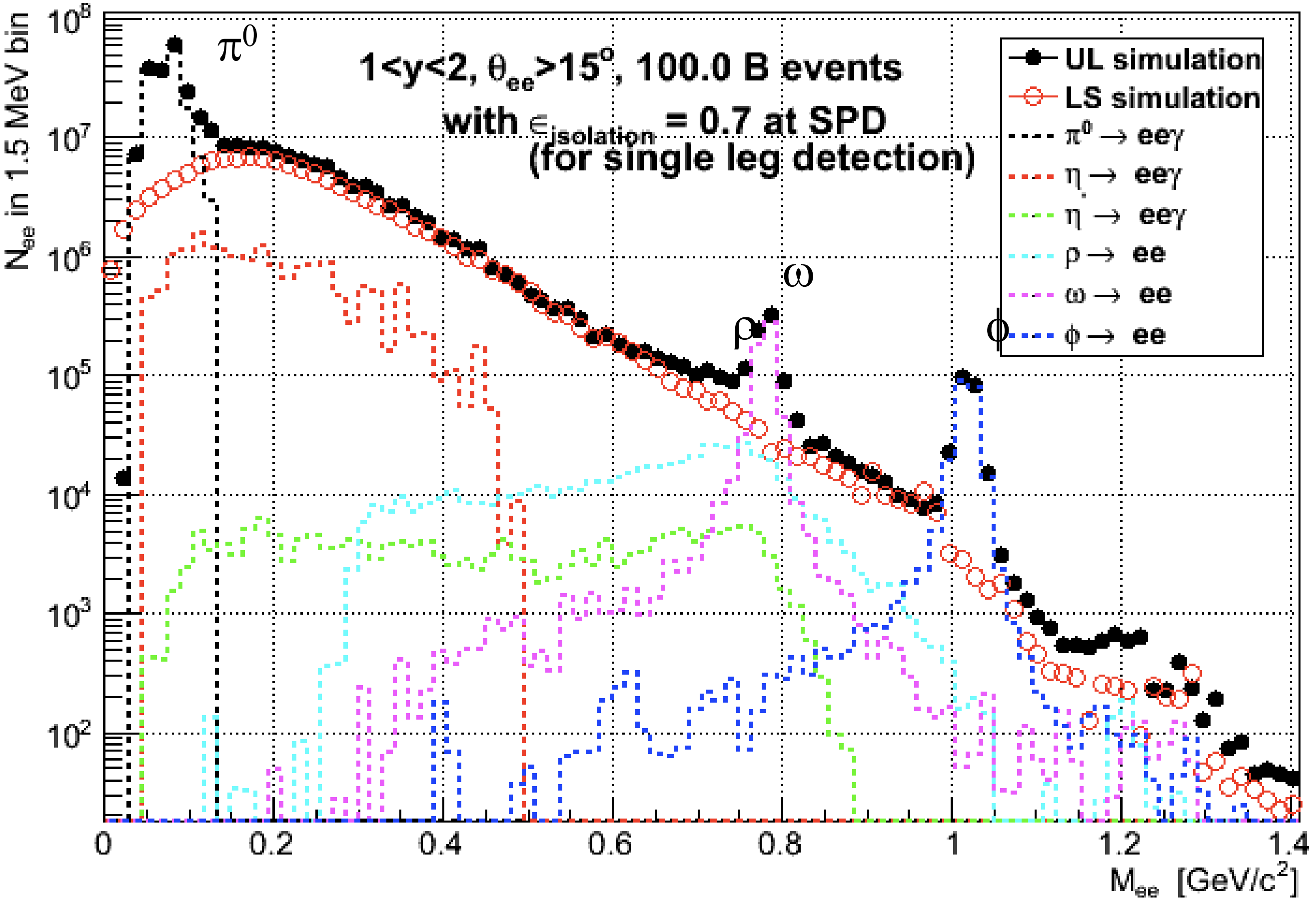






- TOF resolution 50ps
- π/K separation 2.5GeV/c (2.5σ)
- Δp/p = 0.7% - 5% (0.5-5GeV/c)

Simulated di-electron spectrum (preliminary)



Calculations by T. Gunji and T. Sakaguchi

Based on π^0 spectra of JAM

Other hadrons m_T-scaled

b<1fm (0.25% centrality)

Momentum resolution 2%

Electron efficiency 50%

(No detector response)

10^{11} events

⇔100 kHz

x 1 month running

$\varepsilon_{isolation}$ = rejection efficiency of close opening angle Dalitz pair

Solenoid+Dipole setup

Summary : J-PARC HI

- A heavy-ion program at J-PARC is being designed to study dense matter
  - Acceleration schemes with RCS and MR
  - Near-4π HI spectrometer with Toroidal to measure dileptons and hadrons

Prospects

- R&D
  - MRPC-TOF (Tsukuba, JAEA, KEK) in J-PARC E16 (p+A) for hadron measurements
  - DAQ (JAEA,NIAS)

→A conceptual design report (white paper) in this year

International collaboration is very important for success of the project

- We welcome Korean collaborators!

- Reimei workshop at JAEA (Jan 18 – 20, 2016)
  - Prof. Hyun-Chul Kim (Inha University), Makoto Oka, H. Sako (JAEA)
  - Heavy-flavor hadron physics and heavy-ion physics
  - J-PARC Heavy-ion collaboration meeting (Jan 21)

Backup

comments on s=-3 nuclei

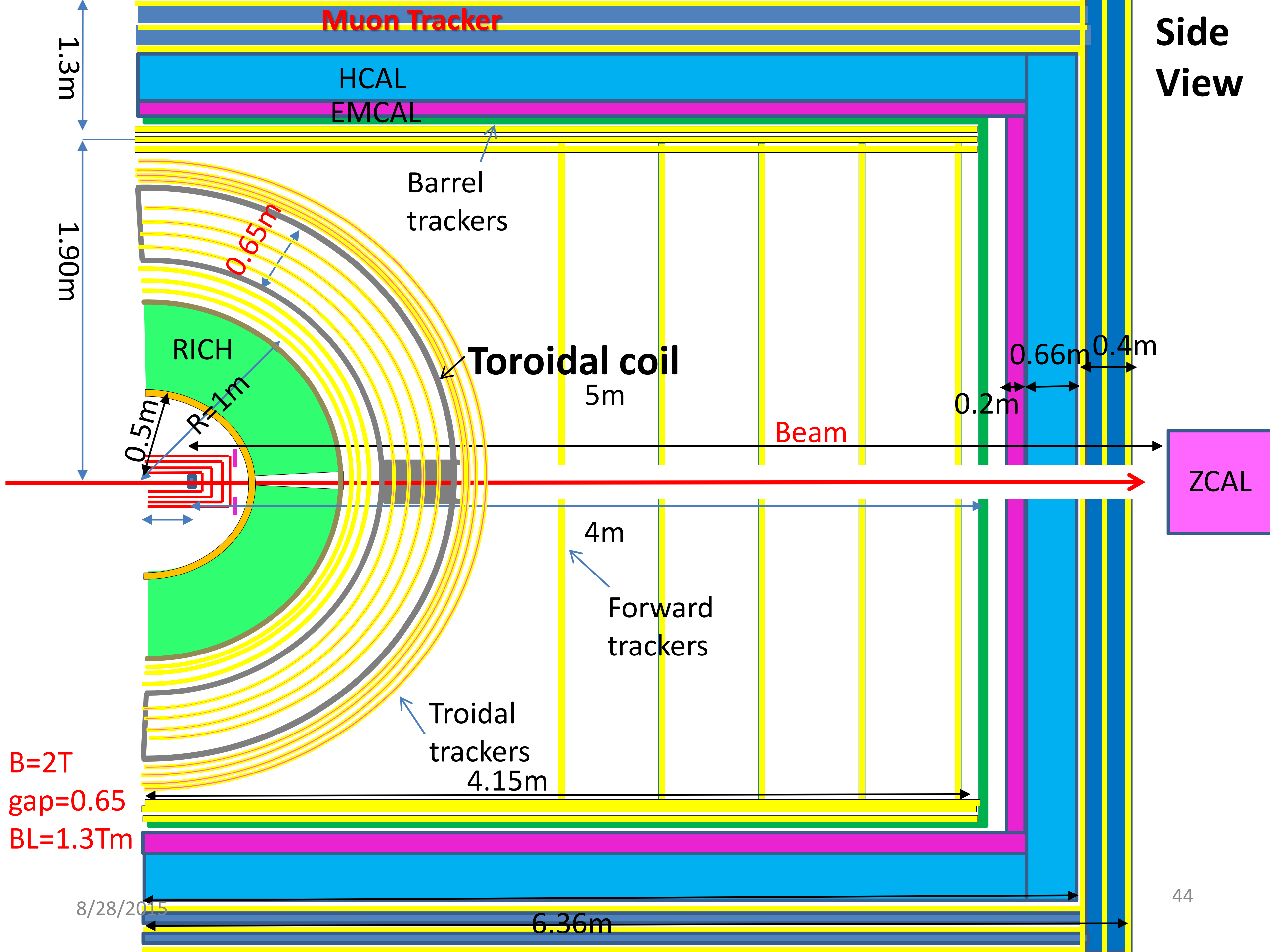
- Smallest triple Λ nuclei will be $^{14}C_{\Lambda\Lambda\Lambda}$, since 3rd Λ should be in p-shell which is only bound larger than A=11 ($^{13}C_{\Lambda}$) .

- Possible smaller s=-3 nuclei can be;

  $^{4}He+\Lambda\Lambda+\Xi^{0}$ system ~10^{-7}

A. J. Baltz, C. B. Dover et al, PLB325 (1994) 7

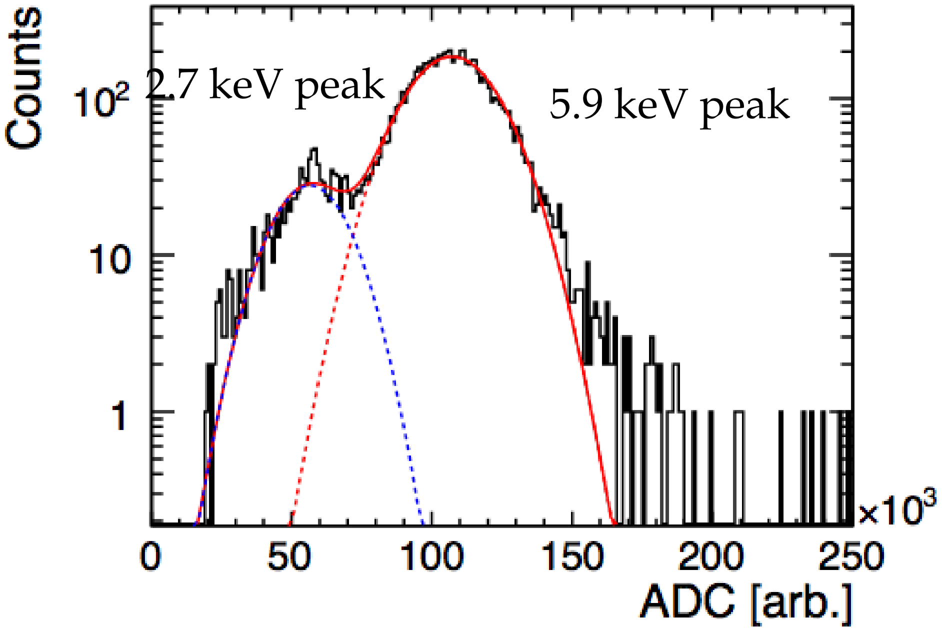
Side View

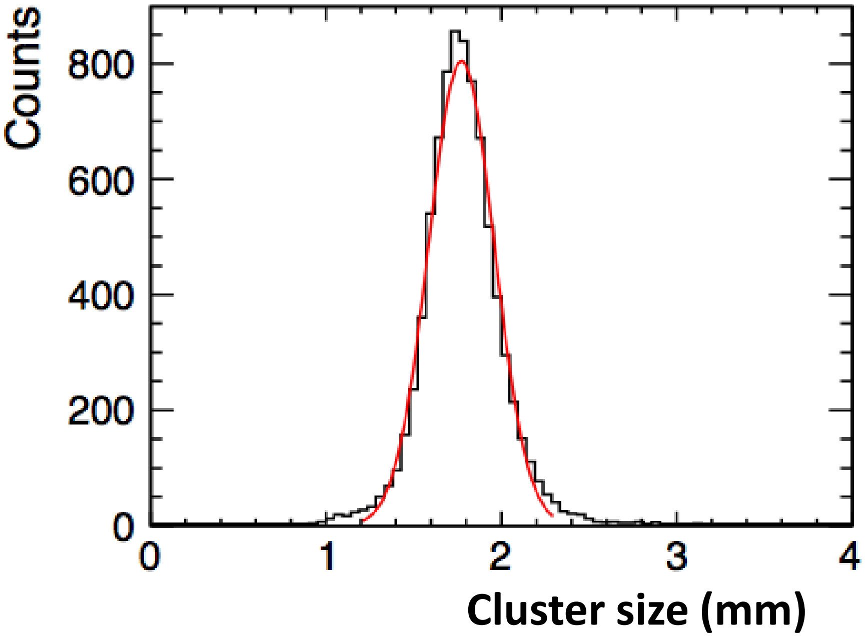


B=2T
gap=0.65
BL=1.3Tm

HypTPC test
with ^{55}Fe (X-ray) source

Amplifier gain : 120fC, Shaping T: 70ns, V_{GEM}.: 315 V





ΔE/E :14.3 ± 0.2 %

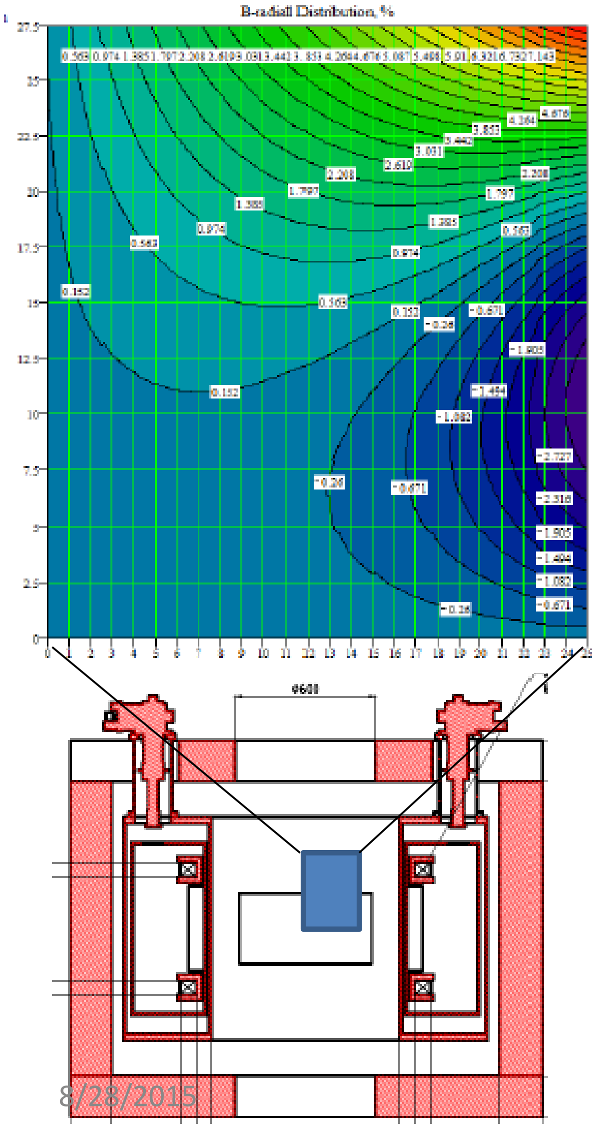
Cluster size : 1.87 ± 0.02 mm

cf. prototype TPC (5 - 10 cm)
: 1.7 ~ 2.0 mm

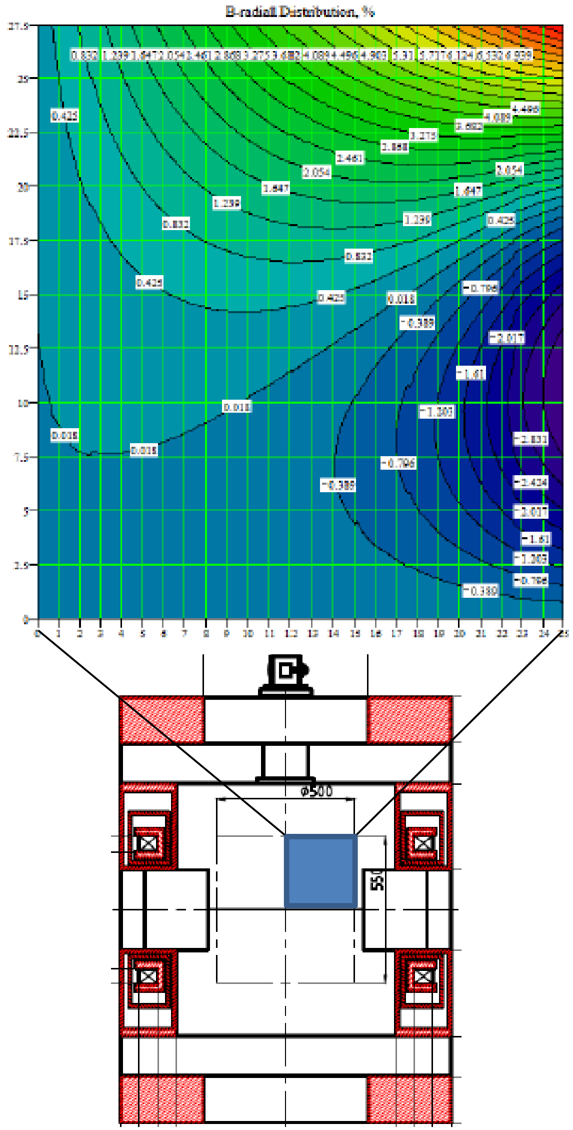
Discharge rate < 1 min^{-1}
Gain ~ 10^4

Magnetic field

Front (x-y) view



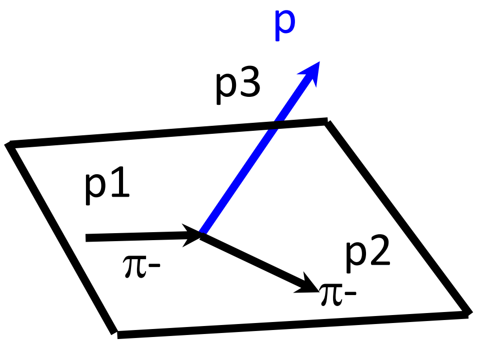
Side (z-y) view



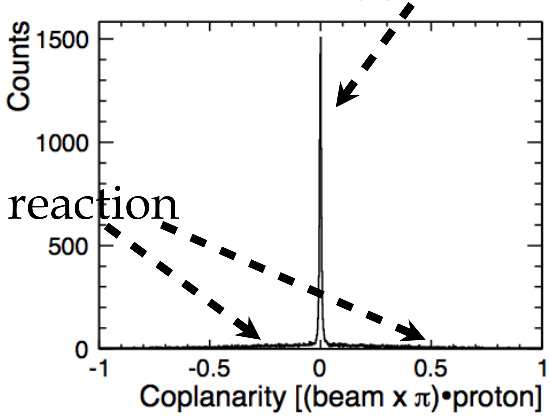
$B_T/B < 3\%$ in most of the volume

Courtesy of J.K. Ahn

Detector simulation (GEANT)



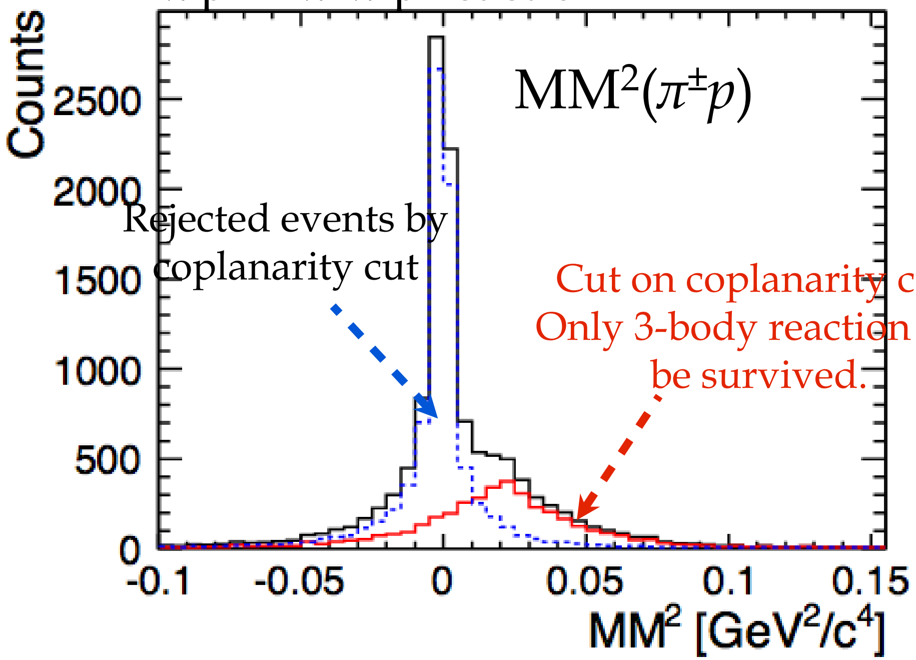
coplanarity
=cosine of angle
Between p1 and
(p2xp3)



Elastic scattering
(Same trigger condition)

3-body reaction

$\pi^- p \rightarrow \pi^- \pi^0 p$ reaction

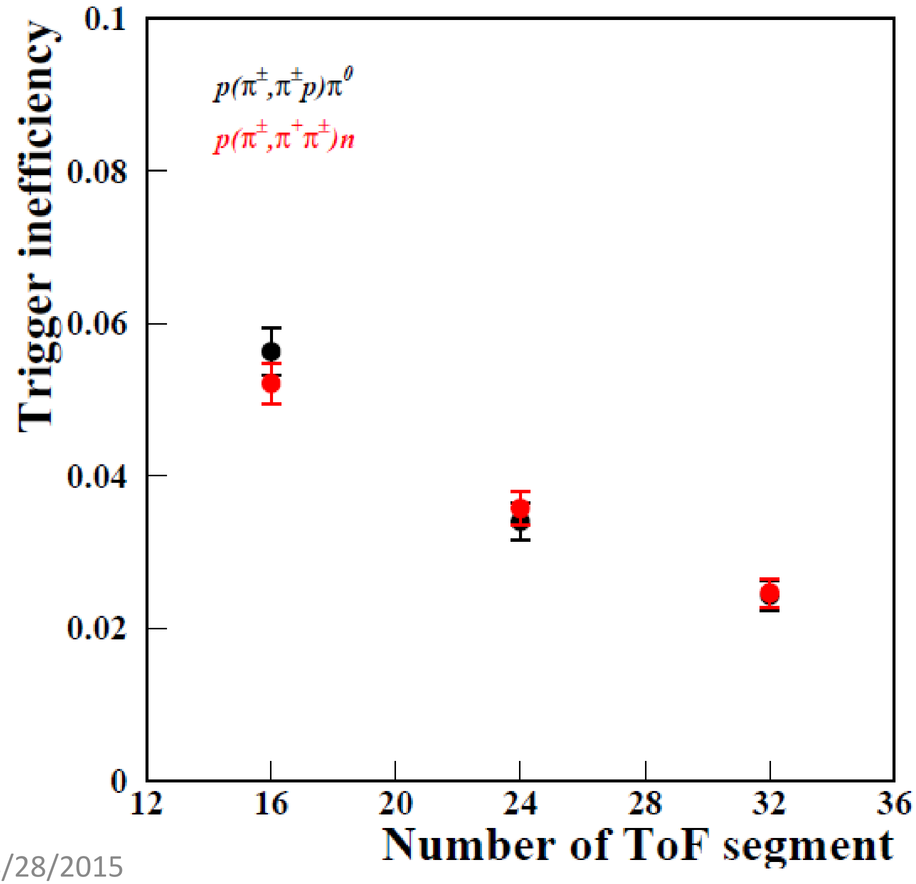


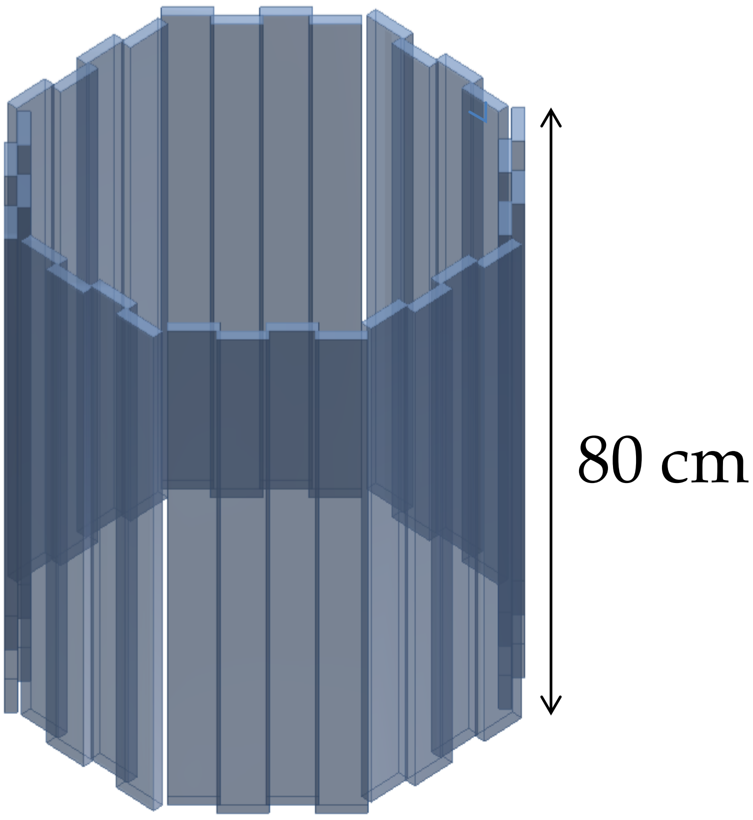
Rejected events by
coplanarity cut

Cut on coplanarity cut.
Only 3-body reaction can
be survived.

Trigger efficiency

2-charged particle trigger
(inefficiency due to double hit)

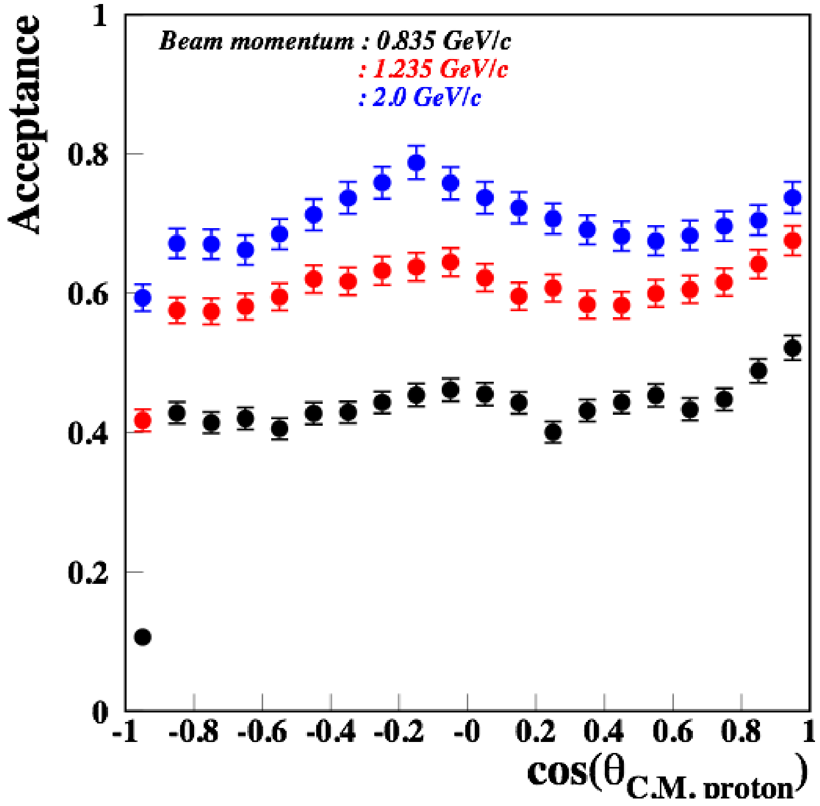


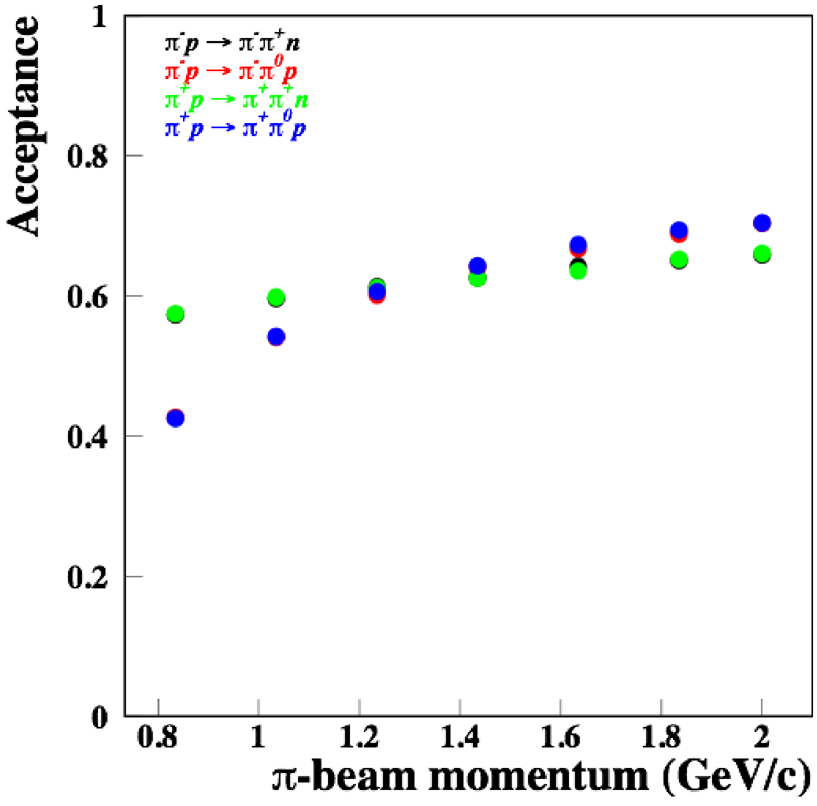


Proposed hodoscope
with 32 segments.

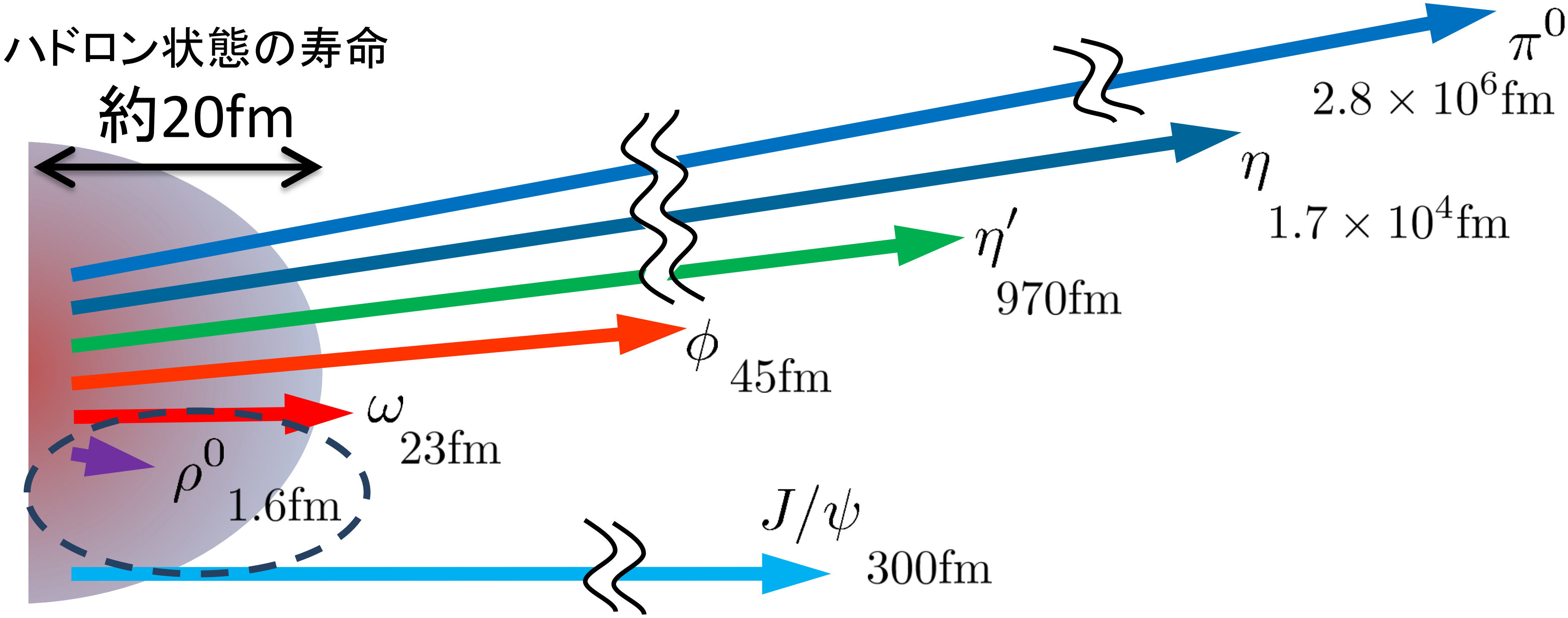
Acceptance

$\pi^+p \rightarrow \pi^+\pi^0p$ reaction

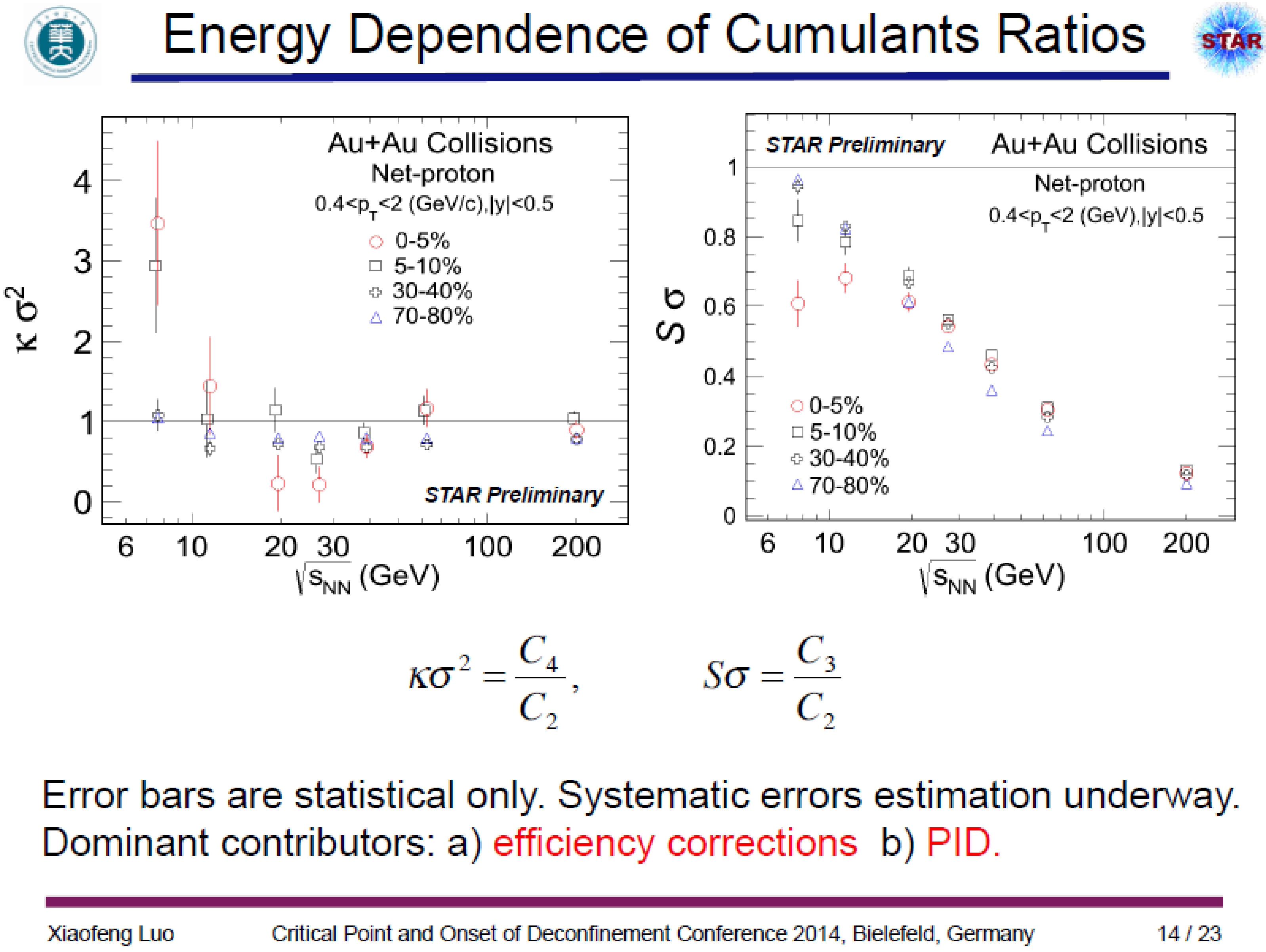




仮想光子の半分くらいは、真空中のメソン崩壊で生成する



- π, η, φの寿命はハドロン状態の寿命と比べはるかに長い。
- これらの粒子崩壊への媒質効果は、基本的に無視できる。
- **ρメソンのみが、例外！**



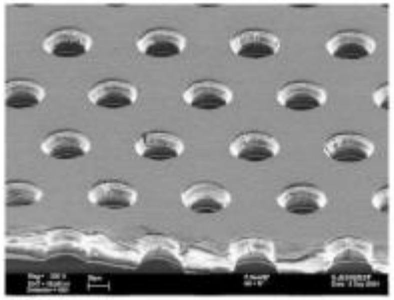
Energy Dependence of Cumulants Ratios

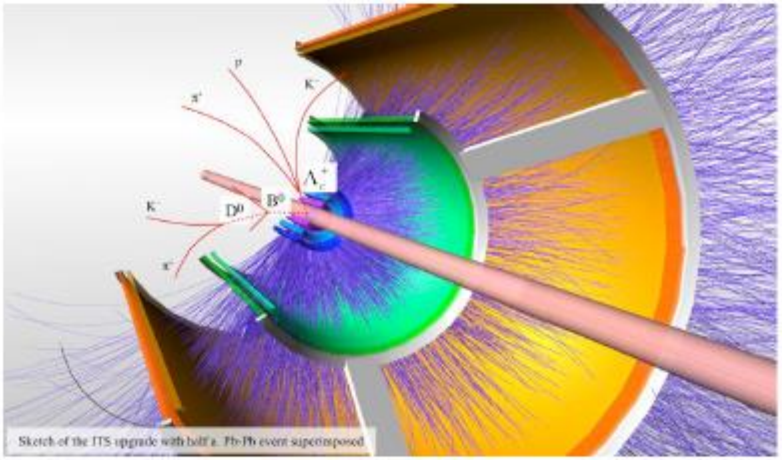
$$\kappa\sigma^2 = \frac{C_4}{C_2}, \qquad S\sigma = \frac{C_3}{C_2}$$

Error bars are statistical only. Systematic errors estimation underway. Dominant contributors: a) efficiency corrections b) PID.

X. Luo, CPOD2014

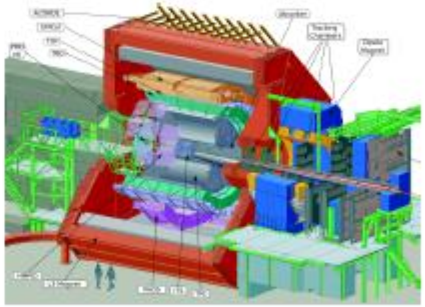
実験技術の向上

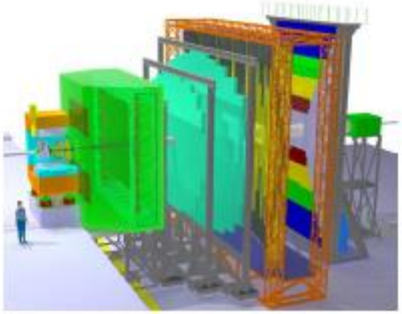




Sketch of the ITS upgrade with half a. Pb-Pb event superimposed

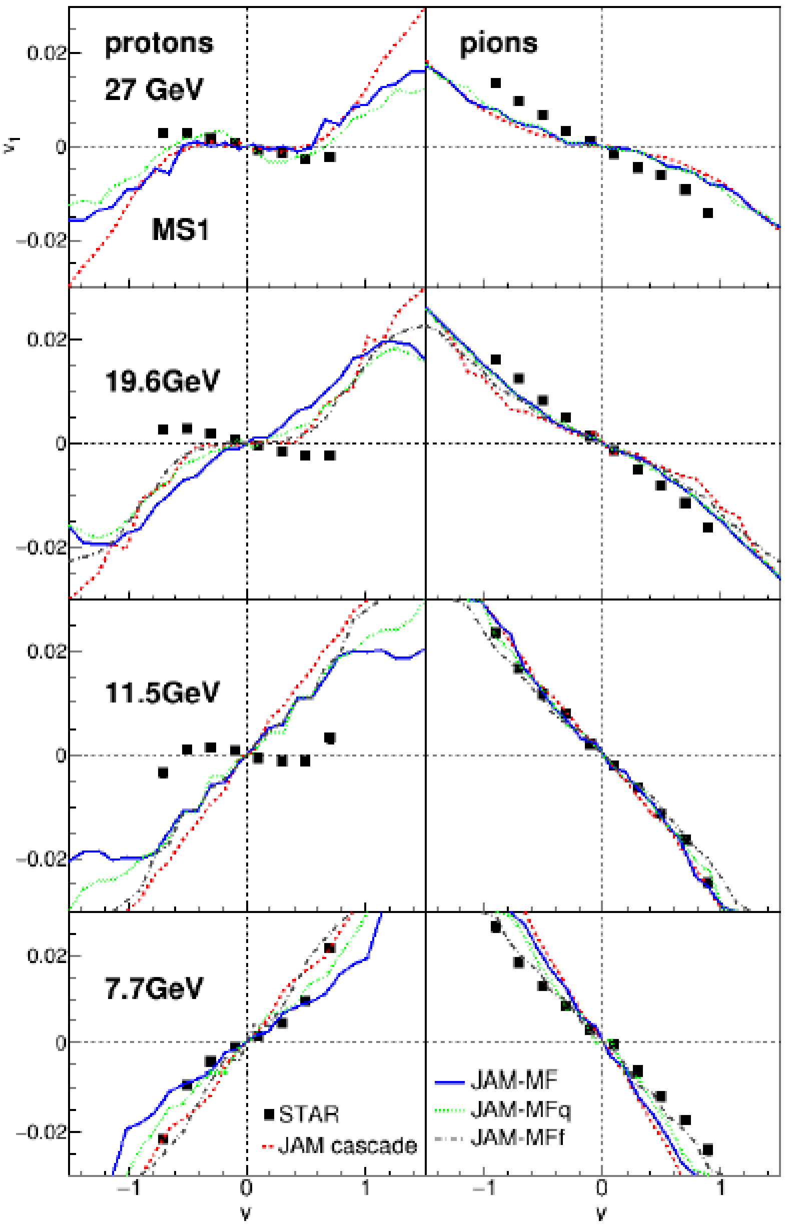
Standard GEM
Pitch=140µm
Hole φ=70µm





- 高レートに耐えうる検出器・データ収集系が利用可能になってきた (例：ALICE, CBM (FAIR))

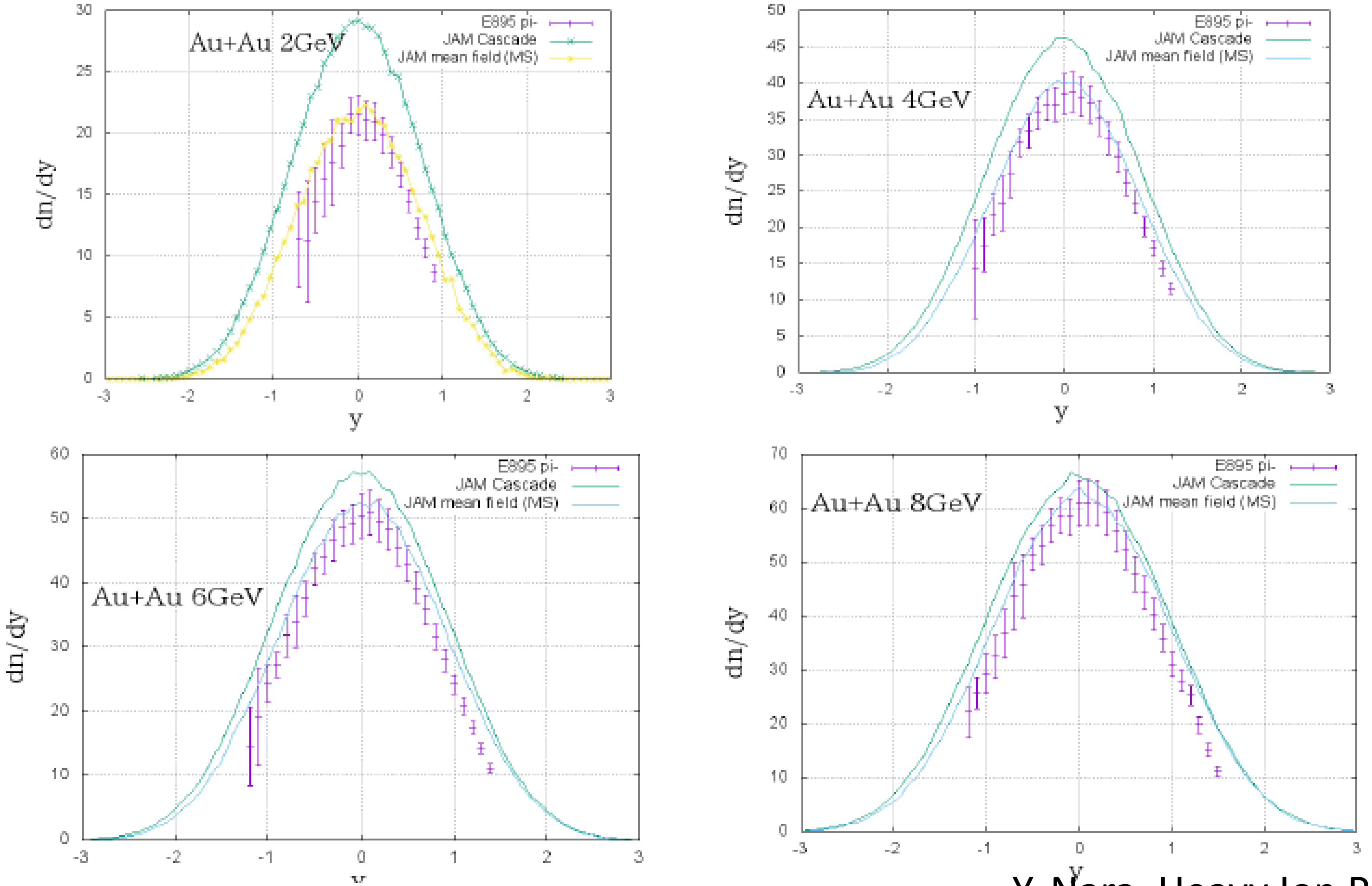
Comparison of STAR data



JAM-MF: only formed baryons feel potentials
JAM-MFq:constituent quarks feel potentials
JAM-MFf: All non-formed hadrons feel potentials

Y. Nara, Heavy Ion Pub
2015/07/14

Effect of mean-field on dN/dy

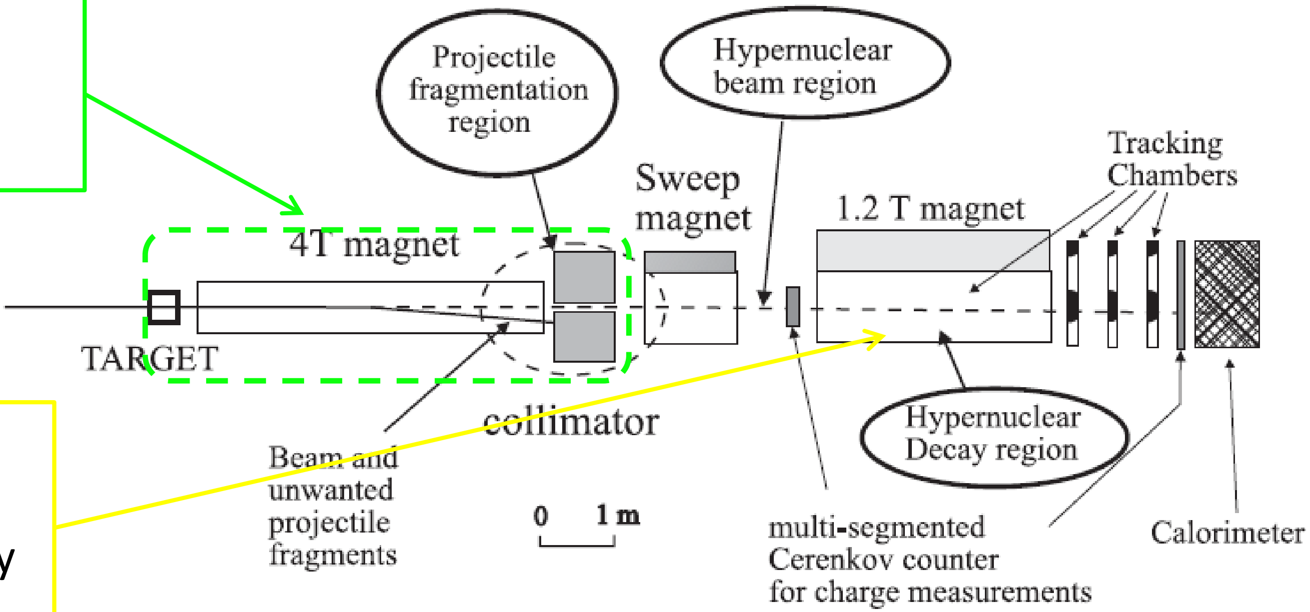


Y. Nara, Heavy Ion Pub 2015/07/14

Hypernuclei measurements (Closed geometry setup)

Setup proposed for J-PARC
Asakawa et al (JHF)

Select near-neutral fragments
With 1st dipole magnet/collimator

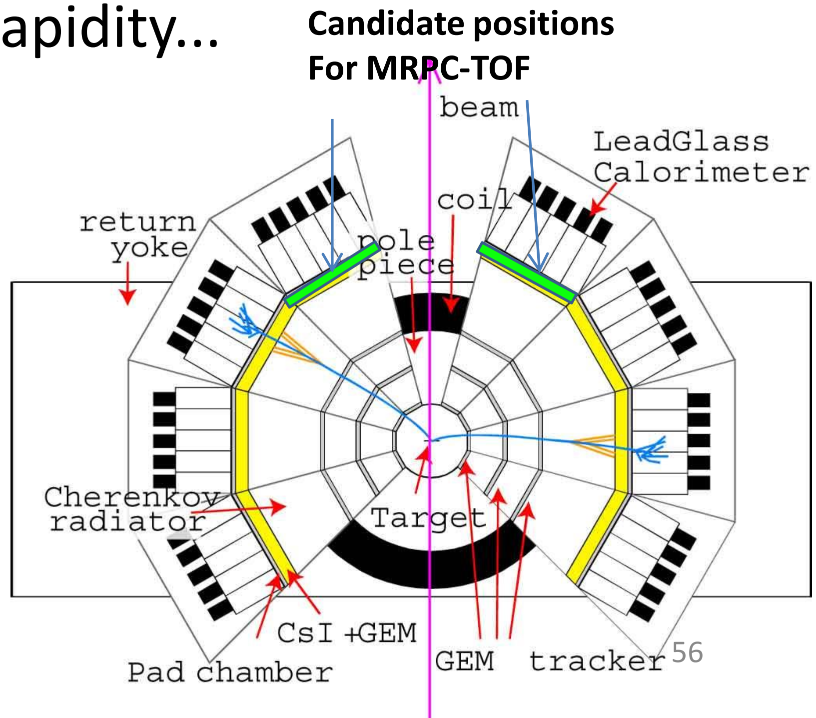


Measure spin precession of polarized hypernuclei in dipole magnet by weak decay of hypernuclei

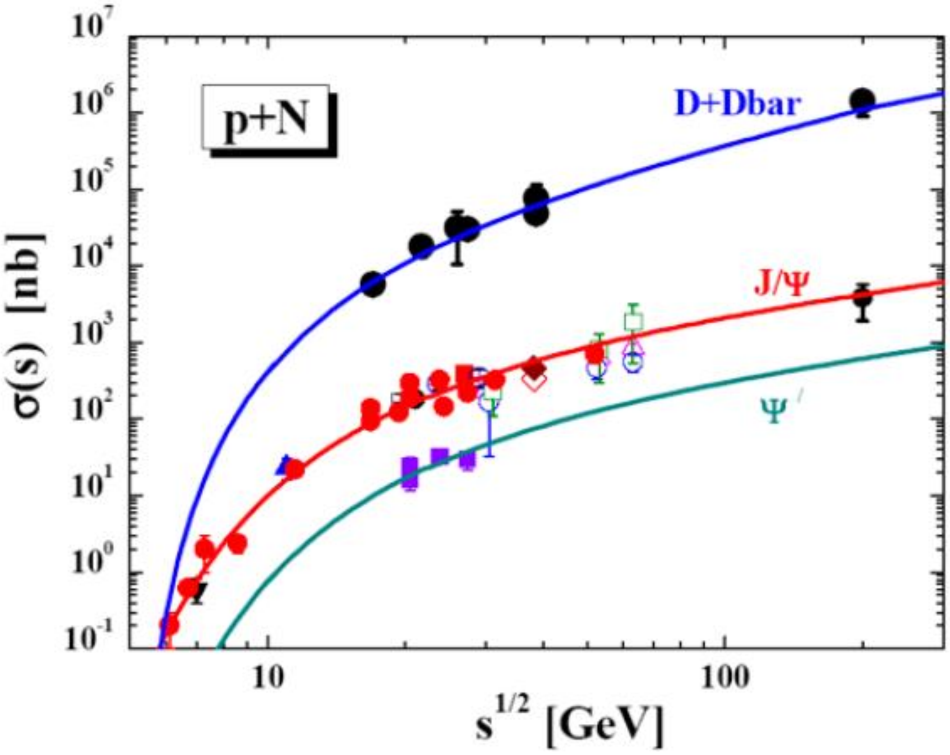
25AGeV, C or Li beams (10^{10}-10^{12} Hz)

R&D Plan

- MRPC-TOF (Tsukuba, KEK, JAEA)
  - Prototype MRPC-TOF achieved 40 ps timing resolution (Univ. Tsukuba)
  - Large size MRPC-TOFs (60x60cm^2) to be developed and installed in J-PARC E16 for hadron measurements
    - $\phi \rightarrow K^+K^-$, hypernuclei at target rapidity...
- DAQ
  - Design based on ALICE-DAQ (NIAS,JAEA)


Candidate positions For MRPC-TOF

Charmed particles



CBM Physics Book,
W. Cassing, E. L. Bratkovskaya and
A. Sibirtsev, Nucl. Phys. A 691 (2001) 753

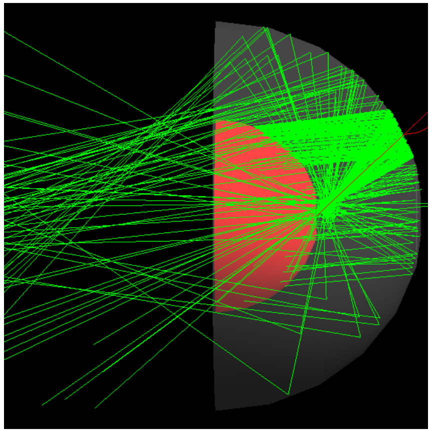
- c-$\bar{c}$ produced in the early stage of collisions
  - D,J/ψ may be modified
  - Probe of high density state

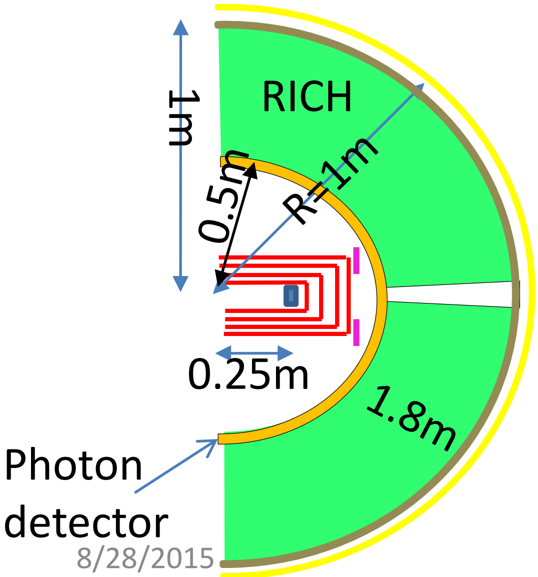
  J-PARC energies close to the production thresholds
  - D (5.07 AGeV),J/ψ (4.77 AGeV)

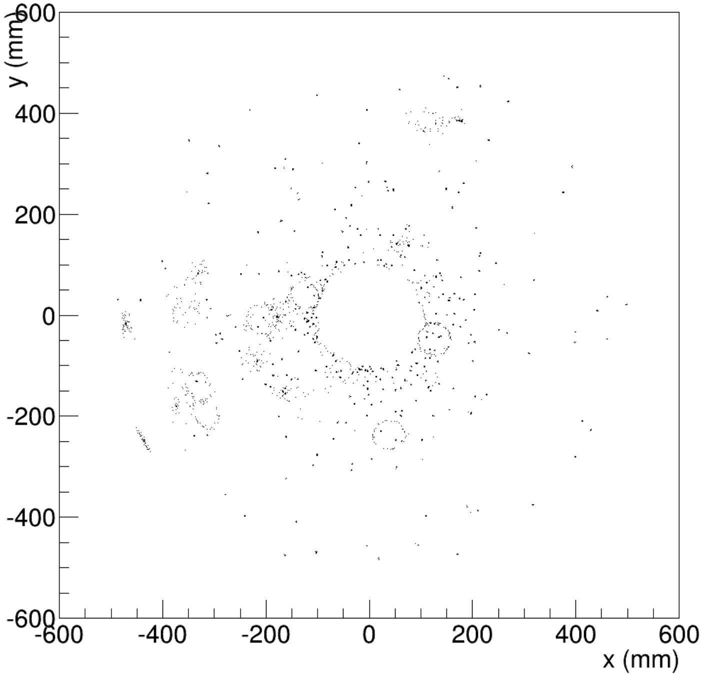
  May be possible with increased beam energy 12 →19 AGeV/c
  - √s= 4.9→6.2GeV (U)
  - Enhancement due to multi-step processes in A+A?

RICH

- Design based on HADES-RICH
- Target shifted to downstream of RICH center
  - Slightly small theta acceptance (<80deg)
  - But rings detected at photon detector at larger theta (avoid overlap with high density charged track at the photon detector
- Radiator C_5F_{12} radiator (n=1.002)
  - π rejection p<3.4 GeV/c





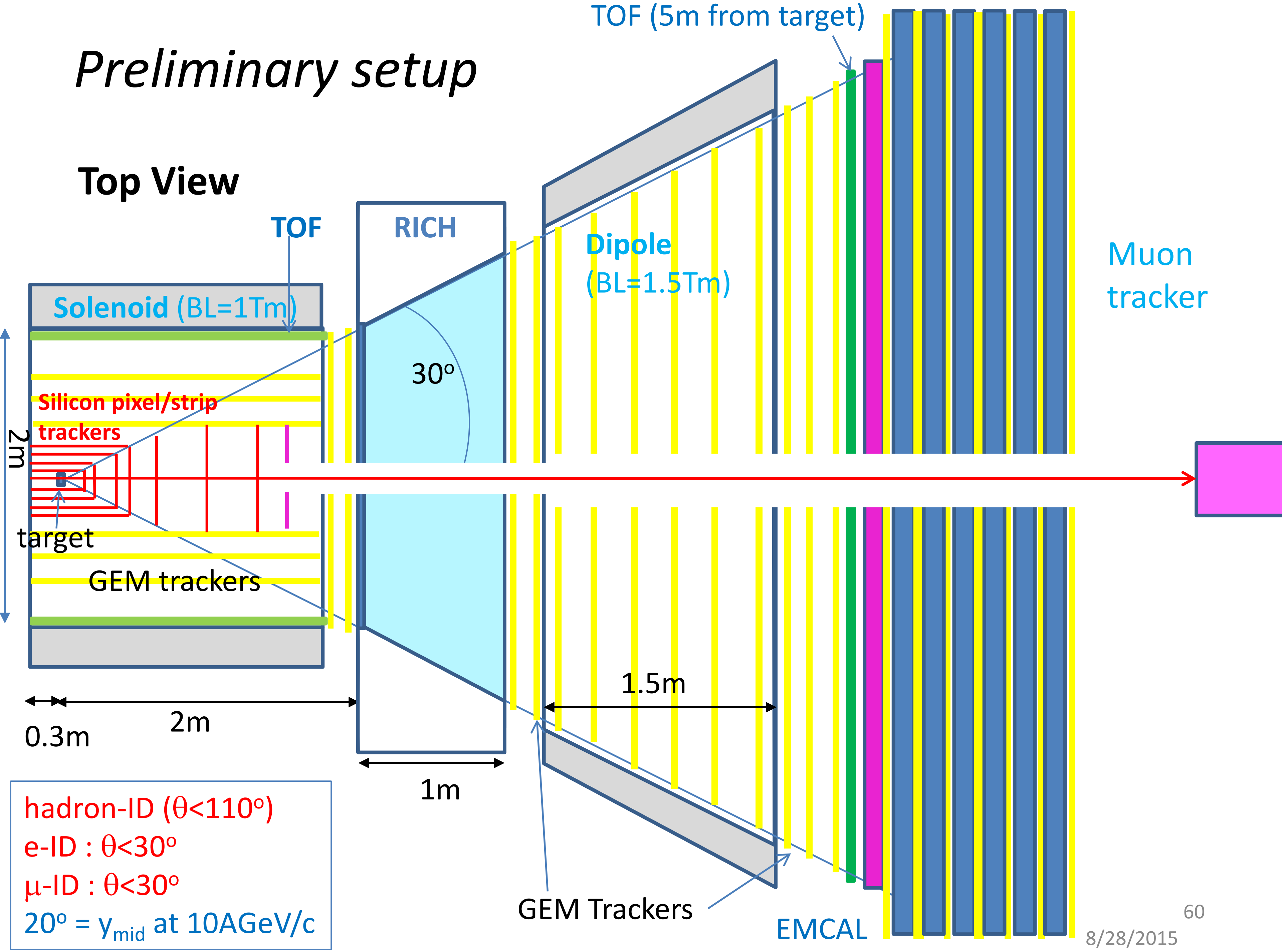


Detectors

- Silicon vertex trackers
  - 4 end cap, 4 barrel layers
    - Pad size : 40-80um
- Spherical (toroid) GEM trackers
  - 3 before toroid, 4 in toroid, 4 after toroid
- Forward trackers (5 planes)
  - FTOF (3.9m)
- Barrel trackers (3 planes)
  - BTOF (2.0m)
- EMCAL (e,γ ID)
  - $PbWO_4$ $15X_0$
- HCAL
  - Pb-Scintillator, 3.8λ_{int}
  - Neutron ID → baryon number fluctuations
- Muon tracker

  EMCAL+HCAL+Fe absorbers (~7λ_{int})+GEM trackers
  - π rejection = 2-4 x 10^{-3}
  - μ efficiency ~ 70%
  - Rejection of μ from weak decay with track matching
  - Punch through π / μ (π decay) = 0.16

Preliminary setup



hadron-ID ($\theta<110^o$)
e-ID : $\theta<30^o$
μ-ID : $\theta<30^o$
$20^o = y_{mid}$ at 10AGeV/c

Status of J-PARC HI Program

- White paper for conceptual design of accelerators and the experiment in JFY 2015
- After this, proceed with the proposal to J-PARC
- …
- After approval, construction of accelerators and detectors within 10 years ?

Detectors

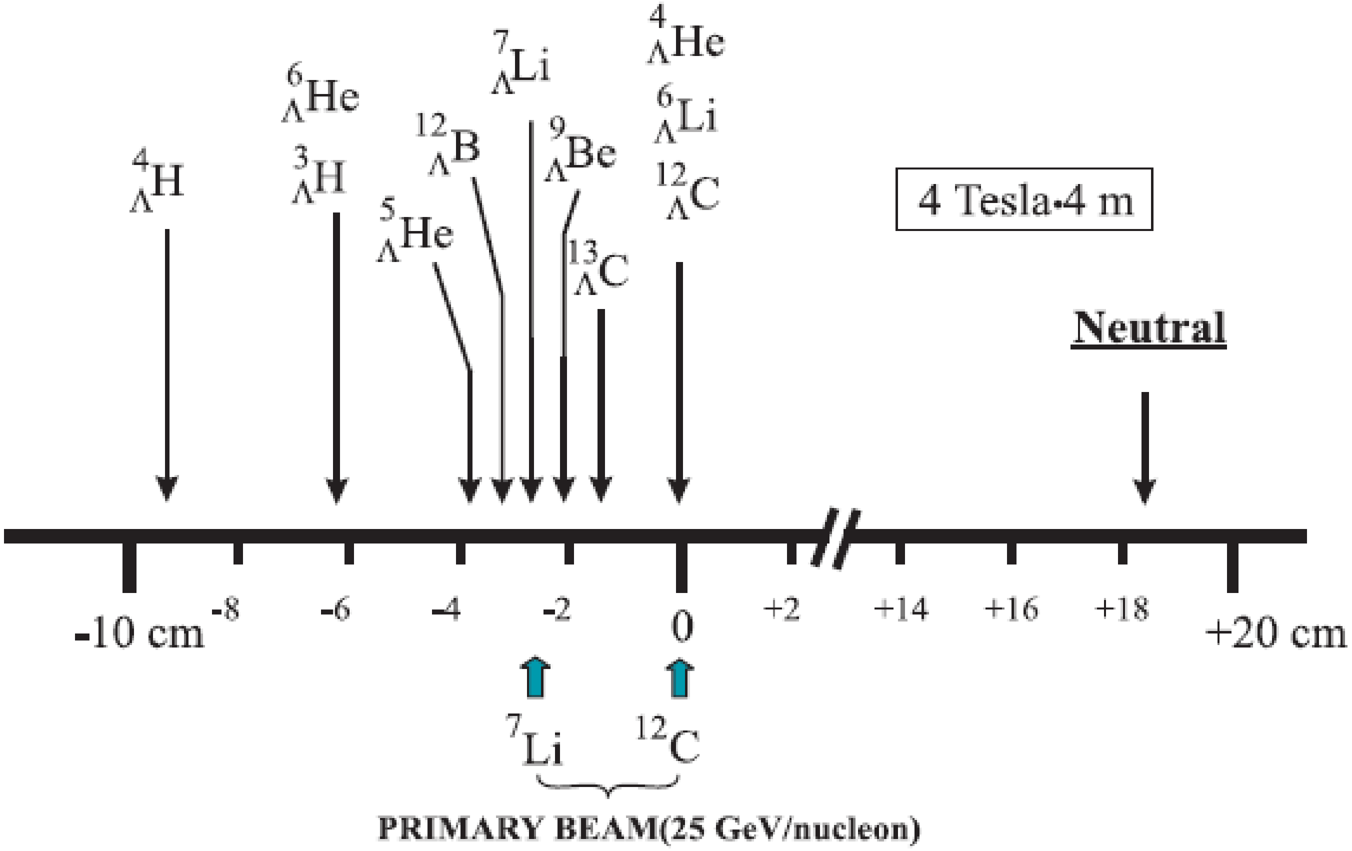
- Silicon vertex trackers
  - 4 end cap layers
    - Pad size : 40,40,80,80um, resolution = pad size/sqrt(12)
  - 4 barrel layers
    - Pad size : 40,40,80,80um, resolution = pad size/sqrt(12)
- Spherical (toroid) trackers
  - 3 before toroid, 4 in toroid, 4 after toroid
- Forward trackers
  - 5 planes, FTOF (3.9m)
  - Pad size = z/1000 (m), Resolution = pad size/10 mm
- Barrel trackers
  - 3 layers, BTOF (2.0m)
  - Pad size = r/1000 (m), Resolution = pad size/10 mm

Exotic particles in HI collisions

- Dibaryon
  - H→ΛΛ→π-pπ-p
  - d*(2380)→dπ+π-
- Kaonic nucleus
  - K-pp→Λp→π-pp
- Resonances
  - K*(892)→πK
  - Δ(1232)→pπ
  - Σ(1385)→Λp
  - Λ(1520)→pK-
  - Ξ(1530)→Ξπ
  - Ω→ΛK–
  - Ξ–→Λπ–
- Penta quarks
  - Θ+(uudd sbar)→pKs
  - Θ+++(uuuu sbar)→pπ+π+
  - Θ0(uddd sbar)→pK-
  - Ns(uudd ubar)→ΛK
  - Σ5(udds ubar)→Λπ
  - Σ5→(uuds dbar)pK0bar
  - …

Separation of hypernuclear beams

- Separation of beams depending on Z/A



Hypernucleus / fragments = 10^{-5}-10^{-6}

QCD和則とスペクトル関数

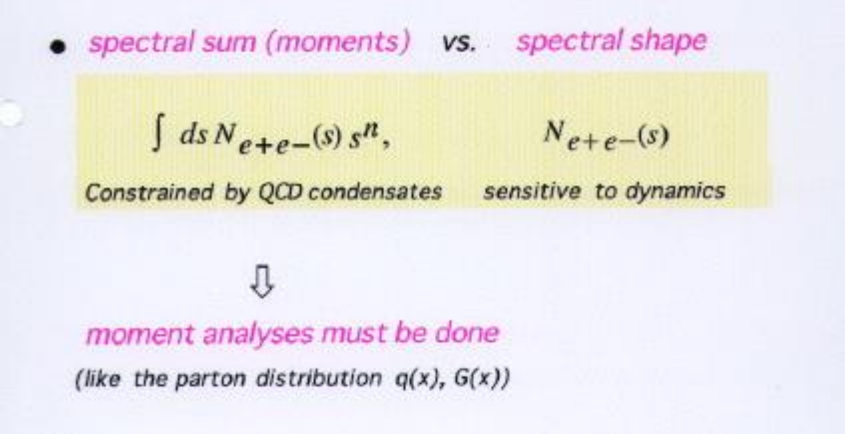
comment by 初田さん

International Conference on Soft Dilepton Production

LBNL, 1997

http://macdls.lbl.gov/DLS_WWW_Files/DLSWorkshop/proceedings.html

スペクトル自身よりも、積分値の方がより直接的に実験とQCD凝縮を比較できる



- spectral sum (moments) vs. spectral shape

$\int ds\, N_{e+e-}(s)\, s^n,$ $N_{e+e-}(s)$

Constrained by QCD condensates sensitive to dynamics

⇩

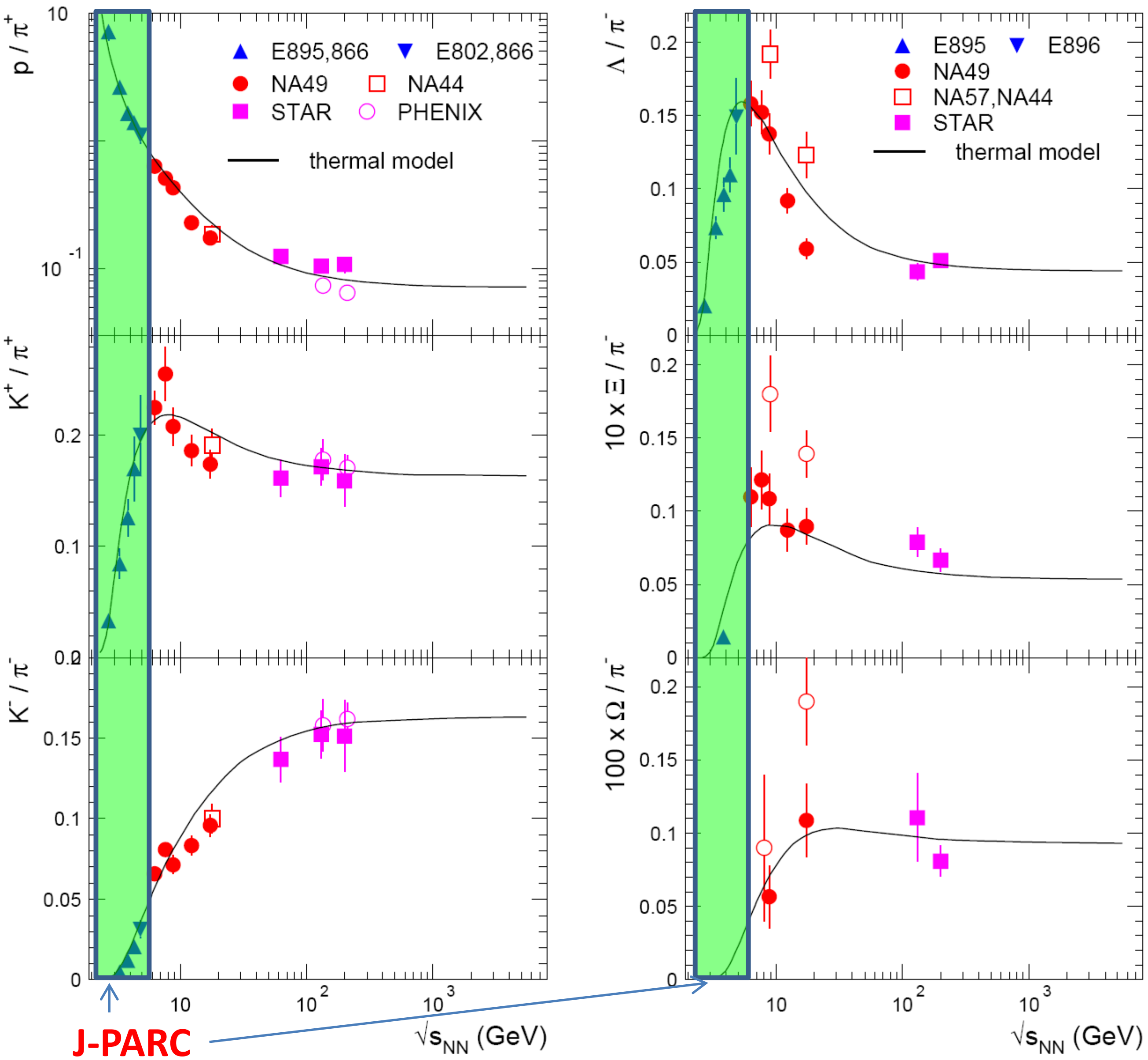
moment analyses must be done

(like the parton distribution q(x), G(x))

See also, Hatsuda, Hayano, RMP**82**, 2949

※実験的に積分値を出すのは誤差との戦いか？

Strange meson/baryons



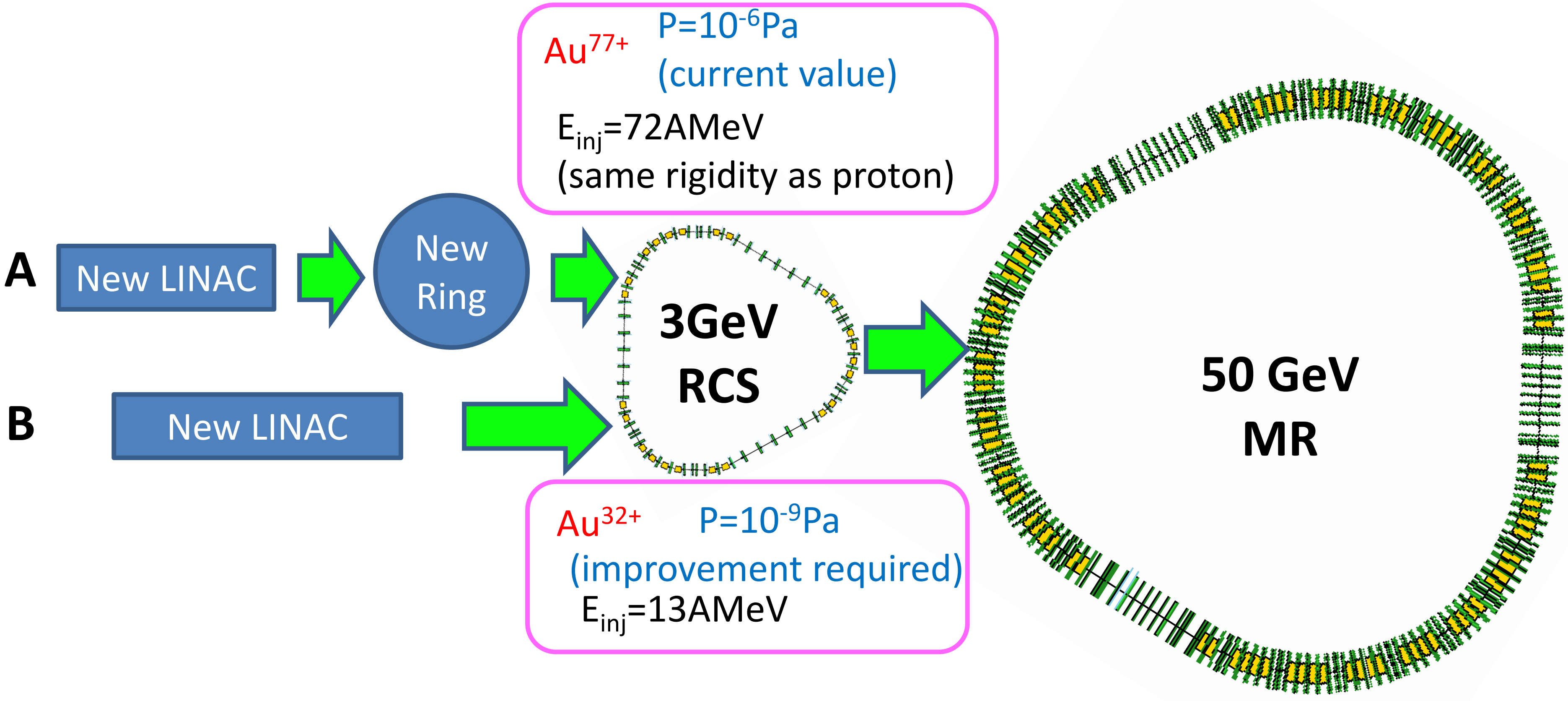
J-PARC

A. Andronic et al, Nucl. Phys. A 837 (2010) 65

Systematic energy scan below the "horn" at ~8 GeV

There is almost no Ξ, Ω measurements

Possible accelerator schemes at J-PARC



A

New LINAC

New Ring

Au^{77+}

P=10^{-6}Pa
(current value)

E_{inj}=72AMeV
(same rigidity as proton)

B

New LINAC

Au^{32+}

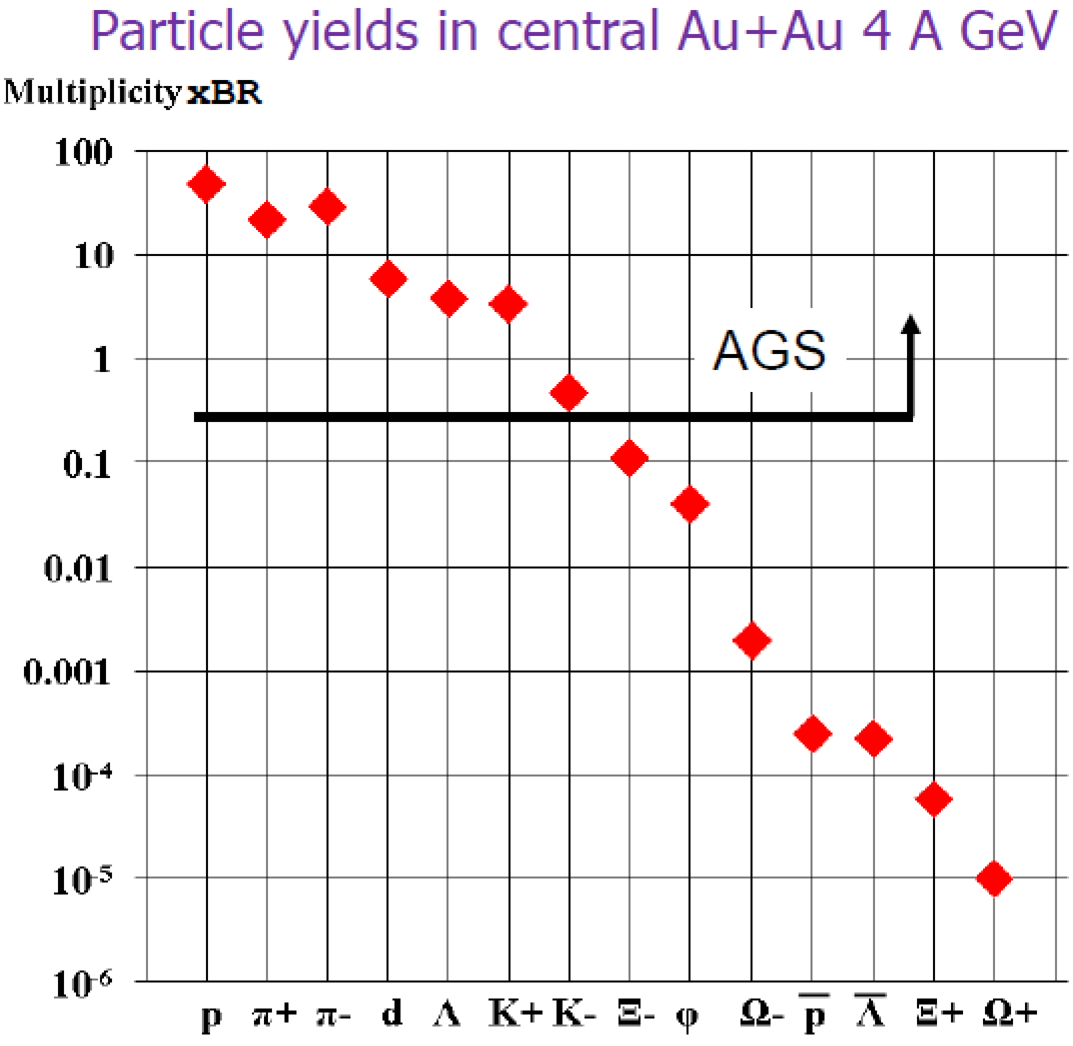
P=10^{-9}Pa
(improvement required)

E_{inj}=13AMeV

3GeV RCS

50 GeV MR

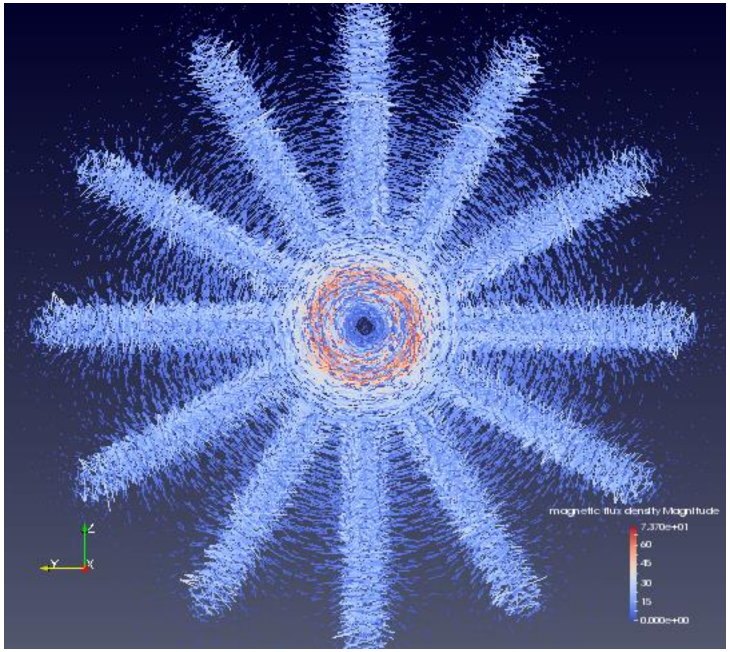
Experimental challenges



C. Hoehne, CPOD2014

Toroid (12 coil configuration)

- Increasing number of coils improves phi uniformity
- 12 coil configuration is good

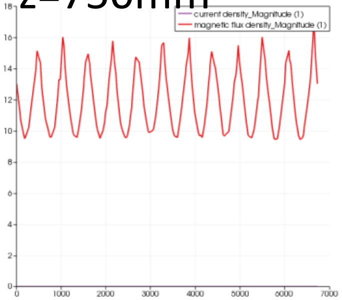


z=250mm, R at coil center

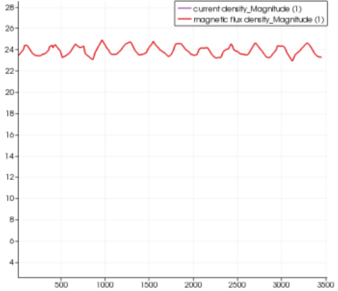
B(T)

rφ(mm)

z=750mm



z=1300mm



Muon ID performance(preliminary)

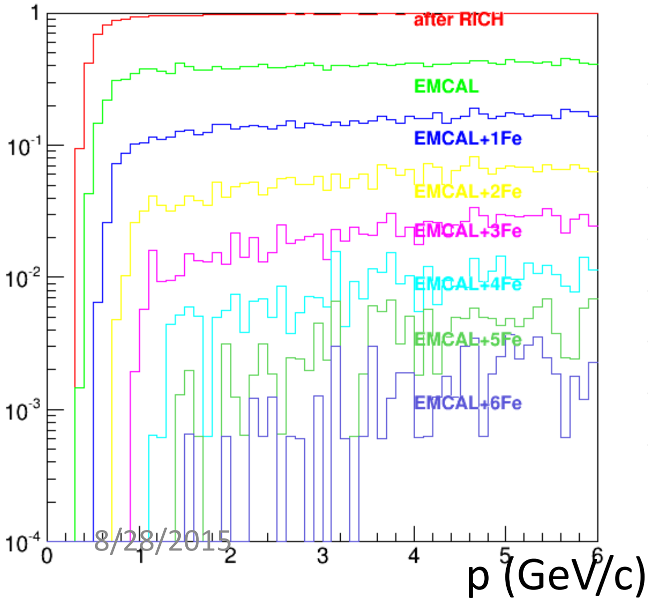
EMCAL (~1λ_{int})+Fe absorber (~1λ_{int})x6
+GEM trackers（7 layers）

・Goal π suppression：1/10 of π→μ decay probability (5m,2GeV/c):4.4x10^{-3}

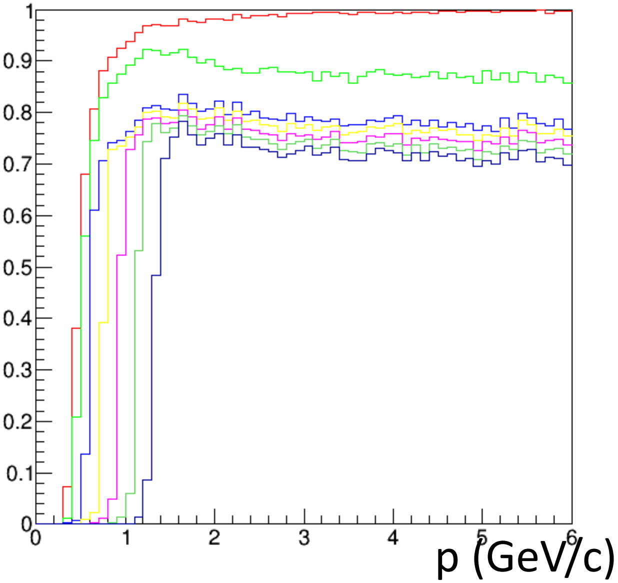
π, μ rejection performance by simulation

- π suppression = 2-4 x 10^{-3}
- μ detection eff ~70%
- punch through π / μ (π decay) = 0.16
- Decay rejection by track matching
  - P (80%), K (95%)

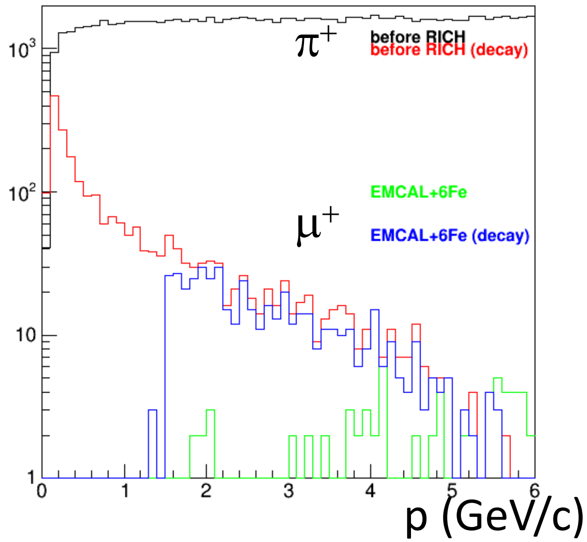
π+ survival probability



μ+ Survival probability



π^+ and decayed μ+
before/after muon absorbers



Hypernuclear physics with HI

Goals

1. Discovery of new hypernuclei and extension of hypernuclear chart
   - S=-1,-2,-3 hypernuclei
   - Proton-rich and Neutron-rich hypernuclei
   - Can be done in mid-rapidity or beam/target rapidity
   - Identification with weak decay to a (light) nucleus + π-
2. **Study of weak decays at beam rapidity**

   With meson beams, due to short decay length these measurements are difficult
   - life time measurement
   - Mesonic decay e.g. ${}^{4}_{\Lambda}H \rightarrow \pi^{-} + {}^{4}He$ (${}^{4}He$ ground state)
     - standard way to identify a hypernucleus
   - Non-mesonic weak decay
     - *Λp → pn (p,n : high momentum) the rest nucleus is exited state, and will break.*
     - *Measurements of residues*
   - magnetic moment
     - never measured!
     - sensitive to hyperon wave function inside hypernucleus
     - Spin and angular momentum structure
     - Spin-dependent YN interaction

Special closed-geometry setup is required

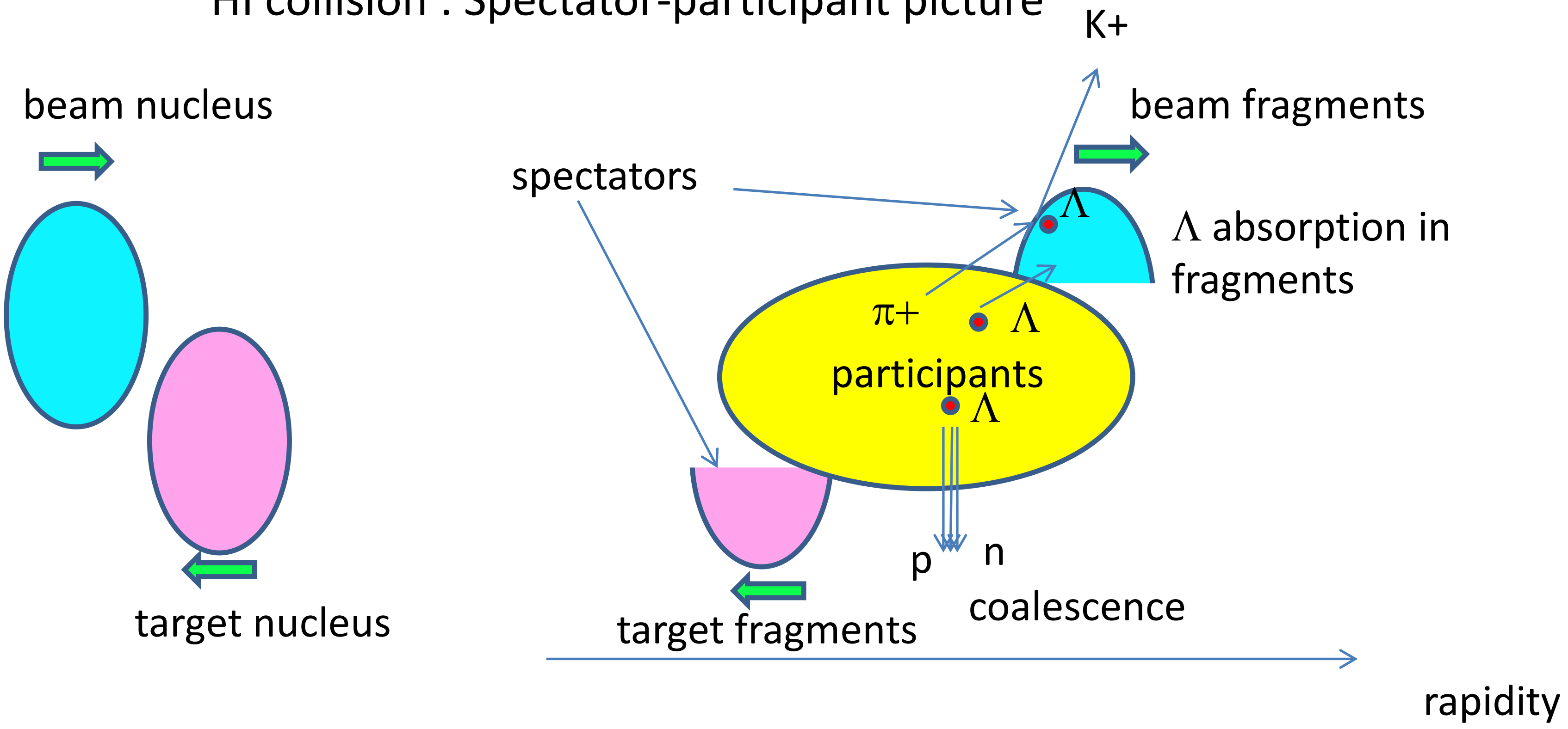
We could utilize full 10^{10} Hz beam?

Simulation study necessary

Introduction

- Hypernuclear production in heavy-ion collisions

HI collision : Spectator-participant picture



K+

beam nucleus

beam fragments

spectators

Λ absorption in fragments

π+

Λ

participants

Λ

Λ

p

n

coalescence

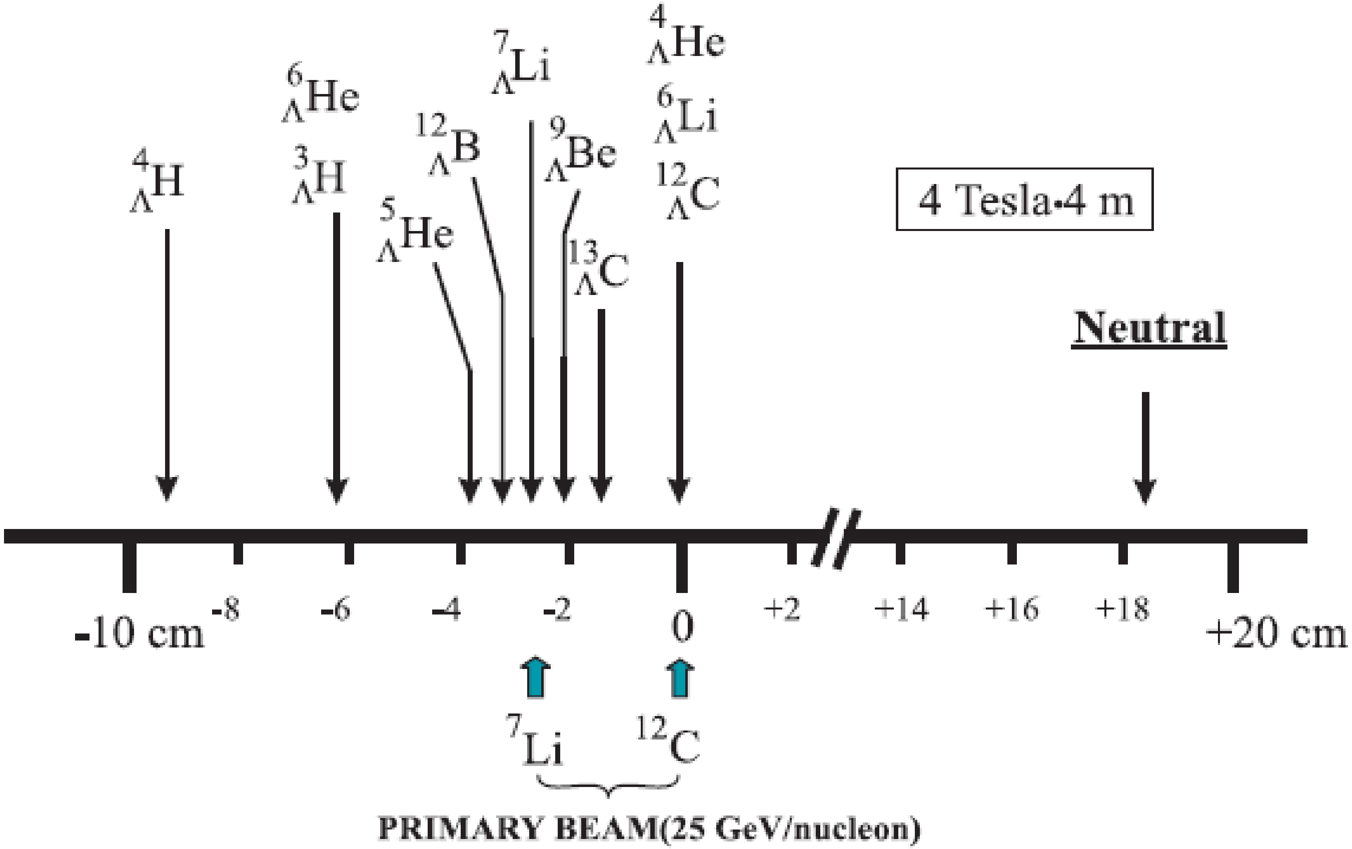
target nucleus

target fragments

rapidity

Separation of hypernuclear beams

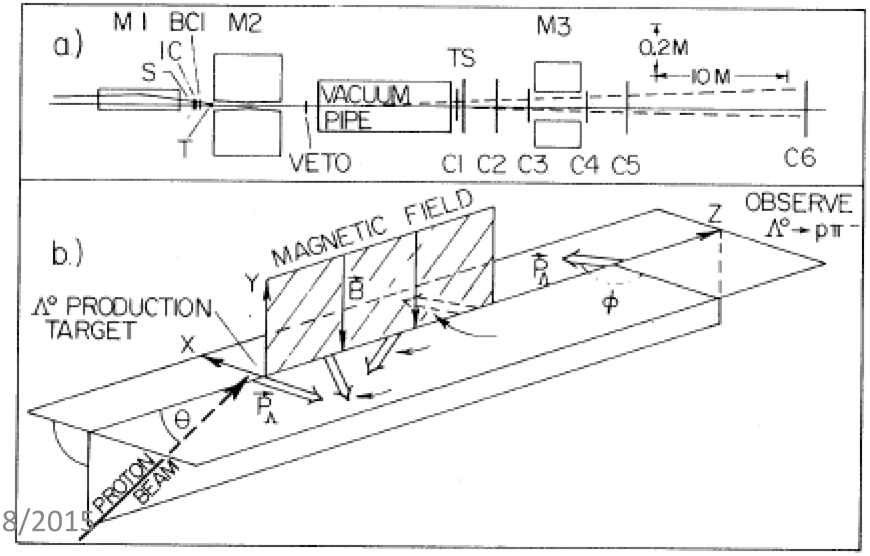
- Separation of beams depending on Z/A



Hypernucleus / fragments = 10^{-5}-10^{-6}

How to measure the magnetic moment

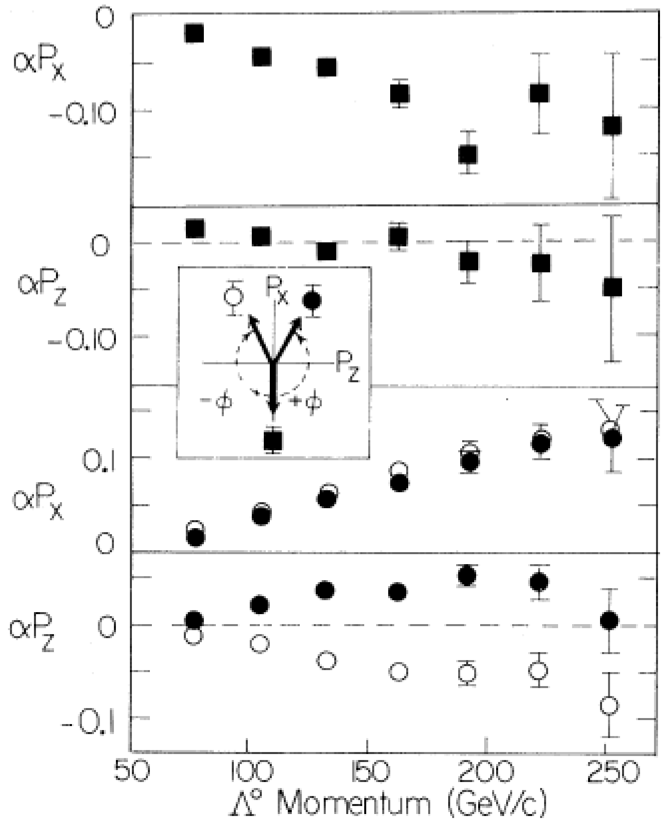
- For Λ case
  - Polarization is transverse to the reaction plane
    - $p+p \rightarrow \Lambda+K^{+}+p$, reaction plane : a plane with p(beam)+Λ
    - Polarization : perpendicular to the reaction plane
    - So measure direction of $\Lambda \rightarrow p+\pi^{-}$ plane w.r.t. the reaction plane



Precise measurement of
Λ magnetic moment
L. Schachinger et al
PRL 41 (1978) 1348

Λ magnetic moment

Polarization measurement
(from p asymmetry w.r.t the reaction plane)

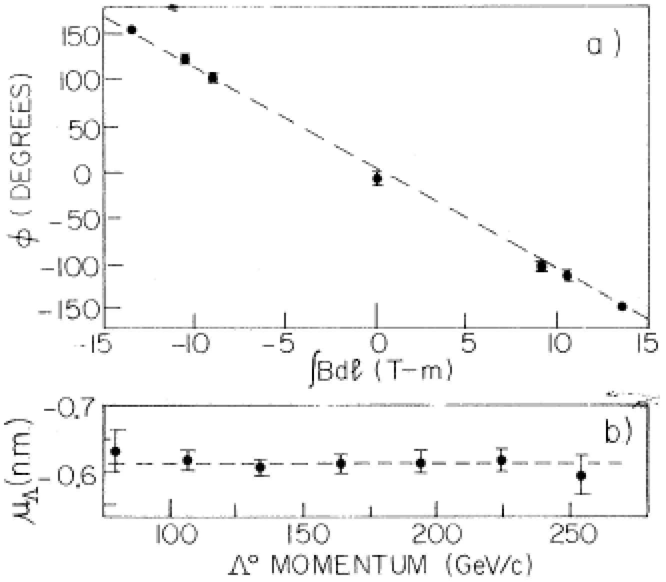


■:B=0

●:B in y+ direction

○:B in y- direction

Precession angle vs BdL



$\varphi = (\mu_\Lambda/\mu_N)(18.30\ \text{deg/T m})\int B\,dL$, where μ_N is the nuclear magneton, $\mu_N = e\hbar/2M_p c = 3.152\,52\times10^{-14}$ MeV/T.[3]

HypHI at GSI

- ^{6}Li beam 3x 10^{6} /s

3.5-day experiment

- ^{12}C graphite target

8.84g/cm^2→interaction prob 10%

- B=0.75T
- TR0-TR2 : SciFi
- BDC, SDC: drift chambers

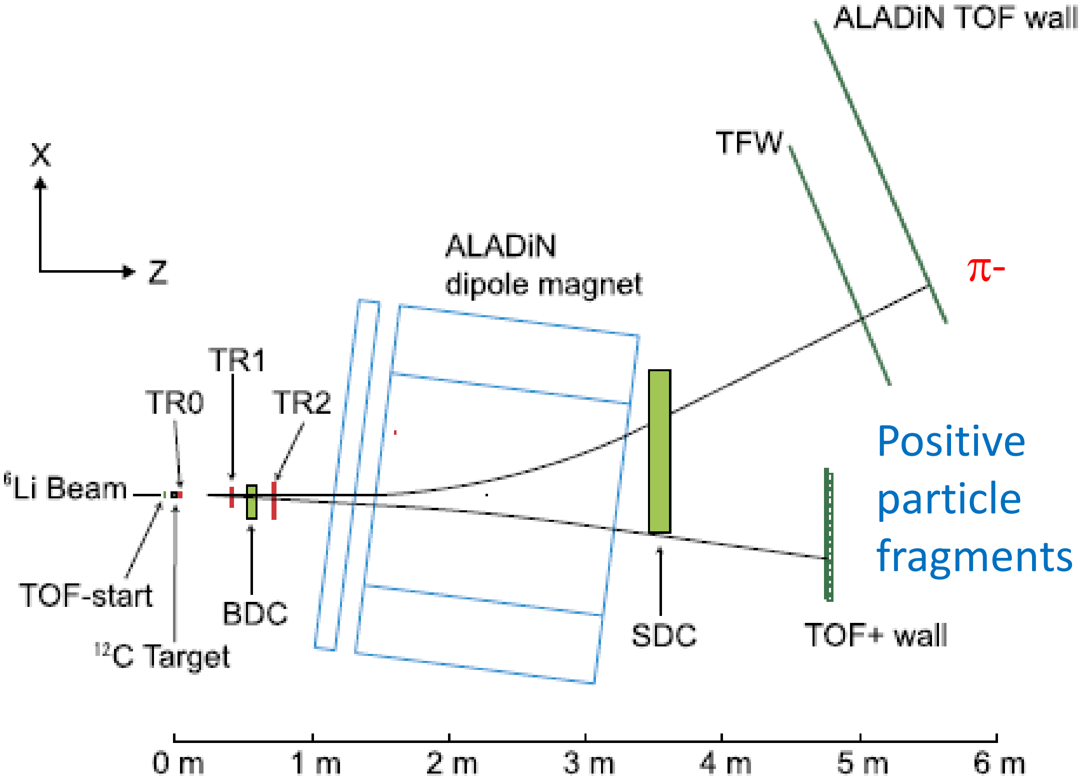


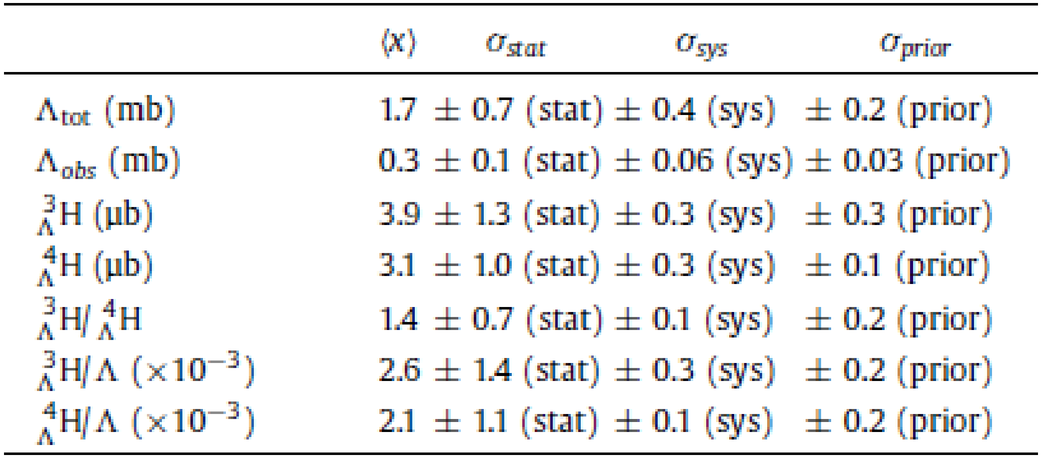
Fig. 1. Layout of the experimental setup.

Reconstructed decays

$$\Lambda \rightarrow p+\pi^{-},\ {}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He}+\pi^{-},\ {}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He}+\pi^{-}$$

Vertex cut required!

HypHI Results



	$\langle x \rangle$	σ_{stat}	σ_{sys}	σ_{prior}
Λ_{tot} (mb)	1.7	± 0.7 (stat)	± 0.4 (sys)	± 0.2 (prior)
Λ_{obs} (mb)	0.3	± 0.1 (stat)	± 0.06 (sys)	± 0.03 (prior)
${}^{3}_{\Lambda}H$ (μb)	3.9	± 1.3 (stat)	± 0.3 (sys)	± 0.3 (prior)
${}^{4}_{\Lambda}H$ (μb)	3.1	± 1.0 (stat)	± 0.3 (sys)	± 0.1 (prior)
${}^{3}_{\Lambda}H/{}^{4}_{\Lambda}H$	1.4	± 0.7 (stat)	± 0.1 (sys)	± 0.2 (prior)
${}^{3}_{\Lambda}H/\Lambda$ ($\times 10^{-3}$)	2.6	± 1.4 (stat)	± 0.3 (sys)	± 0.2 (prior)
${}^{4}_{\Lambda}H/\Lambda$ ($\times 10^{-3}$)	2.1	± 1.1 (stat)	± 0.1 (sys)	± 0.2 (prior)

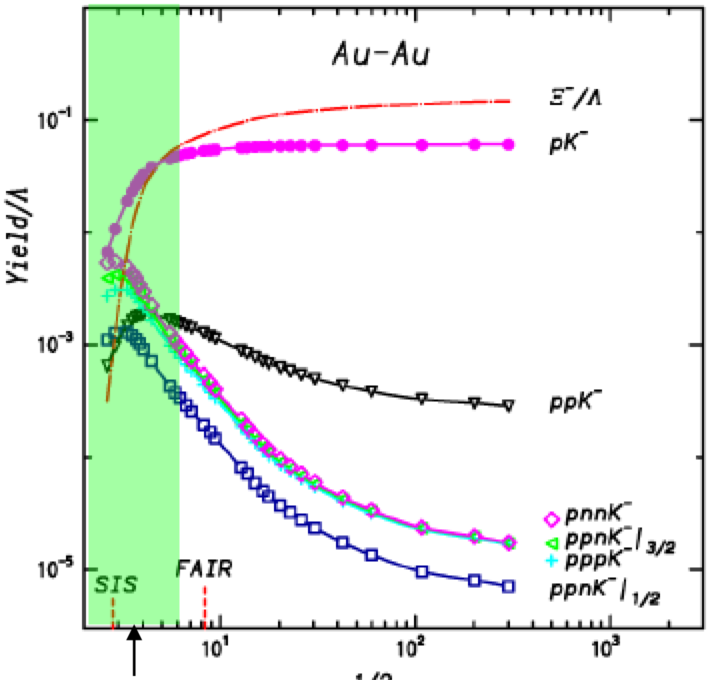
- Comparison of the absolute yields (dN/dy)
  - $^{6}Li+^{12}C$ minimum-bias cross section : $\sigma_{total} = 0.667b$

  - $N(\Lambda) = 2.6x10^{-3}$
  - $N(^{3}{}_{\Lambda}H) = \sigma(^{3}{}_{\Lambda}H)/\sigma_{total} = 3.9x10^{-6}/0.667 = \boxed{5.8x10^{-6}}$
  - $N(^{4}{}_{\Lambda}H) = \sigma(^{4}{}_{\Lambda}H)/\sigma_{total} = 3.1x10^{-6}/0.667 = \boxed{4.6x10^{-6}}$

~$3x10^{-6}$ in p+C
at E16?
p+C/Li+C~1/6
Energy cor=3

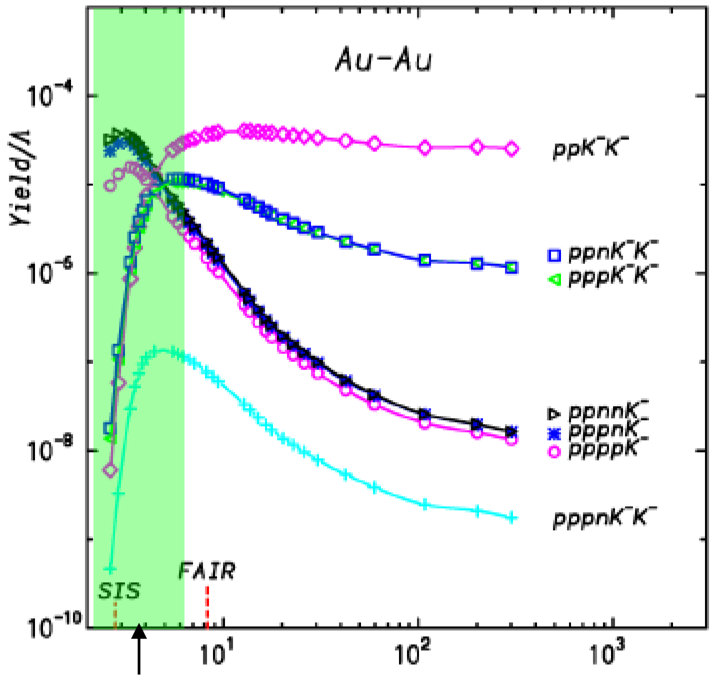
Kaonic nuclei production in HIC

Andronic, PBM, et al, NPA 765 (2006) 211–225



J-PARC

$s^{1/2}$ [GeV]

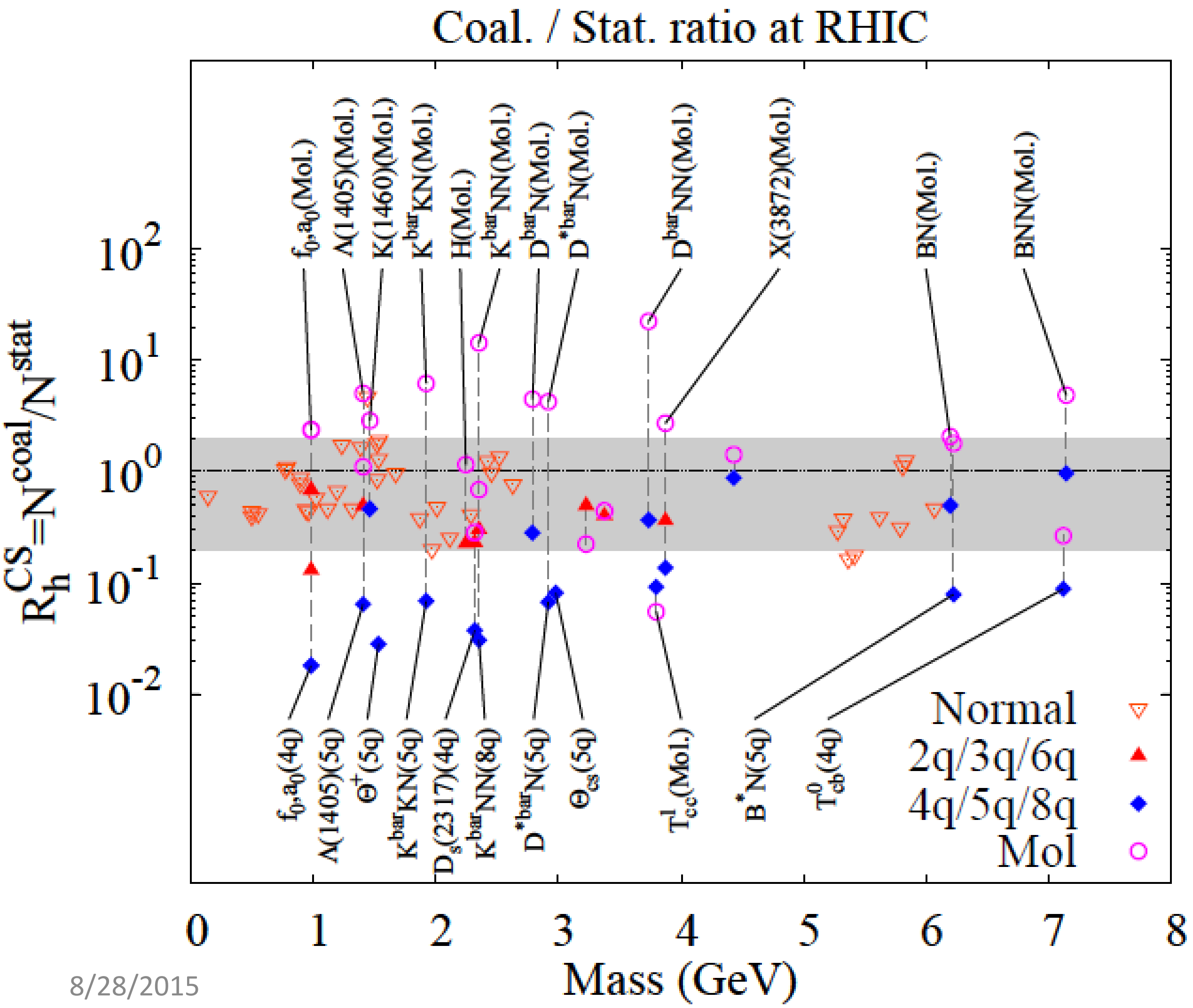


J-PARC

$s^{1/2}$ [GeV]

- Evidence of K^-pp state at J-PARC (E27) ($\pi^+ + d \rightarrow K^+ + K^-pp$), but no other states yet
- Statistical thermal model calculation
- Maximum yields at J-PARC energy range

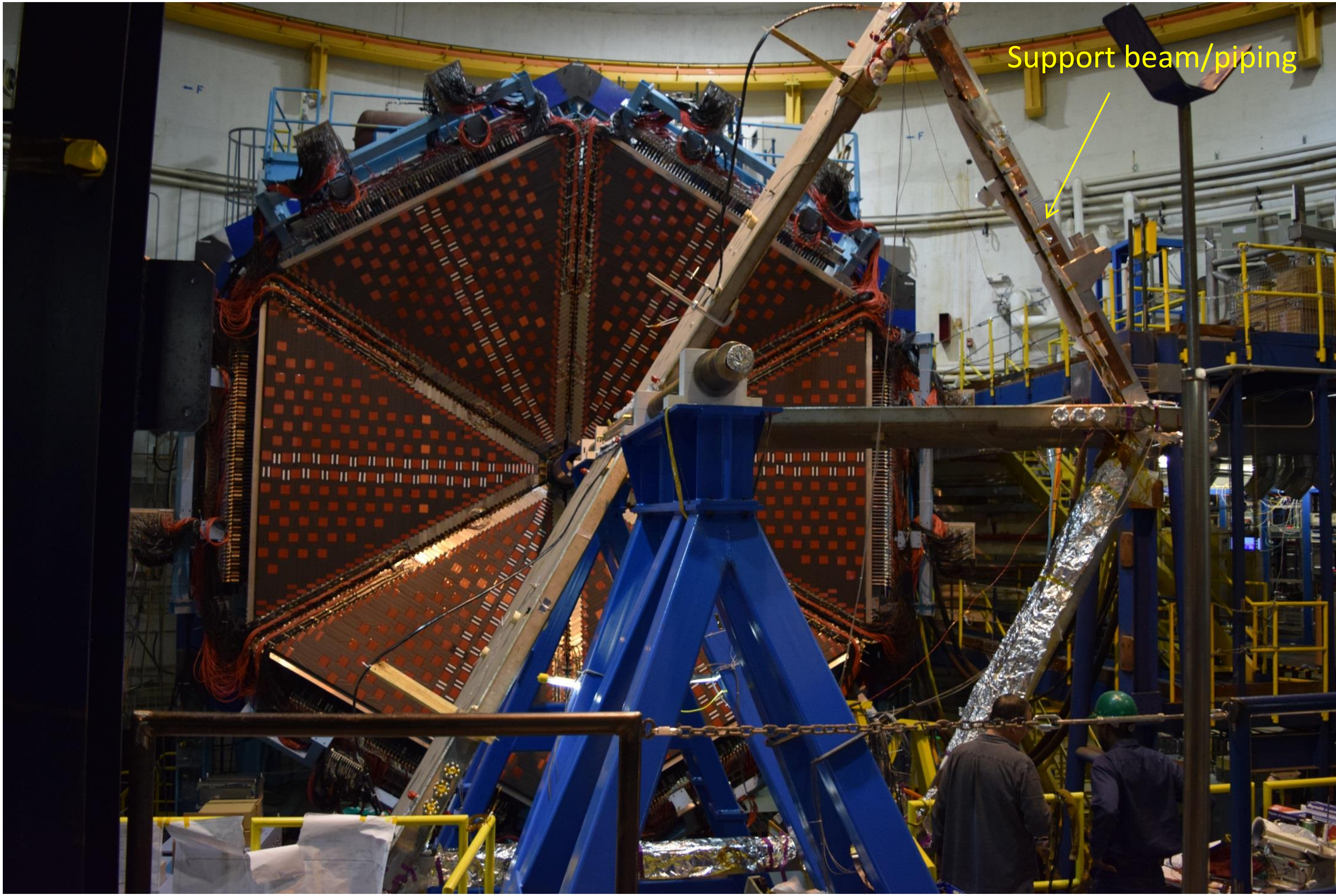
Exotic hadrons in HIC
ExHIC collab (A. Ohnishi, et al)



Yields depend on
the system size
assuming a
coalescence
model (RHIC or
LHC)

J-PARC?

Λ(1405) is KbarN
or 5-quark state?



Support beam/piping

Hypernuclear physics with HI

Goals

1. Discovery of new hypernuclei and extension of hypernuclear chart
   - S=-1,-2,-3 hypernuclei
   - Proton-rich and Neutron-rich hypernuclei
   - Can be done in mid-rapidity or beam/target rapidity
   - Identification with weak decay to a (light) nucleus + π-
2. **Study of weak decays at beam rapidity**

   With meson beams, due to short decay length these measurements are difficult
   - life time measurement
   - Mesonic decay e.g. $^{4}{}_{\Lambda}H \rightarrow \pi^{-} + ^{4}He$ (^{4}He ground state)
     - standard way to identify a hypernucleus
   - Non-mesonic weak decay
     - *Λp → pn (p,n : high momentum) the rest nucleus is exited state, and will break.*
     - *Measurements of residues*
   - magnetic moment
     - never measured!
     - sensitive to hyperon wave function inside hypernucleus
     - Spin and angular momentum structure
     - Spin-dependent YN interaction

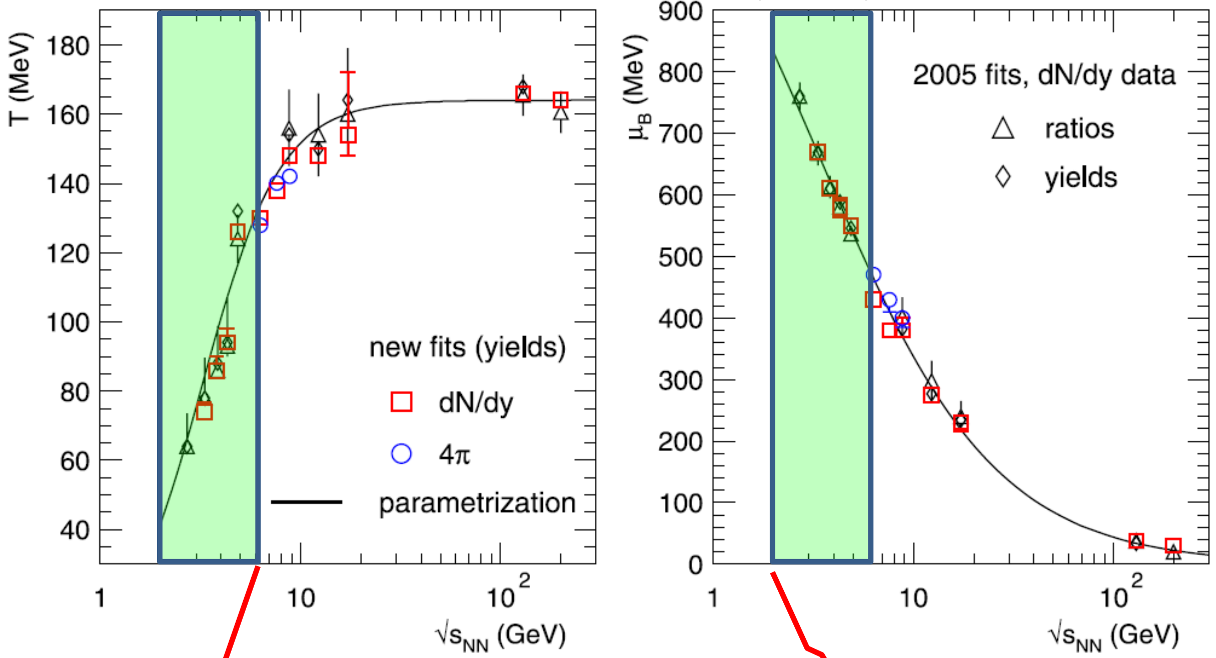
Special closed-geometry setup is required

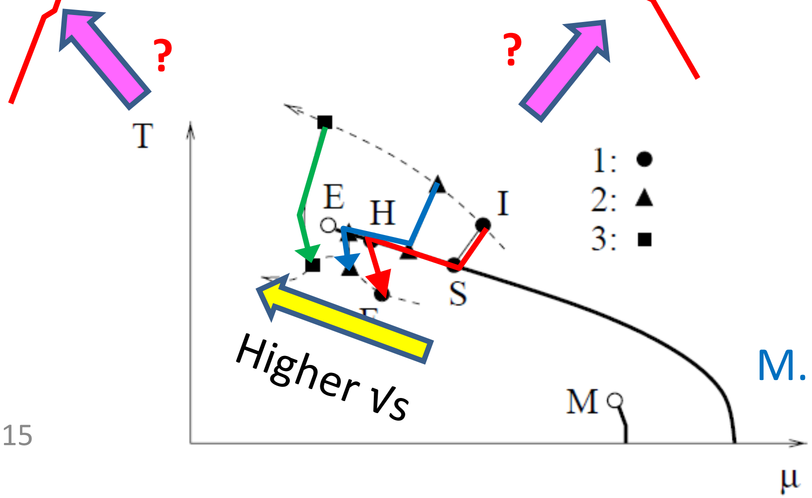
We could utilize full 10^{10} Hz beam?

Simulation study necessary

(T , μ_B) and $\sqrt{s_{NN}}$

A. Andronic, et al, NPA837 (2010) 65-86





- Focusing effect toward the critical point in the system evolution
- We can measure (T,μ_B) as a function of √s with fine steps (almost continuously) and systemactically with the same spectrometer
- Signature for the critical point = step structure?

M. Stephanov PRL81(1998)4816

How about beam demand for space development in Japan?

Comments by Toru Tamagawa (RIKEN)

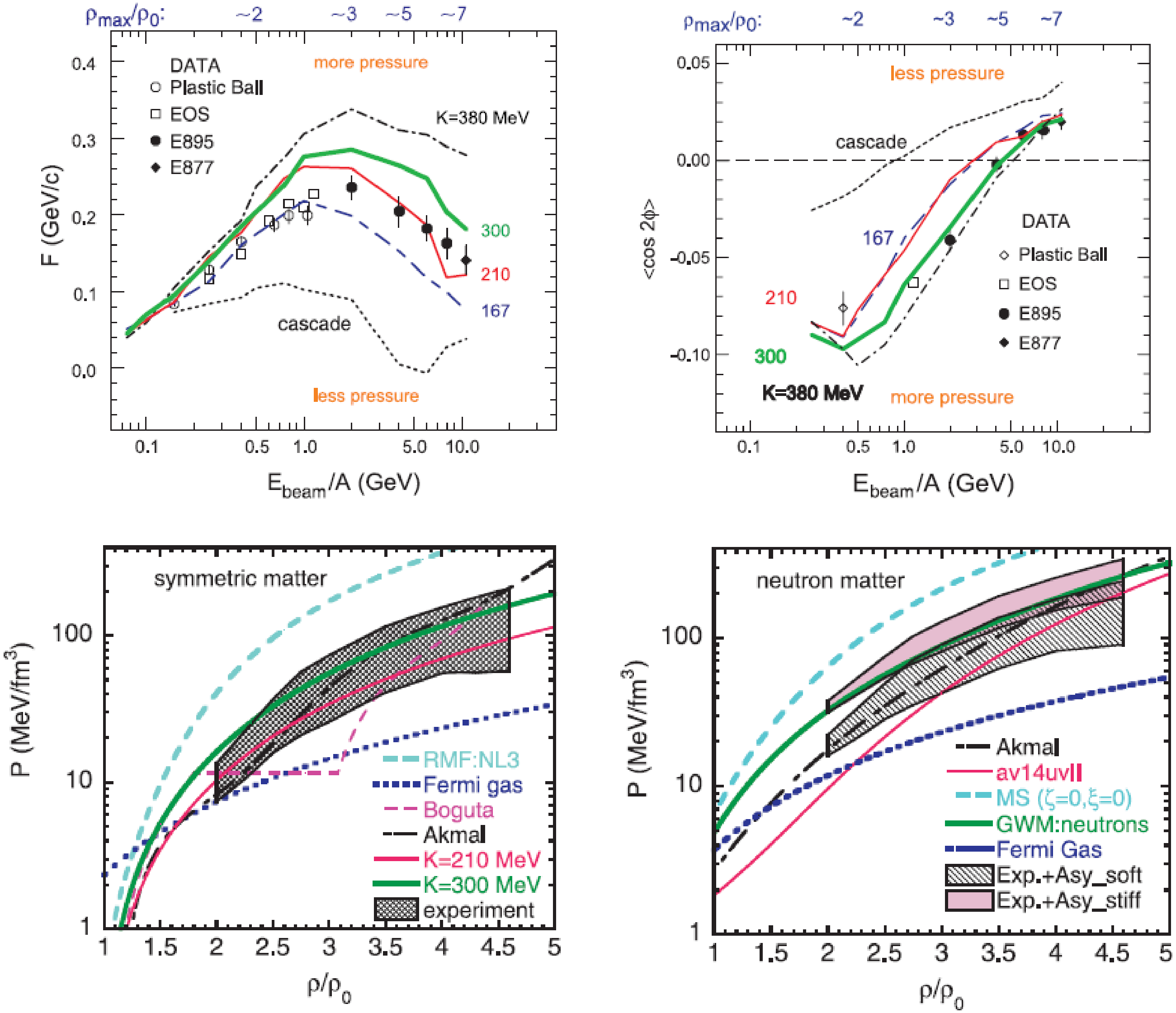
- 宇宙関連では、重イオン照射に一定のニーズがある。特に低エネルギー側でICやセンサーへの照射は、半永久的にニーズが絶えないと思われます。これから CubeSat などの超小型衛星が大学レベルで開発が進むので、自前で放射線耐性を 確認したいというニーズも増えるのではないか。
- 現在最も良く用いられているのは HIMAC (800AMeV)。ユーザーサポート体制が整っている。
- 最近理研もユーザーサポートを強化している。RCNP(200AGeV) でも、衛星搭載用の CCD chip に 陽子を照射する実験を行っているグループがある。

- 地球周回軌道（科学衛星の大半）では、主に低エネルギー側(<1 AGeV)が効く。 低エネルギーなので、ある程度シールドすることが可能。電子機器の single event upset (SEU) などを研究する人は、低エネルギーを希望 する。
- 銀河宇宙線の場合は、高エネルギー(>1-10AGeV)なので、シールドできるほど十分な物質 を宇宙に上げられません。宇宙に人が長期滞在する時や、月とか火星に行く 場合は、こちらのほうが効く。
- もしJ-PARCで行う場合は、低エネルギーも高エネルギーも、MRを使用する必要がある。(70AMeV-10AGeV)

EOS from flow

$$F = \left.\frac{d\langle p_x/A\rangle}{d(y/y_{\mathrm{cm}})}\right|_{y/y_{cm}=1}$$

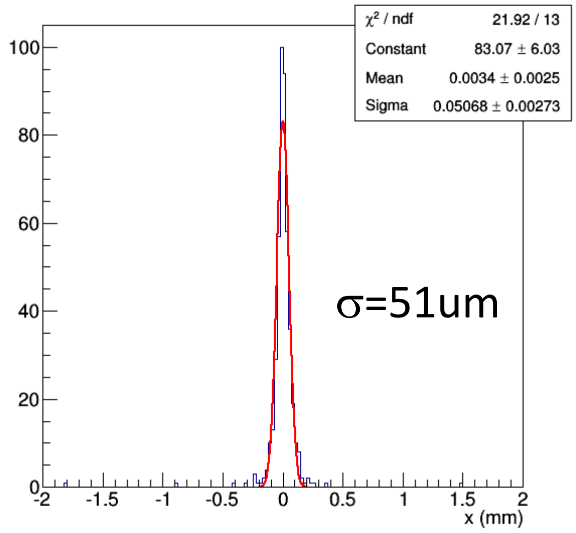
$$K \equiv 9\ dp/d\rho$$



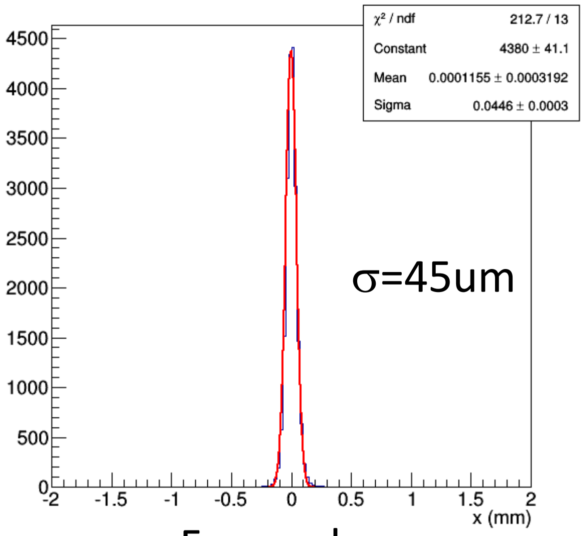
- To measure EOS is one of the ultimate goals of nuclear experiments
- Flow as a function of sqrt(s) may have important information of EOS
  - Danielewicz et al., Science 298 (2002) 1592

Vertex resolution

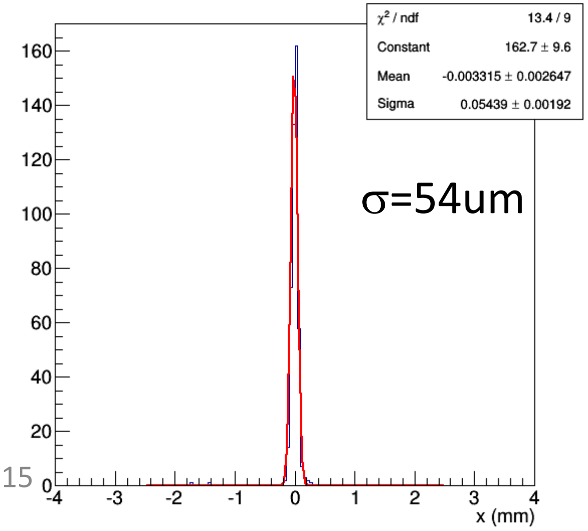
Barrel xca



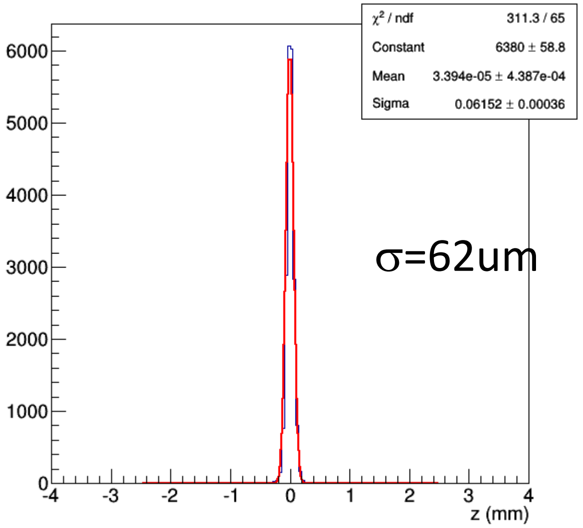
Forward xca



Barrel zca



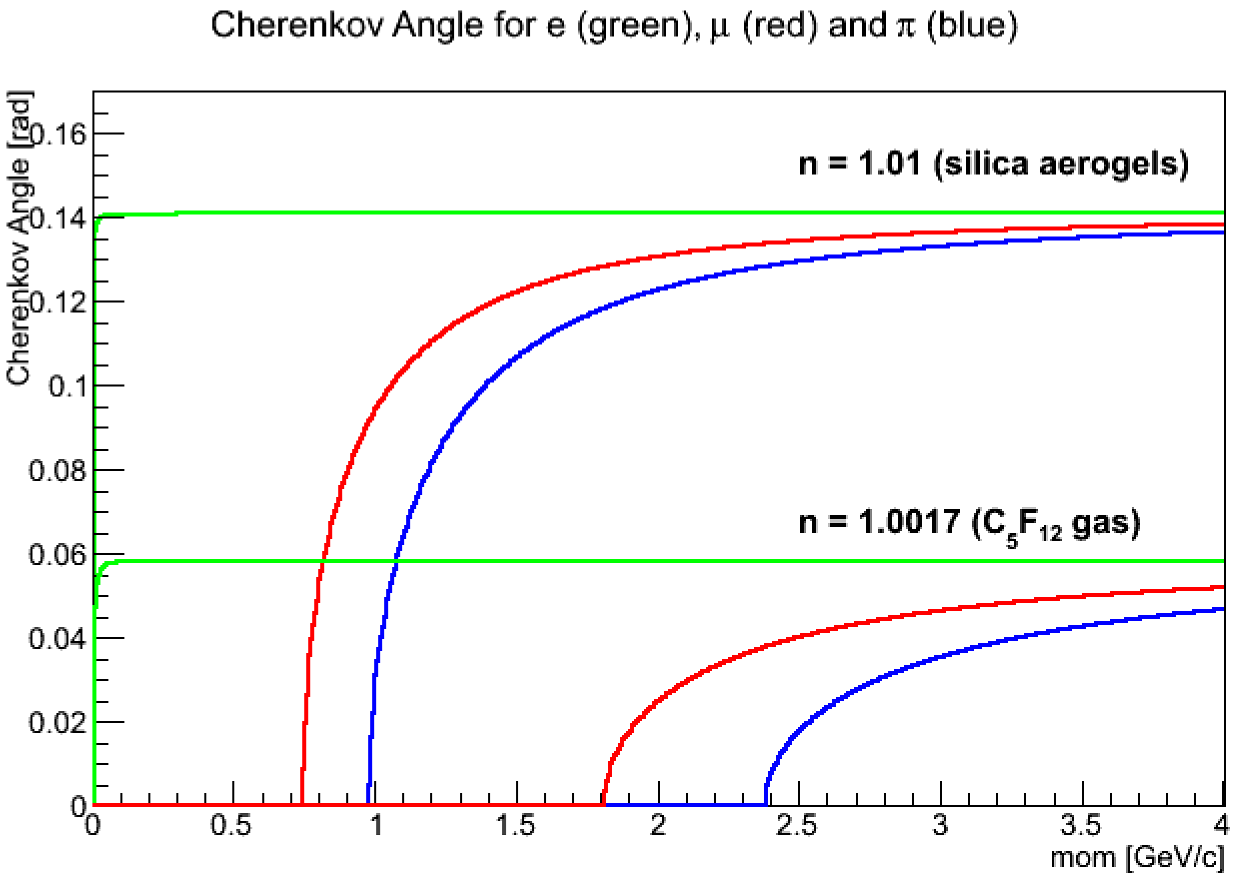
Forward zca



Xca,zca
Closed approach
Of the track
To the target
Position

Good resolution
With 4 layer
40umx40um
and
80umx80um
pixels

μ/π separation with RICH



P<0.8GeV/c

- TOF (MRPD)
- 3σ separation

σ_t=30ps , L=5m

0.8<p<1.5GeV/c

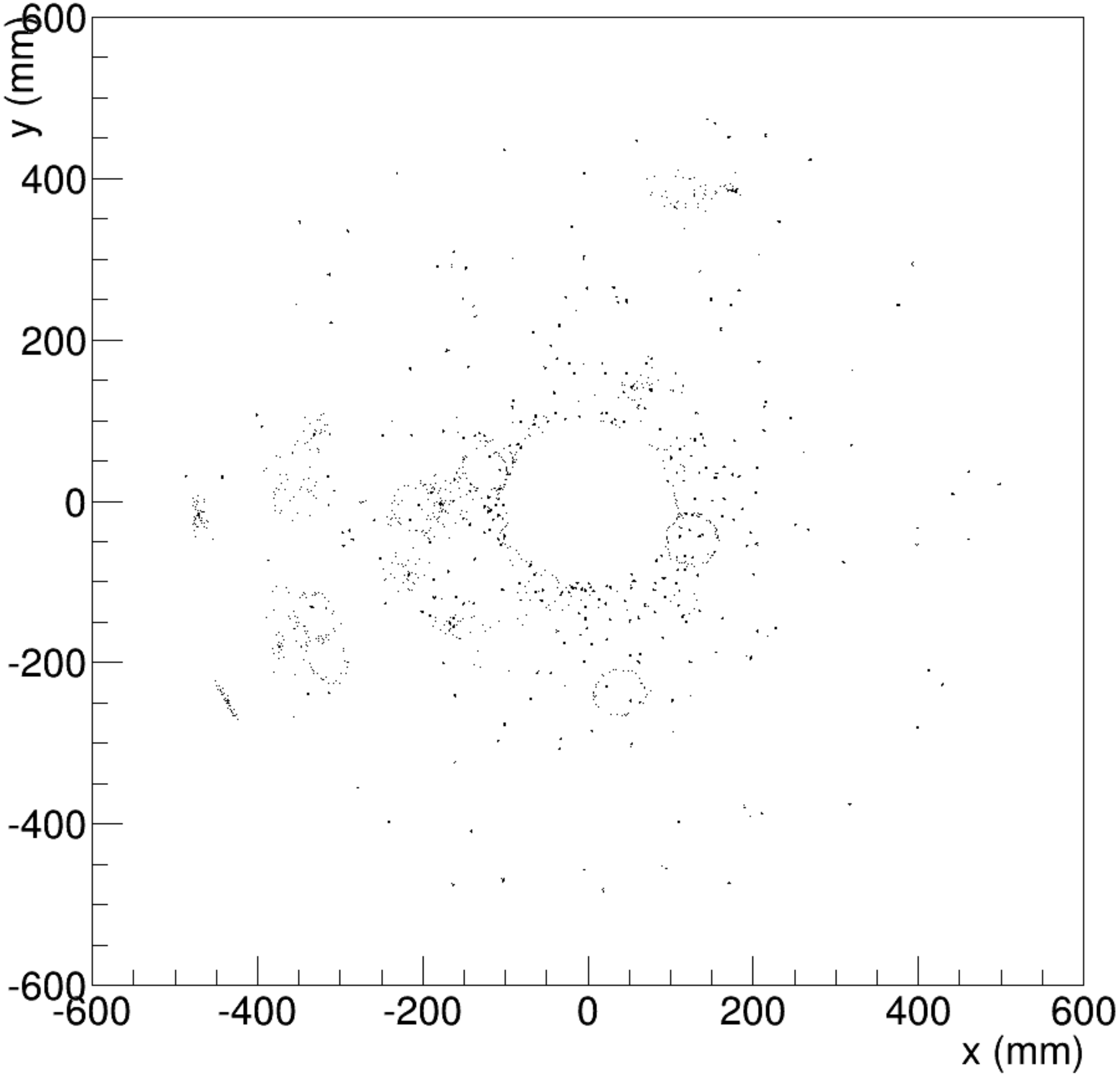
RICH(aerogel)

P>1.5 GeV/c

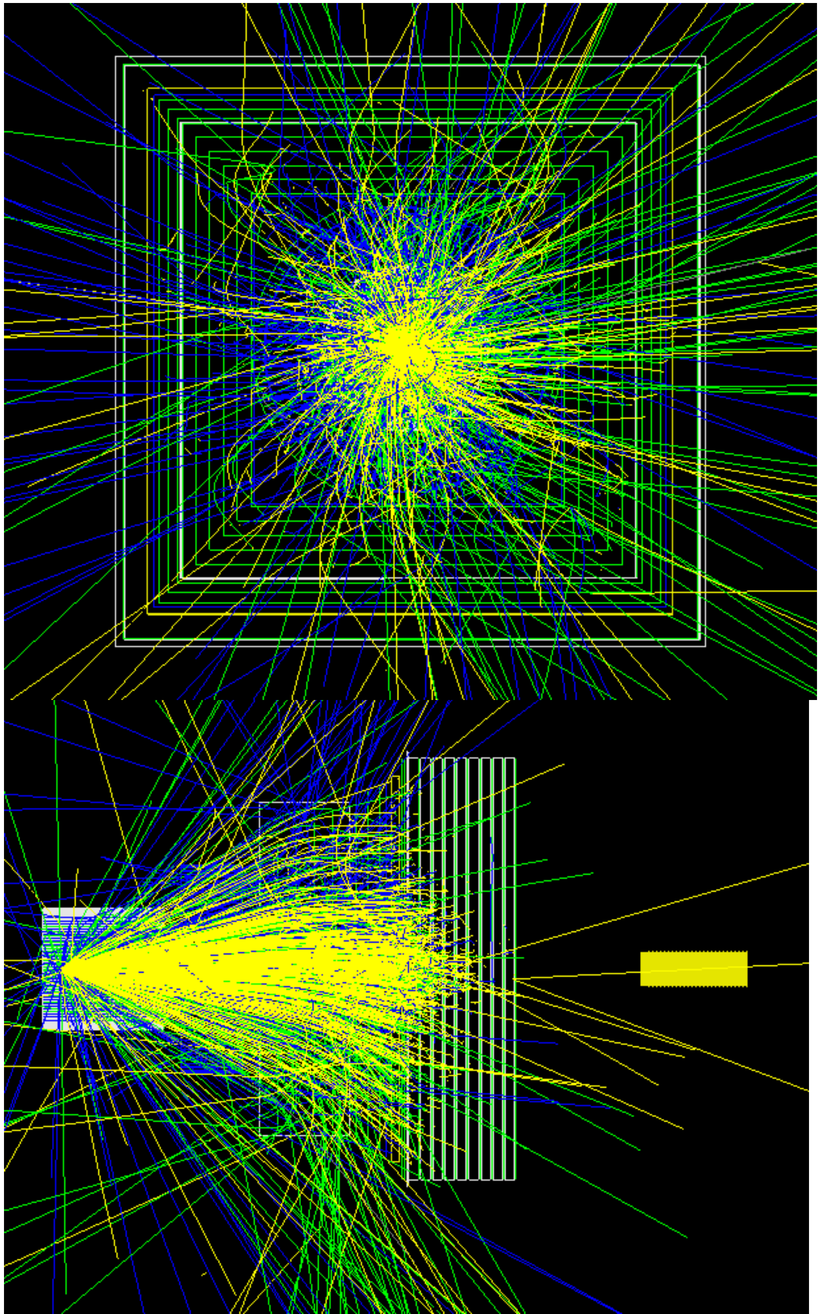
Fe absorbers

+trackers

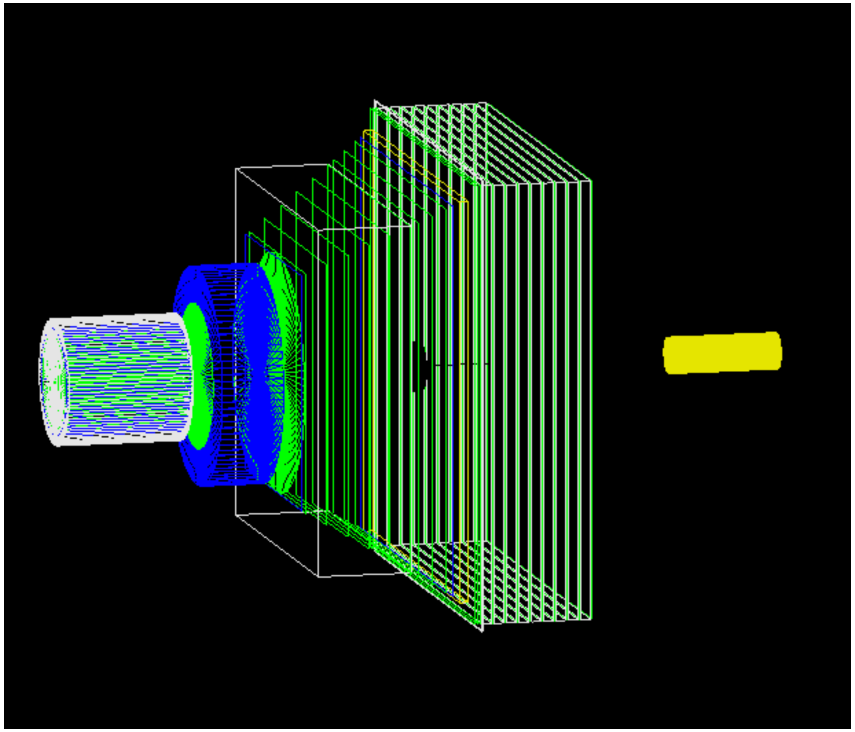
An U+U event



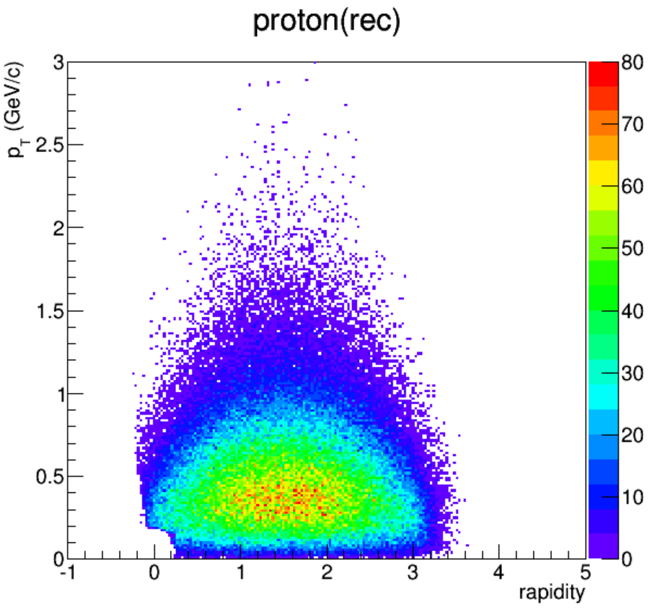
GEANT4 simulation

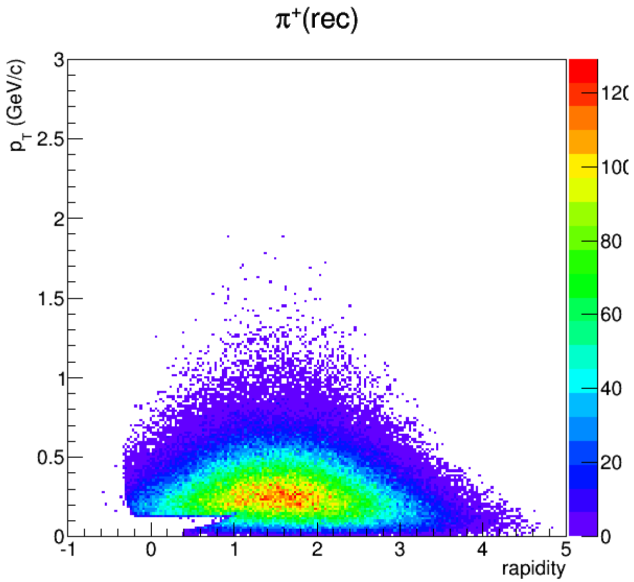


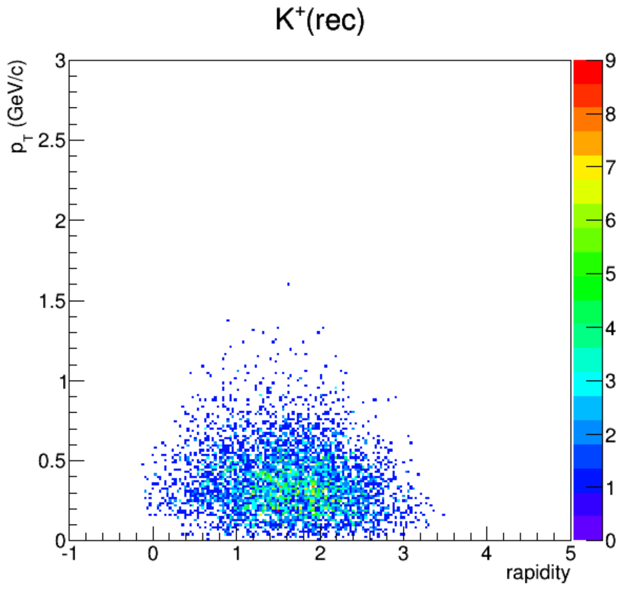
- JAM model
  U+U collisions
  (10AGeV)



U+U at 10 AGeV (Preliminary)





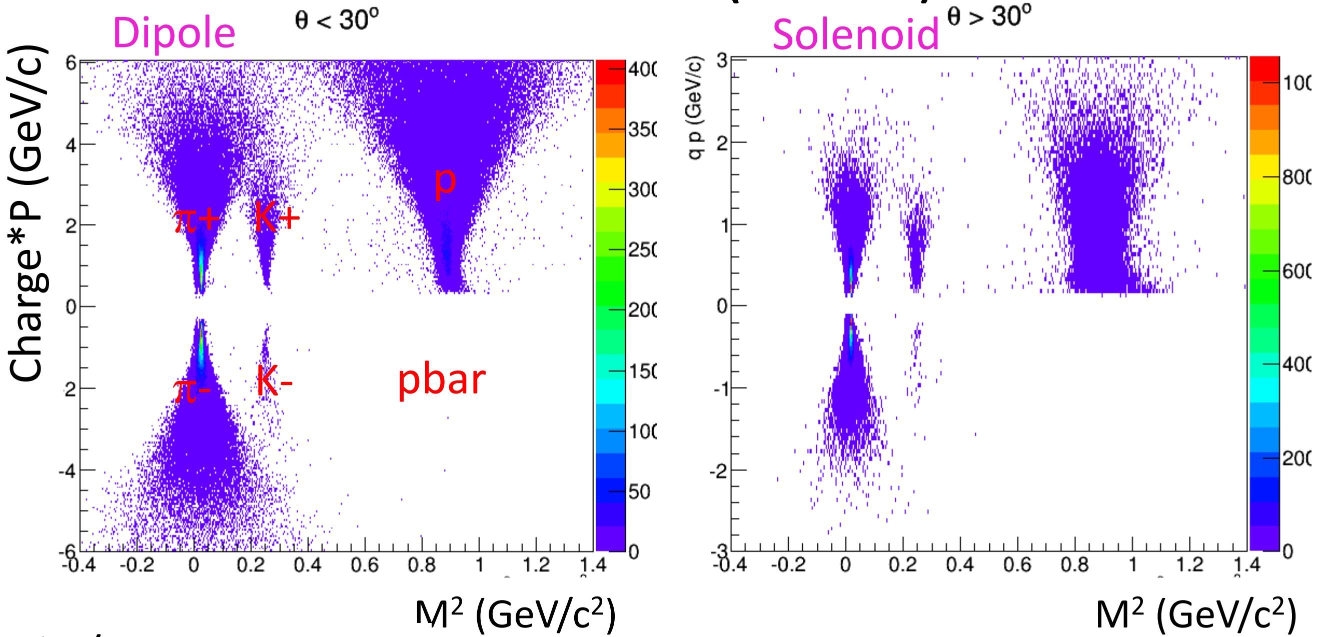


Acceptance
(including decay loss)

p	97.5%
K	72.3%
π	87.1%

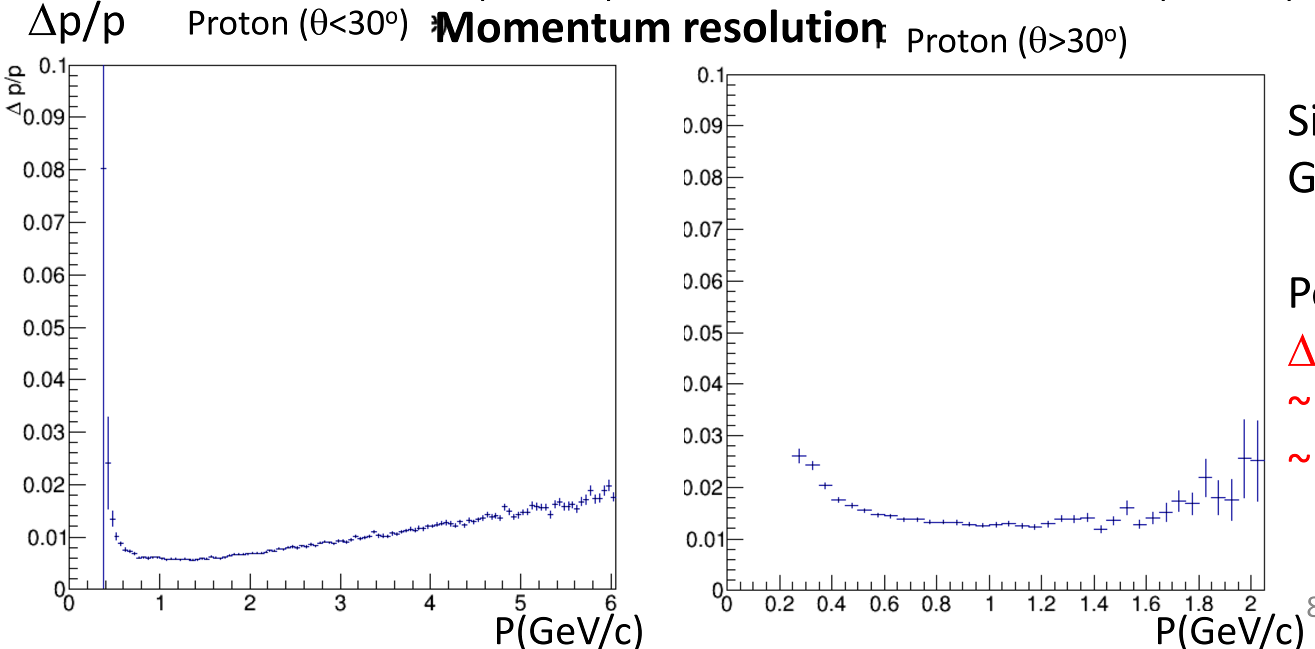
PID and momentum (Preliminary)

Momentum vs m^2 (with TOF)



TOF resolution 50 ps
2σ π-K separation
p<2.8 GeV/c
(dipole)

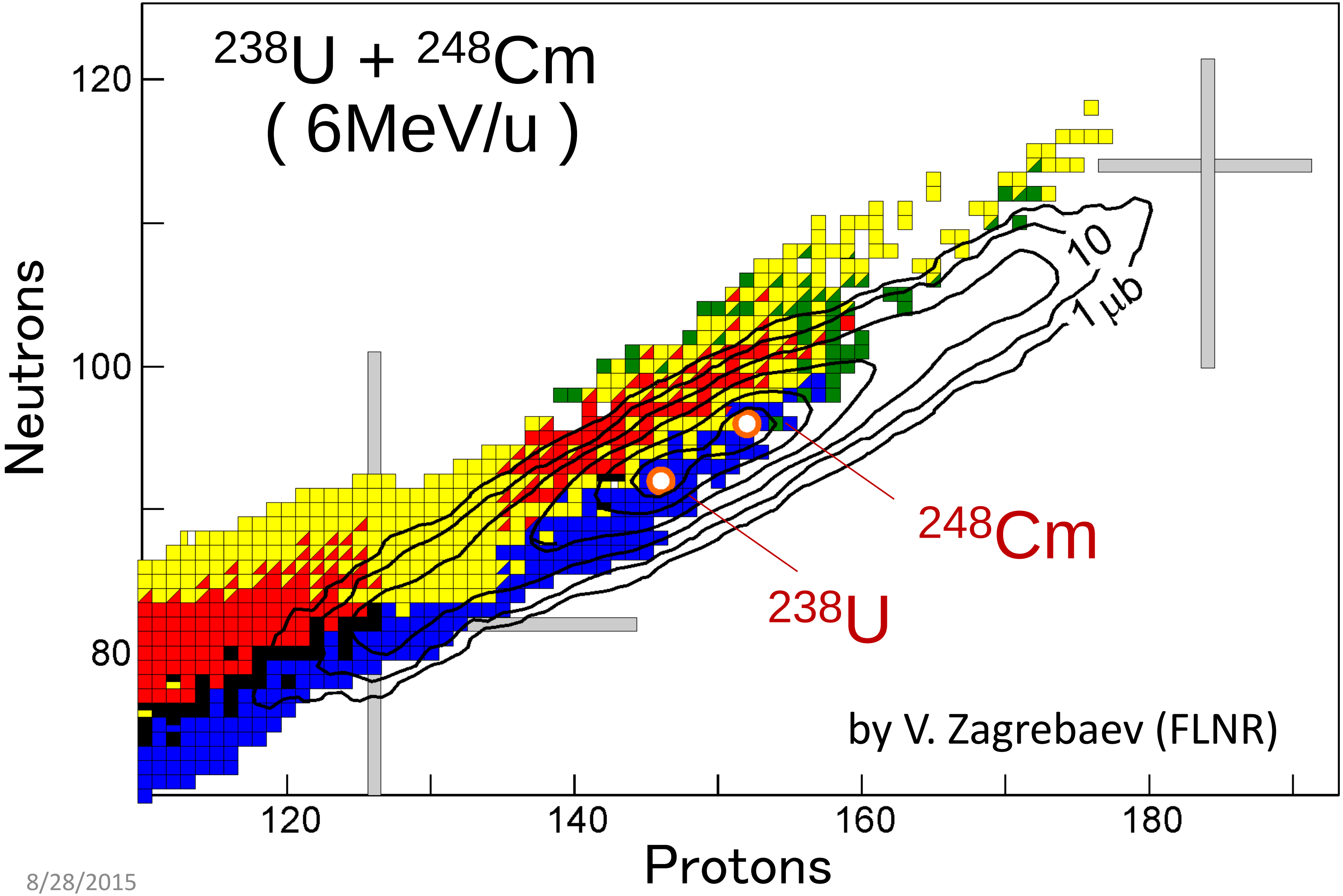
Momentum resolution



Silicon trackers : 14-23 μm
GEM trackers: 0.2-0.4 mm

Position resolution
$\Delta p/p$
~ 0.4% x p (GeV/c) (dipole)
~ 1.5% (solenoid)

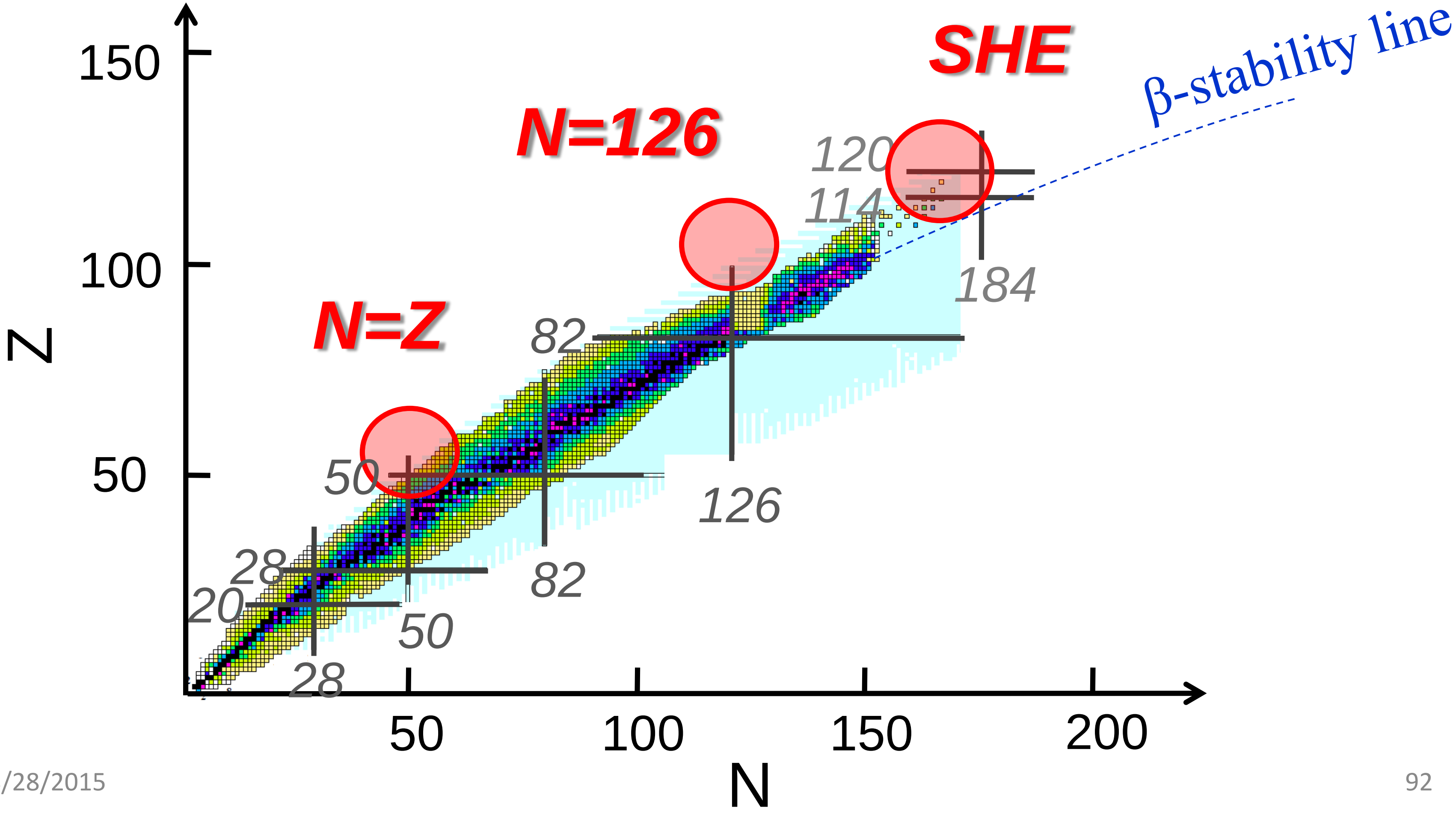
Search for Super-Heavy Nuclei



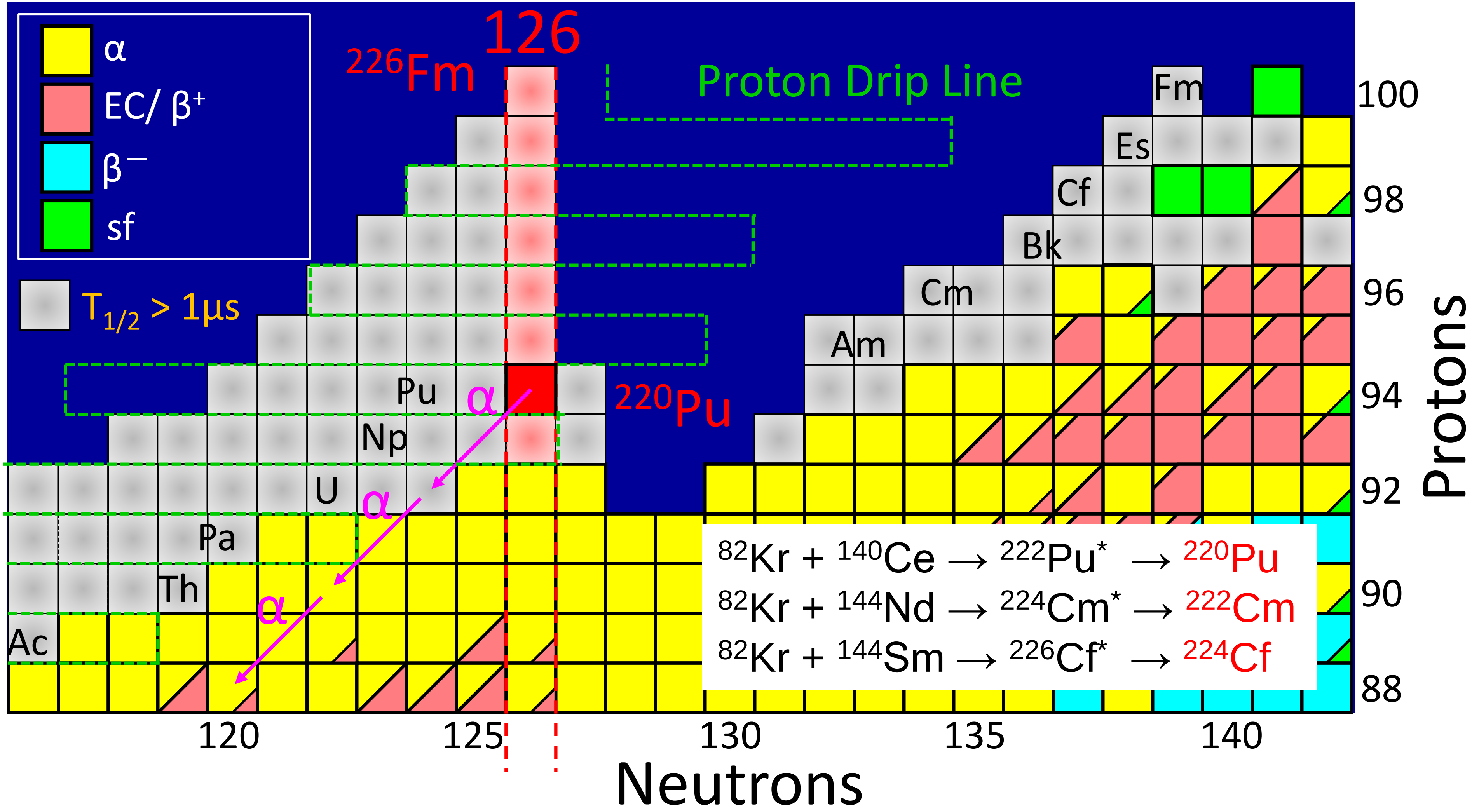
by V. Zagrebaev (FLNR)

Low Energy Program

Search for Heaviest N=Z Nuclei
Search for Super-heavy Nuclei
Search for Heaviest N=126 Nuclei



Search for Heaviest N=126 Nuclei



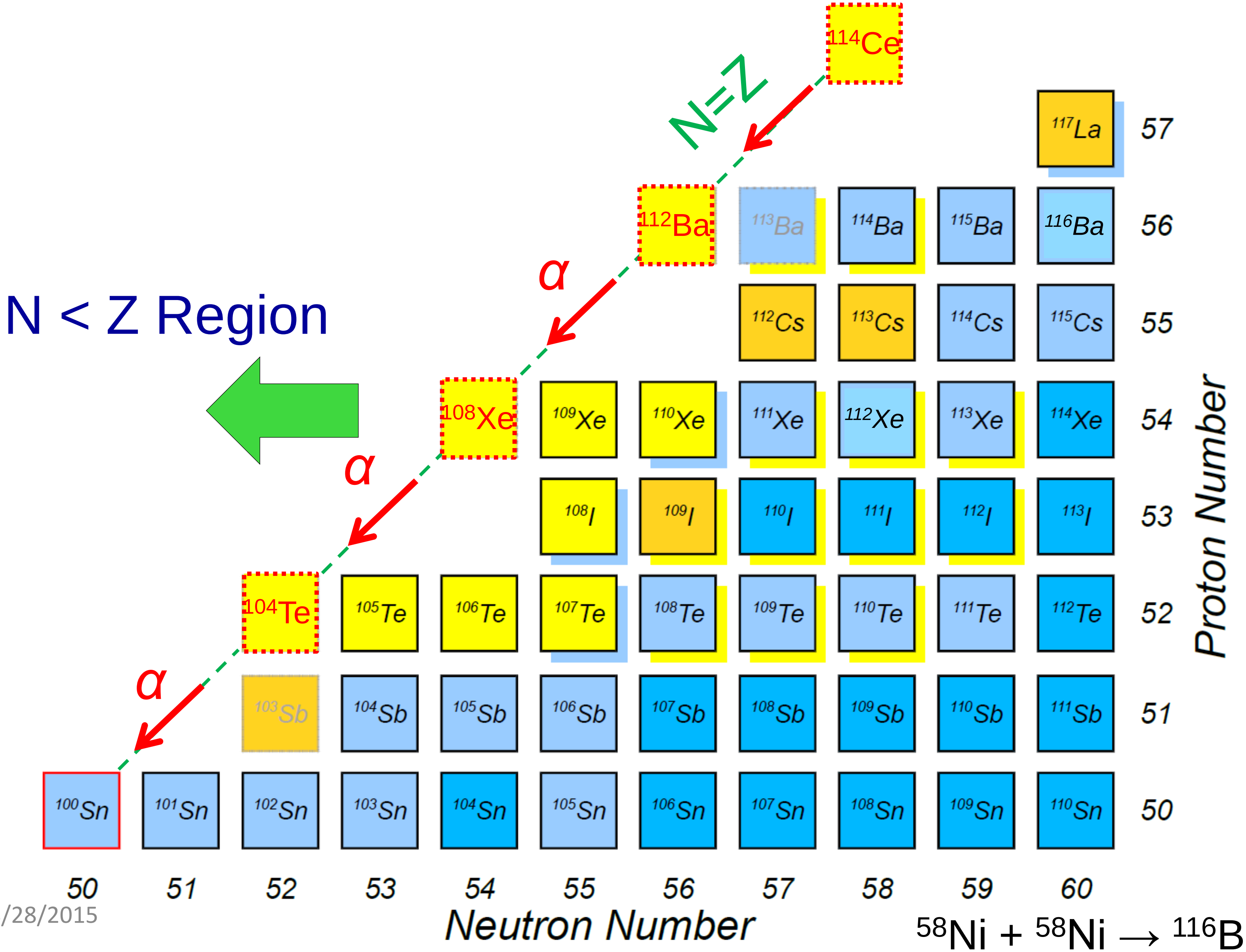
$^{82}\mathrm{Kr} + {}^{140}\mathrm{Ce} \rightarrow {}^{222}\mathrm{Pu}^{*} \rightarrow {}^{220}\mathrm{Pu}$

$^{82}\mathrm{Kr} + {}^{144}\mathrm{Nd} \rightarrow {}^{224}\mathrm{Cm}^{*} \rightarrow {}^{222}\mathrm{Cm}$

$^{82}\mathrm{Kr} + {}^{144}\mathrm{Sm} \rightarrow {}^{226}\mathrm{Cf}^{*} \rightarrow {}^{224}\mathrm{Cf}$

New Region Predicted by H. Koura, ASRC/JAEA

Search for Heaviest N = Z Nuclei



^{58}Ni + ^{58}Ni $\rightarrow$ ^{116}Ba* $\rightarrow$ ^{112}

Beam request for low energy HI experiments

- Ion Species

  Ne, Ar, Fe, Ni, Kr, Xe…, U

- Energy

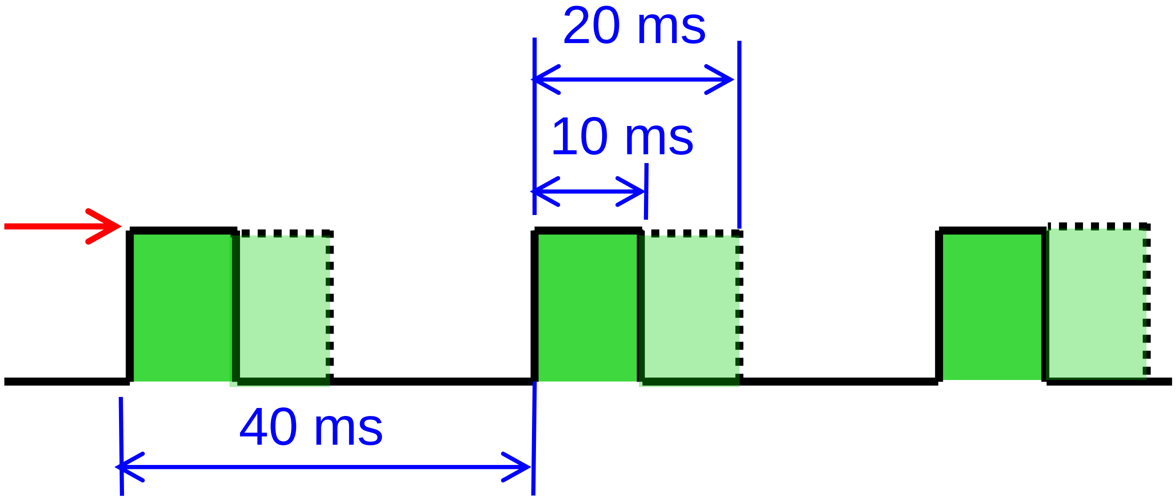
  up to 10 MeV/u

- Beam current (Super-conducting ECR)

  10 pμA (Au,U), 30 pμA (Ni, Kr) or more

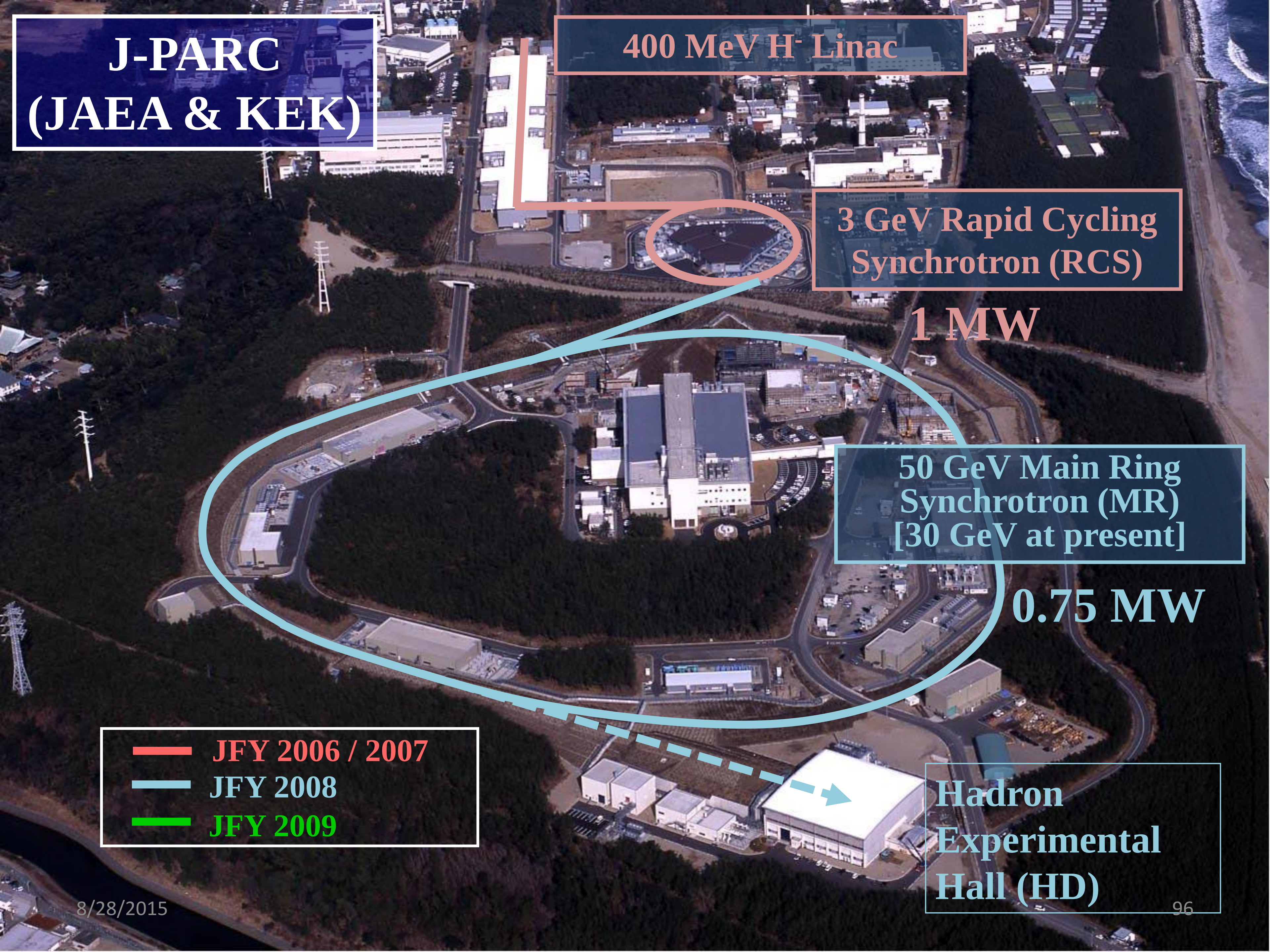
- Beam structure

  25 Hz beam more than 25% duty factor (pulse width 10ms or more)



10 pμA for U
30 pμA for Ni, Kr

J-PARC (JAEA & KEK)



400 MeV H^- Linac

3 GeV Rapid Cycling Synchrotron (RCS)

1 MW

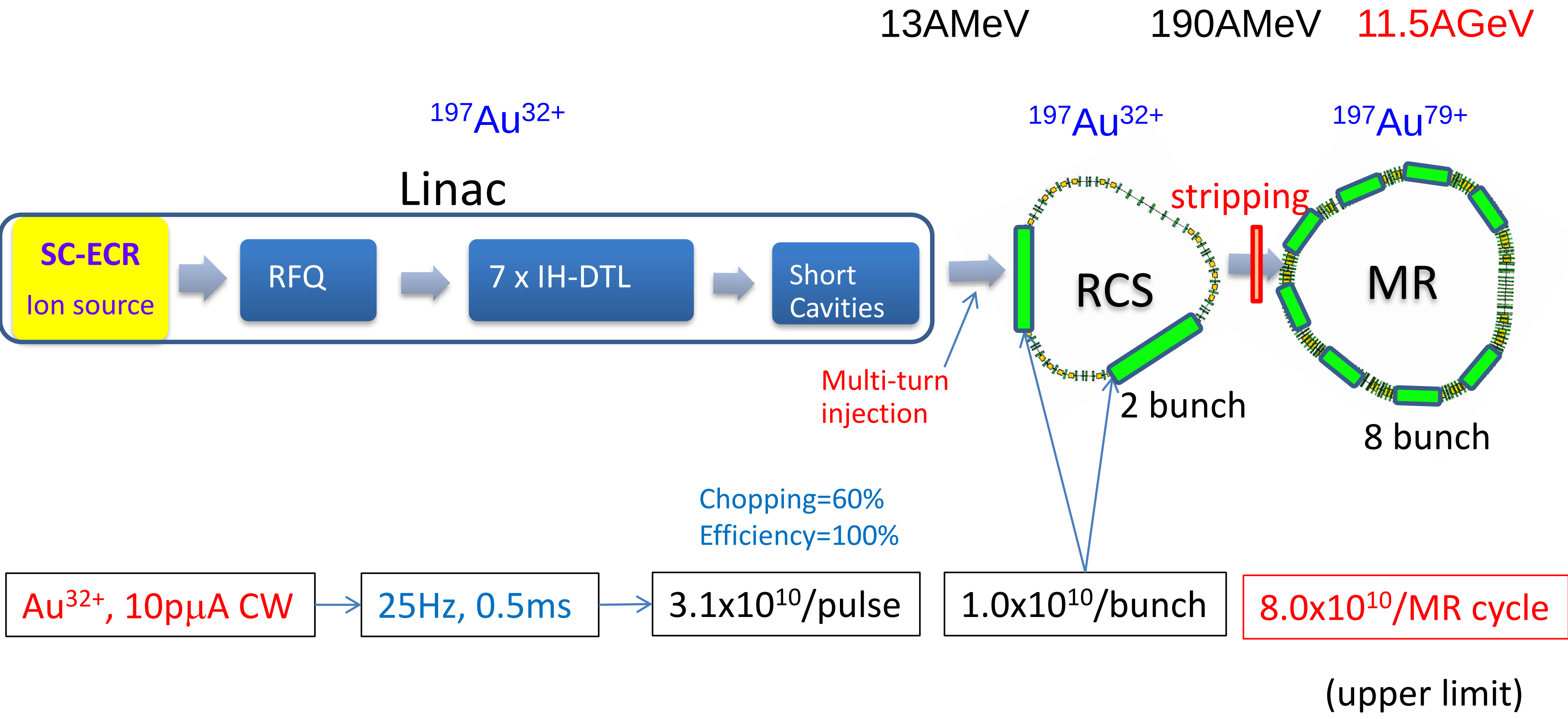
50 GeV Main Ring Synchrotron (MR)
[30 GeV at present]

0.75 MW

Hadron Experimental Hall (HD)

JFY 2006 / 2007
JFY 2008
JFY 2009

An acceleration scheme



13AMeV

190AMeV

11.5AGeV

$^{197}Au^{32+}$

Linac

SC-ECR

Ion source

RFQ

7 x IH-DTL

Short Cavities

Multi-turn injection

$^{197}Au^{32+}$

RCS

2 bunch

stripping

$^{197}Au^{79+}$

MR

8 bunch

Chopping=60%

Efficiency=100%

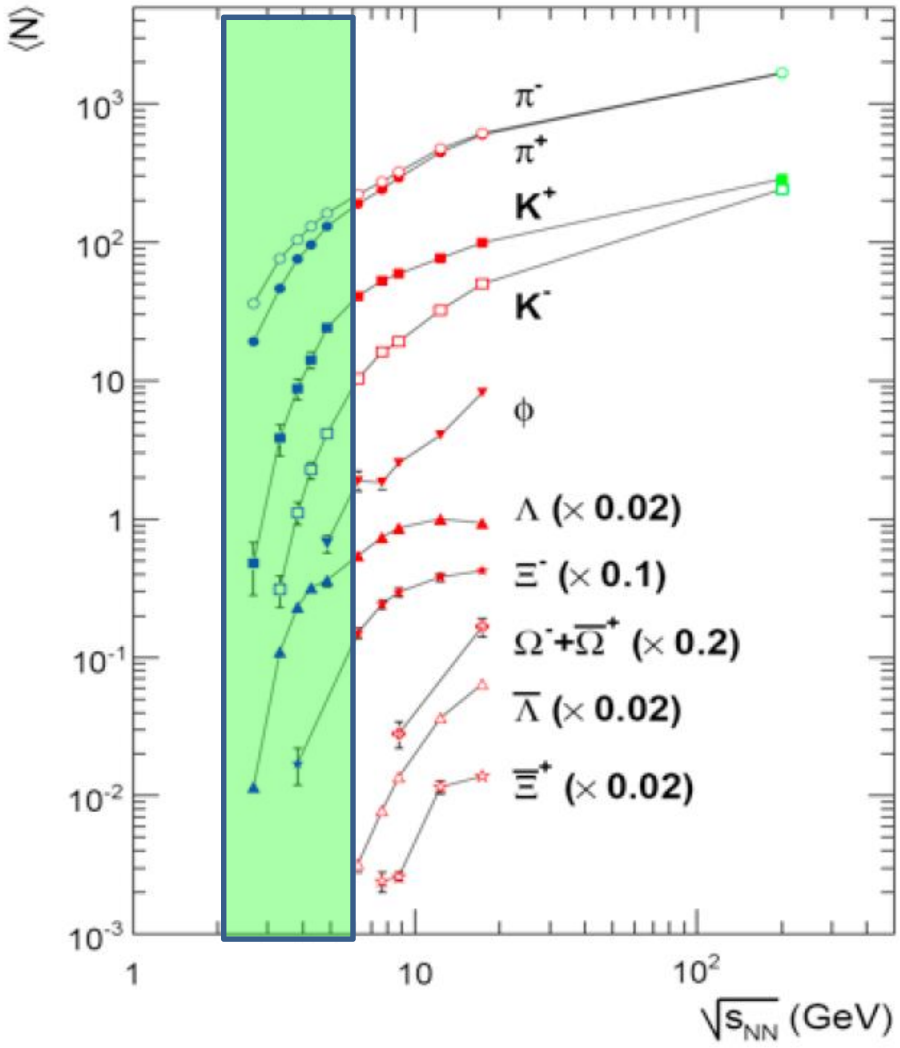
Au^{32+}, 10pμA CW → 25Hz, 0.5ms → $3.1x10^{10}$/pulse

$1.0x10^{10}$/bunch

$8.0x10^{10}$/MR cycle

(upper limit)

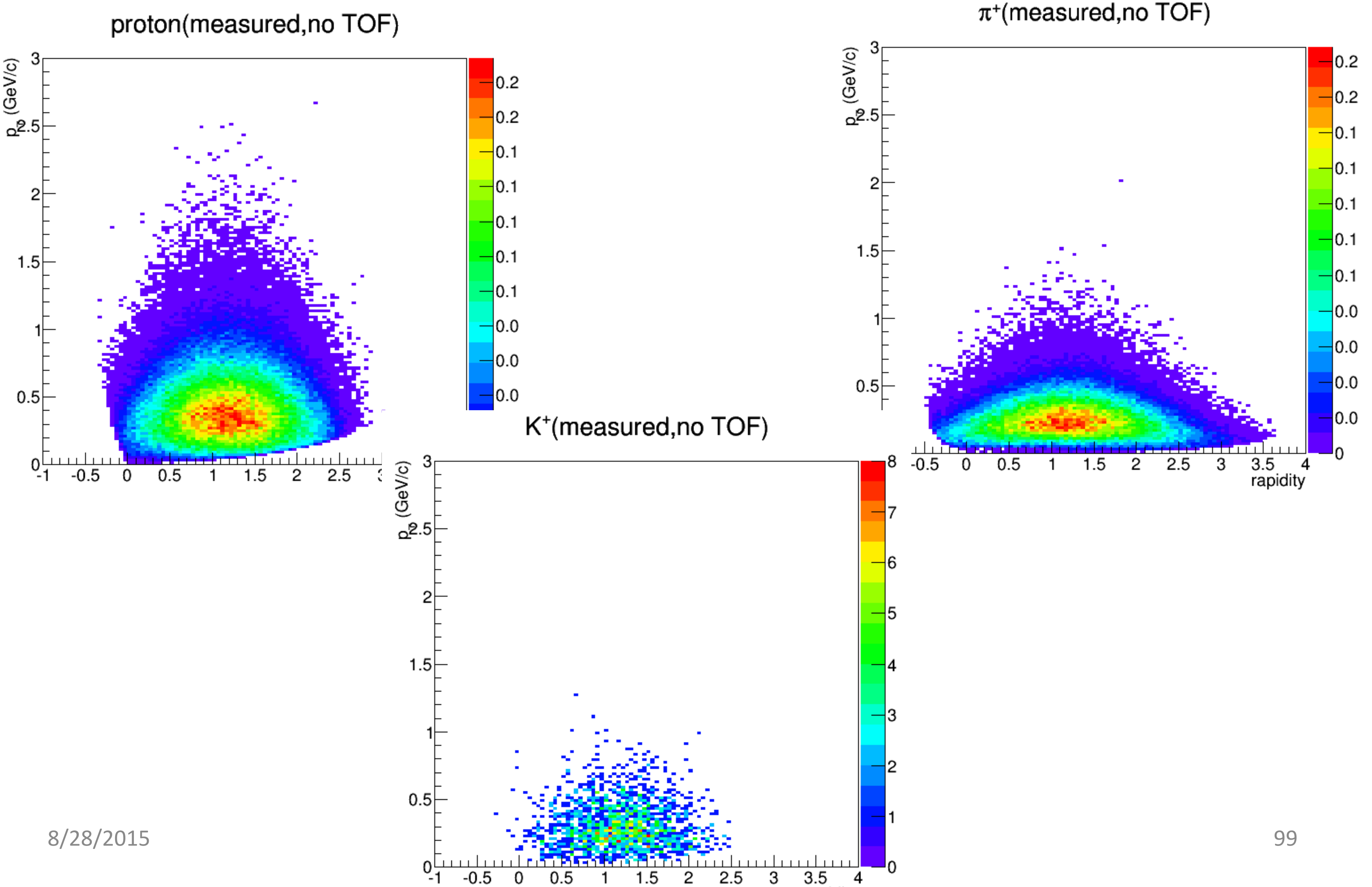
Measured particle multiplicity in Au+Au(Pb+Pb)



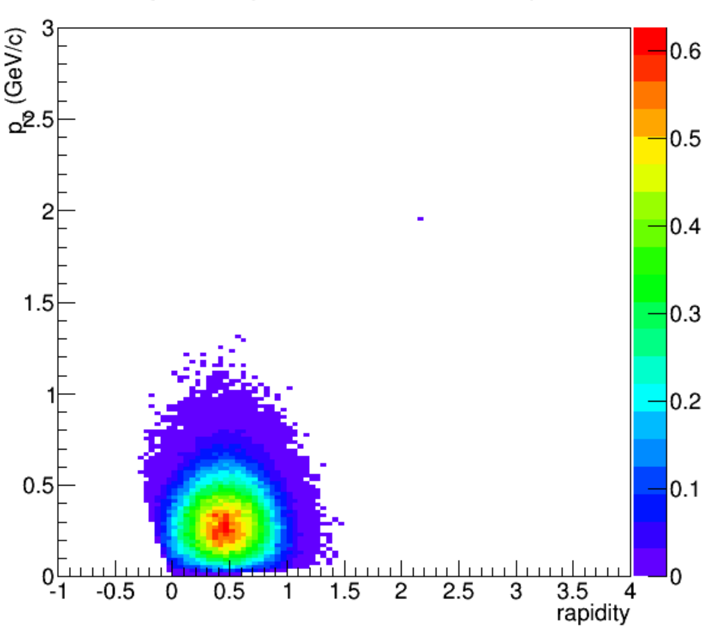
- Ω, Ξ^+, Δ at STAR BES at 7.7GeV
- π^0, p, Pbar, K_s, d, t, ^{3}He measured at AGS
- π^0,η at 1.2AGeV

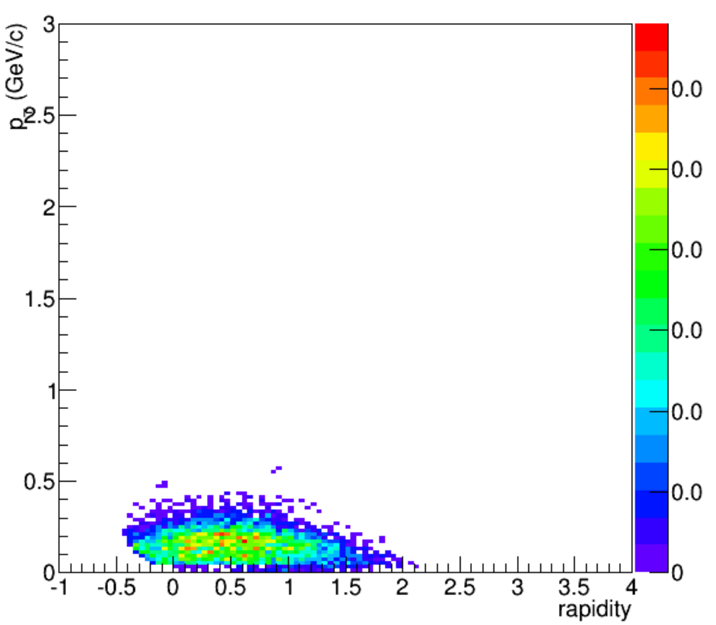
CBM report 2012-1, C. Blume J. Phys. G31 (2005) S57

U+U at 5 AGeV/c

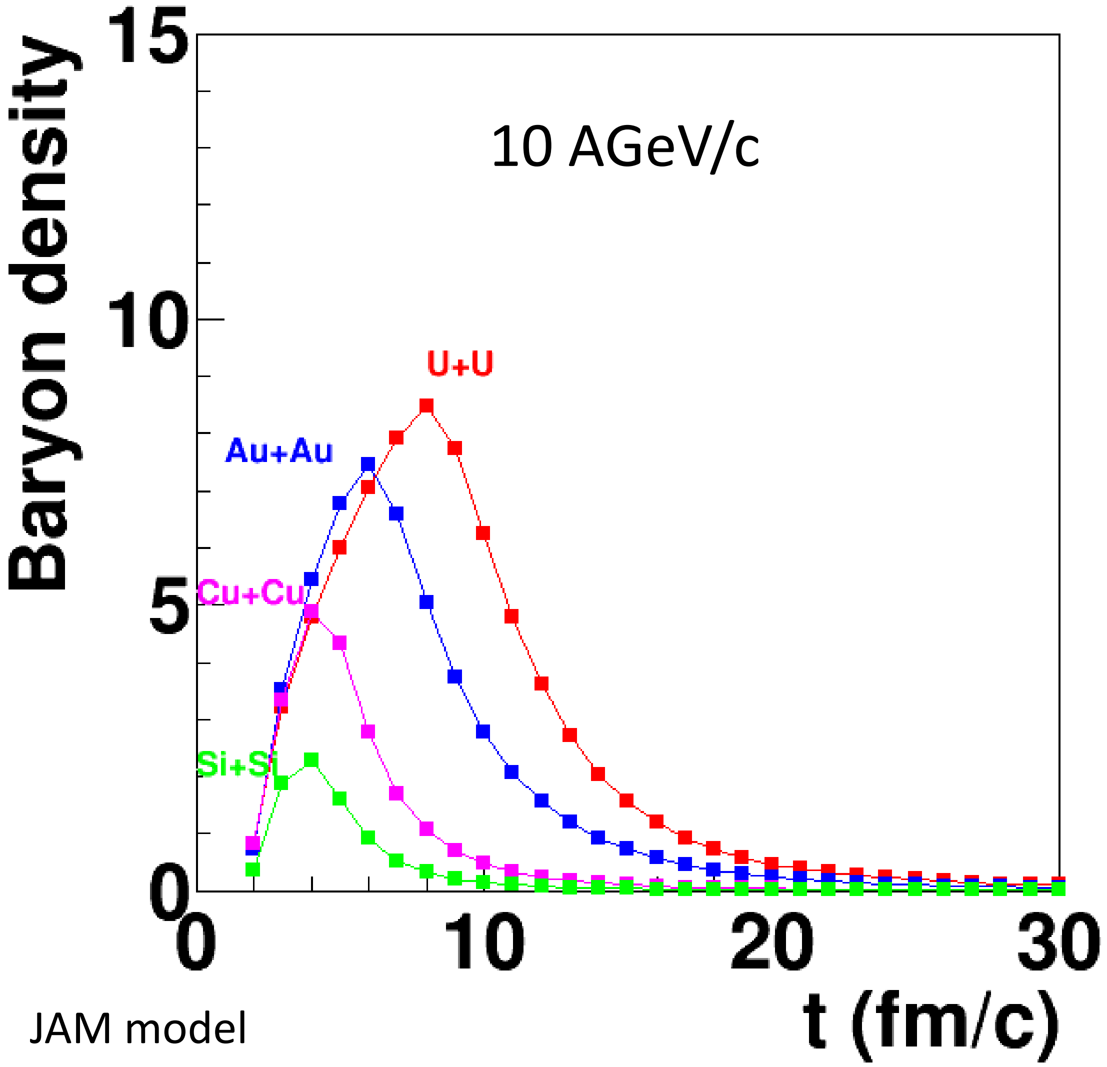

proton(measured,no TOF)
p_T (GeV/c)
0
0.5
1
1.5
2
2.5
3
-1
-0.5
0
0.5
1
1.5
2
2.5
0.2
0.2
0.1
0.1
0.1
0.1
0.1
0.0
0.0
0.0
π⁺(measured,no TOF)
p_T (GeV/c)
0.5
1
1.5
2
2.5
3
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
rapidity
0.2
0.2
0.1
0.1
0.1
0.1
0.1
0.0
0.0
0.0
0.0
0
K⁺(measured,no TOF)
p_T (GeV/c)
0
0.5
1
1.5
2
2.5
3
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
8
7
6
5
4
3
2
1
0

U+U at 1 AGeV/c


proton(measured,no TOF)


π^+(measured,no TOF)

Baryon density from light to heavy ions



ρ/ρ_0

10 AGeV/c

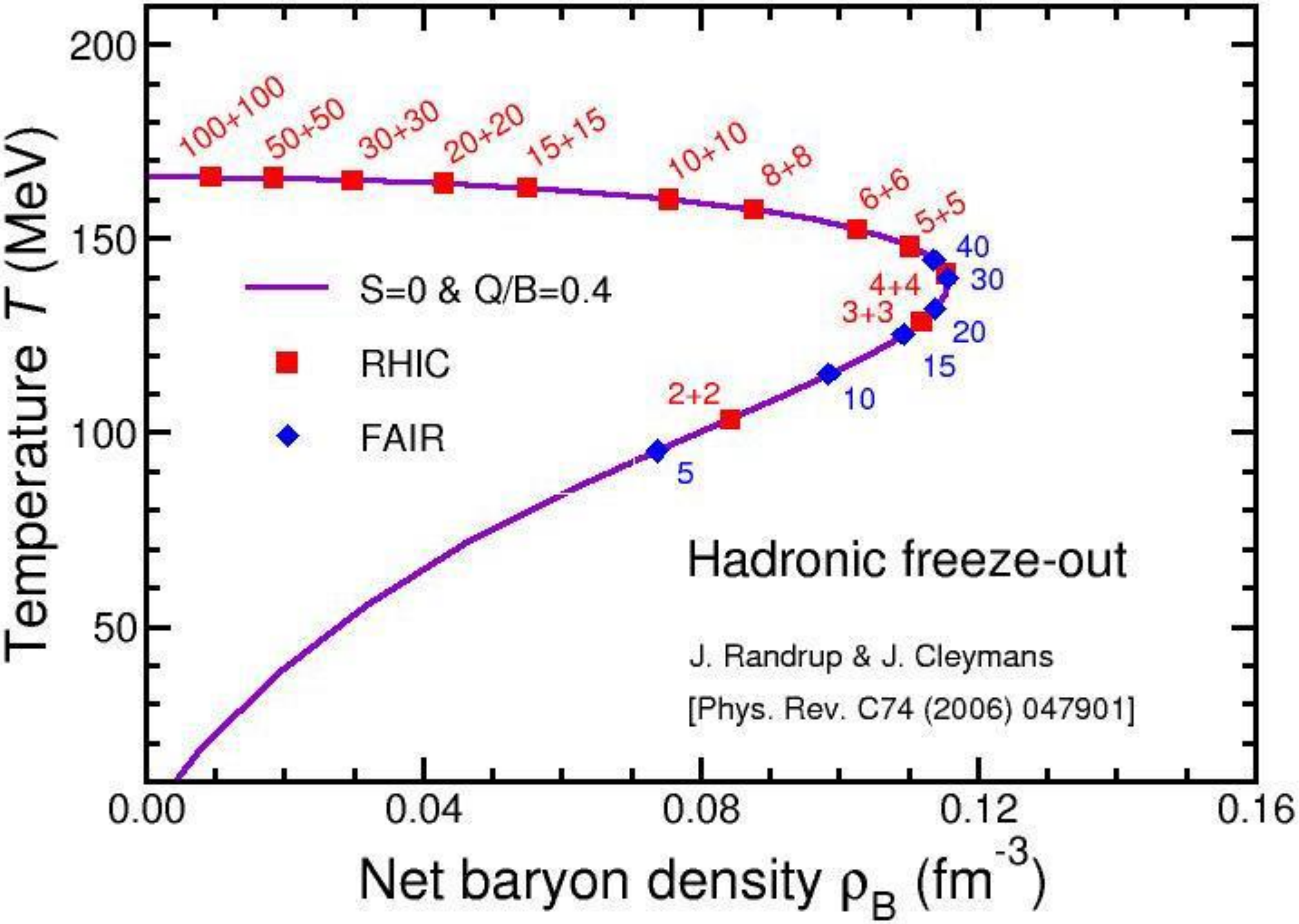
Au+Au→U+U

- Baryon density
  - $7.5\rho_0$ → $8.6\rho_0$
- Duration at $\rho>5\rho_0$
  - 4 → 7 fm/c

U beam is necessary at J-PARC!

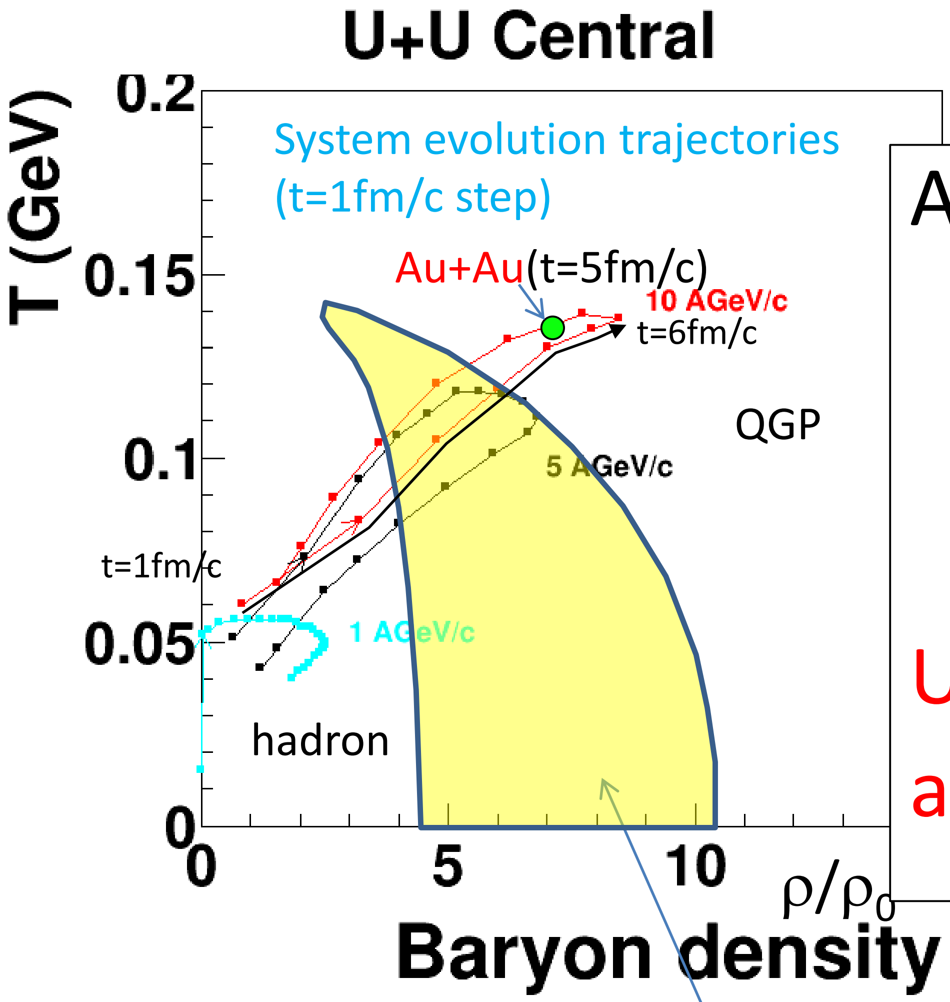
JAM model

Y. Nara, et al, Phys. Rev. C61,024901(1999)



J. Randrup et al., PRC 74, 047901 (2006)

Exceeding phase boundary at J-PARC



Mixed phase

region

Au+Au→U+U

- Baryon density
  - $7.5\rho_0 \rightarrow 8.6\rho_0$
- Duration at $\rho>5\rho_0$
  - 4 → 7 fm/c

U beam is necessary at J-PARC!

Phase boundary ρ=5-10ρ_0

Density of neutron stars ρ=6-10ρ_0

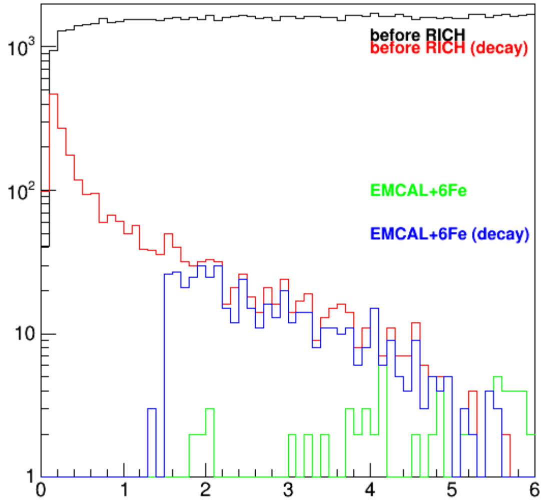
J. Randrup
PRC82 (2010) 034902
Talk by J. Randrup

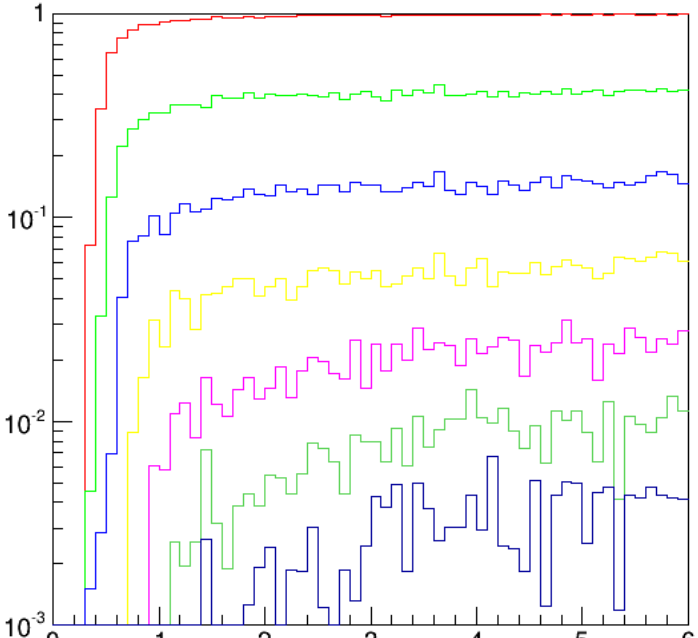
JAM model
Y. Nara, et al, Phys. Rev. C61,024901(1999)

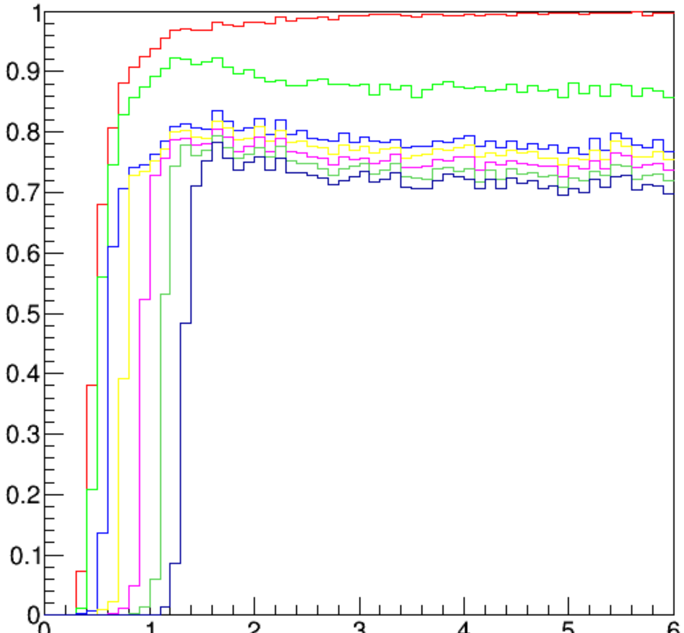
Muon identification (absorber+tracker)

$PbWO_4$ 14cm (~1λ_{int})+Fe absorber 15cm (~1λ_{int})x6

- Pion suppression = 2-4 x 10^{-3}
- Muon efficiency = 70%, cut off p>1.4 GeV/c
- Survived π / μ decayed from π = 0.16
- π decay rejection by track matching ~85%
- K decay rejection by track matching ~95%

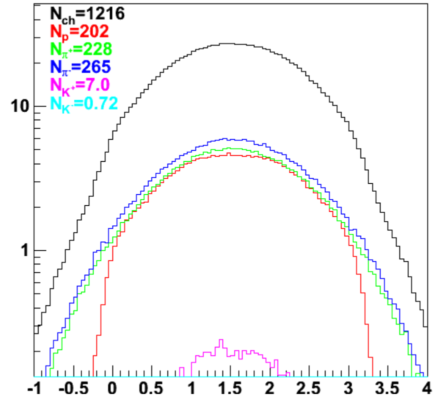


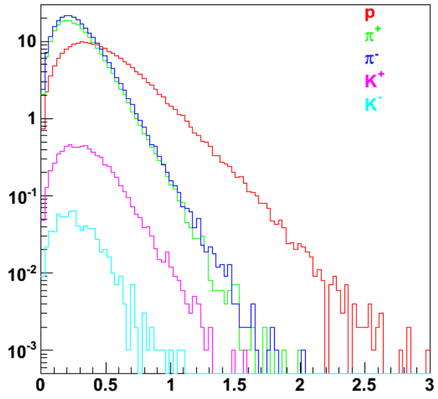




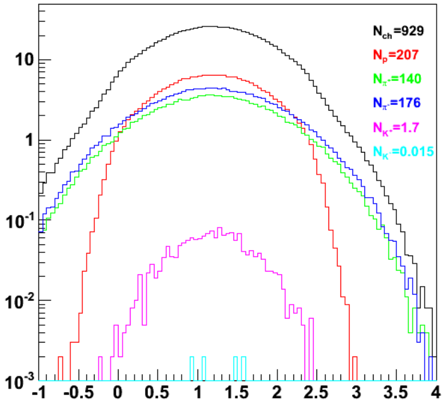
Rapidity and p_T distributions

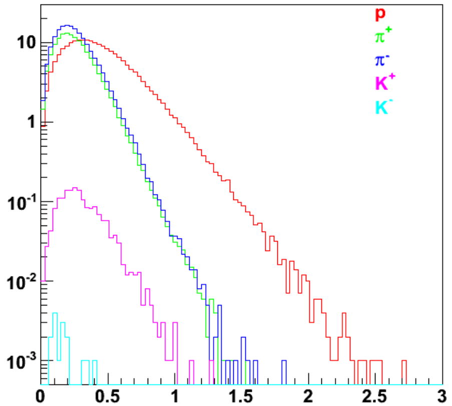
10AGeV/c



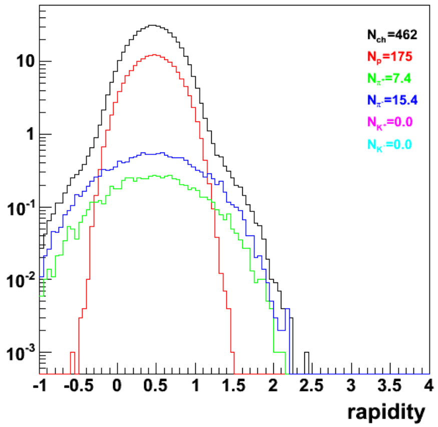


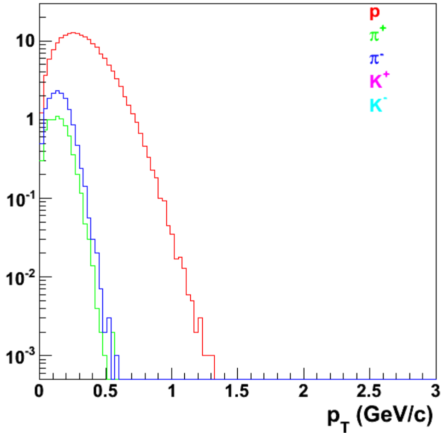
5AGeV/c





1AGeV/c

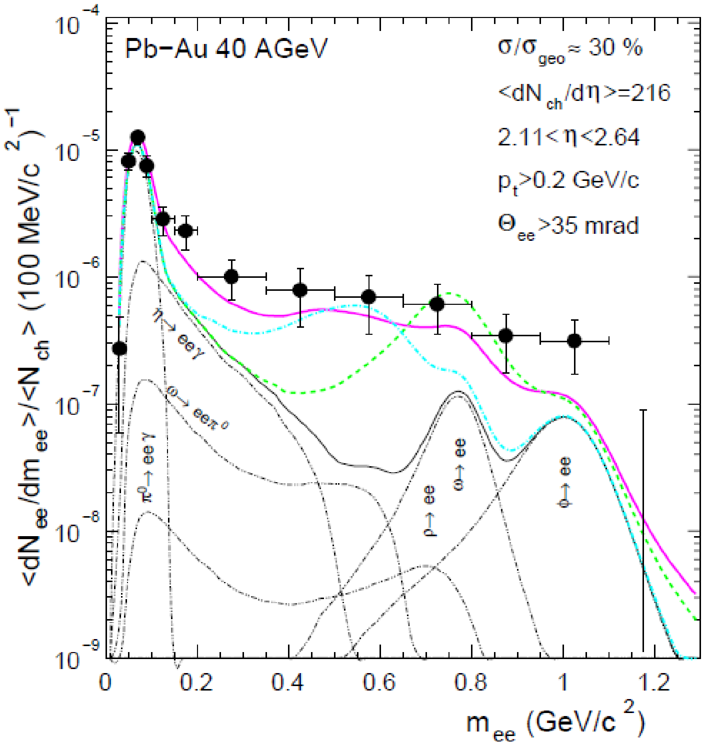




SPS results on low mass dileptons

- Excess in low mass region (LMR) is well confirmed by CERES dielectrons and NA60 dimuon results
- Consistently explained by Ralf-Wambach scenario
  - Hadron multi-body scattering + thermal radiation + in-medium ρ modification

CERES coll. PRL 91 (2003) 042301

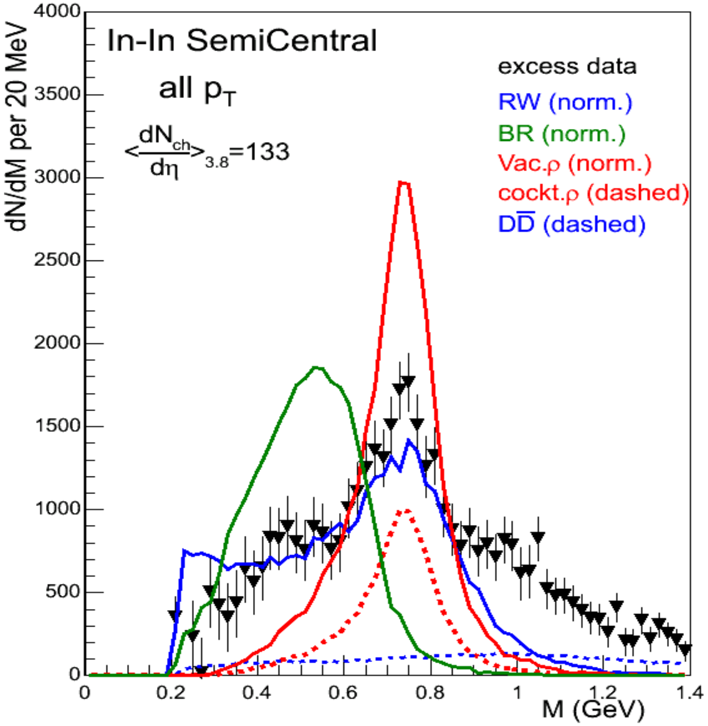


cocktail

Vac ρ

RW

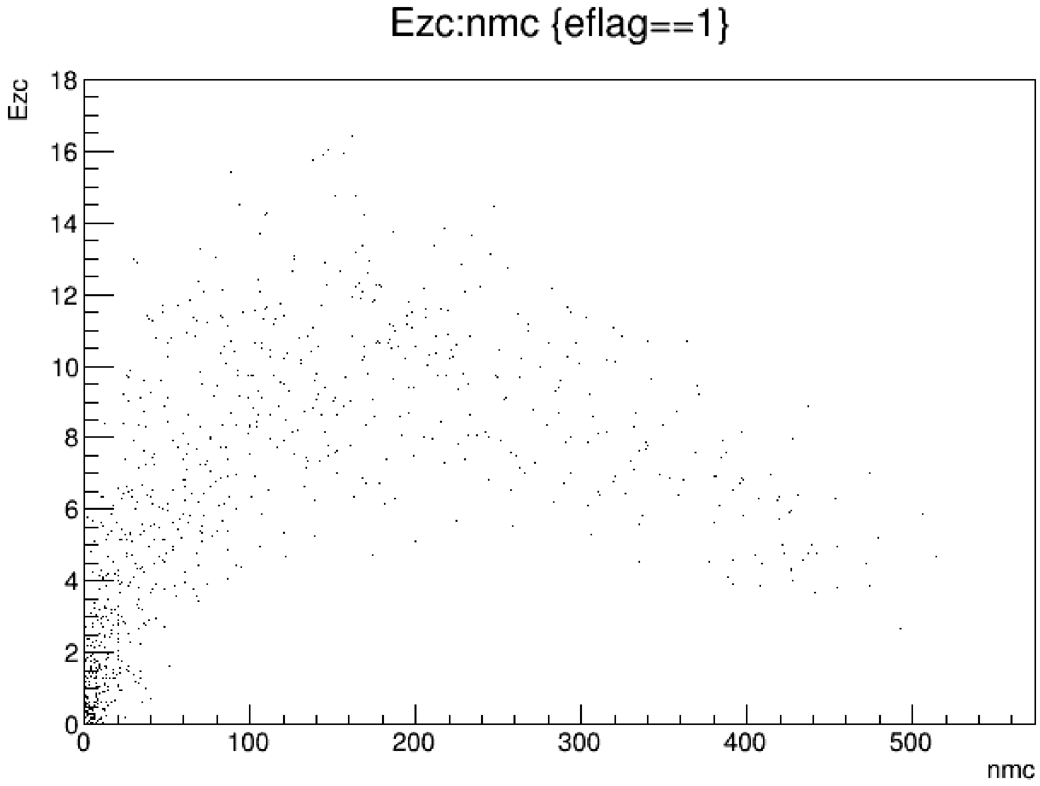
BP

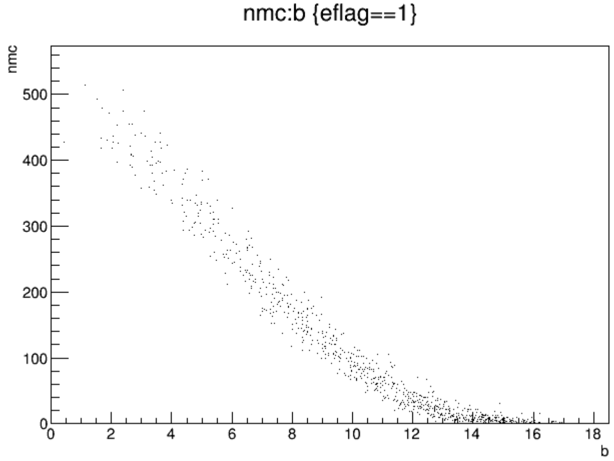


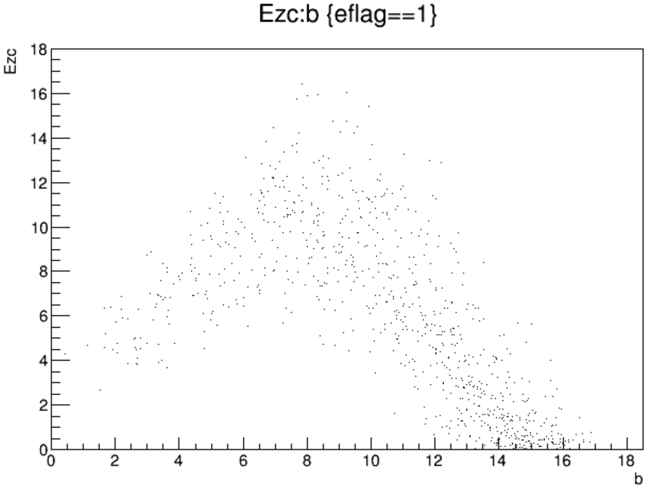
NA60, PRL 96, 162302 (2006)

Centrality determination

ZCAL theta<1.5deg
(Fe(1cm)+Pl scinti(0.3cm)) X 136 layers (=AGS-E866)
Multiplicity Counter (4<theta<14deg)







Centrality Trigger

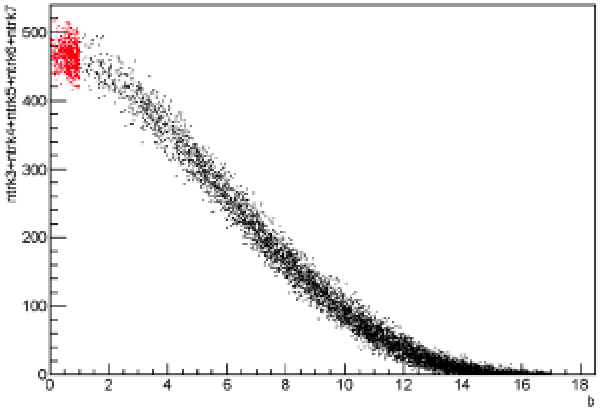
Narrow centrality cut taking advantage of high rate beams

- Ultra-central
- Many narrow centrality ranges

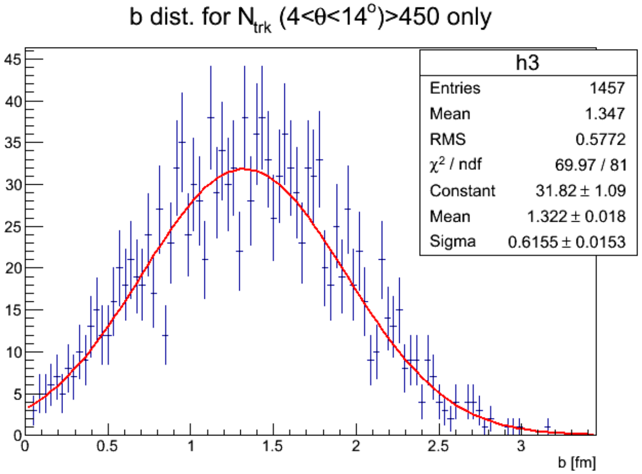
Triggering (E_{lab} = 10GeV case)

- We would like to see very central events
  - assuming b=17fm is maximum
  - b<1fm: ~0.25% central events (Marked as red points)
  - FYI, b<0.5fm → ~0.06%

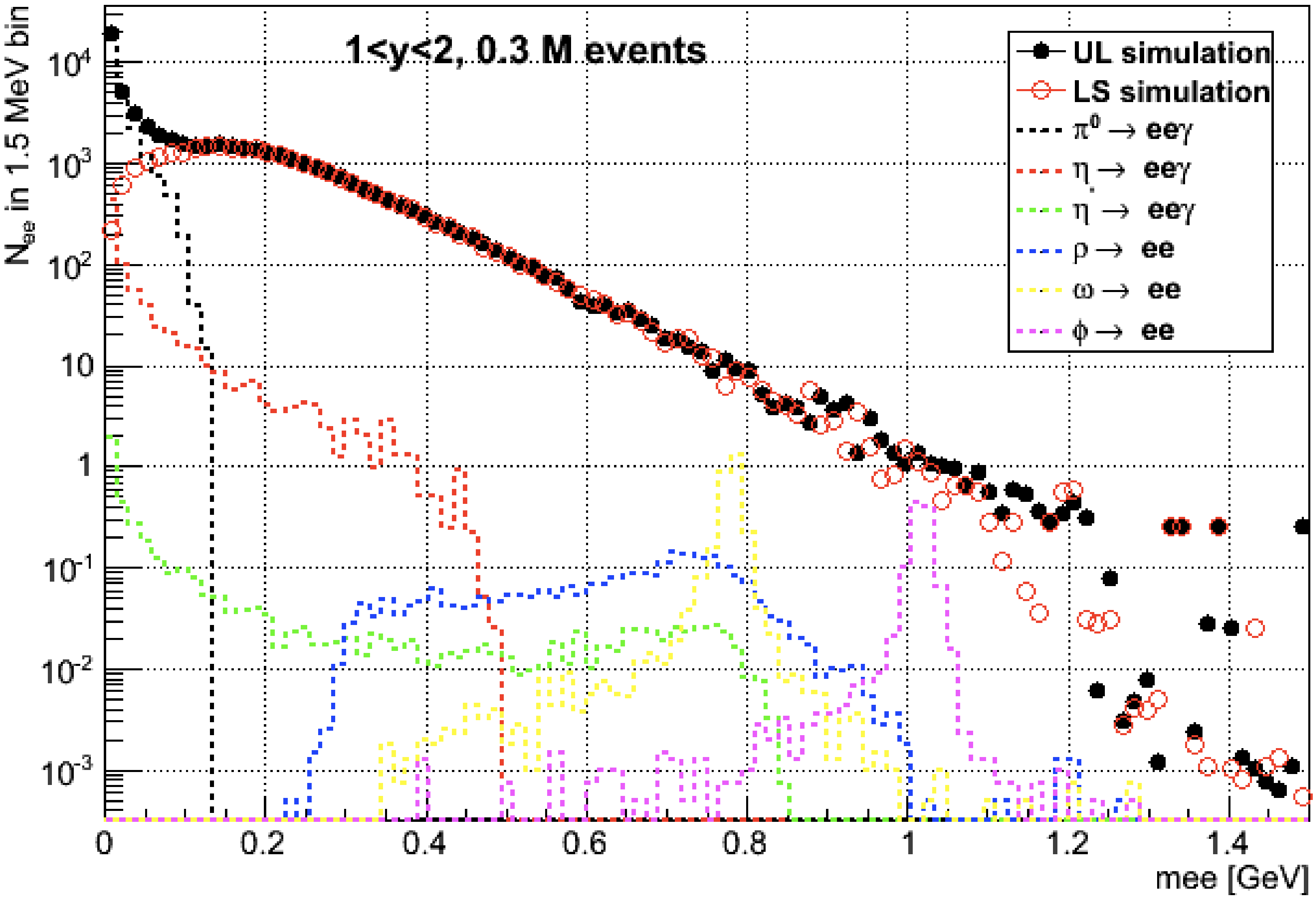
Ntrk(4<θ<14°) vs b

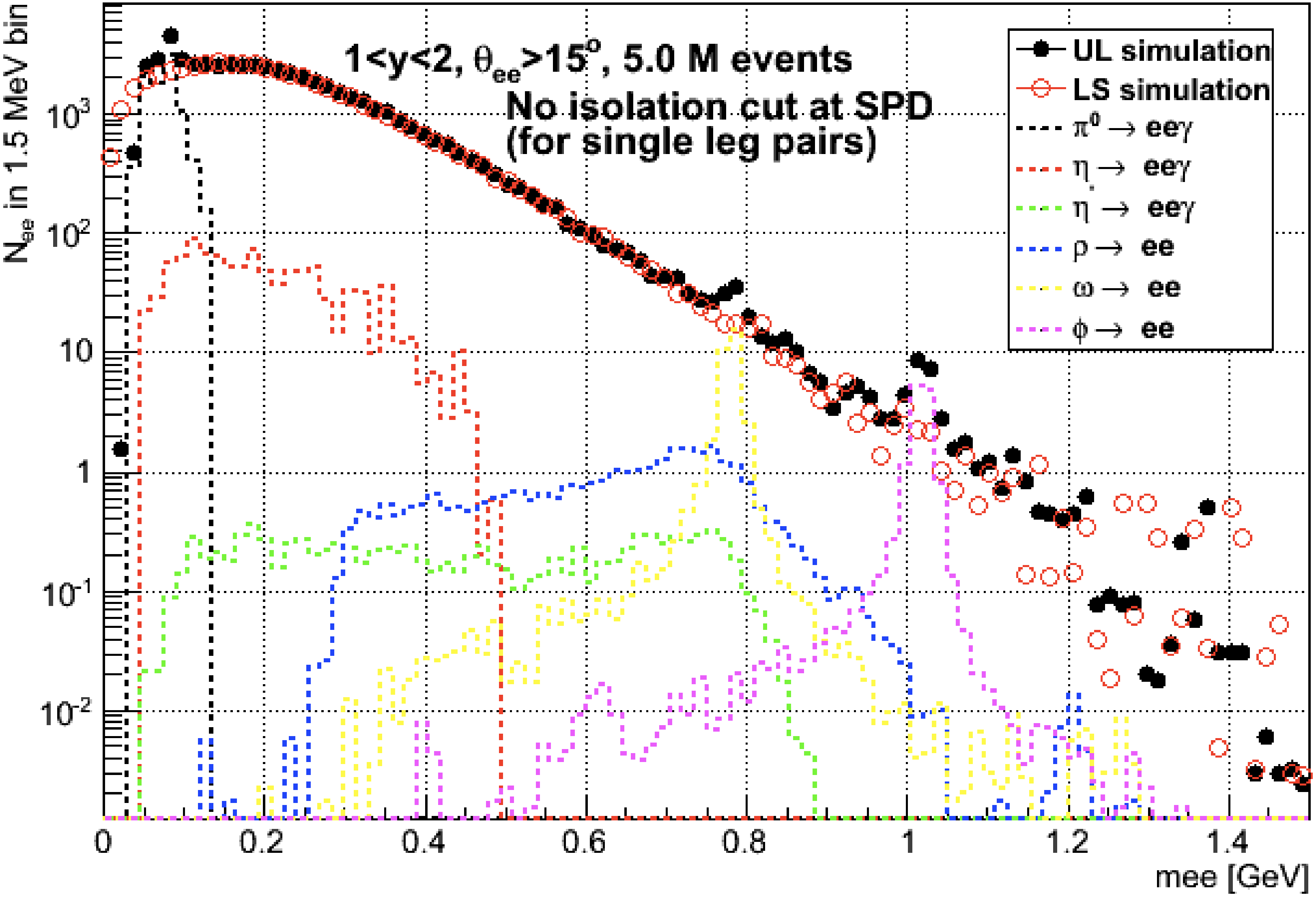


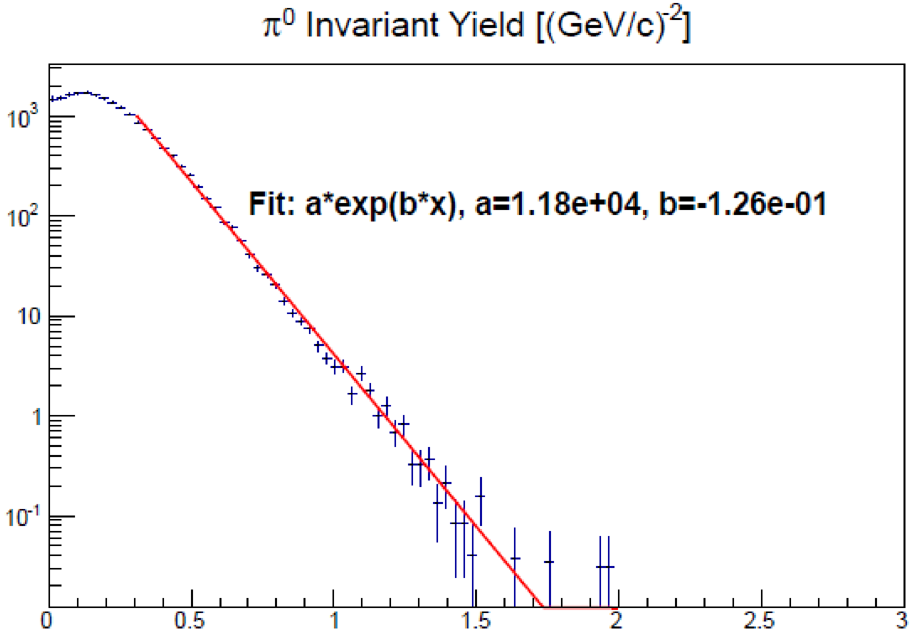
Impact parameter resolution ~0.62 fm

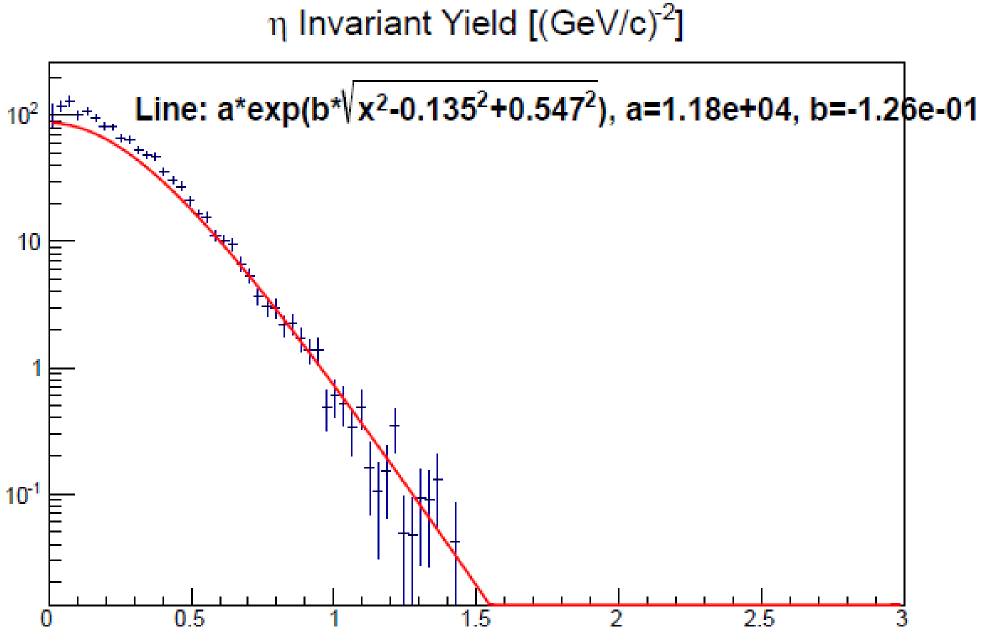


h3	
Entries	1457
Mean	1.347
RMS	0.5772
χ^2 / ndf	69.97 / 81
Constant	31.82 ± 1.09
Mean	1.322 ± 0.018
Sigma	0.6155 ± 0.0153


1<y<2, 0.3 M events
N_{ee} in 1.5 MeV bin
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
0
0.2
0.4
0.6
0.8
1
1.2
1.4
mee [GeV]
UL simulation
LS simulation
$\pi^0 \rightarrow ee\gamma$
$\eta \rightarrow ee\gamma$
$\eta \rightarrow ee\gamma$
$\rho \rightarrow ee$
$\omega \rightarrow ee$
$\phi \rightarrow ee$


1<y<2, θee>15°, 5.0 M events
No isolation cut at SPD
(for single leg pairs)
UL simulation
LS simulation
π0 → eeγ
η' → eeγ
η → eeγ
ρ → ee
ω → ee
φ → ee
Nee in 1.5 MeV bin
10³
10²
10
1
10⁻¹
10⁻²
0
0.2
0.4
0.6
0.8
1
1.2
1.4
mee [GeV]


π^0 Invariant Yield [(GeV/c)$^{-2}$]
Fit: a*exp(b*x), a=1.18e+04, b=-1.26e-01
10^3
10^2
10
1
10^{-1}
0
0.5
1
1.5
2
2.5
3


η Invariant Yield [(GeV/c)$^{-2}$]
Line: a*exp(b*$\sqrt{x^2-0.135^2+0.547^2}$), a=1.18e+04, b=-1.26e-01
10^2
10
1
10^{-1}
0
0.5
1
1.5
2
2.5
3

Why heavy ion for hypernuclei ? (1)

Advantage of heavy ion to K-beam

- S=-3 hypernuclei

  Only possible by HI collisions

- Double hypernuclei

  Fragments from Ξ-C,N,O atoms (Emulsion) ${}^{6}\mathrm{He}_{\Lambda\Lambda}$, ${}^{10}\mathrm{Be}_{\Lambda\Lambda}$

  ${}^{4}\mathrm{H}_{\Lambda\Lambda}$, ${}^{5}\mathrm{H}_{\Lambda\Lambda}$, ${}^{5}\mathrm{He}_{\Lambda\Lambda}$ may be much more produced by HI

- Neutron/proton rich hypernuclei

  Light hypernuclei not produced by (γ,K+) (π-,K+),,,,

  nnnΛ, ${}^{5}\mathrm{H}_{\Lambda}$, ${}^{8}\mathrm{H}_{\Lambda}$, ${}^{10}\mathrm{He}_{\Lambda}$, ${}^{11}\mathrm{He}_{\Lambda}$, ${}^{5}\mathrm{Li}_{\Lambda}$, ${}^{12}\mathrm{Li}_{\Lambda}$, ${}^{6}\mathrm{Be}_{\Lambda}$,,,

KenIchi Imai, J-PARC HI meeting (2013/4/24)

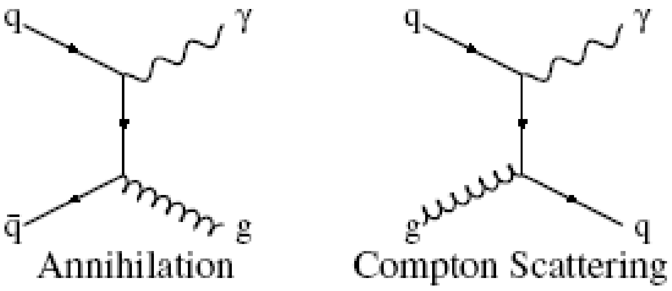
Photon basics

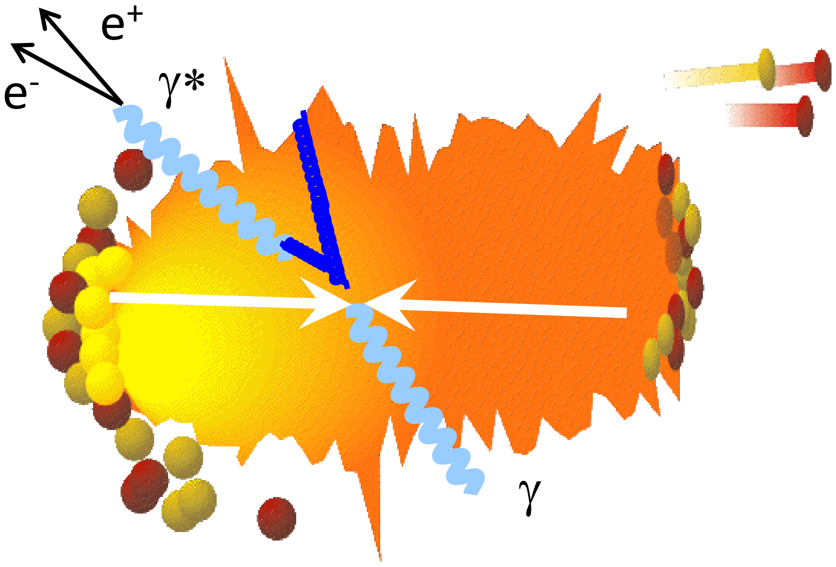
- Production Process
  - Compton and annihilation (LO, direct)
  - Fragmentation (NLO)
  - Escape the system unscathed

- Carry dynamical information of the state

- Temperature, Degrees of freedom
  - Immune from hadronization (fragmentation) process at leading order
  - Initial state nuclear effect
    - Cronin effect (k_T broardening)

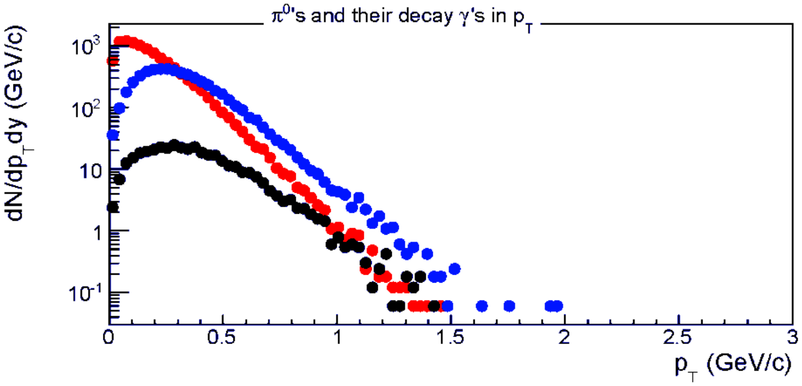
Photon Production: Yield $\propto \alpha\alpha_s$

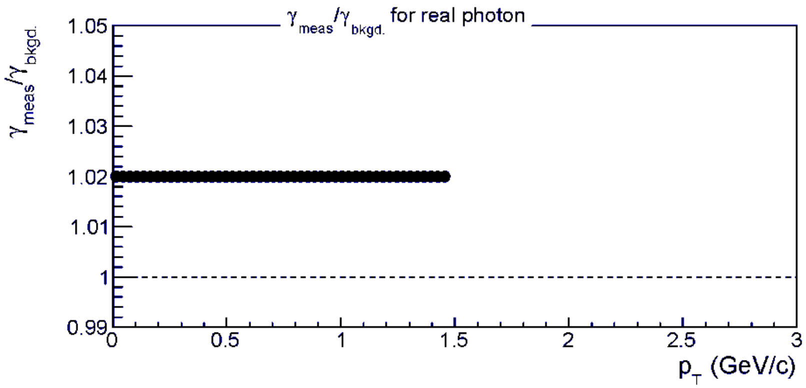


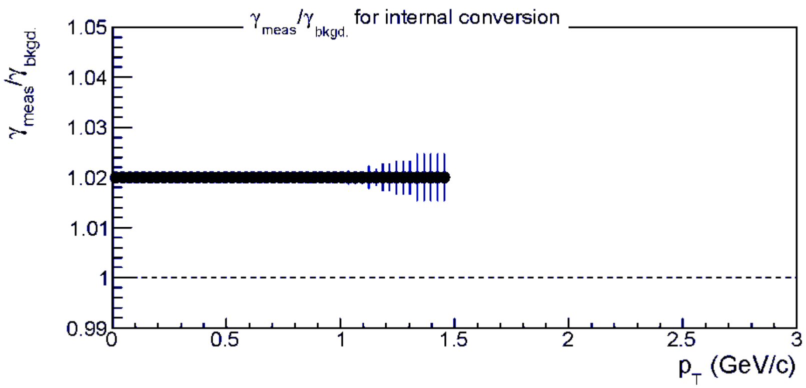


Photon feasibility study

- 0.1 T events 1<y<2, b<1fm
- Blue: pi0, Black: eta, Red: decay photons from pi0 and eta
- Direct photon signal is assumed to be 2% of background photons
- Statistical error only
- No hadron contamination, photon efficiency is taken into account.

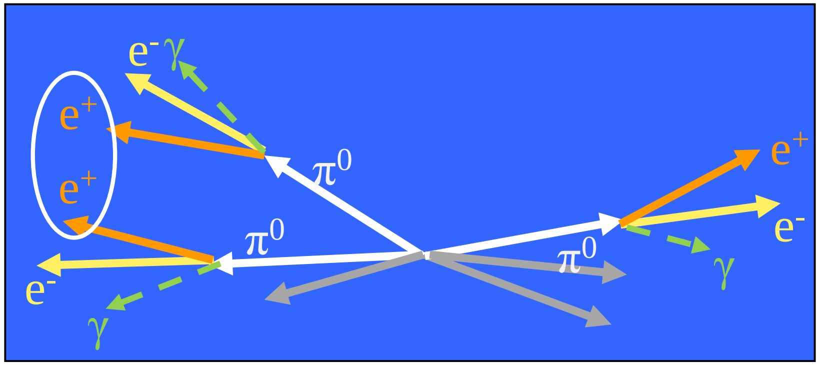






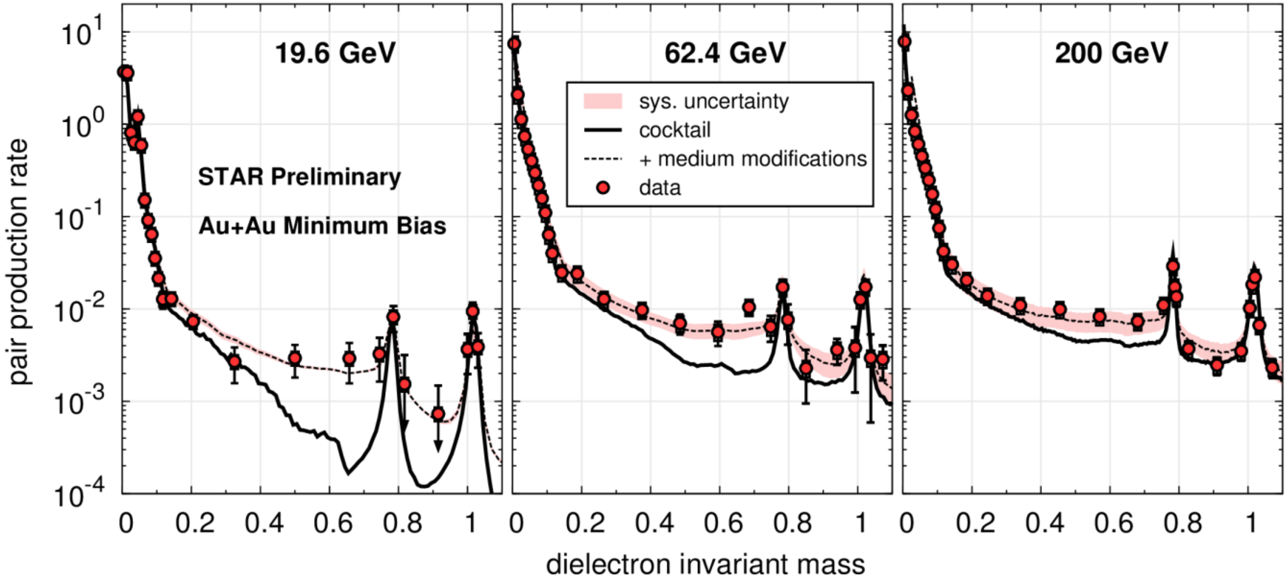
Electron feasibility study

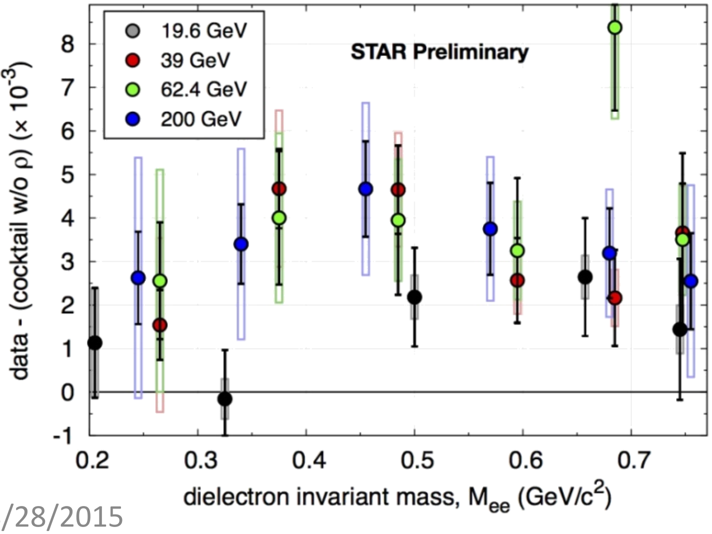
- Huge background is a problem
- Very small jet-originated background
  - No cross-pair
  - No charm contribution



- Based on pi0 spectra obtained from JAM event generator
  - Other hadrons m_T-scaled
- 1<y<2 (in lab), b<1fm (0.25% centrality)
- 0.1T events (by one month running)

Beam Energy Scan of dielectrons

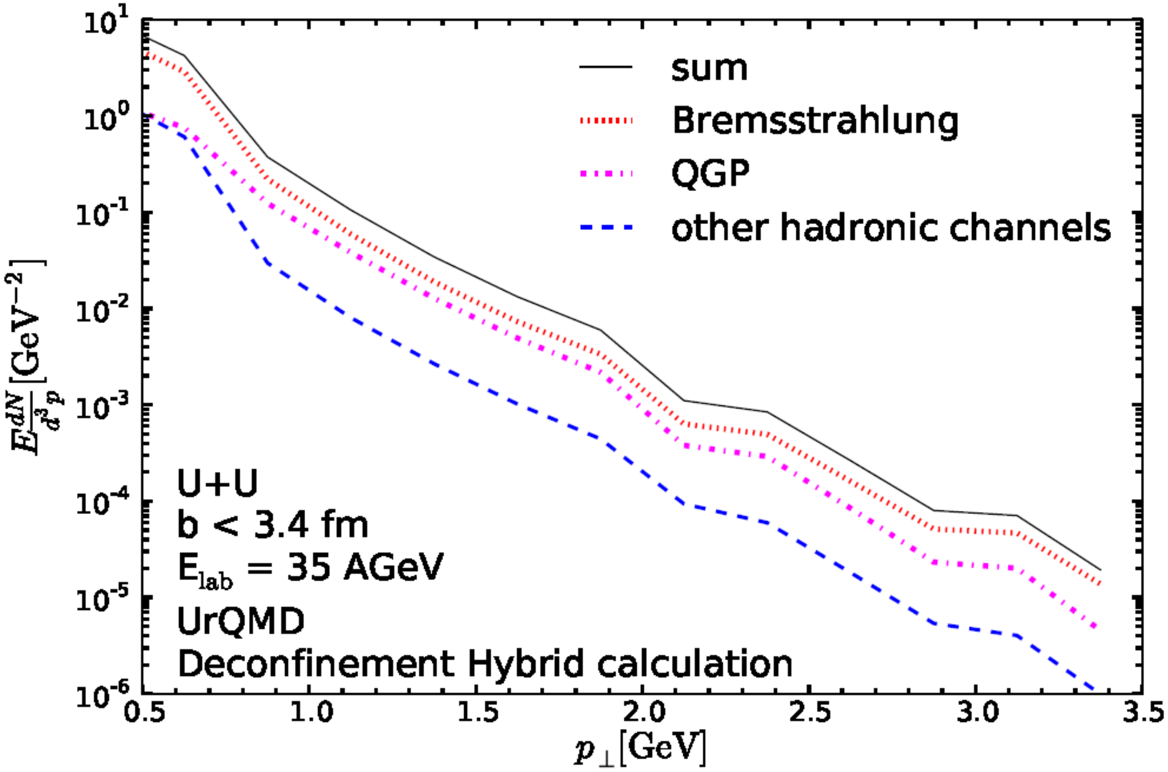




- LMR excess observed for all energies
- systematic measurement of excess
- Model calculations appear to provide robust description from RHIC down to SPS energies
- Measurements consistent with in-medium ρ broadening
  - expected to depend on total baryon density

Photon calculation

- Using UrQMD, low p_T photons are calculated at FAIR energy
  - arxiv:1211.2401
  - Bremsstrahlung $\pi\pi \rightarrow \pi\pi\gamma$ is dominant
- Elliptic flow is estimated of the order of 1-2%



Solenoid spectrometer

- Pixel size (<6x6mm^2 at 1m at θ>10°)

B=2T

Layer	detector	R(cm)	Pixel size(ϕxz) (mm2)	thickness	material	L/X_0
1	SPD	1.5	0.05x0.4	0.3mm	Polyimide(286mm)	1.05e-3
2	SPD	3	0.05x0.4	0.3mm		1.05e-3
3	SSD	10	0.08x1	0.3mm		1.05e-3
4	SSD	14	0.08x1	0.3mm		1.05e-3
5	GEM TR	30	2x10	0.025mm 0.050mm 0.027mm	Kapton(286mm) Mylar(285mm) Cu(1.44mm)	2.32e-3
6	GEM TR	50	3x15			2.32e-3
7	GEM TR	75	5x20			2.32e-3
	He	75			He (568.192m)	1.30e-3
	TOF	85				
Total			→ pTcut=0.26GeV/c			1.25%

Dipole spectrometer (new)

- Pixel size (<6x6mm^2 at 1m at θ<10^o)

B=1T

Layer	detector	Z(cm)	Pixel size(XxY) (mm^2)	thickness	material	L/X_0
1	SPD	7.5	0.05x0.4	0.3mm	Si(0.2mm)+polyimide	1.4%
2	SPD	15	0.05x0.4	0.3mm		1.4%
3	SSD	32	0.08x1	0.3mm		2.1%
4	SSD	44.8	0.08x1	0.3mm		2.1%
5	GEM TR	180	2x10	0.025mm 0.100mm 0.027mm	Kapton(286mm) Mylar(285mm) Cu(14.35mm)	2.32e-3
6	GEM TR	190	3x15			2.32e-3
7	GEM TR	360	5x20			2.32e-3
8	GEM TR	370	5x20			2.32e-3
9	GEM TR	530				
	RICH	410				
	EMCAL	540				
	He	150			He(568.192mm)	2.64e-3

Summary of acceptance and pixel size

Acceptance

	1AGeV	**5AGeV**	**10AGeV**
$\theta<20$deg	23.2%	47.5%	57.5%
$\theta<30$deg	42.9%	64.7%	72.7%
$\theta<40$deg	59.9%	76.0%	81.9%

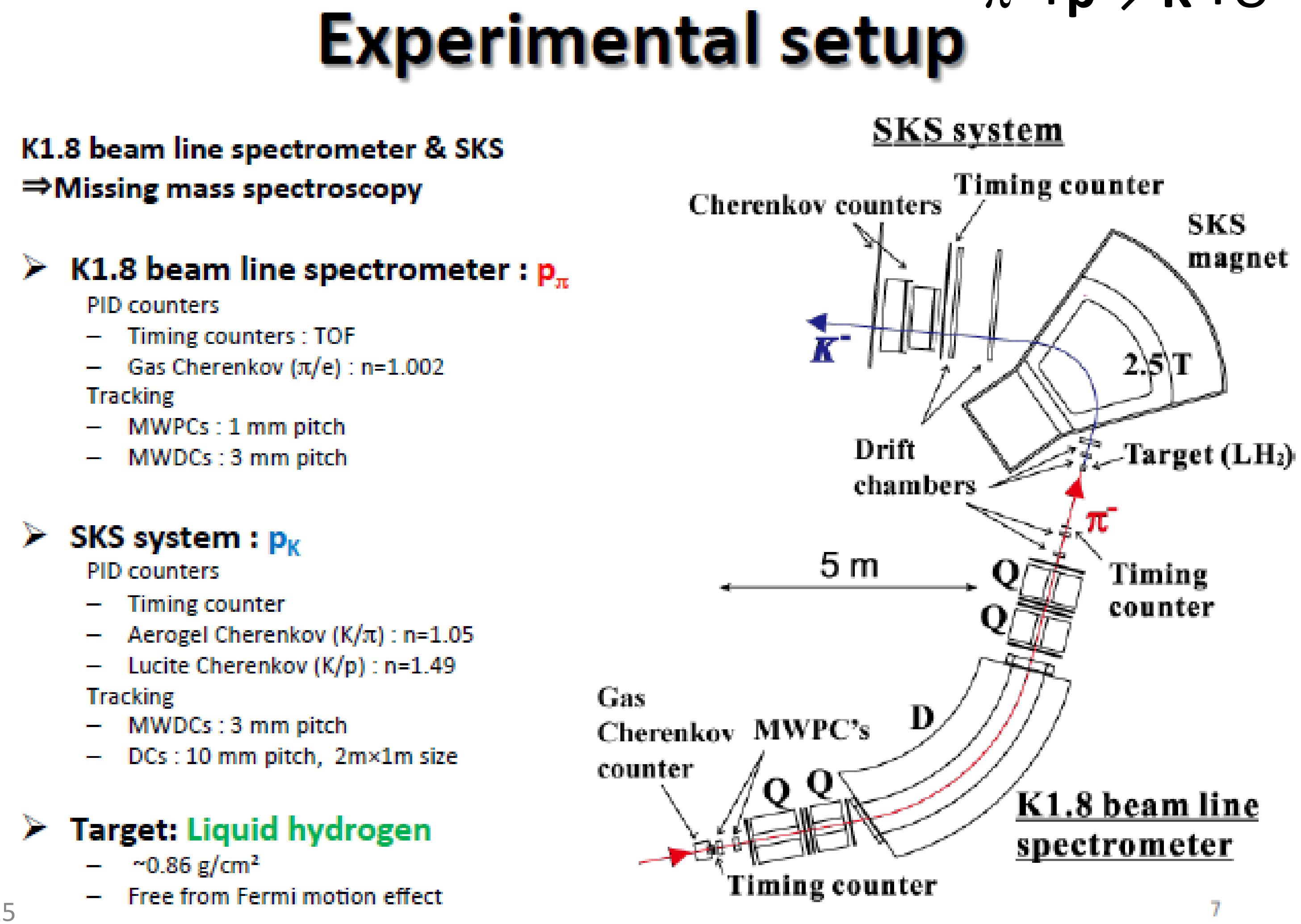
Required pixel size at 10% occupancy at 1m from the target

	1AGeV	**5AGeV**	**10AGeV**
$\theta<2$deg	17x17mm^2	5x5mm^2	3x3mm^2
$\theta=10$deg	18x18mm^2	7.5x7.5mm^2	6x6mm^2
$\theta=30$deg	25x25mm^2	21x21mm^2	20x20mm^2

E19

Search for pentaquark $\Theta^{+}(uudd\bar{s})$

$\pi^- + p \rightarrow K^- + \Theta^+$



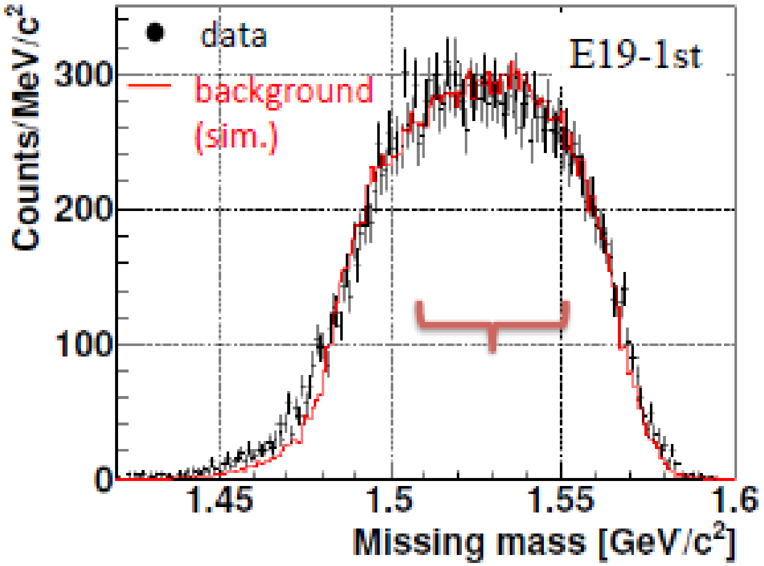
Experimental setup

K1.8 beam line spectrometer & SKS
⇒Missing mass spectroscopy

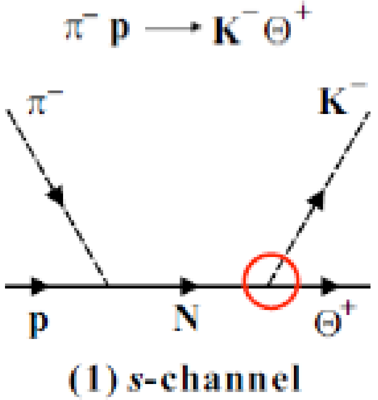
- **K1.8 beam line spectrometer : p_π**
  - PID counters
    - Timing counters : TOF
    - Gas Cherenkov (π/e) : n=1.002
  - Tracking
    - MWPCs : 1 mm pitch
    - MWDCs : 3 mm pitch
- **SKS system : p_K**
  - PID counters
    - Timing counter
    - Aerogel Cherenkov (K/π) : n=1.05
    - Lucite Cherenkov (K/p) : n=1.49
  - Tracking
    - MWDCs : 3 mm pitch
    - DCs : 10 mm pitch, 2m×1m size
- **Target: Liquid hydrogen**
  - ~0.86 g/cm²
  - Free from Fermi motion effect

1st run result of E19

$\pi^- + p \rightarrow K^- + X$ @ 1.92 GeV/c



Shirotori et al., PRL 109, 132002 (2012).



(1) *s*-channel

- No prominent peak structure
- Upper limit: < 0.26 μb/sr @ 1.51−1.55 GeV/c²

✓ s-channel dominance

✓ $\Gamma_\Theta \propto g^2_{KN\Theta} \propto \sigma_{tot}$

➔Upper limit of decay width

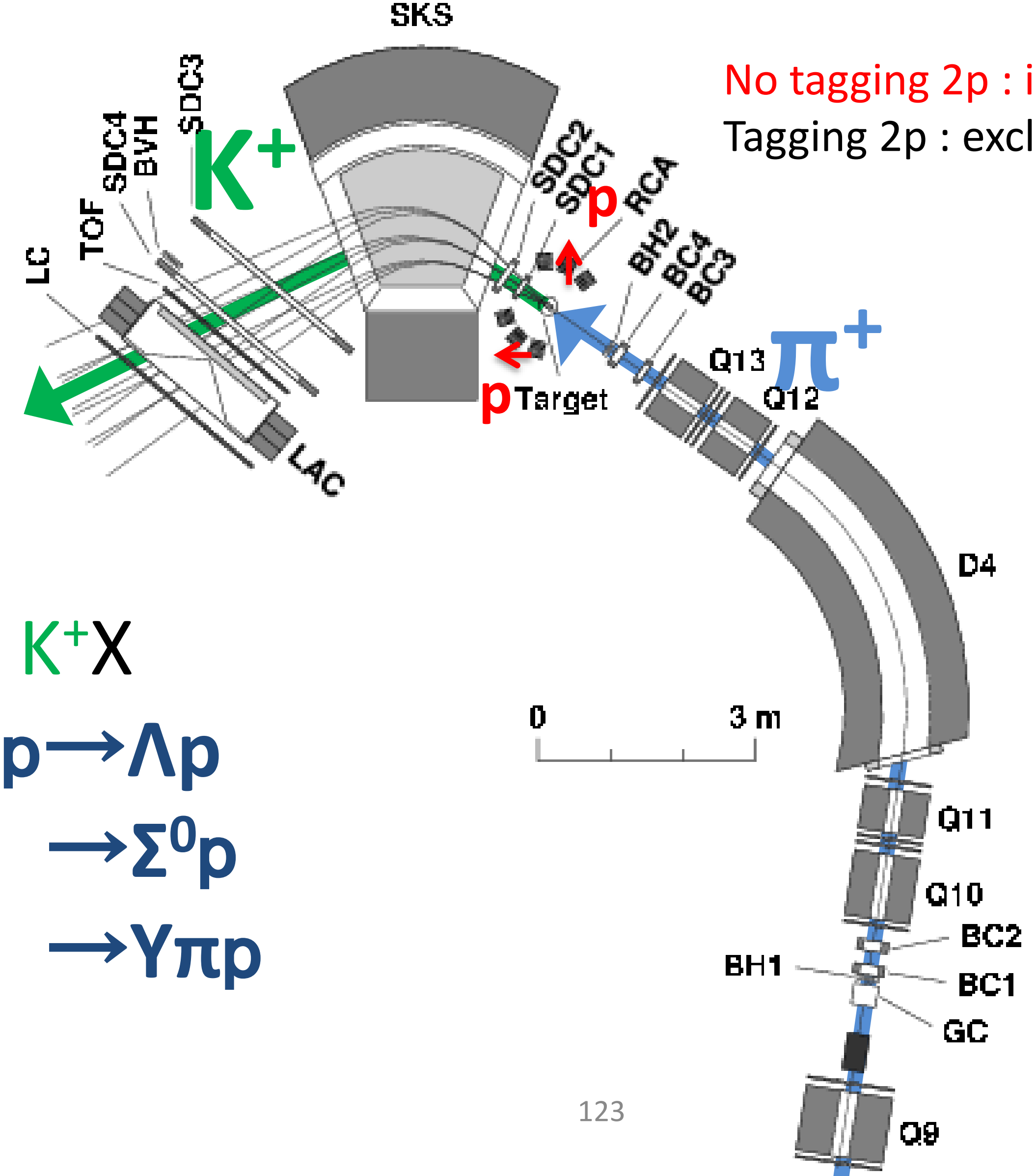
- 0.72 MeV for ½+
- 3.1 MeV for ½-

E27

Search for a $K^{-}pp$ bound state

No tagging 2p : inclusive measurement

Tagging 2p : exclusive measurement



$\pi^{+}d \rightarrow K^{+}X$

$X = K^{-}pp \longrightarrow \Lambda p$

$\longrightarrow \Sigma^{0}p$

$\longrightarrow Y\pi p$

Missing mass spectrum of d(π^+, K$^+$)

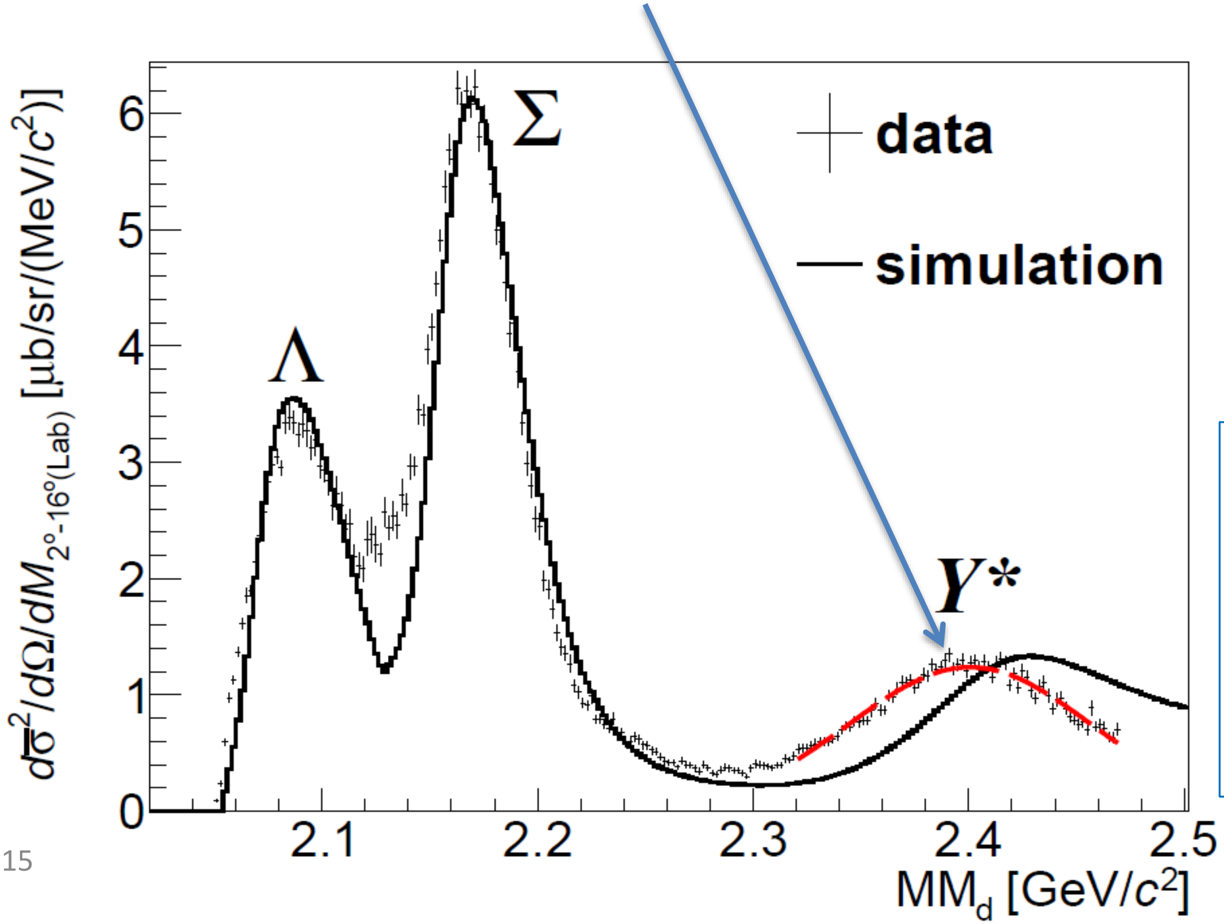
There are a lot of B.G (quasi-free hyperon production).

→It is difficult to identify the K$^-$pp from inclusive spectrum.

In the Λ and Σ region, observed spectrum is almost consistent with simulation.

"Puzzling " Y* peak shift = -32.4 ± 0.8 MeV/c^2

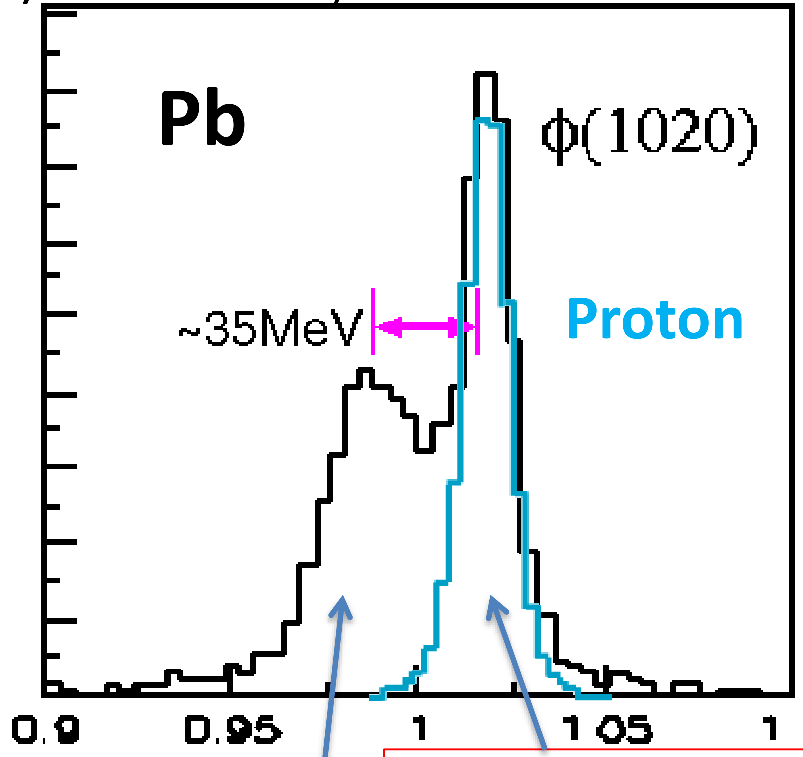
Y*N final state interaction might explain it?



Quasi-free B.G.
- Λ, Σ$^{+/0}$,
- Y*: Λ(1405), Σ(1385)$^{+/0}$,
- Λπ, Σπ

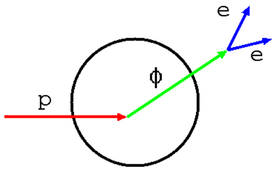
E16 : Goal @ J-PARC

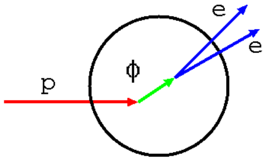
Measurements of ϕ → e+e- in p+A to study in medium modification of ϕ (change of QCD dynamical mass)



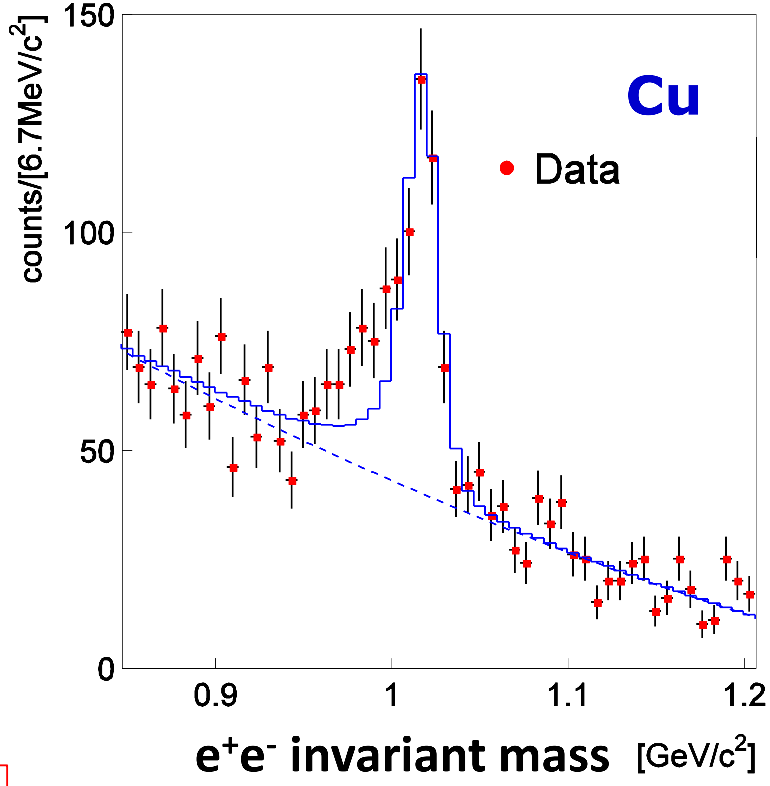
Decays **inside** nucleus

Decays **outside** nucleus





KEK-E325



Large statistics is required